Seasonal stratification and biogeochemical turnover in the limnic reach of a partially mixed dredged estuary

Johannes Pein, Annika Eisele, Tina Sanders, Ute Daewel, Emil V. Stanev, Justus E.E. van Beusekom, Joanna Staneva, Corinna Schrum

9th EuroGOOS international conference, 3-4 May 2021

Helmholtz-Zentrum hereon

Issue

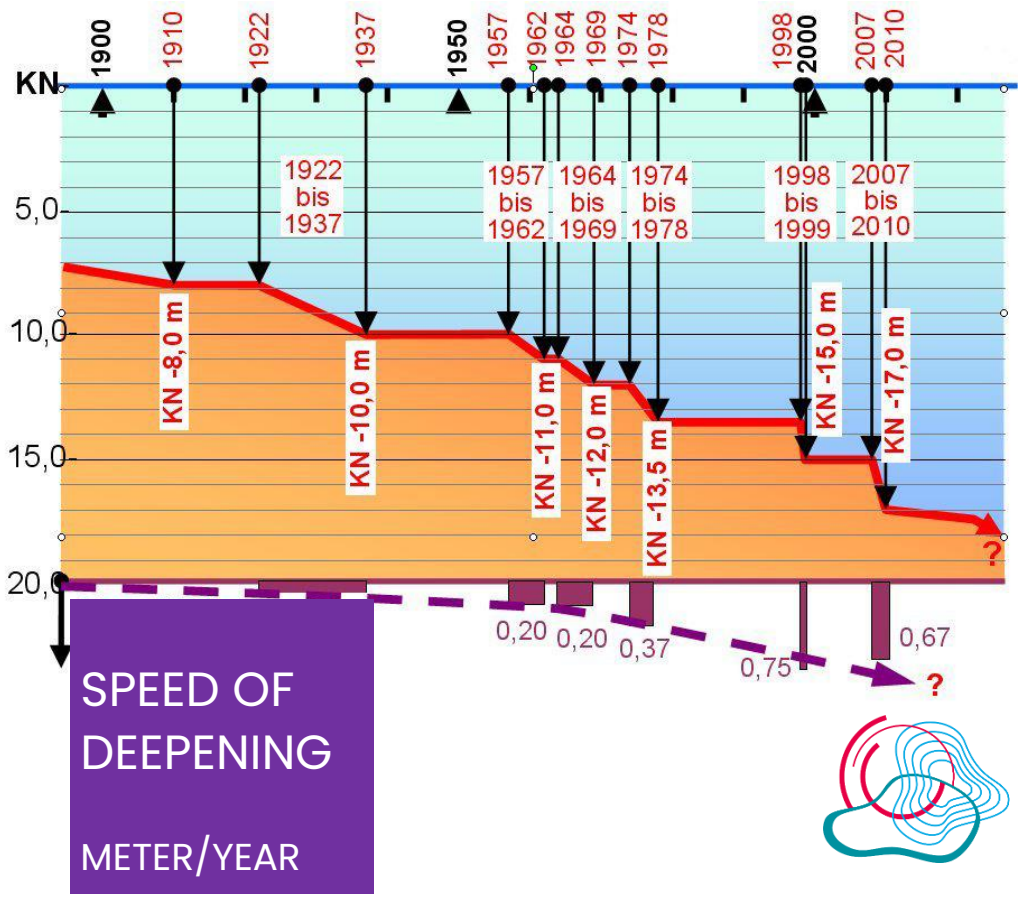
A long history of human intervention

The Elbe estuary has been shaped for centuries by measures such as diking, crosscutting, channel deepening. Industrialisation of the agricultural sector has fueled eutrophication of the Elbe river

What are the physical-biogeochemical interactions in the present system?

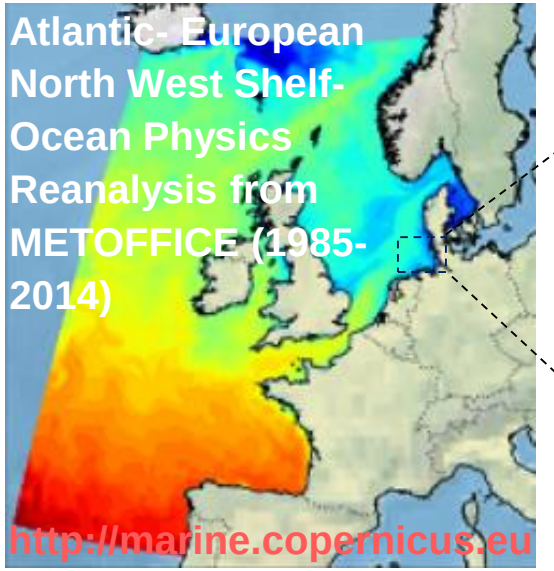
Which are the specific physical-ecological coupling mechanisms, which implications arising from the understanding of the these couplings?

