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BALTIC SEA ACIDIFICATION BY SO_X AND NO_X FROM LAND AND SHIPPING: MODELLING OF PAST AND POTENTIAL FUTURE SCENARIOS

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Outline

- SO_X and NO_X:
  - Shipping emissions and regulations
  - Scrubbers for SO_X reduction
  - Terrestrial sources
- Baltic Sea modelling
  - Hindcast
  - Future scenarios

CO_2 is not the only acidic gas generated by ship motors

FUEL

Carbon
Sulphur

AIR

Oxygen
Nitrogen

MOTOR

EXHAUST

Carbon dioxide
Sulphur oxides (SO_X)
Nitrogen oxides (NO_X)

atmospheric reactions

Sulphuric acid
Nitric acid

Strong acid deposition

While the emitted CO_2 is distributed globally, much of the SO_X and NO_X is deposited within a few hundred km of the source. This is also true of other plume components

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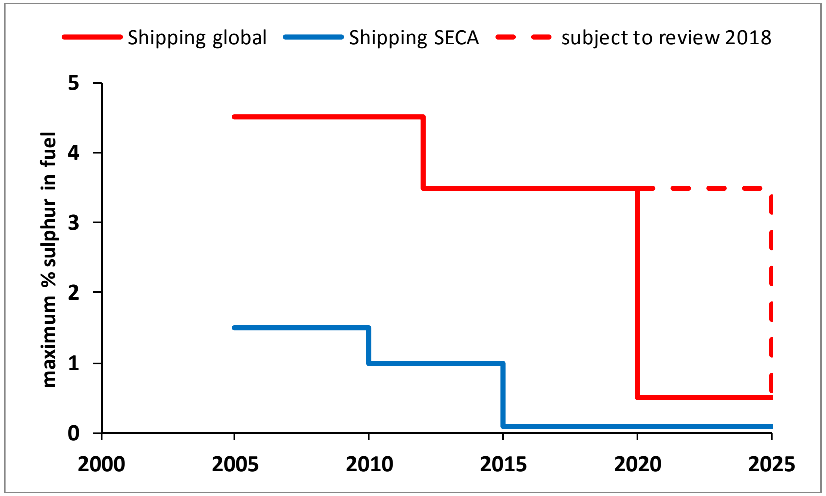
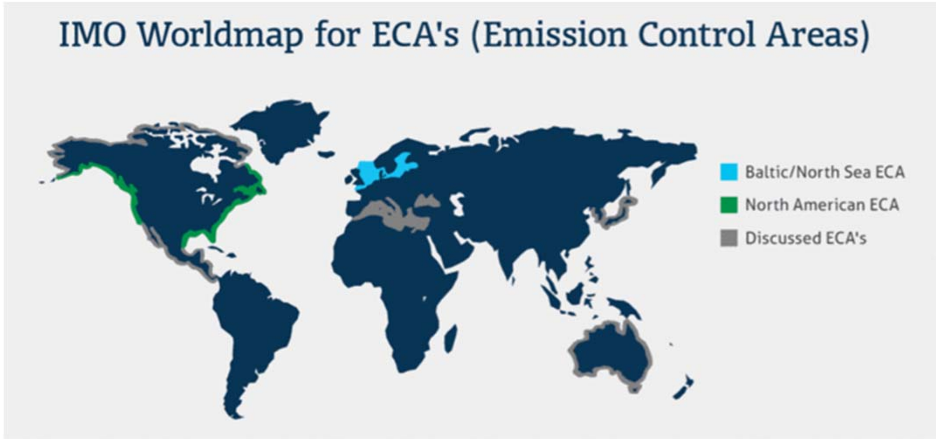
Emissions of SO_X are subject to increasing regulation, particularly in Sulphur Emission Control Areas (SECA)





SECA development is focused on heavily trafficked coastal areas. Controls on NO_X emissions, applying to new builds, are being introduced more slowly

Scrubbers add a new dimension to Ship Plumes

- The new SECA regulations with a maximum 0.1% sulphur in marine fuels, which came into effect in January 2015, have been extremely controversial in Northern Europe:
    - Changing from 1% sulphur to 0.1% doubles the fuel cost
    - The limited scope of SECA risks distorting competition (e.g. SECA in Northern Europe but not the Mediterranean)

- The shipping industry is responding in two ways:
    - Investment in new fuels such as Liquefied Natural Gas and methanol (mostly for new builds)
    - Investment in scrubbers to remove SOx from the smokestack gases

Shipping in SECA 2015: buy expensive fuel, or install a scrubber?

