The Slupsk sill overflow
- Mixing hot spot of eastward spreading saline water

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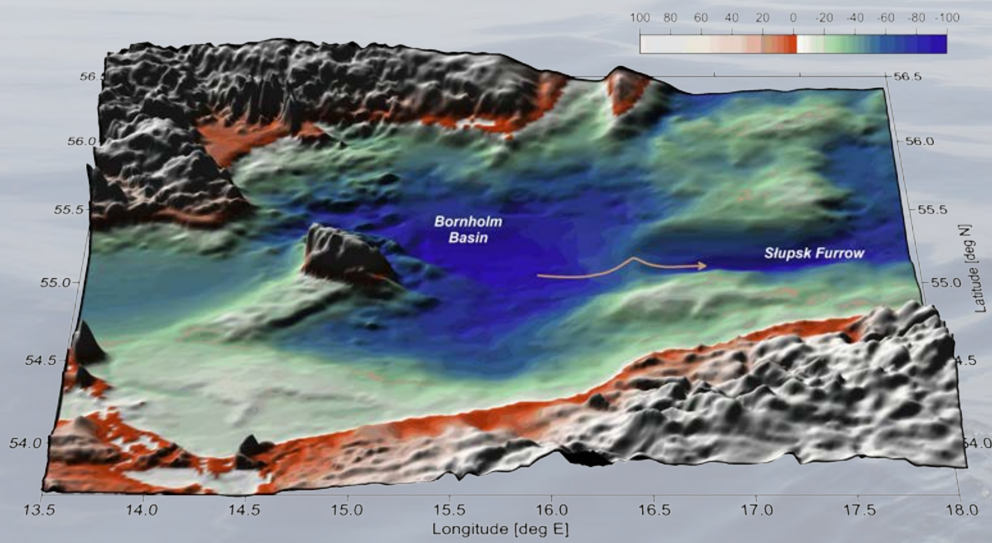

- Baltic overturn circulation
- Inflows of winter 2016/17
- Observations at Slupsk Sill
- Dynamics of the overflow
- Conclusions

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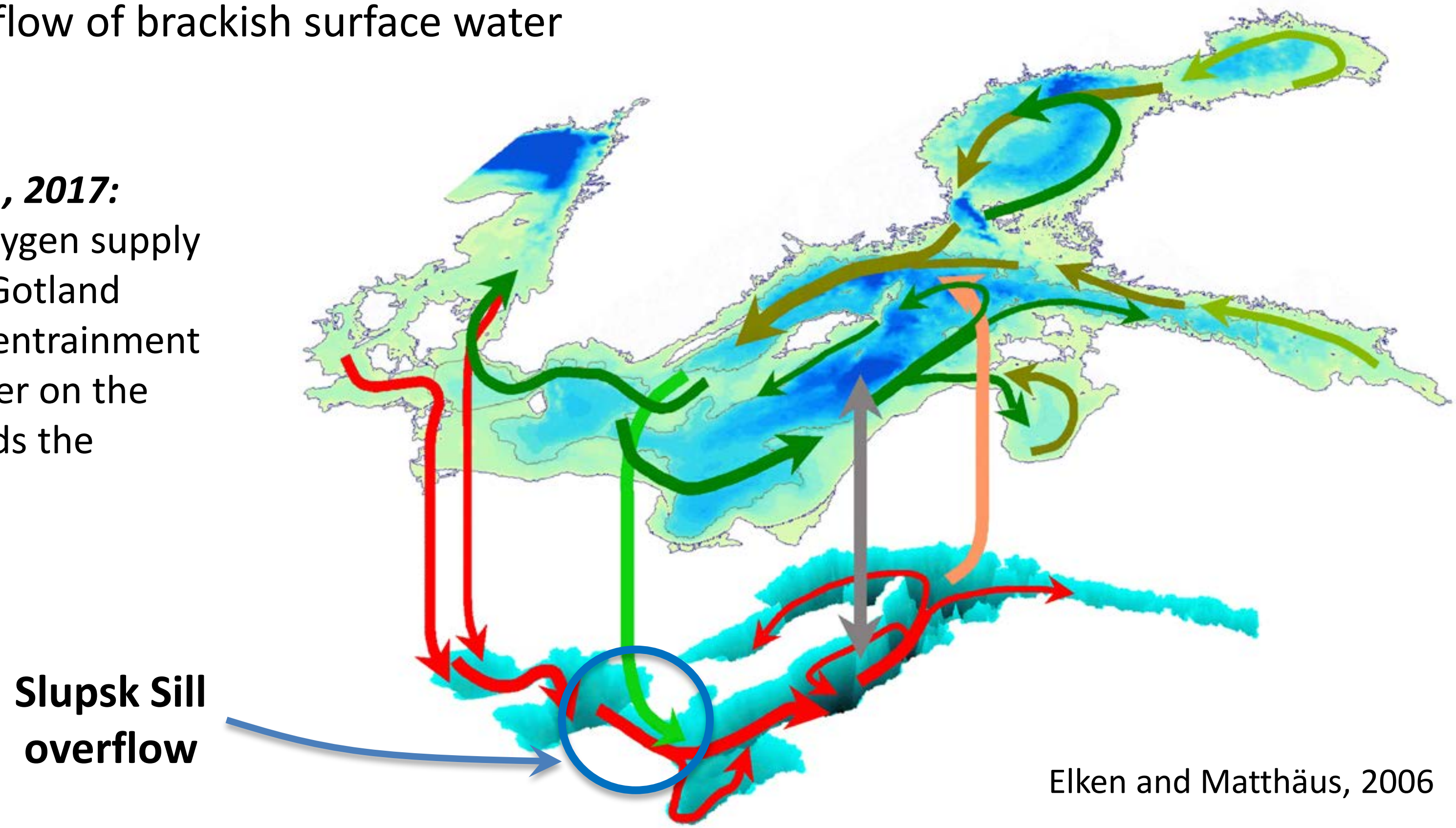
Baltic overturn circulation

- Inflow of saline water, and spreading along the thalweg
- Entrainment of ambient water into saline water flows, with reduction of density and entrainment of oxygen
- Upwelling and diapycnal mixing with low saline water
- Outflow of brackish surface water

