BACC II

3. Recent (mainly 200 years) and current climate change

3.b. Baltic Sea

3.b.i Marine physics

/ formerly: Hydrographic characteristics

outline by Jüri Elken

alternative titles

3.b.i. Stratification and circulation

3.b.i. Circulation and stratification

Introduction

1. Trends and variations in water temperature

2. Changes in stratification and water exchange

3. Circulation and transport patterns

4. Sensitivity to changes in forcing

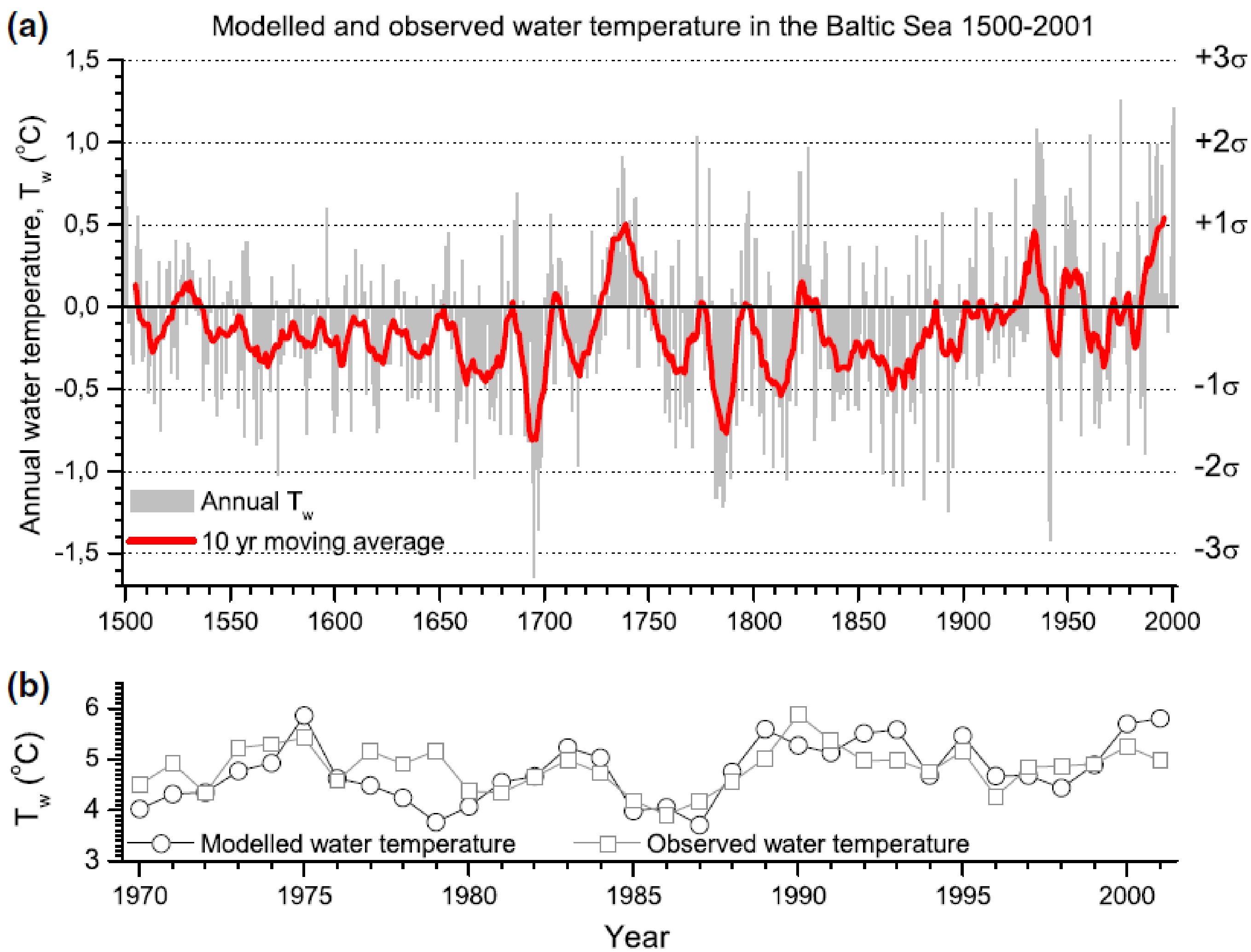
1. Trends and variations in water temperature

- Reconstructed long time series of annually mean temperature
    - *Figure 1 – time series*
    - *relate to cold-warm and dry-wet periods*
- Regional variations in sea surface temperature
    - *Figure 2 – map of recent trends based on remote sensing*
    - *discuss timing and amplitude of seasonal patterns*
    - *note that March SST forces the temperature of intermediate layer*

Figure 1

Annually mean water temperature ove depth and area

Fig. 5 **a** Anomalies of the annual and decadal moving average of the modelled Baltic Sea water temperature over the 1500–2001 period. The *dotted horizontal lines* are the standard deviations of the water temperature during the standard period 1900–1999. The warming in the 1930s and late twentieth century is comparable in magnitude to that in the first half of the eighteenth century. The late seventeenth century and late eighteenth century are the coldest periods in the past 500 years. **b** Observed (*grey squares*) and modelled (*black circles*) water temperatures in the Baltic Sea between 1970 and 2001



D. Hansson, A. Omstedt: Modelling the Baltic Sea ocean climate on centennial time scale

Clim Dyn 2008

Figure 1 (alternative)

Annually mean water temperature ove depth and area

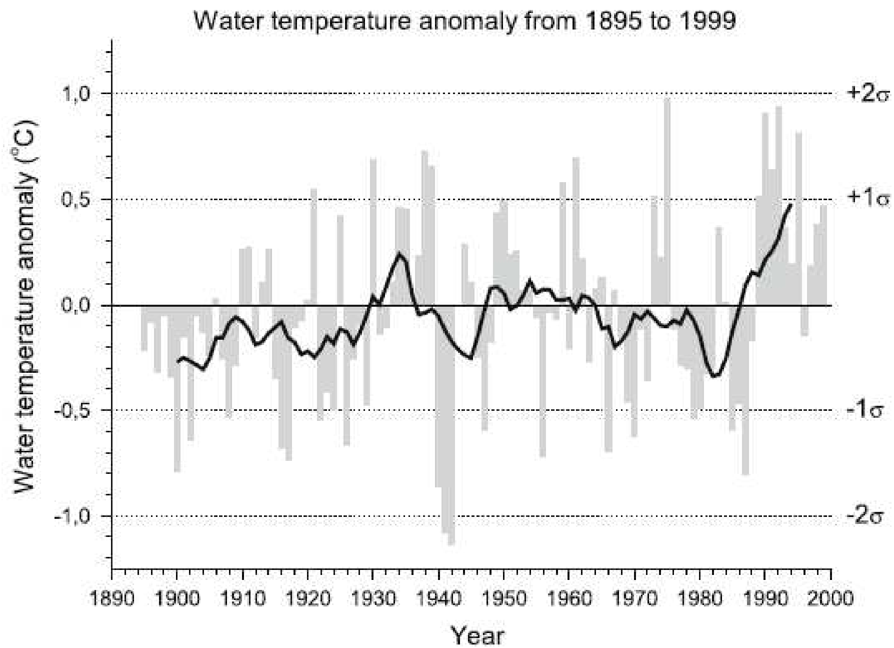


Fig. 3 Modelled annual mean water temperature anomaly over the 1895–1999 period. The anomaly is calculated as the deviation from the long-term mean of the 1900–1999 period. The decadal moving average (*black*) of the individual years (*grey*) reveals three warm periods in the twentieth century: the 1930s, 1950s, and 1990s. Two years have anomalies greater than two standard deviations (*dotted horizontal lines*): 1941 and 1942 where both exceptionally cold years. The warmest year (1975) is less than a tenth of a degree from exceeding two standard deviations

