Introduction to the Physical Oceanography of the Baltic Sea Environment

Baltic Way Summer School, Sept. 18, 2011
Klaipeda University, LITHUANIA

Kai Myrberg
Finnish Environment Institute
Marine Research Centre
Helsinki, FINLAND
Content

1. Basic physical features
2. Climate Change
3. Environmental problems – the state of the sea
   • Future of the Baltic Sea?
Physics
The Baltic Sea climate and water exchange with the North Sea is governed by Global Climate and its variability - North Atlantic climate is described by NAO-index (**North Atlantic Oscillation**)

NAO+ high westerly winds, mild winters, lot of precipitation

NAO- dry, cold winters, northerly wind
Baltic Basin

Mean depth 54m.
(Oceans 3500 m.)
Åland Deep 301m.
Salpausselkä Sill!
Landsort Deep 459m, BS max depth
Gotland Deep 239m.
Straits: Öresund and Belts

Baltic Basin IOW
Baltic Sea basins
Baltic Sea basins
Drainage Basin

• Much larger than the area of the BS
• 1,721,233 km²

A = 392.978 km²
V = 21.205 km²

• 85 milj. People
• 14 Countries (9 coastal)
• Lot of industry, agriculture, cities....
Baltic Sea temperature (yellow), salinity (blue), oxygen (red). Left: Bothnian Sea, Right: Gotland Deep (Furman et al.)
Salinity cross-section: Southern Baltic-Gotlandt Deep-Gulf of Finland (winter 2010)
Saline and oxygen-rich water through pulses....
• 1993 Major Baltic inflow (A. Lehmann)
Energy balance

\[ Q_n = Q_s - Q_r + Q_{La} - Q_{Lo} + Q_c + Q_e + Q_P, \]

where \( Q_n \) is net heat flux.

The sum
\[ Q_R = Q_s - Q_r + Q_{La} - Q_{Lo} \]

is

The radiation balance at sea-surface

\[ Q_c + Q_e \]

is

Turbulent heat
Energy balance

EARTH'S ENERGY BUDGET

Incoming solar energy 100%

Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%

Radiated to space from clouds and atmosphere 64%

Absorbed by atmosphere 16%
Absorbed by clouds 3%
Conduction and rising air 7%

Absorbed by land and oceans 51%

Radiation absorbed by atmosphere 15%
Carried to clouds and atmosphere by latent heat in water vapor 23%

Radiated directly to space from earth 6%
Baltic Sea water balance

- 215 km²/a
- 440 km³/a
- 1660 km³/a
- 175 km³/a
- 1180 km³/a

Volume: 21,205 km³
Fresh water balance

Makean veden tase (kuva 5.8) on $F = (P - E)A + V_r$. 
Water balance

- Precipitation P 50% of River runoff (445 km$^3$/y)
- Annual inflow to BS from Kattegat 1.200 km$^3$ (1000-1.500 km$^3$)
  \( \approx \) about 3 times R which equals to 3.2 m thick water layer at the BS surface
- Monthly water storage max-min 500km$^3$ (1.25m, like R)
Main equations

\[ \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} + w \frac{\partial \mathbf{u}}{\partial z} + \mathbf{f} \times \mathbf{u} = -\left( \frac{1}{\rho_0} \right) \nabla p + D_u + f_w, \quad (2.1) \]

\[ \frac{\partial S}{\partial t} + (\mathbf{u} \cdot \nabla) S + w \frac{\partial S}{\partial z} = D_s + f_s, \quad (2.2) \]

\[ \frac{\partial T}{\partial t} + (\mathbf{u} \cdot \nabla) T + w \frac{\partial T}{\partial z} = D_T + f_T. \quad (2.3) \]
Baltic Sea mean surface circulation
Mean current animation. Depth 5m.
Inertial oscillations
Water circulation

Ekman-spiral:
Upwelling
Upwelling in the Baltic Sea

- Upwelling principles
Upwelling in the Baltic Sea

- Upwelling in relation to wind

27.08.-02.09.2003

NOAA-AVHRR SST °C

Surface pressure [hPa] and geostrophic wind [m/s]
Ice conditions in the Baltic Sea

Probability of freezing
Baltic ice winter

17.3.1981
175 000 km²

3.2.1983
117 000 km²

22.2.1985
355 000 km²

16.3.1987
405 000 km²

19.1.1989
52 000 km²

20.2.1991
122 000 km²
Can the Climate Change be detected in the Baltic Sea?
Global mean temperature

Temperature (°C)
How the Climate Change is now recognized in the BS?

- The sea-surface **temperature** has increased 0.5-0.8 degrees in 50 years,
- The surface **salinity** has decreased by 0.2 per milles (mean salinity 7 per milles)
- Mild or normal ice winters since 1987 until 2010
- New sea-level maxima (increasing frequency of high winds)
What will happen in the Future until 2100?

Precipitation: Decreases in summer (even 45%), increases in winter (even 25-75%)

River runoff decreases in summer, increases in winter even up to 50 % ⇒

BS will NOT be a lake, salinity stratification will remain

Winter floodings will prevent major BS inflows?

Kyllikki Rooväli, Postimees, Pärnu, 2005
Q: Is there ice in the BS in 2100?
A: Yes, but much less than at present. In the future only the easternmost Gulf of Finland the northernmost Bay of Bothnia will be ice-covered during **mild winters**.
Oil accident
Traffic in the GOF during one typical Wednesday (28th of Feb 2007) in ice conditions

Oil transport routes and oil terminals – red

Source: HELCOM AIS Database
Visualized by http://www.smhi.se/seatrack

In statistic Tallinn = Old City Harbour + Paljassaare + Paldiski + Muuga
New oil rescue vessel in the Gulf of Finland—but when?
The state of the Baltic Sea
Total phosphorus and nitrogen loads into the Baltic Sea in 2006

HELCOM PLC-5 Core Group,
Seppo Knuuttila 8.3.2011
Phosphorus and nitrogen concentrations in northern Baltic Proper

Source: Fleming-Lehtinen, SYKE
Algae blooms
State of the BS

- Secchi--depth (Fleming-Lehtinen)
Load reduction recommendation per country (tons/Year)

- Bothnian Bay:
  - P 291 (34%) N 20 780 (29%)

- Bothnian Sea:
  - P 222 (18%) N 896 (5%)

- Gulf of Finland:
  - P 881 (66%) N 11 746 (26%)

- Gulf of Riga:
  - P 300 (19%) N 2561 (25%)

- Baltic Proper:
  - P 242 (45%) N 5621 (27%)

- Danish Straits:
  - P 16 (31%) N 17 207 (30%)

- Kattegat:
  - P 146 (25%) N 1199 (8%)

- P 2500 (37%) N 6967 (8%)

- P 222 (18%) N 896 (5%)

- P 300 (19%) N 2561 (25%)

- P 881 (66%) N 11 746 (26%)

- P 8755 (64%) N 62 395 (29%)
Nutrient loads in St. Petersburg by Vodokanal

Photo: The John Nurminnen Foundation
Phosphorus load from St. Petersburg (tons/year)

Lähde: Vodokanal Pietari, SeppoKnuuttila/SYKE
Near-bottom oxygen conditions in winter 1994
Near-bottom oxygen conditions in winter 2010
This is the Baltic Sea Future—No Thanks!
- The worsening of the State of the valuable BS is a big problem for our society → a binding protection agreement is needed, good administration is required
- The inheritance of socialism makes the protection very complicated
- Loadings and risks of marine transport should be taken care off
- Climate Change requires quick response
- Activity of the Citizens should be supported
Thanks, for your Attention