NON-STATIONARY MODELING OF TRENDS REVEALS SPATIAL PATTERNS OF VARIATIONS IN EXTREME WATER LEVEL CHANGES ALONG THE BALTIC SEA COAST

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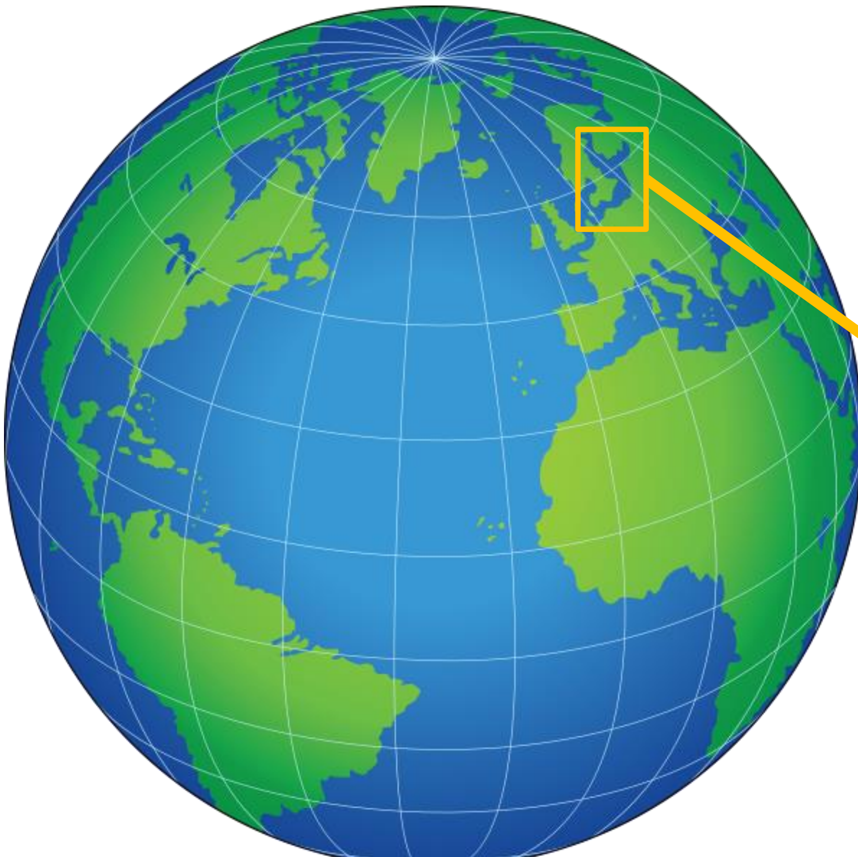
OUTLINE

- Motivation
- NEMO model data
- Non-stationary extreme value modelling
- Results

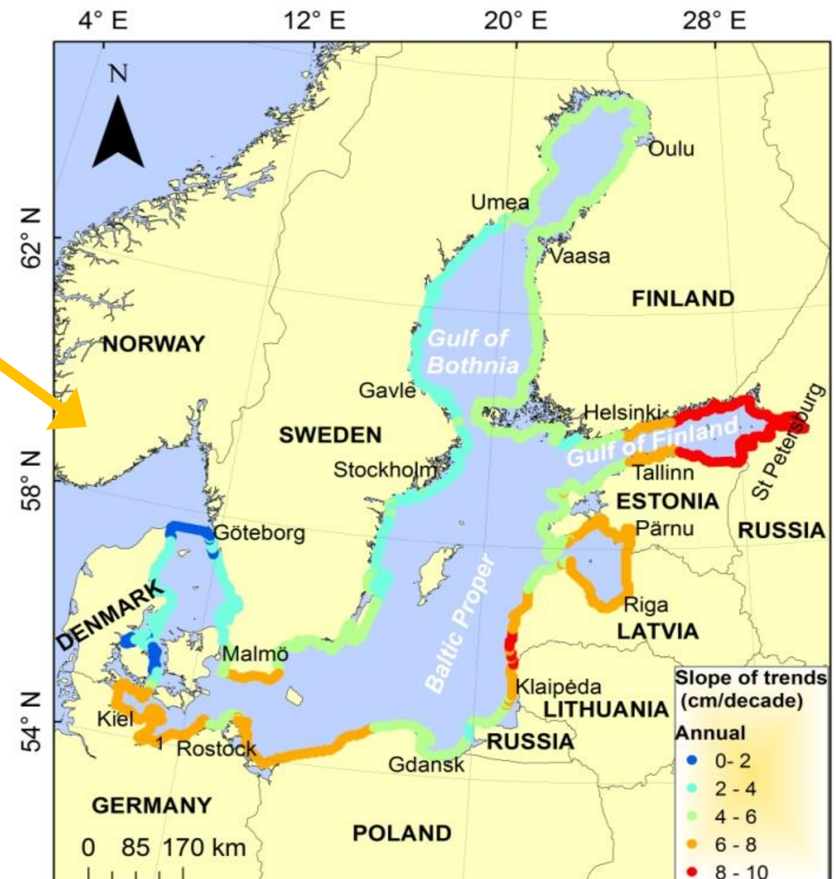
MOTIVATION

- Future: more frequent severe storms lead to increasing height of extreme water levels in coastal regions
- Safety of coastal structures: typical design period 50-100 yrs
- Important: proper return values of extreme events, accounting for non-stationarity due to change of climate variables

