



Floating University course

Use bio-optical parameters as convenient
tool to study marine biogeochemical
processes

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Introduction to Baltic Sea hydrography





Baltic Sea – basic facts



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Baltic Sea is very young – it has been formed during last deglaciation ca. 10000 y. ago and the present form reached only ca. 3000 y. ago

Quantity	Value
Area	392 978 km ²
Volume	21 205 km ³
Mean/max. depth	54 / 459 m
Drainage basin area	1 633 290 km ²
Water renewal time	33 – 50 years
Mean salinity	7.4
Primary production	30 -250 g C m ² yr ⁻¹
Coastal countries	9
Countries in the drainage basin area	14
Population in drainage basin area	85 mln

Lepparanta and Myberg, 2009

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Baltic Sea – unique marine basin



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ESTUARY

?

- High volume of terrstrila inflow
- Low salinity
- Brackish surface water
- Strong stratification with picnocline
- Intesive mixing across picnocline

BIG LAKE

?

- Shallow depth
- Complex bathymetry
- Dominating wind circulation
- Presence of side borders influences circulation

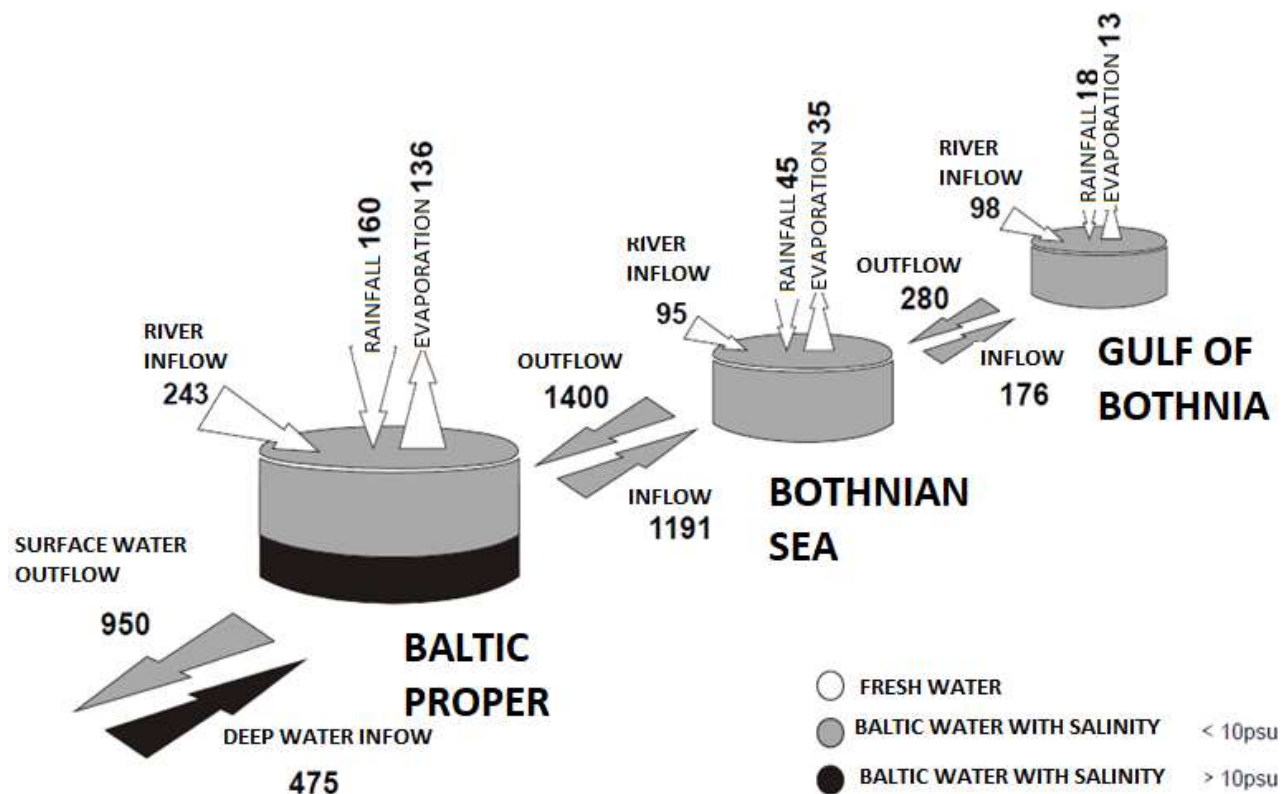
SMALL OCEAN

?

