Biogeochemical fluxes in scenario simulations for the Baltic Sea in the period 1960-2100 with Saint-Petersburg Baltic Eutrophication Model (SPBEM)

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Baltic Earth working group on scenario simulations
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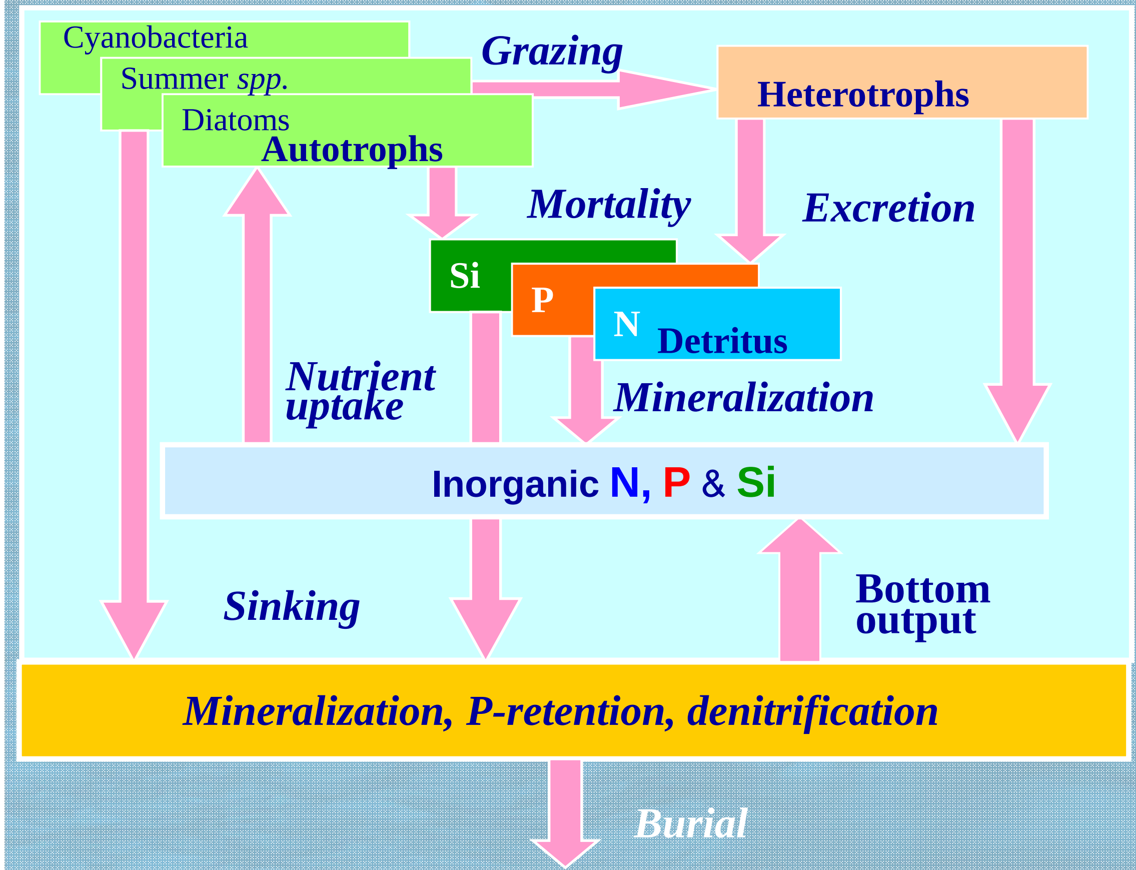
SPBEM