(a)

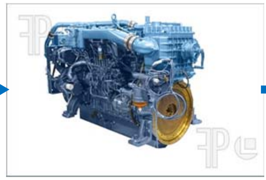
fuel < 0.1% S

low-sulphur emissions

Fuel costs double on switching from 1% S to 0.1% S

(b)

fuel 2-3% S



exhaust gas

scrubber

low-sulphur emissions

seawater

"scrubber water"

- acidic (pH 3)
- contains metals and other toxins

What happens to this??

Cheaper fuel than 1% S

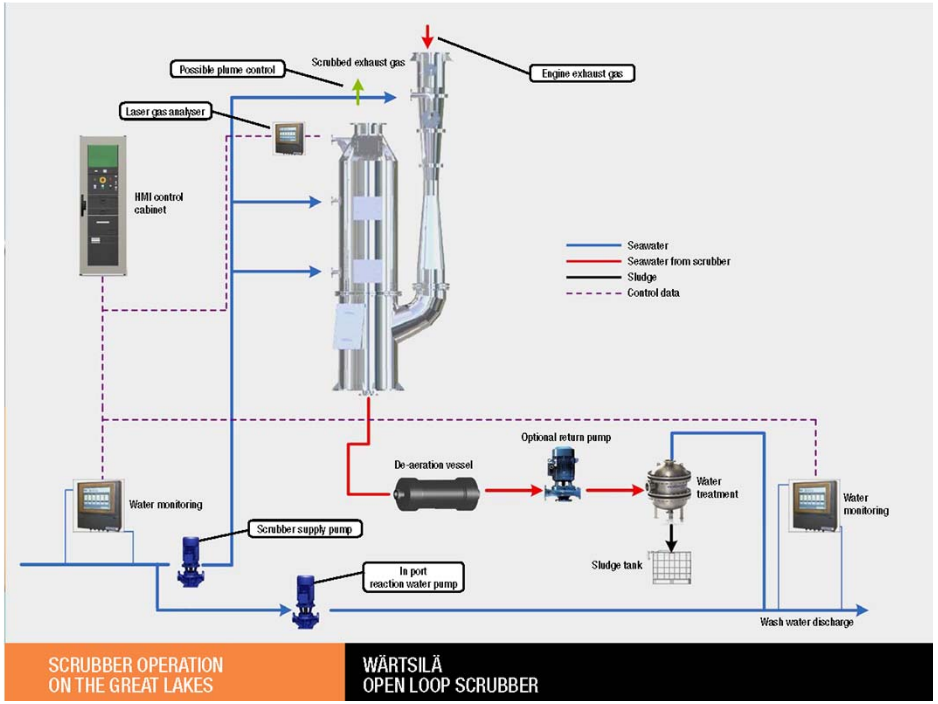
The scrubber absorbs SO_X in a fine spray of seawater

