# Spatial independence of wind storm gust extremes

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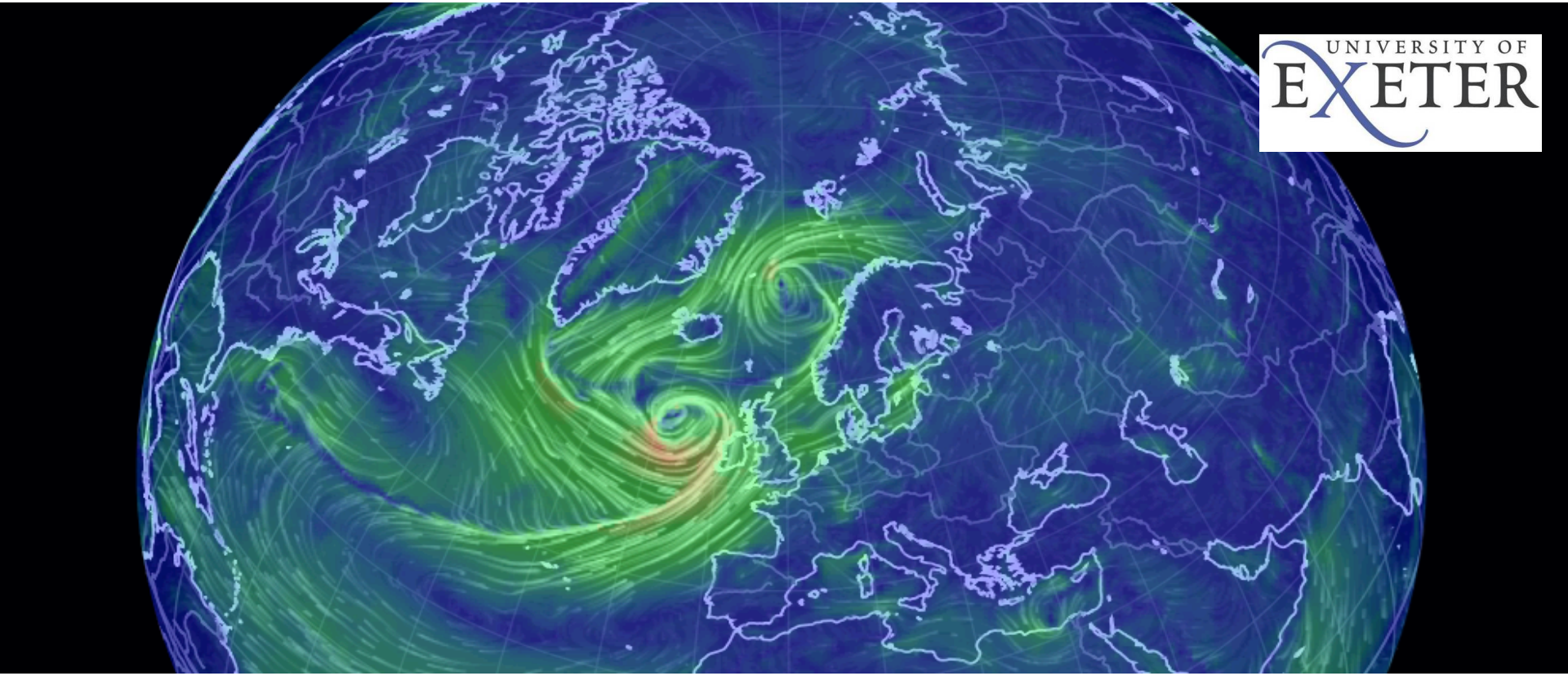
Exeter Climate Systems

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# Geostatistical modelling of windstorms

**Concept:**

Model wind gust speed footprints as realisations of a spatial stochastic process.

This alternative to more mechanistic models based on tracks provides a fast and useful benchmark for testing traditional cat models. *(i.e. scrambled rather than fried eggs!*).


- Dawkins, L.C. and D.B. Stephenson (2018) Quantification of extremal dependence in spatial natural hazard footprints: independence of windstorm gust speeds and its impact on aggregate losses, Natural Hazards in Earth System Science (in press)

- Dawkins, L.C. (2016). Statistical modelling of European windstorm footprints to explore hazard characteristics and insured loss . PhD thesis, University of Exeter, College of Engineering Mathematics and Physical Sciences. Freely available from **ethos.bl.uk**

- Youngman BD, Stephenson DB. (2016) A geostatistical extreme-value framework for fast simulation of natural hazard events, Proc. of the Royal Society A, vol. 472, no. 2189. ← Winner of the 2016 Lloyd's Science of Risk Prize!

