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Sea level change since the Pliocene – a new formalism for predicting sea level in the presence of dynamic topography and isostasy

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Dynamic topography (DT), as reflected in local sea level change, provides a unique lens for studying the imprint of deep Earth dynamics on the Earth's surface. The elevation of paleo-shorelines over long time scales is, however, not only perturbed by DT but also by glacial isostatic adjustment (GIA) and eustatic changes in sea level. Isolating these contributions is essential for efforts to constrain past changes in ice volume or mantle convection models. Previous studies have performed this separation by modeling dynamic topography and superimposing the signal on the elevation of a GIA-corrected paleo-shoreline. However, this approach neglects deformation of the Earth in response to changes in the ocean load and geometry driven by DT. We describe a generalized, gravitationally self-consistent framework for computing sea-level changes that incorporates DT and GIA. The formalism is based on a sea-level theory developed within the GIA community that takes accurate account of viscoelastic deformation of the solid Earth, perturbations in the gravity field, migration of shorelines and the feedback into sea-level of contemporaneous (load-induced) changes in Earth rotation. Specifically, dynamic topography is introduced as a perturbation to the elevation of the solid surface that does not load the Earth because it is dynamically supported. However, water that is displaced by DT is allowed to redistribute, perturb the gravitational field and load (or unload) the ocean floor wherever the water column is increased (or decreased). The problem is complicated by plate tectonics, which (in a tectonic reference frame) leaves changes in topography and DT undefined in areas of the ocean floor where plates have been subducted. We interpolate these regions by imposing mass conservation of both the solid Earth and water on the reconstructed topography.

We use the new formalism to calculate sea level change since the mid-Pliocene (3 Ma) using recent global simulations of dynamic topography that are constrained to fit a large suite of modern geophysical observables. We demonstrate that the results differ significantly from calculations in which dynamic topography is simply added to the elevation of GIA-corrected paleo-shorelines. Moreover, we apply these results to new paleo-shoreline data of Pliocene age from the US east coast, South Africa and southwest Australia to estimate peak eustatic sea level (and, thus, minimum ice volume) during the Mid Pliocene Warm Period.