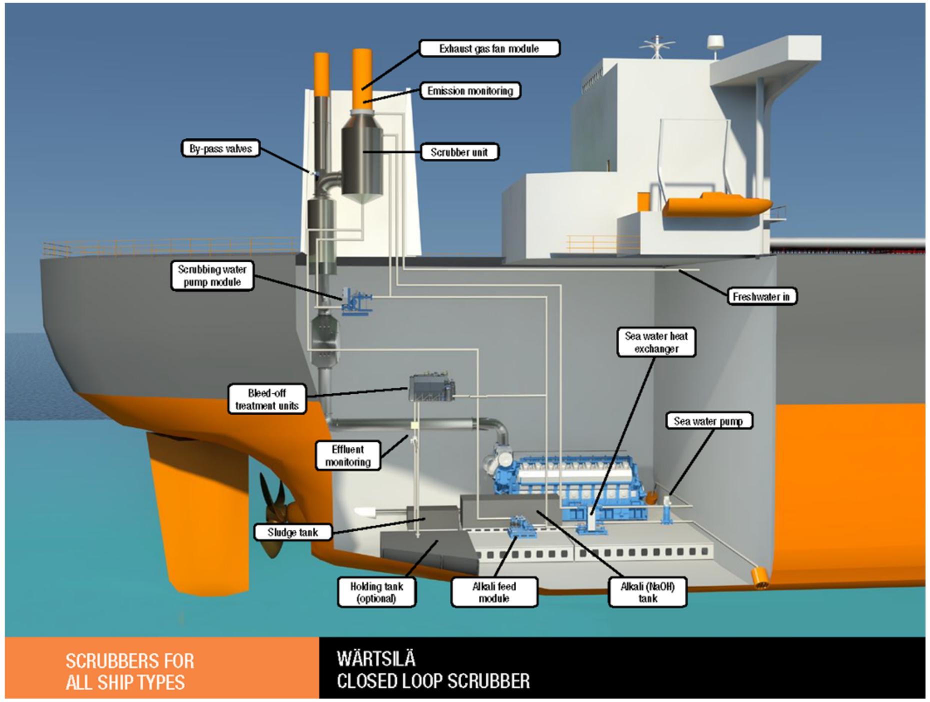
Scrubber operation

SO_X in the exhaust gases is absorbed by a counterflow of seawater:

$$SO_2 + H_2O = H_2SO_3 = H^+ + HSO_3^- \qquad SO_3 + H_2O = H_2SO_4 = 2\,H^+ + SO_4^{2-}$$

This results in water with pH ≈ 3





Open loop: acidified water is discharged

Closed loop: acidified water is neutralised

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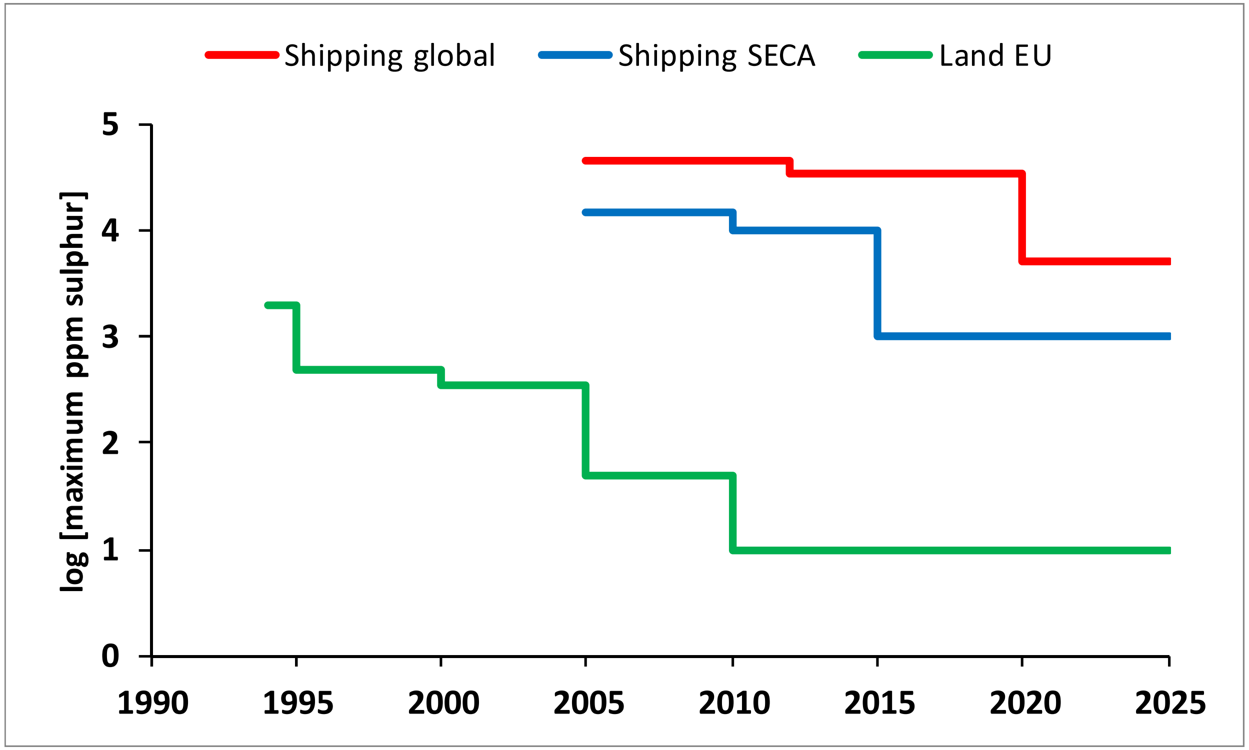
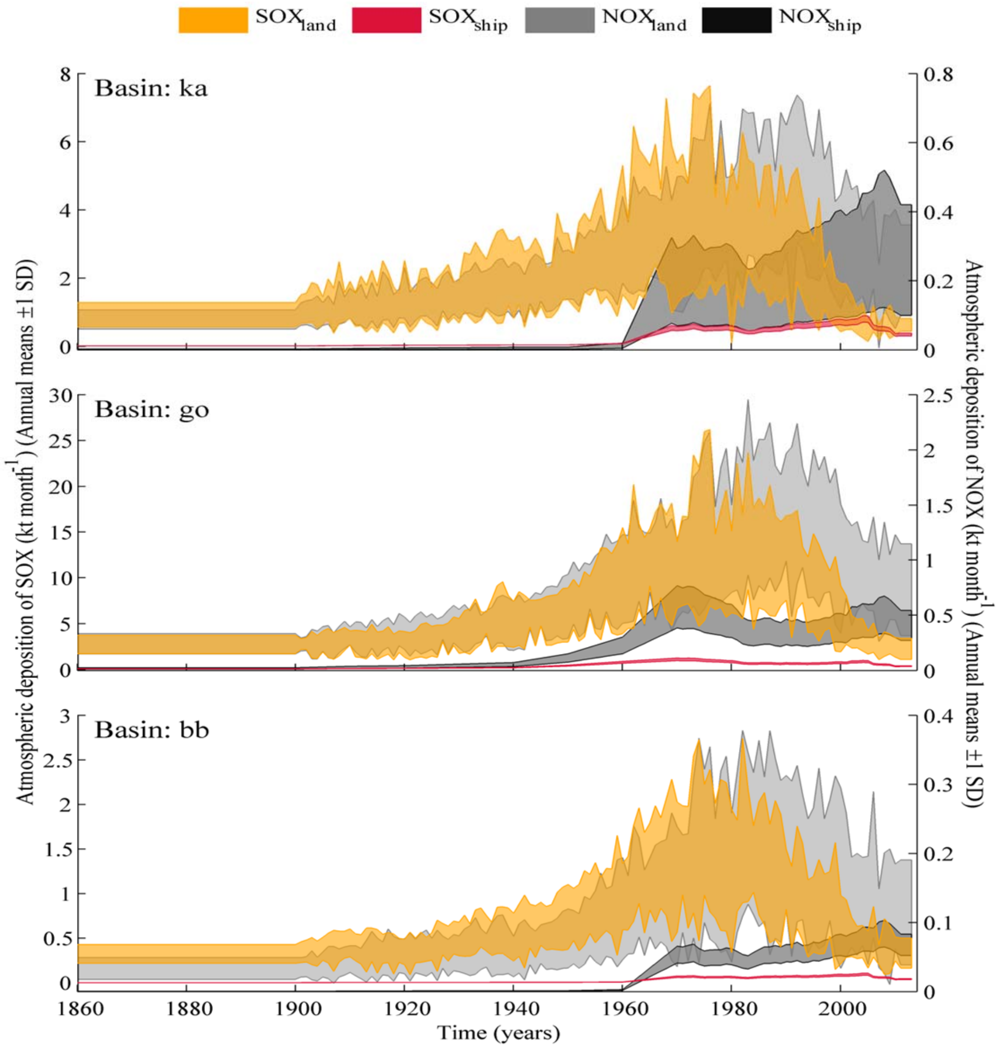
The development of marine SO_X regulations is very slow in comparison with land transport



Note the log scale!

