A comparative study of sea level reconstruction techniques using the 20-year satellite altimetry record.

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Introduction

Sea level reconstruction temporally extends the globally complete sea level dataset provided by satellite altimetry. These long-term reconstructions have significant scientific potential but need to be better verified. This study examines sea level reconstruction in which the covariance of the satellite altimetry data is interpolated using tide gauge data. The choice of basis functions used to describe this covariance is investigated. In particular, the basis of the reconstructions are created using empirical orthogonal functions (EOFs) and cyclostationary EOFs (CSEOFs). These basis functions are then optimally interpolated using a spatially limited dataset consisting of satellite altimetry data at tide gauge locations, termed synthetic tide gauge data.

It has been shown that EOF reconstructions produce more accurate GMSL results with longer training period, and more accurately reproduce trend when they include a homogeneous pattern in the basis [*Christiansen et al*., 2010]. This homogeneous basis pattern is referred to here as EOF0 (mode of 1's). To date, Comparative analysis of reconstruction is rather limited, especially concerning different basis functions. This and continued research will improve confidence and utility of reconstructions in the future.

Data and methods

The 20-year AVISO gridded data product is used as the training data for the reconstructions and truth in the analysis. Each grid point was detrended, and any grid points with discontinuous records were removed. This accounted for approximately 18% of the total grid points, although most of these were at high latitudes and in seasonally icy regions.

The EOF reconstruction techniques are described by Kaplan et al. [1998] and applied to sea level by Church et al.'s [2004] . The CSEOF decomposition technique was developed by Kim et al. [1996] and first implemented in sea level reconstruction by Hamlington et al. [2011].

The 412 synthetic tide gauges locations were selected based on real tide gauges with useful data between 1900 and 2012, as discussed in Hamlington et al. [2011]. There remain realistic geographic distribution biases toward the Northern Hemisphere and Western Europe, as shown in Figure 1. Secndary analysis was completed using 246 tide gauges used from 1950-1960.

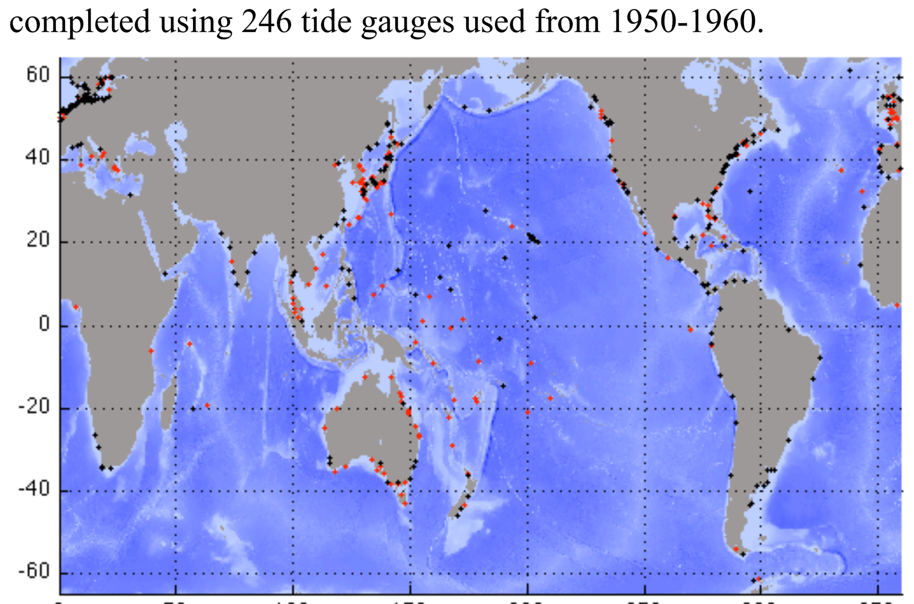

Figure 1. All 412 synthetic tide gauges (black and red). 246 tide gauges operational during the 1950s (black only).

Results

Three reconstructions were created using the same AVISO training and synthetic tide gauge datasets. The reconstructions are considered the CSEOF recon, the EOF recon with EOF0, and the EOF recon without EOF0. Figure 2 shows the comparison of global mean sea level (GMSL) of the training data with each reconstruction. The CSEOF reconstruction reproduces the GMSL well, with a correlation of 0.95. The EOF reconstruction with EOF0 is noisier than the AVISO GMSL with a correlation of 0.55. The EOF reconstruction without EOF0 has a correlation of 0.81 with the training data.

CSEOFs have the ability to capture spatial patterns that vary in time and space. This is possible because the LVs associated with CSEOFs have time dependence, whereas EOF LVs are only spatially dependent. It is shown here that this method for dynamically coupling the spatial modes is beneficial to reconstructing GMSL variance.

