Scenario simulations of the state of Baltic Sea ecosystem in a future climate using the St.Petersburg Baltic Eutrophication Model

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Workshop: Uncertainties of scenario simulations
SMHI, Norrköping, Sweden, 14 October 2010

Objectives

- To simulate the up-to-date physical and ecological state of the Baltic Sea using the **St.Petersburg Baltic Eutrophication Model (SPBEM)**
- To assess the effect of climate change to the eutrophication status in the Baltic Sea through performing scenario simulations in a future climate

Hydrodynamic module of St.Petersburg Baltic eutrophication model (SPBEM)

Neelov et al., 2003. Proc. Estonian Acad. Sci. Biol. Ecol., 52(3): 346-359.

Myrberg K., Ryabchenko V., Isaev A. et al. 2010: Validation of three-dimensional hydrodynamic models of the Gulf of Finland. *Boreal Env. Res.* 15: 453–479.

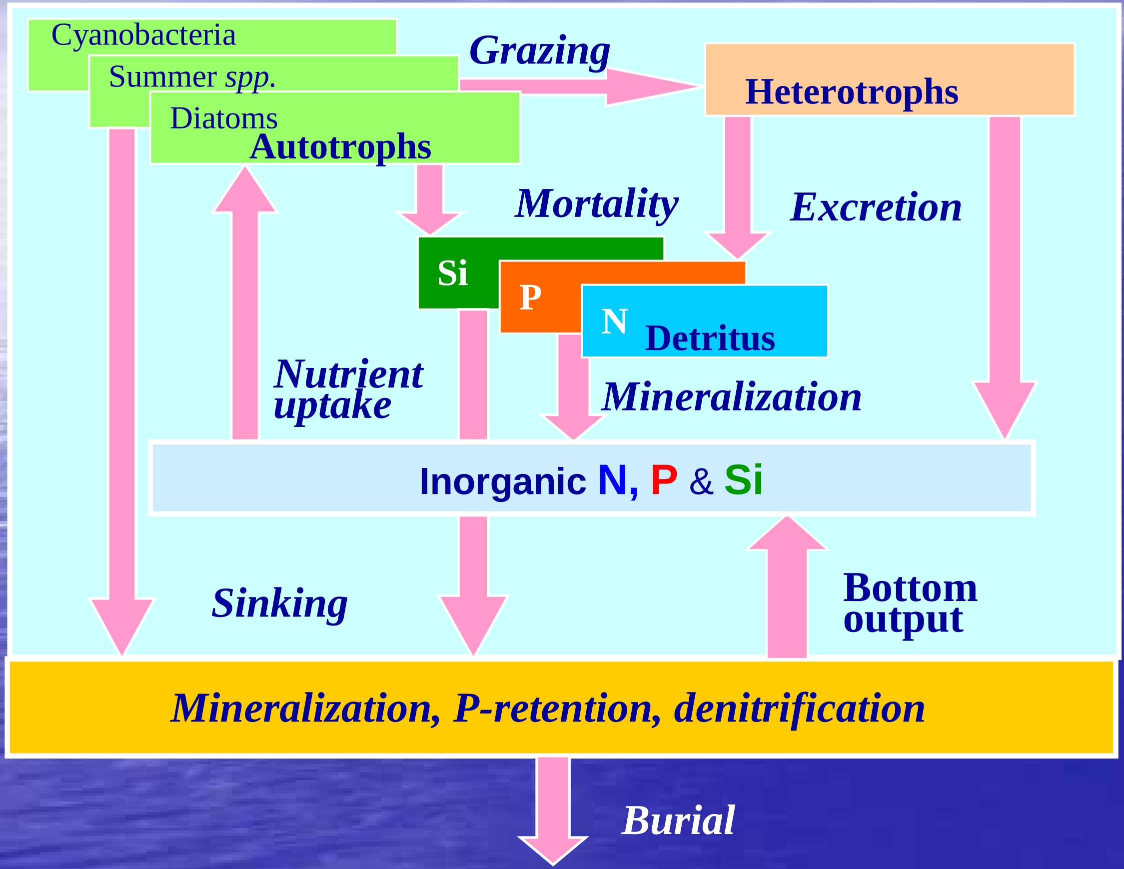
- **is z-coordinate model based on primitive equations of motion, heat and salt transport, and Millero and Kremling(1976) equation of state of sea water.**
- **includes original *k-l* turbulent closure scheme for vertical mixing.**
- **is coupled to a dynamic-thermodynamic model of sea ice**
- **2 versions:**

1) 2nm (4´×2´), 77 levels with dz=2m in the layer (0,100m) and dz=5m below,

2) 5nm (10´×5´), 35 levels with dz=2m in the layer (0,20m), dz=5m in the layer (20,40m) and dz=10м below 40m.

Biogeochemistry module in SPBEM

is based on the model of Savchuk (O.Savchuk, 2002, J.Mar.Systems, **32**, 253– 280)



The module describes nutrient cycling in the coupled pelagic and sediment sub-systems. State variables: 12 pelagic (zooplankton, diatoms, cyanobacteria, flagellates, nitrogen, phosphorus and silica detritus, ammonium, nitrite + nitrate, phosphate, silicate and dissolved oxygen) and 3 sediment (benthic nitrogen, phosphorus and silicon).
Main processes are shown as generalised biogeochemical fluxes driving nutrient biogeochemical cycles in the model.

Model runs

Simulation of the up-to-date state of the Baltic Sea

Atmospheric physical forcing

Run 1 (2000-2006): from GCM ECHAM5, mean monthly values, resolution 1.5º

Run 2 (1961-2006): from ERA-40/RCA kindly provided by Anders Höglund

Scenario simulations under a projection of future changes in climate

Atmospheric physical forcing from GCM ECHAM5 for A2 **SRES-scenario** (moderate greenhouse gas emission) for 2007-2100

Other boundary conditions for all runs:

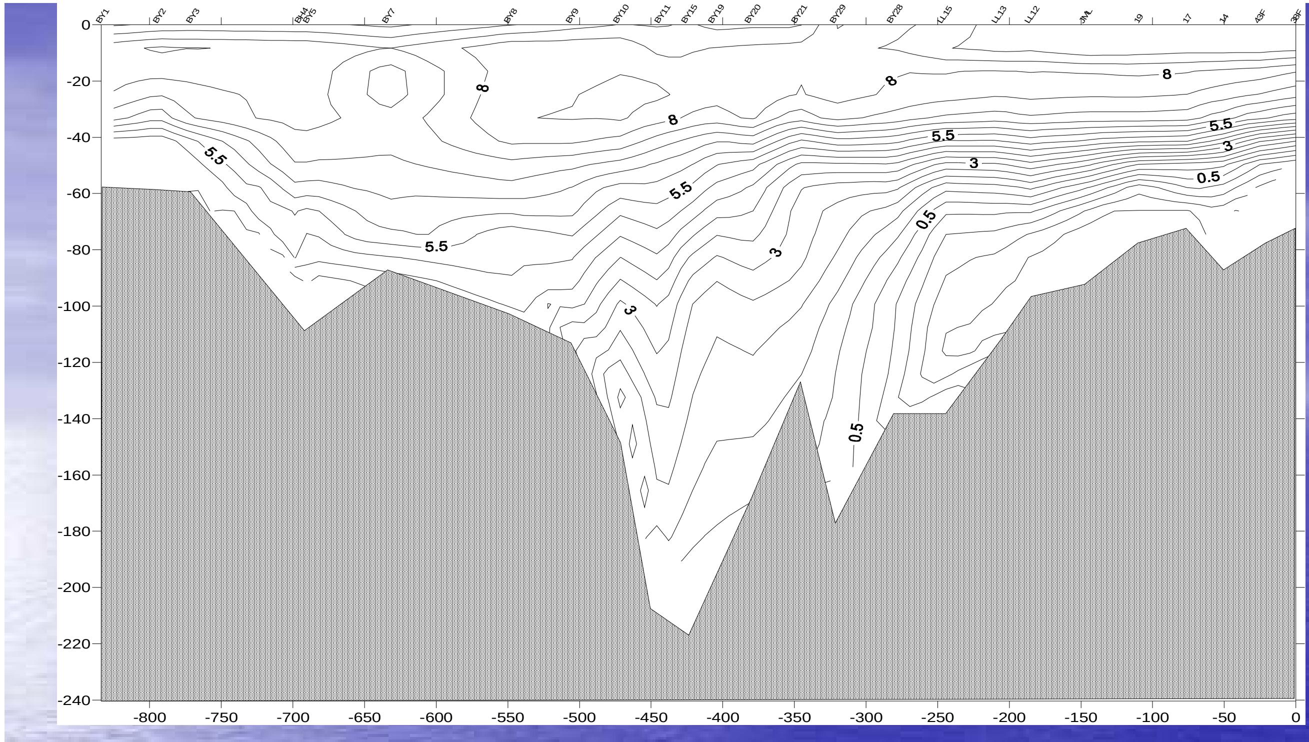
Boundary with the North Sea **:** climatic mean monthly values of water level, temperature, salinity and all biogeochemical variables, which are taken from a model of the North Atlantic and Arctic Ocean (I. Neelov), 60-year averaging

Hydrological forcing **:** climatic mean monthly water discharges for 51 aggregated Baltic rivers

Pollution loads **:** from the MARE program (Savchuk and Wulff, 2007).

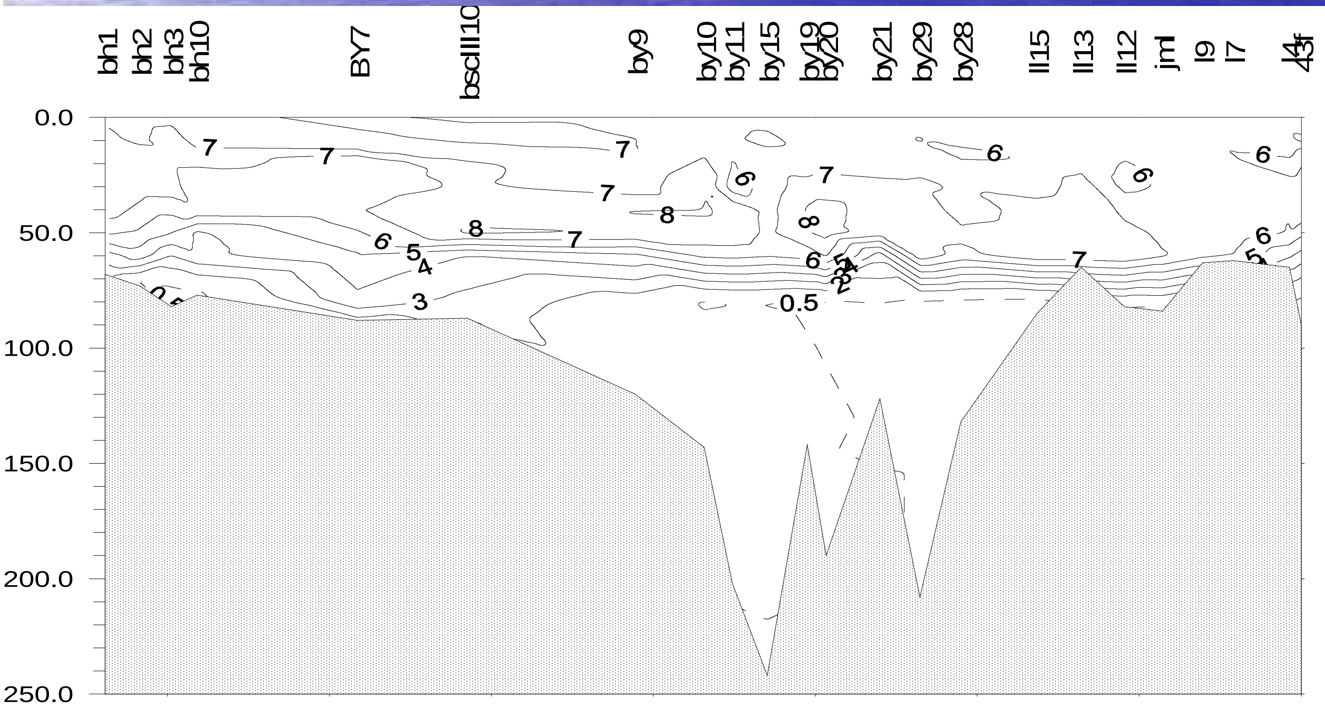
Initial conditions : 1) for temperature, salinity, NO3+NO2, NH4, PO4, SiO2, O2, from the BED for wintertime period of 2000 (run 1) and of 1970 (run 2)

2) distributions of bioavailable nitrogen, phosphorus and silicon in sediments estimated from previous runs

