Return levels of extreme European windstorms, their dependency on the NAO, and potential future risks

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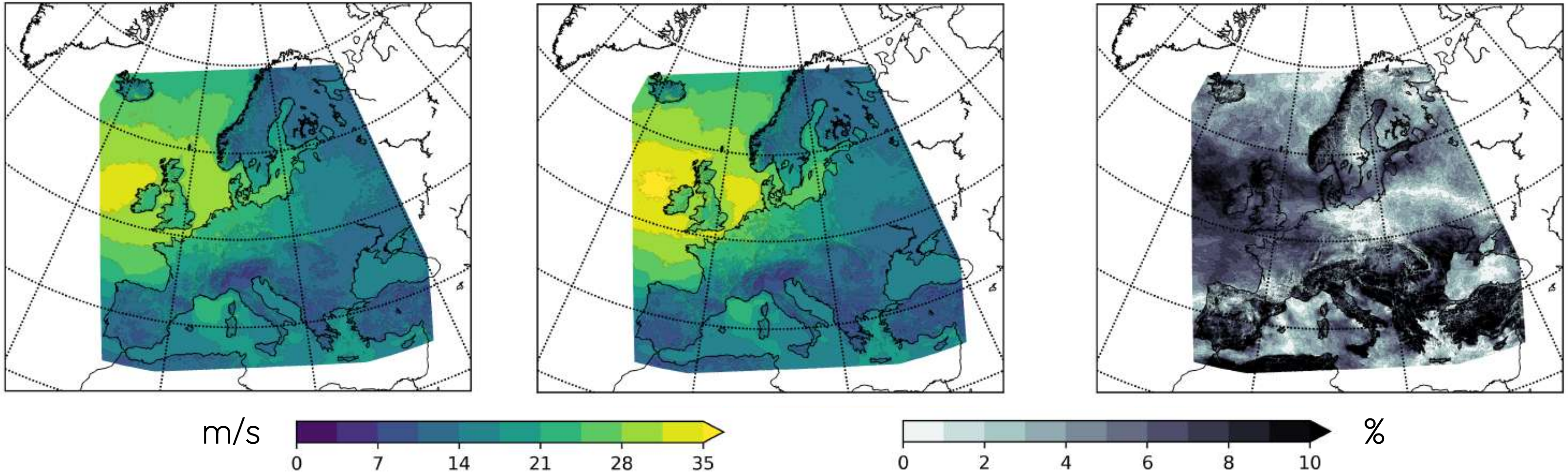
Motivation

- Europe windstorms can cause significant losses >€8 billion (Lothar, 26/12/1999)
- Catastrophe models are the common tool to quantify the 1-in-200 year risk
- These are often complex black-box procedures with multiple data sources
- Risk estimates are very sensitive to the choice of historical period

$\overline{u_1}$ (1972 – 2013) $\quad$ $\overline{u_2}$ (1989 – 2013) $\quad$ $\dfrac{|\overline{u_2} - \overline{u_1}|}{\overline{u_1}}$



Questions Addressed

1. Can we estimate return levels of European windstorms using a simple, transparent statistical model?
2. Is there an optimal catalogue length for estimating return levels?
3. Can our framework give any insights to potential future return levels

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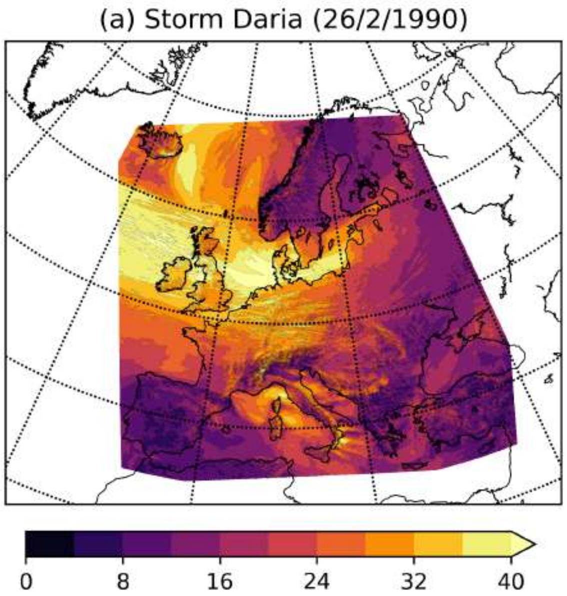
Data

- WISC data for the observed footprints
  - 124 footprints from 1950 - 2014
  - Resolution ~4.4km
  - Dynamically downscaled from ERA-I/20C

- NAO daily data from NOAA CPC (rotated EOF standardized by 1950-2000)



Statistical model for estimating return levels

- Limited footprint quantity (124) so need a simple statistical model with assumptions:
  - Wind gust exceedances are exponentially distributed above a threshold *(u)* (Gumbel domain)

- The model depends on threshold *(u)*, the mean excess above the threshold (σ) and the rate of event occurrence (λ)
  - 124/(2013-1950) = ~2 footprints/year

- This then leads to this expression for the T-year return level:

$$\hat{y} = u + \hat{\sigma}\left(logT + log\hat{p}(u) + log\hat{\lambda}_S\right)$$

Including variations of the NAO

- NAO the dominant modulator of European storm severity
  - Include its influence on our model parameters
- Use quantile regression to generalize our threshold *(u)* to include NAO variations

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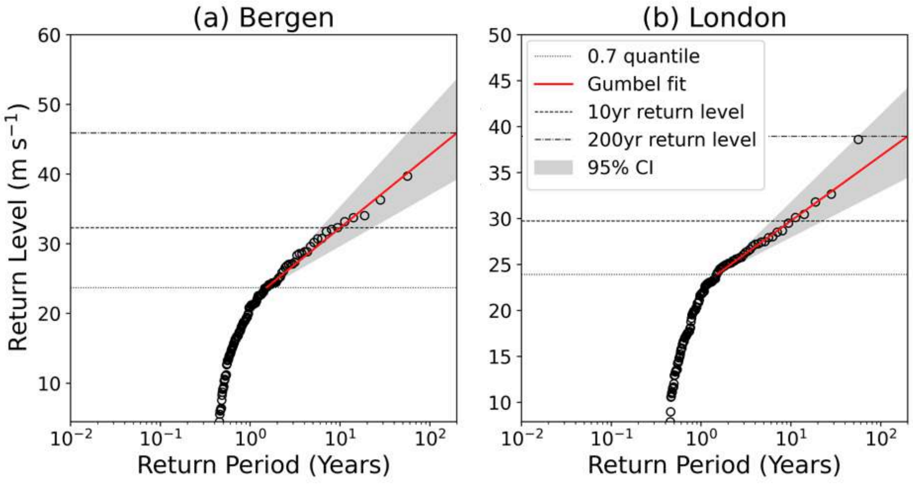

