# Impacts of Aerosol Depositions from Ship Emissions on Marine Primary Productivity, Biological Community Composition and Biogeochemical Cycling

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# Aerosols, Phytoplankton and Ships

Ship aerosols are rich in inorganic components that can promote phytoplankton growth (e.g. N, S, Fe) or that may be toxic to the microbiota (e.g. Cu).

Each year, ocean-going vessels emit between 1.2 and 1.7 million metric tons (Tg) of particulate matter (PM10), values that are comparable to the 2.1 Tg of PM10 emitted annually from road traffic.

Photo: mfame.guru

# Aerosols, Phytoplankton and Ships

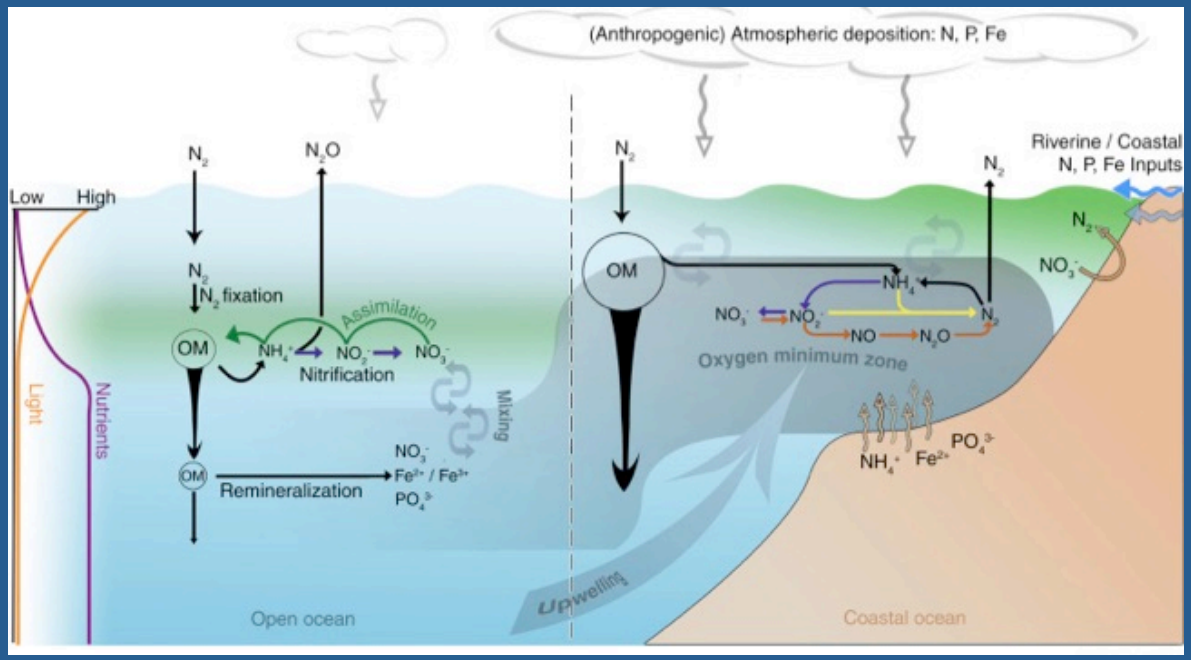



Image Credit: Current Biology

Atmospheric aerosols are important sources of nutrients and trace metals to the ocean, affecting phytoplankton growth, marine productivity, and ultimately carbon sequestration rates.

# Aerosols, Phytoplankton and Ships

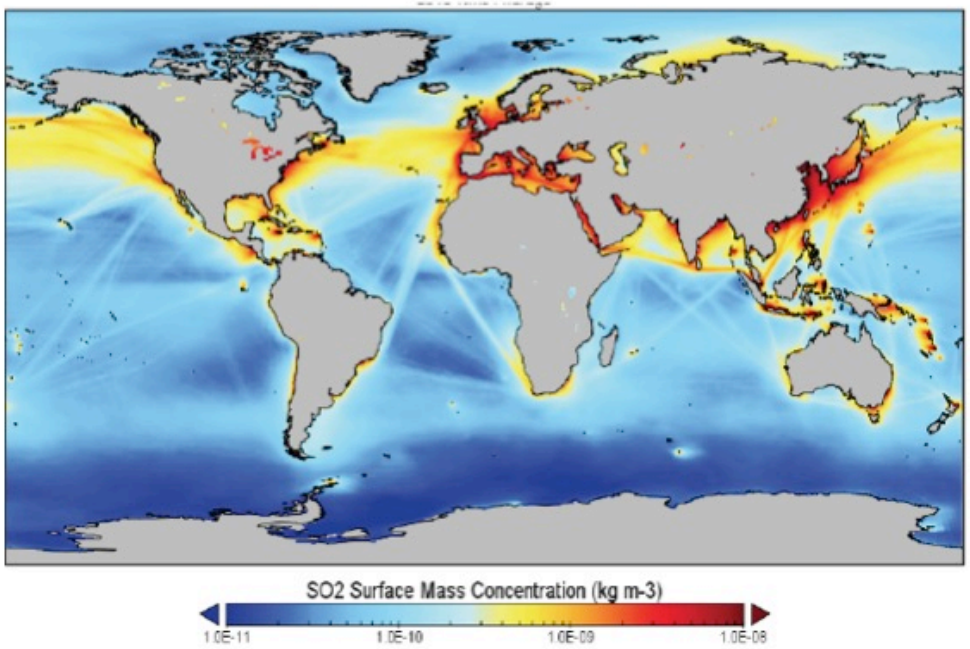
Marine phytoplankton represent a major driver in global biogeochemical cycles and their ability to thrive is sensitive to changes in nutrient availability.

