isep Instituto Superior de Engenharia do Porto

Marine Robotics

Unmanned Autonomous Vehicles in Air Land and Sea
Politecnico Milano – June 2016

Alfredo Martins
INESC TEC / ISEP
Portugal
alfredo.martins@inesctec.pt

Who we are: INESC TEC

- **R&D non-profit research center and technology interface institution**

- Joins researchers from several schools
  - Porto University
  - Porto Polytechnic Institute
  - Minho University
  - UTAD

- 700 researchers, 350 PhDs

- **Robotics and Autonomous Systems**
  - **Aerial, land and marine robotics**
  - Reconfigurable systems
  - Distributed perception
  - Cooperative robotics
  - Long term autonomy

isep Instituto Superior de Engenharia do Porto

ROBOTICS group

Expertise areas

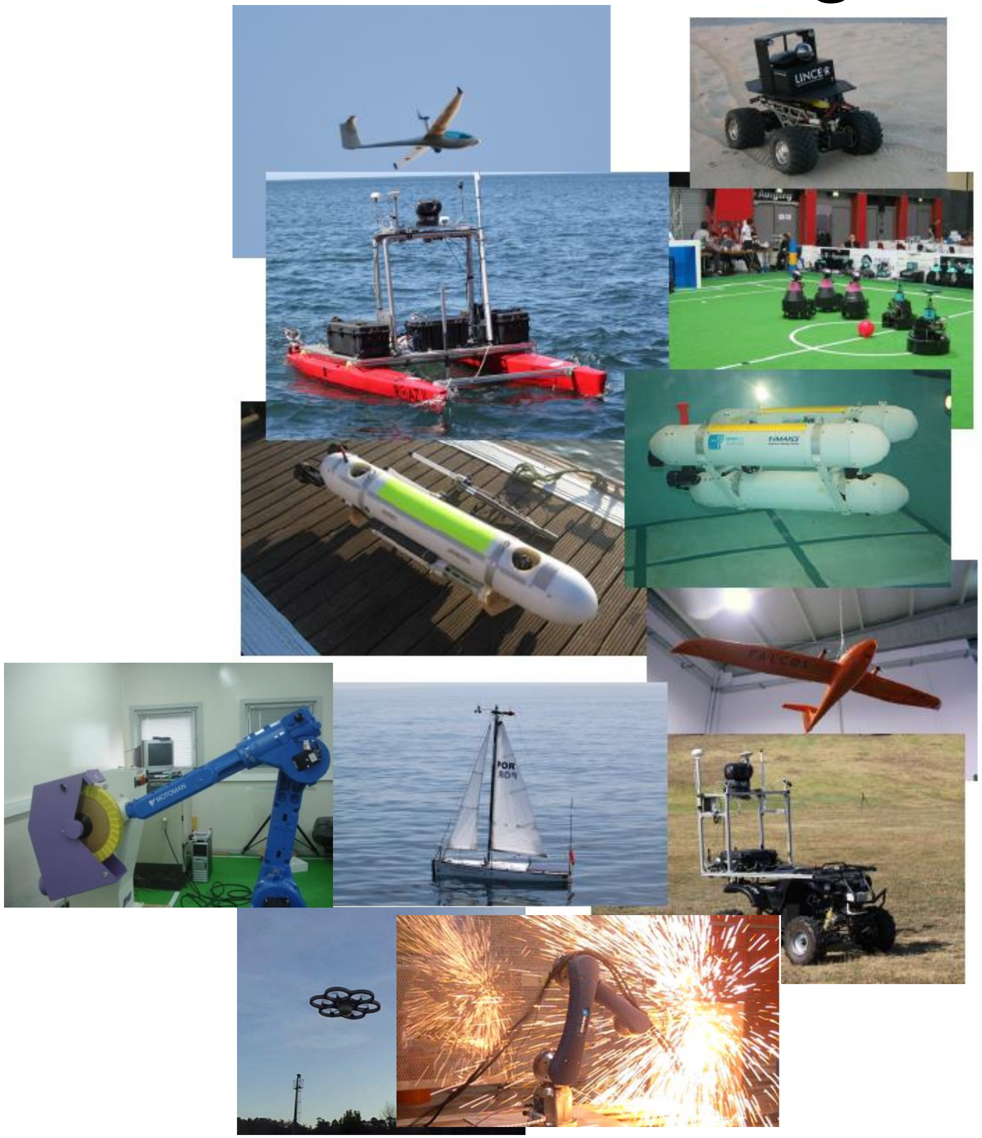
- Platform development
  - Aerial, land and water robotics
  - Industrial and services robotics
- Operations with autonomous robots
- Smart sensors and systems

Research lines

- Reconfigurable systems
- Distributed perception
- Cooperative robotics
- Long term autonomy
- Rapid teaching

Application areas

- Surveillance, security and defence
- Environmental monitoring and mapping
- Risk analysis
- Search and rescue
- Process automation



ISEP

- School of Engineering – Polytechnic of Porto
- Founded in 1852
- 6500 students
- 11 BSc and 11 MSc courses
- International acreditation and best practices

European Accreditation of Engineering Programmes EUR-ACE®

cdio CONCEIVE DESIGN IMPLEMENT OPERATE™

Electrical and computer engineering
Electrical engineering- power systems
Civil engineering
Geotechnical and environmental engineering
Informatics
Computing and medical instrumentation

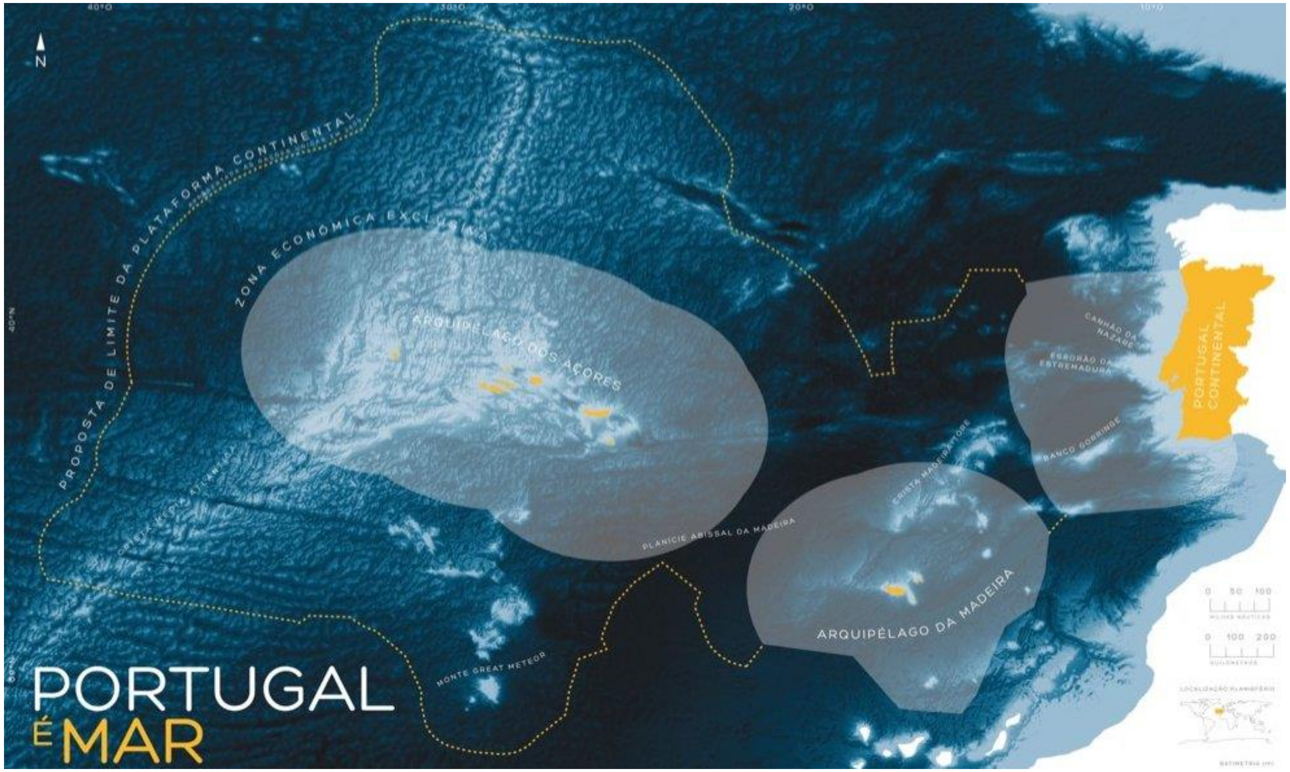
Instrumentation engineering and metrology
Mechanical engineering
Automotive engineering
Systems engineering
Sustainable energies

Autonomous Systems Lab

- Host MSc. Autonomous Systems Course (40 students)
- Support student integration in research activities
- Support undergraduate and MSc. Student laboratory work
- More than 1000 m^2 of lab space
- Water test tank (10m x 6m x 5m)
- Full size Robocup MSL field
- Vision based groundtruth vision systems
- Land , aerial and marine robot platforms

Why Marine Robotics

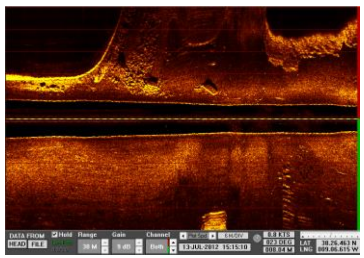
- Increase of economical and scientific interest in the sea
- Research in marine robotic systems
- Portugal interest on the sea economy and exploration of its natural resources



Coastal monitoring and surveillance

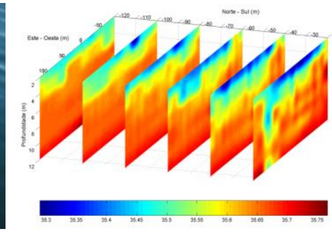
Autonomous bathymetry

- ROAZ ASV
- Bathymetry in the near shore zone
- Risk Assessment
- Precise navigation
- Underwater seabed characterization

Environmental monitoring

- MARES AUV
- Hovering capabilities
- Sewage outfall
- Water quality monitoring
- Plume tracking

Infrastructure inspection

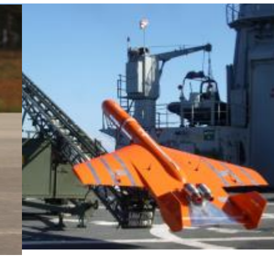
- TriMARES hybrid ROV/AUV
- Visual inspection
- Sonar profiling
- Brazil contracts (Lageado)


Acoustic monitoring

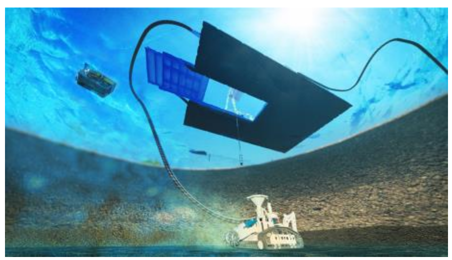
- FAST Autonomous Sailboat
- SLOCUM Glider
- Acoustic recording and processing
- Long term


ICARUS – Air, sea and land search and rescue
FP7
24 partners,
10 countries,
17.5M€

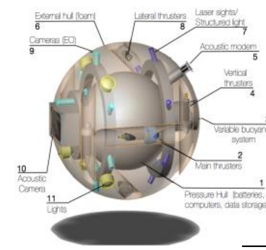
SUNNY- Unmanned Aerial Border patrol,
FP7,
18 partners
10 countries,
13M€

