# European Wind Storms: extreme value analysis of joint wind gusts


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## Introduction

Extra-tropical wind storms are one of the most damaging type of natural catastrophes occurring in Europe . As a result, the extent to which statistical models can reproduce the properties of such storms is of great interest for many insurance and financial applications.

Risk Management Solutions has recently developed a catalogue of historical reconstructions of wind storm gusts over Europe from 1972 to 2010. In this work we focus our attention on bivariate extreme value distributions as derived by anemometer measurements.

This analysis has been applied to a dataset of 15 European countries and highlights relevant aspects of the spatial structure of wind gust *correlation* and its spatial anisotropy.

## Data Description

| dataset | # of stations | earliest record | coverage |
|---|---|---|---|
| GSOD | 500 | 1973 | Europe wide |
| UKMO | 700 | 1970 | Europe wide |
| DWD | 44 | 1972 | Germany |
| KNMI | 34 | 1971 | Netherlands |
| DNMI | 60 | 1987 | Norway |

We define a **storm footprint** as the collection of local maximum gusts over the entire duration of a synoptic storm. Correlations are sought with respect to storm footprints which mainly reflect the structure of insurance contracts that require the identification of separated and unique events.
Storm tracks automatically detected from ERA40/INTERIM reanalysis have been used to separate single storms from continuous station records. This process lead to the identification of 2720 potentially damaging storms that hit the domain in the last 38 years.
Local maxima have been quality checked and transformed to reference winds to sidestep topography and terrain effects. Multi-pass Barnes interpolation has been used to produce storm footprints on a variable resolution grid (VRG), ranging from 1 to 10 km. Gust values are then estimated from reference wind at any VRG cell using local site coefficients derived from Land Use and Land Coverage data. Finally, we have performed an additional aggregation to a coarser resolution, known as CRESTA, to further homogenize the dataset. CRESTA zones are defined with respect to the distribution of population and buildings and cover areas that in most countries correspond to 2 digit postal codes.



## Copulas and Tail Dependance

An useful procedure for constructing extreme value copulas was proposed by Pickands (1981). In the bivariate case an extreme value distribution has the general representation:

$$C(x,y)=\exp\left\{(\ln(F_X(X)+\ln(F_Y(Y))A\frac{\ln(F_Y(Y))}{\ln(F_X(X)+\ln(F_Y(Y))}\right\},$$

Symmetric and asymmetric Gumbel copulas can be represented by Pickands functions:

$$A(w)=(w^r+(1-w)^r)^{1/r}$$
$$A(w)=(1-\alpha)w+(1-\beta)(1-w)+((\alpha w^r+\beta(1-w)^r)^{1/r}$$

