Two-way physics-biogeochemistry coupling constrained by ocean colour data assimilation

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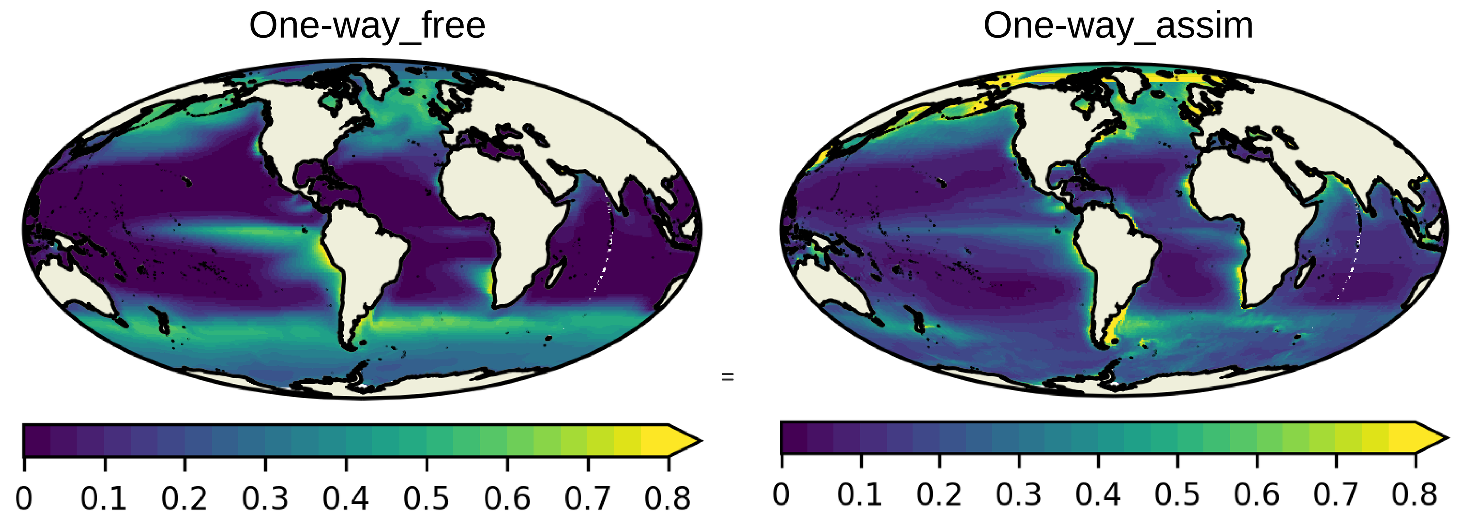
Summary

We implemented two-way physics-biogeochemistry coupling in the global NEMO-MEDUSA model, using 3D model chlorophyll in the light attenuation calculations. This was tested with and without assimilation of chlorophyll observations from ocean colour.

The coupling impacted model physics differently on different time and space scales. The most significant impact was on heat content, with less heat taken up in the coupled model. This change in heat content was approximately doubled by assimilating ocean colour.

The impact of two-way coupling on the biogeochemistry was smaller, affecting magnitudes more than phenology.

By comparing runs with constrained and unconstrained chlorophyll, the uncertainty in the coupling due to errors in free-running model chlorophyll could be assessed. This highlights the importance of data assimilation for improving model processes and predictions.



2010-2019 mean surface chlorophyll (mg m^{-3}) without (left) and with (right) ocean colour data assimilation

Model and experiments

We used the ocean and sea ice components of the UKESM1 Earth system model: NEMO physics, MEDUSA biogeochemistry, CICE sea ice. NEMO and MEDUSA were modified to both use the three-band light attenuation scheme of Lengaigne et al. (2007), which takes chlorophyll as an input. When one-way coupled, NEMO used a constant chlorophyll of 0.05 mg m^{-3} as in UKESM1. When two-way coupled, NEMO used MEDUSA chlorophyll. MEDUSA used MEDUSA chlorophyll in both cases.

ESA CCI ocean colour chlorophyll was assimilated using a 3D-Var configuration of NEMOVAR which updated phytoplankton biomass and chlorophyll (Ford, 2021). No other assimilation was performed.

