EVALUATING THE VULNERABILITY OF THE SHORES OF THE EASTERN BALTIC SEA WITH RESPECT TO EXTREME WATER LEVELS

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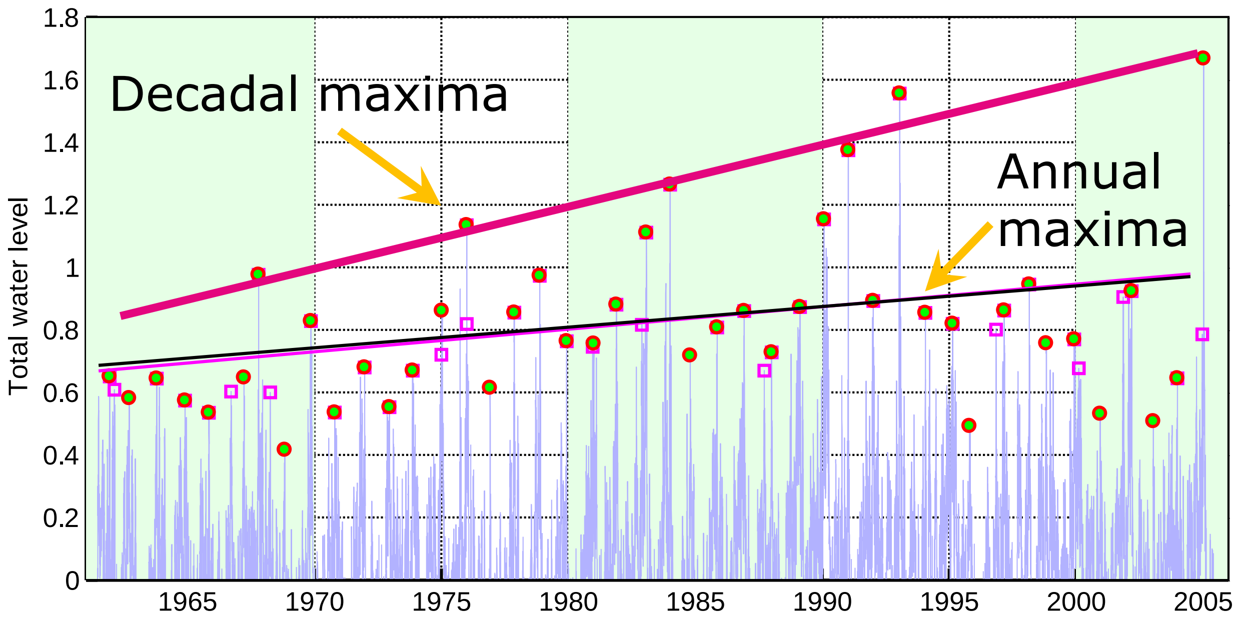
EXTREME WATER LEVELS (EWL)

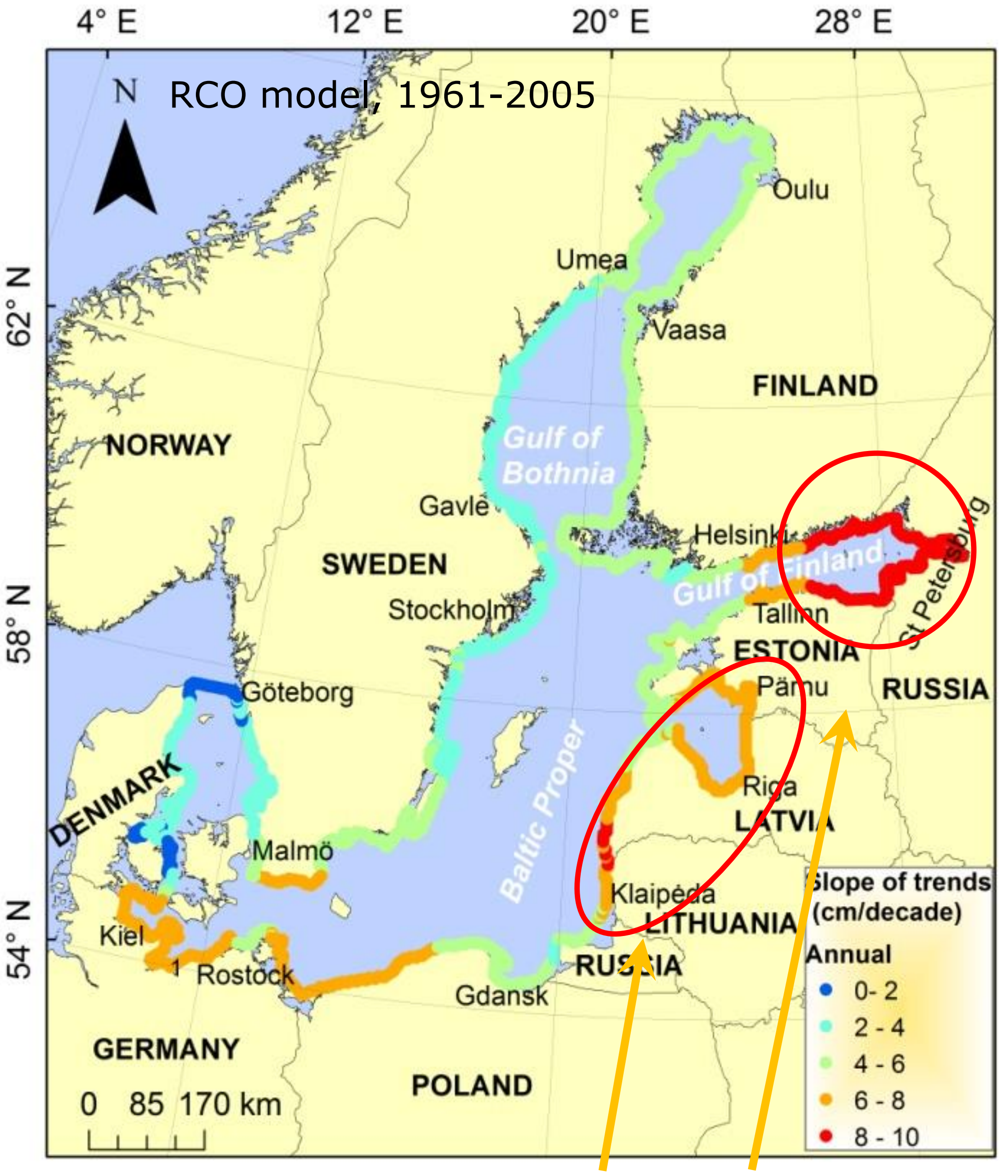
- The risks and damages associated with coastal flooding: large concern of countries with low-lying nearshore areas
- Severe storms lead to increasing height of extreme water levels in coastal regions

