Lloyd's Register Educational Trust

UNIVERSITY OF Southampton

Changes in Marine Extremes

by

Professor Mikis Tsimplis

The LRET Research Collegium
Southampton, 11 July – 2 September 2011

Changes in marine extremes

Mikis Tsimplis,
School of Law and National Oceanography Centre, University of Southampton, UK

Work partly supported by LRET Marine Extremes Network

Which marine extremes matter?

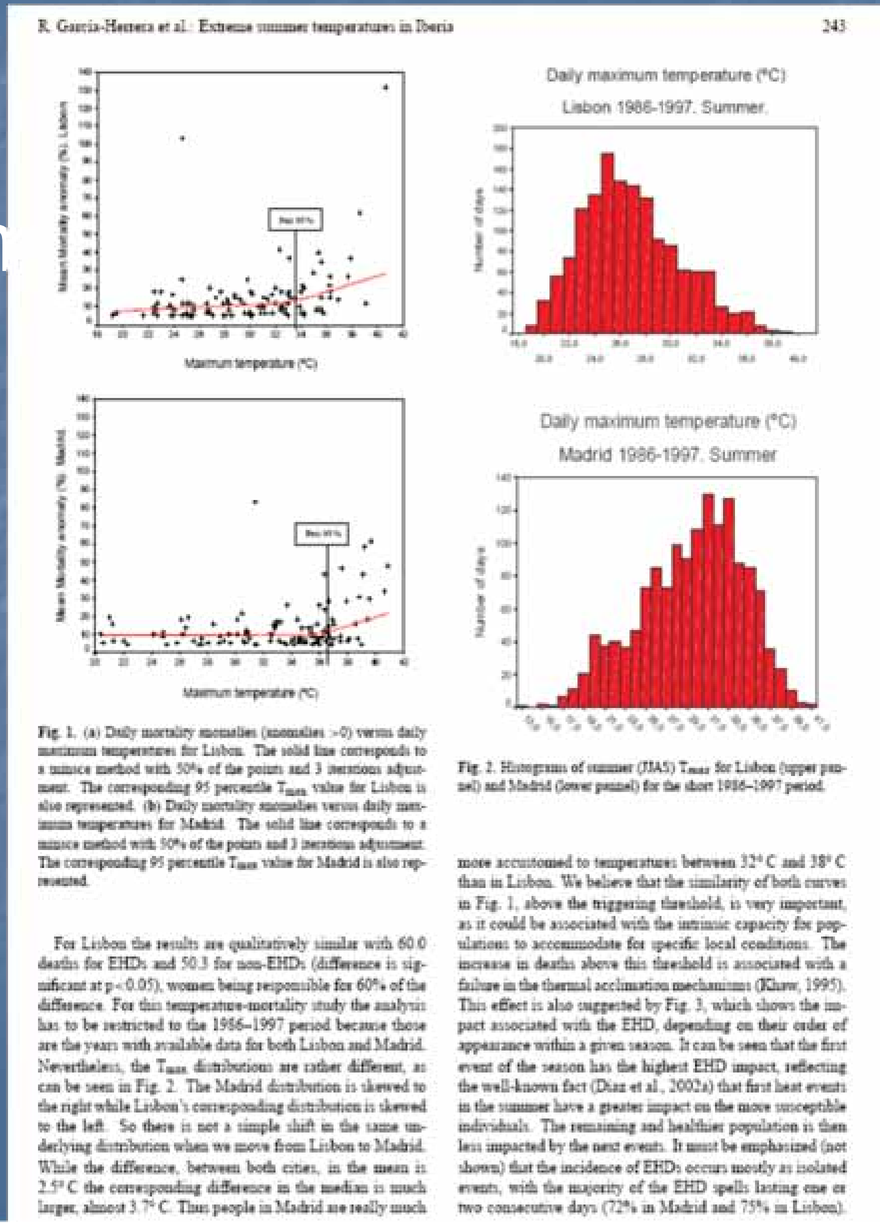
- How are extremes defined?
- Which are the important variables?
  - Sea level
    - Tsunamis
    - Storm surges
  - Wind waves
  - Sea surface temperature
  - PH
  - Salinity
- Thermohaline circulation
- What are the impacts of changes in marine extremes?

Why are extremes of sea level important?

- Coastal population and infrastructure (globally):
  - 1-3 million (additional) people at risk 1-3 ºC
  - 2-15 million(additional) people at risk for 3-6 ºC
- Erosion
- Coastal flooding
- Degradation of coastal land
- Contamination of underground water
- Coastal ecosystem and wetlands lost (30% for highest range of predictions)

How should extremes be defined?

- Statistical definition
- Impact based definition



R. García-Herrera et al.: Extreme summer temperatures in Iberia 243

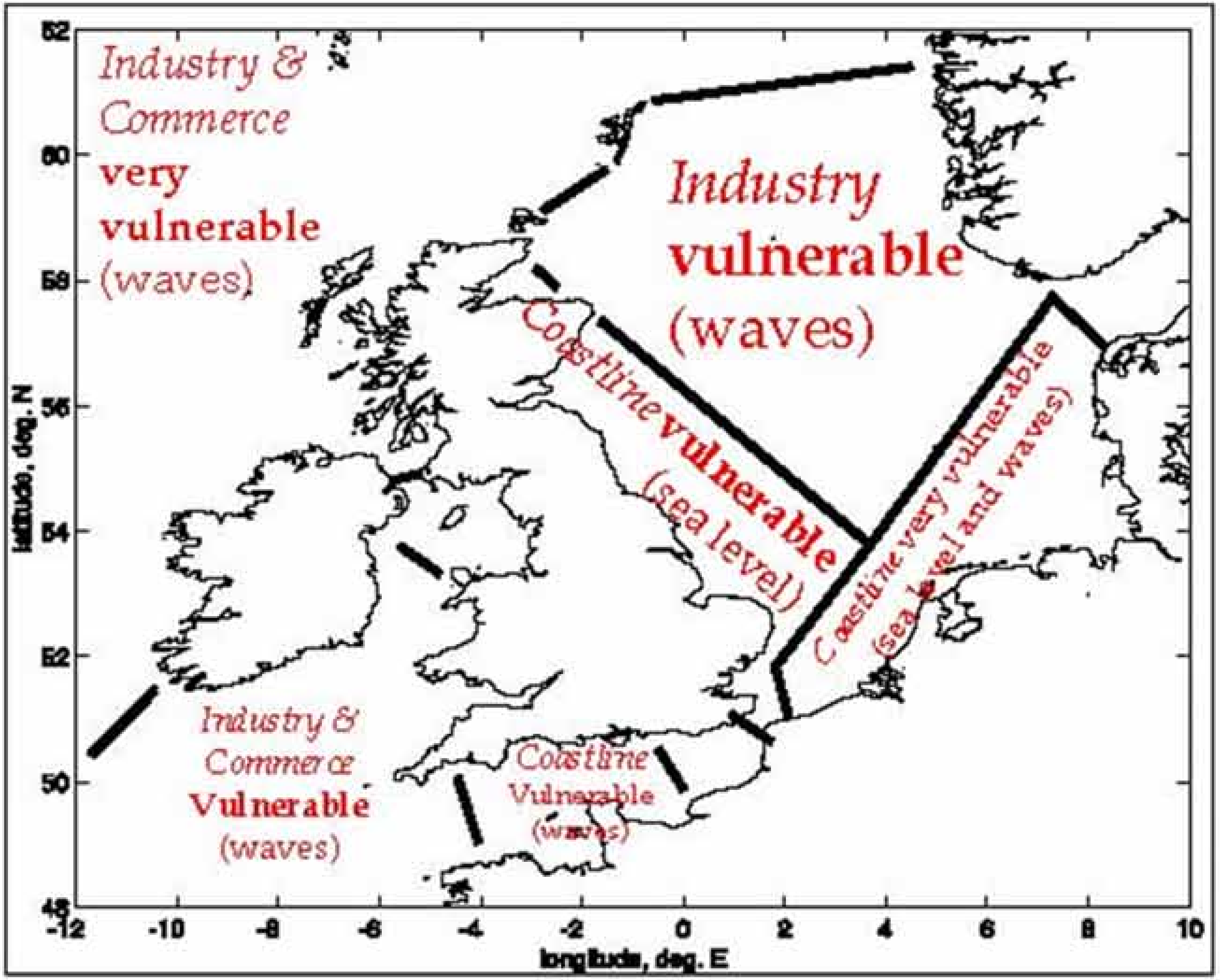
Fig. 1. (a) Daily mortality anomalies (anomalies >0) versus daily maximum temperatures for Lisbon. The solid line corresponds to a minmce method with 50% of the points and 3 iterations adjustment. The corresponding 95 percentile T_{max} value for Lisbon is also represented. (b) Daily mortality anomalies versus daily maximum temperatures for Madrid. The solid line corresponds to a minmce method with 50% of the points and 3 iterations adjustment. The corresponding 95 percentile T_{max} value for Madrid is also represented.

Fig. 2. Histograms of summer (JJAS) T_{max} for Lisbon (upper panel) and Madrid (lower pannel) for the short 1986–1997 period.

For Lisbon the results are qualitatively similar with 60.0 deaths for EHDs and 50.3 for non-EHDs (difference is significant at $p < 0.05$), women being responsible for 60% of the difference. For this temperature-mortality study the analysis has to be restricted to the 1986–1997 period because those are the years with available data for both Lisbon and Madrid. Nevertheless, the T_{max} distributions are rather different, as can be seen in Fig. 2. The Madrid distribution is skewed to the right while Lisbon's corresponding distribution is skewed to the left. So there is not a simple shift in the same underlying distribution when we move from Lisbon to Madrid. While the difference, between both cities, in the mean is 2.5° C the corresponding difference in the median is much larger, almost 3.7° C. Thus people in Madrid are really much more accustomed to temperatures between 32° C and 38° C than in Lisbon. We believe that the similarity of both curves in Fig. 1, above the triggering threshold, is very important, as it could be associated with the intrinsic capacity for populations to accommodate for specific local conditions. The increase in deaths above this threshold is associated with a failure in the thermal acclimation mechanisms (Khaw, 1995). This effect is also suggested by Fig. 3, which shows the impact associated with the EHD, depending on their order of appearance within a given season. It can be seen that the first event of the season has the highest EHD impact, reflecting the well-known fact (Díaz et al., 2002a) that first heat events in the summer have a greater impact on the more susceptible individuals. The remaining and healthier population is then less impacted by the next events. It must be emphasized (not shown) that the incidence of EHDs occurs mostly as isolated events, with the majority of the EHD spells lasting one or two consecutive days (72% in Madrid and 75% in Lisbon).

Extreme Temperatures and mortality

Vulnerability to Positive NAO



Why can extremes change?

- The mean may shift
- The tail of the distribution may change

- Climate models have some skill in describing the mean but less (or no) skill in extremes.

- We will look at sea level extremes (not tsunamis)

Extreme sea levels

- Extreme sea levels are dangerous – not mean sea level rise
- Knowledge of extremes required for coastal protection
  - Usually acquired by observations over a few years
  - Assumptions:
    - Any period is sufficient
    - The distribution remains unaltered
- Climate change
  - May cause changes in extremes
    - Magnitude
    - Storm tracks
- Do tide-gauges work properly during extremes?

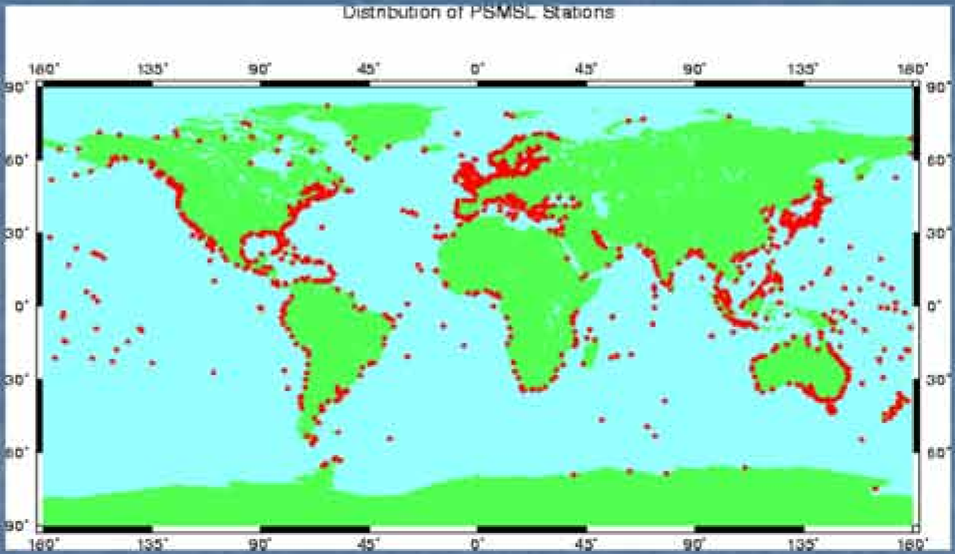
Issues to consider

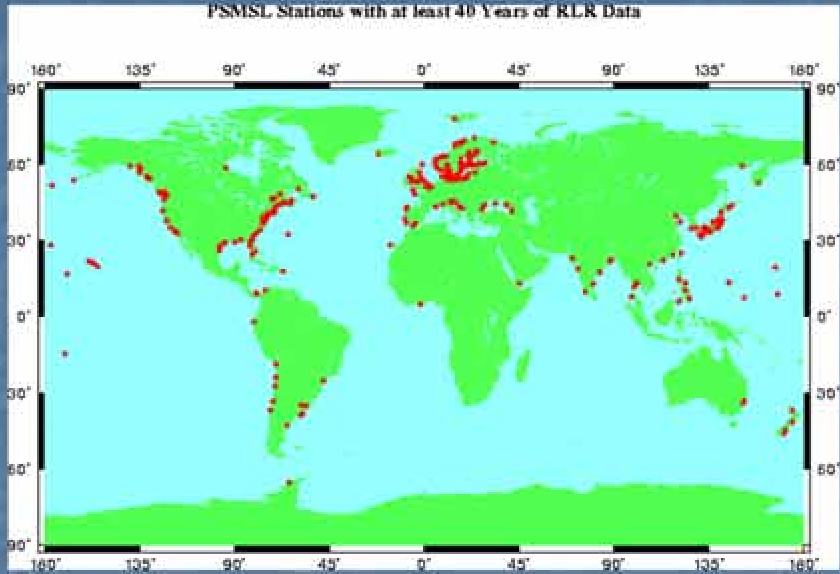
- When are two sea level extremes independent?
- Seasonality
  - Remove or model?
- Mean sea level change
  - Remove or model?
- Tides
  - Deterministic
  - Joint probability
  - Non-linear interaction

What do we need to know?

