Long-term changes in stratification in the Baltic Sea

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Motivation

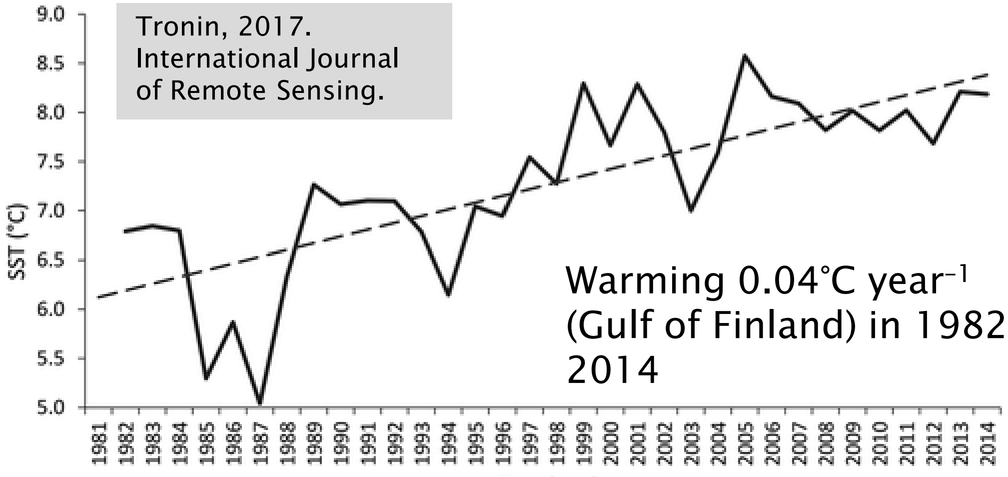
- Due to the small volume of the sea, changes in forcing conditions impact the Baltic Sea quite rapidly.

- Numerous studies have reported sea surface temperature rise in the Baltic, most of the studies are based on the remote sensing or (near) coastal time-series.

- Bottom waters of the Baltic Proper are renewed only by sporadic barotropic Major Baltic Inflows from the North Sea. Investigations are mostly concentrated to the areas from Danish Straits to Eastern Gotland Basin.

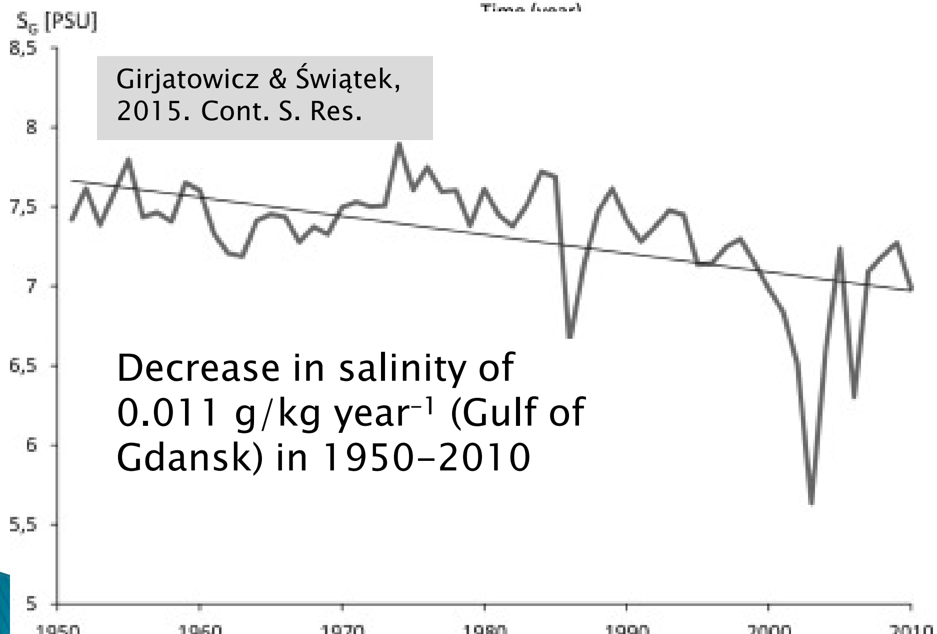
- How deep has the warming signal reached? What are the changes in salinity, density distribution, and stratification? Taking into account the impact of changes in forcing components (atmospheric forcing, exchange of heat energy and freshwater through the sea surface, and input of freshwater from rivers and saltier water through the Danish Straits).

Background – surface layer



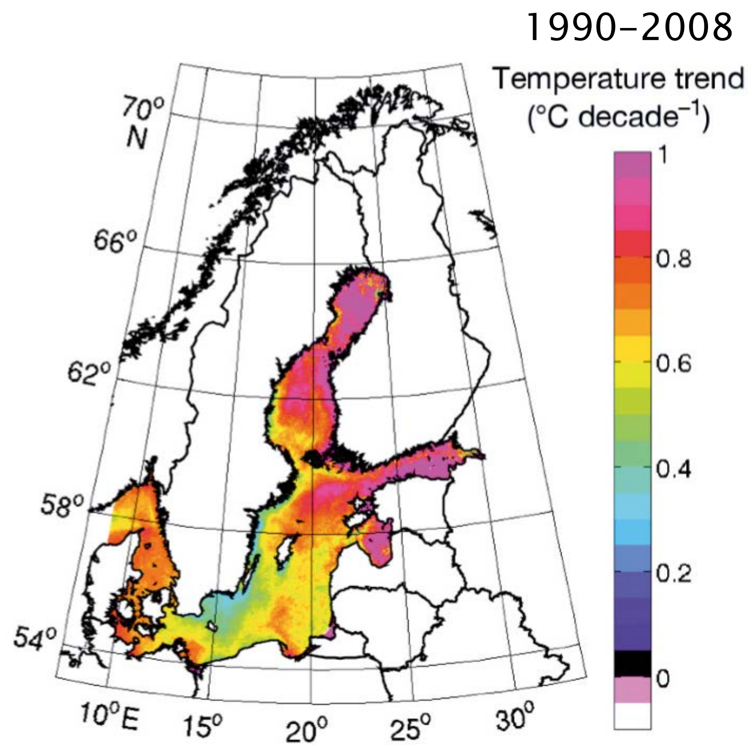
Tronin, 2017. International Journal of Remote Sensing.

Warming 0.04°C year^{-1} (Gulf of Finland) in 1982–2014



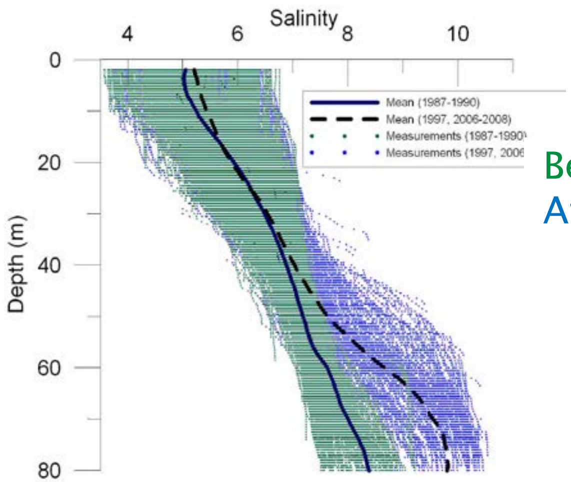
Girjatowicz & Świątek, 2015. Cont. S. Res.

Decrease in salinity of 0.011 g/kg year^{-1} (Gulf of Gdansk) in 1950–2010



Lehmann, Getzlaff, Harlaß, 2011. Climate Research.

