Adaptation to the impacts of climate change and human intervention in the Elbe estuary: model-based identification of possible trade-offs

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Elbe Estuary model

- Coupled hydrodynamical-biogeochemical numerical model (Zhang et al., 2016; Bruggeman & Bolding, 2014; Daewel & Schrum, 2013; Pein et al., 2021)
- 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

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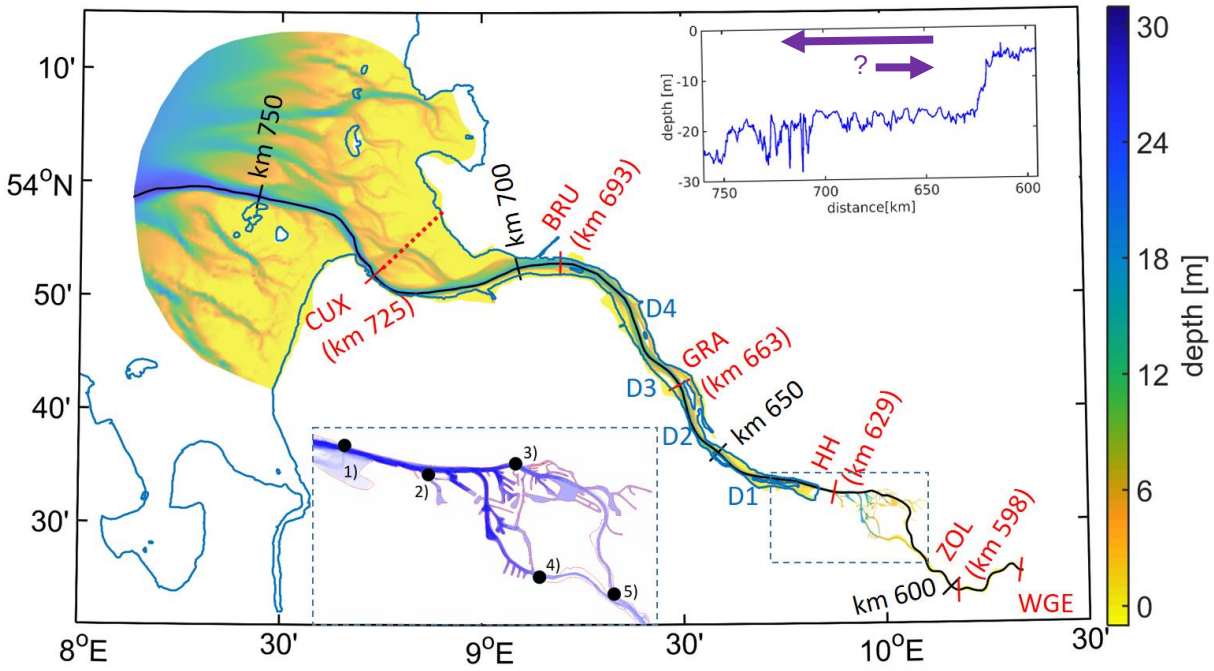
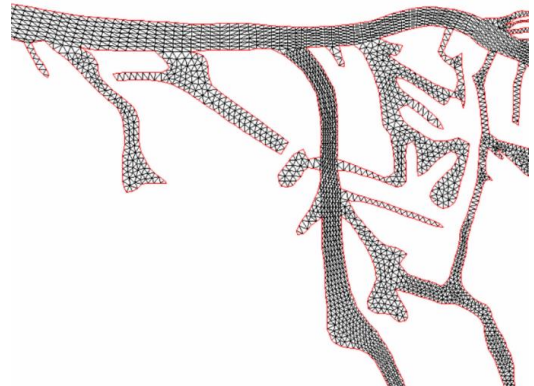
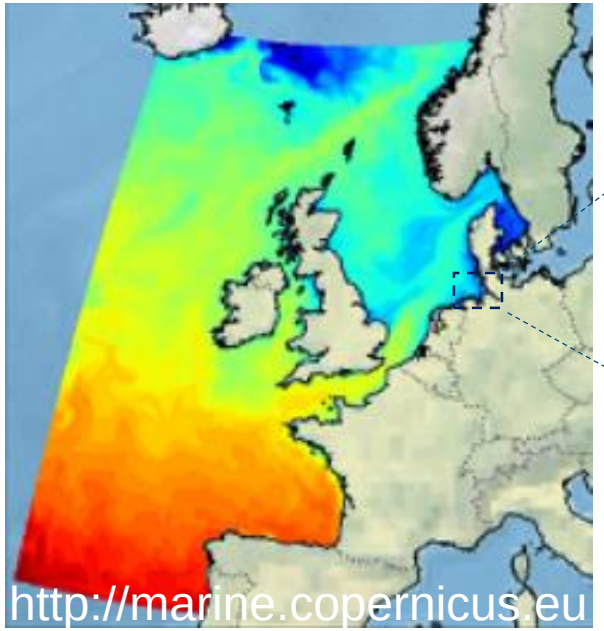
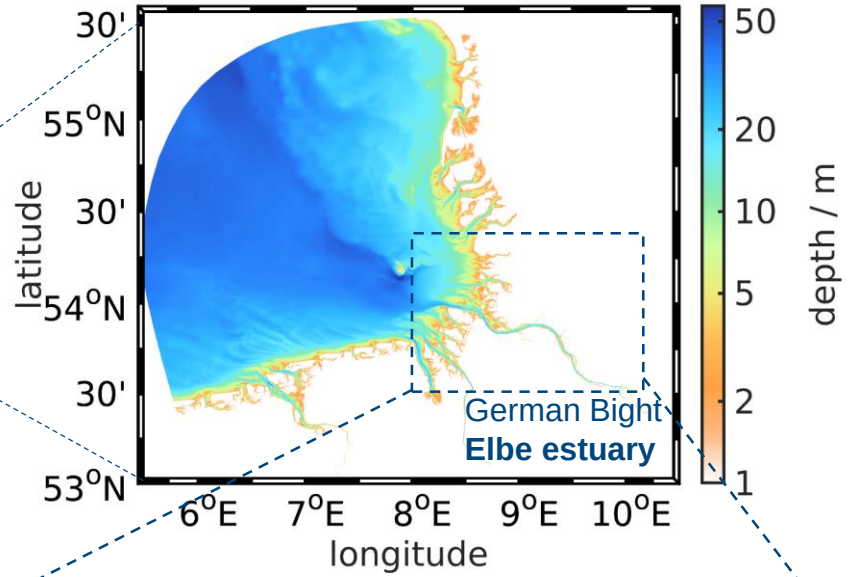


