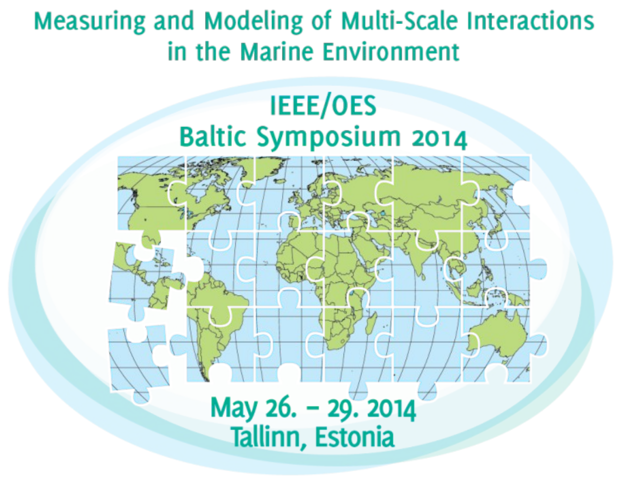
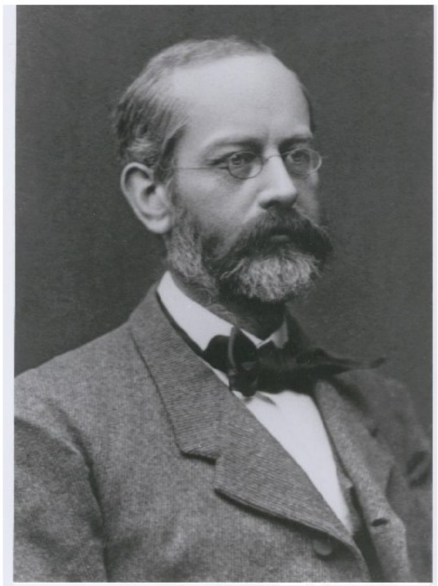
Baltic Earth

