Baltic Sea marine system and process-oriented modelling

By

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Outline

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Problems

1.1 Objective

- To introduce the Baltic Sea marine system using a process oriented approach for building system understanding.
- And based on long-time series introduce climate and climate change

1.2 Some illustrative examples

Measurements of temperatures and other properties are often rare in water bodies. Models and observations needs to support each other.

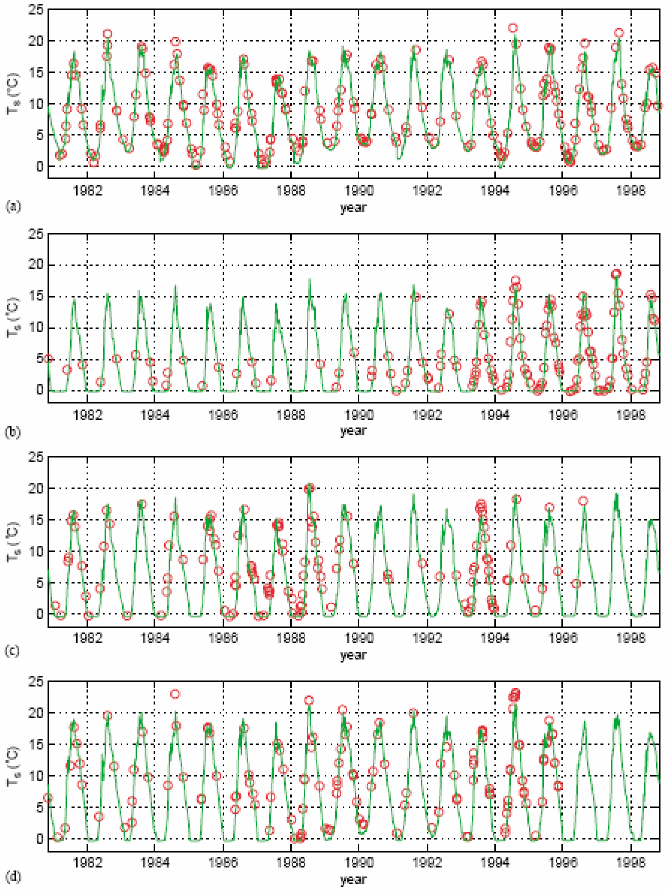
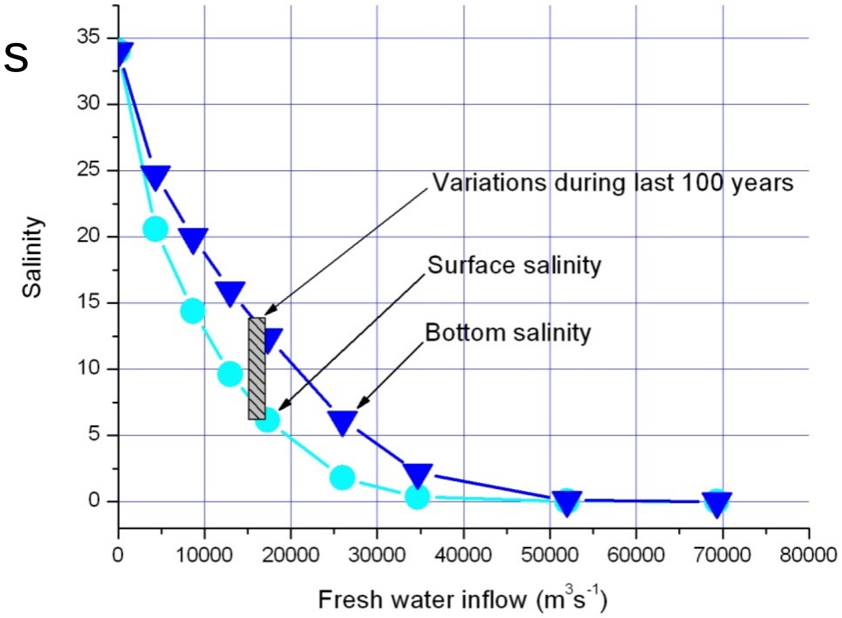


Fig. 6. Observed (circles) and calculated (fully drawn lines) sea-surface temperature in (a) the Eastern Gotland Basin, (b) the Bothnian Bay, (c) Gulf of Finland, and (d) Gulf of Riga.

Modelled and calculated sea surface temperatures from some regions in the Baltic Sea (Omstedt and Axell, 2003)

1.2 Some illustrative examples cont.

Extrapolation is another good reason why we should develop models



Redrawn from Omstedt and Hansson (2006)

1.3 Conservation(1) principals and governing equations

The conservation equation reads

$$\frac{\partial}{\partial t}\phi + \frac{\partial(\phi u_i)}{\partial x_i} = S_\phi \quad where \quad i = 1, 2, 3$$

We dived the properties into three parts

$$u_i = \overline{u_i} + \overset{\square}{u}_i + u_i^{\prime}$$

$$\phi_i = \overline{\phi_i} + \overset{\square}{\phi}_i + \phi_i^{'}$$

The conservation equation now reads

$$\frac{\partial}{\partial t}\overline{\phi} + \frac{\partial(\overline{\phi u_i})}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\Gamma_\phi \frac{\partial}{\partial x_i}\overline{\phi} - \overline{\left(\overset{\square}{\phi}_i \overset{\square}{u}_i\right)}\right) + \overline{S_\phi}$$

$$\Gamma_\phi = \frac{\mu}{\rho\sigma_\phi} + \frac{\mu_t}{\rho\sigma_{\phi t}}$$

The general discretization equation

$$a_P\theta_P = a_W\theta_W + a_E\theta_E + a_S\theta_S + a_N\theta_N + a_B\theta_B + a_T\theta_T + S_\theta$$

Problem 1

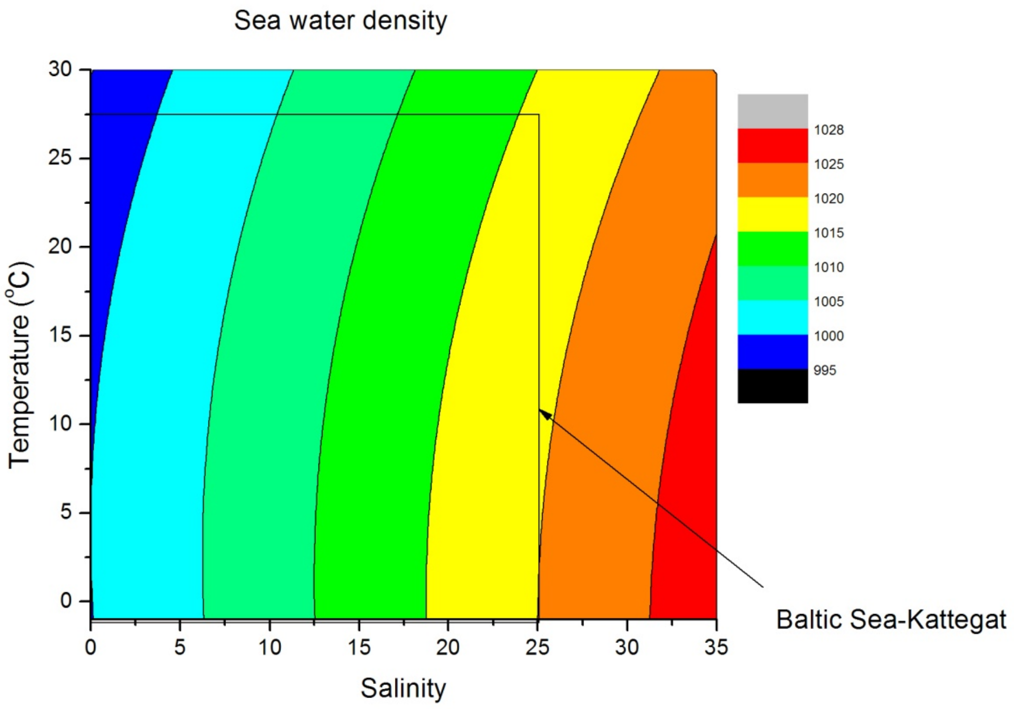
The mean depth of the Baltic Sea is 54 m and its surface area is $3.9\ 10^5$ km^2. How much would the level of the Baltic Sea increase over a year with river water inflow of 15,000 m^3/s and no outflows? If the out flowing volume flow is 30,000 m^3/s, how large would the inflowing volume flow be? If the salinity of the inflowing water is 17, what would the salinity be in the basin?

1.4 Physical aspect

$$\rho = \rho_0 \left(1 - \alpha\left(T - T_{\rho m}\right)^2 + \beta\left(S - S_0\right)\right)$$

$$T_{\rho m} = 3.98 - 0.22S$$

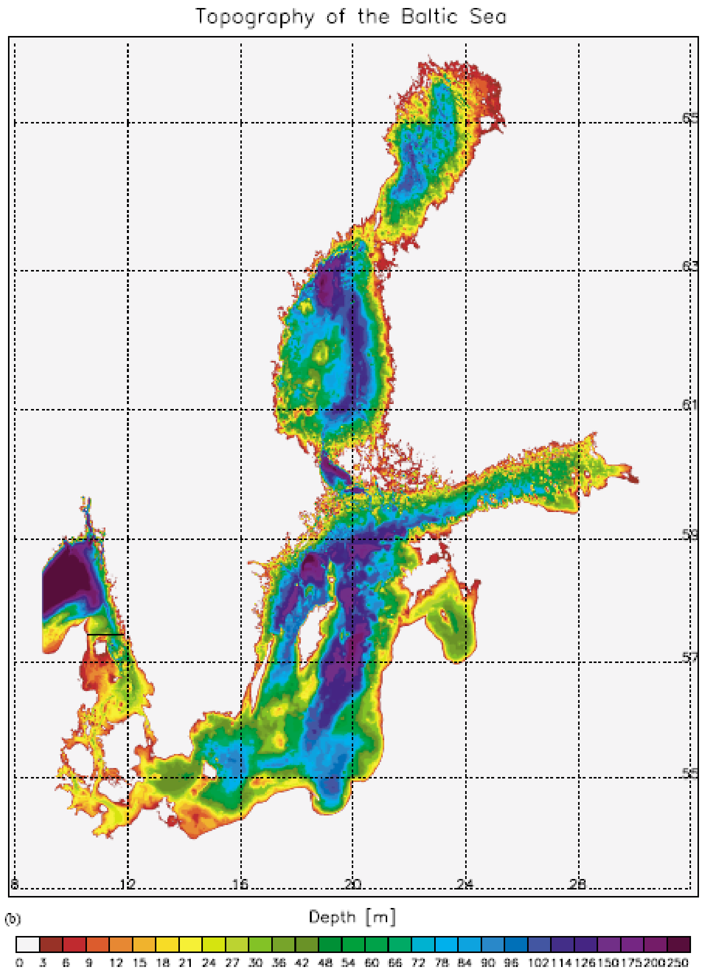
$$T_f = -0.0575S + 0.0017S^{1.5} - 0.0002S^2 - 0.00753P$$



Problem 2

Investigate the equation of state by plotting Equation (5) for different temperatures and salinities. What are the typical densities in the Baltic Sea? What are the dominant factors controlling the density in coastal seas?

1.5 Simplifications



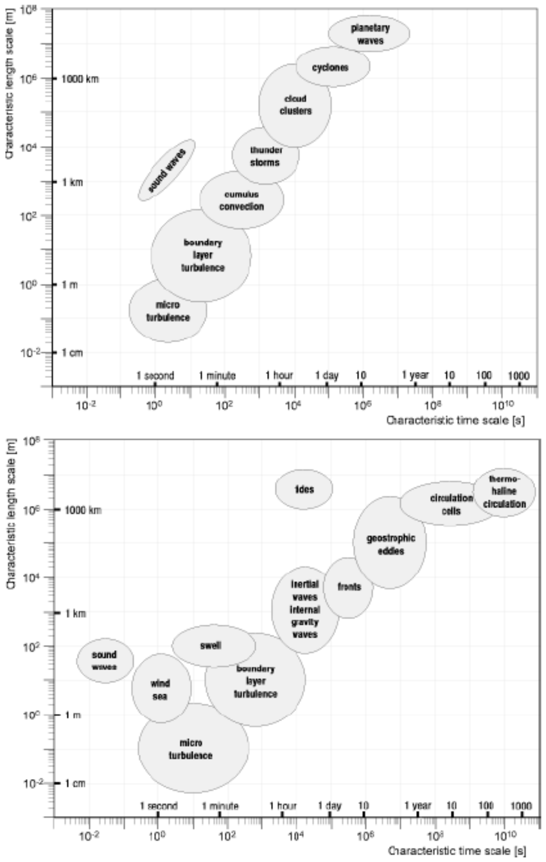


Figure 1-7 Various types of processes and structures in the atmosphere (top panel) and oceans (bottom panel), ranked according to their respective length and time scales. (Diagram courtesy of Hans von Storch)

1.5 Simplifications: scaling

Scaling the momentum equation in x-direction:

$$\frac{\partial}{\partial t}\bar{u}+\bar{u}\frac{\partial \bar{u}}{\partial x}+\bar{v}\frac{\partial \bar{u}}{\partial y}+\bar{w}\frac{\partial \bar{u}}{\partial z}-fv=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\Gamma_h\frac{\partial \bar{u}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_h\frac{\partial \bar{u}}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma_z\frac{\partial \bar{u}}{\partial z}\right)$$

$$\frac{U}{T}\qquad \frac{U^2}{L}\qquad \frac{U^2}{L}\qquad \frac{WU}{L}\qquad \Omega\text{U}\qquad \frac{P}{\rho_0 L}\qquad \frac{\mu_h U}{\rho_0 L^2}\qquad \frac{\mu_h U}{\rho_0 L^2}\qquad \frac{\mu_v U}{\rho_0 H^2}$$

Dividing the estimated terms by: ΩU

$$\begin{array}{ccccccccc}
\frac{1}{T\Omega} & \frac{U}{L\Omega} & \frac{U}{L\Omega} & \frac{WL}{UH}\,\frac{U}{L\Omega} & 1 & \frac{P}{\rho_0 L\Omega \text{U}} & \frac{\mu_h}{\rho_0 L^2\Omega} & \frac{\mu_h}{\rho_0 L^2\Omega} & \frac{\mu_v}{\rho_0 H^2\Omega} \\
R_{ot} & R_o & R_o & \frac{WL}{UH}R_o & & 1 & Ek_h & Ek_h & Ek_v \\
 & & & 1R_o & & & & &
\end{array}$$

Depending on the size of the non-dimensional numbers the equation can be simplified:

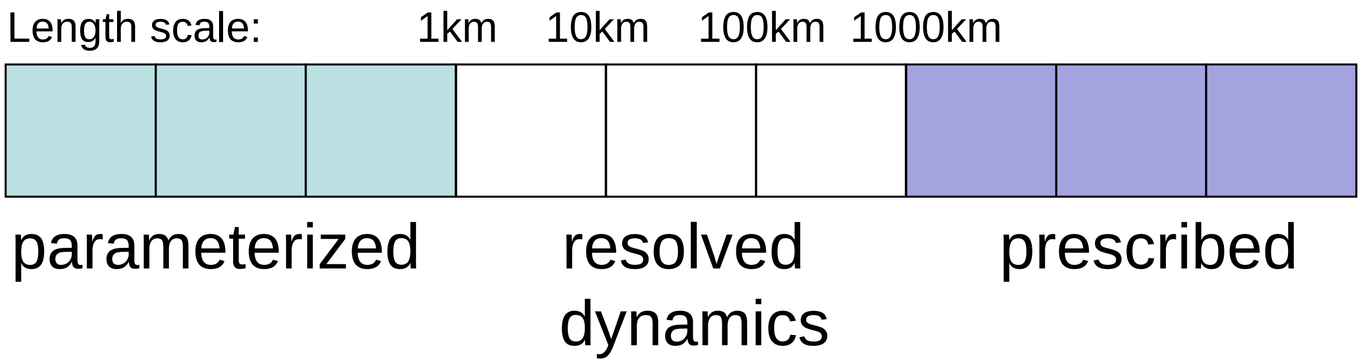
1.5 Simplifications: two examples

- If $Ro_t, Ro, Ek_v \ll 1$ several important analytical aspects of the fluid flow can be derivate. One example is the Taylor-Proudman theorem illustrating that the horizontal velocity field has no vertical shear and that the flow cannot pass changes in bottom topography. Instead all motions follow the depth contours. The bathymetric then give us important information about the circulation and implication for how to divide the water body into dynamically regions.
- If $Ro, Ek_v \ll 1$ and $Ro_t \leq 1$ the change in relative vorticity need to be conserved.

$$\frac{d}{dt}\left(\frac{f+\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}}{H}\right)=0$$

For a change in bottom topography the Equation implies that the fluid flow will change its vorticity. Important consequences for e.g outflowing water from the Baltic Sea.

