Factors controlling DMS production in a global prognostic model

Meike Vogt[1,2], Sergio Vallina[3], Laurent Bopp[4], Erik Buitenhuis[2], Corinne Le Quéré[2,5], Peter Liss[2]

[1] Max-Planck-Institut für Biogeochemie, Postfach 100164, D-07701 Jena, Germany [2] School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK
[3] Department of Marine Biology and Oceanography, Institut de Ciencies del Mar de Barcelona, Passeig de la Barceloneta, 37-49, Barcelona, 08003 Spain [4] Laboratoire des Sciences du Climat et de l'Environnement, Orme des Merisiers, F-91191 Gif-sur-Yvette, France [5] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK

ABSTRACT:

Dimethylsulphide (DMS) is a climatically active trace gas produced from phytoplankton Dimethylsulphoniopropionate (DMSP) and transferred to the atmosphere. We study the factors controlling DMS production and the impact of climate change on DMS emissions. We construct a global prognostic DMS model that reproduces all intermediate steps from DMSP production within the phytoplanktonic cells to DMS emissions at the ocean surface. We investigate the influence of ecosystem composition and environmental parameters on DMS production patterns and the coupling behaviour of DMS and chlorophyll. The model gives results of reasonable magnitude for annual averages of DMS, but cannot yet reproduce the observed decoupling between DMS and chlorophyll-a in the low latitudes. The introduction of a further phytoplankton functional type (Phaeocystis) and a larger sensitivity to environmental stress such as light will improve model efficiency.

1. OCEANIC DMS CYCLE

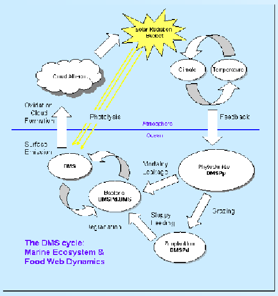
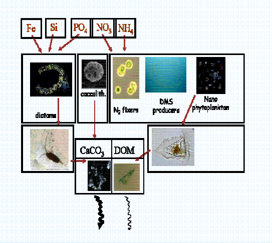


Figure 1: The oceanic DMS cycle

Dimethylsulphide (DMS) is a volatile sulphur compound produced by marine phytoplankton and transferred to the atmosphere. DMS affects the radiative properties of the atmosphere by increasing the concentration of cloud condensation nuclei. It is the main natural source of sulphate aerosols and the major route by which sulphur is recycled from the ocean to the continent. In 1987 Charlson et al. postulated links between DMS, atmospheric sulphate aerosols and global climate. Here, we study the oceanic production of DMSP, an algal precursor of DMS, and DMS itself within the framework of a global biogeochemical ocean model (Le Quéré et al., 2005).

Main factors controlling DMS production:
- Ecosystem composition
- Intracellular production of precursor DMSP
- Active exudation
- Grazing by zooplankton
- Bacterial consumption of DMSP
- Bacterial consumption of DMS
- Cleavage by DMSP-lyase
- Photolysis

2. THE MODEL



We use a global biogeochemical model, comprising 3 phytoplankton functional types, nanophytoplankton, diatoms and coccolithophorids and two zooplankton types, micro- and mesozooplankton, limited by light, Fe, P and Si. Between these compartments, a number of 27 different tracers are transported. The underlying physical model is the OPA-ORCA global circulation model (Madec et al., 1998).

Figure 2: Tracers for the Dynamic Green Ocean Model Planktom9.0

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3. SUMMER PARADOX

In the model, DMS and chlorophyll are more tightly coupled than observed for low latitudes.

Coupling of DMS and chlorophyll-a is sensitive to grazing and to the parametrisation of phytoplanktonic DMS(P) production as a function of environmental stress.
The bacterial yield of DMS from DMSP has also shown to be sensitive to (changes in) environmental conditions.