With EOF basis functions, the limited number of modes explaining the variance do not account for trend well. To overcome this, the constant EOF0 is added to the loading vectors and solved for during the optimal interpolation. The remaining EOFs must be de-meaned and normalized to ensure a change in sea level is not accounted for as a distribution of sea level. Figure 2 shows that information is lost in this de-meaning process, as that is the only difference between the EOF reconstructions.

The same reconstructions were created using a synthetic tide gauge dataset which only contained locations of tide gauges active between 1950 and 1960. Figure 3 shows the principle component time series (PC) calculated from the training data compared with the reconstructed amplitudes for both the full tide gauge dataset and the reduced 1950's tide gauge dataset.

Figure 3 shows that fewer tide gauges does not have a noticeable affect on the CSEOF reconstructed amplitudes, but increases the noise in the EOF reconstructed amplitudes significantly. This can, in part, be attributed to simultaneously fitting a window of spatial patterns to each point in time when optimally interpolating the CSEOFs.

Table 1 expands on this point. Two well known ocean indices were calculated using SSH from the AVISO and reconstruction datasets and the correlation between the true (AVISO) indices and reconstruction indices were found. It is shown that although only 60% of the tide gauge locations are used in the 1950/s reconstruction, CSEOF correlation shows no notable change, whereas EOF correlation falls off significantly.

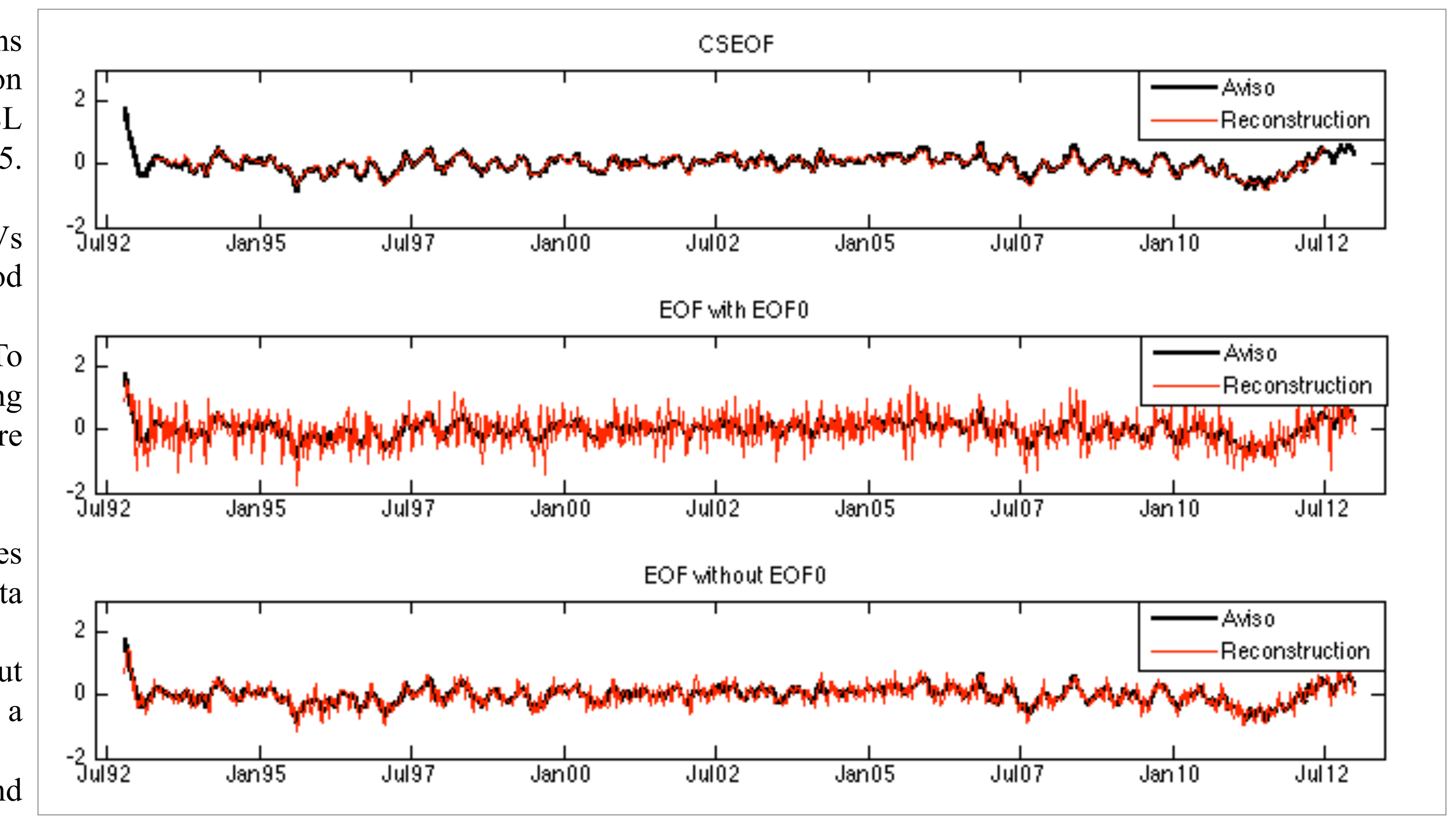

Figure 2. GMSL of datasets with annual and semi-annual signals removed. Correlations are 0.95 (top), 0.55 (middle), 0.81 (bottom).