Neumann et al., 2017:
up to 90% of oxygen supply to the eastern Gotland basin is due to entrainment of ambient water on the pathway towards the central Baltic

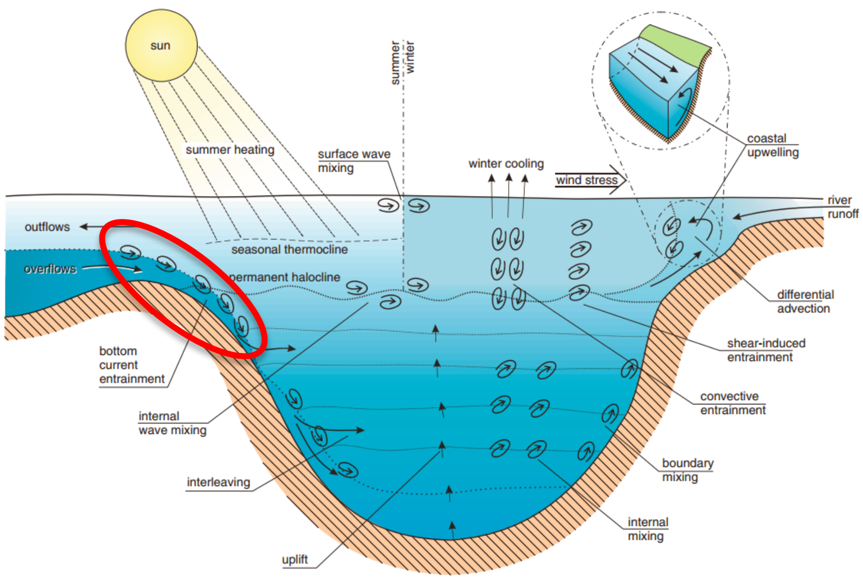


Elken and Matthäus, 2006

Hypothesis:

- **The entrainment into the saline bottom water flow occurs to a large extent on localized hot spots.**
- **The Slupsk Sill overflow is a mixing hot spot.**

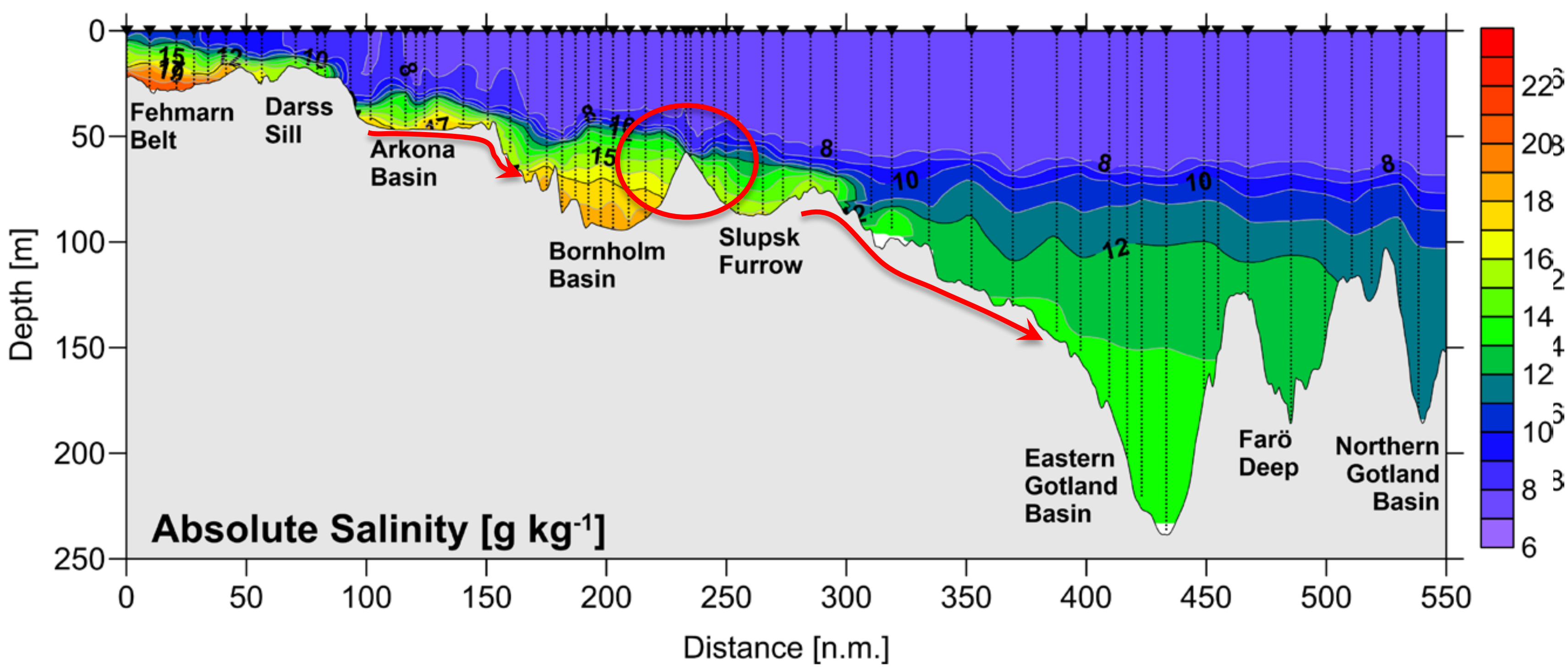
- Gravity flow north of Kriegers Flak (*Umlauf, Arneborg, …*)
- Gravity currents at Slupsk Sill and Furrow (*Zhurbas, Paka, Piechura, …*)
- Low mixing in the interior of Gotland Basin (*Holtermann*)
- Observations of mixing at the basin rims due to interaction with the topography (*Holtermann, Umlauf, …*)



(Reissmann et al., 2009)

