



A Lagrangian perspective of Compound Precipitation and Wind Extremes associated with Cyclones

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Motivation

- First part of work from my PhD was looking at compound extremes from an Eulerian perspective (Owen et al., 2021, Compound precipitation and wind extremes over Europe and their relationship to extratropical cyclones, Weather and Climate Extremes, <u>https://doi.org/10.1016/j.wace.2021.100342</u>)
- Cyclones **are associated** with a high number of wind, precipitation and compound **extremes** over Europe
- By considering an Lagrangian perspective, the spatial pattern and frequency of extremes within cyclones could be explained
- And the characteristics of cyclones that cause such extremes
- This would be useful for **forecasters** and **the reinsurance industry**

Questions

- What is the frequency, spatial pattern and footprint size of wind, precipitation and compound extremes within cyclones over their lifecycle?
- 2. How does the frequency, spatial pattern and footprint size of extremes change with seasonality, intensity and speed?

ERA5 Reanalysis

- 6 hourly total precipitation accumulation
- 6 hourly maximum 10 m wind gusts
- 31 km spatial resolution
- 1980-2018
- Winter half season October to March
- Europe grid box 20W to 40E and 30S to 75N.

TRACK

- Cyclones are identified and tracked using the objective feature-tracking algorithm, TRACK.
- The algorithm identifies 6 hourly vorticity maxima at 850 hPa.



Def: Compound extremes

χ is the **chance** of an **compound extreme** event occurring **given** either a **precipitation** or **wind extreme** is occurring.

$$\chi(p) = Pr(Y(t) > y_p \mid X(t) > x_p)$$

where Y is precipitation, X is wind and y_p and x_p are the corresponding quantiles

 $\mathbf{\Lambda}$

$$\chi = \frac{n_a}{(1-p)n}$$

where n is the total number of timesteps, n_a are the number of cooccurring events and p is 0.99 A co-occurrence is recorded if the precipitation and the wind speed occur: at the same timestep, at the same gridpoint and are each above the 99th percentile.

Def: Cyclone compositing



 Identify and select the tracks to be used. Here all tracks over our Europe gridbox are used.



Find the position of interest e.g. maximum intensity. Extract the extremes within 1110 km of this point.

Rotate to direction of storm propagation and extract the region for averaging.





Catto, J. L., Shaffrey, L. C., & Hodges, K. I. (2010). Can Climate Models Capture the Structure of Extratropical Cyclones?, *Journal of Climate*, 23(7), 1621-1635.

Def: Percentage of extreme events associated with a cyclone

The percentage of extreme events within 1110 km of a cyclone is estimated by



 n_{EVENTS} is the total number of extreme events for a gridpoint

*n*_{*TRACKS*} are the number of tracks

Percentage of wind extremes associated with a cyclone



What is the frequency and spatial pattern of wind extremes?



Percentage of wind extremes associated with a cyclone

- The spatial pattern of extreme wind does not vary much during a cyclones lifecycle.
- The highest chances of extreme winds occur roughly within 500 km behind the cyclone centre within the cold conveyor belt to behind the cold front.
- The frequency peaks at maximum intensity (30%).
- Averaged over whole lifecycle extreme wind occurs in up to 12% of cyclones.

What is the frequency and spatial pattern of precipitation extremes?



Percentage of precipitation extremes associated with a cyclone

- Extreme precipitation occurs ahead of the cyclone centre, in the warm conveyor belt and warm front, this does not change throughout a cyclones lifecycle.
- Cyclones averaged over their whole lifecycle only experience extreme precipitation up to 13% of the time respectively.
- The frequency of extreme precipitation peaks 6 hours before maximum intensity, where it is found in up to 33% of cyclones.

What is the frequency and spatial pattern of compound extremes?



Percentage of compound extremes associated with a cyclone

- Compound extremes occur in a similar location to the precipitation extremes, ahead of the cyclone centre. Again in the region most associated with the warm conveyor belt and warm front
- Compound extremes occur in up to 1.5% of cyclones throughout their whole lifecycle
- Peaking at and 6 hours before maximum intensity, here they occur in up to 5.4% of cyclones.

Def: fraction area of extremes within a cyclone



How does the size of the footprint of extremes change with cyclone lifecycle?

