Downward flux of particulate dimethylsulphoniopropionate (DMSPp) in the tropical open ocean

Sulphur
DMS
DMSP
Zooplankton
Sedimentation

Soufre
DMS
DMSP
Zooplancton
Sedimentation

Martine CORN [a], Sauveur BELVISO [a], Paul NIVAL [b], Alain VIGOT [a] and Patrick BUAT-MENARD [a] *

[a] Centre des Faibles Radioactivités, Laboratoire Mixte CNRS-CEA, avenue de la Terrasse, 91198 Gif-sur-Yvette Cedex, France.

[b] Observatoire Océanologique, Station Zoologique, B.P. 28, 06230 Villefranche-sur-Mer, France.

* Present address: Département de Géologie et Océanographie, Université Bordeaux 1, avenue des Facultés, 33405 Talence, France.

Received 25/10/93, in revised form 24/01/94, accepted 1/02/94.

ABSTRACT

We report results from free-drifting sediment trap deployments at 200 m depth which enable measurement of the diel variations in the downward flux of detrital particulate dimethylsulphoniopropionate (DMSPp) over periods of 24-72 hours in three contrasting trophic regimes of the tropical northeastern Atlantic Ocean off Mauritania. The source of DMSPp was the phytoplankton living in surficial water layers. The three regimes exhibited similar strong diel cycles, the nocturnal fluxes being up to 100-fold lower than the daytime fluxes. High (or low) detrital DMSPp fluxes were associated with high (or low) numbers of pteropods trapped inside the sampling cups. Thus, contamination of sinking material is likely to have occurred, promoting an overestimate of the daytime fluxes. It is concluded that the transport of DMSPp at depths deeper than 200 m is strongly influenced by the downward migration of pteropods during the daylight hours. This mode of transport is shown to be a general process in tropical waters for accelerating DMSPp sedimentation. Under these oceanic and experimental conditions the daily DMSPp flux at 200 m accounted for only about 0.1 % of the DMSPp standing stock. Hence, the DMSPp downward flux is likely to have a minor influence in the upper ocean budget of DMSPp.

Oceanologica Acta, 1994. **17**, 2, 233-236.

RÉSUMÉ

Flux verticaux de diméthylsulfoniumpropionate particulaire (DMSPp) dans l'Océan Atlantique tropical

La variabilité journalière du flux vertical de diméthylsulfoniumpropionate particulaire (DMSPp) a été étudiée avec un pas de temps de 4 heures à l'aide d'une trappe à sédiment dérivante multi-godets de type PPS5/2. Le déploiement s'est effectué en trois sites de richesse biologique contrastée au large de l'upwelling de Mauritanie, à une profondeur de 200 m. Le phytoplancton des eaux superficielles constitue le principal réservoir du DMSPp. Les flux mesurés en chacun des sites présentent des variations nycthémérales très marquées et synchronisées. L'intensité des flux diurnes est jusqu'à 100 fois supérieure à celle des flux nocturnes. Dans la plupart des cas, les flux de forte intensité ont été mesurés à l'occasion de fortes accumulations d'organismes mésozooplanctoniques (ptéropodes du genre *Clio* et *Limacina*) dans les godets, et réciproquement. Ces organismes, qui effectuent des migrations verticales nycthémérales, sont interceptés

par la trappe au cours de leur descente vers les profondeurs où ils séjournent pendant la journée. Il y a donc eu certainement intégration de leurs pelotes fécales et, par conséquent, surestimation des flux journaliers de DMSPp à 200 m de profondeur. Ceux-ci ne représentent cependant qu'au plus 0,15 % du réservoir phytoplanctonique de DMSPp. Le transport actif de DMSPp par le zooplancton accélère donc les échanges de DMSPp entre les eaux superficielles et les eaux profondes, mais n'est pas suffisamment important sur le plan quantitatif pour justifier une prise en compte par les futurs modèles du cycle biogéochimique marin des composés DMSP et DMS.