Baltic Sea modelling as a tool for the study of past climates

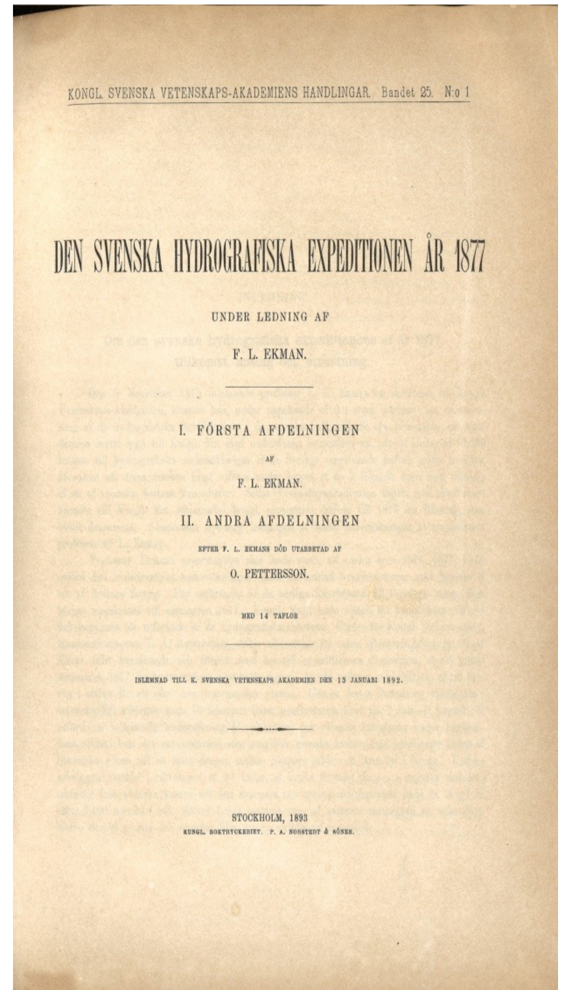
Anders Omstedt



An example: The Swedish Hydrographic Expedition 1877



Fredrik Laurentz Ekman



KONGL. SVENSKA VETENSKAPS-AKADEMIENS HANDLINGAR. Bandet 25. N:o 1

DEN SVENSKA HYDROGRAFISKA EXPEDITIONEN ÅR 1877

UNDER LEDNING AF

F. L. EKMAN.

I. FÖRSTA AFDELNINGEN

AF

F. L. EKMAN.

II. ANDRA AFDELNINGEN

EFTER F. L. EKMANS DÖD UTARBETAD AF

O. PETTERSSON.

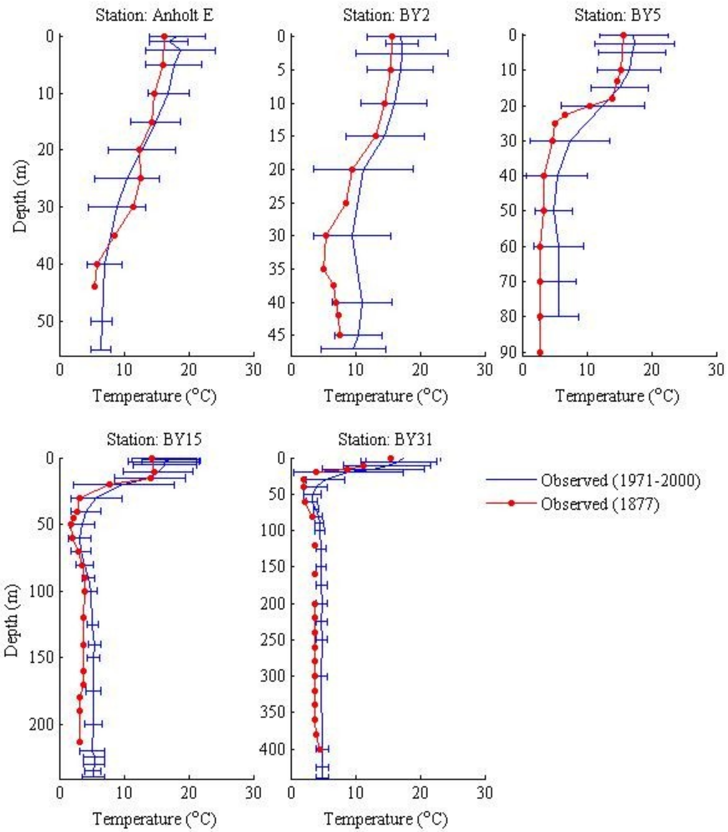
MED 14 TAFLOR

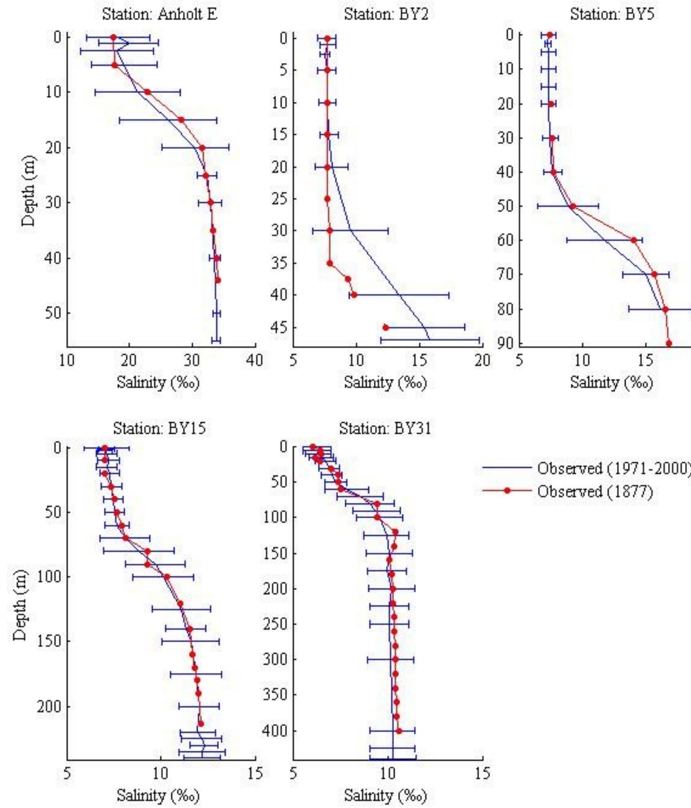
INLEMNAD TILL K. SVENSKA VETENSKAPS AKADEMIEN DEN 13 JANUARI 1892.

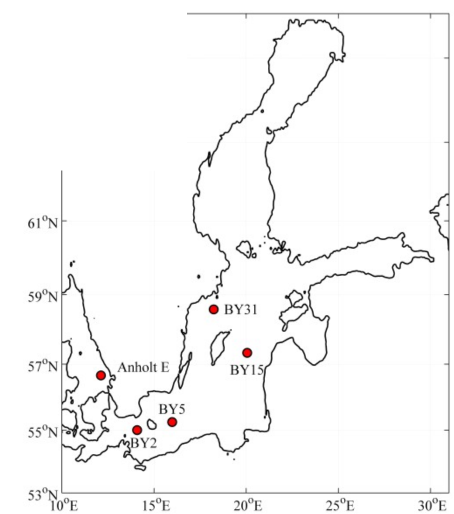
STOCKHOLM, 1893

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER.

The Swedish Hydrographic Expedition 1877 compared to modern summer observations(1971-2000)







The Swedish Hydrographic Expedition 1877

Detection:

- Deep water temperature about 1 degrees colder than present
- No changes in salinity

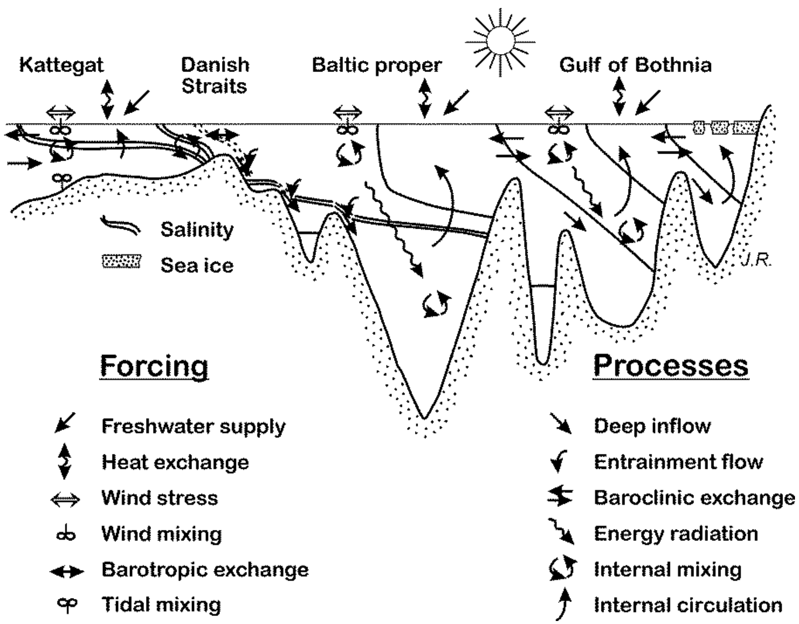
Implication:

- Slight changes in heat cycle and no change in water cycle

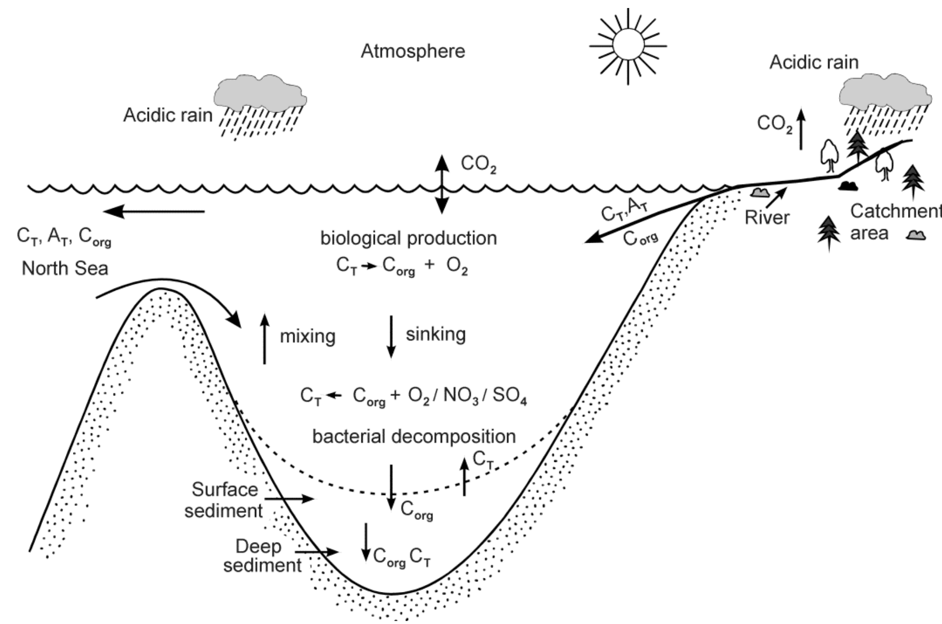
Much more old reports/papers about the ocean are waiting for data mining!

Baltic Sea modelling

Physical part



Biogeochemical part



Baltic Sea modelling (examples from PROBE-Baltic) integrating:

- Model equation and parameterizations
- Forcing from atmosphere (wind, temp., humidity, cloudiness, precipitation, organic and inorganic carbon, nutrients)
- Forcing from rivers, North Sea (amount water, salinity, temperature, sea levels, nutrient, organic and inorganic carbon)
- Initial conditions

Ocean modelling as a tool for the study of past climates

Major ideas:

1. Ocean information data and reports can provide independent information on climate such as sea level, temperatures, ice, salinity, fish stocks etc.
2. Large amount of meteorological and terrestrial data (models, observations, gridded and reconstructed) on decadal and centennial scales freely available but require quality tests. Using these data and models new ocean gridded data sets can be generated.
3. Ocean models a logical tool for integrating large amount of data into Earth system understanding and to evaluate our climate knowledge.
4. Ocean models major tools for water managements and climate scenarios but needs to be tested in many different ways, such as past and present climate conditions.

Reconstructions of Baltic Sea physical and biogeochemical conditions during 1958-2012

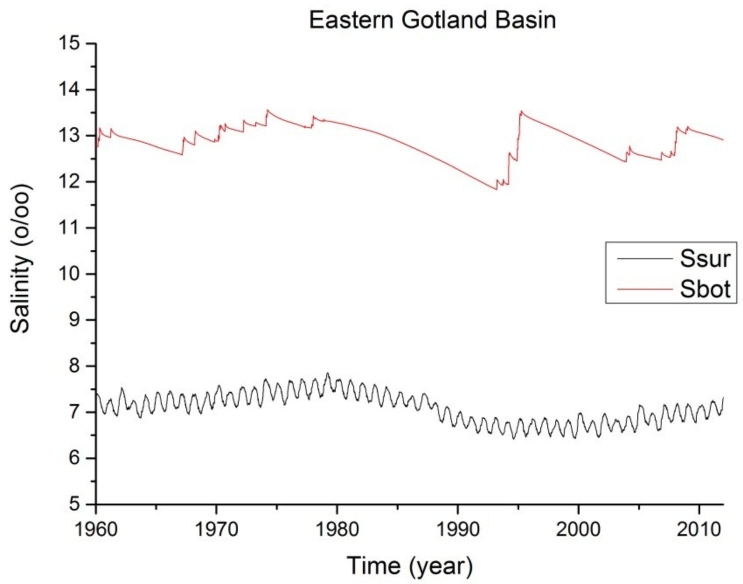
(www.oceanclimate.se)