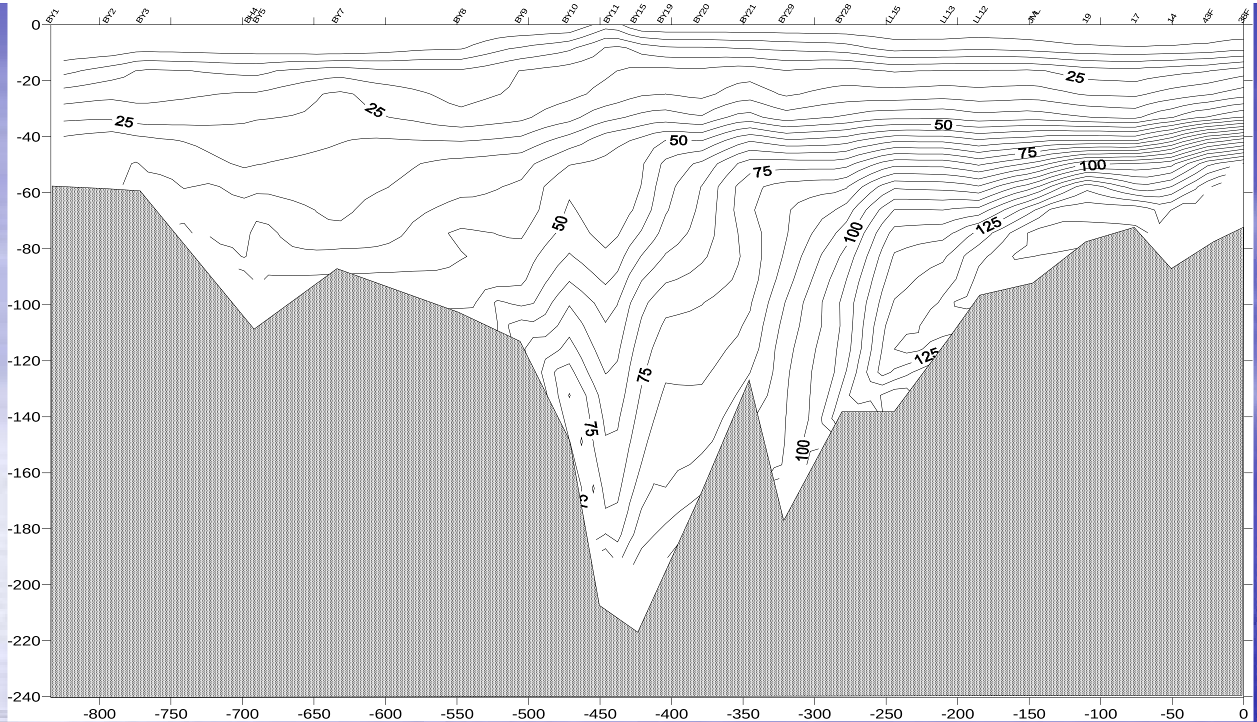


Dissolved oxygen (ml/l) vertical section along the Gulf of Finland and HELCOM stations in the Baltic Proper in ***August 2004***

Model, run 1

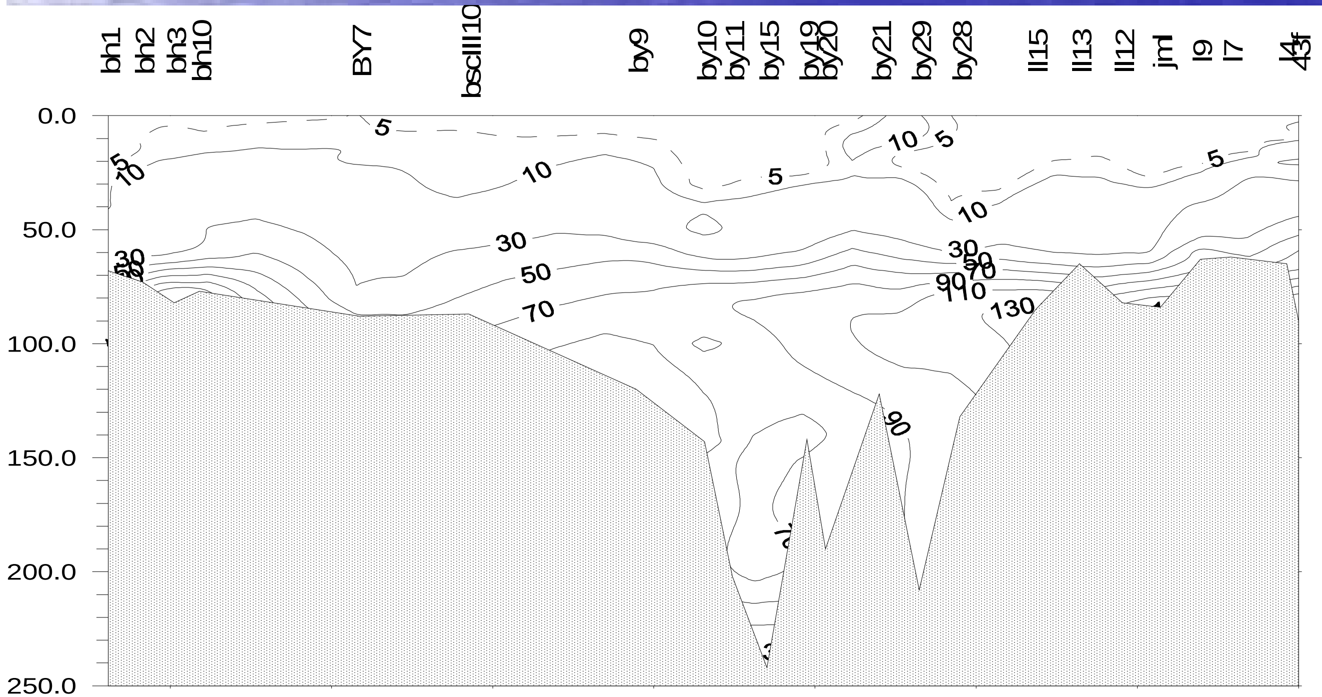


Data from a summer expedition of Russian State Hydrometeorological University (RSHU)



*Phosphates (mg/m**3) vertical section along the Gulf of Finland and HELCOM stations in the Baltic Proper in* ***August 2004***

Model, run 1



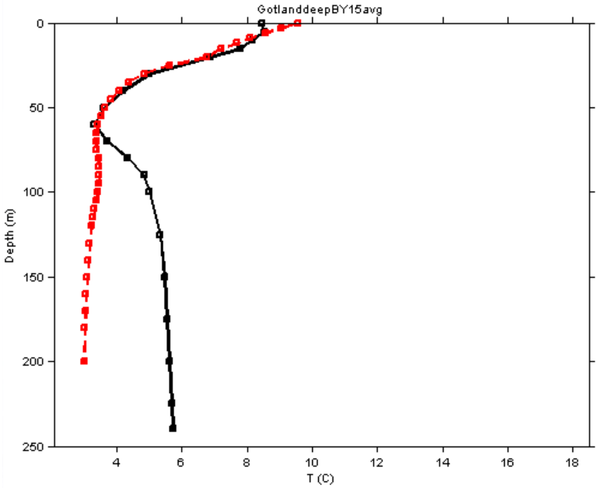
Data from a summer expedition of RSHU

Station BY15 (Gotland Deep) *RUN 1*

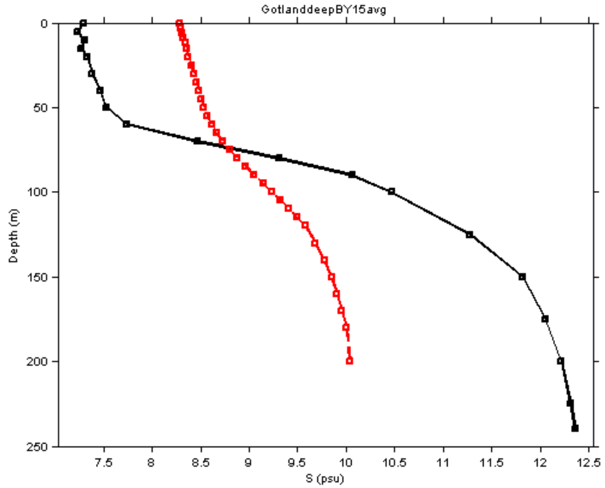
black lines – data averaged over 1970-2008 ; red lines – model results averaged over 2001-2005

DATA: Validation data set compiled from BED(2010), B. Gustafsson and M. R. Medina

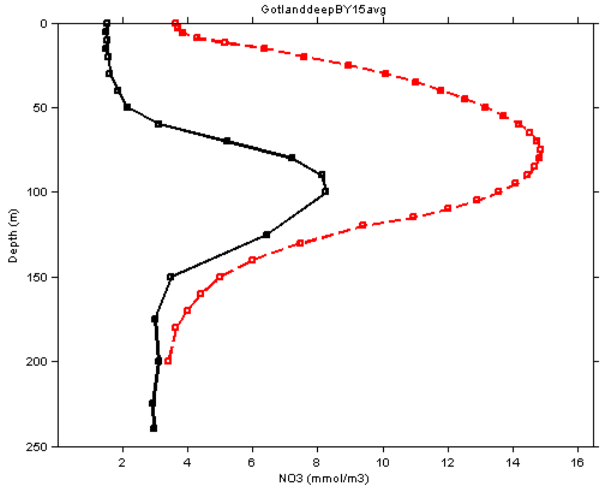
Temperature, ºC



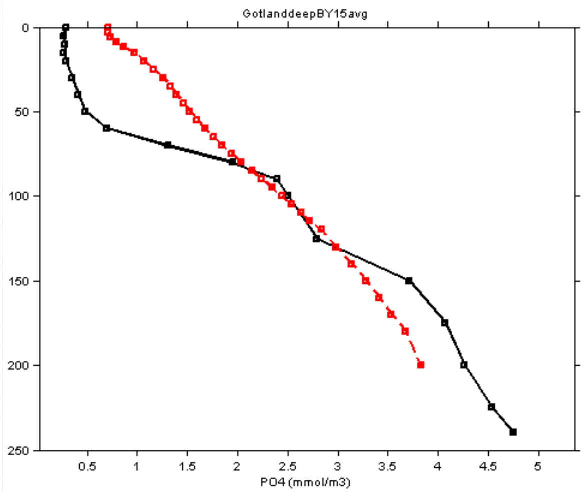
Salinity,‰



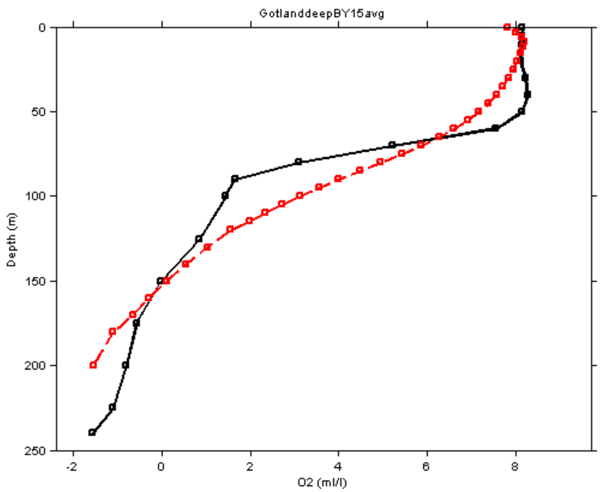
Nitrates mmol/m^3



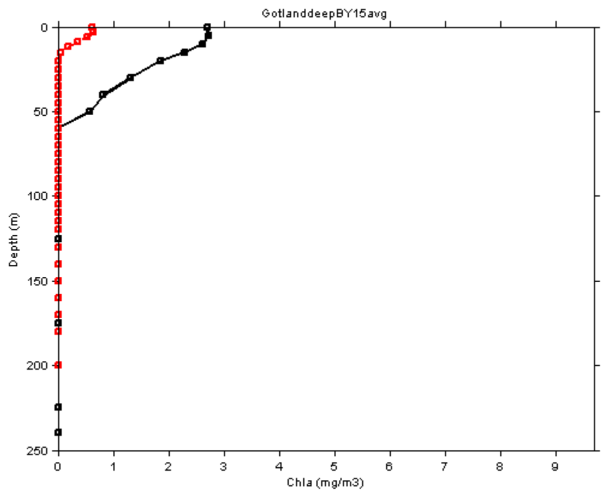
Phosphates, mmol/m^3



Oxygen, ml/l



Chlorophyll-a, mg/m3

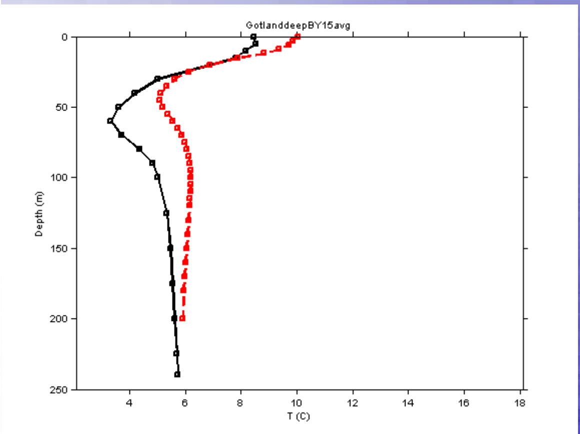


Station BY15 (Gotland Deep) *RUN 2*

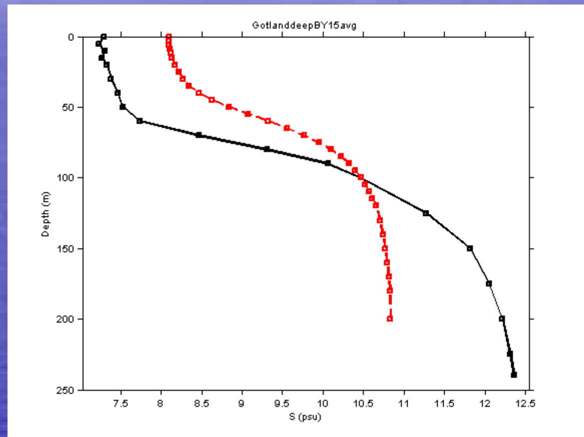
black lines – data averaged over 1970-2008, red lines – model results averaged over 1970-2007