Biogeochemistry module



is based on the model of

O.Savchuk, 2002, J.Mar.Systems, **32**, 253– 280

describes N, P and Si cycling in the coupled pelagic and sediment sub-systems

has 12 pelagic & 3 sediment state variables

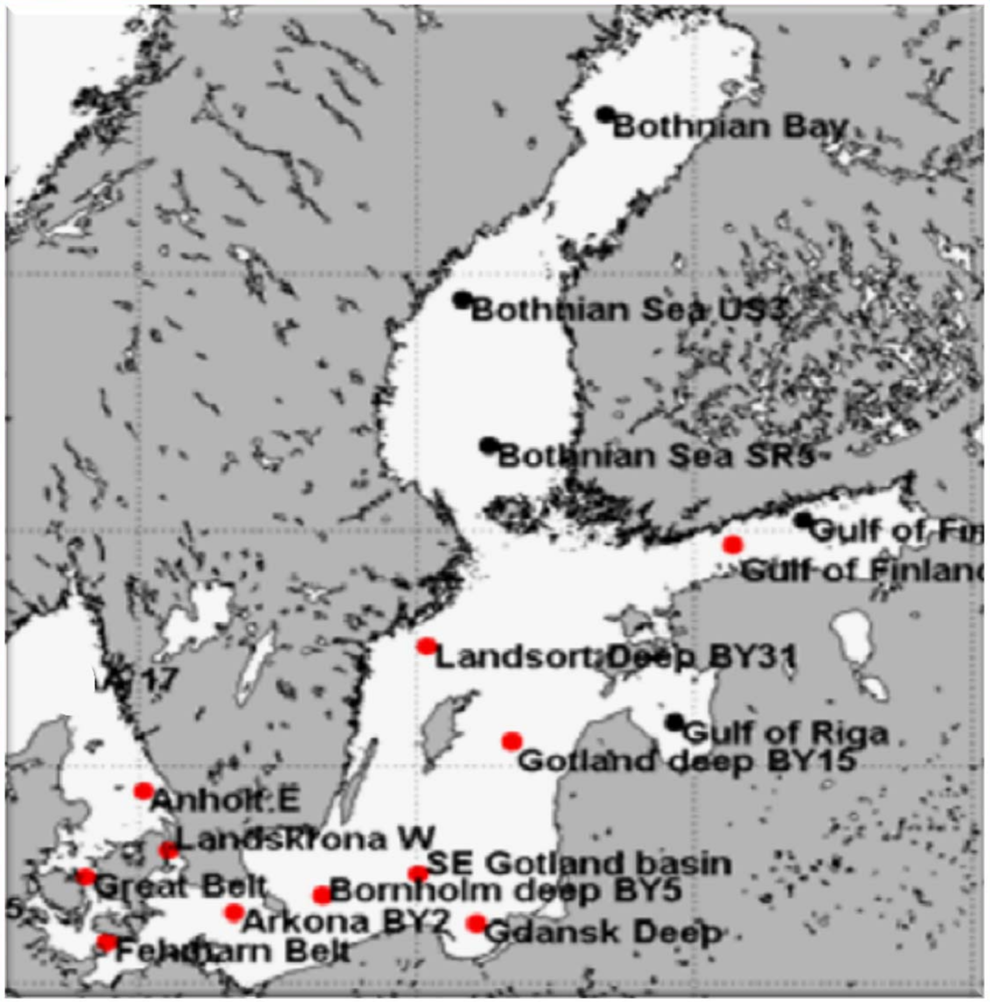
SCENARIOS OF CLIMATE & LOAD CHANGES

Scenario of CO_2 emission	Global climate model	Loads scenario name	Land loads		
			1971-2007	2007-2020	2021-2100
A1B	ECHAM5	REF	Observed mean monthly values	Fixed as mean values averaged over 1997-2003	
A1B	ECHAM5	BSAP	same	Linear Reduction to BSAP target	Fixed target values
A1B	HadCM3	REF	same	Fixed as mean values averaged over 1997-2003	
A1B	HadCM3	BSAP	same	Linear Reduction to BSAP target	Fixed target values

ECHAM5/MPI-OM from the Max Planck Institute for Meteorology in Germany — Roeckner et al. 2006; Jungclaus et al. 2006

HadCM3 from the Hadley Centre in the UK — Gordon et al. 2000

VERIFICATION



Map of the location of 16 oceanographic monitoring stations from the Baltic Environment Database (BED)

Averaged Data from

Gustafsson and Rodriguez-Medina, 2011

Model-data comparison

Mean observed (D) and (M) simulated values averaged over 16 stations (1971-2000), their difference (Δ), and amount of stations in different ranges of "cost" function (C)

Scenario	Upper layer (0-10m)								Near-bottom layer				
	T ann	T wint	T sum	S ann	NO_3 wint	PO_4 wint	O_2 Summ	Chl summ	T ann	S ann	NO_3 wint	PO_4 wint	O_2 aut
	° C			‰	mmol $м^{-3}$		ml/l	mg m $^{-3}$	° C	‰	mmol $м^{-3}$		ml/l
D_{obs}	8.0	1.7	14.4	8.8	5.6	0.5	7.3	2.5	5.4	14.0	6.0	1.6	4.0
Δ ECHAM5	1.1	0.7	1.5	1.5	0.9	0.3	-0.5	0.7	0.5	0.1	3.2	-0.1	0.5
0 ≤ C < 1	16	13	15	5	11	5	15	5	10	2	5	9	11
1 ≤ C < 2	0	3	1	1	3	9	1	8	4	6	3	3	4
Δ HadCM3	0.5	-0.6	2.1	3.7	-0.3	0.3	-0.5	0.4	-0.1	2.0	1.8	-0.1	0.5
0 ≤ C <1	16	14	13	4	10	5	15	4	8	2	7	9	10
1 ≤ C < 2	0	2	3	0	5	8	1	10	7	4	3	3	6

$$C = \left| \frac{M - D}{S_d} \right|$$

$0 \le C < 1$ – good agreement

$1 \le C < 2$ – satisfactory

$2 \le C$ – bad.

RESULTS

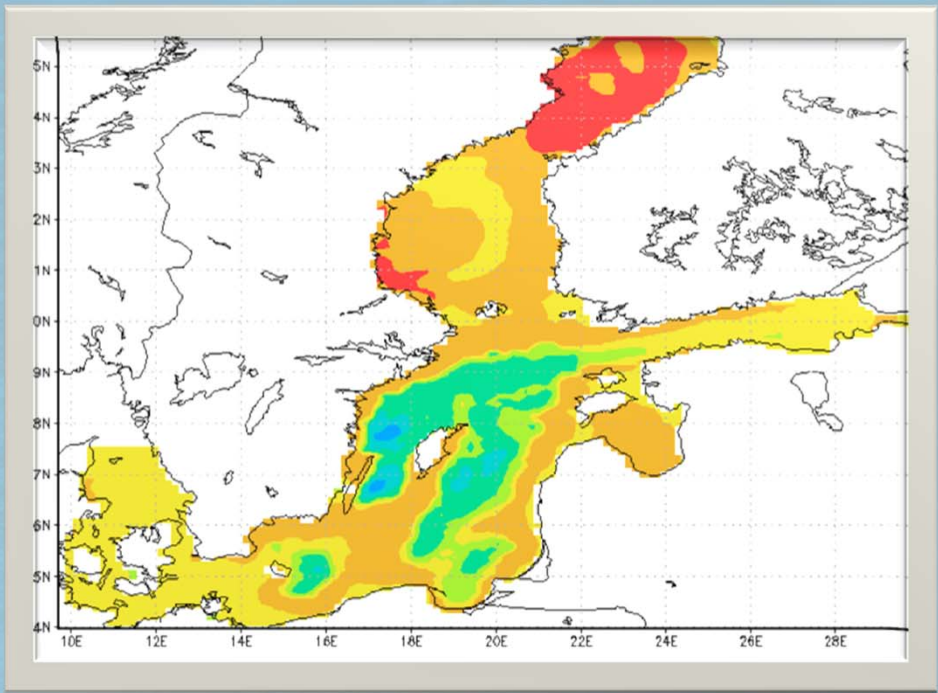
The difference between the future(2071-2100) and modern(1971-2000) values of parameters

