CHAPTER 5 - **Instrumentation**

I) CTD-Rosette – Introduction

II) Oceanographic Instrumentation

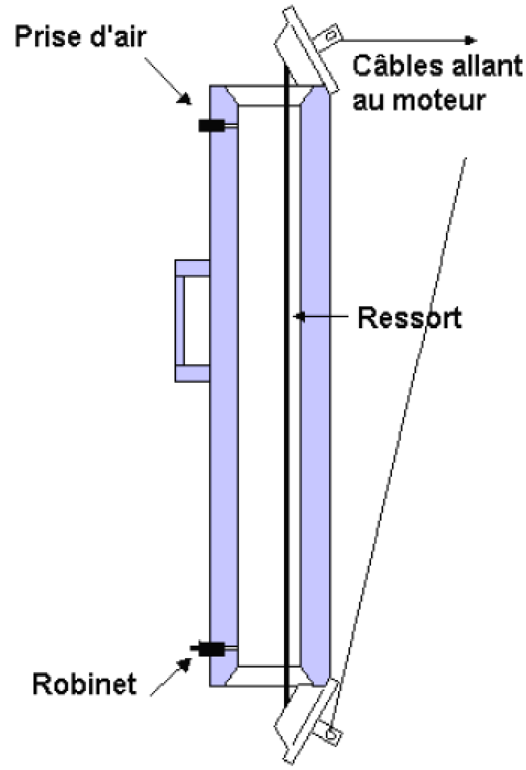
- A) Measurement systems for deriving a specific parameter
  - temperature
  - conductivity
  - pressure
  - speed of sound
  - current velocity
  - position, displacement
  - water height
  - swell
  - turbidity, light attenuation
  - phytoplankton biomass
  - other physical/chemical properties
- B) Measurement platforms at sea
  - campaigns at sea
  - moorings
  - drifters, floats, profilers
  - underwater vehicles

III) CTD-Rosette at MIO

[sources, non-exhaustive list = "Capteurs et instrumentation utilisés en océanographie physique" by J.-P. Girardot; http://www.univ-brest.fr/lpo/girardot; "Instrumentation et métrologie en océanographie physique" by Marc le Menn , Lavoisier editions; Documentation on the calibration of the sensors produced by D. Taillez, G. Coustillier; with all my thanks]

I) CTD-Rosette – Introduction

CTD profiler of the MIO (Phybio campaign 03/2008)



Schematic of a Niskin bottle

The CTD and other sensors of the MIO rosette sampler are located below the Niskin bottles. The instrument package (see Part III) usually comes with a pinger which emits an acoustic pulse every second (or every n seconds) in all directions. Part travels to the surface while another part travels toward the sea bed where it gets reflected. On board the ship, the time between the arrival of the direct and reflected pulses is measured to calculate the distance between the probe and the bottom. The photo above shows a rosette consisting of 12 sample bottles (Niskin bottles), mounted onto a stainless steel frame.
The sensors are linked to electronic data recorders that are placed in a sealed pressure-resistant enclosure. The entire assembly is usually referred to as CTD-Rosette or simply CTD. CTD stands for "**C**onductivity, **T**emperature and **D**epth".

When in use, the CTD is attached to the end of a cable. From a stationary vessel, it is lowered to a chosen depth (generally up to ten meters from the bottom) by unwinding the cable from a winch drum before bringing it back to the surface. This operation is referred to as a station.

During the descent and ascent the measurements are recorded in the internal memory or transmitted directly to the ship. In the latter case, a power cable must be used which usually consists of a non-rotating steel cable with an insulated conductor core. It supplies a current to the electronics of the CTD and is used to transmit the data back to the ship. It is also possible to transmit commands to the probe or to devices associated with it. To ensure a steady connection while the cable unwinds or winds up onto the winch drum, a slip ring (rotating electrical connector) is attached to one side of the drum.

It is interesting to take seawater samples at different depths to analyse them in order to check the proper functioning of the sensors, to refine their calibration, and to bring back samples for the lab-based analysis of some physical or chemical parameters for which the CTD has no onboard sensors. This is achieved by sampling bottles placed vertically next to each other forming a circle (rosette) around the motor which controls their closure. The bottles are open at their top and bottom when the CTD is lowered into the ocean. During the ascent, a command is sent to the motor to close individual bottles at chosen depths (the motor is remotely controlled from the ship and the signal passes through the attached electrical cable).

The probe descends and ascends at a chosen speed (typically at about 1 m/s). This means that the ship can be immobilized for a long period of time, especially when the water column is deep, e.g., a station with a depth of 3600 m may take over 2h to complete. Time-saving techniques have been researched (see next section).

II) Oceanographic instrumentation

A) Measurement systems used

1. Measuring temperature

1.1 CTDs
1.2. Reversing thermometers
1.3. XBTs (reminder)

The e**X**pendable **B**athy**T**hermograph (XBT) made by Sippican Ocean Systems is a classic example of using a thermistor as a temperature sensor. An XBT consists of a plastic sleeve the length of which depends on the model (35 cm for the T7 model) and a coil and an expendable sensor. The casing is placed in a gun-shaped launcher which is connected to a PC.
Once the launcher is armed, the thermistor, located at the front of the sensor, at the centre of a dead weight, is connected to the PC via the cable connection. The probe is launched from the back of the ship on the leeward side by removing the cap which seals the socket and removing the pin. The probe simply drops into the water and unwinds the conducting wire from the coil as it sinks through the water column. Simultaneously, the ship continues to move away from the release point. Data recording begins as soon as the probe touches the water. As the probe descends at a near constant rate, the elapsed time since the release provides an approximation of the depth while the thermistor provides the temperature. Once the wire has run out it simply breaks and the probe is lost.

The accuracy of a T7 XBT is 0.2°C with a resolution of 0.01°C and 2% on the maximum depth with a resolution of 0.65 m. The maximum depth is 900 m if the speed of the vessel is less than 12.5 knots.

Figure: Various XBTs. Top: exploded view of a socket and probe; bottom: fully assembled.

1.4. Hull thermosalinometers

On a ship equipped with a hull thermosalinometer, seawater is pumped toward it and constantly circulates in the conductivity cell. For convenience, the thermosalinometer is typically placed in a laboratory on the ship, a certain distance from the water intake, which means that the temperature is no longer representative of the ocean. Therefore, this device is typically combined with a temperature sensor fixed to the water inlet pipe. As the vessel is subject to pitching and rolling, the water intake is typically located at a depth of 1 to 6 m below the waterline. Strictly speaking, it therefore measures subsurface temperature and salinity; commonly called surface T and S.

1.5. Thermistor chains

They come in the form of long cables consisting of an insulating sheath into which the thermistors are moulded at regular intervals. This instrument is used to measure the temperature at fixed depths with an accuracy of the order of 0.1°C.

2 Conductivity

2.1 CTDs
2.2. Hull thermosalinometers

Important:
- The response time of the conductivity sensors.
- Aligning the response times of the temperature and conductivity sensors to calculate salinity6
- Bio-fouling and conductivity cells.

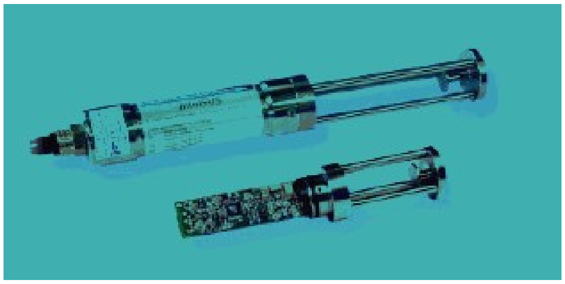
3. Pressure (see Chap 4).

3.1 Piezoresistive pressure sensors
3.2 Piezoelectric pressure sensors

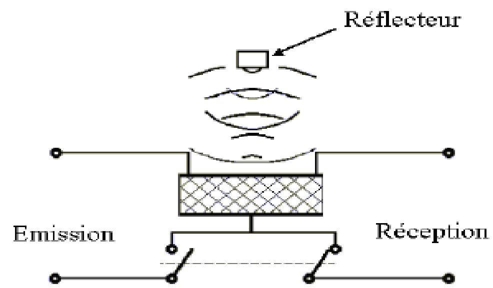
4. Speed of sound

4.1 **Measuring the speed of sound in seawater**
Description of a sound velocity profiler "Bissett-Berman" (after John JAEGER, OCEANOGRAPHIC MEASUREMENT TECHNIQUES AND APPLICATIONS, Bissett-Berman Co - San Diego, California):

Direct measurement is generally obtained by a sensor operating on the principle of echo: A piezoelectric transducer, generally made of Barium crystal, is subjected to an electric pulse which causes it to vibrate at its resonant frequency. The sound energy thus produced travels a fixed distance to a reflector. The reflected wave returns to the transducer where the received acoustic signal is converted into an electrical signal (after the emission of the acoustic signal, the transmitter has switched to receiver mode). Thus the time measured by the device between the start of transmission and the start of reception of the reflected wave is proportional to the speed with which the sound has travelled the fixed distance between the transducer and the reflector (for the return journey).
The piezoelectric material is made of titanium and barium, coated with nickel in order to obtain a corrosion-resistant electrical contact. The transducer is placed on the wall of a box filled with oil at the same pressure thanks to an elastic diaphragm. The transducer resonates at a frequency of 5 MHz when an electric pulse is applied between the side in contact with the oil and that in contact with the sea water. The round trip being 0.1 m, the pulse frequency is 10 times higher than the speed of sound in water. The operation of the sensor is disturbed if the sound pulse is reflected by surfaces other than those of the reflector (e.g., air bubbles, dirt on the sensitive surfaces of the transducer). Water leaking into the oil-filled housing also causes malfunction. The precision obtained with this type of sensor associated with its electronics is 0.06 m/s in a range from 1400 to 1600 m/s.



Sound velocity sensor by Valeport Ltd
Model MINI SVS2



Schematic illustrating the principles of measuring the speed of sound

5. Current velocity (see also Chap 6)

5.1 Rotor current meters
5.2 Single-point Doppler current meters
5.3 Electromagnetic current meters
5.4 Doppler profilers

6. Position and displacement

6.1. The Argos system

The Argos system was designed to locate fixed or slowly moving platforms (speeds < 1 km/day) and to collect physical data measured by these platforms. It was born out of an agreement between NOAA, NASA, and CNES and has been operational since 1978. It involves three systems: a space segment (NOAA satellites in a heliosynchronous circular orbit at low altitude), an earth segment (at Lannion and Toulouse for France), and platforms equipped with transmitters. Unlike the GPS system, it is the terrestrial or marine platform which is responsible for transmitting the signal which will allow its positioning.

6.2. The global positioning system (GPS; see also Chap 3)

7. Water height

7.1. Coastal tide gauges

With the tides being a "slow" phenomenon, coastal tide gauges are designed to filter or eliminate high frequency disturbances. They consist of a vertical pipe called a stilling well, which communicates with the ocean through one or more horizontal orifices, a second well equipped with a "tide staff", basically a precisely graduated ruler. Nowadays, the water level is typically measured automatically (either by acoustics or radar).

7.2. Submerged tide gauges

The most accurate measurements are obtained using an immersed pressure sensor. The water level can be derived from the classic hydrostatic equation: $h = (p-p_{atm}) / \rho g$
In parallel, it is necessary to measure the atmospheric pressure (p_{atm}) and estimate ρ, the water density.

8. Swell

8.1. Wave buoys (accelerometers and magnetic compasses)
8.2. Current meters and pressure sensors
8.3. HF (high frequency) radar

9. Turbidity and light attenuation

“Turbidity” is a parameter with several definitions and is no absolute concept. Turbidity in water is due to suspended matter such as organic and inorganic particles: plankton and other micro-organisms, sediments, etc. As a result, turbidity is commonly defined as an optical property that causes incident light to be scattered and absorbed rather than be transmitted in a straight line. Typically, the purpose of turbidity measurements is to estimate the concentration of particles in the medium.

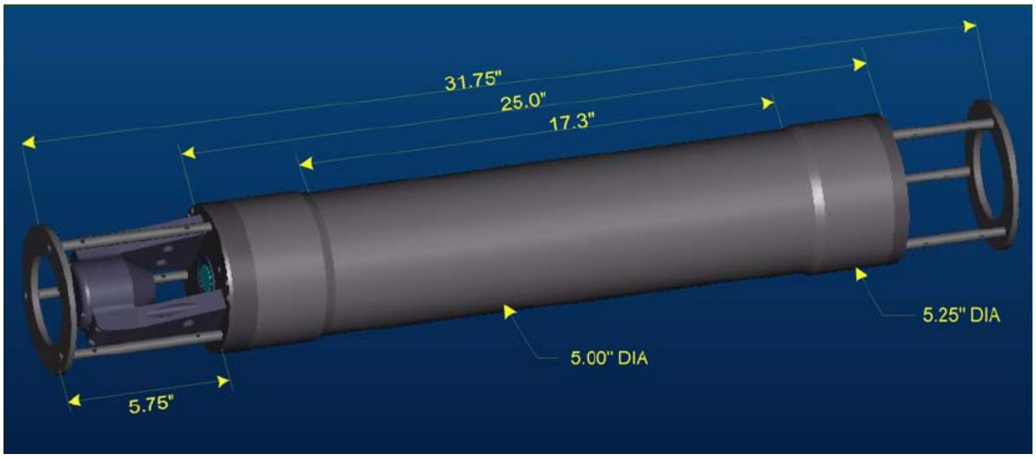
9.1. Transmissometers (see Section 3)
9.2. Nephelometers

Nephelometers are instruments used to measure light scattering (especially in limnology and coastal oceanography). They should - in theory - allow the measurement of diffusion between 0° and 180°, although this is hardly achieved by instruments for *in situ* use. As a result, measurements are made over various ranges of angles depending on the type of instrument and a precise calibration must be carried out. The instruments are calibrated with formazine suspensions of known concentration.

9.3 Scatterometers

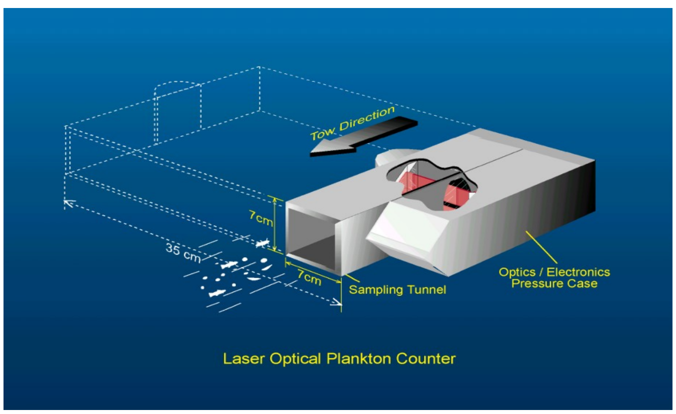
They measure scattering at a specific wavelength and at a given angle. They have been developed commercially since the mid-1990s (HobiLabs and WetLabs , USA). They make it possible to derive the concentration of particles and also information on the size of the particles.

For WetLabs Transmissometer see Section 2
+ LISST = **Laser In-Situ Scattering and Transmissometry.** (Sequoia, Bellevue, WA, USA)
Particle size range: $1\mu m - 200\mu m$

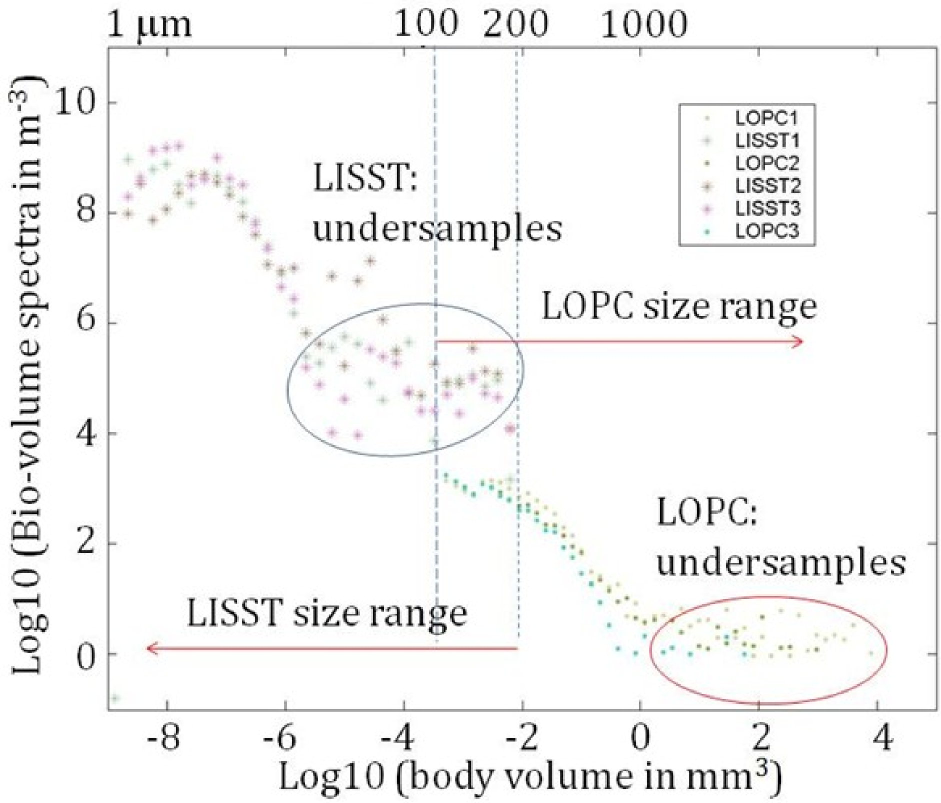


The LISST counts particles in 32 different size classes. The biovolume is calculated as if the particles were spherical (ESD - equivalent spherical diameter).