1.5 Simplifications: grid limitations



Length scale: 1km 10km 100km 1000km

parameterized

resolved dynamics

prescribed

Problem 3

Some say that an oceanographer’s dream is to study the Earth’s rotation by sitting in a bathtub and letting the water drain while he/she is passing over the equator. Would the Earth’s rotation significantly affect the water flow when emptying a bath tub? Assume a horizontal scale of 1 m, a drainage rate on the order of 0.01 m/s, a motion time scale of 1000 s, and an ambient rotation rate of .

Problem 4

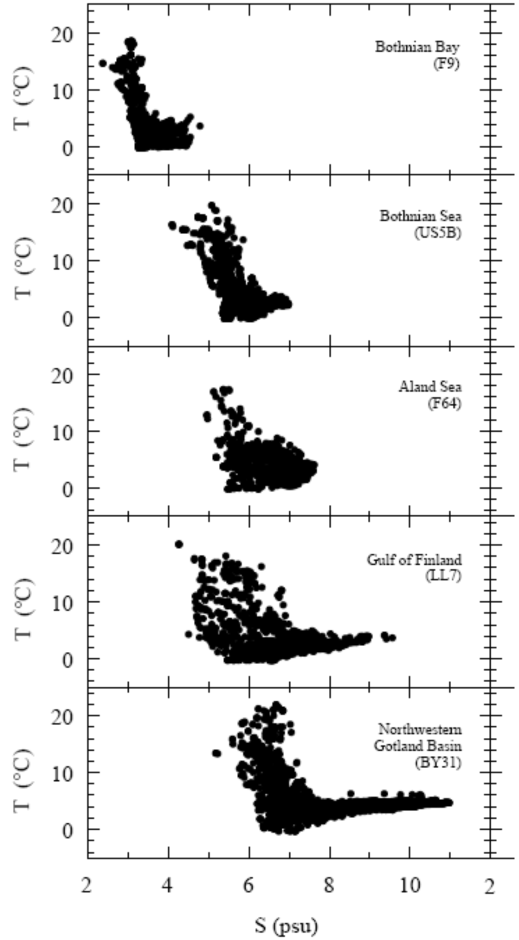
The central Baltic Sea is characterized by a 60-metre-deep surface layer with a salinity of approximately 7. Below the halocline, the salinity is approximately 10. Using the value 8×10^{-4} for the coefficient of salinity expansion, calculate the stratification frequency. What is the horizontal length scale at which rotation and stratification play comparable roles? (Hint: use the equation of state and assume that the density change takes place over 60 m.)

Problem 5

Examine vorticity dynamics by assuming that the outflow from the Baltic Sea into the Kattegat conserves potential vorticity. What happens with the flow when the outflow enters the much deeper Skagerrak? Illustrate how the different components of the relative vorticity might change?

1.6 Water masses

From T-S diagram we get important information about ocean circulation, mixing processes and model performance



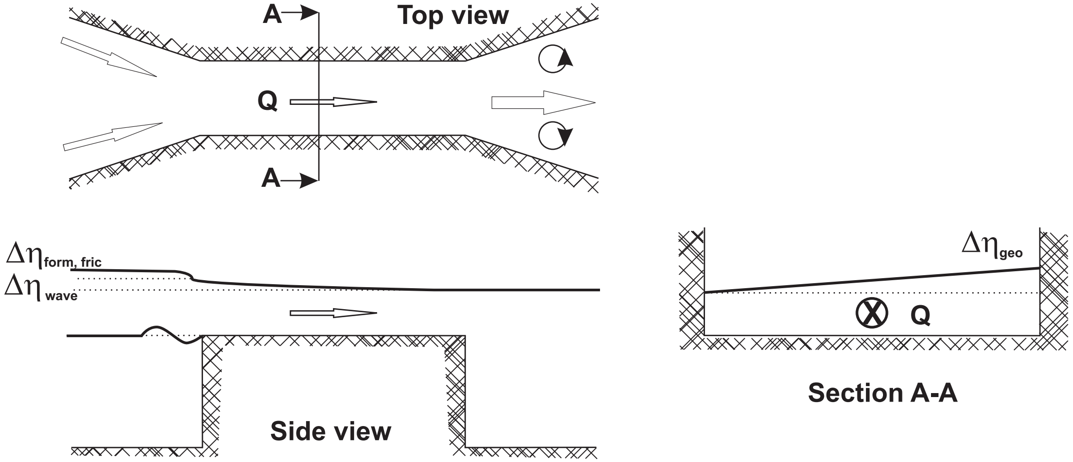
Observed long-term T-S structure in the Northern Baltic Sea (From Omstedt and Axell, 2003).

Problem 6

Use salinity and temperature observations from several different Baltic Sea sub-basins and plot the T–S structure. Discuss the different water masses observed in the data and how they interact with each other (data are available from Anders).

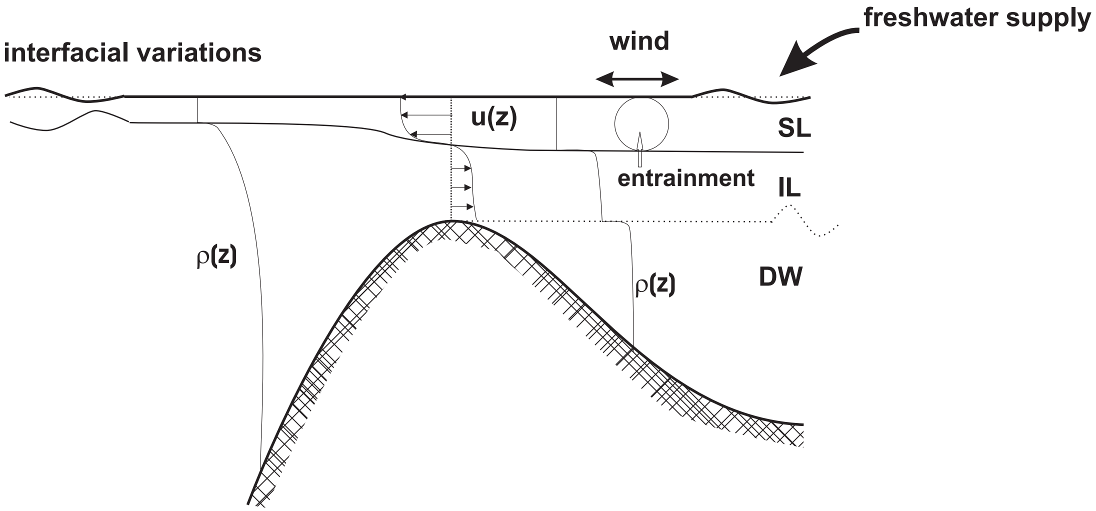
1.7 Strait flows

Inshore-offshore water exchange or between sub basins are often controlled by geometrical constrictions as sills and straits



Exchange through a shallow channel driven by sea level variations(From Green, 2004).

1.7 Strait flows cont.



Exchange through a sill region driven by density variations (From Green, 2004).

1.7 Strait flows cont.
The Northern Kvark Strait flow

A. Omstedt, L.B. Axell / Continental Shelf Research 23 (2003) 265–294

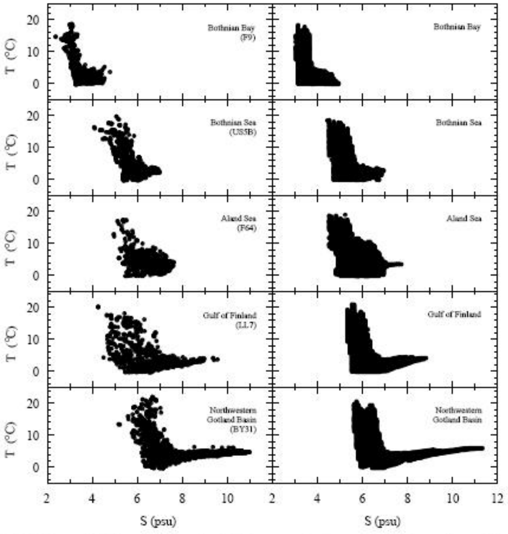


Fig. 2. Observed (left) and calculated (right) long-term *T–S* structures in the northern subbasins.

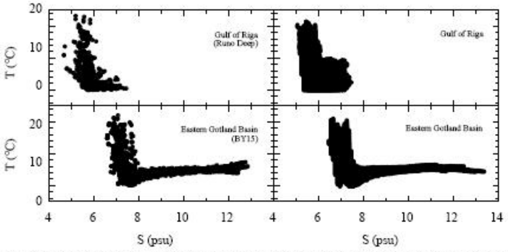


Fig. 3. Observed (left) and calculated (right) long-term *T–S* structures in the eastern subbasins.

A. Omstedt, L.B. Axell / Continental Shelf Research 23 (2003) 265–294 279

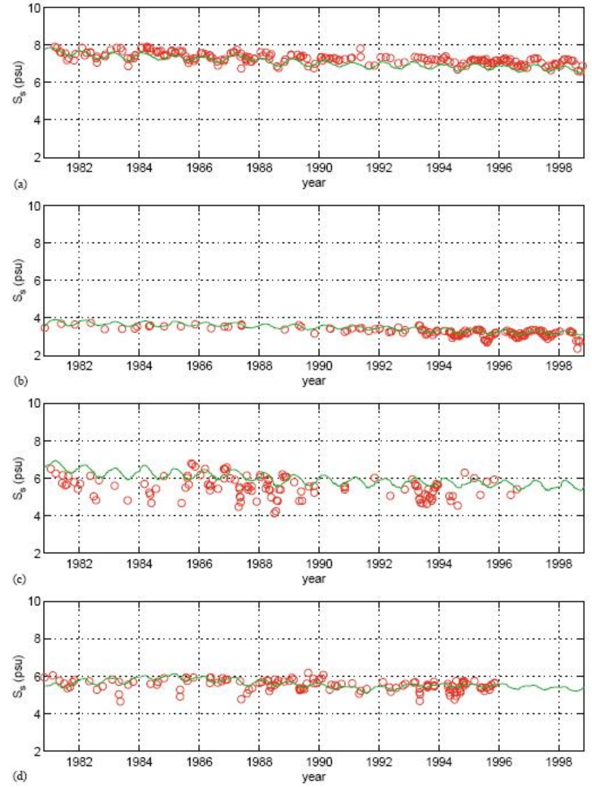


Fig. 8. Observed (circles) and calculated (fully drawn lines) sea-surface salinity in (a) the Eastern Gotland Basin, (b) the Bothnian Bay, (c) Gulf of Finland, and (d) Gulf of Riga.

1.7 Strait flows cont.
The Northern Kvark Strait flow

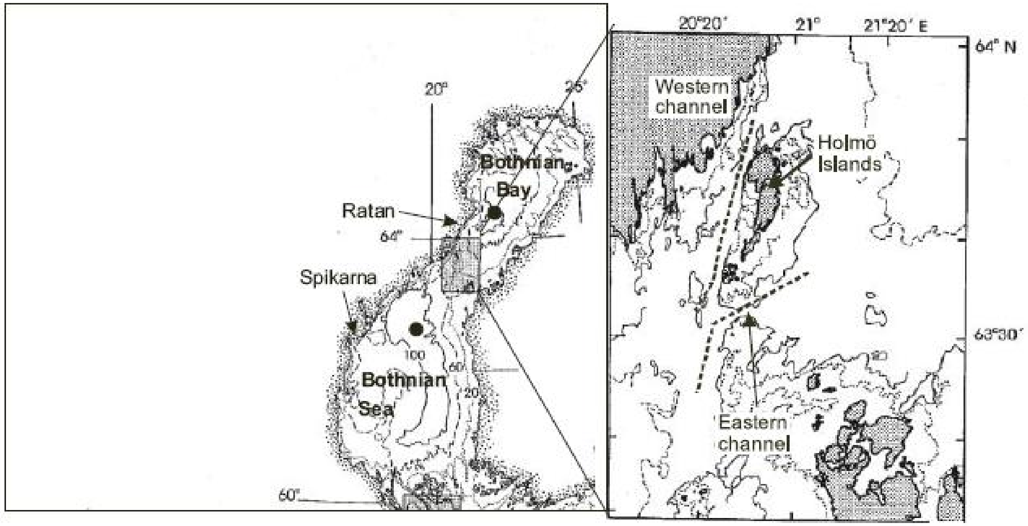


Figure 1. Map of the northern Baltic Sea with the topography of the Northern Kvark shown in detail to the right. The figures are modified from Stigebrandt (2001). The large dots in the Bothnian Sea and the Bothnian Bay indicate the positions of the sampling sites for the historic hydrographic data-set, and “Spikarna” and “Ratan” are the sea-level gauges used.

