Marine Systems & Robotics
Cooperative Marine Robotic Systems: Theory and Practice – Part 1

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impact Erasmus+

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

marum JACOBS UNIVERSITY TAL TECH National Technical University of Athens University of Zagreb Universitat de Girona TÉCNICO LISBOA

The work of many

DSOR Group
dynamical systems and
ocean robotics

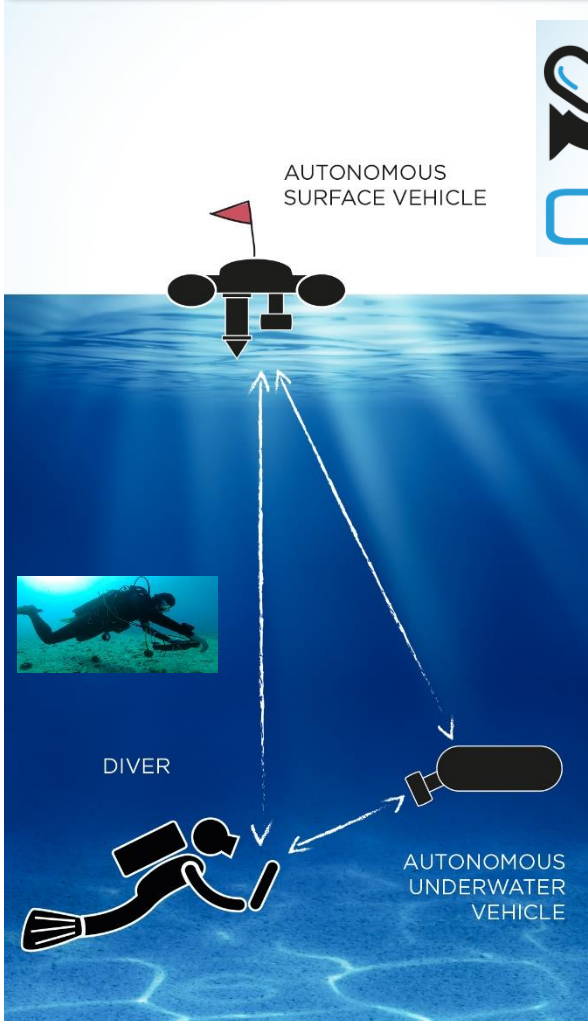
EC-CO_3AUVs 2009-2012

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

EC-MORPH 2012-2016

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

EC-CADDY 2014-2016



CADDY

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

EC-WiMUST 2015-2018

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

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

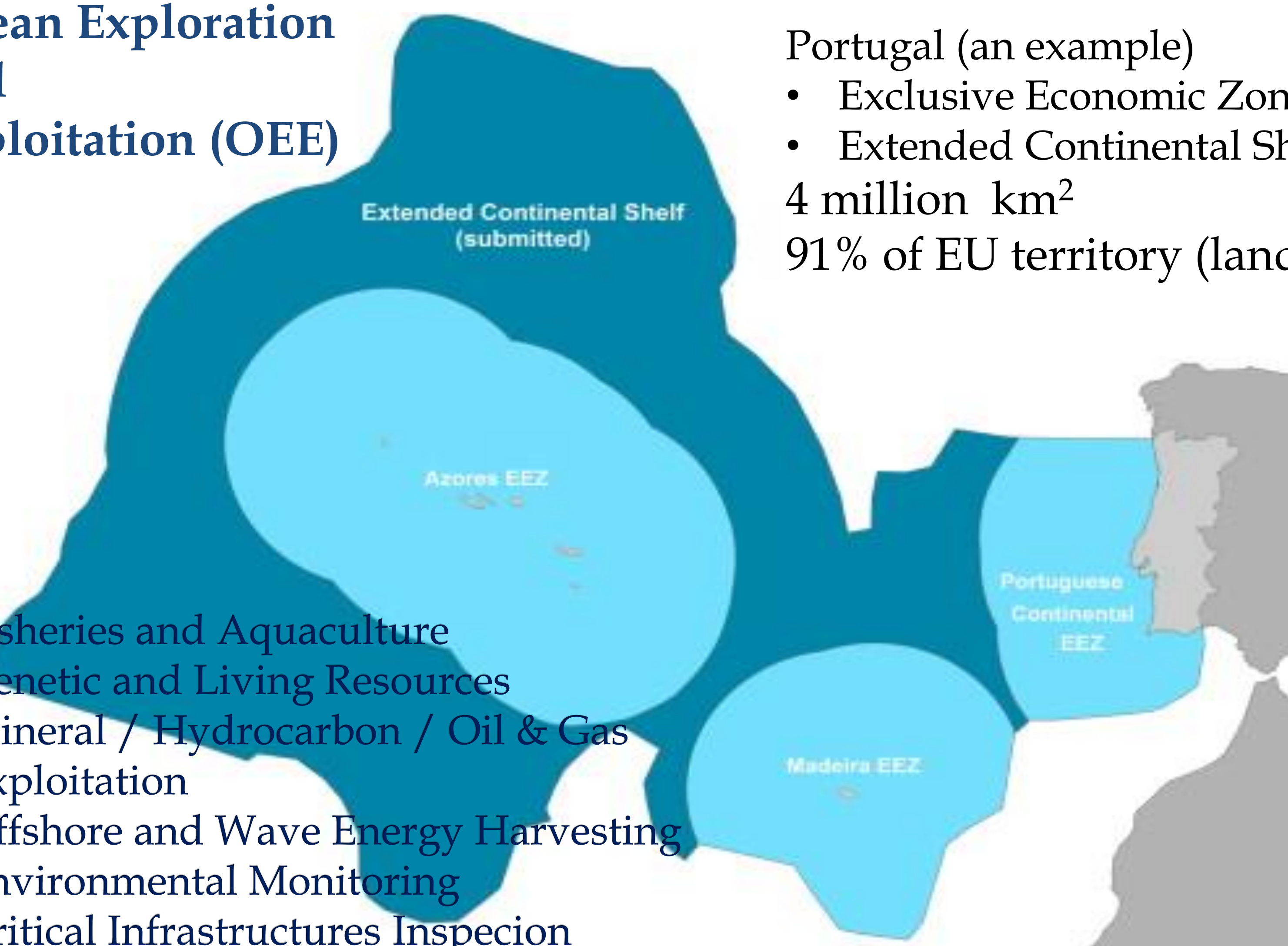
Ocean Exploration and Exploitation (OEE)

Portugal (an example)

- Exclusive Economic Zone
- Extended Continental Shelf

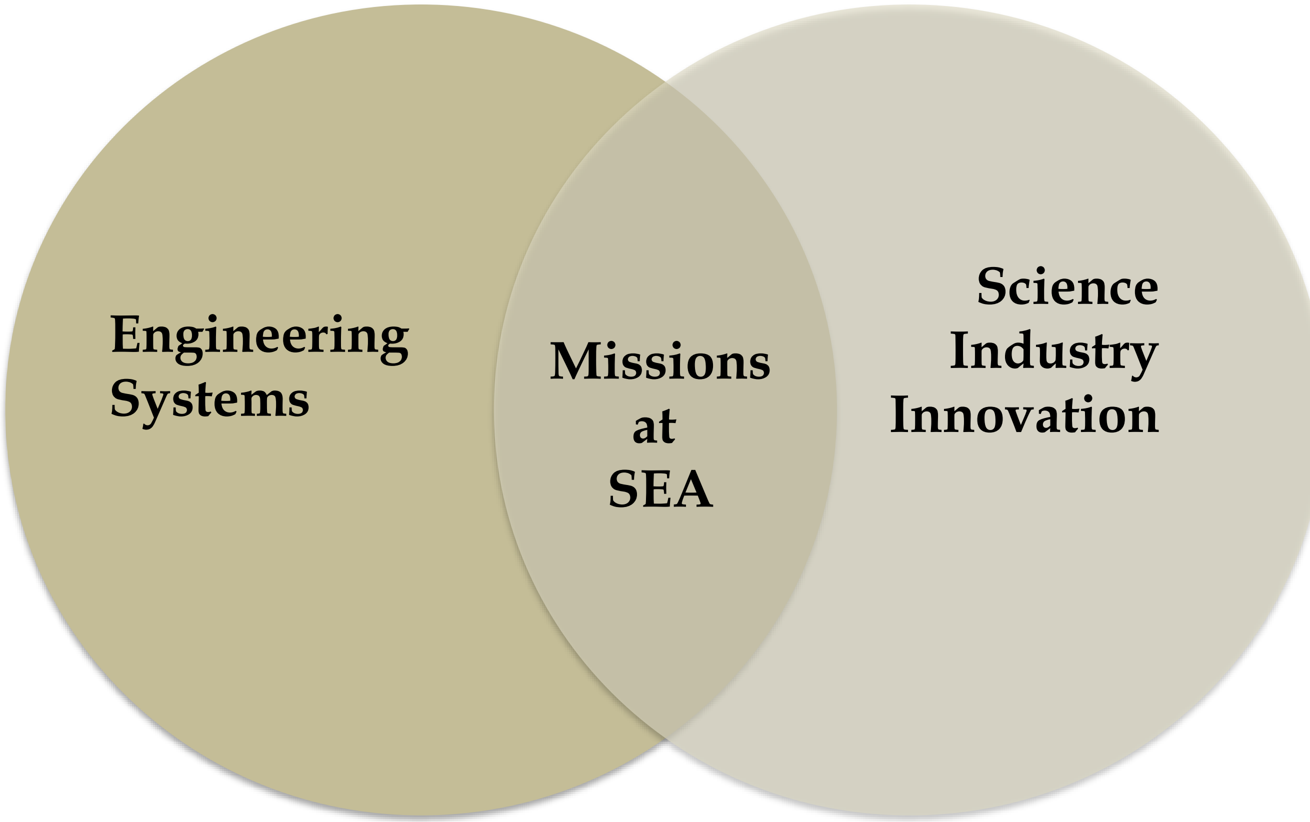
4 million km^2

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 Inspecion
- Maritime Logistics

The Pillars of Ocean Exploration and Exploitation



I - Engineering Systems - Technology
II - Science, Industry, Innovation

Knowledge Transfer, Outreach Activities

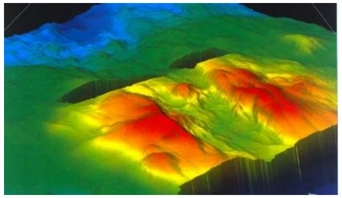
Technology for Science, Industry, and Management

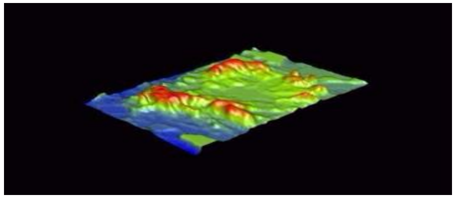
Automatic data acquisition in 3D

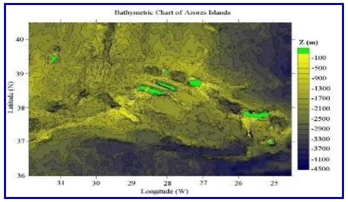
Data fusion

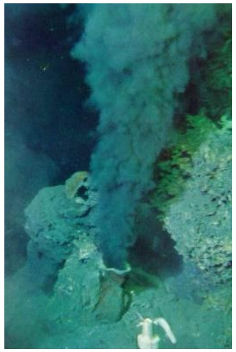
Info generation and dissemination

Scientific and commercial communities; civilian authorities

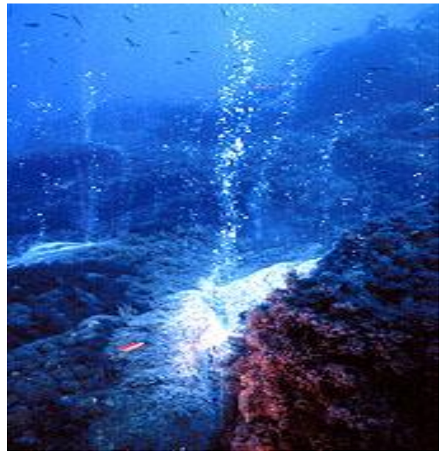


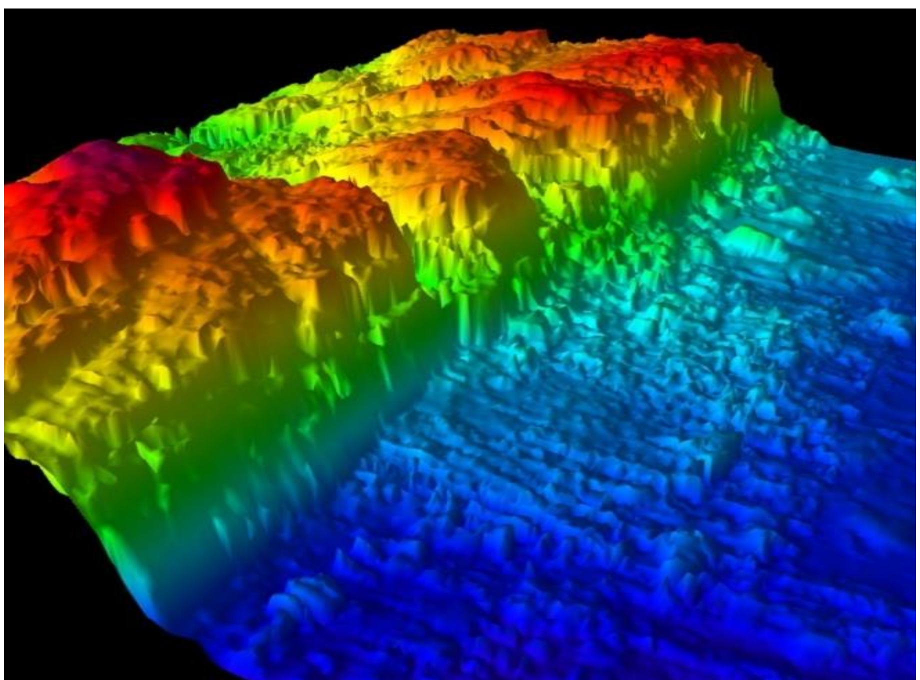






Scientific Challenges





To study the

Physical,
Chemical,
Biologic,
and Geologic

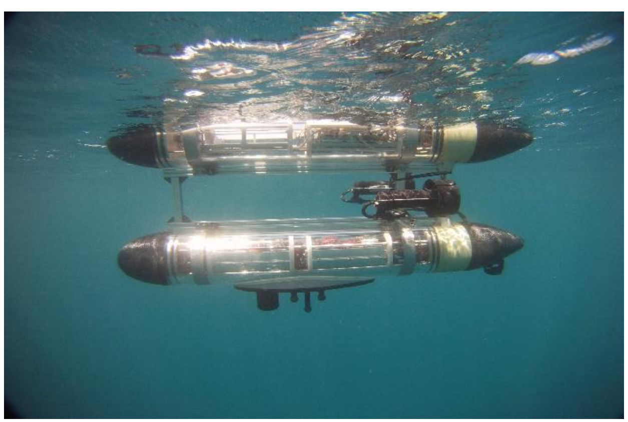
phenomena
that occur in the ocean
and its interfaces
(with the atmosphere
and the Earths´s
interior)

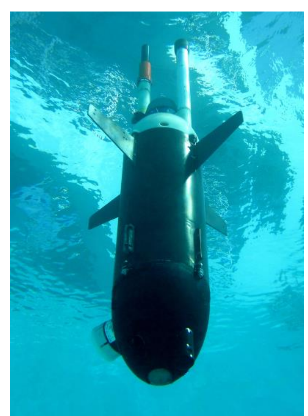
Observe, Monitor, and Map

The tools of the trade

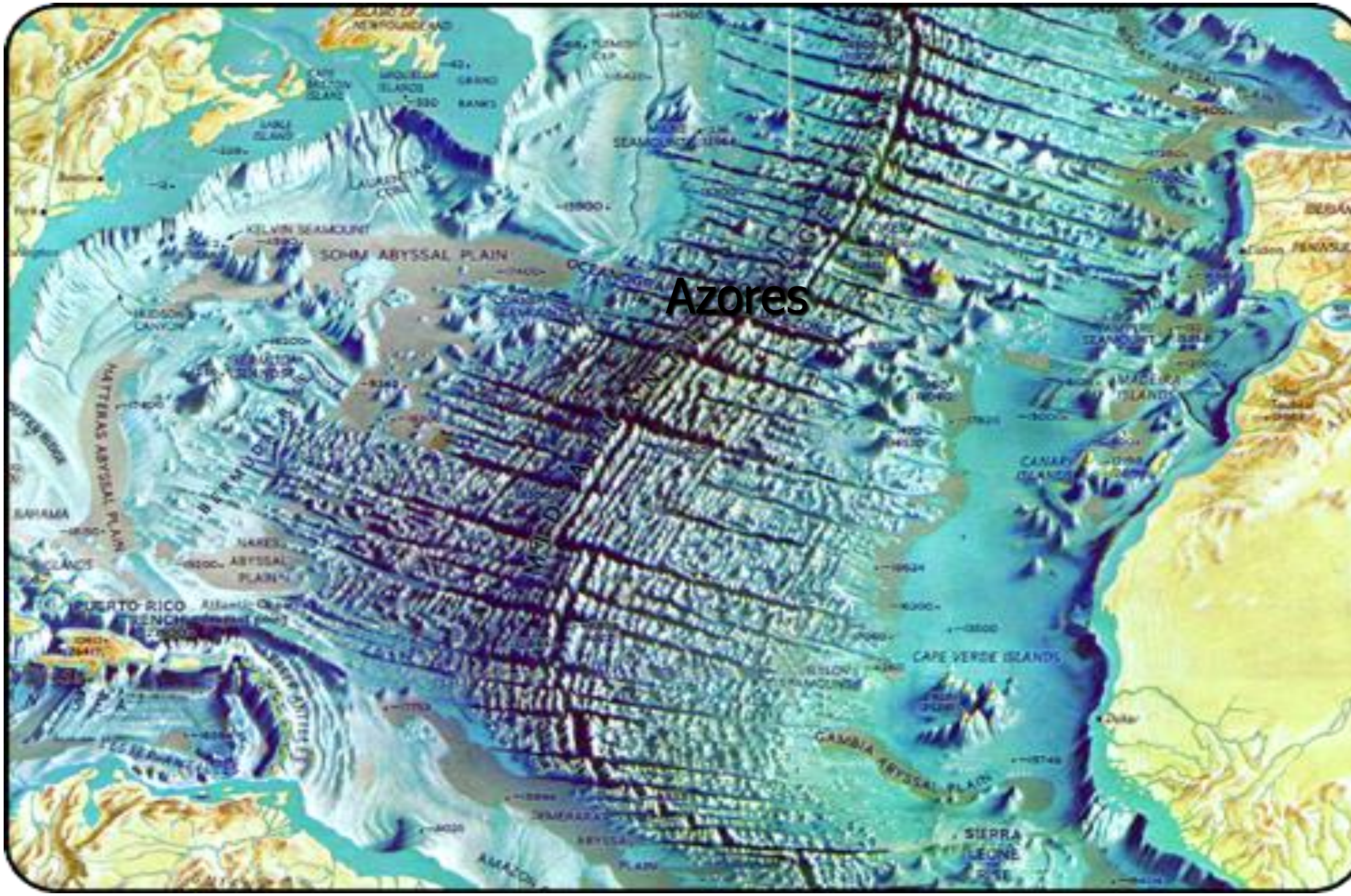
- **Technologies for ocean exploration including networked air and marine robots**