DATA: Validation data set compiled from BED(2010), B. Gustafsson and M. R. Medina

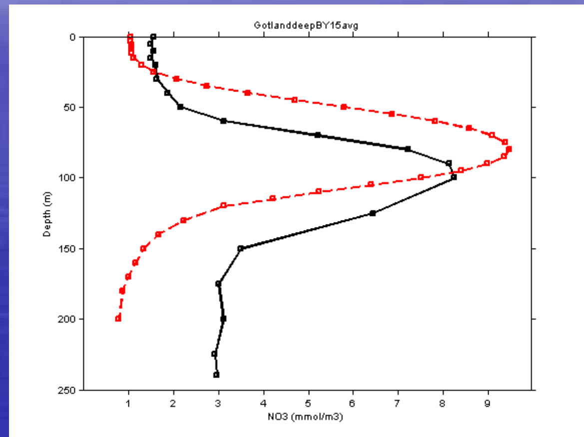
Temperature, ^oC



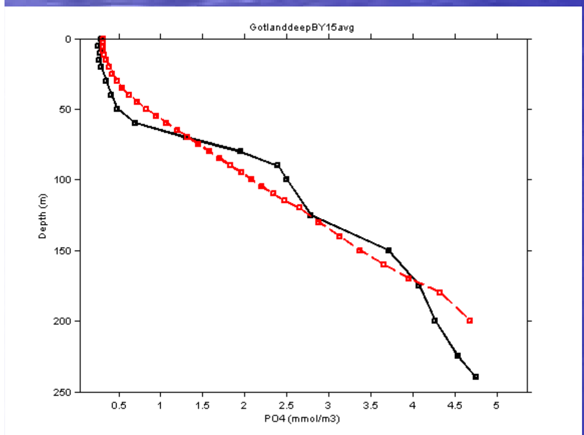
Salinity,‰



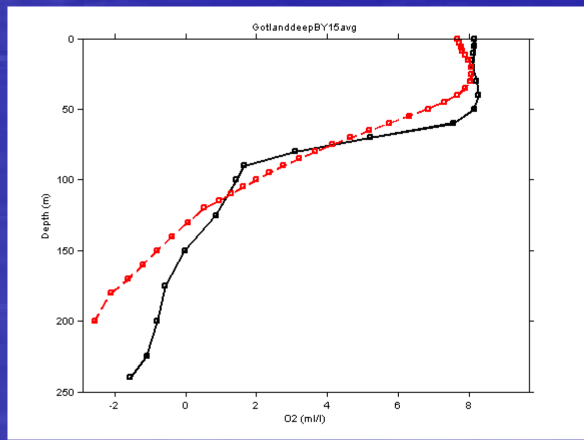
Nitrates, mmol/m^3



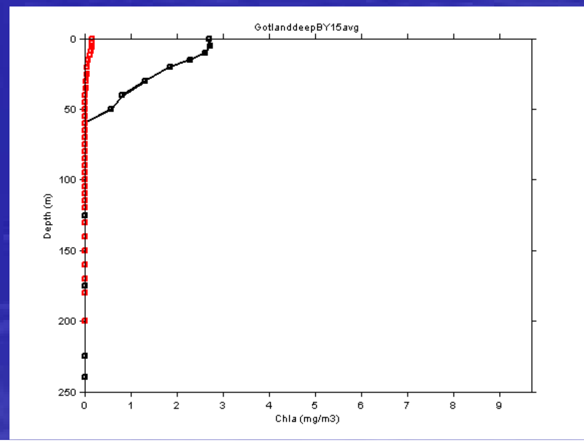
Phosphates, mmol/m^3



Oxygen, ml/l

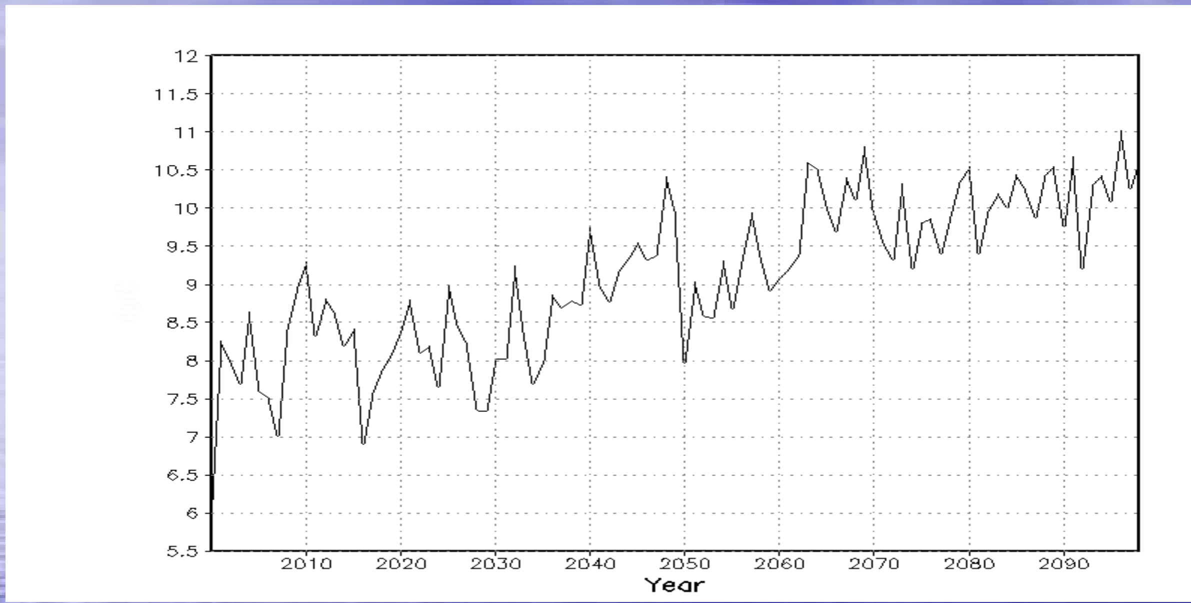


Chlorophyll-a, mg/m3



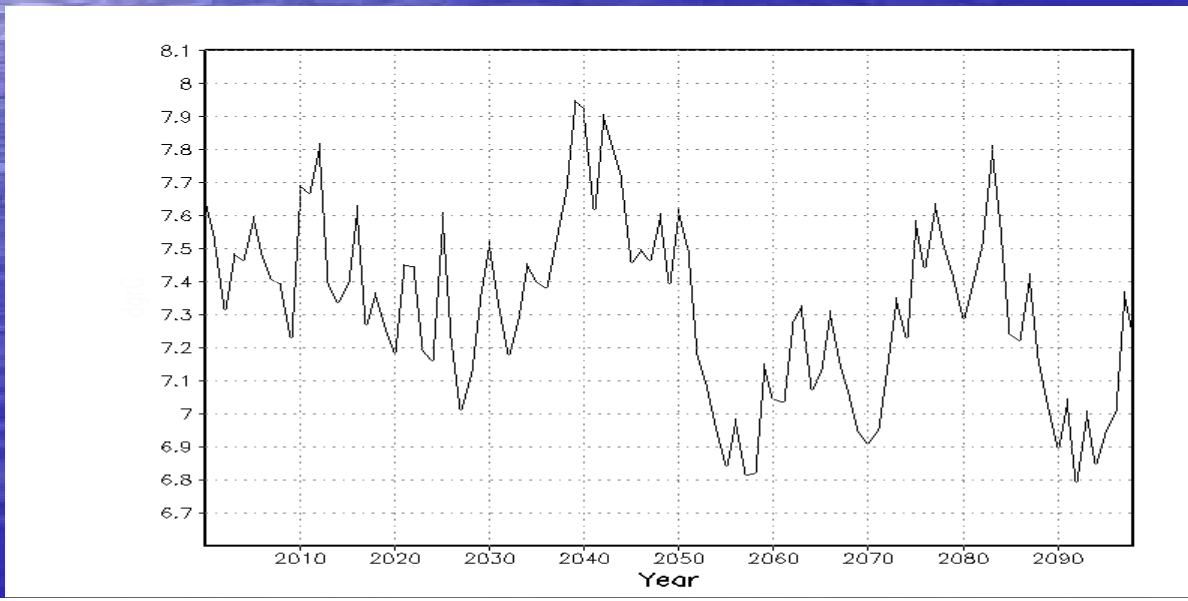
Scenario run under ECHAM5 forcing for moderate greenhouse gas emission

Area-averaged mean annual temperature and salinity at the surface of the Baltic Sea in 2000-2100