General hydrographic situation in March 2017

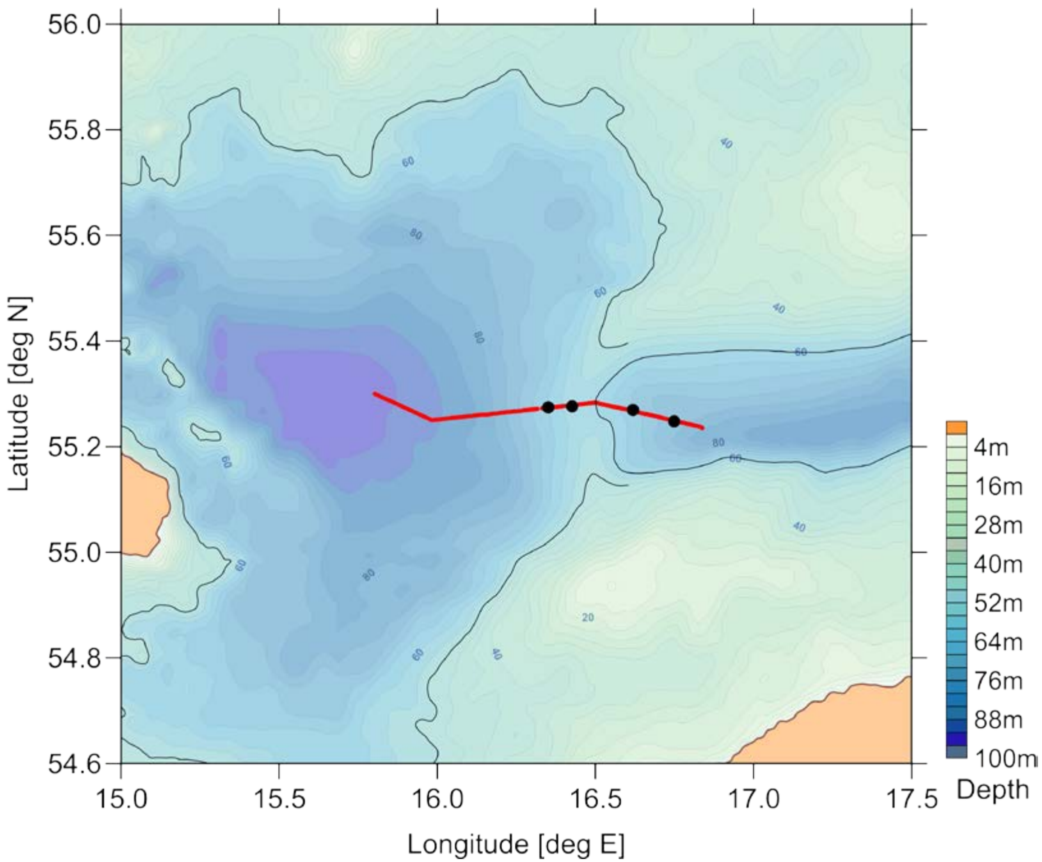
- Two minor barotropic inflows in Autumn (110km³) have reached the Bornholm basin, and passed the Slupsk furrow
- Puls like inflow into the eastern Gotland basin
- Inflow from February (68km³) shift the halocline water in the Bornholm basin eastward and lifts the halocline by 5 to 10m



Observations at the Slupsk Sill

24./25. March 2017

Concurrent observations of hydrographic parameters, TKE dissipation, and currents along a transect across the Sill.



- Microstructure profiler (MSS) equipped with an HR Aquadop
- VMADCP

- 290 single profiles with ca. 250m horizontal and 0.25m vertical resolution.
- Duration 20h

- ! No information about the transversal structure of the flow!