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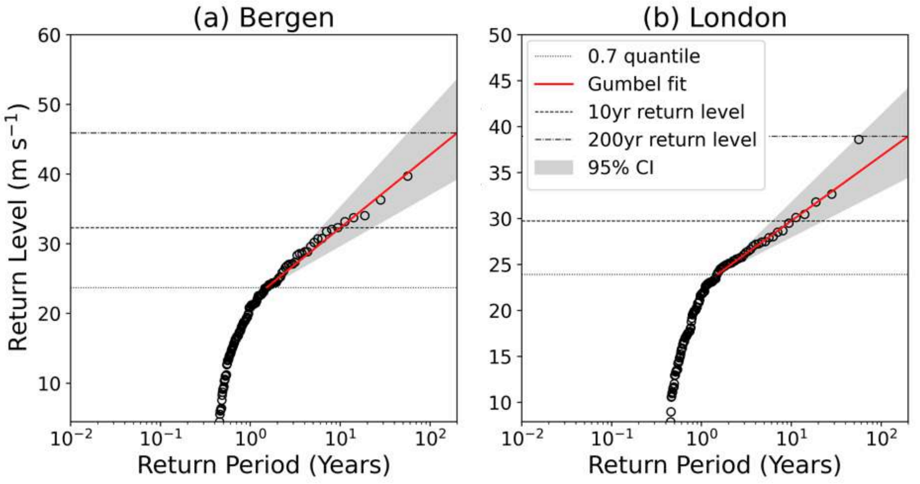
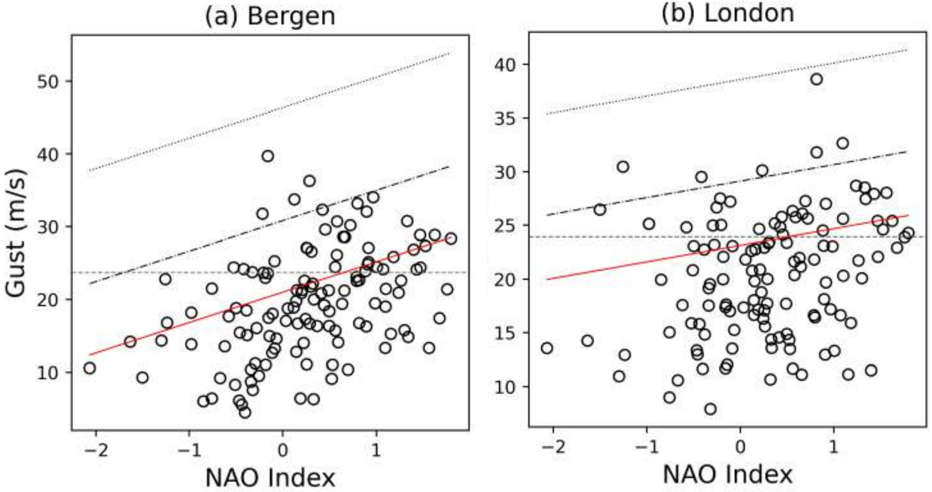
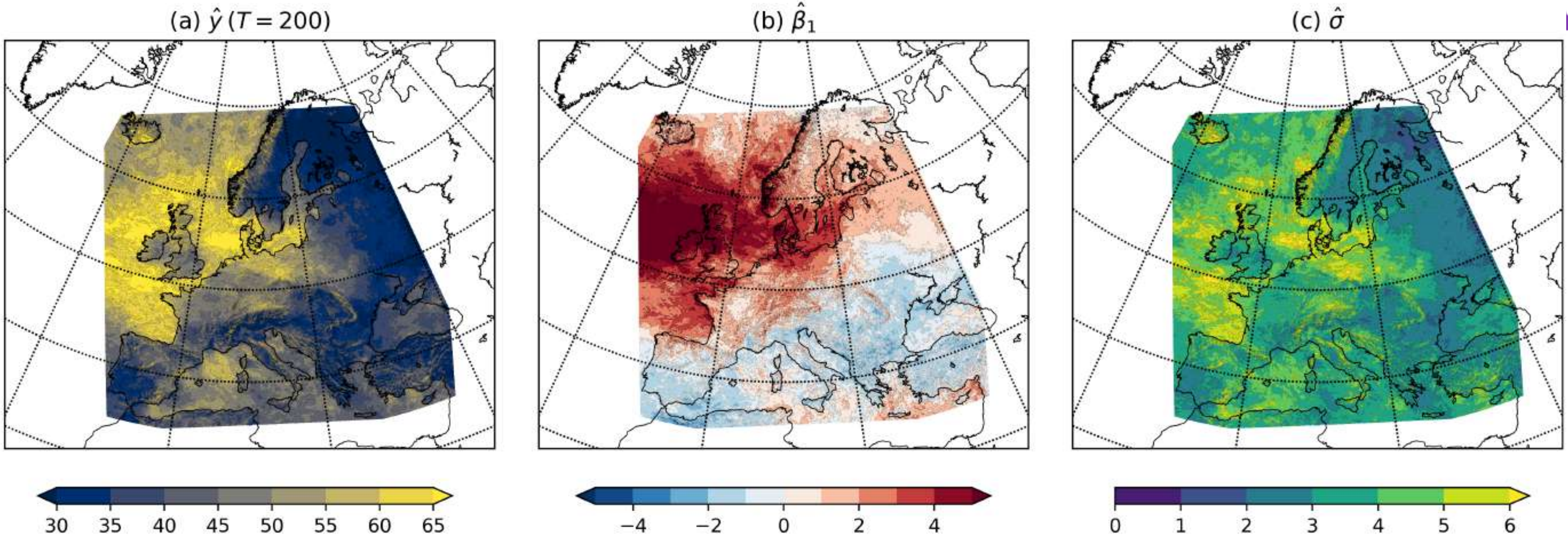
$$u = \beta_0 + \beta_1 x$$





Return level estimates using the NAO

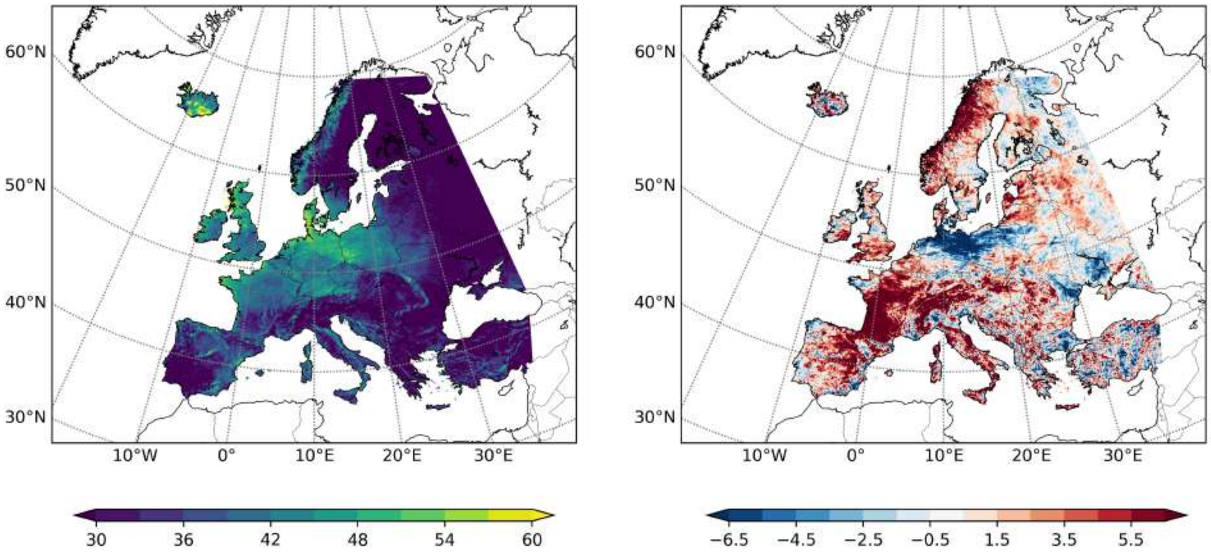


- 200-yr return levels largest over N and NW Europe
- β_1 parameter indicates positive NAO/return level relationship for NW Europe
- σ varies less with no indication of influence from large-scale modes
- The two parameters describe the location and scale parameters of the distribution tail

Return levels from different length catalogues

200-yr return level
1950-2014

(1990-2014)-(1950-2014)



- Different length historical records get drastically different answers
  - Which one is better?

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- So far, the entire WISC catalogue has been used (64 years)
- Can we achieve a good return level estimate with only 5, 10, 20 years?

