Extreme Storminess: How deep can a low become?

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Extreme extra-tropical cyclones

Interesting to study extreme storms (intensity/windspeed/precipitation):

- Extremes may exhibit different behaviour compared with average values.
- Extremes are more impact-relevant (useful for re-insurers).

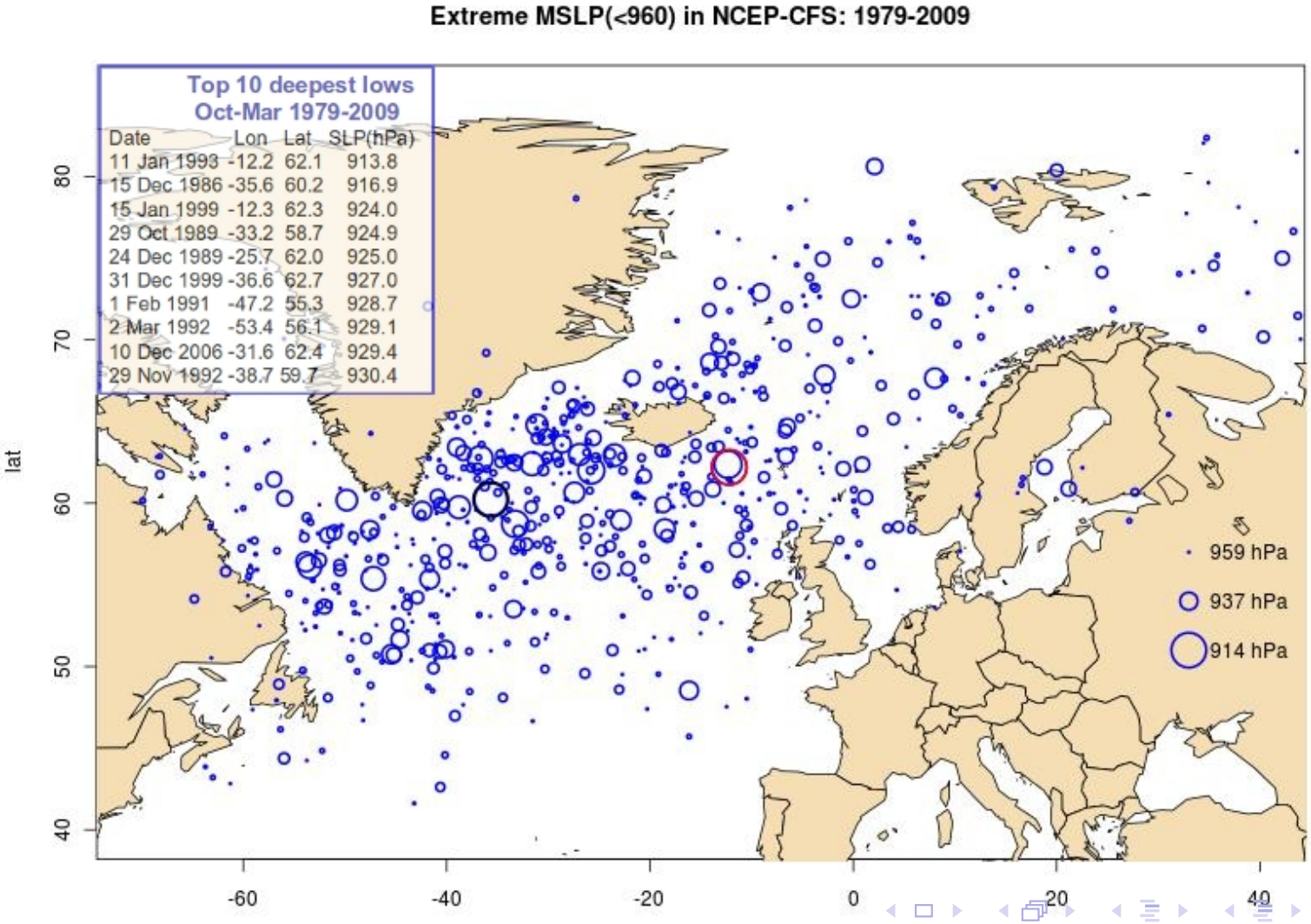
Have considered Sea Level Pressure (SLP) as intensity measure.

