Ocean Predict

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2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Using a coupled model to downscale the effects of climate change and human offshore installations until the year 2100 on the North Sea ocean services

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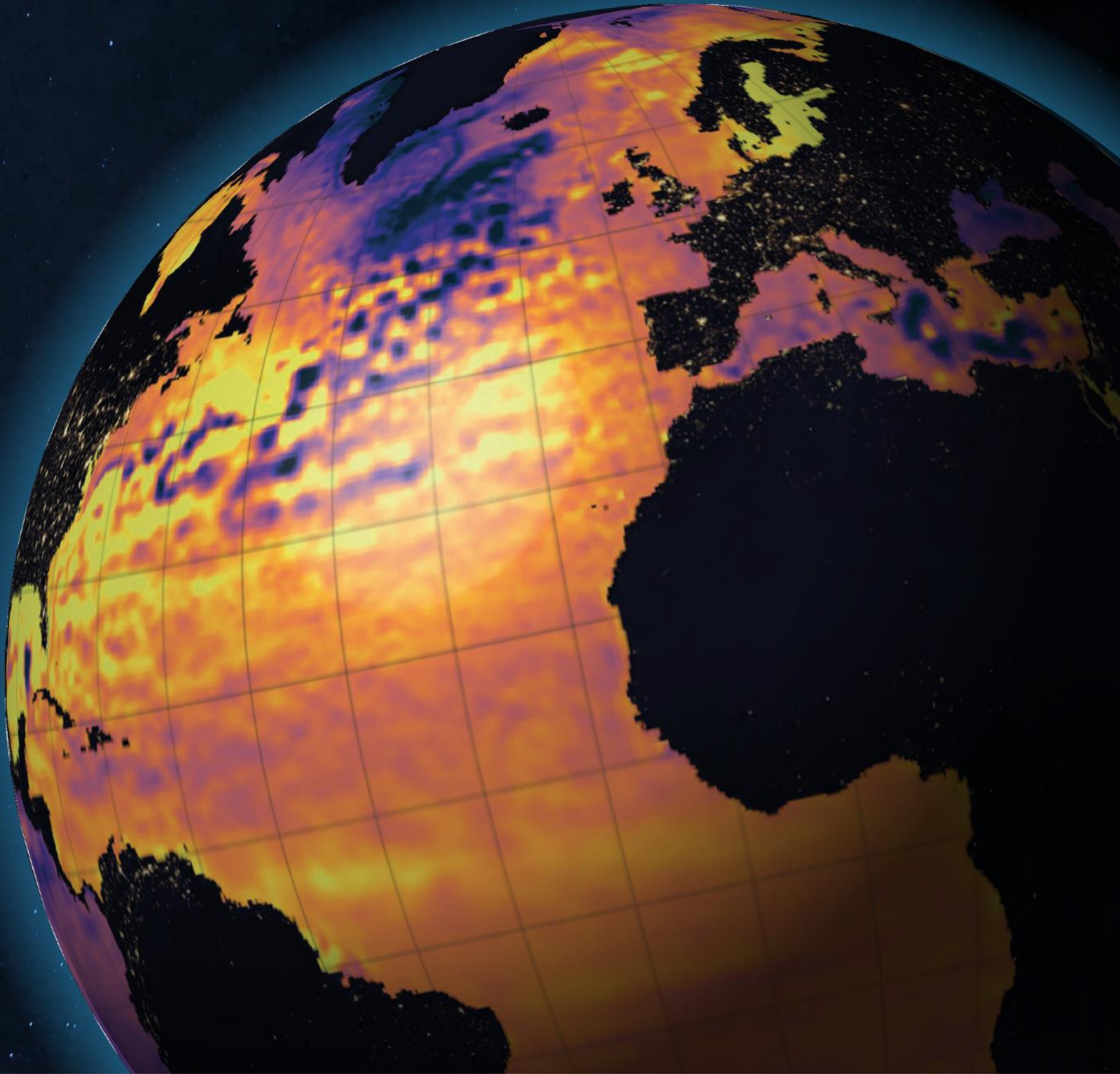
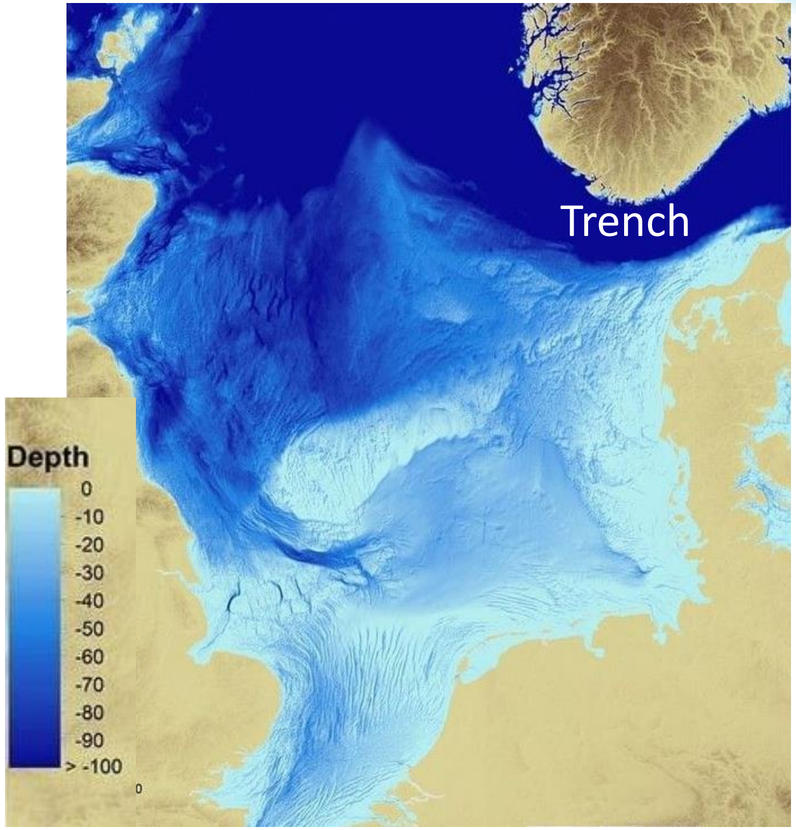
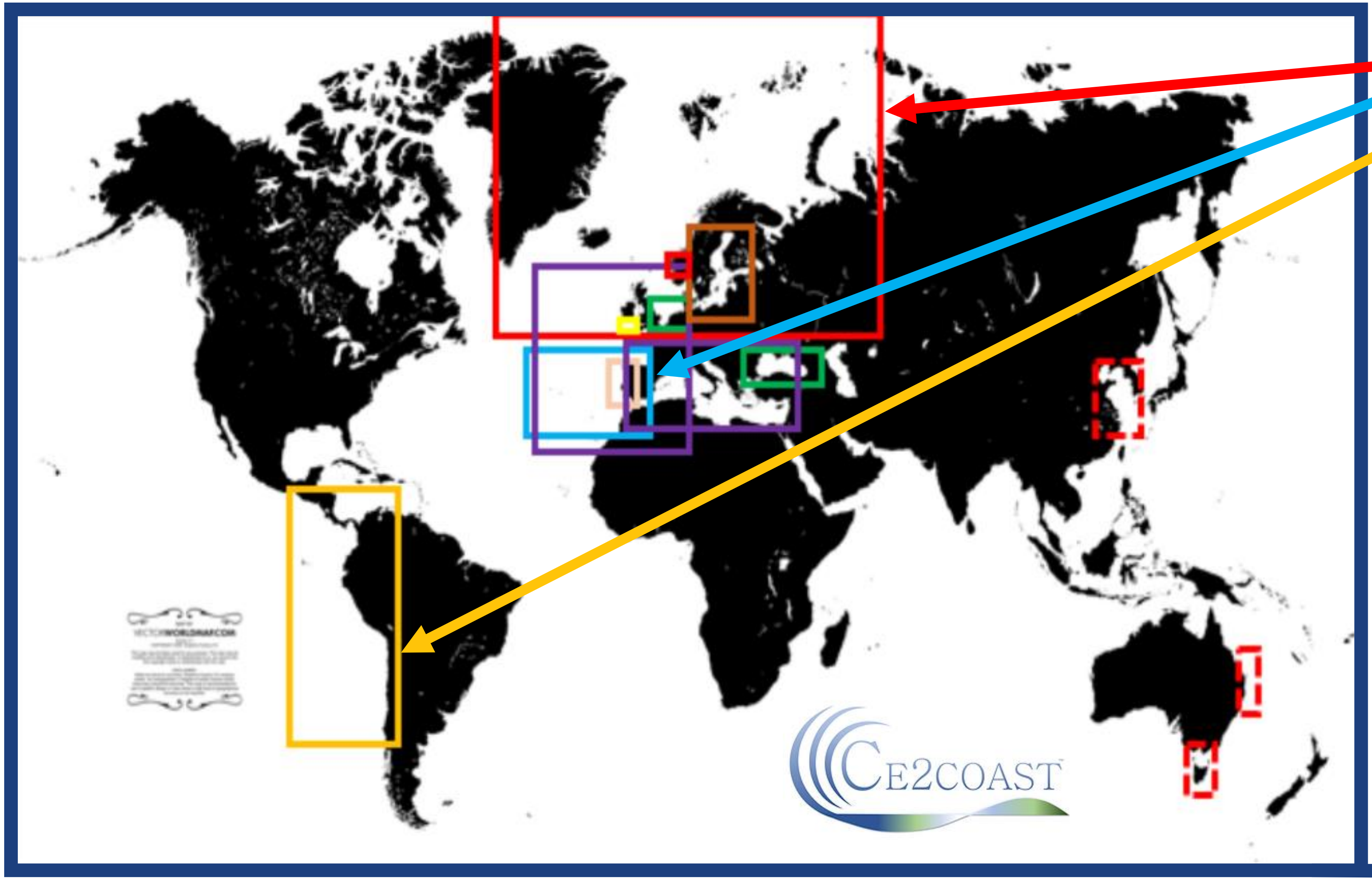