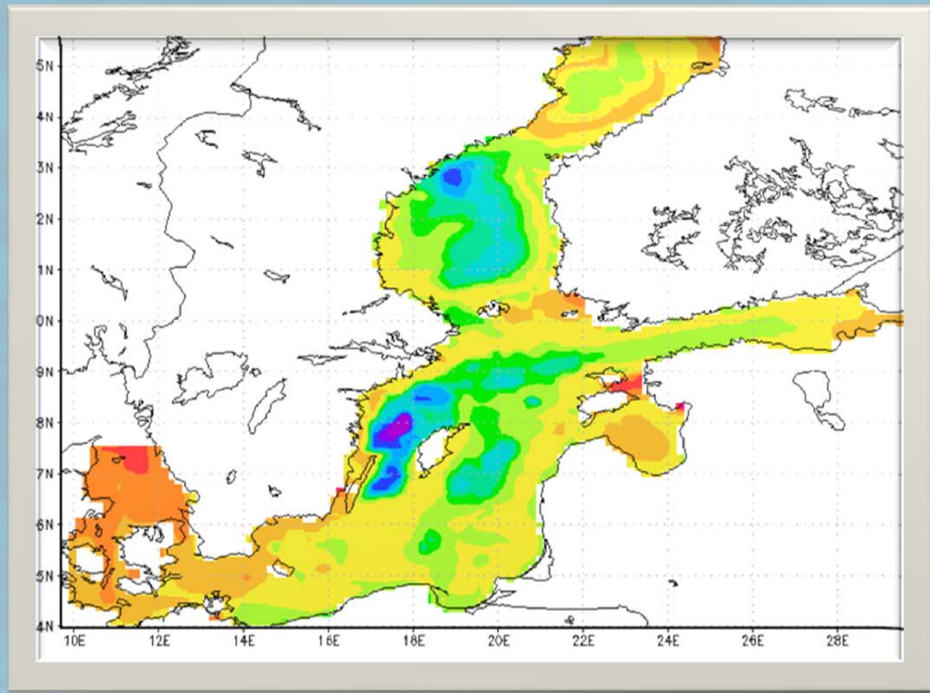
REF	Upper layer (0-10m)								Near-bottom layer				
	ΔT ann	ΔT wint	ΔT summ	ΔS ann	ΔNO_3 wint	ΔPO_4 wint	ΔO_2 sum	ΔChl summ	ΔT ann	ΔS ann	ΔNO_3 wint	ΔPO_4 wint	ΔO_2 aut
ECHAM5	2.1	2.7	1.4	-0.8	2.5	0.4	-0.6	0.8	1.0	-0.3	0.9	0.6	-1.3
HadCM3	2.9	2.9	2.5	-0.2	1.3	0.6	-1.1	0.8	1.2	-0.1	-0.1	0.9	-1.8
BSAP													
ECHAM5	2.1	2.7	1.4	-0.8	1.4	0.3	-0.3	0.3	1.0	-0.3	0.4	0.5	-0.8
HadCM3	2.9	2.9	2.5	-0.2	0.7	0.5	-0.6	0.4	1.2	-0.1	0.0	0.7	-1.0

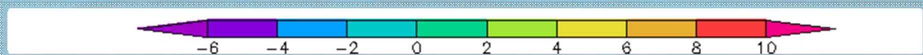
1. Temperature increase in future climate especially in summer is higher in HadCM3 runs
2. . In REF runs, O2 decrease is greater with HadCM3 than with Echam5 forcing
3. Oxygen decrease in near-bottom layer is less in BSAP runs than in REF runs. Unlike ECOSUPPORT simulations, there is an decrease rather than increase of near- bottom oxygen.

RESULTS

Oxygen concentration in the near-bottom layer in the case of HadCM3 forcing with REF loads



