Modelling the interaction between eutrophication, acidification and climate change in the Baltic Sea

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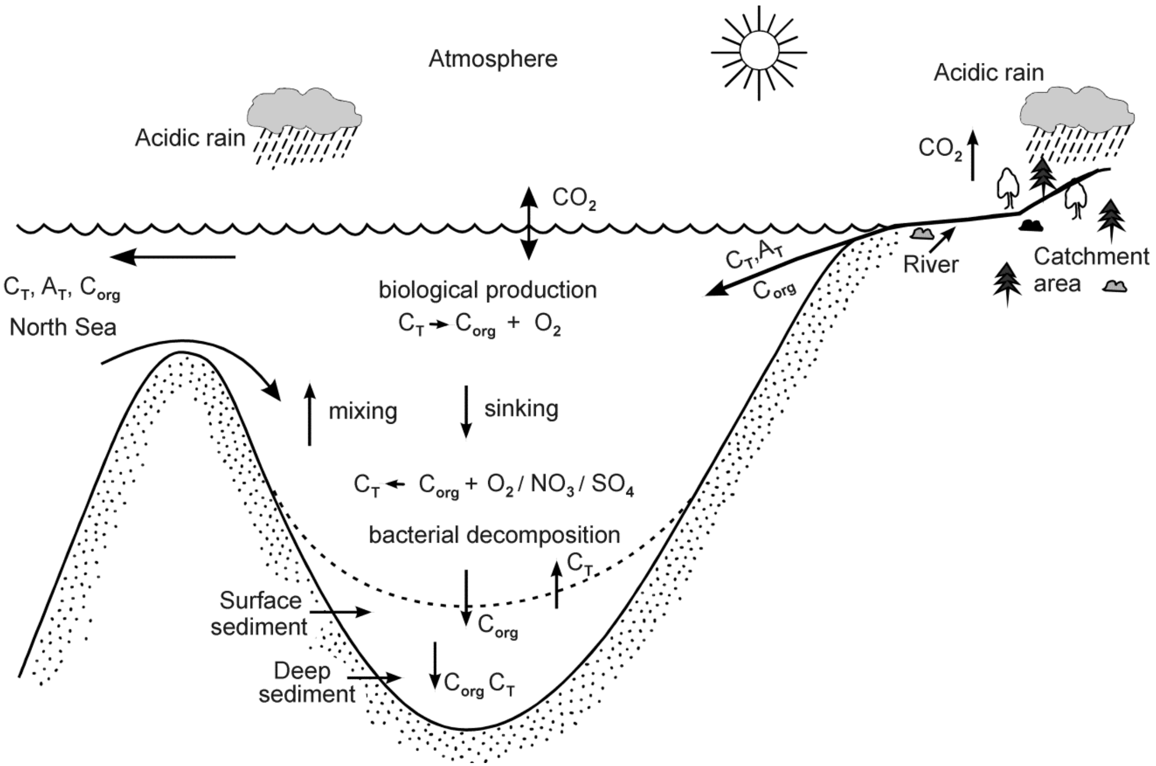
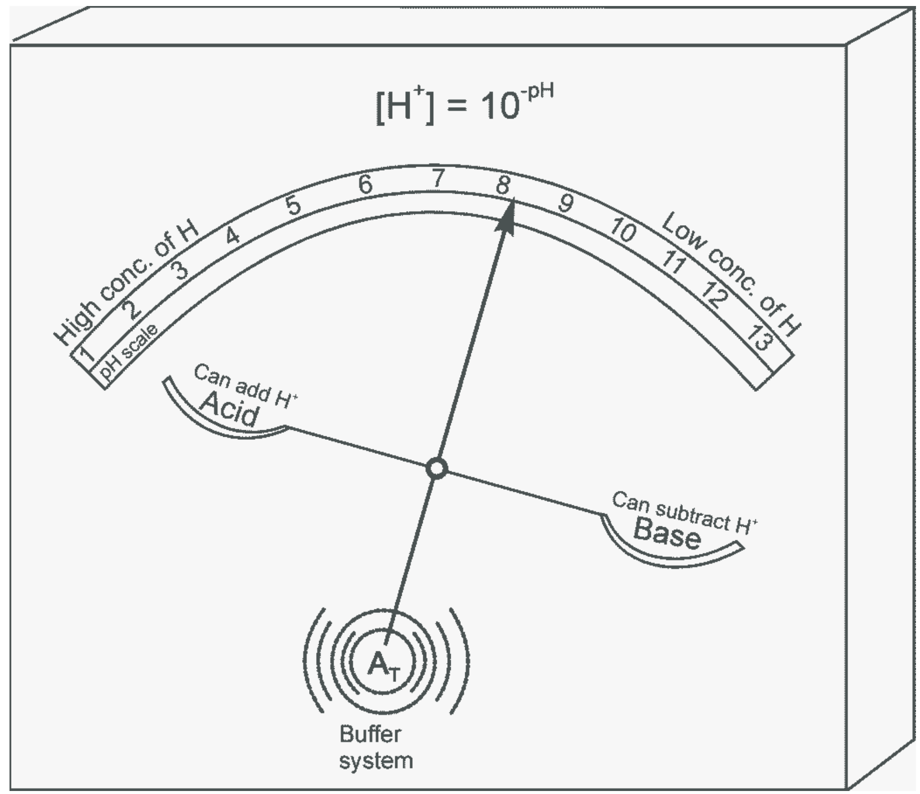
The Baltic Sea CO_2 - O_2 system



The connection between eutrophication, acidification and climate change is through primary production and mineralization of both organic matters from the sea and from land.