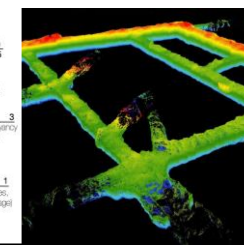


VAMOS – Underwater mining exploitation
H2020
17 partners,
9 countries,
12.4M€



UNEXMIN - Underwater exploration and mapping
H2020,
13 partners,
7 countries,
4.8 M€

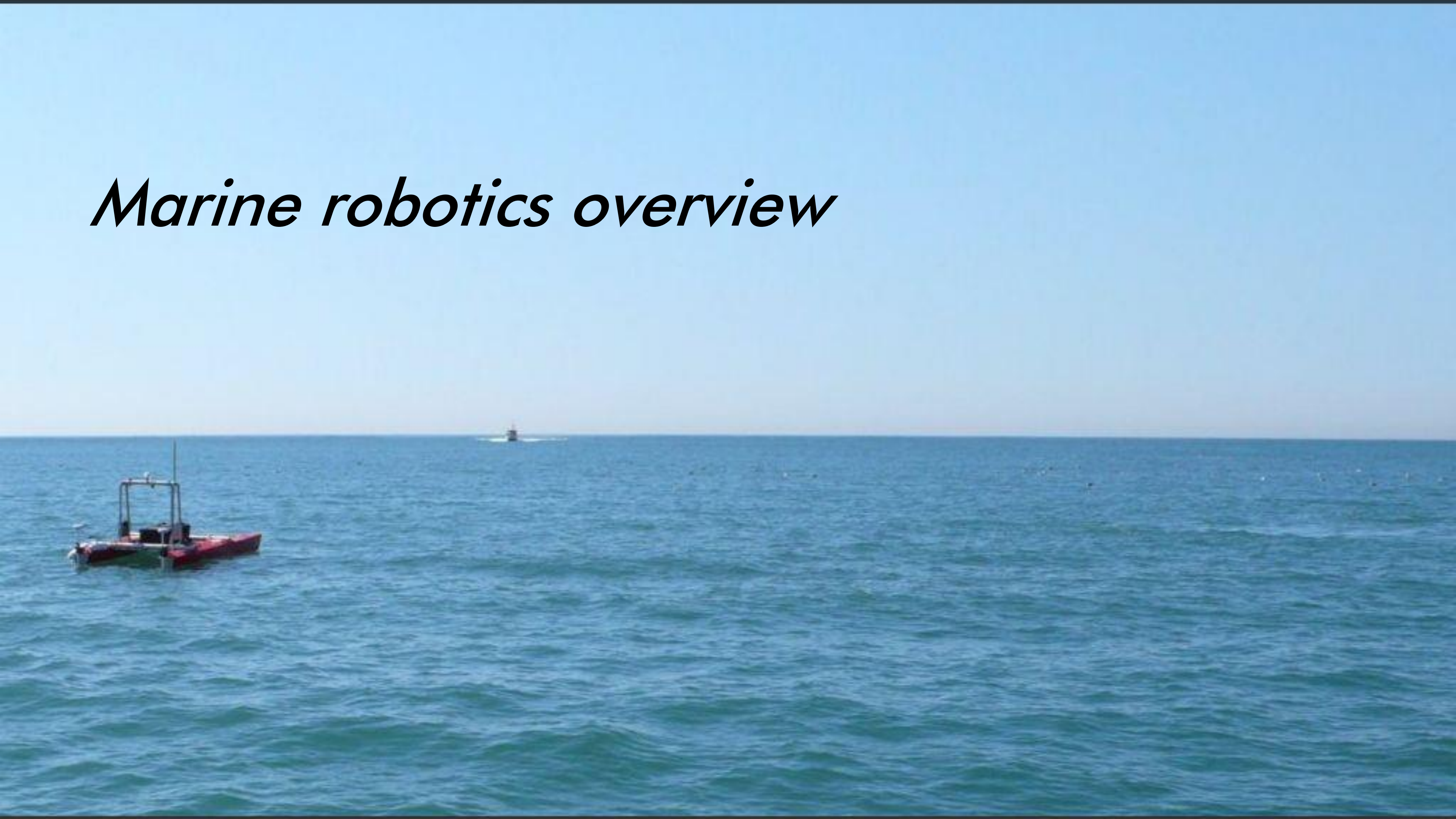




TURTLE – Robotic autonomous deep sea lander
QREN
4 partners
1.3M€

MARES – Hovering modular AUVs
National funds, International contracts
1 M€

Marine robotics overview

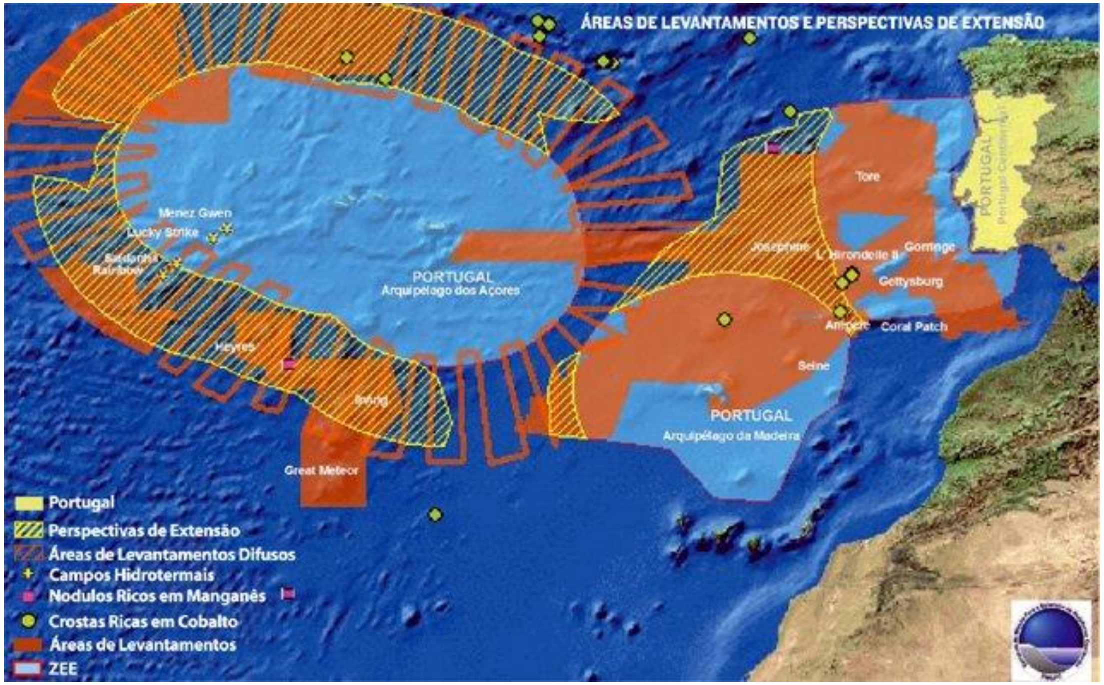


Marine and subsea robotics

- Most of the planet surface is covered with water
- The sea is the last unexplored frontier on earth
- Exploration of underwater resources
- Management of the aquatic environment requires detailed and accurate information
- Physical limitations to the man (little depth and permanence times in the underwater environment)
- Economic motivation, performance / cost

The sea relevance for Portugal

- Exclusive economic zone "immense“;
- Resources in Portuguese waters;
- Exploration, control and surveillance needs;



The sea relevance for Portugal

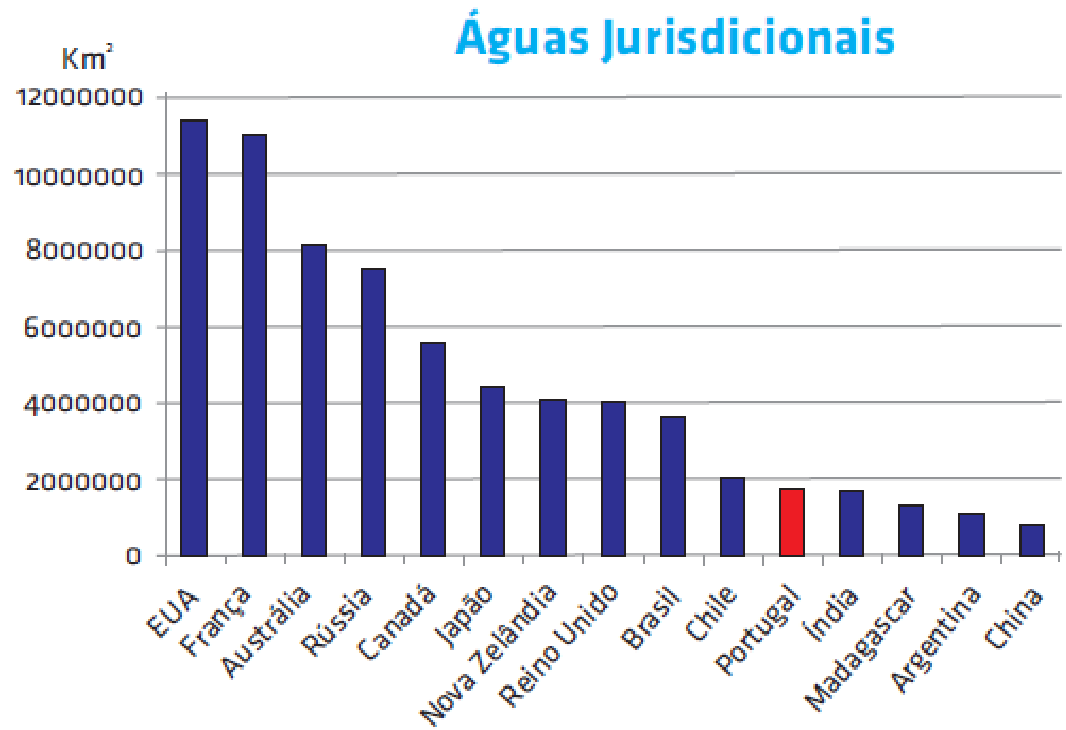
- Portugal has 11th place in the constitutional area in the sea (but 18x territorial area);
- Corresponding to 110th place in territorial area;

	Territory	Inland waters	Territorial sea	ZEE	SAR Areas
Continent	88.600	6.510	16.476	287.715	572.438
Madeira	833	825	10.823	442.316	
Azores	2.331	6.083	23.660	926.149	5.220.302
Total	91.763	13.419	50.960	1.656.181	5.792.740

[in "Portugal, a maritime nation" Portuguese Navy]

The sea relevance for Portugal

- 11% GDP;
- 12% Employment;

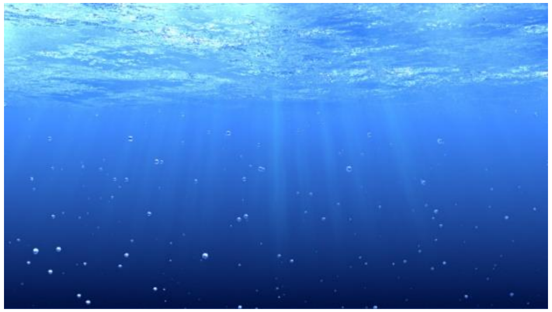


Resources

- Fisheries;
- Minerals on the seabed (metallic nodules);
- Huge biodiversity (eg near hydrothermal vents);
- Tourism and nautical activities;
- Port activity and maritime traffic.

