Amplified global warming due to changes in marine sulfur emissions induced by ocean acidification

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Rationale

A global mean pH lowering of 0.1 units in surface waters has been estimated over the last 200 years. Continuing at the current level of CO_2 release the pH value could drop locally by 0.5 units in year 2100. Field studies show a tendency of reduced DMS production with decreasing pH. On the basis of a set of models we investigate the questions:

- **What are future projections of DMS emissions in an acidified ocean ?**
- **What is the climate impact of altered marine sulfur emissions ?**

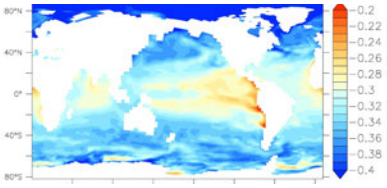


Fig. 1: Annual mean pH change in surface water between the decades 1860-1869 and 2090-2099 based on a ESM run with an IPCC A1B forcing scenario.

Data

The changes of the concentration of dimethylsulfide (DMS), produced by marine biota, at different pH levels were studied within the European Project on Ocean Acidification (EPOCA). One finding of the field study was that DMS production in Arctic waters appeared to be susceptible to changes in pH (Fig. 2). Studies in 2003 to 2006 in a Norwegian already indicated this dependency. For our model study we establish a set of linear fits between pH and DMS concentration.

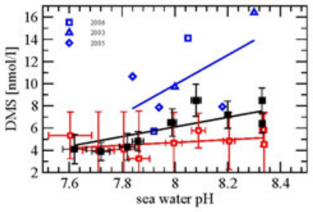
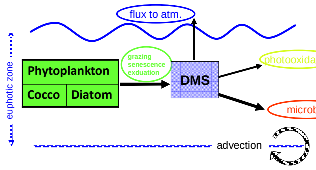


Fig. 2: Averaged measured DMS concentration [nmol/l] from mesocosms which run at different pH values; data from Svalbard (EPOCA, black squares = growing phase; red square = whole period) and from three studies in the Norwegian fjord between 2003 and 2006 (blue squares, data provided with courtesy from F.E.Hopkins). Lines indicate linear data fits, of which the gradients determine γ used to modify DMS production.

Tool

The MPI Earth System Model[1] includes a description of full carbon chemistry, the marine biosphere (HAMOCC) and the DMS cycle[2,3]. In the current study we do not include the feedback through variations of the oceanic DMS emission on the atmospheric sulfur level and, thus the radiation.



Reference run: ESM with atm. forcing (SRES A1B) & land use changes[4] for the time period 1860 – 2099.

3 sensitivity runs: ESM with same forcing as reference run including a multiplicative factor F(γ) for the local DMS production estimated from data (Fig.2) with $F(\gamma) = 1 + (pH_{actual} - pH_{18d})^{*}\ \gamma$; γ ranges from low (0.25), medium (0.58) to high (0.87)

pH_{18d} is the monthly mean pH constructed from the years 1860-1869 of the reference run.

Results & Discussion

The changes in biological production and the wind regimes due to climate change lead to a reduction of the global DMS emission in the reference run (7%) at the end of the 21st century. In the pH sensitive runs we find a significant decrease in the global DMS emission from 12% - 24 % relative to starting conditions (Table 1 and Fig. 3). The climate change only leads to a small increase in radiative forcing (RF=0.08 W/m²) in 21st. Due to ocean acidification changes in DMS emission result in an additional increase in RF of 0.17 - 0.64 W/m². In terms of an equilibrium temperature response this would convert into a warming signal of +0.1 to +0.76 °C only due to the impact of ocean acidification on the marine sulfur cycle.

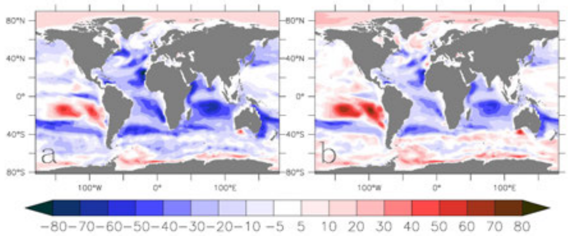


Fig.3 : Annual mean anomaly of marine DMS emission [mgS/m² yr] calculated as difference of the average of 2090-2099 and the average of 1865-1874 for the medium pH-sensitive run (a) and the reference run (b).