+ LOPC = **Laser Optical Plankton Counter.** (Brooke Ocean, NS, Can)
Particle size range: $100\mu m - 30\,mm$



The attenuation of a laser beam as detected by diodes makes it possible to count the particles. If the attenuation is significant on more than three diodes, a pattern recognition attempt is possible. The biovolume is calculated as if the particles were spherical (ESD - equivalent spherical diameter). If the ESD is smaller than 1.5 mm, pattern recognition is not possible.



Comparing the detectable size ranges by the two instruments (courtesy: Meng Zhou)

10 Phytoplankton biomass

10.1. Fluorimeters (see Section 3)

11. Other physico-chemical properties (in situ)

11.1 Dissolved oxygen

- Polarographic or Clark sensors

This instrument consists of two electrodes that are kept at different electric potentials, immersed in a gel that is separated from sea water by a membrane. Dissolved oxygen diffuses, according to its partial pressure, through the membrane and is reduced by the cathode. This creates a current that is proportional to the amount of oxygen that has diffused.

- Optodes

In order to overcome the problems associated with Clark electrodes, another technique appeared in 1996 using the "sol-gel" technology (materials are deposited in layers of very precise thickness and having very specific properties). In the case of oxygen optodes, a reactive salt trapped in the deposit fluoresces under blue radiation. This fluorescence is reduced in the presence of oxygen and this reduction can be measured.

> Definition: An optode or optrode is an optical sensor device that optically measures a specific substance usually with the aid of a chemical transducer. An optode requires three components to function: a chemical that responds to an analyte, a polymer to immobilise the chemical transducer and instrumentation (optical fibre, light source, detector and other electronics). Optodes usually have the polymer matrix coated onto the tip of an optical fibre, but in the case of evanescent wave optodes the polymer is coated on a section of fibre that has been unsheathed. Optodes can apply various optical measurement schemes such as reflection, absorption, evanescent wave, luminescence (fluorescence and phosphorescences), chemiluminescence, surface plasmon resonance. By far the most popular methodology is luminescence.
> (https://en.wikipedia.org/wiki/Optode)

In a solution, the luminescence is determined by the Stern-Volmer equation. The fluorescence of a given molecule is quenched by certain analytes; thus, ruthenium complexes are deactivated by oxygen. When a fluorophore is immobilized in a polymer matrix, it creates countless micro-environments that correspond to various diffusion coefficients for the analyte. This leads to a non-linear relationship between fluorescence and the quencher. This relationship can be modelled in a variety of ways, but the most popular is the two-site model proposed by James Demas (of the University of Virginia).

The signal to oxygen ratio is not linear and optodes are more sensitive to low oxygen concentrations while their sensitivity decreases as the oxygen concentration increases. However, in water, optode sensors can operate across the entire oxygen saturation range, i.e., from 0 to 100%; the calibration is done as for the Clark electrode. As this does not consume oxygen the sensor is not sensitive to agitation, but it does allow for faster signal stabilization, and is therefore recommended.

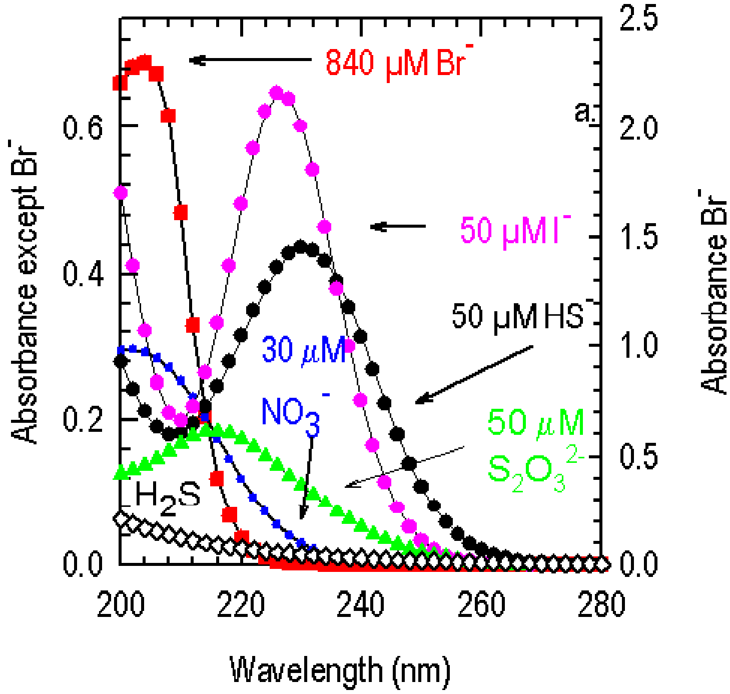
The popularity of optical sensors is increasing due to their low cost, low power consumption, and long-term stability. They are proving to be a viable alternative to electrode-based sensors, or other more complicated analytical instruments, especially in the field of environmental monitoring. However, oxygen optodes do not yet have as good a resolution as cathodic micro-sensors and have too long a response time to be able to be used on profilers descending at a speed of 1 m/s.

11.2 CO_2

The partial pressure of CO_2 is measured by the absorbance of a solution of thymol blue through sea water. CO_2 is brought into equilibrium with this solution through a membrane. As thymol blue is a pH indicator, it changes colour depending on the acidity/basicity of the solution, and therefore the CO_2 concentration. A spectrophotometer makes it possible to quantify this variation in colouration.

11.3 Nutrients

The ISUS (In Situ Ultra-Violet Spectrophotometer) is a sensor used to measure the concentrations of dissolved chemicals directly from their ultraviolet absorption spectra (Johnson and Coletti, 2002). A variety of chemicals absorb light in the UV and each of these chemicals has a unique absorption spectrum.



We can determine the concentration of these chemicals directly, without any chemical manipulation, by measuring the UV absorption spectrum of seawater and then deconvoluting the spectra to obtain the concentration of each component. The ISUS is now commercially available from Satlantic, Inc., as well as SUNA (Submersible Ultraviolet Nitrate Analyzer), which is an ISUS redesigned for lower cost and easy integration into existing water monitoring systems, especially in coastal and freshwater environments.

Source = http://www.mbari.org/chemsensor/isushome.htm
http://www.satlantic.com/nutrient_sensors/nitrate_sensors_isus_v3.asp

B) Measurement platforms at sea

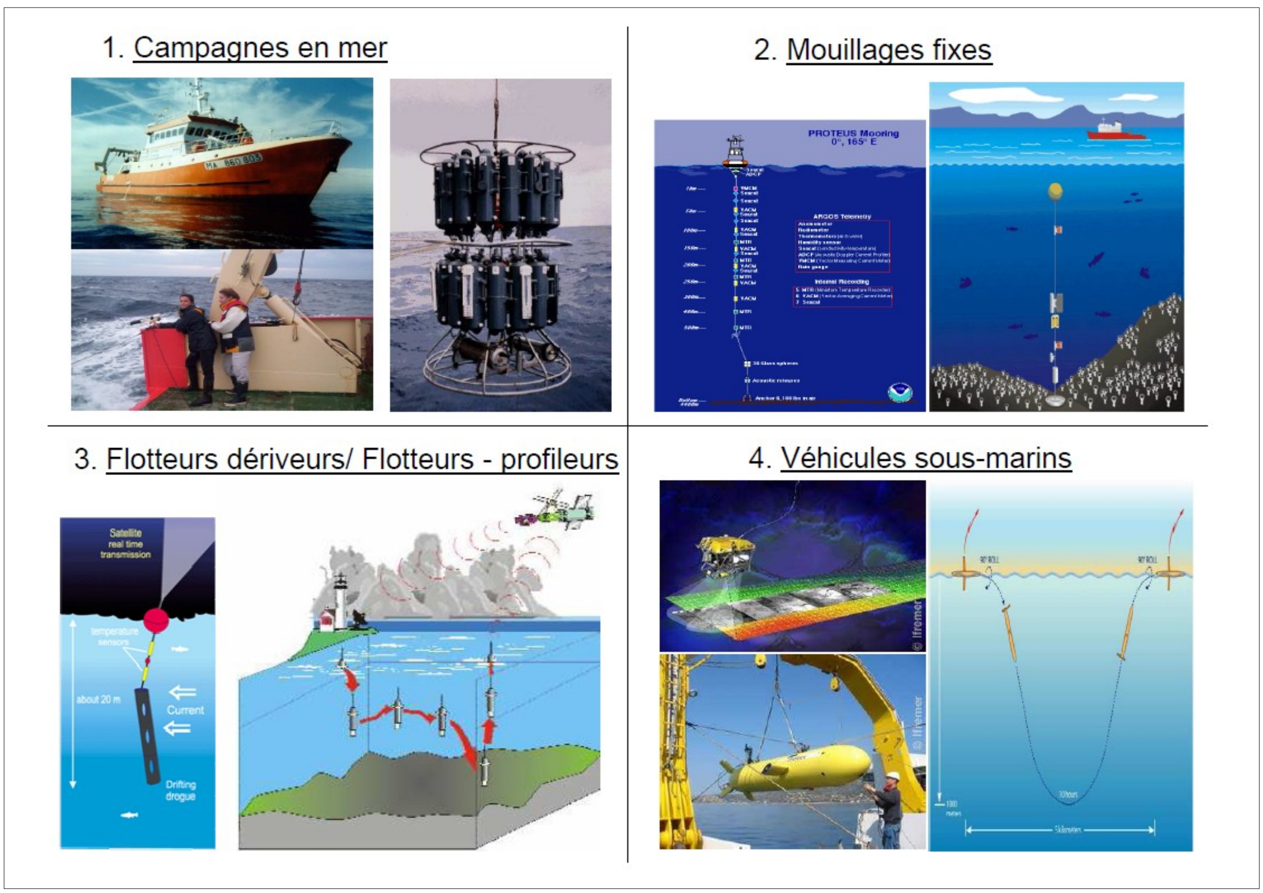
All the measurements we discussed so far can be carried out:

1. During campaigns at sea by deploying instruments according to the designed sampling strategy,

2. On fixed moorings (Eulerian approach) placed at strategic locations,

3. On surface floats and drifters or floating profilers (ARGO floats: Apex (USA), Provor (France), Solo (USA), Ninja (Japan), etc.): Lagrangian approach,

4. On underwater vehicles: ROV, AUV, gliders



B.1. Oceanographic vessels

Oceanographic vessels are essential for carrying out in situ measurement campaigns. Their size can vary from about ten meters (coastal sampling) to a hundred meters (open ocean sampling). In general, these boats are classified based on:

- their means for lowering/raising the measuring instruments;
- their means for positioning and possibly sounding or surface measurement;
- their means for storing and transmitting collected data;
- the laboratories and work areas they are equipped with;
- the types of equipment and carry and the types of measurement they can conduct.

The weight and volume of the instruments to be lowered into the water can vary from a few kilos and a few tens of cubic centimetres to several tons and several cubic meters. For the heaviest and bulkiest loads, oceanographic vessels are equipped with loading cranes, davits or slewing jibs and handling gantries (A-frames).
These A-frames can be tilted using hydraulics from the inside to the outside of the boat, thus making it possible to lower instruments at a sufficient distance from the hull, to prevent them from colliding with the vessel when the sea is rough. They are usually located either at the stern, aligned with the axis of the vessel, or on one of the sides. They are equipped with a pulley guiding the connecting cables of the instruments.
These cables are usually reeled from winches fixed on the deck of the ship. They can be simply steel cables to carry the weight of the instrument or they can also be electronically conducting. In the latter case, their structure consists of a sheath made up of steel strands and a core made up of individually isolated copper conductors. The copper cable is connected to the instrument through a watertight connection. A "sock" consisting of braided metal wires is slipped over the cable in order to reduce the mechanical tension on the conducting wire itself. This "sock" usually comes with a fixing ring to ensure the mechanical connection. Any tensile force on this ring has the effect of tightening the stitches of the “sock” and thus of increasing the gripping force of the cable.
The electric winches are equipped with a guide to allow the orderly winding and unwinding of the cable. Winches and their cables are often dedicated to specific instruments (CTD, current meter, magnetometer, etc.).

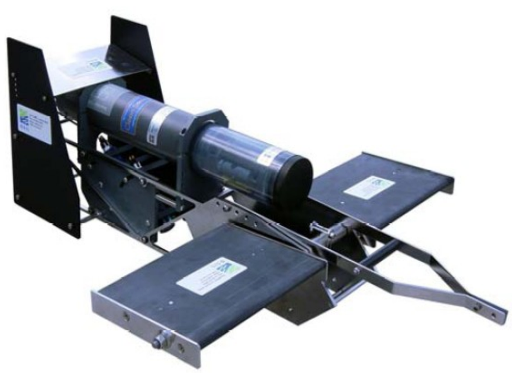
- In France, the cost per day for the use of continued to increase until it became prohibitive to use research vessels for teaching programs and small research projects; so this system was abandoned in 2017.
- positioning and sounding: GPS + attitude and positioning (ship roll and pitch)
- means of data transmission: conducting cable between the instrument and onboard computers, pre-processing and storage; sometimes transmission to ground facilities through satellite links. On the newest vessels, the computers are connected to each other by Ethernet connection. (Wikipedia: Ethernet is a type of wired computer network commonly used in local area networks. Ethernet was originally based on the idea of computers communicating over a shared coaxial cable acting as a broadcast transmission medium. The method used was similar to those used in radio systems, with the common cable providing the communication channel likened to the Luminiferous aether in 19th-century physics, and it was from this reference that the name "Ethernet" was derived.).

