BACC-2

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

3.4. Baltic Sea

3.4.1 Marine circulation and stratification

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Introduction (missing)

3.4.1.1. Trends and variations in water temperature

3.4.1.2. Changes in salinity, stratification and water exchange

3.4.1.3. Circulation and transport patterns and processes

3.4.1.4. Sensitivity to changes in forcing

Concluding remarks (missing)

Working method: literature survey and BACC-2 related highlights detection

Example:

Paper	Period	Data	Findings
			Trends and variations in water temperature
Hanson and Omstedt (2008)	1500-2001	Reconstructed annual means with PROBE, different atmosphere	Mean water temperature over the whole sea: Cold anomaly -0.7 in 1960s and 1780s, warm 0.5 in 1730s, 1930s and presently. Yearly values during 1970-2001 between 3.5 and 6 °C. Individual years: coldest 1941 and 1942, warmest 1975.
MacKenzie and Schiedek (2007)	1861-2005	Reprocessed raw daily observational data	Nearly all of these data series display significant warming and cooling at shorter (multiannual) time scales. In particular, approximately half time series show a warm period in the mid-1900s and that warming has occurred during the last 10–15 years. Temperatures during this first warm period were in many years similar to, and in some individual years even higher than, those measured in the late 1990s and early 2000s. The probability of extremely warm winters, summers and years has increased by two- to fourfold in the 1990s and 2000s relative to the probability in nearly all previous decades. Summer warming rates since 1985 are nearly triple those that could be expected on the basis of the emerging consensus view of the global warming of air temperatures.
Lehmann et al. (2011)	1990-2008	SST, remote sensing	Highest linear trend of annually mean SST – up to 1 °C decade^{-1} in the northern part of the Bothnian Bay, in the Gulfs of Finland and Riga and in the Northern Baltic Proper.
Bradtke et al. (2010)	1986-2006	SST, remote sensing	Highest positive trend more than 2 °C decade^{-1} in August, in the Bothnian Sea and Northern Baltic Proper. At the same time, mean temperature in March decreased by the highest rate in the Gulf of Riga and eastern part of the Baltic Proper.
Siegel et al. (2006)	1990-2004	SST, remote sensing	Highest increasing trend in the Bothnian Sea in July (more than 3 °C decade^{-1}), and in the Arkona and Gotland Sea in August and September (about 1.5 °C decade^{-1}).

Contents with (non-implicit) sub-structure

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- Warming of sea waters
- Temperature changes in deep water
- Reconstruction of 500 years time series

3.4.1.2. Changes in salinity, stratification and water exchange

- Better understood salt cycle and water exchange features and effects
- Specifics of salinity and stratification change in sub-regions
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3.4.1.3. Circulation and transport patterns and processes

- General characteristics of surface circulation
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- Mixing
- Rossby-radius

3.4.1.4. Sensitivity to changes in forcing

- NAO effects on wind
- Changes in upwelling events
- Sensitivity to freshwater supply
- Effects of climate warming
- Effects of changing temperature of maximum density

3.4.1.1. Trends and variations in water temperature

Better understood heat cycle features

- response time to heat flux about year, salinity response (lateral processes) many decades
- cold intermediate layer keeps the memory of the severity of the previous winter (good correlation)
- below 100 m the volume is 12% and temperature variation range small = effect of lateral heat flux is small

3.4.1.1. Trends and variations in water temperature

Warming of sea waters

- record warming during the recent decades since the 1860s
- probability of extremely warm winters and summers increased since the 1990s
- regional observations confirm warming
- independent SST increase estimates from remote sensing: highest in the northern and eastern areas

