EMRA'15 workshop

Appendix II

Invited Presentations

EMRA'15 workshop

CADDY
Cognitive Autonomous Diving Buddy

EU Funded Marine Robotics and Applications

IST, Lisbon, Portugal 18-19 June

EMRA'15

EMRA'15 workshop

Proceedings of the Workshop

Sponsored by the EU CADDY project

ISR-IST Lisbon Portugal

EMRA'15 workshop

Program Committee

Nikola Miskovic, Joerg Kalwa, Giovanni Indiveri, Benedetto Allotta

EMRA'15 workshop

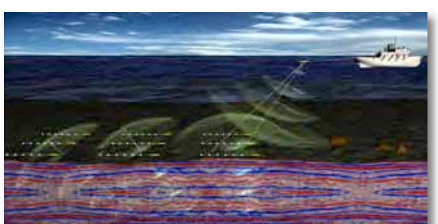
Organizing Committee

(IST/Institute for Systems and Robotics - ISR)

Chair: António Pascoal
Members: João Gomes, Paulo Oliveira, Luis Sebastião

Contacts:

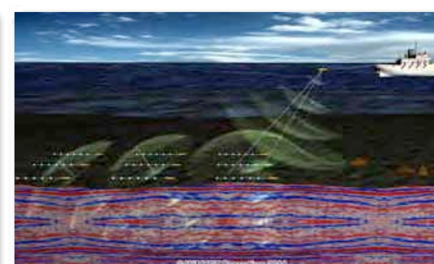
Antonio Pascoal (antonio@isr.ist.utl.pt)
Filipa Almeida (falmeida@isr.ist.utl.pt)




First edition in Rome, Italy 2014

EMRA'15 workshop

The 2nd EMRA workshop **summarized current EU FP7 and H2020 projects on marine robotics** and provided a platform for marine stakeholders to **share and discuss current technological challenges and achievements.**



EMRA'15 workshop

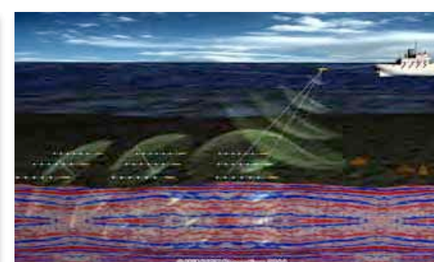
To <u>researchers</u>:

EMRA2015 offered the opportunity to **disseminate current work** and **highlight new application areas** that warrant further R&D effort.

EMRA'15 workshop

To <u>marine stakeholders</u>:

EMRA2015 allowed for **the cross-fertilization of ideas** and offered novel approaches to meet future challenges in ocean ocean exploration and exploitation.

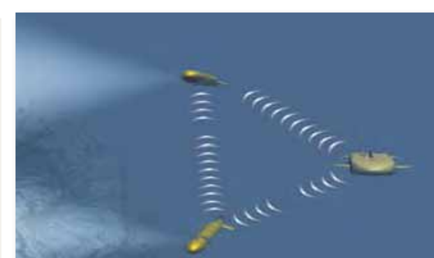


EMRA'15 workshop

Program:

- **11 EU Projects**; Representatives from the **industry.**
- **Invited talks**: issues that are at the crossroads of marine technology, science, and commercial applications (***deep sea mining, offshore wave/ energy, marine habitat mapping, oceanography, marine megafauna tracking***).





EMRA'15 workshop

11 EU projects, 14 invited presentations from the academia and the industry

ARROWS

CADDY
Cognitive
Autonomous
Diving
Buddy

euRathlon

WiMUST

DexROV

MarineUAS
Innovative Training Network on Autonomous Unmanned Aerial Systems for Marine and Coastal Monitoring

MORPH

Pandora
Persistently Autonomous Robots

NOPTILUS

ROBOCADEMY
European Academy for Marine and Underwater Robotics

subCULTron
learn & evolve
long-term
complexify
diversify
underwater society
electric sense
energy-harvesting
forming sub-cultures

EMRA'15 workshop

Session 1. Chair - Antonio Pascoal

9:00 **ROBOACADEMY (EU project)**

9:30 **T1.1 - *Mapping the seafloor in rough terrain with AUVs: mission planning versus real-time responses***
Dana Yoerger, WHOI, USA

11:00 **NOPTILUS (EU project)**

11:30 **T1.2 - *Challenges of seabed mining in a sustainable world: let's do it right!***
Jorge Relvas, Fac. Sciences of the University of Lisbon (FCUL), PT

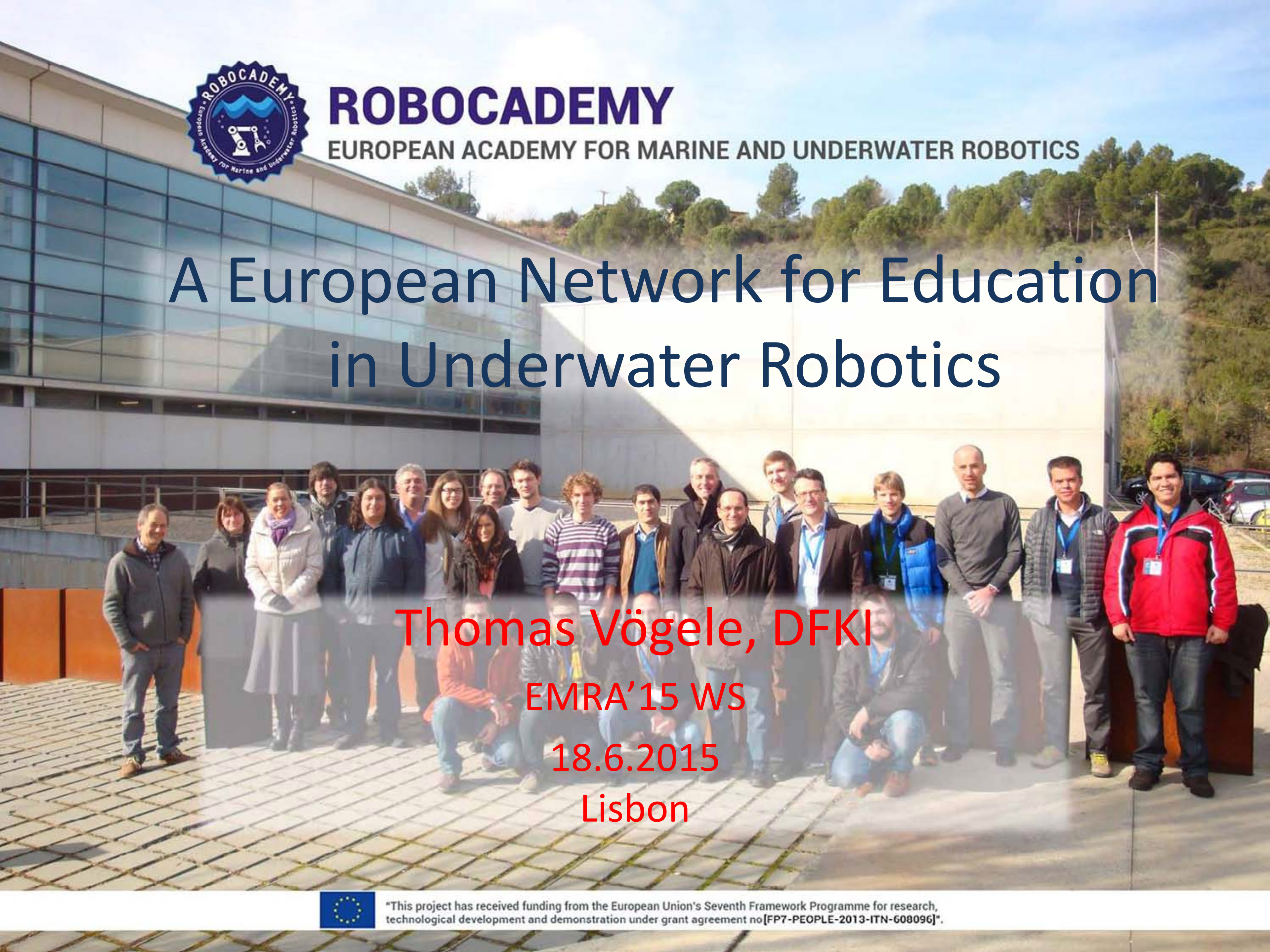
12:00 **EURATHLON (EU project)**

12:30 Open discussion - ***CHAIR D1 -*** **Marcus Cardew**

ROBOCADEMY

EU PROJECT

Thomas Vögele, DFKI, Berlin, DE



ROBOCADEMY

EUROPEAN ACADEMY FOR MARINE AND UNDERWATER ROBOTICS

A European Network for Education in Underwater Robotics

Thomas Vögele, DFKI

EMRA'15 WS

18.6.2015

Lisbon

"This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no [FP7-PEOPLE-2013-ITN-608096]".

The ROBOCADEMY Initial Training Network

- Funded by EU in Marie Curie Programme (FP7)
- Project started 1.1.2013, duration 48 months
- Total budget: 3,6 Mio €

Objectives:

➔ Select **young researchers** worldwide and turn them into highly sought-after **professionals** in the area of **underwater robotics**

1. Develop key **skills** with scientific and soft-skill training
2. Develop enabling **technologies** in underwater robotics
3. Foster **co-operation** between academia and industry

The ROBOCADEMY consortium

ROBOCADEMY
European Academy for Marine and Underwater Robotics

ViCOROB
Computer Vision and Robotics Research Institute

National Oceanography Centre
Natural Environment Research Council

GRAALTech

German Research Center for Artificial Intelligence GmbH

Universitat de Girona

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and Airbus DS

S&T organization
Centre for Maritime Research & Experimentation

National Technical University of Athens
CSL
Control Systems Lab

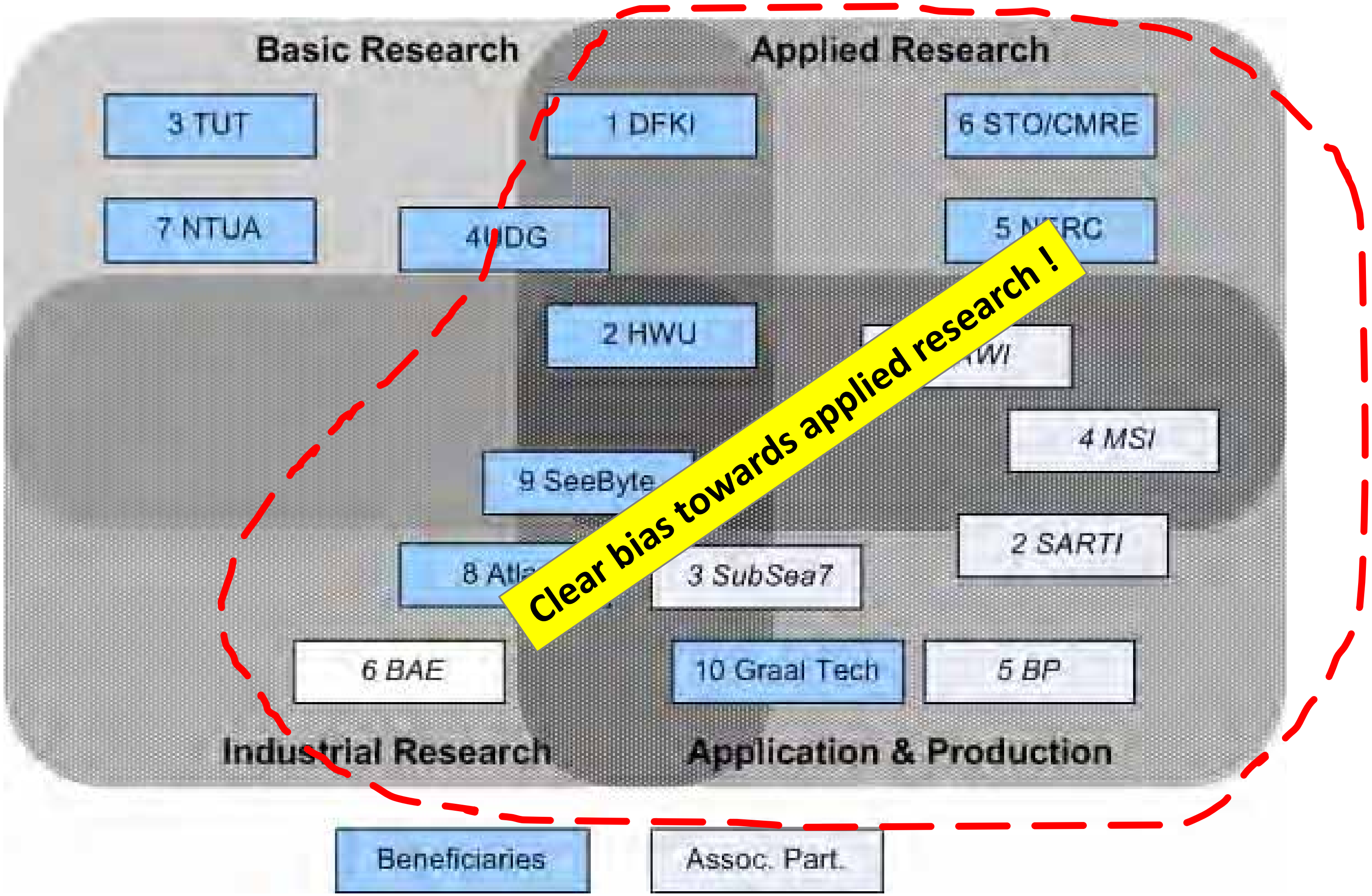
Ocean Systems Laboratory
Heriot-Watt University Edinburgh

seebyte
A BLUEFIN ROBOTICS COMPANY

ROBOCADEMY Associated Partners

N°	Associated Partner name	Short name	Country	Organisation type*
1	Alfred Wegener Institut für Polarforschung	AWI	DE	Public
2	Univesitat Politecnica de Catalunya	UPC - SARTI	ES	Public
3	Subsea7 Ltd.	Subsea7	UK	Private
4	Marine Systems Institute	MSI	EE	Public
5	BP Exploration Operating Co Ltd.	BP	UK	Private
6	BAE Systems Ltd.	BAE	UK	Private

ROBOCADEMY unites Academia & Industry



Three application scenarios

S1 Offshore Energy
Anchor Chain Inspection

S2 Marine Science
Mapping with multiple vehicles

S3 Security
Ship Hull Inspection

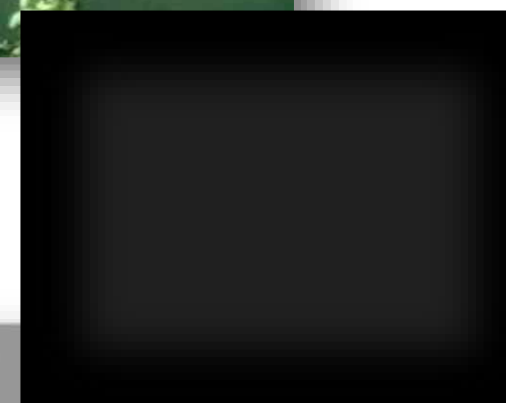
Currents

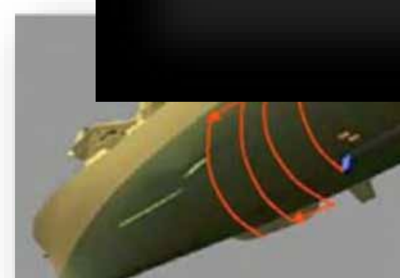
Turbidity

Dynamic environments

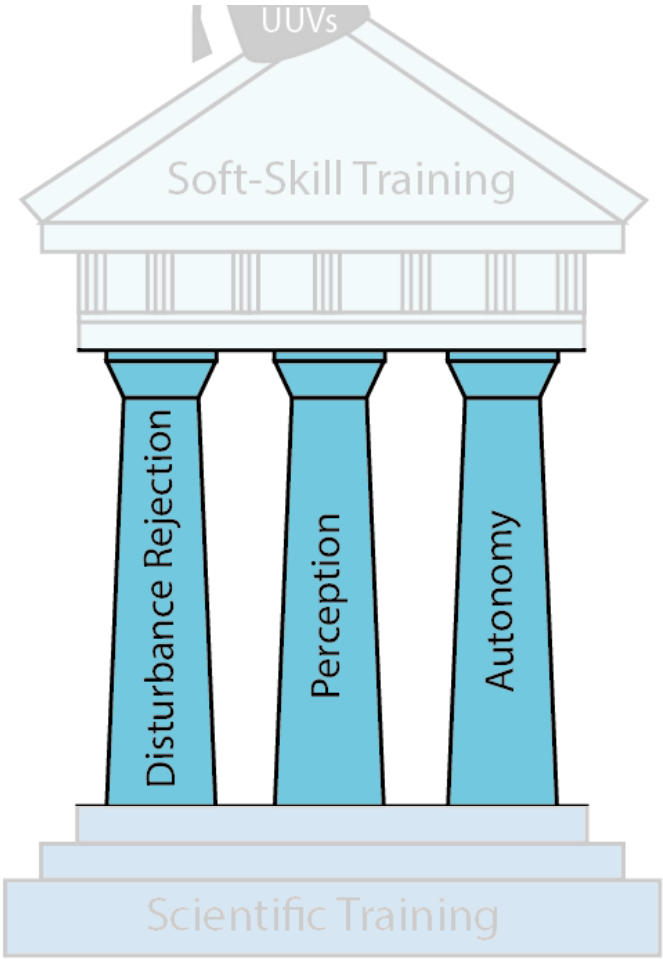
Failing technical components

Robust UW vehicles for **long-term deployment**





The Pillars: Research / PhD programs

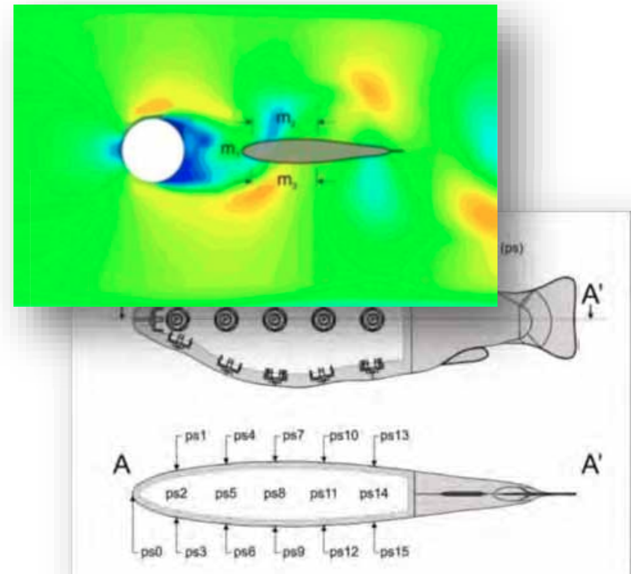


- At the core of Robocademy: 13 interlinked **research projects**
- **13 early stage researchers** (ESRs) as Robocademy fellows
- Requirement: MS in relevant field, no residency in host country, worldwide
- Receive **3 year contracts** at host institute / company
- Objective: develop **key enabling technologies** in three **action lines**

AL1: Disturbance Rejection

Objective: Enable precise robot control under real-world conditions

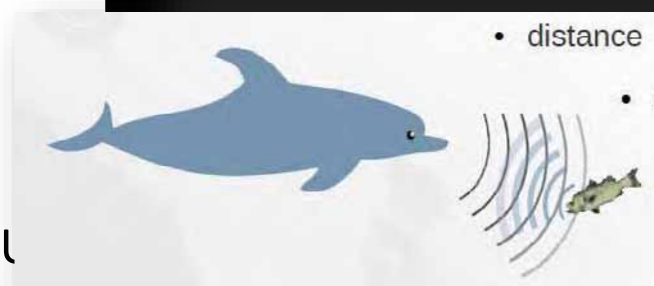
- Fish-like **flow sensors** for improved vehicle control (TUT)
- Machine learning for optimized UUV **motion models** (DFKI)
- Machine learning for automated UUV **fault detection** (DFKI)
- Multi-agent framework for **co-operative AUVs** in real environments (NTNU)



AL2: Perception

Objective: Enable high-resolution environment perception in the ocean under real-world conditions

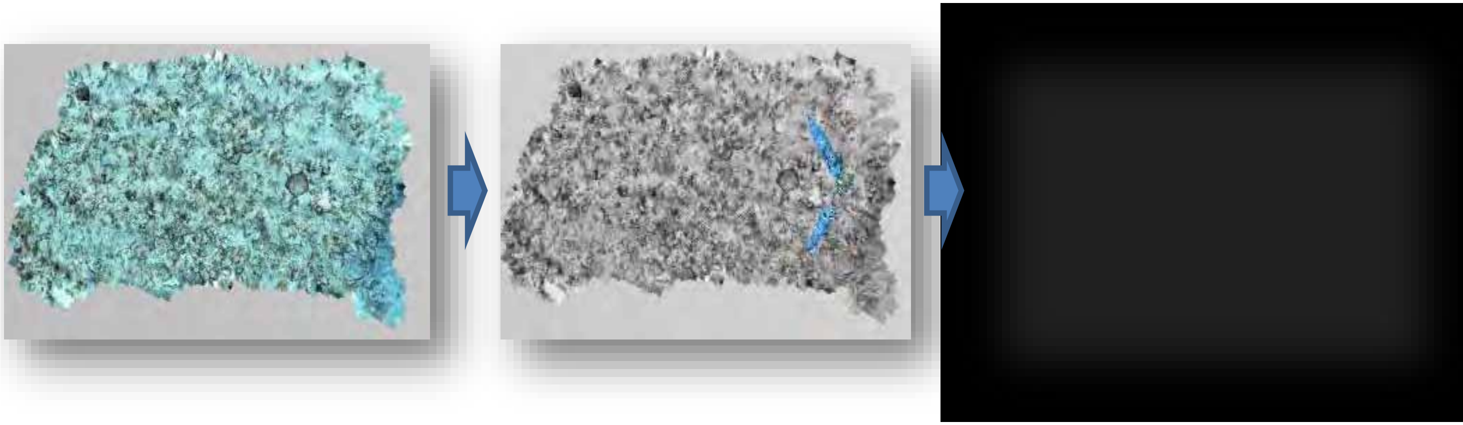
- Object-recognition with **dolphin-sonar** (broadband multi-chirp sonar) (HWU)
- Improved **optical sensing** to compensate for UW effects (UdG)
- **UW perception** with sensor fusion (optical/sonar) (CMRE)
- **Multi-vehicle object recognition** (HWU
- **3-D scene recovery/understanding** (SeeByte)
- Dynamic **single vehicle object recognition** (Atlas)



AL3: Autonomy

Objective: Develop key technologies in support of long-term autonomy of AUVs in dynamic real-world environments.

- Semantic models for **task re-planning** and **failure recovery** (HWU)
- **Multi-vehicle / swarm navigation** and localization (GT)
- Reliable **long-range navigation** under energy constraints and in extreme environments (e.g. under ice) (NOC/NURC)

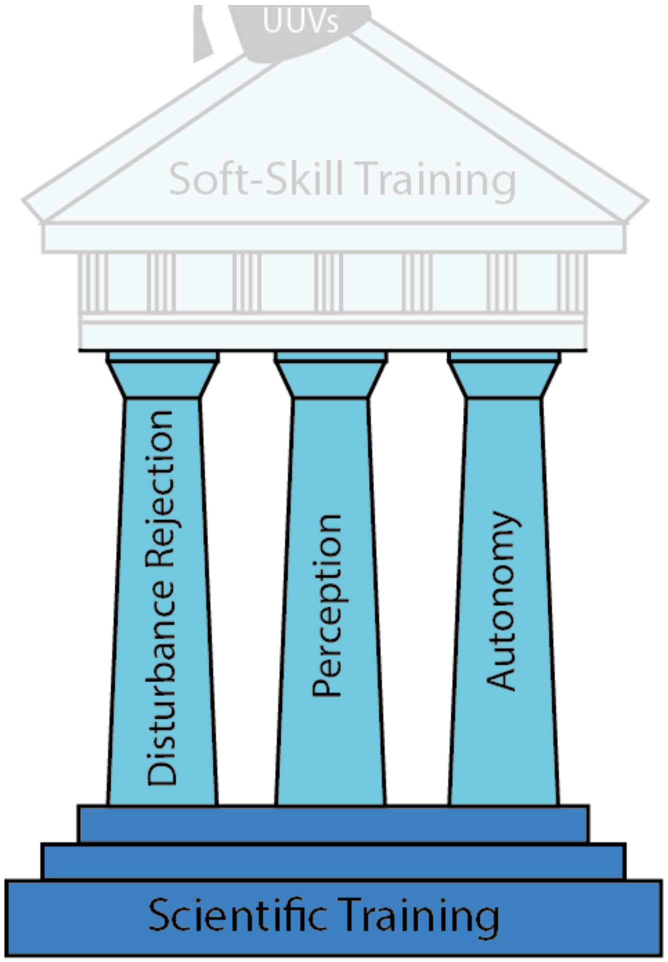


13 Robocademy fellows from 13 countries

PhD support programme

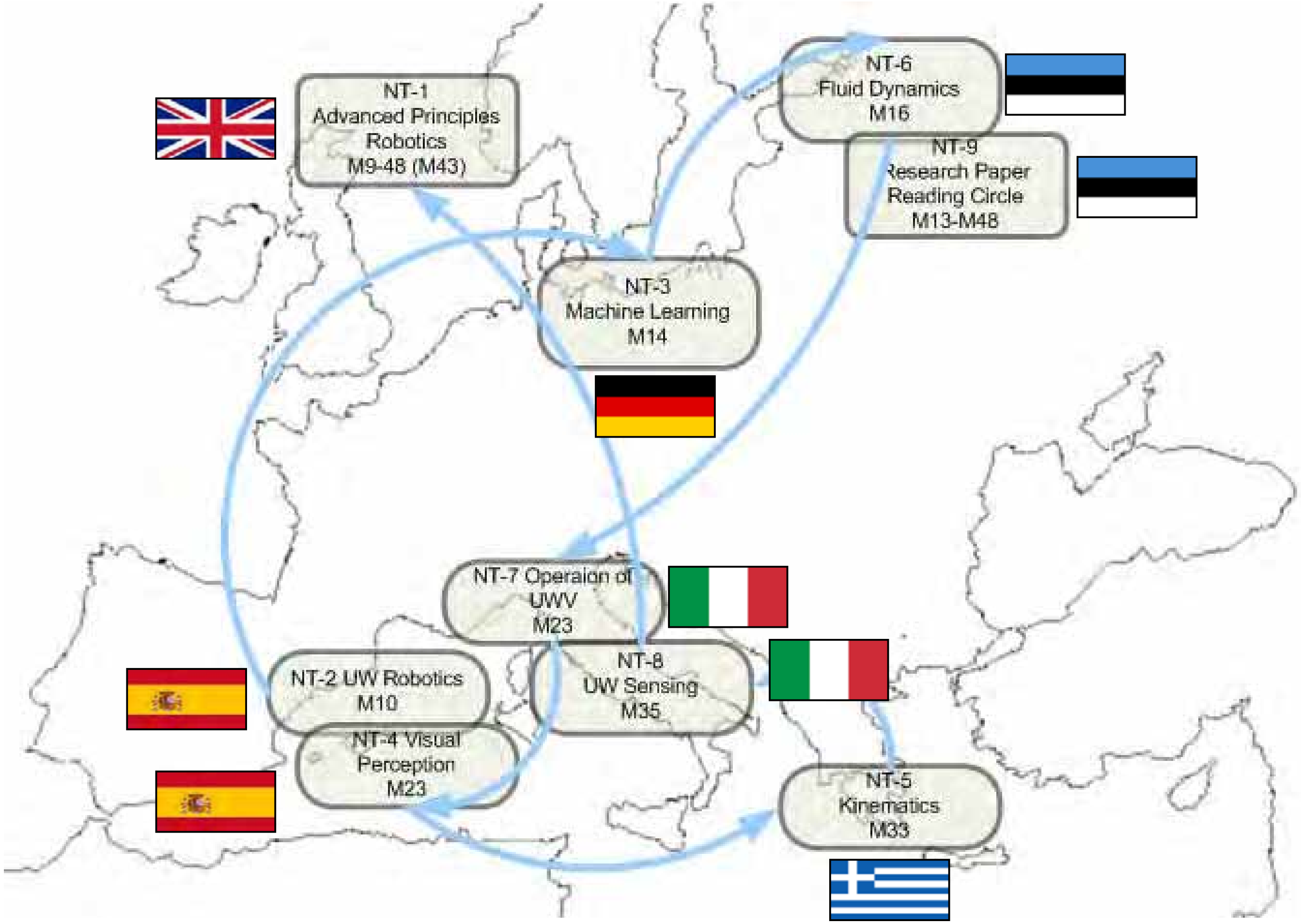
- The PhD effort of each fellow is **supervised** and **co-supervised** by qualified academics (if possible from within the network)
- Each fellow prepares a **Career Development Plan** together with his/her supervisor
- The ROBOCADEMY **Progression Board** supports the fellows and monitors their progress
- **Secondments** of at least 6 months cummulative duration to ROBOCADEMY beneficiaries and associated partners support exchange of ideas and networking with industry and academia

The foundations: Scientific training



- NT-1 Advanced principles of robotics
- NT-2 Autonomous underwater robotics
- NT-3 Machine Learning for autonomous robots
- NT-4 Visual Perception
- NT-5 Robotic Motion Planning for Non-holonomic & Multi-Agent Systems
- NT-6 Fluid dynamics workshop and experimental methodology
- NT-7 Operation of UW vehicles
- NT-8 Underwater sensing and vehicle operation
- NT-9 Research paper reading circle

All academic beneficiaries contribute



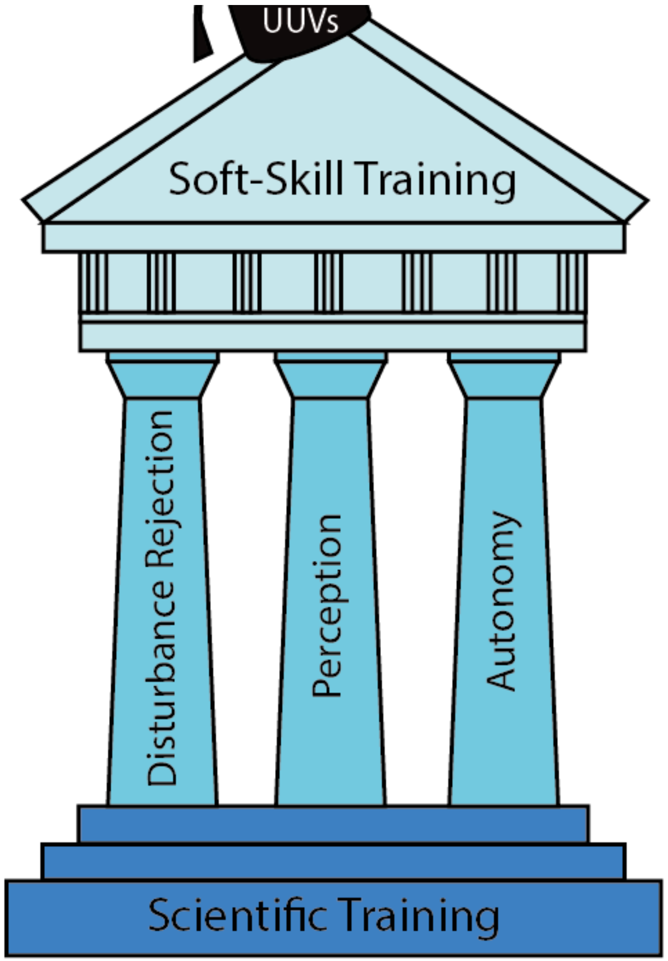
Learning, networking, having fun

Courses at UdG and DFKI

Group photo DFKI UW facility

Visit at associated partner AWI

The roof: Soft-skills



- Working in project teams
- Training courses (e.g. project management, paper writing, proposal writing etc.)
- Secondments to core and associated partners (academia → industry)
- Papers in conferences & journals
- Participation in events (e.g. eurathlon)
- …

Status

- Project is up and running
- All ESRs hired and working
- All research projects in progress
- First network training courses successfully completed
- Secondments will start soon
- Robocademy co-operation for eurathlon
- First papers in progress

Thank you for Attention!

For more information on ROBOCADEMY:

The ROBOCADEMY management team:

Thomas Vögele & Tom Runge, DFKI (Germany)
thomas.voegele@dfki.de/tom.runge@dfki.de

Internet: www.robocademy.eu

Facebook: facebook.com/robocademy

Twitter: @ITN_Robocademy

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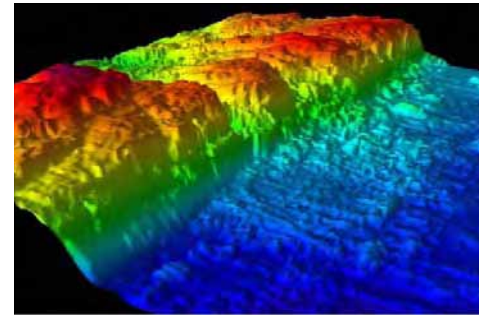

Mapping the seafloor in rough terrain with AUVs: mission planning versus real-time responses

Dana Yoerger, WHOI, USA

ISR-IST Lisbon Portugal

Mapping the seafloor in rough terrain with AUVs:
Mission Planning versus Real-Time Responses

Dana R. Yoerger
Senior Scientist
Dept. of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution

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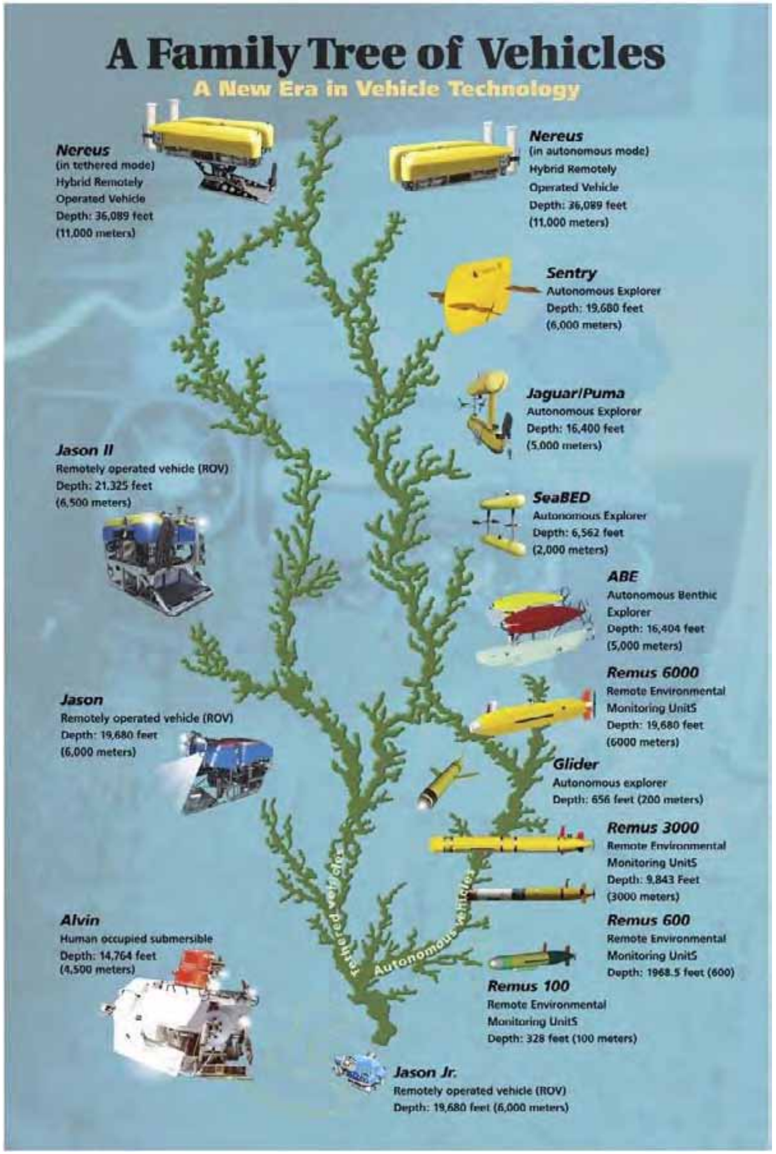
1930

WHOI's Vehicle Family Tree



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Scientific Drivers for Deep Submergence Technology

- Understanding the Dynamics of the Mid-Ocean Ridge
- Search for hydrothermal vents
- Survey for corals on seamounts
  - Benthic ecology
  - Paleoclimate studies from fossil corals
- Deep sea volcanoes
- Subduction zones, exploring the trenches
- Polar exploration: under sea ice and glacial ice
- Methane seeps: carbon budget?
- The unexpected: hydrocarbon plumes from deep sea oil spills.
- What's next?

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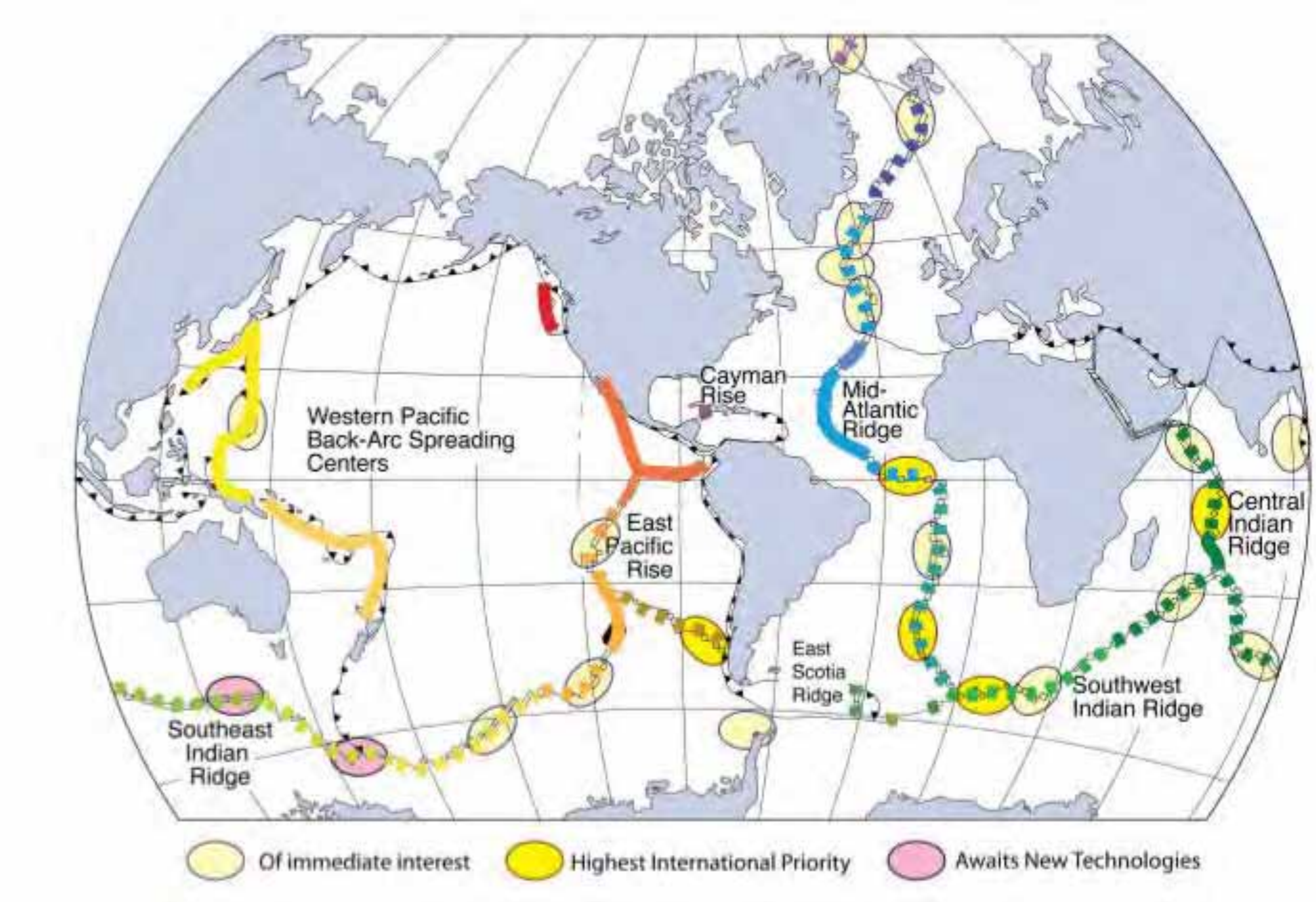
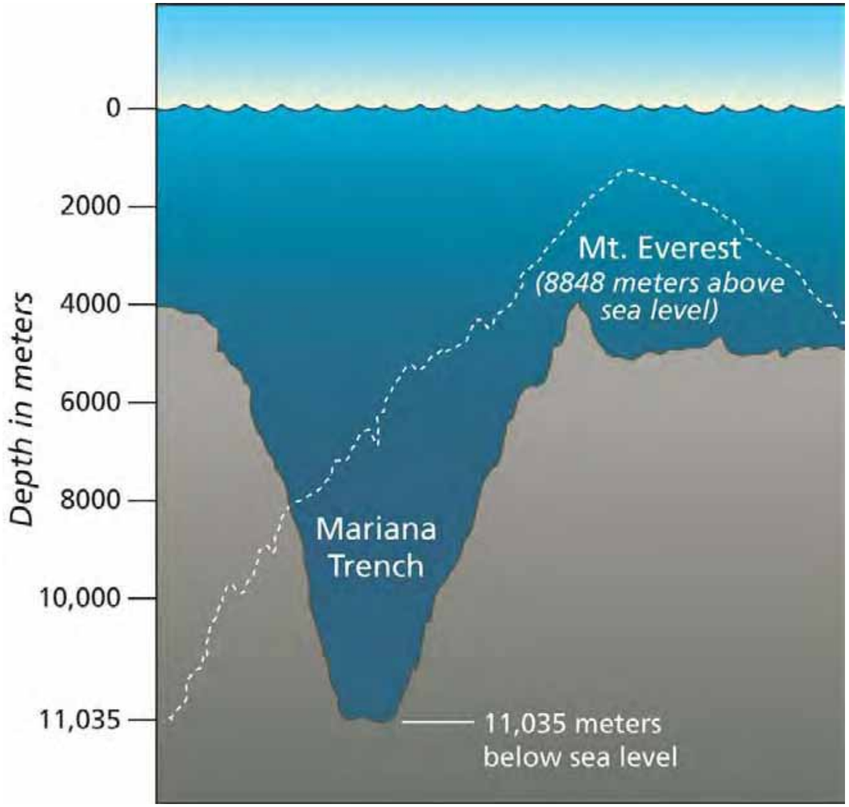
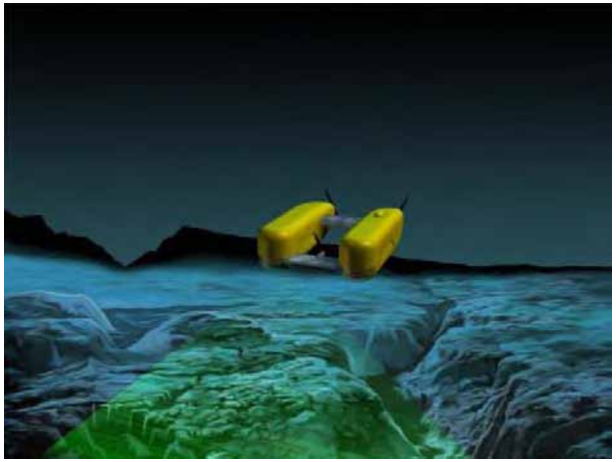
Mid-Ocean Ridge Exploration



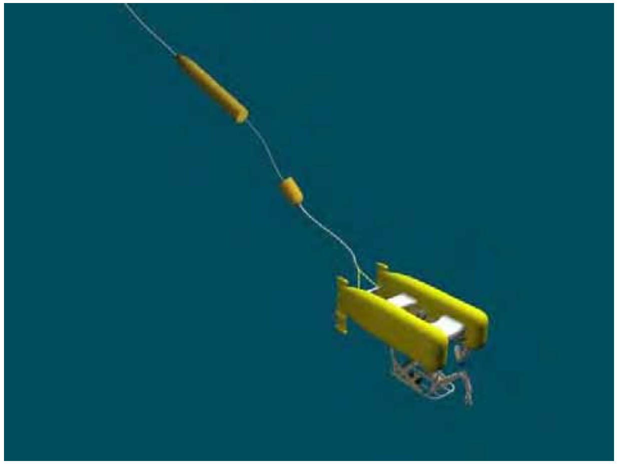
AUVs in Extreme Environments
Abyssal Depths



Mariana Trench



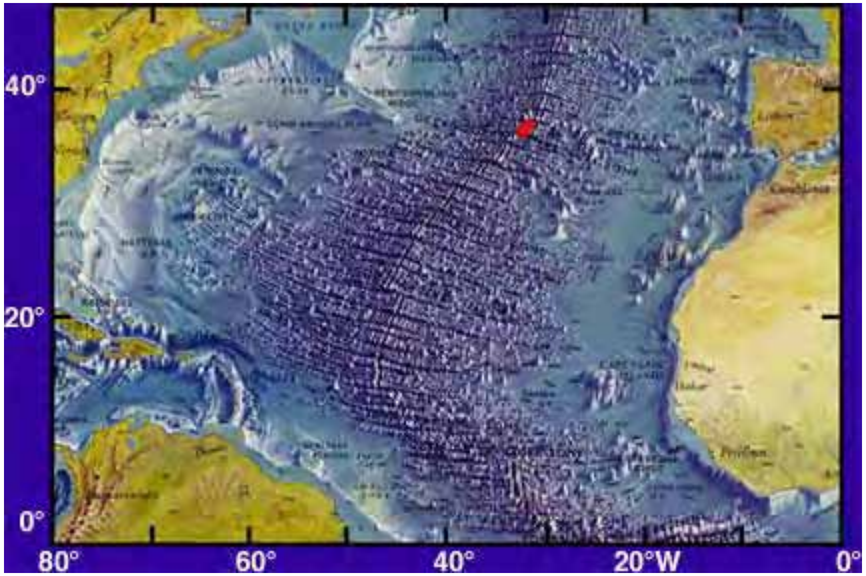
AUV mode



ROV mode

WHOI, Johns Hopkins Univ,
SPAWAR Systems Center

Project Famous 1974: the birth of scientific deep submergence



Physiographic map of the North Atlantic Ocean by Bruce C. Heezen and Marie Tharp

Archemede (France)

Alvin (USA)

Cyana (France)

Photos from WHOI Archives

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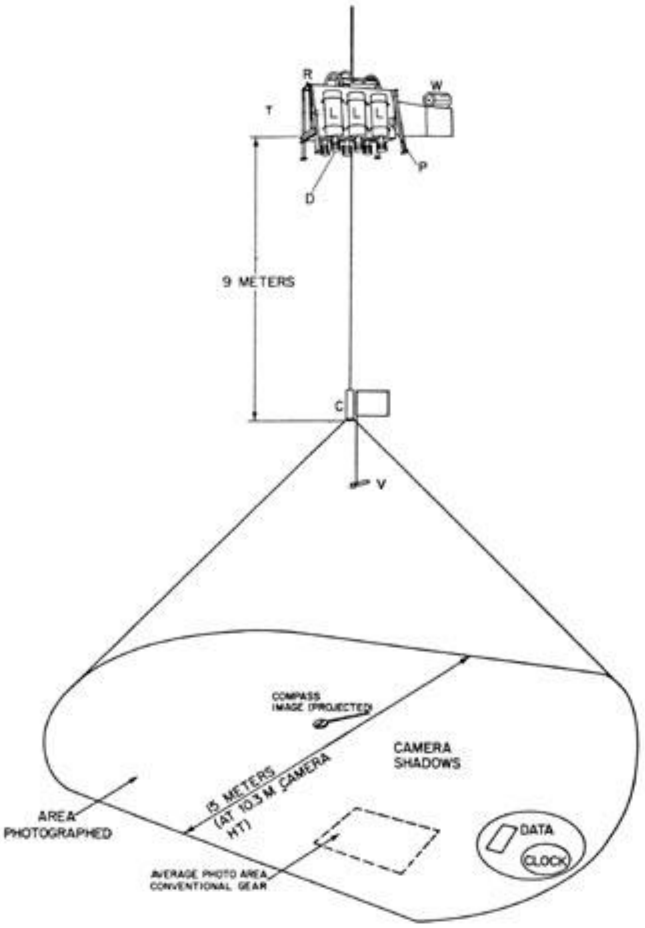
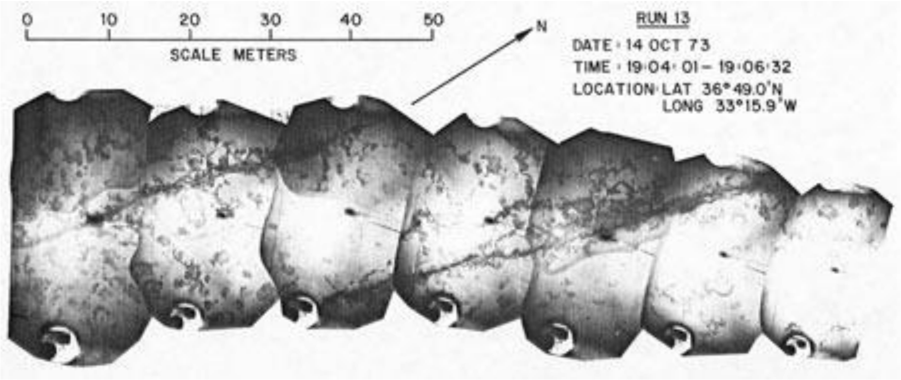
LIBEC: wide-area photography of the deep seafloor



US Navy LIBEC system (WHOI archives)

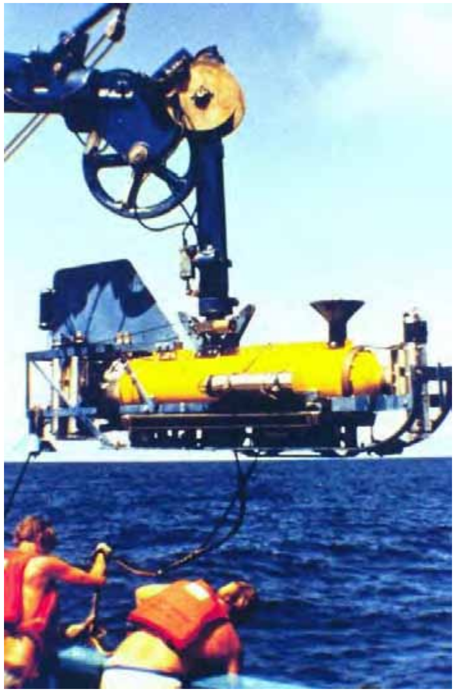
ANGUS Tow Sled (WHOI archives)

FAMOUS photo analysis



LIBEC mosaic (US Naval Research Lab)

Tow Sleds: Deep Tow



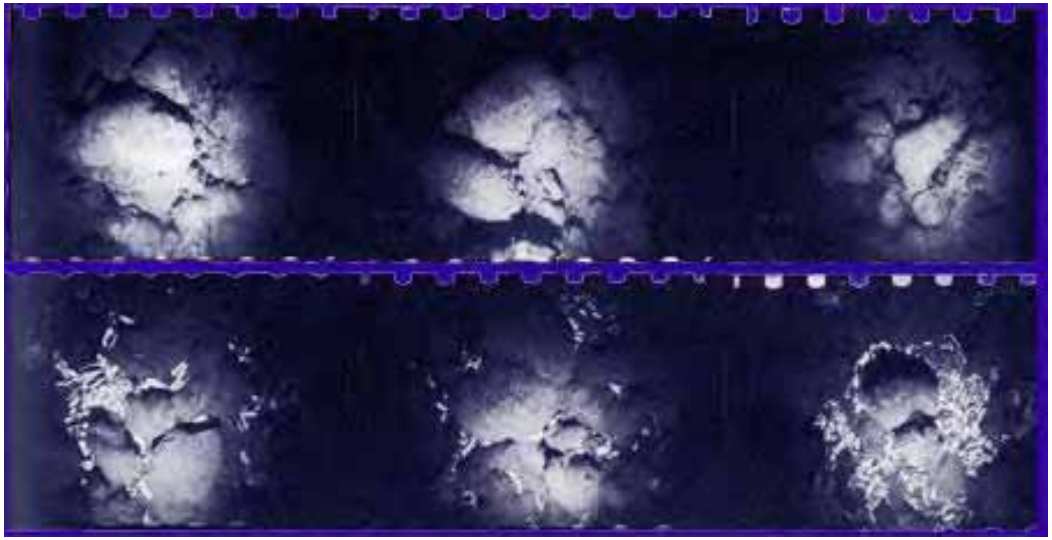
Spiess, F. N. East Pacific Rise: Hot springs and geophysical experiments. Science. 207 (4438):1421-1432. (1980).

Lonsdale, P. and K. Becker. Hydrothermal plumes, hot springs, and conductive heat flow in the Southern Trough of Guaymas Basin. Earth Planet. Sci.Lett. 73:211-225. (1985).

ANGUS survey capabilities

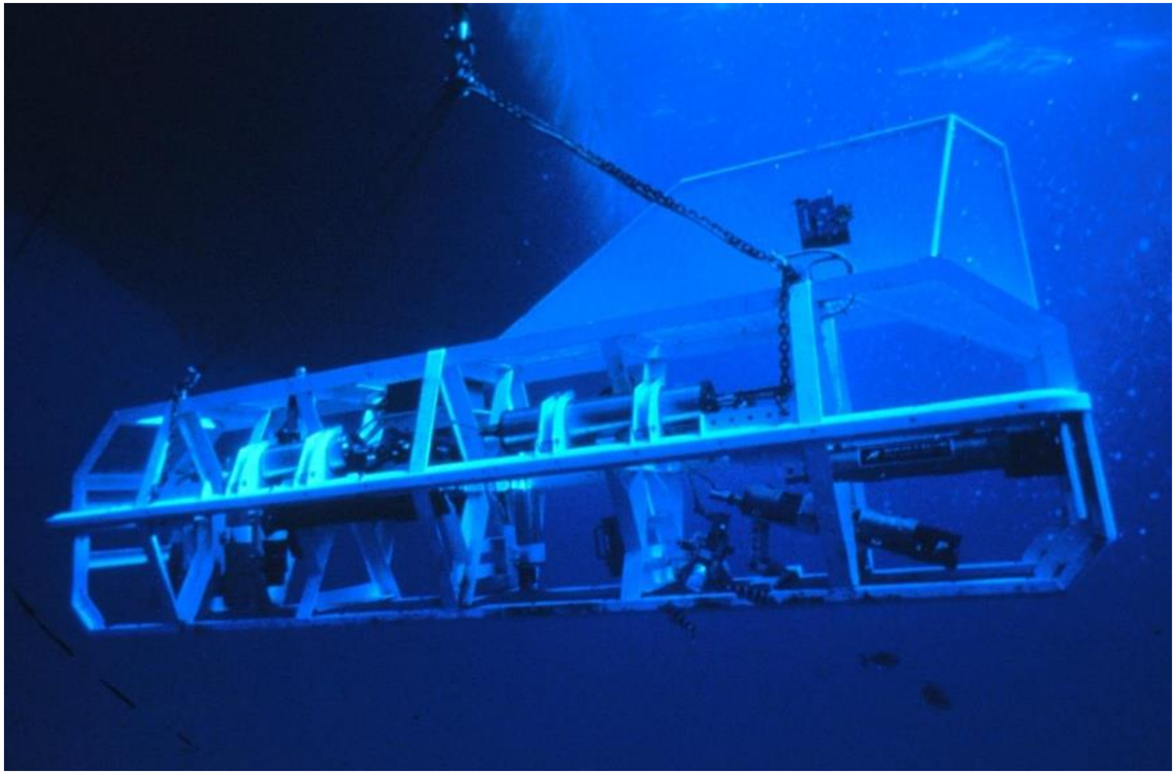
- 35mm film cameras
- On-vessel processing
- LBL acoustic navigation
- Height and temperature determined by pinger trace, manual winch control
- Manual vessel control, often with under-actuated vessels, highly dependent on human skill
- In later years, vessel and winch controlled from science van
- WHOI Towcam and FSU Driftcam are descendents

Discovery and Exploration of Hydrothermal Vents: 1977-1979



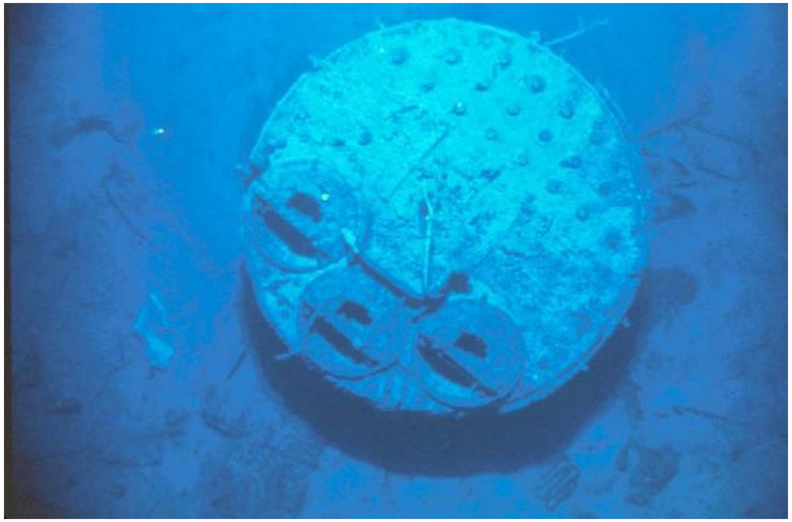
- ANGUS photos and temperature readings used to vector Alvin to vent sites along the Galapagos Rift
- Alvin took close up photos and samples
- Model for our present strategy of AUV geophysical survey followed by ROV or HOV survey

Tow Sled: Argo

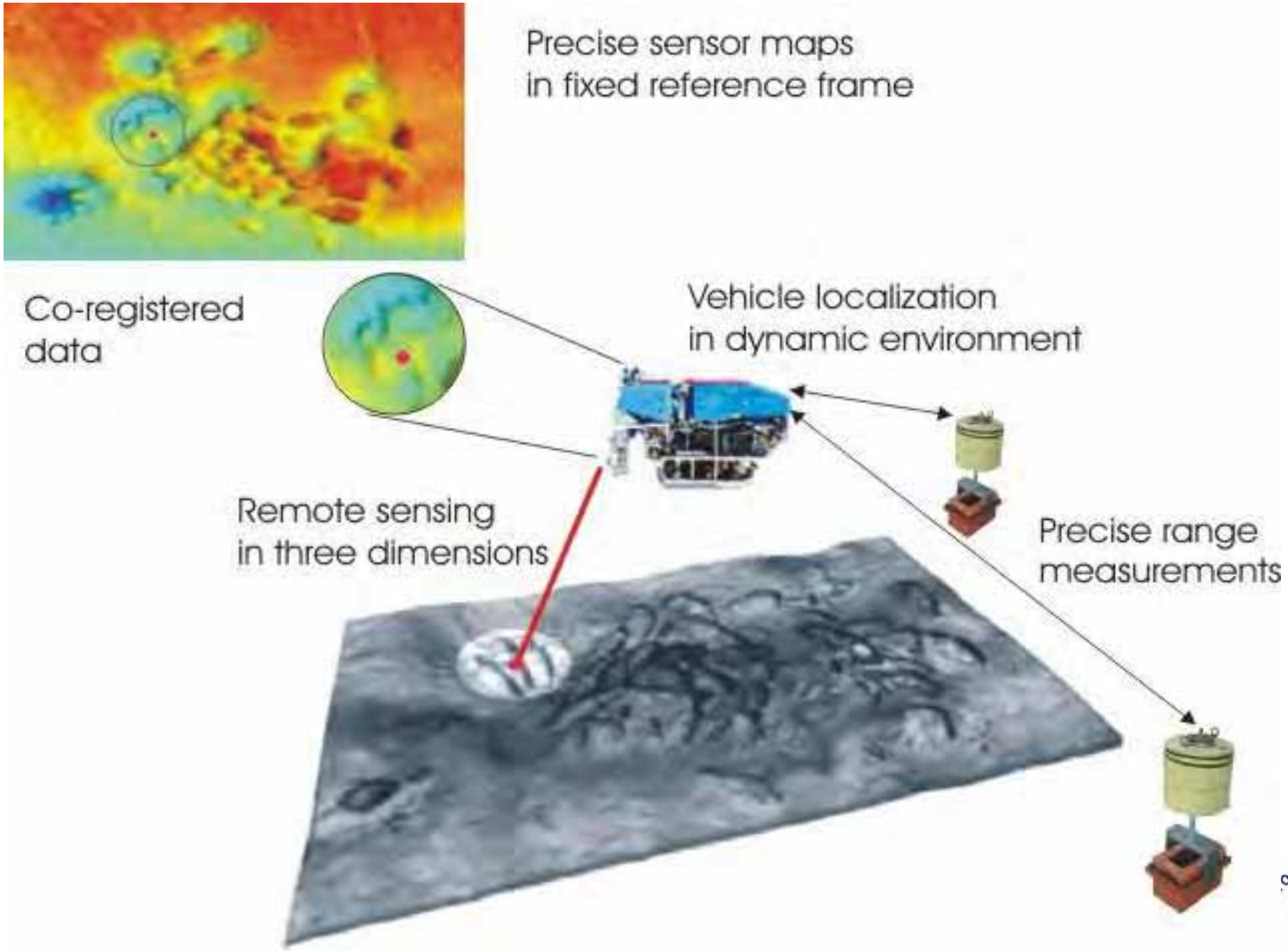


•Coaxial cable: 1 video channel, ~500 watts of power
•SIT camera and strobes
•Klein sidescan
•LBL navigation, flux gate compass, pressure depth

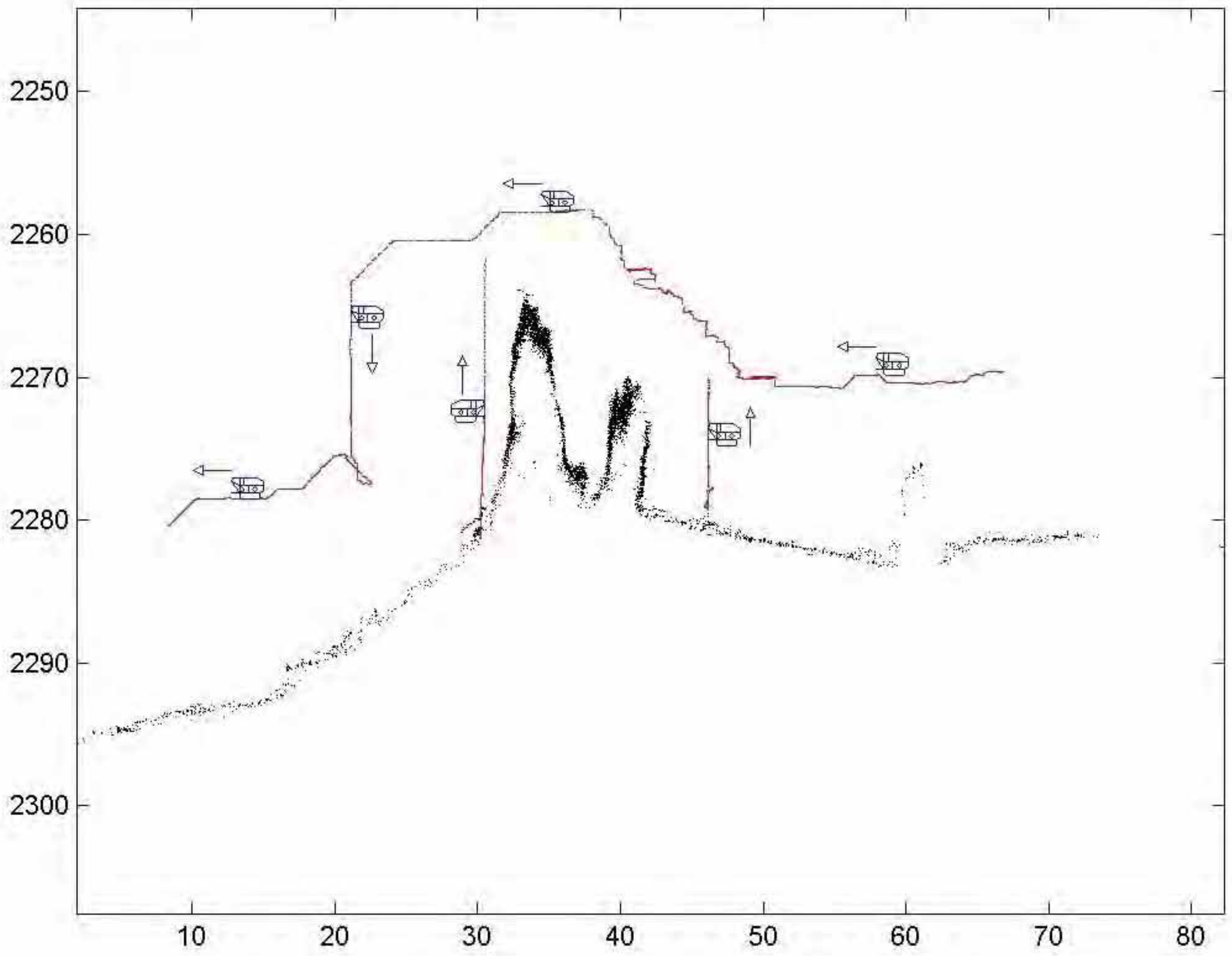
Discovery of Titanic: Argo Tow Sled and ANGUS



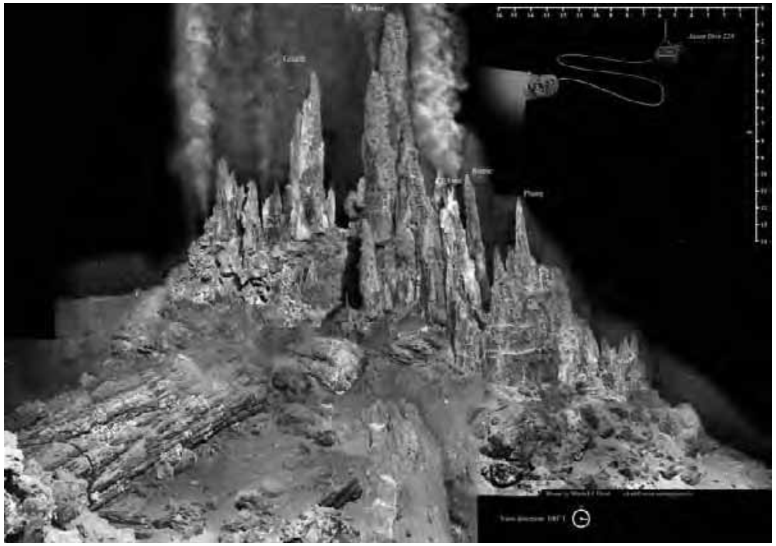
Jason's Closed-Loop Control System

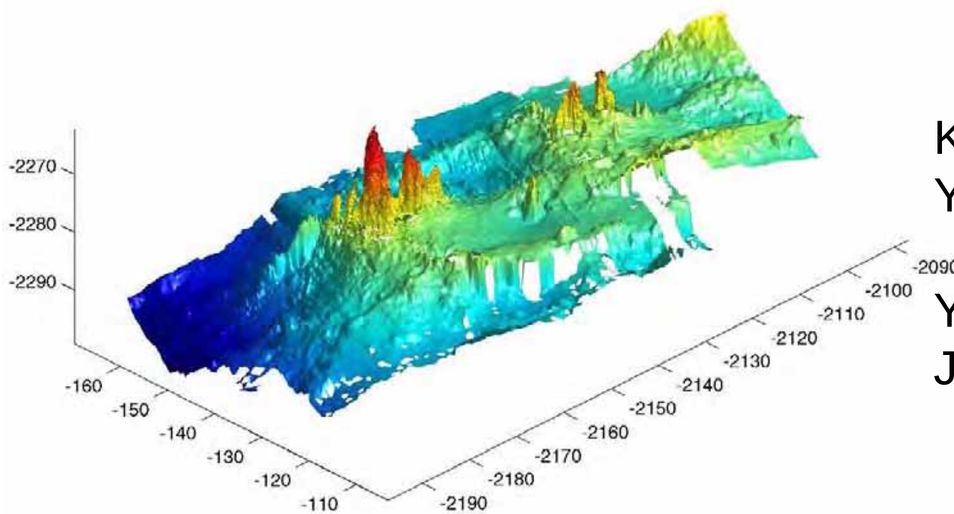


Jason flying closed-loop survey tracks over Faulty Towers



Photomosaics and scanning-sonar maps





Kelley, D.S., J.R. Delaney, and D.R Yoerger. 2001. . Geology 29:959–962.

Yoerger, D.R, Kelley D.S, Delaney, J.R, Int J. Robotics Research, 2000

Autonomous Underwater Vehicles

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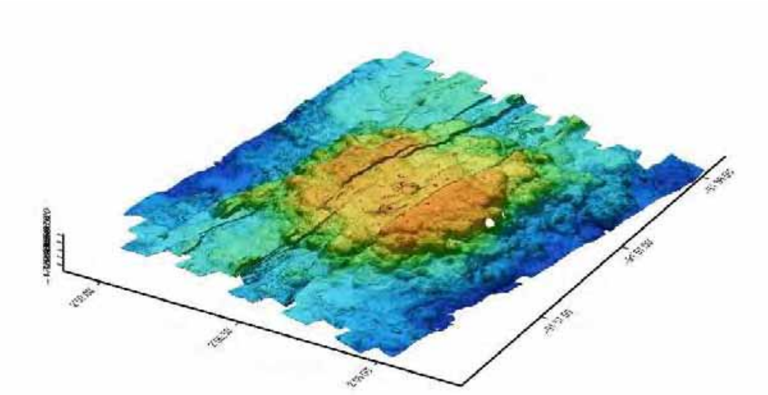
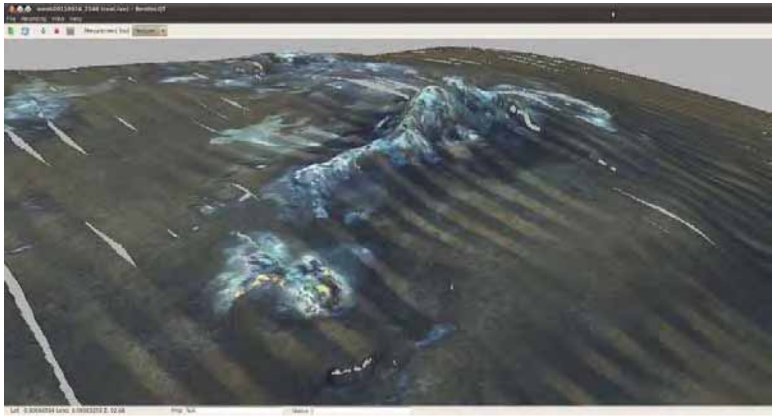
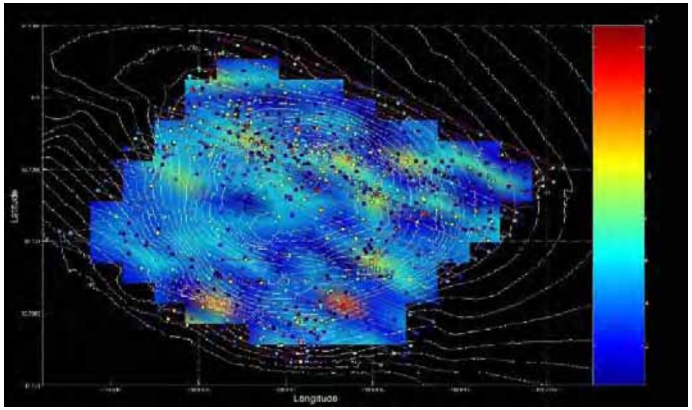
Sentry AUV Data Products



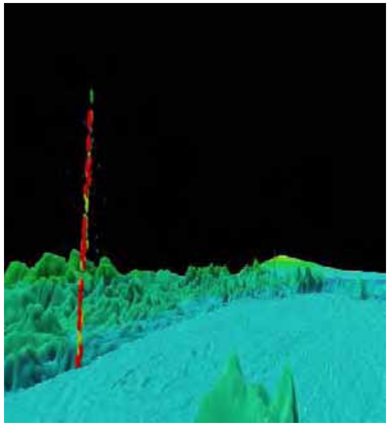
Fine-scale bathymetry



3D photo reconstruction, Australian Centre for Field Robotics (Pizarro)

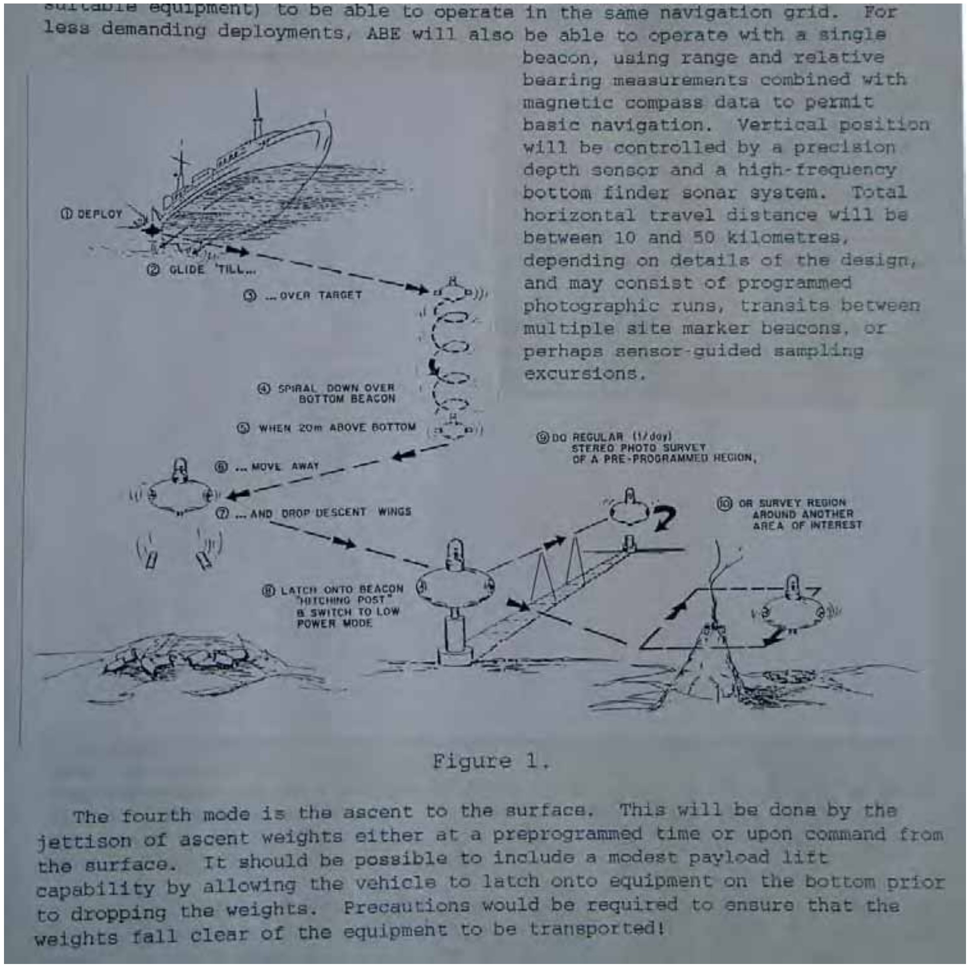


Chemical mapping with Tethys Mass spectrometer (Camilli)



Plume mapping

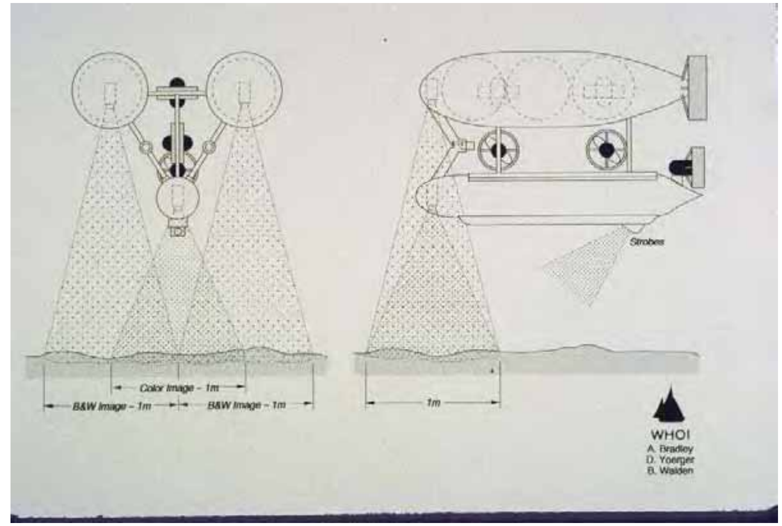
ABE proposal 1989

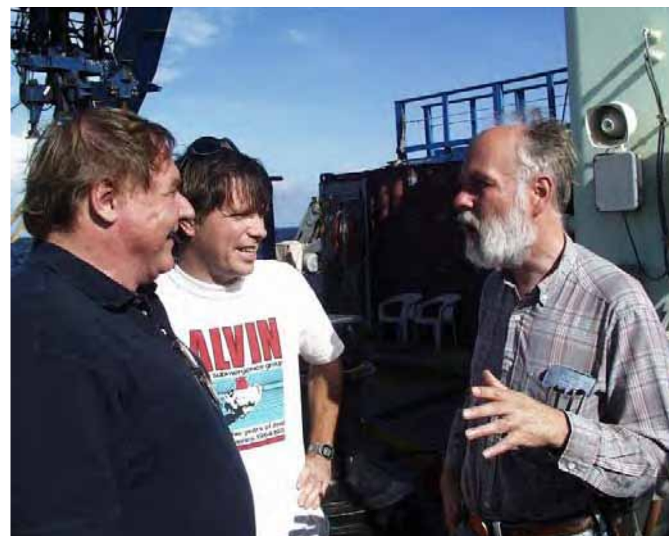


suitable equipment) to be able to operate in the same navigation grid. For less demanding deployments, ABE will also be able to operate with a single beacon, using range and relative bearing measurements combined with magnetic compass data to permit basic navigation. Vertical position will be controlled by a precision depth sensor and a high-frequency bottom finder sonar system. Total horizontal travel distance will be between 10 and 50 kilometres, depending on details of the design, and may consist of programmed photographic runs, transits between multiple site marker beacons, or perhaps sensor-guided sampling excursions.

