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The 20th and 21st Century ocean carbon cycle in CESM1

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Accurate representation of oceanic carbon uptake and its climate sensitivity is integral to robust climate prediction. Here, we present results from 20th and 21st Century integrations performed with the recently-released Community Earth System Model version 1 (CESM1). CESM1 is a fully-coupled global climate model consisting of land, atmosphere, ocean, and sea ice components. An ocean biogeochemistry module represents air-sea CO2 exchange, carbonate system chemistry, and ecosystem sources and sinks of carbon. Using available observations, we document model skill in representing the mean state of the ocean carbon cycle, with a focus on air-sea fluxes and anthropogenic carbon uptake. We examine trends and variability in air-sea CO2 exchange. Finally, we consider the future behavior of the ocean carbon sink under various emission scenarios. CESM1 has a robust representation of the seasonal cycle and spatial distribution of air-sea fluxes; however, as is common with ocean general circulation models, the largest data-model discrepancies are found in the Southern Ocean. While the overall spatial pattern of 20th Century anthropogenic carbon uptake is well simulated, low biases appear in Antarctic Intermediate and Mode Water formation regions, and North Atlantic deepwater formation appears too vigorous. The Equatorial Pacific and high-latitude regions exhibit the strongest interannual variability in air-sea CO2 fluxes. Late-20th Century trends in contemporary and anthropogenic CO2 fluxes are maximum in the Southern Ocean; these trends, however, are significantly different in fully-coupled versus ocean-ice integrations (in the latter the ocean model is forced with atmospheric observations), pointing to a strong regional sensitivity to atmospheric forcing. Substantial reductions in rates of oceanic carbon uptake are evident in the mid- to late-21st Century, depending on the climate forcing scenario. Changes in the oceanic carbon sink are a result of shifts in circulation patterns as well as feedbacks affecting saturation state and biologically mediated fluxes. Our results provide insight into the present and future dynamics of oceanic carbon uptake and its climate sensitivity. Furthermore, we provide a clear view of the capabilities and short-comings of the ocean carbon-cycle representation in a state-of-the-art, fully-coupled, Earth System model.