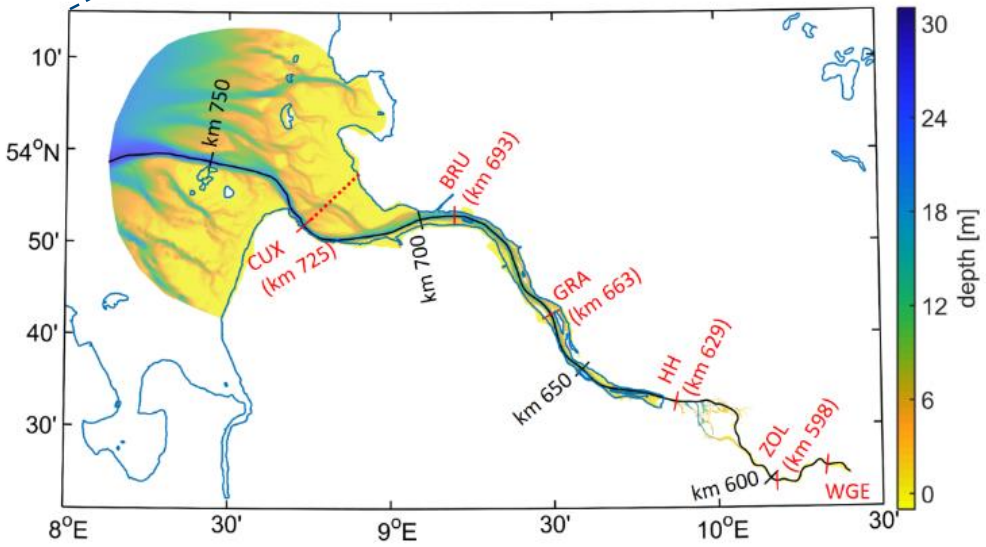


Model nesting

Dynamical downscaling of physical and biogeochemical fields







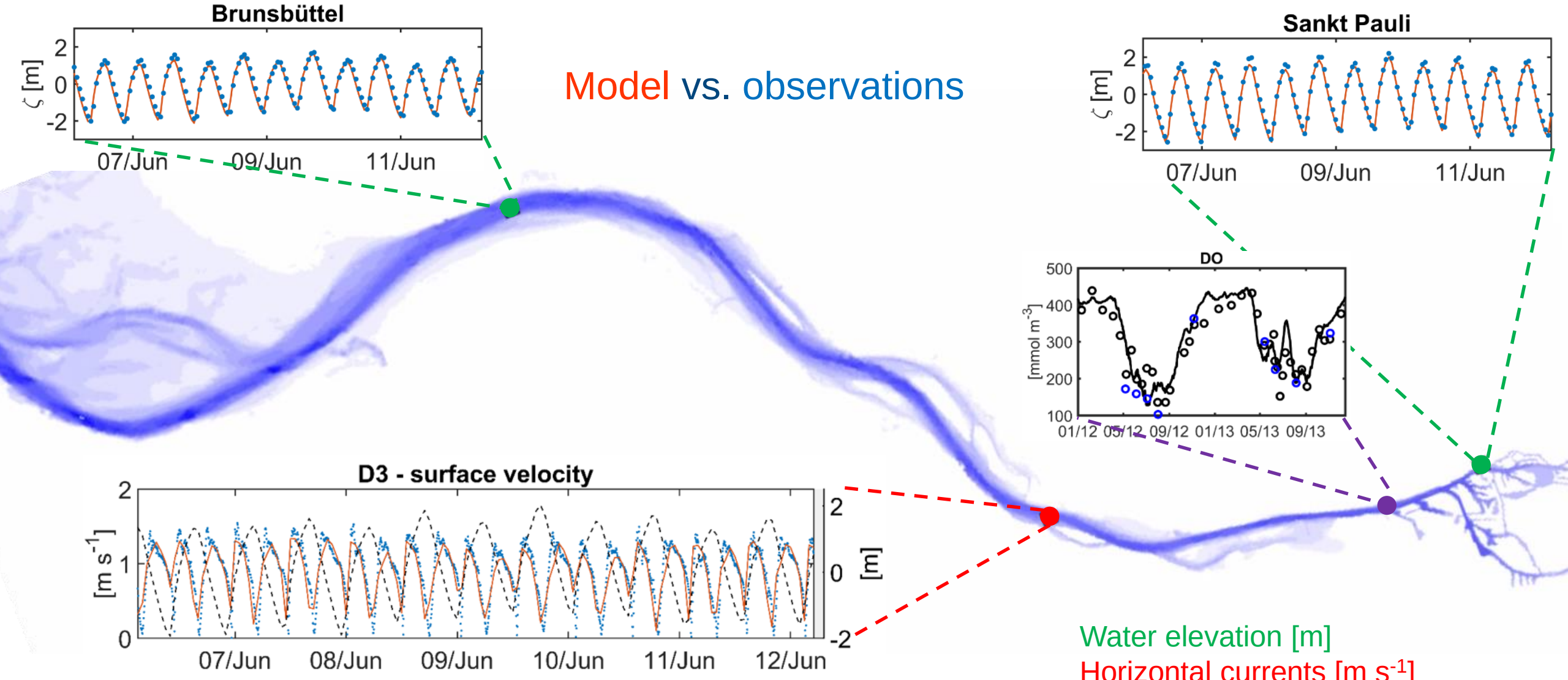
Physical forcing:

- Water elevation
- Currents
- Temperature
- Salinity
- Meteo
- River runoff

Biogeochemical forcing:

- Observed or simulated nutrients, oxygen, organic matter at O.B.
- Daily river discharge
- Monthly chl-a, nutrients, organic matter at tidal weir

