Anatomising one of the largest saltwater inflows into the Baltic Sea since 100 years (December 2014)

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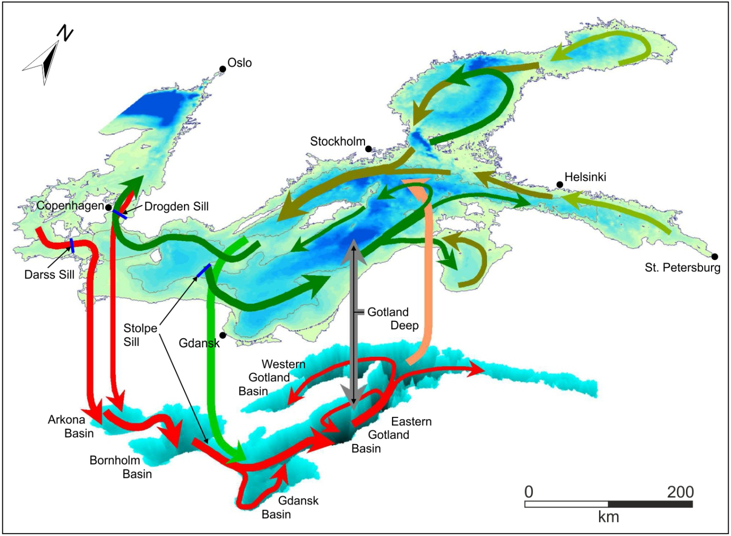
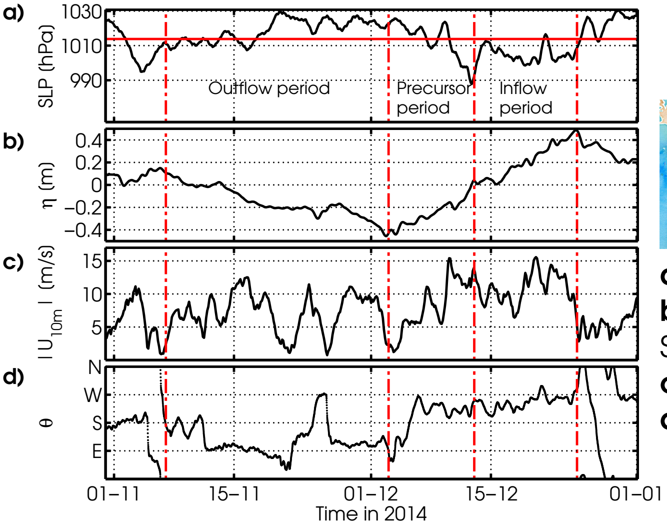
The Baltic Sea “Conveyor Belt”



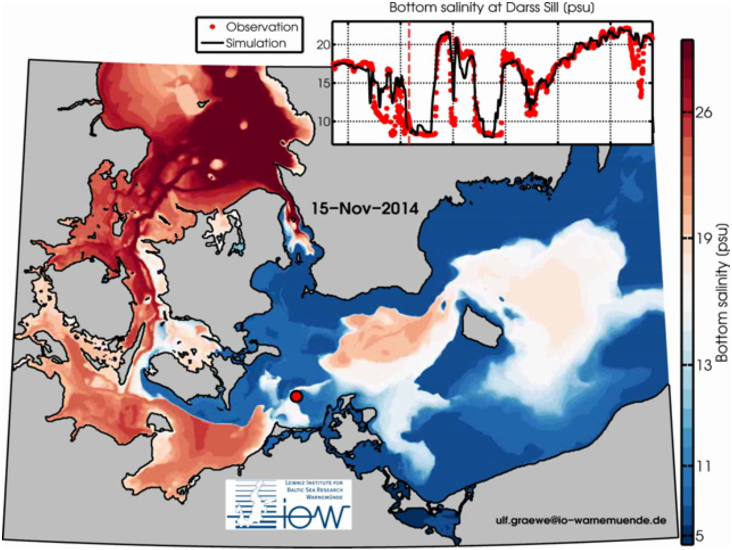
(Elken & Matthäus, 2008)

