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60-year Nordic and Arctic sea level reconstruction based on a reprocessed two-decade altimetric sea-level record and tide gauges

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Introduction

Due to the sparsity and often poor quality of data, reconstructing Arctic sea level is highly challenging. We present a reconstruction of Arctic sea level covering 1950 to 2010, using the approaches from Church et al. (2004) and Ray and Douglas (2011). This involves decomposition of an altimetry calibration record into EOFs, and fitting these patterns to a historical tide gauge record.

Model

As in Church et al. (2004), we use an EOF decomposition of available altimetry data and minimize the cost function

$$(\mathbf{HE}\boldsymbol{\alpha} - \mathbf{G})^{\mathsf{T}}\,\mathbf{R}^{-1}\,(\mathbf{HE}\boldsymbol{\alpha} - \mathbf{G}) + \boldsymbol{\alpha}^{\mathsf{T}}\boldsymbol{\Lambda}^{-1}\boldsymbol{\alpha}$$

where $\mathbf{E}$ are the retained eigenfunctions from a calibration period, $\mathbf{G}$ are the tide gauge records, $\mathbf{H}$ an indicator matrix, $\mathbf{R}$ describes the error covariance, and $\boldsymbol{\Lambda}$ contains the retained eigenvalues.

We perform the reconstruction using cumulated differences between timesteps as in Church et al. (2004), as well as using the approach from Ray and Douglas (2011), which solves for the vertical datum of each tide gauge as part of the solution. The latter approach handles gaps in data relatively well, without allowing errors to accumulate over time.

Data

- Only data above 68°N
- Monthly DTU altimetry data fields used (ERS-1/2 and Envisat, 1993–2012)
- Monthly PSMSL tide gauge data (1950–2010)
- GIA and IB corrections applied to tide gauge data (Peltier ICE-5G and HadSLP2, respectively)
- Use EOF0 and 8 leading altimetry EOFs (explains ≥ 95% variance)
- Optionally use "virtual tide gauges" (altimetry time series at random locations used as if they were tide gauge data) to help cover post-1990 period

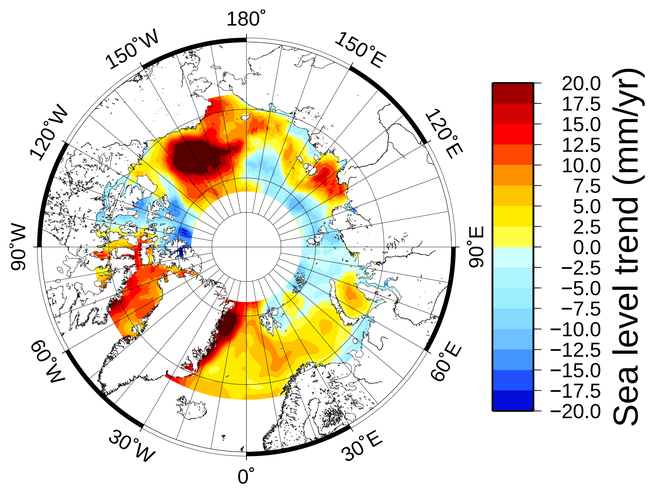
References

- Church, J., White, N., Coleman, R., Lambeck, K. and Mitrovica, J. (2004). Estimates of the regional distribution of sea level rise over the 1950–2000 period. *Journal of Climate*, Volume 17, Issue 13, pp. 2609–2625.
- Ray, R. D., Douglas, B. C., Experiments in reconstructing twentieth-century sea levels, *Progress in Oceanography*, Volume 91, Issue 4, December 2011, pp. 496-515, ISSN 0079-6611, http://dx.doi.org/10.1016/j.pocean.2011.07.021
- Svendsen, P. L., Andersen, O. B., Nielsen, A. A., Statistical selection of tide gauges for Arctic sea-level reconstruction, *Advances in Space Research*, Volume 55, Issue 9, 1 May 2015, Pages 2305-2314, ISSN 0273-1177, http://dx.doi.org/10.1016/j.asr.2015.01.017

