From surface optics to subsurface ecosystem structure: how reflectance assimilation propagates beyond biogeochemistry

Polina Verezemskaya[1], L. Macé[1], L. Vandenbulcke[1], P. Brasseur[2], J.-M. Brankart[2], M. Grégoire[1]

[1] Modelling for Aquatic Systems research group, FOCUS, University of Liège, Sart-Tilman, B5a, 4000, Liège, Belgium
[2] Université Grenoble Alpes, CNRS, INRAE, IRD, Grenoble INP, Institut des Géosciences de l'Environnement (IGE), Grenoble, France

Abstract

Scarcity of observational data for ocean biogeochemistry (BGC) poses a major challenge for calibration and validation of BGC ocean models and data assimilation. Unlike temperature or salinity, BGC variables are often inferred from remote sensing or limited in-situ measurements. Recent developments in ocean-color-based data assimilation show that, while effective, such approaches remain dependent on retrieval assumptions (Brewin et al., 2017). Advances in multispectral satellite remote-sensing reflectance now provide new opportunities for model development and data assimilation.

In this study, we use an Ensemble Kalman Filter-based data assimilation system (OAK; Barth and Vandenbulcke, 2017) to assimilate remote-sensing reflectance (R_{RS}) and correct the ocean biogeochemical state: 3 phytoplankton functional types, particulate organic carbon, and three zooplankton types. To explicitly simulate observation-like reflectances, we employ a coupled ocean physical–biogeochemical–radiative transfer model of the Black Sea (Macé et al., 2025). An ensemble of 20 members, obtained by perturbing optical properties, estimates model uncertainty. For testing the assimilation protocol, we use a twin-experiment approach. A deterministic experiment generates synthetic observations that are then assimilated. Although observations are limited to the surface, corrections are applied across model levels, allowing the signal to propagate to depth through the multivariate covariances of the EnKF.

Our results demonstrate that assimilation of surface reflectance effectively improves ensemble metrics (MAE, CRPS, etc.) compared to a non-assimilative ensemble at both the surface and at depth. Beyond direct corrections to assimilated variables, the coupled model propagates observational updates into photosynthetically available radiation (PAR), dissolved oxygen, chlorophyll, and deep chlorophyll maximum (DCM) depth — reducing DCM depth bias by 95%. We further show that reflectance-based assimilation serves as a diagnostic of model dynamics: correction propagation pathways reveal structural model limitations that can be identified and tracked within the assimilation framework.