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

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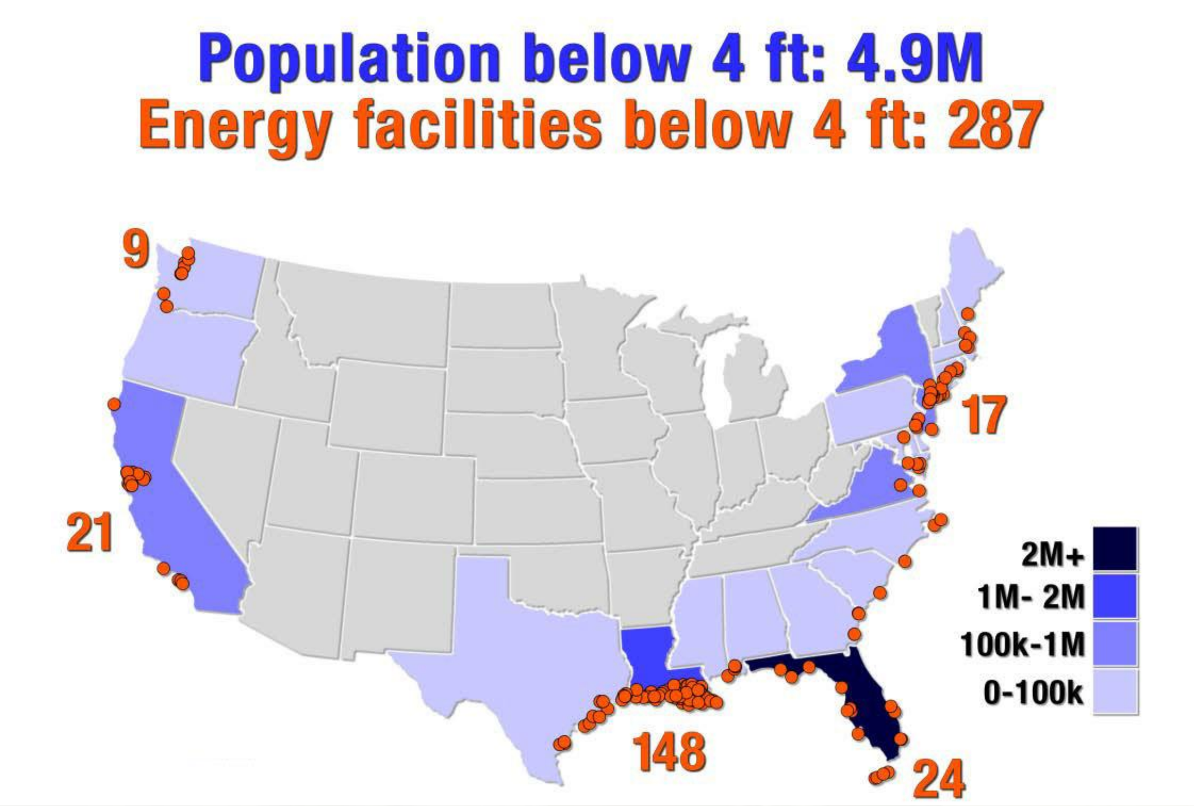
Presentation content

- 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



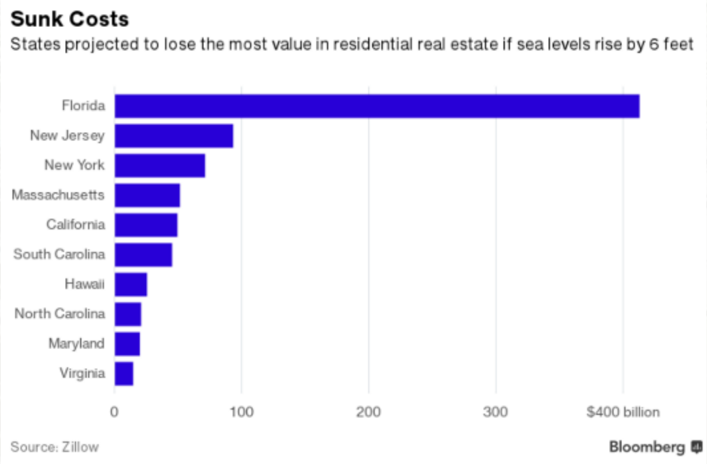
Florida’s Exposure

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

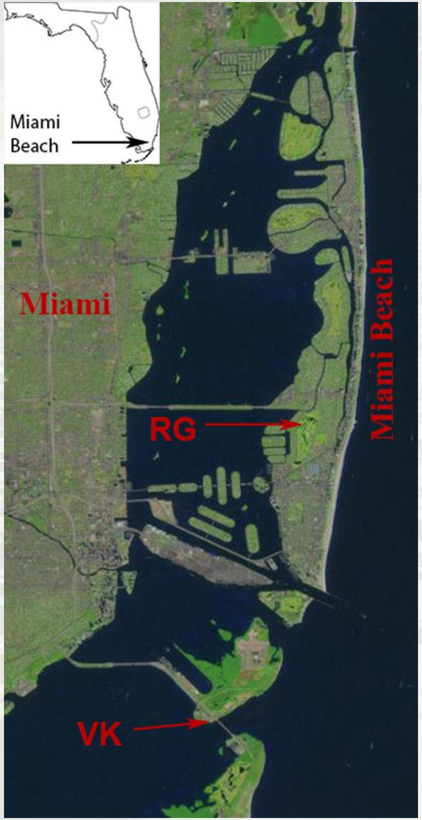
Flooding types/causes

- Rain
- Storm surge
- Tide
    - "Sunny Sky flooding"
    - "Lunar Flooding"