BALTIC SEA – INCREASE IN EXTREME WATER LEVELS



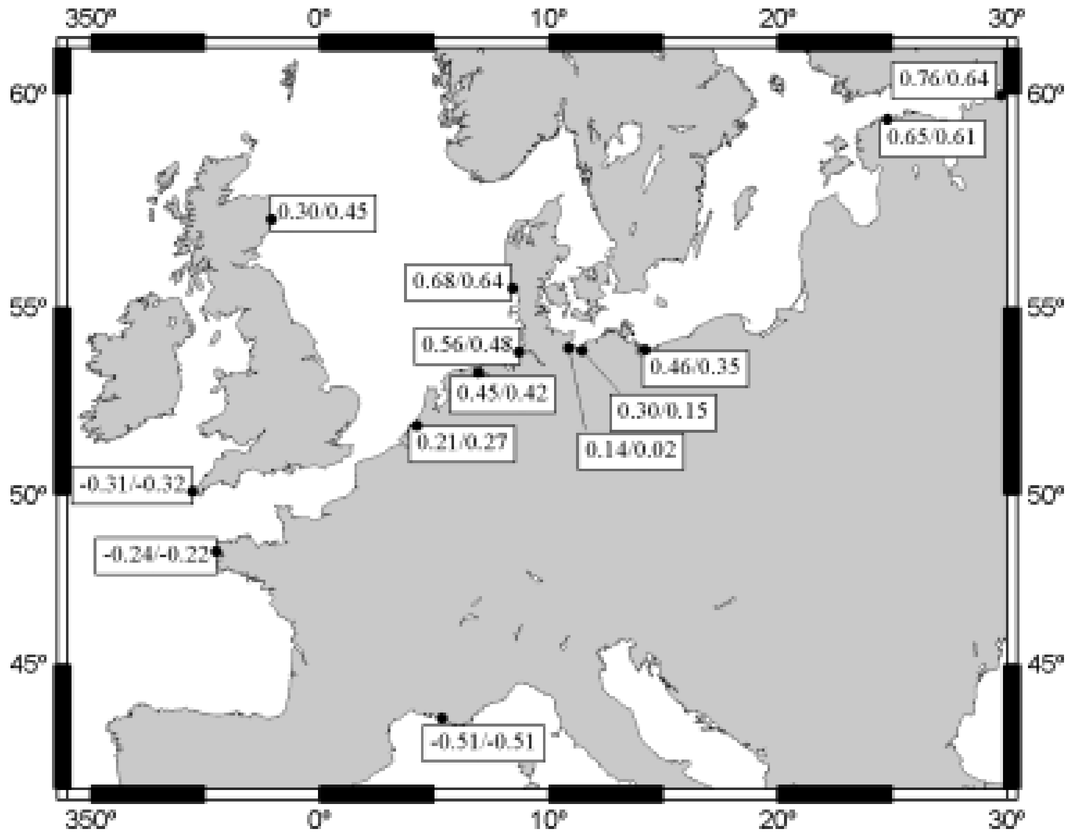
14.7 cm / 50 years trend in maxima
Johansson et al. 2001, Boreal environmental Research, 6, 159



Slope of trends of annual water level maxima over 44 years

MOTIVATION

- A few studies of tide gauges showed a relation of the Baltic Sea level stations with the North Atlantic oscillation index (*Andersson*, 2002; *Jevrejeva et al.*, 2005).
- We expect a relation between the rise of the extremes and NAO, since the NAO was linked to increase in westerly winds and storminess



Correlation between water levels and NAO, Jevrejeva et al. 2005. Explains 10-35% sea level variability

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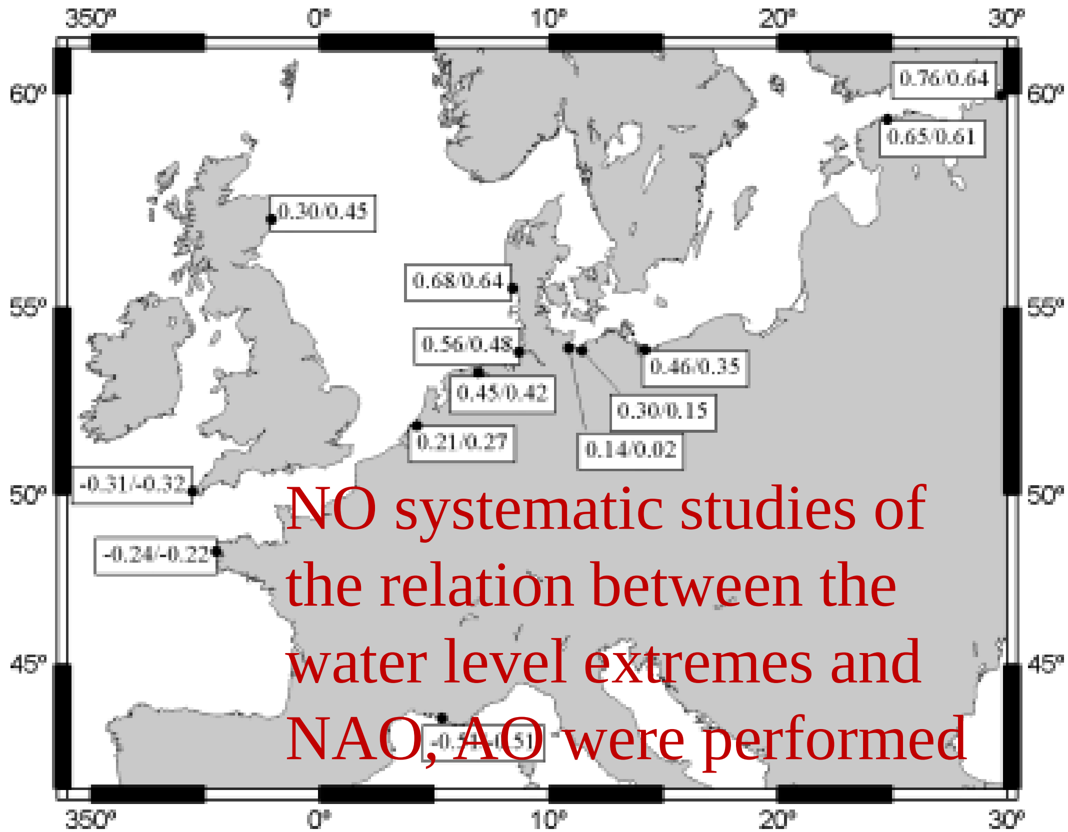

NO systematic studies of the relation between the water level extremes and NAO, AO were performed

Correlation between water levels and NAO, Jevrejeva et al. 2005. Explains 10-35% sea level variability

MOTIVATION

- Are the water level exremes in the Baltic Sea related to NAO?
- Are there linear trends in the parameters of the extreme value distribution?
- Can we model the changes of extreme value distribution with time/climatic indices?

