Helmholtz-Zentrum Geesthacht

Centre for Materials and Coastal Research

Dynamics of the Baltic Sea Straits via Numerical Simulation of Exchange Flows

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Research questions:

- Primary and secondary circulation
- Large-scale and eddy circulation
- Role of bathymetry
- Where do we need high resolution?
- The impact of narrow straits on the dynamics of interconnected basins (water and salt cycles).
- Are the straits dynamics similar to estuarine circulation?
- Data needed

Motivation:

- Use unstructured-grid models to accurately resolve processes in the narrow straits and exchange between the inter-connected basins at the same time (**in one model**).



Estuarine classification

Geyer and MacCready (Annu. Rev. Fluid Mech. 2014. 46:175–97)

 $Fr_f = U_R / (\beta gs_{ocean} H)^{1/2}$, freshwater Froude number measuring the ratio between the net velocity due to river flow and the maximum frontal propagation speed No H.

Hansen-Rattray profile of estuarine circulation:



$$u(z) = \frac{1}{48} \frac{1}{\rho} \frac{\partial \rho}{\partial x} \frac{gh^3}{N_z} \left(1 - 8\frac{z^3}{h^3} - 9\frac{z^2}{h^2} \right)$$

Hansen & Rattray, (J. Marine Research, 23, 104-122; 1965)



 $M^2 = C_D U_T^2 / (\omega No H^2)$

 $M^2 = C_D U_T^2 / (\omega No H^2)$ quantifies the effectiveness of tidal mixing measuring the ratio of the tidal timescale to the vertical mixing timescale.

 C_D is the friction parameter, U_T is the amplitude of the depth-averaged tidal velocity, ω is the tidal frequency, $No = (\beta g_{socean}/H)^{1/2}$ is the buoyancy frequency, H is the depth, U_R is the velocity of river flow, $\beta = 7.7 \times 10^{-4}$ is the coefficient of salinity contraction, and g is the gravitational acceleration.

Well-known (ocean) cases

Denmark Strait (deep part <100 km wide)

Strait of Gibraltar (~300-900 m deep and ~15 km wide)





Less well-known cases of inland estuarine basins - Large salinity contrasts (different frontal dynamics)







Semi-implicit Cross-scale Hydroscience

Integrated System Model; www.schism.wiki

3D, primitive equations, unstructured-grid.

- Upgrade from an existing model (SELFE, A Semi-implicit Eulerian-Lagrangian Finite Element model for cross-scale ocean circulation).

- Uses hybrid finite element and finite volume approach.

- New viscosity formulation (effectively filters out spurious modes without introducing excessive dissipation).



SCHISM Modeling System



- New higher-order implicit advection scheme for transport (TVD²) is proposed to effectively handle a wide range of Courant numbers

- Addition of quadrangular elements into the model
- Flexible vertical grid system (Zhang et al. 2015, OM)
- Model polymorphism that unifies 1D/2DH/2DV/3D cells in a single model grid.

Zhang Y.J., F. Ye, E. V. Stanev, and S. Grashorn (2016): Ocean Modelling.

Status of models: Open-released / Ready-to-be-released / In-development / Free-from-web {model name} / : Dynamic Core

The North Sea - Baltic Sea model



- Open boundary forcing: Copernicus AMM7 (7km)
- Atmospherical forcing: DWD Cosmo EU (7km)
- River forcing: SMHI EHYPE from 34 rivers (North Sea and Baltic Sea)
- ~400 K nodes with a minimum grid side length of ~80m (in the narrow areas of the Little Belt), elsewhere almost uniform resolution of ~3 km.



20 depth / m



57°

Mesh details, Little Belt

Two experiments: COARSE, FINE







Model validation(saninity, MBI)



Major Baltic Inflows (MBI)

Axial properties (COARSE versus FINE)

Similarities and differences with the estuarine circulation











Different appearance of lateral flows

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Impact on the axial circulation

The axial transport through the Sound in COARSE is **12%** smaller.

The ratio between transports in the Great Belt and the Sound changes from 2.7 (in FINE) to 3 (in COARSE).

These "small" differences (lateral velocity ~0.1 *x axial velocity) are important for the overall salt balances.*



Inflow (25-30/10/2014)

Outflow (12-17/11/2014)

Conclusions:

- 1. The role of horizontal resolution is crucial (missing physics in COARSE, analogy eddy-resolving models and non-eddy-resolving models).
- 2. Various appearance of secondary circulatiuon (theory and real situations; straits and estuaries).
- 3. Seamless modelling of interbasin exchange is promissing for process studies.

4. Seamless modelling has also a great potential for operational use, for instance developing interfaces for coupled regional coastal and estuarine predictions. Stanev, E. V., J. Pein, S. Grashorn, Y. Zhang, and C. Schrum (2018). Dynamics of the Baltic Sea Straits via Numerical Simulation of Exchange Flows. Ocean Modelling, 131, 40-58.

Haid, V., E. V. Stanev, J. Pein, J. Staneva, W. Chen (2020). Secondary circulation in shallow ocean straits: Observations and numerical modeling of the Danish Straits. Ocean Modelling, Volume 148, April 2020, 101585