Importance of the North Sea

- Coastal seas sequester most of the organic carbon (OC) buried in the ocean sediments;
- North Sea (NS) accounts for ~0.5% of global OC sequestration in the marine sediments;
- 87% of NS organic carbon is sequestered in the Norwegian Trench (depths >200 m), while its majority is produced in the shallow waters;
- The rapidly changing climate affects all pressures and service, relevant for the North Sea, thus requires assessment for deeper understanding of underlying processes driving the changes and for potential mitigation of negative consequences of the climate change;
- Human activities over the NS either impair its ability to sequester carbon (bottom trawling, oil extraction) or alter it (offshore wind farms, potentially macroalgae harvesting).



CE2COAST: downscaling ESM results for making regional climate predictions



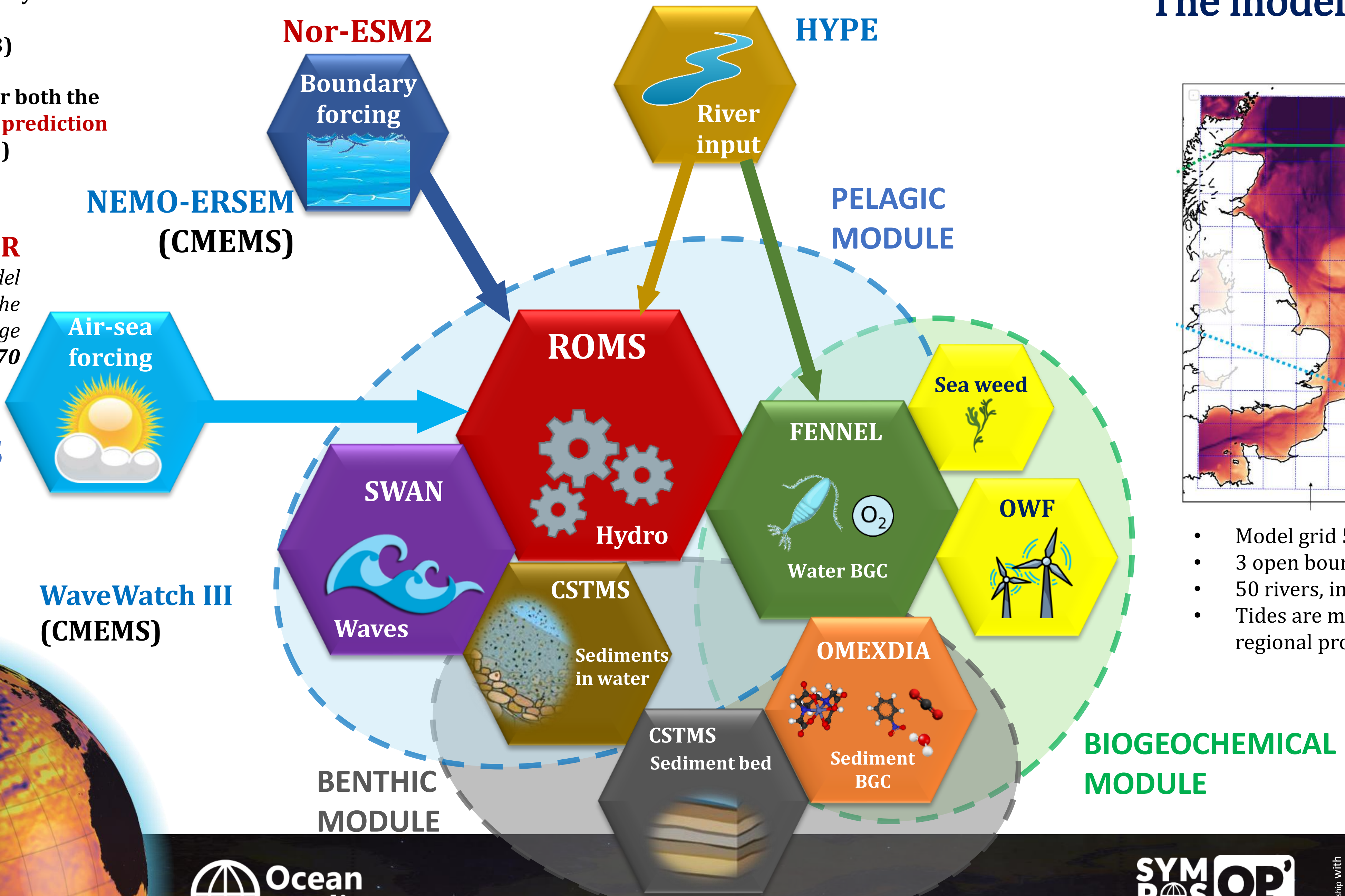
The ESMs can make long-term predictions, but they are not suitable for the regional managerial purposes -> requires dynamical **downscaling** at the regions of interest using RCOMs with tailored characteristics.

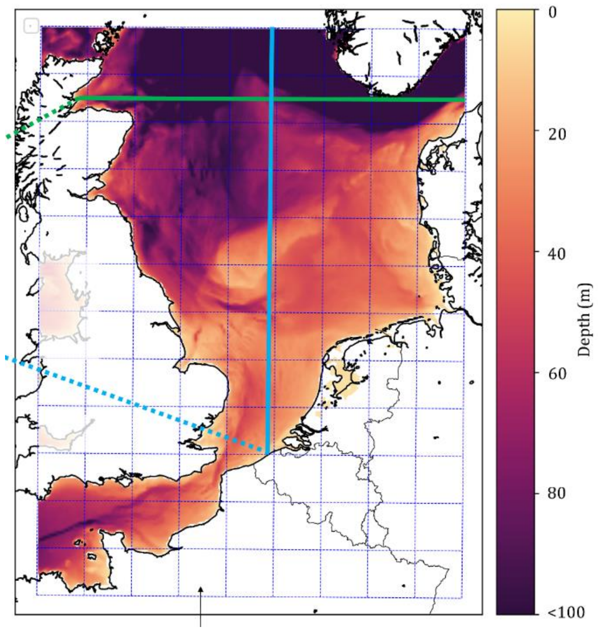
Earth System Model (ESM)

The modelling approach

Blue – used only for the Hindcast (1993 – 2023)

