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New Perspectives in Coastal Marine Environment Management due to New Development in Instrumentation

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Abstract :

A new *in situ* probe which allows direct determination of the particles distribution spectra in the sea as well as an unbiased estimation of the total particle load, has been developed by IFREMER. It has been used in coastal areas and the results give new insights into environmental coastal processes which are described.

This new sensor uses the well-known principle of diffraction pattern analysis previously used in bench-top instruments. However, the rigourous constraints imposed by its oceanographic uses required a completely new design.

This instrument presents numerous advantages in environmental research. Its use in phytoplankton studies is presented and led to a new sampling strategy for toxic dinoflagellates. It allows to study sedimentation and flocculation processes. Finally, sampling of hydrophobic pollutants may be optimized by means of particles population clustering.

Introduction :

In coastal waters, fine particles are a major component of settled sediments. These cohesive sediments are for many reasons of great importance to the marine environment. Aside from the problems of pure sedimentology, these particles play an important role in the transport of some contaminants : hydrophobic pollutants ; possibly, heavy metals and bacteria. Bacteria find on particles a substrate for growth and some ways of survival in microenvironments around particles and colloids. A variable fraction of the particulate material is represented by living organisms, mainly phytoplankton under 150 µm. Phytoplanktonic toxic species may develop up to sufficient densities for inducing deleterious effects to marine life, aquaculture and public health (paralytic, amnesic, diarrhetic,... poisoning).

The distribution of these particles depends on the physical environment (current field and turbulence) and the chemical local structures (nutrient sources and microlayers of organic matter). Indeed, many studies have shown that coastal particle populations are structured in aggregates (or flocs) of large size which are maintained by interparticles forces (Kranck, 1973 ; Trent, 1978 ; Eisma, 1986 ; Bale, 1987). These flocs may be disrupted by the small scale turbulence. In estuarine environments, the "particle" sedimentation rate is more depending on the sedimentation rate of these aggregates than on the individual particle rate (Van Leussen, 1988). In terms of phytoplankton distribution, physical features of a profile may govern the accumulation of some species in very narrow layers (20-60 cm) (Vilicic *et al.*, 1989) where biological and physical conditions are met for an optimal growth of the population. These features have been sampled up to now either by luck or by divers.

Many different techniques based on optical methods such as absorption, diffusion, diffraction or on other physical principles like sedimentation rate (Sedigraph), electrical resistance variations (Coulter principle) and acoustic methods have been developed either for total load estimation or, more rarely for grain-size analysis. The latter required usually water sampling. Analysis after sampling means that the particles may have been subjected to elutriation, to different turbulence status, to transit through pumps or through calibrated orifices. Grain-size distribution of the particle population may be affected, especially by rupture of aggregates due to shear forces (Gibbs, 1981). For these reasons, different *in situ* sensors measuring total particle load have been developed, using acoustic or optical principles (Schaafsma, 1986 ; Huntley, 1982). Acoustic measurements present two major disadvantages relatively to optical techniques: the measure is highly sensitive to small changes in water density and does not discriminate grain sizes. Load estimation techniques using an optical principle may lead to large biases due to differences in particle modes if the size distribution is not known (Huntley, 1982).

For these reasons, we have developed an optical technique based on the analysis of the diffraction pattern of a laser beam interacting with particles *in situ*. The results obtained in this way are theoretically not depending on the population mode. After a brief description of the instrument, different applications of the techniques are presented in the communication. The implications of the new insights acquired are detailed in terms of environmental science and monitoring.

Brief Technical Description

Elements of Theory

The scattering function at small angles for spherical particles with a diameter $D > \lambda$ (light source wavelength), can be approximated by the Fraunhöffer expression for diffraction :

$$\beta(\theta) = K.Q.(\pi D/\lambda)^2.J^2{}_1(\pi D.\sin(\theta)/\lambda)/\sin^2(\theta)$$

where k is a constant and Q the efficacy factor close to 2 in our case. D is the particle diameter and J_1, the first order of Bessel function. This equation shows that the intensity measured at the angle θ is strongly dependent on the particle size and/or the size distribution. So, efficient nephelometry requires the knowledge of the grain size distribution in the medium.