# Windstorm footprints 1979/80-2013/14

**Definition of windstorm footprint**

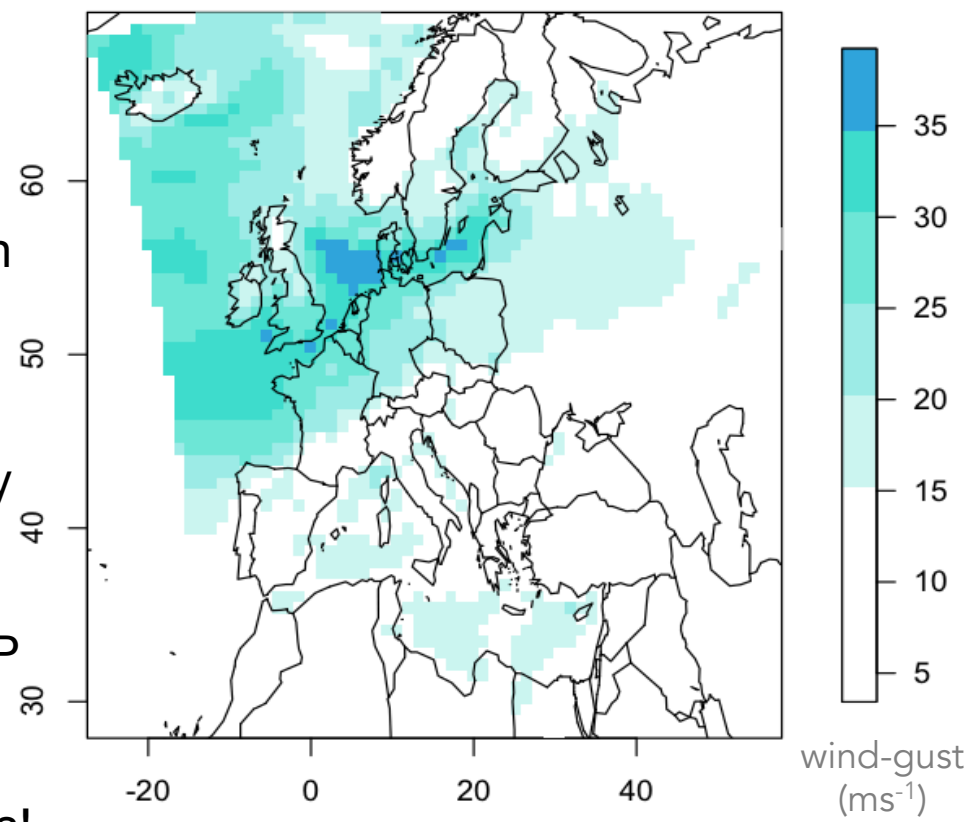
Maximum 3-second wind-gust speed at each grid point in a 72 hour period covering the passage of the storm, centred on the time at which the maximum wind speed over land occurs

Large sample of 6301 storms identified in extended winters (October-March) using objective tracking algorithm.

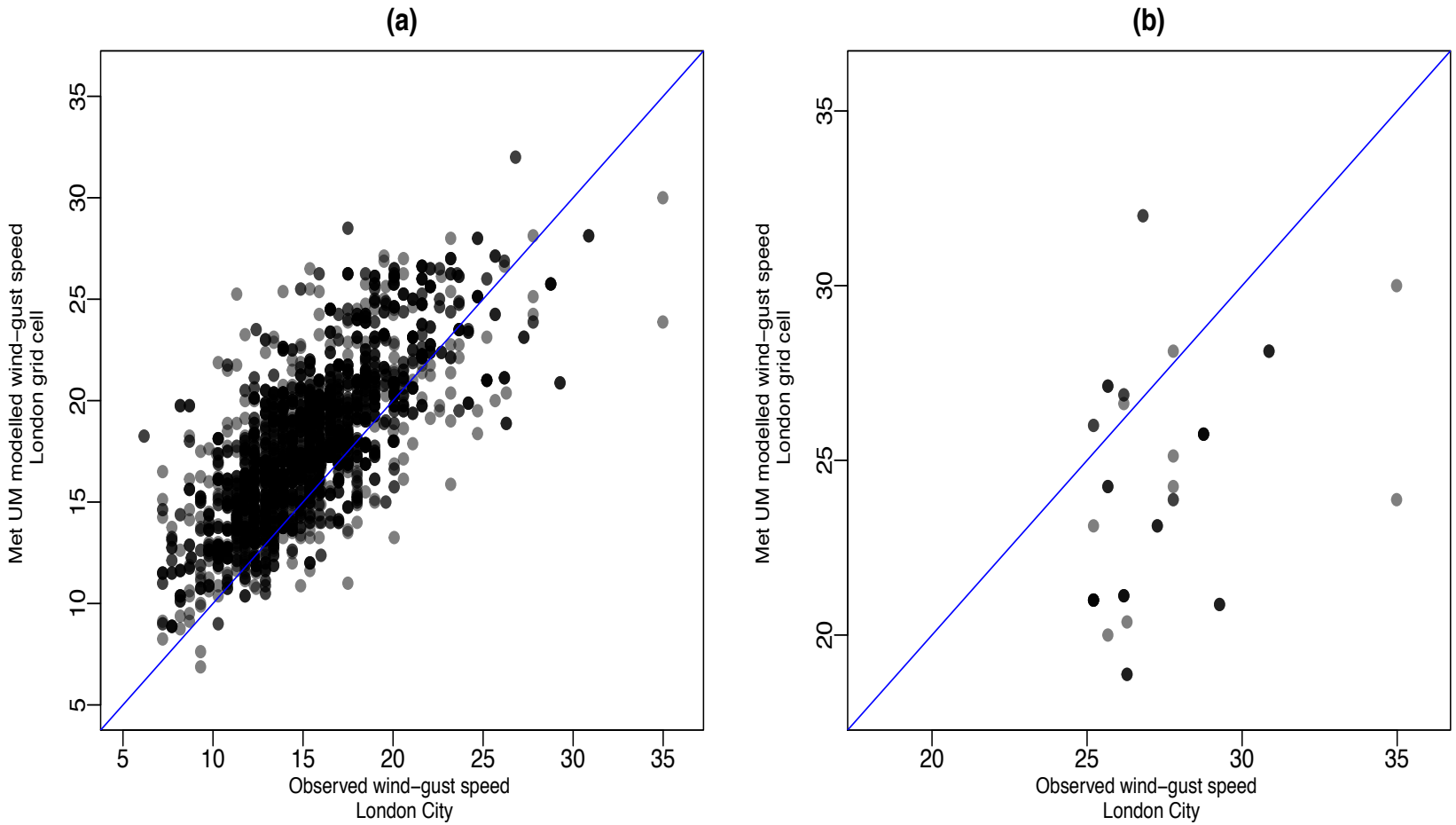
Then footprints created for each storm by dynamically downscaling ERA-Interim using the Met Office 25km resolution North Atlantic-European operational NWP model.

