Supporting Information for "Improved consistency between the modelling of ocean optics, biogeochemistry and physics, and its impact on the North-West European Shelf seas"

Jozef Skákala[1,2], Jorn Bruggeman[1], David Ford[3], Sarah Wakelin[4], Anıl Akpınar[4], Tom Hull[5,6], Jan Kaiser[6], Benjamin R. Loveday[7], Charlotte A.J. Williams[4]and Stefano Ciavatta[1,2]

[1]Plymouth Marine Laboratory, The Hoe, Plymouth, PL1 3DH United Kingdom.

[2]National Centre for Earth Observation, Plymouth, PL1 3DH, UK.

[3]Met Office, FitzRoy Road, Exeter, EX1 3PB UK.

[4]National Oceanography Centre, Joseph Proudman Building, 6 Brownlow Street, Liverpool, L3 5DA UK.

[5]Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, NR33 0HT UK.

[6]Centre for Ocean and Atmospheric Science, University of East Anglia, Norwich, NR4 7TJ, UK.

[7]Innoflair UG, Richard-Wagner-Weg 35, 64287, Darmstadt, Germany.

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Figures

The panels in the Fig.S1-S10 use the following abbreviations: "free 1-way": free run of the one-way coupled model, "free 2-way": free run of the two-way coupled model, "phys

DA 1-way": physical data assimilation into the one-way coupled model, "phys DA 2-way": physical data assimilation into the two-way coupled model, "chl DA 1-way": chlorophyll assimilation into the one-way coupled model, "chl DA 2-way": chlorophyll assimilation into the two-way coupled model, "phys+chl DA 1-way": joint physical data - chlorophyll assimilation into the one-way coupled model, "phys+chl DA 2-way": joint physical data - chlorophyll assimilation into the two-way coupled model.

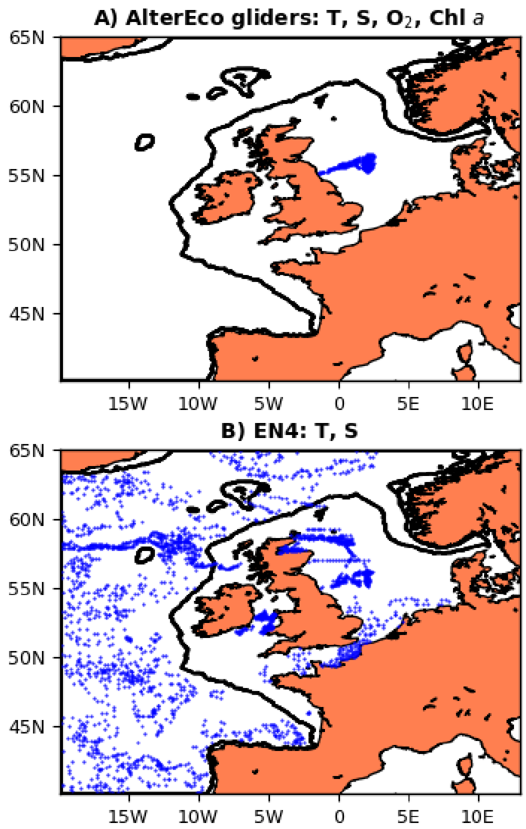

Figure S1. The locations of the 2018 in situ data used both for the assimilation and the validation. The panel A shows the locations of the AlterEco glider measurements and the bottom panel B shows the locations of the EN4 data for temperature and salinity. The EN4 data located outside of the NWE Shelf (bounded by the black line) were used only for assimilation, not for validation.

