Research Experiences
for Undergraduates
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Modeling Sea Level Rise in Florida

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Abstract

In order to attempt to model local sea level rise, we examine altimetry, temperature and salinity, ENSO 3.4, and tide gauge data to fit a model that explains sea level changes in coastal Florida. We analyzed rates and variances of sea surface height anomalies (SSHA) and compare regional and global measurements to local. We modeled sea level changes using both multiple regression and a generalized additive (GAM) approaches. The optimal/appropriate model is a GAM with year, global mean sea level (GMSL), regional SSHA, water temperature and salinity, and ENSO as predictors. Future work should be focused on extending the GAM by including other factors such as average monthly winds, atmospheric pressures, and coastal currents.

Introduction

In recent years, sea levels have been rising and will likely continue to accelerate in the near future[1]. While there currently exist models to predict global sea level changes, GMSL projections may underestimate sea level rise in coastal regions[2][3]. Here we will focus on sea level rise in the state of Florida using satellite altimetry data from 15 coastal locations in the state. Much of what has been published regarding sea level rise in Florida is over a decade old and limited primarily to tide gauges.[3].

Research Objective

What factors are driving sea level rise in coastal Florida? We want to test year, GMSL, regional (North Atlantic & Gulf of Mexico) SSHA, water temperature and salinity, and ENSO 3.4 to see which of these are relevant factors for sea level on the local scale.

Datasets

Altimetry: A gridded sea SSHA dataset was downloaded from NASA's PODAAC portal. The anomalies are referenced to a mean sea surface approximately every 5 days and are corrected for inverse barometer effects. The SSHA data, which span 1992-2019, are from a sequence of satellites including TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 (see Figure 1).

Temperature & Salinity: This dataset contains monthly-averaged ocean temperature and salinity at 5 meters depth from Estimating the Circulation and Climate of the Ocean (ECCO). It is based on the MIT general circulation model (MITgcm) that has been fit to various satellite and sensor observations (least-squares, see Figure 2).

ENSO 3.4: The index was pulled from NOAA's Climate Prediction Center and is calculated from monthly SST anomalies over 5N – 5S and 120 – 170W in the Pacific Ocean.

Tide Gauge: Monthly mean sea level data were retrieved from NOAA's Tides and Currents portal. Seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents were removed.

