Knowledge of the Baltic Sea physics gained during the BALTEX II (2003-2012) and related programmes

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1. New important data sets and tools available

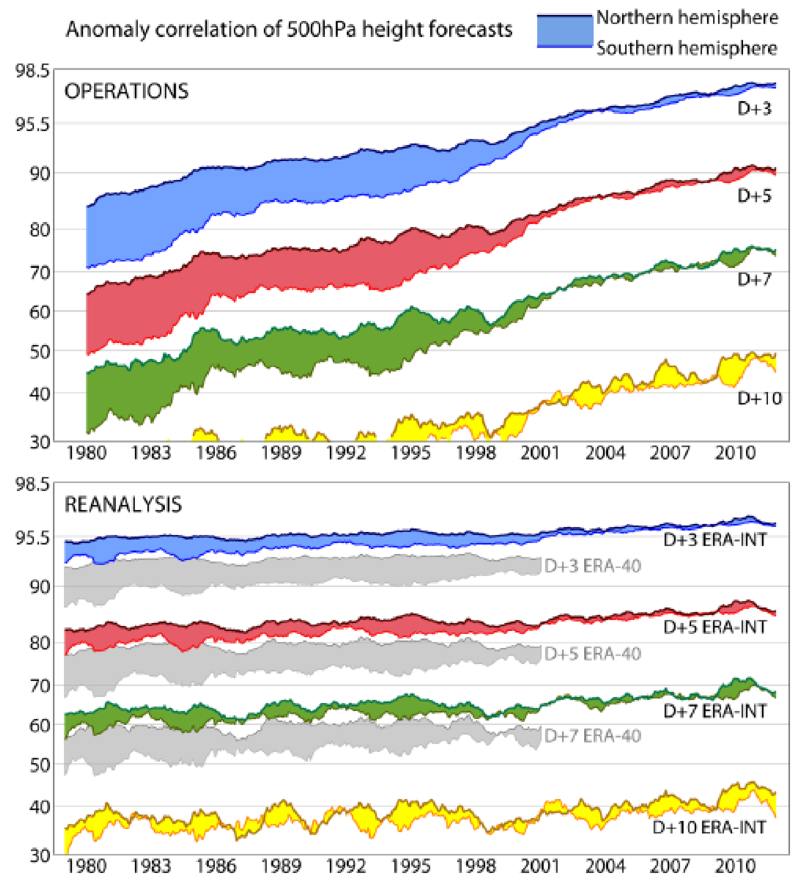
Data assimilation and reanalysis

Data assimilation was developed to provide estimates of the state of the atmosphere, “analyses”, needed to start operational numerical weather forecasts

Large improvements in forecasts have stemmed from better data assimilation and observations

Improvement from 1980 to 2000 comes mostly from improvement to forecasting system

Improvement since 2000 comes from improvement to forecasting system and to observations



Adrian Simmons through Per Kållberg

1. New important data sets and tools available, cont.

Recent key findings:

- Close relation between BALTEX/SMHI 1x1 degree and ERA-40 data sets

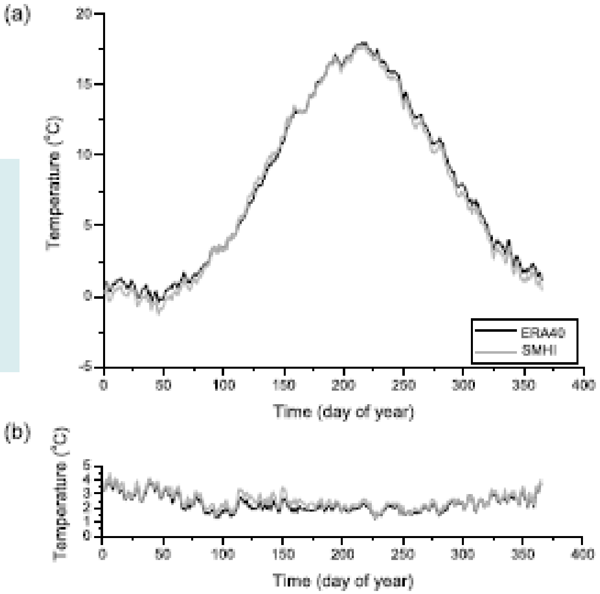
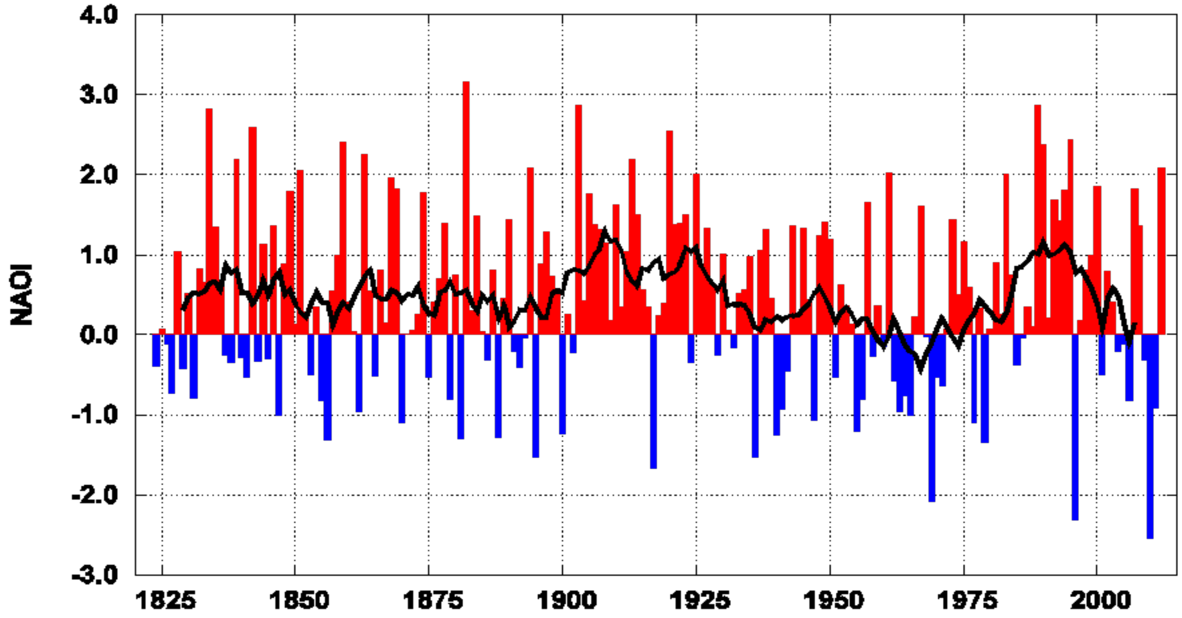


Figure 2 Mean temperature (a) and standard deviation of temperature (b) for the Eastern Gotland Basin

Omstedt et al (2005)

2. Large scale atmospheric circulation and the Baltic Sea



Recent key findings:

- Winter North Atlantic Oscillation indices (NAOI) is strongly related Baltic Sea ice extent and mean sea level
- Correlation with other parameters often varies in time

2. Large scale atmospheric circulation and the Baltic Sea, cont.

Fig. Total number of deep (<980 hPa) cyclones counted, based on NCEP/NCAR reanalysis 4 times daily sea level pressure data (winter, DJFM) Lehmann et al., (2011)
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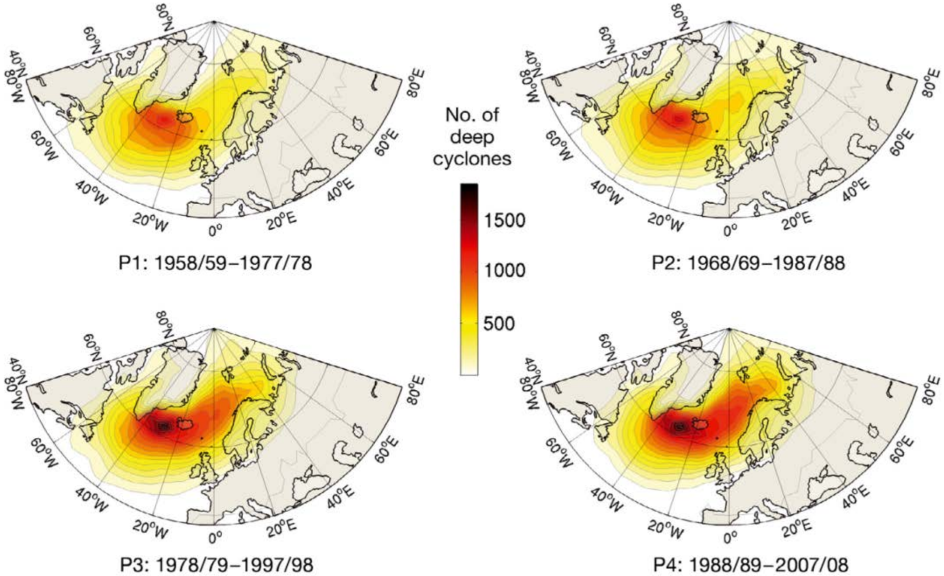
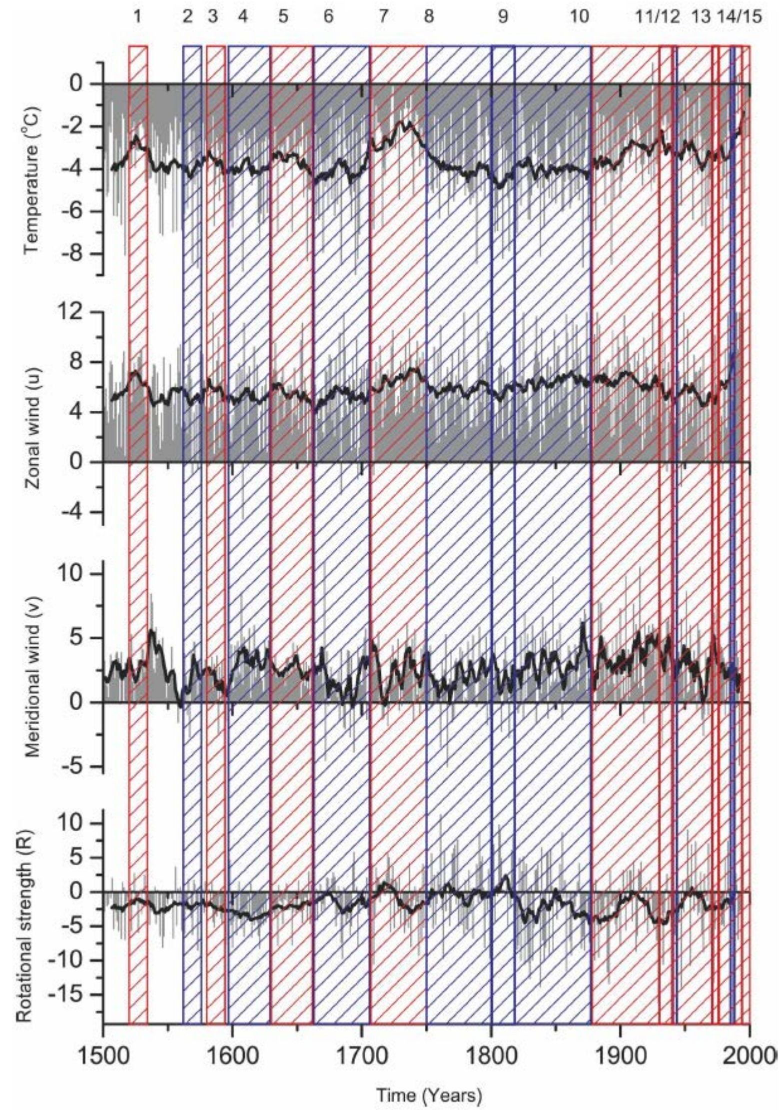


