Extreme Weather and Climate Events:

What are they and where do they come from?

Dr. David B. Stephenson

University of Reading, U.K.

Plan of the talk

- What are extreme events?

- Point process characterisation
  - Example 1: Norwegian megafloods
  - Example 2: Clustering of European storms

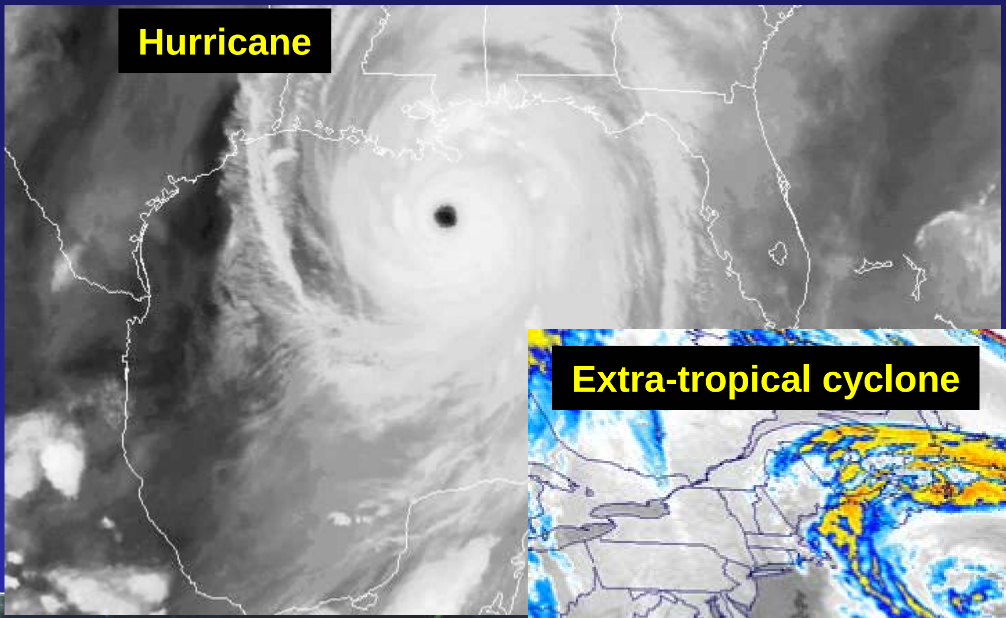
- How will extremes change?

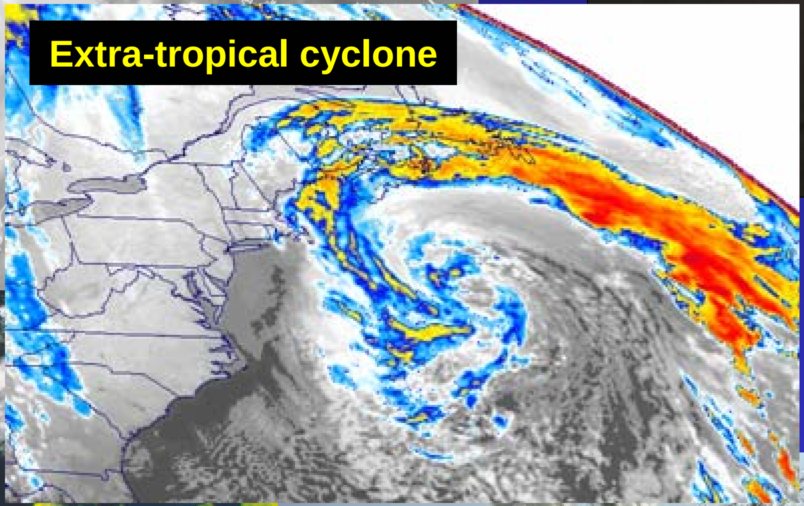
Thanks to Chris Ferro, Caio Coelho, Pascal Mailier

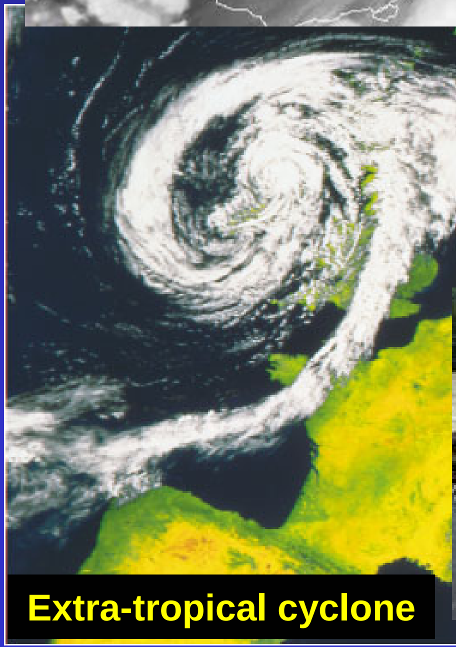
Climate Analysis Group: www.met.rdg.ac.uk/cag

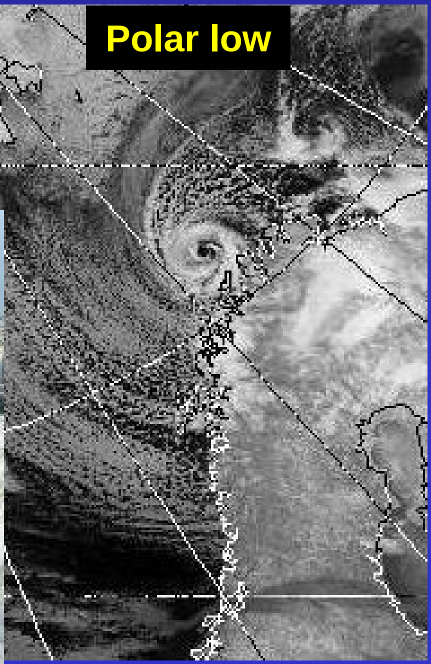
What are extremes?

Examples of wet and windy extremes









Examples of dry and hot extremes

IPCC 2001 definitions

Simple extremes:

"individual local weather variables exceeding critical levels on a continuous scale"

Complex extremes:

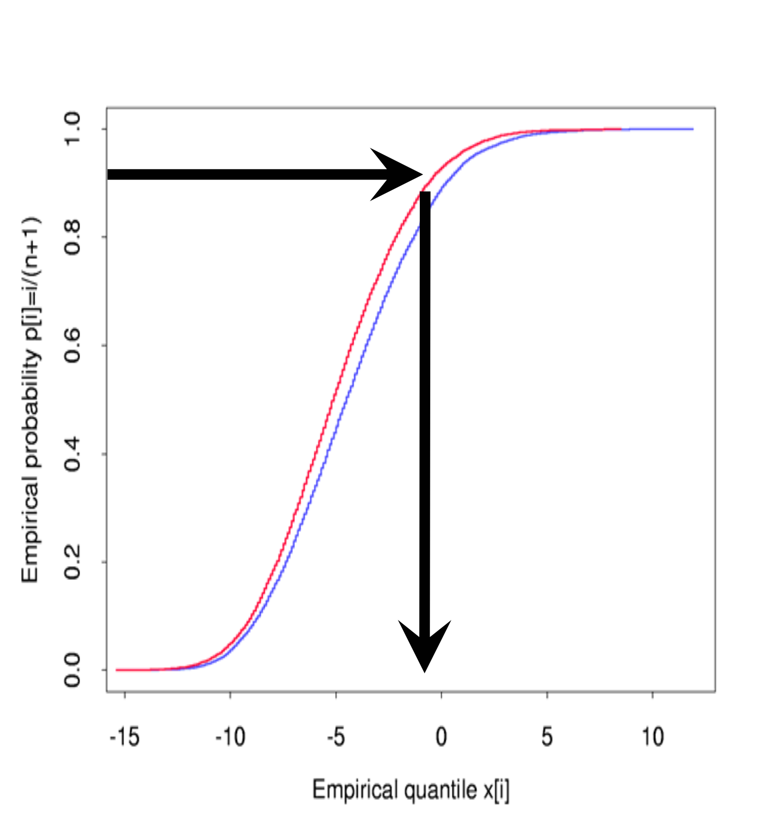
"severe weather associated with particular climatic phenomena, often requiring a critical combination of variables"

Extreme weather event:

"an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile."

Extreme climate event:

"an average of a number of weather events over a certain period of time which is itself extreme (e.g. rainfall over a season)"



Some properties of extreme events

Severity

large impacts (extreme losses):

- Injury and loss of life
- Damage to the environment
- Damage to ecosystems

Extremeness

large values of meteorological variables:

- maxima or minima
- exceedance above a high threshold
- exceedance above all previous recorded values (*record breaker*)

Rarity

small probability of occurrence

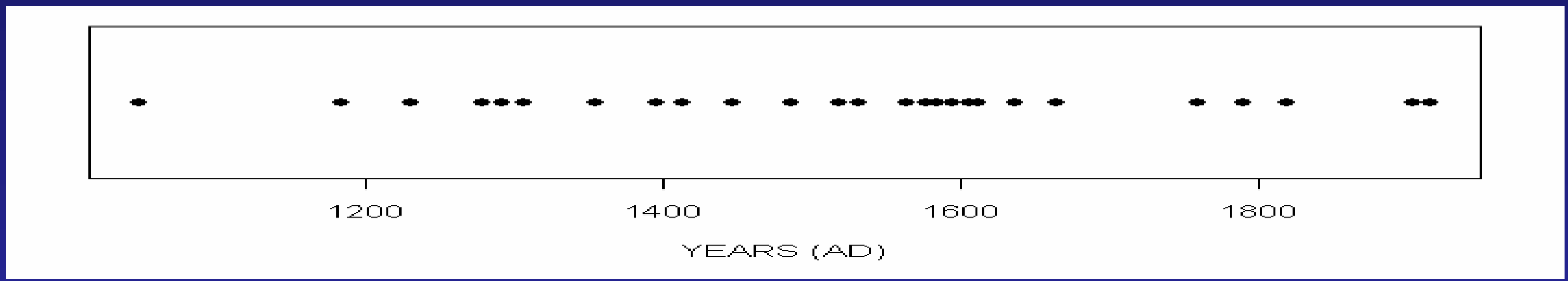
Longevity

- **Acute:** Having a rapid onset and following a short but severe course.
- **Chronic:** Lasting for a long period of time (> 3 months) or marked by frequent recurrence

