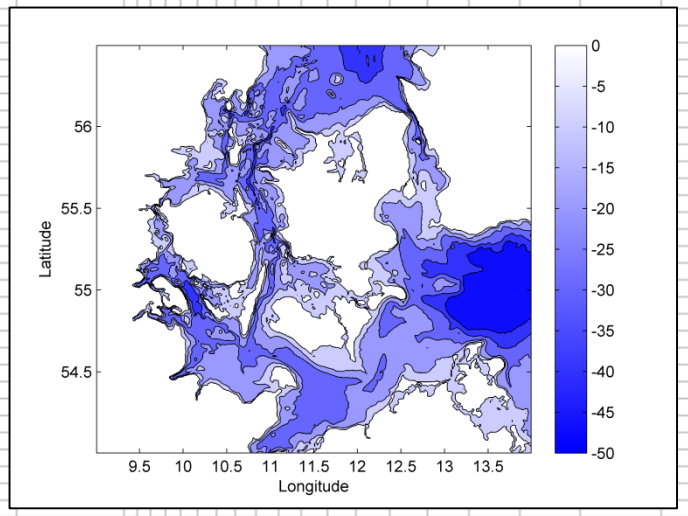
Lars Arneborg, Department of Research and Development, oceanography, SMHI

Analysis of factors influencing the salinity of Baltic inflows and how these may change with sea level rise



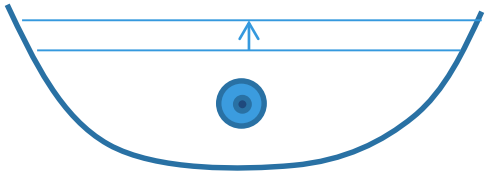
Sea level rise causes increased inflows of saline water

- Hordoir et al. 2015: Increase is larger than what can be explained just by increasing barotropic currents.

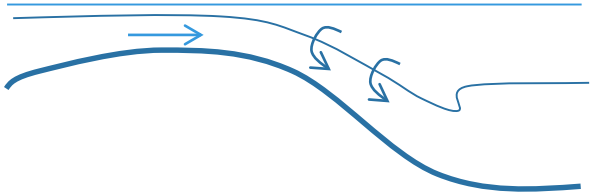
- Meier et al. 2017: Increased inflows causes more stable stratification, which worsens the eutrophication problems.

Why does inflow of saline water increase with a rising sea level?

- Increasing cross-sectional area -> larger volume fluxes (Meier et al. 2017)

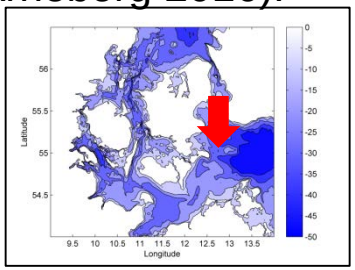


- Reduced entrainment (Hordoir et al. 2015)

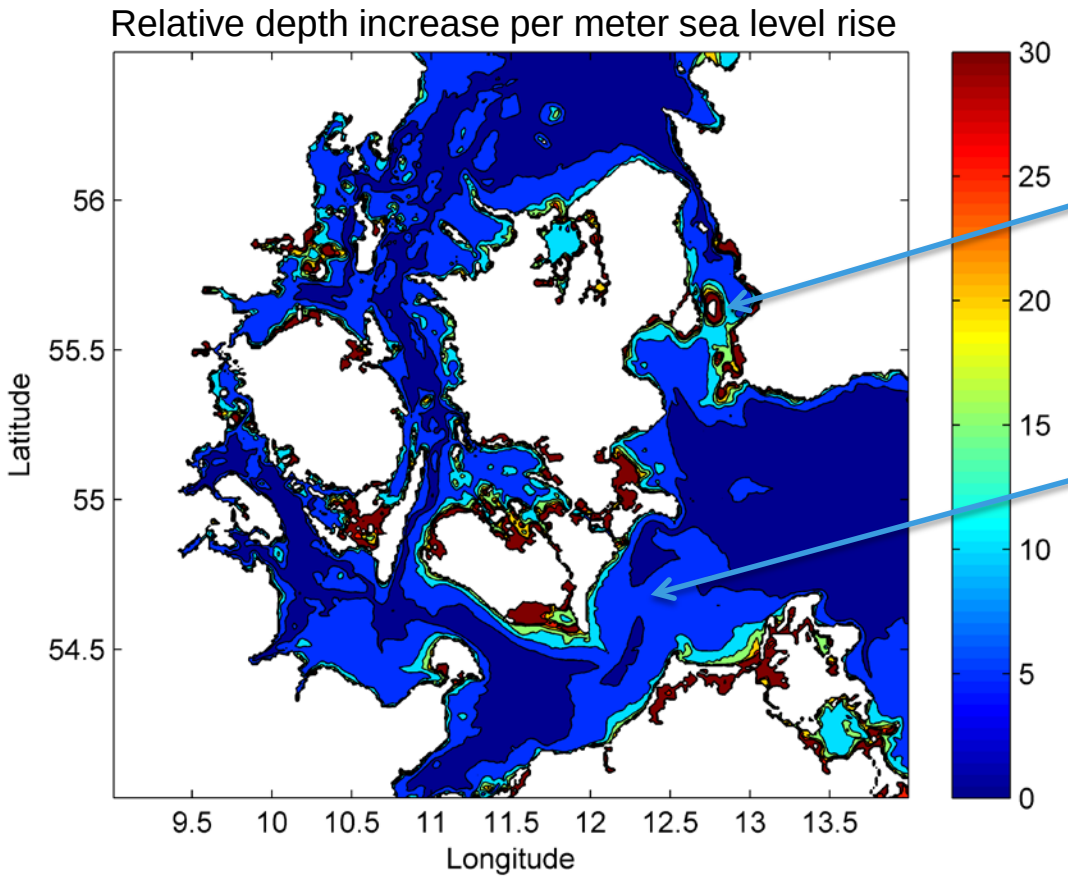


Note: This increases the inflow salinities without increasing the inflow of new water.

- Increase of barotropic volume fluxes in the Sound -> larger overflows of saline water over the Drogden sill (Arneborg 2016).



Arneborg (2016): Barotropic volume fluxes will increase in the Sound and remain relatively undisturbed in the Belt Sea.



Drogden sill: h ≈ 8 m

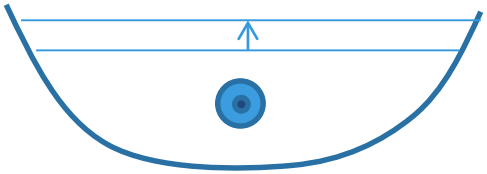
$$\frac{\Delta h}{h} \approx 13\%$$

Belt Sea: h ≈ 20 m

$$\frac{\Delta h}{h} \approx 5\%$$

Why does inflow of saline water increase with a rising sea level?