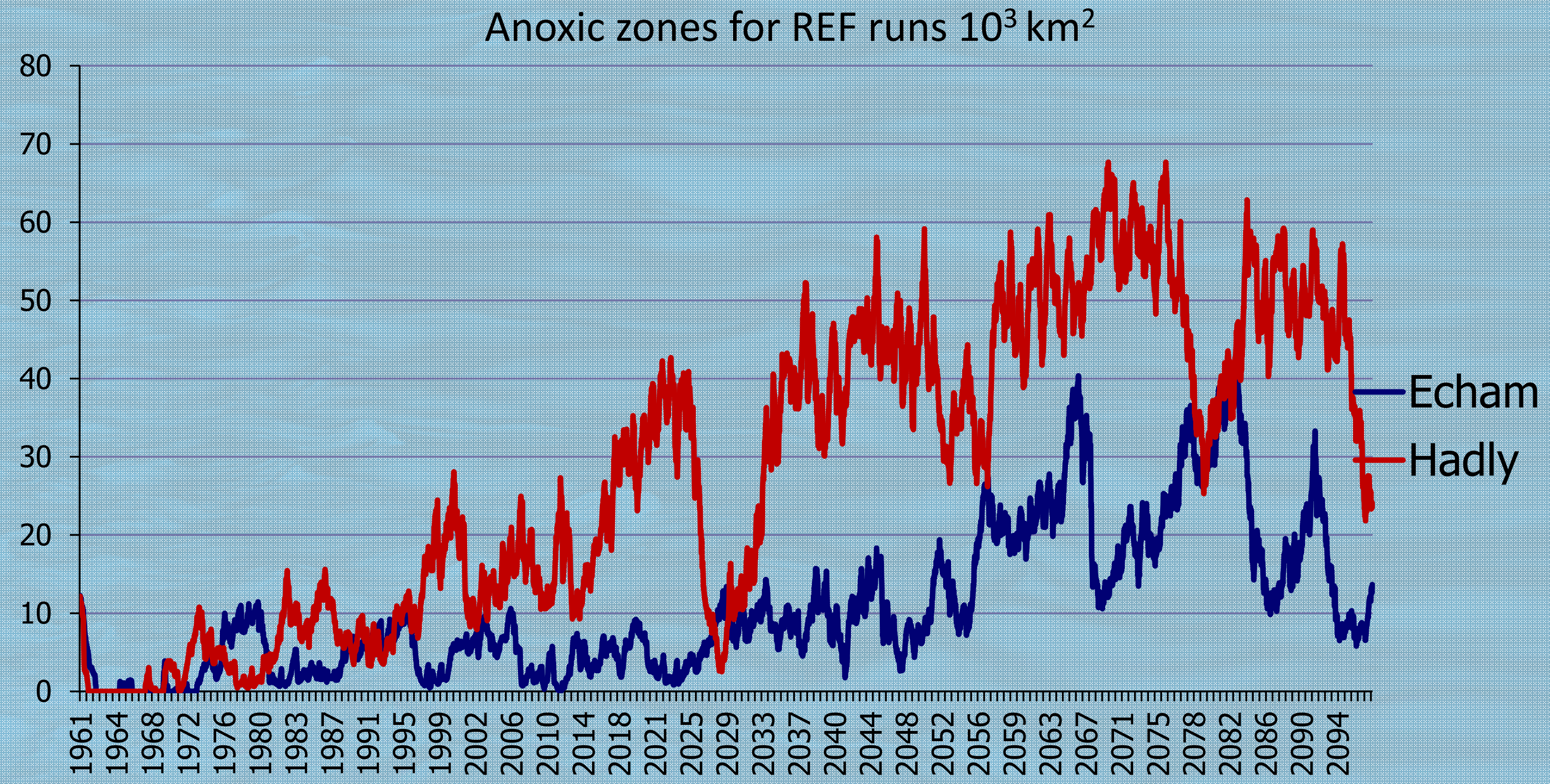




Modern(1971-2000)

Future(2071-2100)

RESULTS

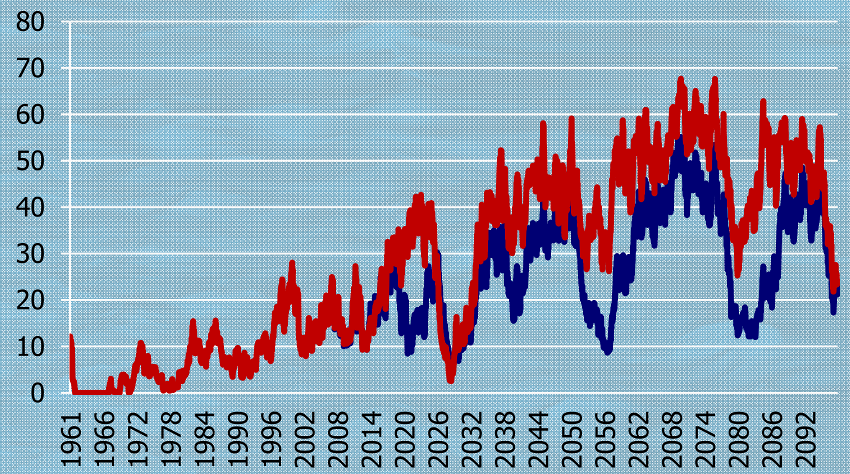


Anoxic zones by the end of 21st century will be wider, compared to current conditions in reference ECHAM5 and HadCM3 runs.