The acid-base balance and total alkalinity

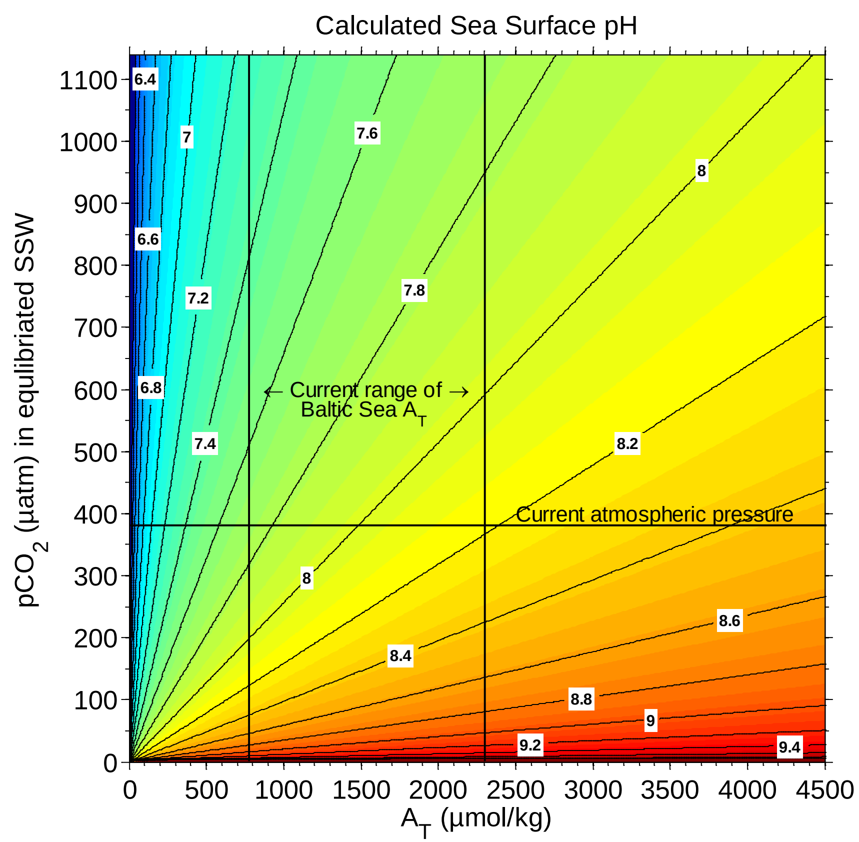


Total alkalinity as the sum of proton (H^+) acceptors minus proton doners

$$A_T = [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [HPO_4^{2-}] + 2[PO_4^{3-}] + [NH_3] + [HS^-] + [OH^-] +$$
$$- [H^+] - [HSO_4^-] \pm \text{minor}$$

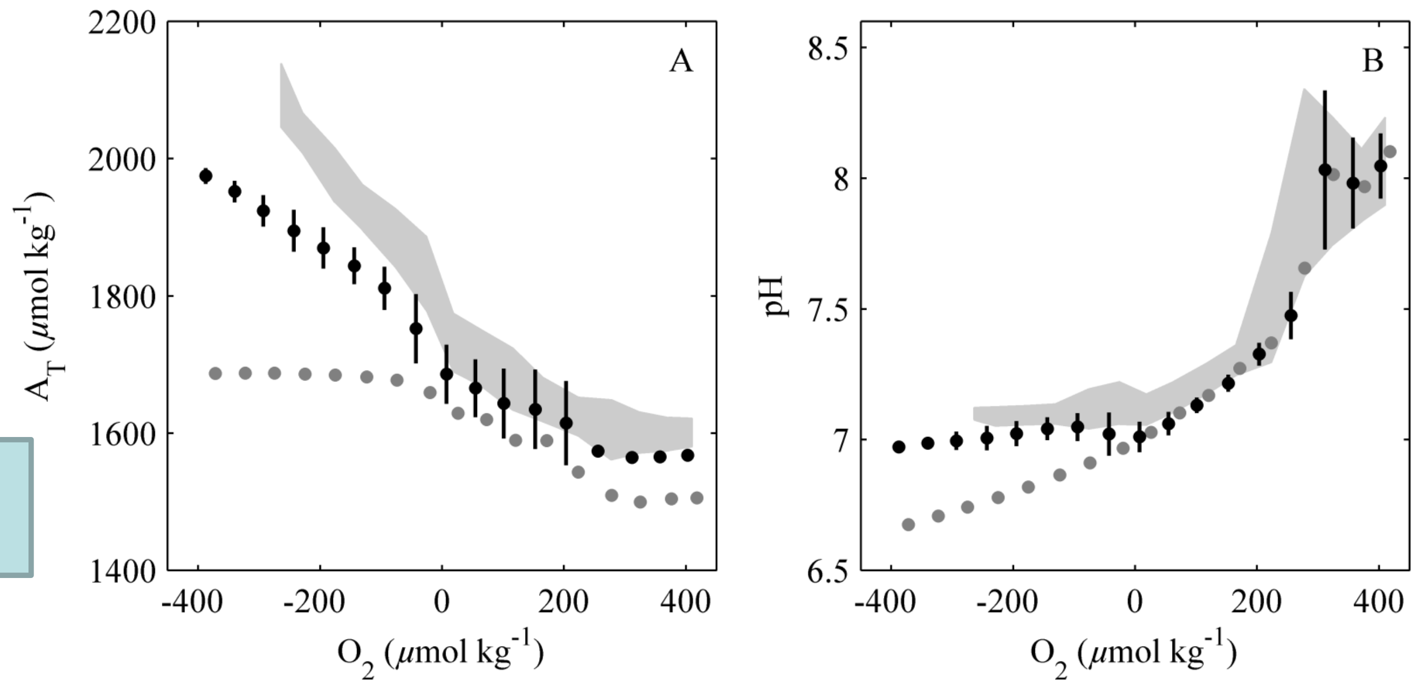
Calculated Baltic Sea surface pH

Rising atmospheric CO_2 and reducing inflow of A_T from river *may cause marine acidification*



Omstedt, Edman, Anderson, Laudon (2010)

pH and alkalinity change in the redox environment of the Baltic Sea



In anoxic waters the alkalinity increases and reduce the pH decrease (buffer effect)

(A) Total alkalinity and (B) pH as functions of oxygen concentration for 0–250 m at station BY15, the Gotland Deep. The observational data (1995–2004) are indicated by ±1 standard deviation of the mean (light gray area). The black markers and lines represent a model run including internal generation of A_T, and the gray markers represent a model run excluding internal generation of A_T.