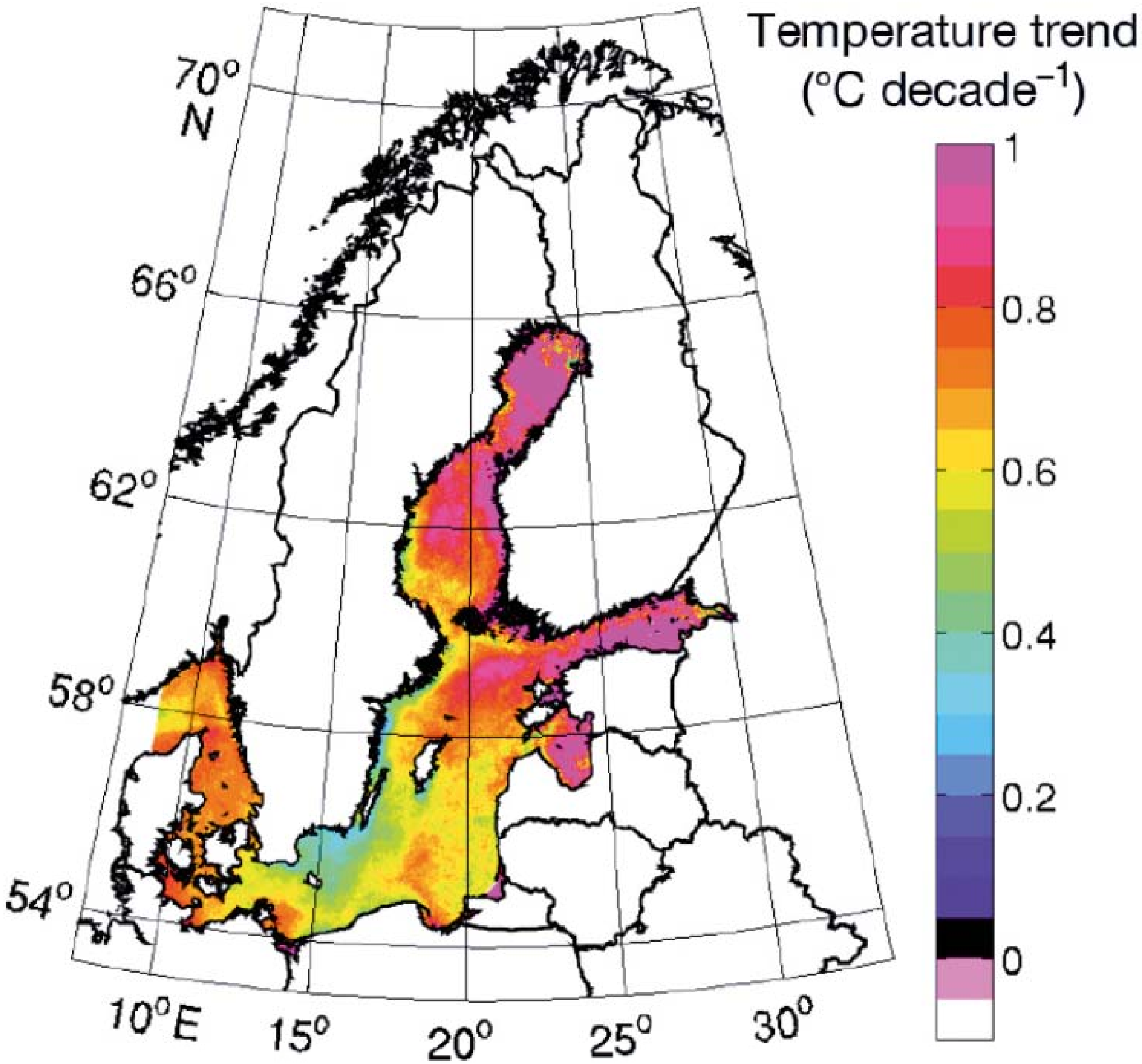

Fig. 3.4.1. Linear trend of the annual mean sea surface temperature based on infrared satellite data (1990 to 2008) provided by the Federal Maritime and Hydrographic Agency (BSH), Hamburg. (Lehmann et al, 2011).