- **Robotic systems for the inspection of critical marine infrastructures and seabed/subbottom mapping**





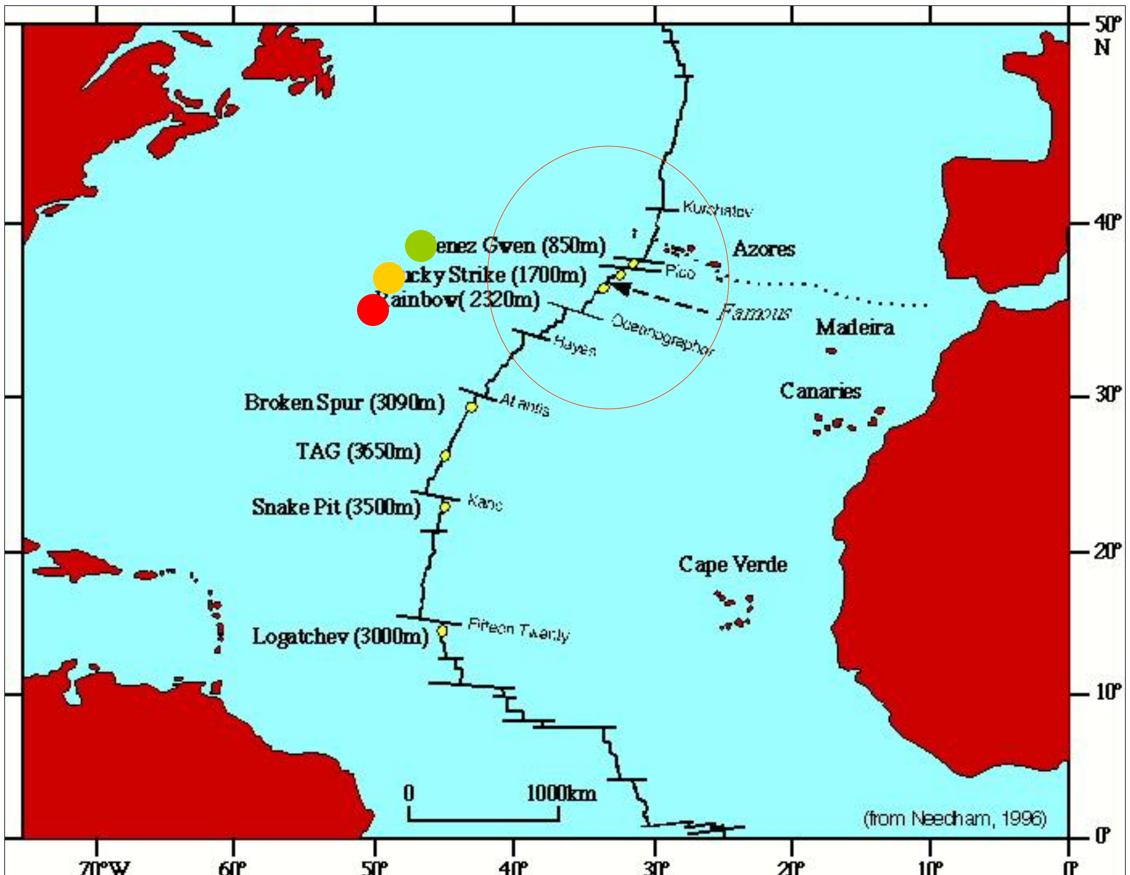
The Middle Atlantic Ridge and the Azores

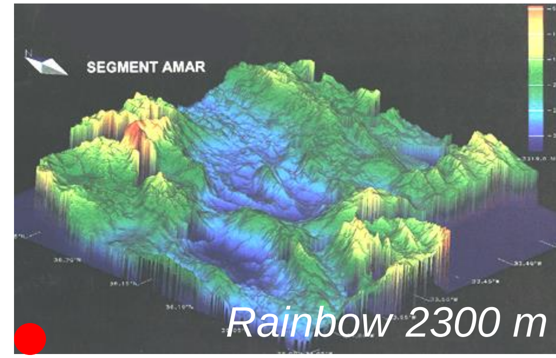


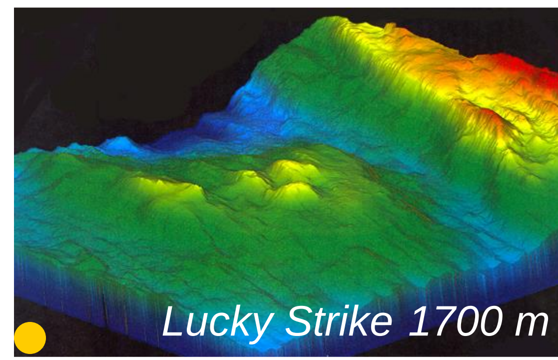
A chain of mountains at the bottom of the Atlantic ocean

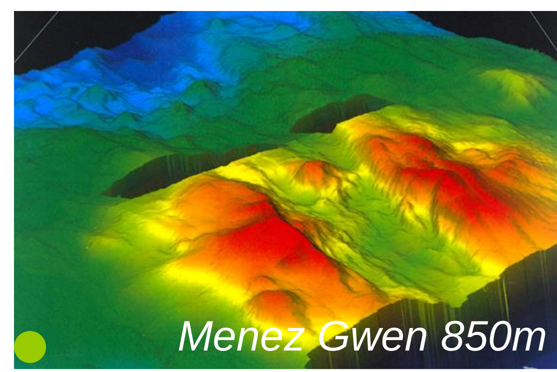
Mission Scenario

Underwater Hydrothermal Vents (Azores, Portugal)

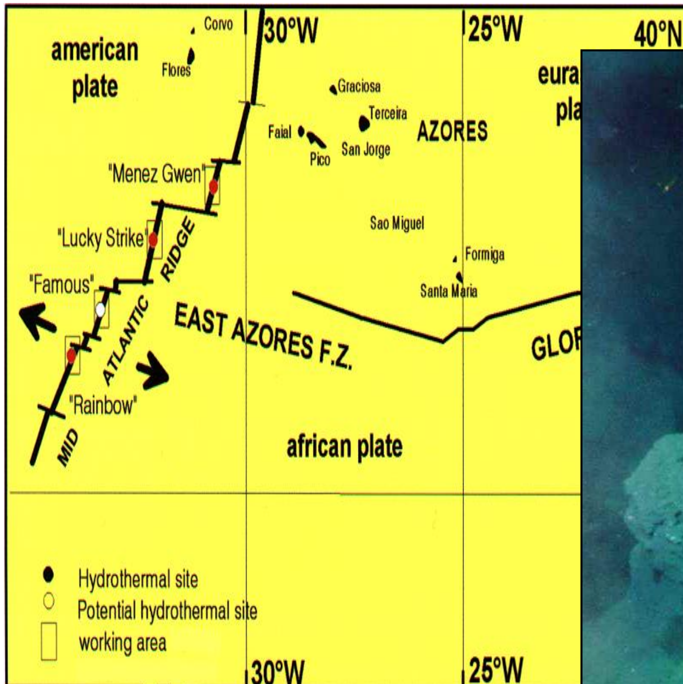


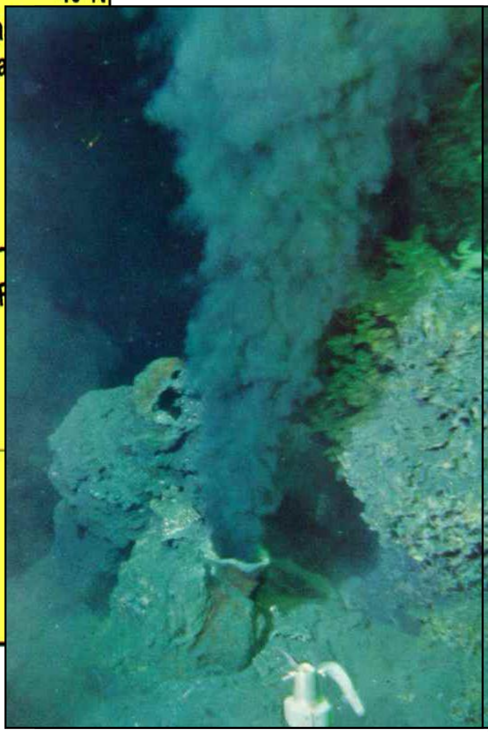


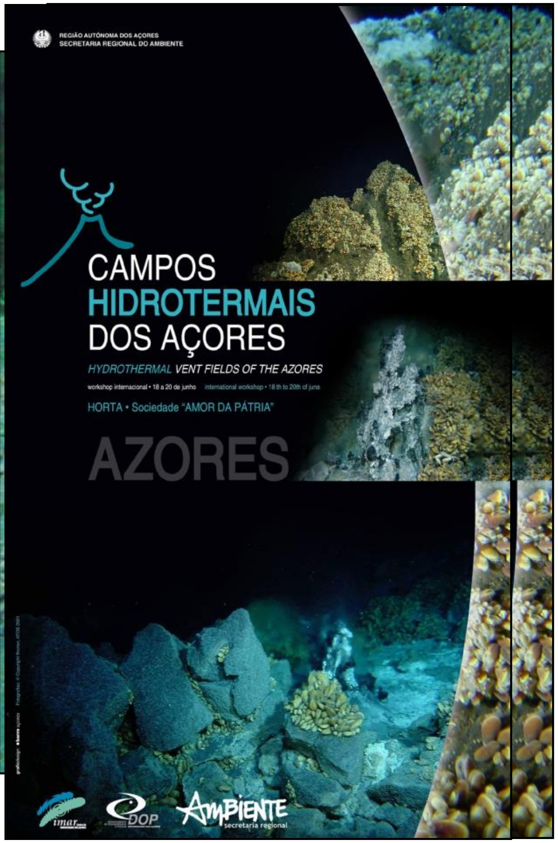




The Azores Triple Junction (ATP)

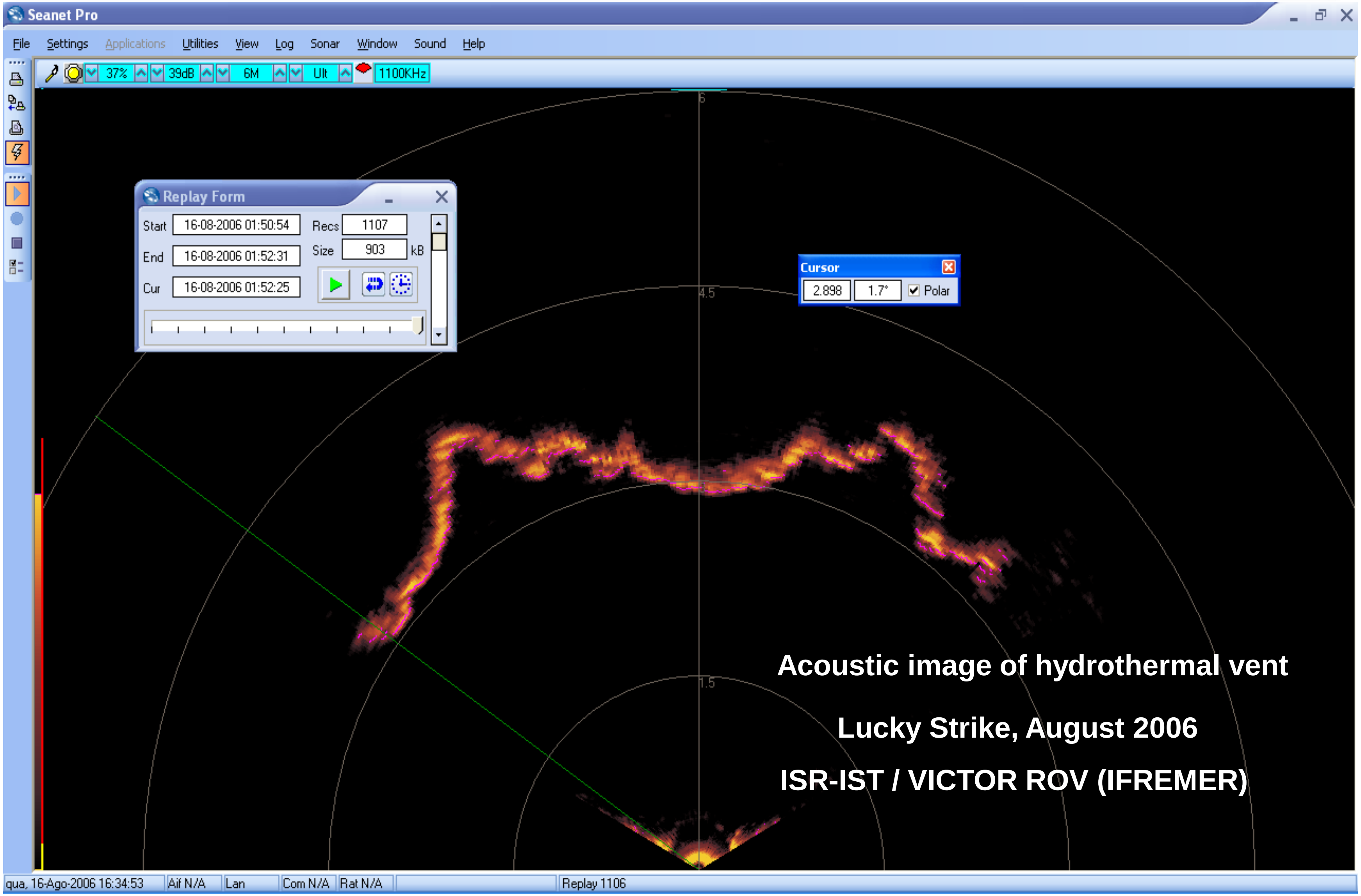






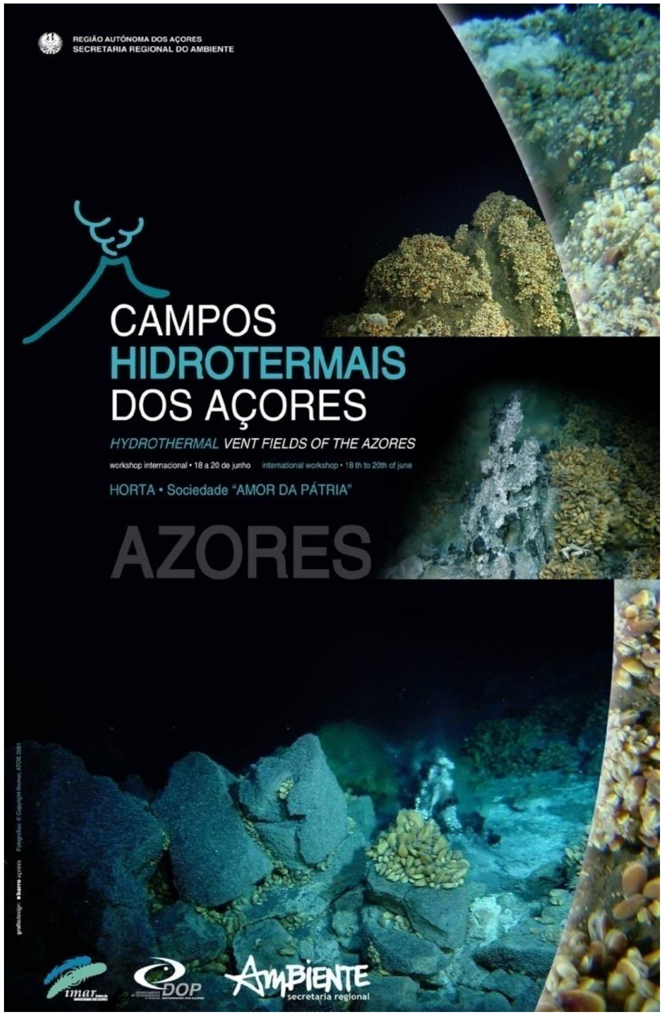
The region harbours a great variety of
seamounts, active underwater volcanoes,
chemosynthetic ecosystems, and "extreme" life forms (extremophyles)