Point process description

Point process ideas

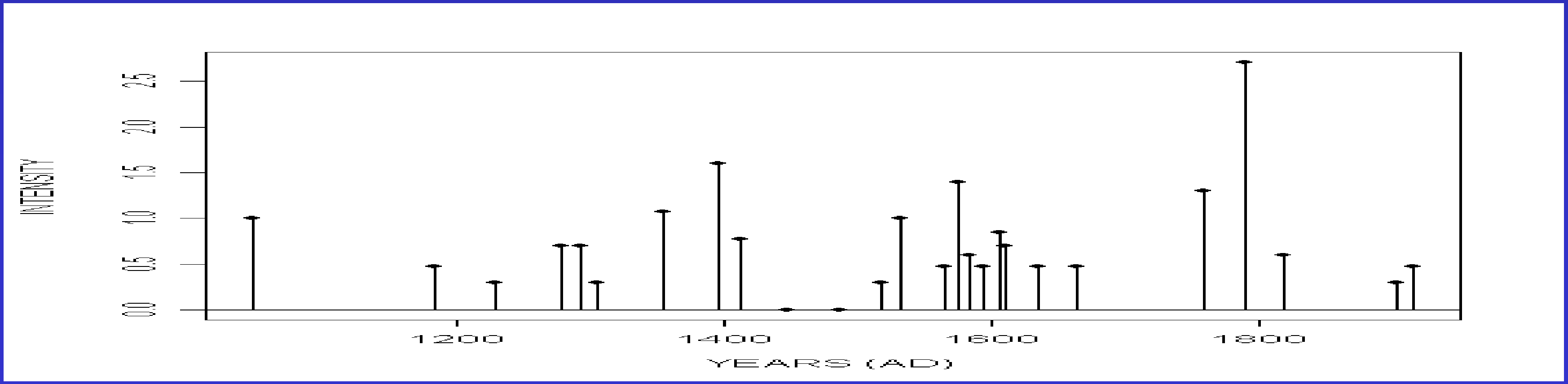
A stochastic process that generates discrete space-time events



RATE of process = probability of event per unit time.

Characterised by counting events in fixed time intervals or by measuring time intervals between successive events.

Marked point process: events also have a magnitude



Attributes of Extreme Event Processes

Rate of the process

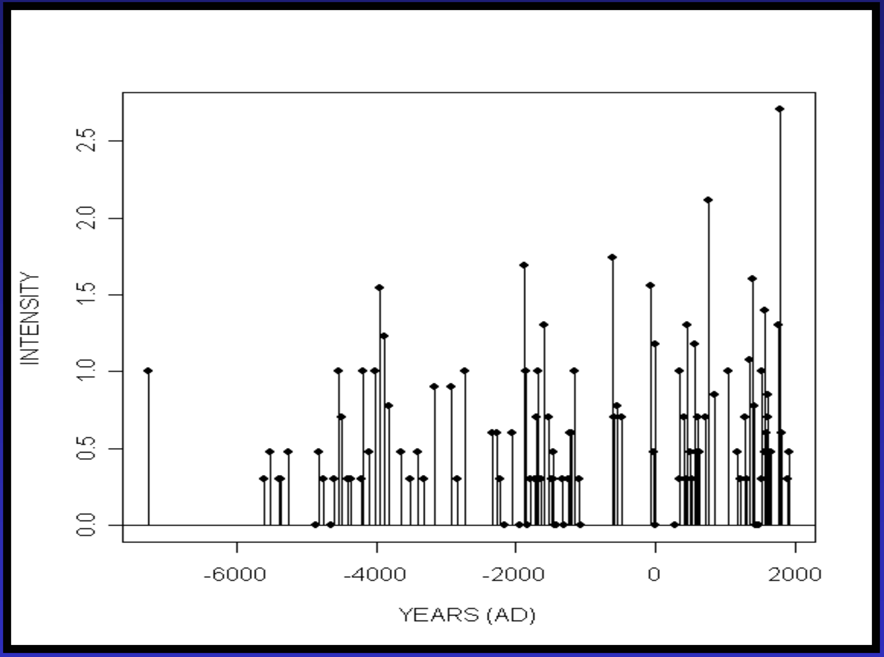
The probability that an event occurs per unit time interval (sometimes called frequency). Note that even constant rate processes give rise to counts that can exhibit large amounts of variability.

Magnitude of the process

The probability distribution of the magnitudes of the events. This can depend also on the rate of the process.

Serial dependency

The statistical dependency of the properties of an extreme event on the properties of other recent extreme events. Serial dependency in event times is known as a clustered process.



