Extreme Event Ecology (E³): Long-term changes in phenological extremes over six decades in Germany

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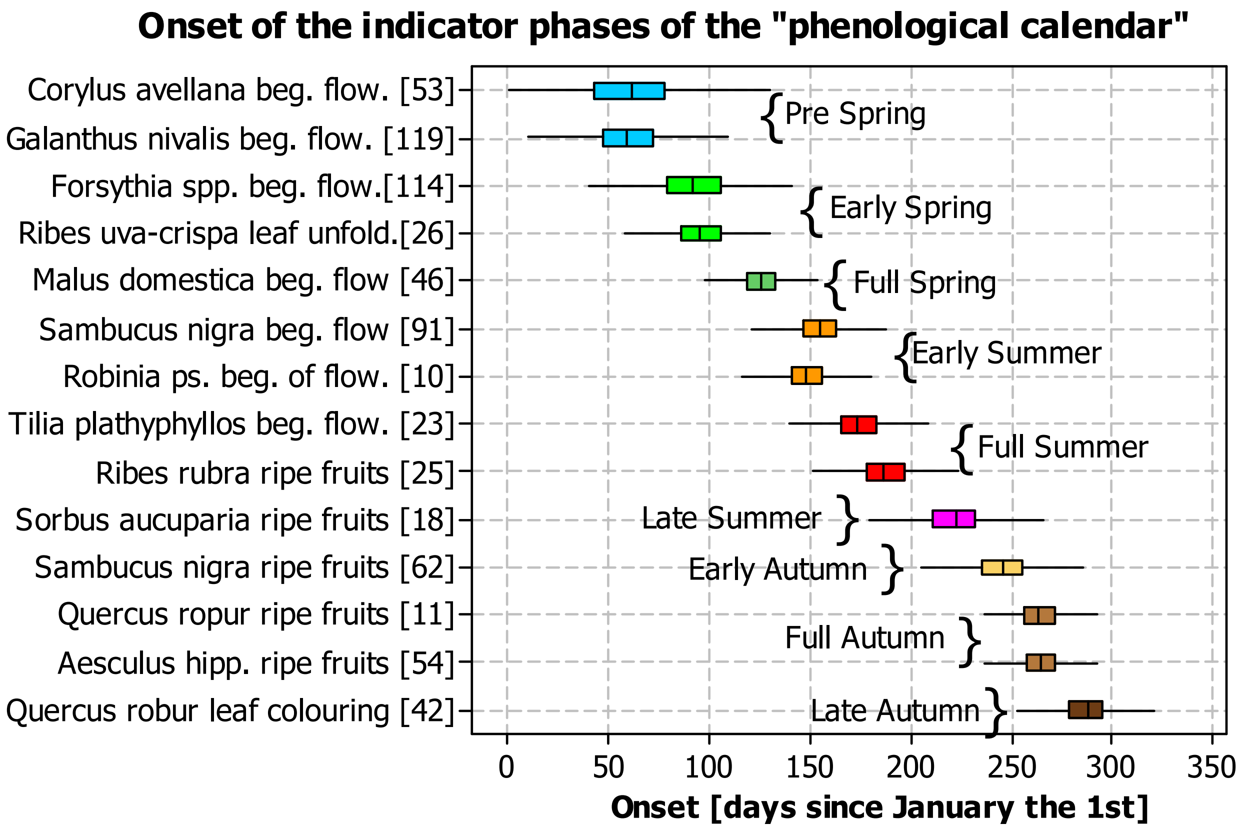
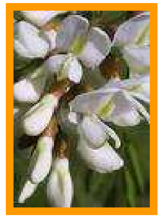
1. Material – Phenological data

- 14 indicator phases of the DWD (1951-2008)
- Records 50+, number of stations [n]

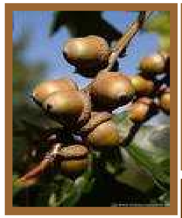








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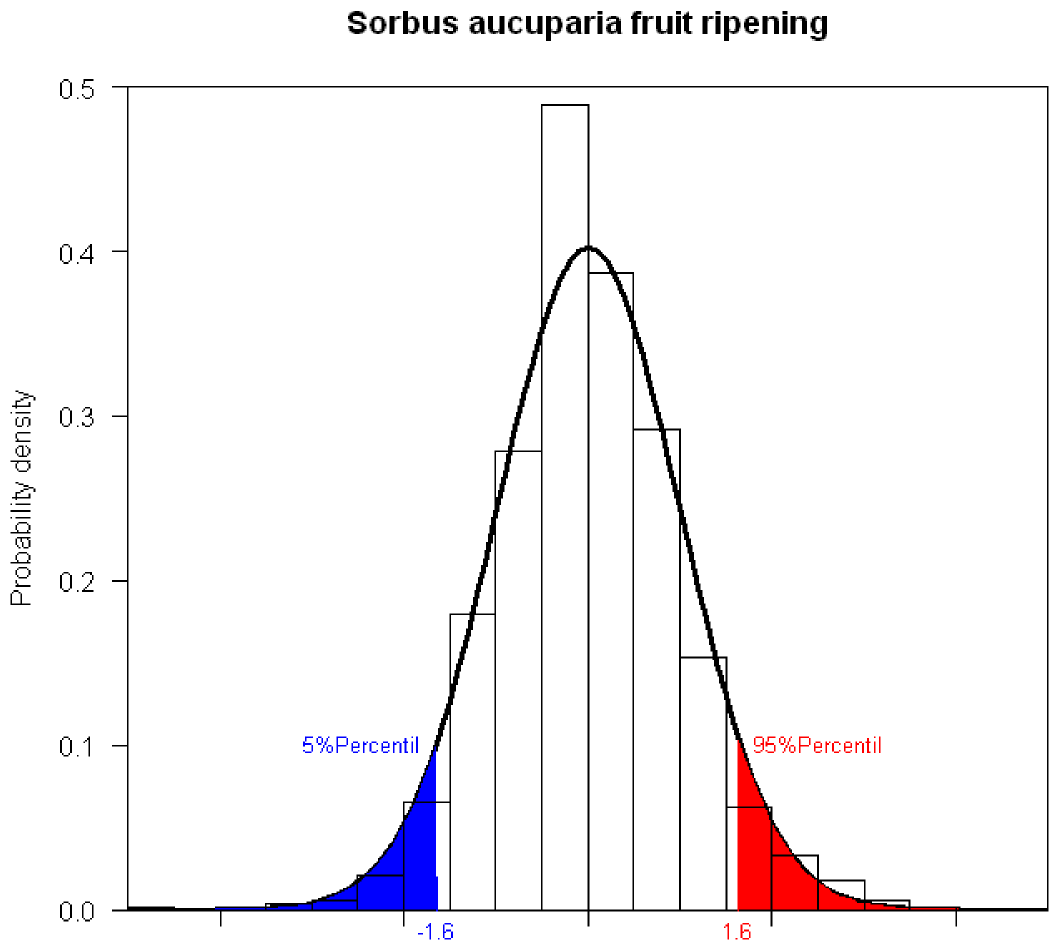
Definition of extremes