D. Hansson, A. Omstedt: Modelling the Baltic Sea ocean climate on centennial time scale

Clim Dyn 2008

Figure 2

Linear trend of annually mean SST

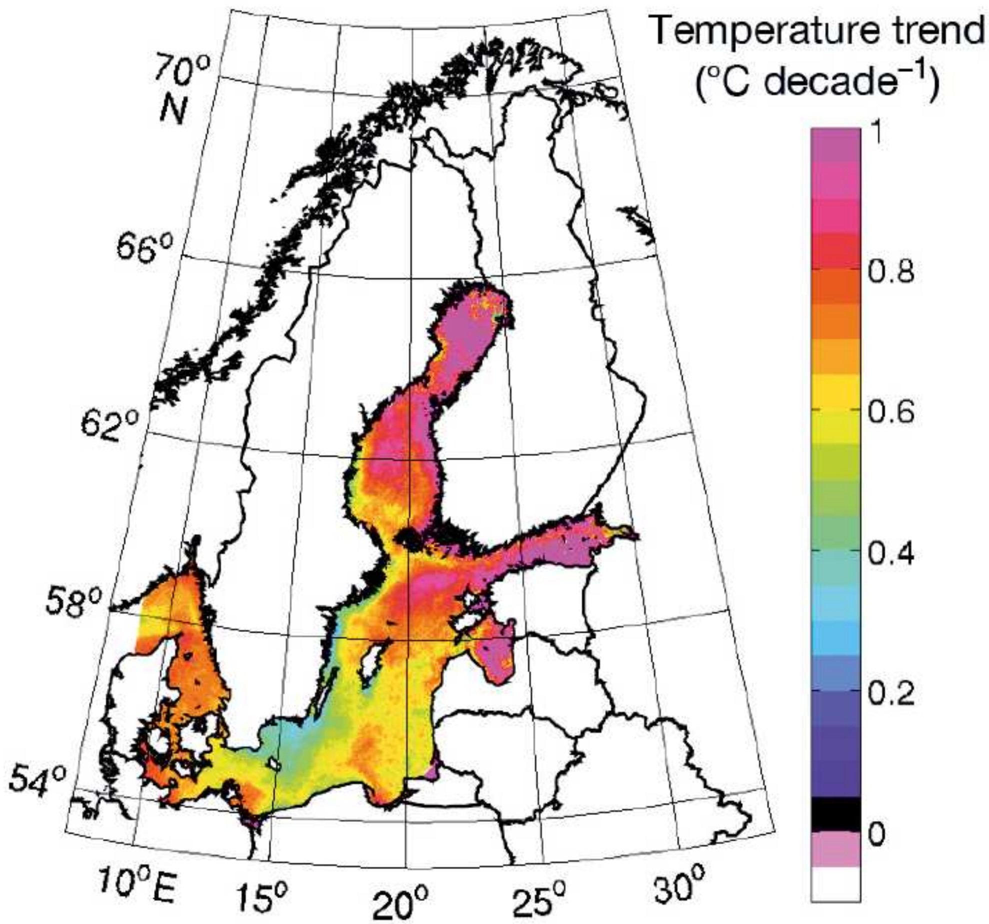


Fig. 10. Linear trend of the annual mean sea surface temperature based on infrared satellite data (1990 to 2008) provided by the Federal Maritime and Hydrographic Agency (BSH), Hamburg

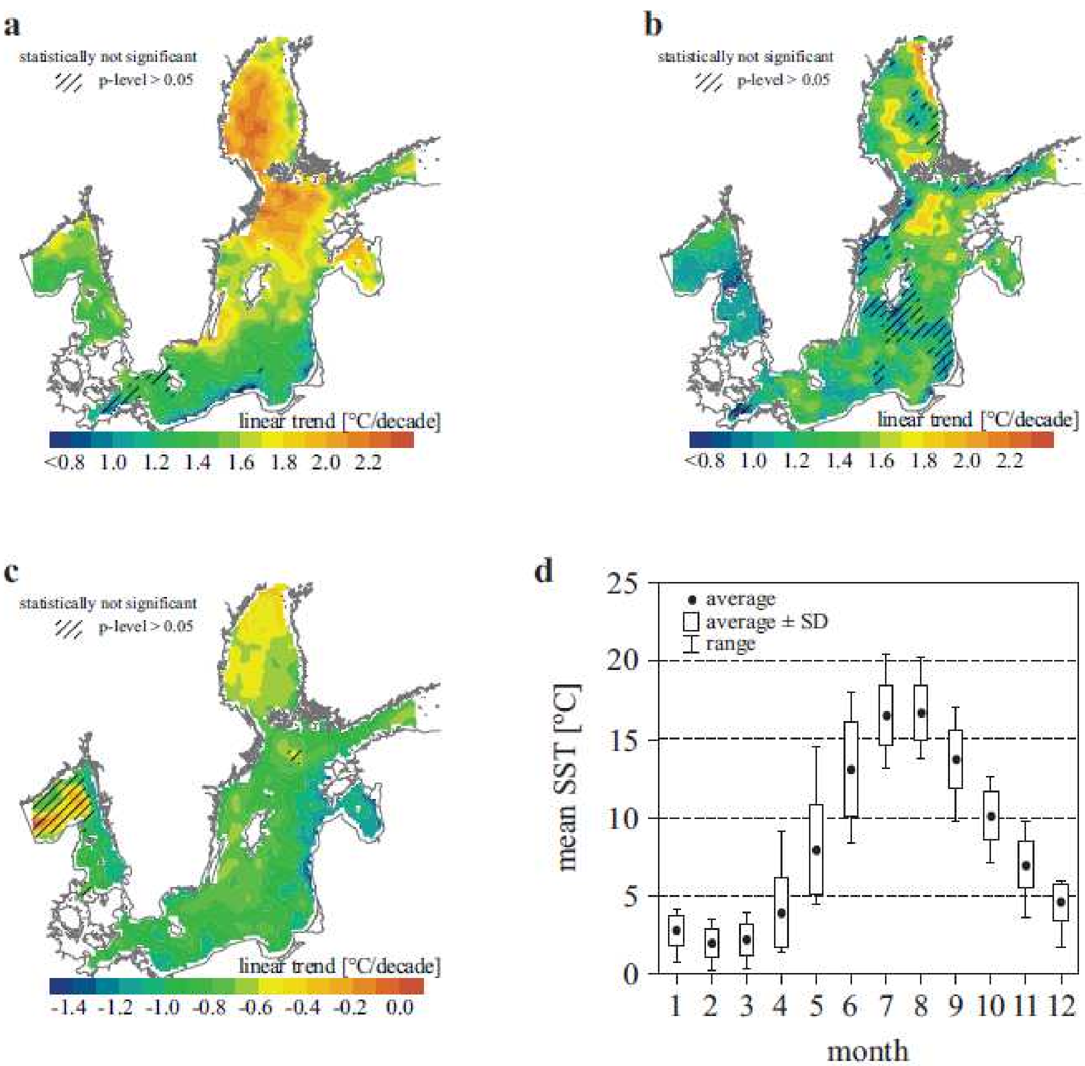
Lehmann et al.: Recent climate variability of Baltic region

Clim Res 2011

Figure 2 (alternative)

Linear trend of mean SST

August
September
March



Remote sensing SST data 1985-2006

means, trends, durations

Figure 5. Spatial distribution of August (a) and September (b) SST mean positive trends from 1986 to 2006, March SST mean negative trends from 1990 to 2006 (c), and variations in monthly mean SST from 1985 to 2006, averaged over the study area (d)

Oceanologia 2010

Figure 2 (alternative)