Figure 1.

The fourth mode is the ascent to the surface. This will be done by the jettison of ascent weights either at a preprogrammed time or upon command from the surface. It should be possible to include a modest payload lift capability by allowing the vehicle to latch onto equipment on the bottom prior to dropping the weights. Precautions would be required to ensure that the weights fall clear of the equipment to be transported!





ABE operations 1994-2010

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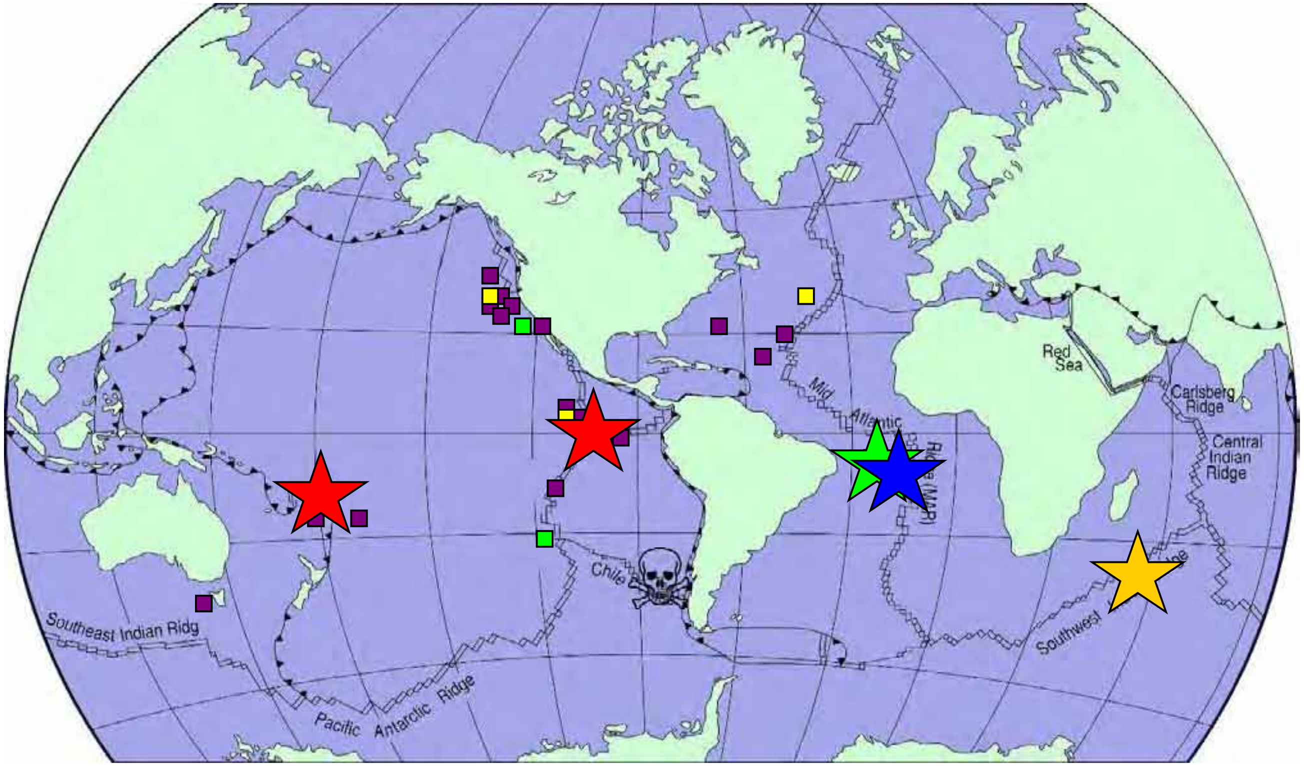
ABE dives 1994-2010



- Completed
- Proposed
- Scheduled
- Vent discoveries
- RIP ABE

222 deep ocean dives
>3500 km of bottom tracks
>1800 hours survey time
many unsupported by ROV or HOV

Operated from 10 vessels from
5 countries
Lost Feb 2010, Chile Triple Junction

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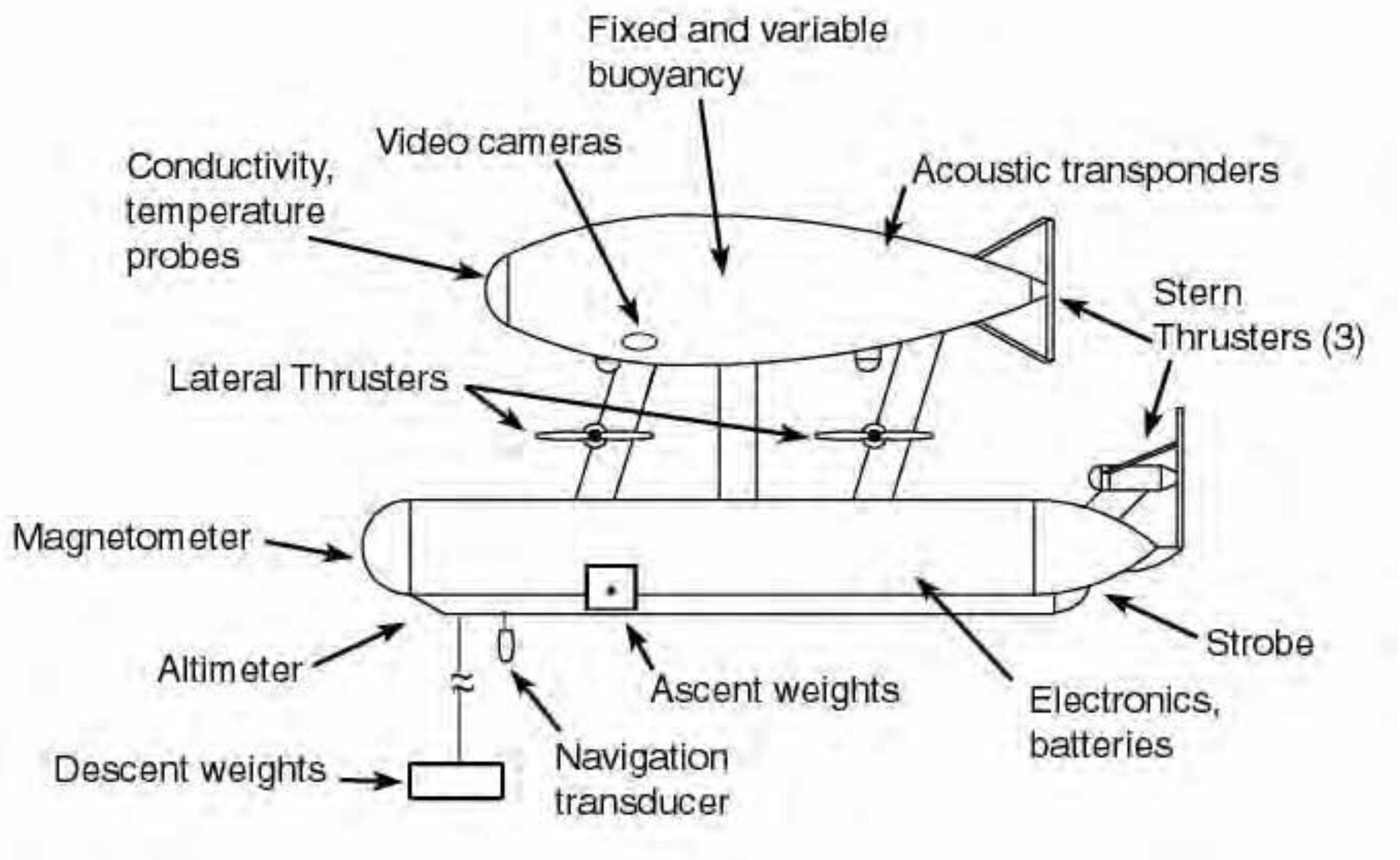
ABE



Fixed and variable buoyancy
Video cameras
Conductivity, temperature probes
Acoustic transponders
Stern Thrusters (3)
Lateral Thrusters
Magnetometer
Altimeter
Strobe
Ascent weights
Electronics, batteries
Descent weights
Navigation transducer

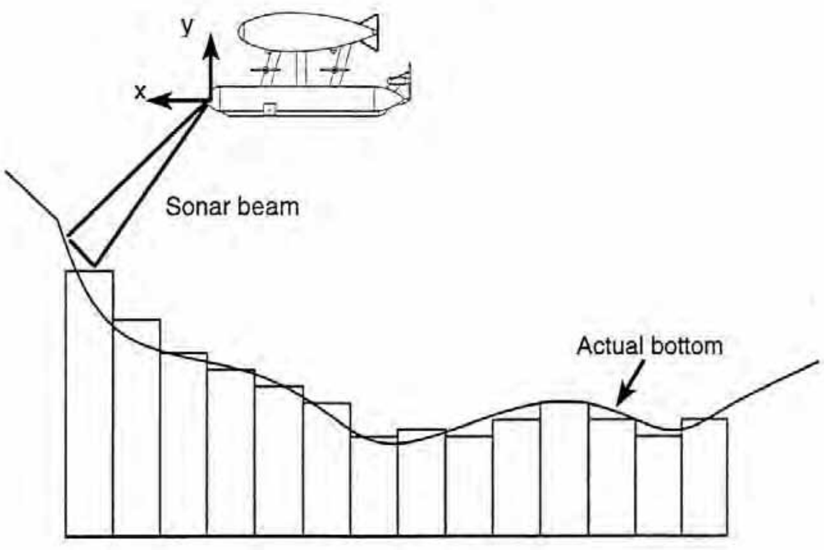
Original ABE Bottom-Following (Bachmayer, Bradley, Yoerger)

Potential Function: $V_j = q_j(1/r - 1/r_j)^k$ where k is an integer

with: $j = 1$ pull-up field
$j = 2$ push-down field

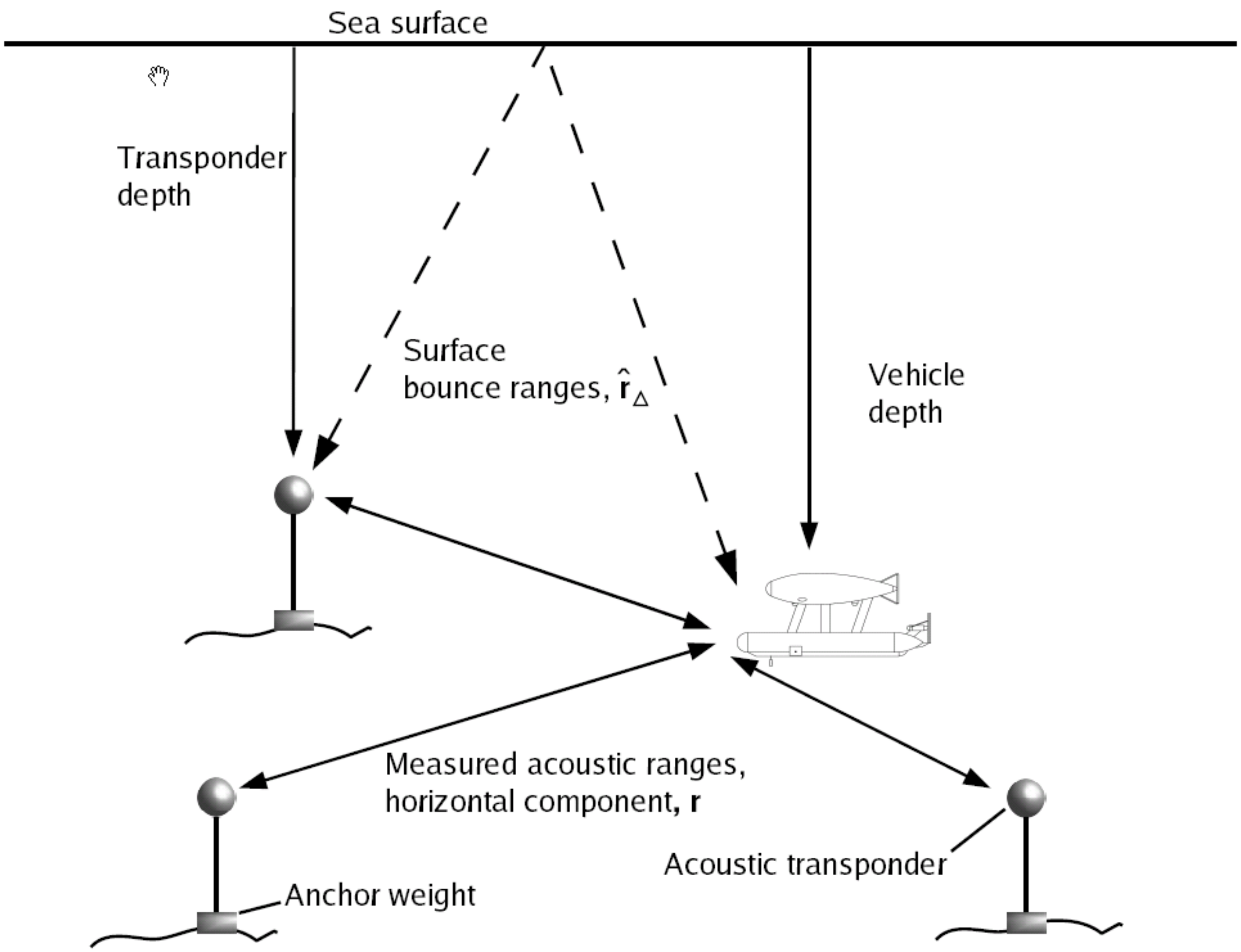
Elliptical distance: $r = \mathrm{sqrt}(x^2/a^2 + y^2/b^2)$

Gradient: $\nabla V_j = -q_j k(1/r - 1/r_j)^{k-1}[(x/a^2)\mathbf{e_x} + (y/b^2)\mathbf{e_y}]/r^3$
where $\mathbf{e_x}$ and $\mathbf{e_y}$ are unit vectors

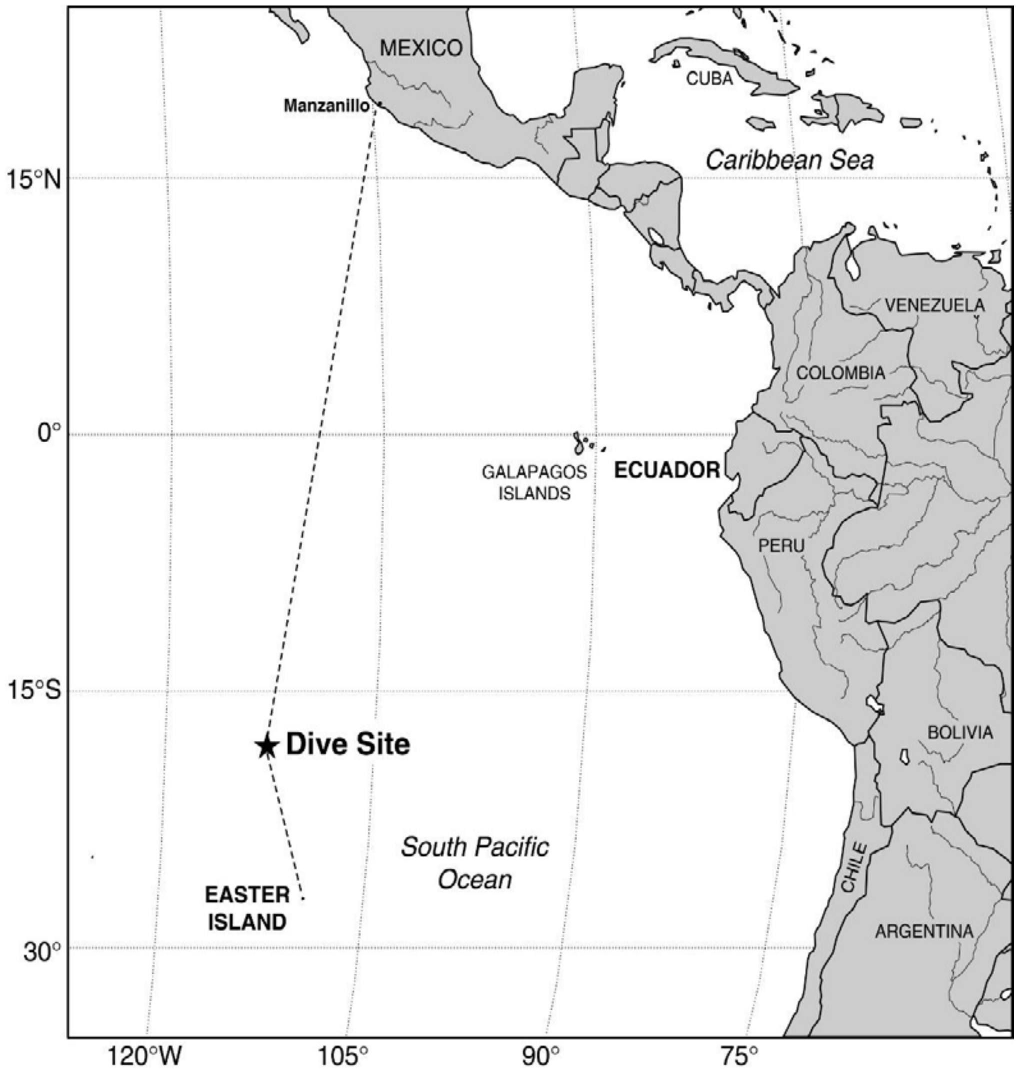


Gridded map

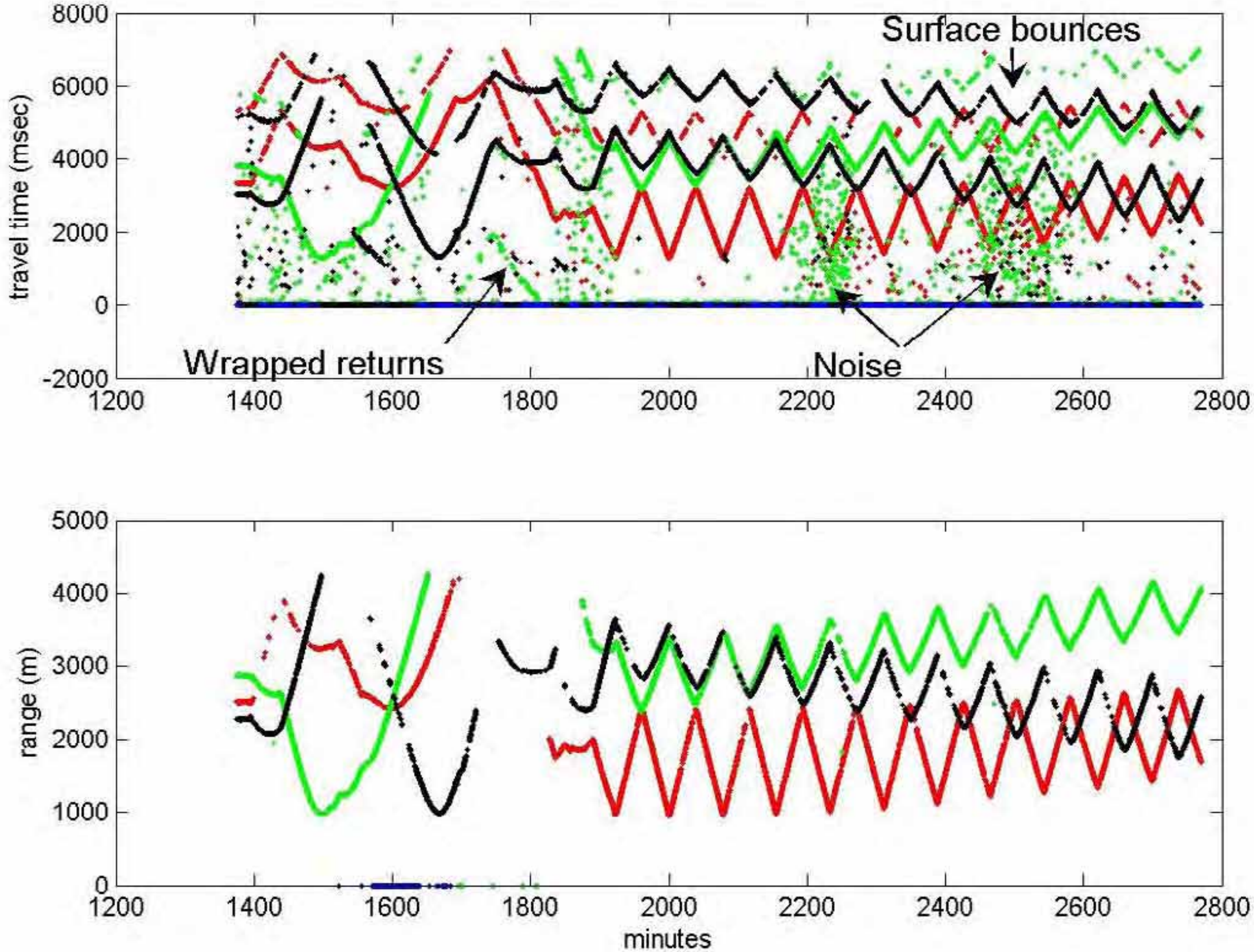
Long Baseline Acoustic Navigation



ABE on the Southern East Pacific Rise (SEPR) 1999 (Sinton, Cormier, Ryan et al)



Surface bounces and random noise



Yoerger et al, Int. J. Robotics Research, 2007

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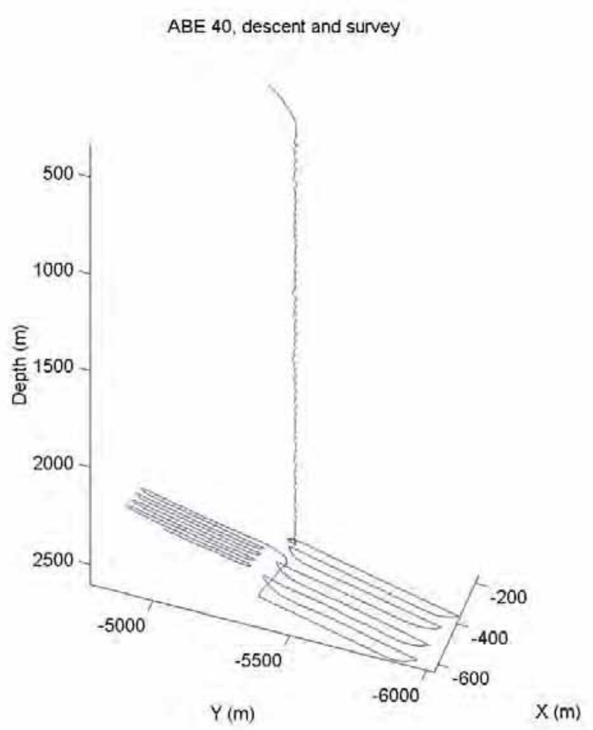
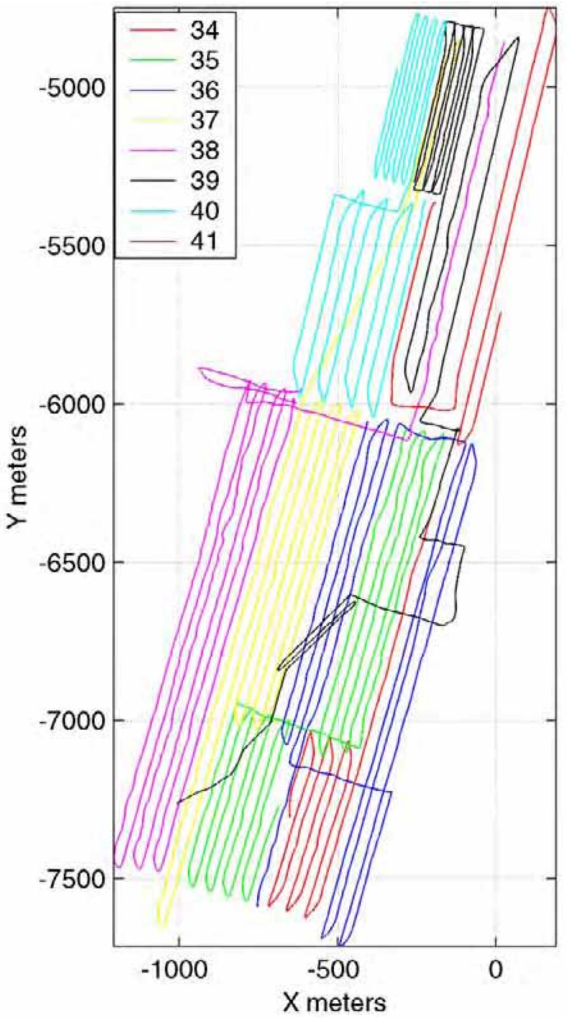
ABE Tracklines, Southern East Pacific Rise, 1999



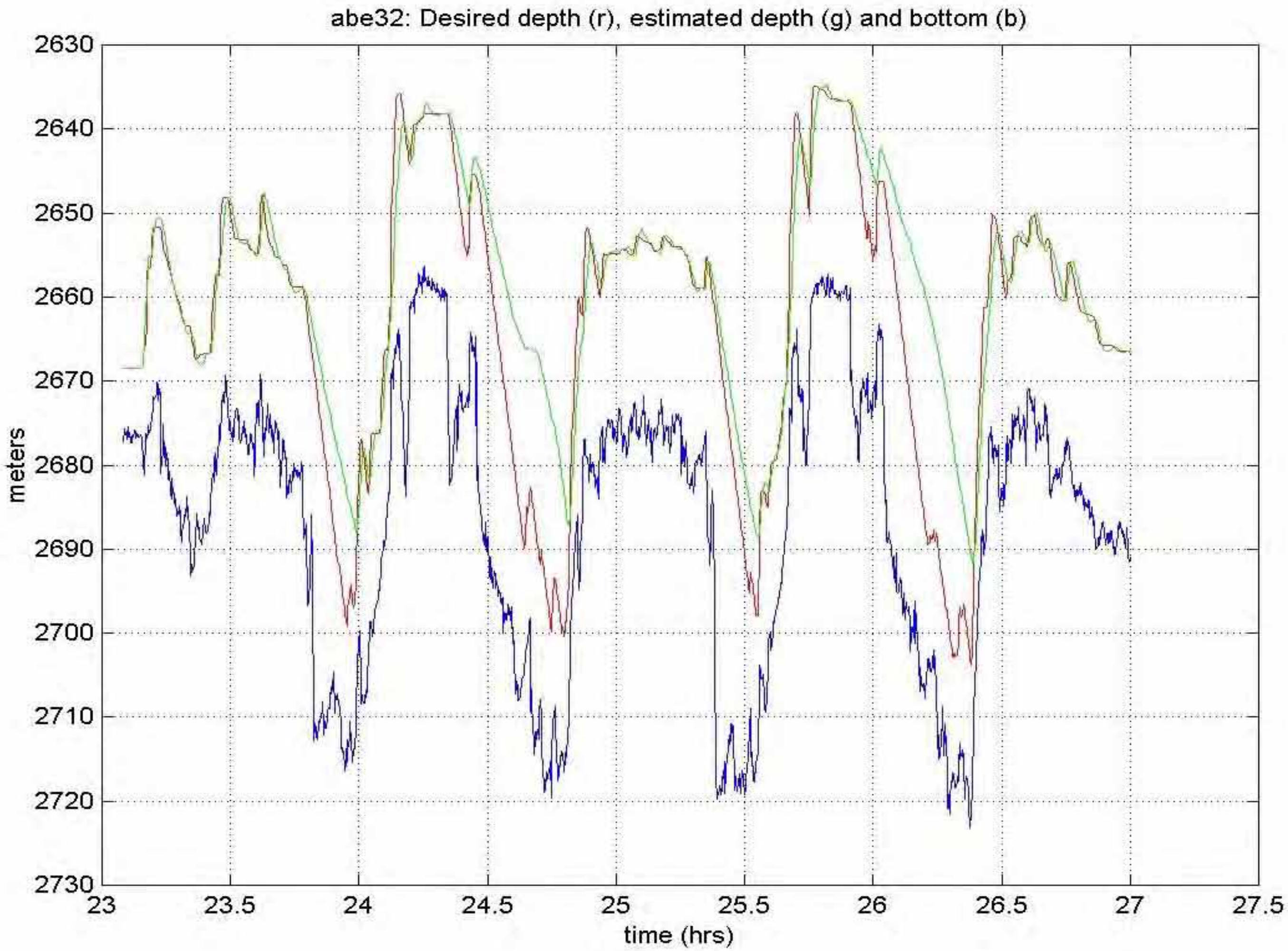
Precise Descents



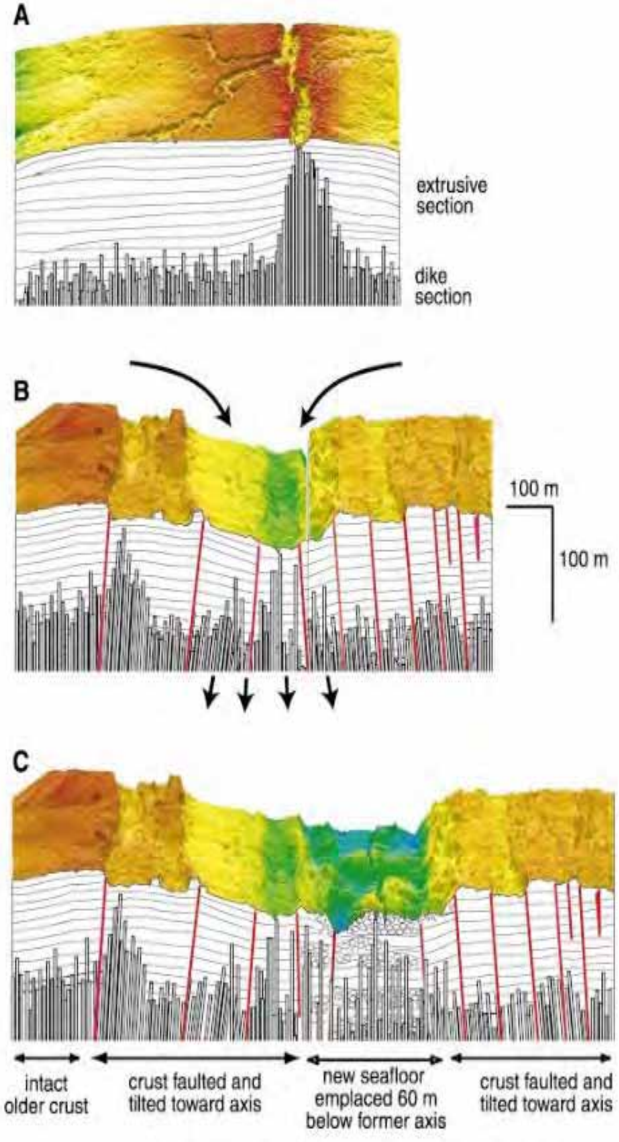
Cormier *et al*, *Geology*, 2003

Tracks from 8 dives

ABE Bottom-Following in 1999 across SEPR Rift Valley

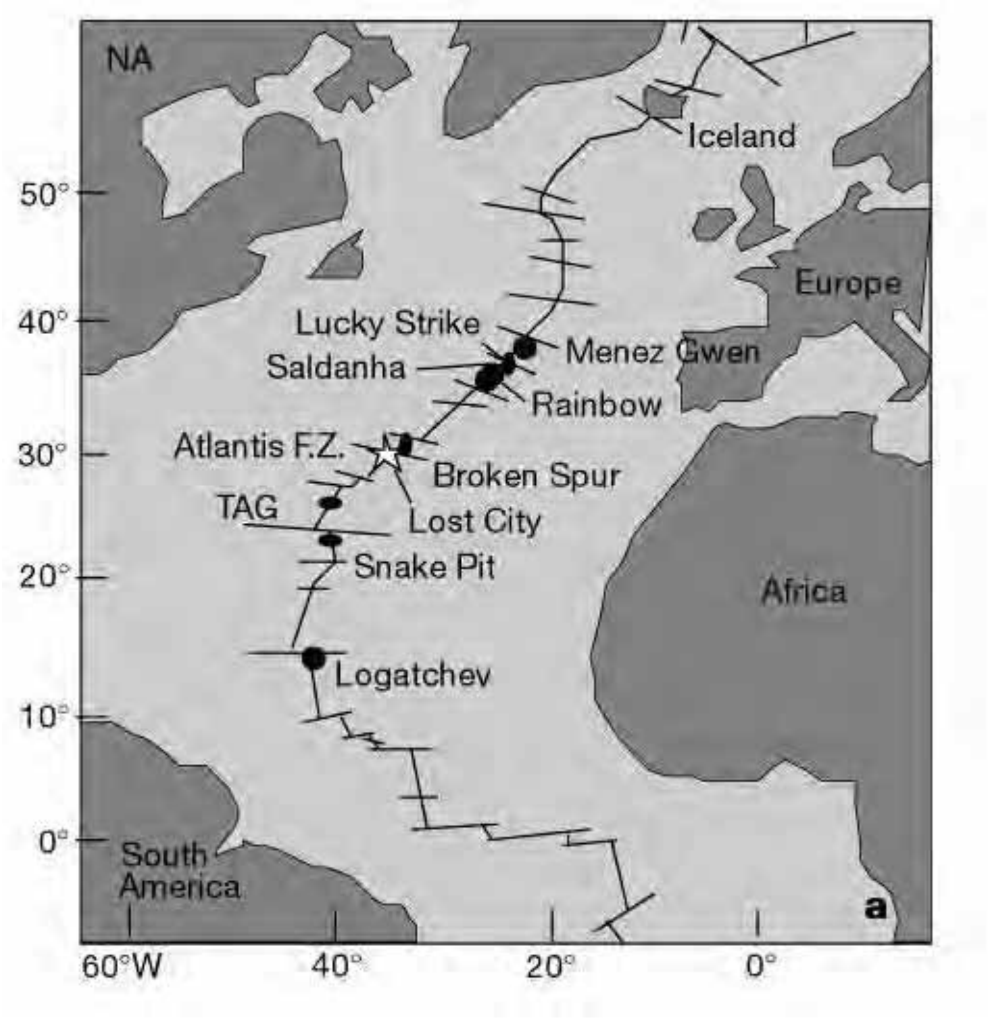


ABE Maps Confirm model of Mid-Ocean Ridge Evolution

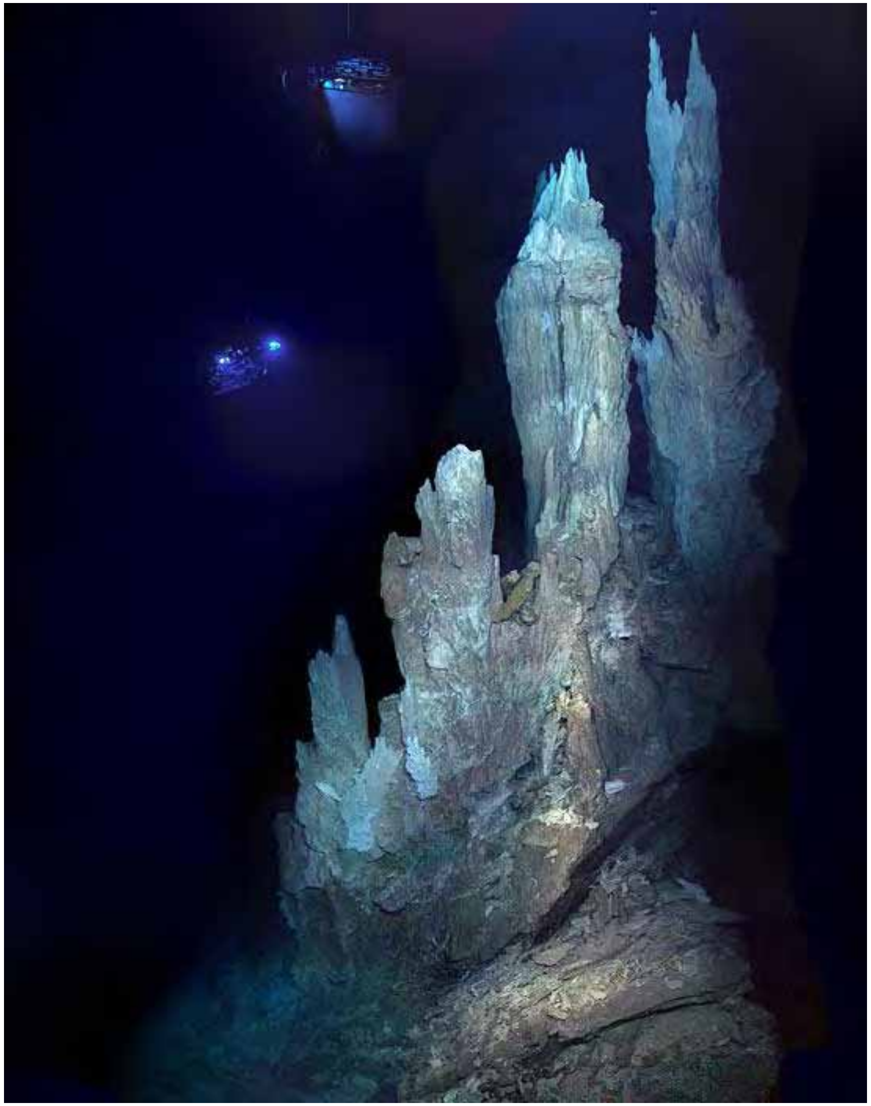


Cormier *et al*, *Geology*, 2003

Lost City Site

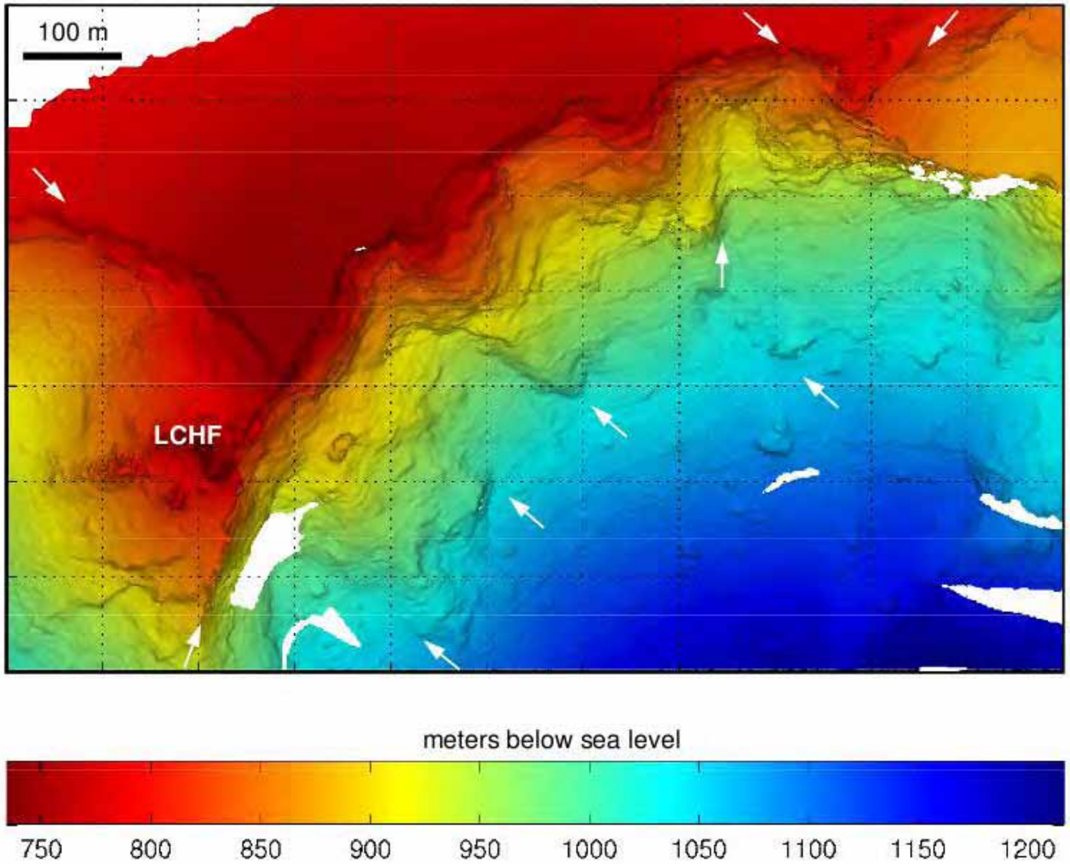


The carbonate structures at the Lost City Field include these spires stretching 90 feet tall.



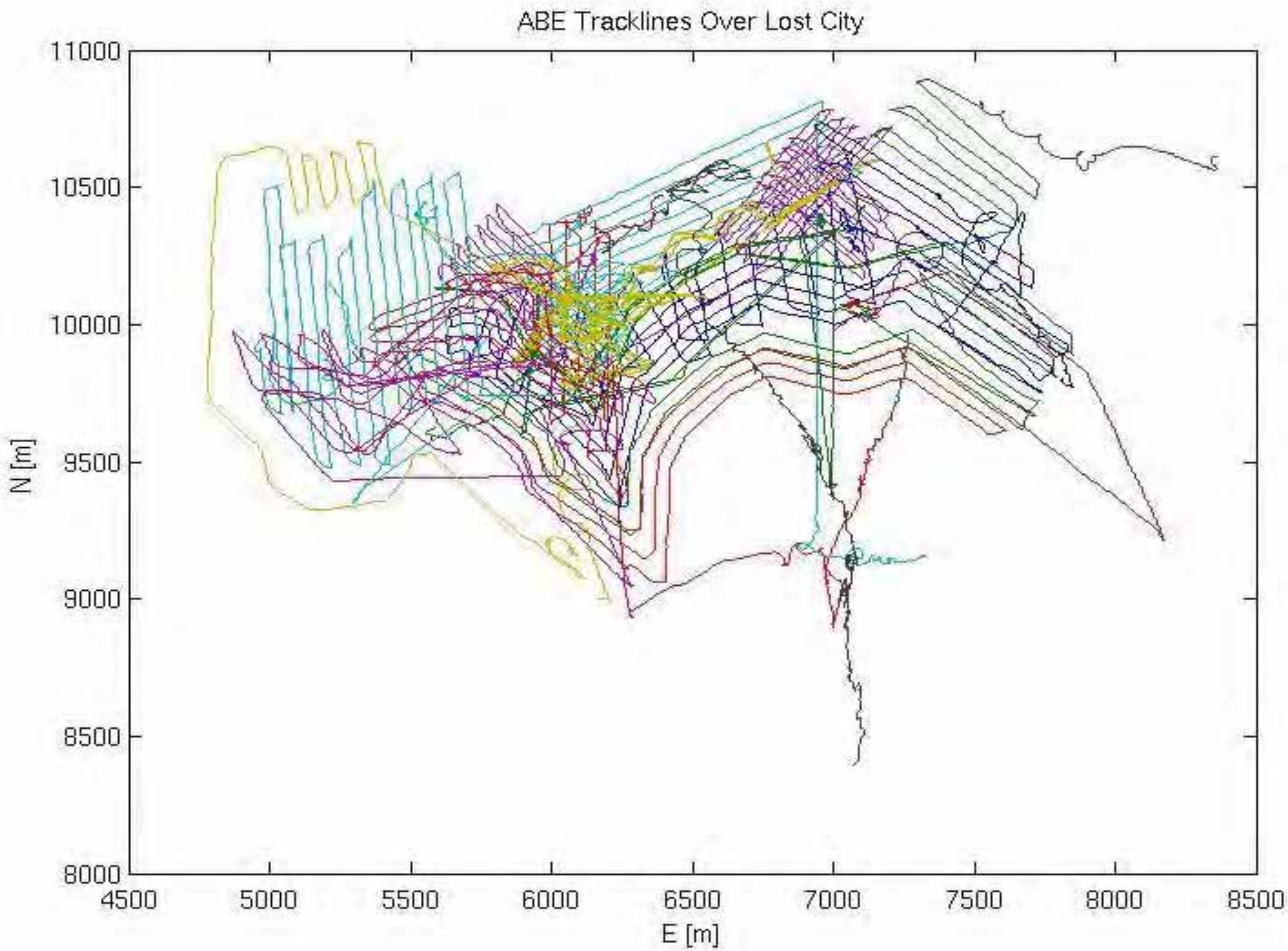
Argus and Hercules ROVs
Photo courtesy Kelley, U of Washington, IFE, URI-IAO, NOAA

ABE Map Reveals Faults that Control the Lost City Hydrothermal Vent Field

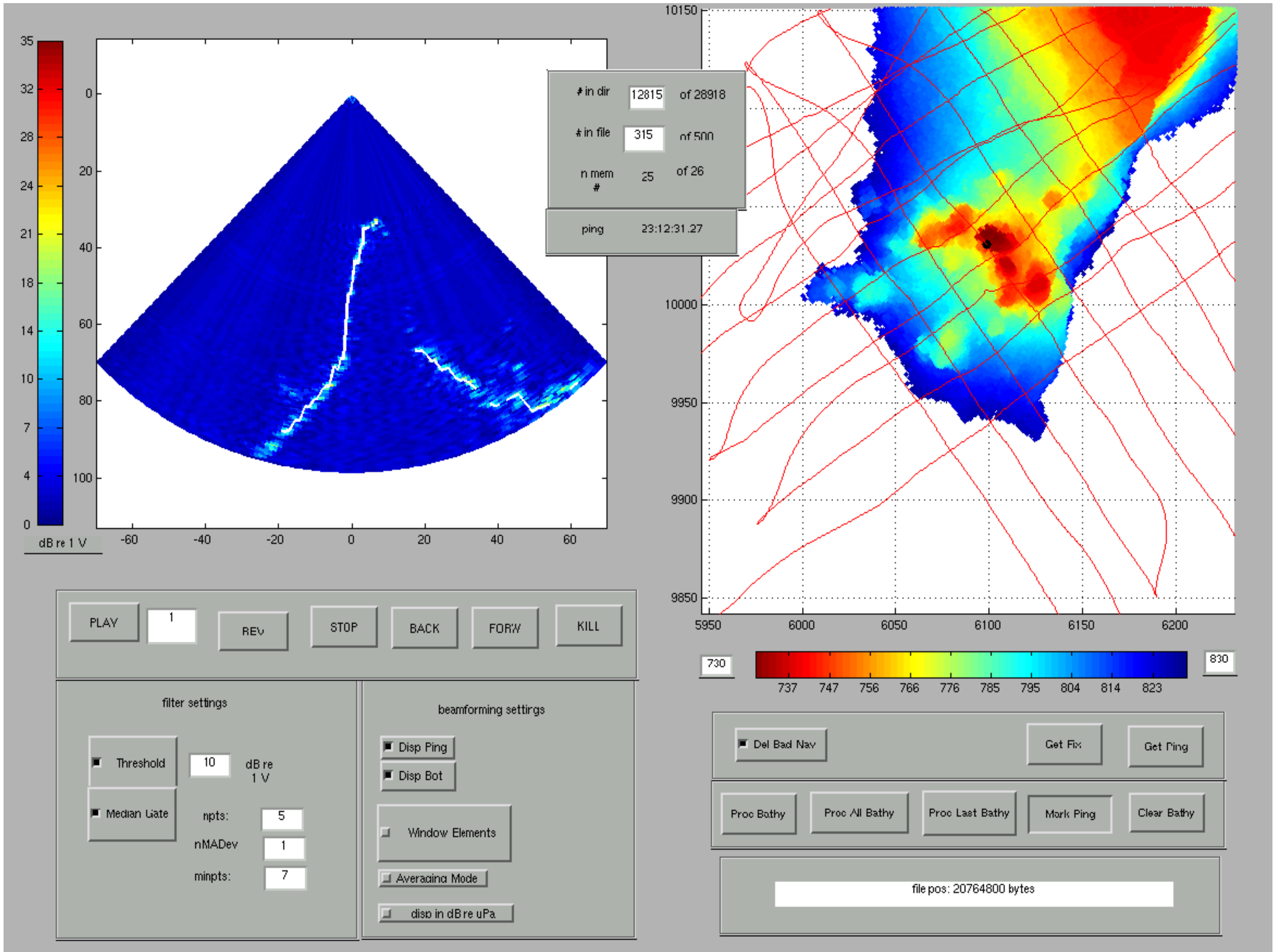


Kelley *et al*, *Science*, 2005
Karson et al, Geochemistry, Geophysics, Geosystems, 2005

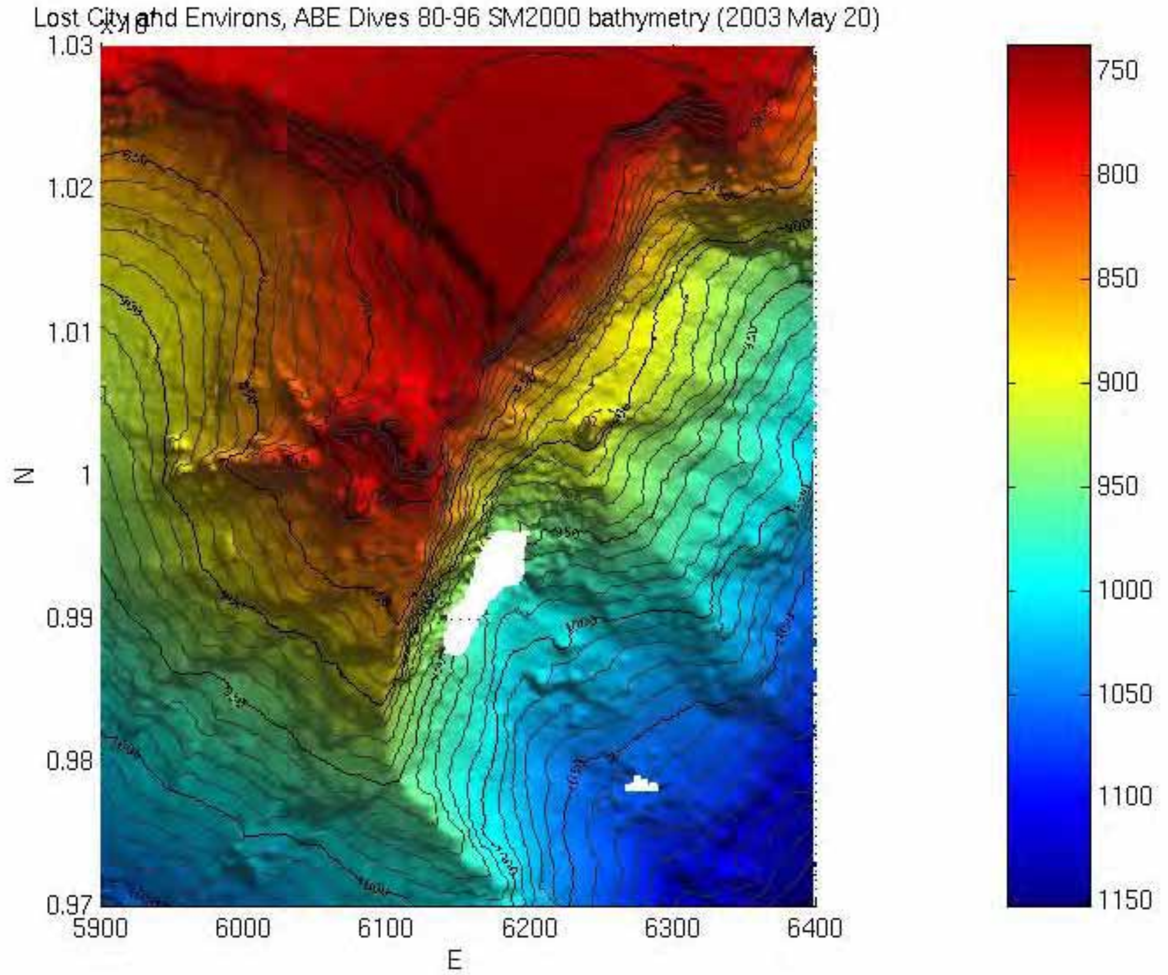
ABE Tracklines at Lost City, 2003



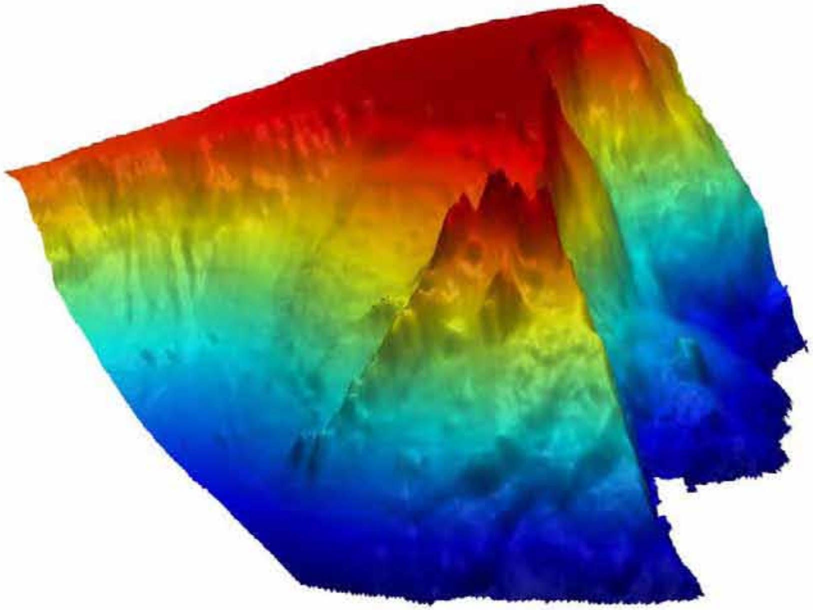
ABE Tracklines over Lost City spires



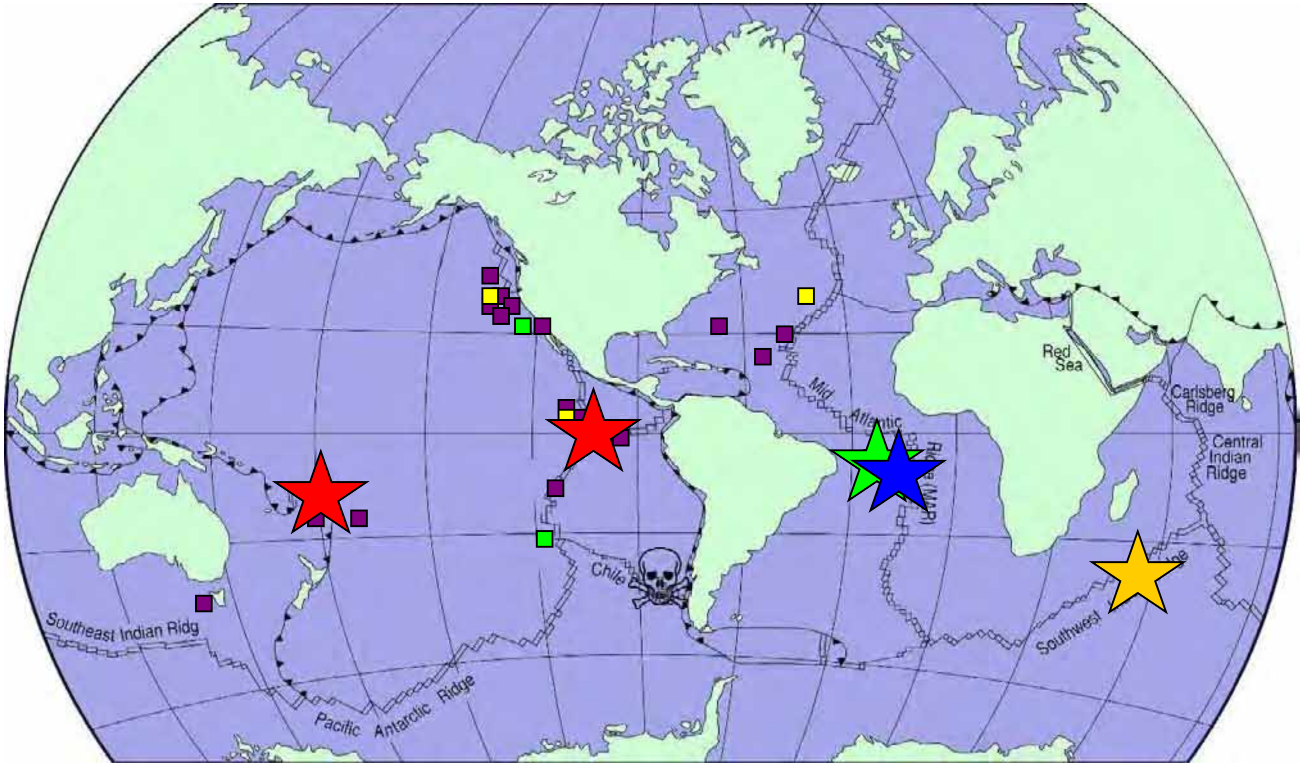
Lost City detailed bathymetry



Lost City detailed bathymetry



ABE dives 1994-2010



- Completed
- Proposed
- Scheduled
- Vent discoveries
- RIP ABE

222 deep ocean dives
>3500 km of bottom tracks
>1800 hours survey time
many unsupported by ROV or HOV

Operated from 10 vessels from
5 countries
Lost Feb 2010, Chile Triple Junction

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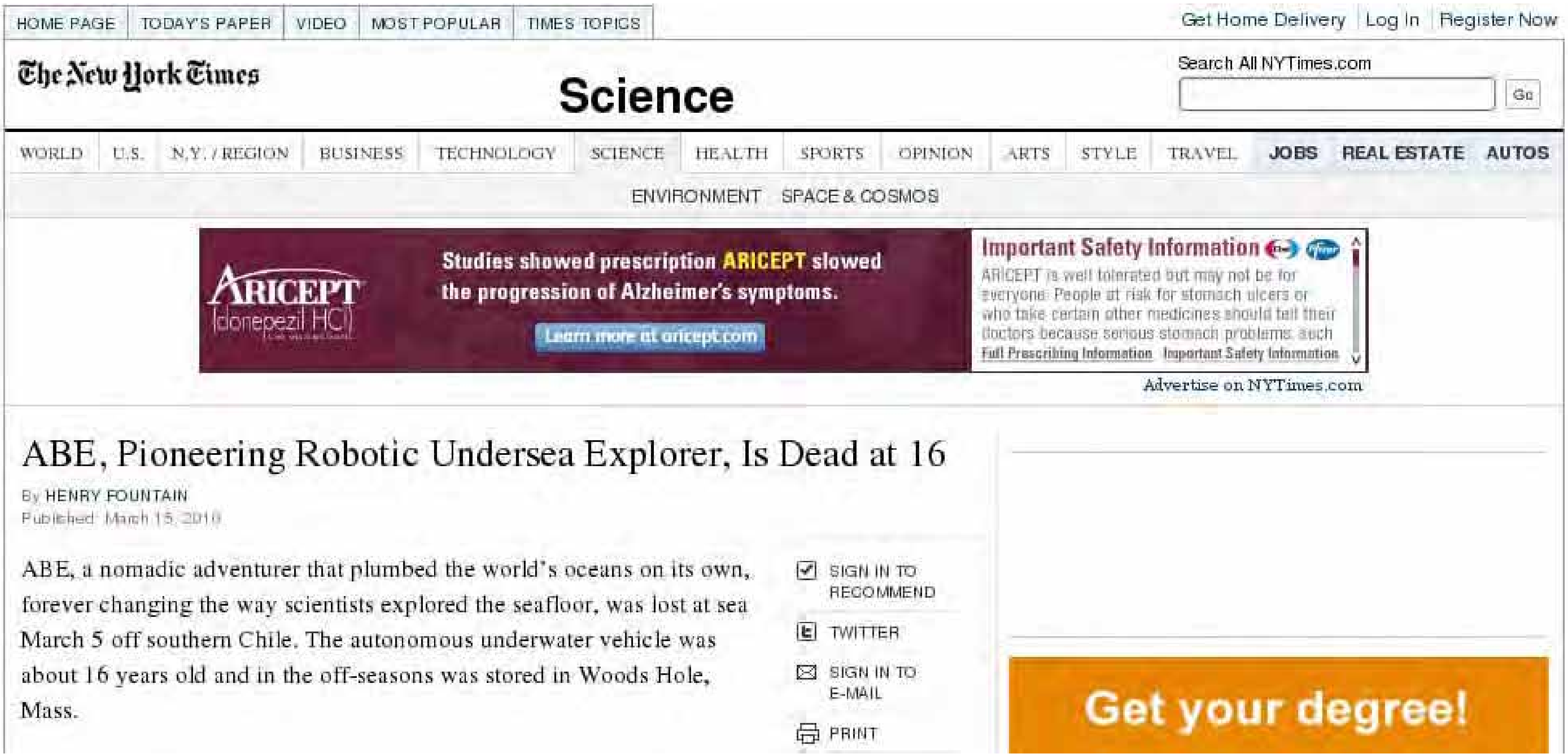
Some consolation...



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ENVIRONMENT | SPACE & COSMOS

ABE, Pioneering Robotic Undersea Explorer, Is Dead at 16

By HENRY FOUNTAIN

Published: March 15, 2010

ABE, a nomadic adventurer that plumbed the world's oceans on its own, forever changing the way scientists explored the seafloor, was lost at sea March 5 off southern Chile. The autonomous underwater vehicle was about 16 years old and in the off-seasons was stored in Woods Hole, Mass.