Standardized phenological onset dates

- Standardization
  $z = x - \mu / \sigma$
  within each station record

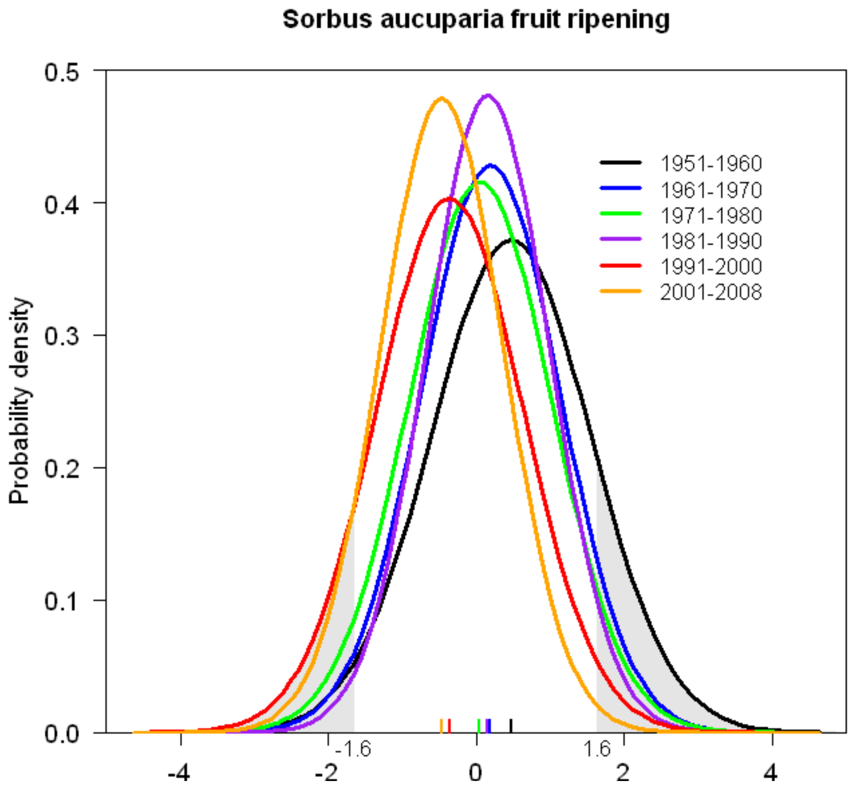
- Fit of Gaussian distribution to all data (1951-2008) for each species

- 5th and 95th percentiles as thresholds for extreme early and late onset dates

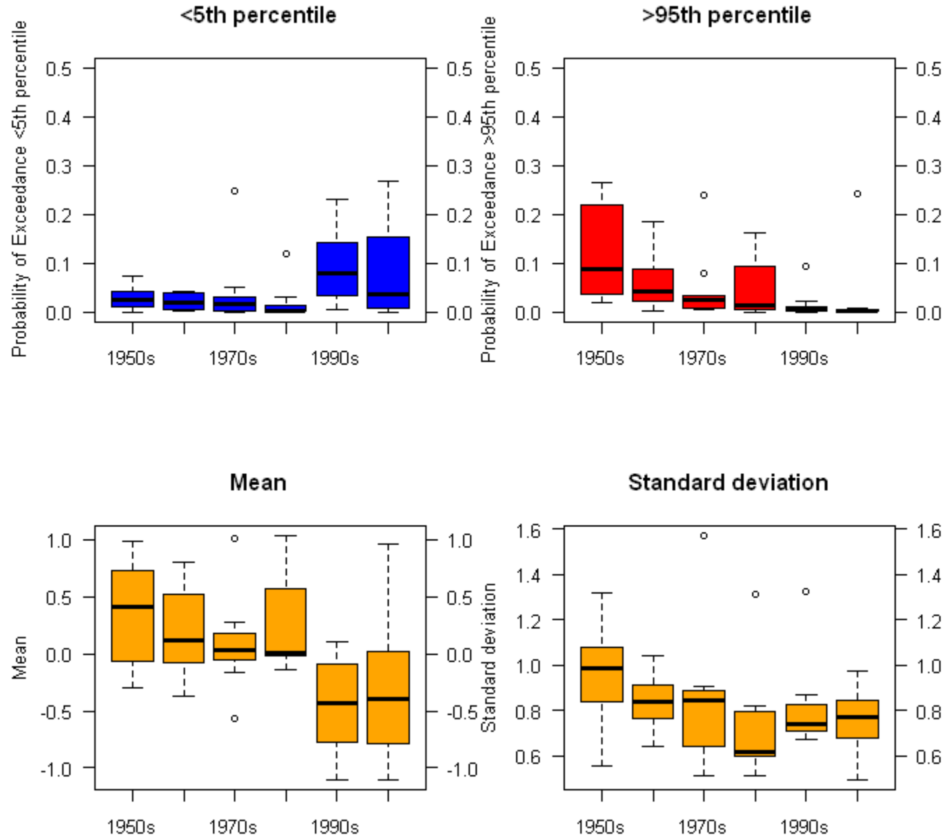
after Trömel & Schönwiese 2007

2.1 Results – Gaussian approach

Summary of mean, standard deviation and exceedances (<5th and >95th percentile) of decadal Gaussian fits for one selected phase



