Authors' responses in red italics

RC1: 'Comment on nhess-2023-39', Anonymous Referee #1, 04 Apr 2023 reply

General comments

The submitted manuscript contains a climatological study of convective cells and mesoscale cyclones and their nature relative to a set of automatically detected near-surface cold fronts. This combination of established front detection, which provides information on large-scale flow, and a radar-based algorithm for detecting and tracking convective cells is unique and novel.

The paper is generally well written, and the illustrations are of high quality. Most parts of the paper are descriptive without going into much detail of the individual forcing mechanisms. Something the author may reserve for the future, but the manuscript could be expanded in this regard as well, for example, by adding more information on surface slope (e.g., orographic lifting in regions along the Black Forest, Harz, Rhön, for example).

The authors derive some interesting properties from their methods, such as cell speed and cell lifetime versus distance to the next cold front. The authors might consider adding more information about the relationship between these properties and front strength or front orientation (some are more zonal some are more meridionally oriented).

We thank the reviewer for taking the time to review the manuscript and for their constructive feedback. The revised manuscript will include several changes based on the reviewer's comments which are outlined in more detail below under each specific comment.

Specific comments:

- Despite the uplift due to the sloping isentropes of the front, there is little discussion of forcing by the upper levels. Presumably, the front is accompanied by a trough, and a simple geopotential contour or vertical motion could be useful for discussing the results.

We initially planned to address forcing mechanisms in the next paper, however the climatological value of certain factors such as convergence, surface moisture and CAPE in the 700 hPa frontal framework would be useful for discussing the results. We will include a new figure (Figure R1) that shows the climatological convergence at different pressure levels as a function of the distance from the 700 hPa front. This provides insight into the forcing at different levels. Thank you for the suggestion.

- It is unclear why a characteristic such as cell lifetime or lightening has a local minimum at the location of the 700-hPa front. The authors are encouraged to comment more on this observation, which is clearly seen in Fig. 10 and only briefly discussed in l. 215. It seems to be a fortunate coincidence that the largest downward motion should occur at the location of the 700-hPa front, but the author should support their hypothesis for example, by plotting vertical motion, surface moisture, and CAPE/CIN.

The new figure (Figure R1) mentioned in the comment above has the climatological CAPE, surface dewpoint and solar heating overlayed. We find that the CAPE is climatologically lowest surrounding the 700 hPa front. However, we believe a more comprehensive analysis would be required taking microphysics into consideration to unravel why the minimum lightning fraction is located at this distance relative to the front. Such an analysis is unfortunately beyond the scope of this current study as it is a climatology.

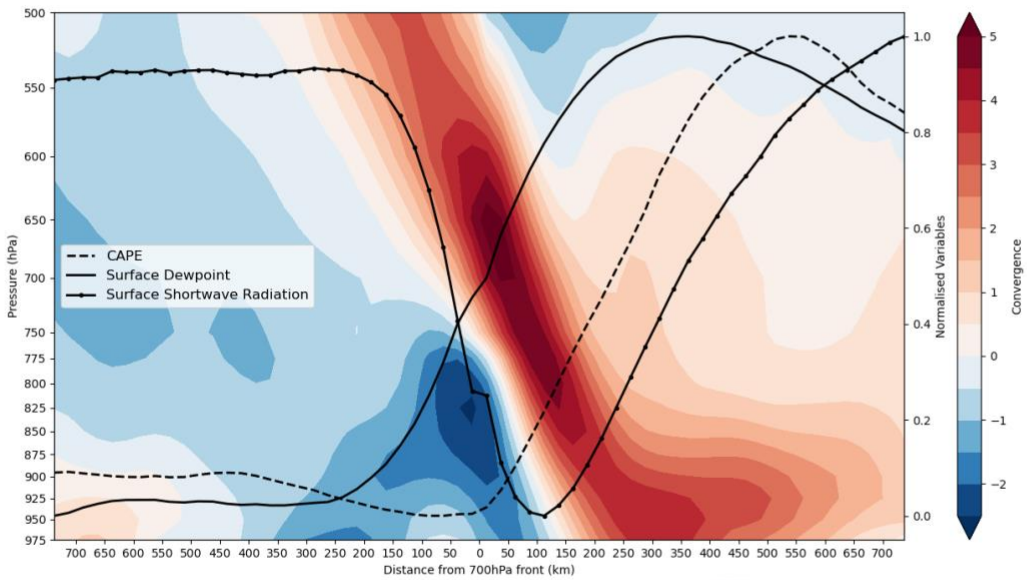

Figure R1: Climatological convergence between 975 hPa and 500 hPa (shaded), MUCAPE (dashed line), surface dewpoint (straight line), surface shortwave radiation (straight dotted line). Excluding convergence, the climatological values of the variables are normalised between 0 and 1 so the distribution around the front can be compared. Variables were derived in ERA5 data.

I think a map of the topography of Germany in steps of hundredths somewhere in the paper might help in understanding some of the local features, especially for the non-frontal cases.

Thank you for the suggestion, we will add contour lines to the current Figure 7f to highlight areas of higher elevation and discuss how the spatial climatology relates to the topography. Indeed, the highest frequency of both cold-frontal convective cells and non-cold-frontal convective cells can be found in the south of Germany in proximity to the Alps. The exception is post-700hPa-frontal cells which appear to be driven more by land-sea interactions.

- Are the post-front cases (Fig. 7a) in the northwest related to land-sea circulations?

This is an interesting question that we plan to address in a future study. We do briefly mention this in the current manuscript (L266–268). Testing this hypothesis would involve deeper analysis in ERA5 or observational data which we see as beyond the scope for this paper since we are primarily focusing on climatology.

