Quantifying environmental drivers of phytoplankton and carbon dynamics through data-driven models

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Phytoplankton, as the foundation of marine food webs, plays a critical role in oceanic ecosystems and global biogeochemical cycles. Comprehensive characterization of phytoplankton dynamics requires the integration of multidisciplinary data, including biological, biogeochemical, and physical variables. This study demonstrates a novel approach linking diverse data sources from the Blue-Cloud data lake, providing interoperable workflows within a Blue-Cloud Virtual Laboratory (VLab). The workflow combines long-term zooplankton and phytoplankton observations from EMODnet Biology with carbon data from Integrated Carbon Observation System (ICOS) and Surface Ocean CO_2 Atlas (SOCAT), and environmental parameters such as sea surface temperature and nutrient concentrations from EMODnet Chemistry. These heterogeneous datasets can be used to identify anomalies in long-term trends and quantify the contributions of key environmental drivers to plankton essential ocean variables (EOVs).

A mechanistic NPZD (Nutrient-Phytoplankton-Zooplankton-Detritus) model, was employed alongside an algorithm to estimate carbon sequestration by the biological carbon pump. The NPZD model simulates phytoplankton dynamics by integrating bottom-up drivers (nutrient availability, photosynthetically active radiation, and temperature) and top-down drivers (zooplankton grazing). Using near real-time data, the model visualizes the temporal contributions of these drivers to phytoplankton abundance and estimates carbon fluxes based on the marine carbon pump process, which governs carbon transfer from surface waters to the seafloor through detrital sinking and decomposition.

Model validation was conducted by comparing predictions of both phyto- and zooplankton biomass, and partial pressure of carbon dioxide of the seawater ($pCO_{2,\ seawater}$) with field observations, using the Root Mean Square Error (RMSE). Parameter sensitivity analysis and selection of the best-performing simulations (top 10% based on RMSE) allowed estimation of confidence intervals around predictions. This model is fully accessible through the Virtual Research Environment of Blue-Cloud 2026. This study highlights the potential of data-driven marine ecosystem modelling, with applications for future scenario testing and ecosystem management.

Keywords
Biogeochemical Modelling; Plankton Dynamics; Carbon Sequestration; Marine Ecology; Environmental Conditions