Hans-Ertel-Zentrum für Wetterforschung

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Estimation of Vertical Wind Gust Profiles

from Regional Reanalysis using Extreme Value Theory

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Motivation

Typical model forecasts and observations of wind gusts are provided for a standard height of 10 m above the surface. However, for many applications wind gusts on higher levels are of increasing relevance, e.g., for the renewable energy sector wind gusts at hub height are important. We present a statistical model for the vertical profile of hourly wind gusts as measured at the Hamburg Weather Mast.

Data

Observations

Wind gusts from the Hamburg Weather Mast

[Lange, 2014]

- gust = hourly maximum wind speed peak over 3 s
- 20 Hz wind measurements with 3d-ultra-sonic-anemometer (METEK USA-1)
- heights: 10 m, 50 m, 110 m, 175 m and 250 m
- period: 01/2004 – 12/2014

Covariates

Regional reanalysis COSMO-REA6

[Bollmeyer et al., 2015]

- covers Europe with ≈ 6 km horizontal grid spacing
- covariates from 25 mast-surrounding grid columns

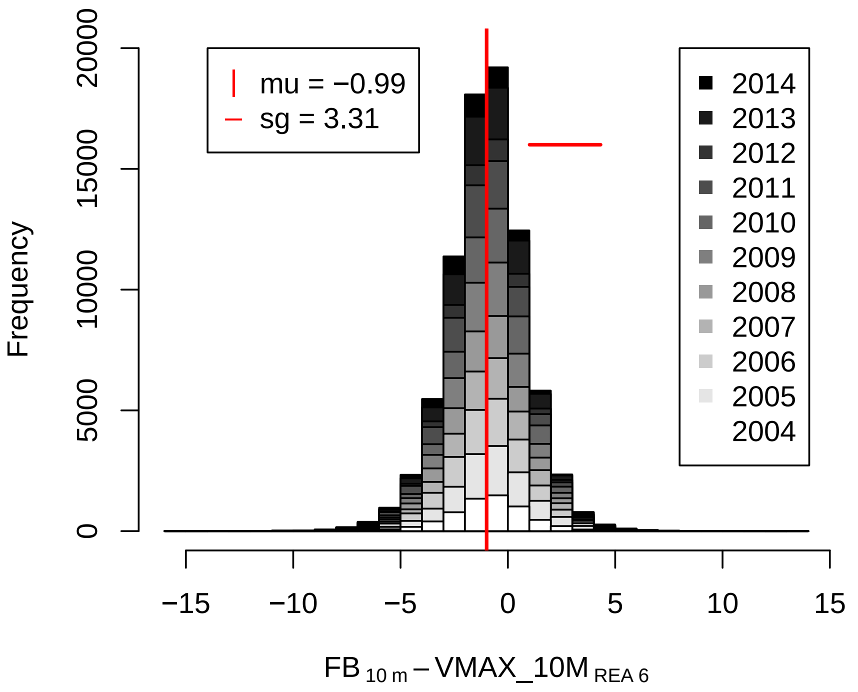

Fig. 1: Comparison of 10 m gust observation and reanalysis diagnostics.

Extreme Value Theorem

Let $M_n = \max\{X_1, ..., X_n\}$ be the block maximum of *iid* RV $X_1, ..., X_n$.

If there exist sequences of constants $\{a_n > 0\}$ and $\{b_n\}$ such that

$$Pr\{(M_n - b_n)/a_n \leq z\} \rightarrow G(z) \text{ as } n \rightarrow \infty \qquad (1)$$

for a non-degenerate distribution function G, then G is generalized extreme value (GEV) distributed with

$$G(z) = \exp\left\{-\left[1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}, \qquad (2)$$

defined on $\{z : 1 + \xi(z - \mu)/\sigma > 0\}$, where $\sigma > 0$.

[Gnedenko, 1943]

Approach

Marginal Profile Models

- consider hourly gusts at 5 heights as GEV distributed with parameters μ and $\ln(\sigma)$ linear covariate-dependent
- chose identical set of standardized covariates for all heights
- censored maximum likelihood parameter estimation (censoring at the height specific 50% - quantile)
- cross validation of 11 years ⇒ 11 estimates
- select the influential covariates with a LASSO

Unifying Vertical Model

- use Legendre Polynomials (constant, linear and quadratic) to describe height dependency of the parameters, e.g.: $\mu_0(z) = \mu_{00}LP_0 + \mu_{01}LP_1(z) + \mu_{02}LP_2(z)$
- infer parameters for unifying model with all heights at once (again via a censored MLE and in a cross validation)