With the exception of two modeling efforts that have indicated significant regional fertilizing effects of Fe and Nitrogen additions from ship emissions, the overall impacts of emissions from maritime transport onto phytoplankton have not yet been studied.

# Satellites, Phytoplankton, Ships

## Satellite Data/ Remote Sensing

Can be used to measure **changes in Chlorophyll-a** using MODIS-Aqua Level 3 **in response to changes in ship emissions using $SO_2$ and $NO_2$ observations** from OMI, MERRA-2, TROPOLI

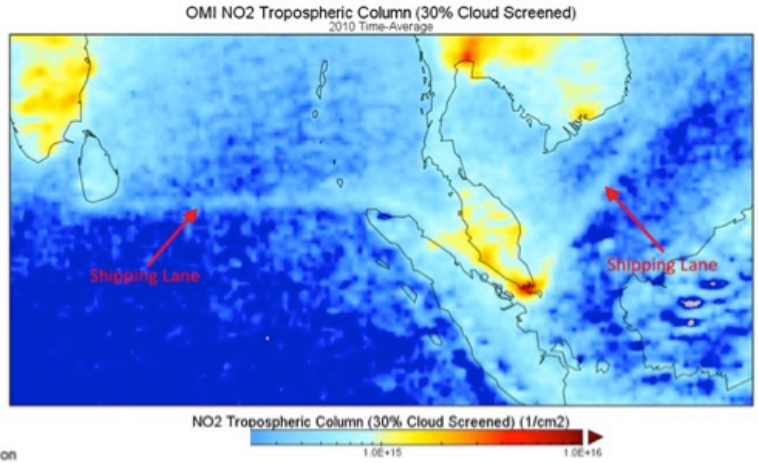


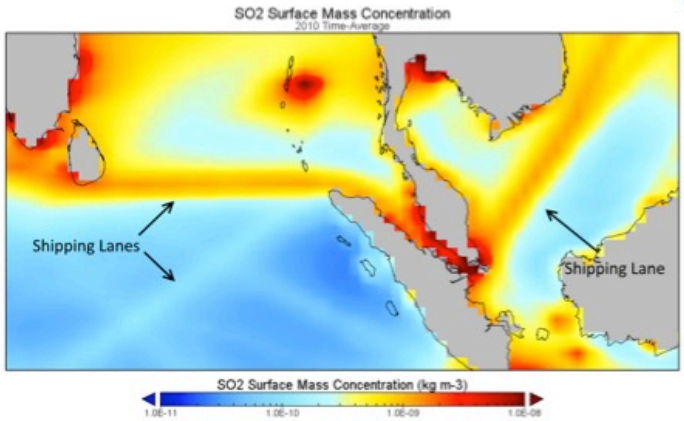

*2010 time-averaged $SO_2$ column mass density (kg. $m^{-3}$ log scale) from MERRA-2. Acker (2017)*

# Satellites, Phytoplankton, Ships

## Remote Sensing Case Studies

Grid-based Chla-$SO_2$ and $NO_2$ correlation analyses can be narrowed to discernible shipping lanes such as the ones shown here




*From NASA Goddard Earth Sciences Data and Information Services Center*

# Satellites, Phytoplankton, Ships

To this date, no published studies using MERRA-2 data to track and/or quantify ship emissions exist. Here, we explore correlations between several remote sensing products, (e.g. MODIS-Aqua Level 3 Chlorophyll-a (Chl-a) Concentration, MERRA-NOBM, OMI NO2/SO2 data, MERRA-2 SO2 data), as well as bottom-up AIS ship traffic inventories to elucidate connections between ship emissions and impacts on marine phytoplankton.

# Goal, Hypotheses, Approach

Research Goal: generate a global composite map that quantifies the relative impact of ship aerosols on marine biogeochemical cycles, primary production rates and carbon export rates in different ocean regions and seasons, now and in the future.

H1) Compared to other sources of nutrients and trace metals, ship emissions cause a significant positive fertilization effect on phytoplankton communities in oligotrophic marine biomes (e.g. center of ocean gyres) and in high nutrients low chlorophyll (HNLC) areas;

H2) compared to other sources of nutrients and trace metals, ship emissions cause a negligible to negative fertilization effect in naturally eutrophic marine biomes (e.g. coastal upwelling zones and areas sustained by aeolian sources) and this effect varies seasonally in both intensity and geographic reach.