Validation of tidal and seasonal dynamics



See details in *Pein et al. 2021* https://doi.org/10.3389/fmars.2021.623714

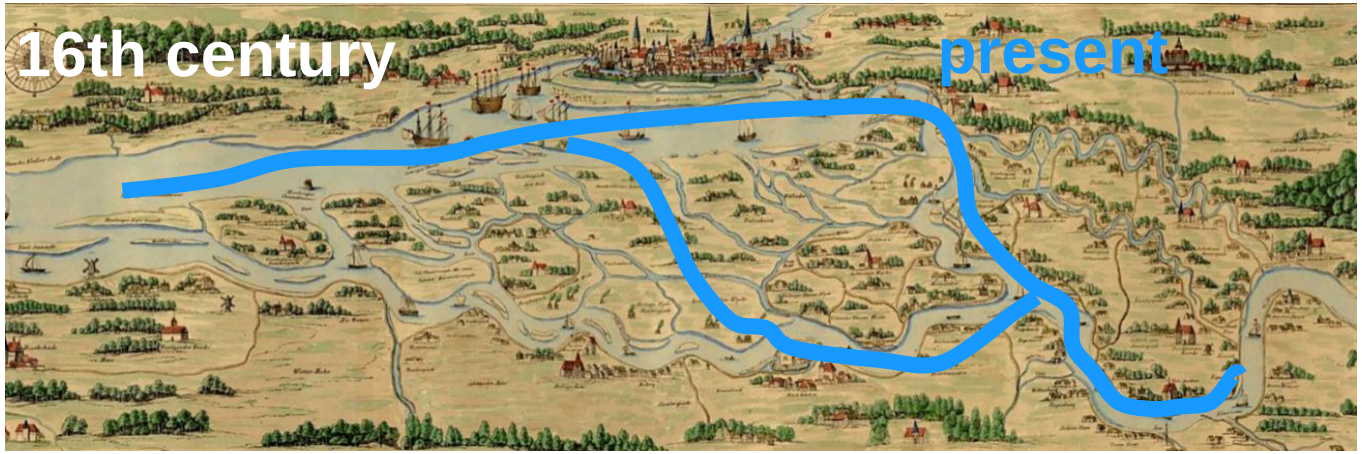
Challenges

From inland delta to industrialised estuary

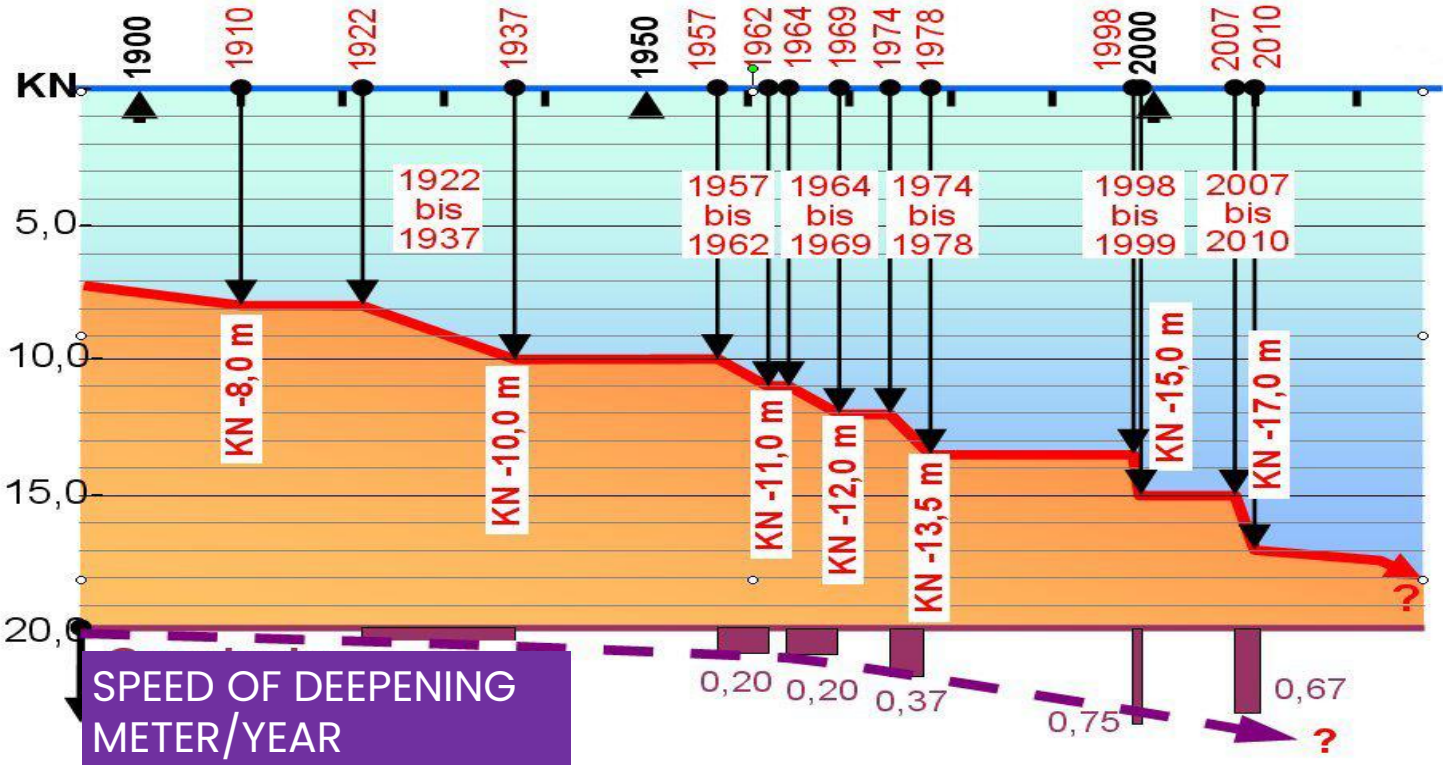
- Coastal protection and dikes
- Punctures, modifications of the river course
- Deepening of the shipping channel
- Industrialization & agriculture → nutrient and pollutant loads
- Sea level rise, decreasing river discharge enhance salinity intrusion, sediment erosion and turbidity

