The next step of this study is to measure the particulate organic matter which is abiotically formed and exported toward the bottom of the 'minicosm'. Results from both the mesocosm (biotic conditions) and the minicosm (abiotic conditions) will help to estimate the biological contribution to the particulate export after a dust deposition event.

These studies taken together demonstrate that (1) dust deposition can be seen as a fertilizing event; (2) the fate of new atmospheric nutrients and, therefore, the intensity of the biological response depend on seawater biogeochemical conditions; (3) atmospheric particles act as ballast material; and, (4) these processes contribute to the increase of the carbon flux to the deep ocean.

References

Armstrong, R., et al. (2002) A new, mechanistic model for organic carbon fluxes in the ocean based on the quantitative association of POC with ballast minerals. *Deep Sea Res. Part II*. 49:219-236.

Boyd, P. and Trull, T. (2007) Understanding the export of biogenic particles in oceanic waters: Is there consensus? *Progress in Oceanography*. 72:276-312.

Bressac, M., et al. (2012) A mesocosm experiment coupled with optical measurements to assess the fate and sinking of atmospheric particles in clear oligotrophic waters. *Geo-mar Lett*. 32:153-164.

Hamm, C. (2002) Interactive aggregation and sedimentation of diatoms and clay-sized lithogenic material. *Limnol. Oceanogr*. 47(6):1790-1795.

Pulido-Villena, E., et al. (2010) Transient fertilizing effect of dust in P-deficient LNLC surface ocean. *Geophys. Res. Lett*. 37:L01603.

Ternon, E., et al. (2010) The impact of Saharan dust on the particulate export in the water column of the North Western Mediterranean Sea. *Biogeosciences* 7:809-826.

Wagener, T., et al. (2008) Dust iron dissolution in seawater: Results from a one-year time-series in the Mediterranean Sea. *Geophys. Res. Lett*. 35:L16601.

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The ocean has a gel-like skin made of proteins

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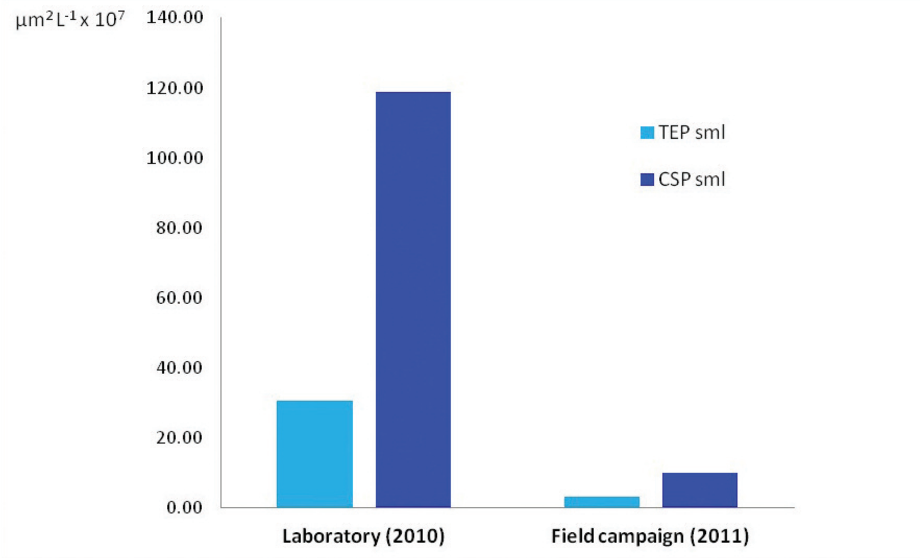
The very surface of the ocean is a peculiar environment responsible of mediating gas fluxes and organic matter transport between ocean and atmosphere. It is called the sea-surface microlayer (SML) and derives from the accumulation of organic material at the surface: These compounds produced by marine organisms form visible slicks that lower seawater surface tension thus influencing air-sea gas and energy exchange. The SML is susceptible to being altered by water movements, wind-driven atmospheric deposition, solar radiation and biological activity.

The SML has been hypothesised as being a hydrated gelatinous matrix of varying thickness entrapping several compounds like lipids, carbohydrates, proteins and specific bacterial communities known as bacterioneuston. Polysaccharides are the major constituent of phytoplankton exudates and comprise a considerable fraction of high molecular-weight dissolved organic matter (HMW>1kDa) in the surface ocean.

In the SML carbohydrates are also present as Transparent Exopolymer Particles (TEP), marine gels that concur to the gelatinous nature of the boundary layer, as recent studies have evidenced. Thanks to their sticky properties,



Λ Figure 1: TEP and CSP total area (µm^2 L^{-1} x 10^7) from the laboratory experiment at Alfred Wegener Institute (2010) and the fjord sampling in Bergen, Norway (2011).

TEPs play an important role in the formation of aggregates colonised by bacteria. Simultaneously, marine gels promote biofilm formation; act as a food source for microorganisms; and, mediate vertical carbon transport, either to the sea surface or to the deep ocean. While the SML enrichment in TEP has been recorded in previous studies, a recently submitted paper (Galgani and Engel, 2012) demonstrated that the SML was not unambiguously dominated by polysaccharidic gel particles, but that proteinaceous compounds in the form of Coomassie Stainable Particles (CSP) were also present in the SML and even outnumbered TEP.

