Vertical profiles of wind gust statistics

from a regional reanalysis using multivariate extreme value theory

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Motivation

Create a stochastic model for wind gusts in different heights as a function of weather model predictions!

Method

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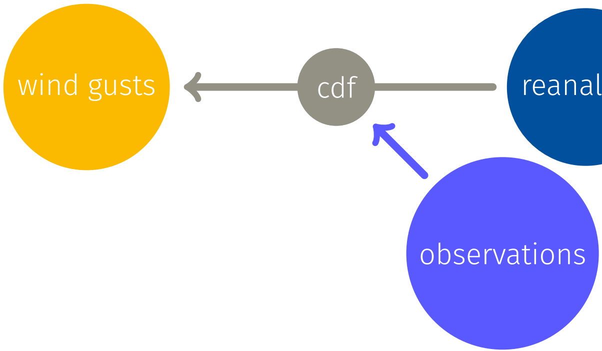
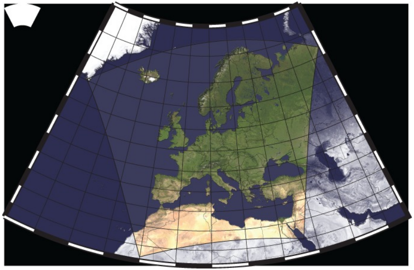


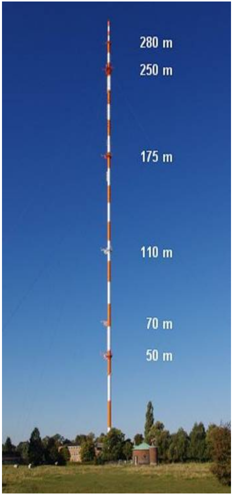
Wind gusts from the **Hamburg weather mast** (Lange 2014)

- in 5 levels (10m, 50m, 110m, 175m, 250m)
- for every 5 min from 2004 to 2014 ⇒ hourly gust maxima of 3 s duration

Hourly **COSMO-REA6** data (Bollmeyer et al. 2015)

- in 40 levels and mast surrounding 25 columns





Extreme Value Theory: model 1 (layer-wise)

Generalized extreme value (GEV) family with cdf

$$G(z) = \exp\Big\{ - \big[1 + \xi(\frac{z-\mu}{\sigma})\big]_+^{-1/\xi} \Big\},$$

and location $\mu \in (-\infty, \infty)$, scale $\sigma \in [0, \infty\}$ and shape $\xi \in (-\infty, \infty)$.

- $P(FB_{\text{alt}} \leq z) \approx G(z; \mu, \sigma, \xi)$ with

$$\mu = \mu_0 + \mu_1 C_1 + \mu_2 C_2 + \mu_3 C_3 + \ldots$$
$$\sigma = \exp(\sigma_0 + \sigma_1 C_1 + \sigma_2 C_2 + \sigma_3 C_3 + \ldots)$$
$$\xi = \xi_0$$

- $C_i(t)$ from COSMO REA6 and identical in every altitude

- Penalized Maximum Likelihood Estimation (LASSO) in a cross-validation method on the years $\mapsto$ 11 estimates

Model 2 (vertical model)

- use Legendre Polynomials:

$$P_0(x) = 1, \quad P_1(x) = x, \quad P_2(x) = \frac{1}{2}(3x^2 - 1) \quad \text{for } x \in [0, 1].$$

- for $x(10\,m) = 0$ and $x(250\,m) = 1$:

$$\begin{aligned}\mu(x,t) = \mu_{00}P_0(x) + \mu_{01}P_1(x) + \mu_{02}P_2(x) + \\ [\mu_{10}P_0(x) + \mu_{11}P_1(x) + \mu_{12}P_2(x)]C_1(t) + \dots,\end{aligned}$$

$$\begin{aligned}\sigma(x,t) = \exp(\,\sigma_{00}P_0(x) + \sigma_{01}P_1(x) + \sigma_{02}P_2(x) + \\ [\sigma_{10}P_0(x) + \sigma_{11}P_1(x) + \sigma_{12}P_2(x)]C_1(t) + \dots).\end{aligned}$$

$\rightarrow$ enables prediction between layers
(double cross-validation on years and levels)

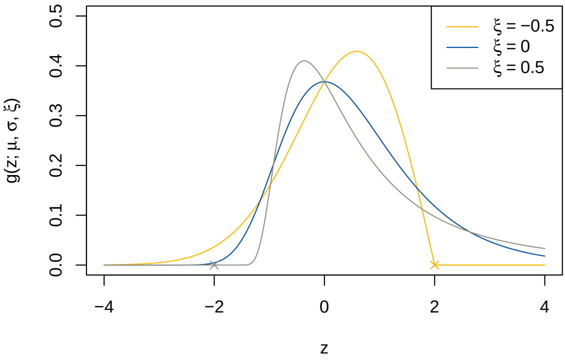
- and fix $\xi = 0$.

