An empirical orthogonal function analysis of ocean shoreline location on the Virginia barrier islands

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November 22, 2022

Abstract

Shoreline change along the Eastern Atlantic shore of Virginia has been studied for the individual barrier islands but not as an integrated system. This study combines the Atlantic shoreline locations for eleven barrier islands obtained from LANDSAT 5, 7, and 8 images. Approximately 250 shoreline locations over a 24-year period from Jan 1990 to Dec 2014 were extracted from the digitized shoreline data at 338 transects. The resulting 338 by 250 matrix was analyzed by the empirical orthogonal function (EOF) technique. The first four principal components (PC) explained 86 percent of the sample variance. Since the data was not detrended, the first PC was the overall trend of the data with a discontinuity in 2004-2005. The 2004-2005 years included storm events and large shoreline changes. PCs 2 to 4 reflect the effects of El Nino events and tropical and non-tropical storms. Eigenvectors 1 to 4 all show the effects of the nine inlets in the island group. Eigenvector (EV) 1 explains 59 percent of the shoreline spatial variance and shows the largest changes at the northern and southern island ends. EVs 2 to 4 reflect the pattern of EV1 but at sequentially smaller percentages of the spatial variance. As a group, the eleven islands are losing ocean side shoreline. The lone exception is Hog Island. Sea level had the strongest correlation with the shoreline loss trend of PC1. The coefficient of determination was 0.41. The NAO and MEI also correlated with PC1 with correlations of determination of 0.05 and 0.12 respectively. These confidence level for the three factors was better than 99 percent. Sea level also correlated with PC3 and PC4. The PCs as a group show that the year intervals 2004-2005 and 2009-2010 had large effects on the shoreline change pattern for the island group. EVs 1 to 4 had the highest range of shoreline change at the island ends indicating the effect the changes of the inlets have on the adjacent islands. The smaller islands as a group had a higher level of eigenvector variance than the other eight islands. Sea level change is the major factor affecting the ocean shorelines of these islands. Continued sea level increase will facilitate loss of ocean shoreline for the barrier islands as a group.

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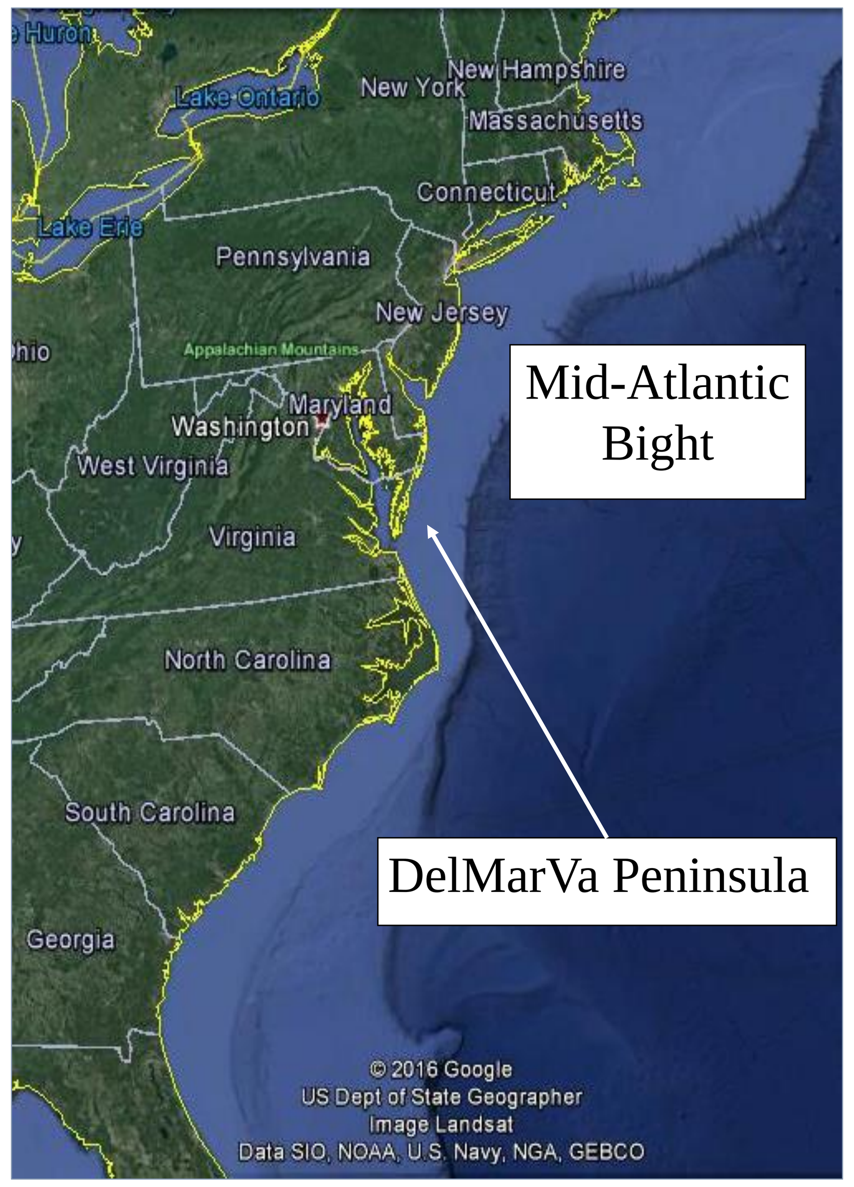
PROJECT LOCATION



