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# Time series of *in-situ* particle properties and sediment trap fluxes in the coastal upwelling filament off Cape Blanc, Mauritania

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ABSTRACT

We compared particle data from a moored video camera system with sediment trap derived fluxes at ~1100 m depth in the highly dynamic coastal upwelling system off Cape Blanc, Mauritania. Between spring 2008 and winter 2010 the trap collected settling particles in 9-day intervals, while the camera recorded *in-situ* particle abundance and size-distribution every third day. Particle fluxes were highly variable (40–1200 mg $m^{-2}$ $d^{-1}$) and followed distinct seasonal patterns with peaks during spring, summer and fall. The particle flux patterns from the sediment traps correlated to the total particle volume captured by the video camera, which ranged from1 to 22 $mm^3$ $l^{-1}$. The measured increase in total particle volume during periods of high mass flux appeared to be better related to increases in the particle concentrations, rather than to increased average particle size. We observed events that had similar particle fluxes, but showed clear differences in particle abundance and size-distribution, and vice versa. Such observations can only be explained by shifts in the composition of the settling material, with changes both in particle density and chemical composition. For example, the input of wind-blown dust from the Sahara during September 2009 led to the formation of high numbers of comparably small particles in the water column. This suggests that, besides seasonal changes, the composition of marine particles in one region underlies episodical changes. The time between the appearance of high dust concentrations in the atmosphere and the increase lithogenic flux in the 1100 m deep trap suggested an average settling rate of 200 m $d^{-1}$, indicating a close and fast coupling between dust input and sedimentation of the material.



## Introduction

The export of organic matter from the surface to the deep ocean plays a key role in the global carbon cycle and is a crucial process for the sequestration of atmospheric carbon dioxide. This occurs by the conversion of carbon dioxide into organic matter via phytoplankton growth in the sunlit surface waters. The organic matter may be removed from the surface ocean if the phytoplankton form settling aggregates. This process is known as the ''Biological Pump'' (Broecker, 1982) and its efficiency is mainly a function of the remineralisation rate and sinking velocity of the organic matter.

The export of particulate organic carbon typically occurs via settling of large marine particles, like marine snow (aggregates >500 µm) or fecal pellets, which are formed from a large variety of organic and inorganic particles in the upper ocean. Particle mass fluxes in the deep ocean are mostly quantified by the application of sediment traps, which collect sinking material over a known time interval and area. However, the sample resolution of deep ocean sediment trap collections is rather low (days to weeks to months) and does not determine which particles determine the mass flux (Lampitt et al., 1993). First, because this method integrates particle sizes and numbers and second, because individual aggregate structures are not preserved in the sample cups due to their fragile nature. The latter makes the collection and study of individual aggregates extremely difficult and was only achieved at the ocean surface using Scuba techniques (e.g. Alldredge and Gotschalk, 1988). Samples of single aggregates below Scuba depths are rarely available despite the improvements of marine technology during the past 30 years. The development of non-destructive methods, like vertically profiling camera systems, provided valuable information about the *in-situ* abundance and size distribution of marine particulate matter through the entire water column (Honjo et al., 1984; Asper, 1987; Ratmeyer and Wefer, 1996; Gorsky et al., 1992; Lampitt et al., 1993). Most camera profiles show a dramatic decrease in the particle abundance within the upper few hundred

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meters of the water column, indicating that the processes determining the amount of material that is being exported, already take place in the upper ocean (Iversen et al., 2010; Stemmann et al., 2004; Jackson and Checkley, 2011). In contrast to sediment traps, *in-situ* cameras can directly detect intrusions of laterally advected material into distinct depth layers (Fischer et al., 2009) and the resuspension of particles above the seafloor (Walsh and Gardner, 1992; Karakas et al., 2006). However, vertical profiles must be regarded as snapshots, because they only measure the actual particle distribution over depth at a certain time point at a certain place. Furthermore, data from profiling systems provide no information about composition, mass and settling velocities of individual particles. Although Guidi et al. (2008) and Iversen et al. (2010) were able to accurately estimate particle fluxes from high resolution camera profiles, these calculations are still based on certain assumptions regarding size-specific mass and settling velocities of the particles due to a general lack of knowledge about individual particle properties.

Time series of paired measurements of optical systems and sediment traps combine the advantages of both methods. However, such studies are rare due to the fact that commercial cameras for long term deployments do not exist and most systems described in the literature are prototypes developed by certain institutes and are no standard study tools. Lampitt et al. (1993), for instance, deployed a camera system at a mooring depth of 270 m in the Porcupine Abyssal Plain for a period of 5 months. The system took pictures every 8.5 min in order to study the seasonal and the daily variations of marine particles. Ratmeyer and Wefer (1996) were able to compare particle abundance and size, acquired by a still image camera, with particle fluxes over three months at a location north of the Canary Islands. Their system was programmed in 4.3 day intervals and allowed to correlate one flux peak with an increase in total particle volume.