Recent key findings:

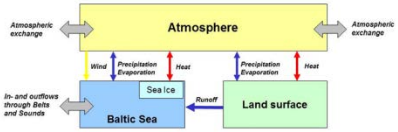
- Recent changes in the warming trend over the Baltic Sea are partly associated with changes in large-scale atmospheric circulation over the North Atlantic

2. Large scale atmospheric circulation and the Baltic Sea: Centennial time scale

Recent key findings:
The climate could be characterized by centennial-scale variability and the modulation of inter annual and decadal signals, often accompanied by rapid shifts. The random initiation and different duration of events and the lack of "cycles" do support a major influence of intrinsic variability in atmospheric climate (Ericsson et al 2007)



3. Water and heat balances



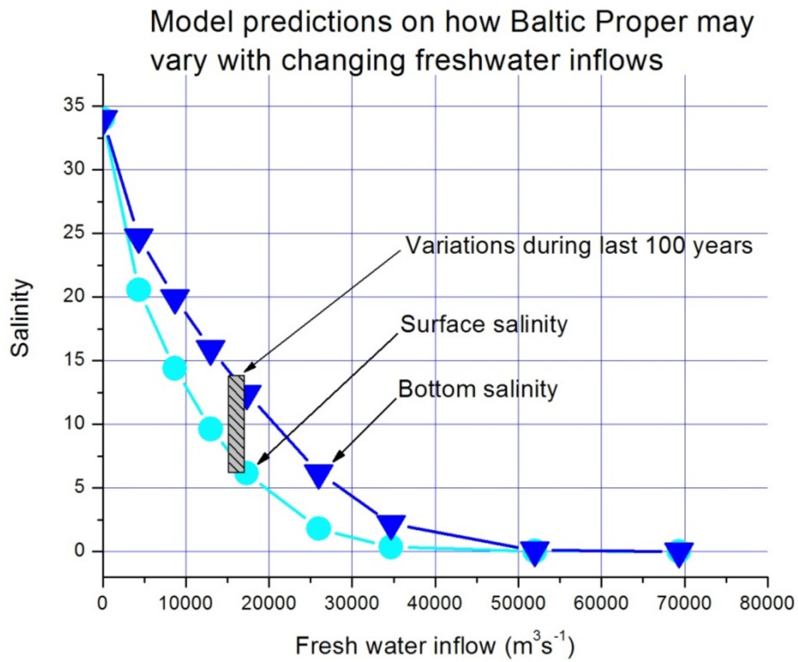
Recent key findings:

- The major water component to the Baltic Sea is river runoff but net precipitation adds freshwater. Both shows large seasonal, inter annual, decadal variations. Groundwater much less.
- The major Baltic Sea heat components are sensible heat , latent heat, net long way radiation and shortwave radiation. Largely changed heat fluxes during ice seasons. Large seasonal and inter annual variations. Long-term net heat balance almost zero illustrating that the Baltic Sea is in balance with the atmosphere.
- Two major time scales one associated with the water balance and salinity on 30 years and one associated with the heat balance and water temperature on 1 year.
- The hydrological cycle in the atmosphere climate models still has severe bias. Bias corrections larger than trends add large uncertainties to climate.

3. Water and heat balances cont.

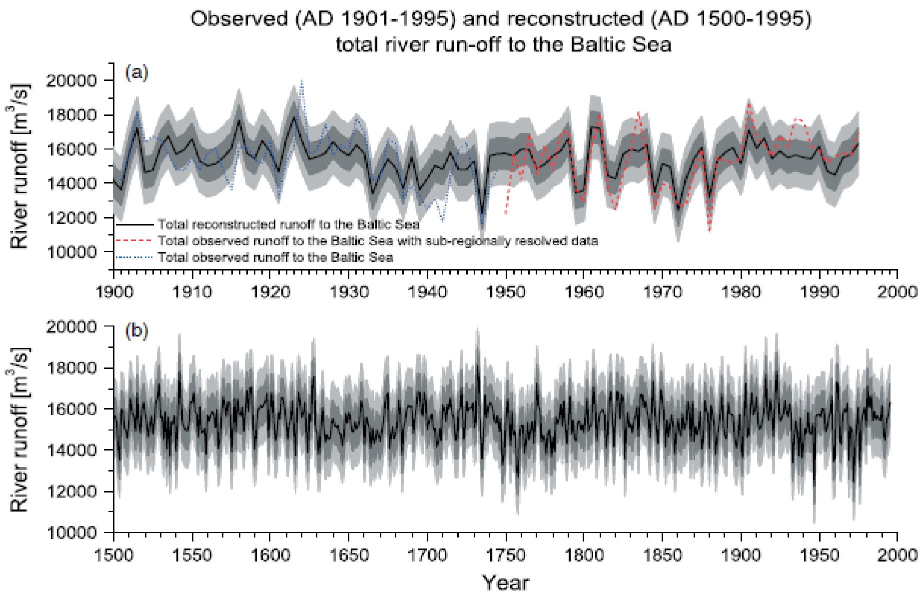
Recent key findings:

- Long-term salinity is dependent in a non-linear way to fresh water inflow
- Some different models indicates that fresh water inflow needs to be increased by a factor of 3-4 before the Baltic Sea will turn into a fresh water system



Omstedt and Hansson (2006)

3. Water and heat balances, cont.: River run off



(Hansson et al , 2010)

Recent key findings:

- No significant long-term change has been detected, although decadal and regional variability is large.
- The south region may become drier with rising air temperatures. This is in contrast to the north region and Gulf of Finland where warmer temperatures are associated with more river runoff.
- Over the past 500 years the total river runoff to the Baltic Sea has decreased by 3% (450 m3/s) per degree Celsius increase.

4. Air-ice interaction

Recent key findings:
The presence of sea ice changes the air-sea heat and moisture fluxes considerably, large negative heat fluxes occur for warm air advection and low cloud cover.

Brummer, Kirchgassner and Muller (2005), The Atmospheric Boundary Layer over Baltic Sea ice, Boundary-Layer Meteorology (2005) 117: 91–109