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TWITTER

SIGN IN TO E-MAIL

PRINT

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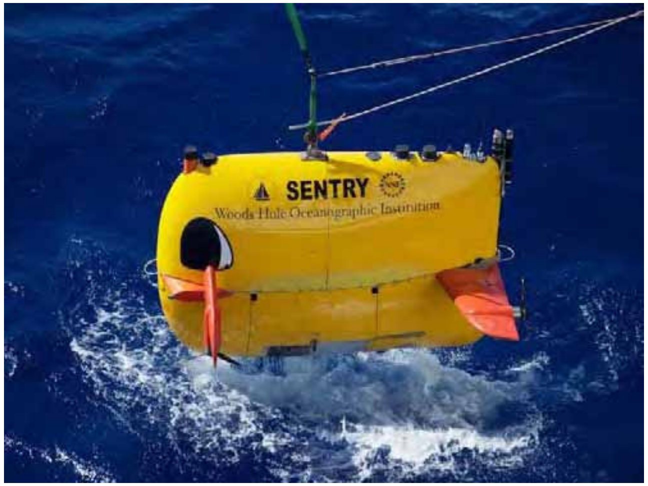
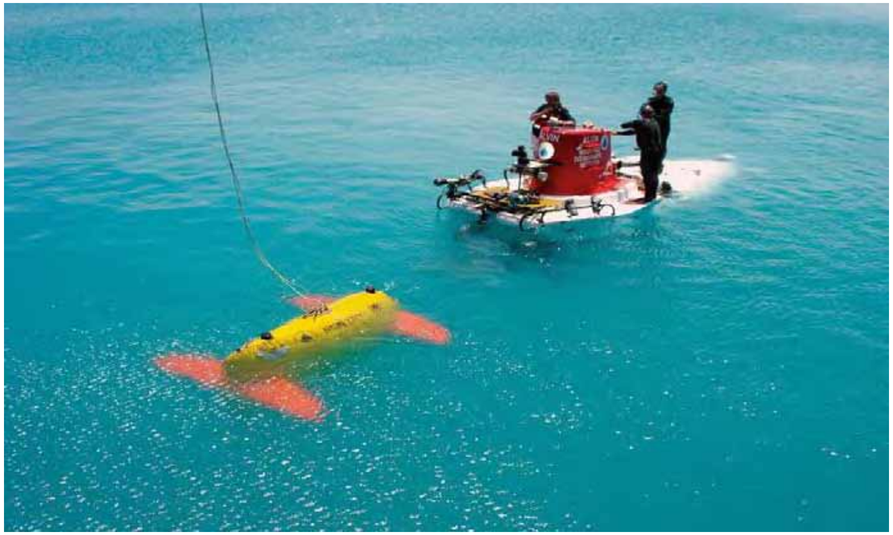
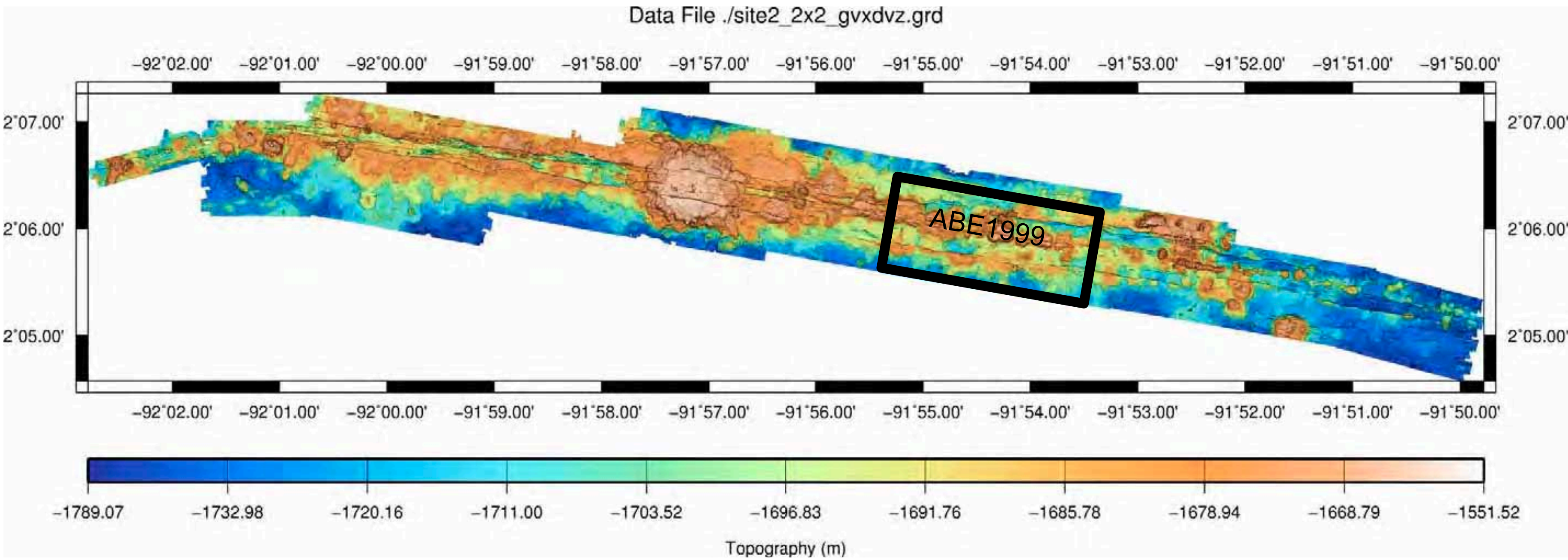
Sentry AUV

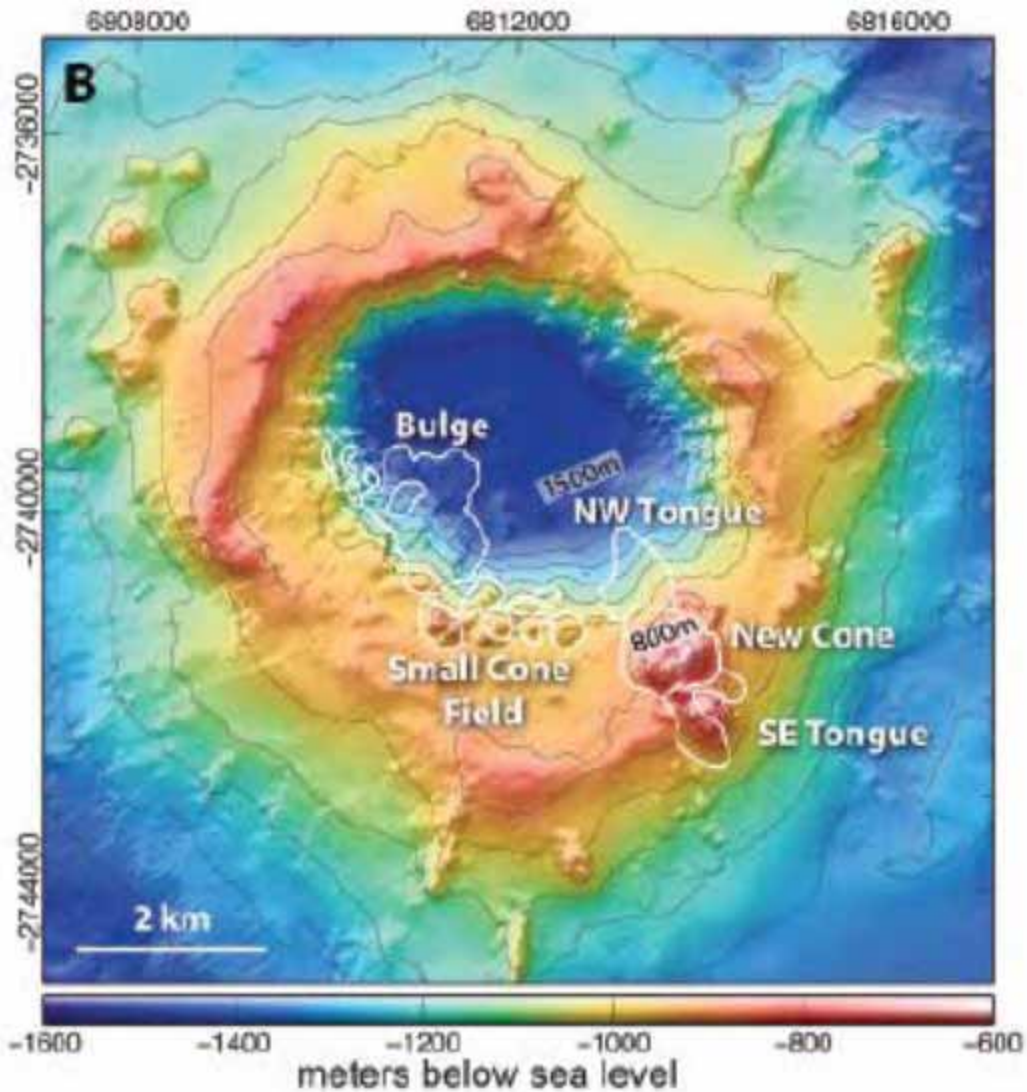




Mapping the Galapagos Rift with Sentry

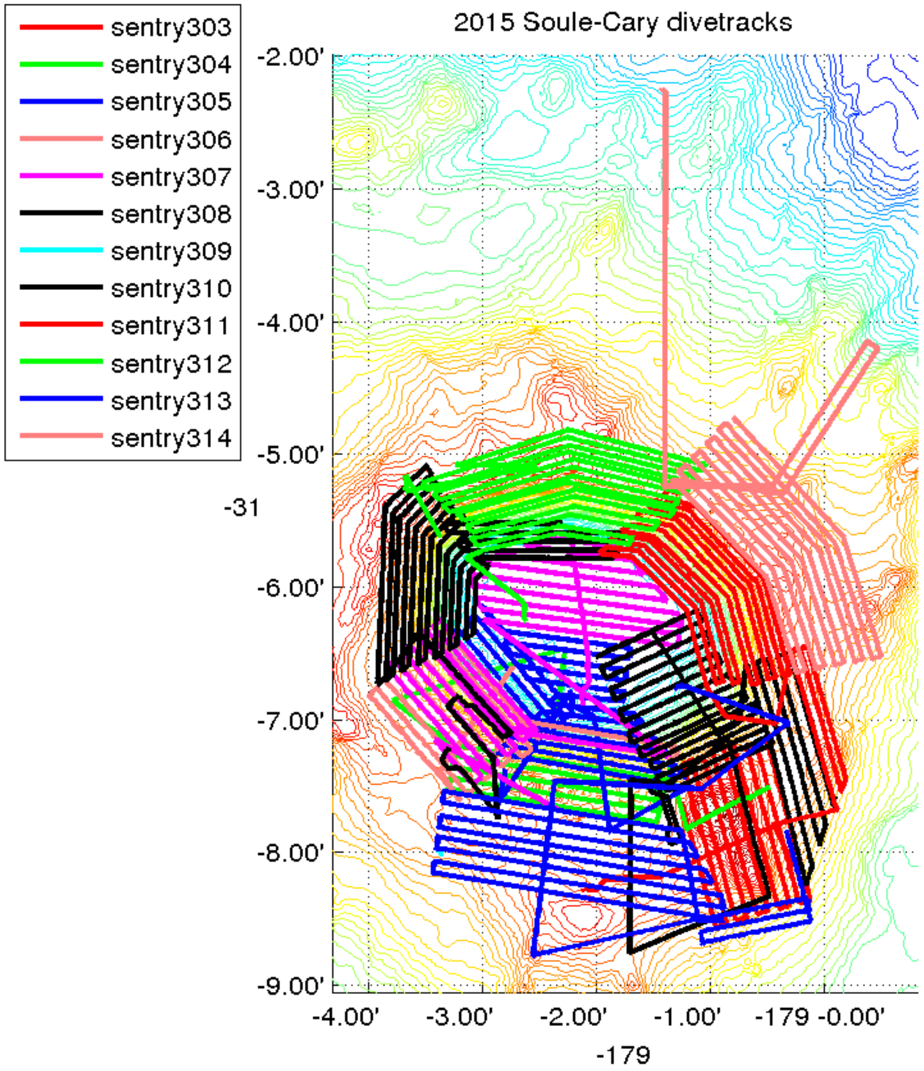


Havre Volcano: erupted explosively in 2012 (Carey, Soule)



Carey et al, EOS Transactions AGU 2014, 95, pp157-164

Havre Volcano: Sentry Tracklines (Carey, Soule, Yoerger)

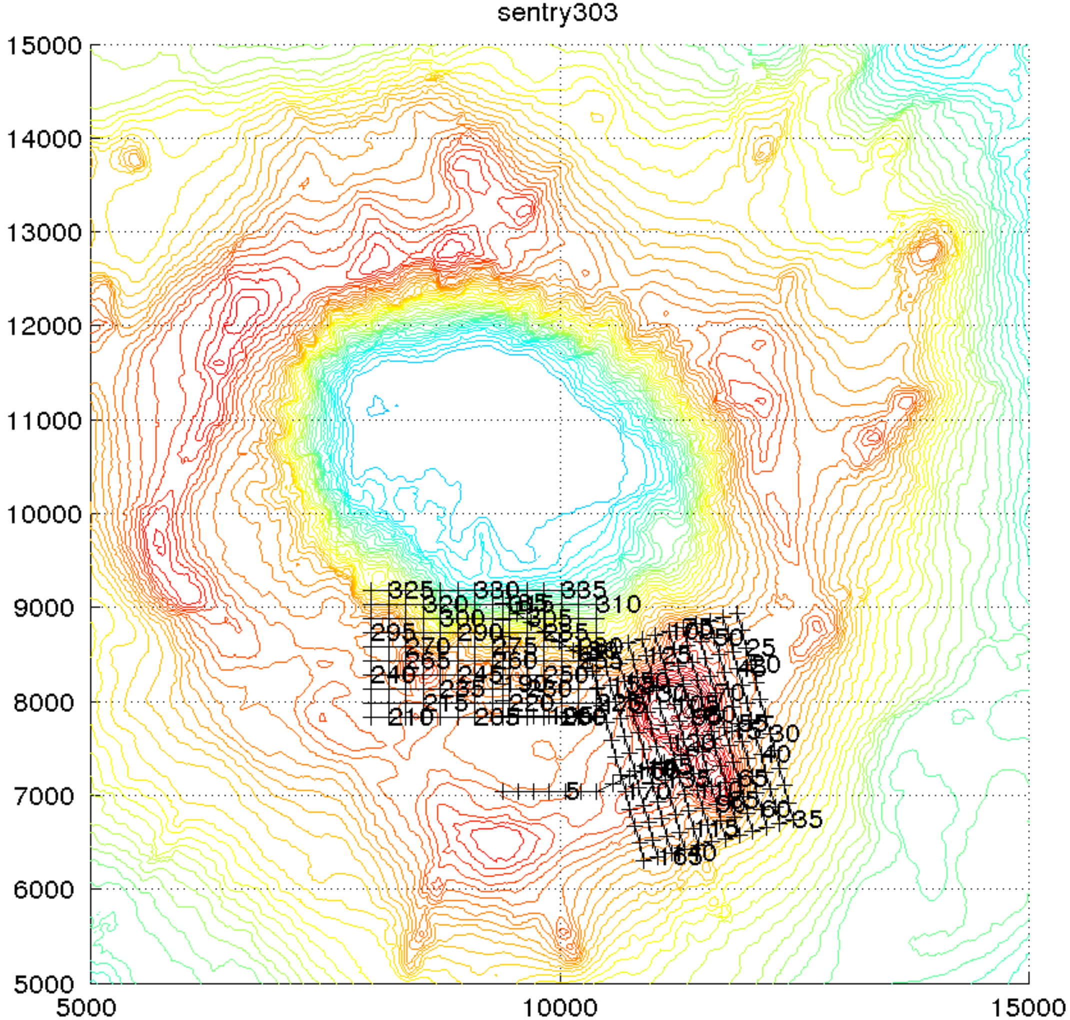


Carey et al, EOS Transactions AGU 2014, 95, pp157-164

Sentry Bottom Following (Jakuba, Kaiser, Yoerger)

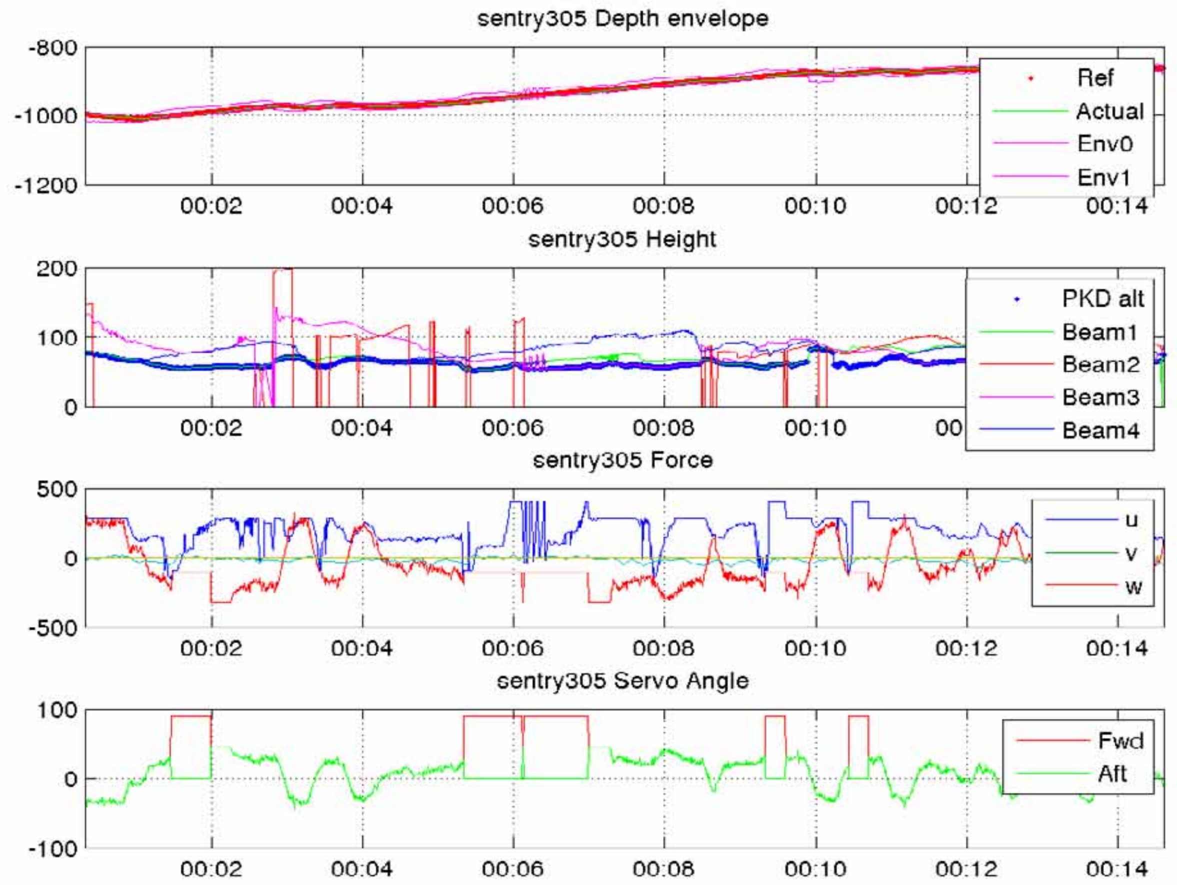
- In mission planning, use vessel multibeam data to choose tracklines that are most achievable, oriented along contours if possible
- Use RDI DVL beams as source of data for height-off-bottom
- Choose the shortest height of the available beams
- Define an “envelope” of a specified thickness at the nominal desired height
- Depth setpoint is driven to the center of the envelope
- If depth is below the envelope, switch to “ROV” mode, slow down, and drive up
- Logic to deal with loss of DVL data (too high or too low? Other DVL quirks such as “search mode”)

Sentry Mission Planning



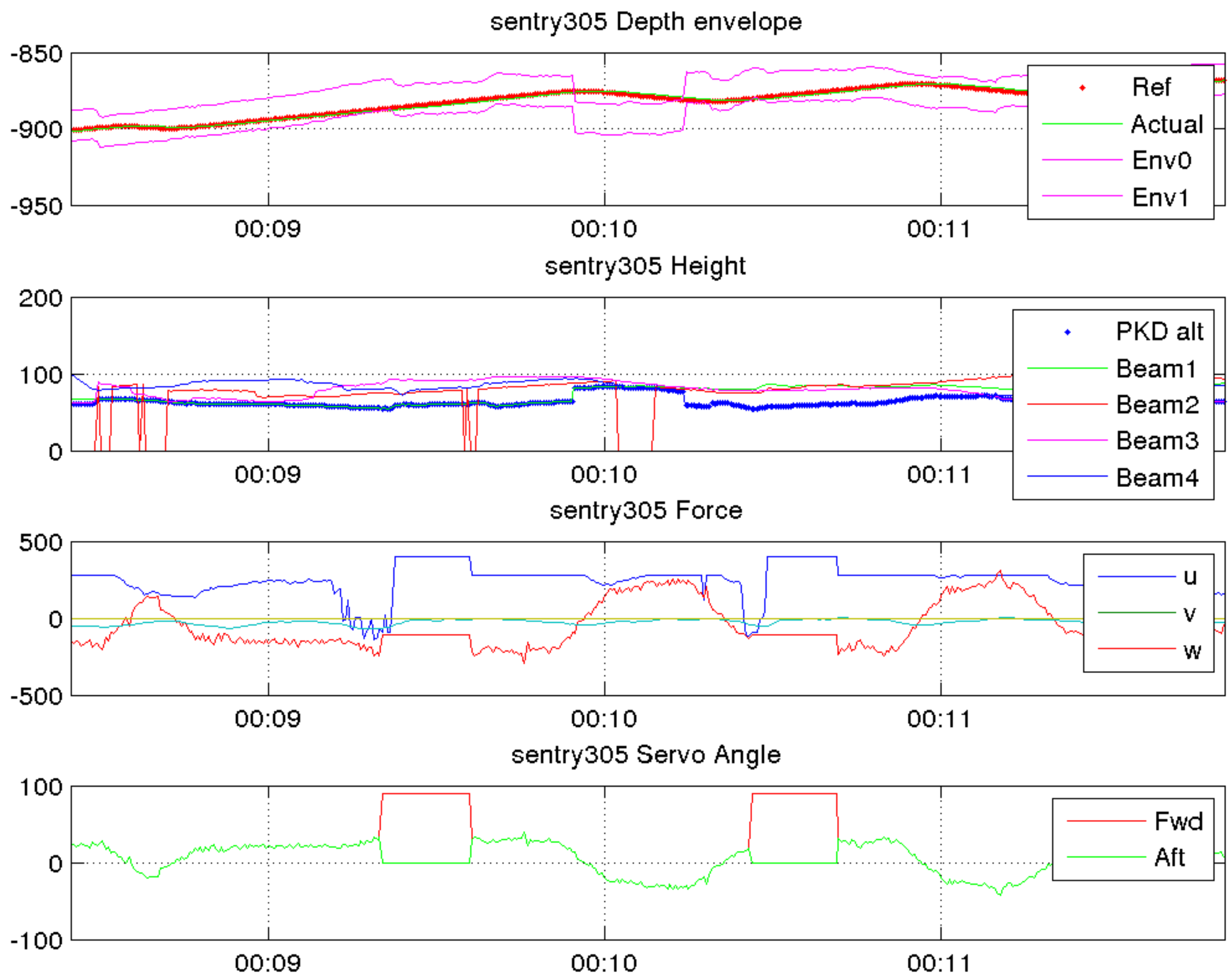
Carey et al, EOS Transactions AGU 2014, 95, pp137-164

Havre Volcano: Sentry Bottom Following (Carey, Soule, Yoerger)



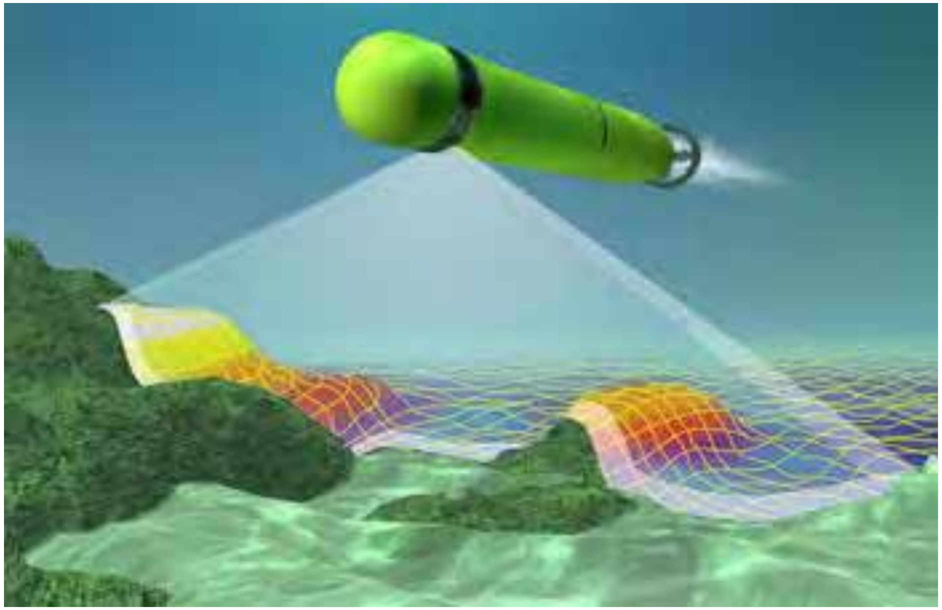
Carey et al, EOS Transactions AGU 2014, 95, pp157-164

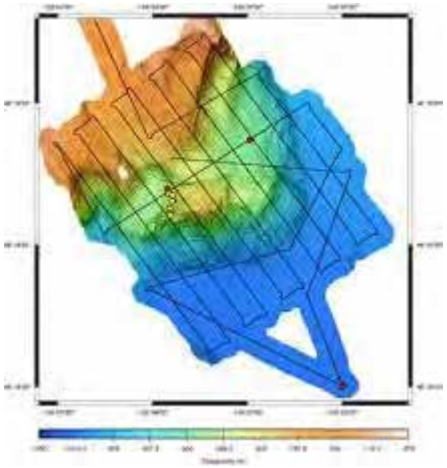
Havre Volcano: Sentry Bottom Following (Carey, Soule, Yoerger)



Carey

MBARI Dorado Bottom Following (Caress, Thomas)





Images courtesy of MBARI

Carey et al, EOS Transactions AGU 2014, 95, pp157-164

MBARI Dorado Bottom Following (Caress, Thomas)

•Vessel bathymetry used explicitly to construct 3D commanded trajectories that respect constraints on vehicle pitch
•DVL heights used in real-time to refine vertical commanded path
•If the vehicle should get too close, the main propulsor is halted, and the vehicle rises passively. The mission resumes when the desired height is achieved.

Carey et al, EOS Transactions AGU 2014, 95, pp157-164

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Formal methods with look-ahead

IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 17, NO. 2, MARCH 2009

A Bottom-Following Preview Controller for Autonomous Underwater Vehicles

Carlos Silvestre, Rita Cunha, Nuno Paulino, and António Pascoal

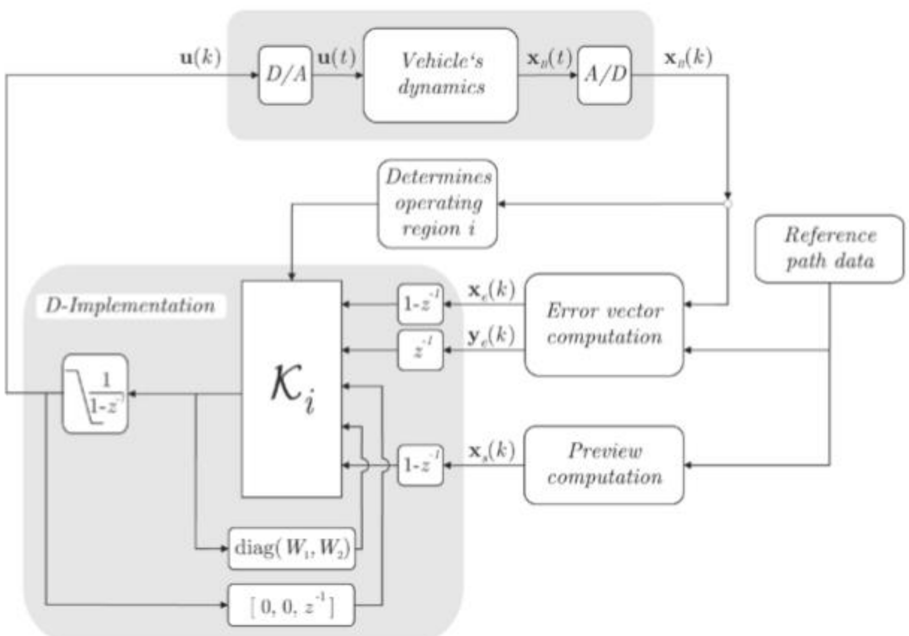


Fig. 9. Implementation setup using gain scheduling and the D-methodology.

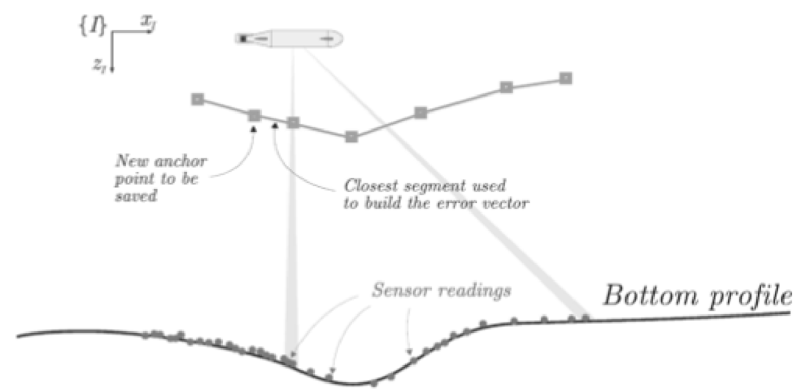
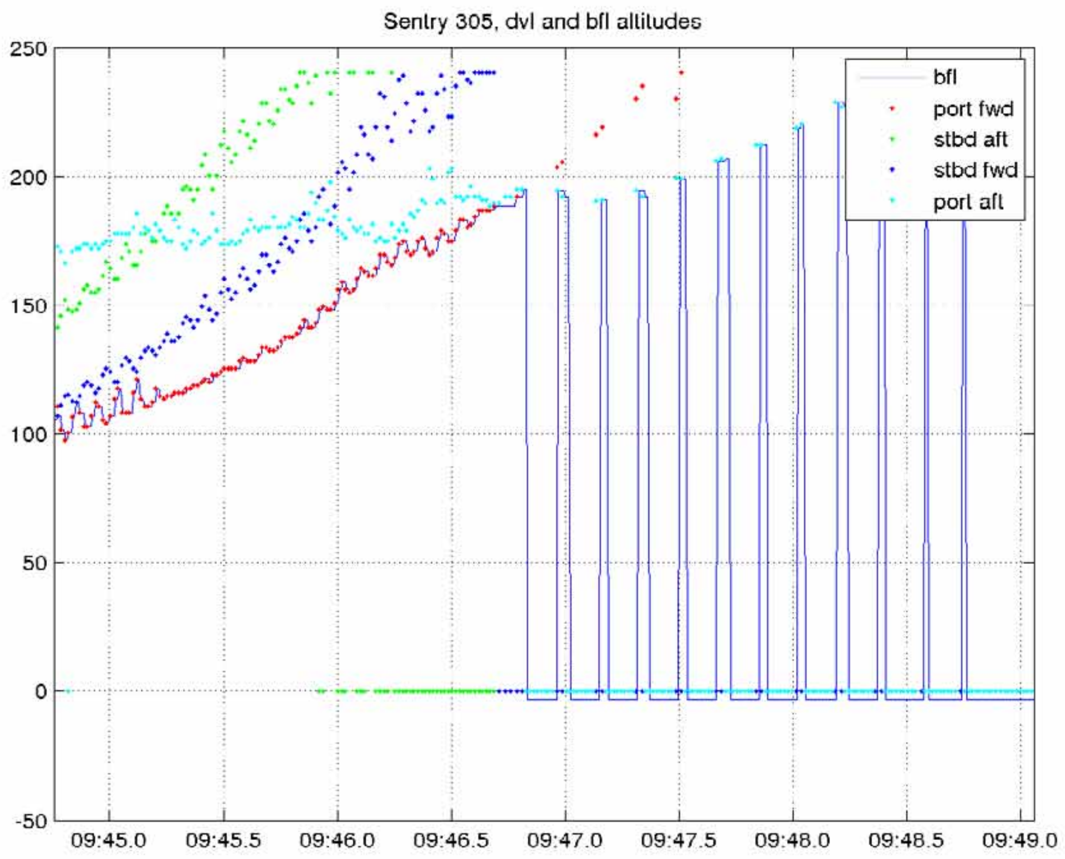


Fig. 6. Final computed path composed by segments of straight lines.

, pp157-164

DVL enters "Search Mode" when less than two beams are received



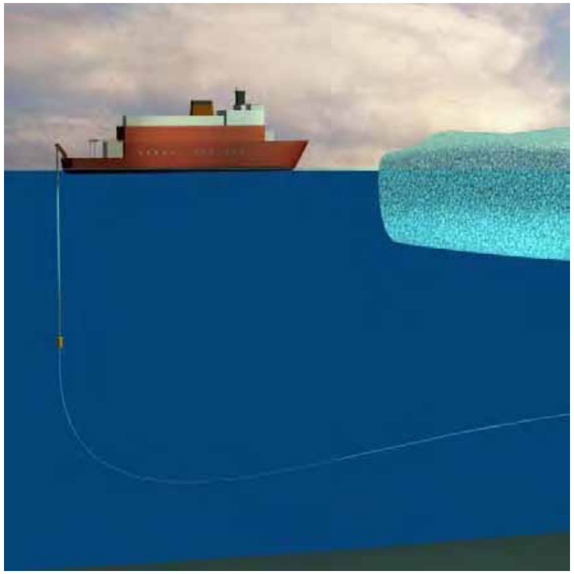
Practical aspects of bottom-following

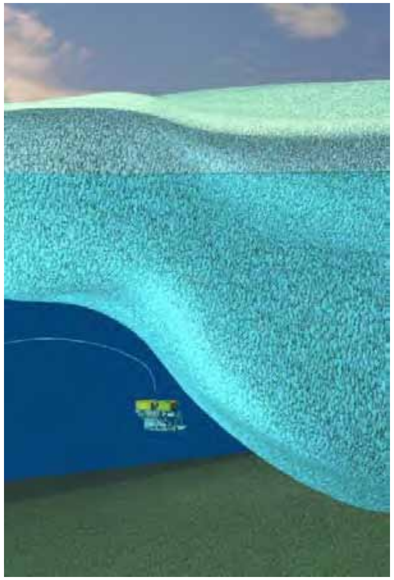
- The terrain is usually 3-dimensional
- Apriori bathymetry is helpful but insufficient
- Height sensors (DVL?) work well MOST of the time, but often fail in the most difficult circumstances
- DVLs are sophisticated devices built for other purposes and may change their behavior with software upgrades from the manufacturer
- DVLs report the same result when the vehicle is very close to the bottom or when it is too high above the bottom
- DVLs can exhibit other unwanted behavior like “search mode” (example)
- A logical layer is required to ensure that the system responds properly to loss of height information

Ideal Bottom-Following

•Take full advantage of pre-existing bathymetry
•Robust to limited resolution of pre-existing bathymetry and navigational error
•Produce optimal (or at least good) trajectories with respect to the vehicle dynamics (forward speed range, turn rate, ascent/descent rate)
•Accommodate imperfect behavior of the height sensors, including dropouts, resets, and ambiguous results
•We should have an analytical framework for the correctness of the algorithms other than simulation and testing

Polar ROV “Nereid UI”
Top Following?





<-20km->

Conclusions

- Scientific exploration technology has advanced significantly over the last 50 years while producing high-quality scientific results
- AUV bottom-following remains a challenge
- A combination of preplanned reference trajectories and real-time responses work best
- Control theoretic methods are very useful, but must be combined with logical layers to deal with non-ideal behavior of sensors for height-above-bottom
- We should formalize our methodologies to embrace both control theoretic methods and graceful handling of sensors

This work has involve many collaborators, from both science and engineering

- Al Bradley: inventor of ABE
- ABE Team: Andy Billings, Rod Catanach, Al Duester, Mike Jakuba, Jordan Stanway
- Sentry Team: Andy Billings, Rod Catanach, Al Duester, Erik Dawe, Cara Lapointe, Scot McCue, Jordan Stanway, Justin Fujii, Zac Berkowitz, Johanna Hansen
- Scientific collaborators: Maurice Tivey, Paul Johnson, Marie-Helene Cormier, John Sinton, Deb Kelley, Dan Fornari, Hans Schouten, Scott White, Jeff Karson, Adam Soule, Rebecca Carey

NOPTILUS
EU PROJECT

Fernando L. Pereira, FEUP, Porto, PT

compLete UnderwaterSystems NOPTILUS

FP7-ICT-2009.6: Information and Communication Technologies

Project overview

Fernando Lobo Pereira
FEUP

June 17th, 2015
IST, Portugal

NOPTILUS

SEVENTH FRAMEWORK PROGRAMME

PROJECT OVERVIEW

NOPTILUS summary

For information regarding this Project: Check the Project Web-Site:
http://www.noptilus-fp7.eu

	Participants
1	Centre for Research and Technology (CERTH, GR)
2	Faculdade de Engenharia da Universidade do Porto (FEUP, PT)
3	Eidgenössische Technische Hochschule Zürich (ETH, CH)
4	Delft University of Technology (TU Delft, NL)
5	Telecommunication Systems Institute (TSI, GR)
6	Imperial College (Imperial, UK)
7	OceanScan - Marine Systems & Technology, Lda (MST, PT)
8	Administração dos Portos do Douro e Leixões, SA (APDL, PT)

Project Acronym: NOPTILUS

Project Number: 270180

Project Start Date: April 2011

Duration: 4 Years

Funded by: EU FP7

Program:
Information and Communication Technologies,
FP7-ICT-2009.6

EU Funding: 3.8 Meuros

SEVENTH FRAMEWORK PROGRAMME

Advancing the state of the art

– Human-operators perform high-level tasks & assign low-level tasks to AUVs;
– Many operators needed in cases of multi-AUV systems;

NOPTILUS single main novelty is **to determine – fully-autonomously & in real-time – the AUVs' trajectories / behavior that <u>maximize situation awareness</u> subject to the <u>severe communication, sensing & environmental limitations</u>**

Technical Objectives

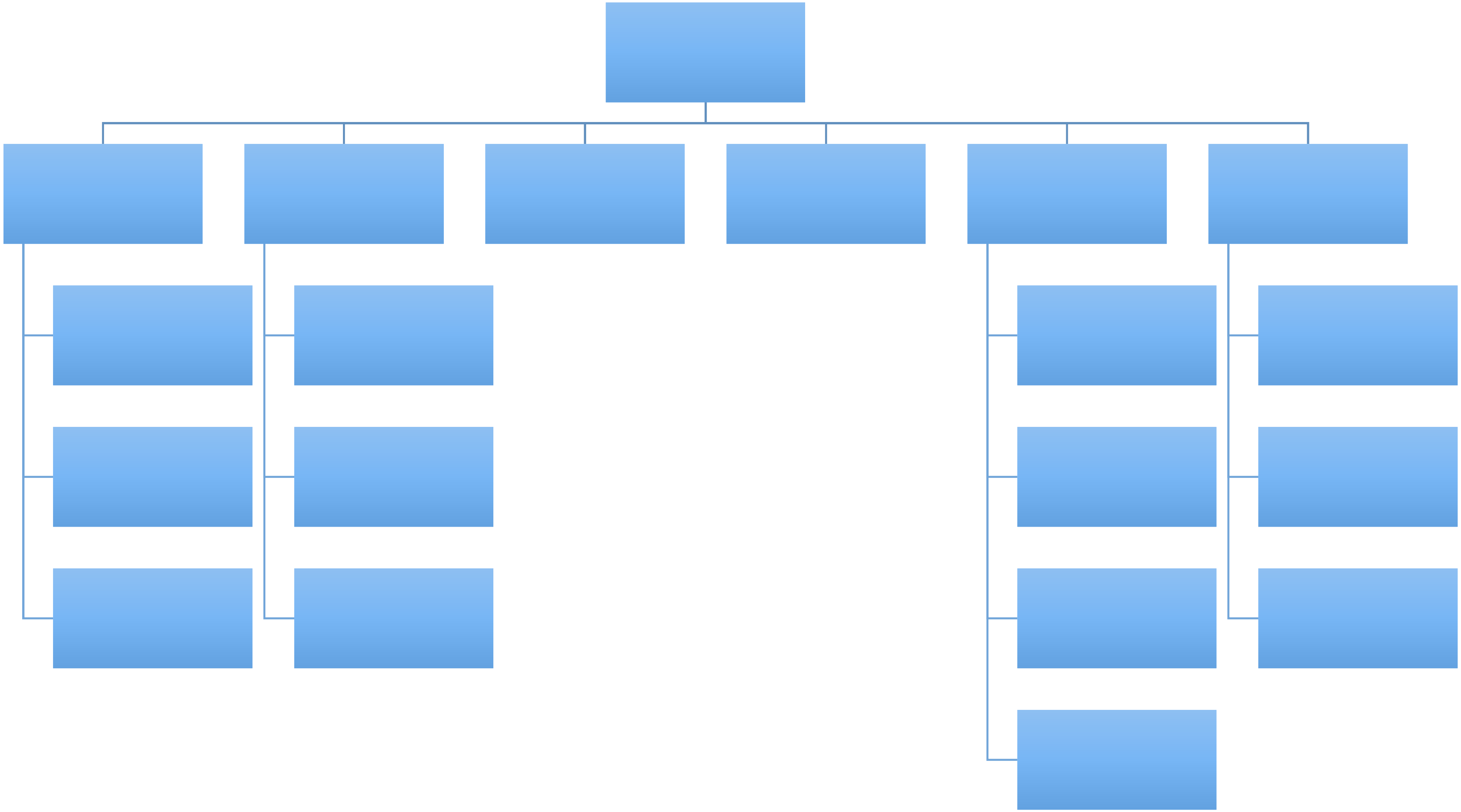
- **Low level Objectives: Improve Communication & Sensing Capabilities (WP3)**
  - Collaborative, cognitive UW acoustic **communications**
  - Underwater cognitive sonar **sensing**
  - **Underwater active vision** using photometric stereo for "seeing through murky waters"
  - **Cooperative localization** & AUV motion strategies for **active localization**
- **Medium-level Objectives (WP4, WP5)**
  - AUV **trajectory control** (depending on localization capabilities)
    - Coordinated motion control
    - Sensory-motor control
  - Distributed & cooperative **map creation ("cartography") and process (e.g., spill, vehicle) tracking**

Technical Objectives

- **High-level Objectives (WP6, WP7)**
  - Situation awareness
  - Automated AUV assignment and trajectory generation for **concurrently optimizing situation awareness and localization/communication/sensing capabilities**

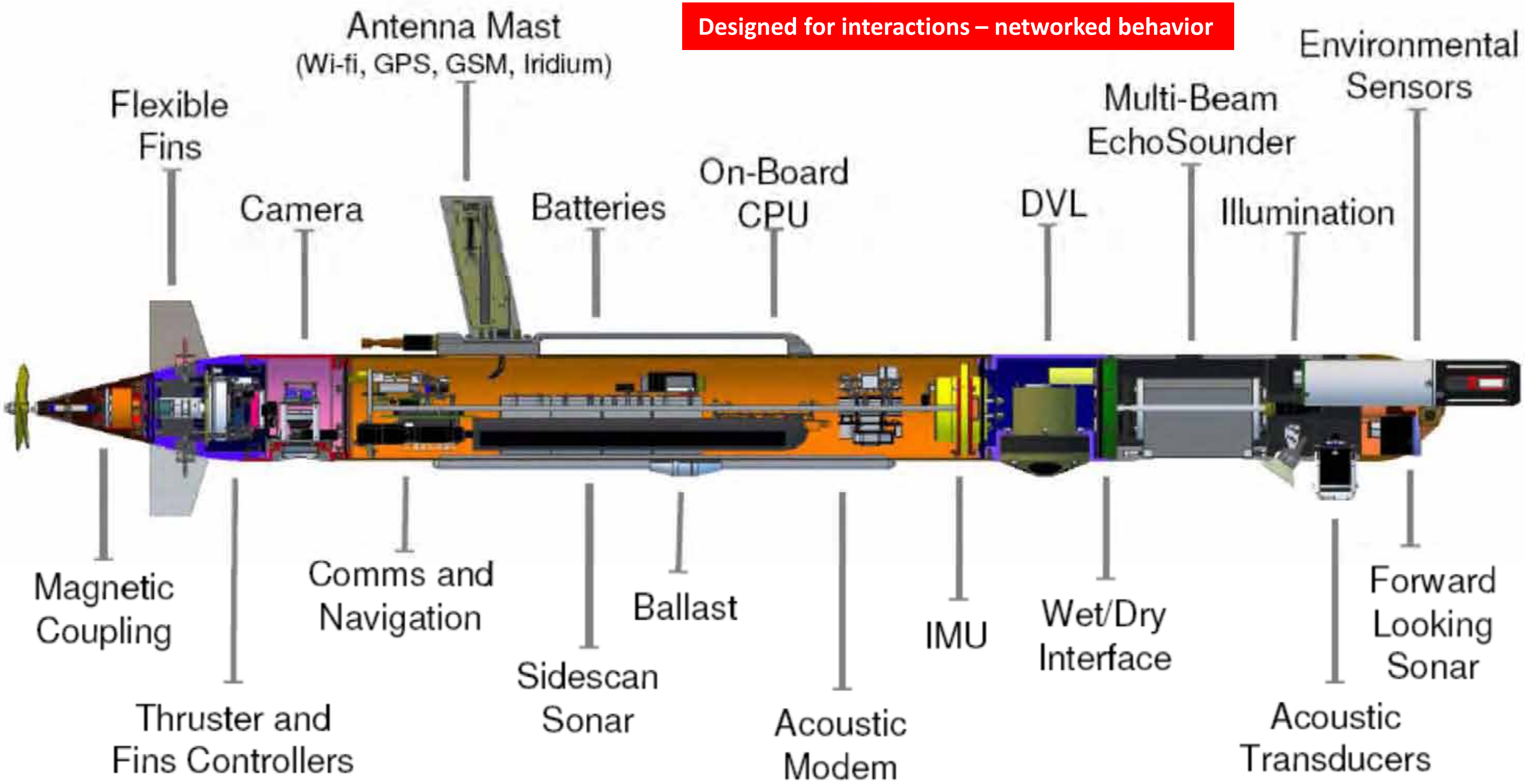
NOPTILUS system

System breakdown structure



Light AUV (LAUV)

Designed for interactions – networked behavior



AUV operations

Making L&R simple

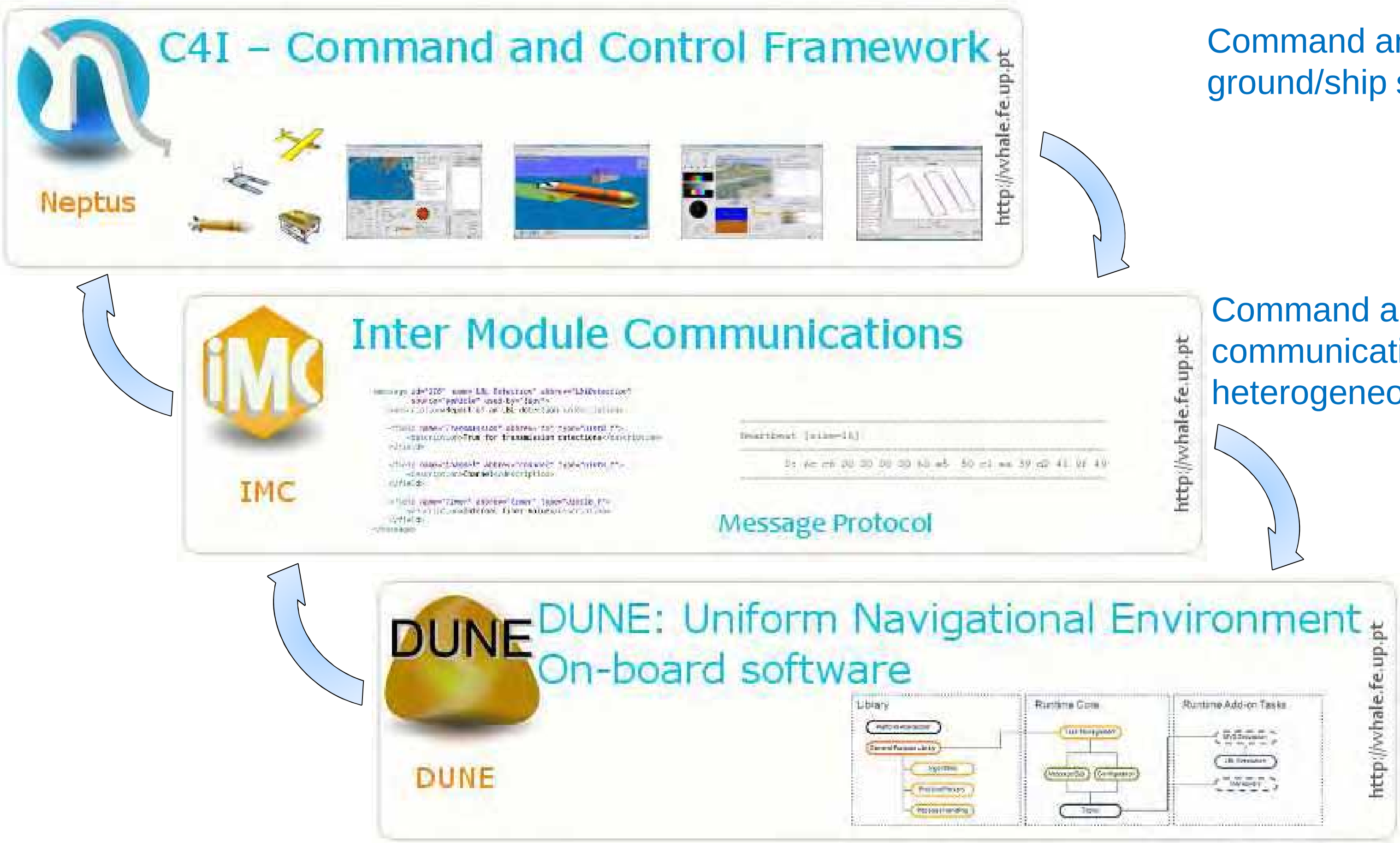
AUV sensors, coms, and computer systems

- Sensors
  - Imagenex 852 echo-sounder.
  - Imagenex 872 Yellowfin sidescan sonar
  - Imagenex 837B Delta T Multi-beam sonar
  - Edgetech 2205 dual-frequency side-scan sonar
  - Lumenera Le165 megapixel camera
  - AML SV Xchange sound velocity sensor
  - Valeport MiniSVS sound velocity sensor
  - RBR XR620 CTD
- Computer systems
  - Main CPU: IEI PM-LX800 with on-board AMD Geode LX 800 (500MHz) processor
  - Secondary CPU: BeagleBone Black AM335x 1GHz ARM Cortex-A8
- Navigation
  - Analog Devices ADIS16488 MEMS IMU
  - Microstrain 3DM-GX3-25 MEMS IMU
  - Honeywell 1700 Tactical grade IMU (1-2 degrees per hour)
  - LinkQuest NavQuest 600 Micro Doppler velocity log
  - U-Blox LEA-6H GPS unit
- Acoustic communications
  - EvoLogics S2CR 18/34
  - Neptune Sonar T217
- Wireless communications
  - Ubiquiti PicoStation M2HP Wi-Fi module
  - Huawei MG323-B dual-band GSM/GPRS module.
  - Iridium 9602 SBD transceiver

Manta Gateway

- Battery powered portable communications hub
- Deployed from ship, RHIBs and buoys
- Technical specifications
  - Programmable
  - GPS
  - Compass
  - Communications
    - 802.11gn 2.4GHz and 5Ghz
    - Freewave
    - Acoustic Modems
    - Delay Tolerant Networking (DTN)
    - LBL Tracking
    - GSM
    - Iridium

LSTS software tool chain



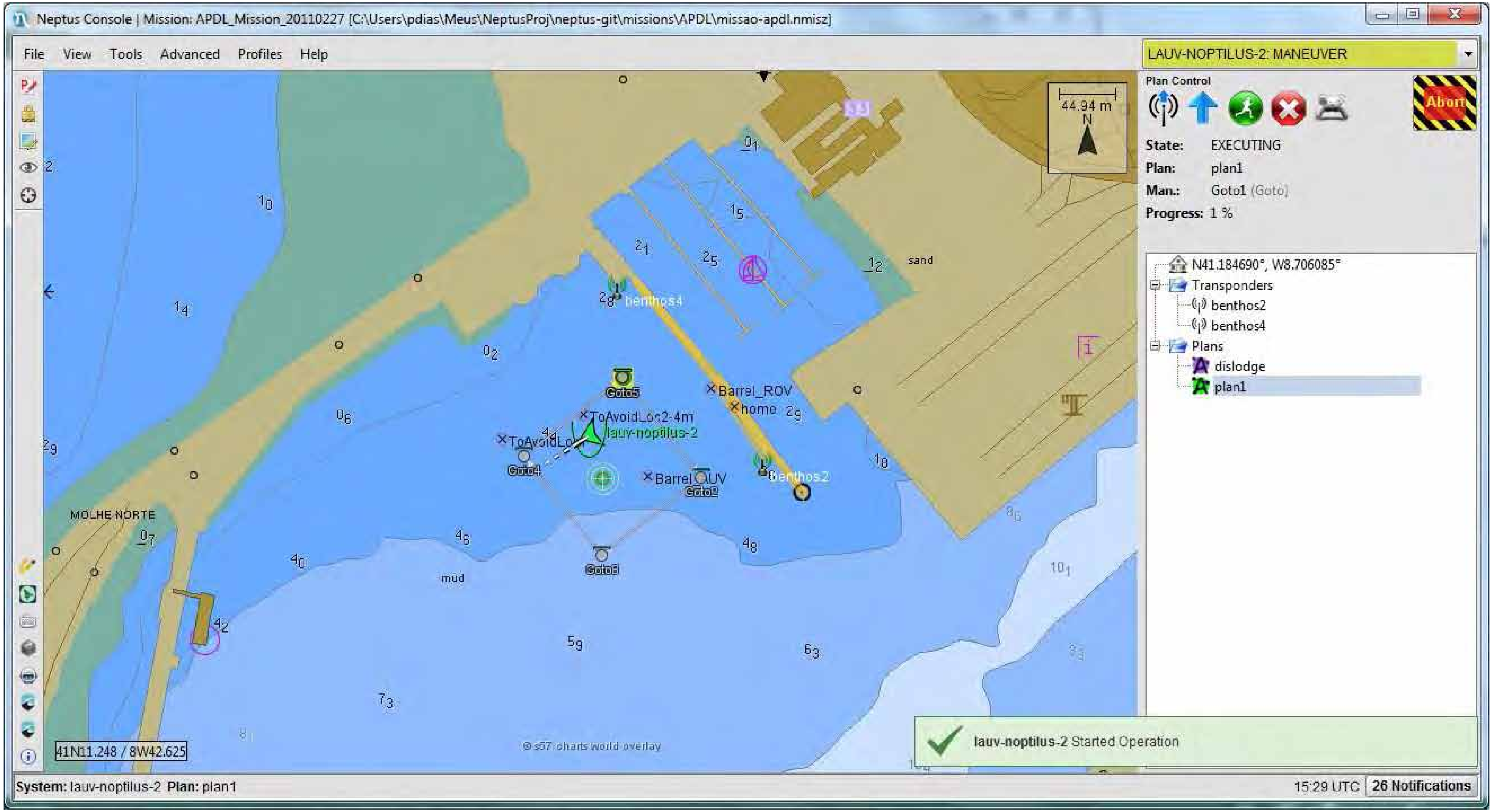
Command and control for ground/ship stations

Command and communications protocol for heterogeneous vehicles

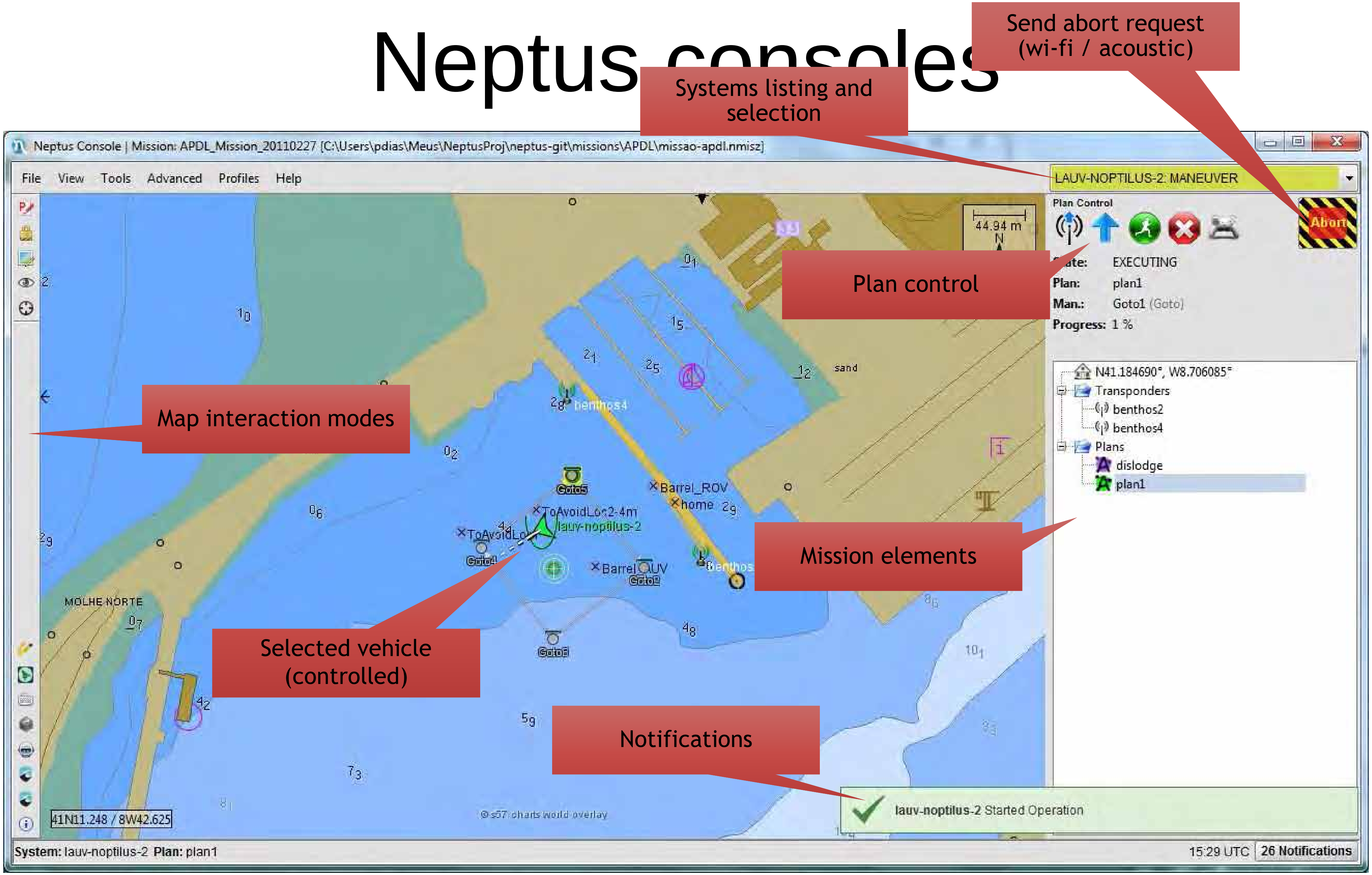
Onboard software for vehicles, gateways

Field tested in thousands of operations with air and ocean vehicles
Users group from 12 countries

Neptus consoles

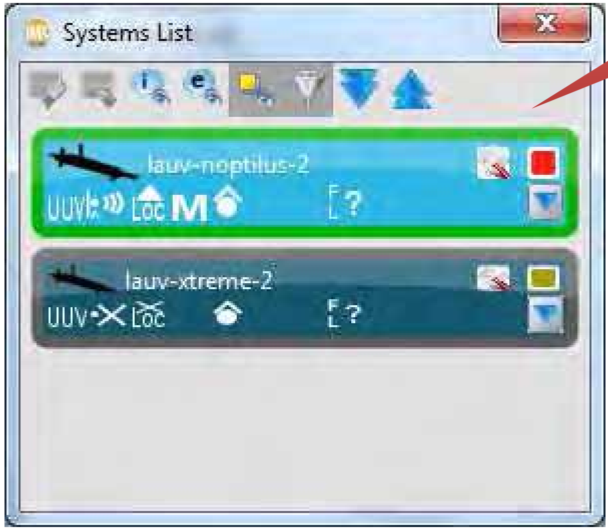


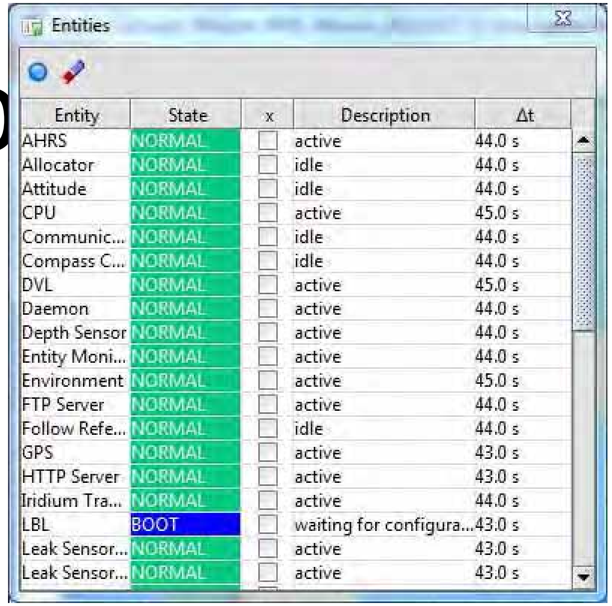
Neptus consoles



Neptus conso

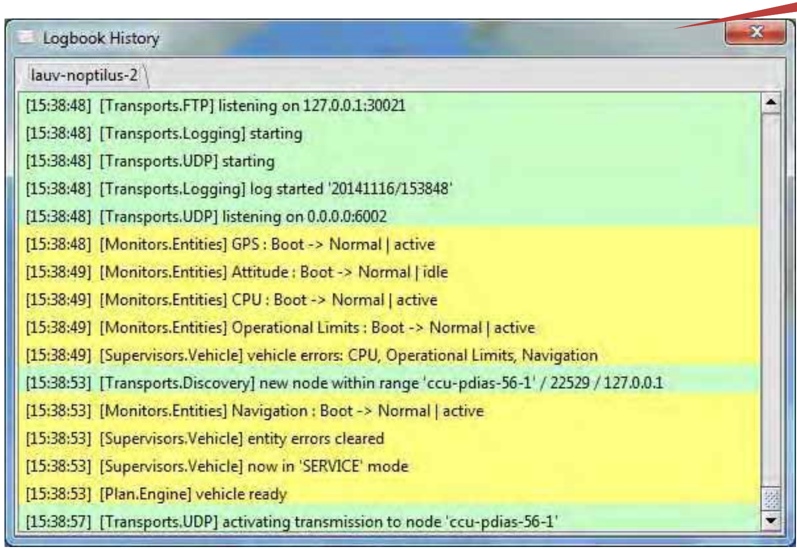
Systems listing and selection



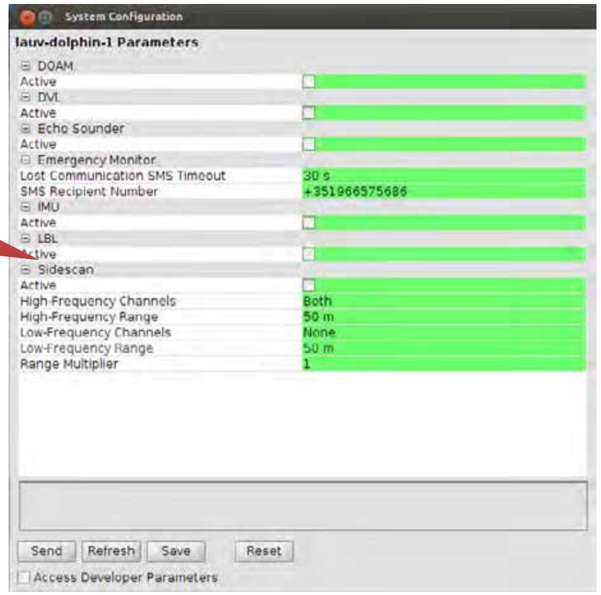


Entity	State	x	Description	Δt
AHRS	NORMAL		active	44.0 s
Allocator	NORMAL		idle	44.0 s
Attitude	NORMAL		idle	44.0 s
CPU	NORMAL		active	45.0 s
Communic...	NORMAL		idle	44.0 s
Compass C...	NORMAL		idle	44.0 s
DVL	NORMAL		active	45.0 s
Daemon	NORMAL		active	44.0 s
Depth Sensor	NORMAL		active	44.0 s
Entity Moni...	NORMAL		active	44.0 s
Environment	NORMAL		active	45.0 s
FTP Server	NORMAL		active	44.0 s
Follow Refe...	NORMAL		idle	44.0 s
GPS	NORMAL		active	43.0 s
HTTP Server	NORMAL		active	43.0 s
Iridium Tra...	NORMAL		active	44.0 s
LBL	BOOT		waiting for configura...	43.0 s
Leak Sensor...	NORMAL		active	43.0 s
Leak Sensor...	NORMAL		active	43.0 s

