Haline Convection due to Sea Ice Brine Rejection in the Northern Baltic Sea

A possible mechanism for deep water formation?

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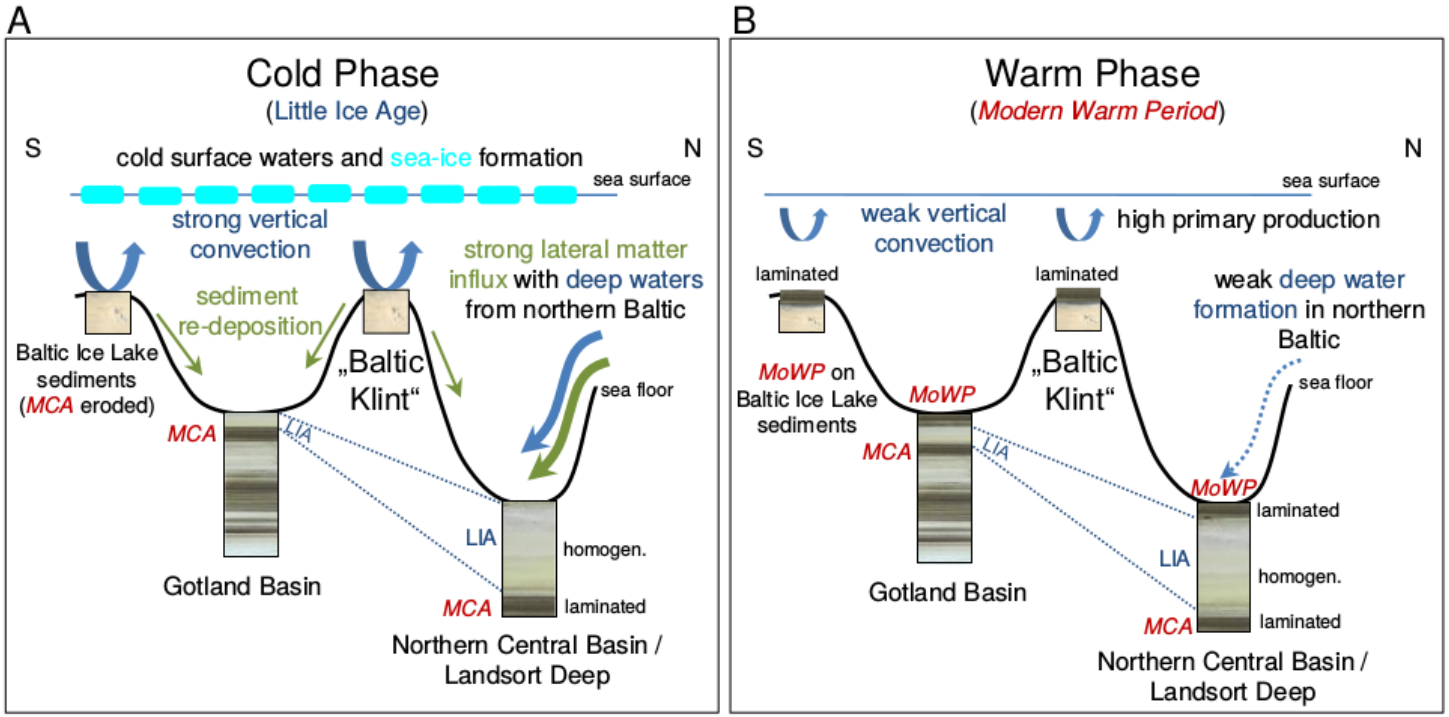
Motivation

Hypothesis (Moros et al., 2018 (in prep.))

Winter-time deep water formation as a second process ventilating the bottom waters of the northern and central Baltic Sea during cold climate phases.



Moros et al., Boreas, 2018 (in prep.)

Evidence from sediment cores, seismoacoustic profiles, hydrographic data and sediment proxies, ...

Motivation

Brine rejection

The process of salt being pushed from forming sea ice into the surrounding seawater, creating saltier, denser brine.

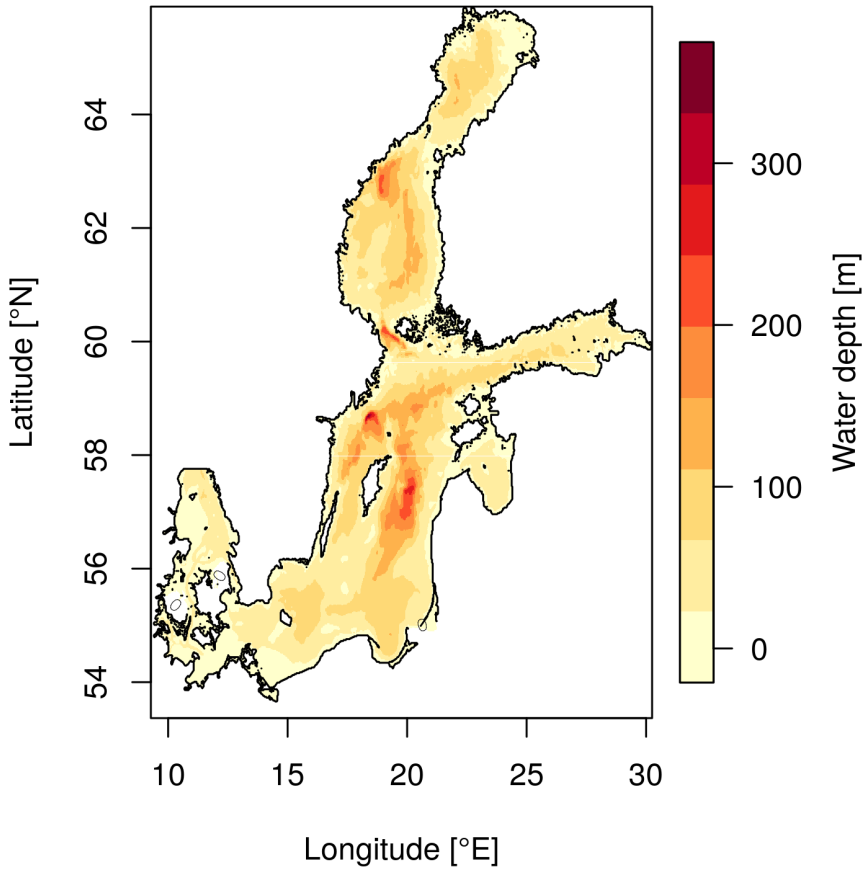
Research Questions

- What is the role of brine rejection in the circulation of the Northern Baltic Sea?
- Is there a contribution to the Baltic Proper deep waters (Landsort deep)?
- How does the situation change in different climate states?