Deep Water Hydrothermal Vents



Underwater Hydrothermal Vents

The Need for Technology



Vents are very hard to study:

Large depth (pressure is high)

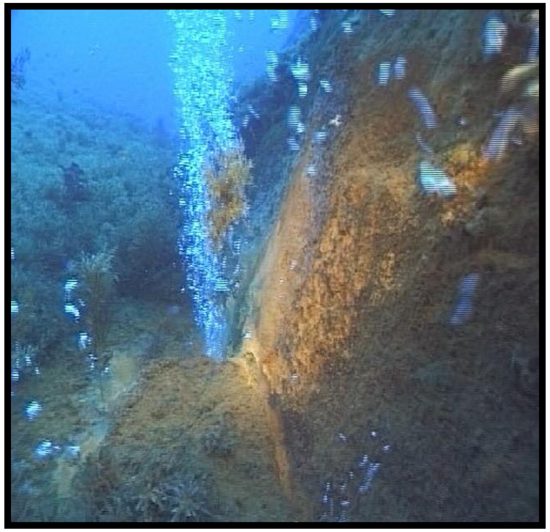
Highly corrosive environment

Lack of optical visibility

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

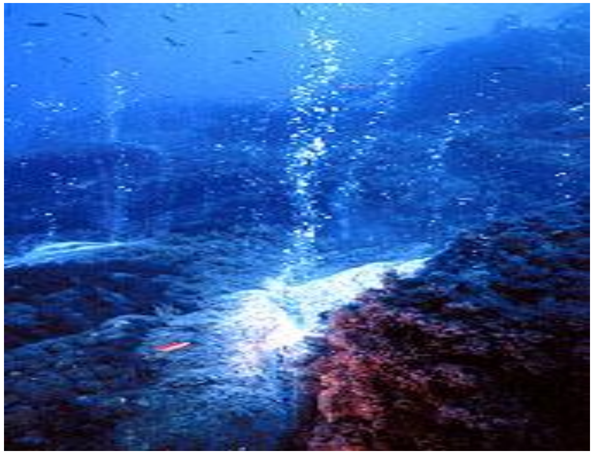
Submersibles: place human lifes at risk

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

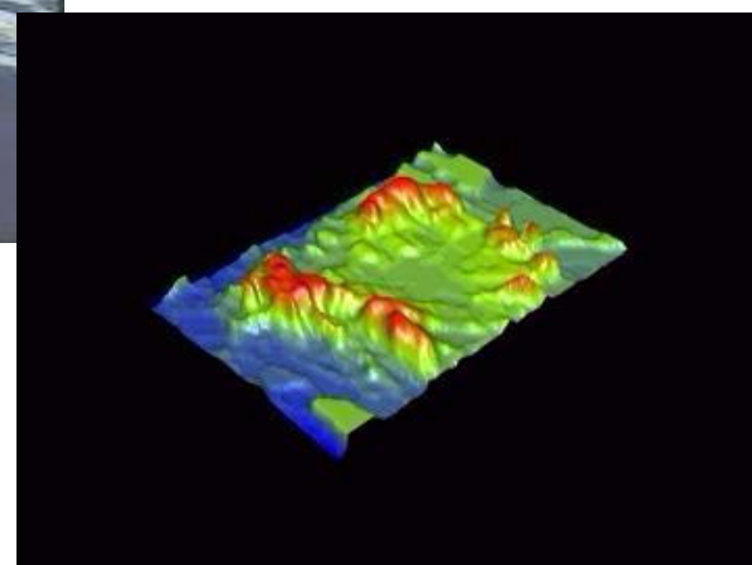
Use an Autonomous Surface Vehicle to MAP the seafloor

Mapping the seabed with an ASV

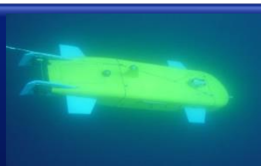
Navigation: GPS

Comms: radio

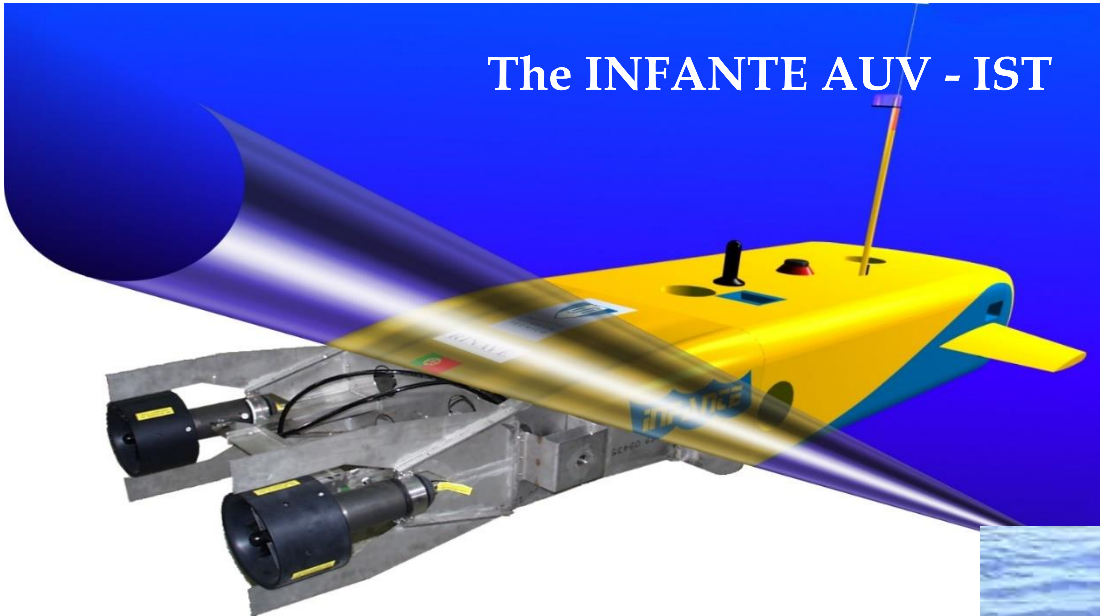
Path following:
Inner-outer loops for accurate tracking in the face of ocean currents and wind.



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



Go deeper with an AUV



Navigation: Dead-reckoning (AHRS and Doppler unit)

Comms: acoustic

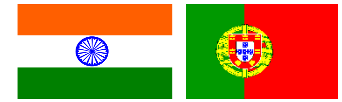
Systems in place:

NGC for

- *Path Following in 3D*
- *Altitude Control*

Mapping sensor suites

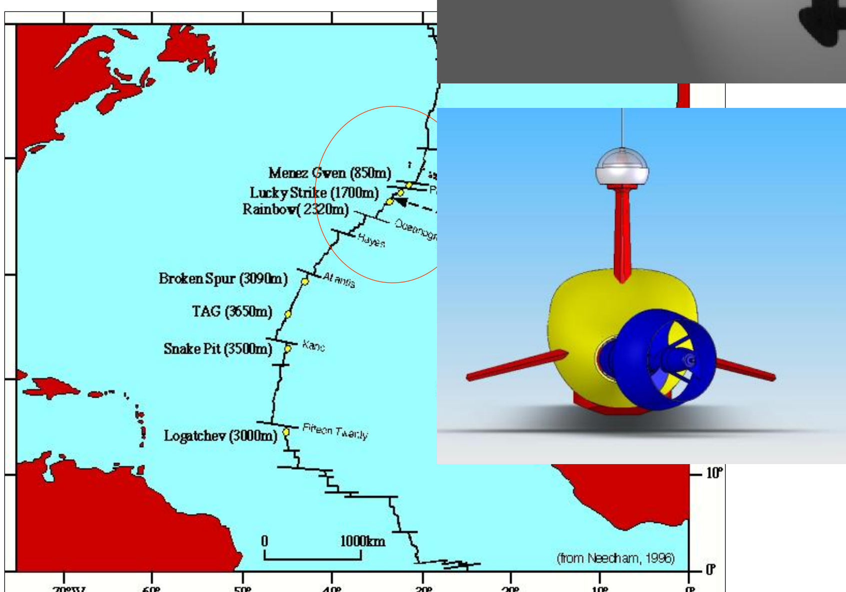
Cooperation with Goa (NIO)



Meeting IN-PT
(since 1999)

INSTITUTO SUPERIOR TÉCNICO

PÓLO DO IST



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

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

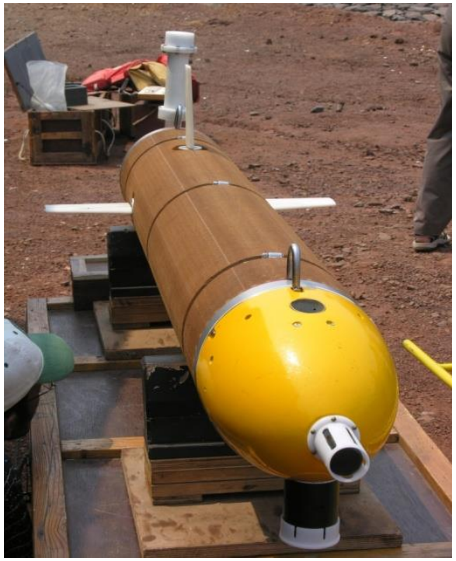
Cooperation with India (NIO and NIOT)

Work and tests in India

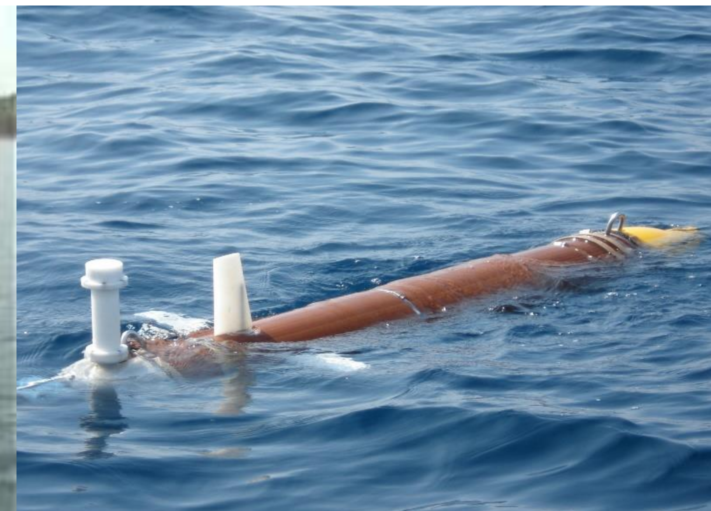
Maya
माया

Amthnem, Goa

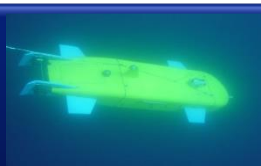
Cooperation with India (NIO and NIOT)



Cooperation with India (NIO and NIOT)



MAYA - AUV



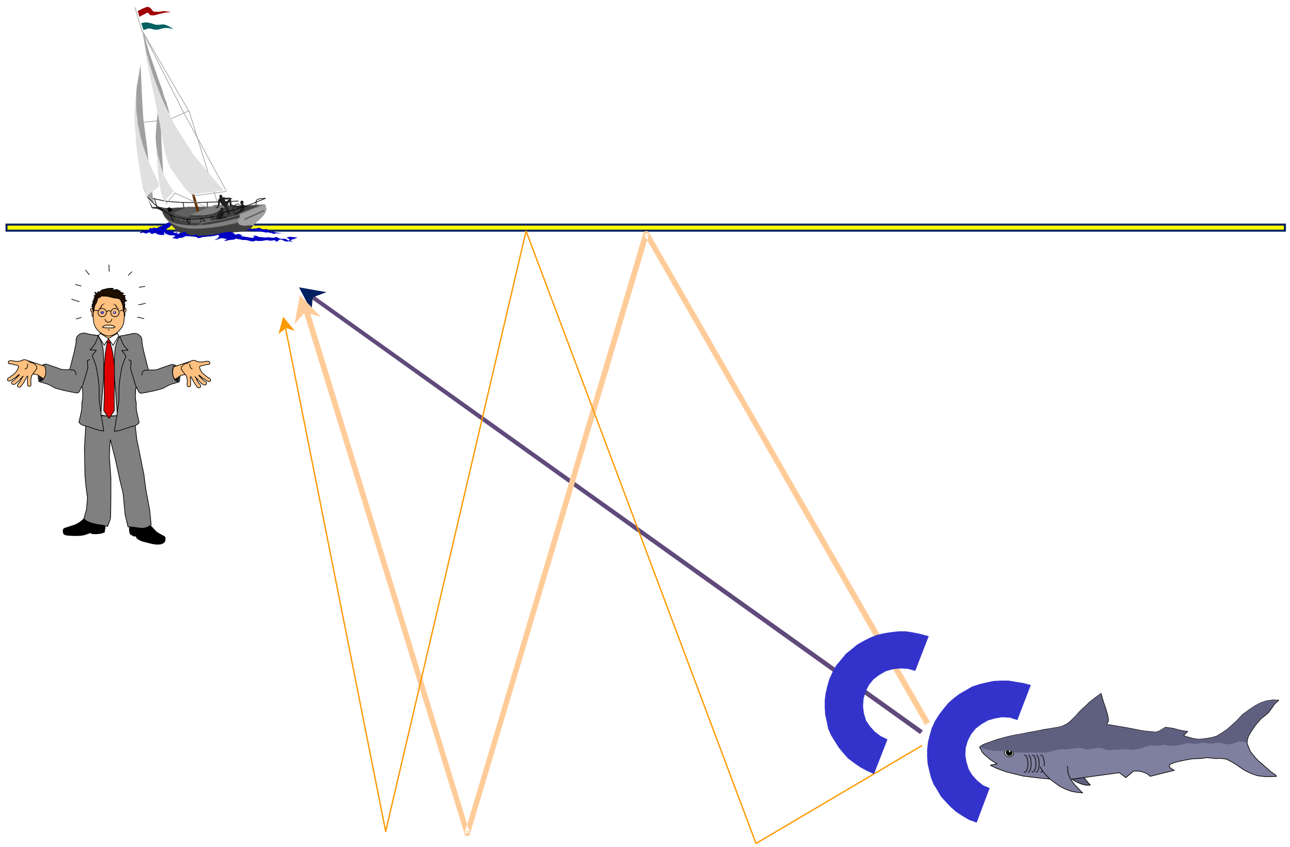
Penetrating the Deep Sea

Challenges

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

Opening the multiple vehicle frontier

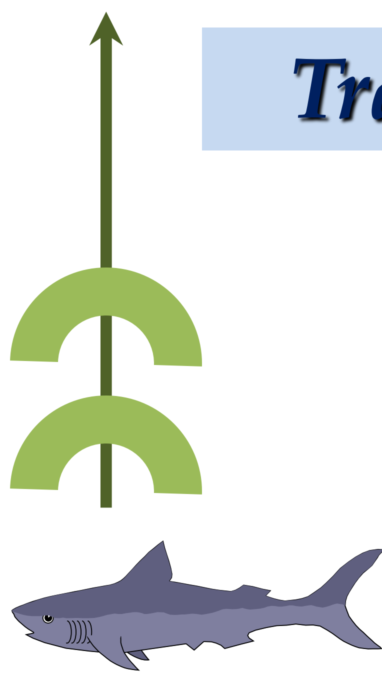
Underwater Communications – *very hard!*



Opening the multiple vehicle frontier

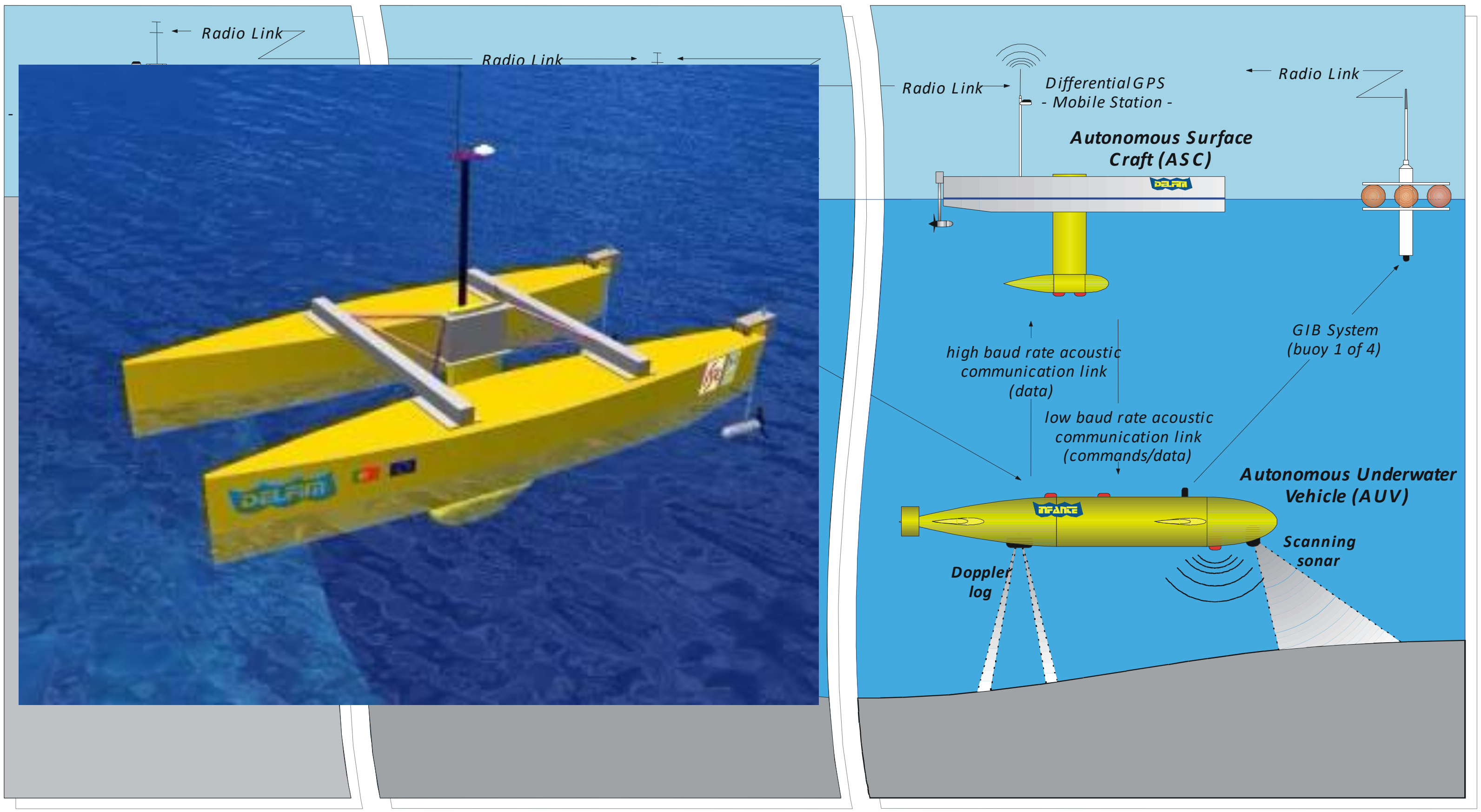
Underwater Communications

Transmit in the vertical !



