Effects of heatwave events on dissolved oxygen in the Elbe Estuary

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Introduction

The Elbe Estuary is an example of the impact of high nutrient loads from the river basin on a land-sea continuum heavily used by humans. In the Elbe Estuary, especially downstream of Hamburg, low dissolved oxygen (DO<4 mg/l, 125 mmol/m³) occurs frequently in summer, even more often undercutting the normative minimum concentration of 7 mg/l (218.75 mmol/m³) for transitional waters according to national legislation.

Extreme heatwaves significantly disrupt estuarine hydrodynamics and biogeochemical processes, reducing DO levels and posing a serious threat to water quality and ecosystem health. Significant hypoxia (DO<2 mg/l) occurred in the waters of the Hamburg deep-water channel in the Elbe Estuary during the superimposed European heatwave in 2018. However, the DO changes in the estuary and bottom waters under the influence of heatwaves are not clear.

In this study, we simulate the spatial distribution characteristics of DO in the Elbe Estuary during the extreme heatwave in 2018 based on the SCHISM (Zhang et al., 2016) 3D coupled hydrodynamic-biogeochemical model and explore its response to extremely high temperatures.

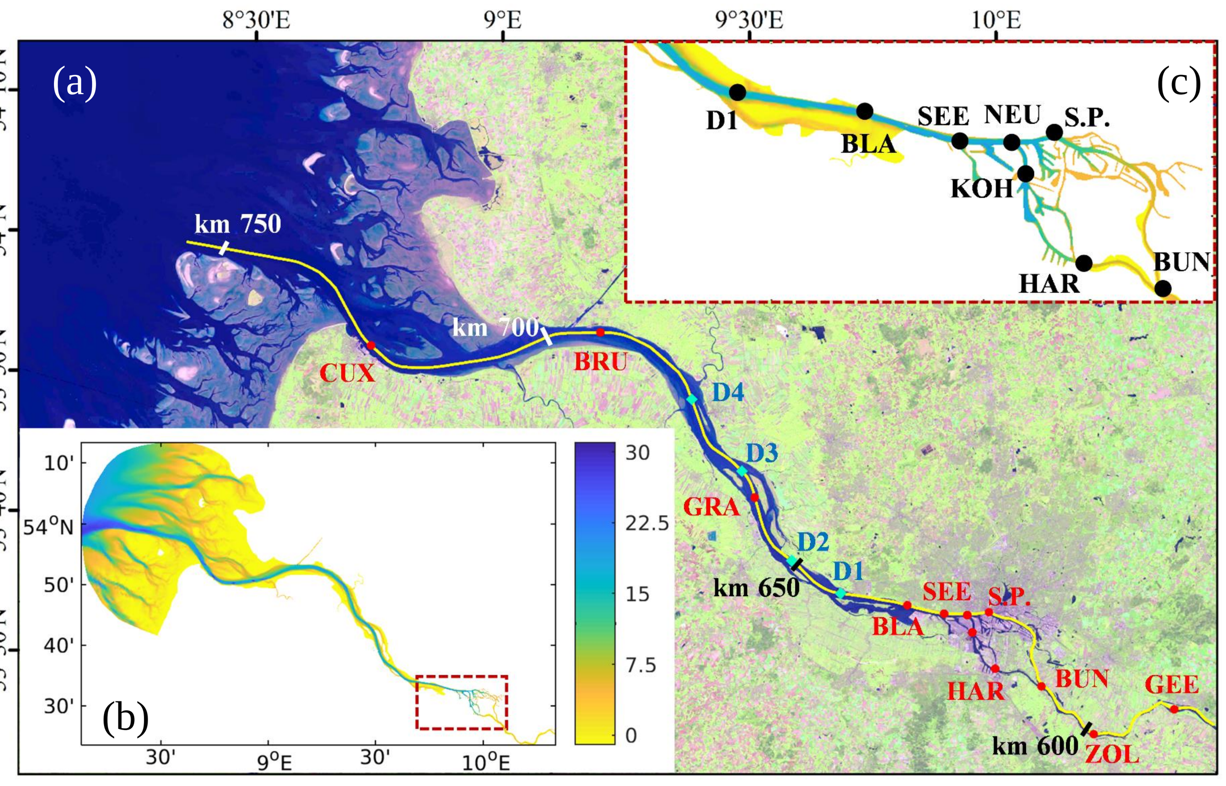

Fig. 1. Study area (a) and model domain with depth given as a background (b-c).

