A new perspective at the ship-air-sea-interface: the environmental impacts of exhaust gas scrubber discharge

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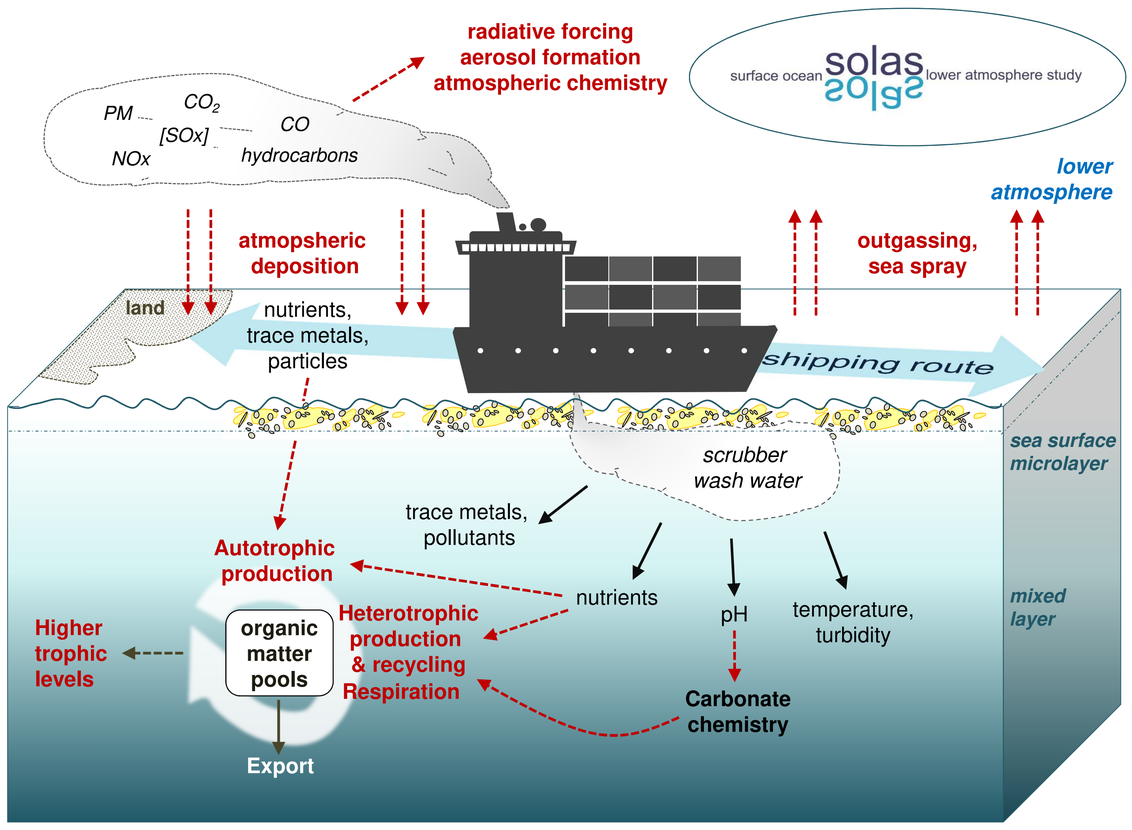
Ship emissions and the air-sea interface

Growing concern about environmental impacts (marine ecosystems to human health) of **increased international maritime transport**.

~80% of shipping fuel is low-grade, high sulfur resulting in **significant emissions** of carbon dioxide (CO_2), sulfur oxide (SO_x), nitrogen oxide (NO_x), heavy metals, particles (PM), and organic matter (OM) to the atmosphere.

- CO_2, SO_x, NO_x affect air quality and climate via **atmospheric chemistry and radiative forcing**.
- Aerosols (including PM and OM), heavy metals, SO_x, NO_x **deposit to and dissolve in the surface ocean.**
- Discharge of pollutants to the ocean may reach the atmosphere by **outgassing and sea spray formation**.

The **increasing use of exhaust gas cleaning systems** ('scrubbers') may lead to other, yet unascertained and unquantified, impacts on the marine environment.