Annually mean SST

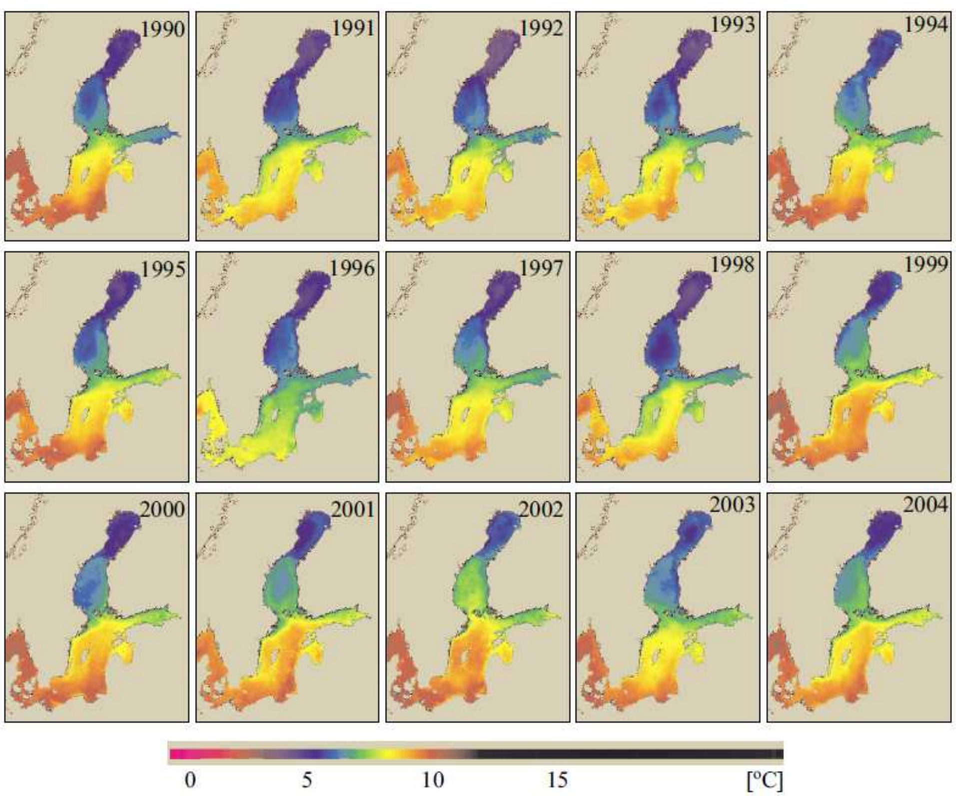


Fig. 3. Yearly mean SST of the Baltic Sea in the period 1990–2004

2006

Seasonal SST trends in 3 locations

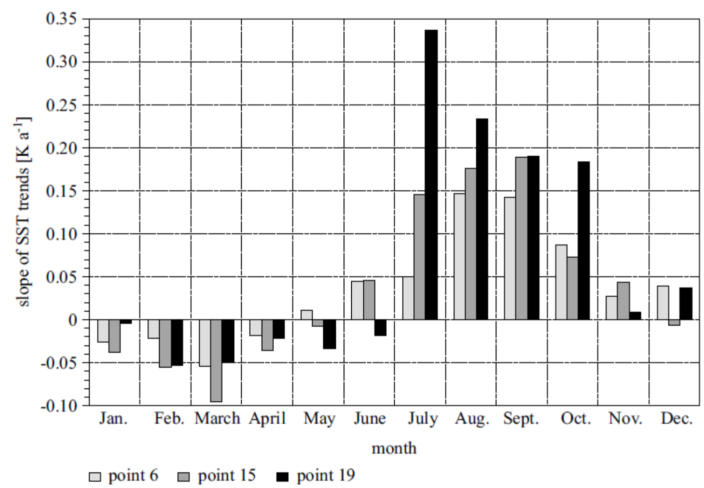


Fig. 8. Slope of the trends in different months in the Arkona Sea (6), Gotland Sea (15) and Bothnian Sea (19)

2. Changes in stratification and water exchange

- Long-term stratification changes in deep basins
    - *Figure 3 - saline water inflows and stagnations, Gotland Deep*
    - *discuss other basins, i.e. SSS, halocline and summer cold layer, stratification strength*
- Saltwater inflow events
    - *discuss inflow types, recent warm inflows, largest 1951 event*
    - *Figure 4 – entrance area time series (good figure missing at the moment)*
    - *Figure 5 – deep temperature changes since 1997 in Gotland Basin, describe nature of warm inflows*
- Halocline depths
    - *Figure 6 – mean and seasonal change of halocline depth*
    - *discuss mixing and regional events of halocline decay and collapse*

Figure 3

Salinity and oxygen in Gotland Deep 1902-2006

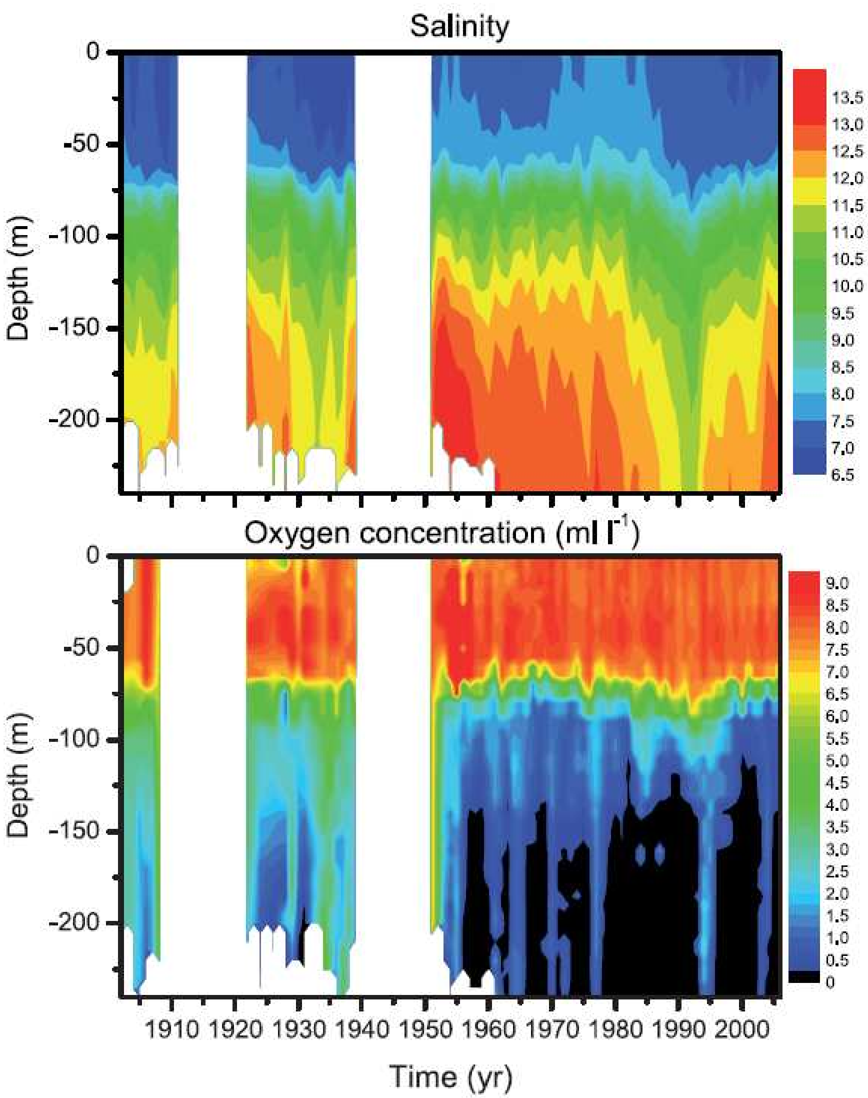


Fig. 2. Observed salinity and oxygen concentration (ml l^{-1}) at the hydrographic station BY15 in the eastern Gotland Basin, using data from the Baltic Environmental Database (BED) and the Swedish Ocean Archive (SHARK).

