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Constraining marine calcium carbonate export and dissolution with a global ocean alkalinity model

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Ocean alkalinity is a fundamental control on the apportionment of CO2 between the atmosphere and the ocean. The primary driver of the ocean's vertical alkalinity distribution is the production of calcium carbonate (CaCO3) by marine organisms at the ocean's surface, and its dissolution at depth. This so-called “CaCO3 counterpump” is poorly constrained in: a) how much CaCO3 is exported from the ocean's surface, and b) at what depth CaCO3 dissolves to return alkalinity to the water column. Here, we created a steady-state 3-D model of global ocean alkalinity using Ocean Circulation Inverse Model (OCIM) transport, biogeochemical cycling as implemented in the AWESOME OCIM framework, and our most recent formulations of calcite and aragonite dissolution kinetics. We investigated four potential mechanisms to describe CaCO3 dissolution, each optimized to match observed alkalinity distributions in all ocean basins: benthic dissolution only, kinetics-driven dissolution below the aragonite and calcite saturation horizons, kinetics-driven dissolution combined with dissolution driven by organic matter respiration, and a constant dissolution scenario. We find that models allowing dissolution above the saturation horizons best match observations, whereas limiting CaCO3 dissolution to below the aragonite and calcite saturation horizons cannot explain excess alkalinity in the upper ocean. Our best performing models require export between 1.1 and 1.8 Gt PIC y-1 out of 73 m, but converge to 1.0 Gt PIC y-1 export at 279 m, indicating that both high- and low-export scenarios can match observations, but high export must be coupled to high dissolution in the upper ocean to effectively recycle alkalinity. Models linking dissolution to organic matter respiration, or imposing a constant dissolution rate, yield relatively similar dissolution profiles below ~500 m, with dissolution exceeding that expected from CaCO3 undersaturation alone. These results demonstrate that dissolution is not a simple function of seawater CaCO3 saturation (Ω) and calcite or aragonite solubility, and that other mechanisms must drive significant dissolution throughout the entire water column.