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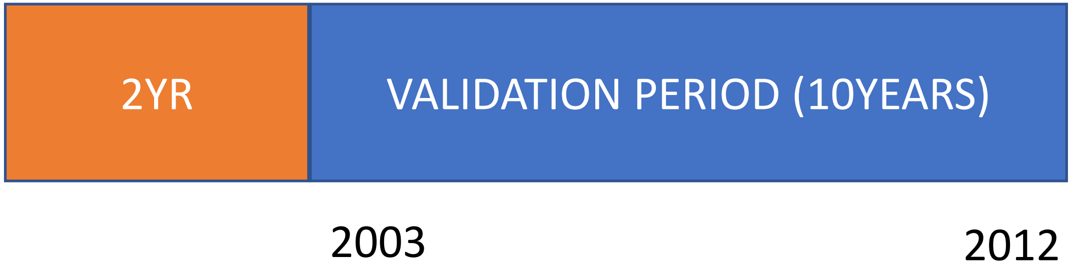

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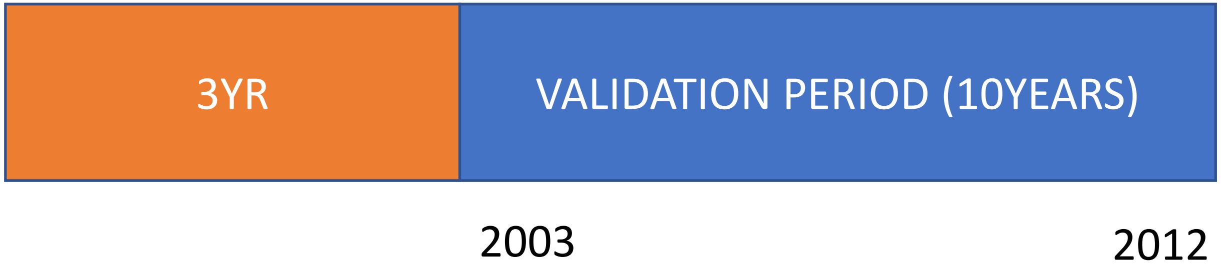

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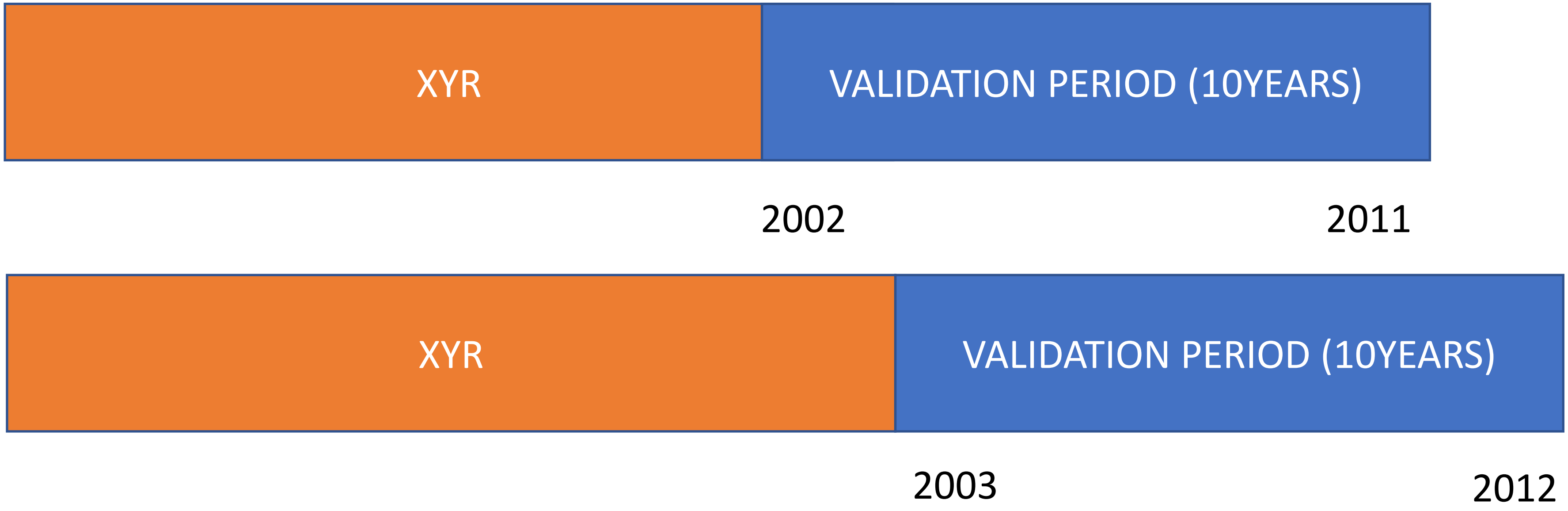