- Mesoscale eddies
- Upwelling
- Internal waves
- Seiches

SEMI-ENCLOSED BASIN \Rightarrow NO TIDES

Block diagram presenting hydrological budget and exchange of water between Baltic Sea basins and the North Sea. The volume transport in km³



Baltic Sea – unique marine basin

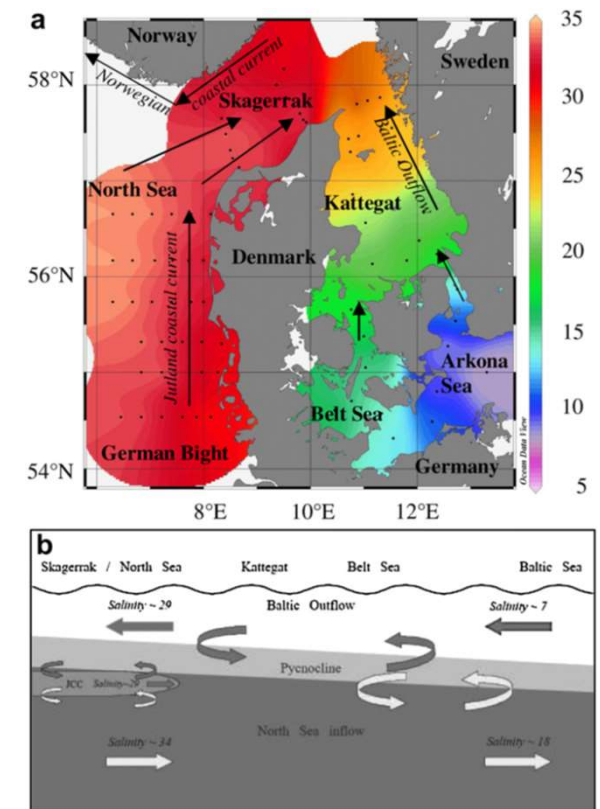
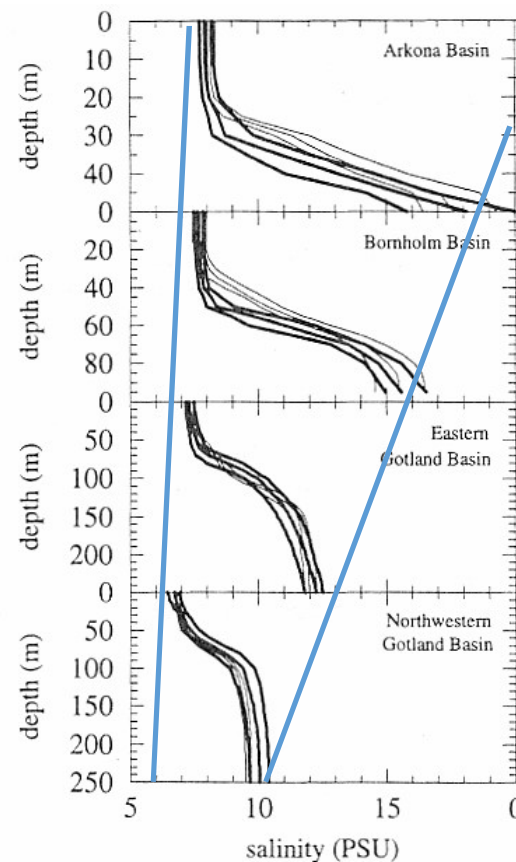


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- Baltic – shallow inland sea;
- Baltic - mesohaline sea
averaged oceanic salinity ca. 35
averaged Baltic Sea salinity ca. 7
- Strong stratification – high gradient between low salinity surface layer and high salinity deep waters;
- Rapid change of salinity with depth (halocline);
- This results with rapid density gradients (pycnocline);
- Significant difference in salinity along main Baltic Sea axis – salinity decreases with distance from Danish Straits



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Baltic Sea – unique marine basin