Image: ESA/Envisat (taken on 15 March 2010), CC BY-SA 3.0 IGO

Model Setup[1]

- Model: GETM (General Estuarine Transport Model)
- Bathymetry: 1 nm horizontal resolution, 50 vertical levels (adaptive coordinates)
- Atmospheric forcing: CCLM-ERAi
- River discharge: GRDC database + climatological annual cycle
- Boundary data: North Sea + Baltic Sea GETM simulation



- Simulation period: Dec 1986 - Sep 1987
- Initial data based on observed profiles[1], 3 months spin-up

[1] from Ulf Gräwe (personal communication)

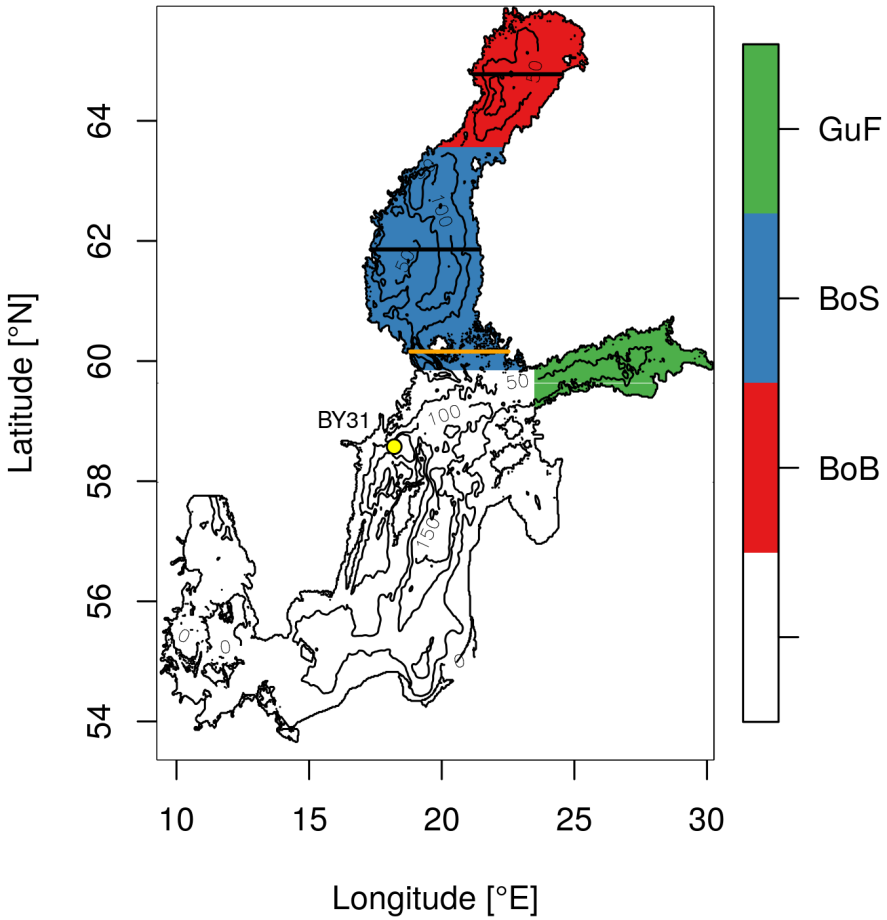
Brine Forcing

- GETM is coupled only to a simple thermodynamic sea ice model → no ice motion and no fluxes between ice and ocean
- Include brine rejection via prescribing freshwater fluxes as surface boundary condition
- Use data from simulations[1] with Modular Ocean Model (MOM)