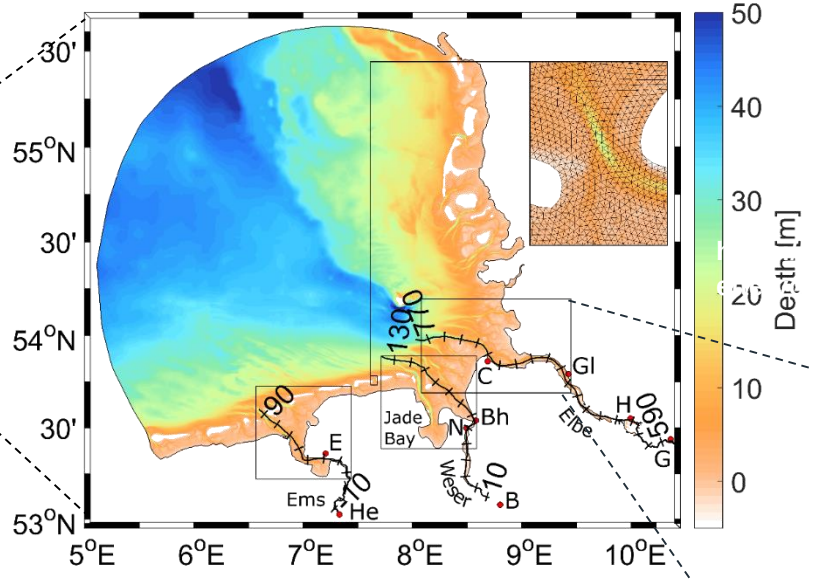
https://de.wikipedia.org/wiki/Chronologie_des_Wasserbaus_an_der_Hamburger_Unterelbe



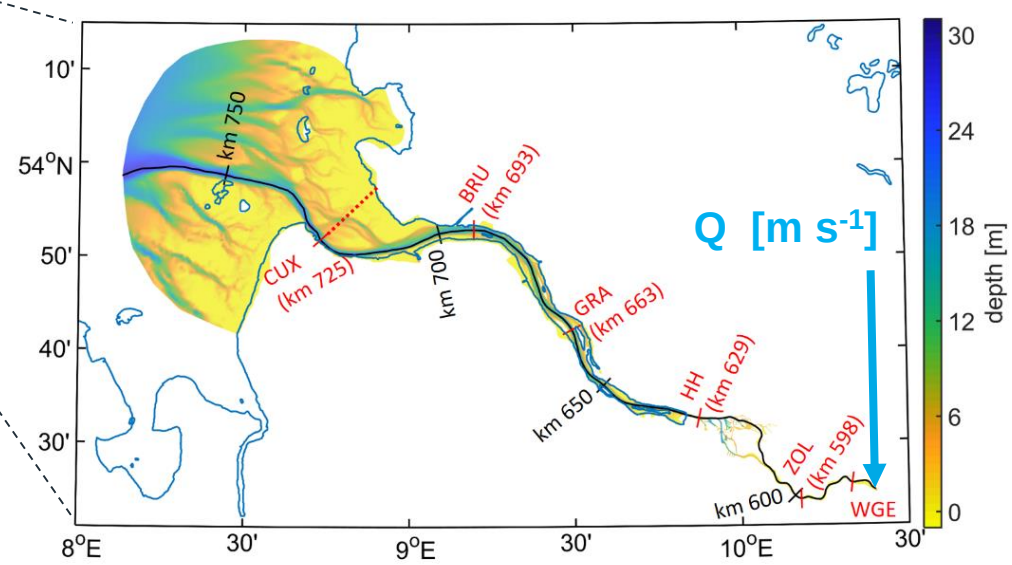
Model nesting

Dynamical downscaling of physics





Stanev et al., 2019



- Water elevation
- Currents
- Temperature
- Salinity

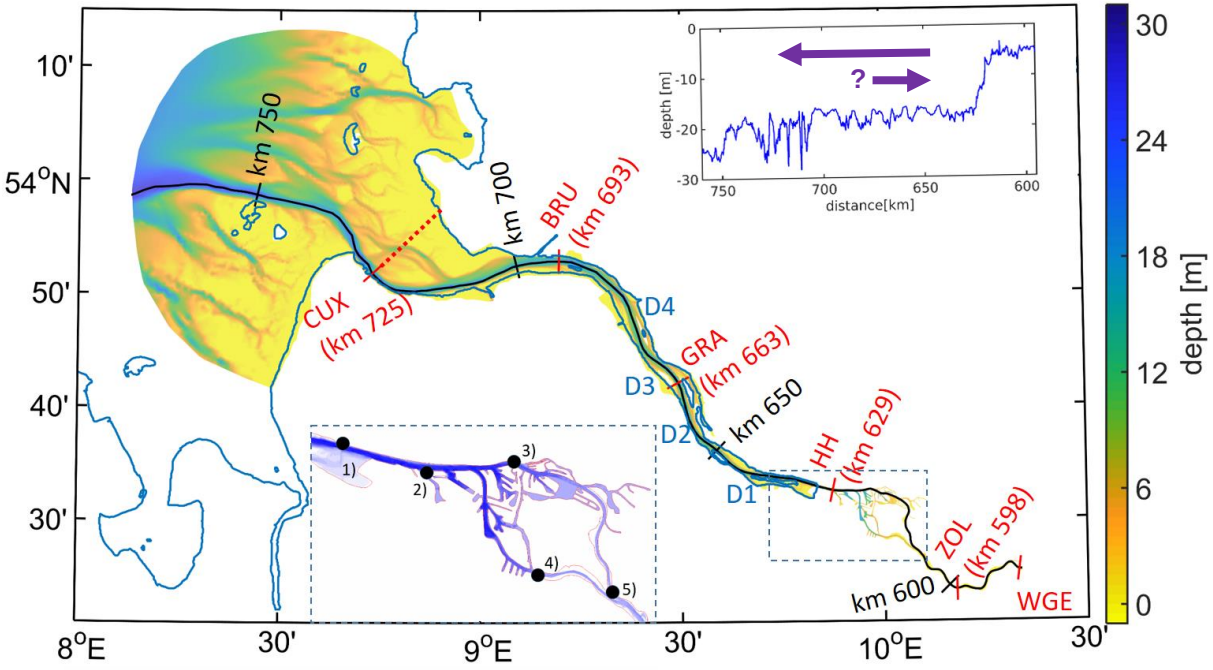
- ICES observations of nutrients, oxygen, organic matter at O.B.
- Daily river discharge
- Monthly chl-a, nutrients, organic matter at tidal weir