Progress in regulating marine NO_X emissions is even slower

Sources of SO_X and NO_X in the Baltic Sea

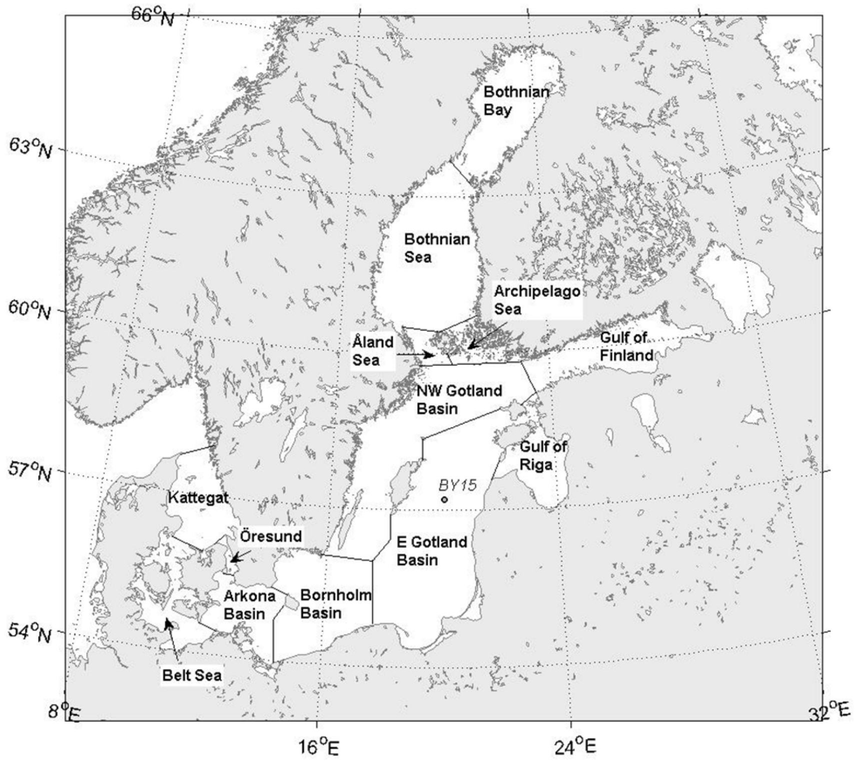


Reconstructed annual atmospheric deposition of SO_x and NO_x from land and sea within ± one standard deviation for the three model sub-basins Kattegat (ka), Eastern Gotland Basin (go) and Bothnian Bay (bb) (Omstedt et al., 2015)

Hindcast modelling

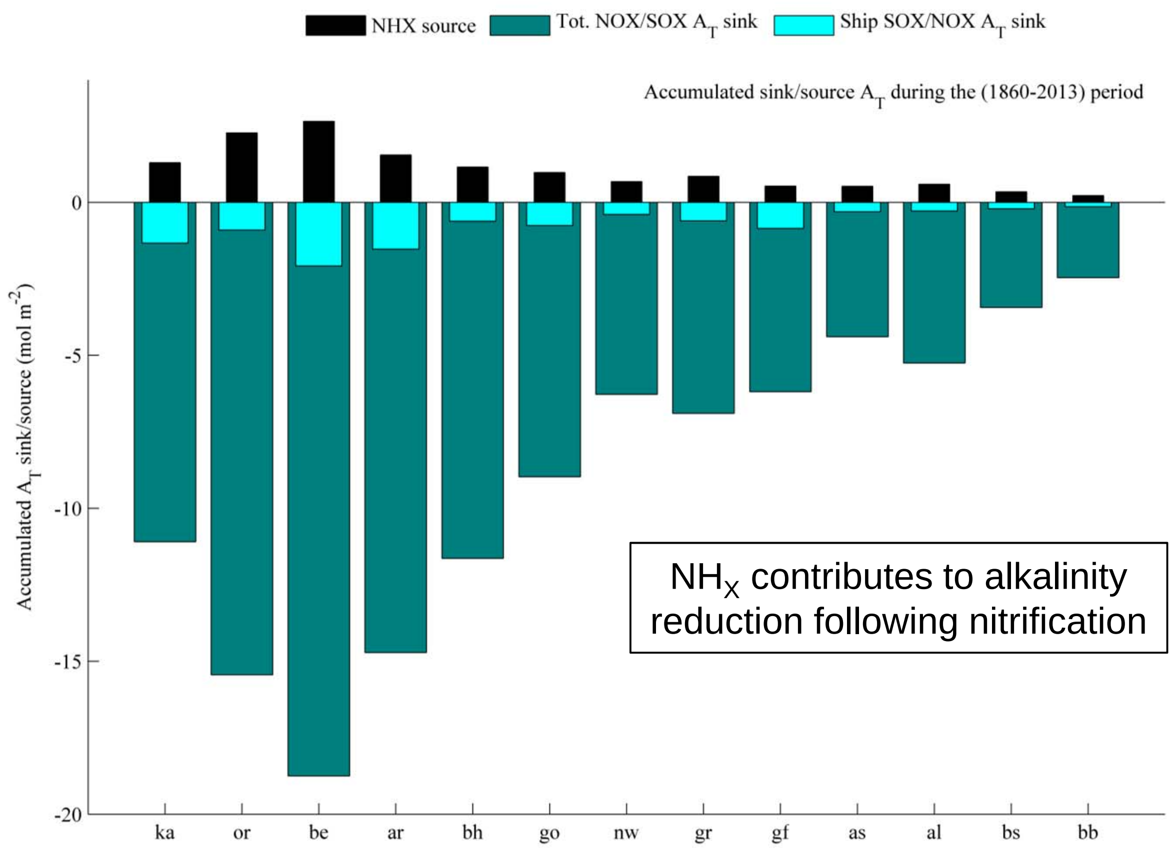
The PROBE model, developed by Omstedt and colleagues, divides the waters from the Kattegat to the Bothnian Bay into 13 basins. The model has been optimised with the help of historical data.