➢ **What are the key dynamical controls of the system?**

➢ **How to conciliate economics and ecosystem?**

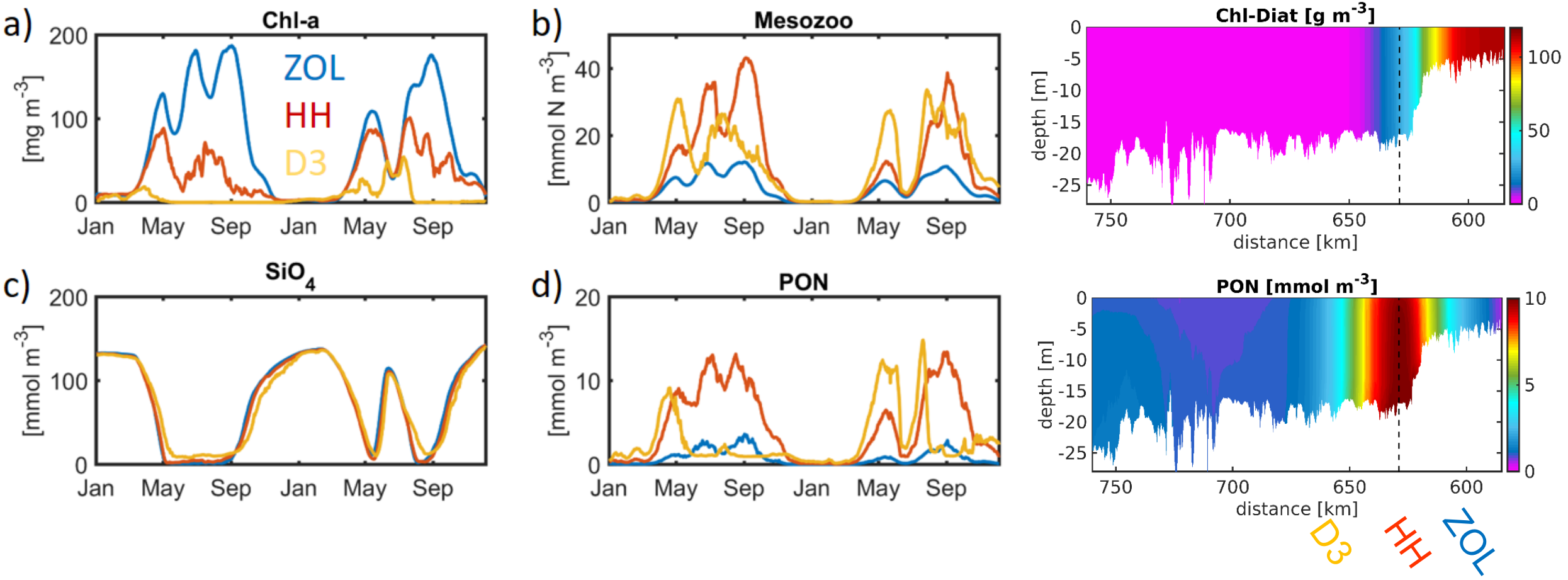


https://de.wikipedia.org/wiki/Chronologie_des_Wasserbaus_an_der_Hamburger_Unterelbe



