Assessing the direct economic costs of sea level rise and storm tide damage in coastal communities using tide gauge data and depth-damage functions

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FEEM & CMCC
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Ca’ Foscari University of Venice
Ph.D. Science & management of climate change
Thesis structure

I. Incorporate tides into sea level rise damage estimates

   A methodology for assessing sea level rise inundation costs in coastal communities using local tide gauge data and depth-damage functions

II. Consider storm tides and damages in a probabilistic framework

   Assessing the costs of storm tide flooding in coastal communities

III. Add sea level rise

   Assessing the future costs of storm tide flooding with sea level rise in coastal communities
1 Introduction
2 Detailed model of coastal flooding damages
3 Tides in sea level rise damage and loss estimates
4 Storm tides in a probabilistic framework
5 Storm tide damages with sea level rise
6 Conclusions
1 Introduction

2 Detailed model of coastal flooding damages

3 Tides in sea level rise damage and loss estimates

4 Storm tides in a probabilistic framework

5 Storm tide damages with sea level rise

6 Conclusions
Local level coastal flooding damages

- People are affected by climate impacts at the local level, and it is appropriate to introduce solutions to target a large number of people (Jabeen et al 2010)

- Grounding climate change at the local level provides benefits of making associated risks and opportunities more relevant to the public and private agents responsible for designing and implementing responses (Hunt and Watkiss 2011)

Aim: quantify potential future impacts of sea level rise and storm flooding at the local level to inform planners and decision makers of economic risks and thereby facilitate management
Literature

• Early economic studies on SLR projected national or global scale costs (e.g. Yohe 1989, Darwin and Tol 2001)

• Studies by Yohe at al. (e.g. Yohe 1989; Gary Yohe, Neumann, and Ameden 1995) provide a conceptual basis for estimating social costs

• More recent shift in the literature on SLR towards the local and regional economic impacts (e.g. Michael 2007; Neumann et al. 2010; Hallegatte et al. 2011; Lichter and Felsenstein 2012)

Research gap

• There is a need to assess the economic impacts and climate change response policy at the local scale (Hallegatte et al. 2010), and specifically to refine the method of estimating the increasing costs of coastal flooding (Michael 2007)
  - Bespoke tools have been developed to deal with particular micro situations, and aggregate, analytic frameworks have been created to deal with macro scale issues, but there is a vacuum of applicable approaches grounded in readily available platforms that can provide local level information for communities coping with climate change (Lichter and Felsenstein 2012)

• Little consideration has been given to the choice of water level used in assessments of SLR damages and losses
Presentation outline

1. Introduction
2. Detailed model of coastal flooding damages
3. Tides in sea level rise damage and loss estimates
4. Storm tides in a probabilistic framework
5. Storm tide damages with sea level rise
6. Conclusions
Costs of coastal flooding

**Direct economic damages** — occur due to the physical contact of property, people, or any other objects with flood water, while indirect damages are induced by the direct damages but occur outside, temporally or spatially, of the flood event

- Direct flood damages to land and structures
- Current stock of land and buildings
- Costs of inaction; adaptation is not considered

**Flood damage assessment** (Merz et al. 2010; de Moel and Aerts 2011):

1. Inundation depth
2. Land use
3. Value of elements at risk
4. Susceptibility of elements at risk to hydrologic conditions
Depth-damage functions

**Non residential**
- Generic depth-damage functions for use in USACE flood damage reduction studies (Kiefer & Willett 1996)

**Residential**
- Generic depth-damage data for use in USACE flood damage reduction studies
  - Basement (Dawson 2003)
  - No basement (Johnson 2000)
Data requirements

• **Elevation of land and structures** – DEM from CT DEEP, parcel and structure locations from the municipal GIS office

• **Water level** – NOAA tides and currents, tide gauge analysis

• **Value of land**

• **Value of structures**

• **Land use type**

• **Number of stories**

• **Basement**

• **Value of structure contents** – content-to-structure value ratio: 50% for residential, 100% for commercial, 150% for industrial, and 100% for public land use
Estimating damages and losses

**When is a property ‘lost’ to SLR?**

- Land elevation < water level
- Structure 1st floor height < water level and damages > 10% of structure value

**When is it damaged by storms?**

- Anytime floodwater contacts structures or contents of structures
- Land value is not lost to storms
Case study areas

