Generating knowledge 2
Example of sensors and installation requirements

Davide Embriaco

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

Example of sensors and installation requirements

- Sensors for marine research
- Measurement goals: monitoring, research
- Scientific data production process:
  - From sensor installation
  - to data acquisition, sharing and publication

- This session provides examples of sensors used in different marine research disciplines and their specific installation requirements

Example of sensors and installation requirements

ITINERIS

Physical Oceanography & chemistry:

- **Sensors:** CTDs (Conductivity, Temperature, Depth), chemical-optical sensors (Dissolved Oxygen)
- **Installation Requirements:** Secure mounting on cabled platform (seafloor) or autonomous platforms (mooring, buoy and seafloor stand alone)

Marine Biology:

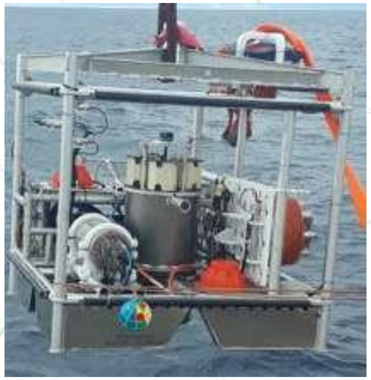
- **Sensors:** Hydrophones, **Installation Requirements:** Underwater deployment, careful calibration

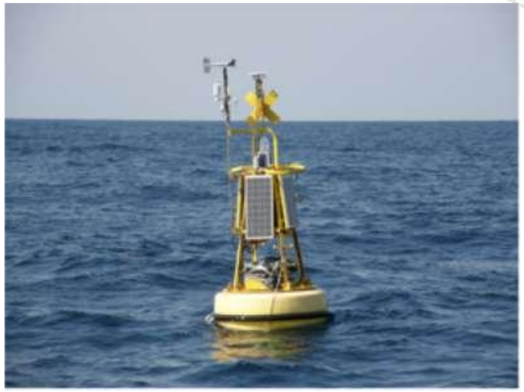
Geophysical Research:

- **Sensors:** Seismometers, Pressure sensors, magnetometers
- **Installation Requirements:** Stable placement on the seabed, protection against sedimentation

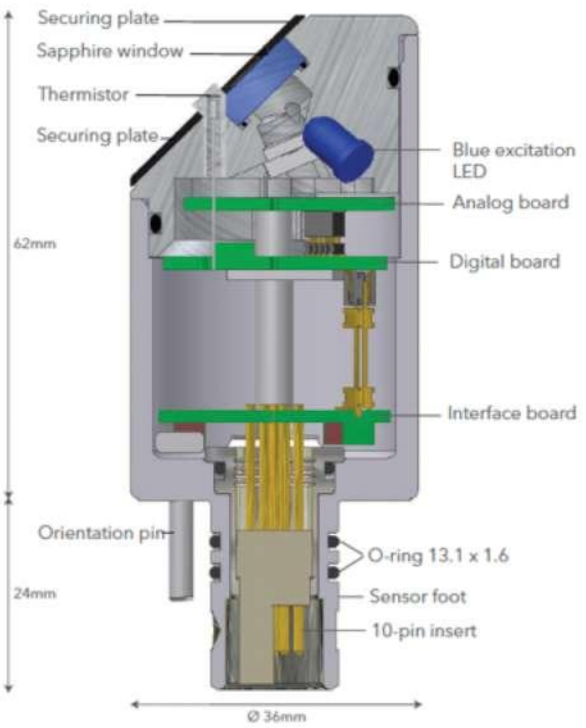
Example of sensors and installation requirements

- Installation on a fixed marine infrastructure
- Data acquisition & communication
- Time synchronization
- Requirements and constrains (fixed platform) for:
  - Cabled seafloor platform
  - Autonomous platform (mooring)





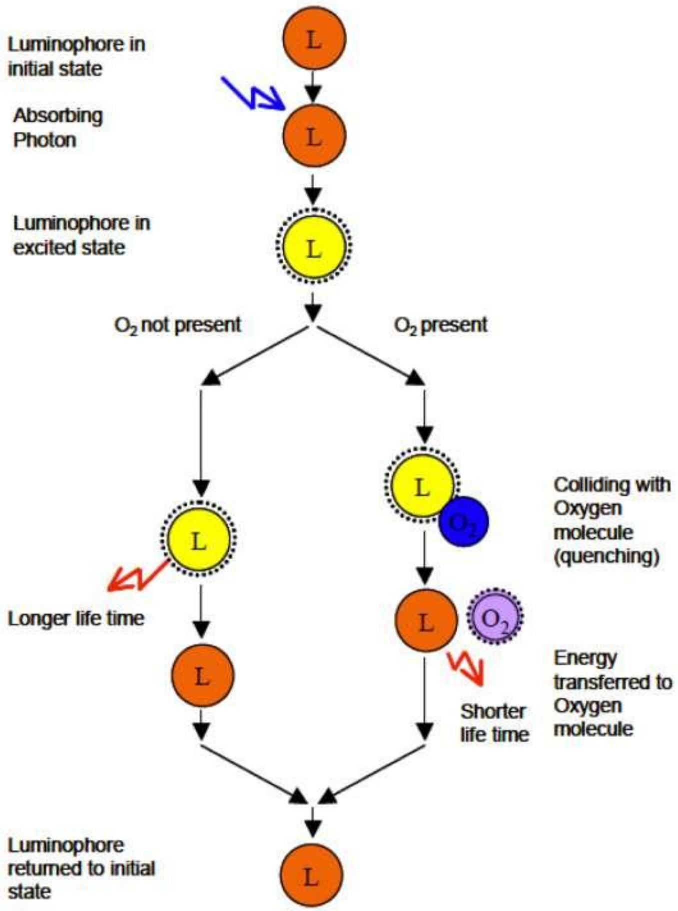
Sensors: Dissolved oxygen



PIN CONFIGURATION

Commercial DO device for underwater use (AANDEERA Optode)