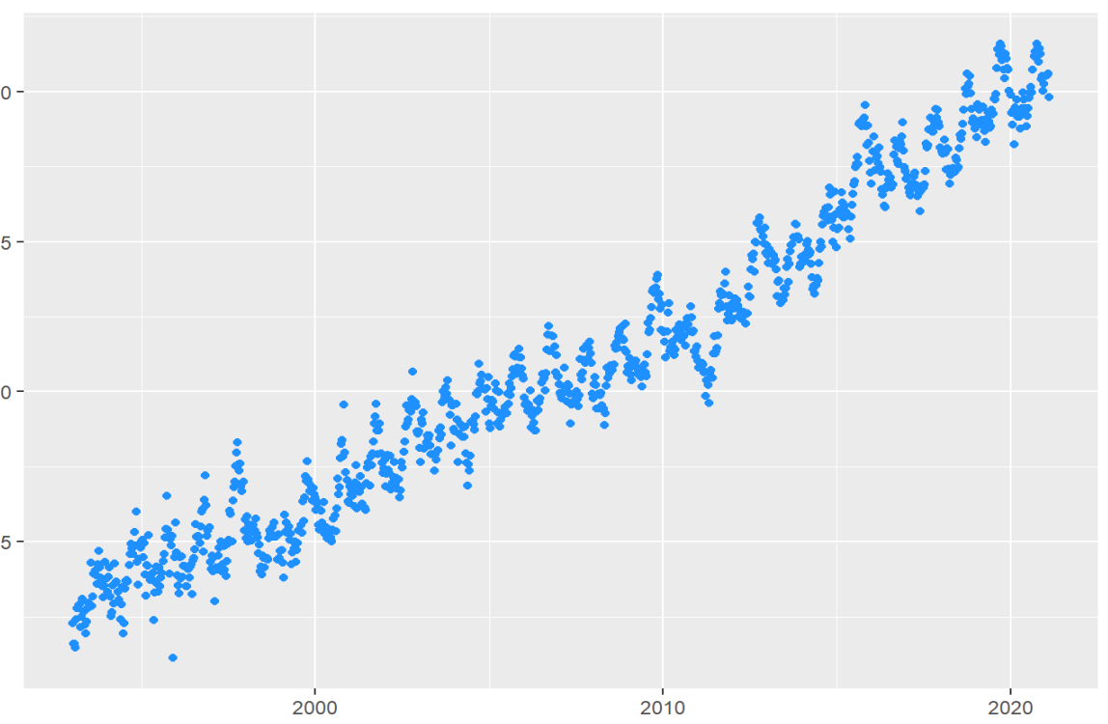

Fig. 1. SSHA (mm) time series generated from altimetry data.

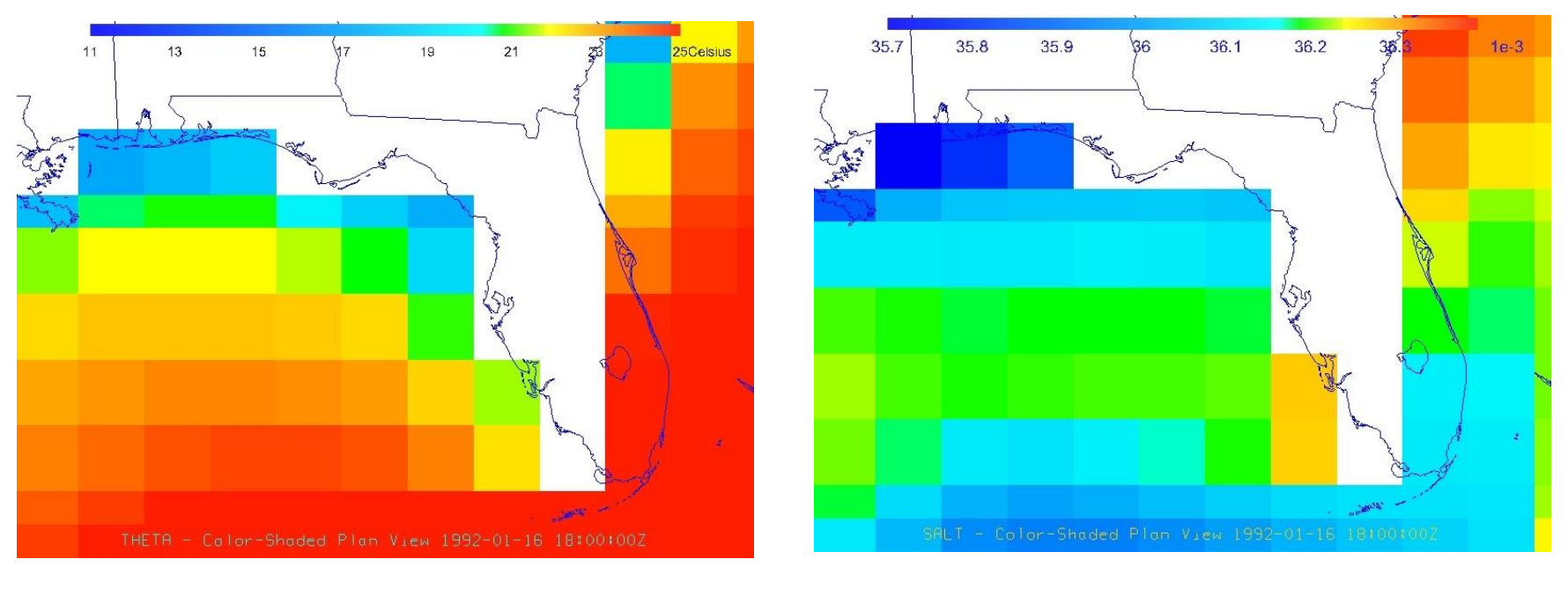

Fig. 2. ECCO model water temperature (left, °C) and salinity data (right, PSU) at 5 m depth from January 1992.

Methods

We performed analysis of our altimetry data by examining the rate (see Figure 3) and variance (see Figure 4) of sea level change at the global, regional (North Atlantic Ocean and Gulf of Mexico, Figure 6) and local scale (i.e., at 15 coastal Florida locations that coincide with tide gauge stations, Figure 5).

