ITINERIS

Measuring the Ocean

1. Observing Systems

Katrin Schroeder (CNR-ISMAR, Venice)

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

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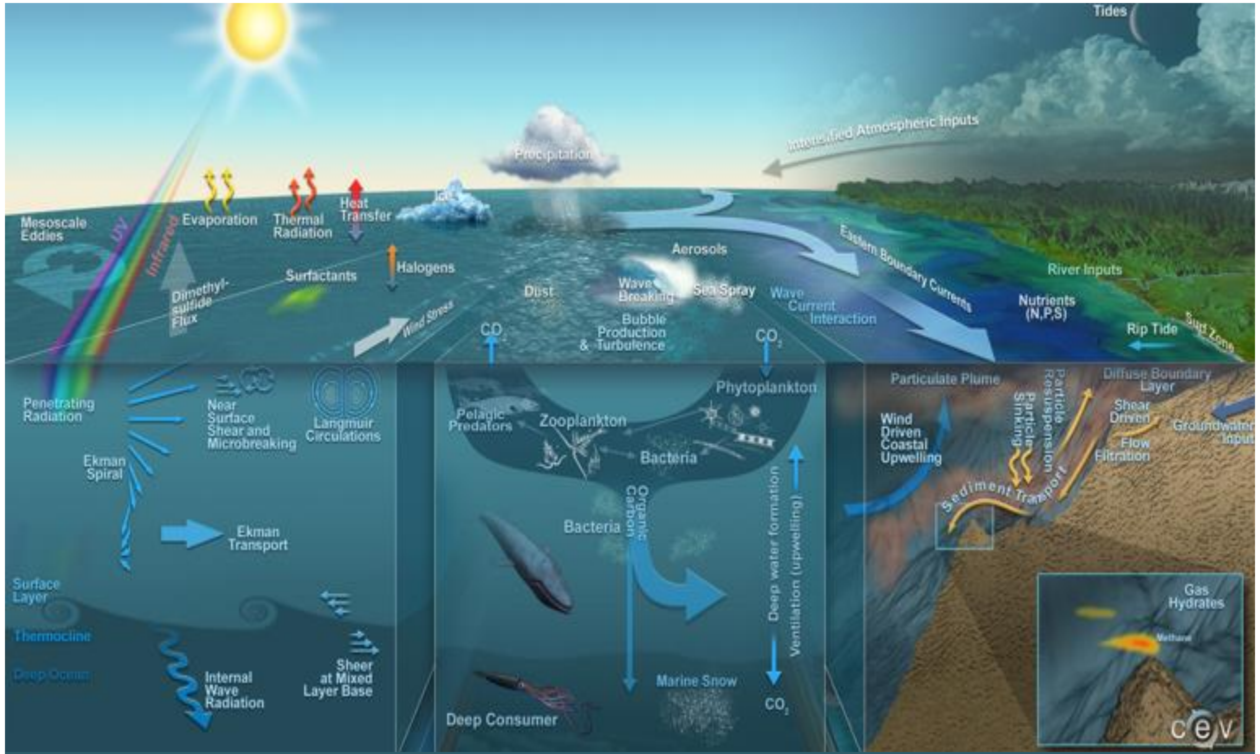
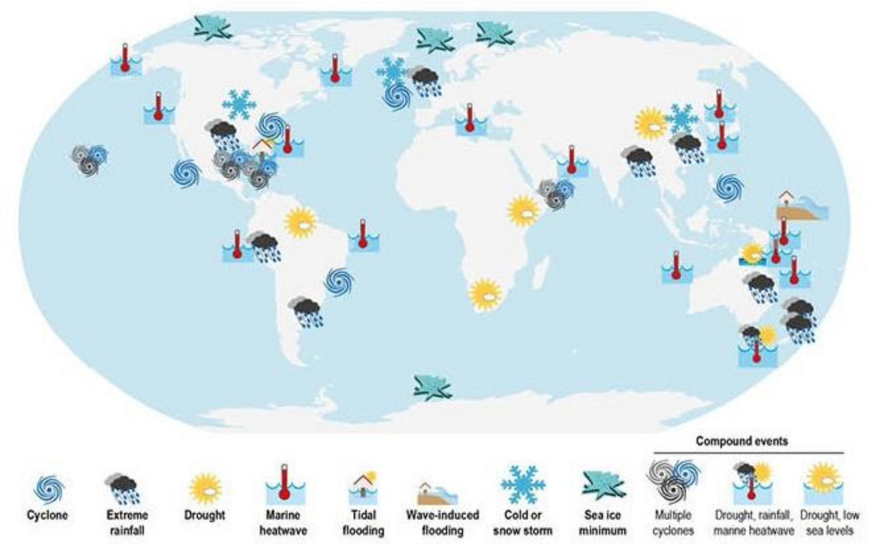
Oceanic processes and their societal relevance



Credits University of Washington

From Pendleton et al., 2020, PNAS



Credits IPCC SROCC

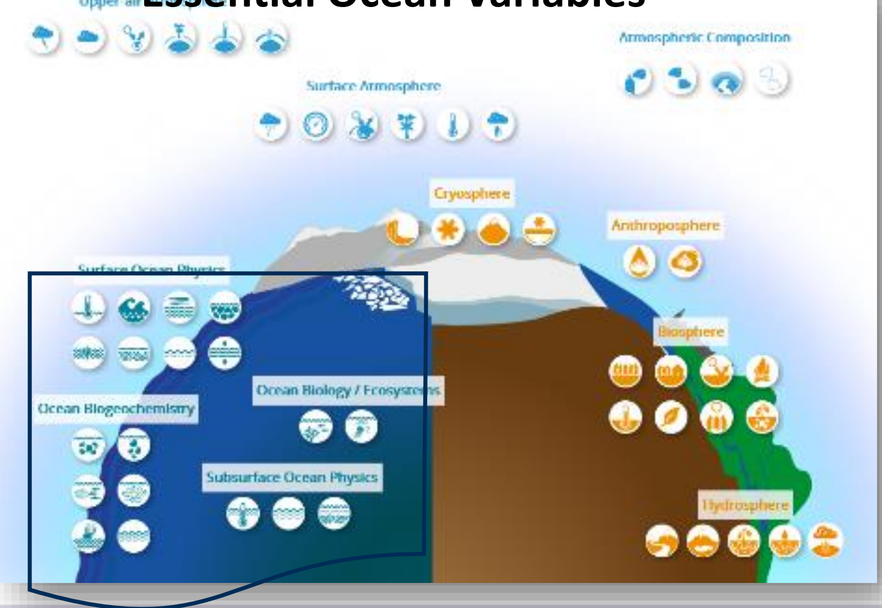
The Ocean Observing System

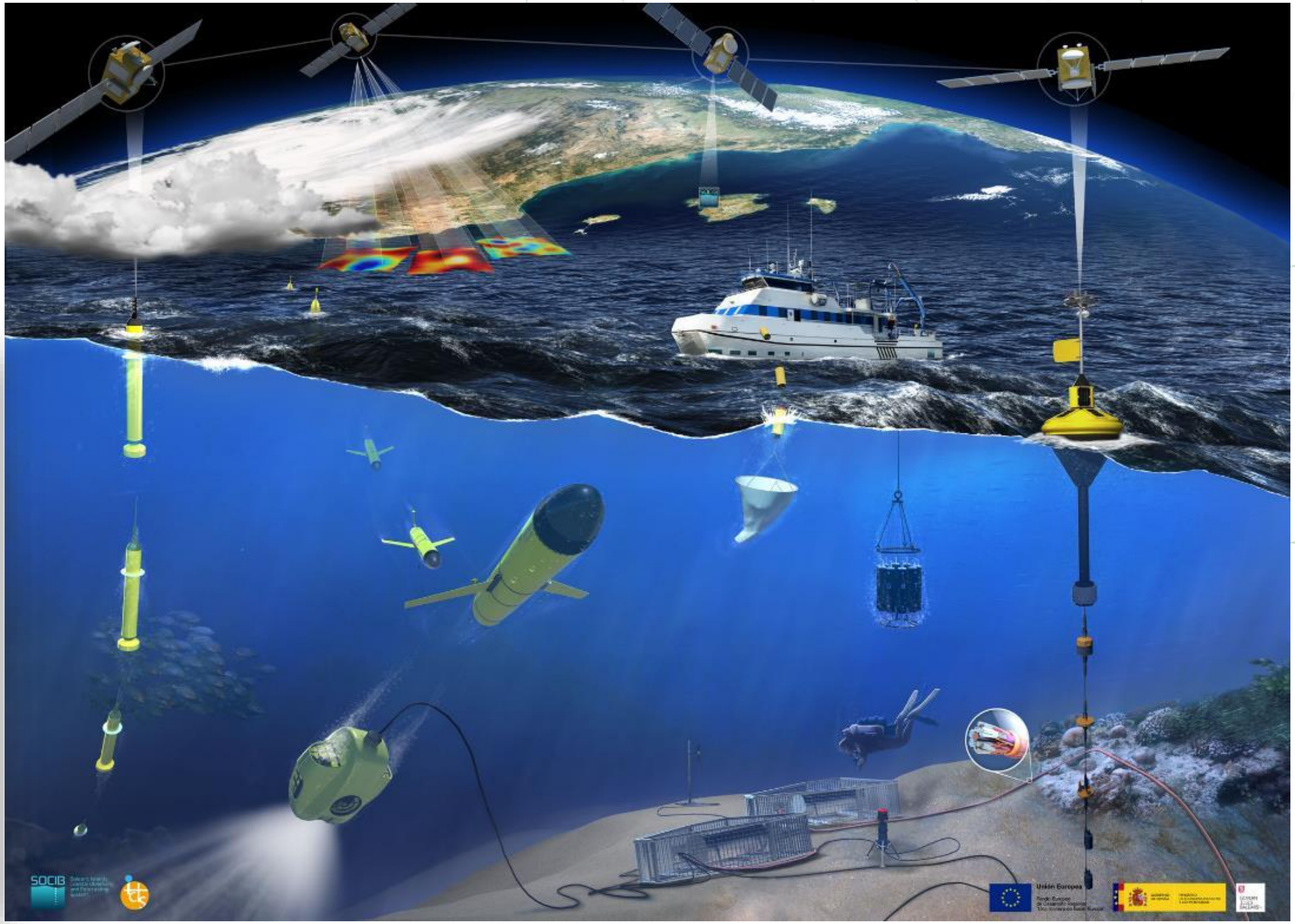
Operational oceanography and ocean and climate change research rely on an integrated sustained multidisciplinary observing system

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

GOOS

Essential Ocean Variables





Observing the Ocean: how?

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Sensors to measure continously and autonomously physical, chemical and biological parameters

- salinity, temperature
- turbidity, oxygen
- chlorophyll, nutrients
- pH, alkalinity
- bathymetry
- primary production

Platforms or structures anchored on the seabed, floating in the water column or drifting at the sea surface, and remote sensing from satellites

- buoys, floats
- gliders
- moorings
- AUVs
- FerryBox
- cabled networks
- remote sensing

Sampling and consecutive lab analyses from research vessels, or shore, including water, sediments and biota

- inorganic trace compounds
- gases (CO2, Ch4, DMS)
- organic micropollutants
- abundancs & function of biota
- food web
- HABs

Comunication systems to transfer in real-time data from sensors to the network and to the land stations

- satcom
- GSM, GPRS
- fibre optics
- acoustics

Data collection and management system for direct control of data quality, and data storage systems to enable data analysis and use for model applications

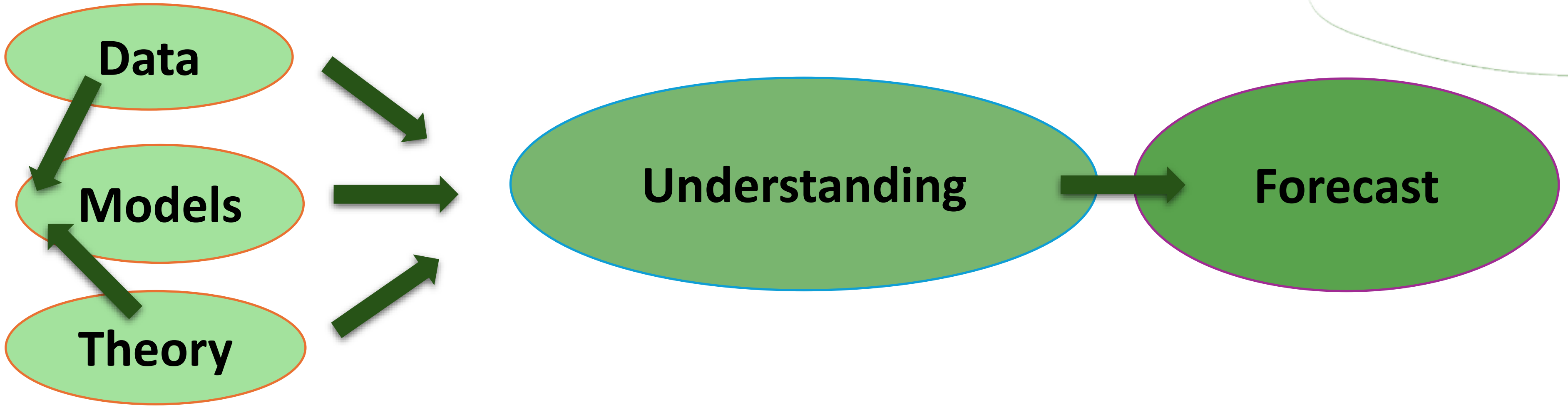
- data bases
- quality control
- data standards

Software and web based information tools to analyse data for trends, compliance to EU directives, to distribute and disseminate data to end users

- data products and subsetting tools
- web
- GIS
- Presentations

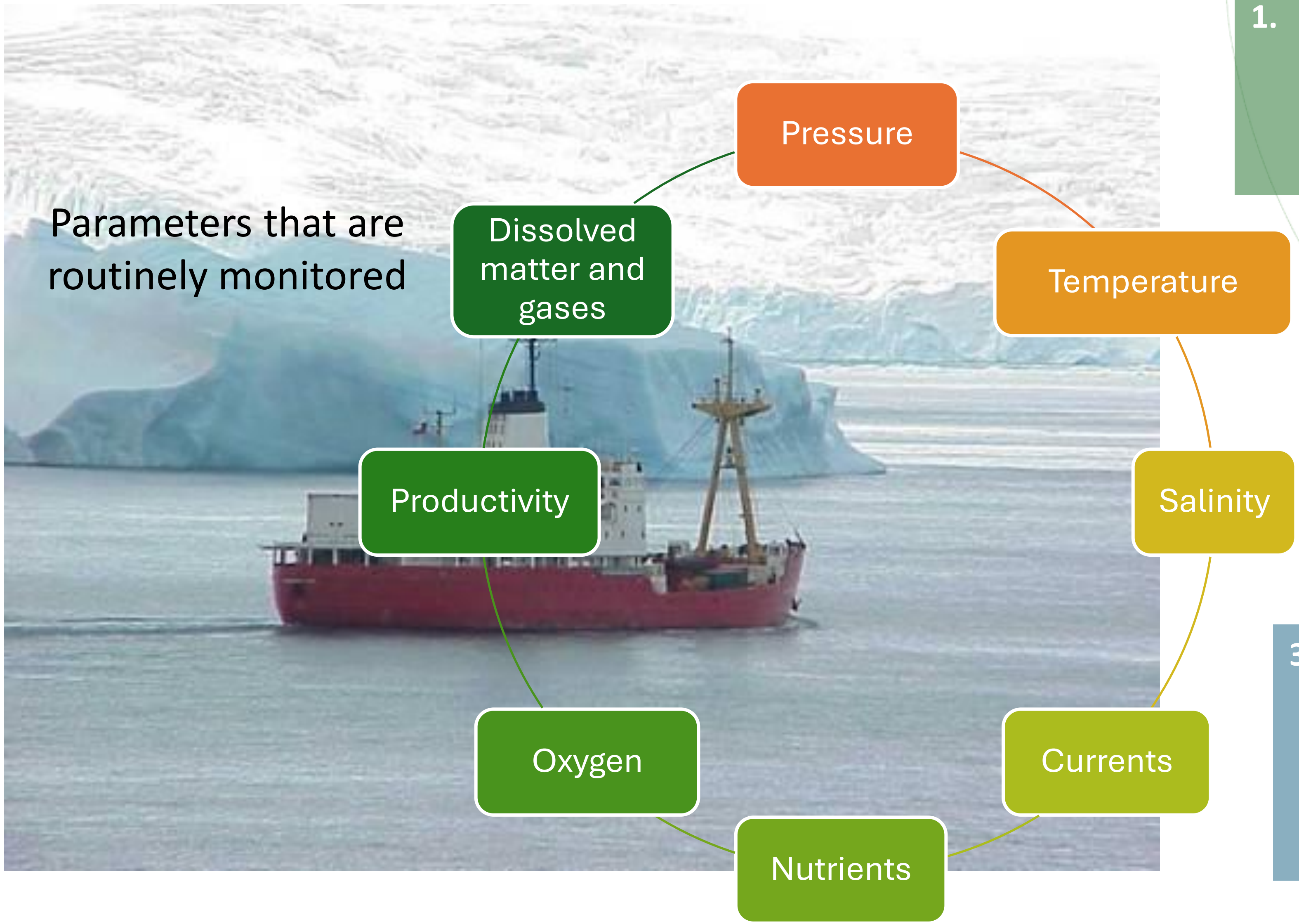
Observing the Ocean: why?

- monitor the state of the seas and the climate
- provide early warning/tracking of high impact weather and oceanographic events
- initialize environmental prediction models (for weather forecasting, seasonal to decadal climate prediction, ocean and wave prediction) and to verify the performance of such models
- support commercial activities (e.g. offshore oil and gas operations)
- provide ground-truth for satellite observations
- improve process understanding to for incorporation into prediction models



Observing the Ocean: what?

Parameters that are routinely monitored



1. **The ocean provides us food**
   We are interested to know the processes that may influence their productivity (temperature, currents, nutrients distribution)

2. **We use the ocean:** infrastructures, maritime transports, gas and oil extractions, recreational use
   We are interested to study the processes that may have an impact on these uses (waves, wind, currents, temperature, salinity)

3. **The ocean influences meteorology and climate**: distribution of rain, droughts, regional climate, storms, CO2 adsorbtion, heat budget
   We are interested in understand air-sea interactions, heat trasport, influence of the ocean on the climate

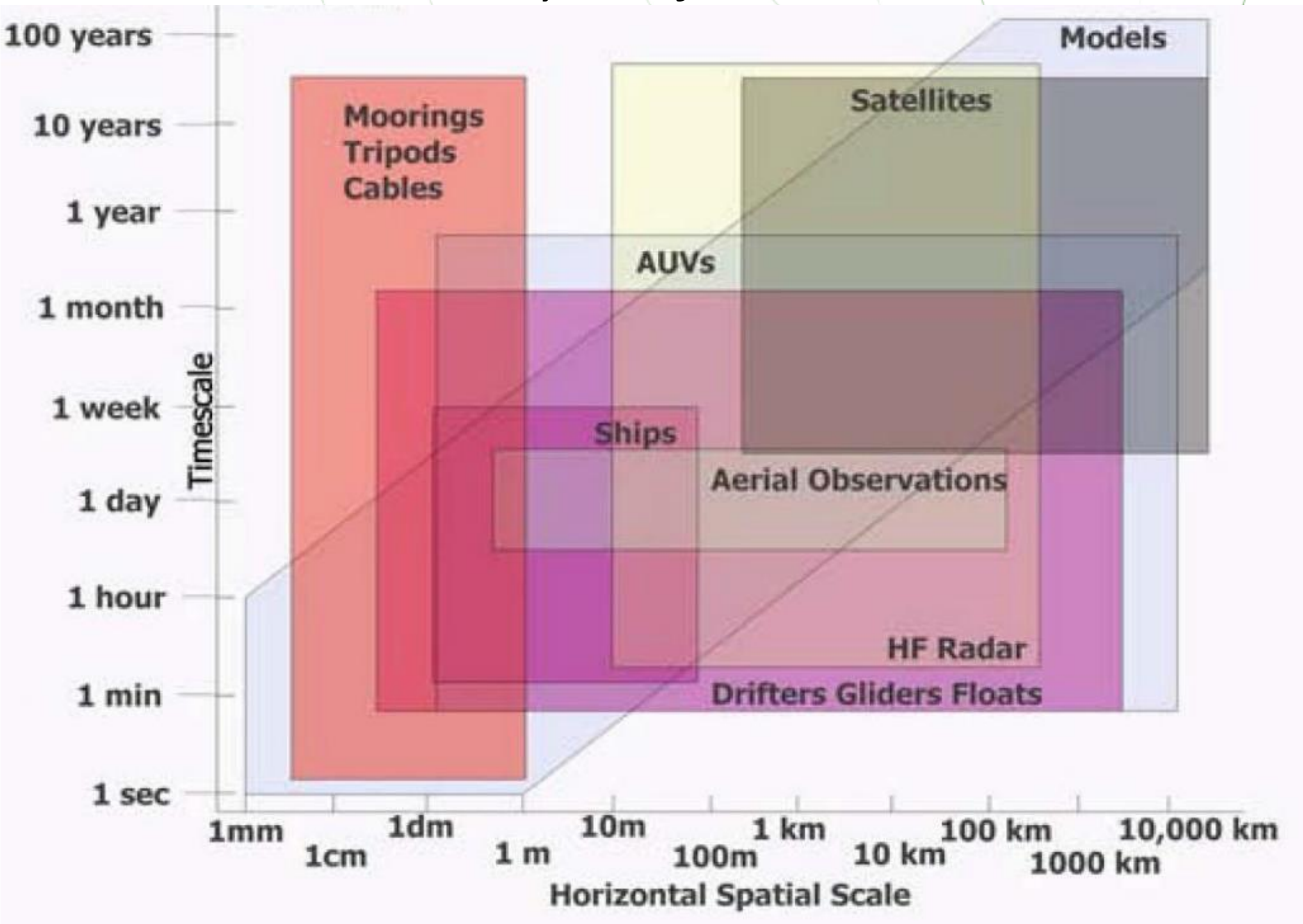
Observing the Ocean: design

The experimental design is a fundamental task, given the high cost of ocean observations

First it is necessary to define **why we do want to make the measurments**?