1.7 Strait flows cont.

Autumn 2004, along-strait flow and density
(Note: strong barotropic currents)

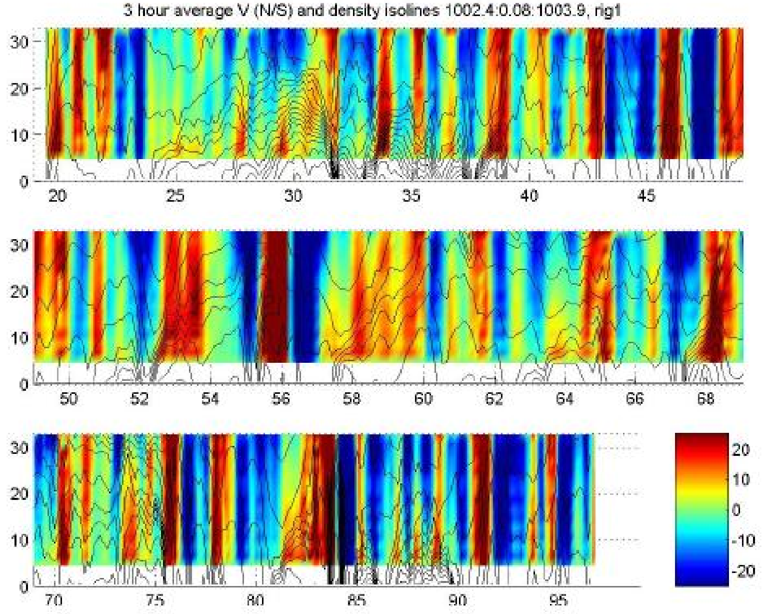
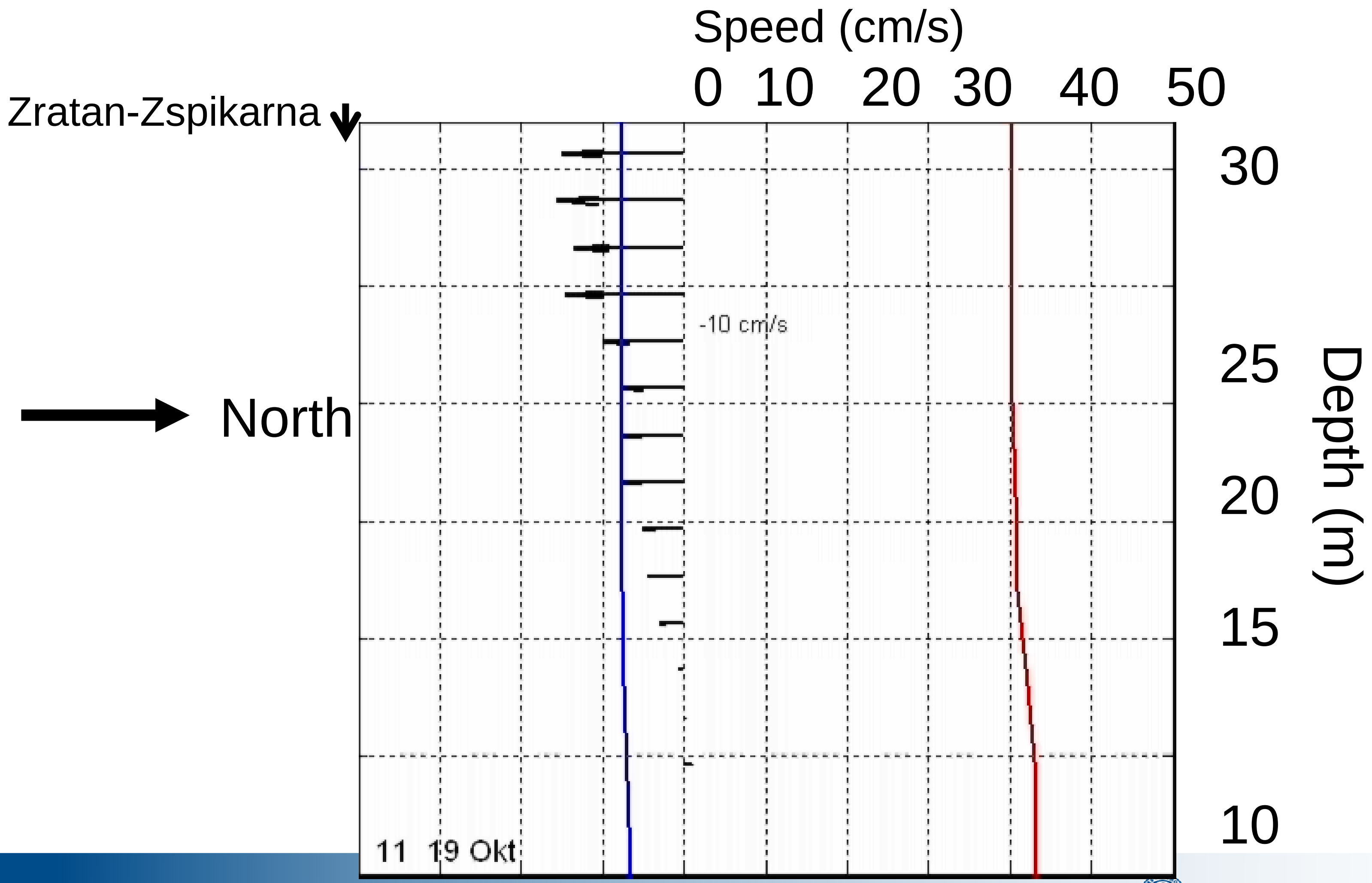
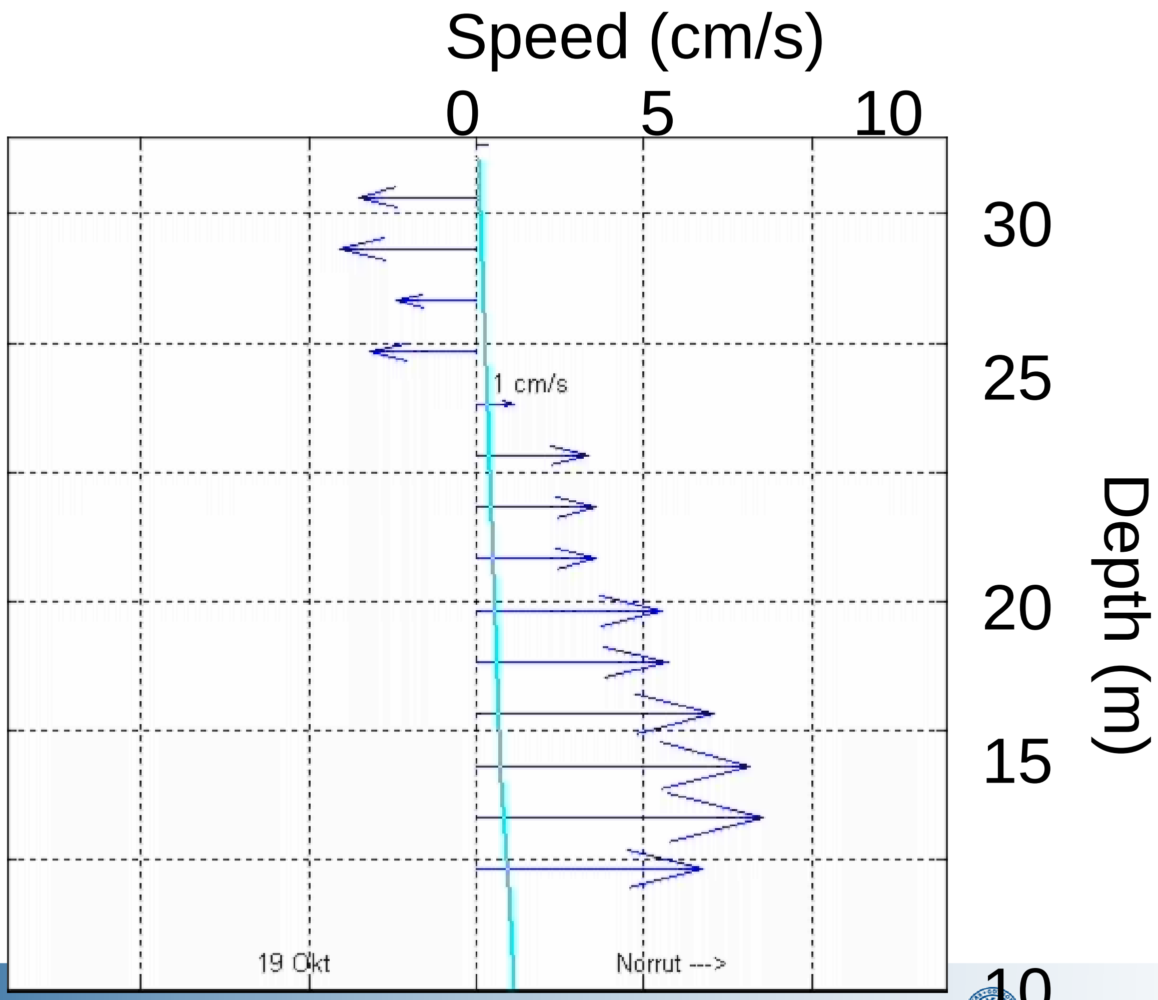


Figure 6. Time-depth plots of the observed along-strait flow velocity (in cm s^{-1}) from the first rig during the observation period. The isolines show the density between 1002.4 and 1003.9 kg m^{-3}, in steps of 0.08.

Temperature (red), salinity (blue) and currents (black)



Baroclinic currents (first EOF mode substracted from current data)



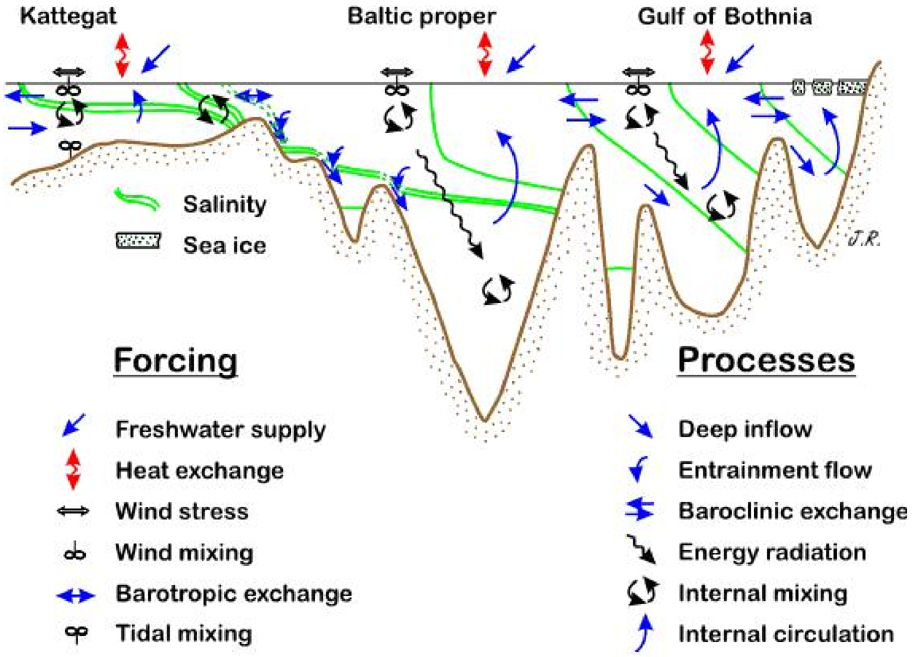
In the Northern Kvark Strait flow one may find one or more of the following co-existing flow regimes:

- The blocked regime: the barotropic forcing becomes large enough to block the strait, i.e. only one water mass is found in the strait.
- The two-layer regime: the vertical stratification consists of two separate homogenous layers and the flow can become hydraulically controlled.
- The stratified regime: due to intense mixing, the stratification and velocity profile in the strait is linear and constant, respectively, over depth.

Problem 7

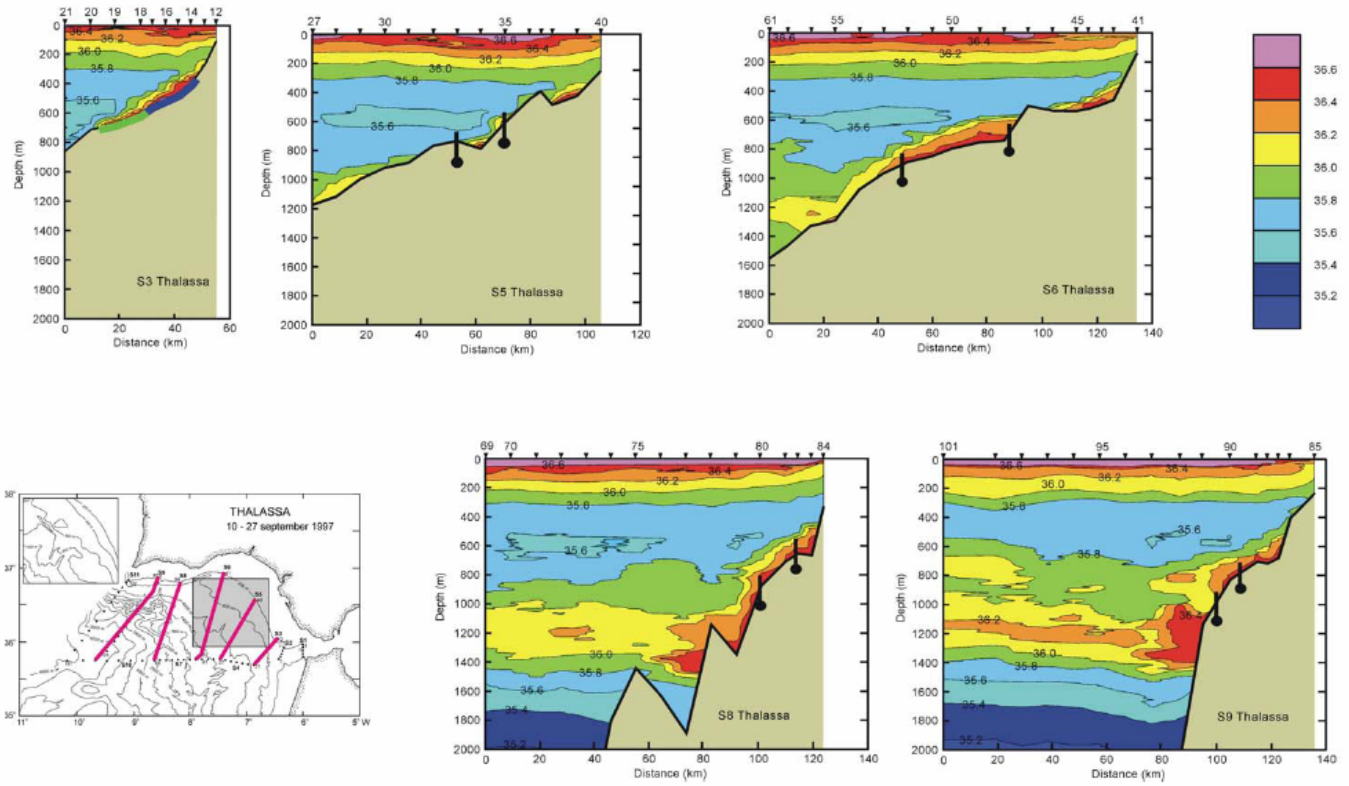
Calculate the mean sea level variations in the Baltic Sea by examine the barotropic strait model given in Equation (11). Assume that the river run of and net precipitation is constant and equal to 15, 000 m^3/s and 1, 000 m^3/s, respectively. Also that the surface area is 3.9 10^5 km^2 and the strait-specific constant (Cs) is typically 0.310^{-5} (s^2/m^5). Use sea level data from the Kattegat to force the model and compare the mean sea level with sea level variations in Stockholm (data are available from Anders).