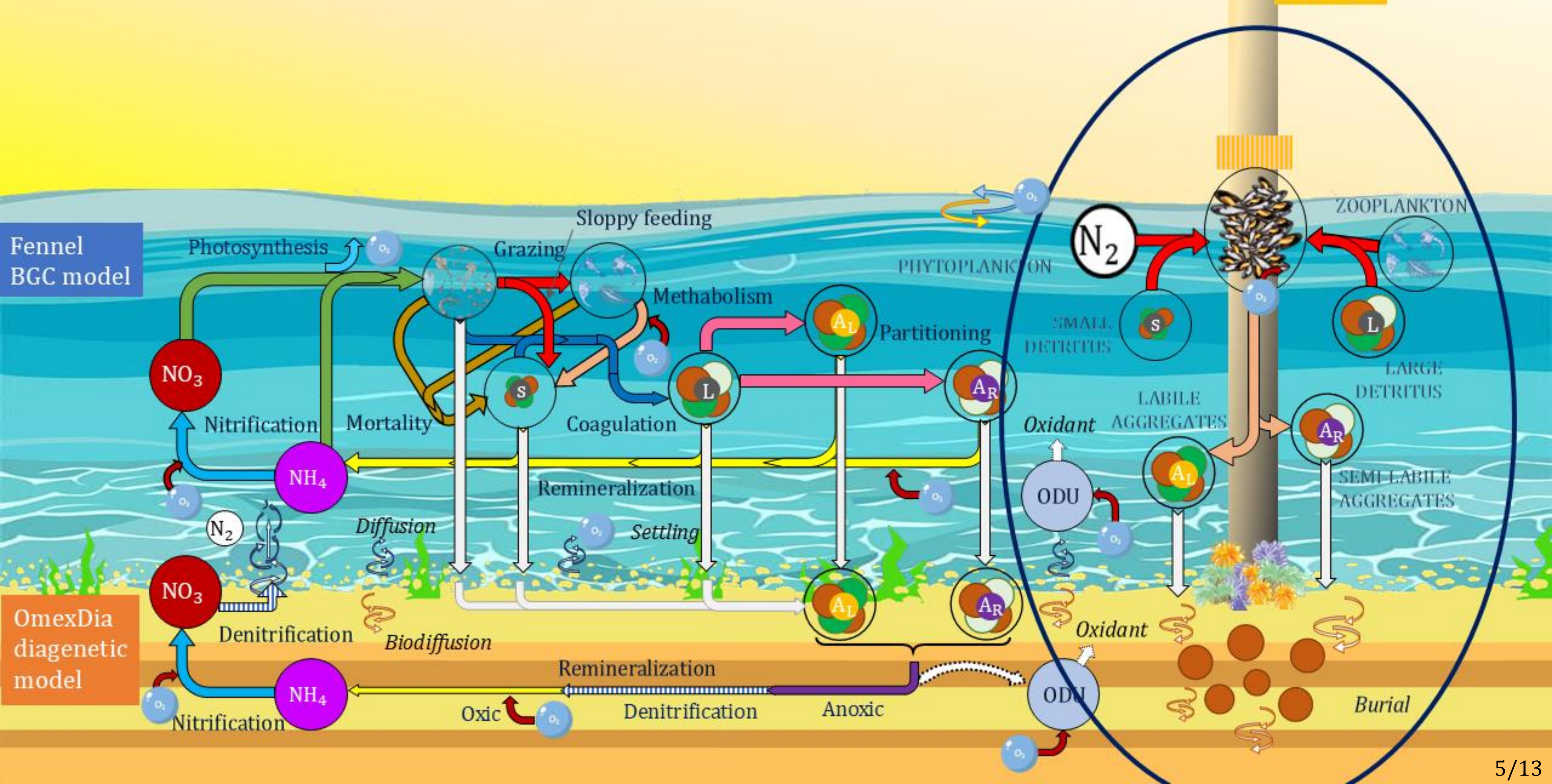
Red – used for both the hindcast and prediction (1993 – 2100)





- Model grid 5x5 km2
- 3 open boundaries
- 50 rivers, including 17 large rivers
- Tides are modulated using TPXO-9 regional product (9 constituents)

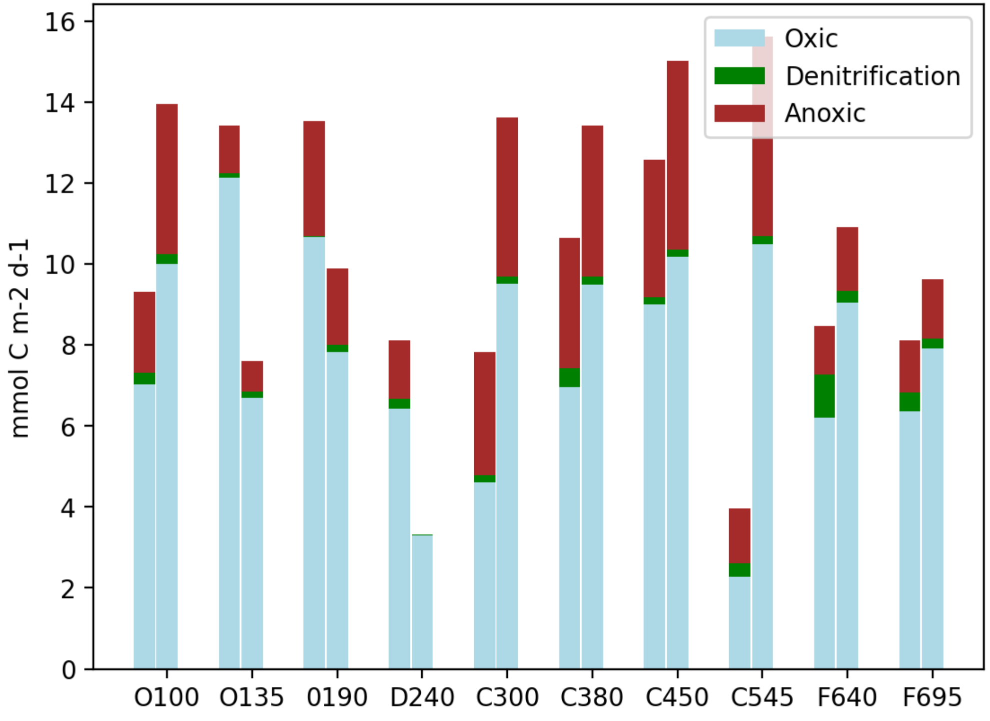
Detailed sketch of the coupled BGC benthic-pelagic model



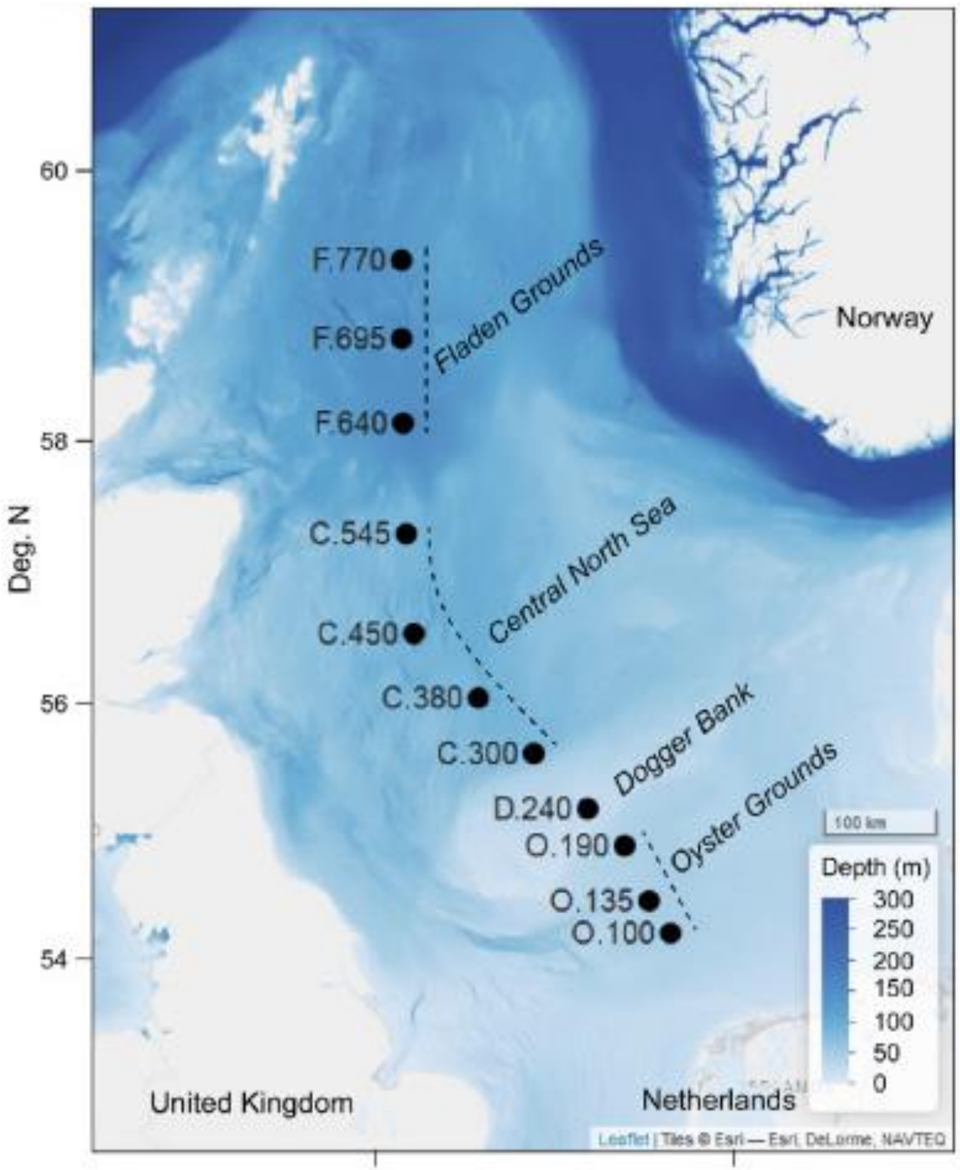
Biogeochemical model validation: remineralization by type across the NS

