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Regional variability in particulate organic matter remineralization depths: an optimization and sensitivity study using a fast Earth system model

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Nutrient distributions and atmospheric CO_2 concentrations are sensitive to changes in the global average depth of particulate organic matter (POM) remineralization in models. Model optimization studies have used this sensitivity to find global mean remineralization depths that result in the statistically best fit to tracer observations such as phosphate (PO_4). However, recent global syntheses of sediment trap data have started to suggest the existence of significant spatial variability in the depth of POM remineralization. A number of hypothetical mechanisms have been proposed to explain this variability invoking a wide range of feedbacks on atmospheric CO_2. Progress has been hindered by the relatively low sampling density of sediment trap data. In response to this, we explore whether there is an optimal set of regionally variable remineralization depths in an Earth system model that best fits observed PO_4 fields and how robust these solutions are.

We develop a new computationally fast phosphorous-only version of the Earth system model GENIE using a transport matrix to represent steady-state circulation. The ocean is divided into 15 biogeochemical biomes within which the remineralization depth is an independent parameter. Latin hypercube sampling is used to produce an ensemble of runs that efficiently sample across the range of potential combinations of remineralization depths, producing probability distributions for each region. Despite sensitivity to the global remineralization depth, we find that PO_4 is actually relatively insensitive to regional changes in remineralization. An optimal combination of remineralization depths in the Atlantic is found that predicts deeper remineralization in the low latitudes and shallower at high latitudes, matching sediment trap observations. Shallow remineralization is also predicted in the North Pacific. However, remineralization depths in the Southern Ocean, South and Equatorial Pacific, and Indian Ocean cannot be successfully constrained. We discuss whether these results reflect underlying mechanisms or alternatively reflect deficiencies in the modelled ocean circulation. Our results suggest that nutrient observations, such as PO_4, may not be able to distinguish reliably between mechanistic models of the biological pump. This has important implications for feedbacks on atmospheric CO_2.