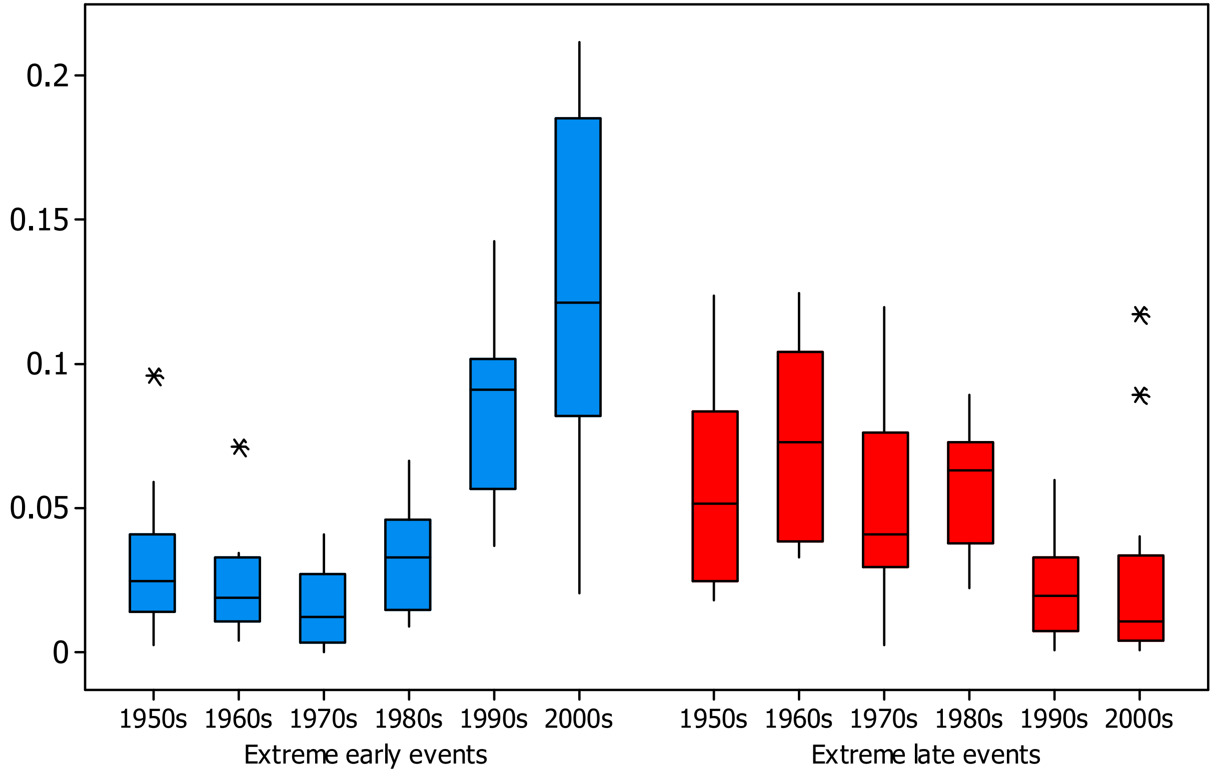
Standardized phenological onset dates



Gaussian fit to all stations for single species by decade, probability of a common 5th and 95th percentile threshold (derived from 1951-2008) for each decade.

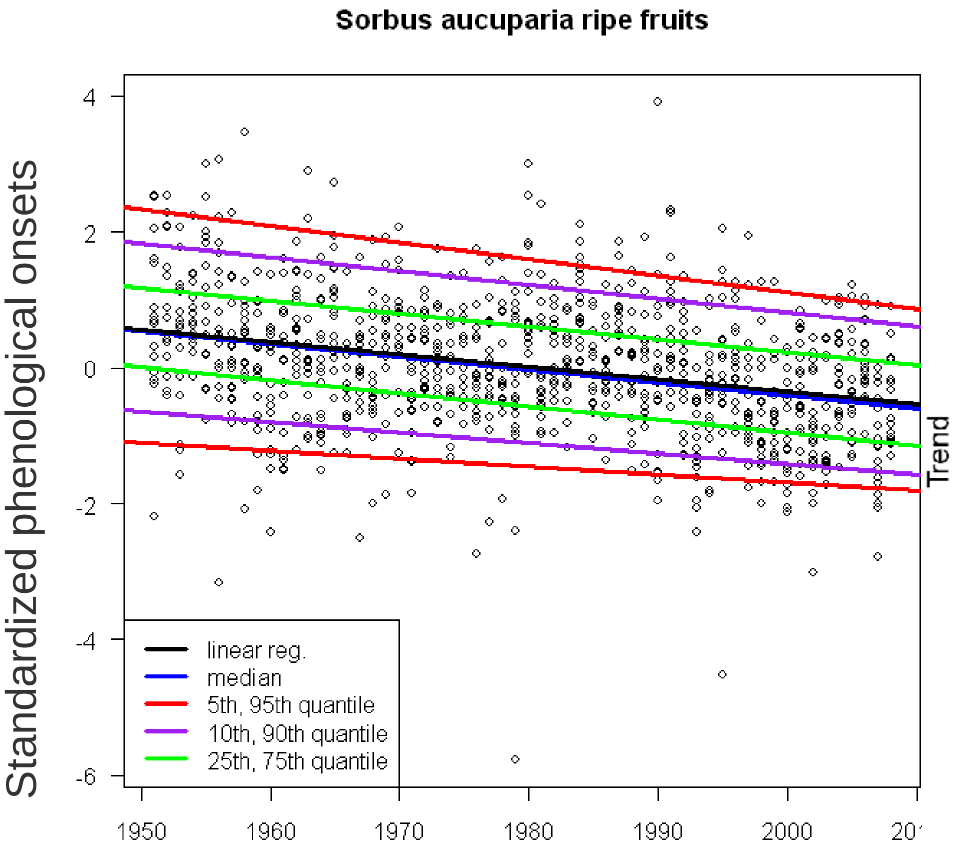
2.1 Results – Gaussian approach

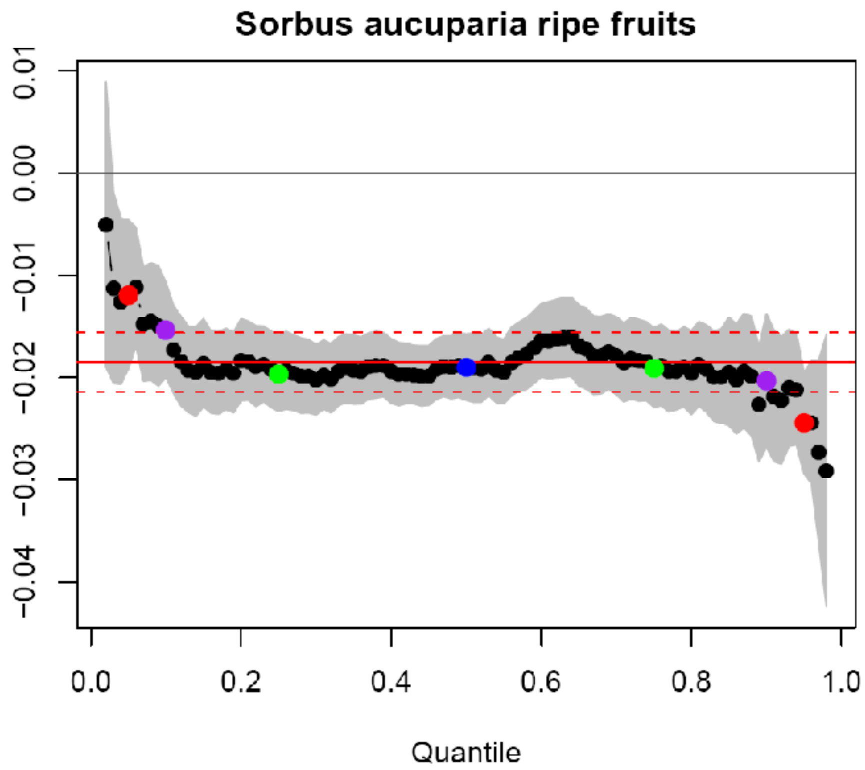
Summary of exceedances (<5th and >95th percentile), collectively for all stations and indicator species by decade (1950s to 2000s)



Gaussian distribution fit to all stations for single species (1951–2008), 5th & 95th percentiles calculated, used as thresholds for each decade. Decadal probabilities averaged by species.