- Consider again:
  - Do we need to know when an extreme value will be reached?
  - Do we need to know for how long the threshold will br exceeded?
  - Do we need to link this with damages?

Where do we measure sea level?





- Less than 10 tide-gauges longer than 120 years

-around 170 longer than 40 years

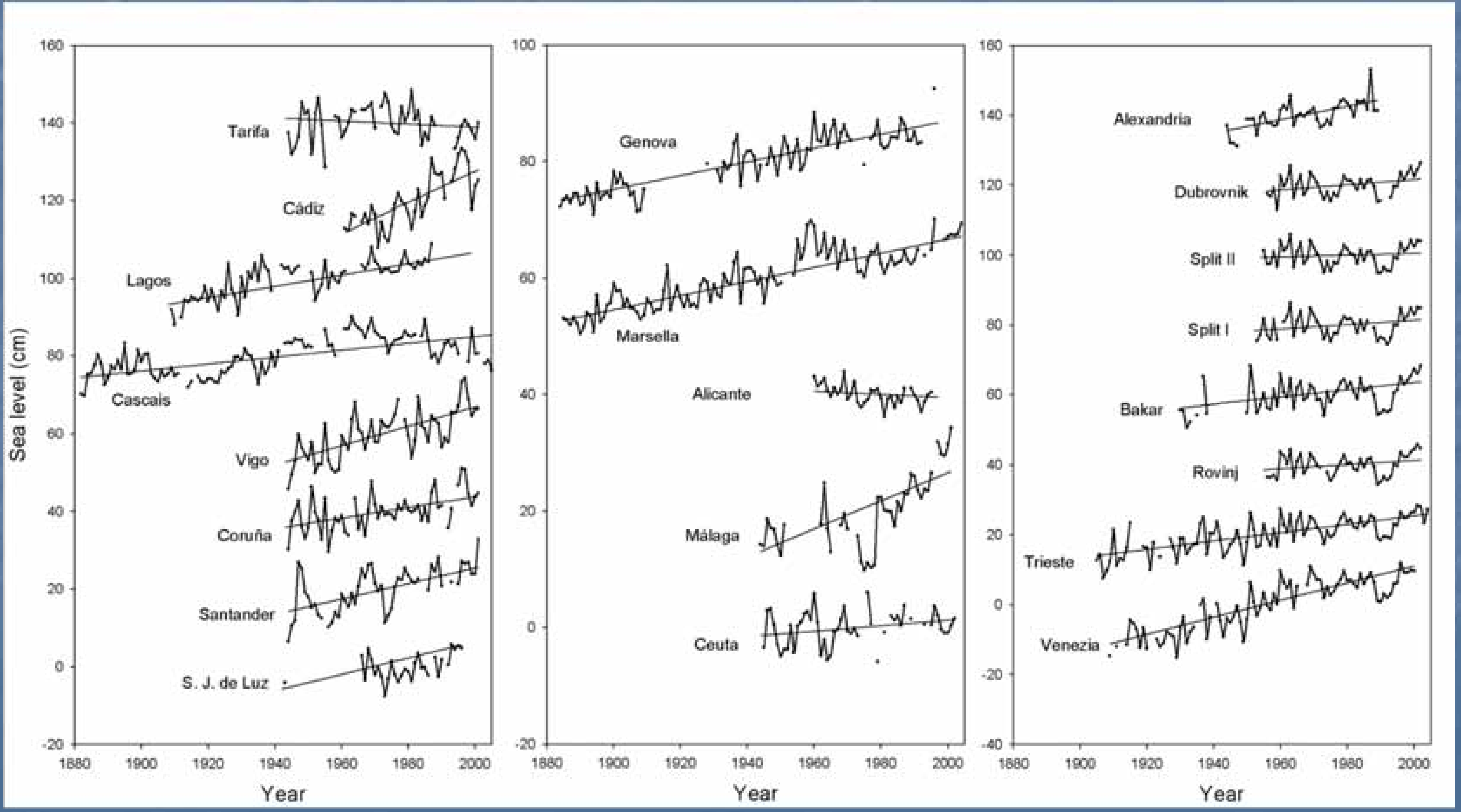
-around 280 good quality presently working (GLOSS)

-around 1600 short records worldwide

-BUT WHERE?

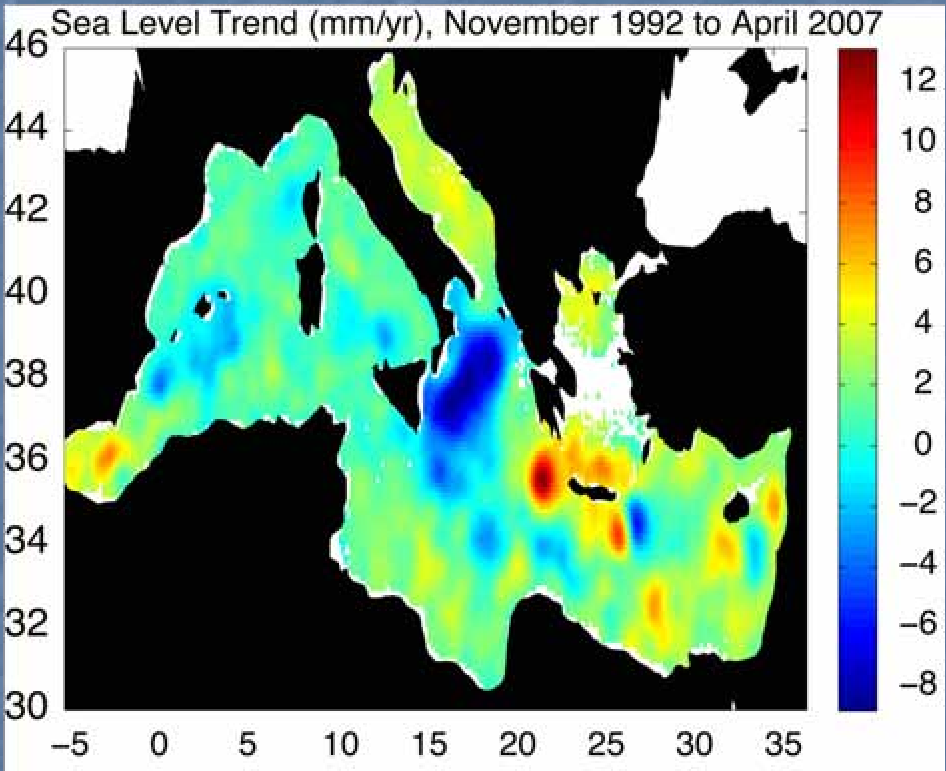
Coastal sea level trends in the Mediterranean

Sea level trends for the longest records give a best estimate of around 1.2 mm/yr

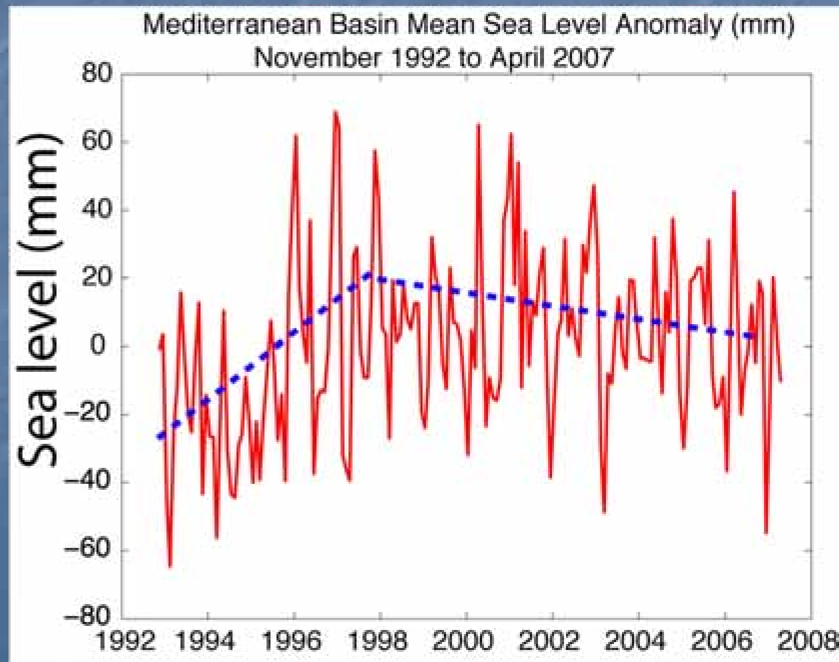


Marcos and Tsimplis, 2008

Is sea level rising in the Mediterranean Sea?



Best estimate of trends from tide gauges 1.2 mm/yr for the period 1920-2007



Sea level rise 1993-2007 (1.4 mm/yr)

Methodology

- Observations
  - Select extremes
    - Year starts October 1st
  - Ensure extremes are independent
    - 3 days
  - Use GEV
- Remove tide and repeat analysis
- Repeat for model data (HIPOCAS)
- Percentiles to explore temporal variability

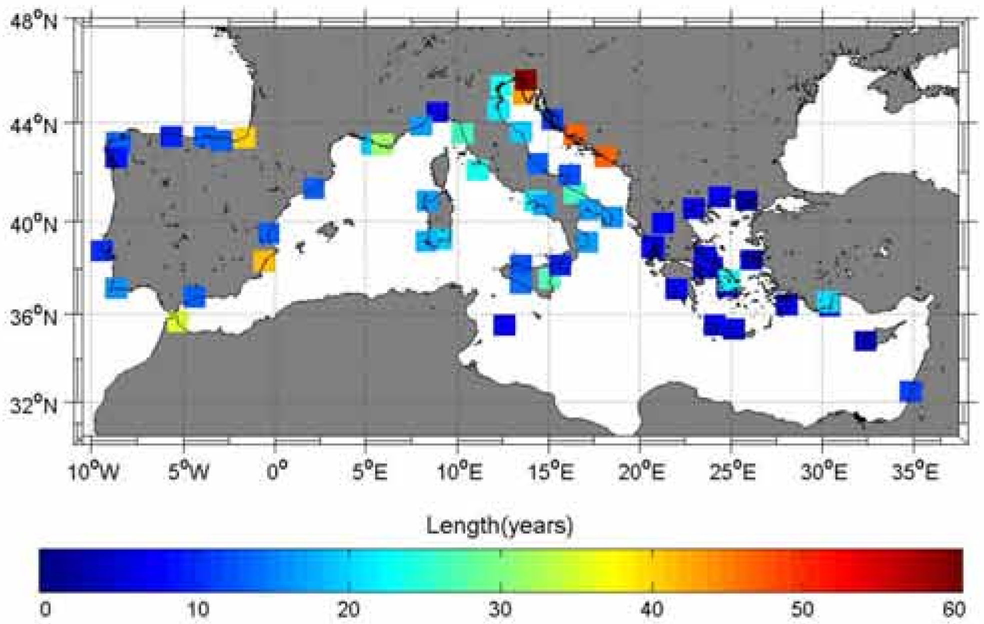
DATA:

73 tide gauge records-

92 time series

-Difficult to obtain hourly data

-Quality controls



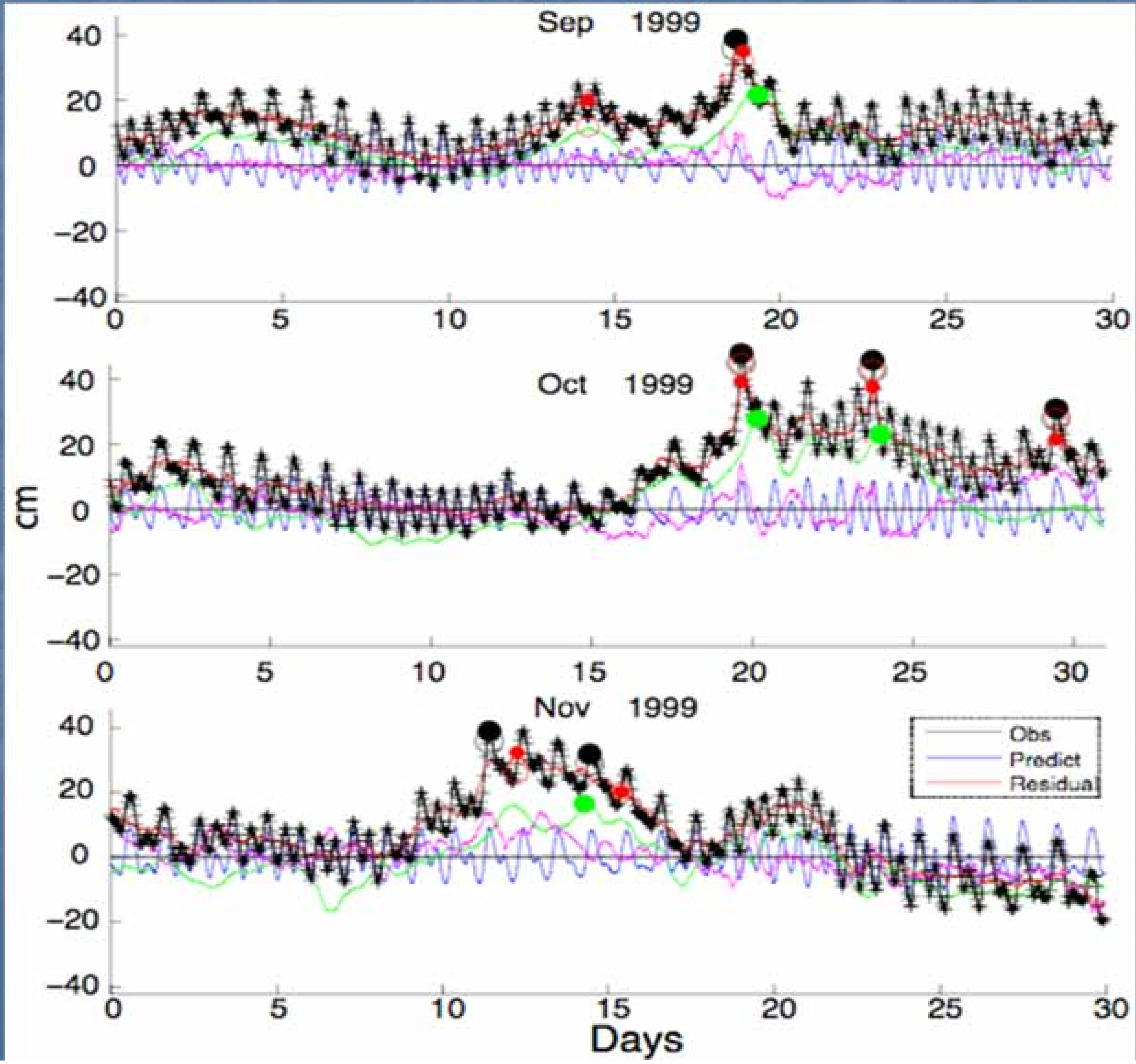
We assume:

Sea level = atmospherically driven sea level component + tide + error

Tide = predicted from the record

Atmospherically driven sea level: Wind + pressure component (no thermohaline circulation, thermal expansion etc.)

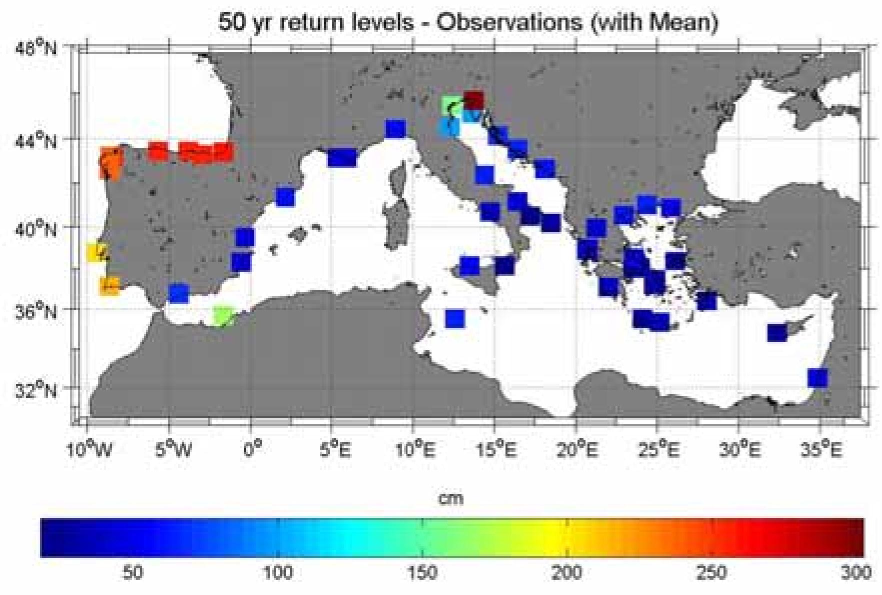
Barcelona showing extremes events with no timing errors

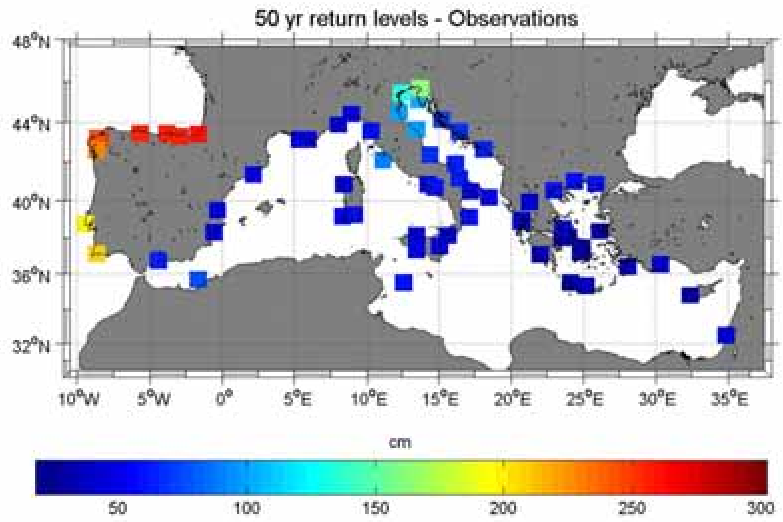


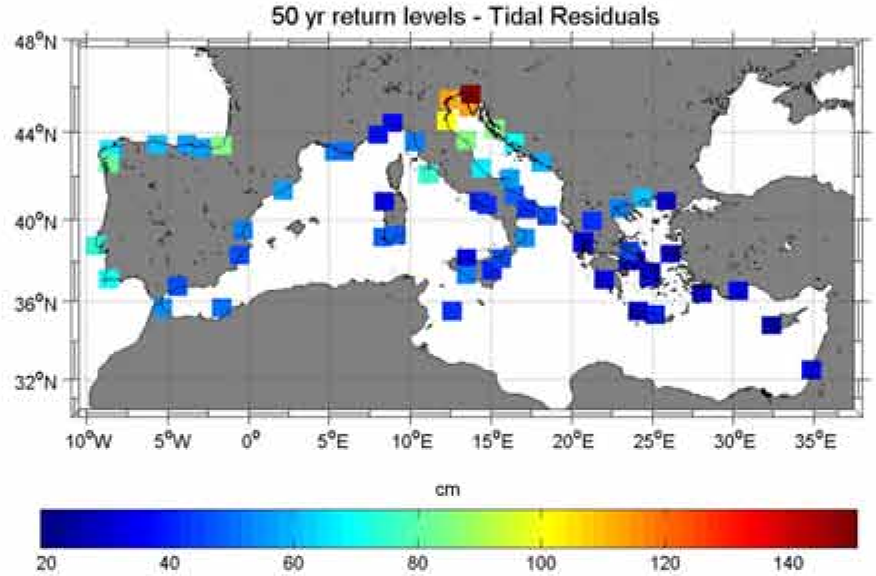
HIPOCAS (1958-2001)
http://www.mar.ist.utl.pt/hipocas/info.asp
Hindcast of Dynamic Processes of the Ocean and Coastal Areas of Europe

Simulates small-scale atmospheric forcing on sea level from wind and pressure effects

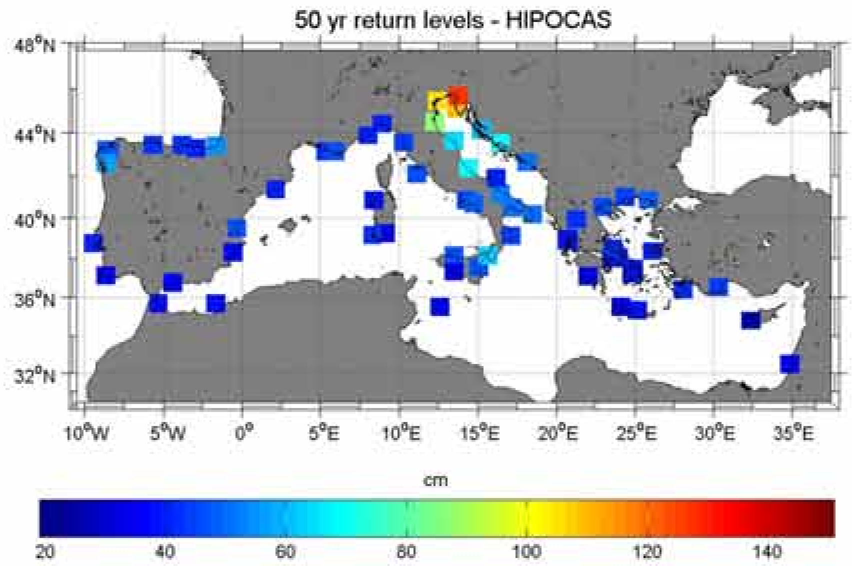
50 year return periods for time series of observations

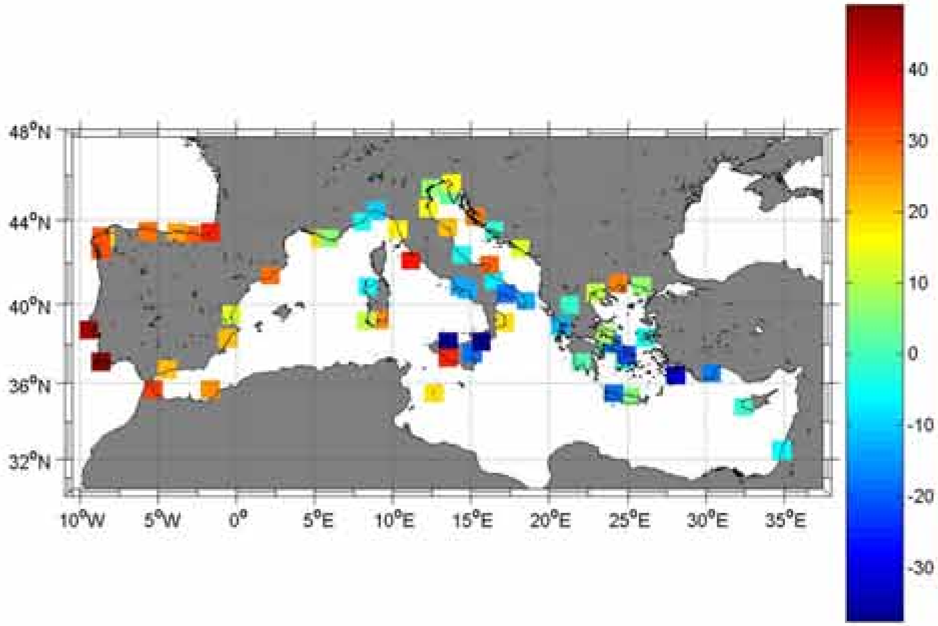






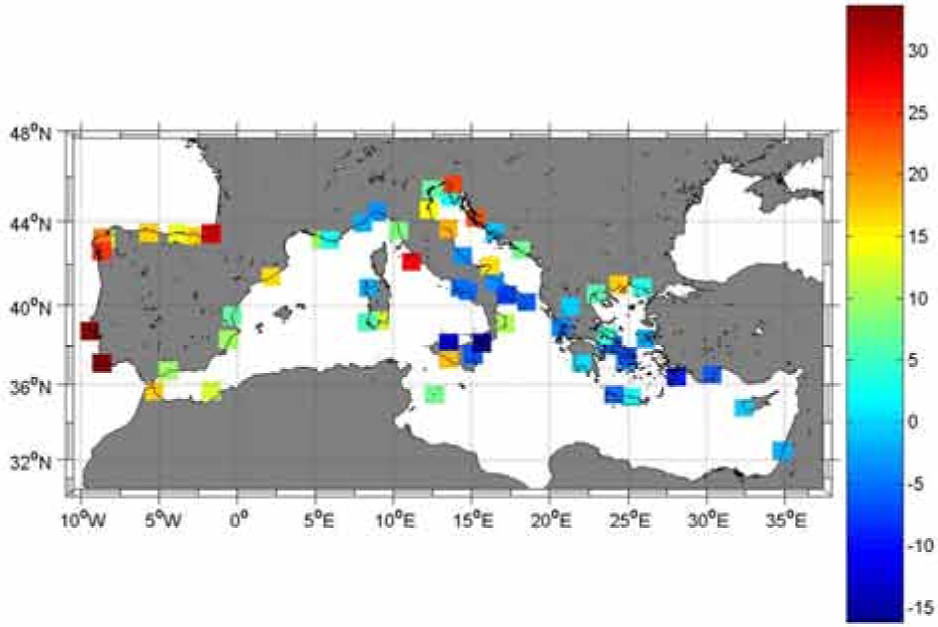
50 year return periods for time series of tidal residuals (above) and the same for HIPOCAS covering exactly the same period as the observations