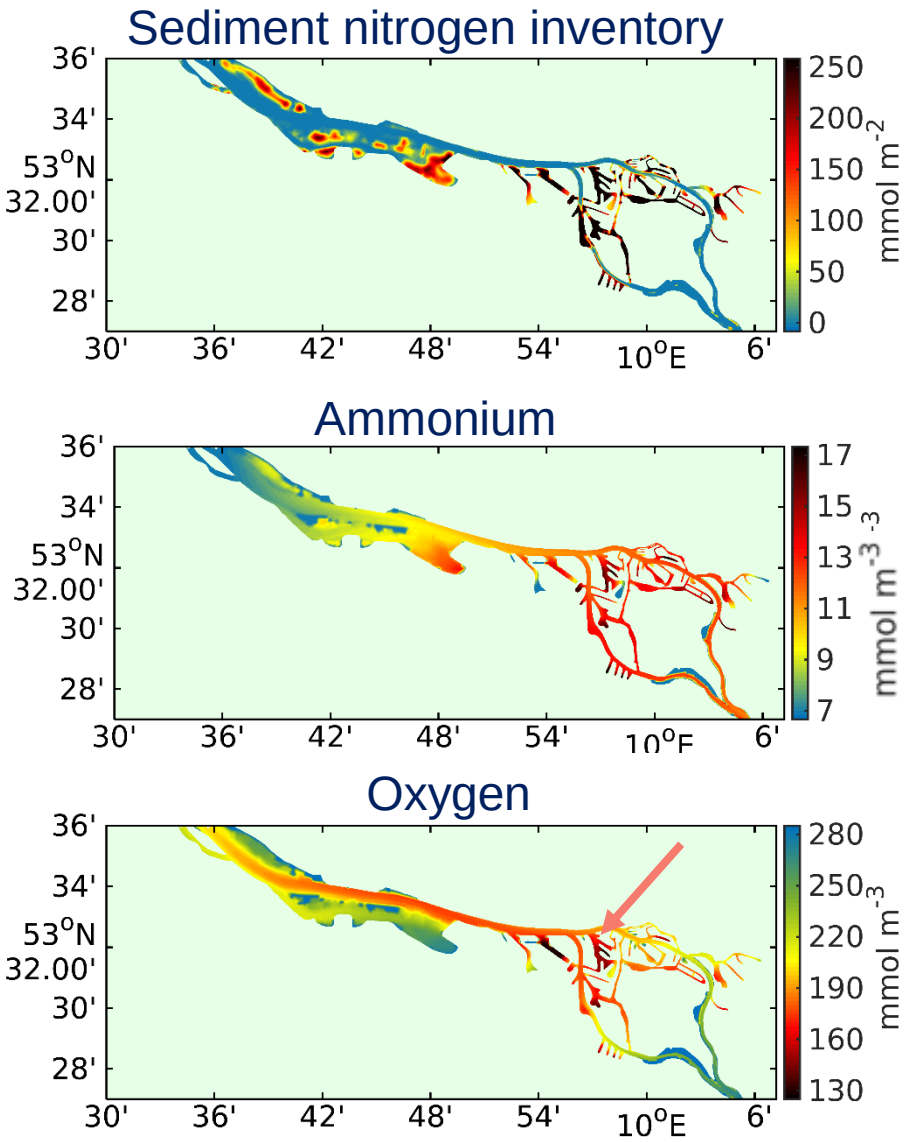
Elbe biogeochemical dynamics

Seasonal dynamics of primary, secondary production

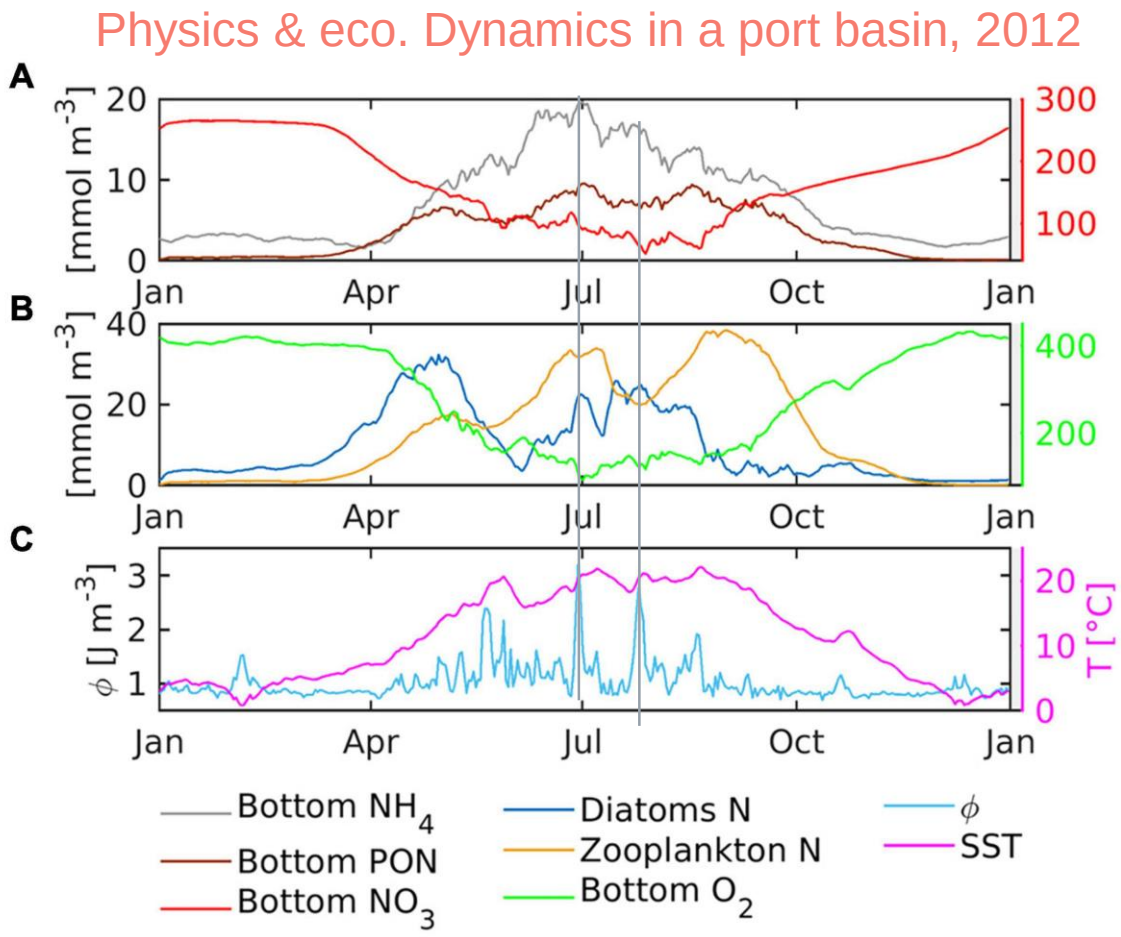


- High primary production in shallow upper estuary
- Collapse of primary producers in dredged channel (port), grazing
- Biogenic particle production (detritus) in port and dredged limnic reach