Article continues on next page

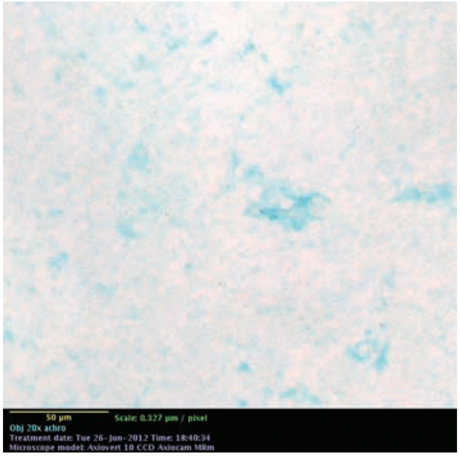
TEP and CSP are transparent, unless differentiated with an amino acid specific dye (Coomassie Brilliant Blue G, for CSP) or with a dye that complexes the carboxyl and half-ester sulfate reactive groups of acidic polysaccharides (Alcian Blue for TEP) . Whether these two kinds of gels represent subunits of the same gel particle or individual gels is currently not known. To address our research objectives, we investigated the gelatinous nature of the SML during two studies in the framework of the German BMBF-funded SOPRAN II project. We conducted indoor experiments with the diatom *Thalassiosira weissflogii* grown under different pCO_2 and incubated in tanks (Galgani and Engel, 2012), and a field campaign in the Raune Fjord, Norway (unpublished data). Our sampling approach with the glass plate referred to the uppermost 100-200 µm of the sea surface. The water below the surface was sampled at a depth of approximately 20cm in both experiments, and enrichment factors (EF) to determine enrichment or depletion of a component in the SML were calculated as follows:

$EF = [x]_{SML} / [x]_{BW}$

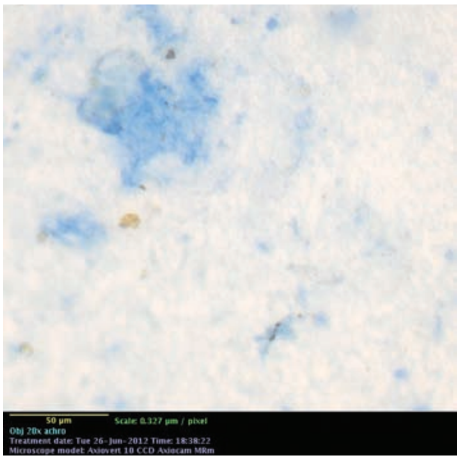
Where *[x]* is the concentration of a given parameter in the SML or in the bulk water (*BW*) (Liss and Duce, 1997).

Results from the indoor experiments evidenced predominantly proteinaceous composition of the surface film as CSP enrichment. These first observations were later confirmed by the field sampling in Norway, where CSP were more abundant in total area in SML with respect to TEP (Fig.1). Moreover, in the fjord CSP were also characterized by bigger particles (Fig.2;3).

Our studies suggest that the microlayer has a proteinaceous gel-like composition with CSP being the dominating gel particles. CSP derive from bacterial exudates and the cell's protein content that can be released through cell disruption and lysis. An enhanced concentration of CSP points out to the importance of bacterial metabolism in the SML. Activities of microbes inhabiting the SML continuously alter its composition and render the very surface of the sea into a unique and mutable environment (Fig.4). Heterotrophic bacteria have been shown to respond to rising CO_2 and sea-surface temperatures: They may mediate air-sea gas exchange processes at the interface between ocean and atmosphere, crucial to understand future feedbacks of climate change.



Λ Figure 2: TEP particles from SML of the fjord



Λ Figure 3: CSP particles from SML of the fjord

Λ Figure 4: Sampling the SML in the Fjord

References

Benner, R. (2002) Chemical composition and reactivity. In: Hansell, D. and Carlson, D., eds., *Biogeochemistry of marine dissolved organic matter. Academic Press 59-90.*

Cunliffe, M. and Murrell, J. (2009) The sea-surface microlayer is a gelatinous biofilm. *The ISME journal 3(9):1001-3*.

Cunliffe, M., et al. (2009) Dissolved organic carbon and bacterial populations in the gelatinous surface microlayer of a Norwegian fjord mesocosm. *FEMS microbiology lett. 299(2): 248-54.*

Engel, A. (2009) *Determination of Marine Gel Particles, Practical Guidelines for the Analysis of Seawater.* CRC Press.

Liss, P. and Duce, R. (1997) *The Sea Surface and Global Change*. Cambridge University Press.

Piontek, J. et al. (2010) Acidification increases microbial polysaccharide degradation in the ocean. *Biogeosciences 7(5):1615-24.*

Sieburth, J. (1983) Microbiological and organic-chemical processes in the surface and mixed layers - Air-Sea exchange of Gases and Particles. NATO Science Series, C.D.Reidel Publishing Company.

Stolle, C., et al. (2009) Bacterial activity in the sea-surface microlayer: in situ investigations in the Baltic Sea and the influence of sampling devices. *Aquatic Microbial Ecology 58:67-78.*

Van Vleet, E. and Williams, P. (1980) Sampling sea surface films: a laboratory evaluation of techniques and collecting materials. Limnol. *Oceanogr. 25(4):764-70.*

Van Vleet, E. and Williams, P. (1983) Surface potential and film pressure measurements in seawater systems. Limnol. *Oceanogr. 28(3):401-14.*

Wurl, O. and Holmes, M. (2008) The gelatinous nature of the sea-surface microlayer. *Mar. Chem. 110(1-2): 89-97*.

Wurl, O., et al. (2011) Production and fate of transparent exopolymer particles in the ocean. *J. Geophys. Res. 116:C00H13.*

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