High dimensional data ~15000 grid points!

Example:
Footprint for windstorm Daria
(24th - 26th January 1990)

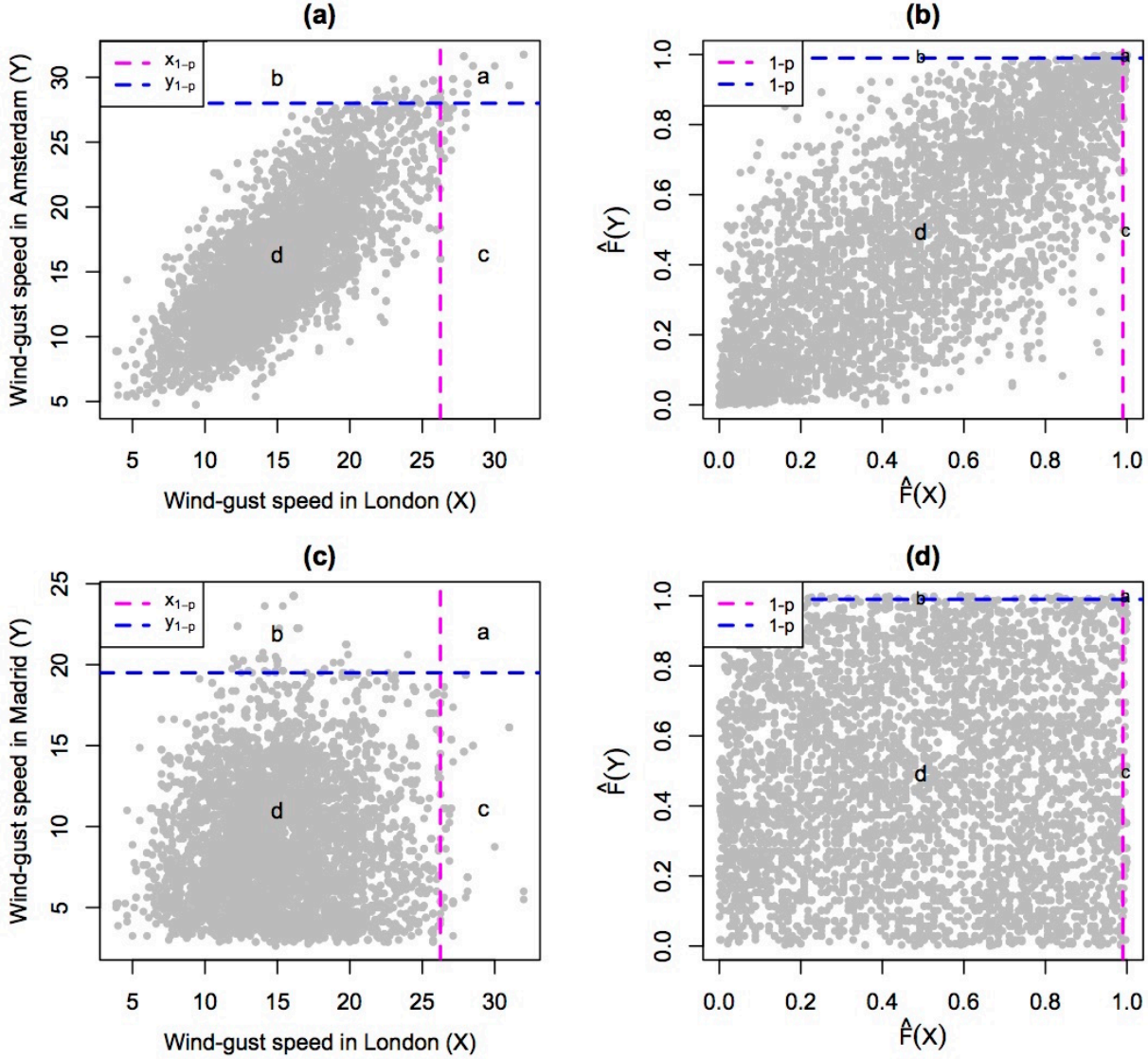


# How good are the model wind gust speeds?




→ Good agreement but with model speeds overestimating at low speeds and underestimating at high speeds (RMSE of 4.5m/s for top 50)