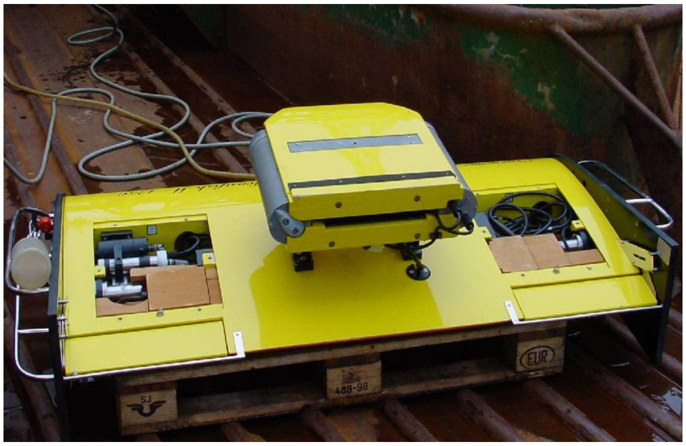
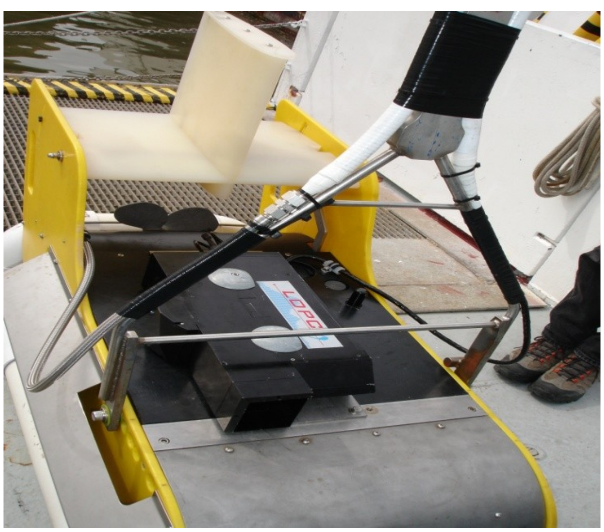
Conducting oceanographic measurements using ships

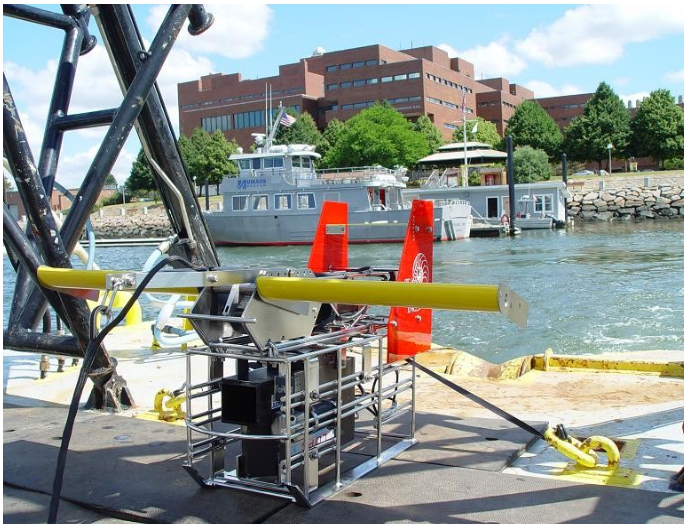
Ships are usually equipped with the instruments described above: CTDs, rosettes with sampling bottles, XBTs, or hull thermosalinometers (possibly other automated optical instruments are added to conduct surface measurements). The thermosalinometers are usually fixed as their removal/installation for every campaign would be to complicated. The other instruments are used depending on the goals of the campaign. A class of instrument that has not been discussed so far are towed instruments.

CTDs and XBTs can be used to obtain temperature-conductivity profiles of the entire water column at fixed locations. The collection of such a profile can take several hours (depending on the depth of the water column). Collecting data from an area requires "transects", i.e., conducting several consecutive fixed point measurements in a linear configuration in order to obtain vertical cross-sections of temperature or salinity. To be able to conduct this transects (and obtain the data) more quickly, possibly at the expense of a slightly lower accuracy, ships may be equipped with a "towed vehicle" or "fish" containing several scientific instruments.

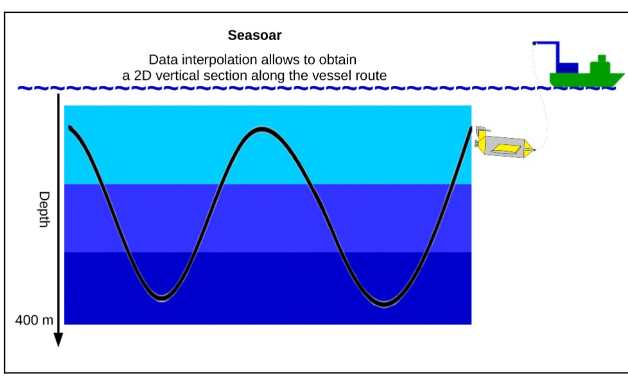
This towed fish, or undulating profiler, gets towed behind the vessel and essentially consists of an underwater "glider" that is towed and piloted from the main vessel through a cable connection by changing the inclination of its fins and thereby allowing it to perform periodic ascents and descents as it is being towed behind the ship, while transmitting the data back to the ship in real time. The resulting profiles usually cover depths from a few meters below the surface to about 500 m depending on the chosen instrument settings.

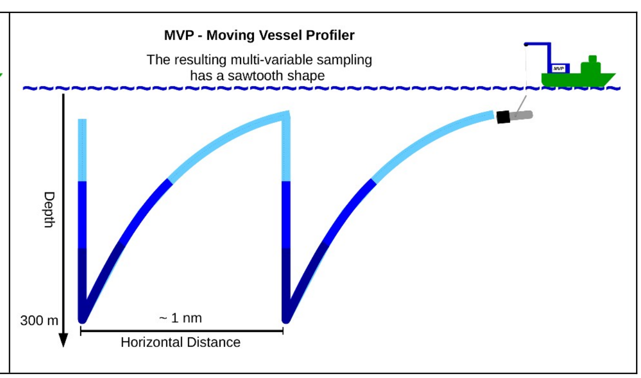
	Minibat Length: 75 cm

	ScanFish
	SeaSoar see animation on website
	Nu Shuttle

	Acrobat
	Moving Vessel Profiler (see Section 3) see animation on website and e.g., FUMSECK

It is necessary to distinguish the different behaviours of the undulating profilers ("towyo" = tow + yoyo) and the MVP; see the following illustrations (courtesy MIO team BioSWOT):





Link to the short film on the MVP by FUMSECK (2019):
https://www.mio.osupytheas.fr/fr/dynamique-oceanique/fumseck-une-campagne-du-projet-bioswot

Other platforms:
Expendable sensors: This is a less precise and more expensive solution.
e.g., expendable bathythermographs (XBTs) (see Section 2)

Autonomous sensors: These probes are no longer connected to the ship by cable
1) Classic. After being launched, the probe dives until it reaches the desired depth. Its surface recovery can cause problems at night, in poor visibility or in bad weather.
2) Expendable (e.g., Provor). This device spends most of its time at a chosen depth. It periodically surfaces to determine its GPS position and these successive position measurements provide an approximation of the current strength at the chose depth. During the ascents and descents it typically also measures temperature and conductivity.

If you are interested in the long-term evolution of a certain parameter, ship-based measurements are both too costly and near impossible in practice due to adverse weather and sea state conditions. These long term measurements are therefore obtained by attaching the instruments to moorings or having them drift through the ocean.

B.2. Moorings

A mooring is an instrumented line designed to remain at a fixed position. A distinction is made between so-called "Eulerian" moorings, referring to the Euler frame of reference in which measurements are taken at fixed positions with regard to the Earth in an otherwise moving medium, and so-called "Lagrangian" moorings, where the observing instrument moves along with the mass of water. Either of these can have a floating device at the surface in which case they are called surface moorings. If they are entirely submerged they are called “subsurface” moorings.

1. The constraints of deploying a mooring

Before deploying a mooring, yon need to study the environment of the chosen site, the local legislation, and the types of instrument you want to used. The environmental study concerns the physical parameters at the deployment site to avoid problems related to horizontal movement, verticality, or poor anchoring. This requires knowledge or at least estimates of the local water density, currents, tides, and the seabed morphology and bathymetry, as well as the weather forecast at the time of deployment. Nautical charts alone are insufficient and a more detailed bathymetric study is usually required to determine the locations of natural and artificial obstacles (wrecks, submarine cables, etc.) at the sea bed and the seabed type (rocky, mud, etc.) and slope.

The preliminary study also concerns the biological and human environment. Coastal areas are often rich in nutrients that promote the development of phytoplankton and a rich biological food web which means that there are plenty of organisms that can attach themselves to the moorings and thereby affect their reliability. There are various approaches that can be used in order to limit this so-called biofouling which has the additional harmful effect of accelerating corrosion and therefore the risk of breakage. Some areas are also popular for human activities such as fishing which can involve the use of dredges or trawls which can lead to the loss of the mooring. Similarly, main shipping lanes must be avoided because it is difficult and dangerous to deploy and recover the mooring in these areas and the moorings themselves can constitute dangers for navigation.

Moorings close to the coast also require permits from the local maritime authorities. In France, you need to specify the areas you want to sample and these zones are called "ZONEX". Depending on the type of mooring, correct marking must be provided to avoid collisions. This can be done using transmitter beacons or flash lamps, but it is also necessary to disseminate information regarding the mooring dimensions and exact position to mariners and fishermen using all available channels. The mooring can be further secured by adding Argos or GPS transmitters which allow the mooring position to be monitored in near real time. Argos transmitters can also be used to control skidding or accidental surfacing following a rupture or dredging.

Also the instruments installed on the mooring line must satisfy various constraints. If they cannot be clamped on the cable, they must be designed to resist pulling. As moorings can be deployed for months or even years at a time, they must have sufficient energy autonomy and data storage capacity. Above all, they must be protected against corrosion to limit the risk of breakage or irreparable deterioration.

2. General information about designing a mooring

2.l. Buoyancy considerations

Any body submerged in water is acted upon by an upward (buoyancy) force, the magnitude of which is equal to the weight of the displaced fluid (this is the famous Archimedes' principle). This upward force, Pa, acts on the body's centre of buoyancy:

$$Pa = \rho V g \qquad [3.1]$$

ρ is the density of the fluid, V the volume of the immersed body, and g the acceleration due to gravity.

This force is opposed by the weight, P, of the submerged body with mass M. This force also acts at the centre of gravity and acts downward:

$$P = M g \qquad [3.2]$$

If the centres of buoyancy and gravity coincide, the difference between these opposing forces gives the weight of the submerged body in water, equivalent to its buoyancy:

$$P_{H20} = (\rho V - M) g \qquad [3.3]$$

Since the water density increases with depth, in a static marine environment, submerged objects will move as follows:

- if P > Pa, they will sink to the sea bed as the buoyancy is negative;

- if Pa> P, they will rise to the surface as the buoyancy is positive;

- if P = Pa, they are at their depth of hydrostatic equilibrium and their buoyancy is zero.

Based on this principle, when designing a mooring the following considerations can be made:
- weights are attached to the base of the mooring to keep it in a fixed position;
- floating devices will be attached to to the top to exert an upward pull that keeps the line vertical

However, the ocean is no static environment and other elements influence the behaviour of the system. The presence of marine currents generates displacement forces Fd of arbitrary directions. In fact, Fd can be decomposed into a vertical lift force and into 2 perpendicular horizontal forces which constitute the drift force and the drag force Ft whose direction is identical to that of the current. For the mooring to remain motionless, a force equal and opposite to Fd must be applied to it. However, in the case of oceanographic moorings the force Ft dominates. Ft can be decomposed into two other forces: (i) pressure drag, Ftp, due to the excess pressure exerted by the fluid on the front of the mooring and the slight pressure deficit created in its lee, and (ii) friction, Ftf, which results from friction of the fluid as it flows past the mooring elements. The amplitude of Ftp depends on the surface area, Sc, of the mooring elements exposed to the flow direction of the current, and the drag coefficient Ct of these elements. The amplitude of Ftf depends on the submerged surface, Sm, of these elements and on a friction coefficient, Cf, of the objects.

Cf and Ct can be calculated and depend on the shape and dimensions of the surface of the objects perpendicular to the direction of the current and on the Reynolds number (ratio of the current speed to fluid viscosity). However, in oceanographic moorings the force Ftp is typically large compared to Ftf to the point that only Ftp needs to be taken into account in the calculations.

By knowing the depths of each instrument on the mooring line, their geometric characteristics, and their orientation in relation to the dominant current we can calculate these different forces for each mooring element and will enable us to devise a combination of dead weights and floatation devices that will keep be mooring vertical and firmly anchored in place. This calculation is generally carried out using dedicated software which makes it possible to simulate the mooring behaviour in different scenarios.

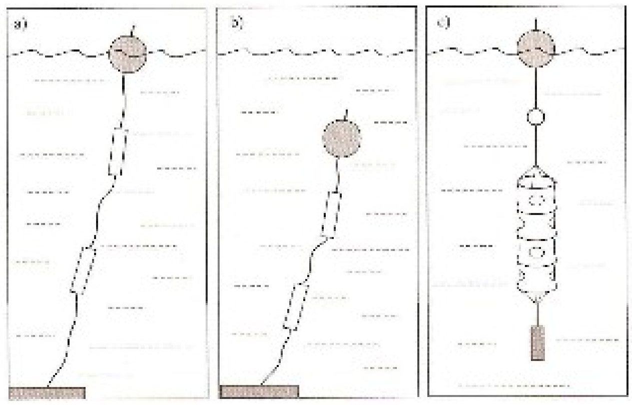
2.2. The different types of moorings

Depending on the types of observations to be made, it is possible to design different types of moorings. The chosen type depends on the desired principle of measurement (Eulerian or Lagrangian) and on the mode of anchoring required. The simplest design is probably the “bottom-mounted” mooring (Figure below), consisting of a frame to which the measuring instruments are attached (current meters, tide gauges, etc.) and which must be installed near the bottom. This is the only type that can ensure that the instruments remain truly immobile throughout their deployment. The frame is held in place by a dead weight as ballast. This weight can either be firmly attached to the frame or releasable. The latter offers the possibility of being activated remotely through acoustic pulses emitted from the surface in order to release the instrument frame from the dead weight. Added floats will allow the instrument frame to ascent to the surface where it can be recovered. Since these systems remain on the sea bed for long periods of time, they face the risk of dredging (from fishing vessels). To reduce this risk, certain forms of metal frames have been designed to make them “non-dredgeable”. In these systems, to limit their height and still allow their recovery, the weights and floats are replaced by inflatable systems that can be acoustically triggered to modify their buoyancy and allow them to rise to the surface.

Example of a bottom-mounted mooring (Ifremer, Ecolophy 2005) with floats that allow it to ascent to the surface.

Acoustic releasers are instruments in their own right and combine electronics and mechanical action. One of their ends forms an integral part of the mooring to be recovered, while the other consists of a hook that can be opened by a motorised release system that is activated by a train of ultrasonic pulses emitted remotely from the surface. The progressive opening of the hook causes the release of a submerged part of a mooring, which can then rise to the surface to be recovered.

When the area of interest is limited to the surface layers, so-called surface moorings are used. They consist of a ballast or "dead weight" placed on the bottom end of the mooring line and a float at the surface which remains visible and marks the position of the line while maintaining the mooring as vertical as possible.

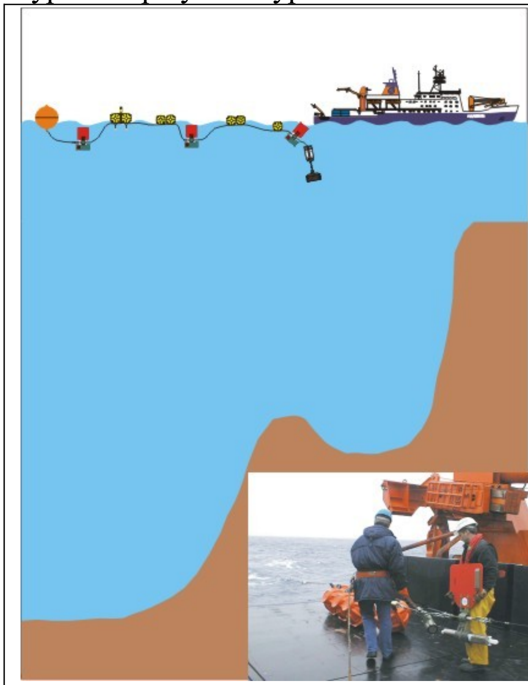


Different types of moorings:
a) surface moorings
b) subsurface moorings
c) drifting Lagrangian moorings

(from Le Menn, 2006)

3. Mooring deployment and recovery

The deployment is a very important phase in the implementation of a mooring and there are two typical deployment types.



A) **"Anchor-last-deployment"**

This method requires an area of open water that is at least as wide as the mooring length. The final mooring location is determined based on assumptions regarding the descending behaviour of the mooring which is subject to uncertainties. The advantage of this method is that the tension on the mooring rope during deployment is low.

