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Modeling the modern oceanic cycle of beryllium isotopes

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Beryllium isotopes, namely cosmogenic meteoric ^{10}Be and stable ^{9}Be, enter the oceans through distinct pathways. Beryllium-10 is produced in the atmosphere and primarily enters the oceans via precipitation, whereas ^{9}Be is sourced from continents. These beryllium isotopes, with a short oceanic residence time (10^2-10^3 years), exhibit non-conservative behavior in seawater. The ratios of ^{10}Be/^{9}Be have been employed as a powerful tool for quantifying various processes, including geomagnetism, sedimentation, continental input, and ocean circulation. Many efforts have been dedicated to understanding the external sources and internal cycling of Be isotopes over the past decade. This presents an excellent opportunity to revisit their modern oceanic cycle.

We here investigate the factors controlling the modern oceanic cycling of Be isotopes using a three-dimensional ocean biogeochemical model, constrained by water-column distributions of ^{9}Be and ^{10}Be compiled from the literature. In addition to modeling previously identified controls, we emphasize the crucial role of marine benthic fluxes and scavenging onto particulate organic matter and opal in regulating the mass balance and spatial distribution of Be isotopes. The transport of Be isotopes between basins by circulation is of lesser importance compared to external inputs at continent/atmosphere–ocean boundaries, except in the South Pacific. As a result, the basin-wide ^{10}Be/^{9}Be ratio primarily reflects the pattern of external inputs across most basins in the modern ocean. Based on our data-constrained oceanic model, we can further assess the sensitivity of basin-wide ^{10}Be/^{9}Be ratios to changes in external sources, such as continental denudation, and internal cycling, such as particle scavenging. The mechanistic understanding developed from this Be cycling model provides important insights into the various applications of marine Be isotopes and offers additional tools to evaluate the individual effects of environmental factors on cosmogenic ^{10}Be/^{9}Be records in marine sediments.