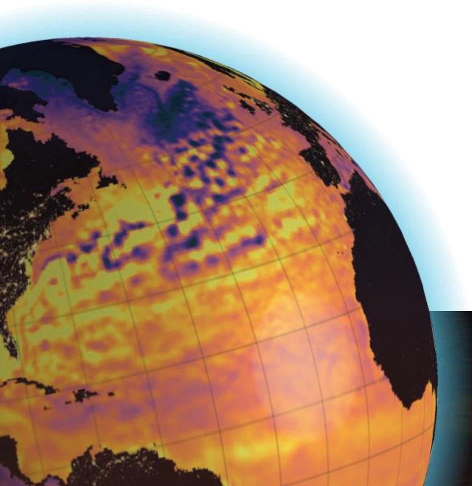
from De Borger, et al. (2021)

The model reproduces spatial variability of different types of OC decomposition across the domain, meaning that it is able to reproduce the OC flux as well.



OC remineralization at the stations across the domain: laboratory results from a field campaign in May (De Borger, 2021) - **left** bars; our model results – **right** bars.





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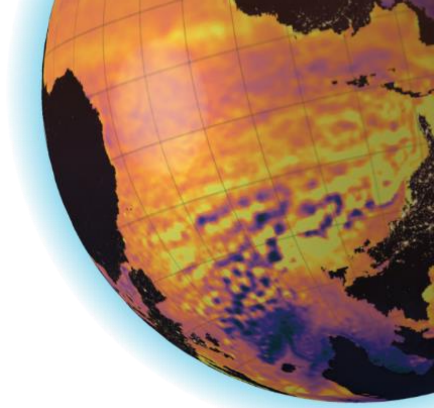
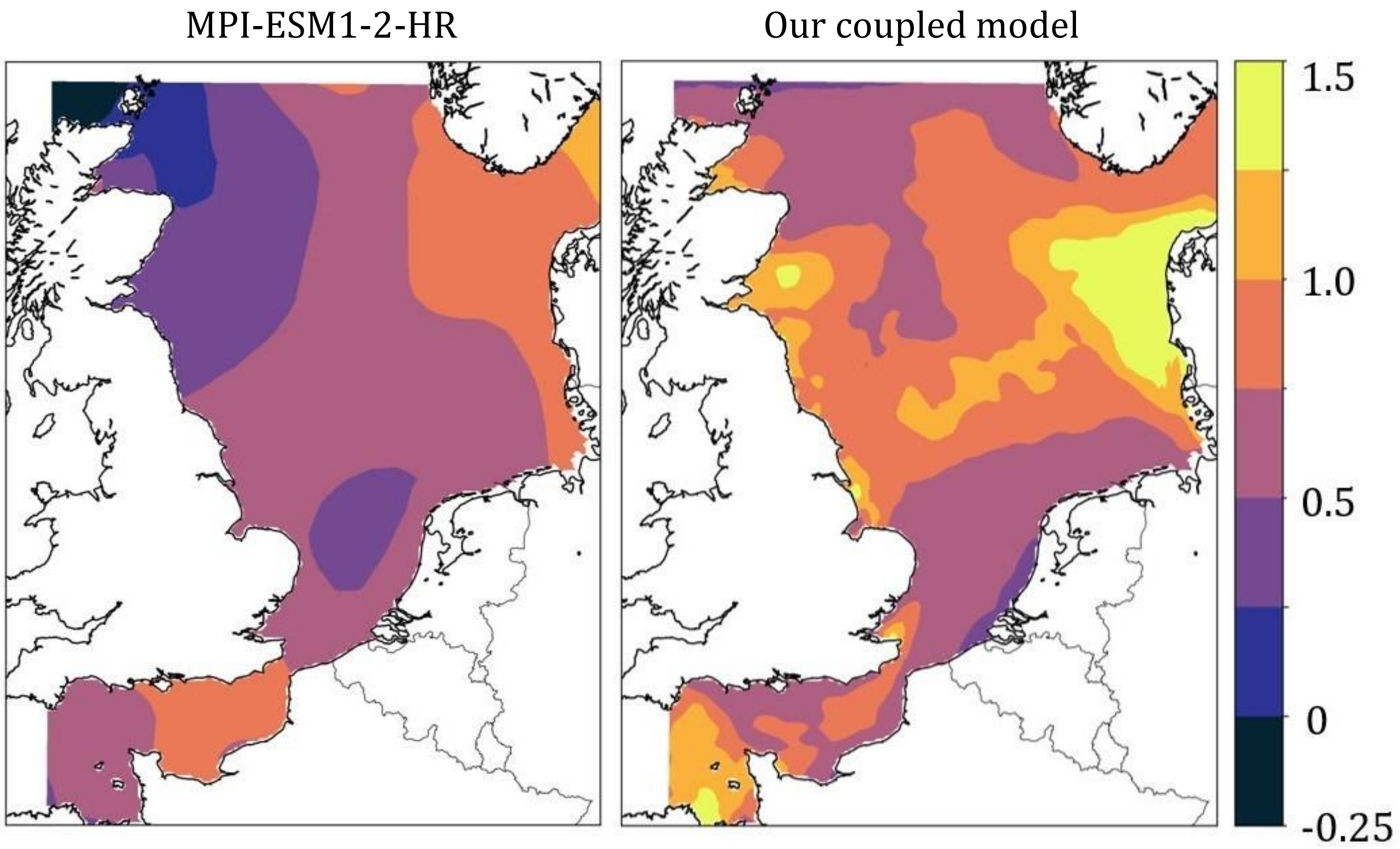
Added value in using an RCOM instead of an ESM





Comparison of mid-century SST raise compared to the modern (1993 – 2022) climate.

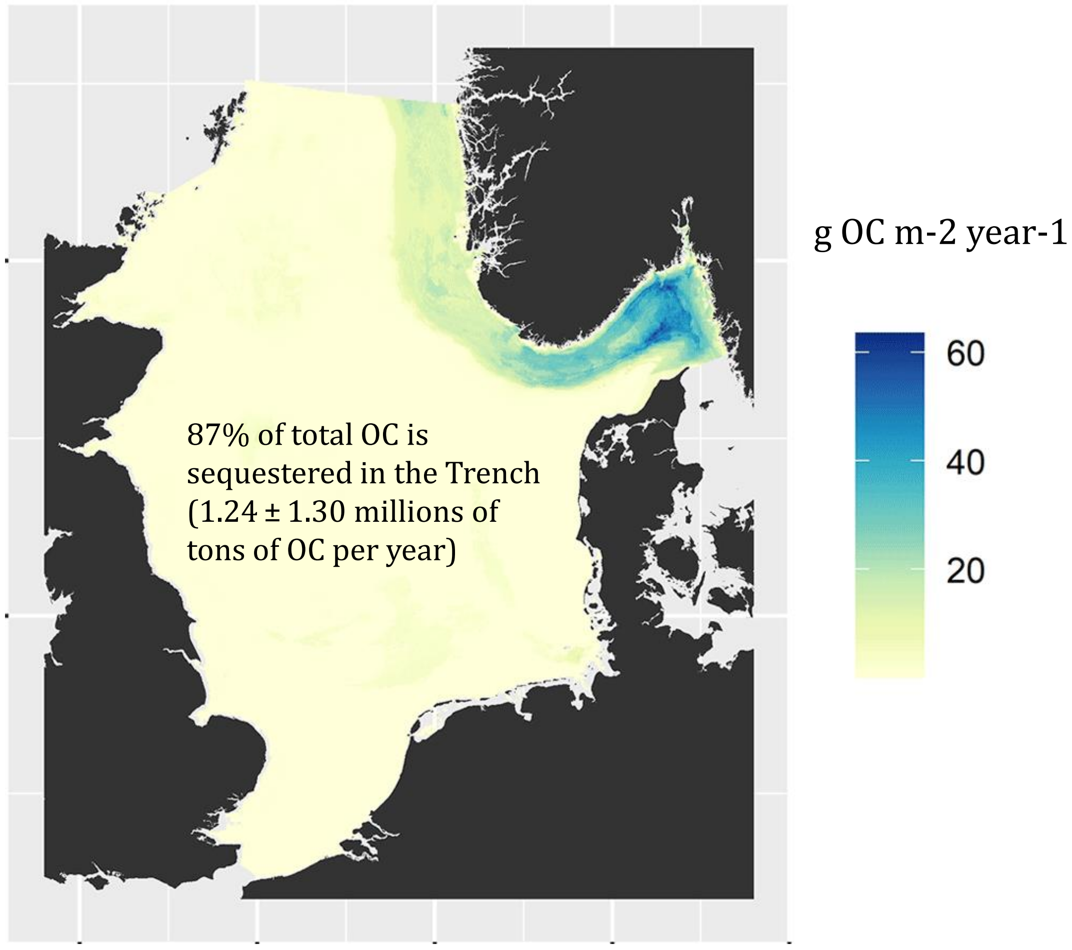
- The results of our model were bias-corrected using satellite SST (spline method);