- How low can SLP get in an extra-tropical cyclone?
- How does this vary spatially and temporally?
- What do future climate projections say about this?

Extreme extra-tropical cyclones

Some recent deep historical storms:

- The Braer Storm was the strongest extratropical cyclone known to occur across the northern Atlantic ocean, with a central pressure of 914mb on 10 January 1993 http://en.wikipedia.org/wiki/Braer_Storm_of_January_1993.
- An extratropical cyclone near Iceland deepened to below 920mb on 14-15 December 1986.

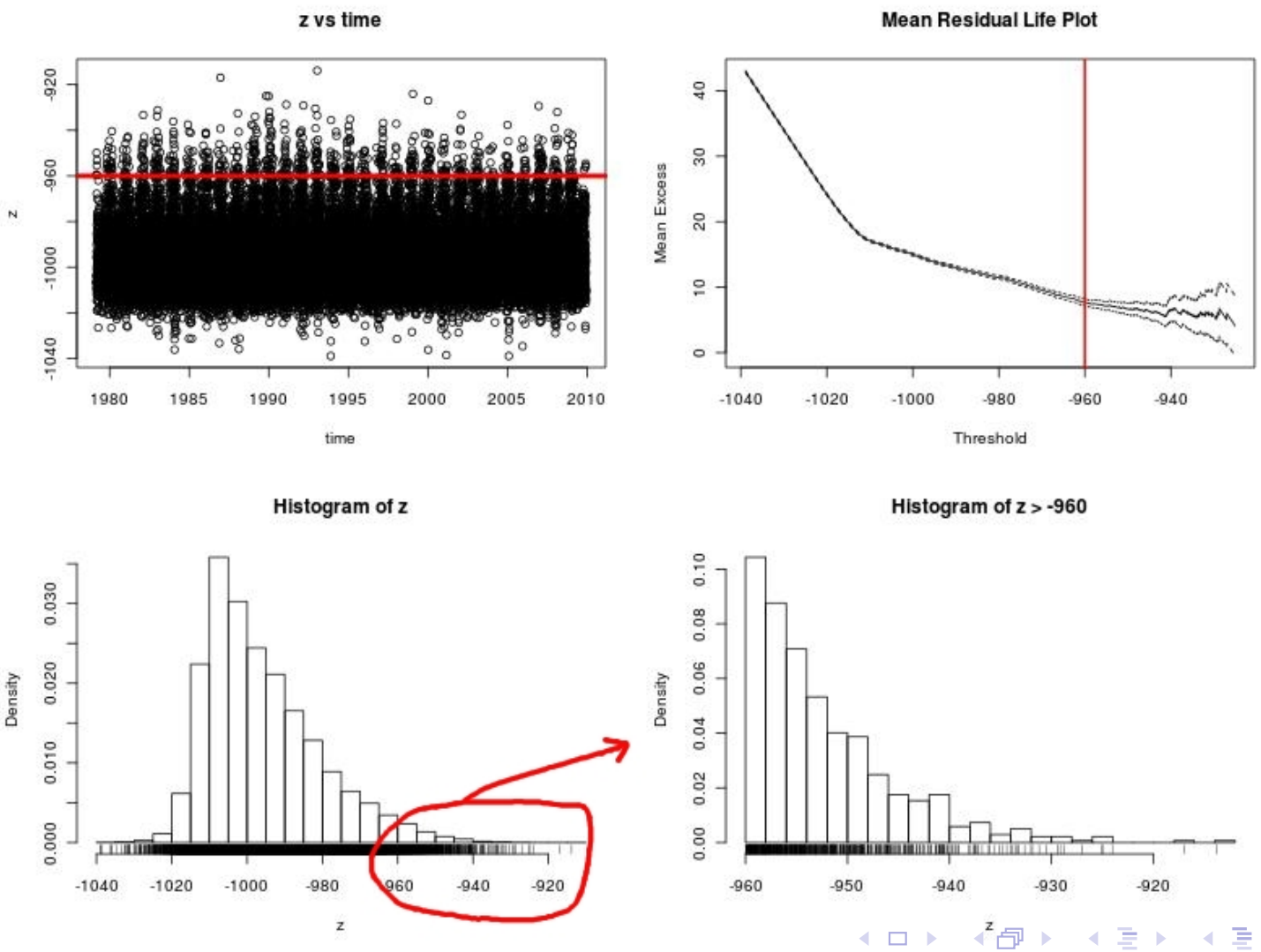


Extreme value theory

- Can use extreme value theory (EVT) to analyse extremes.
- Relatively little has been published on extreme Atlantic storms using EVT. Exceptions include:
  - Sienz et al. (2010), *Extreme value statistics for North Atlantic cyclones*, Tellus
  - Della-Marta and Pinto (2009), *Statistical uncertainty of changes in winter storms over the North Atlantic and Europe in an ensemble of transient climate simulations*, Geophys. Res. Lett.
- In EVT, conventional to look at either maxima or values above a threshold.

Storm tracks: NCEP-CFS reanalysis data

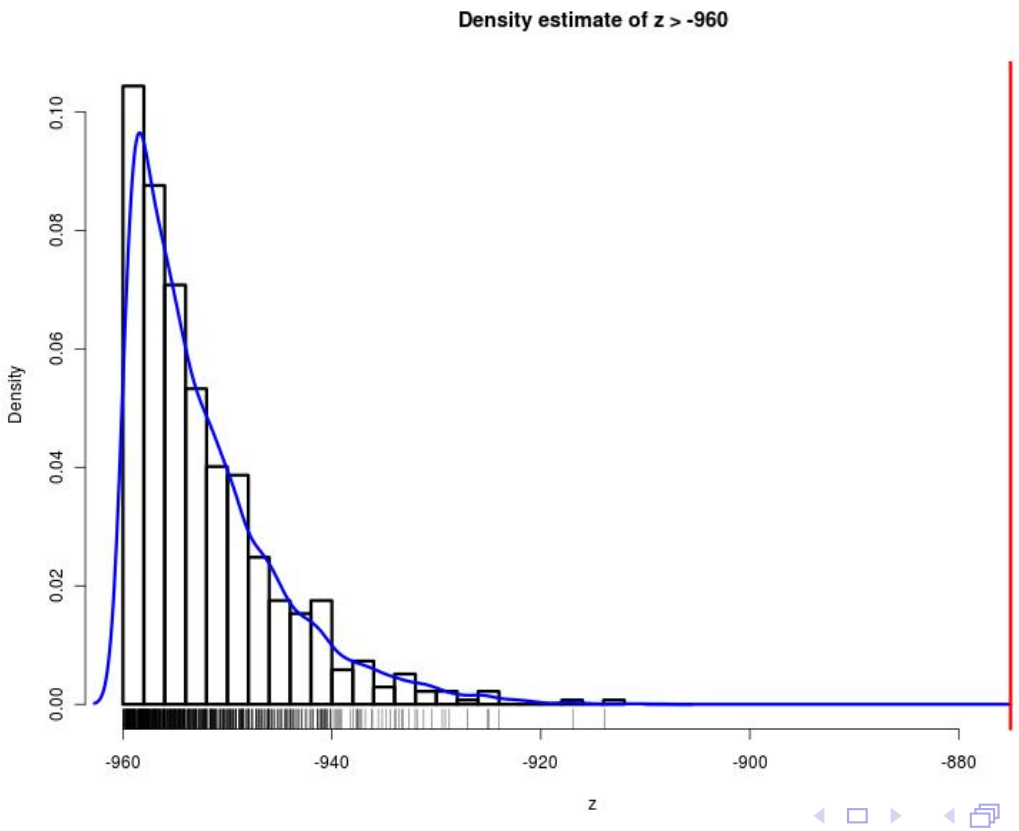
- For each storm track in 1979-2009 defined on 6-hourly measurements, we have taken the minimum pressure for lat $[0, 90]$ and lon $[-90, 90]$.
- In EVT it is conventional to use maxima so considered variable $z = -$pressure. Have used all values of z such that $z > -960$.