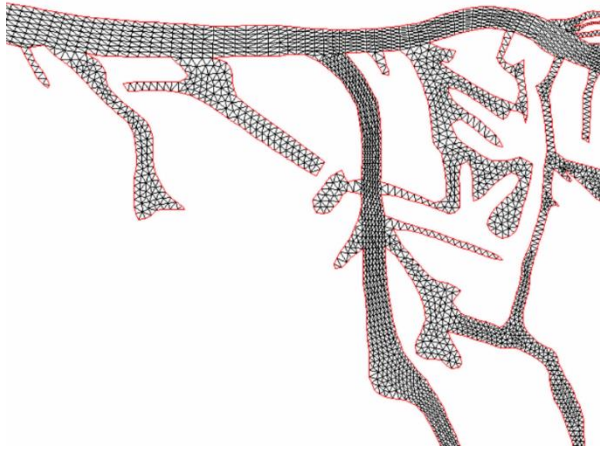
The tool

A 3D coupled hydrodynamical-biochemical model of the Elbe Estuary

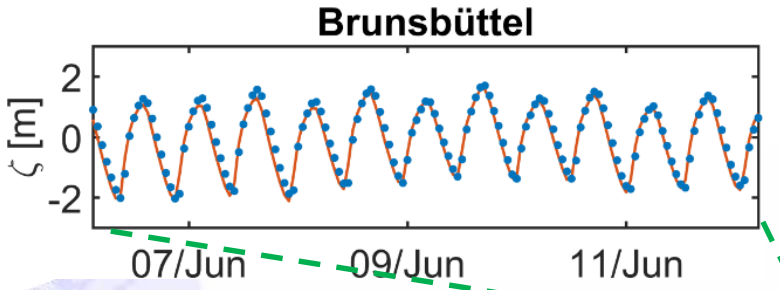
- Coupled hydrodynamical-biogeochemical numerical model
- 3D, unstructured mesh, wetting and drying algorithm
- Baroclinic, benthic-pelagic coupling
- Horizontal mesh: 33k nodes, 60k elements with resolution between 1 km (open boundary) and 30 m (port of Hamburg)
- Vertical grid: 1 layer (tidal flats) to 20 layers (deep channel)

Realistic simulation accounting for tidal motion, freshwater runoff, along-channel dispersion, lateral exchange (channel-flats), vertical mixing of physical and biological properties