# Goal, Hypotheses, Approach

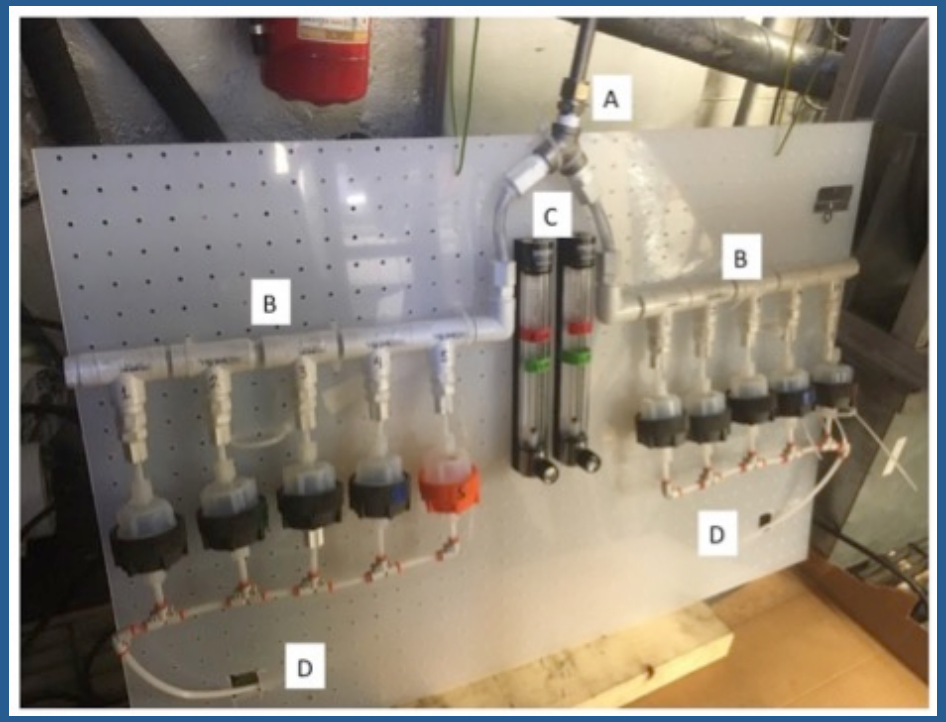
Two-fold Approach:

1) Incubation Experiments to measure the response of phytoplankton to the deposition of aerosols from ship emissions (coastal and open water sites)

2) Remote Sensing Observations (case studies over shipping lanes vs.outside shipping lanes)

Then, model relative impact of ship emissions (vs. other sources of nutrients) by compiling regional and seasonal response curves from 1 and 2 above

# Ship Emissions Collections




Ship emission aerosols collected at testbed engine lab (4-stroke Volvo Penta D3-110 HP marine diesel engine,Chalmers University, Sweeden) equipped with a wet scrubber (see diagram at the bottom of this section)

Three fuel types tested (scrubber OFF)

1% sulfur oil (HGO)
0.1% sulfur (MGO)
0% sulfur (HVO biodiesel)

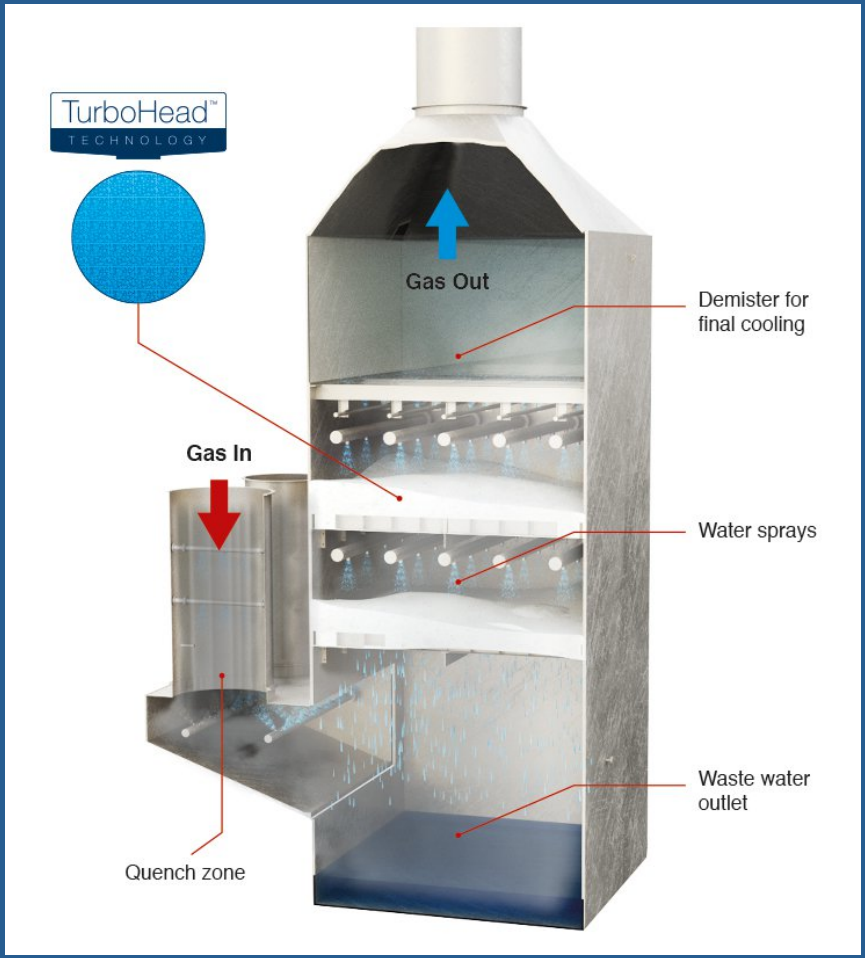
Custom made sampler (above) collects suspended particles directly from engine's exhaust system (via A in picture above) onto trace metal clean Teflon filter membranes (housed in Teflon holders, B). System is powered by two vaccum pumps (not shown in picture, connected via D). Constant 1.5- 2 liters per minute inflow was controlled by gauges (C).

# Ship Emissions Collections


A10 filter membrane is the Sampling Blank from offline filter holder (collecting lab ambient air)


A1 Filter membrane shows particles collected on filter holder that was inline

# Ship Emissions Collections




Scrubber water samples from additional run with HGO were also acquired using a wet scrubber system similar to the one depicted in the diagram here

# Incubation Experiments



Two pilot mesocosm coastal incubation experiments were conducted in summer of 2019: one in Newport Beach, Southern California Bight, USA, and the other at the Kristineberg Marine Research Station (KMRS) in the Skagerrak strait, Sweden.