1.8 Intrusions and outflows



1.8 Intrusions and outflows cont.

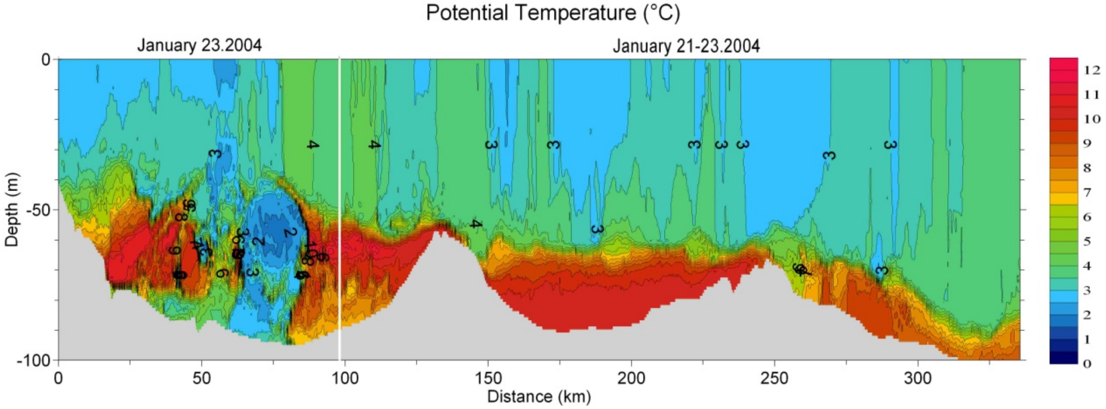
Example: Mediterranean Outflow



From Borenæs et al, 2002

1.8 Intrusions and outflows cont

Example: Baltic Sea inflow



Measured temperatures in the Bornholm Basin (left) and the Stolpe Channel (right) during January 2003. The left illustrates a cold water inflow entering into warm bottom water. In the right figure one can notice a Stolpe Sill overflow with unusual warm temperatures. From Piechura and Beszczynska-Möller (2004).

1.9 Turbulence

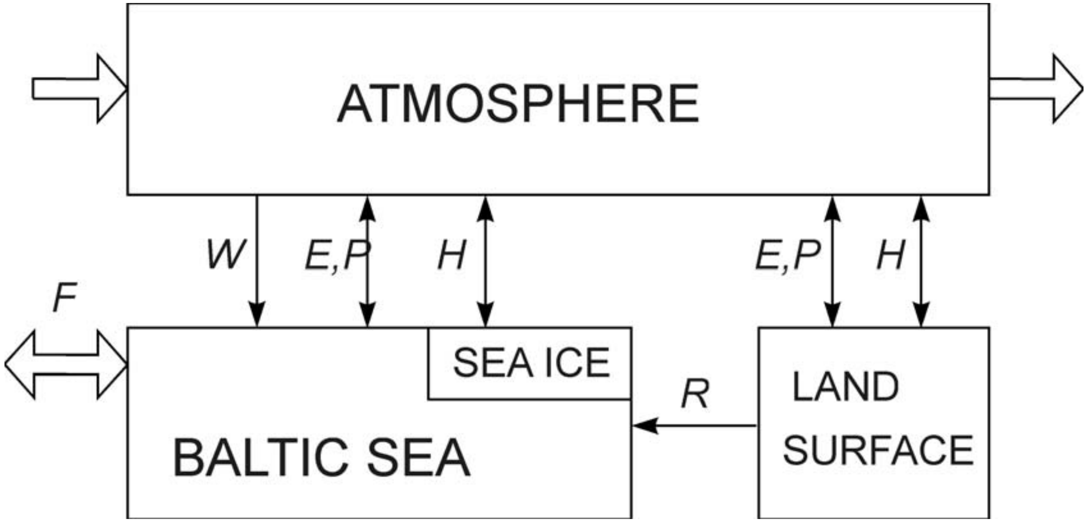
Drawing of a turbulent flow by Leonardo da Vinci circa 1507–1509, who recognized that turbulence involves a multitude of eddies at various scales. (From Cushman-Roisin and Becker, 2008).

Reynolds number $\mathrm{Re} = \frac{UL}{\nu}$

Kinematic viscosity $\frac{\mu}{\rho}$

$$\Gamma_{\rho u_i} = \frac{\mu}{\rho} + \frac{\mu_t}{\rho} \quad [LU]$$

1.10 Water and salt balances



1.10 Water and salt balances cont.

Volume conservation principle:

$$A_s \frac{dz_s}{dt} = Q_i - Q_o + (P-E)A_s + Q_r + Q_{ice} + Q_{rise} + Q_T + Q_S + Q_g$$

Q_i (m^3s^{-1})	Q_o (m^3s^{-1})	Q_o-Q_i (m^3s^{-1})	$(P\text{-}E)A_S$ (m^3s^{-1})	Q_r (m^3s^{-1})	Q_{ice} (m^3s^{-1})	Q_{rise} (m^3s^{-1})	Q_g (m^3s^{-1})	Q_T (m^3s^{-1})	Q_S (m^3s^{-1})
10^5	-10^5	-10^4	10^3	10^4	-10^2	-10^1	10^2	$\pm 10^2$	$\pm 10^1$

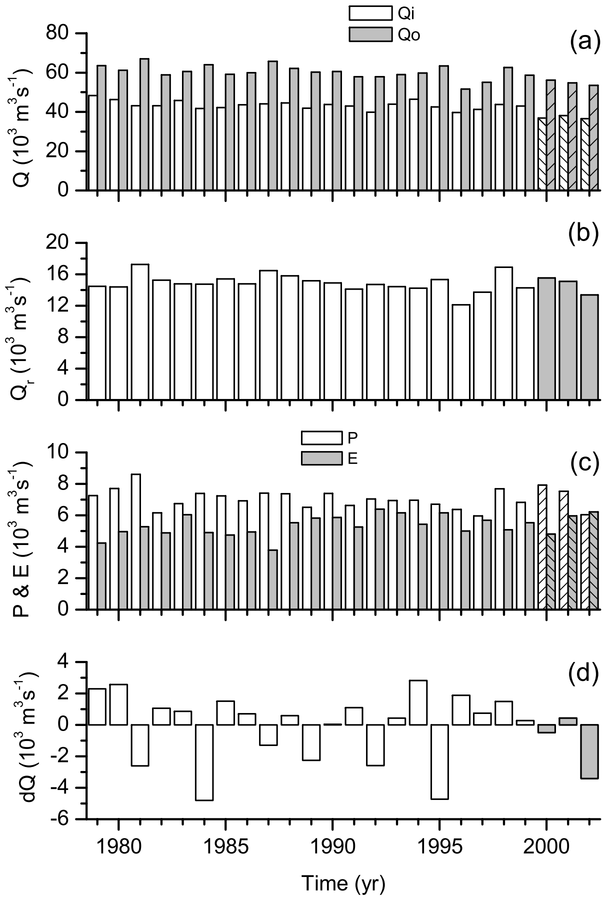
1.10 Water and salt balances cont.

Water balance

$$A_s \frac{dz_s}{dt} = Q_i - Q_o + (P - E)A_s + Q_r$$

Salt balance

$$\frac{dVS}{dt} = S_i Q_i - SQ_o - S((P - E)A_s + Q_r)$$



Baltic Sea (excluding the Kattegat and the Belt Sea) annual means of inflows and outflows (a), river runoff (b), net precipitation (c), and net volume change (d). The BALTEX/Bridge period is indicated. For details see Omstedt and Nohr (2004).

1.11 Heat balance

Heat conservation principle:

$$\frac{dH}{dt} = (F_i - F_o - F_{loss})A_s$$

$$H = \int\int \rho c_p T dz dA$$

$$F_{loss} = (1 - A_i)(F_n + F_s^o) + A_i(F_w^i + F_s^i) - F_{ice} + F_r + F_g$$

$$F_n = F_h + F_e + F_l + F_{prec} + F_{snow}$$

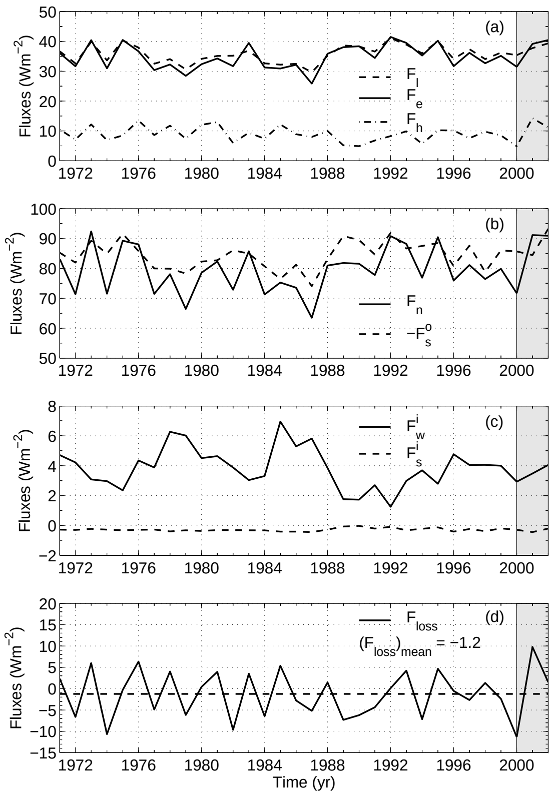
F_n (Wm^{-2})	F_s^o (Wm^{-2})	F_w^i (Wm^{-2})	F_s^i (Wm^{-2})	F_{prec} (Wm^{-2})	F_{snow} (Wm^{-2})	F_i (Wm^{-2})	F_r (Wm^{-2})	F_g (Wm^{-2})	F_o–F_i (Wm^{-2})	F_{loss} (Wm^{-2})
10^2	-10^2	10^0	-10^0	10^{-1}	10^{-1}	-10^{-1}	10^{-1}	10^{-1}	10^0	-10^0

1.11 Heat balance cont.

$$\frac{dH}{dt} = (F_i - F_o - F_{loss})A_s$$

$$F_{loss} = (1 - A_i)(F_n + F_s^o) + A_i(F_w^i + F_s^i)$$

$$F_n = F_h + F_e + F_l$$



Annual means of: sensible heat (F_h), latent heat (F_e), net long-wave radiation (F_l), net heat flux ($F_n = F_h+F_{e+}F_l$), sun radiation to the open water surface (F_s^o), sun radiation through ice (F_s^i), heat flow from water to ice (F_w^i), and net Baltic Sea heat loss $F_{loss} = (1-A_i)(F_s^o + F_h+F_{e+}F_l) + A_i(F_s^i + F_w^i)$, where A_i is the ice concentration. For details see Omstedt and Nohr (2004).

Problem 8

Consider the Baltic Sea with a surface area of 3.9 10^5 km^2. Assume that the volume and heat content of the Baltic Sea do not change over time and that the exchange through the entrance area is accomplished by a two layers flow. Given that the in flowing and the fresh water volumes are equal to 15 000 m^3/s, that the inflowing and out flowing water temperatures are equal to 8 (^oC) and neglect the heat exchange from rivers. What is the estimated heat loss from the Baltic Sea?

1.12 Nutrient balance

- Load from land and atmosphere
- Interaction with sediments
- Internal processes
- Load from other sea regions

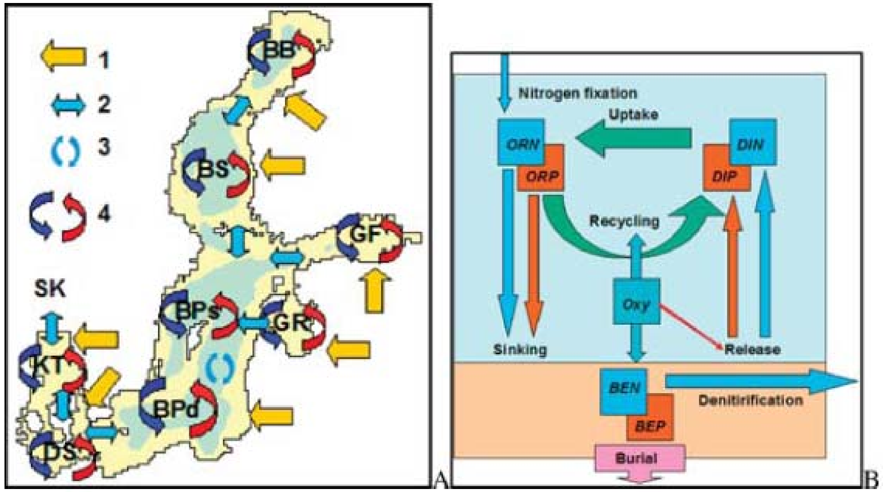
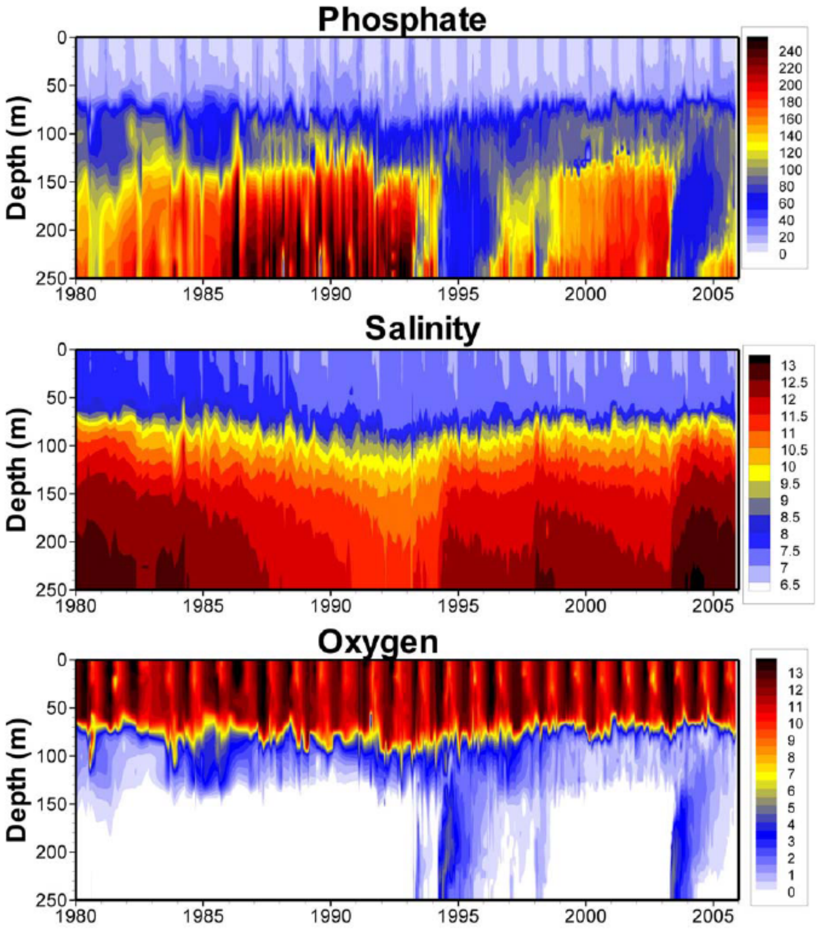


Figure 1. Basic principles of SANBALTS. (A) Nutrient dynamics in the major basins of the Baltic Sea (BB = the Bothnian Bay; BS = the Bothnian Sea; BP = the Baltic Proper; GF = the Gulf of Finland; GR = the Gulf of Riga; DS = the Danish Straits; KT = the Kattegat; Ska = the Skagerrak boundary) is driven by continuous interaction of (1) the inputs from land and atmosphere, (2) the water transports due to horizontal advection and (3) vertical exchange between surface BPs and deep BPd boxes, and (4) biogeochemical processes. (B) Biogeochemical fluxes between pelagic and sediment nitrogen and phosphorus variables.