Underwater environment

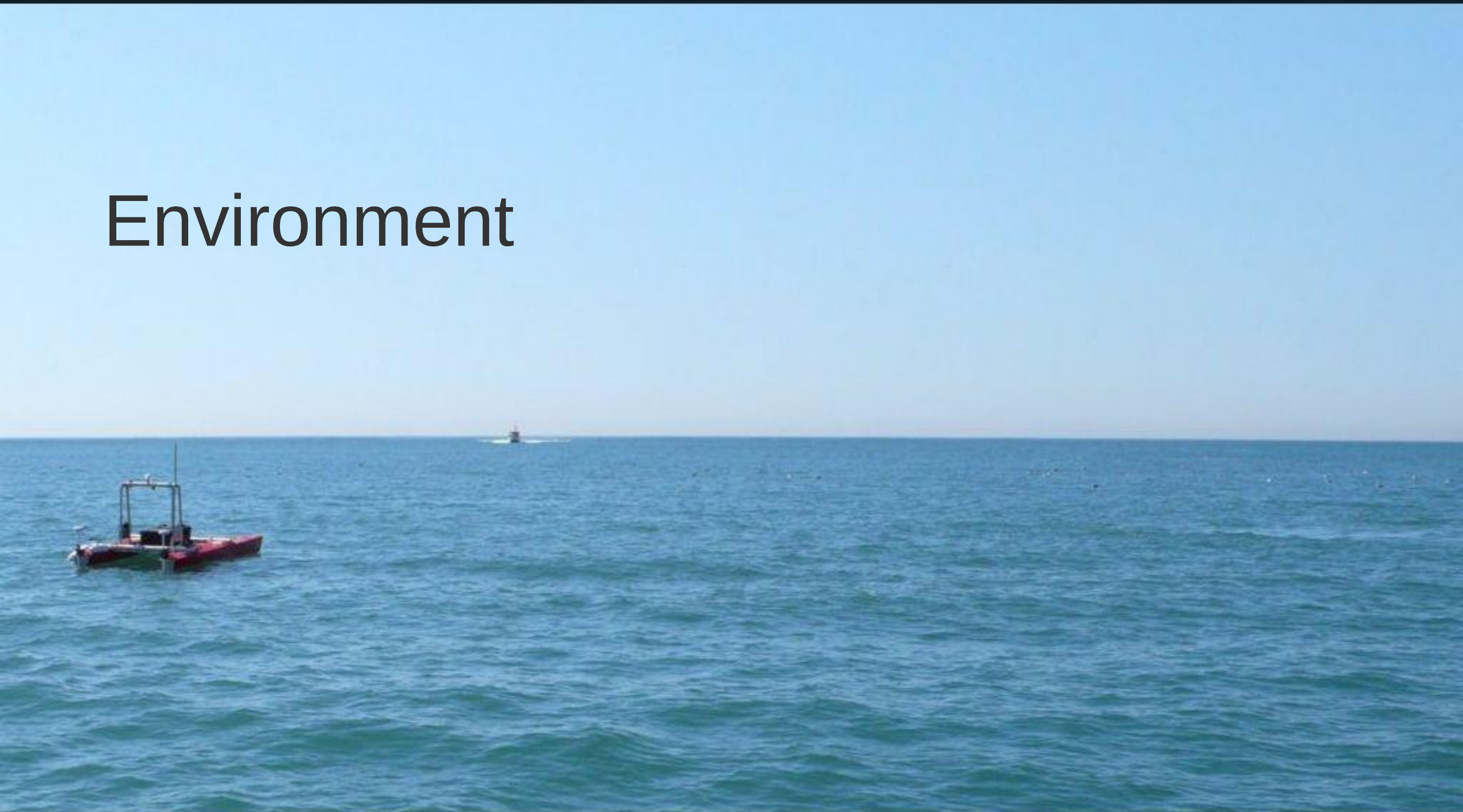
- Diverse means, from river basins to abyssal plains in the ocean
- High pressure (10m water correspond to 1 atmosphere)
- No radio communications
- Environment often little known;
- Adverse environmental conditions (currents, waves, meteorological);
- Vast areas to explore or observe in geographically dispersed and difficult to access points.



Portuguese Sea

- Atlantic Ocean;
- Great extent with difficult or costly access areas
- Continental shelf along the continent with depth up to 150 m
- Climate range and general weather conditions (from Algarve coast to extremes in the center of the Atlantic);
- Abyssal depths and large bathymetric slope areas (eg Azores).

Environment

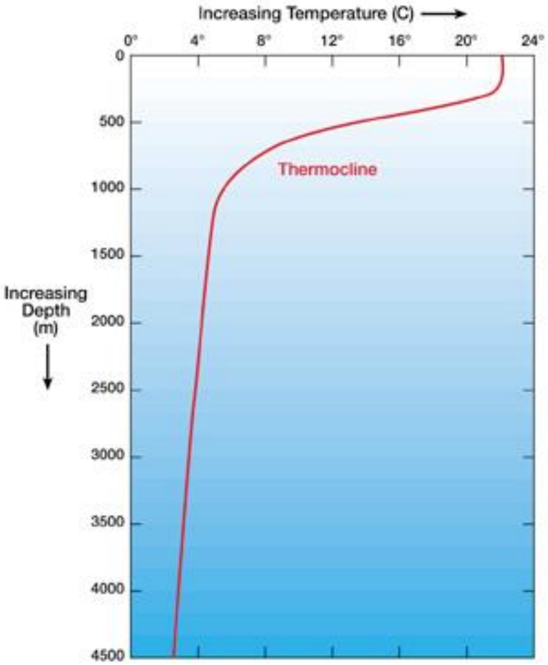


Surface

- Watersheds
  - low waves;
  - Wind relevant for surface robots
  - Variable current (from no current in reservoirs to water courses with strong current).
- Coastal zone
  - Tides;
  - Surf
  - Structures, fishing nets etc.
- High seas
  - Less easy to access
  - weather conditions sometimes very adverse (tides, wind);
  - large distances and high operation cost.

Underwater

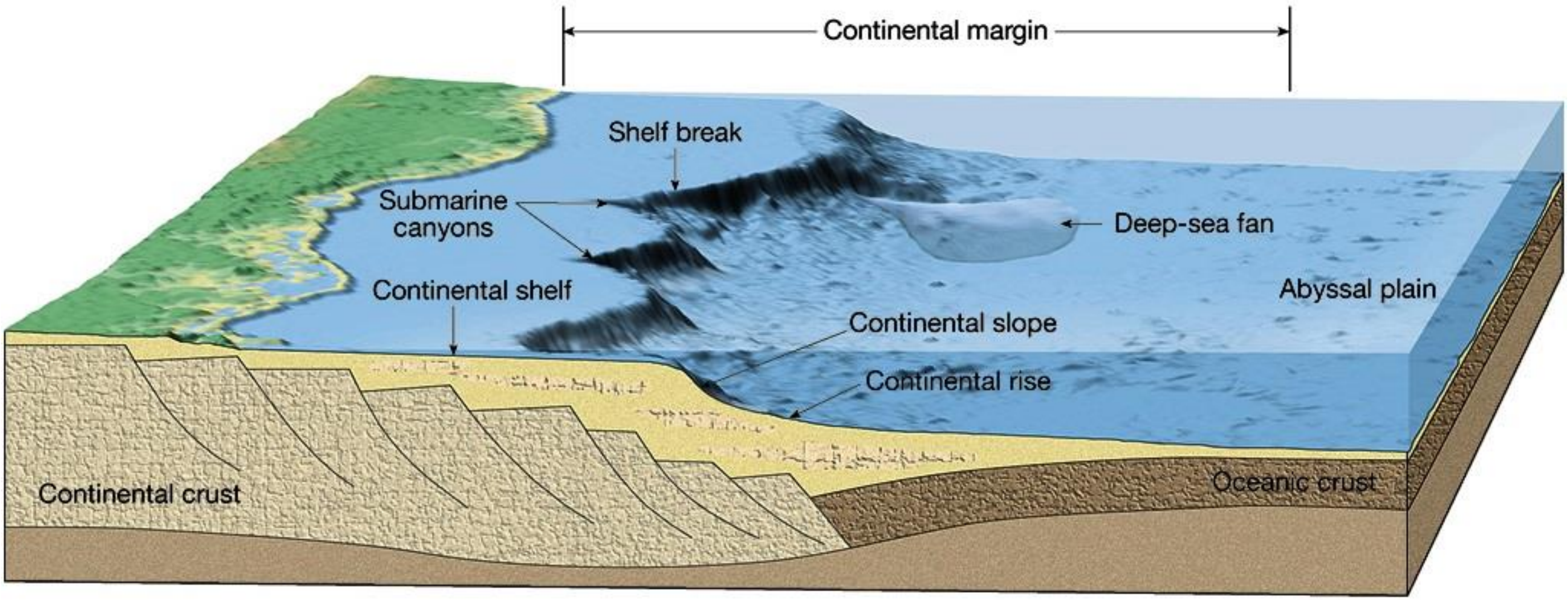
- Pressure;
- Wave effect decreases exponentially with depth;
- Different conditions depending on water environment or ocean (salinity, current);
- Reduced visibility (normally);
- Acoustic propagation dependent on temperature and salinity variations;
- Existence of sometimes sharp boundaries between the water masses with different characteristics (isoclines, isohalines)
- At high water depths there is compression of the water !!!



Special Environments

- Nuclear reactors
  - Radiation
  - Difficult human access
  - High temperature
- Tanks and reservoirs
  - Pollution severe restrictions (eg. water supply)
  - May contain contaminated water
- Plumbing and pipes
  - High currents;
  - Pressure;
  - Flammability constraints (eg sewage);
  - Great flow variability.