Example: Norwegian floods and megafloods

Ongoing collaboration with
Anne-Grete Bøe Pytte, Svein Olaf Dahl

Bjerknes Centre for Climate Research

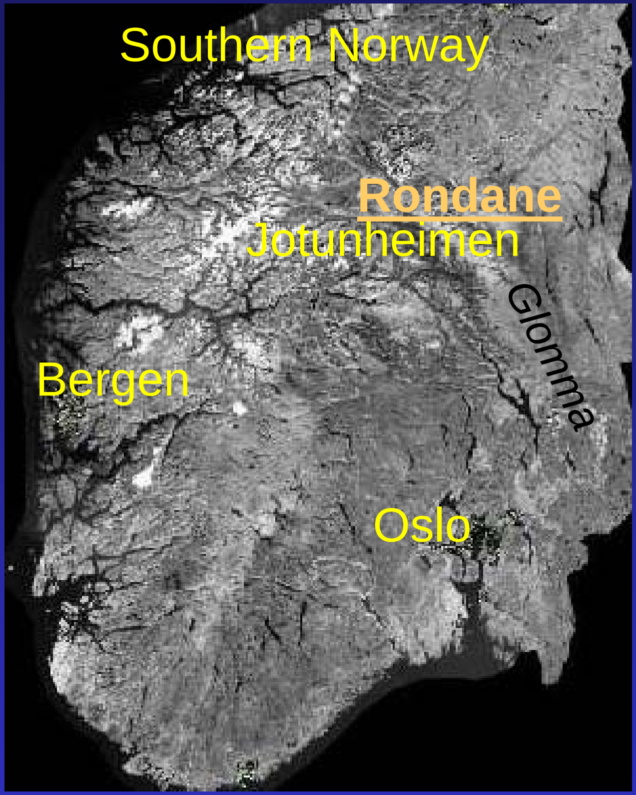

Jostedalen, 1979

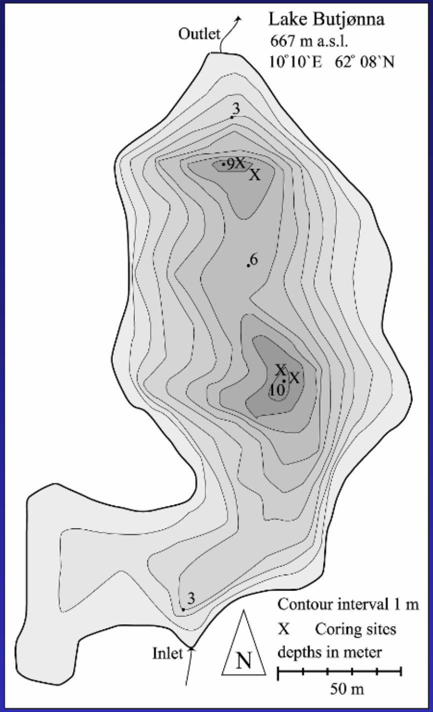
Elverum, 1934

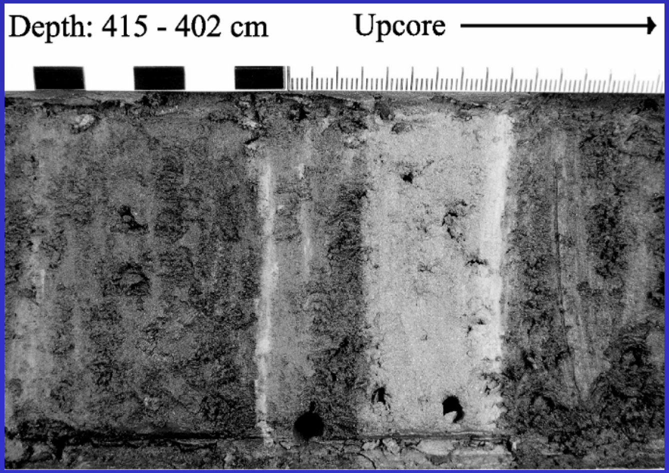

Setra,Drivdalen
Damage from Storofsen, 1789


Skjåk,
gullies and landslides
caused by Storofsen, 1789

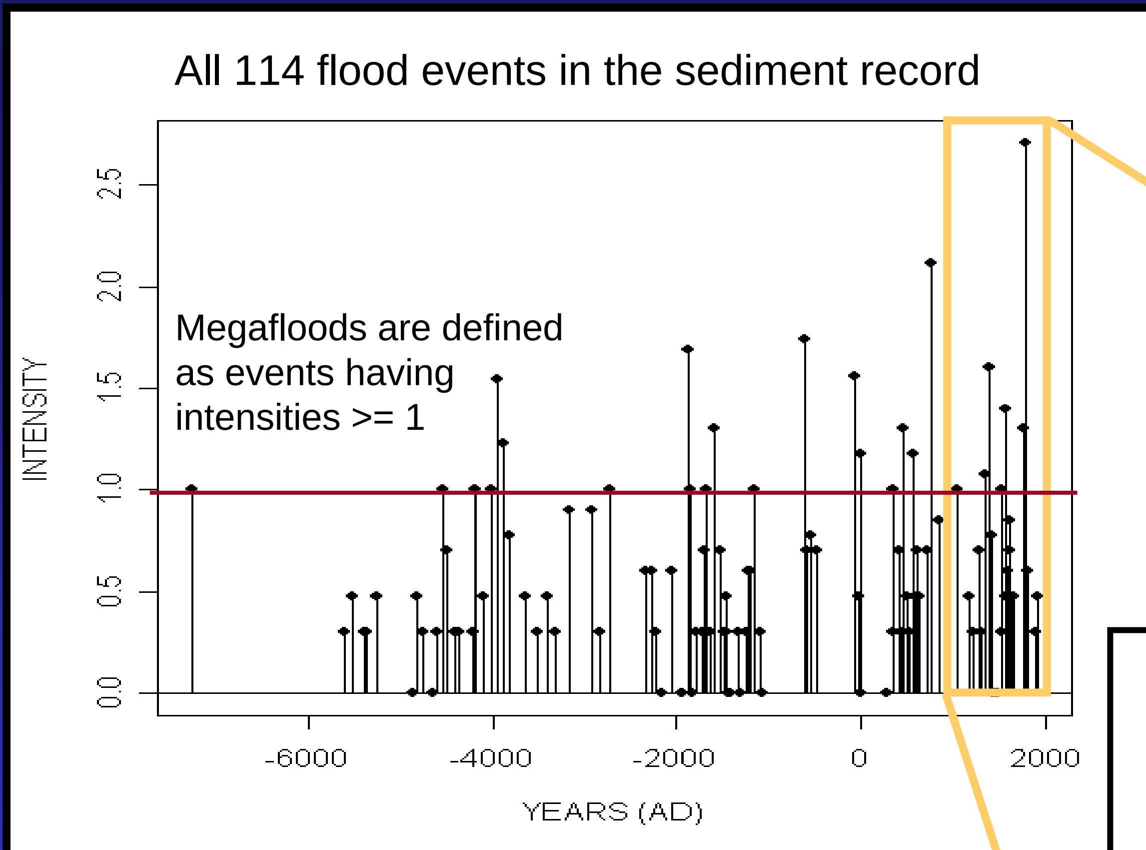
Sediment cores from Lake Butjønna

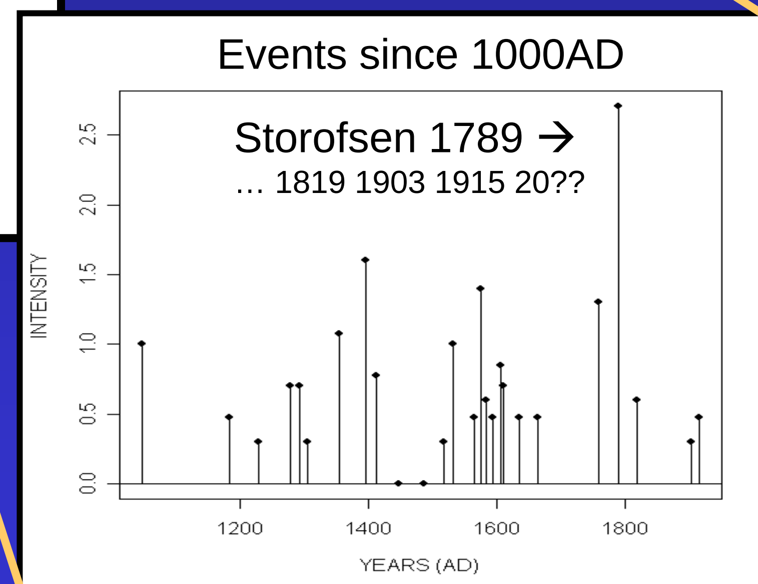






Flood events since 7264BC

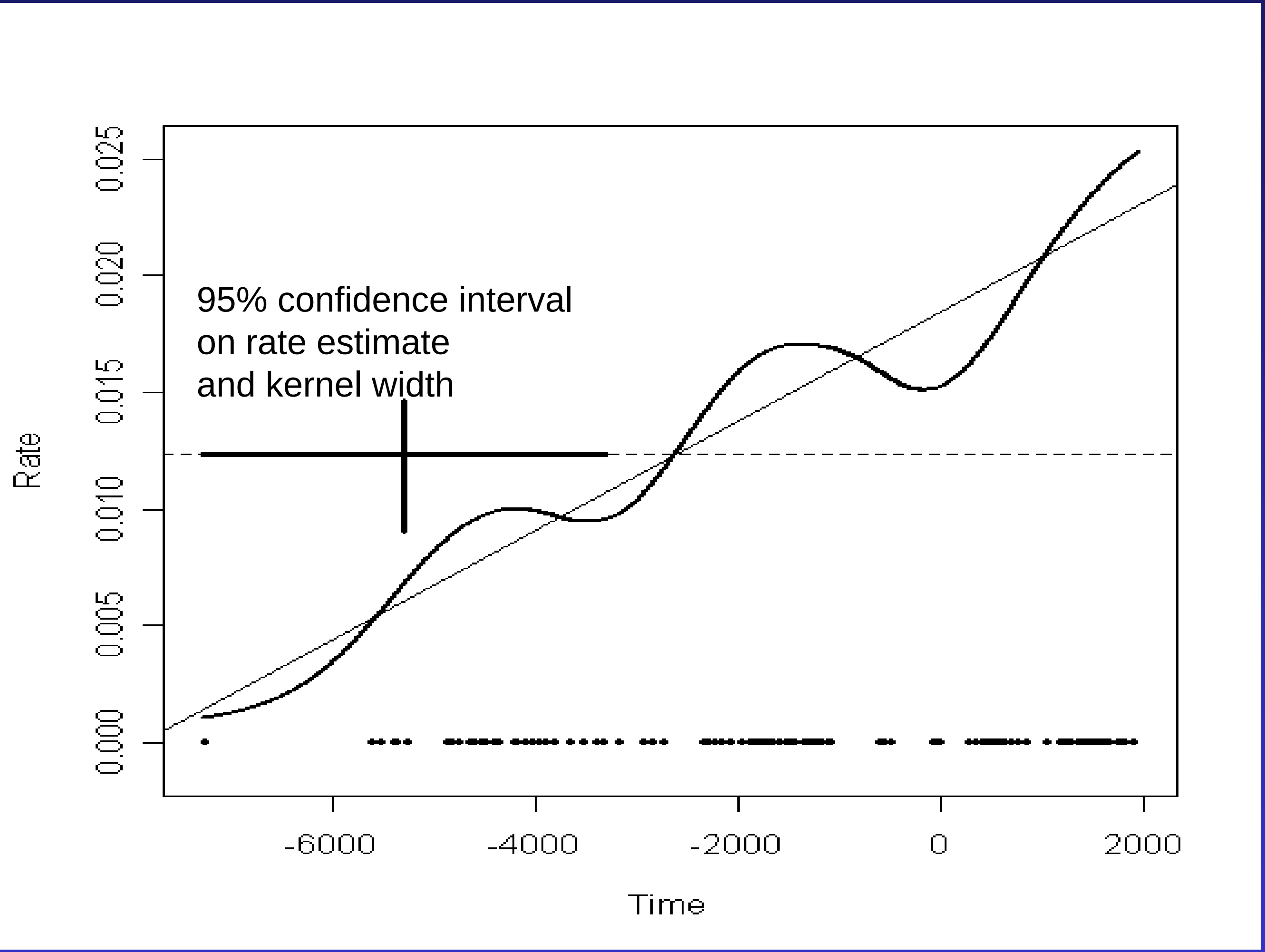




Questions:

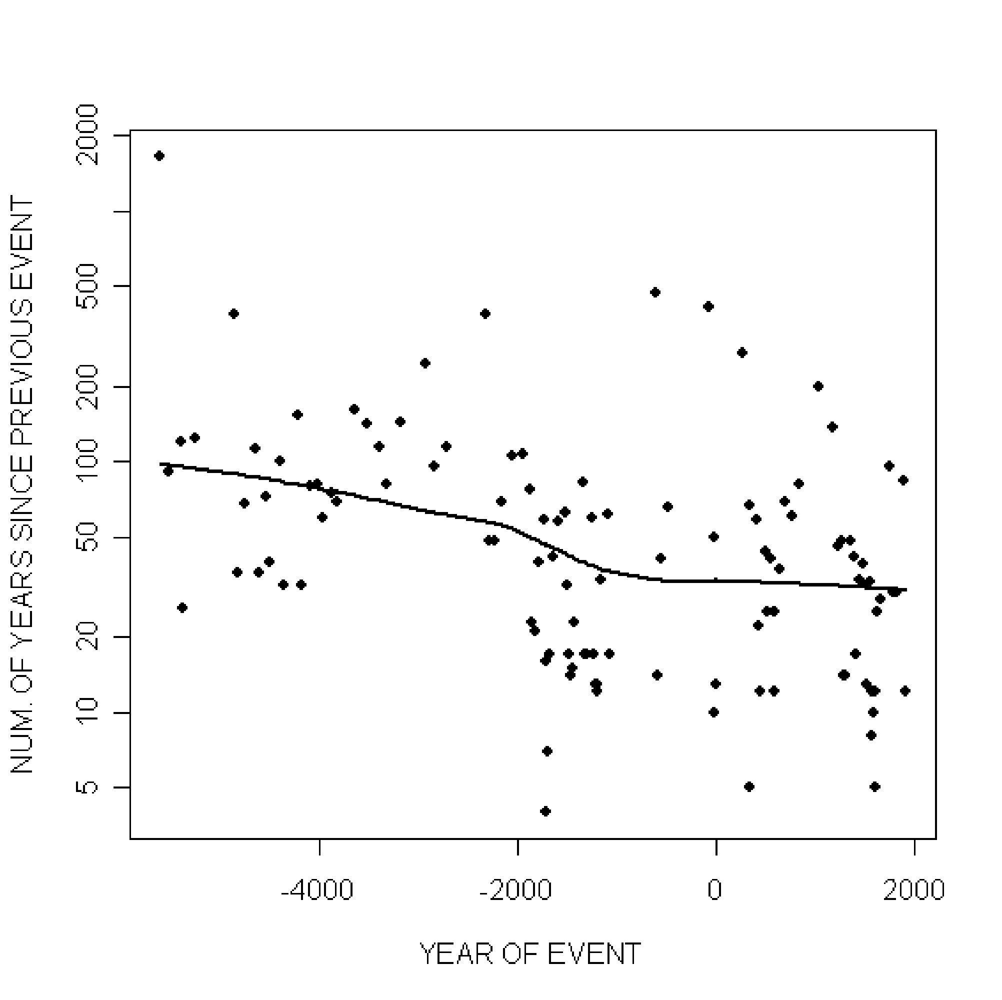
- increasing number of events?
- increasing intensity of events?
- clusters of events?