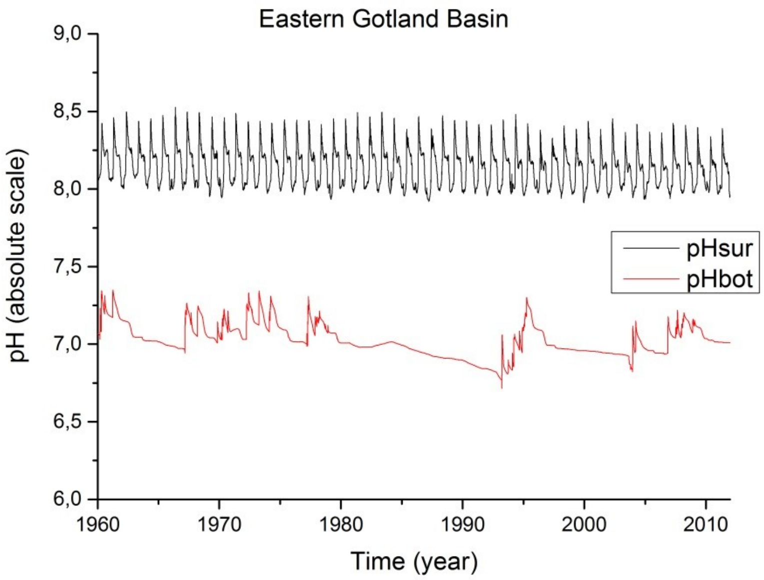
Table 1. Calculated data available in file **PB calculated ocean time series I 1958-2012.zip**

Sub-basin	Acronym	Model depth	Variables	File name
Kattegat	ka	100	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	ka_graph.dat
Öresund	or	30	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	or_graph.dat
Belt Sea	be	40	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	be_graph.dat
Arkona Basin	ar	50	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	ar_graph.dat
Bornholm Basin	b	90	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	bh_graph.dat
E Gotland Basin	go	250	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	go_graph.dat
NW Gotland B.	[illegible]	250	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	nw_graph.dat
Gulf of Riga	[illegible]	50	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	gr_graph.dat
Gulf of Finland	gf	120	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	gf_graph.dat
Archipelago Sea	as	90	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	as_graph.dat
Åland Sea	al	220	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	al_graph.dat
Bothnian Sea	bs	155	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	bs_graph.dat
Bothnian Bay	bb	130	$T_s,T_b,S_s,S_b,O_{2s},O_{2b},PO_{4s},PO_{4d}, NO_{3s}, NO_{3d}, NHT_s ,NHT_d$	bb_graph.dat

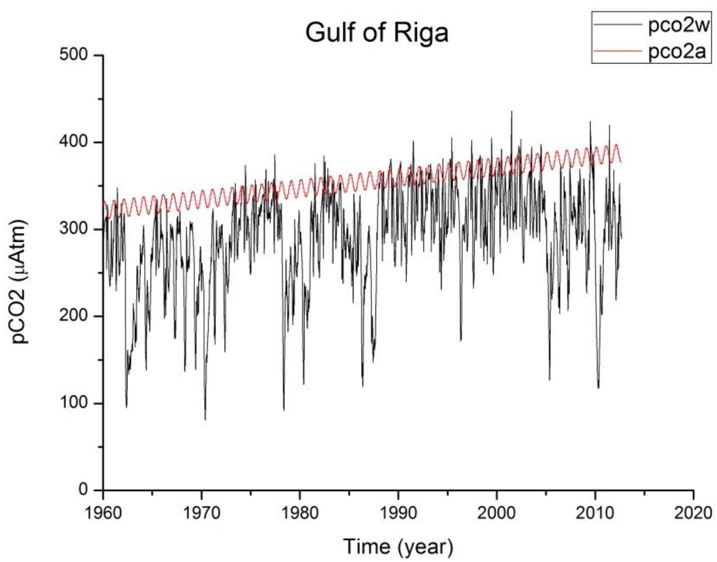
Freely available

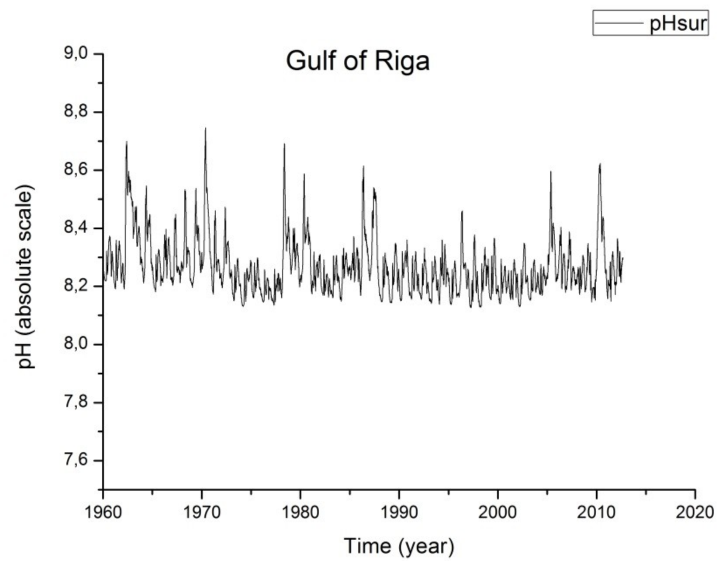
Reconstructions of Baltic Sea physical and biogeochemical conditions during 1958-2012 an example:





Reconstructions of Baltic Sea physical and biogeochemical conditions during 1958-2012 an example:





Freely available

Reconstructions of Baltic Sea physical and biogeochemical conditions during 1500-2001

(www.oceanclimate.se)

Table 1. Calculated data available in file **PB ocean time series I 1893-1999.zip and PB ocean time series I 1500-2001.zip**