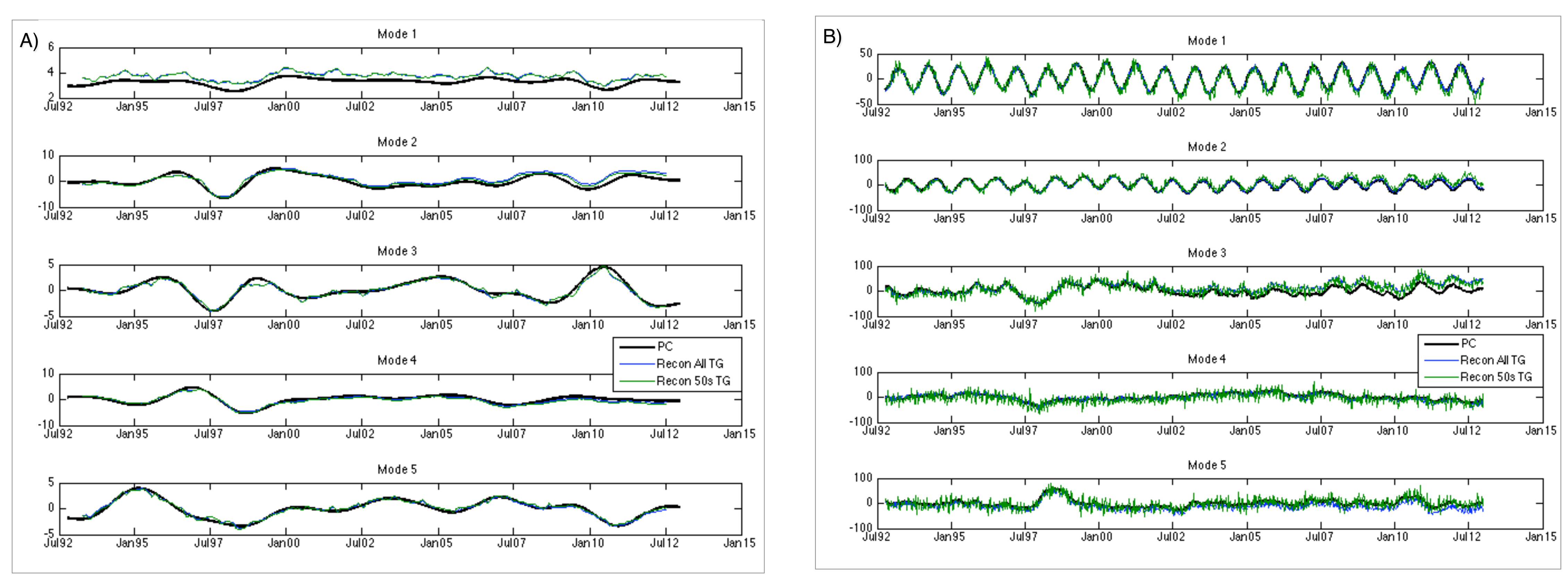

Figure 3. PC time series shown with reconstructed amplitude for A) CSEOF and B) EOF basis functions. Blue is with full tide gauge dataset, green is with 1950-60 tide gauge dataset. Top plots represent mode 1 and increase downward.

Table 1. *Correlation* between AMO and Nino4 indices calculated from AVISO data and reconstructions.

	CSEOF	EOF with EOF0	EOF without EOF0
AMO Full Tide Gauges	0.93	0.26	0.69
AMO 1950's Tide Gauges	0.92	0.17	0.26
Nino4 Full Tide Gauges	0.98	0.93	0.98
Nino4 1950's Tide Gauges	0.98	0.75	0.76

Future work

There is much room for further validation and comparison regarding sea level reconstruction techniques. Initially, the sensitivity to tide gauge noise and location will be tested. This will be done by expanding synthetic tide gauge locations valid for all decadal periods from 1900 onward to see if certain climate signals are not captured when using more realistic tide gauge locations over the last century. For example, was tide gauge sampling during the 20's sufficient to accurately capture PDO? Another major difficulty of sea level reconstruction is noise in the tide gauge data. Analysis is planned to look at how adding noise to the synthetic tide gauges affects the reconstruction properties and whether a certain basis function is more suitable in the presence of noise. Additionally, more investigation of the benefits and drawbacks associated with using the EOF0 mode is planned.

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For further information

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