Rate estimation for all 114 events



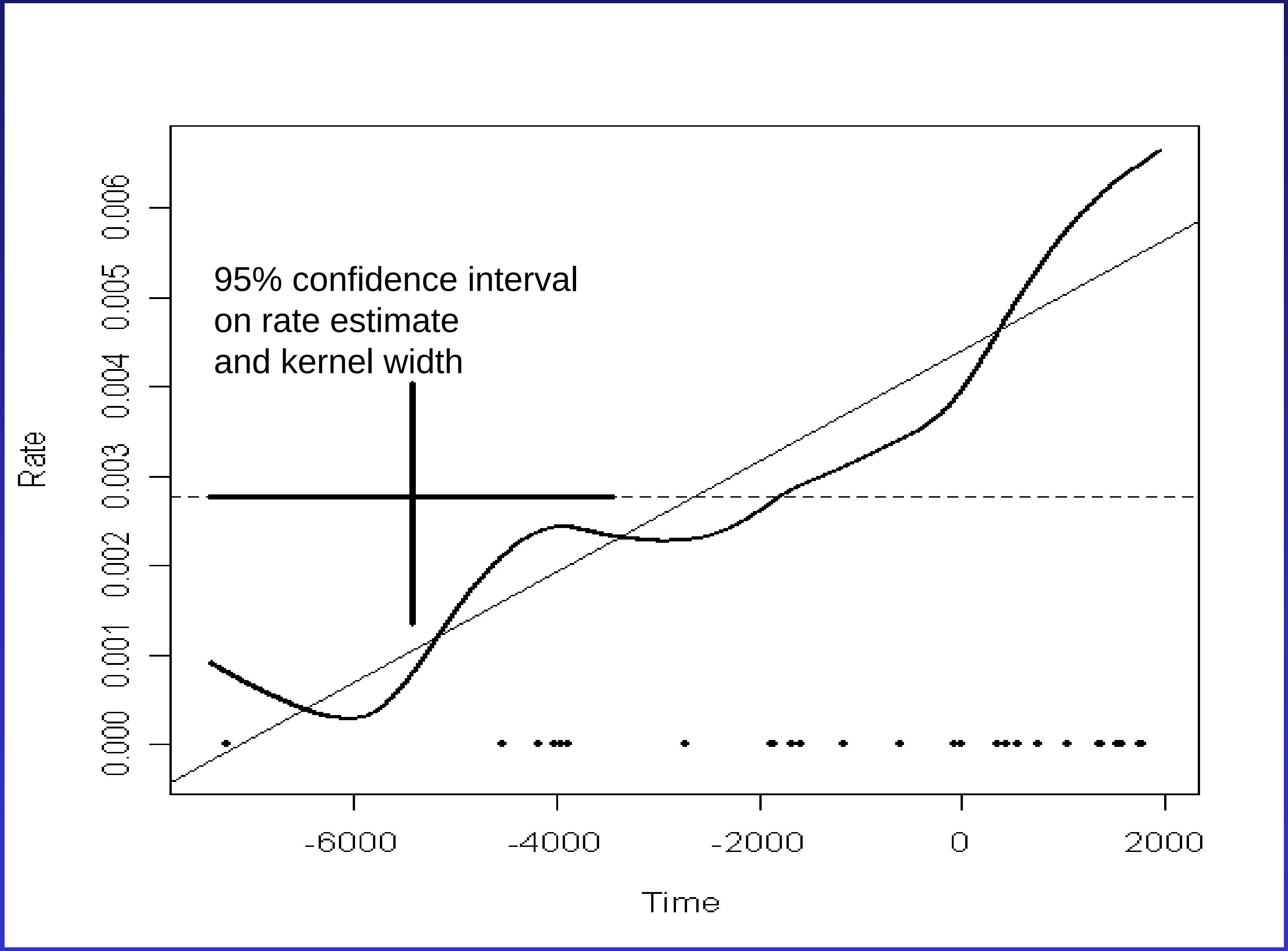
→Mean rate = 1 event every 81.2 years. linear trend +1.90%/century

Time interval between events



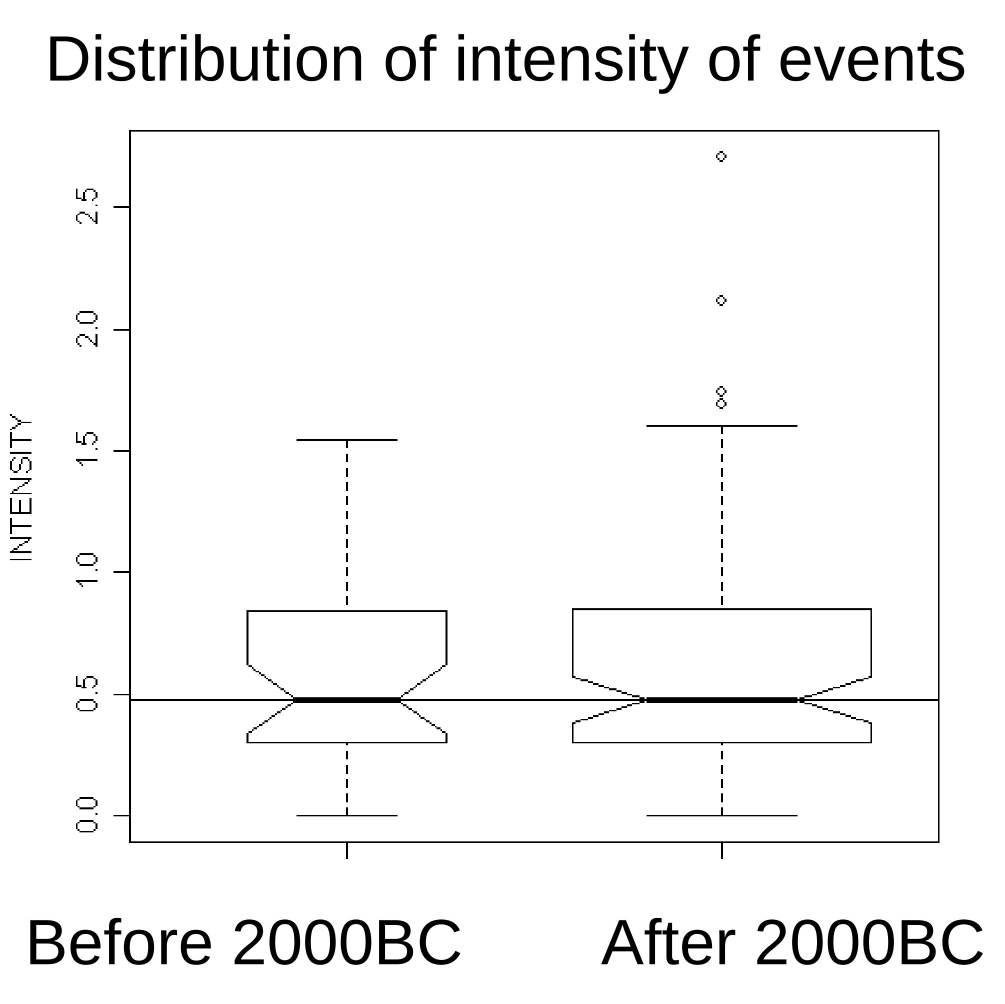
→Decreasing trend in the time between events

Rate estimate for the 26 megaflood events



→Mean rate = 1 event every 361.6 years. linear trend +2.23%/century
Similar trend in rate to that for all events

Has the intensity of the events changed?