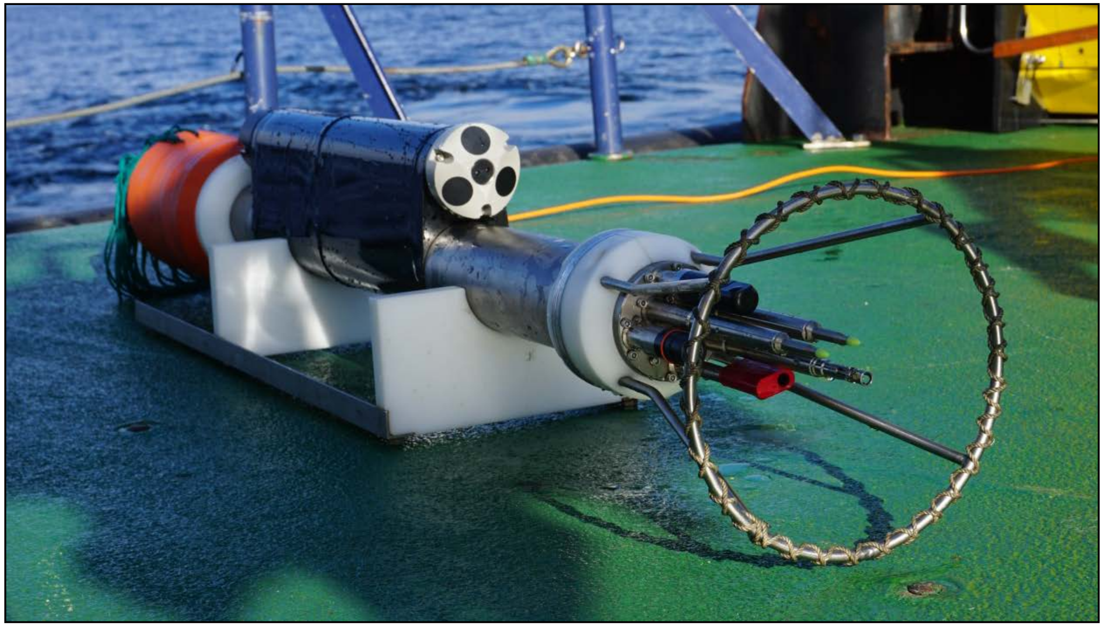
Estimation of local Richardson number

$$Ri = \frac{N^2}{\left(\frac{\partial u}{\partial z}\right)^2}$$

Ratio between stratification and current shear

Ri < 0.25 leads to shear instability

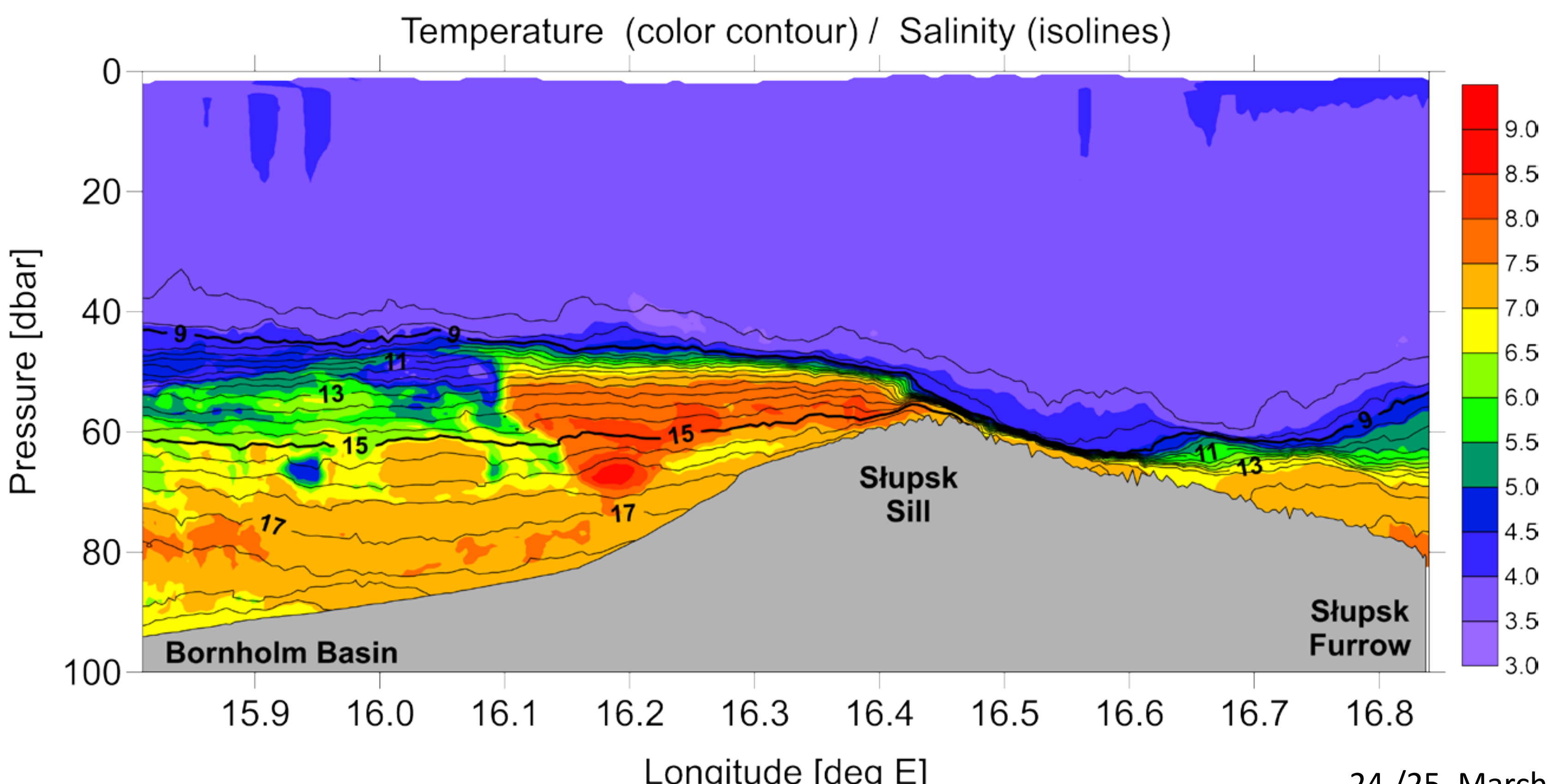
- Requires concurrent observations of hydrographic parameters, TKE dissipation, and current shear.



- Current profile length 2m
- Cell size 5cm
- Current velocity outside the specification range
- Only shear, no current velocity