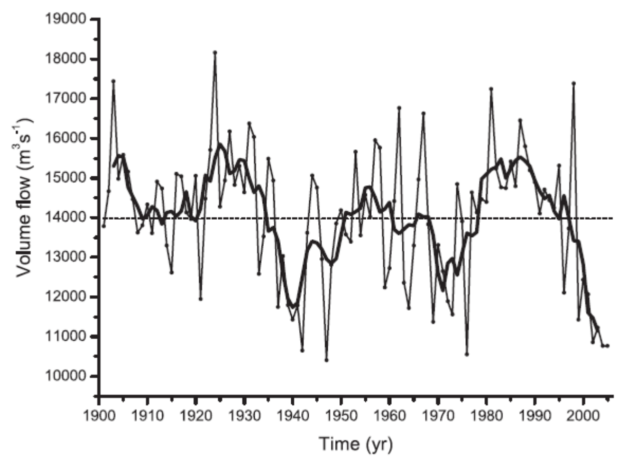


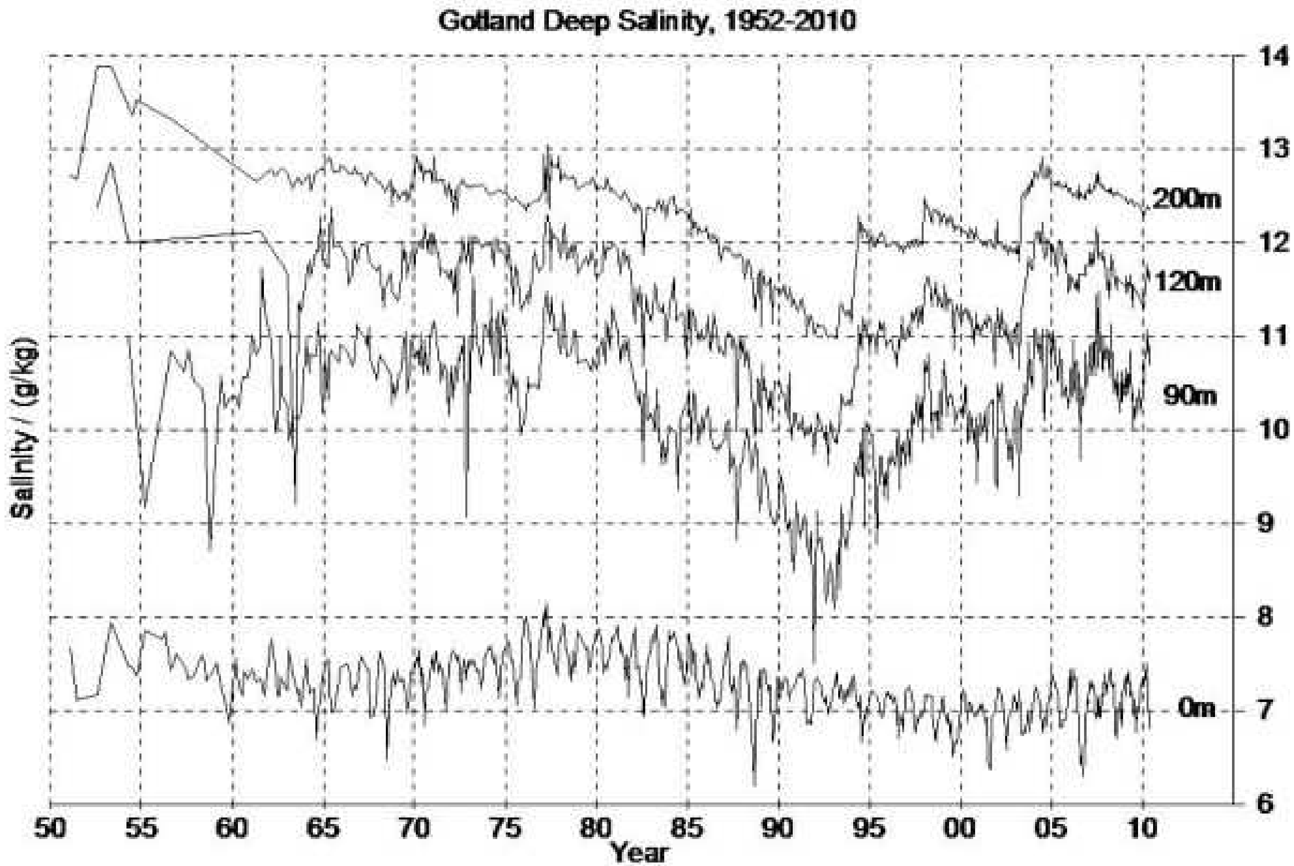
Fig. 3. Total river runoff to the Baltic Sea (not including the Kattegat). Annual mean (dots), total mean (dashed line) and four year running mean (thick line). For a detailed description of the data sources, *see* Material and methods.

Table 2. Volume weighted mean salinities in the different layers obtained from observations as well as the true forcing model run during the period 1961–1990. The mean values for the last 30 years of dry and wet climate experiments respectively are then compared to the true forcing model run.

Depth interval (m)	Observations	True forcing	Climat	
			Dry	Wet
0–60	7.6	7.6	+0.5	–1.6
60–125	9.7	9.3	+0.6	–1.8
125–250	12.0	12.1	+0.7	–1.9
0–250	8.5	8.4	+0.5	–1.7

Figure 3 (alternative)

Salinity in Gotland Deep 1952-2010



State and Evolution of the Baltic Sea, 1952 - 2005
A Detailed 50-Year Survey of Meteorology and Climate, Physics, Chemistry, Biology, and Marine Environment
Editors: Rainer Feistel, Günther Nausch, Norbert Wasmund
Wiley 2008

Figure 4

Entrance area time series

includes largest inflow 1951

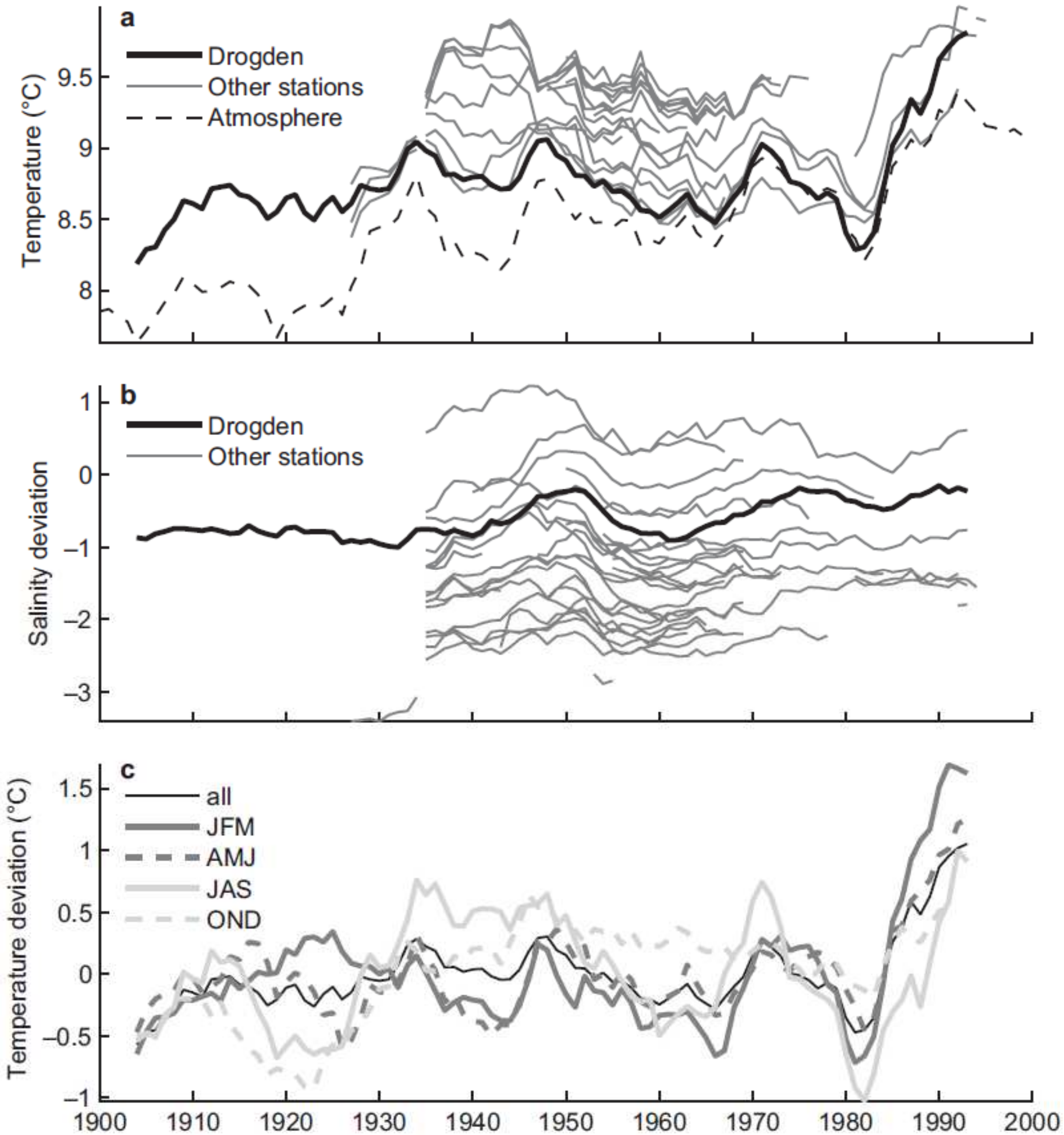


Fig. 6. 10 year running mean surface data. — **a**: temperature. — **b**: salinity deviations from climatology. — **c**: seasonal temperatures (January–March, April–June, July–September, and October–December), deviations from seasonal mean.