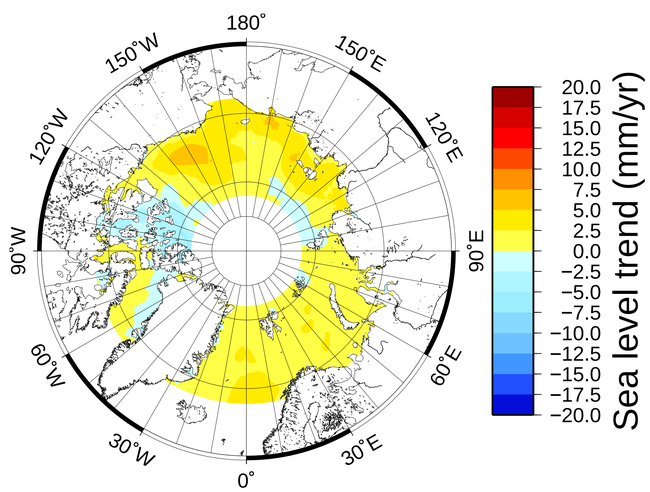
Trends

The trend in the reconstruction for the period 1960–2010, using the Ray and Douglas-based reconstruction, appears generally in line with the development in other GMSL reconstructions. There is a particular positive trend in the Beaufort Gyre area and in the East Siberian Sea. The cumulated differences approach yields locally extreme trends due to the patchy coverage of tide gauge data.

Cumulated differences (Church et al.)

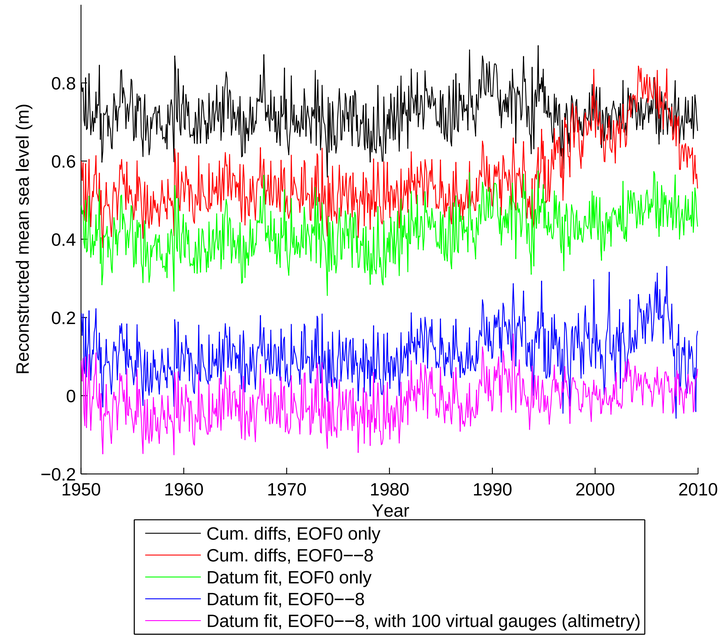


Datum fit (Ray/Douglas)



Different reconstructions

The reconstruction can take on a variety of developments depending on the method chosen. The Ray and Douglas approach appears to be generally robust and able to handle the patchy data coverage in the Arctic.



Method	Trend (mm/yr) 1960–2010	Trend (mm/yr) 1995–2010
Cum. diffs, EOF0 only	0.4 ± 0.3	0.9 ± 1.4
Cum. diffs, EOF0–EOF8	4.3 ± 0.4	5.0 ± 2.6
Datum fit, EOF0 only	2.0 ± 0.3	3.7 ± 1.4
Datum fit, EOF0–EOF8	1.5 ± 0.3	2.0 ± 2.4
Datum fit, EOF0–8, 100 virt.	1.5 ± 0.3	1.8 ± 1.1

Conclusions

- Ray and Douglas method (datum fit) appears able to provide a robust basis for Arctic sea-level reconstruction
- Further refinement may be obtained using "virtual tide gauges" in the altimetry era, seems to even out MSL peak in 2004–08
- Trends and characteristics otherwise quite sensitive to method choice
- Beaufort Gyre area variation apparently overestimated when using tide gauge data and EOFs. May be controlled by using only EOF0 or introducing virtual tide gauges.