# Incubation Experiments

Natural seawater was collected from surface layer (5 m), filtered to remove grazers (200 µm mesh) placed in trace metal
clean polycarbonate bott les (250mL), incubated in flow-through tank for 48 hours.

Treatments included addition of ship emission aerosols extracted from filters (various fuel types) scrubber water containing aerosols from HGO (1%S fuel) nutrients (i.e. positive controls), and no additions (controls)

# Incubation Experiments

The following measurements were taken at time zero, 24 hr and 48hrs:

Chlorophyll a (fluorometrically on a Trilogy fluorometer by Turner Designs, pictured on the right)

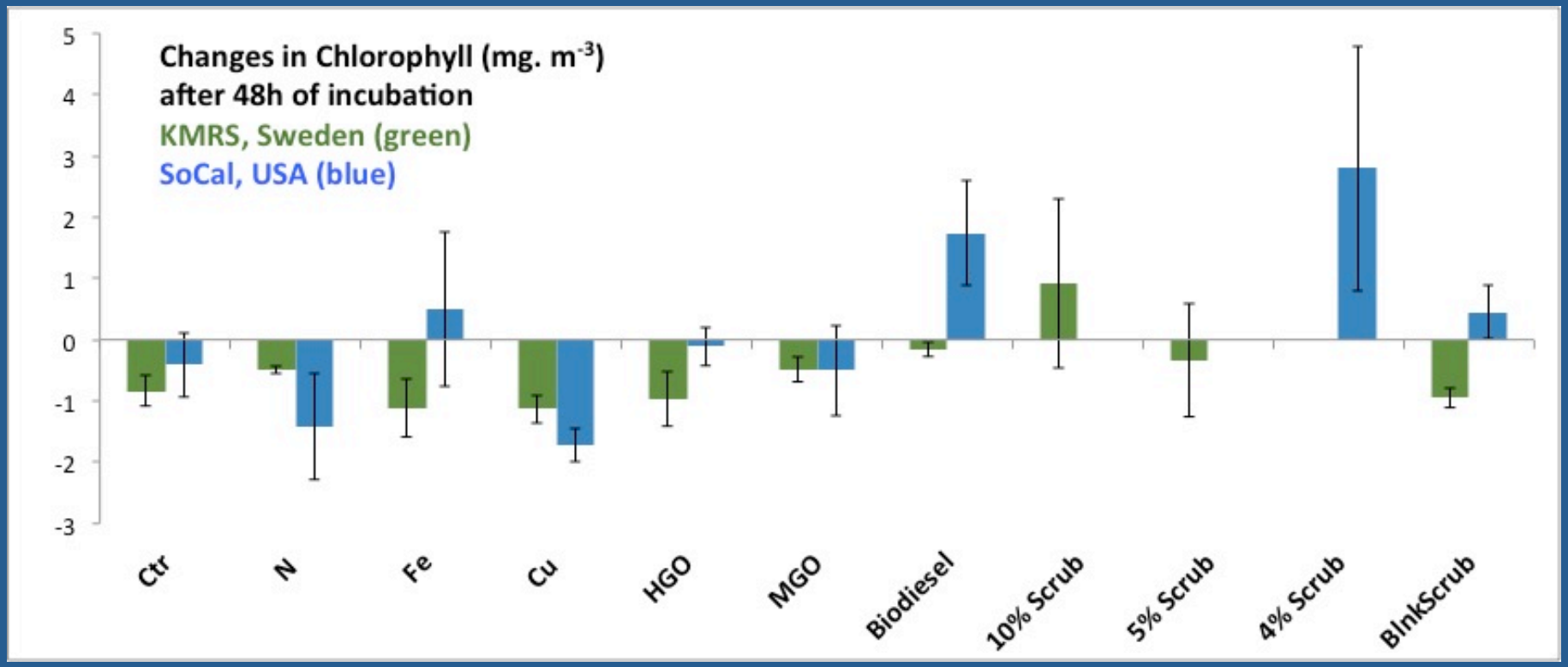
Taxa composition and size structure of marine phytoplankton populations (via Utermoehl settling chamber method for taxonomy and cell counts using microscopy and flowcytometry)

Rates of biological uptake of dissolved nutrients and trace metals (ICPMS)

# Preliminary Results, Next Steps

Results from Pilot Incubation Experiments

Changes in extracted Chlorophyll a concentration in seawater measured before and after 48h of incubation measured with a Turner Designs Trilogy Fluorometer:



# Preliminary Results, Next Steps

Results from Pilot Incubation Experiments
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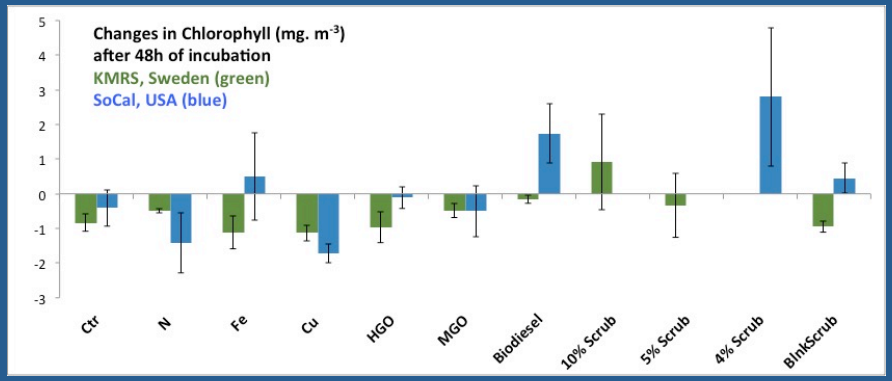
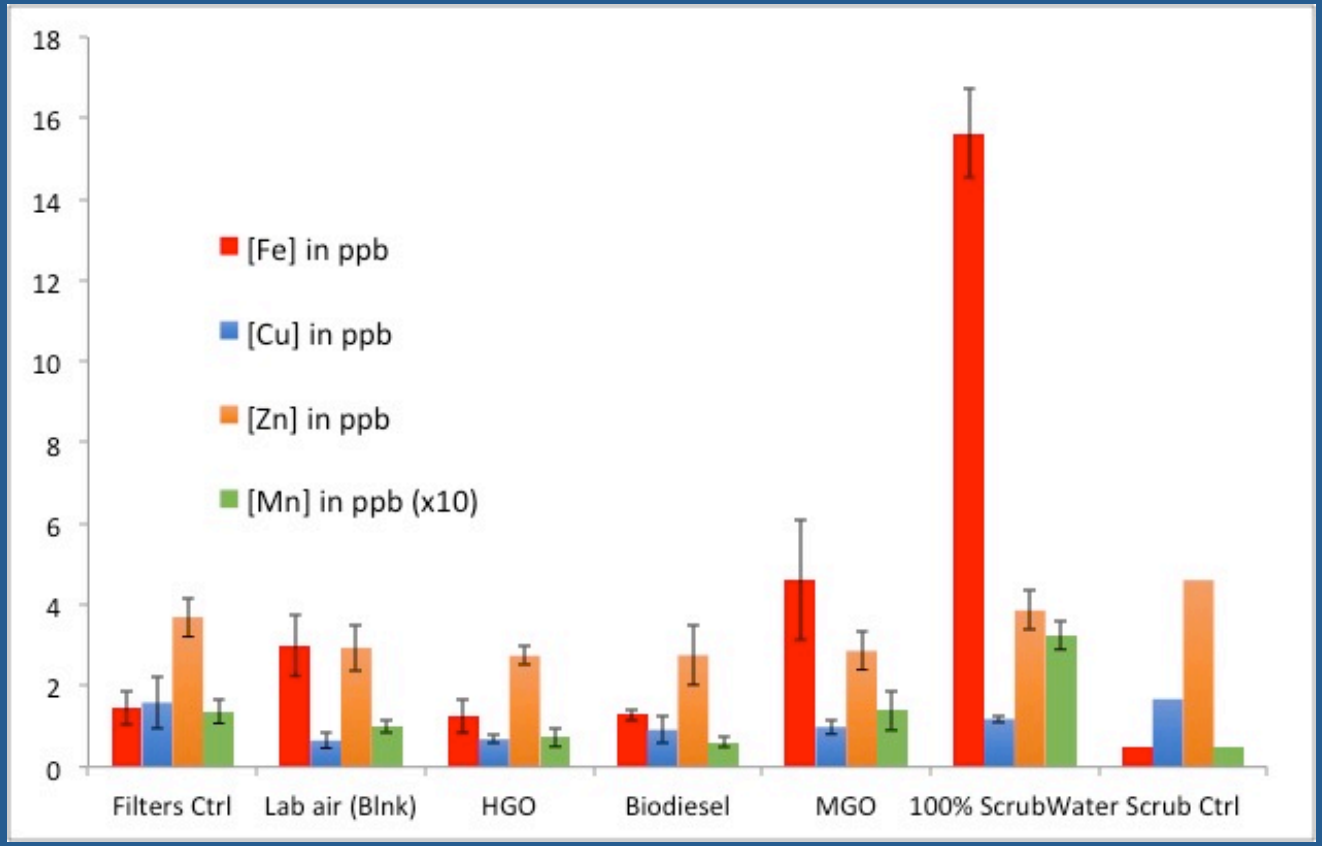



- indicate fertilizing effect of scrubber water additions in both locations

- reveal differences in the effects caused by controlled additions of nutrients (i.e. N, Fe, Cu) and by the addition of aerosols from various fuel types depending on the seawater source location.
- Specifically, added iron and aerosols from biodiesel caused positive effect in SoCal but negative in the KMRS), which suggests different limitation regimes.