Hotspots of eutrophication

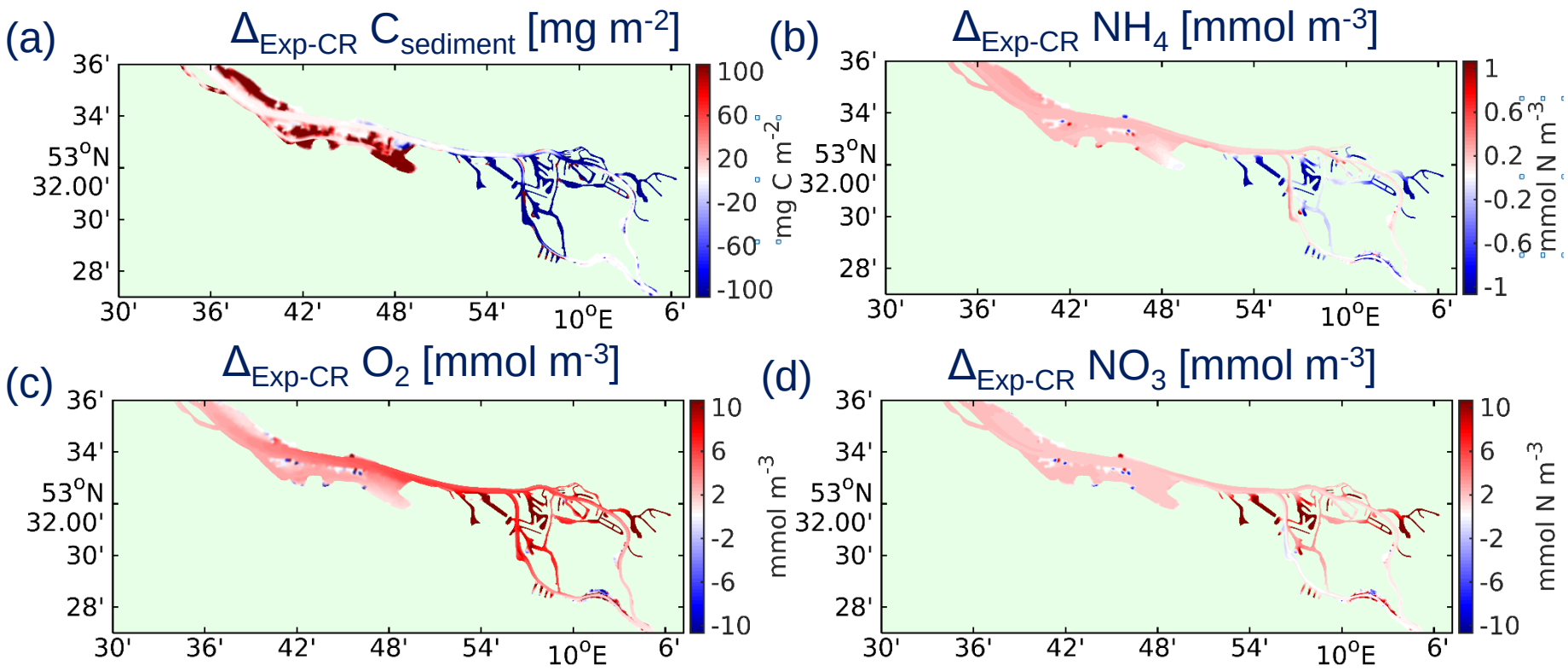


- High concentrations of biogenic particles, sedimentation in port area
- Port basins hotspots of ammonium release and oxygen depletion



Model experiment: Disabling temperature stratification

Changes to biogeochemical mean fields



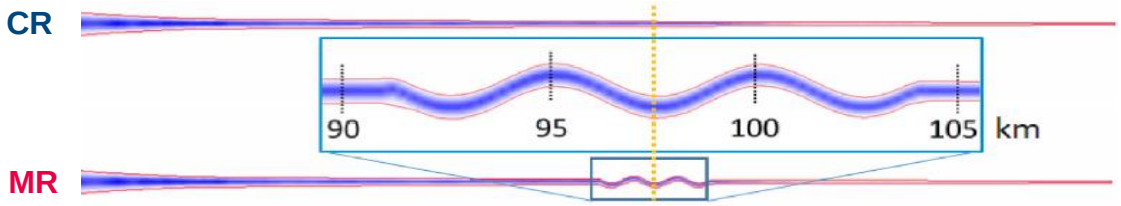
- Increased export of organic sediments from port towards the middle reaches
- Reduced ammonium levels in the port basins
- Improved oxygen levels

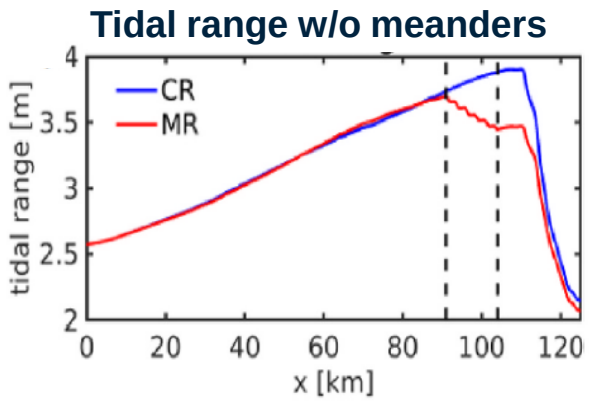
A sustainable adaptation measure?