- 1. What is the aim of the observation?
- 2. Do you want to test a hypothesis or to describe processes?
- 3. What degree of accuracy is required?
- 4. What spatial and temporal resolution is necessary?
- 5. What will be the duration of the measeurements?

Which System for which need



Observing the Ocean: requirements

Since 19th century a lot of measurements have been made by diverse communities for their own needs (Scientists, fishermen, commercial navigators…), BUT

- ✓ Not in an organized way
- ✓ Shared only among small communities
- ✓ Measured over limited periods and areas
- ✓ Not properly archived, without accepted standards on formats and vocabularies
- ✓ scarce metadata information

In Situ data archeology is a hard job providing questionable datasets

Observing the Ocean: requirements

Instruments

- Autonomous instruments (moorings, drifters, profiling floats, gliders…) to monitor over long periods of time
- Ship measurements to monitor along repeat sections regularly

Sustainabilty

Infrastructures

- In order to have all these data available for operational models: a well-designed and robust observing system, good communication to shore to deliver data rapidly
- Operational data centres who work in near real-time, but also perform reanalysis

Coverage & Timeliness

Programs

- Suitable data protocols to distribute data to operational centres in a timely way
- International cooperation to achieve a global coverage, set up an adequate system and maintain it in the long term.

Coordination & Protocols

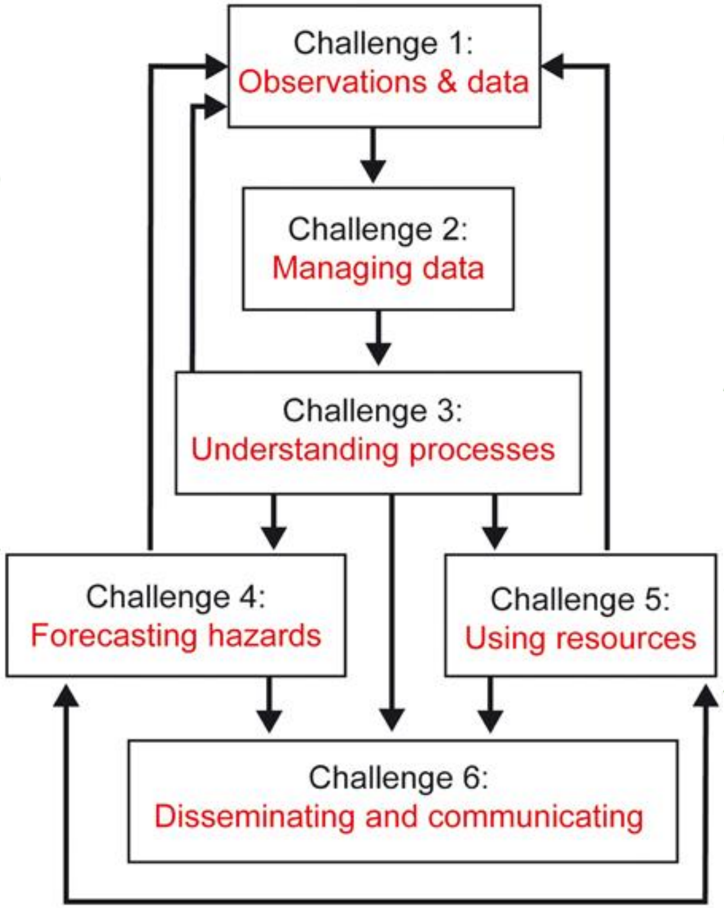
Observing the Ocean: challenges

Several hundred years ago: science was **empirical**, *describing natural phenomena*

Last hundred years: science was **theoretical**, *using models, generalizations*

Last few decades: science became **computational**, *simulating complex phenomena*

Today: science should be **data explorative**, *unifying theory, experiment, and simulations* data

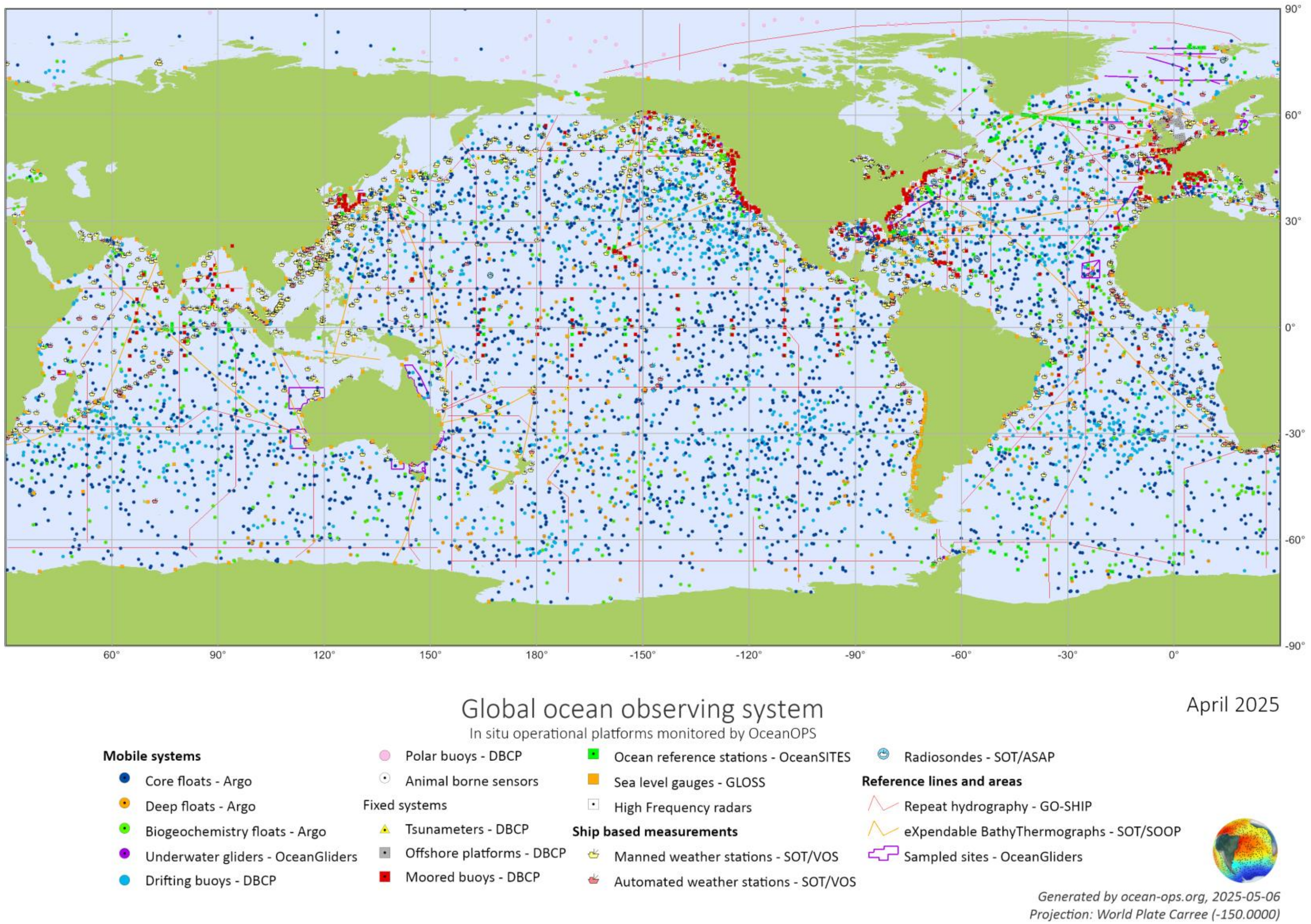


Acocella, 2015, Frontiers

Hey et al., 2009, The Challenges for the Earth system Science. In: The Fourth Paradigm, Data Intensive Scientific Discovery

Global Ocean Observing System (status April 2025)

https://www.ocean-ops.org/board



OceanOPS (**Ocean Observing System Operations Centre**) is an international coordination center that **supports the global ocean observing systems.** It is a joint initiative of the **World Meteorological Organization (WMO)** and the **Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO)**.

Data sharing

Global scale applications requiring integrated observing system (climate change, ocean health monitoring, fisheries assessment,...)

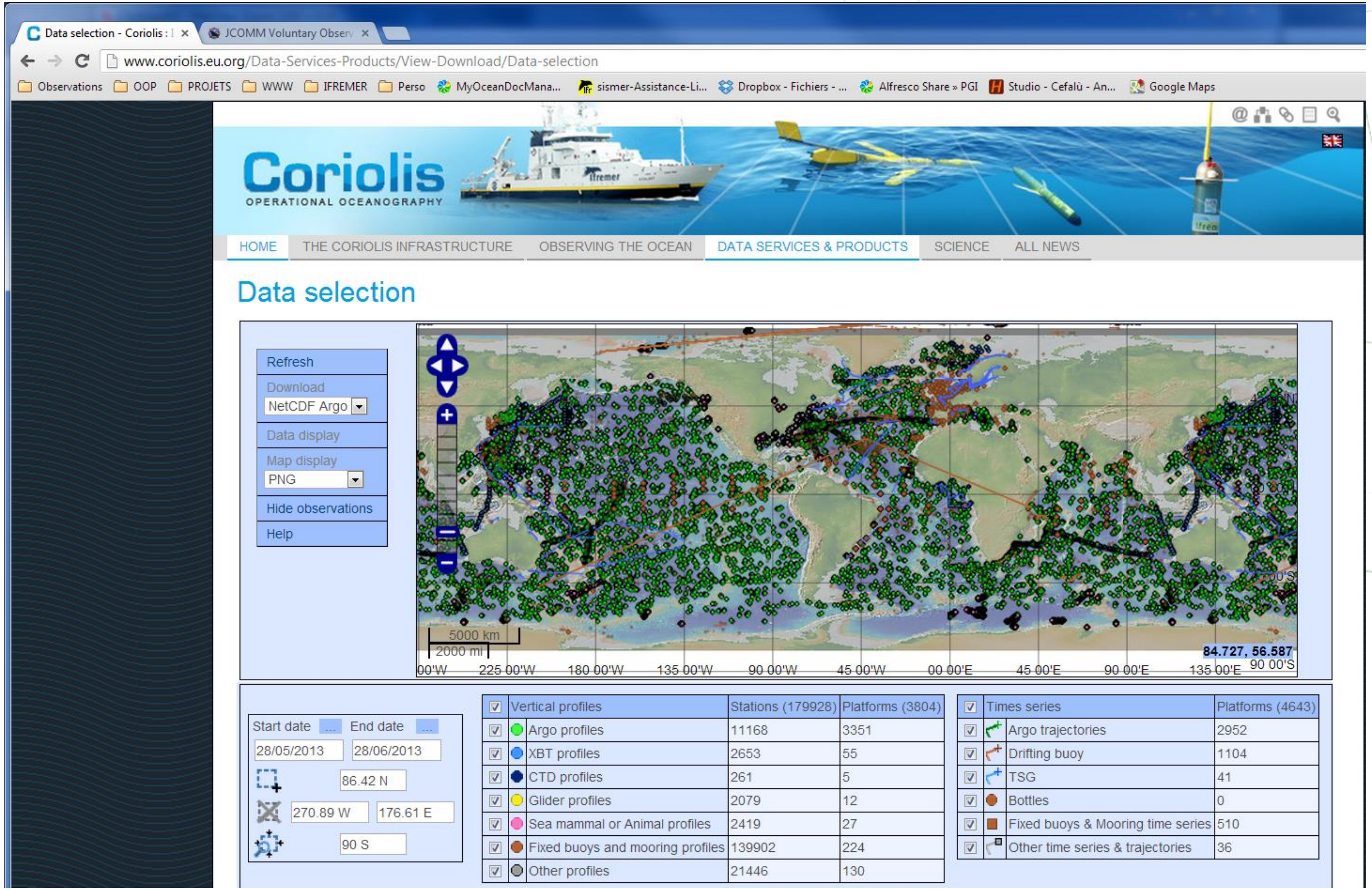
A new paradigm emerging : "Data acquired with public funds should be publicly available"

To be smoothly shared, data must have the following requirements:

- Core parameters
- easily accessible from a unique point
- coherent in terms of:
  - Data format
  - Data Quality
  - Processing chain (clearly documented)
  - Coherent at basin scale level
- available
  - in near real time (within less than 24 hours)
  - in delayed mode after calibration and /or validation with estimation of the accuracy
  - Long time series
- Data management must rely on qualified teams (data management, scientific expertise…)

Coriolis Data Portal

https://www.coriolis.eu.org/Data-Products/Data-selection



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Measuring the Ocean

2. Platforms

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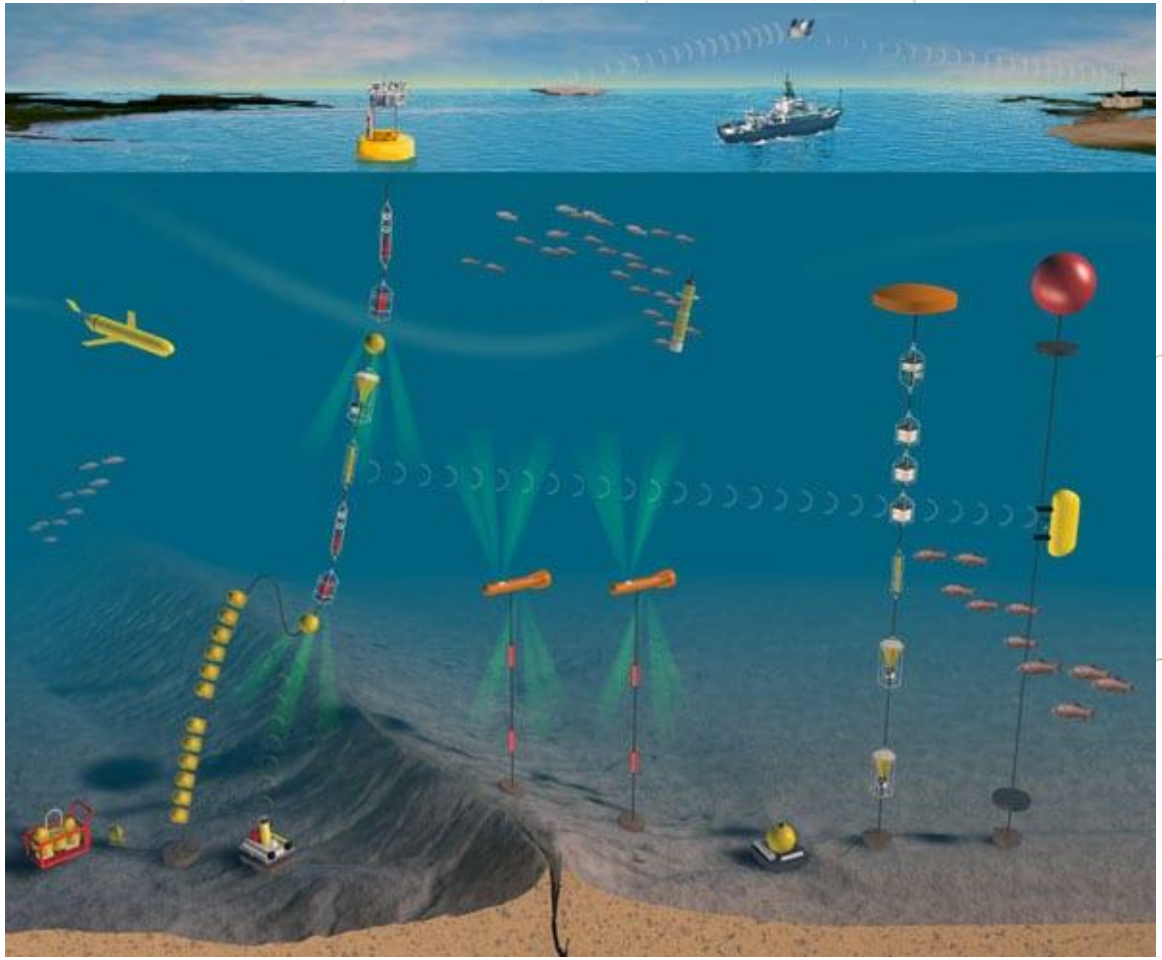
Platforms

In oceangraphy we have the possibility to use different PLATFORMS from which it is possibile to make measurements:

- ✓ Autonomous systems (fixed and mobile)
- ✓ Oceanographic Research Vessels
- ✓ Ships of Opportunity



GOOS OCG networks

The **GOOS (Global Ocean Observing System)** supports a set of **core global ocean observing networks** under the umbrella of the **Observations Coordination Group (OCG)**
These networks are responsible for sustained, systematic in situ observations of the ocean using a range of platforms and technologies.

Argo

Data Buoy Cooperation Panel (DBCP)

Ship Observations Team (SOT)

Automated Shipboard Aerological Programme (ASAP)

Voluntary Observing Ships (VOS)

Ship of Opportunity Programme (SOOP)

Global Sea Level Observing System (GLOSS)

Animal-Borne Ocean Sensors (AniBOS)

A network deploying instruments on seals and

Global Ocean Ship-Based Hydrographic Investigations Programme (GO-SHIP)

OceanSITES

The Global High Frequency Radar

Ocean Gliders

Tsunami Buoys

Key roles of the OCG:

•Harmonize standards and practices across observing networks.

•Foster interoperability and data sharing.

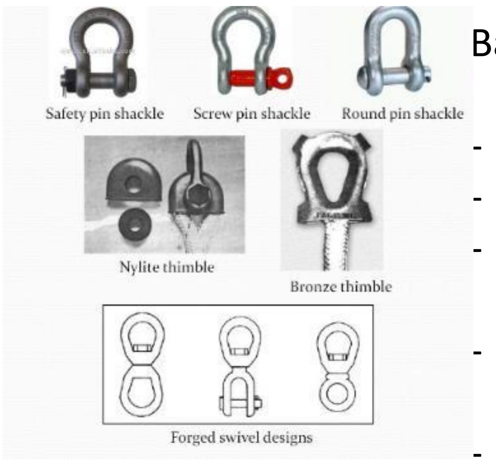
•Support integration of observing systems across domains (physics, biogeochemistry, biology).

•Ensure alignment with broader GOOS goals and global needs (e.g., climate monitoring, marine services, ocean health).