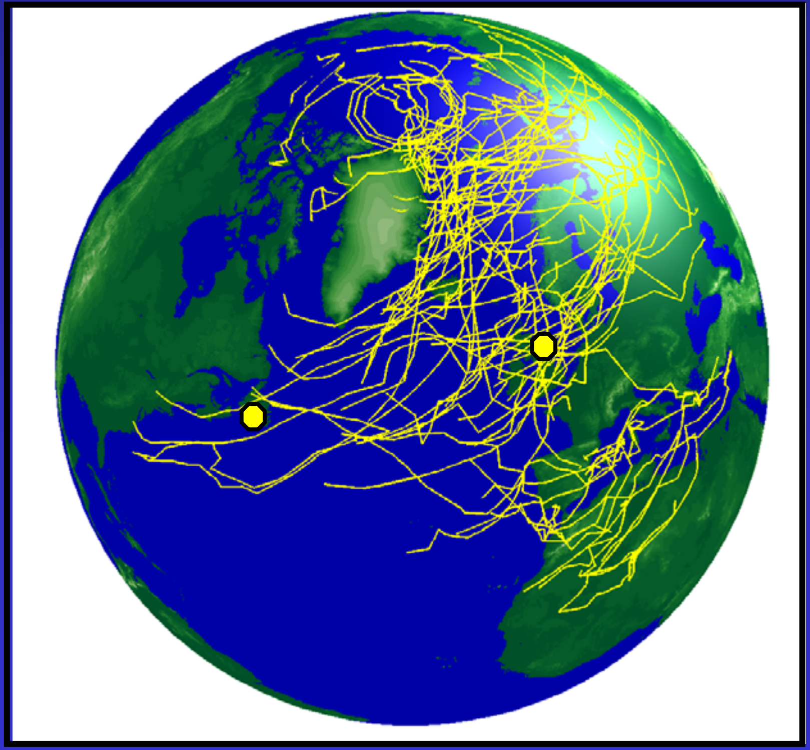


→**No evidence for change in intensity distribution before/after 2000BC**

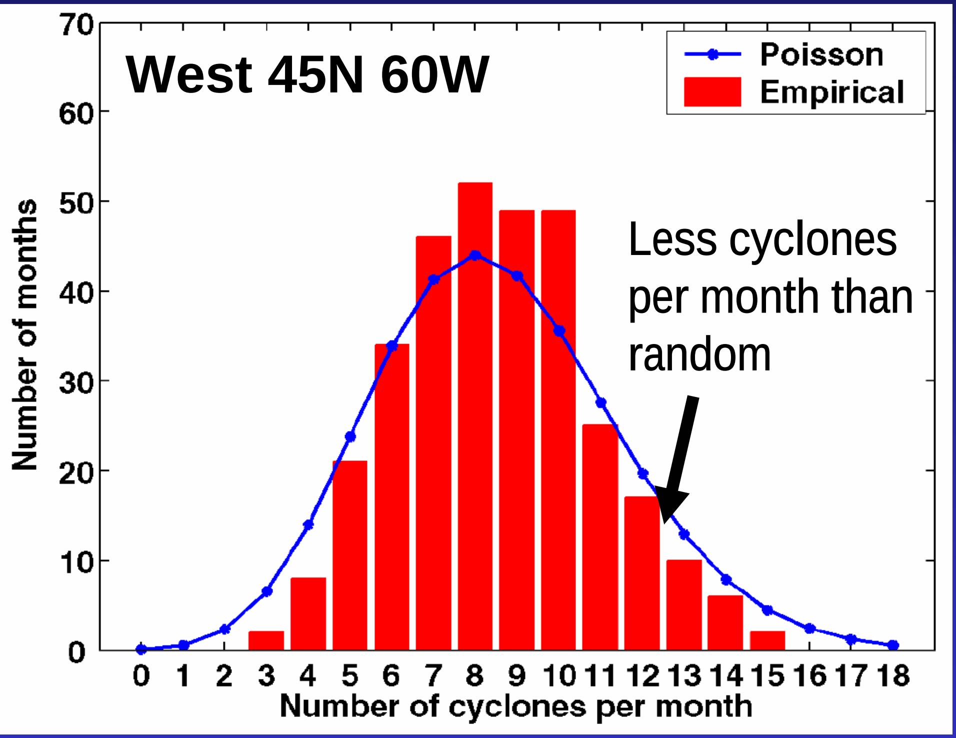
Clustering of Extra-Tropical Cyclones

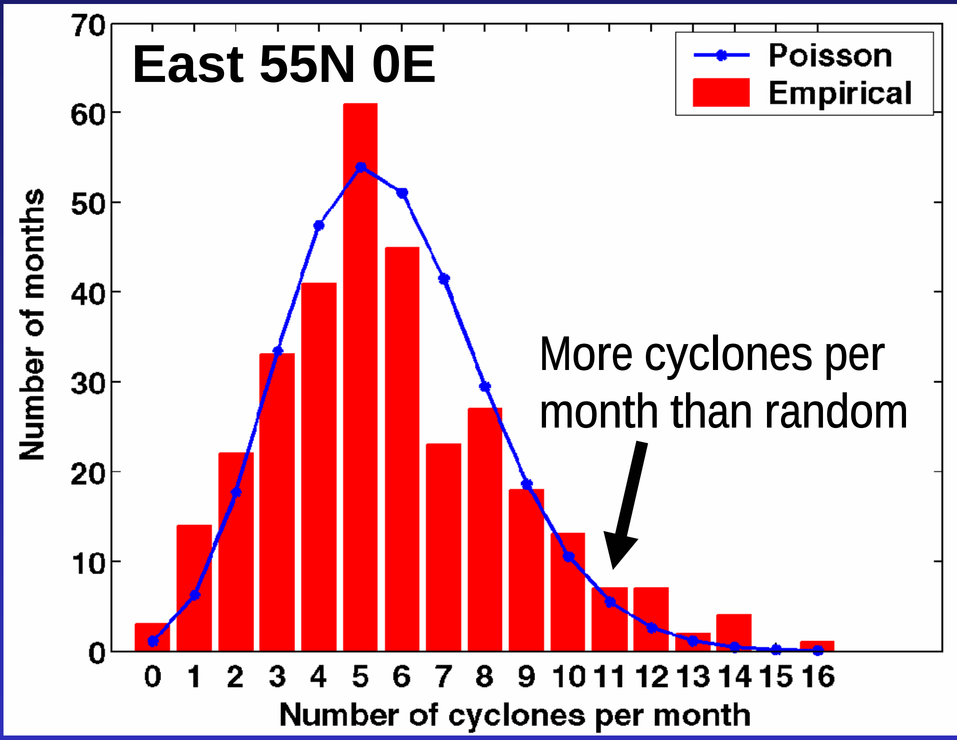
- Objective eastward tracks identified using TRACK software
- NCAR/NCEP 6 hourly 850mb relative vorticity maxima
- Extended winters (1 Oct-31 Mar) from 1948-2003
- Identified 355,450 cyclone tracks in Northern Hemisphere

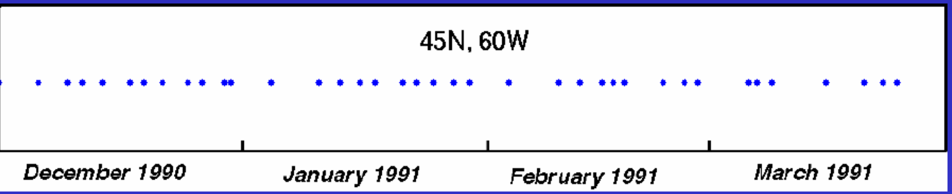
Example: Cyclone tracks crossing Greenwich meridian
1 Oct 1989-31 Mar 1990

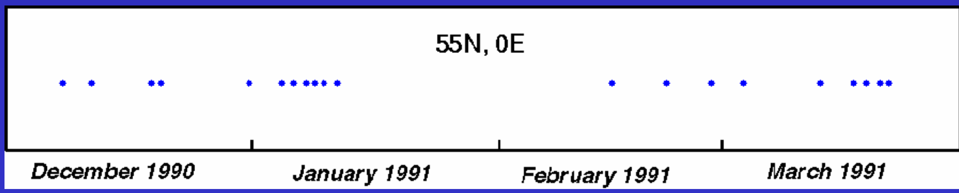


Monthly transits of North Atlantic storms



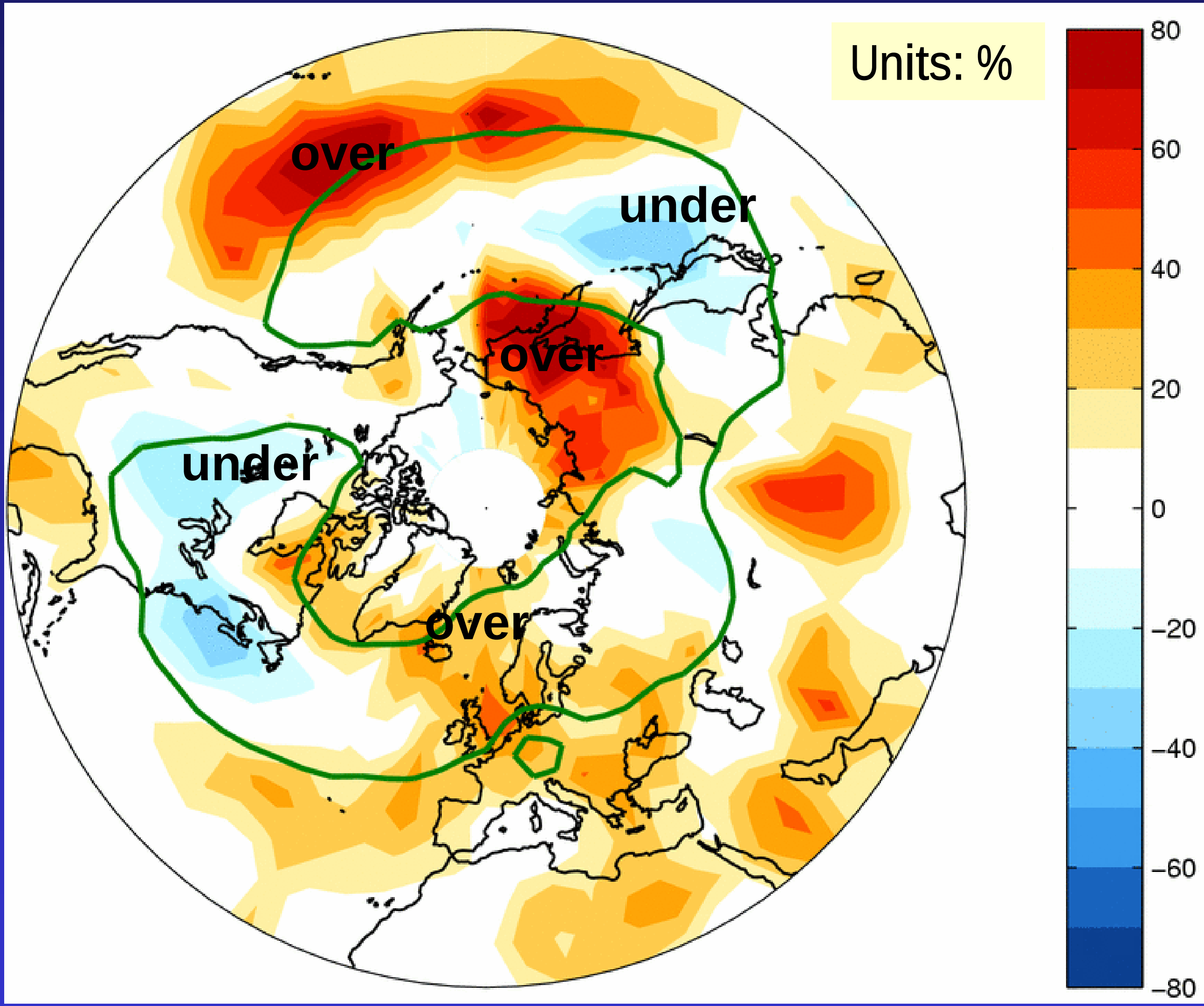






→ regular (in west) and clustered (in east) random processes

Overdispersion of storm transit counts



$$\frac{s_n^2}{\overline{n}} - 1$$

→ Clustering of storms over Europe due to flow-dependence

Can large-scale flow variations explain the overdisperion?