physical principle for measuring DO



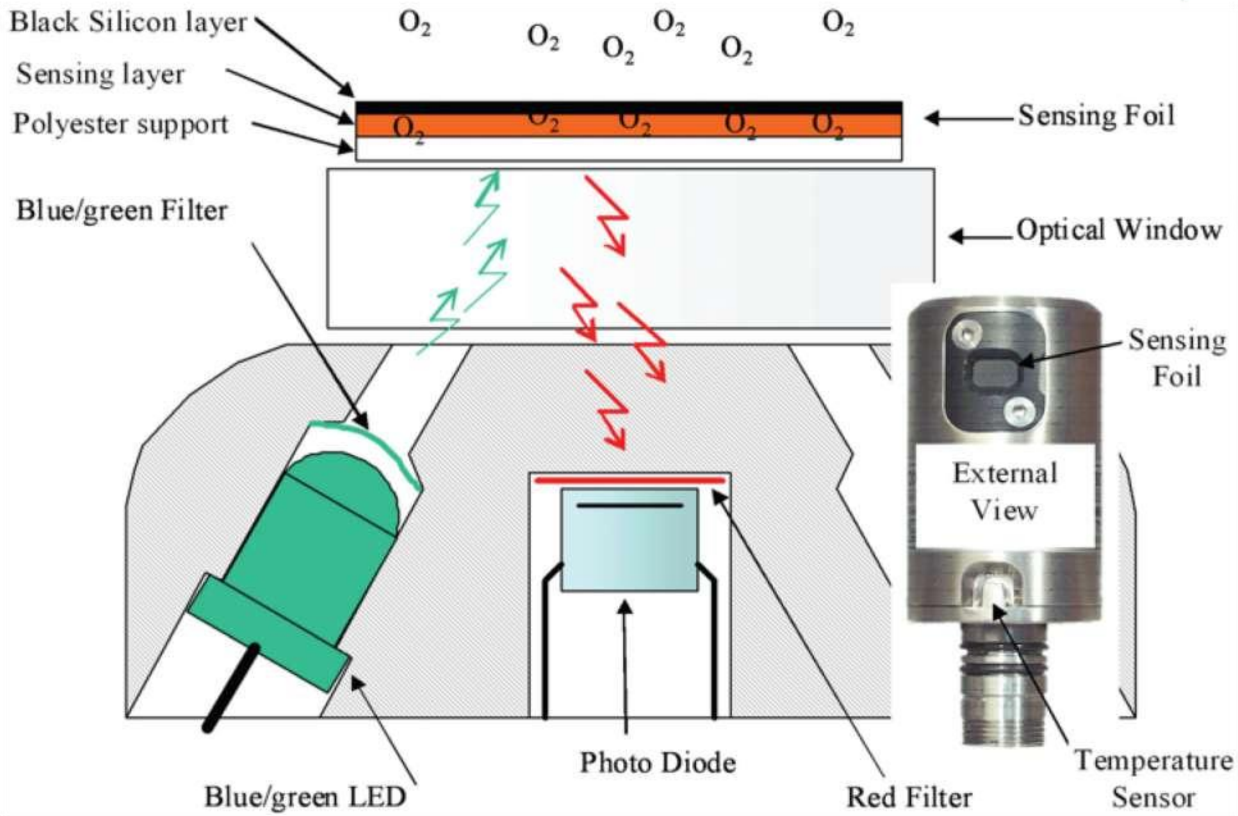
The O_2-concentration is calculated in micro Molar, *μM*, from a 4th degree polynominal:

$$[O_2] = C_0 + C_1P + C_2P^2 + C_3P^3 + C_4P^4$$

where $C_0,..,C_4$ = temperature dependent coefficients calculated as

$$C_x = C_{x0} + C_{x1}t + C_{x2}t^2 + C_{x3}t^3$$

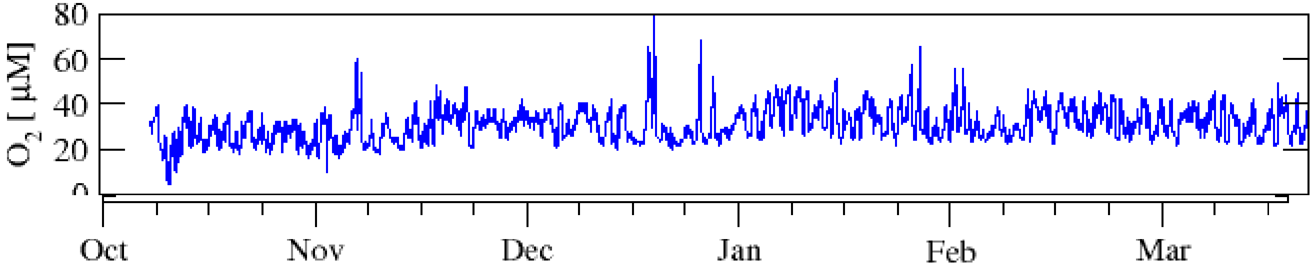
Oxygen Optode measuring principle



The sensor is based on oxygen luminescence quenching of a platinum porphyrine complex. The lifetime measurement, and hence the oxygen measurement, is made by a so-called phase-shift detection of the returning, oxygen-quenched red luminescence

Picture from Anders Tengberg, et al. *Limnol. Oceanogr.: Methods 4, 2006, 7–17*
From: https://www.aanderaa.com/oxygen-sensors

Dissolved oxygen data examples



161 day
Sea of Marmara experiment

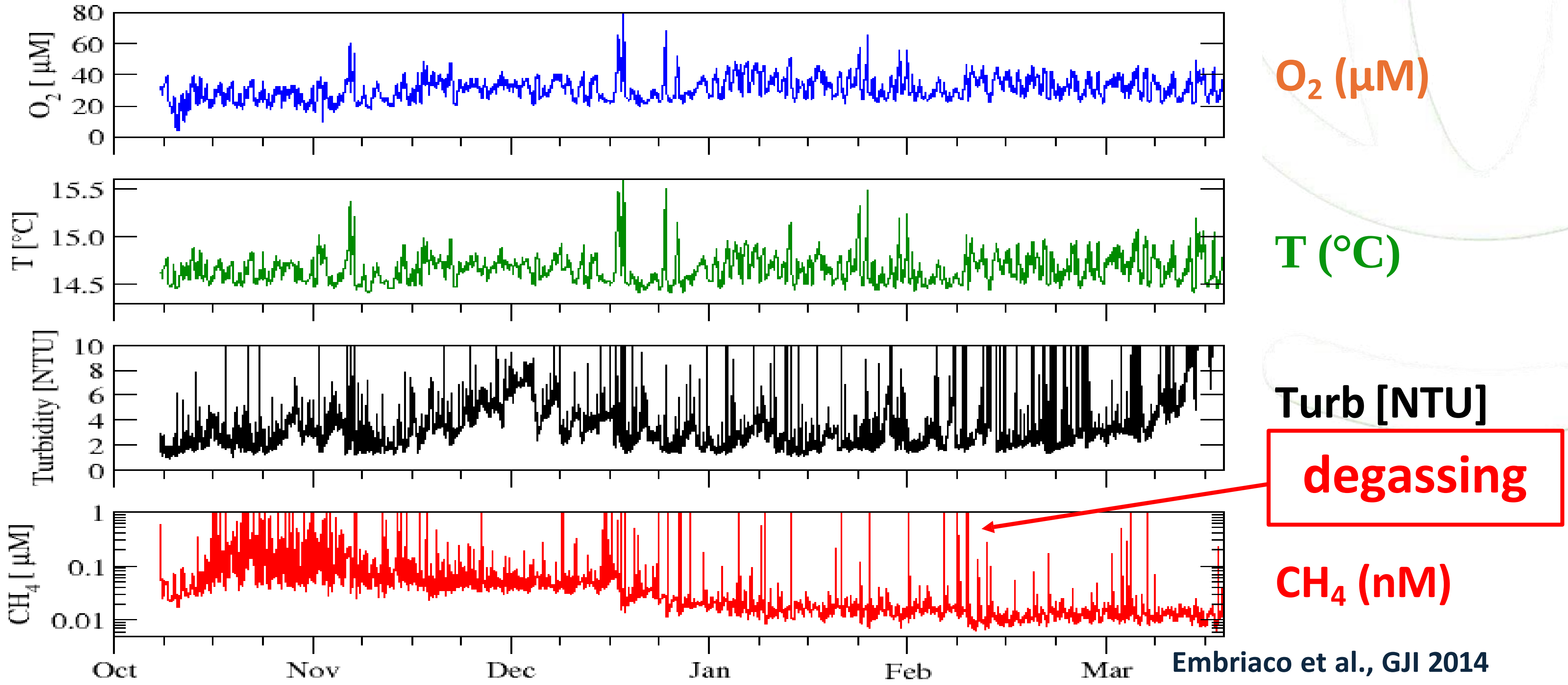
Methane sensors

CALIBRATION RANGES

Temperature:	standard	2-20°C, others on request
Methane:	standard	50nM – 10µM
	sensitive	1nM – 500nM (in pumped flow-through mode)
	low range	20nM – 1µM
	high range	1µM – 40µM
Response time:	reaction time within few seconds T90 between 1 and 30 min depending on version and deployment conditions.	
Special features:	integrated formula (plug & play) correction formula for work under variable oxygen levels	