Background

- Study location is along the East Coast of the US in the mid-Atlantic bight.
- Atlantic shorelines of eleven Virginia barrier islands from 1990 to 2014 digitized using LANDSAT 5, 7, and 8 satellite images and USDA NAIP aerial photos.
- Shoreline locations were combined into a 338 by 250 matrix for empirical orthogonal function (EOF) analysis.
- Resulting eigenvalues (temporal component) and eigenvectors (spatial component) were used for further analysis.
- Principal components (PC) calculated from eigenvalues correlated to sea level, wave height, the north Atlantic oscillation index (NAO), Arctic oscillation (AO), and the multivariate ENSO index (MEI).

Methods and Materials

- LANDSAT and aerial photos were assembled.
- All images were converted to the same geographical projection.
- The eastern shoreline of each island in each useable image was digitized.
- The digitized shorelines were used to produce a shore movement time series at 300m intervals using the Digital Shoreline Analysis System.
- All island shoreline change data combined and analyzed..
- First four eigenvalues and eigenvectors (EV) used for further analysis.
- Correlation for the various indices, cycles, and environmental factors with PCs 1 to 4 determined.

RESULTS

- Table 1 is the fraction of EOF variance explained for both detrended and non-detrended data.
- The years 2004 to 2005 and 2010 to 2011, were years of large shoreline changes to the barrier islands.
- Table 2 summarizes the correlation coefficients and coefficients of determination for the indices and environmental factors used for comparison to principal components 1 to 4 for the non-detrended data
- PC1 correlated to sea level (r^2 = 0.41). The NAO (r^2 = 0.05) and MEI (r^2 = 0.12) also correlated with PC1 at the 0.99 confidence level.
- The NAO correlated with PC4 (r^2 = 0.05) .
- Eigenvector plots for EVs 1 to 4 indicated that most of the spatial changes to the islands were occurring at the inlets.

Table 1. Fraction of the EOF variance explained for non-detrended and detrended shoreline location measurements. A linear trend was removed for the detrended data analysis.

EOF	Non Detrended	Detrended
1	0.59	0.33
2	0.13	0.15
3	0.08	0.08
4	0.06	0.06
5	0.03	0.04
6	0.02	0.03
7	0.02	0.02
8	0.01	0.02
9	0.01	0.02
10	0.01	0.02

Table 2. Correlation coefficients (RHO), significance value (PVAL), and coefficients of determination (Coef_Det) for principal components 1 to 4. PVAL >0.99% significance highlighted.