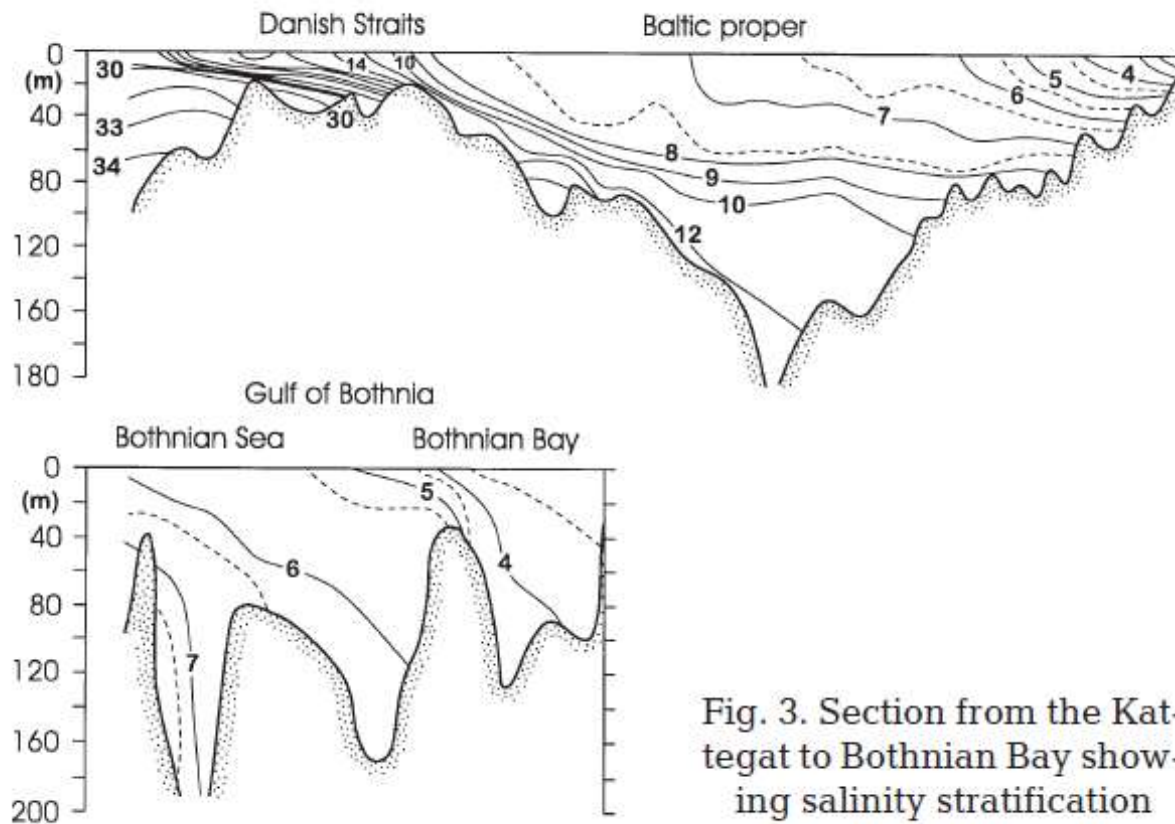
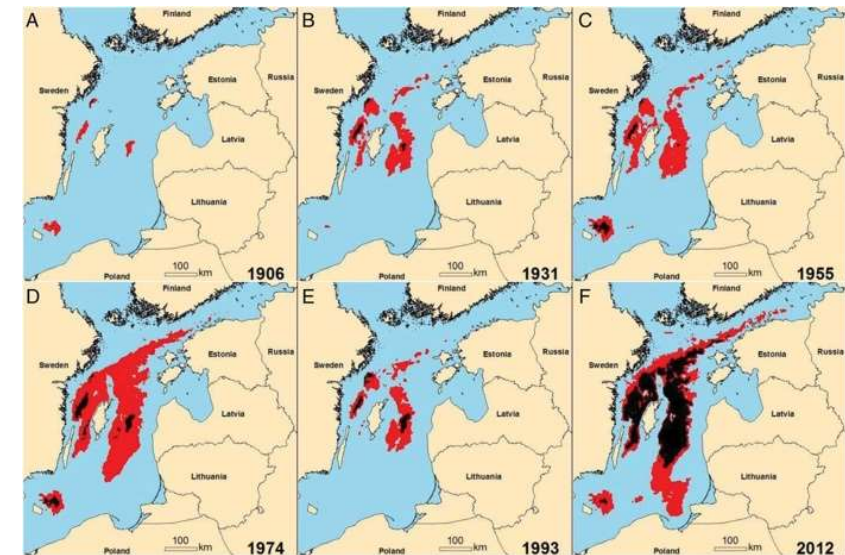


Fig. 3. Section from the Kattegat to Bothnian Bay showing salinity stratification

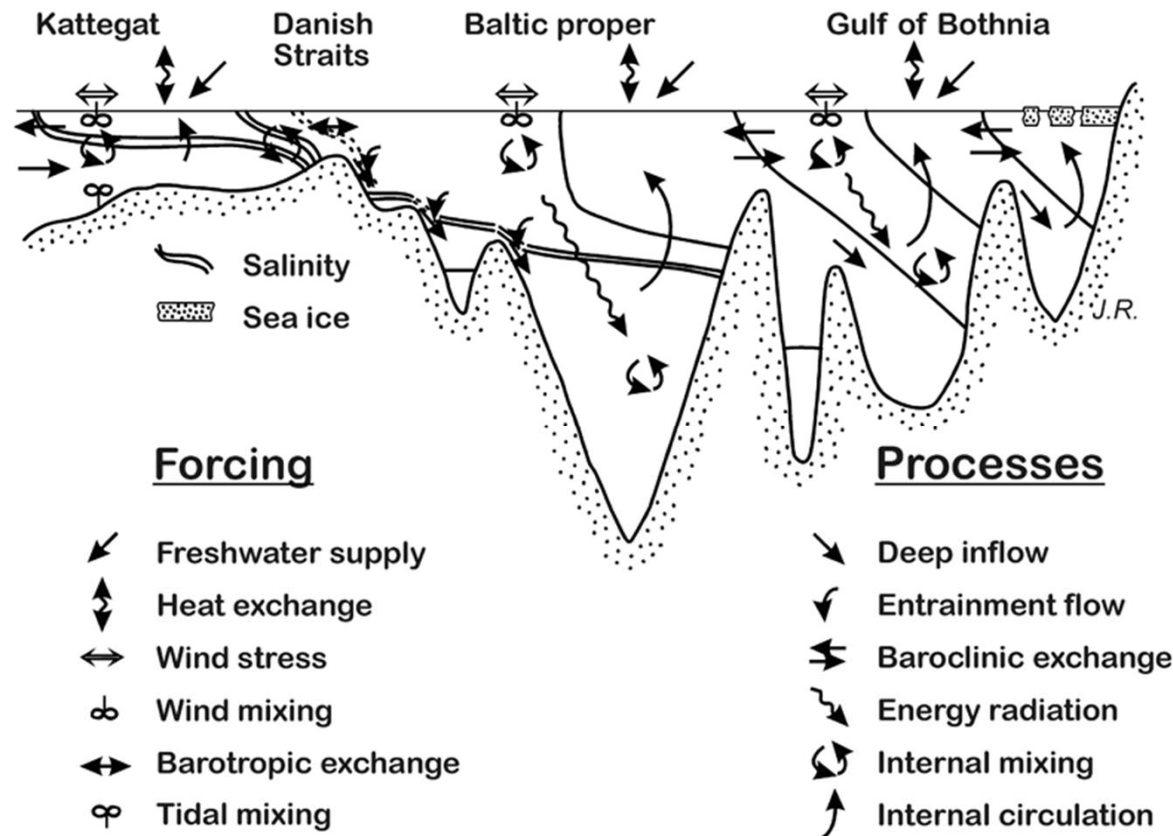
Winsor, P., J. Rodhe, and A. Omstedt (2001). Baltic Sea ocean climate: an analysis of 100 yr of hydrographic data with focus on the freshwater budget, *Clim. Res.*, 18, 5-15.