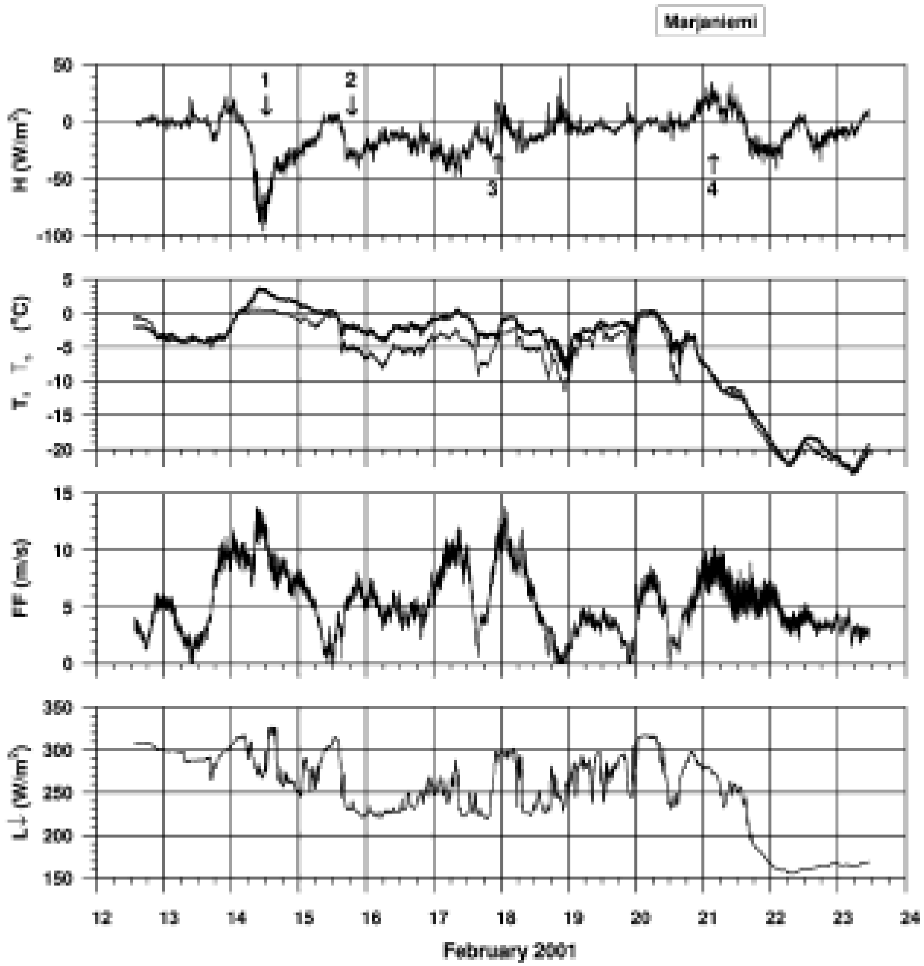


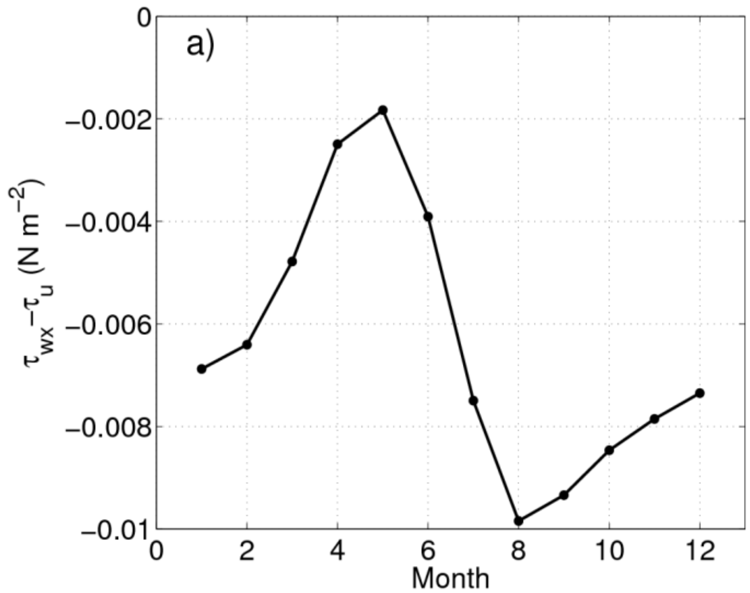
Figure 6. Sensible heat flux H, air temperature T, surface temperature T_s, wind speed FF, and downwelling longwave radiation flux $L\downarrow$ at land-fast ice station Marjaniemi in February 2001. Numbers mark examples of large heat flux events: 1 = warm-air advection, 2 = clouds disappear (see $L\downarrow$), 3 = clouds appear, and 4 = cold-air advection. H was measured with a sonic at 3-m height with 20 s^{-1} sampling frequency and 10-minute averaging time interval. T_s was measured with an infrared radiometer.

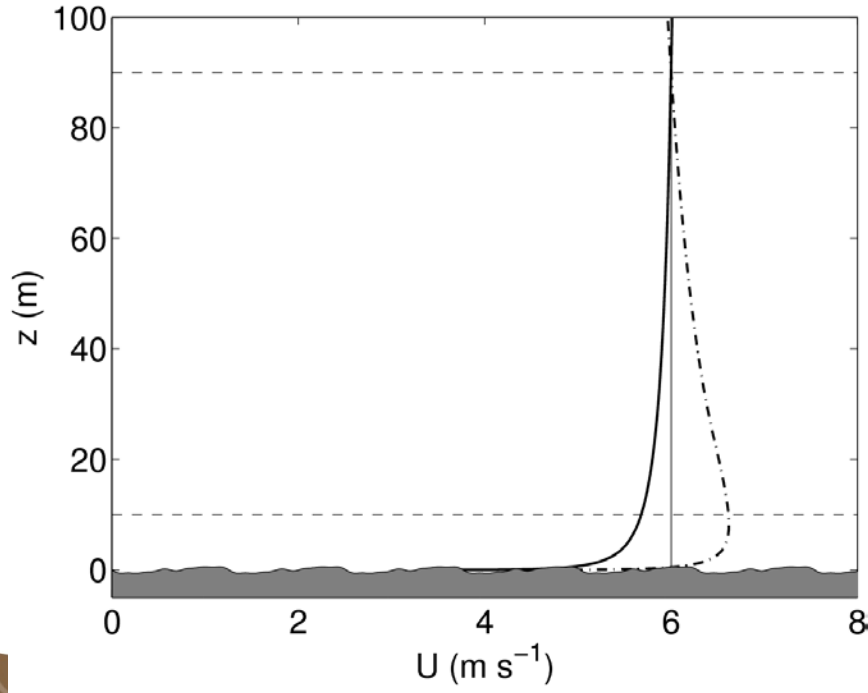
4. Air-sea interaction, cont.

Recent key findings:
The presence of surface swell waves reduces the stress and increase the wind speed at 10 m height in the Baltic Sea.

Carlsson B., A. Rutgersson and A. Smedman : Impact of swell on simulations using a regional atmospheric climate model. *Tellus,* 61A, 527-538. 2009

Carlsson B., A. Rutgersson and A. Smedman : Investigated the effect of including wave effects in the process oriented model PROBE-Baltic. *Bor. Env Res.* 14, 3-17. 2009.





4. Air-sea heat flux, cont.

Recent key findings:
The difference between heat fluxes from various models and remote sensing estimates are too large. There is an indication that the sum of the heat fluxes is relatively small (increased solar radiation is balanced by the other heat fluxes)

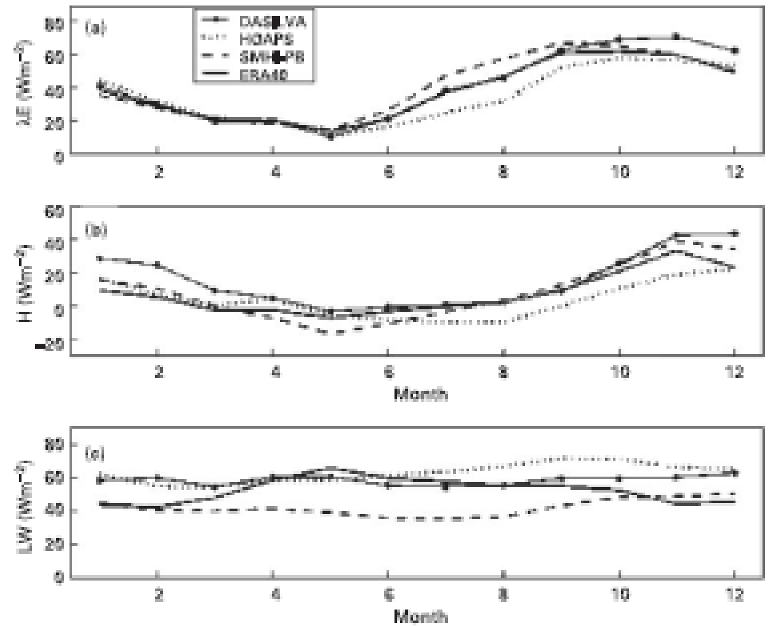


Figure 5 Monthly averages for the period 1988 – 1994 showing the seasonal cycle. Parameters are: (a) latent heat flux, (b) sensible heat flux and (c) long-wave radiation. Units are W m^{-2}. Solid line with dots represents data from DASILVA, dotted line from HOAPS, dashed line from SMHI-PB and solid line from ERA40 database

Doescher, R., H. E. M. Meier : Simulated Sea Surface Temperature and Heat Fluxes in Different Climates of the Baltic Sea Ambio, Vol. 33, No. 4, 242–248. 2004

Rutgersson, A., Anders Omstedt and Youmin Chen: Evaluation of the heat balance components over the Baltic Sea using four gridded meteorological databases and direct observations. *Nordic Hydrol.*, 36, 381-396.

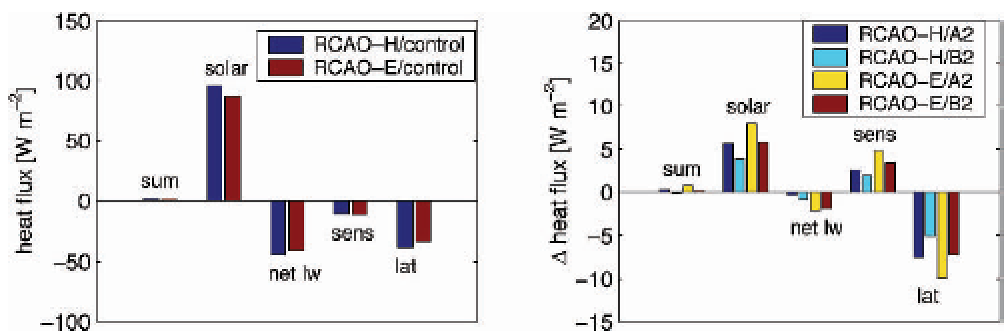
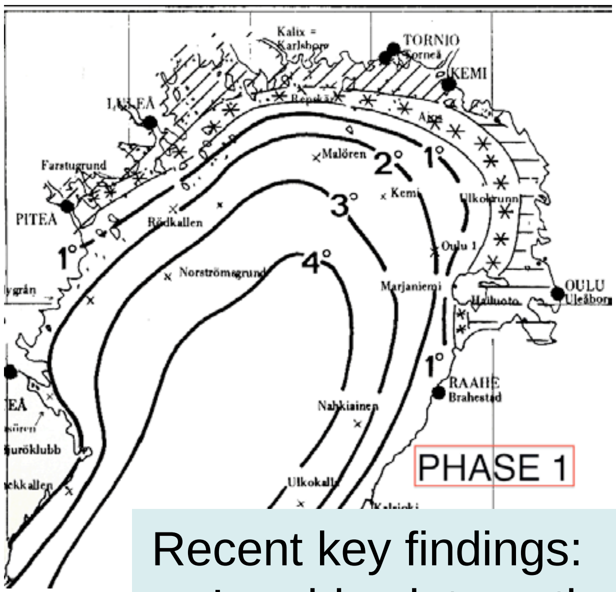


Figure 5. Left: overall mean heat flux from the atmosphere to the ice/ocean system and its components: shortwave ('solar'), net longwave ('net lw'), sensible ('sens'), latent ('lat') and the sum of all components. Right: Differences between heat fluxes of scenario and control experiments (scenario-control).