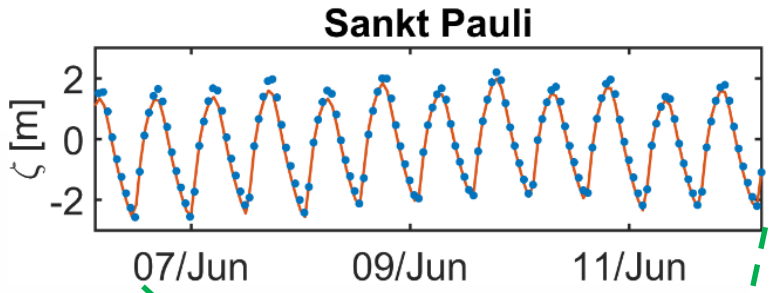


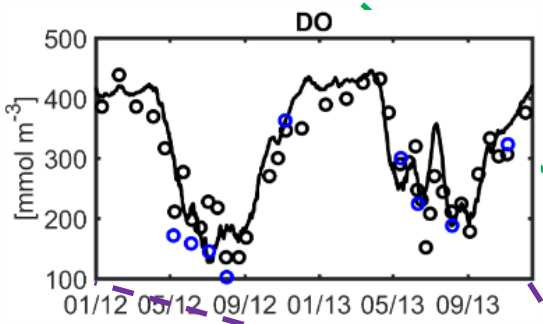


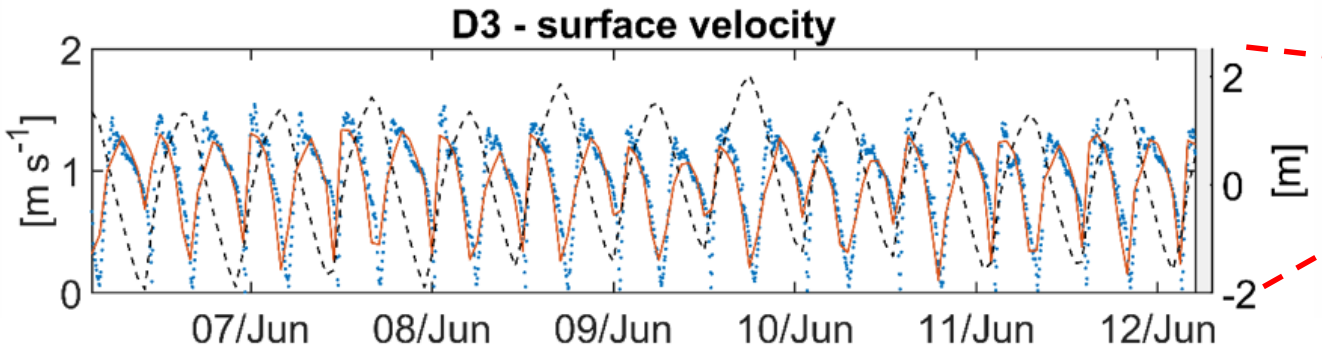
Validation - overview



Model vs. observations







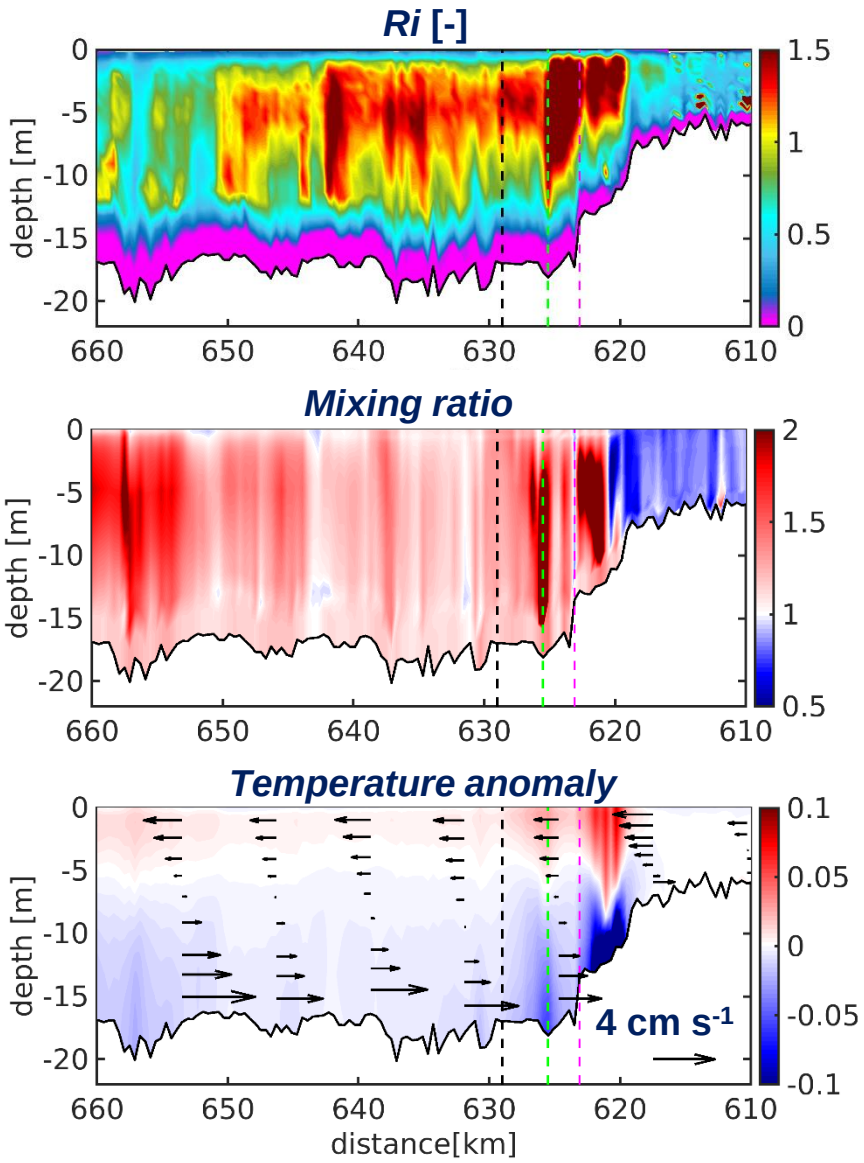
Water elevation [m]

Horizontal currents [m s^{-1}]

Oxygen concentration [mmol m^{-3}]

Helmholtz-Zentrum hereon

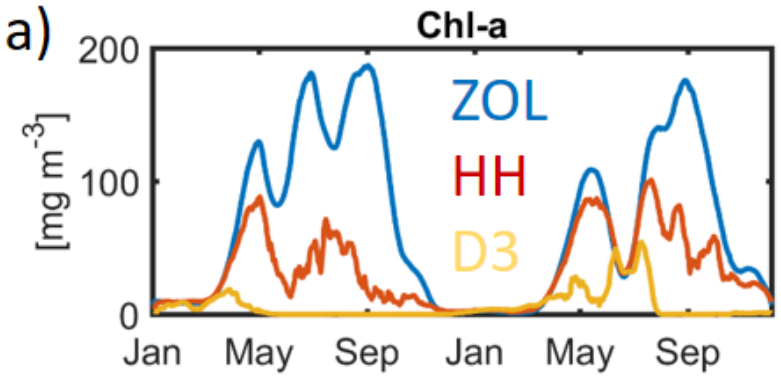
Estuarine physics

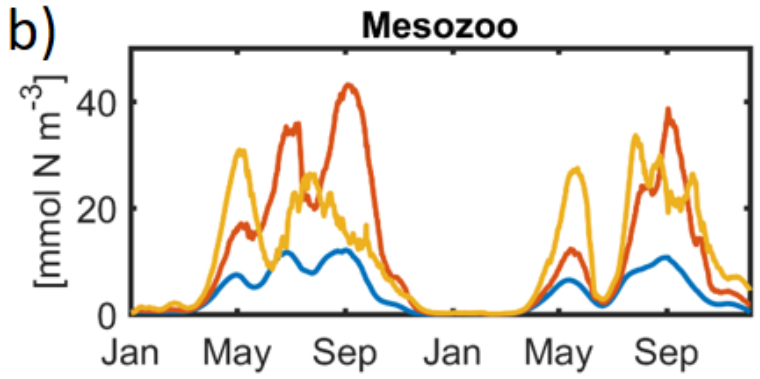


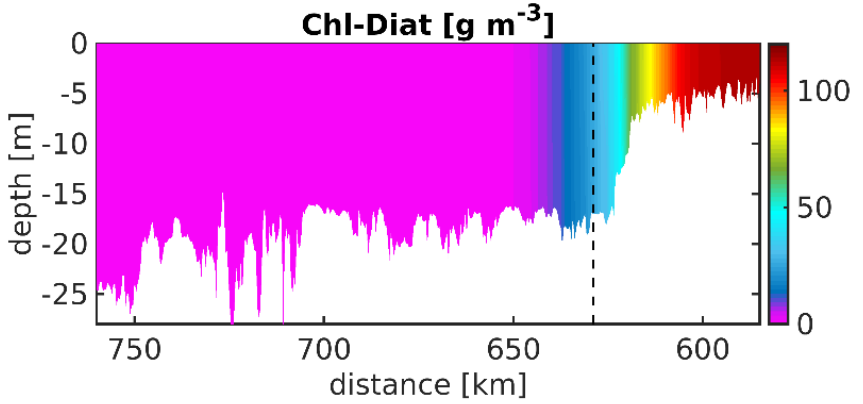
- Physical fields determine transport of tracers, residence time in a certain area, cf. ratio stratification/mixing
- Some physical fields (S,T) directly affect biogeochemical turnover
- Modelling can help to identify circulation patterns or critical for the transport and turnover of properties regions, e.g. residual circulation cells in the limnic regime