From Savchuk and Wulff (2007)

1.12 Nutrient balance, cont.



Variationer i DIP (mg m^{-3}), salthalt och syrgas (g m^{-3}) vid BY15 I östra Gotlandsbassängen. Från Stigebrandt & Gustafsson (2007)

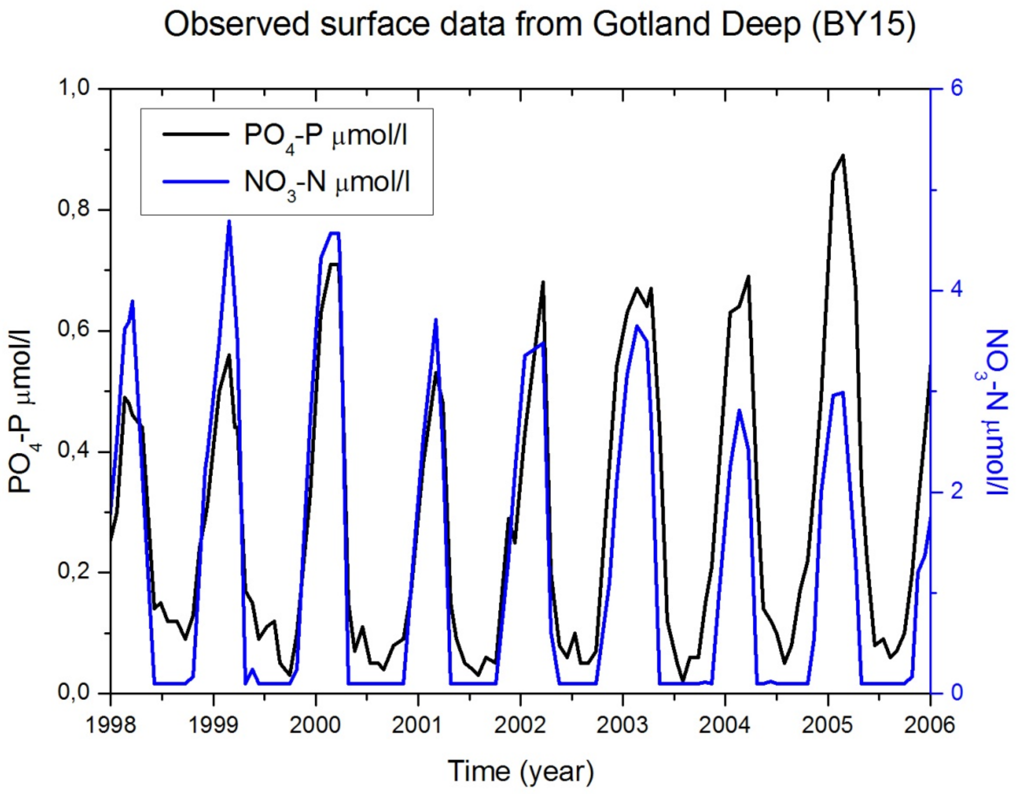
Problem 9

Use P and N observations from the Eastern Gotland Basin and plot the surface properties of PO_4 and NO_3 of the last five years. Discuss the dynamics (data are available from Anders).

1.13 Primary production

Blue-green algae blooming in the Åland Sea during the summer of 2005. Photo by the Finnish Frontier Guard.

1.13 Primary production, cont.



From Omstedt et al., (2009)

1.14 Acid-base (pH) balance

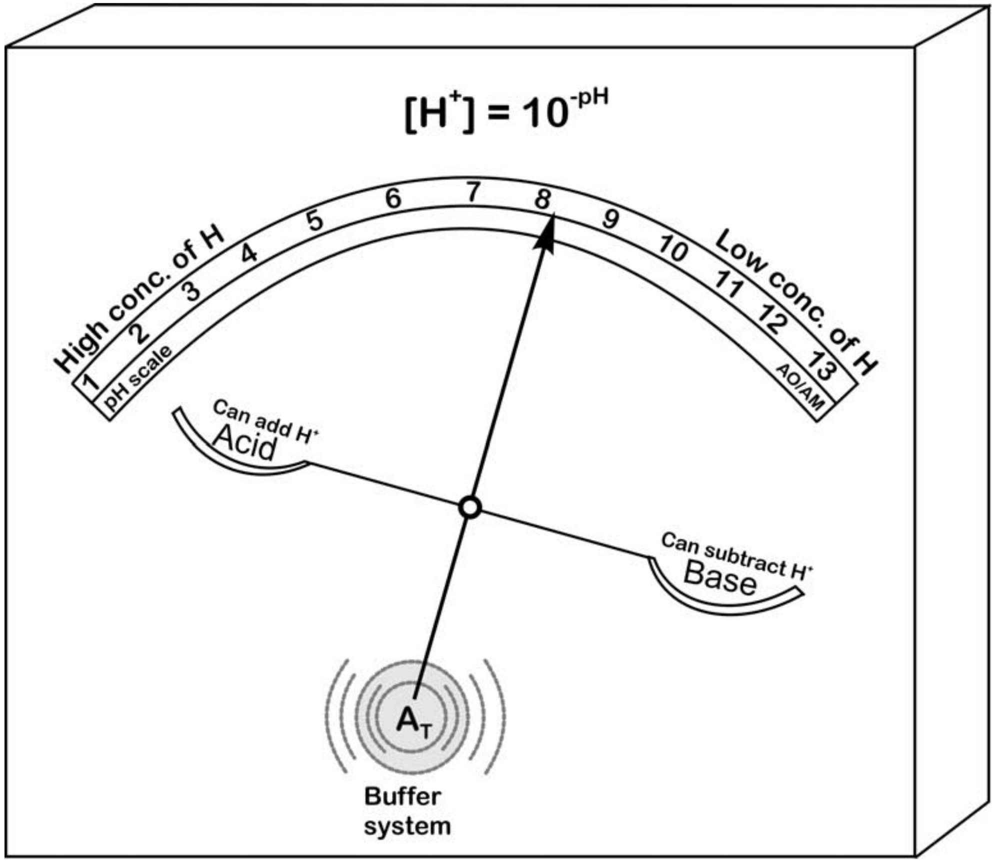
Ocean waters due to antropogenic carbon dioxide:
pH decrease of 0.1 units since 1750
pH decrease of 0.4 units 2100 estimated

Coastal seas also due to antropogenic nitrogen and sulfur deposition at the sea surface:
Total inorganic carbon and total alkalinity change

Coastal seas also antropogenic changes in river runoff:
Changes in volume flow and distribution between surface and ground water flows
Changes in total alkalinity, total organic and inorganic carbon

Coastal seas and eutrophication:
Changes in biological production, mineralization and sediment burial

1.14 Acid-base (pH) balance



From Omstedt (2009)

Proton doners: adding H^+

Carbonic acid (kolsyra) $CO_2 + H_2O \leftrightarrow H_2CO_3$

Sulphuric acid (svavel syra) $2SO_2 + O_2 + 2H_2O \leftrightarrow 2H_2SO_4$

Nitric acid (salpetersyra) $4NO_2 + 2H_2O + O_2 \leftrightarrow 4HNO_3$

Mineralization through CO2 realease

Proton acceptors: subtracting H^+

Limestone (kalk) $CaCO_{3s} \leftrightarrow Ca^{2+}_{aq} + CO^{2-}_{3aq}$

Biological production trough CO2 uptake

Buffert systems

Systems where chemical reactions add or subtract

H+ to keep pH constant.

$$C_T = [CO_2] + [HCO_3^-] + [CO_3^{2-}]$$

$$A_T = [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] - [H^+]$$

$$B_T = [B(OH)_3] + [B(OH)_4^-]$$

A_T ....”the excess of proton acceptors over proton doners”… (Dickson,1981)

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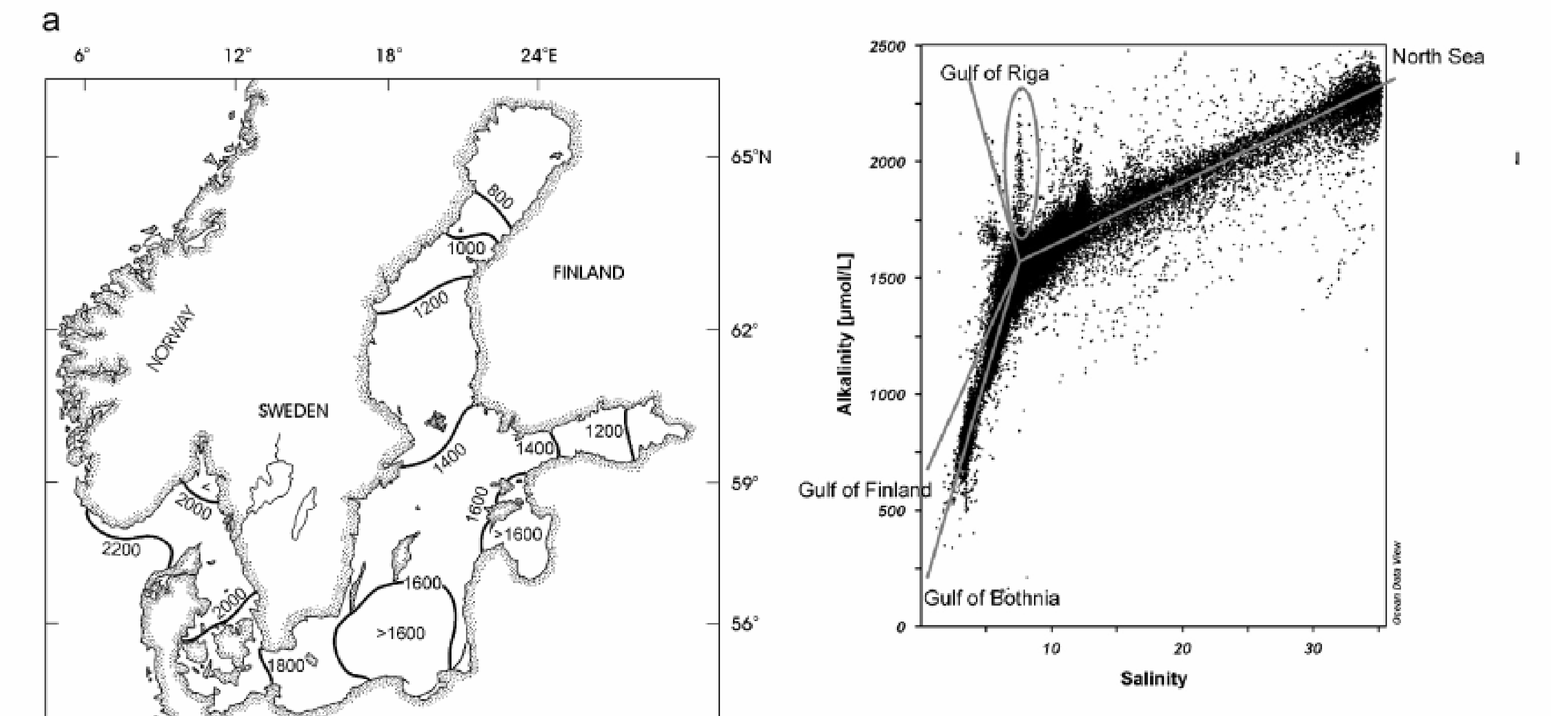
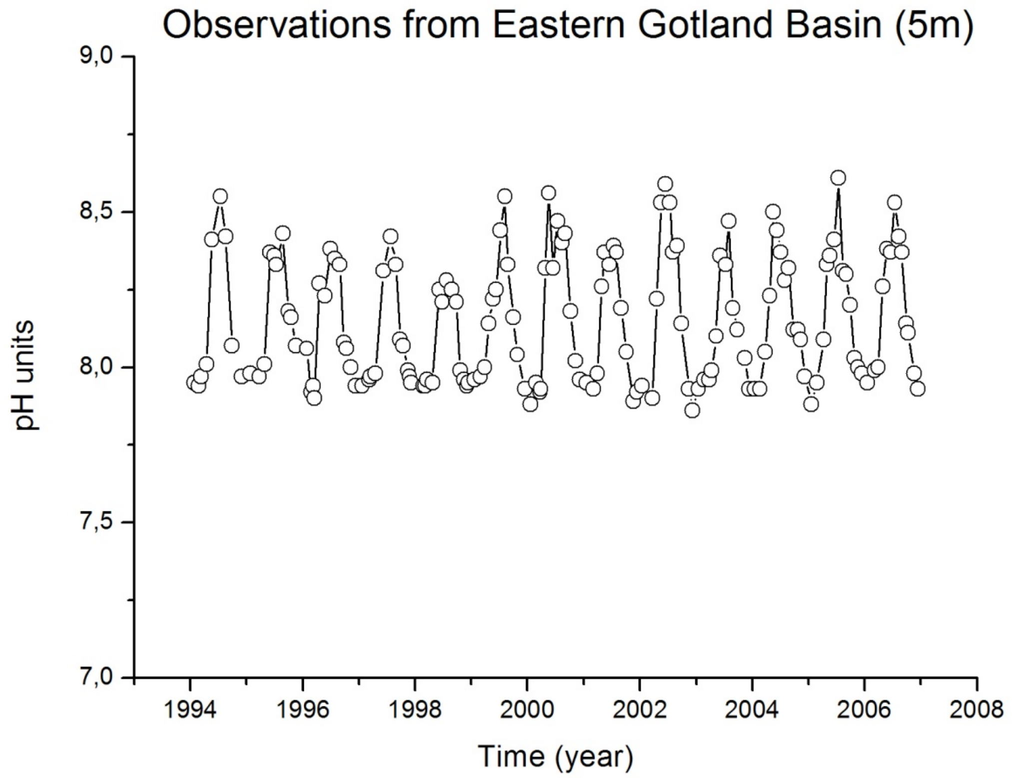


Fig. 5. Mean surface water total alkalinity of the Baltic Sea and its connect salinity (right) (redrawn from Rodhe, 1998).

