

Marine Systems & Robotics

Cooperative Marine Robotic Systems: Theory and Practice – Part 1

Prof. Dr. Antonio Pascoal



<http://impact.uni-bremen.de/>



JACOBS
UNIVERSITY



National
Technical
University of
Athens



University of
Zagreb



TÉCNICO
LISBOA



The work of many



DSOR Group
dynamical systems and
ocean robotics



EC-CO₃AUVs

2009-2012



CO₃-AUVs Final Demo
21-22 March, 2012 - Lisbon, Portugal



FP7-ICT-2007-3 GA 231378 **CO₃-AUVs**: Cooperative Cognitive Control for Autonomous Underwater Vehicles, 2009-2012

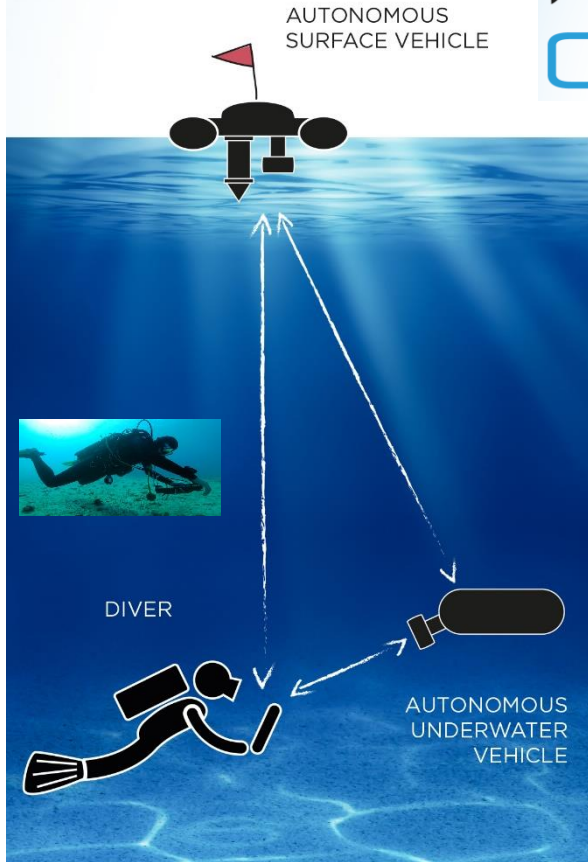




FP7-ICT-2011-7 GA 288704 **MORPH**: Marine Robotic System of Self-Organizing, Logically Linked Physical Nodes, 2012-2016

EC-CADDY

2014-2016



FP7-ICT-2013-2 GA 611373 **CADDY**: Cognitive Autonomous Diving Buddy, 2014-2016





WiMUST

Widely scalable Mobile Underwater Sonar Technology



H2020-ICT-2014-1/ GA 645141 **WIMUST**: Widely Scalable Mobile Underwater Sonar Technology, 2015-2018

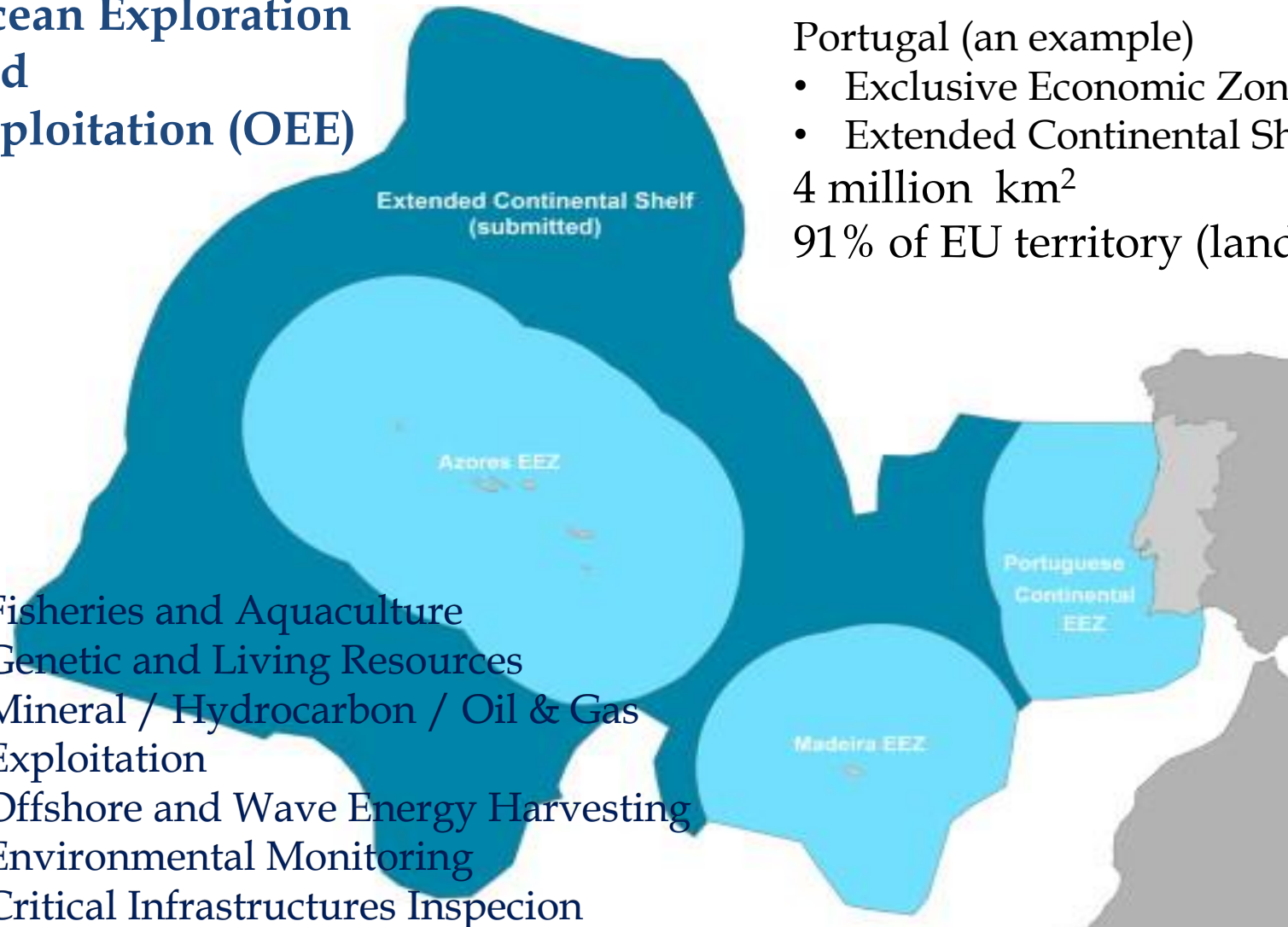


Marine Science, Technology, and Society – why the effort?

Ocean Exploration and Exploitation (OEE)

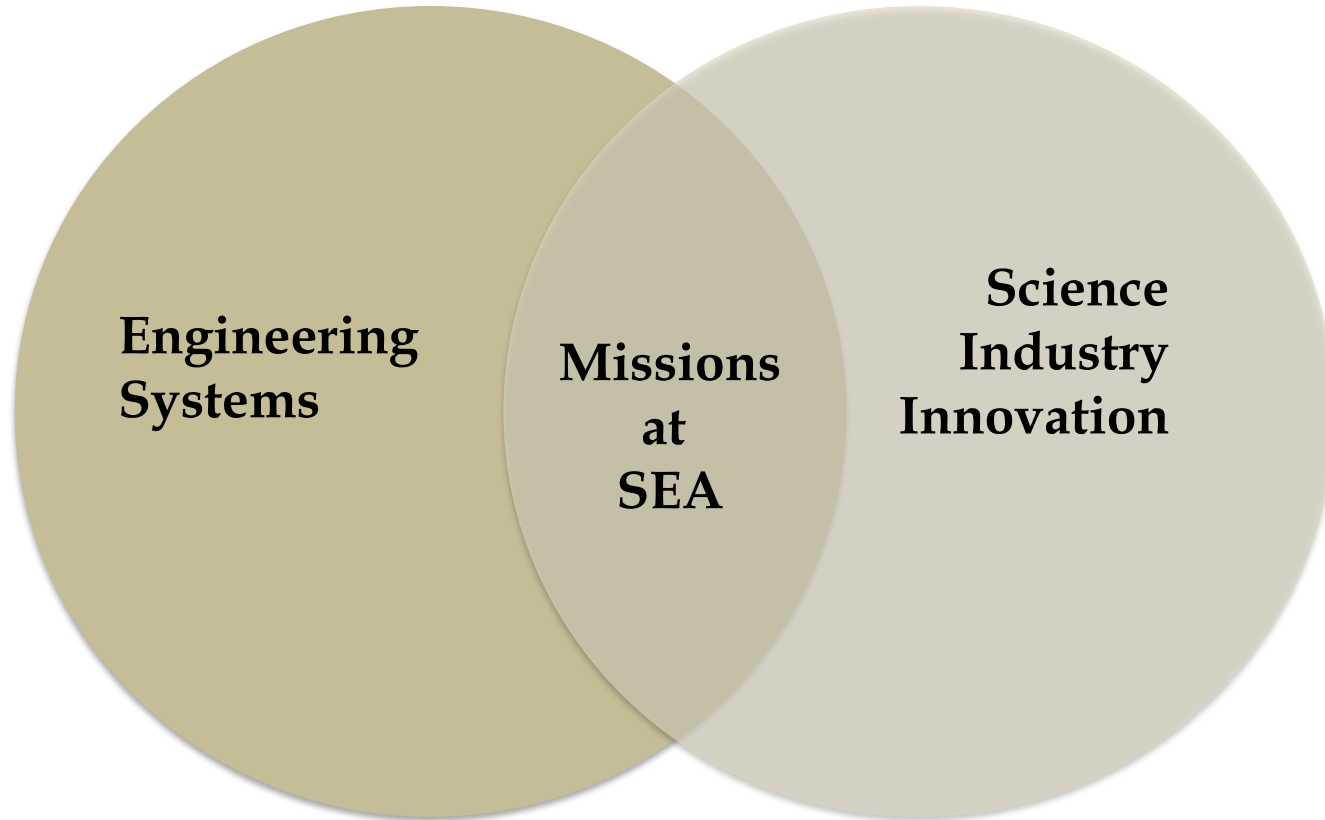
Portugal (an example)

- Exclusive Economic Zone
 - Extended Continental Shelf
- 4 million km²
91% of EU territory (land)



- Fisheries and Aquaculture
- Genetic and Living Resources
- Mineral / Hydrocarbon / Oil & Gas Exploitation
- Offshore and Wave Energy Harvesting
- Environmental Monitoring
- Critical Infrastructures Inspeccion
- Maritime Logistics

The Pillars of Ocean Exploration and Exploitation



I - Engineering Systems - Technology

II - Science, Industry, Innovation

Knowledge Transfer, Outreach Activities

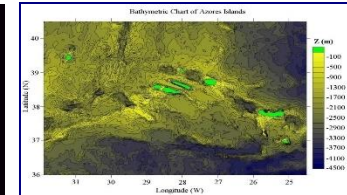
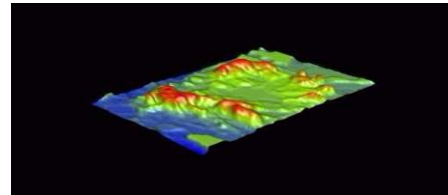
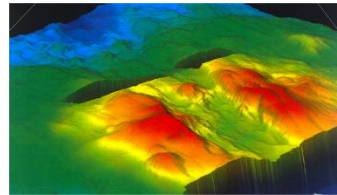
Technology for Science, Industry, and Management

*Automatic data
acquisition in 3D*

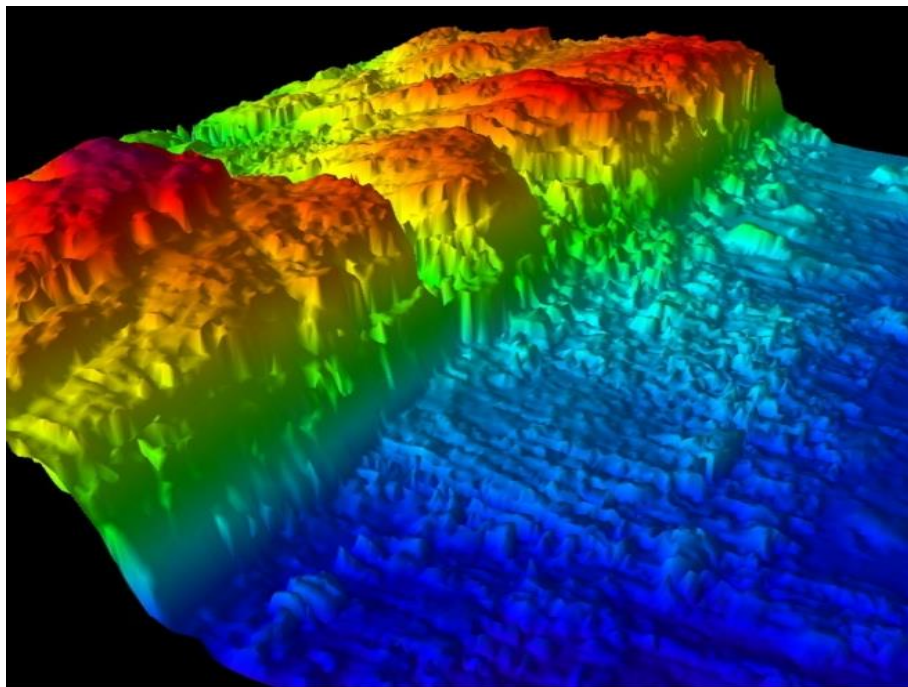
*Scientific and commercial
communities; civilian
authorities*

Data fusion

*Info generation and
dissemination*



Scientific Challenges



To study the
**Physical,
Chemical,
Biologic,
and Geologic**

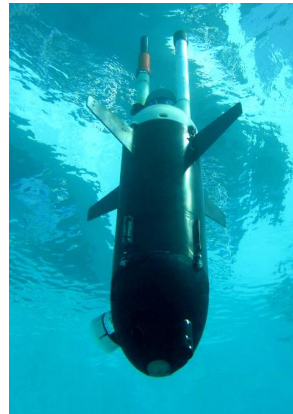
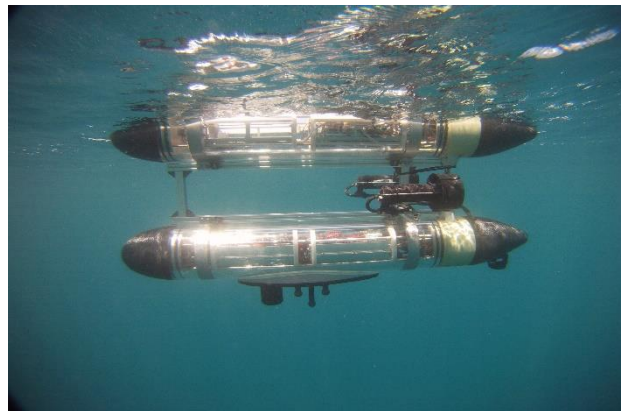
**phenomena
that occur in the ocean
and its interfaces
(with the atmosphere
and the Earth's
interior)**

Observe, Monitor, and Map

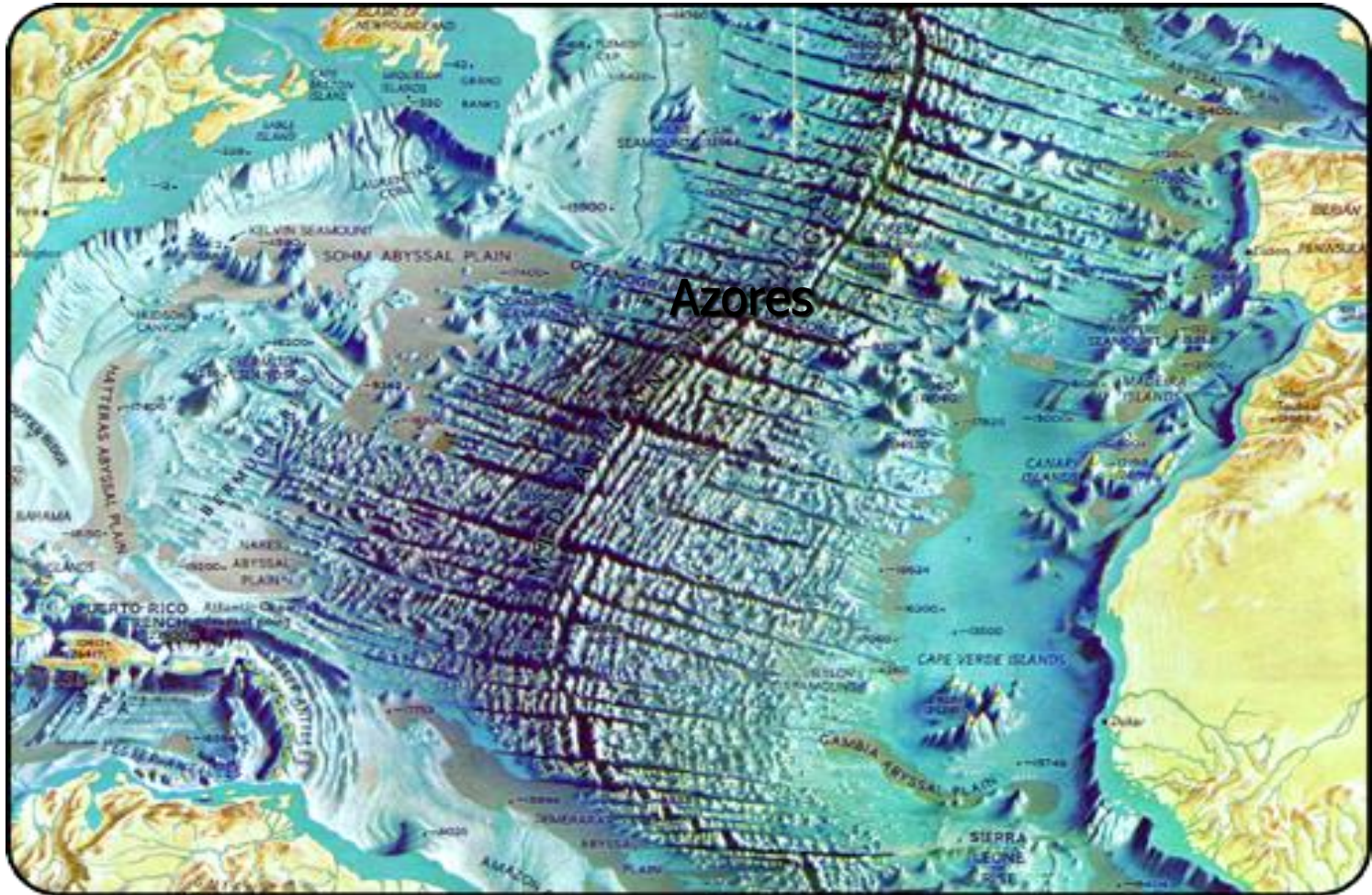


The tools of the trade

- Technologies for ocean exploration including networked air and marine robots
- Robotic systems for the inspection of critical marine infrastructures and seabed/subbottom mapping



