Extreme sea levels: past and future

Svetlana Jevrejeva
National Oceanography Centre, Liverpool, UK

Outline

- Introduction
- Changes in extreme sea levels in the recent past (progress and limitation in understanding)
  - observations
  - modelling
- Future projections by 2100
- Extreme sea levels in warming climate
- Conclusion

Historical evidence of changes in extreme sea levels

Photos from Environmental Agency, UK

North Sea Storm Surge of 1953

- January 31 -1 February, 1953
- **Countries**: Netherlands, Belgium and UK
- **Water level** exceeded 5.6 metres in some locations
- **Fatalities:** 2,551 killed
- **Damages:** 9% of total Dutch farmland flooded, 30,000 animals drowned, and 47,300 buildings damaged

Sea Palling, Norfolk, UK (1 Feb 1953)

Oosterscheldekering and Rotterdam barriers (part of Delta works, The Netherlands)

Tropical cyclones

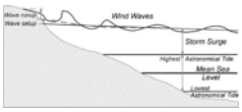
Bay of Bengal Major Surges

1737	**300,000 killed**
1864	**100,000**
1876	**100,000**
1897	**175,000**
1970	**300,000 (tide plus 6m surge)**
2008	**130,000 (Nargis,** $10 billion (USD))

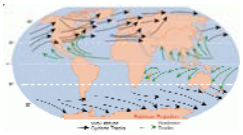
North Atlantic hurricane

Hurricane Katrina, 2005
Fatalities: 1,833
Damage: $108 billion (USD)

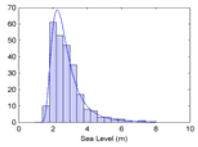
Understanding of coastal extremes



Extreme sea level



Mid-latitude and tropical cyclone tracks

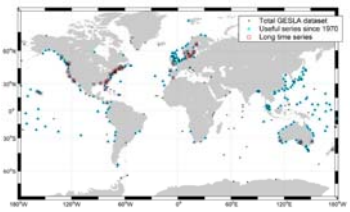


Probability density function for extreme sea levels

Extreme sea levels (Past)

- Do we experience more extremes sea levels in recent past?
- Are there any links between mean sea level rise and extreme sea levels?

Global extreme sea levels

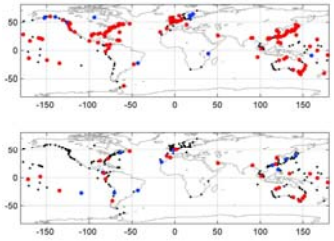


From Menéndez and Woodworth, 2010

Challenges with observational data sets:

- Lack of global representation
- Very limited data in Southern hemisphere
- Most sensitive areas - little data
- Data on extremes harder to find than mean sea level
- Homogeneity issue

Are there any trends in extreme sea levels?



Menéndez and Woodworth, 2010

Estimated trends in (top) annual 99th percentile of sea level, (bottom) 99th percentile reduced to medians. Only trends at a confidence level above 95% are shown in color: red for positive trends and blue for negative trends.

Are there any changes in frequency of extreme sea levels?

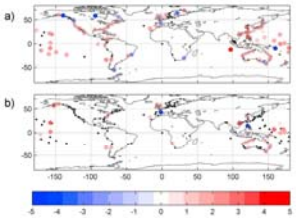
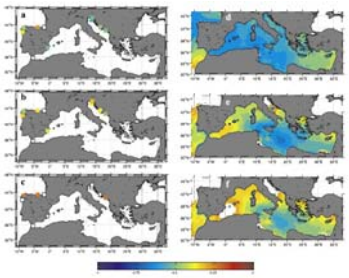


Figure Menéndez and Woodworth, 2010 .
Estimated changes in the frequency of extreme sea level events for the total elevation time series and (b) for the time series with the annual median removed. Changes are the annual percentage of increase/decrease in the occurrence of extreme events relative to the average occurrence rate. Black dots indicate trends with a level of significance below 5%.

Regional extreme sea levels



Marcos, Tsimplis, and Shaw, 2009

Correlations of winter NAO with (a, b, c) observed extremes and (d, e, f) hindcast data index for (top) the 50th percentile, (middle) the 99.9th percentile, and (bottom) the 99.9th percentile with the median subtracted. Only correlations statistically significant at the 5% confidence level are plotted.