Ocean profile

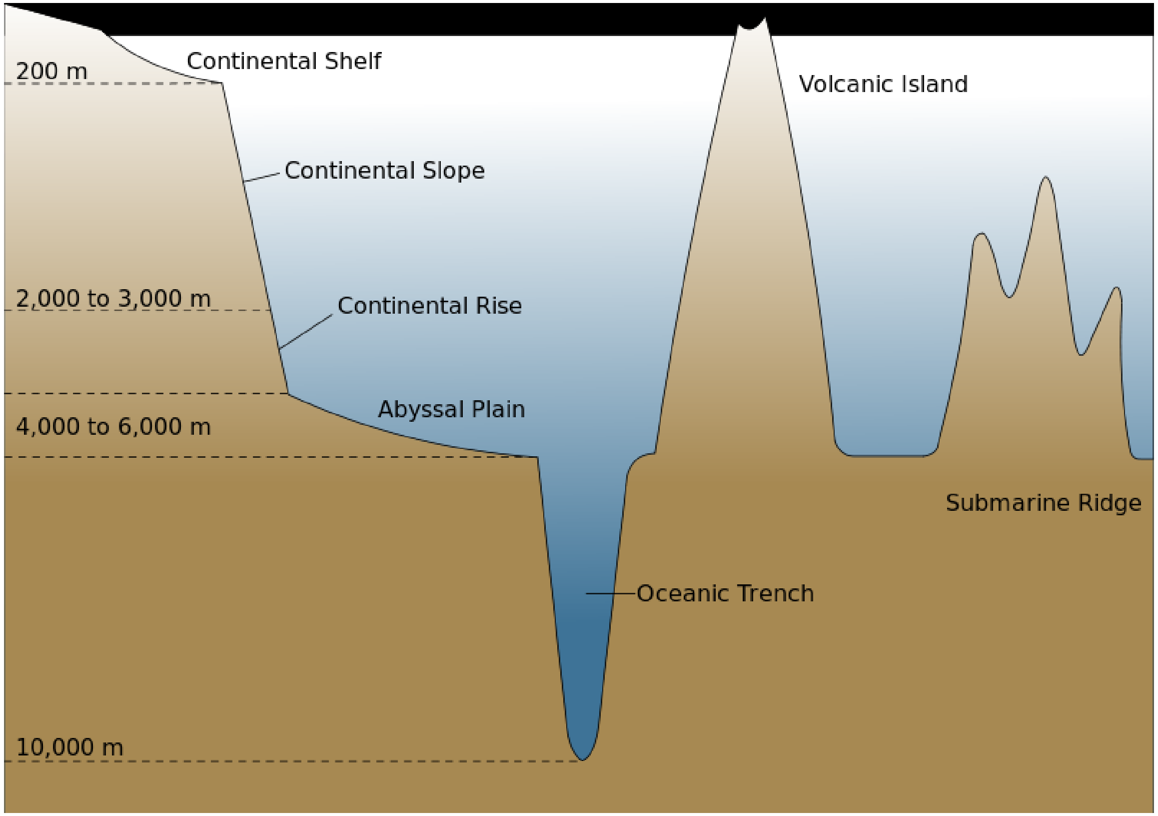


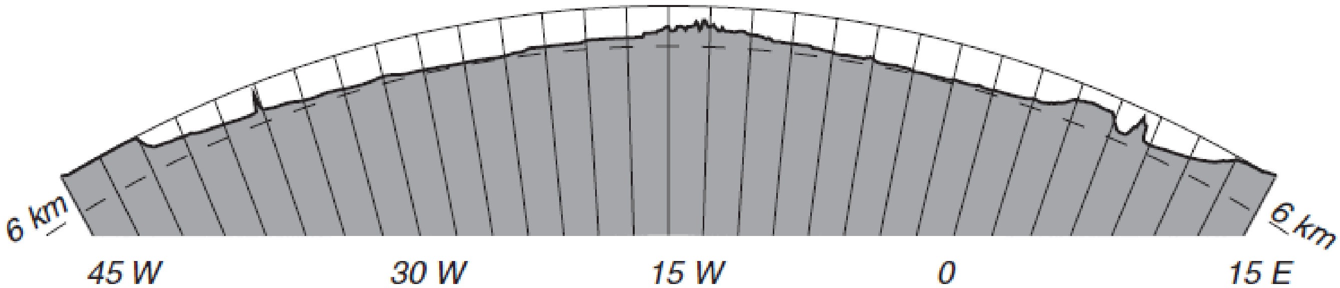
Sea State

- Sea condition classification;
- Also commonly used a scale for the wind (Beaufort Scale);

Sea state	Wave height	Sea Type
0	0	Calm (glassy)
1	0 – 0.1	Calm (rippled)
2	0.1 – 0.5	Smooth
3	0.5 – 1.25	Slight
4	1.25 – 2.5	Moderate
5	2.5 – 4	Rough
6	4 – 6	Very rough
7	6 – 9	High
8	9 – 14	Very high
9	Over 14	Phenomenal

Ocean profile



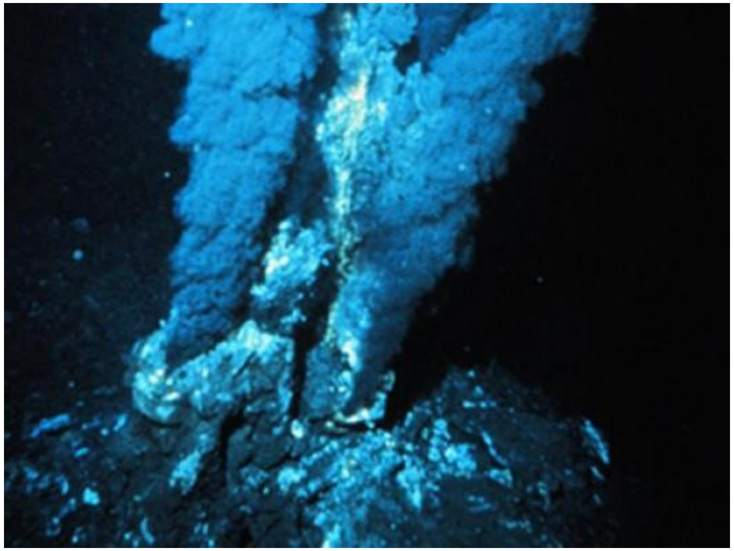


Abyssal plain

- Vast areas on the seabed, high depth (between 4000 and 6000 m);
- No light;
- low temperature;
- Low bio-diversity;
- With mining and petroleum resources;
- Underexplored.

Hydrothermal sources

- In areas of active volcanism (along the fault lines or boundaries of tectonic plates)
- Very different environment
  - High temperature;
  - Presence of toxic chemicals;
  - Extremophile organisms.



Ex: Banco D. João de Castro Azores

Continental shelf

- Underwater extension of the continental shelf;
- From shallow depth to about 150 m;
- Relatively flat area with steep slopes on the outskirts to the abyssal plain;
- Higher economic interest area of the sea.

Coastal zone

- Low depth (up to a few tens of meters);
- Wave swell effect;
- Intertidal area (between tides and up to 5, 6 meters) of difficult operation;
- Economic and social importance;
- Strong human intervention (structures, navigation, fisheries, maritime traffic).

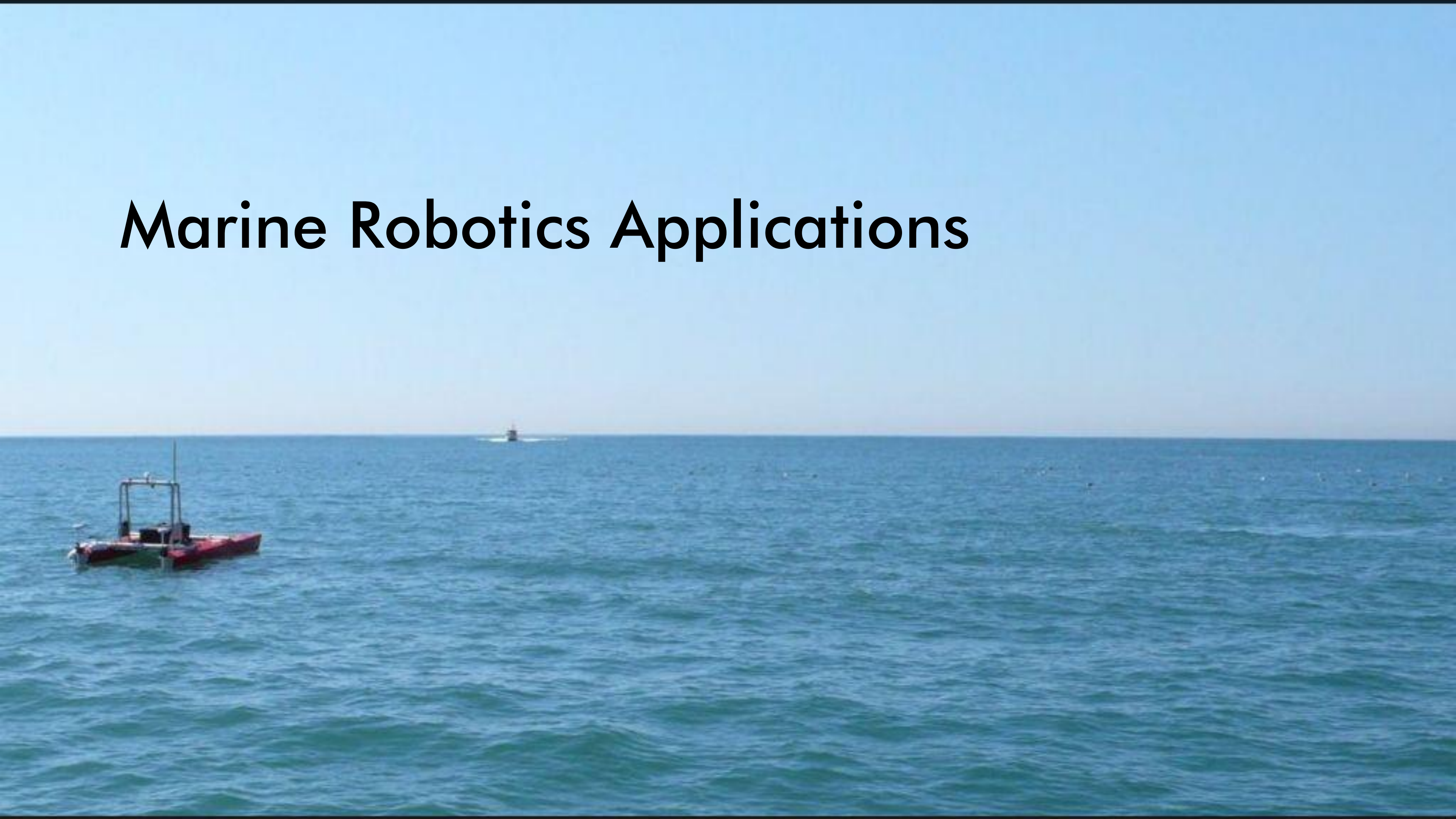
Rivers and estuaries

- Shallowness;
- Variable current (short streams with high currents, estuarine areas with reduced current and dominated by the tide);
- Reduced visibility (sediment at the bottom);
- Irregular topography;
- Limited areas;

Reservoirs

- Little current (except for unloading areas);
- Depths up to 150 m;
- Limited extent;
- Structures of interest (dam, bridges, water harvesting etc.);
- Debris in the bottom;

Marine Robotics Applications



Oil extraction

- With offshore wells from 50 m (North Sea) to a depth of 2400 m;
- Positioning drilling structures, manifolds, pipelines and the sea bottom;
- Risers and anchor cables inspection;
- Survey prospecting;
  - geological characterization;
  - Bottom Morphology;
  - Evaluation of pre-salt deposits.

Current methods

- ROVs (usually large) operated from specialized support vessels;
- Local acoustic positioning systems;
- Visual inspection by the operator - specialized drivers;

Mining in the deep ocean

- Still in early stage of commercial exploitation;
- metallic nodules collection on the seabed and the surface layer of sediment;
- Great depths (abyssal plain and along the volcanic areas);
- geological background characterization;
- ore identification and detection;
- Extraction and processing.

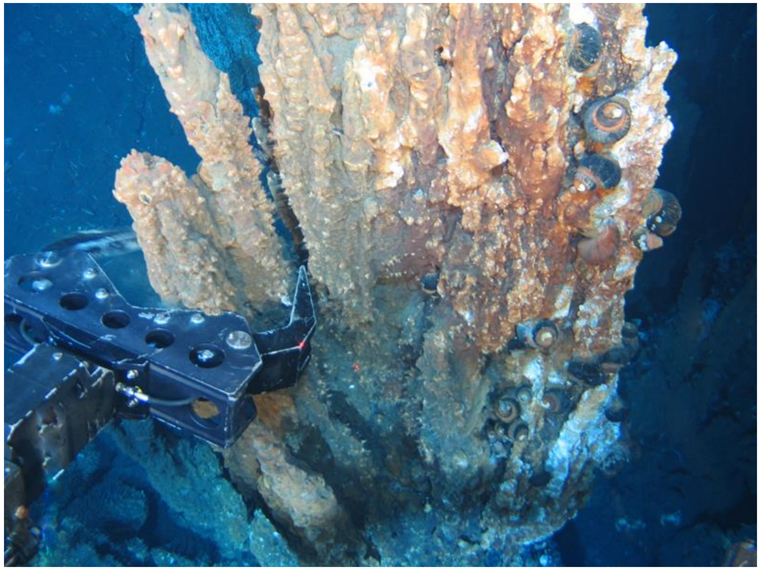
Current methods

- Surveys previous geological by traditional means;
- oceanographic ship with;
- Dedicated sensors as magnetometers;
- Inspection with ROV;
- heavy machinery at the bottom;
- Aspiration of sediment and processing on the surface;
- Strong environmental impact;
- High energy consumption.

220t Rock Trencher (SMD)

Mining

- Need for environmental preservation;
- Water column;
- Biodiversity in place;
- Drilling for economic viability identification;
- Mineral extraction methods;
- New frontiers for mining.



