

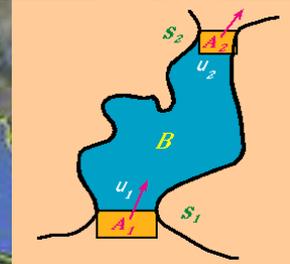
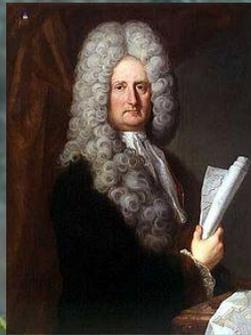
***Cascading ocean basins: numerical simulations of
the circulation and inter-basin exchange in the
Azov-Black-Marmara-Mediterranean Seas system***

E. V. Stanev, J. Pein, S. Grashorn, and J. Y. Zhang

COSS-TT 2018
Madrid, Spain,
September 19th to 21th, 2018.



From Marsili (1681) to (Knudsen (1900) and beyond)
Water cycle and the challenge of basin inter-connections

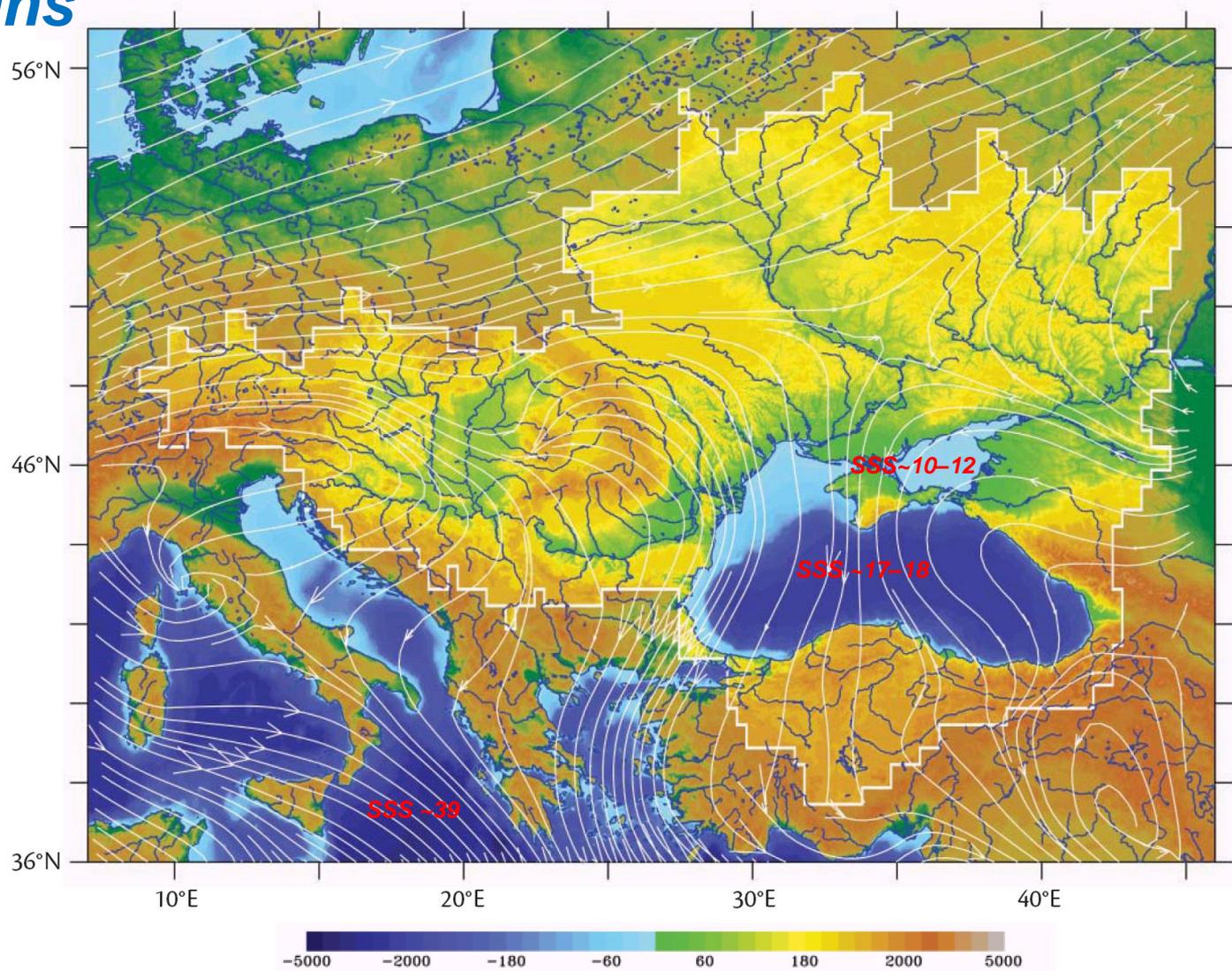


$$Q_1 + R = Q_2$$
$$Q_1 S_1 = Q_2 S_2$$
$$Q_1 = R / (S_1 / S_2 - 1)$$
$$Q_2 = R / (1 - S_2 / S_1)$$

Cascading ocean basins, their connecting straits, estuarine basins

The total freshwater supply of 300km³/year is large compared to the basin volume (~ 5.4 x 10⁵ km³)

Unique water properties are due to small exchange in the straits.



Georgievski and Stanev (2006, Cl. Dyn.)

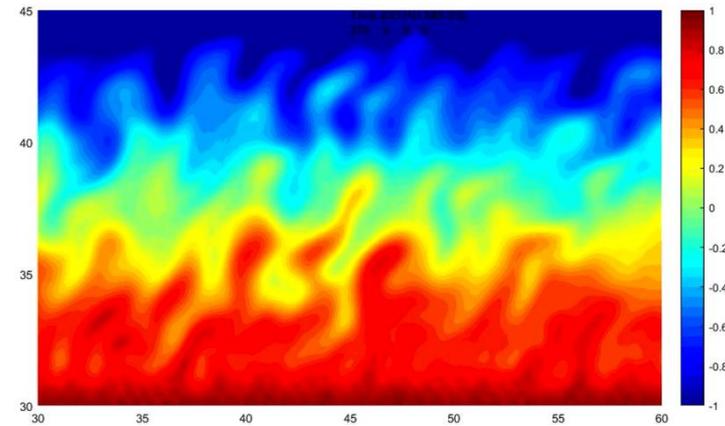
The model *Semi-implicit Cross-scale Hydroscience Integrated System*