Calibration formula and parameters can be provided in format compatible with CTD-probe from different manufacturers (e.g. Seabird, SST)

Methane sensor: data example



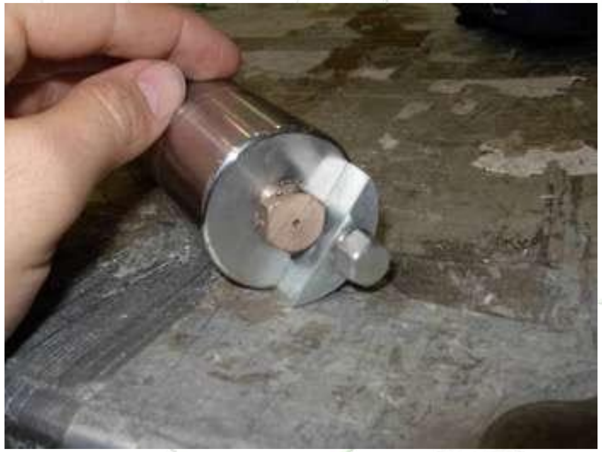
Embriaco et al., GJI 2014

Sensors: Absolute pressure gauge

- Marine pressure sensors are critical instruments used to measure the pressure exerted by the water column in the ocean. These measurements are essential for various oceanographic studies and applications.
- Used to determine depth by measuring the water pressure.
- **Oceanographic Studies:** Monitoring tides, waves, and ocean currents.
- **Climate Research:** Studying sea level rise and its impacts on coastal areas.
- **Marine Geology:** Detecting underwater seismic activity and submarine landslides.
- **Marine hazard:** Detecting of tsunami waves in open ocean

Sensors: Absolute pressure gauge

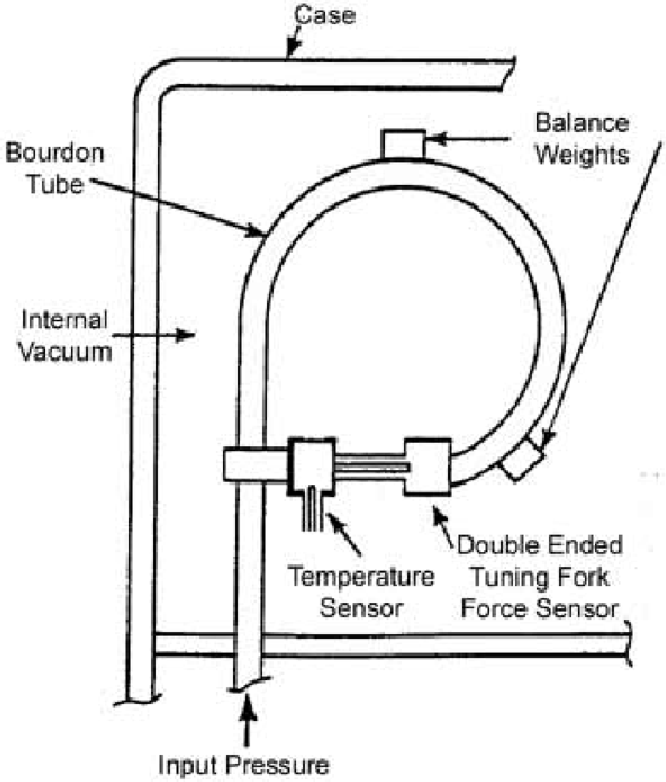
- 0.01% Accuracy, range 0-4000 m , 0-7000 m
- 1×10^{-8} Resolution
- Unique Anti-Fouling Port
- Low Power Consumption
- High Stability (some baseline drift with time)
- Fully Calibrated and Characterized
- ISO 9001 Quality System
- Frequency Outputs or Dual RS-232 and RS-485 Interfaces

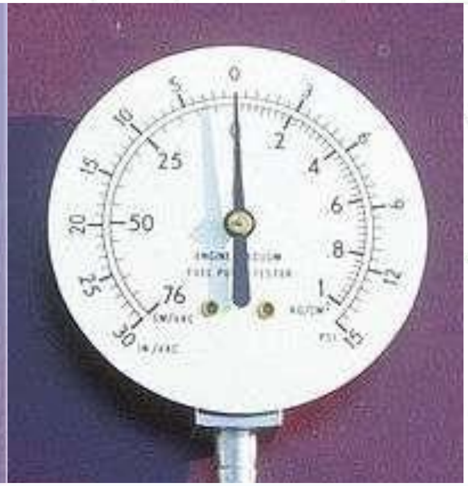


Model: Paroscientific 8CB-4000-I

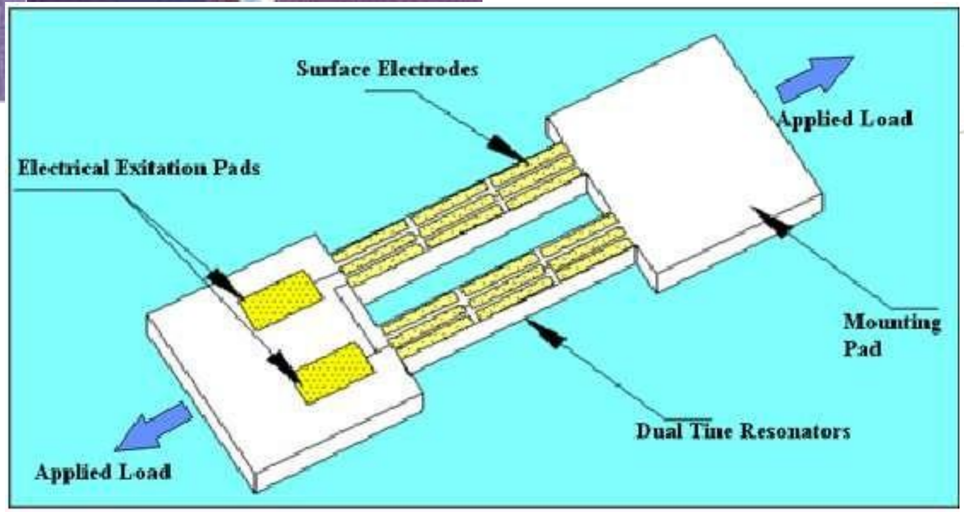
Sensors: Absolute pressure gauge

Model: Paroscientific 8CB-4000-I





Bourdon tube



Sensors: Absolute pressure gauge

Model: Paroscientific 8CB-4000-I

- The oscillation frequency of a quartz crystal is measured
- The frequency depends on the pressure which induces a mechanical distortion on the crystal
- Temperature also produce a frequency shift
- Temperature compensated measurement
- Calibration coefficients

Absolute pressure gauge: how to measure Pressure?