Material and Methods

◘ Model set-up

- Modelling framework SCHISM-ECOSMO;
- Horizontal grid with~42k nodes;
- 21 vertical S-layers;
- Open ocean boundary: CMEMS reanalysis (sea surface height, currents, salinity, temperature, nutrients, oxygen);
- Land boundary: run-off, nutrients, plankton, temperature, oxygen at GEE station;
- Atmospheric forcing from DWD COSMO-EU product with 7km resolution.

◘ Observed data

- Hydrodynamic: tide gauges of the ZDM data portal
- Water quality: FGG and NLWKN data portals

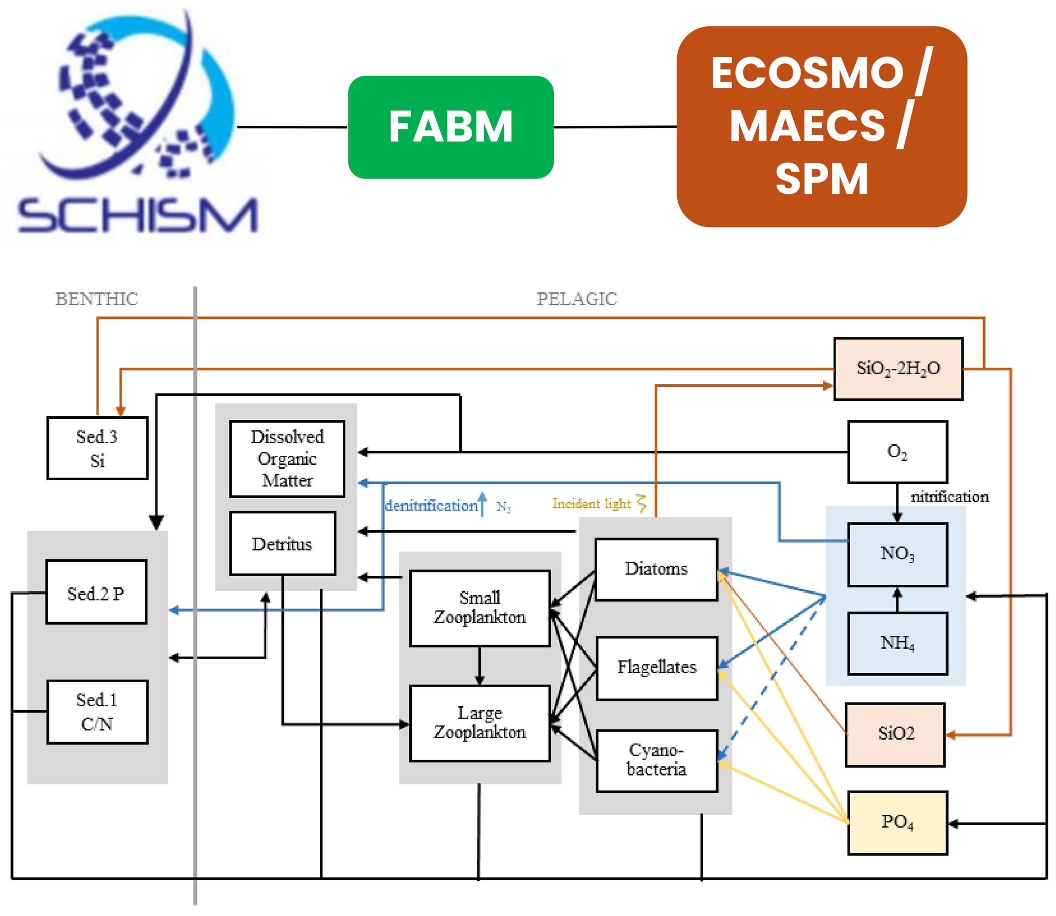

Fig. 2 Scheme of the biogeochemical model ECOSMO II (adopted from Benkort et al., 2020; Pein et al., 2024)

◘ Heatwaves identification

- the 90th percentile threshold (Hobday et al., 2016);
- MATLAB toolbox by Zhao and Marin (2019).

