

# Sulphur aerosols released from melting sea ice may influence Antarctic climate

The familiar seaside 'smell of the sea' is caused by a volatile sulphur compound called dimethylsulphide. This sulphur substance is produced by phytoplankton (microscopic marine plants) in the ocean, as well as by seaweeds, seagrasses and corals.

As far back as 1987, scientists proposed the existence of a feedback cycle involving dimethylsulphide production in the ocean, production of cloud condensation nuclei (the small particles on which cloud droplets form), and global temperature (Figure 1). It was suggested that the major source of cloud condensation nuclei over the unpolluted ocean appears to be dimethylsulphide, produced by phytoplankton, which oxidises in the atmosphere to form sulphate aerosol particles. These particles grow to form cloud condensation nuclei, which then attract moisture to form clouds. As the sulphate aerosol particles are so small (about 0.0002 mm in size), they can reflect incoming radiation back to space keeping the Earth cool.

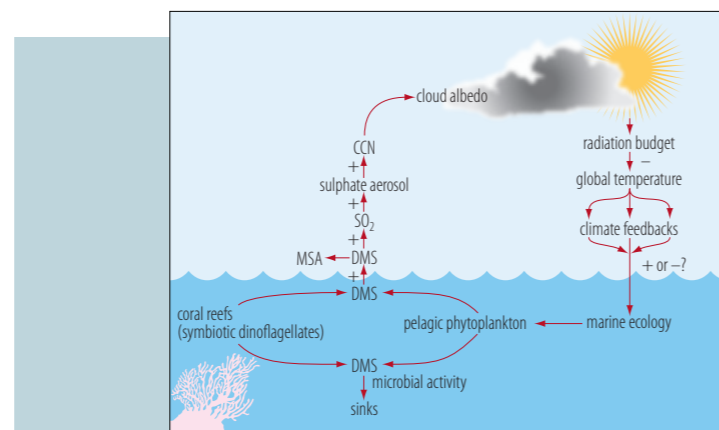
The researchers went on to propose that as the reflectance of clouds and thus the Earth's radiation balance is sensitive to the number of cloud condensation nuclei, biological regulation of global climate is possible through the effects of temperature and sunlight on oceanic phytoplankton and the amount of dimethylsulphide it produces.

This hypothesis has yet to be fully tested but provides a rationale for continued study of the production and fate of dimethylsulphide in the world's oceans. If dimethylsulphide does play an active role in low-level cloud formation, it could be a negative greenhouse gas, since doubling the amount of dimethylsulphide in the atmosphere will lower Earth's temperature by about 1.3°C.

CSIRO measurements at Samoa, Cape Grim in Tasmania and Mawson in Antarctica, helped develop this 'thermostat' theory by showing strong links between sunlight and the concentration of methane sulphonic acid aerosol. As there is no industrial activity in the areas where the measurements were taken, it was assumed that the seasonal variation was due to the natural variability in dimethylsulphide production. Because dimethylsulphide particles form the nuclei of cloud droplets, the implication of the finding was that dimethylsulphide influences cloud formation.

This research prompted us to investigate the cycling of dimethylsulphide in the Southern Ocean. From 1991 to 2006, 14 voyages were made on *Aurora Australis* measuring the concentrations of dimethylsulphide in the atmosphere and seawater of a large section (60°E-165°E) of the Southern Ocean. This work identified the subantarctic zone between 45-53°S and the Antarctic coastal zone, as major sources of atmospheric dimethylsulphide.

We also calculated that the emission of dimethylsulphide by phytoplankton in the Southern Ocean was 4500 million tonnes of sulphur per year, or 28% of the global oceanic



**Figure 1**

Research has suggested that increased temperatures will lead to increased dimethylsulphide (DMS) production (as a result of increased production by 'primary producers' such as marine plants). But for the Southern Ocean this may not be what happens. In 1991 scientists from France, Russia and the United States used the Vostok ice core in Antarctica to reconstruct the atmospheric concentration of methane sulphonic acid (MSA) over the past 160 000 years, covering a whole glacial-interglacial cycle. Their results suggest that concentrations of sulphate aerosols derived from dimethylsulphide and methane sulphonic acid are lower during warm interglacial phases and higher during ice ages.

This diagram illustrates the proposed ocean-atmosphere cycle of dimethylsulphide. SO<sub>2</sub> – sulphur dioxide; CCN – cloud condensation nuclei; cloud 'albedo' – reflectance of sunlight.

Adapted from Liss P.S., Malin G. and Turner S.M. (1993). Production of dimethylsulphide by marine phytoplankton. In: *Dimethylsulphide: Oceans, Atmosphere and Climate. Proc. Intern. Symp. Belgirate, Italy.* (Editors: G. Restelli and G. Angeletti). Kluwer Academic Pub. pp 1-14.

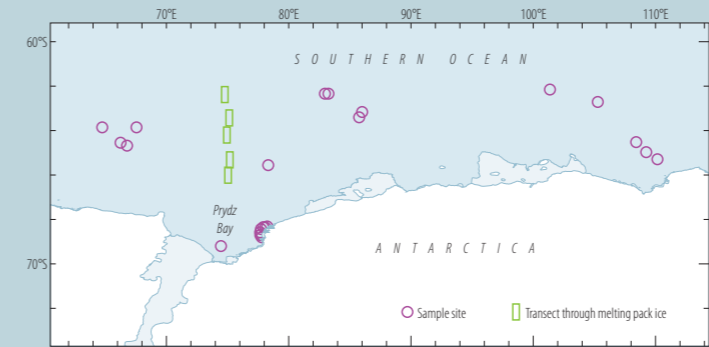
emission estimate – a very large amount. However, this emission is understated because no estimate had been made of the release of dimethylsulphide produced by sea ice algae in melting sea ice.