Atmospheric modelling uses terrestrial and marine emission data, together with a chemical transport model to calculate deposition of SO_X and NO_X



Our modelling results are presented as differences from a "base case" where there is no deposition of SO_X or NO_X

Hindcast: shipping's contribution to alkalinity reduction



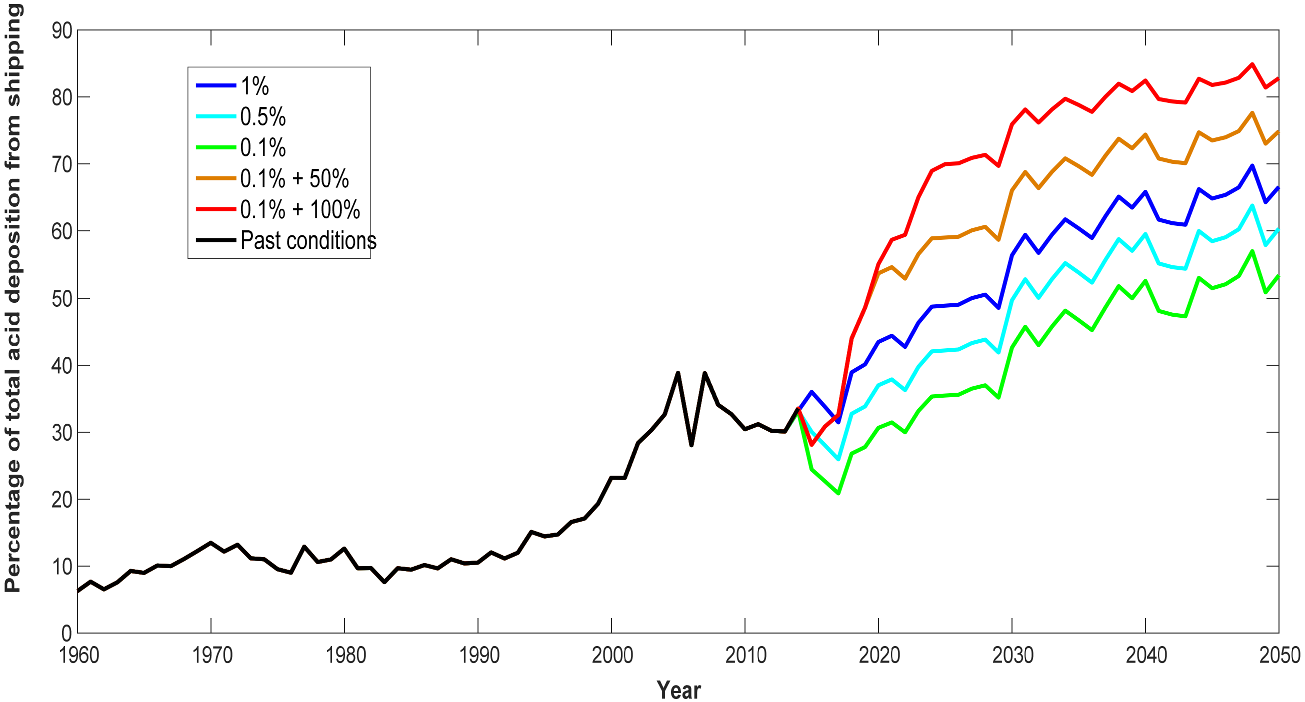
The accumulated sink/source of total alkalinity during the 1860-2013 period based on atmospheric deposition of NH_x, NO_x/SO_x total emissions and from shipping only (Omstedt et al., 2015)