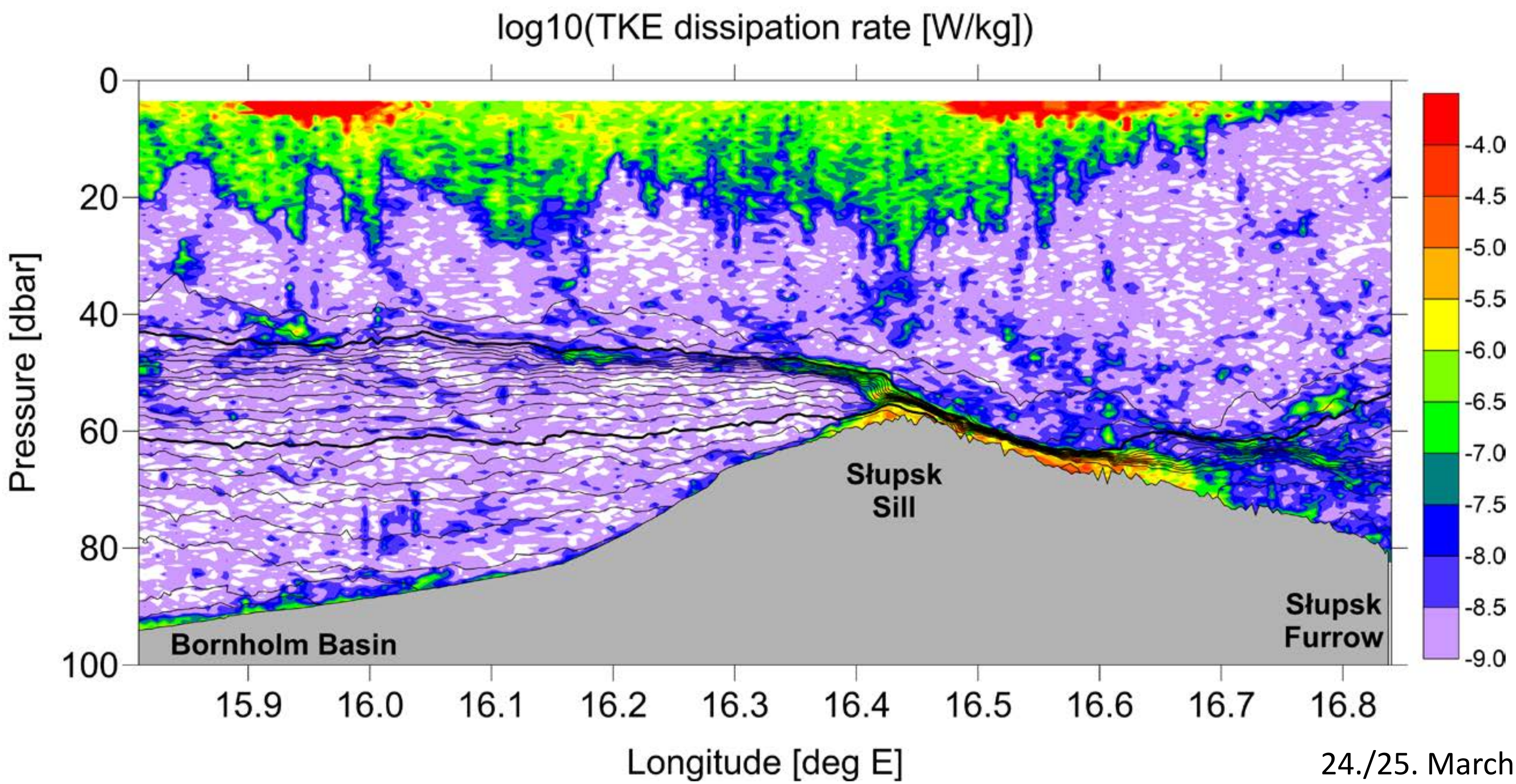
Stratification at the Stolpe Sill area

- High temperature variability in the BB due to the subsequent saline inflows.
- Strong halocline, 5 to 10m above the sill depth.
- Active sill overflow within a 3-4m thick saline bottom layer



TKE dissipation at the Stolpe Sill area

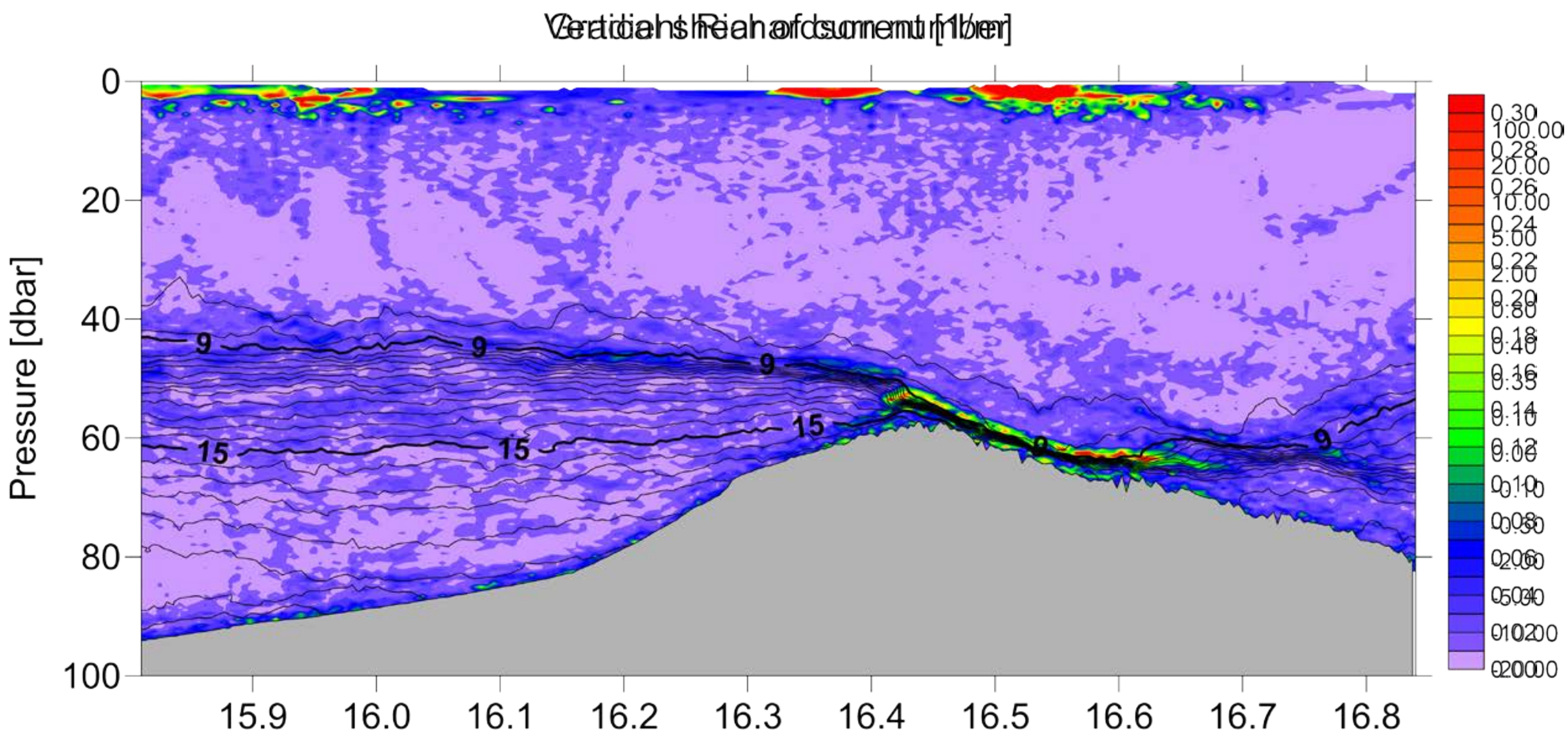
- Wind driven turbulence in the surface layer
- Weak mixing in the basin interior (TKE diss. close to noise level)
- Strong TKE dissipation inside the sill overflow