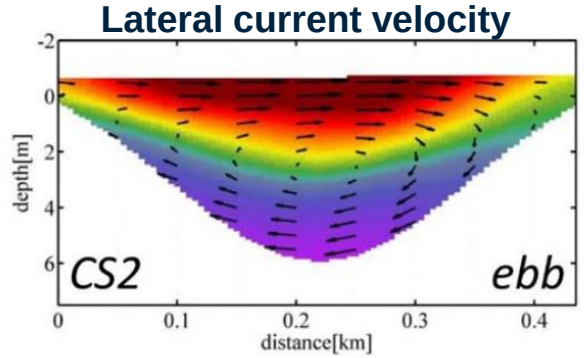
Channel meanders enable rotating ebb current

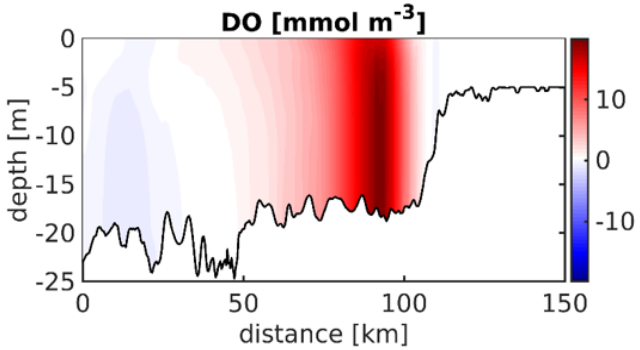
https://de.wikipedia.org/wiki/Chronologie_des_Wasserbaus_an_der_Hamburger_Unterelbe

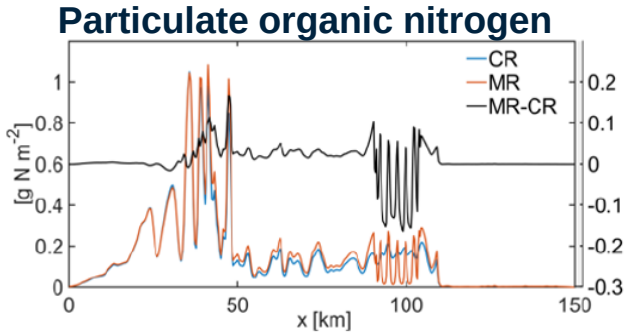
https://yandex.ru/maps

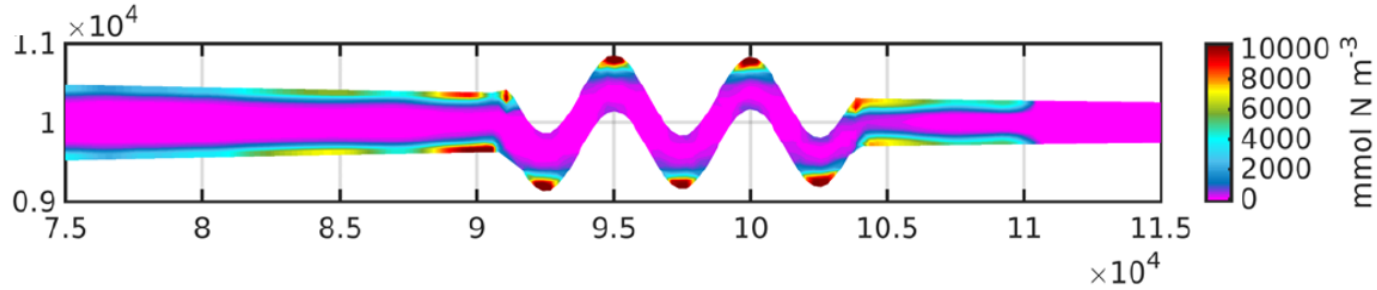












Pein et al., JGR2018; Pein et al., CSR2021

Conclusions

- Flexible and powerful modelling tool tackles estuarine physics and biogeochemical dynamics nested into operational or climate products
- Elbe estuary is not in a sustainable state, economic and ecological costs are high
- Model experiments reveal underlying feedback mechanisms inspiring proposed sustainable adaptation measures
- Climate change likely to increase pressure on infrastructure, might mitigate/shift hotspots of eutrophication

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