5. Sea ice

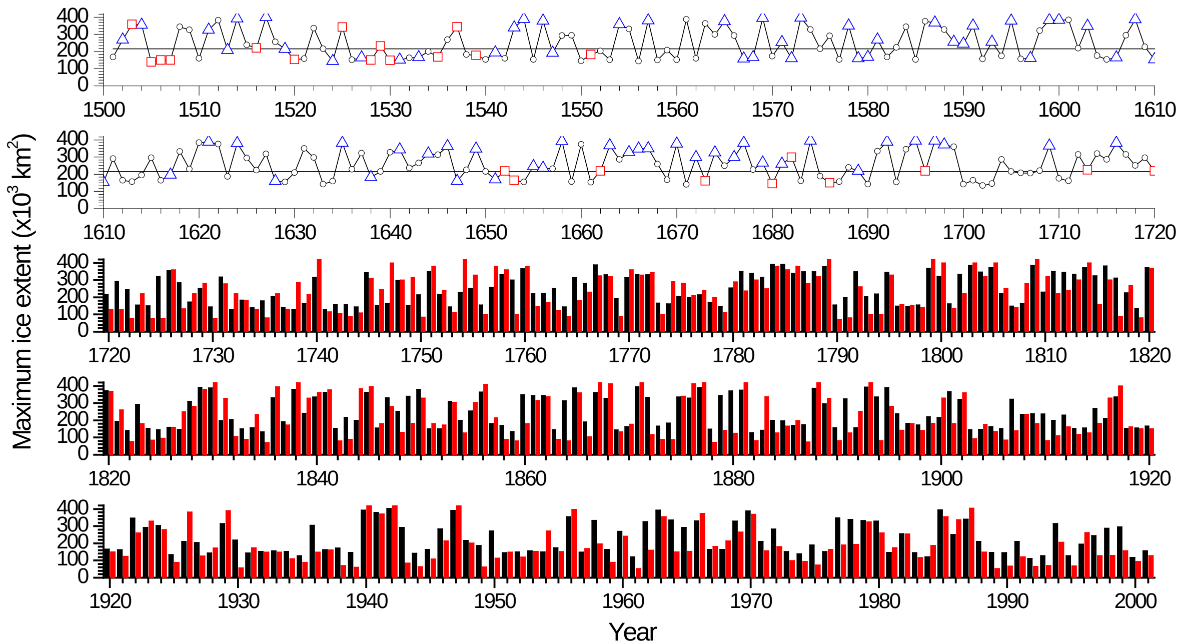


Recent key findings:

- Land-ice interaction has become a major issue recently due to new coastal and offshore constructions and nature protection. This interaction includes bottom scouring, shore modification, and shore ride-up and piling up of ice.
- Sea ice drift under the influence of a fixed boundary (land fast ice) needs to be considered

Leppäranta (2012)

5. Sea ice, cont.



= Cold winter = Model results

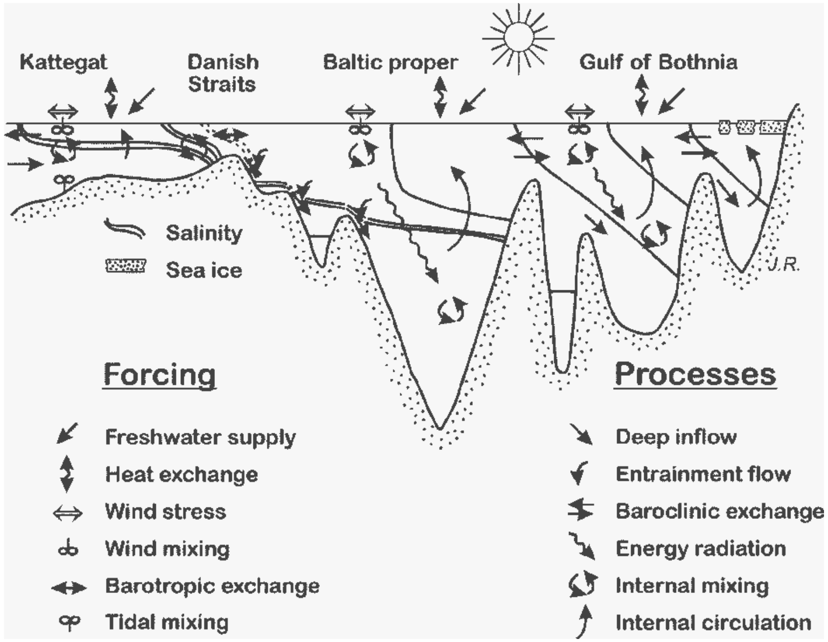
= Warm winter = Observations

Recent key findings:

- Estimated data on annual maximum ice extent (Prof. Jurva) back to 1720 have been validated by independent model study, giving confidence in the Jurva data
- Historical documents support model estimates before 1720

Hansson and Omstedt, 2007

6. Strait/channel flows and turbulence



Winsor et al., 2001

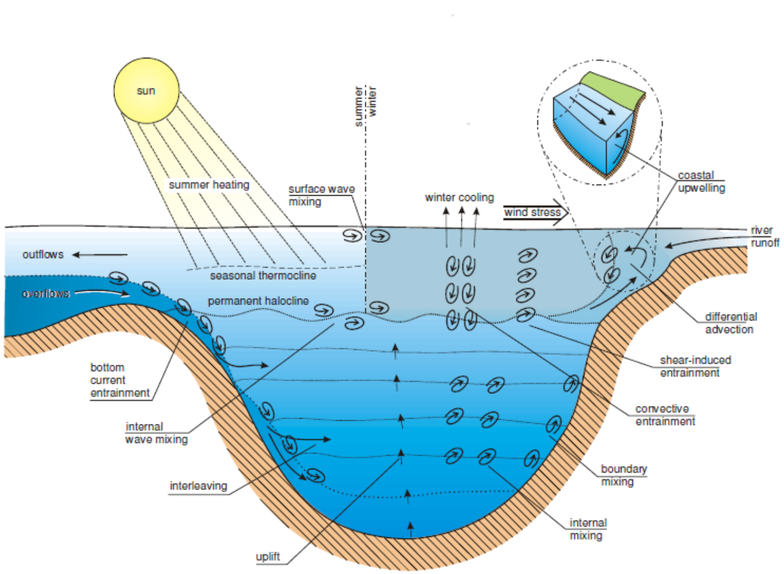


Fig. 1: Scheme of vertical mixing and transport processes in the Baltic Sea.

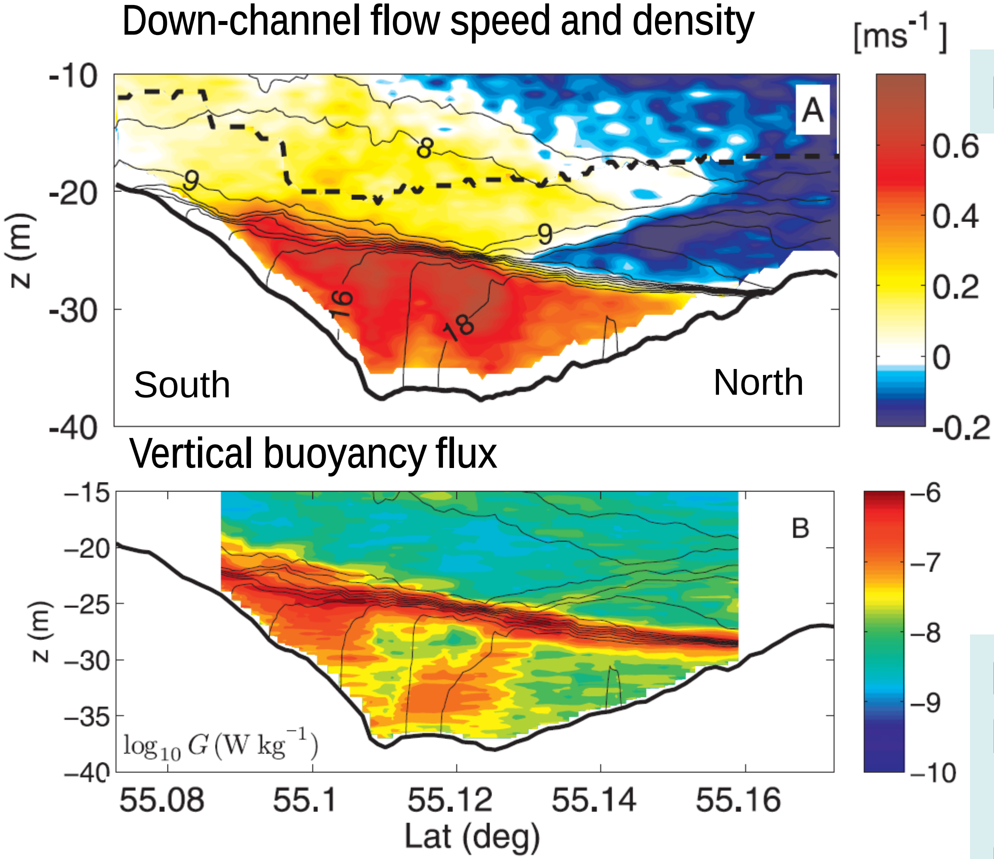
Reissmann et al., 2009

Recent key findings:

- flow regimes are intermittent in time
- hydraulic control occurs less frequently than anticipated
- wider gravitational flows have transverse Ekman circulation
- surface waves are important mixing generators

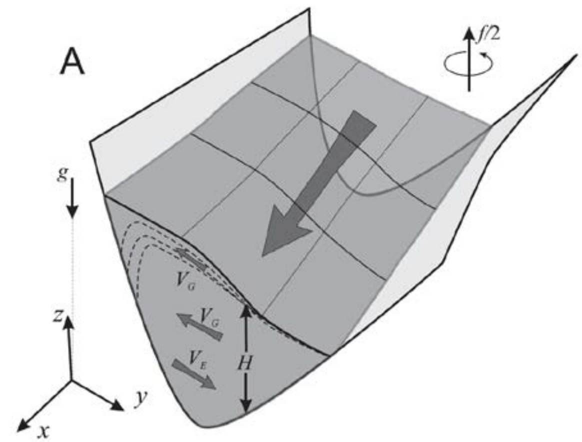
Flow dynamics in the channels: north from Kriegers Flak

Down-channel flow speed and density



Western Arkona Sea near Drodgen

Rotational sub-critical gravity current



Frictional effects (Ekman number ≈ 1):

- ❑ transverse Ekman circulation and interfacial jet
- ❑ downward bending of isopycnals on the right-hand slope
  - ➢ asymmetric density pattern
- ❑ strong entrainment on the right-hand slope

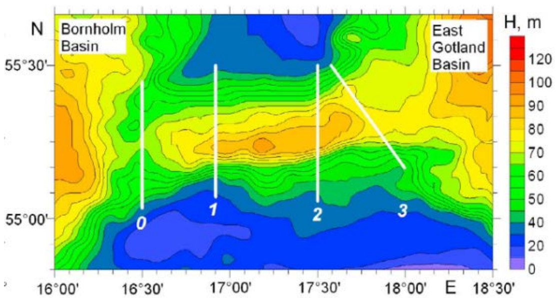
Umlauf, L., & Arneborg, L. (2009). Dynamics of rotating shallow gravity currents passing through a channel. Part I: Observation of transverse structure. Journal of Physical Oceanography, 39(10), 2385-2401.

Umlauf, L., & Arneborg, L. (2009). Dynamics of rotating shallow gravity currents passing through a channel. Part II: Analysis. Journal of Physical Oceanography, 39(10), 2402-2416.

Flow dynamics in the channels: **Stolpe / Słupsk**

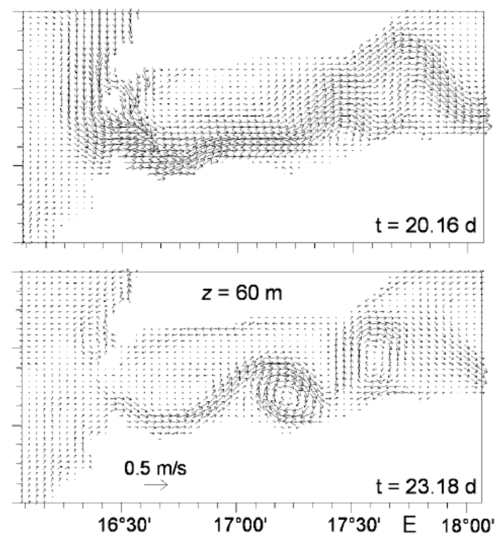
Sub-critical eddy-producing gravity current in a wide channel, including friction effects

Topography and transects



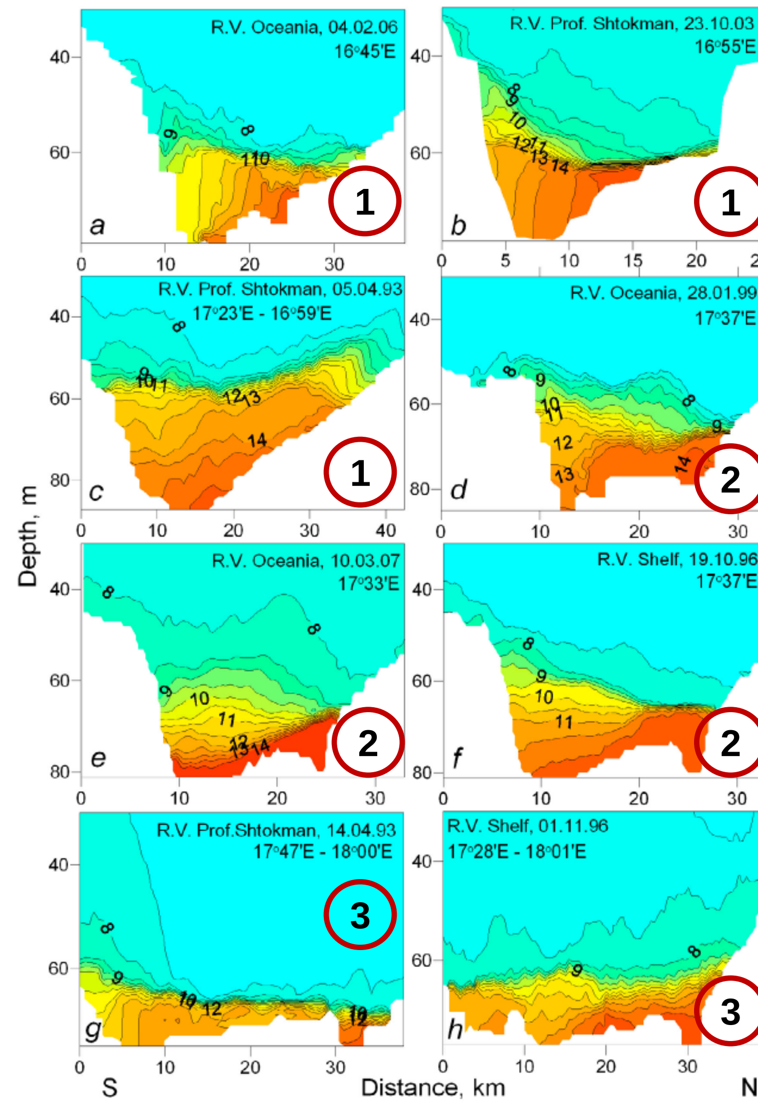
Zhurbas, Elken, Paka, Piechura, Väli et al, (2012). Structure of unsteady overflow in the Słupsk Furrow of the Baltic Sea. JGR

Current maps at 60 m



Cross-channel salinity

ZHURBAS ET AL.: UNSTEADY OVERFLOW IN THE SŁUPSK FURROW

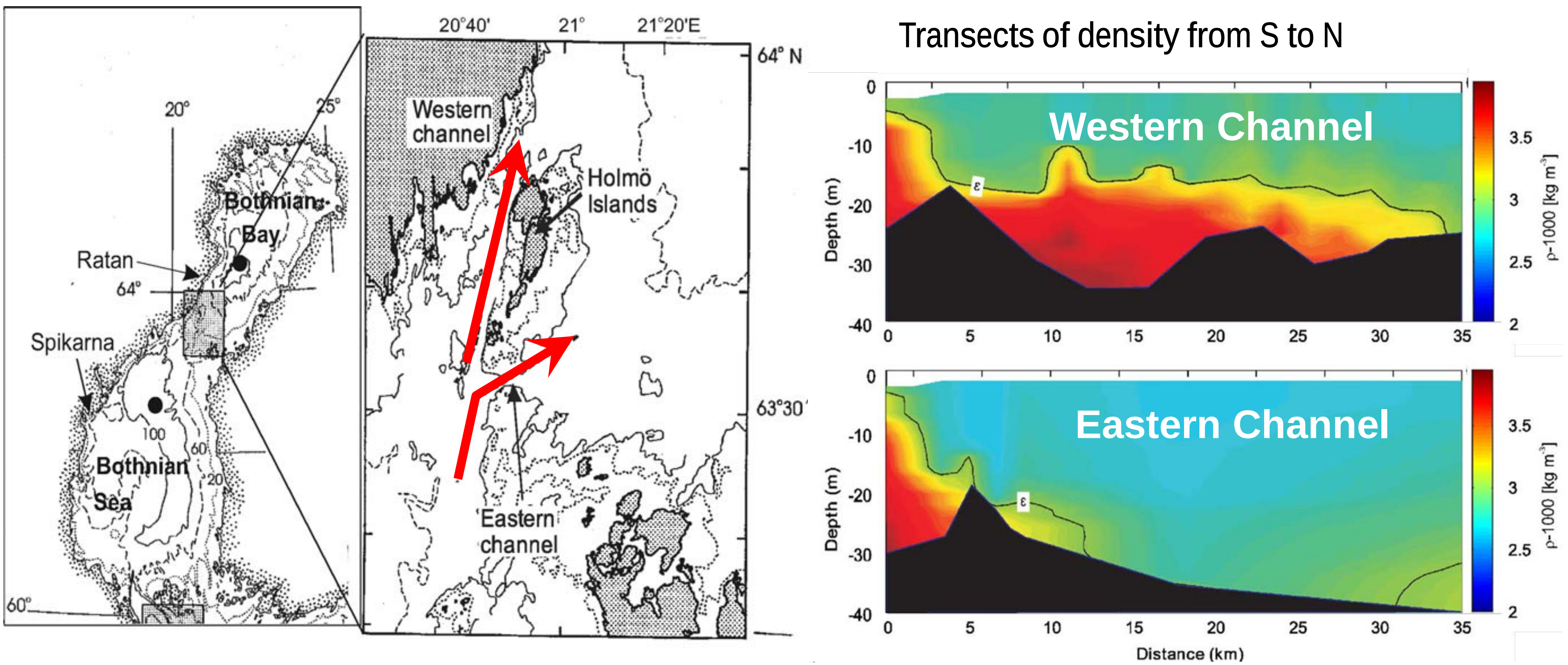


Variety of cross-channel density patterns (pinching and downward bending of isopycnals) is caused by

meandering of the gravity current and mesoscale eddies – mostly above-halocline cyclones and intrahalocline anticyclones