EXTREME WATER LEVELS (EWL)

- Considerable increase in the Gulf of Finland (up to 9 mm/yr)



RCO model near Tallinn



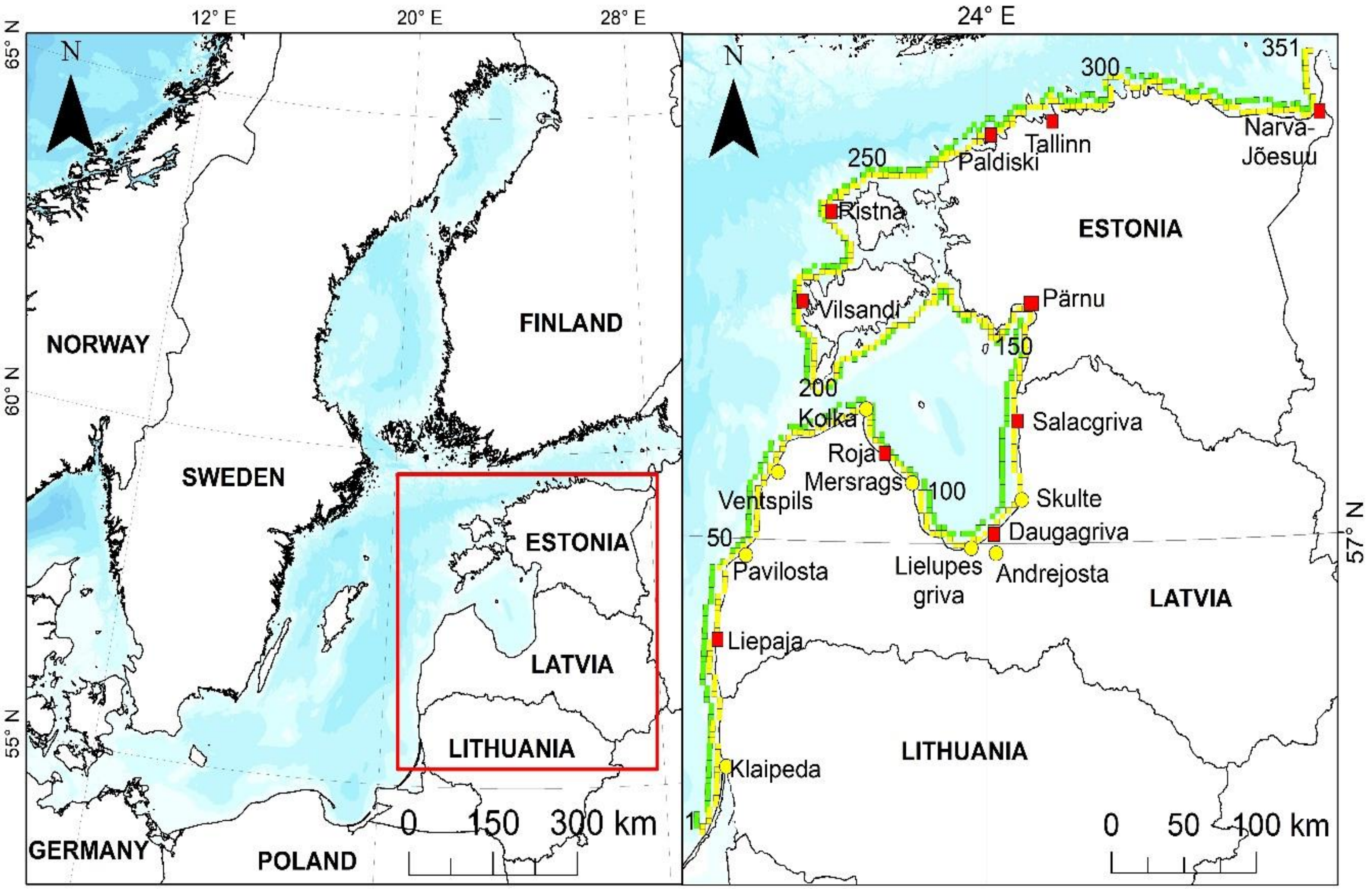
Slope of trends of annual water level maxima over 44 years (Pindsoo and Soomere, 2020)

EXTREME WATER LEVELS IN THE BALTIC SEA

- Combination of drivers that follow different probability distributions:
  - Increased water levels of the entire Baltic Sea: an approximately Gaussian
  - Local storm surges: exponential
  - Wave set-up: Weibull (2-param) or inverse Gaussian (Wald)
- The presence of various distributions (and populations) generates different levels of exposedness and vulnerability of low-lying coastal areas regarding of EWLs and their return periods
- Alongshore variation of the shape parameter of Generalised Extreme Value (GEV) distribution: helpful for classifying the coastal segments by the likelihood of experiencing higher extreme water levels