3.4.1.1. Trends and variations in water temperature

Temperature changes in deep water

- Bornholm deep temperature 1989-2004 has increased by about 1 °C compared to the longer period 1950-2004
- warming also in colder intermediate layer

3.4.1.1. Trends and variations in water temperature

Reconstruction of 500 years time series

- sea water warming during the present period is comparable in magnitude to that in the 1930s and in the first half of the 18th century

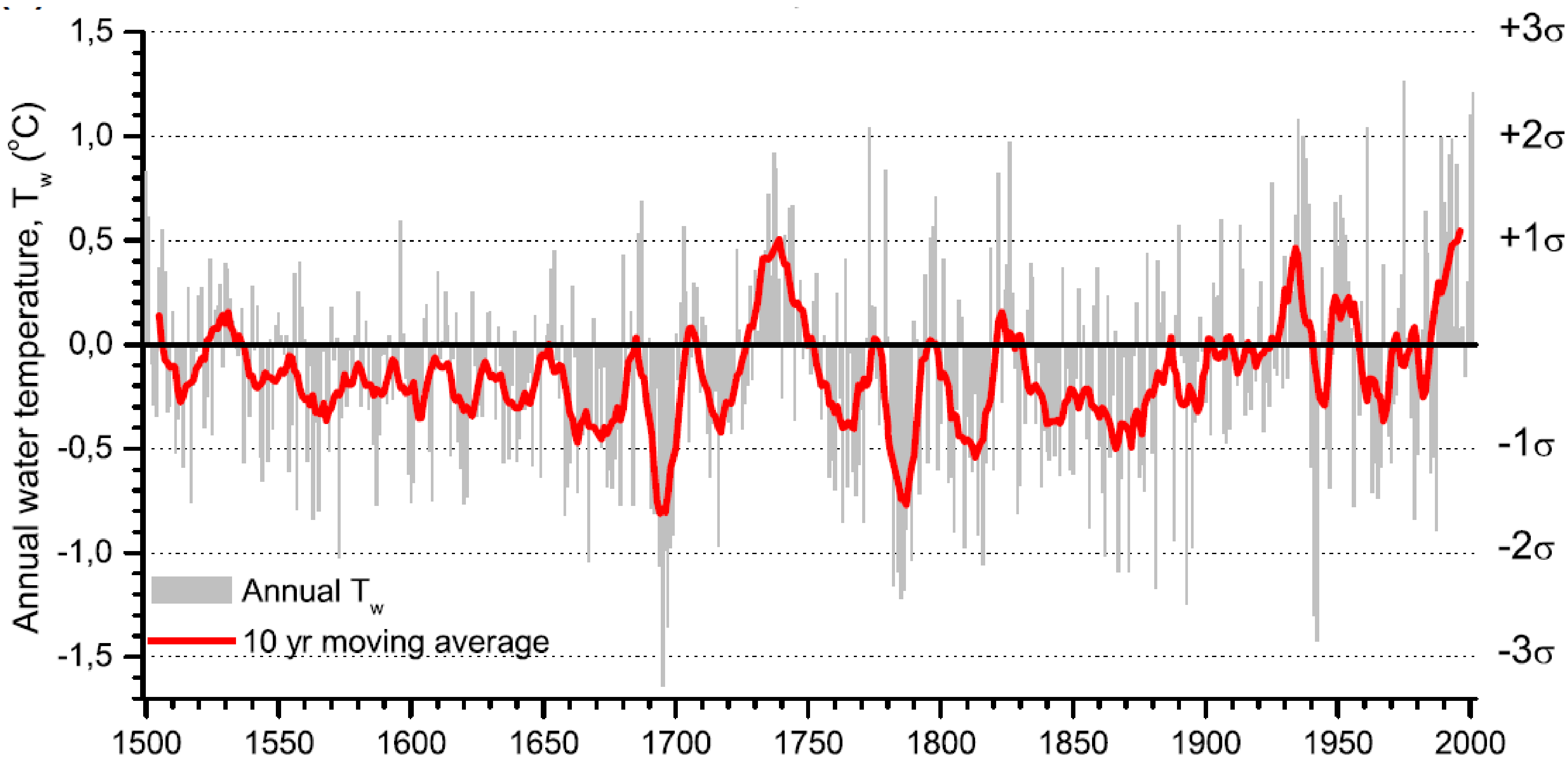

Fig. 3.4.2. Anomalies of the annual and decadal moving average of the modeled Baltic Sea spatially mean water temperature over the 1500–2001 period. The dotted horizontal lines are the standard deviations of the water temperature during the standard period 1900–1999. (Hansson and Omstedt, 2008).