[1] Neumann et al., Geophys. Res. 122(2), 2017

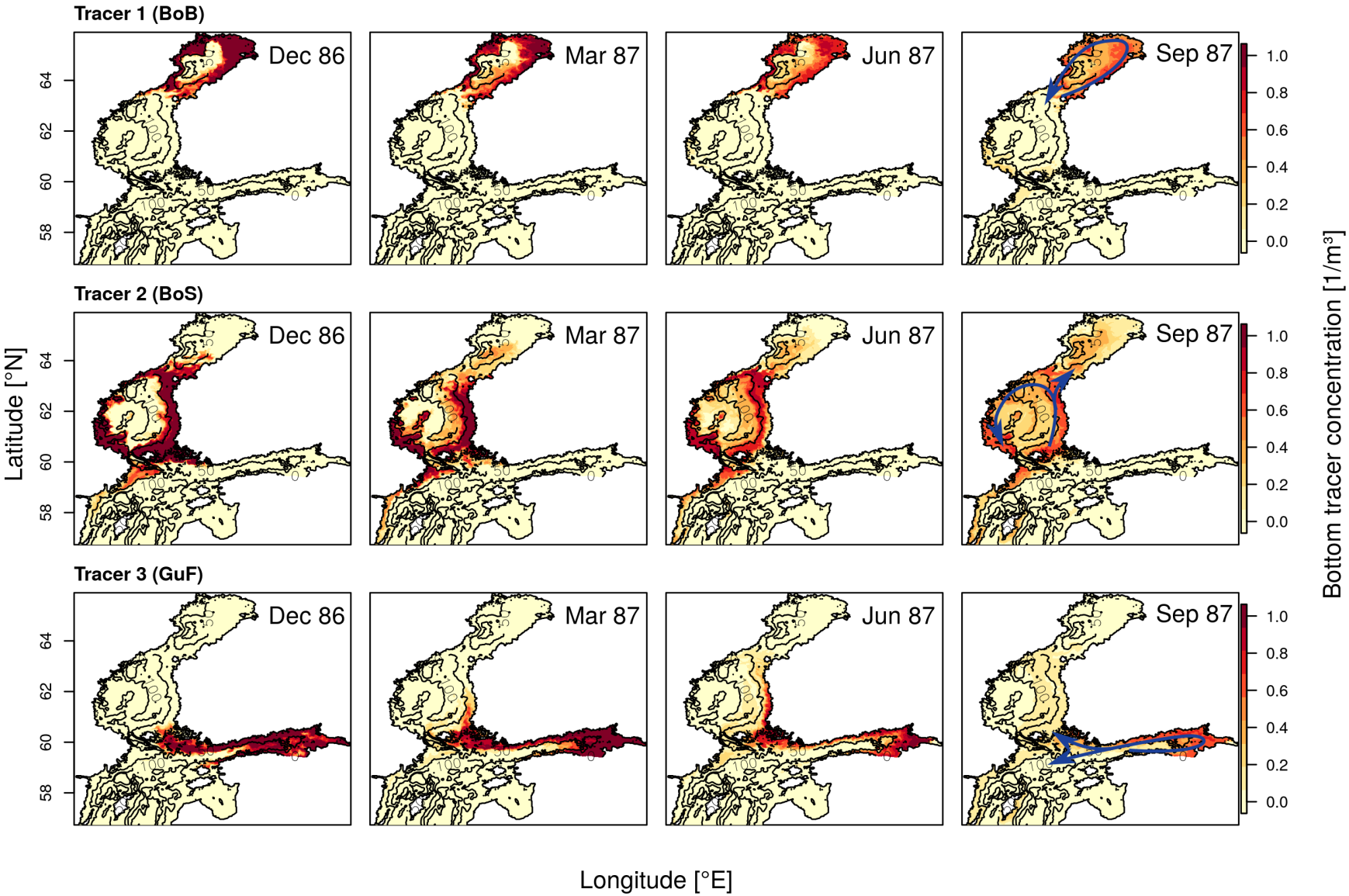
Simulations w/ and w/o brine rejection

- Same experiment without brine forcing (control simulation) and with brine forcing (BR simulation)
- **Passive tracers** marking winter surface water, concentration set to 1 m^{-3} each time step from Dec - Mar



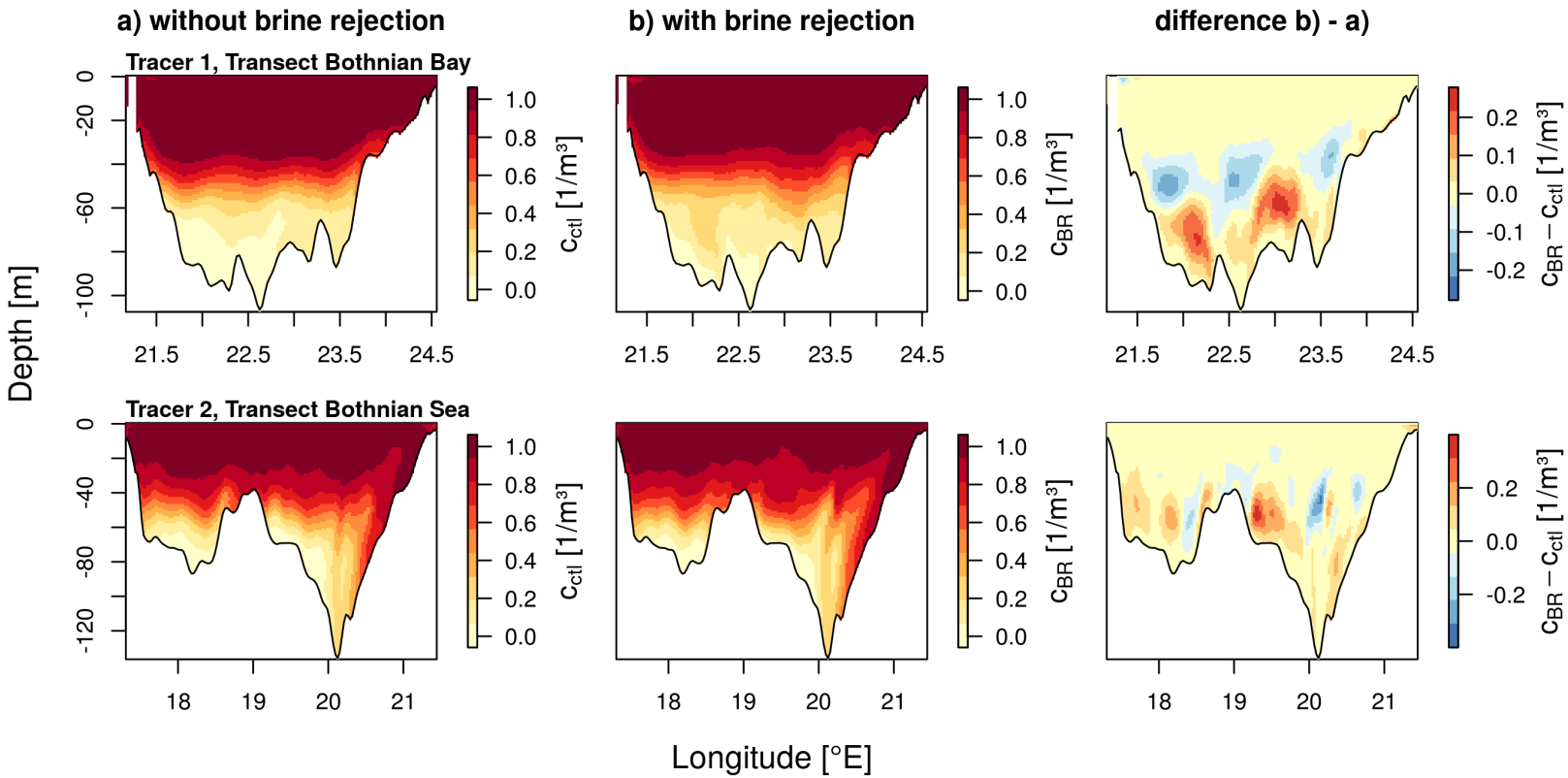
Simulations w/ and w/o brine rejection

Tracer pathways (control simulation)



