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Nitrogen fixation as a key diverging factor of primary production projections in the subtropical North Atlantic Ocean in CMIP6 models

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Human-induced climate change is expected to have a significant impact on primary production in the world's oceans, affecting marine ecosystems and the biological carbon pump. The sixth phase of the Coupled-Models Intercomparison Project (CMIP6) provides a common tool for investigating this impact. However, the extent and direction of the impact can vary widely among these models, partly due to the diverse representations of oceanic biogeochemistry. A comprehensive analysis of the biogeochemistry component in each model is therefore crucial for understanding the origins of diverse responses to similar environmental forcings. In this context, we focused on primary production projections in the subtropical North Atlantic Ocean under the RCP5-8.5 scenario in eight CMIP6 models. To ensure comparability across models with different ocean dynamics, a subtropical region was constructed in the observations using satellite and in-situ measurements from 2000 to 2020. A classification procedure based on a Self-Organizing Maps algorithm was applied to the entire North Atlantic Ocean, and the resulting classification was then used to identify the closest subtropical region in each model. While the eight regions obtained were similar in terms of location and physical boundaries, their surfaces varied from 19.1 to 24.1 million km². Among the eight models, three projected an increase in primary production in the region (up to +19.5 g-C/m2/yr), while the remaining five predicted a decrease (down to -33.4 g-C/m2/yr), despite a consistent decrease of nitrate concentrations across models. Nitrogen fixation, a crucial source of nitrogen in the area, emerged as a key differentiating factor among these models. Three of them (IPSL-CM6A-LR, CanESM5-CanOE, CanESM5) featured an implicit representation of diazotrophy, with no effective control from other nutrients. This led to a substantial increase in nitrogen fixation under the influence of rising temperatures. In IPSL-CM6A-LR and CanESM5-CanOE, the heightened nitrogen fixation sustained ammonium concentrations, enabling an increase in primary production with NH4 serving as an alternative nitrogen source. However, in CanESM5, where only one nitrogen pool was represented, the increase in nitrogen fixation was insufficient to offset the nitrogen decrease, resulting in a decline in primary production. In the models with an explicit representation of diazotrophs (MPI-ESM1-2-LR, CESM2, CESM2-WACCM), primary production was limited by declining phosphate concentrations, leading to a decrease in both nitrogen fixation and primary production. Finally, in models without any representation of

nitrogen fixation, primary production decreased when nutrients were initially limiting (UKESM1-0-LL) and increased if they were not (ACCESS-ESM1-5). In conclusion, biogeochemical models with a more realistic representation of diazotrophy consistently projected a decline in primary production in the subtropical North Atlantic Ocean throughout the 21st century. The increases observed in some models were attributed to the absence or inadequate representation of interactions between phosphate, ammonium, and diazotrophy, making such scenarios unlikely. Consequently, an explicit representation of diazotrophs seems necessary for projecting the primary production response to climate change in the subtropical North Atlantic Ocean.