- Spatial variability of the SST is enhanced in the RCOM compared to the ESM;

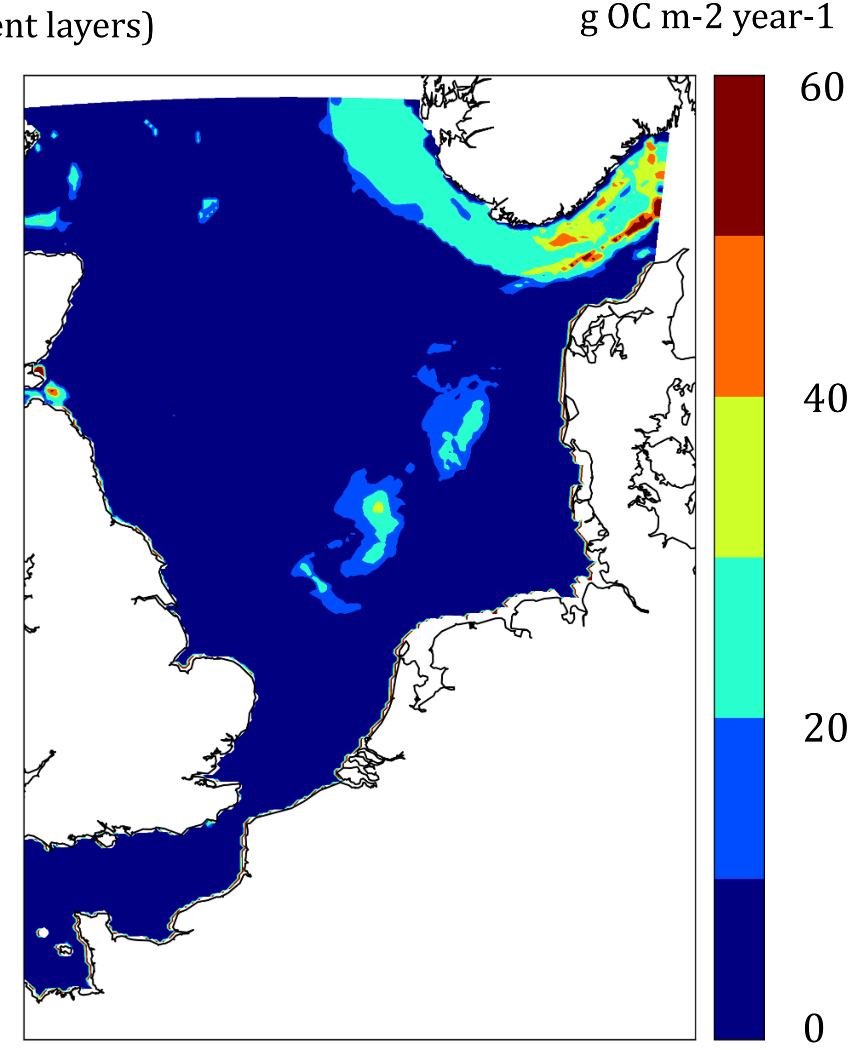
- Model simulations show an increase of 1.5 °C in the annual SST by the end of the XXI century compare to the current ocean climate, while the primary production (PP) does not show a clear trend.

Biogeochemical model validation: sequestration of slow-degrading carbon

Sequestration = Flux – Remineralization (excluding the uppermost sediment layers)



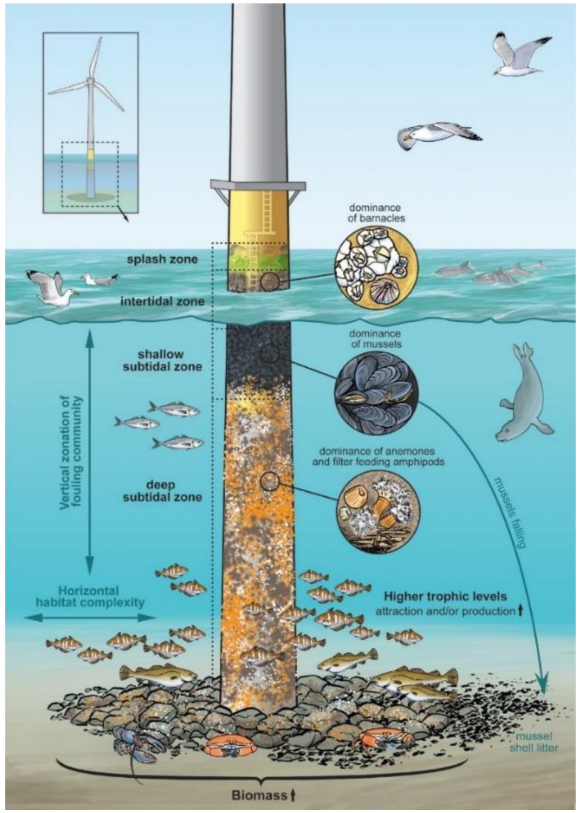
ML-estimates from Diesing, et al. (2021)
Results are within previous (non-modelling) estimates.



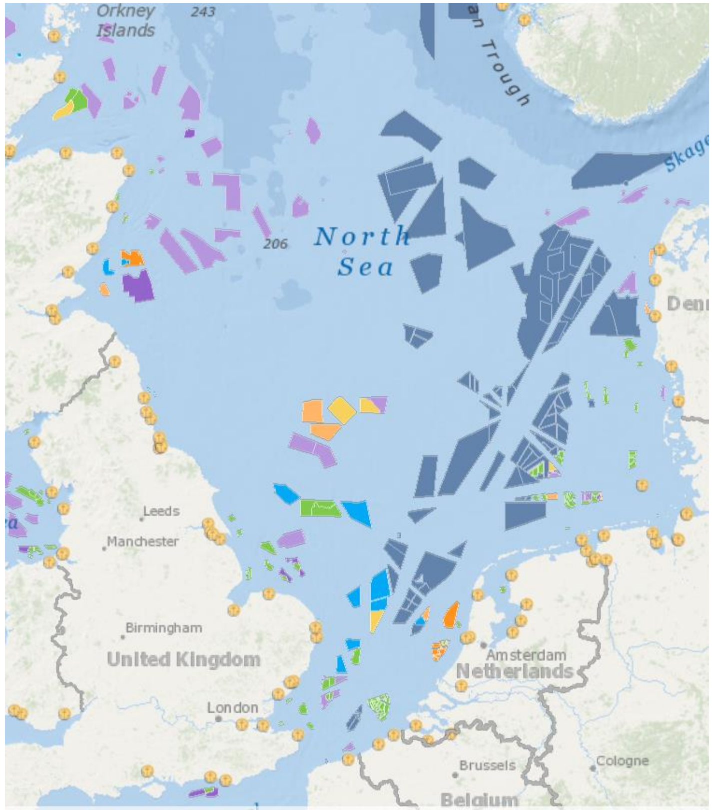
Our model results

Yearly OC sequestration in the Norwegian Trench corresponds to the previous estimates.