Edman and Omstedt (2013)

Primary production and mineralization

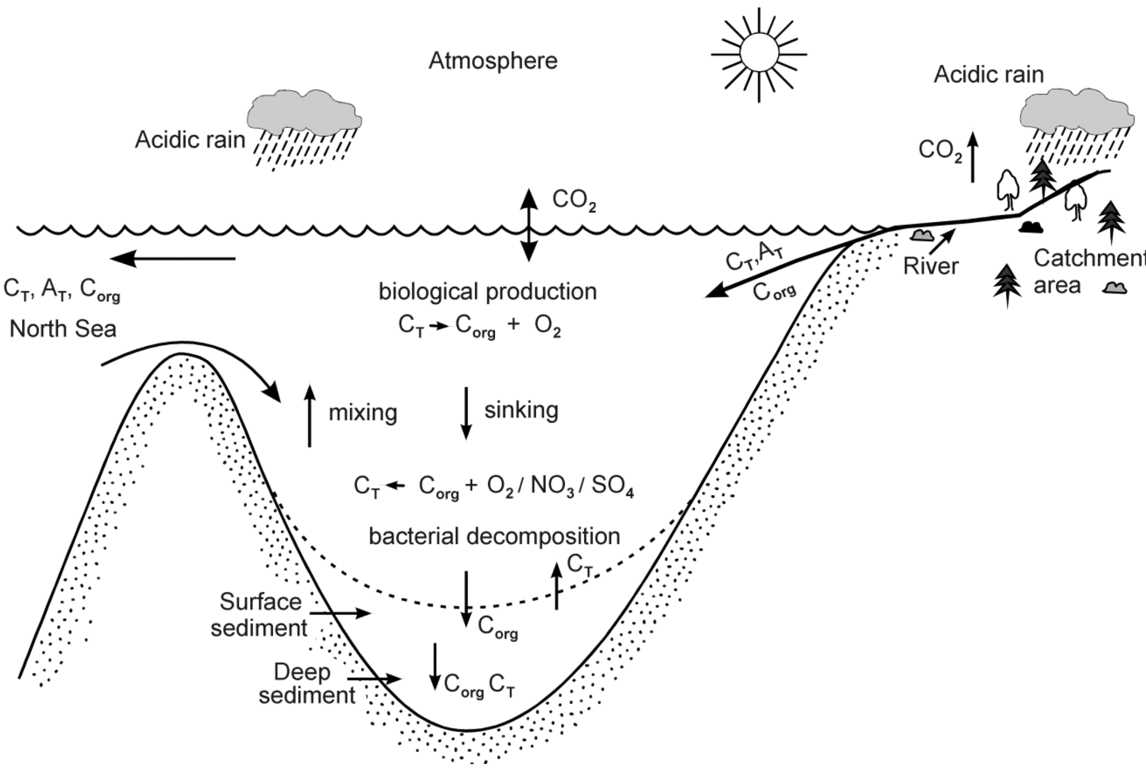
Primary production (pH increase)

Mineralization:
Oxygen reduction (pH decrease)

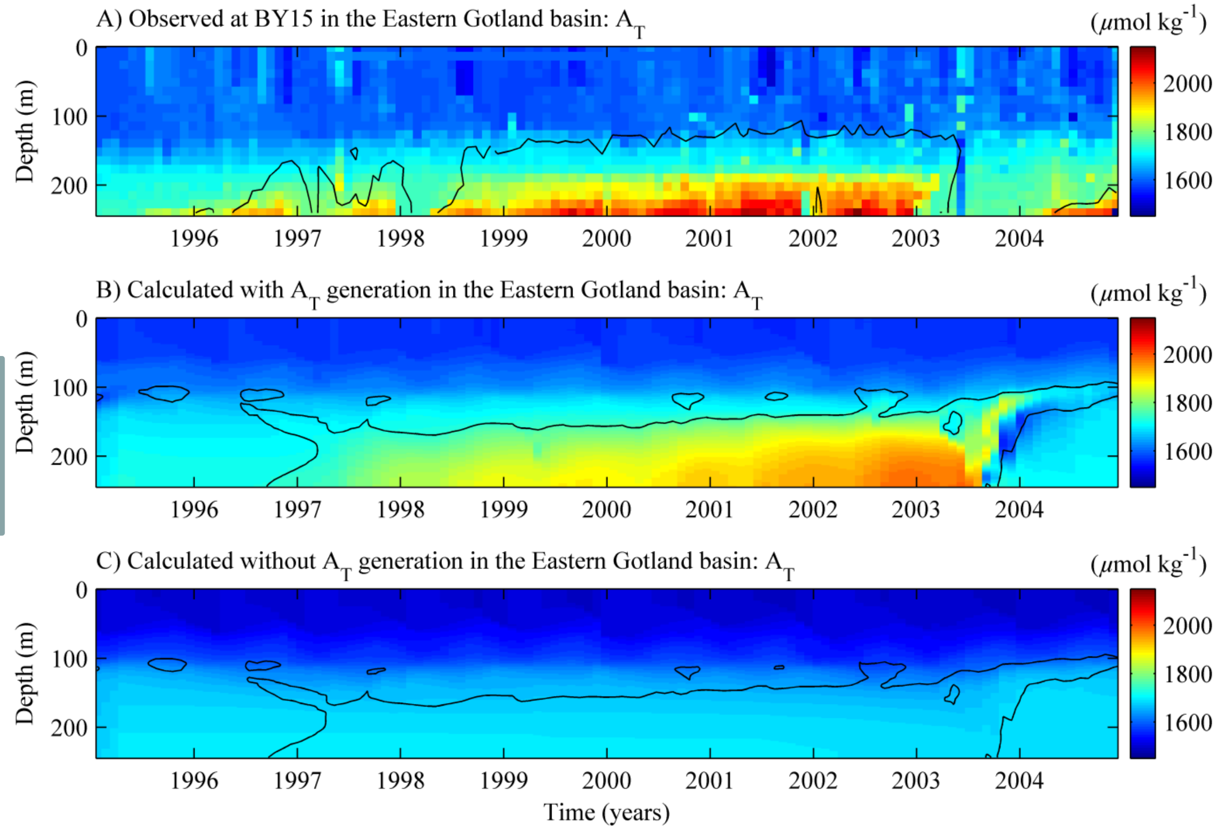
Nitrate reduction
(irreversible, buffered*) pH decrease)