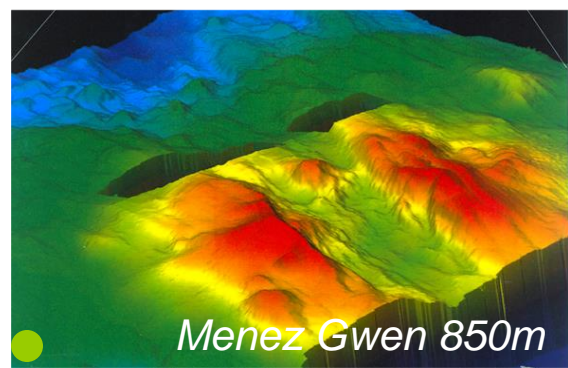
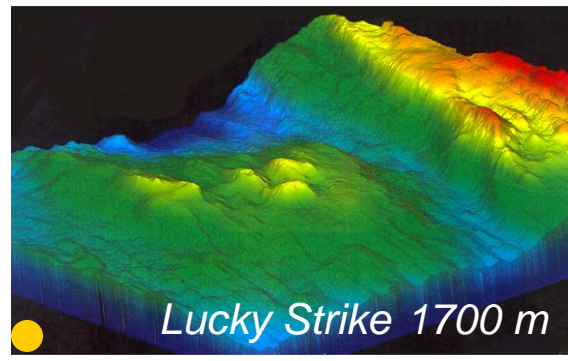
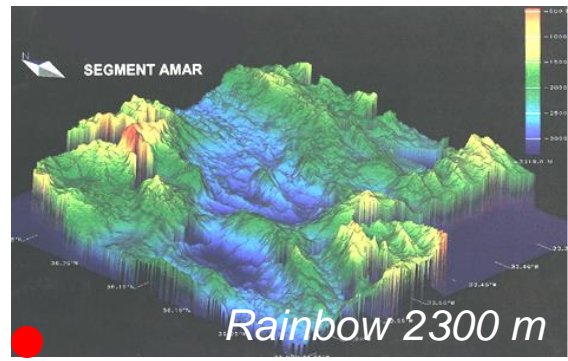
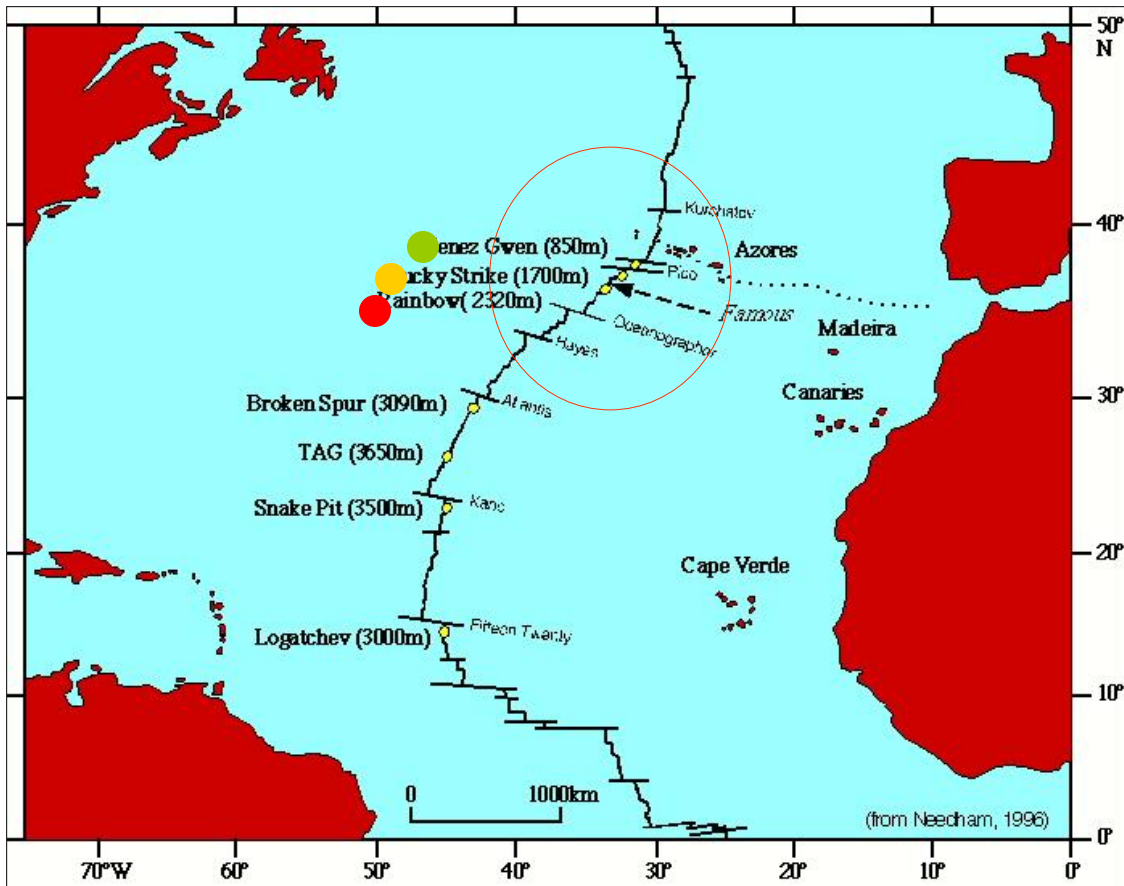
The Middle Atlantic Ridge and the Azores



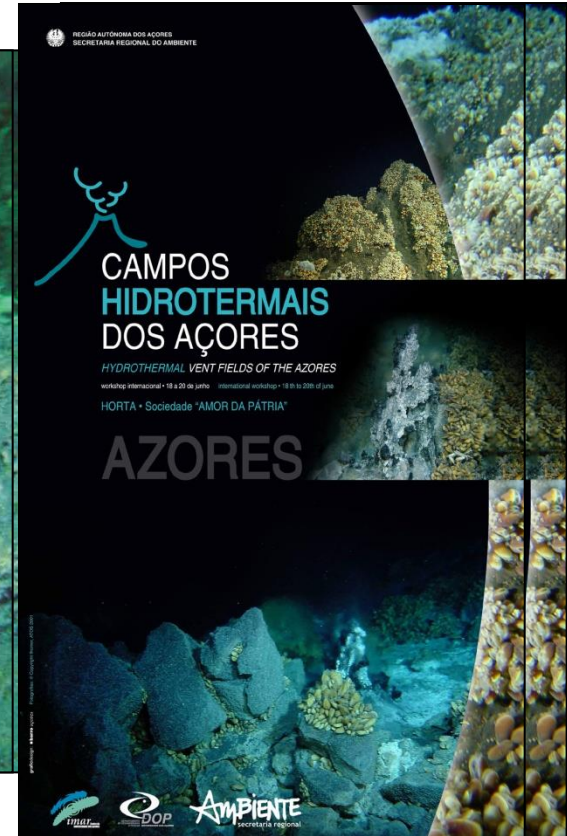
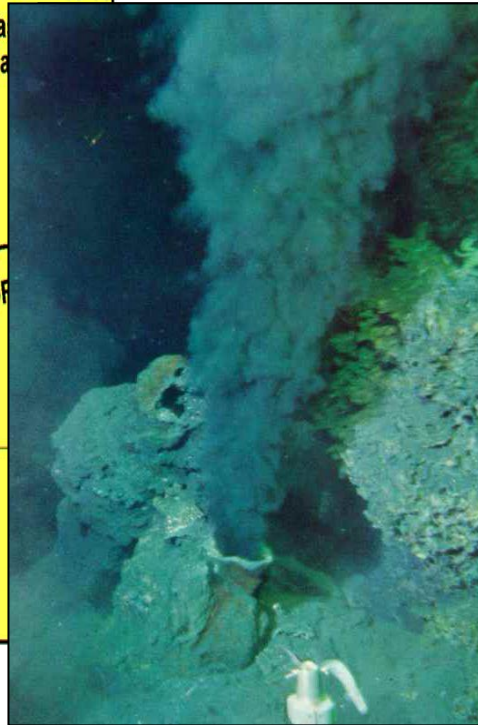
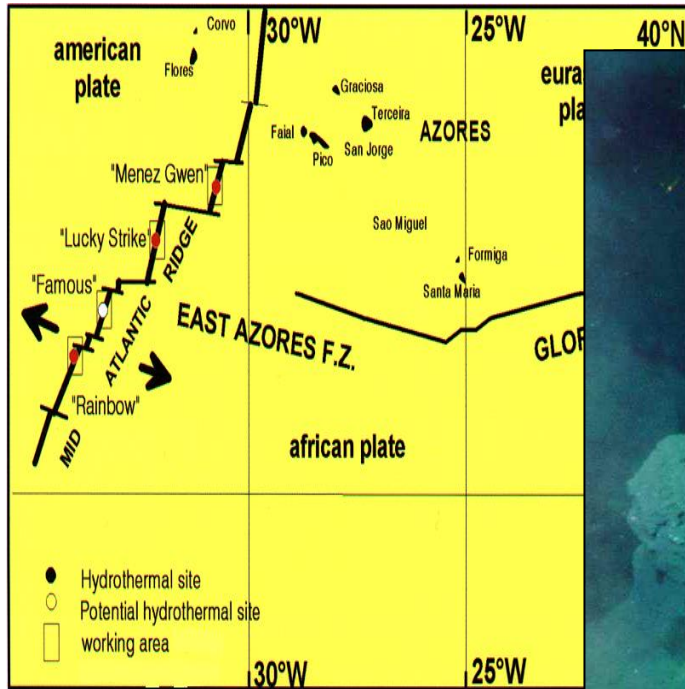
A chain of mountains at the bottom of the Atlantic ocean

Mission Scenario

Underwater Hydrothermal Vents (Azores, Portugal)

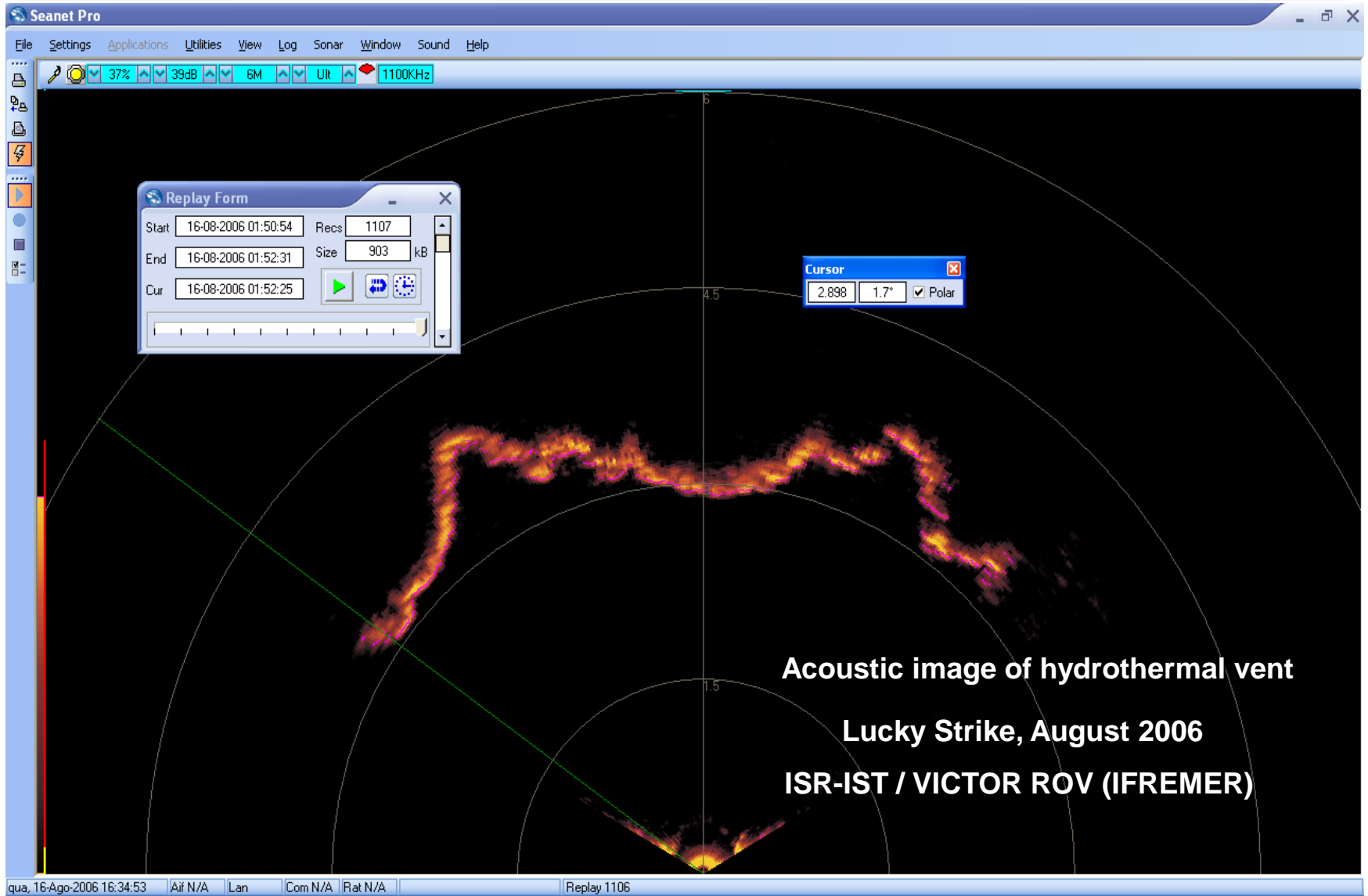


The Azores Triple Junction (ATP)



The region harbours a great variety of *seamounts, active underwater volcanoes, chemosynthetic ecosystems, and "extreme" life forms (extremophiles)*

Deep Water Hydrothermal Vents

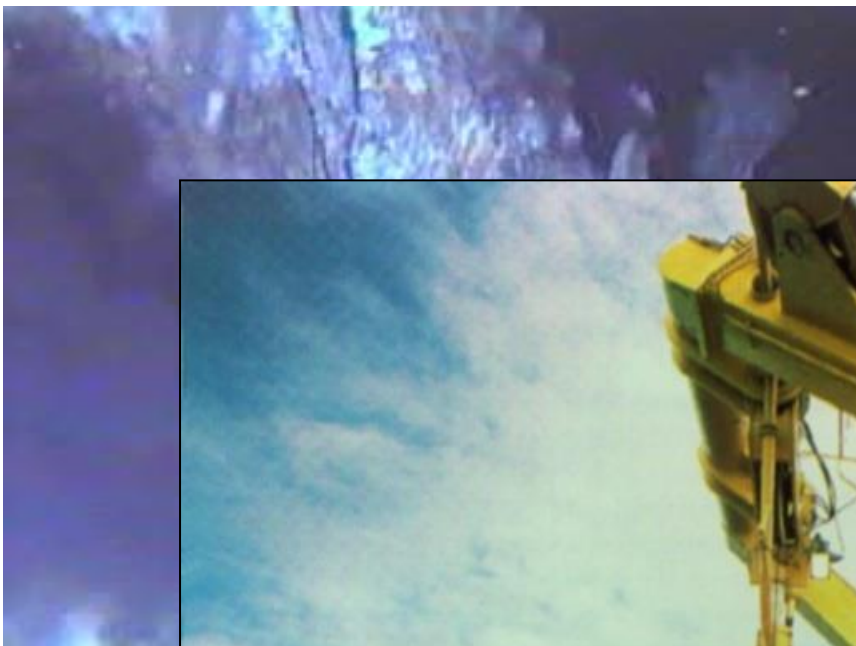


Acoustic image of hydrothermal vent

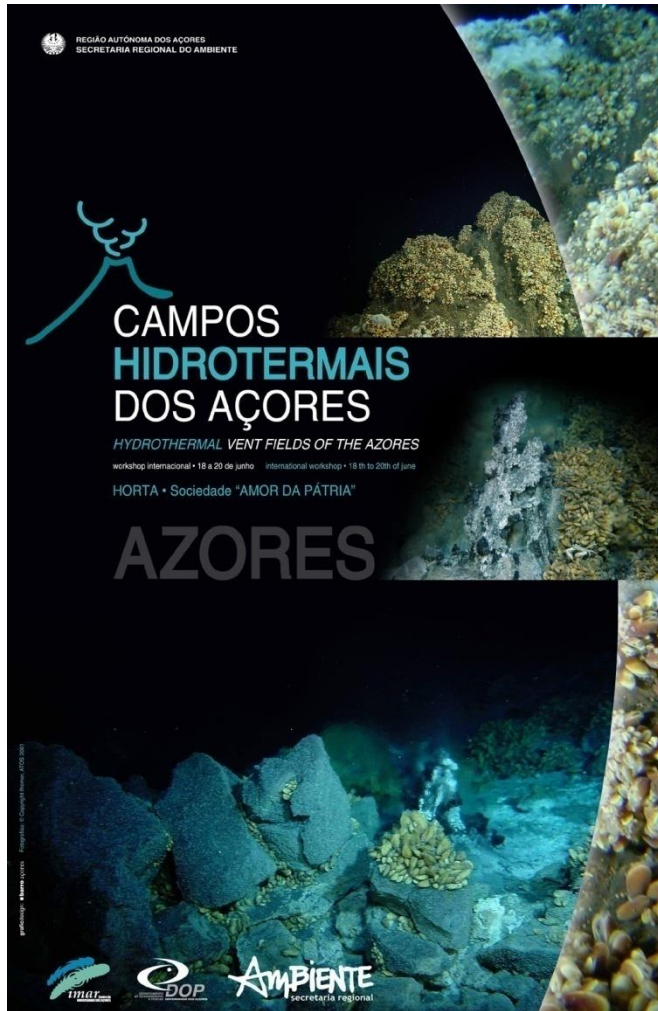
Lucky Strike, August 2006

ISR-IST / VICTOR ROV (IFREMER)

Underwater Hydrothermal Vents



The Need for Technology



Vents are very hard to study:

Large depth (pressure is high)