2.2 Results – Quantile Regression



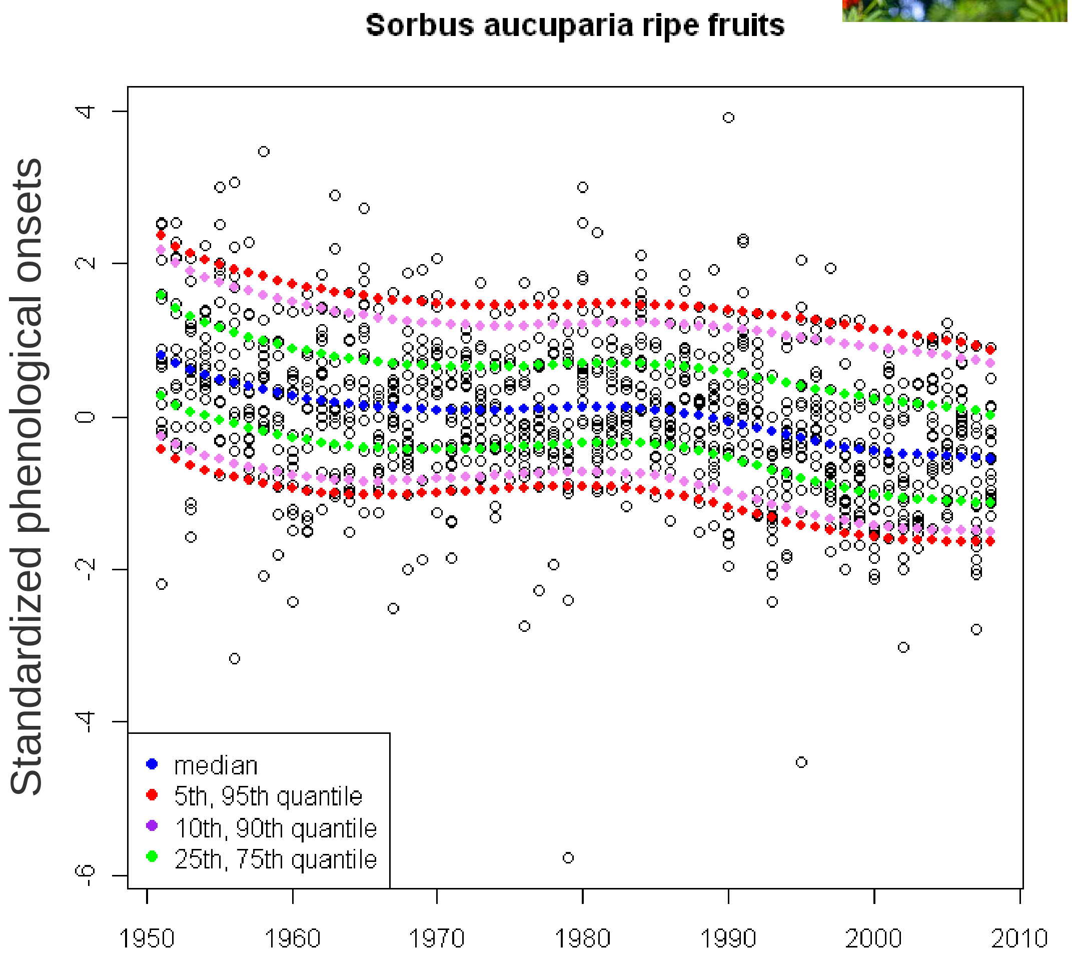


- Quantile regression of standardized onset data at all stations against year (1951-2008)
- All quantiles advancing (= negative trend), trend by linear least square regression in red.
- The majority of stations is exhibiting earlier onsets, the earliest are constrained.

after Koenker 2005

2.2 Results – Boosting Additive Quantile Regression

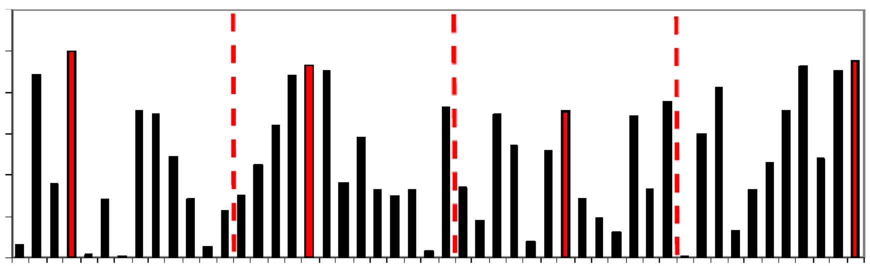
- Uses spline functions with numbers of knots estimated for nonlinear terms
- Non-parametric variable and model selection is supported by a boosting algorithm
- Results indicate approximately linear decrease of each of the quantiles in time



after Frenske et al. 2009

2.3 Extreme Value Theory (EVT)

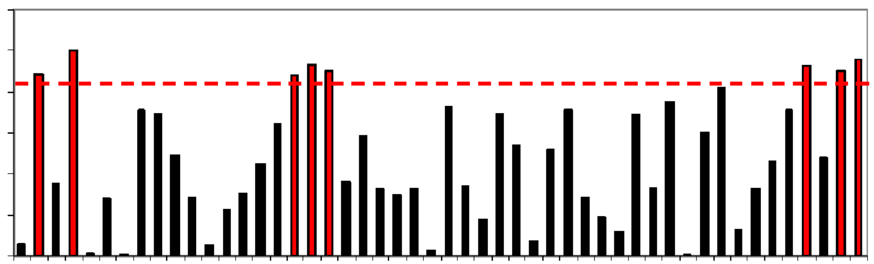
- Only the extreme values in records are analyzed
- 2 methods for selecting those extreme values
- Block maxima: observations are grouped into successive blocks and the maxima within each block are selected
- Peaks over threshold (POT): observations exceeding a given high threshold are selected



Block maxima

↓

Generalized extreme value distribution (GEV)



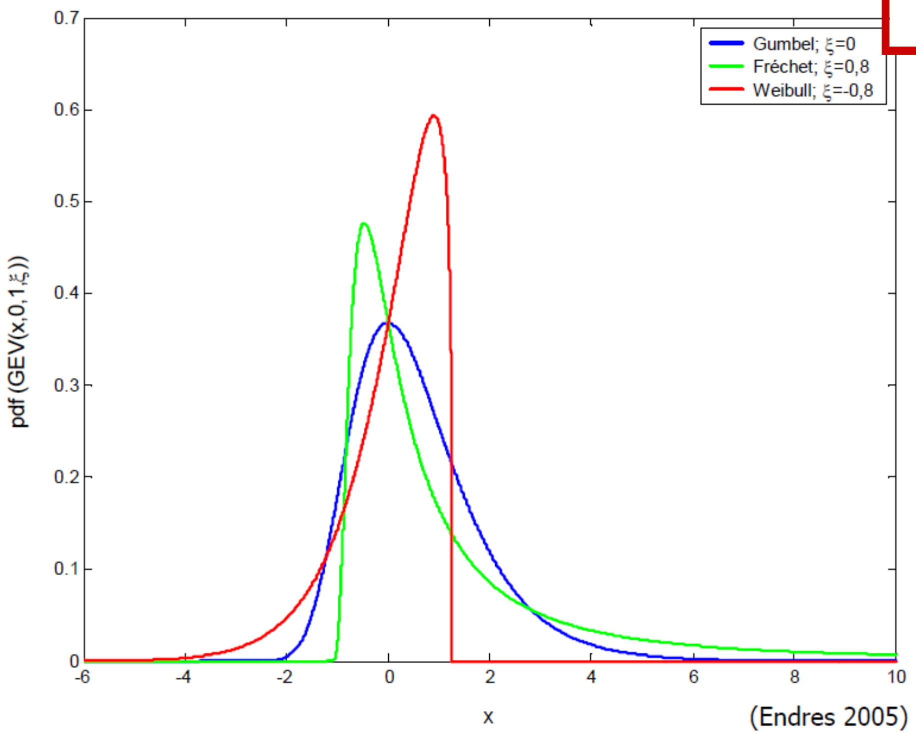
Peaks over threshold (POT)