Sulfate reduction
(reversible, buffered*) pH decrease)

*) Buffered due to Alkalinity increase



Alkalilinity change in the redox environment of the Baltic Sea

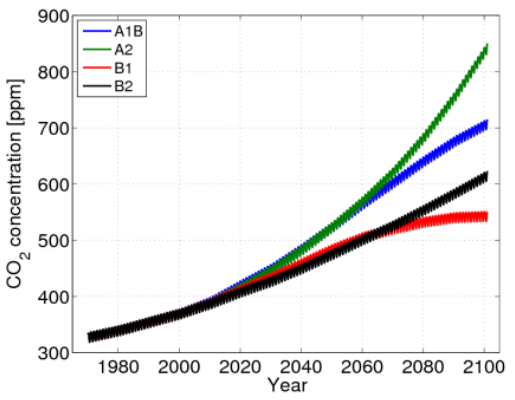


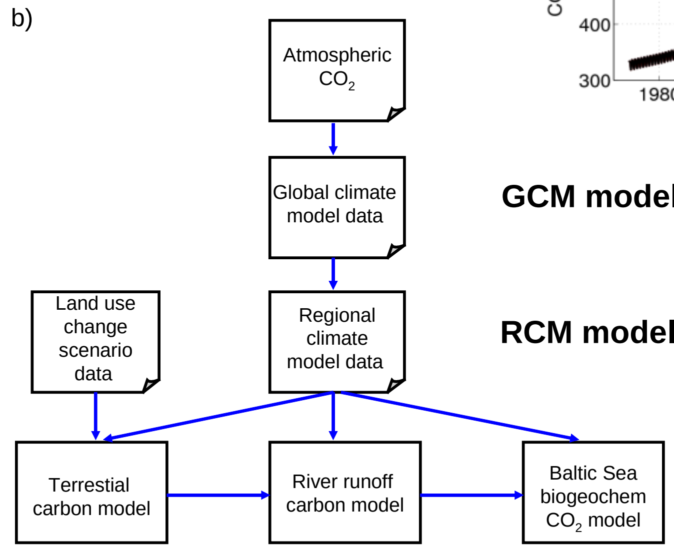
Calculation with internal A_T generation needs to be included otherwise modeled pH values may become too low.

Fig. 8. Total alkalinity at the BY15 station in the Eastern Gotland basin.
The redoxcline (zero oxygen concentration) is indicated by thin black lines.
(A) Observations (SHARK-data). (B) Model results with internal A_T generation and depletion.
(C) Model results without internal A_T generation and depletion.

Edman and Omstedt (2013)