MODELLED AND OBSERVED WATER LEVELS

- Water level data extracted from the Rossby Centre Ocean Model (RCO, Meier et al., 2003)
  - 2x2 nautical miles, temporal resolution 6 h
  - May 1961–May 2005
- RCA4-NEMO (Hordoir et al., 2013)
  - 2x2 nautical miles, temporal resolution 1 h
  - 1961–2009
- Observed data:
  - 14 observation sites along the coastline of Baltic countries
  - Mostly covering years 1961–2018



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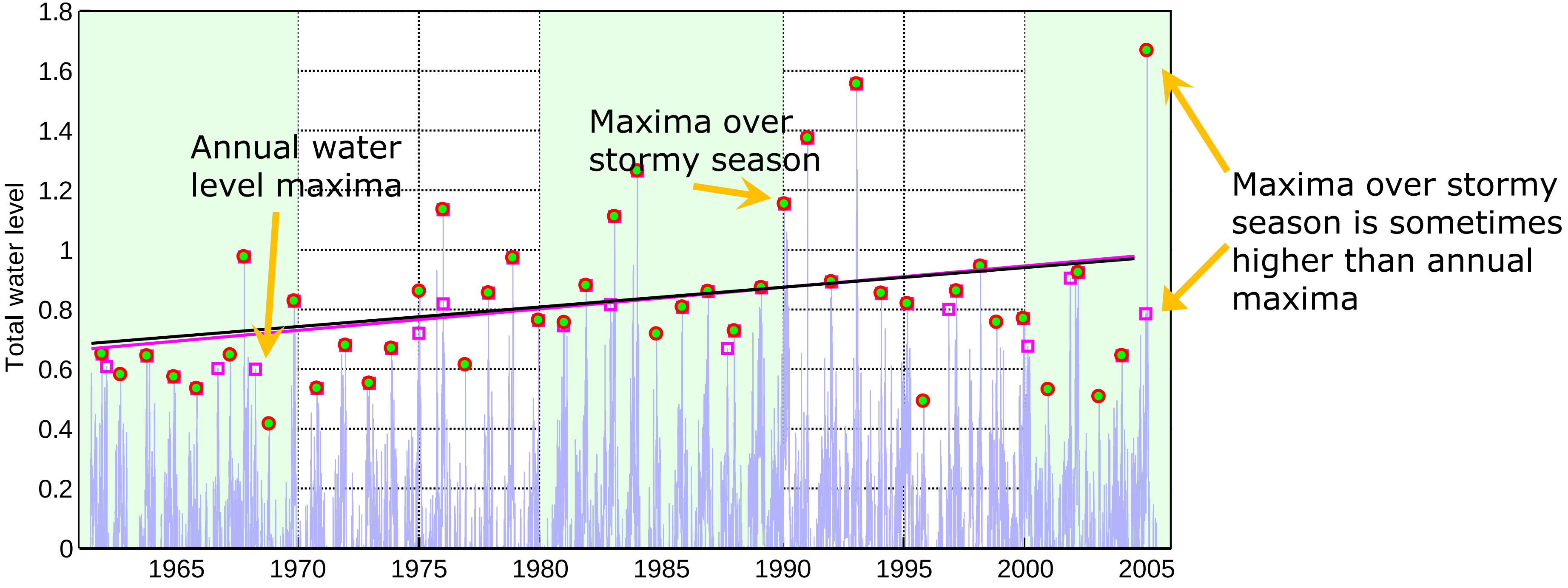
TWO SETS OF MAXIMA

- Single water level values de-meaned
- Annual maxima:
  - Values may be correlated: impact of clusters of storms (Dec–Jan)
- Maxima over stormy season (July–June):
  - Contain annual highest water levels
  - Cleary separated by spring season → uncorrelated