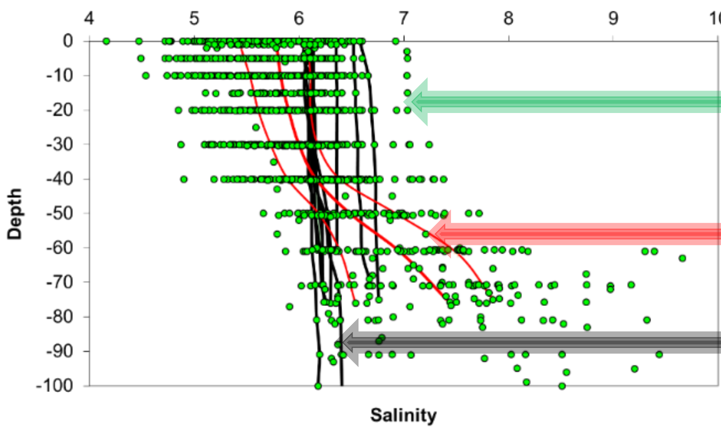
Background – GoF salinity profiles



Before mid-nineties
After mid-nineties

Liblik and Lips (2011)

- Halocline was weaker before major inflow in 1993
- Strong and shallow halocline in the Baltic Proper induces stronger stratification in the Gulf of Finland

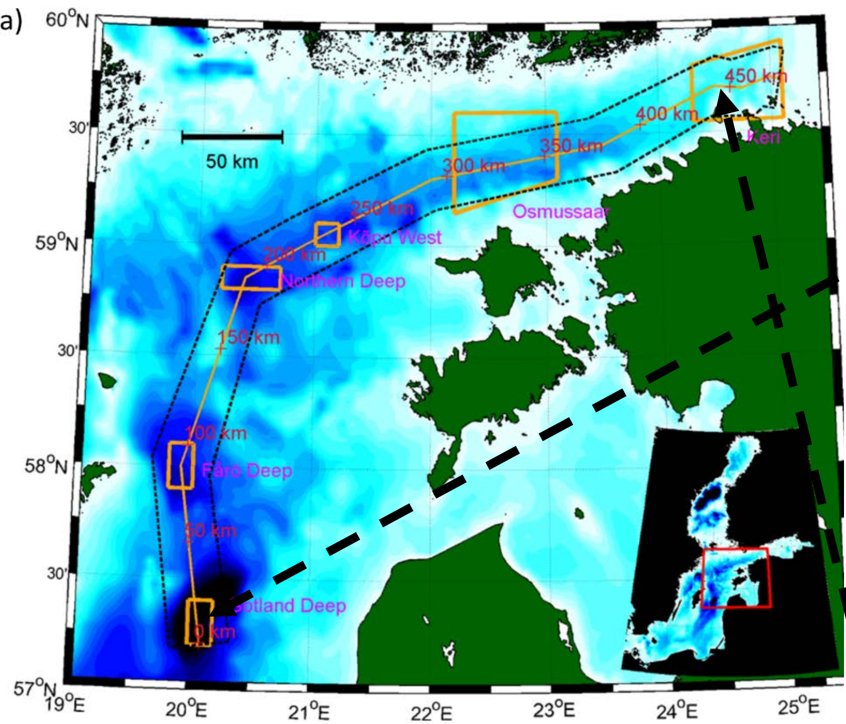


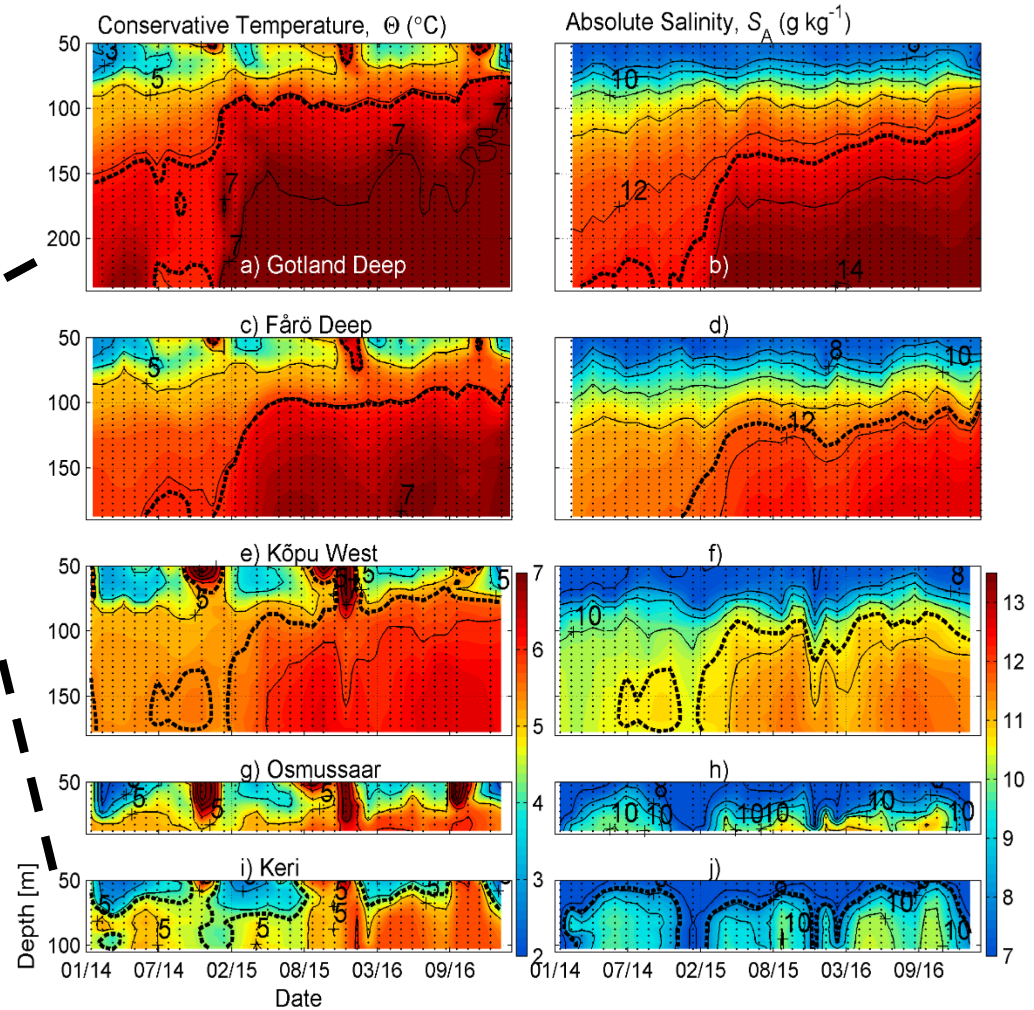
Salinity values observed **during winter (Dec–Jan)** at station LL7