LASSO variable selection

selected variables in	μ	σ
10 m wind gust diagnostics	μ_{VMAX_10M}	σ_{VMAX_10M}
wind horizontal (barotropic mode)	μ_{V_EOF1}	
wind horizontal (baroclinic mode)	μ_{V_EOF2}	σ_{V_EOF2}
mean wind in 700 hPa	μ_{M_V700}	σ_{M_V700}
SD of wind in 700 hPa		
mean vertical wind in 700 hPa		
SD of vertical wind in 700 hPa		
mean pressure tendency	μ_{dP}	
Lifted Index		σ_{LI}
water content		
SD of CAPE		
wind difference $\lvert\bar{V}\rvert_{6km} - \lvert\bar{V}\rvert_{1km}$		
temperature in 2 m		
annual cycle		

Verification: Continuous Ranked Probability and Quantile Skill Score (CRPSS / QSS)

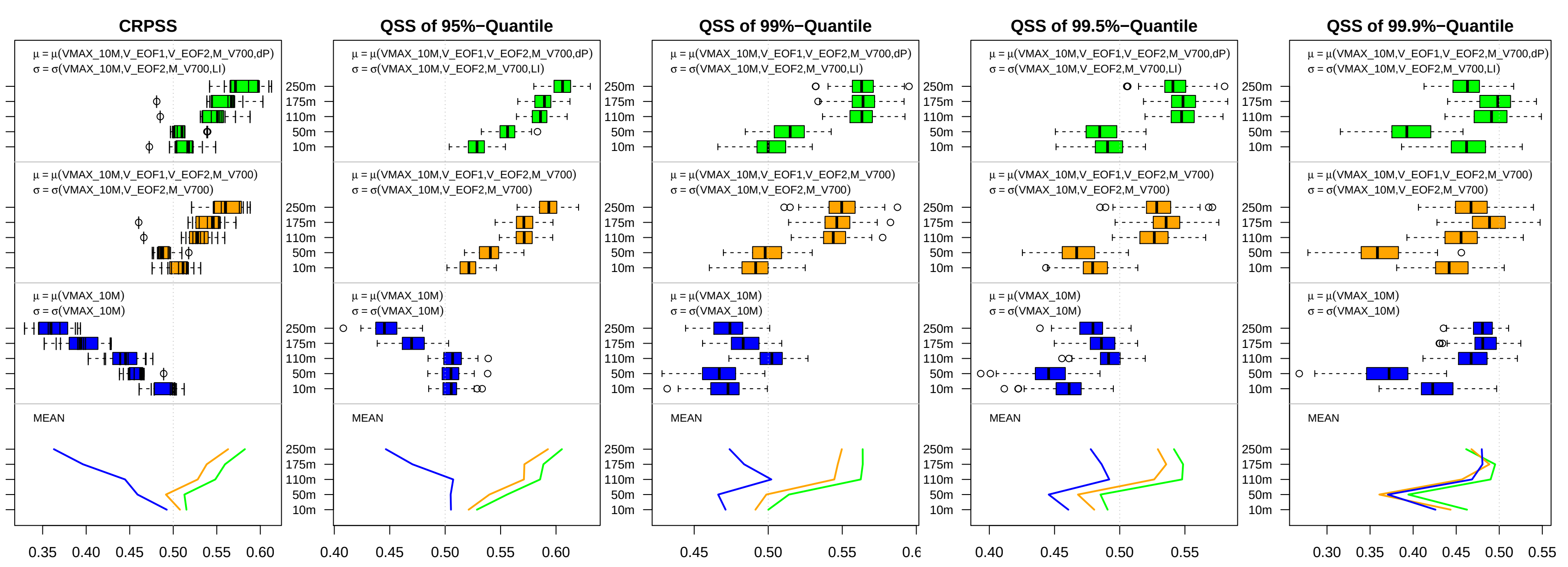

Fig. 2: CRPSS for the 11 years (left); and QSS for the 95%-, 99%-, 99.5%- and 99.9%-quantiles on 100 bootstrapped samples each representing full 11 years (four right); the reference is the climatology and the unifying vertical models are with all variables from the LASSO (green), with only wind covariates (orange), and with only the 10 m gust diagnostic (blue).