Mineral deposits [in www.nautilusminerals.com]

Nautilus mining machines [smd.co.uk]

Submarine cable instalation

- Large tracts (thousand km);
- Deposited on the bottom, buried or fixed;
- Depths variable (from the continental shelf to the abyssal plains and submarine canyons).

Support Ship [Global Marine Systems]

Current methods

- Specialized ships;
- Digging deep vehicles (crawlers, trenchers);
- High depth Workclass ROVs.

“Arado” submarine [in: smd.co.uk]

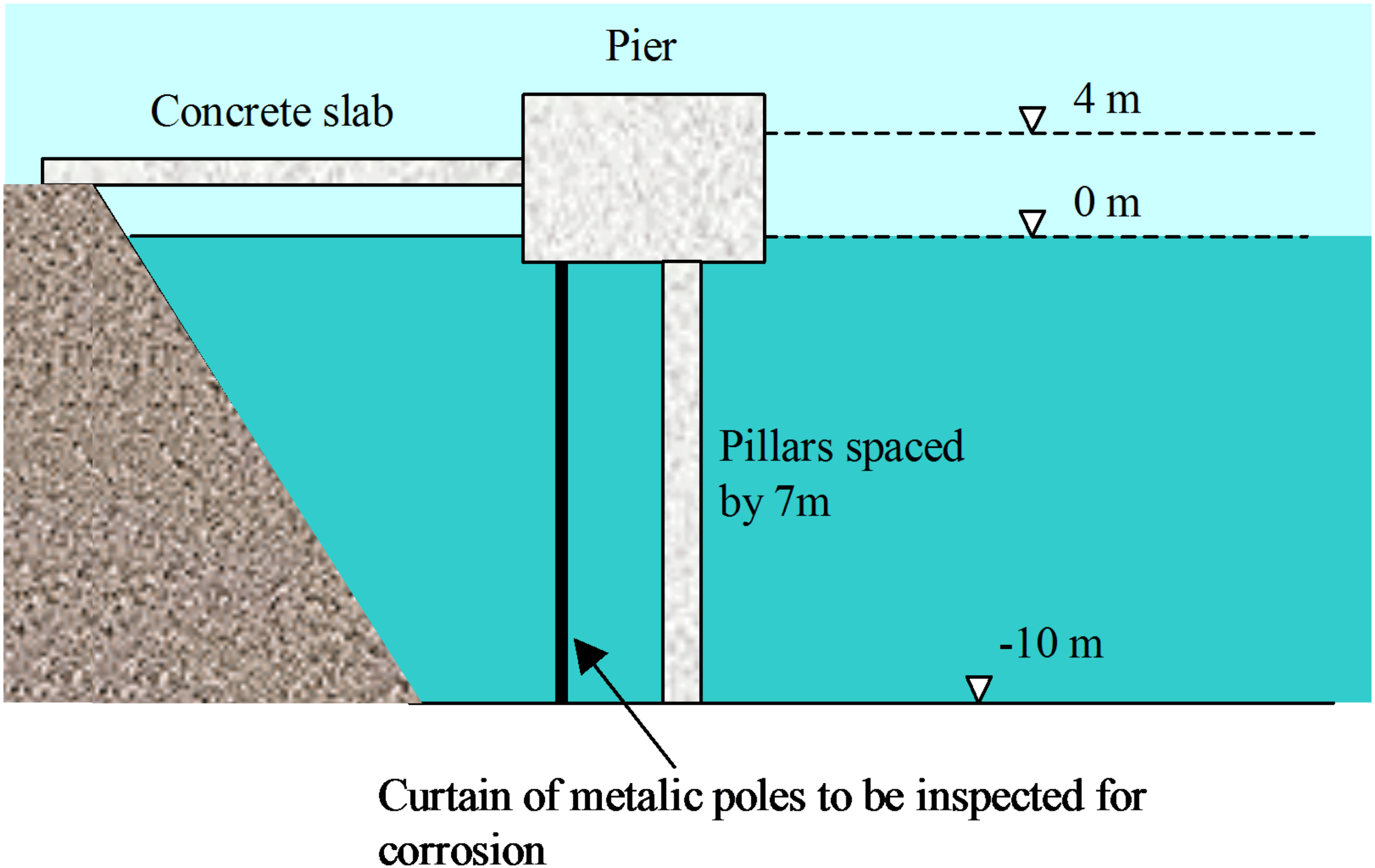
Port Security

- Low depths (less than 20 m);
- Intrusion detection;
- Contraband detection;
- Detection of mines and explosive devices;
- Identification, verification and monitoring of maritime traffic;
- Acoustic monitoring

Current methods

- Surface patrol with conventional means;
- Air Patrol in particular cases;
- Underwater inspection with divers / inspection ROV only when available.

Port structure inspection



Port structures inspection

- Structures;
  - Pier (walls and / or slabs);
  - Support pillars;
  - Sheet pile curtains;
  - Tetrapods and breakwater structures abroad;
- Corrosion in structures, structural failures;
- Growth and establishment of marine life;
- Visual inspection;
- Poor visibility;
- Positioning requirements;

- Divers;
- ROV inspection.

APDL photos

Ship hull Inspection

- Periodic inspections;
- Hull, rudders and propellers;
- Evaluation of growth and marine growth;
- Corrosion;
- High costs in case of dry dock;
- Variability in the hulls and areas concerned;
- Format, size, time window available etc.;
- Cleaning and maintenance.

Current methods

- Divers;
- ROV inspection;
- Drydock.

Bridges and dams

- Silting evaluation;
- Structural state of the pillars;
- Dam walls;
- Water catchments;
- High currents;
- Debris assessment at the bottom or near structures.

Current methods

- ROV inspection;
- Divers;
- When possible evaluation during periods of reduced flow or low water level.

Bathymetry

- Large scale;
  - Big ocean areas;
- Sediment Rating amounts
  - Dredging verification;
  - Morphological models of coastal zone;
  - Silting of rivers, bars, estuaries and harbors.
- Temporal and spatial characterization;
- Recurring update needs;
- High positioning accuracy for specific applications.

Current methods

- Small boats and hydrographic ships;
- Acoustic means: single beam sonar and multi-beam;
- Side scan sonar complementarity;
- Subottom profilers to evaluate sediment.

Oceanographic data collection

- Water flow Characterization
  - CTD, salinity, pressure, temperature;
  - Dissolved oxygen;
  - Ph;
  - Turbidity;
  - Chemical elements.
- Sea currents
- Study of marine geology
  - Seismology;
  - Volcanism and hydrothermal vents;
  - geological environment characterization.
- Temporal and spatial characterization;
- Vast areas of the ocean;
- Long periods of time.

Marine biology studies

- Tracking cetaceans and marine animals;
- Long-term studies;
- High areas of study;
- Identification of species;
- Ecosystem characterization;
- Great variability of the environment (from the sea surface to the abyssal depths);
- Variability in life study (from single-celled organisms, plankton to large cetaceans).

Current methods

- Tags ID for large animals;
  - GPS;
  - Iridium, ARGOS.
- Water samplers;
- Diverse means (oceanographic ships, small boats, ships opportunity)
- Study campaigns;
- Characterization and acoustic tracking.

Search and Rescue

- Large areas
- adverse weather conditions
- Most of the deaths occurs in the sea near the coast in the surf zone
- Need for very short response times

Current methods

- Aerial operations with human detection;
- Lifesavers and light means (boards, buoys, jetski);
- Naval means (boats, ships) to search;
- Ferries and lifejackets for closed seas;
- Operating difficulties at night.

Marine pollution management

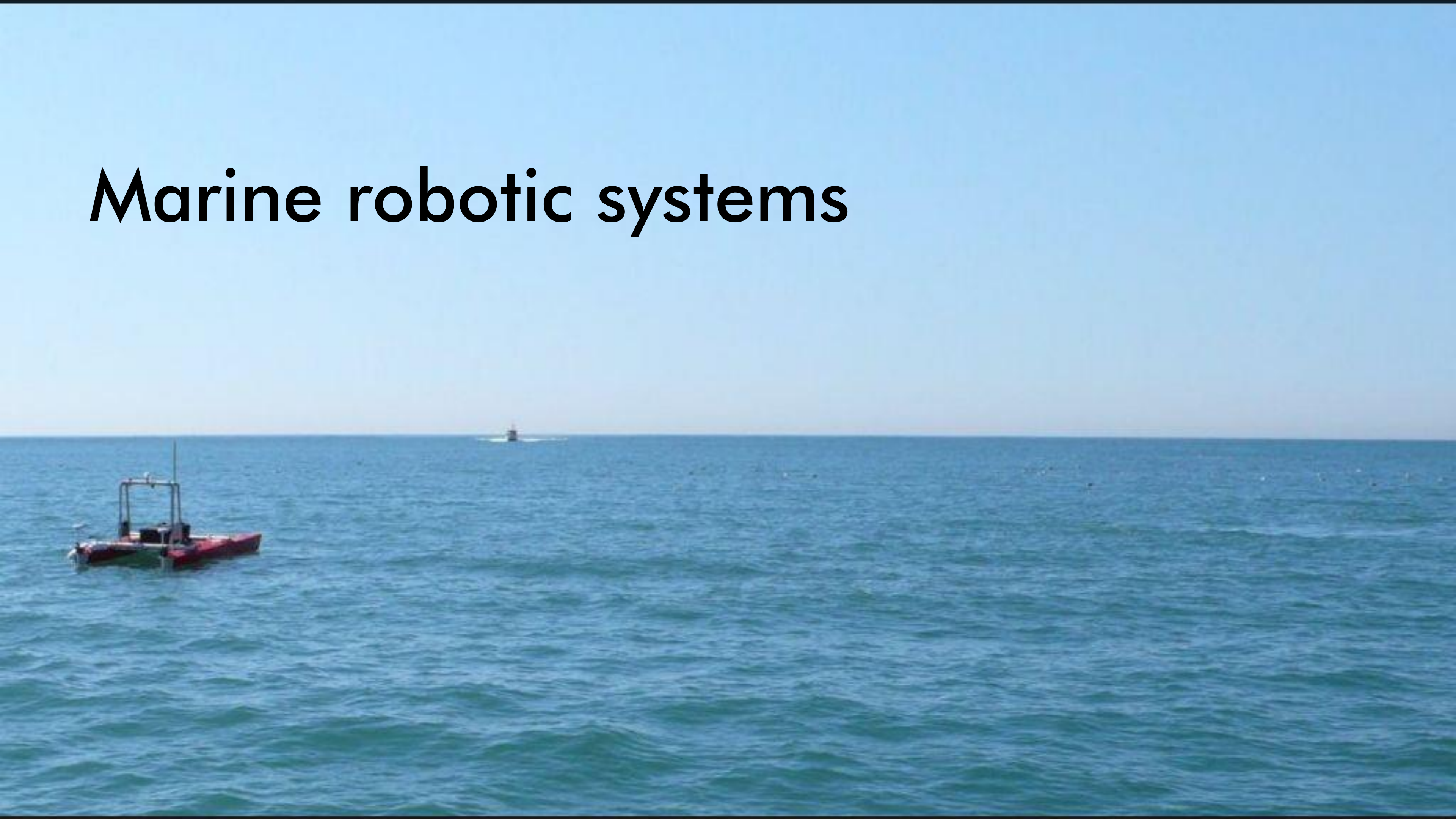
- Oil spills
- Effluent plume effects (along the coast)
- Circumscription, and location
- Containment, cleaning and collection
- Characterization of long term effects of pollutants (eg effluent)

Current methods

- Ships and boats manned
- Little use of robots in oil spills
- AUV in the characterization of feathers (effluent).