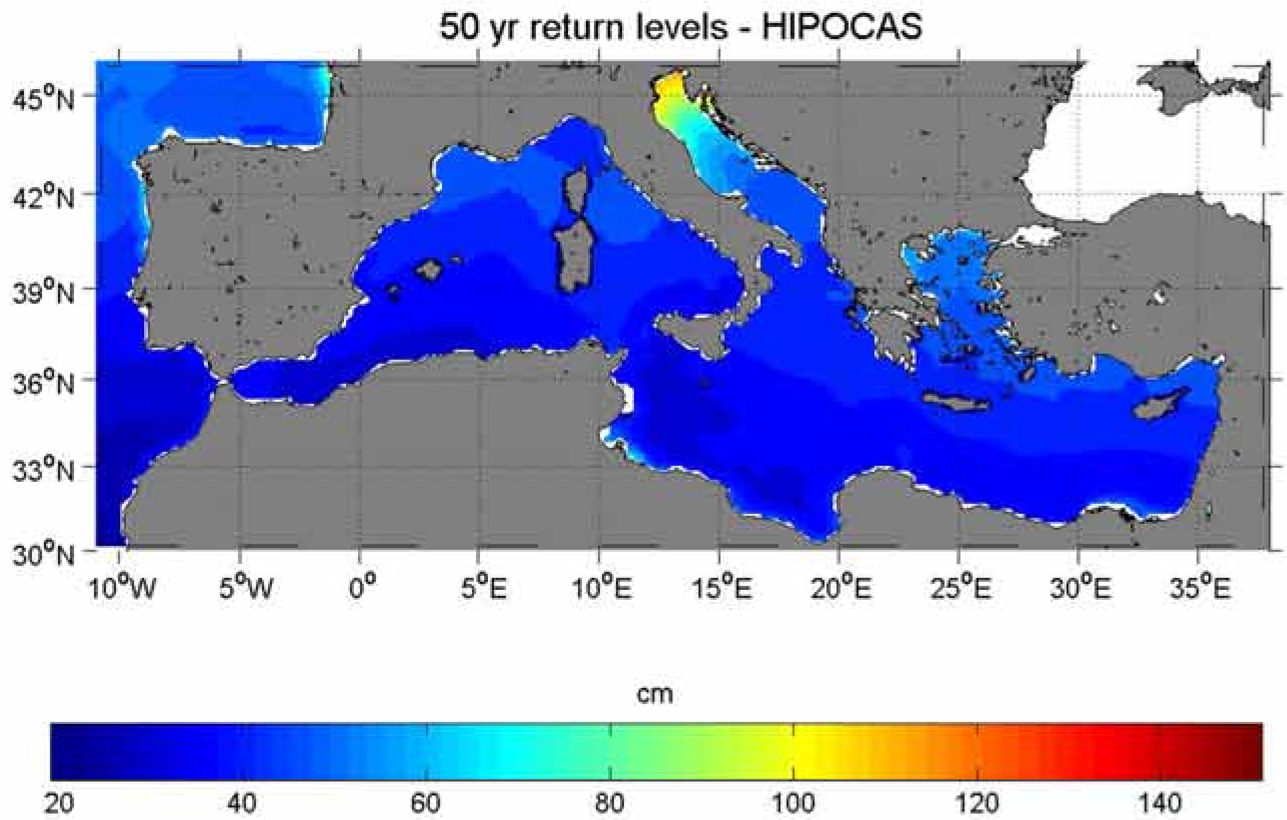


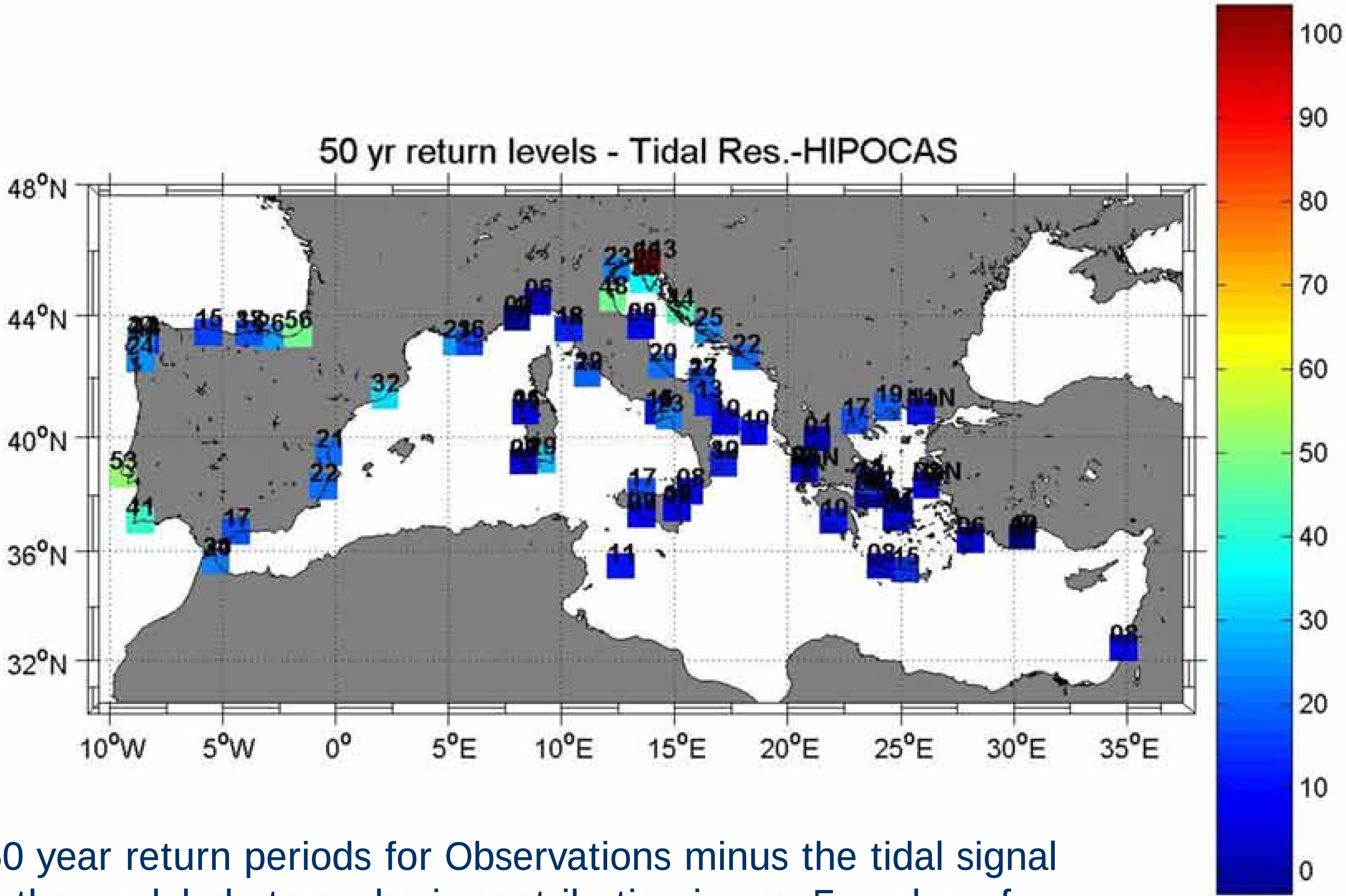


50 yr Return levels:
Percentage of difference Tidal
Residuals - Hipocas

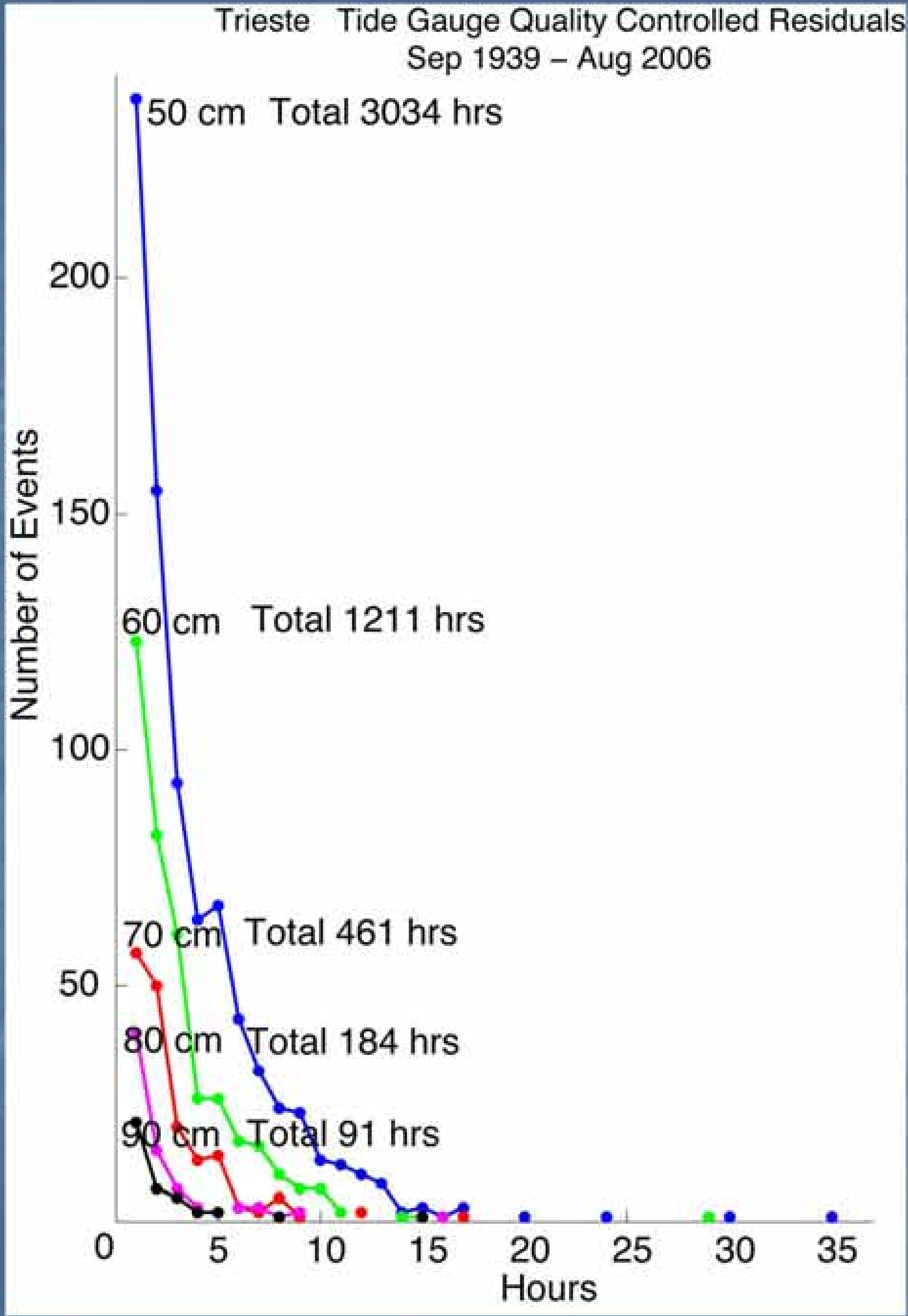
50 yr Return levels:
Difference (in cm) between tidal
residuals and HIPOCAS.



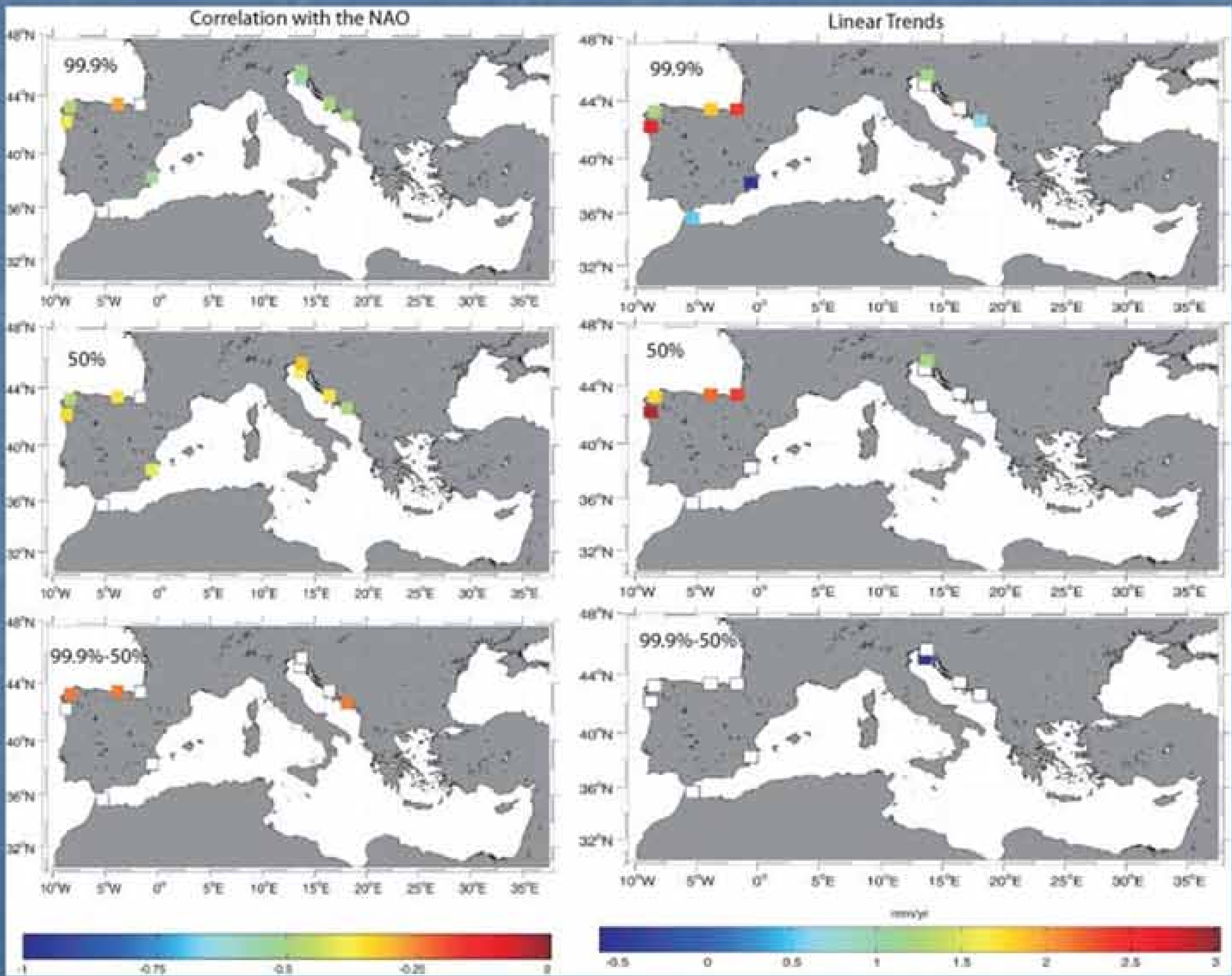

50 yr return levels - HIPOCAS
45°N
42°N
39°N
36°N
33°N
30°N
10°W
5°W
0°
5°E
10°E
15°E
20°E
25°E
30°E
35°E
cm
20
40
60
80
100
120
140



50 year return periods for Observations minus the tidal signal – the modeled atmospheric contribution in cm. Error bars for predictions?