Fig. 3. Total alkalinity versus salinity for all data of the Baltic Sea. Straight lines are guidelines, illustrating the mixing regimes. In the figure, the Bothnian Bay and the Bothnian Sea are merged to the Gulf of Bothnia. Encircled data originate from anoxic deep waters.

Observed pH data



Modelling the acid-base (pH) balance in the Baltic sea

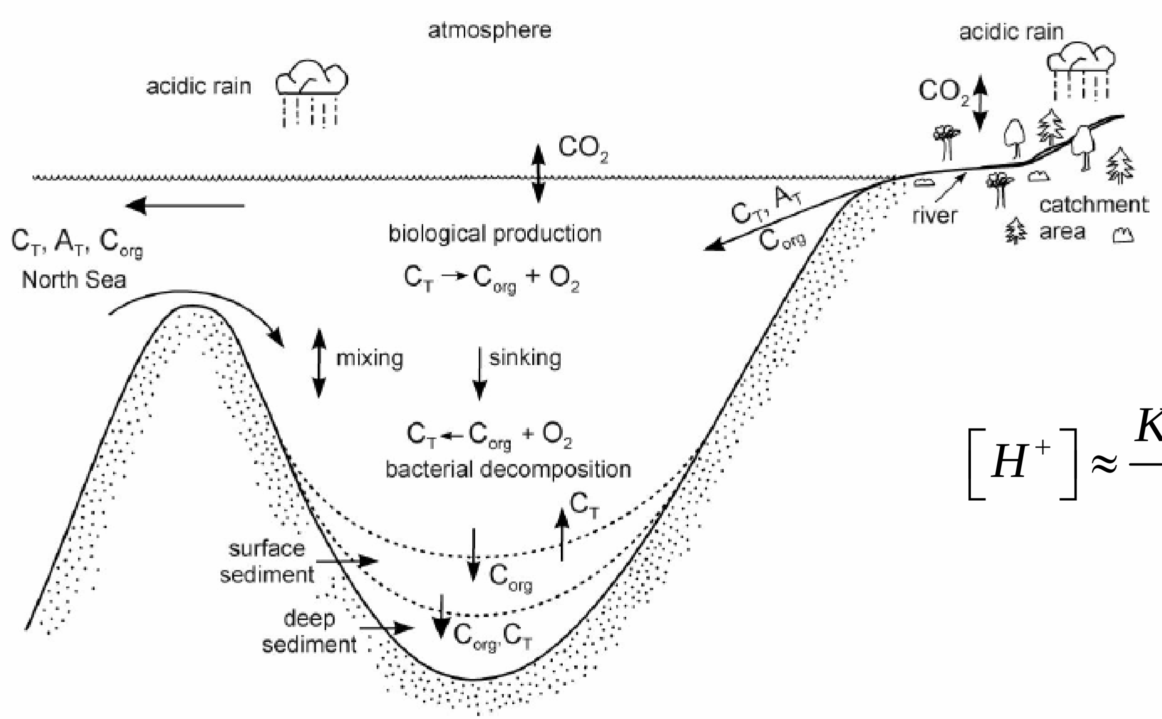


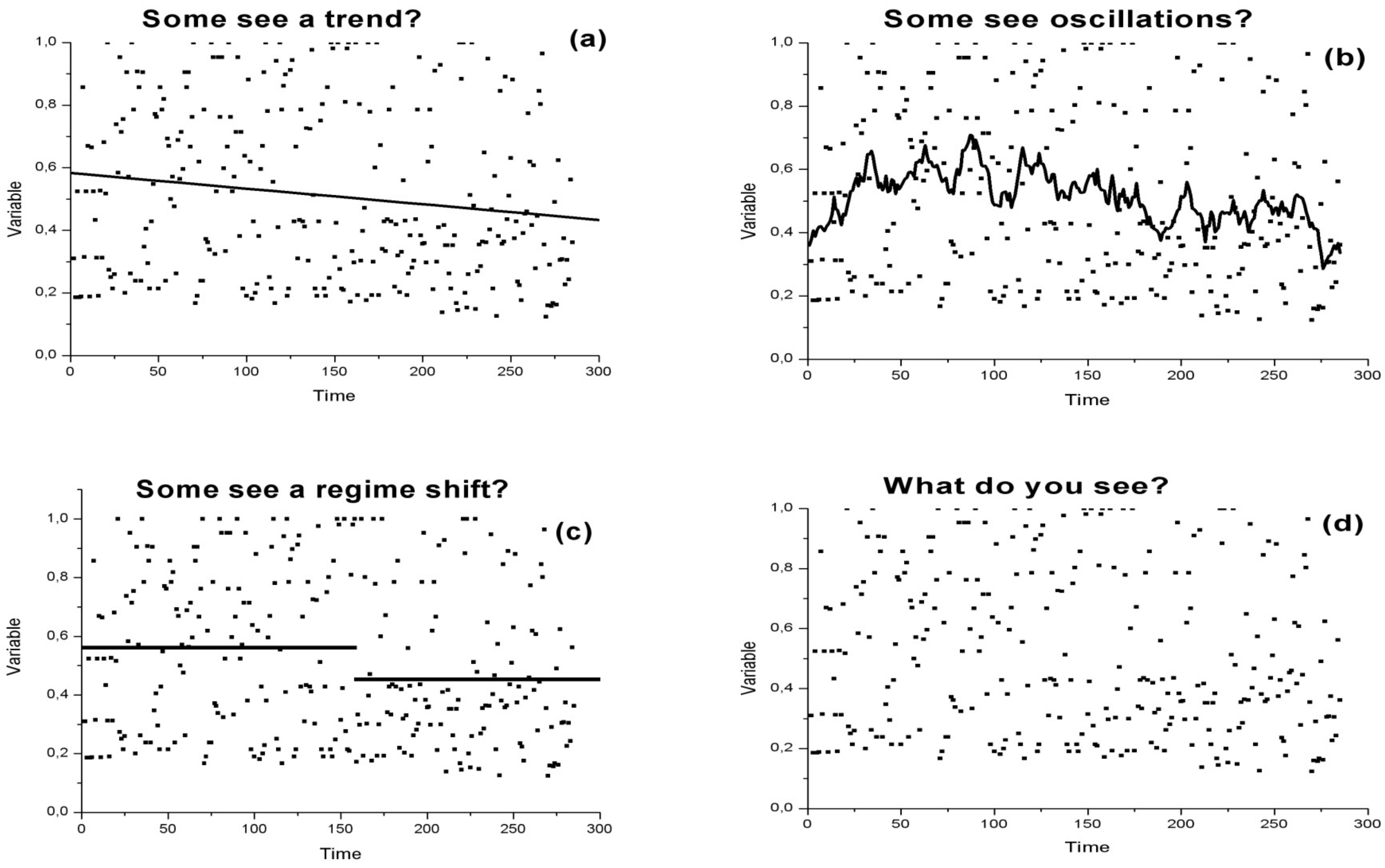
Fig. 2. A sketch of the Baltic Sea CO_2 system. A_T, C_{org}, and C_T indicate total alkalinity, total organic carbon, and total inorganic carbon; O_2 and CO_2 indicate oxygen and carbon dioxide concentrations.

$$\left[H^+\right] \approx \frac{K_2\left(2C_T - A_T\right)}{A_T - C_T}$$

Problem 10

Use pH observations from the Eastern Gotland Basin and plot the surface values. Discuss what controls the seasonal and long-term variations of the acid–base balance (data are available from Anders).

1.15 Climate change

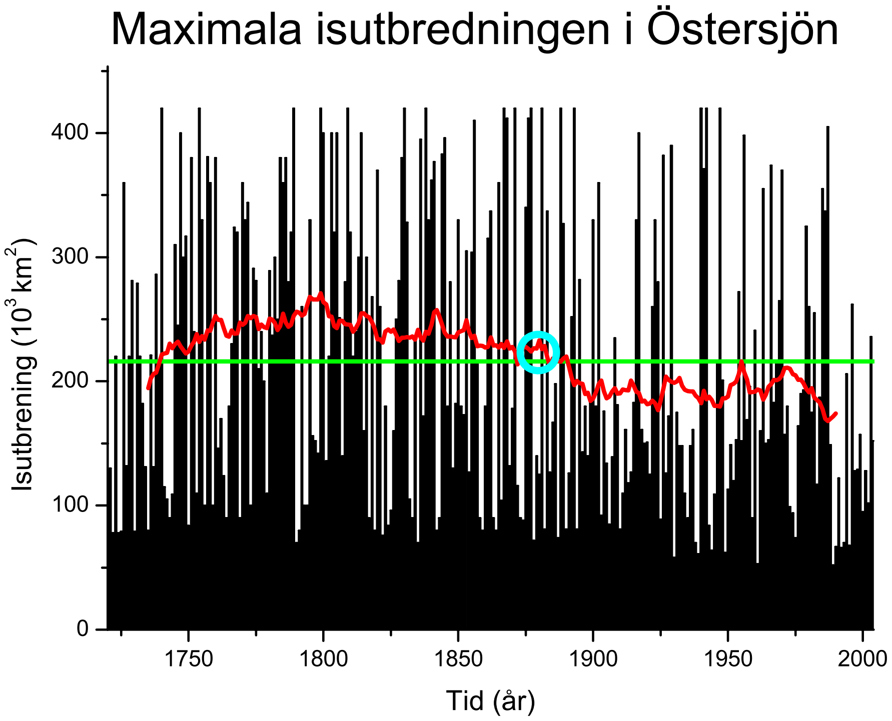

Some see a trend? (a)

Some see oscillations? (b)

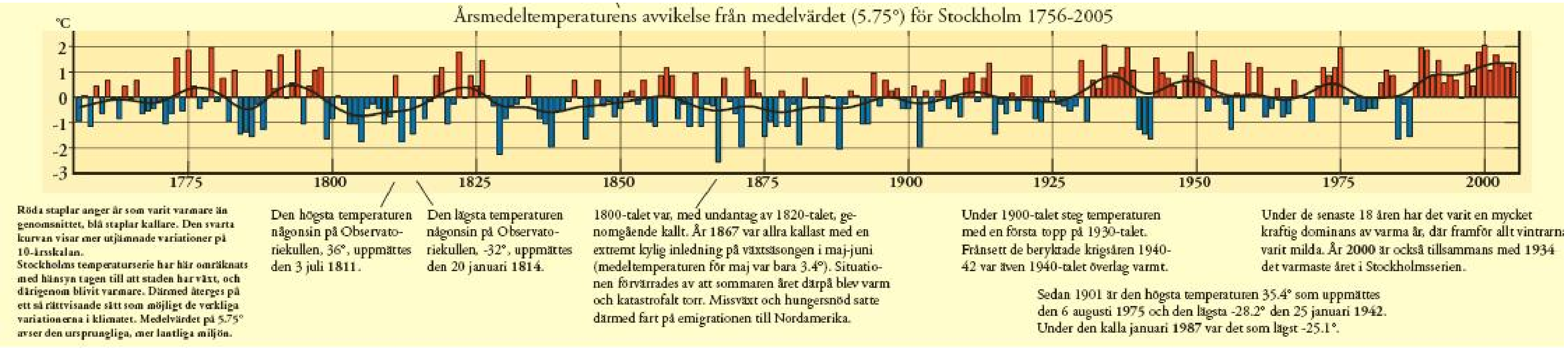
Some see a regime shift? (c)

What do you see? (d)

Maximum annual ice extent (MIB)



Stockholm air temperature



Årsmedeltemperaturens avvikelse från medelvärdet (5.75°) för Stockholm 1756-2005

Röda staplar anger år som varit varmare än genomsnittet, blå staplar kallare. Den svarta kurvan visar mer utjämnade variationer på 10-årsskalan.
Stockholms temperaturserie har här omräknats med hänsyn tagen till att staden har växt, och därigenom blivit varmare. Därmed återges på ett så rättvisande sätt som möjligt de verkliga variationerna i klimatet. Medelvärdet på 5.75° avser den ursprungliga, mer lantliga miljön.

Den högsta temperaturen någonsin på Observatoriekullen, 36°, uppmättes den 3 juli 1811.

Den lägsta temperaturen någonsin på Observatoriekullen, -32°, uppmättes den 20 januari 1814.