- Increasing cross-sectional area -> larger volume fluxes (Meier et al. 2017)



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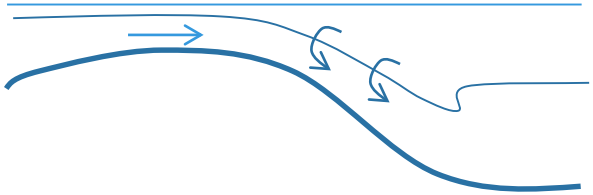

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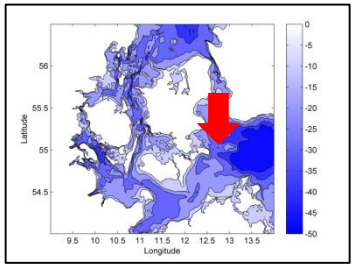
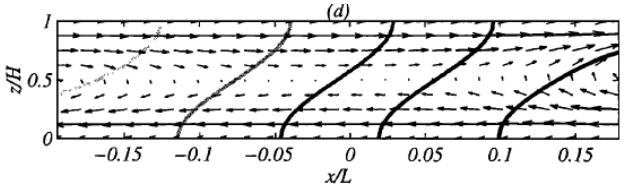


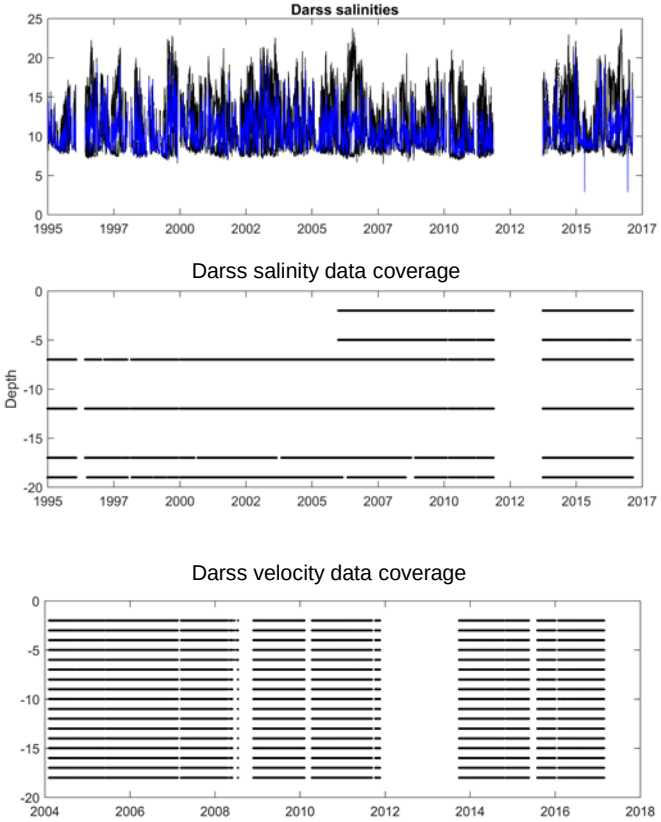
- Increased baroclinic flows?

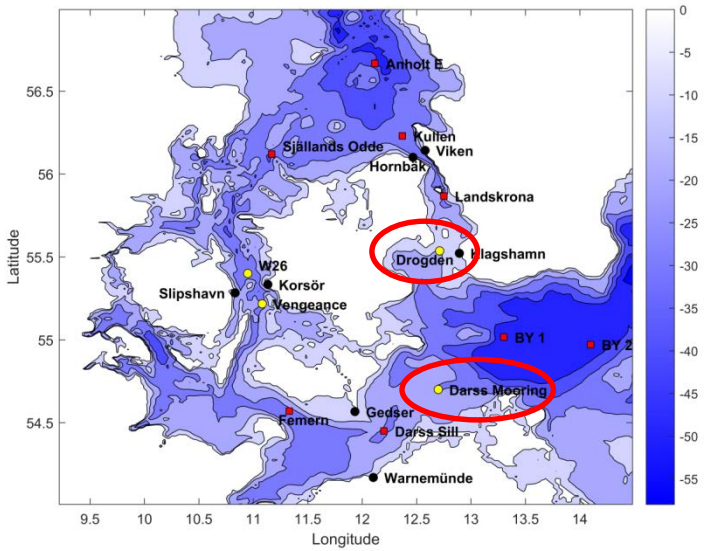


Hogg et al. (2001)