Stationary extreme value model

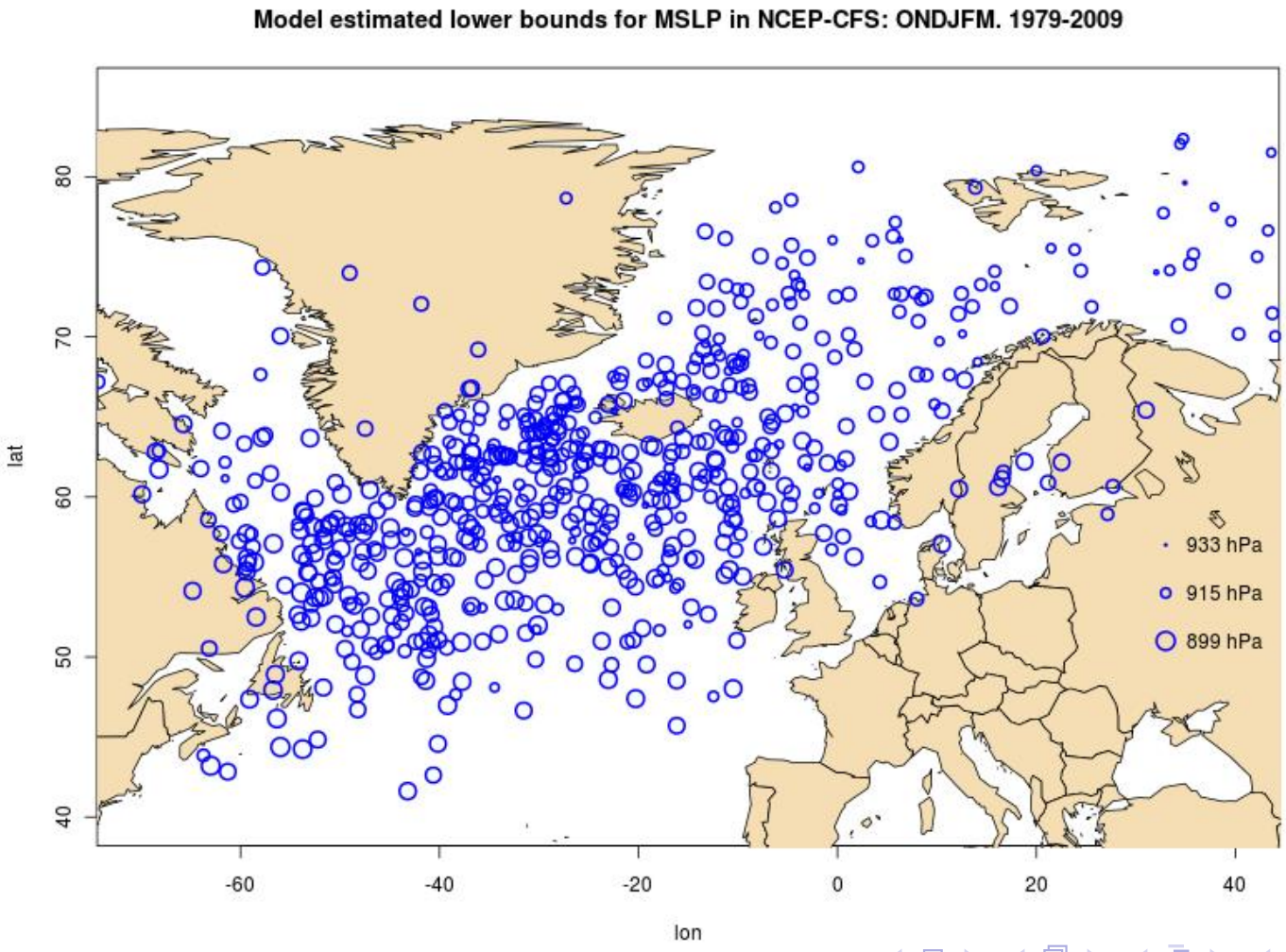
- Point process model fit to z. Equivalent to modelling exceedances as a Generalized Pareto distribution (GPD).