Because the studies by Lampitt et al. (1993) and Ratmeyer and Wefer (1996) proved that optical systems are able to record flux events, we developed and deployed an optical system together with sediment traps in a mooring array for two years. The aim of the study was to record the seasonal variation in particle abundance and size-distribution with a camera-system in combination with vertical flux patterns collected with sediment traps in order to study transport processes and *in-situ* particle properties over longer periods in the upwelling system off Cape Blanc, Mauritania. Video recordings and trap samples were collected during two subsequent deployments of the eutrophic $CB_{eu}$ mooring located 120 nm off the coast, between spring 2008 and early winter 2010. The video camera was deployed within the mooring array at a depth of 1100 m, one hundred meters above the sediment trap, and was programmed to record 30 s of video in three day intervals.

## Materials and methods

The $CB_{eu}$ mooring was first deployed in 2003 and has been serviced on an annual basis ever since. The data presented here are from the $CB_{eu}6$ and $CB_{eu}7$ moorings that were recovered and redeployed during the RV Poseidon cruise 365 and the RV Maria S. Merian cruise 11 in 2008 and 2009, respectively. The $CB_{eu}6$ deployment period was from the 26th of April 2008 to the 28th of March 2009, followed by the $CB_{eu}7$ mooring deployed between the 1st April 2009 and the 28th of Febuary 2010. The moorings were equipped with a sediment trap and a Multi Sensor Platform (MSP) both described below (Table 1).

### *Multisensor platform (MSP)*

The MSP is a hexagonal glass fibre reinforced plastics frame with a height of 2.20 m, a diameter of 1 m and a total weight of ~150 kg. It was equipped with a particle video-recording system (PVS) and a *Falmouth Scientific* 3DACM Conductivity, Temperature and Depth sensor (CTD). The MSP was placed 100 m above the sediment trap and, according to the pressure sensor, was located at 1110 m depth during the $CB_{eu}6$ deployment and at 1145 m depth during $CB_{eu}7$. The CTD measured temperature, pressure and conductivity and was further equipped with a compass and an acoustic current meter, providing absolute current direction and velocity. Additionally, a tiltmeter provided the tilt angle and tilt direction of the MSP. The CTD was programmed to collect 30 s of data every 6 h and averaging these measurements into a single value which was saved in its memory buffer.

The Particle Video-recording System PVS consisted of a Sony HD camcorder with a standard 1080i HD resolution (1440 × 1080 pixels). The optical setup of the camera was based on a still camera systems used and described by Honjo et al. (1984), Asper (1987) and Ratmeyer and Wefer (1996). The PVS was programmed via a microcontroller connected to the camera's LANC interface, which was programmed to record a video sequence of 30 s every three days at midnight. Each video sequence was illuminated with a 50 Hz *Deep Sea Power & Light* Seastrobe 2000, which was mounted at a distance of 45 cm perpendicular to the optical axis of the camcorder. The strobe light created a 12 cm wide slab of light whereby a defined sample volume of 6.47 l was illuminated. For size calibration, a scale was mounted at the opposite side of the strobe and was visible in the recordings. The entire unit was powered by a 12V/38Ah DSPL battery. The total recording time was limited by the 60 min recording length of the Mini-DV tapes, used by the camera. Unfortunately, a fault in the firmware prevented recordings during the $CB_{eu}6$ deployment after the 31st of December 2008, resulting in a gap in the recordings between January and April 2009.

Upon recovery of the PVS, the DV tape was digitalized into one AVI-file with full 1080i HD resolution. Subsequently, the Adobe Premiere Software package was used to separate the AVI file into individual video sequences of 30 s length, according to their recording date. Due to memory limitations of the image analysis software, we only used the first 15 s of the each sequence. Individual frames from each sequence were grabbed and saved as a BMP image stack, providing a total of 375 images for a 15 s video recording at a frame rate of 25 FPS. The BMP image stack was converted into an 8 bit grey scale image stack with 256 grey values, to ease the image analysis. Many video sequences could not be used, because the autofocus of the camera activated accidently for unknown reasons. As a result, the camera focus was outside the illuminated sample volume, thus, 79 of 196 video sequences were discarded. This amounted to a total number of 57 usable video sequences from the $CB_{eu}6$ deployment and 60 usable video sequences from the $CB_{eu}7$ mooring.

The 8 bit grey scale image stacks were analysed using the IMAGEJ image analysis software. An 8 bit greyscale image covers 256 grey scale values, where a pixel with a grey value of 0 appears black and a pixel with a value of 255 appears bright white. By setting a grey value threshold, the background can be subtracted and the software recognises areas with a grey scale value above a certain threshold as a particle. Pixels below the threshold were treated as background and were excluded from the data set.

The image analysis software extracted the size of individual particles recognised on each of the 375 frames that belonged to one sequence as a circular area, given in $mm^2$. These data were saved to a worksheet, which was used for further calculations. The particle abundance was calculated by counting all particles found in every single frame and by dividing this number by 375. Hence, the particle abundance is the total number of particles averaged over all frames. From the area, the Equivalent Spherical Diameter (ESD) of each individual particle was calculated and likewise averaged over all frames to one value. The total particle