Confidence and sensitivity of sea-level reconstructions

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Introduction

Reconstructions of historical sea level on the timescale of a few decades to slightly more than a century has been notably established, for example in Church et al. (2004) and Church and White (2011), using satellite altimetry from 1993 onwards to establish a calibration period for a model. From this calibration period, empirical orthogonal functions (EOFs) are obtained, the time-variable amplitudes of which are then constrained by tide gauge records. Thus, both historical mean sea level and regional distributions can be estimated. Minimum/maximum autocorrelation factors (MAF) (Switzer and Green, 1984) is a decomposition technique developed to isolate noise components from multivariate data, based on the assumption that the desired signal is spatially (or temporally) correlated with a shifted version of itself, while noise will generally be uncorrelated.

Model

As in Church et al. (2004), the amplitudes of each EOF are determined by employing a regularized optimal interpolation as described in Kaplan et al. (2000). However, in this preliminary analysis, the tide gauge data are represented by extracts from satellite altimetry, which allows the convenience of a vertical datum consistent between the calibration period and the "tide gauge" record. The unknown tide gauge datums are handled in Church et al. (2004) by using first differences of the time series, and in Ray and Douglas (2011) by solving for the datum of each gauge.

Analysis

For this analysis, 455 pre-selected tide gauge positions (from Church et al., 2004, selected for time series length and geodetic quality) have been used, in order to emulate a real reconstruction problem, though isolating the influences of tide gauge position and choice of calibration period. This analysis focuses on the influence of the character of the calibration period, and the resulting reconstruction error for various lengths of the calibration period. The influence of the prominent 1997/98 El Niño event has also been examined, showing a more Central Pacific El Niño-like pattern in the leading EOFs when excluding 1997/98 from the calibration period.

The error of the reconstruction with respect to known satellite altimetry for different lengths of the calibration period is shown in Figure 1. It appears that for calibration periods shorter than approximately 10 years, the error rapidly accumulates when moving away from the calibration, whereas the error seems largely stationary at a moderate level for longer calibration periods. This might be connected to the fact that all three reconstructions include 10 EOFs, and so may capture undesirable signals for the shortest period. To estimate the influence of geographical distribution, separate solutions have been made with only Northern Hemisphere and Southern Hemisphere gauges, respectively, see Figure 2. The MAF technique has been very preliminarily studied for this project, recovering some ENSO-like patterns, but with some work still needed to correctly handle masked-out areas in data grids.

Conclusions

The inclusion of a spatially uniform pattern (sometimes referred to as "EOF0") in the model basis has been found to be crucial in appropriately reconstructing global mean sea level, more so than the spatial distribution of tide gauges or the choice of the EOFs. This is in line with Christiansen et al. (2010), who also noted that the resulting performance is comparable to a simple arithmetic mean of the tide gauges; for improvement, they suggest using long-term climate simulations as an alternative way of obtaining the EOFs.

Regularization is of little concern for this preliminary analysis, since using actual altimetry data does not introduce the sparse coverage or possibly contradictory constraints of tide gauges. Indeed, it makes only a tiny difference in this study. In this case, limiting the choice of available to either hemisphere does not make much difference to the overall accuracy of the reconstruction; however, this study does not take into account the quality of the actual tide gauge data, only their spatial positions.

The MAF transform, while providing spatially "smooth" patterns, does not address the issue of missing data more than does the EOF. In addition, sea surface variability occurs on a variety of scales, including large-scale oscillation patterns like the ENSO and mesoscale phenomena, and any covariance across spatial scales may be poorly captured by the MAF transform.

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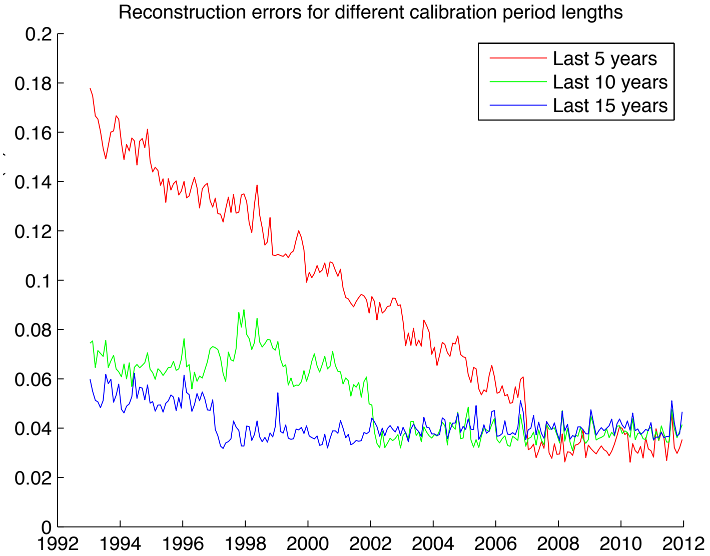