The consequence of vertical stratification and stagnation of bottom waters – hydrogen sulfide deserts



Carstensen, et al., 2014 PNAS 111 (15) 5628-563



Exciting forces and processes controlling water circulation in the Baltic Sea

Winsor, P., J. Rodhe, and A. Omstedt (2001). Baltic Sea ocean climate: an analysis of 100 yr of hydrographic data with focus on the freshwater budget, *Clim. Res.*, 18, 5-15

Types of inflows of saline water into the Baltic Sea



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Barotropic inflow

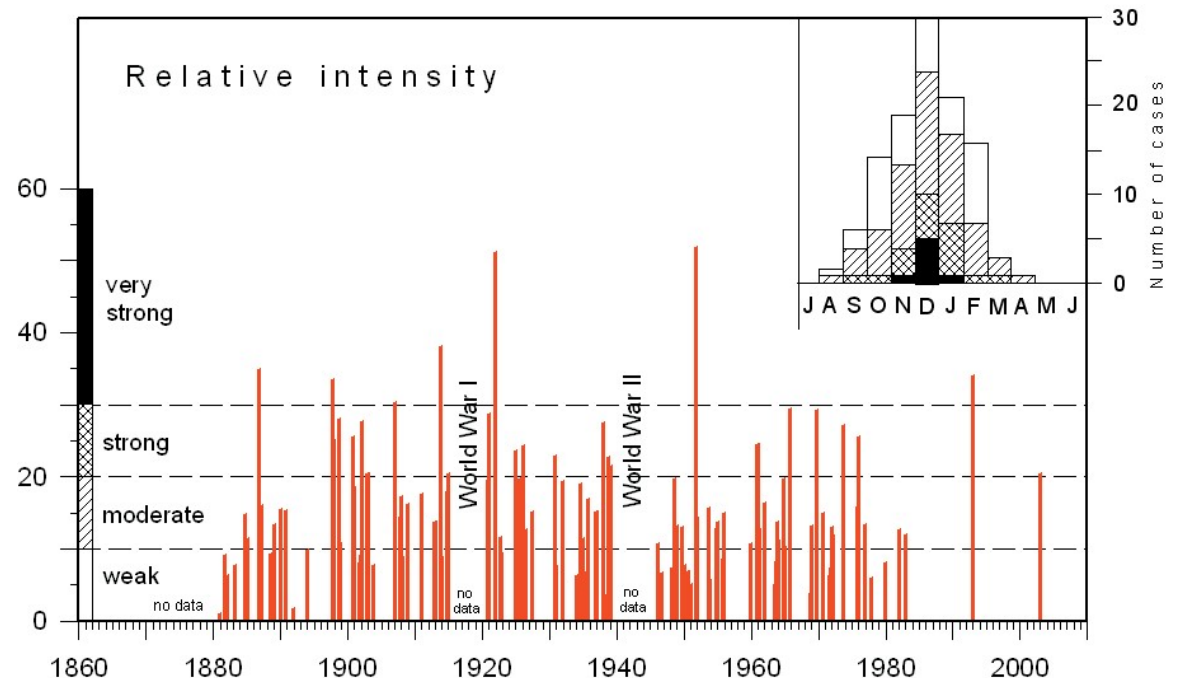
- The barotropic inflow is forced by the difference in water level between Kattegat and Arkona basin;
- Those inflow usually occur during fall and winter storms;
- To initiate the barotropic inflow the specific atmospheric circulation is necessary:
 - in the first phase long lasting easterly winds (associated with high atmospheric pressure over Russia) that intensify the Surface oligohaline water outflow and lowering water level in Arkona Basin are required,
 - in the second phase rapid reverse of atmospheric circulation from easterly to westerly winds is required what causes the compensating inflow through the Danish Straits.