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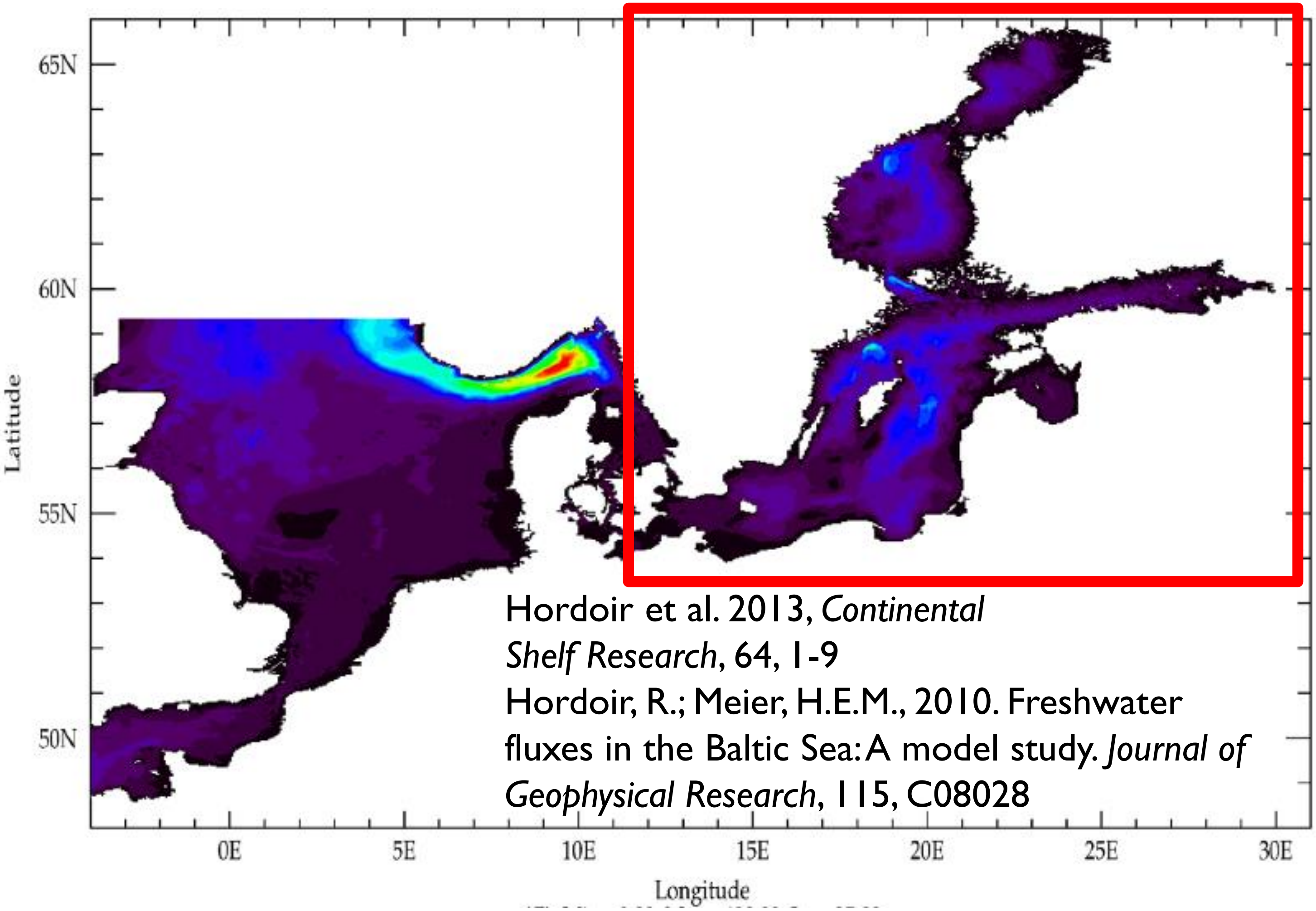
NEMO BALTIX MODEL



Hordoir et al. 2013, *Continental Shelf Research*, 64, 1-9

Hordoir, R.; Meier, H.E.M., 2010. Freshwater fluxes in the Baltic Sea: A model study. *Journal of Geophysical Research*, 115, C08028

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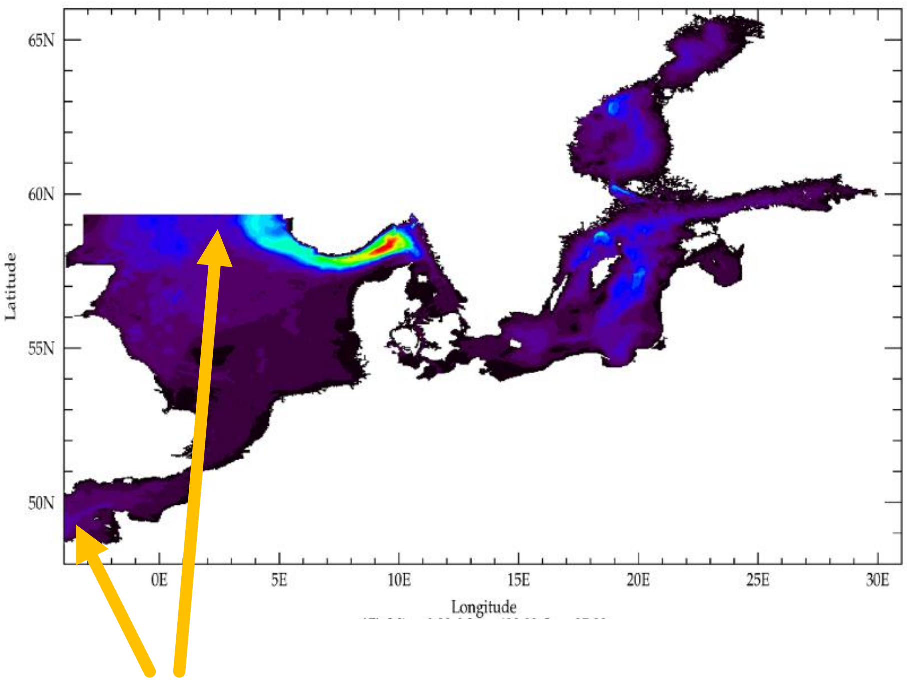
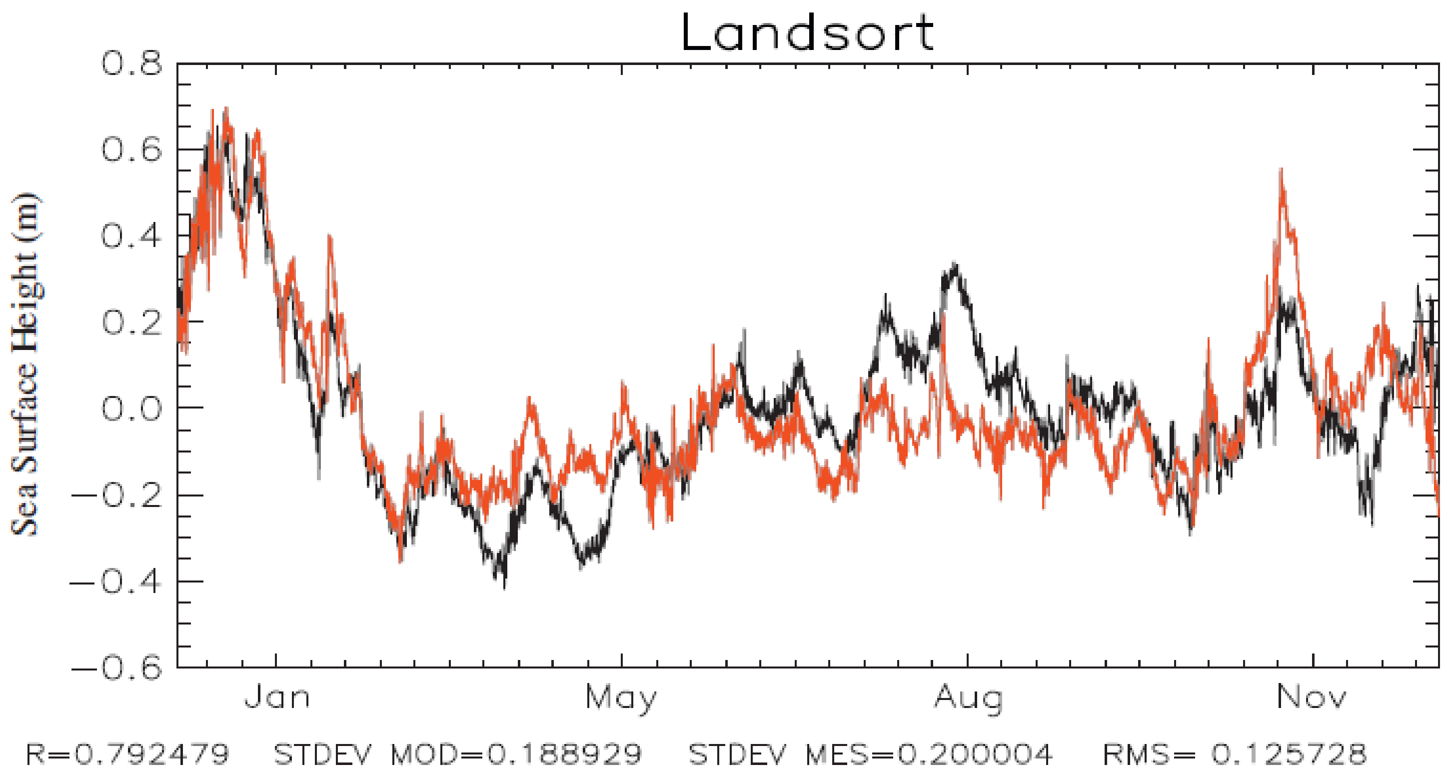