Quasi-Poisson regression:

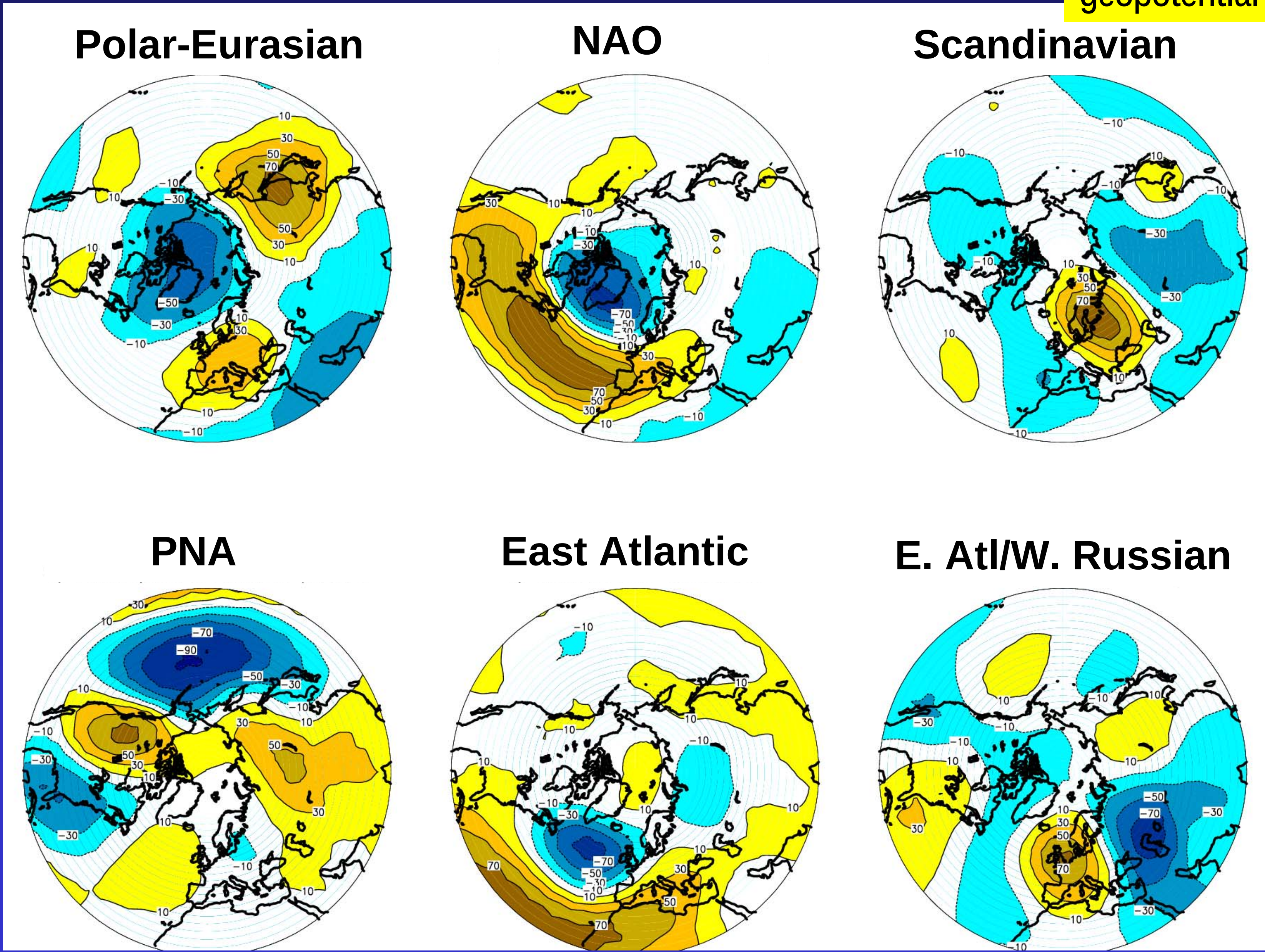
$$n \mid x \sim Poisson(\mu)$$

$$\log(\mu) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i$$

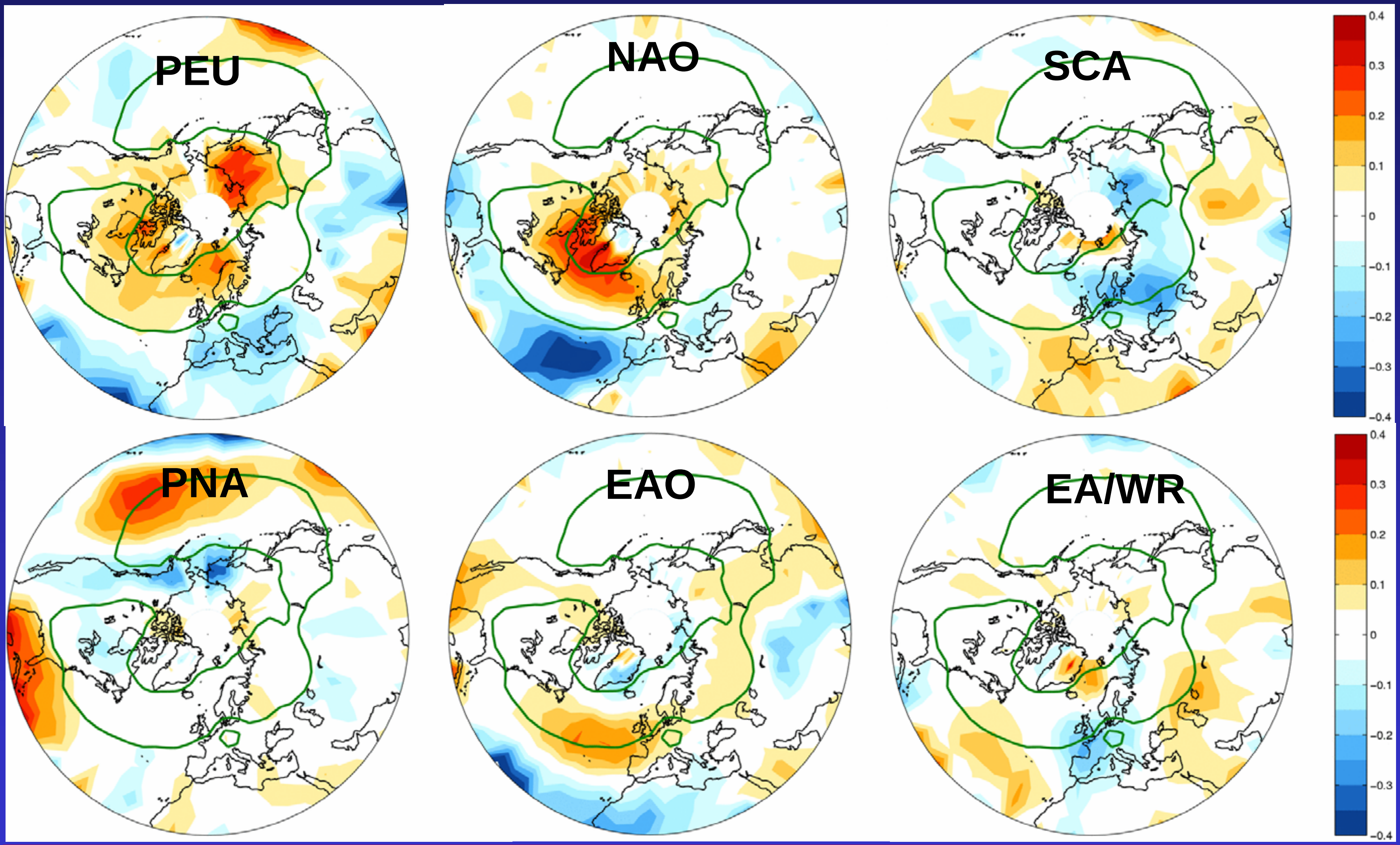
n = number of storms crossing a 20^0 N-S barrier
μ = flow-dependent rate
x_1, x_2, … , x_k = teleconnection indices
Maximum likelihood estimation of $ß_0$, $ß_i$

Teleconnection patterns

Leading rotated EOFs of 700mb geopotential height



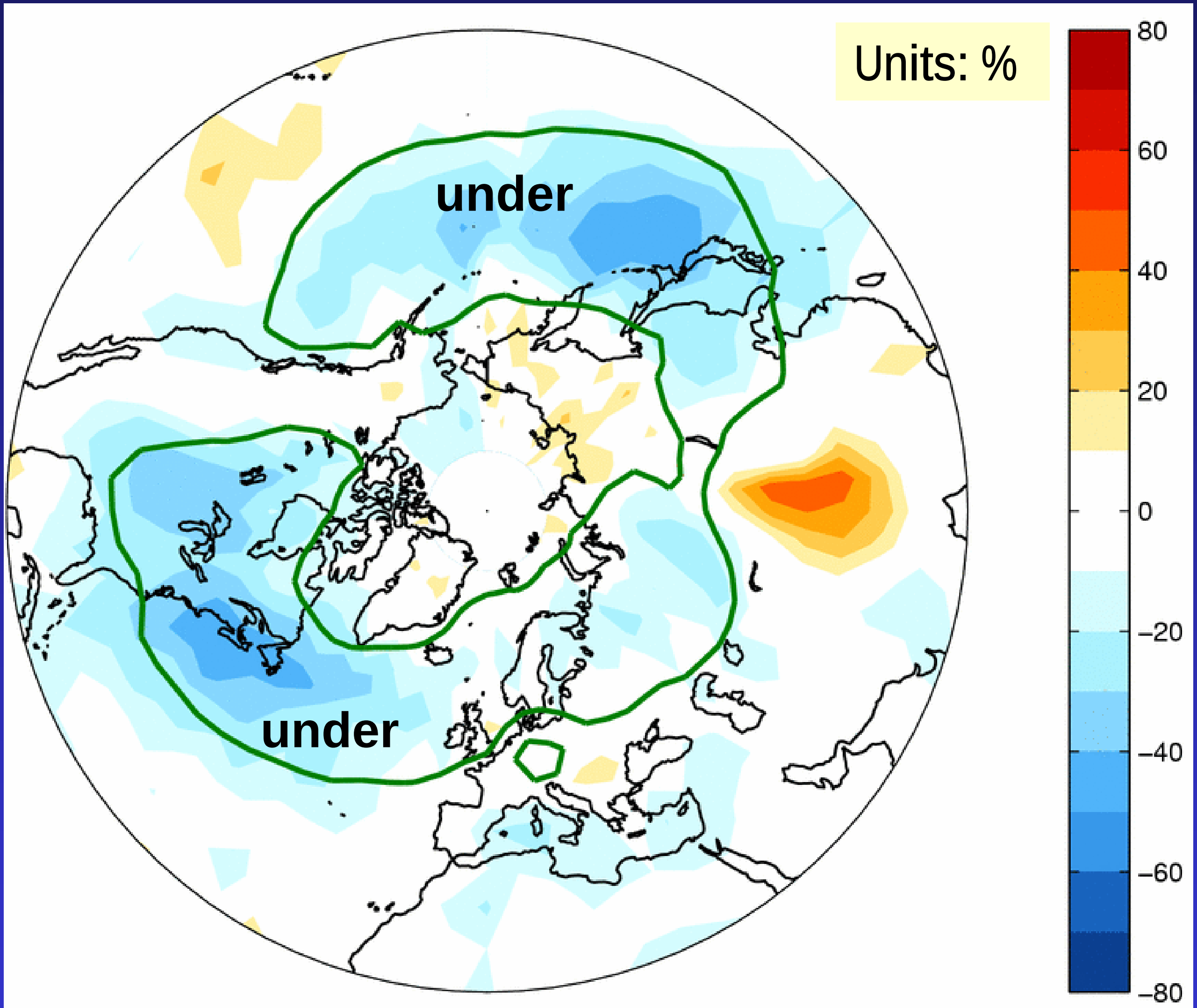
Estimated ß regression parameters



→ all teleconnection patterns are important for cyclone rates

Green lines outline area with >5 storms/month passing 20° N-S line

Residual overdispersion



$$\frac{s_n^2}{\overline{n}} - 1$$

→ Now only underdispersion in baroclinic waveguide (regular waves)