Instituto Superior de Engenharia do Porto

Marine robotic systems



Marine Robotics

- Large covered areas by automatic devices;
- Cost / performance;
- Reduce security risks;
- Robots can operate in environments where human presence is virtually impossible (eg abyssal plains or nuclear reactors).

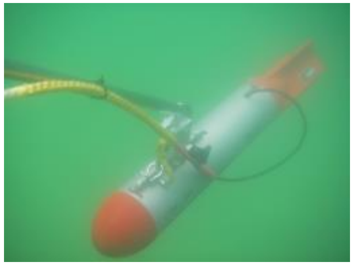
Systems

- **ASV Autonomous surface vehicles**;

- ROV (Remotely Operated Vehicles);

- **AUV (Autonomous Underwater Vehicles);**

- Towfish



- Fixed systems (measuring stations, oceanographic buoys, acoustic navigation nets, etc.)

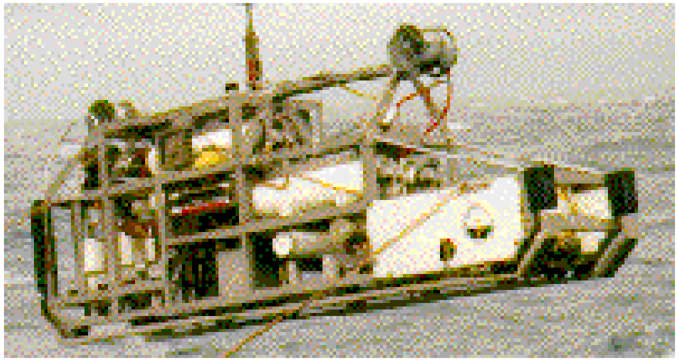
Operation Systems Support

- Research vessels and / or support;
- Oil rigs;
- Support means on fixed structures;
- Boats or small boats.

Trailing vehicles (towfish)

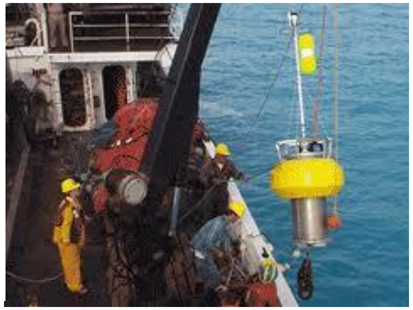
- Vehicles dragged by boats;
- They have little or no control board;
- They are "boxes" transmission dedicated sensors;
- May or may not have electrical connection to the boat propeller;
- Different types of sensors (sonar side scan, magnetometers etc.).





Fixed Systems

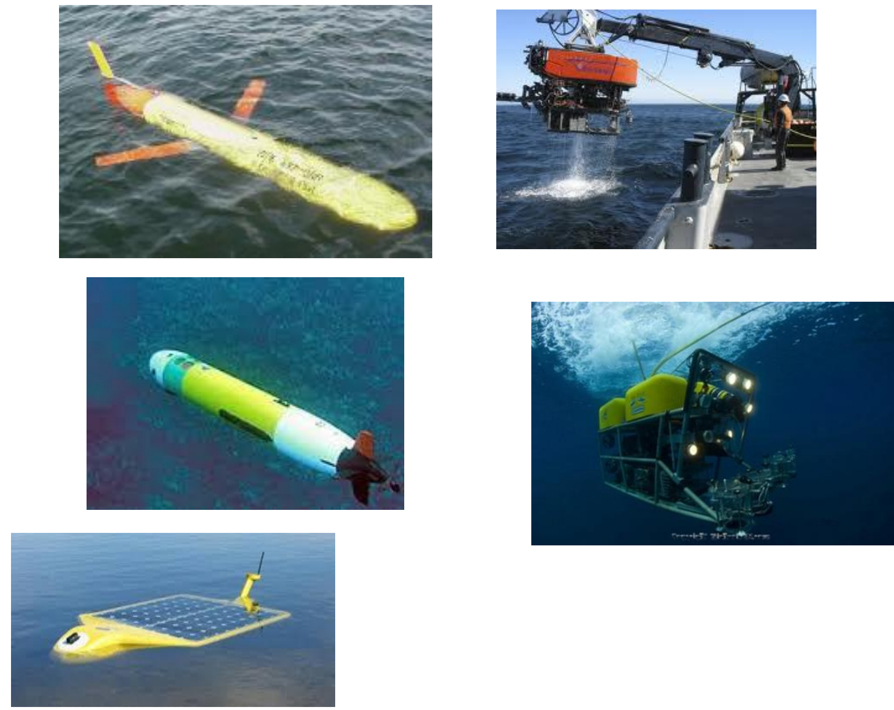
- Wide range of systems (from simple sensors to dock stations for AUV)
- Fixed at the bottom, next to structures or buoys Common solution for measuring oceanographic data;
- With radio communication or local data storage
- Fixed or mobile positioning (Drifters).



Autonomous marine vehicles

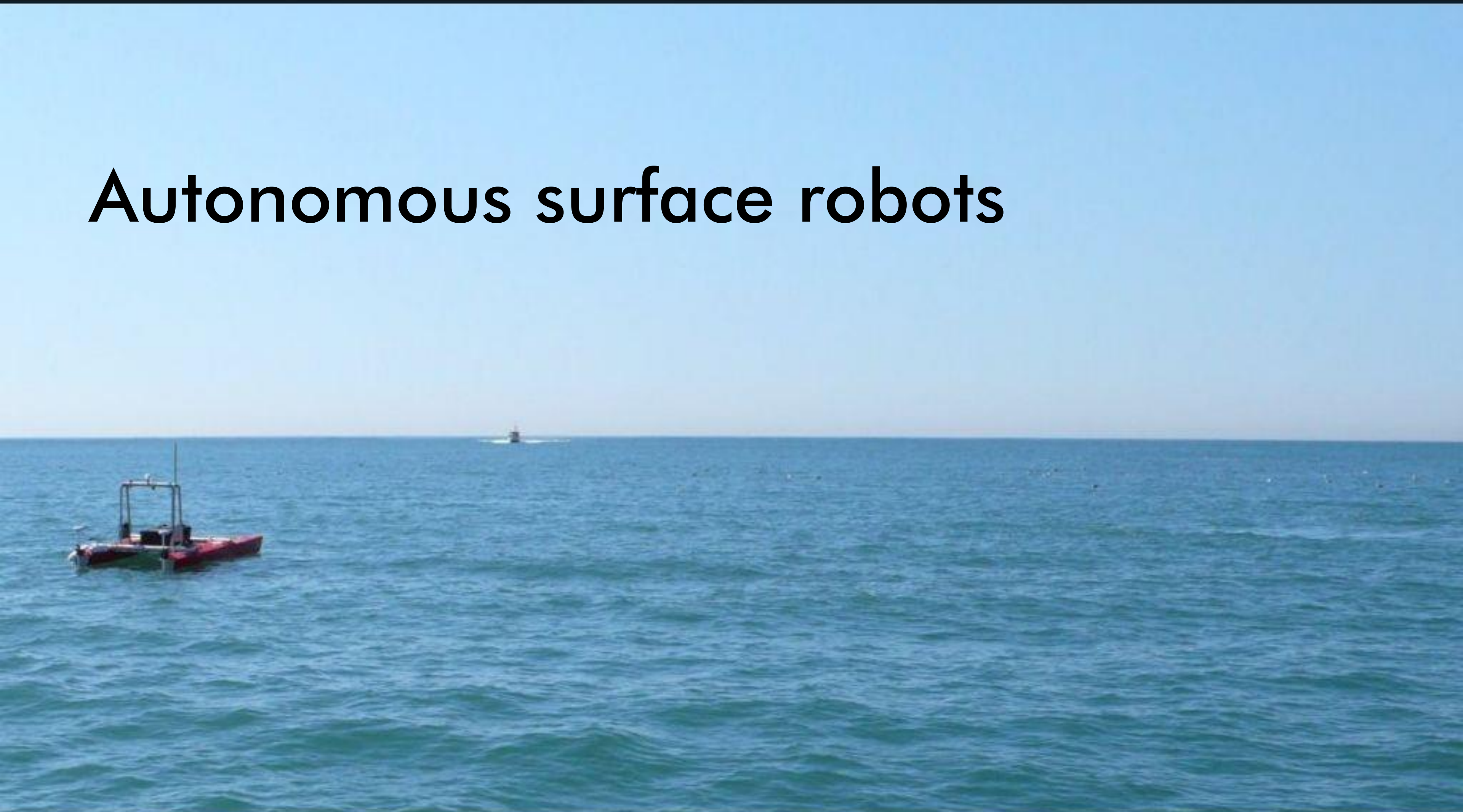
Surface

Underwater



Instituto Superior de Engenharia do Porto

Autonomous surface robots



Surface robots

- Military applications
  - Surveilance
  - Patrol
  - Intervention

- Civilian applications
  - Science data gathering
  - Monitoring
  - Bathymetry
  - Long term permanence
  - Monitoring

Surface robots

- Propulsion
  - Propeller;
  - Hydrojet (propeller);
  - Flippers (very inefficient);
  - Engines combustion or electric.

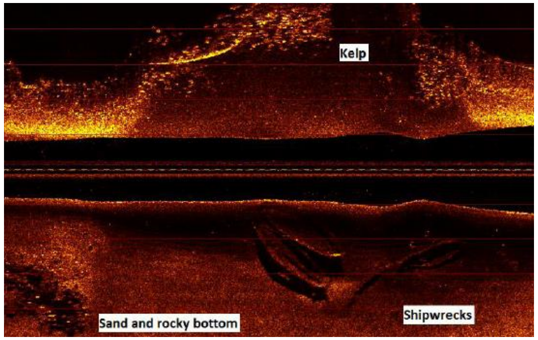
- Direction
  - Control Surface (rudder);
  - Differential Propulsion;
  - Vectorized thrust.

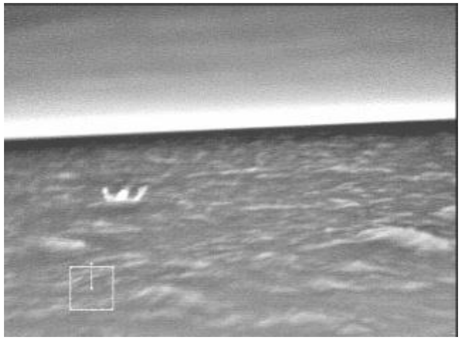
- Usual traditional boats settings (monohull or catamaran);

- Special cases (SWATH, hovercraft).

ROAZ

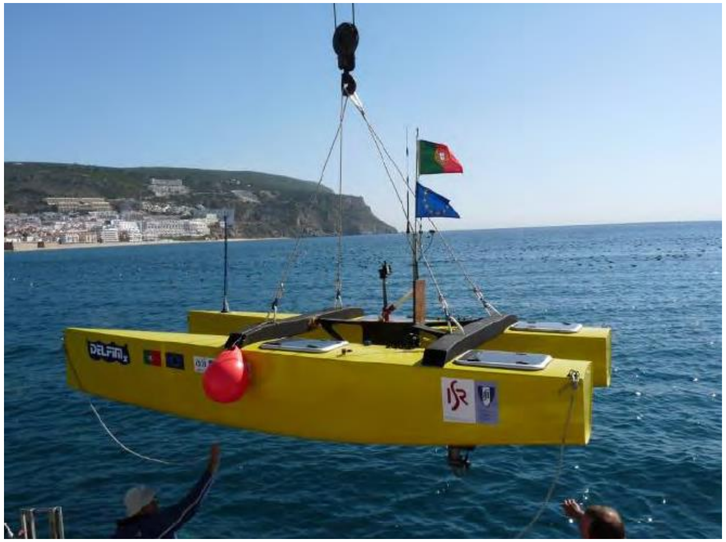
- LSA-ISEP (INESC TEC);
- Catamaran (4.2 m);
- Electric propulsion (autonomy 10 hr);
- Research platform marine robotics and validation of applications;
- Operation at sea, high operability, multi-use;
- Accuracy RTK GPS, IMU;
- Visible and infrared light cameras;
- Sidescan sonar, multibeam, subbottom profiler;
- CTD;
- 3D laser scanner;
- CPU board and autonomous operation;
- Image processing on board;
- Bathymetry, coastal modeling, security, search and rescue ...