Runs from 2010-2019 were performed at 1° global resolution:

Run name	Assimilation	Chl for NEMO light	Chl for MEDUSA light
One-way_free	None	0.05 mg m^{-3}	MEDUSA chl
One-way_assim	Chl	0.05 mg m^{-3}	MEDUSA chl
Two-way_free	None	MEDUSA chl	MEDUSA chl
Two-way_assim	Chl	MEDUSA chl	MEDUSA chl
Input_bgc	None	0.05 mg m^{-3}	Two-way_assim
Input_phys	None	Two-way_assim	MEDUSA chl
Input_both	None	Two-way_assim	Two-way_assim

References

Cheng et al. (2022) Past and future ocean warming, *Nature Reviews Earth & Environment*

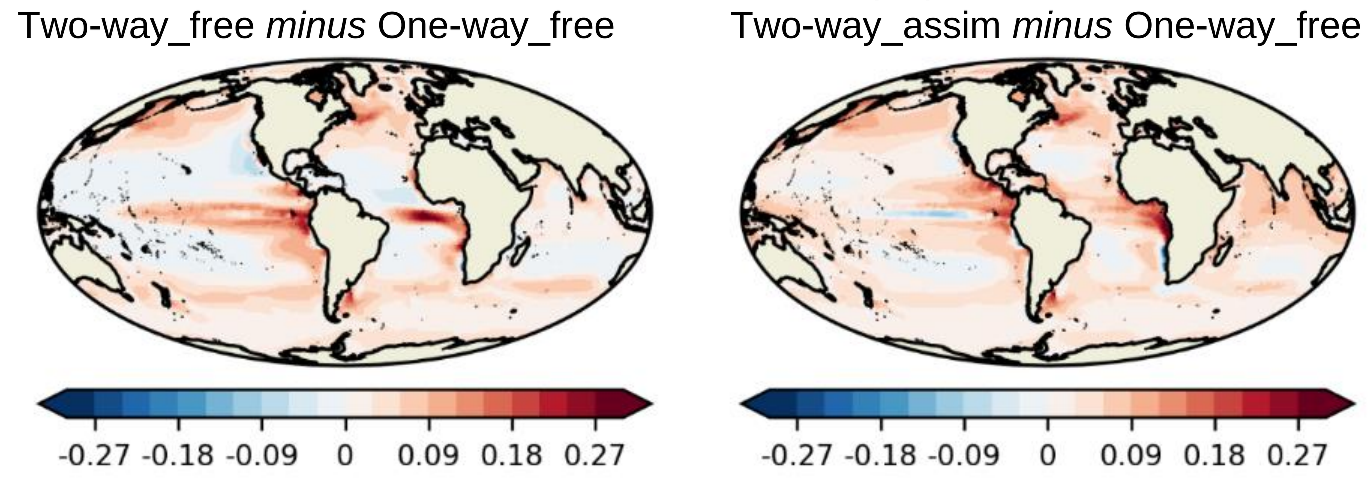
Ford (2021) Assimilating synthetic Biogeochemical-Argo and ocean colour observations into a global ocean model to inform observing system design, *Biogeosciences*

Lengaigne et al. (2007) Influence of the oceanic biology on the tropical Pacific climate in a coupled general circulation model, *Climate Dynamics*