Simultaneous scattered light measurement at different angles allows the knowledge of the grain size distribution. The light intensity received on the i^{th} detector can be expressed by :

$$I_i = \Sigma_j(N_jA_{ij}) \quad \text{with summing on all the size classes}$$

or

$$I_i = \Sigma_j(V_ja_{ij}) \quad V_j \text{ being the total volume of the } j^{th} \text{ class}$$

Without any calibration, only the relative volume abundance ($\alpha_i=V_i/V_{total}$) can be obtained as long as the particles are not too close (Babinet's principle). However, I_i can be also expressed as : $I_i = KV_t.\Sigma_ja_{ij}\alpha_j$ leading to $V_t= I_i/(K.\Sigma_ja_{ij}\alpha_j)$ where K is a size dependent factor including the amplification of each channel.

After load calibration, the instrument can be used as a grain size analyzer and a total particle cross-section detector anywhere without any specific calibration.

Technical Description

The quality of the measure depends mainly on the geometry of the probe. The stiffness of the optical axis is the most critical parameter. The elements of a commercially available instrument (Grain Size Analyzer HR715, Cilas, France) have been integrated in an original setup meeting the tolerance requirements on alignment and insuring water tightness of the system up to 100 m depth. The alignment of the light source along two parallel axis as shown on Fig.1 allows a good stiffness of the optical bench. The optical axis continuity is achieved by a glass optical block consisting in two mirrors and the measuring cell itself in which seawater flows freely. Particles interact with a parallel beam of 30 mm diameter produced by a He-Ne laser beam. The parallel beam limits the "speckle" induced by different positioning of particles in the 1 or 3cm thickness cells used. The radial dispersion of the energy is measured by a 16-photosensor board located in the focal plane of the lens and giving informations about 16 size classes (upper diameter limits : 1,1.5,2,3,4,6,8,12,16,24,32, 48,64,96,128,196 µm)

Measurement rates are fixed to 30 s and one measure corresponds to an average of 64 diffraction pattern samplings. The probe is powered (24V) from the surface and a RS232C link allows the data transmission from the probe and additionnal sensors for real-time data representation.

A depth gauge is included in the probe which, weather permitting, allows a direct control at the winch of the probe immersion. A CTD probe, a fluorometer and a profiling currentmeter are synchronized in terms of data transmission. Data are processed and plotted in depth profiles in real time on a PC screen. A sampling array of eight syringes (1.2 liter) can be electrically triggered. This equipment allows to describe accurately a profile and to sample any peculiarity detected. When needed, a 4 cm-diameter hose was attached to the assembly close to the measuring cell and allowed peristaltic pumping of the water layer at a 30l/min flow rate.

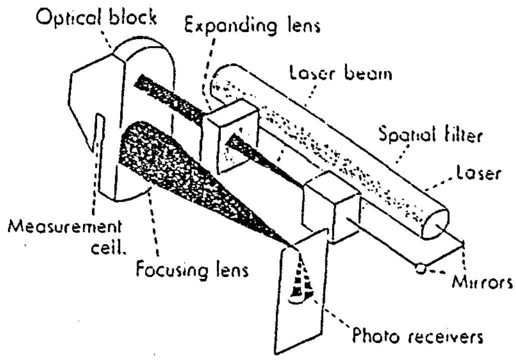

Fig. 1 : Lay Out of the Grain Size Analyzer

Validation

The instrument has been validated against other techniques in grain-size analysis and total dry weight of particles.

Laboratory calibration was conducted by means of a circulation chamber clamped on top of the measurement cell. Dead volume was kept to a minimum. Calibration beads suspension were pumped into the cell by a peristaltic pump placed after the cell. Water was pumped 2 cm above the measuring zone ; the feeding tube was then clamped. Data acquisition was performed as long as the load estimate was stable. The circulation cell was then emptied into a container for Coulter Counter analysis. This procedure allowed to limit the sampling variance which was found too high in case of few measurements as convection may have been created in the circulation chamber inducing elutriation. Different unimodal populations of calibrated beads (Polysciences, USA) have been analyzed and their measured diameters fitted the specifications. Concentrations of particles have been compared to the load estimate. Results are summarized in Table 1.