Shear and Ri-number at the overflow

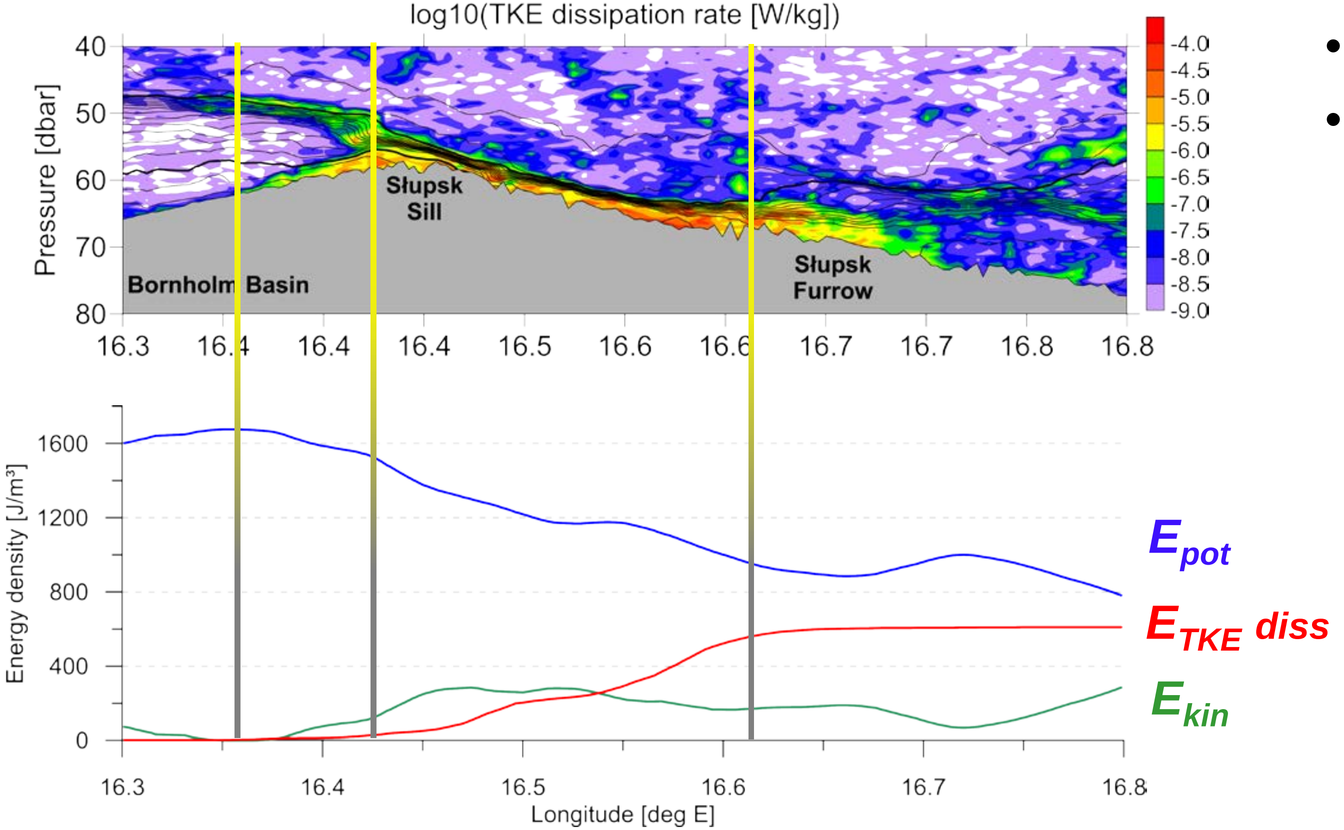
- Enhanced current shear at the halocline and along the bottom, with local maxima in the overflow
- Ri < 0.25 in the surface and the boundaries of the overflow

$$Ri = \frac{N^2}{\left(\frac{\partial u}{\partial z}\right)^2}$$



Energy budget estimations

$$E_{pot}(x) + E_{kin}(x) + \underline{E_{TKE}(x)} + \int_{x0}^{x} \frac{\partial E_{TKE}(x)}{\partial t} dt = const$$