Model; www.schism.wiki



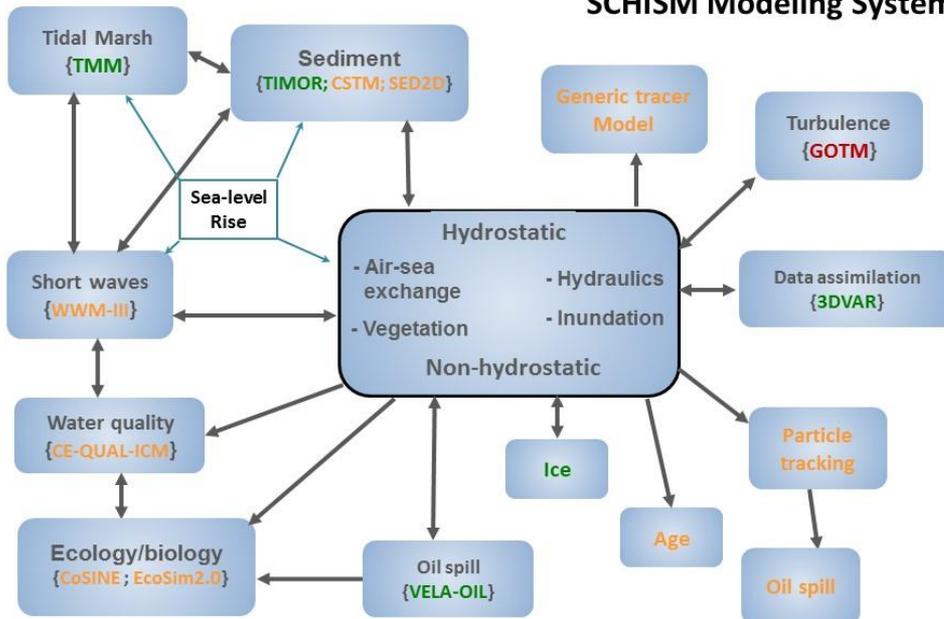
3D, primitive equations, unstructured-grid.

- 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).



- New higher-order implicit advection scheme for transport (TVD^2) 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.

SCHISM Modeling System



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

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

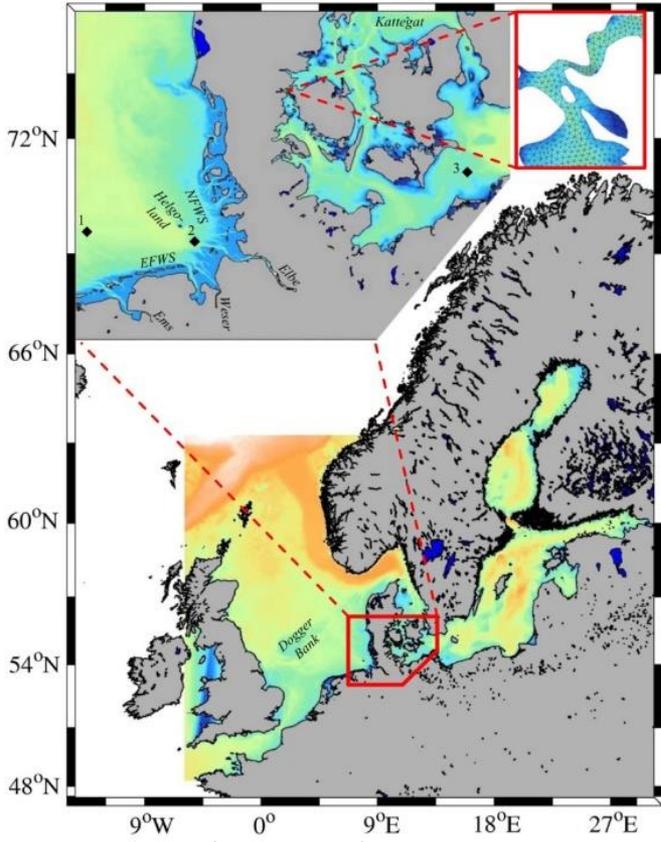
Well-known (ocean) cases

Denmark Strait (~200 m deep and ~300 km wide)
Strait of Gibraltar (~300 m deep and ~15 km wide)

Less well-known cases of inland estuarine basins

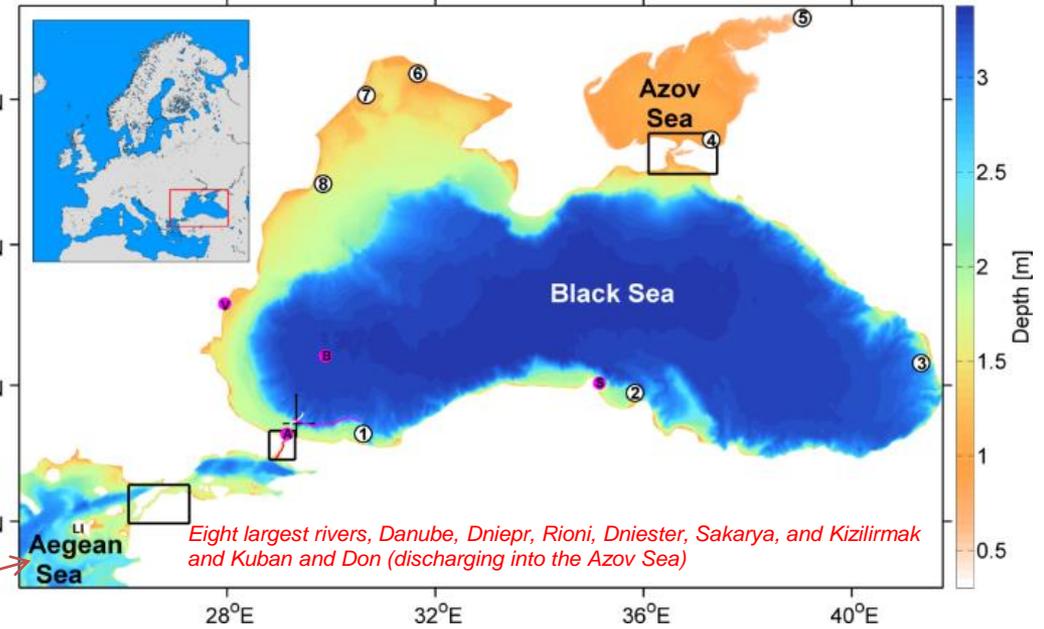
The North Sea - Baltic Sea model:
~400 K nodes with a minimum grid side length of ~80m (in the narrow areas of the Little Belt), elsewhere almost uniform resolution of ~3 km.

