Semi-empirical sea-level modelling

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Semi-empirical sea-level models (SEMs) exploit physically motivated empirical relationships between global sea level and certain drivers, in this thesis it is global mean temperature. This model class evolved as a supplement to process-based models (Rahmstorf (2007)) which were unable to fully represent all relevant processes. They thus failed to capture past sea-level change Rahmstorf *et al.* (2012) and were thought likely to underestimate future sea-level rise. Semi-empirical models were found to be a fast and useful tool for exploring the uncertainties in future sea-level rise, consistently giving significantly higher projections than process-based models.

In this thesis different aspects of semi-empirical sea-level modelling have been studied. Models were first validated using various data sets of global sea-level and temperature. SEMs were then used on the glacier contribution to sea level, and to infer past global temperature from sea-level data via inverse modelling. Periods studied encompass the instrumental period covered by tide gauges (starting 1700 CE (Common Era) in Amsterdam) and satellites (first launched in 1992 CE), the Common Era from -1000 CE onwards, and the full length of the Holocene (using proxy data). Accordingly different data, model formulations and implementations have been used.

It could be shown in Bittermann *et al.* (2013) that SEMs correctly predict 20th century sea-level when calibrated with data until 1900 CE. SEMs also turned out to give better predictions than the Intergovernmental Panel on Climate Change (IPCC) 4th assessment report (AR4, IPCC (2007)) models, for the period from 1961–2003 CE.

With the first multi-proxy reconstruction of global sea-level as input, estimates of the human-induced component of modern sea-level change and projections of future sea-level rise were calculated (Kopp *et al.* (2015)). It turned out with 90% confidence that more than 50% of the observed 20th century sea-level rise is indeed anthropogenic. With the new semi-empirical and IPCC (2013) 5th assessment report (AR5) projections the gap between SEM and process-based model projections closes, giving higher credibility to both. Combining all scenarios, from strong mitigation to business as usual, a global sea-level rise of 25–121 cm relative to 2000 CE, is projected with 90% confidence. The decision for a low carbon pathway could almost halve the expected global sea-level rise by 2100.

Present day temperature and thus sea level is driven by the globally acting greenhouse-gas forcing. Unlike that, the orbital forcing, acting on Holocene timescales, results mainly in a northern-hemisphere temperature change. Therefore a semi-empirical model can be driven with northern-hemisphere temperatures, which makes it possible to model the main subcomponent of sea-level change over this period. It showed that an additional positive constant rate of the order of the estimated Antarctic sea-level contribution is then required to explain the sea-level evolution over the Holocene. Thus the late Holocene sea-level can be interpreted as the sum of a temperature induced sea-level drop and a positive long-term contribution, likely an ongoing response to deglaciation coming from Antarctica.

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