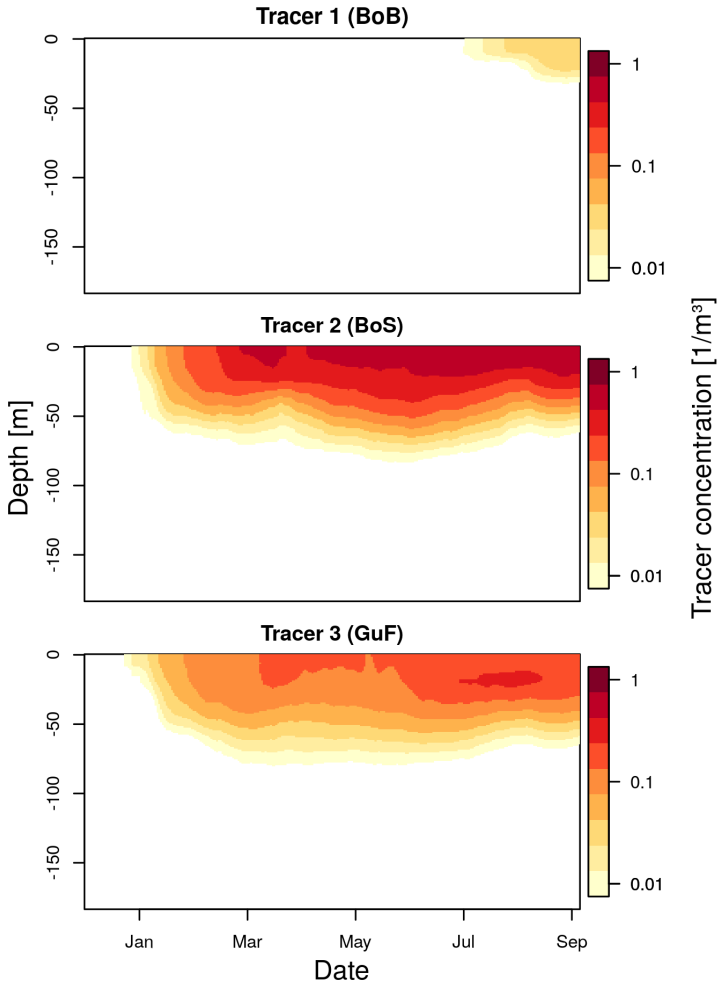
Changes in vertical structure / convection