Diameter µm	Slope	Slope Std.Err.	Intercept	Intercept Std.Err.	Corr. r^2	n
2.92	4641990	202429	-57699	64010	0.996	6
6.5	419170	22304	-1862	9412	0.989	6
15.6	15157	491	-478	404	0.997	6
25.7	3329	92	-93	81	0.999	6
48	440	14	-10	9	0.997	5

Table 1 : Linear correlation parameters between quantity of particles and load estimate

Intercepts were not significantly different from zero. The slope decreases with the increasing size as it compares a number of particles with their volume ; it follows a multiplicative law : Slope = A. $(\text{Diameter})^b$ with b = -3.3.

A natural mud sediment treated in accordance with Riviere's method (1977) in order to remove all organic has been analyzed for its grain-size distribution with Coulter counter and the grain-size analyzer. The two analyses led to approximatevely the same distribution (Fig. 2). However, some discrepancies appear in the lower range (< 30 µm) : they probably represent a difference between measurement principles. As the particles are not spherical, it can be interpreted as the differences of estimations based on volume (Coulter) and cross section measurements.

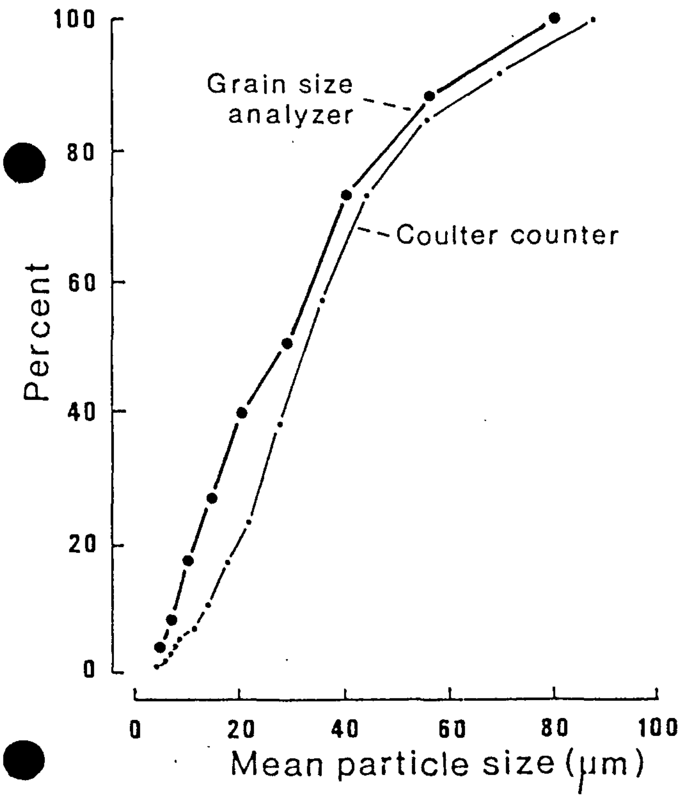

Fig. 2 : Comparison of a Coulter Counter and a Grain Size Analysis of a sediment without organic matter (cumulative distribution).