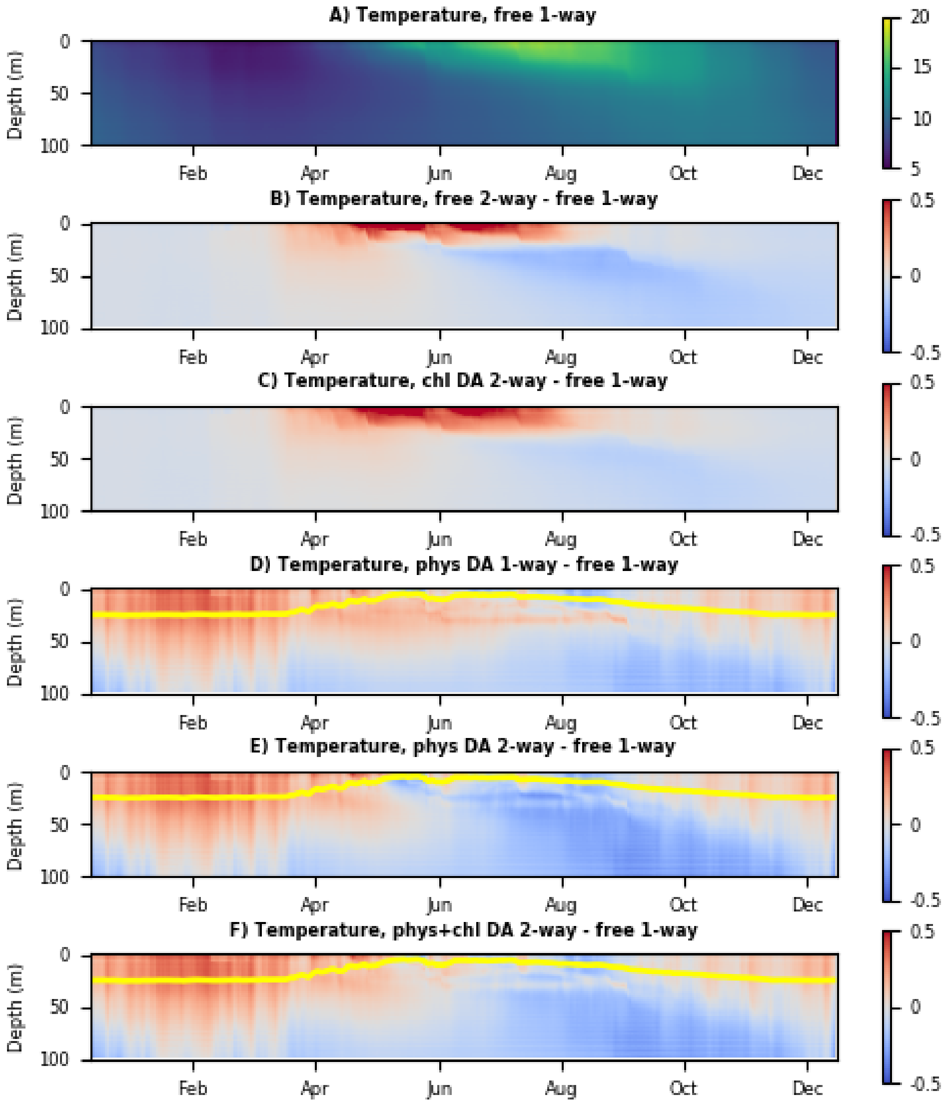

Figure S2. The panel A shows Hovmöller diagram (time on the x-axis vs depth on the y-axis) for the temperature (C) of the one-way coupled free run ("free 1-way"), where the values for each day and depth represent the horizontal spatial averages throughout the NWE Shelf (bathymetry < 200m). Panels B-F show the same Hovmöller diagrams, but for the differences between the two-way coupled, or assimilative runs and the reference, free one-way coupled model run. The purpose of the panels B-F is to provide an understanding of how the bio-optical module and the assimilative model components influence the temperature of the reference free one-way coupled run. The yellow lines in the panels D-F show the MLD of the physical data assimilative runs to indicate the vertical scale of impact of the SST assimilation.

