Storm Surges and Sea-Level Rise: Statistical Analysis of Tide Gauge Data

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Motivation

- ❖ Sea level rise puts low-lying areas and coastal populations at risk of inundation, and could displace hundreds of millions of people worldwide.

- ❖ Historical tide gauge data shows that global mean sea level (GMSL) has been rising at 1.2±0.02 mm/year from 1900 to 1990 (IPCC, 2013)

- ❖ From 1993 to 2010, sea level has risen by 3.0±0.07 mm per year (IPCC, 2013). This rate is about twice as large as during the preceding 80 years.

Research Questions

1. What does time series analysis of historical tidal data tell us about future storm surges in Baltimore, Maryland?
2. What is the probability of extreme flooding events in Baltimore over the next 100 years?
3. If the risk of storm surge is increasing, how quickly can we detect it?

Background Information

Climate change has long been associated with rising sea levels caused by thermal expansion of the ocean, melting of glaciers, melting of ice sheets, and glacial isostatic rebound. Climate change is also expected to change the frequency and intensity of tropical cyclones.

- ➤ Climate change leads to more frequent large, high-intensity storms, producing larger storm surges, and thus more damage to coastal areas. Five factors affect the height of storm surges:
  - The pressure effect.
  - The direct wind effect.
  - The effect of the earth's rotation.
  - The effects of waves.
  - The rainfall effect.

- ➤ Burning fossil fuels like gasoline, methane, and propane releases heat-trapping carbon dioxide into the atmosphere. This results in an increase in the Earth's temperature and causes thermal expansion of the ocean.

- ➤ Global warming has also led to melting glaciers and shrinking ice sheets on Greenland and Antarctica, causing additional local sea level rise.
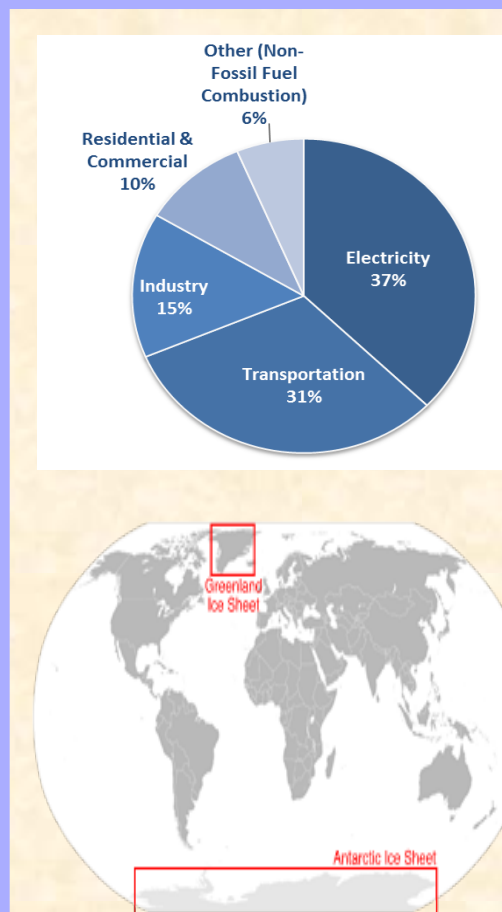
Method

We use extreme value analysis to estimate the frequency and magnitude of extreme storm surge events.

Using observed tide gauge data, we estimate the parameters of the Generalized Extreme Value (GEV) distribution. The GEV distribution combines the Gumbel, Frechet, and Weibull extreme value distributions, thus allowing for a range of possible shapes (Coles, 2001). The GEV has three parameters (location, μ; scale, σ; and shape, ξ) and is given by:

$$F(x; \mu, \sigma, \xi) = exp\left(-\left(1 + \xi\left[\frac{x-\mu}{\sigma}\right]\right)^{-1/\xi}\right)$$

For each tide gauge station data set, we estimate location (μ), scale (σ), and shape (ξ).

We simulate potential future storm surges by imposing known changes to the location and scale parameters. This provides future time-series that include specified changes in the 100-year storm surges.

Using these simulated futures, we estimate when we have sufficient data to detect the increases in extreme storm surge events.