# Aggregate losses depend on joint distribution




London-Amsterdam

London-Madrid

Joint loss (points in a) is strongly determined by dependency between sites:
e.g. some dependency between London & Amsterdam but not London & Madrid

# Measuring extremal dependence in wind speeds

$$\chi(p) = \frac{\Pr(X > x_{1-p} \,\&\, Y > y_{1-p})}{\Pr(X > x_{1-p})}$$

$$\bar{\chi}(p) = \frac{2\log p}{\log \chi p} - 1$$

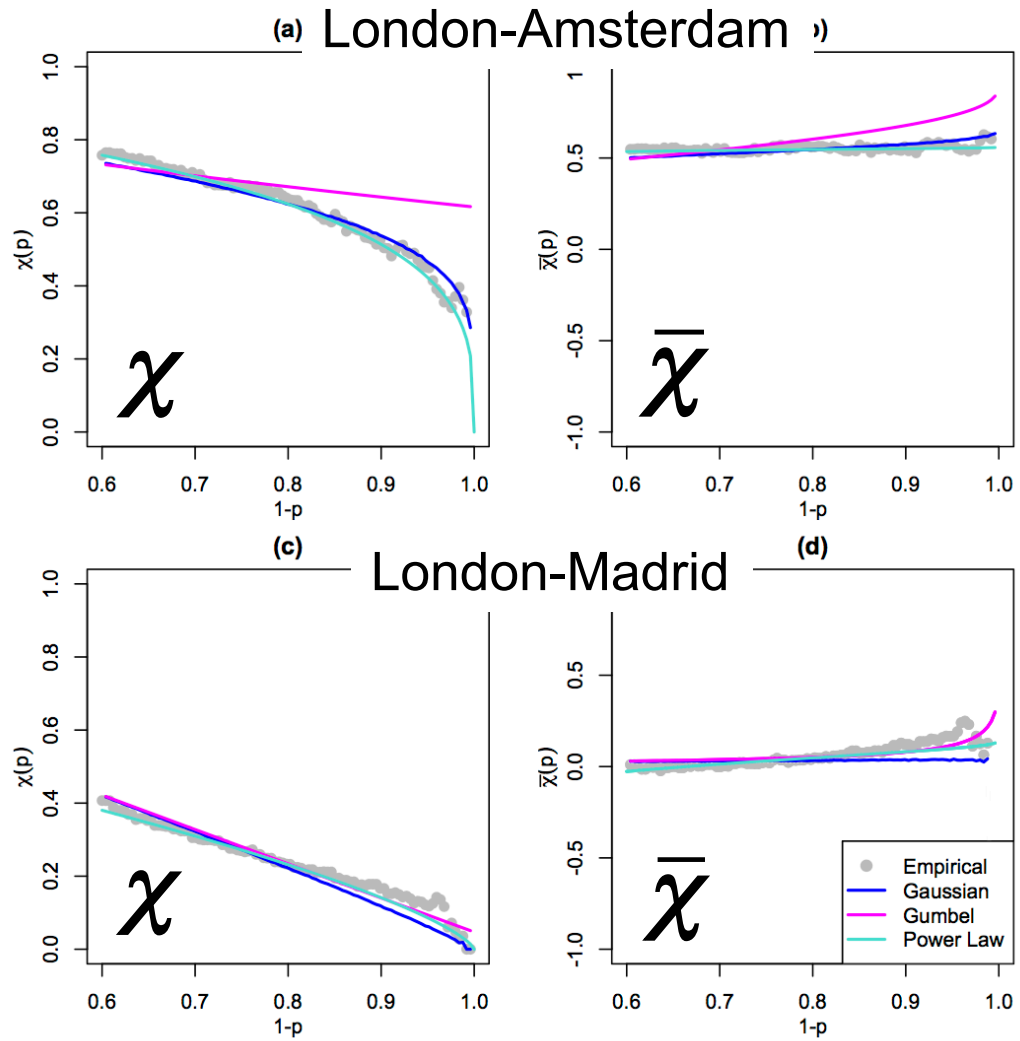
*As* $p = \Pr(X > x_{1-p}) \to 0$ either:

$\chi \to 0$ (extremal independence)

or $\neq 0$ and $\bar{\chi} \to 1$ (extremal dependence).