Surface temperature, ºC

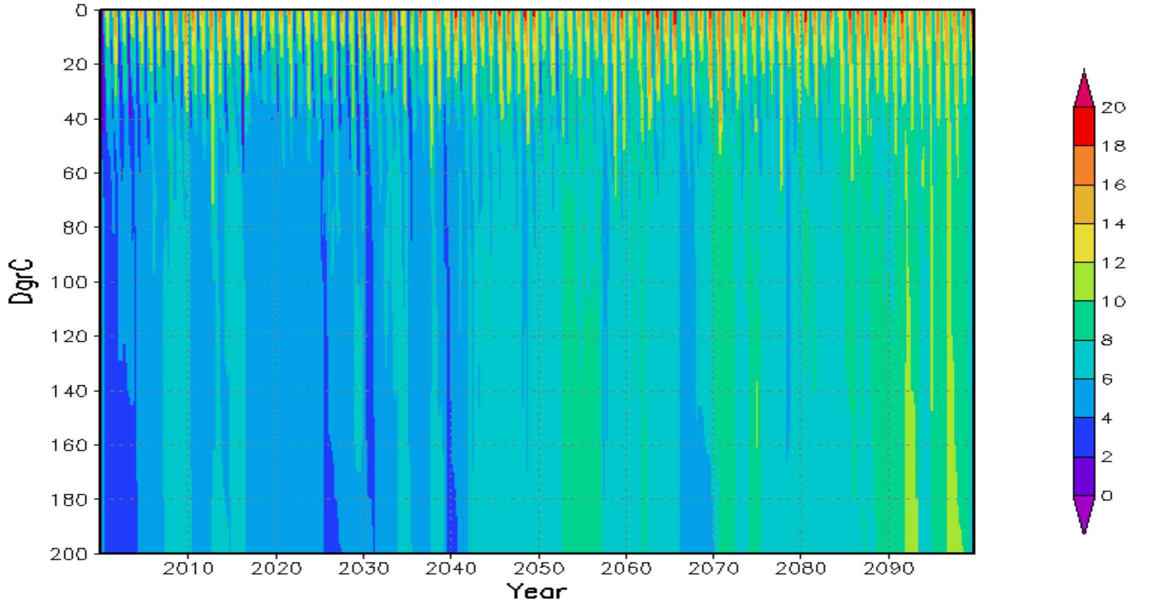
ΔT=3.5 ºC
dT/dt=0.35 ºC /10yr

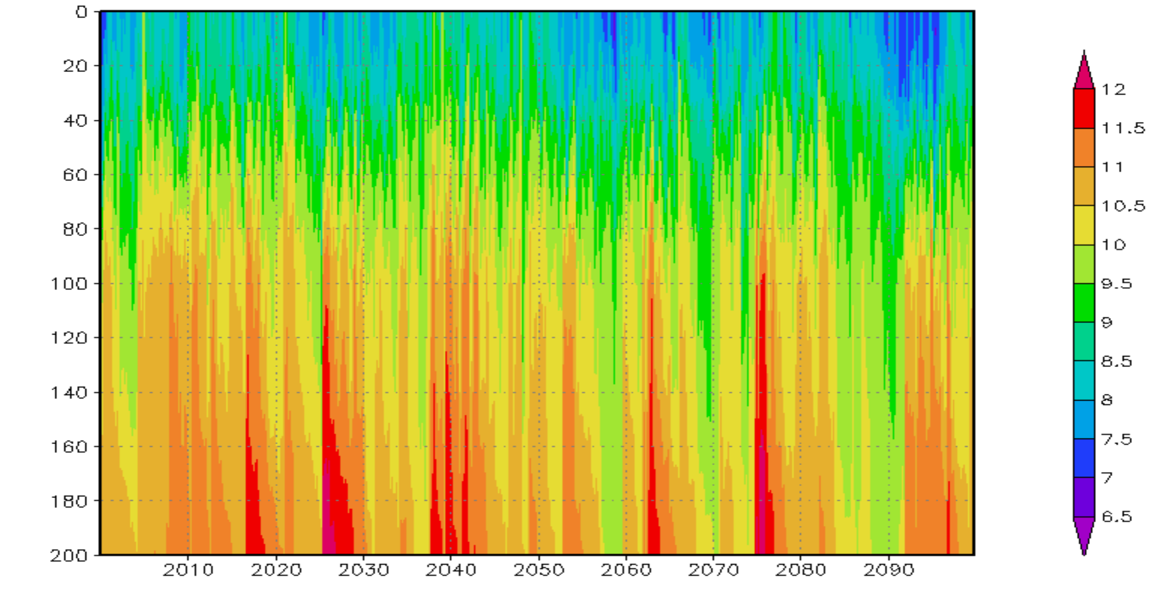


Surface salinity, ‰

ΔS= -0.3 ‰
dS/dt= -0.03 ‰ /10yr

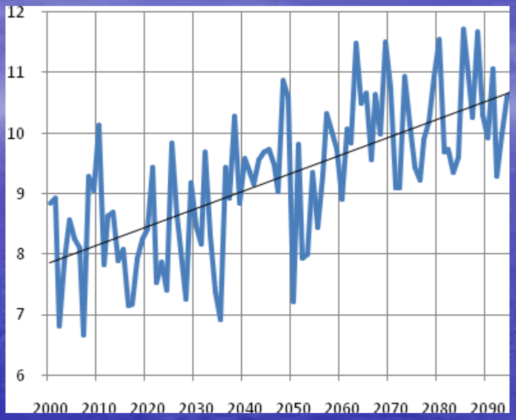
Time-depth plots at station BY15 (Gotland Deep) for the period from 1 Jan 2000 to 31 Dec 2100





Temperature, ºC

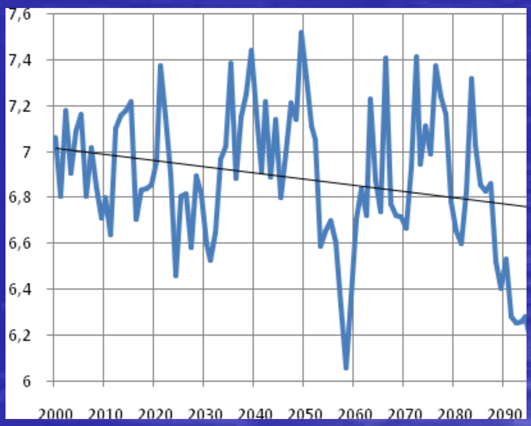
Mean annual SST



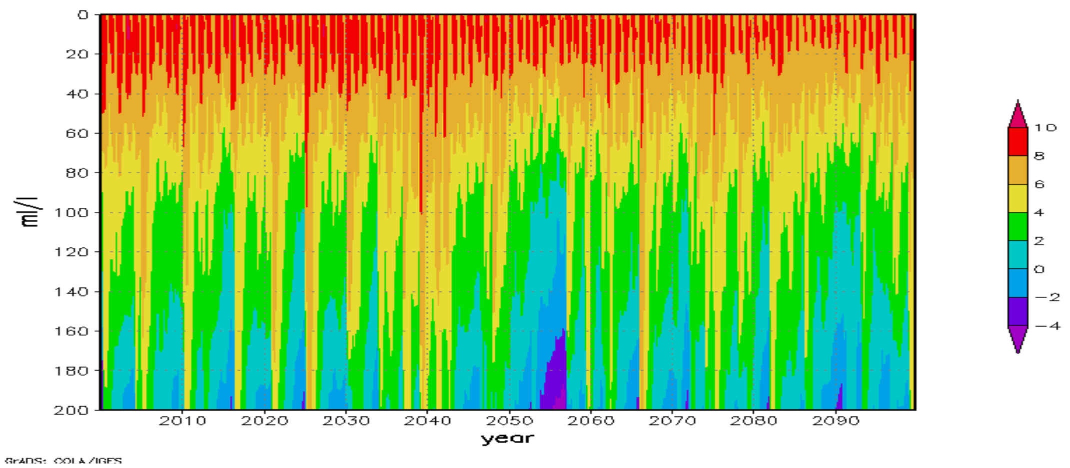
ΔT=2.95 ºC, dT/dt=0.29 ºC /10yr

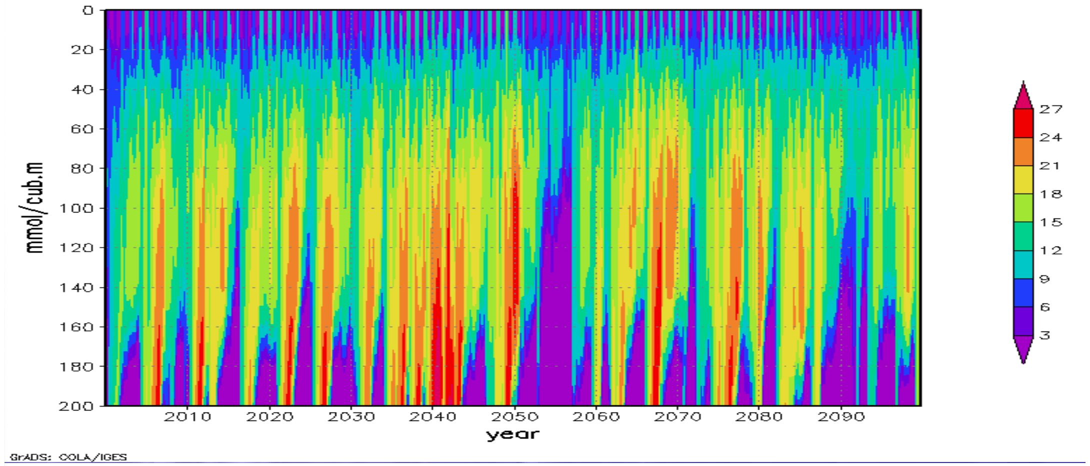
Salinity,‰

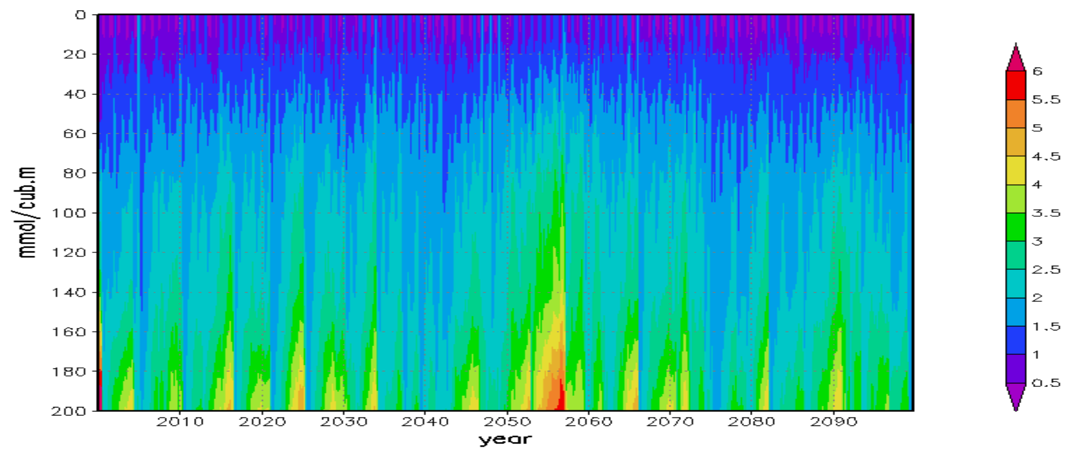
Mean annual SSS



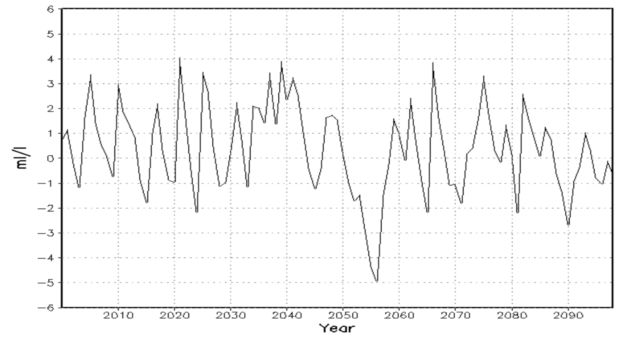
ΔS=- 0.2 ‰, dS/dt=-0.02 ‰ /10yr



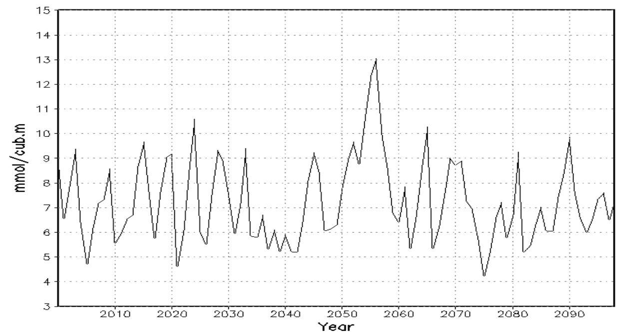




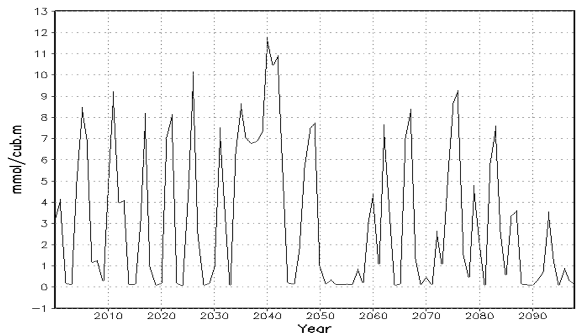
Station BY15 (Gotland Deep)
Near-bottom
dO_2/dt=-0.1ml/l /10yr



dNO_3/dt=+0.1mmol/m3/10yr

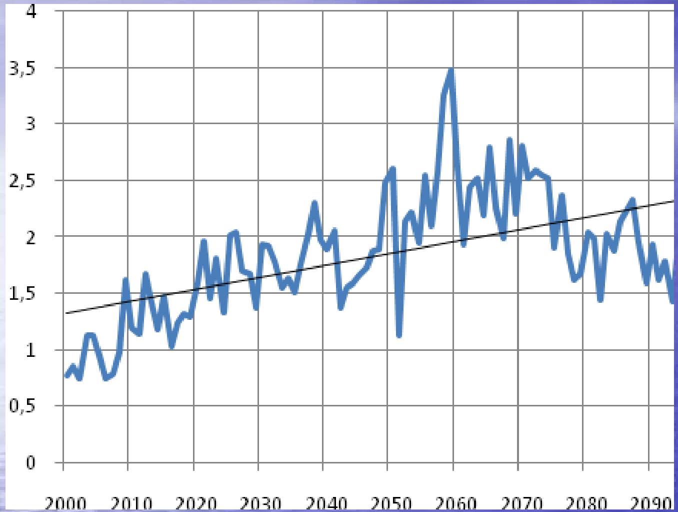


dPO_4/dt=-0.2mmol/m3/10yr

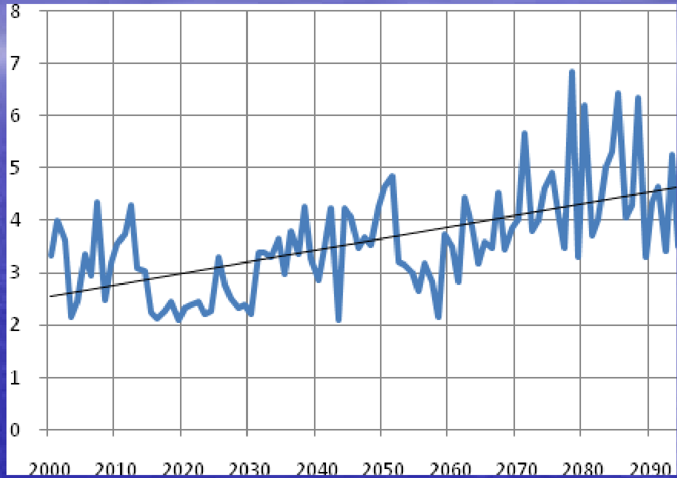


Area-averaged annual primary production (g N/(year m²) of the Baltic Sea for different algae