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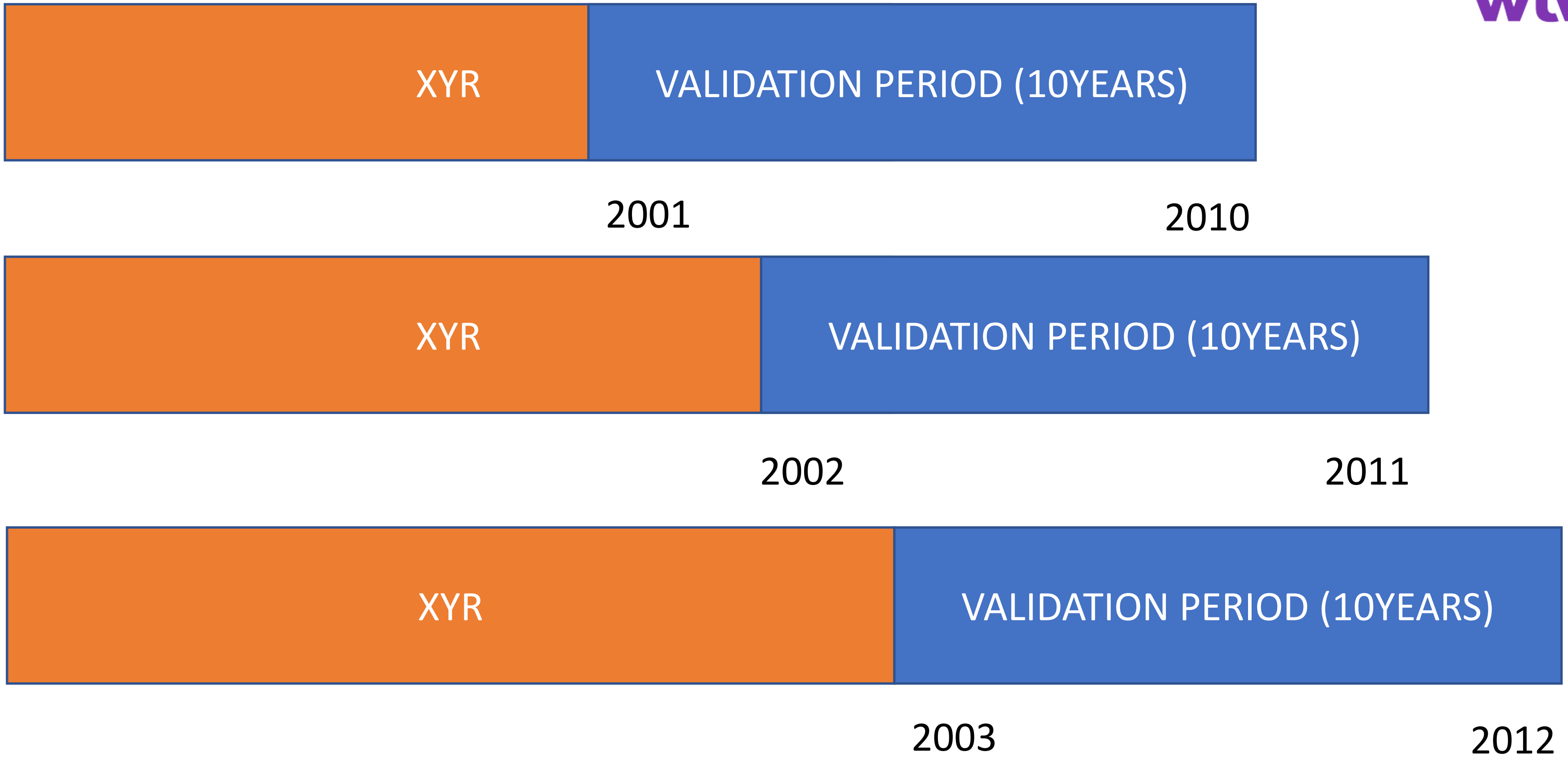
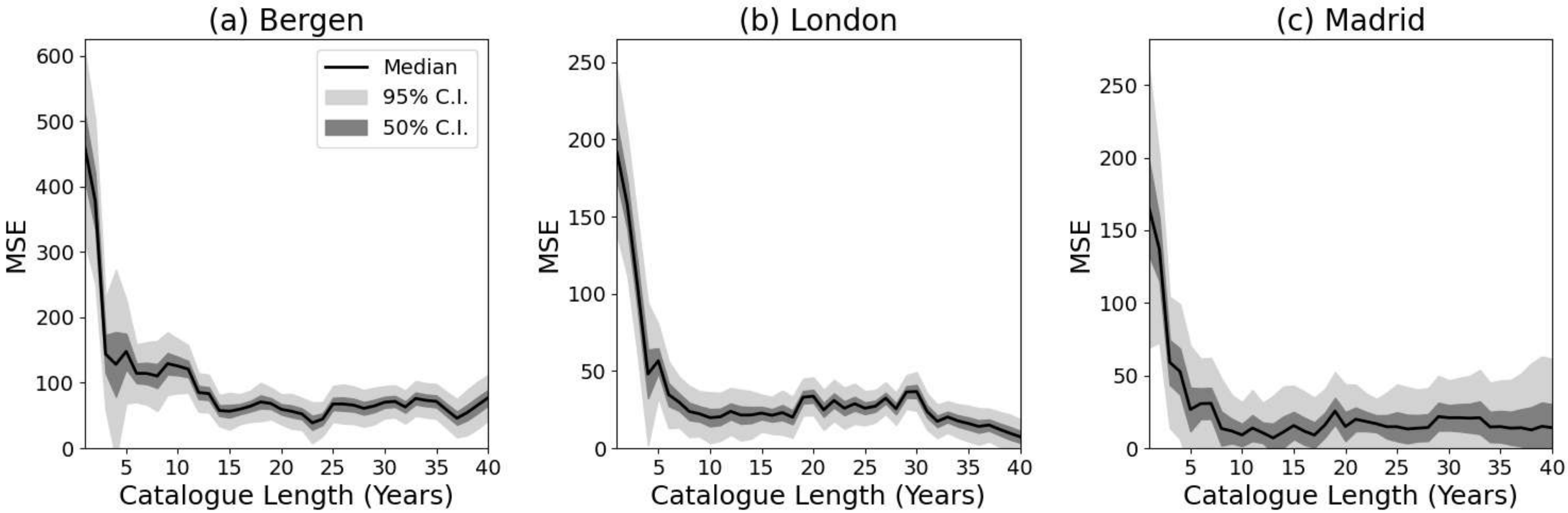


200-year return level with catalogue length



- The 3 locations show similar shape MSE curves
- Highest MSE at short catalogue length – inter-annual variability is large
- Reduces to a minimum after 10-20 years

Improving catalogue length estimation through simulation

- WISC events occur ~2.1 years
- We know exceedances and that excesses are exponentially distributed
- NAO cycle ~70 years and varies ±1.5 st. dev.
- Can simulate events at this rate with these NAO phases to estimate gusts

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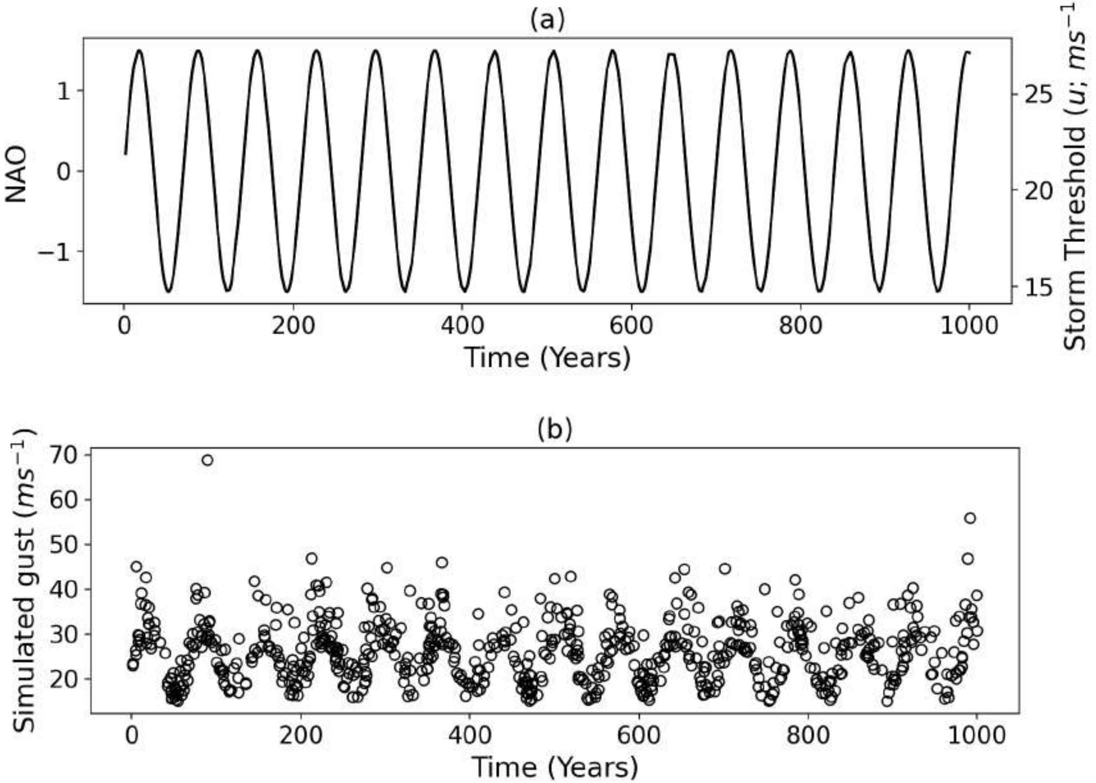
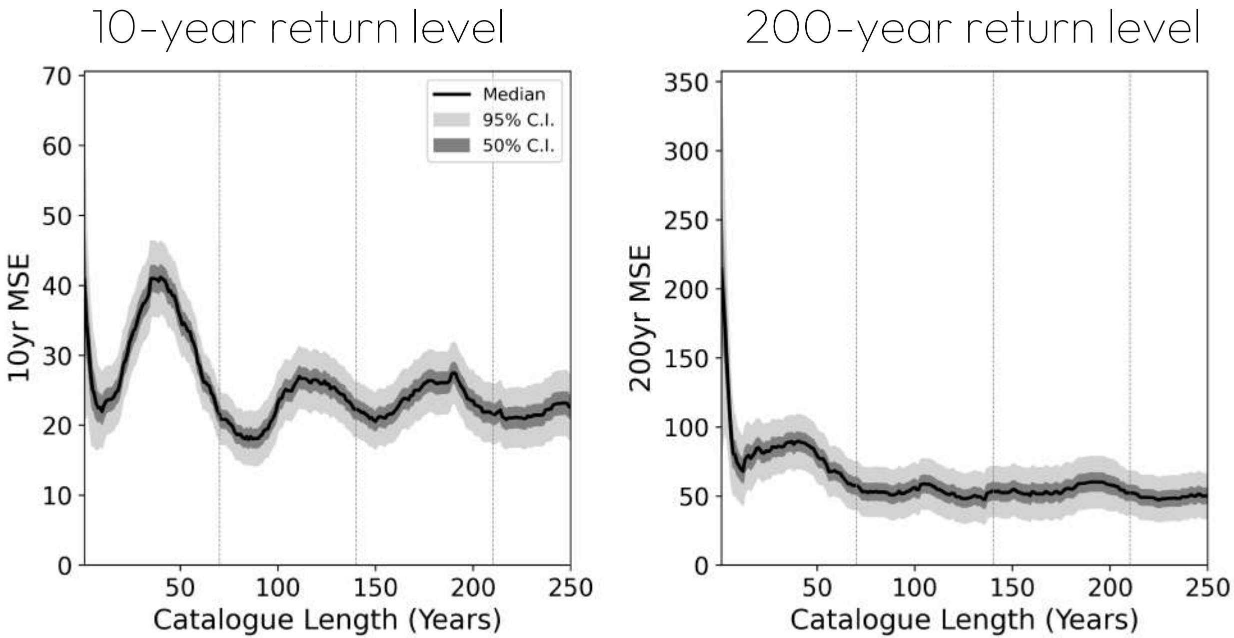
- Can simulate events at this rate with these NAO phases to estimate gusts
- Repeat previous MSE estimation