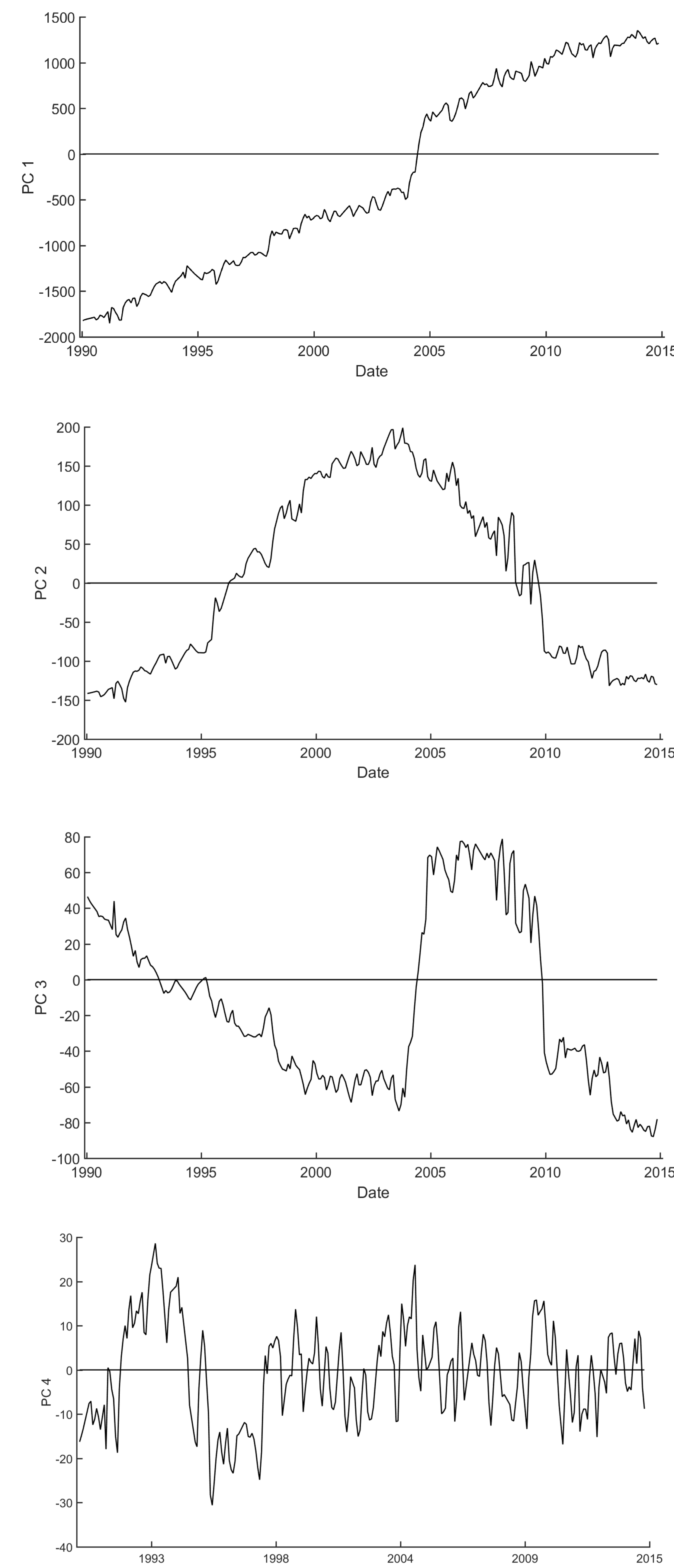
	PC1			PC2			PC3			PC4		
Factor	PVAL	RHO	Coef_Det	PVAL	RHO	Coef_Det	PVAL	RHO	Coef_Det	PVAL	RHO	Coef_Det
AO	0.0137	-0.142	0.020	0.090	-0.100	0.010	0.011	0.146	0.020	0.0824	-0.100	
NAO	1.15E-09	-0.217	0.047	0.182	-0.080		0.631	0.146		0.000115	-0.221	0.049
MEI	1.15E-09	-0.343	0.117	0.030	-0.130	0.017	0.017	0.080	0.006	0.0286	-0.127	0.016
Waves	0.0116	0.146	0.021	0.057	0.110		0.799	0.015		0.075	0.103	
Sealevel	1.7E-35	0.637	0.406	0.614	-0.029		0.019	-0.135	0.018	0.2813	0.063	