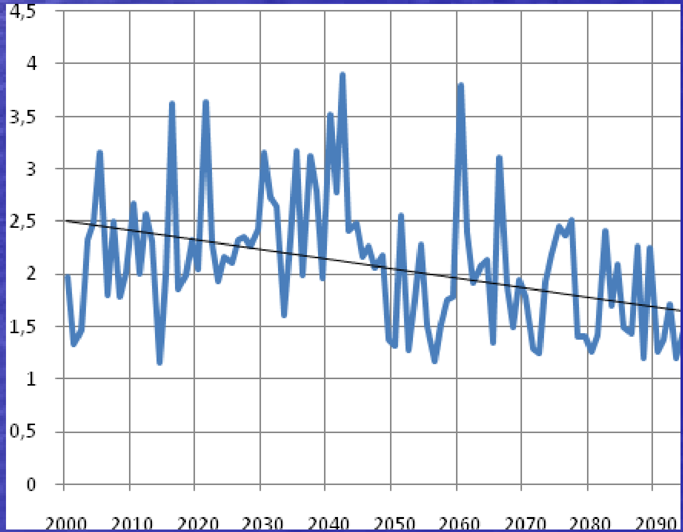
Blue-green algae



Flagellates



Diatoms



Concluding remarks

1. Modelled and observed characteristics (temperature, salinity, nutrients, dissolved oxygen, chlorophyll) of the Baltic Sea in 1970-2007 are in a qualitative agreement .

SPBEM underestimates vertical salinity stratification and strongly underestimates chlorophyll "a".

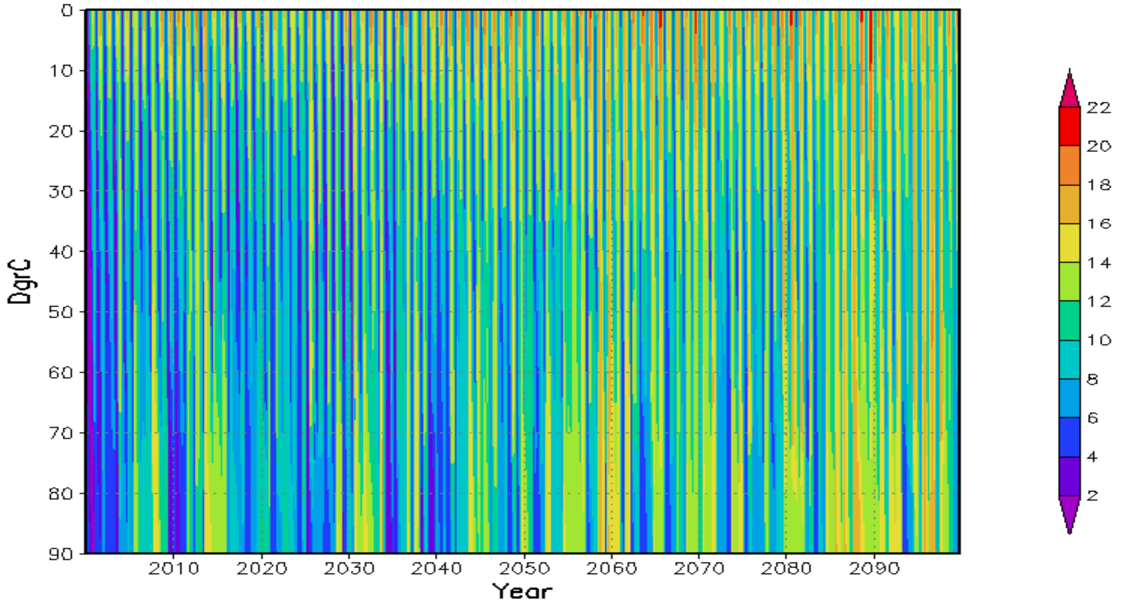
2. As it follows from the scenario simulation with moderate emission of CO_2, the area-averaged sea surface temperature growth for the Baltic Sea by the end of the 21st century will be about 3.5ºC.

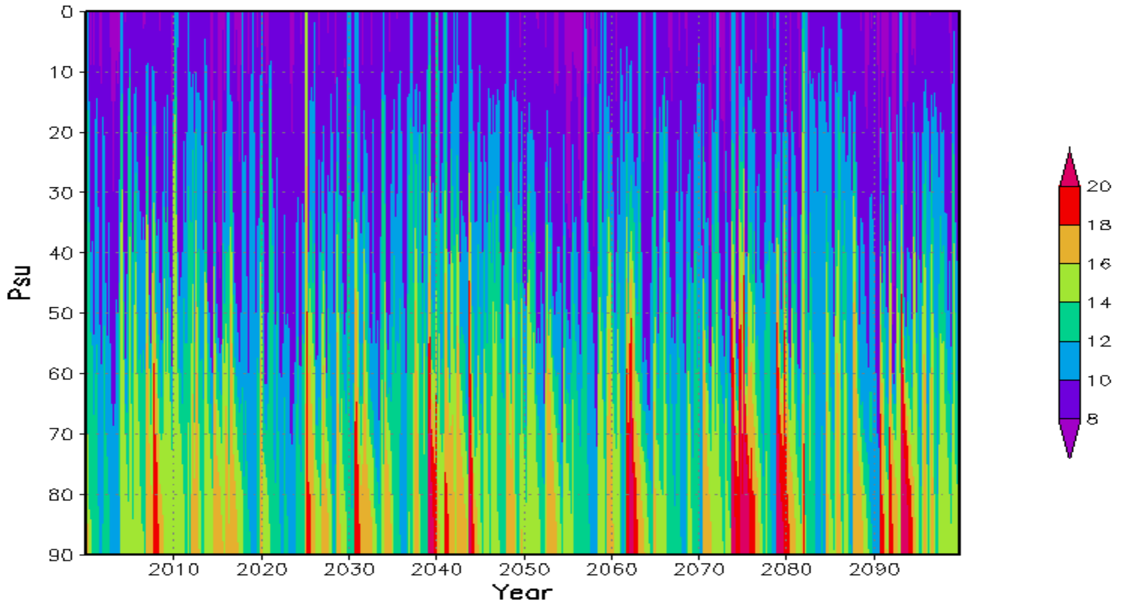
3. The model primary production of phytoplankton will grow during the whole century. The production of different type of algae differ from each other. In particular, the production of diatoms will drop that could be explained by increase in water temperature limiting the growth of spring cryophile diatoms.

Future plans:

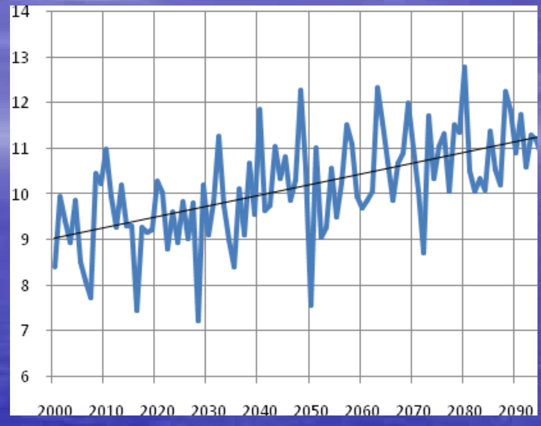
- to do more detailed comparison between SPBEM results and: 1) the validation data set of Gustafsson and Medina and 2) similar results from ECOSUPPORT models (RCO-SCOBI, ERGOM, BALTSEM)
- to better fit the model to observations for modern period
- to re-run SPBEM on 2nm grid under ERA-40/RCA forcing for 1961-2007

Time-depth plots at station BY5 (Bornholm Deep) for the period from 1 Jan 2000 to 31 Dec 2100