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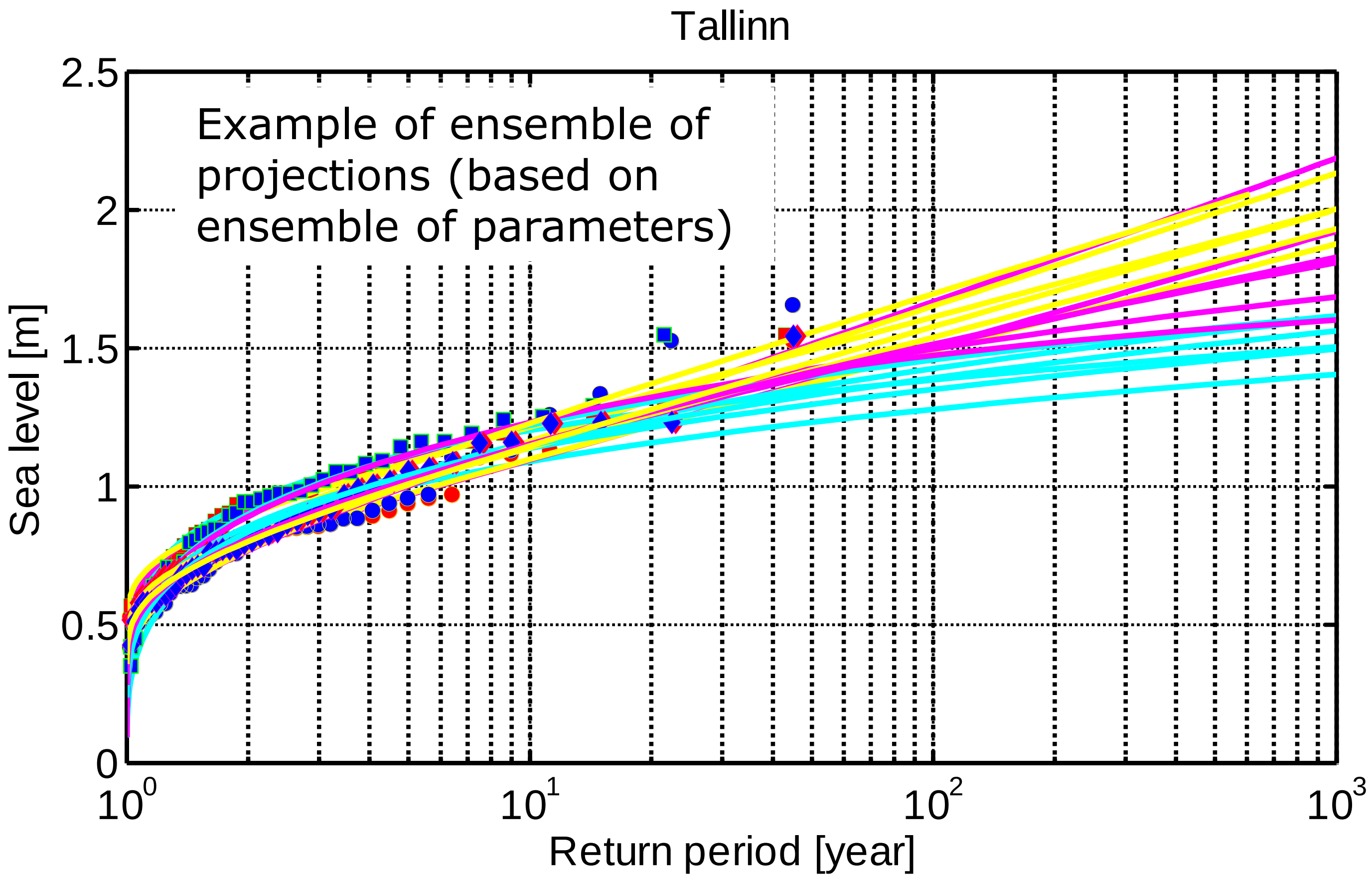
AN ENSEMBLE OF PARAMETERS (AND PROJECTIONS)

40 projections:

- 2 sets of block maxima of RCO and RCA4-NEMO (calendar and stormy year):
  - Method of moments: biased, unbiased
  - Maximum likelihood: methods implemented in Matlab and Hydrognomon
  - Weibull distribution (2-parameter)
  - Gumbel distribution



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GENERALISED EXTREME VALUE (GEV) DISTRIBUTION

- The standard (stationary) case GEV cumulative distribution function

shape parameter

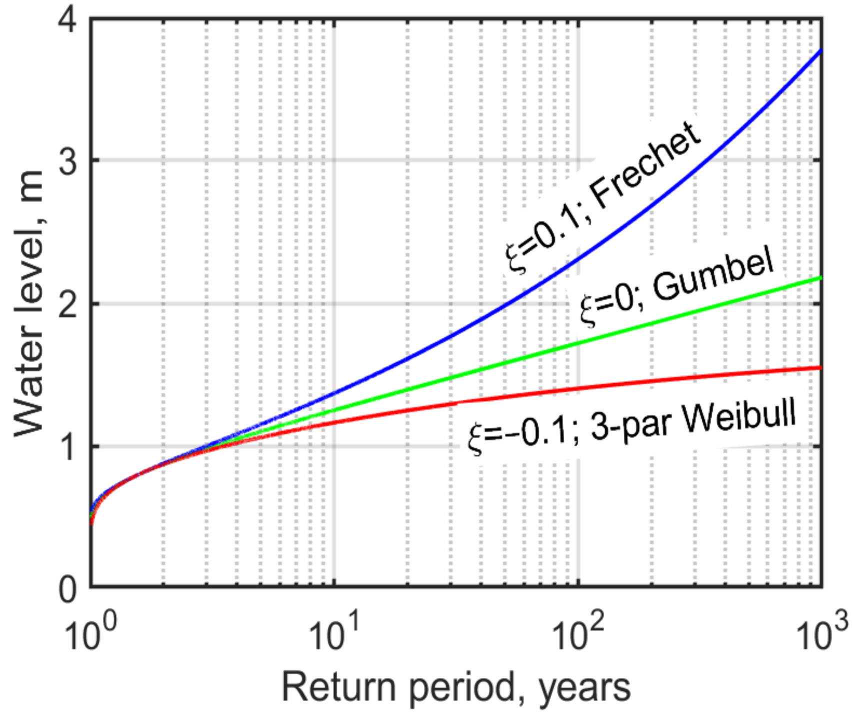
location parameter

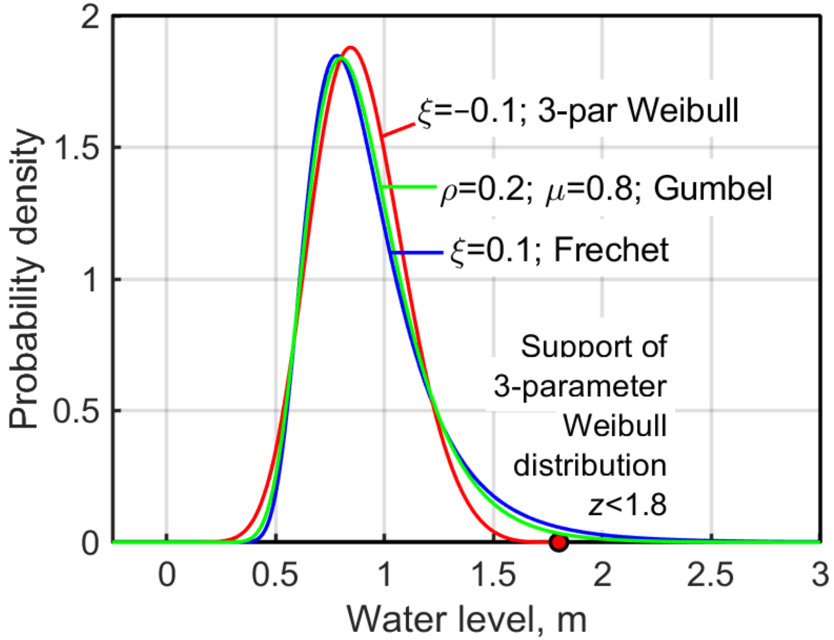
$$F_{st}(x;\mu,\sigma,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}$$