Median and quartile values of all data

Collapsed stratification is occasionally observed **in winter**

Background – deep layer

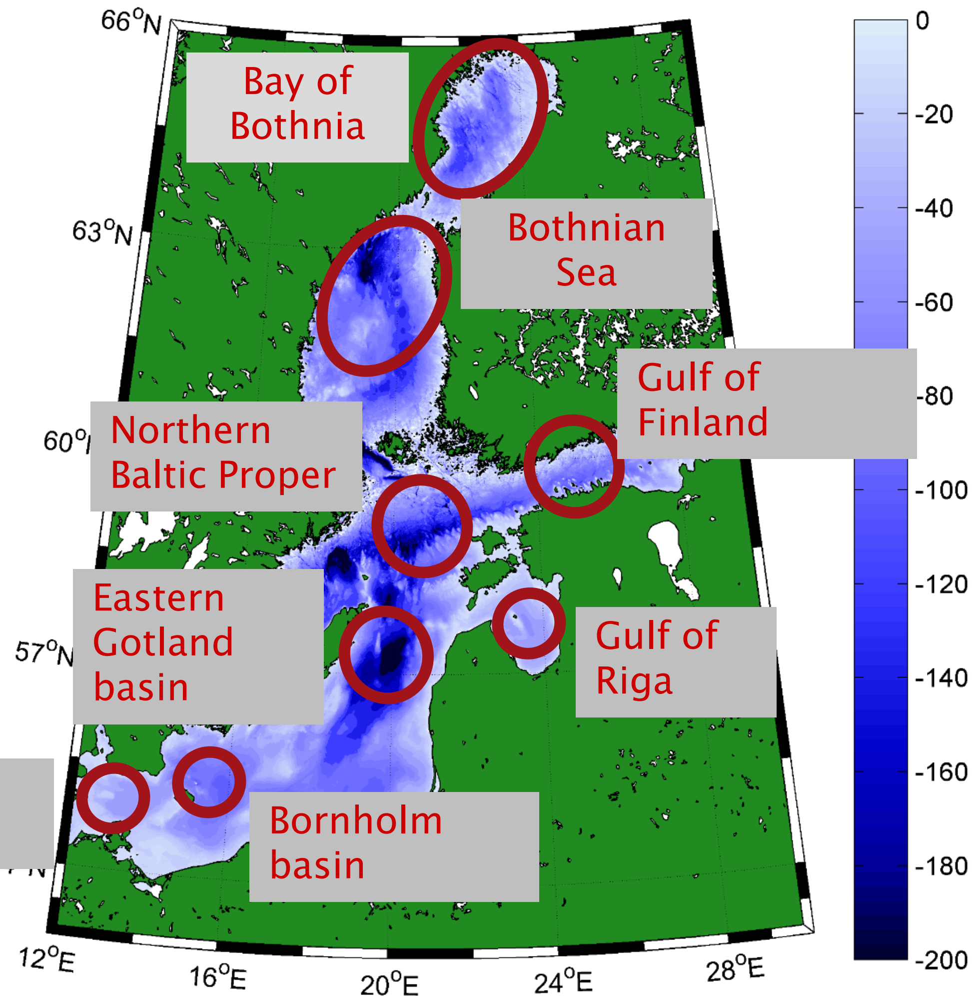




Liblik, Naumann, Alenius, Hansson, Lips, Nausch, Tuomi, Wesslander, Laanemets and Viktorsson, 2018. Frontiers in Marine Science.