We first used a multiple regression to model the sea level changes. We considered 6 potential predictors (year, GMSL, regional SSHA, water temperature, water salinity, and ENSO) and all combinations of interaction terms between these predictors[5]. We used BIC to determine the most relevant terms for this model.

A generalized additive model (GAM) was also developed to model sea level changes. In GAM, the response is modeled as the sum of the smoothed functions of the predictors which adds substantial flexibility to model sea level changes[6]. Given the 6 potential predictors, there are 57 possible GAM combinations. We ran all 57 model permutations at each of the 15 locations and averaged both the R-squared and AIC values for each model to identify the optimal model for all locations.

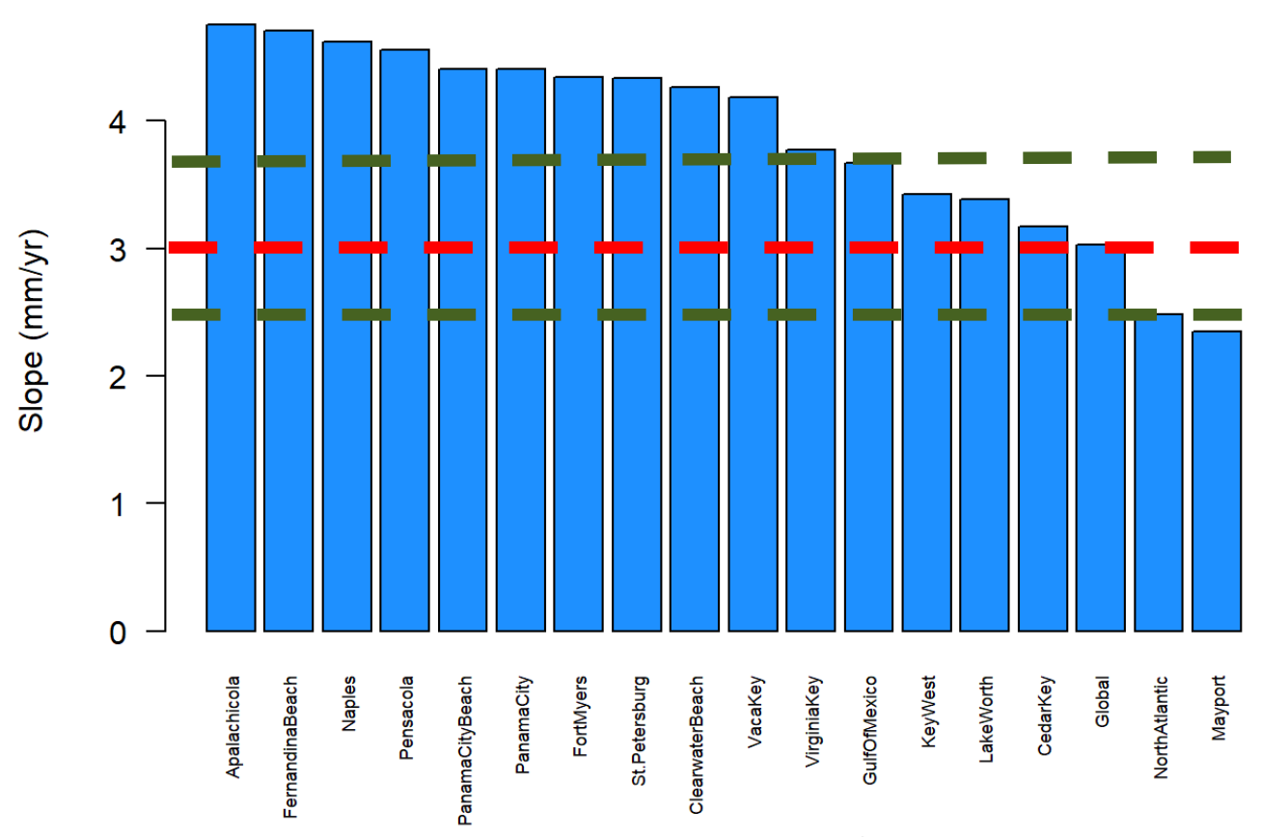

Fig. 3. SSHA slopes (mm/yr) for the 15 Florida locations versus GMSL (red dashed line) and regional SSHA (green dashed lines).