scale parameter

- $\xi < 0$ - Weibull (Type III) distribution
- $\xi > 0$ - Fréchet (Type II) distribution
- $\xi \to 0$ - Gumbel (Type I) distribution

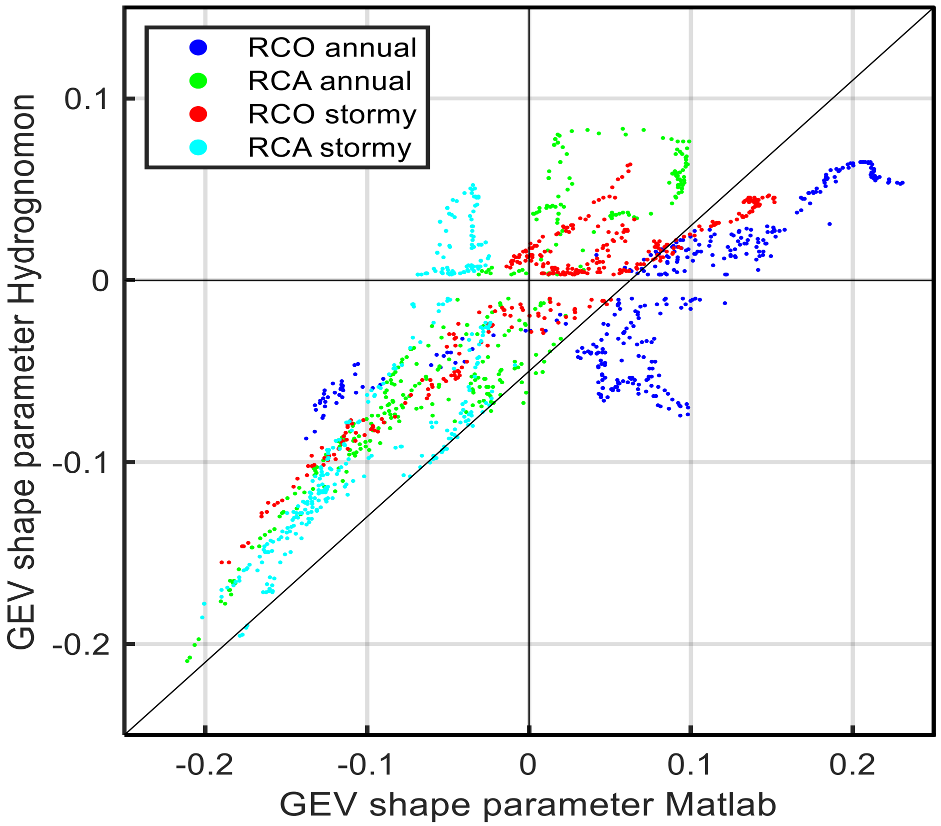
Generates different levels of exposedness and vulnerability of low-lying coastal areas



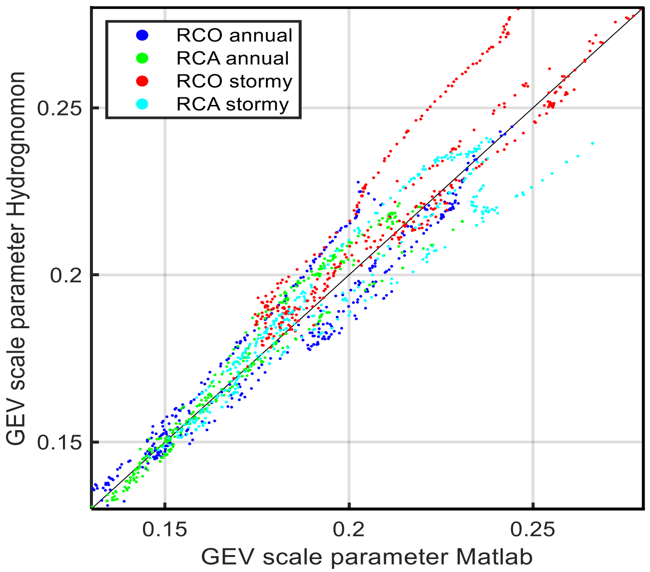


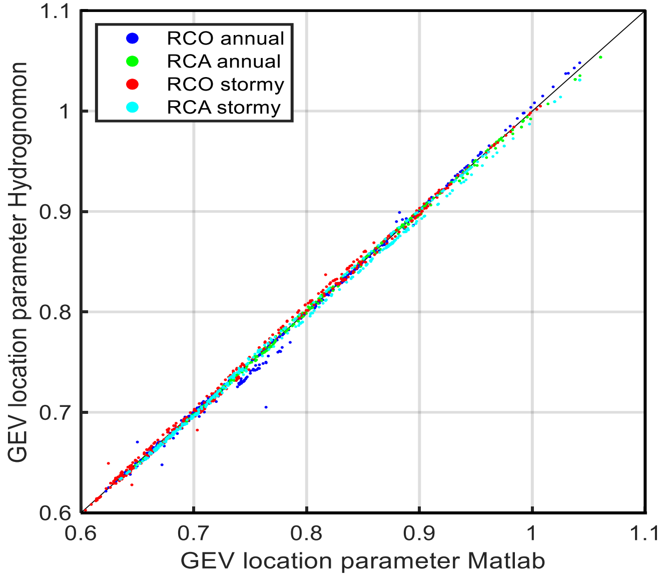
A COMPARISON OF ESTIMATES OF GEV PARAMETERS