Flow dynamics in the Northern Kvark Strait (1)

Two channels between the Bothnian Sea and the Bothnian Bay

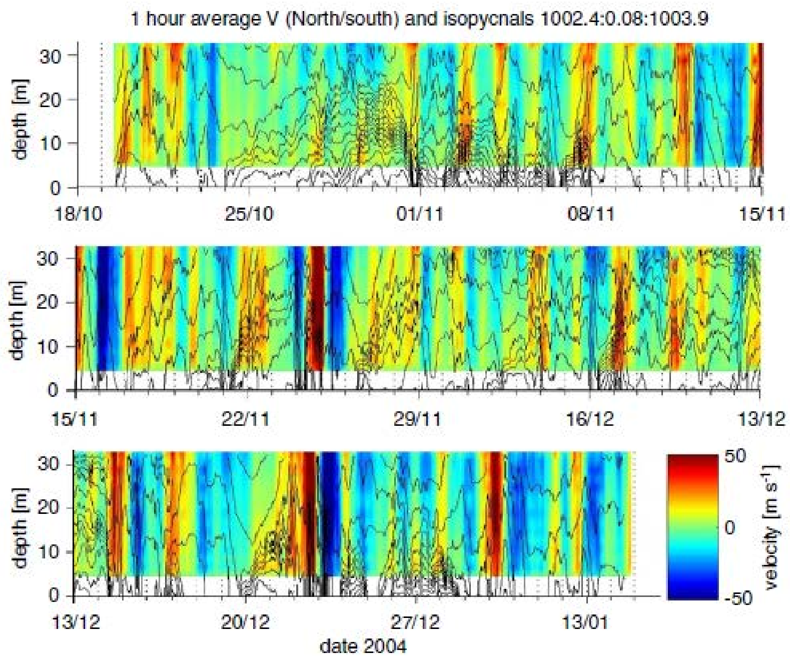


Green, M.J. A., Liljebladh, B., & Omstedt, A. (2006). Physical oceanography and water exchange in the Northern Kvark Strait. Continental shelf research, 26(6), 721-732.

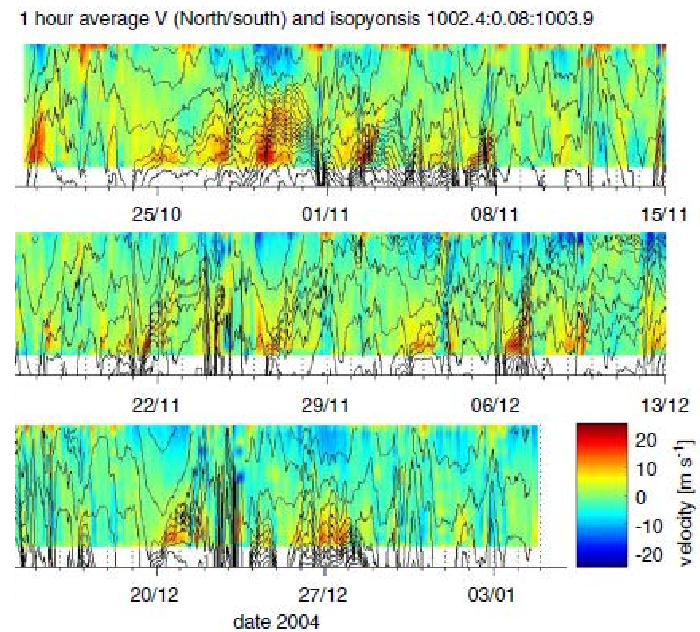
Flow dynamics in the Northern Kvark Strait (2)

Along-channel currents (positive north) (a) and with first EOF mode subtracted (b)

(a)



(b)



Temporal intermittency of flow regimes

(1) barotropically blocked regime — 45% of time

(2) two-layer regime

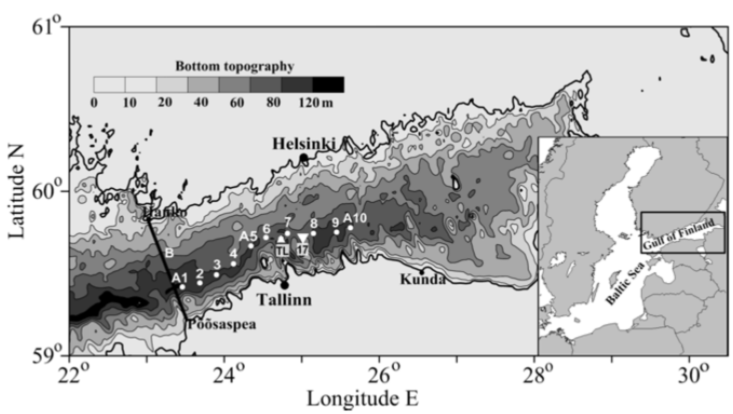
(3) continuously stratified regime — 55% of time, mainly hydraulically controlled (Fr ≈ 1)

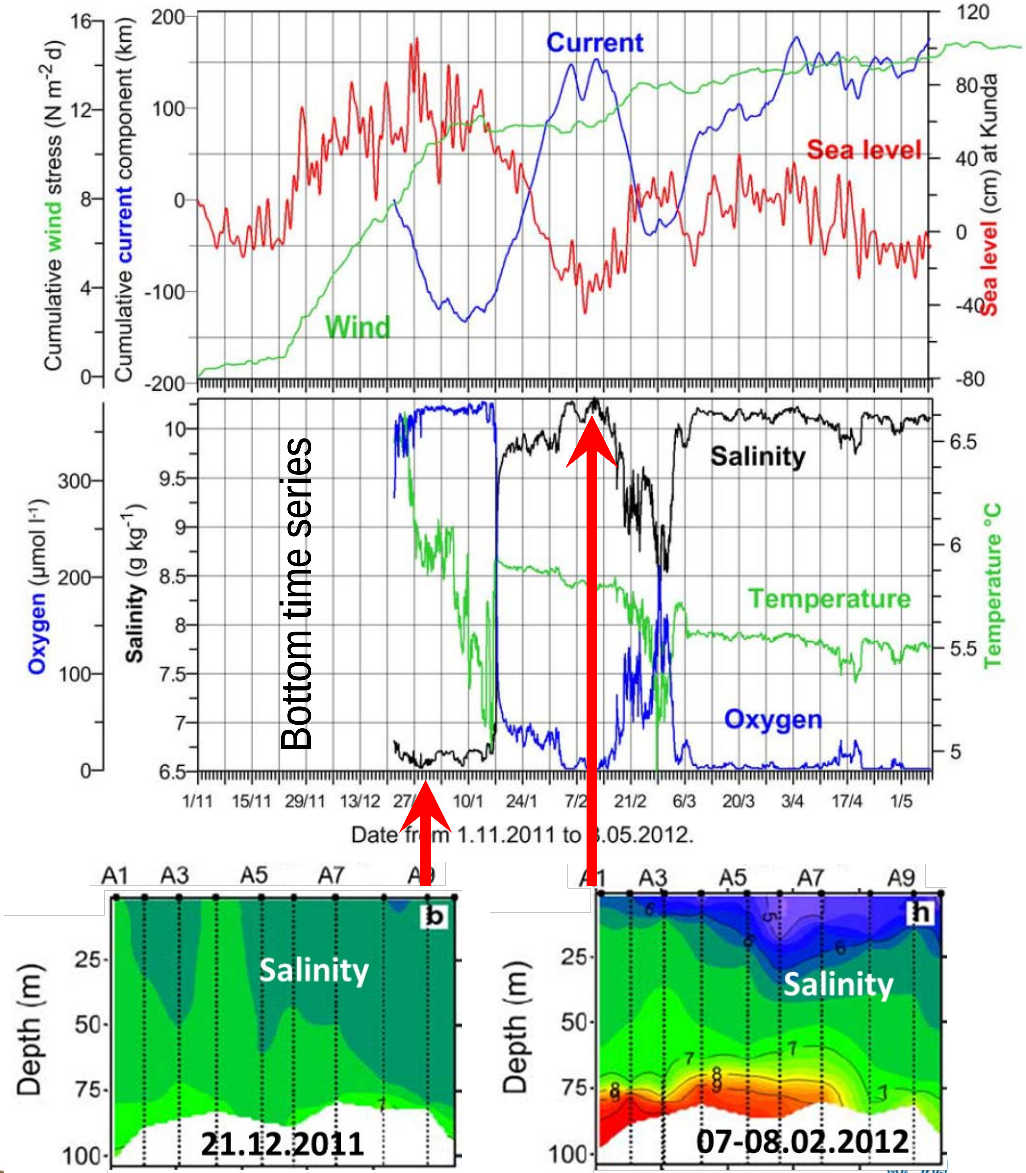
Green, M.J. A., Liljebladh, B., & Omstedt, A. (2006). Physical oceanography and water exchange in the Northern Kvark Strait. CSR, 26(6), 721-732.