Miami Beach - Flood frequency analysis

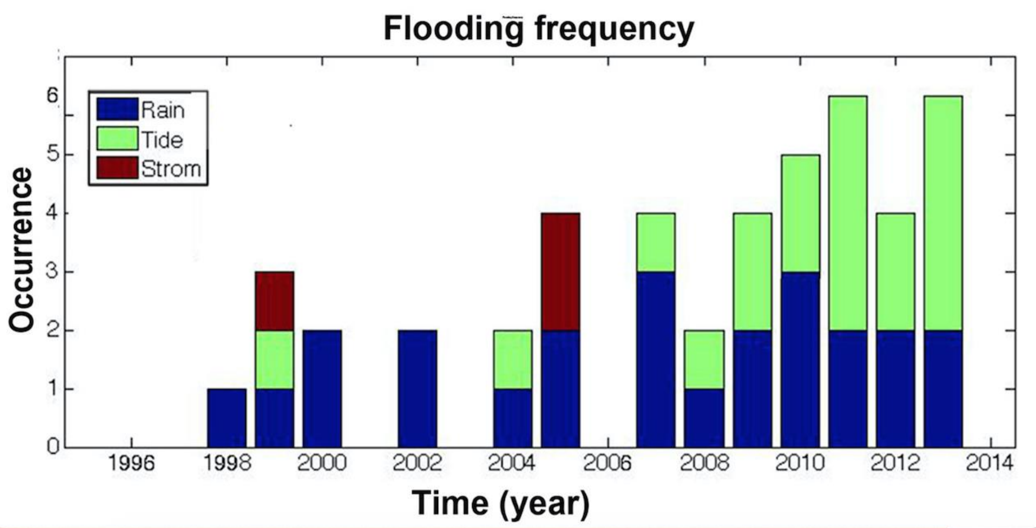
Data types

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



Miami Beach flooding

Miami Beach flooding frequency



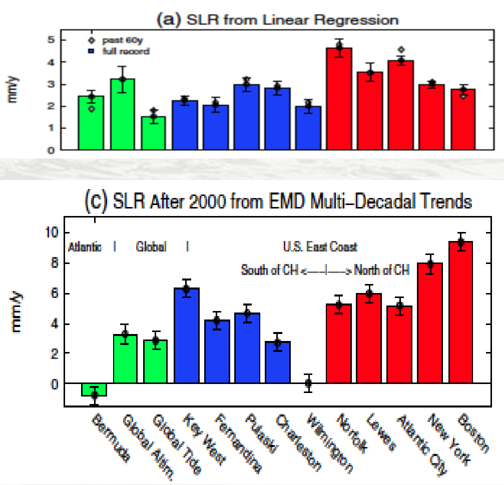
Flooding frequency

- **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

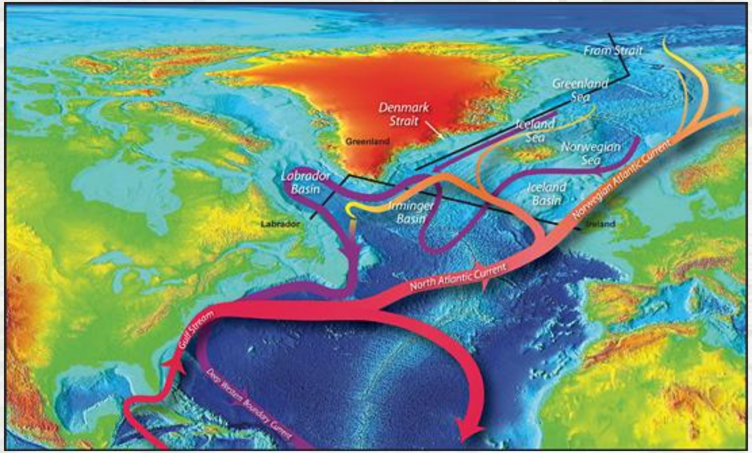
Sea level rise, spatially uneven and temporally unsteady: Why the U.S. East Coast, the global tide gauge record, and the global altimeter data show different trends

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

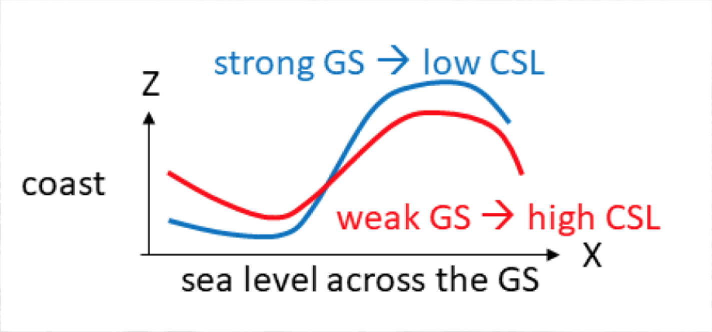


Ezer (2013)

Sea Level Rise due to Ocean Dynamics



Atlantic Meridional Overturning Circulation (AMOC)