- The extensive scatter of GEV shape parameters: straightforward use of a Gumbel for EWL estimates is not justified



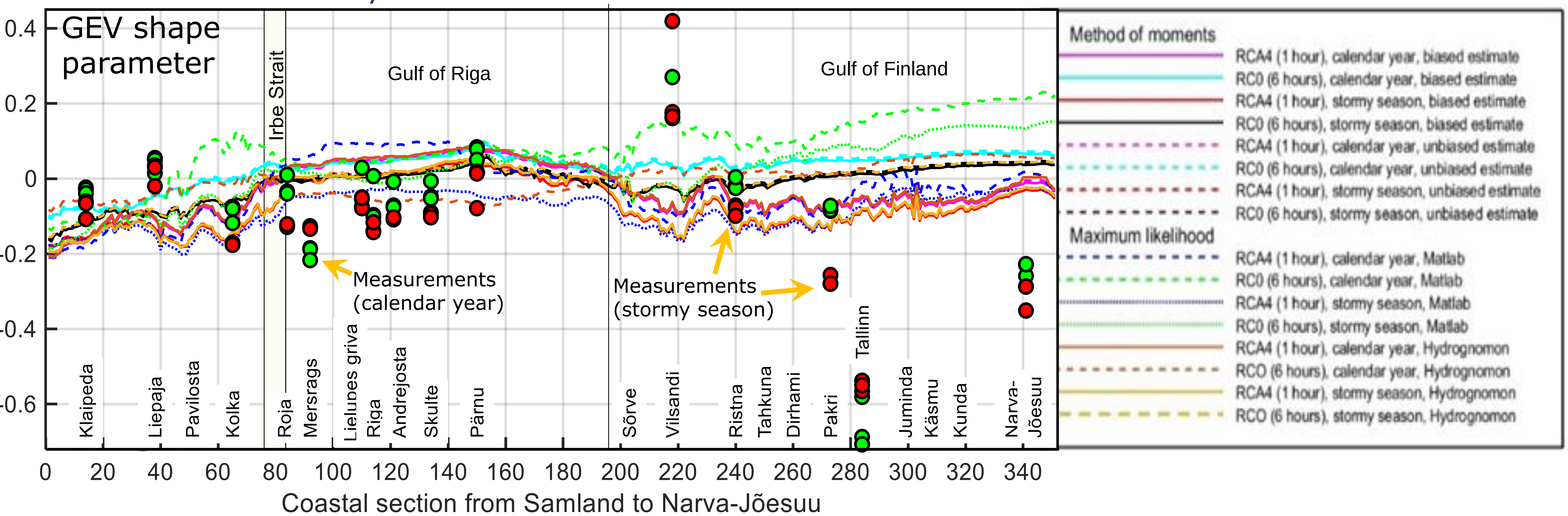
- Estimates of the scale parameter qualitatively follow each other
  - estimates for single coastal sectors differ (up to 35%)
- The values of the location parameter estimated using different methods match each other well





ALONGSHORE VARIATION OF THE GEV SHAPE PARAMETER

- The average of the estimates of the GEV shape parameter changes its sign several times along the study area:
  - It is <0 on the Baltic Proper shores of Latvia and Lithuania, the West of Tallinn until Sõrve
  - 0 in most of GOR (except Pärnu), in open shores of West Estonian Archipelago and at the part of the northern coast of Estonia
  - and >0 at Pärnu and the shores of Gulf of Finland to East of Tallinn
- The match between the estimates of the shape parameter from recorded and modelled data varies considerably



THE SHAPE PARAMETER AS A CORE PARAMETER CHARACTERISING VULNERABILITY OF A COASTAL SEGMENT

- Alongshore sign changes reflect a switch to fundamentally different nature of the future of EWLs in the respective coastal sectors