Parameter	Estimate (s.e.)	95% Conf. Interval
μ	-919.26 (2.74)	$[-923.46, -911.86]$
σ	4.42 (0.788)	$[3.27, 6.70]$
ξ	-0.10 (0.03)	$[-0.162, -0.026]$
Upper bound	-875.04 (8.51)	$[-903, -766]$



Spatio-temporal explanatory variables

- The stationary model ignores any spatio-temporal variation.
- Explanatory variables in μ such that $\mu = \beta_0 + \beta_1 \text{NAO} + \beta_2 \text{lat} + \beta_3 \text{lon}$. All were found statistically significant.
- Can then plot map of lower bounds for pressure:



Divide and test

- Map of lower bounds indicates little spatial variability in intensity.
- Divide the map on 0° meridian, fit GPD to exceedances and form hypothesis test on whether GPD parameters are different in each half.

$$\begin{aligned} y = z - \text{thresh} &\sim \text{GPD}(-960, \sigma, \xi) \\ log(\sigma) &= \beta_0 + \beta_1 \text{mer} \\ \xi &= \gamma_0 + \gamma_1 \text{mer} \end{aligned}$$

- Formed hypotheses: $\beta_1 = 0$ and $\gamma_1 = 0$. Both were accepted by hypothesis test.

Parameter	Estimate (s.e.)	Conf. Interval
β_1	-0.026 (0.13)	[-0.30,0.23]
γ_1	-0.14 (0.10)	[-0.29,0.07]

- However must still allow for spatial variability for better inference.