Optimal catalogue length with simulated gusts



- 200-yr similar pattern as before, high MSE at short catalogue which reduces to minimum after ~15 years
- 10-yr has an oscillation due to the greater contribution of the NAO
  - Having an NAO signal more similar to the 10-year period is important – better to sample a full NAO cycle

Using our framework for climate change

- In the last 50 years the NAO trend is ~0.15 standard deviations per decade
- Assume this will continue and the average NAO will be +1.5 in 100 years

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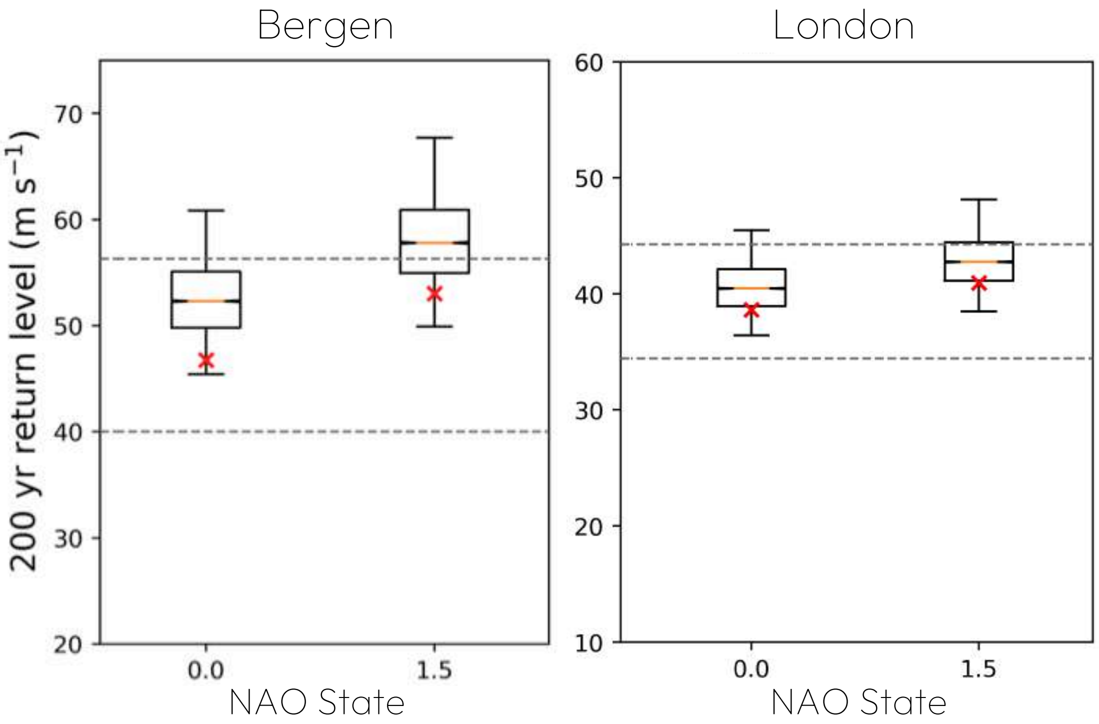
- 200-yr return level with an NAO of +1.5
- Future return levels are at the upper limit of the historical range
  - More evident for the more NAO dependent locations



Key Points

- Developed a simple and transparent framework for estimating return levels of European windstorms from observed footprints
- NAO is the key modulator of return levels through its influence on our model threshold (tail location parameter)
- 20 years of data is needed to get the best estimate of 200-year return levels
- Theoretical future NAO states indicate increases in return levels above the historical uncertainty
  - Potential for unprecedented extremes

NHESS paper in discussion!

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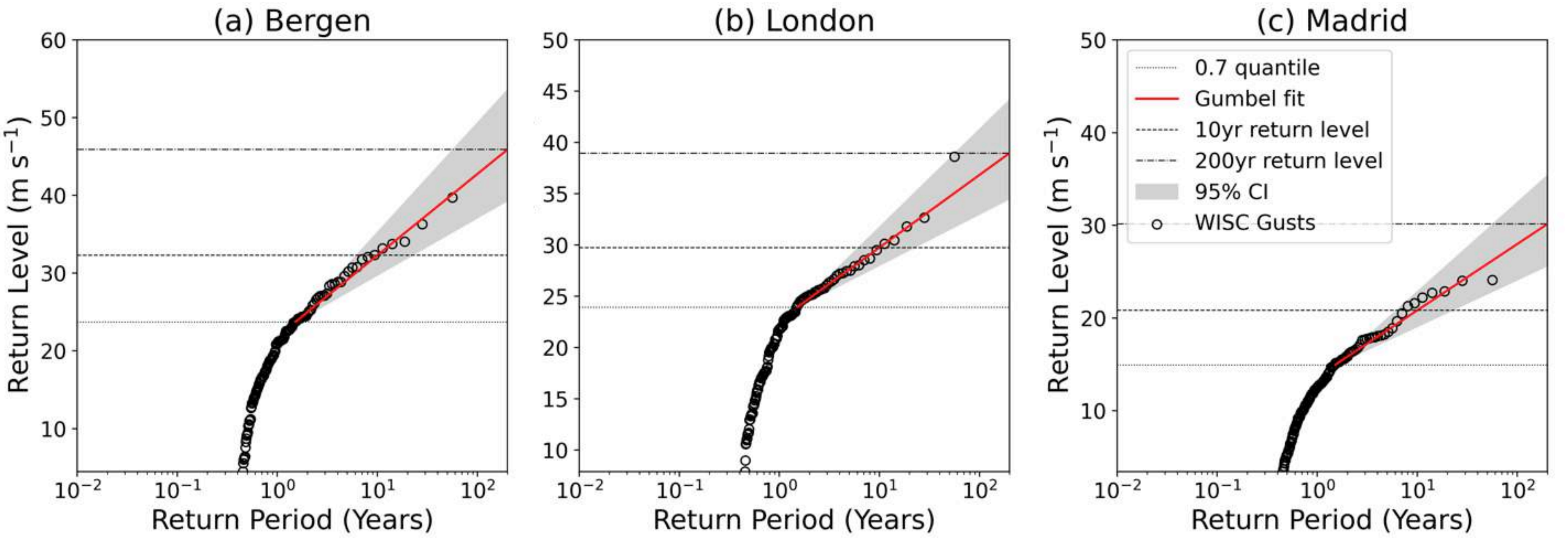
Additional Slides

