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ORIGINAL PAPER

Variability in abundance and fluxes of dimethyl sulphide in the Indian Ocean

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Abstract Dimethyl sulphide (DMS) is a biogenic gas of climatic significance on which limited information is available from the Indian Ocean. To fill this gap, we collected data on DMS and total dimethylsulphoniopropionate ($DMSP_t$) by participating in a dozen cruises. Here, we discuss the variability in DMS and $DMSP_t$ in the north and central Indian Ocean in terms of their spatial and temporal variation. DMS and $DMSP_t$ exhibited significant spatial and temporal variability. Apart from the concentration gradients in DMS within the Arabian Sea, Bay of Bengal and Central Indian Ocean basins, differences in average abundances were conspicuous between these basins. The Arabian Sea contained more DMS (mixed layer average was 7.8 nM) followed by the Bay of Bengal (2.8 nM) and the Central Indian Ocean (2.7 nM). The highest concentrations of DMS and $DMSP_t$ (525 nM and 916 nM, respectively) were found in upwelling regimes along the west coast of India during the Southwest monsoon and fall intermonsoon seasons. Average surface DMS was the highest in the Arabian Sea. On the other hand observed sea-to-air fluxes of DMS were higher in the Bay of Bengal due to the prevalence of turbulent conditions. In the Arabian Sea wind speeds were low and hence the sea-to-air fluxes. The total diffusive flux of DMS from the study area to atmosphere is estimated to be about 1.02×10^{12} g S y^{-1}, which contributes to 4.1–6.3% of the global DMS emission

Keywords DMS · $DMSP_t$ · Fluxes · Indian Ocean · Monsoon

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Introduction

Dimethyl sulphide is the most dominant of the reduced sulphur gas found in surface layers of the ocean (Lovelock et al. 1972). The emission of dimethyl sulphide from seawater is expected to balance the excess sulphur deposition over the remote oceans (Charlson et al. 1992). Charlson et al. (1987) proposed a hypothesis, known as the CLAW (after the authors Charlson, Lovelock, Andreae and Warren) hypothesis connecting biogenic DMS emissions to changes in albedo, in which increased production of DMS due to global warming is expected to lead to more sulphate aerosols and subsequently to more cloud condensation nuclei (CCN) that in turn enhances back radiation.

In seawater, DMS is produced from dimethylsulphoniopropionate (DMSP), which in turn is produced by phytoplankton. Specific species of phytoplankton are found to be responsible for most of the DMSP production in seawater. According to Liss et al. (1993) the potential for production of DMS in various taxonomic groups follows the order:

$$\text{Coccolithophores} > \textit{Phaeocystis} > \text{Dinoflagellates} > \text{Diatoms}$$

DMSP in phytoplankton was initially proposed to function as an osmolyte (Vairavamurty et al. 1985). Over the years we now have evidence for its role in other processes such as for cryopreservation (Kirst et al. 1991), as a deterrent against grazing (Dacey and Wakeham 1986; Wolfe and Steinke 1996) and against bacteria (Wolfe et al. 1997). In the recent past the anti-oxidant role of DMSP is becoming more popular (Sunda et al. 2002). Factors controlling DMSP production, its conversion to DMS, fate of DMSP and DMS sulphur in the marine environment are well documented in the review by Stefels et al. (2000) and in the present issue.

Extensive measurements on DMS and DMSP have been done in different parts of the oceans (Kettle et al. 1999 and references therein) including estuarine and lagoon waters (Iverson et al. 1989; Moret et al. 2000). A few studies have been made in the Indian Ocean, which include Hatton et al. (1999), Shenoy et al. (2000, 2002), Kumar et al. (2002) and Shenoy and Patil (2003) and some unpublished data in eastern Indian Ocean (of T.S. Bates, as mentioned by Kettle et al. 1999) and for Amsterdam station (Nguyen et al. 1990, 1992).

Hatton et al. (1999) found elevated concentrations of DMS, DMSP and dimethyl sulphoxide (DMSO) in the eutrophic zone (Arabian Sea) immediately after the SW monsoon. In addition DMSO concentrations were found to correlate with near surface DMS and DMSP. Shenoy et al. (2000) reported the first ever measurements of DMS from the Bay of Bengal where salinity appeared to play an important role in the DMSP production. Shenoy et al. (2002) documented five times higher concentrations of DMS and DMSP in winter season of 1999 than that in 1998, which has been attributed to differences in physical forcing and associated biological processes. In a time series experiment carried out in estuarine waters of Goa, on the west coast of India, Shenoy and Patil (2003) recorded elevated concentrations of DMS and DMSP during the monsoon season (maximum DMS 15.4 nM and $DMSP_t$ 419.5 nM) due to the possible prevalence of mixed population of diatoms and dinoflagellates. Covariations among oceanic and atmospheric DMS and atmospheric SO_2, wet deposition of methane sulphonic acid (MSA), non-sea salt (NSS) SO_4^{-2}, and rain acidity have been shown by Nguyen et al. (1990, 1992) near Amsterdam island (southern Indian Ocean).

While the biogeochemistry of carbon dioxide and nitrogen species are reasonably well known, particularly in the northern Indian Ocean, our knowledge of sulphur species is limited. DMS and associated sulphur compounds are climatically important, particularly in the monsoon-dominated tropical Northern Indian Ocean, in regard to air–sea interactions and feedbacks. Significant diversity in physical and associated biological regimes in the Indian Ocean together with dynamic climate offers a potentially interesting region to understand the DMS cycling and its controlling factors. Therefore, this study has been undertaken to study spatial (especially inshore–offshore gradients off the coast of India and surface variation) and temporal variations of DMS and $DMSP_t$ in the Indian Ocean and to evaluate its atmospheric emissions in regional and global context.

Material and methods

Sampling for this study was attempted keeping in view the large spatial and temporal variability of the biogeochemical processes in the Indian Ocean. Data were collected for temperature, salinity, dissolved oxygen, nitrate, chlorophyll *a*, DMS and $DMSP_t$ in seawater. Besides, data were collected for wind speed and atmospheric temperature. Figure 1a depicts the study area in the Indian Ocean, where a dozen oceanic expeditions were undertaken on board ORV Sagar Kanya (SK) and FORV Sagar Sampada (SS) covering a total of 320 stations. Data were mainly collected