Semi-parametric extreme models

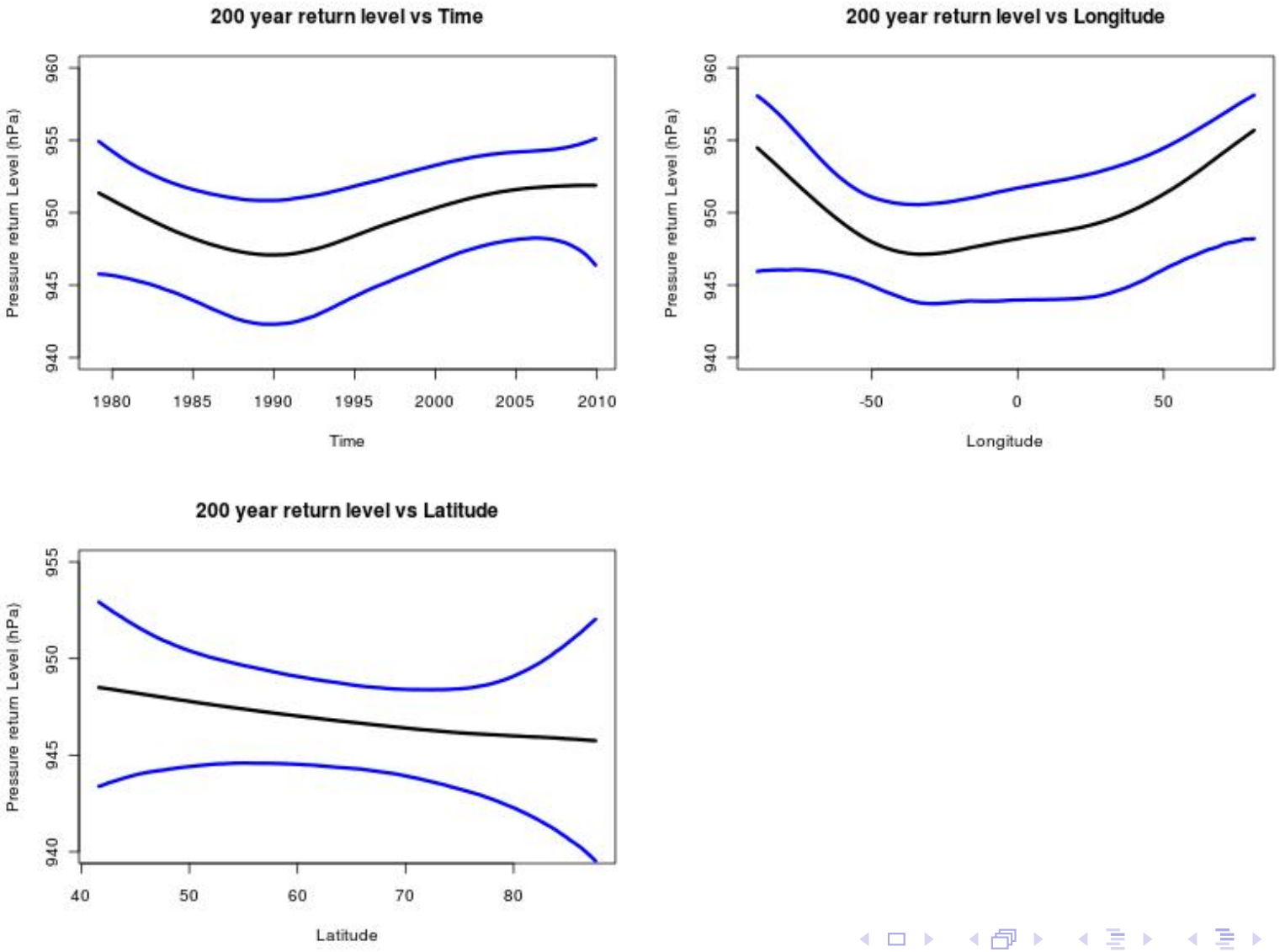
- Not clear how time, longitude and latitude affect distribution of extremes.
- Semi-parametric models: parameters are modelled as unknown functions of variables.

$$
\begin{aligned}
y &\sim \text{GPD}(-960, \sigma, \xi) \\
log(\sigma) &= s(\text{time}) + s(\text{lon}) + s(\text{lat}) \\
\xi &= f(\text{time}) + f(\text{lon}) + f(\text{lat})
\end{aligned}
$$

- Also exceedance rate is modelled as a function of time : $\lambda = g(\text{time})$
- Model was estimated using penalised splines.