ERA 40 reanalysis forcing
RCA Samuelsson et. al. 2011

- 1979 – 2012 time period
- BaltiX configuration developed by SMHI
- 2 nautical miles resolution (3.7 km)
- 1 hour time resolution – good to catch extremes, not catching very fast variations
- Joined exchange of water between the North Sea and the Baltic Sea
- River runoff forcing O'dea et al. 2012 and Meier 2007

NEMO MODEL VALIDATION



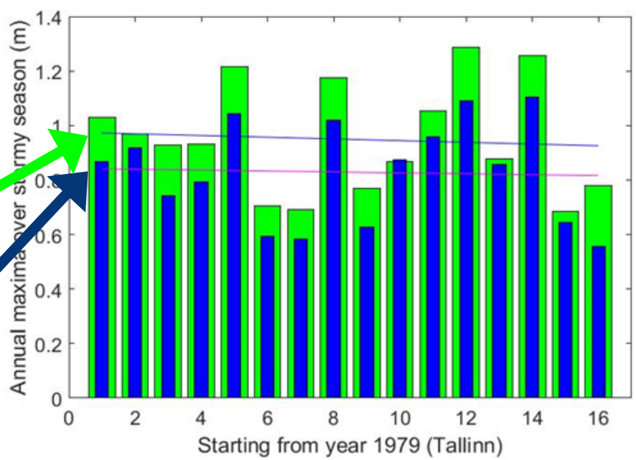
Hordoir et al. 2013, *Continental Shelf Research*, 64, 1-9

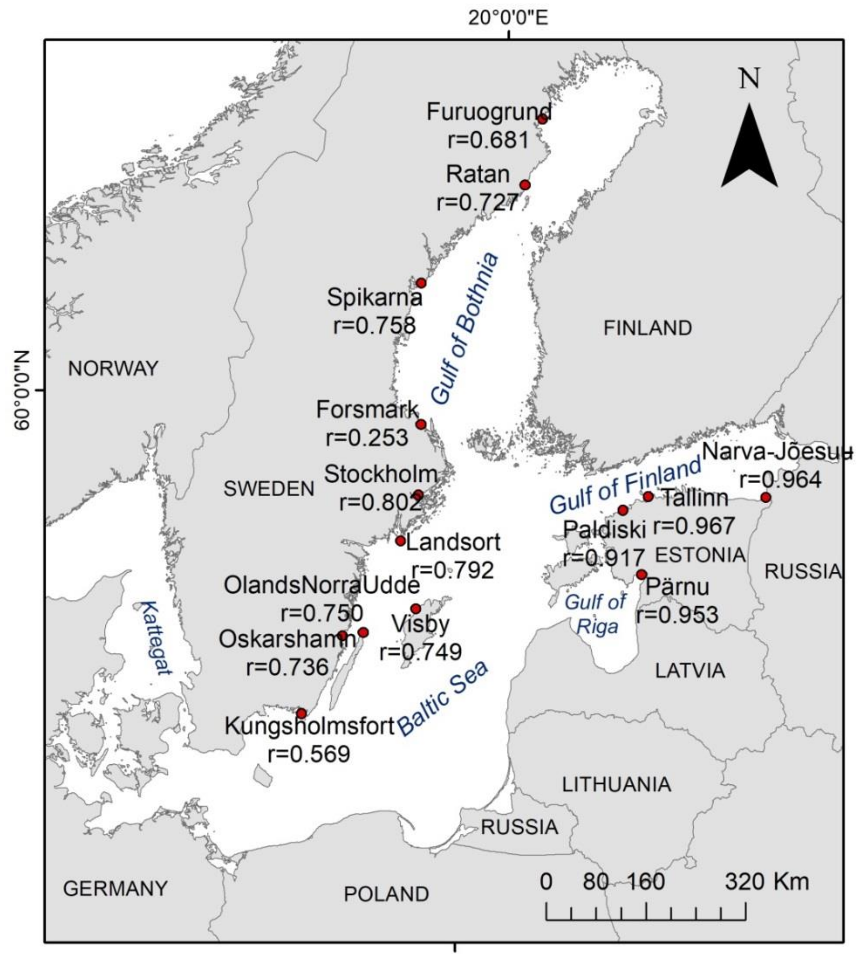
NEMO MODEL VALIDATION

- Auspicious correlation with water level measurements in the Baltic Sea
- Some differences in STDEV and maxima (eastern part of the sea)
- Model replicates well sea level variations