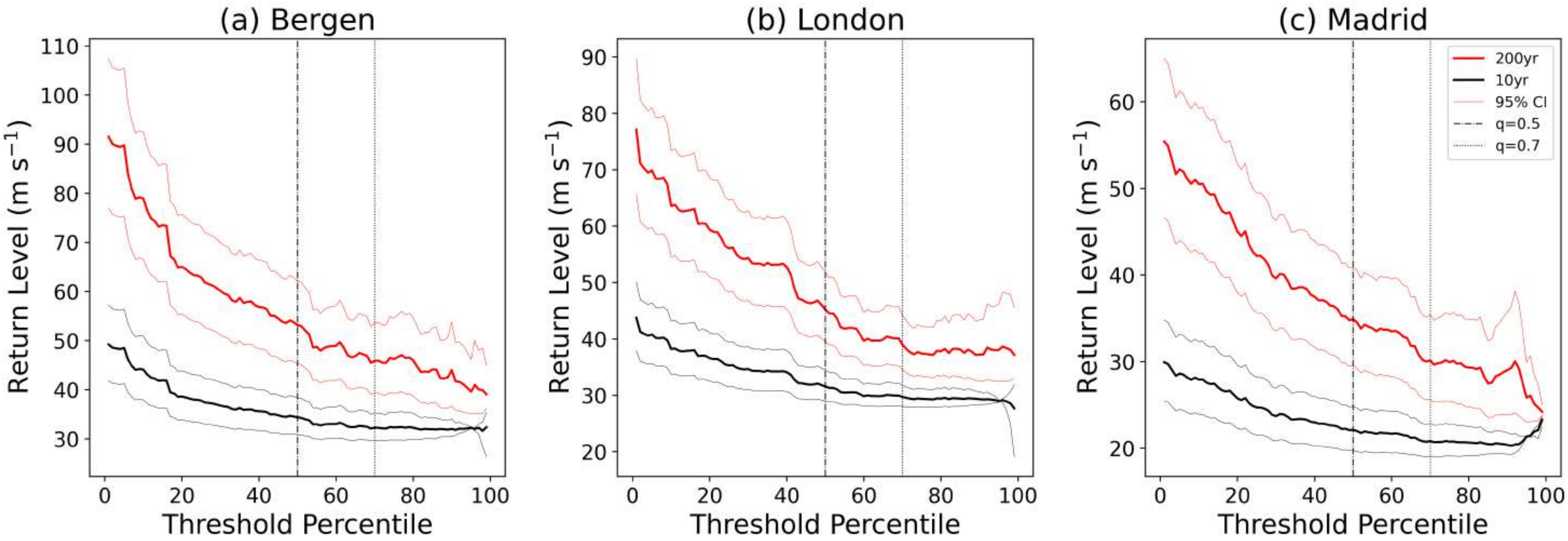
Return level estimate across Europe (No NAO)