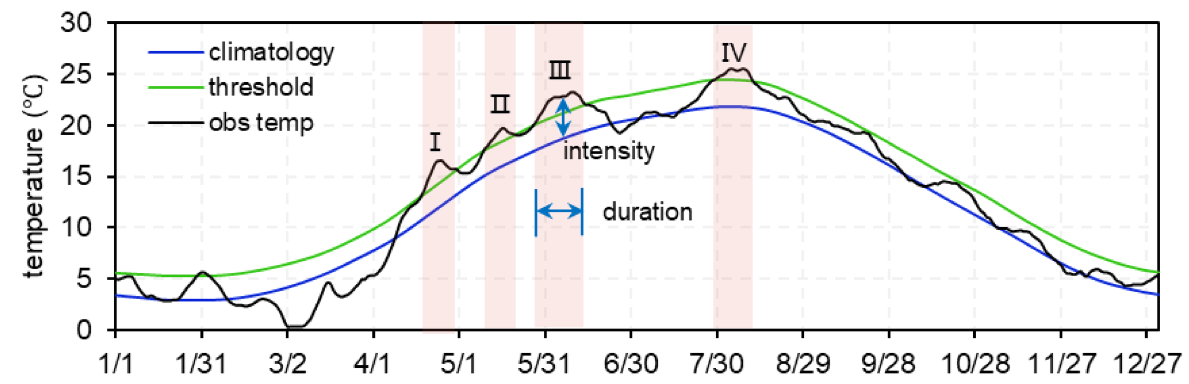

Fig. 3. Heatwave identification at SEE station in the Elbe Estuary in 2018.

◘ Potential energy anomaly (PEA)

- Quantify the intensity of stratification in the water column (Simpson et al., 1981)

$$\emptyset = \frac{1}{D}\int_{-H}^{\eta} gz(\rho - \bar{\rho})dz \qquad D = \eta + H$$

Results

◘ Validation

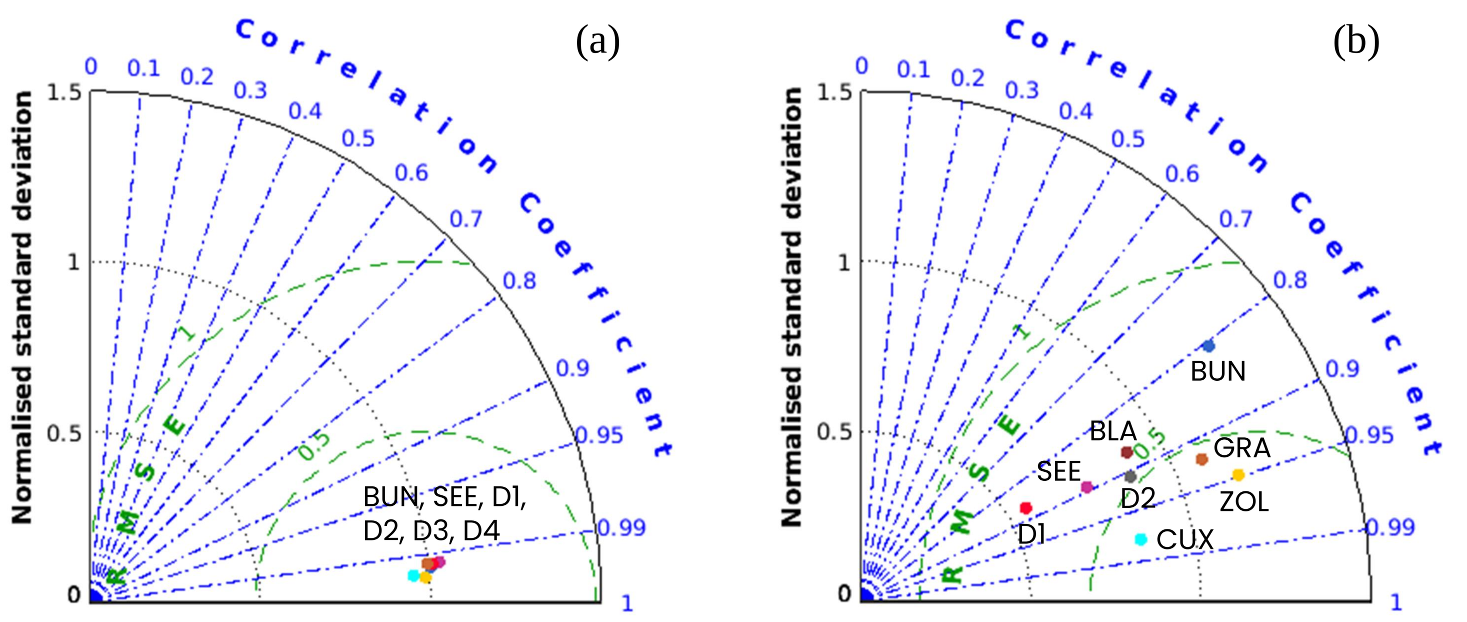

Fig. 4. Taylor diagram of simulated temperature (a) and DO (b) against respective observations at several stations along the river channel.