Baltic-C modelling system and scenario design





GCM models: ECHAM5, HADCM3, CCSM3

RCM model: RCA3

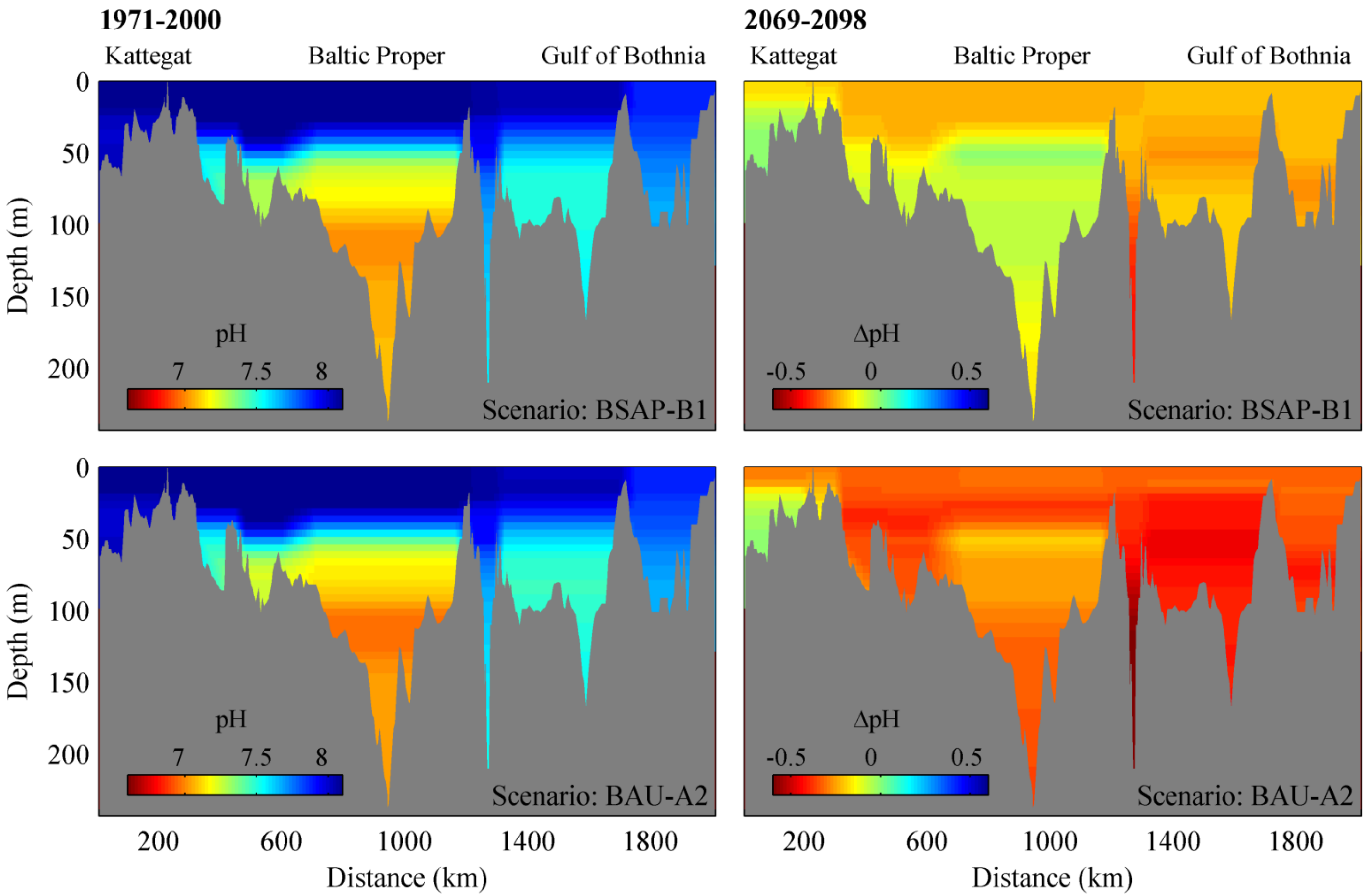
Terrestrial model: LPG-GUESS

River runoff model: CSIM

Baltic Sea model: PROBE-Baltic

Omstedt, Edman, Claremer, Frödin, Gustafsson, Humborg, Hägg, Mörth, Rutgersson, Schurgers, Smith, Wällstedt and Yurova (2012)

Model results based on two possible developments: Successful management (BSAP-B1) and management failure (BAU-A2)



Omstedt, Edman, Claremer, Frödin, Gustafsson, Humborg, Hägg, Mörth, Rutgersson, Schurgers, Smith, Wällstedt and Yurova (2012)