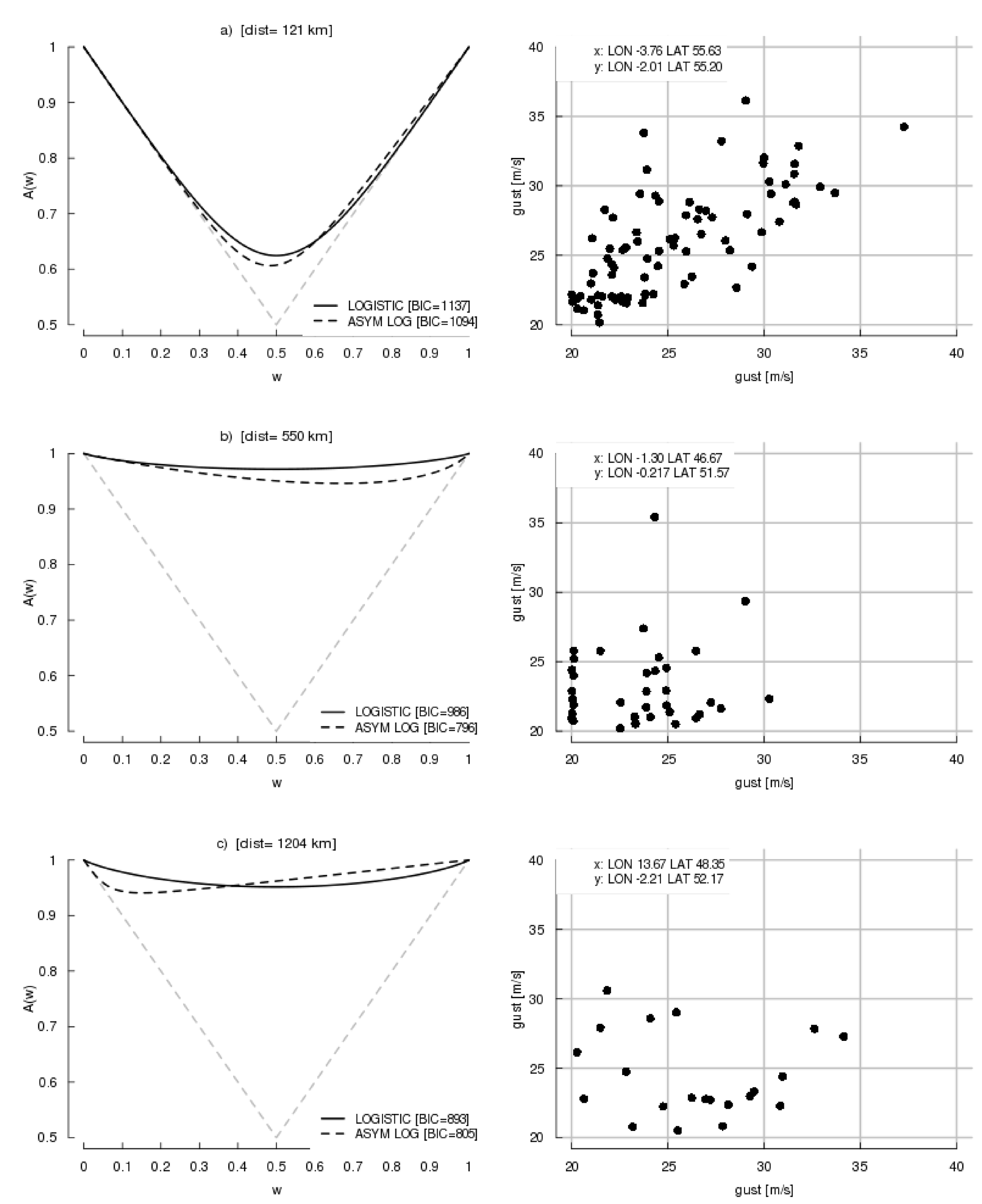
As a measure of tail dependence we use the conditional probability of one variable being extreme given that the other is extreme:

$$\chi=\lim_{n\to\infty}p(F_X(X)>u\,|\,F_Y(Y)>u),$$

$\chi$ is related to the Pickands representation *A* by,

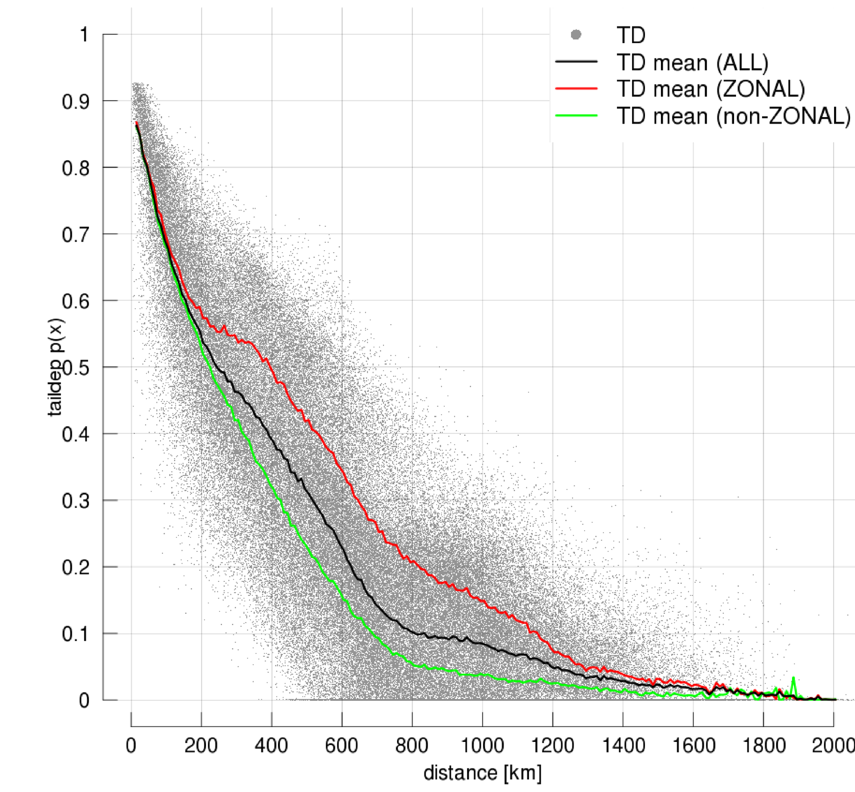
$$\chi=2(1-A(1/2)),$$

## Pickands Functions



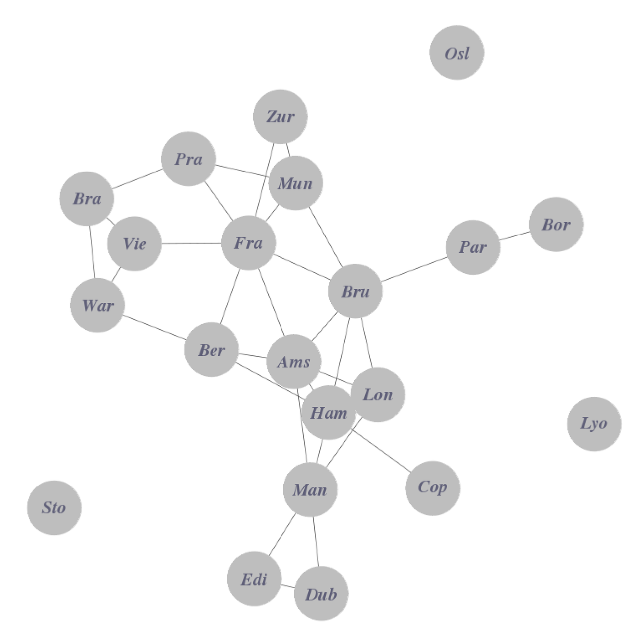

Parameter fitting of the copula and marginal parameters has been performed using *censored likelihood* as proposed by Ledford and Tawn (1984).
Bayesian Information Criterion has been used for model selection. The asymmetric model proved to be the better model for the majority of pair locations.