Short summary about change in past extreme sea levels

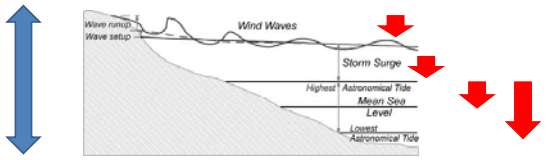
Questions were:

- Do we observe more extremes sea levels in recent past?
- Are there any links between mean sea level rise and extreme sea levels?

Sea level extremes by 2100

"Prediction is very difficult, especially if it's about the future" (Niels Bohr, Danish Nobel Prize-winning physicist, 1885-1962)

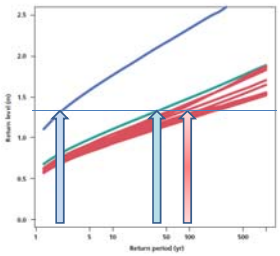
Modelling of extreme sea levels



Observations

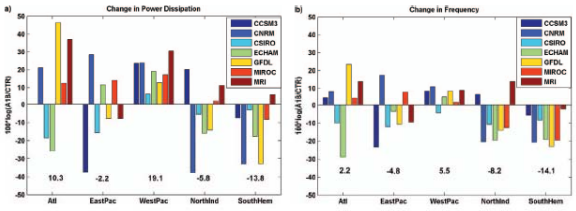
Modelling of components

Sea level rise and changes in return period



UK Climate Projections science report: Marine & coastal projections , 2009

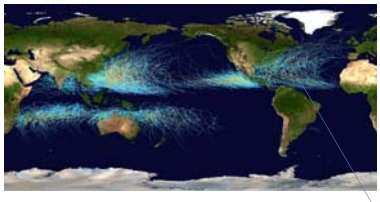
Projections using CMIP3 outputs



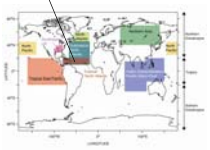
Emanuel et al, 2008

Are there any links between global warming and an increase of extreme sea levels?

Hurricanes



Main Development Region (MDR)



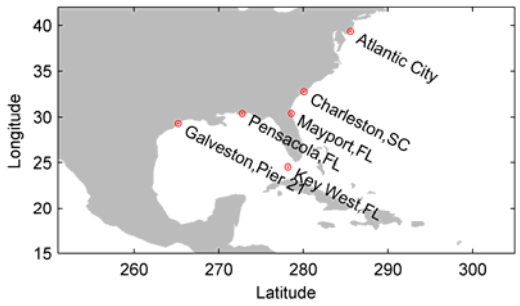
Saffir–Simpson Hurricane Scale

Category	Wind speeds
Five	≥157 mph, ≥252 km/h
Four	130–156 mph, 209–251 km/h
Three	111–129 mph, 178–208 km/h
Two	96–110 mph, 154–177 km/h
One	74–95 mph, 119–153 km/h
Additional classifications	
Tropical storm	39–73 mph, 63–118 km/h
Tropical depression	<38 mph, <62 km/h

Motivation

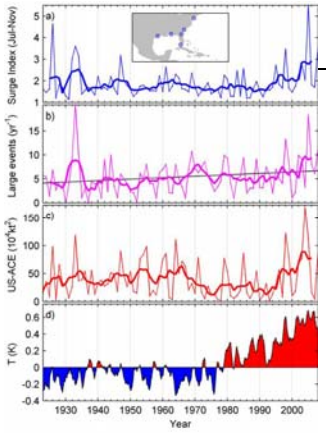
- Historical hurricane observations (e.g. PDI, ACE, number of tropical cyclones…..) give conflicting information on past trends in number and intensity of hurricanes
- Climate models suggest that warming will **reduce/increase** frequency of hurricances (Knutsen et al, 2008/Emanuel et al, 2008)
- There is no agreement between scientists about the link to the global/local temeprature (or SST, or SST in MDR)
- Storm surges are the most harmful aspect of hurricanes and the measure of storm surge intensity would therefore be a good candidate measure of hurricane activity