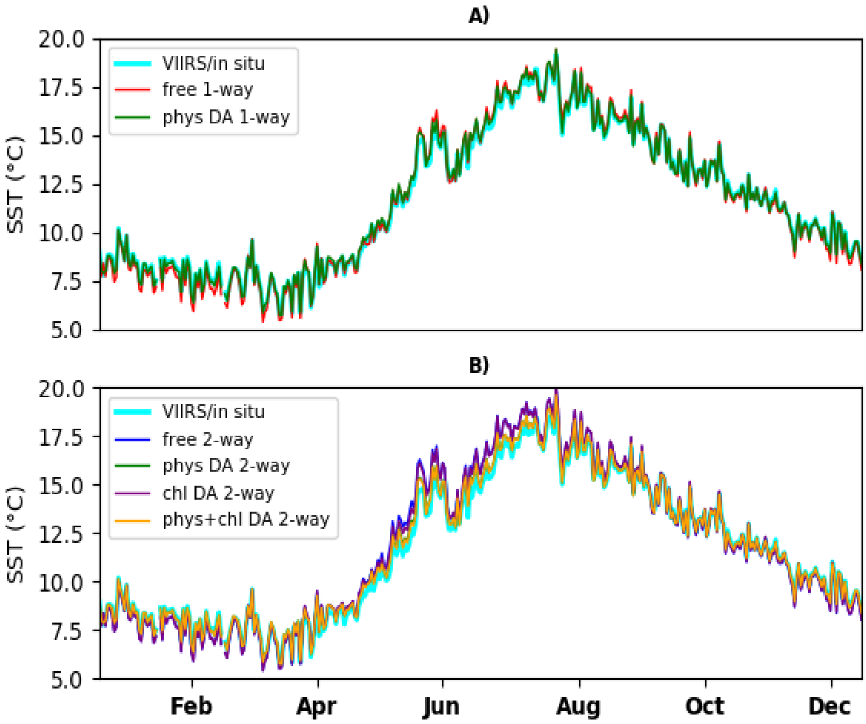

Figure S3. The 2018 time-series of SST averaged throughout the NWE Shelf compared between the different one-way, two-way coupled, free, or assimilative simulations and the VIIRS/in situ data. Panel A compares the different one-way coupled runs, i.e. the one-way coupled free run with the physical data assimilative run, panel B compares the different two-way coupled runs, i.e. the two-way coupled free run with the physical data assimilative run, the chlorophyll assimilative run and the run assimilating both physical data and chlorophyll. To consistently compare the model simulations with the VIIRS/in situ SST, the model outputs were masked wherever there were missing satellite data. The missing satellite data are due to the movements of clouds and atmospheric disturbances and the missing values are responsible for the small time-scale fluctuations in the different curves shown in the three panels. We do not show the one-way coupled runs assimilating chlorophyll, as those have by definition no impact on the simulated temperature.

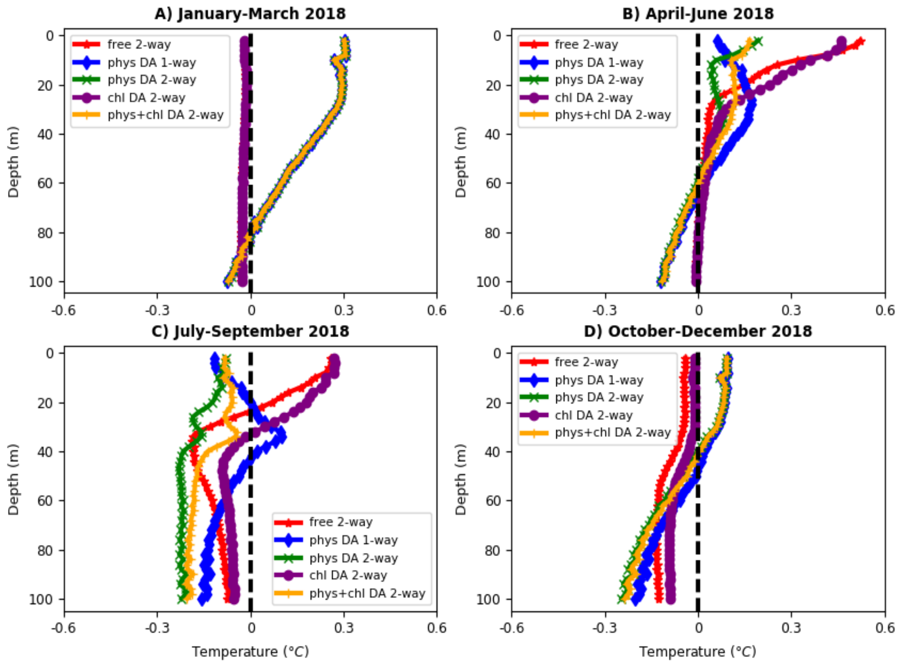

Figure S4. The seasonal differences in temperature (x-axis, °C) between the two-way coupled, or assimilative runs and the reference, one-way coupled free run. The differences are shown as a function of depth (y-axis, m), and averaged throughout the seasonal period and the NWE Shelf.