↓

Generalized pareto distribution (GPD)

after Coles 2001

2.3 GEV distribution (block maxima)



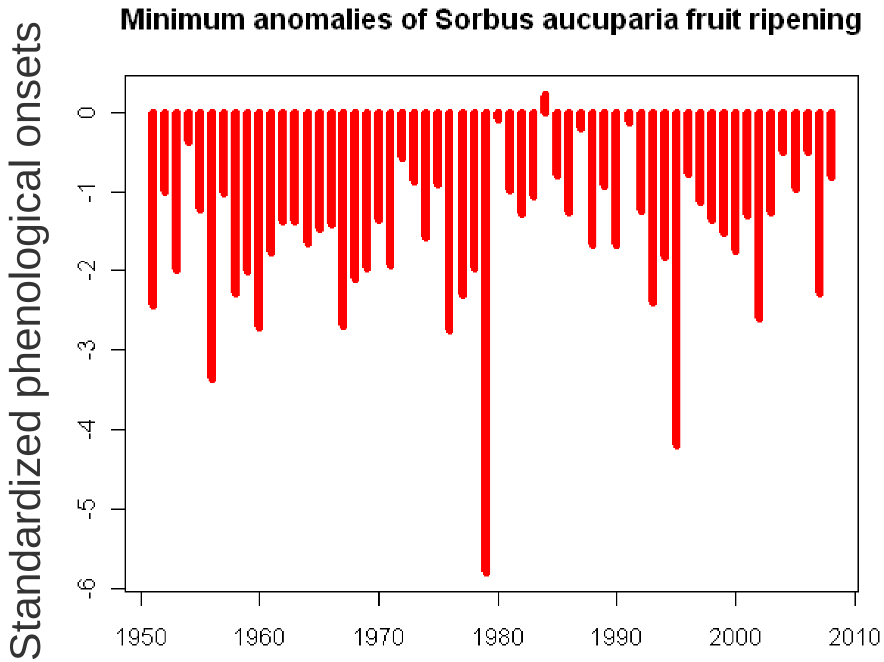
(Endres 2005)

$$GEV_{\xi,\mu,\sigma}(x) = \begin{cases} e^{-\left(1+\xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-1/\xi}} & for\ \xi \neq 0 \\ e^{-e^{-\left(\frac{x-\mu}{\sigma}\right)}} & for\ \xi = 0 \end{cases}$$

- μ: average (location parameter)
- σ: standard deviation (scale parameter)
- ξ: form parameter
- for ξ = 0: *Exponential Tail (**Gumbel**)*
- for ξ > 0: *Heavy Tail (**Fréchet**)*
- for ξ < 0: *Finite Tail (neg. **Weibull**)*

The raw data of block maxima (here one annual extreme out of all stations) are a sequence of independent random variables having a common distribution function (GEV).

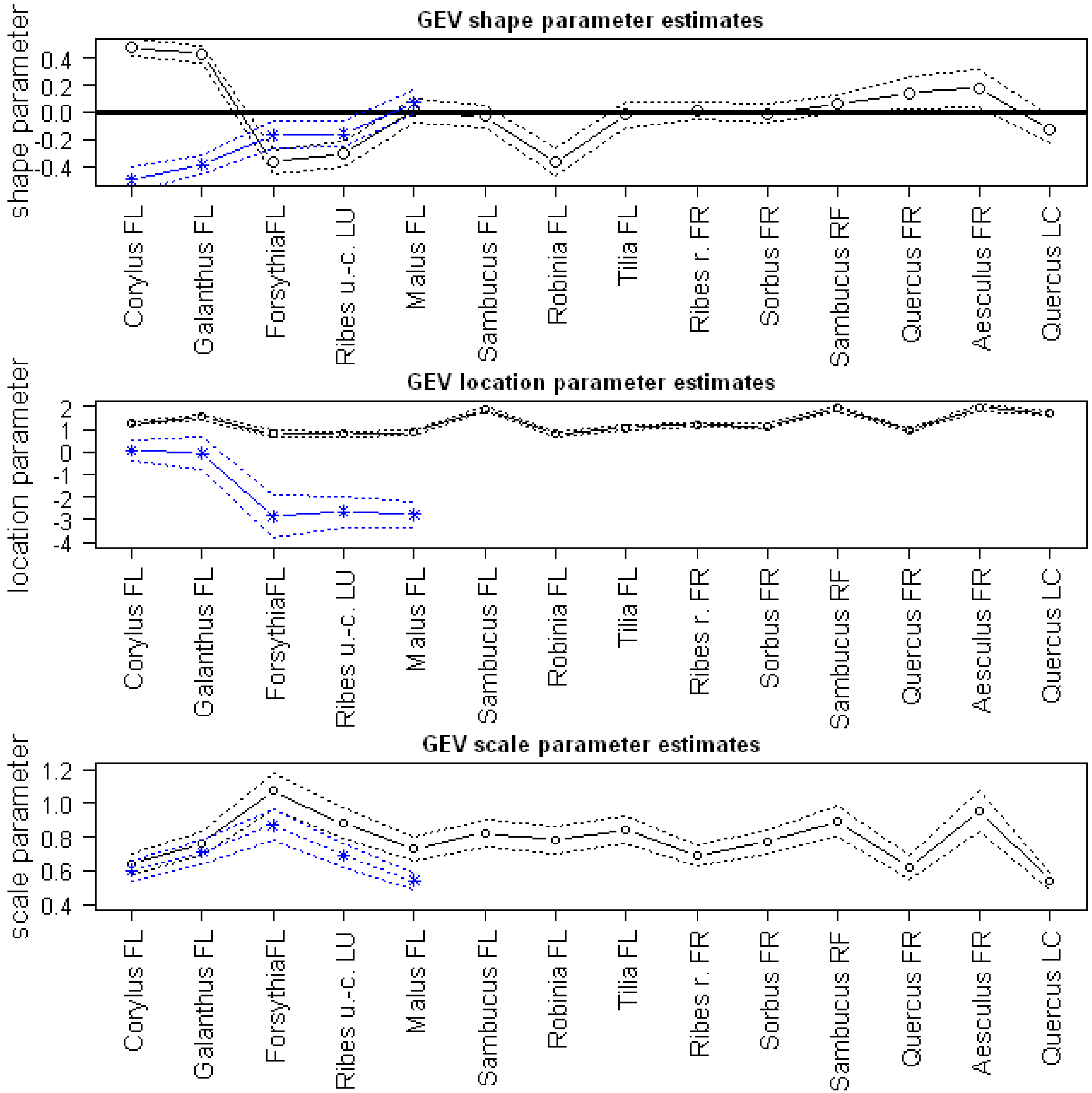
2.3 Results of GEV



	Parameter	Estimate	Std. Error
Sorbus	Location (μ)	1.13	0.11
	Scale (σ)	0.77	0.07
	Shape (ξ)	-0.01	0.07
	Negativelog-likelihood	75.64	
Sorbus & *Covariate*	Location (μ_0)	1.47	0.82
	Location (μ_1)	0.31	0.09
	Scale (σ)	0.65	0.08
	Shape (ξ)	0.13	0.12
	Negativelog-likelihood	69.45	