Baroclinic inflows

- the exciting force initiating baroclinic inflows is difference in water density between Baltic Sea and the North Sea waters;
- baroclinic inflows carried much smaller water volume compared to barotropic ones;
- they are much frequent;
- they propagate over Stolpe sill in the forms of ,overflow'.

Categorization of inflows of saline water into the Baltic Sea according to volume transport measured at Danish Strait gateway

weak <100 km³,
moderate 100-200 km³ 41 moderate inflows since 1898
strong 200-300 km³ 1898 (two times), 1900, 1902 (two times), 1914, 1921, 1925, 1926, 1960, 1965, 1969, 1973, 1976 i **2003**.
very strong > 300 km³. 1897 (330 km³), 1906 (300 km³), 1922 (510 km³), 1951 (510 km³) i **1993/94 (300 km³)**.

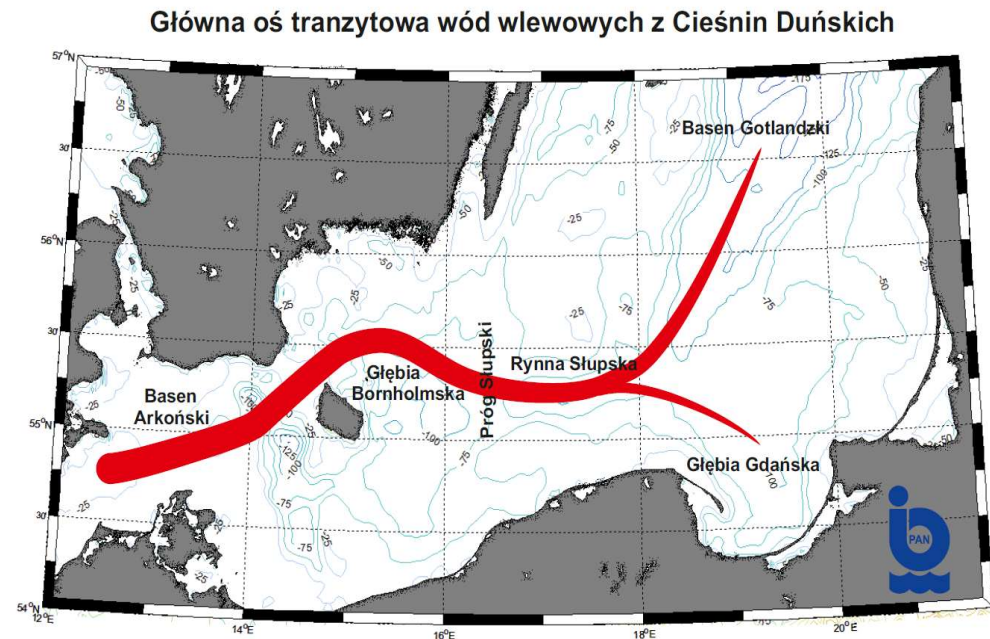


Significance of inflows

- Inflows of saline water prevent Baltic Sea to become fresh water lake;
- Inflows are the main source of oxygen in deep waters below pycnocline;
- Inflows impact the biogeochemical cycle of dissolved organic matter in deep waters;
- Inflows have direct impact on benthic communities and cod stock spawning.

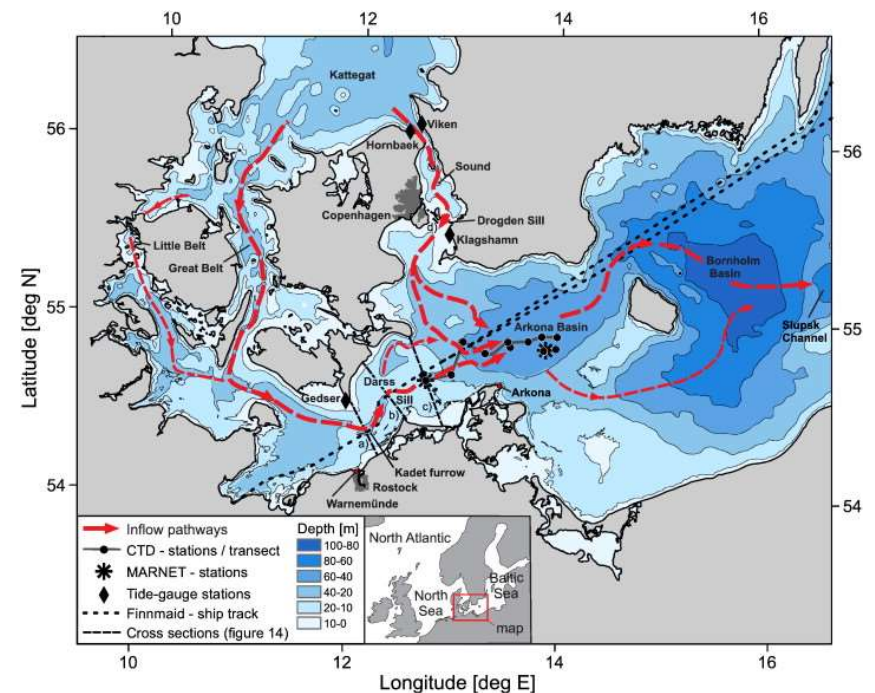
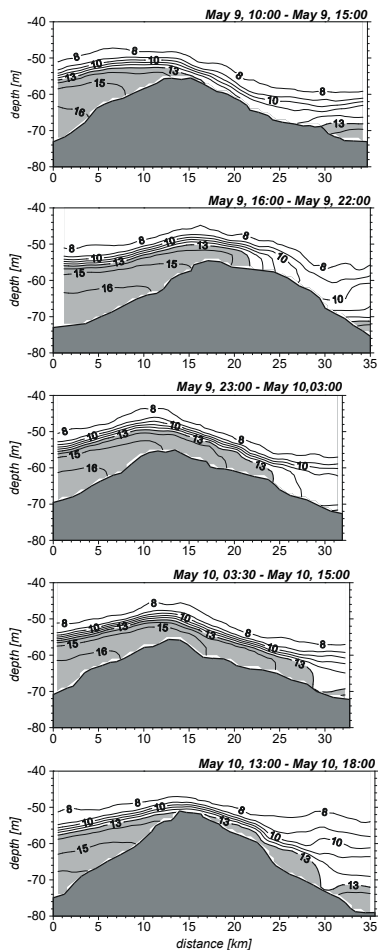