Madsen and Hojerslev 2009 BER

Figure 4 (alternative)

Entrance area time series

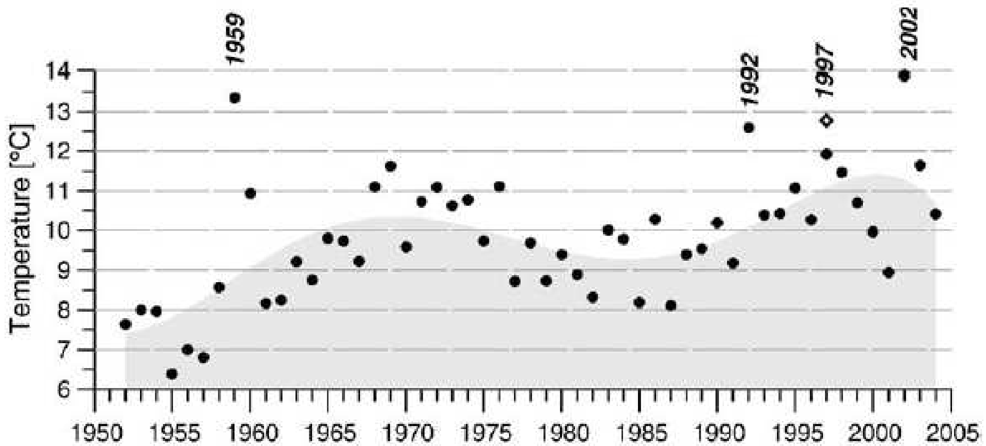


Fig. 11. Annual temperature maximum in the halocline layer (salinity between 8.95 and 14.3) of the Bornholm Basin. In 1997, the core warm inflow water was found just below the defined halocline. This value is indicated by a diamond symbol.

V. Mohrholz et al. / Journal of Marine Systems xx (2006) xxx–xxx

there could be something else

Figure 5

Recent deep temperature changes in Gotland Basin

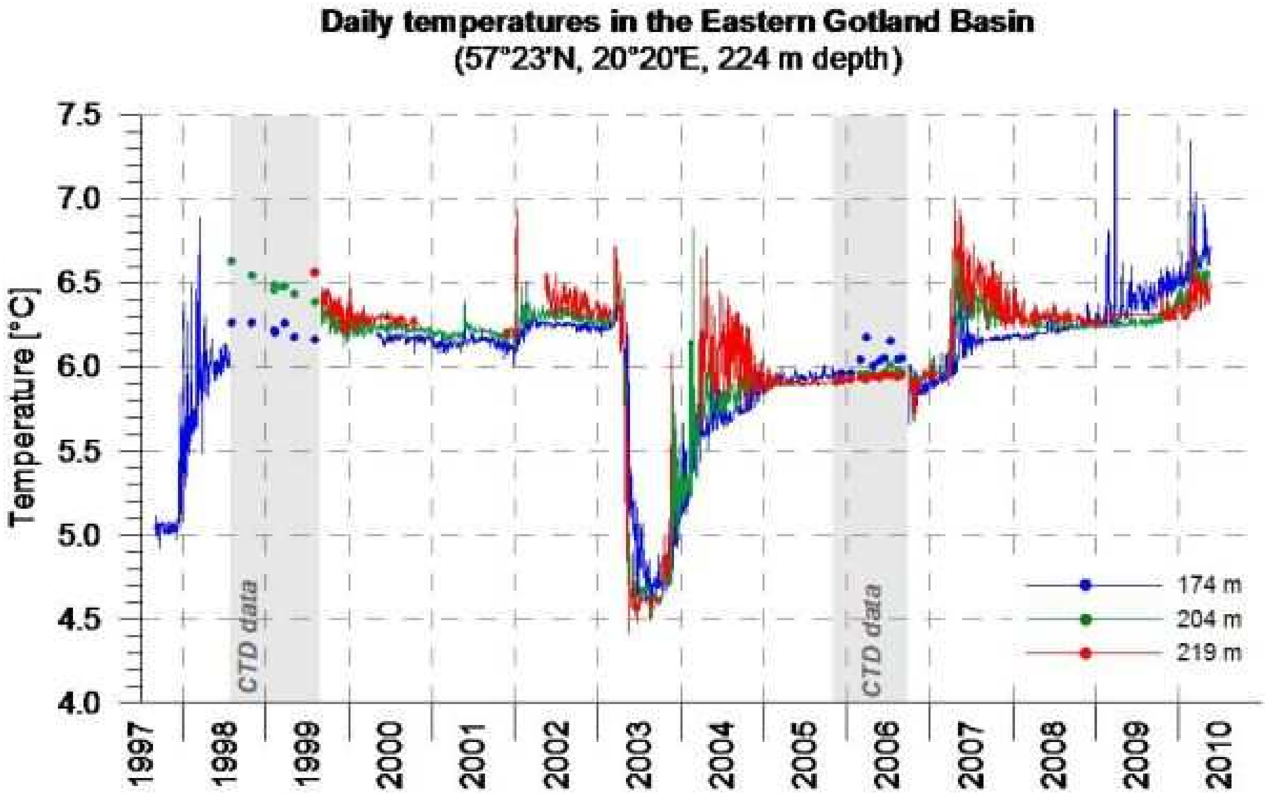


Fig. 1. Temperature series 1997–2005 of the EGB mooring near the Gotland Deep (Fig. 4) at 174, 204 and 219 m depth. Bathymetric depth at the anchor position is 224 m. The temperature signals caused by the latest cold (January 2003) and warm (all others) inflow events are indicated by arrows

Updated from HELCOM fact sheets

R. Feistel, G. Nausch, E. Hagen   Unusual Baltic inflow activity in 2002–2003 and varying deep-water

OCEANOLOGIA, 48 (S), 2006.
pp. 21–35.