Our (SCHISM) model areas



Stanev et al. (2018, OMOD)

The Black Sea model:
~104K nodes with a minimum grid side length of ~80m, coarsest resolution ~3km, 53 levels in the deepest parts of the Black Sea

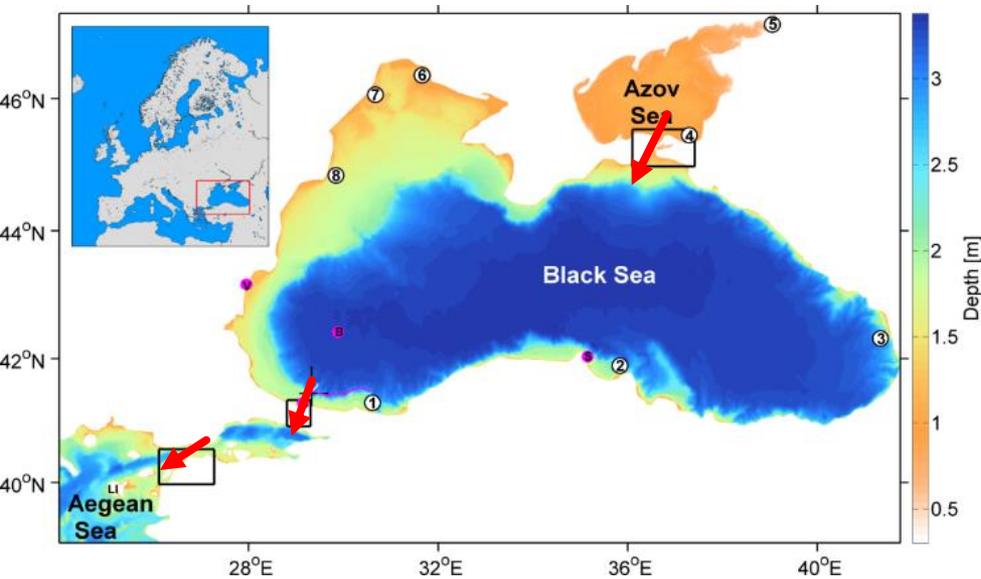


Eight largest rivers, Danube, Dniepr, Rioni, Dniester, Sakarya, and Kizilirmak and Kuban and Don (discharging into the Azov Sea)

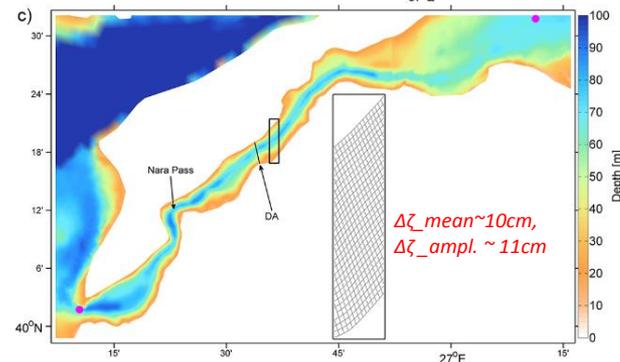
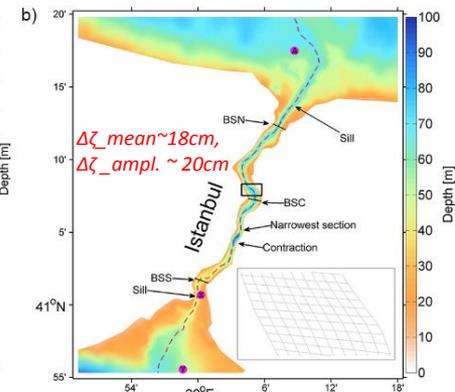
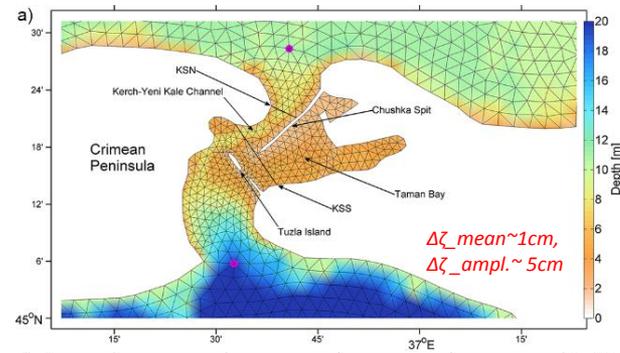
Stanev et al. (2017, ODYN)

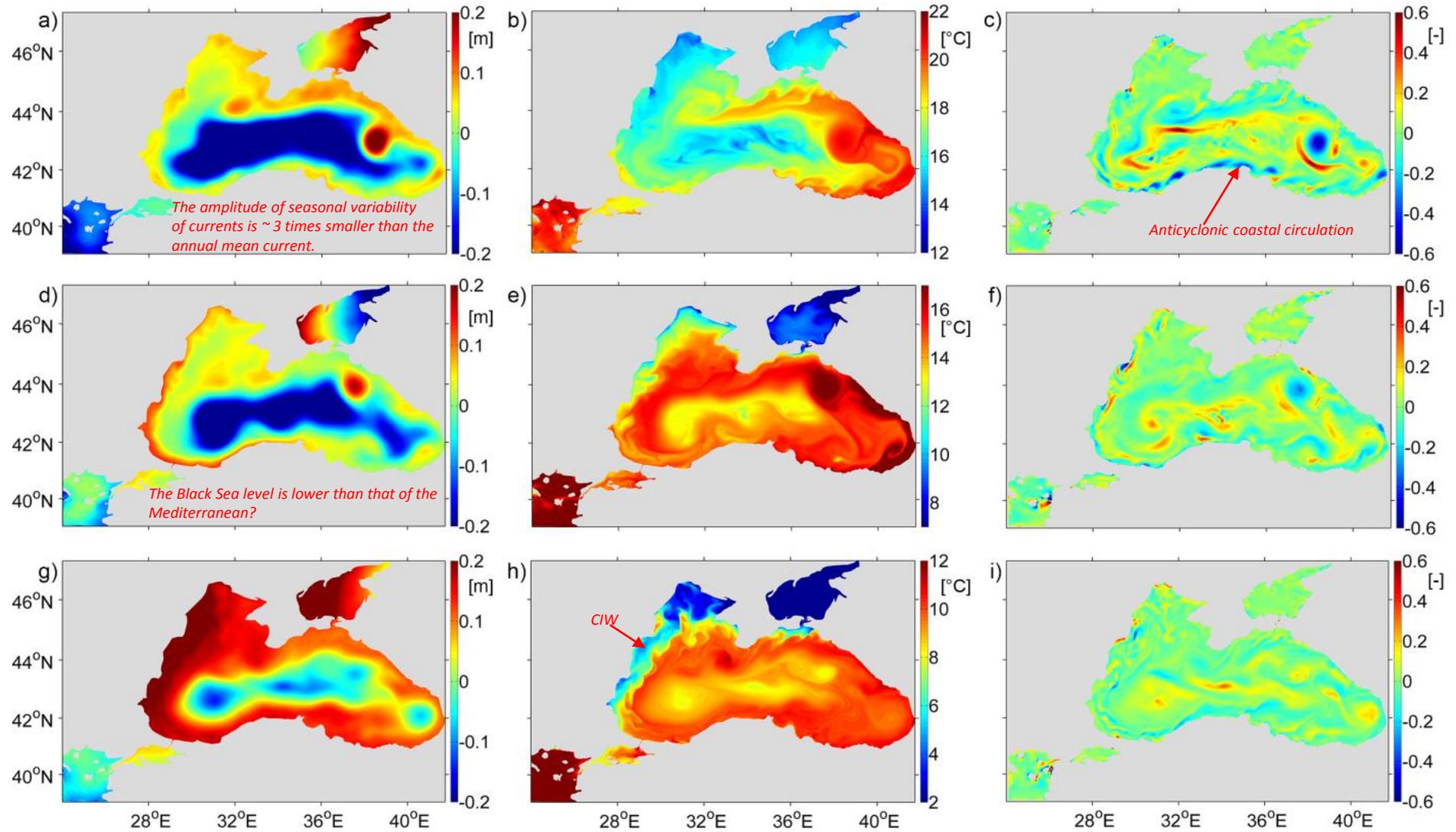
The only open ocean Boundary (Copernicus product)

Cascading basins



Atmospheric forcing:
data from the 0.2° ECMWF product and buk
parameterizations using simulated SST.