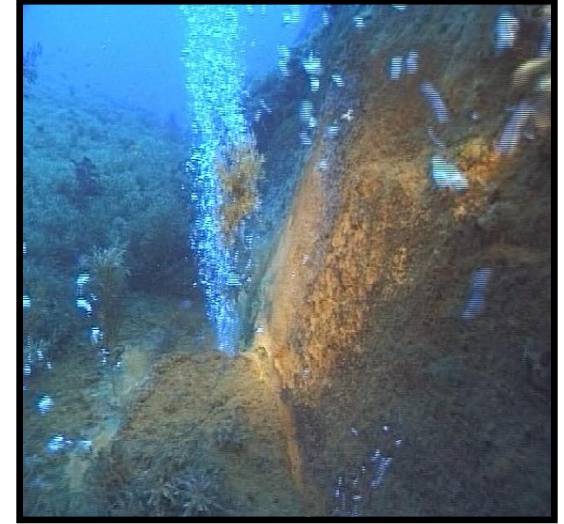
Highly corrosive environment

Lack of optical visibility

Navigation is a challenge (lack of a GPS-like system)

Submersibles: place human lives at risk

Shallow Water Hydrothermal Vents



Hydrothermal activity at
the D. João de Castro
seamount
Azores, PT

Single Agent Operations: shallow water



No humans on board, please



Use an Autonomous Surface Vehicle to MAP the seafloor





Mapping the seabed with an ASV



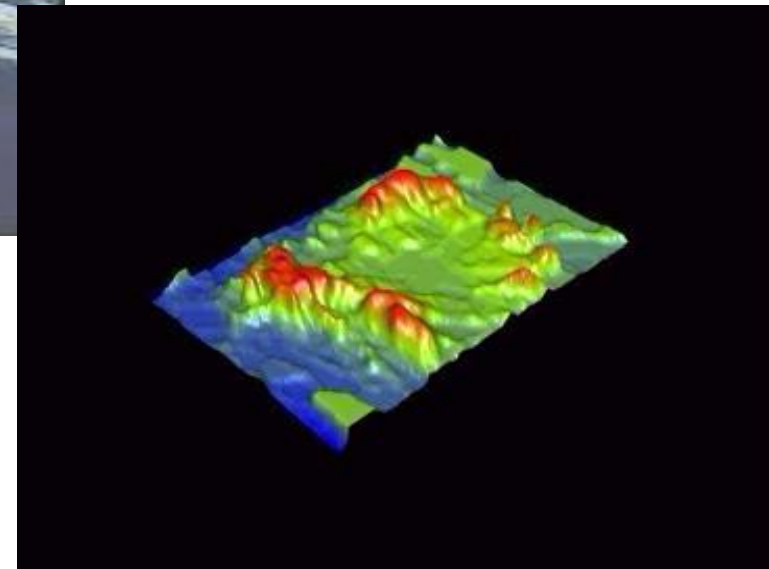
The DELFIM ASV - IST

Navigation: GPS

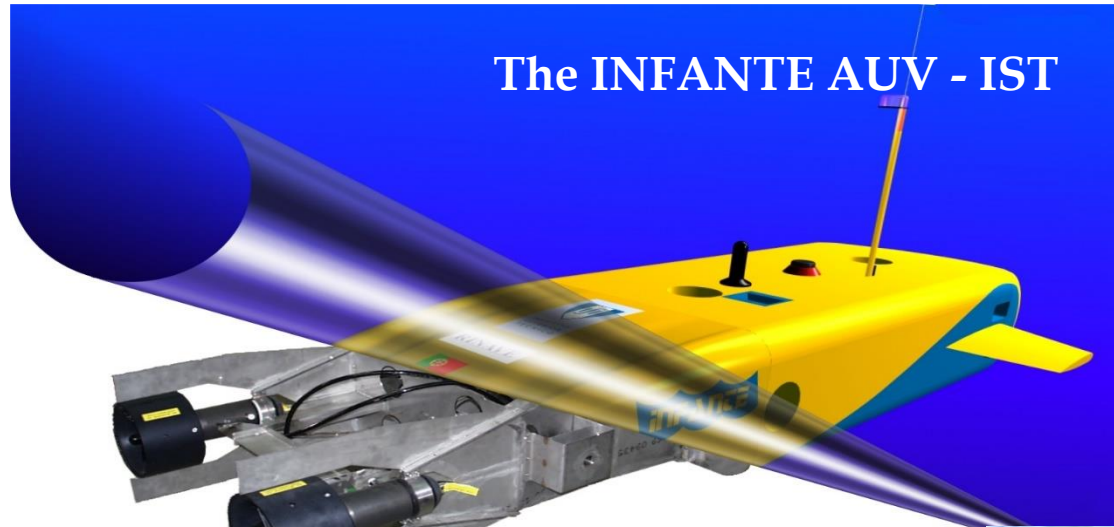
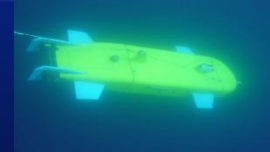
Comms: radio

Path following:
Inner-outer loops for accurate tracking in the face of ocean currents and wind.

Systems in place:
Navigation, Guidance and Control for Path Following



Go deeper with an AUV



The INFANTE AUV - IST

Navigation:
Dead-reckoning
(AHRS and Doppler
unit)

Comms: acoustic

- Systems in place:**
NGC for
- Path Following in 3D*
 - Altitude Control*
- Mapping sensor suites*



Cooperation with Goa (NIO)

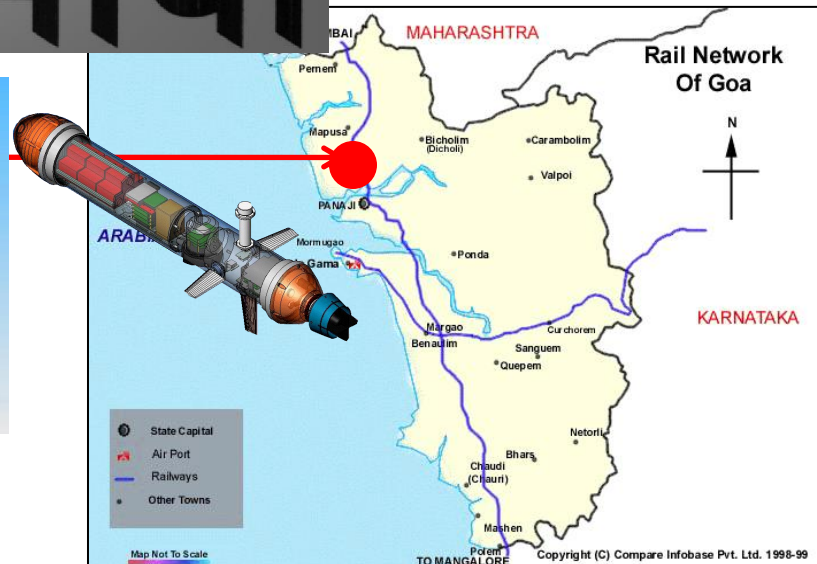
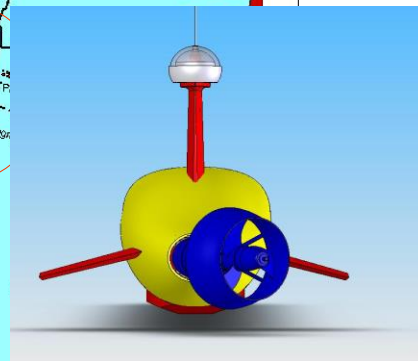
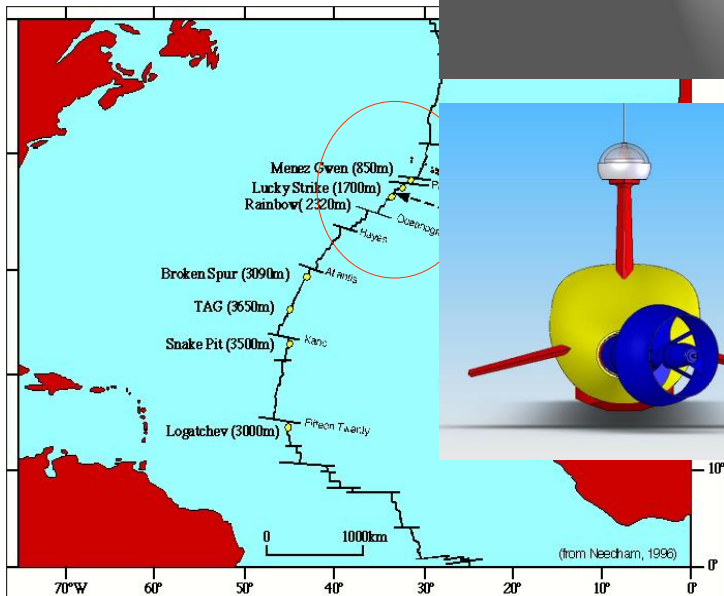


Meeting IN-PT (since 1999)

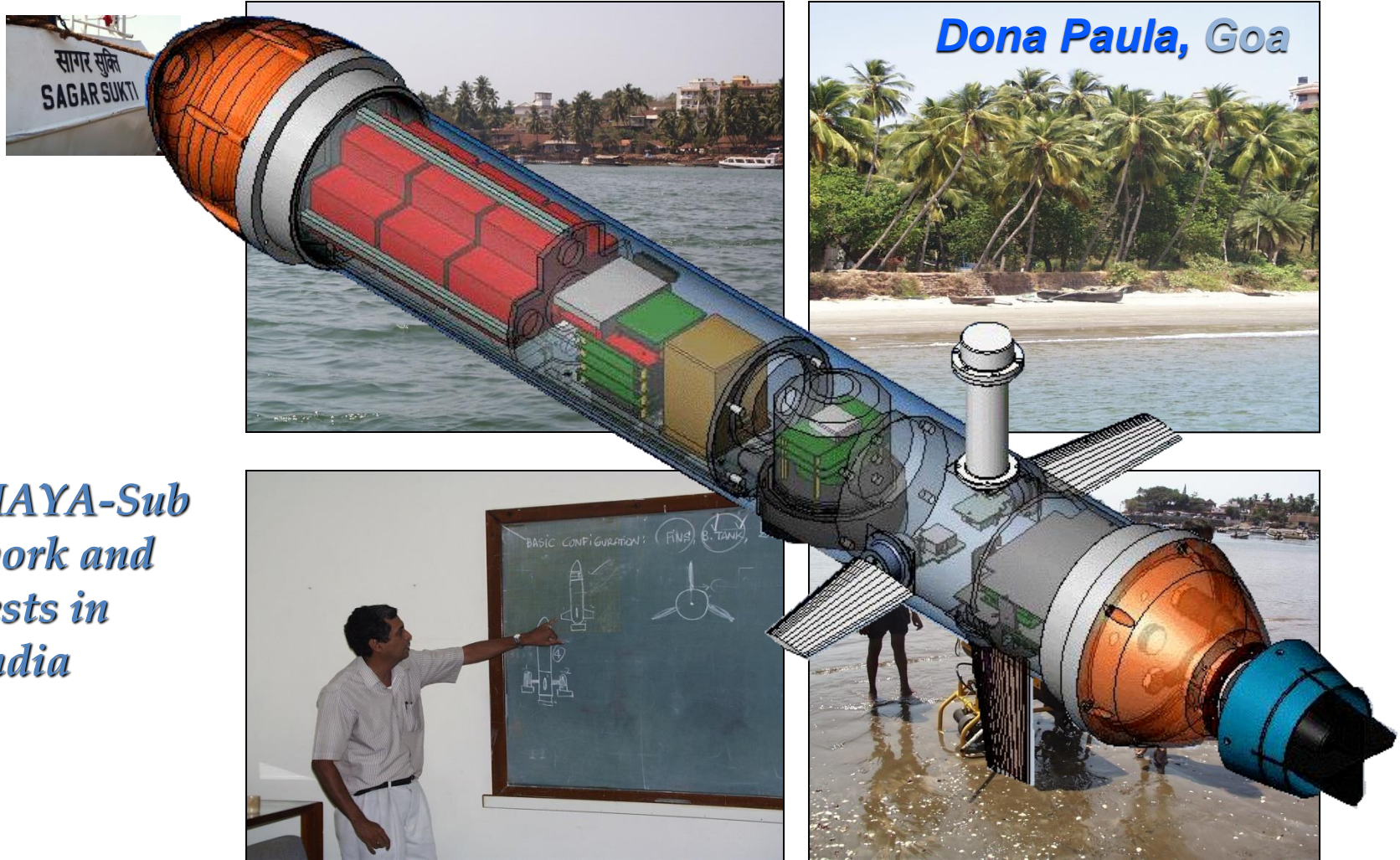


Maya

माया



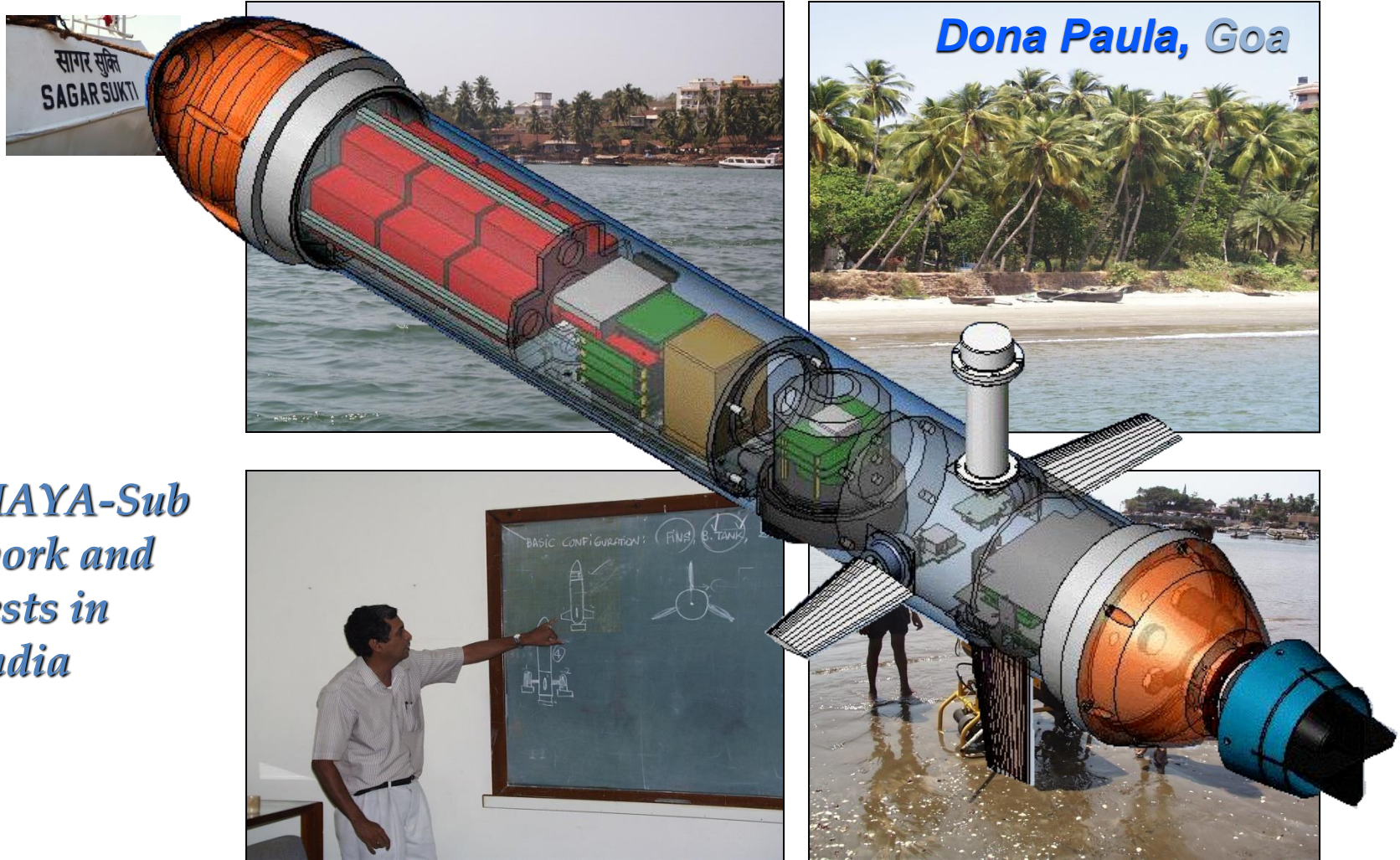
The MAYA AUV – IST/NIO



*MAYA-Sub
work and
tests in
India*

Interchange of Researchers PT-INDIA; co-project via Web

The MAYA AUV – IST/NIO

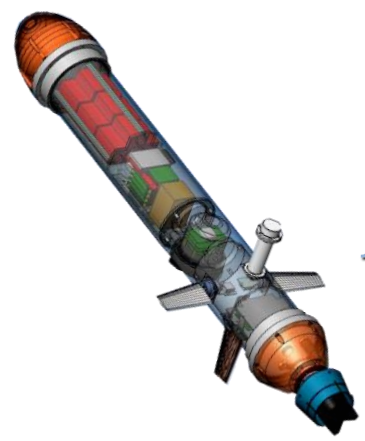


*MAYA-Sub
work and
tests in
India*

Interchange of Researchers PT-INDIA; co-project via Web

Cooperation with India (NIO and NIOT)

Work and tests in India



Maya
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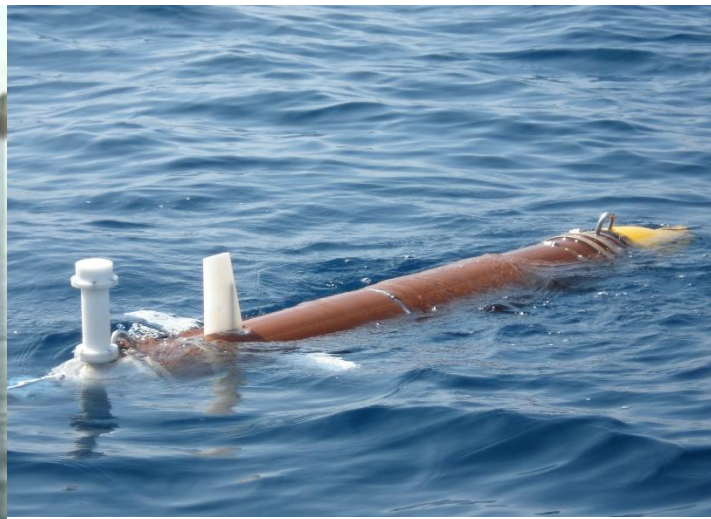
Amthnem, Goa



Cooperation with India (NIO and NIOT)



Cooperation with India (NIO and NIOT)