Measured water level

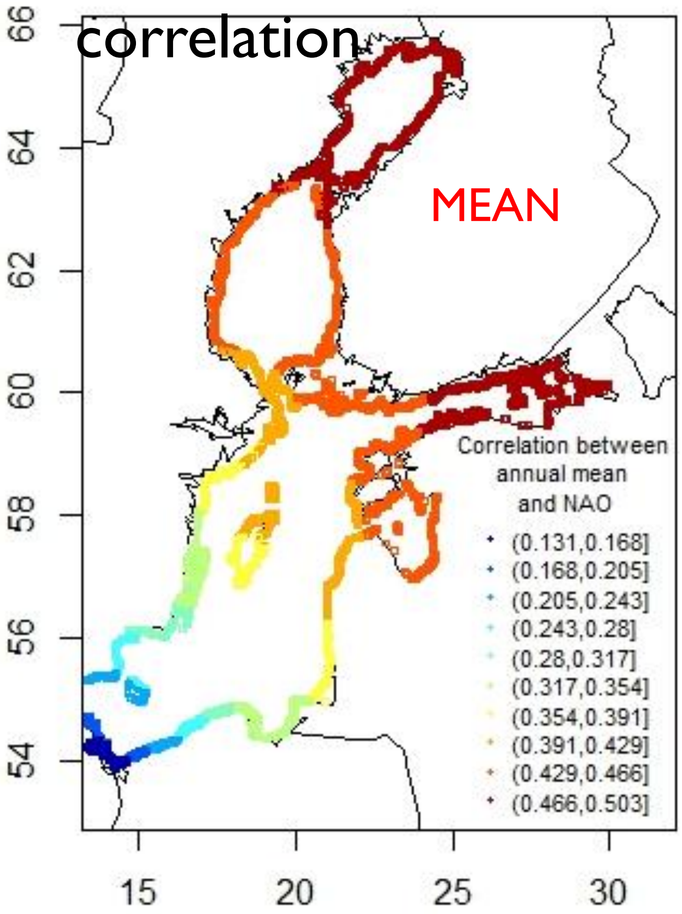
Modeled water level



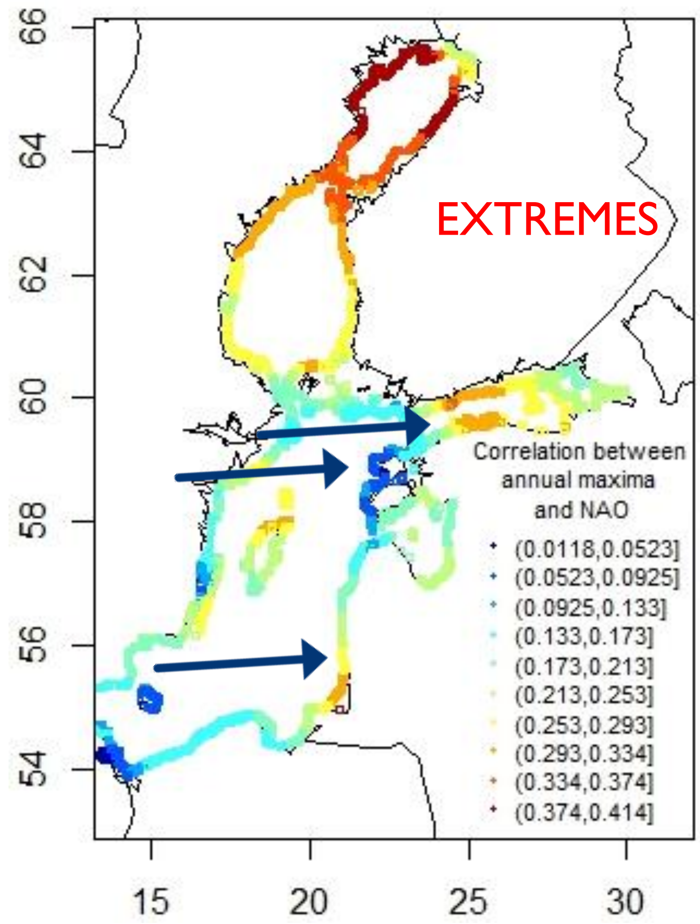


CORRELATION WITH NAO

Strong spatial variance of correlation



Different spatial characteristics



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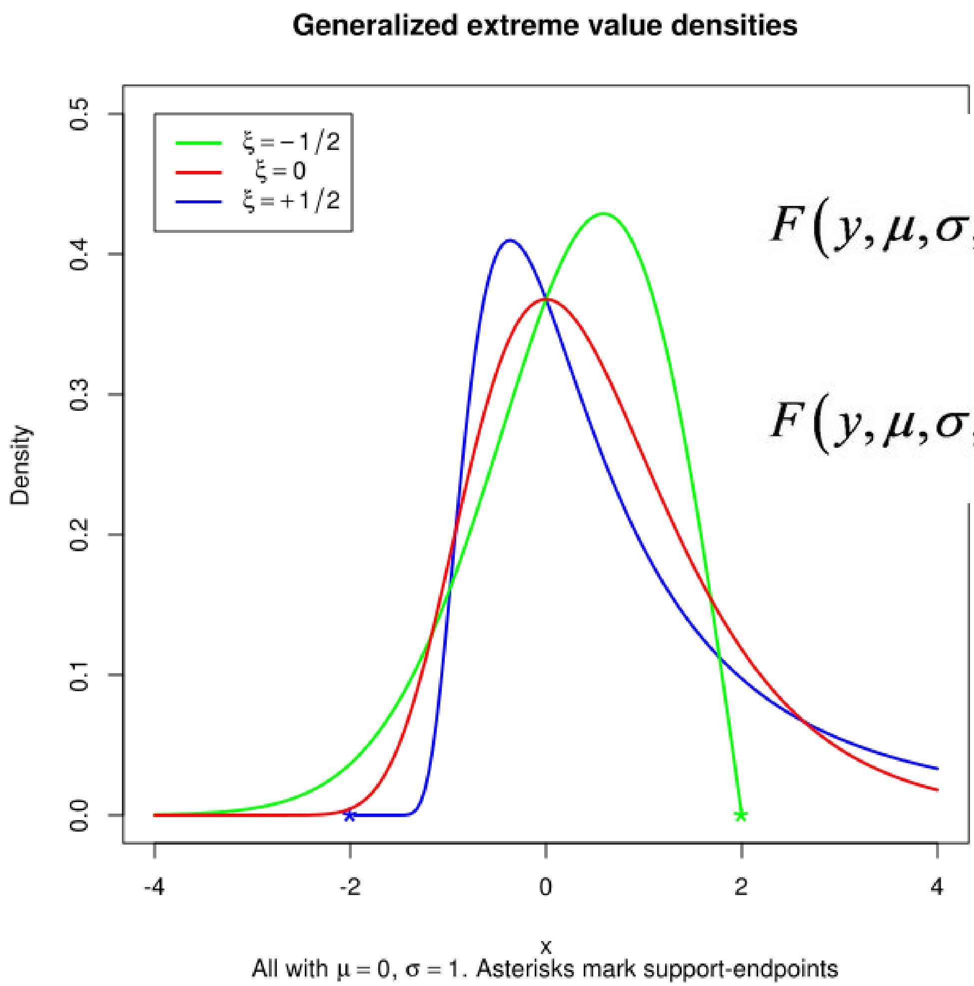
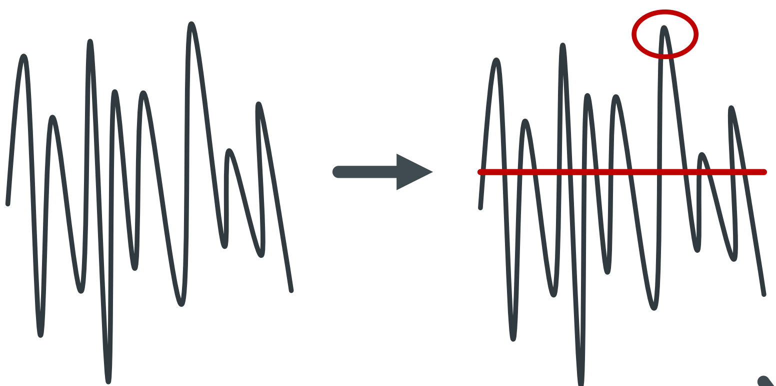
NON-STATIONARY EXTREME VALUE MODELLING