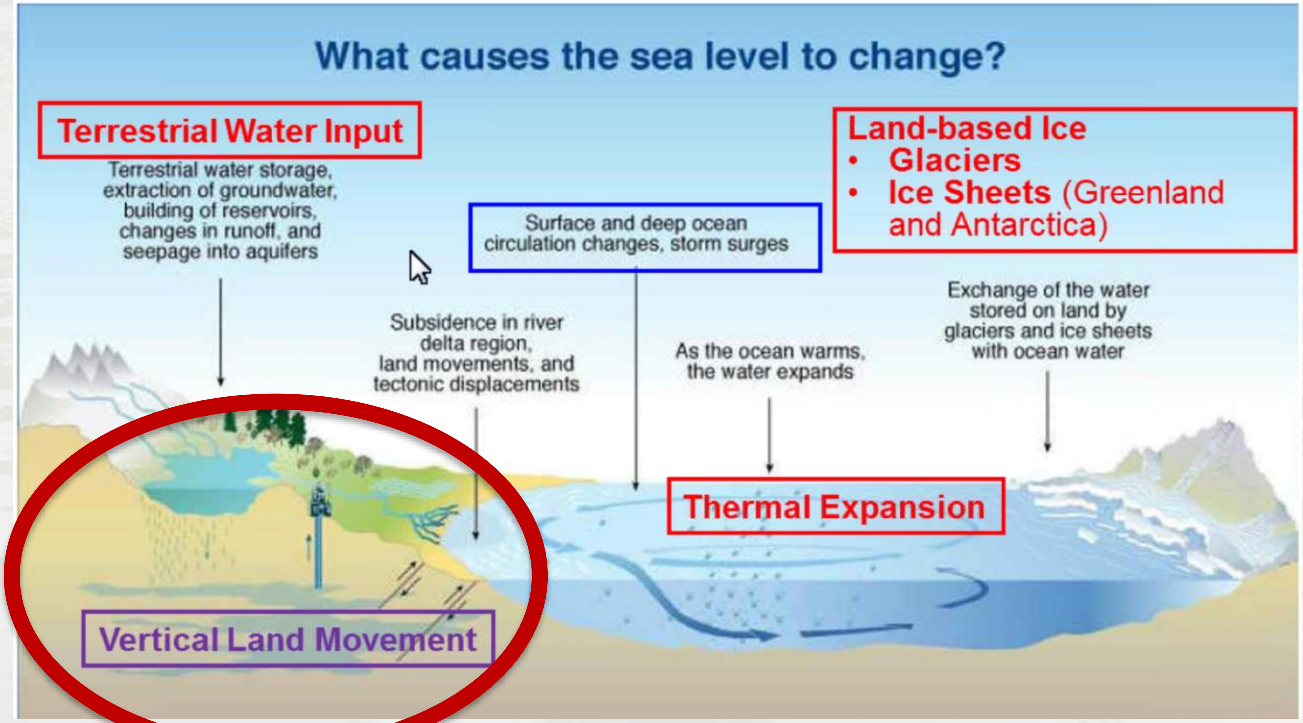


Freshwater increase in the Northern Atlantic due to Arctic ice melt weakens the AMOC circulation (Yin et al., 2012).

⇒ Further weakening of the Gulf Stream (GS)

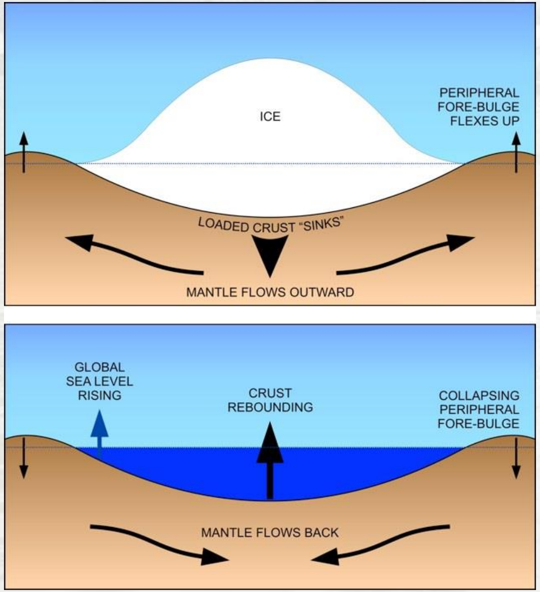
⇒ High rates of SLR along the US Atlantic shores

Causes of Sea Level Rise: global, regional, local



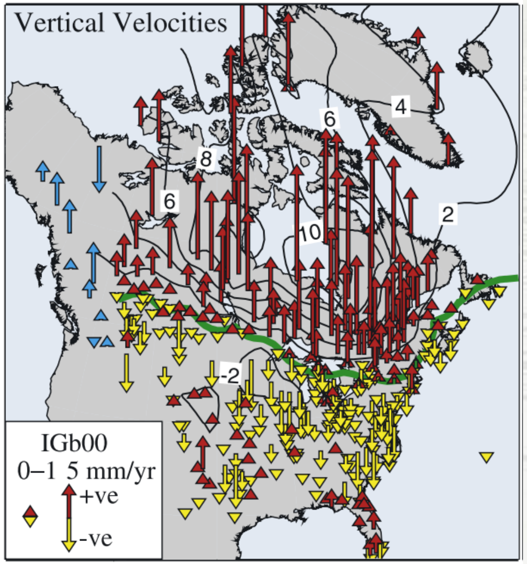
[Source: modified after IPPC 2007 report]

Regional vertical land movements
Glacial Isostatic Adjustment (GIA)



Source: Canadian Geodetic Survey

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



Sella et al. (2007)