3.4.1.2. Changes in salinity, stratification and water exchange

Better understood salt cycle and water exchange features and effects

•water exchange with the North Sea
•earlier and recent stratification changes in the Gotland Deep: low salinity period (such periods occurred also earlier; new knowledge about the 1951 inflow
•new „baroclinic“ inflows since 2003, response in deep temperature

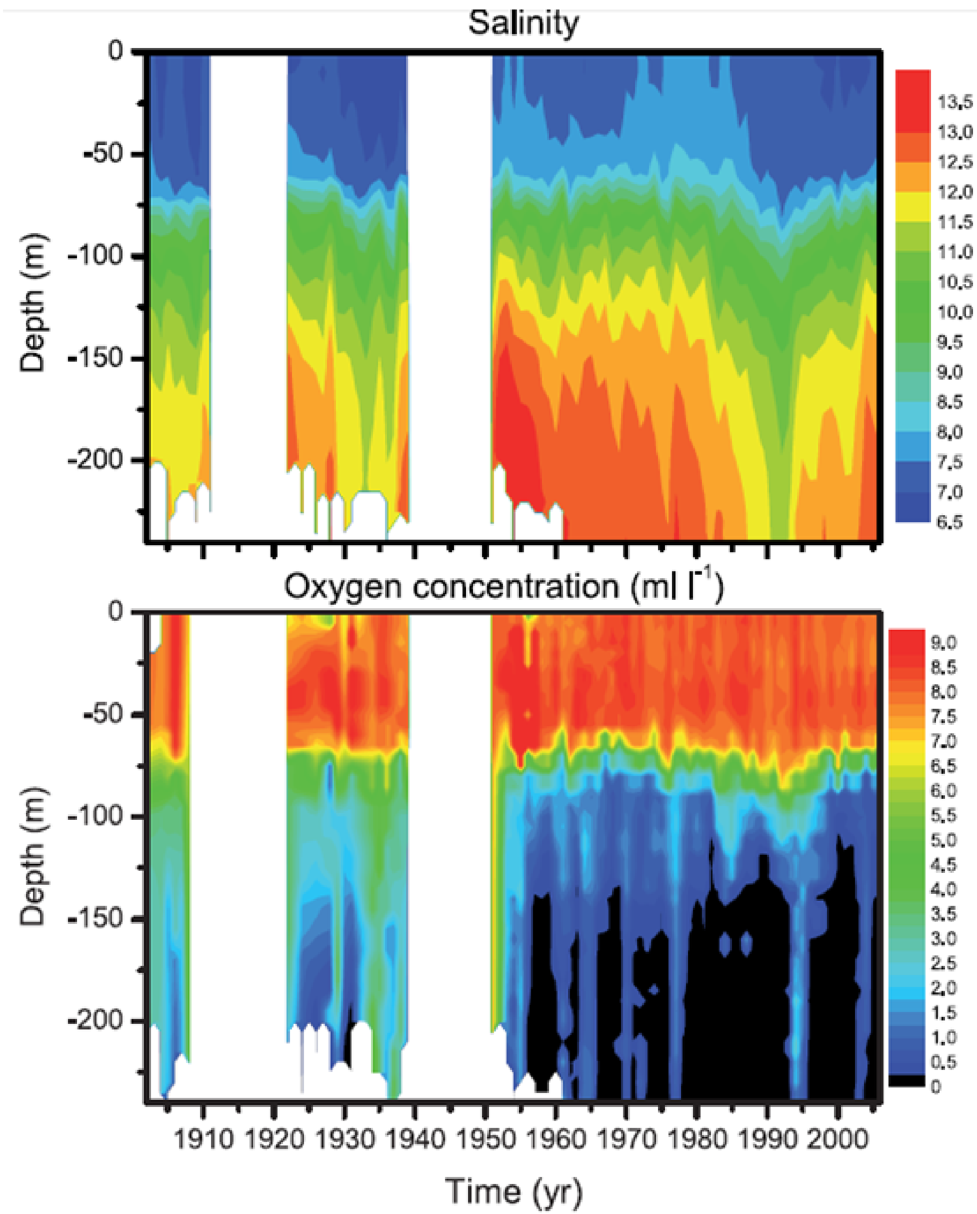

Fig. 3.4.3. Observed salinity and oxygen concentration in the Gotland Deep. // Now taken from Gustafsson and Omstedt, 2009; to be redrawn with most recent data. Perhaps a line/dot graph with vertically mean salinity could be also useful. May be oxygen can be omitted? //