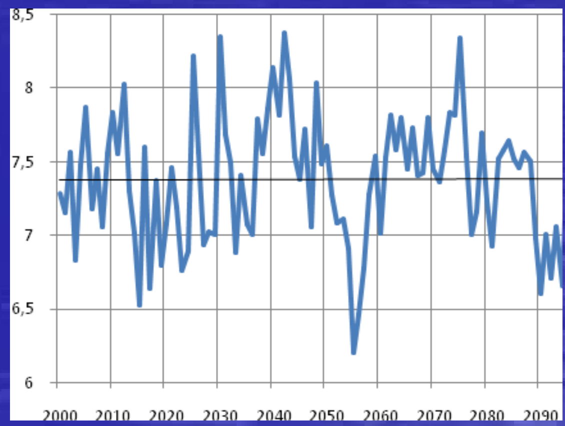


Mean annual temperature, ºC
SST

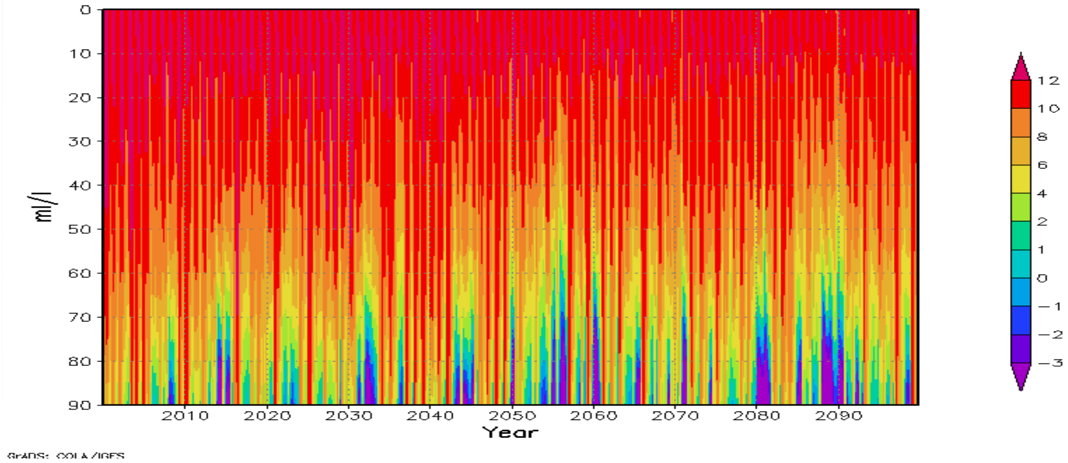


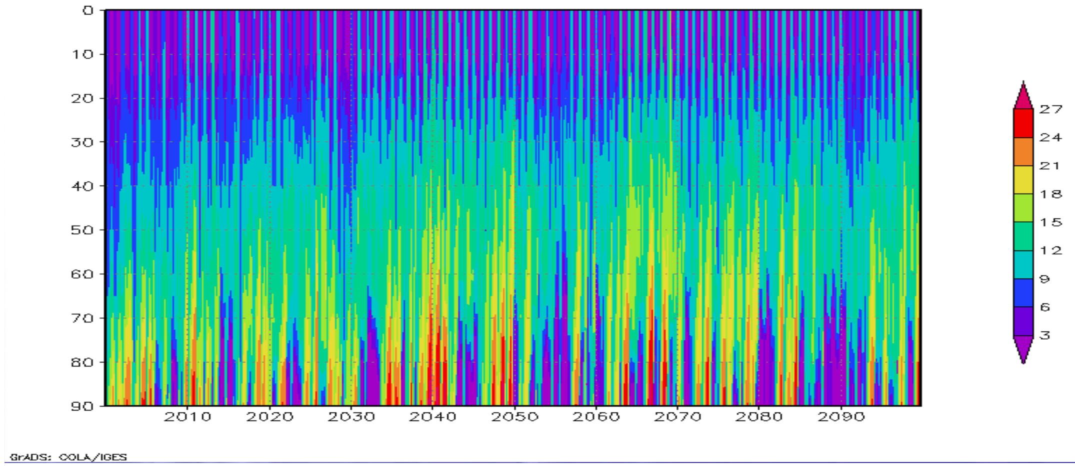
ΔT=2.25 ºC, dT/dt=0.23 ºC /10yr

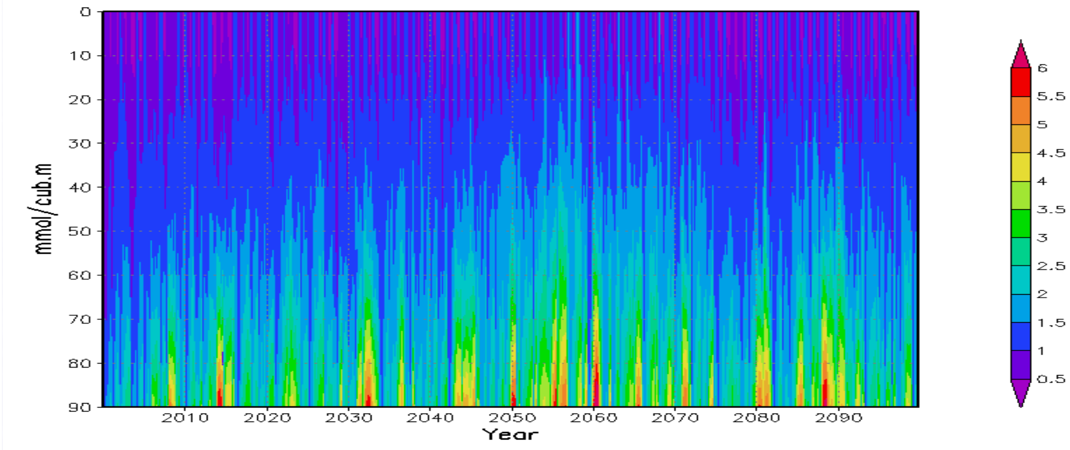
Mean annual salinity, ‰
SSS



ΔS= 0.0 ‰, dS/dt=0.0 ‰ /10yr



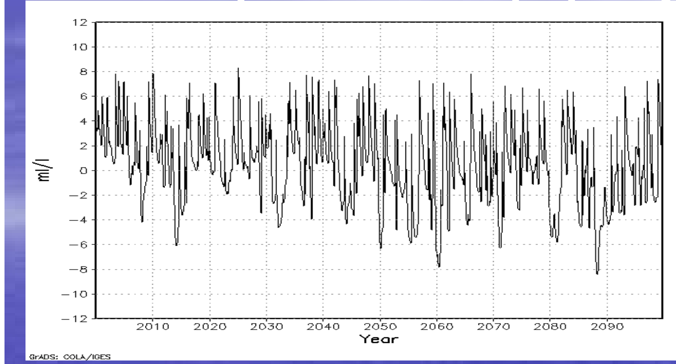




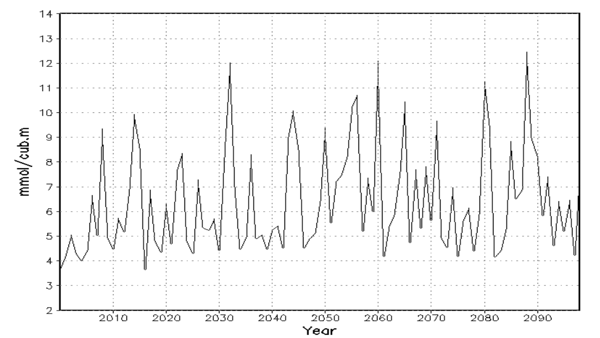
BY5 (Bornholm Deep)

Near-bottom

$dO_2/dt=-0.1$ ml/l /10yr



$dNO_3/dt=+0.1$ mmol/m3/10y



$dPO_4/dt=-0.2$ mmol/m3/10yr

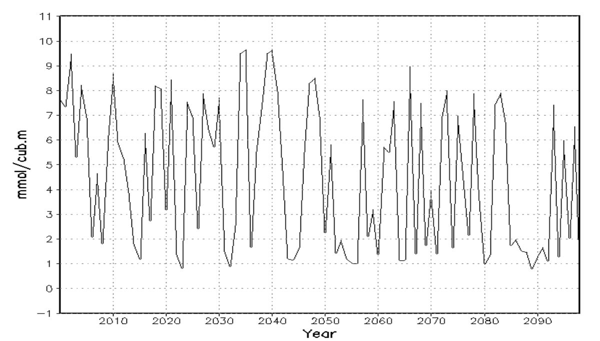


Table 1. Forecasts of changes in the near-surface air temperature in the Baltic Region for 2000-2099 from different AOGCM

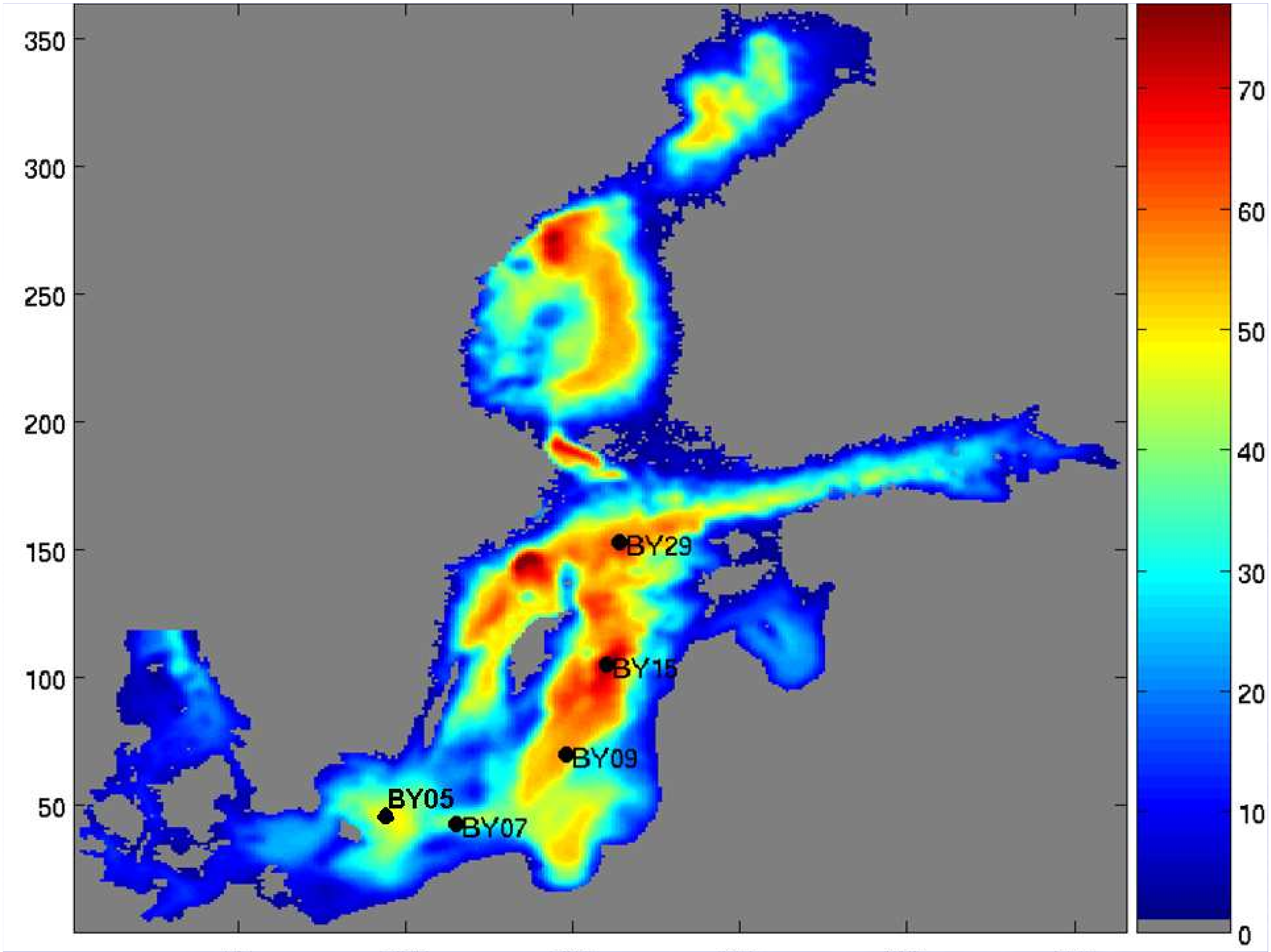
Model	Emission scenario	Increase in mean annual temperature for 100 years, °C				Decrease in pick-to-pick amplitude of temperature for 100 years, °C			
		Whole region	Southern Baltic	Baltic Proper	Northern Baltic	Whole region	Southern Baltic	Baltic Proper	Northern Baltic
ECHAM	**A2**	**6.0**	**5.5**	**6.3**	**6.8**	**8.8**	**6.5**	**7.1**	**8.1**
ECHAM	B1	4.2	4.2	4.7	4.5	4.6	2.1	7.3	4.8
GFDL	A2	2.9	3.5	2.8	2.9	4.2	1.5	6.4	5.6
GFDL	B1	0.5	-0.4	-0.2	1.2	-5.3	-8.4	-3.9	-1.4
Ensemble 16 models	A2	3.8	3.3	3.5	4.3	2.6	1.2	0.0	4.1
Ensemble 16 models	B1	2.0	1.6	1.9	2.1	2.4	1.0	1.9	4.0

Scenarios A2 and B1 correspond maximal and minimal emission of CO_2 in the atmosphere.

Table 2. Forecasts of changes in precipitation P and evaporation E (mm/day) in the Baltic region for 2000-2099 from different AOGCM

Model	Emission scenario	Increase in mean annual values for 100 years		Increase in maximal annual values for 100 years		Increase in minimal annual values for 100 years	
		P	E	P	E	P	E
ECHAM	**A2**	**0.39**	**0.26**	**0.53**	**0.13**	**0.0**	**0.26**
ECHAM	B1	0.05	0.20	-0.20	0.21	0.21	0.08
GFDL	A2	0.37	-0.03	0.33	-0.12	0.49	0.14
GFDL	B1	0.09	0.00	0.29	0.14	-0.10	0.02
Ensemble 16 models	A2	0.24	0.10	0.30	0.07	0.14	0.12
Ensemble 16 models	B1	0.20	0.08	0.29	0.16	0.02	0.07

Increase in mean annual precipitation for 100 years does not exceed 17% for scenario A2 and 10% for scenario B1. For evaporation the corresponding values are 23% (scenario A2) and 17% (scenario B1).



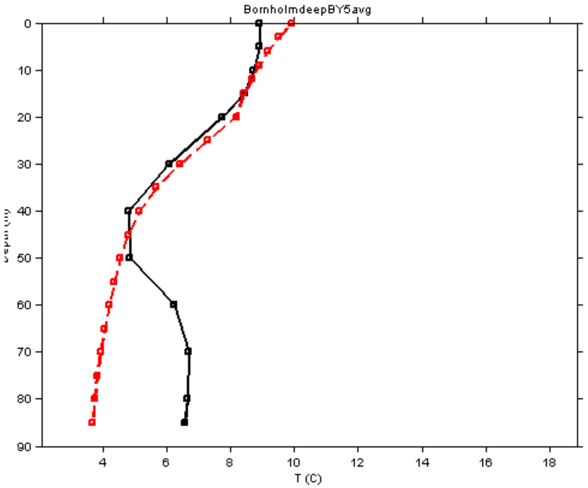
350
300
250
200
150
100
50
BY29
BY15
BY09
BY05
BY07
70
60
50
40
30
20
10
0

Station BY5 (Bornholm Deep)

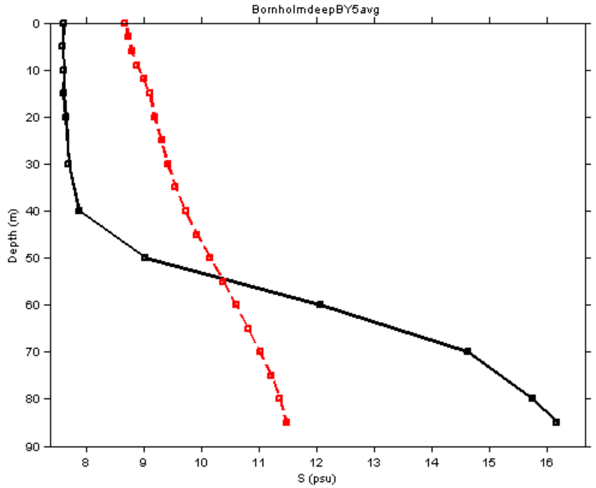
black lines – data averaged over 1970-2008, red lines – model results averaged over 2001-2005

DATA: Validation data set compiled from BED(2010), B. Gustafsson and M. R. Medina