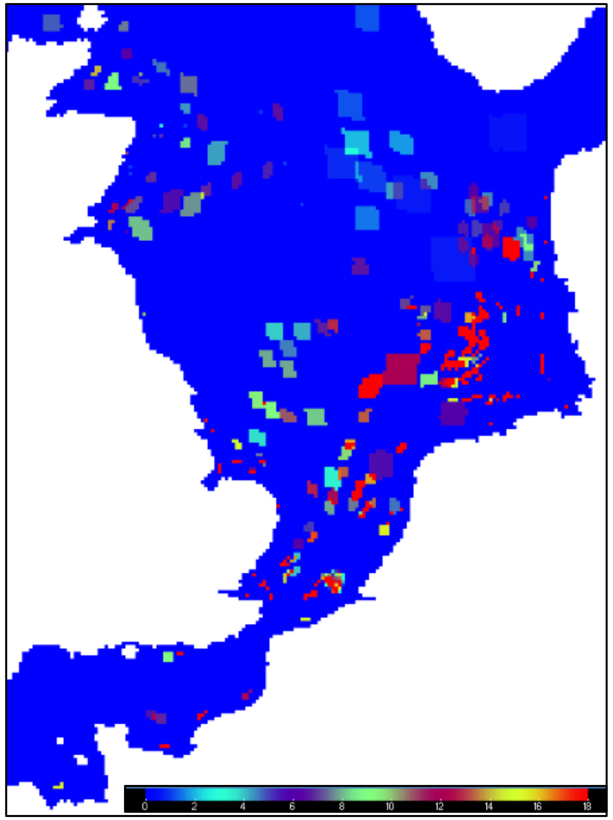
Offshore wind farms (OWFs) at the Horizon 2035



OWF ecosystem hotspot
from Degraer. et al. (2020)



Map of projected OWFs by 2035
https://map.4coffshore.com/offshorewind/



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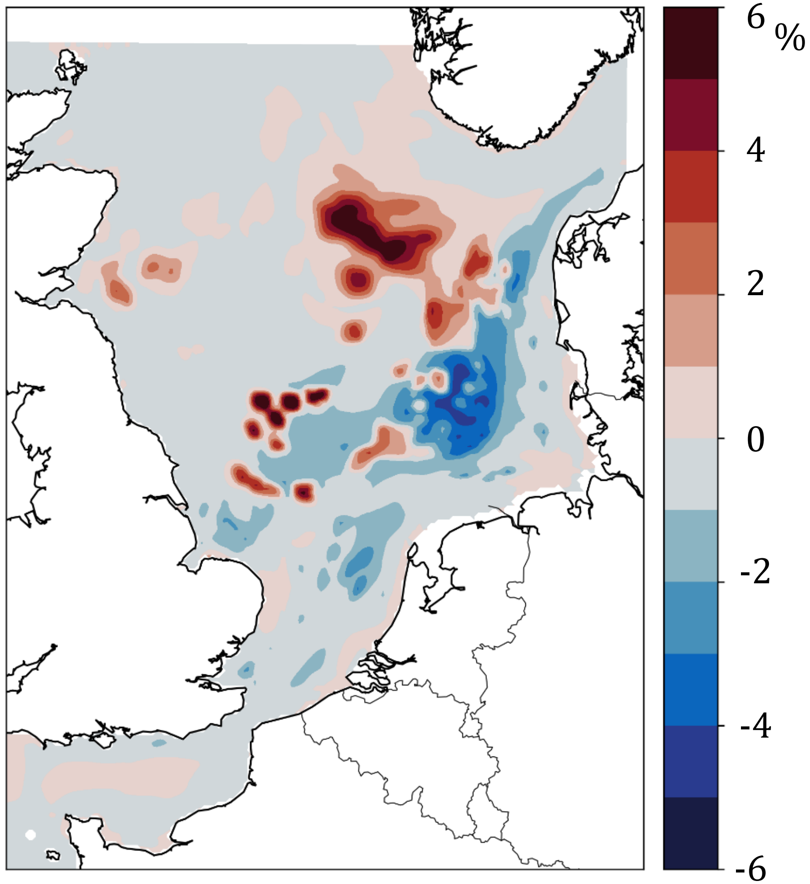
Implementation of OWFs in our model

Monopiles per grid cell
(25 km2)

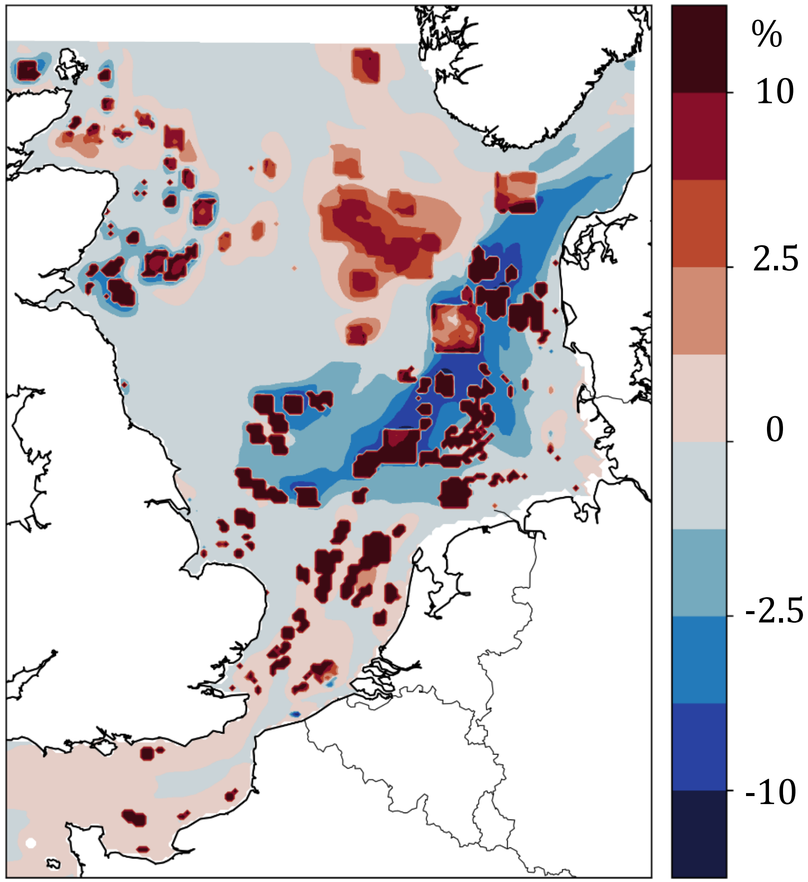
- Provide hard substrate for filter feeders (e.g. blue mussels), that rapidly deliver OC to the bottom through excretion;
- Previous estimates (Ivanov, 2021) put production of OC-rich fecal pellets from a single monopile foundation around 1 kg per day;
- OWFs implemented into the model though their mean diameter (hard substrate fouling area), density per grid cell and locally enhanced bioturbation.