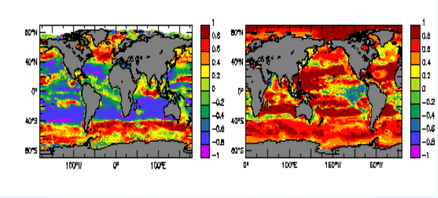

Figure 3: Correlation of DMS (Kettle et al.,2000) and chlorophyll-a. (Seawifs) and modelled parameters

In the open ocean there are two clearly separated coupling zones for DMS. In the high latitudes, DMS and chlorophyll-a are tightly coupled. In the Tropics, DMS and chlorophyll-a are anti-correlated. During the summer, maximum DMS concentrations lag several months behind maximal chlorophyll-a concentrations. This is known as the "summer paradox" (Toole and Siegel, 2004) and has been described from samples from the Bermuda Atlantic Time-series Station (BATS). We investigate the reasons for the decoupling behaviour of DMS. With the current structure and set of parameters, the model cannot (yet) reproduce the decoupling behaviour. Modelling observed effects as described in Vila-Costa et al. (2006) and Vallina et al. (2007) will be required to obtain a better decoupling of these parameters.

4. ENVIRONMENTAL STRESS

DMS has been shown to be sensitive to environmental conditions such as light, temperature and nutrients.
Vallina et al. (2007) showed a strong correlation to the light dose received in the mixed layer depth.

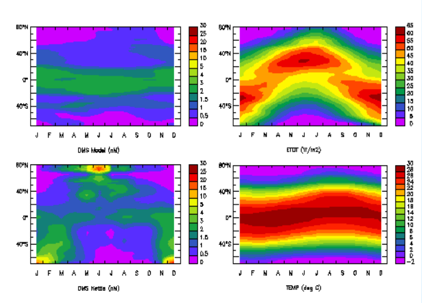

Figure 4: Hoevmoller plots for observed and modelled DMS, surface irradiation and temperature.

Figure 4 shows the seasonal variation of observed (Kettle et al. 2000) and modelled DMS. DMS and light show very similar temporal patterns. The seem to covary throughout the year. There also appears to be s strong inverse relationship between observed DMS concentrations and temperature, which would support the cryohypothesis (Stefels 2000) for DMS production. Intracellular DMSP quota and processes leading to DMS production have to be sensitive to these environmental parameters.

SUMMARY:

- A multiple phytoplankton functional type model can be useful for DMS modeling, as different PFT have different intracellular DMS quota and inhabit different ecological niches.
- DMS production is sensitive to both environmental parameters such as light and temperature and to ecosystem composition.
- In order to explain the summer paradox, factors such as light have to be included.
- Direct exudation of DMS by plankton contribute to the observed spatial and temporal DMS patterns.

5. ECOSYSTEM COMPOSITION

The ecosystem composition is crucial for DMS production. Diatoms produce little DMSP, coccolithophorids, some dinoflagellates and Phaeocystis are prolific DMSP producers. Hence, their global distribution will affect DMS fields. Changes in ecosystem composition due to climate change may lead to altered DMS production patterns.

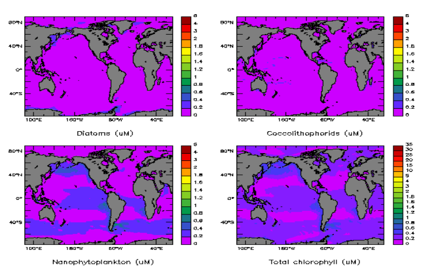

Figure 5: Model ecosystem composition in terms of chlorophyll in u mol/L.

6. GLOBAL PROGNOSTIC MODEL

The prototype…

- shows a reasonable order of magnitude of DMS concentrations
- overestimates DMS in the Tropics (nanophytoplankton abundance)
- underestimates the high latitudes (absence of Phaeocystis)

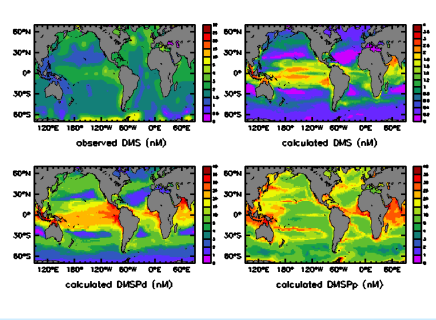

Figure 6: Comparison of the observed (Kettle et al., 2000) (top left) and the calculated DMS concentrations [nM] (top right).

The oceanic cycle of DMS is a complex chain of intertwined mechanisms, some of which are poorly understood. A prognostic approach to DMS modelling considers every step in the chain shown in Figure 1 according to its importance. We develop such an approach in a global biogeochemical model (Le Quéré et al., 2005). Here, we present the prototype of our prognostic model. The prototype reproduces the order of magnitude of DMS in the low latitudes. It does not reproduce the high DMS concentrations in the high latitudes.