Perfect independence $(\chi = p, \bar{\chi} = 0)$

Perfect dependence $(\chi = 1, \bar{\chi} = 1)$




$\chi \to 0$ so no evidence of extremal dependence as assumed in previous studies

e.g. Bonazzi, A., Cusack, S., Mitas, C., and Jewson, S. (2012). The spatial structure of European wind storms as characterized by bivariate extreme-value copulas. Nat. Hazards Earth Syst. Sci. , 12:1769-1782.

# Copula models of dependency

Dependency between two variables can be quantified by factoring out the marginal distributions.

Any joint probability can be written as a function of the marginal probabilities:

$$\Pr(X \le x \,\&\, Y \le y) = C(u,v)$$

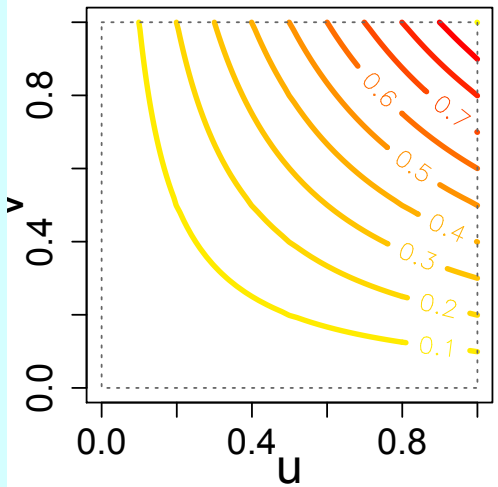
where

$$U = \Pr(X \le x) = F_X(x)$$

$$V = \Pr(Y \le y) = F_Y(y)$$

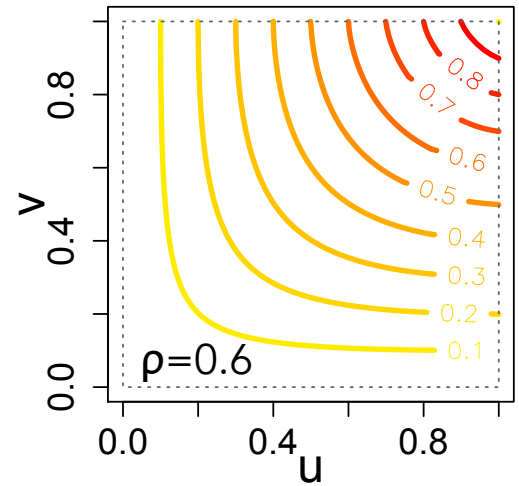
Independent

$$C(u,v) = uv$$



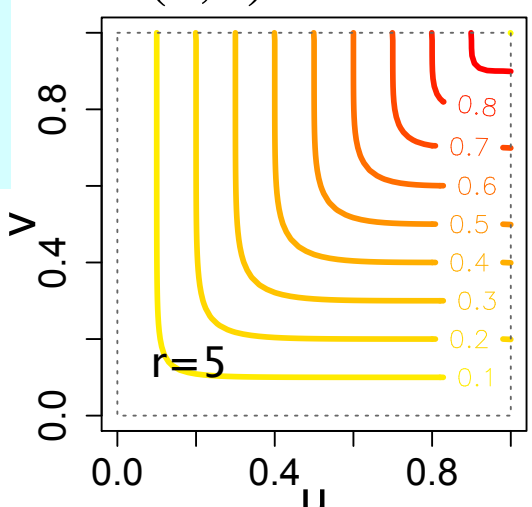

Gaussian/Normal

$$C(u,v) = \Phi_\Sigma(\Phi^{-1}(u), \Phi^{-1}(v))$$



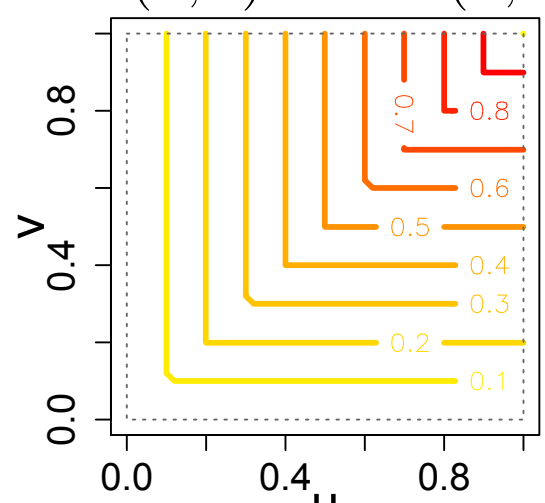