Negligible effect in Florida

Local vertical movements in Florida

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

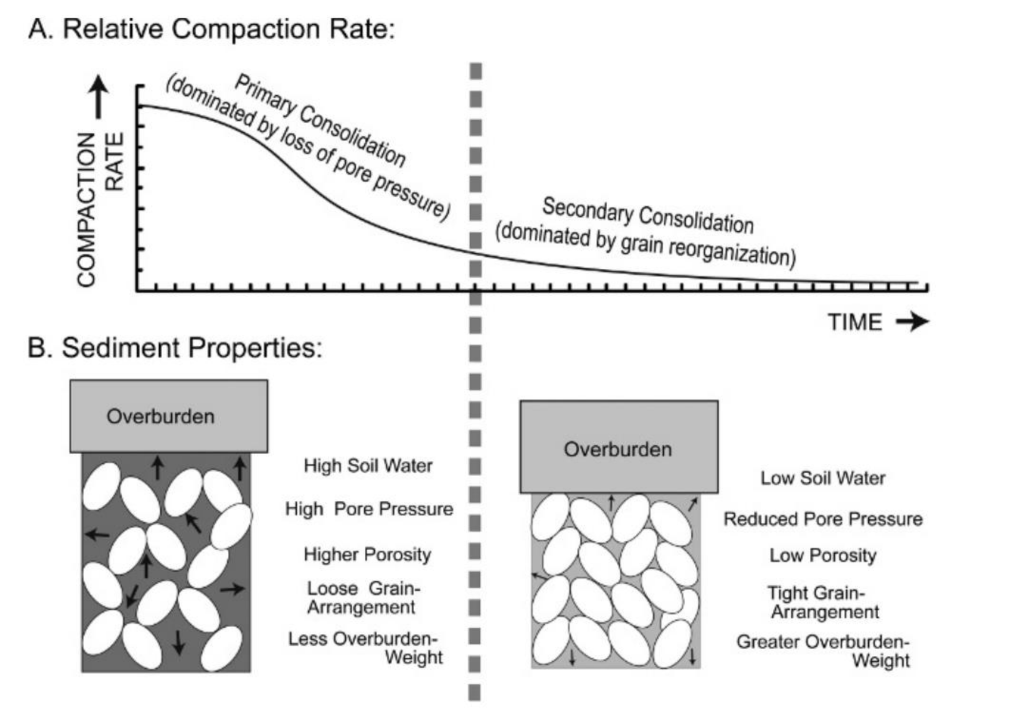
- soil oxidation
- sinkhole activity
- Peat collapse
- sediments compaction

Source: *Ramesh Reddy*

Source: FDOT

Source: F. Skaler

Sediment compaction

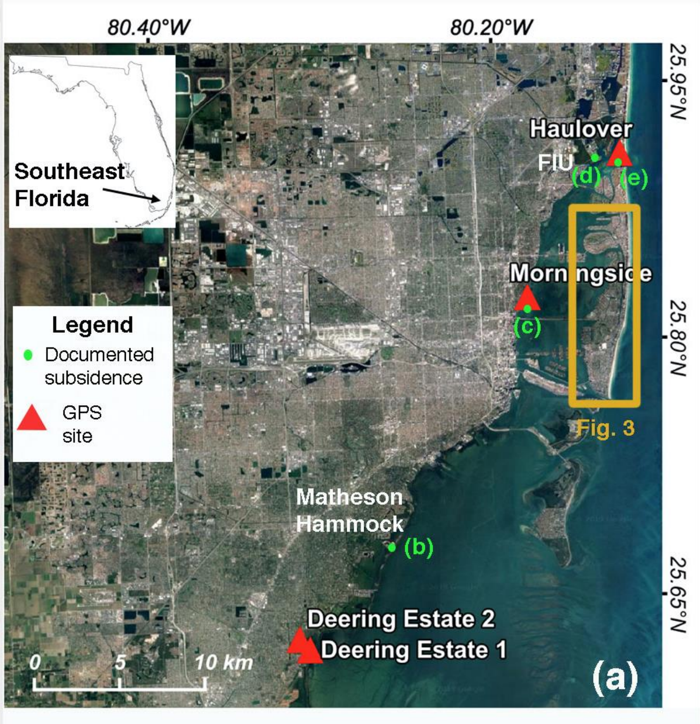


Yuill et al. (2009)

Coastal subsidence in southeast Florida

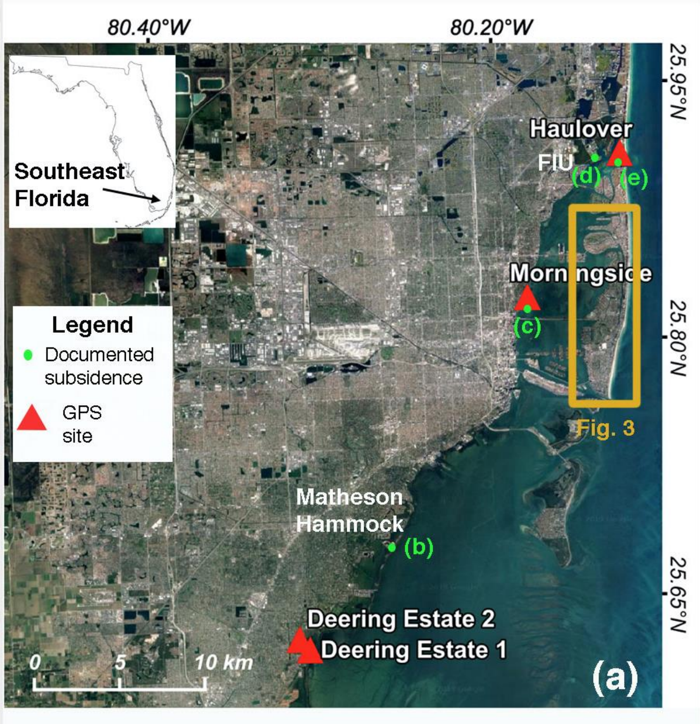
- Field observations
- Geodetic monitoring
  - GPS
  - InSAR