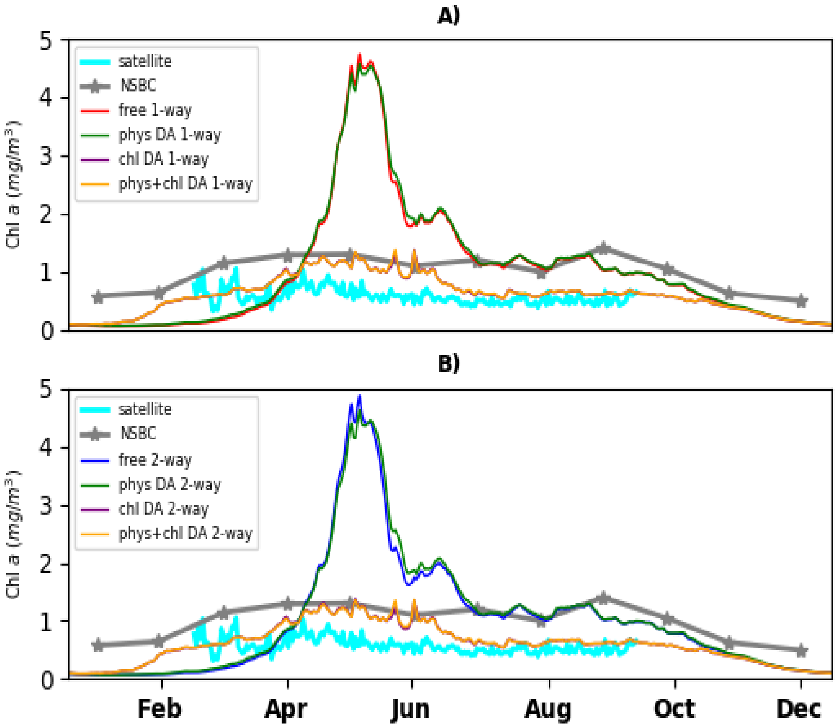

Figure S5. The 2018 time-series of surface chlorophyll *a* concentrations (mg/m^3) averaged throughout the NWE Shelf compared between the different one-way, two-way coupled, free, or assimilative simulations and the satellite data, as well as with the NSBC climatological data-set. Panel A compares the different one-way coupled runs, i.e. the one-way coupled free run with the physical data assimilative run, the chlorophyll assimilative run and the joint physical data-chlorophyll assimilative run, panel B compares the different two-way coupled runs, i.e. the two-way coupled free run with the physical data assimilative run, the chlorophyll assimilative run and the joint physical data-chlorophyll assimilative run. The chlorophyll assimilative run from both panels A and B is hard to see, as the line is nearly identical with the joint physical-chlorophyll assimilative run. The satellite data were considered only in the March-September period as the data outside this period are scarce and limited only to the southern part of the NWE domain. The small time-scale fluctuations in the satellite data are due to the missing values caused by the movement of clouds and atmospheric disturbances.