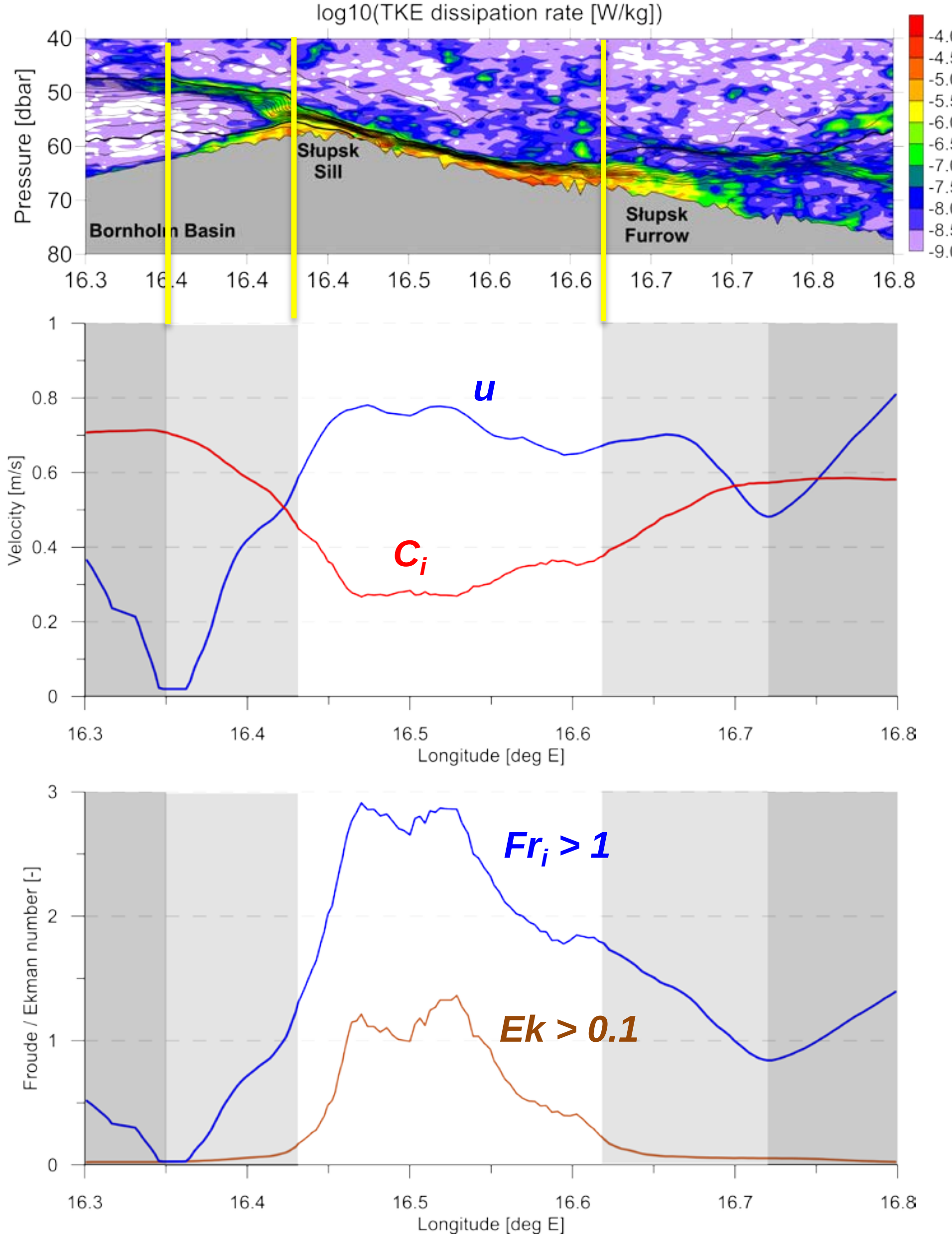


- Energy density
- The magnitude of TKE dissipation compares to the loss of potential Energy.

Estimation of current velocity and speed of internal waves

$$Fr_i = \frac{u}{\sqrt{g' h_e}} \qquad Ek = \frac{\nu}{f D^2}$$

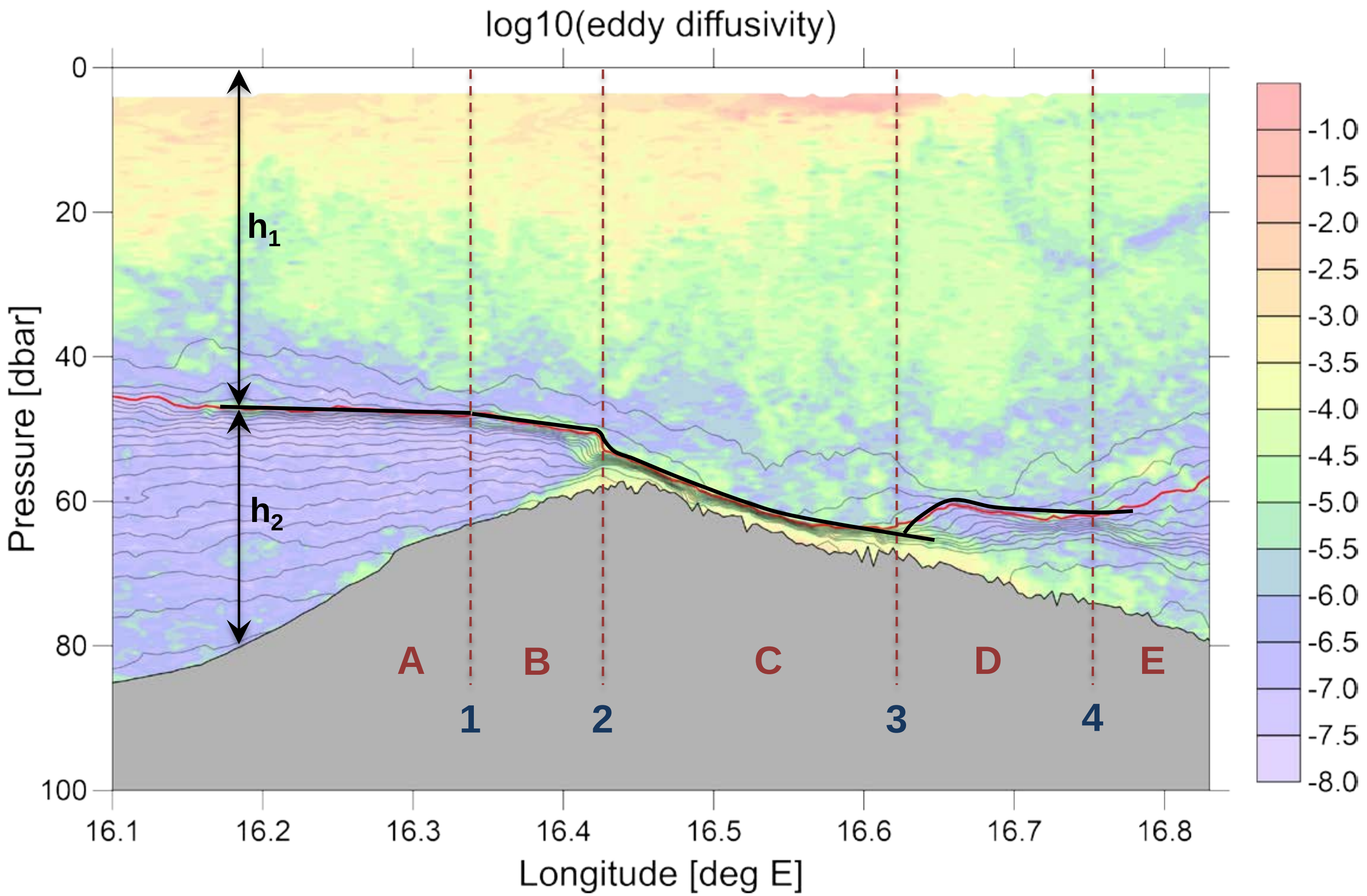
- Flow velocity estimated from the kinetic energy
- Supercritical flow on the downstream side of the sill
- The supercritical flow is dominated by the eddy viscosity