Milford, Connecticut, USA

27.7 km coastline
52,000 population

Case study area #1

Bayview beach
1.5 km
sandy beach
predominantly residential

Case study area #2

Milford harbor
1.5 km long
Harbor
mixed land use
High resolution data

Digital elevation model:
Coastal Connecticut 3ft LiDAR data
  - CT DEEP, elevation data collected by FEMA in 2006
  - Vertical accuracy +/- 1 foot, horizontal accuracy +/- 3 feet
High resolution data

Spatial data:
Municipal GIS maps of properties and structures

Municipal property data:
- Value of land
- Value of structures
- Land use type
- Number of stories
- Basement
High resolution data

Results

- Sea level rise losses calculated using land (A), structure (B), and land and structure (C) elevation points.
- Using both land and structure elevation points takes advantage of the most detailed data and provides the most accurate loss estimates.

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<th>Datum &amp; year</th>
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</tbody>
</table>
1 Introduction

2 Detailed model of coastal flooding damages

3 Tides in sea level rise damage and loss estimates

4 Storm tides in a probabilistic framework

5 Storm tide damages with sea level rise

6 Conclusions
The role of tides

• Tidal variability

Conditions determining how much tides rise and fall:
1. Phase of the moon
2. Moon’s distance from earth in its elliptical orbit
3. Moon’s declination to the north or south
4. Other factors: geography and shape of a shoreline, underwater topography, the speeds of traveling ocean waves, local winds and weather patterns

• Tide gauge data
  o Data available for Bridgeport, CT:
    - Monthly mean (1964-present)
    - Daily (1996-present)
    - H/L tide (1996-present)
    - Hourly (1996-present)
Tides

- Monthly data
  - Sea level rise
  - Mean tidal levels
Tides

- High tide/low tide data
  - High tide water levels
  - Probability of high tide water levels
Tides with SLR

<table>
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<tr>
<th>Sea level rise scenario</th>
<th>Sea level rise rate 2006-2055 (cm/yr)</th>
<th>Sea level rise 2046-2065 (cm)</th>
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Including tides in flood damage estimates

Results

- Results highlight the difference between using MSL to assess damages as opposed to including the role of the tides.
- Damage depends on where a property is actually located, not on the definition of sea level, however some damages may not be captured when insufficient consideration is given to the choice of water level.

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Future SLR losses (with tides)

<table>
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<tr>
<th>Year</th>
<th>Bayview land loss</th>
<th>Bayview structure loss</th>
<th>Harbor land loss</th>
<th>Harbor structure loss</th>
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<td>5%</td>
<td>0%</td>
</tr>
<tr>
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<td>7%</td>
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<td>9%</td>
<td>2%</td>
<td>7%</td>
<td>0.001%</td>
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<td>2100</td>
<td>11%</td>
<td>4%</td>
<td>12%</td>
<td>0.092%</td>
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![Graph of Sea level rise losses](image)

![Graph of Bayview property value](image)

![Graph of Harbor property value](image)
Future SLR losses (with tides)

Harbor sea level rise losses

Bayview sea level rise losses
Presentation outline

1 Introduction
2 Detailed model of coastal flooding damages
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Storm tides

- Hurricanes & nor’easters
- Storm surge vs storm tide
- Importance of tidal level
- Probability of storm arriving at high, low, or mid tide
Storm tides

- High water events vs flood events
- Probability of occurring vs probability of causing damage
Storm tides

Results:

- Yearly probability of flood event and associated damages
- Return rate of damages
- Expected damages

![Graph showing probability of yearly storm tide damage and expected damages vs. water level in meters NAVD88.](image-url)

- Expected damages
- Return rate of damages
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Storm tides with SLR

- Sea level rise
  - Probability of highest daily water level with SLR
  - Yearly probability of a storm tide occurring and causing damage
  - Return rate of flood event
Storm tides with SLR

Results:

- Yearly probability of a flood event occurring and the potential damages
- Expected damages

[Graphs showing probability and damages for Bayview and Harbor]
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Conclusions

• Detailed model of coastal flooding damage
  o Incorporates tidal effects
  o Includes storms in probabilistic framework capturing distribution over time
  o Integrates effects of tides and storms
  o Includes sea level rise

• Amended flood damage assessment methodology to assess SLR losses, storm tide damages, and storm tide damages with sea level rise
  o Depth-damage functions
  o High resolution data
  o Tide gauge analysis
Thank you.

Questions or comments?

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