◘ Stratification increases in port area during heawaves

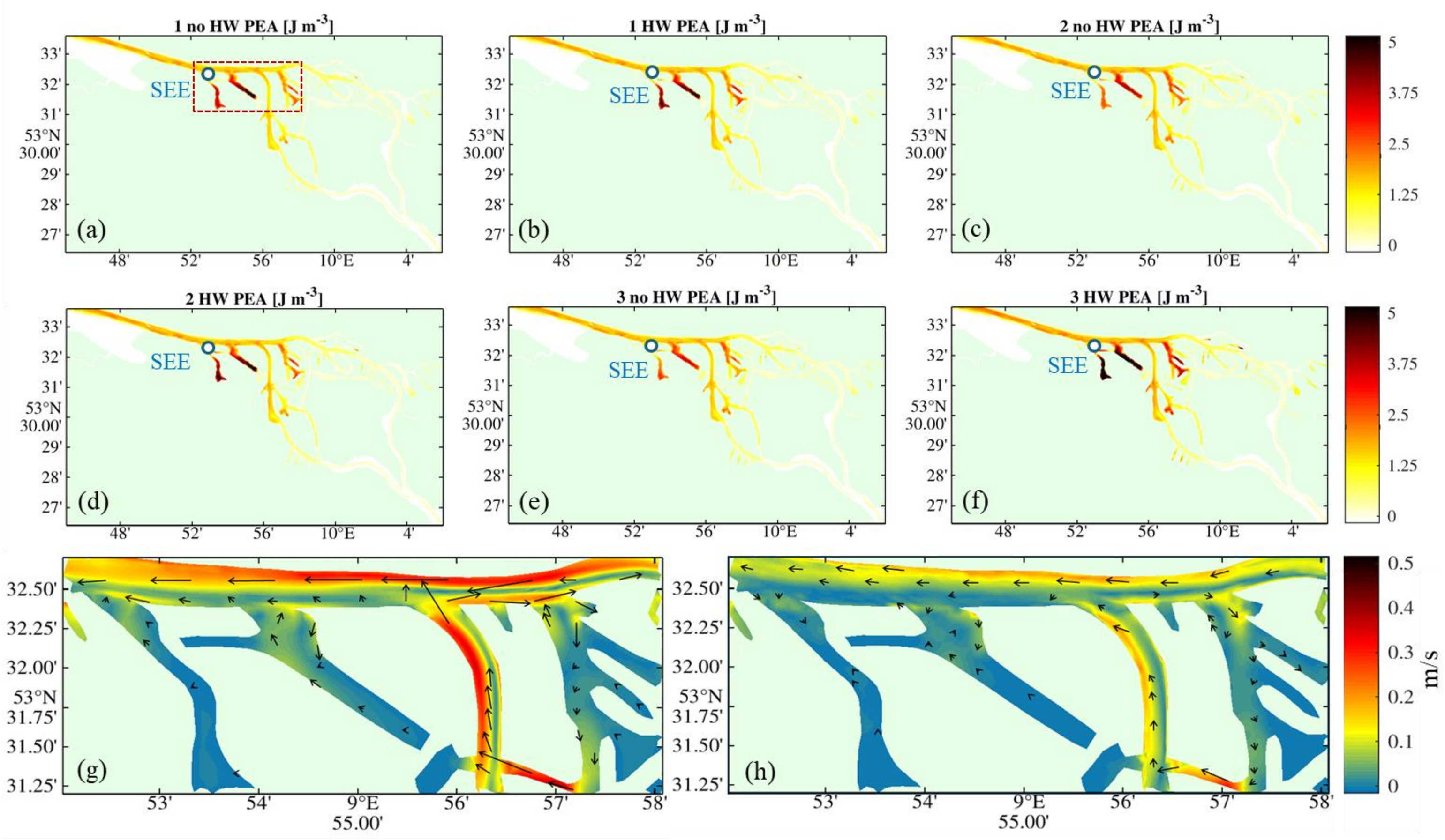

Fig. 6. Time-averaged potential energy anomaly without and with heatwave events (a-f). The red dashed box in panel (a) marks the area shown in (g-h) which depict simulated subtidal surface (g) and bottom (h) residual velocity fields during the third heatwave. Arrows indicate the direction of residual flow.