Matheson Hammock county park

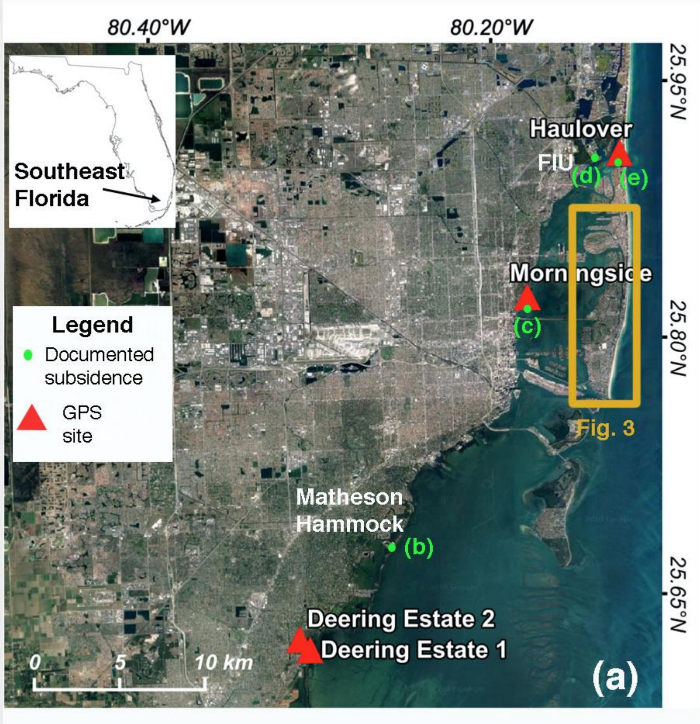


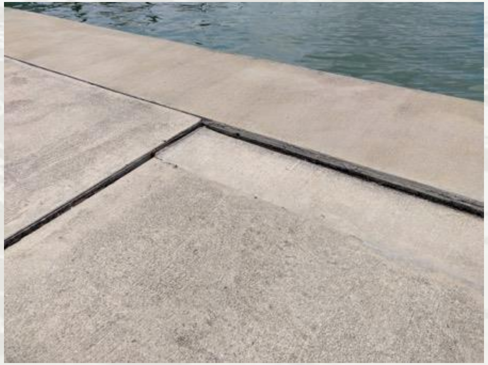
Matheson Hammock county park

Morningside city park

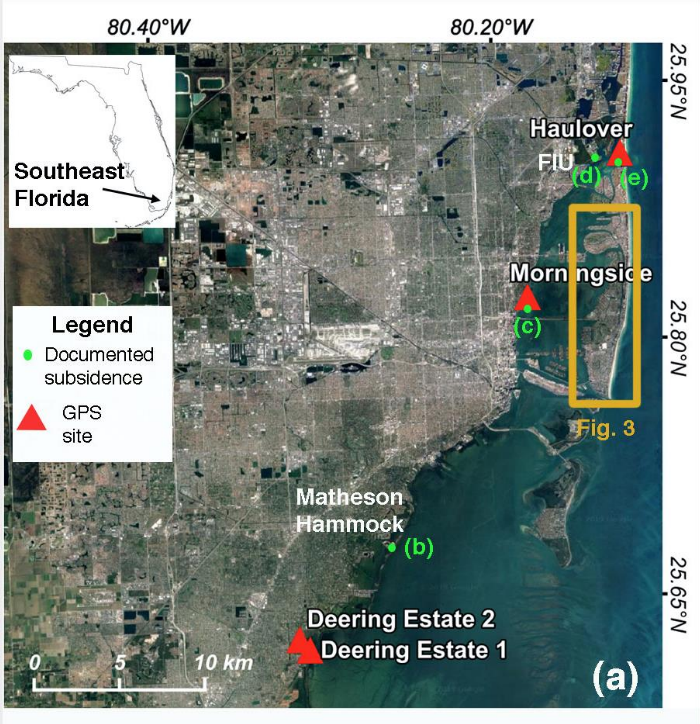


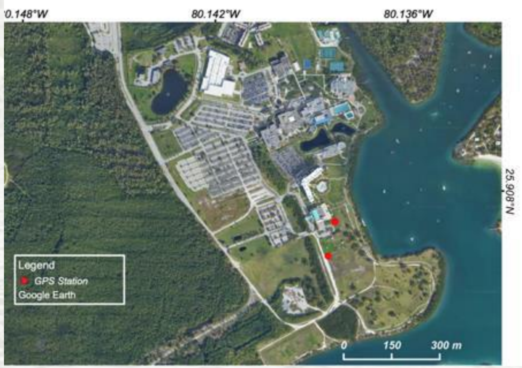
Haulover county park



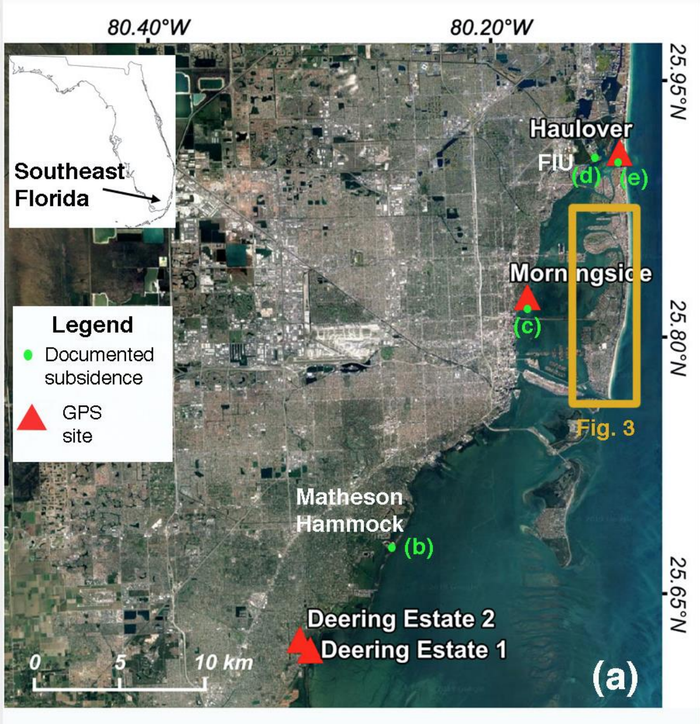


FIU – Biscayne Bay Campus





Deering Estate – approved GPS site

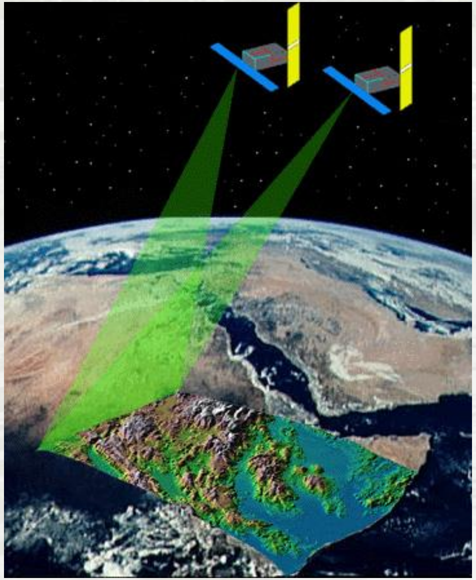


GPS station design and construction