Oceanologica Acta, 1994. **17**, 2, 233-236.

INTRODUCTION

Dimethylsulphide (DMS) plays an important role in the marine environment because it contributes to the acidity of precipitations (Nguyen *et al.*, 1992), affects the condensation nuclei concentration in remote marine areas (Putaud *et al.*, 1993) and, consequently, could contribute to marine cloud formation and climate regulation (Charlson *et al.*, 1987). Since DMS appears to arise primarily from dimethylsulphoniopropionate (DMSP), it is important to understand the processes controlling the cycling of DMSPp in the oceanic upper water column (Malin *et al.*, 1992). Dacey and Wakeham (1986) demonstrated experimentally that zooplankton grazing results in the release of DMS from algal cells containing DMSPp and gave a reasonable indication for the presence of DMSPp in fecal material. The loss of particulate DMSP from surface sea water via sinking particles, however, has not yet been specifically investigated.

EXPERIMENTAL DETAILS

We carried out six experiments at sea as part of the JGOFS-France Eumeli project during May and June 1992 on R/V *L'Atalante (Eumeli 4). Eumeli* is based on the study of three sites, respectively eutrophic, mesotrophic and oligotrophic, off Mauritania, at latitude 20°N (Fig. 1). The oligotrophic site (site O, 21°N-31°W) is located 1 500 km off the Mauritanian coast, on the abyssal plain. The mesotrophic site (site M, 18°30'N-21°W), above a terrace at 3 000 m, is under the influence of the Mauritanian upwelling despite the distance from the coast (> 300 km). The eutrophic site (site E, 20°30'N-18°30'W), at about 500 m water depth, is as close as possible to the active upwelling area. The coast is arid and riverless. Particle samples were collected using a free-drifting sediment trap (Technicap, PPS5/2) of a 1 m^2 mouth area and able to sample sequentially up to 24 samples each of 250 ml. Prior to deployment, the sampling flasks were filled with DMSP-free sea water collected at a depth of 250 m. No fixative solution was added in order to prevent interferences with the gas chromatographic analytical method. The trap was deployed at 200 m depth from 5-6 and 13-14 June (site E), 31 May-3 June and 16-17 June (site M), 25-28 May and 22-23 June (site O) for periods of one-three days. Current profiles measured using a shipboard Doppler current profiler showed that the relative movements of the water masses and of the sediment trap system

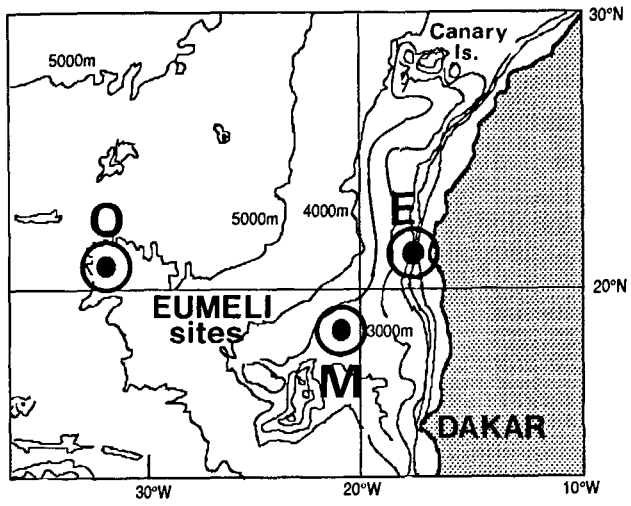

Figure 1

Position of the eutrophic (E), mesotrophic (M) and oligotrophic (O) sites in the tropical northeastern Atlantic Ocean.