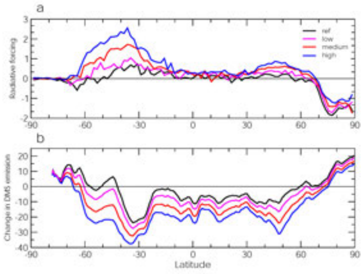


Fig.4 : Annual zonal mean anomaly of total top of the atmosphere radiative forcing [W/m²] (a) and of DMS emission [mgS/m² yr] (b) calculated as difference of the average of 2090-2099 and the average of 1865-1874 of the pH sensitive runs (low,medium,high) and the reference run (ref). See legend in panel a.

Our study highlights that oceanic uptake of anthropogenic CO_2 may cause a positive feedback on climate warming which has been unrecognized previously: changes in the acidity of seawater and its effect on DMS emissions leads to a significant increase in radiative forcing.

	Reference run		pH sensitive runs (21st)		
	19th	21st	low	medium	high
DMS production [TgS/yr] DMS emission [TgS/yr]	182 29	160 (-12%) 27 (-7%)	147 (-18%) 25.5 (-12%)	132 (-26%) 24 (-17%)	118 (-35%) 22 (-24%)
	Climate only		Ocean acidification - climate		
Change in radiative forcing [W/m²] Equiv. temperature response [°C]	0.08 0.04-0.09		0.17 0.1-0.21	0.40 0.23-0.48	0.64 0.37-0.76

Table 1 : Global annual fluxes calculated for the reference run and the pH sensitive runs for the preindustrial period (19th=average of 1865-1874) and for the end of the 21st century (21th=average of 2090-2099). Change in top of the atmosphere radiative forcing as calculated with ECAM5.5-HAM2 and estimated equilibrium temperature response based on a climate sensitivity of 2.1 and 4.4 °C for a doubling of CO_2 (IPCC,2007) are given for the reference run (climate only) and the pH-sensitive runs (ocean acidification run minus reference run) .

We evaluate the climate impact of the changed DMS emission due to ocean acidification by forcing the atmosphere model with sulfur chemistry and aerosol microphysics (ECHAM5.5-HAM2) with DMS flux fields from the reference or one of the pH-sensitive runs. Remote areas in the southern hemisphere show the highest response in the radiation forcing (Fig. 4). In equatorial regions change in DMS emission are not reflected in the radiative forcing. The northern polar oceans DMS emissions increase due to the retreat of sea ice resulting in a negative radiative forcing.

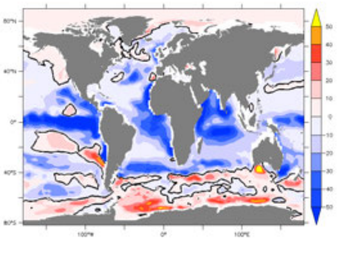


Fig 5 : Anomaly of organic material flux [mg C/m² d] at 90 m depth between the end of the 21st century and preindustrial times. Contour line denotes 0.

The overall biological production is reduced by the end of the 21st century as compared to preindustrial times by about 17% due to increased ocean stratification and, thus, reduced nutrient transport to the euphotic zone (Fig.5). In the Southern Ocean, south of 60° S, we find small enhancement in production due to the retreat of the ice cover and due to a shift of the wind regime which induces changes in the upwelling pattern.

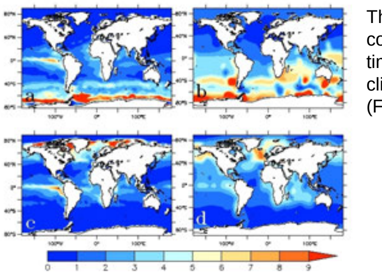


Fig 6 : Simulated monthly mean sea surface DMS concentration in nmolS/l for the preindustrial period 1865-1875 (a,c) and from the climatology[5] (b,d) for January (a,b) and July (c,d).

The simulated surface DMS concentration for preindustrial times agrees well with the climatology by Lana et al. (2011) (Fig.6).

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Data provided by Frances E. Hopkins and Stephen D. Archer,
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