Sea Level Rise Impacts on Storm Surges Along the US Coasts

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Modelling sea level rise impacts on storm surges along US coasts

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Using gauge measurements from a set of locations along the lower-US coasts and projections of global sea level rise

– we estimate the magnitude of extreme storm surges through a GPD analysis;
– we estimate local sea level rise out to 2050;
– we combine the two to assess changes in the frequency of extreme sea levels from storm surges due to changes in mean sea level.
Outline

- Extreme value statistics of storm surges along the Atlantic, Gulf and the Pacific Coast
- Future sea level rise by “downscaling” from the semi-empirical model proposed by Vermeer and Rahmstorf (PNAS 2009)
- Combining the two under the assumptions of independence and no change in variability to estimate changes in frequency of rare events.
Data
(local trends and extreme analysis)

55 gauges with almost complete hourly data over the 30 year period 1979-2008 and monthly data over the 50 year period 1959-2008.

Hourly data is used for extreme value analysis.

Monthly data is used to compute long term trend in order to detrend the time series before analyzing maximum values and use observed trend to “resize” global SLR trends (historic and future)
Extreme Value Analysis

• We compute **daily maxima of hourly observed levels after detrending** by a linear fit (using the 50 years of monthly data).

• We use the entire year rather than separating seasons.

• We perform a “**peak-over-threshold**” analysis choosing the **98th percentile** (always higher than the expected high tide) of the observed value distribution as the threshold, fitting a GPD to the exceedances after declustering* to avoid double counting a single storm.

* This turns out to be in almost all cases redundant since the spell length of these exceedances rarely exceeds a handful of hours, so the daily maxima are rarely over consecutive days because of a single storm straddling multiple days.
Results from GPD analysis

50-year Return Levels (meters)

Values are referenced to Mean High Water (a measure of high tide at the gauge)
Results from GPD analysis

100-year Return Levels (meters)

Values are referenced to Mean High Water (a measure of high tide at the gauge)
Now for the Sea Level Rise Component

- Vermeer & Rahmstorf (2009) propose a semi-empirical model estimating the relationship between
  - global average temperature change, $T - T_0$
  - the fast (yearly) component of temperature change, $dT/dt$
  - and the yearly rate of global sea level rise, $dH/dt$ as in

$$\frac{dH}{dt} = a(T - T_0) + b \frac{dT}{dt}$$
In the VR09 equation $a,b$ and $T_0$ are estimated from observations.

Then, a simple model (MAGICC) can be run to produce current and future global average temperature projections exploring uncertainties related to model structure (climate sensitivity), carbon cycle feedback strengths, emission scenarios.
Downscaling global average SLR rates to local rates

For each of the MAGICC trajectories of global average temperature we compute the (average) rate of sea level rise during the 1959-2008 period using the semi-empirical relationship, \( G^0 \)

During the same period we can compute the relative rate at gauge \( k \), \( H^0_k \).

We define the local component of SLR at gauge \( k \), \( L_k \), as the difference between the two:

\[
L_k = H^0_k - G^0
\]

In most cases \( L_k \) is the result of land movement due to isostatic adjustment (mostly rebound of the land masses after the retreat of the large ice sheets that used to extend over North America).

We apply this local component, unchanged, to the projected future rates of global SLR based on MAGICC simulations of global temperature over 2008-2050. I.e., for each MAGICC simulation, we derive a future global rate, \( G^1 \) and we modify it for location \( k \) as in

\[
H^1_k = G^1 + L_k
\]
Current trends and future SLR

Local SLR trends (1959-2008) (mm/year)

Local SLR (2008-2050) (meters)
What does this all mean for changing return periods/return levels?

Storm surges in TOKE POINT, WILLAPA BAY, WA

Today's 100-yr event becomes the 20-yr event by 2050
The big picture

How often will today’s 100-year event recur in 2050?
Caveats and Conclusions

• Broad brush analysis, no modeling of local effects besides what’s in the observed record.
• Relies on 50 year of data to determine the local component. Does not isolate sources.
• Relies on an extrapolation. Actually two (GPD and VR09)!
• Assumes no effect of mean sea level on surge intensity (more water available for the surge, less friction?), and no changes in storm intensity (stronger winds in the future? Changes in ENSO characteristics?).

• Mean sea level change is considered the most significant factor for near term changes in storm surge characteristics (IPCC AR4).
• A combination of absolute sea level change and current variability of extremes determines how “new” the future will be compared to the present.
• Even if not among the locations that might experience the faster rise in sea level, locations along the West coast see the most significant changes in return periods/return levels due to the relative low variability in extremes at present.
What does this have to do with CESM?

Use of other simulations of global average temperature under new scenarios or directly modeled Sea Level Rise, with its spatial patterns of differential change along the coasts, comparing simplified approach to more fully modeled future SLR scenarios.

(Remember Bill Lipscomb’s talk on Monday!)