ITINERIS

$$P = C(1 - T_0^2/Tau^2)[1 - D(1 - T_0^2/Tau^2)]$$

Where: P = pressure
Tau = pressure period (microseconds)
U = temperature period (microseconds) – U_0 (microseconds)
$C = C_1 + C_2U + C_3U^2$
$D = D_1 + D_2U$
$T_0 = T_1 + T_2U + T_3U^2 + T_4U^3 + T_5U^4$

Pressure coefficients: C_1 C_2 C_3 D_1 D_2 T_1 T_2 T_3 T_4 T_5

Calibration Coefficients		
U0:	5.789717	µsec
Y1:	-4027.267	deg C / µsec
Y2:	-14469.34	deg C / µsec²
Y3:	-148055.3	deg C / µsec³
C1:	-27829.47	psi
C2:	-1412.122	psi / µsec
C3:	96550.93	psi / µsec²
D1:	0.0394791	
D2:	0.0000000	
T1:	30.05617	µsec
T2:	0.594138	µsec / µsec
T3:	59.25795	µsec / µsec²
T4:	46.41182	µsec / µsec³
T5:	2476.481	µsec / µsec⁴
TC:	0.6781335	

- resolution depends of measuring period : longer measuring time : better precision

Absolute pressure gauge: how to measure Pressure?

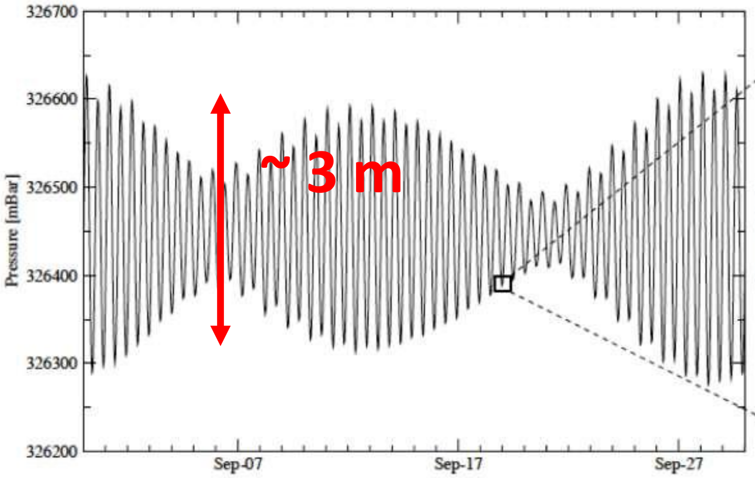
Resolution (ppm)		Integration Time (sec)	
OI=0	OI=1	OI=0	OI=1
678.200	339.100	0.001	0.002
226.100	113.000	0.003	0.006
84.770	42.390	0.008	0.016
61.650	30.830	0.011	0.022
39.890	19.950	0.017	0.034
19.950	9.970	0.034	0.068
10.120	5.060	0.067	0.134
5.061	2.530	0.134	0.268
2.037	1.018	0.333	0.666
1.018	0.509	0.666	1.332
0.509	0.254	1.333	2.666
0.204	0.102	3.332	6.664
0.102	0.051	6.664	13.328
0.051	0.025	13.328	26.656
0.025	0.013	26.656	53.312
0.015	0.007	45.872	91.744

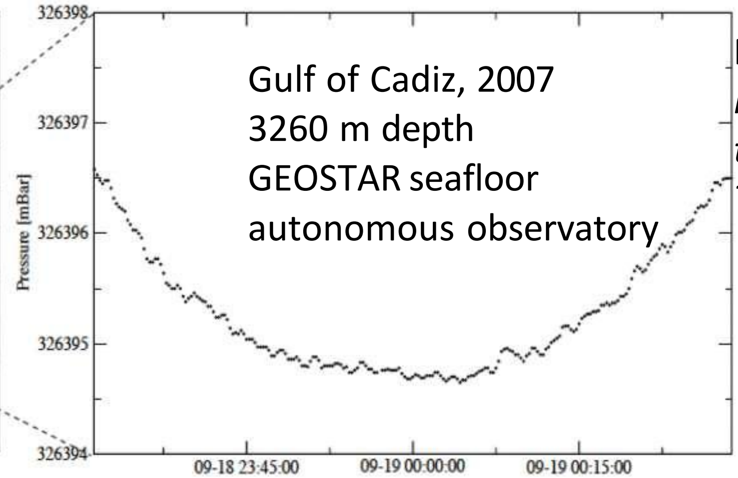
- 6 sec integration time -> 0.1ppm (with a full range of 4000m correspond to .4 mm water depth equivalent)
- 1 sec integration time -> 1 ppm (4 mm resolution)

Tsunami detection : monitor the pressure to detect small variation in water column down to few cm of equivalent water in open ocean _> high resolution & high precision.

Typical sampling rate : every 15 s : enough for the requested resolution and good to reconstruct tsunami wave (typical frequency 2 min – 2 h)

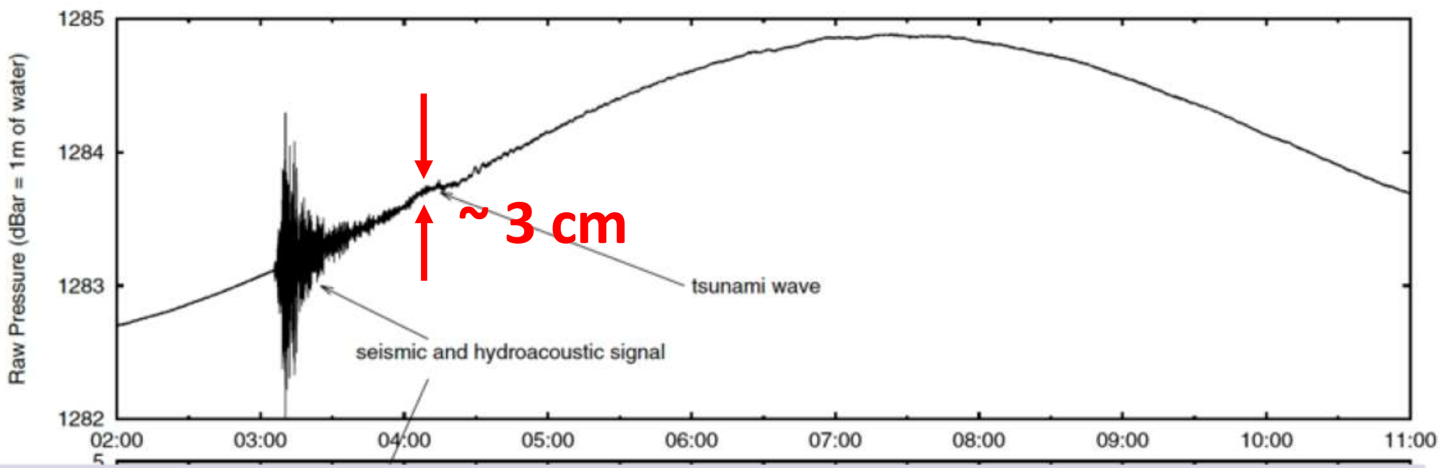
Pressure sensors : Data examples from fixed platform





From : Miranda et al. (2010)
Marine seismogenic-tsunamigenic prone areas: The Gulf of Cadiz