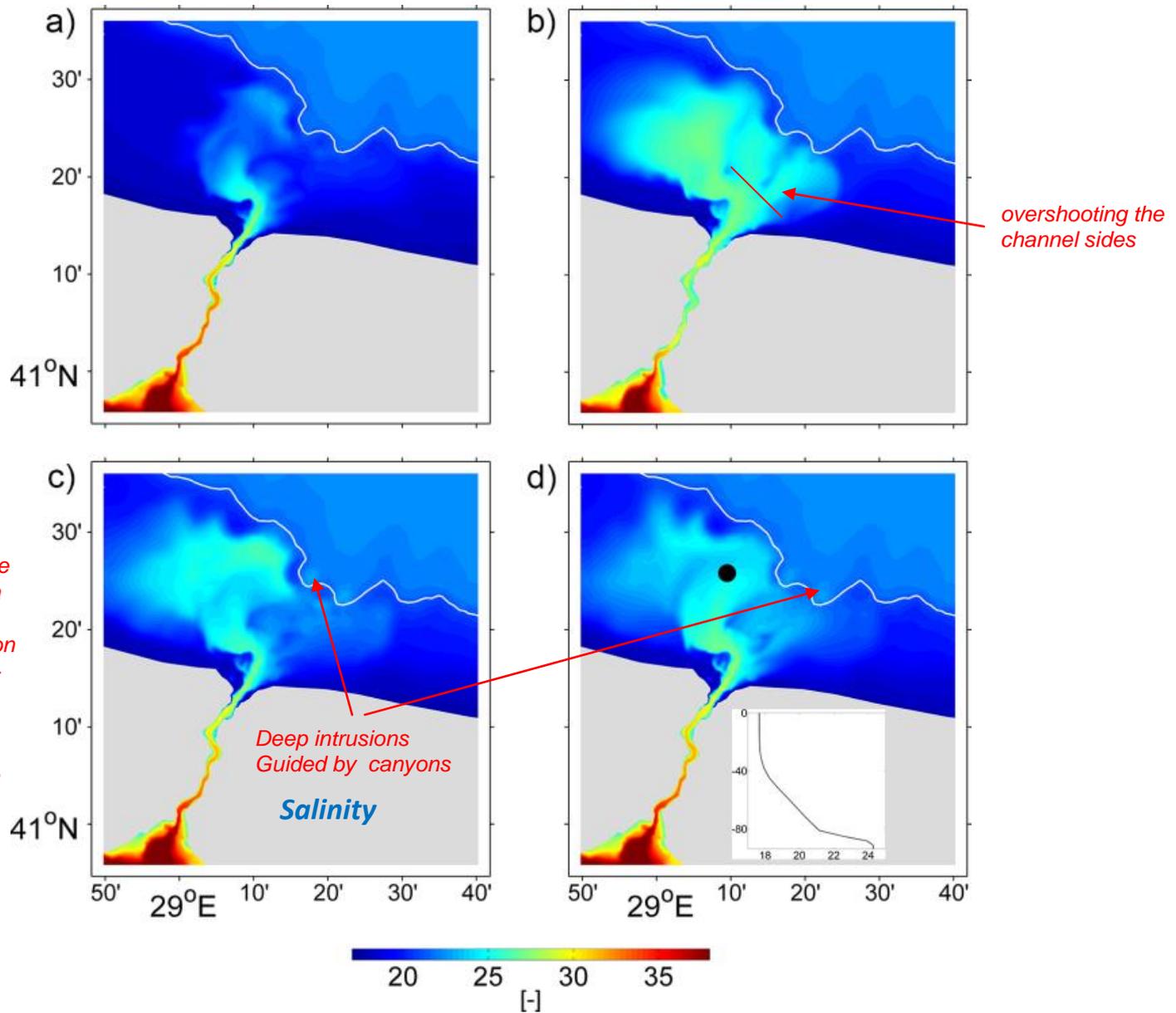




Sea level (a, d, g), SST (b, e, h) and relative vorticity at sea surface normalized by the Coriolis parameter (c, f, i). (a, b, c) corresponds to 08-Oct-2008, (d, e, f) to 12-Nov-2008, and (g, h, i) to 22-Jan-2009. Note that the SST colorbars have different ranges.