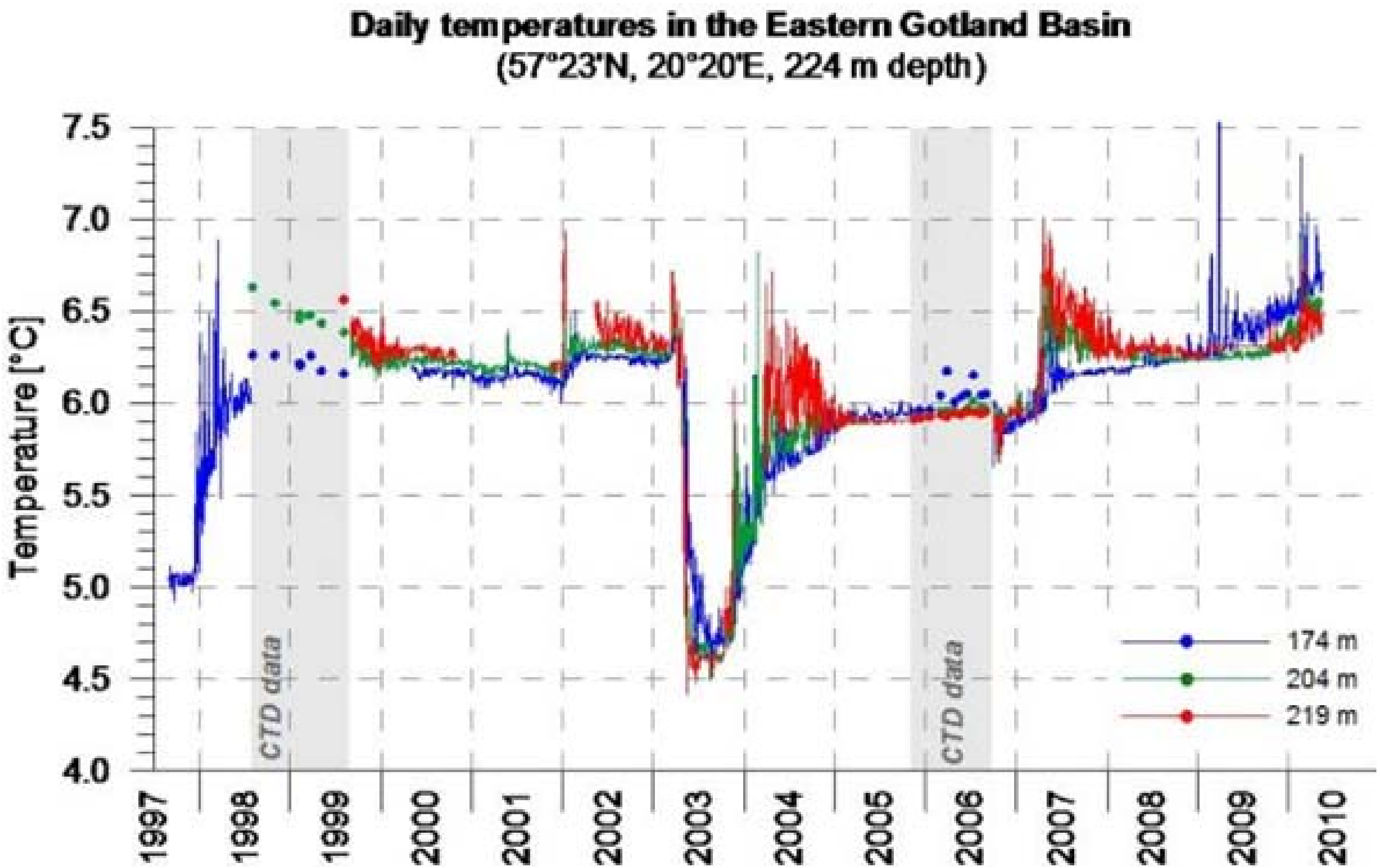

Fig. 3.4.4. Temperature series August 1997- May 2010 of the Eastern Gotland Basin mooring near the Gotland Deep at 174, 204 and 219 m depth. No important inflow events occurred since 2003. Thus, the stagnation period lasting since 2004/2005 is intensified. Some recent baroclinic inflows in 2006 and barotropic inflows in 2007 and 2009 changed the deep water temperatures and improved the oxygen situation in the southern Baltic slightly, but not in the deeps around Gotland. From Feistel et al, 2006, updated from HELCOM Indicator Fact Sheets 2010, Online.