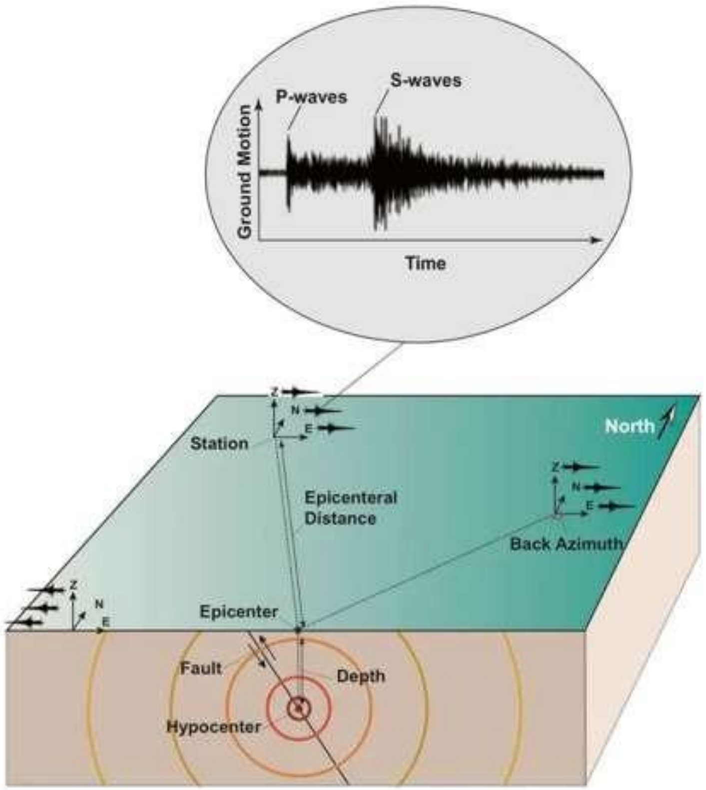
28 October 2012 (03:04 UTC) Haida Gwaii earthquake & tsunami , Pacific Ocean
Detected at 1200 m depth
Chierici et al 2017 J. Geophys. Res. Oceans, 122, doi:10.1002/2016JC012170.

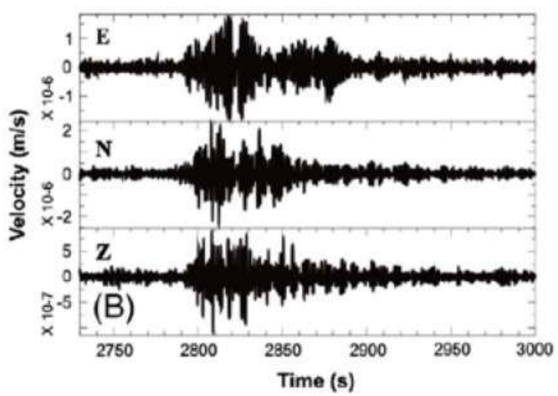


Sensors: Seismometer

Seismometers are instruments used to detect and record seismic waves generated by earthquakes, volcanic activity, and other ground motions.

- Detects seismic waves: P-waves (Primary), S-waves (Secondary), and surface waves.
- Records ground motion on seismograms.
- Used in geophysical research to study Earth's interior and monitor seismic & volcano activity

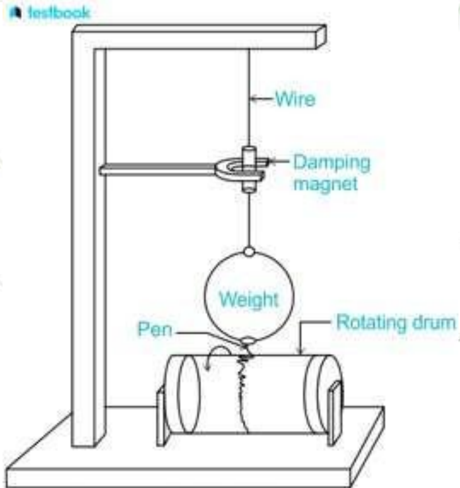




Volcano activity (ETNA) detected by SN1 seafloor observatory in 2003 (from *Journal of Marine Systems 130 (2014) 12–30 DOI: 10.1016/j.jmarsys.2013.09.010*)

Sensors: Seismometer, how it works

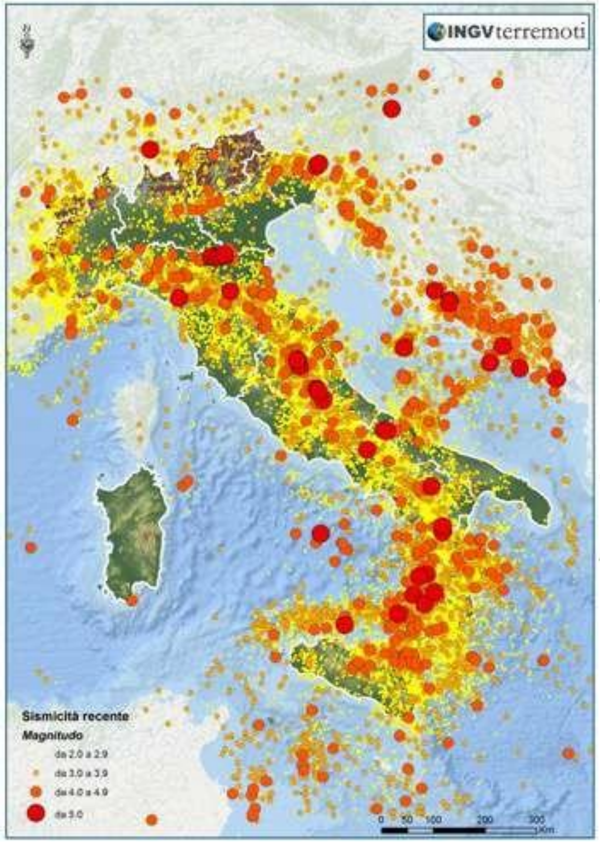
- Seismometers operate based on the principle of inertia. A mass suspended within the instrument remains stationary as the ground moves during seismic events, allowing the instrument to measure ground motion relative to the stationary mass
- Inertia of the mass: The core component that remains stationary while the ground moves.
- Electromagnetic sensors: Convert ground motion into electrical signals.
- Data recording: Signals are recorded digitally and analysed to determine the characteristics of seismic events.
- Needs for a high accurate time reference



Sensors: Seismometer, why in a marine infrastructure?

National seismic Network (INGV)

- Italian seismic network is mainly land based
- Large number of earthquake at sea
- Marine installation to increase the spatial coverage and better define marine events