Gumbel: slow increase in EWLs

Fréchet: rapid increase in EWLs

Weibull: slowest increase in EWL

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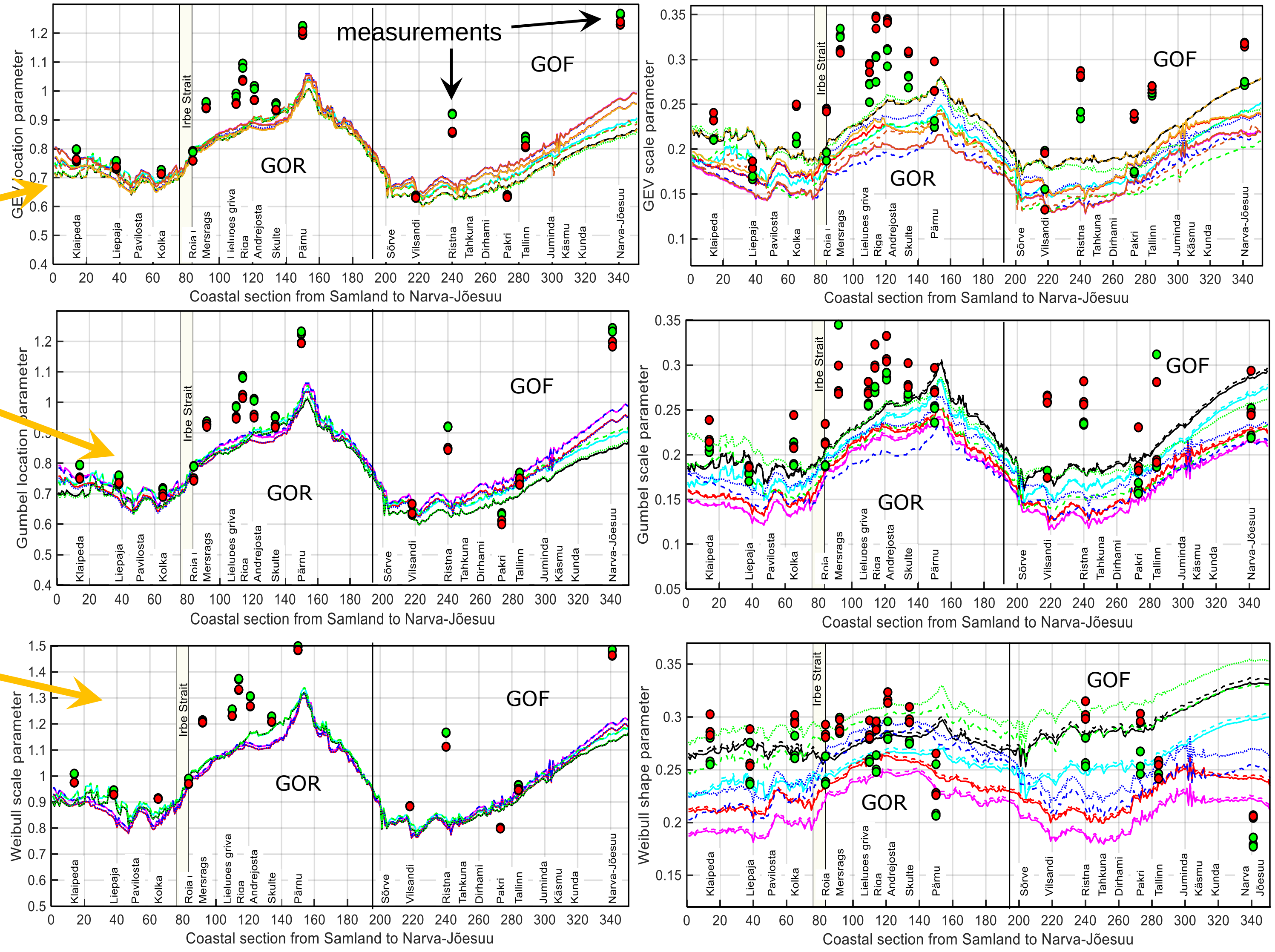
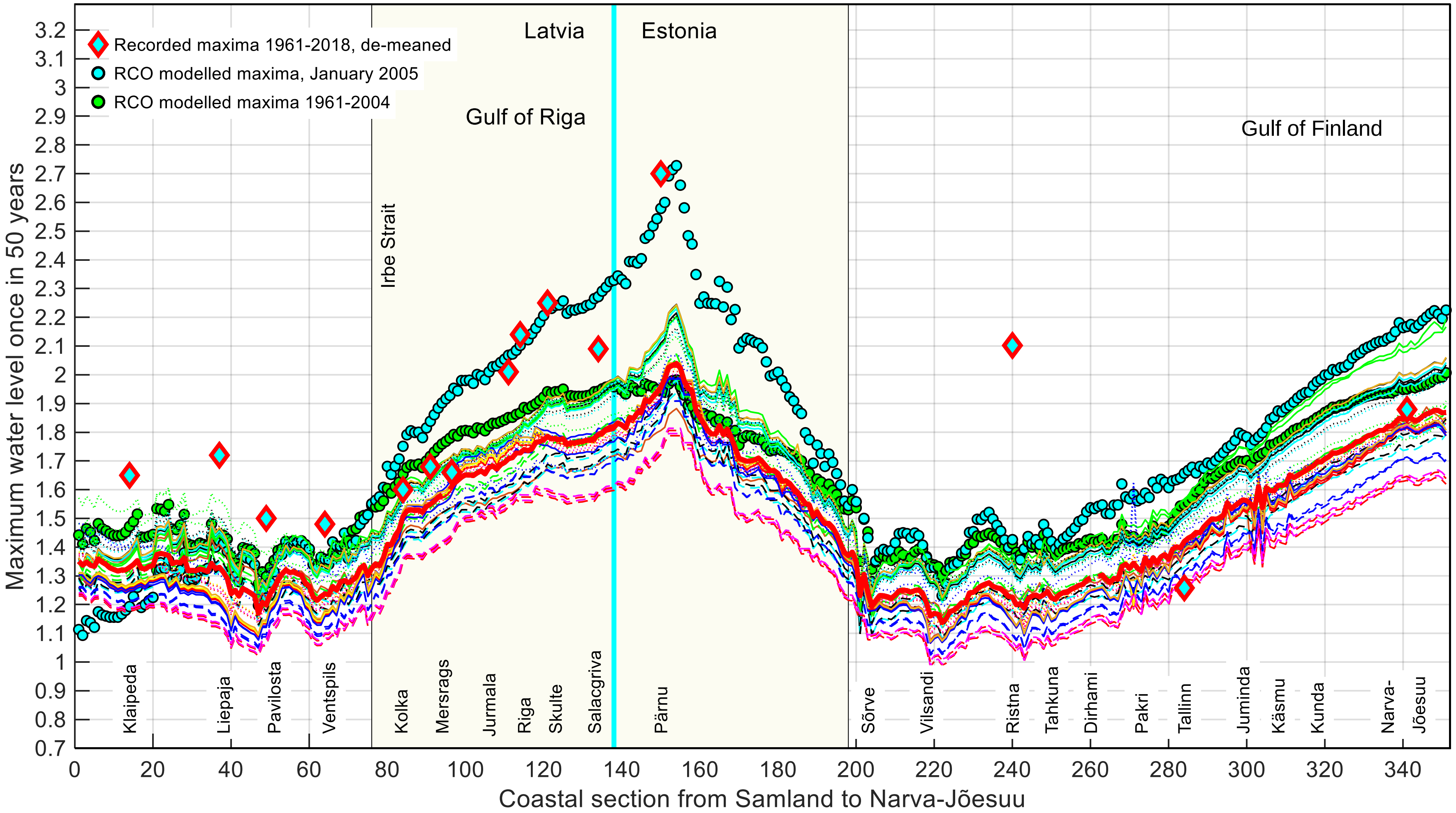
LOCATION AND SCALE PARAMETERS