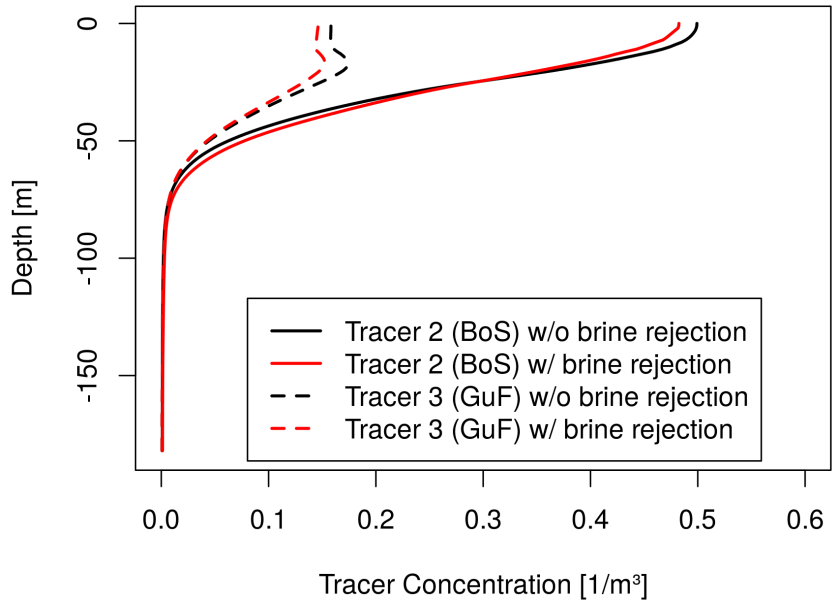
Mean tracer concentration in February



Simulations w/ and w/o brine rejection

Landsort Deep tracer concentrations



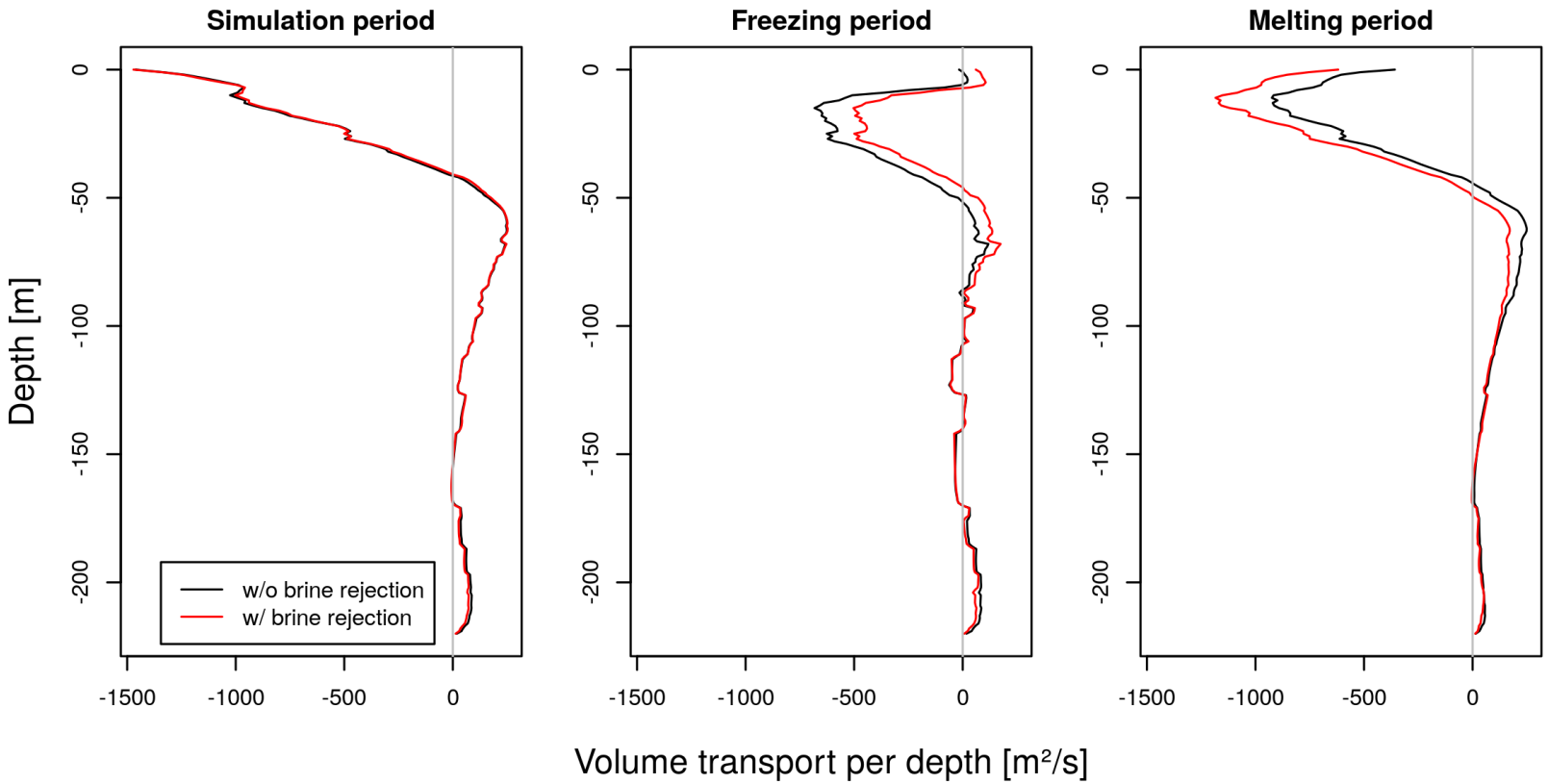


⇒ Tracer accumulates in the surface layer above the halocline

Simulations w/ and w/o brine rejection

Transports through Aland & Archipelago Sea

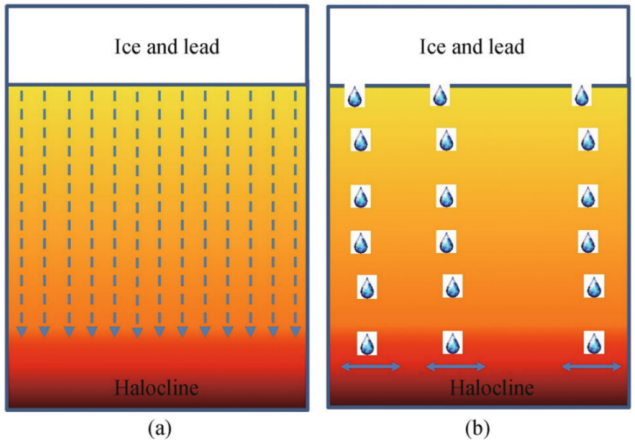
Depth profile of volume transport



- Difference in net transport profile on seasonal scale
- Estuarine circulation maintained

Brine rejection parameterization (BRP) experiments

- Localized brine rejection in leads



Jin et al., Front. Earth Sci., 2015

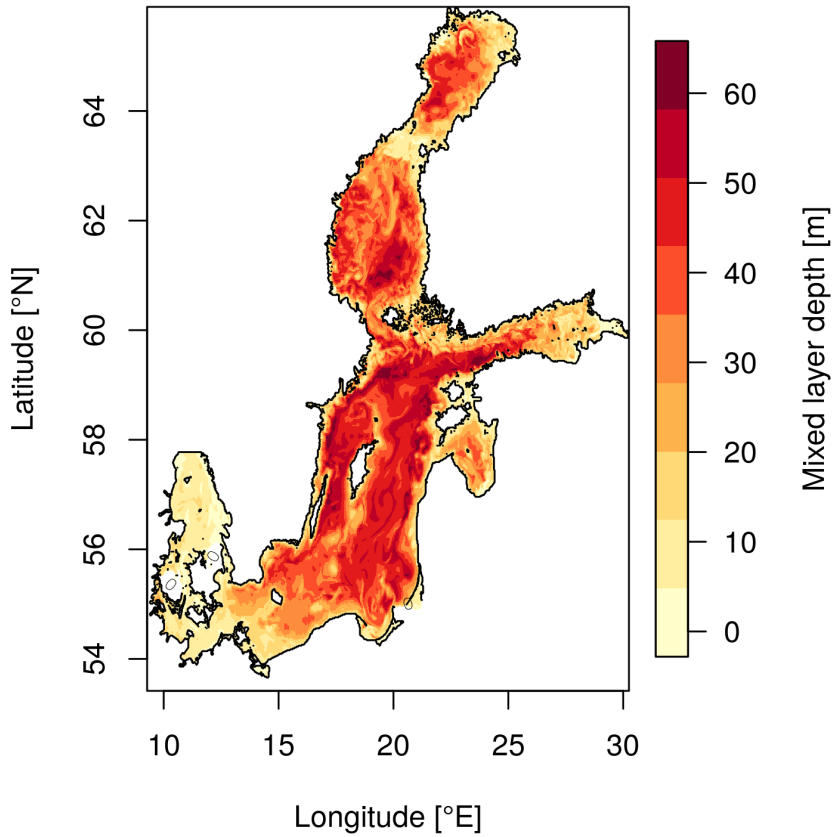
- Subgrid-scale brine rejection parameterization (Nguyen et al., J. Geophys. Res., 2009):

$$s(z) = \begin{cases} Az^n & \text{if } |z| \leq |D_{sp}| \\ 0 & \text{if } |z| > |D_{sp}| \end{cases}$$