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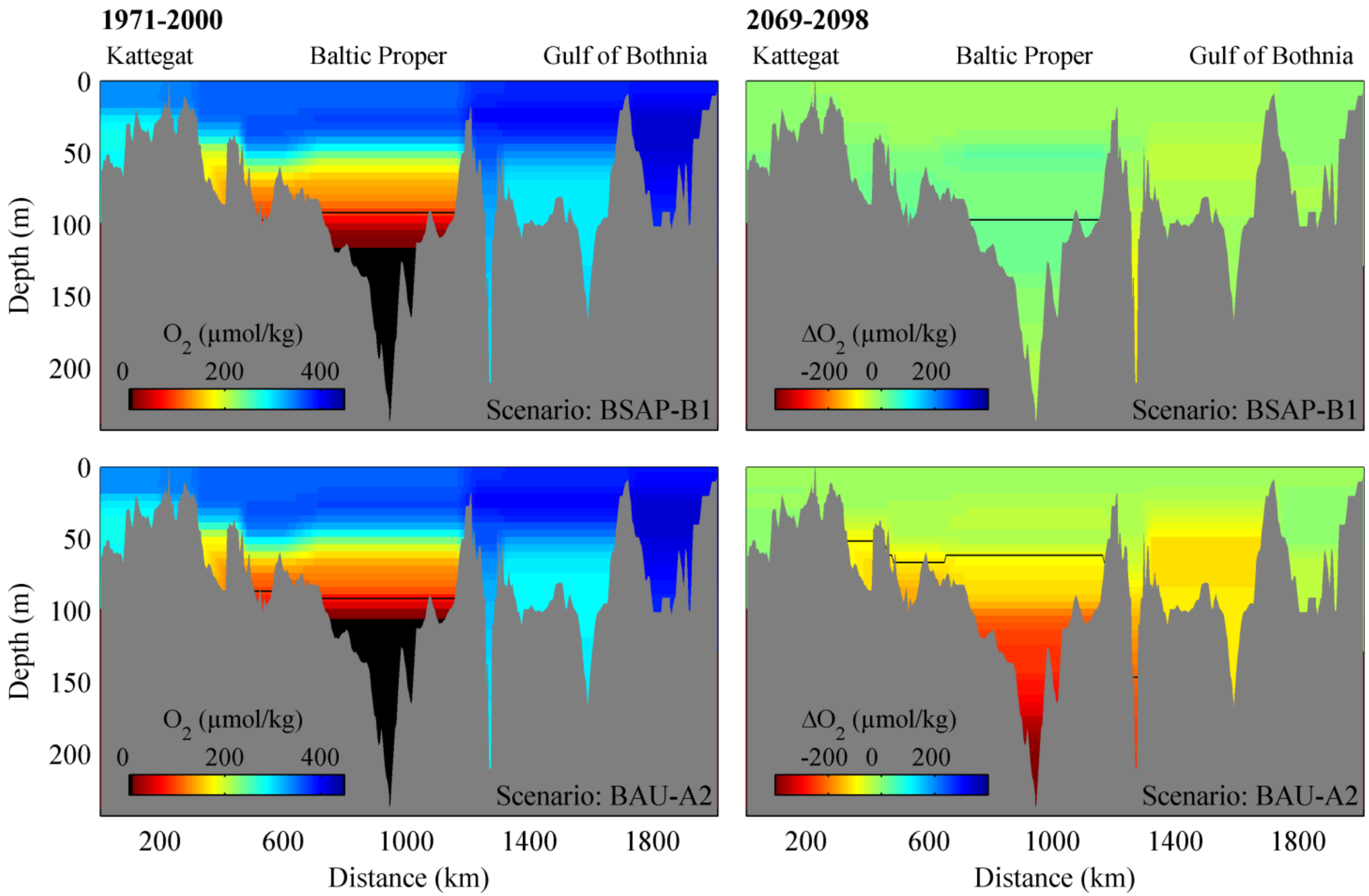
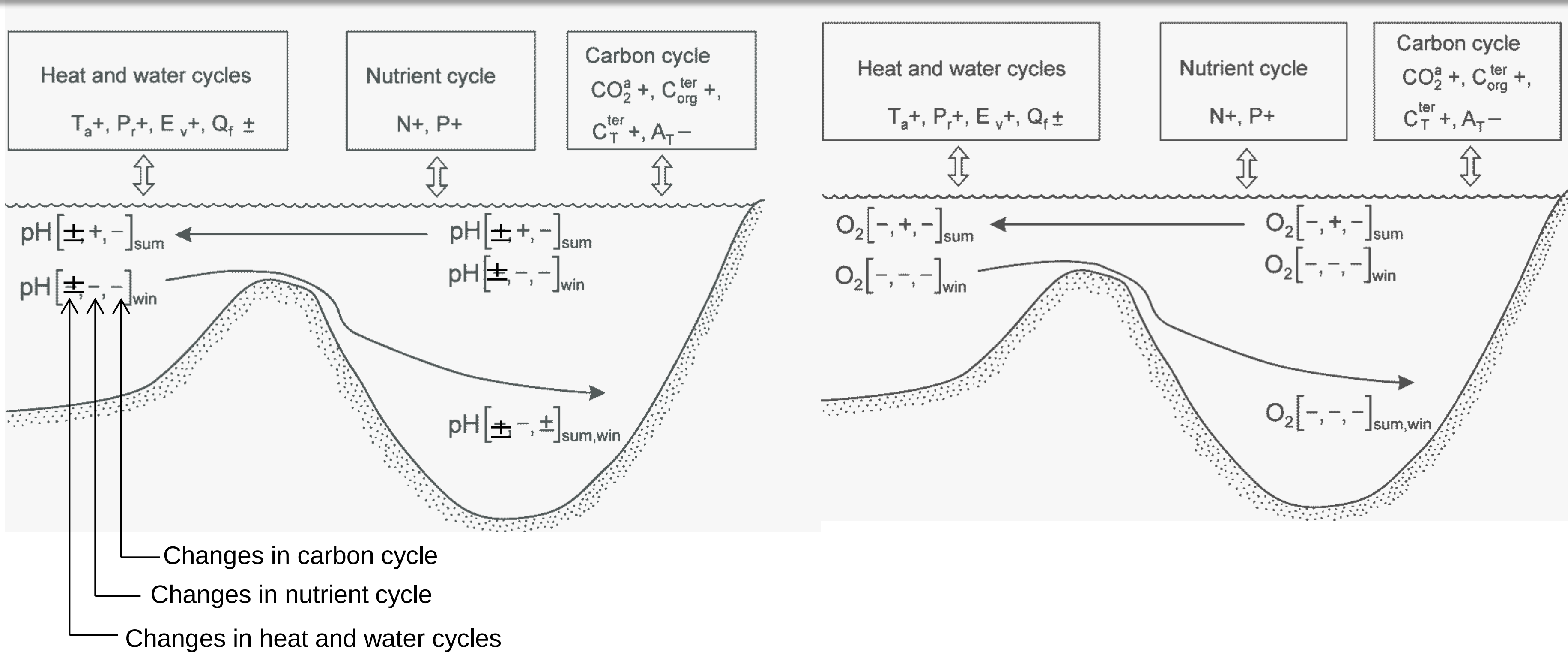
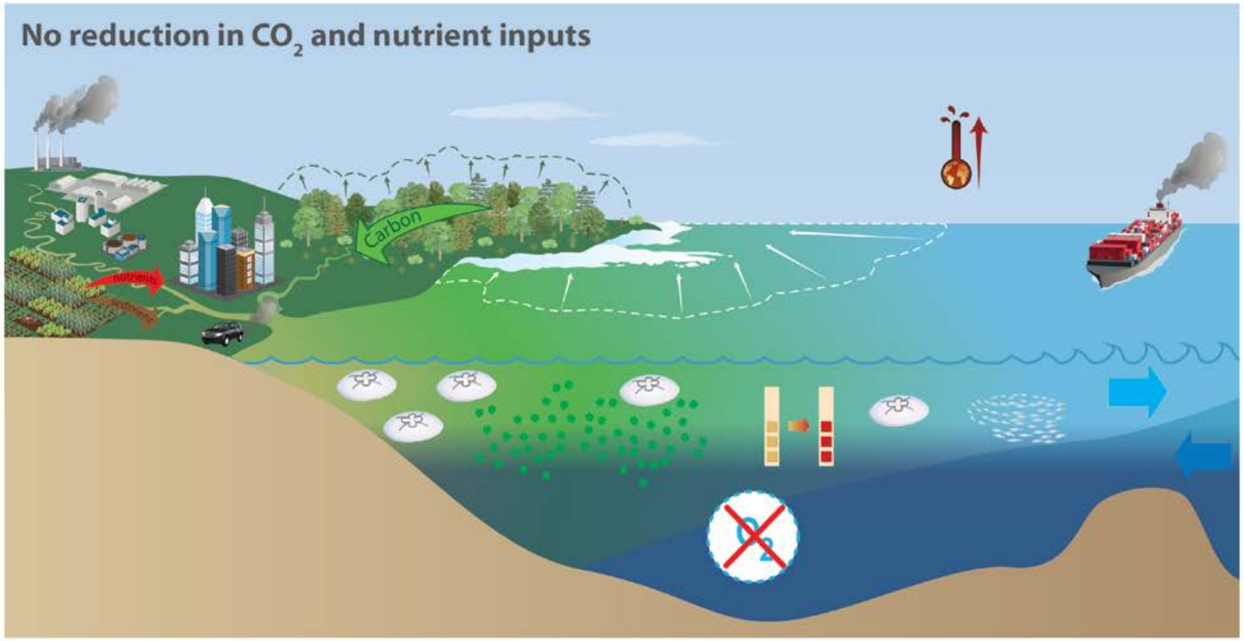


