UNDERWATER VISION PROFILER- A SENSOR FOR DETAILED ASSESSMENT OF PARTICLES (> 100 µM) AND LARGE PLANKTON DISTRIBUTION

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INTRODUCTION

The mid- and deep-water layers of the oceans remain one the remaining unknown ecosystem on earth despite it's fundamental importance on global biogeochemical fluxes. Observing this ecosystem remain technologically challenging. Underwater imaging technologies are promising tool for the study and quantification of mid- and deep-water zooplankton and marine particles. The zoogeography and spatial distribution of fragile midwater zooplankton are basically unknown because they cannot be sampled adequately with plankton nets. Bottles and moored and floating, pumps and sediment traps are undoubtedly the most commonly deployed instruments used to evaluate particle flux by collecting sinking material. Also widely used, these instruments cannot provide a synoptic view of the particle flux because of the technological constraints to have simultaneous mooring in many places. In addition, these instruments integrate the collection of over time and space and it is difficult to study individual organism or particle so as to infer mechanistic information.

Direct observation and collection of components of the deep pelagic ecosystem from manned and unmanned vehicles have documented the in situ behaviour, taxonomic diversity, spatial distribution, and relative abundance of plankton and also the spatial distribution of particle size spectra. Both components of the ecosystem are seldom acquired simultaneously also zooplankton are also responsible for the aggregation, fragmentation and remineralisation of a large proportion of the particulate organic matter produced at the surface of the oceans. For a better understanding of the processes leading to the export of these particles from the euphotic zone, it is important to evaluate the distribution of the particulate matter and of the zooplankton in the water column simultaneously. Imaging systems allow quantification of zooplankton and particles over scales of centimetres to kilometres.

The Underwater Vision Profiler (UVP) has evolved through 4 previous generations and was built to study large (> 100 μm) aggregates and zooplankton simultaneously and to quantify them in a known volume of water (Fig. 1). The latest version, UVP5, is a miniaturized instrument of comparable capabilities. In this extended abstract we describe the UVP hardware, together with ZooProcess and Plankton Identifier software that are used to treat the data. We illustrate the procedures for sample and data analysis through application of the UVP system to an oceanic transect in one of the most oligotrophic and less studied area of the tropical Pacific Ocean. We propose standards for the long-term archiving and sharing of raw and processed images and output files. We demonstrate a semiautomatic classification approach based on human validation of automated zooplankton image analysis that provides highly reliable results that are appropriate for quantitative ecological and biogeochemical studies.

HARDWARE and SOFTWARE

The UVP5 weighs less than 30 Kg in air and is rated to 3000 m. It contains an intelligent camera, optics, pressure and angle sensors, acquisition and piloting board, dedicated electronic power boards and batteries. The UVP5 acquires only on focus images in a virtual volume of water delimited by a light beam issued from red light-emitting diodes (LEDs) of 625 nm wavelength housed in two independent glass cylinders. The red light was chosen to reduce zooplankton phototactic behavior and to prevent contamination by the sun light at the surface. The typical flash duration is 100 µs to prevent image blur. Two lighting units are fixed on an aluminum plate facing each other to allow a better light homogeneity in the field of view (FOV) of the camera. The typical light beam is 4x20 cm leading to a sampling volume of 1.02 Liter per image.

The piloting software runs the piloting board. The software monitors the system status and handles communications with both user and camera. Acquisition and process sequences can be piloted by the user or support vector such as ROV or AUV through either the RS232 or an external switch for complete flexibility. Sequences can also be started by preset time with a very low power consumption sleeping mode between the sequences. Thousands of time programmed sequences can be implemented allowing very long deployments on moorings. An intelligent depth controlled mode helps using the system on CTD rosette. The software also monitors data from up to 8 analogue sensors and sends them to the camera with the pressure to be interfaced with the images in real time. The piloting board converts summarized data from the images sent by the camera

to the DA converter for real time display on the CTD software. The UVP can be easily mounted on a CTD rosette or any other suitable vectors.