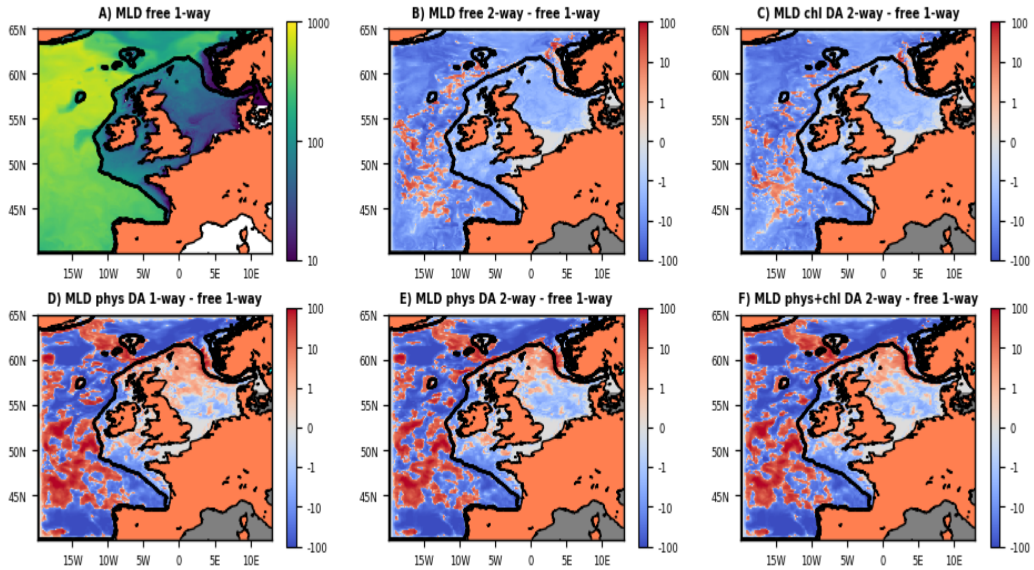

Figure S6. Panel A shows the mixed layer depth (MLD, in m) of the one-way coupled free run (the reference run). The MLD values are averaged for the spring bloom period between March-May 2018. The panels B-F show the relative changes (relative to the one-way coupled free reference run, in m) in MLD carried by the two-way coupled free run (panel B), chlorophyll assimilation into the two-way coupled model (panel C), physical data assimilation into the one-way coupled (panel D) and into the two-way coupled model (panel E) and the joint physical data-chlorophyll assimilation into the two-way coupled model (panel F). All panels B-F show the difference between the MLD of the specific two-way coupled, or assimilative simulation and the one-way coupled free run (panel A). The black line shows the boundary of the continental shelf (bathymetry $<$ 200m).

