Modeling Sea Level Rise Using Simulations and Observations

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Why sea level rise in Florida?

Sea level rise = increase in level of the world’s oceans

- Global mean sea level (GMSL) is rising 3 mm/yr (no GIA)
- Florida is sinking while the ocean is rising at a faster rate and poses a great threat of flooding
- By 2050-2060, sea level rise may increase up to 0.5 m in Florida

http://www.copenhagendiagnosis.com/
Why do we care?

- Reveals the extent to which local sea level relates to the regional (“adjacent”) basins (Atlantic Ocean and Gulf of Mexico) and global sea level.

- Indicates to what degree (if any) local or regional factors influence sea level (water temperature, salinity, wind, hydrology, currents, etc.).

- GMSL projections from climate models may underestimate mean sea level rise in coastal regions.

- Local infrastructure and planning (8,436 mi of coastline).

- Florida sea level climate studies are a decade old e.g., *(Mitchum, 2011)*.
Research Objectives

What is driving sea level in coastal Florida?

- Do large scale sea level estimates (regional and global levels) impact sea level in coastal Florida?
- Do various climate factors (water temperature, salinity, and El Niño Southern Oscillation) impact sea level in coastal Florida?
Data

Overall, the time period investigated was 1992-2019

- Global altimetry
- Regional altimetry (North Atlantic, Gulf of Mexico)
- Local (FL) altimetry
- Temperature and Salinity (at 5 m depth)
- ENSO 3.4 index

Averaged all datasets to a yearly resolution to remove seasonal signals

Scientists have detected an acceleration in sea level rise (skepticalscience.com)
Altimetry Data

- Collected from satellites (different satellites for different time periods)
- Global/regional = ~every 10 days
- Local = ~every 5 days
- Corrected for inverse barometer effects
- ****Not corrected for isostasy****

GMSL altimetry time series (1992-2021)

Cliff Mass Weather Blog: High Pressure Produces Low Sea Level

Inverse barometer effect
Local Altimetry

GMSL Altimetry

Regional (Basin) Altimetry

Measured in Sea Surface Height Anomaly

Local Altimetry
Sea Surface Height Anomaly (SSHA)

- How altimetry data is processed
  - A spatiotemporal mean map is computed using grids from all available years (1992-2019) and then is subtracted from individual grid values to estimate anomalies

Temperature & Salinity Data (1992-2019)

- Monthly-averaged ocean temperature (°C) and salinity (PSU) at 5 meters depth from Estimating the Circulation and Climate of the Ocean (ECCO)

- Based on the MIT general circulation model that has been fit to various satellite and sensor observations
ENSO 3.4 Data

- El Niño Southern Oscillation
- Index based on sea surface temperature anomalies over region shown
- Affects the atmospheric circulation
- Data from PMEL
What we’ve done

- Three scales: global, regional (basin), and local sea level
- Looked at trends and variability across these scales
- Compared local sea level with both basin and global rates
- Modeled SSHA data against climate indices
Our Goal: Modeling Sea Level in Florida
15 altimetry locations that correspond to tide gauge stations along coastal FL
Trend

Regional Slopes

Global Slope
How Can We Model Sea Level?

Linear/Multiple Regression

Global Average Sea Level Anomalies

ENSO 3.4 Index

Year

Regional Sea Level Anomalies

Water Salinity

Water Temp.
*Darker boxes = more relevant predictors/models*
Best Multiple Regression Model:

Local SSHA = \text{year} \cdot \text{regional SSHA} \, x_1 + \text{year} \cdot \text{GMSL} \, x_2 + \text{GMSL} \cdot \text{ENSO} \, x_3 + \text{regional SSHA} \cdot \text{ENSO} \, x_4 + \text{temperature} \cdot \text{salinity} \, x_5 + \text{intercept}

Lack of Homoscedasticity
(red line does not follow \( y = 0 \) line)

All interaction terms

Probably not linear
How Can We Model Sea Level?

Using a **Generalized Additive Model (GAM)**

- Nonparametric model fitted using cubic splines
- Response is modeled as the sum of the smoothed functions of the predictors which adds substantial flexibility to model sea level changes

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Best GAM:

- R² values across all 15 locations range from 0.7 to 0.95 (very good)
- Lowest average Akaike information criterion (AIC) values
Smoothed Predictor Functions

- Year
- Regional (Basin) SSHA (m)
- GMSL (m)
- ENSO
- Salinity (PSU)
- Temperature (°C)
These four panels depict criteria that assess whether the model assumptions are met.
Year as a Predictor?
Smoothed Predictor Functions (model without year)

- Regional (Basin) SSHA (m)
- GMSL (m)
- ENSO
- Salinity (PSU)
- Temperature (°C)
GAM Output

QQ-Plot

Residuals vs. linear predictor

Histogram of residuals

Response vs. Fitted Values
Year as a Predictor?

Examining a model without year...

AGEST model

Less ambiguity, but worse fit (lower $R^2$ values, higher AIC values)
Conclusions

- Regional (basin) and GMSL contribute to local sea level (similar behavior)

- Water temperature (5 m depth), water salinity (5 m depth), and ENSO 3.4 index are all relevant factors for local sea level in Florida

- Florida coastal sea levels are rising faster than GMSL

$$3 \text{ mm/yr} \quad \text{(global, no GIA)} \quad \text{vs.} \quad >4 \text{ mm/yr} \quad \text{(FL, no GIA)}$$
Future Work

Altimetry ➔ Tide Gauge (Ground Truth)

Year as predictor (proxy variable) ➔ More Factors?

- Average monthly winds
- Atmospheric pressures
- Coastal currents

(Prandi et. al)
Future Work

What happened in 2011 in Florida?


Questions?