India - Portugal



MAYA - AUV





Penetrating the Deep Sea

Challenges

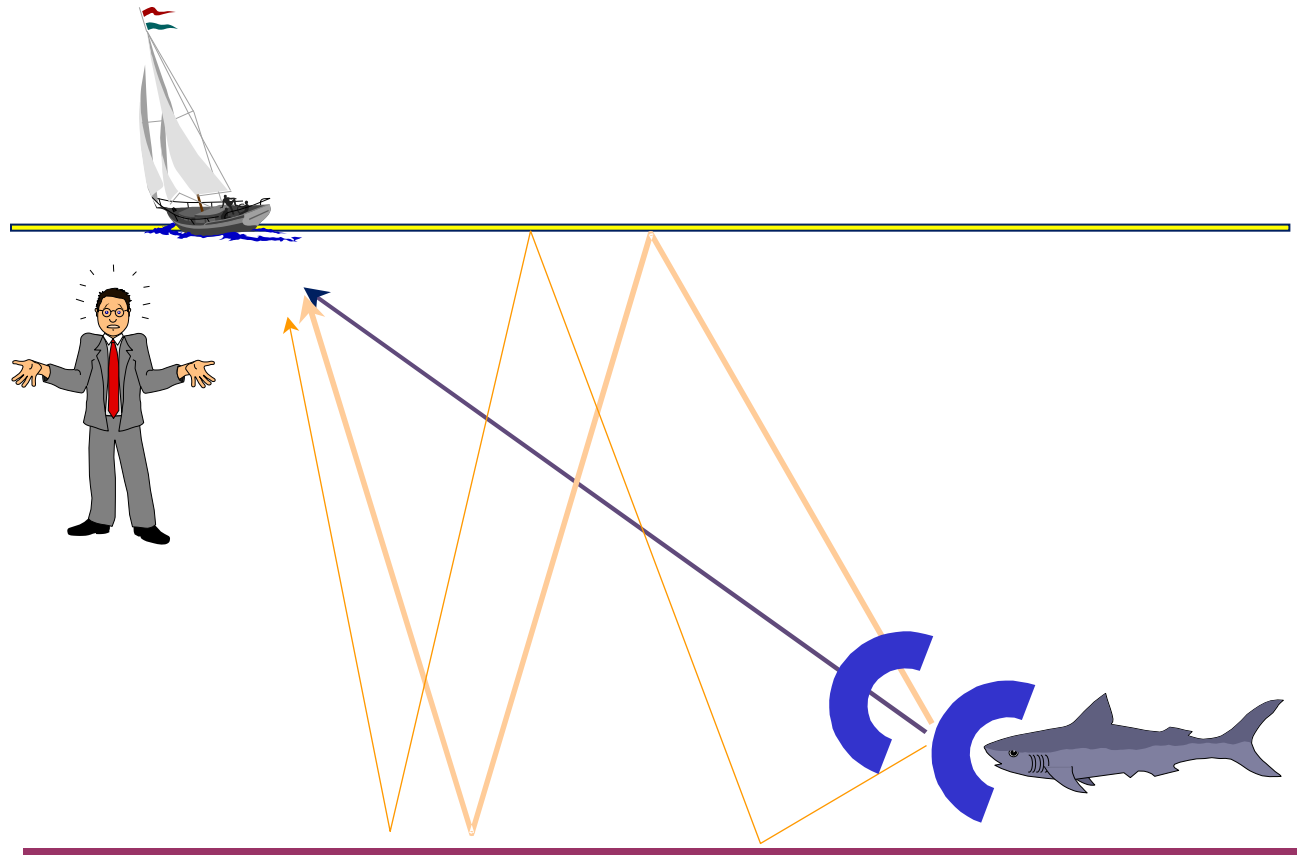
- Tremendous pressure
- Highly corrosive environments
- Lack of optical visibility
- Navigation is exceedingly hard (no GPS)
- Low acoustic communication bandwidth (32kb/s)



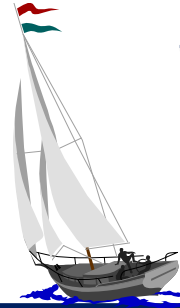
Opening the multiple vehicle frontier

32

Underwater Communications – *very hard!*

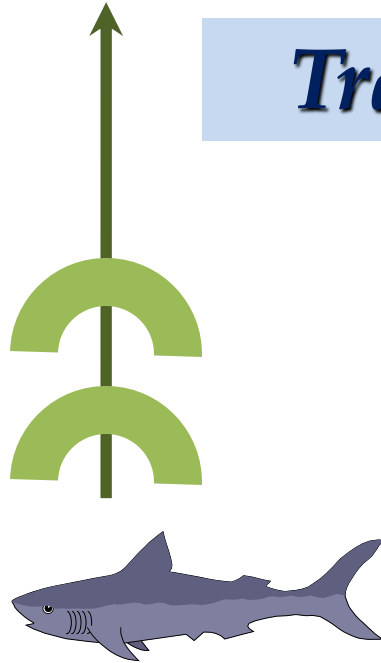


Opening the multiple vehicle frontier



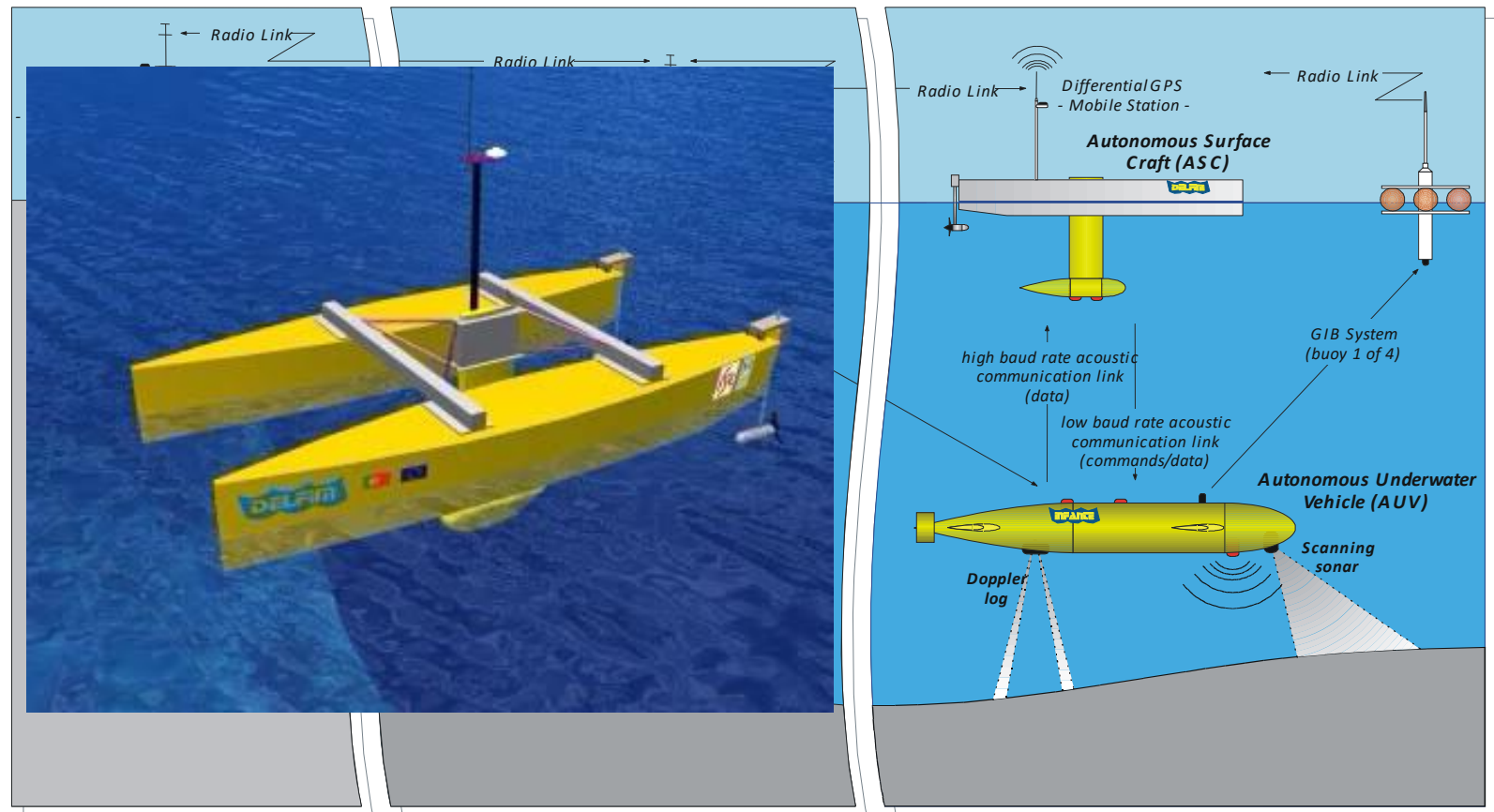
Underwater Communications

Transmit in the vertical !



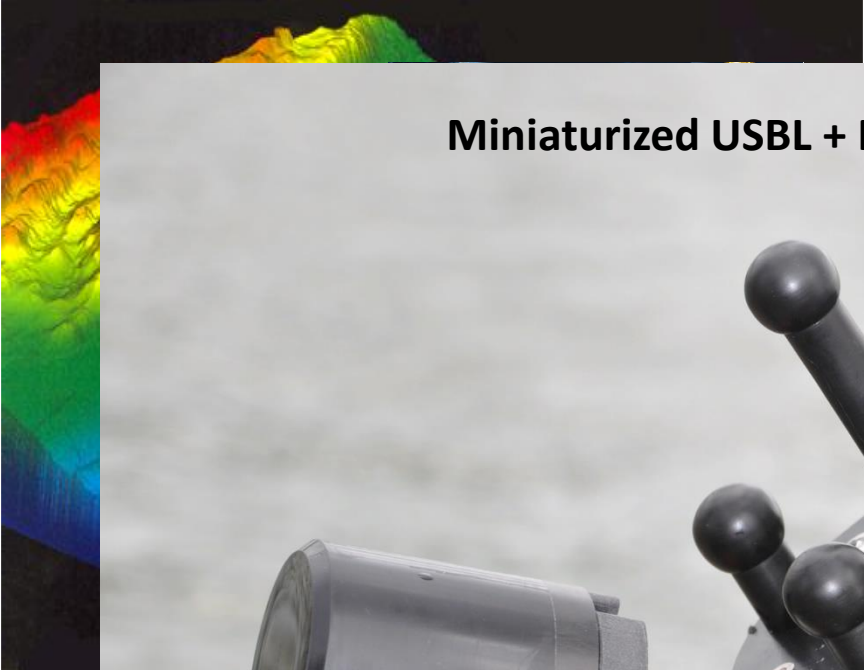
Multi-vehicle operations

The **ASIMOV** concept (ASIMOV project, EC – 2000) – PT, FR, UK



Difficulties: no reliable comms, miniaturized acoustic positioning systems, and tools for seamless implementation of Motion and Mission Control systems (ROS was not born yet!)

Networked Systems : a New Era (2009 -)



**Miniaturized USBL + Ranging Device + Acoustic Modems
[Evologics, Germany]**



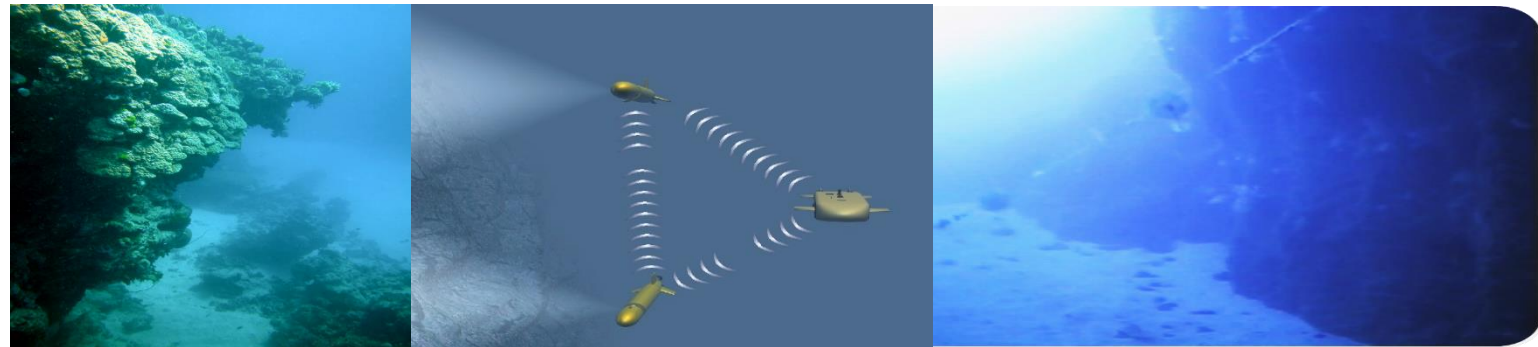
-
-
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and Control



MORPH / EC (2012-2016)

Cooperative Marine Robots for Marine Habitat Mapping in Complex Underwater Environments: A New Paradigm



MORPH / EC (2012-2016)

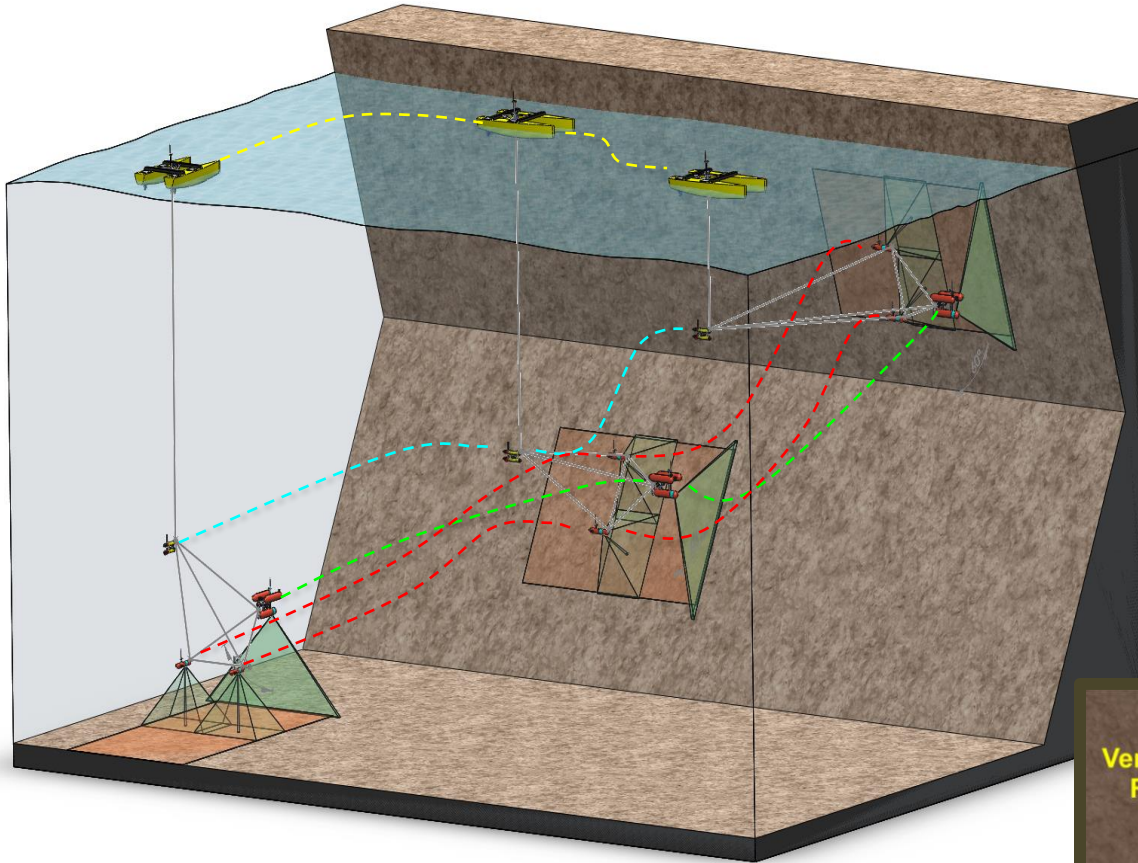
Habitat Mapping in complex 3D environments



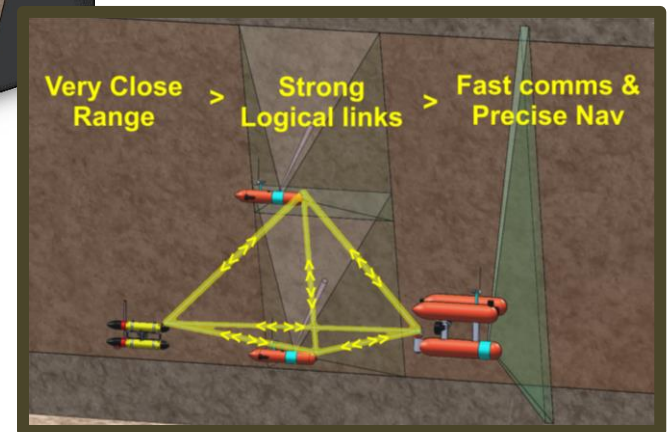
Underwater cliffs, canyon walls, fracture zones, seamount flanks, hydrothermal chimneys

MORPH / EC (2012-2016)

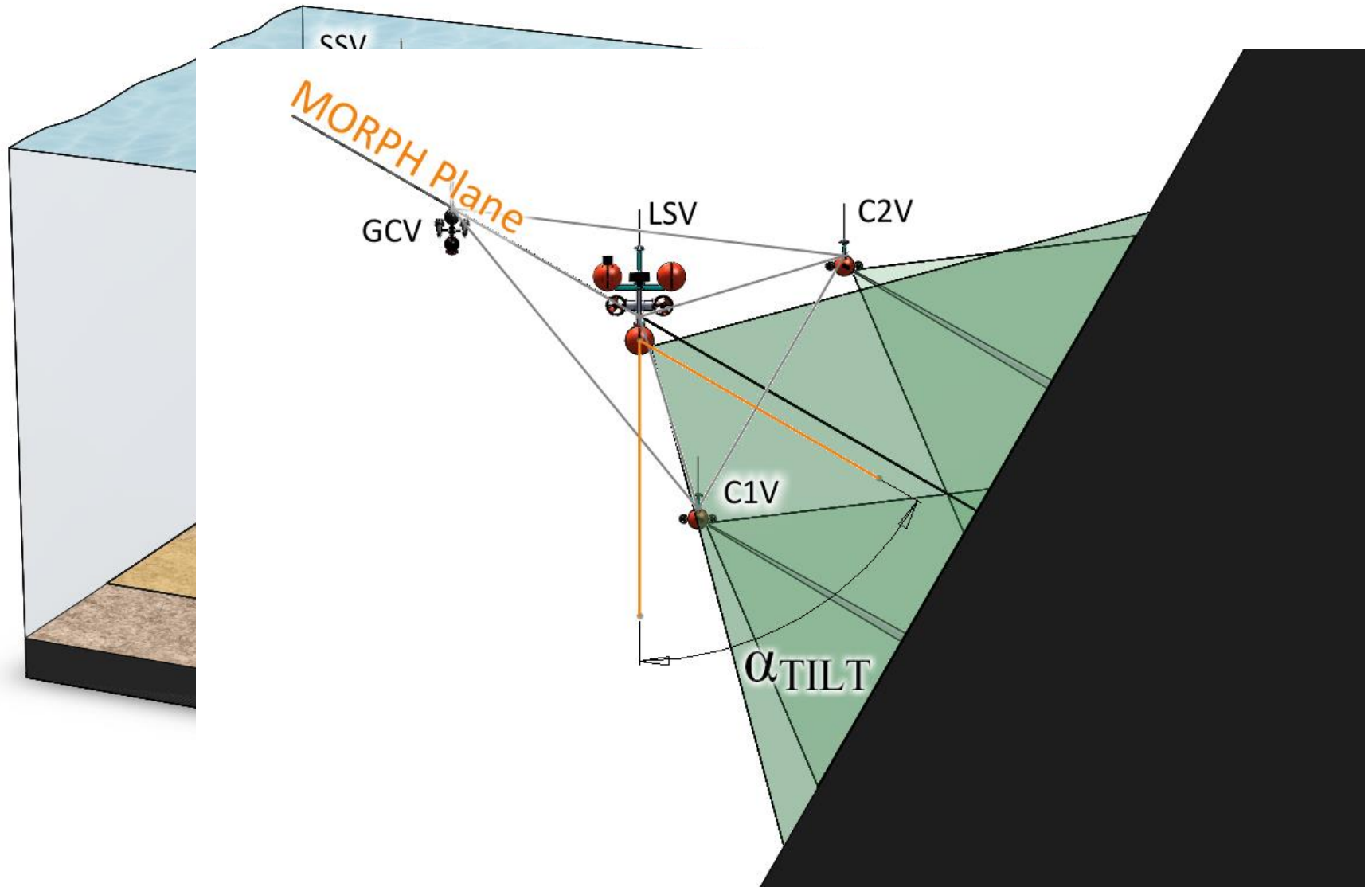
A team of agents
operating as a
virtual super
marine vehicle