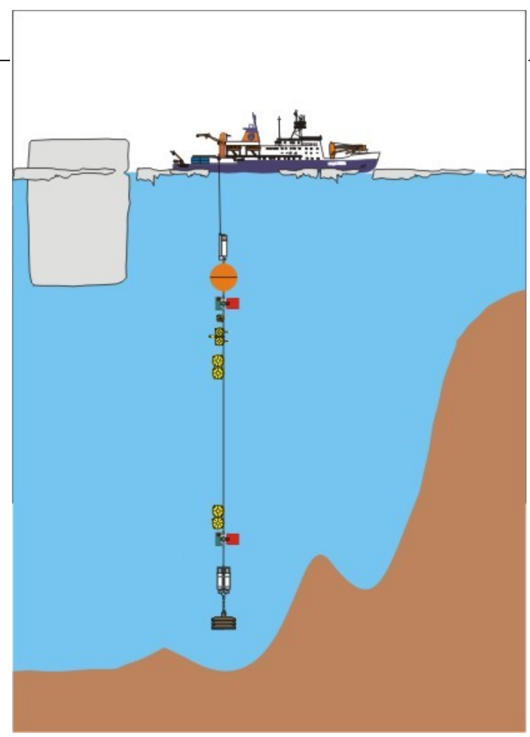
- **deployment needs a lot of open space**

B) **"Anchor-first-deployment"**

The vessel remains stationary at the intended mooring location and deploys the mooring starting with its anchor first. This allows for mooring deployments through relatively small openings in an otherwise frozen surface for instance. The mooring is lowered using the deep sea winch and released with a standard acoustic release which sits at the top of the mooring line. In this approach, the vessel can still manoeuvre to find the exact position and water depth for placing the instruments. Because the full force of the anchor weight of approximately 1000 kg is pulling on the mooring line, this method cannot be used in rough sea states.

\+ **requires little open space**

\- **unsuitable in rough seas; dangerous**

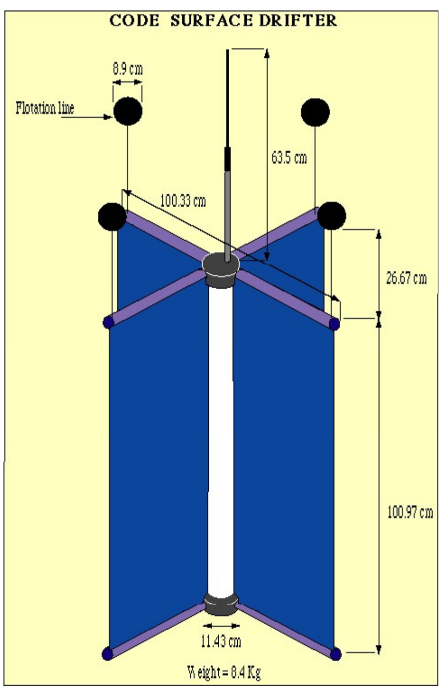


The method used to recover a mooring depends on the mooring type: if a surface float is attached, the line is pulled (by hand or winch) and the instruments unhooked gradually; if it has an acoustic release the mooring is recovered once it has ascended to the surface.

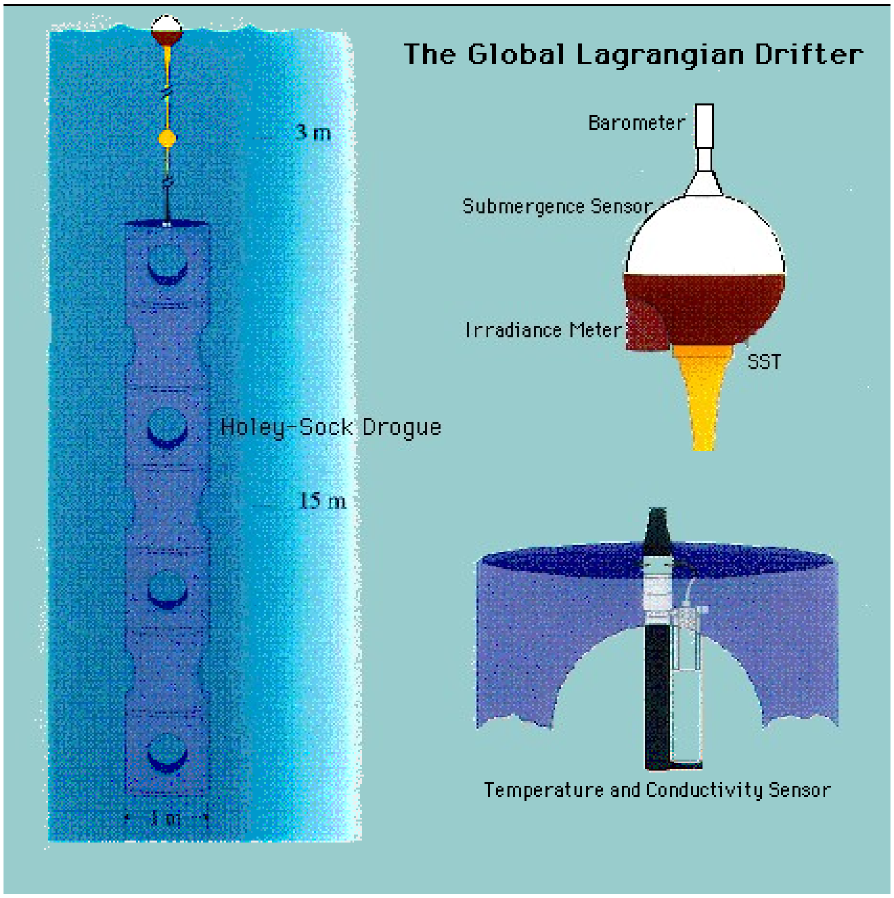
B.3. Floats and Drifters

1. Brief history and operating principles

Acoustic transmitter	Acoustic receiver		date
1 Drifter	Ship	10 kHz; 5 km Swallow float (subsurface)	1955
2 Drifter	Ship	3 kHz; 50 km	1970
3 Drifter	Navy bases	200 Hz; SOFAR (SOund Fixing And Ranging) channel	1975
4 Drifter	+ ALS Autonomous Listening Stations	200 Hz; SOFAR channel	1978
5 Mooring	Drifter	RAFOS (opposite of SOFAR)	1980
7 Drifter transmits to ARGOS	ALACE = Autonomous Lagrangian Circulation Explorer		1996
6 MARVOR	= RAFOS + ALACE "Mach Mor" (French Brittany dialect) sea horse		1994 France
8 ALACE -> PALACE (Profiling ALACE)			
9 MARVOR -> PROVOR (acoustic RAFOS function removed)			
10 APEX (0 to 2000 m; + T, conductivity, pressure)			2000
11 PAGODE (coastal profiler; between profiles)			2002
12 PNG (next generation profiler; Ifremer)			



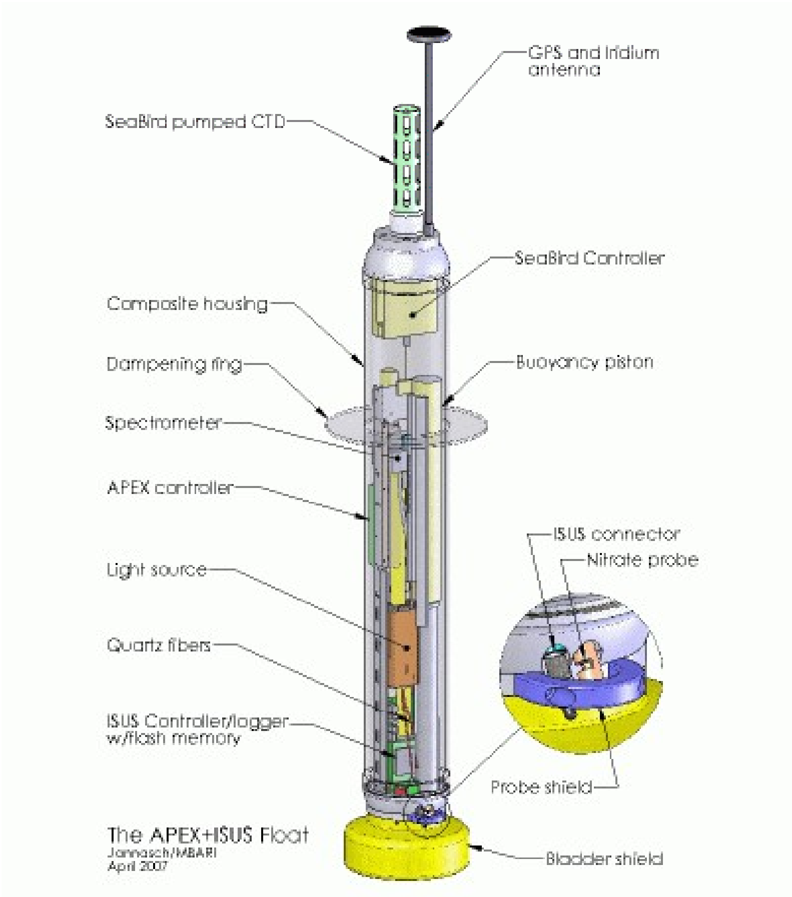
CODE drifter is similar to the one used in the Coastal Dynamics Experiment (CODE) in the early 1980's (Davis, 1985)



Typical WOCE/TOGA Lagrangian Drifter (Sybrandy and Niiler, 1991)

LATEX campaign
June 2007

Lagrangian float being deployed; the “sock” (drogue/anchor) starts to submerge

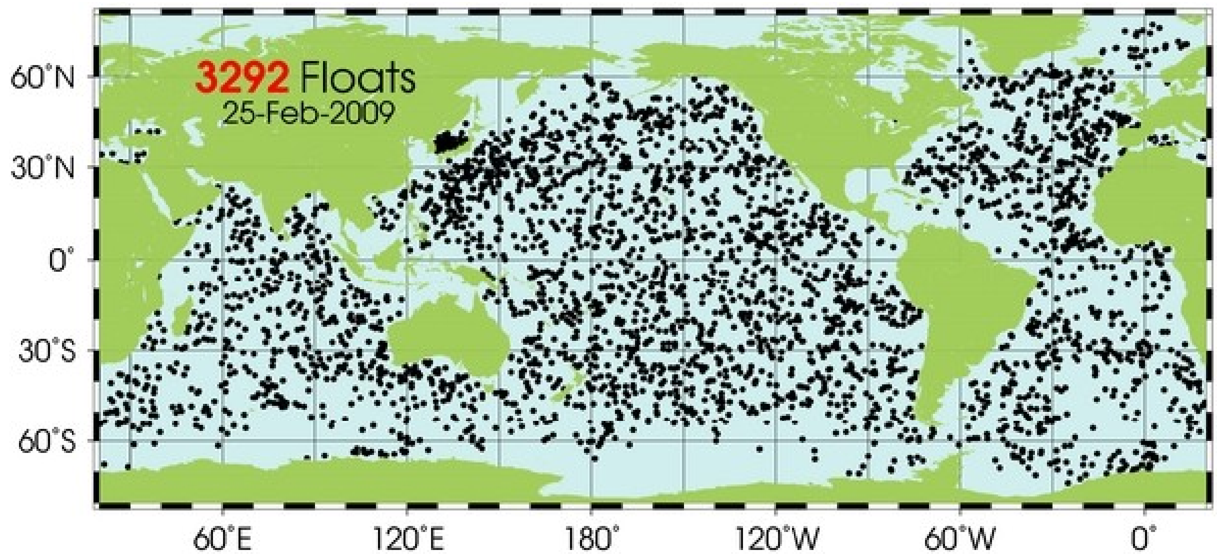


APEX floats:

	April 2007: Integration of ISUS into the Webb Apex float was done by Dana Swift (UW), Luke Coletti and Hans Jannasch (MBARI) http://www.mbari.org/chemsensor/APEXISUS.htm

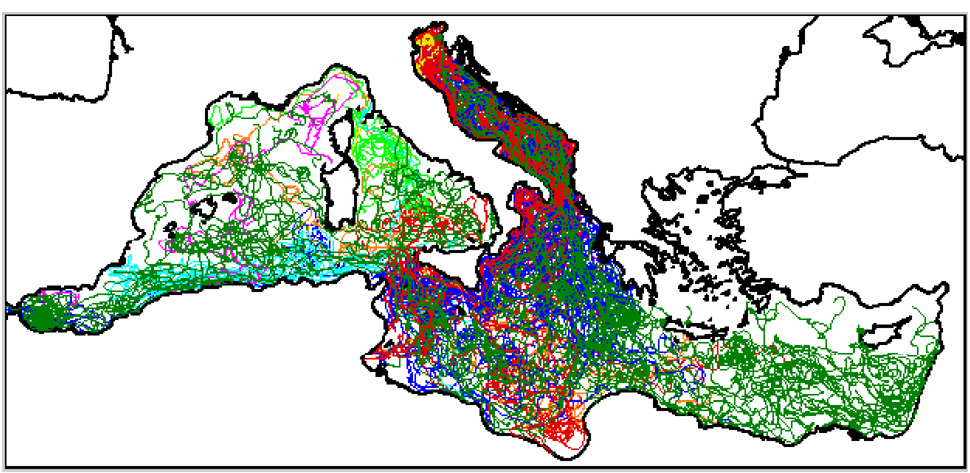
USA: National data buoy center http://apex.ndbc.noaa.gov/ndbc/index.html

Argo is a global array of 3,000 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean. This allows, for the first time, continuous monitoring of the temperature, salinity, and velocity of the upper ocean, with all data being relayed and made publicly available within hours after collection.



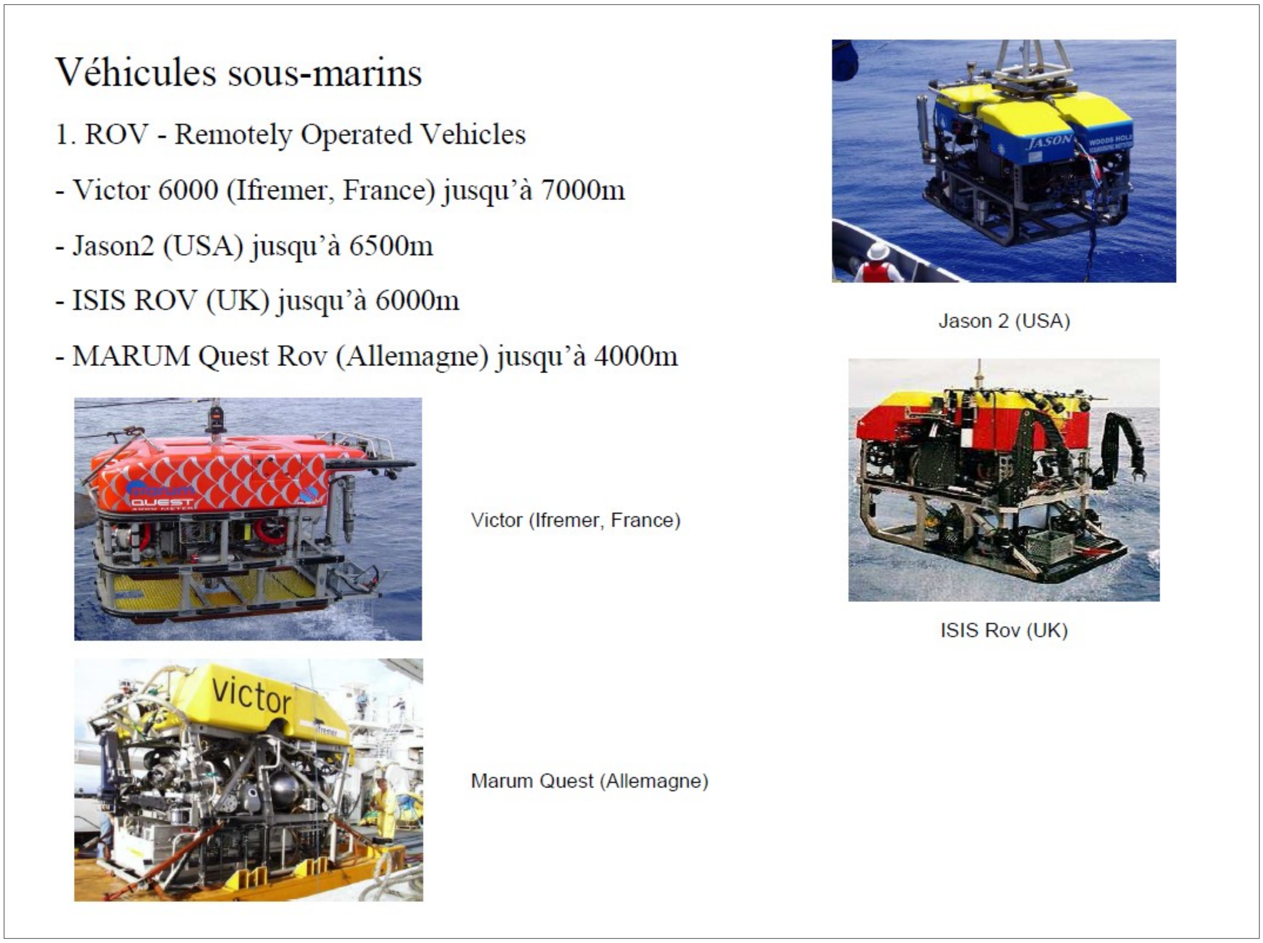
Positions of the floats that have delivered data within the last 30 days (http://www-argo.ucsd.edu/)

Mediterranean



Trajectories of all Mediterranean and Black Sea floats as obtained from the MedArgo database (http://nettuno.ogs.trieste.it/sire/medargo/trajectories.php)

3.4. <u>ROVs, AUVs, gliders, etc.</u>



2. AUV - Autonomous Underwater Vehicles

2.1. AUV propulsés

.