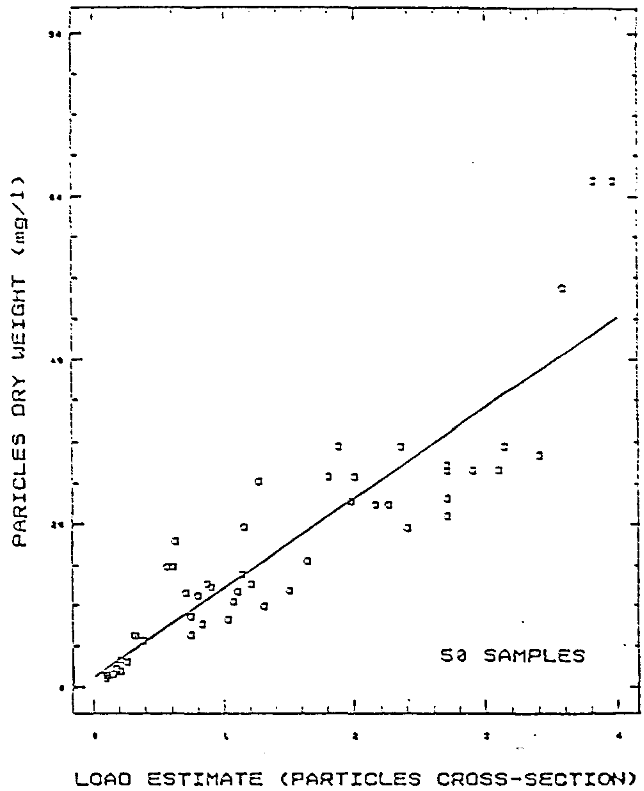

Fig. 3 : Linear correlation between load estimate and dry weight. (Dry weight = 1.23 + 11 * Load $r^2 = 0.80$).

In situ load estimations have been compared to dry weight measurements in different areas. Fig. 3 represents the linear relationship between the two parameters obtained on 50 pairs of measurements. These samples were collected during a field trip during which different types of suspensions have been observed. Despite these large variations, the grain-size analyzer estimates quite well the amount of particles in suspension.

Applications and Perspectives

Distribution of particles in estuarine waters

The first application of this technique has been done in the Seine estuary. This river which pass through Paris drains a large area and has an average flux of 400 m^3/s with extrema of 100 and 1800 m^3/s. Two stations were studied during a tidal cycle. Fig. 4 represents a profile obtained offshore where there is still a slight halocline. There is a accumulation of particles in the pycnocline (5 times more than in the adjacent layers). This accumulation is constituted mainly by large particles over 96 µm (85 %). Under this layer, population profiles correspond to sediment with an increase of larger particles abundance close to the bottom. Above the pycnocline, the profiles are quite typical of what is to be found in the surface waters of the bay.

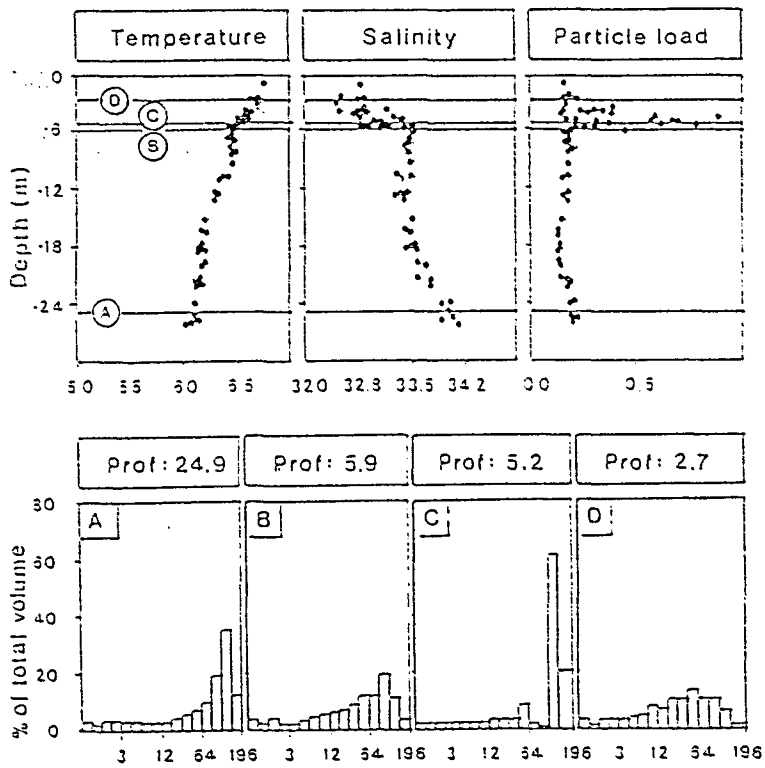

Fig. 4 : Offshore vertical profiles in the Seine Bay
top : temperature, salinity and load vs. depth (vertical axis in meters)
bottom : four histograms at selected depths

A more inshore profile (Fig. 5) is less saline and there is no pycnocline but a continuous gradient of density. However, an intermediate layer presents a minimum load. It can be interpreted as a maximum shear layer between the surface layer going offshore and the inshore going bottom layer. At this interface, around 4.1 m, one can observe a greater importance of the large particles (60 %).