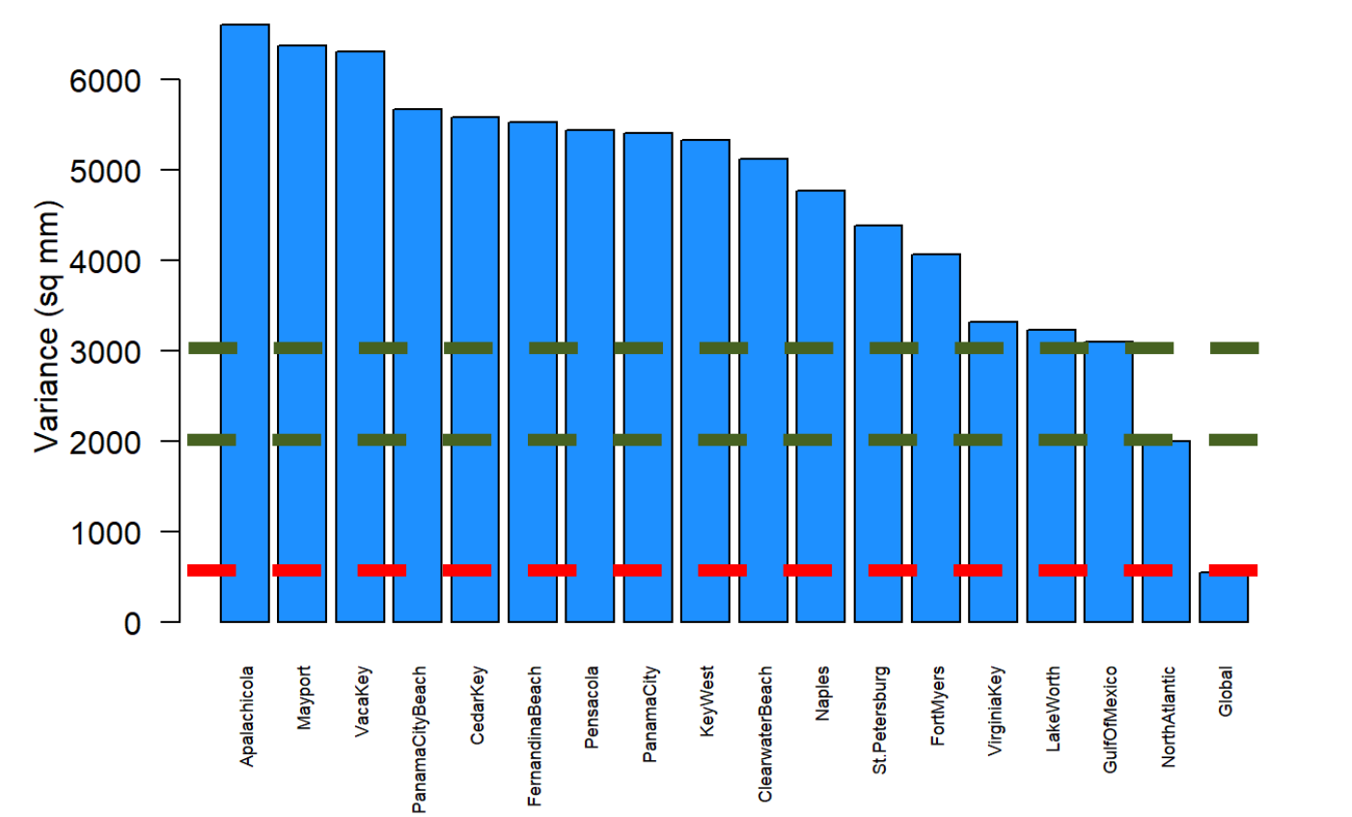

Fig. 4. The SSHA variances (mm^2) of the 15 Florida locations versus global (red dashed line) and regional (green dashed lines).