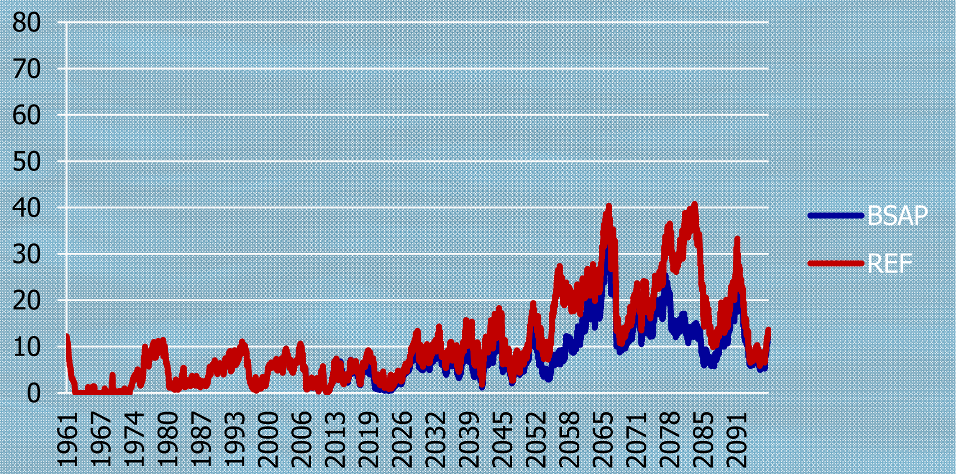
RESULTS

Comparison between REF and BSAP runs

Anoxic zones(HadCM3) 10^3 km^2

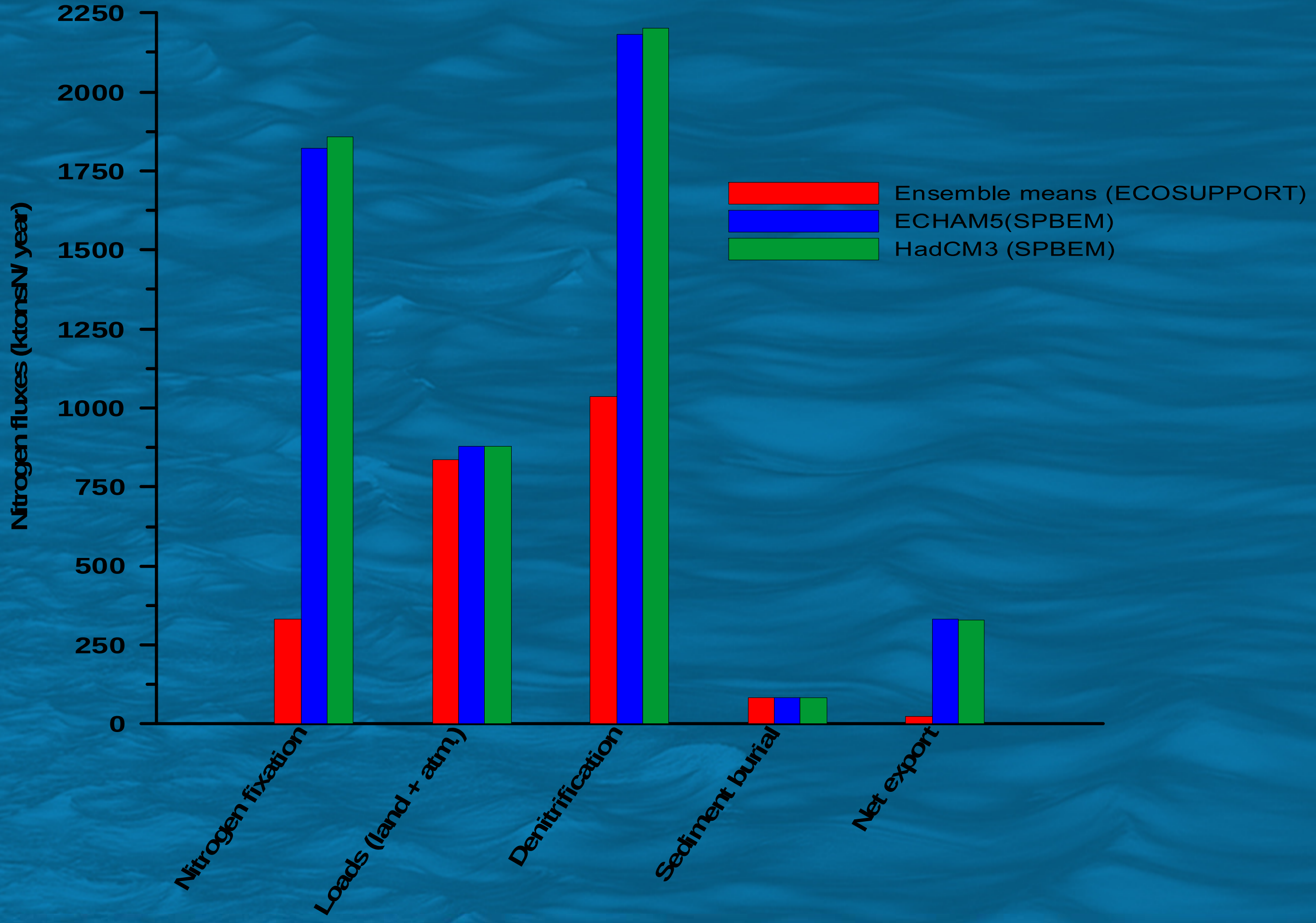


Anoxic zones(Echam5) 10^3 km^2



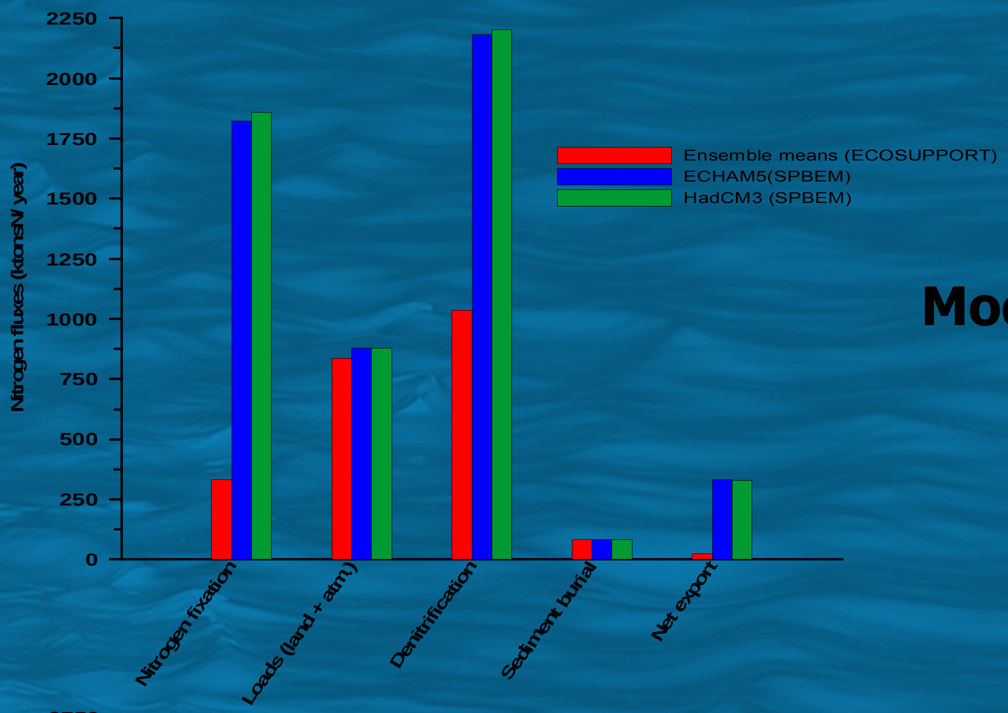
1. According to the ECHAM5 and HadCM3 driven BSAP scenario simulations, nutrient load reduction suggested in BSAP will not lead to any fundamental changes in the water quality in the end of this century.
2. Areas of anoxia and hypoxia will grow, but slower than in the reference runs.