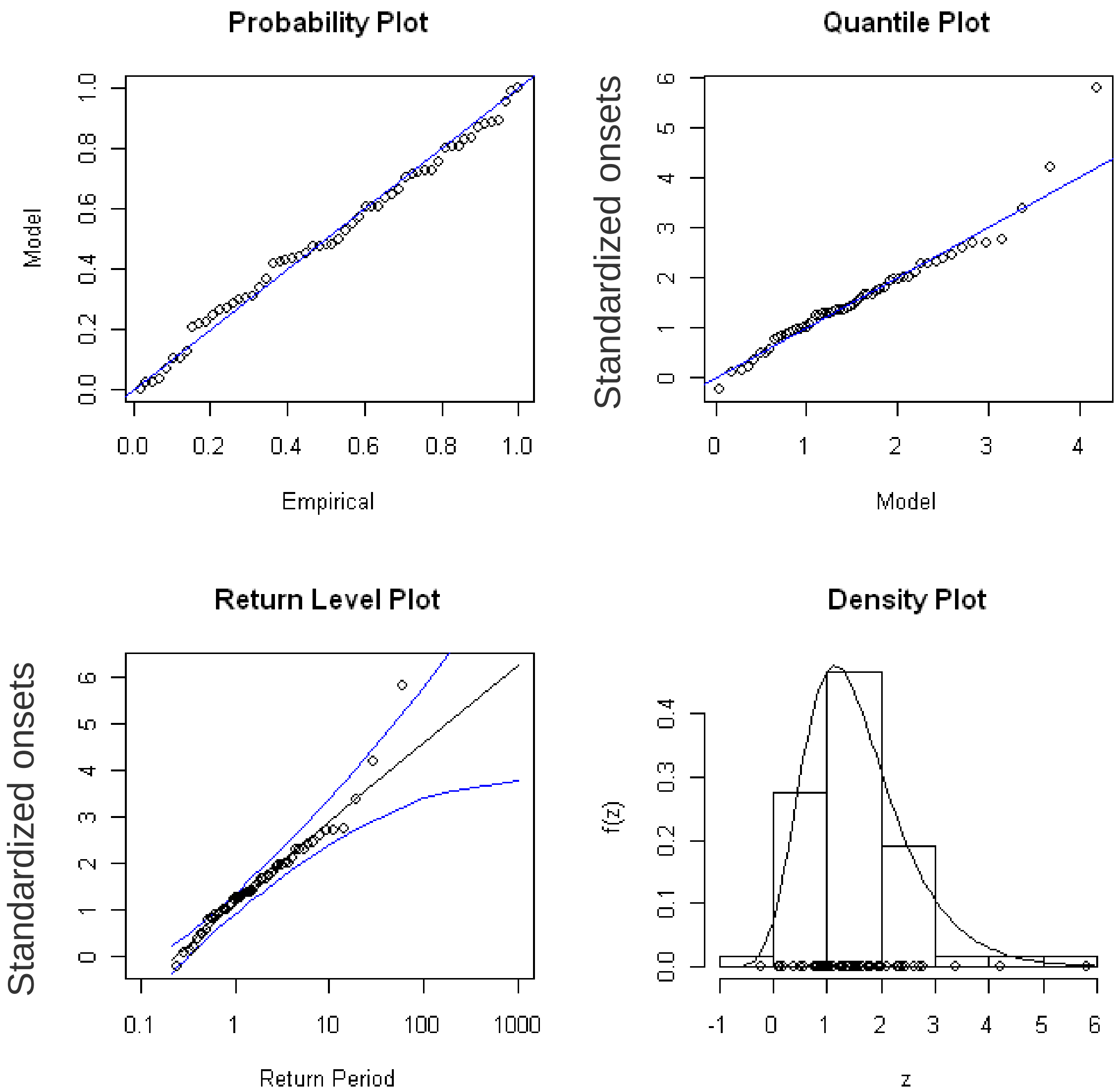
- Annual minimum (n=18 stations) of standardized phenological onsets of *Sorbus aucuparia* ripe fruits. Results of the GEV parameter estimates within 1951-2008.
- Likelihood ratio test (5% level) for ξ =0 does not reject Gumbel hypothesis (light tailed). Gumbel distribution suggests that there is no absolute minimum in fruiting onset dates, but the lower tails drops quickly.
- GEV parameter estimations which incorporate mean spring temperatures as covariate in the location parameter which is modeled as linear regression $\mu(x) = \mu_0 + \mu_1 x$, where x is the mean spring temperature.

2.3 Results for GEV parameter estimates



for ξ = 0:*Exponential Tail* (***Gumbel***)
for ξ > 0:*Heavy Tail* (***Fréchet***)
for ξ < 0:*Finite Tail (neg.* ***Weibull***)