Setting the stage



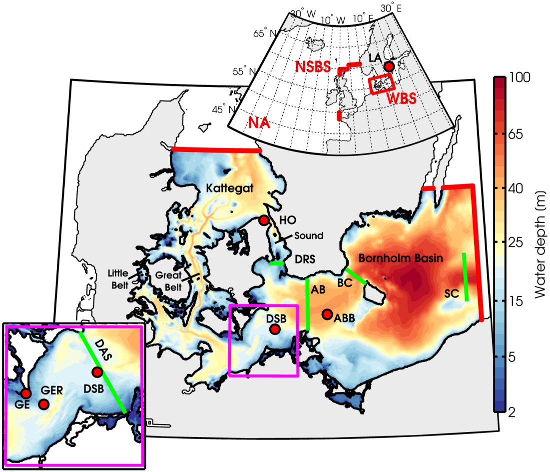
a) Air pressure
b) Sea level in Stockholm
c) Wind speed
d) Wind direction

The inflow in December 2014



The inflow in December 2014

Domain of numerical model



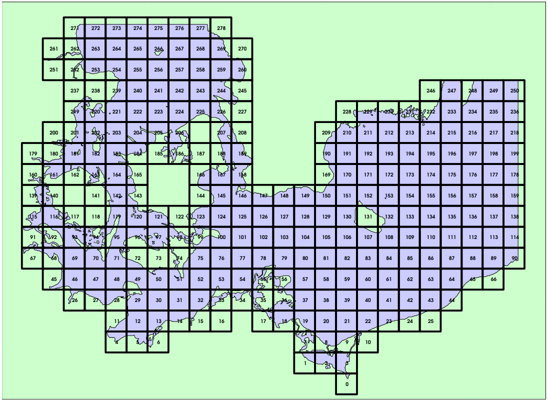
Setup

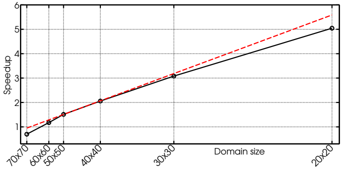
- North Atlantic 2D surge model 4 nm
- North Sea - Baltic Sea 1 nm, 42 vertical levels
- 600 m horizontal resolution, 60 vertical levels

Hydrodynamic core

- General Estuarine Transport Model (GETM, Burchard & Bolding 2002, www.getm.eu)
- Public domain (GPL, www.sourceforge.net)
- Git, CMAKE, Fortran 95+2003 (Fortran 2008), NetCDF
- Navier Stokes Equations (hydrostatic) on finite volumes
- Free surface with explicit time-stepping
- Advection schemes use directional split fractional steps
- Orthogonal grids (distorted aspect ratio, Δx vs. Δz)
- GOTM - $k - \epsilon$ closure (Umlauf et al. 2006, www.gotm.net)
- Boundary-following vertical coordinates (+ adaptation (Hofmeister et al. 2010))
- Full wind waves physics (Moghimi et al. 2013)
- Alternative nonhydrostatic extension that avoids elliptic PDE
- Atmospheric forcing prescribed externally (TROPOS + IOW, atmosphere/ocean coupling)

Parallelisation

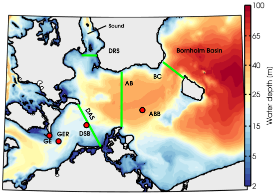




- Hybrid parallelisation (MPI + OpenMP)
- Scales on 100-3000 cpus
- Accelerator cards?
- Computation at HLRN

Transport estimates

$$Q = \int_T \int_A u(x,z,t)\Big|_{u^+} S(x,z,t)\Big|_{S>17} dA\,dt$$

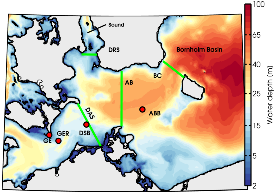


Volume (km^3)			
	Darss Sill	Drogden Sill	$\sum$
Mohrholz et al. 2015	248	64	**312**
GETM	240	76	**316**