- **GEV (and Gumbel)** location parameters indicates the most typical values of water level maxima or minima:
  - The typical annual maxima are fairly modest (<1 m), except in Pärnu and eastern GOF
  - The scatter of different estimates is small
  - The match with parameters of measurements varies alongshore
- **GEV scale** parameter characterises the width of the relevant probability density distribution
  - Large difference between different estimates
- **Weibull scale** parameters of different estimates almost coincide
- Alongshore variation of **Weibull shape** parameter has smaller amplitude of changes in comparison with GEV and Gumbel, scatter is bigger



ENSEMBLE OF PROJECTIONS OF EXTREME WATER LEVELS

- The spread of the set of projections of an EWL that would occur once in 50 yr is almost constant, approximately 0.4 m along the entire study area
- An appropriate projection of EWLs can be obtained as a weighted average of the resulting ensemble of projections



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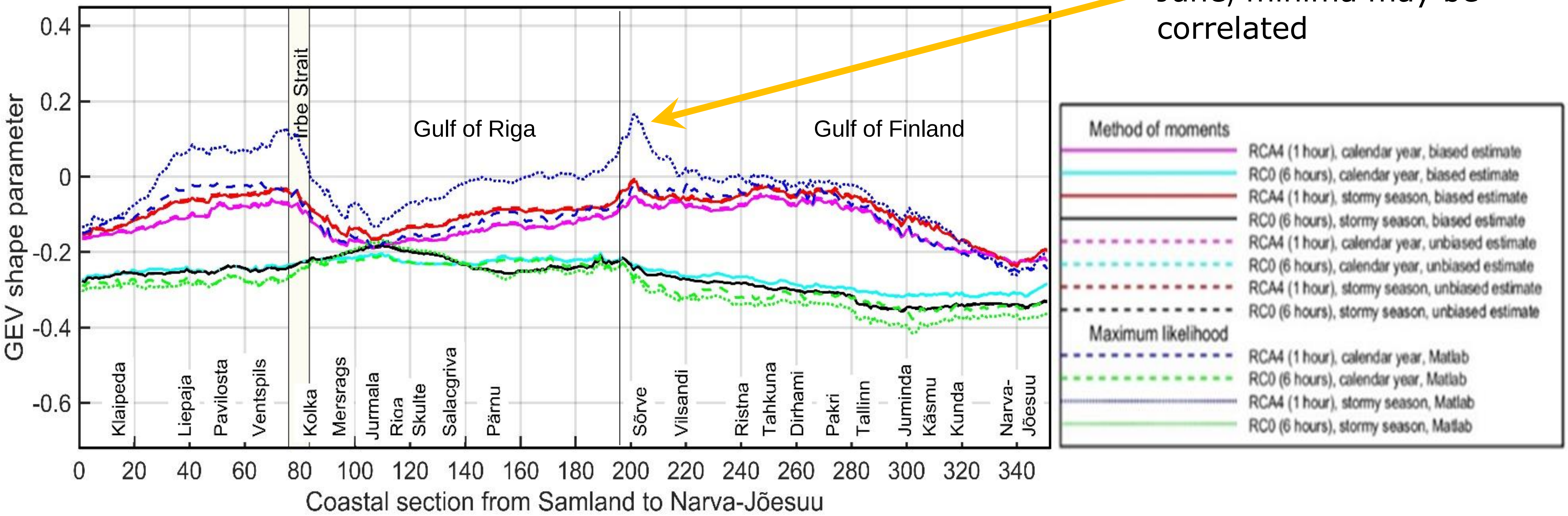
GEV SHAPE PARAMETER FOR WATER LEVEL MINIMA

- Negative surges are formed slowly during high atmospheric pressure and offshore winds and they persist for longer time
  - The GEV shape parameters values are mostly negative, this reflects presence of 3–parameters Weibull: decrease in the minima is likely modest
- Estimates of different models form clearly separated groups

Stormy season (July – June) minima may be correlated



CONCLUSIONS

- The nature of extreme water levels (EWL) may radically vary along the shores of eastern Baltic Sea
  - Fréchet distribution in the eastern parts of GOF and GOR → rapid increase in EWLs possible
  - Gumbel distribution in the rest of Gulf of Finland and at the West Estonian archipelago → slower increase in EWLs
  - 3-parameter reversed Weibull distribution on the open shores of Latvia and Lithuania → slowest increase in EWLs
- The Gumbel: appropriate tool for estimates of EWL in the eastern Baltic Sea
- 3-parameter Weibull: most suitable for projections of extremely low water levels, except few locations where Gumbel is applicable
- Different methods for estimates of the parameters of the GEV distribution may lead to considerably different results

Thank you for your attention!

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