Bosporus Strait

Bottom arrested plume

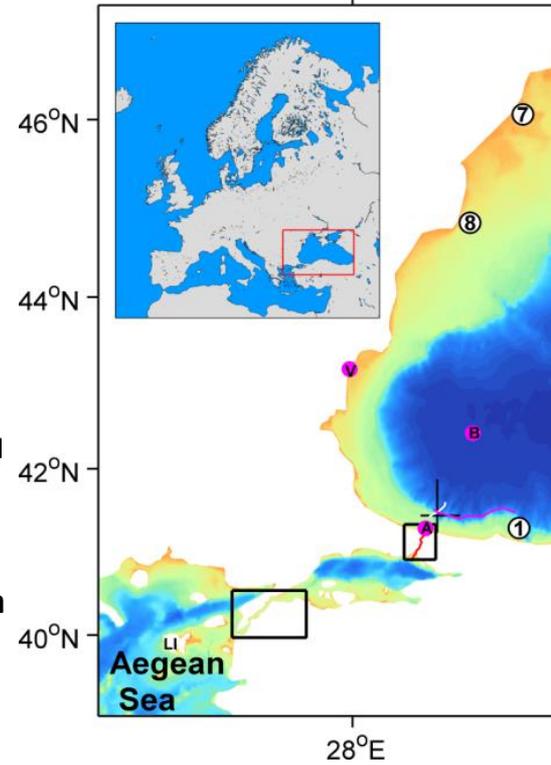
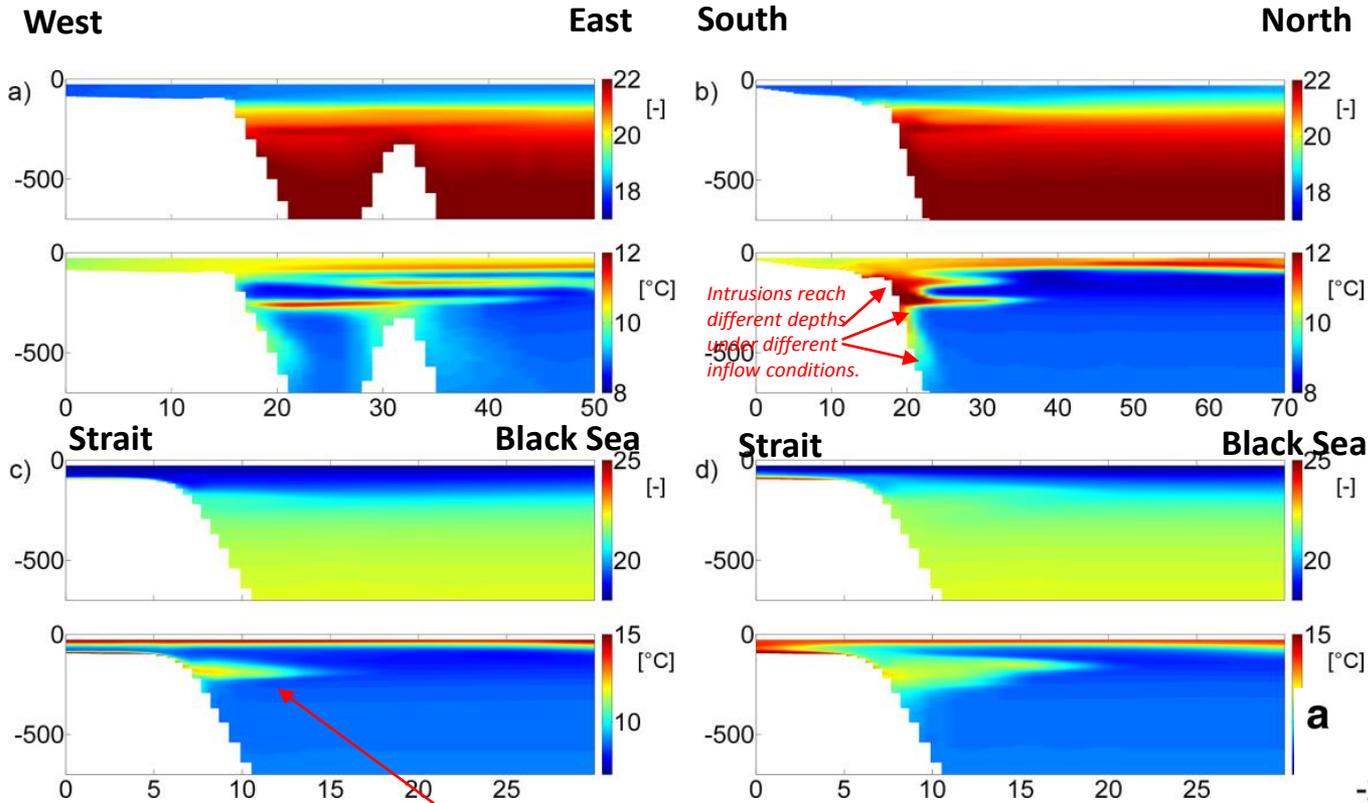


- The change in the meteorological conditions resulted in a three-fold increase of the inflow into the Black Sea from ~15,000 m³/s on November 21 to 47,000 m³/s on November 23 (mean value is ~10,000 m³/s).

- The cascading of the saltier water can be considered as an extreme event.

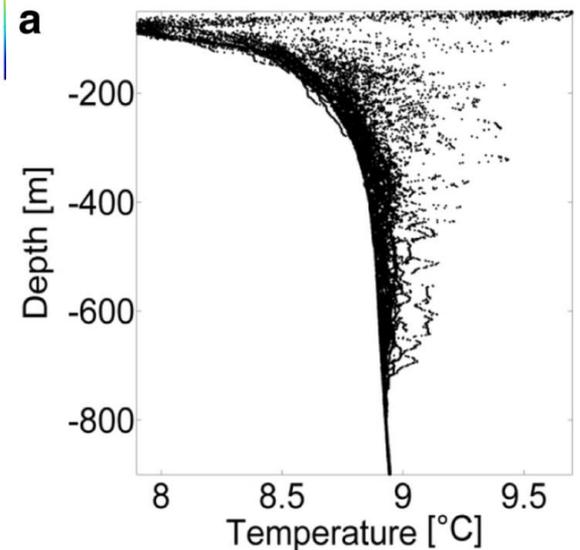
Salinity during the inflow event in November 2008. White isoline is the 250m isobath. The individual frames correspond to 00:00 GMT on (a) Nov. 21, 2008, (b) Nov. 23, 2008, (c) Nov. 25, 2008 and (d) Nov. 27, 2008.

Intrusions from the Bosphorus Strait and intermediate water mass formation



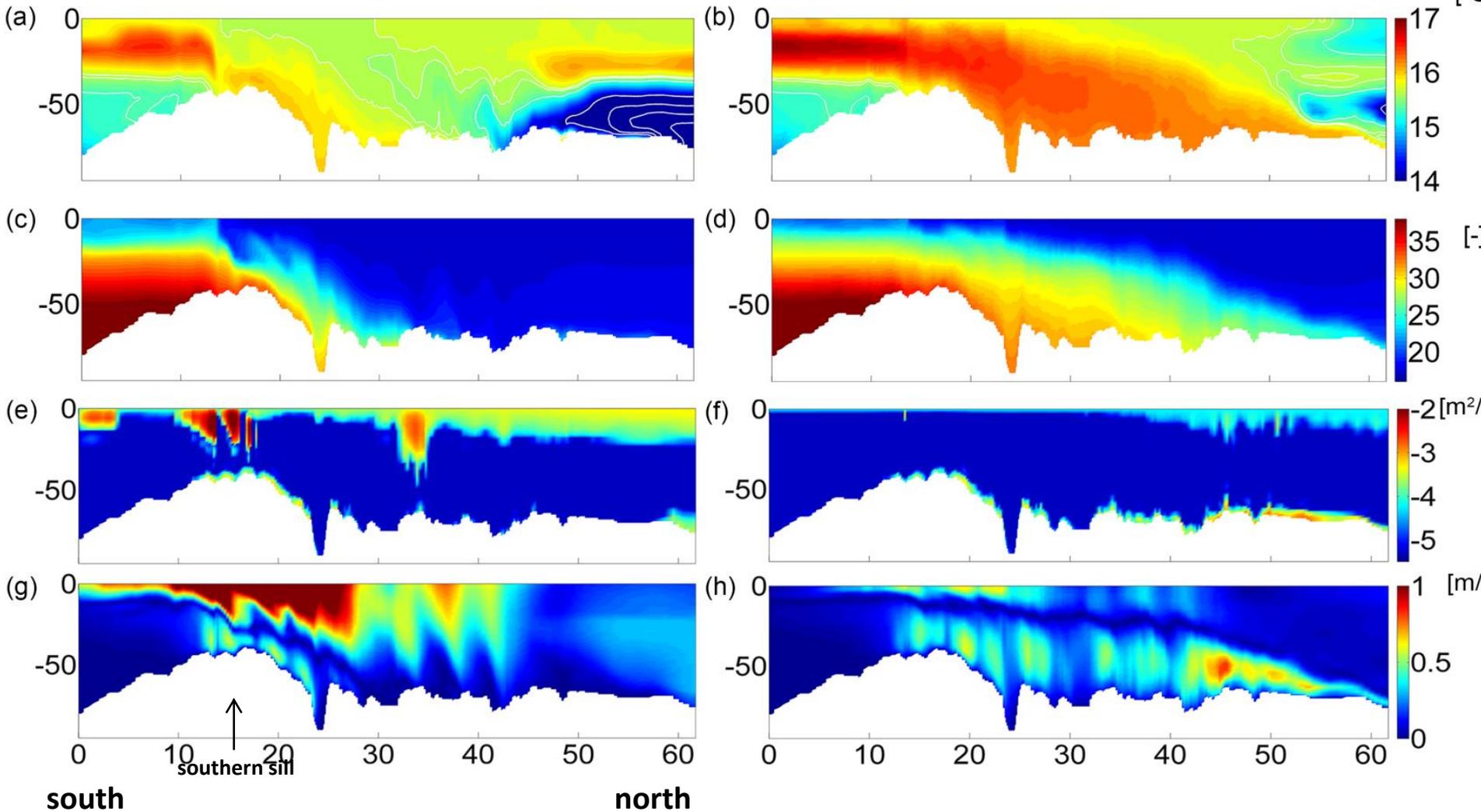
Earlier models and interleaving process.