Sub-basin	Acronym	Model depth	Variables	File name
Kattegat	ka	100	Ts, Tb, Ai, hi	ka_graph.dat
Öresund	or	30	Ts, Tb, Ai, hi	or_graph.dat
Belt Sea	be	40	Ts, Tb, Ai, hi	be_graph.dat
Arkona Basin	ar	50	Ts, Tb, Ai, hi	ar_graph.dat
Bornholm Basin	bh	90	Ts, Tb, Ai, hi	bh_graph.dat
E Gotland Basin	go	250	Ts, Tb, Ai, hi	go_graph.dat
NW Gotland B.	nw	250	Ts, Tb, Ai, hi	nw_graph.dat
Gulf of Riga	gr	50	Ts, Tb, Ai, hi	gr_graph.dat
Gulf of Finland	gf	120	Ts, Tb, Ai, hi	gf_graph.dat
Archipelago Sea	as	90	Ts, Tb, Ai, hi	as_graph.dat
Åland Sea	al	220	Ts, Tb, Ai, hi	al_graph.dat
Bothnian Sea	bs	155	Ts, Tb, Ai, hi	bs_graph.dat
Bothnian Bay	bb	130	Ts, Tb, Ai, hi	bb_graph.dat

Freely available

Reconstructions of Baltic Sea physical and biogeochemical conditions during 1500-2001

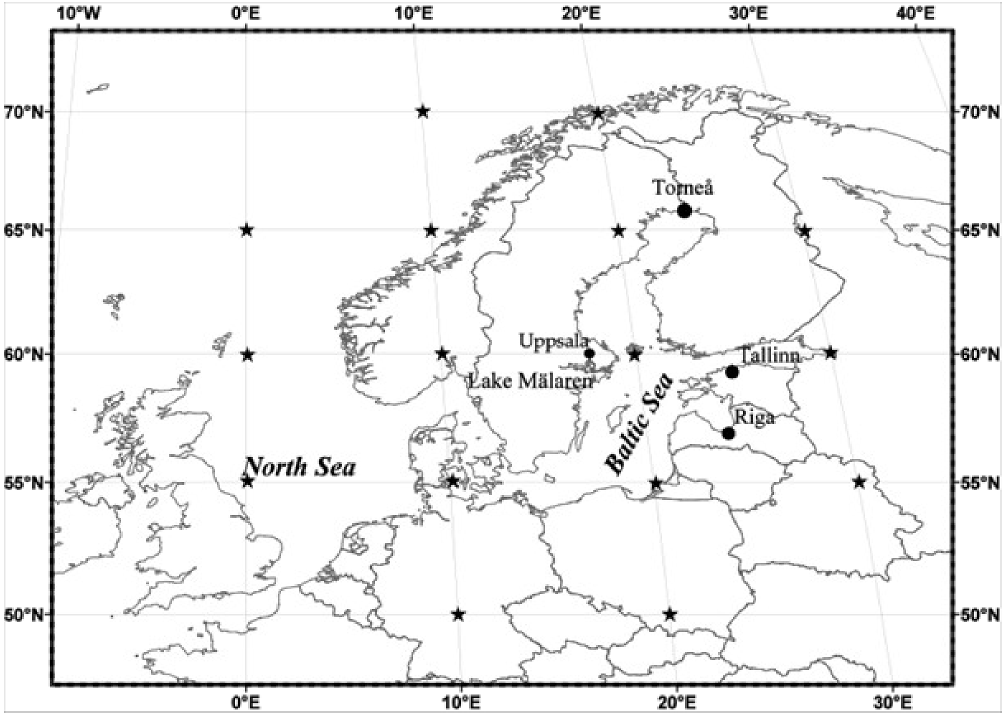
(www.oceanclimate.se)

Table 2. Calculated data available in file **PB ocean time series II 1893-1999.zip** and **PB ocean time series II 1500-2001.zip**

Sub-basin	Acronym	Variables	File name
Kattegat	ka	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	ka_res2.dat
Öresund	or	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	or_res2.dat
Belt Sea	be	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	be_res2.dat
Arkona Basin	ar	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	ar_res2.dat
Bornholm Basin	bh	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	bh_res2.dat
E Gotland Basin	go	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	go_res2.dat
N W Gotland Basin	nw	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	nw_res2.dat
Gulf of Riga	gr	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	gr_res2.dat
Gulf of Finland	gf	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	gf_res2.dat
Archipelago Sea	as	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	as_res2.dat
Åland Sea	al	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	al_res2.dat
Bothnian Sea	bs	Tac,Tw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	bs_res2.dat
Bothnian Bay	bb	Ta,cTw,Wac,Fh,Fe,Fl,Fn,Fsw, Fice	bb_res2.dat

And other model parameters on request

Recontructing the climate of the Northern Europe during past 500 years



The Baltic Sea and Skagerrak region where the stars indicate the pressure points used when calculating the atmospheric circulation indices (Eriksson *et al*., 2007).