3.4.1.2. Changes in salinity, stratification and water exchange

Specifics of salinity and stratification change in sub-regions

- important for regional ecology
- higher salinity variations upstream (SW) from the Gotland Deep
- in SE (Lithuanian) waters recent increase of stratification strength
- in the Gulf of Finland salinity change is not synchronous to the Gotland Deep: increased stratification strength, but oxygen conditions good (explanations: decreased ice coverage = better mixing, + more frequent halocline collapse)

3.4.1.2. Changes in salinity, stratification and water exchange

Note on 500 years salinity reconstruction

- salinity has slowly increased by 0.5 psu since 1500, peaking in the middle of 18th century
- present salinity values are nearly as high as during 18th century maximum
- historically several fresher periods when the mean salinity decreased from the maximum value of about 7.8 psu to about 6.5 psu

3.4.1.3. Circulation and transport patterns and processes

General characteristics of surface circulation

- important concepts
- long-term features: cyclonic circulation
- short-term currents forced by variable wind stress

3.4.1.3. Circulation and transport patterns and processes

Recent findings of surface circulation system and related processes

- new model results on mean circulation, detailed description + eddies
- sub-regional features:
    - variability patterns in the Gulf of Finland
        - current response to wind on shallow banks
        - features of Lagrangian transport variability
    - wave impacts on coastal currents
    - circulation in the Gulf of Bothnia