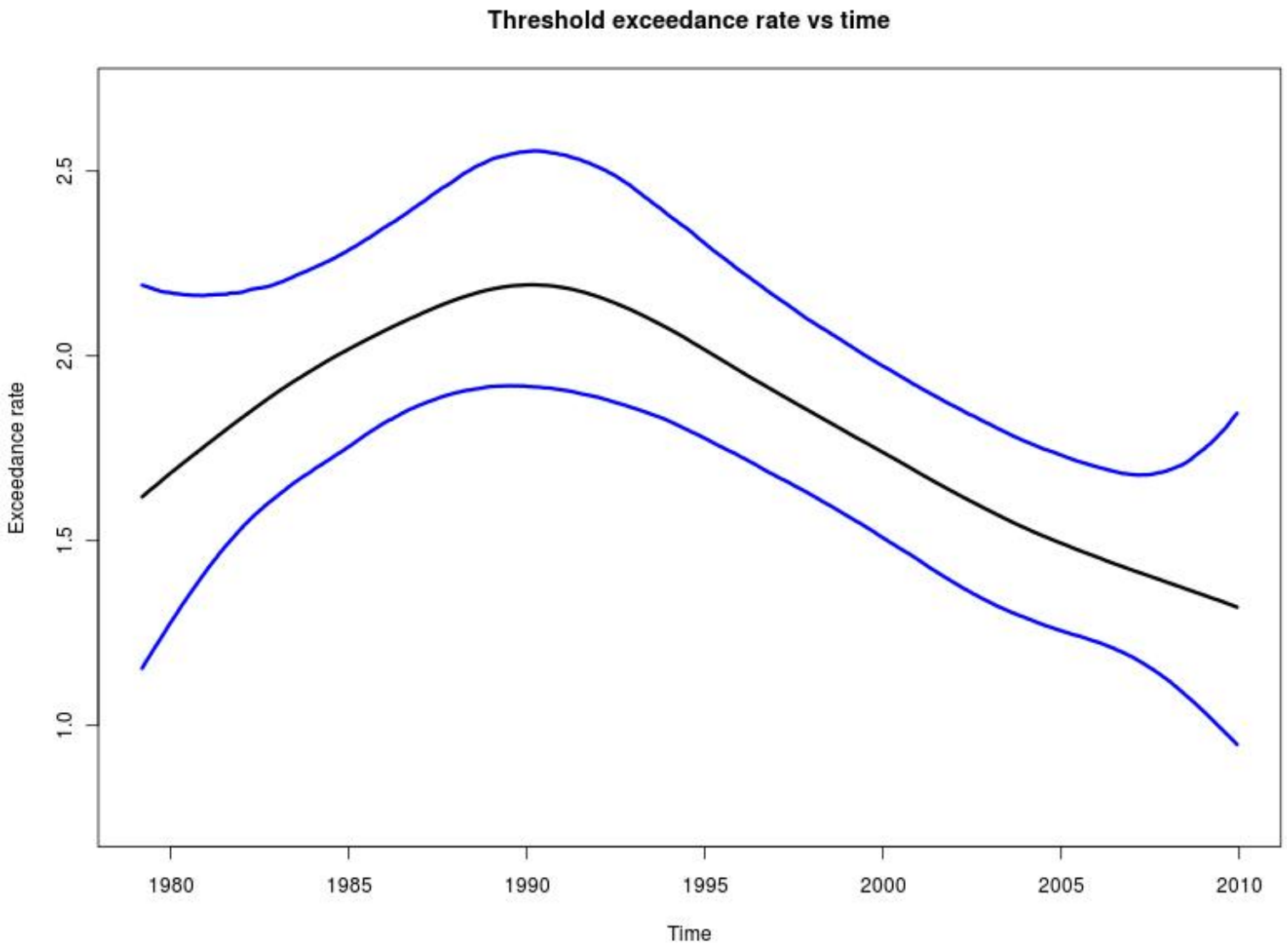
200 year return level

Can summarise model using the N-year return level. This is the estimated value of $z = -$pressure expected to happen on average once in N years.