Trieste Tide Gauge Quality Controlled Residuals
Sep 1939 – Aug 2006
50 cm Total 3034 hrs
60 cm Total 1211 hrs
70 cm Total 461 hrs
80 cm Total 184 hrs
90 cm Total 91 hrs
Number of Events
200
150
100
50
0
5
10
15
20
25
30
35
Hours

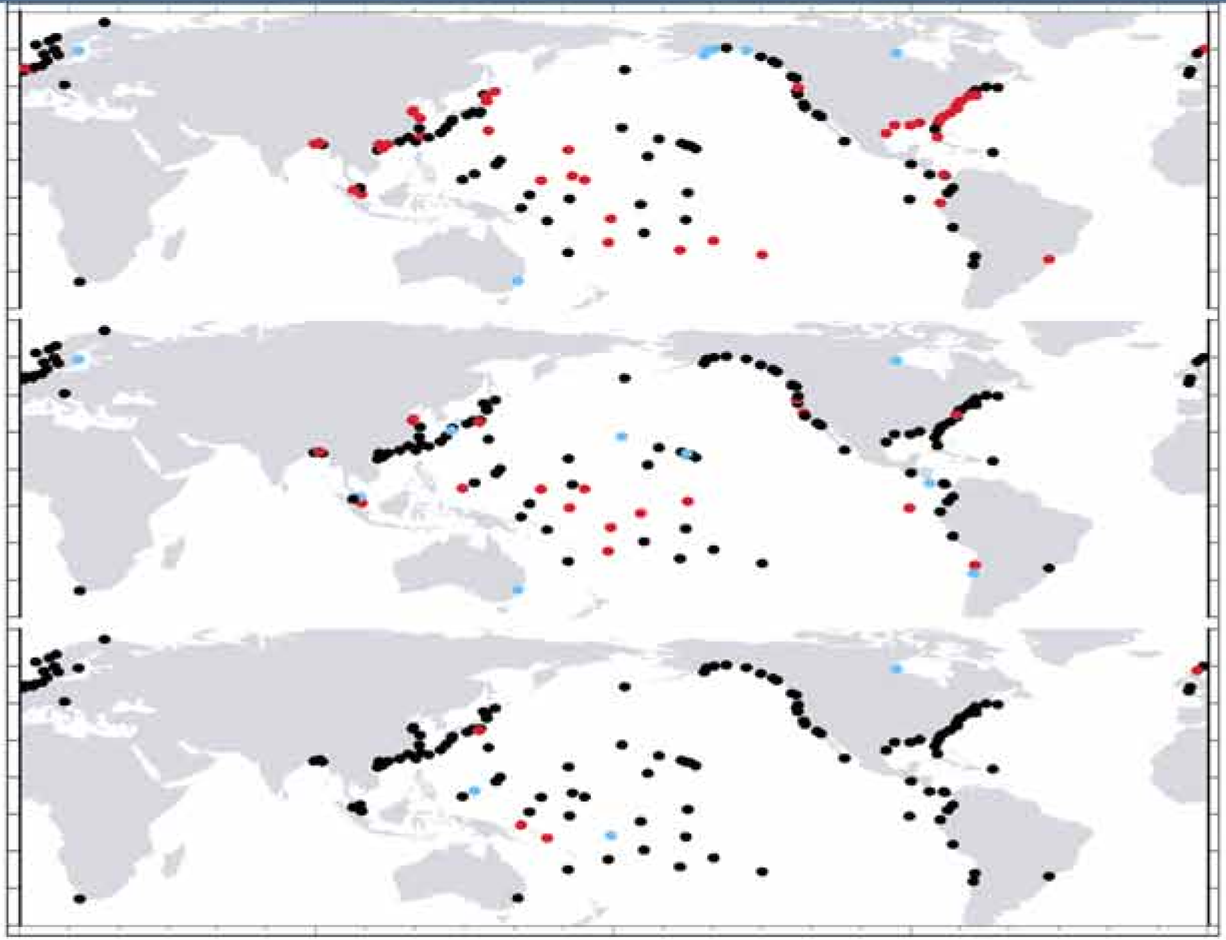
Are there any changes in time the extremes? If yes, are these different to the changes in the median sea level? Are they linked with the atmospheric forcing? Only time series 40 years or longer are used.



Conclusions

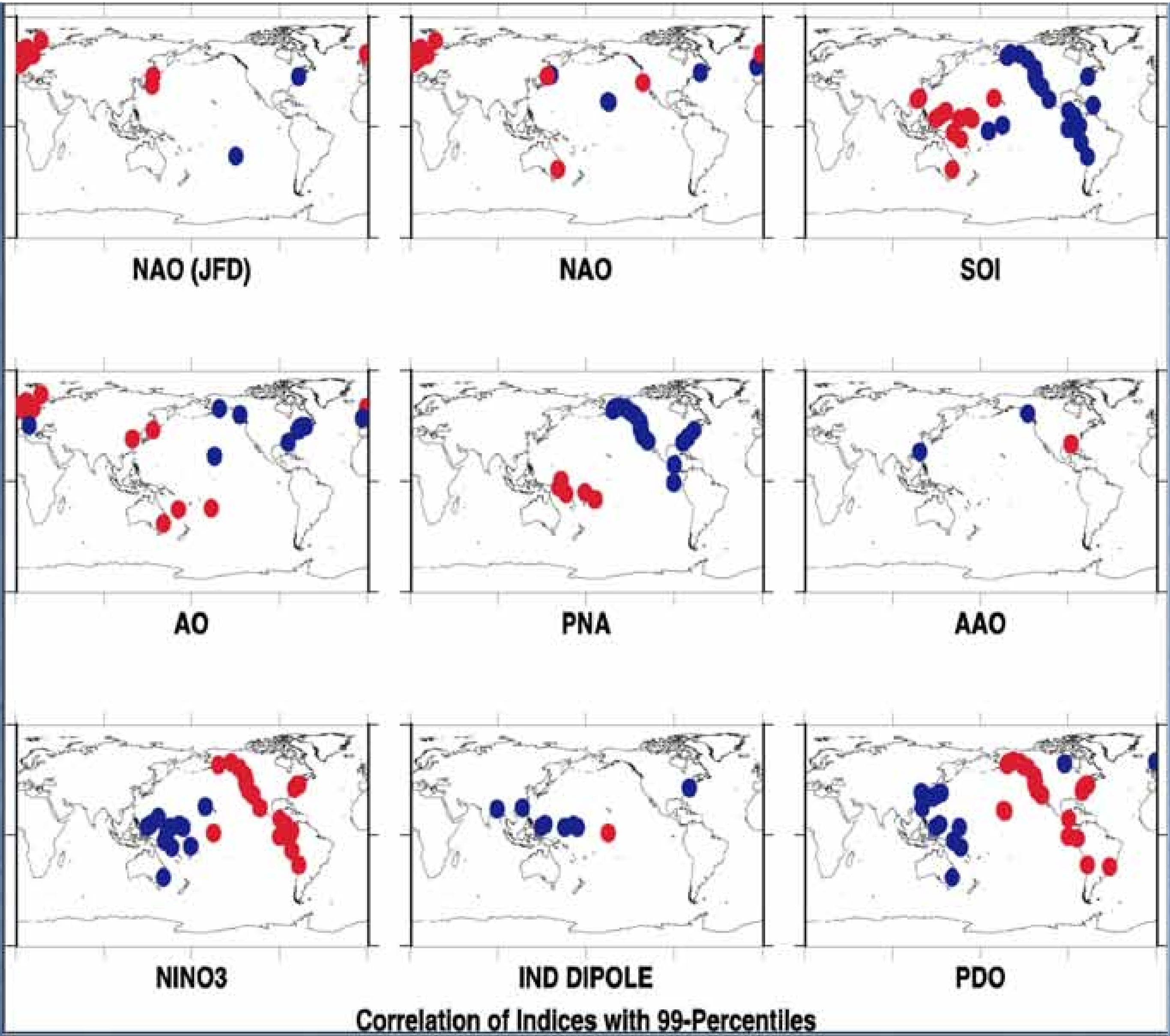
- Sea level in the Mediterranean Sea has been rising at approximately 1.2 mm/yr – lower than the global average
- However there is large spatial variability
- Extremes show coherent spatial structures
- They are modelled to about 20 cm accuracy in return levels within the Mediterranean Sea
- This indicates:
  - extremes are atmospherically driven;
  - Modelling on future climate can be based on simple 2d model
  - Can provide estimates in areas where no data exist
- Changes in extremes are (so far) in line with changes in the mean sea level, which are linked with the NAO.

Sea Level Extremes- hourly values for each year- 99% percentile



1. Distribution of tide gauge stations selected for percentile time series analysis. (Top) Stations with observed trends in 99-percentile significantly different from zero are shown in red (positive trend) or blue (negative trend) while others are shown in black. (Middle) As before but with 99-percentile time series reduced to medians. (Bottom) As before but with 99-percentile time series reduced to medians and with the tidal contributions to the percentiles removed.

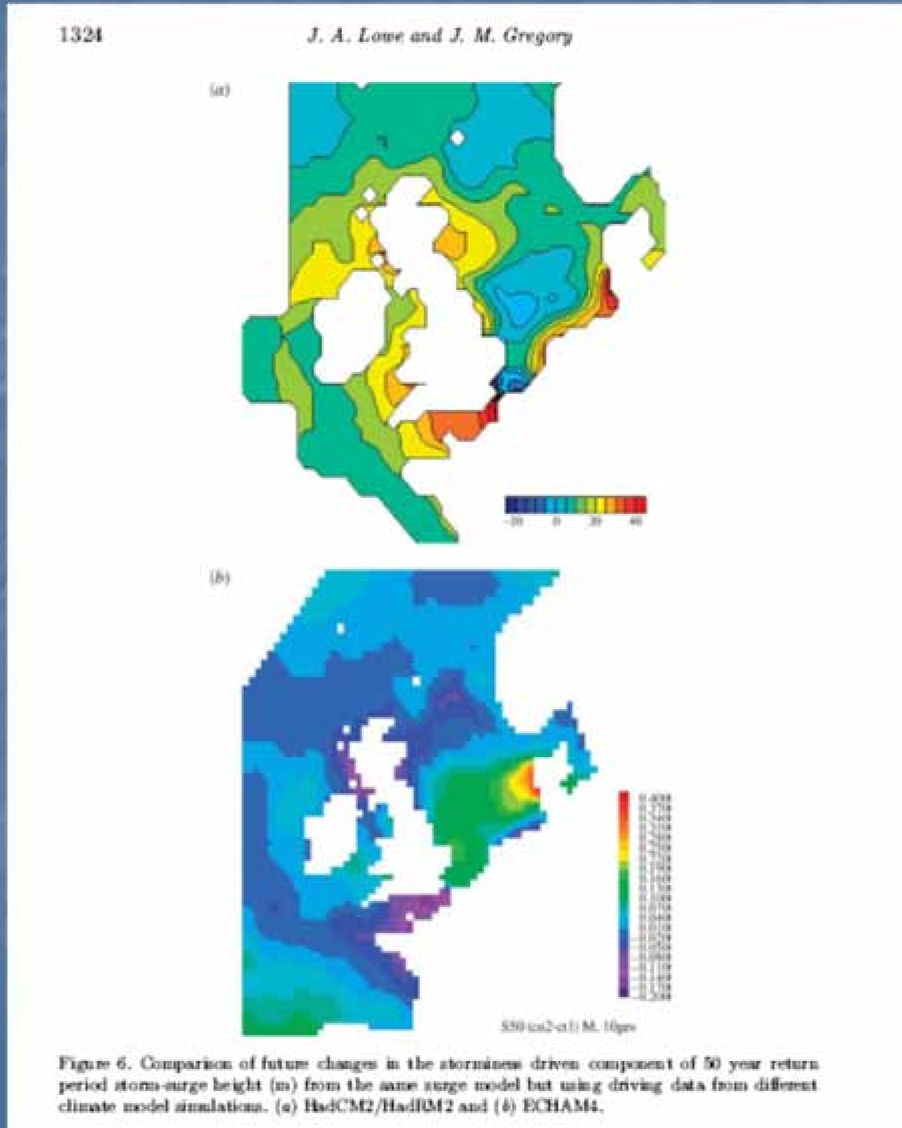
Woodworth and Blackman, (2003)



Woodworth and Blackman, (2003)

See also Woodworth and Blackman, 2002 *Int. J. Climatol.* On 230 years of high water levels in Liverpool

Models of Extreme storm surge



1324 *J. A. Lowe and J. M. Gregory*

(a)

(b)

Figure 6. Comparison of future changes in the storminess driven component of 50 year return period storm-surge height (m) from the same surge model but using driving data from different climate model simulations. (a) HadCM2/HadRM2 and (b) ECHAM4.