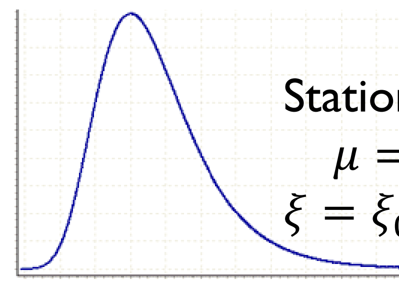
$$F(y,\mu,\sigma,\xi)=\exp\left[-\left(1+\xi\left(\frac{y-\mu}{\sigma}\right)\right)^{-\frac{1}{\xi}}\right],\xi\neq 0$$

$$F(y,\mu,\sigma,\xi)=\exp\left[-\exp\left(-\frac{y-\mu}{\sigma}\right)\right],\qquad \xi=0$$

NON-STATIONARY EXTREME VALUE MODELLING

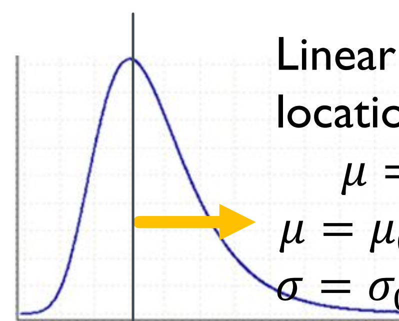


Annual maxima, removed annual mean variations, to create a stationary dataset



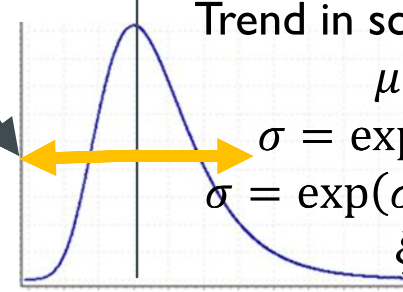
Stationary

$\mu = \mu_0, \sigma = \sigma_0,$
$\xi = \xi_0$



Linear trend in location

$\mu = \mu_0 + \mu_1 t,$
$\mu = \mu_0 + \mu_1 * NAO,$
$\sigma = \sigma_0, \xi = \xi_0$



Trend in scale

$\mu = \mu_0,$
$\sigma = \exp(\sigma_0 + \sigma_1 t),$
$\sigma = \exp(\sigma_0 + \sigma_1 * NAO)$
$\xi = \xi_0$

Implemented in ISMEV package in R https://cran.r-project.org/web/packages/ismev/ismev.pdf

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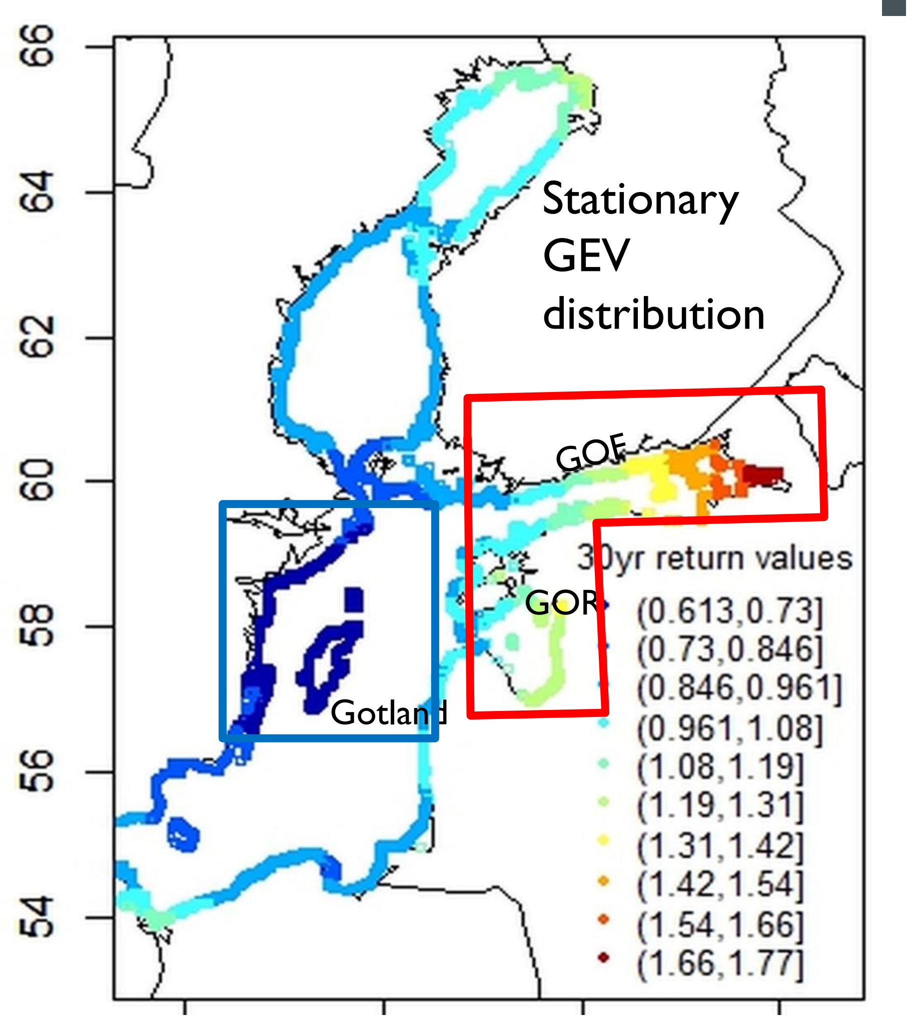
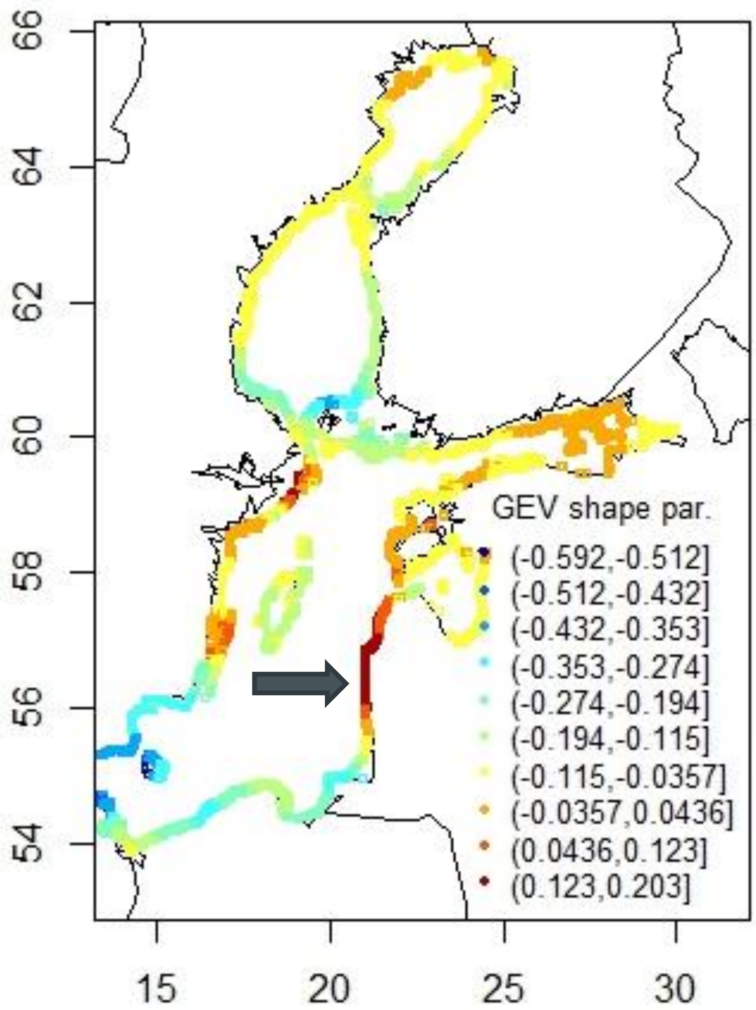
30-YEAR RETURN VALUES ALONG THE BALTIC SEA COAST