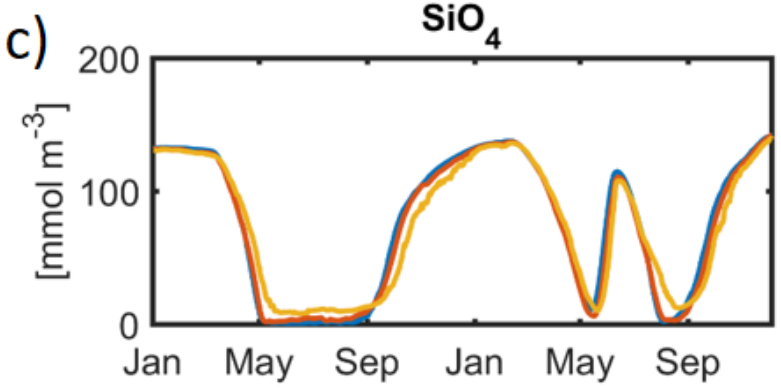
Helmholtz-Zentrum hereon

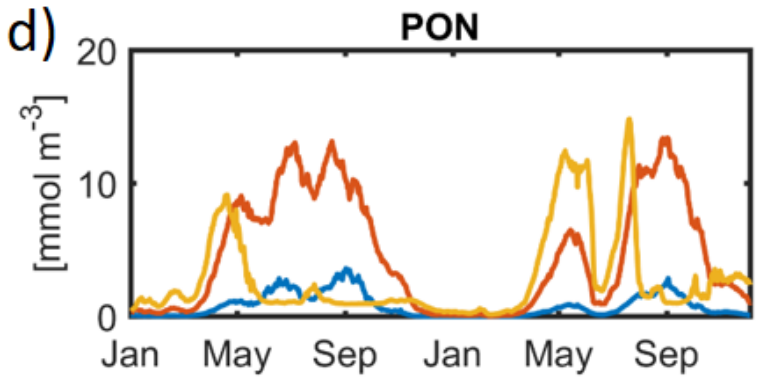
Elbe biogeochemical dynamics

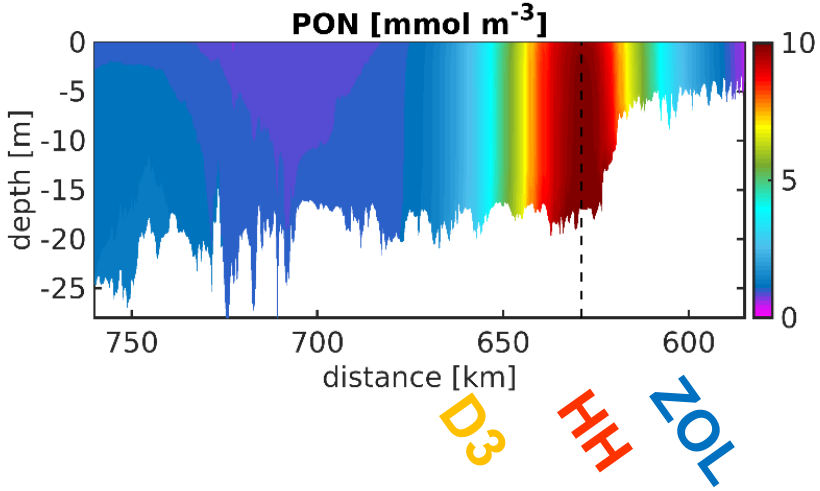






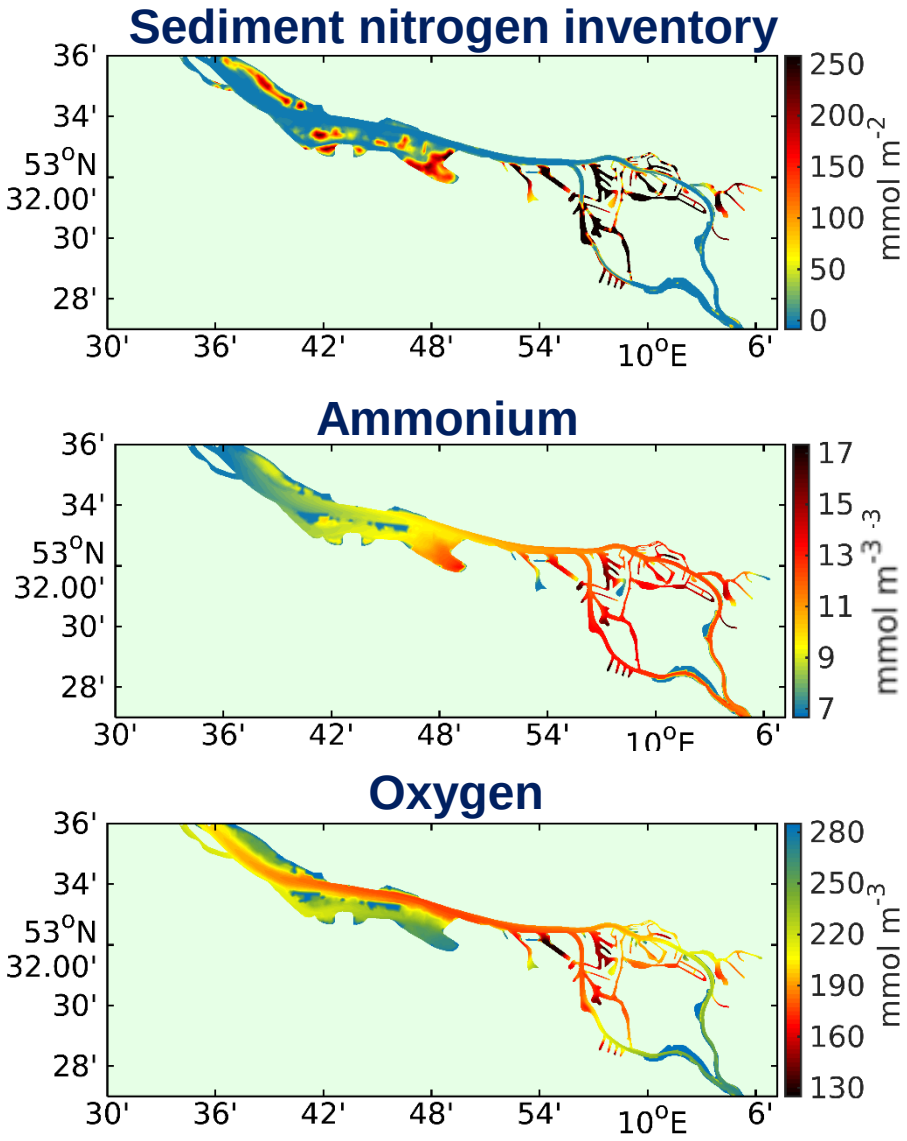




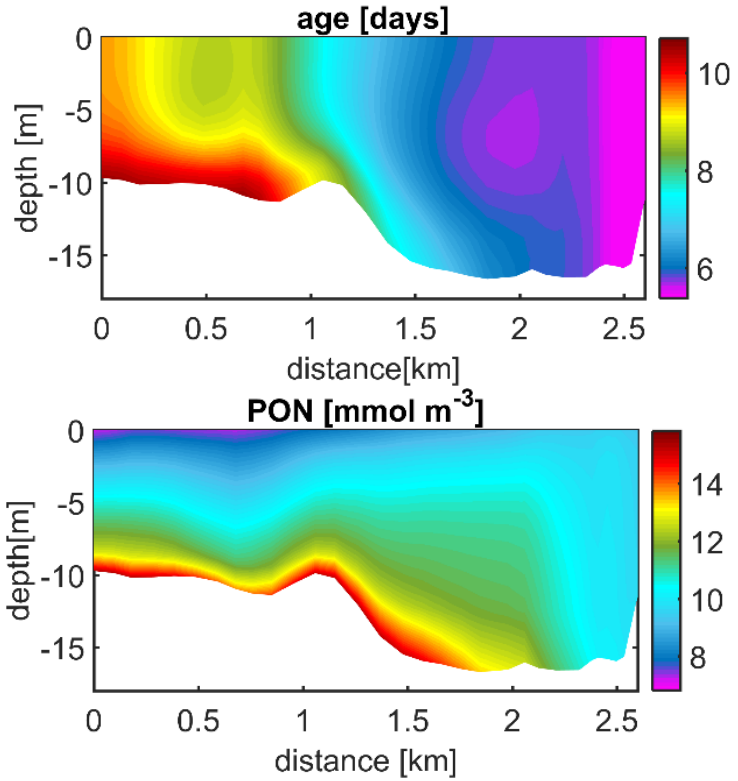


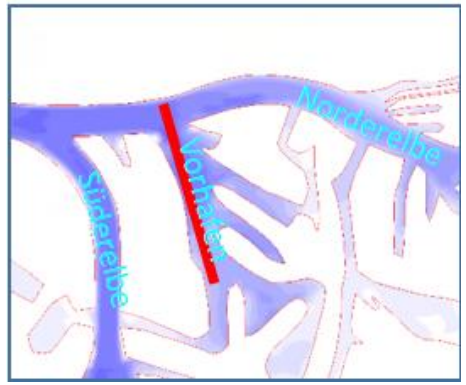
- High primary production in shallow upper estuary
- Collapse of primary producers in dredged channel (port), grazing
- Biogenic particle production (detritus) in port and dredged limnic reach