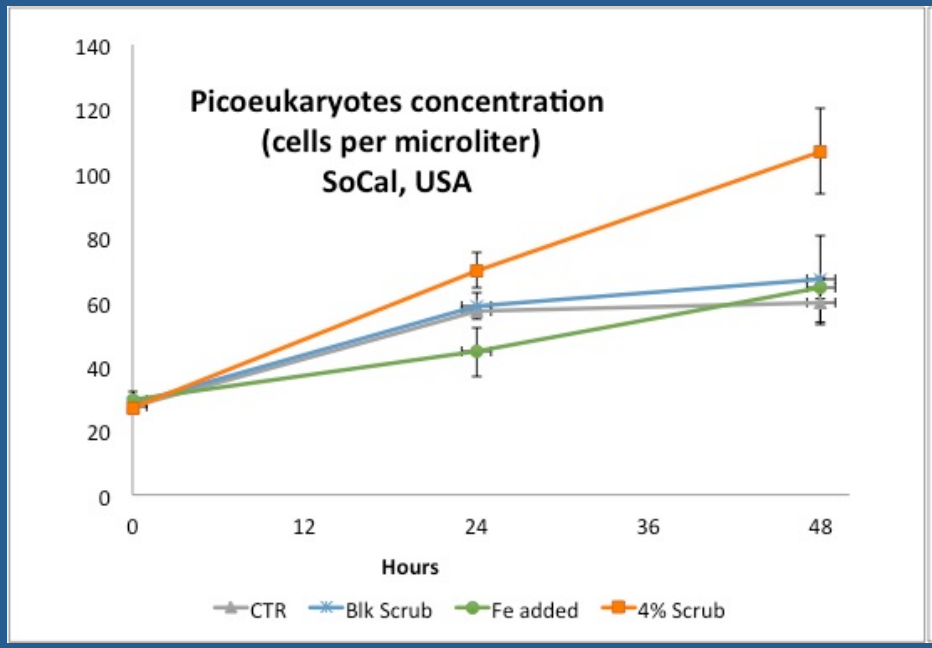
# Preliminary Results, Next Steps

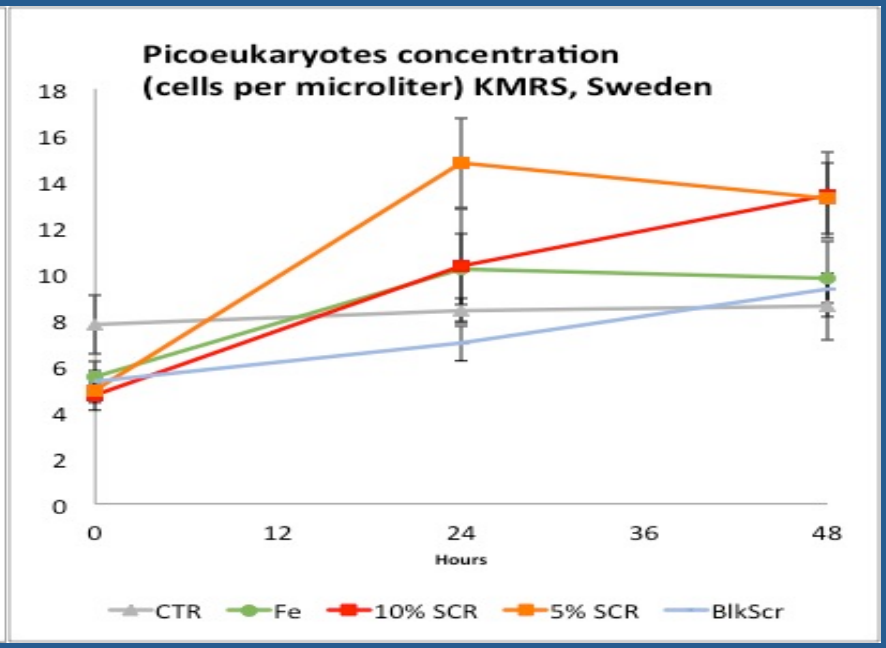
Trace Metal concentration results show significantly higher content of Iron (Fe) and Manganese (Mn) in scrubber water samples (vs. filters and controls)