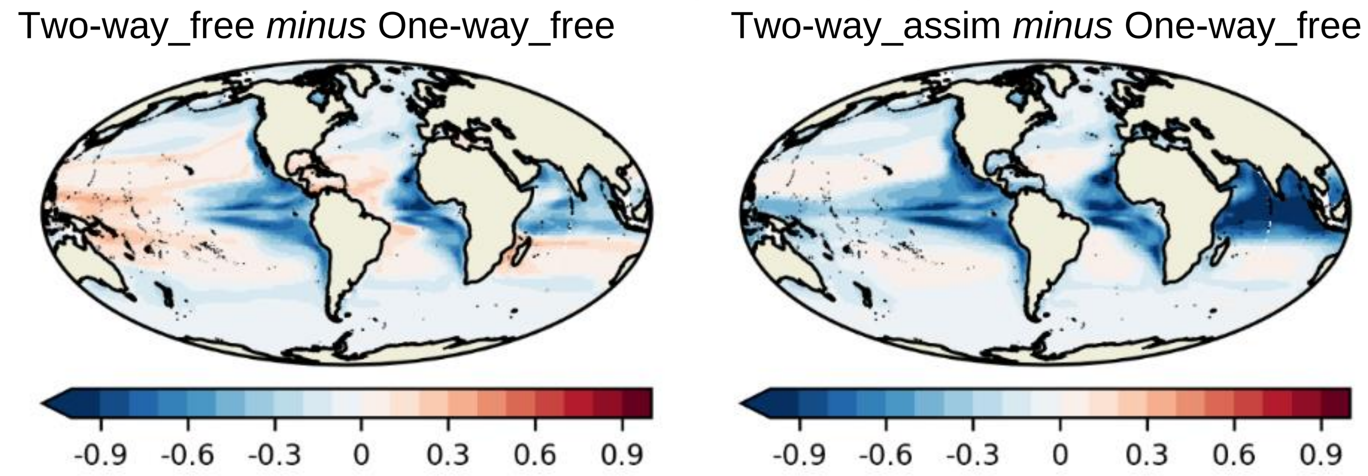
Impact on physics

On average, coupling raised surface temperature (SST) and lowered sub-surface temperature, but this varied regionally and seasonally. The impact was enhanced when assimilating chlorophyll. By the final year of the 10-year run, global heat content in the upper 300m was 1.98 x 10^{22} J lower without assimilation, and 4.09 x 10^{22} J lower with assimilation. To compare, Cheng et al. (2022) estimated that from 1958-2019 upper 700m heat content increased by 0.38 x 10^{22} J yr^{-1}.

2010-2019 mean SST (°C)

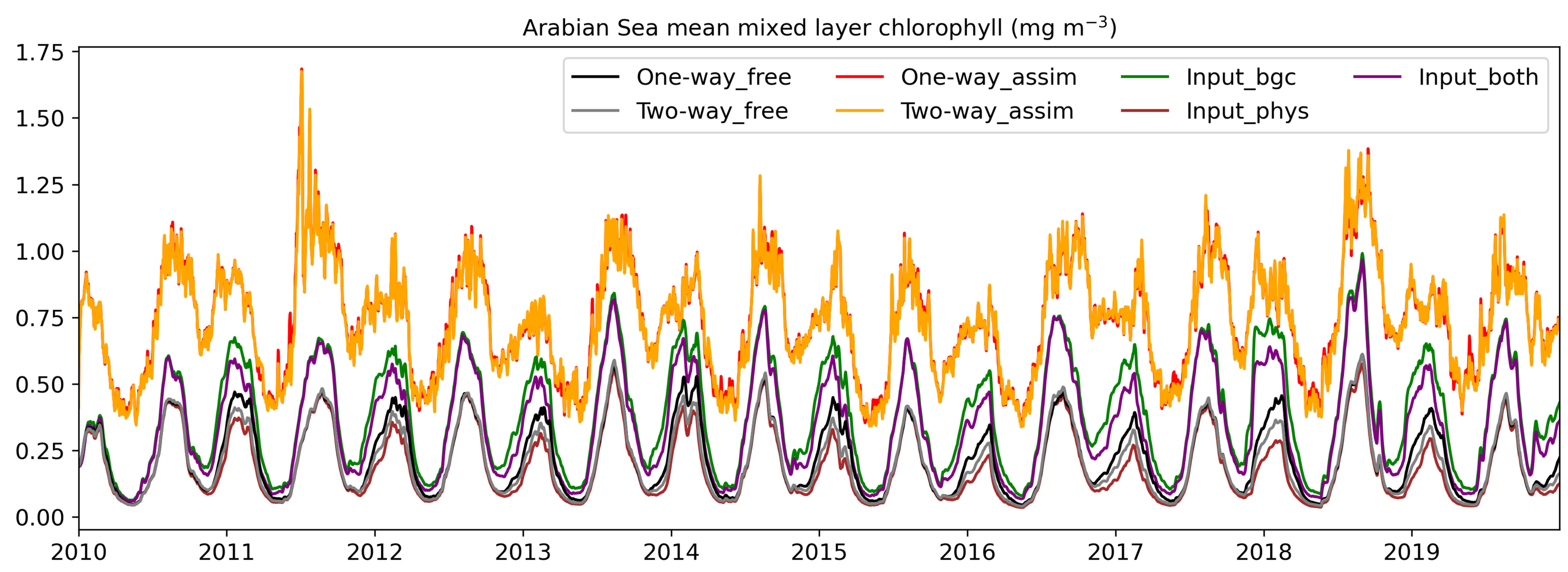


2010-2019 mean temperature (°C) at 100m



Impact on biogeochemistry

The impact of two-way coupling on biogeochemistry was generally small. On average, chlorophyll was slightly reduced at the surface, and slightly increased sub-surface. Except at specific locations, bloom timing was unchanged. Data assimilation had a larger impact, which overrode that of the coupling. By forcing the light penetration of NEMO and/or MEDUSA with offline chlorophyll output from Two-way_assim, but allowing the model chlorophyll to evolve unconstrained, the impact of having more accurate light penetration could be assessed.



Recommendations

- Using chlorophyll in physics light attenuation is important, but chlorophyll needs to be realistic.
- In reanalysis and forecasting, chlorophyll should be constrained by data assimilation.
- Developments to improve chlorophyll are recommended for all Earth system models.

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