Biogeochemical gradients



- High concentrations of biogenic particles, sedimentation in port area
- Port basins hotspots of ammonium release and oxygen depletion





Helmholtz-Zentrum hereon

Unravelling the effects of stratificaton in the deepened fairway

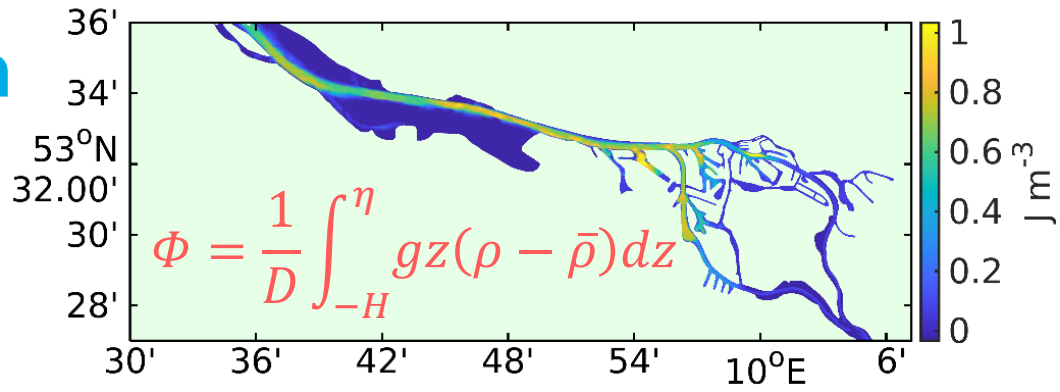
- Deepened channel manifests summer stratification
- Stratification potentially inhibits vertical exchange, e.g. mixing dissolved oxygen towards channel bottom
- Simple model experiment:

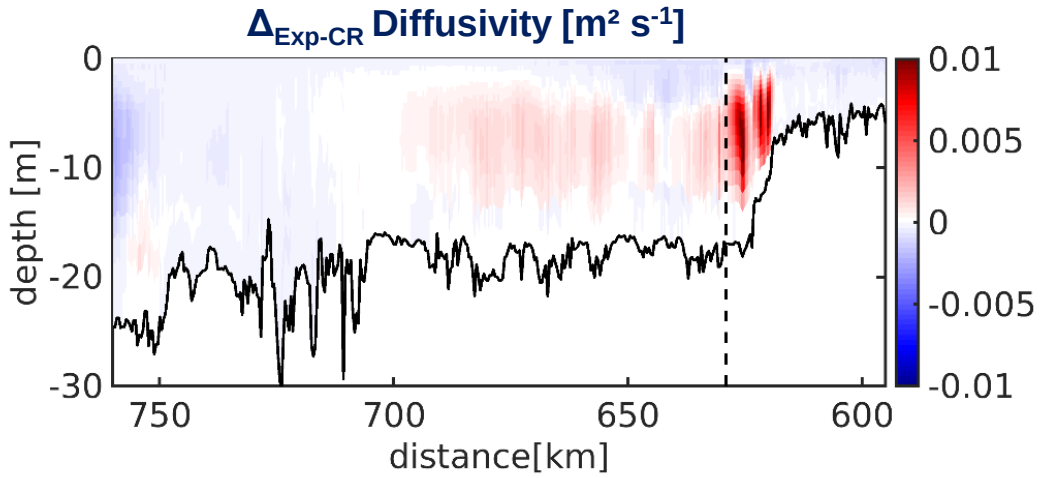
Equation of state:

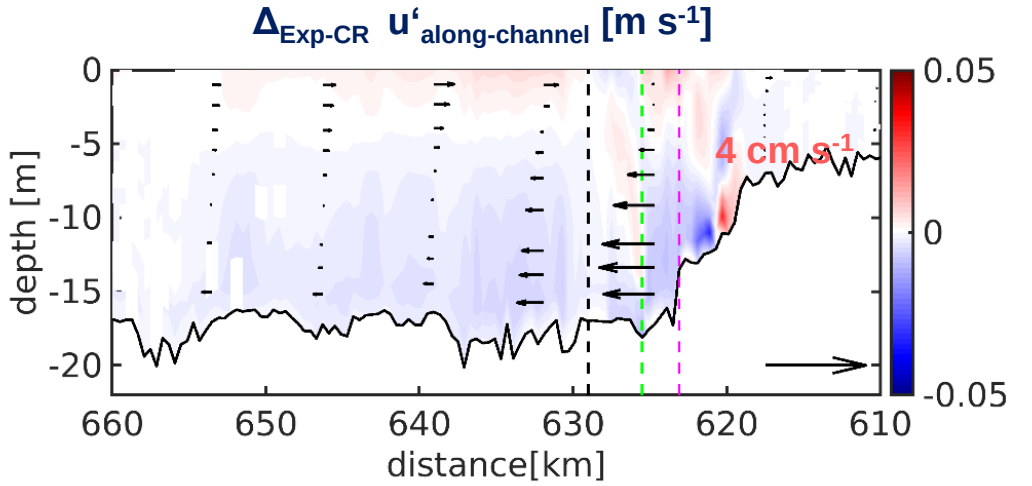
$$\rho = \rho(S, T, p)$$

constant

- Disabling the thermal stratification leads to:
  - Changed estuarine circulation
  - Increased vertical mixing
  - Enhanced oxygen levels