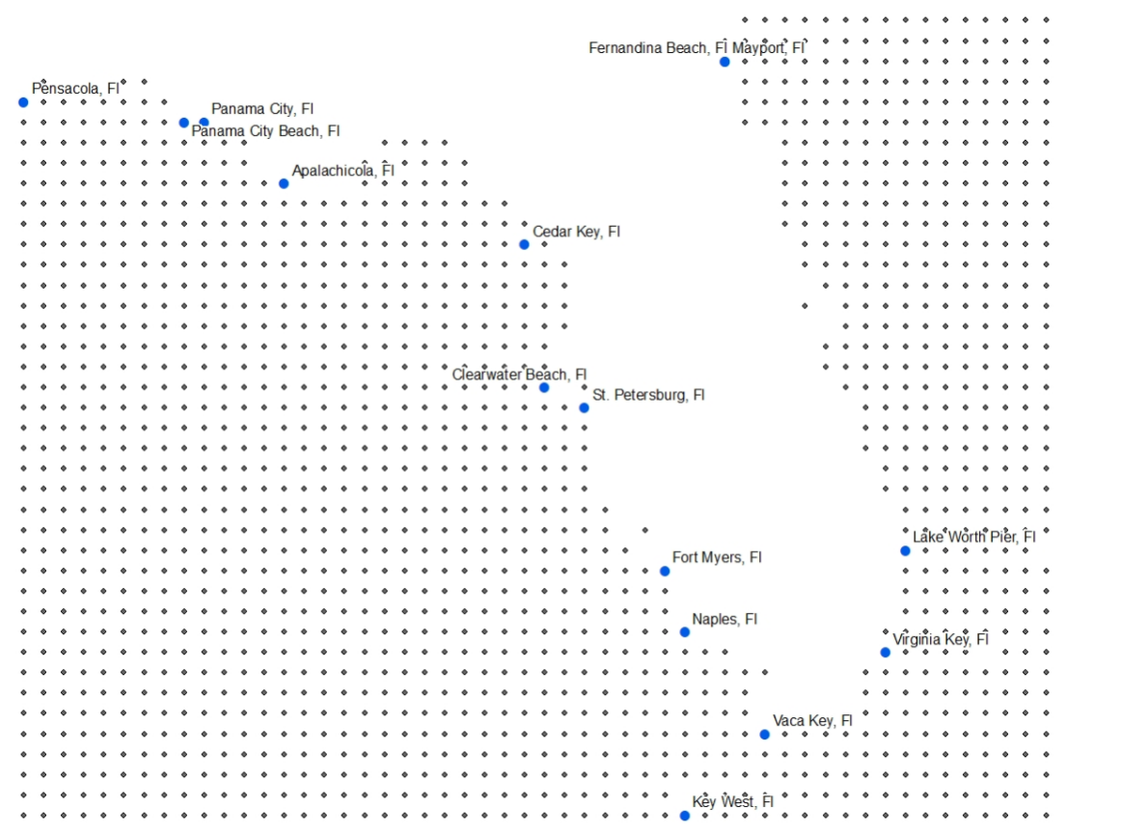

Fig. 5. The coastal Florida locations where the altimetry data were extracted (blue points).

Fig. 6. The relevant regional basins (Atlantic and GOM) with respect to this study.

Results

Trends and Variability: GMSL rates (red dashed line, see Figure 1) are ~3 mm/yr (not adjusted for isostacy). Local sea level rise exceeds GMSL at 14 out of 15 of our selected locations and ranges from ~2.5 mm/yr (Mayport) to from ~5 mm/yr (Apalachicola). Local variability ranges from ~2000 (Lake Worth) to ~6200 (Apalachicola) mm^2 (see Figure 4) and is larger than both the regional (green dashed lines) and global variances.

Multiple Regression (not shown): The model with the lowest BIC was one that consisted of 5 interaction terms (year*regional, year*GMSL, GMSL*ENSO, regional*ENSO, salinity*temperature). Because this model was heteroscedastic and consisted of only interaction terms, we determined that this model was probably not the best fit for our data.

GAM (Optimal): The GAM with the highest average R-squared and lowest average AIC is the model involving year, global average, adjacent basin anomalies, water temperature, water salinity, ENSO 3.4 Index (all 6 predictors, Figure 7). Figure 8 indicates that our assumptions for this model are met. The smoothed predictor functions for this model are shown in Figure 9.