Localisation des sites eutrophe (E), mésotrophe (M) et oligotrophe (O) dans l'Océan Atlantique tropical.

were coherent. Sequential flux samples were collected over 4h sampling periods. After trap recovery, living or dead mesozooplankton trapped inside the sample cups were systematically removed so that only detrital particles (fecal pellets, detritus) and organisms < 2 mm were analysed. Each entire sample was resuspended and aliquots were taken using a Motoda splitting box for determinations of DMSPp. The DMSPp of the 60-120 ml-aliquot was determined on board after treatment with cold alkali followed by gas chromatographic analysis with flame photometric detection of evolved DMS (Belviso *et al.*, 1990). Water samples were also collected for phytoplanktonic DMSPp using rosette bottle samplers fixed to a CTD system.

RESULTS AND DISCUSSION

Figure 2 presents results for the two deployments carried out at each site: at intervals of one, two and four weeks at sites E, M and O respectively. The experiments showed that diel variations in DMSPp flux were always evident at 200 m depth. High flux of DMSPp generally occurred during daytime and low fluxes during periods

of surface-water darkness. However, there was a marked difference in fluxes measured in the evening and early night (18-2 hours) and those measured at the end of the night (2-6 hours); the latter were always significantly higher. It is apparent from these data that the same mechanism controls the vertical flux of DMSPp at 200 m depth.

It is well known that trapped zooplankton in sediment traps is a source of contamination and alteration of collected materials (Fowler and Knauer, 1986). Observations and countings were carried out on the organisms removed from the traps during our second visit to the sites, in June. They reveal that pteropods accounted for the major fraction of zooplankton biomass. Pteropods are planktonic gastropods. They are ciliary mucus-feeders that consume microplankton. Pteropod populations were dominated at site E by taxa *Limacina* (2 mm) and *Clio* (5-10 mm), at site M by taxa *Clio* and at site O by taxa *Limacina*. Figure 2 shows that pteropods were more abundant in the daytime samples than in the night-time samples. High (or low) DMSPp fluxes tend to be associated with high (or low) numbers of pteropods. Contamination of passively sinking material is likely to have occurred, promoting an overestimate of the daytime fluxes. Thus, it appears that the downward migration of pteropods, to spend the daylight hours at depths deeper than 200 m, is responsible for the transport of DMSPp. Some events, however, show DMSPp fluxes to be high whereas pteropods were not found in samples cups. Since pteropod fecal pellets are very compact and sink at rates of 50-200 m d^{-1}, it is not unlikely that a maximum flux occurring at night in upper water layers, when pteropods prey on DMSP-containing phytoplankton, could be simply shifted to a daytime arrival due to the time required for surface-produced particles to sink to 200 m. It is concluded that the migratory pteropods and their fast sinking fecal pellets are controlling the downward flux of DMSPp in tropical Atlantic Ocean waters during springtime.

We now discuss the importance of these processes in influencing the upper ocean budget of DMSPp by comparing the DMSPp standing crops, calculated from its vertical distribution between the surface and 150 m, to the daily downward fluxes through 200 m depth. At the outset, it should be pointed out that our data cannot provide a reliable estimate of the fate of DMSPp production by sinking particles because: 1) trap material was too contaminated by the abundant populations of pteropods; 2) some bacterial decomposition of DMSPp is likely to have occurred since the samples were not poisoned; and 3) measurements of upper ocean DMSPp production rate were lacking. Most of the DMSPp standing crop was located above 70 m at sites E and M. The integrated quantity of DMSPp over 70 m was about 4 and 7.3 mmol m^{-2}, respectively