Statistical downscaling using gridded data of pressure and temperatures

1. Characterizing the large scale atmosphere
   $Y = f(X_1, X_2 \ldots X_N)$
2. Hunt for good predictors based on air pressure
3. Assume balance between pressure and wind (geostrophy) and decompose the velocity field into its 5 basic components:

$$\mathbf{V}_h = \mathbf{V}_0 + \mathbf{R} + \mathbf{E} + \mathbf{D}_1 + \mathbf{D}_2$$
$$\mathbf{V}_0 = (U_0\mathbf{i}, V_0\mathbf{j})$$
$$\mathbf{R} = \tfrac{1}{2}\zeta(-y\mathbf{i} + x\mathbf{j})$$
$$\mathbf{E} = \tfrac{1}{2}\varepsilon(x\mathbf{i} + y\mathbf{j})$$
$$\mathbf{D}_1 = \tfrac{1}{2}\delta_1(y\mathbf{i} + x\mathbf{j})$$
$$\mathbf{D}_2 = \tfrac{1}{2}\delta_2(x\mathbf{i} - y\mathbf{j})$$

$$\varepsilon = \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}, \quad \zeta = \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y}, \quad \delta_1 = \frac{\partial U}{\partial y} + \frac{\partial V}{\partial x}, \quad \delta_2 = \frac{\partial U}{\partial x} - \frac{\partial V}{\partial y}$$

4. Regional pressure predictors superior over simple indices such as NAO.

Reconstructions of Baltic Sea. Maximum annual ice extent

Fig. 8 Modelled (*black*) and reconstructed/observed (*red*) MIB over the 1720–2001 period. Model results and observations are in good agreement. The earliest records of ice extent are from 1720; however, it was not until the 1880s that continuous measurements began to be made from deployed light ships. The minimum observed MIB is indicated by a *dashed line*

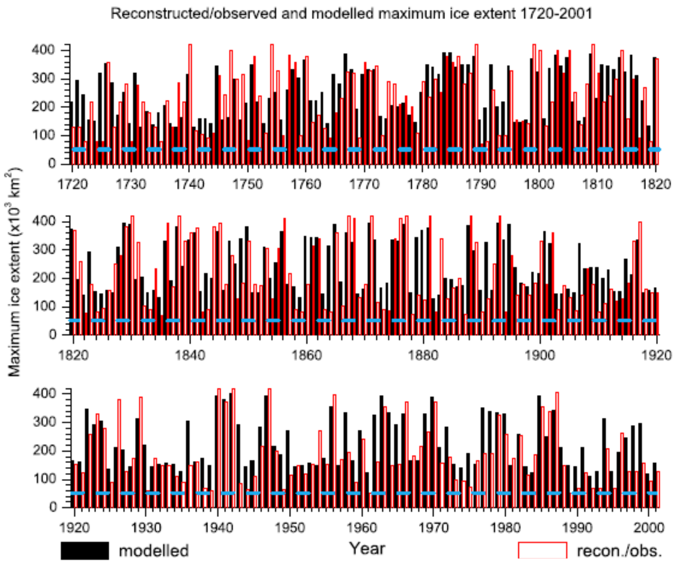
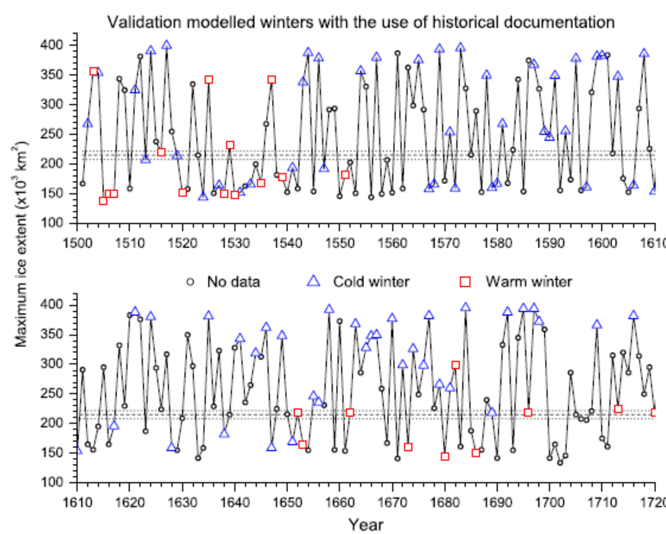


Fig. 9 Modelled winters prior to 1720 are validated with historical documents (*triangles* denote documented cold winters and *squares* denote mild winters), giving information about both cold and mild winters. Documented data are available for 150 events occurring during 100 of the 219 years between 1500 and 1720. Approximately seven of ten-modelled winters with corresponding documented winter data can be considered as validated