Fixed autonomous systems

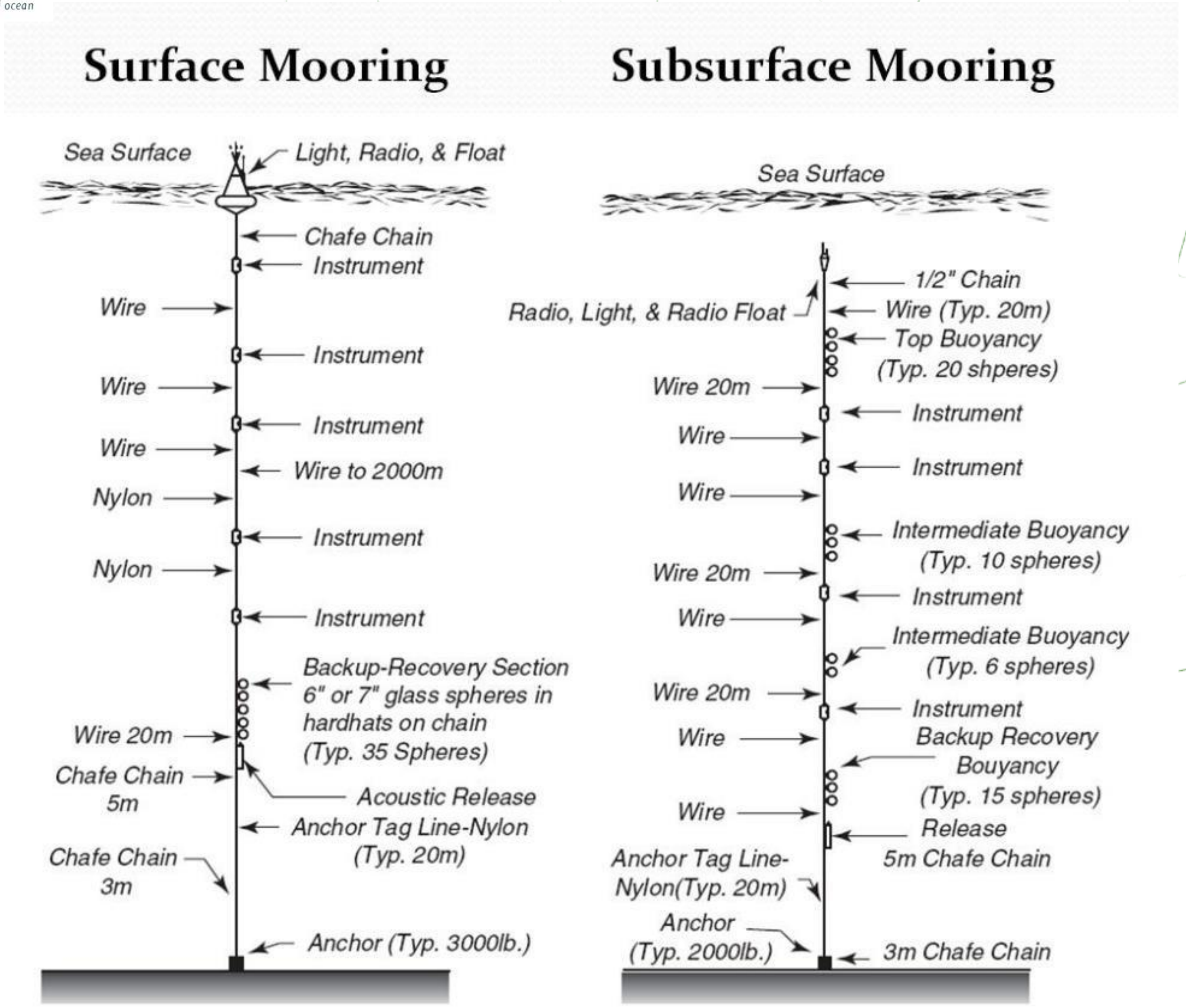
Moorings: an instrumented cable moored on the seafloor with a weight, with a variable number of self-recording instruments and buoys

These systems measure the seawater properties at high temporal resolution at a fixed location in space (EULERIAN APPROACH), the data can be transmitted remotely or are recorded on internal memories and then downloaded when the mooring is recovered with a ship (weeks, months, or years after deployment)



Basic Components

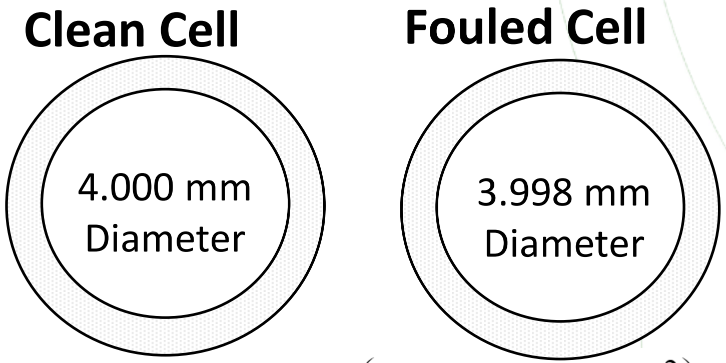
- Flotation (buoys)
- Line system (rope/chain, hardware)
- Instruments (CT, ADCPs, sediment traps…)
- Anchor (concrete block, railway wheel)
- Acoustic Releases



Fixed autonomous systems

Common problems of mooring line systems

- Mooring line failure
  - Biofouling
  - Drift
- Hardware failure
  - Corrosion
- Fishbite
- Manmade
  - vandalism
  - vessel damage



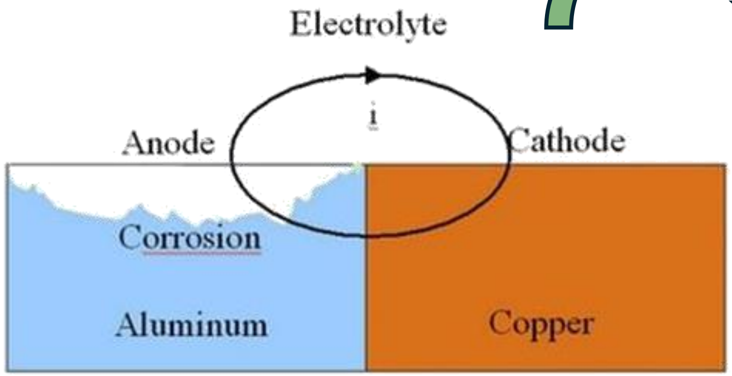
$$\textbf{Salinity Error} = 35\left(1 - \frac{\textit{fouled diameter}^2}{\textit{clean diameter}^2}\right)$$

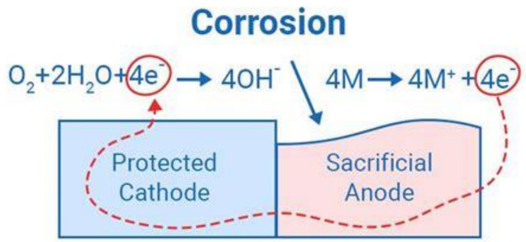
$$= 35\,(1 - (3.998)^2 / (4.000)^2)$$

$$= 0.035 \text{ PSU}$$

Galvanic Corrosion

- Dissimilar metals in contact with each other
  - differences in electrochemical potential cause accelerated deterioration
  - passive/cathodic materials deteriote active/anodic materials
- Prevention
  - sacrificial anodes





Fixed autonomous systems

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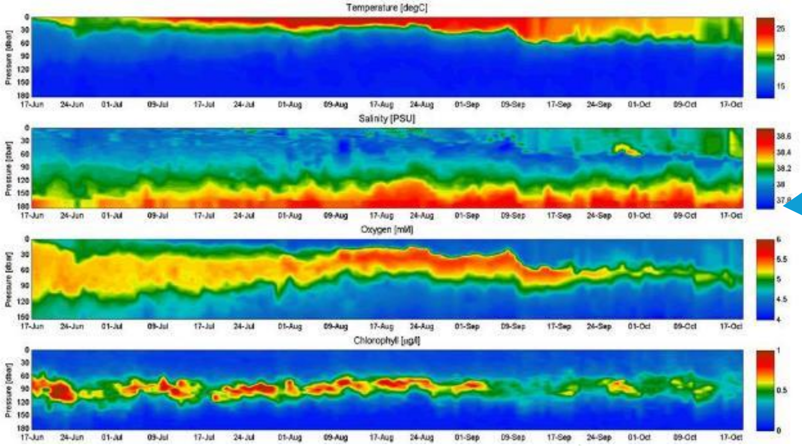
Mooring Sensors

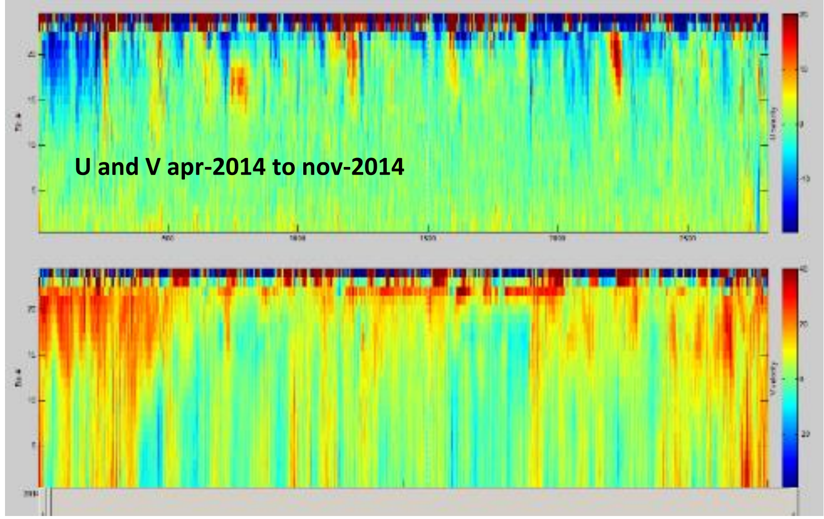
CTD

ADCP

CO2 probe



Yoyo data Jun13-Oct13 (Aracri et al., 2016)



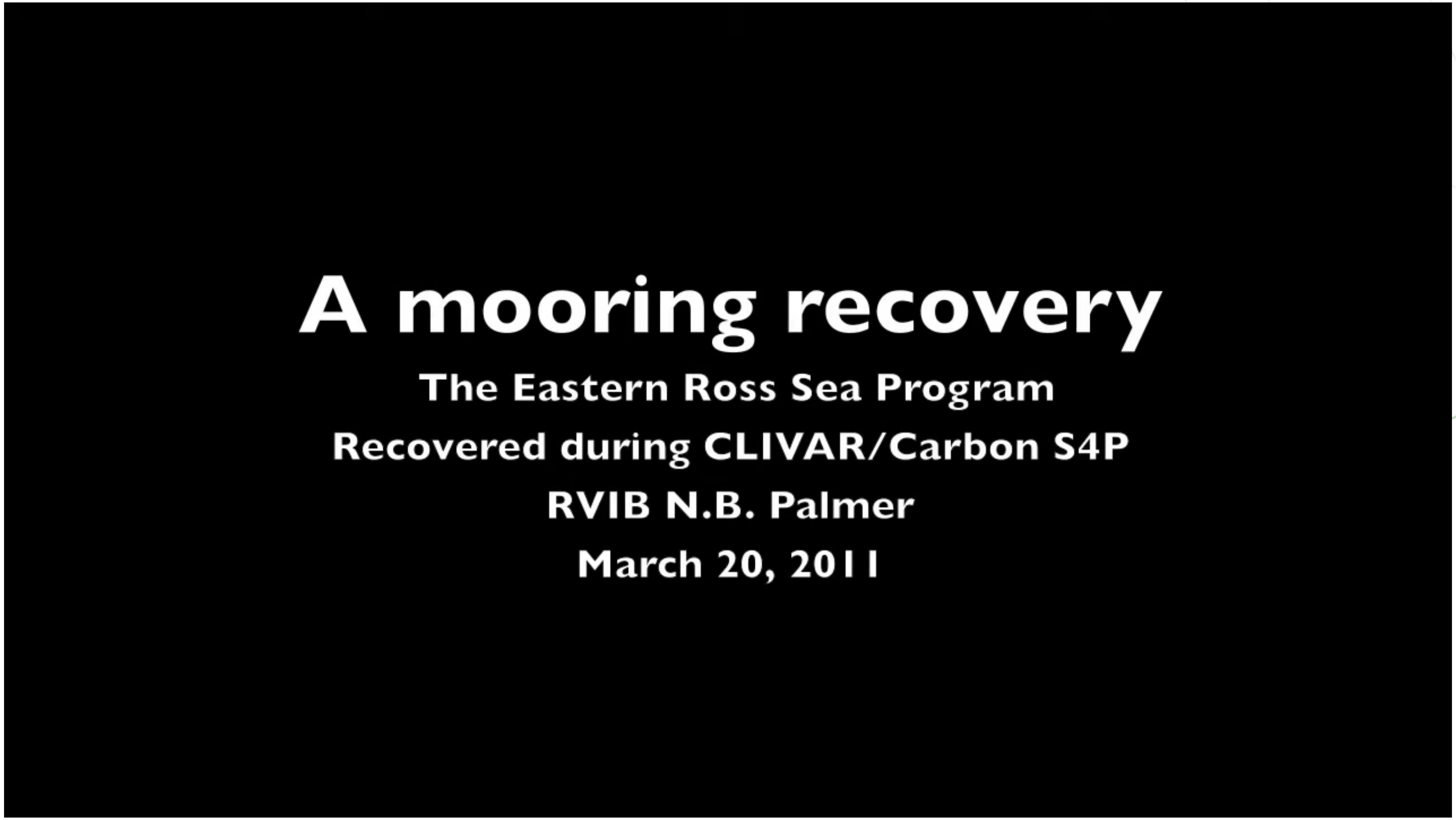
Profiling probe

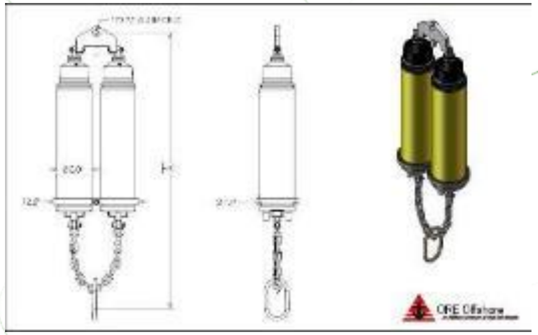
Fixed autonomous systems

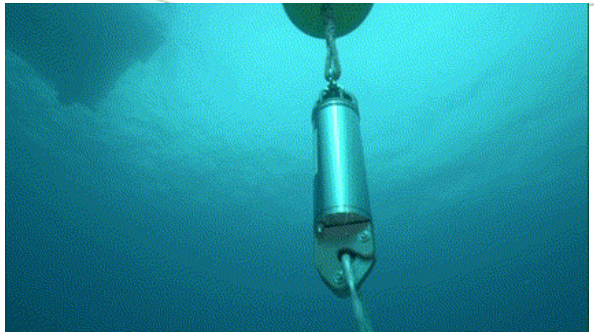
Deployment of a mooring

Fixed autonomous systems

Recovery of a mooring







Fixed autonomous systems

Meteo-oceanographic buoys or platforms

A measuring platform of meteorological and oceanographic parameters.

It is a sort of offshore marine laboratory: completely autonomous, powered by wind and solar energy, comunicating via satellite with the institute on shore.

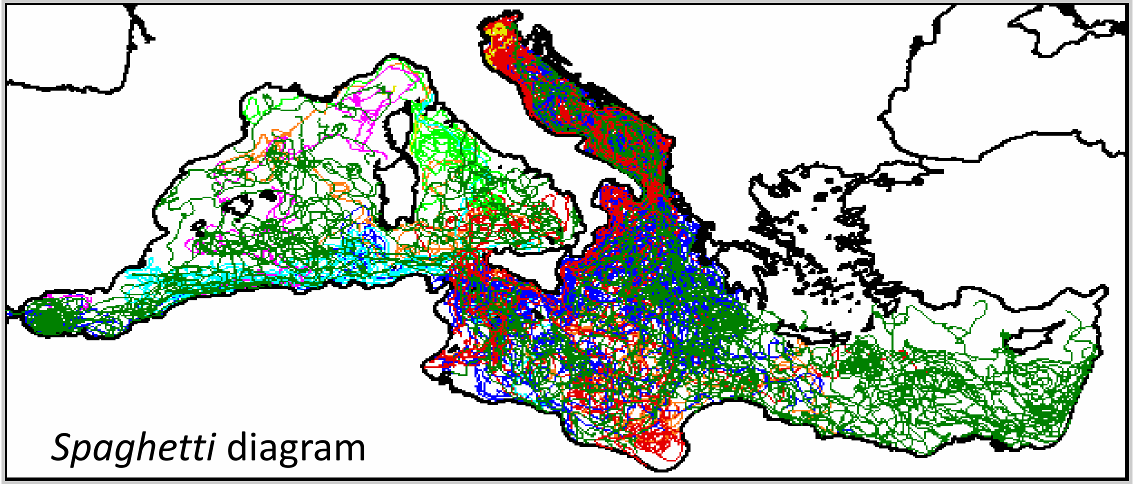
The platforms may be equipped with a set of meterological sensors, and below the sea surface, with oceanographic sensors along the water column

Mobile autonomous systems
Floating buoys (drifter)

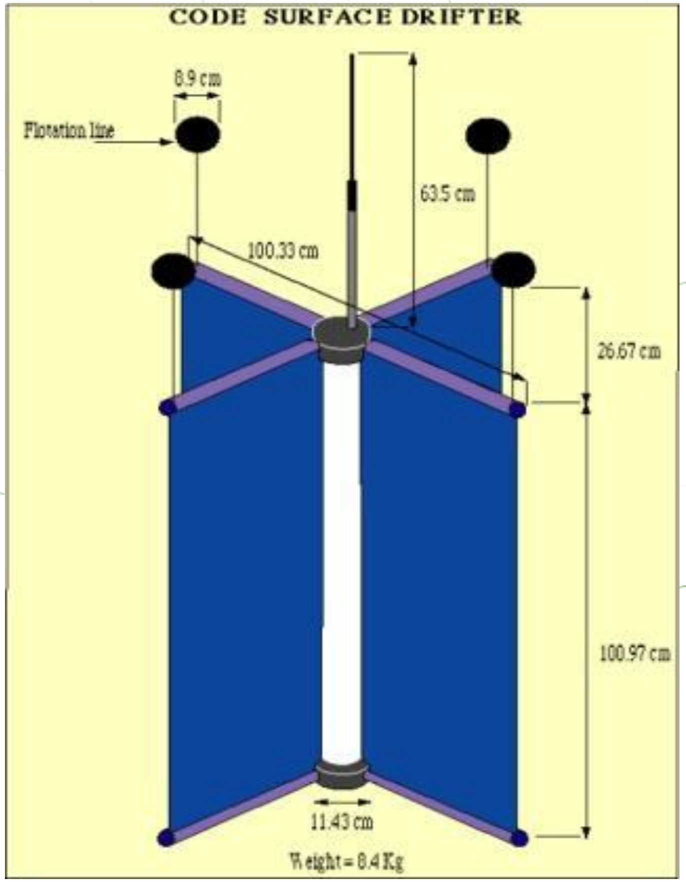
DATA BUOY COOPERATION PANEL

Buoys that passively follow the currents (at surface or at predefined depths). At regular interval they transmit their position via GPS. They are generally equipped with temperature sensors.

→Information on the currents and surface temperature in real time (**LAGRANGIAN APPROCH**: the instrument follows a water «particle»)



Spaghetti diagram



Mobile autonomous systems

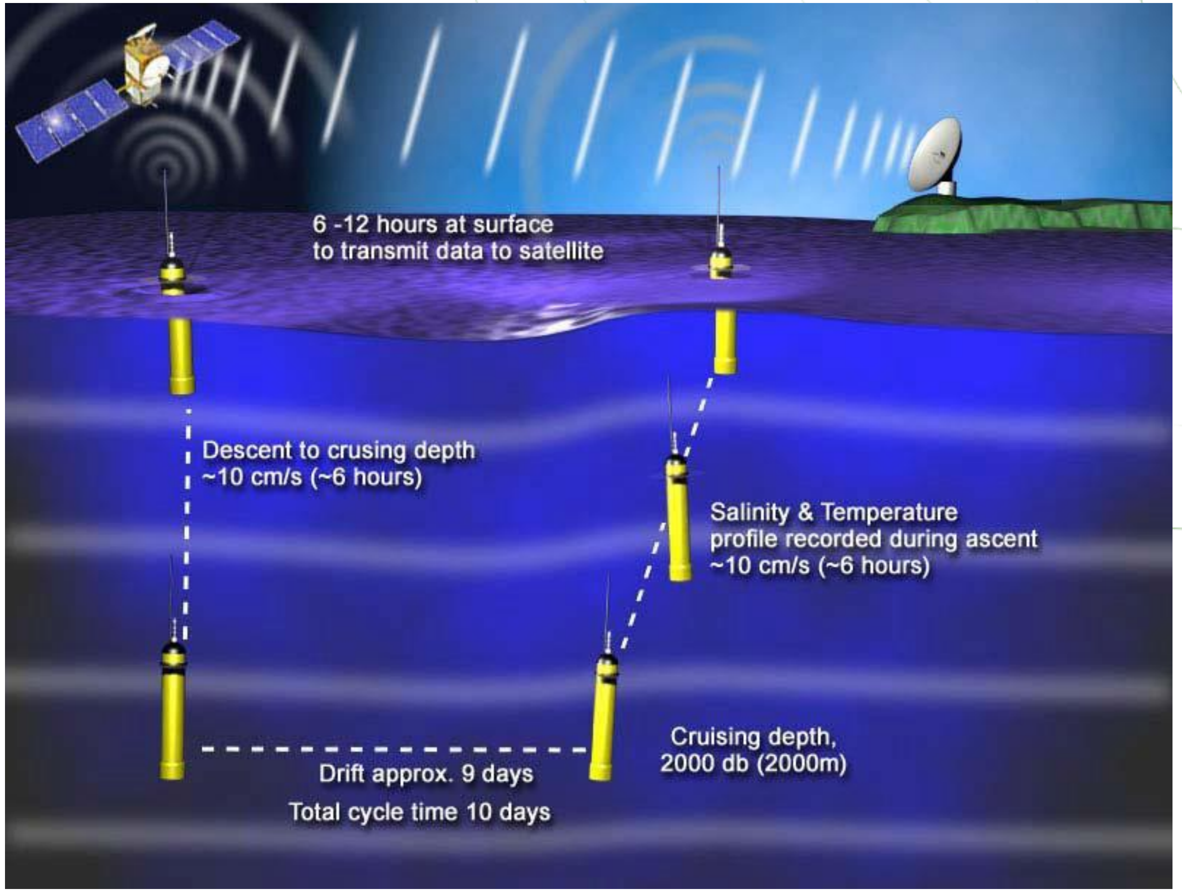
Profiling floats (ARGO floats)

Subsurface autonomous instrument which measures vertical profiles of temperature and salinity.