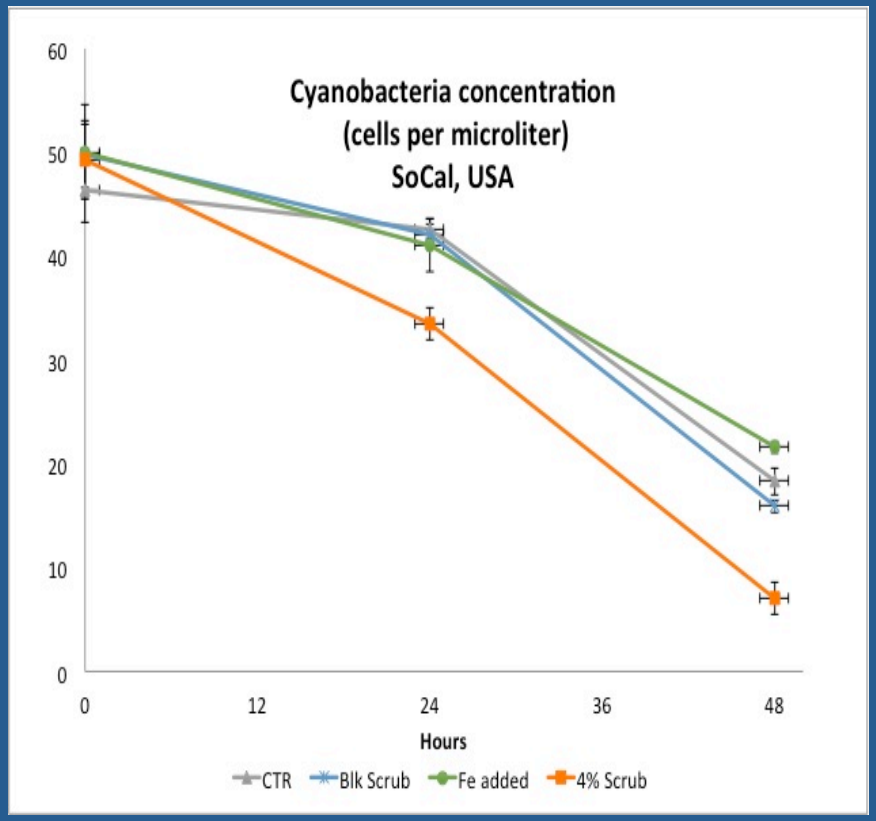


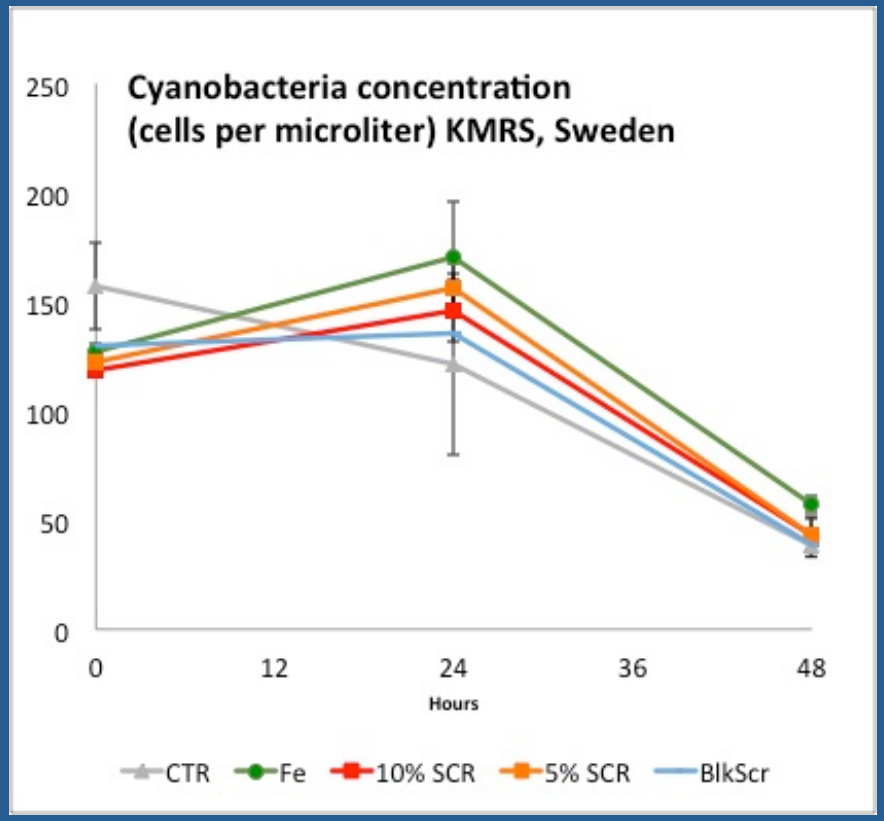
Flowcytometry results from pilot incubation experiments:

In scrubber water addition treatments (orange and red lines below), picoeukariotes grew while cyanobacteria died. This indicates that groups were affected differently by scrubber water additions (possible trigger for shifts in community composition?) Results from added Fe treatments (+1 uM Fe, green lines below) were comparable to controls (grey and blue lines) for both phyto groups, thus high Fe content in scrubber water may not have been the only factor causing changes in Chla and/or in composition responses