- a) zonal salinity and temperature cross-sections on January 9, 2009;
- b) is the same but for a meridional section on January 4, 2009;
- (c and d) are plotted along the red line in Fig. 1 near the exit of the Strait on November 8, 2008 and November 26, 2008



- Sequence of “lock exchange”-like events, followed by backward displacements of the front.

- What is **more important** for the transport through the Bosphorus, the sea-level difference associated with the **estuarine character** of the Black Sea, or the **mechanical forcing** (wind and atmospheric pressure)?

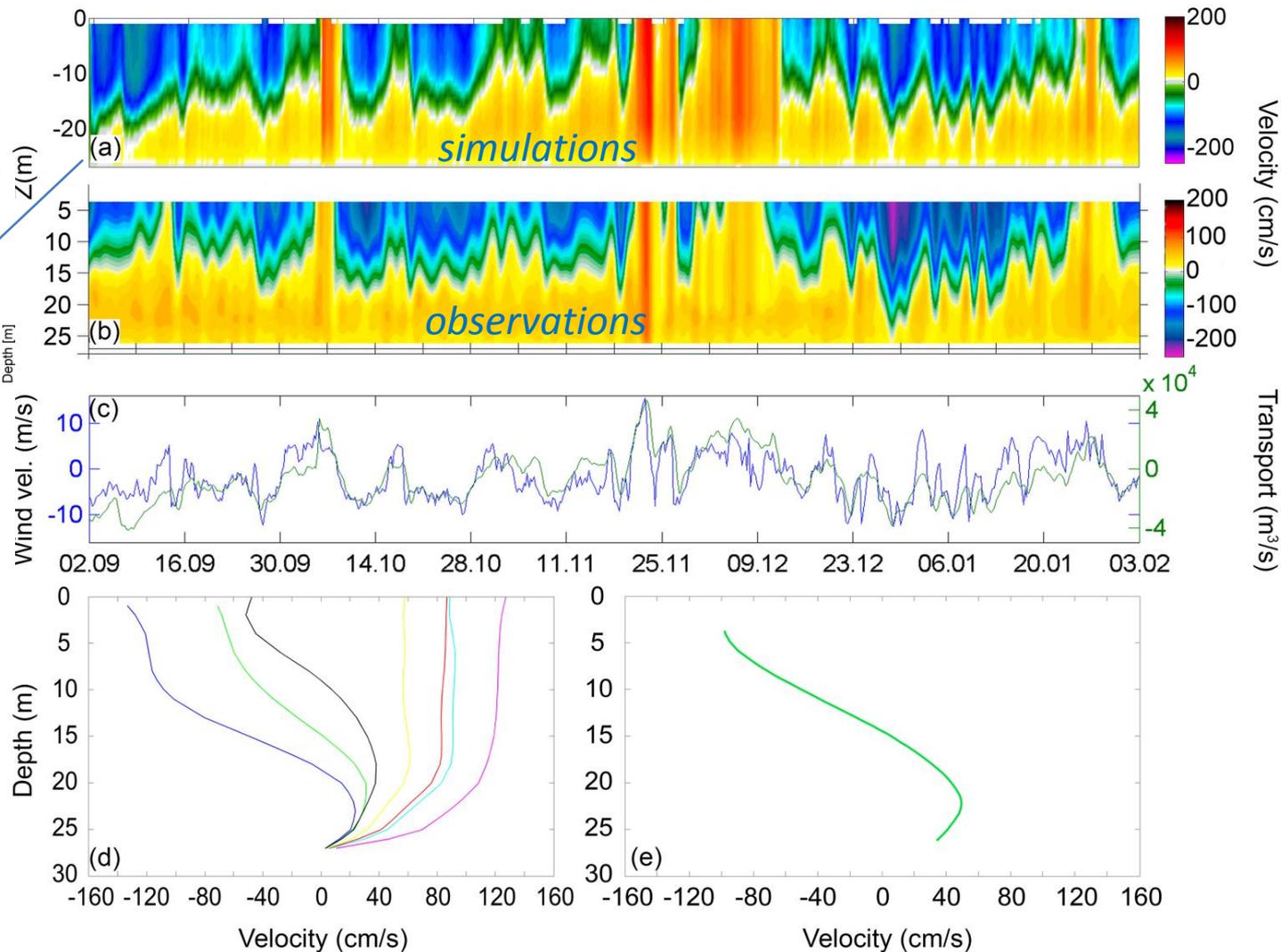
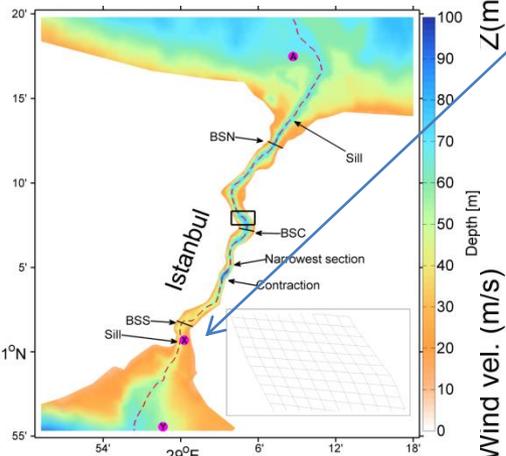


Along-Bosphorus-Strait transects at 12:00, 2008-10-26 (a, c, e, g) and at 00:00, 2008-11-02 (b), (d), (f), (h).

The following isolines are plotted in (a) and (b) to better represent the mixing of cold intermediate water in the strait: 11, 12, 13, 14, 15.30, 15.57 and 15.65 °C.