Example: Storm Emma

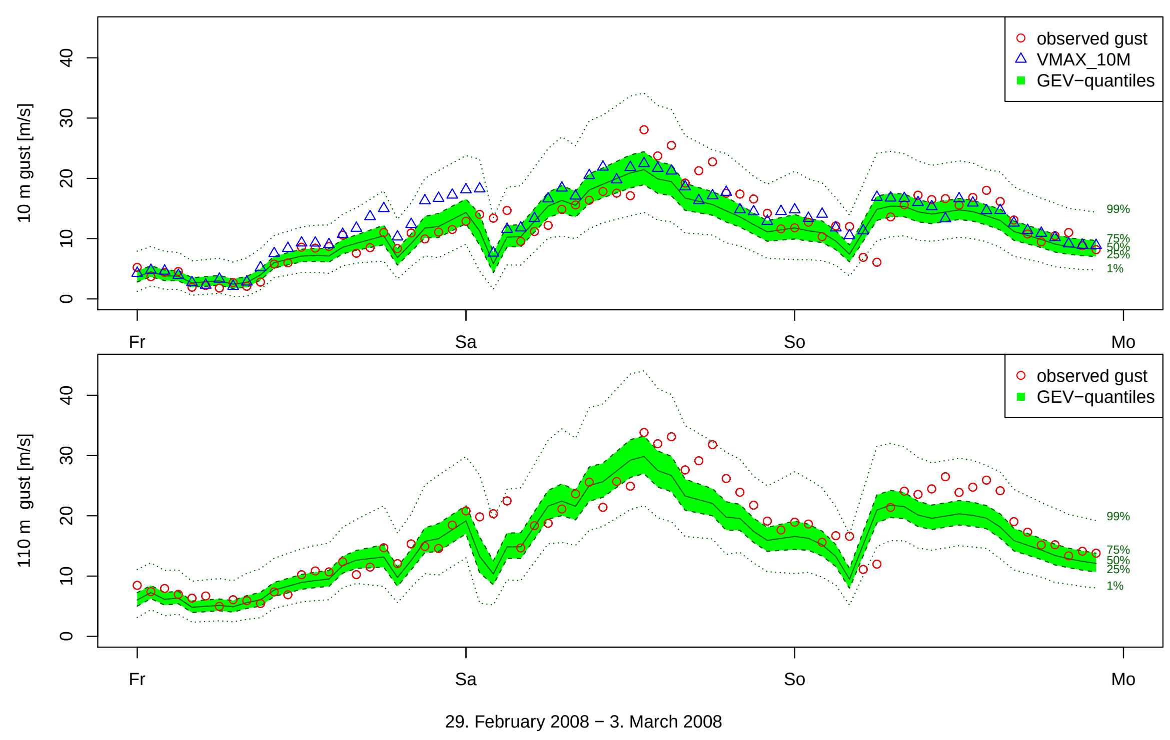

Fig. 3: Modeled wind gust quantiles for Storm Emma (2008) at Hamburg in 10 m with corresponding REA6 gust diagnostic (top) and in 110 m (bottom) with observations as measured at the Hamburg Weather Mast.

Dependency between layers

- dependency between two GEV RV can be analysed by the non-parametric Pickands dependency function $A(\omega)$ [Pickands, 1981]
- the model residuals are able to capture gust dependencies with respect to stability

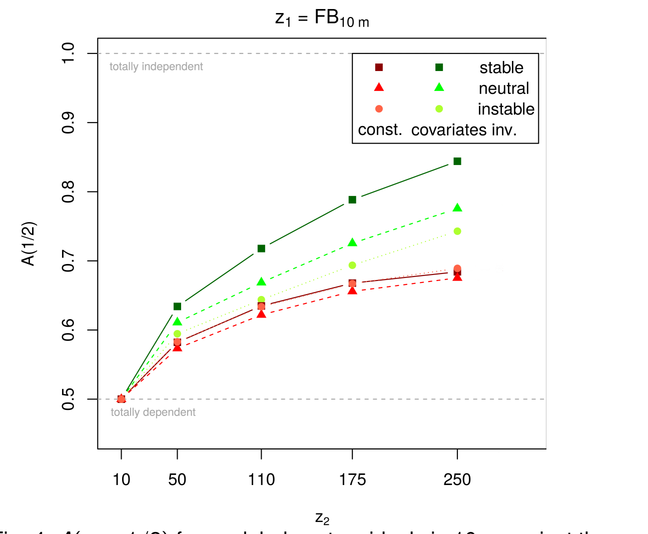

Fig. 4: $A(\omega = 1/2)$ for modeled gust residuals in 10 m against those in higher levels, with (green) and without covariates involving transformation(red). The stability criterion is the Lifted Index: stable ($LI \geq 6$), neutral ($6 > LI \geq -2$), instable ($-2 > LI$).

References

Bollmeyer, C. et al. (2015). *Towards a high-resolution regional reanalysis for the European CORDEX domain.* Quarterly Journal of the Royal Meteorological Society. DOI: 10.1002/qj.2486

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