Salt (Gt)			
	Darss Sill	Drogden Sill	$\sum$
Mohrholz et al. 2015	2.60	1.38	**3.98**
GETM	2.40	1.44	**3.88**

Error estimates

Salinity (psu)			
	BIAS	RMSE	STD
Darss Sill (DSB)	+0.2±0.1	0.7±0.5	0.7
Arkona Buoy (AB)	-0.1±0.2	0.8±0.5	0.7
Current speed (cm/s)			
Darss Sill (DSB)	-1.0±1.0	6.0±4.0	5.0
Arkona Bouy (AB)	-2.0± 1.0	6.0±4.0	5.0



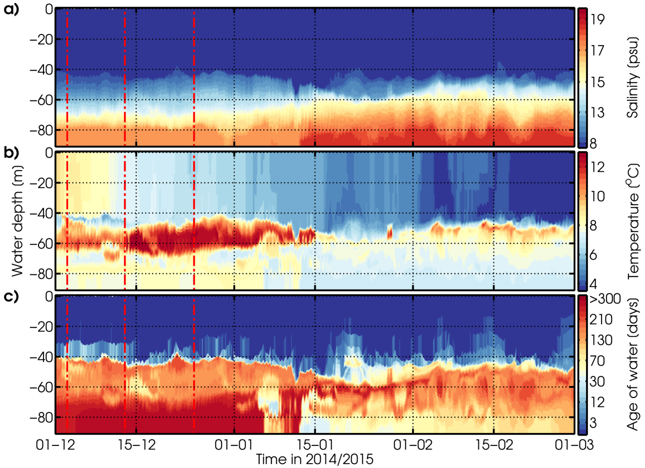
Error measures of bottom salinity and bottom current for stations Darss Sill and Arkona Basin (BIAS=simulation-observation)

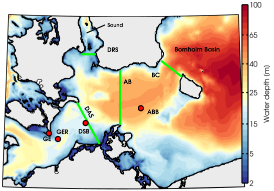
Monte Carlo Analysis (MCA)

Volume (km^3)			
	Darss Sill	Drogden Sill	$\sum$
Mohrholz et al. 2015	248	64	**312**
GETM	240	76	**316**
GETM (MCA)	217.1±13.4	74.0±2.6	**291.0±13.65**

Salt (Gt)			
	Darss Sill	Drogden Sill	$\sum$
Mohrholz et al. 2015	2.60	1.38	**3.98**
GETM	2.40	1.44	**3.88**
GETM (MCA)	2.51±0.17	1.38±0.05	**3.89±0.18**

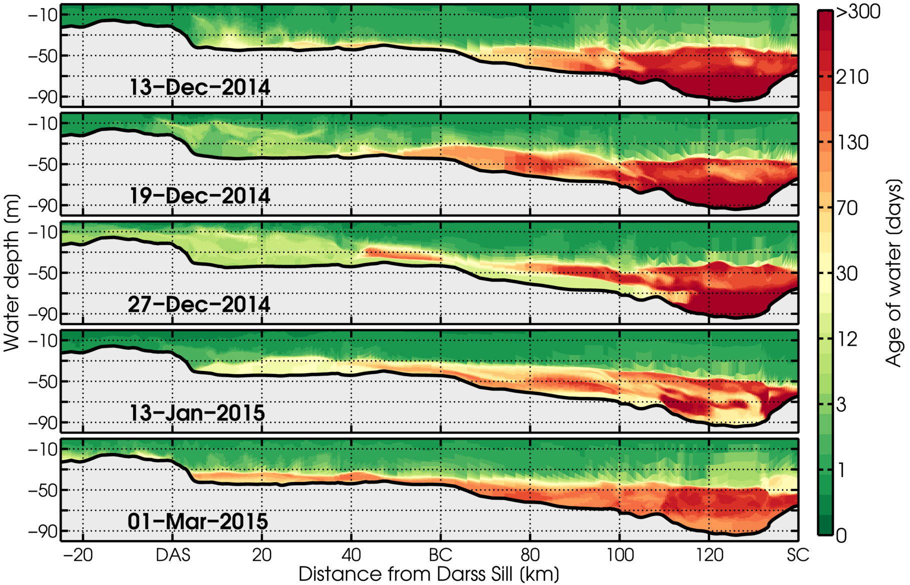
Flow dynamics





a) Salinity
b) Temperature
c) Age

Age of water masses



Conclusion

Comparison of the five strongest major Baltic inflows since 1897 (Fischer and Matthäus, 1996) with the actual inflow in December 2014.