The image analysis software is implemented in the camera to acquire and process images in real time. The gain, shutter, and trigger for the LED pulses are controlled. Four modes of operation are provided to adapt the system to users' needs. These modes are: (1) Full process: all images are saved and processed in real time limiting the acquisition to 3 Hz, and (2) Image acquisition only: the images are recorded on the flash memory or the hard drive providing up to 3.5 Hz rate, and (3) Mixed process: the images are acquired and processed to get size and grey level for each object. Vignette images or full images of objects above a preset pixel size limit are saved on the flash memory or the hard drive. This mode saves memory, keeps images of "interesting targets" to be identified later and allows a rate up to 5.5 Hz, and (4) Process only: the images are processed and only the size and mean grey value of each of the detected object is saved in a text file. This fastest mode can achieve 6 Hz rate. The pressure and environmental data are saved with the measurements from the objects and some summarized data are transmitted to the user in real time.

The UVP calibration follows 2 critical steps: (1) Calibration of one image water volume, and (2) Calibration of the size of particles in metric unit. Particle counting is very sensitive to step 1 while particle sizing depends on step 2.

AUTOMATIC AND SEMI-AUTOMATIC RECOGNITION OF PLANKTON AND MARINE PARTICLES

The system allows to obtain automatically size, shape and gray levels of any object larger than 100µm in ESD. In the marine environment most of them are aggregates of detritus. Objects larger than 600µm are stored as images of "interesting targets". They can be analysed by a semi-automatic recognition method using the same software as for the Zooscan (see abstract of session 02B Session 2C: Biochemistry and ecosystems). It allows metadata acquisition and the processing of the images. The vignettes of the objects are enhanced and a scale bar is added with the depth and the number of the source image. A Plankton Identifier or PID file is created containing the variables of every object and the corresponding depth. Prediction of the most representative categories of organisms is done in Plankton Identifier using the Random Forest method. After the prediction, vignettes are automatically copied into the prediction folders and the identification validated by expert. During the Arcticnet-Malina experiment onboard the NGCC Amundsen last July 2009, only 8% of the total 41000 "interesting targets" prediction had to be corrected to get the final zooplankton dataset sorted in 7 groups in quasi real time (Fig. 1 b and c). Further analysis can be performed by sharing images through the Internet with a network of taxonomic experts so as to increase the taxomic details. For example 21 morphotypes were recognized in global analysis of mesopelagic plankton using the UVP 4 [5].

All metadata information, particle measurements and object identifications are loaded with the available data into a single Matlab standardized database facilitating the data process, merging of data from different UVP versions and rapid printout for particles and zooplankton.

DISCUSSION

Biogeochemical modeling uses mostly particles results from sediment trap deployments unfortunately, this method is integrative and not adapted to high resolution studies in space and time. The UVP provides complementary information on particles size distribution at high spatial resolution (one image every 20 cm at 1 m s^{-1}). It was showen that particle size distribution can be used to estimate the potential particles settling speed and fluxes in the water column at global scale [2]. This proxy of particle flux can be used to get detailed vertical resolution of the fluxes and derive the particle remineralization rate that is used by biogeochemical modelers to describe the decrease of the export with depth [2]. As an example, we show the spatial transect of calculated flux in the Tropical Pacific during the BIOSOPE cruise (Fig. 2).

The UVP can also be used to describe spatial evolution of carbon flux in different hydrological regimes, frontal zones, equatorial systems [1], eddies or gyres [3,7]. The possibility to work at high spatial resolution revealed that particle distributions can be constrained in space inducing heterogeneous export in the open ocean. Eddies can distribute and export particles in structures smaller than 100 km wide with an impact on the distribution of organisms that feed on settling material. In addition macrozooplankton mesopelagic distribution in mesoscale eddies or in global comparison can also be studied [5].

Assessment of spatial variation of particle distributions is as important as the estimation of their temporal variation at one location. The former will provide information on mechanisms that transform the particles and potentially decrease the carbon export to the mesopelagic layer in–specific regions [6]. Seasonal variations of the carbon flux have been observed in the past. These variations have been correlated to the variations of primary production and to the variations of the phytoplankton community. Episodic particle flux 'events' have also been described but they are very difficult to resolve with sediment traps or with UVP5 unless you are in the field when the bloom occurs.