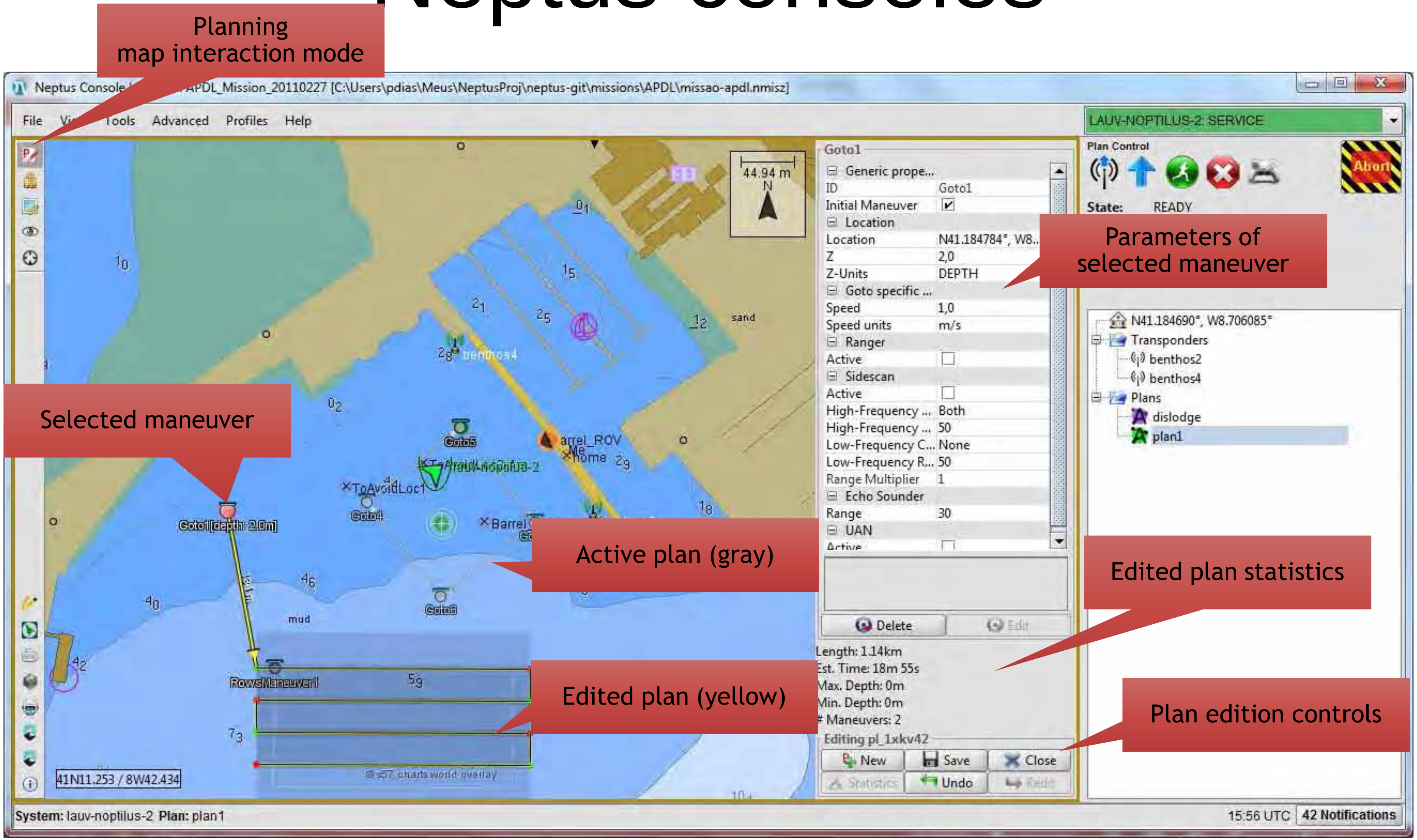
Vehicle Log Book



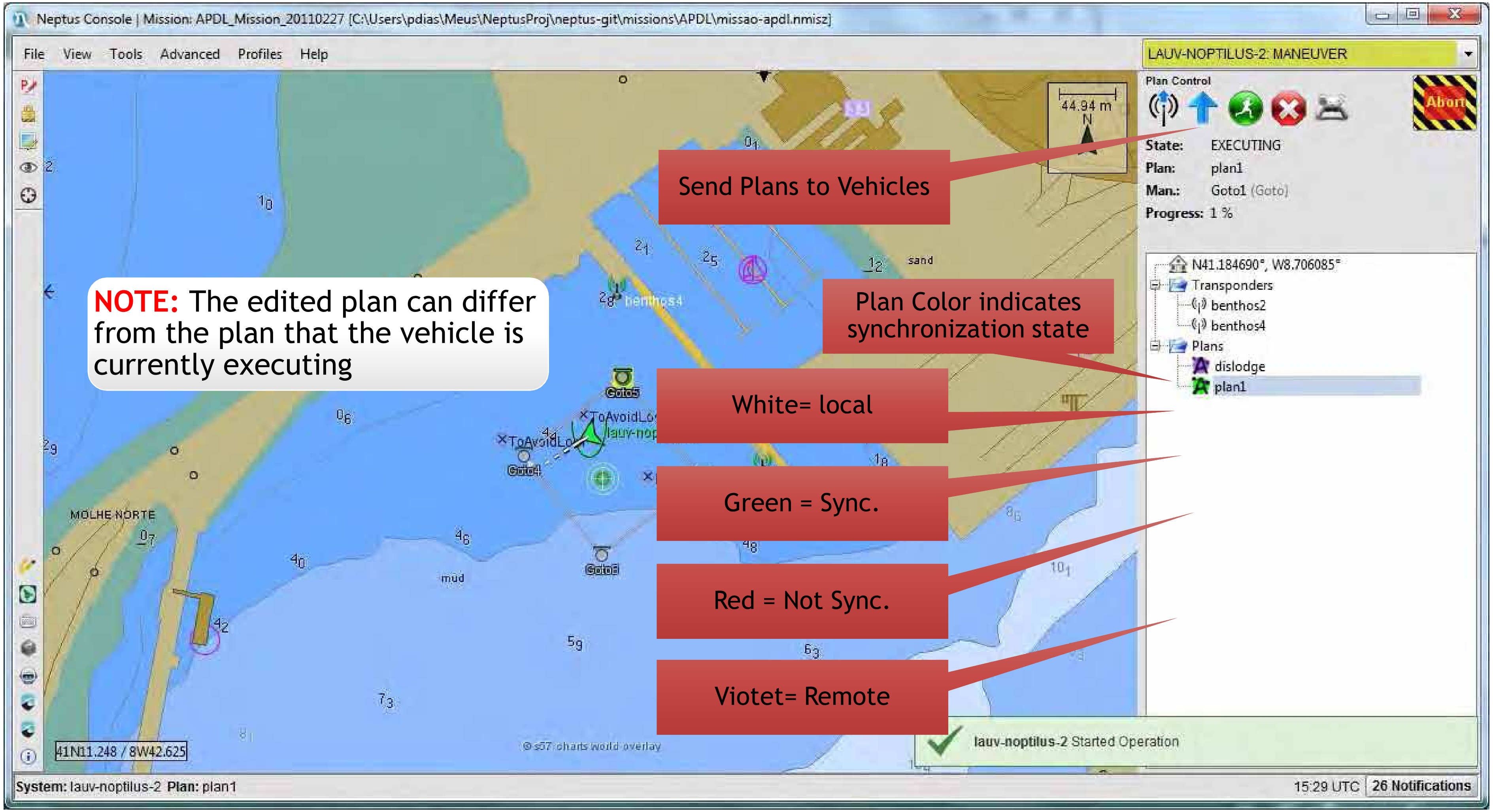
Vehicles Configurations



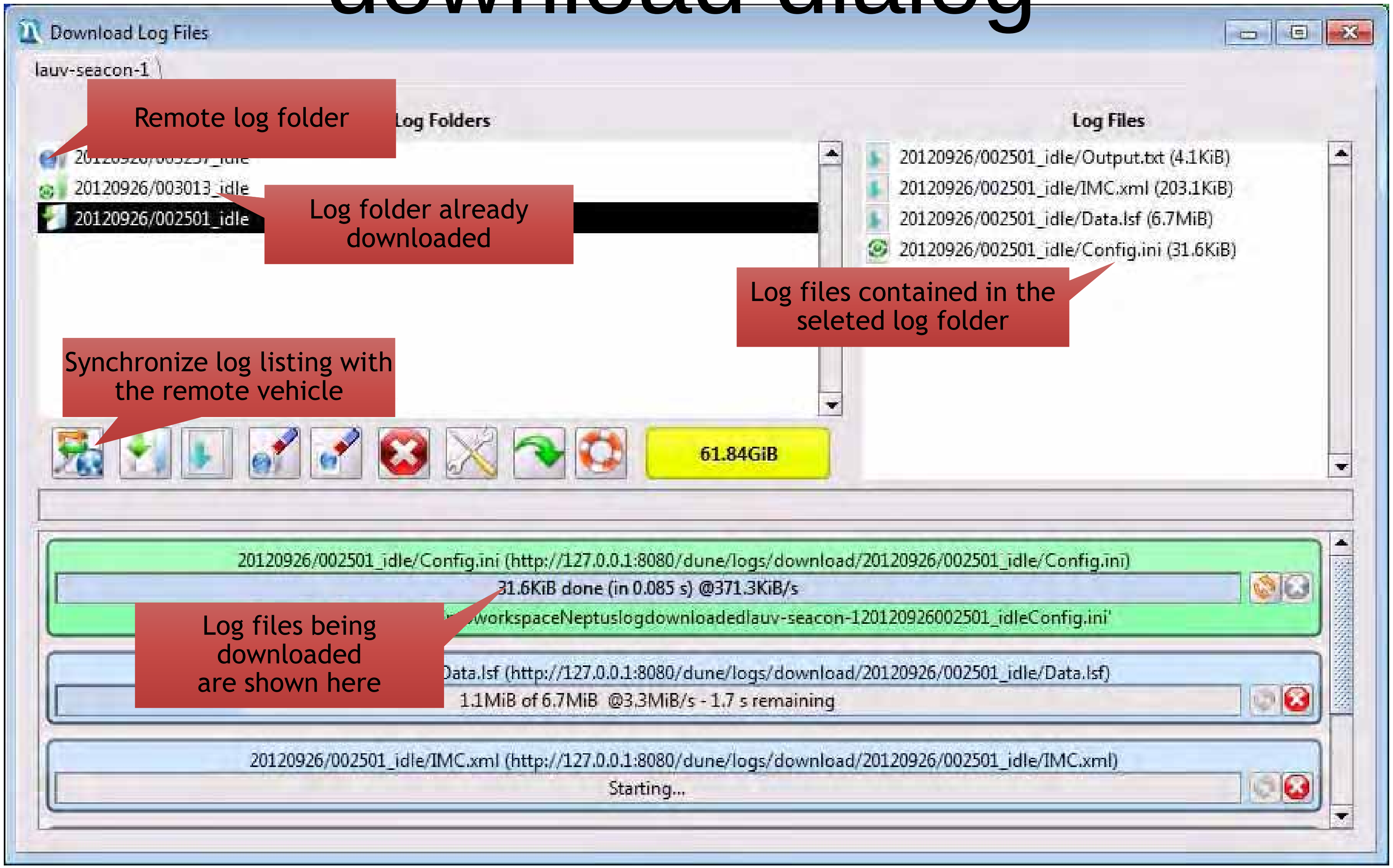
Neptus consoles



Neptus consoles

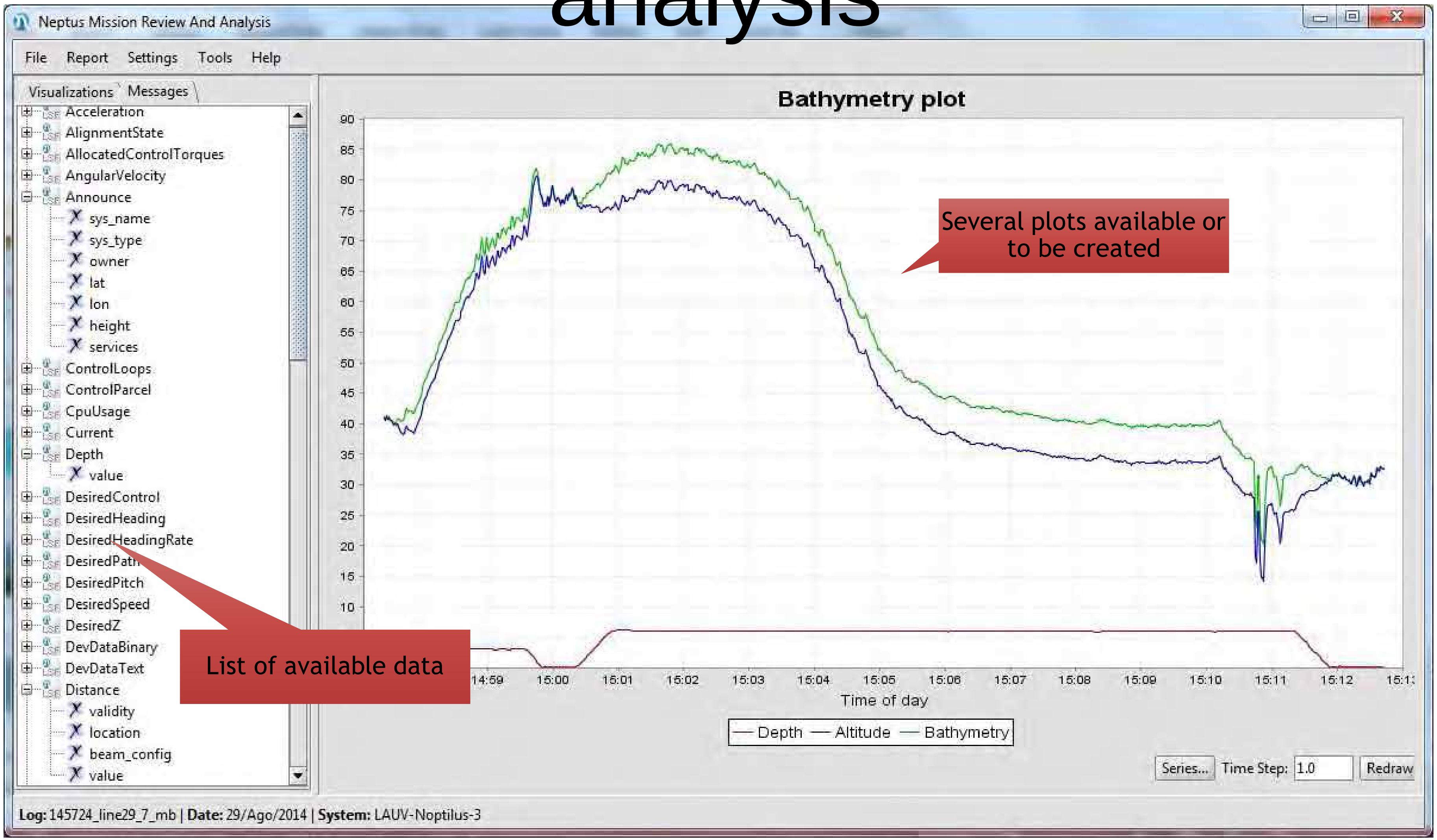


Neptus consoles – Log download dialog



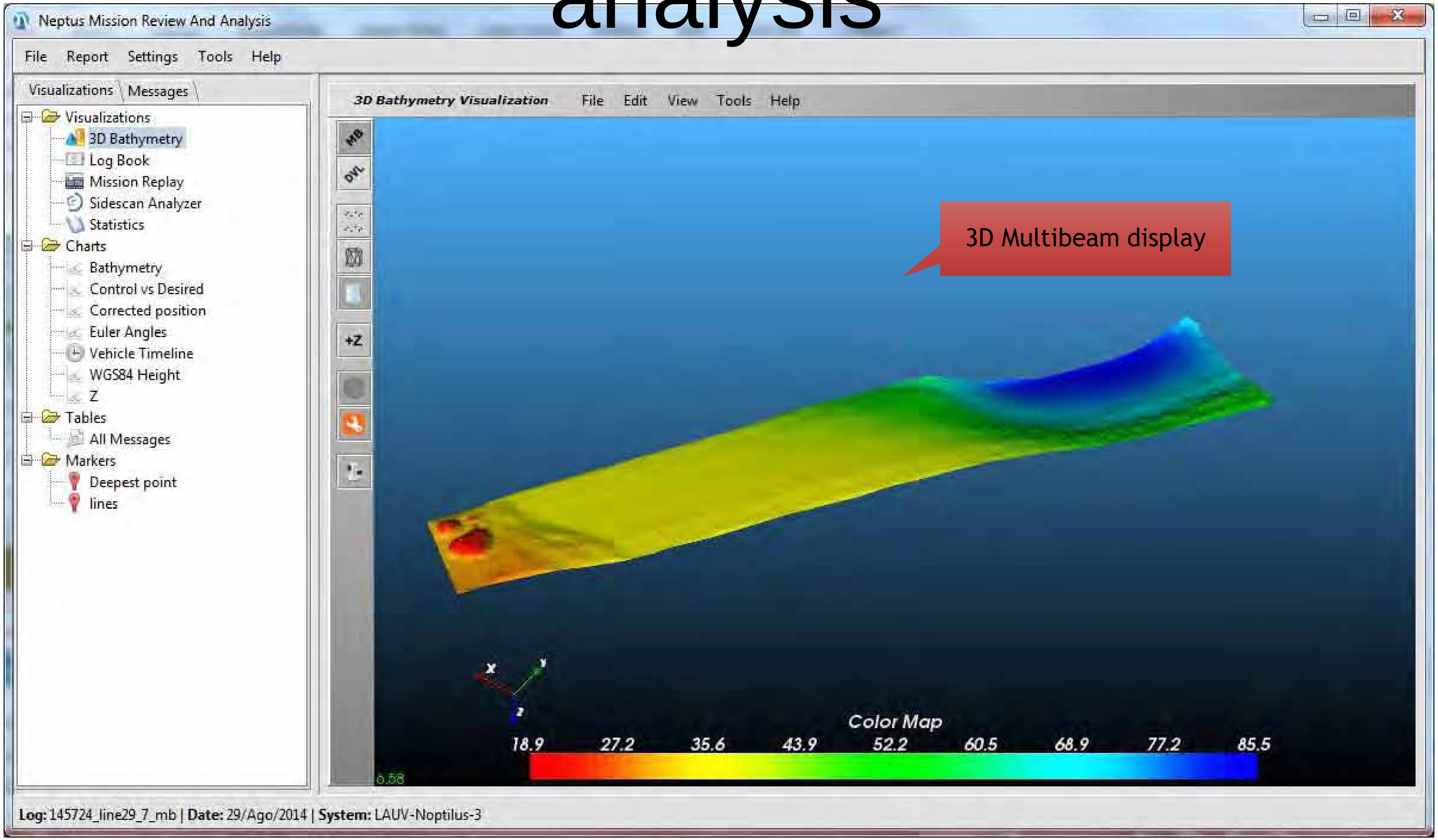
Neptus mission review and analysis

Neptus mission review and analysis

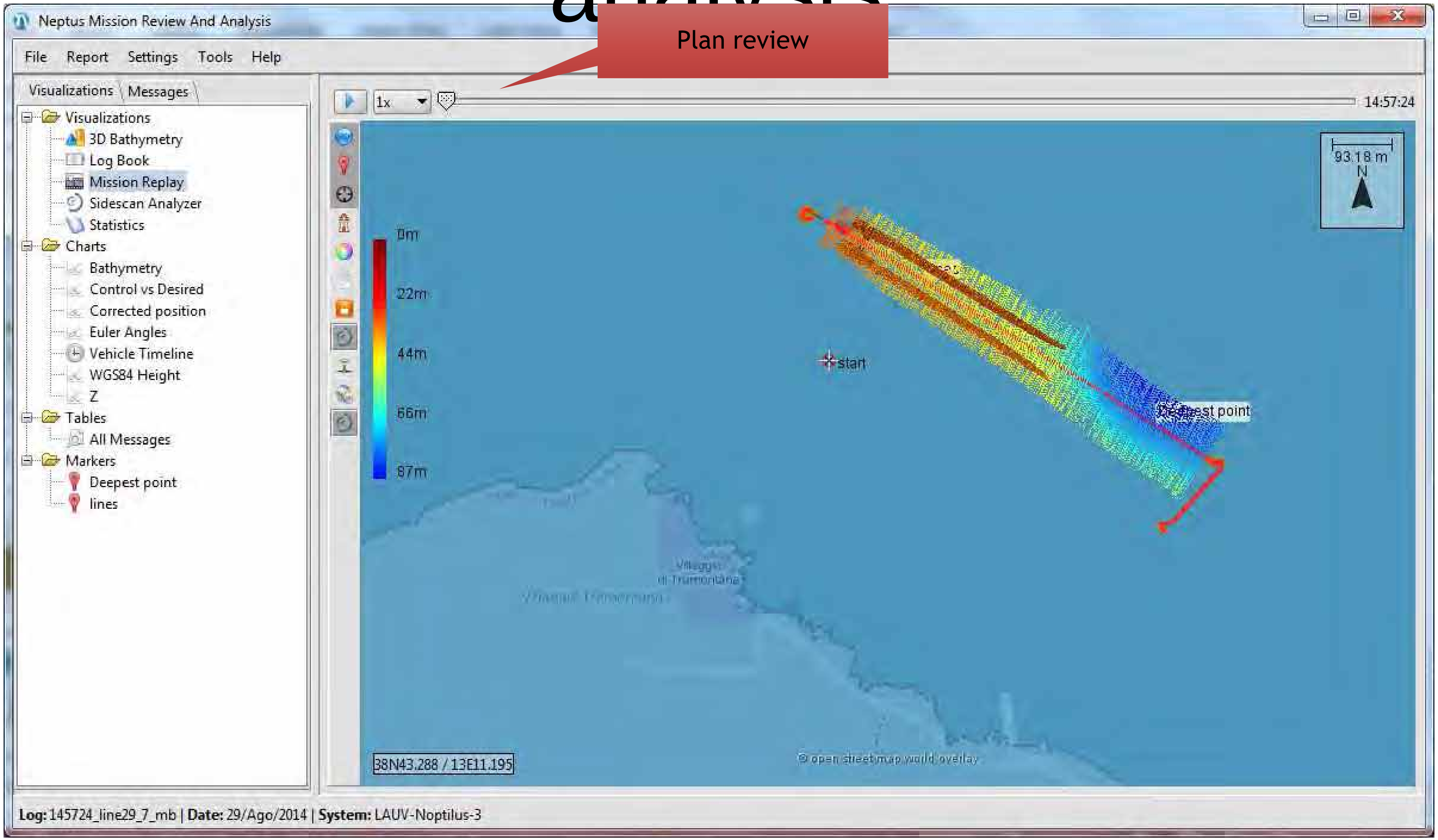


Neptus mission review and analysis

Neptus mission review and analysis

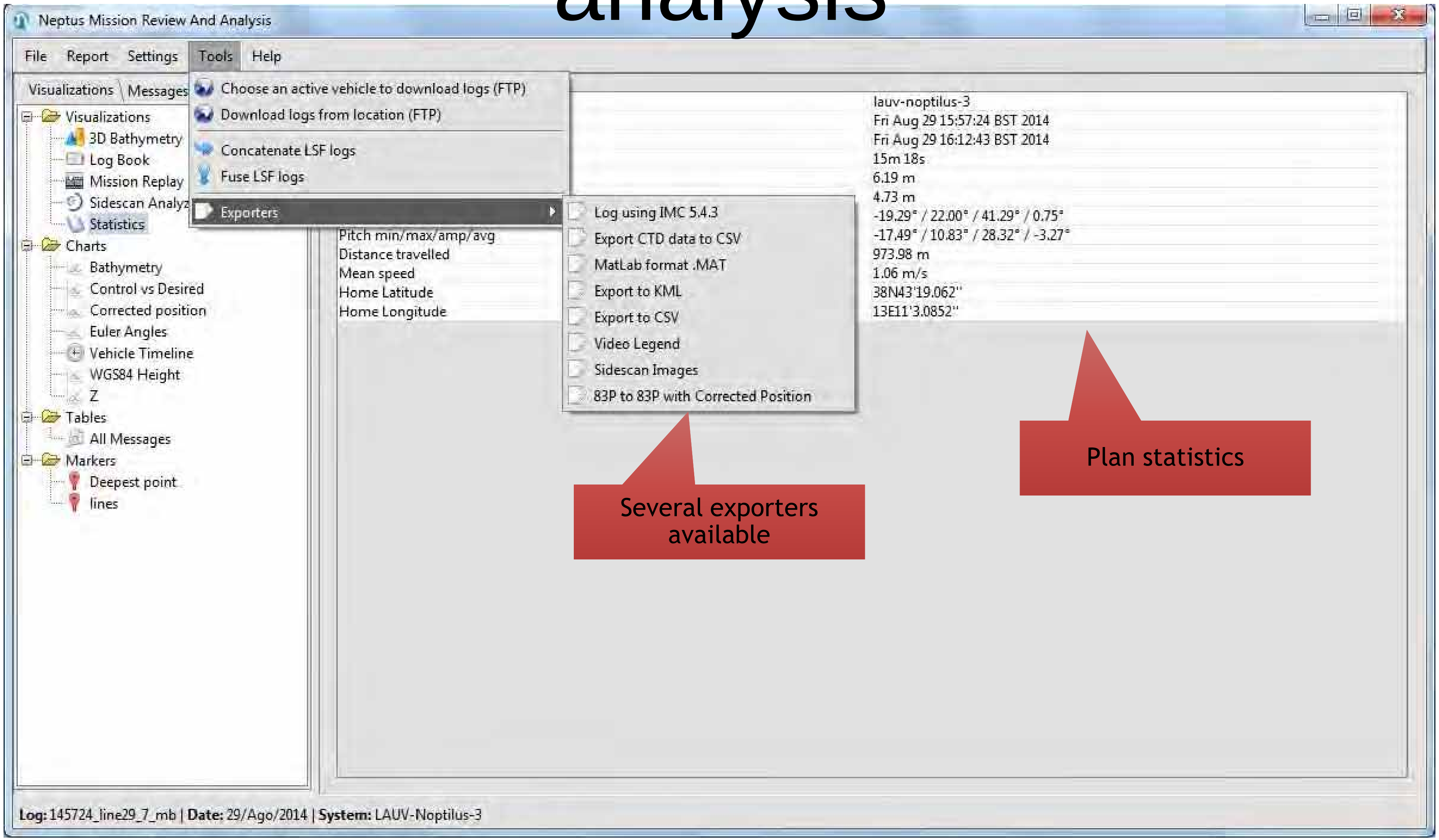


Neptus mission review and analysis



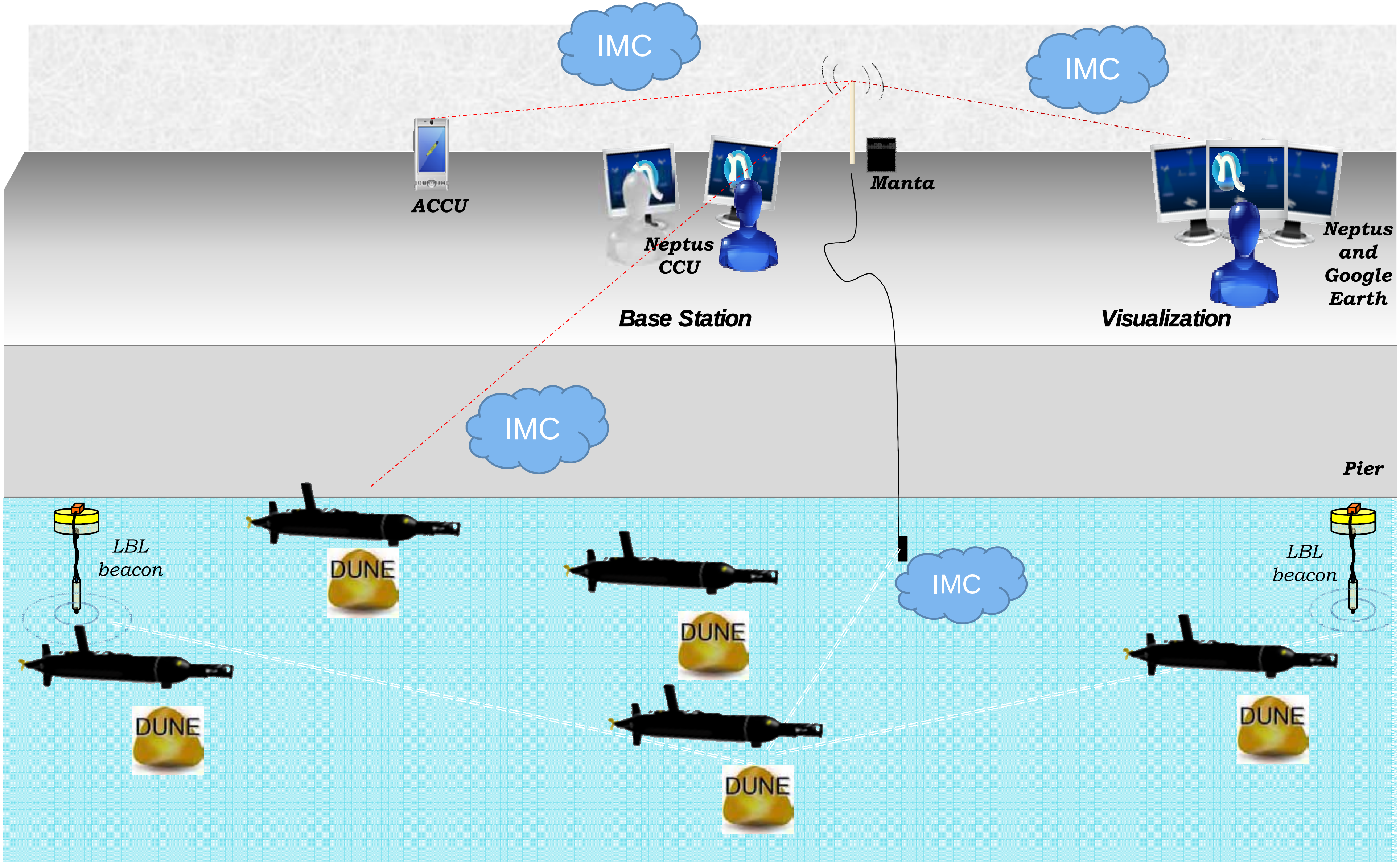
Plan review

Neptus mission review and analysis



Operations

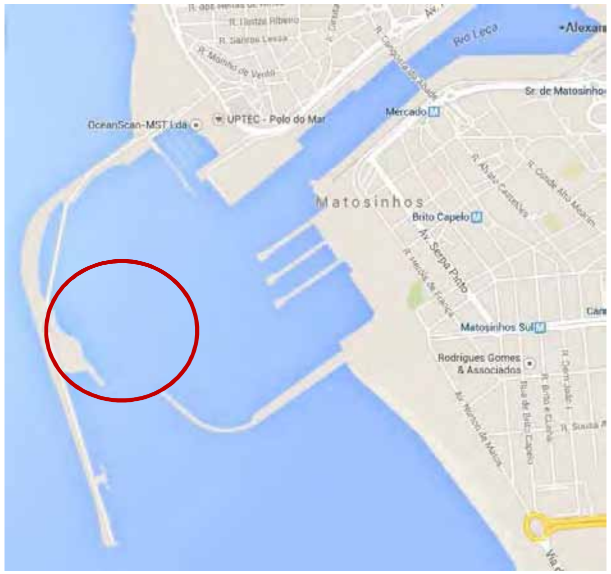
Setup


IMC
IMC
ACCU
Manta
Neptus CCU
Neptus and Google Earth
Base Station
Visualization
IMC
Pier
LBL beacon
LBL beacon
DUNE
DUNE
IMC
DUNE
DUNE
DUNE

APDL: lost container

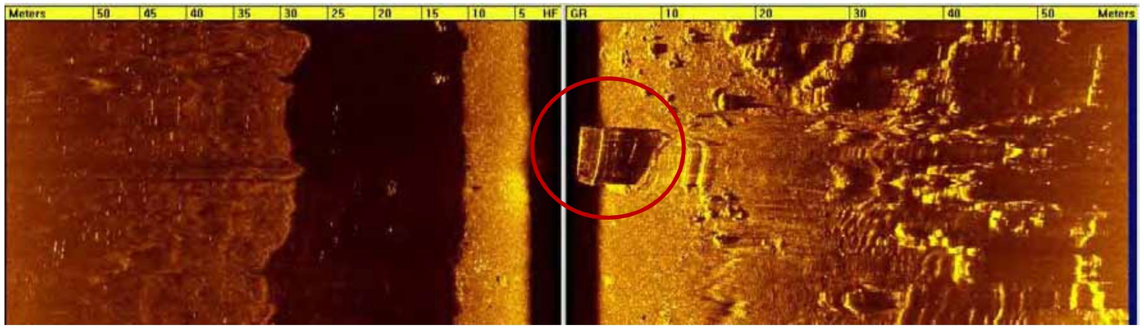
Scenario

- Second week Jan 2014
- Severe sea conditions
- Container lost inside the harbor
- Location unknown
- Navigation safety at stake
- Terminal closed



APDL: container found

- Time-critical problem
- APDL not able to find container
- Closure of harbor considered
- APDL contacted FEUP for help
- NOPTILUS system deployed
- Container found in a couple of hours
- Container recovered
- Terminal re-opened to operations



APDL testing & evaluation (1-2 weeks/month)

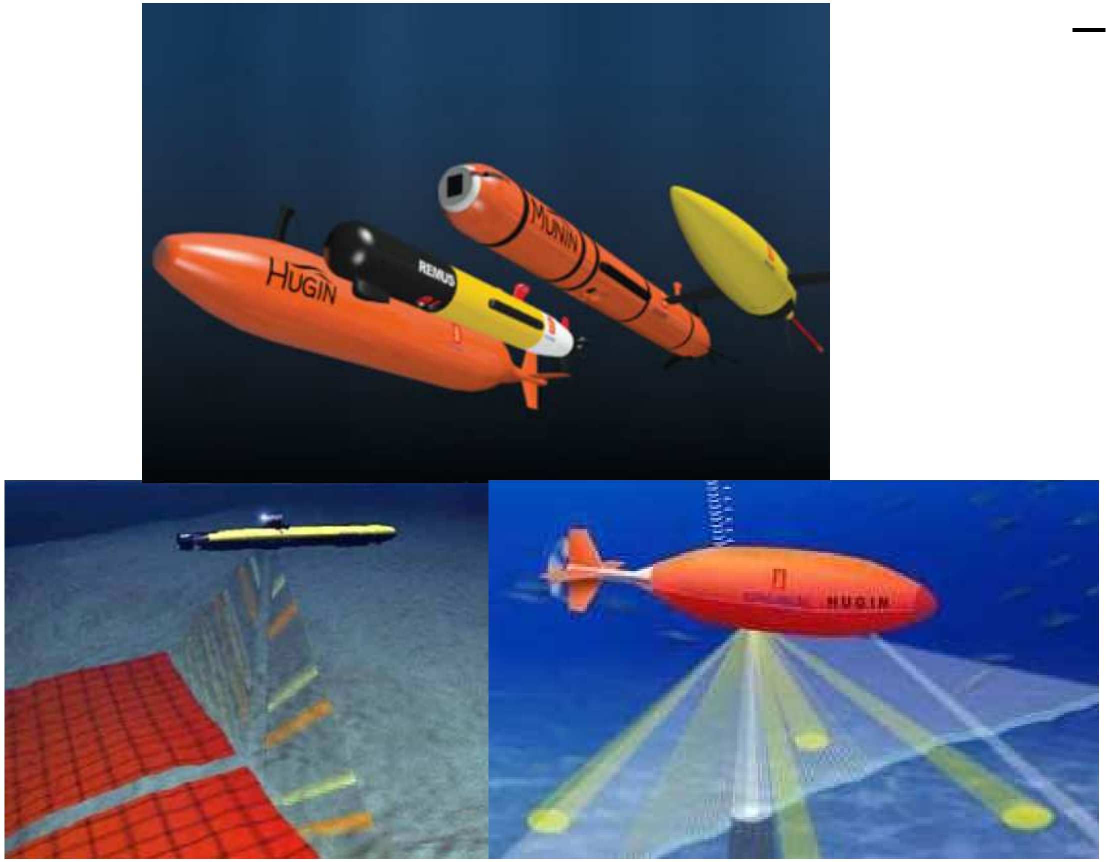


Operations outside the harbour

The NOPTILUS project
A fully-autonomous navigation system of teams of AUVs for static/dynamic underwater mapping

Problem Definition

Optimal Trajectory Generation for Underwater Map Construction:

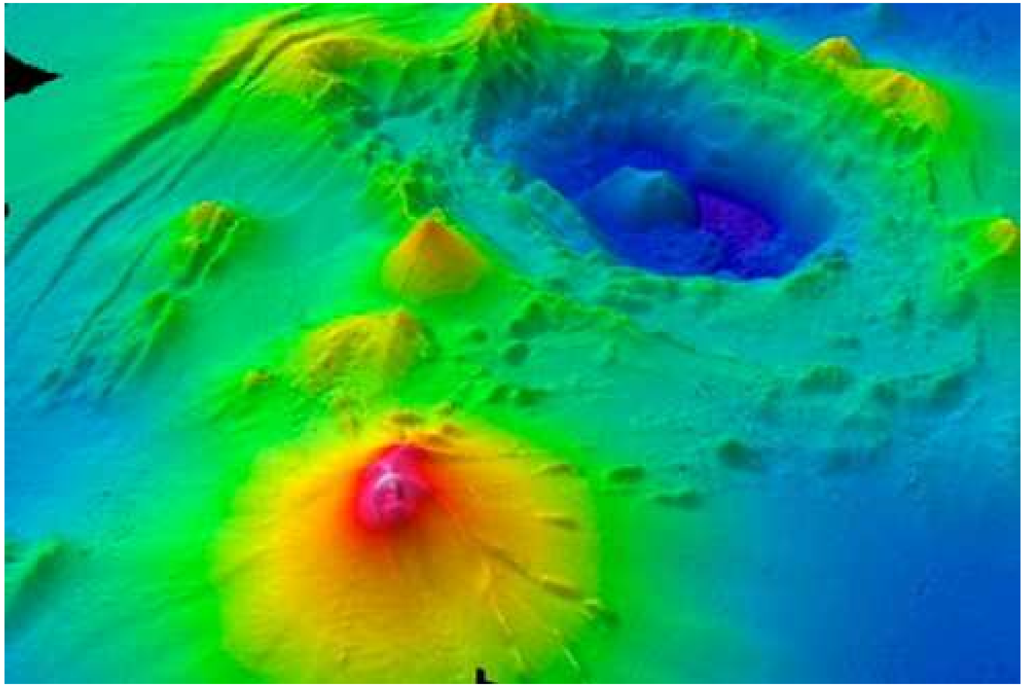


- employing a various number of heterogeneous AUVs

NOPTILUS

Problem Definition

Optimal Trajectory Generation for Underwater Map Construction:

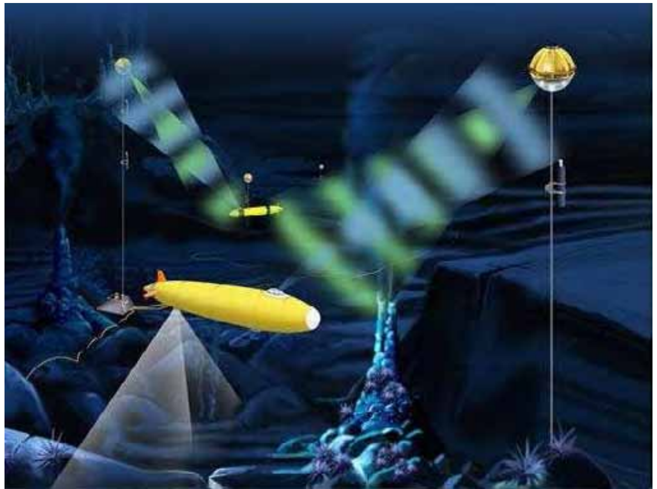


- employing a various number of heterogeneous AUVs
- **inside a morphologically unknown terrain**

NOPTILUS

Problem Definition

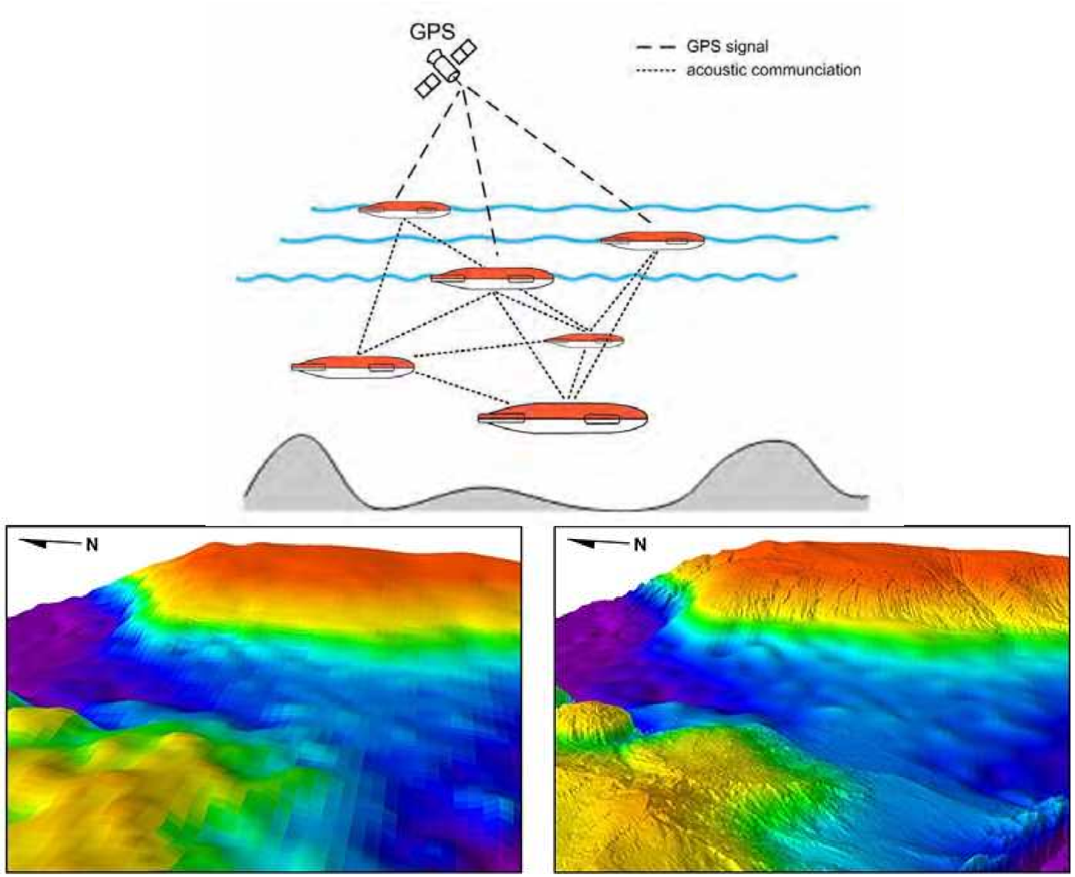
Optimal Trajectory Generation for Underwater Map Construction:



- employing a various number of heterogeneous AUVs
- inside a morphologically unknown terrain
- **exploiting in the best possible way the "gained" information coming - in realtime - from the AUVs' sensors**

Problem Definition

Optimal Trajectory Generation for Underwater Map Construction:

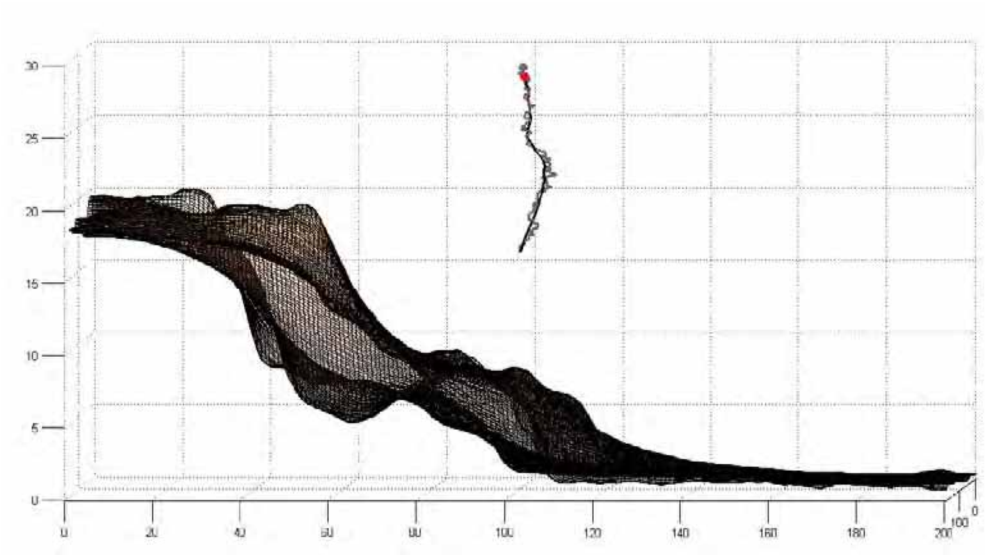


- employing a various number of heterogeneous AUVs
- inside a morphologically unknown terrain
- exploiting in the best possible way the "gained" information coming - in realtime - from the AUVs' sensors
- **improving the overall SLAM efficiency**

NOPTILUS

Problem Definition

Optimal Trajectory Generation for Underwater Map Construction:



- employing a various number of heterogeneous AUVs
- inside a morphologically unknown terrain
- exploiting in the best possible way the "gained" information coming - in realtime - from the AUVs' sensors
- improving the overall SLAM efficiency
- **be able to perform secondary tasks**

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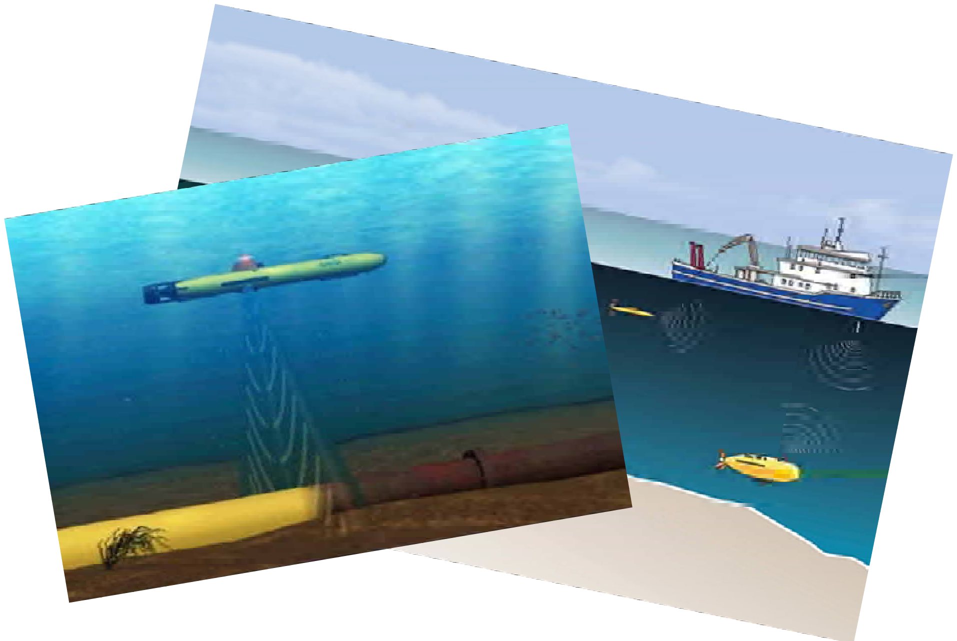
Significance

Plethora of applications:

- harbor security
- post-disaster infrastructure inspection
- continuous infrastructure monitoring to prevent accidents
- underwater archaeology
- habitat mapping
- etc



Hardness

The vast majority of the missions rely on off-line calculated trajectories

- applying exploration patterns similar to lawn mower

Even simplified versions have been proven NP-hard

One-step-ahead optimization techniques or relaxed versions of the NP-hard may overcome that but:

- the closed form that relates the SLAM efficiency to the overall multi-robot team dynamics is not trivial
- optimizing SLAM efficiency may lead to severe deadlocks

NOPTILUS

The proposed optimal-based control methodology

- Based on PCAO – Parametrized Cognitive Adaptive Optimization-, an optimal control-based approach
- Extremely computational fast and efficient
- Employs Bellman's Principle (or, equivalently, the Hamilton-Jacobi-Bellman equation)
- "Optimality" is guaranteed in cases of
  - Events/incidents (addition or removal of an AUV, an event identified by the situation understanding mechanism, etc)
  - Operator commands (e.g., so as to modify the missions objectives)
- Optimization-based: allows to interface with other modules (by appropriately modifying/revising the performance criterion)

NOPTILUS

The proposed optimal-based control methodology

The final PCAO-based NOPTILUS navigation module:

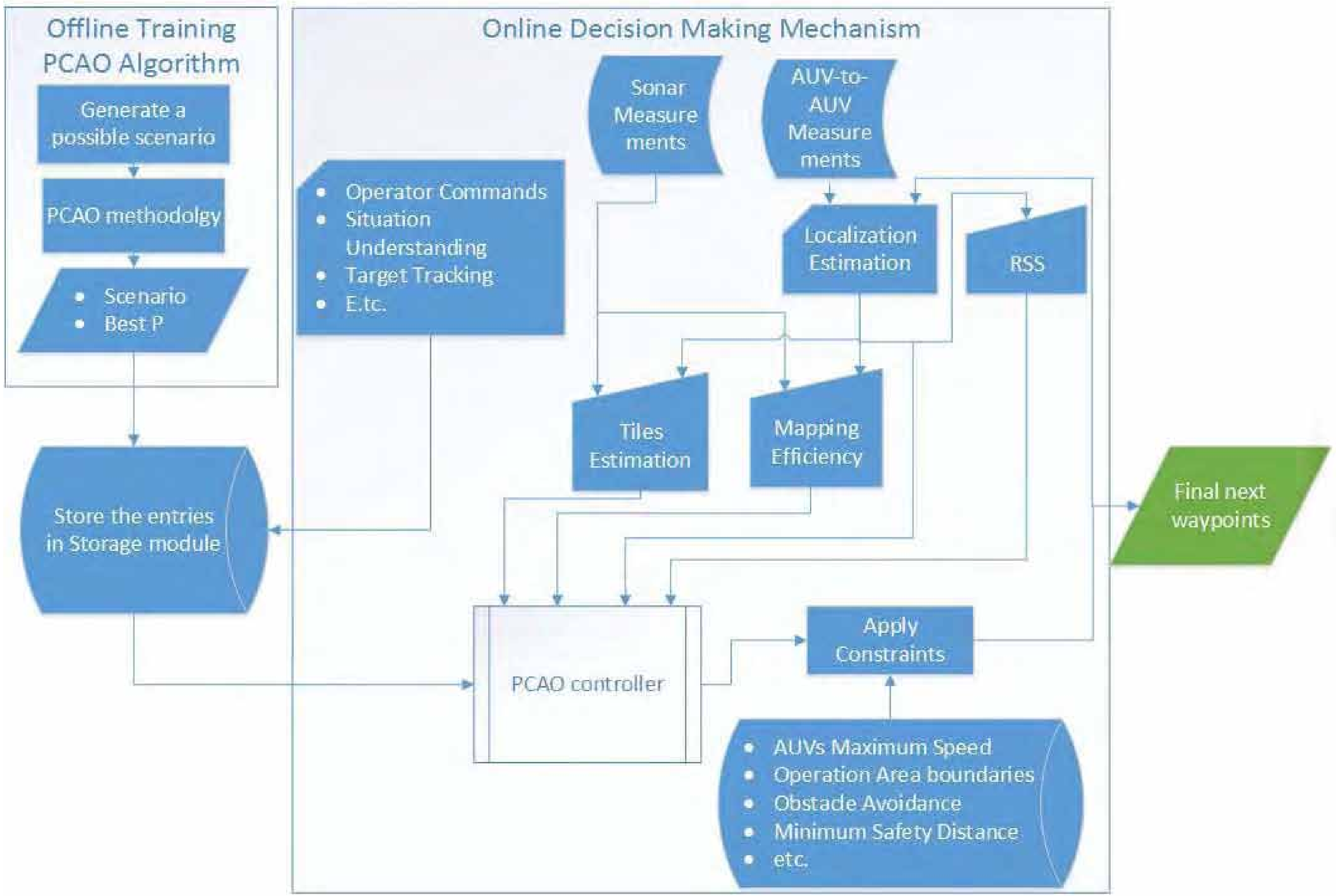
- Employs a transformed version of the mapping accuracy/coverage
- Automatic re-design in cases of events, incidents or operator commands

%

- Interfaced to
    - Localization module
    - Underwater Acoustic Communication Maps
    - Situation Understanding Module
    - Operator Commands

NOPTILUS

Complete NOPTILUS System



Real Life Experiments

- **Scenario1**: Team of 3 AUVs face a malfunction
- **Scenario 2**: 2 AUVs deployed to perform mapping and target tracking
- Both the experiments were conducted
  - In a square area 240x240 meters.
  - Under severe weather conditions (yellow alarm)
  - The duration of each experiment was T = 450 timesteps (where by a new time-step is defined whenever new waypoints are sent to the AUVs)

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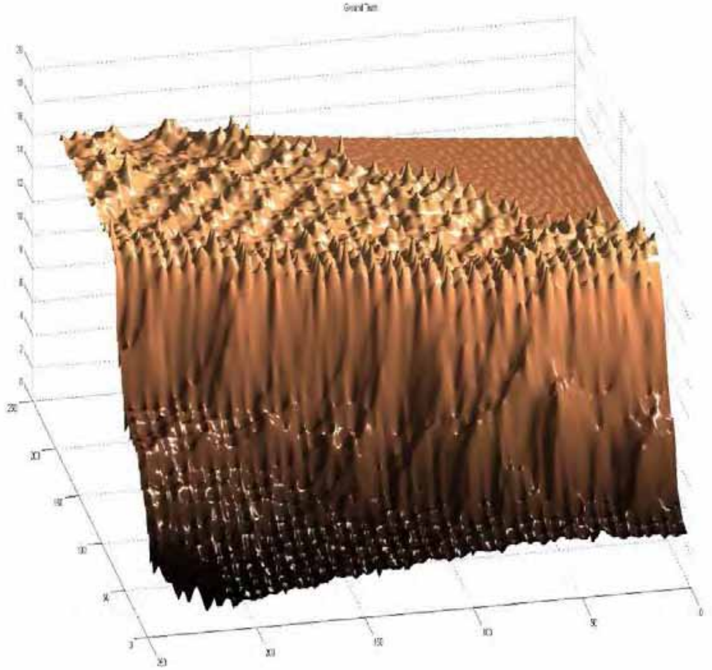
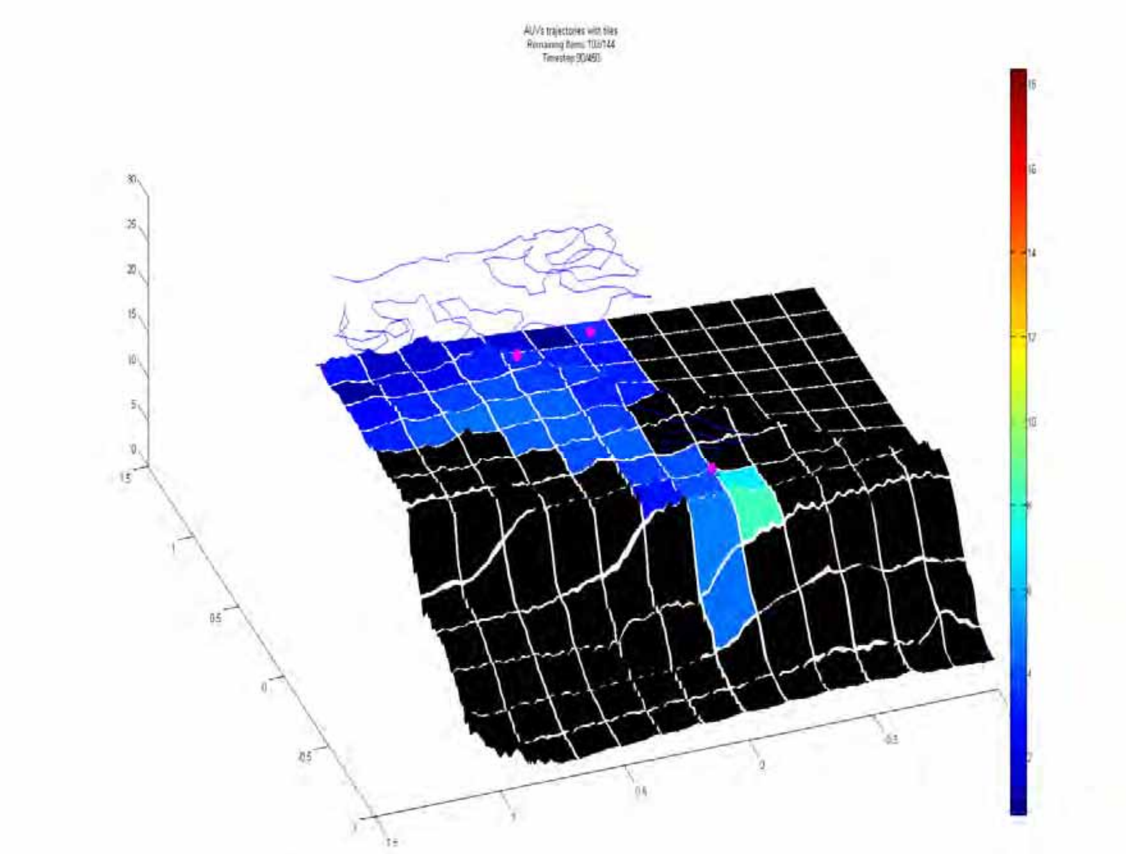
Ground Truth Map



Today's Usual Practice

NOPTILUS

Scenario 1- AUV malfunction

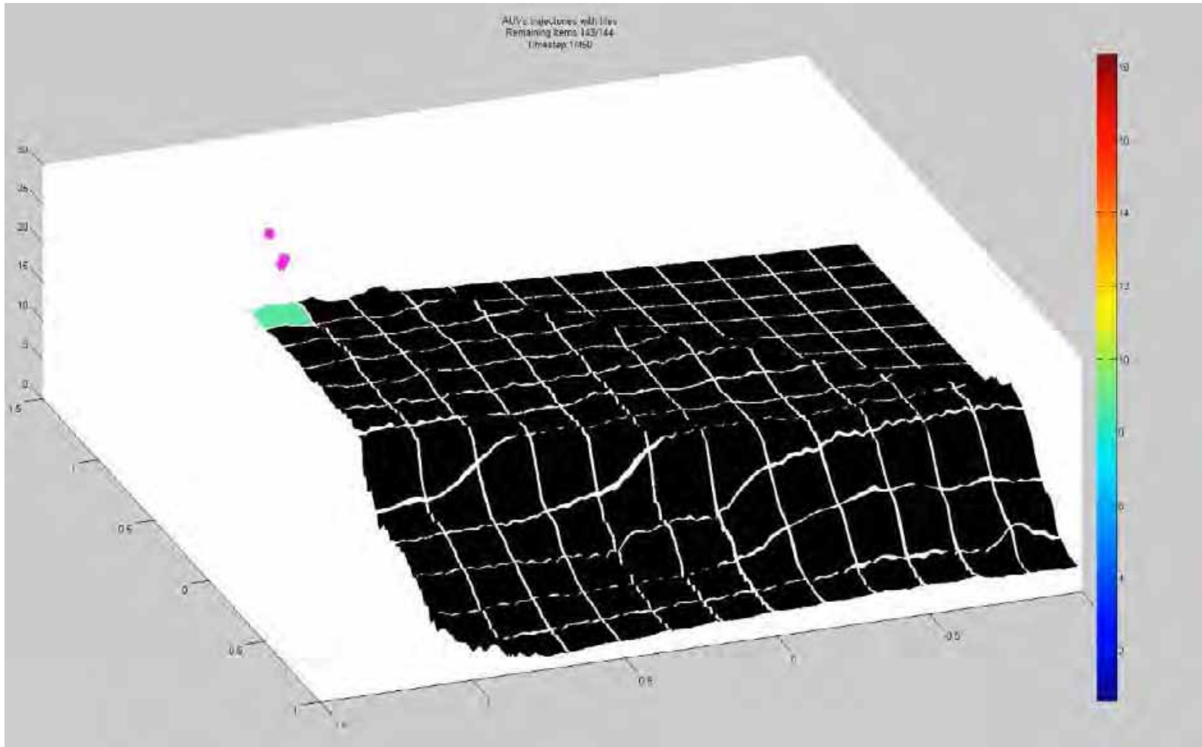


Graph explanation

- ***Blue lines*** → AUVs trajectories
- ***Magenta sphere*** → current AUV position
- ***Black tiles*** → Unknown territories (have not ever been measured by any of AUVs)
- ***Colorful tiles*** → sub-areas where the AUVs have started (and may completed) their estimation process.
  - ***Dark-blue***: A perfect match between the estimated and ground truth map is acquired
  - ***Dark-red***: The estimated one doesn't have any correspondence with the actual surface

NOPTILUS

Scenario 1- Video Demonstration



Time-step 100 → One of the AUV's propeller didn't responds to our control commands

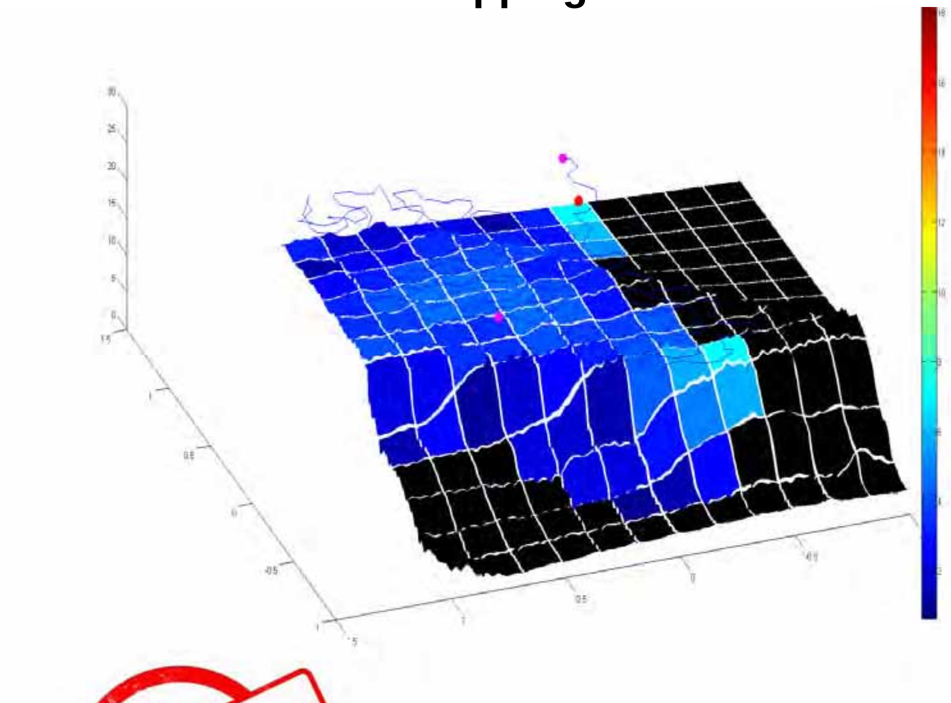
Compact Navigation scheme

– minimize the revisits in already estimated tiles

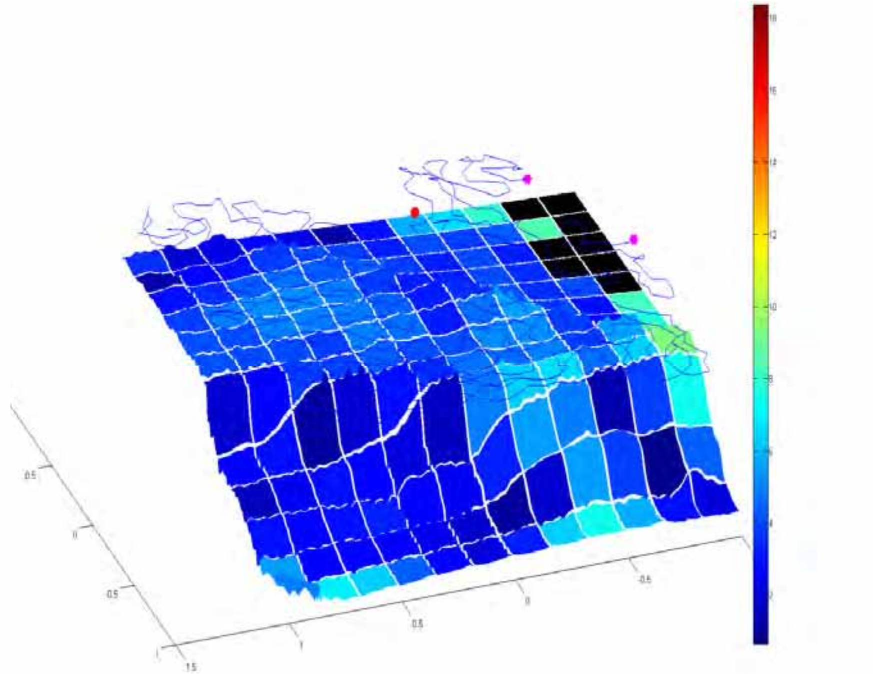
NOPTILUS

Scenario 1 – Operation Reproduction
A closer look

Navigation algorithm assimilates the new system dynamics and continue its mapping task

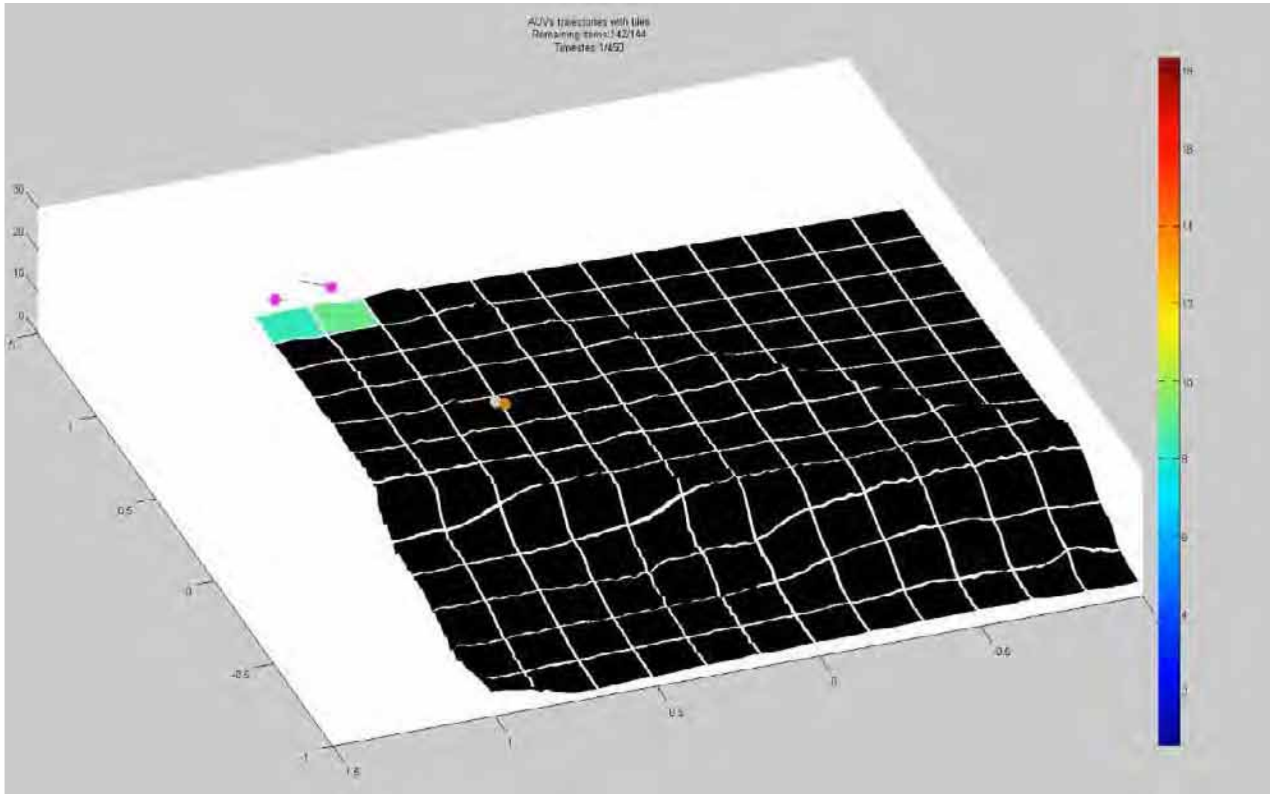


Another AUV swept the tiles, that would had been normally assigned to the malfunctioned one.



NOPTILUS

Scenario 2 – Target Tracking



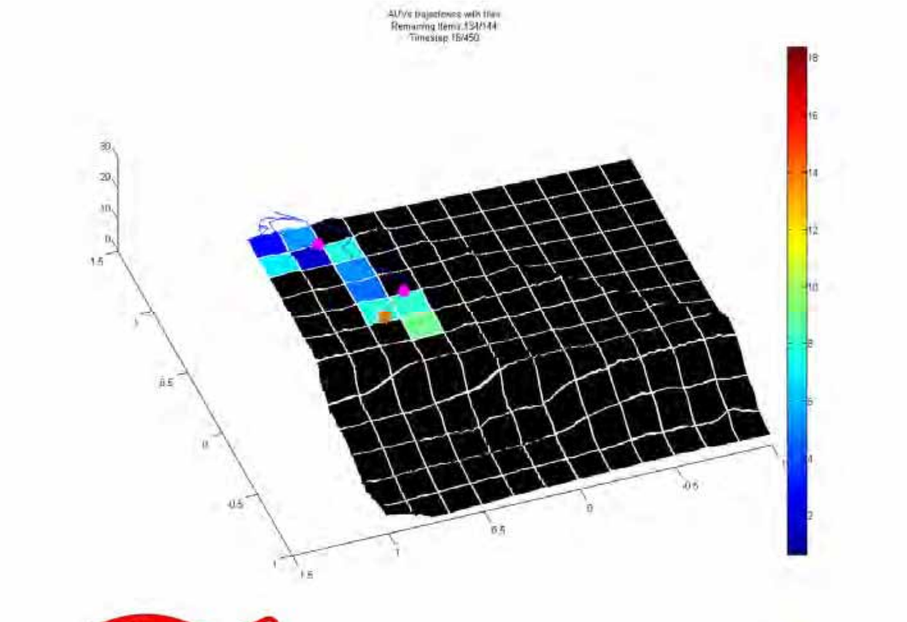
REAL LIFE EXPERIMENT

- The moving target is marked as brown sphere, while its estimation is marked as gray sphere.
- Minimize Euclidean distance between one AUV and the moving target.
- The task of mapping for this AUV becomes a ***secondary*** objective.
- At the same time, the other one is building an accurate map of the underwater surface.

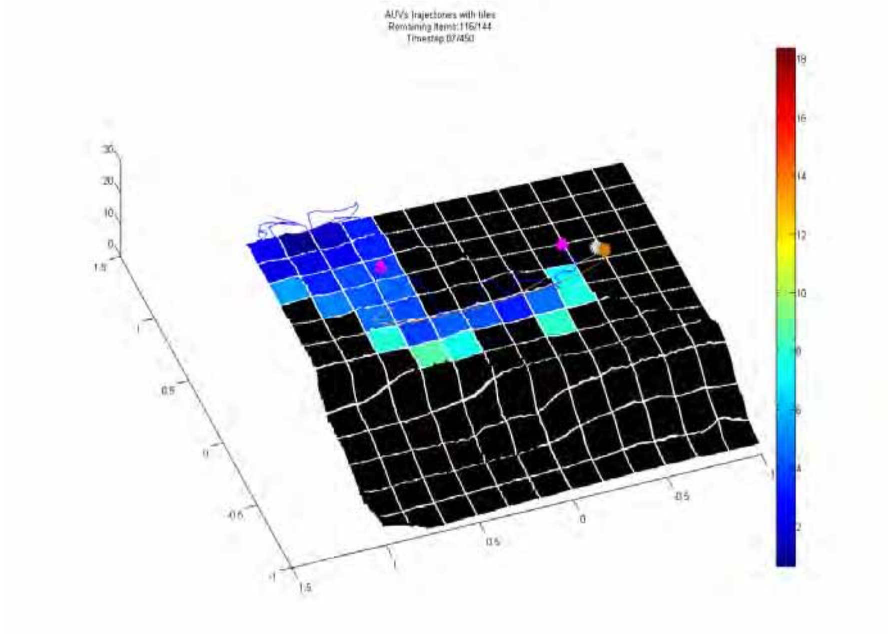
NOPTILUS

Scenario 2 – Correcting the incomplete tiles' estimation by the second AUV

The first AUV (on the right) performs a "sloppy" tiles' estimation (cyan-green tones) , in order to be able to "chase" the moving target

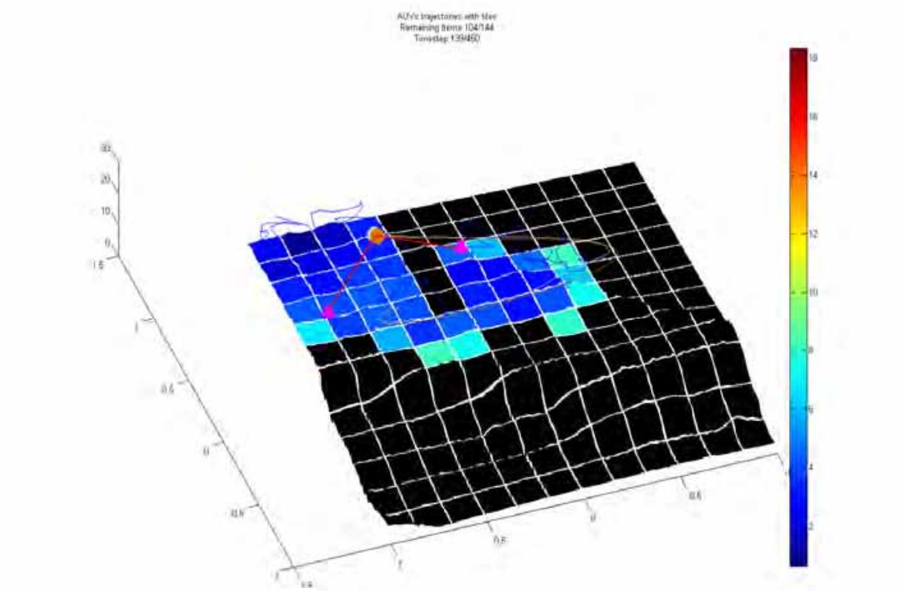


The second AUV revisits the poorly estimated tiles and achieves the satisfactory level of mapping accuracy

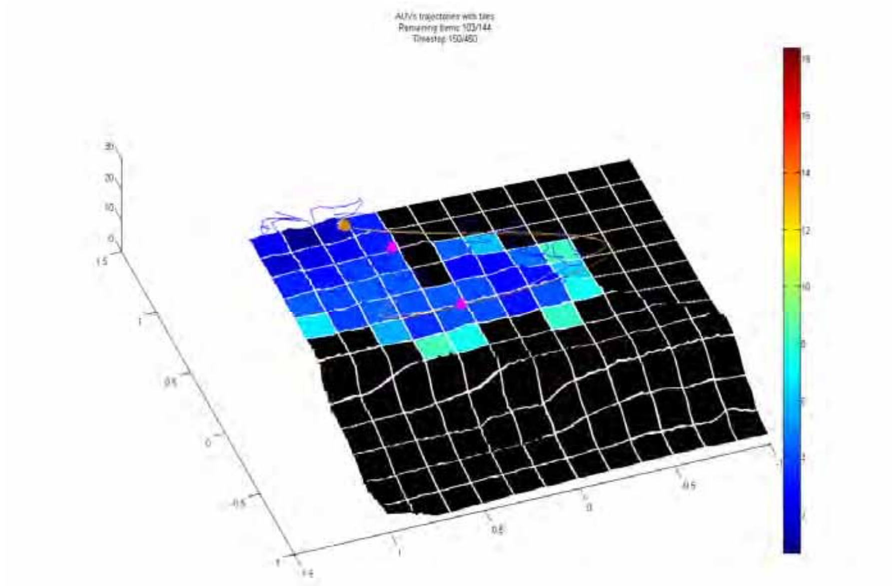


Scenario 2 – “Switch” in Target Monitoring

The target is assigned to first (right AUV), but the distance between both the AUVs and target is more or less the same

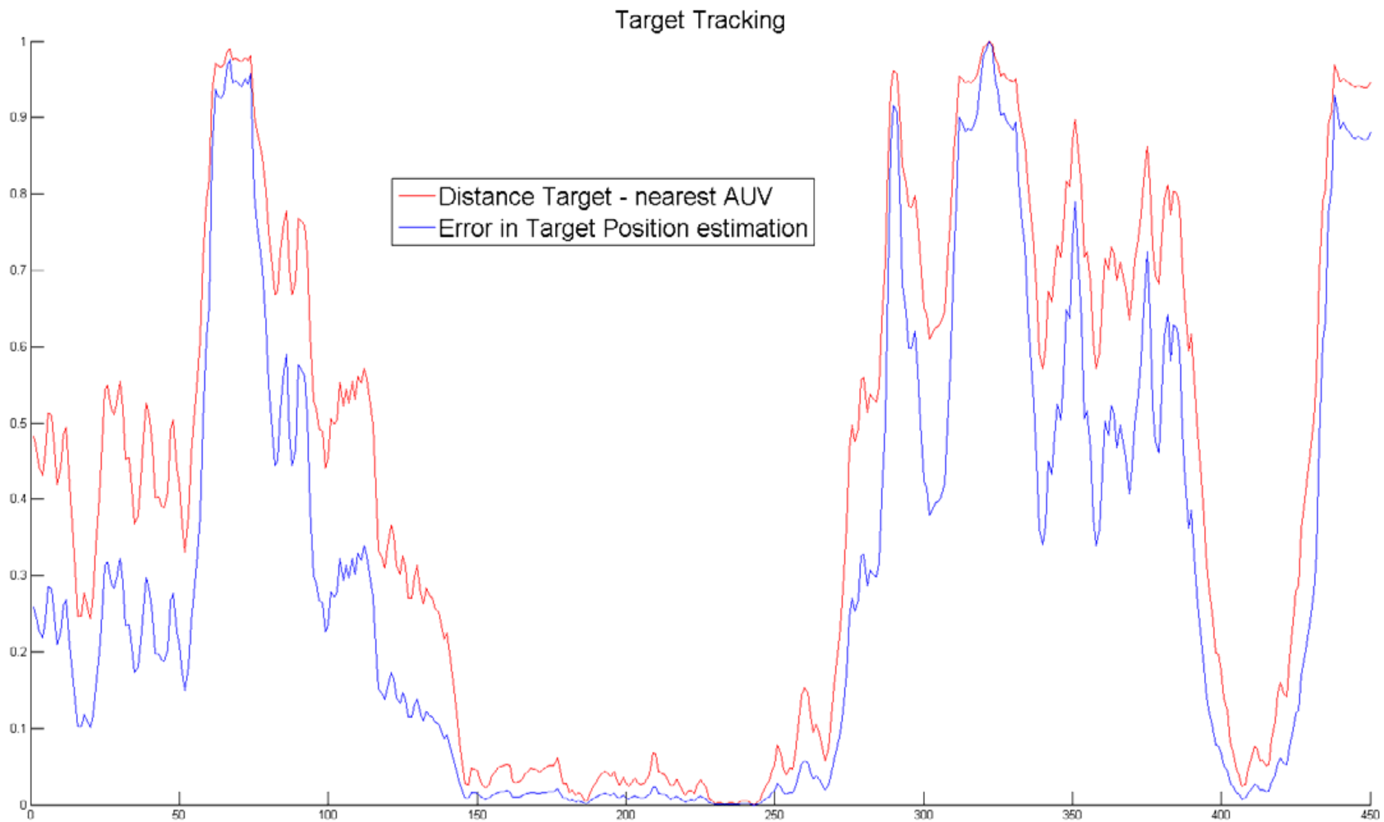


Noptilus-1 now is responsible for the target tracking, relieving the Noptilus-3 for this “burden” in order to perform a dedicated mapping task



The algorithm chooses to make the transitions only when the AUVs have more or less the same distance from the target, in order to avoid undesirable increases in the estimation error of target’s motion.

Scenario 2 – Error in tracking estimation



Conclusions

- Extend the basic PCAO-based methodology so as to incorporate:
  - a revised version of the mapping efficiency
  - information coming from other NOPTILUS modules
- PCAO's superiority against other state-of-the-art optimization algorithms

- *Ideal* for real-life implementations
  - utilizing heterogeneous vehicles
  - independent of the SLAM methodology employed
  - deal with various fault situations/events/operator commands

NOPTILUS

EMRA'15 workshop

Challenges of seabed mining in a sustainable world: let´s do it right!

Jorge Relvas, Univ. Lisbon, PT

Lisbon, Portugal
June 18, 2015

EMRA'15 workshop

INSTITUTO DOM LUIZ
LABORATÓRIO ASSOCIADO

LISBOA | UNIVERSIDADE DE LISBOA

Talk outline

1 – Mineral resources: a societal issue

2 – Deep sea resources

- REY – Rare Earth Elements and Yttrium
- Mn Nodules and Polymetallic Crusts
- SMS and Ophiolite-Hosted Massive Sulfides

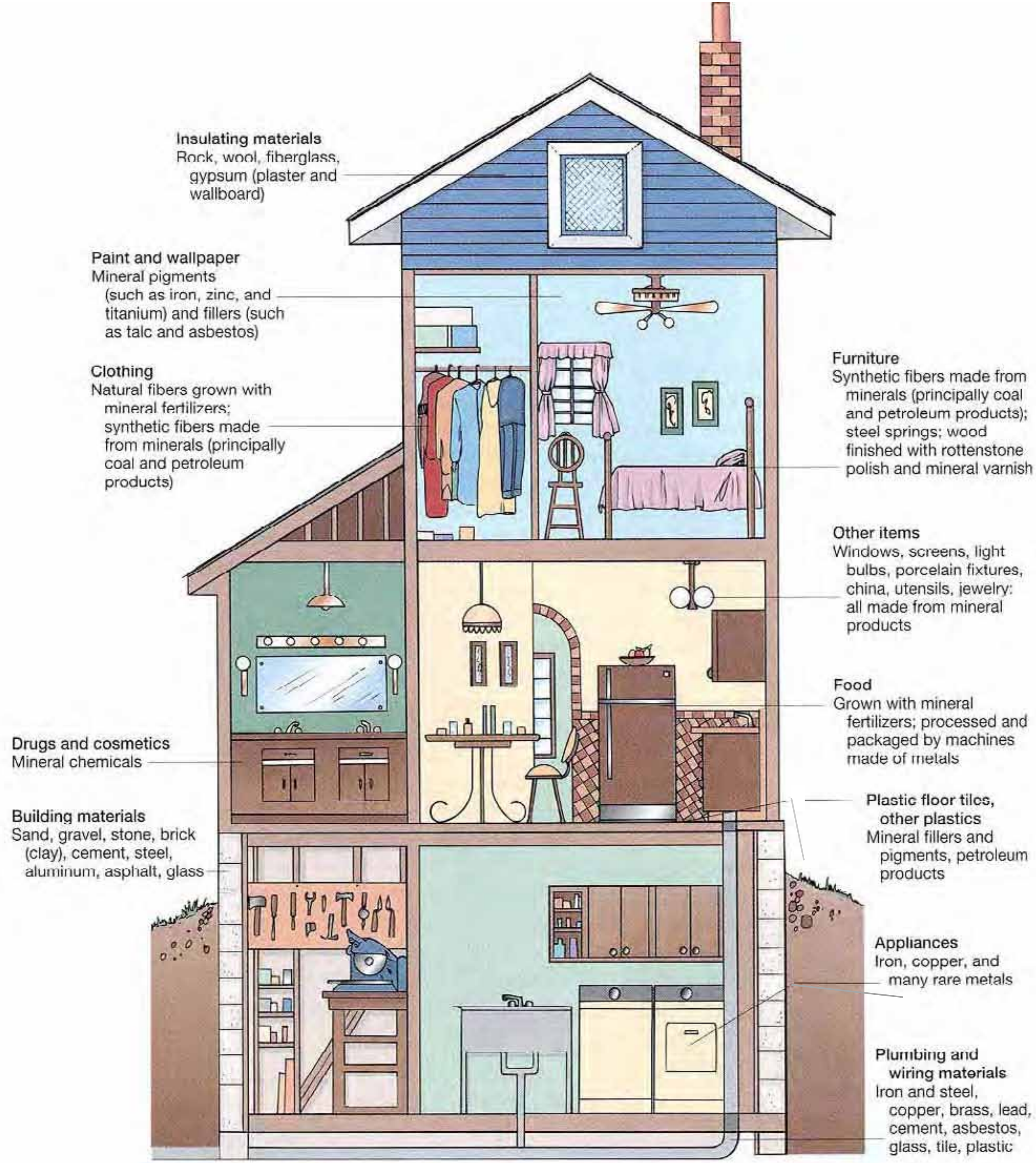
3 – Sub-seafloor replacement

4 – Seabed mining: the future is now

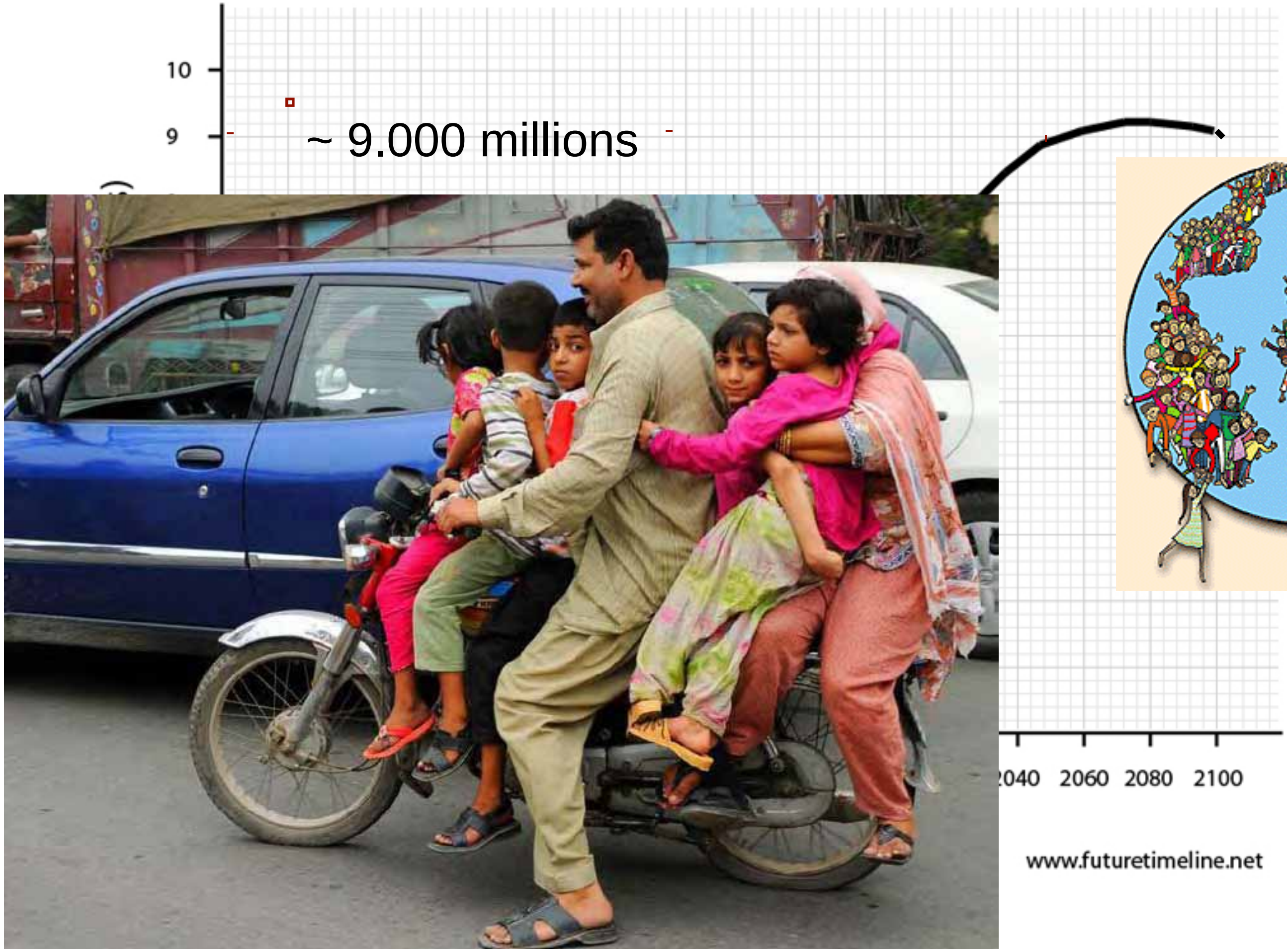
5 – Protect the ocean: let’s do it right

6 – Marine resources of Portugal

Look
around
everything
is made of
something



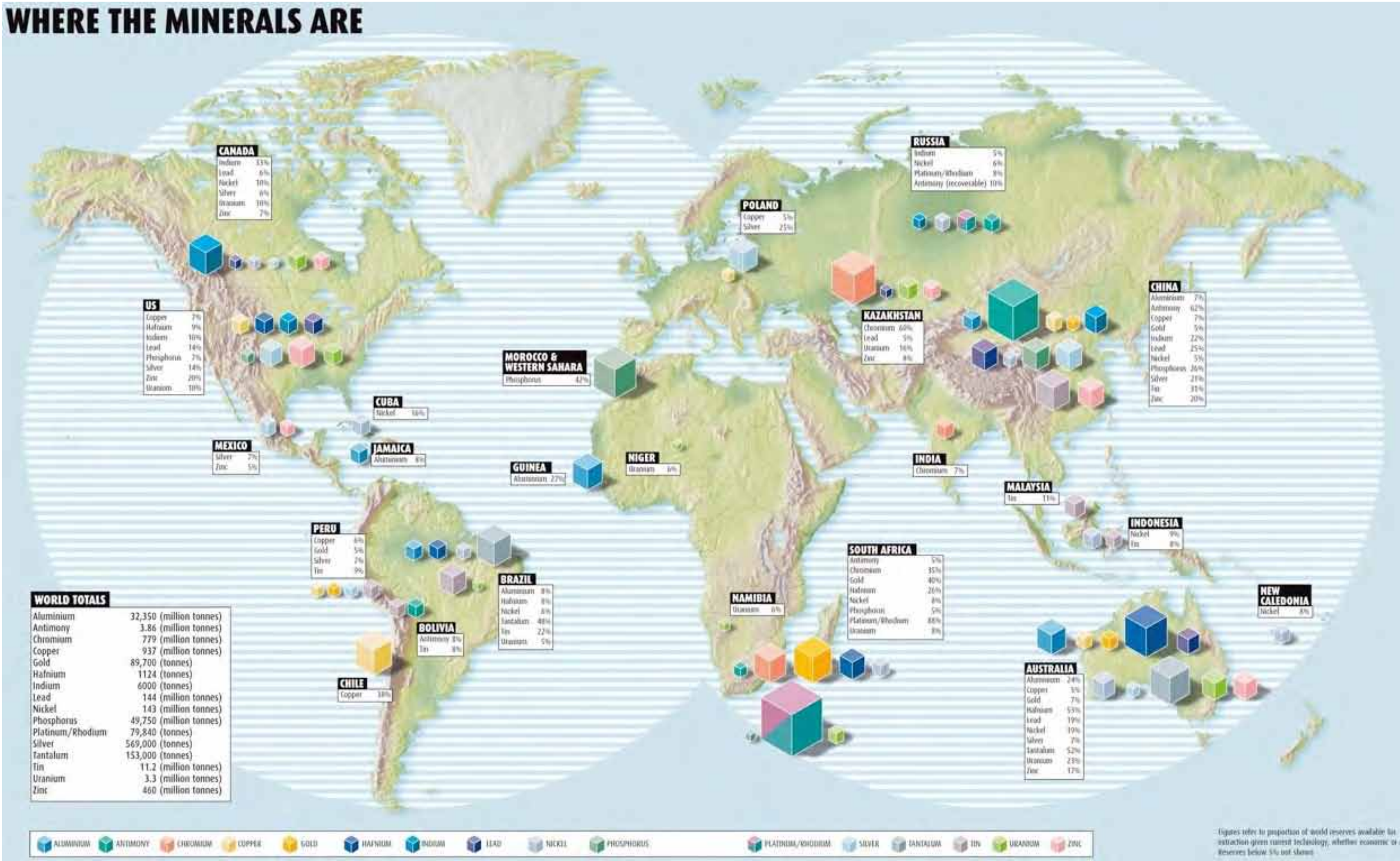
1,6 million kilograms of minerals, metals and fuels in their lifetime!