Sensitivity experiments

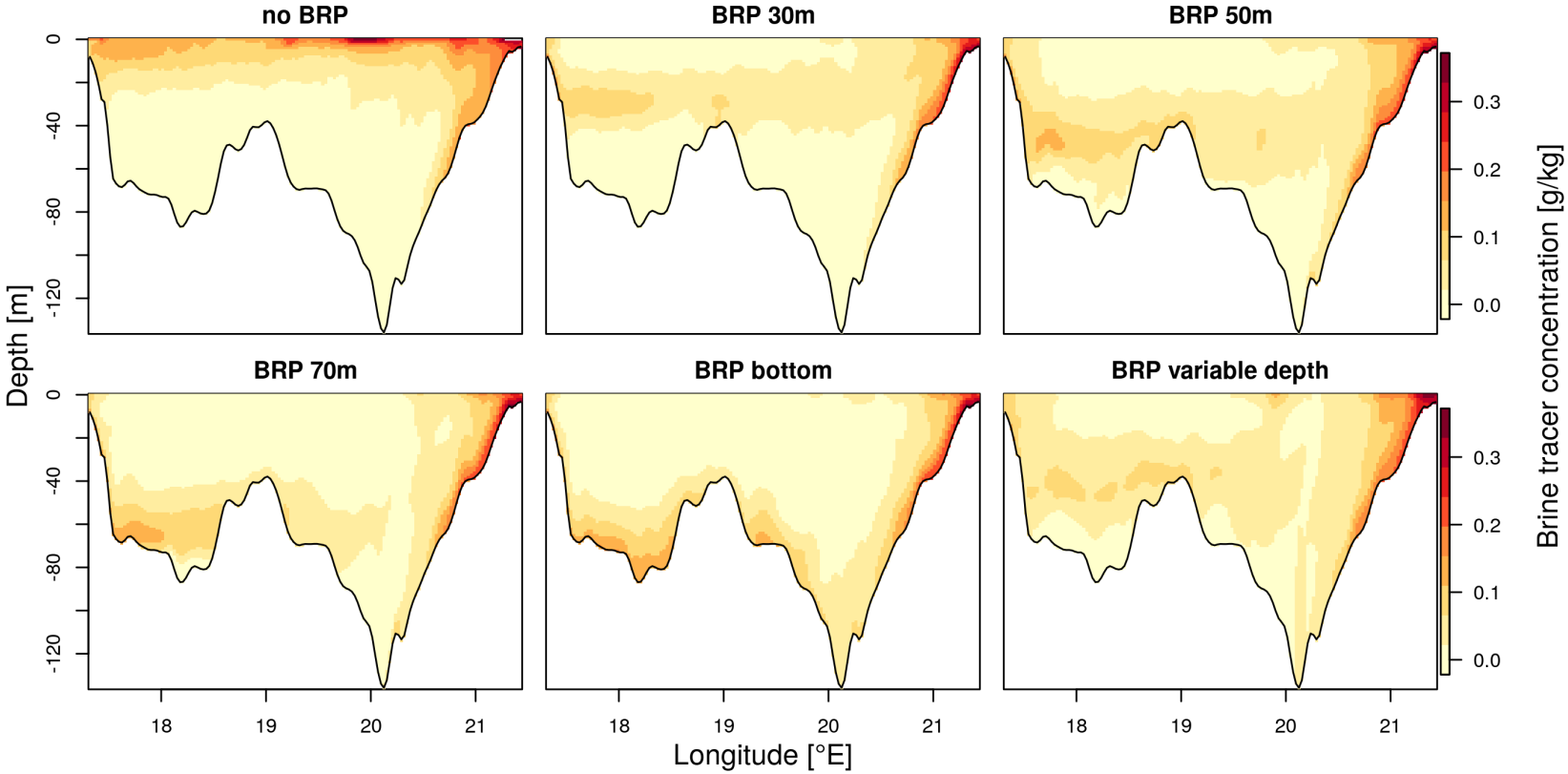
- Repeated simulations with BRP with $n = 5$ for 5 different D_{sp}
  - fixed depths (30m, 50m, 70m)
  - bottom
  - variable mixed layer depth determined by density criterion $\Delta\rho = \rho_{D_{\text{sp}}} - \rho_{\text{surface}} = 0.3\text{kg/m}^3$
- Attention: different tracer initialization
  $\Rightarrow$ Brine tracer: marking salt rejected from sea ice (unit g/kg), vertically distributed according to BRP

Mixed layer depth in January according to density criterion:



Vertical structure with BRP

Tracer 2 (BoS) concentration in Bothnian Sea transect in February (mean)