## Tail dependence



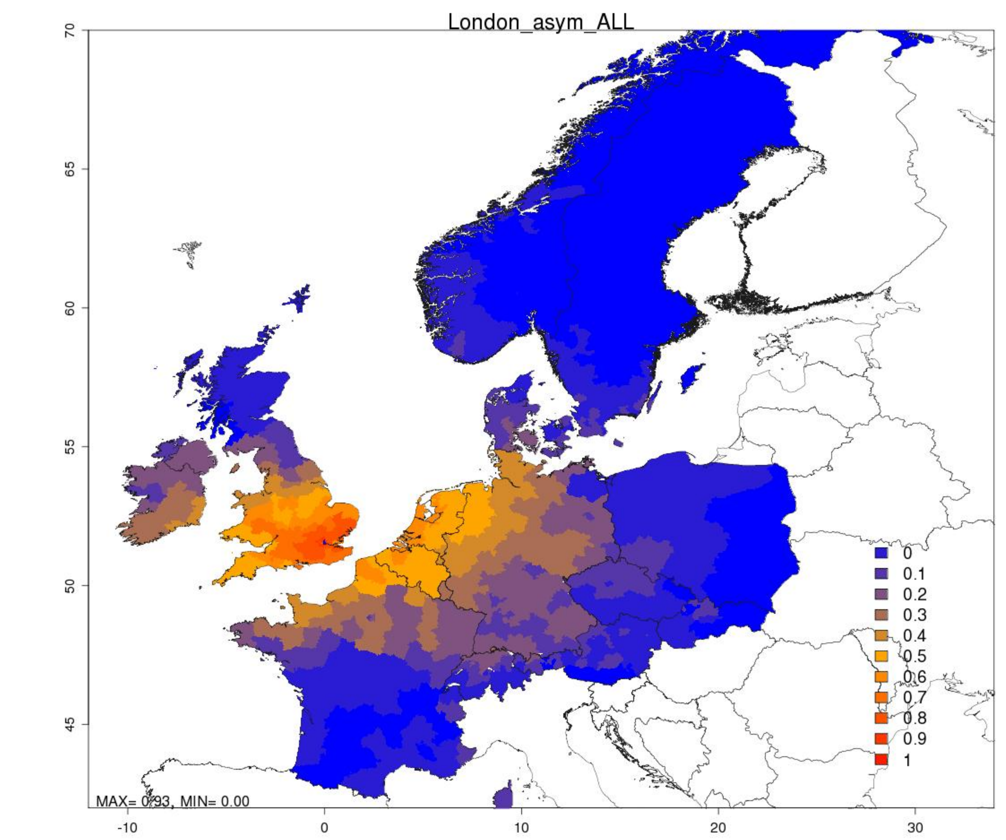

Tail dependence is generally a function of distance between locations. Up to a distance of 500 km, tail dependence is consistently high. Any two locations within a radius of 500 km have probability 0.45 to experience extreme gust during the passage of single extra-tropical storm.
We separated Zonal CRESTA pairs assuming predominant storm direction from west to east and computing bearing angle between western and eastern cities. Zonal pairs are defined to have bearing angle between 60 and 120 degrees. For the distance bin [500 - 1000] km the probability $\chi$ is 0.15 averaged over all copulas, and 0.26 when only zonal pairs are considered. The probability of joint extreme events almost doubles along the West-East direction.

## Extreme Events Graph



To visualize the pair-wise relations, we have drawn a graph using the 22 cities as vertices and tail-dependence as edge strength. The exceedence threshold value is 0.4.
Key drivers of this wide region of highly inter-correlated vertices are storms in the 1990s. Storm Daria ranks as the most or second most intense event in UK, Germany, Belgium, and Netherlands. Storm Vivian ranks within the four most intense events in UK, Germany, Denmark, Belgium, Switzerland, Luxemburg, Ireland, and Czech Republic.
Interestingly, London and Paris are not linked in the graph.

## London $\chi$




*Tail dependence $\chi$ centered in London*

## North Atlantic Oscillation

The North Atlantic Oscillation is responsible for variations in the orientation and strength of the Atlantic jet-stream and it is generally recognized to modulate low-frequency storm variability across the Atlantic and Europe.
Here we look for evidence that NAO also modulates the *tail dependence* of country-wide Storm Severe Index (SSI) defined as:

$$SSI=\left(\frac{\sum_i (X-X')^3 A_i}{\sum_i A_i}\right)^{1/3}$$

| Country pair | $\chi$ all storms | $\chi$ NAO+ | $\chi$ NAO- |
|---|---|---|---|
| *count ratio* | *100%* | *64%* | *36%* |
| UK-FR | 0.489 | 0.568 | 0.447 |
| UK-DE | 0.300 | 0.273 | 0.329 |
| FR-DE | 0.161 | 0.167 | 0.131 |
| UK-DK | 0.204 | **0.185** | **0.001** |
| FR-DK | 0.00 | 0.001 | 0.001 |
| DE-DK | 0.531 | 0.542 | 0.480 |

While the large majority of storms are observed during positive phase of NAO, there is not a clear signal suggesting a similar pattern for the dependence structure of country wide SSI. However there is a notable increase in the strength of tail correlation between UK and Denmark with NAO+.

## Key Points

- Spatial structure of tail dependence favors correlation along East-West direction.
- No clear signal suggesting NAO influence on dependence structure of SSI.
- This analysis constitutes a correlation benchmark for the European Wind Storm model (EUWS 2011) based on NWP simulations developed by RMS.