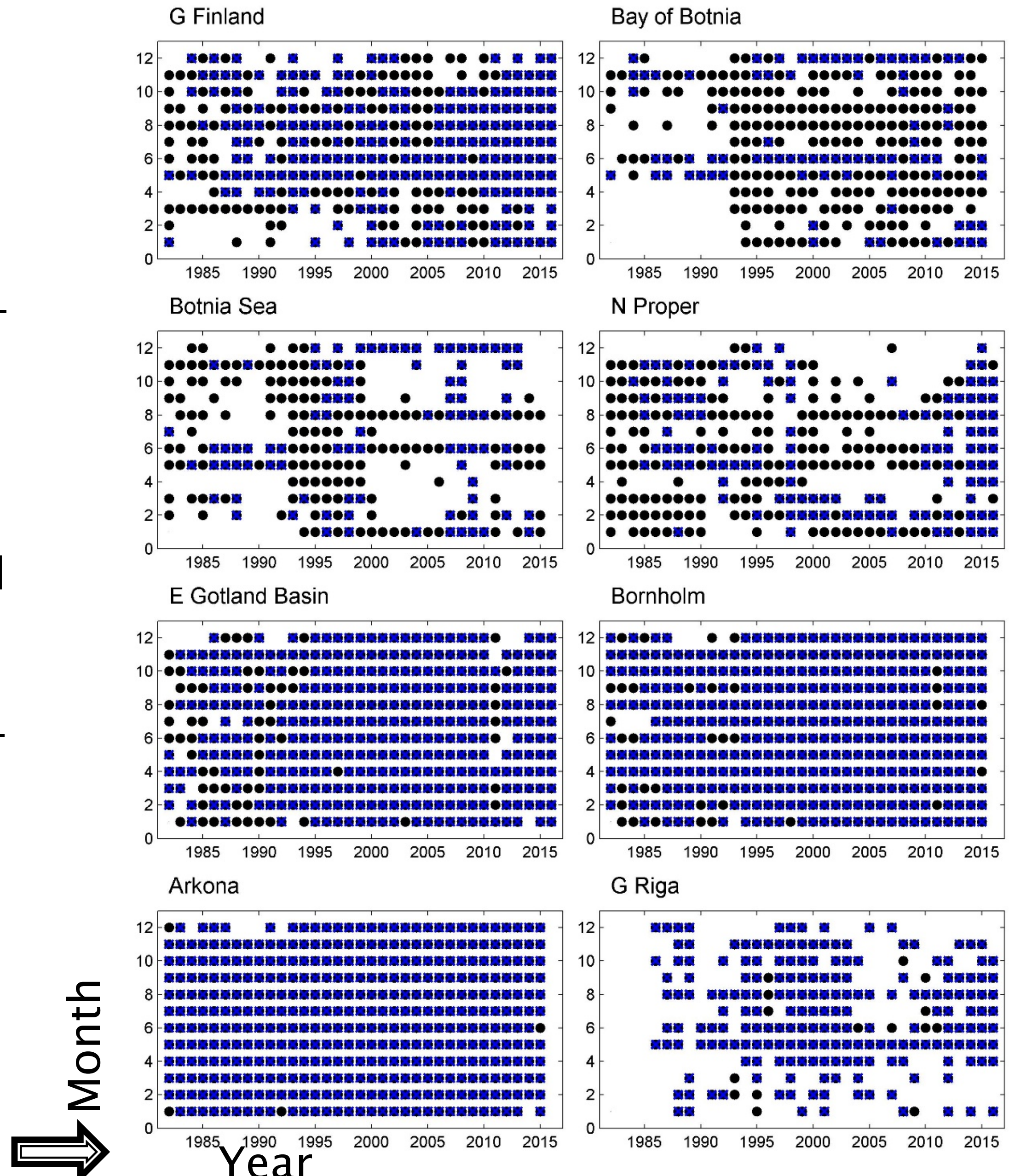
2014 Jan – 2017 Mar

Eight areas, data from 1982–2016



Data

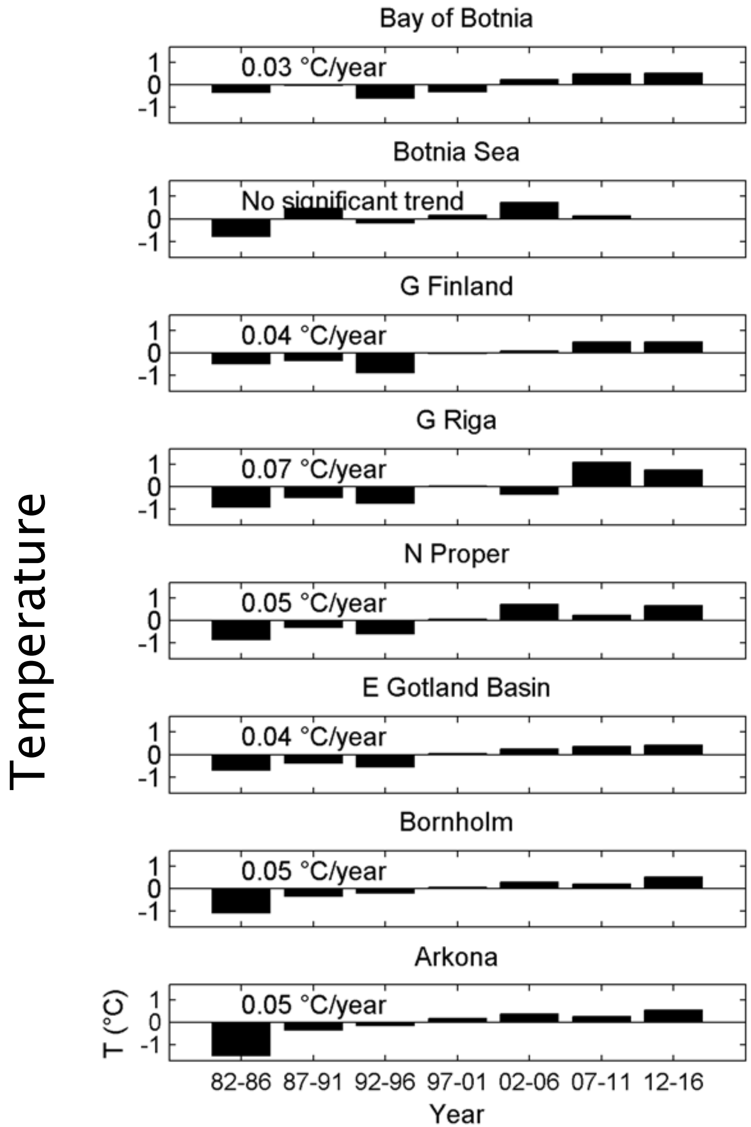
- HELCOM ICES database
- Copernicus Marine Service in-situ data (ship CTD and mooring data)
- CTD database in Department of Marine Systems at TUT and its predecessors
- Profiling moorings and point-recorders data from Department of Marine Systems at TUT
- At least one measurement available, also measurements from deep layer are available



Calculation steps

- Daily mean profiles within areas
- 10-day mean profiles
- Mean annual cycle
- Anomalies from annual curves
- Monthly mean anomalies
- Annual mean anomalies and seasonal (Dec-Feb, Mar-May, Jun-Aug, Sep-Nov) mean anomalies
- Difference in mean anomalies between periods 1982-1991 and 2007-2016

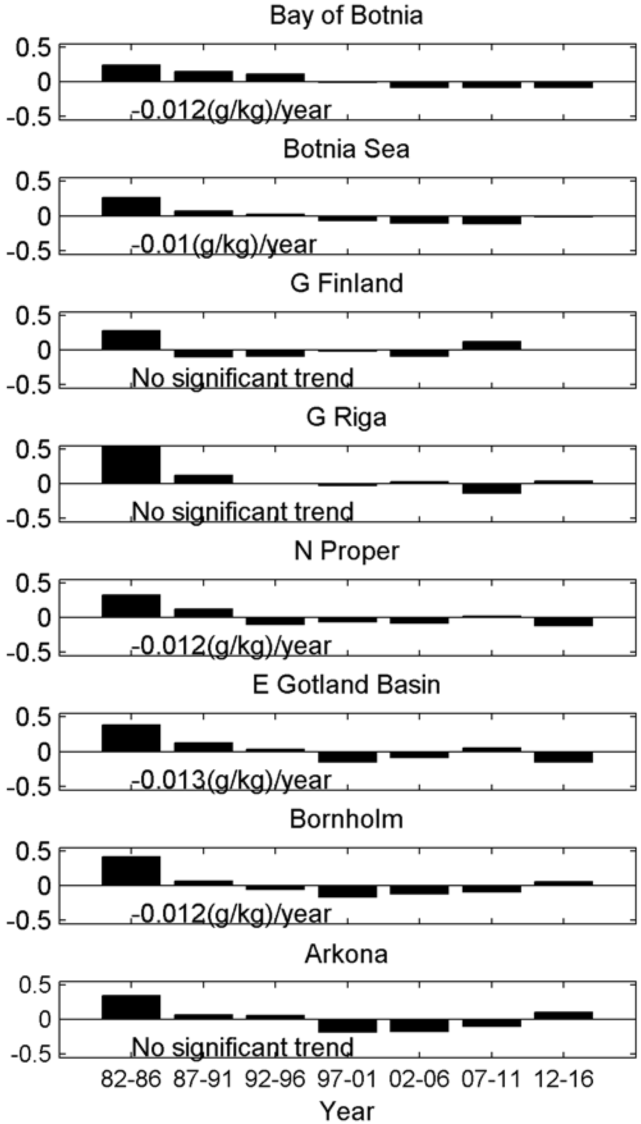
Surface layer temperature: pentadal averages and trends



Temperature trend +0.04 °C to +0.05 °C a year in most of the areas can be detected;

Higher/lower trends were found in the areas, where less data is available.

Surface layer salinity: pentadal averages and trends

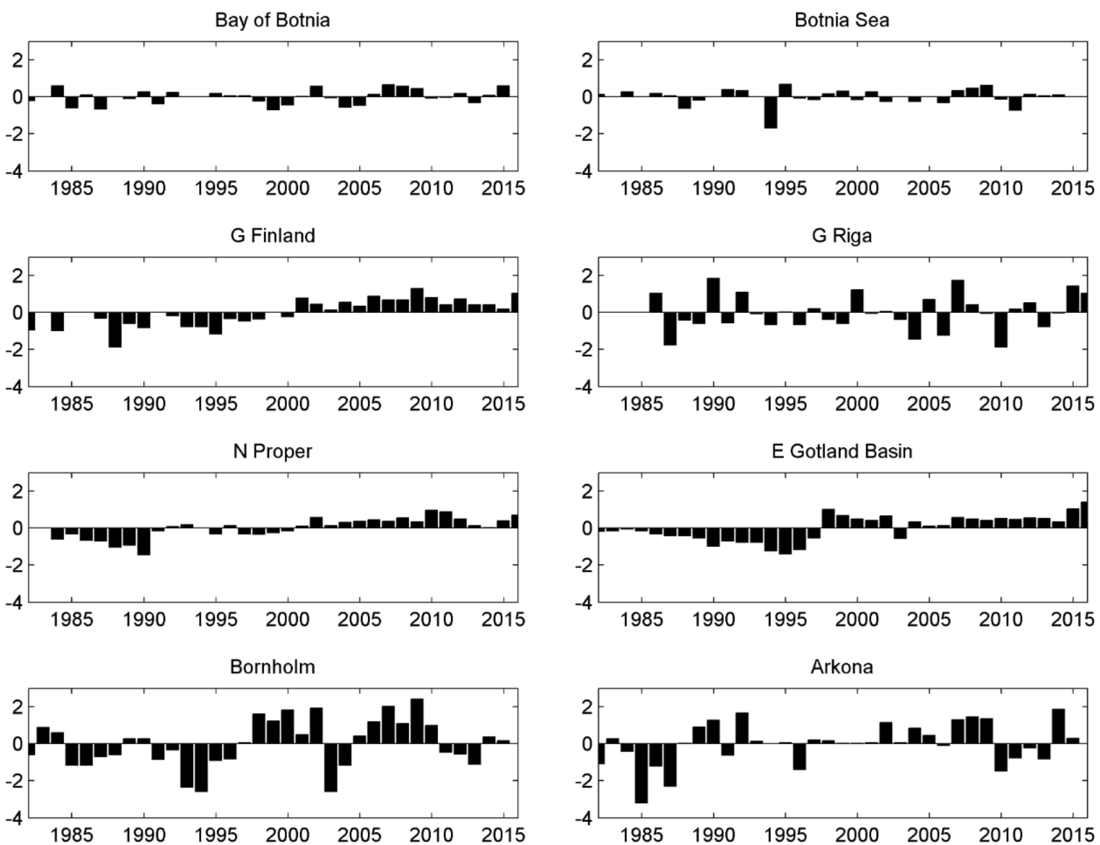


Salinity trend −0.010 to −0.013 g/kg in most of the areas can be detected;

No significant trend was found in the Gulf of Finland, Gulf of Riga and Arkona basin.