- Would be possible to add some information on the frontal strength in terms of temperature or humidity gradients alongside the characteristics of the convective cells (e.g., lifetime)? It looks like the 700-hPa front line is behind a strong gradient in humidity reminiscent of squall lines (Fig. 2a).

This is also a very interesting question. We found that there is no clear relationship between the strength of the equivalent potential temperature gradient and the number of cells, i.e., a stronger equivalent potential temperature gradient at the front does not necessarily increase the number of cell detections. We suspect this highlights the importance of thermodynamic processes and other smaller-scale sources of lift on the development of convective cells, e.g., orography, outflow boundaries etc. We hope to address such aspects in more detail in a future study.

Regarding Figure 2a the strong theta-e gradient ahead of the 700 hPa front is linked to a secondary (smaller-scale) cold-front that formed in the warm sector. See Figure R2 below.

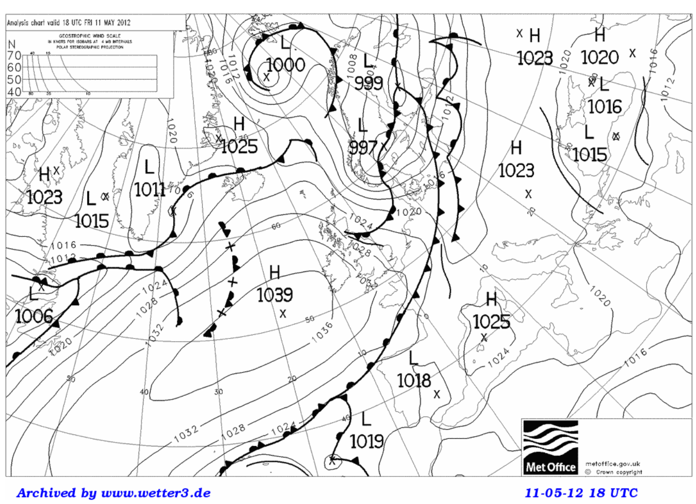

Figure R2: Synoptic analysis from the Met Office on 11th May 2012 at 18 UTC

> To justify the 750 km, the author could also perform a test against randomization. The number of additional cells attributed to a front when the distance is increased in 50-km increments can be plotted against the same but using radar data from a randomly chosen date. At the radius where both changes in the additional number of cells become equal, the increase in additional cells attributed to the front can no longer be distinguished from noise. Below this threshold, however, the increase is more than noise and is therefore physical.

We randomly sampled cell-front distances by shuffling all cold front timesteps between 2007 to 2016 (April–September). This process was repeated 100 times, and the range of the samples is shown by the whiskers in the plot below indicating the 5th and 95th percentiles (Figure R3). The mean of all 100 samples is represented by the orange line, while the blue line represents the cell count (real sample). We observe a sample bias for pre-700hPa-frontal cells, as already mentioned in the manuscript (L229-L230). Instead of using the timestep count to assess the bias, we will include the figure below in the Appendix and refer the readers to it. In the warm-sector, the cell count is significantly higher than the randomised sample, with a maximum ratio of 2.8 (black line). The overlap between the random sample and the real sample is between 950–1100 km (95% confidence), with a second overlap at around 100 km. If we based our distance limits on the overlap of the randomised sample and the real sample, we would select 100 km and 1000 km. However, we also want to focus on the differences between pre-700hPa-frontal cells (more frequent than the random sample) and post-700hPa-frontal cells (less frequent than the random sample). As mentioned earlier, this figure will be included in the Appendix and referred to in the first results section. Thank you for the suggestion and the valuable addition to the paper.

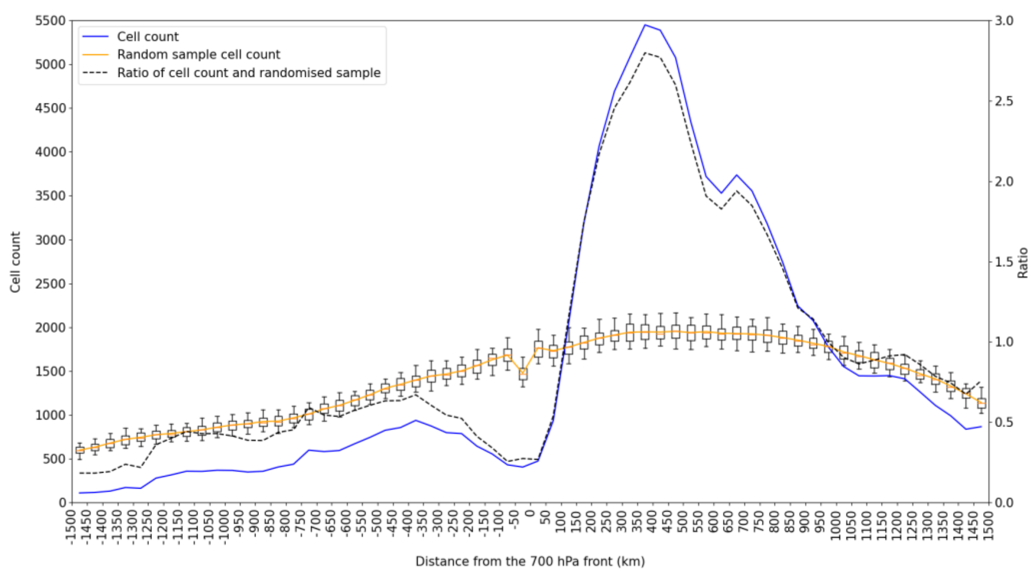

Figure R3: Cell count (blue), random sample cell count mean (orange) and ratio of cell count and randomised sample (black) on the secondary axis. The random sample was performed 100 times and the 5th and 95th percentiles are shown by the whiskers of the boxplots.