Observations

Darss sill station

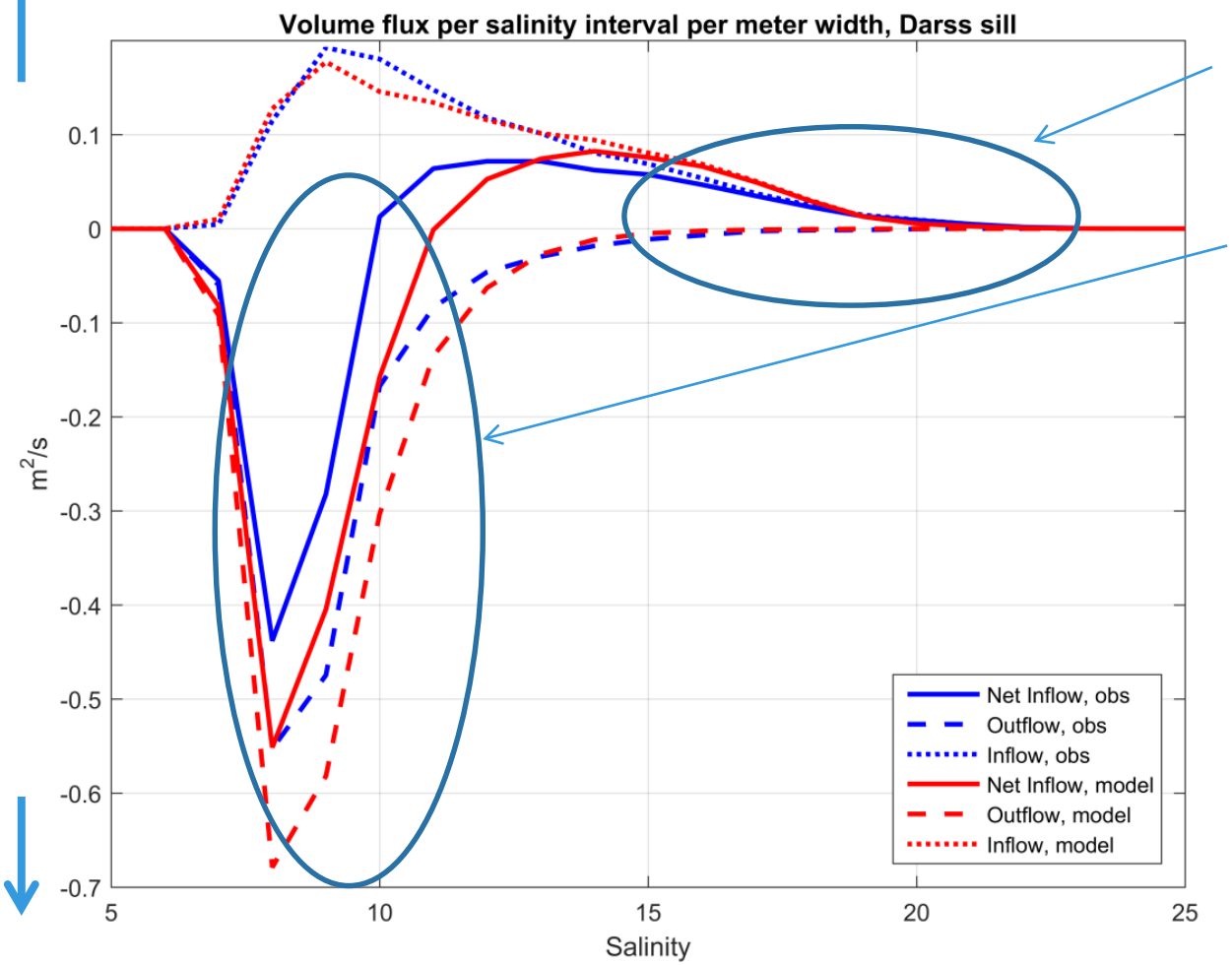




Data downloaded from CMEMS data base

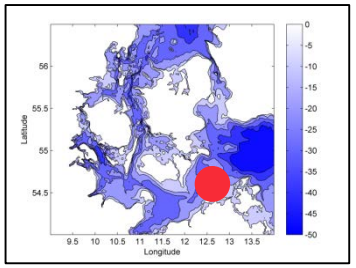
Validation, NEMO-Nordic 2nm, Darss sill

Inflows



Outflows

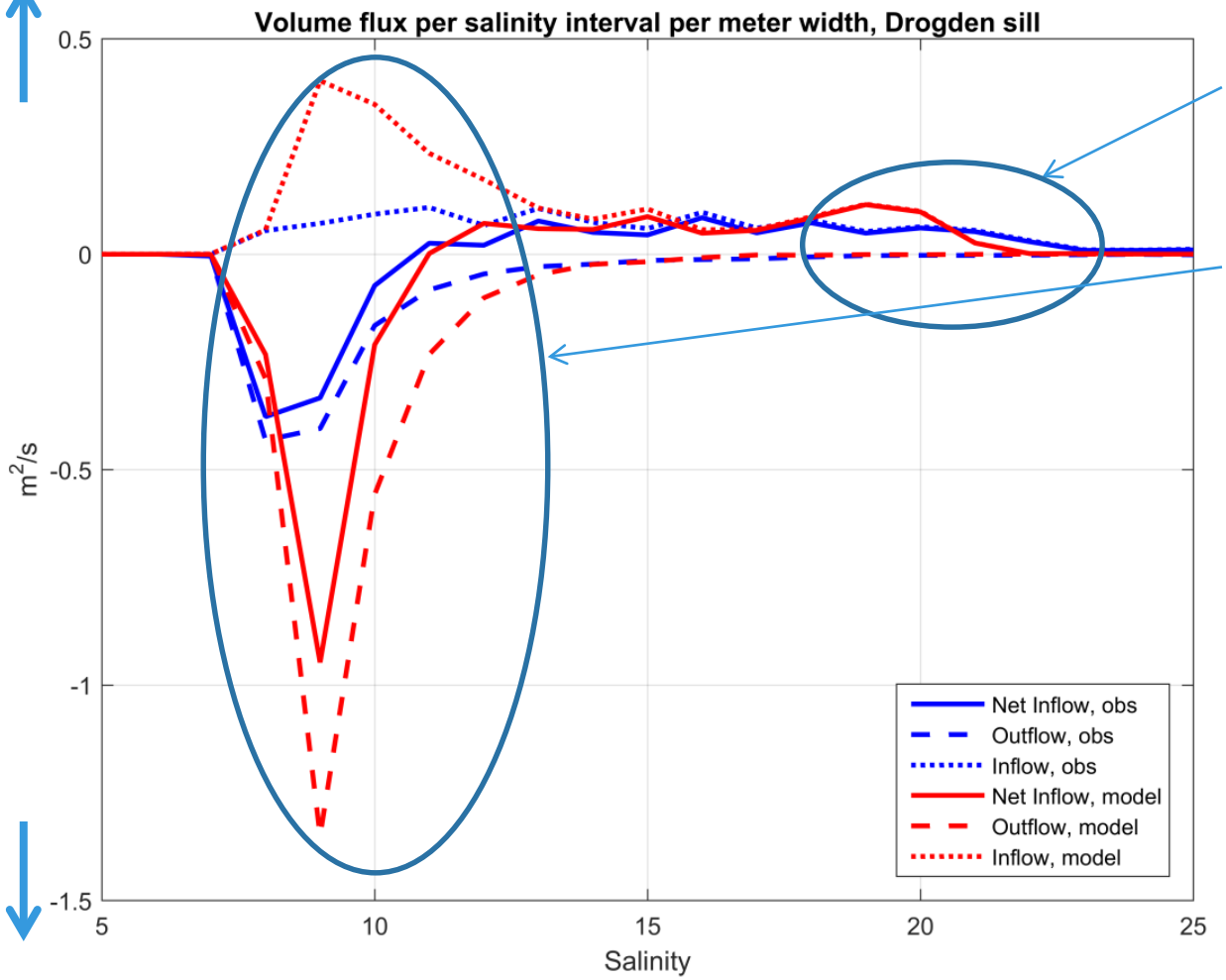
- Somewhat too large inflows for S<19 and too small for S>19
- Outflows are too large and happen at a too high salinity.



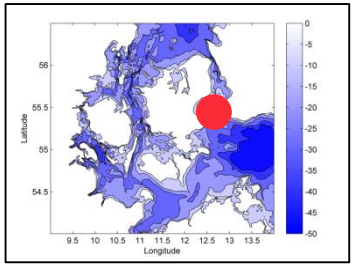
Validation, NEMO-Nordic 2nm, Drogden sill