Restriction on Gumbel distribution

Weibull

Gumbel

Frechét

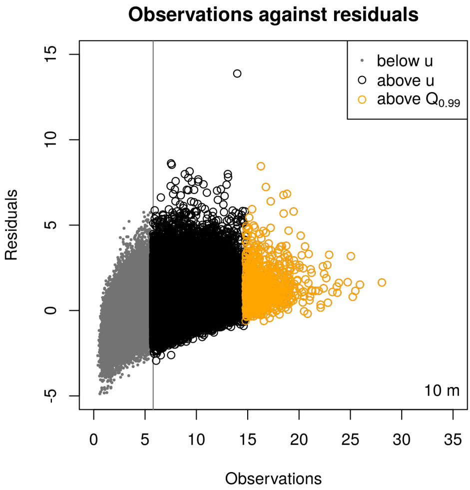


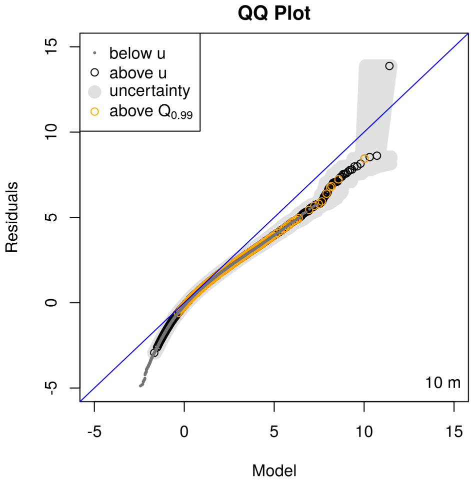
Results

LASSO selection

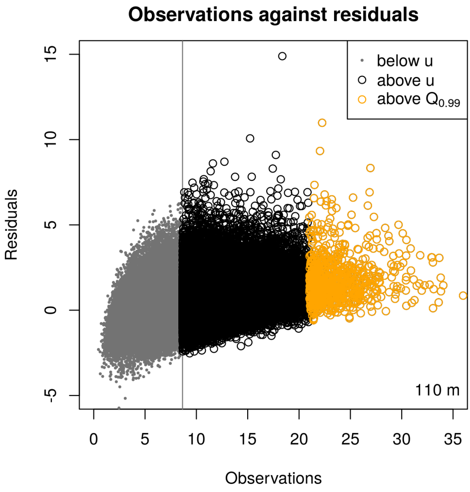
LASSO selection (×) in Model covariates (grey) for	LP1 ∼ const.		LP2 ∼ lin.		LP3 ∼ quad.	
	μ	σ	μ	σ	μ	σ
Wind gust diagnostic in 10 m (VMAX_10M)	×	×				
Temporal variance (±2 h) of VMAX_10M		×		×		
Barotropic mode of horizontal wind in mast layers	×		×			
Baroclinic mode of horizontal wind in mast layers		×	×			
Mean horizontal wind in 700 hPa	×	×	×			
SD of horizontal wind in 700 hPa						
Mean vertical wind in 700 hPa						
SD of vertical wind in 700 hPa		×				
Pressure tendency	×	×				
Lifted index		×				
Water content grid column	×					
SD of CAPE						
Diff abs. horizontal wind in 6 km and 1 km						
Temperature in 2 m						
Annual cycle		×				