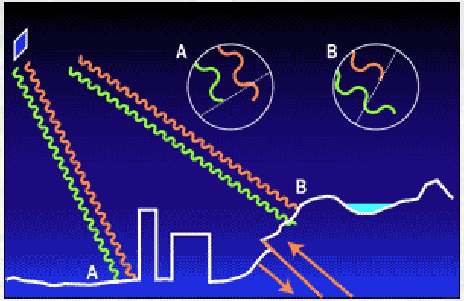
Construction by UNAVCO

PBO (Plate Boundary Observatory) design

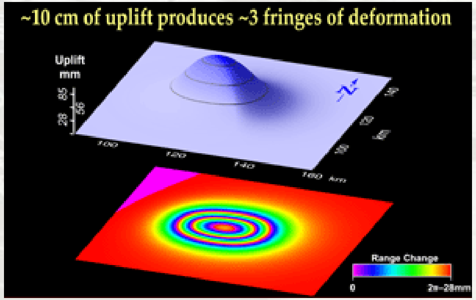
Interferometric Synthetic Aperture Radar (InSAR)



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



Changes in surface location result in detectable phase changes

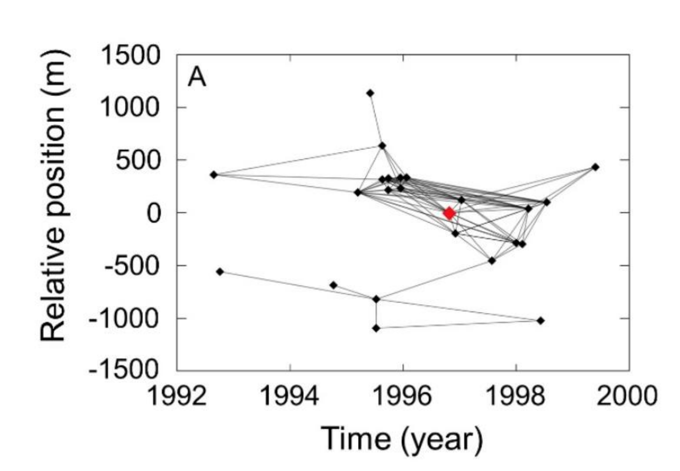


Fringes – 1 cycle (2π) = ½ λ

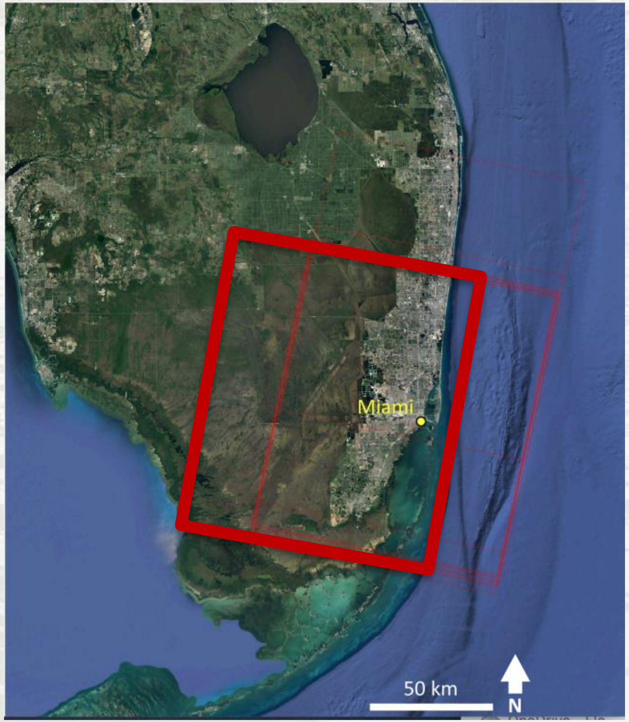
InSAR analysis of Miami Beach subsidence