Omstedt, Edman, Claremer, Frödin, Gustafsson, Humborg, Hägg, Mörth, Rutgersson, Schurgers, Smith, Wällstedt and Yurova (2012)

The Baltic Sea CO_2 - O_2 system in the future?



Summary: No reductions



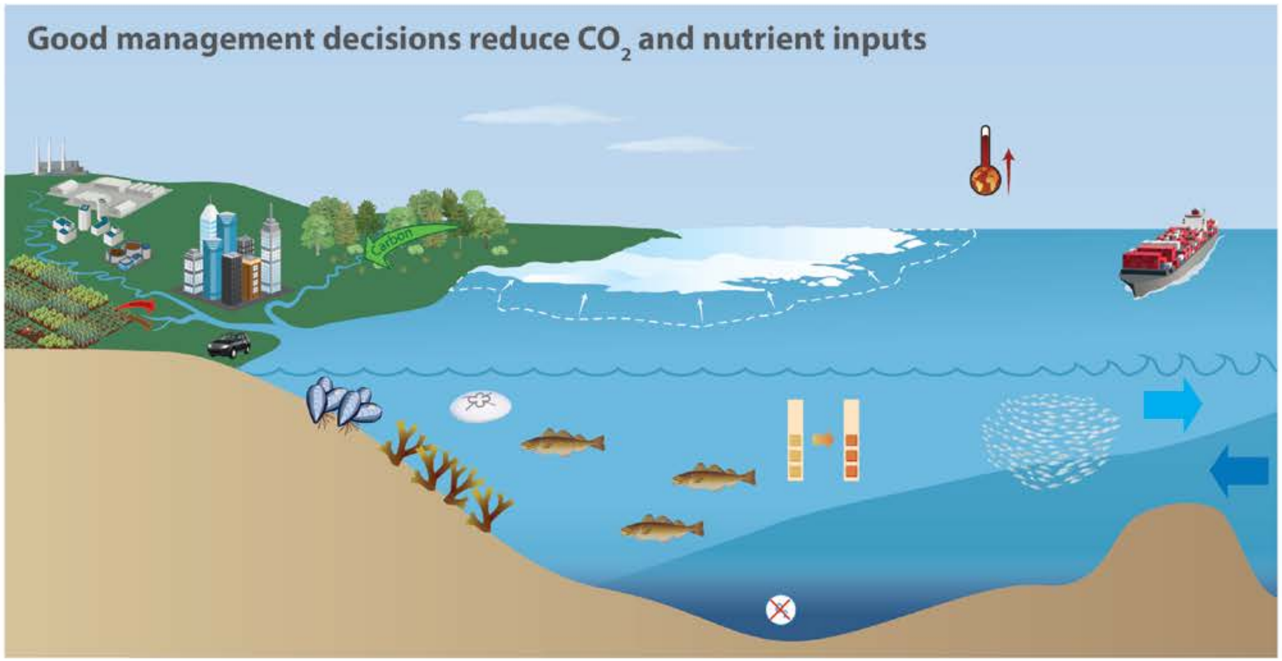
With no reduction in CO_2 emissions and nutrient inputs, water temperatures will increase, sea ice will decrease, and cyanobacteria blooms worsen.

Increased CO_2 emissions lead to increased marine acidification. More nutrient inputs leads to increased algal blooms, while warmer waters decreases the uptake of O_2 in the water. Increased acidification and increased anoxic waters will threaten the marine ecosystem.

- *Increased air and water temperatures*
- *Decreased sea ice*
- *Acidification worsens*
- *Reduced water quality*
- *Increased cyanobacteria blooms*
- *Increased forest growth & carbon transport*
- *Poor coastal biodiversity & health*
- *Increased anoxia*

Diagrams created by the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu) with guidance from A. Omstedt.

Summary: Good managements



Good management decisions such as:

- switching to alternative renewable energy for industry, vehicles, and shipping;
- improved land management and farming practices;
- improved lifestyle choices including food consumption, travelling, and living.

While marine acidification and climate change will continue, it will be slowed down.

Slight increase in air and water temperature
Slight decrease in sea ice
Slight increase in marine acidification
Improved water quality
Good coastal biodiversity & health
Decreased anoxia

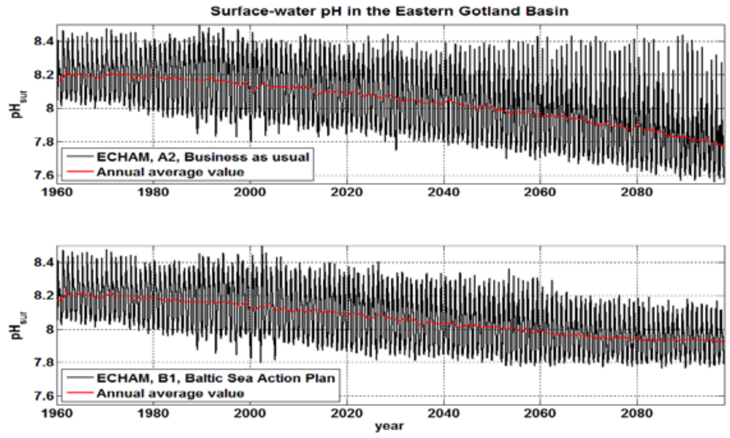
Diagrams created by the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu) with guidance from A. Omstedt.