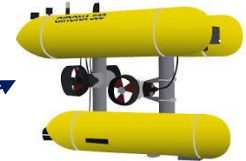
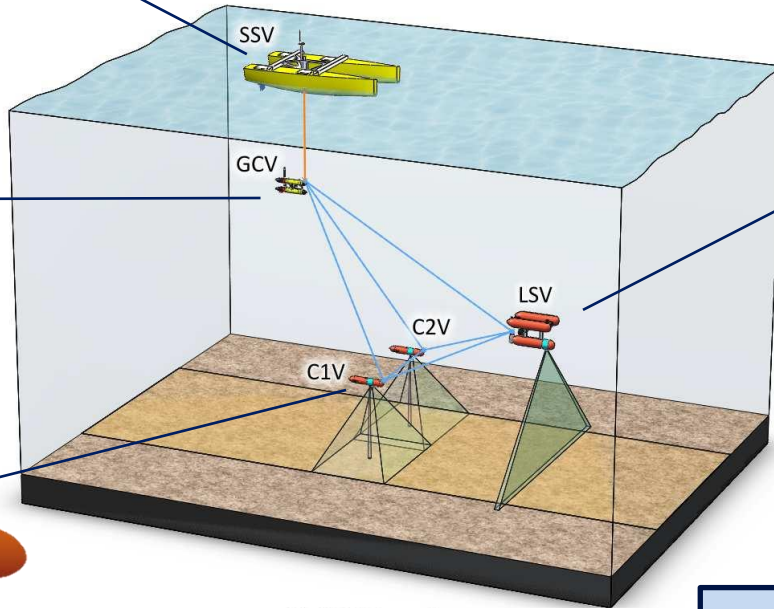
Key MORPH concept:
*a self-reconfiguring robot for operations in
complex 3D marine environments*



The adaptive MORPH configuration



MORPH Vehicles



9 partners
5 vehicle providers



TÉCNICO LISBOA



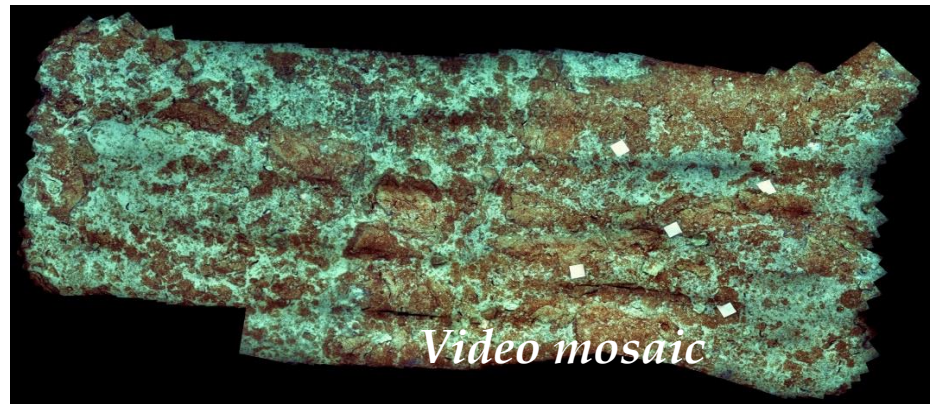
IACOBS UNIVERSITY

ILM ENAU UI IVERSITY OF TECHNOLOGY

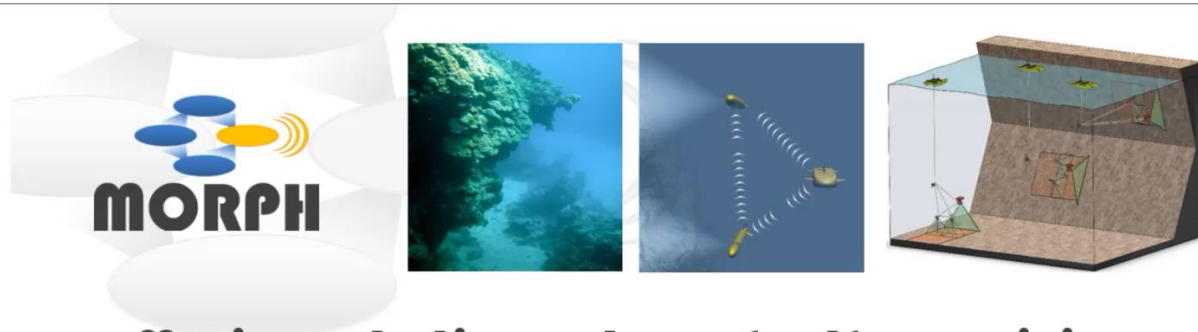


MORPH / EC (2012-2016)

Cooperative Marine Robots for Marine Habitat Mapping
in Complex Underwater Environments: A New Paradigm



MORPH Azores, PT, 2014



**Marine robotics system of self-organizing
logically linked physical nodes**

Azores trials 2014



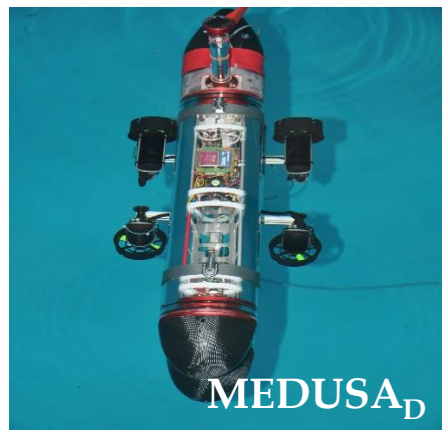
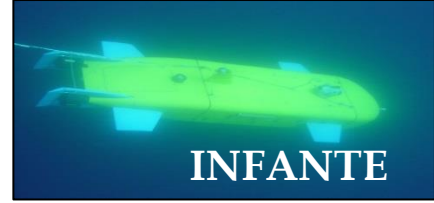
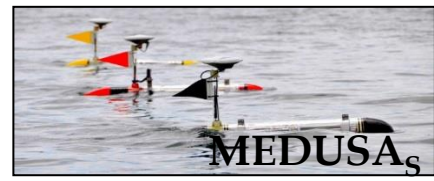
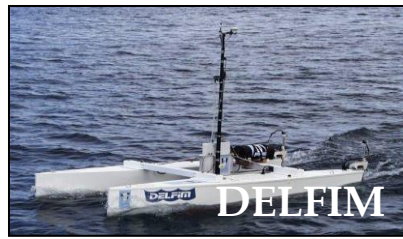
MORPH Girona , SP, 2015



Making it all happen: UAVs, AUVs, ASVS

Transition from the Lab to the Real World

through *in-house development of advanced systems and tools* (e.g. marine and air robots, software tools for operational oceanography).



**Fleet of 3 autonomous surface and 4 underwater robots
Several air vehicles**



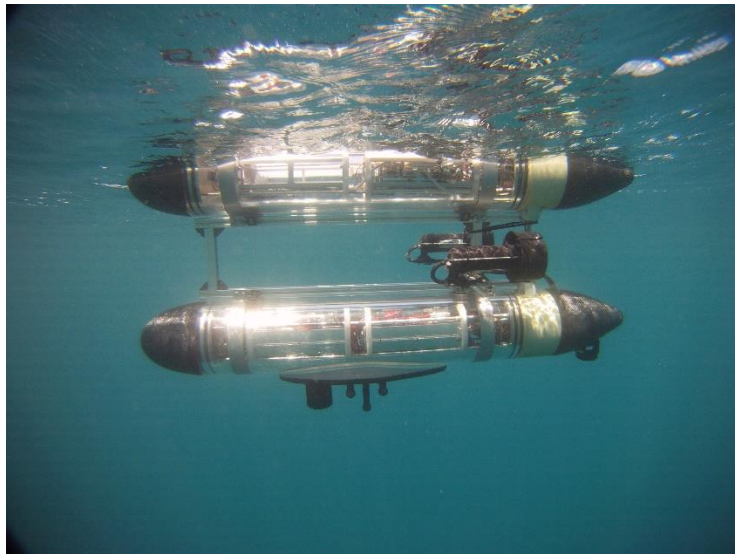
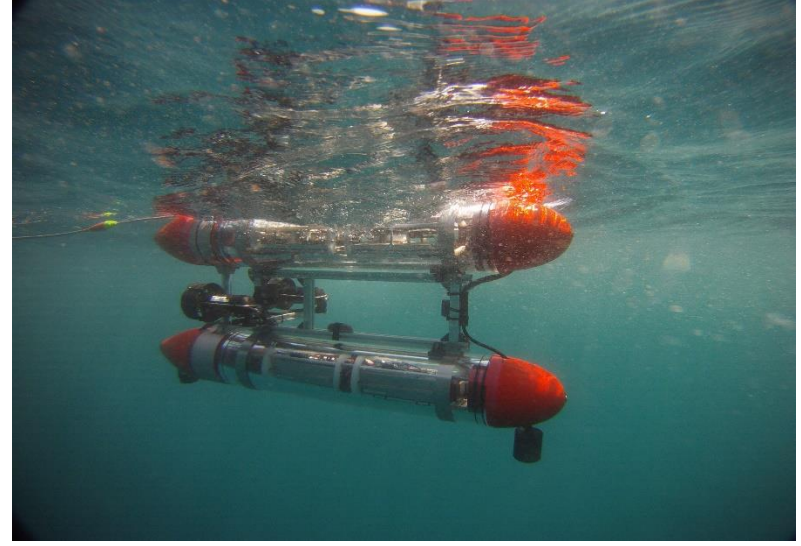
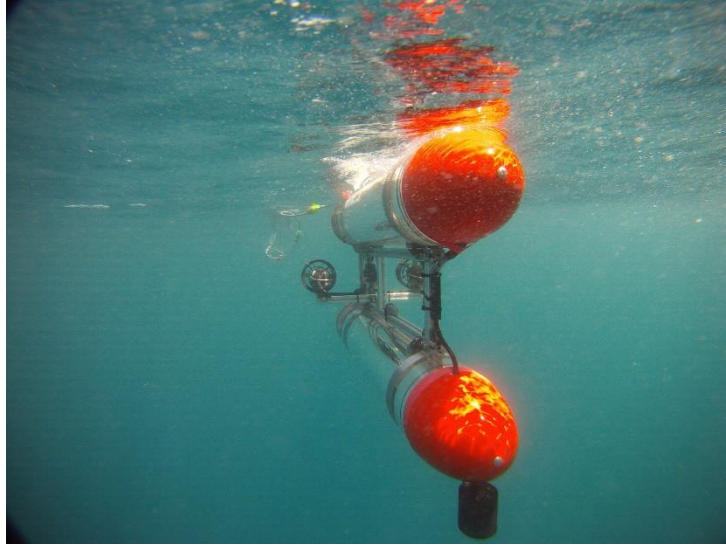
The sea-going machines



The MEDUSA vehicles



Labs and equipment



Acoustics-enabled formation control
(MORPH project, AZORES, Sept. 2014)

The MEDUSA-class vehicles (AUV/ASV)



Transportation and deployment



3 MEDUSAs can be transported in a van or small trailer



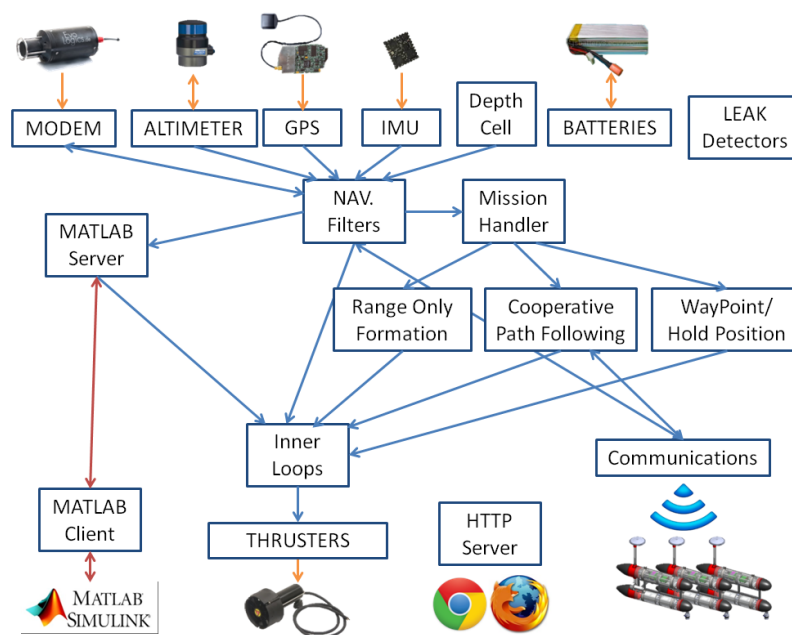
Transportation to water by a single person in a cart

The same cart can be used to deploy/recover the vehicle



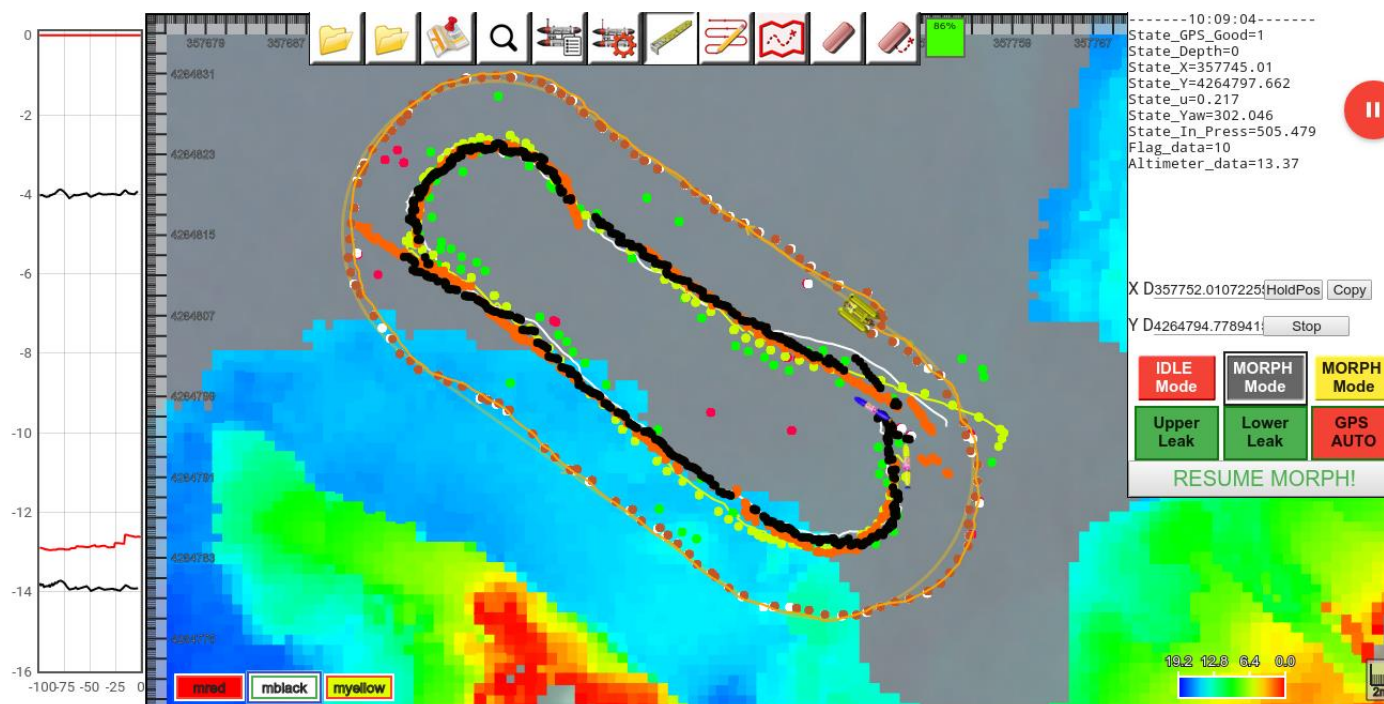
Software architecture overview

- Built in **ROS** (Robot Operating System)
- Easy to extend: create *nodes* that *subscribe* to existing *topics* to obtain information, then *publish* to other *topics* related to lower-level features
- Lots of *packages* publicly available from the community



Mission control console

- Browser-based: works in different OSs and browsers, adopting Google's *Material Design* guidelines – ongoing
- Enables operator to visualize vehicle positions in a map, monitor vehicle states, issue commands to vehicles
- Design/load complex missions or bathymetry data from files