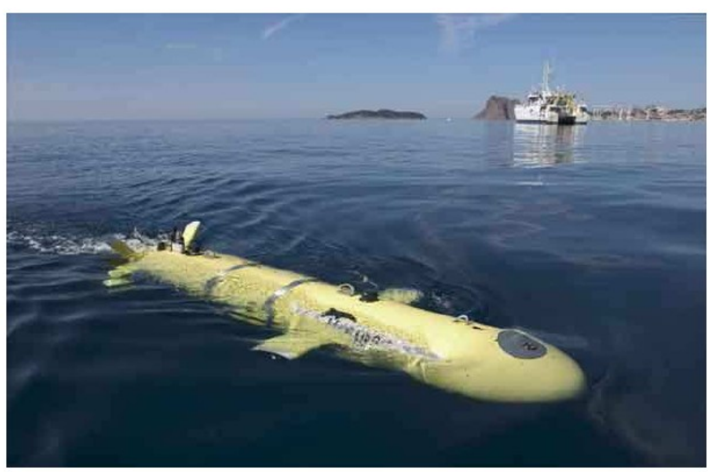
REMUS (USA)

REMUS (stands for Remote Environmental Monitoring Units) is a compact Autonomous Underwater Vehicle built by Hydroid Inc. Our REMUS #255 carries the following equipment on board:
Dual 1200kHz RDI Acoustic Doppler Current Profiler (ADCP)
Seabird SBE49 FastCat CTD
YSI 600-XL CTD
WET Labs ECO-FLNTU meter (chlorophyll, turbidity)
Marine Sonic Sea Scan 900kHz sidescan sonar
GPS and acoustic navigation

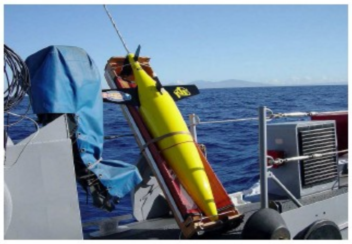
L'AUV *Asterx* fait parti d'une flottille pour la surveillance sous-marine en domaine côtier, de taille moyenne il est facilement mobilisable.

Caractéristiques :
- 3000 mètres d'immersion
- 4,5 mètres de long
- 793 kg dans l'air dont 200 kg de déplacement en capacité d'emport
- Vitesse max 5 noeuds
- 100 km d'autonomie maximum
- Souplesse d'intégration de charge utile pour des études avec sondeur multifaisceaux, ADCP, sondeur de pêche, spectromètre
- Centrale inertielle, loch Doppler, base longue, base courte, base courte inverse, navigation intégrée
- Liaisons radio et acoustique, capacité de stationnement au fond et balise de repositionnement pour une mise en oeuvre sécurisée.

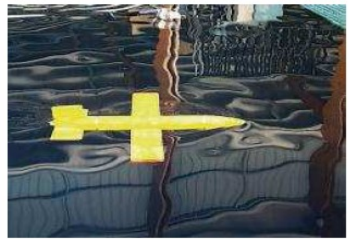
AsterX (Ifremer, France)



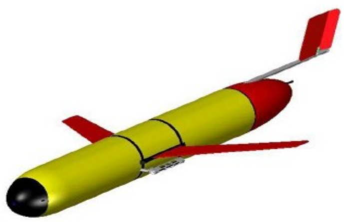
Exemples de gliders



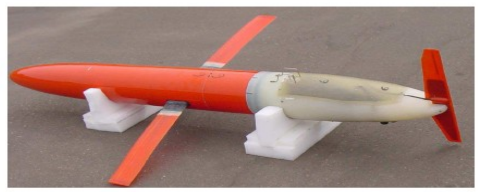
Seaglider (USA)



Glider français de l'ENSIETA

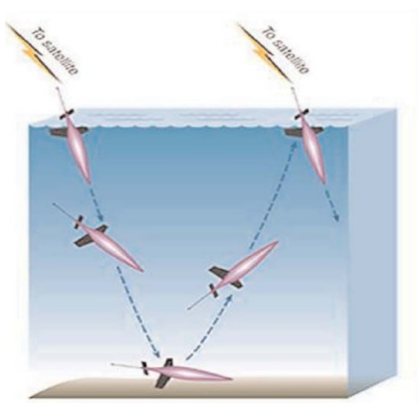


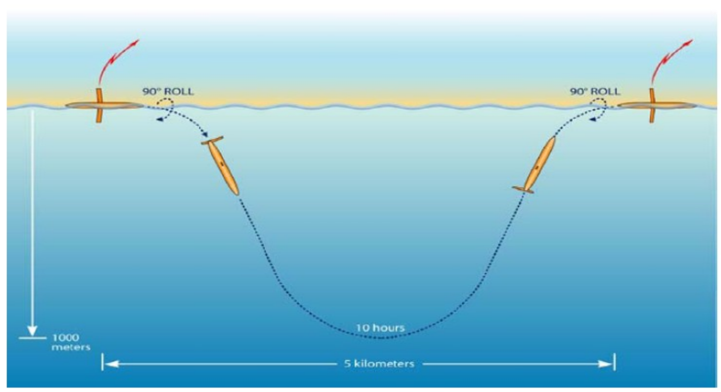
SLOCUM glider (USA)



SPRAY glider (USA)

Glider – principe de fonctionnement





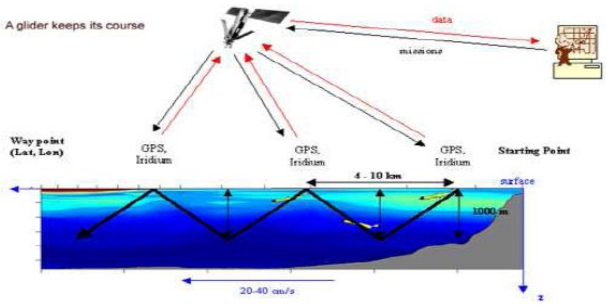
Principe

Ils se déplacent dans l'océan en contrôlant leur flottabilité (suivant les systèmes : il fait varier son volume ou son poids).

Mouvement vertical : capacité à modifier sa flottabilité pour plonger ou remonter grâce à un système de pompage d'huile à l'intérieur ou à l'extérieur, dans une vessie, de la coque du glider. Pas besoin de moteur.

Mouvement horizontal : conversion de la vitesse verticale en vit. horizontale grâce à leur portance sur l'eau (les courants peuvent les freiner ou les accélérer)

Glider – trajectoires



Trajectoire en 'dents de scie' entre surface et profondeur programmée (transparent)
Ex :
* Slocum pour aller à 1000m il faut 2 à 6 km entre 2 points de surface.
* Transmission des données en surface et/ ou nouvelle-modification de mission

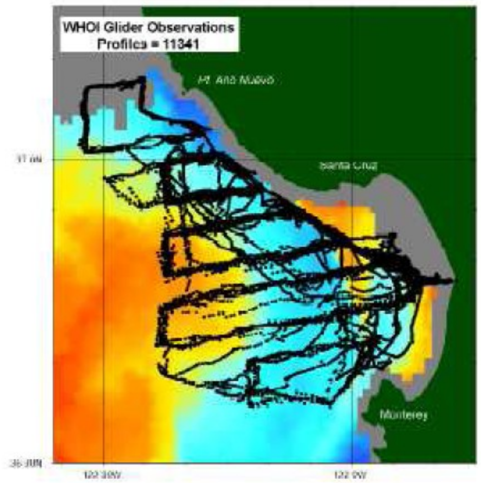


Figure 1: Location of profile data collected by WHOI glider fleet during AOSN-II superimposed on an AVHRR sea surface temperature image showing the relatively cool Ano Nuevo upwelling plume. Ten WHOI gliders collected hydrographic and vertically-averaged velocity data along five closed circuits spanning the Ano Nuevo upwelling plume and performed adaptive sampling experiments using multi-vehicle clusters. Dives were to 200 m or 5 m above the bottom. Data transmission consisted of approximately 75 Kbytes every 2 hours.

Glider – spécifications

Spray	
Hull	Length 200 cm, Diameter 20 cm, Mass 51 kg, Payload 3.5 kg
Lift Surfaces	Wing span (chord) 120 (10) cm, Vertical stabilizer length (chord) 49 (7) cm
Batteries	52 DD Lithium CSC cells in 3 packs, Energy 13 MJ, Mass 12 kg
Volume Change	Max 900 cc, Motor & reciprocating pump, 50 (20) % efficient @ 1000 (100) dbar
Communication	Iridium, 180 byte/s net, 35 J/Kbyte. GPS navigation
Operating	Max P 1500 dbar, Max U 45 cm/s, Control on depth+altitude+attitude+vertical W
Endurance	U = 27 cm/s, 18° glide, Buoyancy 125 gm, Range 7,000 km, Duration 330 days
Cost	Vehicle $50,000, Refueling $2850
Slocum	
Hull	Length 150 cm (overall 215), Diameter 21 cm, Mass 52 kg, Payload 5 kg
Lift Surfaces	Wing span (chord) 120 (9) cm swept 45°, Stabilizer length (chord) 15 (18) cm
Batteries	250 Alkaline C cells, Energy 8 MJ, Mass 18 kg
Volume Change	Typical 450 cc, 90 W motor & single-stroke pump, 50% efficient @ 200 dbar
Communication	Freewave LAN, 5.7 Kbyte/s, 3 J/Mbyte, 30 km range – or – Iridium. GPS navigation
Operating	Max P 200 dbar, Max U 40 cm/s, Control on depth+altitude+attitude+vertical W
Endurance	U = 35 cm/s, 25° glide, Buoyancy 230 gm, Range 500 km, Duration 20 days
Cost	Vehicle $70,000, Refueling $675
Seaglider	
Hull & Shroud	Length 180 cm (overall 330), Diameter 30 cm, Mass 52 kg, Payload 4 kg
Lift Surfaces	Wing span (av chord) 100 (16) cm, Vertical stabilizer span (chord) 40 (7) cm
Batteries	81 D Lithium cells in 2 packs, Energy 10 MJ, Mass 9.4 kg
Volume Change	Max 840 cc, Motor & reciprocating pump, 40% (8%) efficient at 1000 (100) dbar
Communication	Iridium, 180 byte/s net, 35J/Kbytes. GPS navigation
Operating	Max P 1000 dbar, Max U 45 cm/s, Control on depth+position+attitude+vertical W
Endurance	U = 27 cm/s, 16° glide, Buoyancy 130 gm, Range 4600 km, Duration 200 days
Cost	Vehicle $70,000, Refueling $1375

NB : EGO (European Gliding Observatories)
http://www.lodyc.jussieu.fr/gliders/EGO/index.php

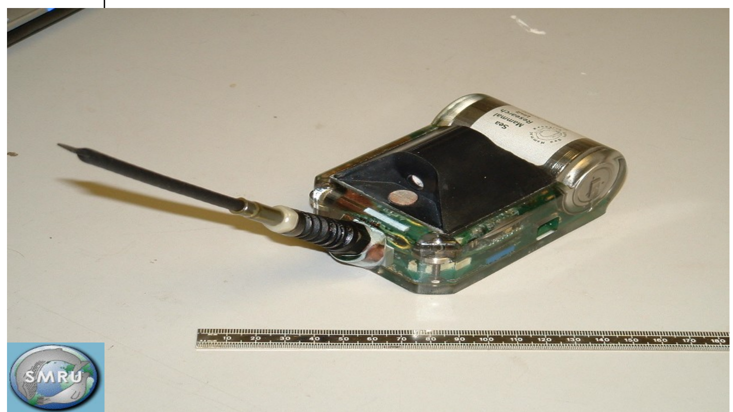
New technological advances:

The Waveglider (utilises wave and solar power)

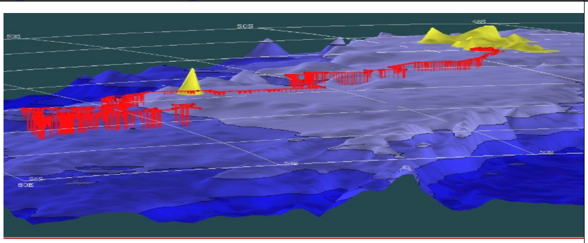
http://www.liquid-robotics.com/platform/how-it-works/

3.5 Other (non-Lagrangian) moving platforms

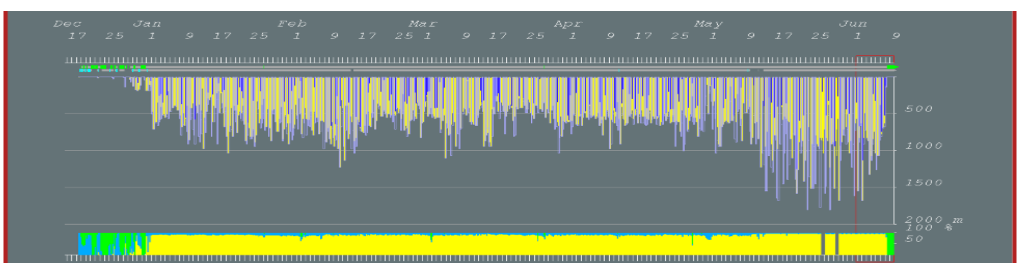
Arctic

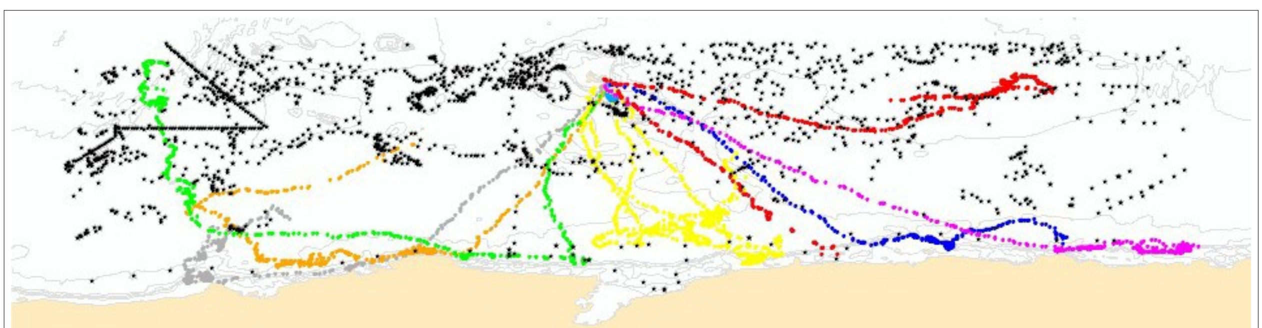


The CTD used for this study is a standard model (Valeport, Model 606+ CTD; http://www.valeport.co.uk); resolution: 0.002 °C, 0.003 ms/cm, 5 dbar



Track and benthic dives (>1500 m) of the elephant seal male 2845 (August 2003) max depth: 1812 m on June 9, 2003





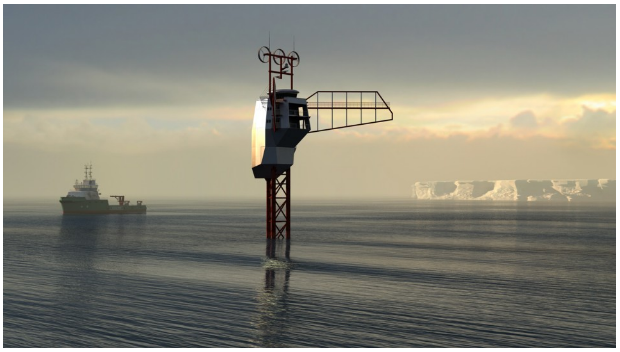
Data from elephant seals added to the Coriolis database.