In order to assess the amount of dimethylsulphide in Antarctic sea ice, 62 sea ice cores of pack and fast ice were collected over an area extending between 64°E and 110°E and the eastern Antarctic coastline, from 1997 to 1998 (Figure 2). Very high and variable dimethylsulphide concentrations were found in different sections of these cores, suggesting that different species of ice algae produce varying amounts of this sulphur compound.

On the basis of these results we estimated that Antarctic sea ice contains as much as 290 million tonnes of sulphur. As sea ice melts, considerable quantities of dimethylsulphide produced by the sea ice algae could be released into the atmosphere. We wondered if we could detect this by satellite.

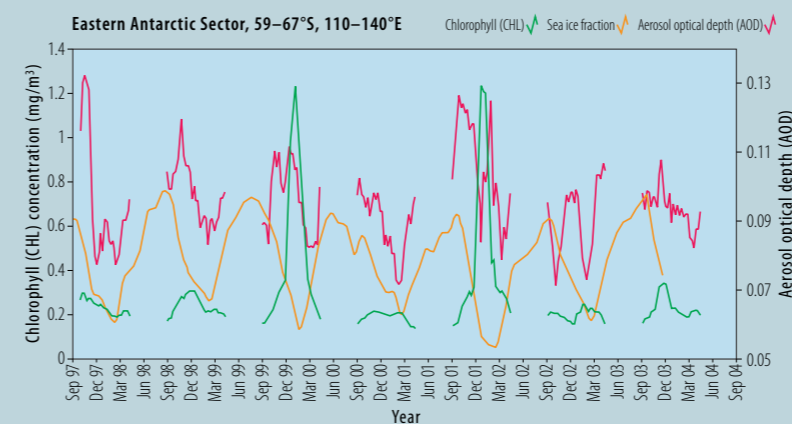
To find out, we obtained satellite information on chlorophyll concentration in the ocean and aerosol concentration from the ocean surface to the top of the atmosphere (aerosol optical depth) – a potential proxy of dimethylsulphide. Satellite data on sea ice extent was also obtained and the information analysed in four bands around Antarctica: 50-55°S, 55-60°S, 60-65°S and 65-70°S.

Between 50-60°S, chlorophyll concentration and aerosol



**Figure 2**

The sea ice is 20 million km<sup>2</sup> – the size of Russia – and in late spring-early summer 80% of this area melts into the surrounding seawater. Sixty-two sea ice cores were collected at 27 sites across eastern Antarctica (64° to 110°E) and processed for dimethylsulphide (circles). Rectangles represent a 500 km transect through melting pack ice in 1998.



**Figure 3**

The satellite data for eastern Antarctica shows the main aerosol optical depth (AOD – red line) peak often precedes the chlorophyll (CHL) peak (green line) by up to six weeks, and coincides with melting sea ice (orange line) in October/November. The duplet AOD peaks in 1999-2000, 2001-2002 coincides with very high CHL maxima in summer, most probably generated by phytoplankton blooms. In December 1998 a 500 km transect through the melting pack ice (rectangles, Figure 2) found very high concentrations of dissolved dimethylsulphide, which did not seem to be generated by *in situ* phytoplankton production, agreeing with the satellite record for that year which showed low CHL after ice melt.

optical depth were positively correlated. This suggests that phytoplankton production in open polar waters is a strong source of sulphate aerosols in these regions, as previous results have confirmed.

However, in the 60-70°S band for the eastern Antarctic the aerosol peak precedes the chlorophyll peak by as much as six weeks (Figure 3). This result was unexpected and we believe reflects a large pulse of dimethylsulphide and other substances released in October-November from algae contained in the melting sea ice. But what evidence do we have for this?

During mid-December 1998, we found very high concentrations of dissolved dimethylsulphide in a 500 km transect through the melting ice edge in eastern Antarctic from 62-70°S. Chlorophyll concentrations throughout the transect were relatively low, suggesting an ice-edge algal bloom had not developed. Although our results do not provide unequivocal proof of a sea ice sulphur source, the decoupling of the chlorophyll and aerosol signal south of 60°S is consistent with the hypothesis that sea ice melting and a release of sulphur from sea ice algae, is contributing to the aerosol load over the Antarctic sea ice in the spring to early summer period.

Further satellite data and field surveys over a longer time frame are needed to test our hypothesis. However, it is possible that aerosol measurements could identify the timing of any

large-scale extent of sea ice melting around Antarctica. The size of this signal may provide insights on the amount of dimethylsulphide-derived sulphate aerosols that are emitted from the Antarctic sea ice in the spring-summer period.

Sea ice maximal extent has decreased by 175 km in eastern Antarctica since the 1950s. Our results suggest that this loss of sea ice would have decreased emissions of dimethylsulphide in this region, and consequently levels of dimethylsulphide-derived aerosols, such as methane sulphonic acid. This decreasing trend in methane sulphonic acid since the 1950s is evident in the ice core record of this region, but what effect this may have on the radiative climate (amount of reflected sunlight) over the Southern Ocean is unknown. Longer ice core records and more direct aerosol and dimethylsulphide measurements over the sea ice are needed to resolve this question.

For more information visit: <<http://www.scu.edu.au/schools/esm/staff/pages/gjones/index.html>>.

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