- The highest return values:
- Gulf of Finland (GOF) 1 m to 1.7 m
- Gulf of Riga (GOR) ~1.2 m, in eastern bayhead 1.3-1.4 m
- The lowest values are located along the Swedish coast, near the island of Gotland



SHAPE

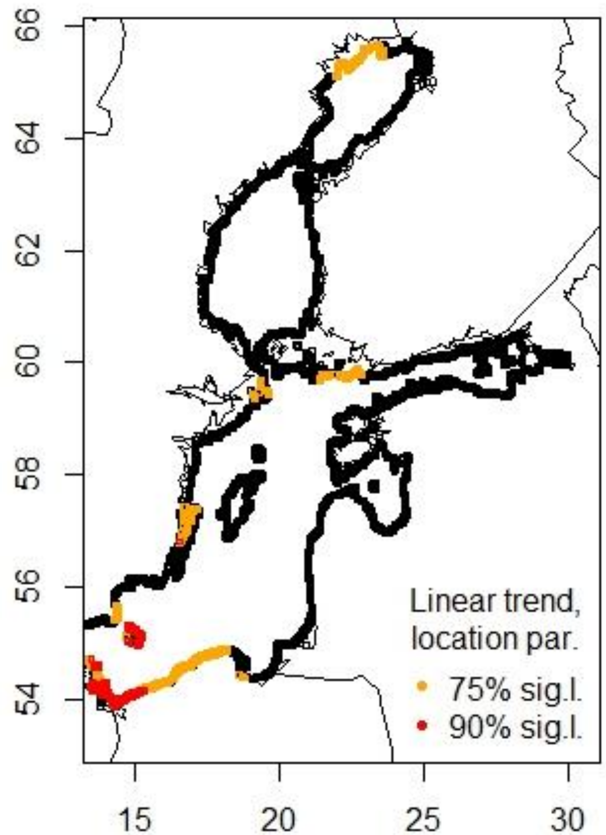
- Positive shape next to the Gulf of Riga