Inflows

Outflows

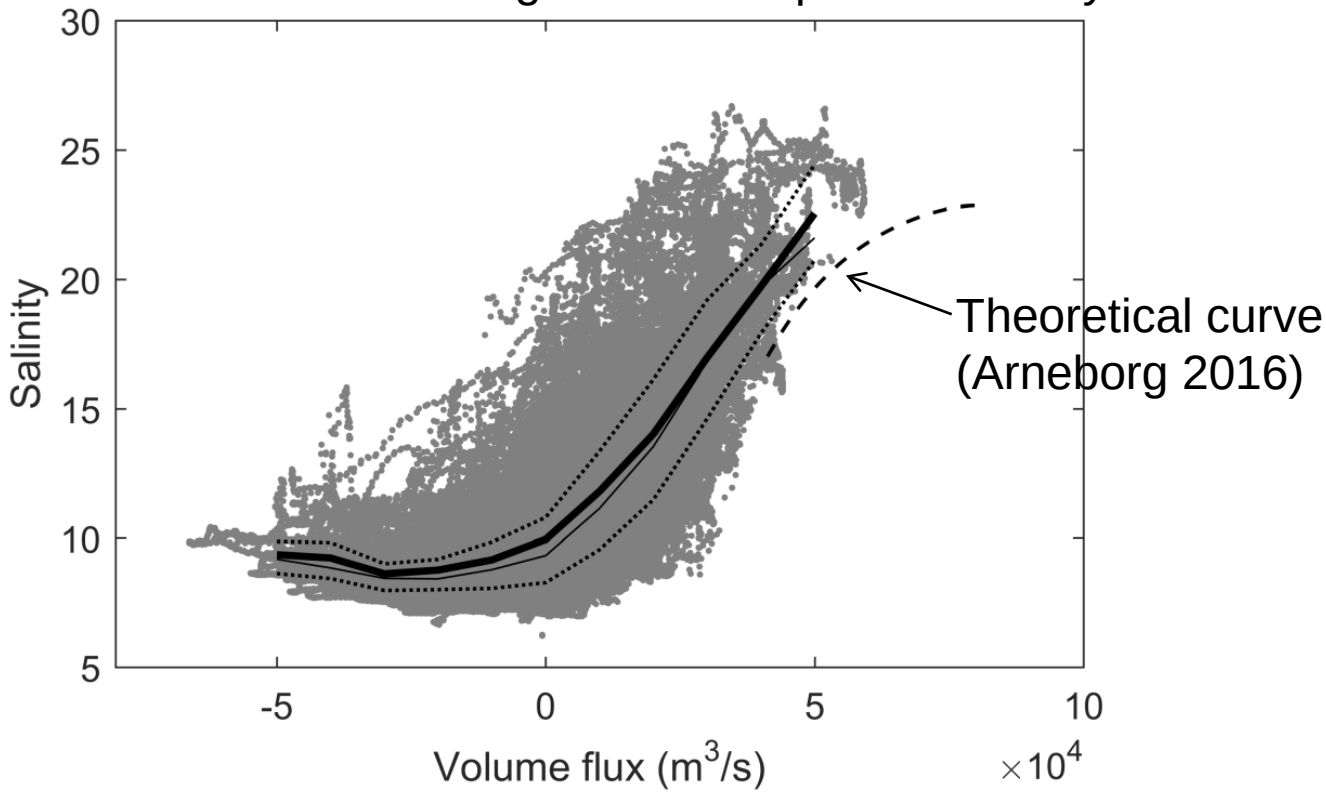


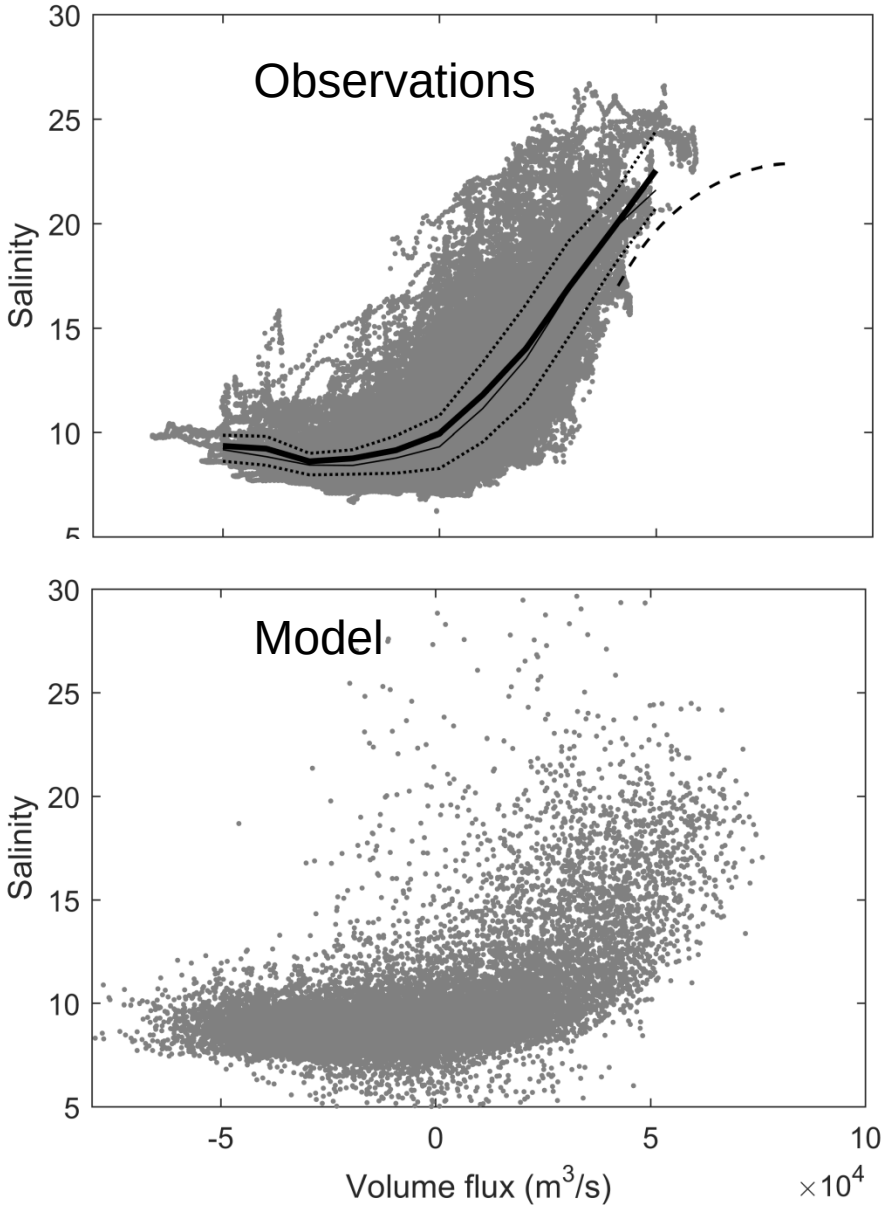
- Somewhat too large inflows for S<21 and too small for S>21
- In- and outflows are too large for 9<S<12.



Observations (Drogden sill)

Salinity over the Drogden sill vs barotropic volume flux averaged over the previous 3 days.