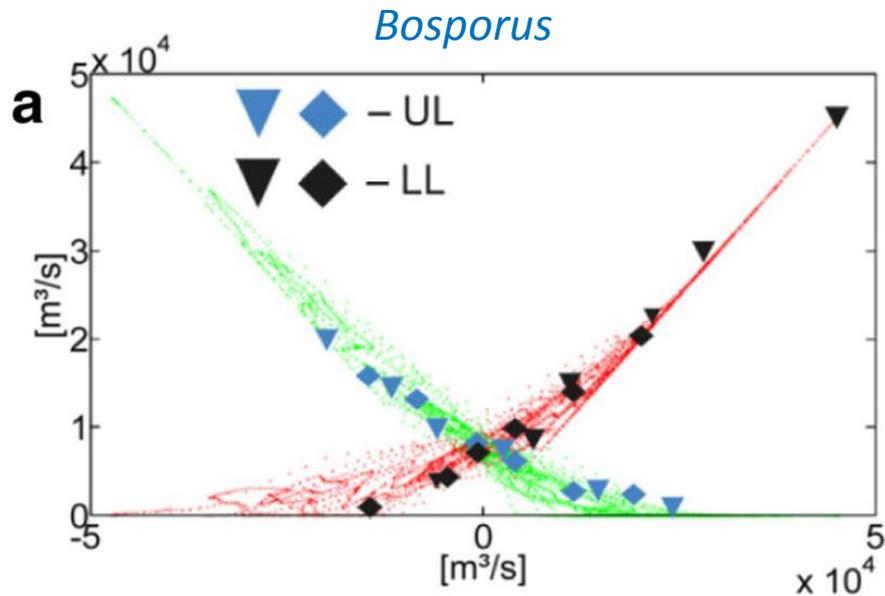
Bosporus Strait

positive towards
the Black Sea

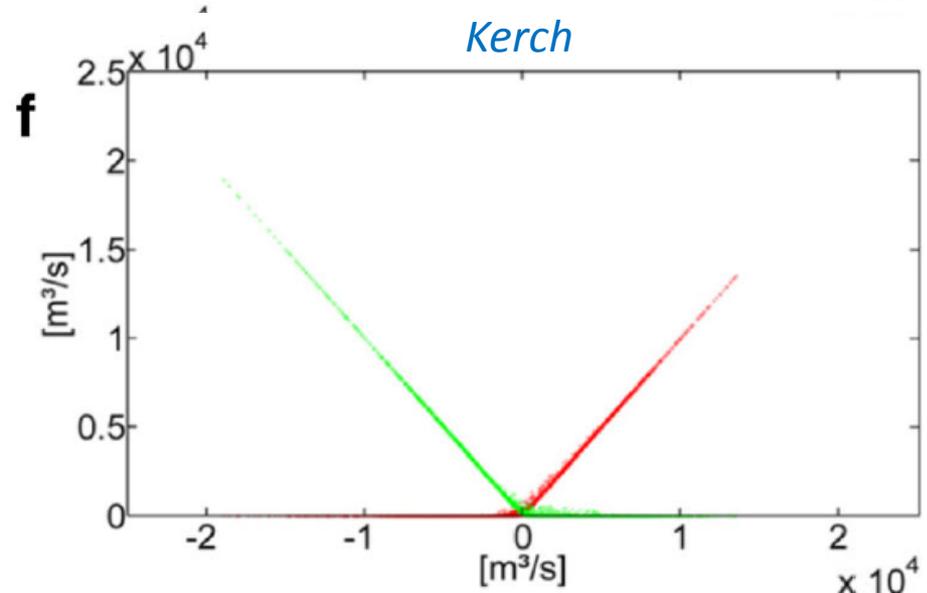
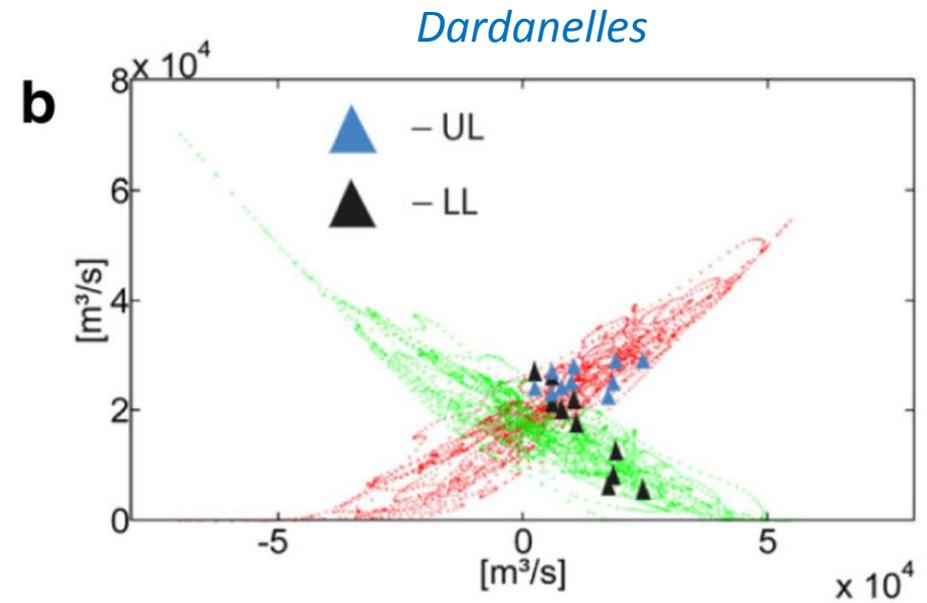


The individual lines in (d) correspond to: red: 06.10.08 00:00, blue: 26.10.08 12:00, black: 02.11.08 00:00, magenta: 22.11.08 18:00, cyan: 06.12.08 00:00, yellow: 21.01.09 00:00. The green lines in (d) and (e) show time averaged profiles for the period in (a-b).