- The largest footprint of wind extremes occurs at maximum intensity
- The largest footprints of precipitation and compound extremes occur 6 hours before maximum intensity

- It is important to know how the storms with the largest footprints of wind and precipitation behave since they can cause the largest risks.
- The top 10% most extreme footprint storms extremes peak at the same time.
- However the relationship is much weaker, particularly with the compound extremes.

Mean area fraction of extremes for



How does the frequency and spatial pattern of extremes change over the extended winter period?

Percentage of wind extremes for each month



- The spatial pattern of wind extremes does not change over the winter half year
- The chance of a wind extreme grows during the season, peaking in January at 15% and then comes back down again

How does the frequency and spatial pattern of extremes change over the extended winter period?

Percentage of precipitation extremes for each month



- The spatial pattern of precipitation extremes does not change over the winter half year
- Precipitation peaks in October at 22% and slowly decreases during the season

How does the frequency and spatial pattern of extremes change over the extended winter period?

Percentage of compound extremes for each month



- The spatial pattern of compound extremes over the winter half year does not change greatly.
- There is not a clear trend of seasonality throughout the season.
- Although February and March have a lower chance of compound extremes than the other months.

How does the size of the footprint of extremes change over the extended winter period?

- Wind peaks in January 3.97%
- Precipitation peaks in October 2.73%
- Compound varies much less but largest months are Jan and Dec 0.7%

• Storms that cause the largest footprints of extremes change very little throughout the winter half year over Europe



Mean area fraction of extremes for

How does the frequency and spatial pattern of extremes change with intensity?

The most intense cyclones have far larger percentages of compound, wind and precipitation extremes than all cyclones

Extreme wind

- occurs up to 100% of the time in the top 1% most intense cyclones
- compared to only 12% in all cyclones
- up to 8 times more likely

Extreme precipitation

- occurs up to 70% of the time in the top 1% most intense cyclones
- compared to 13% in all cyclones
- up to 5 times more likely

Compound extremes

- occur up to 34% of the time in the top 1% most intense cyclones
- compared to 1.5% in all cyclones
- Up to 23 times more likely

Percentage of wind, precipitation and compound extremes for



How does the size of the footprint of extremes change with intensity?

- The more intense a storm, the larger the mean area fraction of extremes surrounding it.
- This is particularly true for wind extreme footprints (stronger correlation).

- Similarly with the top 10% most extreme footprint storms
- Although the relationships are not as strong (smaller correlations).

Mean area fraction of extremes for



How does the frequency and spatial pattern of extremes change with speed?

Percentage of wind, precipitation and compound extremes for wind extremes for slow, medium and fast moving cyclones



- The speed a cyclone is moving at maximum intensity affects both the frequency and spatial pattern of wind, precipitation and compound extremes within a cyclone.
- Faster cyclones have roughly 2 times larger percentages of extremes.
- Faster cyclones have extremes focussed more southwards than slow moving cyclones
- Which increases the chance of compound extremes

How does the size of the footprint of extremes change with speed?

- The faster a storm at maximum intensity the larger the ٠ surrounding area of extremes.
- This relationship is seen much stronger in the fastest storms. ٠

- No clear relationship was found between the mean area fraction of extremes around a extreme footprint storm and speed.
- This suggests the most extreme footprint storms average speed ٠ at maximum intensity makes little difference to the size of the footprint of extremes.

0.094 a) All storms 0.090 0.056 20 30 10 Average speed (km/h)



Mean area fraction of extremes for

30

fraction area (%)

Summary

1. What is the frequency, spatial pattern and footprint size of wind, precipitation and compound extremes within cyclones over their lifecycle?

Wind extremes are focussed behind the cyclone centre within the cold conveyor belt, up to 30% of the time. Peak at max intensity

Precipitation and compound extremes

occur mainly ahead of the cyclone centre, in the warm conveyor belt, up to 33% and 5.4% of the time. Peak 6 hours before max intensity

Wind extreme footprints are almost 2times larger than precipitation and almost5 times larger than compound.

2. How does the frequency, spatial pattern and footprint size of extremes change with seasonality, intensity and speed?

The spatial structure of the wind, precipitation and compound extremes within a cyclone averaged over Europe is fairly **consistent** and **varies very little** with **seasonality**, **intensity** and **speed**.

The **frequency** of extremes and **footprint** size however **varies** largely.



Percentage of extremes associated with a cyclone at maximum intensity





Thank you! Any questions?

Additionally feel free to contact me at: lb663@exeter.ac.uk