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Calcite and aragonite undersaturation under rising atmospheric CO_2 and global warming

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Magnitude and pattern of ocean acidification due to increasing atmospheric CO_2, both for the recent past and the near future, will be investigated using the reduced complexity, Bern2.5D physical-biogeochemical climate model and a series of IPCC emission scenarios and stabilization profiles. We specifically study the impact of global warming and induced ocean circulation changes on the projected ocean pH and carbonate ion reductions. Projected changes in surface pH, carbonate ion concentration and $CaCO_3$ saturation states compare well with earlier studies. Estimated pH changes since preindustrial times for the present are close to 0.1. For stabilization of atmospheric CO_2 at 1000 ppm (scenario WRE1000), corresponding to the upper end of atmospheric CO_2 levels applied, and year 2100 (year 2500), high latitude surface pH is projected to decrease by up to 0.35 (0.65) compared to the preindustrial state, and high latitude surface waters will become undersaturated in both calcite and aragonite after 2100. Global warming slightly moderates changes induced by anthropogenic CO_2 (by 10% at most) due to the reduced oceanic CO_2 uptake. Global warming also delays undersaturation with respect to both aragonite and calcite by about 25 years in Southern Ocean and North Atlantic surface waters. In the extreme case of a complete shutdown of the North Atlantic Deep Water formation after 2100 and a large-scale reorganization of the global thermohaline circulation in scenario WRE1000, undersaturation becomes largest in the North Atlantic ocean by the end of year 2200, due to the associated large changes in surface salinity. Modeled changes in export production have a minor impact on ocean acidification levels and $CaCO_3$ saturation states in all scenarios.