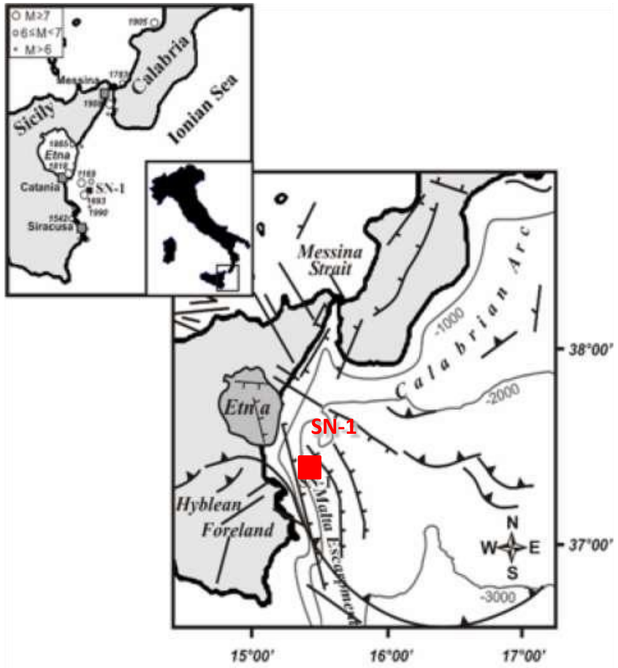


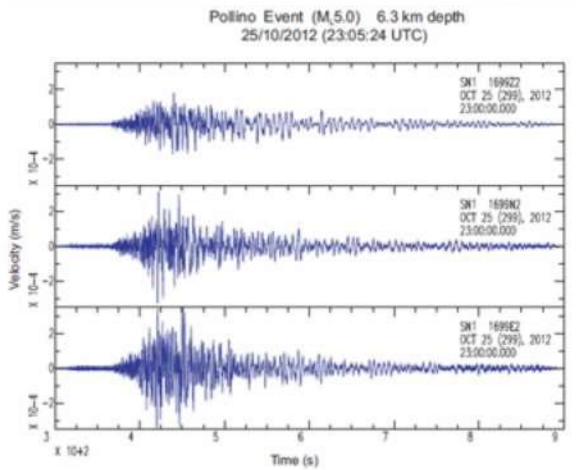
1985-2014 earthquake Ml >=2

Seismometer data at EMSO Western Ionian Sea

NEMO-SN1 seismological data

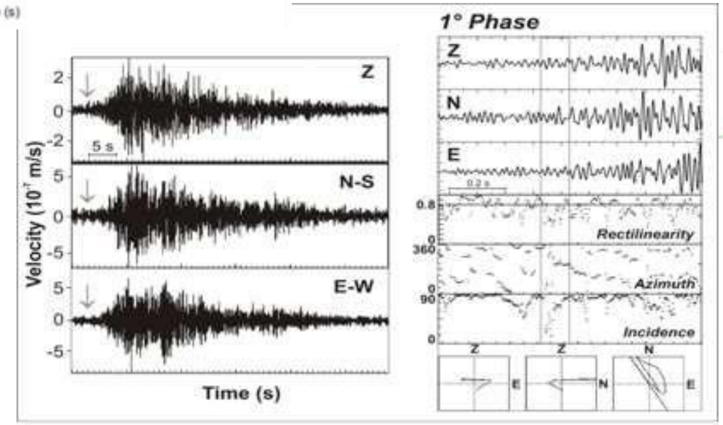
Geo-hazards:





earthquakes

submarine landslides



Sensors: Magnetometers

- **Scalar Magnetometers:** Measure the total strength of the magnetic field.
- **Vector Magnetometers:** Measure the strength and direction of the magnetic field components (X, Y, Z axes).
- **Proton Precession Magnetometers:** Measure the frequency of protons precessing in a magnetic field.
  - When protons in a hydrogen-rich fluid are aligned with an external magnetic field and then perturbed, they precess at a frequency proportional to the magnetic field strength.
- **Optically Pumped Magnetometers:** Use alkali metal vapors (e.g., cesium or rubidium).
  - Employ optical pumping to align the spins of the electrons, which then precess in the magnetic field.
  - The precession frequency, detected via laser light absorption, is proportional to the magnetic field strength.

Working Principle of Magnetometers

- **Overhauser Effect:** Involves the transfer of polarization from electron spins to nuclear spins in a substance such as a liquid rich in free radicals (commonly a mixture of hydrogen and a free radical).
  - An RF (radio frequency) field is applied to the sample, causing the electron spins to become highly polarized.
  - The polarization is then transferred to the hydrogen nuclei (protons), significantly increasing their magnetic resonance signal.

Magnetometer in a marine infrastructure

ITINERIS

Marine Magnetic Field Variations:
- Track changes in the magnetic field caused by ocean currents, tidal forces, and seafloor composition.
- Contribute to magnetotelluric studies to assess the subsurface geological structure.

Environmental and Oceanographic Monitoring:
- Detect environmental changes such as temperature, salinity, and seafloor composition that impact the magnetic field.
- Monitor ocean circulation patterns and their effects on the marine environment.

Space Weather Effects:
- Study how solar wind and geomagnetic storms affect the magnetic field in the ocean.
- Provide insights into space weather's influence on marine systems.

Geophysical Baselines & Global Models:
- Establish long-term baseline data for magnetic field studies.
- Contribute to global geomagnetic models and detect deviations in the Earth's magnetic field.

Magnetometer data in a marine infrastructure

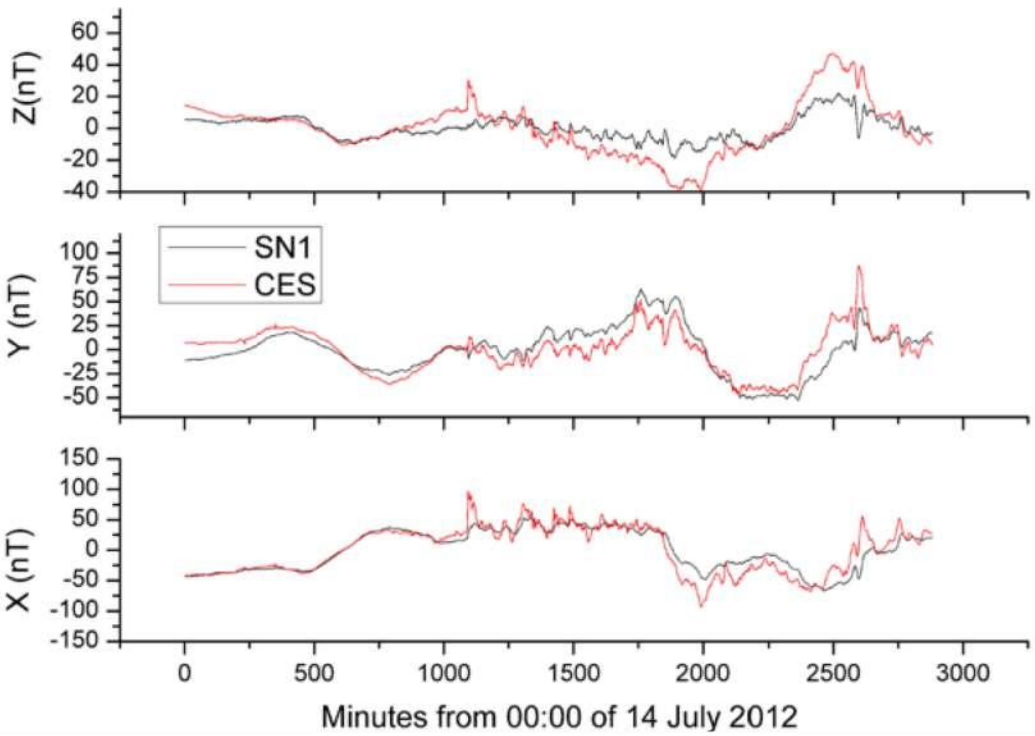
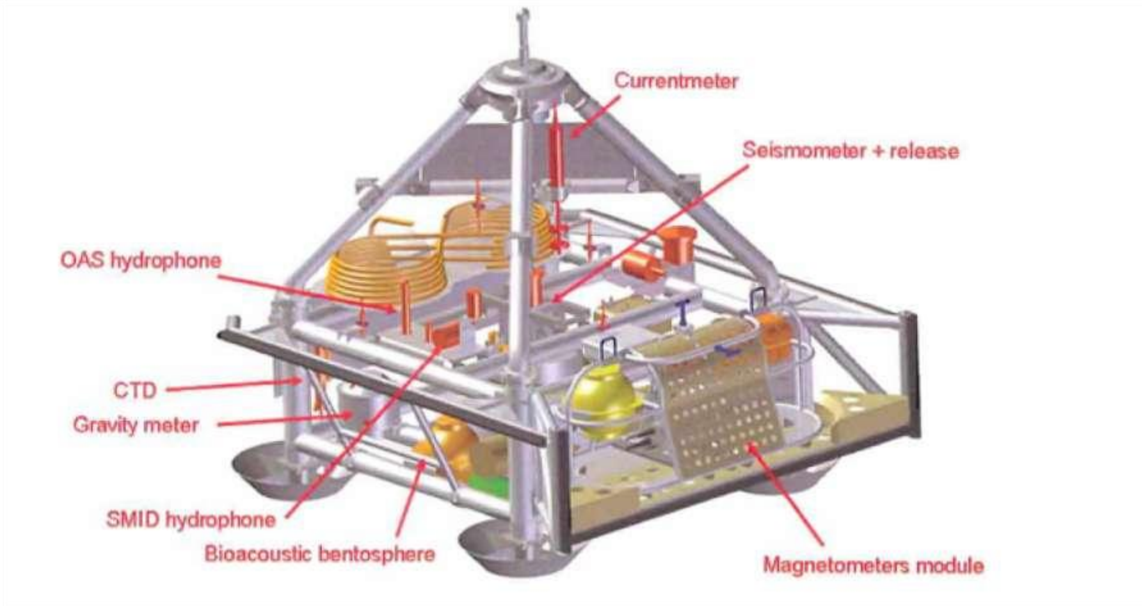


Figure 8. X,Y and Z magnetic components as recorded for the NEMO-SN1 seafloor observatory (SN1; black lines) and the Cesarò land magnetic station (CES; red lines).