SSS might be more sensitive to (more frequent westerly) wind due to longitudinal gradients in the Gulf of Finland and Arkona basin.

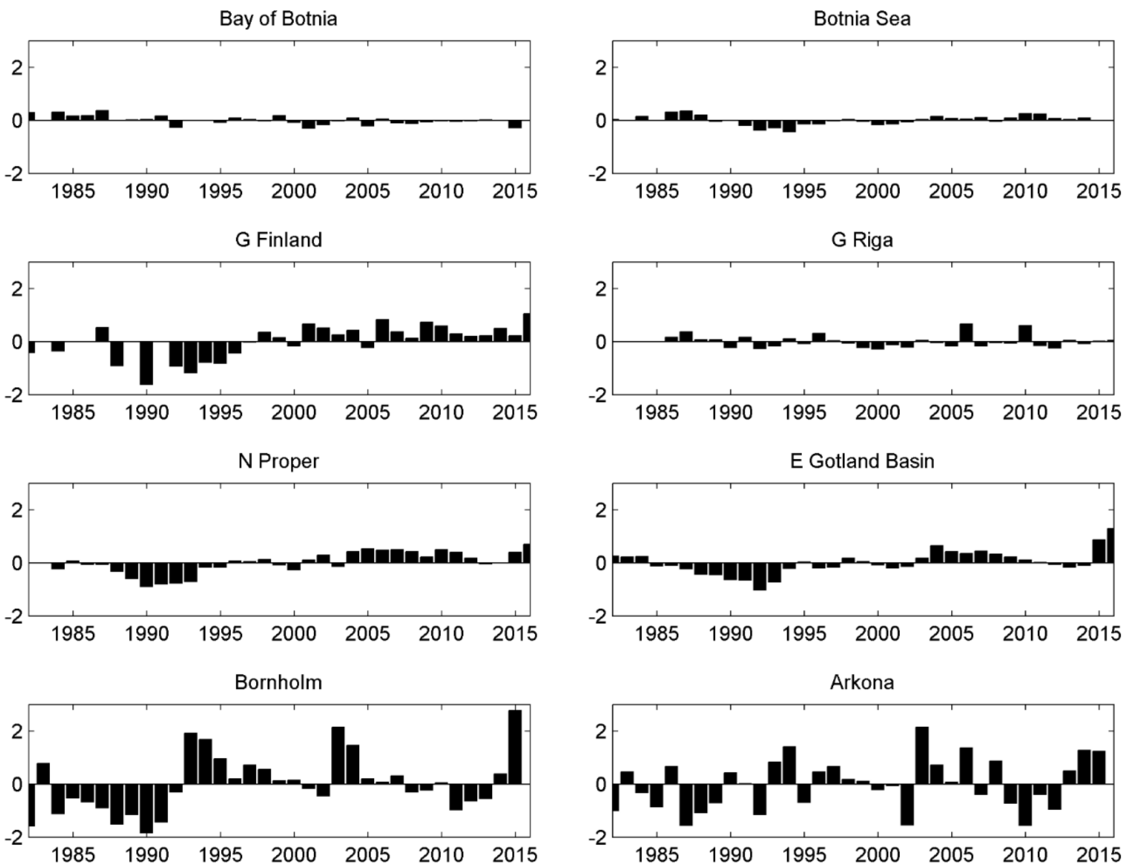
Deep layer: annual averages of temperature



No clear trend in the Gulf of Bothnia and Gulf of Riga

Warmer deep layer in recent decade in the Gulf of Finland, Northern Baltic Proper and Eastern Gotland Basin

Deep layer: annual averages of salinity



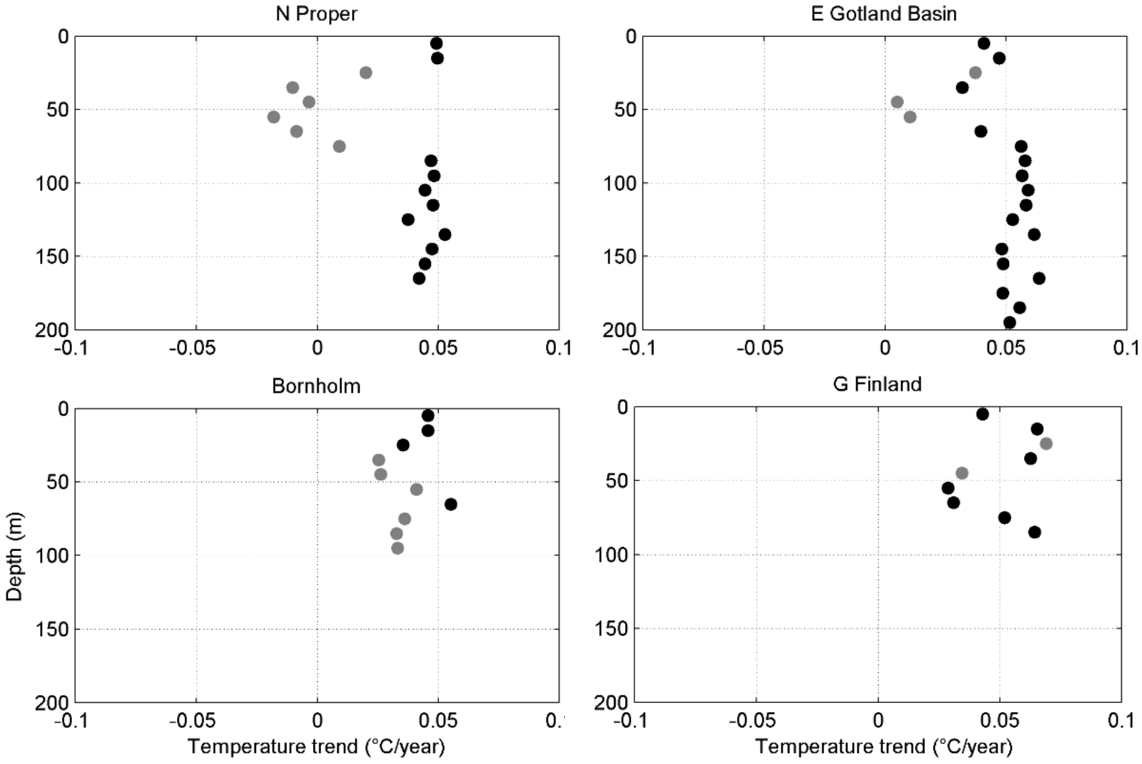
Sills block deep layer inflow from Baltic Proper to Gulf of Bothnia and Riga

Stronger signal can be observed in the Gulf of Finland

Eastern Gotland Basin and Northern Baltic Proper react to MBIs

Rapid reactions to MBIs in Bornholm and Arkona basin.