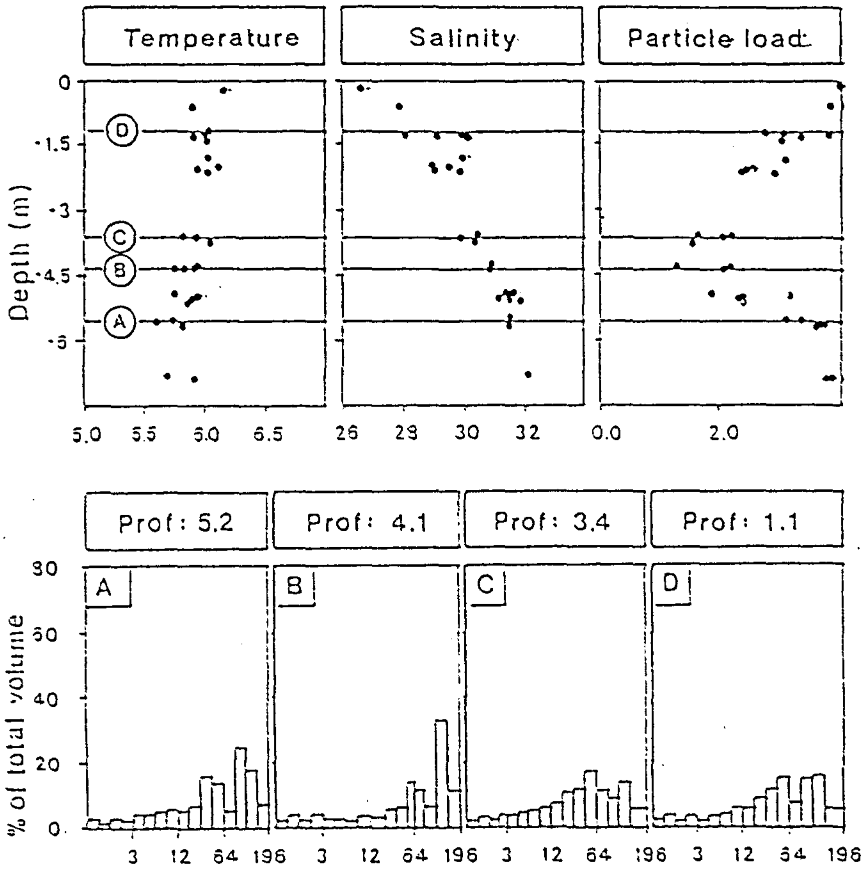

Fig. 5 : Inshore profiles (legend as Fig. 4)

The accumulation of these large particles have been observed in any pycnocline, either due to temperature or salinity gradients, in different areas of the french coastal zone. They are associated to zones with limited agitation. In most cases, these layers did not exceed 40 - 50 cm thickness.

Particle Populations Evolution (Sedimentation and Flocculation)

A common feature of the coastal waters profiles is the association of pycnocline layers with the presence of large particles between 96 and 128 µm. In order to decide if this distribution results from some accumulation from above layers or from some other mechanism, some kinetics studies of the evolution of particulate material have been conducted using the same instrument. For this purpose, the circulation cell used for calibration was filled up with water sampled in these layers immediately before. Fig. 6 represents the variations of the apparent load in two cases : one kept still and the other, with some ponctual agitation. In the second case, agitation lowers the apparent load to the order of magnitude observed initially ; a subsequent increase is, then, observed.