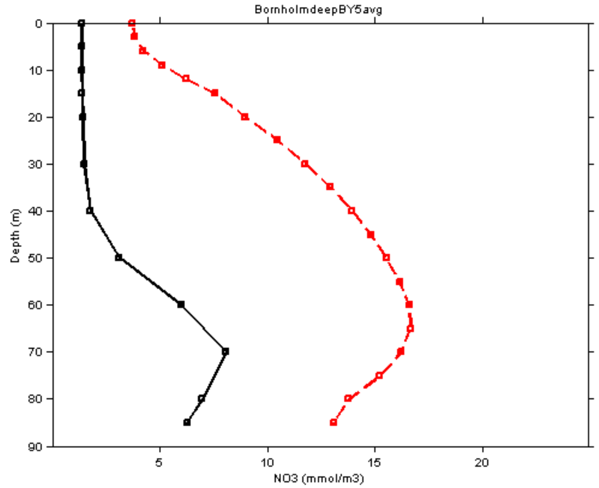
Temperature, ºC



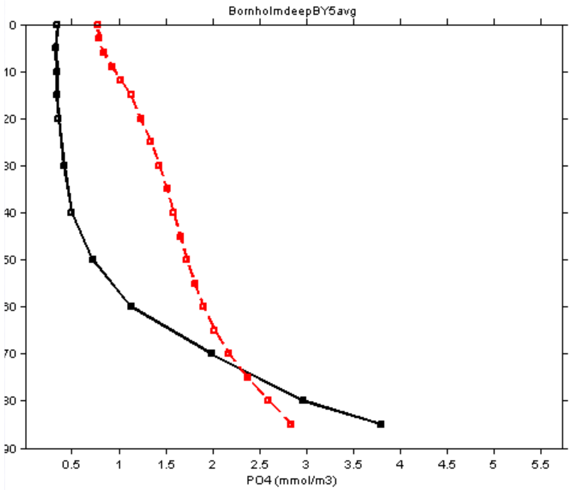
Salinity,‰



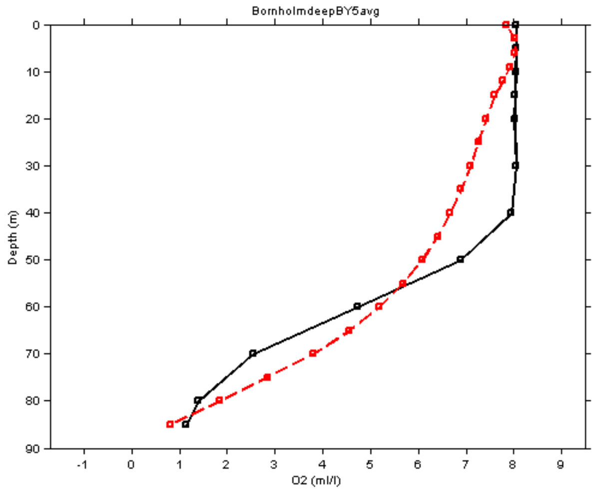
Nitrates mmol/m^3



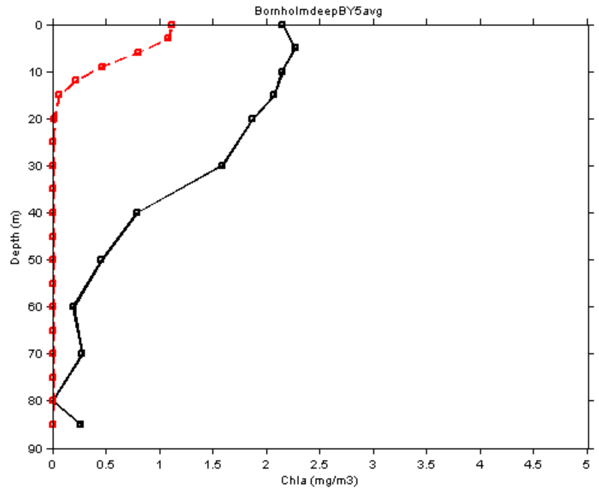
Phosphates, mmol/m^3



Oxygen, ml/l

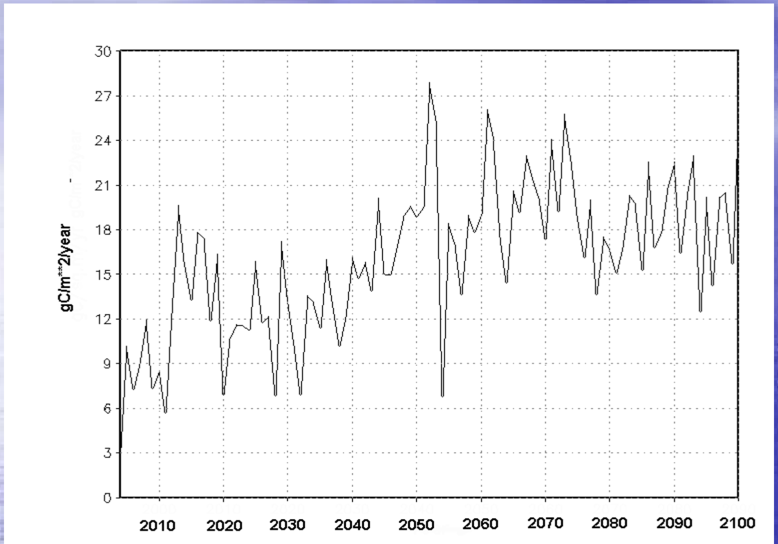


Chlorophyll-a, mg/m3

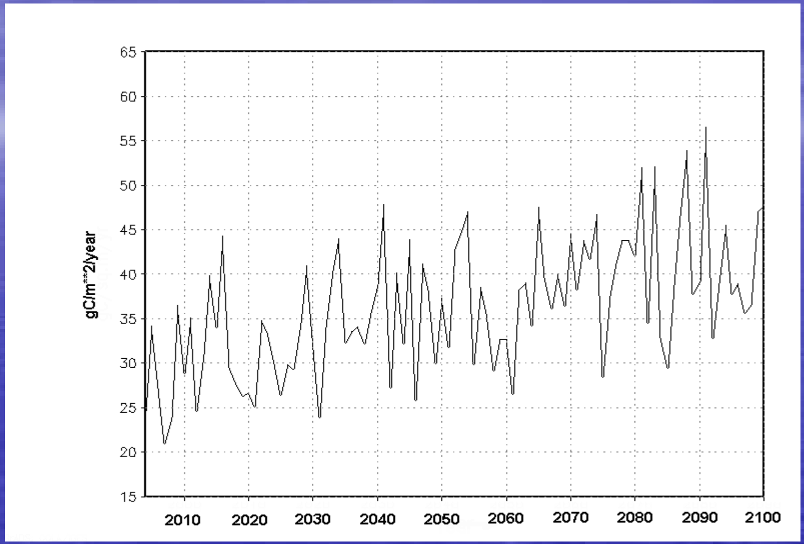


Area-averaged annual primary production (g C/(year m^2) of the Baltic Sea for different algae

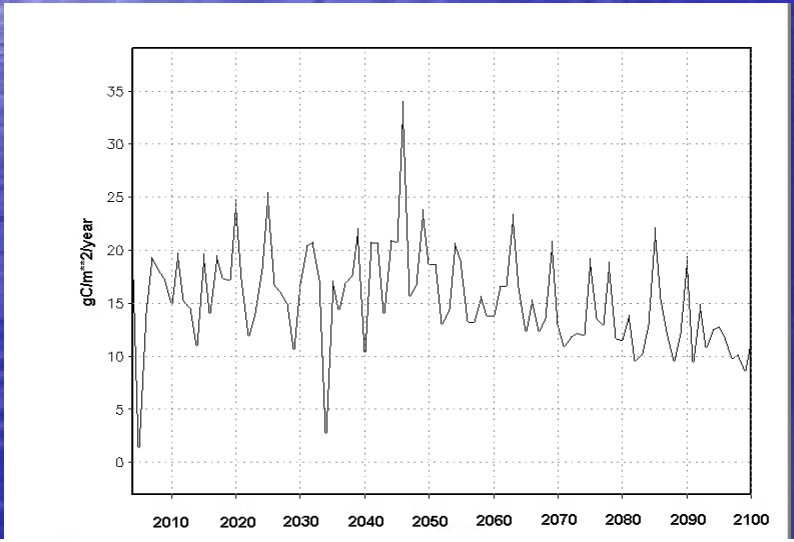
Blue-green algae



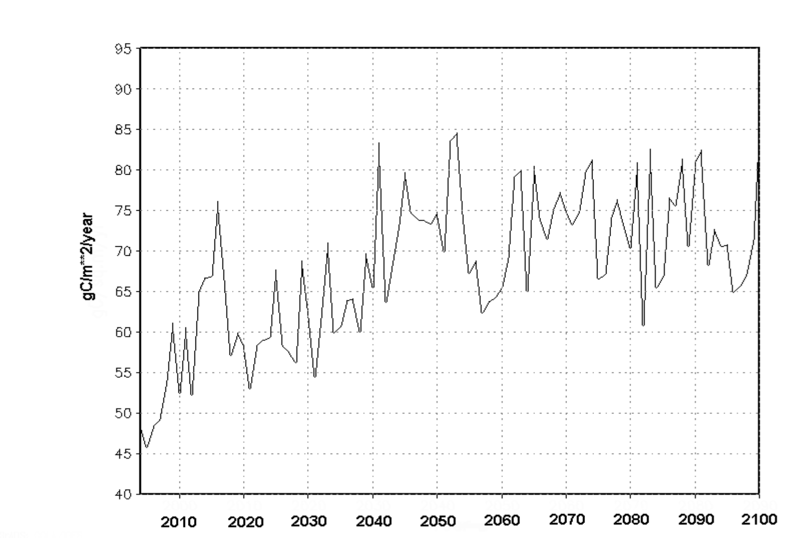
Flagellates



Diatoms



Total production



Restoring conditions for salinity to a part of model domain westwards 16°E

$$S = S + \frac{dt}{\tau}(S_* - S).$$

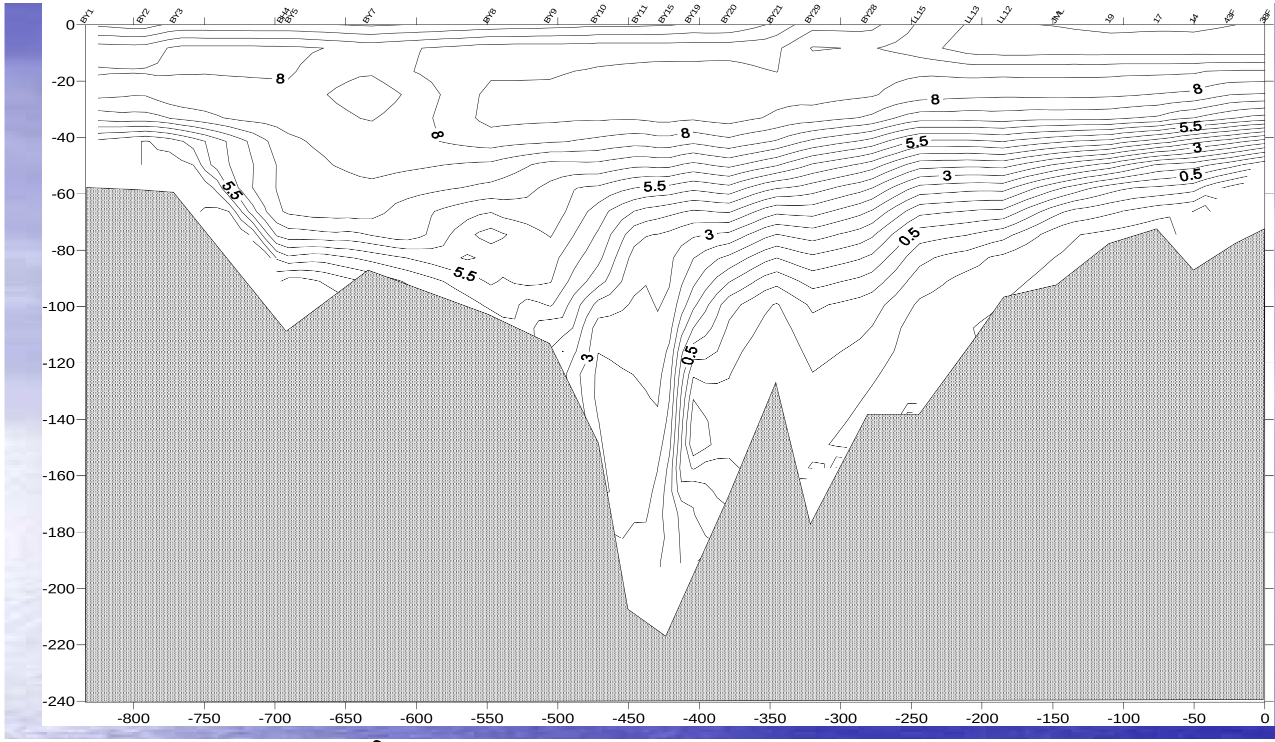
where *S* – calculated salinity, S_* - observed salinity, *dt* – time step, τ = 90 days