Multi-vehicle operations

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



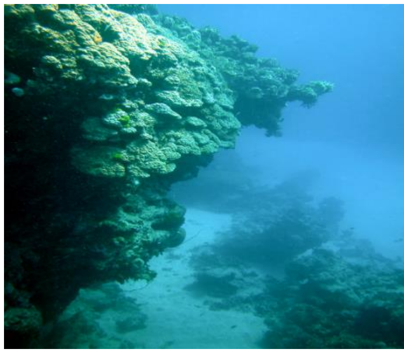
*Difficulties: **no** reliable comms, miniaturized acoustic positioning systems, and tools for seamless implementation of Motion and Mission Control systems (ROS was not born yet!)*

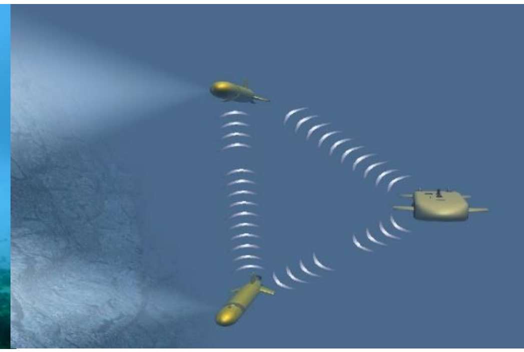
Neworked Systems : a New Era (2009 -)

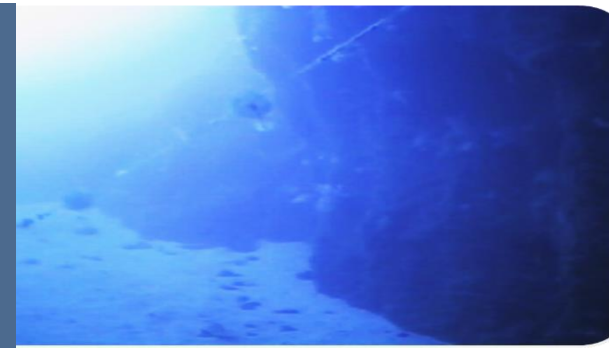
and Control

MORPH / EC (2012-2016)

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







ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and EADS

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Consiglio Nazionale delle Ricerche

imar

S&T organization CMRE

Universitat de Girona

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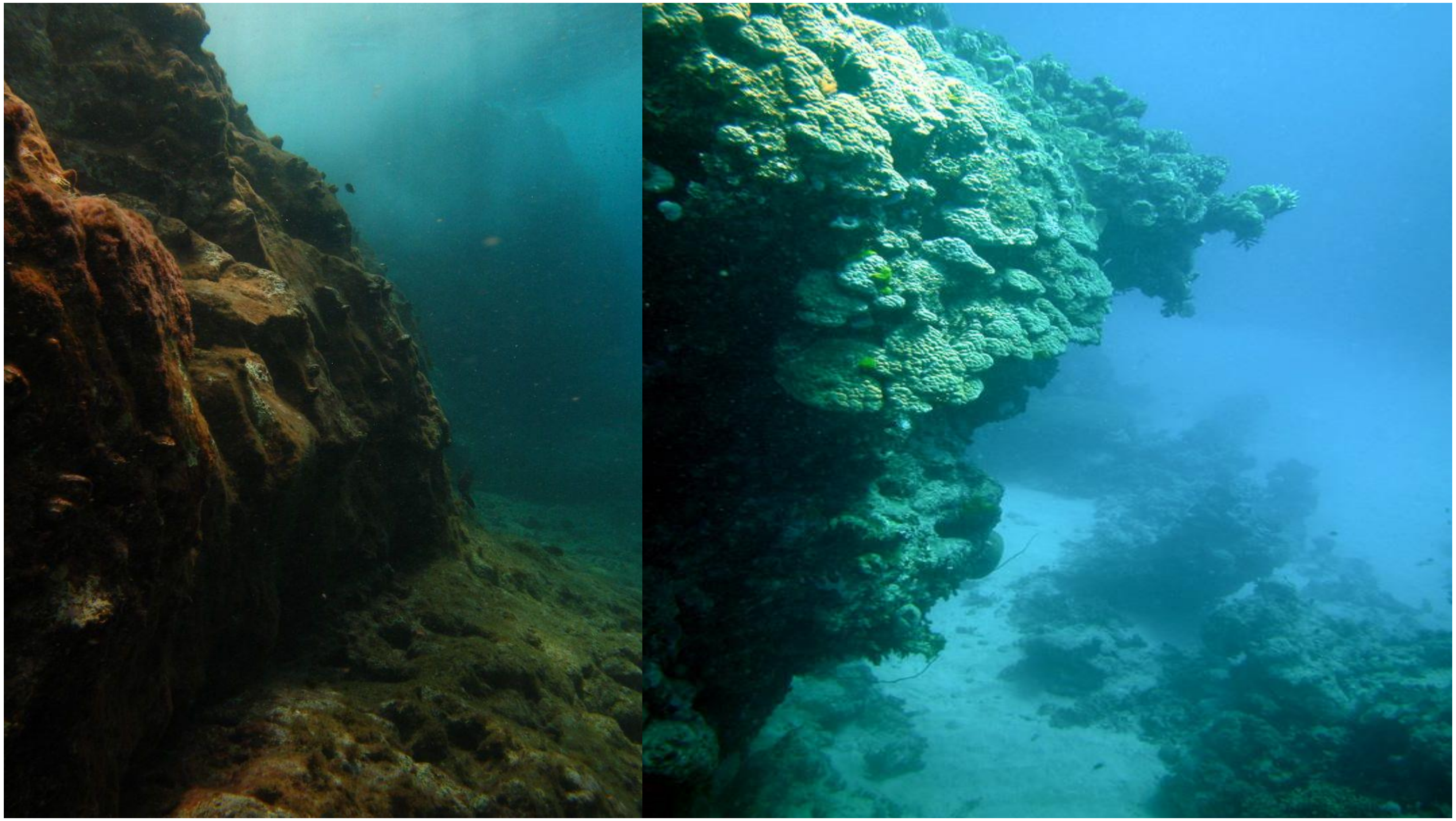
DOP

MORPH / EC (2012-2016)

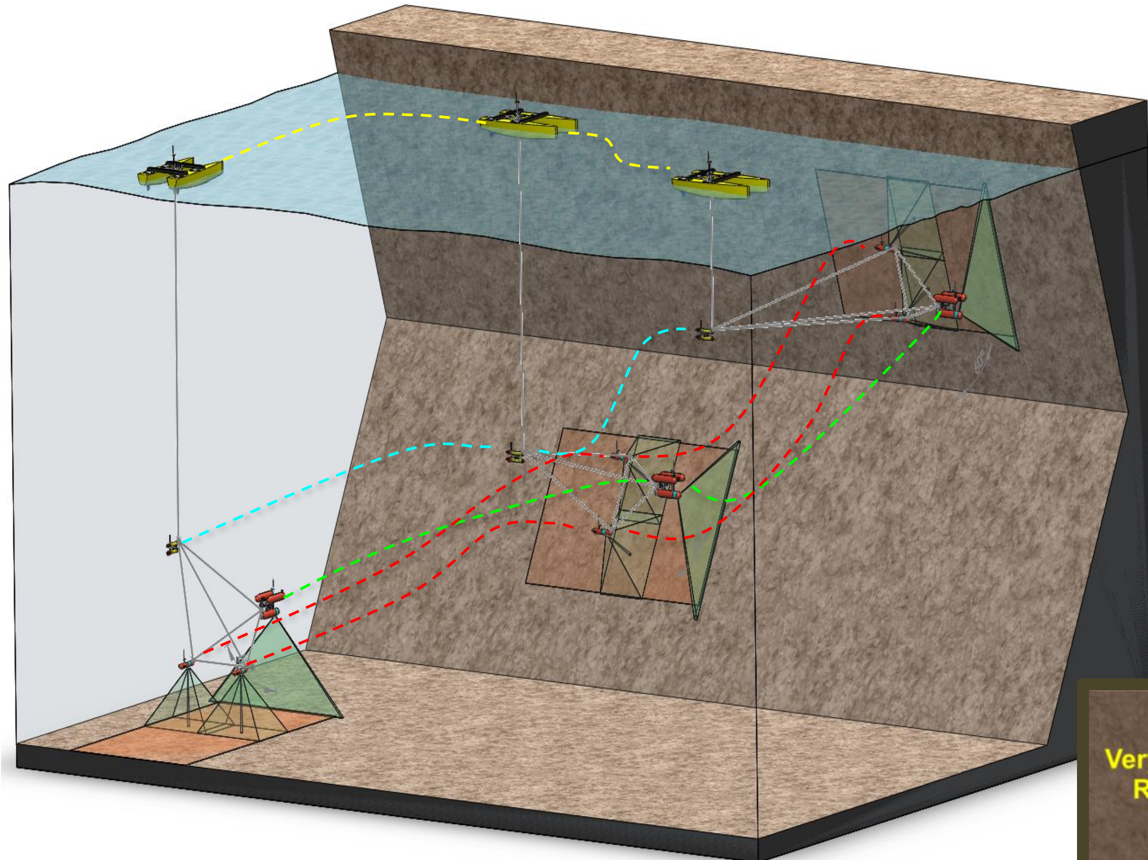
Habitat Mapping in complex 3D environments



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

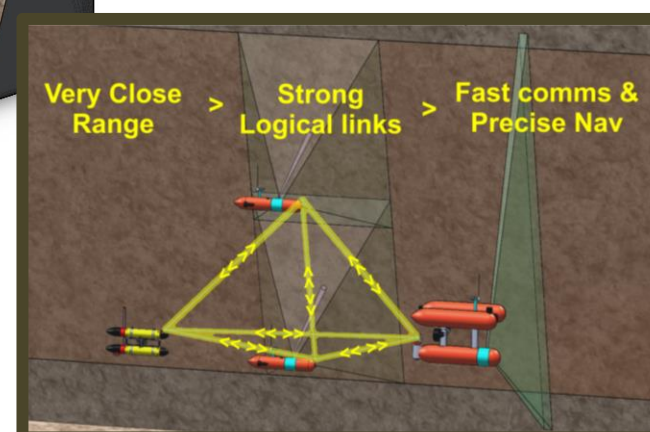
The EC MORPH project

MORPH / EC (2012-2016)