Reconstructions of Baltic Sea.
Karl X ice march 1658

Karl X on the ice march over the Little and Great Belts, 1658

30 Jan. Swedish army crosses the Little Belt; partly broken and thin ice with snow, several drowned due to weak ice

6 Feb. Swedish army (2000-3000 men) crosses the Great Belt; cold temperatures, no losses

19 Feb. Preliminary peace treaty between Sweden and Denmark

Reconstructions of Baltic Sea. Calculated ice extent

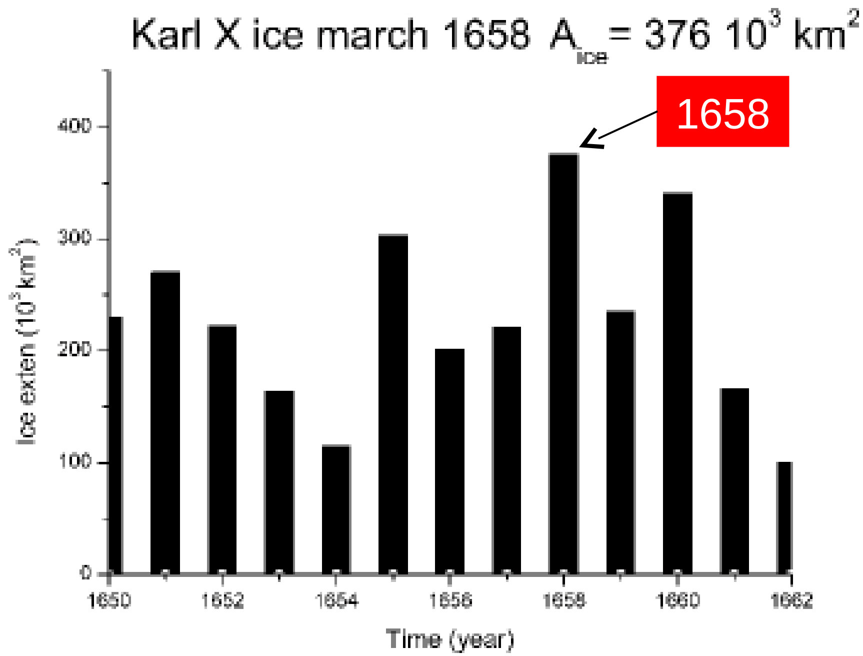
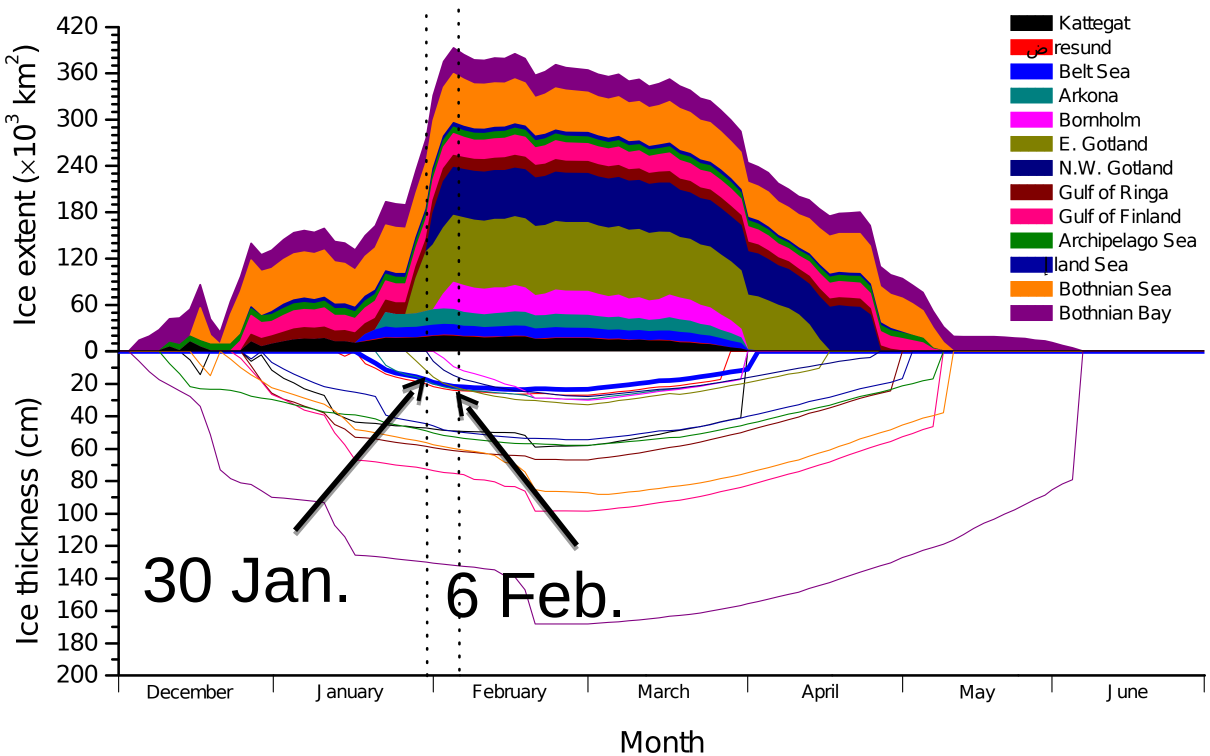


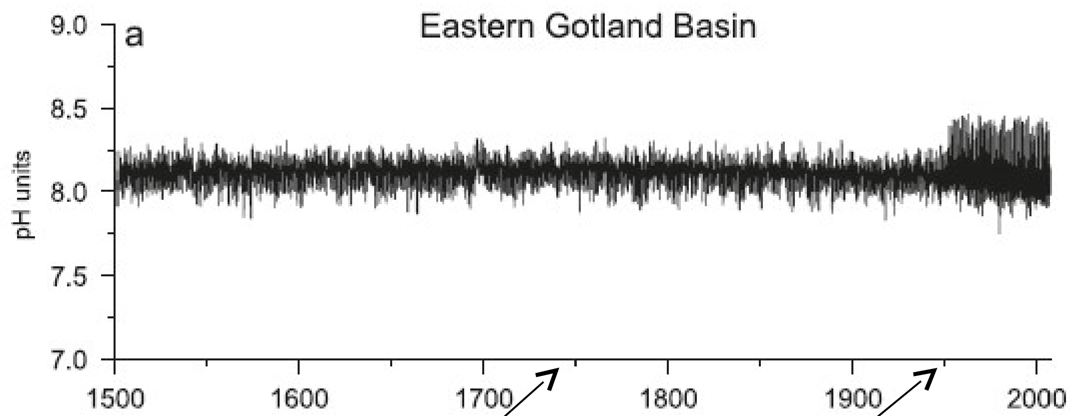
Figure 2. Model calculation of the Baltic Sea ice cover extent. The climate model calculations of the ice cover extent in the 1650s. The model indicates that there was a great deal of ice in 1658, which is consistent with the historical fact that King Carl X Gustaf and his army walked across the Little Belt and the Great Belt that year.