10
9
~ 9.000 millions
2040 2060 2080 2100
www.futuretimeline.net

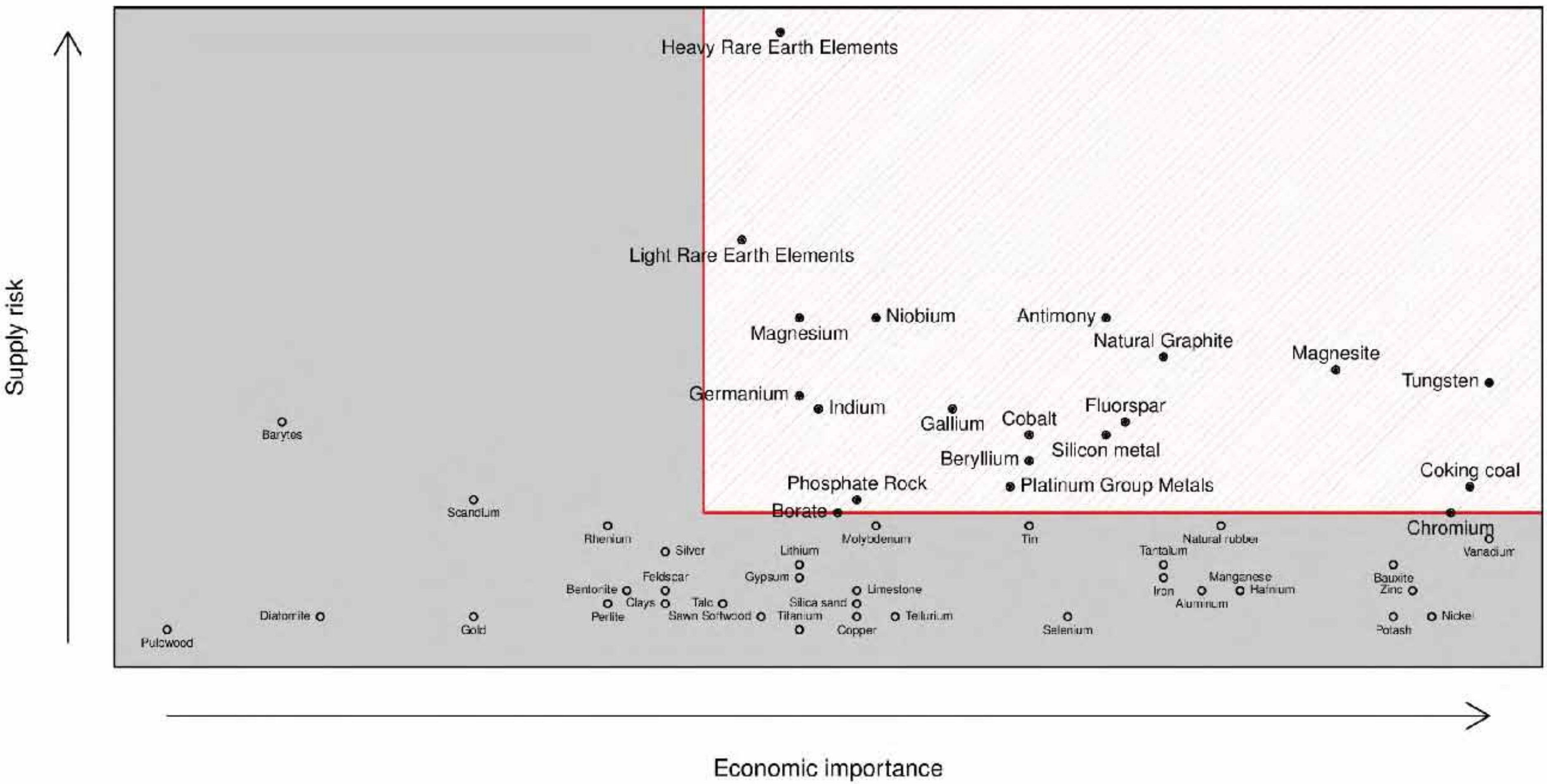
Mineral Resources and Society

It can't be grown, it has to be mined….

Where the minerals are

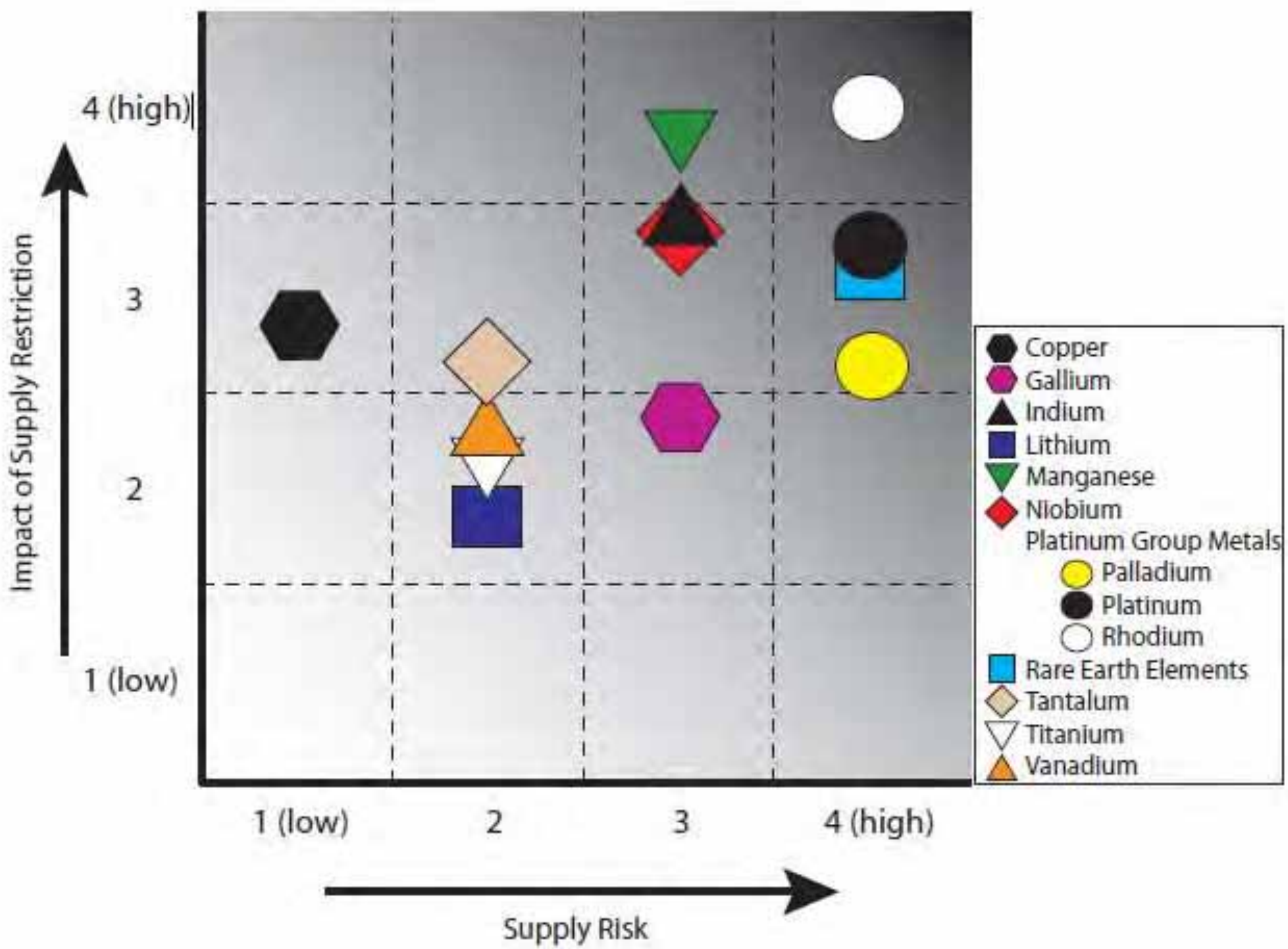


Economic Importance *vs.* Supply Risk

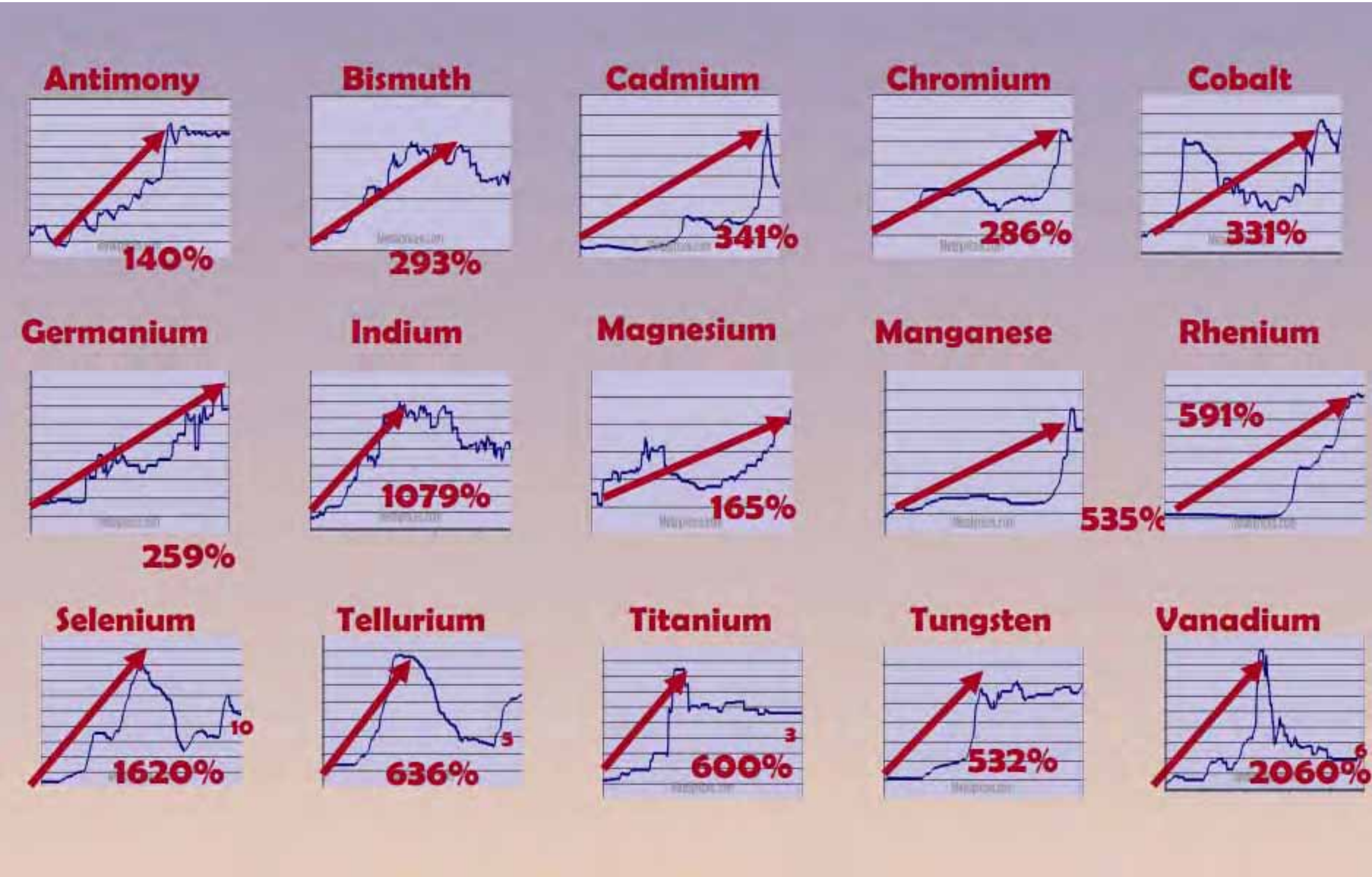


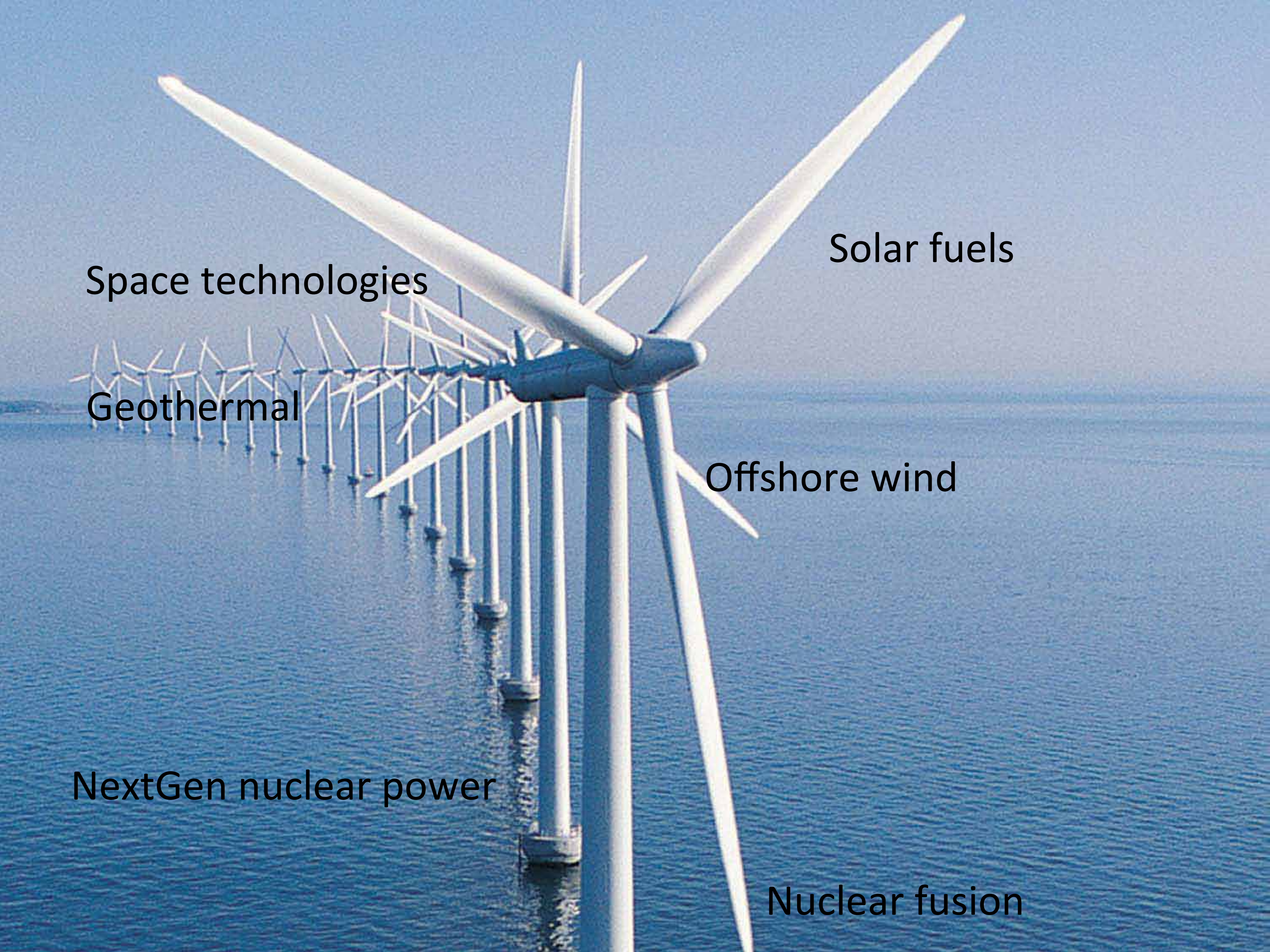
Report on Criticakl Raw Materials for the EU, May 2014, Ad hoc Group on defining Raw Mareials

Criticality matrix 2014



Prices Rise


Antimony
140%
Bismuth
293%
Cadmium
341%
Chromium
286%
Cobalt
331%
Germanium
259%
Indium
1079%
Magnesium
165%
Manganese
535%
Rhenium
591%
Selenium
1620%
10
Tellurium
636%
5
Titanium
600%
3
Tungsten
532%
Vanadium
2060%
6


Space technologies
Solar fuels
Geothermal
Offshore wind
NextGen nuclear power
Nuclear fusion

Critical raw materials for green energy

- [illegible]
- [illegible]

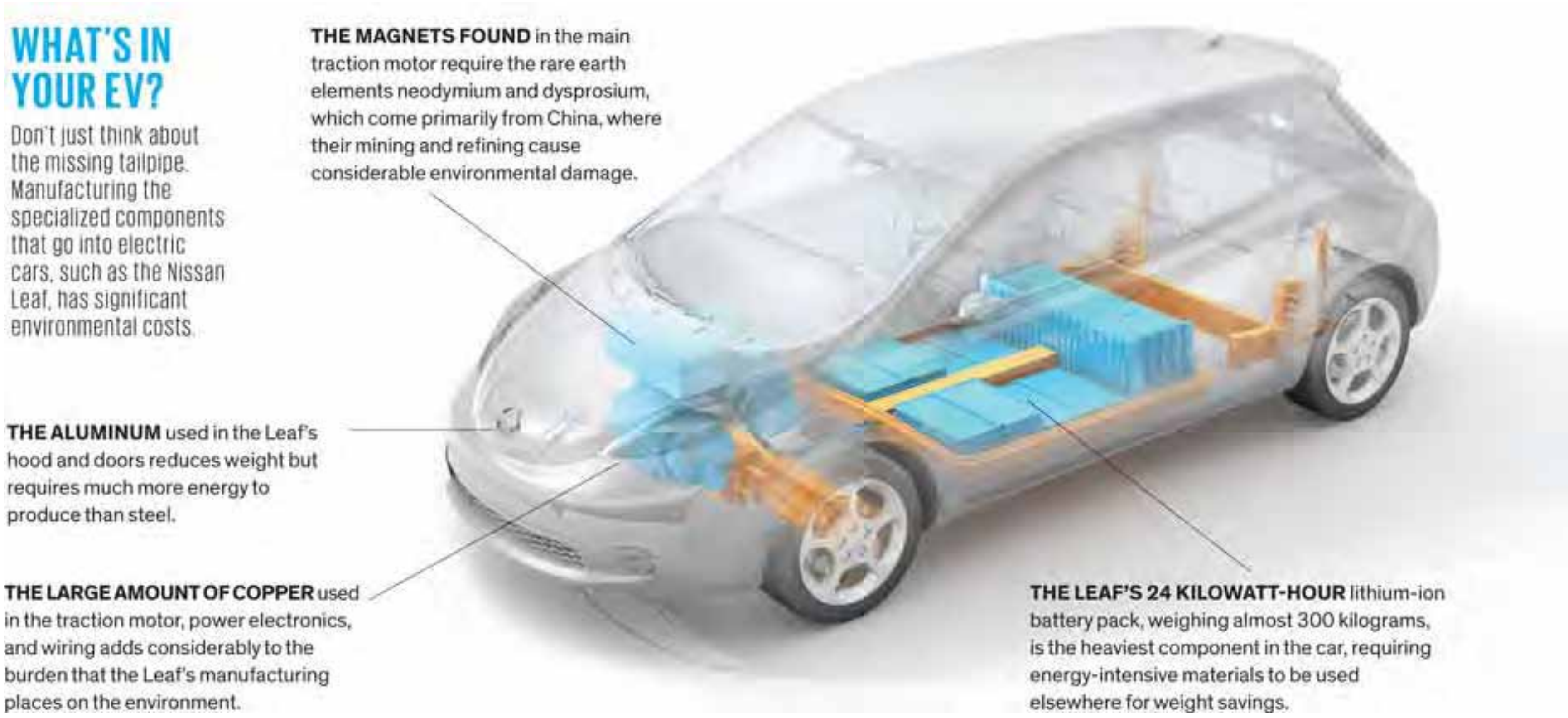
[illegible]

Strategic and Critical Materials with uses in Alternative Energy applications for which the U.S. is dependent on imports for 50% or more of consumption

Commodity	**Primary Sources**	***Applications in Alternative Energy***
Antimony	China	Thermoelectric/paraelectric materials
Barium	China	Thermoelectric/paraelectric materials
Bismuth	China, Mexico	Thermoelectric/paraelectric materials
Cobalt	Kinshasa,Australia	Photovoltaics (solar cells)
Gallium	China	Photovoltaics, paraelectric materials
Germanium	Belgium,Canada	Photovoltaics (solar cells)
Indium	China, Canada	Solar cells, thermo/paraelectric materials
Manganese	Gabon, S. Africa	Photovoltaics
Nickel	Canada	Fuel cells
Platinum group	South Africa	Fuel cells, para/thermoelectric mtrls
Rare Earths	China	Fuel cells, para/thermoelectric mtrls
Scandium	China, Russia	Thermoelectric/paraelectric materials
Selenium	Canada	Solar cells, thermoelectric materials
Strontium	Mexico	Thermoelectric/paraelectric materials
Tantalum	Brazil	Thermoelectric/paraelectric materials
Tellurium	Belgium, Germany	Solar cells, thermoelectric metrls, semiconductors
Tin	Peru	Thermoelectric materials
Titanium	Australia, S. Africa	Solar cells
Vanadium	Czech Rep., S. Africa	Fuel cells
Zinc	Canada, Mexico	Photovoltaics, fuel cells, thermoelectric mtrls


FUTURE
IS NOW
GO TWIZY!

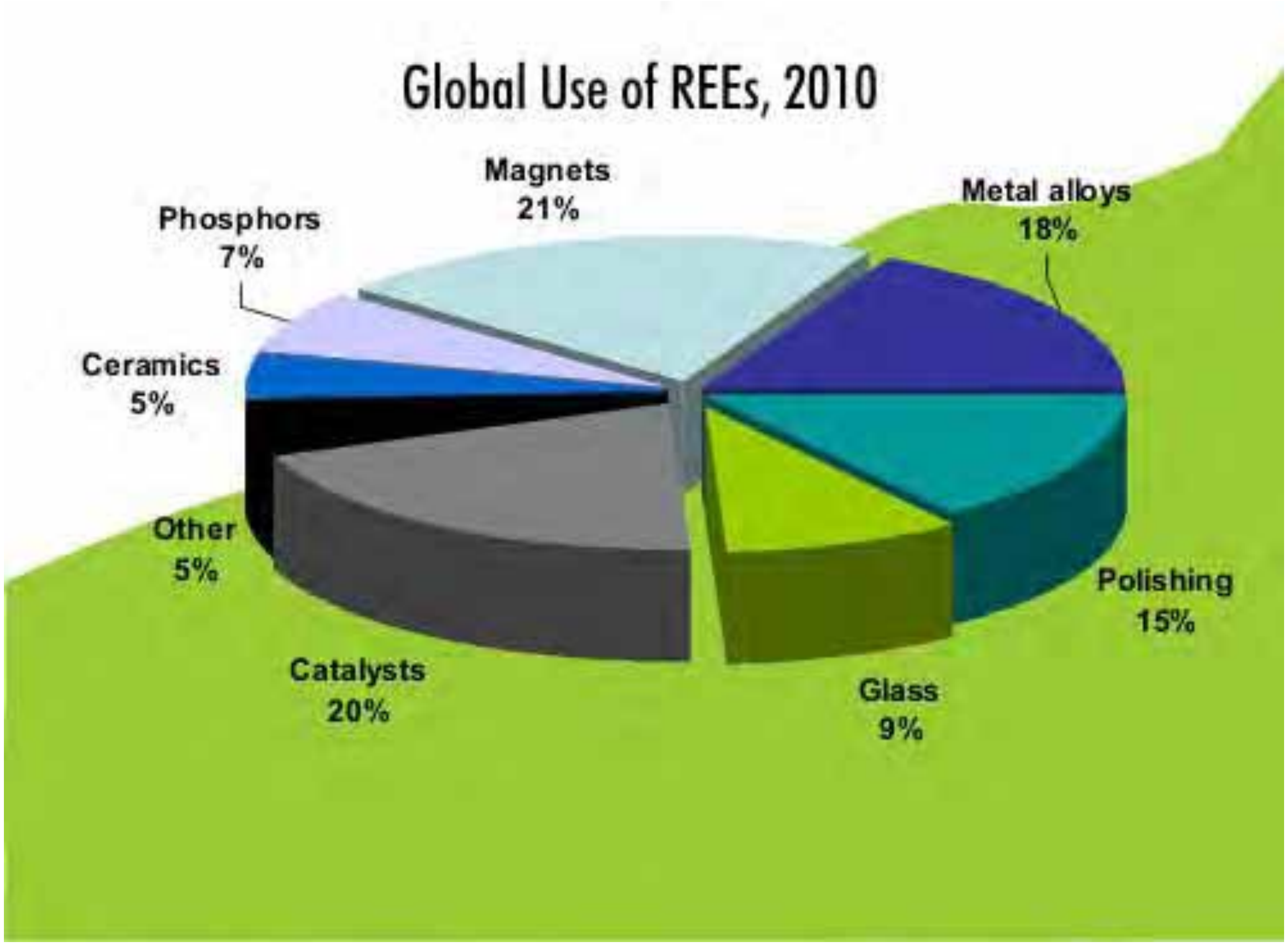
What's in your electric car?



Cobalt & electric cars

- Y•5 RN�T MB �� D�s �Pt
- ..55 O MINTB ��P L
- ...555 555 |TBL T��T
- �P�L�B | CPT�b�, TB Y75 555 |p�

REE & Global Use



REE & High Tech Apps

Z	Symbol	Name	Etymology	Selected applications
21	Sc	Scandium	from Latin *Scandia* (Scandinavia).	Light aluminium-scandium alloys for aerospace components, additive in metal-halide lamps and mercury-vapor lamps,[4] radioactive tracing agent in oil refineries
39	Y	Yttrium	after the village of Ytterby, Sweden, where the first rare earth ore was discovered.	Yttrium aluminium garnet (YAG) laser, yttrium vanadate (YVO_4) as host for europium in TV red phosphor, YBCO high-temperature superconductors, yttria-stabilized zirconia (YSZ), yttrium iron garnet (YIG) microwave filters,[4] energy-efficient light bulbs,[5] spark plugs, gas mantles, additive to steel
57	La	Lanthanum	from the Greek "lanthanein", meaning *to be hidden*.	High refractive index and alkali-resistant glass, flint, hydrogen storage, battery-electrodes, camera lenses, fluid catalytic cracking catalyst for oil refineries
58	Ce	Cerium	after the dwarf planet Ceres, named after the Roman goddess of agriculture.	Chemical oxidizing agent, polishing powder, yellow colors in glass and ceramics, catalyst for self-cleaning ovens, fluid catalytic cracking catalyst for oil refineries, ferrocerium flints for lighters
59	Pr	Praseodymium	from the Greek "prasios", meaning *leek-green*, and "didymos", meaning *twin*.	Rare-earth magnets, lasers, core material for carbon arc lighting, colorant in glasses and enamels, additive in didymium glass used in welding goggles,[4] ferrocerium firesteel (flint) products.
60	Nd	Neodymium	from the Greek "neos", meaning *new*, and "didymos", meaning *twin*.	Rare-earth magnets, lasers, violet colors in glass and ceramics, didymium glass, ceramic capacitors
61	Pm	Promethium	after the Titan Prometheus, who brought fire to mortals.	Nuclear batteries
62	Sm	Samarium	after mine official, Vasili Samarsky-Bykhovets.	Rare-earth magnets, lasers, neutron capture, masers
63	Eu	Europium	after the continent of Europe.	Red and blue phosphors, lasers, mercury-vapor lamps, fluorescent lamps, NMR relaxation agent
64	Gd	Gadolinium	after Johan Gadolin (1760–1852), to honor his investigation of rare earths.	Rare-earth magnets, high refractive index glass or garnets, lasers, X-ray tubes, computer memories, neutron capture, MRI contrast agent, NMR relaxation agent, magnetostrictive alloys such as Galfenol, steel additive
65	Tb	Terbium	after the village of Ytterby, Sweden.	Green phosphors, lasers, fluorescent lamps, magnetostrictive alloys such as Terfenol-D
66	Dy	Dysprosium	from the Greek "dysprositos", meaning *hard to get*.	Rare-earth magnets, lasers, magnetostrictive alloys such as Terfenol-D
67	Ho	Holmium	after Stockholm (in Latin, "Holmia"), native city of one of its discoverers.	Lasers, wavelength calibration standards for optical spectrophotometers, magnets
68	Er	Erbium	after the village of Ytterby, Sweden.	Infrared lasers, vanadium steel, fiber-optic technology
69	Tm	Thulium	after the mythological northern land of Thule.	Portable X-ray machines, metal-halide lamps, lasers
70	Yb	Ytterbium	after the village of Ytterby, Sweden.	Infrared lasers, chemical reducing agent, decoy flares, stainless steel, stress gauges, nuclear medicine
71	Lu	Lutetium	after Lutetia, the city that later became Paris.	Positron emission tomography – PET scan detectors, high-refractive-index glass, lutetium tantalate hosts for phosphors

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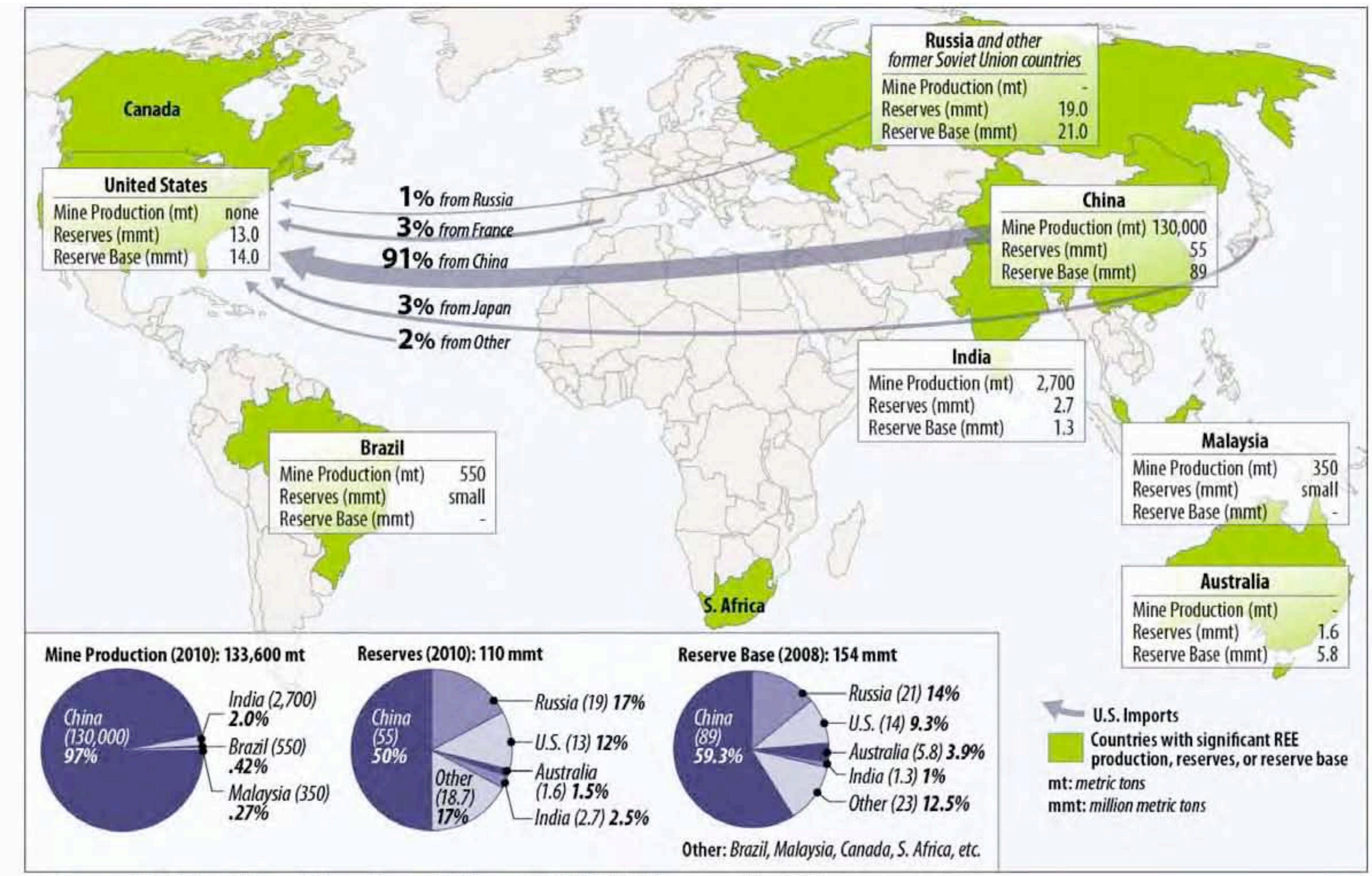
UNIVERSIDADE DE LISBOA

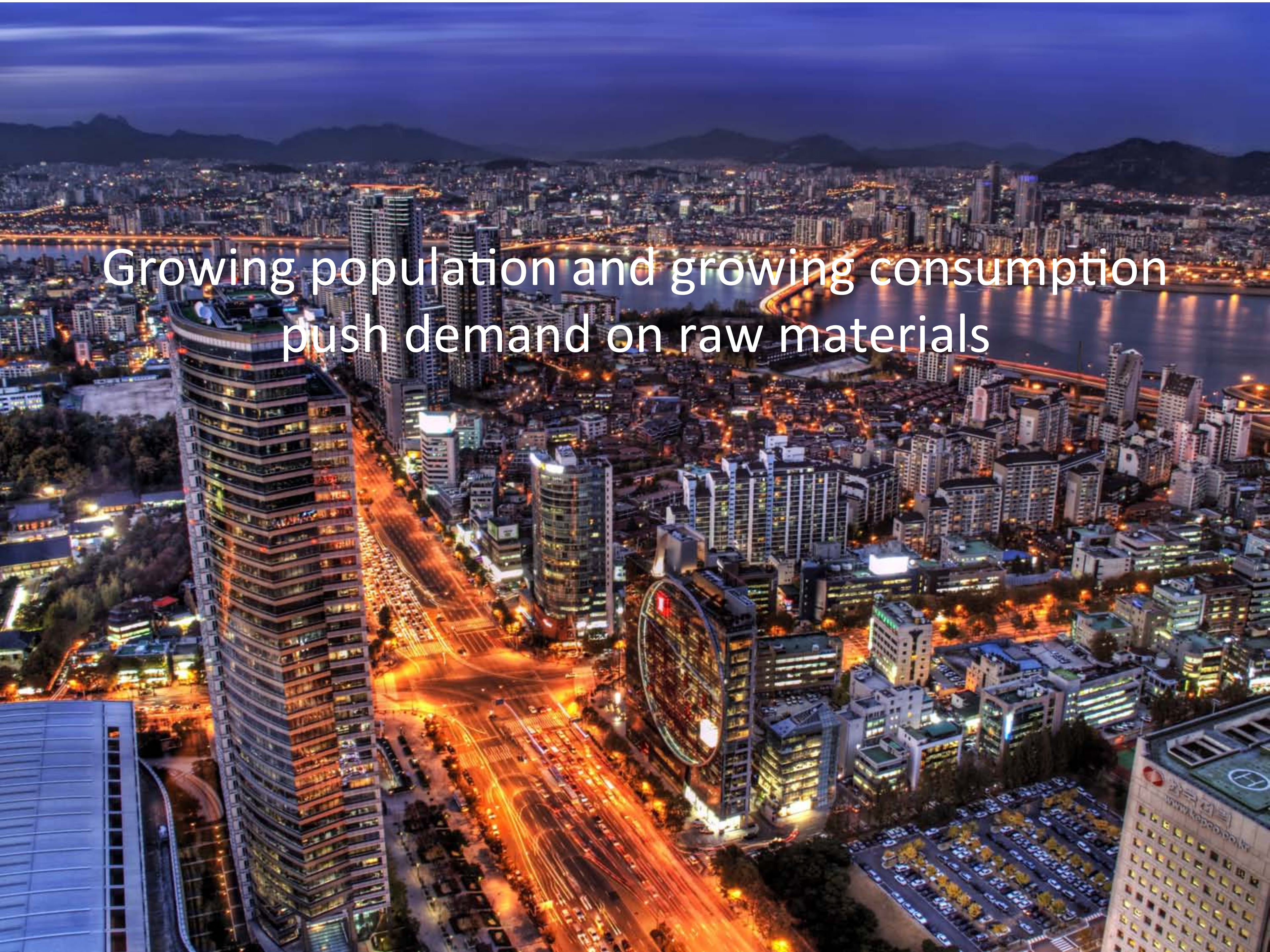
Resource scare 2011

- China produced 97% of the rare earths (La, Ce…)
- (also: much W and Mo; South Africa: 95% of PGE)

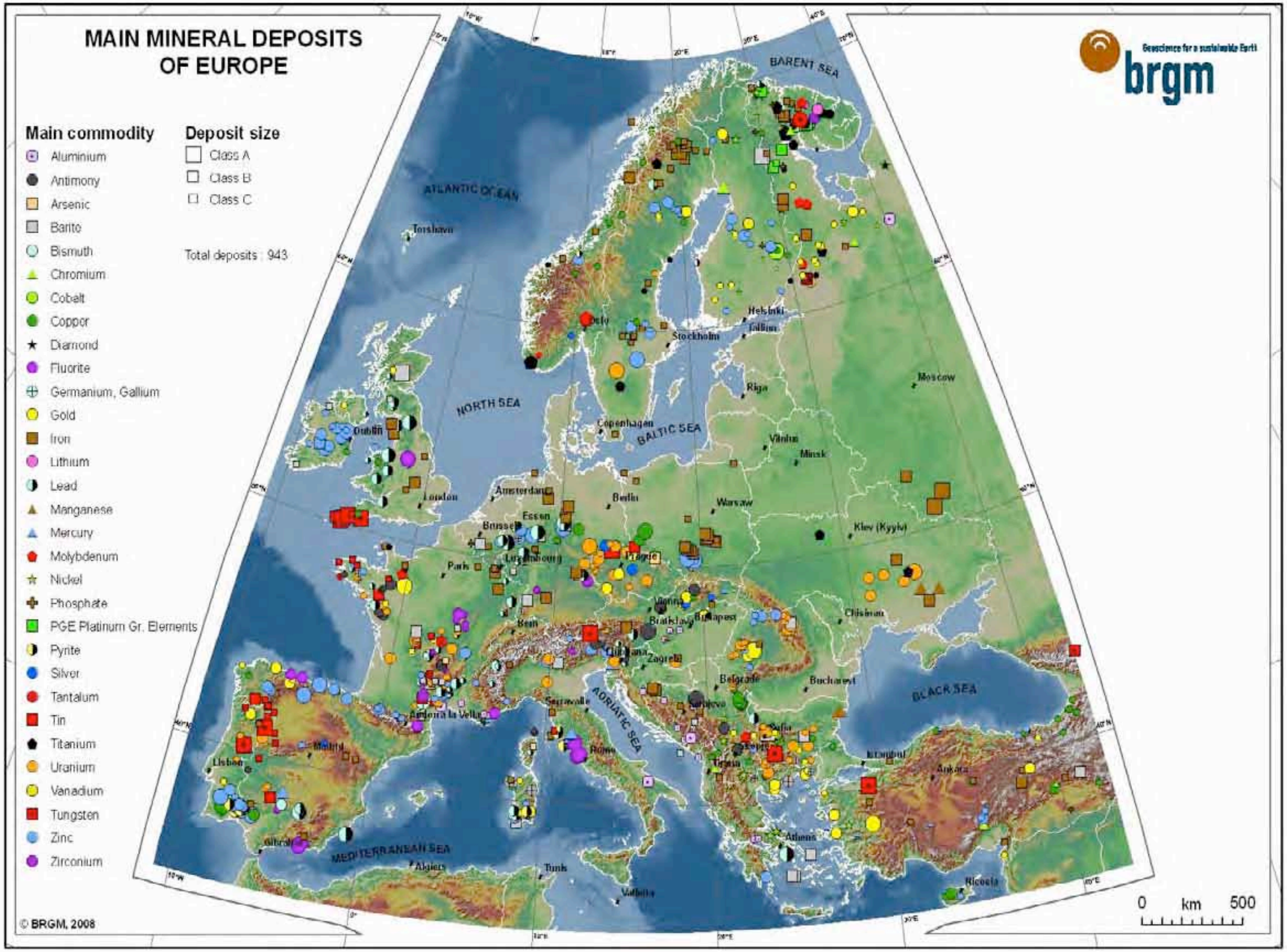


Source: U.S. Geological Survey, Mineral Commodity Summaries, 2008-2011. (Figure created by CRS.)

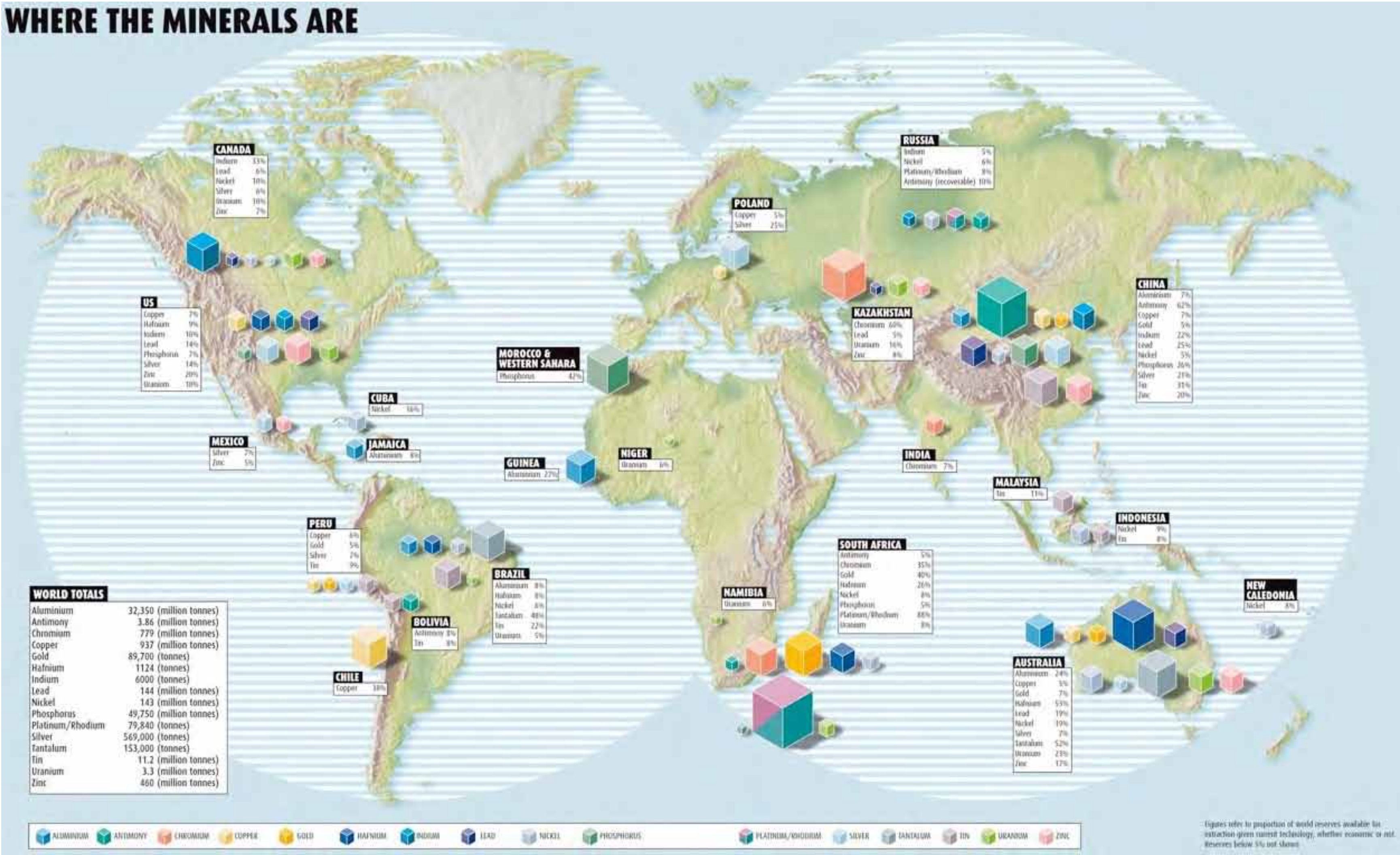
Growing population and growing consumption push demand on raw materials



Europe: a mining past



Europe: alarm bells



Europe: alarm bells

- Europe produces only 3% of its total metal consumption
- Urgent action needed!

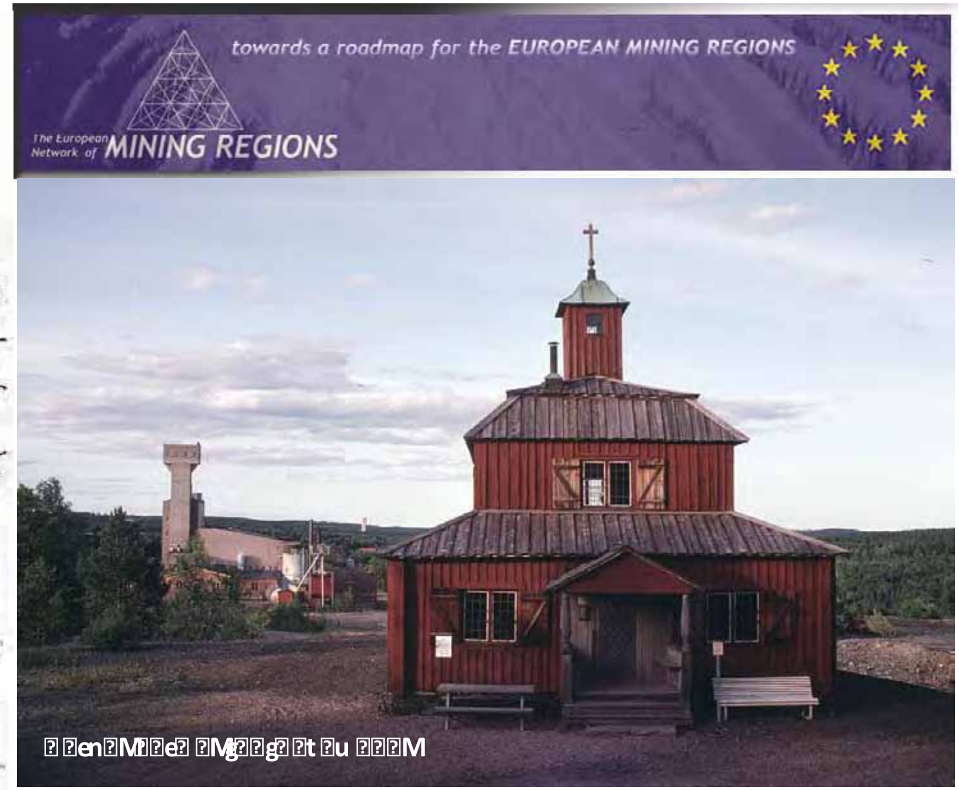
Europe: alarm bells

Antimony	**Beryllium**	**Borates**	**Chromium**	**Cobalt**	**Coking coal**	**Fluorspar**
Gallium	**Germanium**	**Indium**	**Magnesite**	**Magnesium**	**Natural Graphite**	**Niobium**
PGMs	**Phosphate Rock**	**REEs (Heavy)**	**REEs (Light)**	**Silicon Metal**	**Tungsten**	

This 2013 list includes thirteen of the fourteen materials identified in the previous report, with only tantalum (due to a lower supply risk) moving out of the EU critical material list. Six new materials enter the list: borates, chromium, coking coal, magnesite, phosphate rock and silicon metal. Three of these are entirely new to the report. None of the biotic materials were classified as critical. Whilst this analysis highlights the criticality of certain materials from the EU perspective, limitations and uncertainties with data, and the report's scope should be taken into consideration when discussing this list. It is worth recalling that all raw materials, even when not critical, are important for the European economy and therefore not being critical does not imply that a given raw material and its availability to the European economy should be neglected. Moreover the availability of new data may affect the list in the future; therefore the policy actions should not be limited to critical raw materials exclusively. In addition, information for each of the candidate materials is provided by individual material profiles, found in two separate documents attached to this report. Further analysis is provided for the critical raw materials within these profiles.

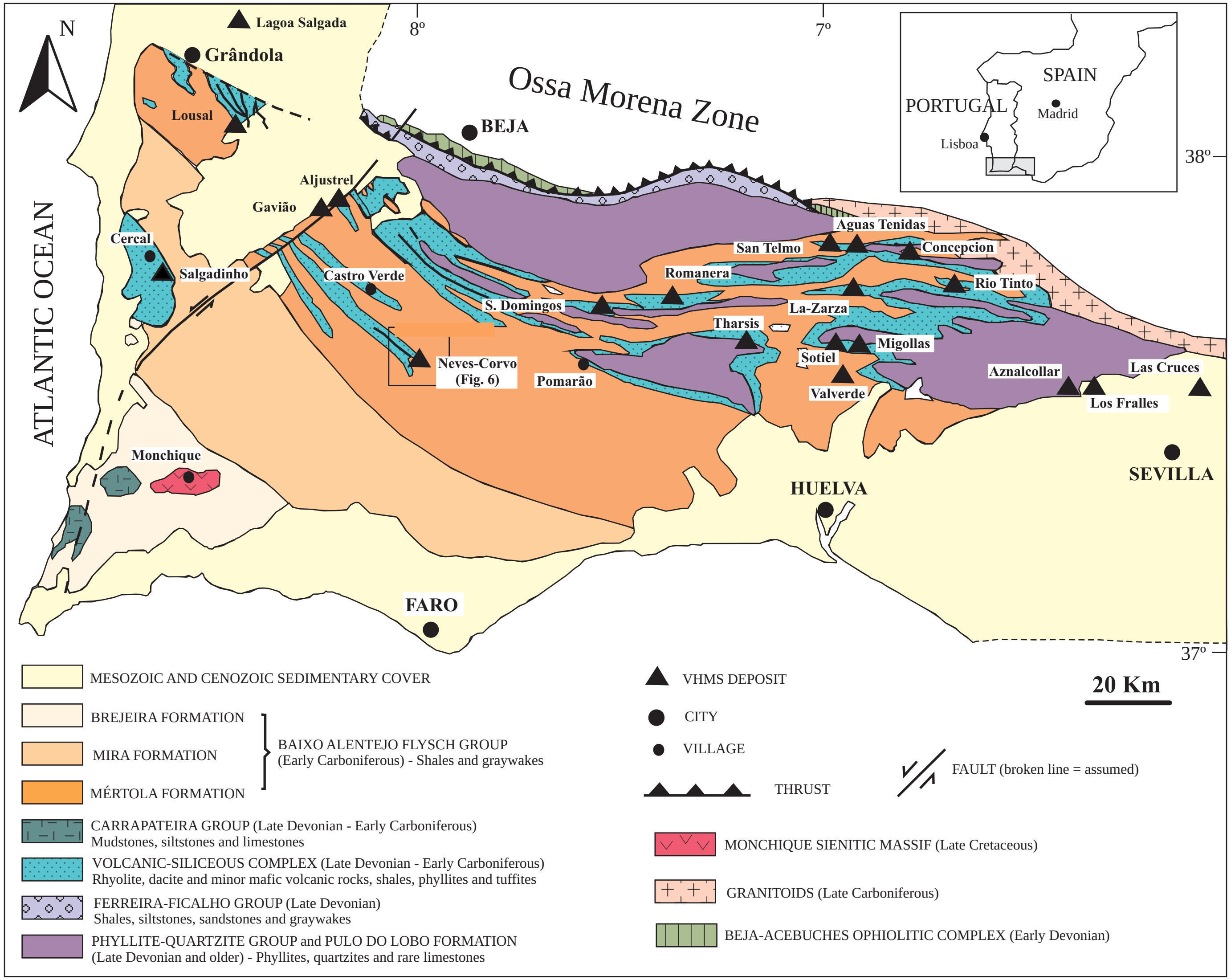
Report on Criticakl Raw Materials for the EU, May 2014, Ad hoc Group on defining Raw Mareials

Europe: alarm bells



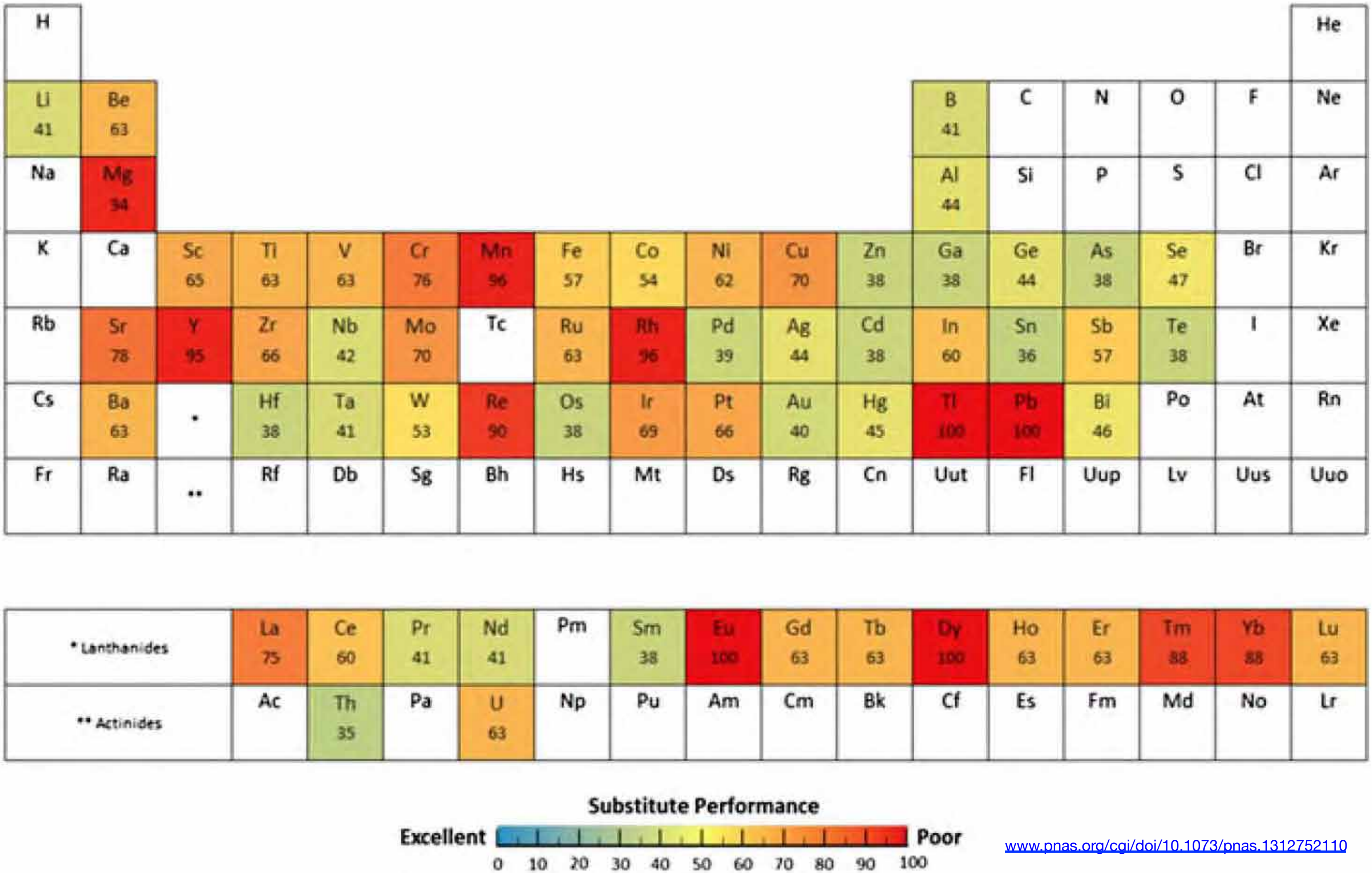
EMRA'15 workshop

Europe: alarm bells

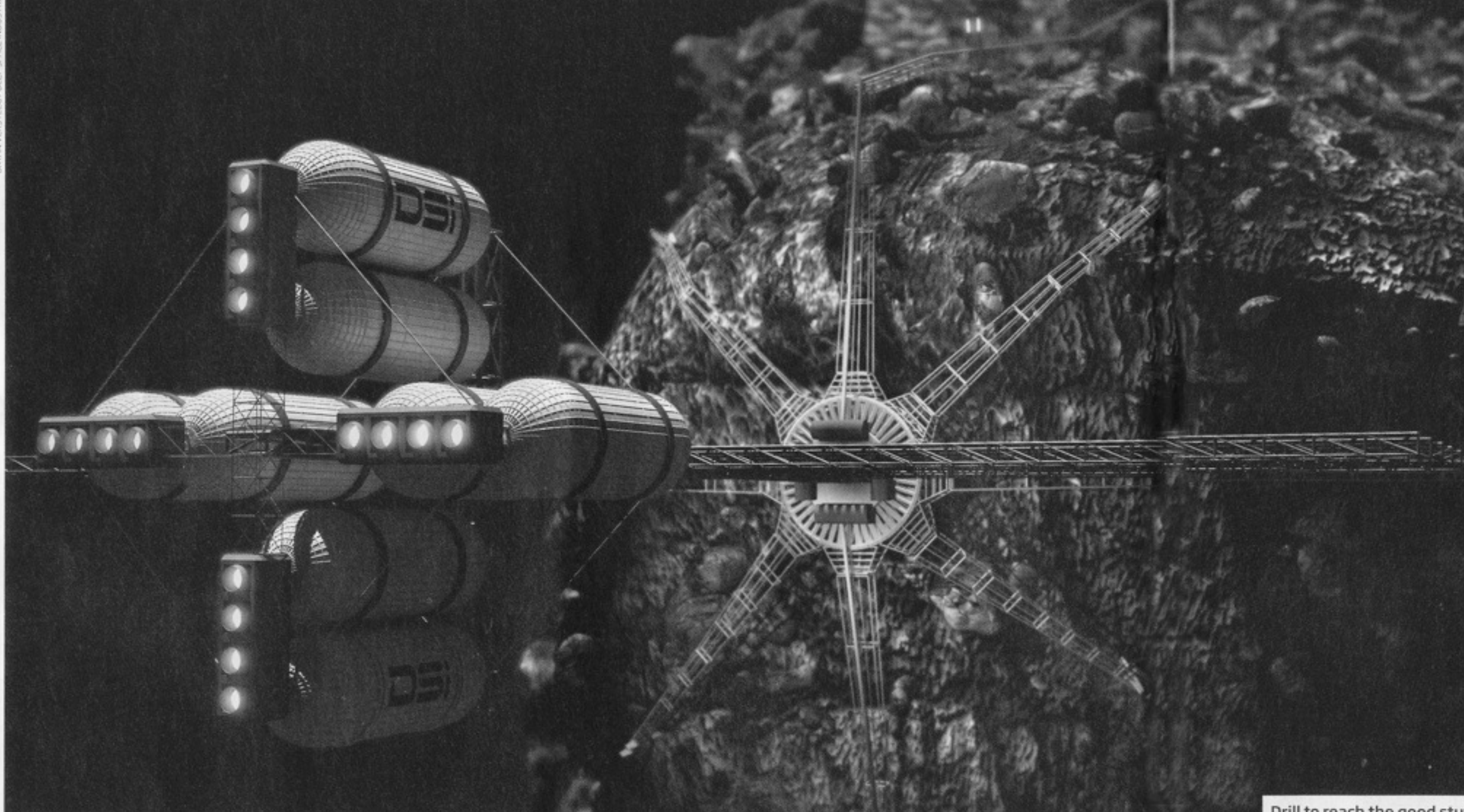


, Reducing, Replacing

Substitute performance



www.pnas.org/cgi/doi/10.1073/pnas.1312752110



Drill to reach the good stuff

BRYAN VERSTEEG / DEEP SPACE INDUSTRIES

Space mining: the next gold rush?

Michael Slezak, Sydney

FOLLOW the money and you will end up in space. That's the message from a first-of-its-kind forum on mining beyond Earth.

Convened last week in Sydney

The forum comes hot on the heels of the unveiling last year of two private asteroid-mining firms. Planetary Resources of Washington says it will launch its first prospecting telescopes in two years, while Deep Space Industries

Within a few decades, these firms may be meeting earthly demands for precious metals, such as platinum and gold, and the rare earth elements vital for personal electronics, such as yttrium and lanthanum. But like the gold rush pioneers who transformed the western US, the first space miners won't just enrich themselves. They also hope to build an off-planet economy free of any bonds with Earth, in which the materials extracted and

a kilogram of gold or a kilogram of water?" asks Kris Zacny of HoneyBee Robotics in New York. "Gold is useless. Water will let you live."

Water ice from the moon's poles could be sent to astronauts on the International Space Station for drinking or as a radiation shield. Splitting water into oxygen and hydrogen makes spacecraft fuel, so ice-rich asteroids could become interplanetary refuelling stations.

Companies are eyeing the iron

used in 3D printers to make spare parts or machinery. Others want to turn space dirt into concrete for landing pads, shelters and roads.

"Anything that can be extracted from asteroids and brought back to Earth orbit – provided it can be used – has a value similar to the launch cost of the material it's replacing," says Mark Sonter, one of the founders of Deep Space Industries. Back-of-the-envelope calculations show that a tonne of asteroid dust should be worth

April 24, 2012 9:26 AM

Asteroid mining venture backed by James Cameron, Google CEO Larry Page

Artist's rendition of asteroid mining (Planetary Resources)

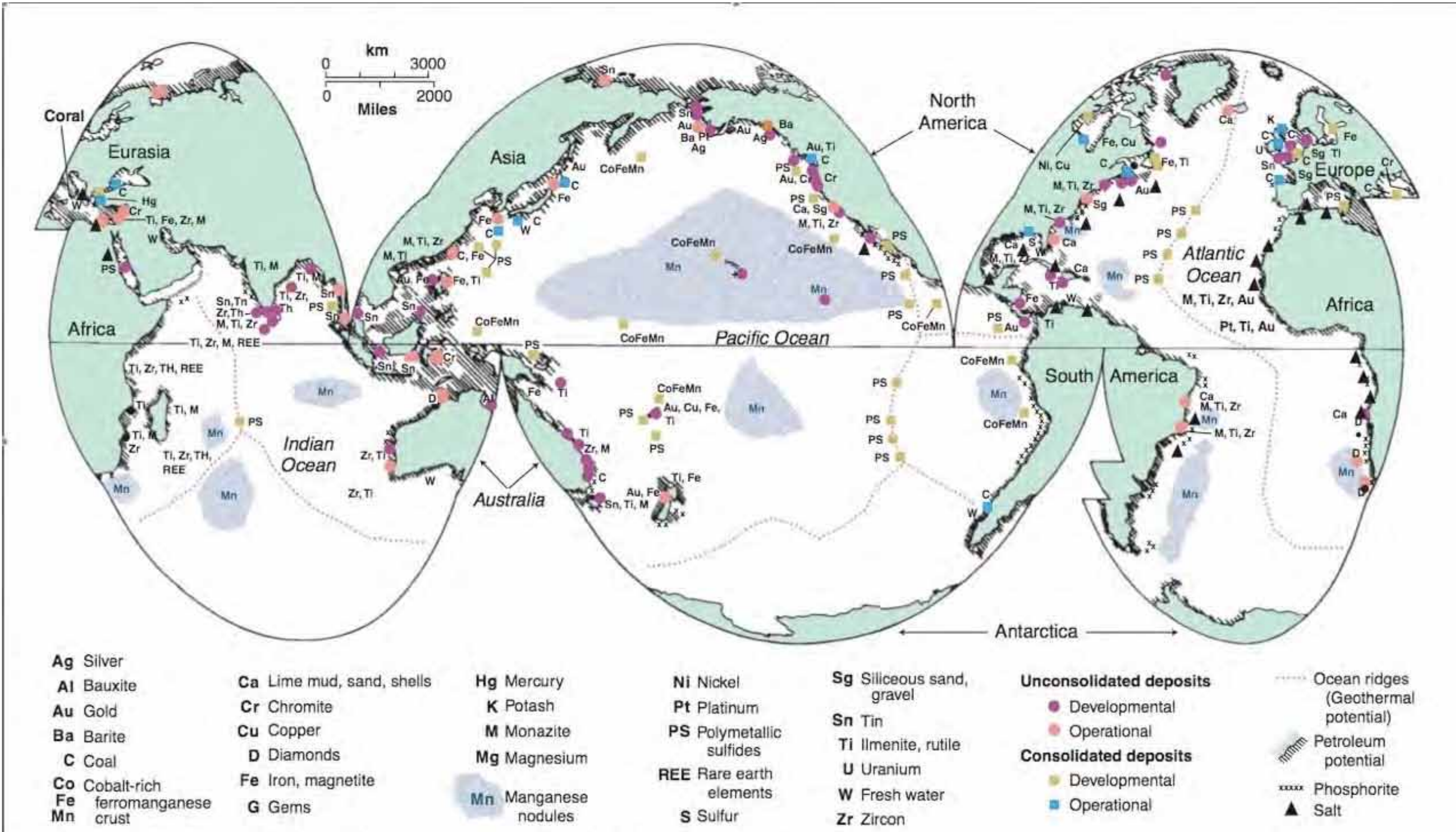
(AP) WASHINGTON - A group of high-tech tycoons wants to mine nearby asteroids, hoping to turn science fiction into real profits.

The mega-million dollar plan is to use commercially built robotic ships to squeeze rocket fuel and valuable minerals like platinum and gold out of the lifeless rocks that routinely whiz by Earth. One of the company founders predicts they could have their version of a space-based gas station up and running by 2020.

The inaugural step, to be achieved in the next 18 to 24 months, would be launching the first in a series of private telescopes that would search for rich asteroid targets.

Several scientists not involved in the project said they were simultaneously thrilled and skeptical, calling the plan daring, difficult - and highly expensive. They struggle to see how it could be cost-effective, even with platinum and gold worth nearly $1,600 an ounce. An upcoming NASA mission

Marine mineral resources

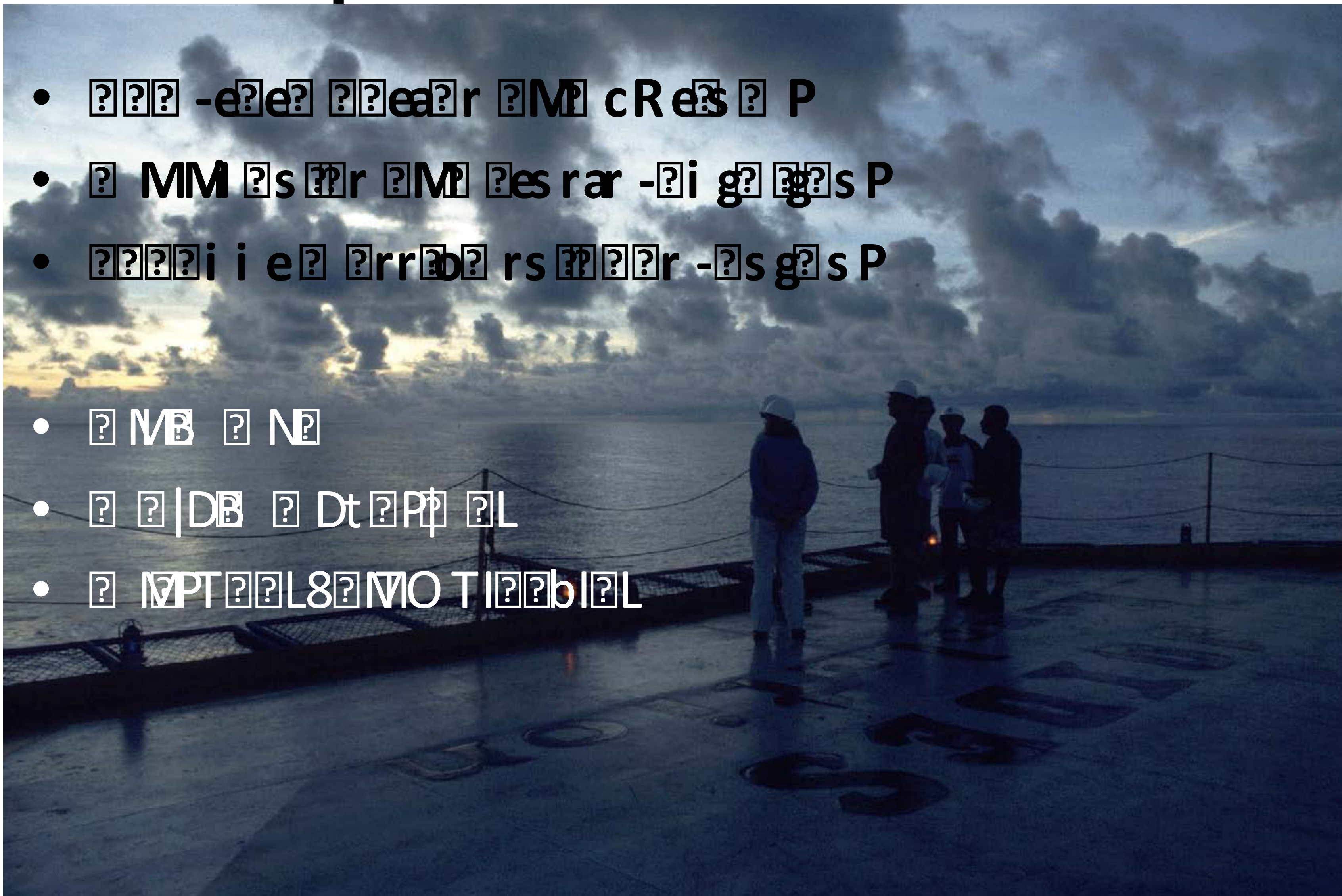


Global distribution of marine mineral resources known at this early stage of ocean exploration.

Erosion of the continents

- Cassiterite (Thailand, Indonesia)
- Gold sands (Alaska, N Zealand, Filipines)
- Diamonds (Namibia, South Africa)
  - <200m depth
  - Value US$ $10^9 \cdot a^{-1}$
- Sand and gravel
  - Construction
  - Beach recovery

Deep sea resources



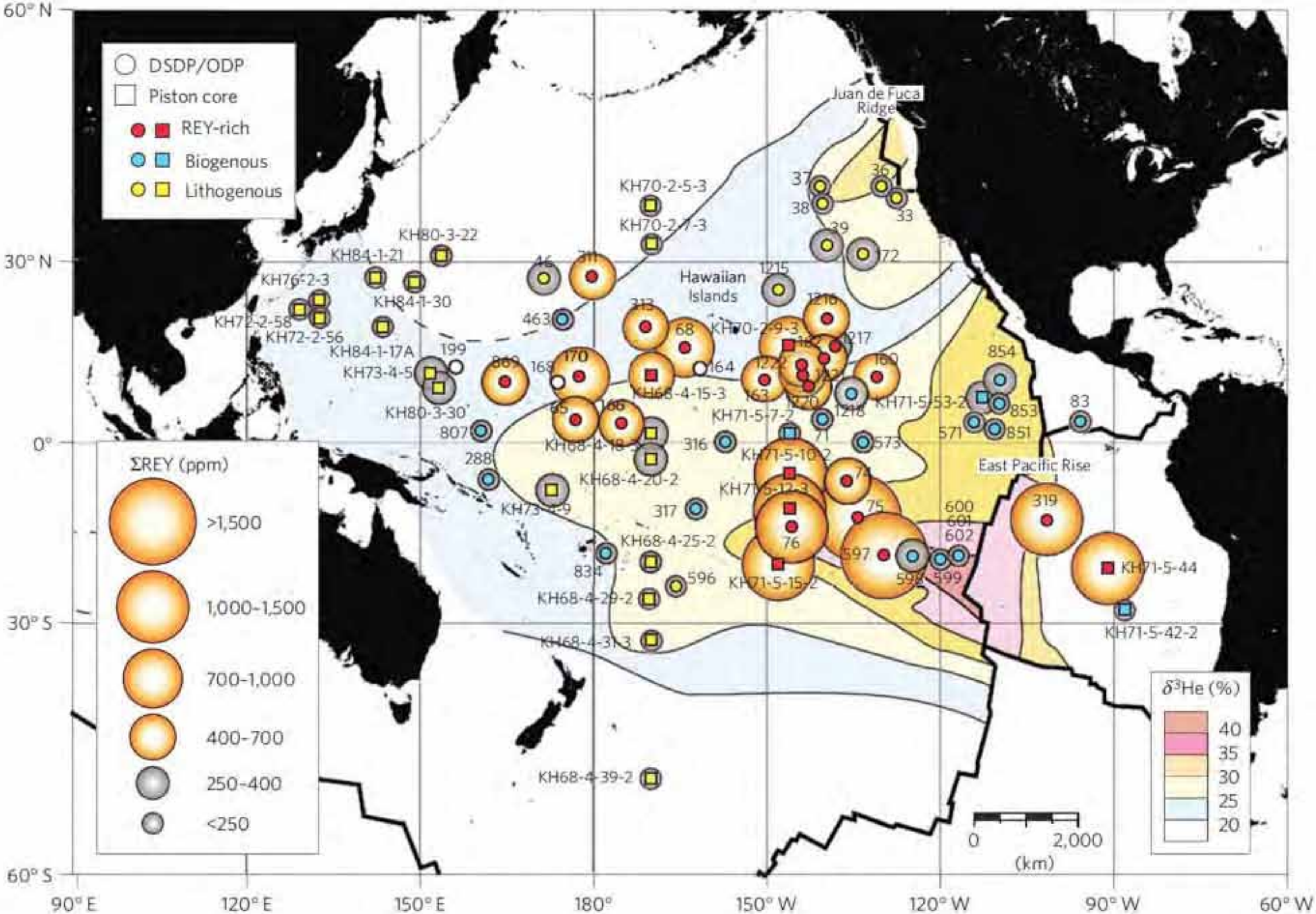
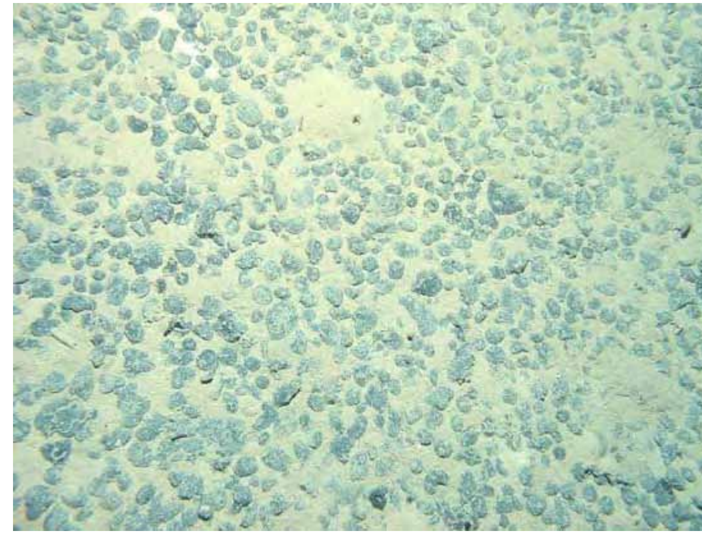
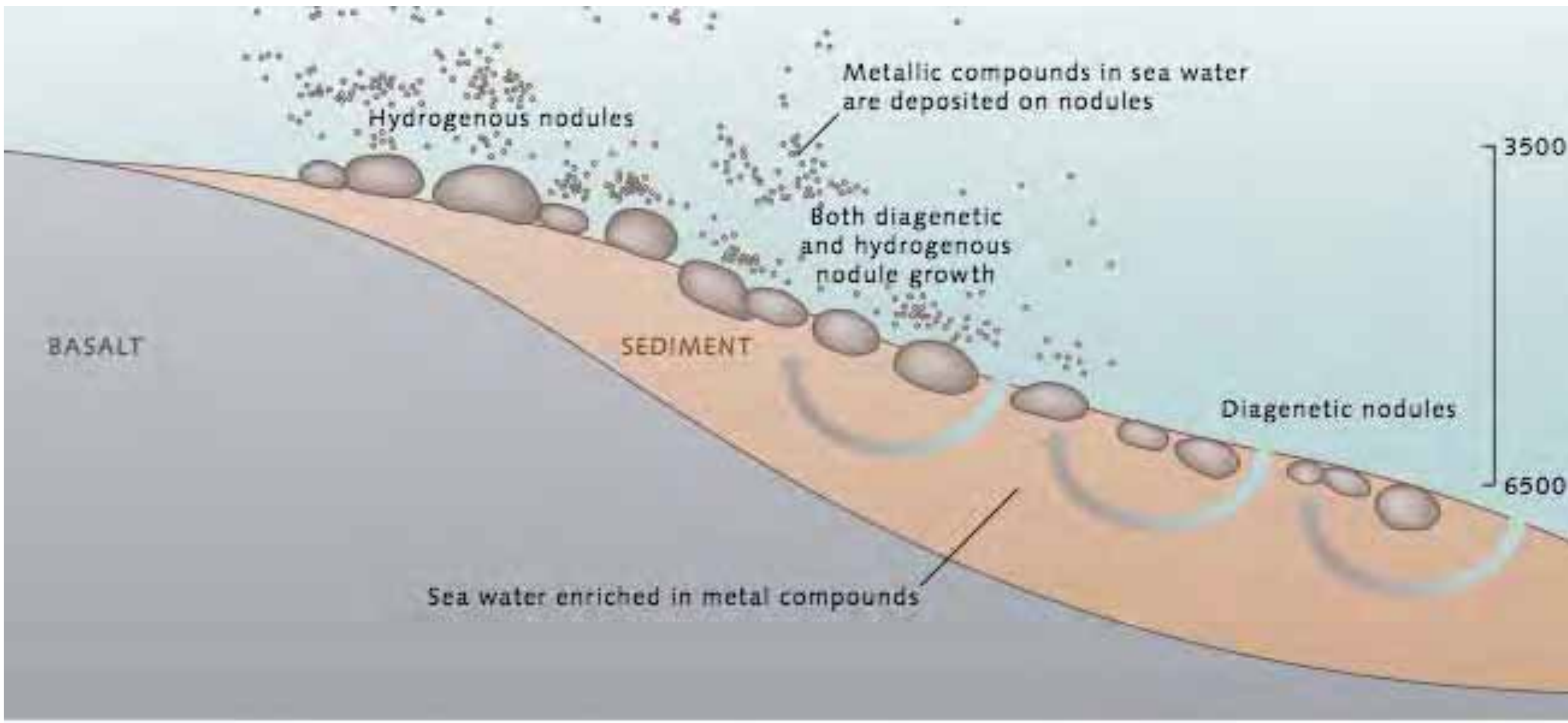


Figure 1 | Distribution of average ΣREY contents for surface sediments (<2 m in depth) in the Pacific Ocean. Circles represent DSDP/ODP sites and squares represent the University of Tokyo piston core sites, with colours corresponding to the dominant origin of surface sediments. Open symbols are sites lacking samples from the sediment surface. Contours represent helium-3 anomalies (δ^3He) of mid-depth seawater[12]. REY-rich mud with average ΣREY >400 ppm is designated as a potential resource in this study.