Figure 6

Mean halocline depth and seasonal difference

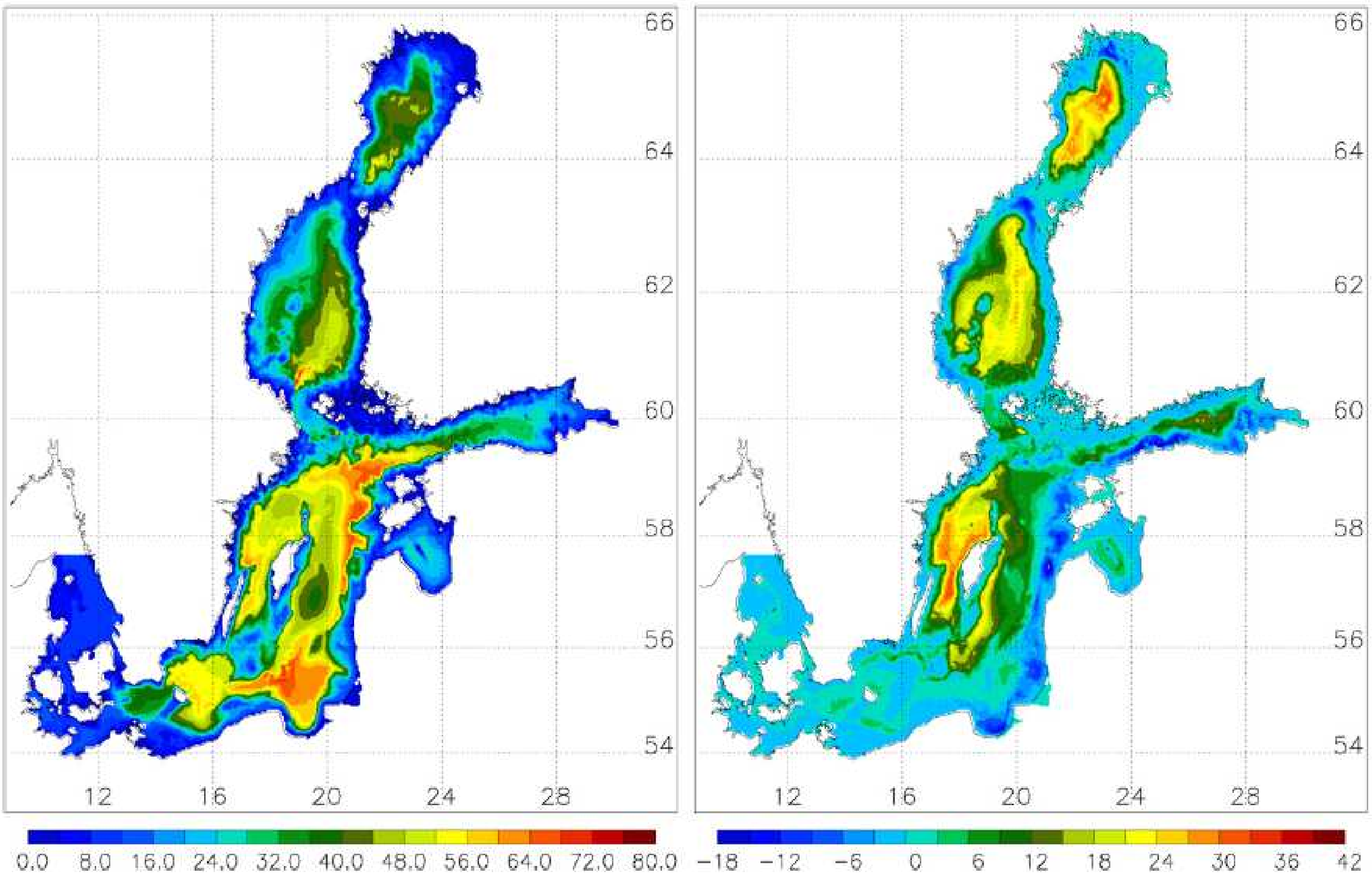


Fig. 7. Halocline depths (in m) for 1981−2004: annual mean (left panel) and difference between spring and autumn means characterizing the seasonal variation (right panel).

H.E. Markus Meier / Estuarine, Coastal and Shelf Science 74 (2007) 610−627

3. Circulation and transport patterns

- Mean currents or transports, if possible mean maps over specific decadal periods
    - *Figure 7* – *maps of currents or transports (good figure missing)*
    - *discuss changes in current speed (increasing?)*
- Freshwater spreading patterns
    - *Figure 8* – *juvenile freshwater patterns*
    - *discuss area with* $S < 5$ *PSU*
- Saltwater spreading patterns
    - *discuss if pathways have been changed*

Figure 7

maps of currents or transports (good figure missing)

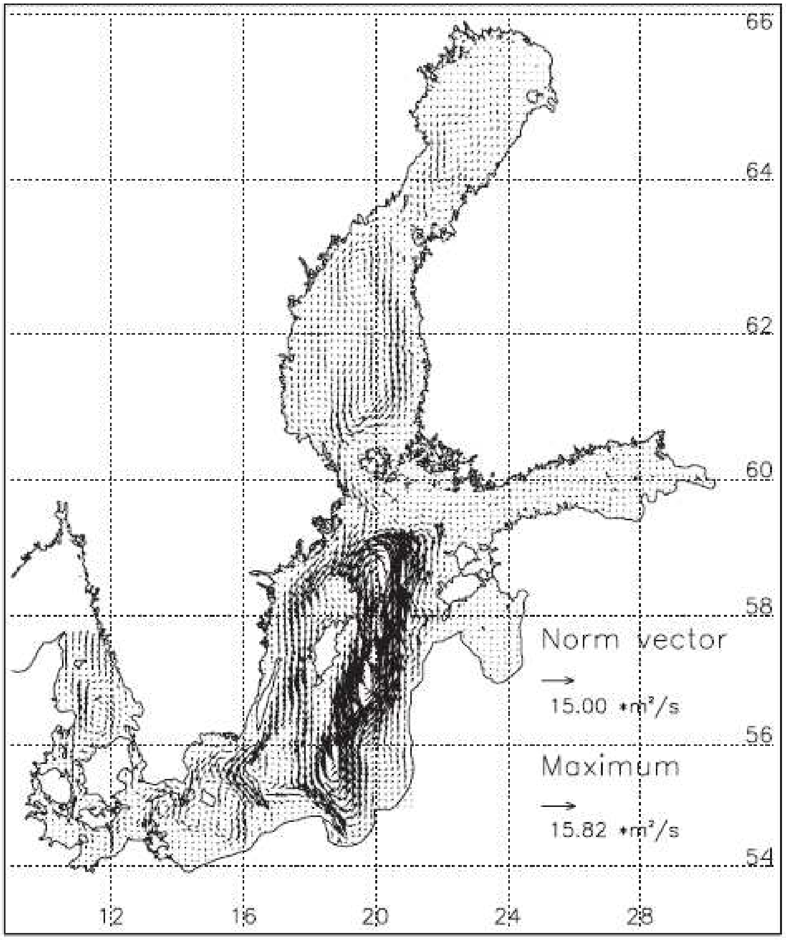


Fig. 8. Annual mean transport per unit length (in $m^2 s^{-1}$) for 1981–2004 above the halocline. Only vectors at every third gridpoint of the model are shown.

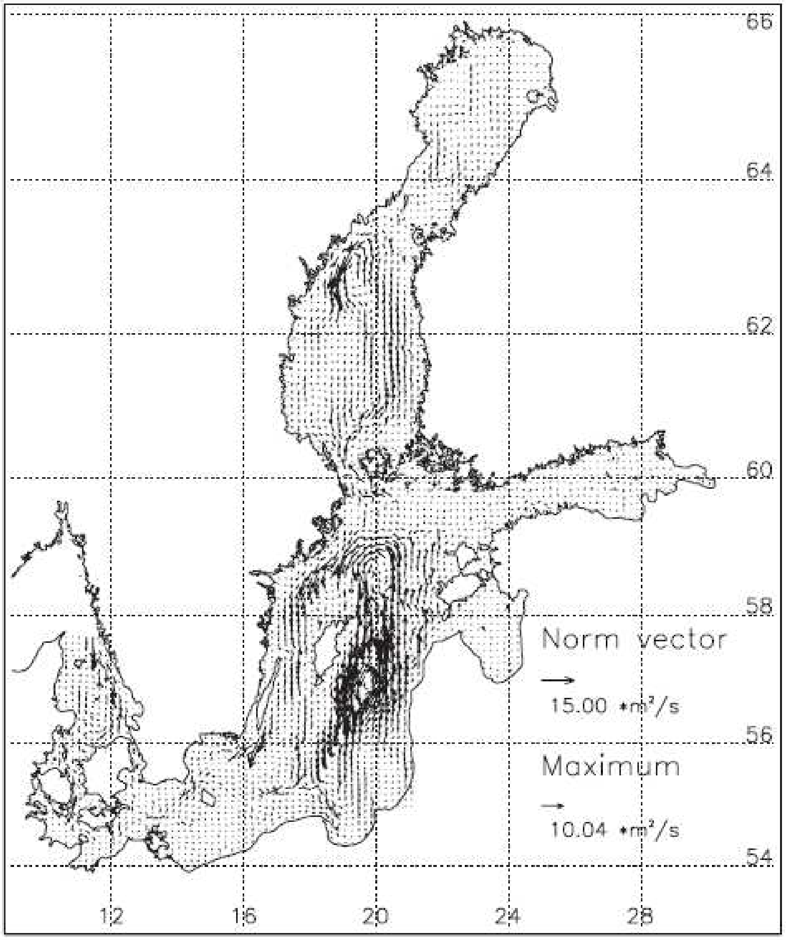
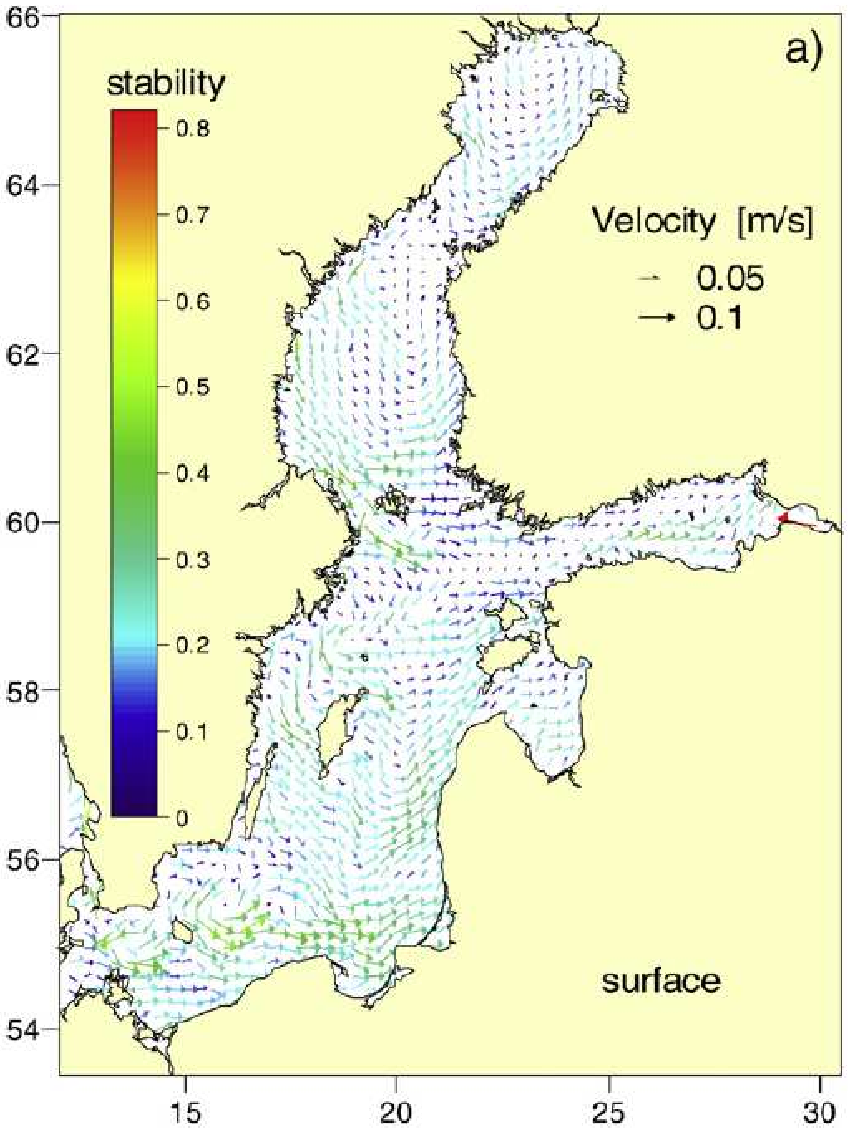