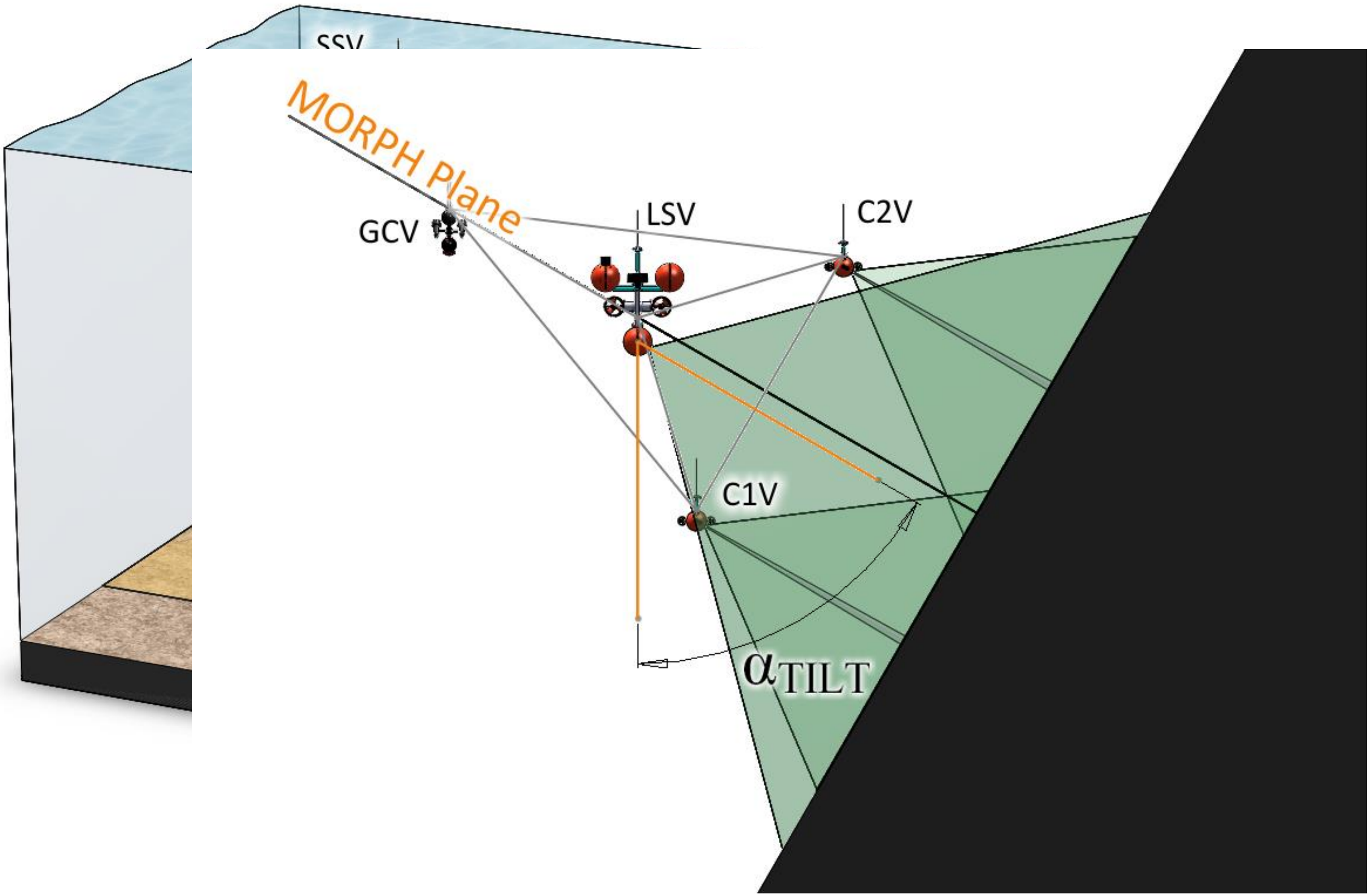


A team of agents operating as a virtual super marine vehicle

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

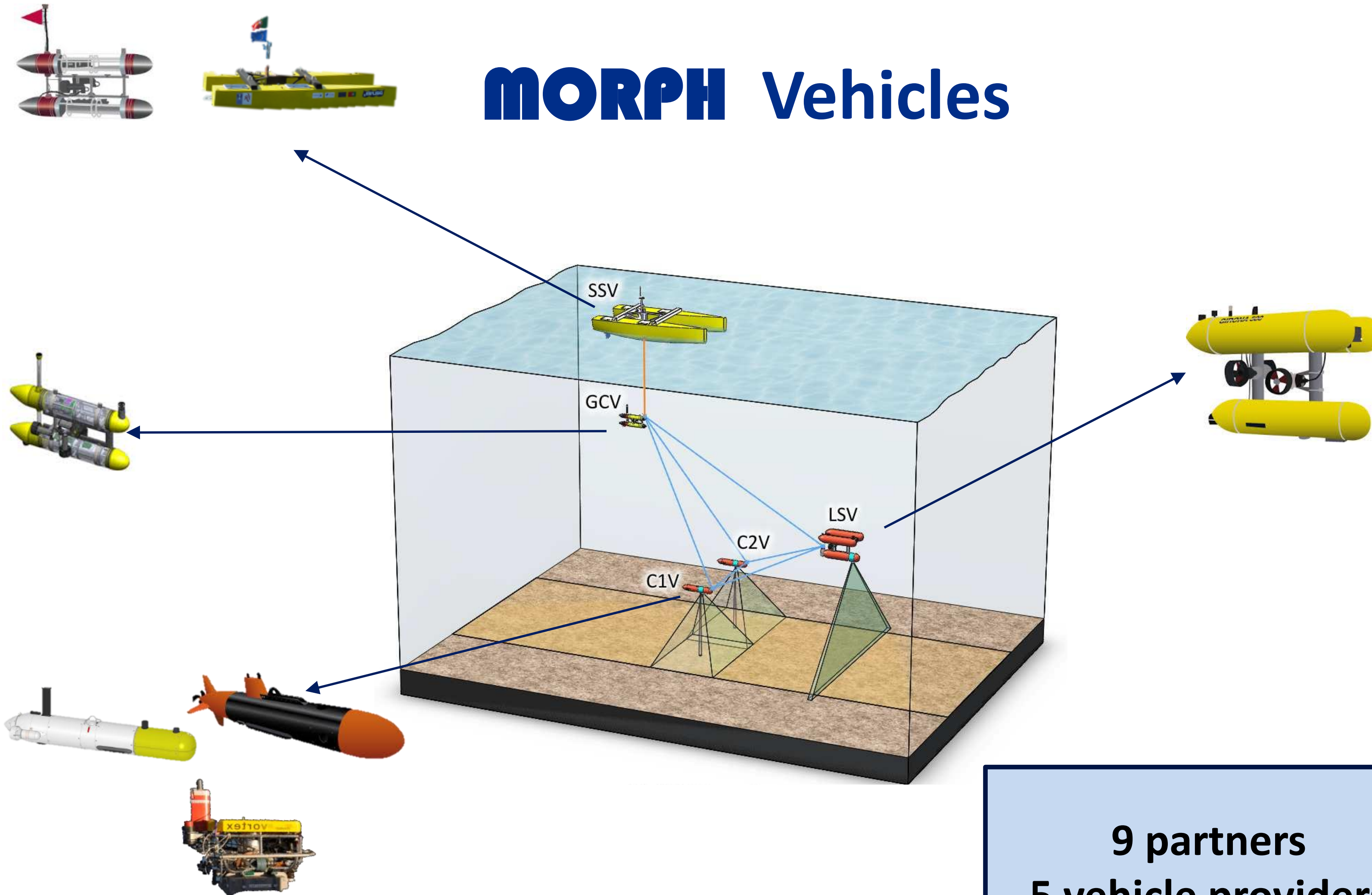


The adaptive MORPH configuration



The EC MORPH project

MORPH Vehicles

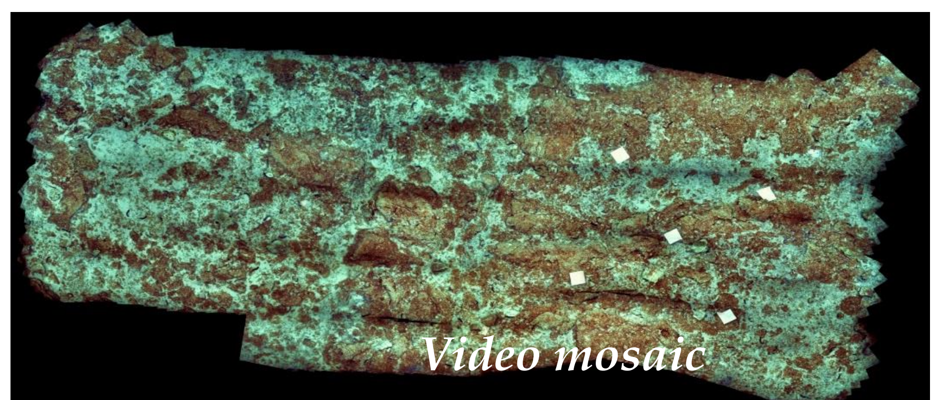


9 partners
5 vehicle providers

The EC MORPH project

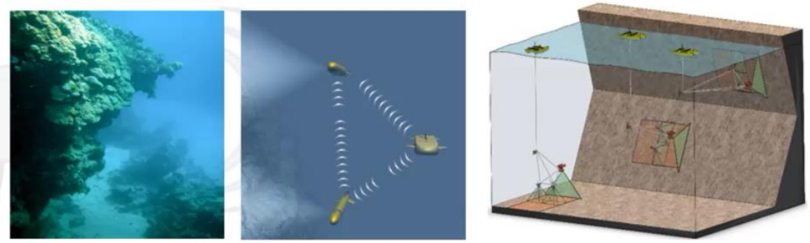
MORPH / EC (2012-2016)

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



MORPH Azores, PT, 2014

MORPH



Marine robotics system of self-organizing logically linked physical nodes

Azores trials 2014

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DOP
S&T organization CMRE
ATLAS ELEKTRONIK A joint company of ThyssenKrupp and EADS
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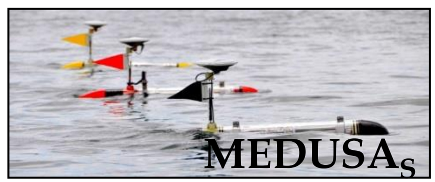
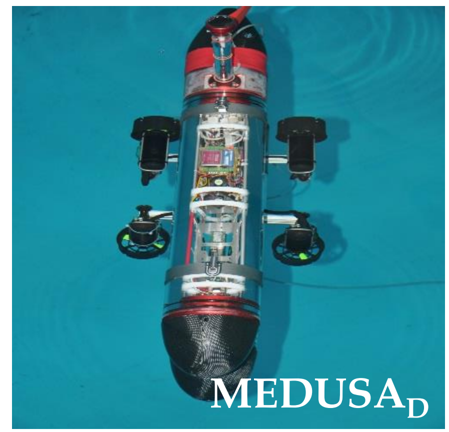
MORPH Girona , SP, 2015

1:32

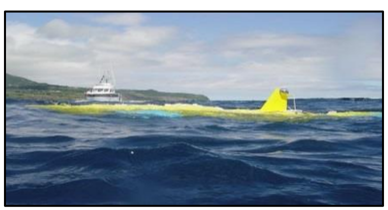
Making it all happen: UAVs, AUVs, ASVS

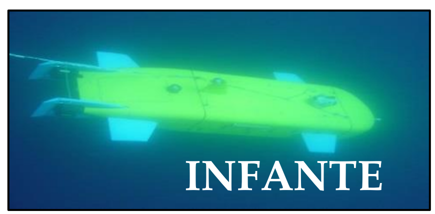
Transition from the Lab to the Real World
through ***in-house development of advanced systems and tools*** (e.g. marine and air robots, software tools for operational oceanography).





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

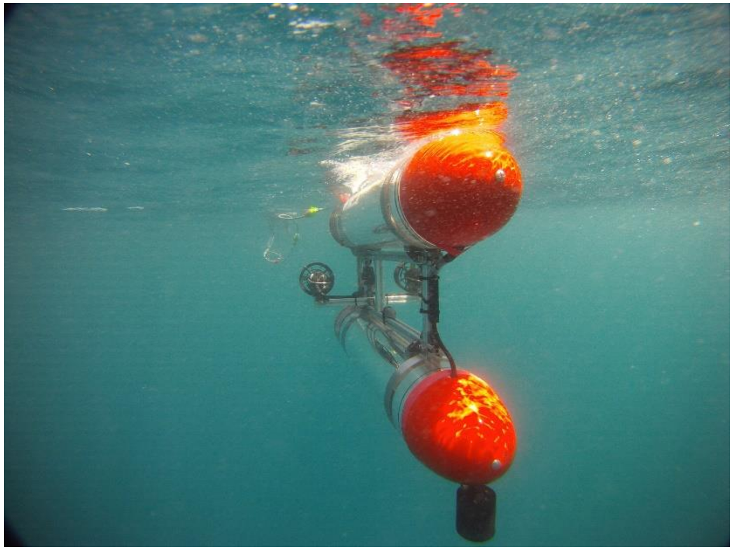


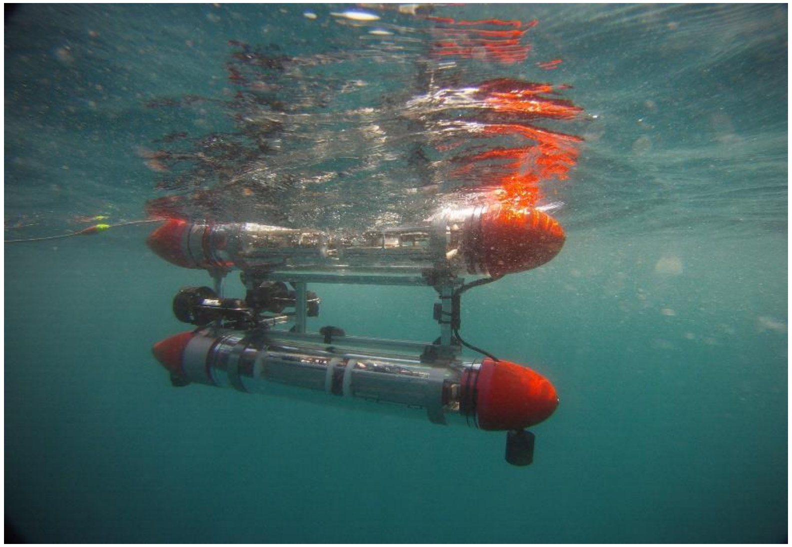


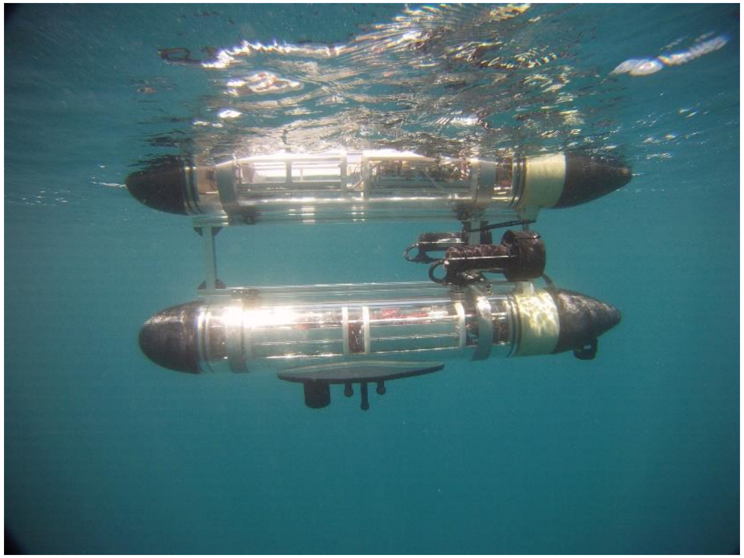
The sea-going machines

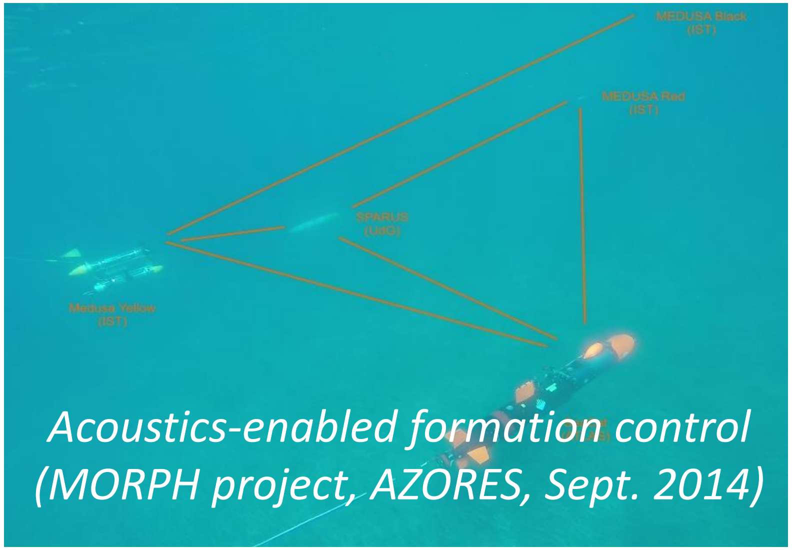
The MEDUSA vehicles

Labs and equipment









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

The MEDUSA-class vehicles (AUV/ASV)

Transportation and deployment

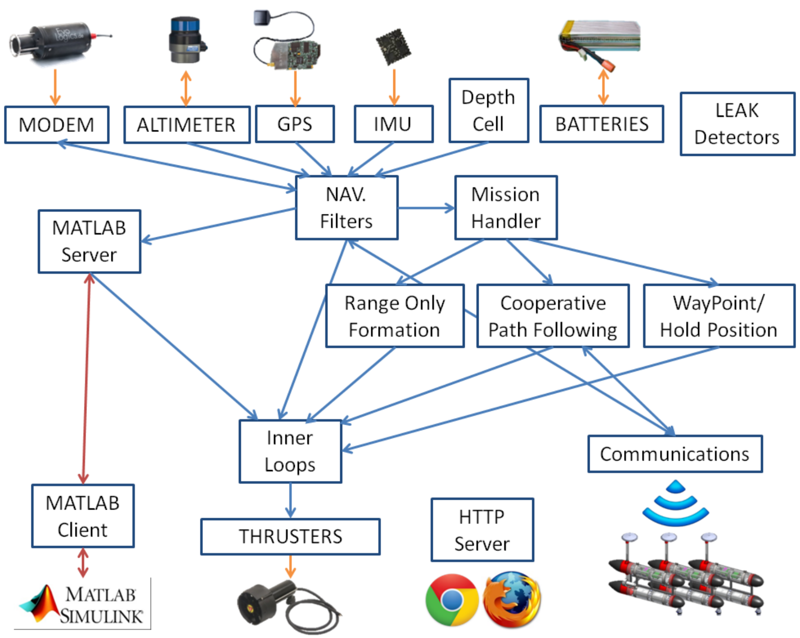
3 MEDUSAs can be transported in a van or small trailer

Transportation to water by a single person in a cart

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

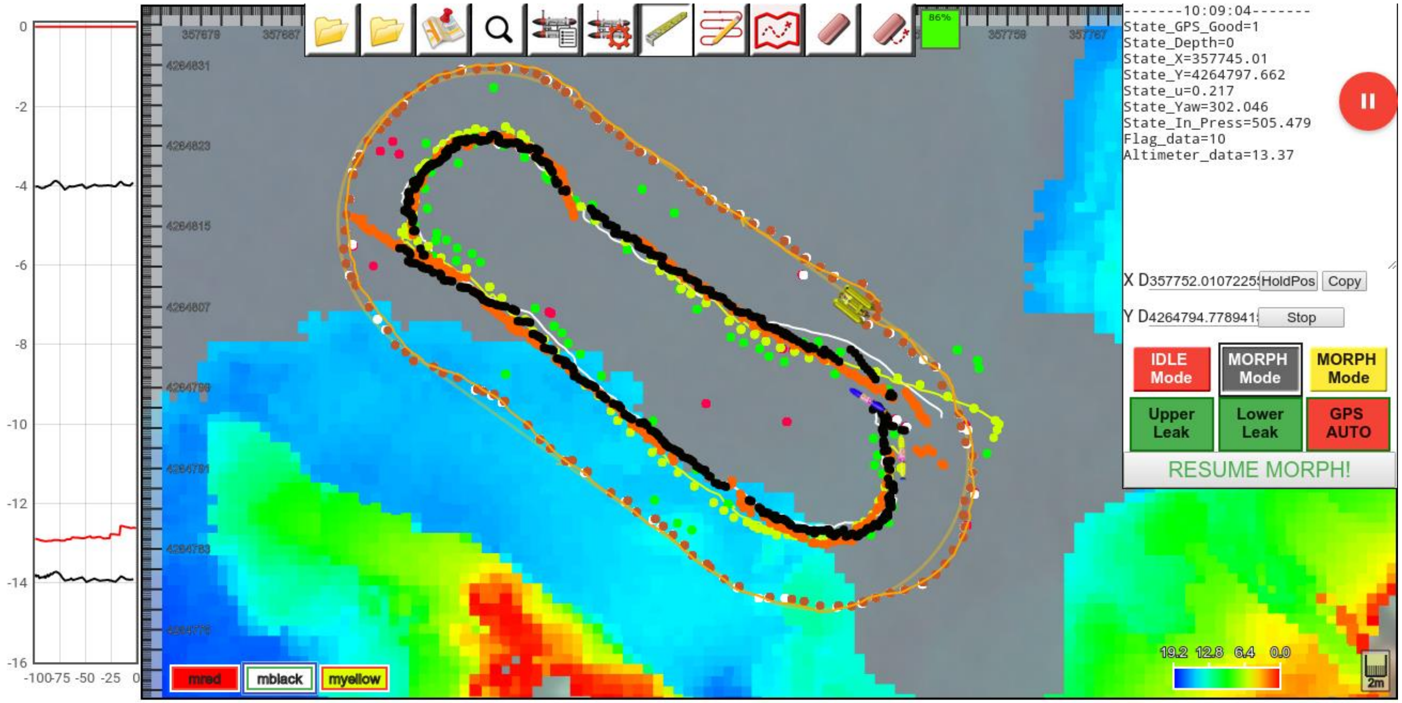
Software architecture overview

- 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

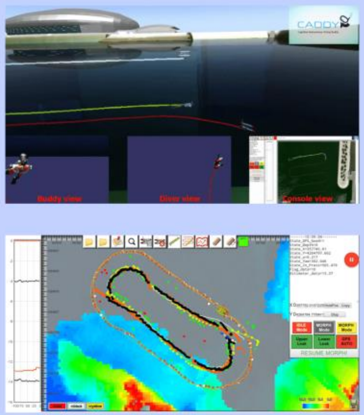
- Browser-based: works in different OSs and browsers, adopting Google's *Material Design* guidelines – ongoing
- Enables operator to visualize vehicle positions in a map, monitor vehicle states, issue commands to vehicles
- Design/load complex missions or bathymetry data from files