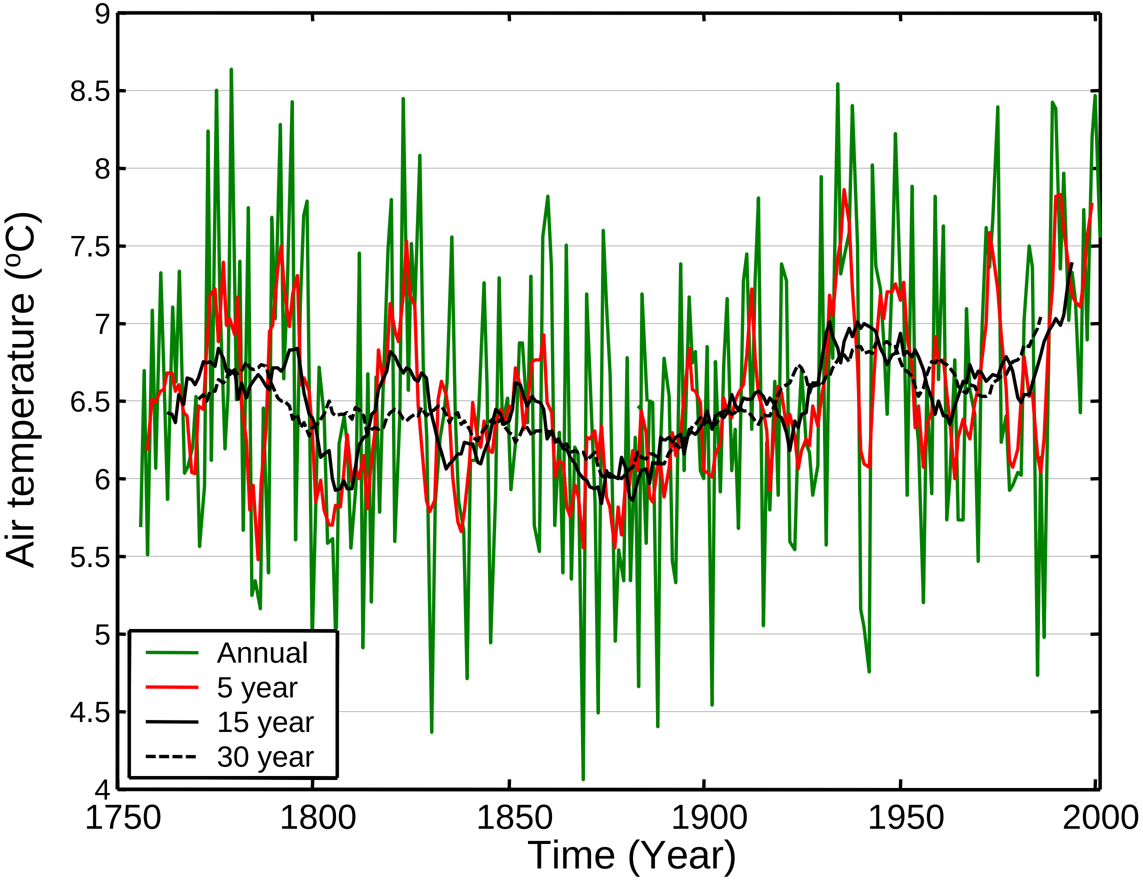
1800-talet var, med undantag av 1820-talet, genomgående kallt. År 1867 var allra kallast med en extremt kylig inledning på växtsäsongen i maj-juni (medeltemperaturen för maj var bara 3.4°). Situationen förvärrades av att sommaren året därpå blev varm och katastrofalt torr. Missväxt och hungersnöd satte därmed fart på emigrationen till Nordamerika.

Under 1900-talet steg temperaturen med en första topp på 1930-talet. Frånsett de beryktade krigsåren 1940-42 var även 1940-talet överlag varmt.

Under de senaste 18 åren har det varit en mycket kraftig dominans av varma år, där framför allt vintrarn varit milda. År 2000 är också tillsammans med 1934 det varmaste året i Stockholmsserien.

Sedan 1901 är den högsta temperaturen 35.4° som uppmättes den 6 augusti 1975 och den lägsta -28.2° den 25 januari 1942. Under den kalla januari 1987 var det som lägst -25.1°.

What is climate and climate change?



From Omstedt et al., 2004

What can we see from time serie analyses?

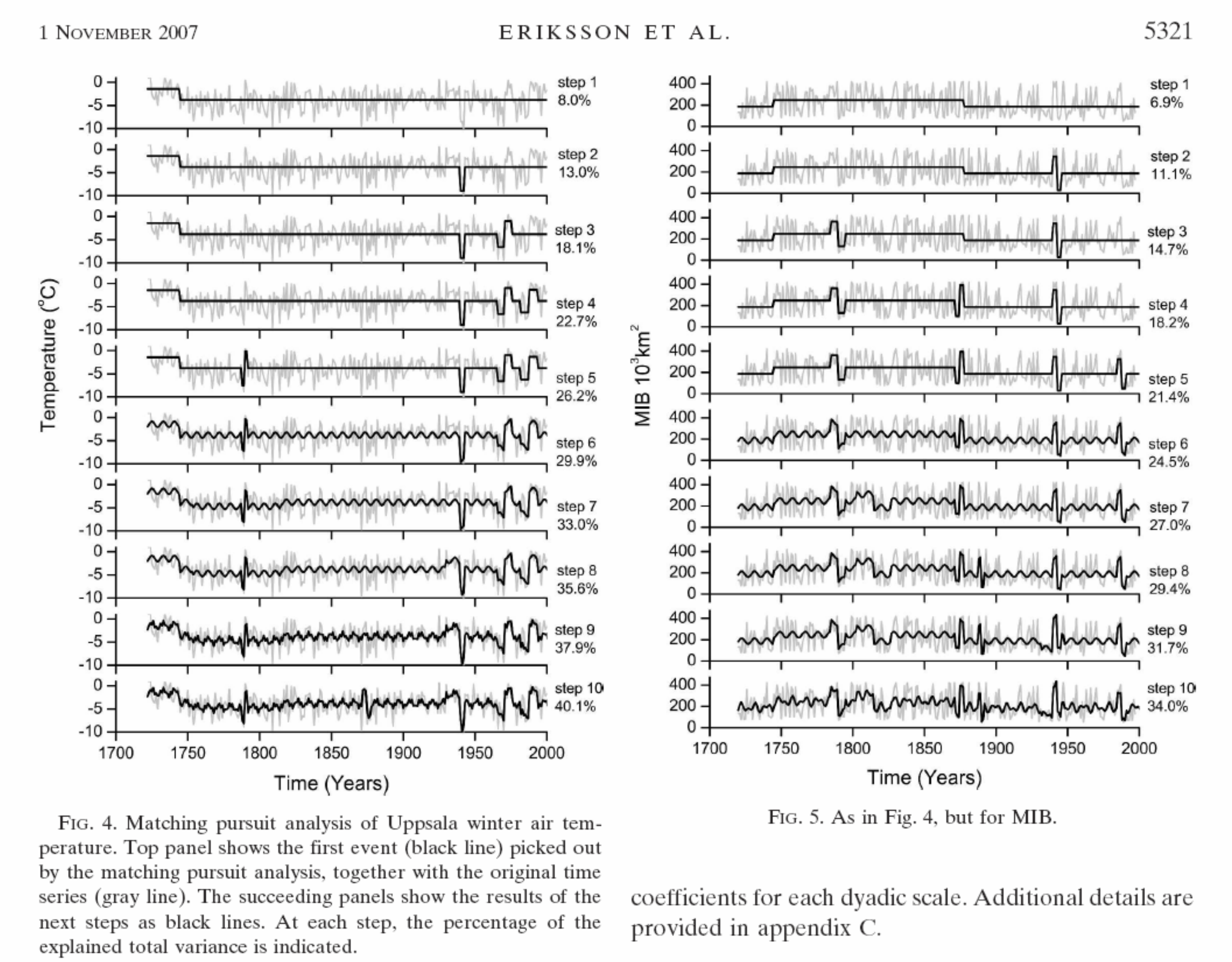


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FIG. 4. Matching pursuit analysis of Uppsala winter air temperature. Top panel shows the first event (black line) picked out by the matching pursuit analysis, together with the original time series (gray line). The succeeding panels show the results of the next steps as black lines. At each step, the percentage of the explained total variance is indicated.

FIG. 5. As in Fig. 4, but for MIB.

coefficients for each dyadic scale. Additional details are provided in appendix C.

What can we see from time serie analyses?

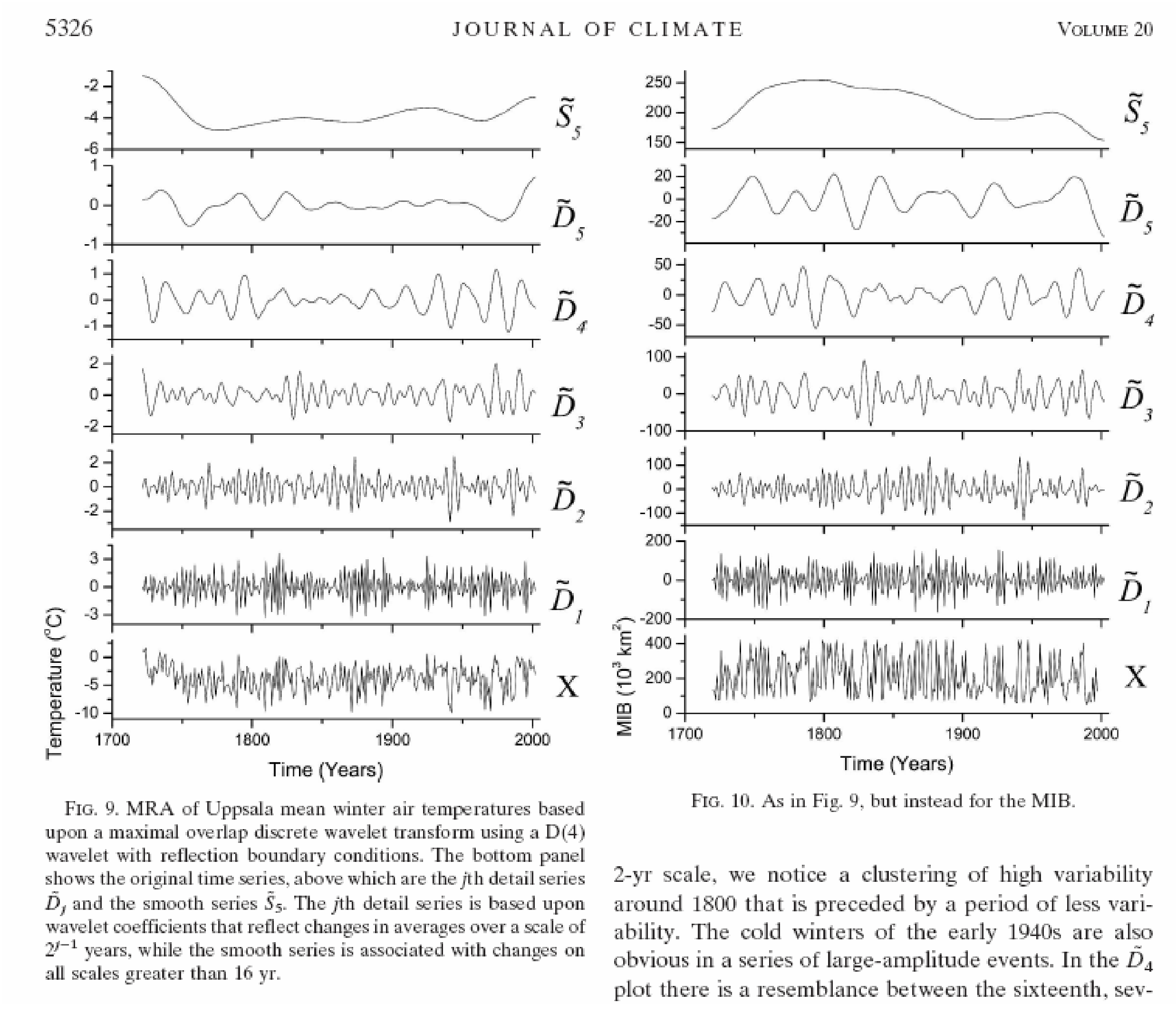

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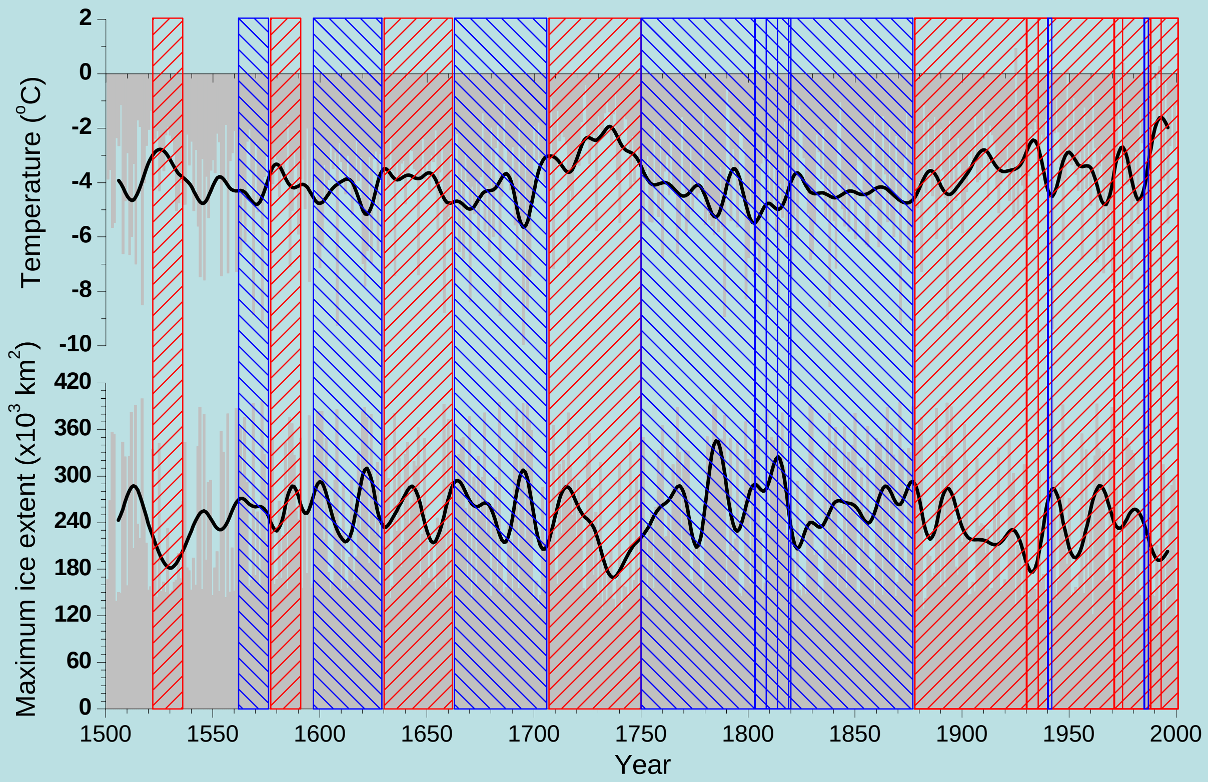
FIG. 9. MRA of Uppsala mean winter air temperatures based upon a maximal overlap discrete wavelet transform using a D(4) wavelet with reflection boundary conditions. The bottom panel shows the original time series, above which are the jth detail series $\tilde{D}_j$ and the smooth series $\tilde{S}_5$. The jth detail series is based upon wavelet coefficients that reflect changes in averages over a scale of 2^{j-1} years, while the smooth series is associated with changes on all scales greater than 16 yr.

FIG. 10. As in Fig. 9, but instead for the MIB.