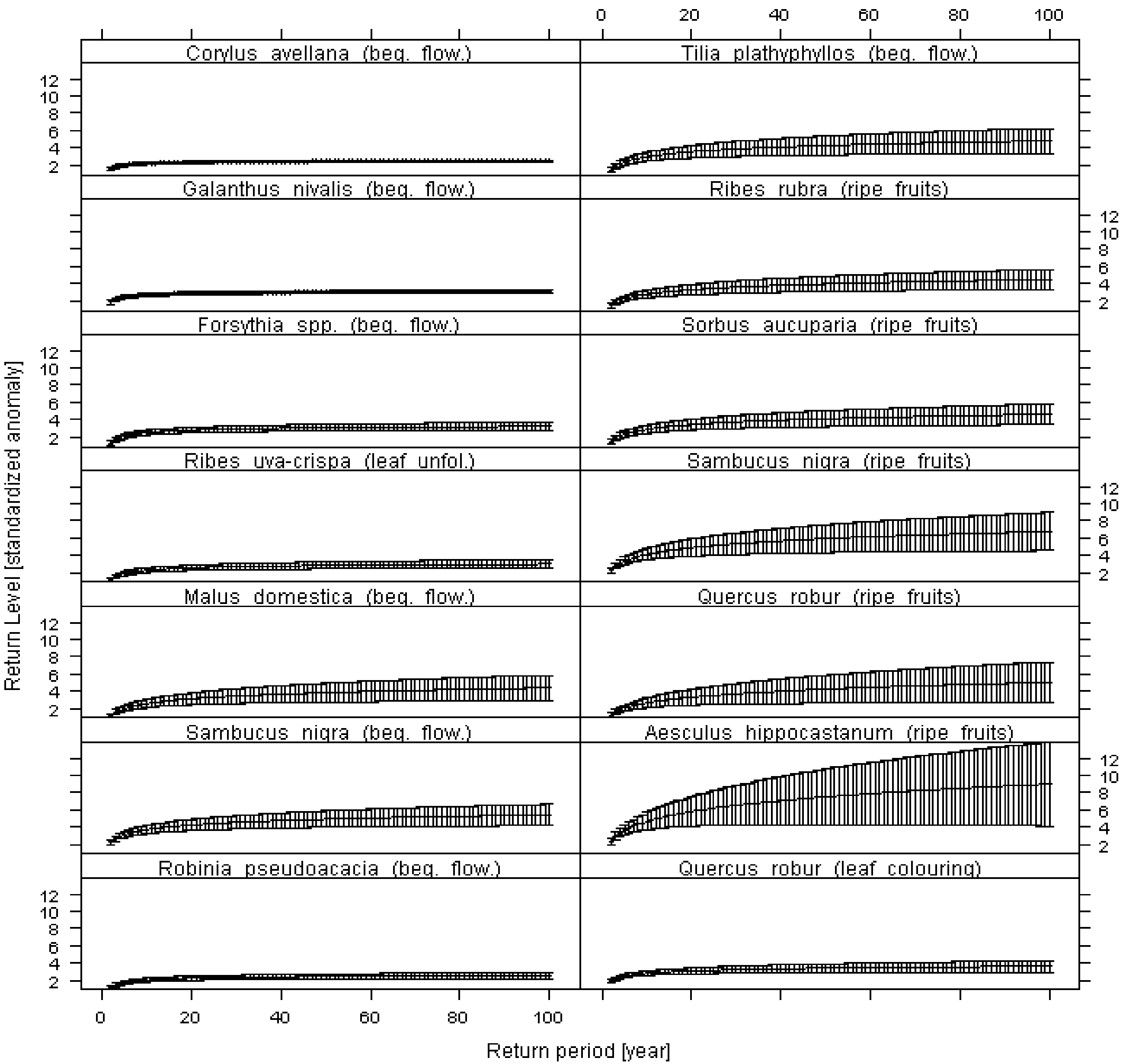
2.3 Results of GEV



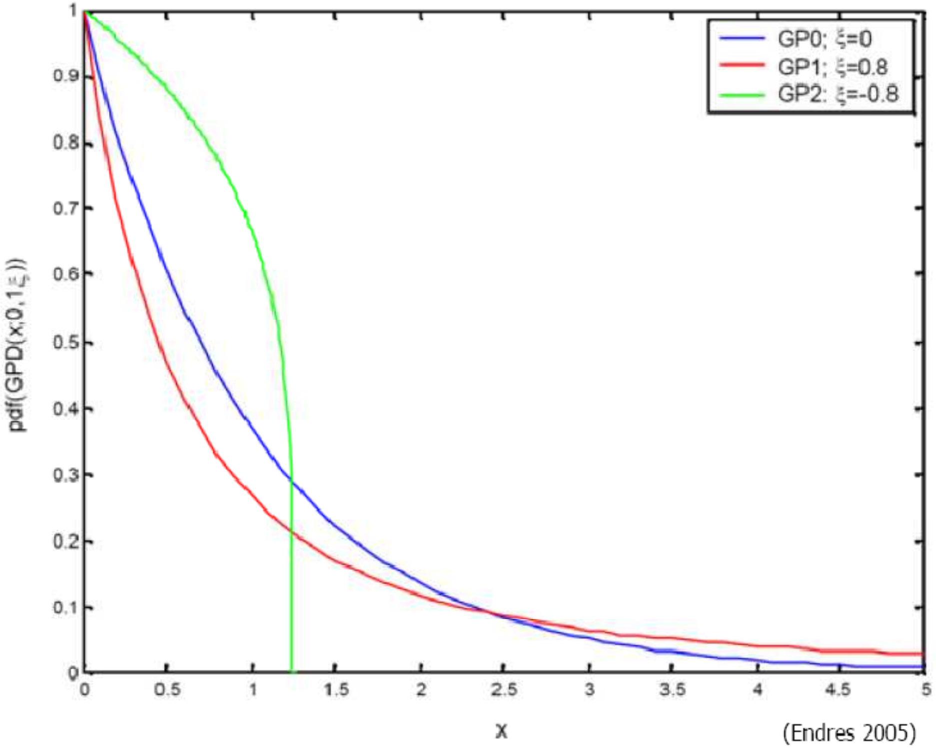
- Probability and quantile plots suggest that model describes data accurately
- Each 10 years an early event by 2 –3 standard deviations might occur
- For a 100 year event the model might not give accurate predictions