These vehicles float passively at a preprogrammed pressure level and then rise to the ocean surface at a predetermined time interval to broadcast collected information to a satellite.

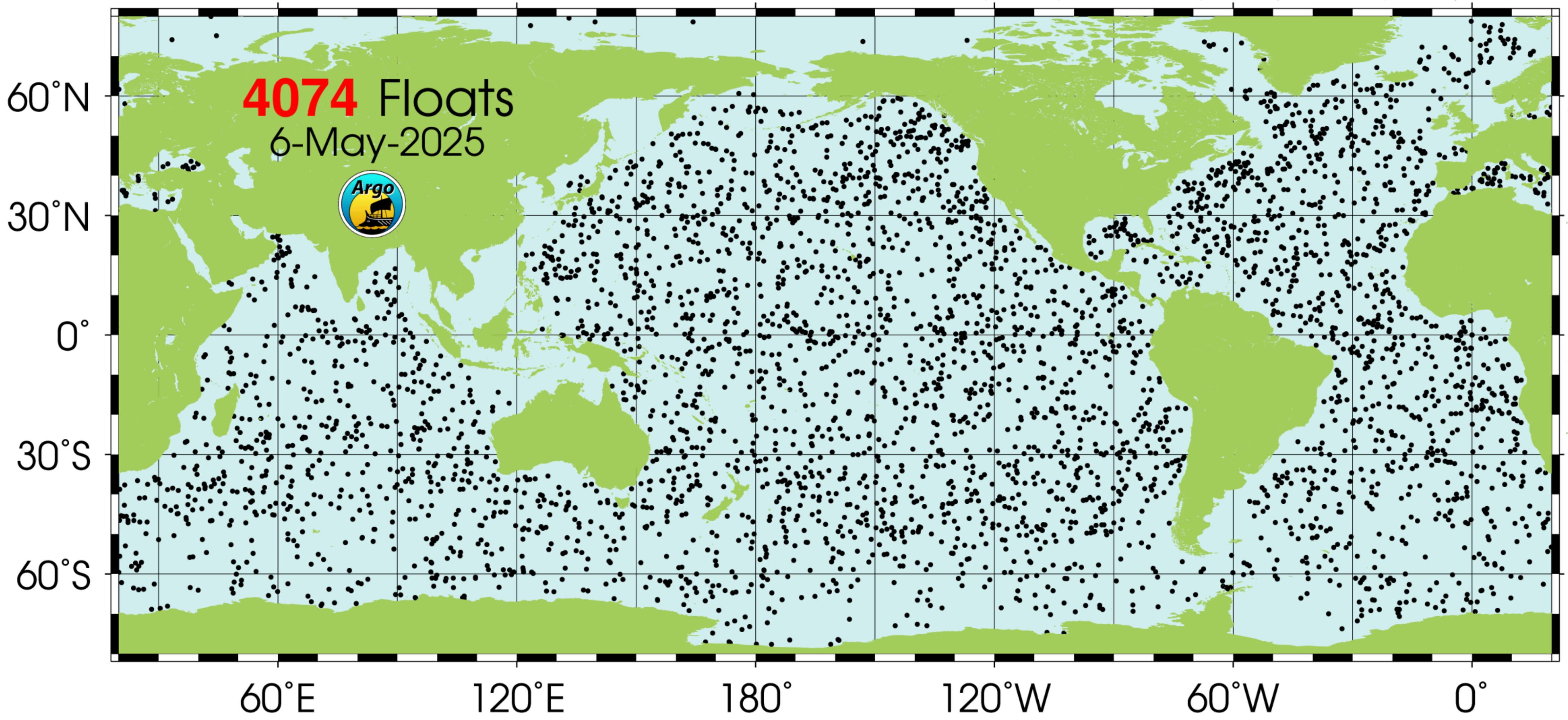
Satellite technology is used to record the float position as well as date and time of receipt of the data

Several different sensors may be attached to the profiling float (compromises must be made between the weight and power usage of the sensors and the intended lifetime of the profiling float's battery).



Mobile autonomous systems

Profiling floats (ARGO floats)

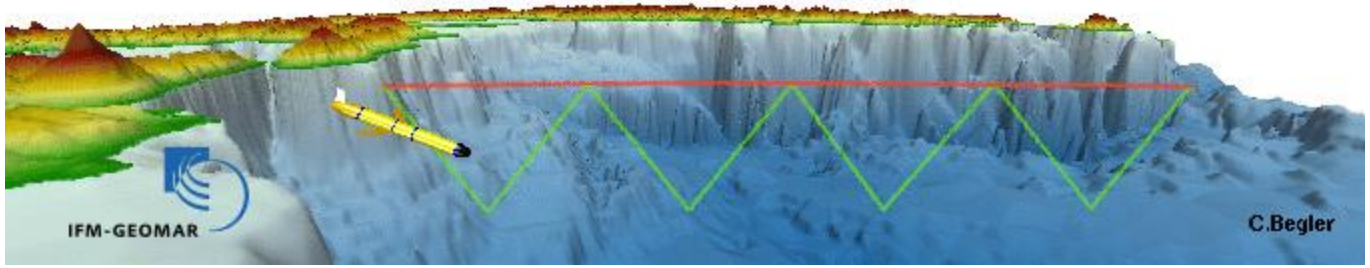


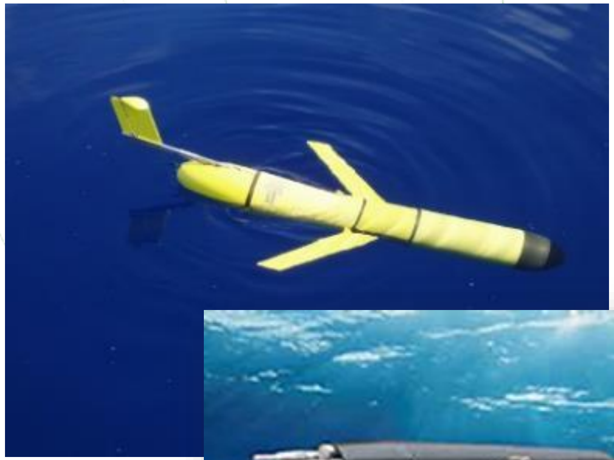
Mobile autonomous systems

Gliders

Autonomous active vehicles, which route is programmed before deployment, which measure T, S and other parameters (oxygen, fluorescence…). It is propelled by buoyancy force.

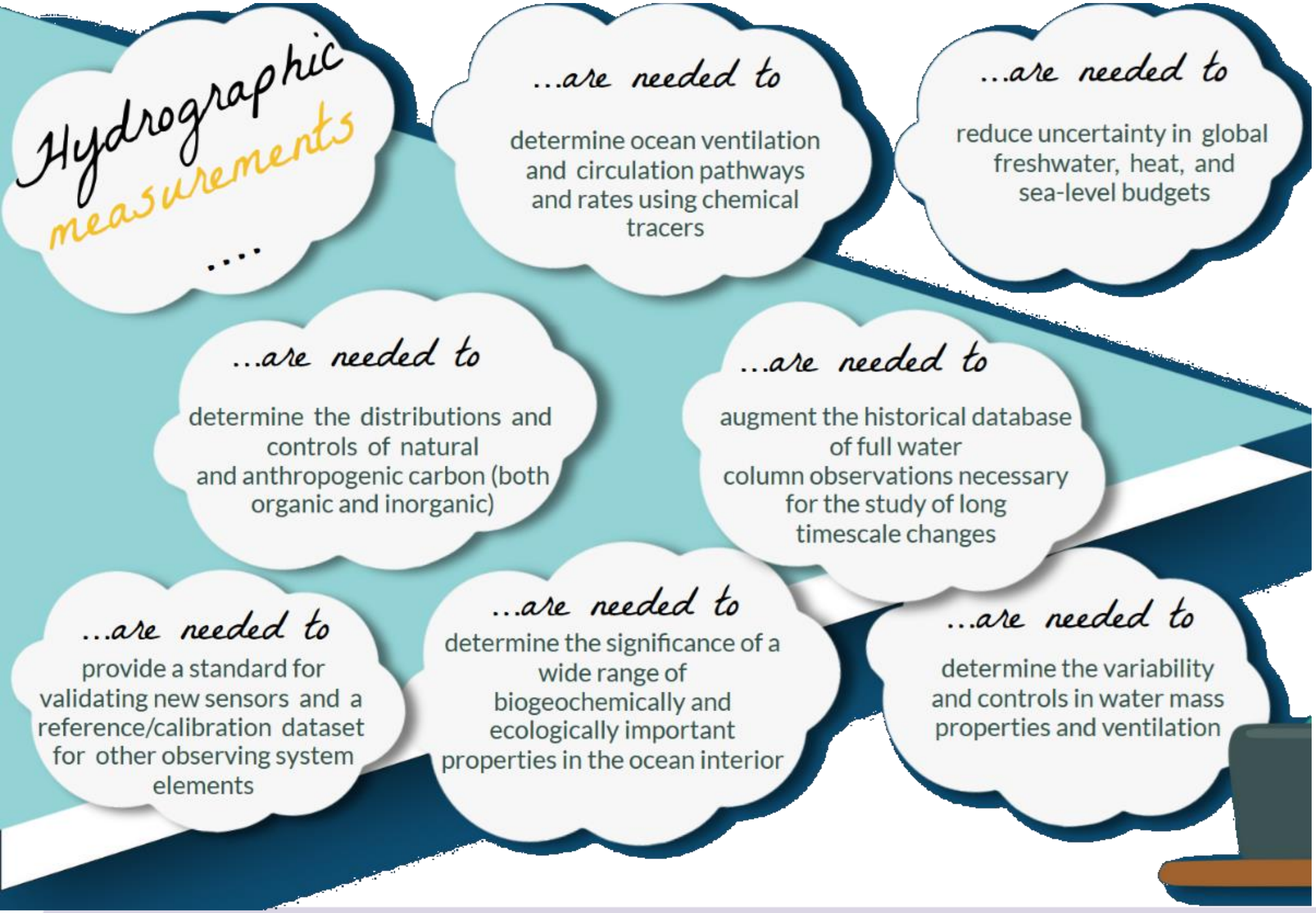
Gliders can travel several thousands kilometers while making several hundred descents and ascents underway, thus achieving high vertical and horizontal resolution





Oceanographic Research Vessels

A major part of the multidisciplinary oceanographic observations is done on board of Research Vessels



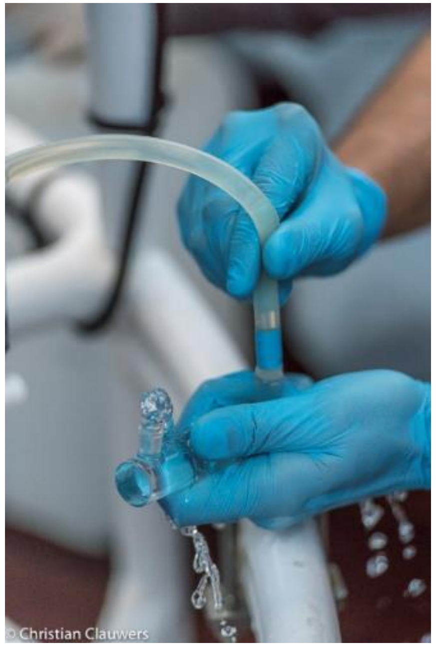
Our new R/V at CNR, GAIA BLU

Our former coastal R/V at CNR, DALLAPORTA

Oceanographic Research Vessels

The operations that are carried out on board of the oceanographic research vessels include:

- ✓ Deployment of profiling or drifting buoys
- ✓ Periodic deployment (and recovery) moored instruments (*moorings*)
- ✓ Deployment (and recovery) of autononous measurment platforms
- ✓ Deployment of AUVs
- ✓ Water sampling and their treatment, analysis or conservation



Oceanographic Research Vessels

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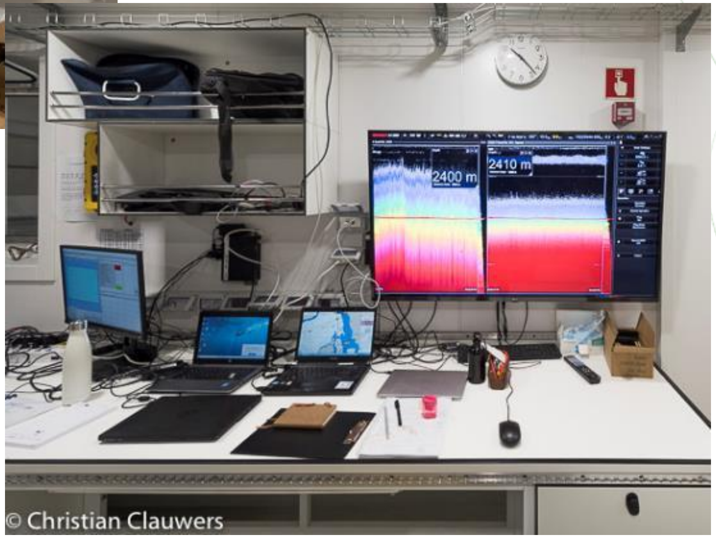
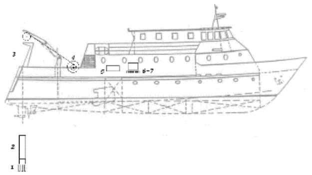
Dry Lab
Data Acquisition Systems
Data Processing
PCs
Deck Units
...



Wet Lab
Water sample analysis
Freezers
Filtrations
Net cast sample analysis
....

Oceanographic Research Vessels



Rosette and Niskin bottles

Niskin bottles are cylindrical pressure-resistant plastic containers with rubber spring-loaded end-caps that allow the collection of a variety of volumes of seawater (about 1.2 to 10 liters) at selected depths in the water column.

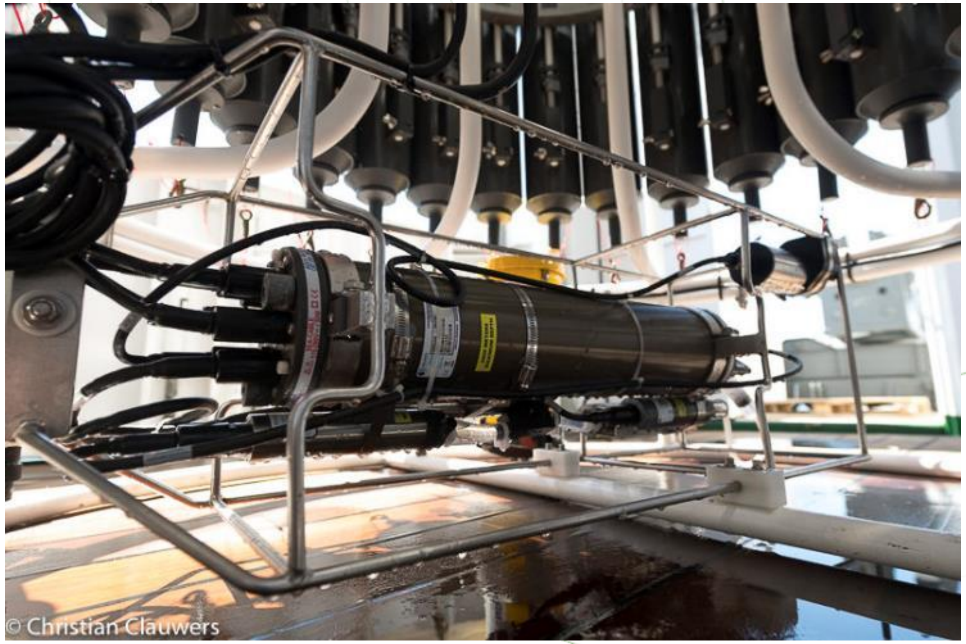
Niskin bottles are frequently mounted around a circular rosette sampler metal frame with the capacity to hold as many as 36 bottles. The rosette frame is attached at the end of a wire with an electrical conductor. The bottles can then be closed at any depth.

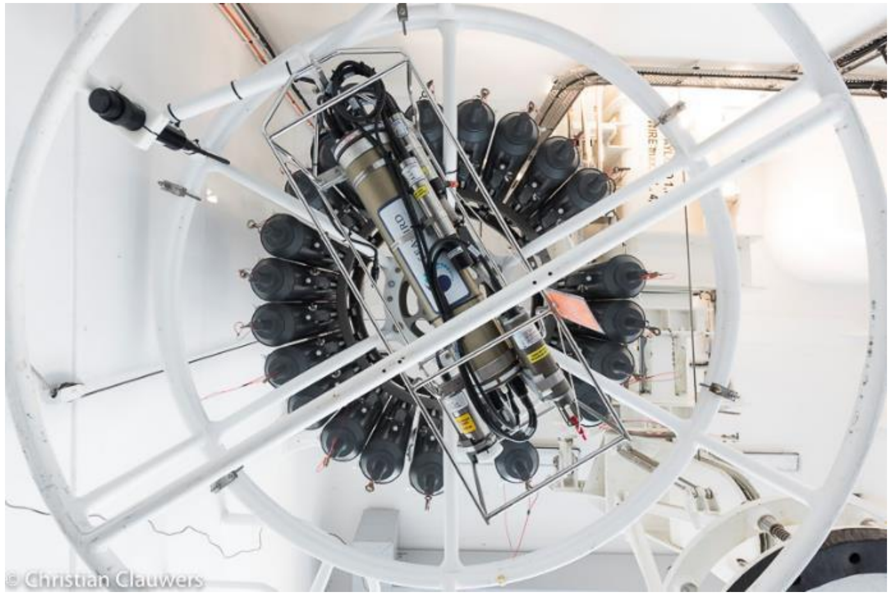
When the closed Niskin bottles are brought back on deck, water samples can be collected from each bottle and then analyzed for different dissolved and particulate constituents. The rosette frame may include other high-frequency sampling instruments.

Oceanographic Research Vessels

CTD Conductivity-Temperature-Depth (pressure)

CTDs are a combination of a pressure sensor (measured pressure is converted to depth), a resistance temperature measurement device (usually a platinum thermometer), and a conductivity sensor used to compute salinity.
The response time of CTD sensors is an important factor that determines the ability of the CTD to make “continuous” measurements.



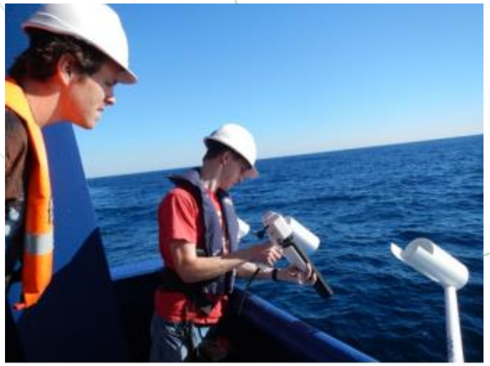


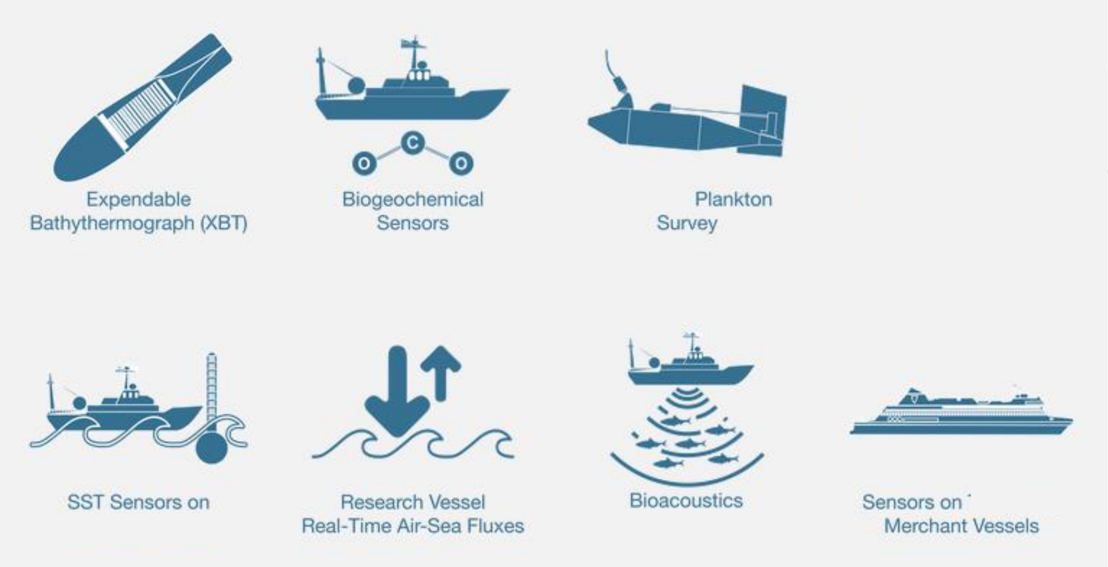
For instance, lowering the CTD at speed of 1 m/s and typical range of response time of temperature sensors can provide the vertical profiling at resolution 0.05 m to 0.3 m.
New sensors are developed to measure continuously other variables (e.g. dissolved oxygen content, chlorophyll concentration, etc.).