2-yr scale, we notice a clustering of high variability around 1800 that is preceded by a period of less variability. The cold winters of the early 1940s are also obvious in a series of large-amplitude events. In the $\tilde{D}_4$ plot there is a resemblance between the sixteenth, sev-

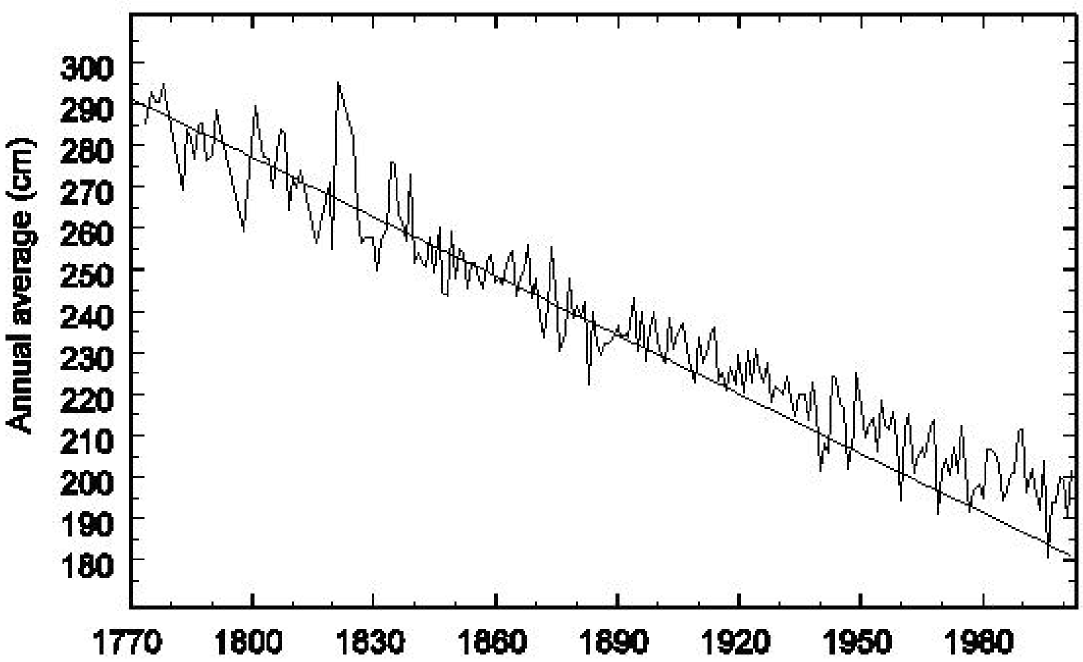
Characterizing the European sub arctic winter climate (Eriksson et al., 2007)



Perioder

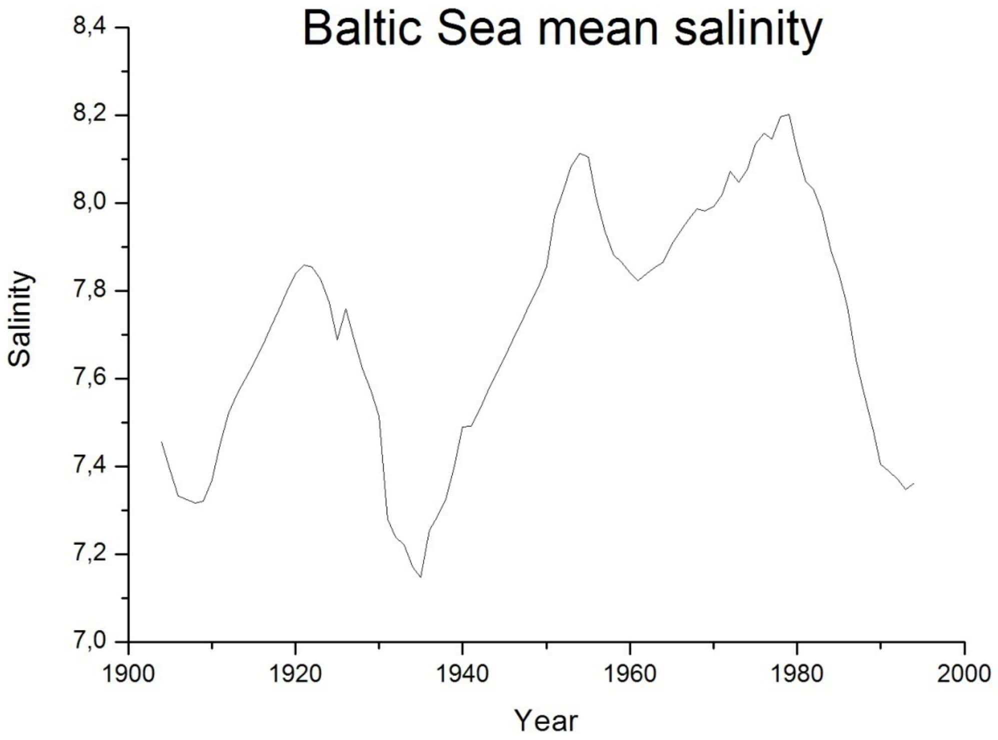
1522-36	Mild
1562-76	Cold
1577-91	Mild
1597-1629	Cold
1630-62	Mild
1663-1706	Cold
1707-50	Mild
1750-1877	Cold
- 1803-20	Cold
1878-2000	Mild
- 1930-39	Mild
- 1940-42	Cold
- 1971-75	Mild
- 1985-87	Cold
- 1988-93	Mild

Stockholm sea levels words longest

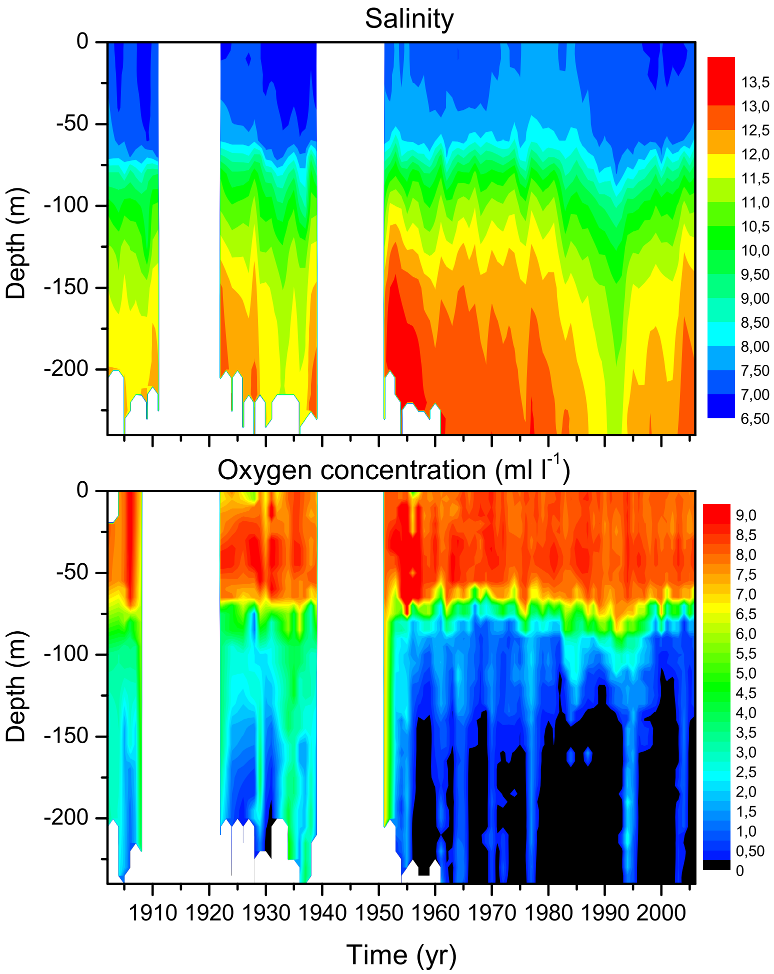


Baltic Sea mean salinity

(mean over the whole Baltic Sea and all depth, Winsor et al 2001,2003)

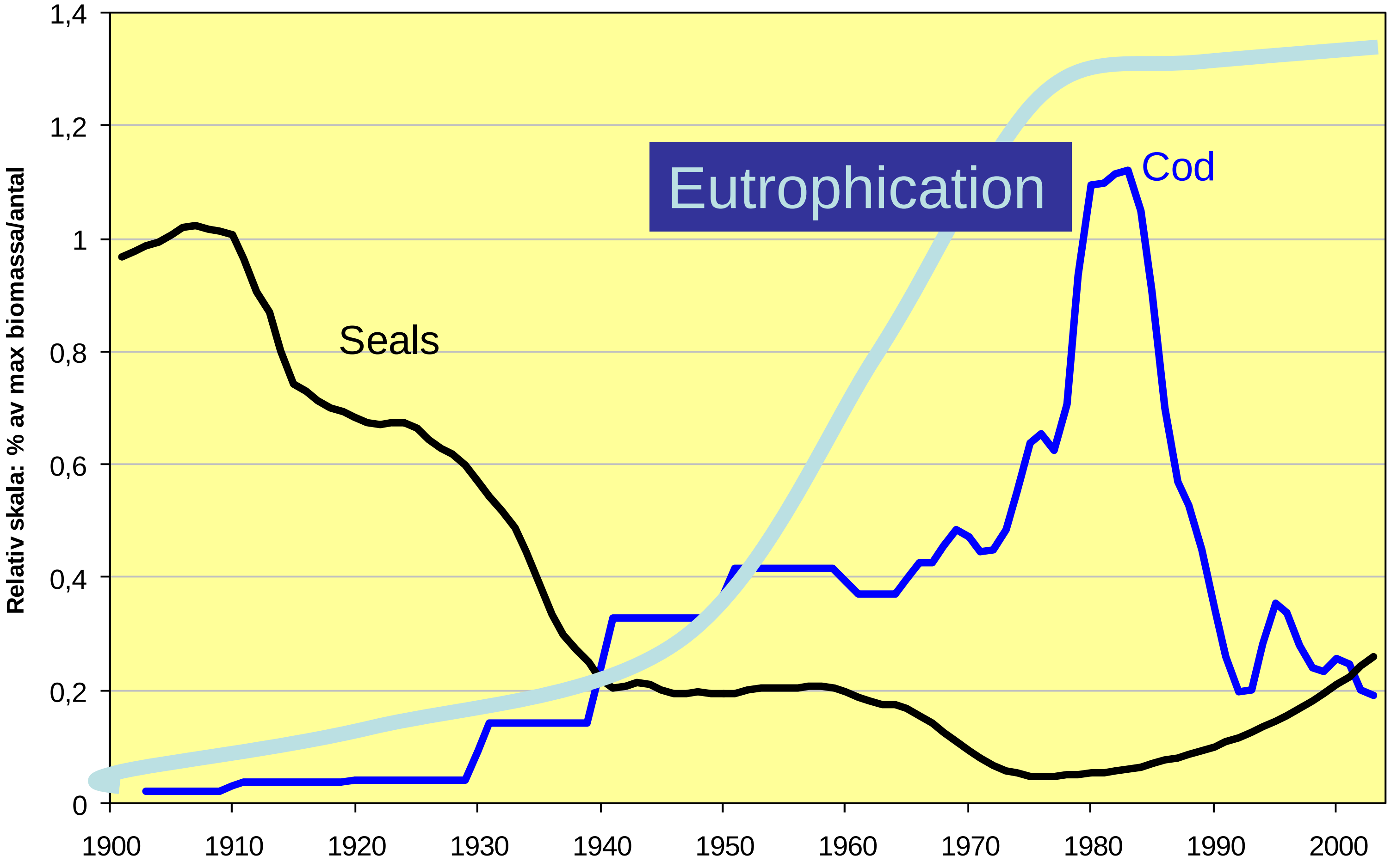


Observed oxygen concentration show increased areas with anoxic conditions



Gustafsson and Omstedt, 2008

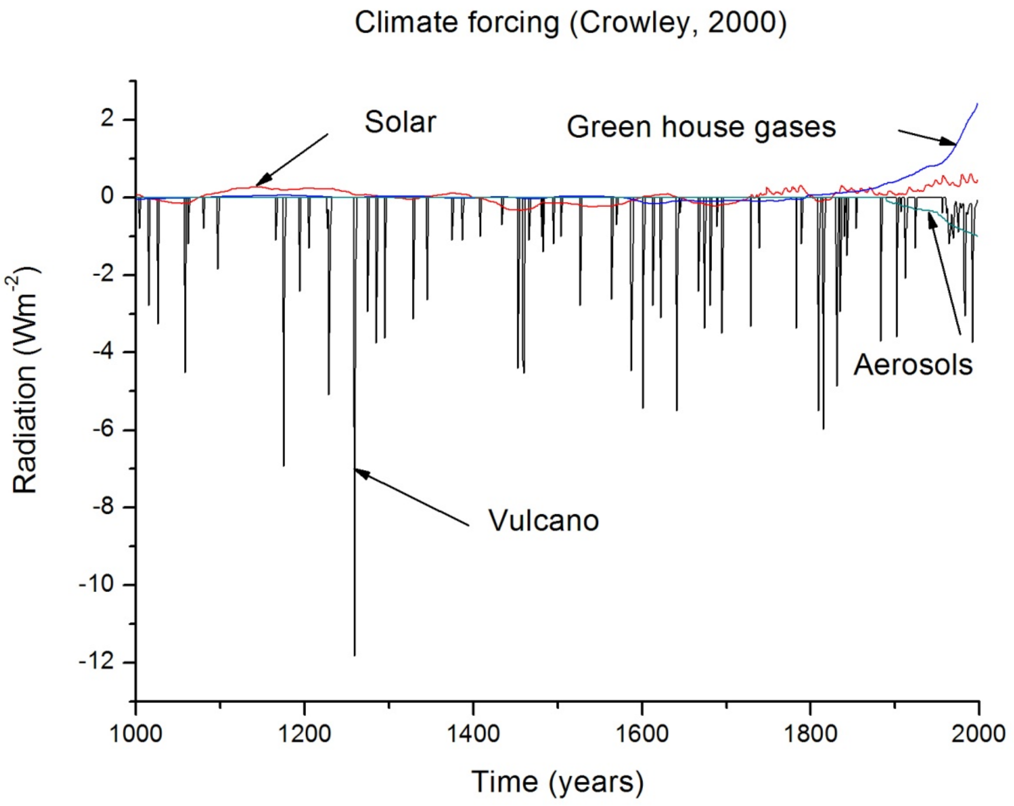
Large changes in the Baltic Sea ecosystems



From Fredrik Wulff

Climate forcing

$$\Delta T_s / \Delta F = \lambda$$



Problem 11

Investigate the climate variability and trends in Stockholm air temperature observations. What is determining the trend? What are the causes of the trend? Can trends tell us anything about the future (data are available from Anders).

Problem 12

Compare the Stockholm air temperature observations with the long-term variations in sea surface temperatures at Christianö. Examine the trend of the 15-year running mean data for the period since 1900(data are available from Anders).

Problem 13

Investigate Stockholm sea level variations in relation to climate change. Assume, as Ekman (2003) did, that the apparent land uplift could be determined from the trend from 1774 to 1864 (data are available from Anders).

Thanks for your interest!

Organic Carbon ↔ CO_2 ↔ pH ↔ Alkalinity

Baltic - C

Baltic Sea Experiment

BALTEX

A GEWEX / WCRP Project