Flow dynamics in the Western Gulf of Finland

Persistent strong SW winds create during the winter
- ➢ anti-estuarine transport
- ➢ stratification collapse
- ➢ oxygenation of bottom layers

By ceasing the SW winds, stratification and hypoxia are rapidly restored

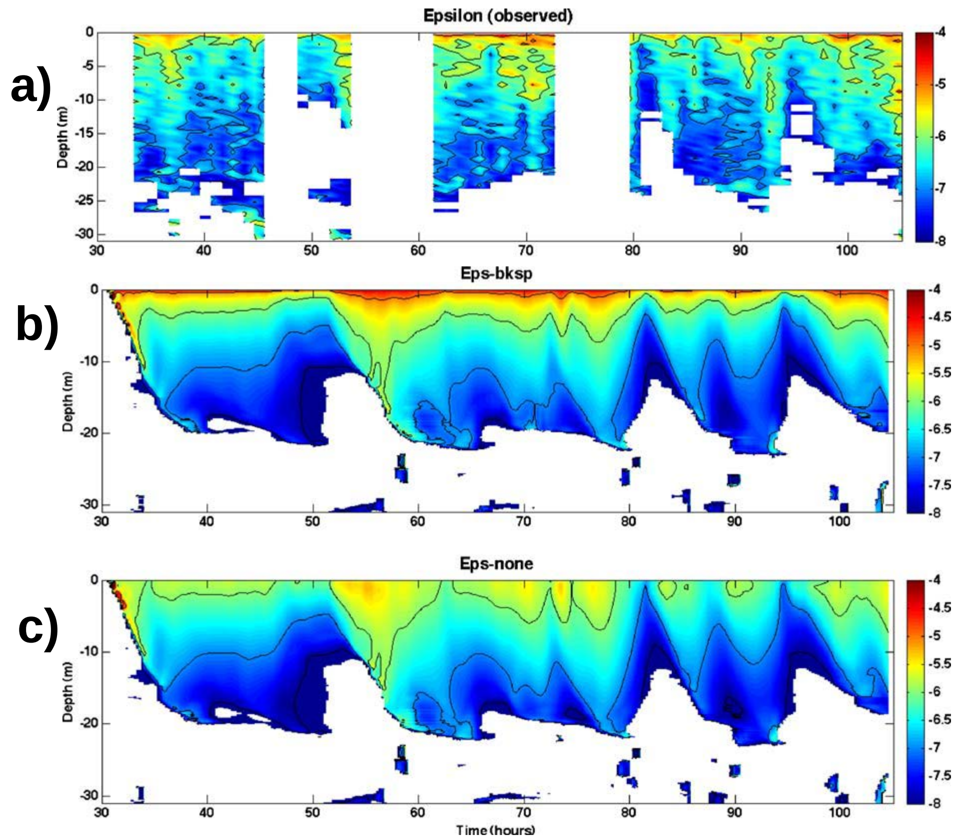




Liblik, T., Laanemets, J., Raudsepp, U., Elken, J., & Suhhova, I. (2013). Estuarine circulation reversals and related rapid changes in winter near-bottom oxygen conditions in the Gulf of Finland, Baltic Sea. Ocean Science Discussions, 10, 727-762.

Turbulence generation by surface waves (Stokes drift)

Microstructure observations in the Bornholm Basin



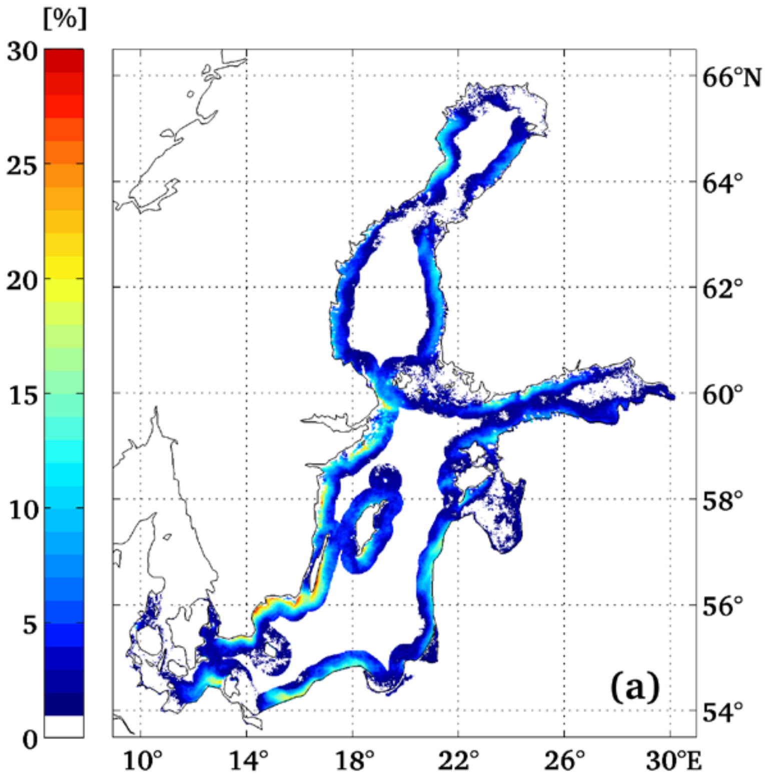
TKE dissipation rate (in W kg^{-1})
a) observed
b) modeled with wave breaking and Stokes drift
c) modeled with wind dependence only

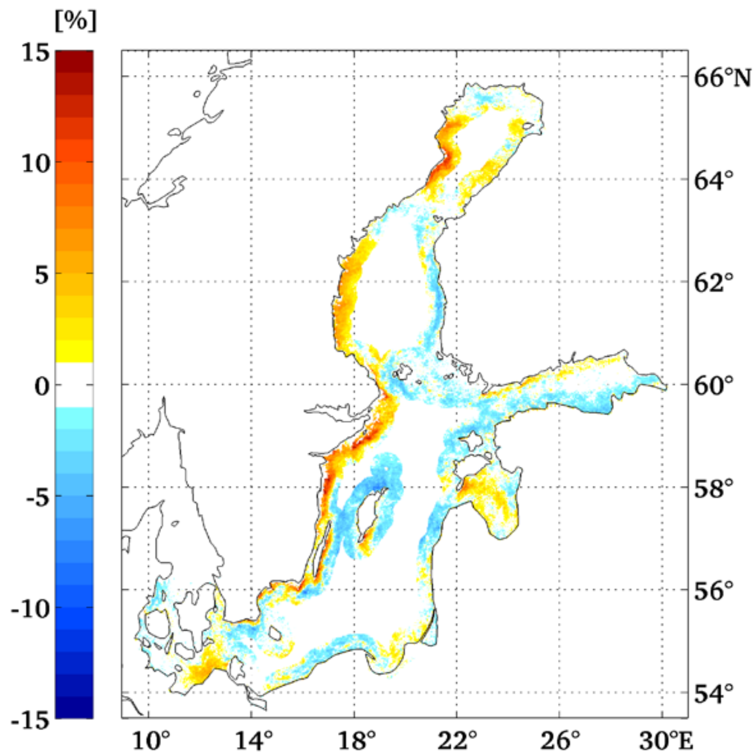
Stokes production of turbulent kinetic energy in the mixed layer is of the same order of magnitude as the shear production and must therefore be included in mixed layer models.

Presently most of the models count only the shear production (friction velocity) due to wind speed, not the effects of waves.

Kantha, L., Lass, H. U., & Prandke, H. (2010). A note on Stokes production of turbulence kinetic energy in the oceanic mixed layer: observations in the Baltic Sea. Ocean Dynamics, 60(1), 171-180.

