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Factors controlling the footprint of European winter windstorms

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Vigorous winter extra-tropical cyclones are known to produce damaging windstorms at the surface in parts of Europe, but the footprint – or the product of its mean area and intensity – varies significantly between storms. Previous studies have assessed the dynamics and impacts of individual windstorm case studies. Here, we expand on this topic by identifying systematic relationships between windstorms' footprints, their parent cyclones and cyclonic growth factors in large data sets.

Our data sets include 59 winters in ERA-20C reanalysis and 165 total winters in 3 runs simulated with the MPI Earth System Model under historical forcing. Windstorms are first identified by tracking clusters of anomalous surface wind speeds over time, which are then matched to their parent cyclones using an objective scheme. Their footprints are calculated by aggregating each windstorm's Storm Severity Index (SSI) within the European region. Comparing extremes of windstorm footprints, we find that higher footprints are associated with lower minimum core pressures and faster growing cyclones. Furthermore, windstorms experience their fastest growth within an 18-hour window of a cyclone's fastest growth and typically form two days after cyclogenesis. Cyclones which produce the highest windstorm footprints in Europe are more likely to generate near the Gulf Stream and intensify on the southwestern flank of the British Isles, a result consistent in both reanalysis and model data.

Then, we shift our attention to cyclonic growth factors such as Eady Growth Rates, lower-level potential vorticity (PV), jet streams, SST gradients, and land-sea contrasts. These factors are composited at the genesis and intensification phases of cyclones in the West and East Atlantic, respectively. The composites are separated for high- and low-windstorm footprint cyclones. We find stronger baroclinicity, jet streams and lower-level PV anomalies at the intensification phase for high-footprint cyclones compared to low-footprint cyclones. At the genesis phase, there is evidence for stronger meridional land-sea contrasts and baroclinicity. We find that SST gradients may play a role in the genesis frequency of a windstorm-forming cyclone in this region, but not necessarily on its subsequent European footprint. This SST gradient signal differs between both data sets.

Our results suggest that a specific chain of events will increase the probability that the footprint of a European windstorm is maximized. Its parent cyclone will likely form in the west Atlantic owing to baroclinicity associated with meridional land-sea contrasts, SST gradients or the eddy-driven jet stream. The cyclone gradually grows as it traverses the Atlantic ocean and intensifies on the southwestern flank of the British Isles. This is due to a combination of a transient downstream jet, higher baroclinicity, or latent heat release in the cyclone core. Finally, the windstorm follows shortly afterwards, entering Europe in its strongest phase.