Delfim, Delfimx

- ISR-IST
- Catamaran, aluminum hull
- Relay communications for AUVs
- acoustic communications vertically with AUVs
- electric propulsion
- MOOS
- Missions cooperative control and path following (EU FP7 Grex, Co3auv)



[1] A. Aguiar, J. Almeida, M. Bayat, B. Cardeira, R. Cunha, A. Hausler, P. Maurya, A. Oliveira, A. Pascoal, A. Pereira, M. Rufino, L. Sebastiao, C. Silvestre, and F. Vanni, "Cooperative Autonomous Marine Vehicle motion control in the scope of the EU GREX Project: Theory and Practice," in OCEANS 2009-EUROPE, 2009, pp. 1–10.

Sesamo / Charlie

- CNR-ISSI Genova (Italy)
- Study of the water interface layer / air boundary
- small catamarans (2.4 x 1.7 m 300kg Charlie)
- electric propulsion, steering rudders

[1] M. Caccia, “Autonomous Surface Craft: prototypes and basic research issues,” in 2006 14th Mediterranean Conference on Control and Automation, 2006, pp. 1–6.
[2] M. Caccia, R. Bono, G. Bruzzone, E. Spirandelli, G. Veruggio, A. M. Stortini, and G. Capodaglio, “Sampling sea surfaces with SESAMO,” IEEE Robotics & Automation Magazine, vol. 12, no. 3, pp. 95–105, Sep. 2005.

SCOUT

- Adapted canoe
- Electric propulsion
- MOOS
- Developed at MIT
- Low cost R & D platform
- Monitoring and multi-vehicle cooperation

[1] J. Curcio, J. Leonard, and A. Patrikalakis, "SCOUT — A Low Cost Autonomous Surface Platform for Research in Cooperative Autonomy," in Proceedings of OCEANS 2005 MTS/IEEE, 2005, pp. 1–5

Ribcraft USV

- VaCAS - Vtech (Virginia Polytechnic and State University)
- Semi-rigid 4.8m
- 50 HP, 20 knots
- Ibeo laser scanner (line) mounted on pan and tilt
- DGPS

[1]C. Sonnenburg, A. Gadre, D. Horner, S. Kragelund, A. Marcus, D. J. Stilwell, and C. A. Woolsey, “Control-Oriented Planar Motion Modeling of Unmanned Surface Vehicles,” in OCEANS 2010 MTS/IEEE SEATTLE, 2010, pp. 1–10.

AutoCat

- MIT Sea Grant
- Research Platform (since 1993, ARTEMIS, ACES, 2000 AutoCAT)
- Survey accuracy and communications relay for AUVs
- 20 knots, electric propulsion
- Control software similar to the Odyssey AUV
- Freewave RF modem
- DGPS
- PC104 133MHz

[1] J. Manley, J. Curran, B. Lockyer, J. Morash, and C. Chryssostomidis, “Applying AUV lessons and technologies to autonomous surface craft development,” in MTS/IEEE Oceans 2001. An Ocean Odyssey. Conference Proceedings, 2001, vol. 1, pp. 545–549.

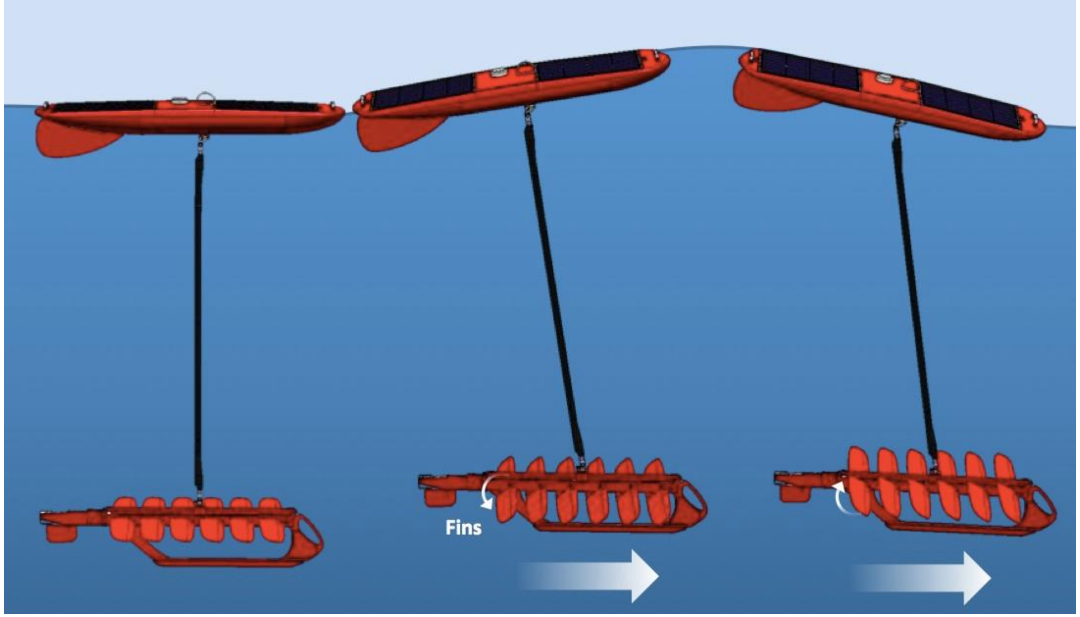
CSIRO Aut. Syst. Lab - Autonomous Boat

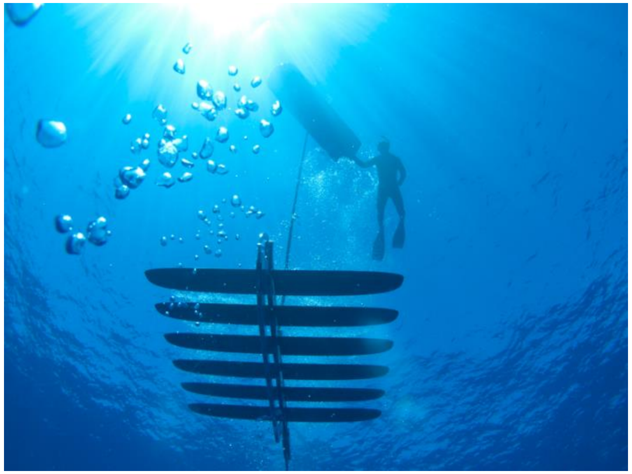
- CSIRO - ICT Centre, Autonomous Systems Lab (Australia)
- Research platform for interaction with networks of distributed sensors (WSN)
- environmental monitoring
- Catamaran
- electric propulsion
- Photovoltaic panels
- PC board
- GPS

[Image: CSIRO]

WaveGlider

- Wave propulsion
- 2 bodies
  - Surface board
  - Control surfaces at 6m depth
- Long term permanence at sea



