# Reconstruction of Global Mean Sea Level Variations Using Altimeter and Tide Gauge Data: A Sensitivity Analysis

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## Abstract

Satellite altimetry and tide gauges provide complementary measurements of sea level change: the former has excellent spatial resolution, but only over the last decade; and the latter provides measurements that extend back over most of the last century, but with poor spatial resolution. Several recent papers have explored combining these two datasets to reconstruct sea level change over the past 50-75 years. The approach involves computing an EOF analysis of the satellite altimeter sea level record, and then using multidecadal tide gauge data to estimate the temporal variations of the principal components. The method basically assumes that the EOFs from the decade-long altimetry record span the variance of sea level change over the time period of the reconstruction. There are of course errors introduced via this assumption, and thus one might ask how these errors affect the reconstruction of past sea level changes, and in particular, the reconstruction of global mean sea level variations. Other variables used in the reconstruction can also affect the results. This investigation examines the sensitivity of these reconstructions to variables such as the number of empirical orthogonal functions used, the number of tide gauges used, the location of those tide gauges, and the relative weighting of the tide gauges in the reconstruction. The results of these tests will be used to place bounds on the likely errors in the reconstructed sea level estimates.

## Background

If only tide gauge data were used to calculate global mean sea level a poor spatial sampling of tide gauges would provide a value for sea level at that time. Tide gauges represent what is going on near the coast well but may not provide the best information about what is occurring further out in the ocean. The reconstruction process, however, provides global estimates of local sea level rise so changes in sea level in a particular area can be examined.

Previous sea level reconstruction processes have been performed by several different methods. Each reconstruction uses a different number of empirical orthogonal functions (EOF), a different tide gauge data set and processes the data differently. By investigating the sensitivity of these analyses to the different initial assumptions, more confidence may be obtained on the results of these reconstructions.

All sea level reconstructions start by using principle component analysis on the satellite altimetry data set to compute empirical orthogonal functions. The EOFs consist of both an amplitude map and a time series over the area and time period of the altimetry record. The amplitude map, in this case, provides values of sea level on a 1x1 degree grid. The time series for this particular reconstruction uses monthly values for the time series. In the reconstruction process, the tide gauge time series replaces that of the empirical orthogonal functions. A least squares fit is then used to provide the best estimate of the sea level at each gridded location for the length of the reconstruction.
One of the limitations of the reconstruction process however, is only just over one decade worth of data is available for use in the EOF construction. Consequently, decadal variability over the measured timeframe will increase errors for the reconstructions when a different decadal variability is occurring.

For more information on the reconstruction process, the references provided will give more detail.

## Reconstruction Methodology

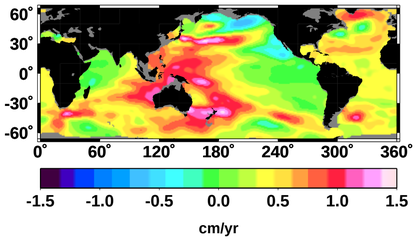
This particular reconstruction uses altimeter data from both TOPEX/POSEIDON and Jason data. The altimeter data used 133 months worth of data between 1993 and 2004. All tide gauges used in the reconstruction was taken from the Permanent Service for Mean Sea Level RLR data set. The tide gauges selection criteria used, required tide gauges to have a specified length of the record. Several other gauges were eliminated by manual inspection of the tide gauge record. Often these gauges were eliminated because local effects were influencing the tide gauge and would not provide good observations of global mean sea level. The gauges from the Baltic and North Sea were also removed for the calculation of global mean sea level. A seasonal signal was removed from the tide gauges and a post glacial rebound model was also applied to the tide gauges. The post glacial rebound model used for this correction was the ICE4G model.

The reconstruction was run from 1950 to 2000. The reconstructions stops at 2000 due to the decrease in available tide gauge data. Several different tide gauge selection criteria exists for these reconstructions. A 20 year tide gauge set designates that the tide gauges selected had over 20 years worth of valid data.

This reconstruction differs from other reconstructions in that it is designed to remove any biases in the tide gauge data. The tide gauge values were differenced from one month to the next so the change in sea level were the data inputted into the reconstruction. The results of the reconstruction were then integrated to obtain the values of sea level at the location of the different grid points.

## Satellite Altimetry Trends

The satellite altimetry from TOPEX/POSEIDON and Jason were combined over the tim e frame of 1993 to 2004. The trends of the altimetry were computed and depicted below




## Acknowledgements

The tide gauge data set supplied by the Permanent Service for Mean Sea Level. The TOPEX/POSEIDON and Jason data were supplied by PO.DAAC. Work on this project was funded by a Jason Science Investigation Grant.