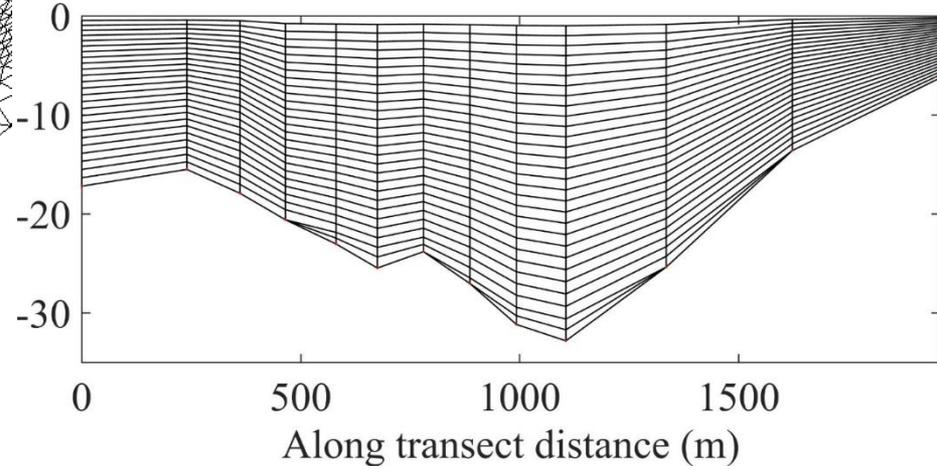
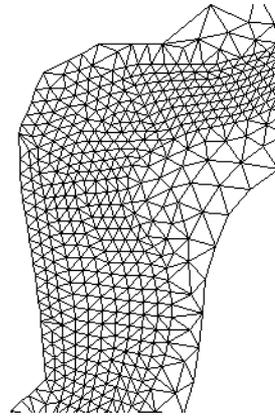
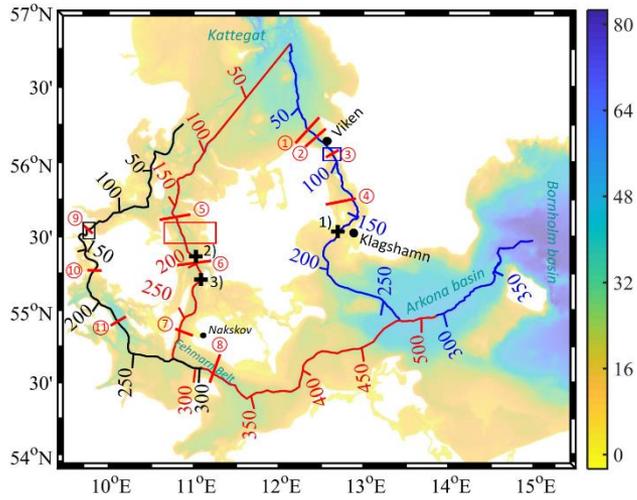
Dependence of transport in each layer on the total transport



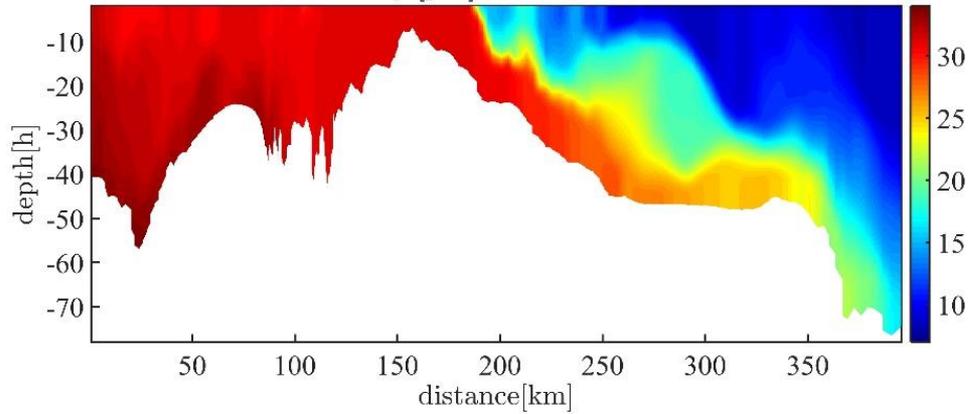
upper layer (red symbols) and
bottom layer (green symbols)



Other similar ocean cases: The Baltic Sea



The Sound - Salinity [psu]. Time: 21-Dec-2014 06:00:00



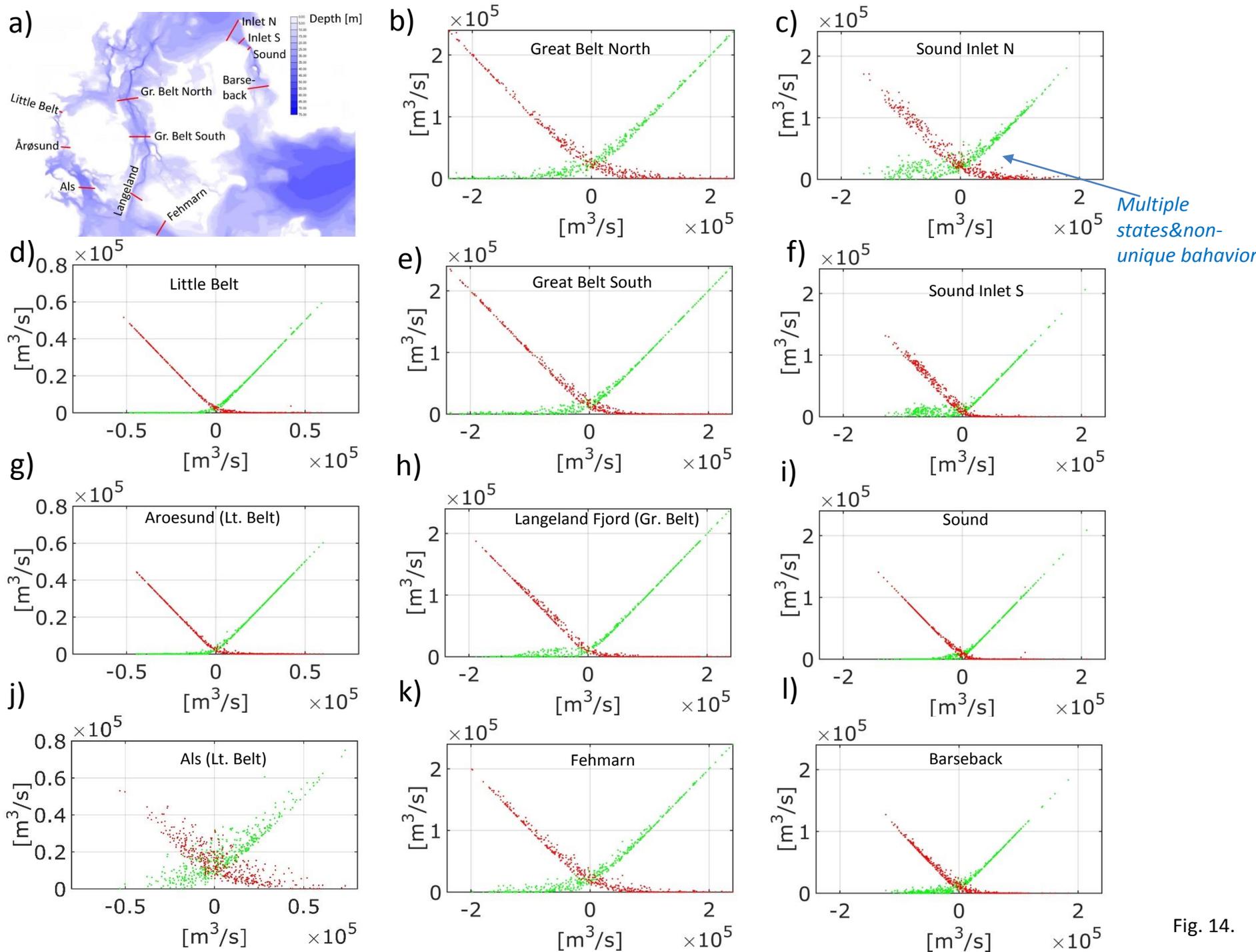


Fig. 14.

Conclusions:

Seamless modelling of interbasin exchange is promising for process studies.

I hope it has also a great potential for

- operational use,*
- downstream services and*
- developing interfaces for coupled coastal and estuarine predictions.*