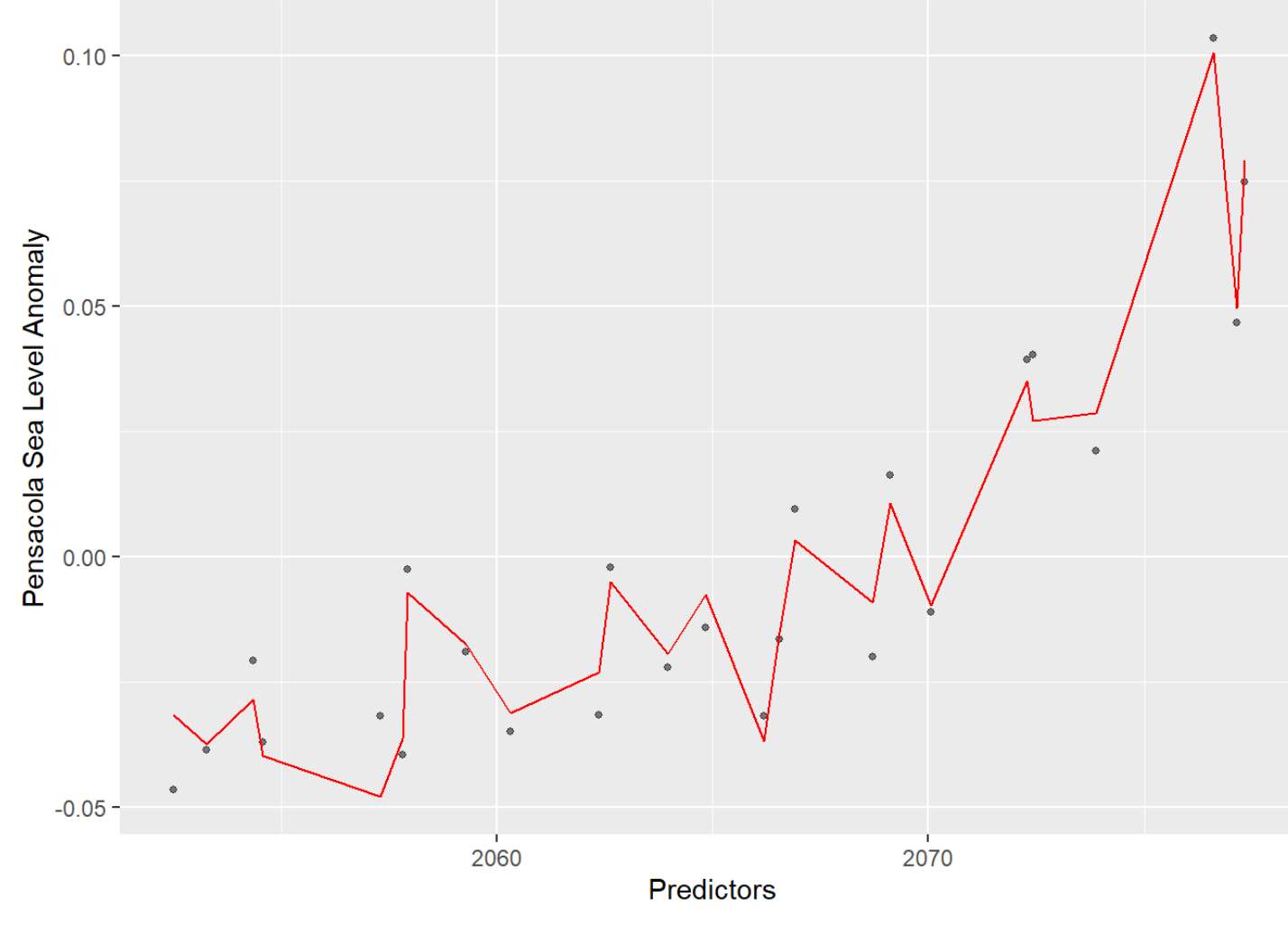

Fig. 7. The optimal GAM fitted at one of the 15 Florida locations (Pensacola). The dots represent the observed values, and the red line is the smoothed spline fit. The x-axis represents a combination of predictors, while the y-axis is the observed SSHA (in mm) at the location.