Legal aspects of ship emissions and scrubbers

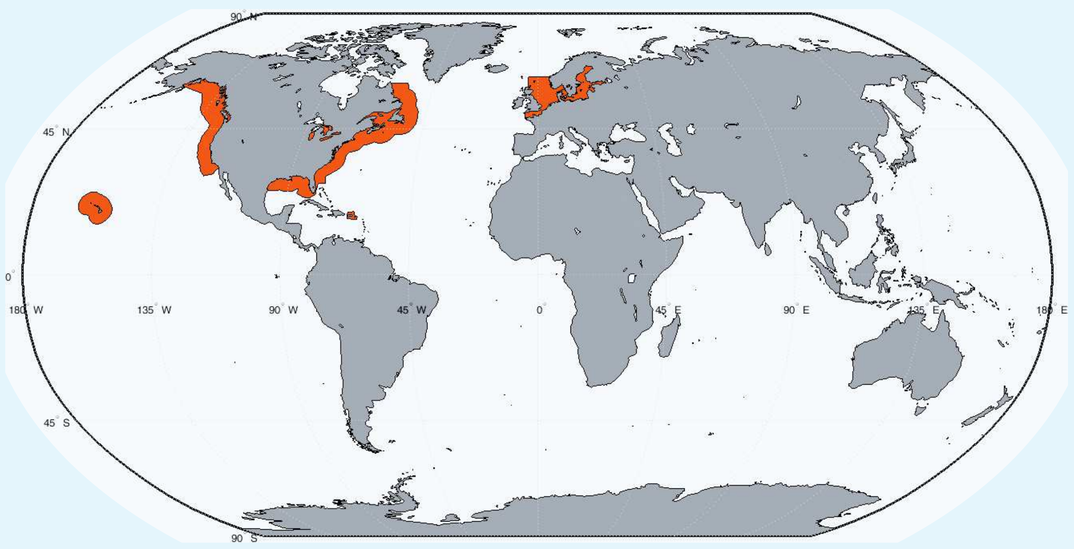
Global and regional efforts to reduce the environmental impact of ship emissions:

International regulations on ship emissions:

1982	UN Convention on Law of the Sea, Article 192-196: source-based approach, central role of flag states
1992	Annex VI of the International Convention for the Prevention of Marine Pollution from Ships (MARPOL)
2008	Revision of Annex IV (NO_x Technical Code, ECAs)
2011	Revision of Annex IV (control of greenhouse gases)
2012	European Union's Sulfur Directive 2012/35

- Although **the atmosphere and the ocean** are tightly coupled, international law and regulation treats both very differently.
- MARPOL Annex VI Regulation 4 states that **scrubbers can be used** if SO_x in exhaust ≤ emissions from engines using low-sulfur fuel.
- Numerous **guidelines** for levels of monitoring and compliance of scrubber wash water were released by MEPC.

Emission control areas (ECAs)



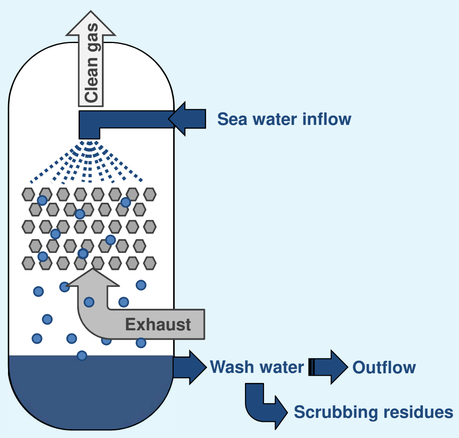
Five sulfur **emissions control areas** (orange): Baltic Sea, the North Sea, North American area (most of U.S. and Canadian coast), and the U.S. Caribbean Sea area.

Sea area	Date of regulations	Sulfur limits (% m/m)
Emission control areas (ECAs)	Before 1 July 2010	1.5%
	1 July 2010 - 1 Jan 2015	1.0%
	After 1 Jan 2015	0.1%
Other sea areas	Before Jan 2012	4.5%
	1 Jan 2012 - 1 Jan 2020	3.5%
	After 1 Jan 2020	0.5%

ECAs are not limited to SO_x, but can also deal with PM and NO_x.

Options for emission reductions

Exhaust gas cleaning systems operating in open loop mode, ('scrubbers'), are low-cost alternatives to high-cost, low-sulfur fuel.



Wet scrubber technology:

SO_x dissolves in seawater/freshwater spray and is removed from the exhaust gas:

$$SO_2\ (gas) + H_2O + {}^1/_2\,O_2 \rightarrow SO_4^{2-} + 2H^+$$

$$HCO_3^- + H^+ \rightarrow CO_2 + H_2O$$

The resulting wash water has **very low pH** and **elevated temperature**.

Scrubber residues: Contaminants include polycyclic aromatic hydrocarbons (PAHs), heavy metals, and nitrate, but in practice amount and composition of scrubber residues is not well known.

Alternative technologies (removing SO_x and/or NO_x): novel engine technologies, exhaust gas recirculation, fuel conversion or switching, selective catalytic reduction, wetpacs, humid air motor, fuel emulsifier.

Research priorities

Monitoring:
- Increased **global monitoring of ship emissions** and effect of emission reduction technologies.
- Improved **spatial and temporal measurements of pollutants** along shipping lanes/in ports.
- **Comparison** of alternative emission reduction technologies.

Experimental studies:
- Increased **understanding of the ecological and biogeochemical effects** of wash water discharge from shipping (considering seasonally- and spatially-variable phytoplankton communities, cumulative effects and interactive effects with other environmental parameters).

Forecasting:
- Improved **modelling of ship emissions** and the use of scrubber technology in the future.

Legislation:
- Improved aspects of **implementation, compliance, inspection and enforcement**.
- Increased **standards of scrubbers**, **identify new ECAs** and establish more **port reception facilities for advanced waste management of scrubber residues** (sludge)**.**

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