Gumbel

$$C(u,v) = e^{-((-\ln u)^r + (-\ln v)^r)^{1/r}}$$

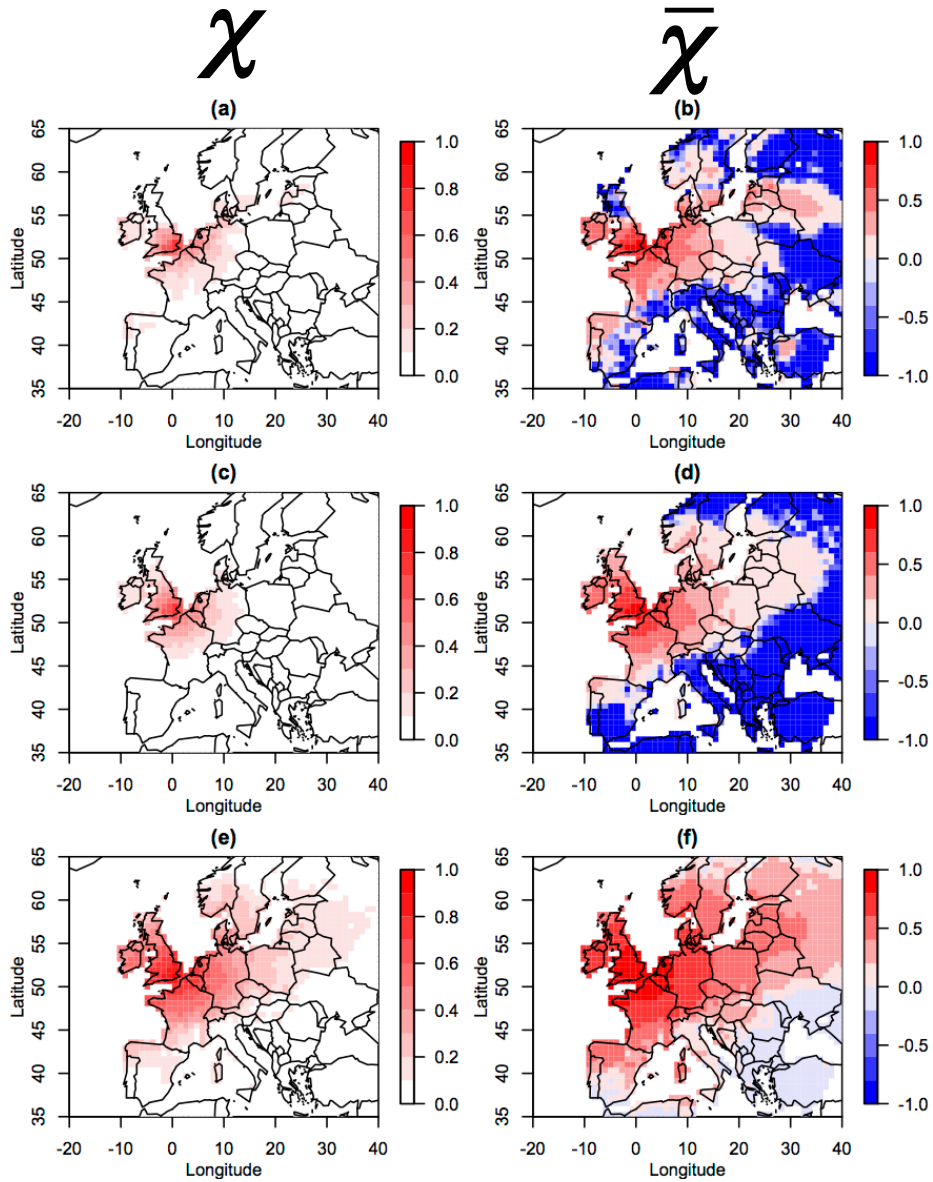



Perfectly Dependent

$$C(u,v) = min(u,v)$$



# Wind speed p=0.01 dependency with London



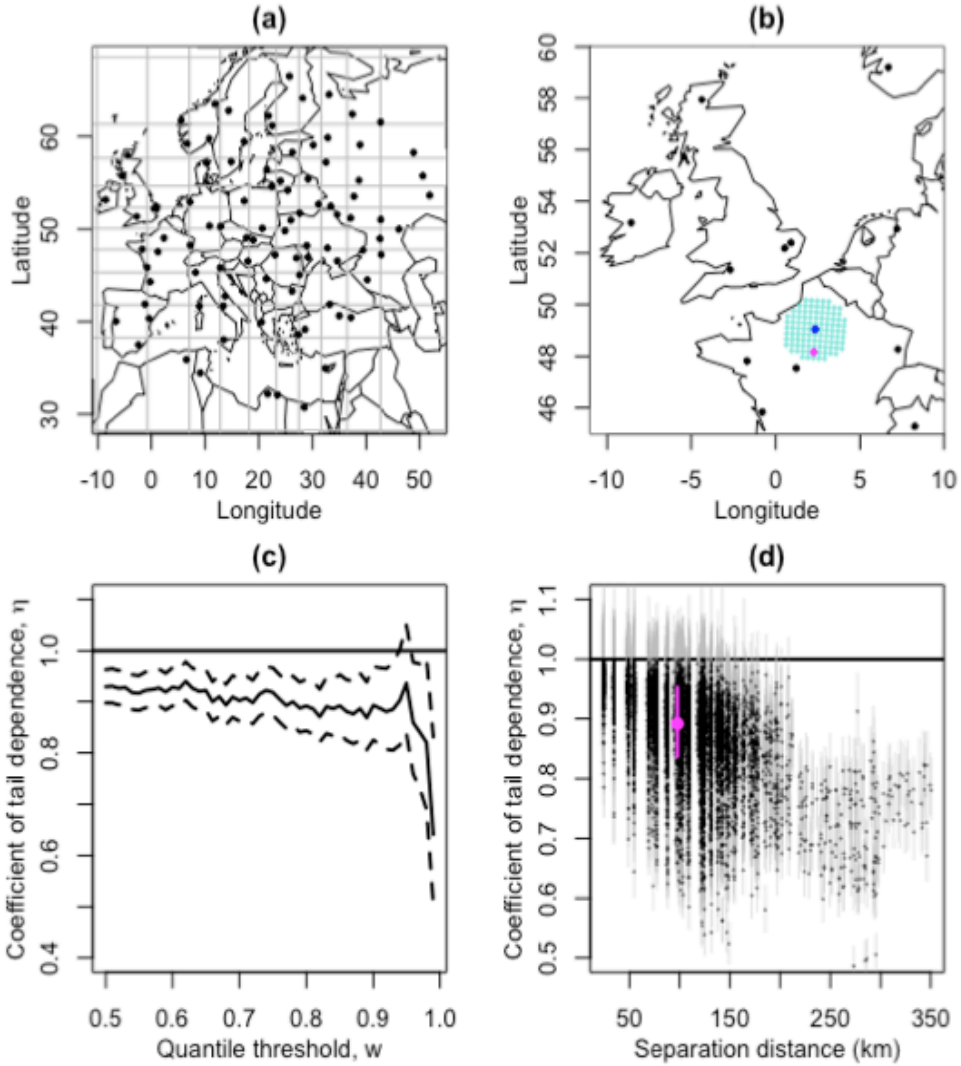

Empirical copula

Gaussian copula

Gumbel copula

→ Gaussian copula matches empirical whereas Gumbel overestimates dependence

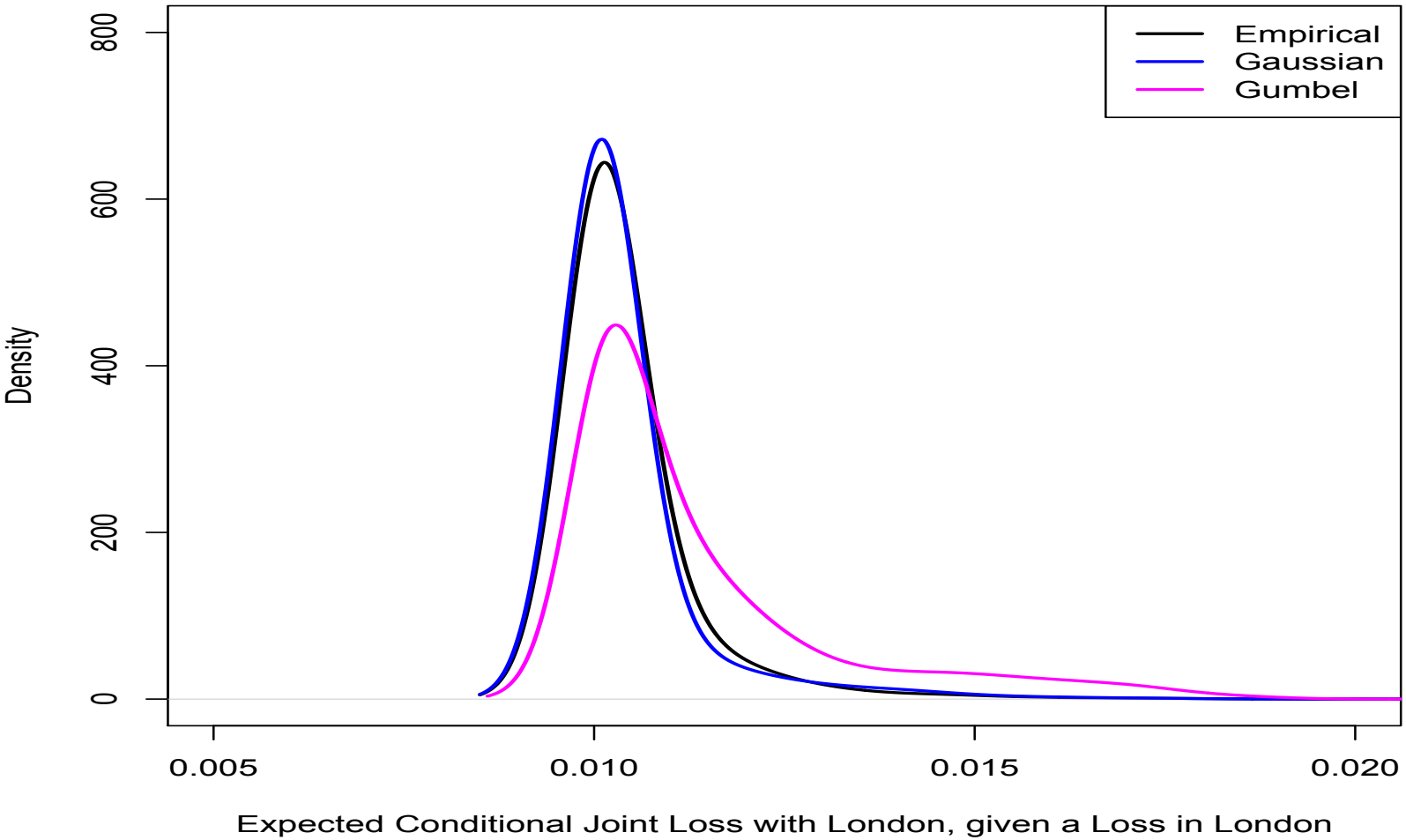
# Dependency between different locations across Europe