Excluding the creation of particulate matter during the time course of experiment, one can only think of a reorganization of particles. Fig. 7 shows clearly that important changes occured during the time of the experiment : globally, an large increase of the proportion of particles above 96 µm associated to a fast decrease in the percentages of smaller particles and, even, a disappearance in the case of the 64-96 µm class. These comments are true for the two experiments. This process is reproducible and depends strongly on the agitation of the water. The lability of particles associations is evident, considering Fig. 7 where the histograms of the two initial and the final distributions are compared. The small discrepancies may be due to the changes of water parameters which may have occured during the agitation (gas bubbles, for instance).

Fig. 6 : Time evolution of the apparent load
one sample kept still and the other agitated after 1 hour

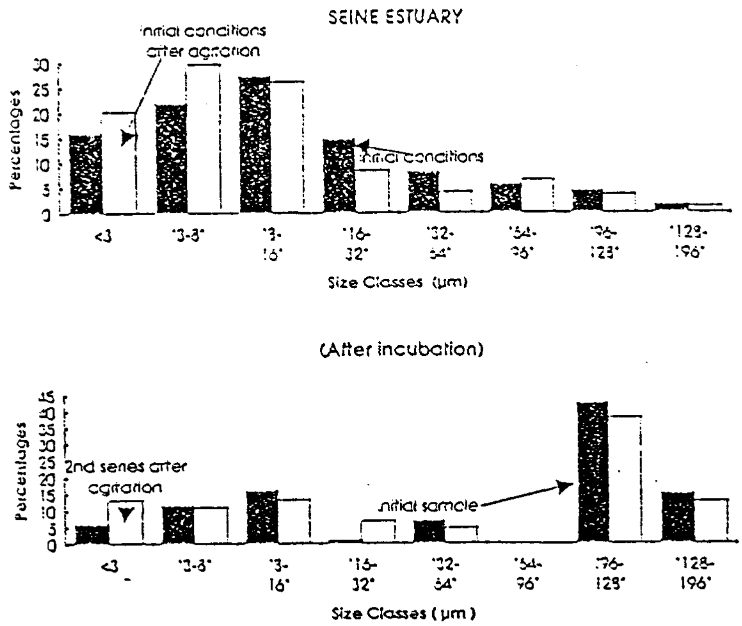

Fig. 7 : Population evolution during incubation
top : initial conditions after sampling (filled cases)
and after agitation (empty cases)
bottom : final conditions after incubation

The aggregation of particles together with dissolved (or colloidal) organic matter and inclusion of interstitial water may explain the apparent load increase.

Phytoplankton

Some field studies were performed on the West Coast of France. In this region, dinoflagellate outbreaks occur regularly and impinge on the economics of the region. *Dinophysis sp.* (Diarrhetic Shellfish Poisoning) has been recorded offshore. During the summer months, a strong thermocline and a weak halocline are established in this area. The profiles represented on Fig. 8 are representative of the 18 profiles obtained during a lagrangian station based on the thermocline displacement. Eleven water samples have been selected from the data transmitted on board. Below 20 m and above 18 m, two homogeneous layers in terms of particles can be observed. Particle load in the thermocline increased significantly and was not associated with any clear increase in fluorescence. This accumulation of particles is due to large size particles (Fig. 8d). These particles are mainly constituted of organic aggregates which can be easily disrupted by agitation.