ERS-1/2 data

- Total of 24 acquisitions
- Time span: 1993-1999



SBAS connection network

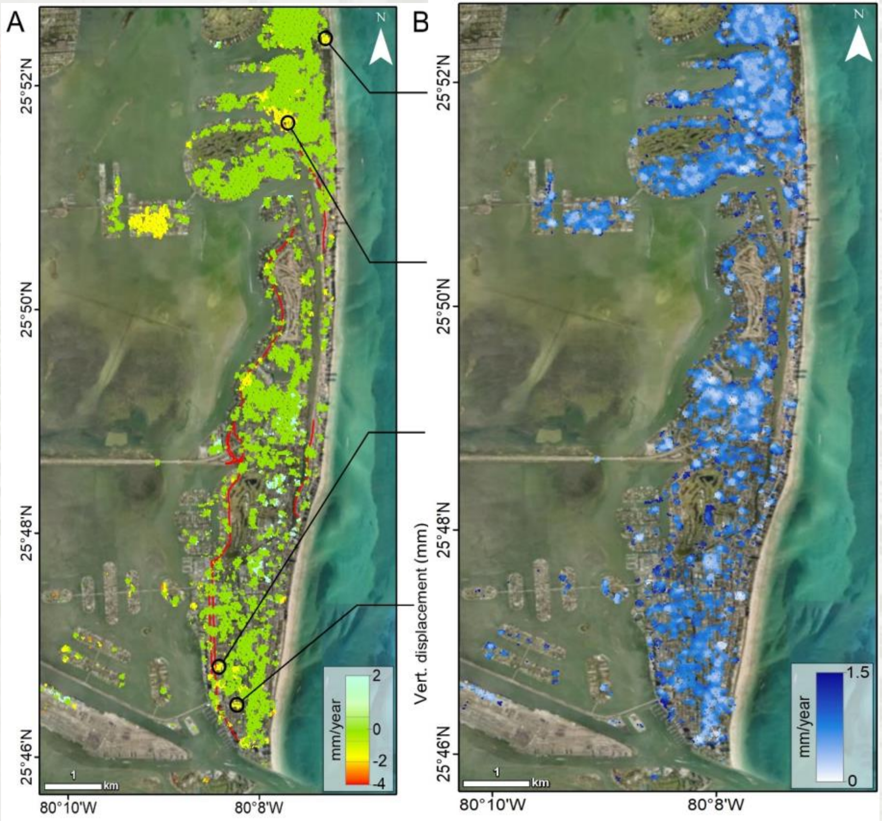


ERS-1/2 track 240

Land subsidence in Miami Beach

(1993-1999)

Velocities

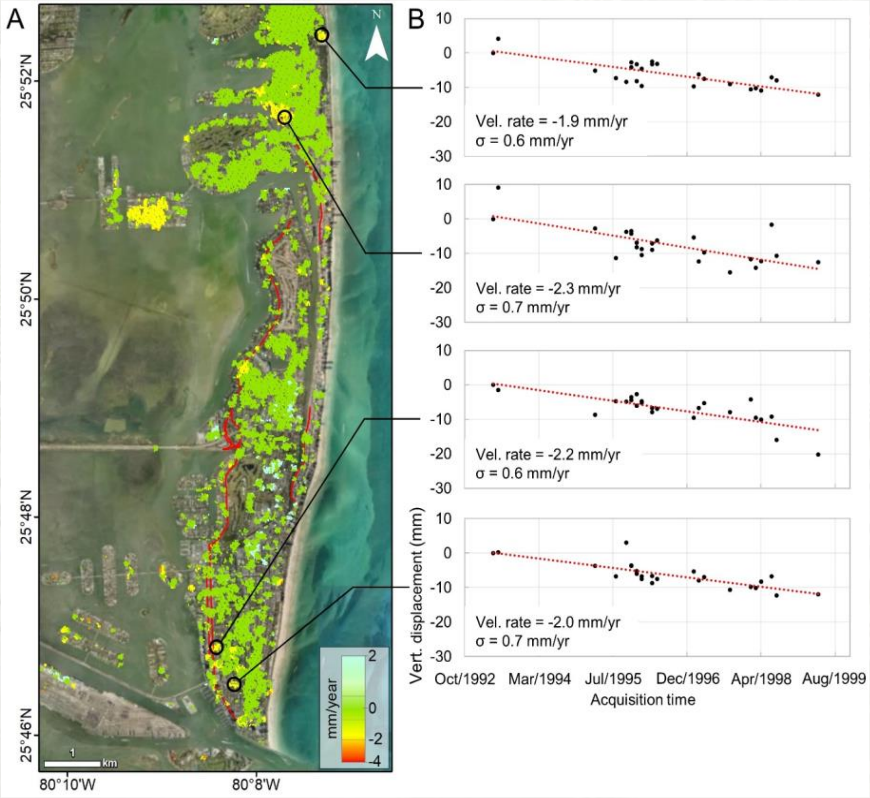


Uncertainties

Fiaschi and Wdowinski (2019)