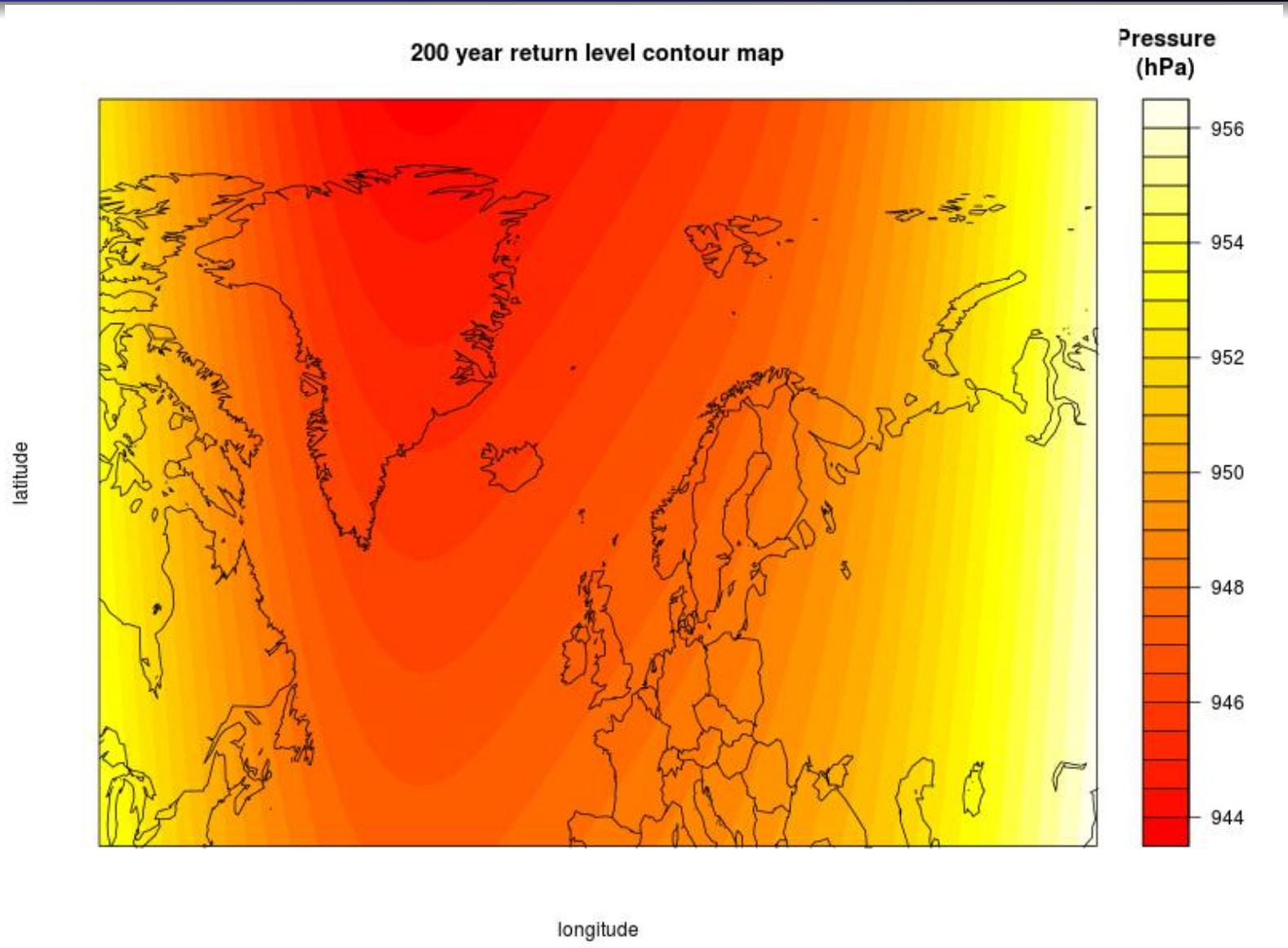


Exceedance rate

Monthly threshold exceedance rate dropping after 1990?



200 year return level contour map



Clearly model needs to account for interaction between longitude and latitude!

Summary

- Used extreme value modelling to analyse extreme intensity Atlantic storms from re-analysis data.
- Stationary model indicates storms can get as low as 875hPa.
- Extreme storm intensity may be less spatially variable than expected.
- Clear need for spatial model to allow for variation in storm occurrence.