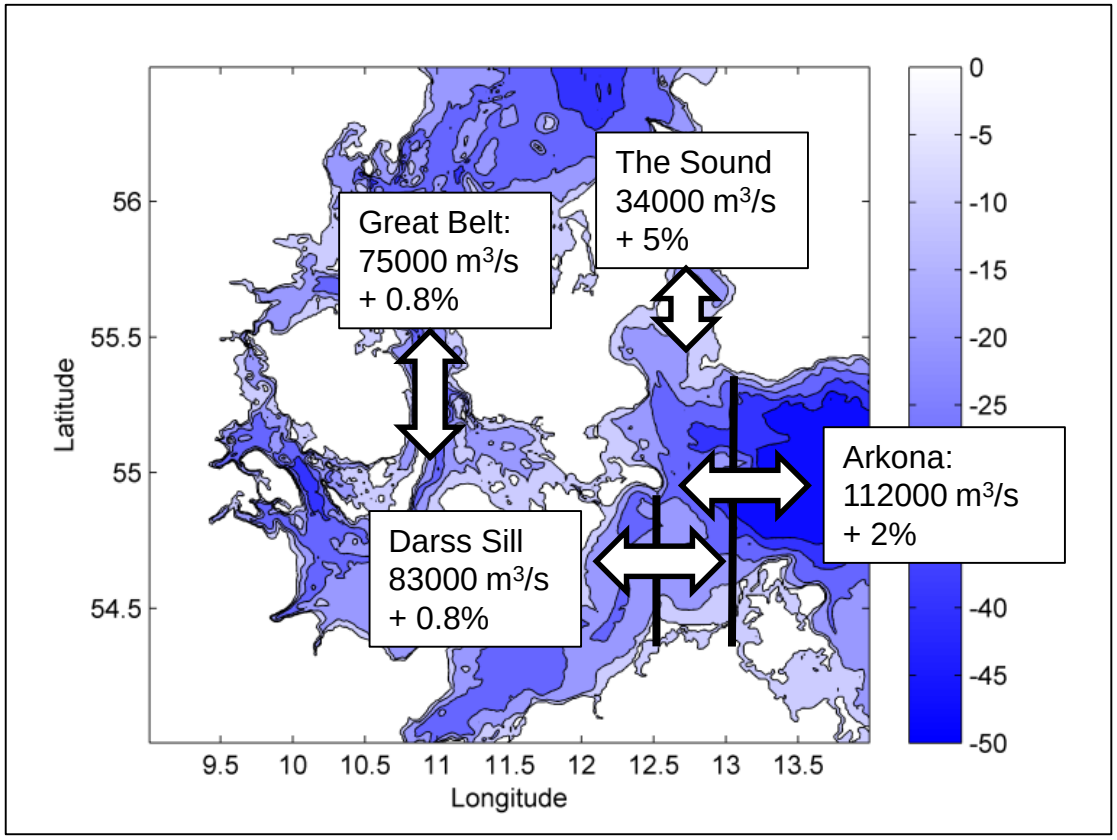




Model validation, Drogden

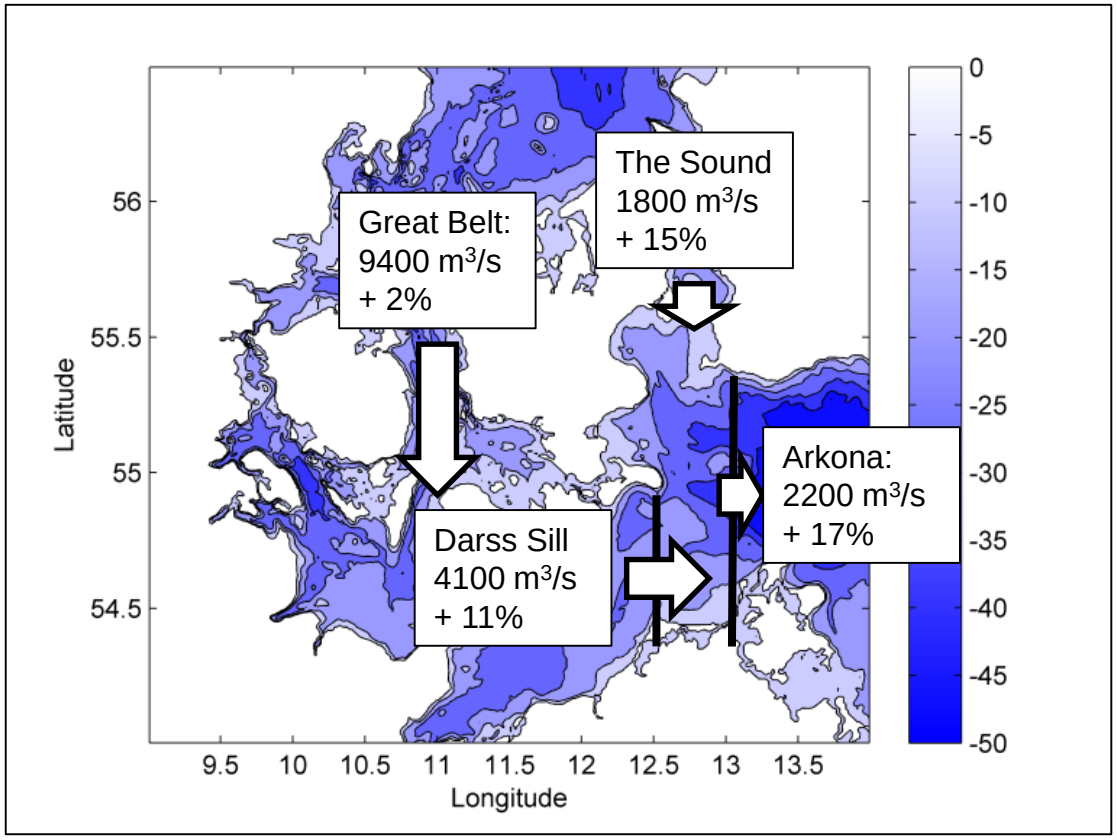
- Large model salinities tend to be smaller than observed and occur at larger barotropic inflow volume fluxes.

Barotropic fluxes (std), and changes with sea level rise:



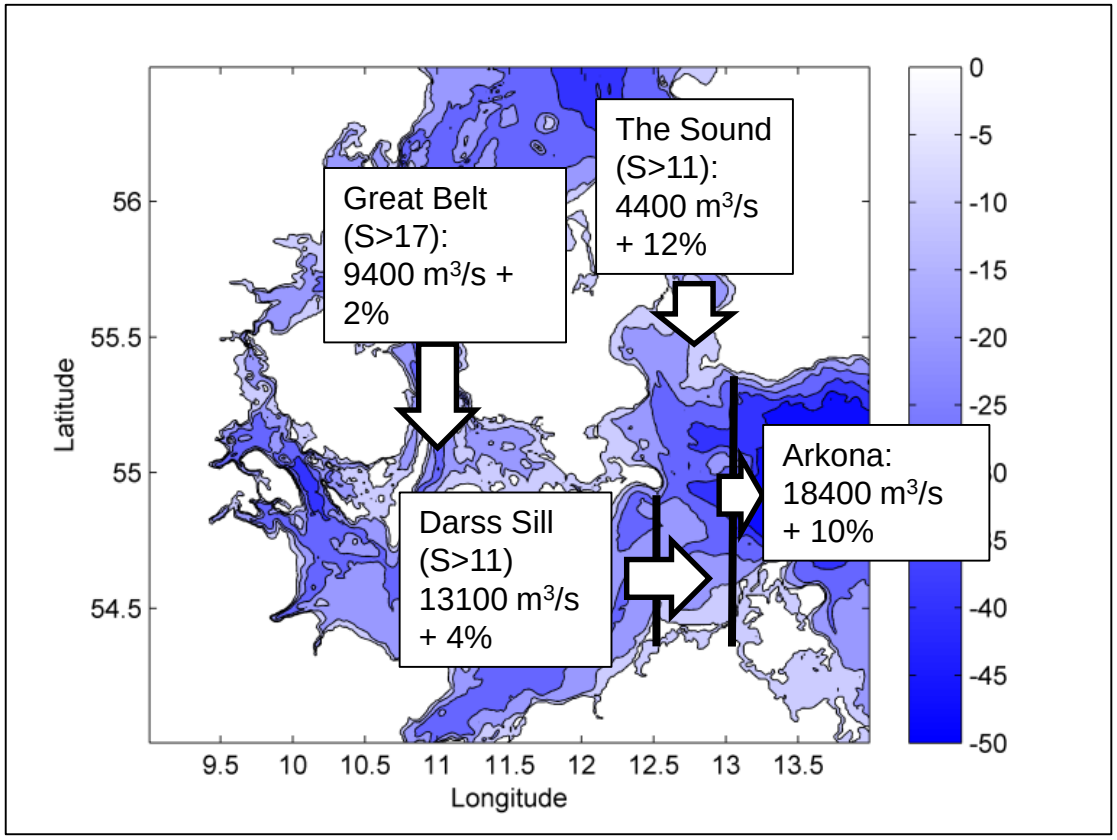
- Barotropic fluxes increase mainly over the Drogden sill (the Sound).

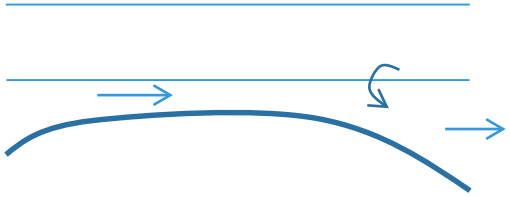
Inflow of water with S>17 and increase with 1.5 m sea level rise:



- Entrainment over the S=17 isohaline decreases with rising sea level.
- Entrainment decreases both in the Belt sea and inside the sills.
- Overflow of ”new” dense water mainly increases over the Drogden sill.

Inflow of water with S>11 over the sills and S>17 in the Great Belt + increase with 1.5 m sea level rise:





- Entrainment over the main halocline decreases marginally
- The main increase in inflows with S>11 is caused by increased overflows over the Drogden sill.

Summary

- Model results support theory in that sea level rise mainly influence barotropic flows in the Sound, whereas those in the Belt Sea remain nearly unchanged. This is due to the relatively larger decrease in friction in the Sound relative to the Belt Sea. *This also means that baroptropic velocities in the Belt Sea tend to decrease with rising sea level*.

- The model reproduces observations relatively well at the Darss sill. At the Drogden sill, the model is not as good.

- The processes controlling overflows in the Sound are not well known.

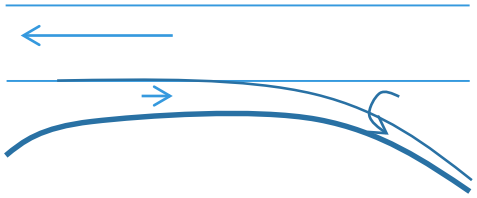
- According to model results, inflow of water with S>17 increases both due to decreased entrainment and due to larger flows through the Sound.

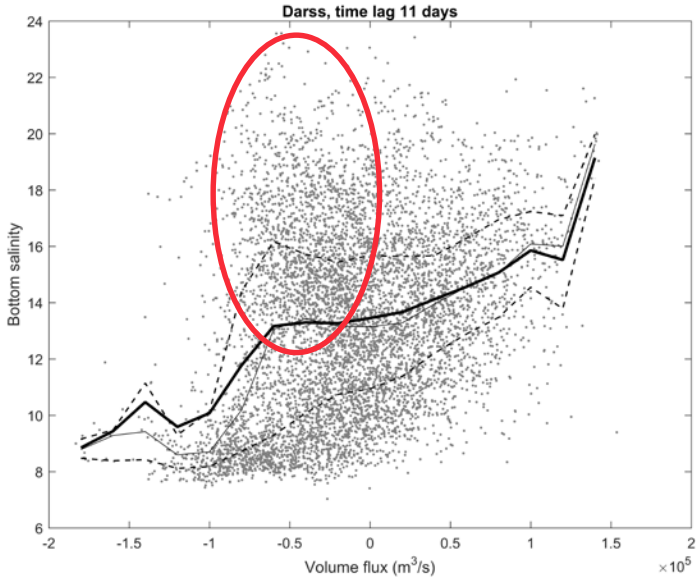
- According to model results, inflow of water with S>11 increases mainly due to increased overflows in the Sound.