◘ Dissolved oxygen decrease in the bathymetric jump during heatwaves

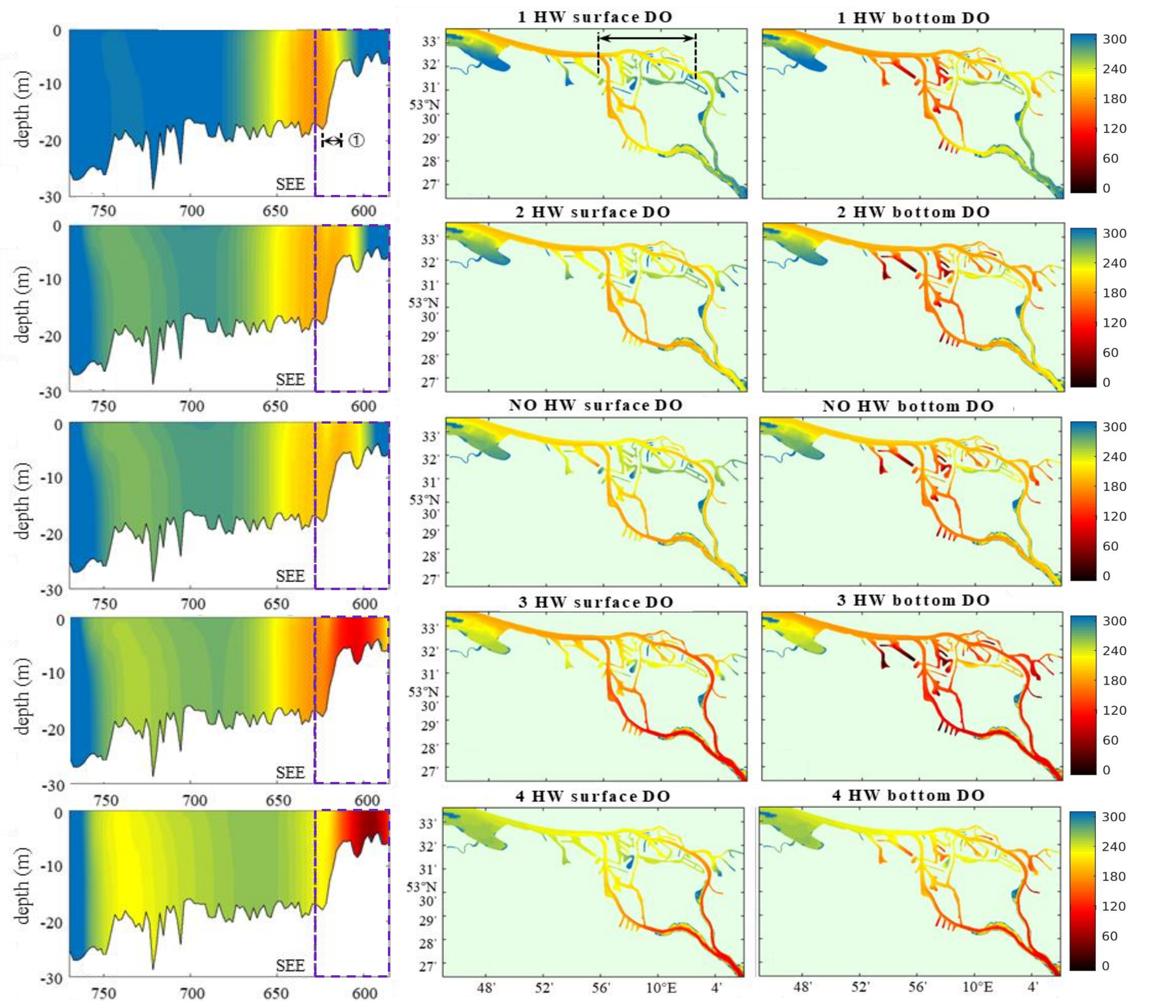

Fig. 5. Vertical distribution of DO along the river channel with and without heatwaves in the Elbe Estuary in 2018 (1st column). The 2nd and 3rd columns are the distribution of surface and bottom DO, which region is upstream of the dotted line box in the 1st column.