Local vertical land movements

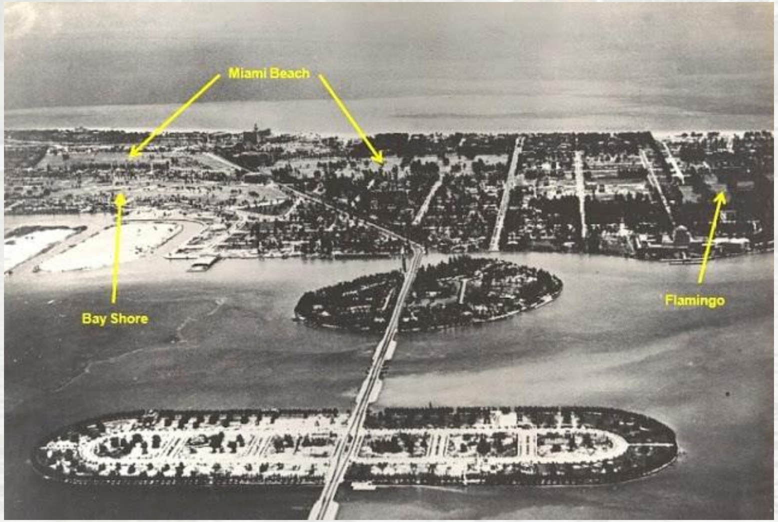
Land subsidence in Miami Beach (1993-1999)



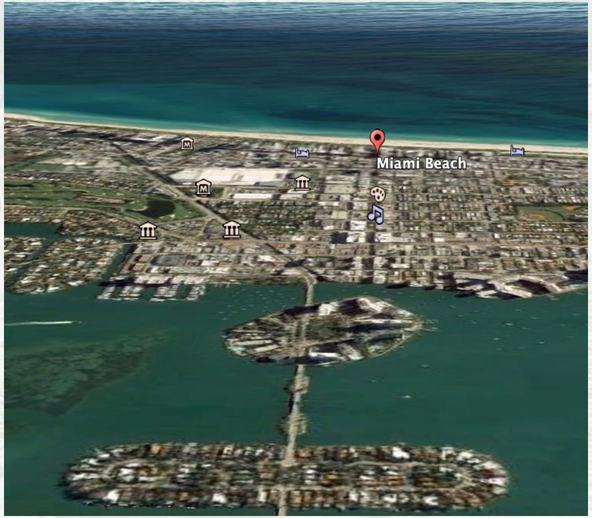
Fiaschi and Wdowinski (2019)

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

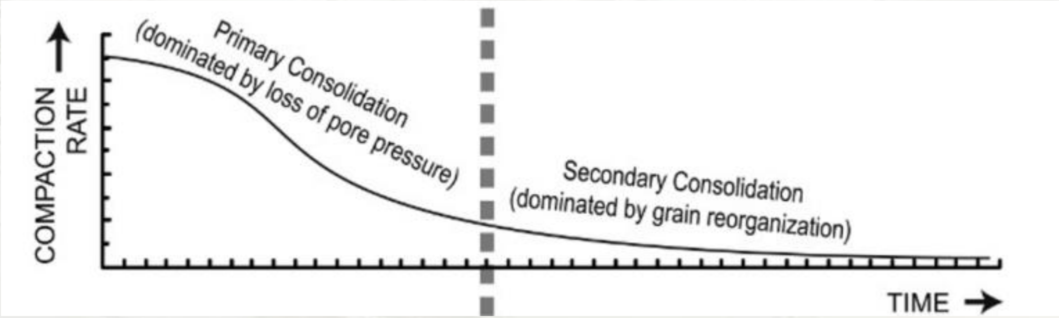
Reclaimed land in Miami Beach



Dec. 1st, 1927 *(DigitialMiamiBeachArchives.com)*



Dec. 13th, 2017 *(Google Earth)*



Yuill et al. (2009)

Future work

GPS

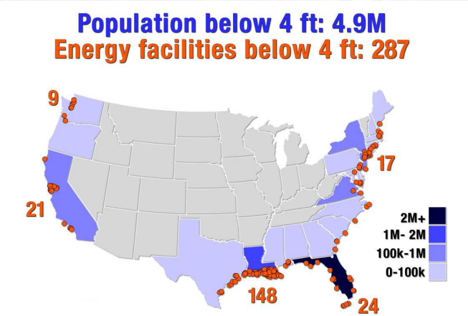
- Construct the 4 stations
- Monitor land movement over a period of at least 3 years

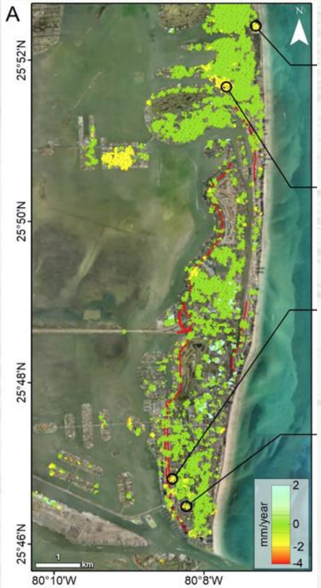
InSAR

- 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

- **Florida Office of Insurance Regulations** - support

- Talib Oliver (FIU) and John Galetzka (UNAVCO) - selecting locations for CGPS stations