Diagnostic plots after Stephanson & Gilleland 2006; Gilleland & Katz 2005

2.3 Results of GEV return levels



2.3 GPD distribution (POT)

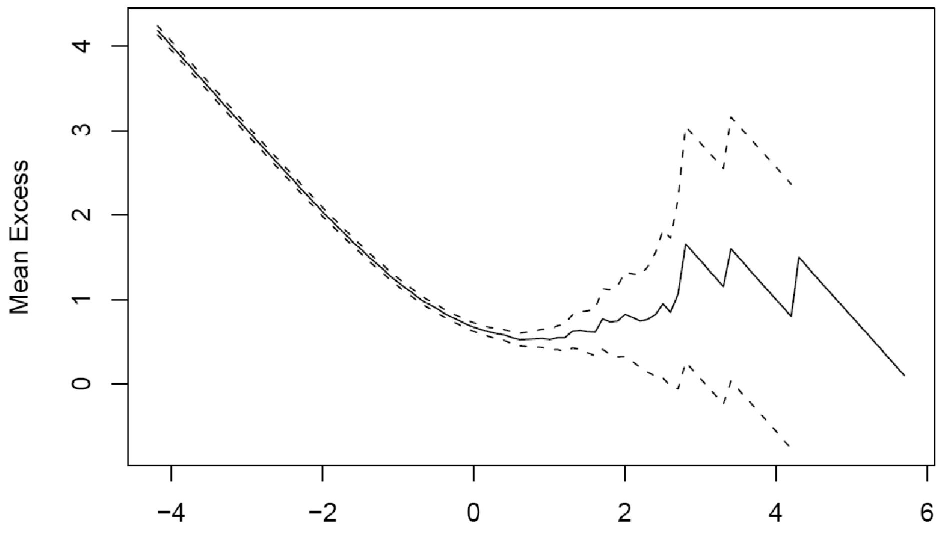


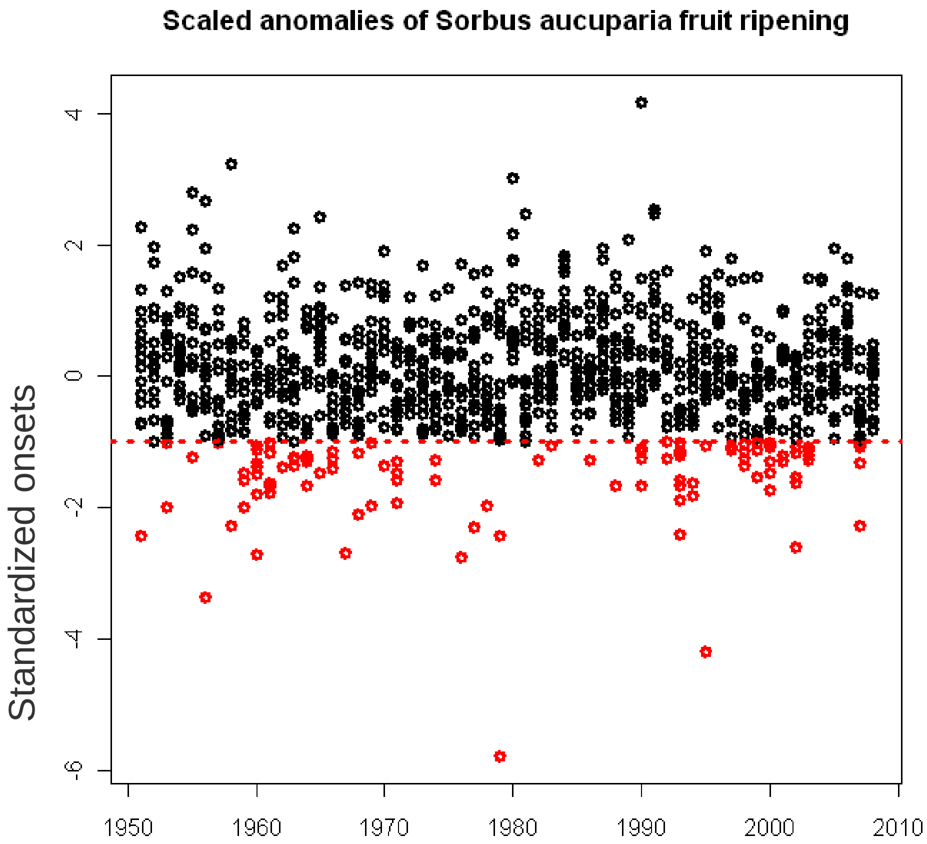
$$GPD_{\xi,\sigma}\,(x - x') = 1 - \left(1 + \xi \cdot \frac{x-x'}{\sigma}\right)^{-1/\xi}$$

- x‘ threshold
- for ξ = 0: *Exponential Tail* (***Exponential, GPO***)
- for ξ > 0: *Heavy Tail* (***Pareto, GP1***)
- for ξ < 0: *Finite Tail* (***Beta, GP2***)

The raw data of peak over threshold data (here annual data of all stations) are a set of variables having a common distribution function (GPD).

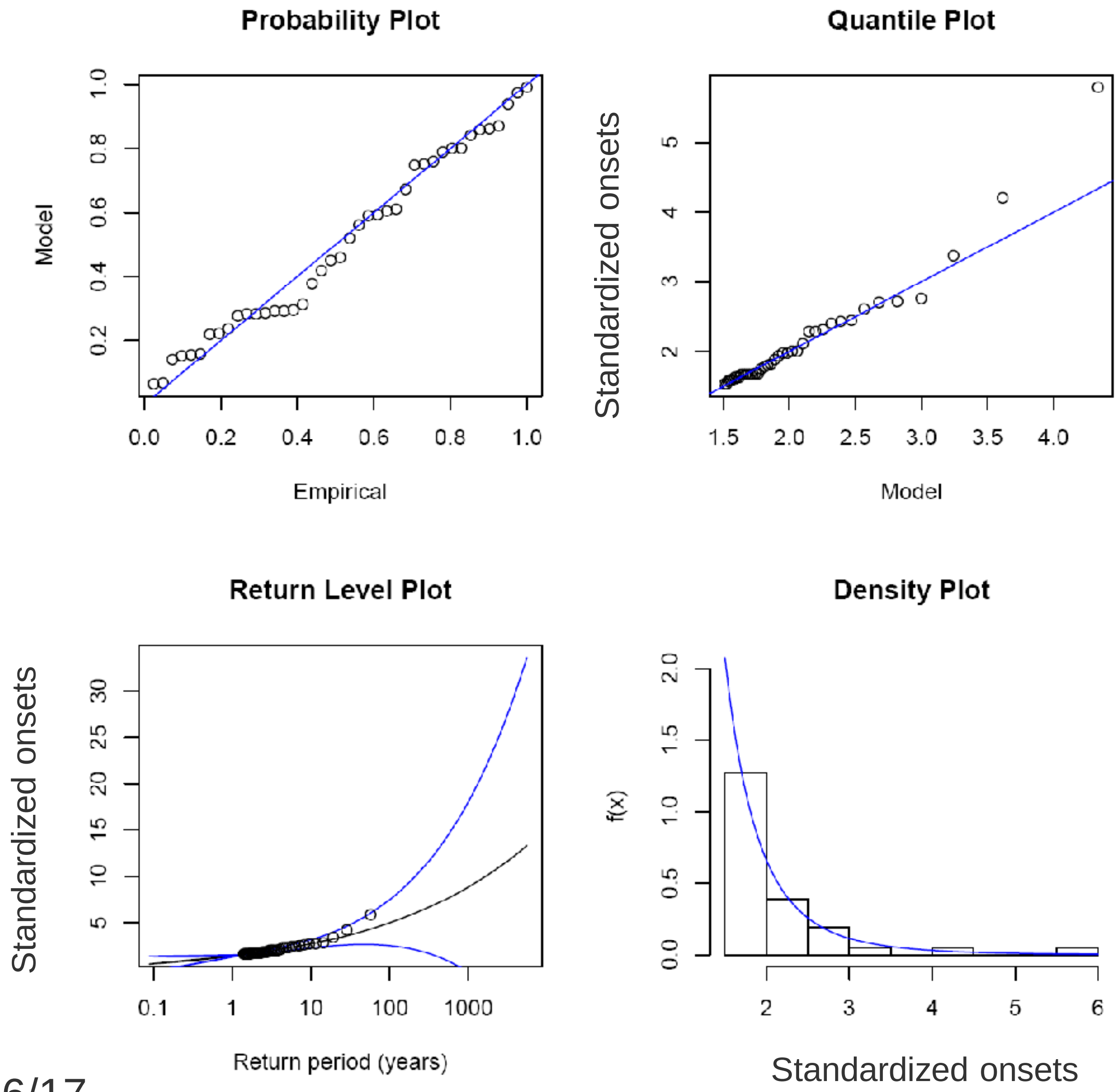
2.3 GPD (POT)





- Note: To identify extreme low values, the standardized data have to be convert to negative.
- Mean residual life plots are used to find the lowest threshold where the plot is nearly linear.
- The plot appears roughly linear from 1 or 1.5 onwards, so -1.5σ is a plausible threshold.

2.3 Results of GPD



- Probability and quantile plots suggest that model describes data fairly well
- Each 10 years an early event by 2 - 3 standard deviations might occur
- For a 100 year event the model might not give accurate predictions

3. Conclusions

- EVT methods are urgently needed in applied ecological sciences.
- Phenological data lack high frequency in annual measurements (=1 !).
- Number of stations might substitute for this when standardized.
- Data seem Gaussian distributed, however it‘s not the best fit for the tails.
- Regarding 14 indicator phases, probability of extreme early events strongly increased over decades (spring phases) only probability of extreme early leaf coloring in late autumn decreased.
- Quantile regression exhibits different changes over time for quantiles than for the mean (classical least square linear regression). Extremes (10^{th} and 90^{th} percentile) advance less than the median.
- Application of EVT (GEV, GPD) suffer from low amounts of phenological data.
- Results suggest that every 10 years, an extreme early event below 2 to 3 standard deviations might occur, suggesting that current screening procedures should not cut out automatically these potentially informative data.