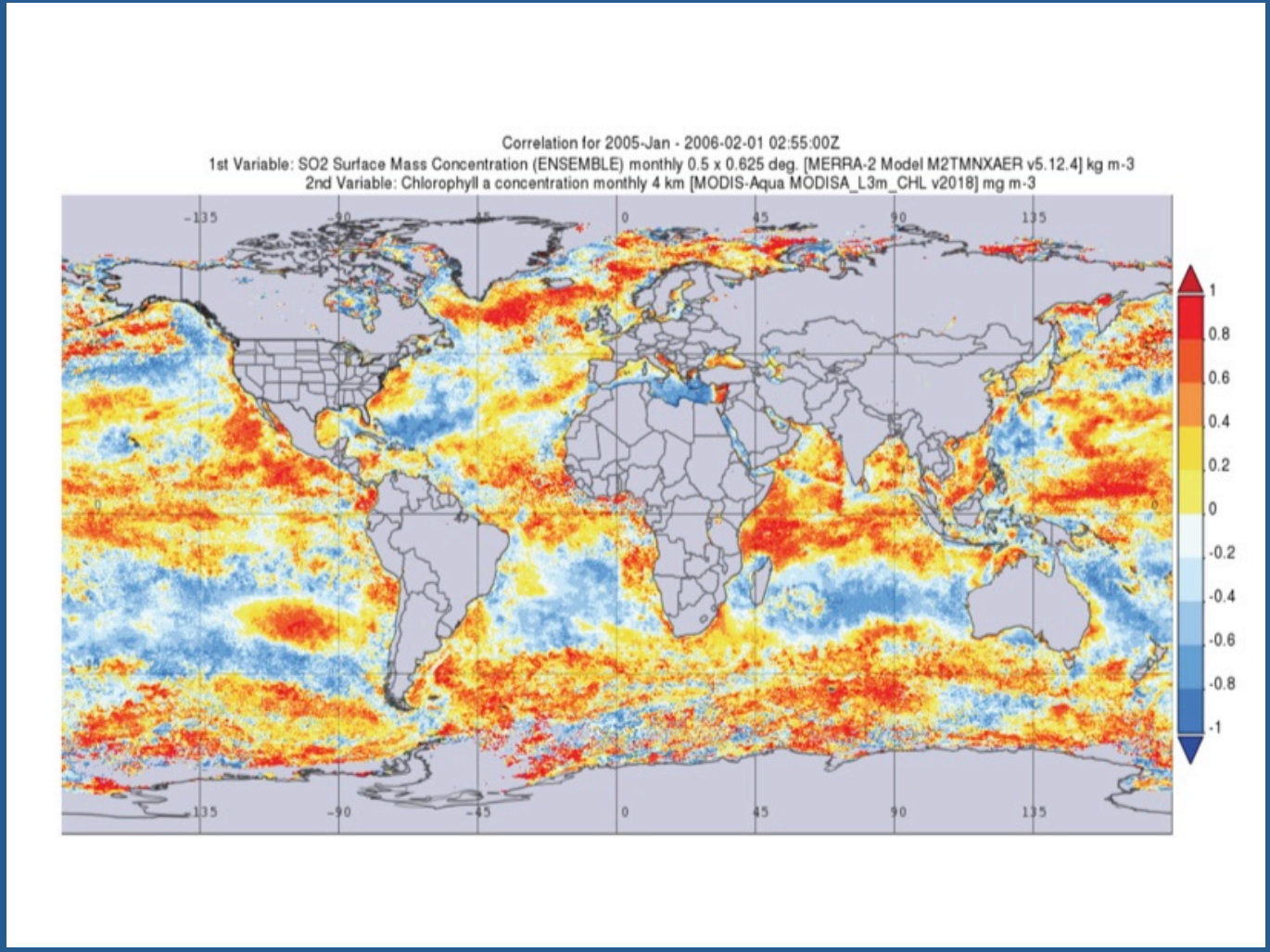




Cyanobacteria concentration
(cells per microliter)
SoCal, USA
60
50
40
30
20
10
0
0
12
24
36
48
Hours
CTR
Blk Scrub
Fe added
4% Scrub


Cyanobacteria concentration
(cells per microliter) KMRS, Sweden
250
200
150
100
50
0
0
12
24
36
48
Hours
CTR
Fe
10% SCR
5% SCR
BlkScr

Remote Sensing Component

Illustration of correlation map that can be generated using MODIS and MERRA-2 data (note: this is a simple linear regression using no corrections, masks or calibrations)

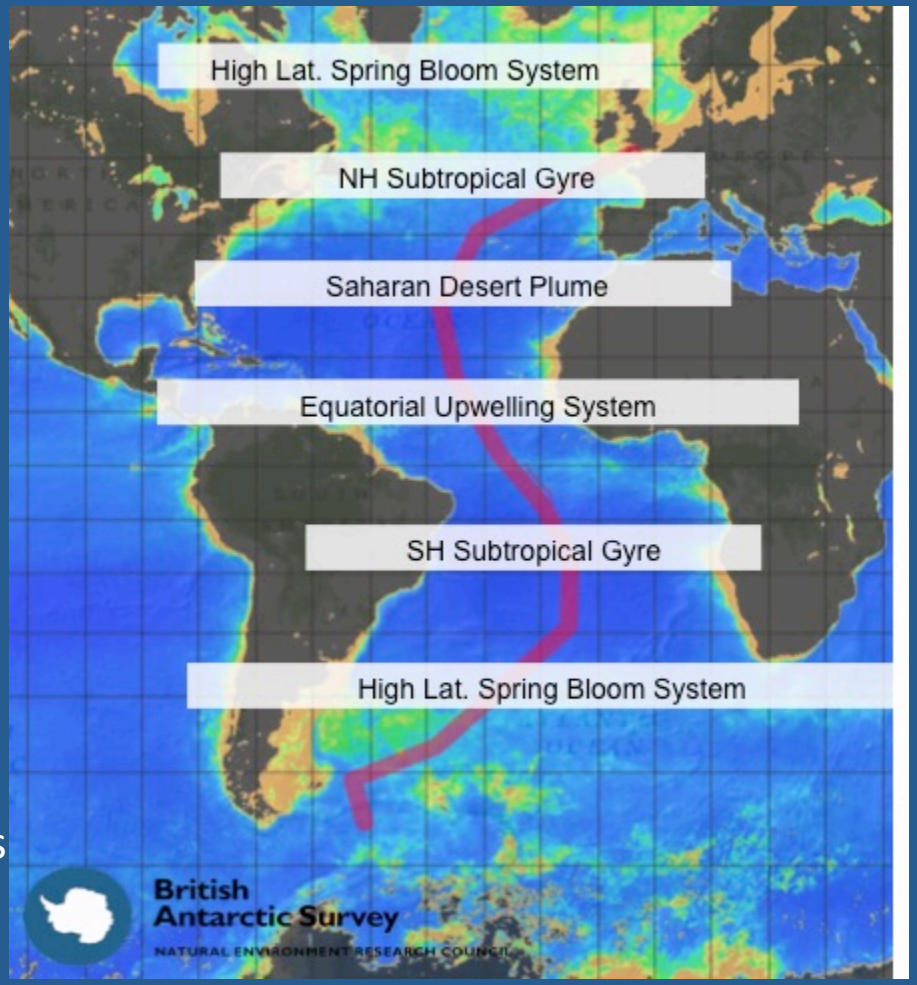


NEXT STEPS:

1) Conduct full-scale incubation experiments (1 per month for a year at the same location): determine seasonal variability in responses of phytoplankton community to ship emission aerosol additions.

2) Conduct shipboard incubation experiments with water from offshore areas: determine spatial variability in response of phytoplankton communities from various biomes to ship emission aerosol additions.

3) Implement correlation analysis techniques to remote sensing case studies: generate spatial masks of affected shipping lanes and conduct new series of grid-based correlation analyses to elucidate relationships between ship emissions and marine primary productivity using remote sensing data




LOOKING FOR COLLABORATIONS!!!
UPCOMING CRUISES INTO HNLC/ OLIGOTROPHIC AREAS?
PLEASE TAKE ME ALONG!!!

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