The UVP5 is a promising tool that may help to understand mechanisms at the origin of particles

and zooplankton distribution spatial and temporal variability. The understanding of these mechanisms is critical and will allow modelers to better parameterize their biogeochemical models. Because UVP5 can be interfaced with a CTD, it can be used as a sensor with high frequency data acquisition. Considering the particles size range and the zooplankton data acquisition, the UVP5 may become an interesting instrument for the investigation of the 'twilight' and the deep zones.

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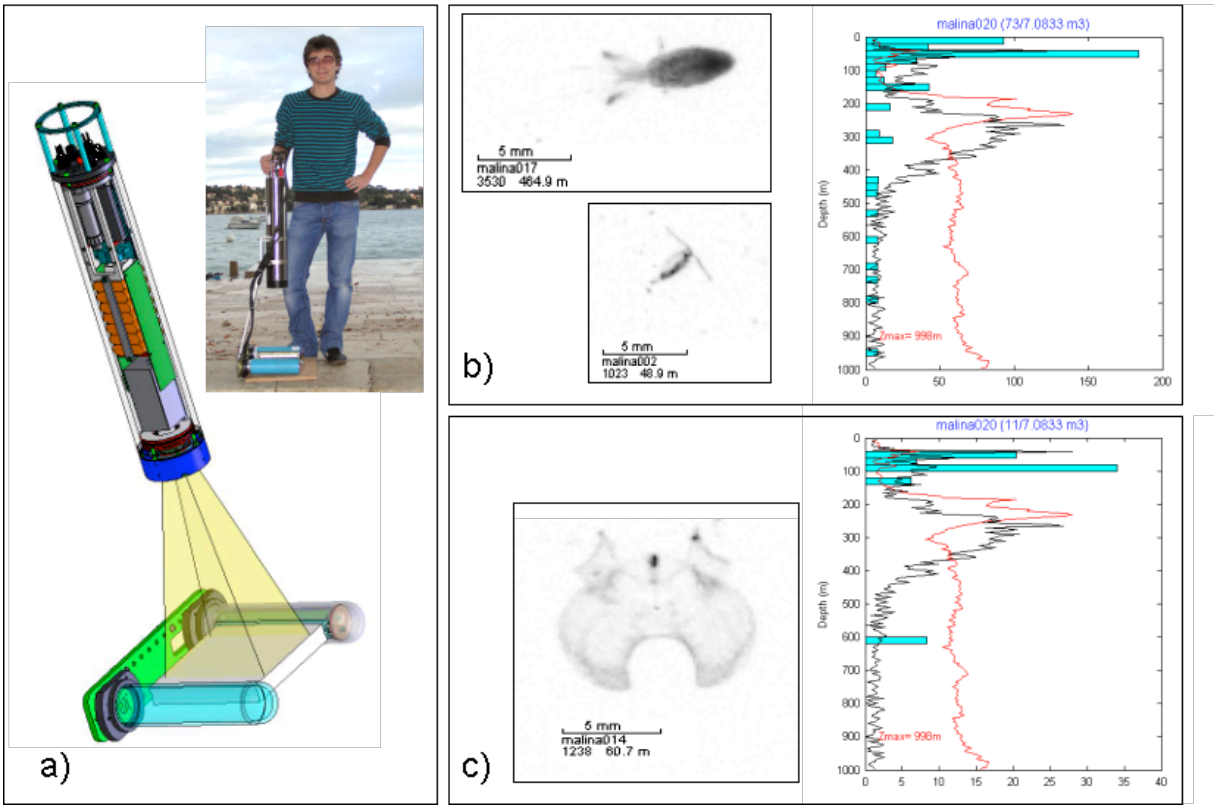

Figure 1: a) UVP5, b) specimens and vertical distribution of copepods (blue), particles below 200 µm (black) and particles above 500 µm (red) at station 20 of Malina cruise, c) specimen and vertical distribution of appendicularia (blue), particles below 200 µm (black) and particles above 500 µm (red) at station 20 of Malina cruise.

