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Projection of Global Coccolithophore Abundance Based on the CMIP6 from Machine Learning Perspective

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Coccolithophores play a fundamental role in the marine carbon cycle, yet projecting their future changes under climate forcing remains challenging. In this study, we developed a machine learning framework to project global coccolithophore abundance in the modern surface ocean and under different climate scenarios. Our model was built upon integrated datasets of in-situ observations, including sea surface temperature (SST), nutrients, carbonate system parameters, and records of field-measured cell abundance and mean biovolume data for various coccolithophore species. Climate simulations from the CMIP6 GFDL-ESM4 model were used for projecting future scenarios. Of the four candidate architectures evaluated in our study, XGBoost was the best model producing results with the highest correlation and lowest root mean square error relative to observations. The reliability of our model was also independently validated by comparing the projected coccolithophore distribution in the modern ocean against MODIS/Aqua Particulate Inorganic Carbon products. Mean biovolume, aqueous CO_2, and SST were identified as the three dominant predictors by SHAP analysis, highlighting the primacy of cell size, carbonate chemistry, and temperature in controlling coccolithophore distribution. Relative to the historical baseline, both SSP2-4.5 and SSP5-8.5 scenarios project increased coccolithophore abundance across much of the low-latitude ocean, especially between 10°S and 20°N, while declines in coccolithophores are projected for regions in the Southern Ocean. High coccolithophore abundance is expected to persist in tropical and subtropical oceans through the end of the 21st century under both scenarios. Notably, coccolithophores of different sizes exhibit distinct spatial response patterns to climate forcing, likely due to their differential sensitivity to changes in carbonate chemistry, highlighting a potential shift in coccolithophore community structure under climate change, with implications for the efficiency of the biological carbon pump.