Nonlinear trends in global and regional sea level

Proudman Oceanographic Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Abstract

We analyze the Permanent Service for Mean Sea Level (PSMSL) database of sea level time series using a method based on Monte Carlo Singular Spectrum Analysis (MC-SSA). We remove 2-30 year quasi-periodic oscillations and determine the nonlinear long-term trends for 12 large ocean regions. In contrast with linear trends, where the rate of mean sea level rise is constant, our results reveal the evolution of sea level rise during the 20th century and show that the highest regional rates of up to 3-5 mm/yr occurred between 1920-1950 (with some regional variations). Our global sea level trend estimate of 2.4 mm/yr for the period from 1993 to 2000 is comparable with the 2.6 mm/yr sea level rise calculated from TOPEX/Poseidon altimeter measurements. We show that over the last 100 years the rate of 2.5 mm/yr occurred between 1920 and 1945 and resulted in a sea level rise of 48 mm, is likely to be as large as today's.

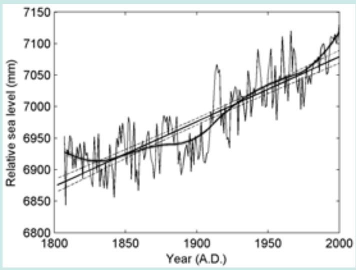
Motivation

The main questions we answer:

1. Is it achievable to reconstruct global sea level using the tide gauge records?
2. Can we provide additional information using the nonlinear trends compare with linear estimations?

Most tide gauge records demonstrate distinctly non-uniform trends, which makes the linear trends sensitive to the arbitrarily chosen start and end dates. Here we apply MC-SSA to extract nonlinear long-term trends from time series of mean sea level. We filter the low frequency variability by removing the statistically significant 2-13.9 year oscillations associated with large scale atmospheric circulation; along with multi-decadal oscillations (14-30 year periods). We then estimate the nonlinear long-term trend, providing the statistical significance of the trend, and its confidence intervals.

Figure 2 shows the linear and nonlinear trends for sea level at Brest (France). Note the small confidence intervals of the nonlinear compared with the linear fits. To date linear fits have generally been used to estimate sea level rise despite the clear inconsistency of the data to a linear model. The nonlinear trend shows more rapid rise around 1920-40, than at present and slight decreasing of sea level prior 1840 which is not detected by the linear trend.



Picture from (Moore, J.C., A. Grinsted and S. Jevrejeva. 2005. The new tools for analyzing the time series relationships and trends. EOS, vol., 86, 24)

For trend analysis we use a novel approach (Moore et al., 2005), providing:

- Rate for each year
- Statistical significance (against red/white noise model, using MC)
- Contribution from the trend to the total variance
- Errors
- Confidence interval

Data

We use all relative sea level (RSL) monthly mean time series in the Permanent Service for Mean Sea Level (PSMSL) database [*Woodworth and Player*, 2003]. Detailed descriptions of the RSL time series are available at www.pol.ac.uk/psmsl. RSL data sets were corrected for local datum changes and glacial isostatic adjustment (GIA) of the solid Earth [*Peltier*, 2001].

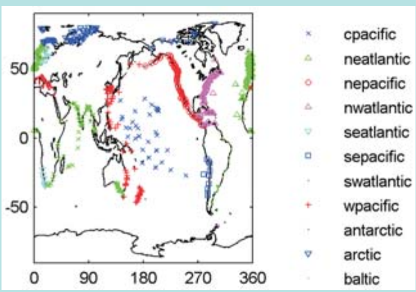


Figure 2. Location of tide gauges included in this study (12 regions).

Results

Regional trends

In contrast with linear trends, where the rate of mean sea level rise is constant, our results (Figure 3) reveal the evolution of sea level rise during the 20th century and show that the highest regional rates of up to 3-5 mm/yr occurred between 1920-1950 (with some regional variations, e.g. the later maximum for the Southwestern Atlantic and Western Pacific). The major contributions to the global sea level rise during 1920- 1940 are from the Northwestern Atlantic (4.2 ± 1.0 mm/yr), Indian (3.5 ± 1.0 mm/yr), and Mediterranean (3.1 ± 1.0 mm/yr) regions. Even smoothed by the 30 year SSA window, the trends from the different ocean regions show slightly dissimilar patterns and still demonstrate some cyclic variability. This cyclicity is associated with longer term oceanic variations, changes in thermal expansion and water mass adding to the ocean, which may provide non uniform regional sea level rise, and melting of continental ice leads to the significant geographic variations in the sea level change due to both gravitational and loading effects.

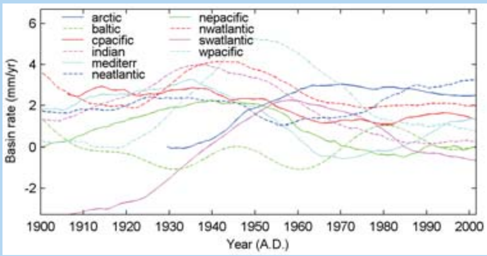


Figure 3. Rates of nonlinear sea level trends in the regions defined in Figure 1, found using an SSA embedding dimension equivalent to 30 years. Errors are not shown in the plot, but the maximum error is about 1 mm yr^{-1}. Note that extrapolation at data boundaries means that curves are increasingly more uncertain within 30 years of the start and end of the records.

Nonlinear trend in global sea level

Applying a least squares linear regression analysis to the global sea level in Figure 4 gives a trend of 1.8 mm/yr between 1900 and 2000, as found in earlier studies. However, our results show that global sea level rise is irregular and varies greatly over time, it is apparent that rates in the 1920-1945 period are likely to be as large as today's. Nevertheless, uncertainties remain.

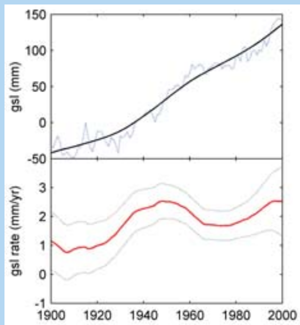


Figure 4. Top: Nonlinear trend in global sea level using an SSA embedding dimension equivalent to 30 years. Paralleling the trend is the 95% confidence interval in the trend found by considering the mismatch between the regional sea level curves, dashed curve is the yearly global sea level. Bottom: the rate of the global sea level trend, and its confidence interval.

Conclusion

- We demonstrate that advanced statistical methods improve error estimations and reduce uncertainties for calculation of regional and global sea level rise using the tide gauge data sets.
- We show that the development of global sea level rise is highly dependent on the time period chosen and the global sea level rise occurred during the period from 1920 to 1945 is comparable with present day rate of sea level rise.
- Nonlinear sea level trends for the ocean regions are non uniform even after 30 year smoothing (trends in high latitude ocean regions have huge uncertainties, which is a challenge for future study).
- We also show that low frequency, multi-decadal variability is significant and that linear trends do not properly represent this.

Jevrejeva et al., 2006. Nonlinear trends and multi-year cycles in sea level records, JGR, 2005JC003229