Ships of Opportunity (SOOP Programme)

Routine observations are carried out from ships of opportunity (container ships, passenger ships) which run predefined routes

- meteorological observations
- deployment of expendable temperature probes
- continous registration of surface temperature and salinity
- other continously operating sensors (pH, pCO2, currents, chlorophyll, plankton)
- deployment of autonomous measurement systems





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3. Sensors

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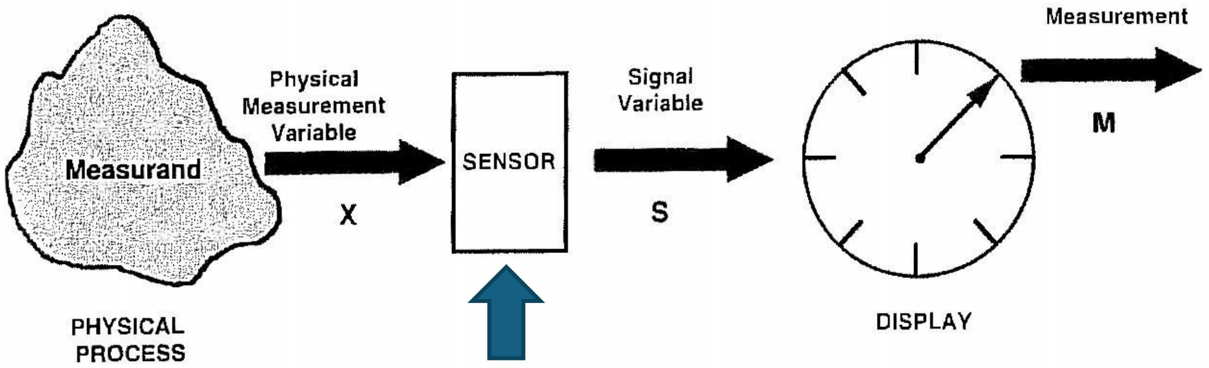
Simple instrument model



This element converts the physical variable input into a signal variable output

Conditioning is the process whereby the signal variable output of a sensor is transformed/translated to make it more manageable to be converted into engineering units. This usually involves:

- amplification
- filtering
- digitization

Ideally, the process should cause little or no degradation of the signal (loss of information)

The signal variable output

The sensor behaves as a *transducer* that converts the physical variable input in one form of energy into the signal variable output in another form of energy, often electrical. In the case of most marine sensors, the output signal is one of the following:

- a voltage
- a current
- a frequency

Data storage

- Flash memories
- Low power hard discs
- Static RAM devices
- Microprocessor-based controllers & Mini PCs

Data transmission

- Satellite-based systems (Iridium, Argos)
- Land-based systems (GSM, VHF radio)

Basic terminology

Sensitivity of a sensor

the minimum input of physical parameter that will create a detectable output change

Range of a sensor

the maximum and minimum values of applied parameter that can be measured.

The *dynamic* range is the total range of the sensor from minimum to maximum.

Precision

is the degree of repeatability of a measurement. The *stability* of a sensor may be viewed as its precision over an extended interval of time.

Resolution of a sensor

the smallest detectable incremental change of input parameter that can be detected in the output signal.

Response time of a sensor

is the time required for a sensor output to change from its previous state to a final settled value within a tolerance band of the correct new value.

Time constant of a sensor

is the time required for the sensor output to reach approximately 63% of the final value following a step change in the input parameter.

Accuracy

is the ability to report the truth within a specified margin of error

It is assured by proper calibration using standard and/pr certified Reference Material

Error

is the deviation of a measured (or calculated) value with respect to the «true» value

Uncertainty

is the expected accuracy associated with a measurement.

It is estimated and reported as an interval within which the «true» value is expected to lie with a stated level of confidence (usually 95%)

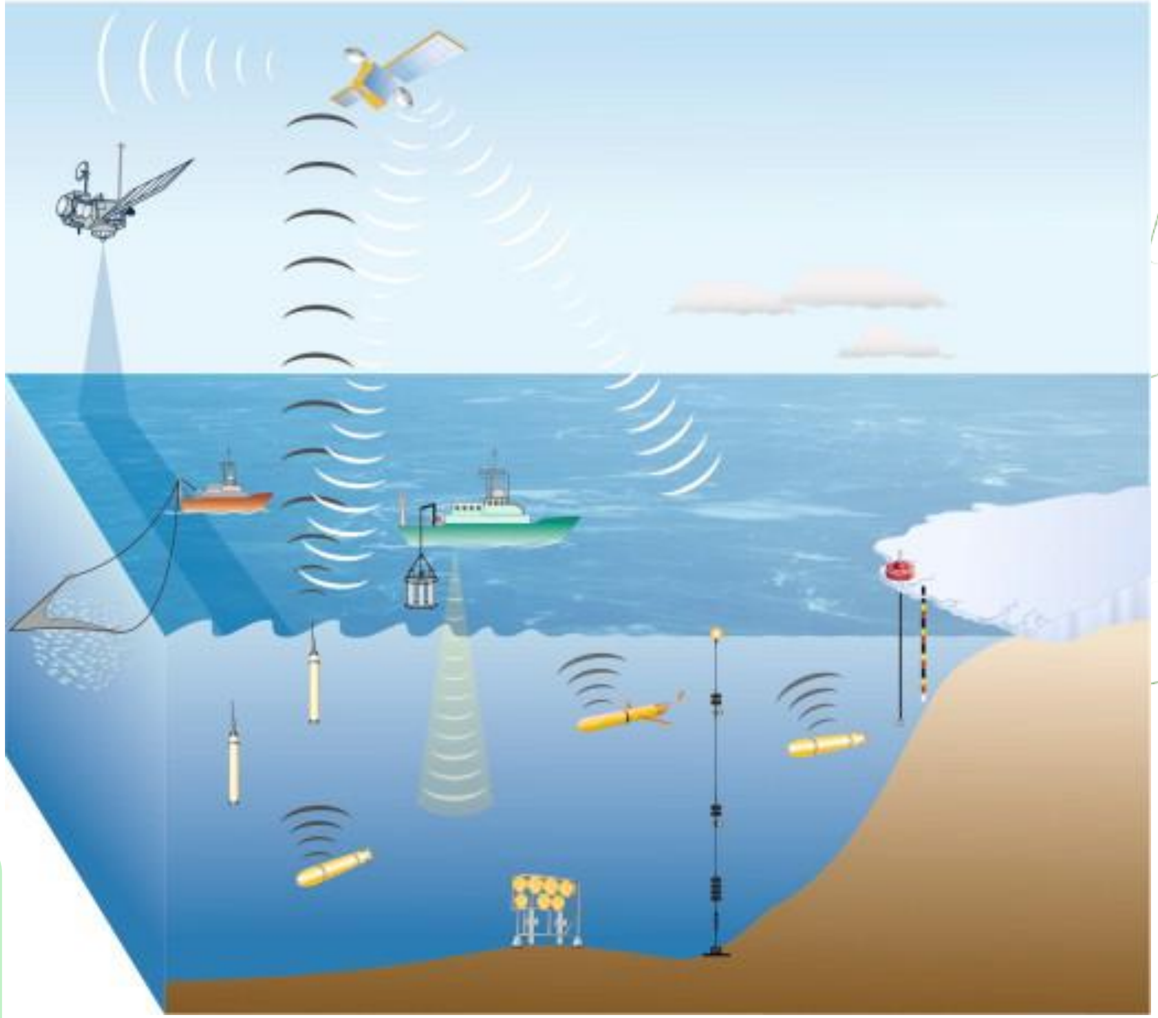
Choosing a sensor

Define the measurand

Consider the conditions under which the measurements will be made

Define realistic performance criteria based on end-use requirements

Consider maintenance, power and data management needs



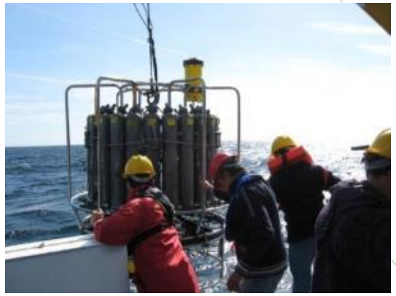
CTD probes

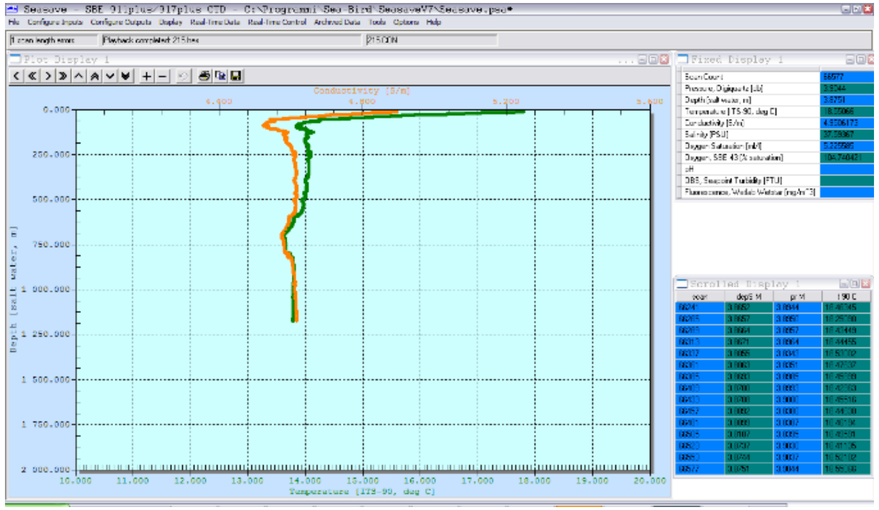
The most used system to acquire vertical profiles of physical properties is the **CTD (conductivity – temperature – depth)**

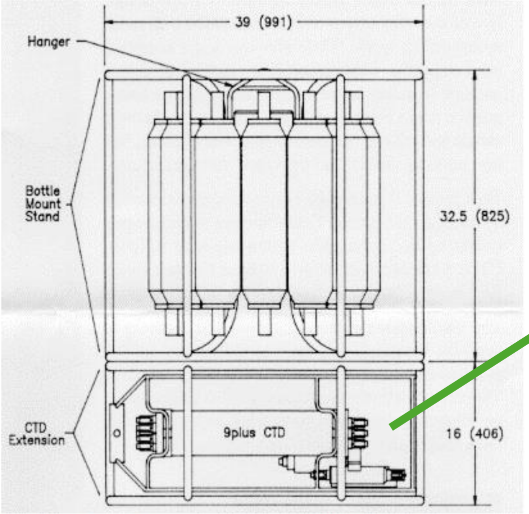
This probe provides high resolution vertical profiles (sampling @24Hz…1 m/s yields 24 measurements every meter)

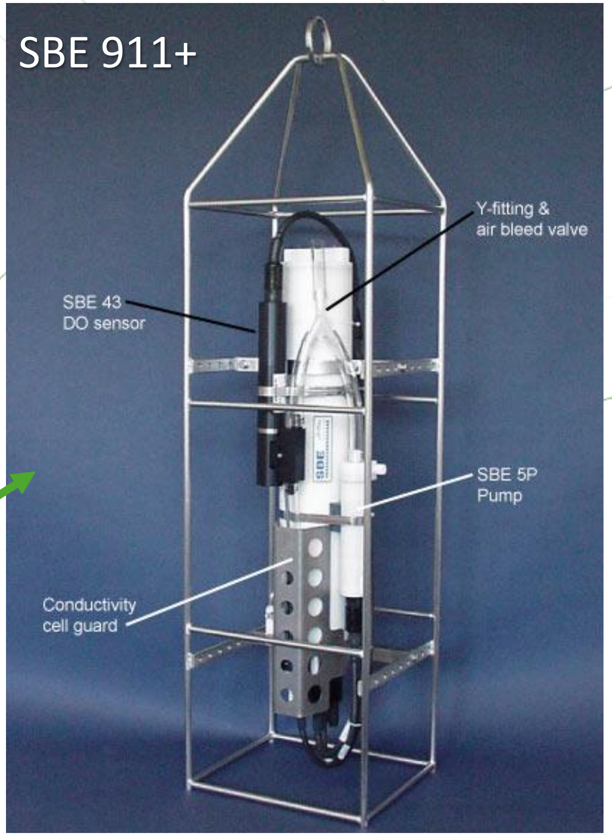
To the basic configuration other sensors are added, to measure oxygen, fluorescence,turbidity….

During the cast it is possible to visualize the profile in real time thanks to the hydrological cable

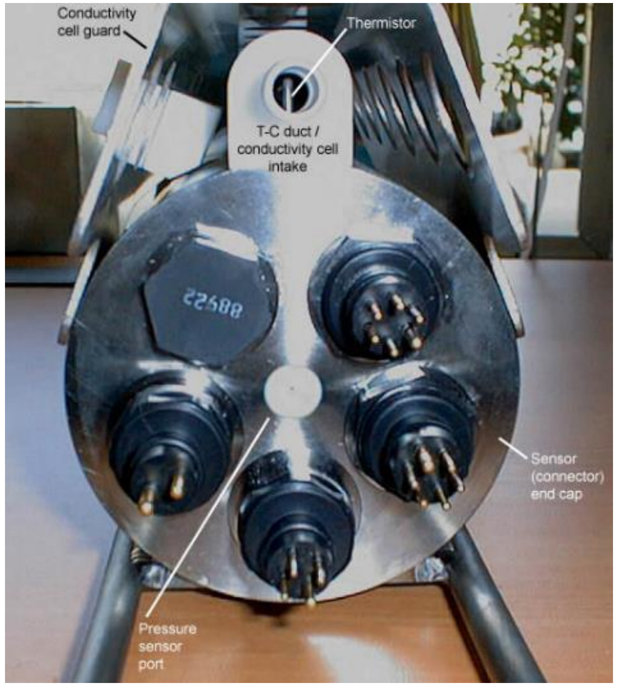


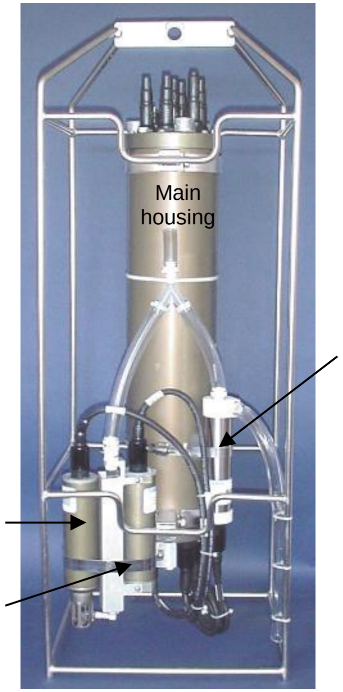




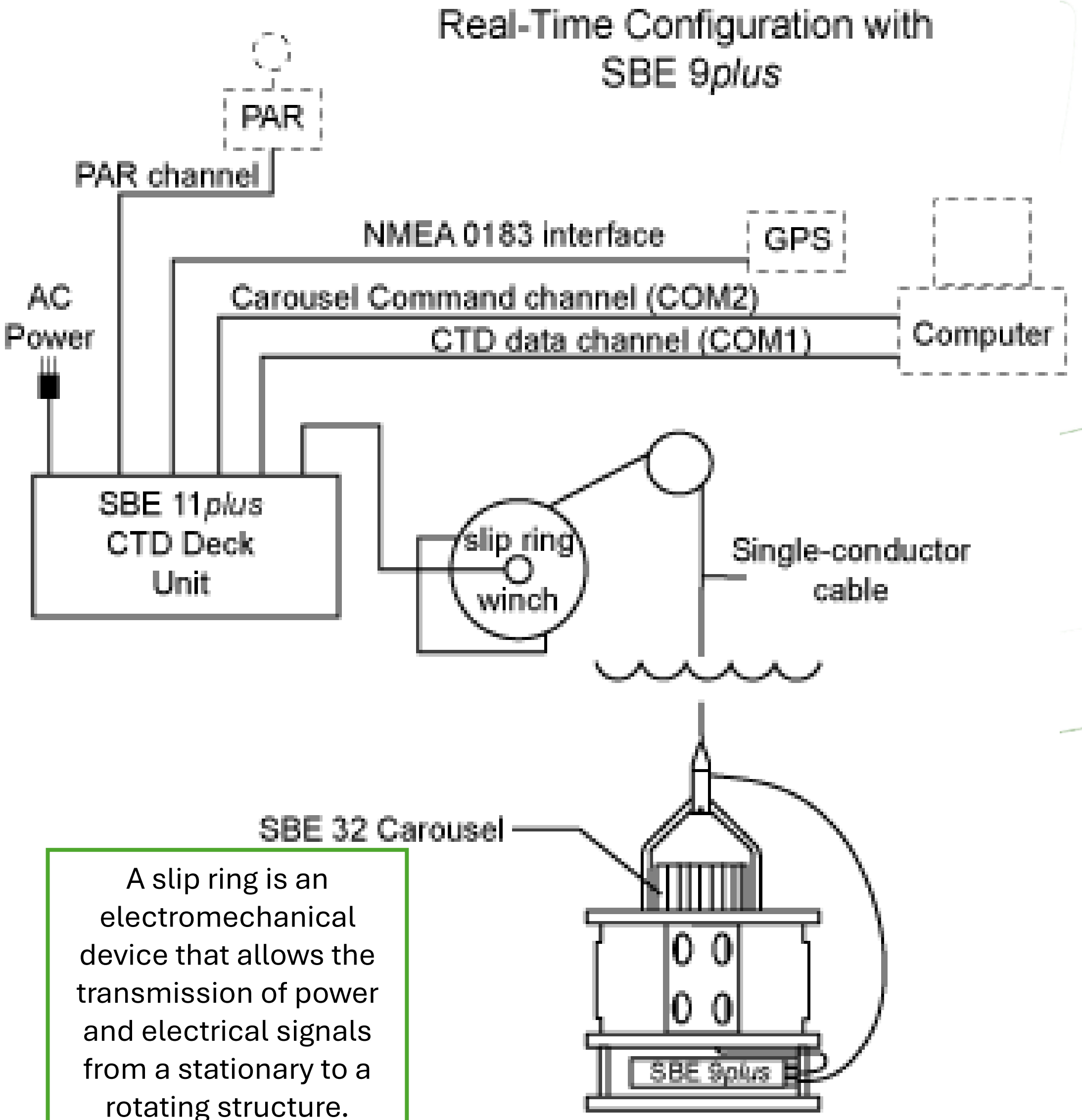


CTD probes





SBE 9*plus* CTD in cage (shown with standard T & C sensors & pump)



A slip ring is an electromechanical device that allows the transmission of power and electrical signals from a stationary to a rotating structure.