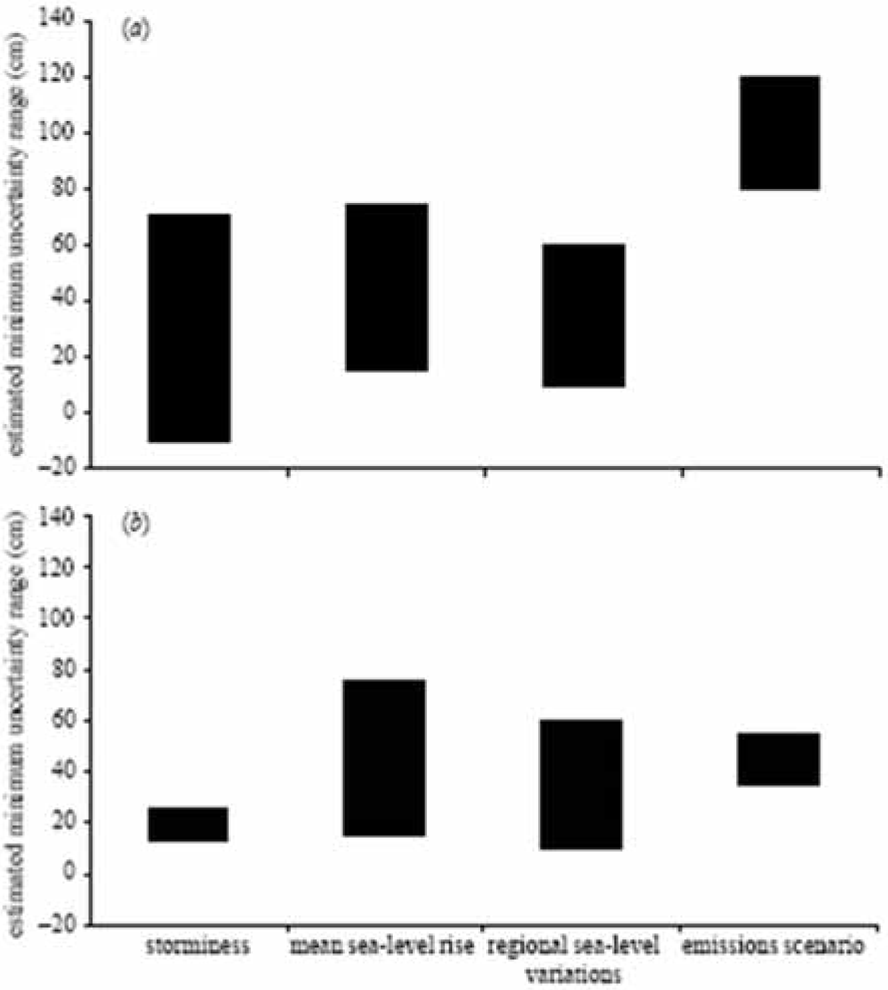
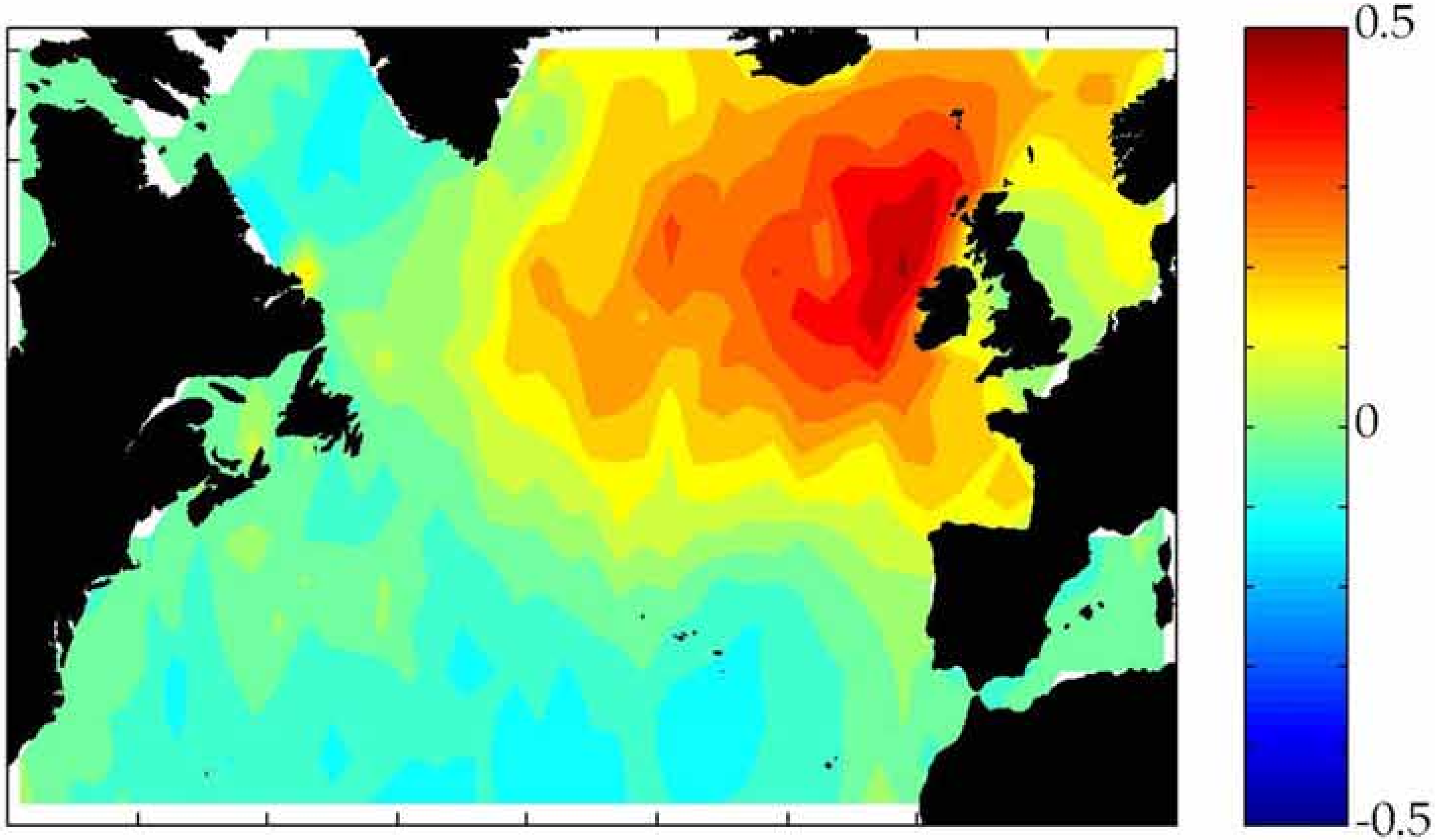


Figure 7. Comparison of the minimum range of uncertainty from the effect of changes in storminess on surges, the effect of global average sea-level rise, the spatial pattern of time-average sea-level rise, and the uncertainty in future emissions. (*a*) Southend, (*b*) Immingham.

Sensitivity of Average Winter Wave Height to NAO (metres/ unit index)



D. Woolf and P. Challenor

Iris Grabemann and Ralf Weisse, 2008

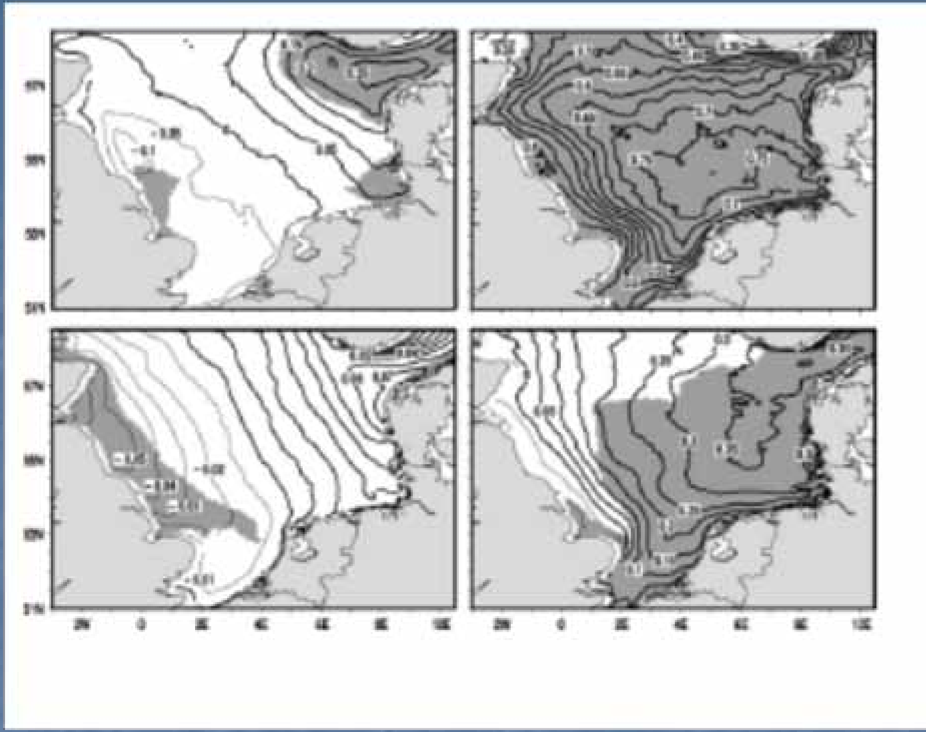


Fig. 9 Mean climate change signal for long-term 50 (left) and 99 percentile (right) wind speed in meters per second (upper row) and significant wave height in meters (lower row). Gray shading indicates areas where the climate change signal has at least the same sign in all simulations, i.e., for all scenarios and model realizations

Mori et al., 2010
A1B scenario
EI = EXTREME VALUE/MEAN

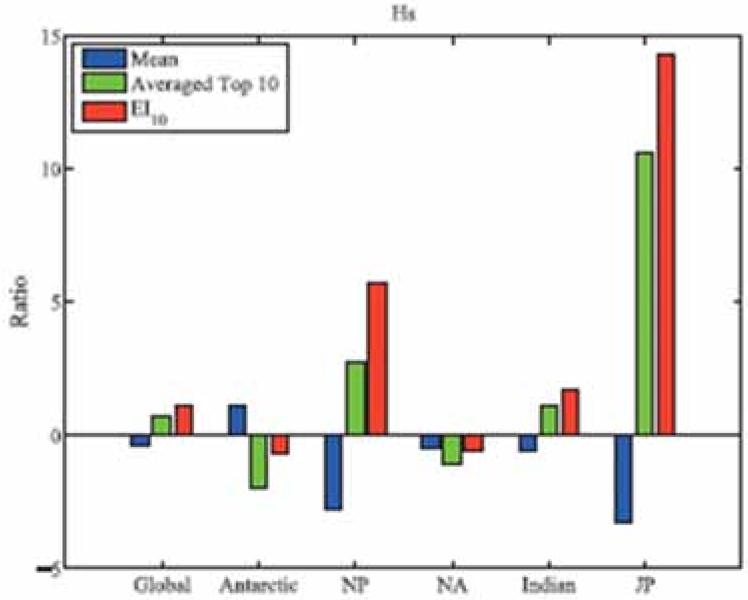


Figure 5. Spatially averaged mean, top 10 and EI of H_s (NP: Northern Pacific, NA: Northern Atlantic, JP: Pacific Ocean near Japan)

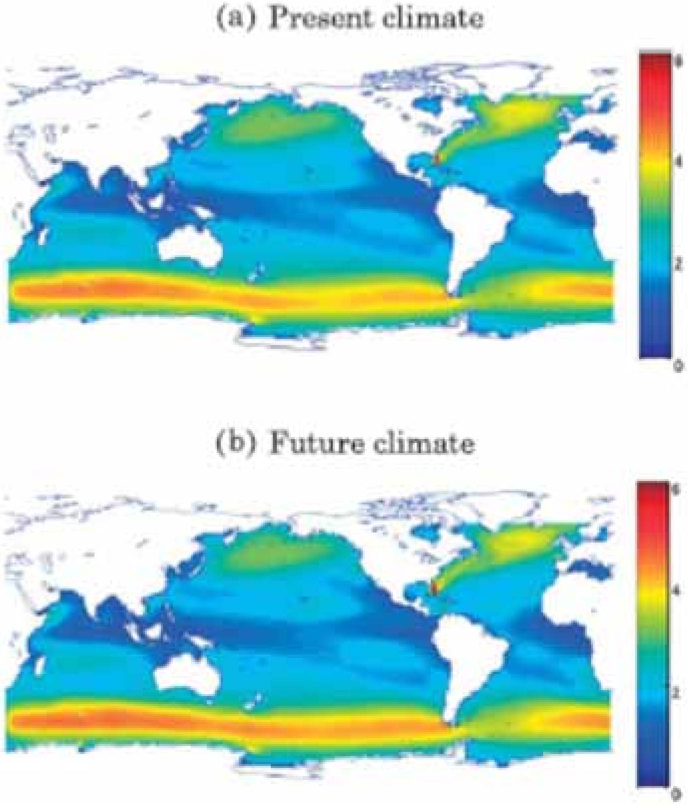


Figure 2. Period averaged $\overline{H}_s$

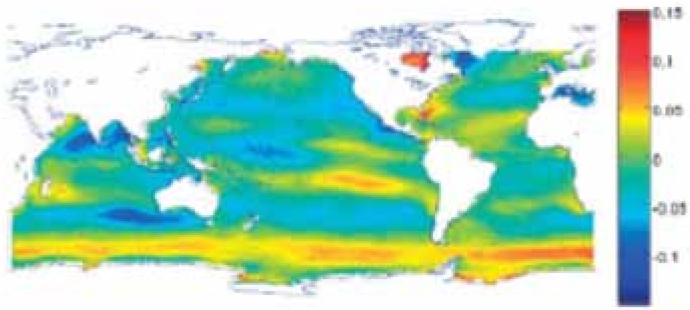


Figure 3. Difference of $\overline{H}_s$ between future minus present climate normalized by present climate