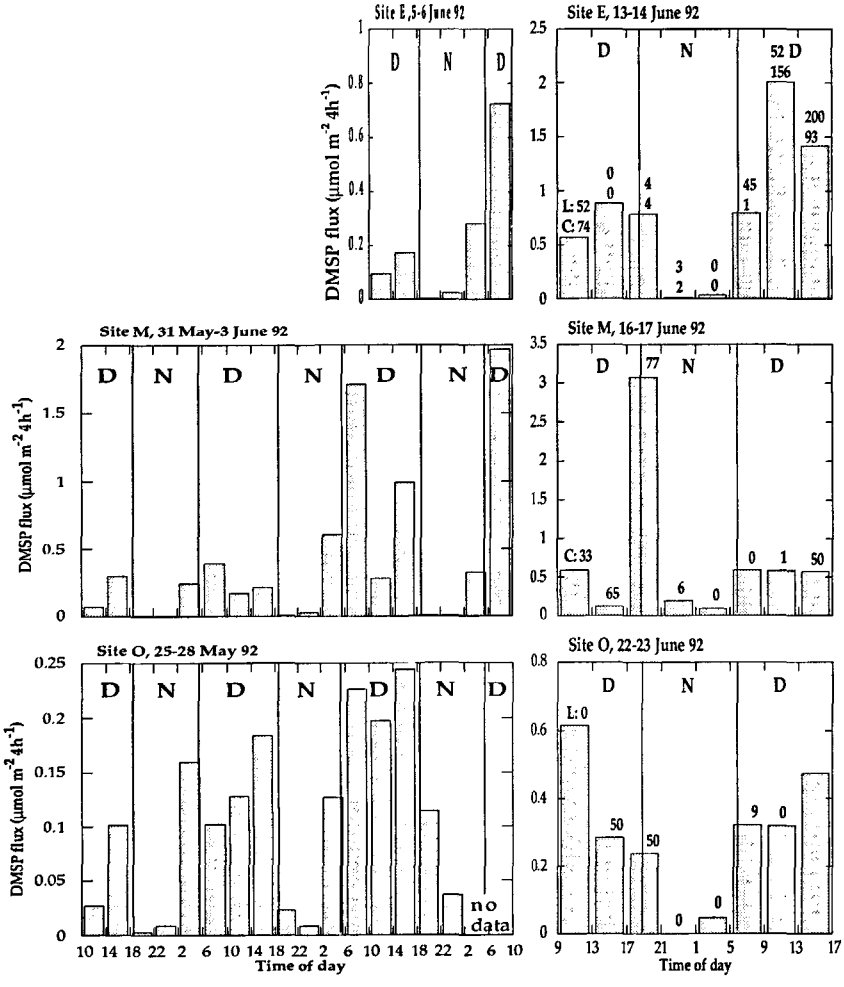

Figure 2

DMSPp fluxes at 200 m depth versus *time of day at the sites E, M and O in May-June 1992. Bold numbers at the top of the columns indicate numbers of pteropods (L: taxa* Limacina, *C: taxa* Clio*) trapped inside the sampling cups. Times of sunset and sunrise are represented by vertical lines. D = day, N = night. Note the different vertical scales.*

Variabilité temporelle des flux de DMSPp à 200 m de profondeur en mai-juin 1992. Les nombres qui figurent en gras au-dessus des histogrammes indiquent le nombre de ptéropodes (L: genre *Limacina*, C: genre *Clio*) présents à l'intérieur des godets de la trappe à sédiment dérivante. Les traits verticaux représentent les heures de lever et de coucher du soleil. D = jour, N = nuit. Noter que l'axe des ordonnées est variable.

(Tab. 1). At site O, the vertical distribution of DMSPp was broader and its standing crop above 150 m was about 2 mmol m^{-2}. Fluxes are given in Table 1. They were calculated at each site from the most recently collected samples. A first-order approximation of the loss rate of DMSPp can be made by comparing the flux of DMSPp at 200 m with the standing crop of DMSPp. As an example, at site E from 13-14 June the flux of DMSPp at 200 m was 5.7 µmol m^{-2} d^{-1}. The standing crop of particulate DMSP was 4 mmol m^{-2}; thus, approximatively 0.1 % of the DMSPp standing crop was transfered daily. At site M and O we calculated 0.07 %. Therefore, the flux of DMSPp at 200 m driven by diel migrators and sinking fecal pellets appears to be of very low intensity. Consequently, most detrital DMSPp should be recycled in the water column before reaching 200 m.