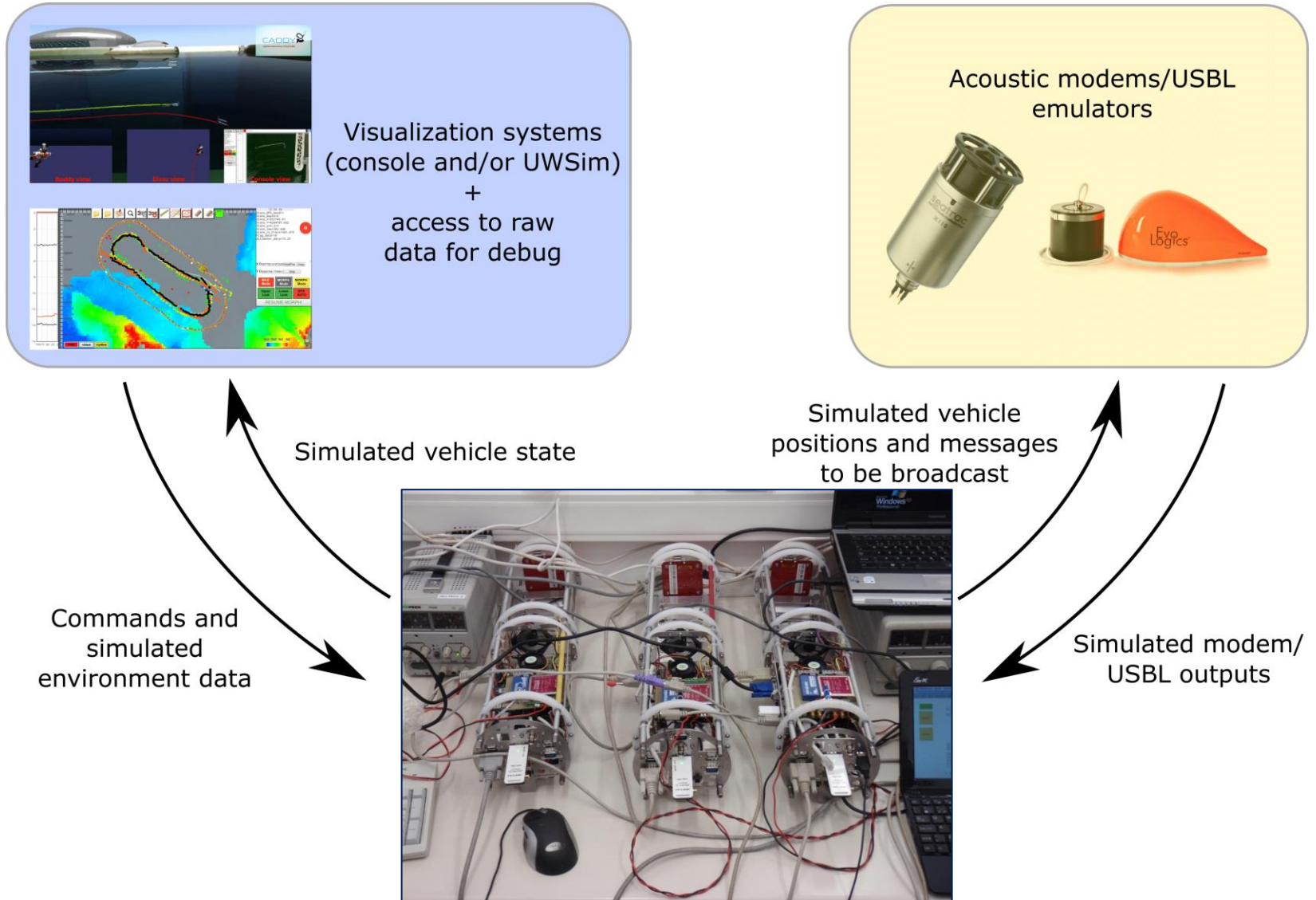


Mission programming

- Draw missions containing complex shapes by connecting segments
- Can be exported and imported through mission files



Simulation pipeline





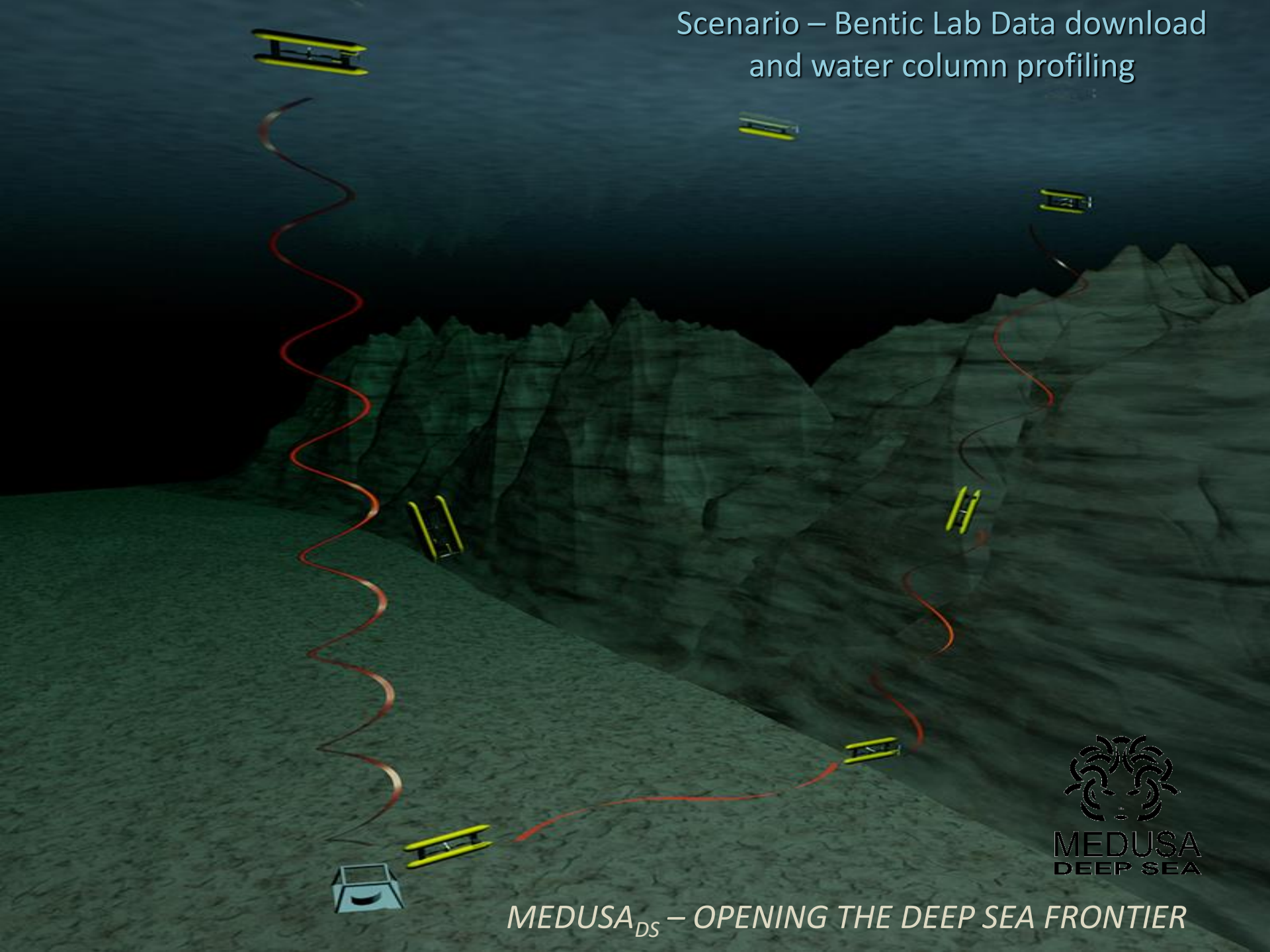
“MEDUSA_{DS} – OPENING THE DEEP SEA FRONTIER”

(2015-2017)

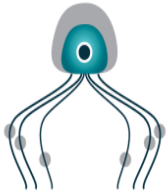
MEDUSA_{DS} / EC (2015-2017)



Scenario – Benthic Lab Data download and water column profiling

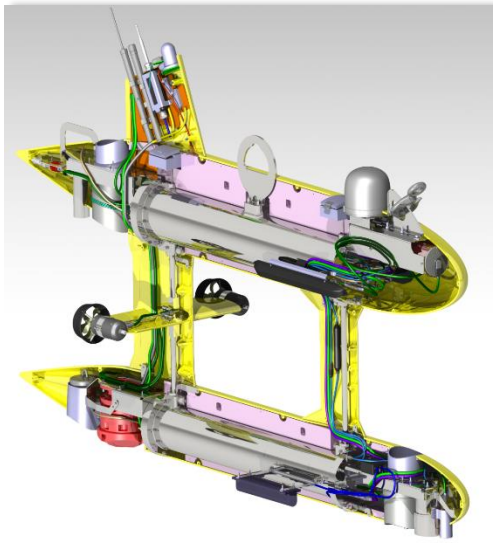


MEDUSA_{DS} – OPENING THE DEEP SEA FRONTIER



MEDUSA
DEEP SEA

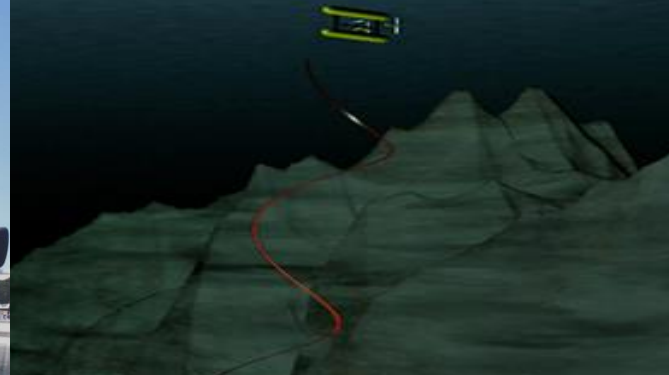
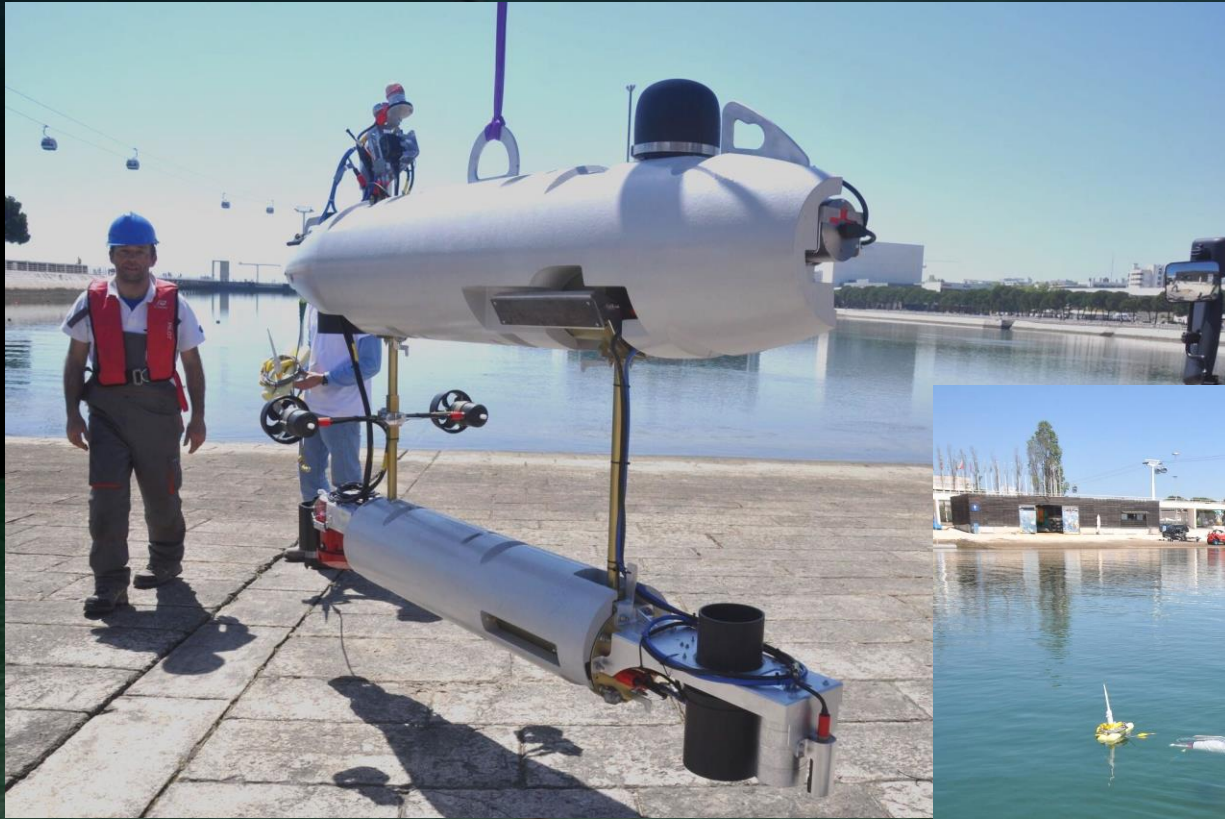
OPENING THE DEEP-SEA FRONTIER



*Tales of
Housing pre*



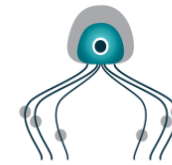
Scenario – Benthic Lab Data download and water column profiling