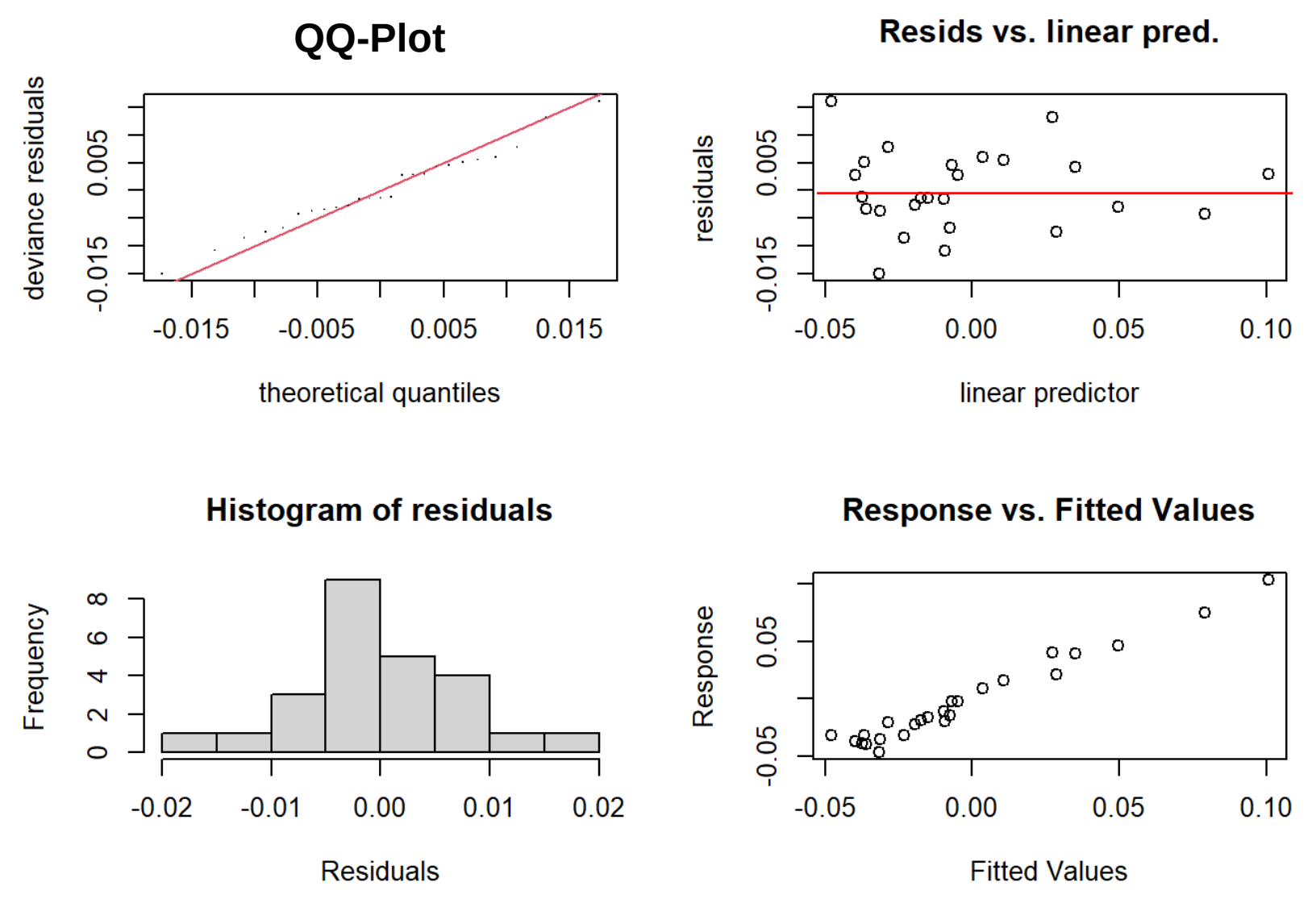

Fig. 8 GAM model output. The four panels depict criteria that assess whether the model assumptions are met.

