Arctic Sea Level Change over the altimetry era and reconstructed over the last 60 years

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Abstract
The Arctic Ocean process severe limitations on the use of altimetry and tide gauge data for sea level studies and prediction due to the presence of seasonal or permanent sea ice.

Good altimetric data is seen to crucial for sea level studies and profoundly for sea level datasets. With recent data from the Cryosat-2 SAR altimetry the time-series now runs from 1991-2015 a total of nearly 25 years.

The DTU Arctic Sea level dataset.

The fraction of all possible data over 20 years (1992-2012) is shown. Left the fraction of all data (weekly basis) from AVISO. Right: The fraction of all data in the DTU Arctic Sea level data set. In the North Atlantic, this fraction is close to 1 (all data available) whereas in the Beaufort region in the interior of the Arctic the fraction is close to 0 (no data) for the AVISO datasets due to the editing relative to the old CLS/GM MSS. For the DTU dataset the fraction is some 10-20% indicating important Recovery of data.

Below The leading eight EOFs (EOF1-EOF8) derived from satellite altimetry data between 68 ºN and 82 º N. Besides these eight EOFs, an additional EOF9 was introduced as a constant for the region. The scaling for the EOFs is arbitrarily not given.

Stable Arctic Sea level reconstruction

Sea level reconstruction is usually carried out using an ordinary least squares regression (OLS). Assuming two datasets to be related by a linear equation, one may obtain the parameters for that linear equation through regression. Defining a response variable, y, a multivariate predictor X and model parameters β the regression equation becomes:

\[ y = X\beta + \epsilon \]

where \( y \) are the residuals, we want to obtain the "best" estimate for \( \beta \). The canonical technique for satellite- and tide gauge-based sea level reconstruction was established in Church et al. (2004).

In the canonical reconstruction we shall solve for sea level coefficients (\( \epsilon \), \( \beta \)), that is, a scalar coefficient for each eigenfunction per timestep or temporal points M of the tide gauge dataset, while spatially covering the I leading eigenfunctions in the dataset.

Minimizing the cost function, one obtains the solution for \( \epsilon \): a

\[ \epsilon = P E \beta R^T G \]

where

\[ P = (E^T R^{-1} E + \lambda)^{-1} \]

G is the data matrix, R is the error covariance matrix, \( H_n(x) \) is the indicator matrix which is zero everywhere, except at \( H_n(x) = 1 \) where \( x \) is the tide gauge index and \( n \) is the index of its closest pixel in the calibration grid. A is the selected eigenvalue.

A detailed description of the reconstruction technique using ridge regression and its adaptation to the Arctic Ocean is available online from (Svendsen, 2015). A significant adaptation of the technique from Church et al. (2004) is necessary when reconstructing Arctic sea level, as the tide gauge records are too short and scattered for the reconstruction which in the approach by Church et al. (2004) demanded continuous time series throughout the period 1956 to today.

Consequently the technique had to be adapted to allow for sparse and incomplete datametrics as input to the reconstruction. Estimation of the covariance matrix has to be adapted to be computed from available (incomplete) data. To extract as much information as possible from the tide gauge dataset, we solve for the \( \beta \) coefficients once per timestep (rather than all at once), with a time-variable H matrix that selects the available tide gauges at that point in time.

A different reconstruction approach is discussed in Ray and Douglas (2011), where no differencing is used, and instead one uses the original tide gauge records and solves for the vertical datum of each individual tide gauge as part of the solution. This is done to address the integration error that can accumulate as one moves back in time, as nothing forces the reconstruction back to reality when errors appear in Equation 2.

Reconstruction results.

A number of parallel reconstructions were made for the Arctic to compare results using cumulated differences (as Church et al. (2004) and a reconstruction solving for the tide gauge datums (Ray and Douglas, 2011). In total 8 different reconstructions were implemented.

Temporal outages in the tide gauges or vertical datum shifts in the time series generally needs careful handling in both methods. A straightforward method is to split the affected tide gauge in two if temporal outages larger than a certain time and vertical offset larger than a certain amount is encountered. Here we included a study of the effect on the sea level reconstruction accounting for vertical outages longer than 6 month and vertical jumps larger than +/- 25 cm.

References

References


References


The decadal means for the 1950-2010 period relative to an arbitrary mean. Indeed the decadal means shows very little variations in the first three decades similar to the work by Prochutinski et al (2009) and Parol (2021) which gives good faith in the sea level reconstruction.