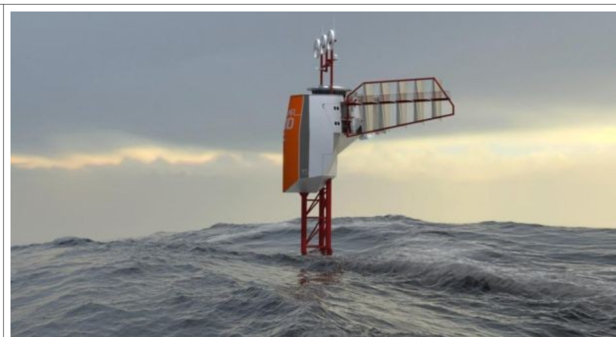
3.6 FLIP (FLoating Instrument Platform) – another "special" platform

http://en.wikipedia.org/wiki/RV_FLIP
First deployed in 1962 by the Office of Naval Research (USA) and operated by Scripps Institution of Oceanography. The platform is 108 meters long and is designed to partially flood and pitch backward 90°, resulting in only the front 17 meters of the platform pointing up out of the water, with bulkheads becoming decks. When flipped, most of the ballast for the platform is provided by water at depths below the influence of surface waves, hence FLIP is stable and mostly immune to wave action similar to a spar buoy. At the end of a mission, compressed air is pumped into the ballast tanks in the flooded section and the platform, which has no propulsion, returns to its horizontal position so it can be towed to a new location.

Other more recent platforms

Polar Pod (http://jeanlouisetienne.com/polarpod/)
Jean-Louis Etienne expedition (funded by the French state; Dec 2017), the pod was drifting around the Antarctic continent in the Circumpolar Current for one year while sending data in real-time.
The Polar Pod was inspired by the FLIP (see above) and its design is a synthesis between the American FLIP and the float technology of large offshore wind turbines. This platform is specially adapted for the study of:
Atmosphere-ocean exchanges (CO2, acidification); wave dynamics; validation at sea of satellite measurements; current measurements and vertical profiles; plankton sampling; recording acoustic transmissions of marine mammals, krill, and ocean floor noise; measurements of aerosols and their sources; observation of marine fauna, whales, seabirds, ...
Technical characteristics of the POLAR POD
It is 100 m high and weighs 720 tons. It is designed to withstand the biggest waves occurring in the “furious fifties" (50-60°S latitude). Observations are transmitted via satellite uplink. Its natural period of oscillation is different from that of sea swell which prevents resonances with the movements of the sea.





The Polar Pod project aims to construct a kind of vertical ship which should complete two round-the-world trips by the end of 2023 in the waters of the Antarctic Circumpolar Current, the most powerful current in the world's oceans. Being without hull, it will be moved along by the currents as its main body will be suspended at depth through the addition of ballast weights. Its design is intended to provide sufficient stability even with strong swells while, being without an engine, disturbing the ambient environment (to be measured) as little as possible. As it can remain at sea all year round, this new tool should pave the way for new research (CNRS-INSU newsletter n°363, 03/31/2021).

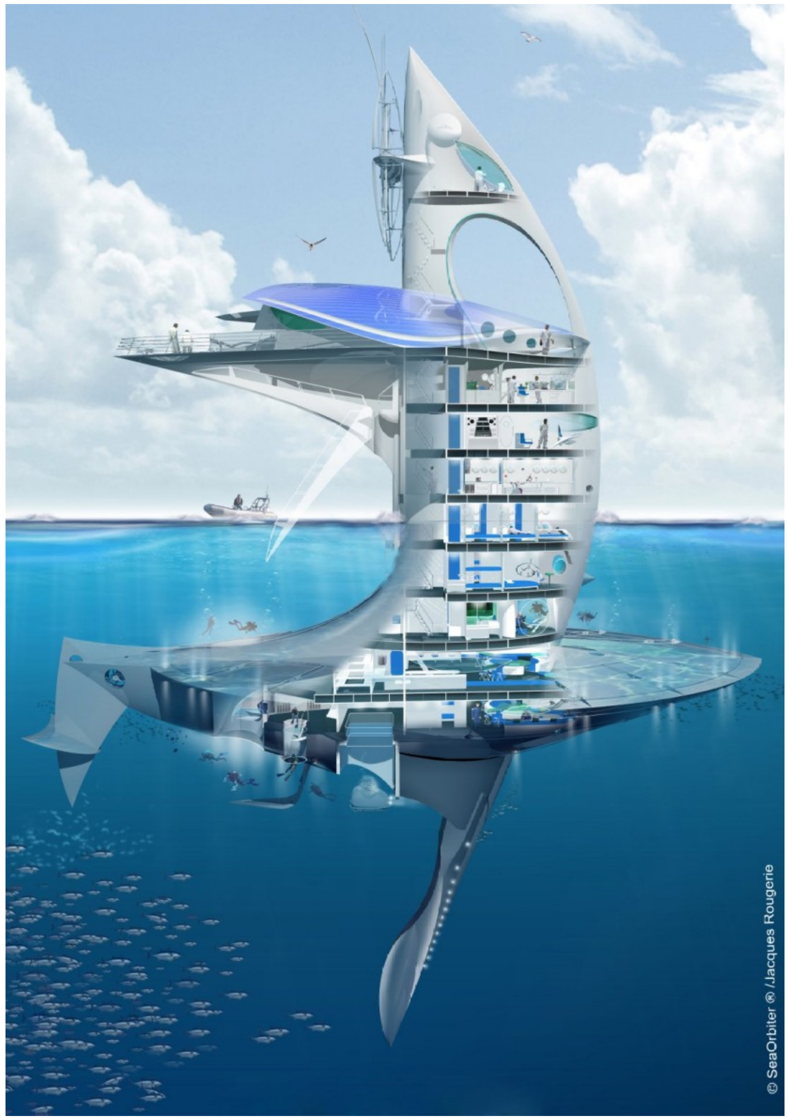
Sea Orbiter (http://seaorbiter.com/vaisseau/)
Jacques Rougerie Foundation (an architect by profession but passionate about the sea) - scientific popularization

https://en.wikipedia.org/wiki/SeaOrbiter:
SeaOrbiter is a project of the "Floating oceanographic laboratory" organisation. It is headed by French architect Jacques Rougerie, oceanographer Jacques Piccard and astronaut Jean-Loup Chrétien. In 2012 the cost was estimated to be around US$52.7 million.

As proposed, the laboratory would be a semi-submersible oceangoing craft weighing 1,000 tonnes. It would have a total height of 51 metres with 31 metres below sea level. It is designed to float vertically and drift with the ocean currents but has two small propellers allowing it to modify its trajectory and manoeuvrer in confined waters. Underwater robots would be sent from the laboratory to explore the seabed. The hull would be made of an alloy of aluminium and magnesium.

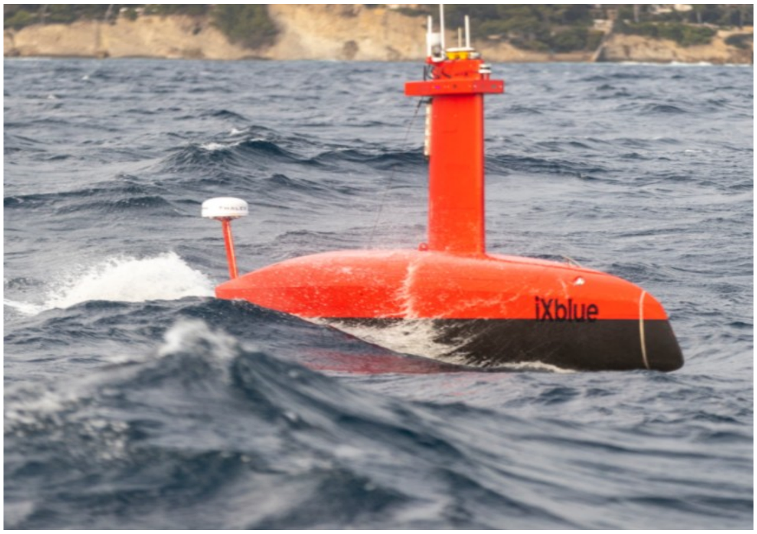
The SeaOrbiter is planned to allow scientists and others a residential yet mobile research station positioned under the oceans' surface, with laboratories, workshops, living quarters and a pressurized deck to support divers and submarines.

Construction was due to start in 2014 but by May 2015, only the Eye of SeaOrbiter has been completed, and as of early 2021, there is no news of any other construction.



There is also a lot of development towards having autonomous platforms

The Directorate of the French Oceanographic Fleet (DFO) is studying the possible addition of autonomous ships (Unmanned Surface Vehicles - USVs) to the French Oceanographic Fleet. These systems could complement existing ships in order to obtain better temporal/spatial coverage or replace them entirely for targeted and very specific applications. The general objective is cost-optimization while maximizing the fleet's environmental impact and the quantity and quality of the data acquired (see https://www.flotteoceanographique.fr/Toutes-les-actualites/Une-mission-d-evaluation-du-navire-autonome-DRIX-d-iXblue).



Test mission of the autonomous vehicle DRIX by iXblue.

Between November 10 and 15, 2021, the Ships and Onboard Systems Unit at the Oceanographic Fleet Department will test a next-generation ship, the DRIX, designed by the company iXblue.

III) ON-BOARD TEACHING - MIO CTD – TETHYS – MVP

A) **MIO CTD**
equipped with

- SBE 3 temperature sensor
- SBE 4 conductivity sensor
- Digiquartz pressure sensor
- SBE 13 oxygen sensor
- Sea-Tech transmissometer (optical path 25 cm)
- Biospherical irradiance sensor (PAR)
- Chelsea, Acquatracka III or Wetlabs FLRTD fluorometers

+ rosette or carousel Sea-Bird SBE 32, equipped with 12 Niskin bottles of 12 L each

Instrument calibration (adapted from D. Taillez, G. Coustillier and M. Lafont)

1) Pressure
Digiquartz pressure sensors have a very low drift which means that they do not have to be recalibrated regularly. Normally, they are calibrated by Ifremer's calibration service in Brest, which has a pressure balance. If there is a drift of the zero value of the sensor we use this correction:

$$P = a \times P_{measured} - b \qquad \text{(when close to 0.999)}$$

Digiquartz sensors should not exhibit any hysteresis.

2) Temperature
The SEABIRD temperature sensor come with an accuracy of 0.002°C and a typical stability of 0.0003°C per month.
Before and after a major campaign, or at least once per year, the sensor is calibrated by SEABIRD in their calibration centre which is approved by the US National Bureau of Standards.

The sensor provides the temperature in the new practical temperature measurement scale, adopted in 1990 (ITS-90). The conversion between this and the old (1968) system is given by:

$$T_{[ITS\text{-}90]} = 0{,}99976 \times T_{[IPTS\text{-}68]}$$

It should be noted that it is necessary to return to the 1968 system for calculating salinity as those formulas have not been changed.
To obtain the conservative temperature and absolute salinity, it is necessary to use the TEOS10 scripts.

3) Conductivity
The conductivity sensors may exhibit some significant drift as biofouling can change their geometry. Typically, the accuracy of a SEA-BIRD conductivity sensor is 0.0003 S/m (which

roughly corresponds to 3 thousandths absolute salinity and is stable to 0.0002 S/m per month (2 thousandths).

The drift during a cruise is calculated by measuring salinity samples on board (reminder: salinity is unitless).
To obtain the absolute salinity, it is necessary to use the TEOS10 scripts.

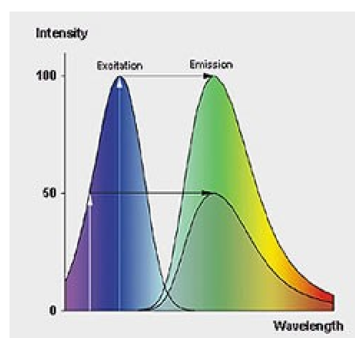
4) Dissolved oxygen
The oxygen sensor is an electrode sensor using Clark's method. The current that flows through the electrodes is proportional to the amount of oxygen that has diffused.
Although calibrated before a campaign, an oxygen sensor is always recalibrated at sea using a chemical method (Winkler), if possible after each profile. The calculation method used for the calculation of dissolved oxygen is the method described by Owens and Millard. The values are given in two forms: in ml/L and in µmol/kg which is the standard unit.

5) Fluorescence
The fluorimeter makes it possible to estimate phytoplankton concentration based on chlorophyll *a* fluorescence. When exciting cells containing chlorophyll *a* with an appropriate light source (here a blue light emitted by a flash lamp), they emit a red light around 685 nm. As a first approximation, the measured energy is directly proportional to the quantity of chlorophyll *a*:

$$\text{chl}a \ (\text{mg m}^{-3}) = A \times V_{\text{measured}} + B$$

A and B can be determined through a simple regression analysis of discrete observations of chlorophyll *a* made by other methods (spectrophotometry or HPLC).

However, there is a sizeable error associated with this linear fit, due to the fact that fluorescence varies with phytoplankton species, ambient lighting conditions, the presence of particles other than phytoplankton, etc. This is why fluorescence values are usually given in "relative units", because what matters most to the biologist is the depth of the fluorescence maximum.

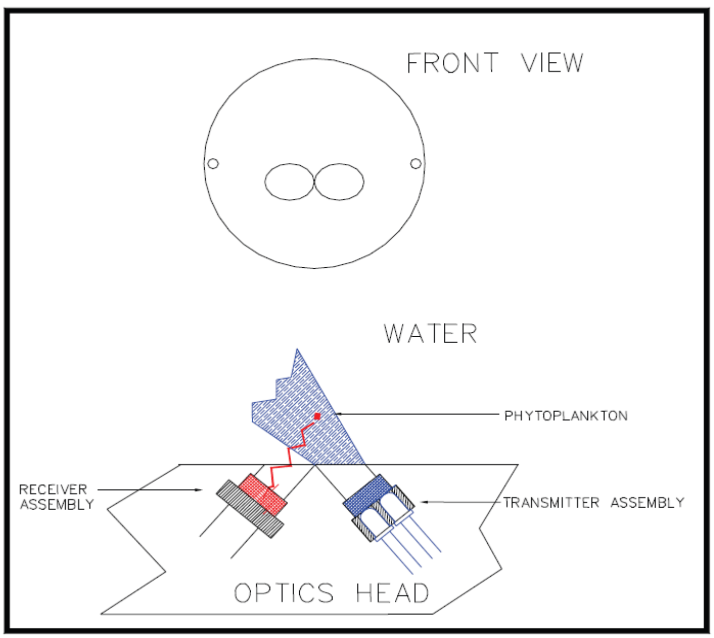


The wavelengths used can vary depending on the instrument. The following table gives the wavelength of the centre of an excitation/emission band as well as the width of the band in parentheses.

Fluorometer	Excitation	Emission
Chelsea AcquaTracka (COM until 2010, refurbished, currently in use)	430 nm (105 nm)	685 nm (30 nm)
Turner	460 nm	620-715 nm

WetLabs FLR ECO (MIO)	470 nm	695 nm
WetLabs WetStar	460 nm	695 nm
Ancien SeaTech	425 nm (200 nm)	685 nm (30 nm)

Ex/Em: 470/695 nm • Sensitivity: 0.02µg/l • Linearity: 99%R^2 • Range: 0.01–125 µg/l
The *Environmental Characterization Optics*, or *ECO* miniature fluorometer allows the user to measure relative chlorophyll, CDOM, uranine, phycocyanin, or phycoerythrin concentrations by directly measuring the amount of fluorescence emission in a sample volume of water. The *ECO* uses an LED to provide the excitation source. An interference filter is used to reject the small amount of out-of-band light emitted by the LED. The light from the source enters the water volume at an angle of approximately 55–60 degrees with respect to the end face of the unit. Fluoresced light is received by a detector positioned where the acceptance angle forms a 140-degree intersection with the source beam. An interference filter is used to discriminate against the scattered excitation light.



Optical configuration of *ECO* fluorometer

Other possible environmental applications:
* Obtain **CDOM** fluorescence across a wide range of environments, from mangrove swamps to oligotrophic blue water.

Ex/Em: 370/460 nm • Sensitivity: 0.09 ppb QS • Linearity: 99%R^2 • Range: 0–500 ppb

* *ECO* phycobilin fluorometers have the high resolution necessary for early detection of either blue-green (phycocyanin) or brown (phycoerythrin) algae. These fluorometers are relative measurement instruments and should be calibrated by cell counts for a particular water mass.