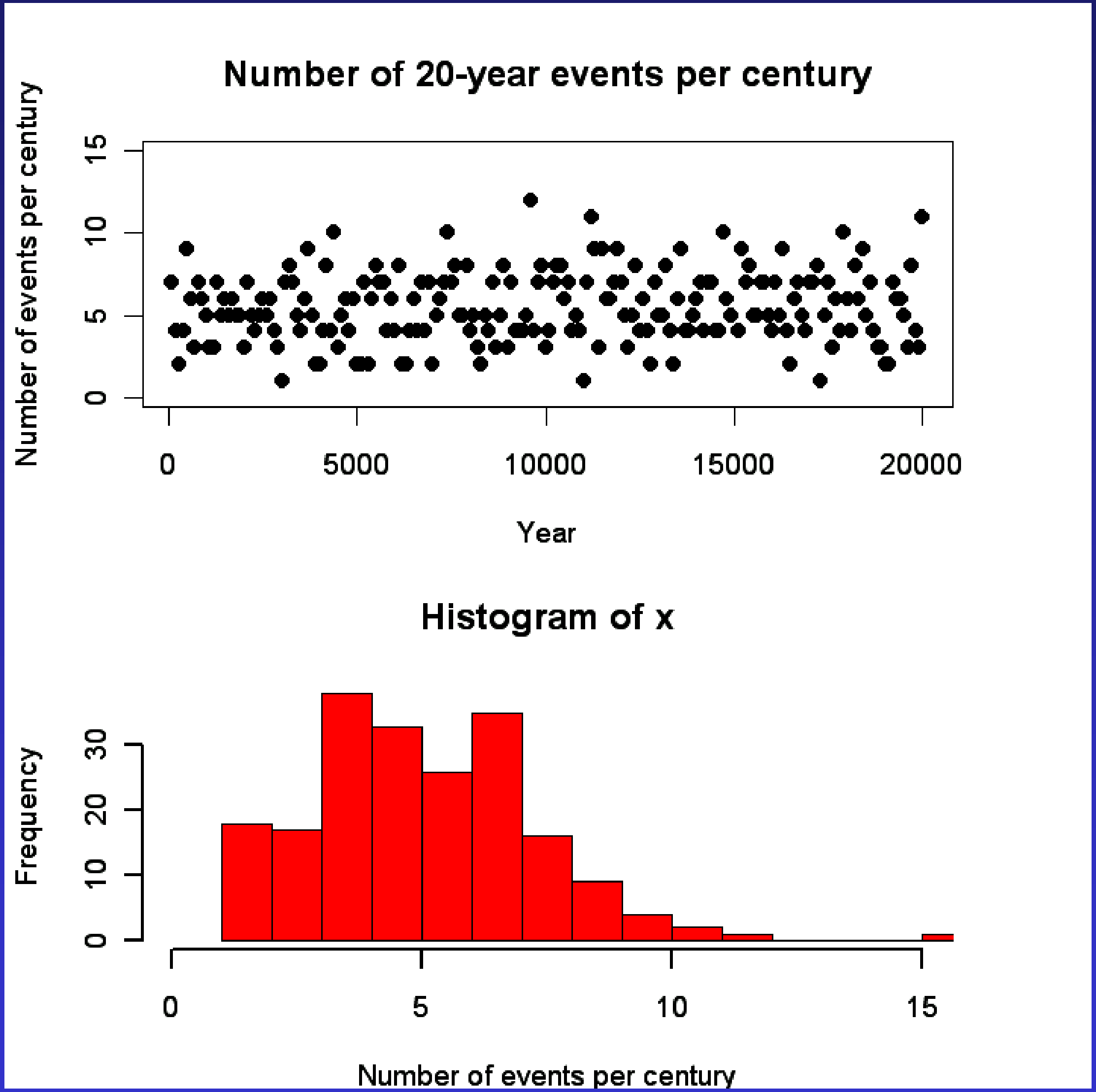
The Clustering of UK buses

Is this because bus drivers really love each other?

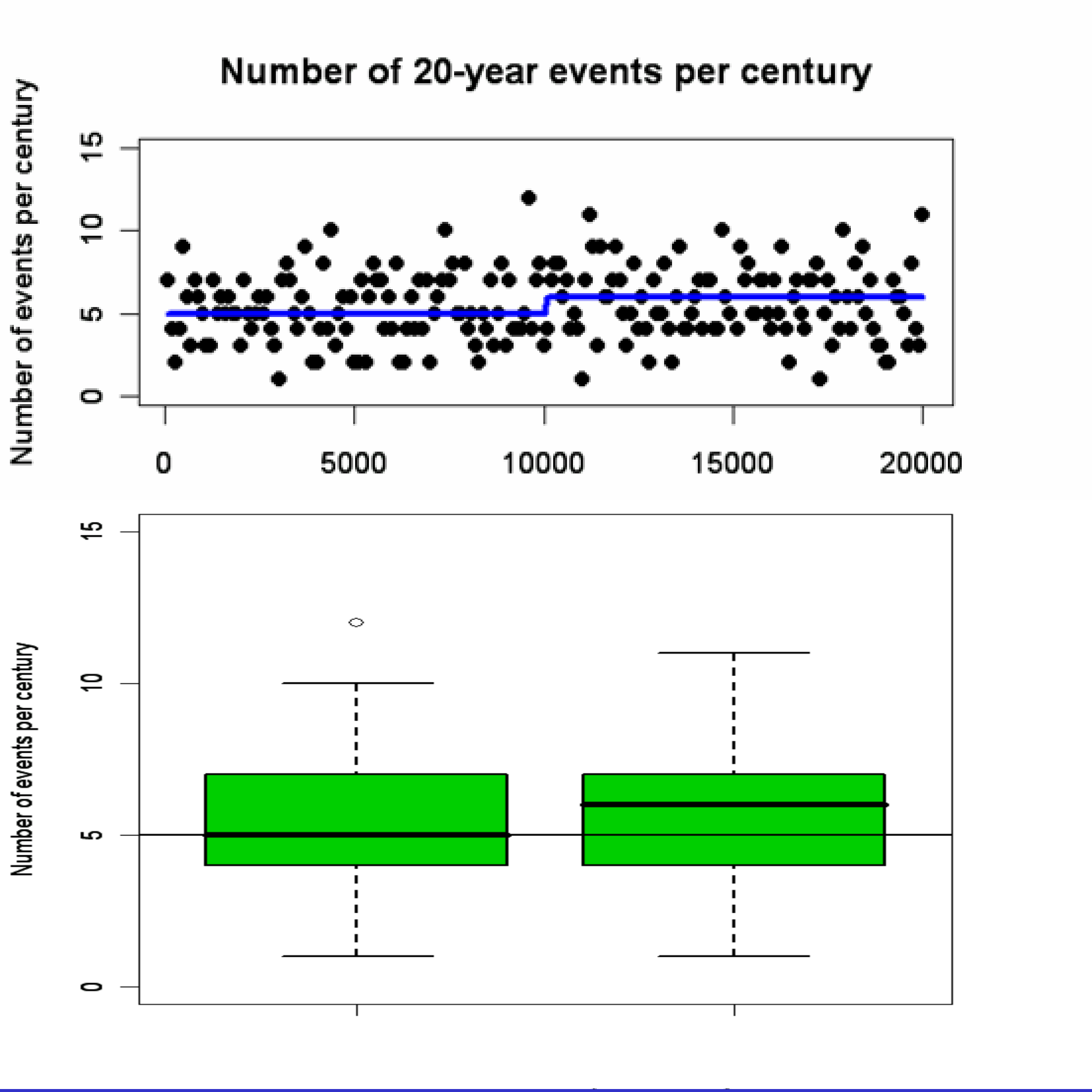
Don’t think so! More to do with rate of arrival depending on time varying background traffic flow.

How will extremes change?

Has the rate of extreme events changed?



Yes! Step increase in rate by 20%



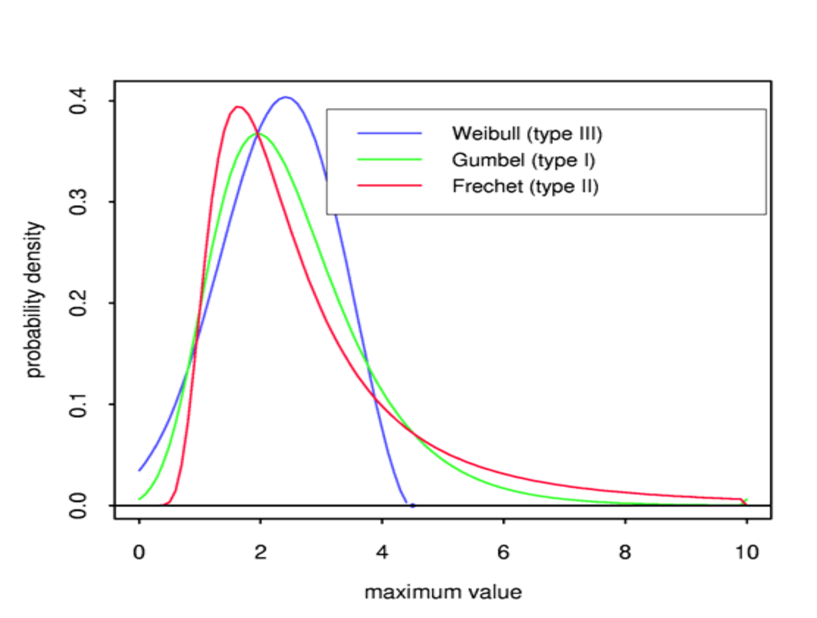
Data produced by simulation from Poisson distribution with means of 5 and 6

→ Difficult to detect changes in rate of rare events!