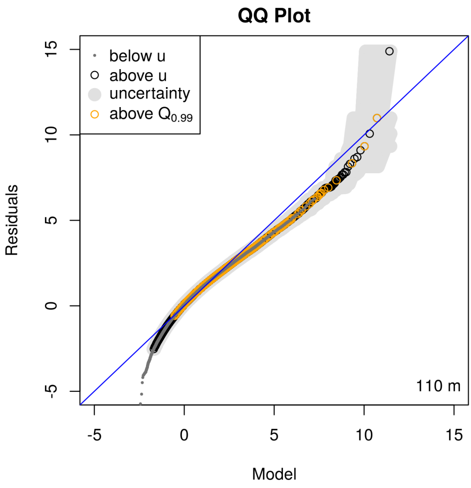
Residuals in 10 m



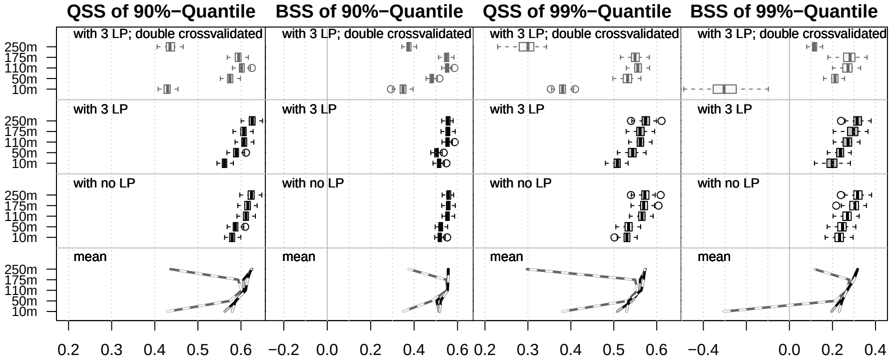


Residuals in 110 m





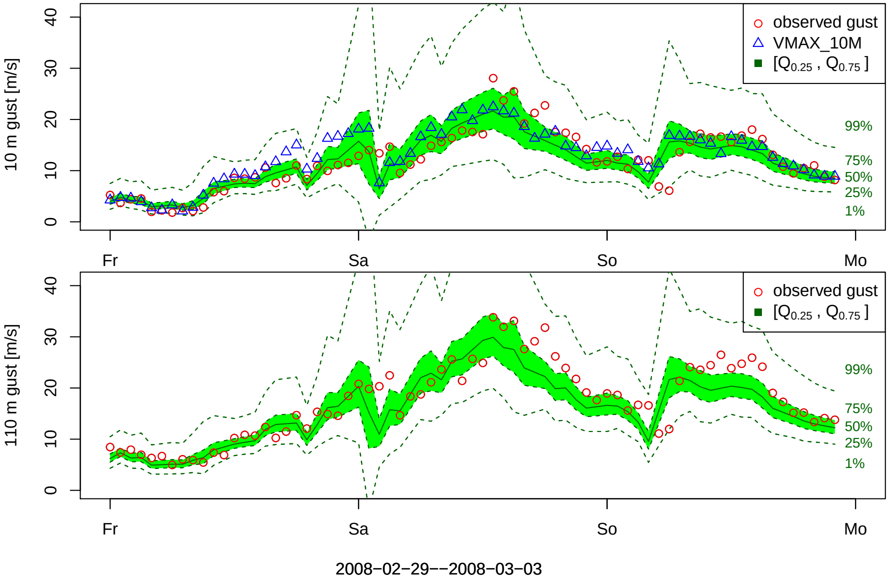
Verification: skill scores against layer-wise constant model



The quantiles correspond with increasing height towards thresholds [ms^{-1}] of

10.3, 13.1, 14.4, 15.7, 16.9 [90 %]
14.8, 19.3, 21.0, 22.6, 24.0 [99 %]

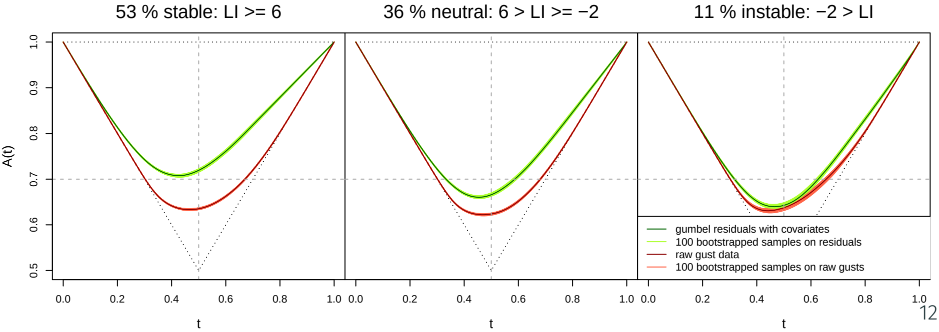
Example: Storm Emma



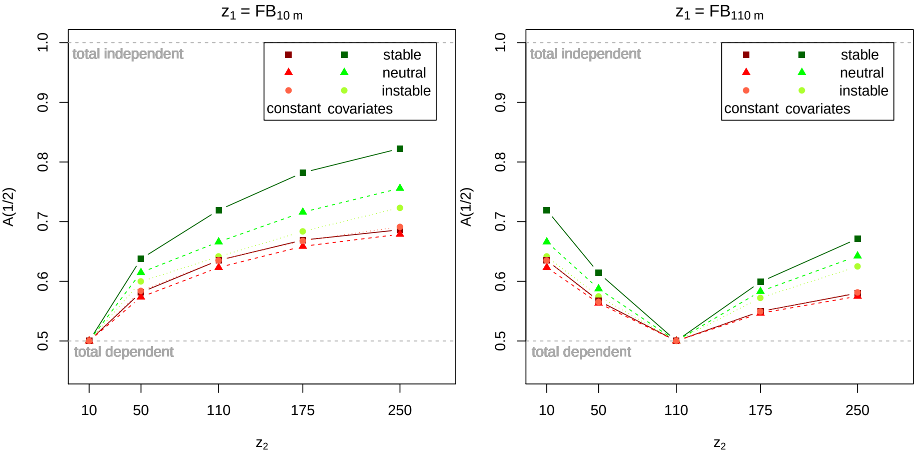
Dependency

Dependency function

- Non-parametric Pickands dependency function in the bivariate case (Pickands 1981)
  $A(t) = n \left[\sum_{i=1}^{n} \min\left(\frac{x_i}{t}, \frac{y_i}{1-t}\right) \right]^{-1}$ for $t = \frac{y}{x+y}$ with X, Y Frechét
- Distinguish between stable and instable situations
  $t = \frac{F_{110\ m}}{F_{10\ m} + F_{110\ m}}$



Dependency function



Conclusion

- the LASSO works for $\xi = 0$
- some outlier in the residuals exists, but high gusts are captured
- gusts in interior layers can be predicted
- dependency between the layers can be reduced

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