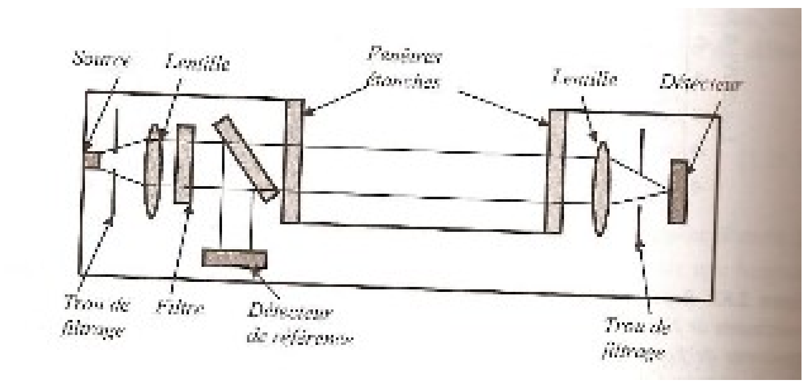
Phycocyanin Ex/Em: 630/680 • Sensitivity: 0.05 ppt • Linearity: 99%R • Range: 0–400 ppt
Rhodamine (and Phycoerythrin) Ex/Em: 540/570 nm • Sensitivity: 0.03 ppb • Linearity: 99%R^2 • Range: 0–230 ppb

* Dye tracers can be done ex with fluorescein: **Uranine** (fluorescein) Ex/Em: 470/530 nm • Sensitivity: 0.05 ppb • Linearity: 99%R^2 • Range: 0–400 ppb

(for more details see the WetLabs website: http://www.wetlabs.com/)

6) Transmission – Attenuation of light

The attenuation of a light beam propagating through sea water is due to scattering (b) and absorption (a), the sum of which is called the attenuation (c = a +b). Transmissometers are instruments that attempt to measure these losses.



Schematic of the working principle of a transmissometer (from WetLabs, C Star)

The Sea-Tech transmissometer measures the attenuation of a collimated 660 nm light beam over an optical path length of 25 cm. The signal measured in air corresponds to a transmission of 100% as serves as a reference for the signal measured in water; **the higher this coefficient the clearer the water**. For optically pure sea water and an optical path of 25 cm, we get Tr = 91.3%

This is expressed by the attenuation coefficient, c, which is linked to transmission via

$$Tr = e^{-cz} \qquad \text{let} \qquad c = -\ln(Tr)/z$$

where Tr = Tr %/100 and where z is the optical path length. Since z = 25 cm, we get c = -4ln(Tr)

c has units m^{-1}. In optically pure water its value is 0.364 m^{-1} (for an optical path of 25 cm), which yields Tr = 91.3 % with regard to the reference value in air. However, nowadays many instruments are calibrated with respect to pure water (instead of air) such that the transmission in pure water is 100%.

7) PAR or light quanta (quantum is another name for a photon)

PAR (Photosynthetically Available Radiation) is measured as the number of photons with wavelengths between 400 and 700 nm (it is therefore a non-spectral quantity), incident on a given surface during a certain time interval from any direction (unit: photons/s/m^2 or Einstein/s/m^2; with 1 Einstein = 1 Na photons = 6.023×10^{23} photons; Na being the Avogadro number).

$PAR = \int_{400}^{700} E_o \frac{\lambda}{hc} d\lambda$ often given in units $\mu E\, m^{-2} s^{-1}$

Careful, PAR is neither a spectral measurement (as it does not correspond to any specific wavelength), nor is it a measure of energy.
Beware of PAR values provided in Watts. If this is the case, this means that these PAR values (= number of photons) have undergone a conversion based on a hypothesis of the composition of the water, and therefore of the distribution of the photons.
This conversion usually uses the article from Morel and Smith, 1974 (Limnol, 19 (4), Relation between total quanta and total energy for aquatic photosynthesis); where the conversion factor is given as $1\, Watt \approx 2.5\, 10^{18}\, quanta\, s^{-1} \approx 2.5\, 10^{18}\, photons\, s^{-1} \approx 4.2\, \mu E\, s^{-1}$. This conversion cannot be applied to coastal or oligotrophic waters.

Reminder: 1 Watt = 1 J/s = 1 N m/s = 1 kg m^2/s^3

+ use of a Secchi disc
Count the number of meters for which you can see the disc (note the angle of inclination of the rope if it is inclined)

SECCHI	I50	I30	I15	I5	I1	I01
2	0.82	1.42	2.23	3.52	5.42	8.13
3	1.22	2.12	3.35	5.29	8.13	12.19
4	1.63	2.83	4.46	7.05	10.84	16.25
5	2.04	3.54	5.58	8.81	13.54	20.32
6	2.45	4.25	6.70	10.57	16.25	24.38
7	2.85	4.96	7.81	12.34	18.96	28.44
8	3.26	5.67	8.93	14.10	21.67	32.51
9	3.67	6.37	10.04	15.86	24.38	36.57
10	4.08	7.08	11.16	17.62	27.09	40.63
11	4.49	7.79	12.28	19.38	29.80	44.70
12	4.89	8.50	13.39	21.15	32.51	48.76
13	5.30	9.21	14.51	22.91	35.22	52.82
14	5.71	9.92	15.62	24.67	37.92	56.89
15	6.12	10.62	16.74	26.43	40.63	60.95
16	6.52	11.33	17.86	28.20	43.34	65.01
17	6.93	12.04	18.97	29.96	46.05	69.08
18	7.34	12.75	20.09	31.72	48.76	73.14
19	7.75	13.46	21.20	33.48	51.47	77.20
20	8.15	14.16	22.32	35.24	54.18	81.27
21	8.56	14.87	23.44	37.01	56.89	85.33
22	8.97	15.58	24.55	38.77	59.60	89.39
23	9.38	16.29	25.67	40.53	62.31	93.46
24	9.79	17.00	26.78	42.29	65.01	97.52
25	10.19	17.71	27.90	44.05	67.72	101.58
26	10.60	18.41	29.01	45.82	70.43	105.65
27	11.01	19.12	30.13	47.58	73.14	109.71
28	11.42	19.83	31.25	49.34	75.85	113.77
29	11.82	20.54	32.36	51.10	78.56	117.84
30	12.23	21.25	33.48	52.87	81.27	121.90
31	12.64	21.95	34.59	54.63	83.98	125.96
32	13.05	22.66	35.71	56.39	86.69	130.03
33	13.46	23.37	36.83	58.15	89.39	134.09
34	13.86	24.08	37.94	59.91	92.10	138.16

Table of depths (in metres) of illumination levels with respect to the Secchi depth (in metres) given in the first column

B) **Téthys II**
La flotte>Navires>Navires côtiers>Téthys II
(http://www.flotteoceanographique.fr/La-flotte/Navires/Navires-cotiers/Tethys-II)

This oceanographic vessel carries out scientific research missions mainly in the Mediterranean Sea. It can perform ten-day missions up to 200 miles from port. This instrumented coastal vessel meets the needs of researchers in the field of marine geosciences, physical and biological oceanography, bio-geochemistry, and ocean chemistry. It also contributes to long-term observation missions of the marine environment and to research and test missions in the various fields of marine technology. This ship can also carry out teaching missions for 2nd and 3rd year university students.

Vessel characteristics

- **Overall length**: 24.90 m
- **Overall width**: 7.50 m
- **Draft**: 3.20 m
- **Diesel capacity**: 30 m^3
- **Consumption**: 110 litres/h
- **Deck crew**: 7
- **Berths for scientists, technicians, and hydrographers**: max 12
- **Mean speed while in transit and while performing a transect**: 10 knots
- **Mean speed during sampling**: 11 knots
- **Autonomy**: 10 days at 11 knots
- **Fresh water capacity**: 21 m^3

- **Waste water capacity**: 3 m³
- **Construction**: 1993, Piriou shipyard in Concarneau, France
- **Owner**: CNRS-INSU

Propulsion/auxiliaries

- **Main engine**: classic type, electric diesel POYAUD UD 25V12 478 KW at 1300 rpm
- **Thruster**: tube/propeller 558.8 mm generating thrust of 660 kgf
- **Electricity production**: one 85 KVA Perkins engine generator + one 55 KVA Perkins engine generator, 6 and 3 KVA inverters.

Navigation and positioning

- Autopilot Havant Navitron NT 777
- Radar JRC JMA 5200
- Radar JRC JMA 5100
- Digital Gyrocompas System navigat XMK2
- Two DGPS RS Supreme SAAB
- AIS SAAB
- Maxsea navigation software and charts
- ECDISPILOT BASIC navigation software and charts

Installed equipment – Communication

- Phone by GSM

> Note: The Global System for Mobile Communications (GSM) is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices such as mobile phones and tablets. It was first deployed in Finland in December 1991. By the mid-2010s, it became a global standard for mobile communications achieving over 90% market share, and operating in over 193 countries and territories. 2G networks developed as a replacement for first generation (1G) analogue cellular networks. In Europe, the GSM standard uses the 900 MHz and 1800 MHz frequency bands. The United States uses the 850 MHz and 1900 MHz bands. Thus, mobile phones that can operate in Europe and the United States are qualified as tri-band (sometimes denoted tri-band), and as dual-band those operating only in Europe.
> The GSM standard authorizes a maximum speed of 9.6 kbps, which makes it possible to transmit voice as well as low-volume digital data, for example text messages (SMS, for Short Message Service) or multimedia messages (MMS, for Multimedia Message Service).

- Inmarsat phone services

> Note: Inmarsat is a British satellite telecommunications company offering global mobile services. It provides telephone and data services to users worldwide, via portable or mobile terminals which communicate with ground stations through fourteen geostationary telecommunications satellites. The present company originates from the International Maritime Satellite Organization (INMARSAT), a non-profit intergovernmental organization established in 1979 at the behest of the International Maritime Organization (IMO) (the United Nations maritime body) to establish and operate a satellite communications network for the maritime community. Today, Inmarsat's network provides communications services to a range of

governments, aid agencies, media outlets and businesses (especially in the shipping, airline and mining industries) with a need to communicate in remote regions or where there is no reliable terrestrial network.

- Phone and fax via VSAT uplink with extended Mediterranean coverage

The acronym VSAT stands for very small aperture terminal and designates a two-way satellite communication technique that uses parabolic antennas with diameters <3 m (generally between 0.75 m and 1.2m). This communication technique therefore requires few resources on the ground. VSAT can therefore be useful for connecting a small site to communication networks, whether for telephony or for Internet access.
NB: VSAT is a concept and not a standard and can therefore be implemented differently by different manufacturers.

+ Installed equipment:
- SMDSM radio Sailor RT 2048 VHF
- One VHF DSC RM 2042 (70ASN)
- One navtex NT 900
- One skanti 2182 WR 6000
- Two VHF portable FM transceivers YAESU
- One gonio VHF Océanide MK2
- Brother FAX-T104

IT network
- VSAT system: Satellite uplink allowing permanent communication (24/7) in the extended Mediterranean with speeds equivalent to a terrestrial ADSL network.
  RJ45 network sockets on the bridge (priority on board) as well as in the dry and wet labs
- WIFI; Max bit rate (BURST): 1024 kbps with a contention of 8:1, meaning that this bandwidth can be shared by up to 8 boats or it can be used entirely by a single ship
- Workstations: Windows XP, Linux

Scientific equipment and facilities
- Simrad EA600 dual frequency sounder 12/200 kHz
- JMC f-3000 dual frequency sounder 50/200 kHz
- 2-head Hemisphere VS330 GPS (position, heading and attitude; output available via DB9 sockets on the bridge and the wet/dry labs)
- Hull-mounted ADCP RDI Ocean Surveyor 75 kHz (current measurements)
- Central Météo France batos
- 10-AU-005-CE Turner Designs fluorometer
- Thermosalinometer SBE 21 (4Hz sampling frequency)
- An acoustic boom
- 2 scientific labs with a total surface of about 14 m²
- wet lab: 9.4 m²
- multipurpose lab: 4.5 m²

- 1 scientific office space on the bridge: 3 m²
- Rear deck area: 22 m²
- Room for one 10-foot container on the rear deck

Deck gear

A-frame

- CMU 5 tons

Mobile winches

- 1 x fishing winch L: 2100 m, D: 14 mm
- 1 x coring winch L: 4000 m, D: 10.5 mm
- 1 x hydrological winch L: 3000 m, D: 4.8 mm
- 1 x electric (conducting cable) winch L: 3600 m, D: 6.45 mm
- Starboard side crane: WWL: 1 T at 5.10 m

Crew areas

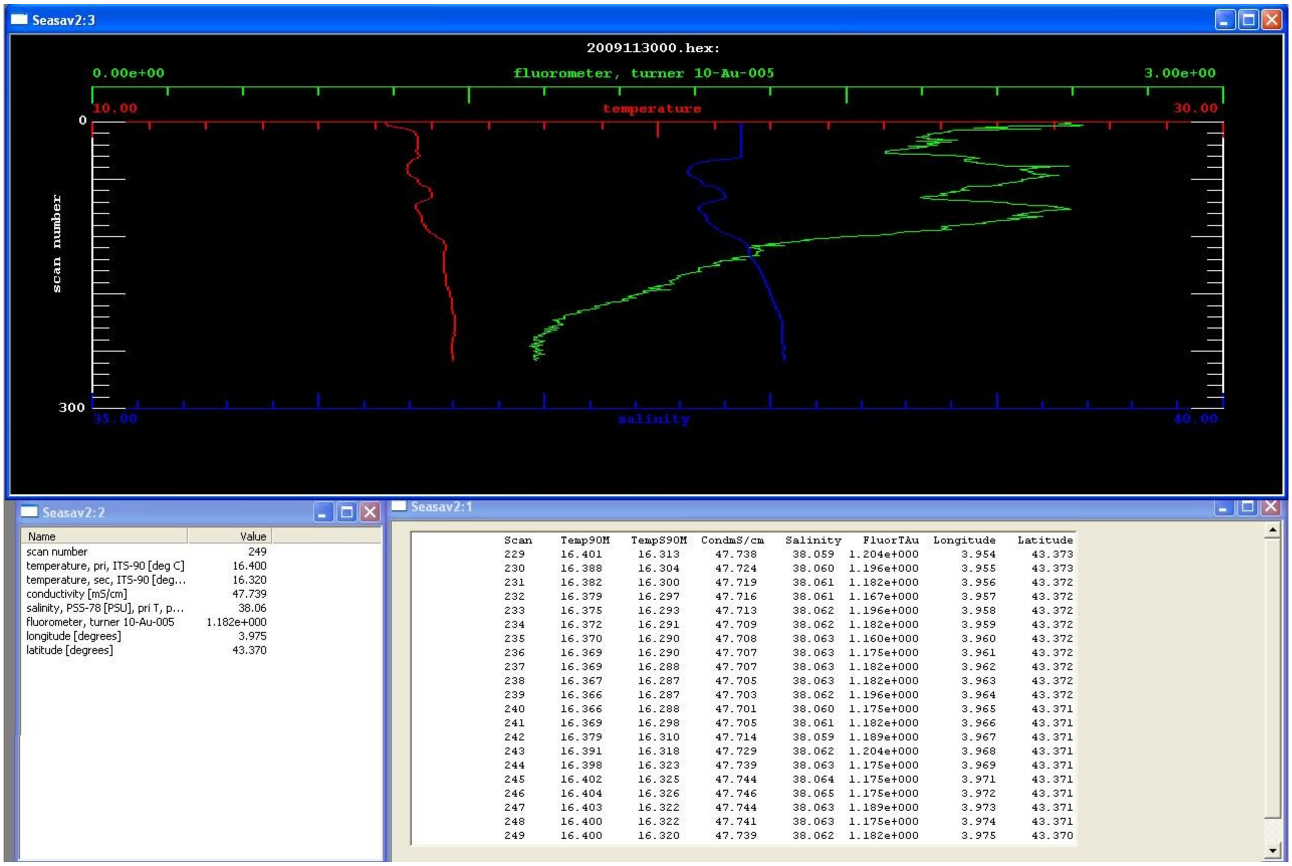
The ship is a **2nd category vessel (<200 miles from shore)**
In this configuration, the ship can host

- main crew: 7
- special personnel: 8
- total: 15

The vessel can also operate as a **3rd category vessel** for shorter (<24h) campaigns that remain closer to the coast **(< 20 miles from shore)**

- main crew: 7
- special personnel: 12
- total: 19

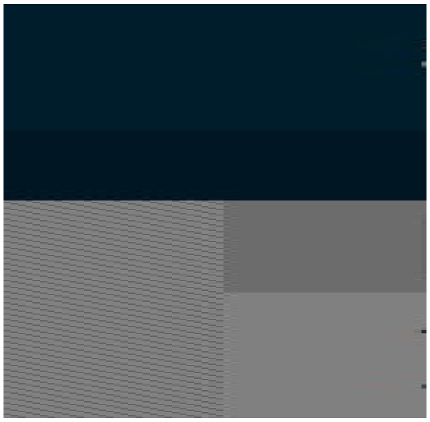
The Thermosalinometer samples the water pumped to the surface (sample frequency 4Hz) screenshot:



On the lower left screen, the first temperature is that of the thermosalinometer Seabird (measured together with conductivity) located in the wet lab; while the second temperature is that of the hull thermistor.