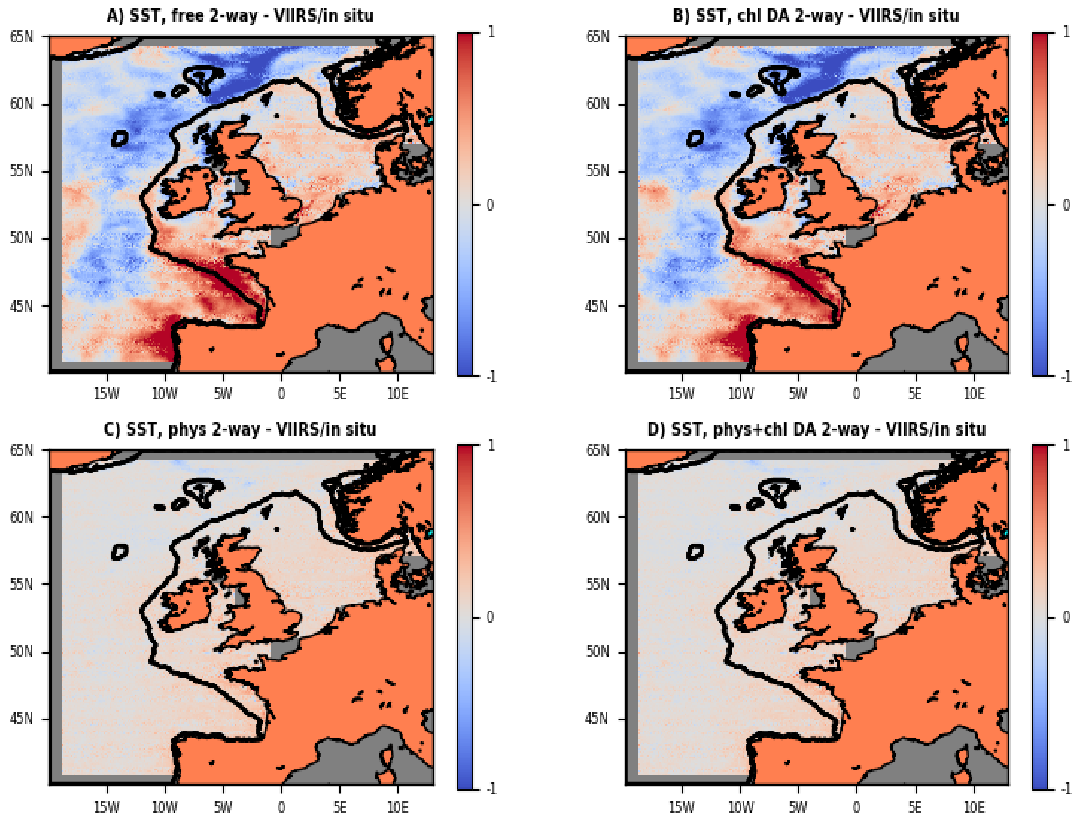

Figure S7. The model to VIIRS/in situ SST differences in °C. The differences are shown for the: free two-way coupled model (panel A), physical data assimilation into the two-way coupled model (panel B), chlorophyll assimilation into the two-way coupled model (panel C), and joint physical data-chlorophyll assimilation into the two-way coupled model (panel D).