Remote Sens. 2016, 8, 298; doi:10.3390/rs8040298

Magnetometer at seafloor platform



Magnetometers module must be put far away from observatory after deployment and during acquisition

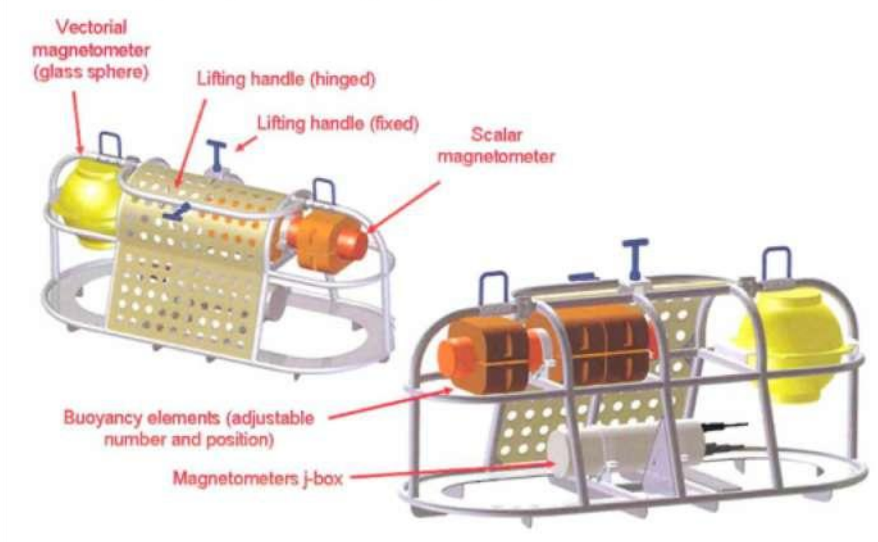


Figure 3-1: magnetometers module

Hydrophones

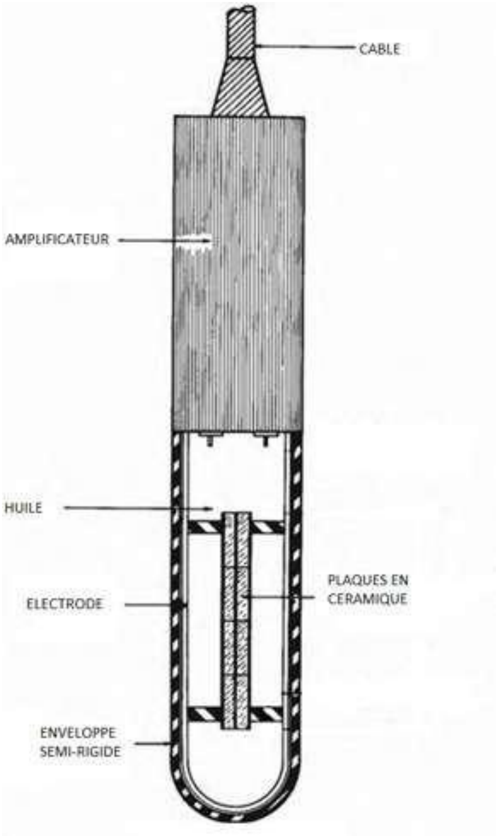
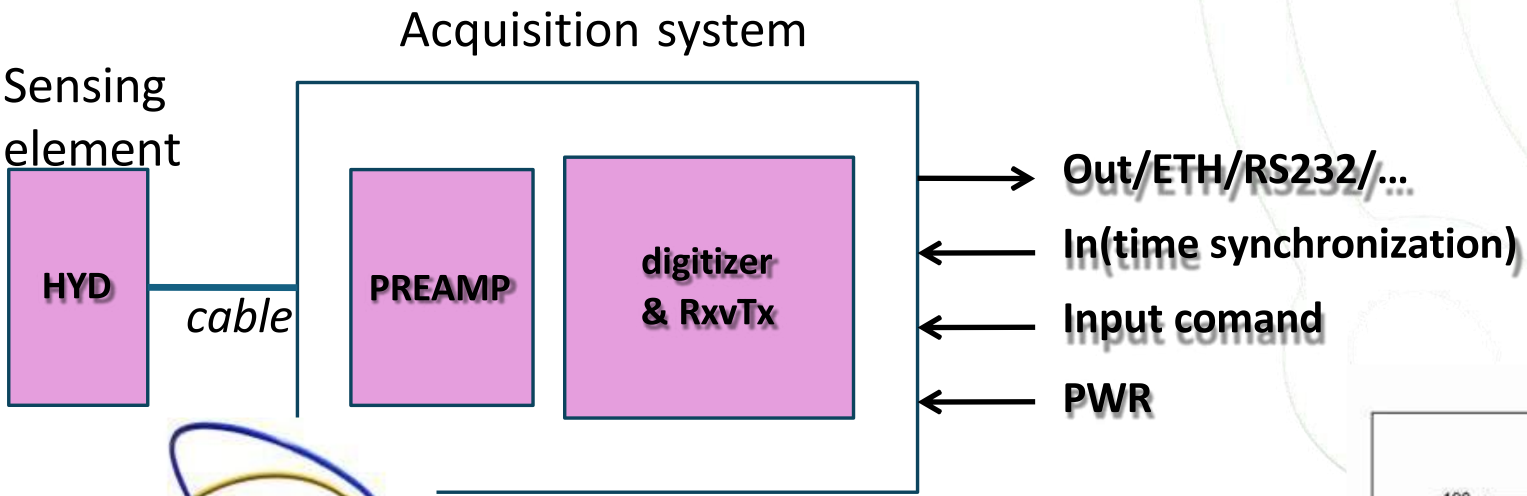


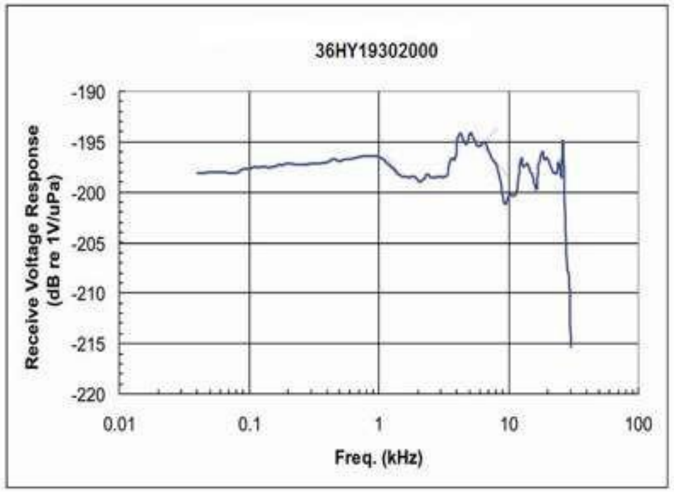
Figure source: wikicommons

- Hydrophones convert acoustic energy (sound waves) traveling in water into electrical signals.
- The piezoelectric element inside the hydrophone vibrates in response to the sound waves.
- These vibrations generate an electrical signal proportional to the sound wave.
- The signal is transmitted through a cable to a preamplifier and to a recording device.