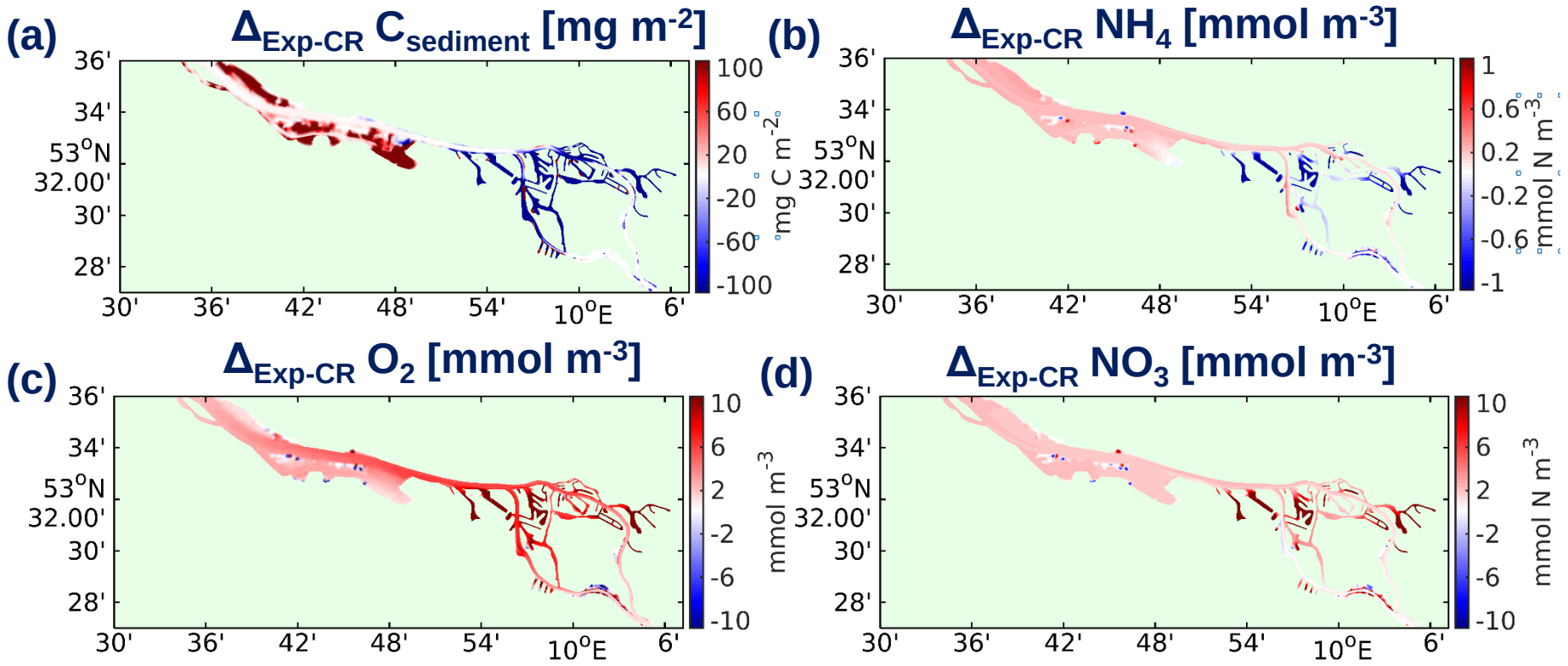






Impact of „disabled“ thermal stratification

Changes to biogeochemical mean fields

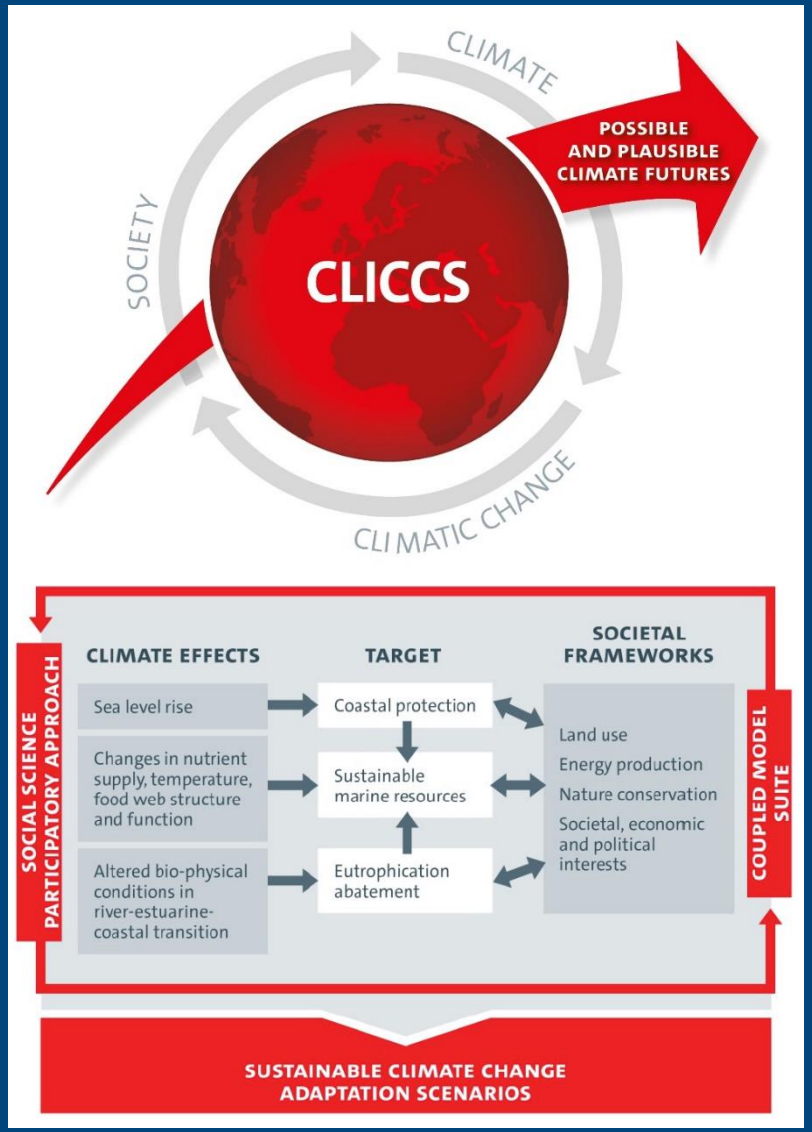


- Increased export of organic sediments from port towards the middle reaches
- Reduced ammonium levels in the port basins
- Improved oxygen levels

Helmholtz-Zentrum hereon

Conclusions

- Unstructured coupled 3D model reproduces the observed dynamics
- Elbe estuary has two zones showing typical estuarine circulation: 1) salinity front, 2) dredged limnic reach
- Port region, port basins hotspot of heterotrophic decay, risk of hypoxia
- Stratification in the dredged channel enhances particle trapping in the port area, promotes heterotrophic turnover
  - Engineered system more vulnerable
  - Sensitivity experiments reveal cause-effect relationships (→ Stakeholder dialog)



DFG Deutsche Forschungsgemeinschaft
German Research Foundation