Mission programming

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

Simulation pipeline



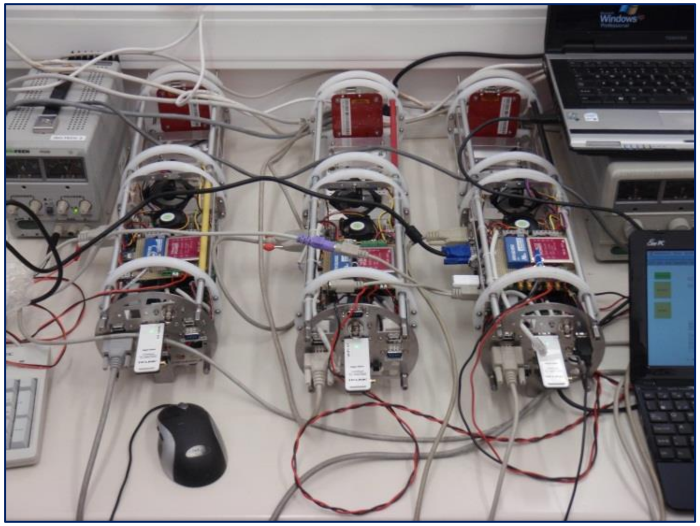
Visualization systems (console and/or UWSim)
+
access to raw data for debug

Acoustic modems/USBL emulators

Simulated vehicle state

Simulated vehicle positions and messages to be broadcast

Commands and simulated environment data



Simulated modem/ USBL outputs

MEDUSA DEEP SEA

ICELAND LIECHTENSTEIN NORWAY
eea grants

CAUTION
YOU ARE LEAVING YOUR COMFORT ZONE

“MEDUSA$_{DS}$ – OPENING THE DEEP SEA FRONTIER”

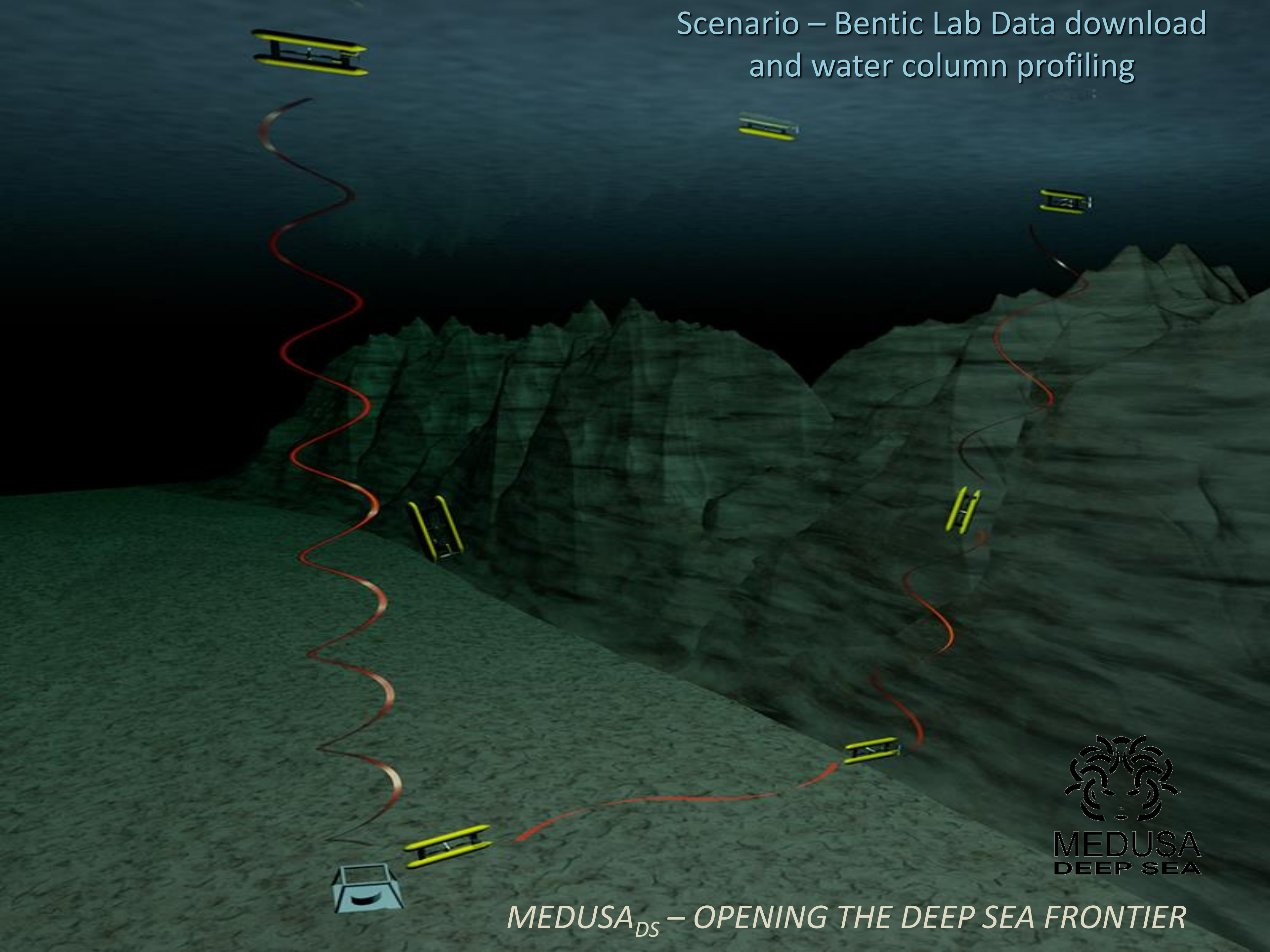
(2015-2017)

GOVERNO DE PORTUGAL | MINISTÉRIO DA AGRICULTURA E DO MAR

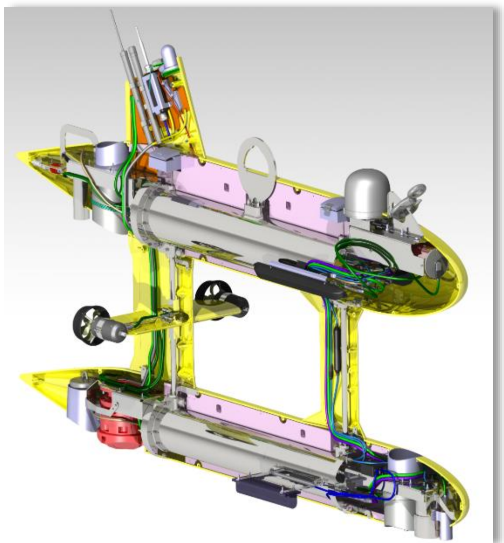
dgpm Direção-Geral de Política do Mar

MEDUSA$_{DS}$ / EC (2015-2017)

Scenario – Bentic Lab Data download and water column profiling



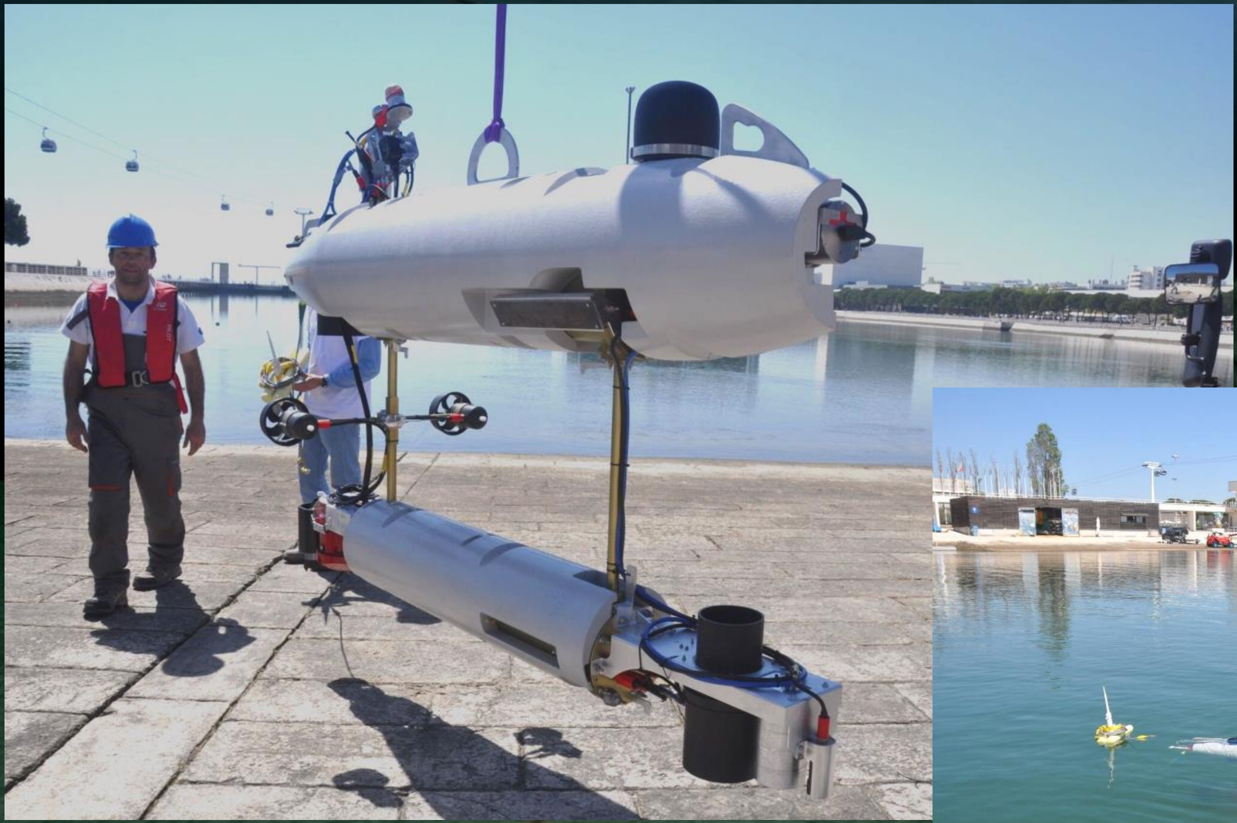
MEDUSA
DEEP SEA
OPENING THE DEEP-SEA FRONTIER



Tales of

Housing pre

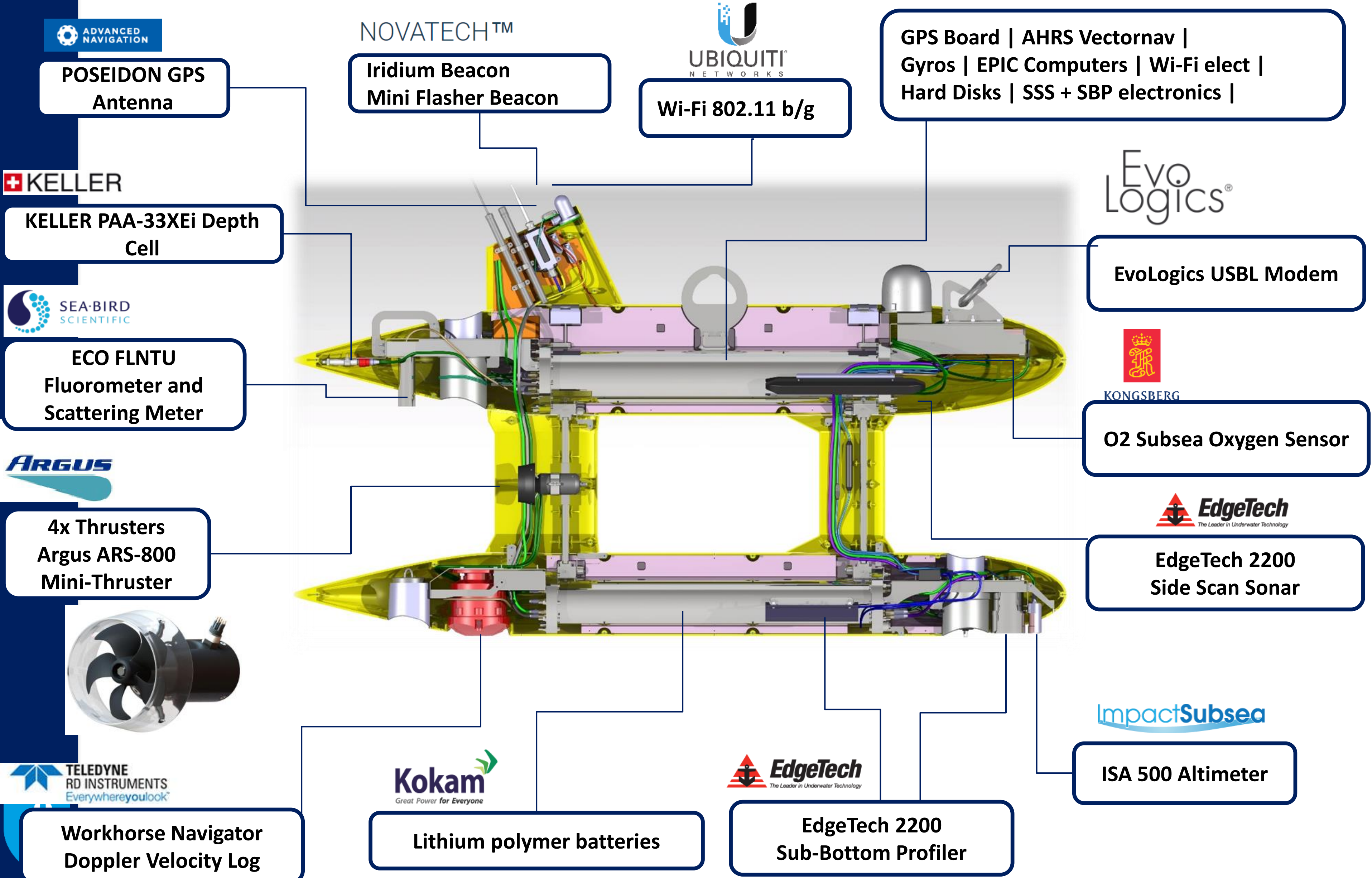
Scenario – Bentic Lab Data download and water column profiling



