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Modeling Sea-Level Change using Errors-in-Variables Integrated Gaussian Processes

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We perform Bayesian inference on historical and late Holocene (last 2000 years) rates of sea-level change. The data that form the input to our model are tide-gauge measurements and proxy reconstructions from cores of coastal sediment. To accurately estimate rates of sea-level change and reliably compare tide-gauge compilations with proxy reconstructions it is necessary to account for the uncertainties that characterize each dataset. Many previous studies used simple linear regression models (most commonly polynomial regression) resulting in overly precise rate estimates. The model we propose uses an integrated Gaussian process approach, where a Gaussian process prior is placed on the rate of sea-level change and the data itself is modeled as the integral of this rate process. The non-parametric Gaussian process model is known to be well suited to modeling time series data. The advantage of using an integrated Gaussian process is that it allows for the direct estimation of the derivative of a one dimensional curve. The derivative at a particular time point will be representative of the rate of sea level change at that time point.

The tide gauge and proxy data are complicated by multiple sources of uncertainty, some of which arise as part of the data collection exercise. Most notably, the proxy reconstructions include temporal uncertainty from dating of the sediment core using techniques such as radiocarbon. As a result of this, the integrated Gaussian process model is set in an errors-in-variables (EIV) framework so as to take account of this temporal uncertainty. The data must be corrected for land-level change known as glacio-isostatic adjustment (GIA) as it is important to isolate the climate-related sea-level signal. The correction for GIA introduces covariance between individual age and sea level observations into the model.

The proposed integrated Gaussian process model allows for the estimation of instantaneous rates of sea-level change and accounts for all available sources of uncertainty in tide-gauge and proxy-reconstruction data. Our response variable is sea level after correction for GIA. By embedding the integrated process in an errors-in-variables (EIV) framework, and removing the estimate of GIA, we can quantify rates with better estimates of uncertainty than previously possible. The model provides a flexible fit and enables us to estimate rates of change at any given time point, thus observing how rates have been evolving from the past to present day.