Fig. 9. As Fig. 8 but transport below the halocline.

H.E. Markus Meier / Estuarine, Coastal and Shelf Science 74 (2007) 610–627

Figure 7 (alternative)

maps of currents or transports (good figure missing)



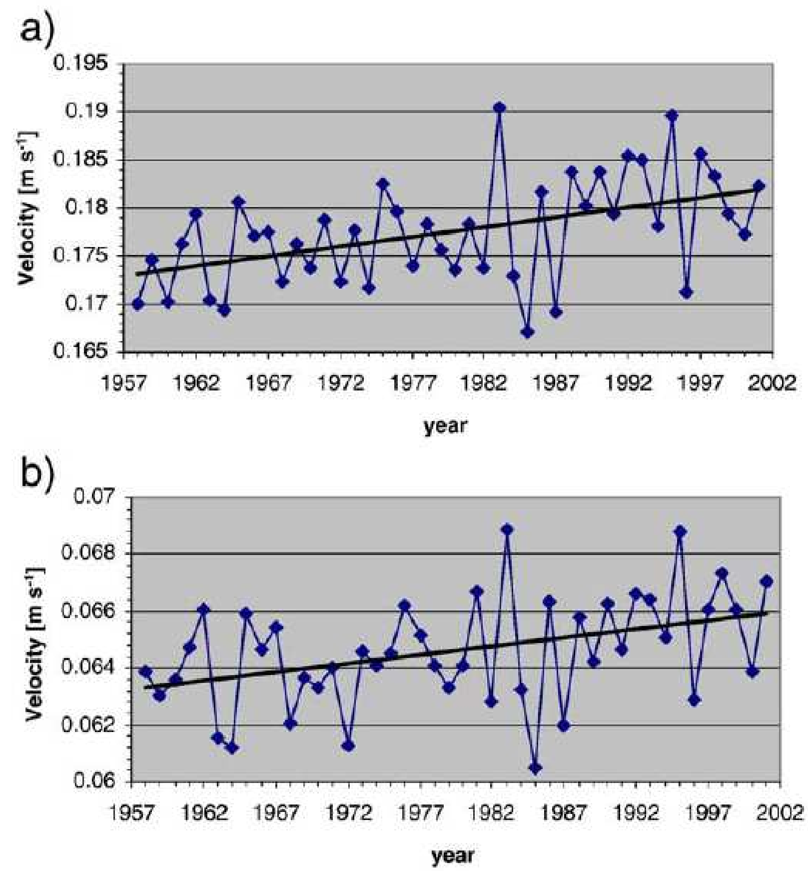


Fig. 12. a) Yearly averaged velocities [ms^{-1}] surface currents in the Baltic Sea in 1958–2001 b) Yearly averaged velocities [ms^{-1}] of currents at 20 m depth in the Baltic Sea in 1958–2001.

J. Jędrasik et al. / Coastal Engineering 55 (2008) 849–860

Figure 8

freshwater spreading patterns

Juvenile freshwater heights 1961-2004

Are there decadal differences?

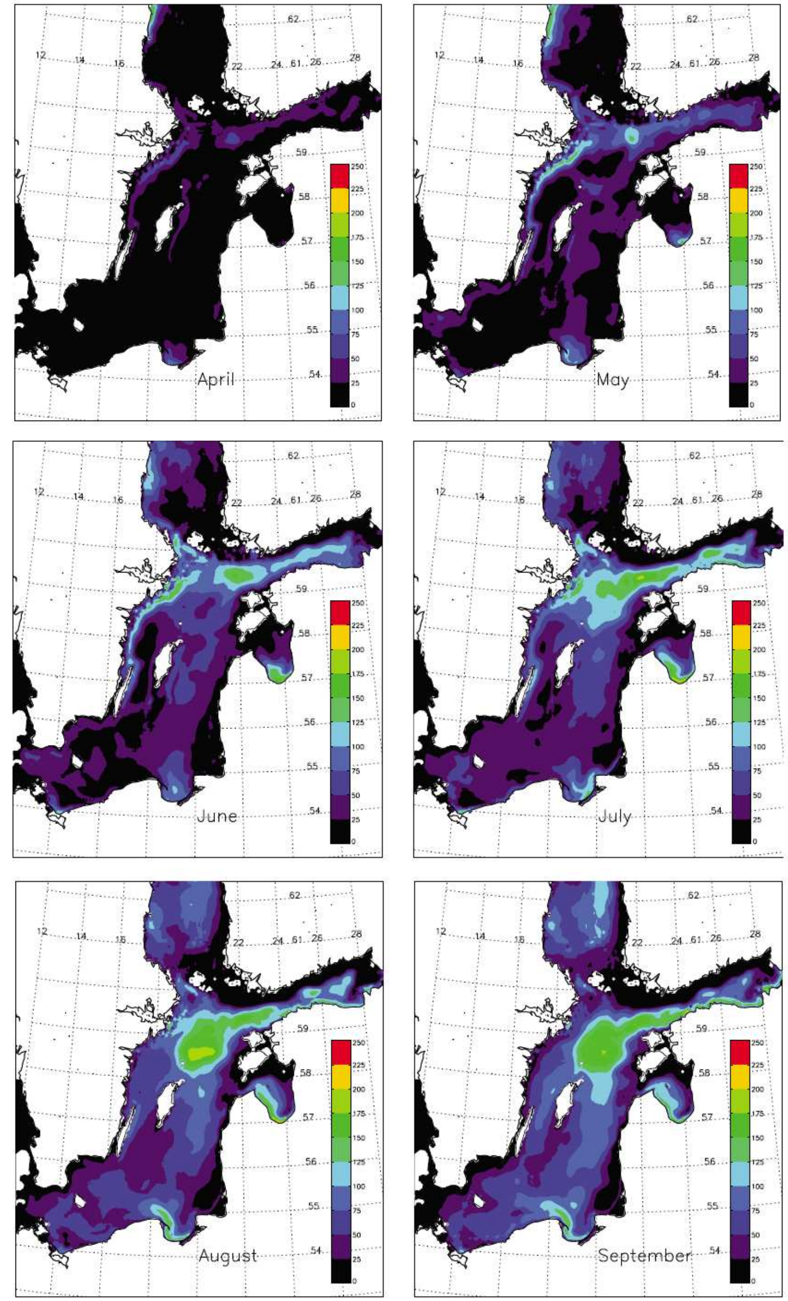


Figure 6. Juvenile freshwater height (in cm) in the Baltic proper for April–September calculated from the tracer marking freshwater from the rivers.

