GPS and InSAR monitoring of coastal subsidence in Florida: Implications to coastal flooding hazard assessments

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Presentation content

• Florida vulnerability to Sea Level Rise (SLR)
• Case study of Miami Beach
• Cause for Sea Level Rise:
  Global, Regional and Local contributions
• Coastal subsidence
  – Field observations
  – GPS monitoring
  – InSAR data analysis
• Summary
• Acknowledgments
Vulnerability to Sea Level Rise

Population below 4 ft: 4.9M
Energy facilities below 4 ft: 287

[Map showing distribution of population and energy facilities below 4 ft.]
Florida’s Exposure

Florida’s population – 19.5 million people

>75% of FL’s population resides in the 35 coastal counties, which occupy only 57% of the land but contributed 79% of the state’s economy (> $584 billion)

**Less than 3 feet:**
- 300,000 homes
- $156 billion property value

**At 6 feet**
- Nearly 1 million homes
- >$400 billion in property value
Recurrence Flooding Miami Beach

Flooding types/causes
- Rain
- Storm surge
- Tide
  - “Sunny Sky flooding”
  - “Lunar Flooding”
Miami Beach - Flood frequency analysis

Data types

• Tide gauge (Virginia Key)
• Rain gauge (RG)
• Media reports
• Insurance claims
• Miami Beach documentation
Miami Beach flooding

Miami Beach Rain Events 1998 - 2013

Miami Beach Tide Events 1998 - 2013

Legend
Rain
SPURS Rain Station
NOAA Rain Station

Legend
Tide
SPURS Rain Station
NOAA Rain Station

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Miami Beach flooding frequency

Flooding frequency

• **Rain induced events**
  - 1998-2005 – Average of 1 event per year (9 events in 8 years)
  - 2006-2013 – Average of 2 events per year (15 events in 8 years)

• **Tide induced events**
  - 1998-2005 – Average of 0.2 events per year (2 events in 8 years)
  - 2006-2013 – Average of 2 events per year (16 events in 8 years)
Accelerating rates of SLR

Sea level rise, spatially uneven and temporally unsteady: Why the U.S. East Coast, the global tide gauge record, and the global altimeter data show different trends

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Period</th>
<th>A mean SLR (mm/y)</th>
<th>B SLR after 2000 (mm/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston, MA</td>
<td>42.35°N</td>
<td>71.05°W</td>
<td>1921-2012</td>
<td>2.77±0.23</td>
<td>9.36±0.6</td>
</tr>
<tr>
<td>New York, NY</td>
<td>40.70°N</td>
<td>74.01°W</td>
<td>1893-2012</td>
<td>3.00±0.15</td>
<td>7.91±0.6</td>
</tr>
<tr>
<td>Atlantic City, NJ</td>
<td>39.36°N</td>
<td>74.42°W</td>
<td>1911-2012</td>
<td>4.09±0.20</td>
<td>5.17±0.6</td>
</tr>
<tr>
<td>Lewes, DE</td>
<td>38.78°N</td>
<td>75.12°W</td>
<td>1947-2012</td>
<td>3.54±0.41</td>
<td>5.97±0.6</td>
</tr>
<tr>
<td>Norfolk, VA</td>
<td>36.95°N</td>
<td>76.33°W</td>
<td>1948-2012</td>
<td>4.66±0.41</td>
<td>5.22±0.6</td>
</tr>
<tr>
<td>Wilmington, NC</td>
<td>34.23°N</td>
<td>77.95°W</td>
<td>1935-2012</td>
<td>2.01±0.31</td>
<td>0.04±0.6</td>
</tr>
<tr>
<td>Charleston, SC</td>
<td>32.78°N</td>
<td>79.93°W</td>
<td>1935-2012</td>
<td>2.83±0.31</td>
<td>2.72±0.6</td>
</tr>
<tr>
<td>Ft. Pulaski, GA</td>
<td>32.03°N</td>
<td>80.90°W</td>
<td>1935-2012</td>
<td>3.00±0.31</td>
<td>4.67±0.6</td>
</tr>
<tr>
<td>Fernandina, FL</td>
<td>30.67°N</td>
<td>81.47°W</td>
<td>1939-2012</td>
<td>2.06±0.34</td>
<td>4.19±0.6</td>
</tr>
<tr>
<td>Key West, FL</td>
<td>24.56°N</td>
<td>81.81°W</td>
<td>1913-2012</td>
<td>2.27±0.21</td>
<td>6.26±0.6</td>
</tr>
</tbody>
</table>

Ezer (2013)
Sea Level Rise due to Ocean Dynamics

Atlantic Meridional Overturning Circulation (AMOC)

Freshwater increase in the Northern Atlantic due to Arctic ice melt weakens the AMOC circulation (Yin et al., 2012).

⇒ Further weakening of the Gulf Stream (GS)
⇒ High rates of SLR along the US Atlantic shores
Causes of Sea Level Rise: global, regional, local

[Source: modified after IPCC 2007 report]
Regional vertical land movements
Glacial Isostatic Adjustment (GIA)

Regional-scale uplift and subsidence due to viscous (time dependent) mantle flow in response to past ice melt.

Source: Canadian Geodetic Survey

Negligible effect in Florida

Sella et al. (2007)
Local vertical movements in Florida

Subsidence in Florida typically occurs at the local scale due to:

- soil oxidation
- sinkhole activity
- Peat collapse
- sediments compaction

Source: F. Skaler

Source: Ramesh Reddy

Source: FDOT
Sediment compaction

Yuill et al. (2009)
Coastal subsidence in southeast Florida

- Field observations
- Geodetic monitoring
  - GPS
  - InSAR
Matheson Hammock county park
Matheson Hammock county park
Haulover county park
FIU – Biscayne Bay Campus
Deering Estate – approved GPS site
GPS station design and construction

Construction by UNAVCO
PBO (Plate Boundary Observatory) design
Interferometric Synthetic Aperture Radar (InSAR)

Two or more data acquisition of the same area from nearby location (< 1000 m)

Changes in surface location result in detectable phase changes

Fringes – 1 cycle \((2\pi) = \frac{1}{2} \lambda\)
InSAR analysis of Miami Beach subsidence

ERS-1/2 data
- Total of 24 acquisitions

SBAS connection network
ERS-1/2 track 240
Land subsidence in Miami Beach
(1993-1999)

Fiaschi and Wdowinski (2019)
Local vertical land movements
Land subsidence in Miami Beach (1993-1999)

- Subsidence rate 2-3 mm/yr
- Mainly in the western side of the city over reclaimed wetlands

Fiaschi and Wdowinski (2019)
Reclaimed land in Miami Beach

Dec. 1st, 1927 (DigitalMiamiBeachArchives.com)  Dec. 13th, 2017 (Google Earth)

Yuill et al. (2009)
Future work

**GPS**
- Construct the 4 stations
- Monitor land movement over a period of at least 3 years

**InSAR**
- Use Sentinel-1 data
  - Systematic data acquisition began in September 2016
  - Expected results – better coverage and improved uncertainties (12 day repeat acquisition)
- Expand analysis to entire coast of Florida
Summary

• Florida is vulnerable to coastal flooding hazard, because of its low elevation and high population concentration along the coast.

• In the coastal subsidence project we evaluate the contribution of local land subsidence to coastal flooding hazard using cGPS and InSAR observations.

• Preliminary InSAR results reveal localized patches (< 0.2 km$^2$) of subsidence with rates of 2-3 mm/yr.

• In areas subjected to land subsidence, coastal flooding hazard is significantly higher compared to non-subsiding areas.
Acknowledgements

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