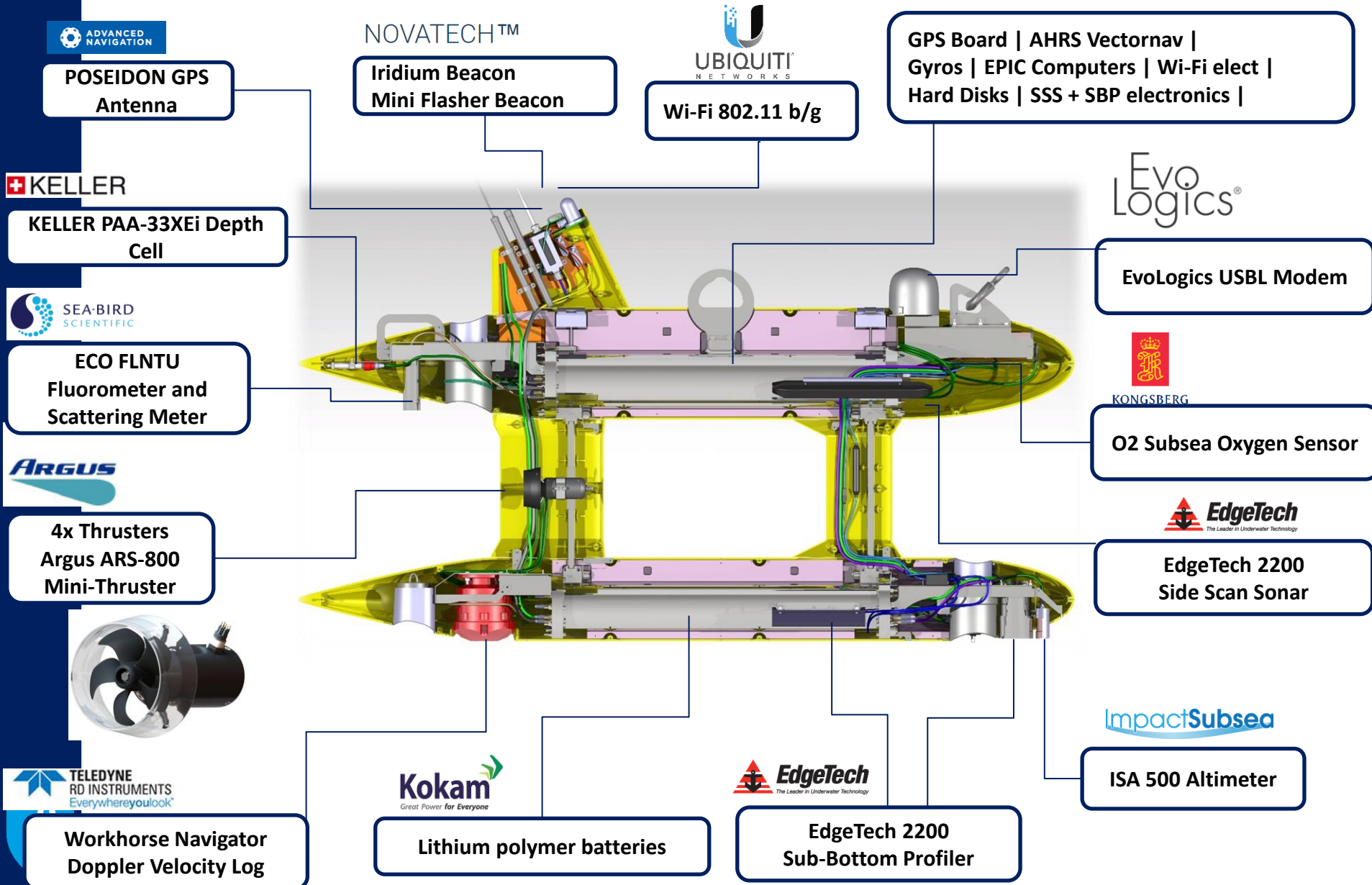
MEDUSA
DEEP SEA

MEDUSA_{DS} – OPENING THE DEEP SEA FRONTIER

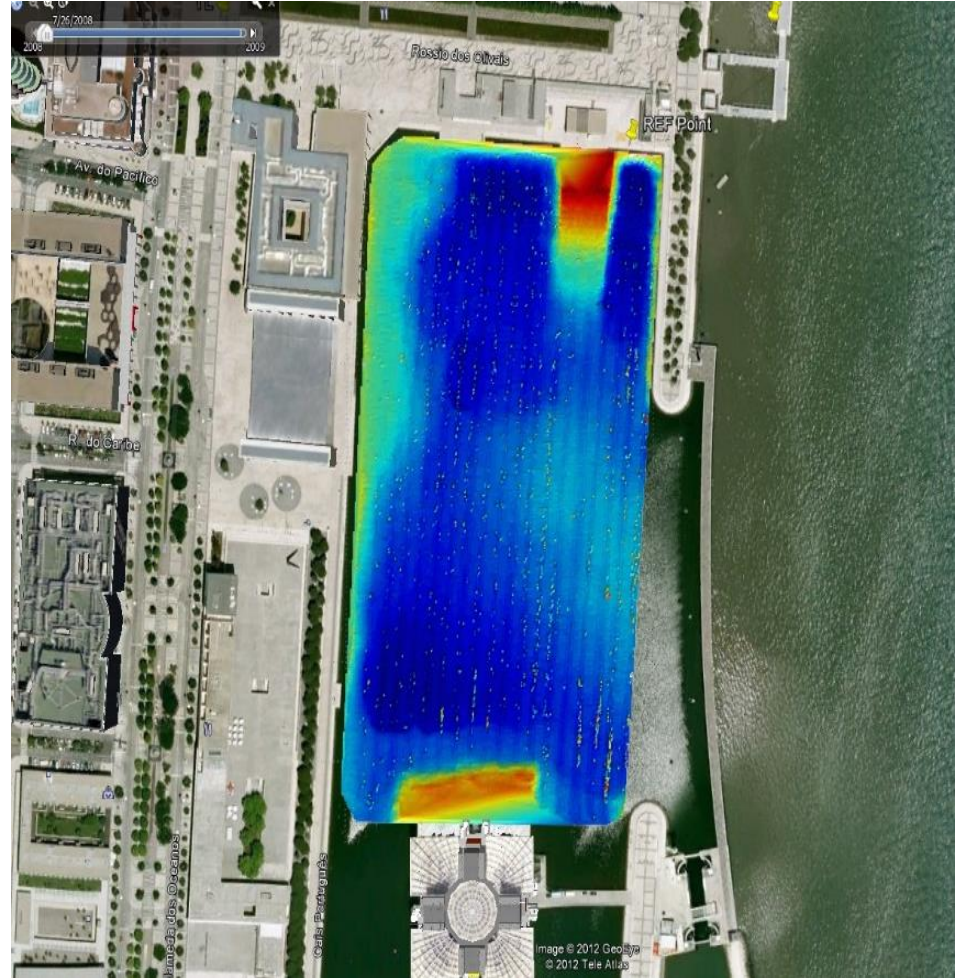
System Breakdown



MEDUSA
DEEP SEA



Test Facilities

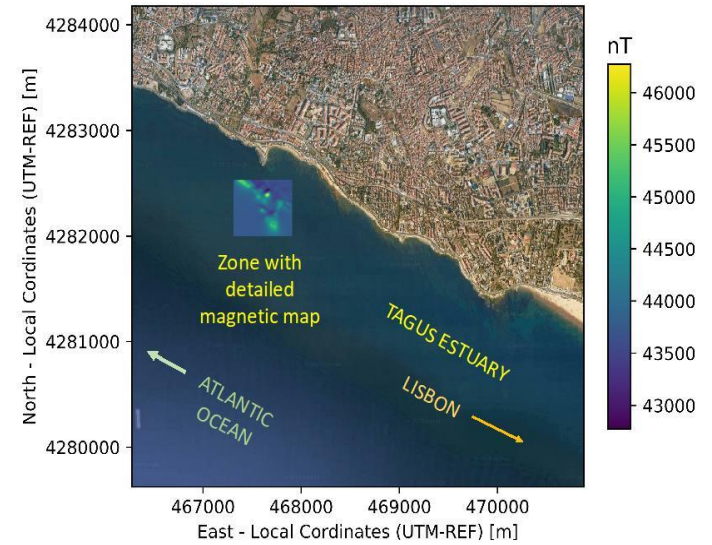


EXPO'98 Site, Lisbon, PT

Test Facilities



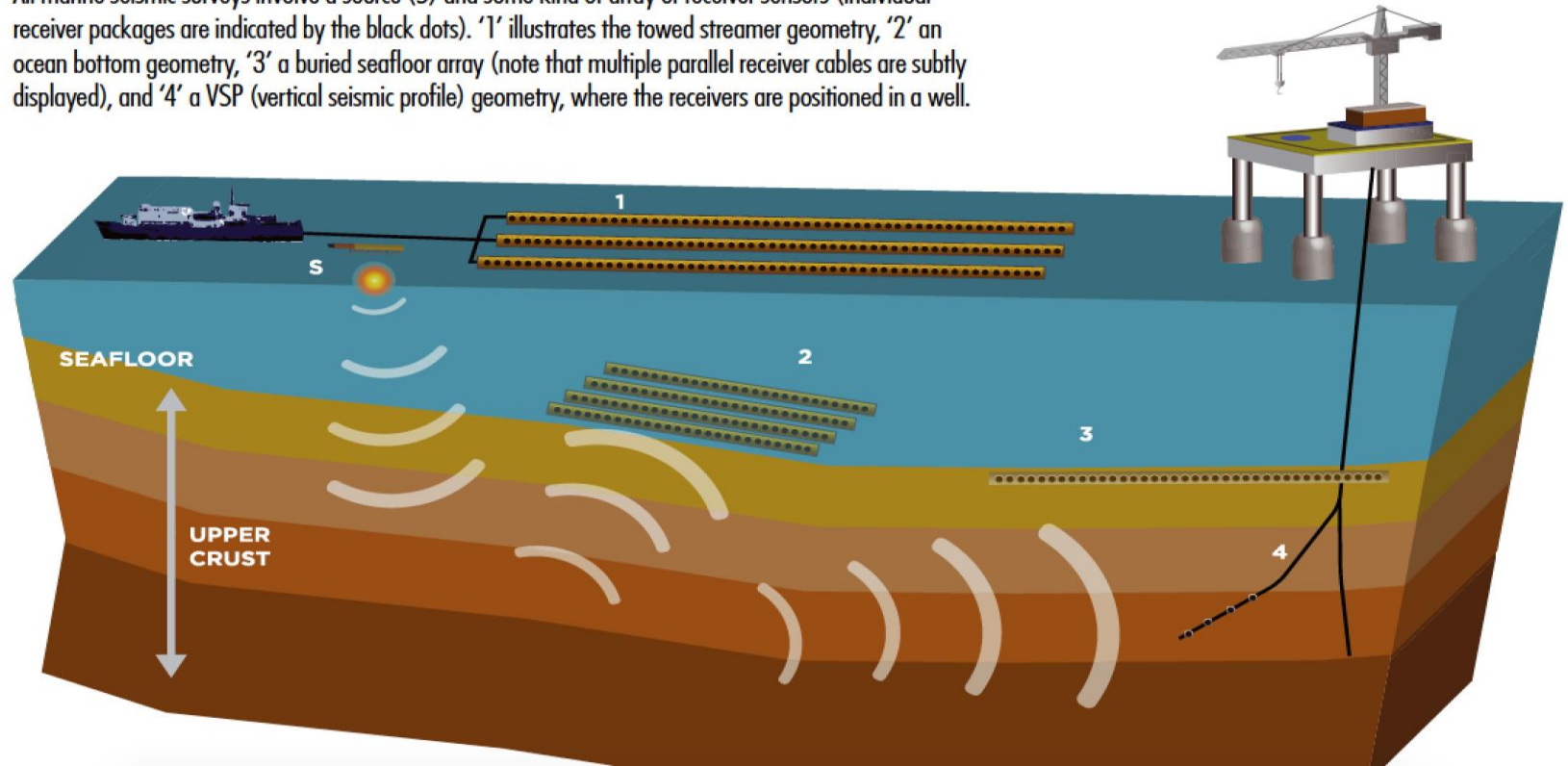
S. Pedro do Estoril - Prior Total Magnetic Field Map



Tagus River, Portugal

Probing under the seabed : the EC WiMUST project

All marine seismic surveys involve a source (S) and some kind of array or receiver sensors (individual receiver packages are indicated by the black dots). '1' illustrates the towed streamer geometry, '2' an ocean bottom geometry, '3' a buried seafloor array (note that multiple parallel receiver cables are subtly displayed), and '4' a VSP (vertical seismic profile) geometry, where the receivers are positioned in a well.



S-acoustic source

1-Towed receiver geometry (hydrophones)

2- Ocean bottom geometry

3- Buried seafloor array

4- Vertical seismic profiler

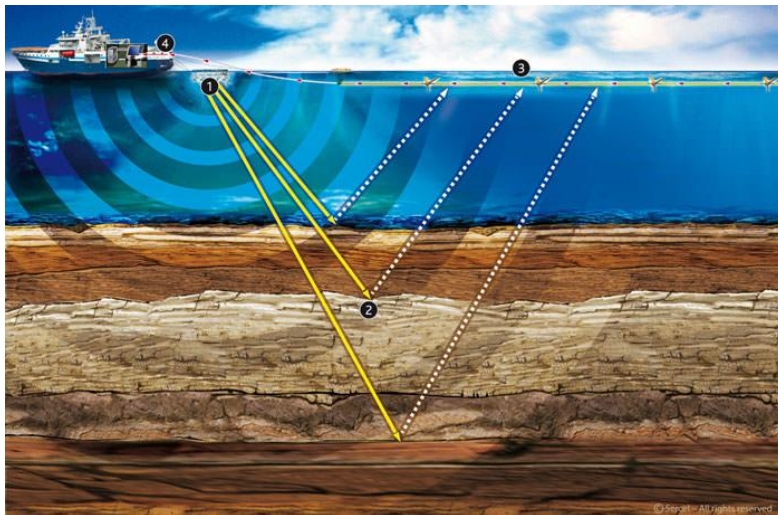


WiMUST

Widely scalable Mobile
Underwater Sonar Technology

Marine seismic surveys

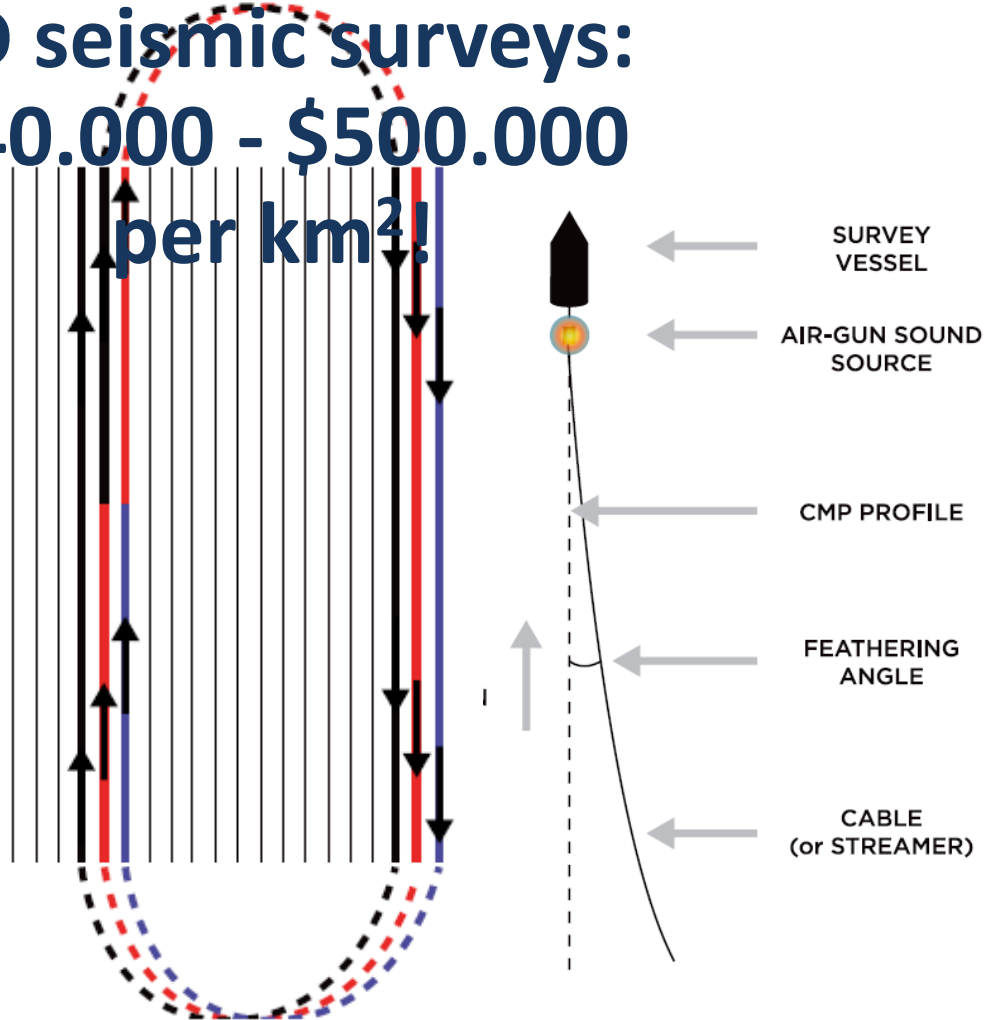
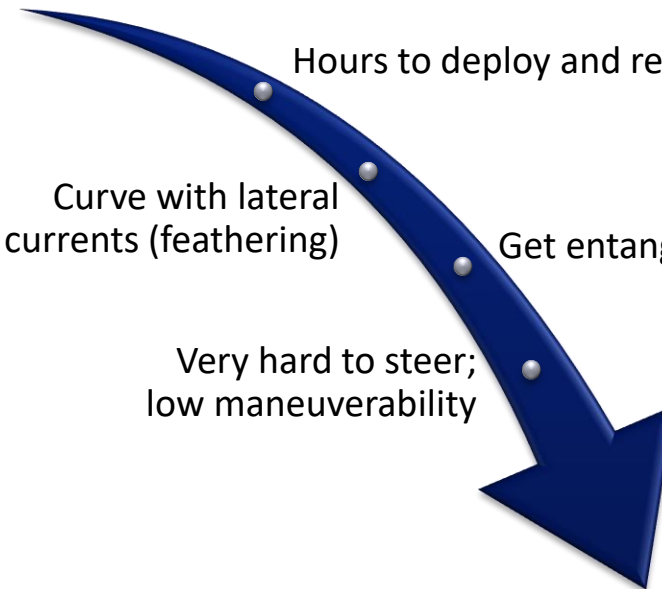
- Vessel tows **acoustic sources** and long cables (**streamers**) up to 10km long, equipped with **hydrophones**, very close to the surface
- Acoustic sources shoot, waves reflect/refract off geological features on and beneath the seabed, hydrophones pick up these reflections
- Processing allows for inference of geophysical features



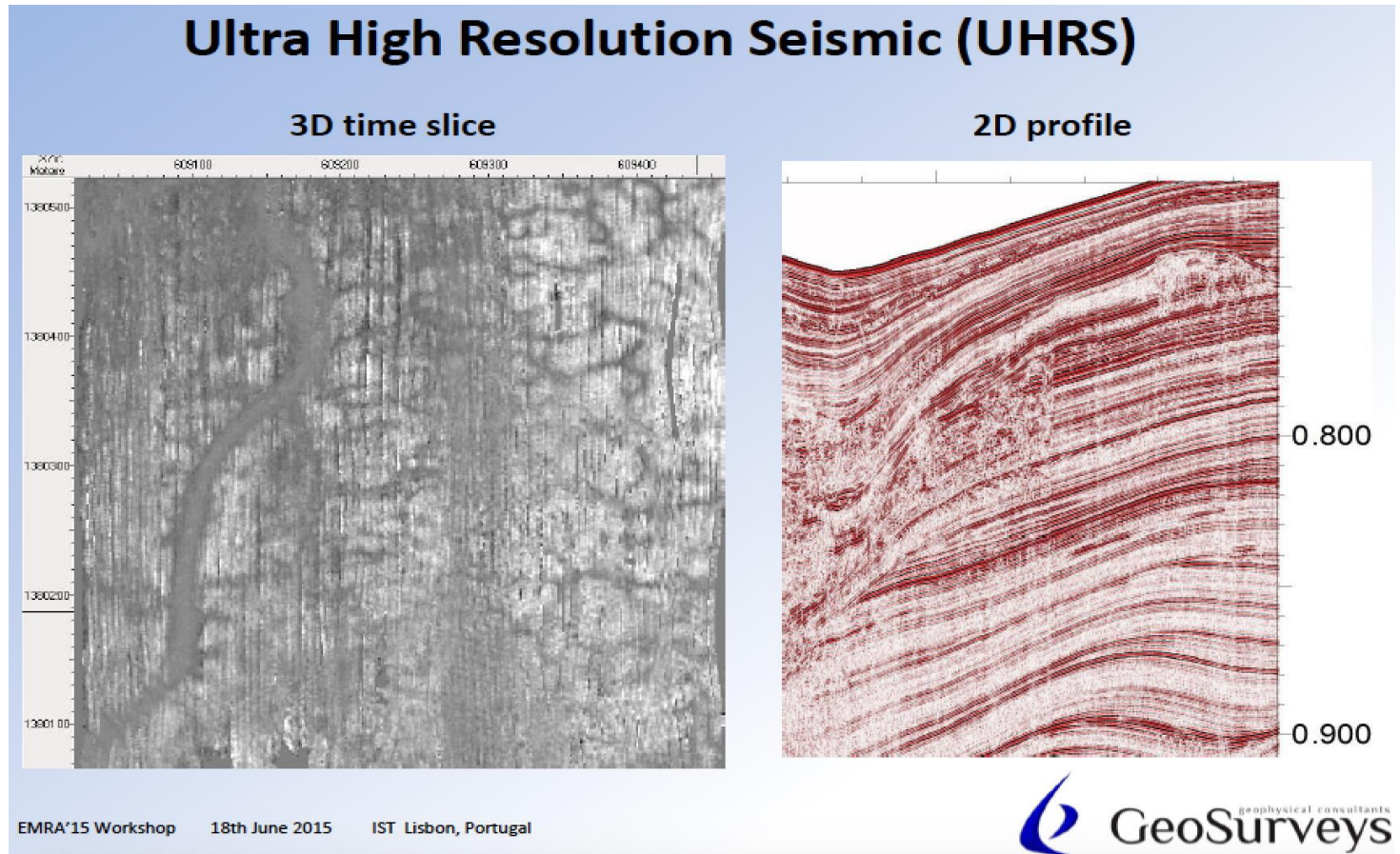
Marine seismic surveys

3D seismic surveys:
\$40.000 - \$500.000
per km²!