CTD probes

When instruments are deployed into the water, it is always necessary to know the depth at which they are placed

Originally just the the lenght of the deployed rope or cable was measured, which give a maximum depth which is true only if the rope is perfectly vertical (no winds, no waves, no currents)

More accurate: measure the PRESSURE of the overlying water column, which relates to DEPTH through the hydrostatic equation:

$$\frac{\partial p}{\partial z} = g\rho$$

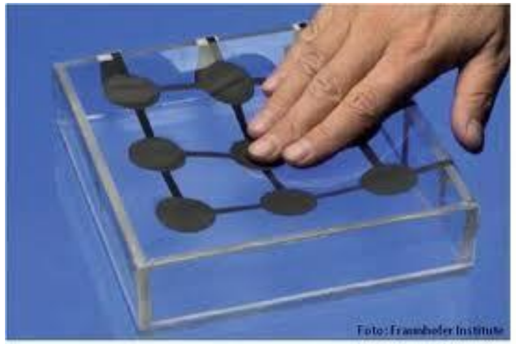
strain gauge pressure sensor

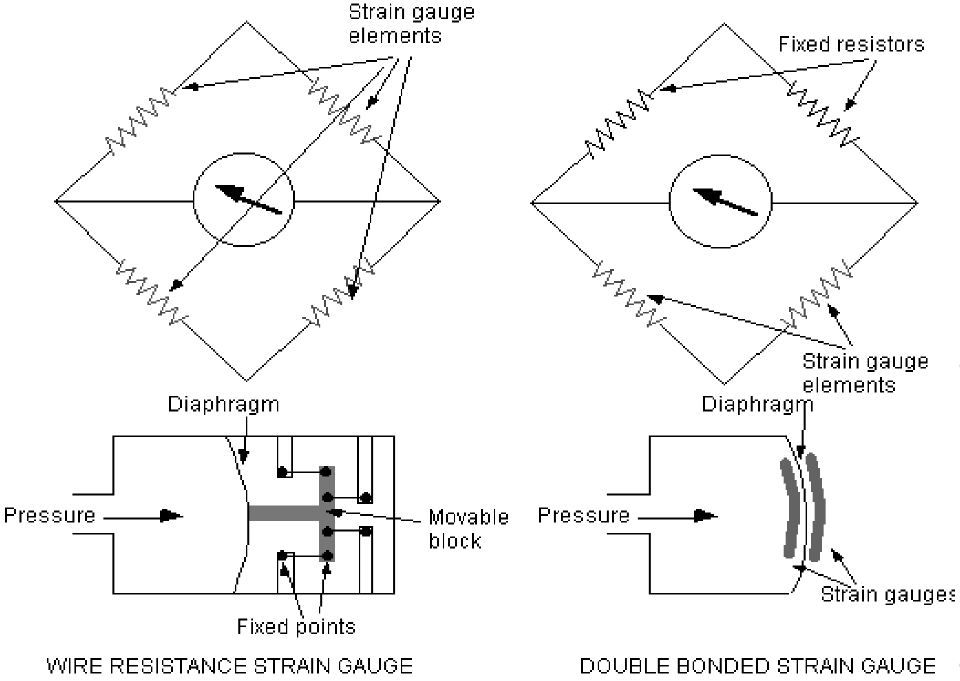
Digiquartz® pressure sensor

In oceanography we use 1 dbar = 10^4 Pa ≈ 1 m

CTD probes - pressure

strain gauge pressure sensor

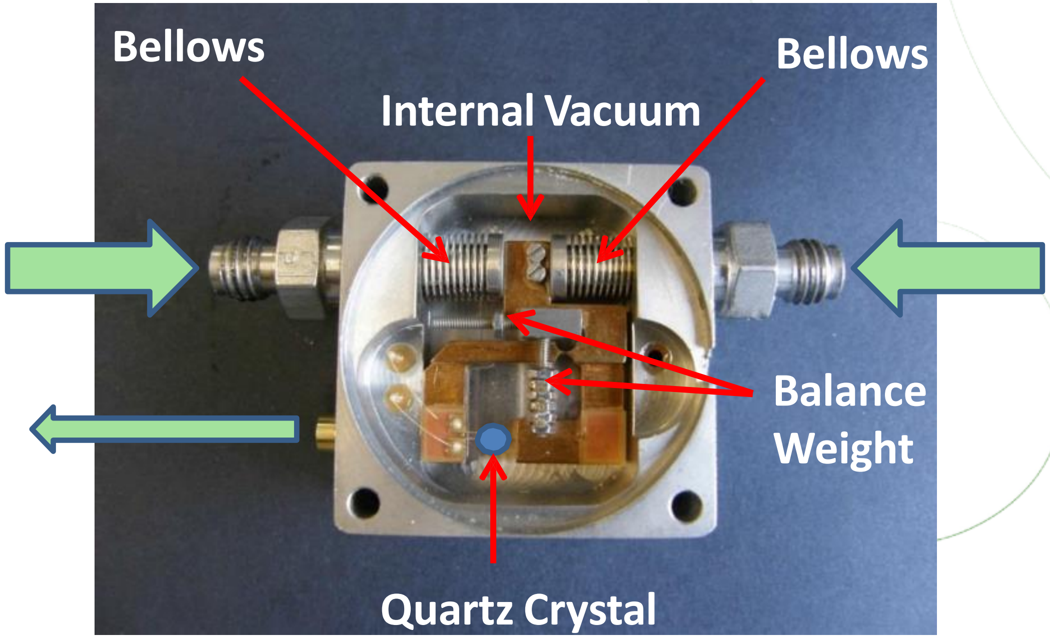




An electric transducer "strain-gauge" that uses the variation of the resistance of metals that undergo a mechanical stress. One resistance is fixed to a flexible membrane which on one side is subject to hydrostatic pressure. When the membrane deflects under pressure the voltage and the resistance change (resolution ±0.002 %)

CTD probes - pressure

Digiquartz® pressure sensor

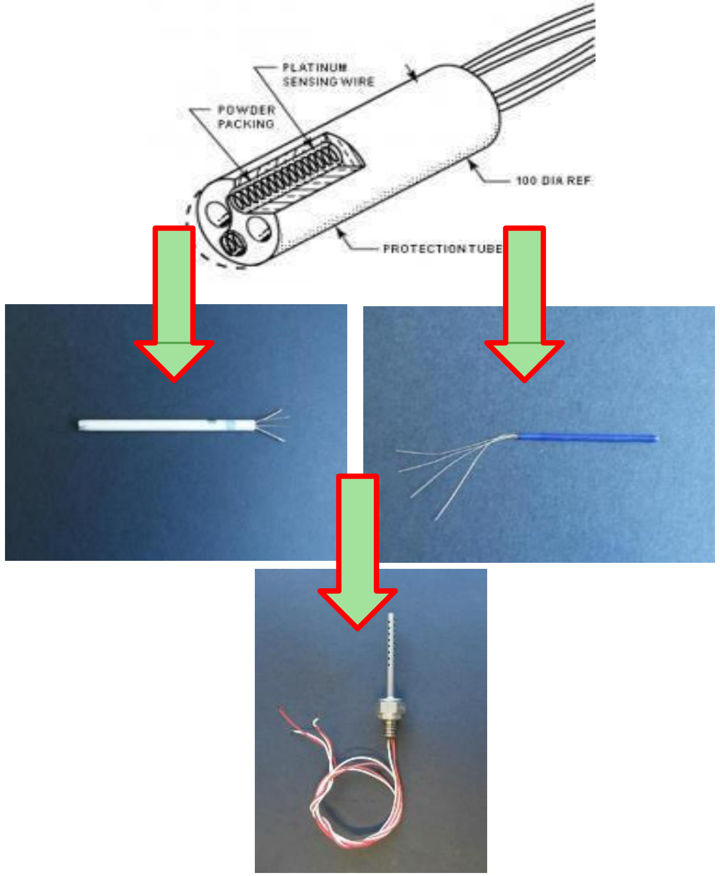


The frequency also varies with temperature, which should be determined with precision in order to correct this effect

Digiquartz®: measures the oscillating frequency of a quartz crystal, that varies with the stress induced by pressure. This method provides the most precise measurements of pressure (in dynamic trim): ± 0.01% accuracy, precision ± 0.001% of the total range. (resolution ±0.001 %)

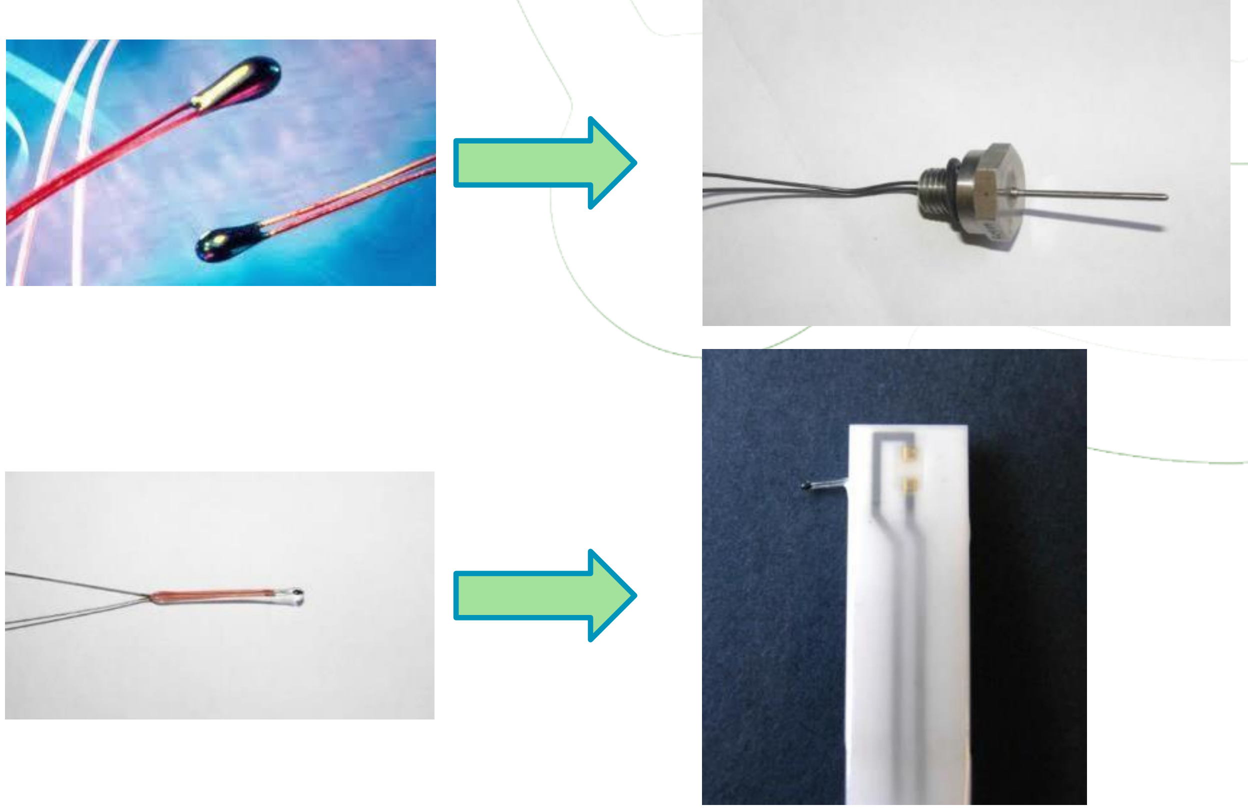
CTD probes - temperature

The Platinum Resistance Thermometer (PRT) uses the electrical resistance of platinum wire to measure temperature.



The thermistor is a seminconductor characterized by a resistance that varies rapidly and with a known relationship with temperautre.

If calibrated carefully it yields an accuracy of **± 0.001°C**.

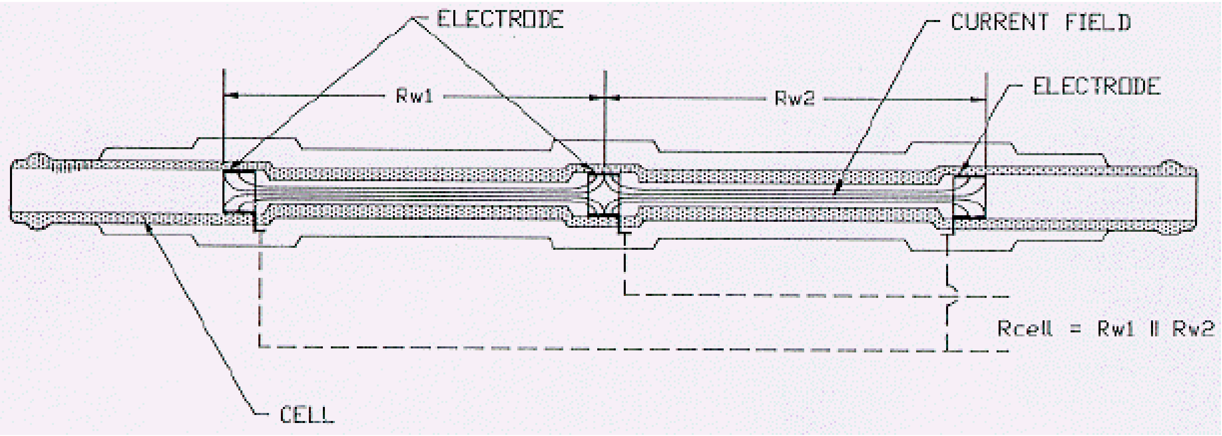


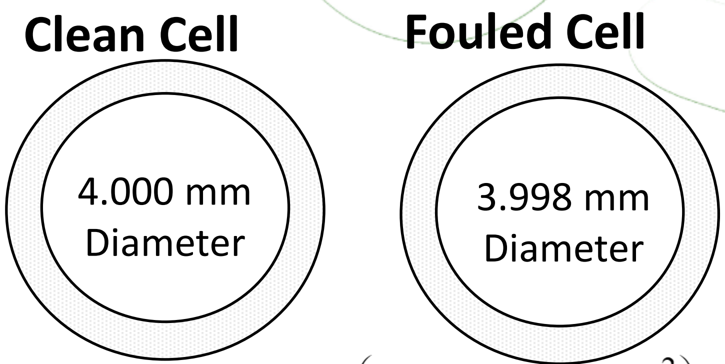
CTD probes - conductivity

Salinity is determined as ratio between the conductivity of seawater and the known conductivity of an international standard seawater
Conductivity depends both on salinty and temperature → precise temperature is needed.
The simultaneous T&C measurement allows the calculation of S, but the two sensors have different response times and then the profiles must first be aligned (during postprocessing)

Conductivity sensors are relatively unstable and need frequent recalibration. They measure conductance, i.e. the amount of electrical current that can pass through the water

The conductivity is calculated from the conductance using a scale factor (cell constant) that indicates the relationship between the path length within the cell and the cross-sectional area of the sampled volume.





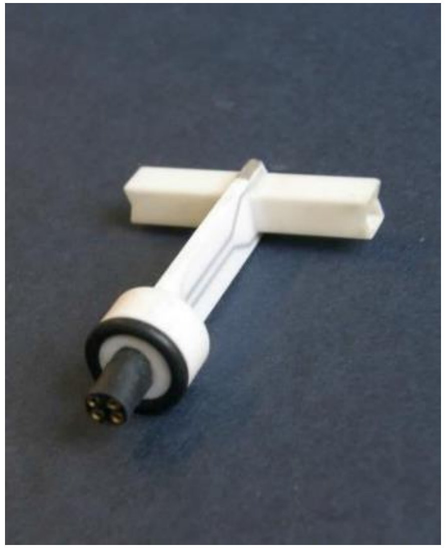
Salinity Error $= 35\left(1 - \frac{\text{fouled diameter}^2}{\text{clean diameter}^2}\right)$

$= 35 \,(1 - (3.998)^2 / (4.000)^2)$
$= 0.035$ PSU

Changes in the geometry of the cell can influence measurement

CTD probes - conductivity

«electrode cell» type conductivity sensor

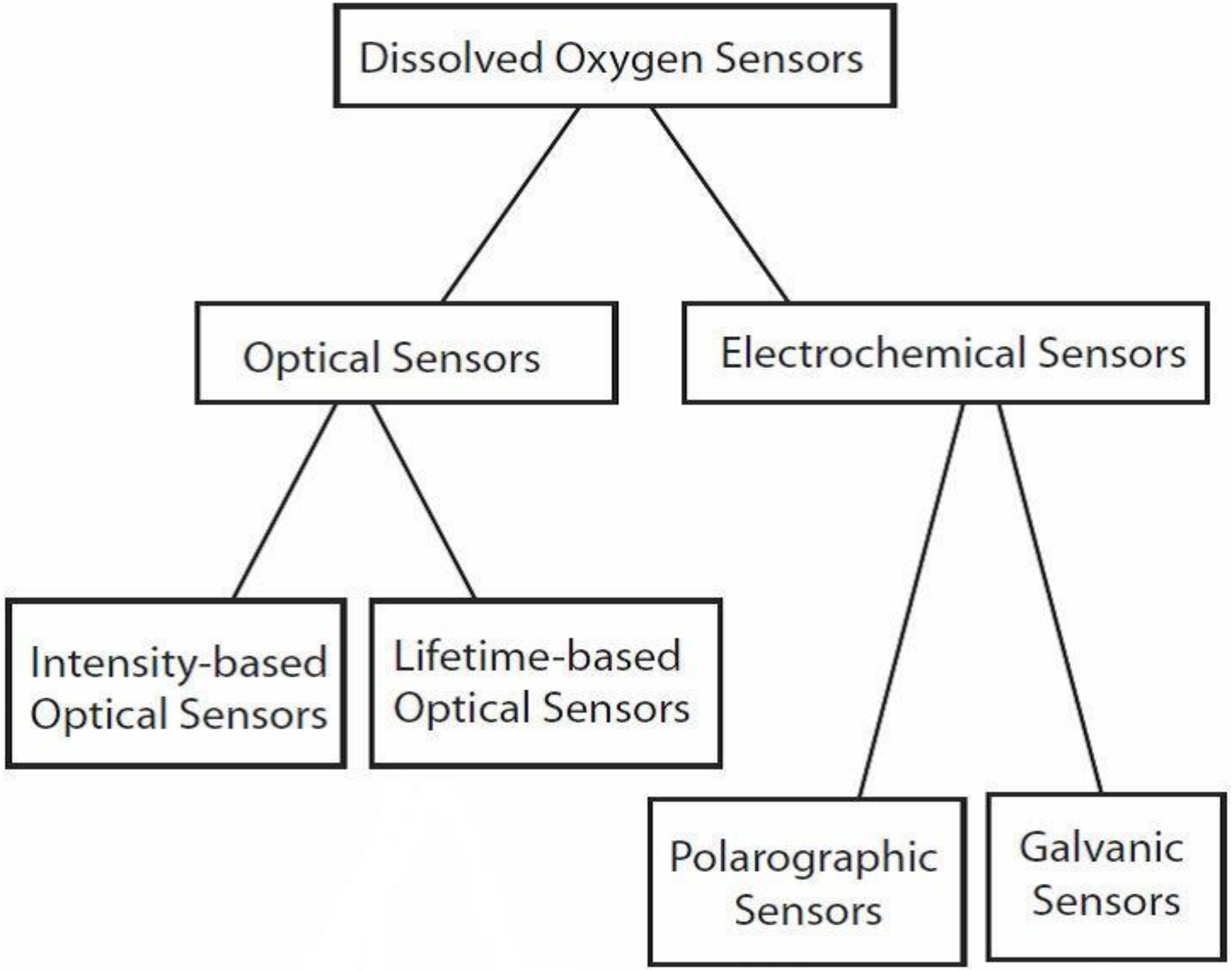


This type of sensor uses electrodes to measure the conductivity of the seawater in the measuring cell.

«inductive cell» type conductivity sensor

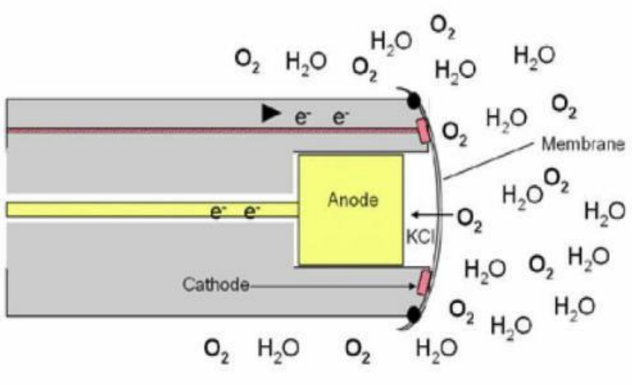
This type of sensor uses a transformer to couple a known voltage to the seawater in the measuring cell, and detects the resulting current flow using a second transformer core. The current measurement is then used to derive the conductivity of the seawater in the cell.

Chemistry-dissolved Oxygen



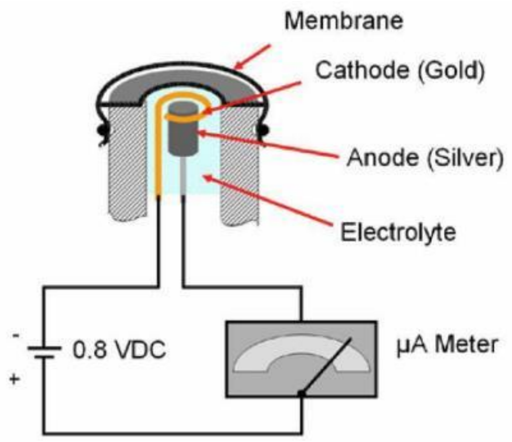
Chemistry-dissolved Oxygen

The electrochemical (polarographic) DO sensor



A constant voltage of 0.8 volts is applied between the cathode and the anode, which polarizes the two electrodes.