Modern climate, 1971-2000

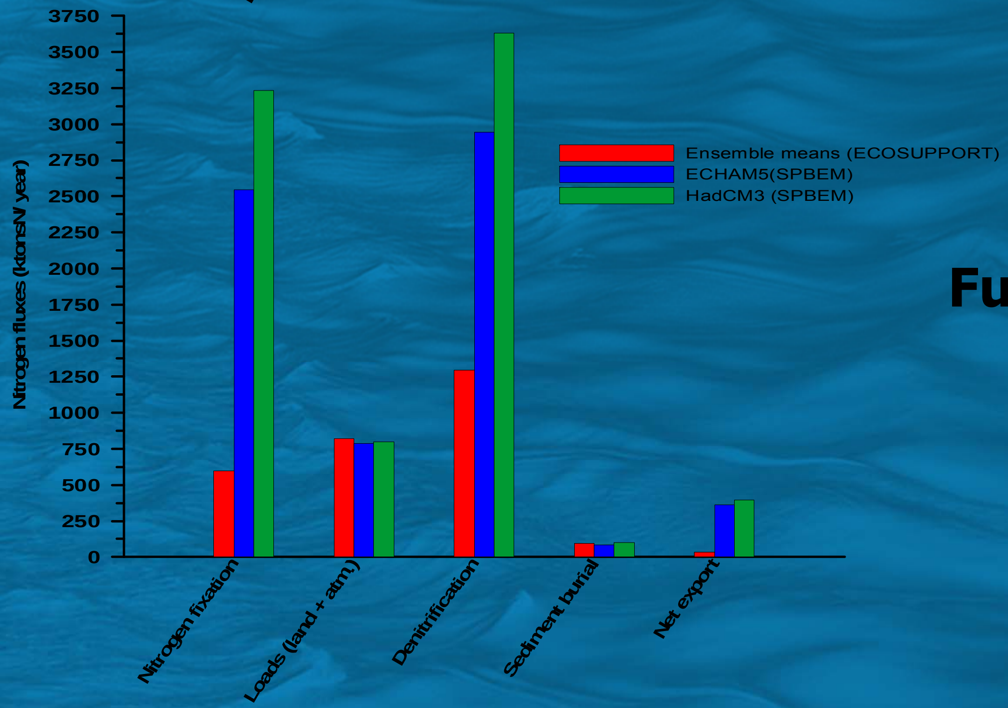


Nitrogen fixation and denitrification in SPBEM runs are much higher than in ECOSUPPORT ensemble simulations

Why?



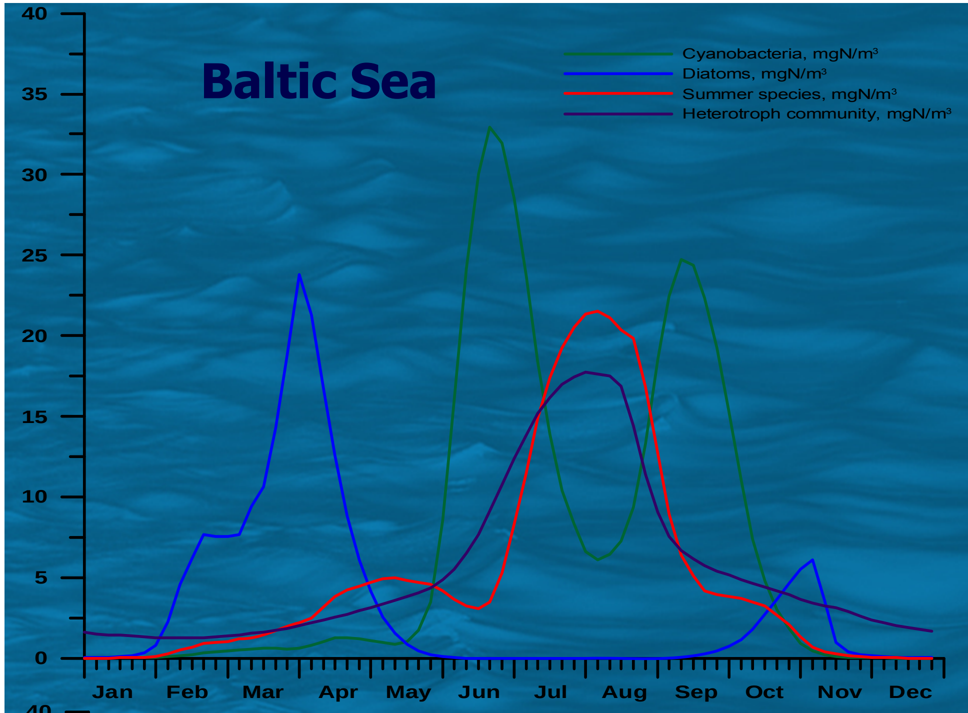
Modern climate, 1971-2000

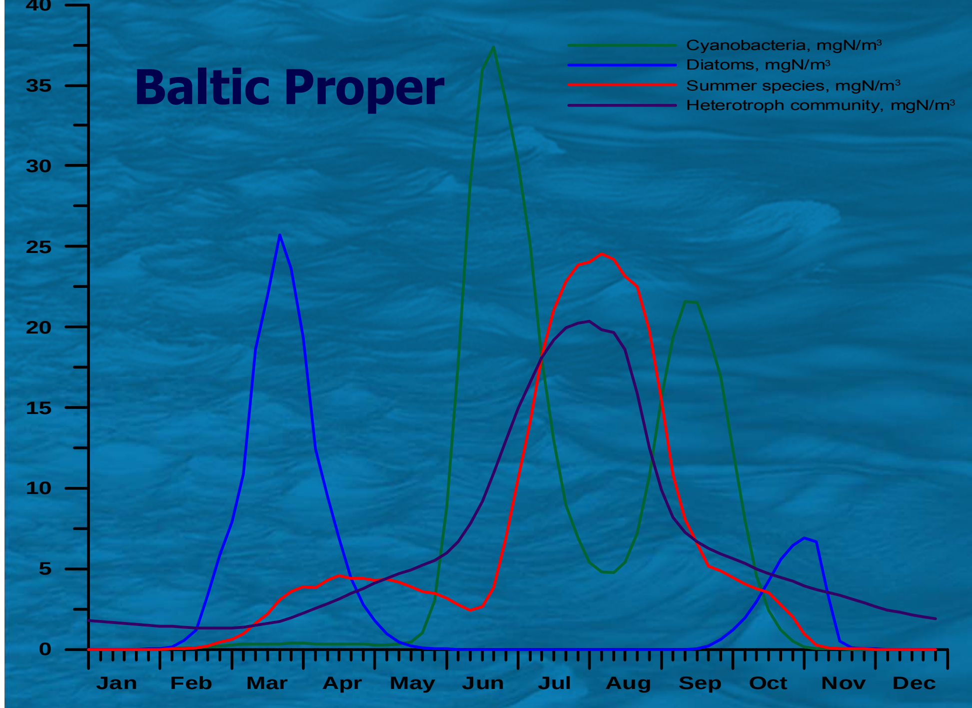


Future climate, 2071-2100

SPBEM ECHAM run

Seasonal succession of diatoms, summer species, cyanobacteria and zooplankton in the upper layer, averaged over 1971-2000