Reconstructions of Baltic Sea.
Calculated ice thickness



Calculated ice extent and thickness, 1658

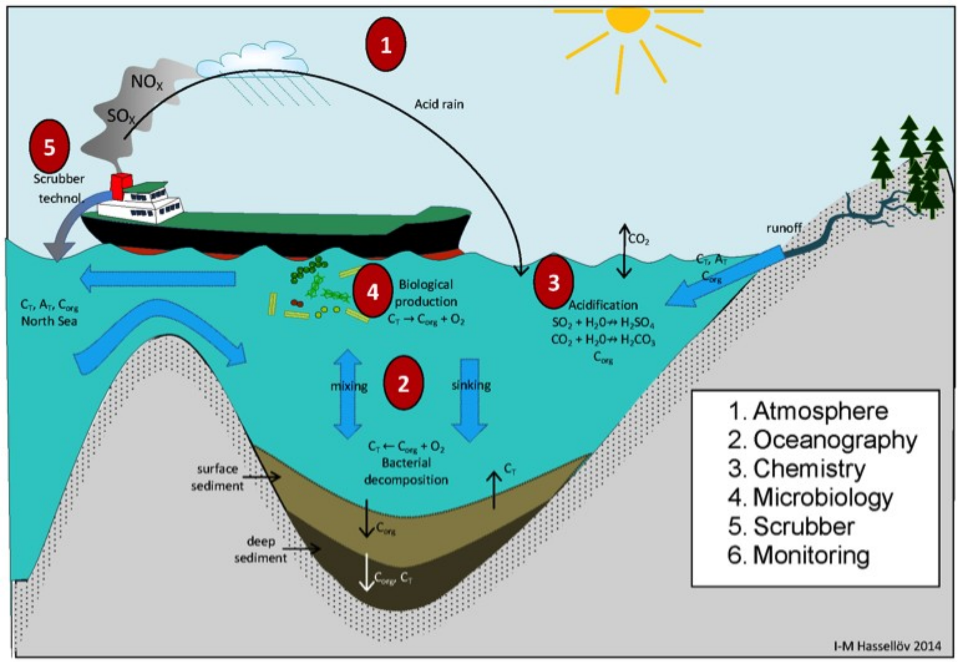
Reconstructions of Baltic Sea: Sea surface pH



Nutrient load start to increase

CO_2 start to increase

Present on going: Commercial shipping as a source of acidification in the Baltic Sea. FORMAS research program 2014-2016



http://www.lighthouse.nu/SHIpH/

Summary

- The work to understand the past Baltic Sea climate conditions can be seen as a large puzzle where humanist researchers and scientists of many disciplines can piece together a picture of past and ancient climates
- Baltic Sea modelling can bridge the different disciplines and by making model reconstruction freely available the data sets may hopefully improve this communication?

Thanks for your interest!

Presented results based on:

Edman, M., and A., Omstedt (2013). Modeling the dissolved CO_2 system in the redox environment of the Baltic Sea. Limnol. Oceanogr., 58(1), 2013, 74-92

Ekman, F.L., and O., Pettersson (1893). Den svenska hydrografiska expeditionen år 1877. Kungl., Svenska Vetenskapliga Akademiens handlingar, Band 25., No. 1.

Eriksson, C., A. Omstedt, J.E. Overland, D.B. Percival, H.O. Mofjeld (2007). Characterizing the European sub-arctic winter climate since 1500 using ice, temperature and circulation time series. Journal of Climate 20, 5316-5334. DOI 10.1175/2007JCLI1461.1

Gustafsson E, (2011). Modelling long-term development of hypoxic area and nutrient pools in the Baltic Proper. J. Marine Sys. 94, 120–34.

Hansson, D. and A., Omstedt, (2008). Modelling the Baltic Sea ocean climate on centennial time scale; temperature and sea ice. Climate Dynamics 30, 763-778. DOI 10.1007/s00382-007-0321-2

Hansson, D., Eriksson, C., Omstedt, A., and D., Chen (2010). Reconstruction of river runoff to the Baltic Sea. Int. J. Climatol., DOI: 10.1002/joc.2097

Omstedt, A., (2011). Guide to process based modelling of lakes and coastal seas. Springer-Praxis books in Geophysical Sciences, DOI 10.1007/978-3-642-17728-6. Springer-Verlag Berlin Heidelberg.

Omstedt, A., Edman, M., Claremar, B., Frodin, P., Gustafsson, E., Humborg, C., Mörth, M., Rutgersson, A., Schurgers, G., Smith, B., Wällstedt, T., and Yurova, A. (2012). Future changes of the Baltic Sea acid-base (pH) and oxygen balances. Tellus B, 64, 19586, http://dx.doi.org/10.3402/tellusb.v64i0,19586.

Omstedt, A. , Gustafsson, E. and K., Wesslander, (2009). Modelling the uptake and release of carbon dioxide in the Baltic Sea surface water. Continental Shelf Research 29, 870-885. DOI: 10.1016/j.csr.2009.01.006

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