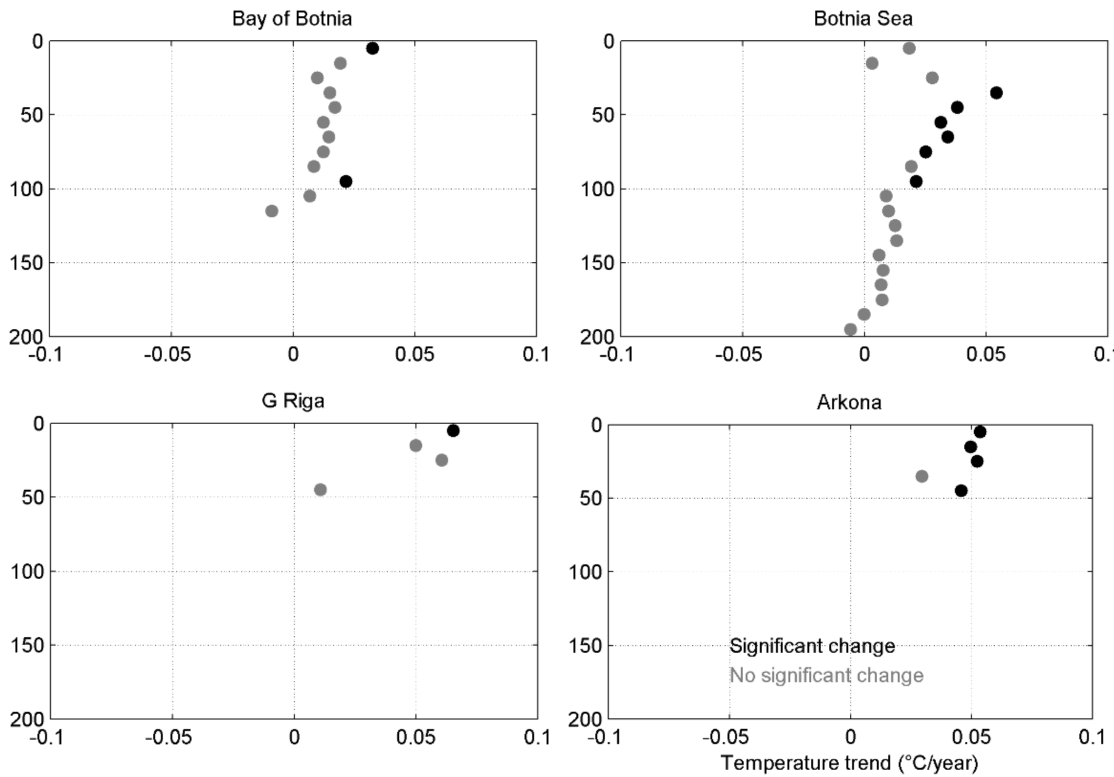
Temperature trends °C per year 1982–2016



Three-layer basins have similar vertical trend structure:

- warming of 0.04–0.06 °C a year in the upper 20–40 m and in the deep layer
- Intermediate layer has no trend or slight warming (Gulf of Finland)

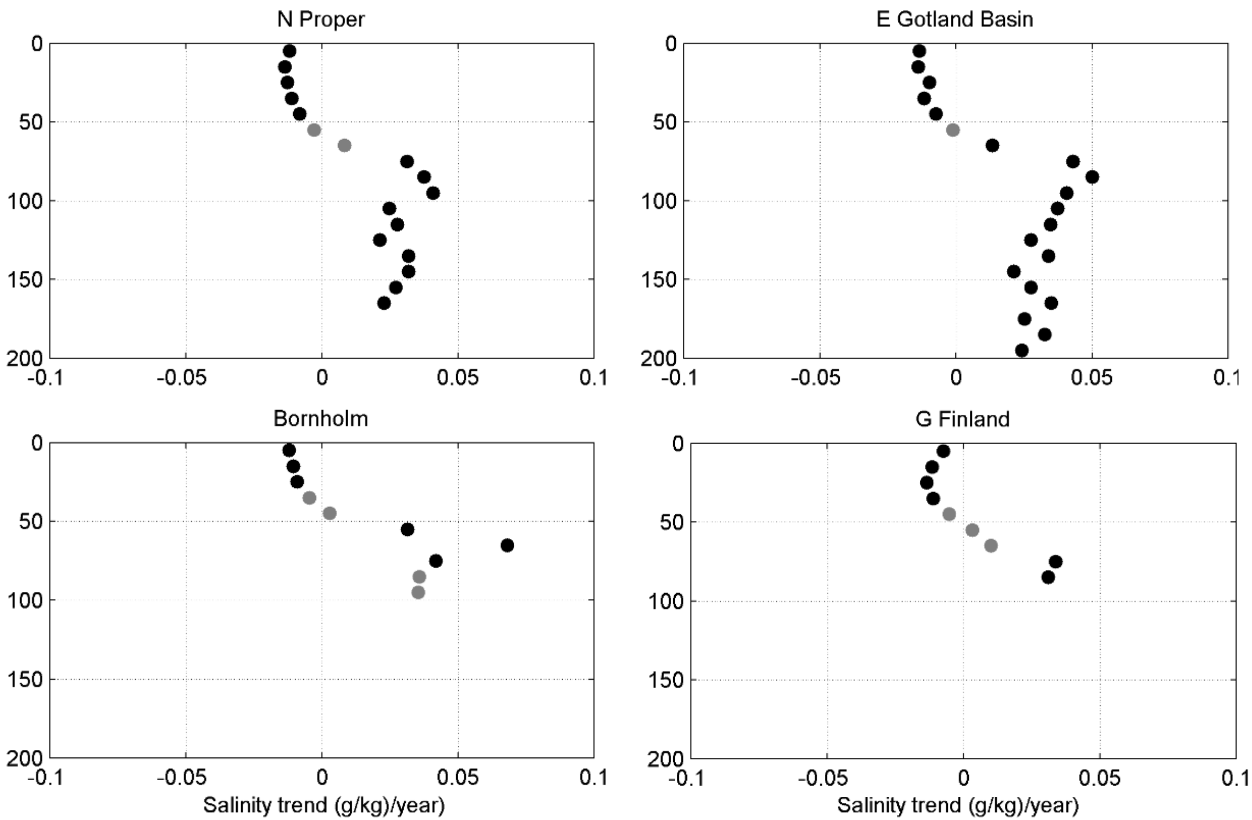
Temperature trends °C per year 1982-2016



Two-layer basins have

- Significant warming in the surface layer (except Bothnian Sea)
- No trend in the deep layer (except Arkona basin)

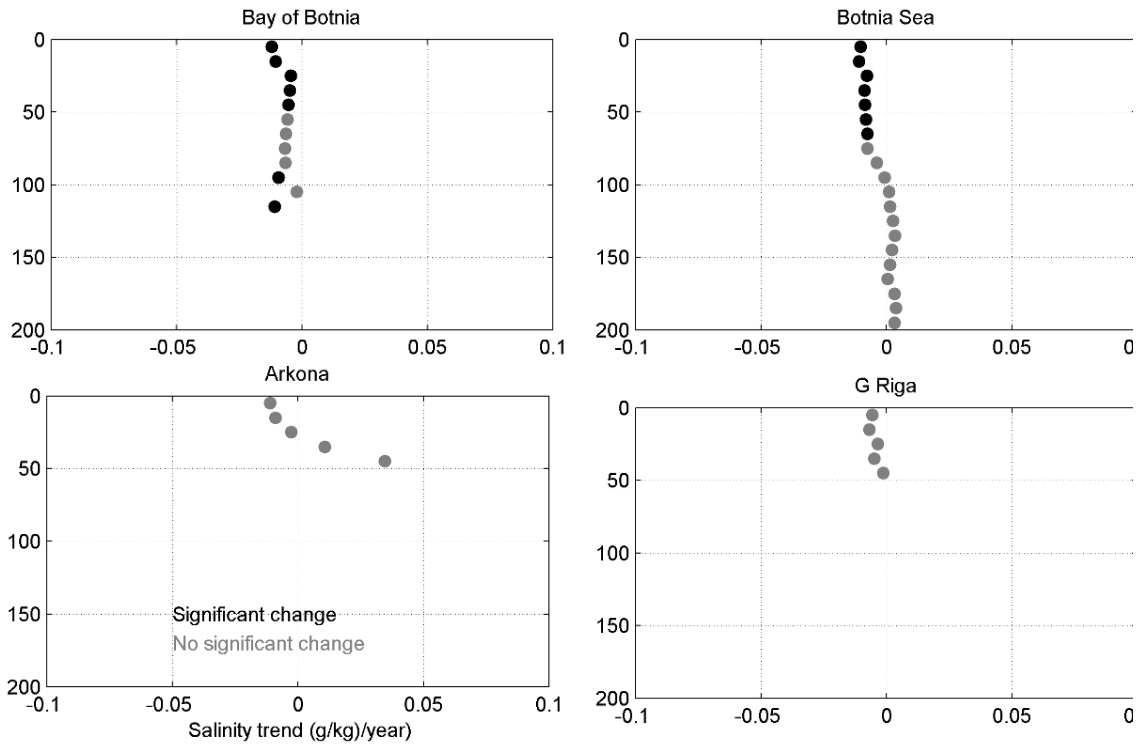
Salinity trends g/kg per year 1982-2016



Three-layer basins have similar vertical trend structure:

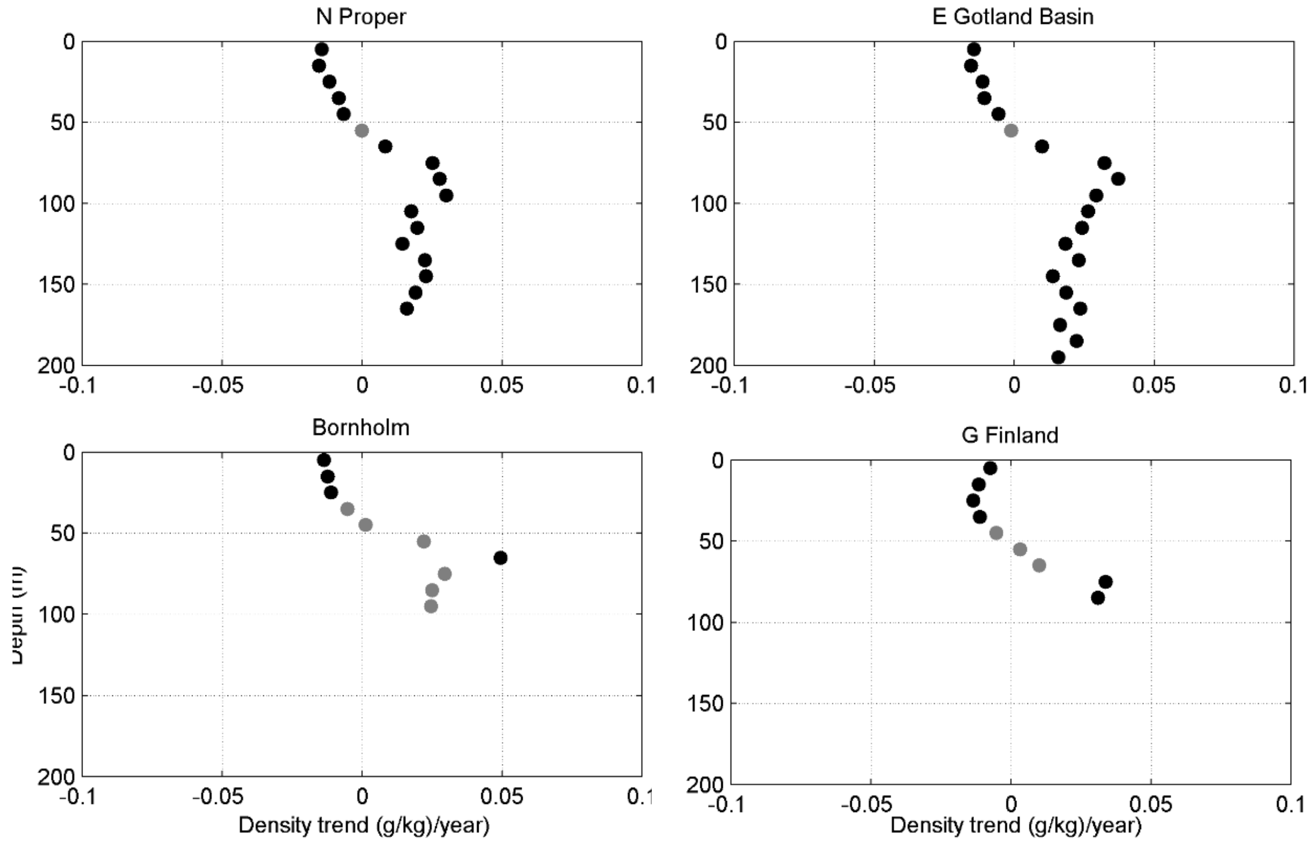
- Freshehing in the upper 40 m
- No trend in the intermediate layer
- Increasing salinity in the deep layer

Salinity trends g/kg per year 1982-2016



- Freshening tendency in the upper layer in two-layer basins as well;
- Increase in the deep layer can be observed only in the Arkona basin.
- Rest of the basins have complete turn-over of the water column during winters.

Density trends kg/m³ per year 1982–2016



Three-layer basins:

- Negative density trend in the upper layer, positive density trend below halocline