Discussion

- How high resolution is needed in order for models able to describe the processes that controll overflows in the Sound?

- What about baroclinic exchanges? Observations show that bottom layer inflows happen in the Belt Sea even at rather strong outflows. Is this properly described in the models?

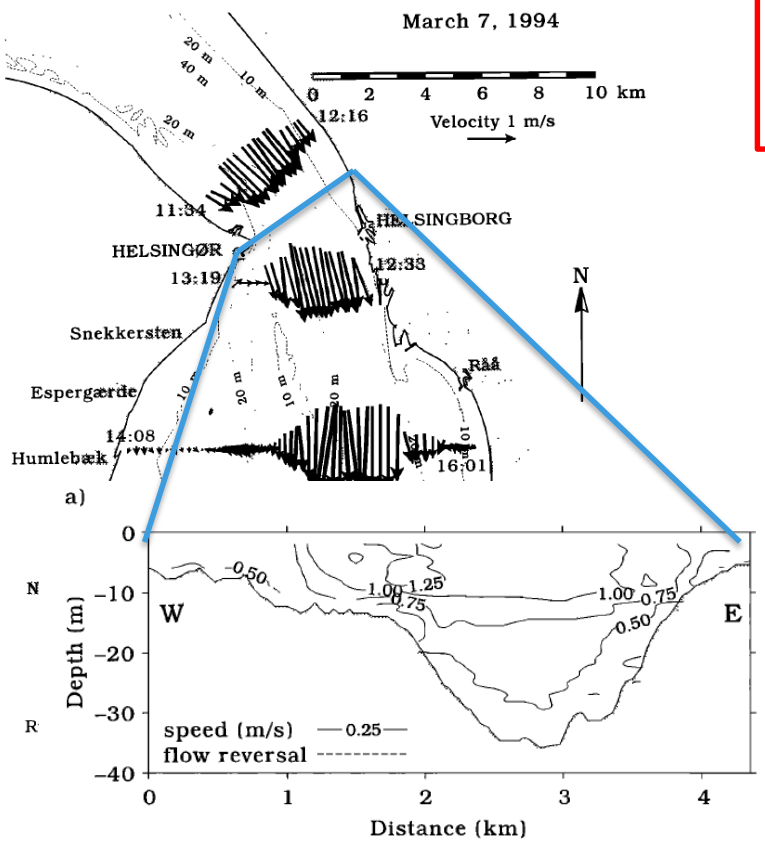




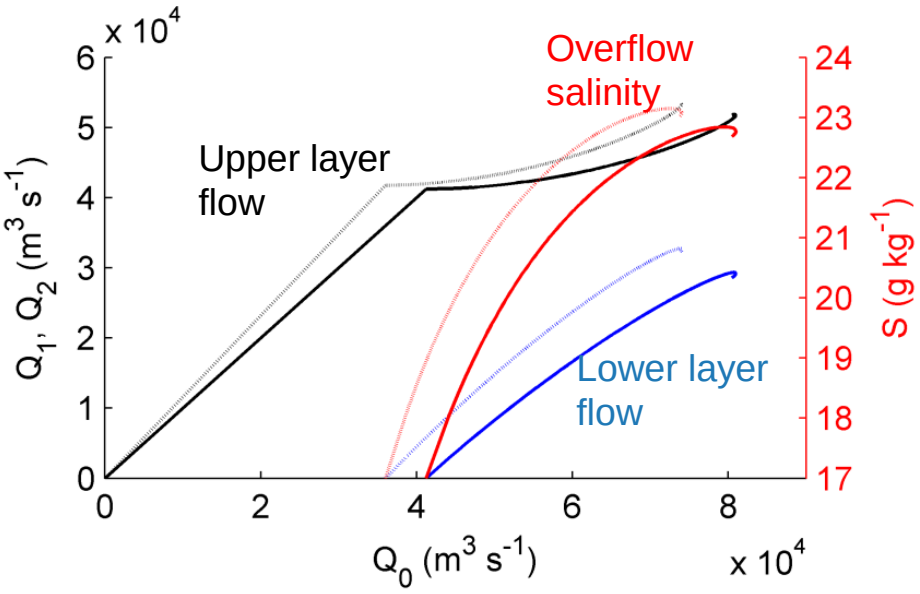
Thanks!

Do internal hydraulics control the flow of lower layer water in the Sound? (Arneborg 2016, Nielsen 2001):

Controlled flow: $G^2 \equiv \frac{{U_1}^2}{g'h_1} + \frac{{U_2}^2}{g'h_2} = 1.$



Nielsen 2001



Barotropic inflow strength

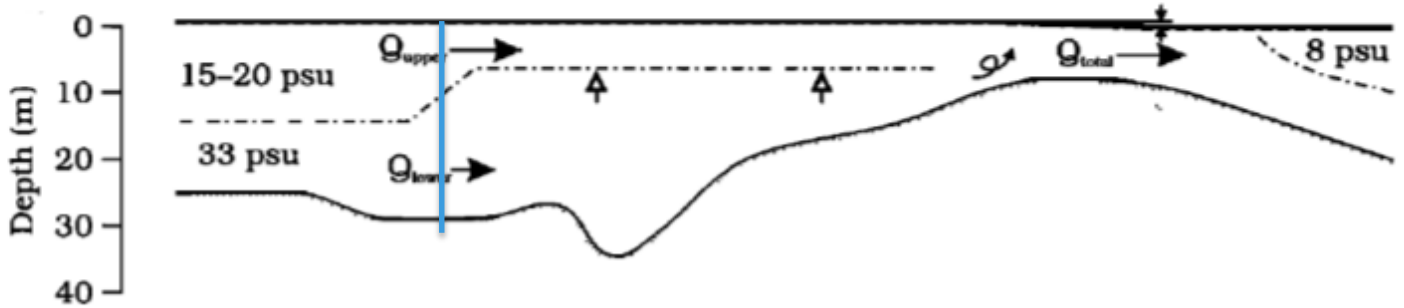
Arneborg 2016

Two-layer flow through the Sound

Weak barotropic inflows (G < 1):

