The Dimethylsulfide (DMS) cycle in the ocean-atmosphere system and its response to anthropogenic perturbations

Silvia Kloster
Cornell University

H. Feichter, E. Maier-Reimer, K. Six, P. Stier, E. Roeckner, P. Wetzel, M. Esch
Max Planck Institute for Meteorology, Hamburg, Germany

Motivation

CLAW: Charlson, Lovelock, Andreae and Warren, 1987

- Radiation budget
  - Global temperature
    - Climate feedbacks
      - Phytoplankton abundance and speciation
        - Marine ecology
          - Atmosphere
            - Sulfate aerosol
              - SO$_2$
                - DMS
                  - Cloud condensation nuclei
                    - Cloud albedo
                      - Radiation budget
                        - Global temperature
                          - Climate feedbacks
                            - Phytoplankton abundance and speciation
                              - Marine ecology
                                - Atmosphere
                                  - Sulfate aerosol
                                    - SO$_2$
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                                        - Cloud condensation nuclei
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positive/negative feedback?

Cloud albedo

Radiation budget

Global temperature

Climate feedbacks

Atmosphere

Cloud condensation nuclei

Sulfate aerosol

SO$_2$

DMS

Ocean

Phytoplankton abundance and speciation

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DMS

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Atmosphere

Ocean
Atmosphere GCM
ECHAM 5

Ocean GCM
MPI-OM

COUPLER
(OASIS)

Sulphur chemistry &
Aerosol model
HAM

DMS flux to the atmosphere

DMS cycle
biogeochemistry model
HAMOCC5

Dust deposition
MPI-OM/HAMOCC5

- Marine carbon cycle (Maier-Reimer, 1993)

- NPZD ecosystem model (Six and Maier-Reimer, 1996, Maier-Reimer, 2005)
  - simulates the plankton dynamic
  - compartments: Nutrients, Phytoplankton, Zooplankton, Detritus
  - Limiting Nutrients: Phosphate, Nitrate and Iron

- DMS cycle in the ocean (Kloster et al., 2005)
HAMOCC5/DMS cycle ocean

- DMS cycle in the ocean

[Diagram showing the cycle with nodes: DMS, DMSPd, Phytoplankton DMSP, and connections to Ocean and Atmosphere. Key processes include flux to the atmosphere, senescence, photo-oxidation, microbial consumption, and zooplankton grazing. Factors such as Temperature, Light, and Nutrients are also indicated.]
HAMOCC5/DMS cycle ocean

- DMS cycle in the ocean (Kloster et al., 2006)

**DMS production:**

\[DMS_{prod} : \text{depending on the destruction of diatoms and coccolithophorids} \]
\[f(\text{export of silicate, export of calcium carbonate})\]

**DMS decay:**

\[DMS_{UV} : \text{photo-oxidation} \]
\[f(\text{solar irradiance})\]
\[DMS_{bac} : \text{microbial consumption} \]
\[f(\text{temperature})\]
\[DMS_{flux} : \text{flux to the atmosphere} \]
\[f(\text{temperature, wind speed})\]

\[
\frac{d[DMS]}{dt} = DMS_{prod} - DMS_{bac} - DMS_{UV} - DMS_{flux}
\]

The parameterization has been optimized to fit observed DMS sea surface concentration measurements reported in the Kettle and Andreae, 2000 database (more than 15,000 observations).
DMS cycle in a warmer climate

Transient climate simulation (IPCC 4AR simulation)

simulation period: 1860 - 2100

- solar and volcanic forcing (1860-2000)

- greenhouse gases forcings
  2001-2100: SRES A1B scenario

- aerosol and aerosol precursor emissions (BC, POM, SO$_2$) from the NIES emission scenario
  2001-2100: SRES A1B scenario

- DMS emissions are calculated interactively (Kloster et al., 2007)
Transient climate simulation

Global mean temperature deviation from 1961-1990

2m temperature

Observations
Global trend

CLAW: warmer climate → increase in the DMS sea surface concentration
This study: warmer climate → decrease in the DMS sea surface concentration

What happens in the ocean?
DMS sea surface concentration

annual mean

1861/1890

2061/2090 - 1861/1890

-10%
DMS sea surface

annual mean

1861/1890

2061/2090 - 1861/1890

-10%
Response to climate change

- DMS sea surface concentration
  -
- Phytoplankton
  -
- Nutrients
  -
- Mixed layer depth
  -
- Stratification
  +
- Sea surface temperature
  +
DMS sea surface concentration

annual mean

1861/1890

2061/2090 - 1861/1890

-10%
minimum MLD

annual mean

1861/1890

2061/2090 - 1861/1890

-6%
minimum MLD

MLD

Solar radiance $I_0$

euphotic zone

Depth [m]

100
50
150

MLD

MLD +

minimum MLD

2061/2090 - 1861/1890

-6%
Summary/Global trends

DMS flux [Tg(S)/year]

-10%

DMS burden [Tg(S)]

-3%

DMS sea concentration [nanomol/l]

-10%

DMS flux [Tg(S)/year]

-10%

DMS lifetime [d]

+7%
Conclusion

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positive/negative feedback?

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Cloud albedo

Radiation budget

Global temperature

Climate feedbacks

Atmosphere

Ocean

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Ocean

Sulfate aerosol

SO$_2$

DMS

Cloud condensation nuclei

DMS

SO$_2$
Conclusion

This study:

• changes in the ocean dynamic control the DMS production and DMS sea surface concentration, like:
  
  • enhanced ocean stratification $\Rightarrow$ reduced nutrient transport
  • enhanced summer mixed layer depth in the Southern Ocean $\Rightarrow$ reduced light exposure of phytoplankton

which lead to a reduction of the DMS sea surface concentration in a warmer climate

• Changes in the atmospheric DMS concentration are not only controlled by changes in the DMS emissions, but also by changes in the DMS lifetime in the atmosphere.

Future Plans

Fire at the intersection of the global carbon and water cycles

- Improved fire algorithm in CLM-CN
- How does the fire strengthen the feedback between the carbon cycle and the climate system during the 21st century
- Fire interact with the climate through:
  - atm. CO2 concentration
  - aerosol concentration
  - albedo; via deposition of BC on snow and sea ice
  - ecosystem carbon and energy fluxes; mediated by aerosol diffuse radiation, changes in albedo and ozone concentrations