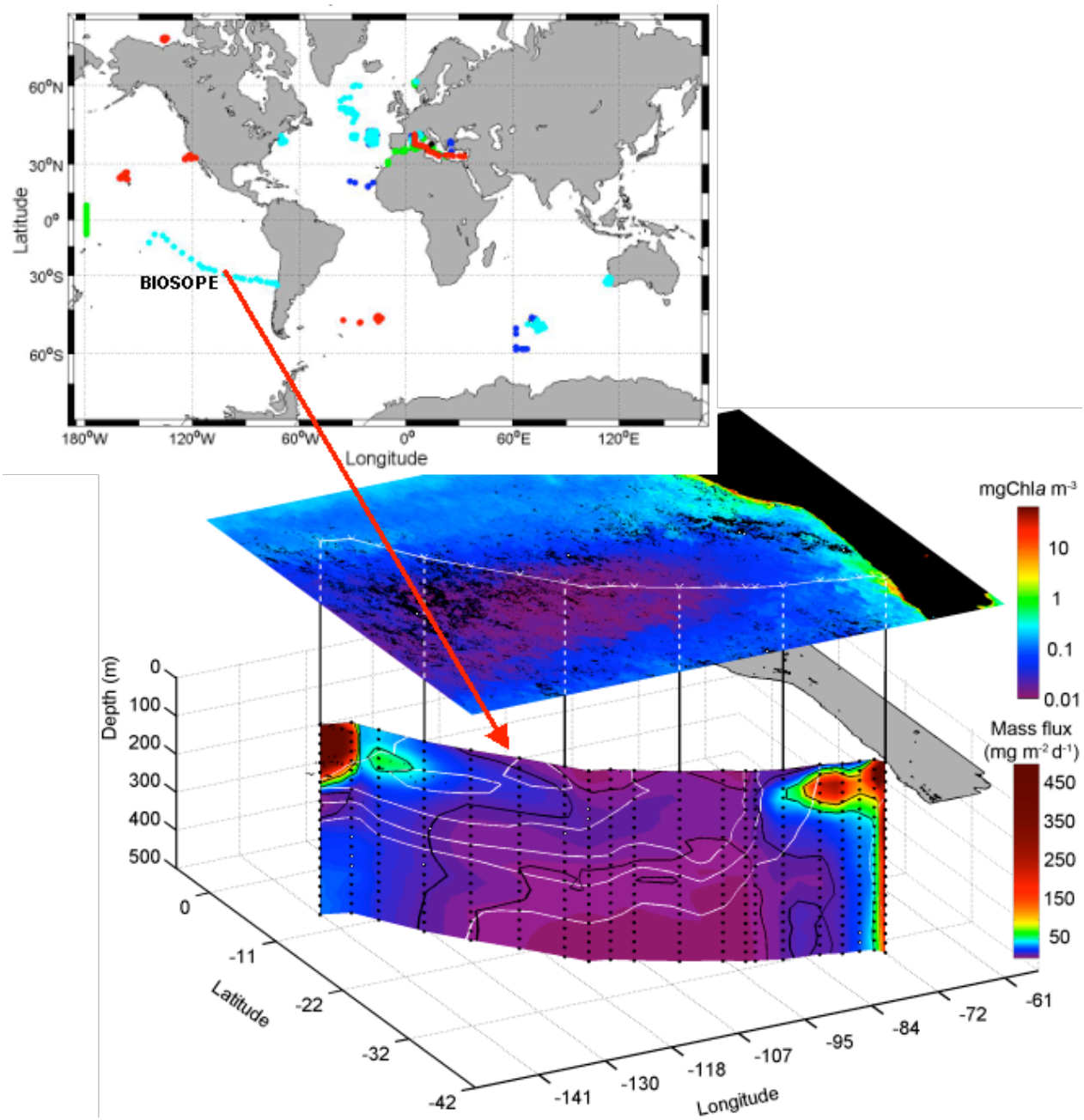

Figure 2: Upper panel: Map showing the location where the different UVP have been used since 1991 (green UVP2, dark blue UVP3, light blue UVP4, red UVP5). All the particle data from the different UVP have been intercalibrated. Middle panel: Surface Chlorophyll a by Seawifs. Lower panel : Mass flux of LPM in mgDWm^{-2} d^{-1} estimated from size measurements of every individual particle recorded during the vertical deployment of the UVP. Only data from 0– 500m are shown for better visualisation of the upper water column structures. Isohalines are in white.