The presence of the electrolyte held under the membrane permits a current to flow. The sensor detect a change in this current caused by the variable partial pressure of dissolved oxygen



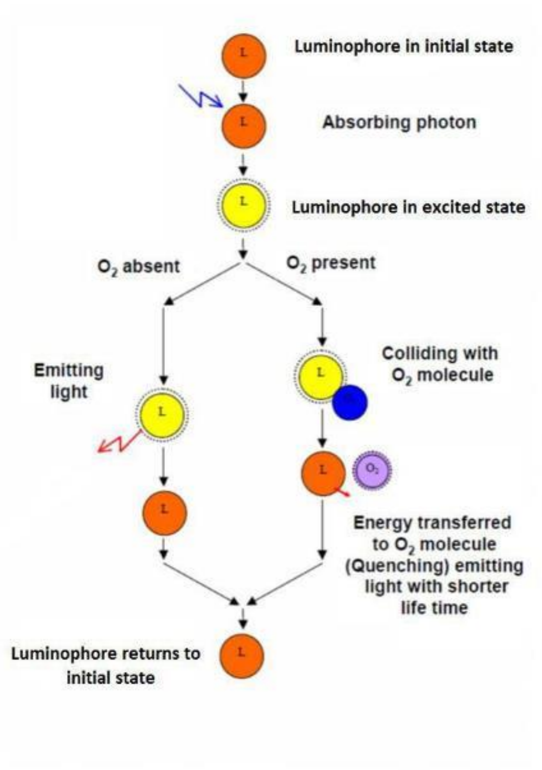
The more oxygen passing through the membrane and being reduced at the cathode, the greater the electrical signal (current) read by the probe. As oxygen increases, the signal increases and, conversely, as oxygen decreases, the signal decreases.

«Beckman» type polarographic oxygen sensor

«Clark» type polarographic oxygen sensor

Chemistry-dissolved Oxygen

The optical DO sensor

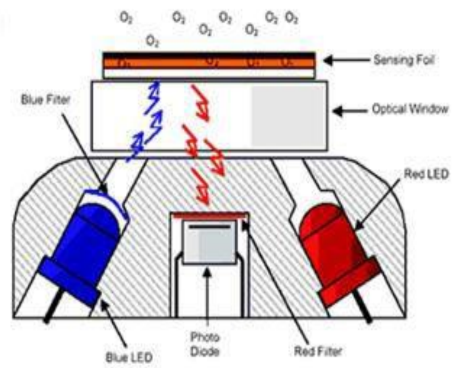


In an optical DO sensor, light of the proper wavelength (blue) is emitted, causing the dye (luminophore) in the sensing element to luminesce or glow in a different known wavelength (red).

Oxygen dissolved in the sample affects the luminescence of the dye

.

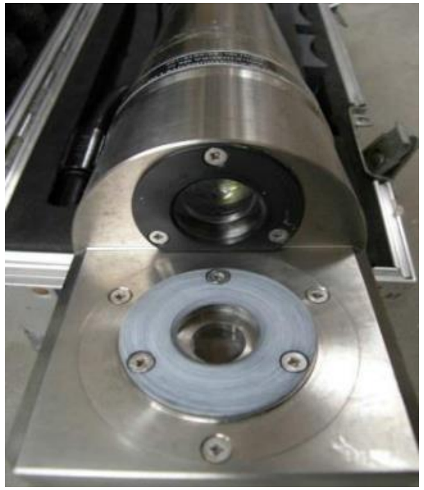
The dye's luminescence is then determined with an appropriate light detector using a reference measurement for comparison.

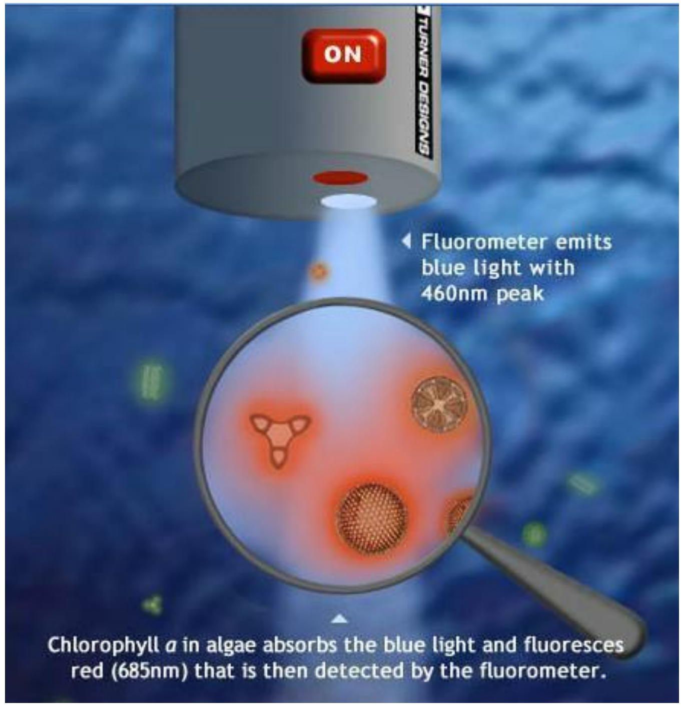


Oxygen Optode

Biology-fluorescence

Fluorometer



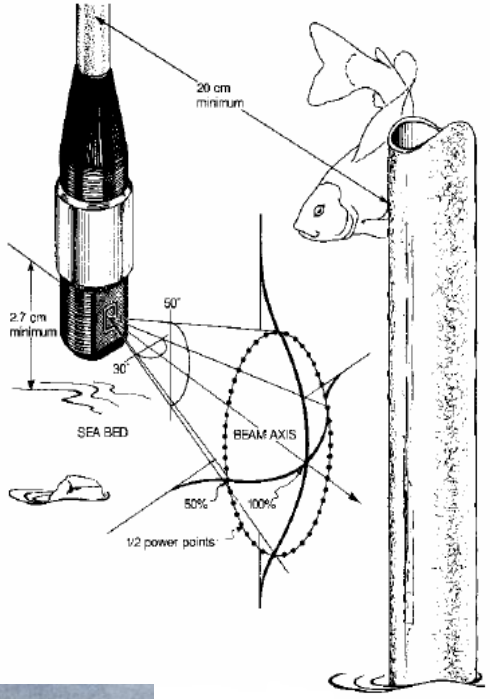


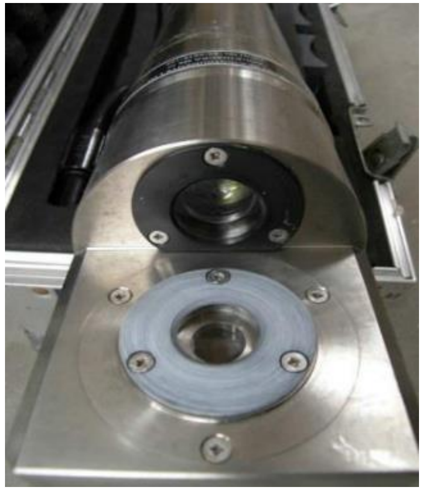
Fluorescence is the molecular light absorption of energy at one wavelength and its instantaneous re-emission at another, usually longer, wavelength.

The fluorometer exploits the fluorescing ability of certain molecular species (like Chorophyll *a*) to provide measures of their concentrations.

Biology-turbidity

The Nephelometric Turbidimeter





Turbidity is an optical property arising from the interaction between light and suspended particles in a solution.

The nephelometric turbidimeter measures turbidity by measuring the light scattered by a solution at one (usually 90°) or more angles to an incident light beam

Infrared light is generally used for the incident light beam because it does not penetrate very far in water.

ITINERIS

Measuring the Ocean

4. Calibration

Katrin Schroeder (CNR-ISMAR, Venice)

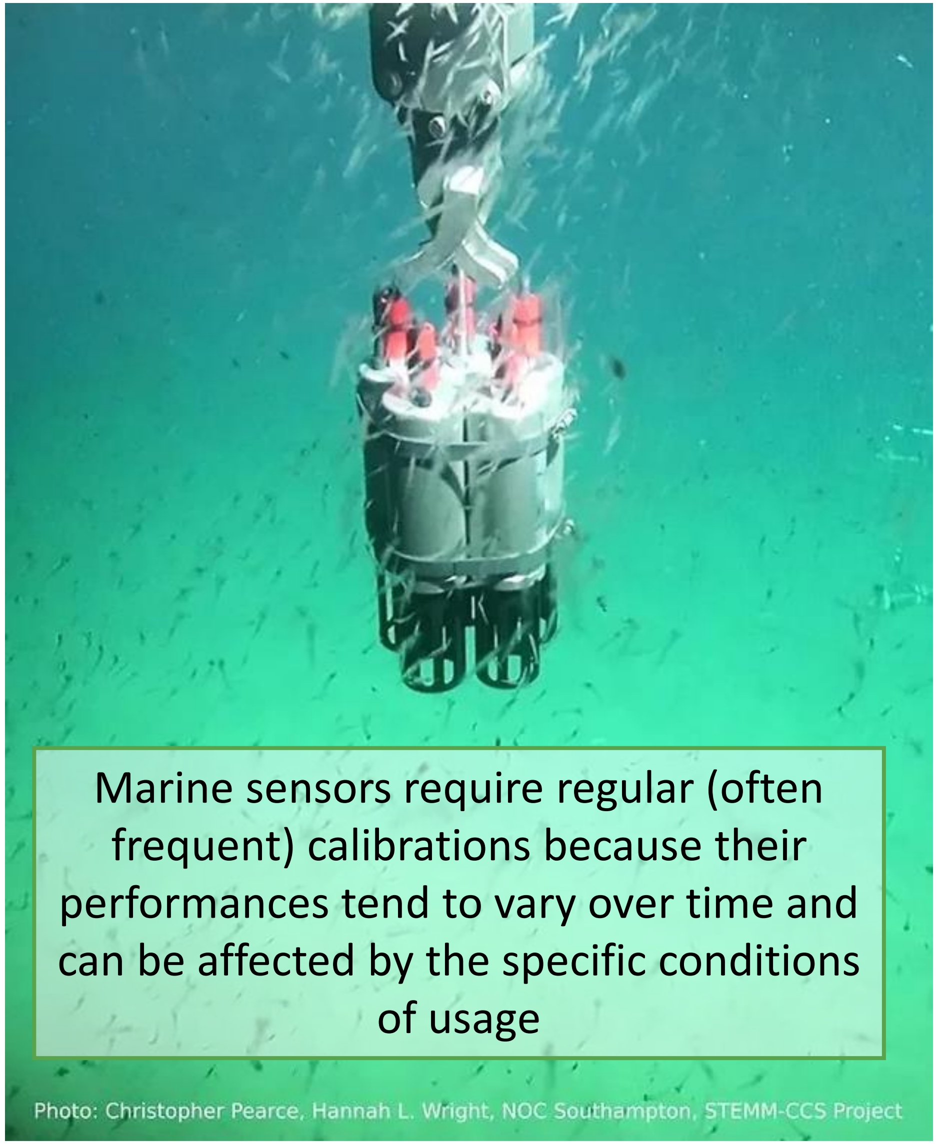
IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani

Calibration



Marine sensors require regular (often frequent) calibrations because their performances tend to vary over time and can be affected by the specific conditions of usage

Photo: Christopher Pearce, Hannah L. Wright, NOC Southampton, STEMM-CCS Project

You cannot calibrate marine sensors in the field (this is called «field correction»)

Sensor calibrations should be verified ideally once a year

Proper field maintenace: poorly maintained instruments often need long and complicated procedures to restore to a condition that would permit a proper calibration

Calibration

<u>Calibration</u> is the process whereby a measurement standard or instrument is compared with another standard or instrument to report, or adjust, any variation in the accuracy of the item being compared

The prime requirement for calibration is the availability of appropriate and accurate standards

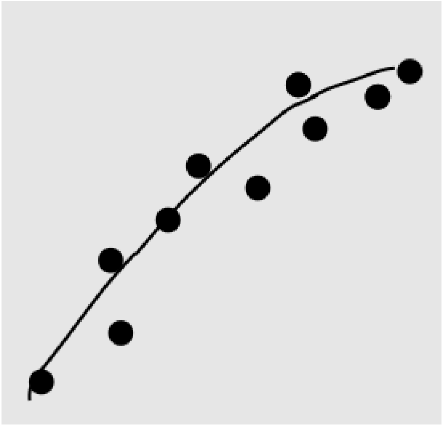
Proper calibration assures comparability of measured data

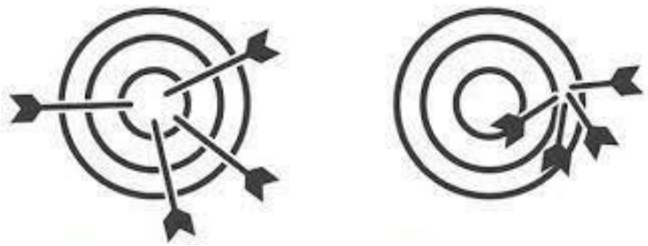
The sensors response is compared to the standard at multiple points spanning the sensor's measurement range.

This allows instrument non-linearity to be identified and permits the linearization of its response by the application of calibration coefficients

The Accuracy of the calibration depends on:

- accuracy of the reference(s)
- stability and homogeneity of the calibration bath
- precision with which the comparisons are made





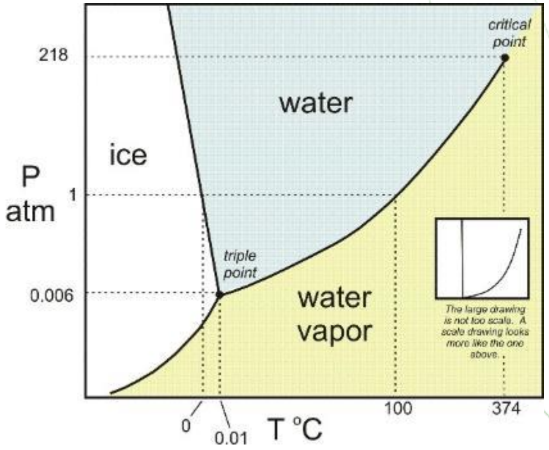
Temperature calibration

A temperature calibration is done by comparing the temperature readings of the instrument being tested with those of a Reference System in a thermostatic bath

unit to be tested

thermostatic bath

Simultaneous acquisition of temperature data from the unit and the Reference System



The principal fixed points of the International Tempearture Scale of 1990 (ITS-90) used in Oceanography:

The triple point of water (TPW) = 0.01 °C

Melting Point of Gallium (MPGa) = 29.7646 °C

The Reference System is constituted by

- high-precision Digital Thermometer
- Standard Platinum Resistance Thermometer (SPRT)
- Standard Resistor

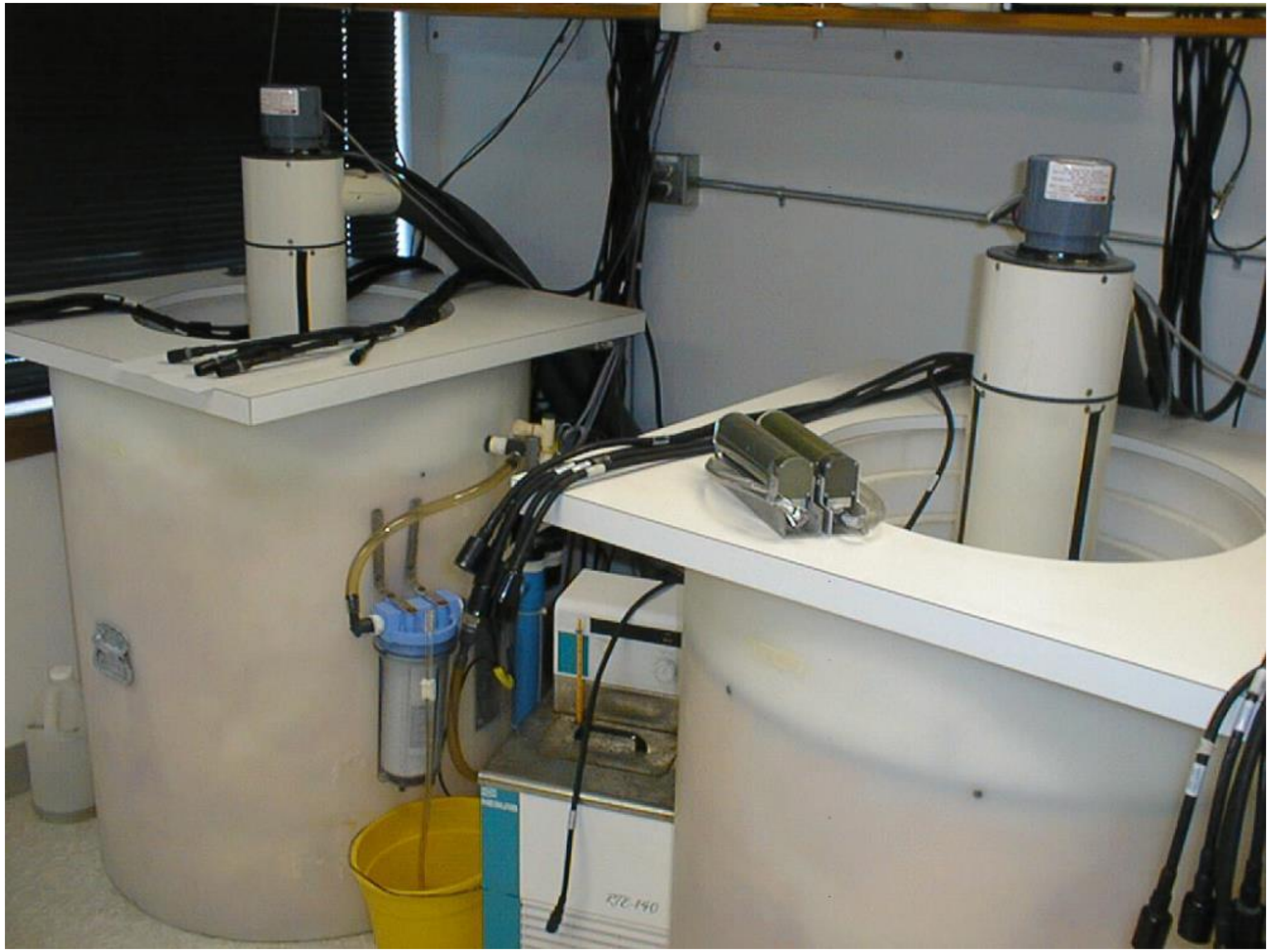
Temperature calibration

SEACAT/MicroCAT Cal. Lab.

Ultra-stable computer automated calibration systems perform thousands of C-T calibrations per year with unmatched accuracy and yield statistical data giving high confidence in performance and quality.

Argo CTD Cal. Lab.

Conductivity calibration



SBE 4 Conductivity Baths

Conductivity is a function of both temperature and salinity.

The method by which conductivity cells are calibrated involves changing the temperature in a bath of a single salinity to yield a range of conductivities (e.g., from 2.6 S/m to 6 S/m between 1 and 32 °C at a salinity of approximately 35 PSU.).

Conductivity calibration

Conductivity Reference: **IAPSO Standard Seawater**

Guildline Portasal and Autosal (Conductivity comparator)

Autosal setup: www.youtube.com/watch?v=tPrfeS4SeOM

Autosal Standardisation & Sample Run: www.youtube.com/watch?v=mb5kgMGKWK0

The Autosal employs a continuous flow system, where the sample water is drawn under low air pressure from the original sample bottle.