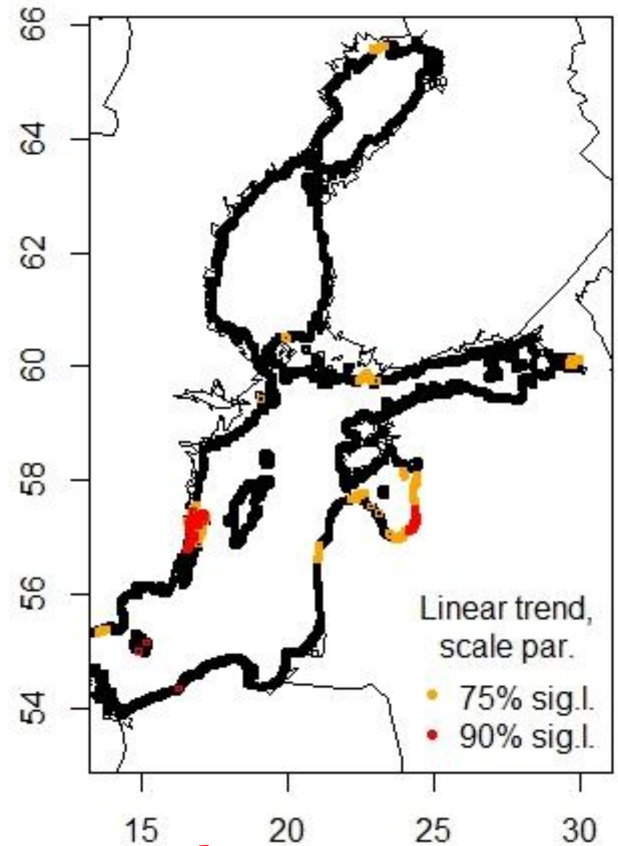
Stationary GEV distribution

TESTING LINEAR TREND APPROACH

$\mu = \mu_0 + \mu_1 t$



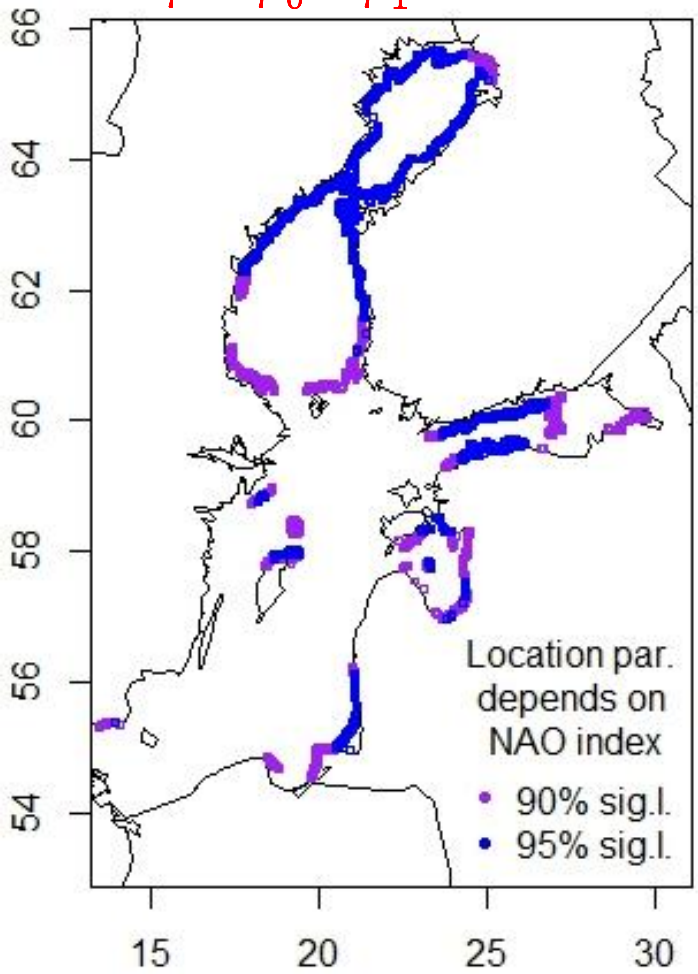
$\sigma = \exp(\sigma_0 + \sigma_1 t)$

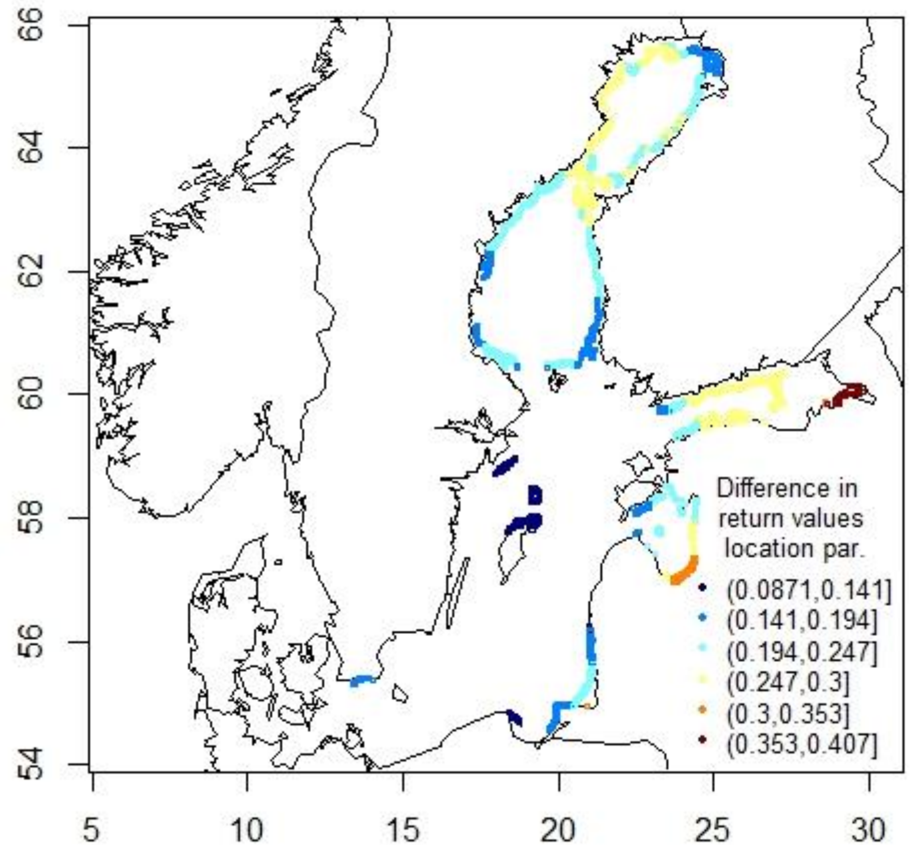


Difference between stationary and non − stationary is 15% for 30 − yr return period

CLIMATIC INDICES APPROACH

$\mu = \mu_0 + \mu_1 * NAO$

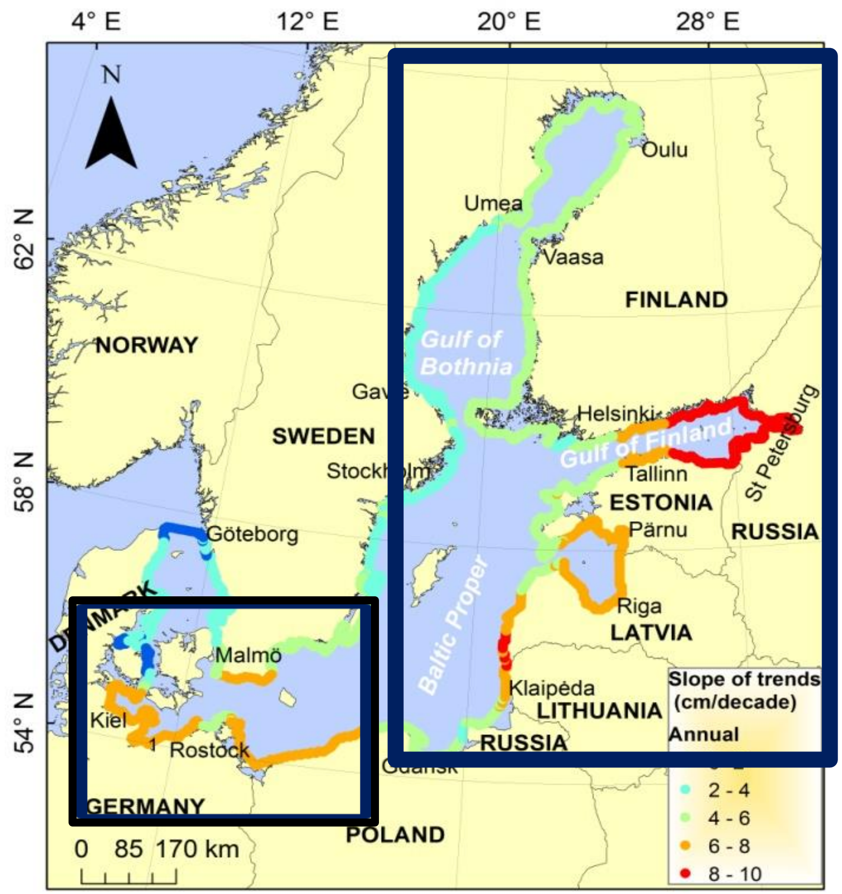




$\textbf{Difference between stationary and non} - \textbf{stationary is 28\% for 30} - \textbf{yr return period}$

DIFFERENT CAUSES OF WATER LEVEL EXTREMES RISE

- German Coast did not show strong correlation with NAO and AO in both correlation analysis and extreme value modelling. But showed strong linear trends in the location parameter
- Gulf of Botnia, Gulf of Finland, Gulf of Riga, patches in the Eastern Baltic Coast are clearly affected by changes in NAO
- We can use the SST in summer to predict NAO in winter (Rodwell et al. 1999) -> predict return periods, major flooding events



SUMMARY

- Performed systematic analysis of the water level extremes in the Baltic Sea
- We show that it is extremely important to take into account non-stationarity when dealing with extremes – the difference between stationary and non-stationary return periods is 10%-30%
- GEV modelling helped to understand the cause of increases of extremes in the Baltic Sea – the Northerh and Eastern parts are mainly affected by changes in NAO, the German coast is not related to NAO, but shows significant linear trend in location parameter, when the whole distribution is shifting as a whole
- For the Northern and Eastern Baltic Sea we can predict major flooding events using a relation between the summer SST and winter NAO (Rodwell et al., 1999)