Sensitivity experiments

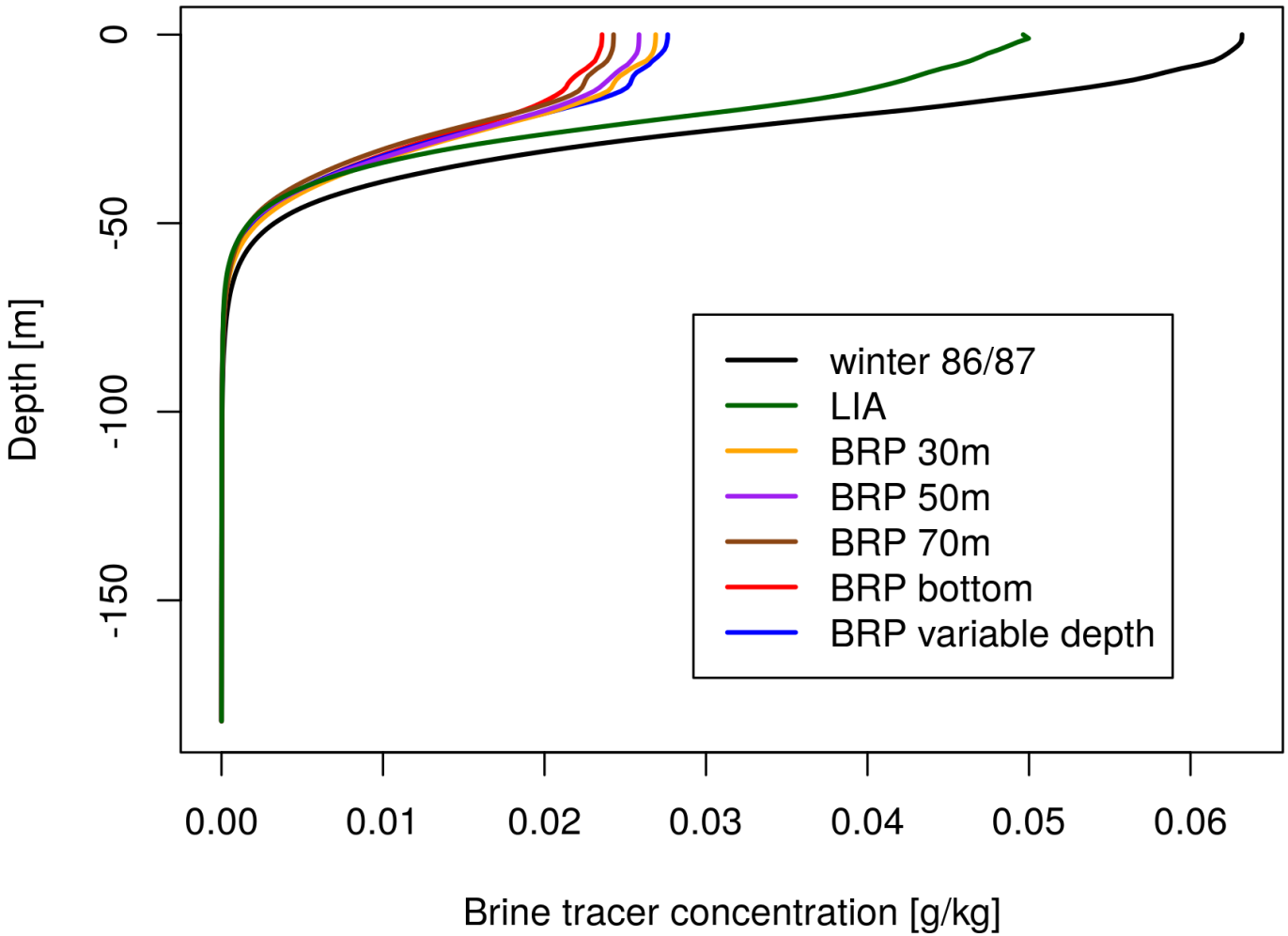
Little Ice Age (LIA) experiment

Modifications:

- Air temperature reduced by 2 °C (Kabel et al., 2012)
- Specific humidity
- Increased freshwater fluxes due to ice growth/melt by 15% (estimated with Stefan's Law for ice growth)

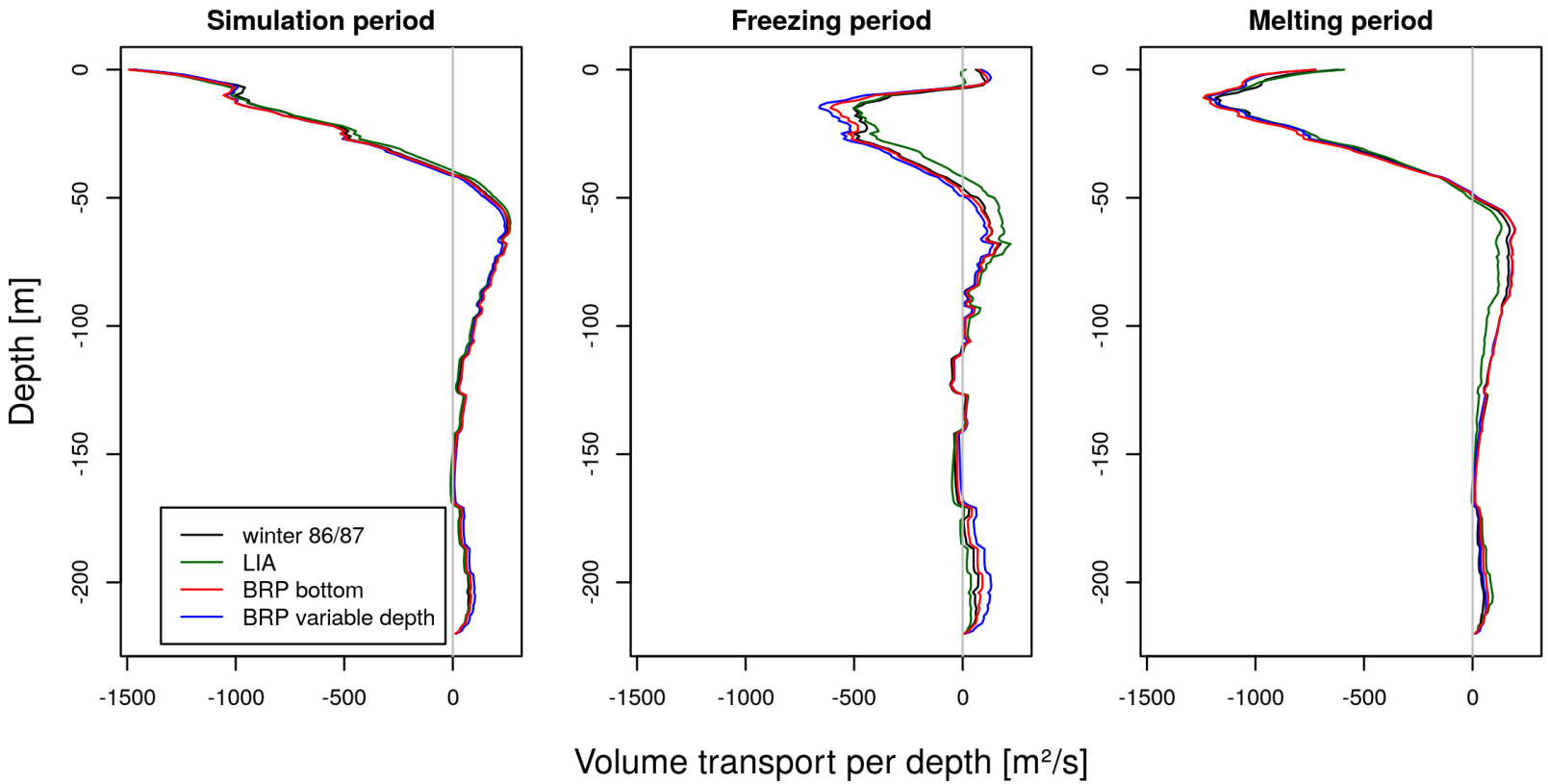
Landsort Deep tracer concentrations

Mean brine tracer concentration (Mar - Sep)