Justifying the choice of threshold

University of Exeter

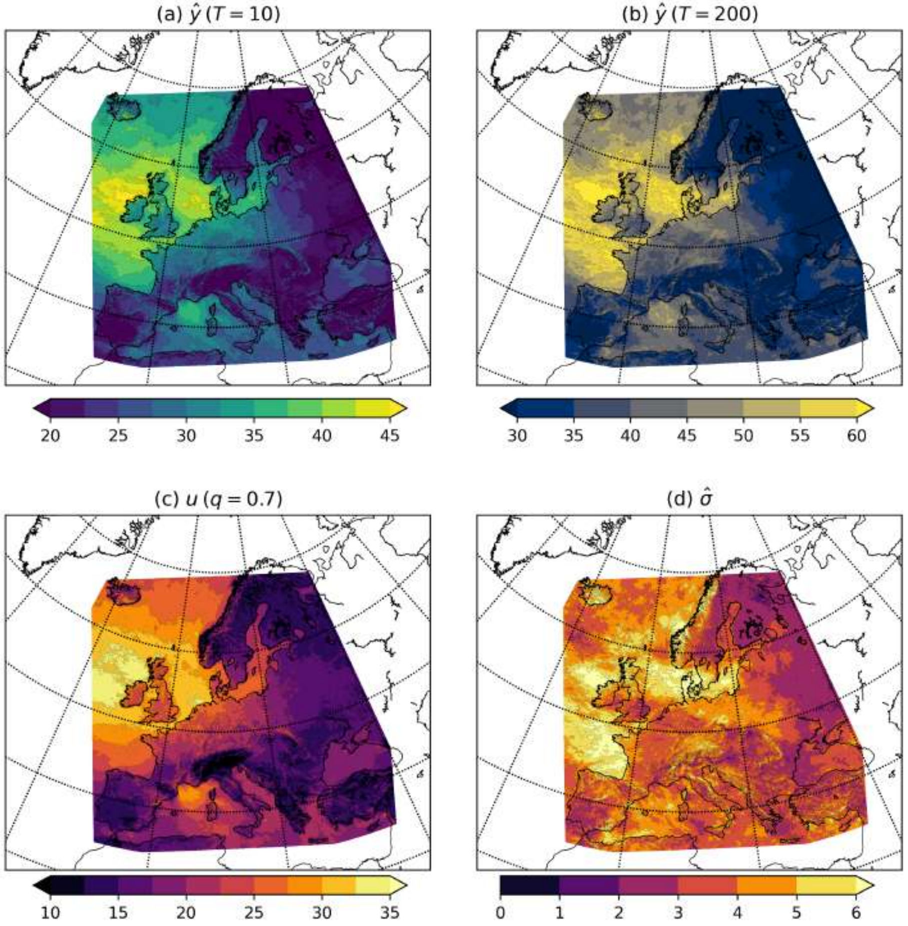
wtw



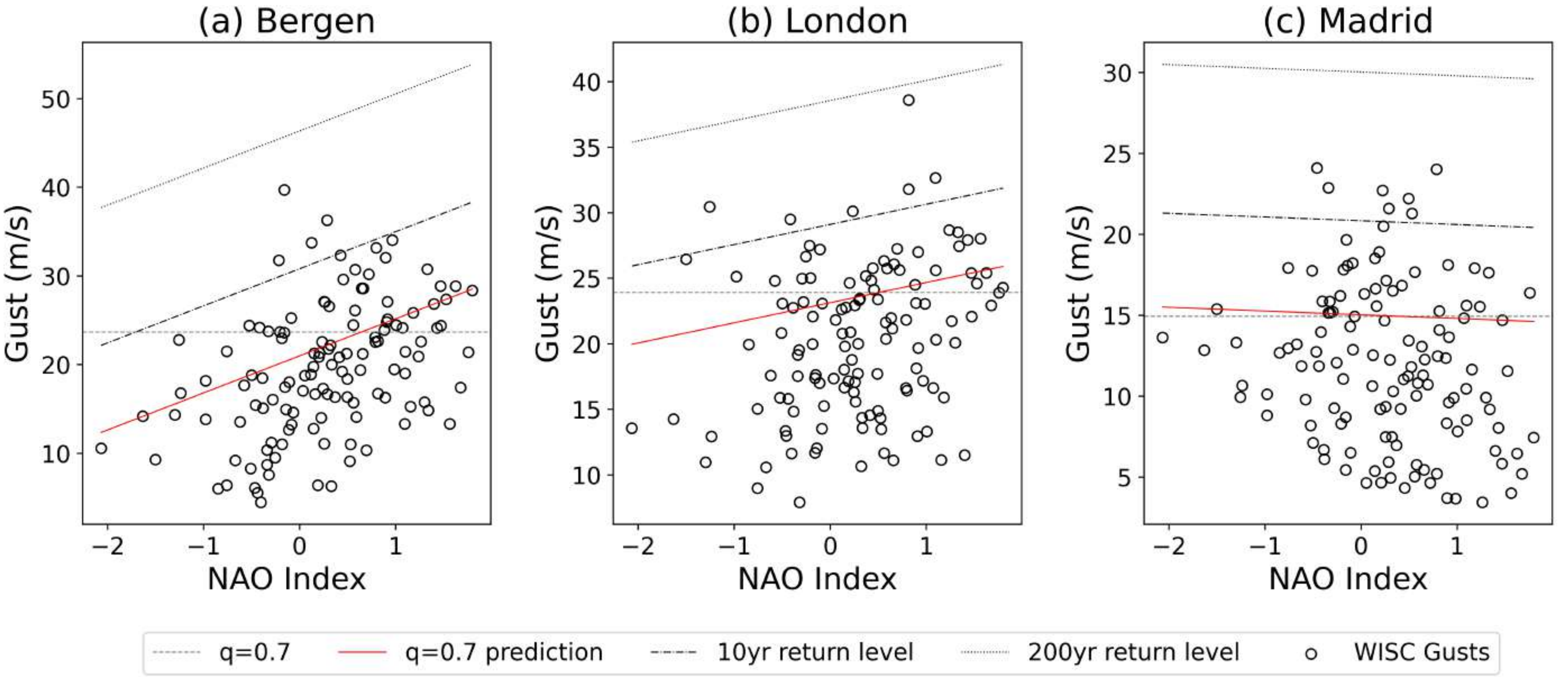
- Use the 0.7 quantile to fit our model
- Above this threshold get low variation in our estimated return level

Return level estimate across Europe (No NAO)

- Different structure in T=10 and T=20 due to influence of NAO varying



Return level estimate across Europe (with NAO)



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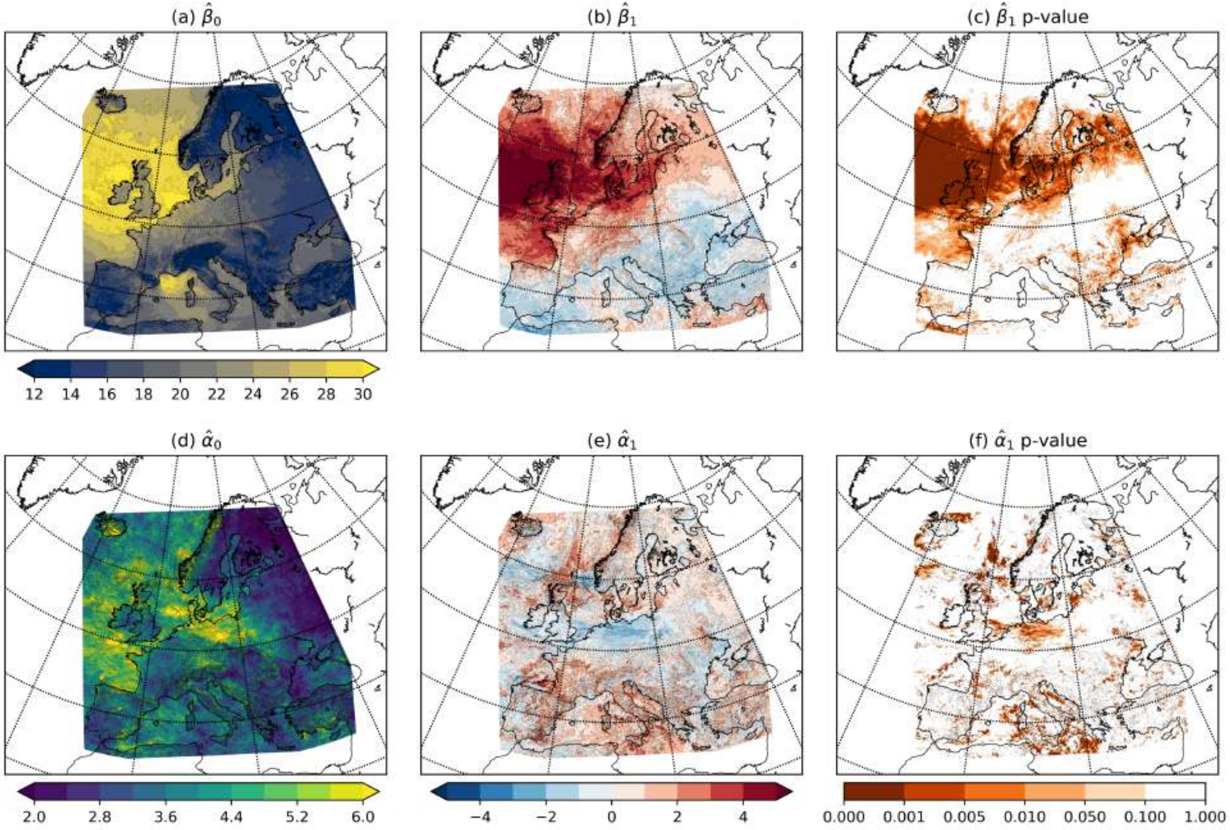
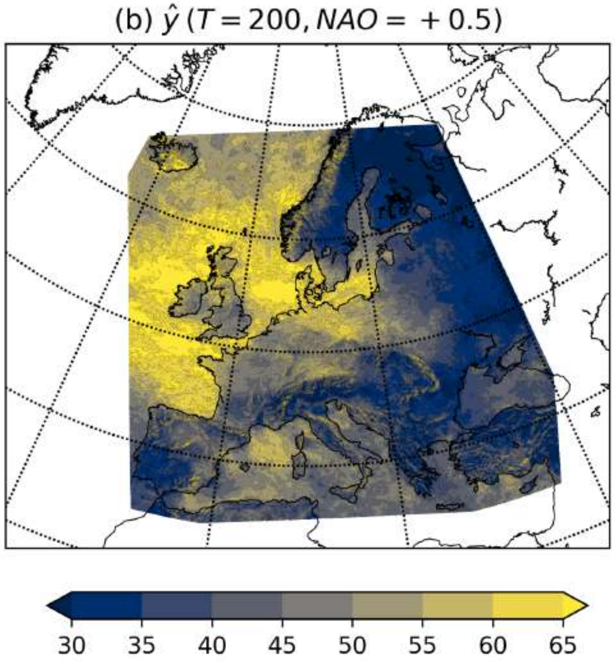
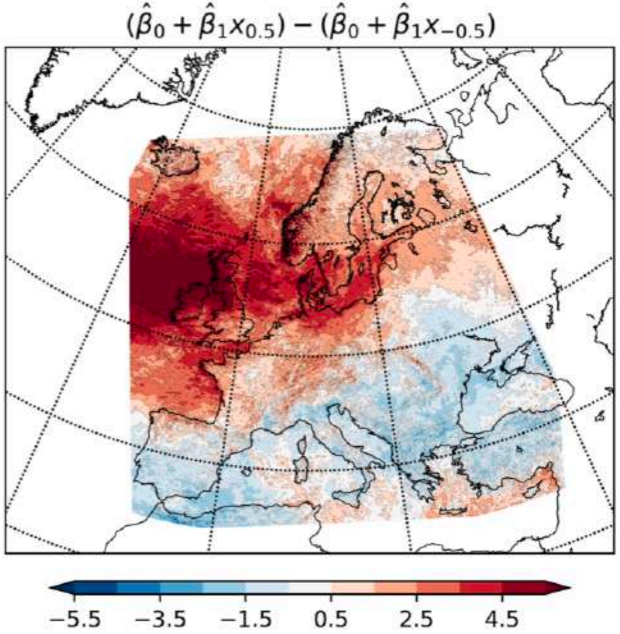