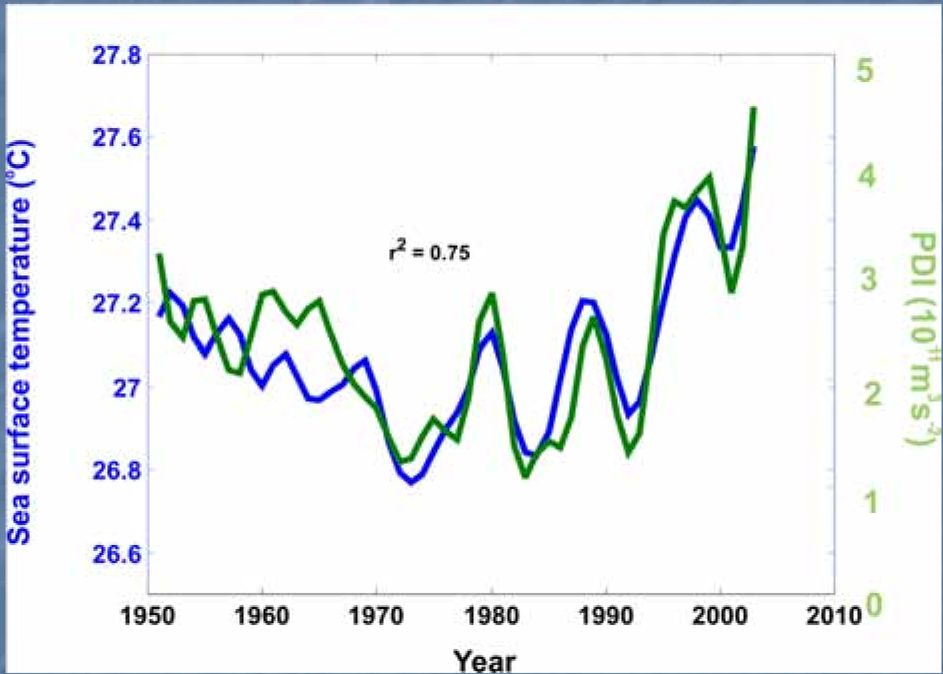
The problem

- Sea level extremes show trends
- These trends are in line with mean sea level rise
- Warmer atmosphere/ocean are supposed to support more energetic storms
- Is there any evidence of increase in tropical storm activity?

PDI is proportional to the time integral of the cube of the surface wind speeds accumulated across all storms over their entire life cycles.

There is some recent evidence that overall Atlantic hurricane activity may have increased since in the 1950s and 60s in association with increasing sea surface temperatures…

Hurricane Katrina, Aug. 2005



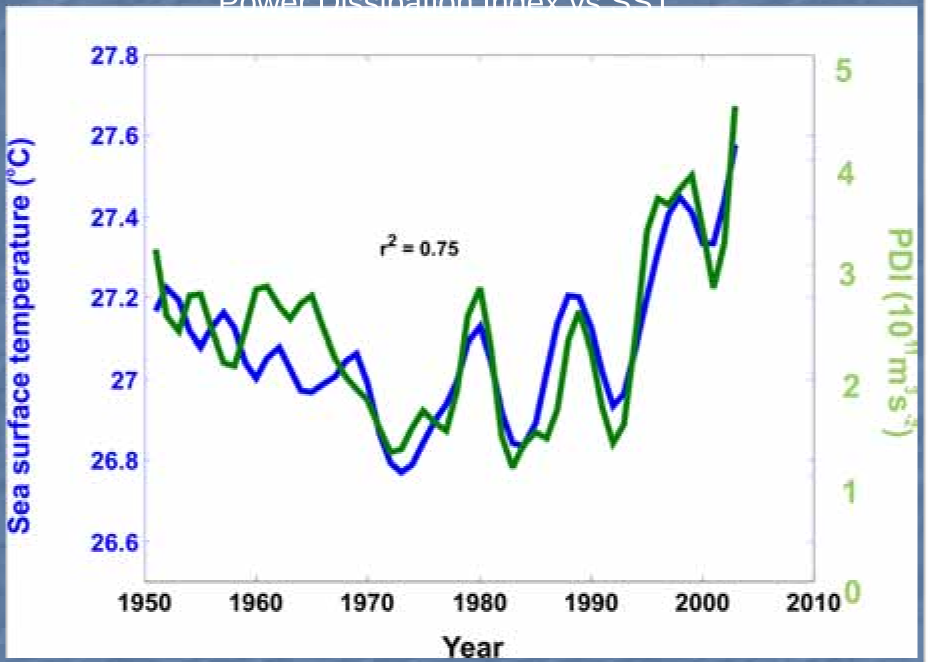
Source: Kerry Emanuel, J. Climate (2007).

There is some recent evidence that overall Atlantic hurricane activity may have increased since in the 1950s and 60s in association with increasing sea surface temperatures…

What are the implications of pronounced future warming for Atlantic Power Dissipation Index (PDI)?

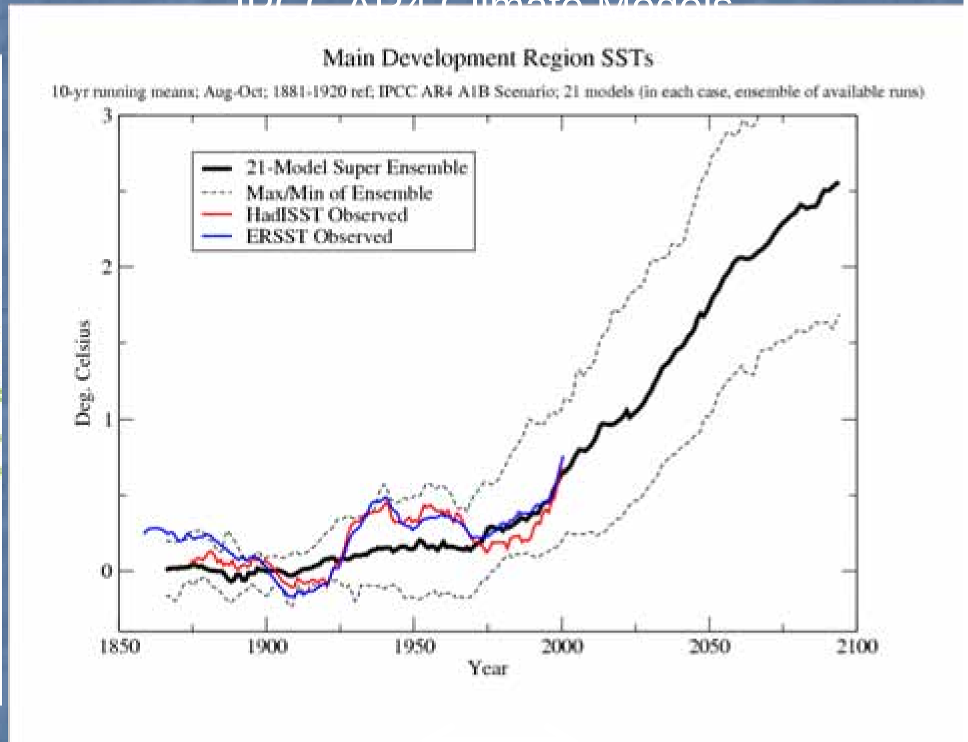
Observations

Power Dissipation Index vs SST



~1950 - 2005

IPCC AR4 Climate Models

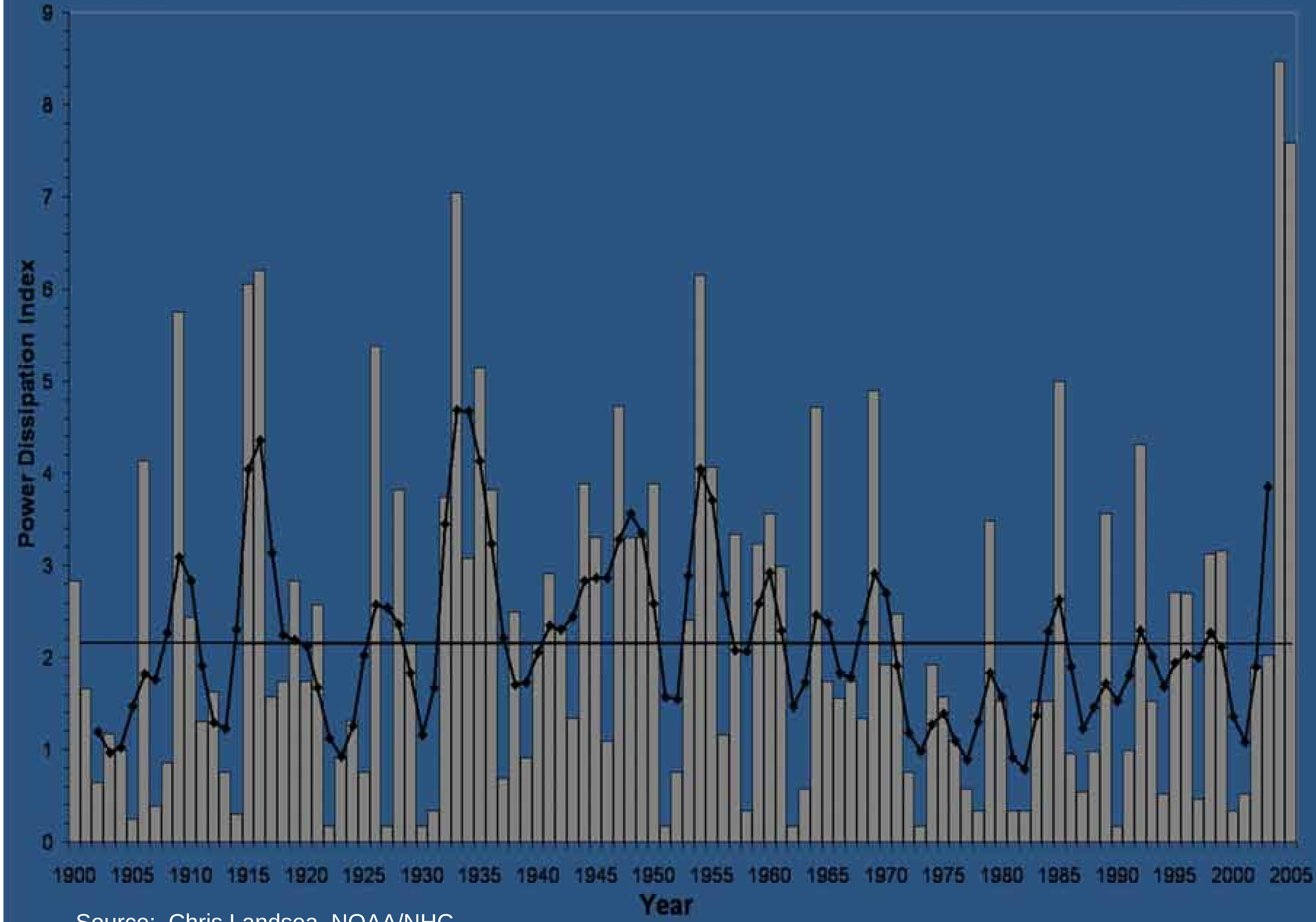


~1950-2005

PDI is proportional to the time integral of the cube of the surface wind speeds accumulated across all storms over their entire life cycles.

Source: Kerry Emanuel, J. Climate (2007).