7. Upwelling



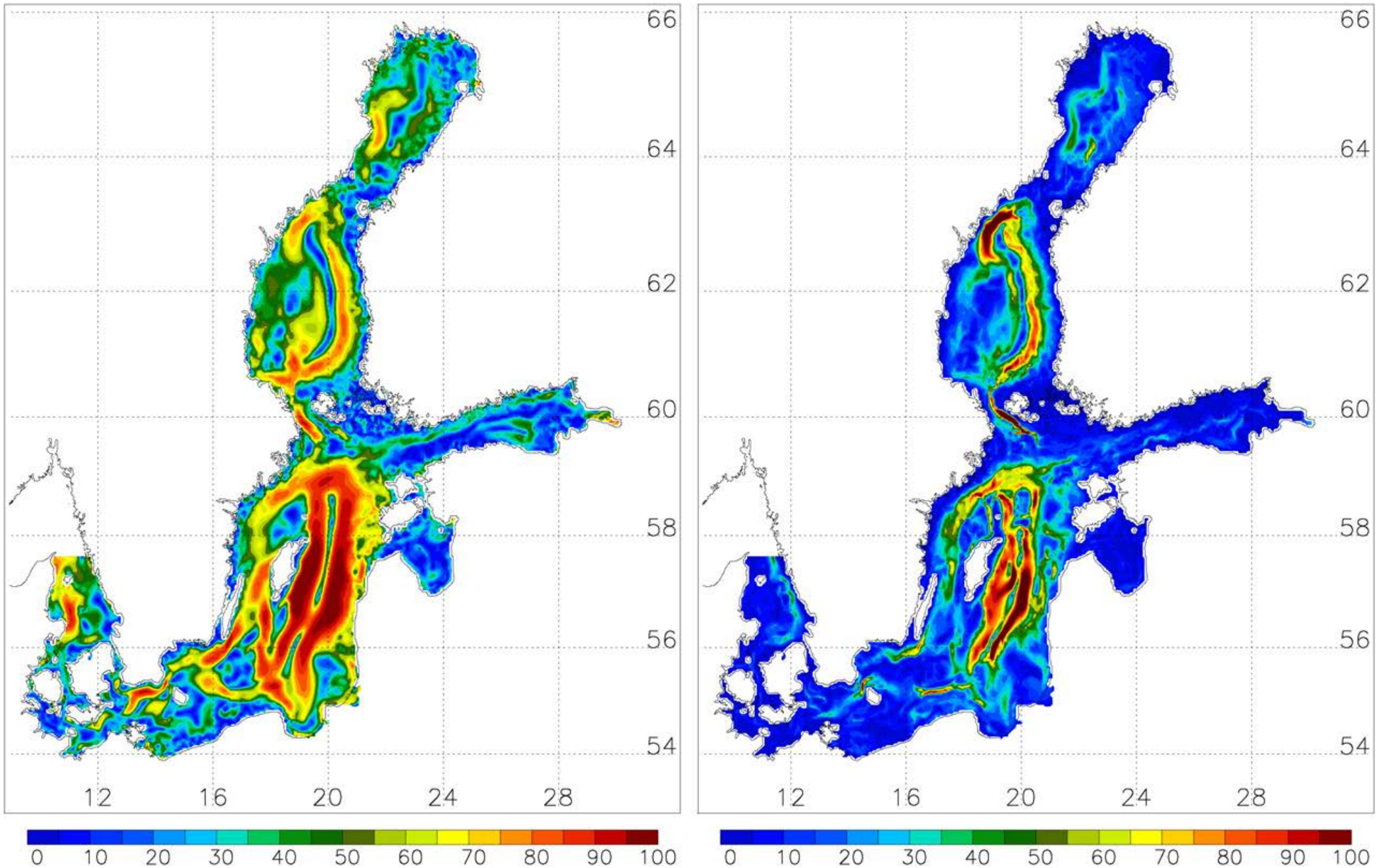


Upwelling frequencies [%] based on 443 SST maps for the period 1990–2009 (May–September):

Trend for upwelling frequencies [% decade−1] May–September (1990–2009) based on the analysis of 443 weeks

Andreas Lehmann, Kai Myrberg, Katharina Hoflich (2012)

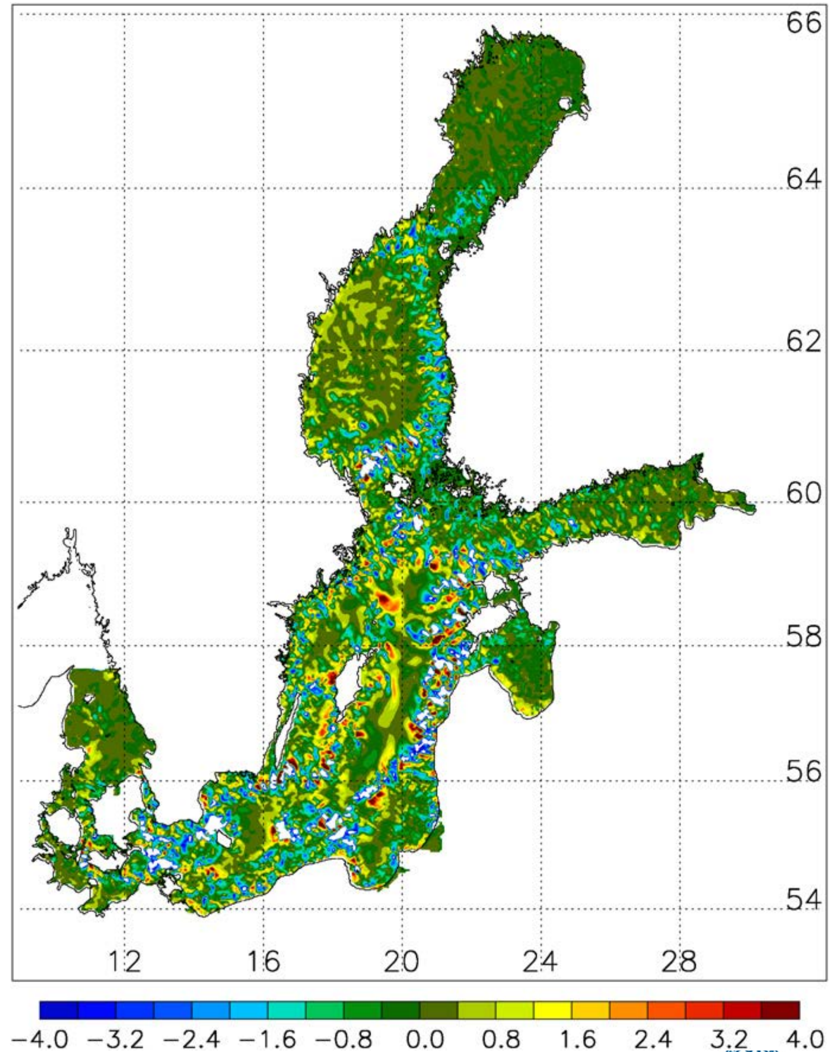
8. Modelling circulation and water age



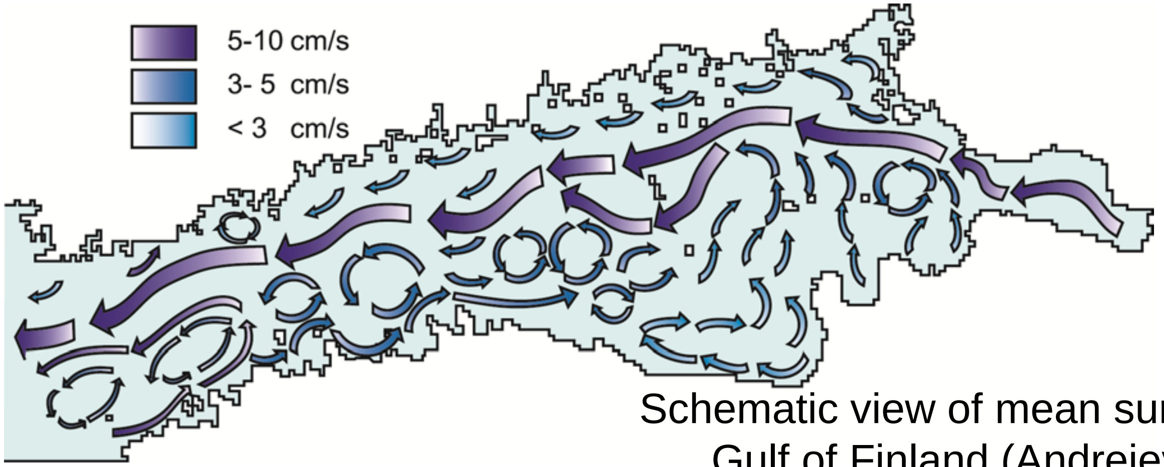
Persistency (in %) of the mean transport above (left panel) and below (right panel) the halocline for 1981-2004 (Meier, 2007)

Model implications "the large-scale vertical circulation are rather patchy, Meier (2007)"

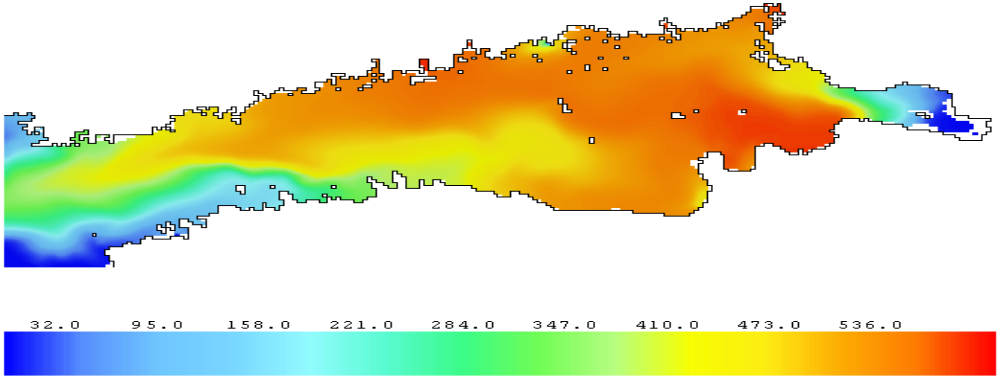
Mean vertical mass flux across the halocline of the tracer marking inflowing saltwater in the Arkona Sea (Meier, 2007)



8. Modelling circulation and water age, cont.



Schematic view of mean surface circulation in the Gulf of Finland (Andrejev, Myrberg, Lundberg, Alenius, BER 2004)



Water age (in days in the surface layer in the Gulf of Finland (Andrejev, Myrberg, Lundberg, Tellus 2004)

9. Some major findings and improvements (2003-2012)

- New data sets available (gridded datasets and long term data sets)
- New understanding regarding large scale circulation and the Baltic Sea
- Improved water and heat balances
- Improved understanding on sea ice drift
- New knowledge about strait flow dynamics and turbulence

  Improved understanding of sub-basin processes such as upwelling
- Improve understanding of processes related to air-sea and air-ice interaction
- Improved Baltic Sea models and coupling to land and atmosphere

10. Missing knowledge and future research needs

- In and out flows dynamics need more research efforts
- Strait flows and turbulence mixing needs more research
- Deep water circulation
- Costal processes during the ice season
- The hydrological cycle in the atmosphere climate models still has severe bias. Bias corrections larger than trends add large uncertainties to climate predictions
- River runoff data is not yet easy available. A major failure in the present science development.
- Efforts to homogenous hydrological and oceanographic observations are missing

Knowledge of the Baltic Sea physics gained during (2003-2012) illustrates interesting developments and the need for a new decade of research on physical processes. New research Initiatives are needed that promote physical oceanography.

Thanks