Influence of the OWFs on biogeochemistry of the water and sediment

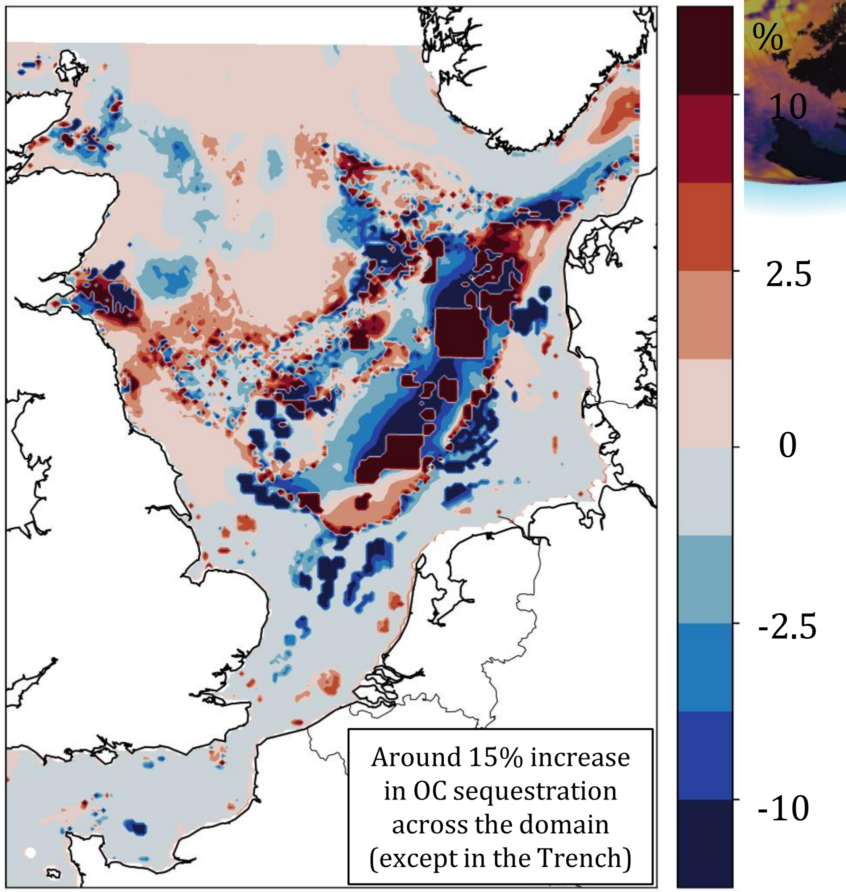
100 * (No OWF run – OWF run) / OWF run



Impact on vertically-integrated primary production



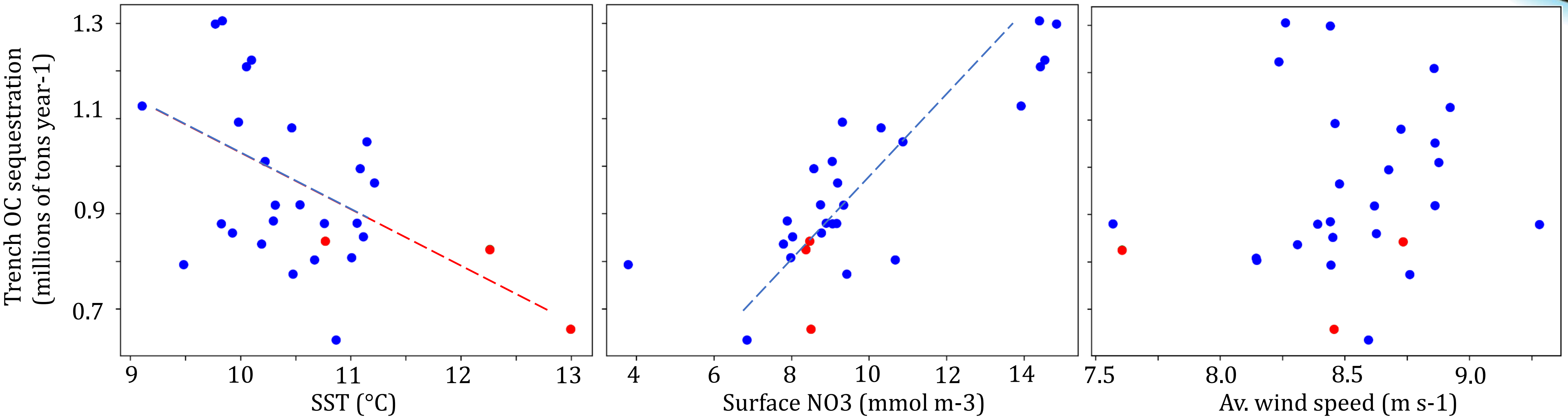
Impact on total OC remineralization in the sediment



Impact on carbon sequestration

How OC sequestration changes from year to year? Preliminary results.

Red dots – prediction simulations (2035, 2065, 2095). Blue dots – hindcast years.
All points correspond to a domain-averaged annually-averaged variables.



With a raise of water temperature, the OC burial in the Trench sediment decreases.

Nutrient availability on the shelf (depends on the river discharge) affects OC production and thus sequestration

Wind speed in the autumn slightly correlates with OC deposition in the Trench, possibly though its impact on the bottom stress and stratification dynamics.

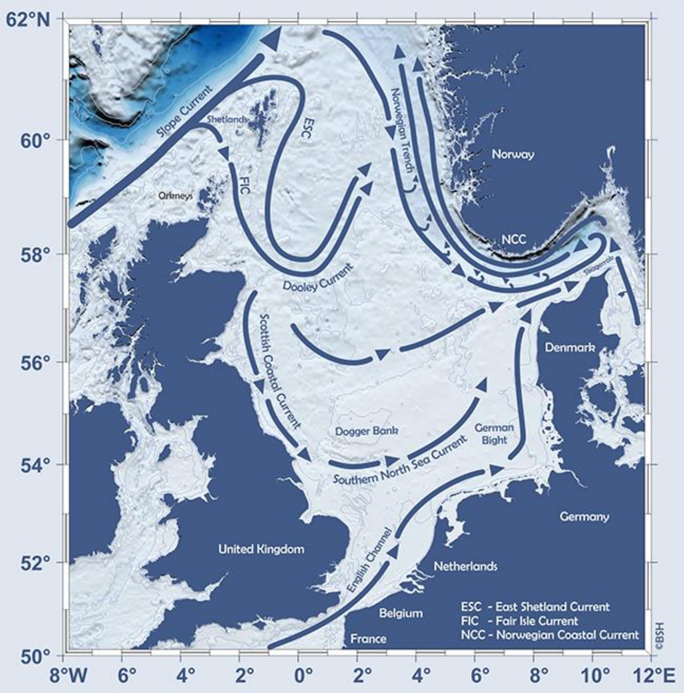
Take-away messages

1) Despite the PP projection not showing a clear trend over the course of XXI century, OC remineralization in the water and sediment intensifies (with the rise of the water temperature), compromising the ability of the NS to sequester organic carbon;

2) OWFs alter the OC flux to the bottom and its sequestration over the domain excluding the Norwegian Trench, while the effect on the sequestration in the Trench has not been confirmed;

3) OWFs will not offset the negative effects of the climate change on the OC sequestration by the North Sea.

The little effect of the OWFs on the Trench OC sequestration might have something with the pattern of residual currents in the NS.



Source: https://www.bsh.de/

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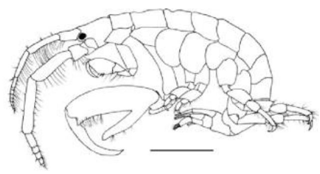
Thank you!

Limitations of the OWF setup



Jassa Herdmani

1) Mussels are already grown, they don't die;

2) Mussels don't have a seasonal cycle with optimal conditions for growth (8 – 15 °C);

3) Other filter feeders (e.g. *Jassa Herdmani*) are not part of the model;

4) Different types of OWF turbine foundations projected for the NS by 2035 are not implemented due to lack of available data;

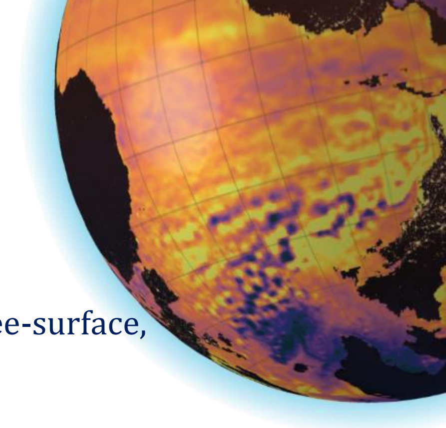
5) Bottom stress at the OWFs is not altered (although satellite images suggest a higher bottom stress). Nor currents or waves or winds.

6) There are estimates that suggest 50% release of total sequestered OC during the OWF decommissioning phase.

Source: NASA

Turbid wakes at the OWFs observed from the satellite.

Some literature



1) **Hydrodynamical model**: Shchepetkin, A. F., & McWilliams, J. C. (2005). The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean modelling, 9(4), 347-404.