CONCLUSIONS

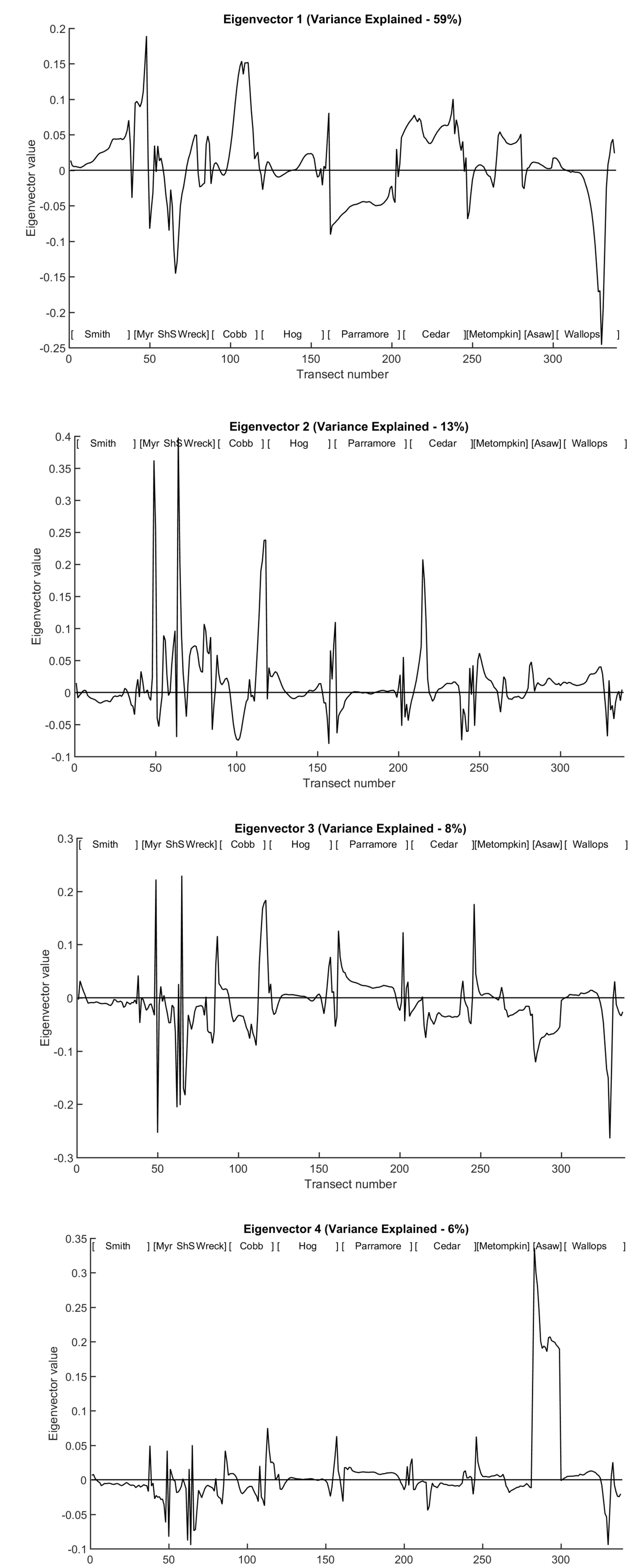
- Sea level rise is the largest environmental factor affecting the eleven islands of the five factors evaluated in this study. .
- The NAO and MEI indices are important in describing episodic shoreline events on these islands.
- Steady shoreline retreat narrows parts of the islands to the point that they are sensitive to episodes of sudden shoreline loss episodic events.
- Large shoreline change events are episodic and are associated with extra-tropical storms, hurricanes, and high water tidal events.

Plots of the first four principal components (PC) and eigenvectors calculated from non-detrended data of shoreline movement for the eleven Virginia barrier islands. The first four eigenvalues and eigenvectors explain 86 percent of the total data set variance. The PCs are calculated from the eigenvalues. The eigenvectors are the spatial component of the data set. The island names are added to the eigenvector plots for spatial reference.

Principle Components



Eigenvectors



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