Digital hydrophones



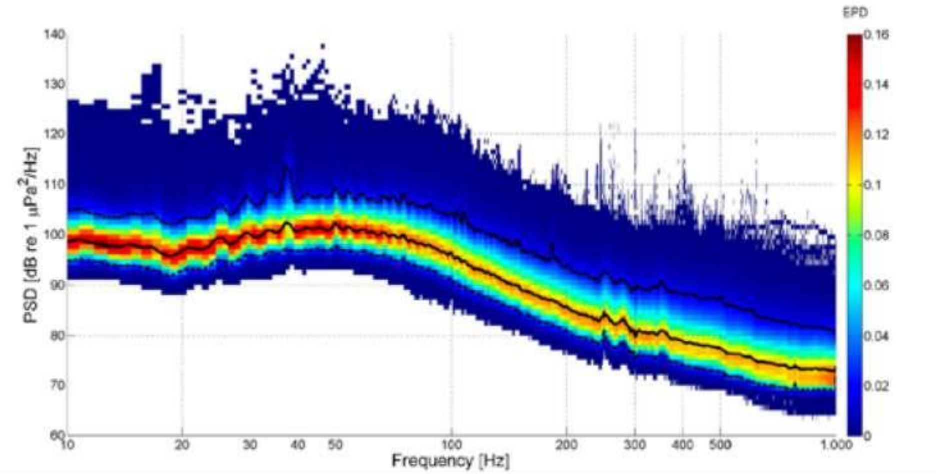
Frequency response band



Hydrophones application

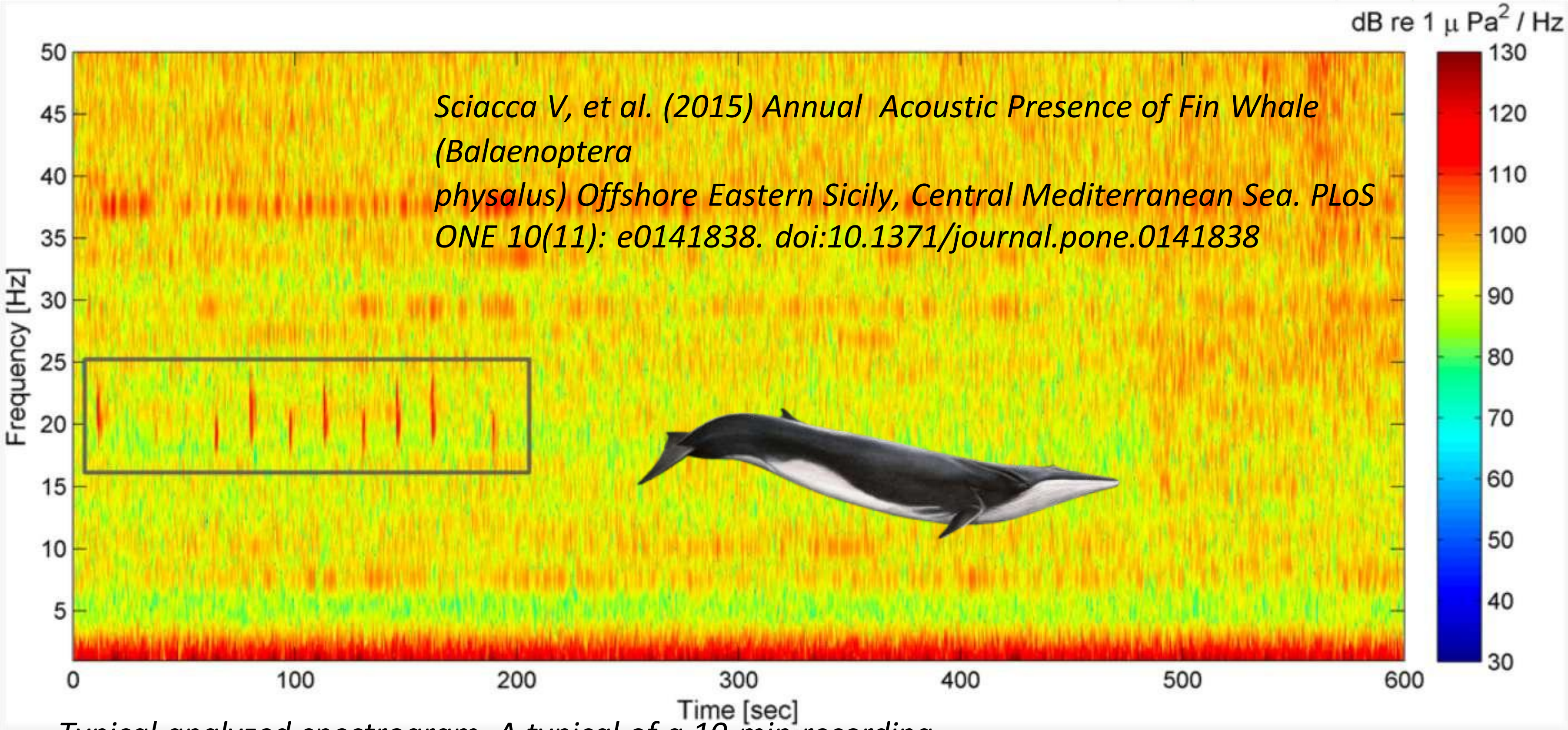
- Hydrophones have a wide range of applications in marine research and industry
- Marine Biology: Monitoring marine mammal vocalizations and fish behaviour.
- Oceanography: Studying underwater currents and turbulence.
- Seismology: Detecting underwater earthquakes and volcanic activity.
- Underwater (anthropic) noise monitoring.

Viola et al. Continuous monitoring of noise levels in the Gulf of Catania (Ionian Sea).
Study of correlation with ship traffic,
Marine Pollution Bulletin 121 (2017) 97–103
http://dx.doi.org/10.1016/j.marpolbul.2017.05.040



Hydrophones: mammals detection

Sciacca V, et al. (2015) Annual Acoustic Presence of Fin Whale (Balaenoptera physalus) Offshore Eastern Sicily, Central Mediterranean Sea. PLoS ONE 10(11): e0141838. doi:10.1371/journal.pone.0141838



Typical analyzed spectrogram. A typical of a 10-min recording, computed and analyzed by expert operators. A sequence of 20 Hz calls, here included for clarity in a grey box, has been visually identified in this file.

Time synchronization

- High accuracy time synchronisation is needed for
  - seismometers to contribute to localization of earthquake sources
  - hydrophones to track acoustic sources (mainly marine mammals)

- In a cabled infrastructure : NTP (Network Time Protocol) accuracy ~ 1ms using a GPS local receiver as NTP server

- Western Ionian Sea infrastructure implemented PTP (Precision Time Protocol) which may reach an accuracy of few microseconds :
  - data are timestamped at sea with microsecond precision (seismometers & hydrophones)
- Oceanographic sensors (low sampling rate) require less time precision: internal clock may be good

ITINERIS

THANKS!

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