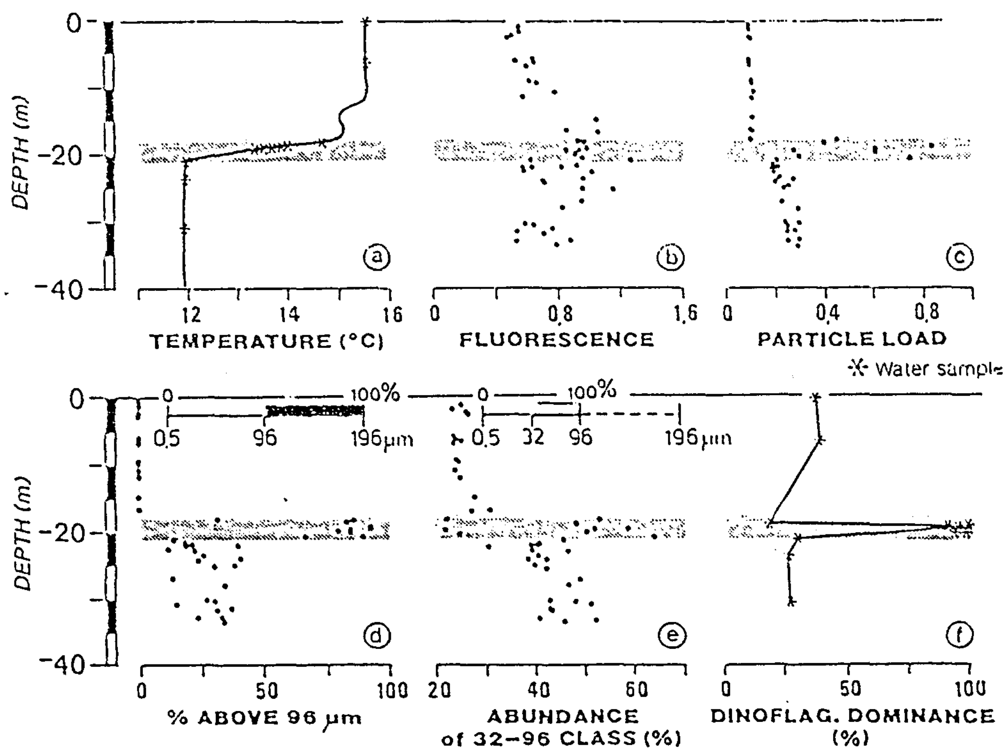

Fig. 8 : Vertical profiles offshore of La Rochelle.
8a : Temperature ; 8b : Fluorescence ; 8c : Particle Load ;
8d : Percentage of aggregates ; 8e : Contribution of the 32-96 µm particles ;
8f : Dominance of dinoflagellates.
The hatched area represents the thermocline and the * symbol water sampling.

When particulate content under 96 µm is normalized to 100 %, it can be seen that particles between 32 and 96 µm predominate in that layer (Fig. 8e). When compared to the phytoplankton samples (Fig. 8f), the dominance of dinoflagellates is clear in that discontinuity layer (depth from 20.09 to 20.50 m). Microscopic observations revealed the presence of small particles and algae under 12 µm in the surface layer. In the bottom layer, particle populations were mainly of sedimentary origin. The thermocline layer particles were mainly organic detritus, terrestrial plant debris and few siliceous particles associated in this case with dinoflagellates (*Ceratium*, *Pyrocystis*, *Dissodinium* and *Dinophysis*).

It is to be noted that the species of interest, in this case, was nowhere to be found in the water column except in that layer. These results have some important implications for the ecological study of this population.

Conclusions and Perspectives

This new technique of measurement allows a reliable description of the particles along a vertical profile as well as a sampling of fine vertical structures. These structures were sampled with great difficulty or, more commonly, were simply missed.

The vertical distribution of aggregates resembles to the coprecipitation processes used in plant sewage treatment but, in our case, instead of sinking down to the bottom, they accumulate at a density or shear barrier. As most of the major pollutants are hydrophobic and tend to adsorb on particles, (over 95 % of the polychlorinated biphenyls (P.C.B.) are in the particulate phase) it is very likely that these flocs layers are more concentrated in pollutants than the adjacent layers. On the other hand, pollutant analysis is very costly in time : a program in progress is trying the feasibility of indexing sampling for hydrophobic pollutants on a multivariate analysis of the particle populations in order to reduce the analyses costs.

The prediction of "red tides" in coastal areas in France is critical to the economics of shellfish production. In most cases along our littoral, these bloom originate offshore and are subsequently transported inshore. Offshore, the algae develop mainly in the pycnocline layers and a correct risk assessment depends on the ability of detecting the presence of such algae in very narrow layers.

This communication presented only one development of instrumentation which allowed to bring new insights into the coastal environmental studies and therefore in their monitoring. The complexity of coastal systems let us think that considerable efforts have to be put into the development of new technologies applied to the coastal environment.

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