Sketch of the over flow dynamics

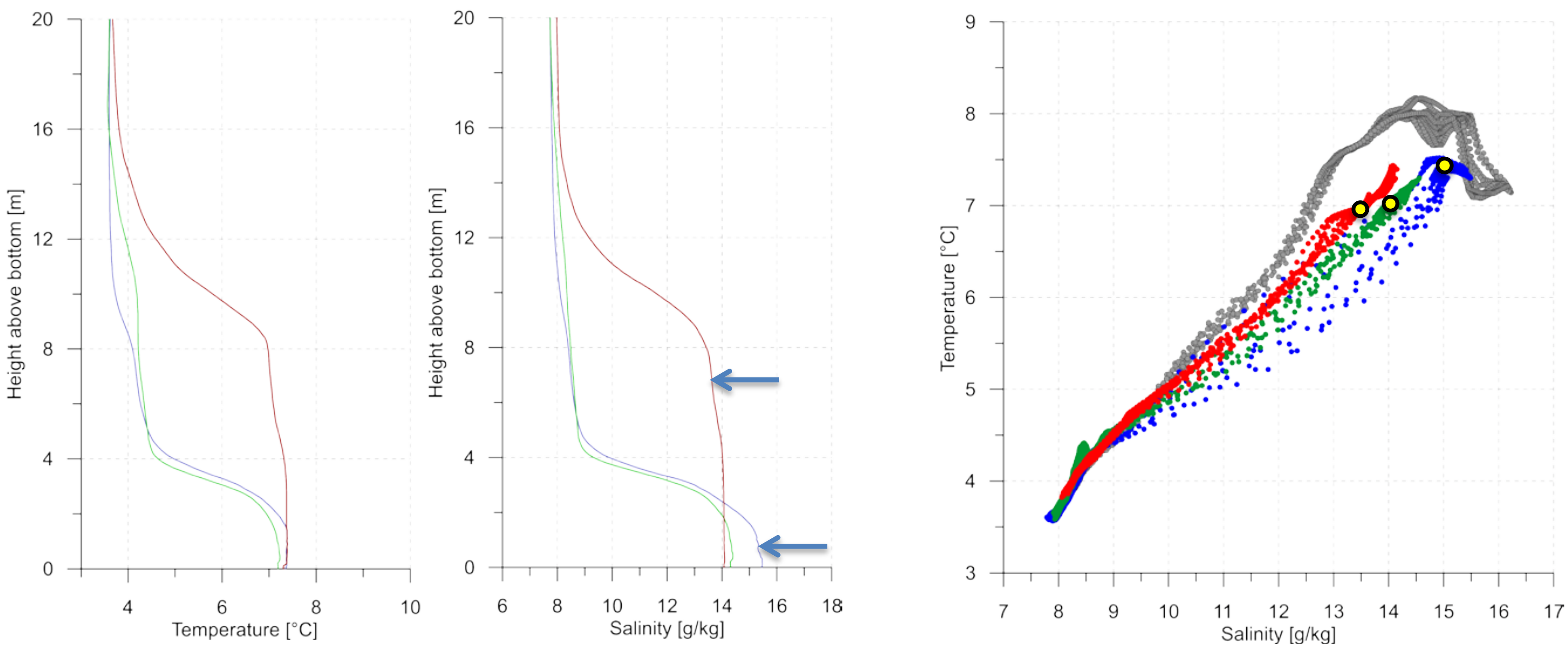
Two layer model,
layer separation at salinity of 9.5 g/kg

B: acceleration area
C: supercritical overflow
D: internal hydraulic jump



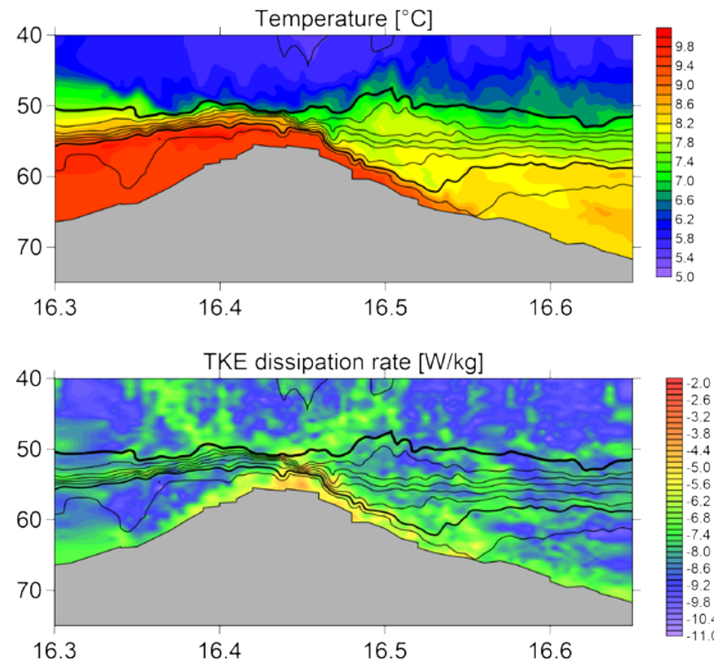
Entrainment of ambient water into the flow

- Decrease in salinity of inflowing saline water from 15 to 14 g/kg in the supercritical flow.
- Further dilution to 13.5 g/kg in the internal hydraulic jump.
- Entrainment of appr. 18%, and 12% ambient water respectively



Open questions

- **How often exists a supercritical overflow? What are the necessary preconditions?**
  - Subcritical overflow observed by *Zhurbas et a., 2012* → higher impact of earth rotation
  - Observations from January 2016 (*Mohrholz and Naumann*)



- **What is the transversal structure of the supercritical flow and the internal hydraulic jump?**
- **What are the implications for numerical models?**

Summary

- The overflow at Słupsk Sill is one of the mixing hotspots along the pathway of saline water towards the central Baltic.
- TKE dissipation rates at the Sill (10^{-5} W/kg) exceed the TKE dissipation in the adjacent Bornholm Basin and Słupsk Furrow by two orders of magnitude.
- The observed overflow at the Słupsk Sill was hydraulically controlled. It consists of a super critical flow followed by an internal hydraulic jump.
- Mixing and entrainment at the super critical part can be attributed to generation of shear instabilities between the inflowing saline water and the overlaying water. At their interface the estimated gradient Richardson number is well below 0.25.
- The total entrainment of ambient water into the inflowing saline water at the Słupsk Sill was estimated with about 30% of the inflow volume.

Additonal parameters

- Strong halocline, high eddy diffusivity and enhanced turbidity
- VMACDP supplied no data inside the overflow