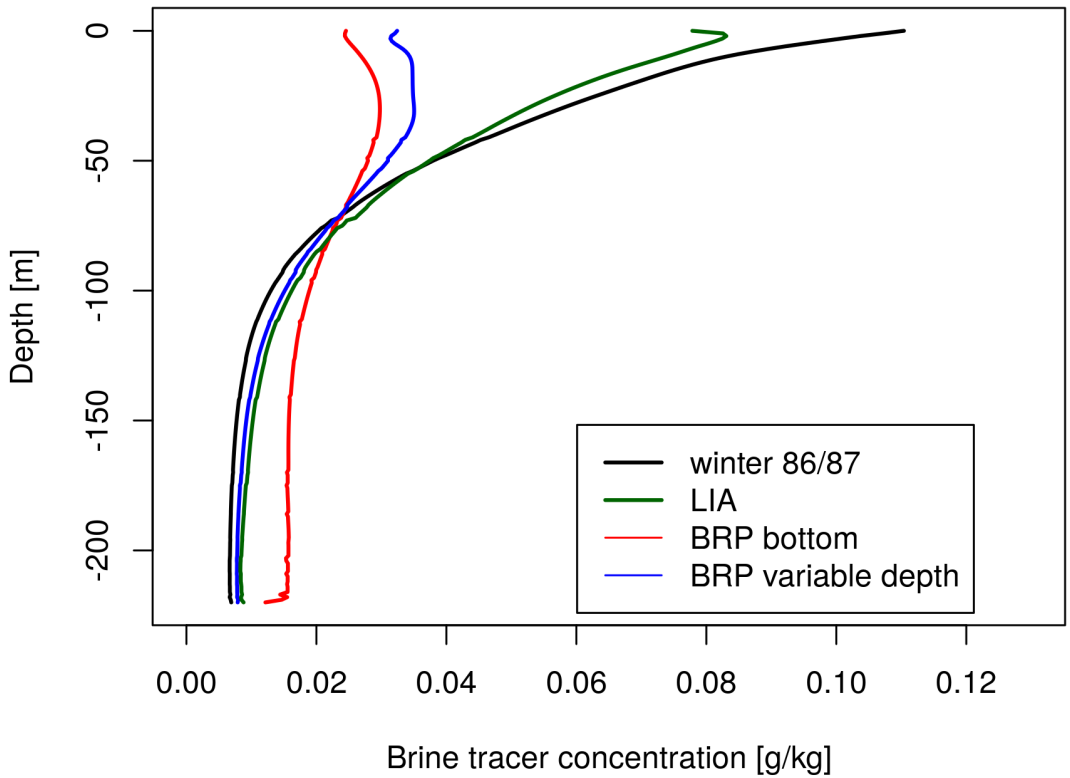
Transports through Aland & Archipelago Sea

Depth profile of volume transport



Transports through Aland & Archipelago Sea

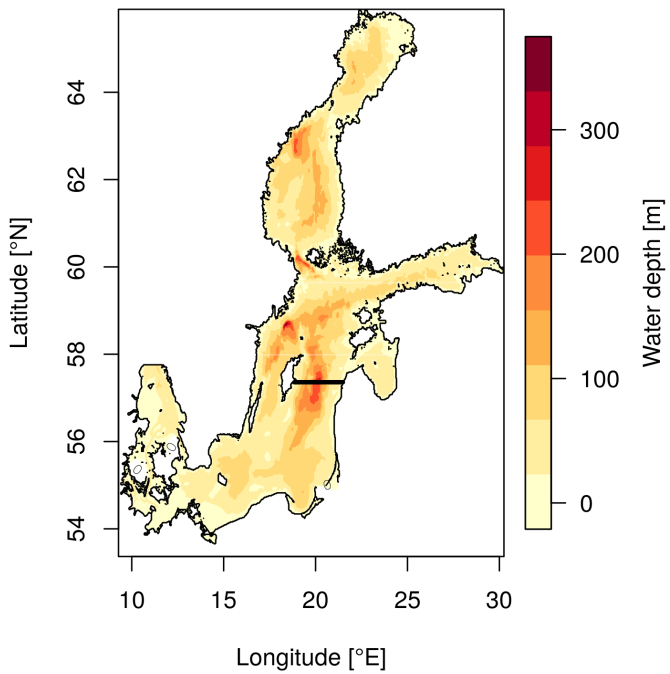
Mean brine tracer concentration

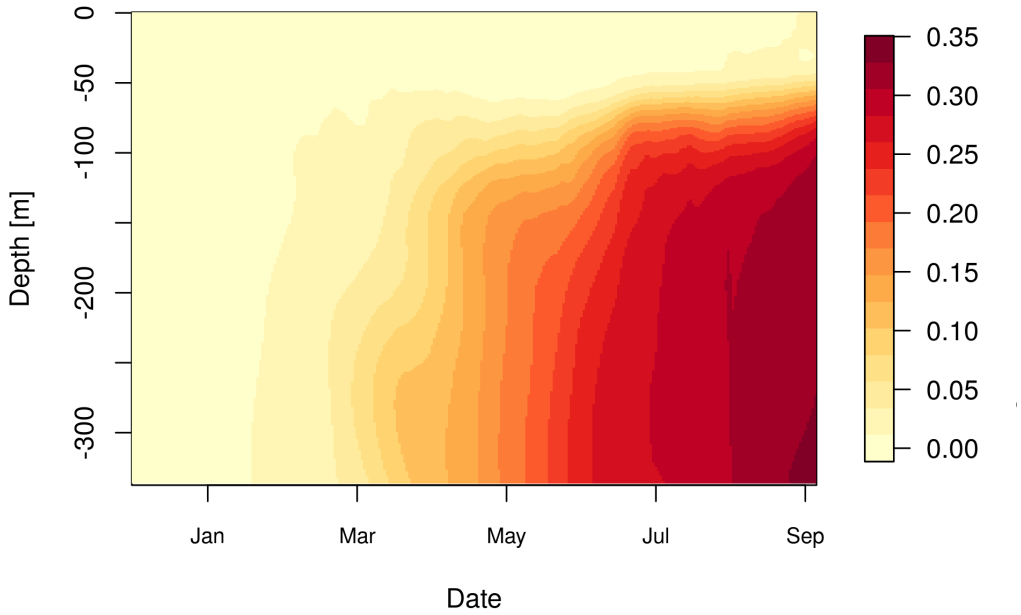


- Enhanced convection
- Lower tracer concentration in surface layer $\Rightarrow$ lower tracer transport

Source of Landsort Deep Water

- Tracer release depth: 70-120 m





Landsort deep water is formed in intermediate depths of Eastern Gotland Basin

Conclusions

- Within the GETM model: no evidence found for deep water formation in the Northern Baltic Sea ventilating the Baltic Proper/Landsort Deep $\Rightarrow$ classical estuarine circulation is maintained
- Brine rejection parameterization and LIA simulation lead to reduced tracer concentrations in the surface layer at Landsort because of increased convection
- Landsort deep water is formed in intermediate depths of Eastern Gotland Basin

But:

- Caution: Model has too strong salt water inflows / estuarine circulation
- Still possibility for brine induced small-scale bottom gravity currents through Western Aland Sea (?)
- Nevertheless: Brine rejection important process $\Rightarrow$ increased local winter-time convection in the Northern Baltic, seasonal signal in salinity profiles, estuarine circulation, ...