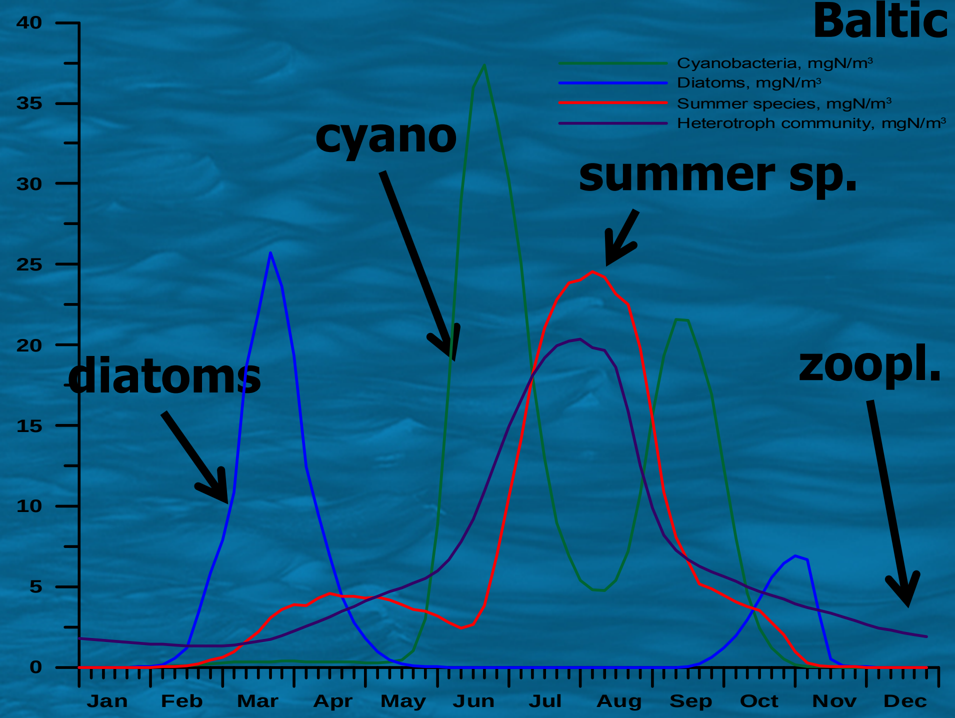


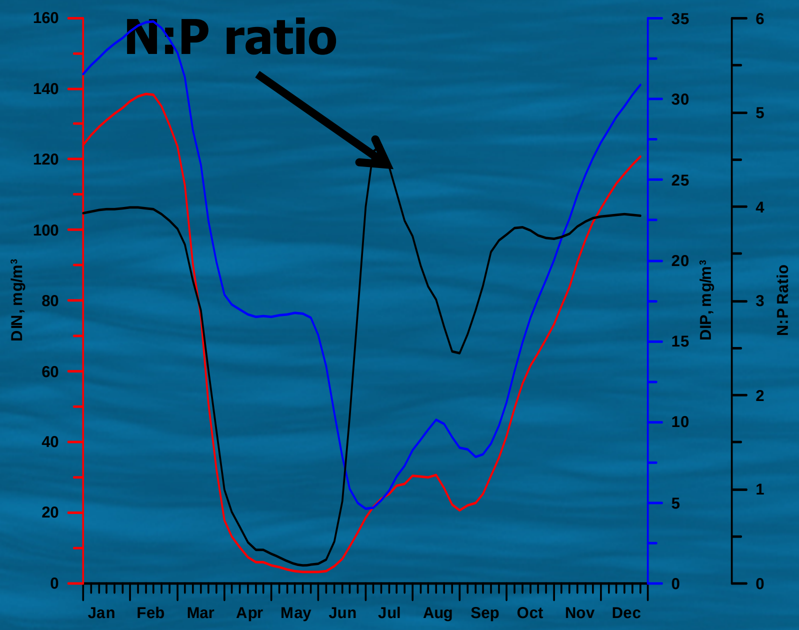
SPBEM ECHAM run

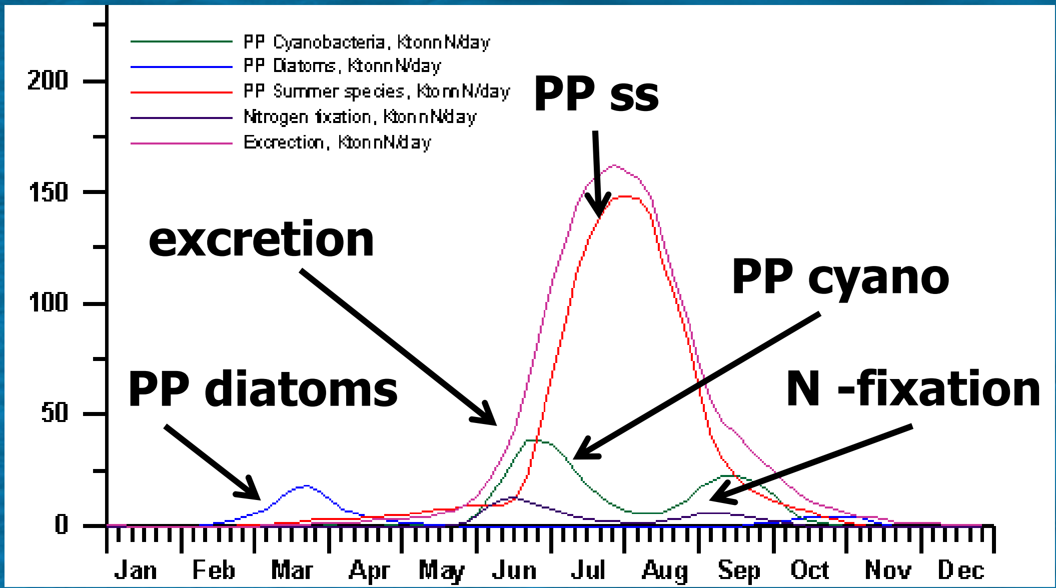
Table 3. Calculated (M) and observed (D) values of nitrate, phosphate, ammonium, dissolved oxygen and chlorophyll *a* in the sea upper layer (0-10m) at 2 monitoring stations in the Baltic Proper (averages over the period 1971 to 2000).