Data

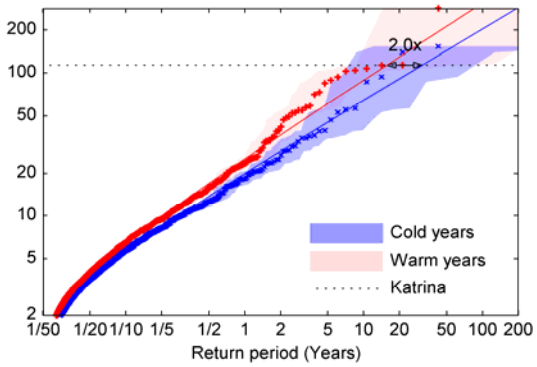


Grinsted et al, 2012

Storm surge index



Grinsted et al, 2012



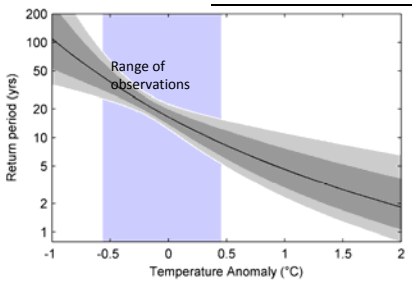
Grinsted et al, 2012

$$f_{m=(k,\mu,\sigma)}(x)=\begin{cases}\frac{1}{\sigma}\left(1+k\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{k}}e^{-\left(1+k\frac{x-\mu}{\sigma}\right)^{-\frac{1}{k}}} & \text{for } 1+\frac{k(x-\mu)}{\sigma}>0 \text{ and } k\neq 0\\ \frac{1}{\sigma}e^{\frac{\mu-x}{\sigma}-e^{\frac{\mu-x}{\sigma}}} & \text{for } k=0\\ 0 & \text{otherwise}\end{cases}$$

$$k=k_0(1+a_kT)$$
$$\sigma=e^{s_0(1+a_sT)}$$
$$\mu=\mu_0(1+a_\mu T)$$

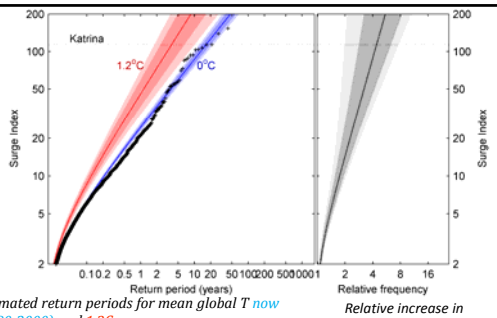
Non-stationary GEV fitting to surge time series

How does Katrina change in likelihood with T?



Relationship between return period and global average temperature for Katrina magnitude (and greater) events. Shading is 5-95% confidence interval

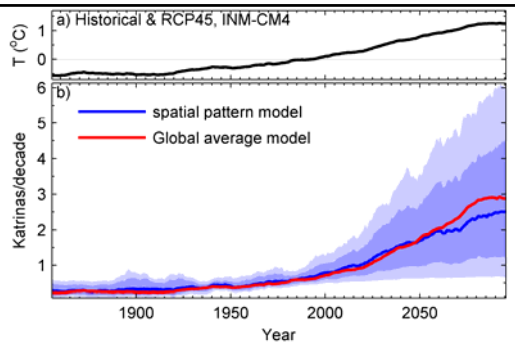
Grinsted et al, 2012



Estimated return periods for mean global T now (1980-2000) and 1.2C warmer

Relative increase in frequency associated with 1.2C warming

A warming of 1.2°C corresponds roughly the warming projected under the RCP4.5 scenario by 2100



Number of Katrina magnitude surge events per decade (b) for RCP45 projected changes in temperatures change. Confidence interval (5-16-84-95%).

Grinsted et al, 2013

Conclusion

- Extreme sea levels will change by 2100 due to sea level rise
- There is no agreement in increase/decrease in tropical cyclone activity and changes in mid-latitude cyclone tracks
- Some empirical models suggest a greatly increased hurricane activity (storm surges) in a warmer world, doubling of Katrina events during the 20th century
- Global warming ~1.2C results in 2-8 fold increase of Katrina magnitude events