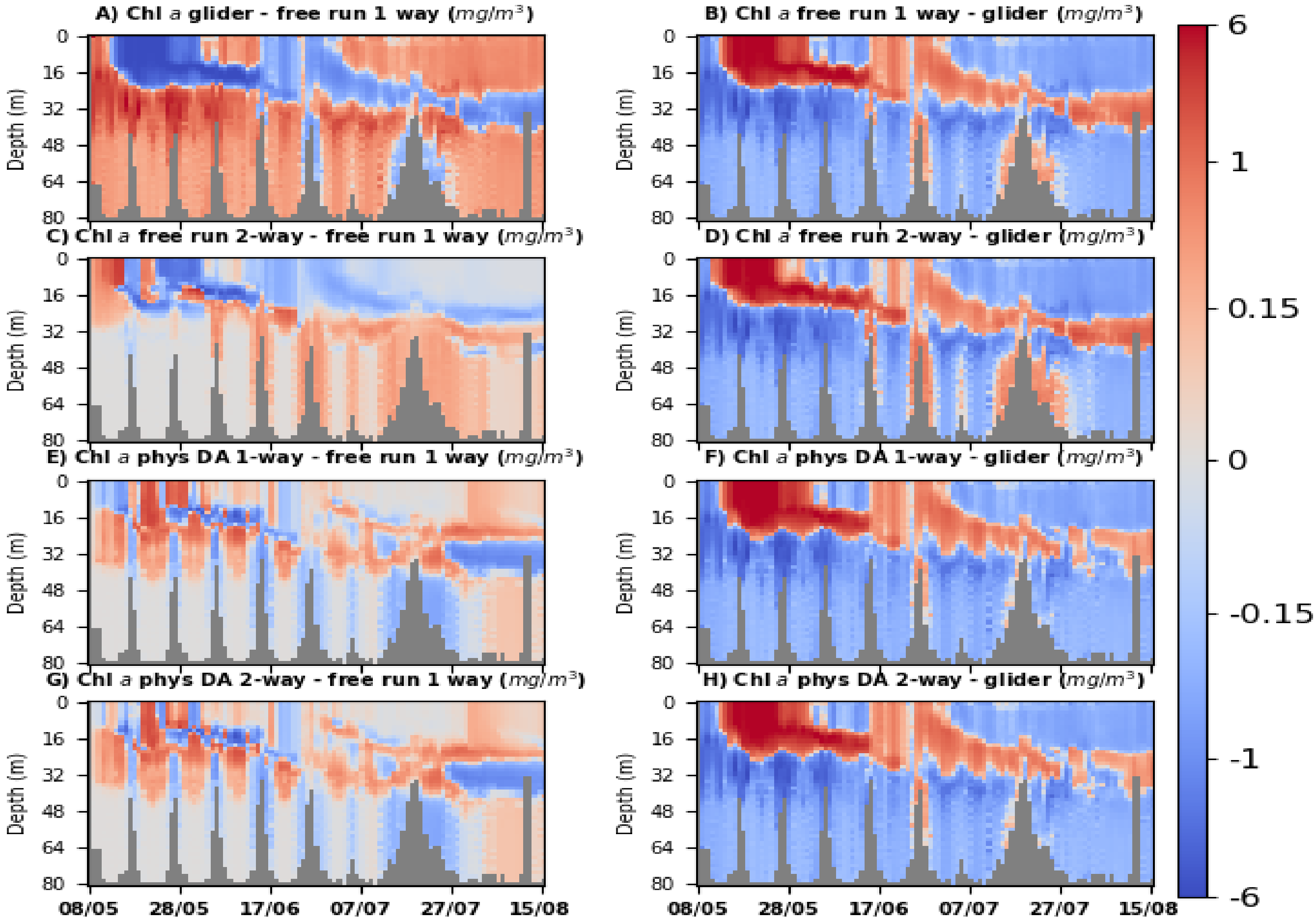

Figure S8. Hovmöller diagram for chlorophyll concentrations (mg/m^3) measured by the Cabot glider in the central North Sea during an early May to mid-August 2018 mission. The right-hand panels (B,D,F,H) show the chlorophyll differences between the free one-way coupled model run (panel B), free two-way coupled model run (panel D), the physical data assimilation into the one-way coupled model (panel F), the physical data assimilation into the two-way coupled model (panel H), and the Cabot glider observations (model minus glider). The left hand panels show the differences between the observations, or model simulations and the reference, free one-way coupled model run. The purpose of the left-hand panels is to show the desired changes to the one-way coupled model (panel A) and how these changes are realized by the biogeochemical feedback in the free run (panel C) and in the physical data-assimilative runs (panels E and G).

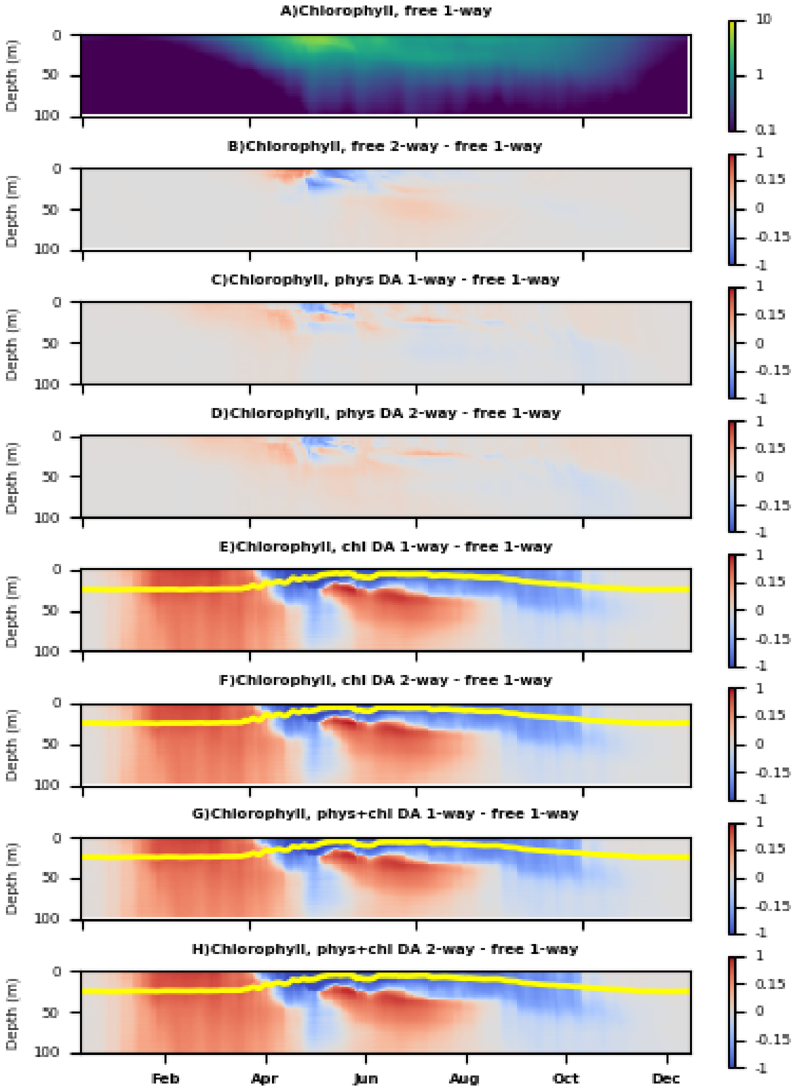

Figure S9. Impact of two-way coupling and assimilation on the simulated chlorophyll concentrations (mg/m^3). The panel A shows Hovmöller diagram (time on the x-axis vs depth on the y-axis) for the one-way coupled model free run, where the values for each day and depth represent the horizontal spatial averages throughout the NWE Shelf (bathymetry < 200m). Panels B-H show the same Hovmöller diagrams, but for the differences between the two-way coupled, or assimilative runs and the reference, free one-way coupled run. The yellow lines in the panels E-H show the mixed layer depth, providing the boundary of the region in which the ocean color assimilation directly updates the simulated chlorophyll.