Table

Values of DMSPp standing crops, daily fluxes of DMSPp at 200 m depth and DMSPp accumulation rates in the tropical Atlantic Ocean in June 1992.

Quantités intégrées de DMSPp, flux journaliers de DMSPp à 200 m de profondeur et taux d'accumulation respectifs, dans l'Océan Atlantique tropical en juin 1992.

SITES	STANDING CROPS mmol m^{-2}	FLUXES µmol $m^{-2}d^{-1}$	ACCUMULATION RATES % d^{-1}
E	4.0 (70 m)*	5.7	0.14
M	7.3 (70 m)	5.1	0.07
O	2.0 (150 m)	1.4	0.07

* Integration depth

CONCLUSION

The role of zooplankton in the oceanic DMS cycle was highlighted by Dacey and Wakeham (1986). These authors suggested that DMS production associated with grazing of phytoplankton by zooplankton may be the major mechanism of DMS production in many marine settings. Leck *et al.* (1990) indeed found significant correlations of DMS concentration with copepods and total zooplankton biomass for samples collected in the Baltic Sea. Our sediment trap data obtained in contrasting trophic regimes characterizes the general involvement of zooplankton in the cycle of the major DMS precursor, DMSPp. However, the downward flux of DMSPp in tropical waters, mainly driven by diurnally migratory pteropods and possibly by fast sinking pteropod fecal pellets, appears to have a minor influence in the upper ocean budget of DMSPp.

Acknowledgements

The authors wish to thank the Captain and Crew of R/V *L'Atalante* for their help and cooperation, D. Tailliez and C. Bournot for taking charge of the hydrographic work at sea, and P. Newton and C. Lambert for helpful discussions. This work was supported by the French Centre National de la Recherche Scientifique (CNRS), Institut National des Sciences de l'Univers (INSU), Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) and Commissariat à l'Énergie Atomique (CEA). This is CFR contribution 1549.

REFERENCES

Belviso S., S.-K. Kim, F. Rassoulzadegan, B. Krajka, B.C. Nguyen, N. Mihalopoulos and P. Buat-Ménard (1990). Production of dimethylsulphoniumpropionate (DMSP) and dimethylsulfide (DMS) by a microbial food web. *Limnol. Oceanogr.*, **35**, 1810-1821.

Charlson R.J., J.E. Lovelock, M.O. Andreae and S.G. Warren (1987). Oceanic phytoplankton, atmospheric sulfur, cloud albedo and climate: a geophysiological feeback. *Nature*, **326**, 655-661.

Dacey J.W.H. and S.G. Wakeham (1986). Oceanic dimethylsulfide: production during zooplankton grazing on phytoplankton. *Science*, **233**, 1314-1316.

Fowler S.W. and G.A. Knauer (1986). Role of large particles in the transport of elements and organic compounds through the oceanic water column. *Prog. Oceanogr.*, **16**, 147-194.

Leck C., U. Larsson, L.E. Bagander, S. Johansson and S. Hajdu (1990). Dimethylsulfide in the Baltic Sea: annual variability in relation to biological activity. *J. geophys. Res.*, **95**, 3353-3363.

Malin G., S.M. Turner and P.S. Liss (1992). Sulfur: the plankton/climate connection. *J. Phycol.*, **28**, 590-597.

Nguyen B.C., N. Mihalopoulos, J.-P. Putaud, A. Gaudry, L. Gallet, W.C. Keene and J.N. Galloway (1992). Covariations in oceanic dimethylsulfide, its oxidation products and rain acidity at Amsterdam Island in the southern Indian Ocean. *J. atmos. Chem.*, **15**, 39-53.

Putaud J.-P., S. Belviso, B.C. Nguyen and N. Mihalopoulos (1993). Dimethylsulfide, aerosols and condensation nuclei over the tropical northeastern Atlantic Ocean. *J. geophys. Res.*, **98**, 14863-14871.