Rank	Time	Salt (Gt)	Volume (km^3)
1	November/December 1951	5.17	225
2	December 1921/January 1922	5.12	258
3	**December 2014**		
	Mohrholz et al., 2015	**3.98**	**198**
	GETM	**3.89$\pm$0.18**	**190.1$\pm$11.43**
4	November/December 1913	3.80	174
5	January 1993	3.40	159

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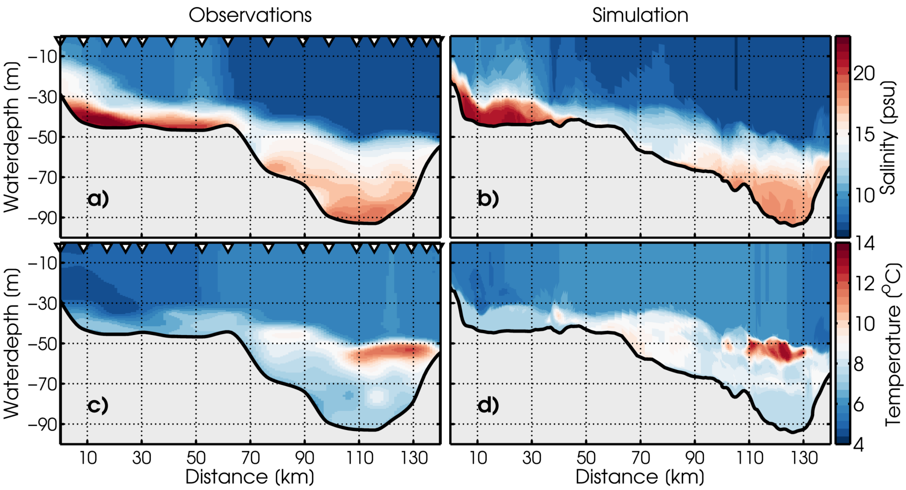
- Model agrees with the observations (within 95% confidence intervals)
- The inflow has the potential to oxygenate the deeper basins
- Impact on hypoxia ?

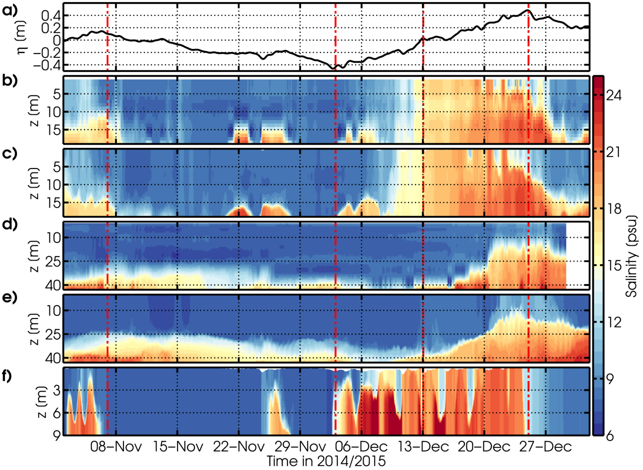
Conclusion

Validation



Comparison of a measured and modelled transect through the Arkona Basin and Bornhom Basin (12-14 Jan 2015).

Validation



a) SSH at Landsort
b) observed salinity at Darss Sill
c) modelled salinity
d) observed salinity at Arkona Basin
e) modelled salinity
f) modelled salinity at Drogden Sill

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Uncertainty in transport estimates:

$$Q_S = \int_{\widehat{T}} \int_{\widehat{A}} u\widehat{(x,z,t)}\Big|_{\widehat{u}^+} S\widehat{(x,z,t)}\Big|_{\widehat{S}>17} \mathrm{d}\widehat{A}\,\mathrm{d}t$$

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