Figure 1: Global mean reconstruction error (with respect to satellite altimetry) for different calibration periods (shown in legend). All reconstructions shown include 10 EOFs in addition to an EOF0, and are fitted to the pseudo-tide gauges using an OLS fit. All tide gauge locations from the PSMSL database are used.

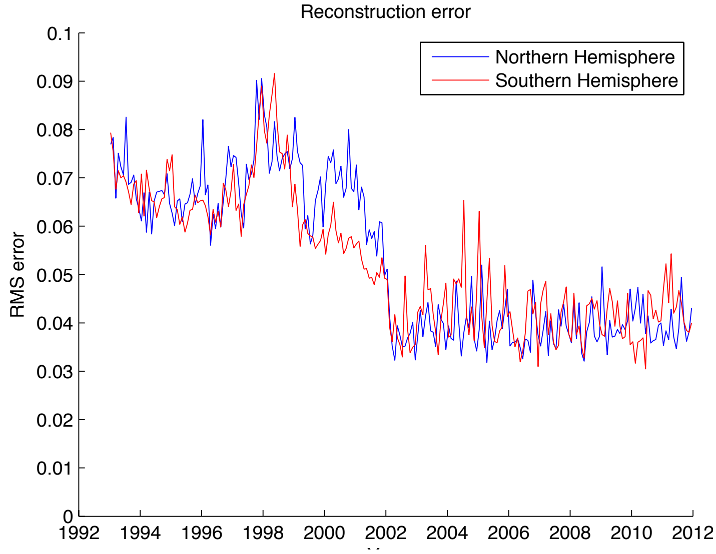

Figure 2: Global mean reconstruction error (with respect to satellite altimetry) for calibration patterns fitted to gauges only in the Northern or Southern Hemisphere, respectively. 364 of the 455 gauges used are in the Northern Hemisphere, while the remaining 91 are in the Southern Hemisphere. All reconstructions shown include 10 EOFs in addition to an EOF0, and are fitted to the pseudo-tide gauges using a Kaplan-based model.

Modeling Sea Level Rise and Ice Sheet Evolution using the Community Ice Sheet Model within the Community Earth System Model

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Introduction

Predicting future sea level rise requires comprehensive ice sheet models that can capture the important dynamics within the ice sheet. In addition, such an ice sheet model must be coupled with an Earth System Model to address the response of the ice sheets to future changes in forcing, including both the surface mass balance and melting due to ocean waters reaching the ocean-ice shelf interface. This brief note describes recent progress in developing the Community Ice Sheet Model (CISM) and coupling this model within the Community Earth System Model (CESM). A broad set of activities is described, including ice sheet dynamics, subglacial hydrology, surface mass balance and ocean-ice shelf coupling.

The Community Ice Sheet Model (CISM)
The CISM effort is focused on developing an ice sheet model suitable for use within coupled climate models for projections of future sea level rise. Initially, CISM started with the Glimmer model that simulated ice sheet dynamics based on the shallow ice approximation on uniform, rectilinear grids (Rutt et al. 2009). Initial development focused on coupling Glimmer with the CESM model (see below).

More recently, the dynamics of the model has been upgraded to a higher-order approximation to the full Stokes model, namely the first-order scheme of Blatter and Pattyn (2003). Improved solvers and domain-decomposition based parallelism were also implemented to allow for efficiency on larger computational grids and at higher resolution (Lemieux et al. 2011; Evans et al. 2012). This higher-order, parallel implementation of CISM formed the basis for simulations that were included in the SeaRISE (Bindschadler et al. 2013) and Ice2Sea (Edwards et al. 2013a; Edward et al. 2013b; Shannon et al. 2013) intercomparison efforts. Model output compares reasonably well with observed ice flow and, when perturbed with observational time series of changing ice flux, with observed ice sheet elevation changes (Price et al. 2011).

Current projects are developing new dynamical formulations on variable-resolution horizontal grids. Variable-resolution