Knowing the expected changes in extreme events, we then ask whether we can detect these changes in a single simulated time-series when compared to control simulations (with no changes in the parameters).
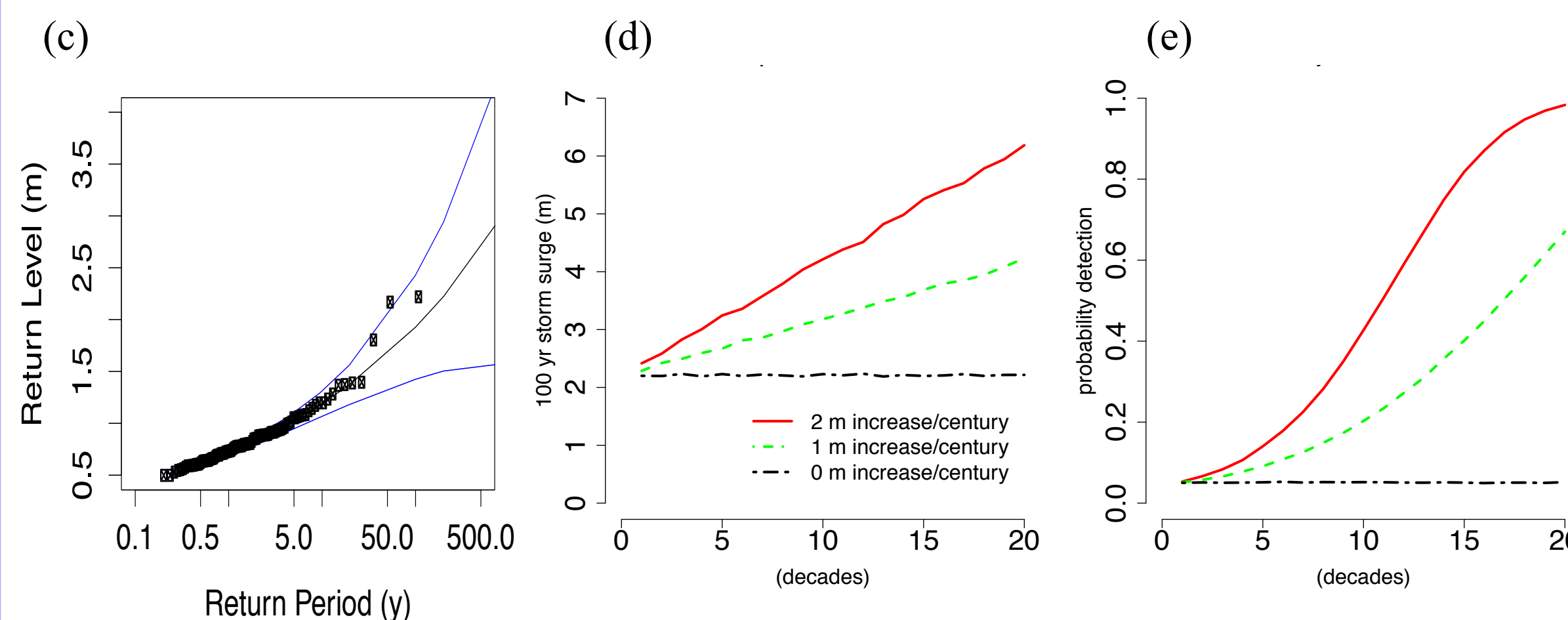
Data and Results for Baltimore, MD