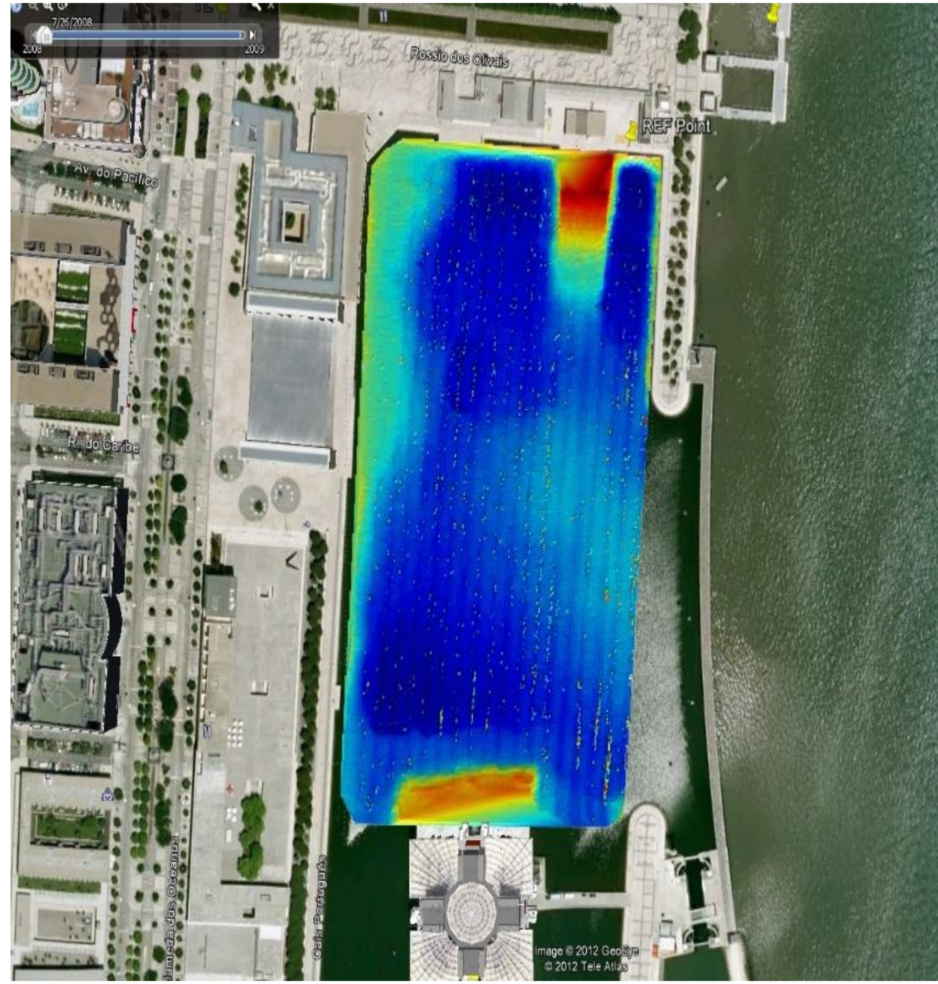
MEDUSA DEEP SEA

MEDUSA$_{DS}$ – OPENING THE DEEP SEA FRONTIER

System Breakdown



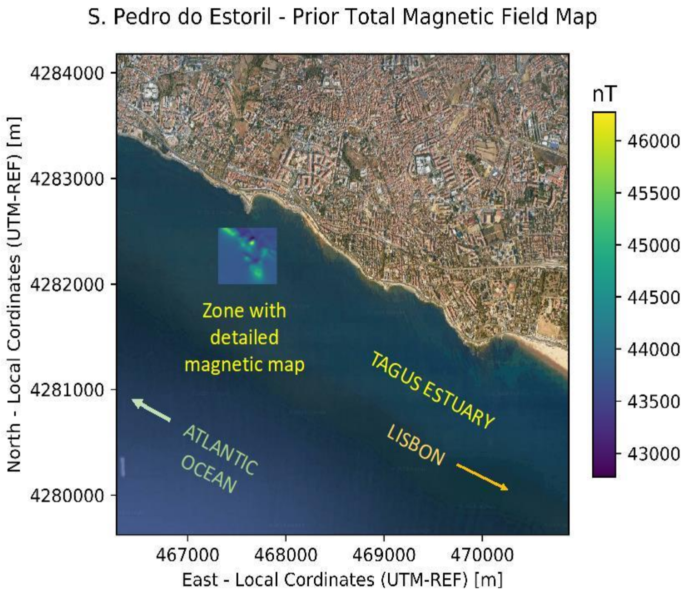
Test Facilities



EXPO'98 Site, Lisbon, PT

R&D Infrastructures

Test Facilities

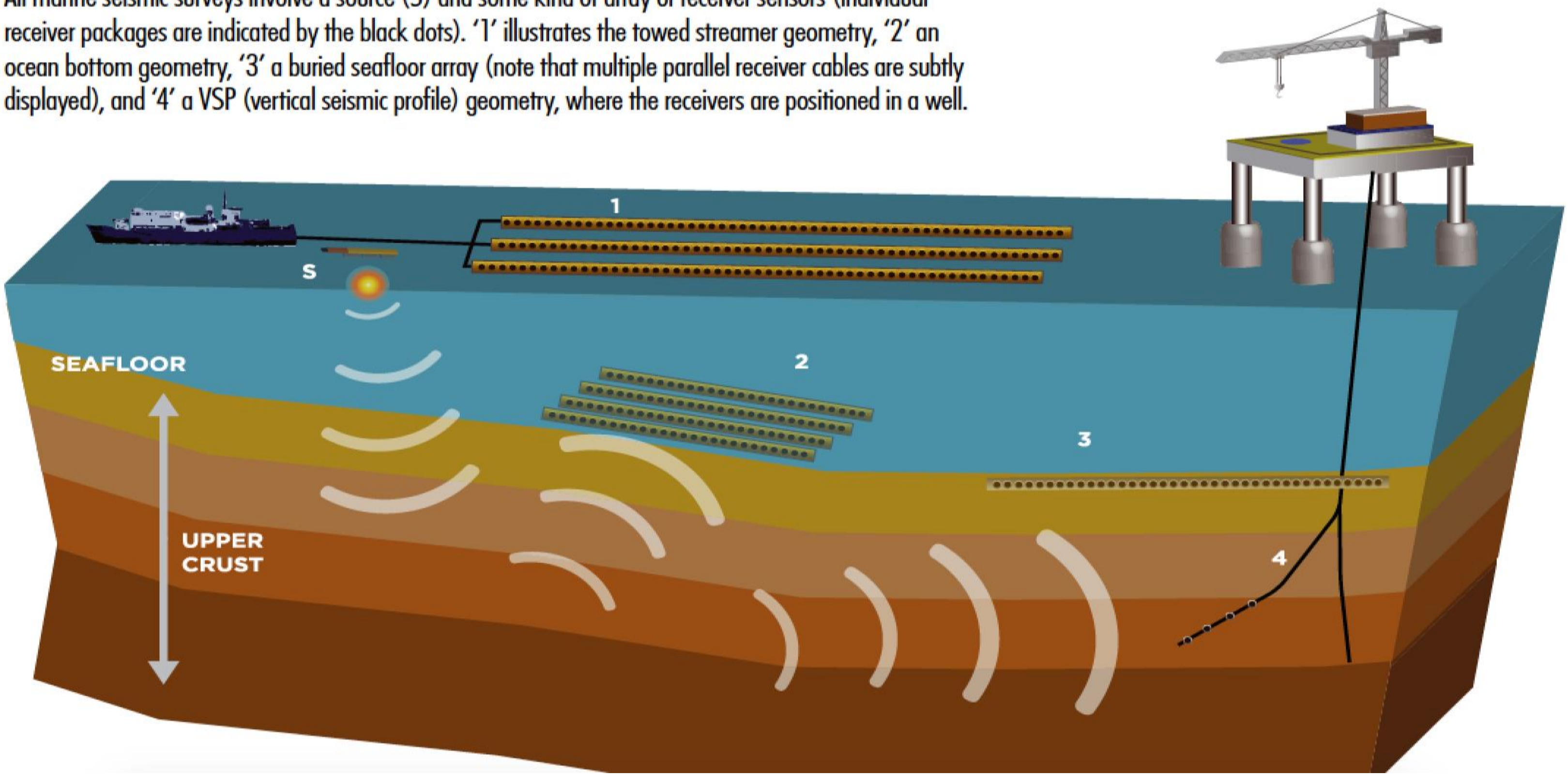


Tagus River, Portugal

Marine Seismic Surveys

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

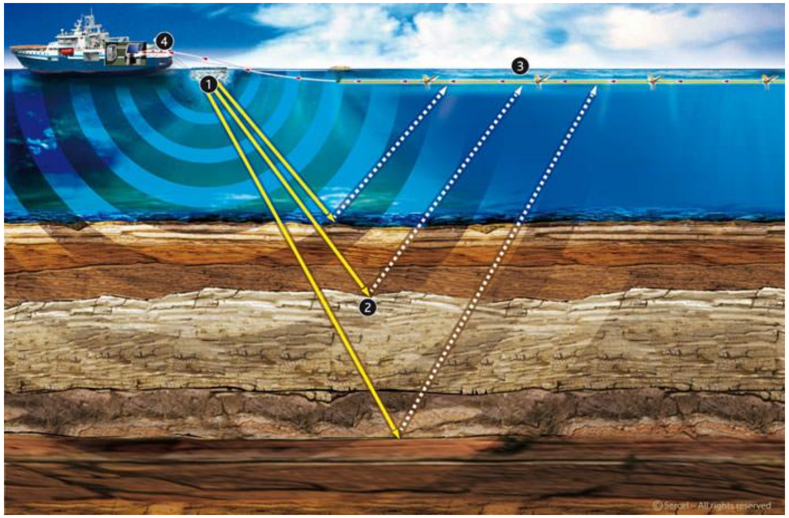
WiMUST
Widely scalable Mobile Underwater Sonar Technology

Marine seismic surveys

- Vessel tows **acoustic sources** and long cables (**streamers**) up to 10km long, equipped with **hydrophones**, very close to the surface

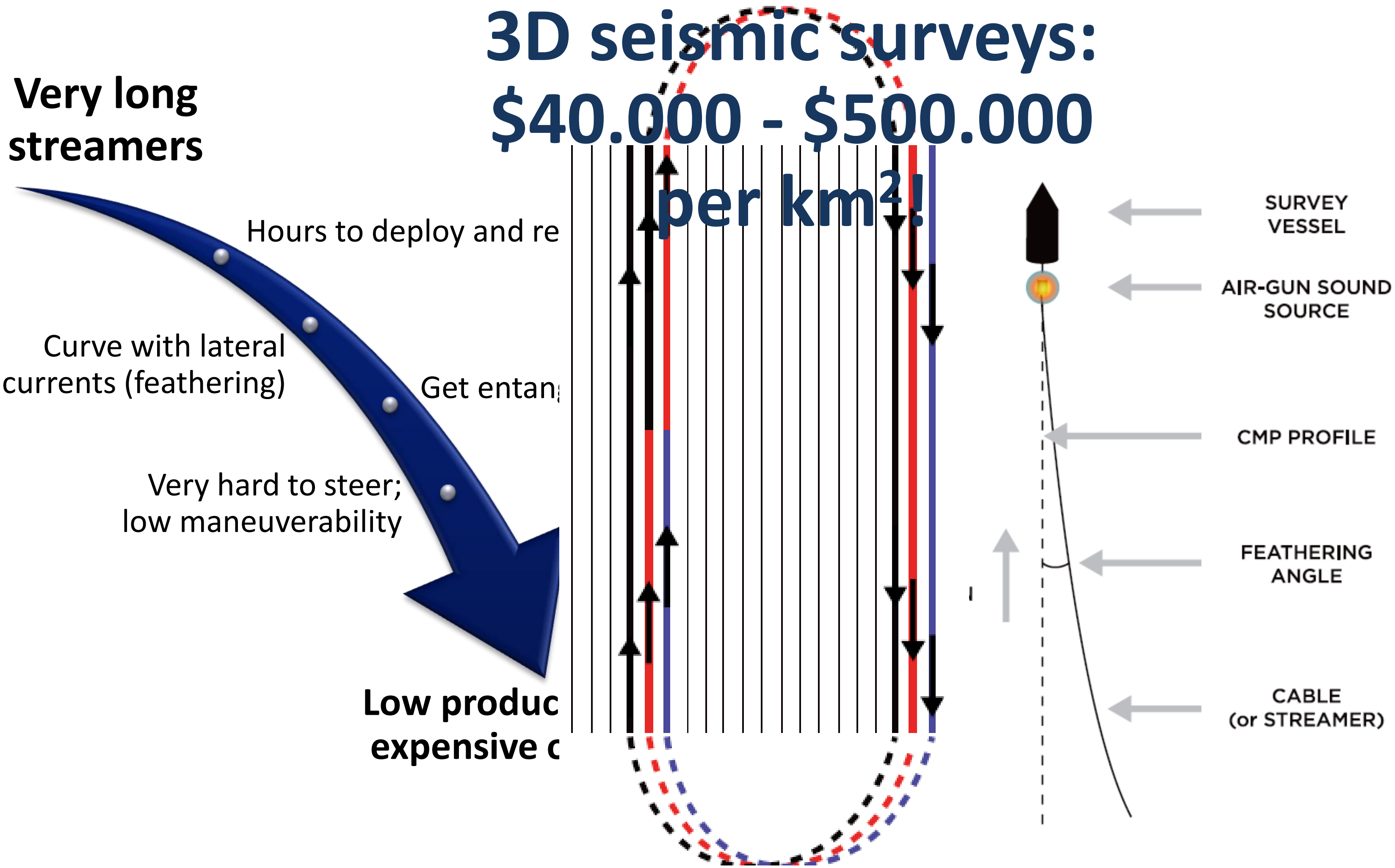
- Acoustic sources shoot, waves reflect/refract off geological features on and beneath the seabed, hydrophones pick up these reflections