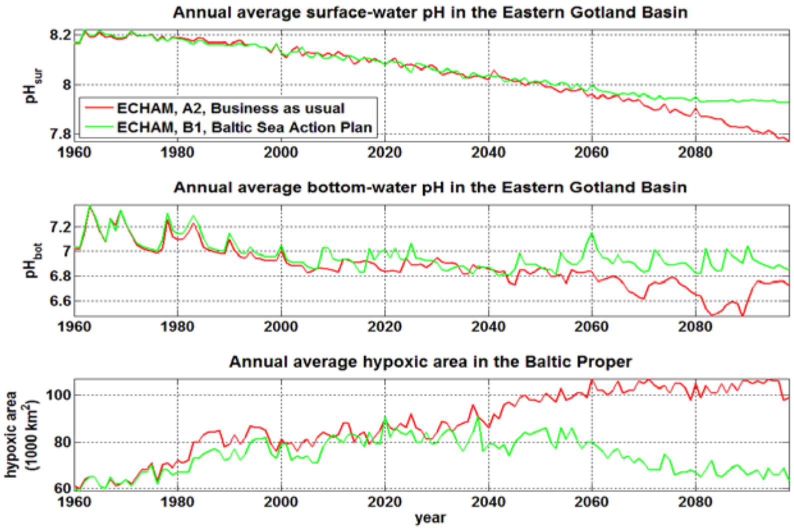
Summary and conclusions

- Marine acidification is influenced by increasing atmospheric CO_2, eutrophication, changes in alkalinity from rivers, changes in redox state and indirectly climate change.
- The acidification is not sensitive to GCM used or GCM initial conditions. Instead the main factor is the CO_2 emissions. On that climate and river changes add modifications. Changes in hydrology may considerable change the Baltic Sea alkalinity distribution.
- Increased nutrient load will not inhibit future acidification in the Baltic Sea, but the seasonal pH cycle will become amplified due to increased biological production and mineralization. All examined scenarios indicate future acidification of the whole Baltic Sea and at all depth.
- Apart from decreasing pH, we also project a decreasing saturation state of calcium carbonate, a decreasing respiration index, and increasing hypoxic and anoxic waters, all of which will further threaten the marine ecosystem.
- The Baltic Sea will most probably become more acid in the future. Substantial reductions in fossil-fuel burning are needed and are not in conflict with the nutrient reductions suggested in the Baltic Sea Action plan.

Thanks for your interest!

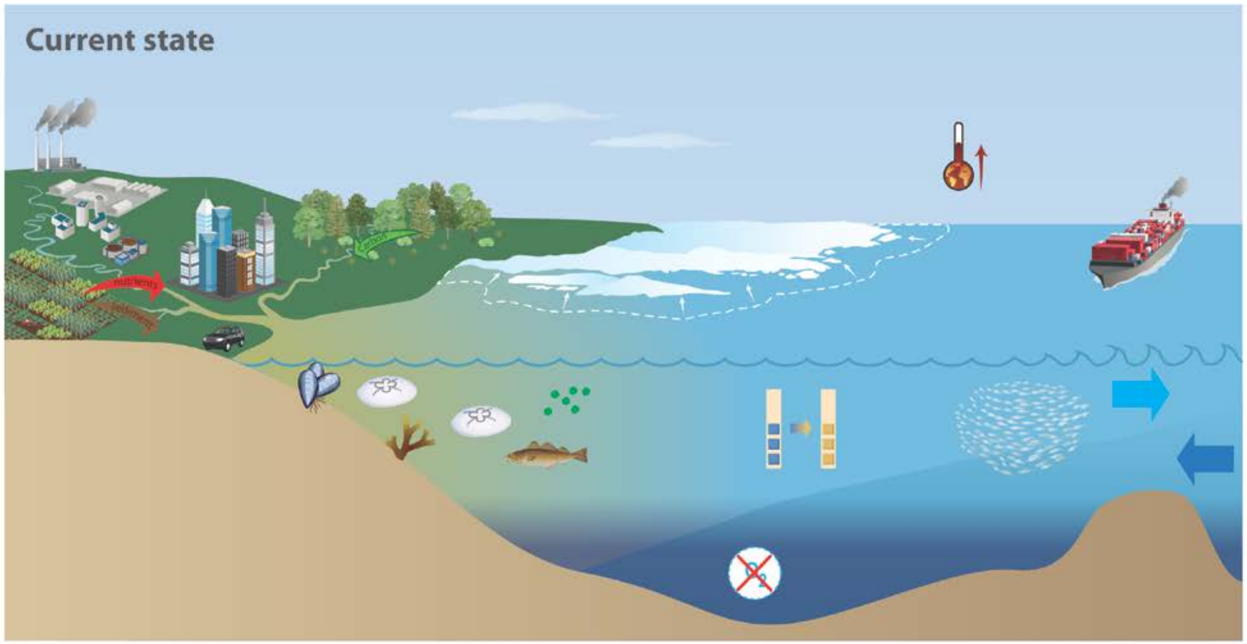
Management options: Marine acidification and hypoxia or?





Omstedt, Edman, Claremer, Frödin, Gustafsson, Humborg, Hägg, Mörth, Rutgersson, Schurgers, Smith, Wällstedt and Yurova (2012)

Summary: Current state



The Baltic Sea will become more acidic and more nutrients will leak into the system unless strong steps are taken to reduce CO_2 and nutrient loads.

- *Increasing air and water temperatures*
- *Decreasing sea ice*
- *Slight increase in marine acidification*
- *Declining water quality*
- *Annual cyanobacteria blooms*
- *Increasing forest growth & carbon transport*
- *Fair coastal biodiversity & health*
- *Anoxia*

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