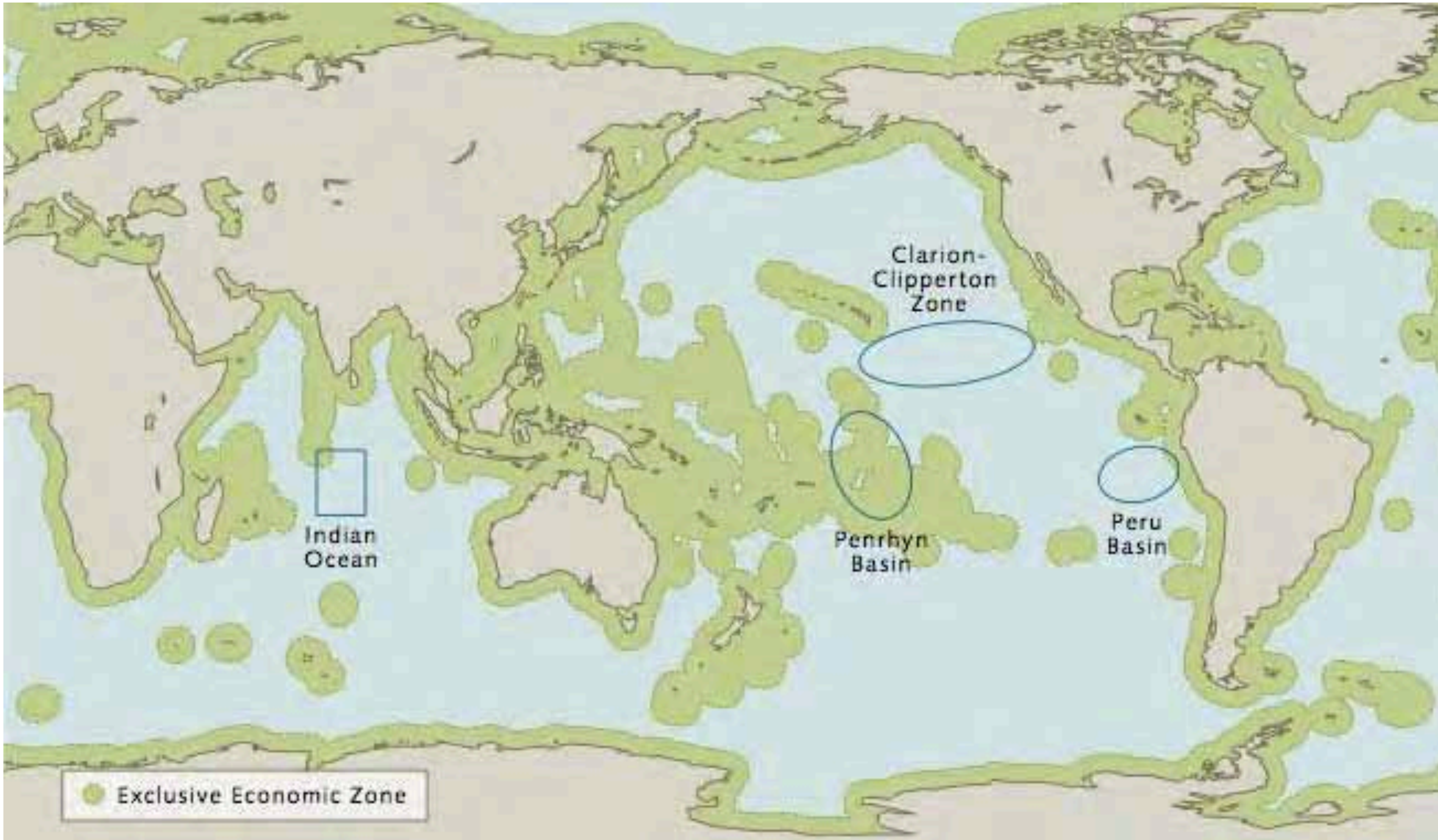
Mn nodules





Metallic compounds in sea water are deposited on nodules
Hydrogenous nodules
3500
Both diagenetic and hydrogenous nodule growth
BASALT
SEDIMENT
Diagenetic nodules
6500
Sea water enriched in metal compounds

Mn nodules


Clarion-
Clipperton
Zone
Indian
Ocean
Penrhyn
Basin
Peru
Basin
Exclusive Economic Zone

Mn nodules

Chemical components of manganese nodules from different marine regions				
Elements	Manganese nodules of the CCZ	Manganese nodules of the Peru Basin	Manganese nodules of the Indian Ocean	Manganese nodules of the Cook Islands area
Manganese (Mn) **	28.4	34.2	24.4	16.1
Iron (Fe) **	6.16	6.12	7.14	16.1
Copper (Cu) *	10,714	5988	10,406	2268
Nickel (Ni) *	13,002	13,008	11,010	3827
Cobalt (Co) *	2098	475	1111	4124
Titanium (Ti) **	0,32	0.16	0.42	1.15
Tellurium (Te) *	3.6	1.7	40	23
Thallium (Tl) *	199	129	347	138
Rare earth elements and yttrium *	813	403	1039	1707
Zirconium (Zr) *	307	325	752	588

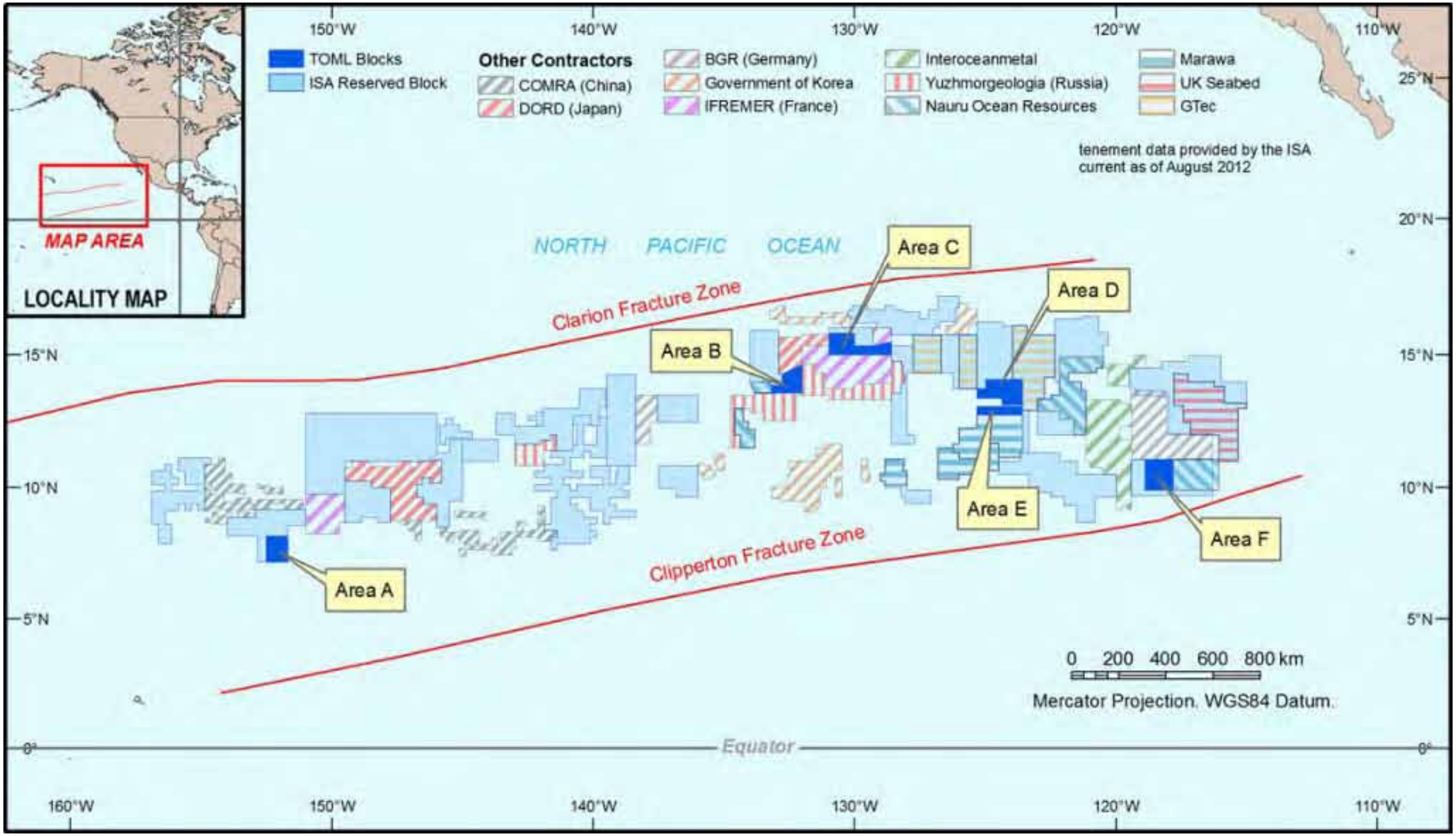
? TP?? ? ???B ???o?Mn k8~5•/
m??LJ ??B N?8???|??PL??B8??bCR??8??T??VNB ? ? ? IOB BH

: CCO
: : n | v

Mn nodules (Co, Ni, Y, Tl)

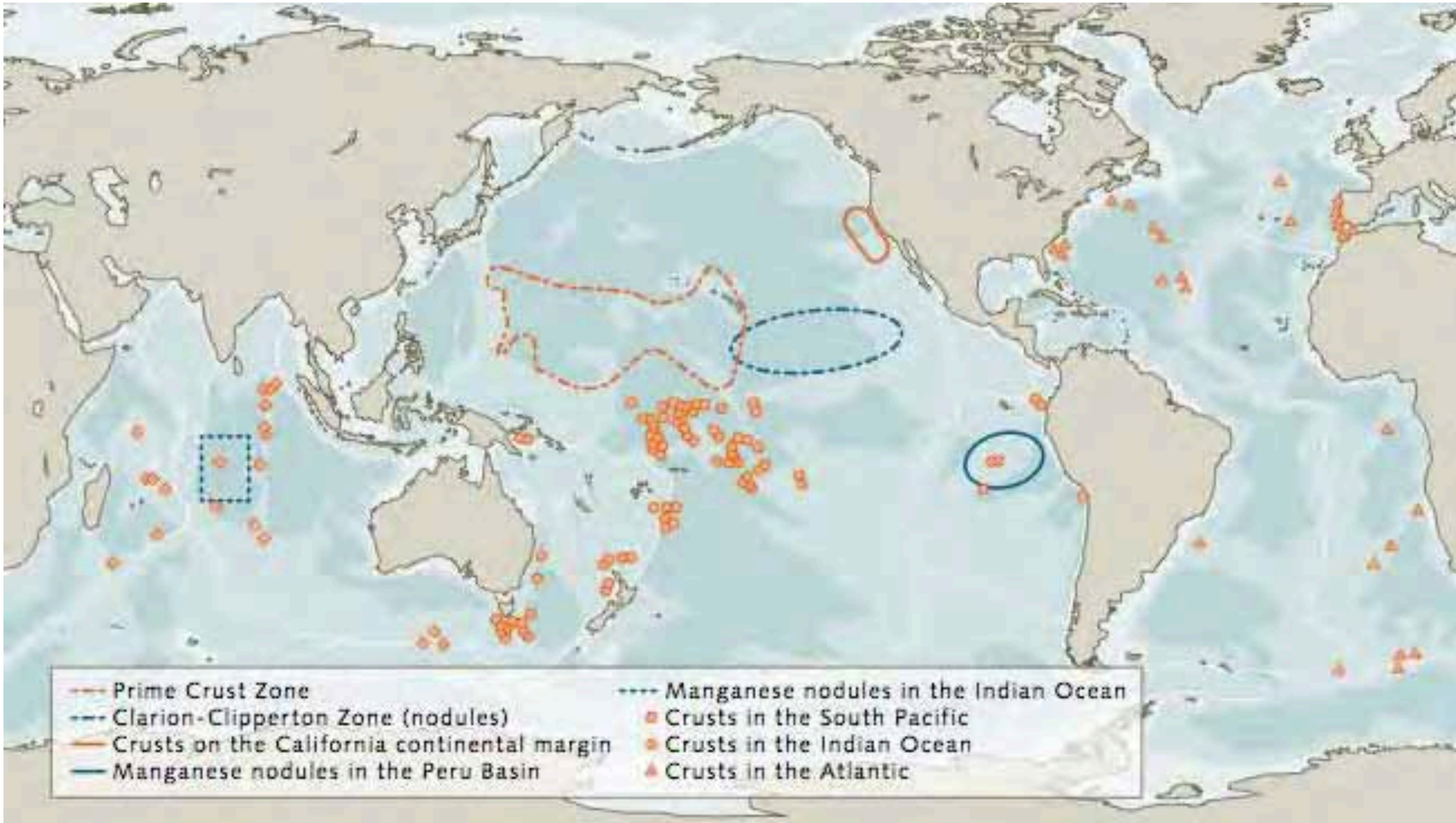
Metal content of manganese nodule occurrences in millions of tonnes			
Elements	Clarion-Clipperton Zone (CCZ)	Global reserves and resources on land (both economically recoverable and sub-economic reserves)	Global reserves on land (economically recoverable reserves today)
Manganese (Mn)	5992	5200	630
Copper (Cu)	226	1000+	690
Titanium (Ti)	67	899	414
Rare earth oxides	15	150	110
Nickel (Ni)	274	150	80
Vanadium (V)	9.4	38	14
Molybdenum (Mo)	12	19	10
Lithium (Li)	2.8	14	13
Cobalt (Co)	44	13	7.5
Tungsten (W)	1.3	6.3	3.1
Niobium (Nb)	0,46	3	3
Arsenic (As)	1.4	1.6	1
Thorium (Th)	0.32	1.2	1.2
Bismuth (Bi)	0.18	0.7	0.3
Yttrium (Y)	2	0.5	0.5
Platinum group metals	0.003	0.08	0.07
Tellurium (Te)	0.08	0.05	0.02
Thallium (Tl)	4.2	0.0007	0.0004

Mn nodules



LOCALITY MAP
MAP AREA
TOML Blocks
ISA Reserved Block
Other Contractors
COMRA (China)
DORD (Japan)
BGR (Germany)
Government of Korea
IFREMER (France)
Interoceanmetal
Yuzhmorgeologia (Russia)
Nauru Ocean Resources
Marawa
UK Seabed
GTec
tenement data provided by the ISA
current as of August 2012
NORTH PACIFIC OCEAN
Clarion Fracture Zone
Clipperton Fracture Zone
Area A
Area B
Area C
Area D
Area E
Area F
0 200 400 600 800 km
Mercator Projection. WGS84 Datum.
Equator
160°W
150°W
140°W
130°W
120°W
110°W
25°N
20°N
15°N
10°N
5°N
0°

Polymetallic crusts



TP B oMn k8~5•/

mLJ B N8|PLB8bCR8TMNB IOB BH

Polymetallic crusts

Metal contents in millions of tonnes				
Elements	Cobalt crusts in the Prime Crust Zone (PCZ)	Global reserves on land (economically minable deposits today)	Global reserves and resources on land (economically minable as well as sub-economic deposits)	Manganese nodules in the Clarion-Clipperton Zone
Manganese (Mn)	1714	630	5200	5992
Copper (Cu)	7.4	690	1000+	226
Titanium (Ti)	88	414	899	67
Rare earth oxides	16	110	150	15
Nickel (Ni)	32	80	150	274
Vanadium (V)	4.8	14	38	9.4
Molybdenum (Mo)	3.5	10	19	12
Lithium (Li)	0.02	13	14	2.8
Cobalt (Co)	50	7.5	13	44
Tungsten (W)	0.67	3.1	6.3	1.3
Niobium (Nb)	0.4	3	3	0.46
Arsenic (As)	2.9	1	1.6	1.4
Thorium (Th)	0.09	1.2	1.2	0.32
Bismuth (Bi)	0.32	0.3	0.7	0.18
Yttrium (Y)	1.7	0.5	0.5	2
Platinum group	0.004	0.07	0.08	0.003
Tellurium (Te)	0.45	0.02	0.05	0.08
Thallium (Tl)	1.2	0.0004	0.0007	4.2

sms environments

- [illegible]
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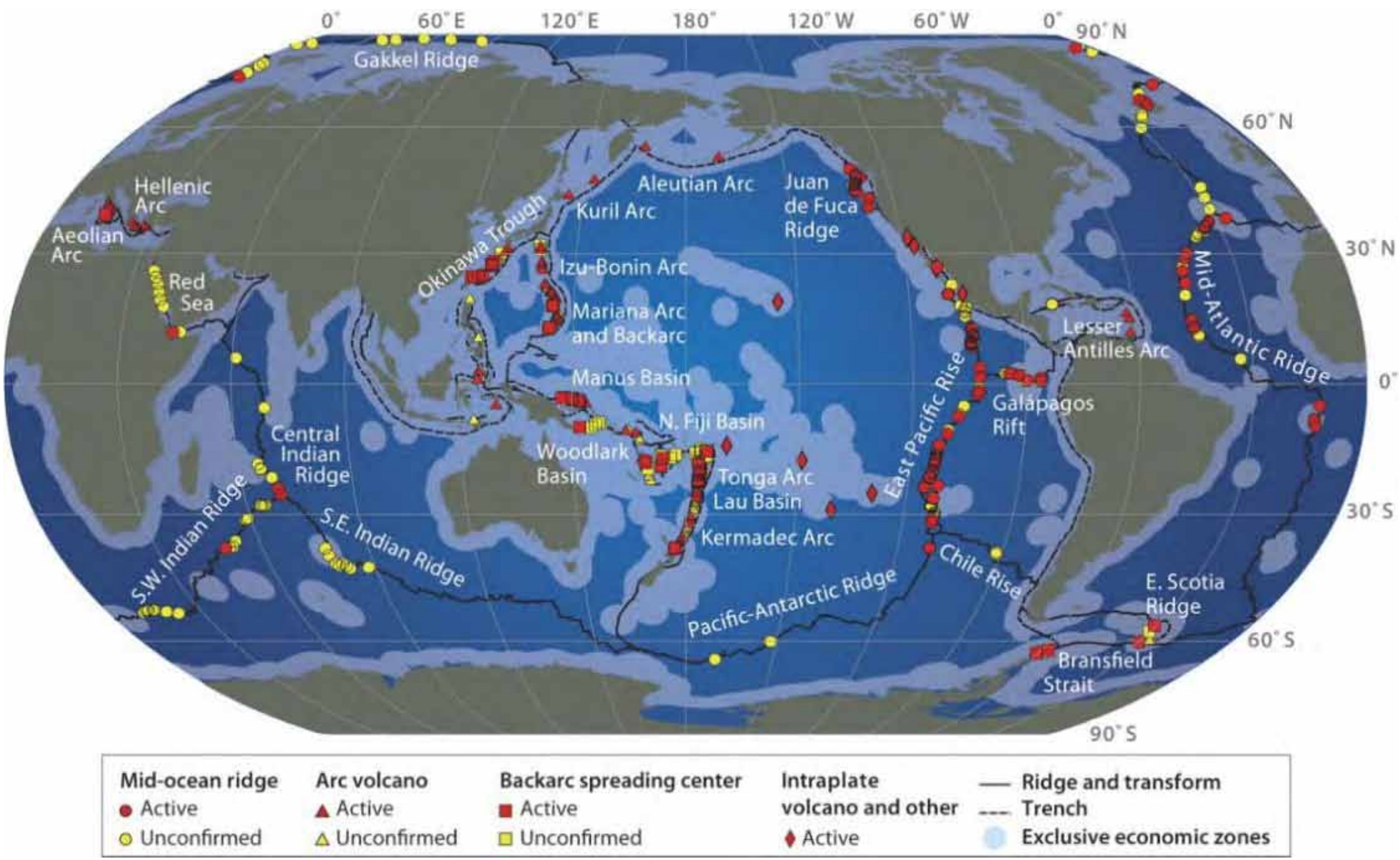
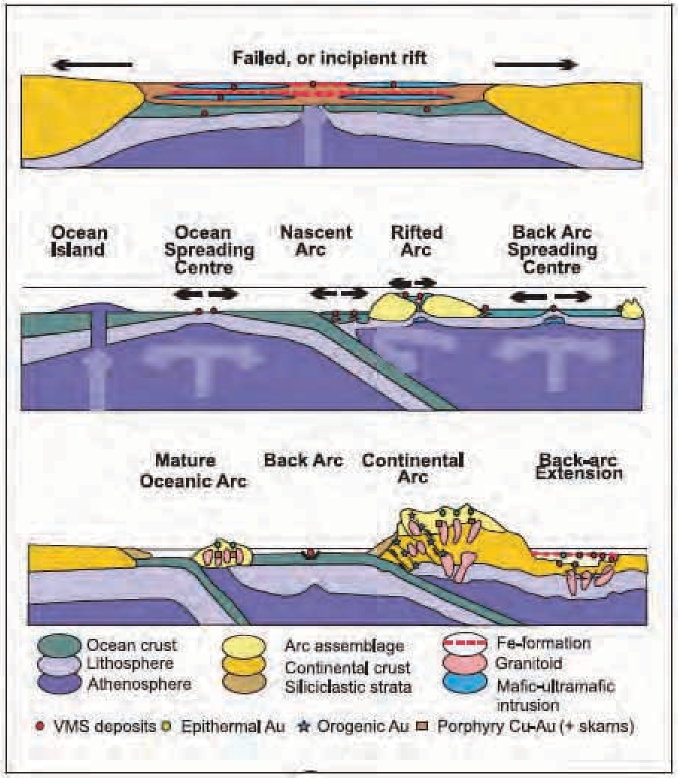
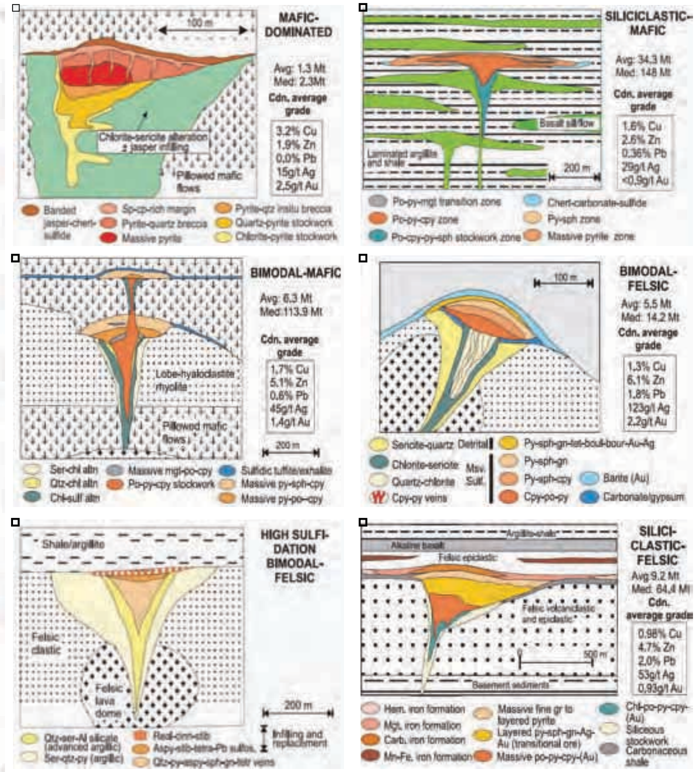
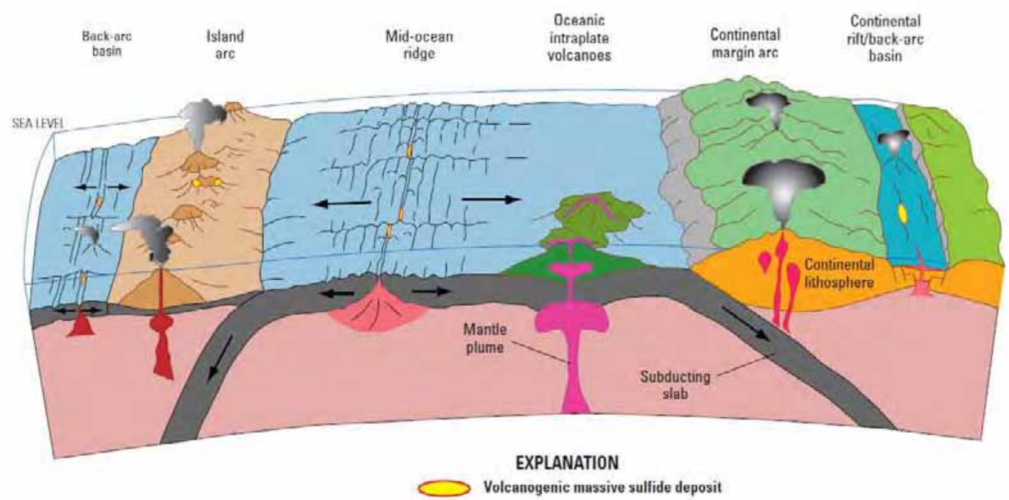
Modern SMS Systems



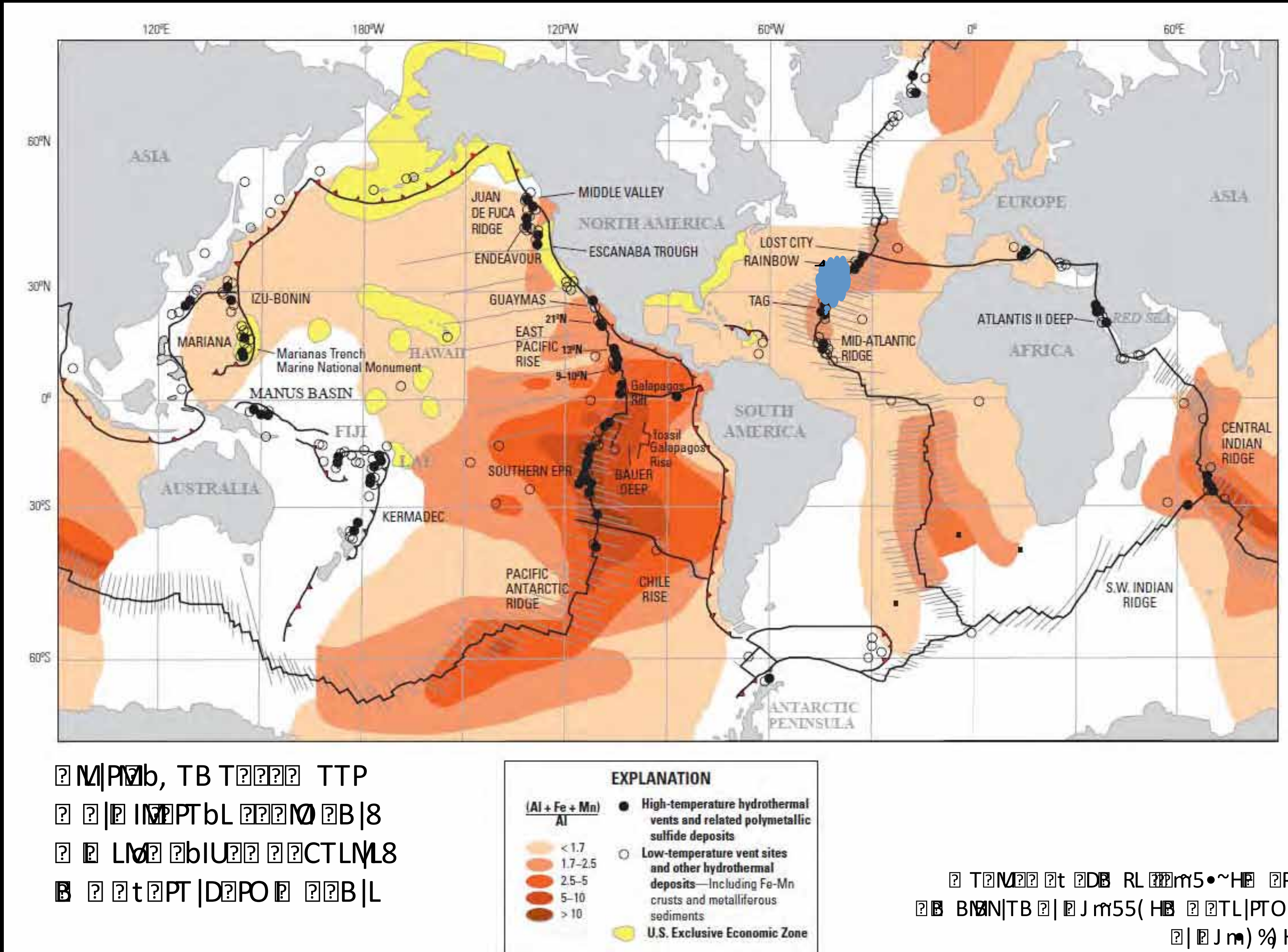
(Elosta, 2014)


Failed, or incipient rift
Ocean Island
Ocean Spreading Centre
Nascent Arc
Rifted Arc
Back Arc Spreading Centre
Mature Oceanic Arc
Back Arc
Continental Arc
Back-arc Extension
Ocean crust
Lithosphere
Athenosphere
Arc assemblage
Continental crust
Siliciclastic strata
Fe-formation
Granitoid
Mafic-ultramafic intrusion
VMS deposits
Epithermal Au
Orogenic Au
Porphyry Cu-Au (+ skarns)


MAFIC-DOMINATED
Avg: 1.3 Mt
Med: 2.3Mt
Cdn. average grade
3.2% Cu
1.9% Zn
0.0% Pb
15g/t Ag
2.5g/t Au
SILICICLASTIC-MAFIC
Avg: 34.3 Mt
Med: 148 Mt
Cdn. average grade
1.6% Cu
2.6% Zn
0.36% Pb
29g/t Ag
<0.9g/t Au
BIMODAL-MAFIC
Avg: 6.3 Mt
Med: 113.9 Mt
Cdn. average grade
1.7% Cu
5.1% Zn
0.6% Pb
45g/t Ag
1.4g/t Au
BIMODAL-FELSIC
Avg: 5.5 Mt
Med: 14.2 Mt
Cdn. average grade
1.3% Cu
6.1% Zn
1.8% Pb
123g/t Ag
2.2g/t Au
HIGH SULFIDATION BIMODAL-FELSIC
SILICI-CLASTIC-FELSIC
Avg 9.2 Mt
Med: 64.4 Mt
Cdn. average grade
0.98% Cu
4.7% Zn
2.0% Pb
53g/t Ag
0.93g/t Au


Back-arc basin
Island arc
Mid-ocean ridge
Oceanic intraplate volcanoes
Continental margin arc
Continental rift/back-arc basin
SEA LEVEL
Continental lithosphere
Mantle plume
Subducting slab
EXPLANATION
Volcanogenic massive sulfide deposit

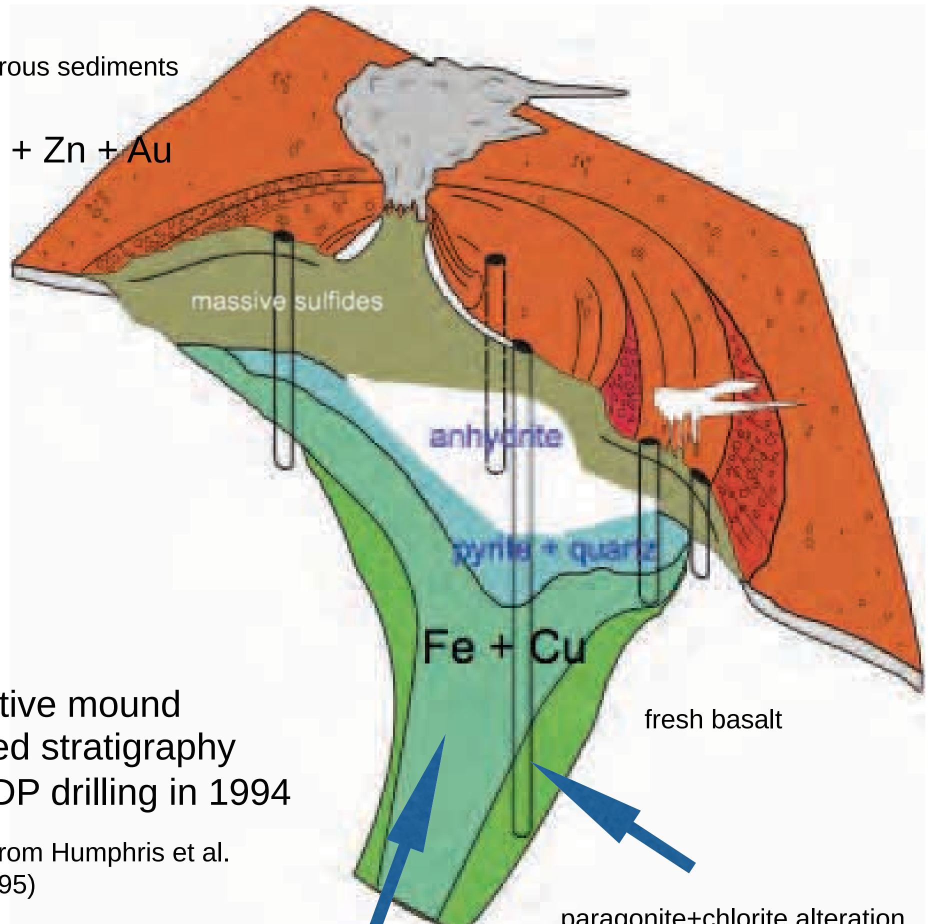
VMS Mineralization at the Modern Seafloor



TAG

metalliferous sediments

Cu + Zn + Au



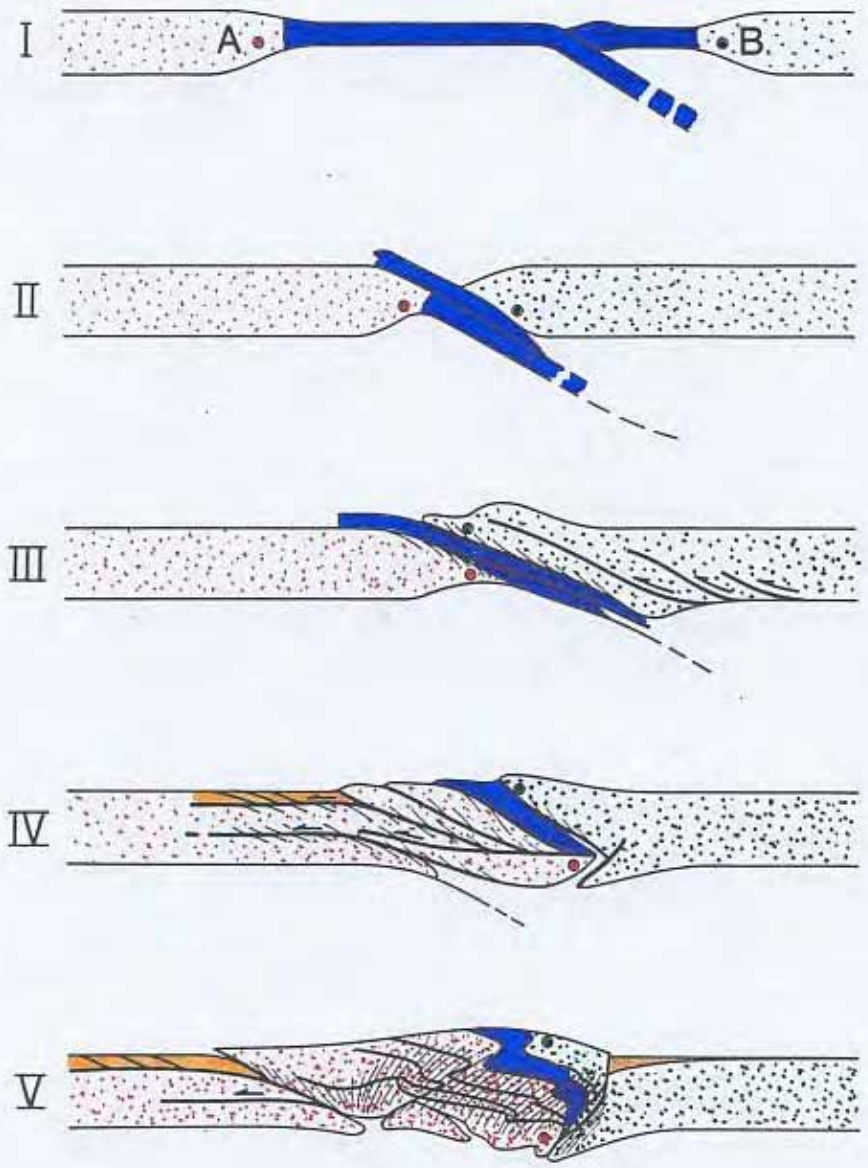
silicified wallrock breccias

TAG active mound simplified stratigraphy from ODP drilling in 1994

(modified from Humphris et al. Nature, 1995)

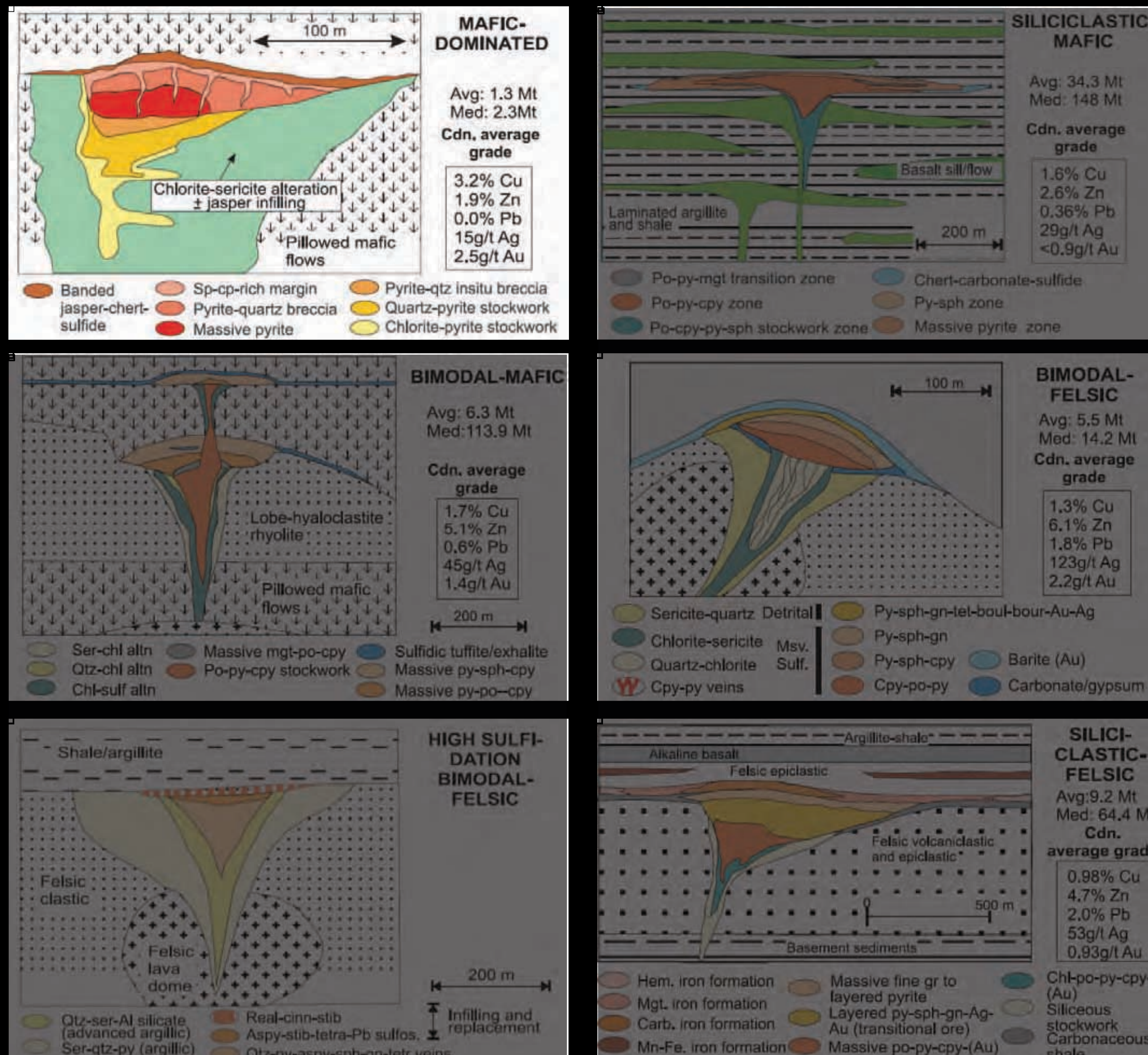
	surface (n=120)	ODP (n=95)
Cu (wt.%)	7.4	2.1
Zn	12.1	0.6
Au (ppm)	3.1	0.5
Ag	173	8
Pb	316	72

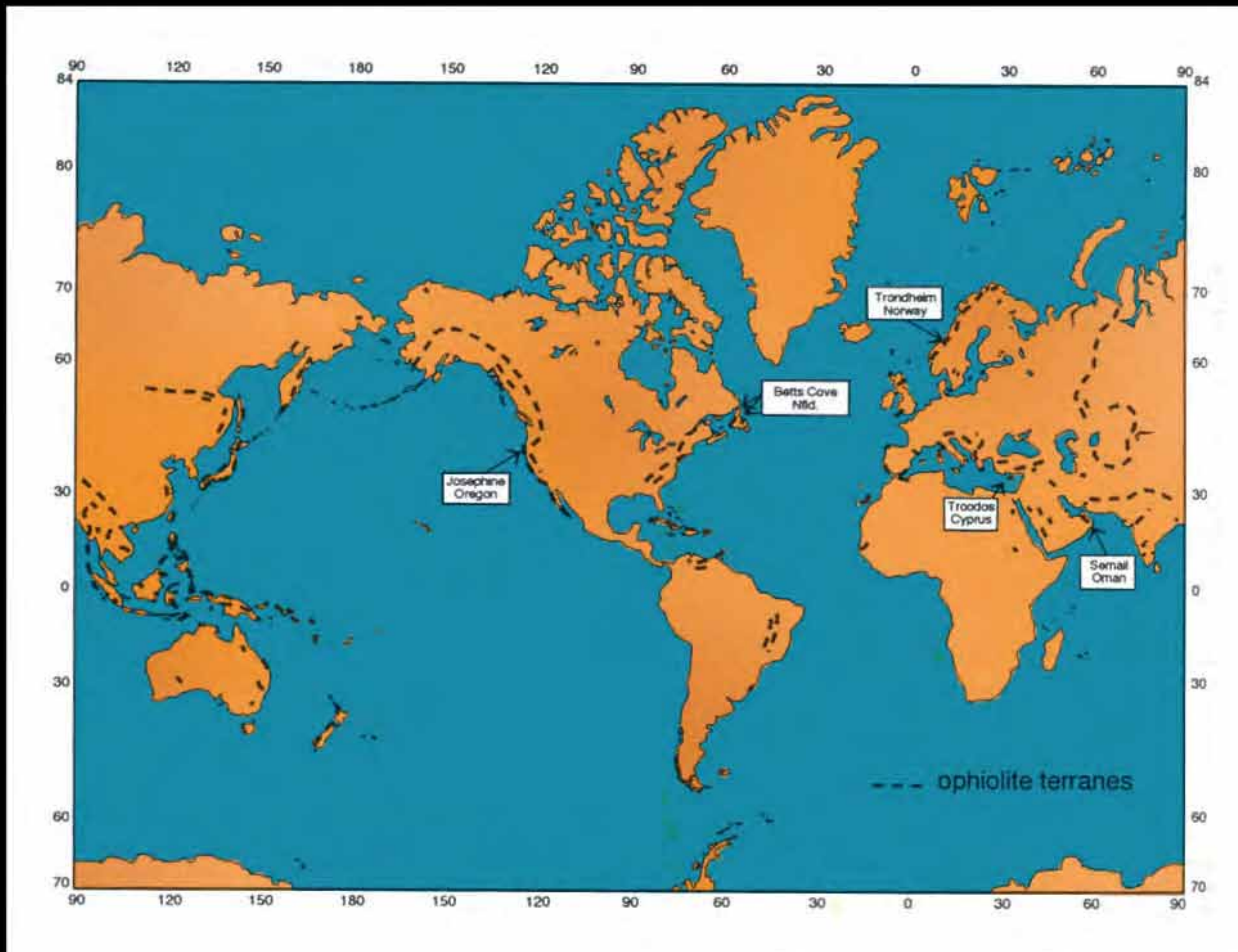
How do the ophiolites form?



?? ?B ? TCDMINy?fDTL|?? ?? ? ??CTLMyL

?MDTITNM?
?I? LM,?? TB ?TP
?? ? ??CTLMyL



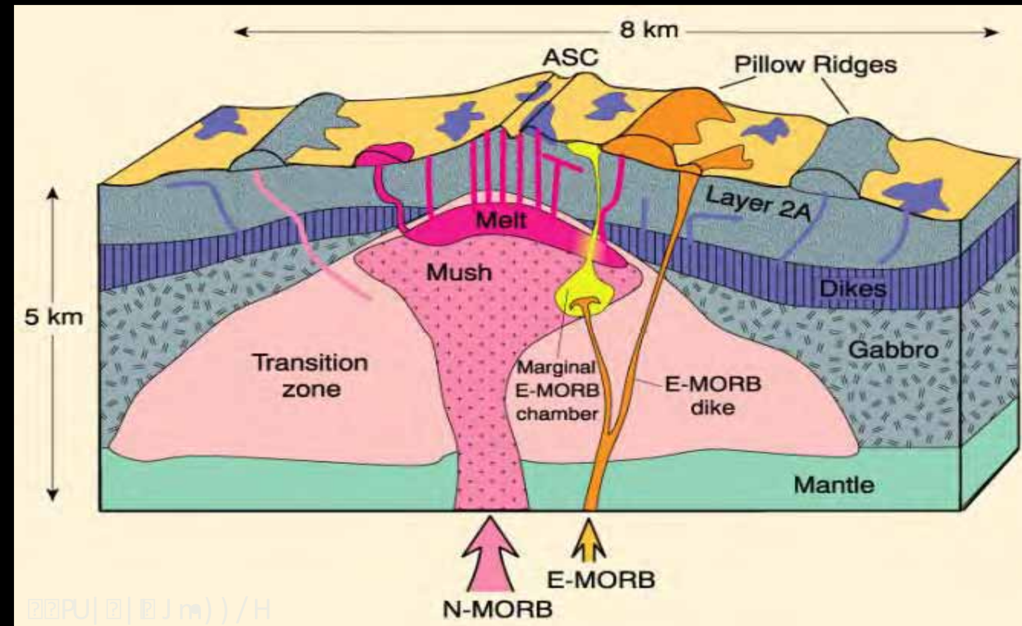


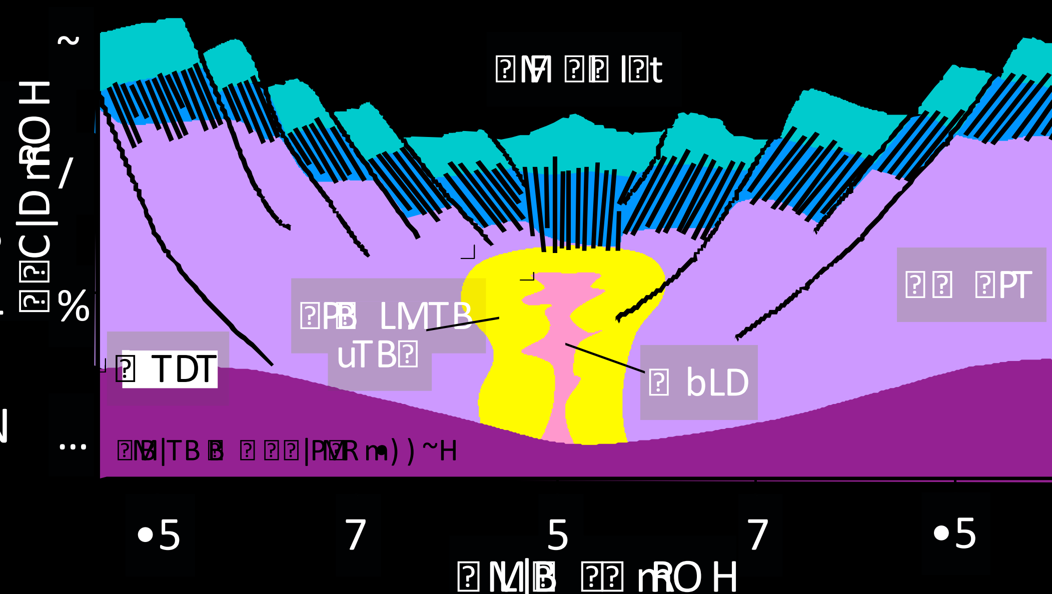
Trondheim
Norway
Betts Cove
Nfld.
Josephine
Oregon
Troodos
Cyprus
Semail
Oman
ophiolite terranes

Major ophiolite-hosted VMS deposits worldwide
(> 2 million tonnes; compilation by Galley and Koski, 1999))

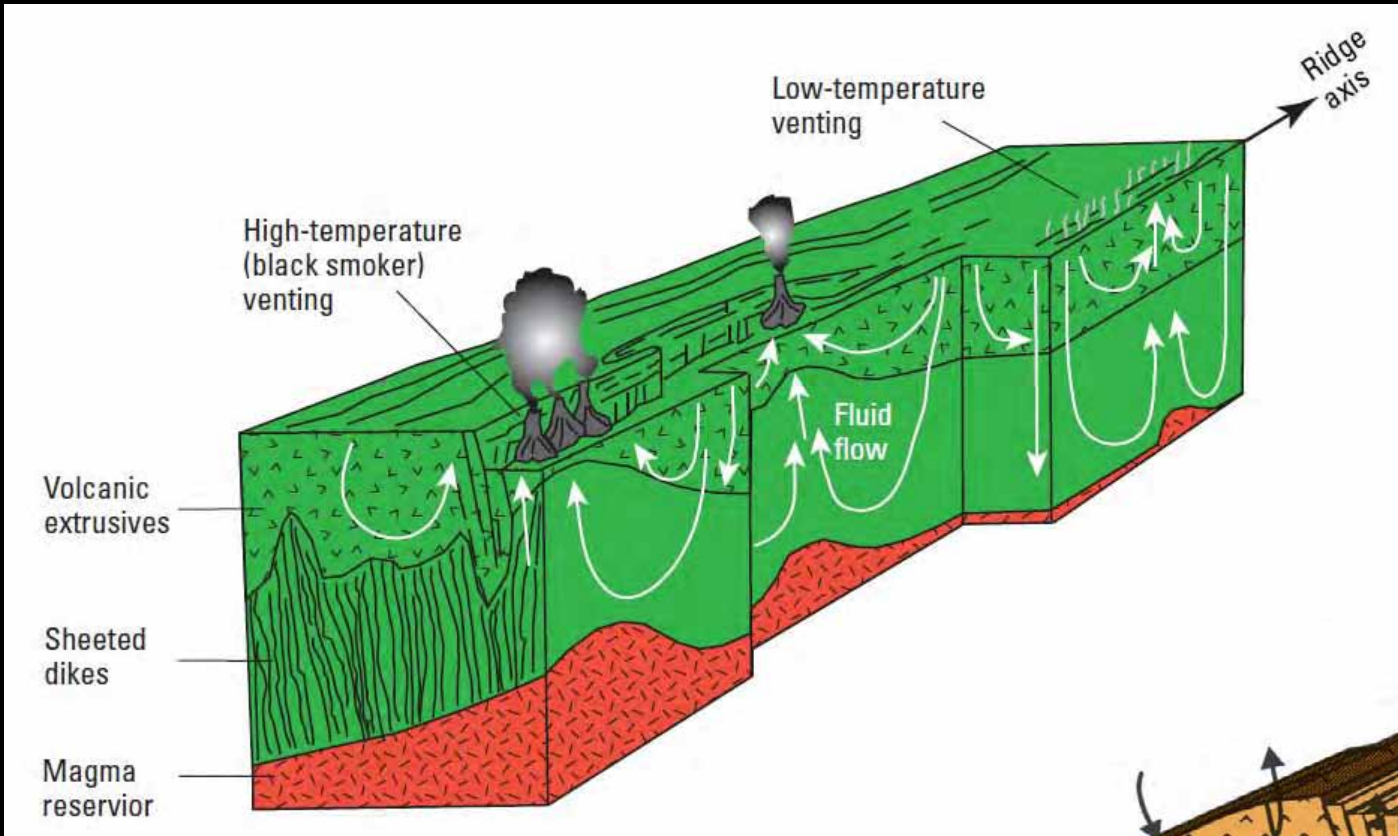
Deposit	Locality	Age	Volc/Sed	M Tonnes	Cu (%)	Zn (%)	Ag (ppm)	Au (ppm)
NORTH AMERICA								
Canada								
Tilt Cove	Nfld	Ord.	Volc.	6.1	1.24	-	-	-
Whales Back	Nfld	Ord.	Volc.	3.8	1.05	-	-	-
Little Bay	Nfld	Ord.	Volc.	3.1	1.32	-	-	0.07
United States								
Beatson	Alasca	Eocene	Sed.	5.4	1.65	-	-	-
Big Mike	Nevada	U. Paleo.	Volc.	4.0	1-10.5	-	-	-
Turner-Albright	Oregon	L. Juras.	Volc.	3.3	1.5	3.3	15	3.8
EUROPE								
Finland								
Saramaki	Finland	E. Prot.	Sed.	34.0	0.71	0.63	-	-
Outokumpo	Finland	E. Prot.	Sed.	28.5	3.8	1.07	8.9	0.8
Luikonlahti	Finland	E. Prot.	Sed.	7.5	0.99	0.5	-	-
Vuonos	Finland	E. Prot.	Sed.	5.9	2.45	1.6	11	0.1
Norway								
Lokken	Trondheim	Ord.	Volc.	25.0	2.1	1.9	19	0.29
Skorovass	Trondheim	Ord.	Volc.	6.6	0.73	1.65	10	0.1
Spain								
Barna	Galicia	L. Paleo.	Volc.	20.0	0.55	-	-	-
Arinteiro	Galicia	L. Paleo.	Volc.	11.0	0.67	-	-	-
MIDDLE EAST								
Oman								
Hyal As Safil	Oman	Cret.	Volc.	8.0	2.3	0.12	9.5	-
Lasail	Oman	Cret.	Volc.	8.0	2	0.04	-	-
Arja	Oman	Cret.	Volc.	3.0	2	0.06	-	-
Cyprus								
Limni (stockwork)	Cyprus	Cret.	Volc.	16.0	1	-	-	-
Mavrovouni	Cyprus	Cret.	Volc.	15.0	4	0.5	39	0.3
Phoenix (stockwork)	Cyprus	Cret.	Volc.	15.0	0.5	-	-	-
Kalavasos-Mousoulos	Cyprus	Cret.	Volc.	6.9	1	0.5	6	1.71
Skouriotissa	Cyprus	Cret.	Volc.	5.4	2.3	0.06	69	-
Agrokipia B	Cyprus	Cret.	Volc.	4.5	0.4	0.06	-	-
Limni	Cyprus	Cret.	Volc.	4.2	1.41	-	2.7	3.39
Kinousa	Cyprus	Cret.	Volc.	4.0	1.5	-	-	-
Kokkinopezoula	Cyprus	Cret.	Volc.	3.5	0.2	-	-	-
Mathiati	Cyprus	Cret.	Volc.	3.0	0.2	1	-	-
Pitharakhoma	Cyprus	Cret.	Volc.	2.3	0.25	0.25	-	-
Turkey								
Asikoy	Kure	Cret.	Sed.	31.6	2.17	-	-	-
Bakibaba	Kure	Cret.	Volc.	4.4	2.2	-	-	-
ASIA								
Japan								
Ochiaizawa	Japan	Cret.	Sed.	6.8	2.2	-	-	-
Phillipines								
Barlo	Luzon	Cret.-Paleo.	Volc.	2.1	1.6	-	-	-
China								
Deerni	Qinghai	Cret.	Volc.	>50.0	-	-	-	-

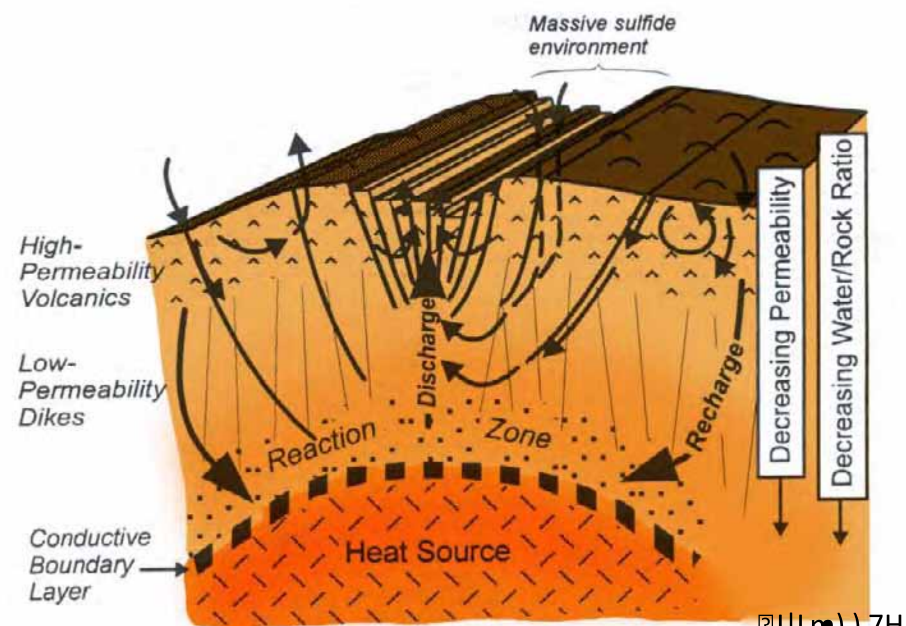
Spreading rate control



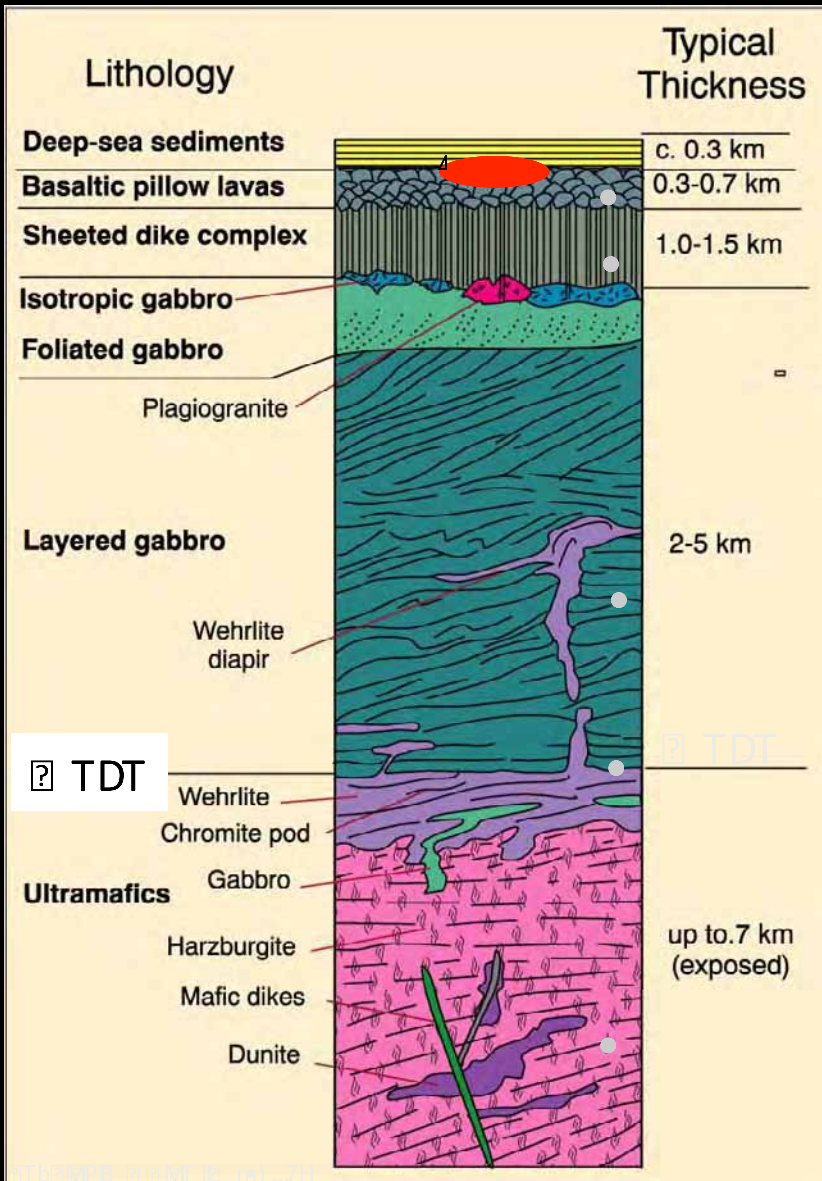


VMS distribution within ophiolite suites

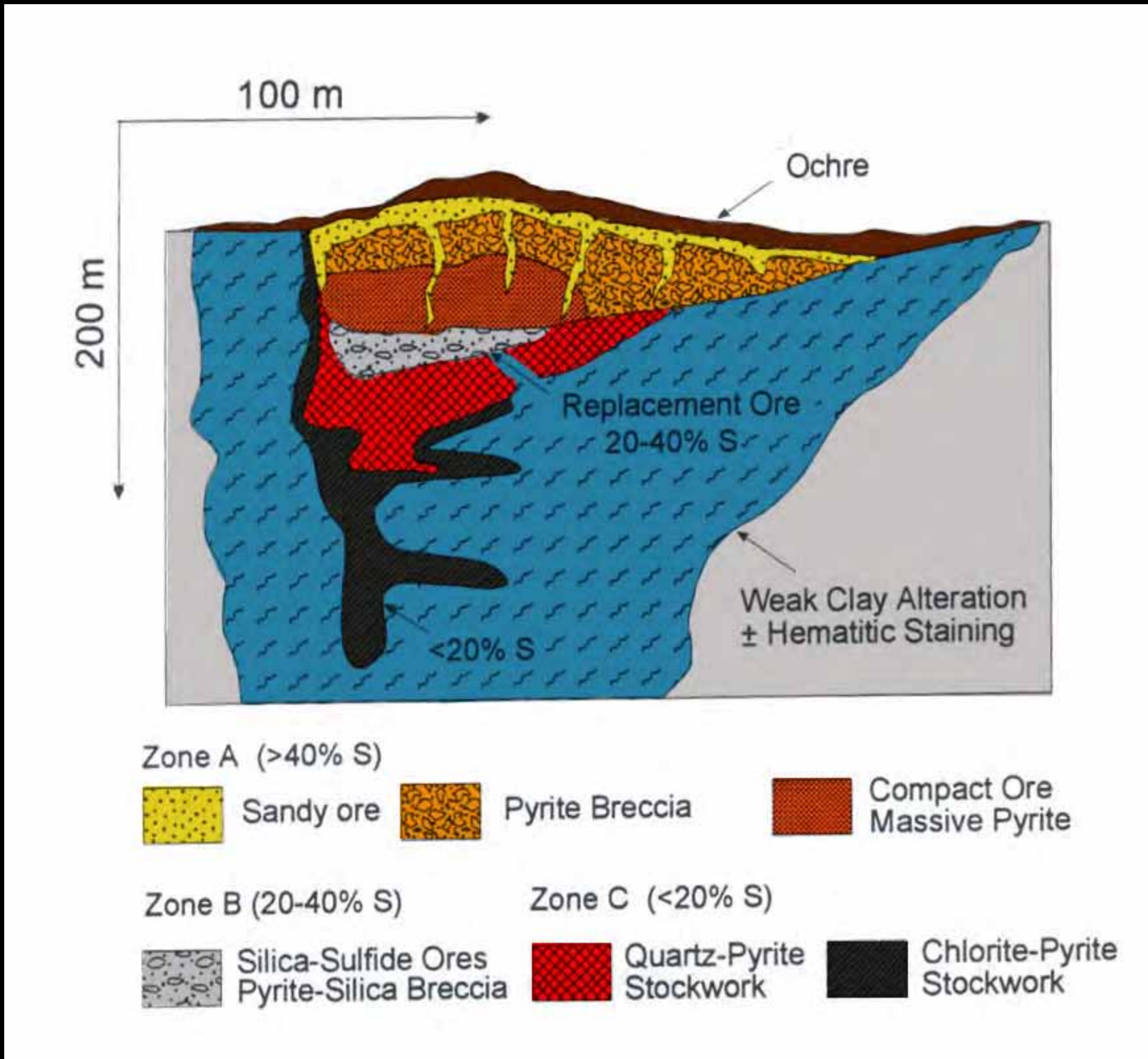


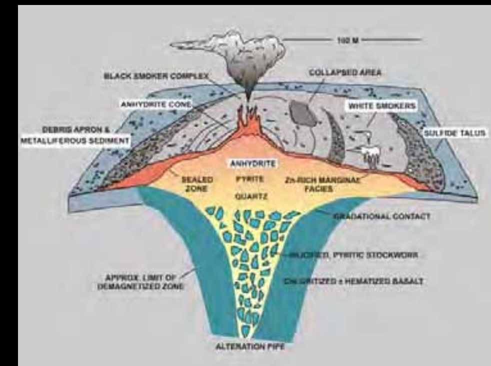


VMS distribution within ophiolite suites

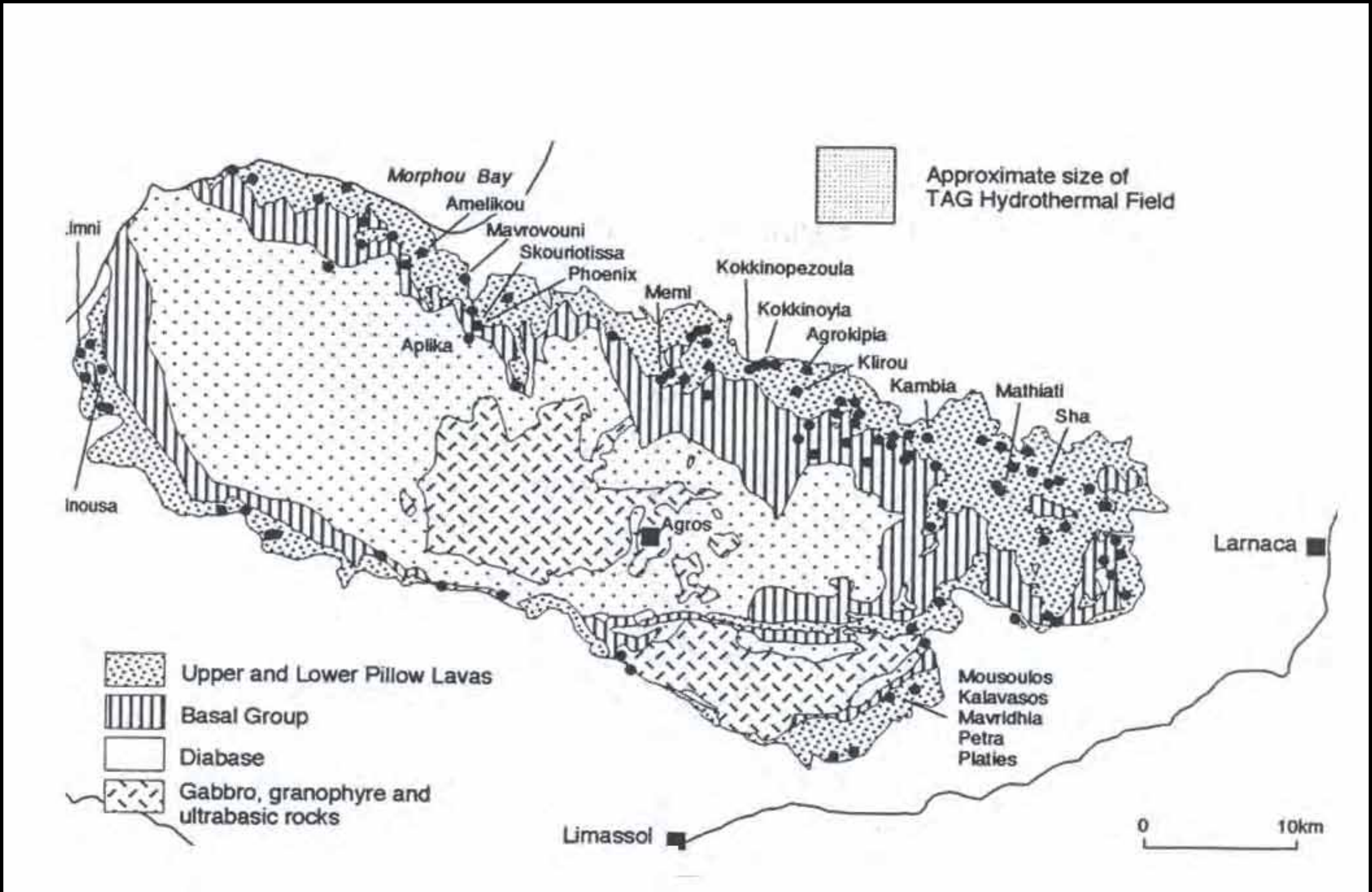


Hydrothermal alteration and mineralization





TROODOS, CYPRUS



From Hannington et al. (1996)

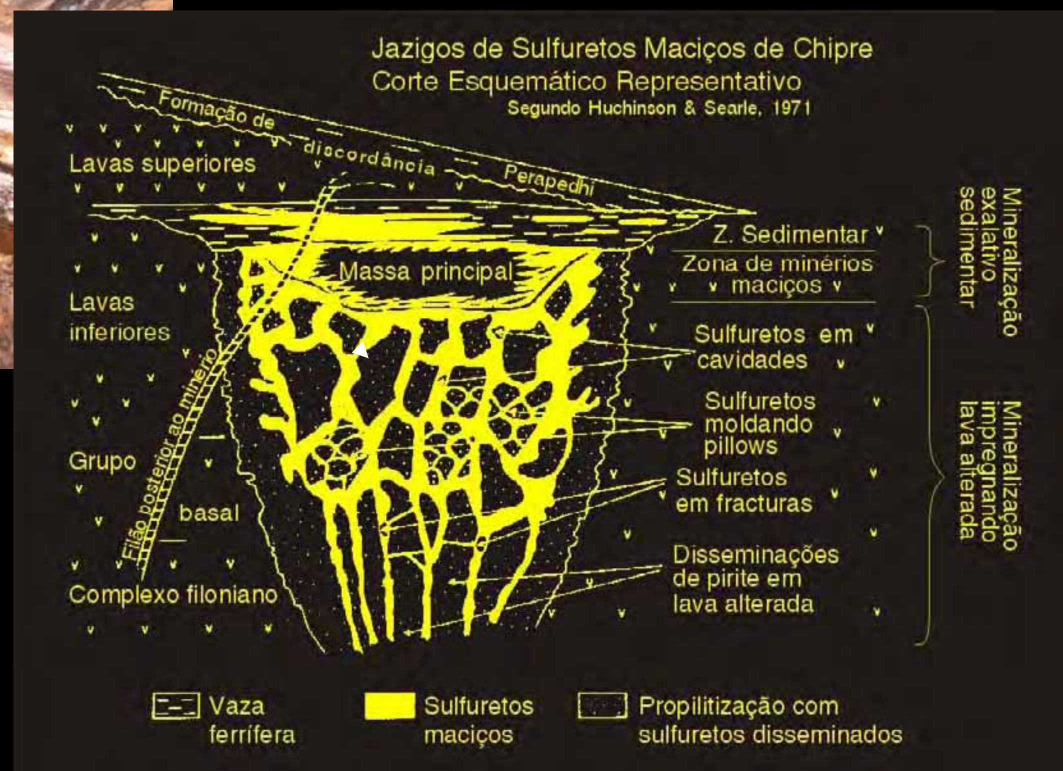
Photo F. Barriga

TROODOS
(Cu (Zn) Au)

Hutchinson and Searle (1971)