Write down a few temperature pairs as simultaneously as possible in order to assess the difference and see if it is systematic.

ADCP Ocean Surveyor 75 kHz (70 bins, first bin at 19m; for a bin size of 8m → range~19 +69*8 = 571 m or 19:8:571)



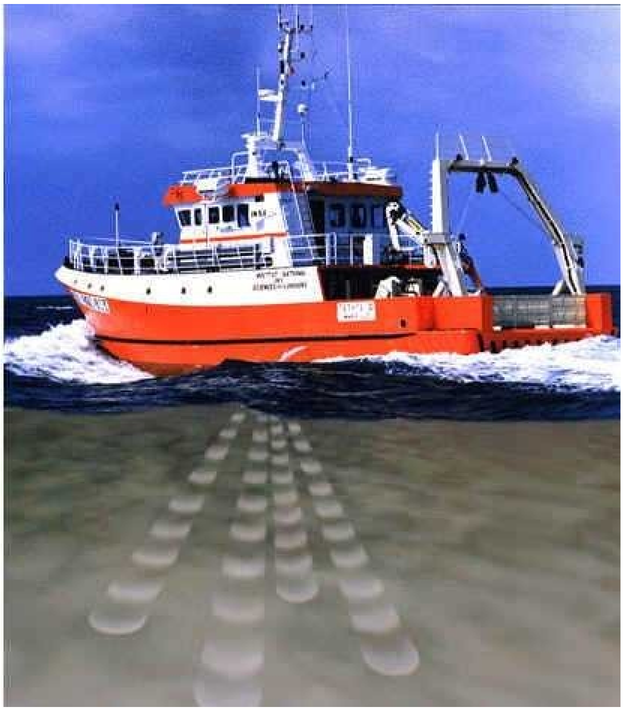
- Patented BroadBand signal processing combined with NarrowBand processing.
- Patented phased array transducers, significantly reducing transducer size.
- Combined current profiling, backscatter profiling, and Doppler velocity logs.
- Patented 4-beam design for data reliability.

(http://rdinstruments.com/product/adcp/ocean-surveyor-adcp)

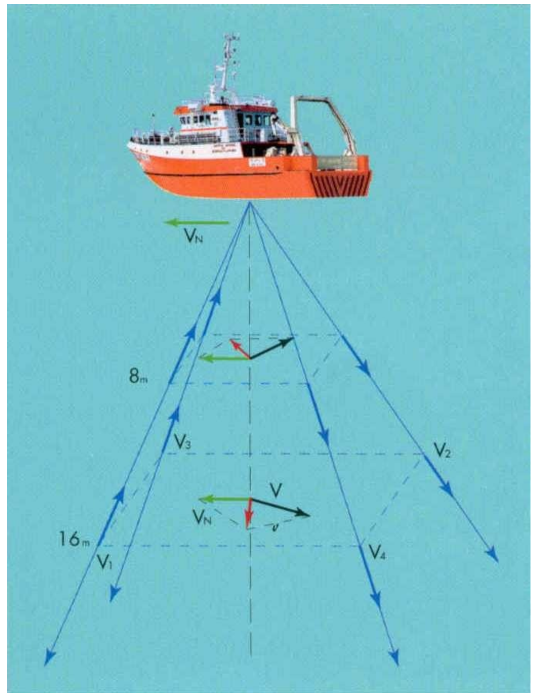
Below: earlier version of the ADCP (until January 2015) ADCP RDI BB (BroadBand) 150 kHz with 4 transducers

	
Attaching the hull-mounted ADCP	Under the hull (seen from the front)

Source: http://www.dt.insu.cnrs.fr/adcp/inst_tech.php

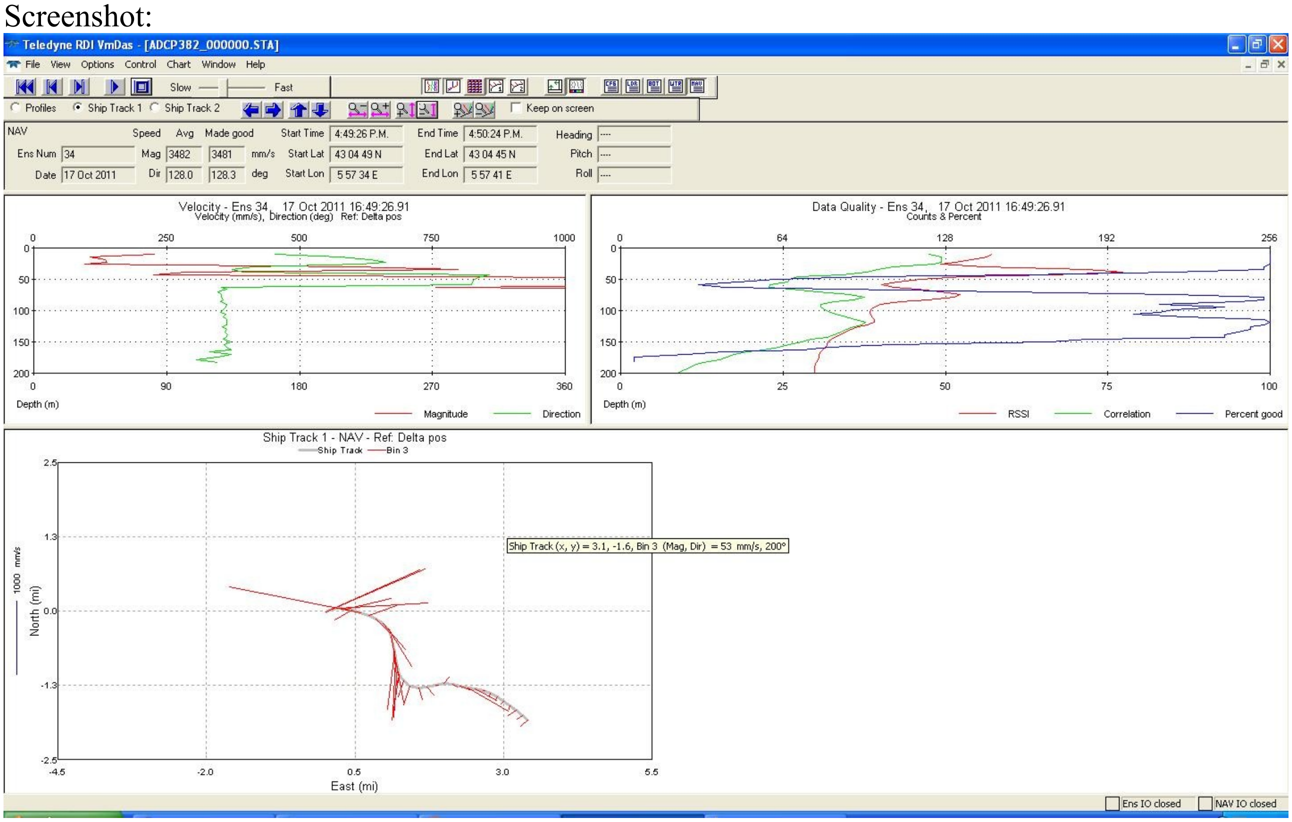


Acoustic measurements using the ADCP



Calculating the current velocity

Screenshot:



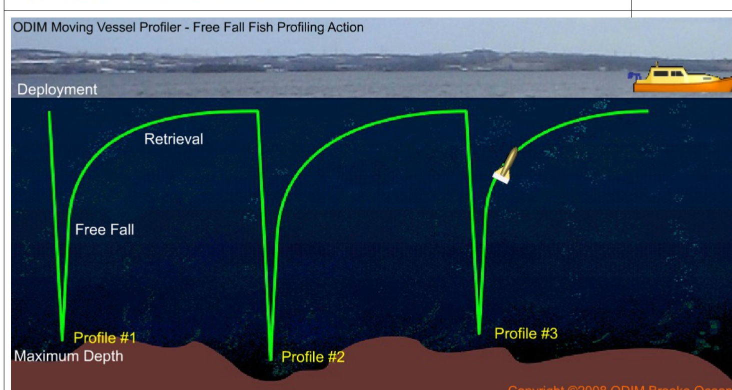
C) MVP

The M*oving Vessel Profiler* is an innovative piece of equipment for performing vertical profiles while the ship is in motion, which makes it an exceptional tool for studying small scale processes (submesoscale dynamics, plankton patchiness, ...).

The MVP system consists of a winch, an conducting cable, and a profiling platform (the "fish"). It is a towed system that performs vertical profiles from the surface to about 300m depth, while the ship is steaming at between 4 to 10 knots.

The winch, the cable, and the small "fish" equipped with temperature/speed of sound/pressure sensors are managed by Genavir.

The MIO also has a larger fish, type MSFFF- MultiSensor Free Fall Fish, equipped with CTD sensors, fluorimeter, and LOPC (Laser Optical Particle Counter). It is therefore a unique instrument for synoptic studies targeting small scales (e.g., ref biblio) and physical-biological coupling.

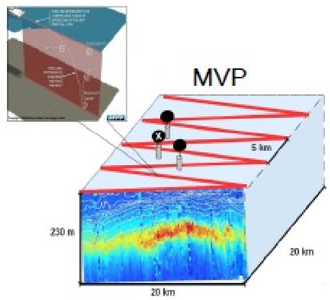
	Installing the MVP on R/V Téthys (OSCAHR 2015)
	*~2 km horizontal resolution* *~1 m vertical resolution*

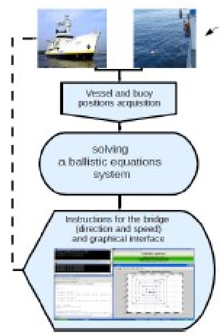
These “fish” descend vertically with a speed of about 4 m/s. The number of vertical profiles obtained per horizontal distance travelled depends on the depth sampled and the speed of the vessel.

Lifetime:
The MVP system has no lifetime limit but requires regular maintenance (replacement of the cable and parts, calibration of the sensors, etc)

Purchase cost: 400,000 Euros
Operating cost: 8,000 Euros
The winch is operated by Génavir; the MSFFF fish is operated by MIO: sensor calibration, consumables.

MIO's MSFFF fish will be made available to the wider oceanographic community. The MVP and MSFFF fish were already used in 2015 during OUTPACE (PIs: T. Moutin and S. Bonnet) and OSCAHR (Pis: A. Doglioli and G. Gregory). Their use is envisaged for the PEACETIME 2017 campaign (Pis: C.Guieu and K.Desboeufs) and has been requested for the PUFFALIS (PI: C.Menkes, March 2018), BIOSWOT (PI: F d'Ovidio, 2018), and CLOCHEMED (PI: B. Zakardjian) campaigns.

<table>
<tr>
<td>




Lagrangian navigation
see available LATEX tools
http://www.mio.univ-amu.fr/LATEX

Article summarizing the LATEX campaign: Petrenko, A.A. et al (2017). A review of the LATEX project: mesoscale to submesoscale processes in a coastal environment. Ocean Dynam., doi: 10.1007/s10236-017-1040-9. (can be downloaded from the publications section on my web page)</td>
<td></td>
</tr>
<tr>
<td>SPASSO Software Package for an Adaptive Satellite-based Sampling for Ocean campaigns (http://www.mio.univ-amu.fr/SPASSO)</td>
<td>MVP transsects at Station B – Outpace 2015
Courtesy A. de Verneil</td>
</tr>
</table>

manufacturer pages:
http://www.brooke-ocean.com/mvp_main.html
http://www.brooke-ocean.com/flash-mvpfish.html

video
https://www.youtube.com/watch?v=d7pscTN_x-g

References:

Li, Q. P., Franks, P. J., Ohman, M. D., & Landry, M. R. (2012). Enhanced nitrate fluxes and biological processes at a frontal zone in the southern California current system. JPR.

Meunier, T., Barton, E. D., Barreiro, B., & Torres, R. (2012). Upwelling filaments off Cap Blanc: Interaction of the NW African upwelling current and the Cape Verde frontal zone eddy field. JGR

de Verneil, A., and P. J. S. Franks (2015), A pseudo-Lagrangian method for remapping ocean biogeochemical tracer data: Calculation of net Chl-a growth rates, J. Geophys. Res. Oceans, 120, 4962–4979, doi:10.1002/2015JC010898.

APPENDIX: Ship log and log sheets

a) Instructions for deploying the CTD

	Communicate with the crew to plan the station
	Before stopping at the station, note the weather information: true wind (at 10 meters), pressure, T air and humidity. Ask the captain for information on cloudiness (in eights: 1 = clear, 8 =overcast), visibility and the sea state.
	Check to ensure that the Niskin bottles are all open
	Start the Seabird software and set the file name for the next station
	Before deployment, switch on the power
	On deck someone removes the syringe (conductivity) and the PAR cap
	Deploy the CTD and start acquiring data
	Lower it to 10 m
	Check when the pump comes on and see whether the different measurements coming in are valid (temperature, salinity, ...)
	When all is running, ask the crew to bring it back to the surface and stop the acquisition
	Check the depth
	CTD a bit before the surface
	Restart the data acquisition overwriting the previous file (from the test at 10m)
	Ask the crew to lower the CTD to a depth XX at 1m per s
	Check the profile acquired during the descent
	Take decisions on the depths where the Niskin bottles will be closed during the ascent
	To close the next bottle: - tell the captain to raise the CTD to depth YY - check that the depth has been reached - say the main depths out loud so the captain can check the depth given by the winch - at depth YY, close one or several bottles - wait a few seconds for the Niskin light to go out before firing the next bottle
	Surface approach Stop the data acquisition
	Ask the captain to bring the CTD back on board
	Switch off the power to the CTD
	Replace the cap over the PAR sensor
	Rinse the conductivity probe with demineralised water and replace the syringe

	After the end of the CTDs, rinse the CTD
	Leave the bottles semi-open by placing the ends of plastic pipes at both ends

b) CTD ship log and measurements other than CTD, e.g., Cortiou Bottle

PROFIL CTD

Sonde Type / N°
SBE 9plus /

Mission :	PHYBIO_2017
Bateau :	TETHYS II

Date :
Station :

Position	Début	Fond	Fin
Latitude			
Longitude			
Heure HL / TU			

Sonde Bateau	
Prof. Profil	
Nom Fichier	
Opérateur	

Météorologie		Unité
Heure d'observation		HL / TU
Vent Direction		degrés
Vent Vitesse		Nœuds
Pression atmosphérique		hpa
Température air		°C
Humidité		%
Température mer surface		°C
Salinité surface		
Etat de la mer		
Nébulosité (de 1 à 8*)		octas
Visibilité		Km
* 1 dégagé, 8 couvert		

Carrousel			
b	Profond.	T °C	Salinité
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Vérification de l'enregistrement du fichier sur le disque "STORING DATA TO DISK "	

OBSERVATIONS

OPERATION à la mer
(Hors CTD)

Mission :	PHYBIO_2017
Bateau :	TETHYS II

Date :		Station		
Opération 1				
	Heure HL/TU	Latitude	Longitude	Sonde Bateau
Début				
Fin				
Nature de l'opération :				
Echantillons prélevés :				
Commentaires :				
Opération 2				
	Heure HL/TU	Latitude	Longitude	Sonde Bateau
Début				
Fin				
Nature de l'opération :				
Echantillons prélevés :				
Commentaires :				

Météorologie			Unité
Heure d'observation			HL / TU
Vent	Direction		degrés
	Vitesse		Nœuds
Pression atmosphérique			hpa
Température air			°C
Humidité			%
Température mer surface			°C
Salinité surface			
Etat de la mer			
Nébulosité (de 1 à 8*)			octas
Visibilité			Km

* 1 dégagé, 8 couvert