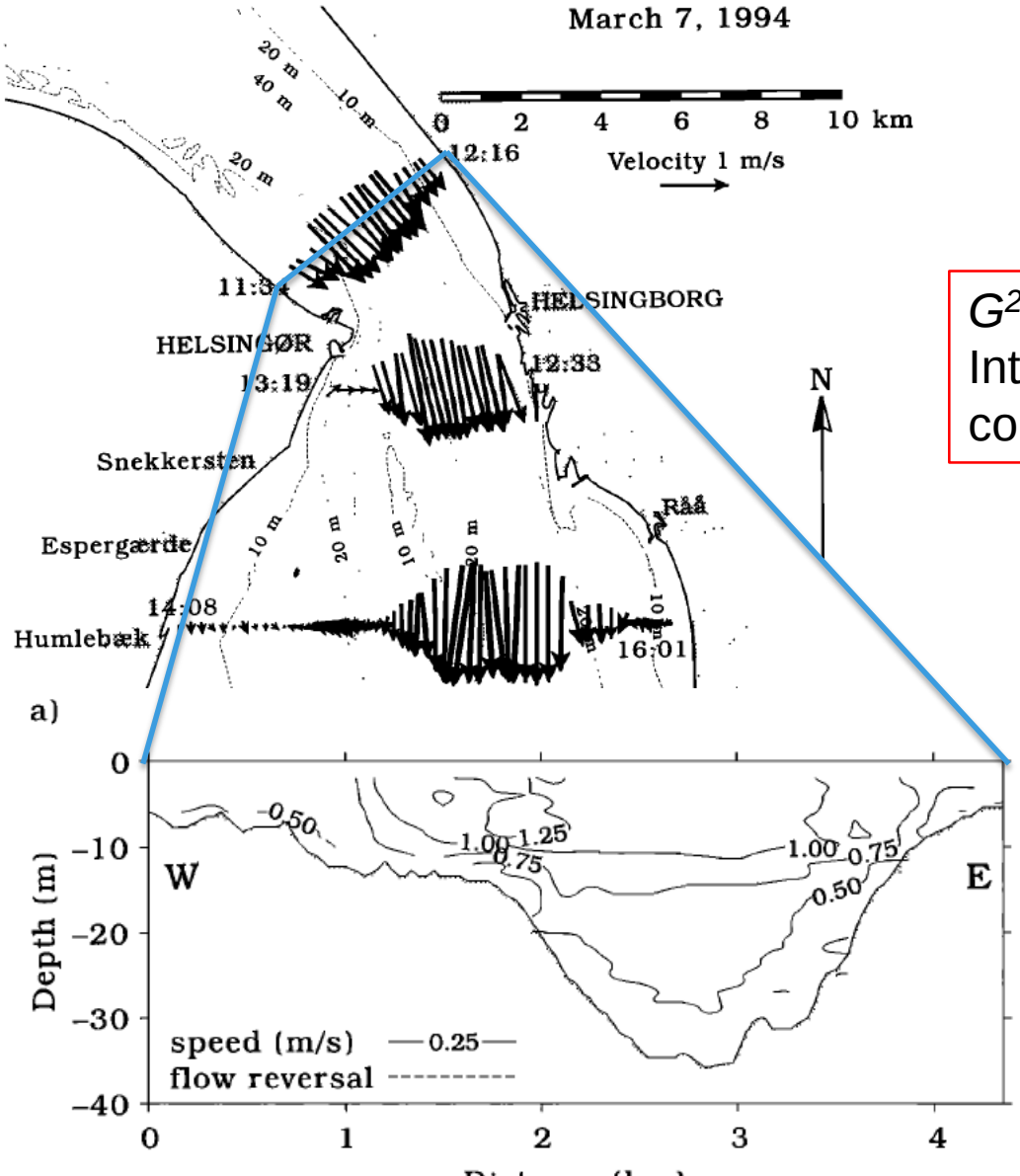
Internal waves can propagate upstream with information about the blocking of the lower layer at Drogden.

Strong barotropic inflows (G ≥ 1):

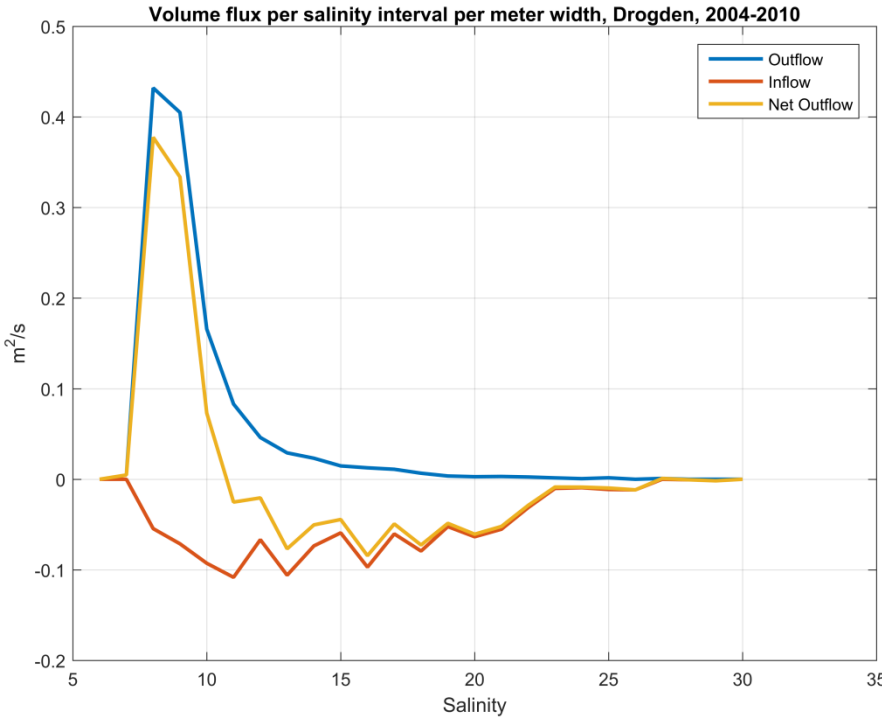


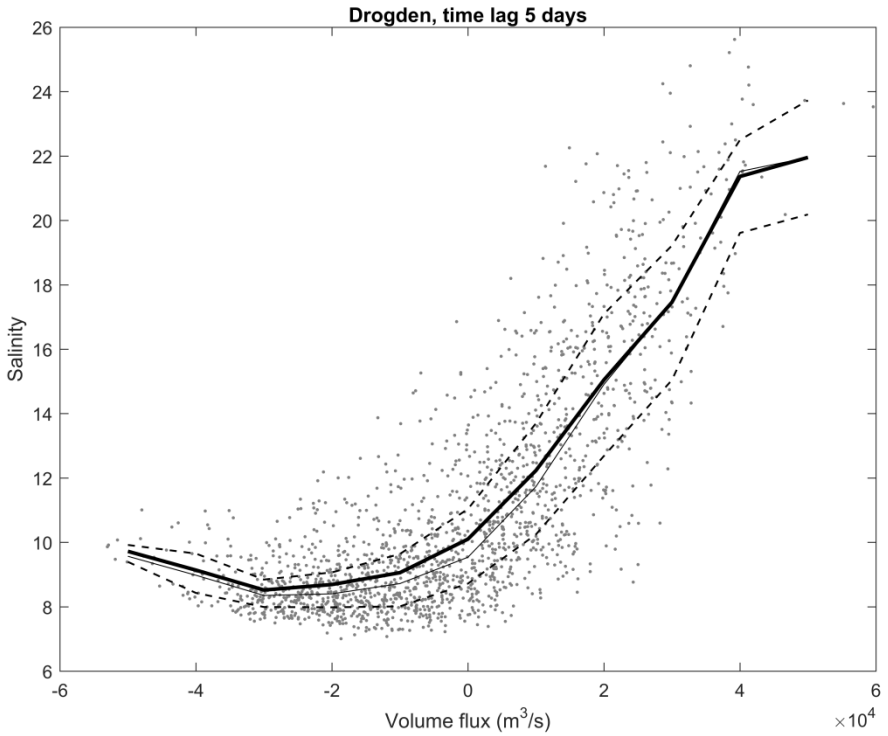
Information about the sill is no longer present upstream of the control.