4. Sensitivity to changes in forcing

- Temperature dependence on air temperature /
- Salinity response to freshwater discharge
  - *Figure 9 – response curves*
- Circulation and mixing response to winds
  - *discuss the effect of changing speeds and directions*

Figure 9

Sensitivity to changes in freshwater

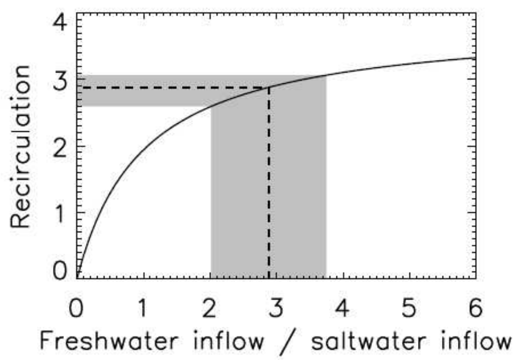


Figure 10. Recirculation factor as a function of the normalized freshwater inflow, i.e., the ratio between freshwater and saltwater inflows. Dashed lines show present climate using standard figures [*Stigebrandt*, 2003]. The shaded area indicates the range between 30% increased and reduced freshwater inflows.

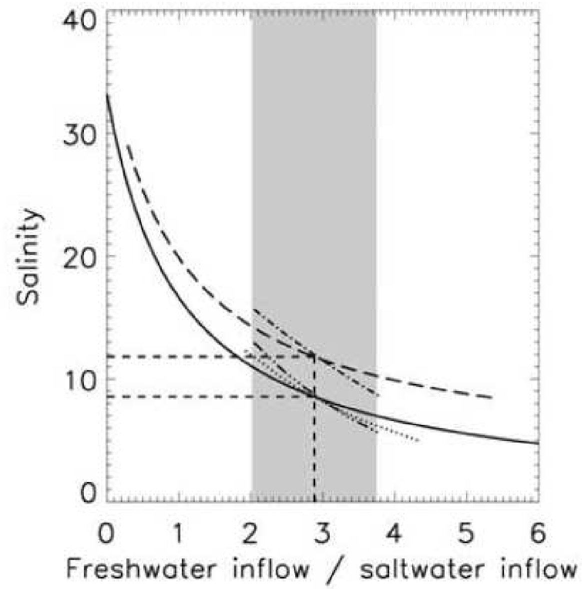


Figure 11. Total mean sea surface salinity (SSS) and deep water salinity (in ‰) as a function of the normalized freshwater inflow: SSS (solid line) and deep water salinity (long-dashed line) of the analytical model following *Stigebrandt* [2003], SSS of the process-oriented model by *Stigebrandt* [1983] (dotted line), and mean SSS in 1.5 m depth (dash-triple-dotted) and deep water salinity in 100 m depth (dash-dotted line) at BY15 of the RCO model for 1951–1998. Dashed lines show present climate using standard figures [*Stigebrandt*, 2003]. The shaded area indicates the range between 30% increased and reduced freshwater inflows.

Figure 9 (alternative)

Sensitivity to changes in freshwater

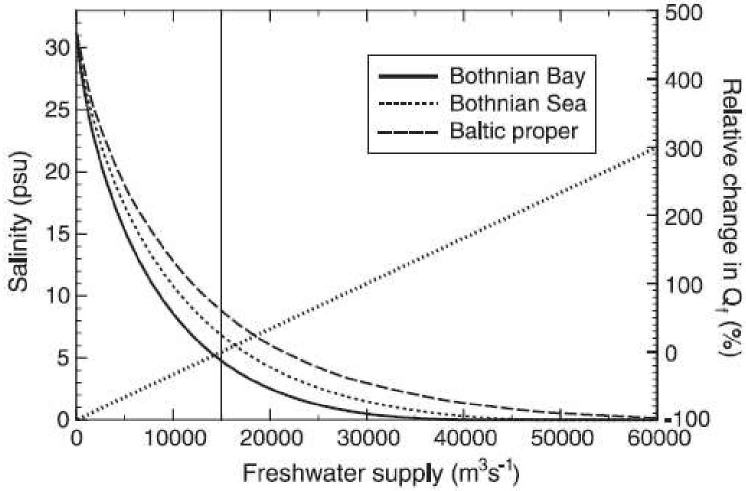


Fig. 8. Computations of steady-state salinity in the Baltic proper, Bothnian Sea and Bothnian Bay vs freshwater supply. The increase of supply of freshwater is distributed as in the present-day Baltic Sea.

A. Stigebrandt, B.G. Gustafsson / Journal of Sea Research 49 (2003) 243–256

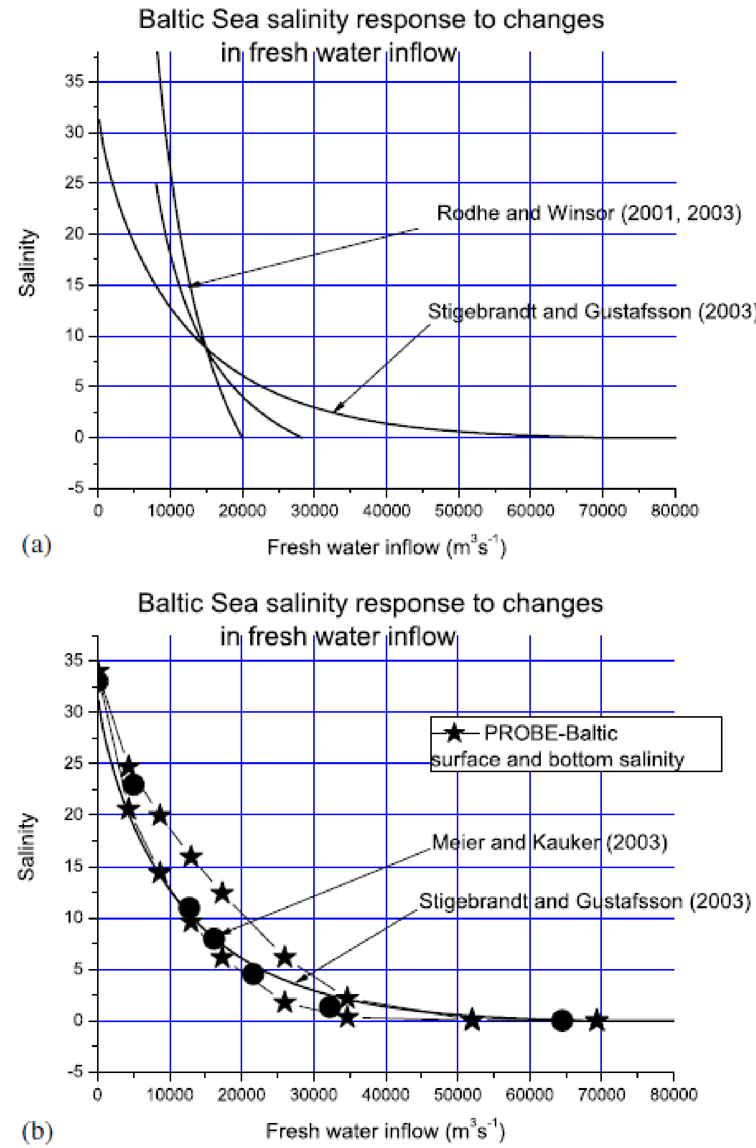


Fig. 8. Calculated steady-state salinities in relation to change in freshwater inflows.

A. Omstedt, D. Hansson / Continental Shelf Research 26 (2006) 236–251