- Regressing NAO on threshold is significant for NW Europe.
- With less NAO influence the role is not significant
- No robust significance for alpha parameters

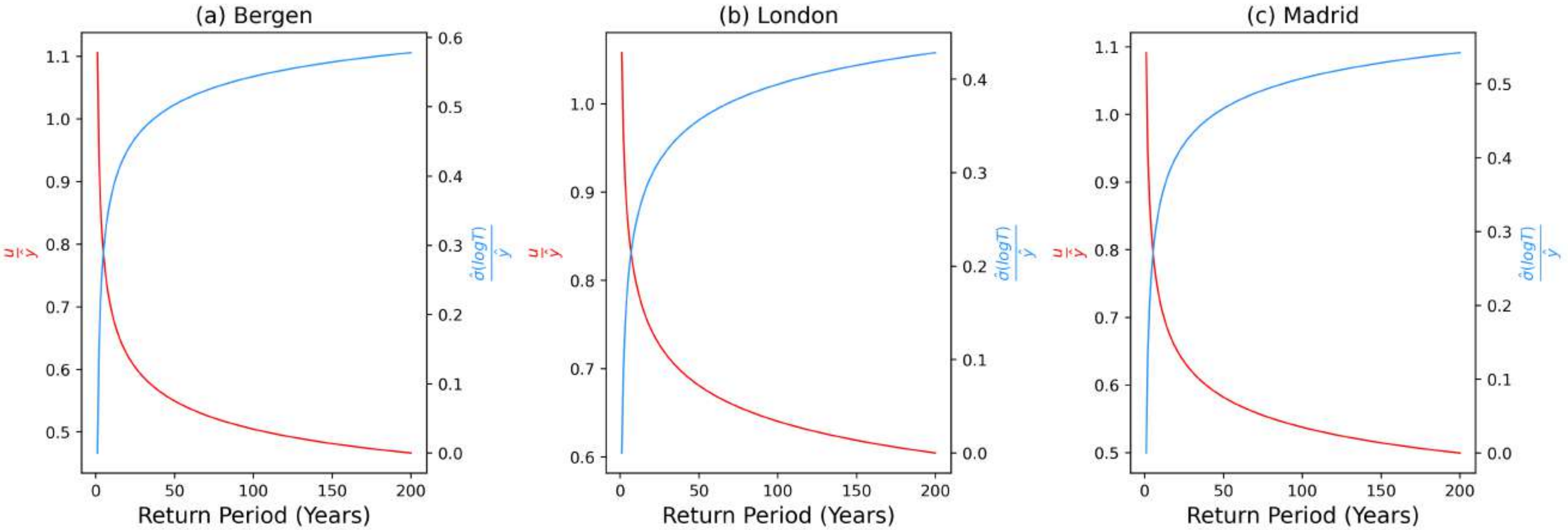
Different return levels based on NAO state





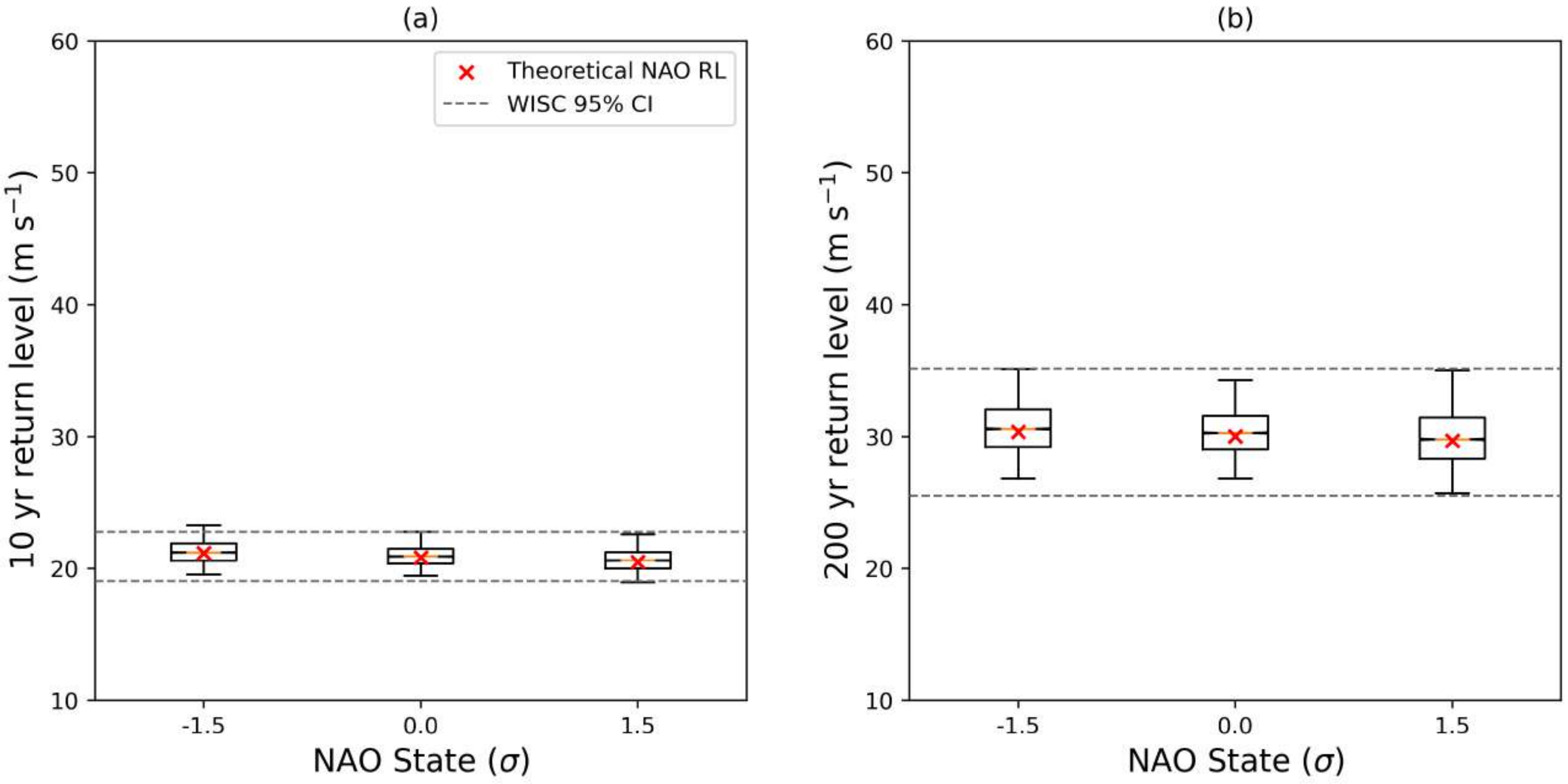
- 200-yr return level varies with NAO input and largest impact over NW Europe

Role of the NAO for different return levels



- NAO (red line) much more important at shorter return period, with longer return periods dominated by the mean excess (blue line)

Future return levels across Europe



- At Madrid the lack of NAO influence means that future return levels similar