Modelling of future scenarios

Scenario no.	Shipping not using wet scrubbers		Shipping using wet scrubbers	
	% of total	% S in fuel	% of total	% S in fuel
1	100	1.0	0	
2	100	0.5	0	
3	100	0.1	0	
4	50	0.1	50	2.7
5	0		100	2.7

- Climate forcing follows RCP 4.5
- Traffic increases by 2.5% per year (cargo). 3.9% per year (passengers)
- No additional NO_X regulation is assumed

Future scenarios: shipping will become a major source of alkalinity reduction



The proportion of strong acid deposition to the Baltic Sea due to shipping in the five future scenarios (Turner et al., in preparation)

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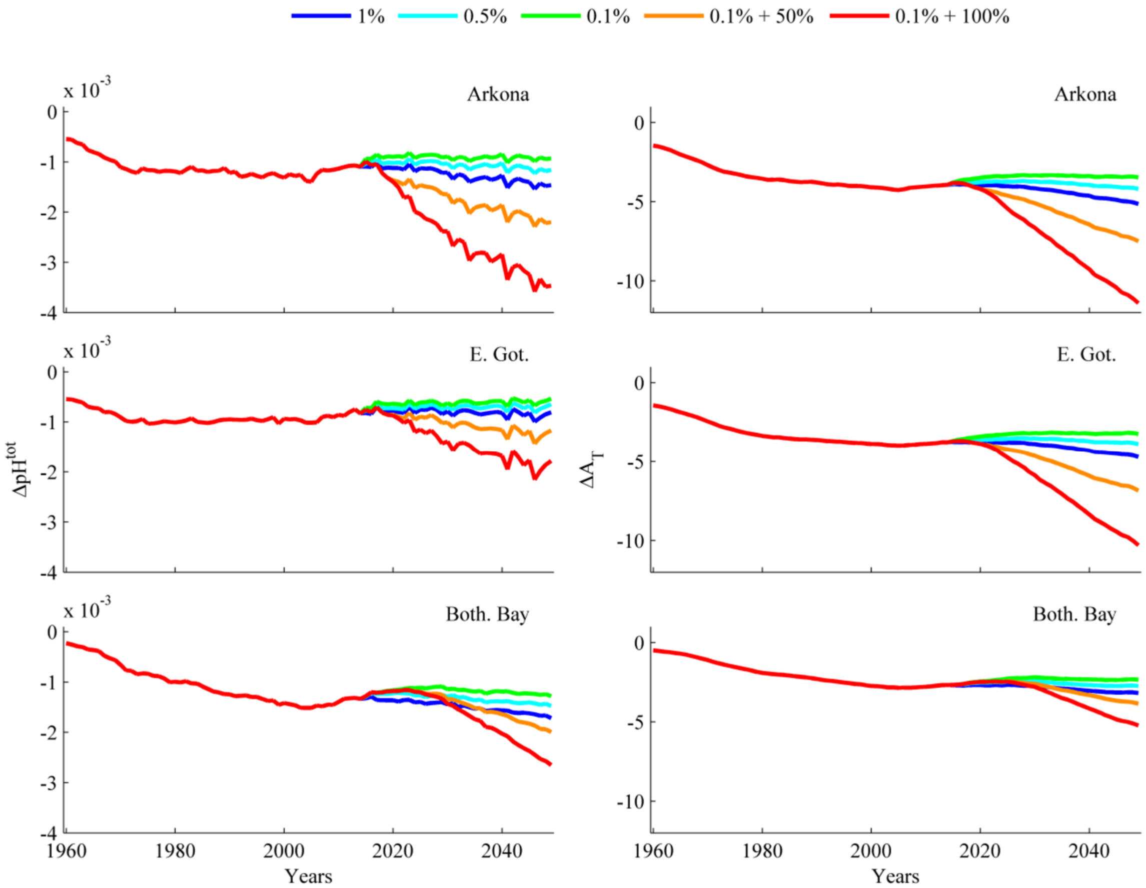
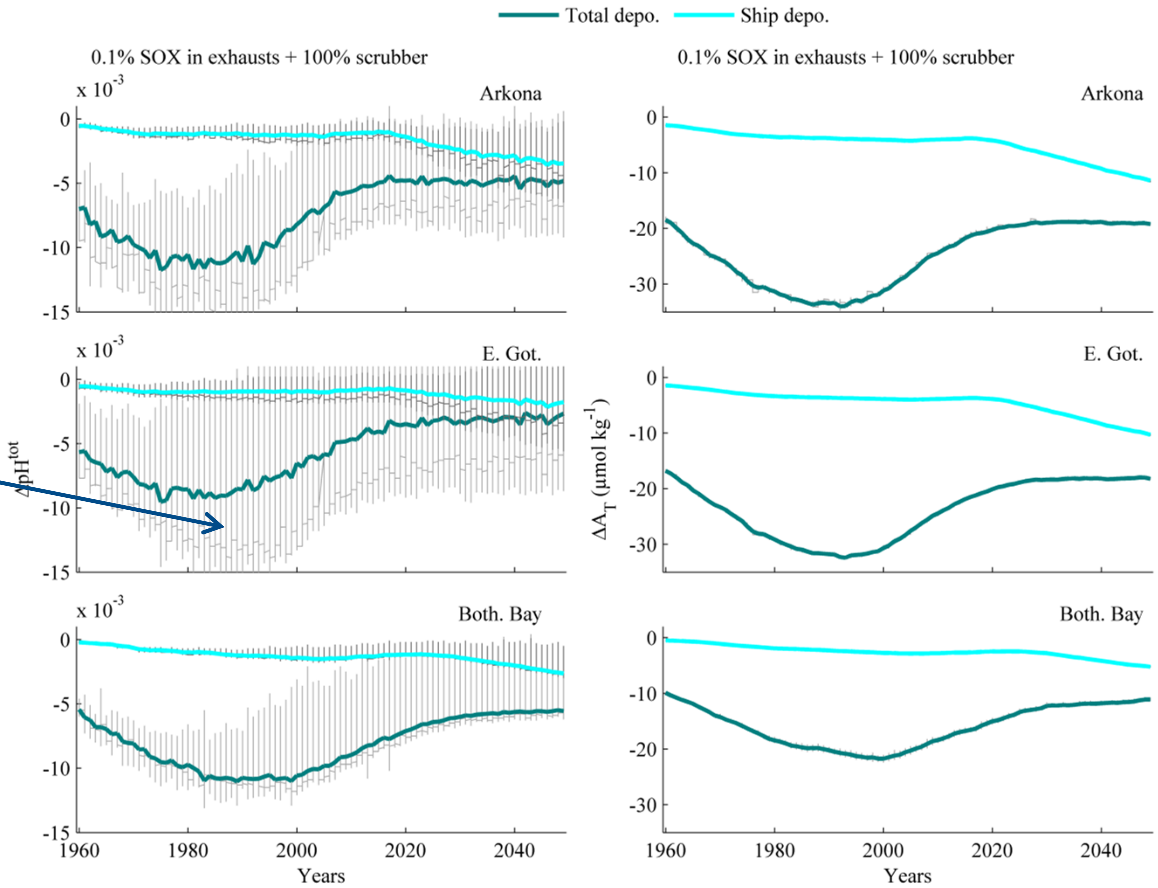
Future scenarios: acidification from scrubbers



Modelled future changes in pH and alkalinity due to shipping in surface waters of the Arkona Basin, East Gotland Basin and the Bothnian Bay, according to the five future scenarios (Turner et al., in preparation)

Future scenarios: acidification from scrubbers

Annual pH variations



Modelled future changes in pH and alkalinity in surface waters of the Arkona Basin, East Gotland Basin and the Bothnian Bay, assuming that all ships use open-loop scrubbers (scenario 5) (Turner et al., in preparation).

Future perspectives

- Acidification is probably not the major environmental consequence of scrubber operation
- In addition to the low pH, publicly available analyses from early scrubber systems show that the outlet water contained high concentrations of metals such as copper and zinc, as well as toxic organic compounds
- Research is needed on the environmental consequences of these releases, particularly in heavily trafficked areas
- The results of such research should be used to develop improved regulation of scrubber use