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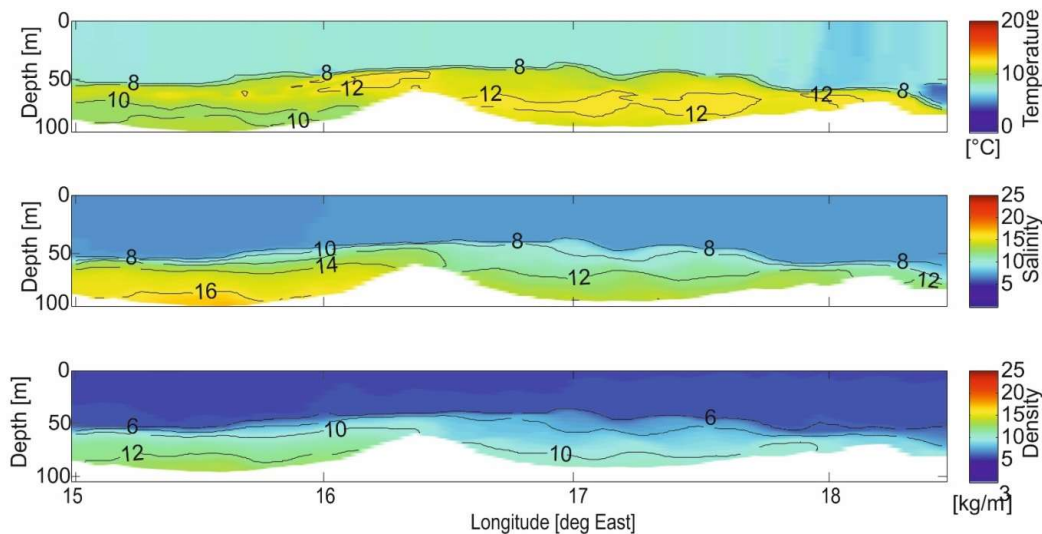


The overflow sequence of baroclinic inflow over Stolpe Sill

- The pulsating overflow of dense water over the sill \Rightarrow propagation of isolated lenses in the Słupsk Channel
- maximal currents velocities up 40 cm/s
- maximal propagation of the lense up to 10-20 cm/s
- Duration period – from several to 24 hours
- Volume transport of saline waters ($S > 13$) ca. 1 km^3

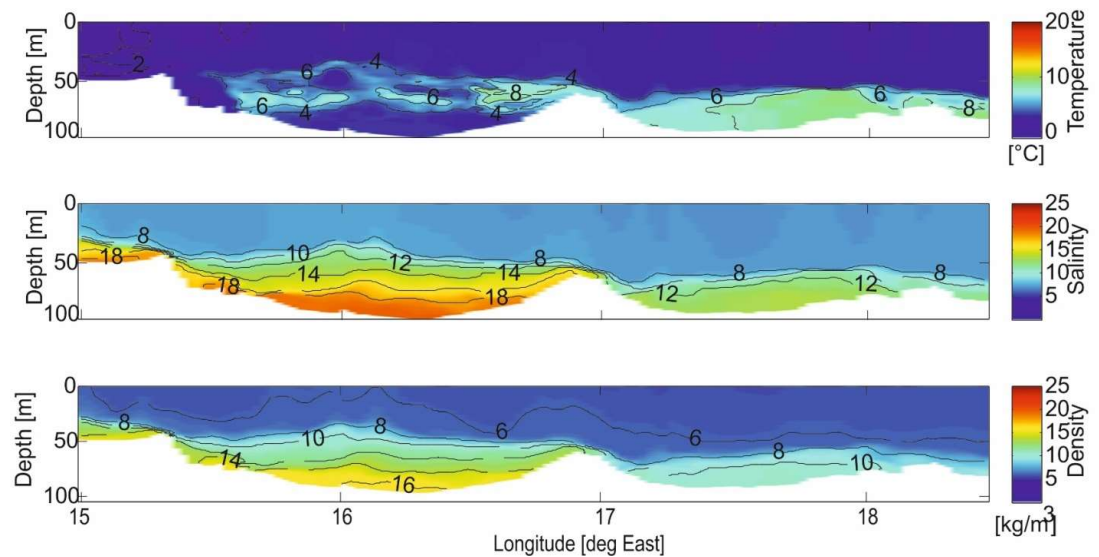


Two last major inflows into Baltic Sea – February 2003 and November 2014



The vertical distribution of temperature, salinity and density
along main axis of inflow propagation – December 2002