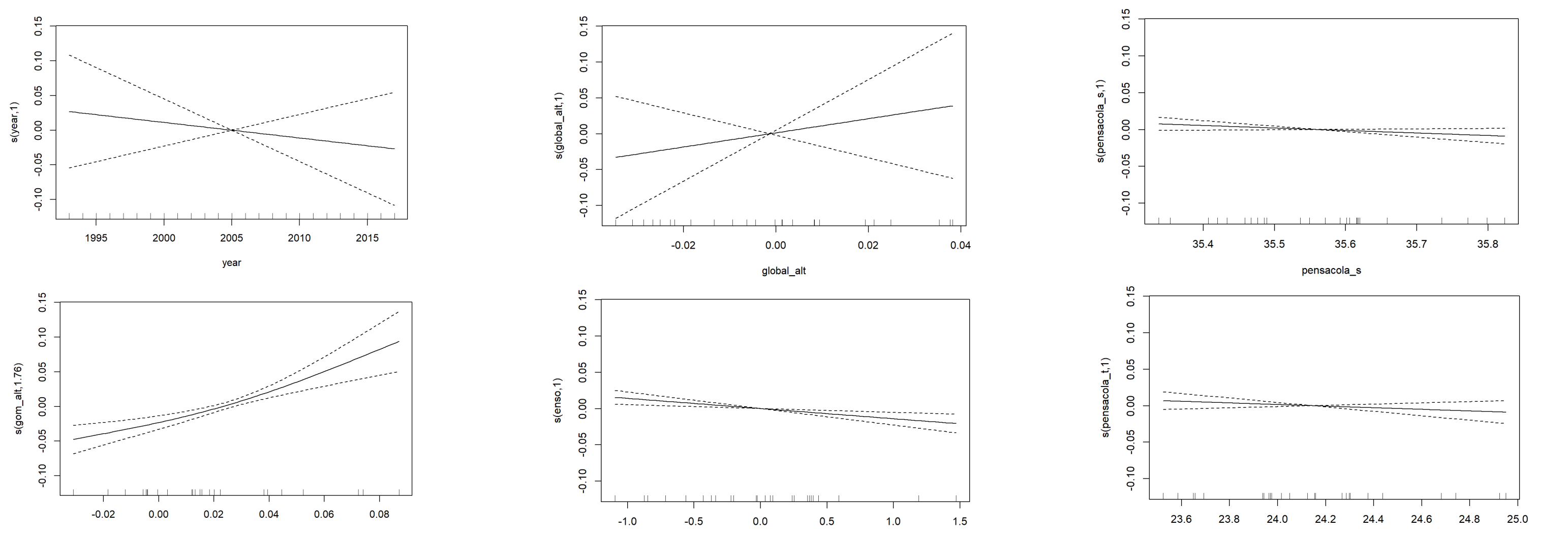

Fig. 9. A 'figure matrix' depicting the smooth predictor functions (solid lines) and confidence intervals (dotted lines) for the GAM. Shown top left to right is: year, GMSL, and salinity. Bottom left to right is: regional SSHA, ENSO, and water temperature,

Conclusions and Discussion

- Both regional and global sea levels contribute to local sea level.
- Local sea level variances are higher than both regional and global (local variability is comparable across coasts.)
- Water temperature, salinity, and ENSO 3.4 are all relevant factors for predicting sea level change in Florida.
- In general, Florida coastal sea level is rising faster than GMSL.

In our model the variable 'year' was found to be a relevant predictor. Given that the year represents a non-physical variable indicates that there are other unknown (important) factors that are contributing to sea level rise in Florida.

Future Work

- Factors such as average monthly winds, atmospheric pressures, and coastal currents should be considered in future models[4].
- Tide gauge data (considered "Ground Truth") should be used in addition to altimetry data.
- A noticeable jump in the trend across all Florida locations in 2011 (not shown) and should be further explored.

References

[1] Peruyera, G., 2012. A Future Submerged: Implications of Sea Level Rise for South Florida. *Fla. A & M UL Rev.*, *8*, p.297.

[2] Beckley, B.D., Lemoine, F.G., Luthcke, S.B., Ray, R.D. and Zelensky, N.P., 2007. A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimetry based on revised reference frame and orbits. *Geophysical Research Letters*, *34*(14).

[3] Mitchum, G.T., 2011. Sea level changes in the Southeastern United States. *Florida Climate Institute*.

[4] Prandi, P., Cazenave, A. and Becker, M., 2009. Is coastal mean sea level rising faster than the global mean? A comparison between tide gauges and satellite altimetry over 1993–2007. *Geophysical Research Letters*, *36*(5).

[5] Tamisiea, M.E. and Mitrovica, J.X., 2011. The moving boundaries of sea level change: Understanding the origins of geographic variability. *Oceanography*, *24*(2), pp.24-39.

[6] Hastie, T.J. and Tibshirani, R.J., 1990. *Generalized additive models* (Vol. 43). CRC press.