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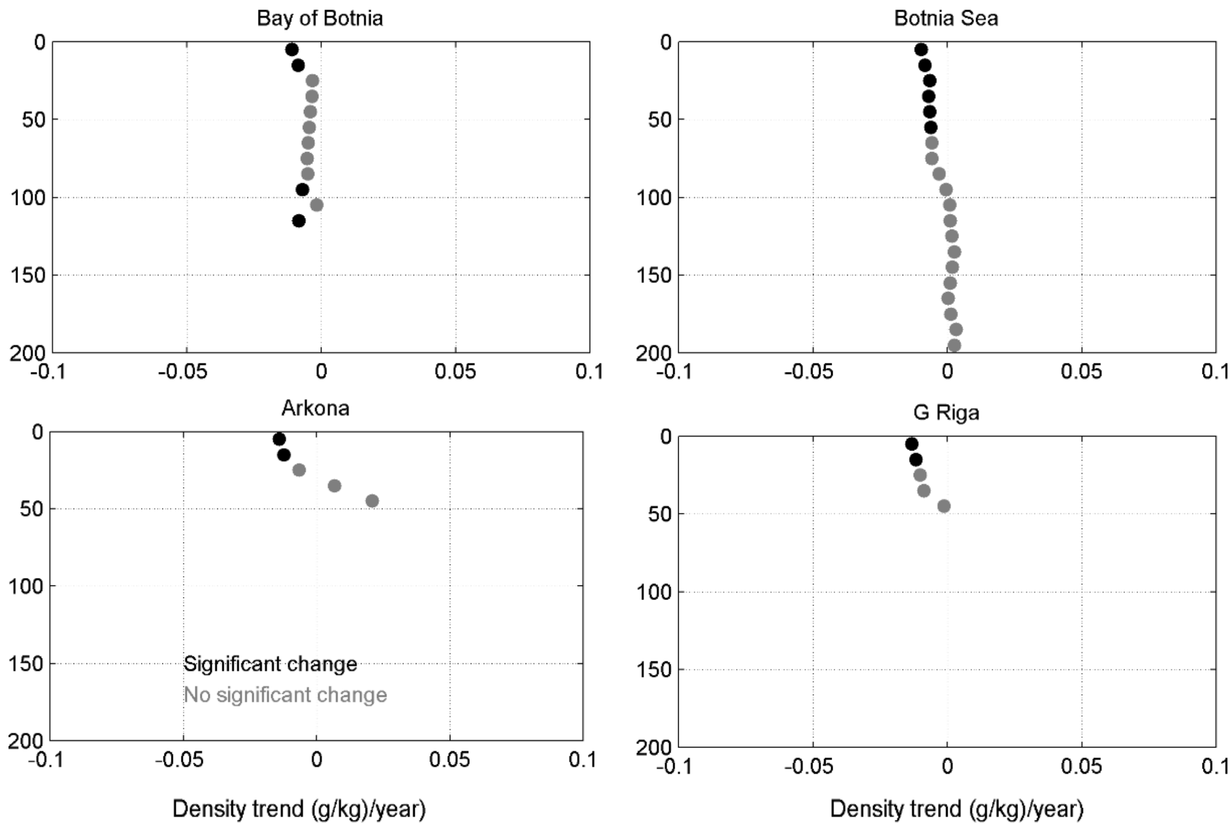
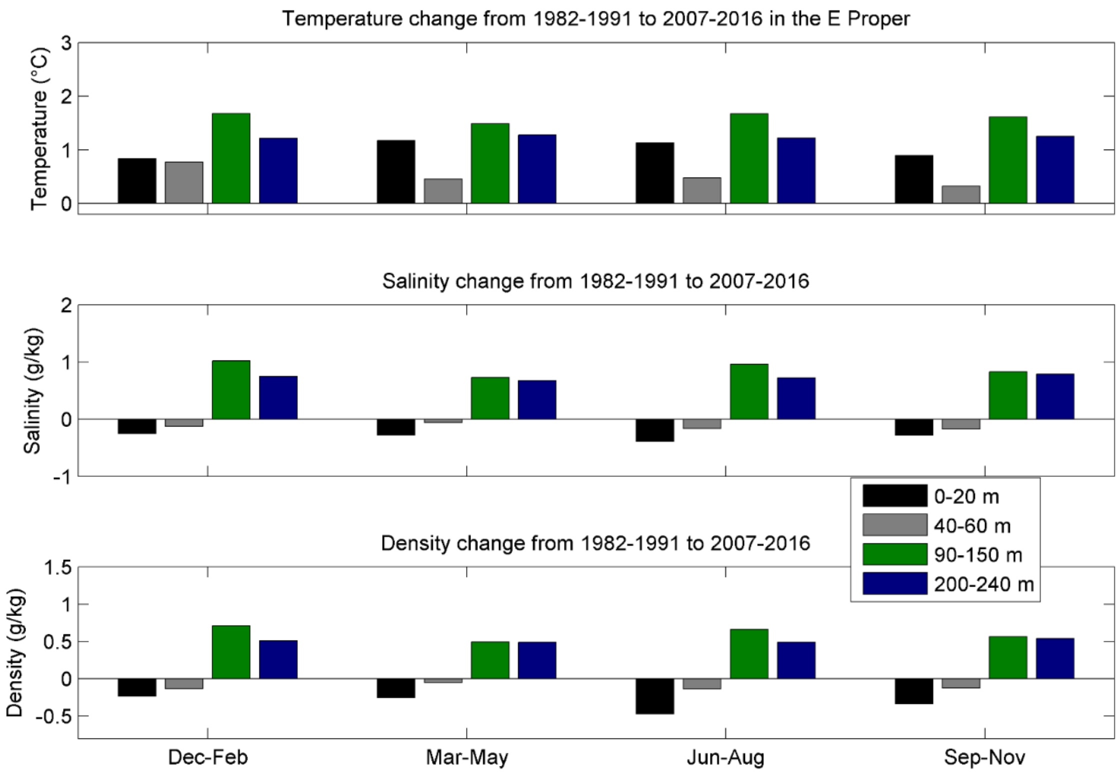
Density trends kg/m^3 per year 1982–2016



Two-layer basins:

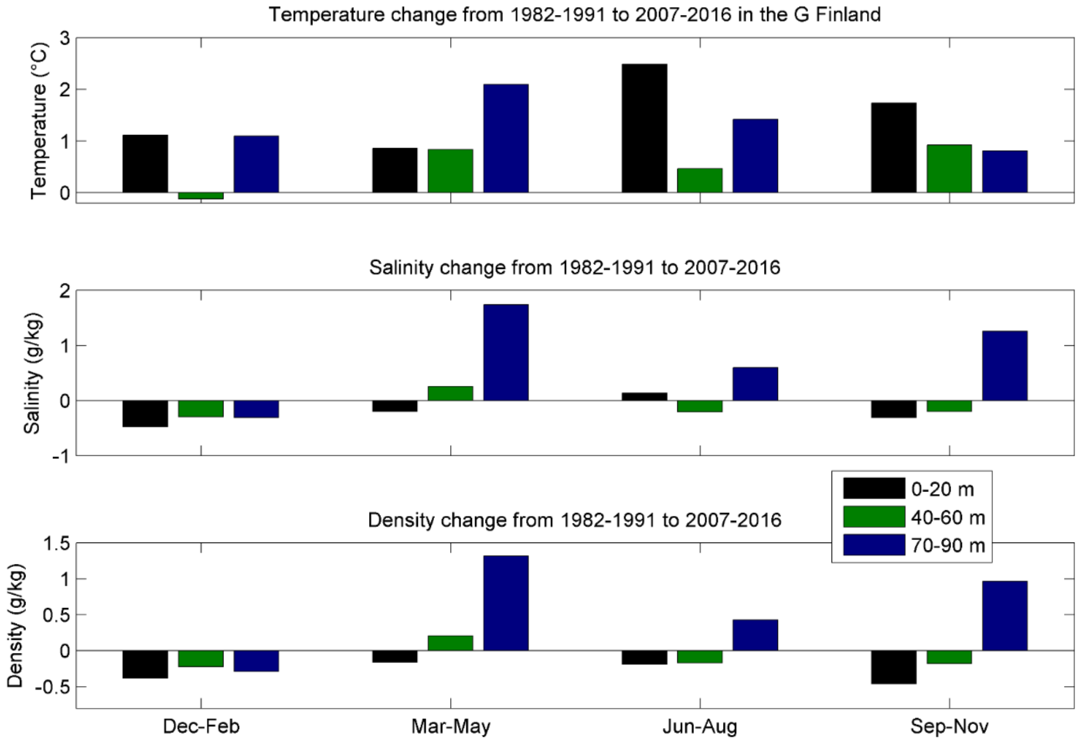
- Negative density trend in the upper layer, no strong trend in the deep layer

Changes from 1982-1991 to 2007-2016 by seasons, Eastern Gotland Basin



- No seasonality in changes in most of the areas
- Both pycnoclines are stronger in later period

Changes from 1982–1991 to 2007–2016, Gulf of Finland



- Salinity/density in the bottom layer in the Gulf of Finland has increased in spring, summer, and autumn
- In winter, such change does not reveal likely due to increased estuarine circulation reversal events

Changes in vertical density differences from 1982-1991 to 2007-2016

Density difference change (kg/m^3)

	Upper pycnocline (from 0-20 m to 40-60 m)	Deeper pycnocline (from 40-60 m to bottom layer)	Bottom – surface
Gulf of Finland	0,20	0,70	0,90
Bothnian Sea	0,15	0,05	0,20
Northern Baltic Proper	0,36	0,71	1,07
Eastern Gotland Basin	0,21	0,62	0,83
Bornholm Basin	0,77	0,51	1,28
Arkona Basin	0,46		0,46
Gulf of Riga	0,18		0,18

Conclusions

- The three layers have had different trends in temperature and salinity over last 35 years.
- Upper and deep layer in the three-layer basins have been getting warmer by ~0.05 °C per year.
- Freshening of the upper layer by 0.010-0.013 g/kg per year has occurred in most of the basins.
- The stagnation period before 1993 MBI ended up with much fresher deep layers than any stagnation period after 1993. Thus, salinity of deep layers has increased.
- Stratification has strengthened through both pycnoclines in most of the areas.
- You are welcome to join with your ideas and/or data

Thank you!

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