The vertical distribution of temperature, salinity and density
along main axis of inflow propagation – February 2003

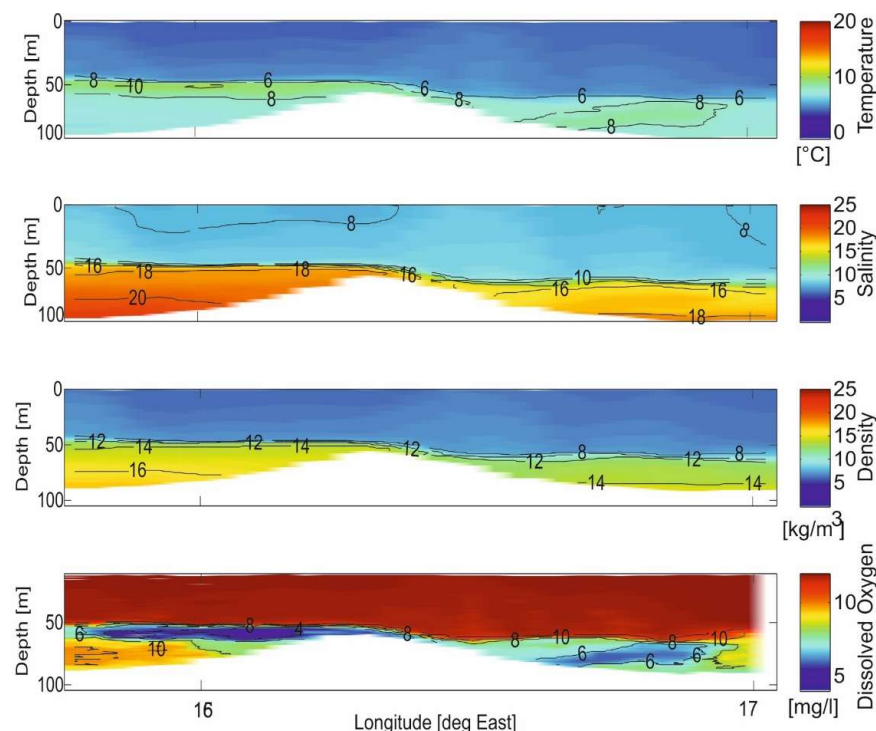
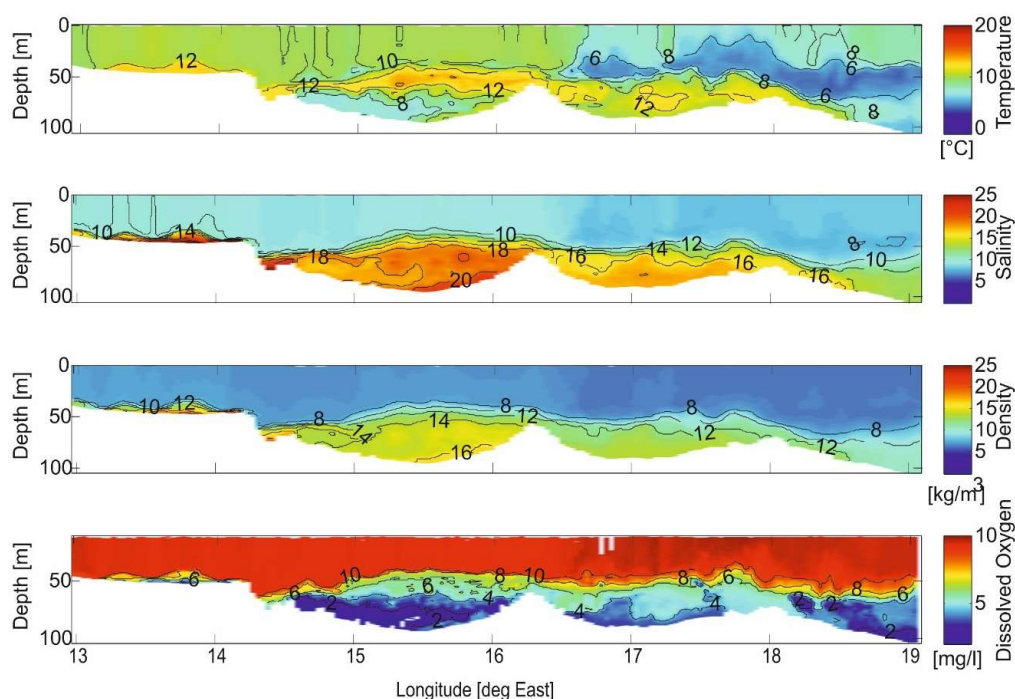