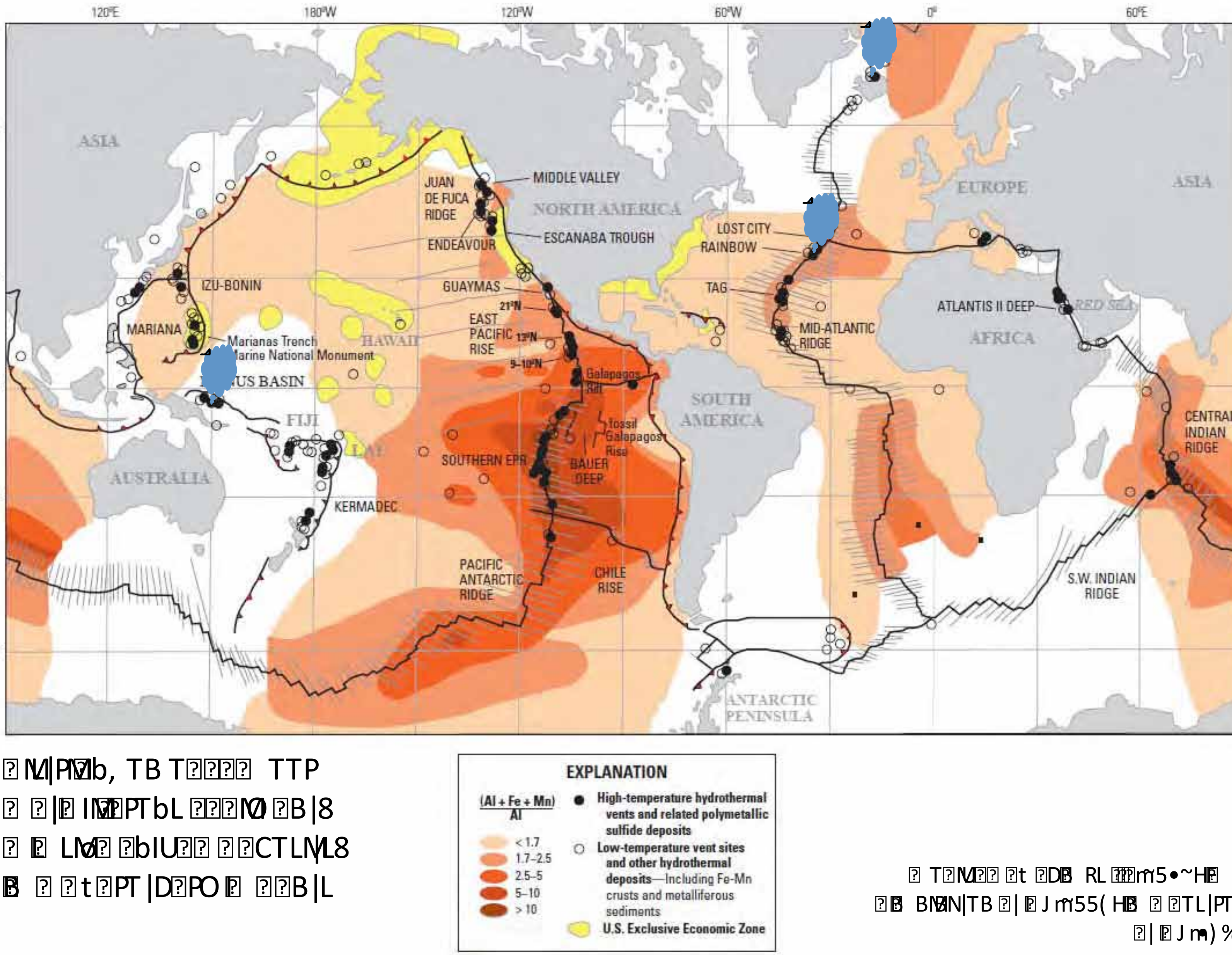
TROODOS
(Cu (Zn) Au)

Photo F. Barriga

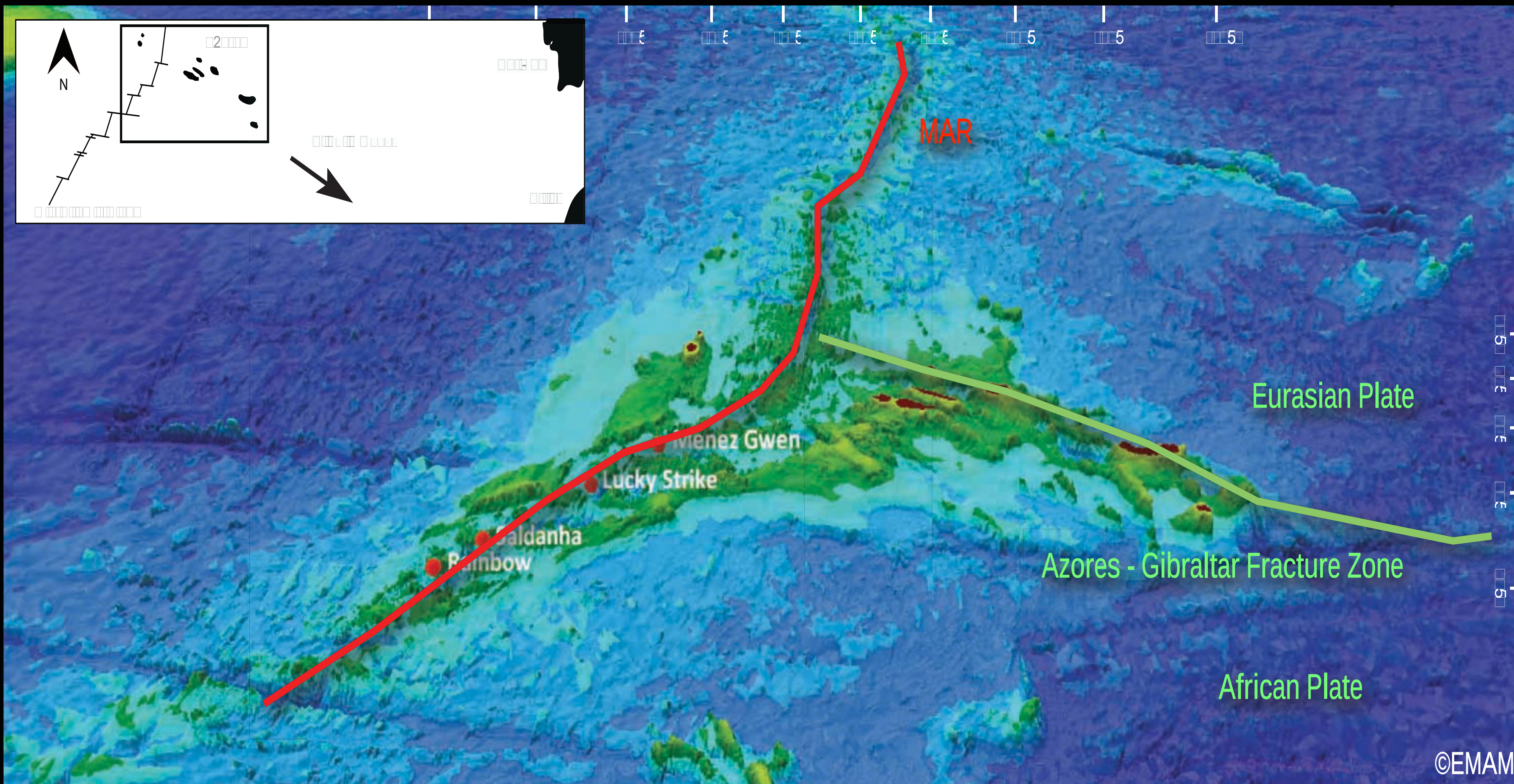


Hutchinson and Searle (1971)

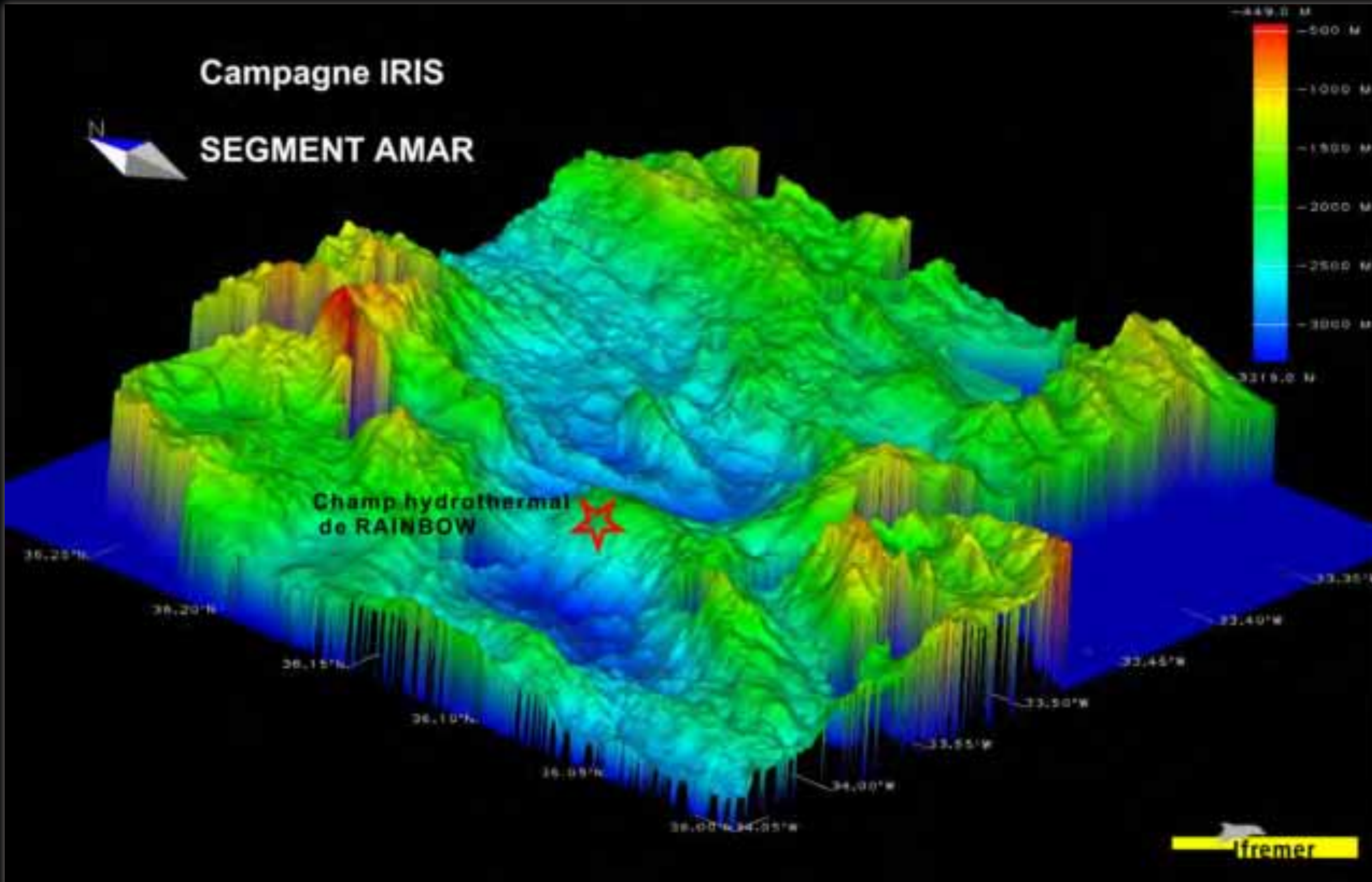
VMS Mineralization at the Modern Seafloor



Mid-Atlantic Ridge



Rainbow


Campagne IRIS
N
SEGMENT AMAR
Champ hydrothermal
de RAINBOW
-500 M
-1000 M
-1500 M
-2000 M
-2500 M
-3000 M
Ifremer

Rainbow

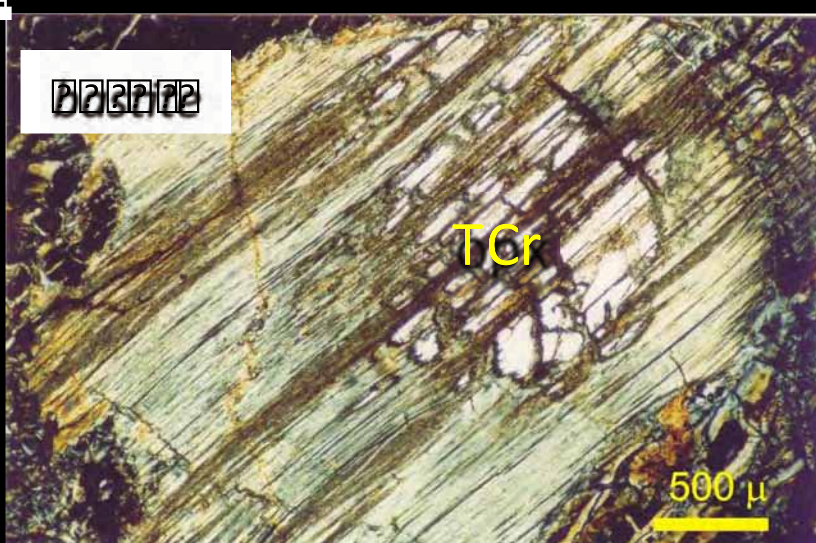
Serpentinization

m5J• N5J) HMk 3 m5J~ N•J…H~M/ 3 5Jk N˜3S 3 ~~

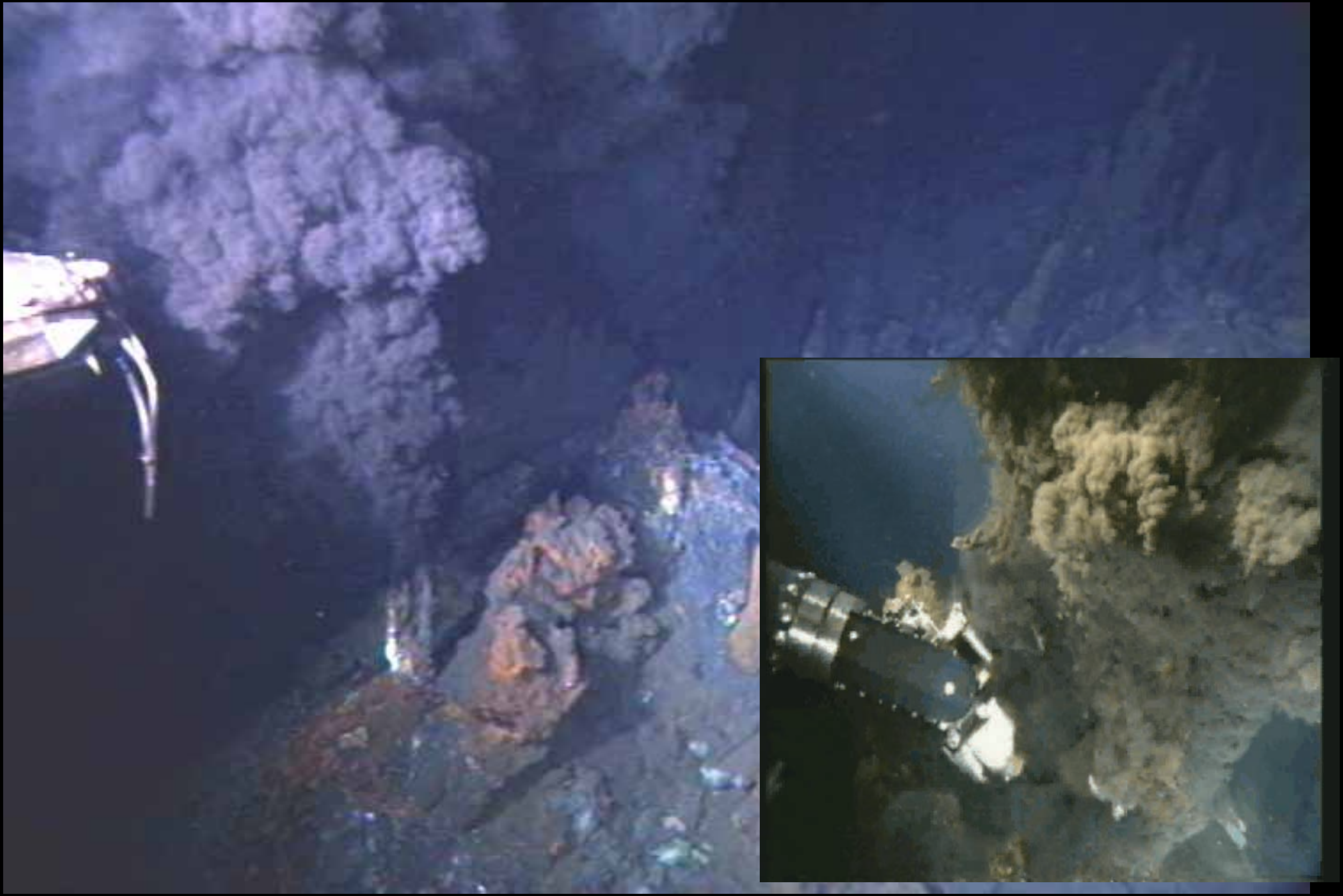
□ NkM~7m H/ 3 5Jk˜3S

k˜3S 3 ~S 3 ~~ * k/ 3 /

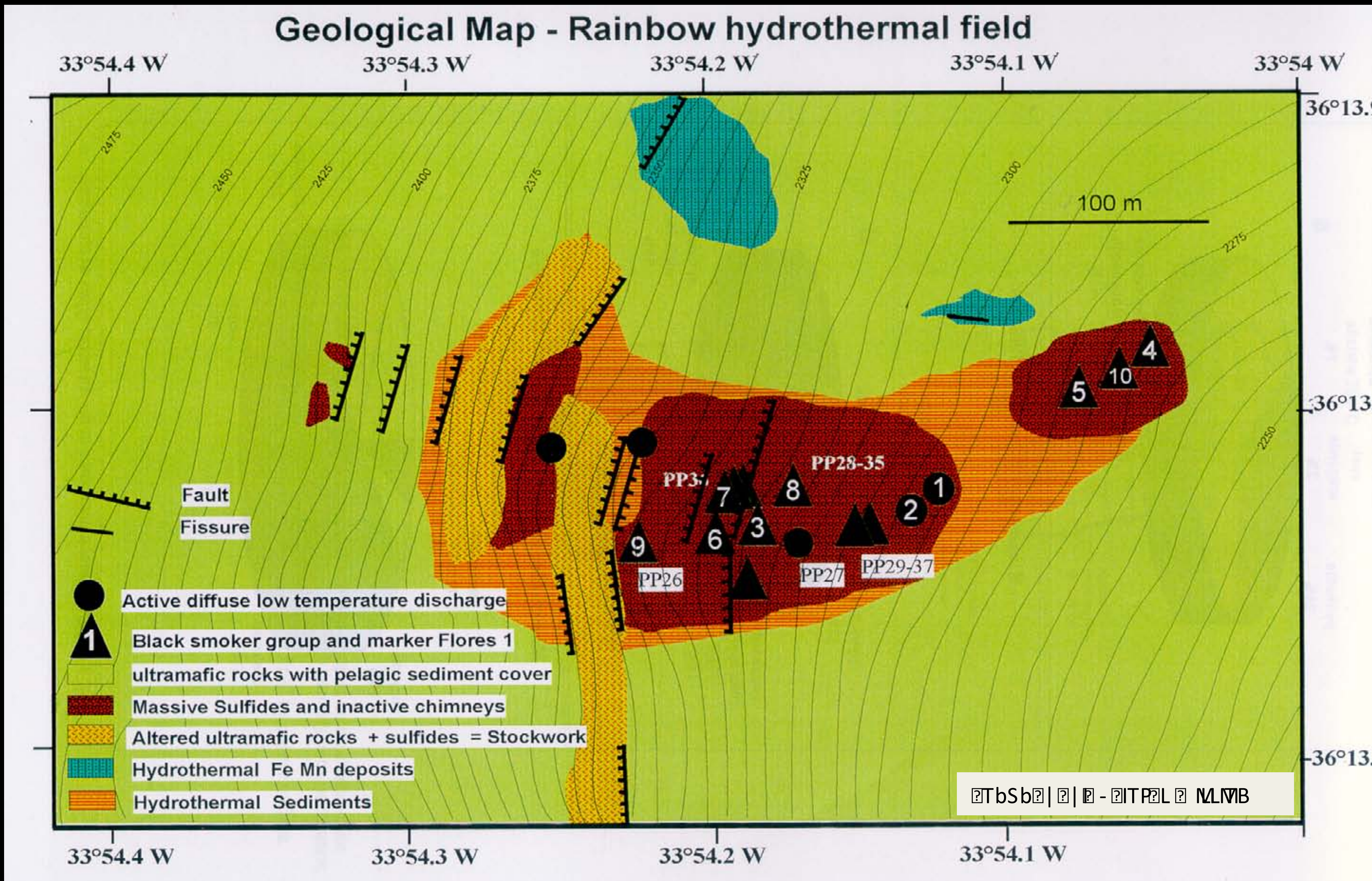
Rainbow



Rainbow



Rainbow

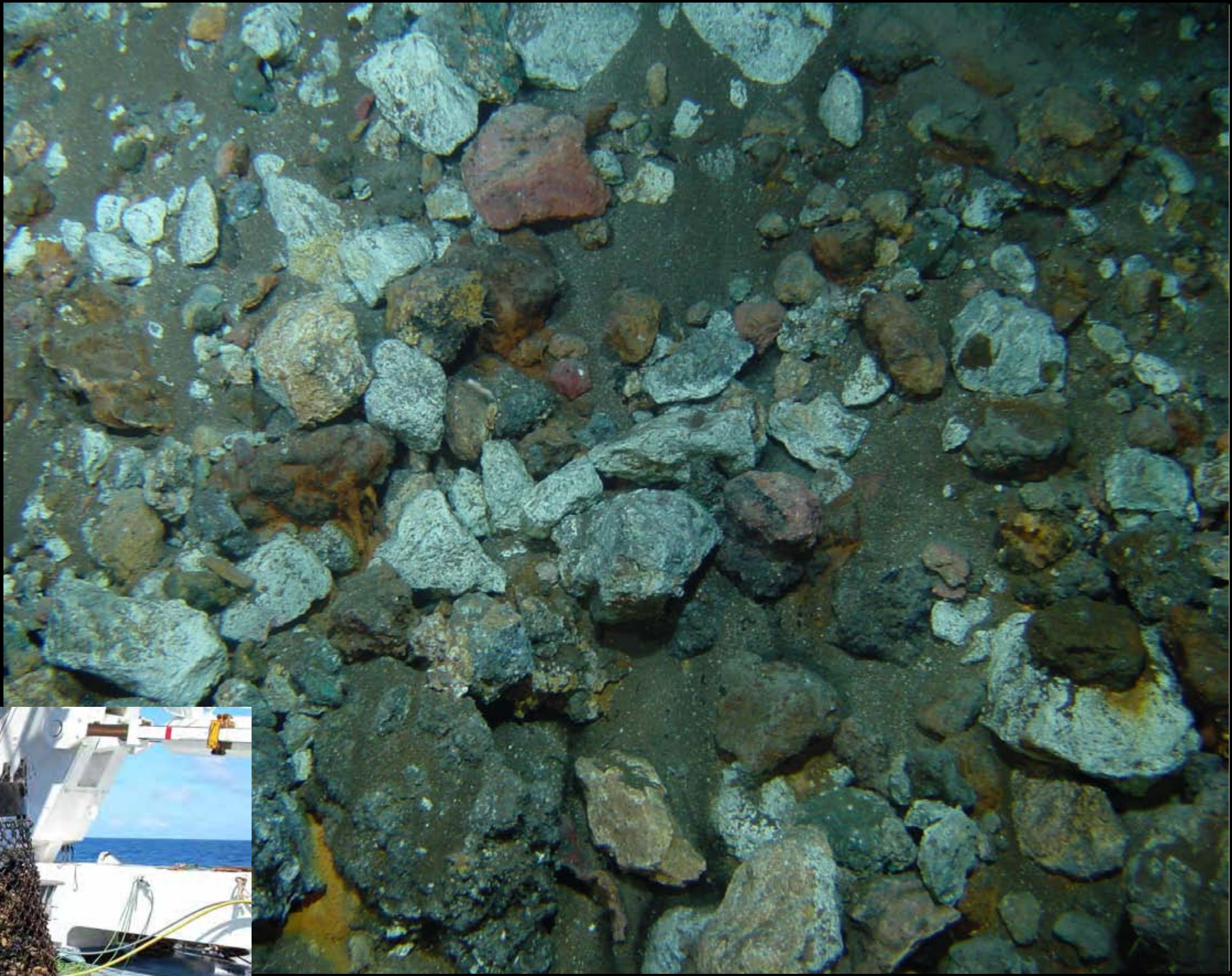


Geological Map - Rainbow hydrothermal field
33°54.4 W
33°54.3 W
33°54.2 W
33°54.1 W
33°54 W
36°13.9
36°13.8
36°13.7
100 m
2475
2450
2425
2400
2375
2350
2325
2300
2275
2250
Fault
Fissure
PP28-35
PP26
PP27
PP29-37
1
2
3
4
5
6
7
8
9
10
Active diffuse low temperature discharge
Black smoker group and marker Flores 1
ultramafic rocks with pelagic sediment cover
Massive Sulfides and inactive chimneys
Altered ultramafic rocks + sulfides = Stockwork
Hydrothermal Fe Mn deposits
Hydrothermal Sediments

Rainbow


Massive Sulfide
Chimney Fragment
Metalliferous Sediments

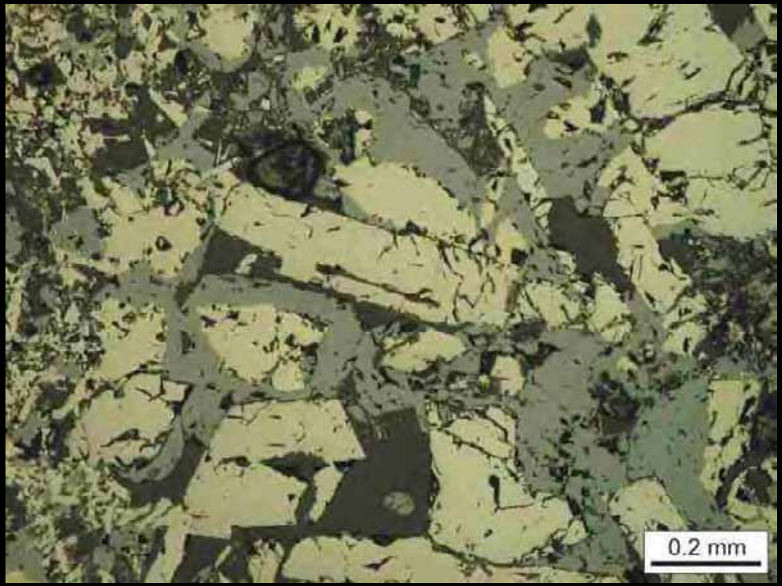
Rainbow



Rainbow

Rainbow

Rainbow



8.35 wt Cu

5.1 wt% Zn

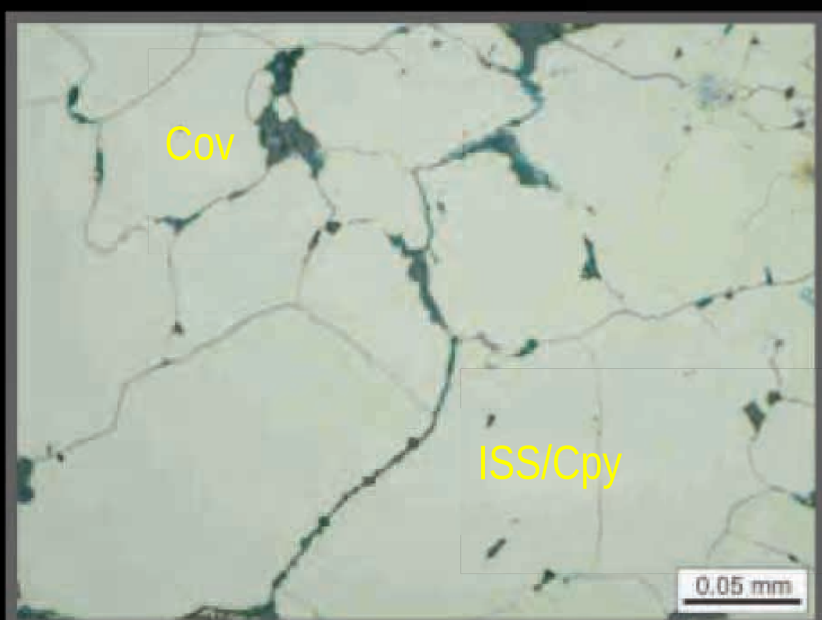
0.57 wt % Co

5.7 ppm Au

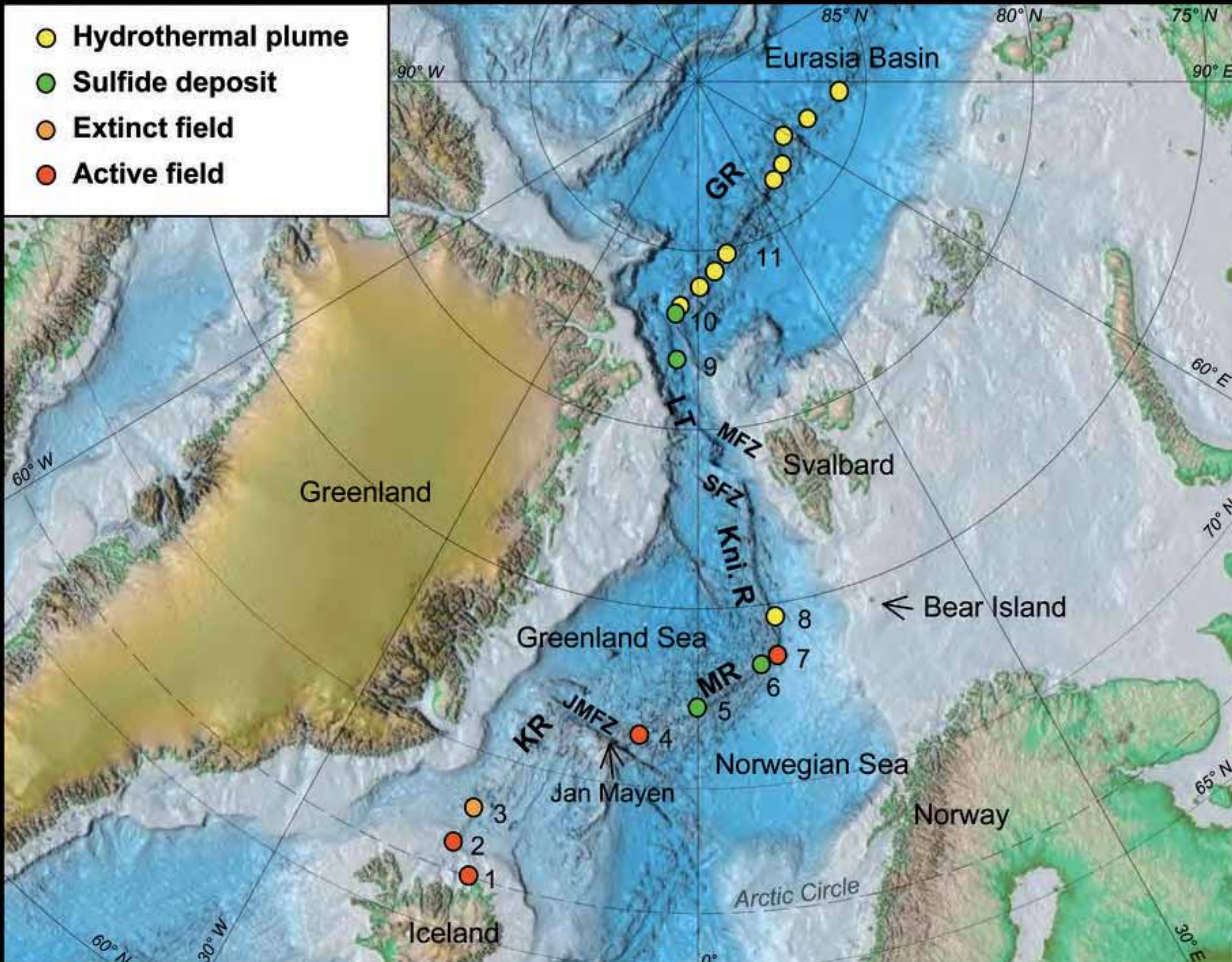
n.d. Ni

Rainbow

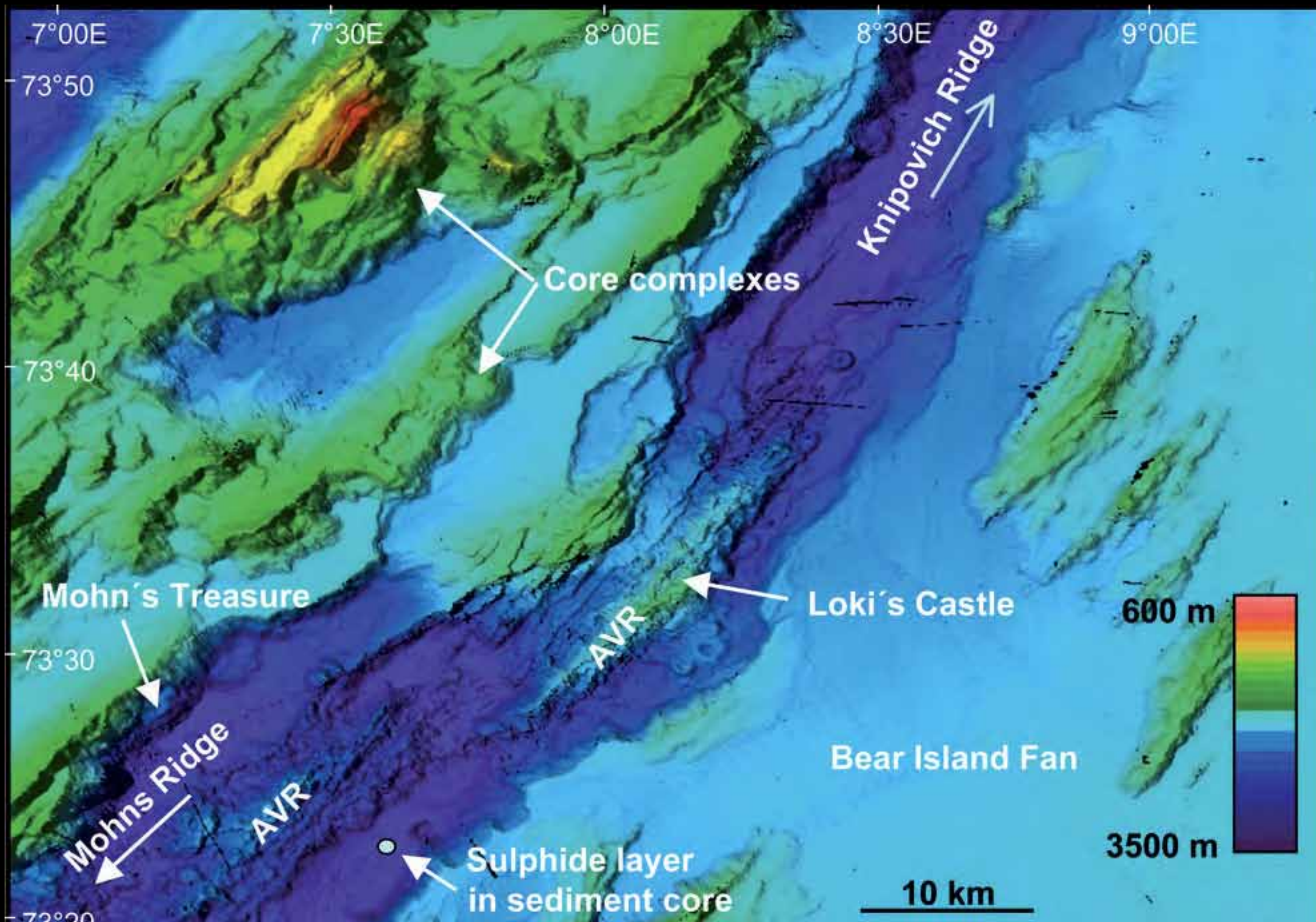
27.98 wt% Cu
0.63 wt % Co
672 ppm Zn
6.3 ppm Au
n.d. Ni



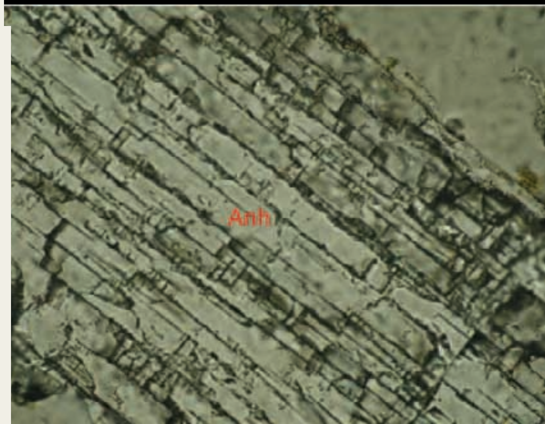
Artic Ocean: ultra-slow spreading ridges

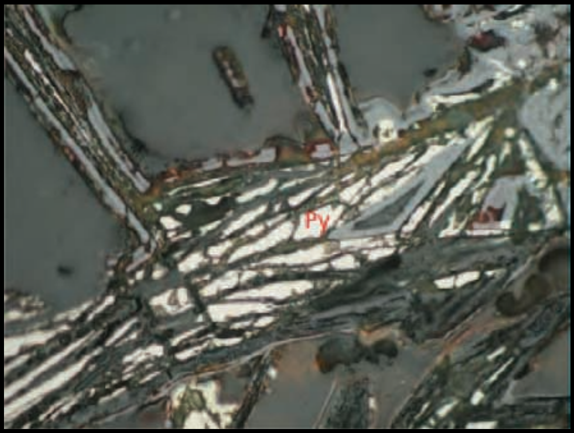


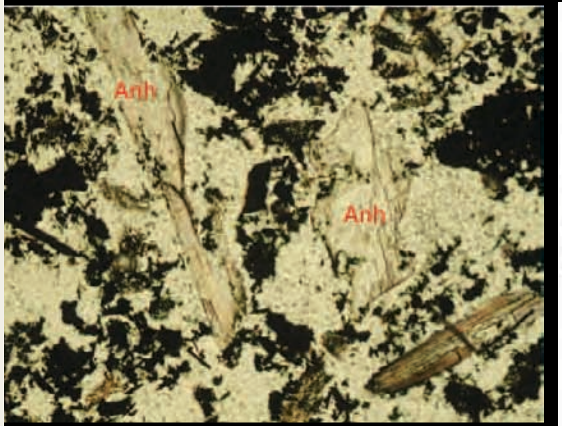
Loki’s Castle

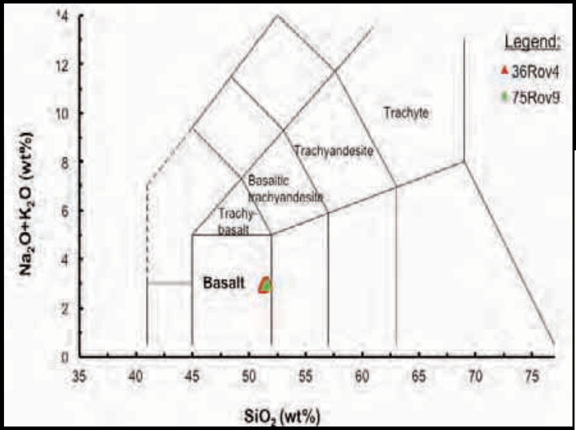


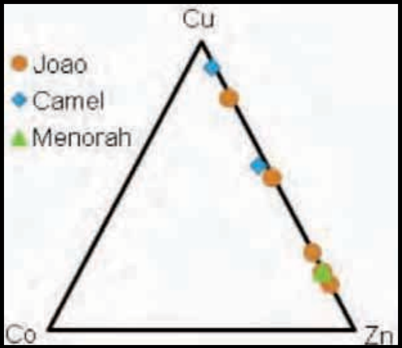
Loki’s Castle





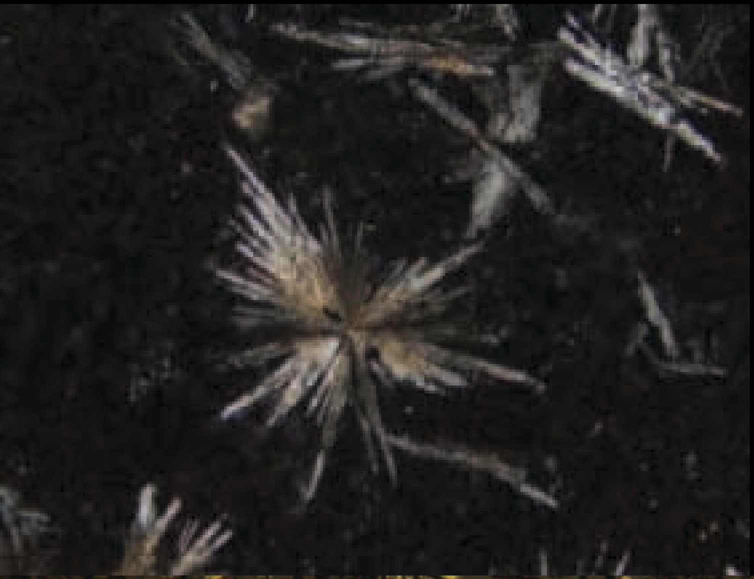
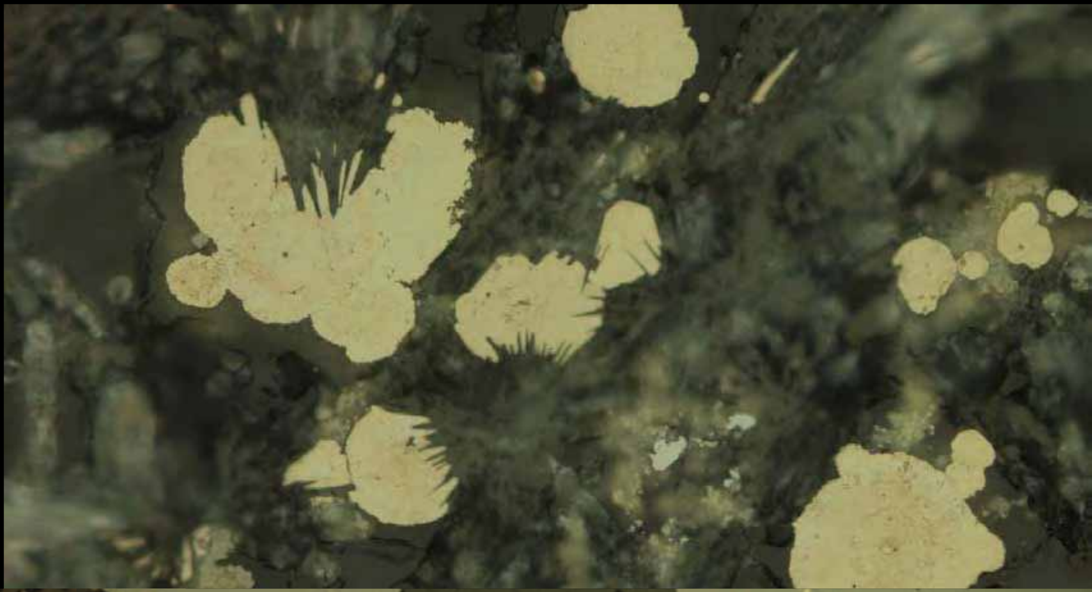


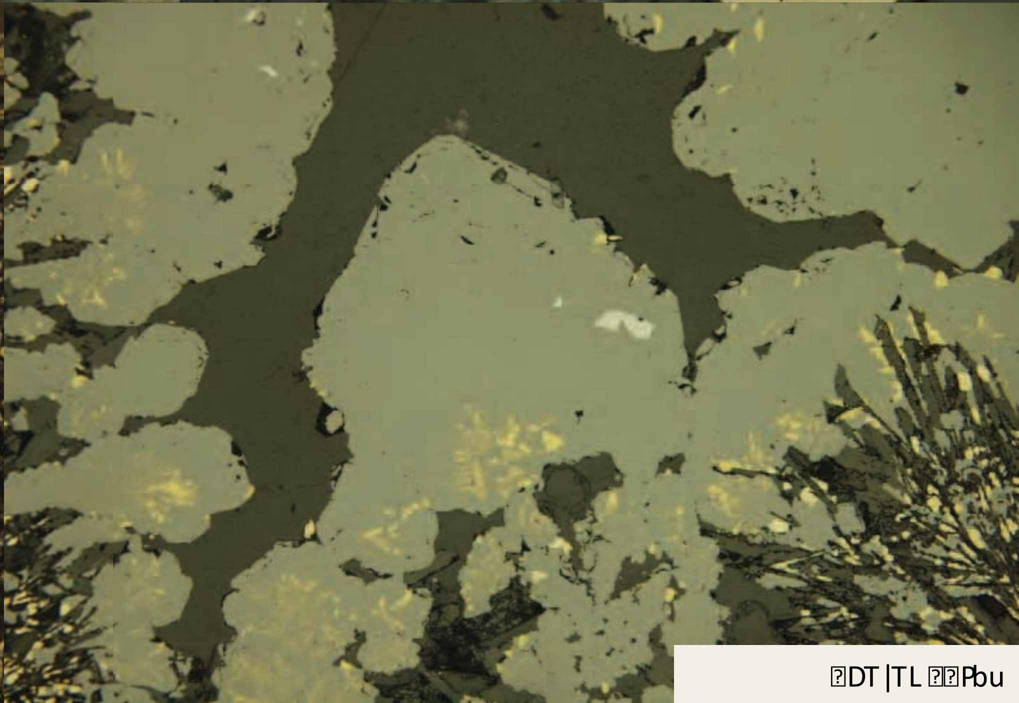




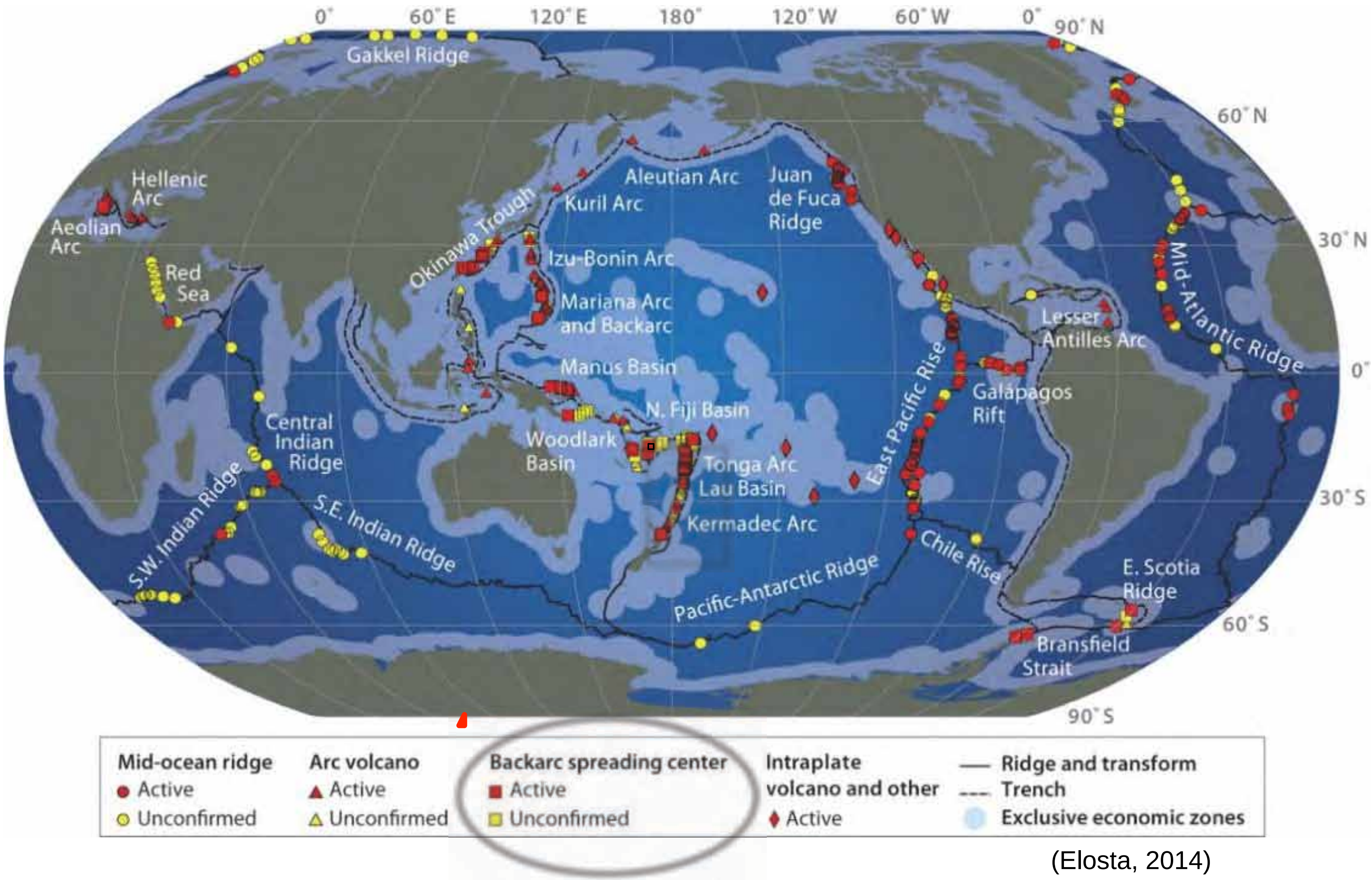
Jan Mayen

Jan Mayen

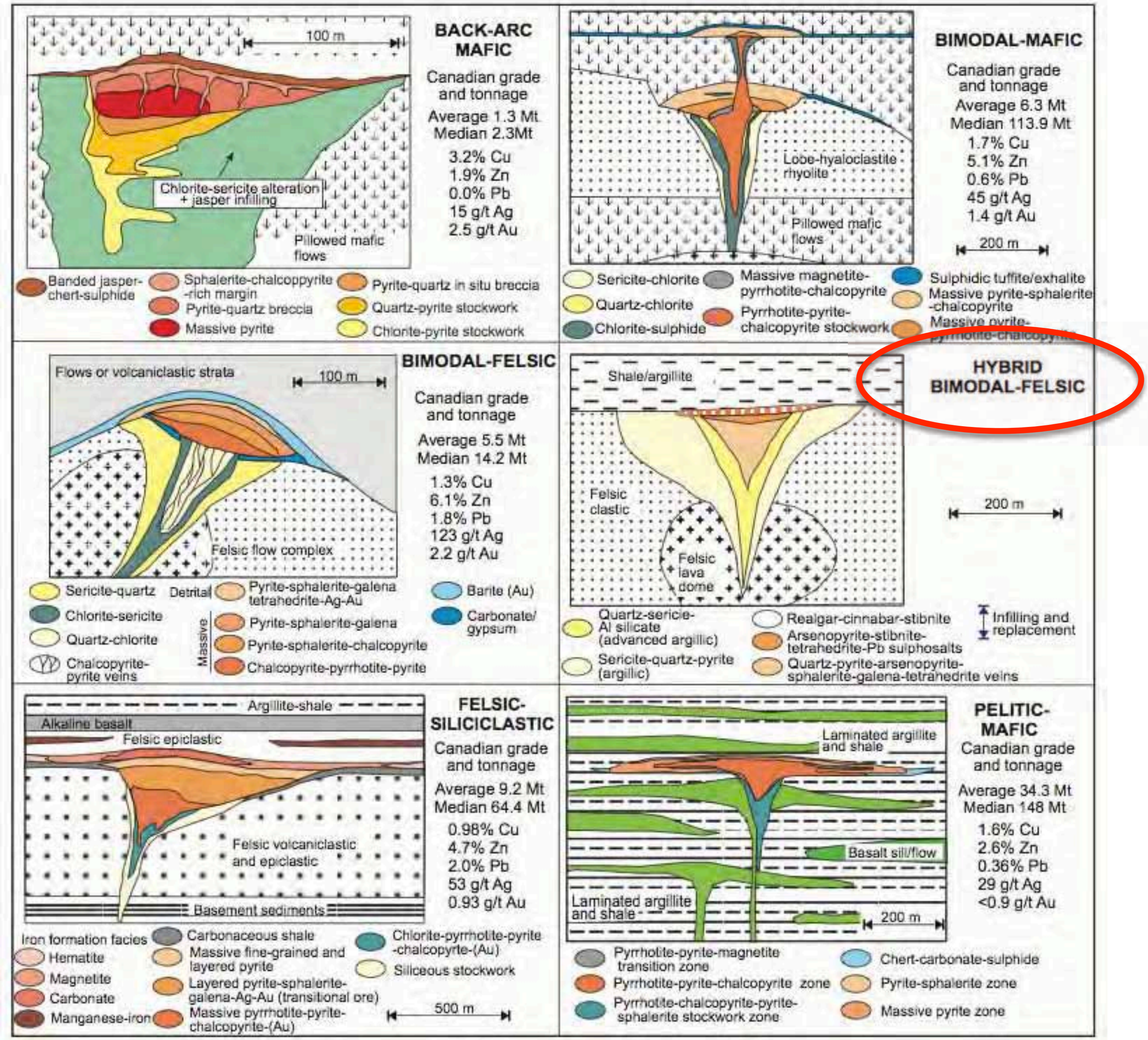


DT |TL Pbu

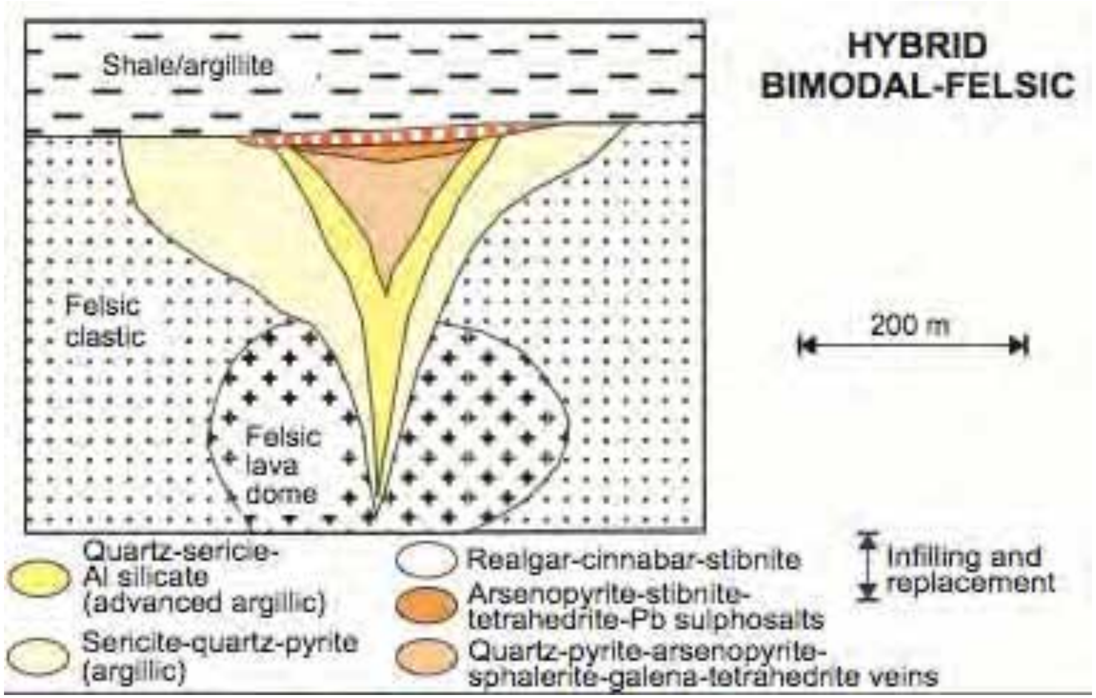


0°
60°E
120°E
180°
120°W
60°W
0°
90°N
60°N
30°N
0°
30°S
60°S
90°S
Gakkel Ridge
Hellenic Arc
Aeolian Arc
Red Sea
Okinawa Trough
Kuril Arc
Aleutian Arc
Juan de Fuca Ridge
Izu-Bonin Arc
Mariana Arc and Backarc
Manus Basin
N. Fiji Basin
Woodlark Basin
Tonga Arc
Lau Basin
Kermadec Arc
Central Indian Ridge
S.W. Indian Ridge
S.E. Indian Ridge
Pacific-Antarctic Ridge
East Pacific Rise
Chile Rise
Galápagos Rift
Lesser Antilles Arc
Mid-Atlantic Ridge
E. Scotia Ridge
Bransfield Strait
Mid-ocean ridge
Active
Unconfirmed
Arc volcano
Active
Unconfirmed
Backarc spreading center
Active
Unconfirmed
Intraplate volcano and other
Active
Ridge and transform
Trench
Exclusive economic zones

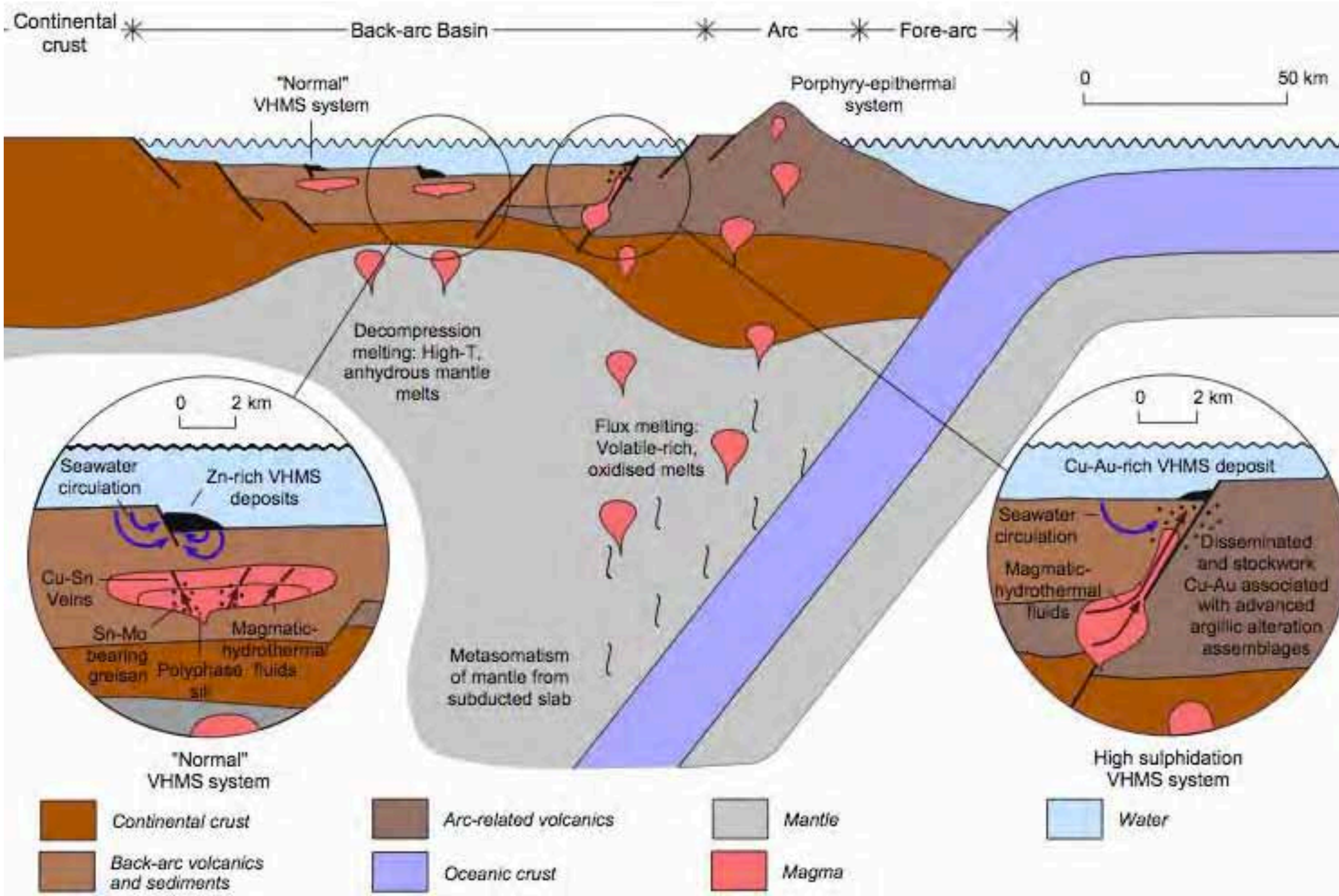
(Elosta, 2014)



(Galley et al., 2007, modified from Barrie and Hannington (1999) by Franklin et al. (2005), with the addition of the hybrid bimodal felsic as a VMS-epithermal subtype of bimodal-felsic)

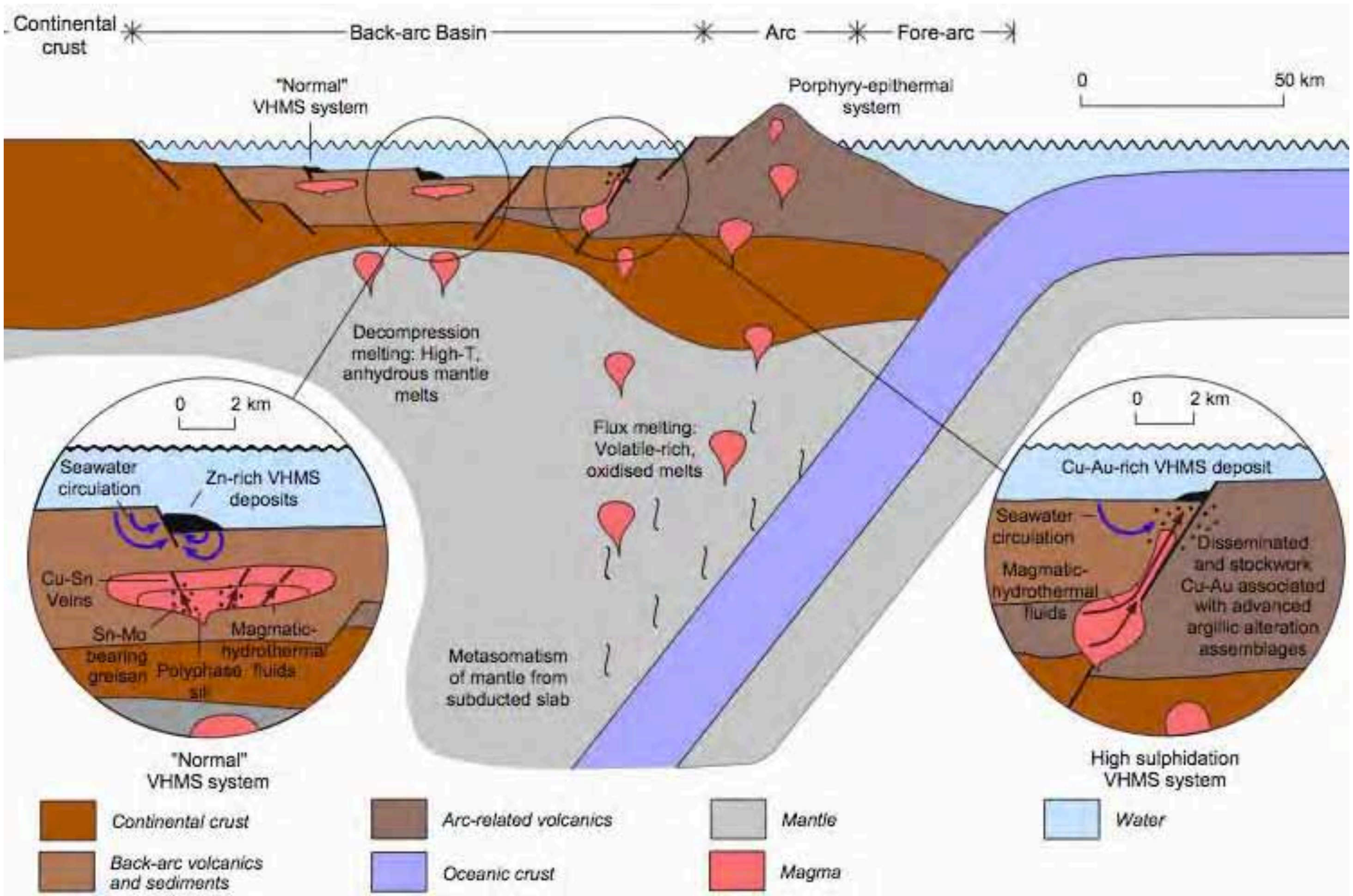


Galley et al., 2007, after
Franklin et al. (2005),

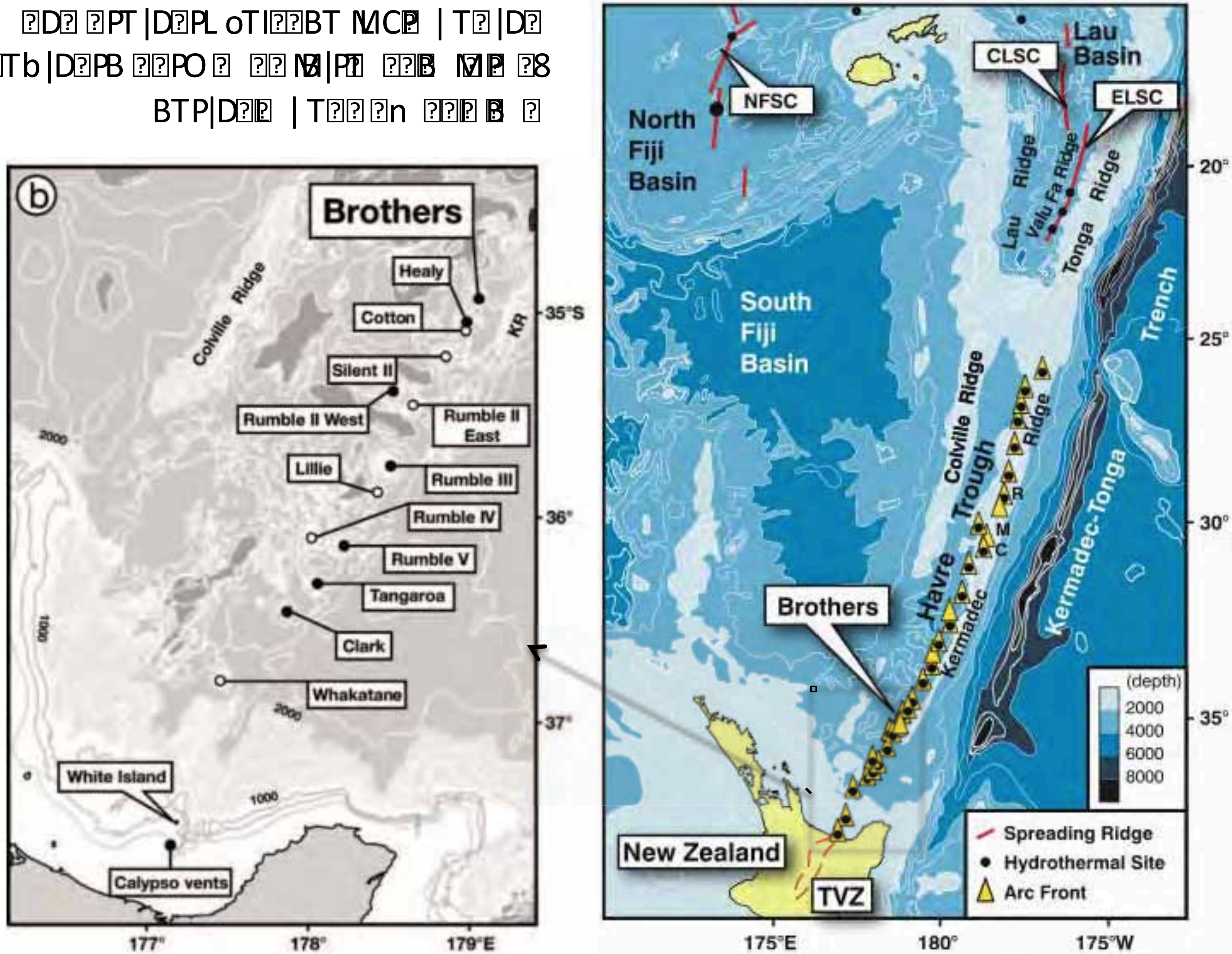


(Huston et al., 2011)

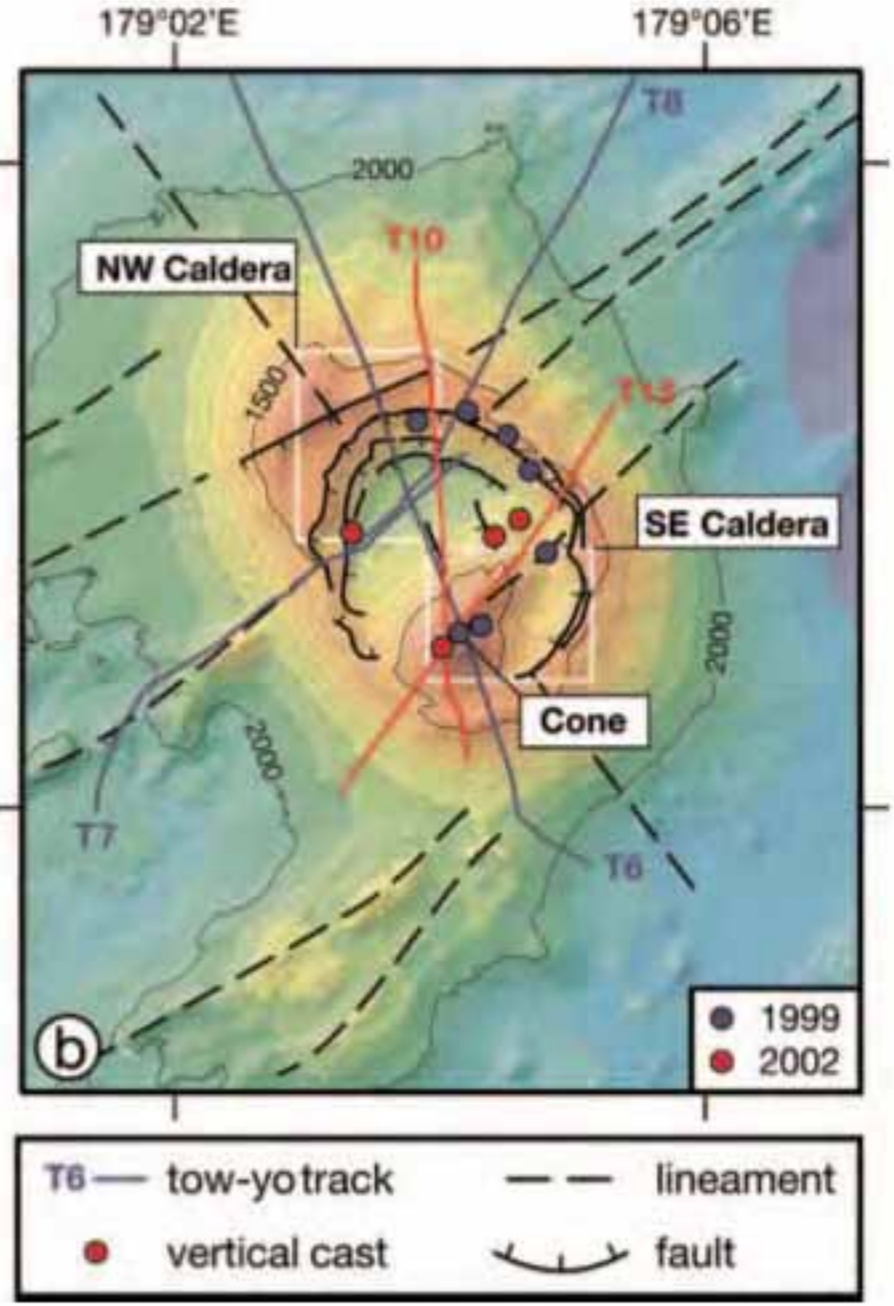
Gi e p ni r ar TPO PTO L Pff TO M TP bM- BT oM B TPO N O, TB |PMb, TBLJ



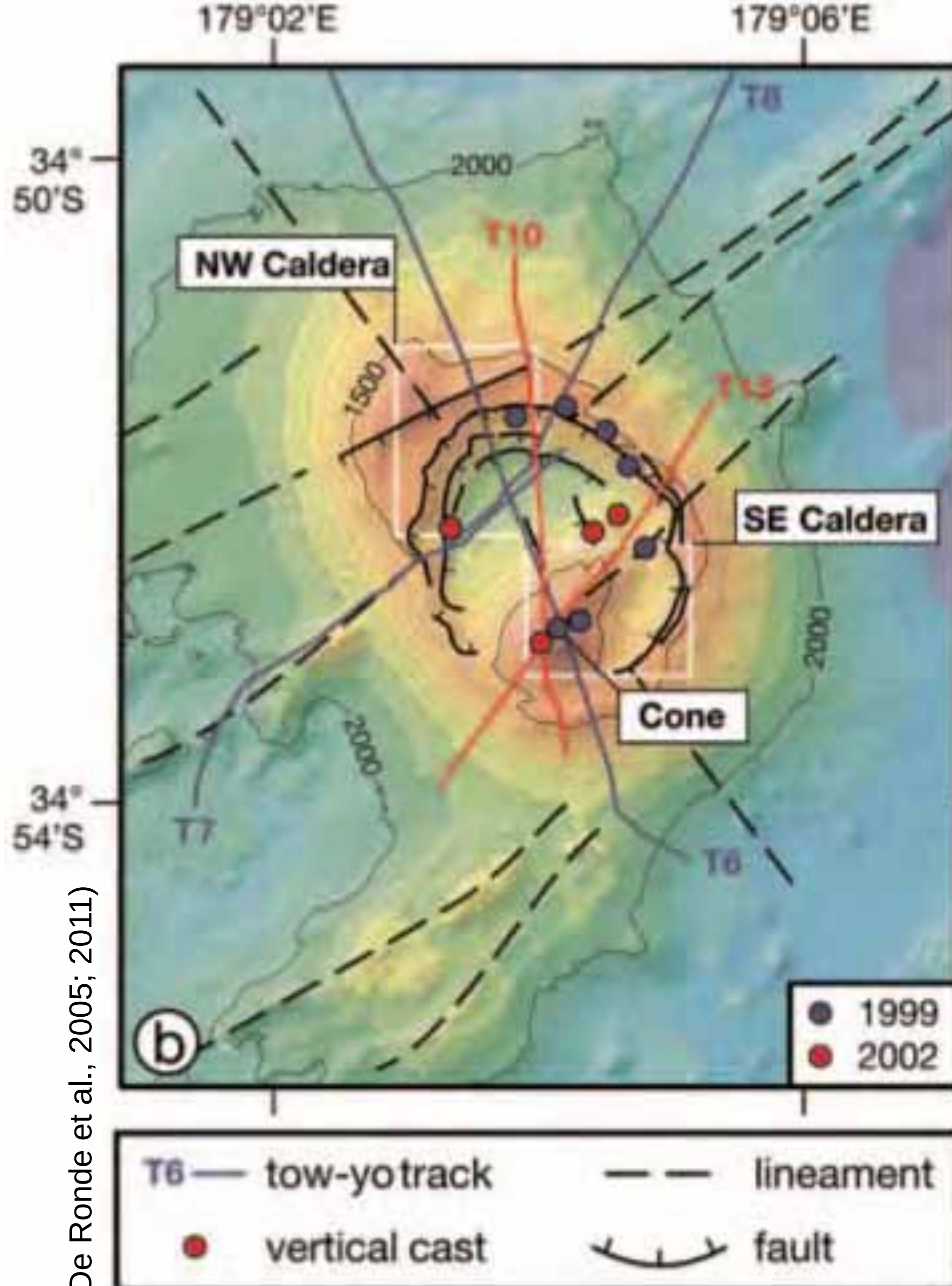
(Huston et al., 2011)