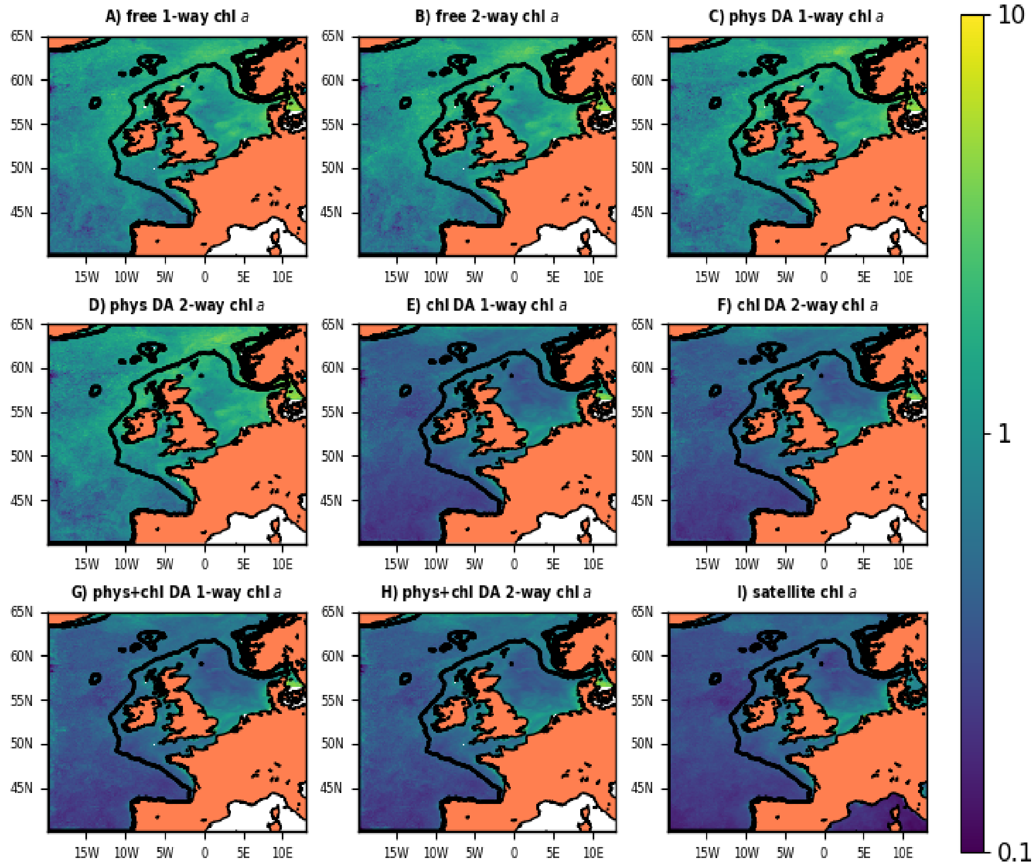

Figure S10. The 2018 mean surface chlorophyll concentrations (in mg/m^3). The different panels compare: the one-way coupled model free run (panel A), the two-way coupled model free run (panel B), the physical data assimilation into the one-way coupled model (panel C), the physical data assimilation into the two-way coupled model (panel D), the chlorophyll assimilation into the one-way coupled model (panel E), the chlorophyll assimilation into the two-way coupled model (panel F), the joint physical data-chlorophyll assimilation into the one-way coupled model (panel G), the joint physical data-chlorophyll assimilation into the two-way coupled model (panel H), and the assimilated satellite ocean color observations (panel I). The black line shows the continental shelf boundary (bathymetry ¡ 200m).