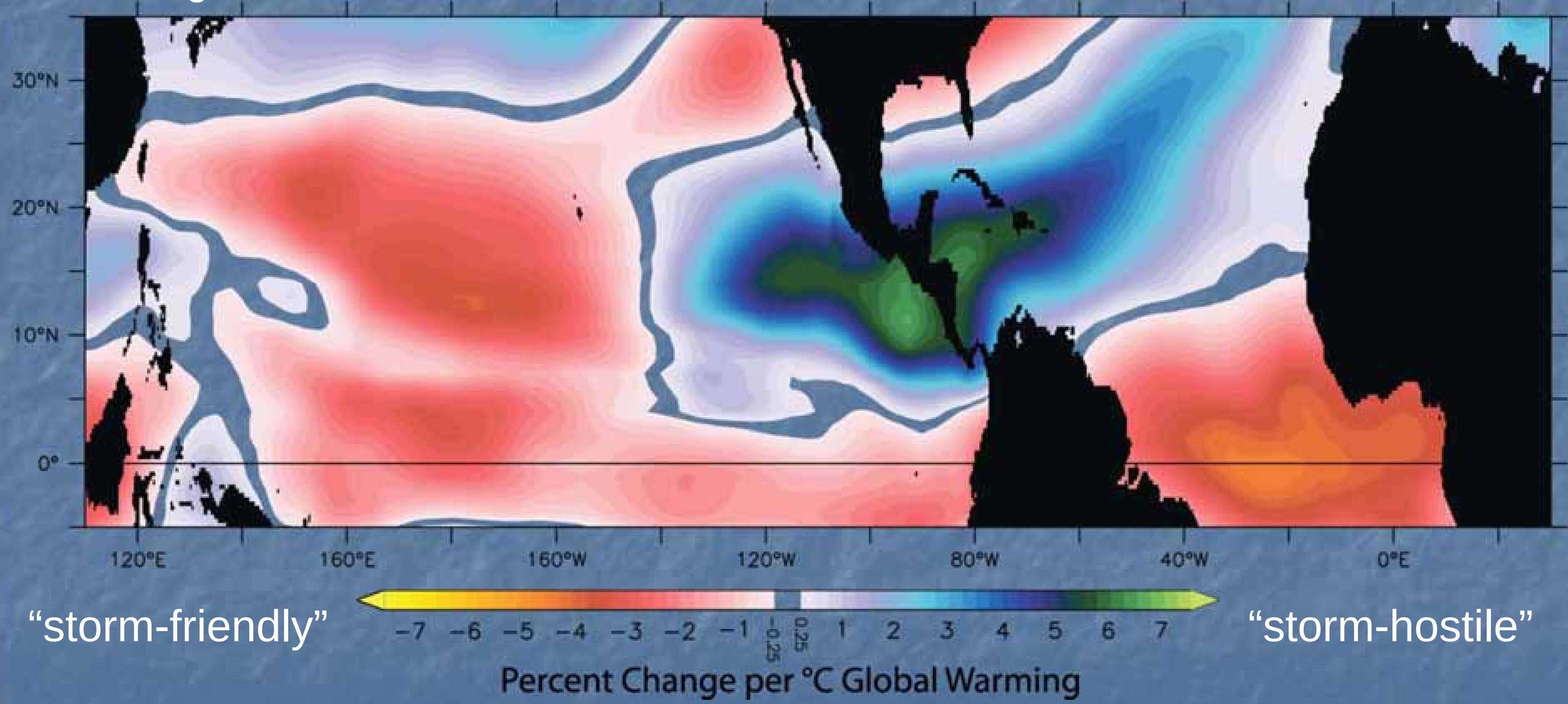
A measure of annual U.S. landfalling hurricane activity shows no clear long-term trend since 1900…



Source: Chris Landsea, NOAA/NHC

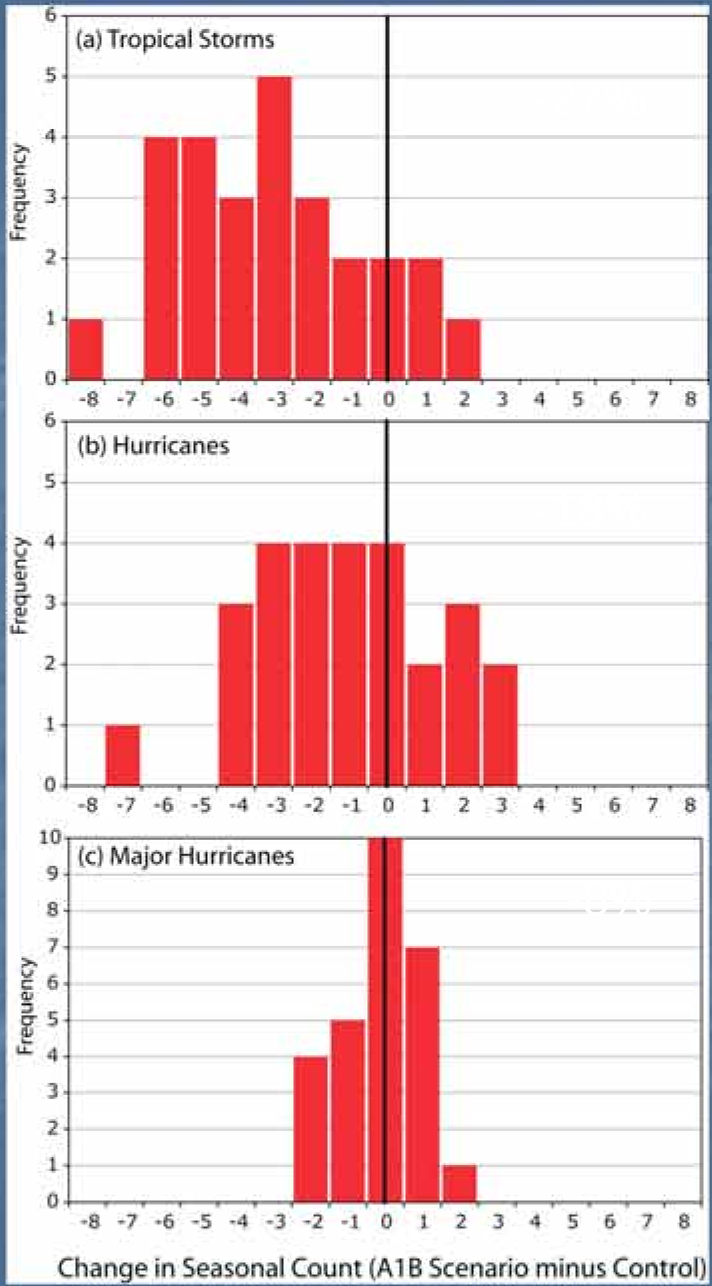
Late 21st Century projections: increased vertical wind shear may lead to fewer Atlantic hurricanes

Average of 18 models, Jun-Nov



Source: Vecchi and Soden, *Geophys. Res. Lett.,* (2007)

Projected changes in Atlantic hurricane/tropical storm numbers:

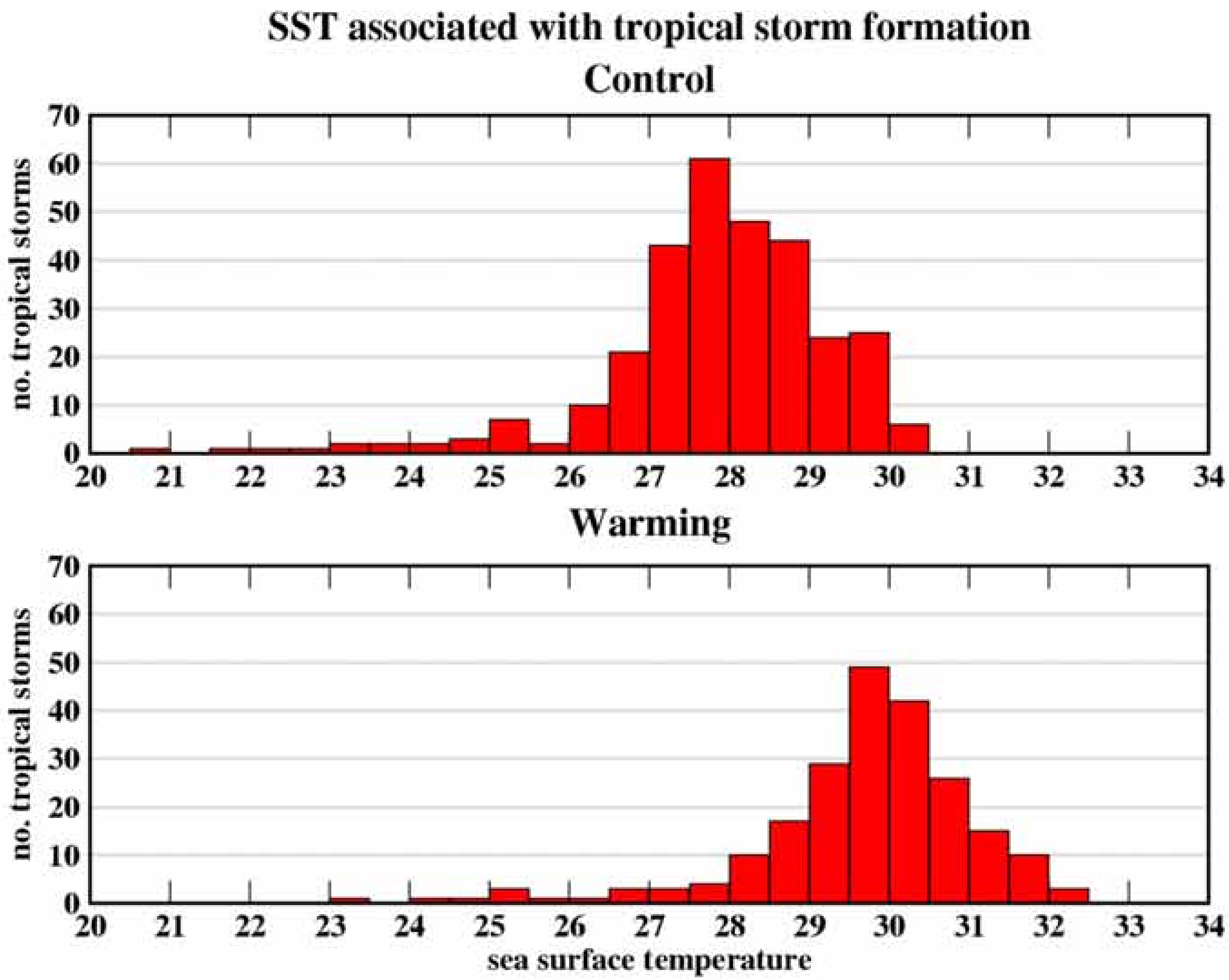


Late 21st century; Zetac regional model downscaling of CMIP3 multi-model ensemble climate change signal.

Note: U.S. Landfalling hurricanes: -30%

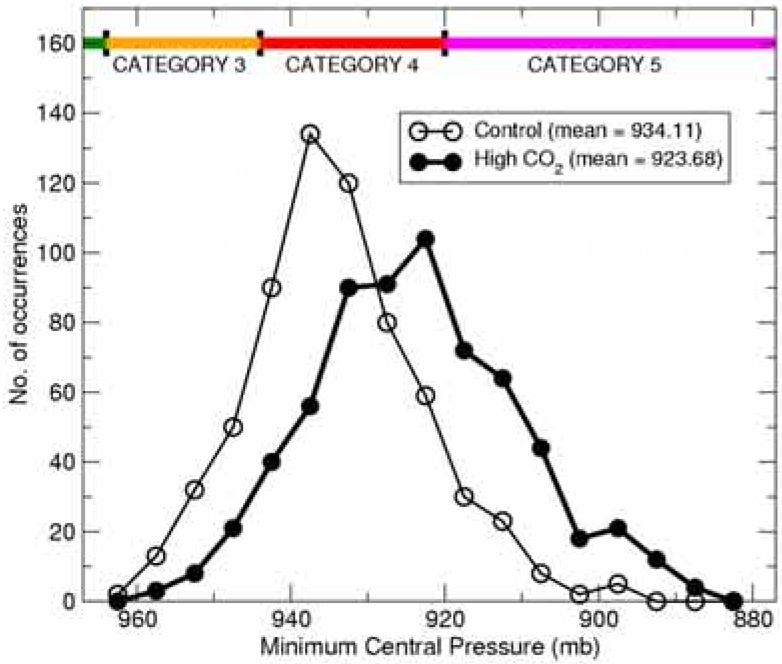
Source: Knutson et al., *2008*, submitted.

The 26.5^{o}C “threshhold temperature” for tropical storm formation:
a ***climate dependent*** threshhold…

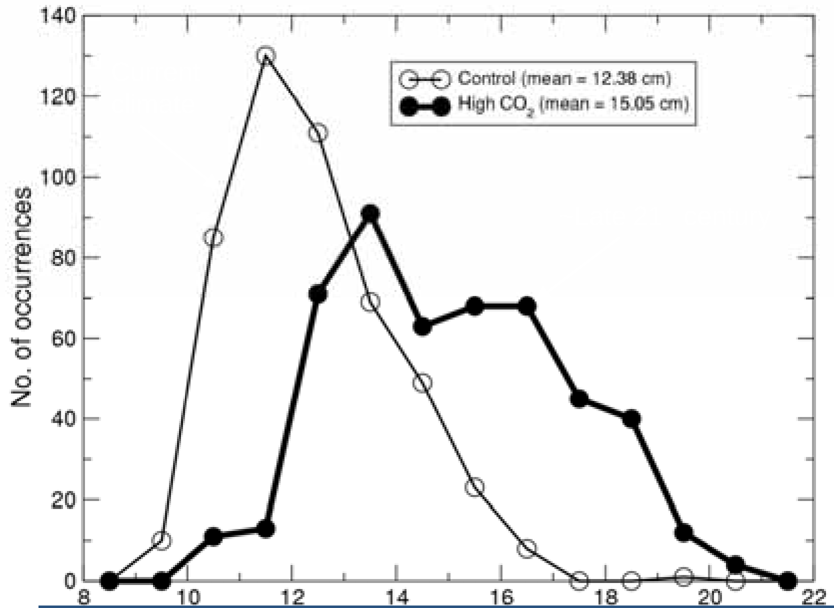


Hurricane models project increasing hurricane intensities and rainfall rates with climate warming... ...but probably not detectable at present.

Hurricane Intensity



Hurricane Rainfall Rates



6-hr accumulated rainfall [cm] within ~100 km of storm center.

Sensitivity: ~4% increase in wind speed per ^{o}C SST increase

Sensitivity: ~12% increase in near-storm rainfall per ^{o}C SST increase

Sources: Knutson and Tuleya, *J. Climate*, 2004 (left); Knutson and Tuleya (2008) Cambridge Univ Press (right).
See also Bengtsson et al. (*Tellus* 2007) and Oouchi et (*J. Meteor. Soc. Japan,* 2006); Walsh et al. (2004) Stowasser et al. (2007).

Storminess

- No evident changes
- Models suggest
  - decreased number of hurricanes and storms
  - Increased strength
- Model dependant results
- Attribution not easy

Other extremes

- Not enough data available!