Data:
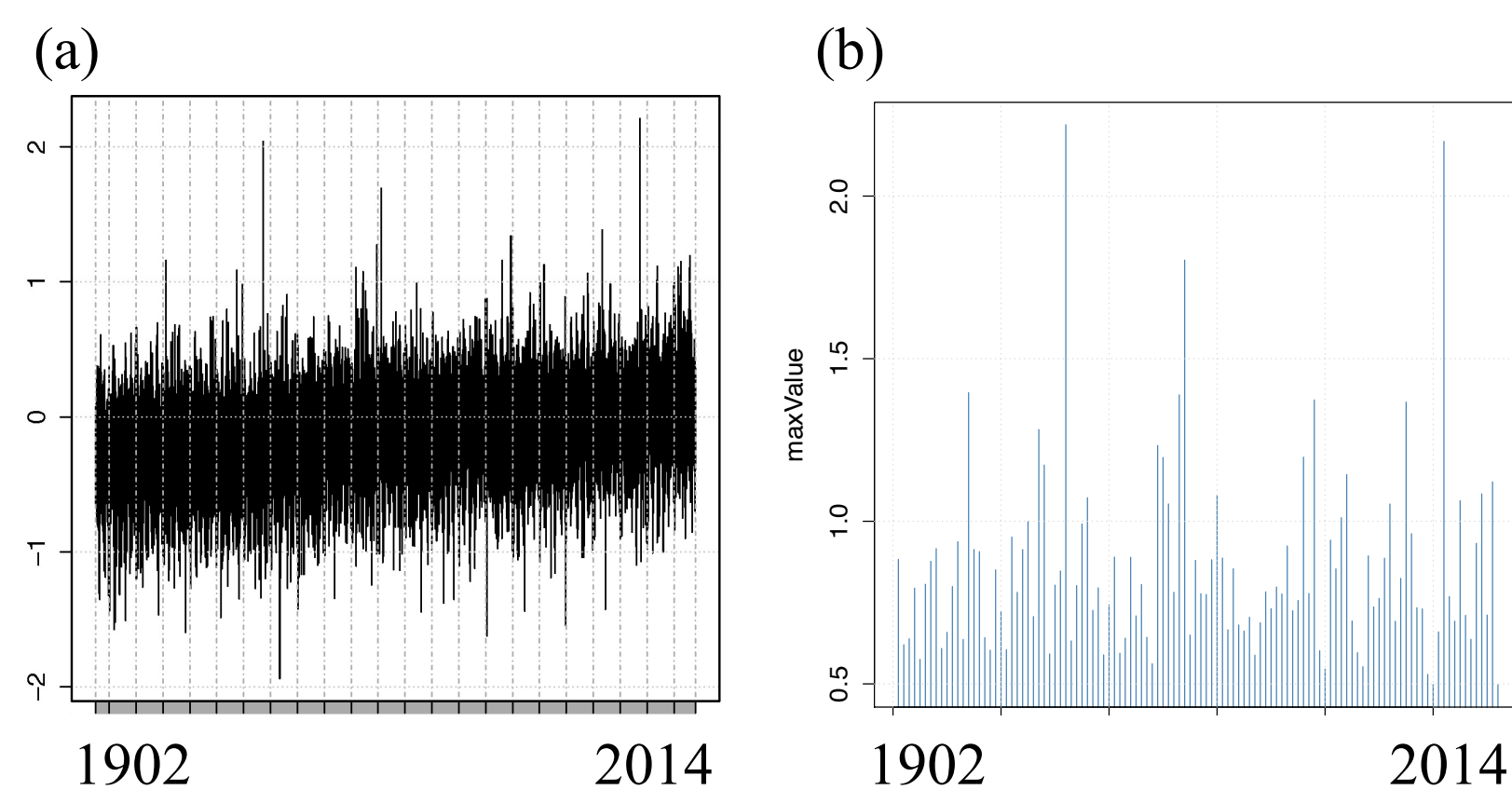
(a) Raw tide gauge data
(b) Annual block maxima
(c) Estimated Return Level
(d) Simulated increases in 100-year storm surges
(e) Probability of detecting the imposed increases in 100-year storm surges

Results:

The 100 Year Storm Surge

Tide Gauge City	location (μ)	scale (σ)	shape (ξ)	100-year surge
Baltimore, MD	0.72	0.16	0.20	1.9 m
Annapolis, MD	0.65	0.16	0.12	1.6 m
Atlantic City, NJ	0.86	0.19	-0.07	1.6 m
Washington, DC	0.88	0.28	0.33	4.0 m
Wilmington, DE	0.60	0.17	-0.16	1.2 m
Charleston, NC	0.65	0.14	0.27	1.9 m
New London, CT	0.80	0.20	0.13	2.0 m
Newport, RI	0.70	0.17	0.15	1.9 m

Conclusions

Scientific Findings

- ➤ The estimate of the 100-year storm surge event has significant uncertainty when given our limited historical data.

- ➤ Reliable detection of changes to the 100-year storm surge events takes at least several decades of new observations.

Related Facts

- Coastal cities most at risk are also cities that power the global economy, like New York, Miami, Shanghai, and Mumbai.

- Sea level will continue to rise, but the extent to which it does will depend largely on the emission choices we make today.

Personal learning experiences

Team work, collaboration, social networking skills, R, extreme value analysis, Linux/Unix skills, poster presentations.

Acknowledgments

References

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