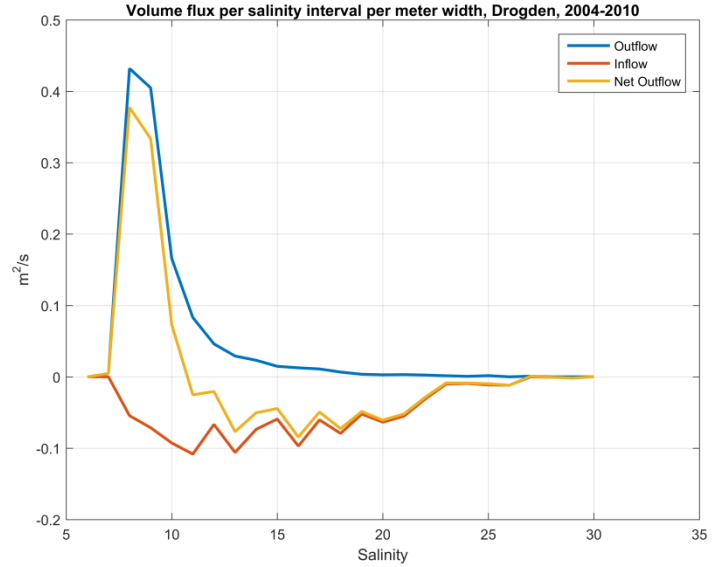
Holtegård Nielsen (2001)

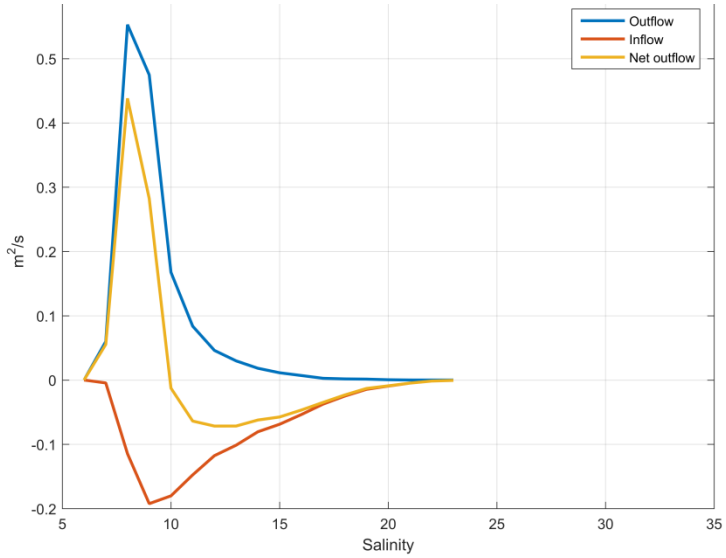


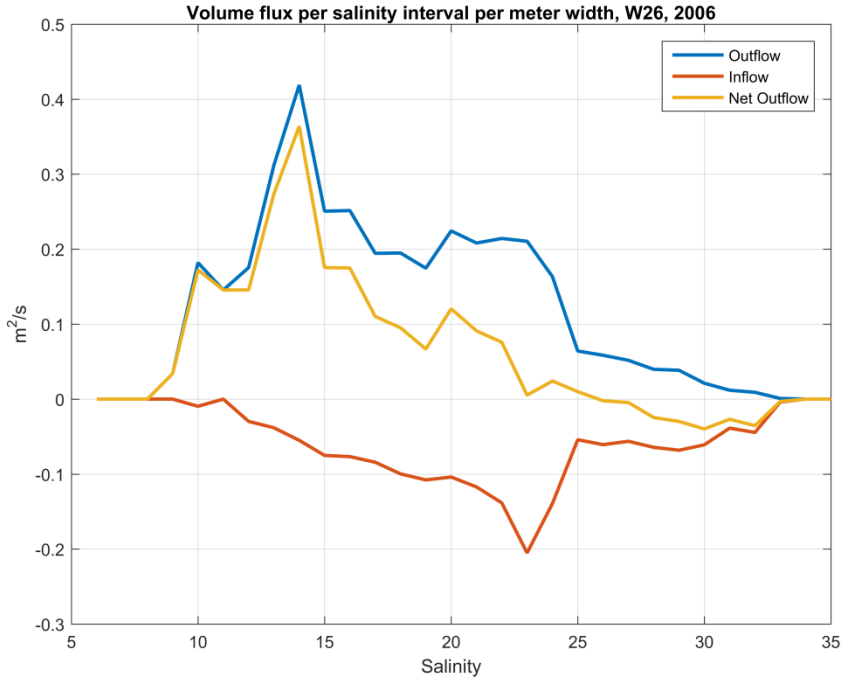
$G^2 = 1$
Internal hydraulic control!


Volume flux per salinity interval per meter width, Drogden, 2004-2010
Outflow
Inflow
Net Outflow
m²/s
Salinity

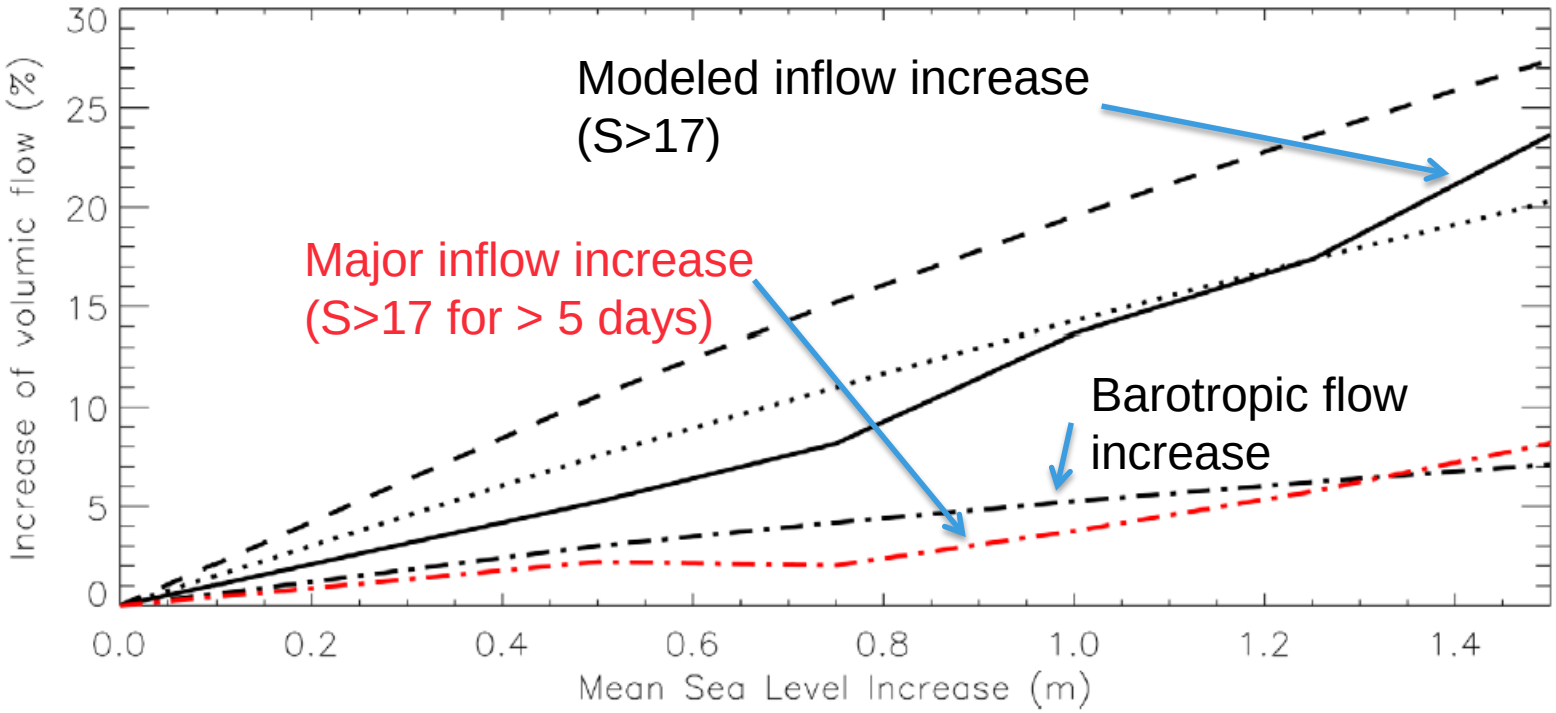

Drogden, time lag 5 days
Salinity
Volume flux (m³/s)
×10⁴


Volume flux per salinity interval per meter width, Drogden, 2004-2010
Outflow
Inflow
Net Outflow
m2/s
Salinity


Outflow
Inflow
Net outflow
m2/s
Salinity


Volume flux per salinity interval per meter width, W26, 2006
Outflow
Inflow
Net Outflow
m2/s
Salinity

Model results: Increased inflow of water with salinity larger than 17 g/kg (Hordoir et al. 2015)



Inflow of salt water is larger than the increase in barotropic flows.