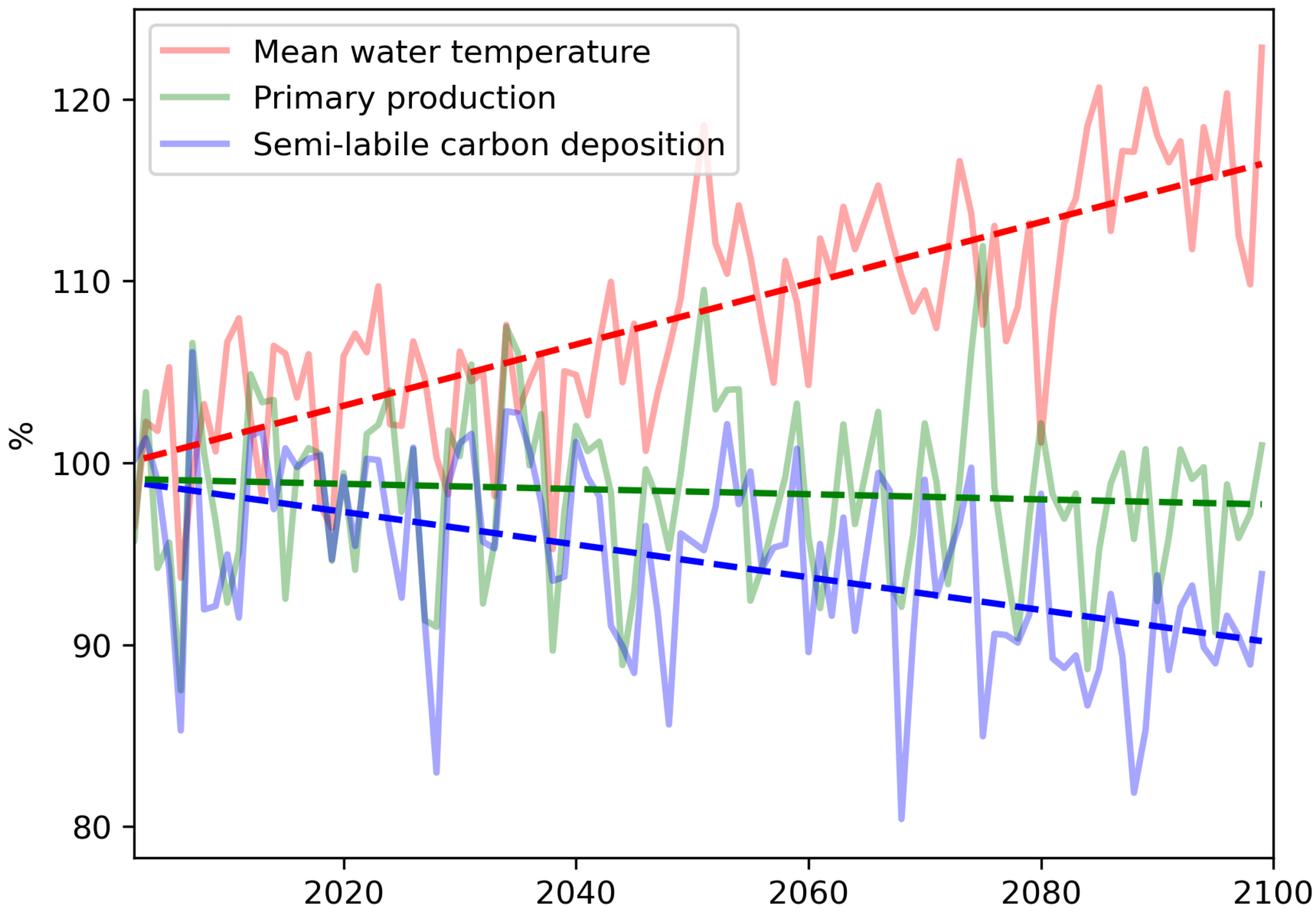
2) **Sediment model**:
- Warner, J. C., Sherwood, C. R., Signell, R. P., Harris, C. K., & Arango, H. G. (2008). Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model. Computers & geosciences, 34(10), 1284-1306. 2) Sherwood, C. R., Aretxabaleta, A. L., Harris, C. K., Rinehimer, J. P., Verney, R., & Ferré, B. (2018).
- Cohesive and mixed sediment in the regional ocean modeling system (ROMS v3. 6) implemented in the Coupled Ocean–Atmosphere–Wave–Sediment Transport Modeling System (COAWST r1234). Geoscientific Model Development, 11(5), 1849-1871.

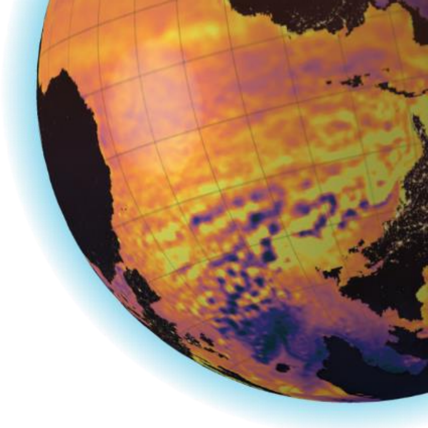
3) **Biogeochemical model**: Fennel, K., Wilkin, J., Levin, J., Moisan, J., O'Reilly, J., & Haidvogel, D. (2006). Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget. Global Biogeochemical Cycles, 20(3).

4) **Diagenetic model in the sediment**: Soetaert, K., Herman, P. M., & Middelburg, J. J. (1996). A model of early diagenetic processes from the shelf to abyssal depths. Geochimica et Cosmochimica Acta, 60(6), 1019-1040.

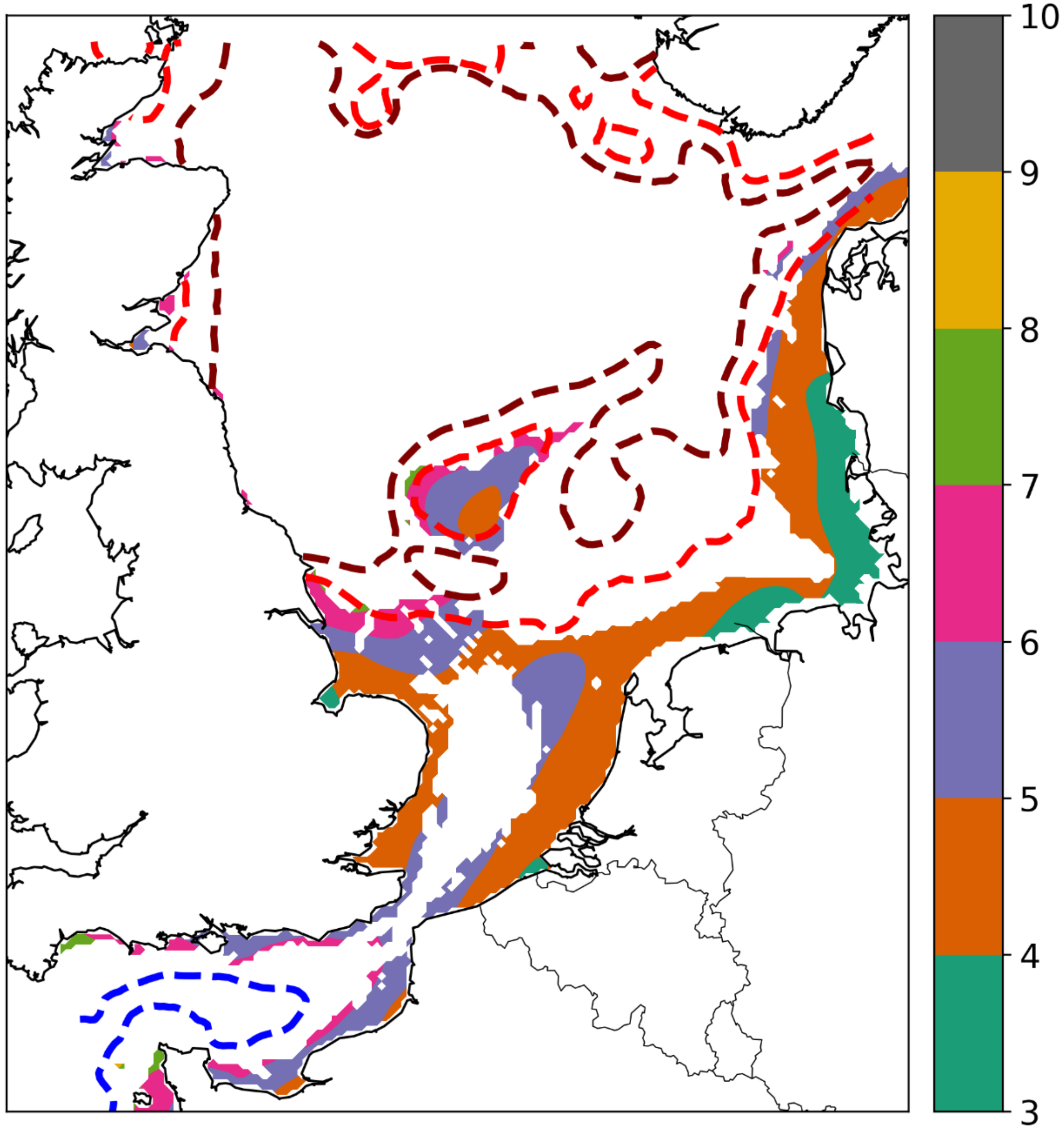
5) **Benthic-pelagic coupling**: Moriarty, J. M., Harris, C. K., Fennel, K., Friedrichs, M. A., Xu, K., & Rabouille, C. (2017). The roles of resuspension, diffusion and biogeochemical processes on oxygen dynamics offshore of the Rhône River, France: a numerical modeling study. Biogeosciences, 14(7), 1919-1946.

6) **OWF model**: Ivanov, E., Capet, A., De Borger, E., Degraer, S., Delhez, E. J., Soetaert, K., ... & Grégoire, M. (2021). Offshore wind farm footprint on organic and mineral particle flux to the bottom. Frontiers in Marine Science, 8, 631799.





Increase in the mean water temperature by 1.4 °C by the end of the XXI century will result in decrease in mean carbon deposition by about 9% due to its higher remineralization rates in the water column.



Map of the annual number of optimal months for the blue mussels in the current climate (colored) and its change in the future change (dashed lines) (SSP370) defined as the number of months during which the average temperature varies between 8 – 15 °C (optimum for the blue mussels.