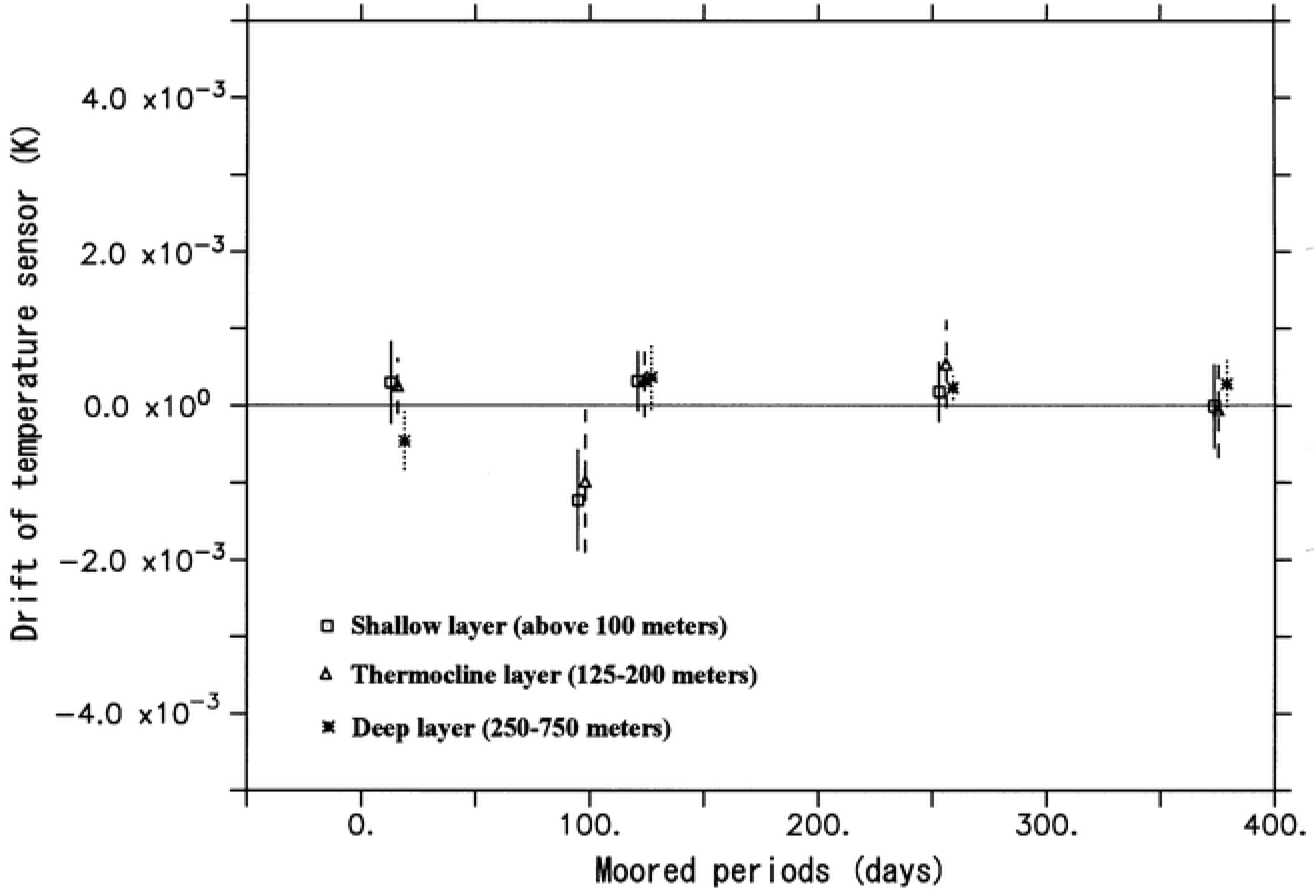
A high stability temperature control bath and heat exchanger maintain this sample at a precisely defined temperature during analysis, avoiding the need for temperature compensation.

The accuracy is better than 0.002 PSU

Sensor drift

Sensor drift is the degradation of the initial calibration accuracy

- Temperature drift (thermistor aging), typically 0.001°C in first year, (1 ppm equivalent salinity) and 2-3 millidegrees in 10 years
- Pressure drift typically < 1dbar/year
- Conductivity drift is the most unpredictable and has the largest effect on Salinity accuracy

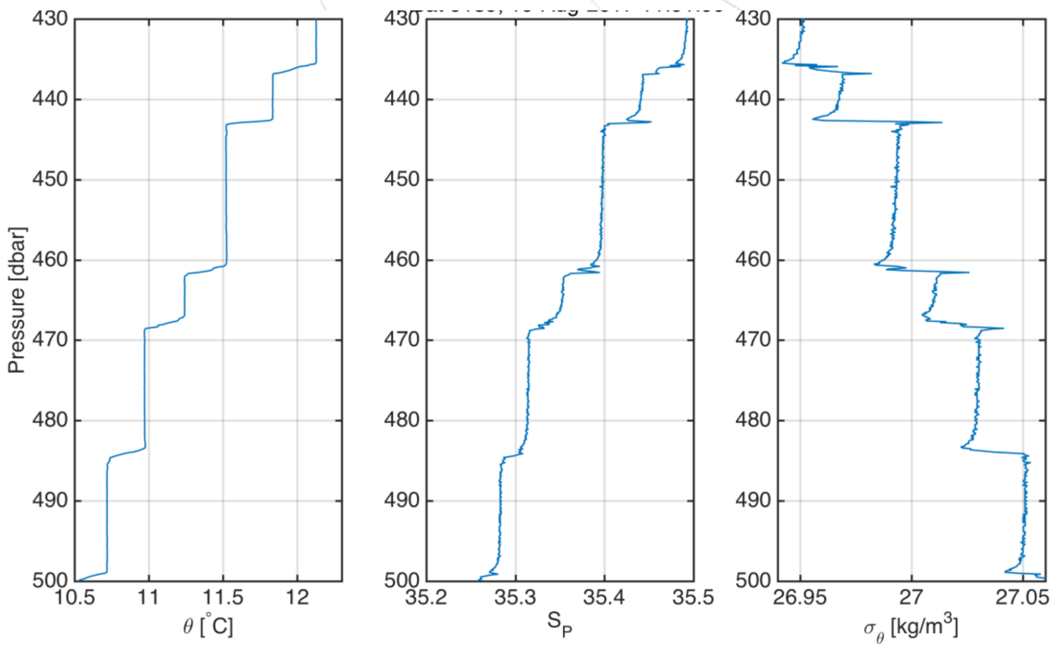


Dynamic errors

Dynamic accuracy is calibration accuracy degraded by errors associated with instrument use in a changing ocean, in conditions that are not found in the calibration environment. Impact is significant on moving platforms, particularly when transiting through gradients.

The primary sources of dynamic errors in CTD measurements are:

- Turbulent wakes (*shed wakes*)
- Unequal response times of T & C sensors
- Measurements of T & C poorly coordinated in time or space
- Thermal mass error in conductivity cells.

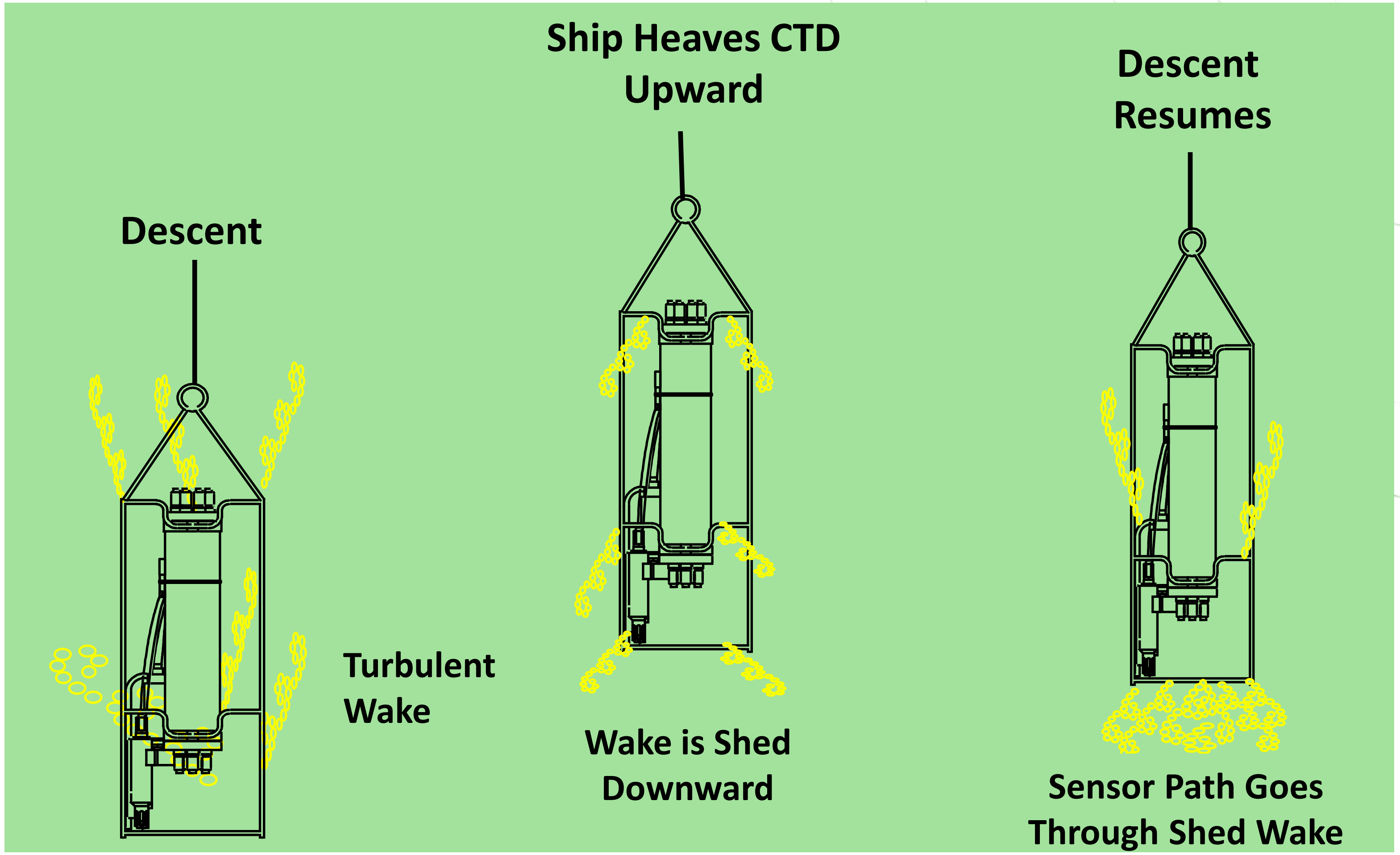


Dynamic Errors: Shed Wakes

Shed Wakes are generated by the modulating effect of ship heave on the instrument motion through the water, causing contamination of temperature and conductivity measurements and resulting in spiking in S and σ

Shed wakes affect all profiling CTDs and a CTD's design is not the cause of shed wake errors.

Shed wake error is commonly unrecognized and often misinterpreted as CTD instrument error.



Increase S accuracy

- Matched response times of T & C sensors
- Controlled flow (pump) for fixed response times
- Coordinating measurements in space and time

If T and C sensors have the same response times and are physically co-located, the computation of salinity will be made correctly.

When the response times are increasingly different, and when the salinity gradient in the ocean becomes larger, the salinity computations will contain error displayed as spikes in the plotted data.

To the degree that sensor response times can be well matched, the potential for salinity accuracy is increased. Sea-Bird uses flow-controlled (pumped) sensors to control sensor response time.

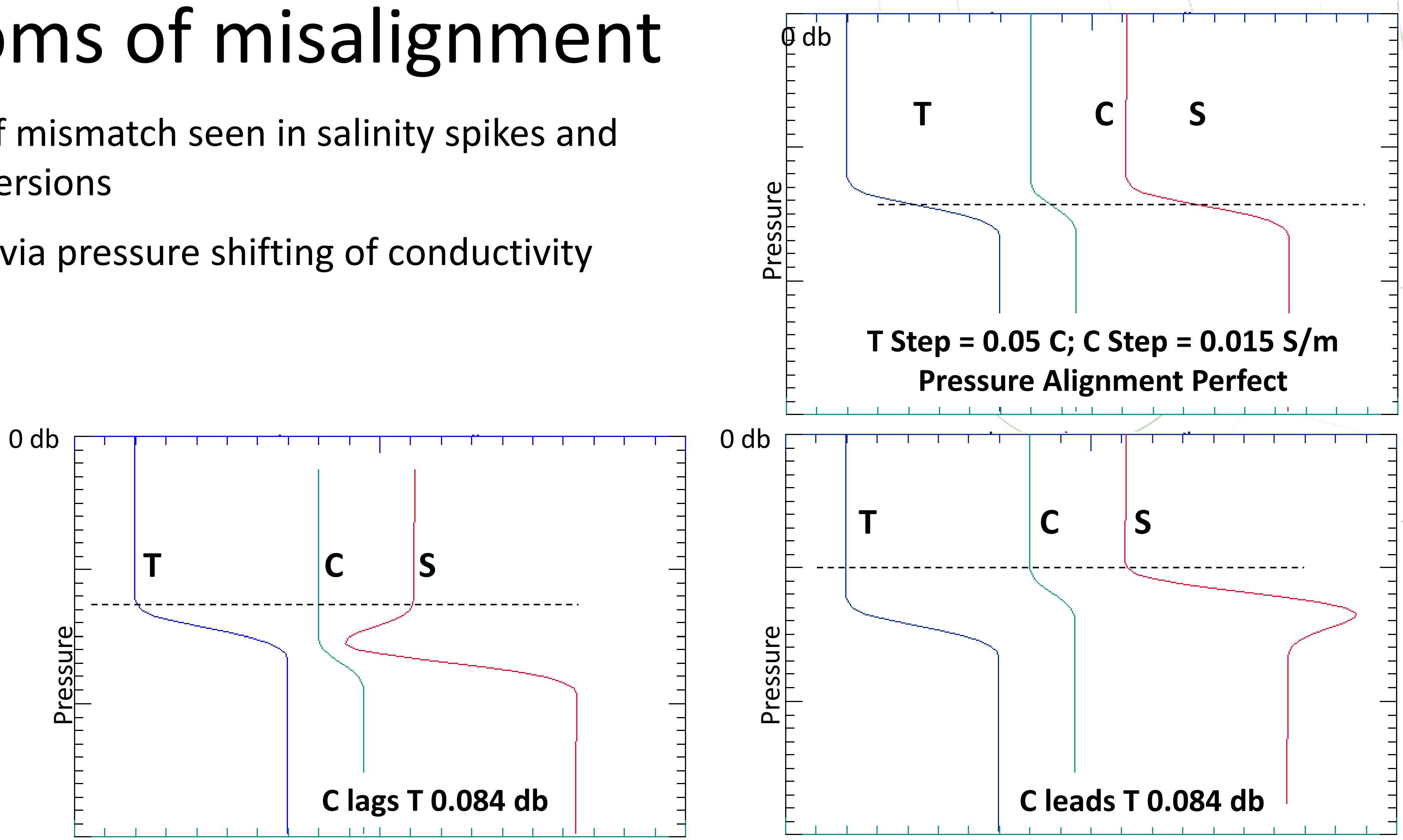
Pumped vs Free-Flushed Sensors

- SBE CTDs use a pump to keep time responses matched and constant and a “T-C Duct” to force measurements of T & C to be made on exactly the same "piece" of water
- Time lag between the T measurement and the C measurement due to “transit time” of water through the duct.
- Flow rate is constant so the time lag is constant
- Compensated by advancing the C measurement in time (via hardware or software) to correspond with the proper T measurement.

- Conductivity sensor response time is determined entirely by the flow rate through the cell (faster flow = faster response).
- CTDs with free-flushed cells will experience continually changing flow rates primarily resulting from ship heave.

Symptoms of misalignment

- Evidence of mismatch seen in salinity spikes and density inversions
- Correction via pressure shifting of conductivity



Increase S accuracy

All conductivity cells have mass and therefore have the capacity to store heat.

- As a cell moves from warmer to colder water, heat stored in the cell is lost to the surrounding water.
- Depending on cell design, varying amounts of that heat actually warm the water within the measurement area of the cell, changing (raising) its conductivity.

Because CTD temperature sensors are not located inside the conductivity cell, the temperature reported by the CTD (assumed accurate) will be slightly different (lower) that the actual temperature inside the conductivity cell. As a result, when those measurements of T & C are used in the salinity equation, the computed salinity will contain an error.

Minimizing Thermal Mass Error

thermal mass error is largely a function of flow rate. The less time water resides inside the cell, the smaller the error. In pumped CTDs, thermal mass error is predictable because flow is constant and can be minimized in data processing.

In free-flushed CTD systems, the constantly varying flow rate in the cell makes it impossible to correct for thermal mass error.

Field "calibrations"

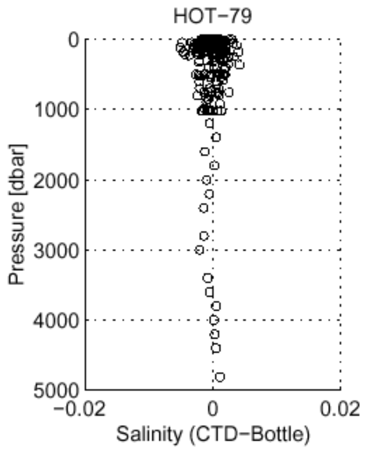
- Pressure
  - Slope and offset, typically use offset only
  - Best practice, measured in the lab against a barometer
  - In a pinch, on deck (We know where sea level is, right?)
- Temperature
  - Slope and offset, typically use offset only
  - Reversing thermometers
  - SBE 35 reference thermometer
- Conductivity
  - Slope and offset, typically use slope only
  - Discrete salinity samples
- Dissolved oxygen
  - Calibration equation contains slope and offset
  - Discrete samples

These require water samples

Laboratory determinations of salinity

Winkler titrations of dissolved oxygen

Field “calibrations”

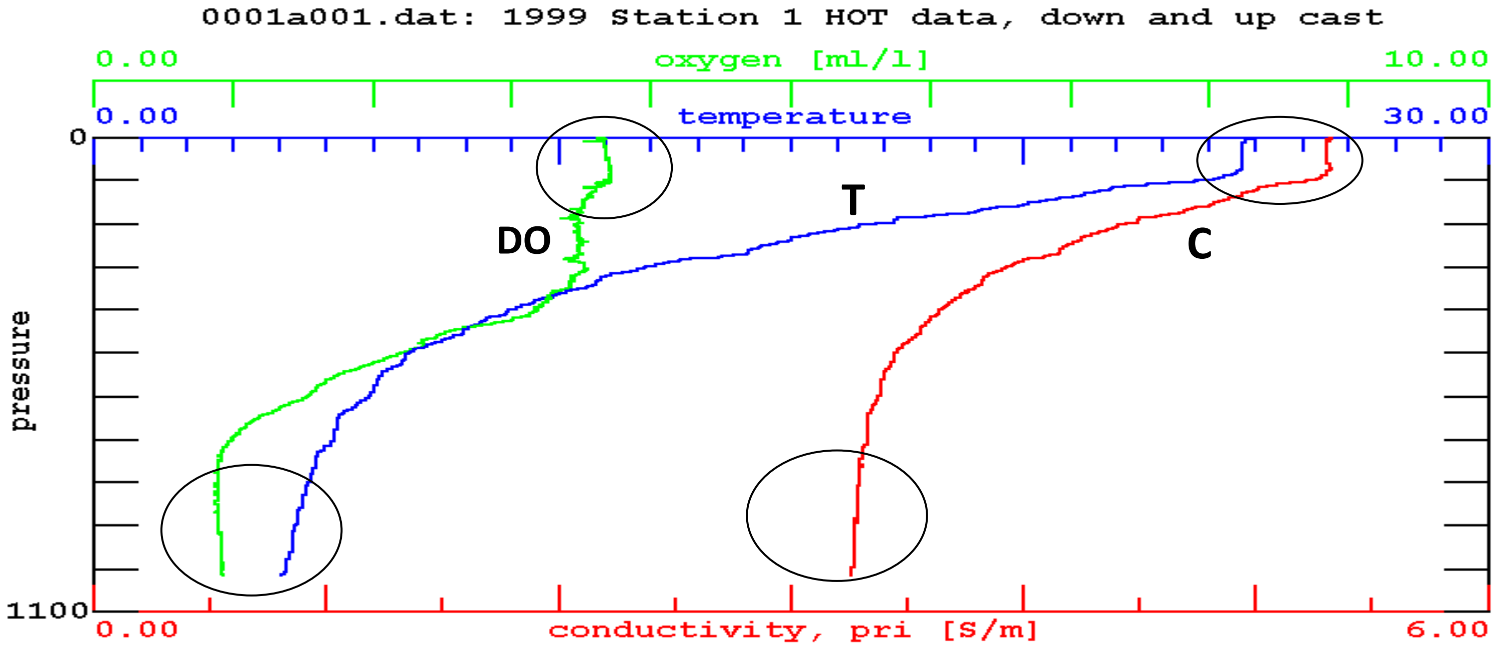


Where to sample:

in parts of water column where changes of the parameter of interest are small compared to size of CTD package, paying attention to possible sample bottle leaks

LEAK CHECK:

- Run underwater package down deep to uniform water
- Close all water bottles
- Run salinities on each water bottle
- Compare salinities, fix leakers, and repeat



Salinity field "calibrations"

Correct conductivity, not salinity!

As with pre\post-cruise calibrations, correct conductivity with slope:

$$slope = \frac{\sum_{i=1}^{n} \alpha_i \beta_i}{\sum_{i=1}^{n} \alpha_i \alpha_i}$$

- Where
  - n = number of samples
  - α = CTD conductivity
  - β = true (bottle sample) conductivity

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THANKS!

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