How to deal with this uncertainty?

Get hold of more data:

- longer historical series (e.g. paleoclimate)
- multi-model ensembles of simulations
- spatial pooling of extremes over regions



$$\Pr(X \le x) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

Imaginative inference:

- extreme value theory: infer extremal properties by fitting appropriate statistical models to large values

- relate changes in extremes to changes in the centre of the distribution

- relate extremes to other factors and use these to make predictions about extremes (e.g. global mean temperature, SSTs, NAO)

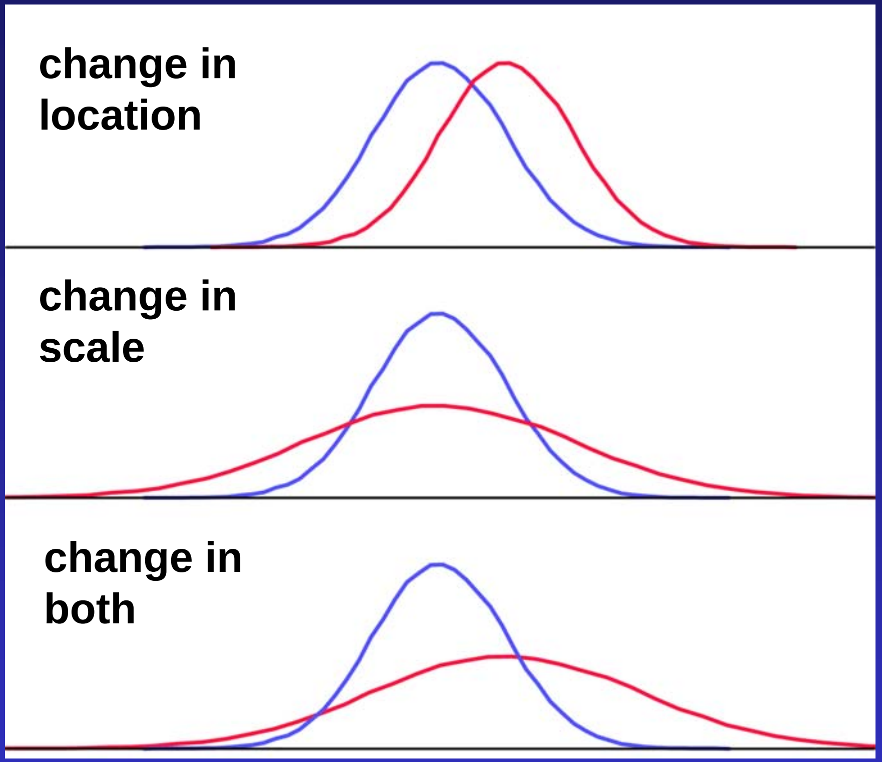
Physical insight about key processes

Explaining changes in the extremes

Describe changes in quantiles in terms of changes in the location, the scale, and the shape of the parent distribution:

$$\Delta X_{\alpha} = \Delta X_{0.5} + \frac{\Delta IQR}{IQR}(X_{\alpha} - X_{0.5})$$

$$+ \text{ shape changes}$$

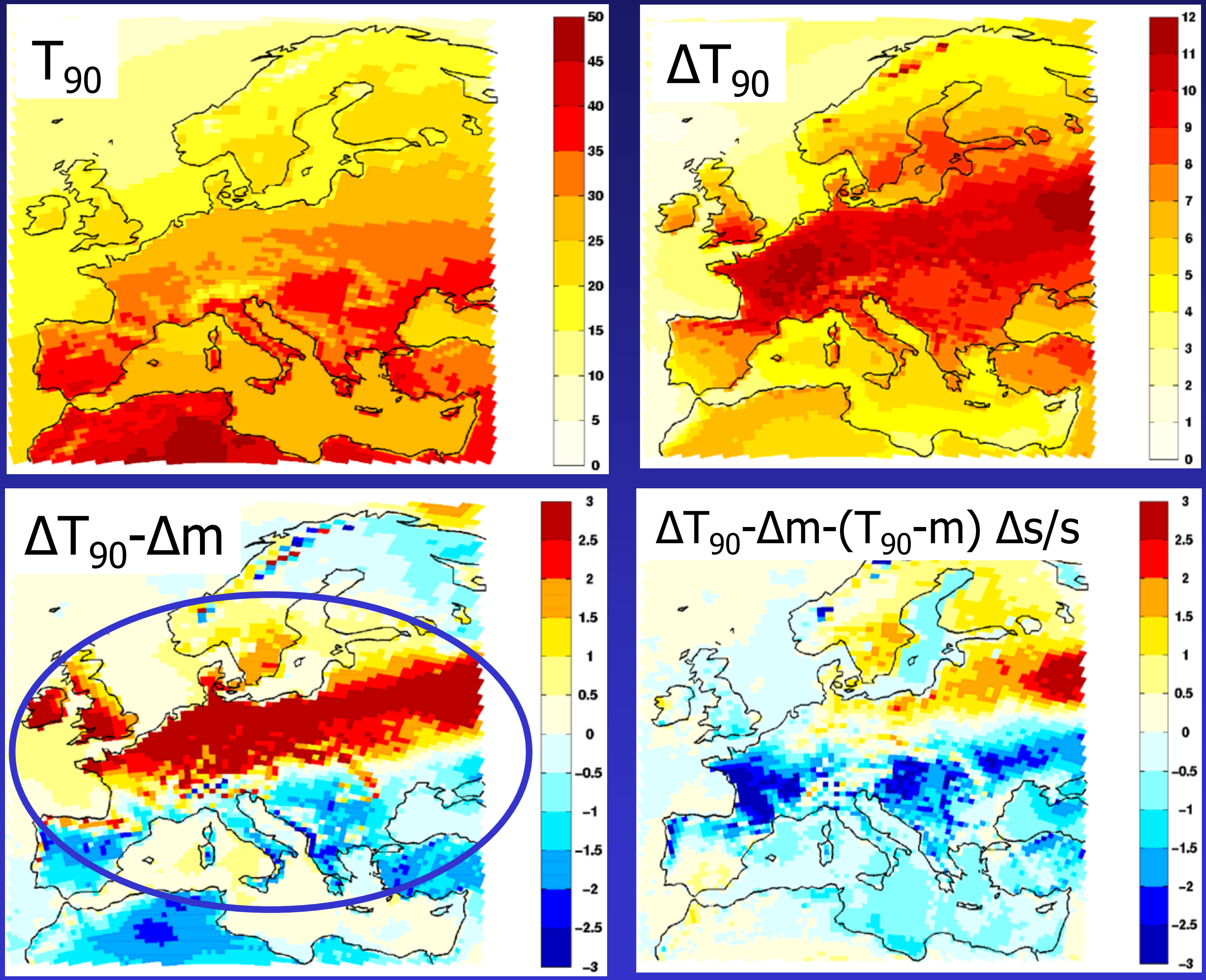


The *quantile shift* is the sum of:

- a location effect (shift in median)
- a scale effect (change in IQR)
- a shape effect

Ferro, C.A.T., D.B. Stephenson, and A. Hannachi, 2005: Simple non-parametric techniques for exploring changing probability distributions of weather, J. Climate, (in press).

Regional Model Simulations of daily Tmax



→ Changes in scale and shape both very important

European Union Project: ENSEMBLES

WP4.3 Understanding Extreme Weather/Climate Events

Provision of statistical methods for identifying extreme events and the climate regimes with which they are associated. More robust assessments of the effects of climate change on the probability of extreme events and on the characteristics of natural modes of climate variability.

- How can we best estimate future possible changes in return values for extreme events?

  multi-model ensemble → tail probabilities

- Do we understand the key processes that lead to these changes?

- Which factors are most important for determining changes in extreme events?

us!

http://www.ensembles-eu.org

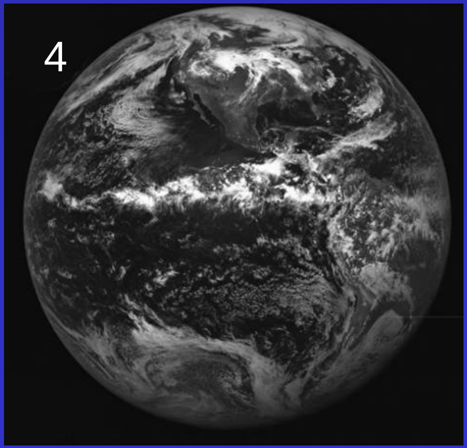
Processes that cause extremes

1. Rapid growth due to instabilities
Fast growth of weather systems caused by positive feedbacks
e.g. convective instability, baroclinic growth, etc.

2. Displacement
Survival of a weather system into a new spatial region or time period
e.g. transition of a tropical cyclone into mid-latitudes.

3. Conjunction
Simultaneous supposition of several non-rare events
e.g. freak waves.

4. Intermittency
Varying variance of a process in space or time
e.g. precipitation.



5. Persistence or frequent recurrence:
Chronic weather conditions leading to a climate extreme
e.g. drought, unusually stormy wet season, persistent blocking.

6. Natural variation
Chance occurrence due to natural variations.

Summary

- Extremes are fascinating but have no single unique definition
- Simple extremes can be treated as marked point processes: rate, magnitude, clustering
- Rarity leads to large sampling uncertainty so statistical and physical inference has to be used

Worse than extreme weather …

extreme ironing!

The End