Two last major inflows into Baltic Sea – February 2003 and November 2014

2014/2015 inflow propagation and dissipation sequence



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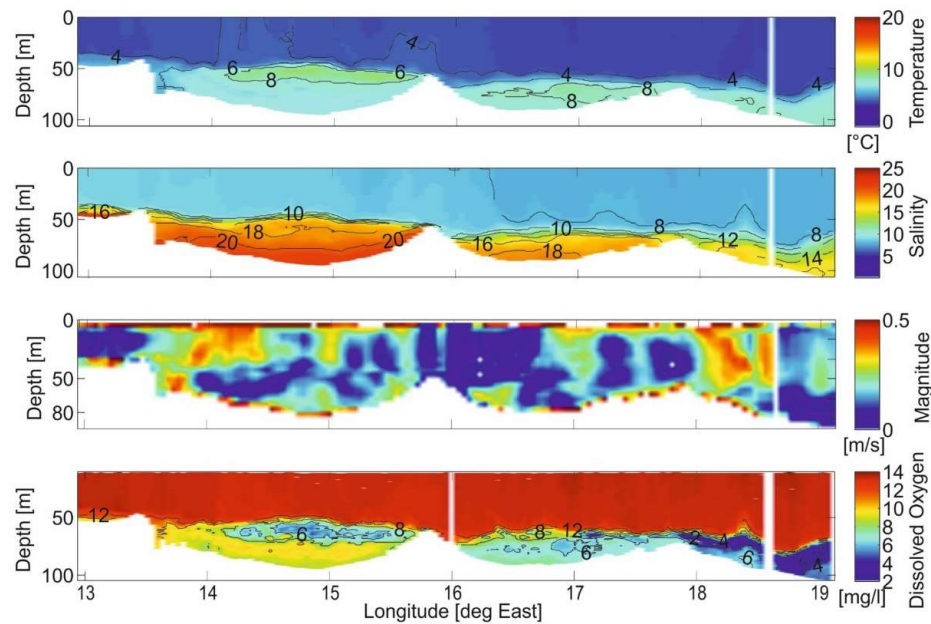
The vertical distribution of temperature, salinity, density and dissolved oxygen along main axis of inflow propagation, November 2014, left, January 2015 right

Two last major inflows into Baltic Sea – February 2003 and November 2014

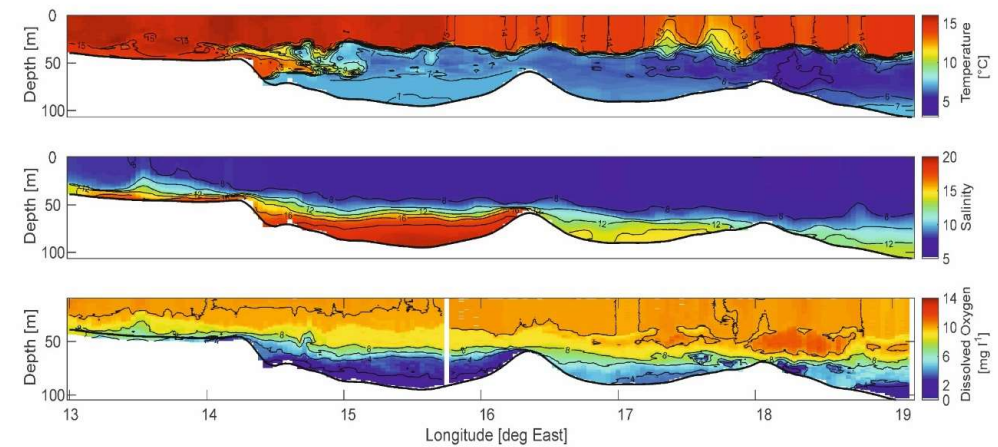
2014/2015 inflow propagation and dissipation sequence



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The vertical distribution of temperature, salinity, integrated currents velocities, and dissolved oxygen along main axis of inflow propagation in February 2015



The vertical distribution of temperature, salinity, integrated currents velocities, and dissolved oxygen along main axis of inflow propagation in October 2015

Take home message



- The Baltic Sea is very young inland water, which hydrology is dominated by the fresh water discharge from vast drainage area;
- Surface and bottom waters in the Baltic Sea are separated by the density boundary – the pycnocline
- The Baltic Sea bottom water is under severe oxygen deficit resulting in creation of the hydrogen sulfide dead zones;
- Inflows of the saline water from the North Sea is the only mechanism of renewal of bottom waters and supply of dissolved oxygen
- The strongest inflows to the Baltic Sea are the barotropic inflows;
- The frequency of strongest inflows decreased from, 5-7/decade to 1/decade;
- It is projected the frequency of strongest inflows will continue to decrease due to climate change;
- The strong inflow observed in 2014-2015 has been significant (ca. 200 km³ saline water and ca. 4 GT of salt), but did not remediate the oxygen deficit in the deep waters;
- The irregular barotropic inflows are becoming significant for bottom water renewal in the Baltic Sea;