$$\bar{\chi} \rightarrow 2\eta - 1$$

→ Very little evidence for asympotic extremal dependence

# Distribution of total loss given a p<0.01 loss in London

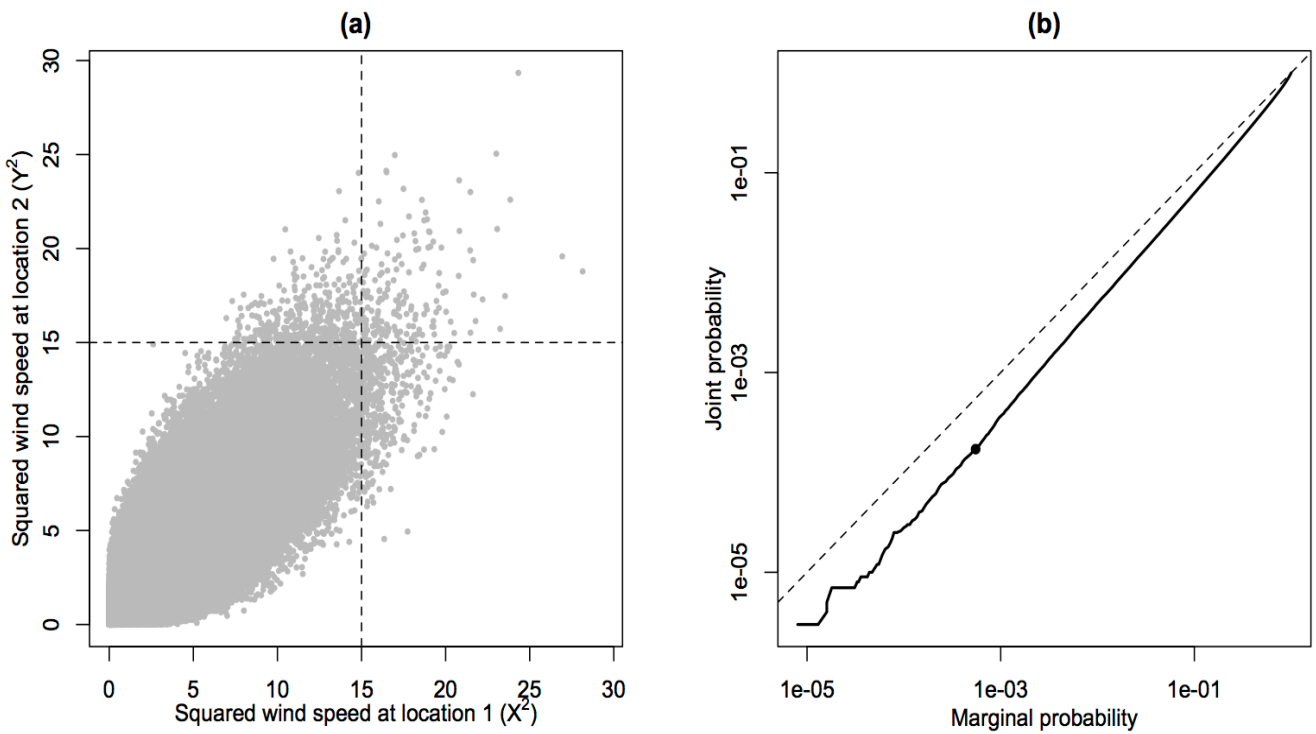



→ Gaussian copula matches empirical whereas Gumbel overestimates total losses

# Extremal dependence in homogeneous turbulence

Homogeneous turbulence can be simulated using spatially correlated Gaussian velocity components (Von Karman, 1937).

What does this imply for extremal dependence of squared wind speeds $u_1^2+v_1^2$ and $u_2^2+v_2^2$ at different locations?




Even for highly correlated velocities, the joint probability of exceedance appears to drop off faster than the marginal probability at higher thresholds i.e. $\chi \rightarrow 0$ (not asymptotically extremally dependent).

# Summary

- There is not strong evidence for spatial extreme dependence in 6301 dynamically-downscaled European windstorm footprints;
- Dependence and aggregate losses overestimated by copula models that have extremal dependence e.g. Gumbel;
- Gaussian copula appears to fit the data well, which allows fast geostatistical simulation of footprints.

**LIVE LAPTOP DEMONSTRATION**

**Thank you for your attention:**
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