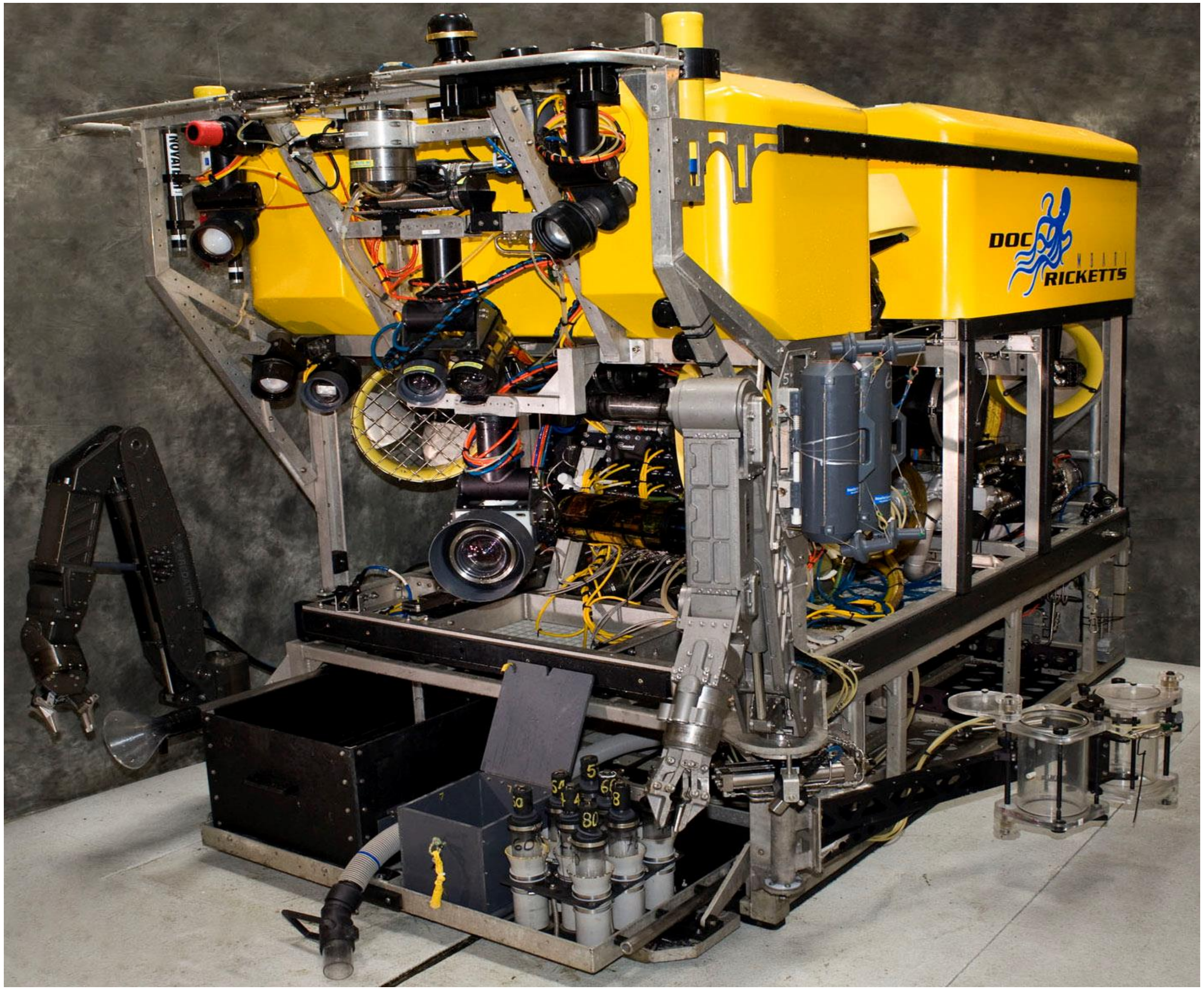


Autonomous Underwater Vehicles

ROVs

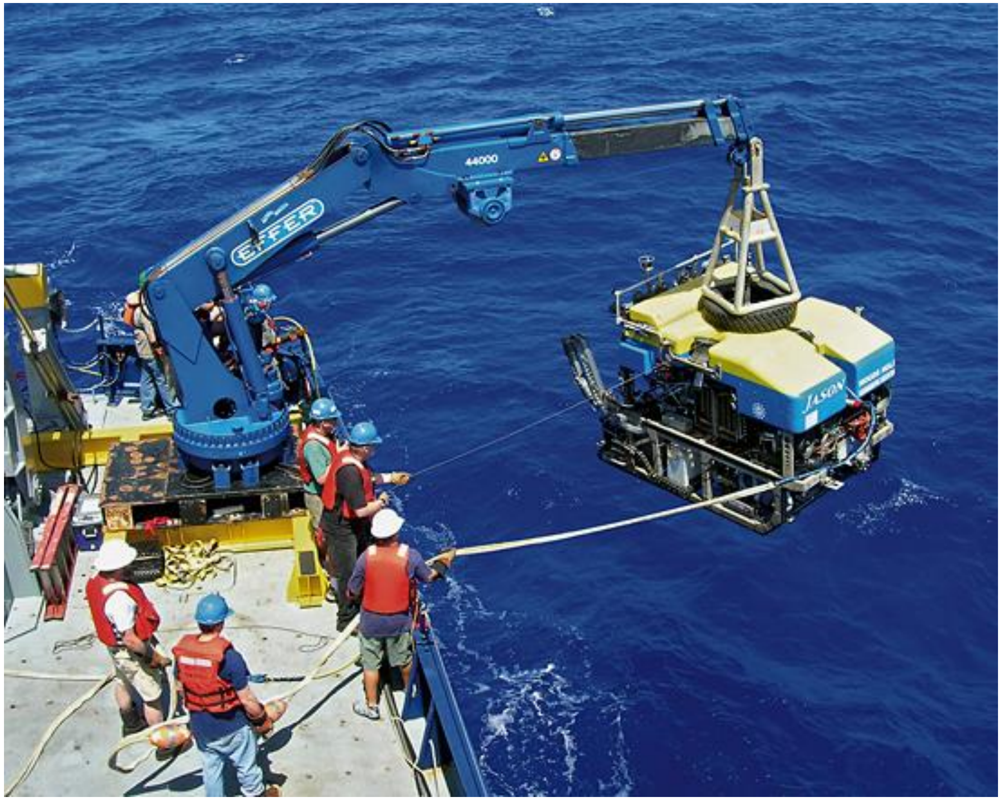
- Cable
  - Power
  - Communications
- Floating foam
- Multiple motors
- Low speed high maneuverability
- Manipulating arms
- Workclass, inspection
- Relevant tool in offshore exploration
- From 1Kg vehicles to multiple tons up to 6000m

Typical ROV



JASON

- WHOI
- ROV line since 1990
- 6500m depth
- 3.6 ton, 3.4x2.4x2.2m (20mm diam tether)
- 1.5 nos
- 6 motors BLDC (120 Kgf cada)



[Imagens:www.whoi.edu]

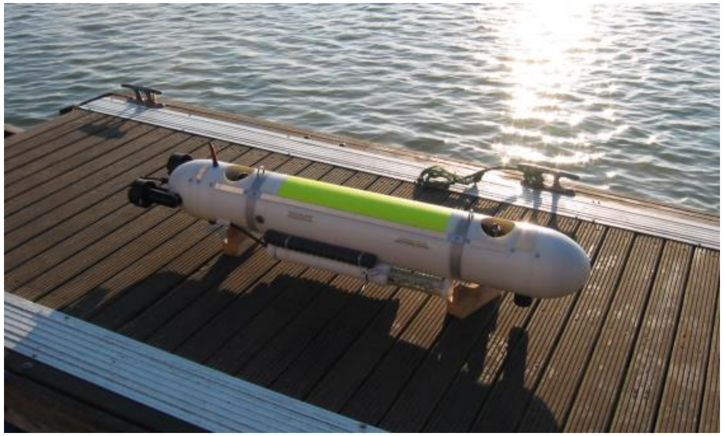
ROV Deep sea operations

Trenchers


SMD
FUGRO
www.titanheavytransport.co.uk
www.titanheavytransport.co.uk

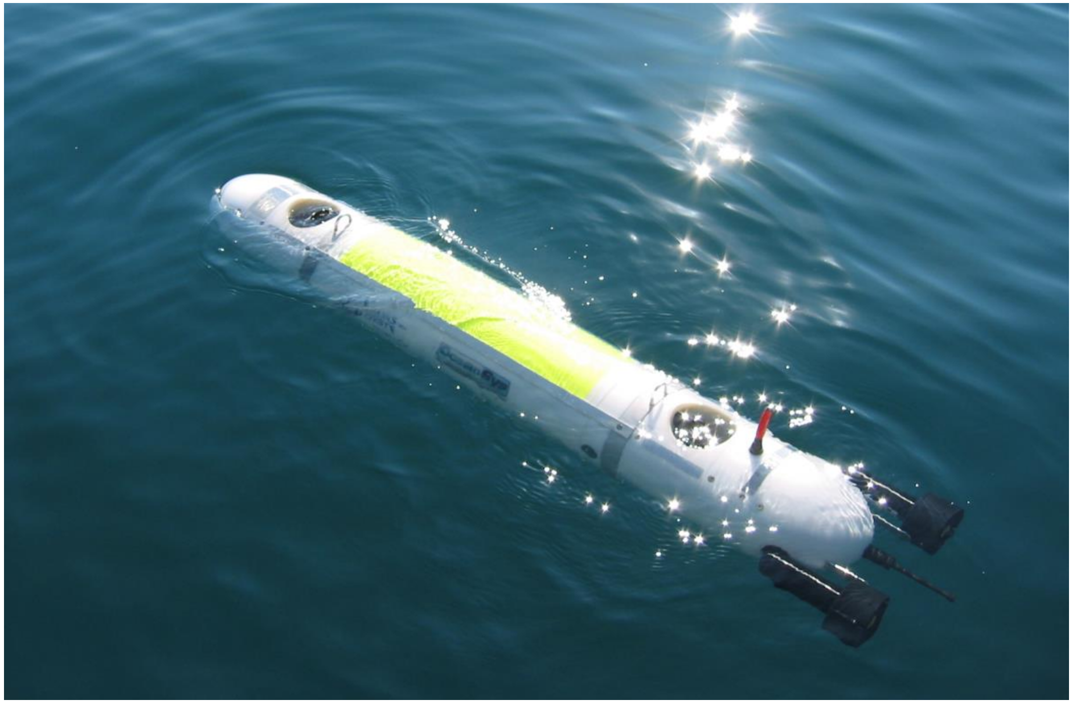
AUVs

- Autonomous submarines
- No cable
- In general without communications
- Multiple payloads
- Wet hull
  - Water inside
  - Electronics and batteries in watertight compartments
  - Pressure proof sensors
  - Ex: Bluefin 21
- Dry hull
  - External hull pressure resistant
  - Wet sections
  - Ex: REMUS 100, MARES



MARES AUV

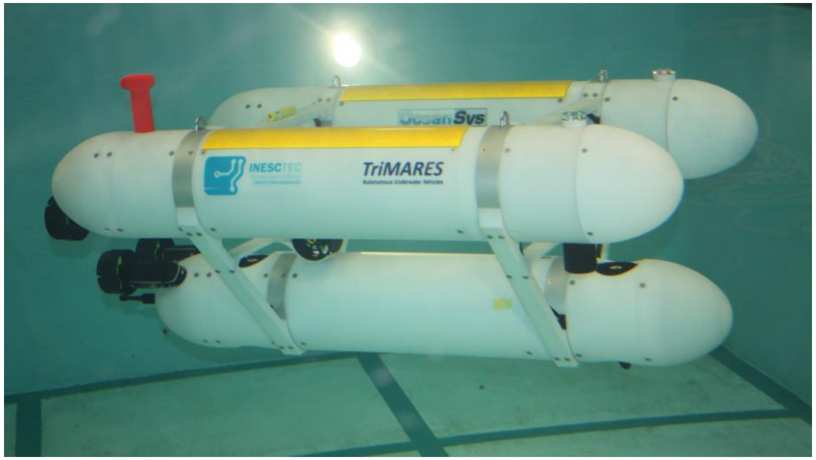
- Applications
  - Mapping
  - Monitoring
  - Inspection
- Modular
- Vertical control
- 35Kg, 1.5m, max. depth 200m



Trimares AUV

- CEB Lageado – Electric power dam in Brasil
- Application
  - Basin and structures inspection
  - Bottom basin mapping

- Trimares AUV Modular
  - 75Kg, 3 knots, 10 hr
  - LBL
  - Optional ROV mode



Deep ocean AUVs

- ABE (4000 m) , Nereus (11000m)
- Build at WHOI
- AUV or ROV
- Both lost at sea (Abe in March 2010 offshore Chile)
- NEREUS lost in **10 May 2014**

ABE – Autonomous Benthic Explorer

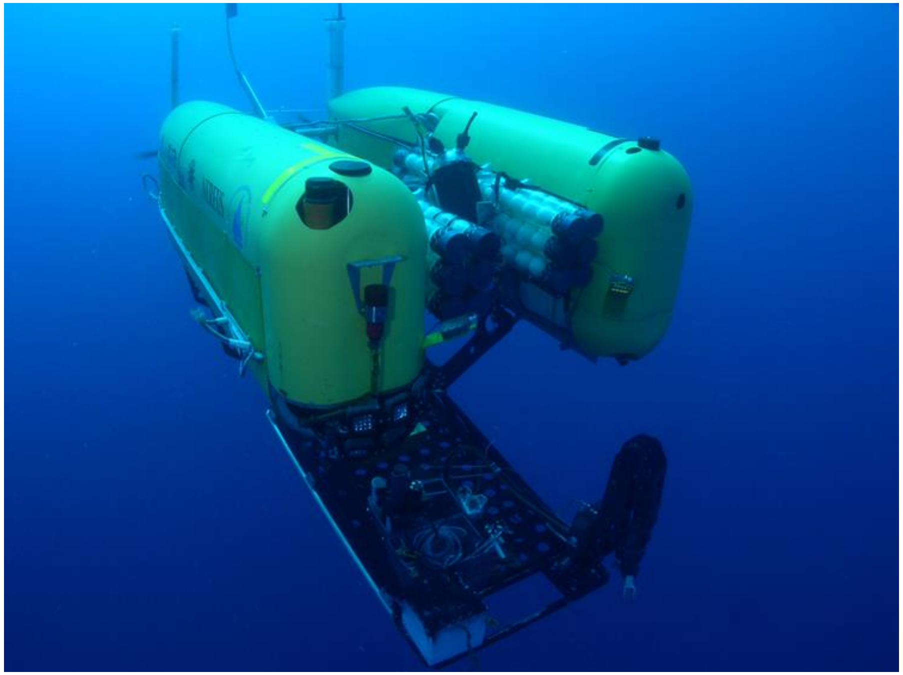
- WHOI
- More than 200 dives since 1996
- Lost at sea near Chille in March 2010
- LBL,DVL
- 4500m depth
- 5 thrusters
- 3x2x2.5m, 550kg
- 14-20 hr autonomy (20-40km)
- 5KWh de batteries (Li-Ion)
- Ascente and descent with droppable weights – 1000m/hr
- Extensive set of sensors

[Image:WHOI]

[1] D. R. Yoerger, A. M. Bradley, B. B. Walden, H. Singh, and R. Bachmayer, “Surveying a subsea lava flow using the Autonomous Benthic Explorer (ABE),” International Journal of Systems Science, vol. 29, no. 10, pp. 1031–1044, Oct. 1998.]

NEREUS

- Hybrid ROV AUV
- Full ocean depth
- Only AUV that reached the Marianas trench
- Ceramic spheres as flotation (cause of failure)



Gliders

- Submarines that glide in the water – "fly"
- Variable buoyancy (oil reservoir and bladder)
- IO-IO motion
- Long term presence at sea
- Reduced speed