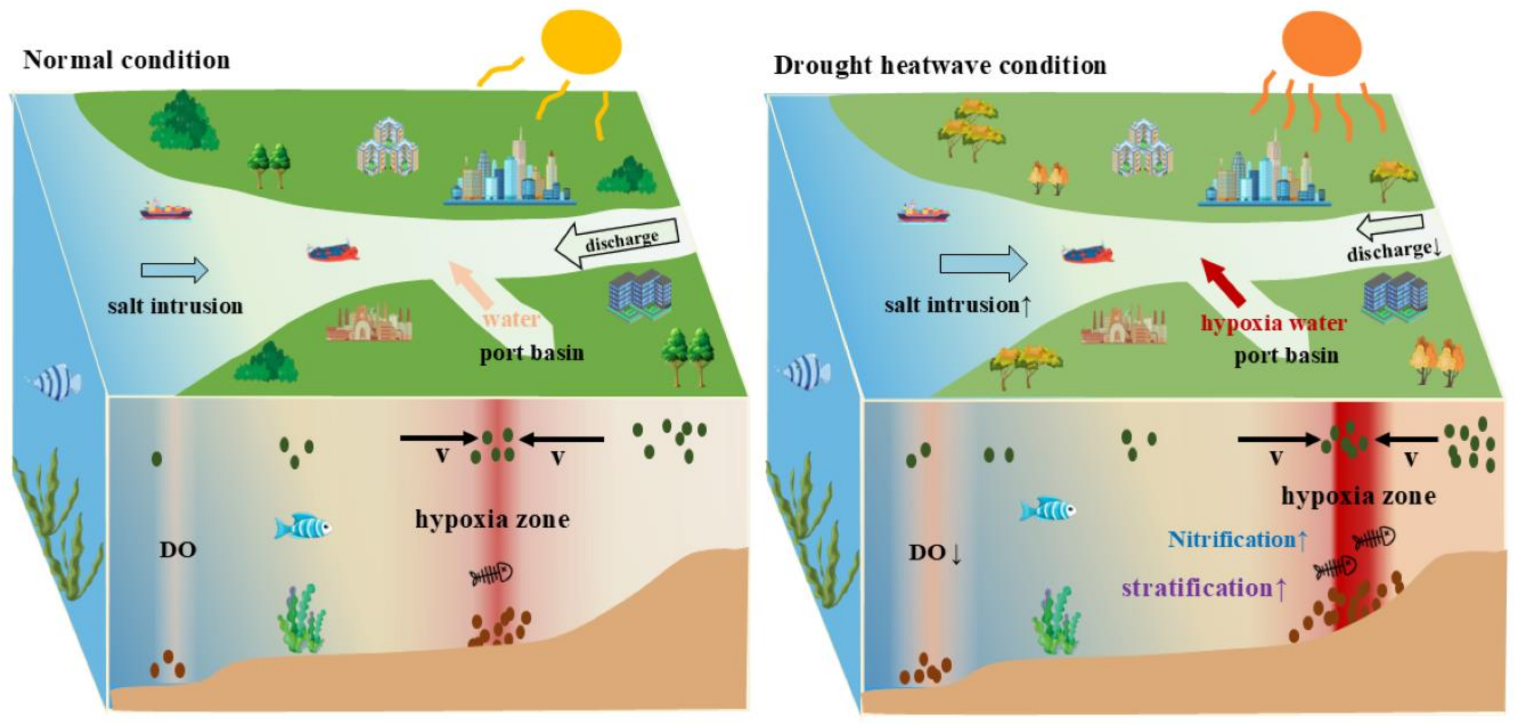

Fig. 7. conceptual sketch of estuarine DO in normal vs. drought-heatwave climates

Summary

- DO depletion is more severe during heatwaves than in warmer non-heatwave periods.
- The lowest DO zones migrate upstream with declining discharge and heatwave intensity.
- Low-oxygen water from the port area inhibits the exchange between bottom and surface waters, resulting in lower DO zones or even hypoxia zones in the bottom water column.

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