- Processing allows for inference of geophysical features

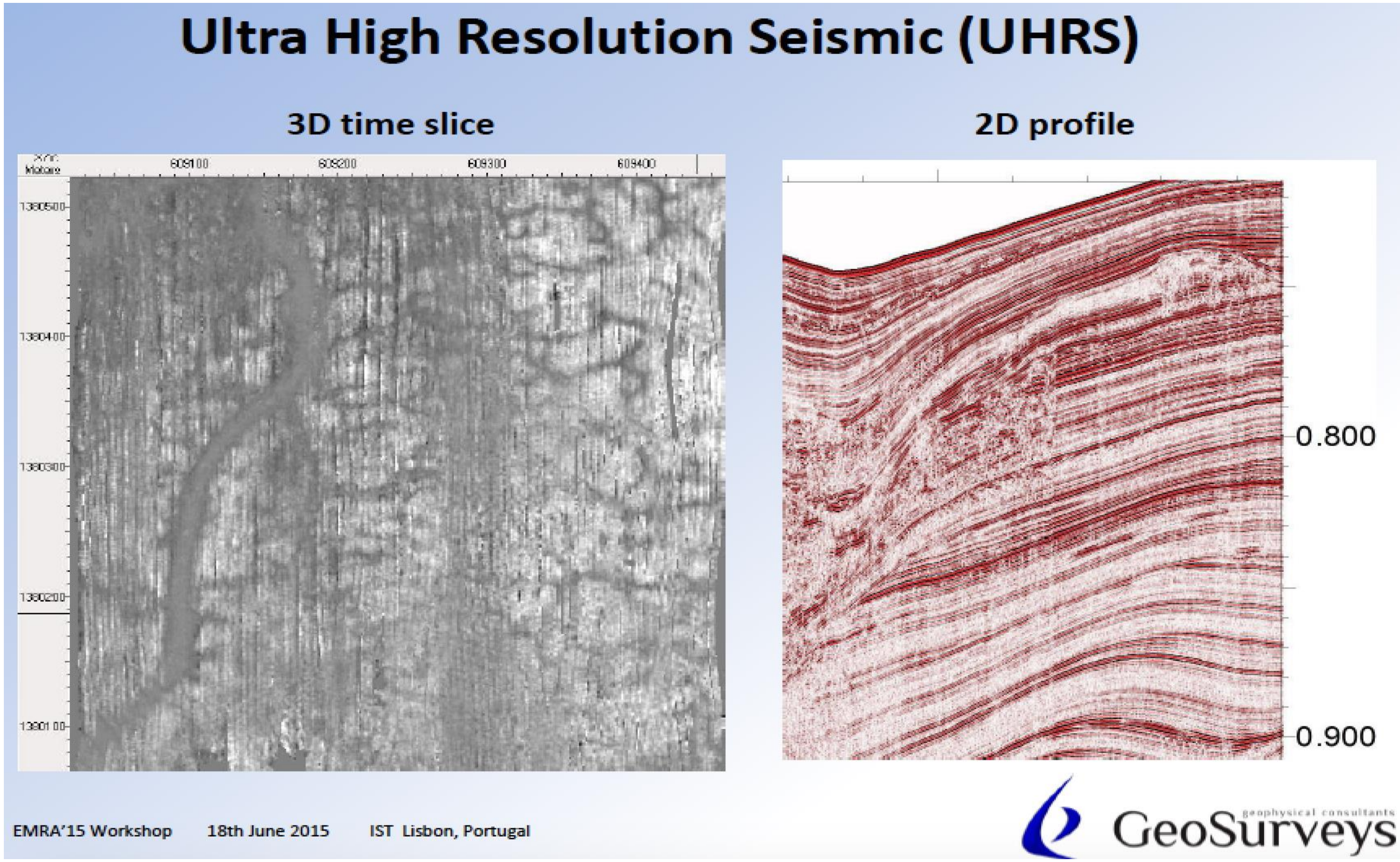


Marine seismic surveys

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

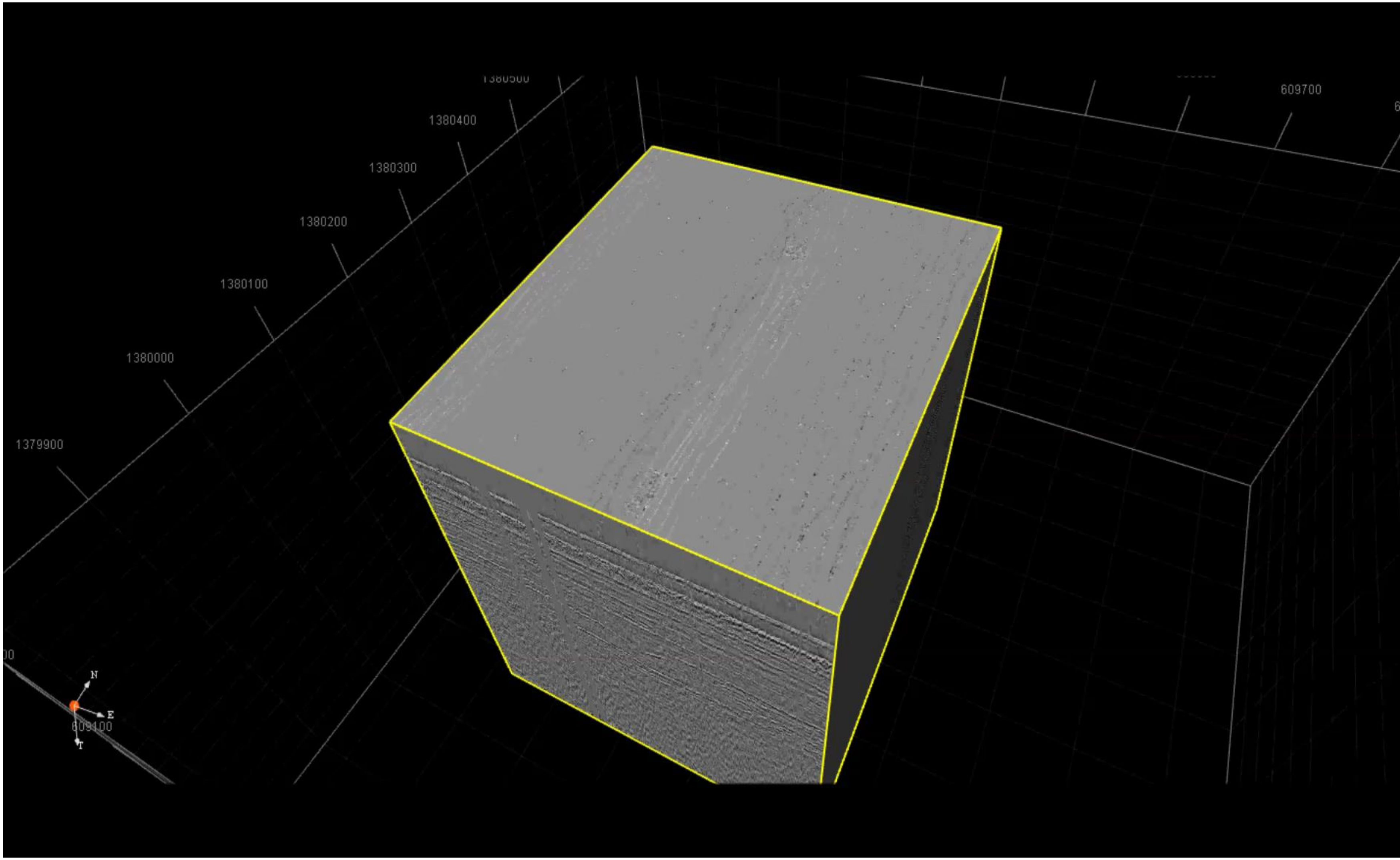


Ultra high resolution Seismic Surveys in 2D and 3D



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

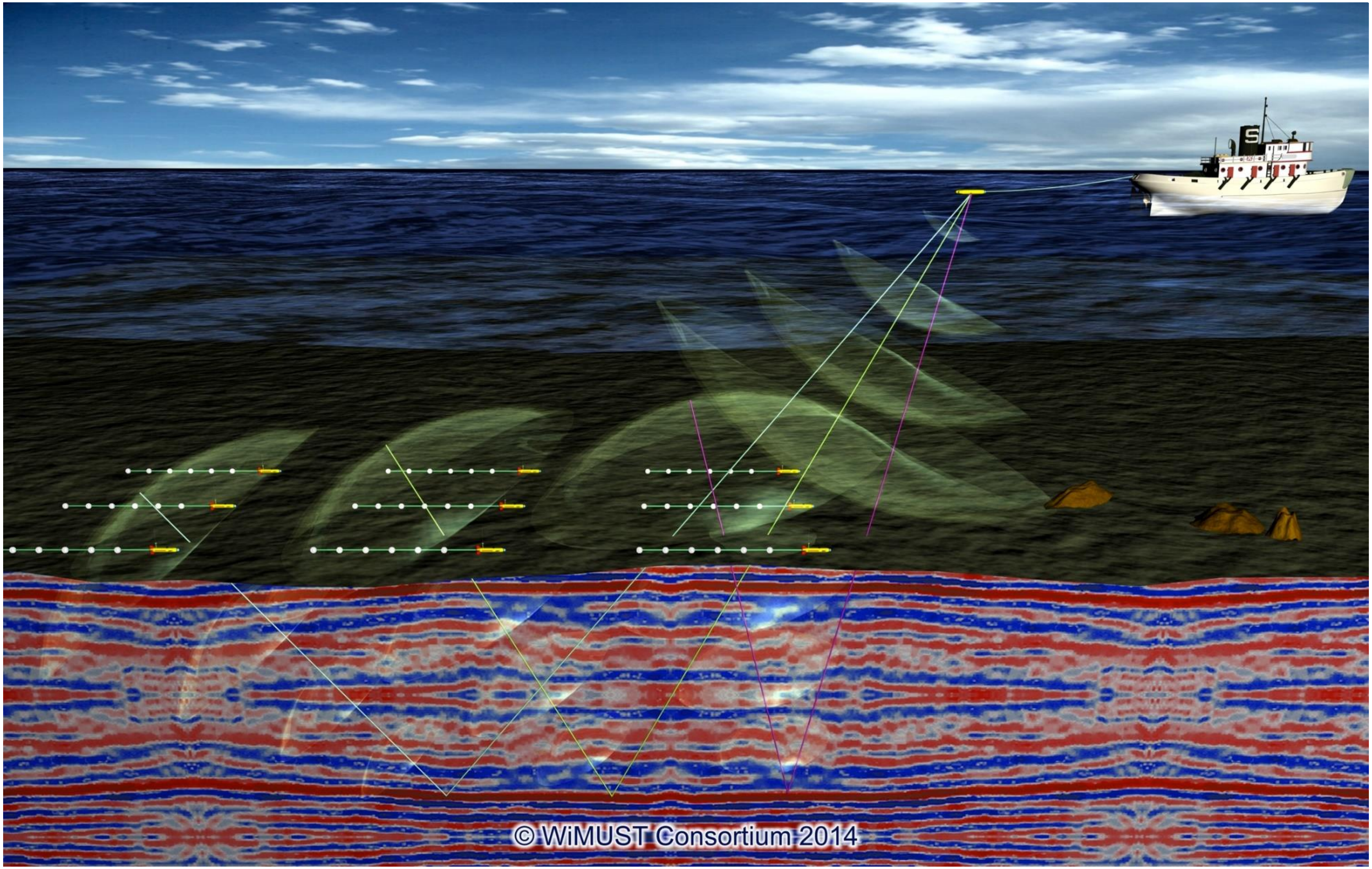
Ultra High Resolution Seismic (UHRS) surveys



Courtesy of Henrique Duarte, GeoSurveys, Aveiro, PT

The WiMUST concept

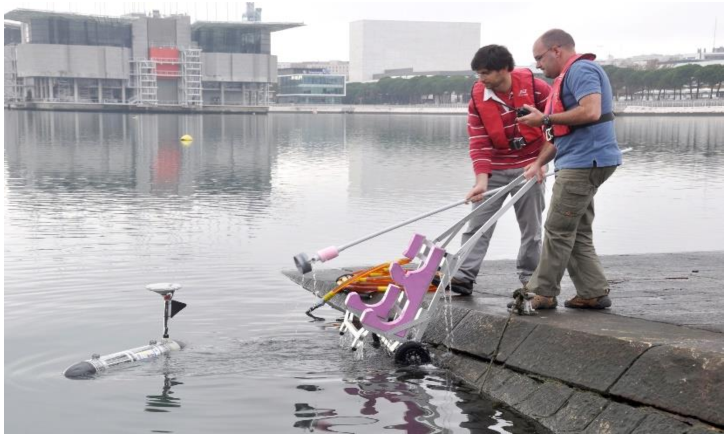
WiMUST
Widely scalable Mobile
Underwater Sonar Technology

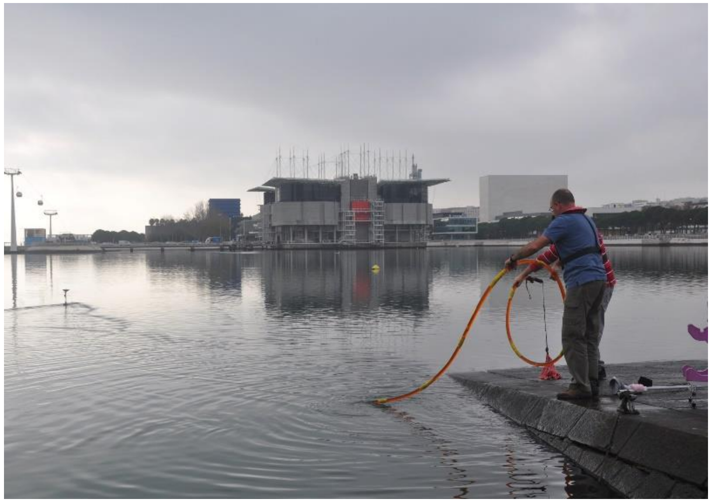


The WiMUST concept

2:42

A new concept: automated seismic surveys





A new concept: automated seismic surveys

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

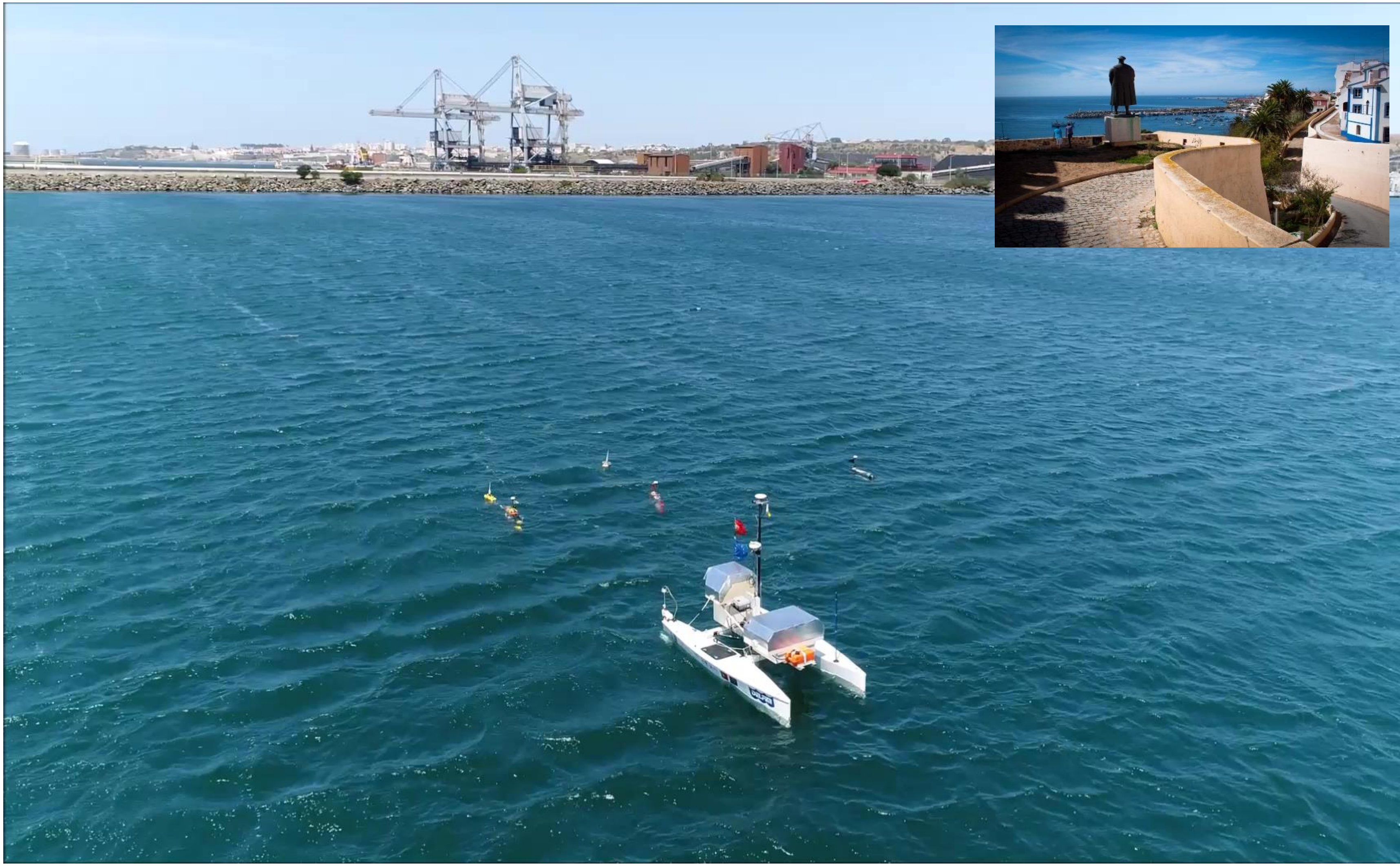
The EC WiMUST project

Integration of Sparkers and Power Supplies on Autonomous Vehicles

Integration of Sparkers and Power Supplies on Autonomous Vehicles

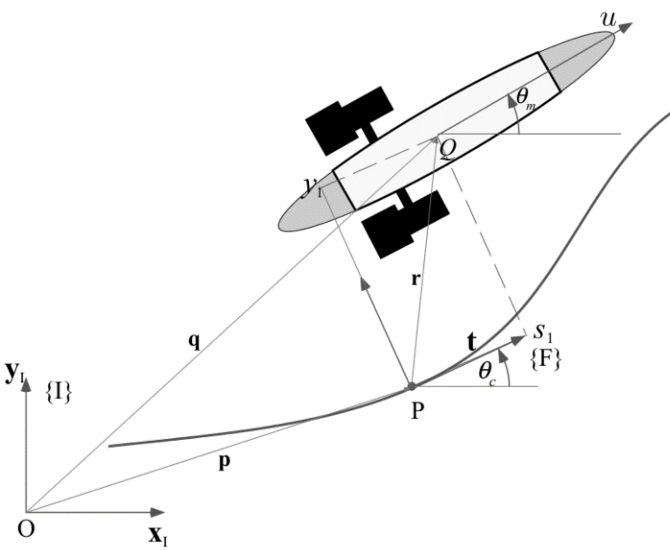
ULISSE, ISME, Italy

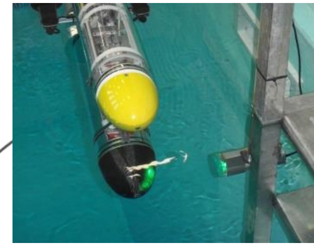
Automated Sparkers/Receivers: Field Tests

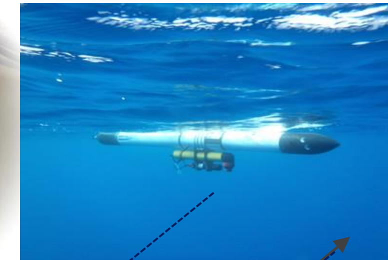


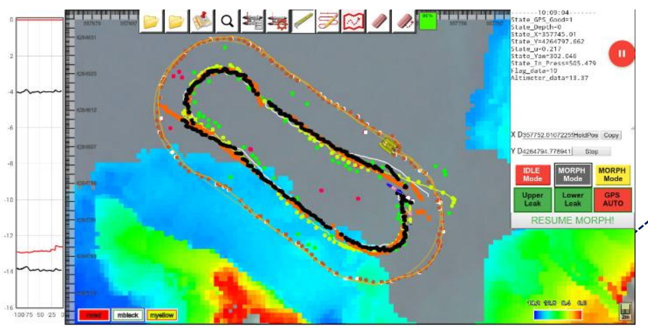
SINES. July 2017

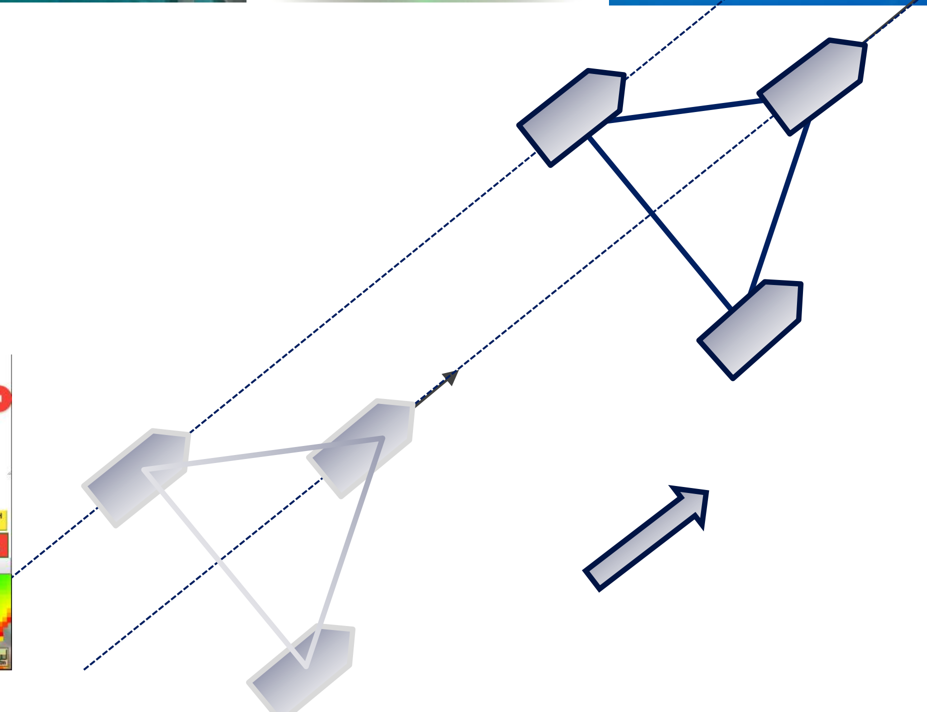
The theory behind: a glimpse





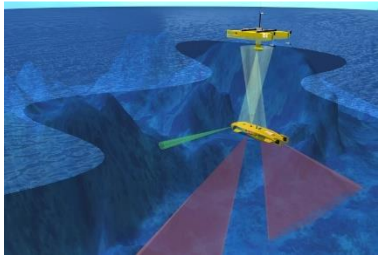
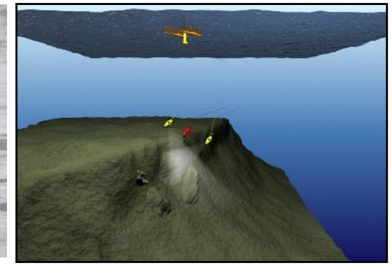






Cooperative, Networked Motion Planning, Navigation, and Control

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

Theoretical Framework

Strong parallel with Cooperative UAVs

Questions ?