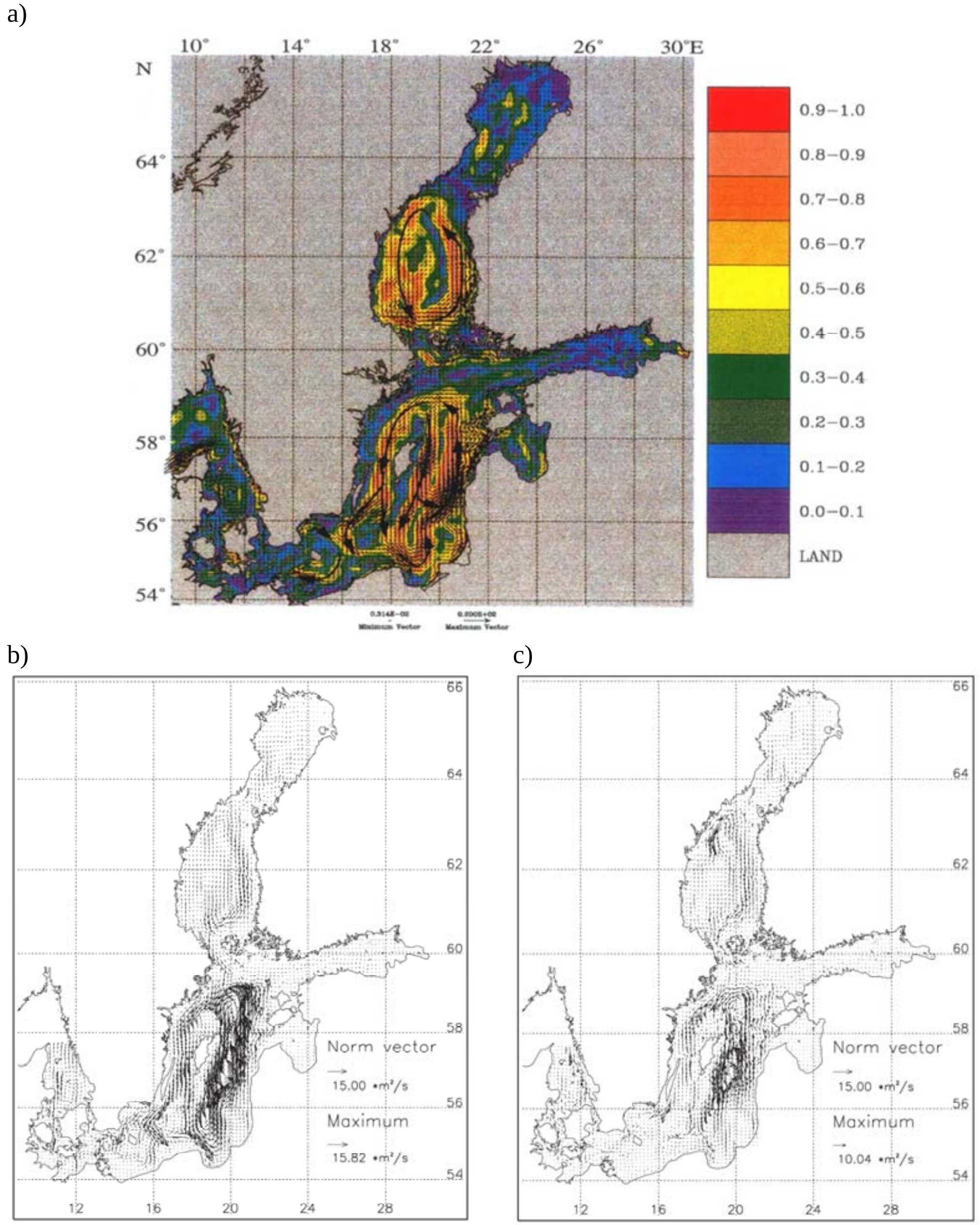

Fig.3.4.5. Baltic Sea circulation as viewed from the modeling results. Average barotropic currents (a) for 1992-1995 (in cm/s) with the flow stability contours (Lehmann and Hinrichsen, 2000), and average transports per unit length (in $m^2\ s^{-1}$) for 1981-2004 above (b) and below (c) the halocline (Meier, 2007).

3.4.1.3. Circulation and transport patterns and processes

Dynamics in the bottom layer

- haline „conveyor belt“
- halocline processes in the NE Baltic Proper
- short-term currents forced by variable wind stress

3.4.1.3. Circulation and transport patterns and processes

Water age

- age of Belt Sea water < 14 years in the Baltic Proper and up to 40 years in the northern Bay of Bothnia
- surface water has longer age than bottom water (all sources included)
- shorter ages near river mouths and nearby coastal areas

3.4.1.3. Circulation and transport patterns and processes

Mixing

•advective-diffusive balance: lateral inflow -> vertical advection <-> mixing
•diapycnal mixing due to internal waves: energy sources/sinks not yet well known
•role of deep entrainment, eddies, coastal upwelling, winter-time convection, surface wave breaking, Stokes production of turbulent KE, Langmuir cells
•near-inertial motions

3.4.1.3. Circulation and transport patterns and processes

Rossby-radius

•new data available
•changes due to stagnation etc determined

3.4.1.4. Sensitivity to changes in forcing

NAO effects on wind

- wind field changes dependent on NAO -> wind-forced current and transport components as well
- BSI describes with better correlation

3.4.1.4. Sensitivity to changes in forcing

Changes in upwelling events

- changes in typical upwelling zones and frequencies
- most frequent upwelling along the Swedish east coast and the Finnish coast of the Gulf of Finland, positive trend of frequencies
- caused by increased SW and W winds, in summer (JJA) partially reverse trends occured

Fig. 3.4.6. Changes in upwelling frequencies. Figure missing at the moment

3.4.1.4. Sensitivity to changes in forcing

Sensitivity to freshwater supply

- increased freshwater inflow and wind speed both result in decreased salinity; non-linear dependence of salinity to forcing

3.4.1.4. Sensitivity to changes in forcing

Effects of climate warming

- air temperatures for completely ice-covered and ice free sea determined (-6 and 2°C)
- seawater temperature increase clear, but salinity change quite uncertain yet

3.4.1.4. Sensitivity to changes in forcing

Effects of changing temperature of maximum density

- (when salinity decreases ,TMD increases)
- spring convection timing significantly changed (= effects on spring blooms)
- changes in development of frontal systems