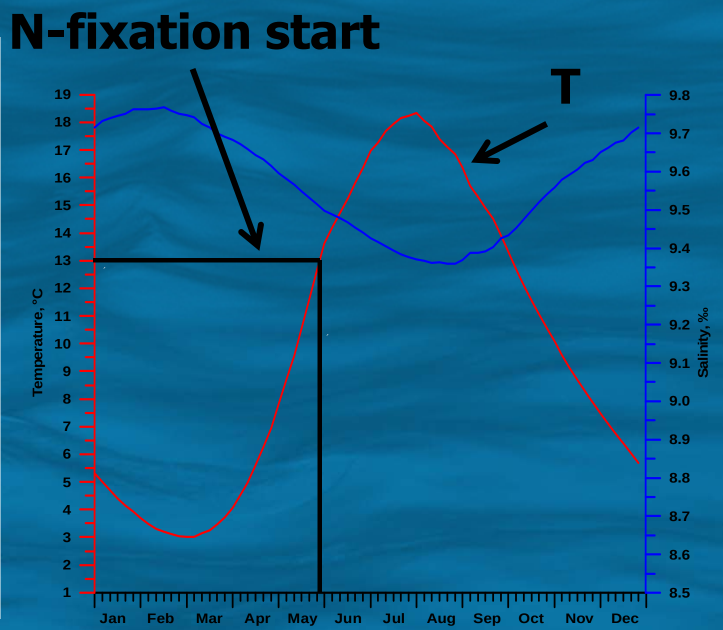
Station and forcing	Mean winter nitrate, mmol m^{-3}		Mean winter phosphate, mmol m^{-3}		Mean summer oxygen, $ml \cdot l^{-1}$		Mean summer chlorophyll a conc., $mg \cdot m^{-3}$	
	M	D	M	D	M	D	M	D
SE Gotland Basin ,E	9.2	4.8	0.8	0.5	6.2	7.4	3.0	2.9
Gotland Deep BY15, E	9.2	4.0	1.0	0.6	6.8	7.5	3.2	3.1
Entire Baltic Sea	6.4	5.6	0.8	0.5	6.8	7.3	3.2	2.5

Baltic Proper









1. By this moment, N:P ratio reaches its minimum after N-limited spring bloom creating favorable conditions for N-fixation
2. Modeled summer T is higher than observed by 1.5 C and reaches prescribed NF-threshold (13 C) earlier (in the beginning of June)
3. The Redfield DIP excess is also two-three times higher than observed because of the overestimated winter values
4. Taken together, all these conditions lead to a massive nitrogen fixation and strong cyanobacteria bloom already in June
5. Zooplankton biomass increases accordingly, accompanied by increased nutrient excretion, thus introducing fixed nitrogen into biotic cycles
6. Intensification of nutrient regeneration favors the growth of summer species. As a result, their PP is much higher than PP of diatoms and cyanobacteria.

So, we have in SPBEM much more intensive recycling within water column under the same external loads as in ECOSUPPORT.

Initial (in 1970) mean volume averaged pools of dissolved inorganic nitrogen (DIN) and phosphorus (DIP) and area averaged pools of nitrogen and phosphorus in the sediments (in kton) for the entire Baltic

	Water DIN	**Water DIP**	**Sediment N**	**Sediment P**
ECOSUPPORT Ensemble mean	1600	600	3000	900
SPBEM	2400	700	13000	2400

The main reasons of that are:

1) higher initial P and N sediment content in the BS (in the comparison with ECOSUPPORT simulations);

2) higher summer temperatures.

CONCLUSIONS

1. Changes in eutrophication indicators in reference HadCM3 driven run is greater than in similar ECHAM5 driven run.

The main reason is higher water temperature increase, ΔT, in HadCM3 run which will (1) reduce oxygen concentrations due to its lower solubility in warmer water and (2) accelerate organic matter mineralization and oxygen consumption. Expanding hypoxia will increase phosphorus release from the sediments resulting in reduced removal of phosphorus from the ecosystem, while simultaneous increase of denitrification leads to augmented removal of nitrogen from the ecosystem. Higher ΔT together with increased nitrogen fixation will intensify primary production and increase phytoplankton biomass .

CONCLUSIONS

2. According to the ECHAM5 and HadCM3 driven BSAP scenario simulations, nutrient load reduction suggested in BSAP will not lead to any fundamental changes in eutrophication indicators in the end of this century. In particular, areas of anoxia and hypoxia will grow, but slower than in the reference runs.

3. The estimates are qualitatively consistent with the estimates of ECOSUPPORT project, but impact of climate change on eutrophication was much stronger.

4. As the analysis of biogeochemical fluxes showed, nitrogen fixation and denitrification in SPBEM runs are several times higher than in ECOSUPPORT ensemble simulations. The main reasons of that are: 1) higher initial P and N sediment content; 2) higher summer temperatures in modern climate.

5. These simulations should be viewed as sensitivity analysis of the model solution to the initial conditions, which, as was shown, are a significant source of uncertainty of the final result.