Table 1. The basic features of hydrodynamic modules of E-MAPS models

Model ID	HIROMB	OAAS	SPBEM	EIA	COHERENS	MIKE3
Horizontal grid and resolution	Spherical Arakawa C grid, 4´×2´	Spherical, Arakawa C grid, 4´×2´	Spherical Arakawa B grid, 4´×2´	Spherical Arakawa C grid, 4´×2´	Spherical, Arakawa C grid, 4'×2'	Spherical, Arakawa C grid, 4´×2´
Vertical grid and resolution	z-coordinate 78 levels min dz=2m	z-coordinate 78 levels min dz=2m	z-coordinate 78 levels min dz=2m	z-coordinate 20 levels min dz=2.5m	σ-coordinate 50 levels	z-coordinate 120 levels min dz=2 m
Vertical turbulence scheme	*k-ω* model	Kochergin scheme (1987)	*k-l* model	*k-ε* model	*k-ε* model	*k-ε* model
Horizontal turbulence for momentum	Smago-rinsky (1963)	Smago-rinsky (1963)	Smagorinsky (1963)	Smagorinsky (1963)	none	Smagorinsky (1963)
Horizontal turbulence for T and S	Smago-rinsky (1963)	Smago-rinsky (1963)	K_l=const= 10^6 cm^2s^{-1}	none	none	Smagorinsky (1963)
Advection scheme for momentum	Conservati-ve and fully 3D scheme, based on Zalesak	Upwind scheme	3d order scheme (Fujii and Obayashi , 1989)	TVD- superbee scheme	upwind scheme	3d order scheme QUICKEST(Vested et al., 1992)
Advection scheme for tracers (T, S and others)	Conservati-ve and fully 3D scheme, based on Zalesak	TVD-superbee scheme	3d order scheme (Fujii and Obayashi , 1989)	TVD- superbee scheme	TVD-superbee scheme	3d order scheme QUICKEST(Vested et al., 1992)
Convection	Hydrostatic model, convective adjustment	Hydrostatic model, convective adjustment	Hydrostatic, k_z=1m^2s^{-1} for unstable stratification	Hydrostatic, k_z=1m^2s^{-1} for unstable stratification	Hydrostatic model, convective adjustment	Non-hydrostatic model
Equation of state	UNESCO (1981)	Millero and Kremling (1976)	Millero and Kremling (1976)	UNESCO (1981)	UNESCO (1981)	UNESCO (1981)

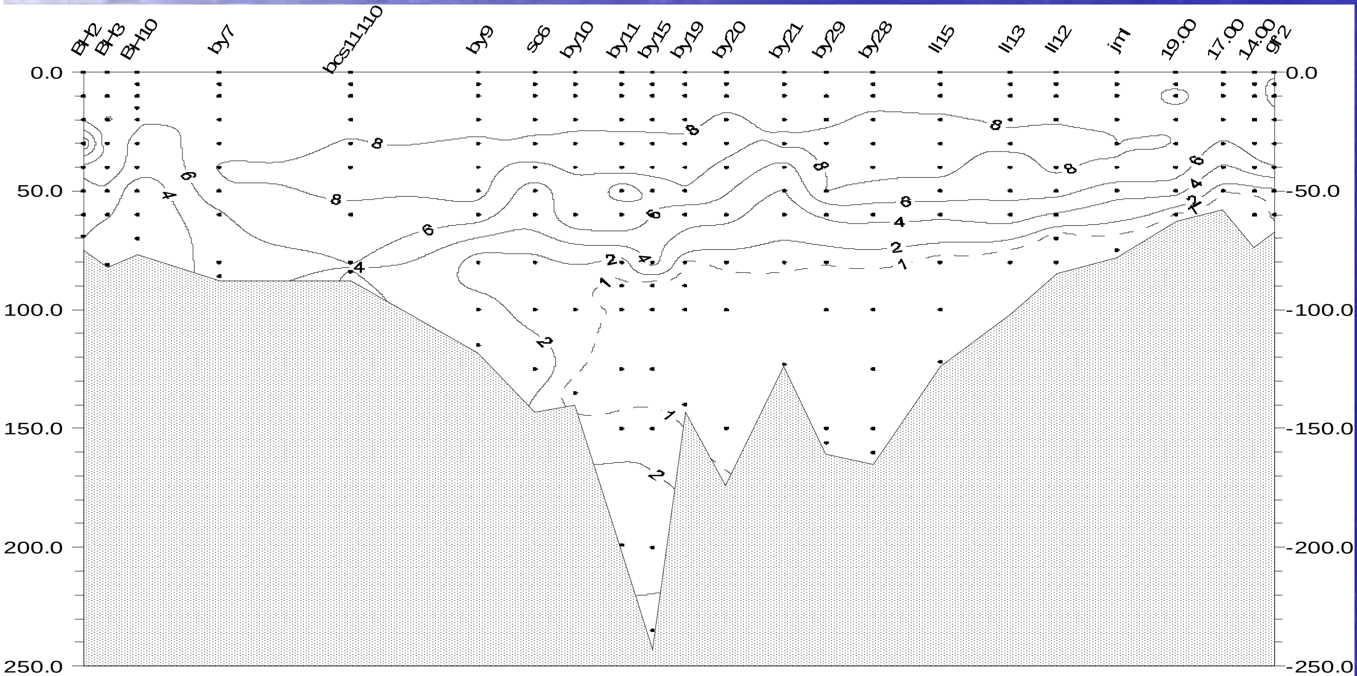
Initial conditions

- 3-D fields of temperature, salinity, NO3+NO2, NH4, PO4, SiO2, O2, from the BED averaged for wintertime period (January- March) of two years: 1995-96
- zero values for current velocity, sea level, ice thickness and concentration
- Typical winter values for phyto- and zooplankton, detritus (homogeneous distributions)
- Estimated spatial distributions (2-D fields) of bioavailable nitrogen, phosphorus and silicon in sediments

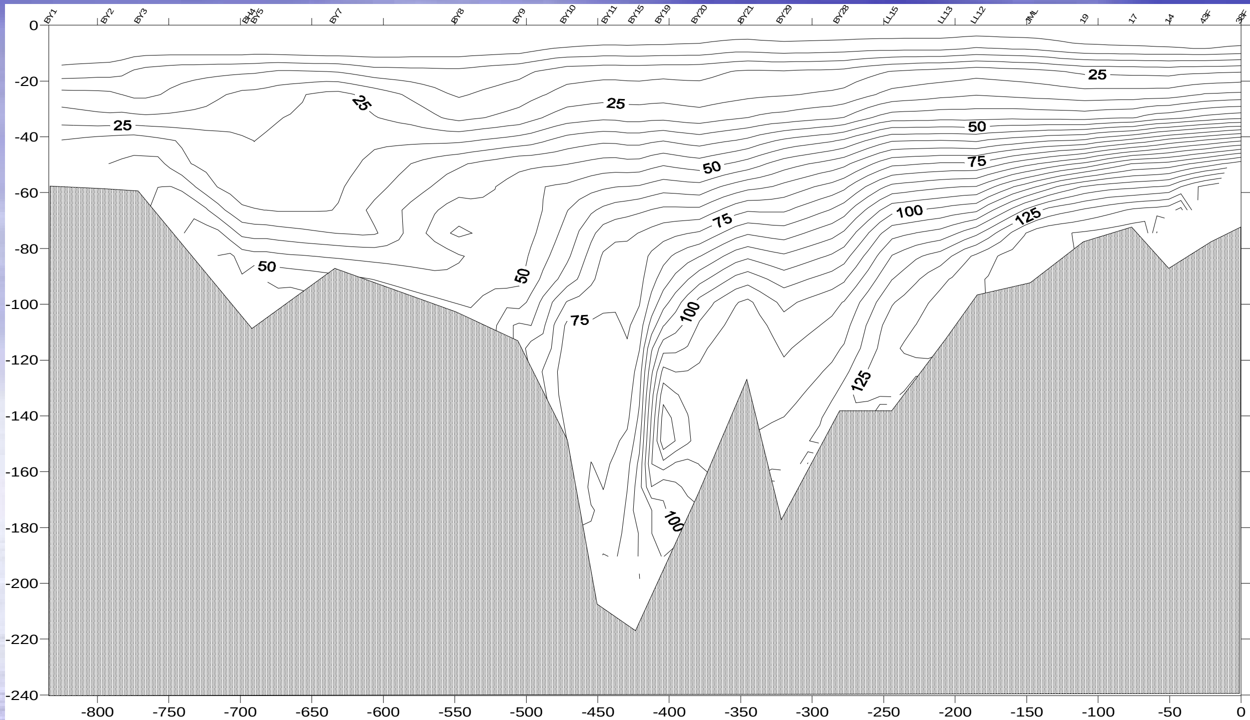


*Dissolved oxygen (ml/l) vertical section along the Gulf of Finland and HELCOM stations in the Baltic Proper in **August 2003***

Model

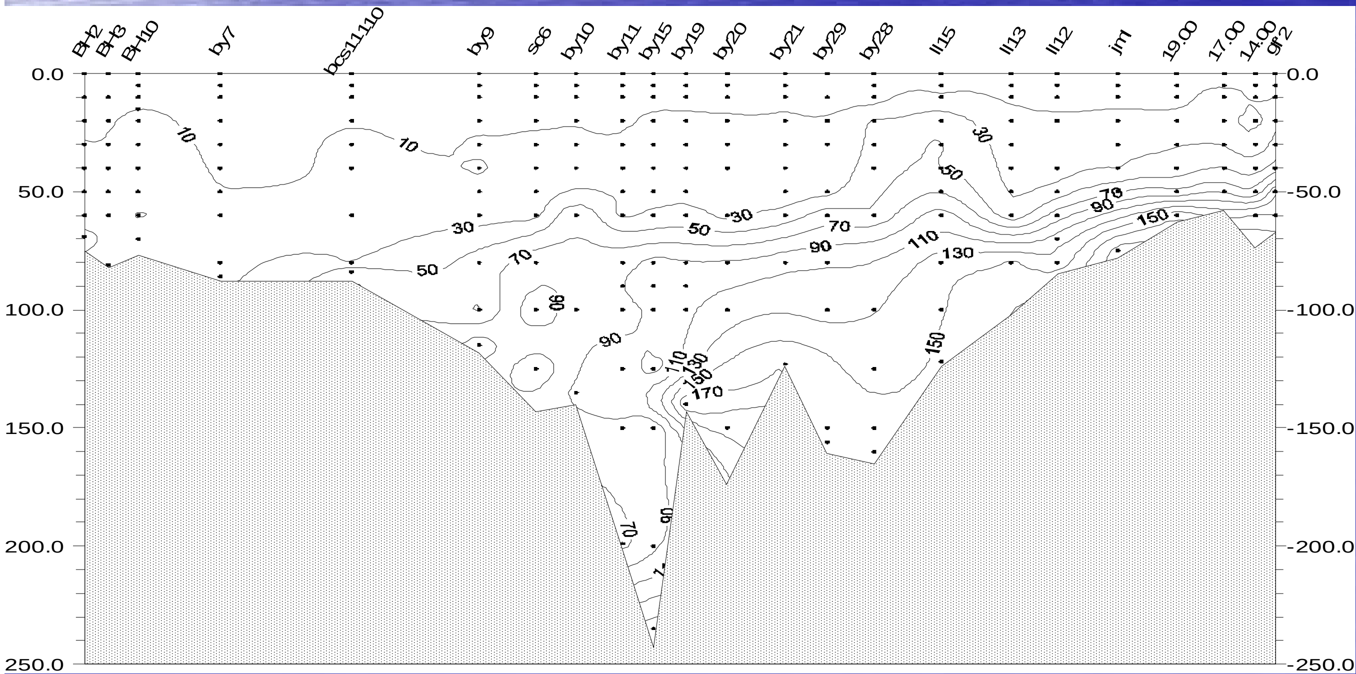


Data from a summer expedition of RSHU



*Phosphates (mg/m**3) vertical section along the Gulf of Finland and HELCOM stations in the Baltic Proper in* ***August 2003***

Model



Data from a summer expedition of RSHU