Very long streamers

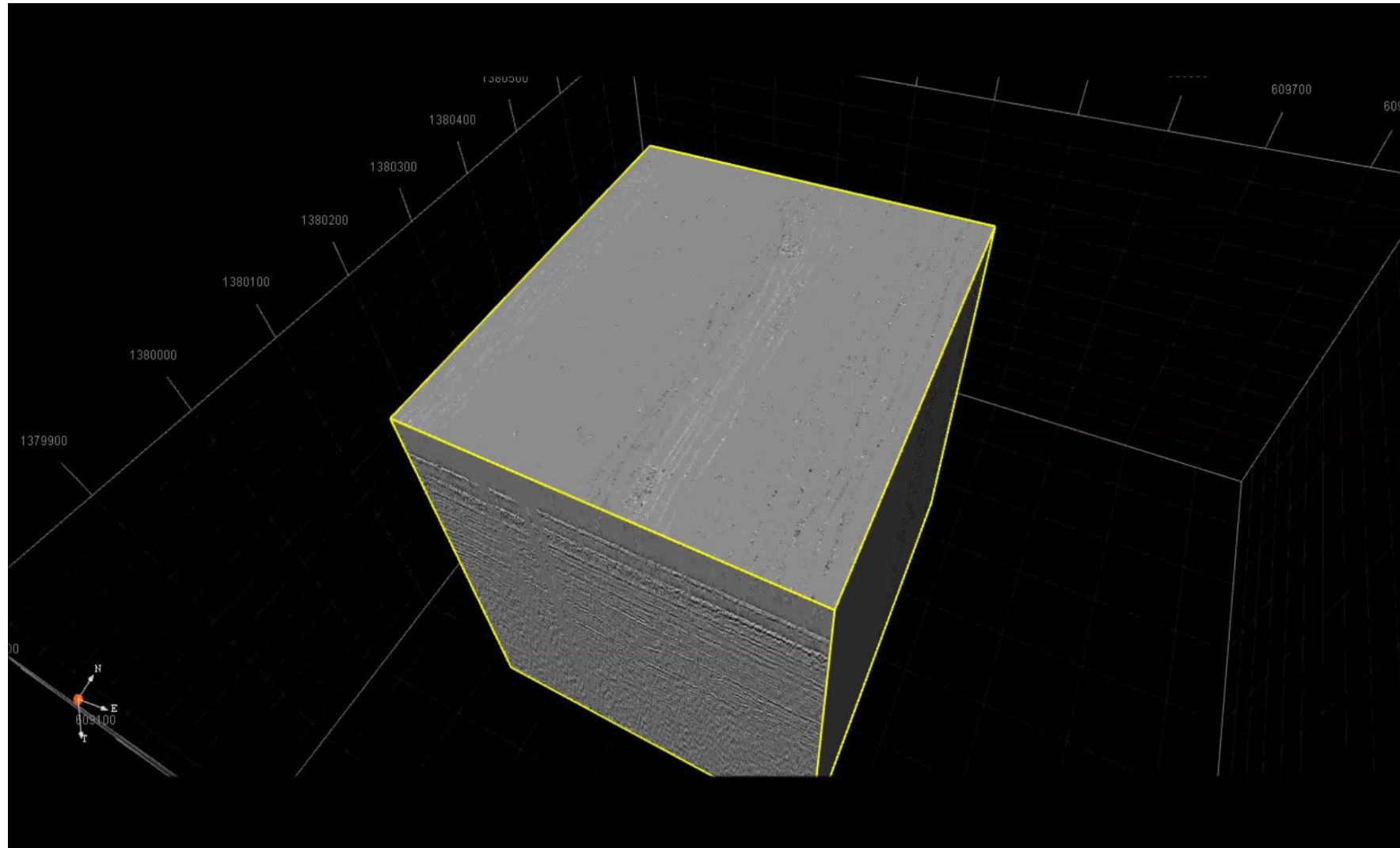


Ultra high resolution Seismic Surveys in 2D and 3D 64



Key applications: design of foundations for overwater and subsea structures and anchors; assessment of burial performance for pipelines and cables – marine windfarms

Ultra High Resolution Seismic (UHRS) surveys



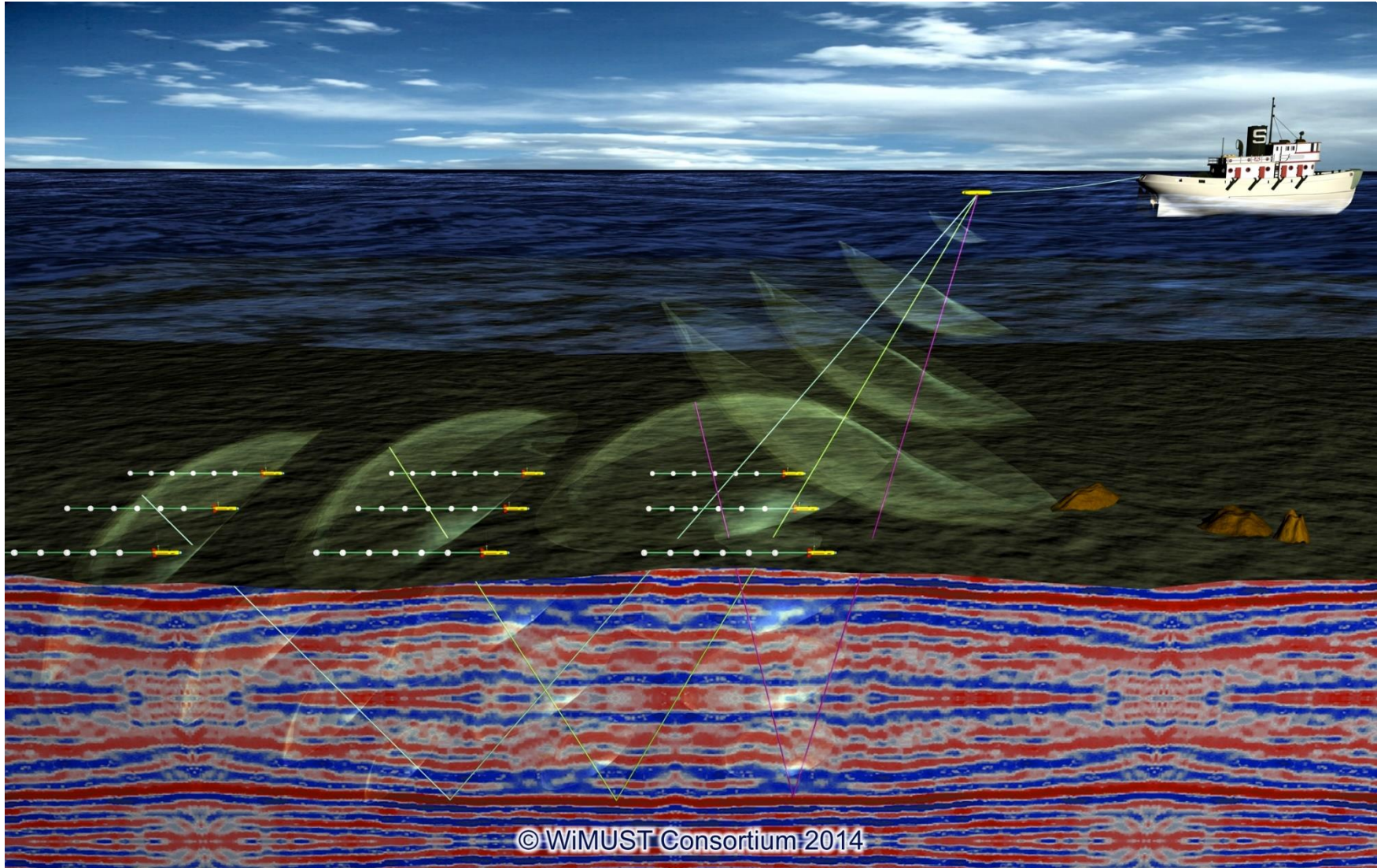
Courtesy of Henrique Duarte, GeoSurveys, Aveiro, PT



The WiMUST concept

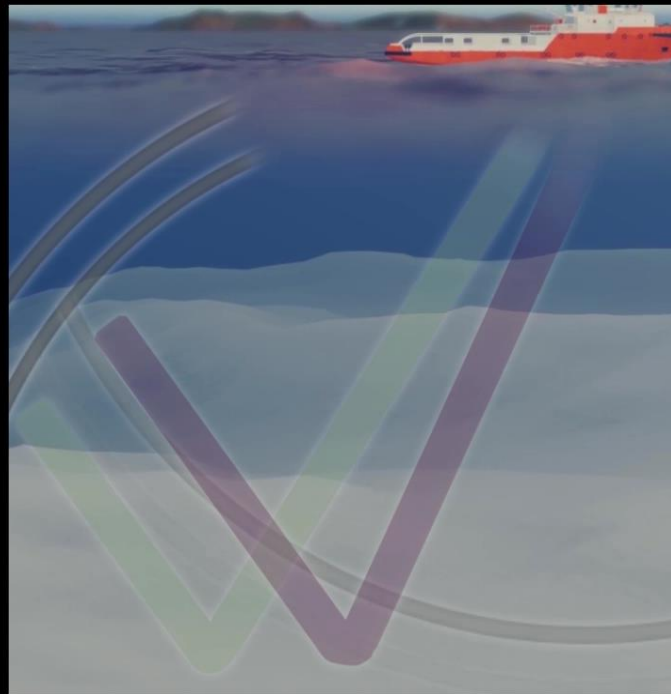


WiMUST
Widely scalable Mobile
Underwater Sonar Technology



The WiMUST concept

2:42



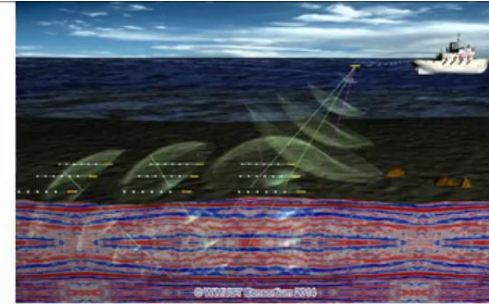
A new concept: automated seismic surveys



A new concept: automated seismic surveys



WiMUST
Widely scalable Mobile
Underwater Sonar Technology



WimUST **Widely scalable mobile Underwater Sonar** **Technology**

Lisbon trials December 2015
- 2 ASVs towing 2 streamers -

<http://www.wimust.eu/>



University of
Hertfordshire



Integration of Sparkers and Power Supplies on Autonomous Vehicles (world premiere)



Integration of Sparkers and Power Supplies on Autonomous Vehicles

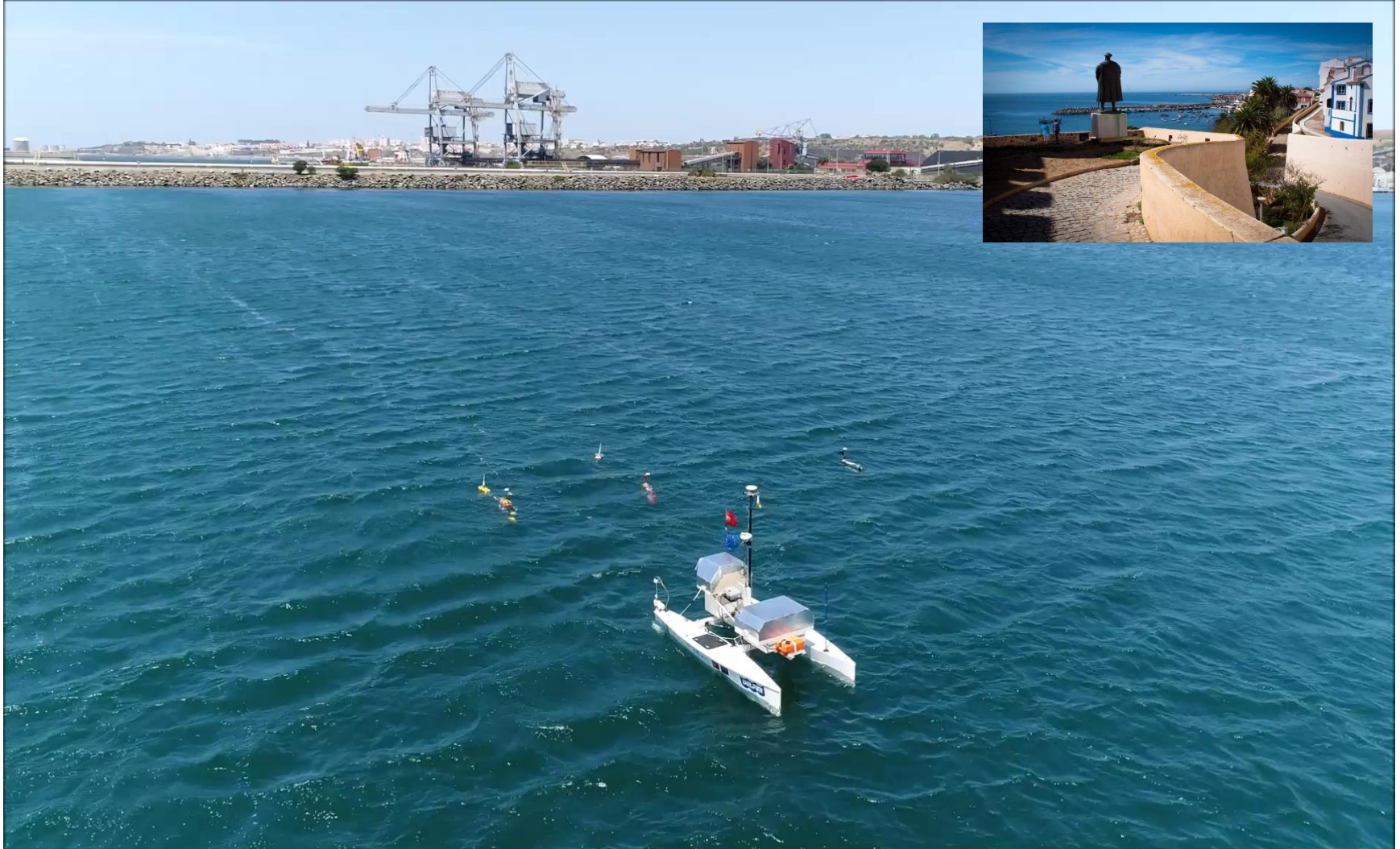


Integration of Sparkers and Power Supplies on Autonomous Vehicles



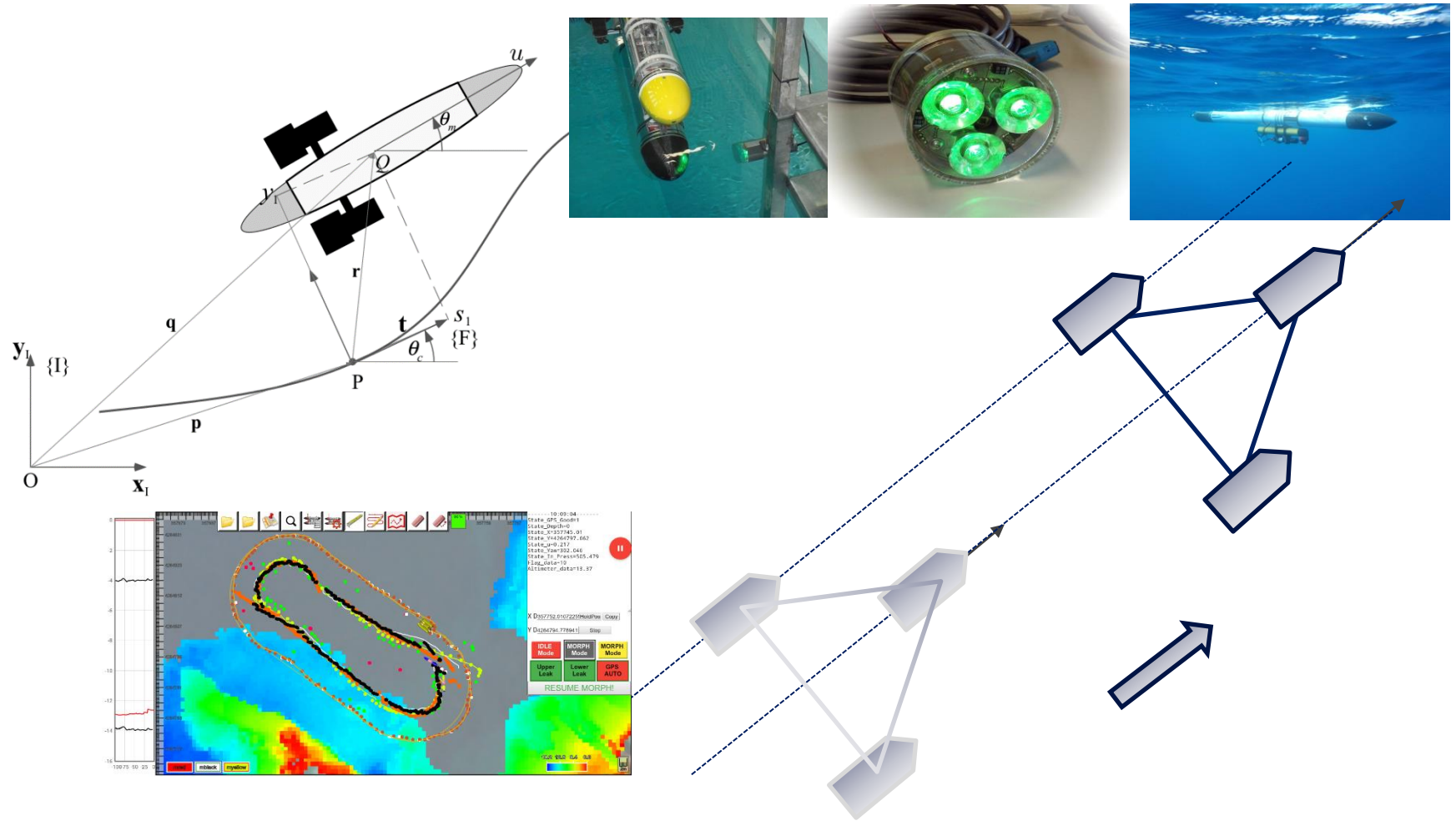
ULISSE, ISME, Italy

Automated Sparkers/Receivers: Field Tests



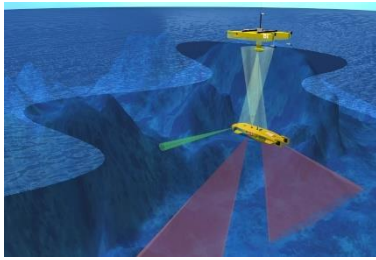
SINES. July 2017

The theory behind: a glimpse



Cooperative, Networked Motion Planning, Navigation, and Control
Nonlinear Control and Estimation, Range-based Localization, Optimization, Event-Driven Systems, Optical and Acoustic Communications





Mission
specification

Cooperative motion planning

Nominal trajectories &
desired vehicle formation

Cooperative motion control

Global and local, relative vehicle positions

Cooperative navigation

Cooperative systems: key blocks required

Strong parallel with Cooperative UAVs

Time-Critical Cooperative Control of Autonomous Air Vehicles

I. Kaminer • A. Pascoal • E. Xargay • N. Hovakimyan
V. Cichella • V. Dobrokhodov

The advent of powerful embedded systems and communications networks has spawned widespread interest in the problem of cooperative motion control of multiple autonomous vehicles that will be engaged in increasingly demanding scientific and commercial missions.

Time-Critical Cooperative Control of Autonomous Air Vehicles presents a theoretical framework that addresses new and challenging multiple vehicle mission requirements, yielding control strategies for temporal coordination of networked autonomous agents that are subjected to tight spatial constraints.

The book gives the reader a thorough, integrated presentation of the different concepts, mathematical tools, and networked control solutions needed to tackle and solve a number of problems in the general area of time-critical cooperative control. In particular, it integrates algorithms for path following and time-critical coordination that together give a team of unmanned air vehicles (UAVs) the ability to meet simultaneously desired spatial and temporal specifications.

By including case studies in the control of fixed-wing and multirotor UAVs, the book effectively broadens the scope of application of the methodologies developed. The theoretical presentation and simulations are complemented with the results of actual flight tests with real UAVs.

This book is intended for researchers and practitioners from academia, research labs, commercial companies, government agencies, and the international aerospace industry.

About the authors

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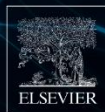
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ENGINEERING



Butterworth-Heinemann
An imprint of Elsevier
elsevier.com/books-and-journals

ISBN 978-0-12-809946-9



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Questions ?