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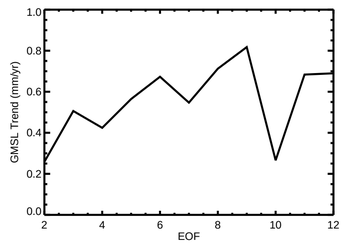
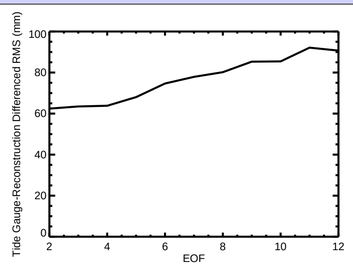
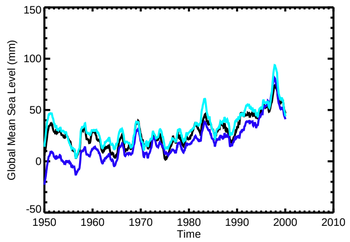
## EOF Sensitivity



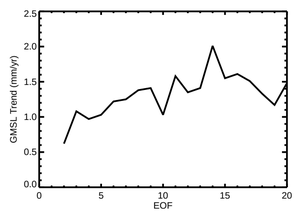

The numbers of EOFs were varied from 2 to 12 to examine the effect of the number of EOFs on the trend, differenced RMS and time series. A 20 year tide gauge set was selected for this analysis. The actually numbers will vary depending on what tide gauge data are selected.




The RMS between the tide gauges and the reconstruction remained relativly flat through the first couple of EOFs before a gentle climb.

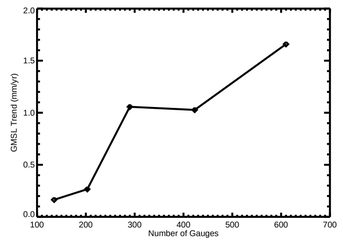



Three different time series are depicted in the above plot. The black line represents the time series of the summation of the first 12 EOFs in the reconstruction. The dark blue line represents the time series for the first 10 EOFs and the light blue line for the first 8 EOFs.

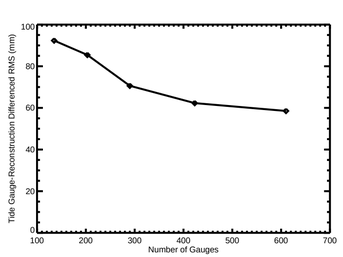



This is a plot of a trend against varying EOFs with a 10 year tide gauge data set.

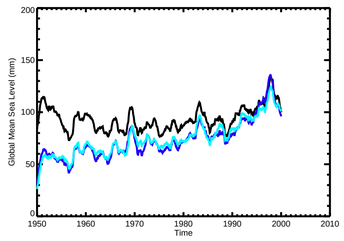
## Number of Gauges Sensitivity



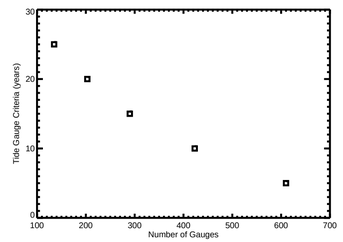

This graph was created by varying the tide gauge selection criteria to allow for a different number of gauges to be used in the reconstruction. Five different reconstruction were run with varying minimum tide gauge length to select the gauges. All of these trends were computed with 10 EOFs.




As more gauges were added to the reconstruction, the RMS difference between the tide gauges and the reconstruction decreased.

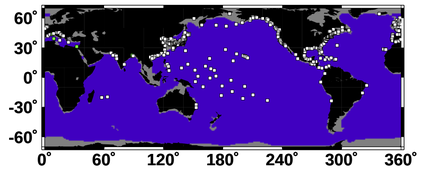



The black line is for the tide gauge set with a 20 year minimum criteria. The dark blue line is for the 15 year case and light blue for the 10 year case.

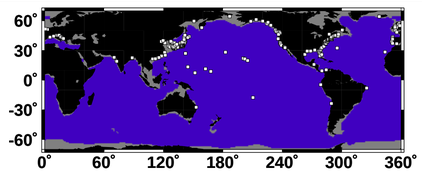



This graph displays how the tide gauge selection criteria relates to the number of gauges used for that reconstruction.

## Tide Gauge Locations



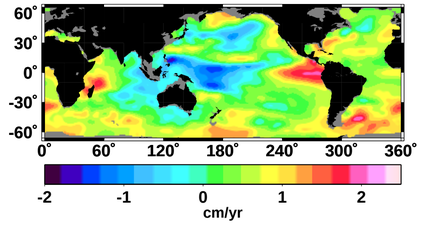

This plot is of the location of all the gauges used in the 10 year minimum tide gauge data set. There are a total of 430 gauges used in this data set.




The 20 year minimum tide gauge data set's gauges are shown in the figure above. This data set has a total of 204 gauges.

## Weighting Matrix Effects

A weighitng matrix was constructed based on weighting the tide gauge locations by the number of tide gauges within a certian radius. In this case, a gauge was weighted by one over the number of gauges within a 1000 km radius. The reconstruction of the real tide gauges was run with this weighting matrix. The global mean sea level and mean square error of the reconstruction were the same as withouth the weighting matrix.




The above figure depicts the local trends over the 50 year reconstruction for a 15 year tide gauge set and the first 10 EOFs.

## Conclusions

- The 50-year sea level reconstruction has been shown to be moderately sensitive to variations in the analysis variables, such as the tide gauge selection criteria and the number of EOFS used.
- The greatest sensitivity is in the early years of the reconstruction when the least number of tide gauges are available. This causes variability in the reconstructed rate of sea level rise for the 50-year dataset.
- Future work will focus on developing an error budget for the reconstruction, and developing an appropriate data weighting scheme.

## References

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