(De Ronde et al., 2005; 2011)

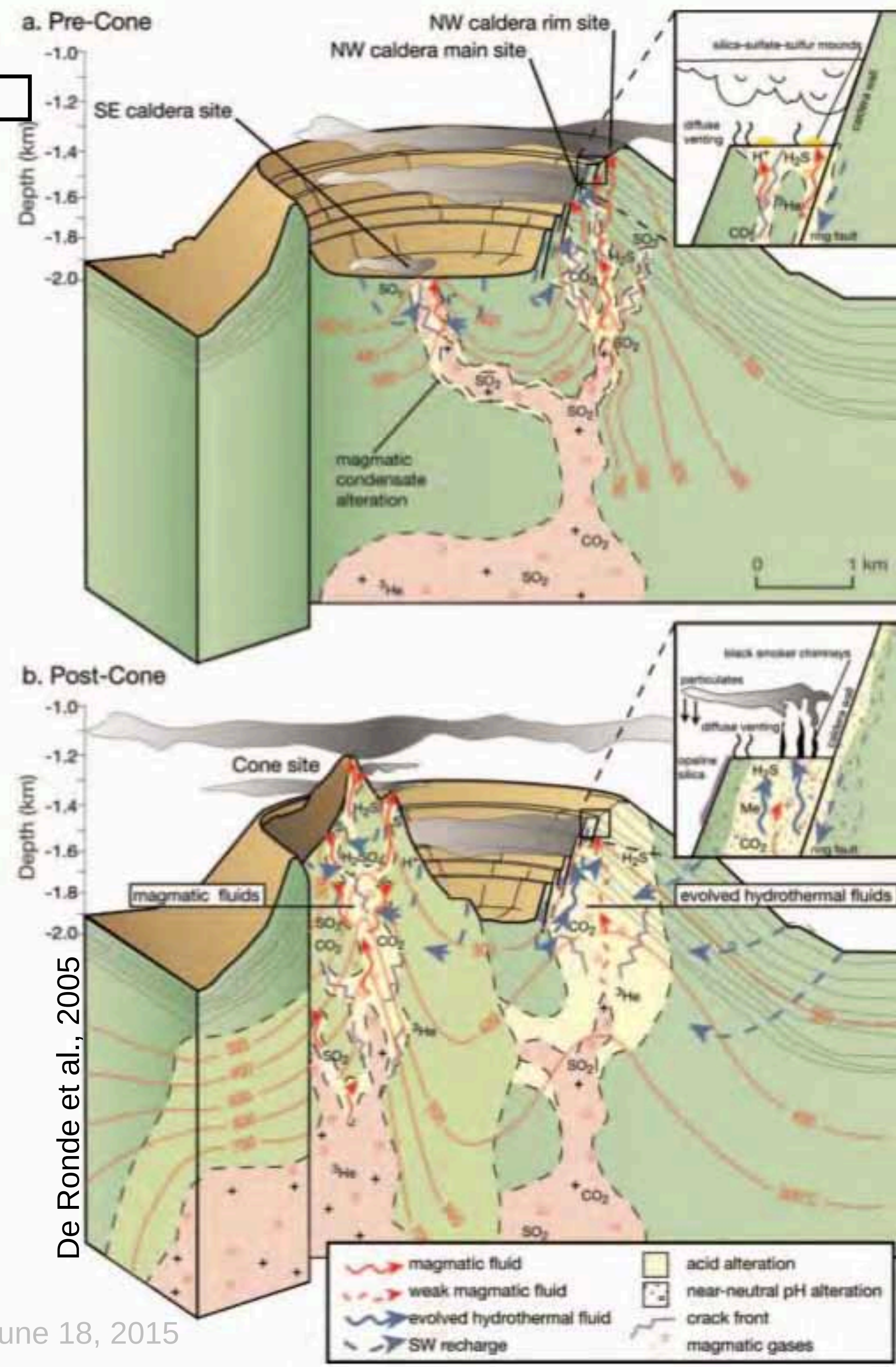


(De Ronde et al., 2005; 2011)



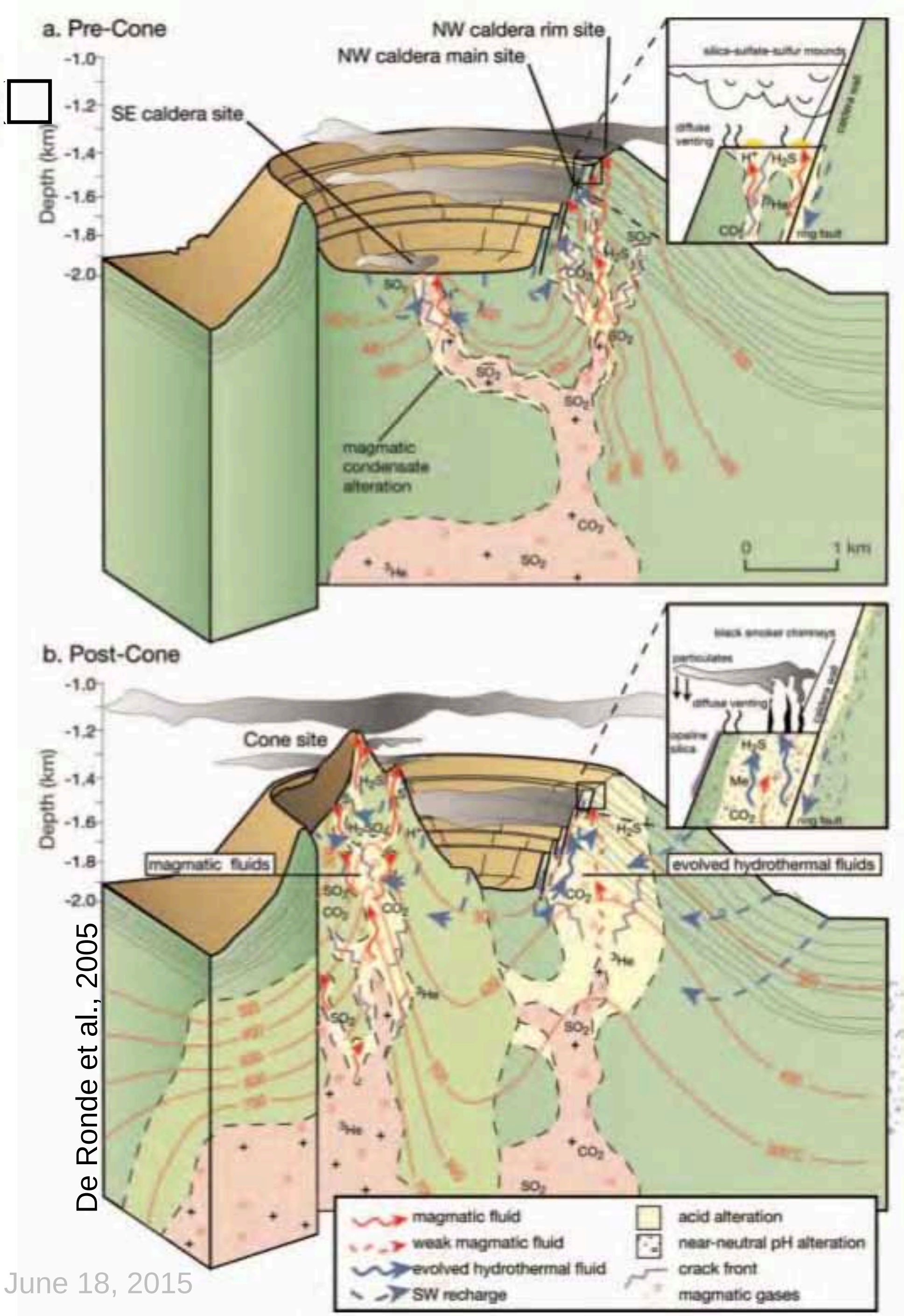
(De Ronde et al., 2005; 2011)

Magmatic-Hydrothermal System, Brothers Volcano



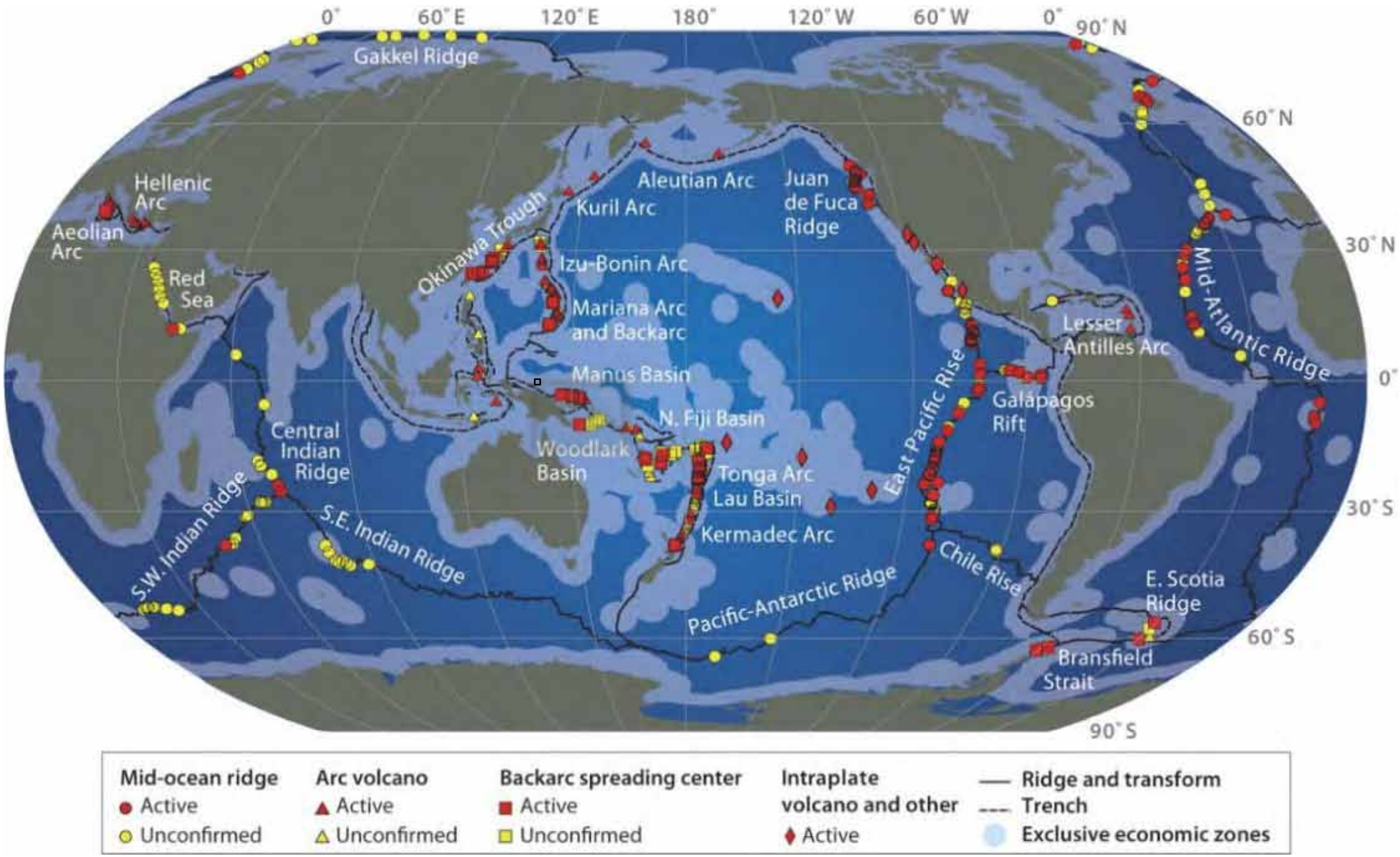
De Ronde et al., 2005

Magmatic-Hydrothermal System, Brothers Volcano

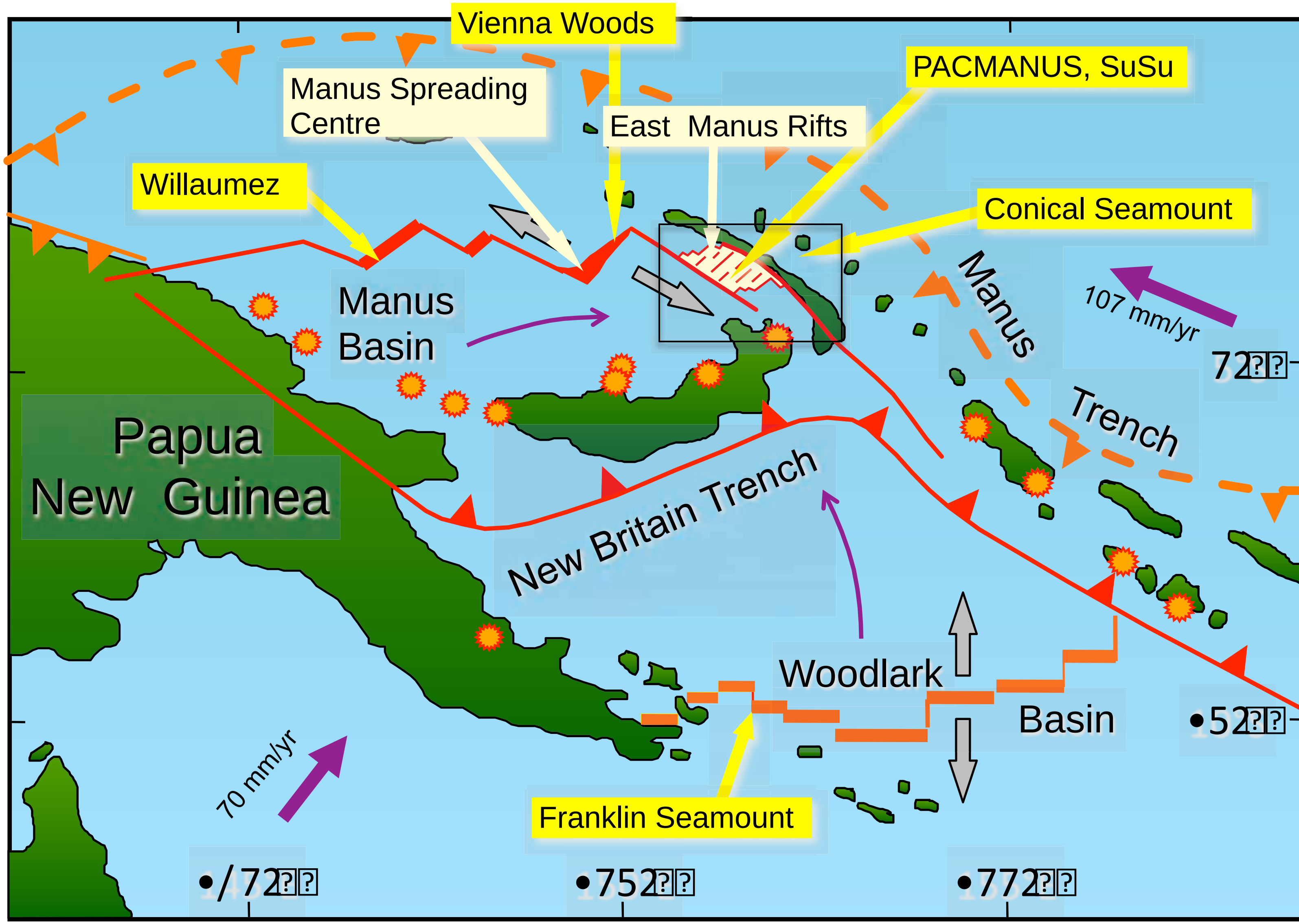


De Ronde et al., 2005

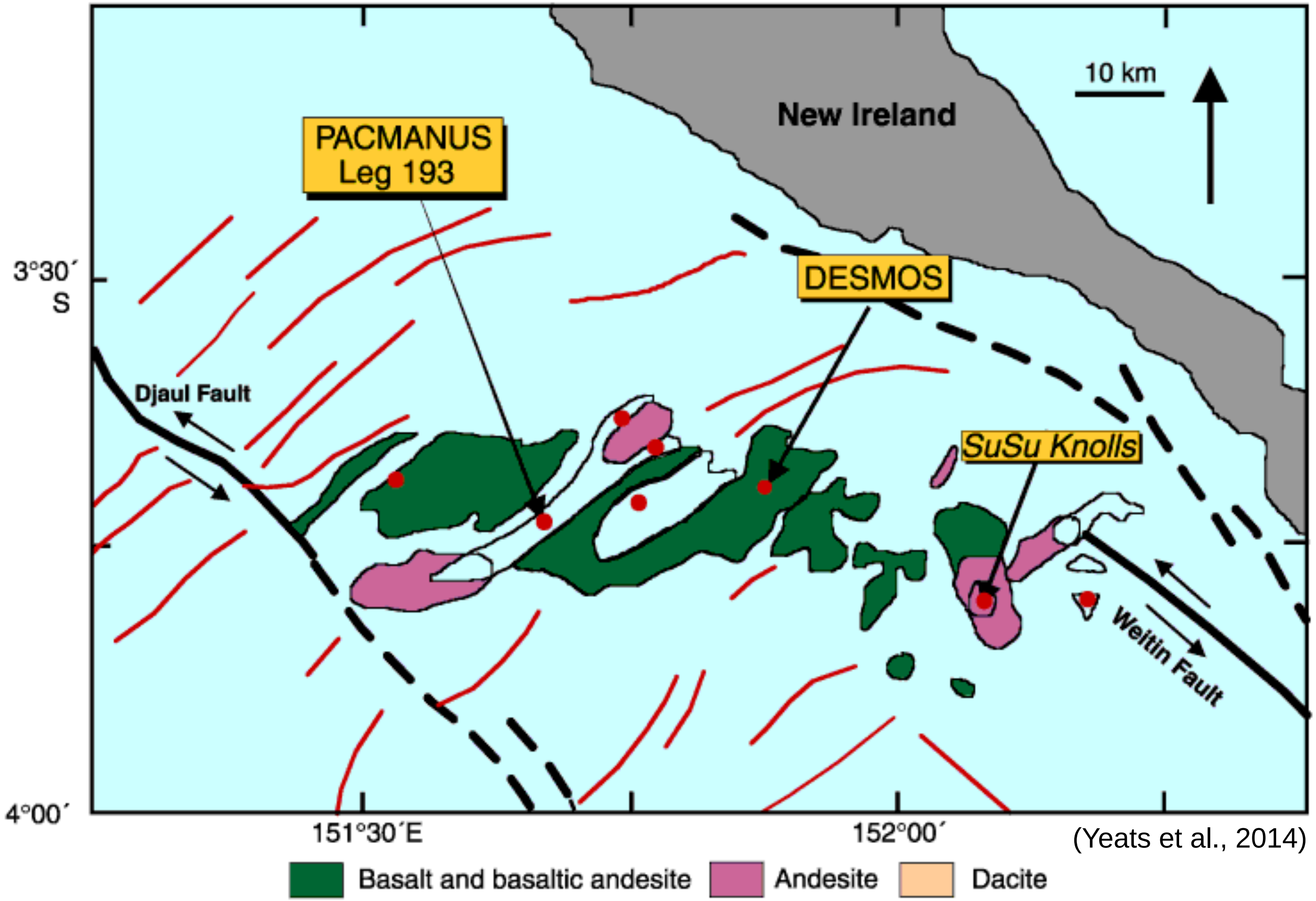
Modern SMS Systems



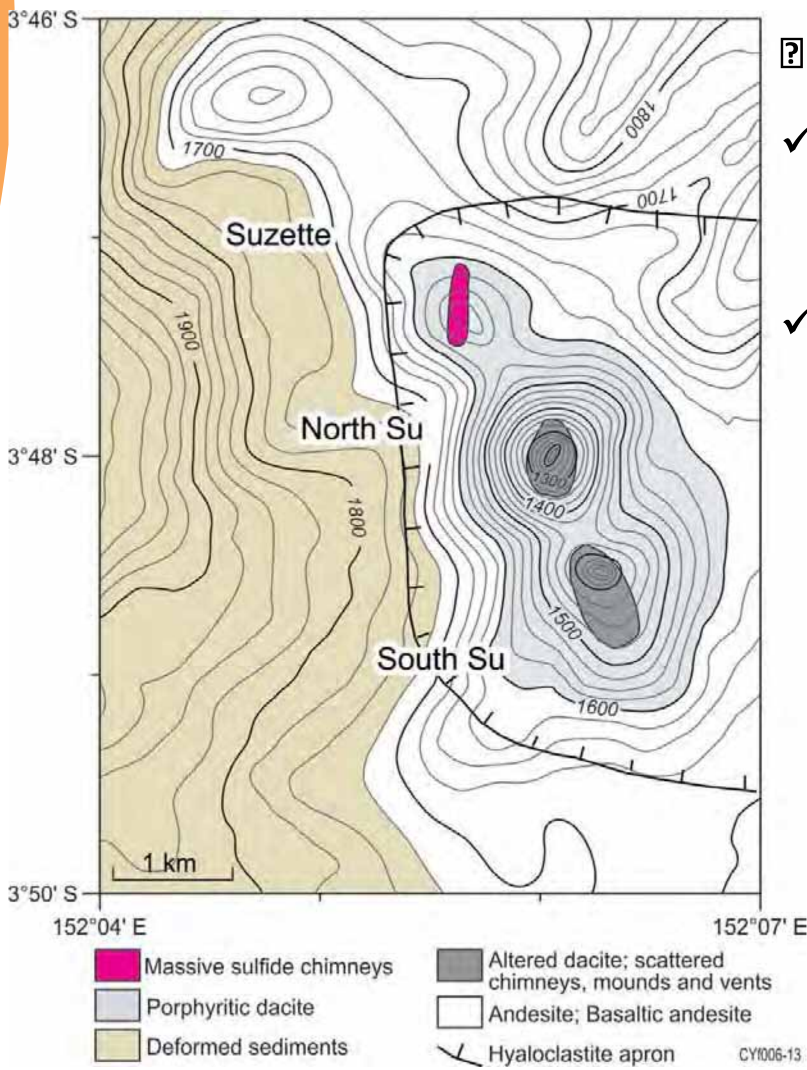
(Elosta, 2014)



Vienna Woods
PACMANUS, SuSu
Manus Spreading Centre
East Manus Rifts
Willaumez
Conical Seamount
Manus Basin
Manus Trench
107 mm/yr
Papua New Guinea
New Britain Trench
Woodlark Basin
70 mm/yr
Franklin Seamount

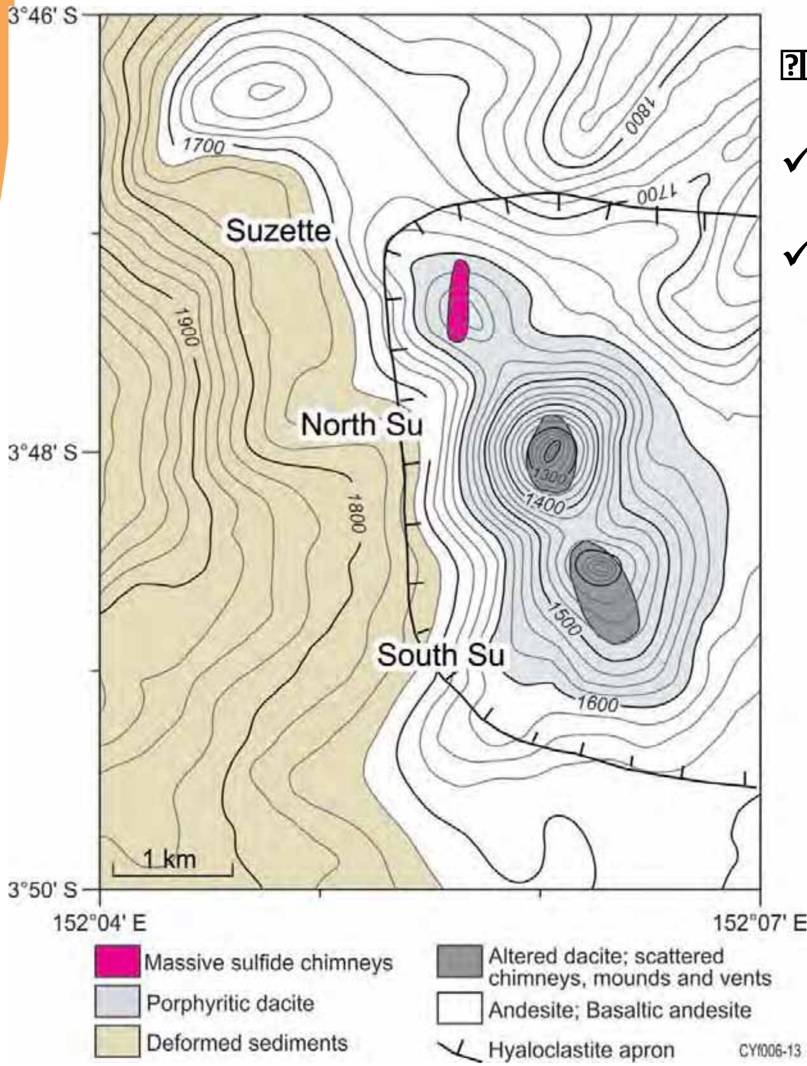


(Yeats et al., 2014)



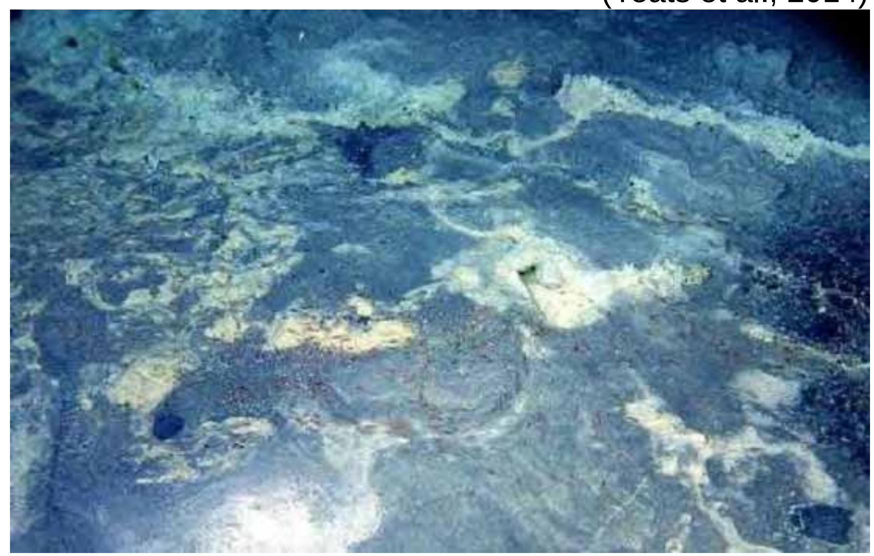
(Yeats et al., 2014)

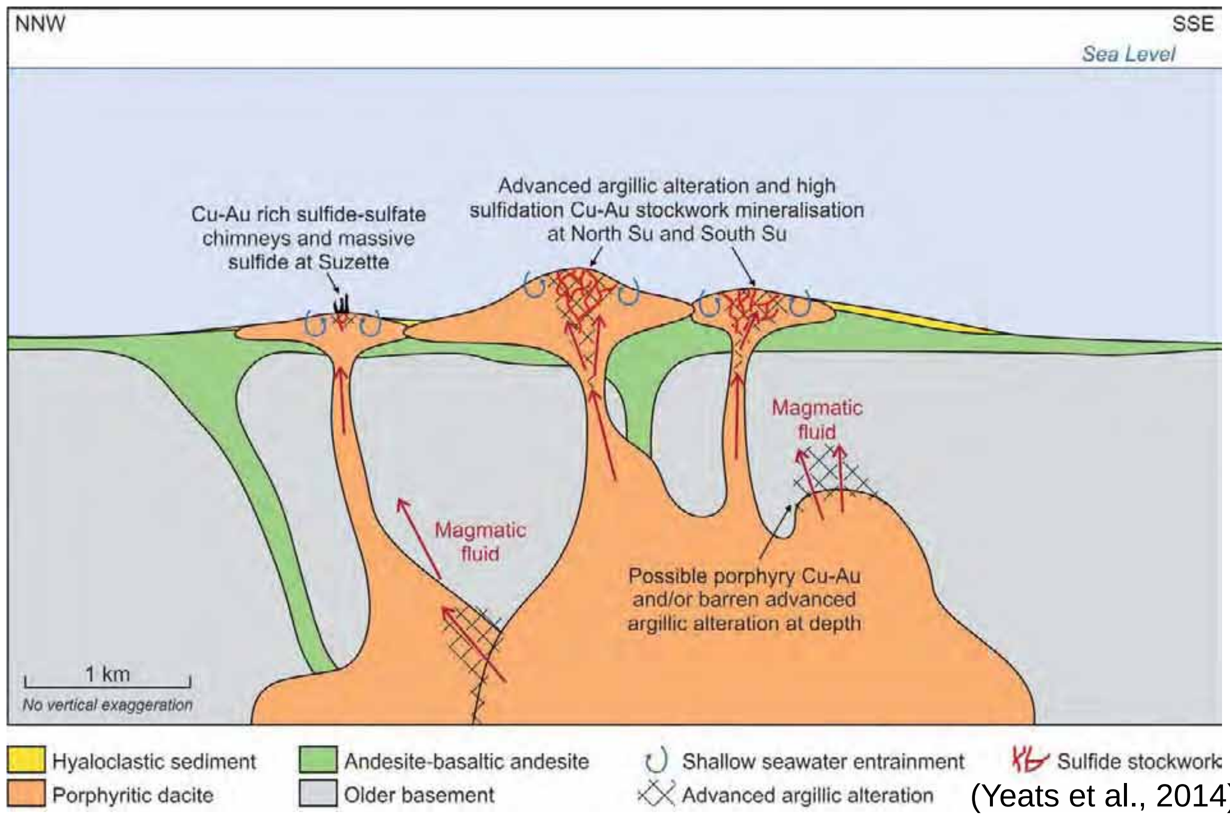
Susu Knolls Hydrothermal Field



(Yeats et al., 2014)

(Yeats et al., 2014)

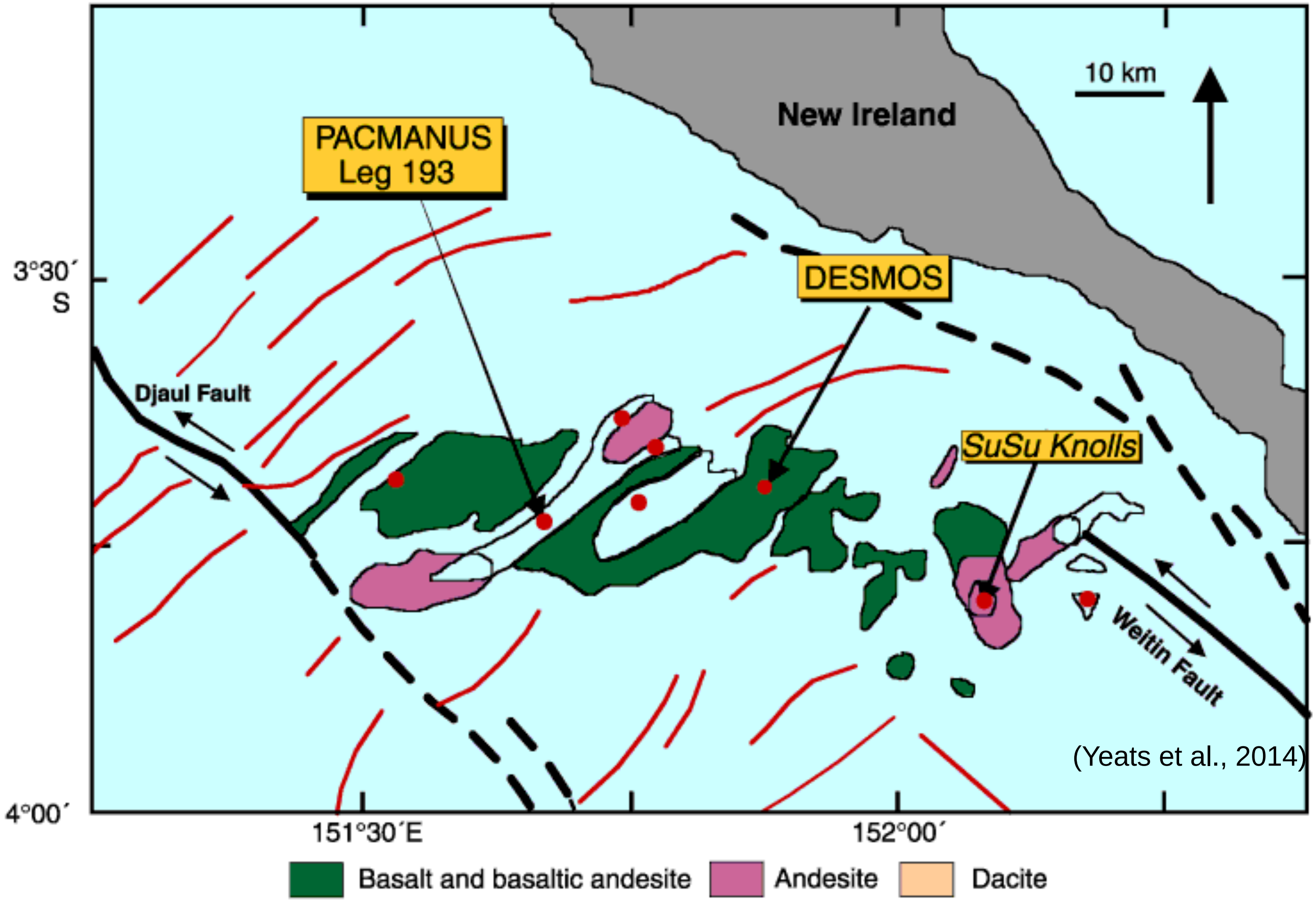




(Yeats et al., 2014)

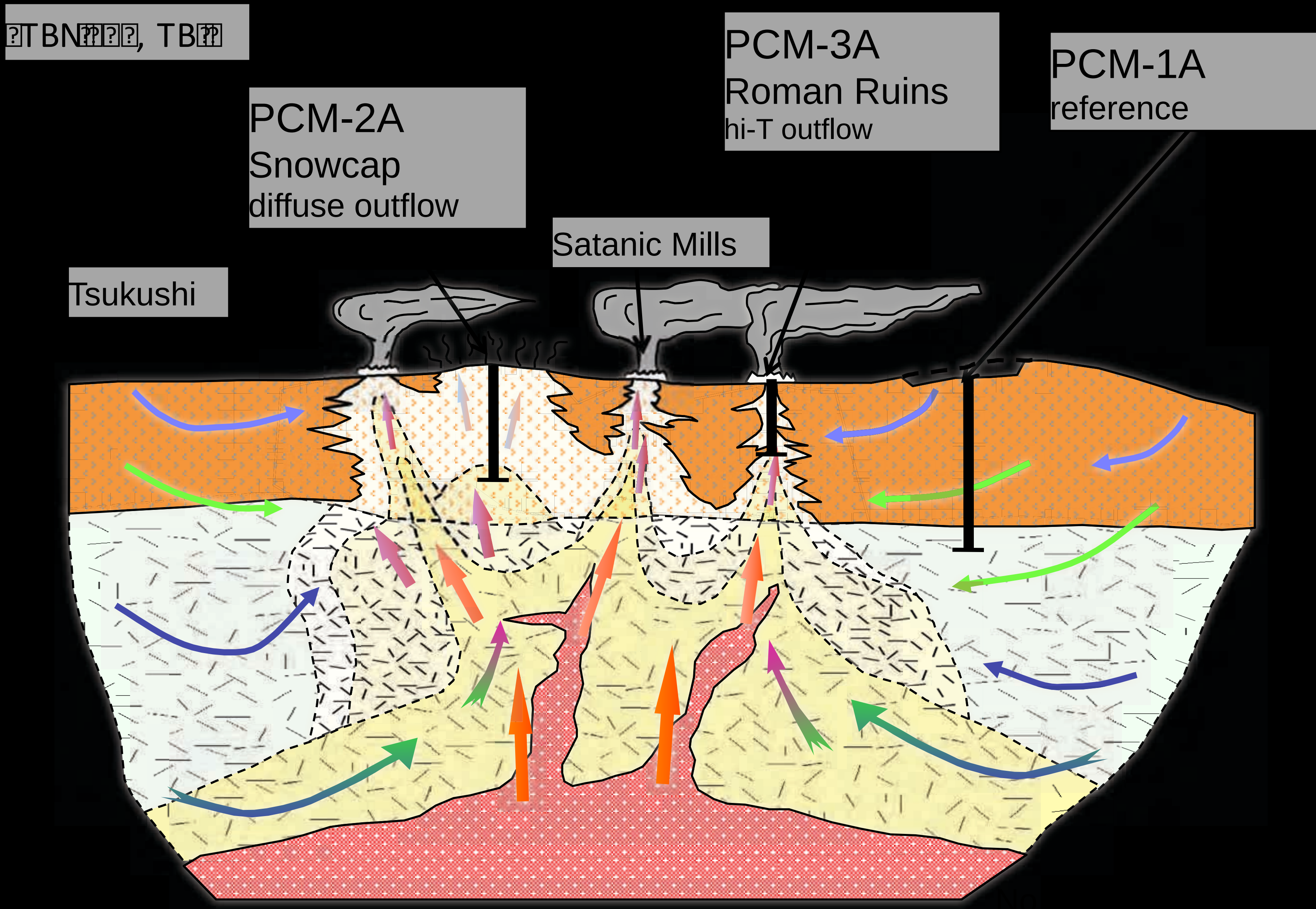

J2-192 2006/04/27 20:50:48 H=339 D=0556

Eastern Manus Basin



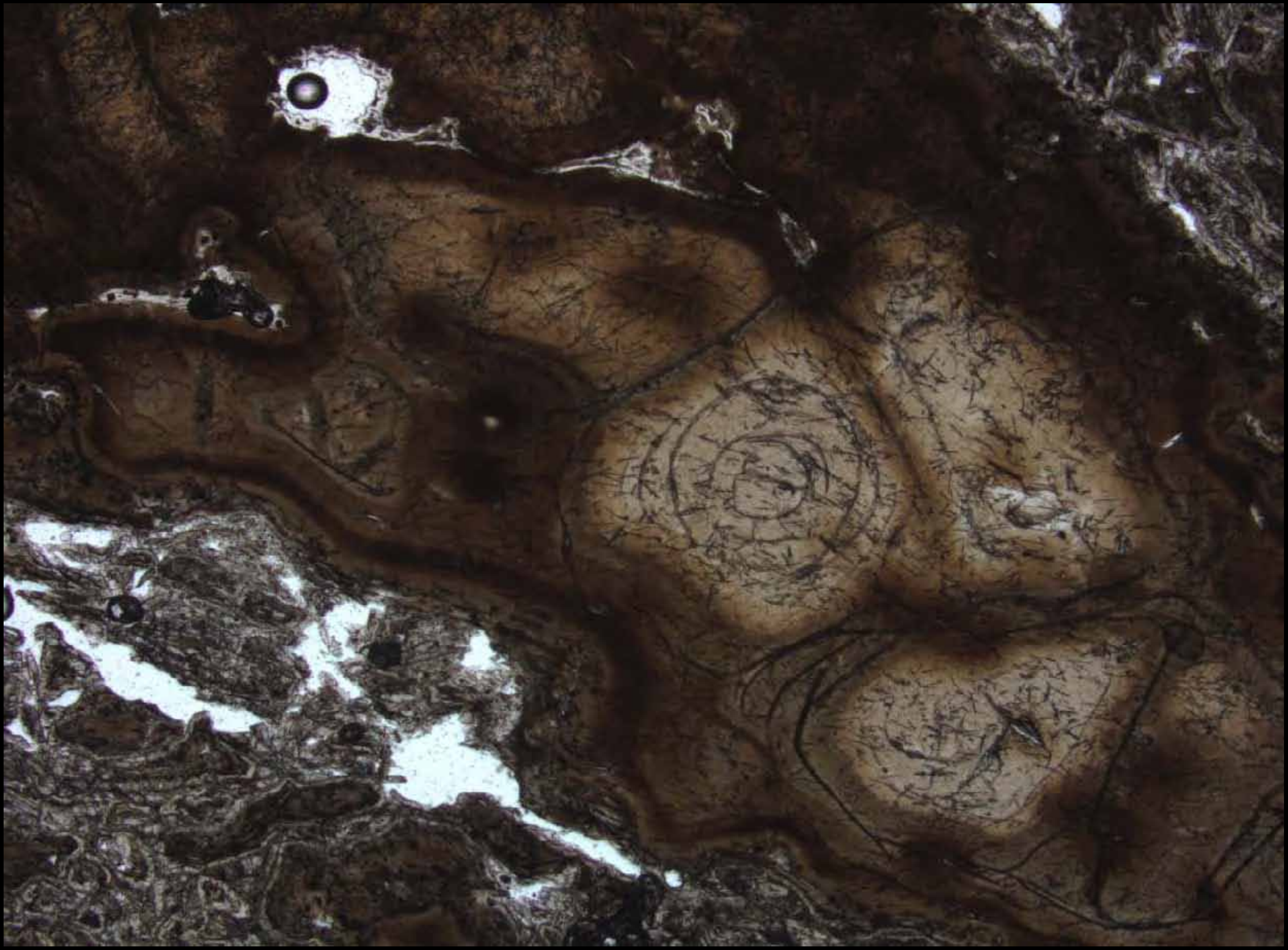
(Yeats et al., 2014)

Pacmanus hydrothermal field

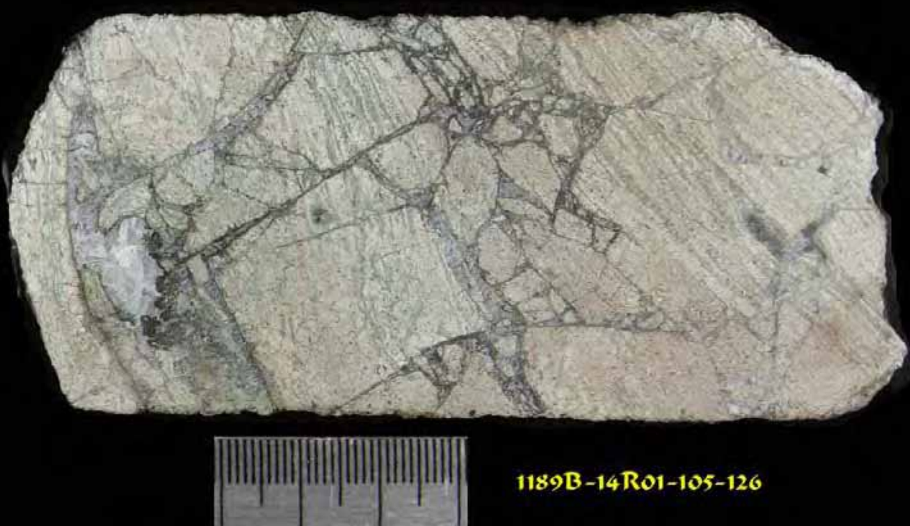


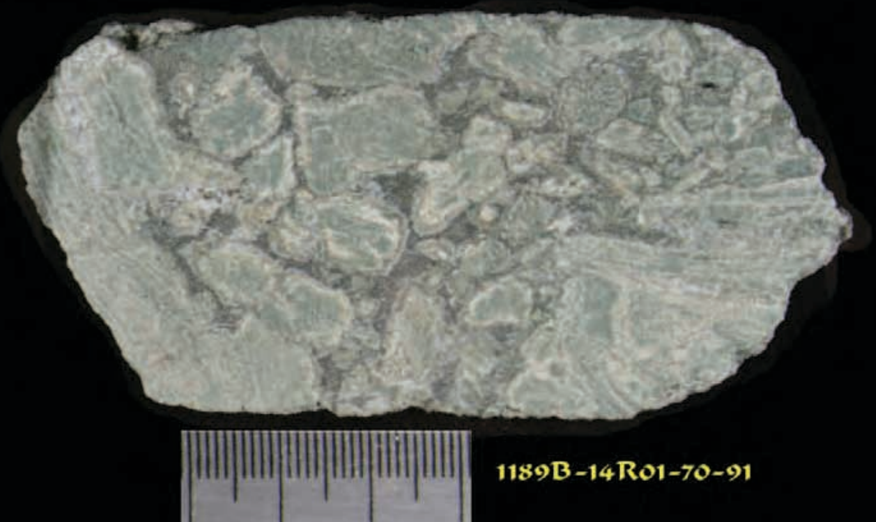
Pacmanus hydrothermal field – ODP/Leg 193

Roman Ruins: dacitic volcanic rocks

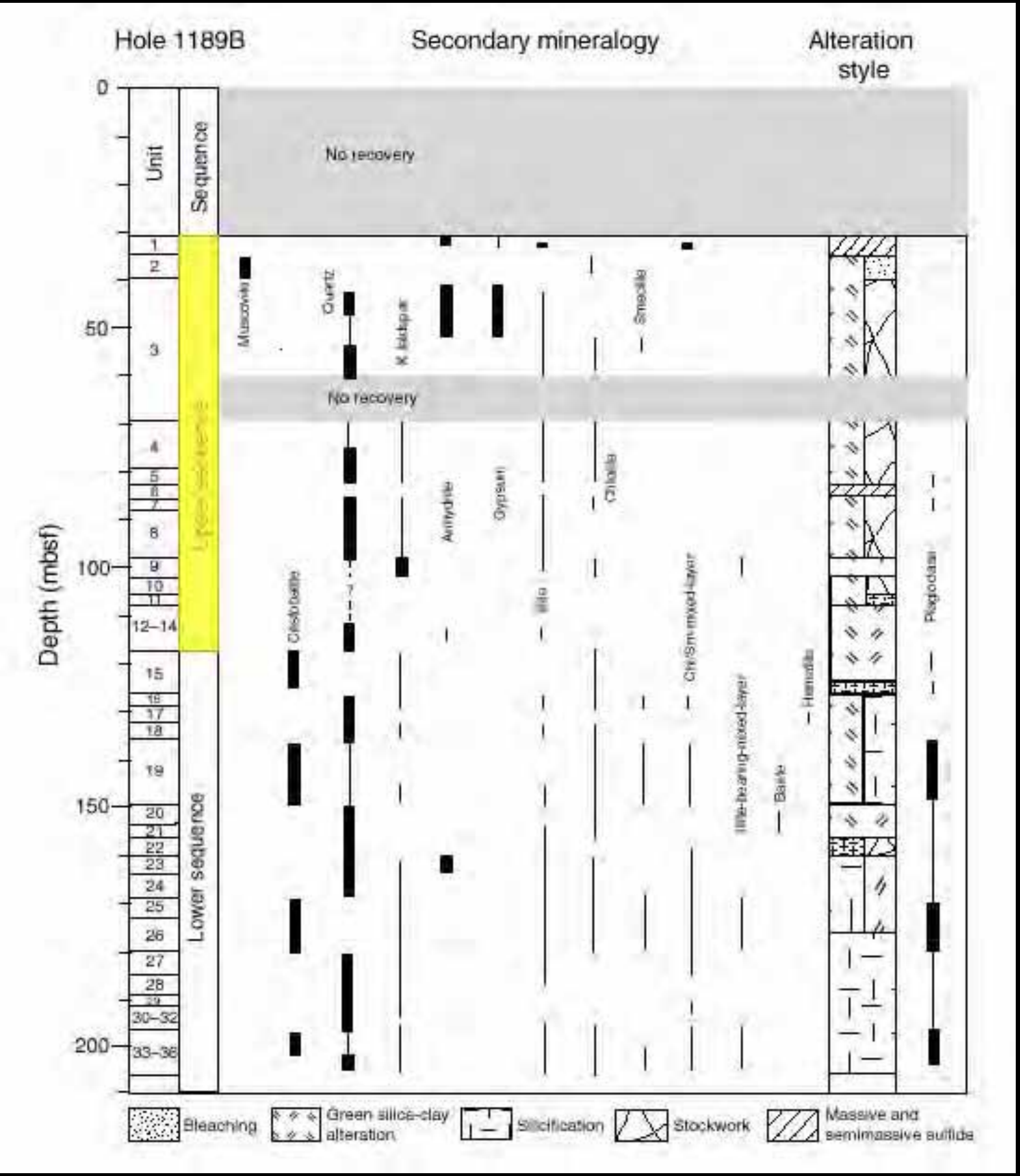


Pseudobreccia *vs.* hydrothermal breccia





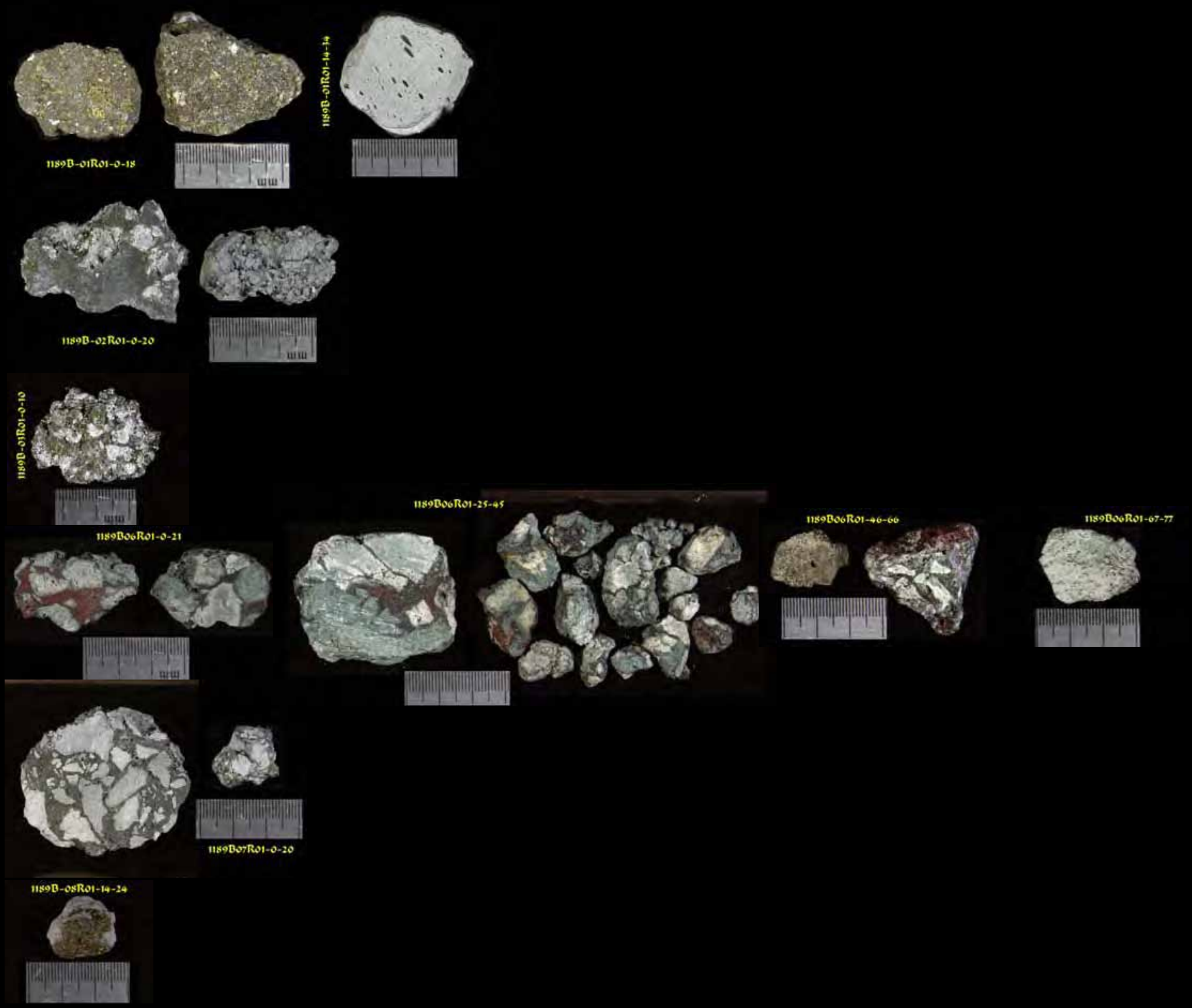
Subseafloor replacement: Hole 1189B



Subseafloor replacement: Hole 1189B

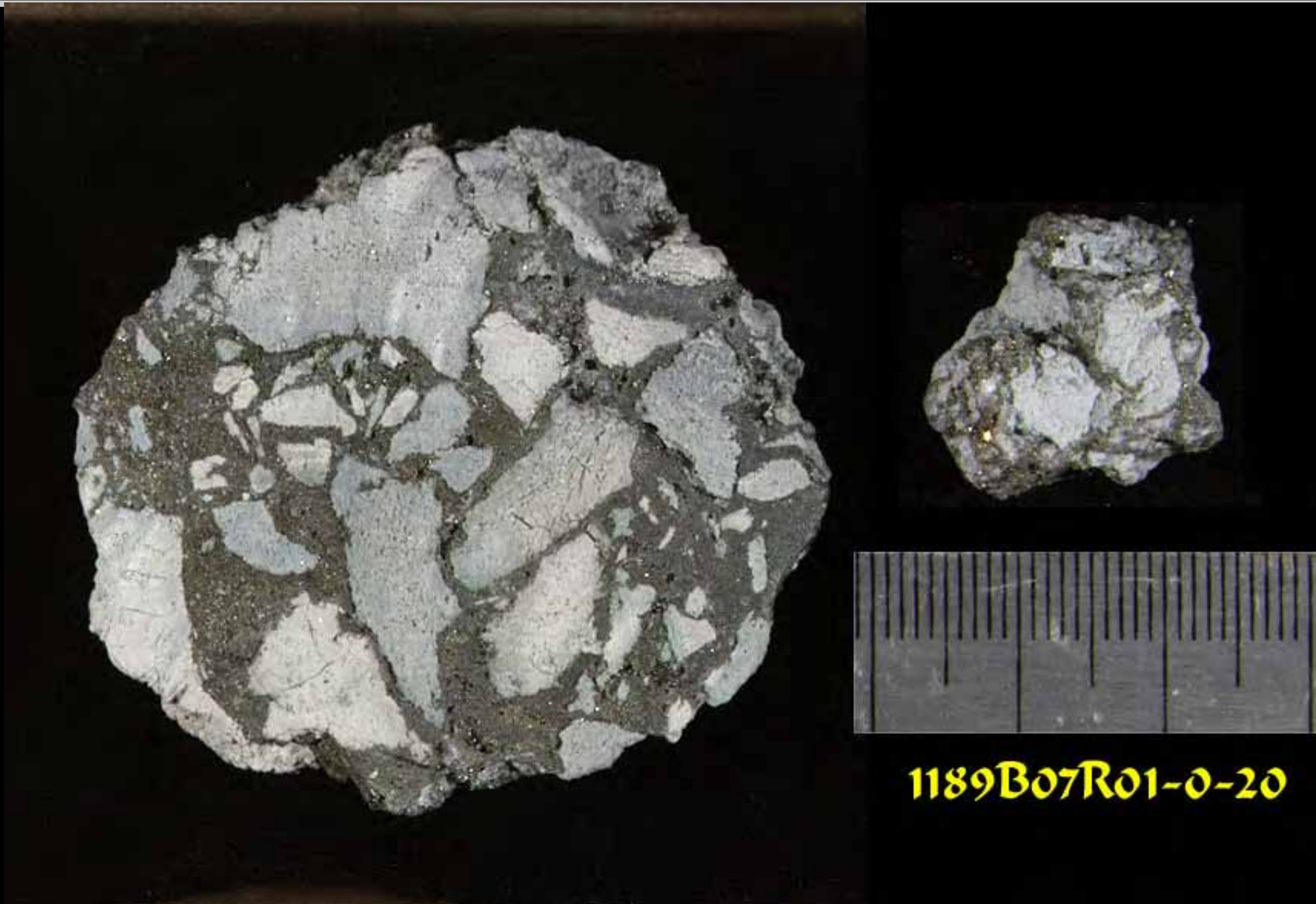
- 31 to 117.9 m:
  - less than 1% recovery
  - 86.9 m drilling in 8h10m (Dec 24, 2000)

Subseafloor replacement: Hole 1189B



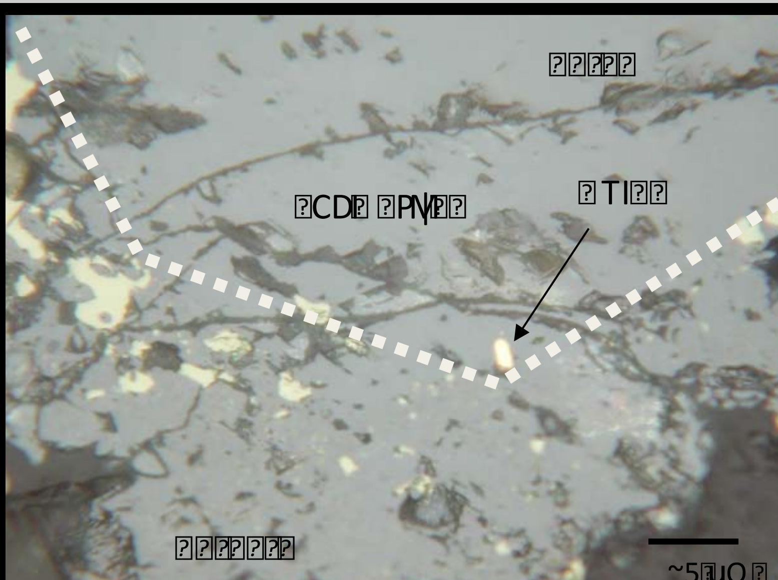
Subseafloor replacement: Hole 1189B

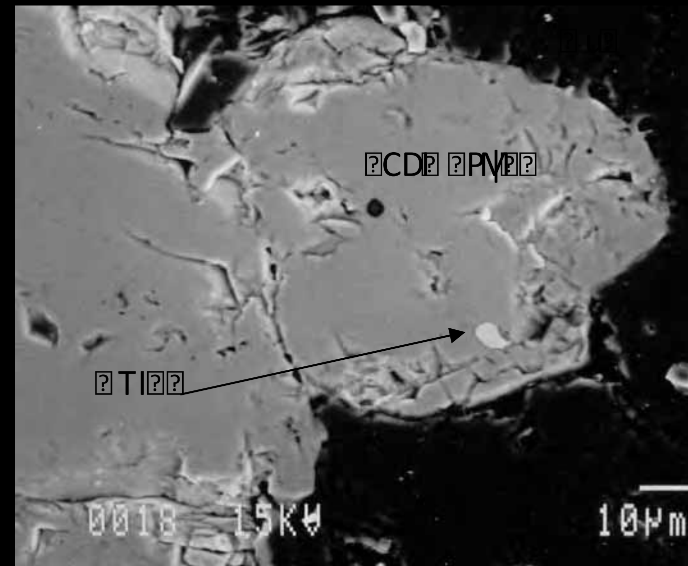
Subseafloor replacement: Hole 1189B

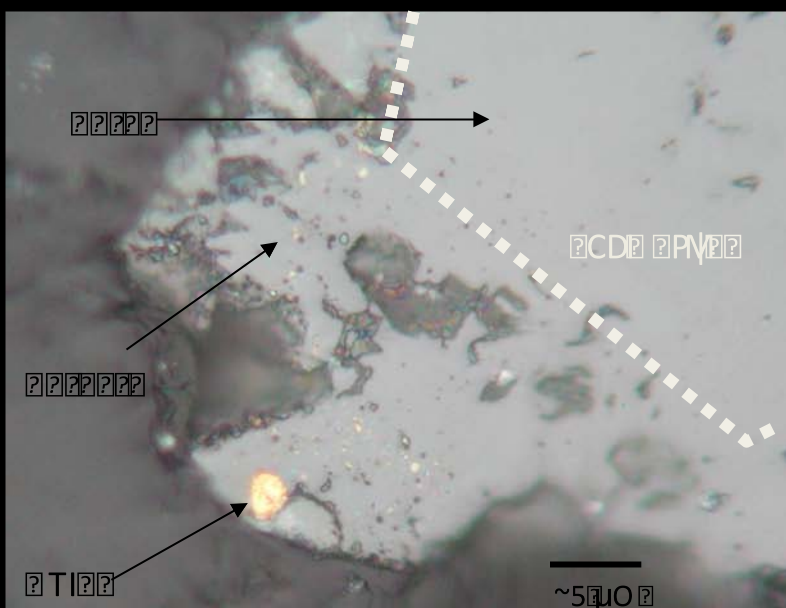


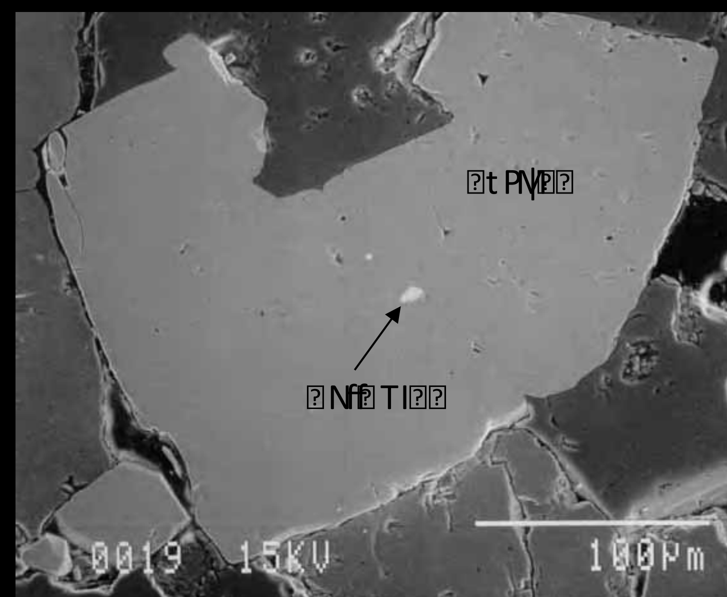
Subseafloor replacement: Hole 1189B

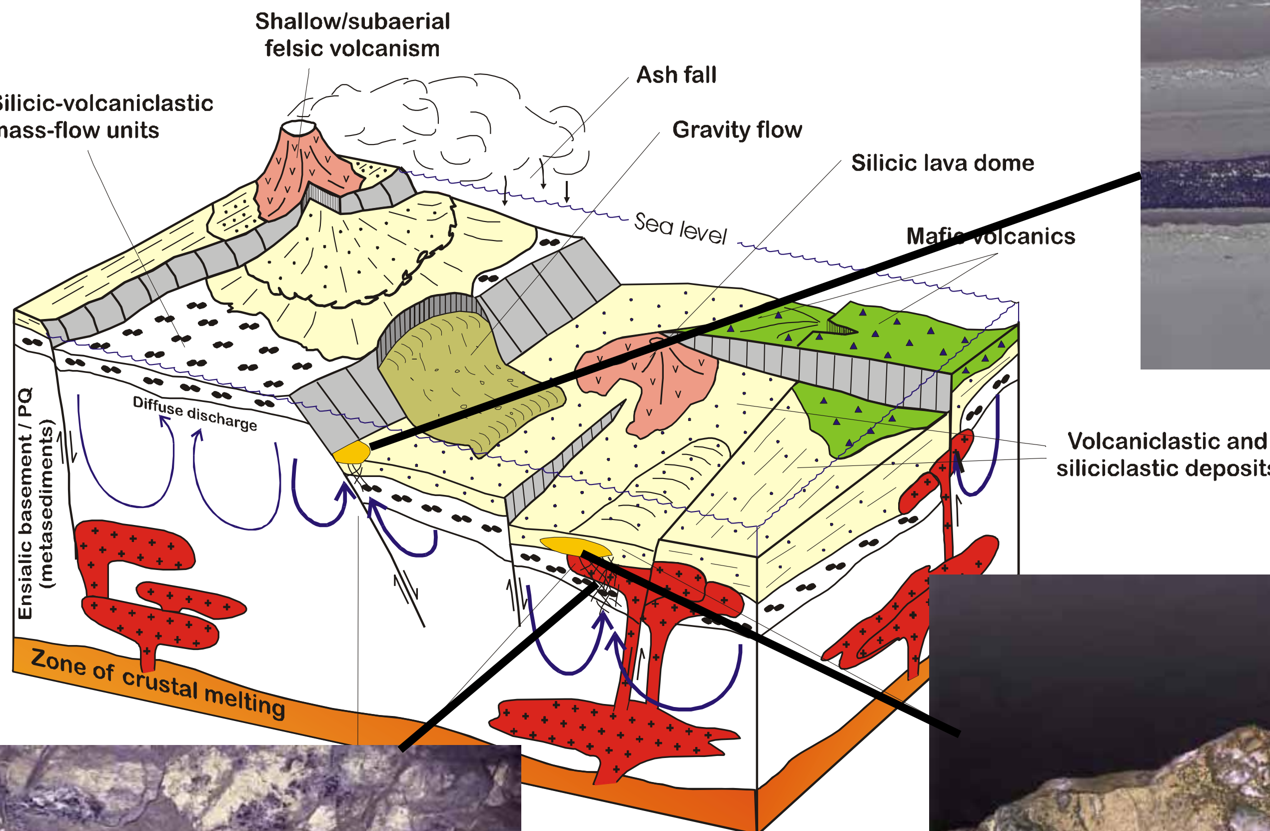
Roman Ruins: gold



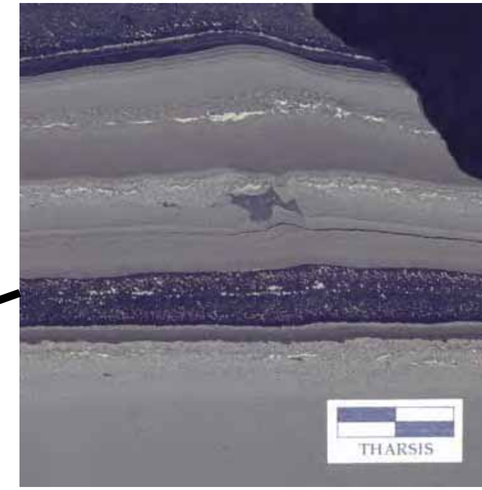








Shallow/subaerial felsic volcanism
Ash fall
Silicic-volcaniclastic mass-flow units
Gravity flow
Silicic lava dome
Sea level
Mafic volcanics
Diffuse discharge
Ensialic basement / PQ (metasediments)
Volcaniclastic and siliciclastic deposits
Zone of crustal melting



THARSIS

Textural evidence for replacement

*Shallow subsurface replacement of muds/shales;

EMRA'15 workshop

Textural evidence for replacement

*Shallow subsurface replacement of muds/shales;

Textural evidence for replacement

*Shallow subsurface replacement of muds/shales;

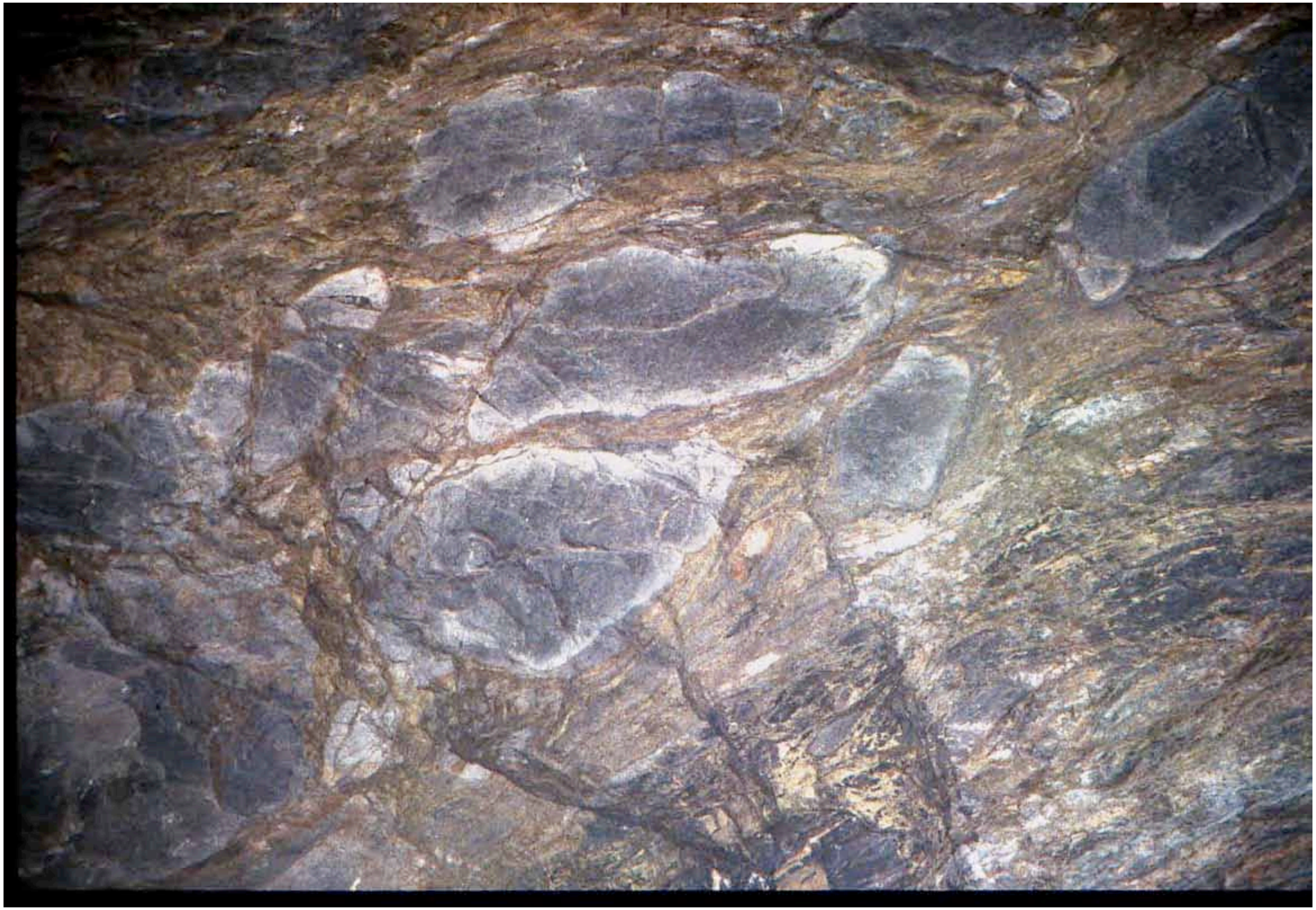
Textural evidence for replacement

*Shallow subsurface replacement of volcanogenic siltstone;

Textural evidence for replacement

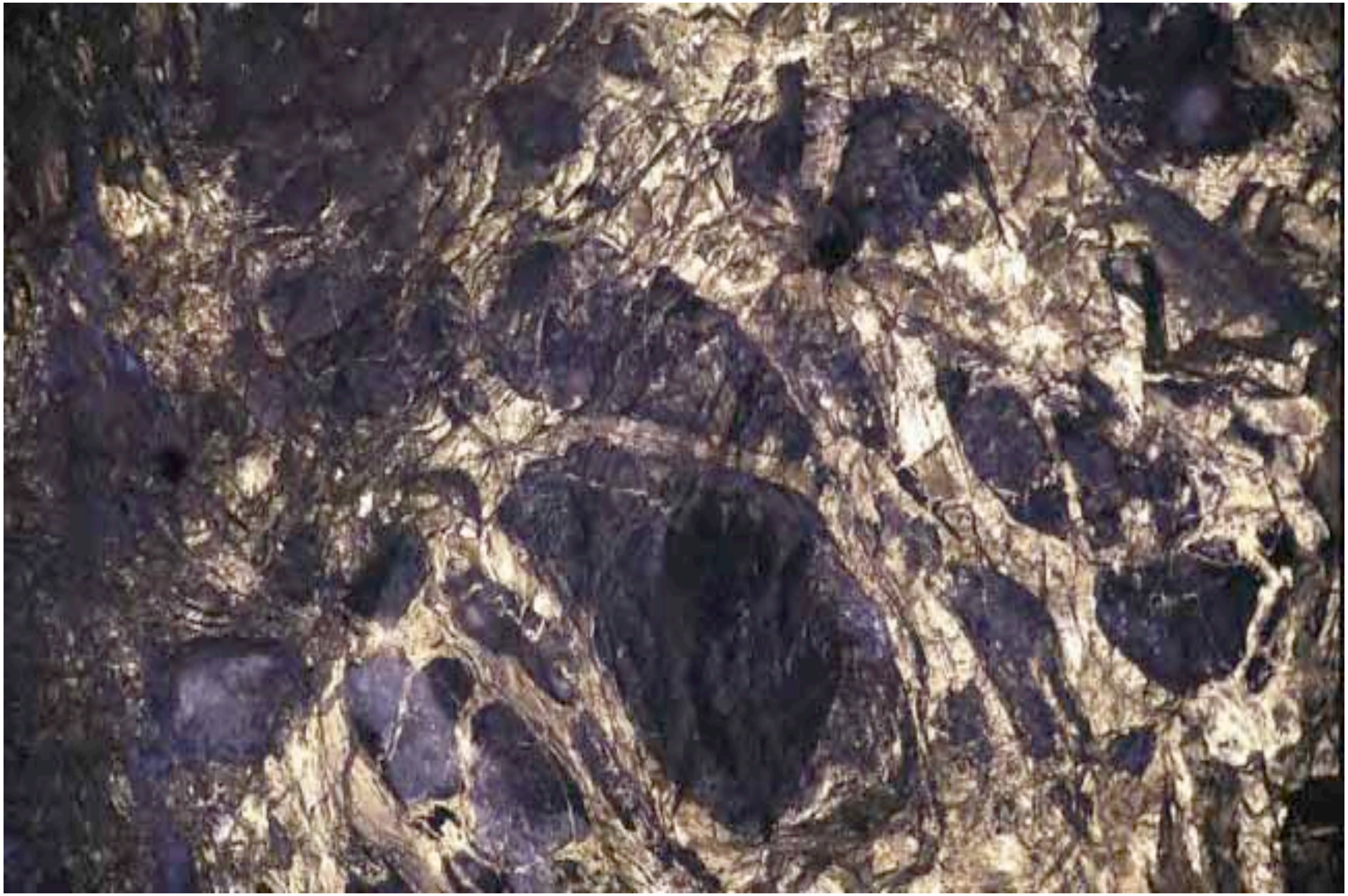
*Shallow subsurface replacement of coherent felsic volcanics

Textural evidence for replacement



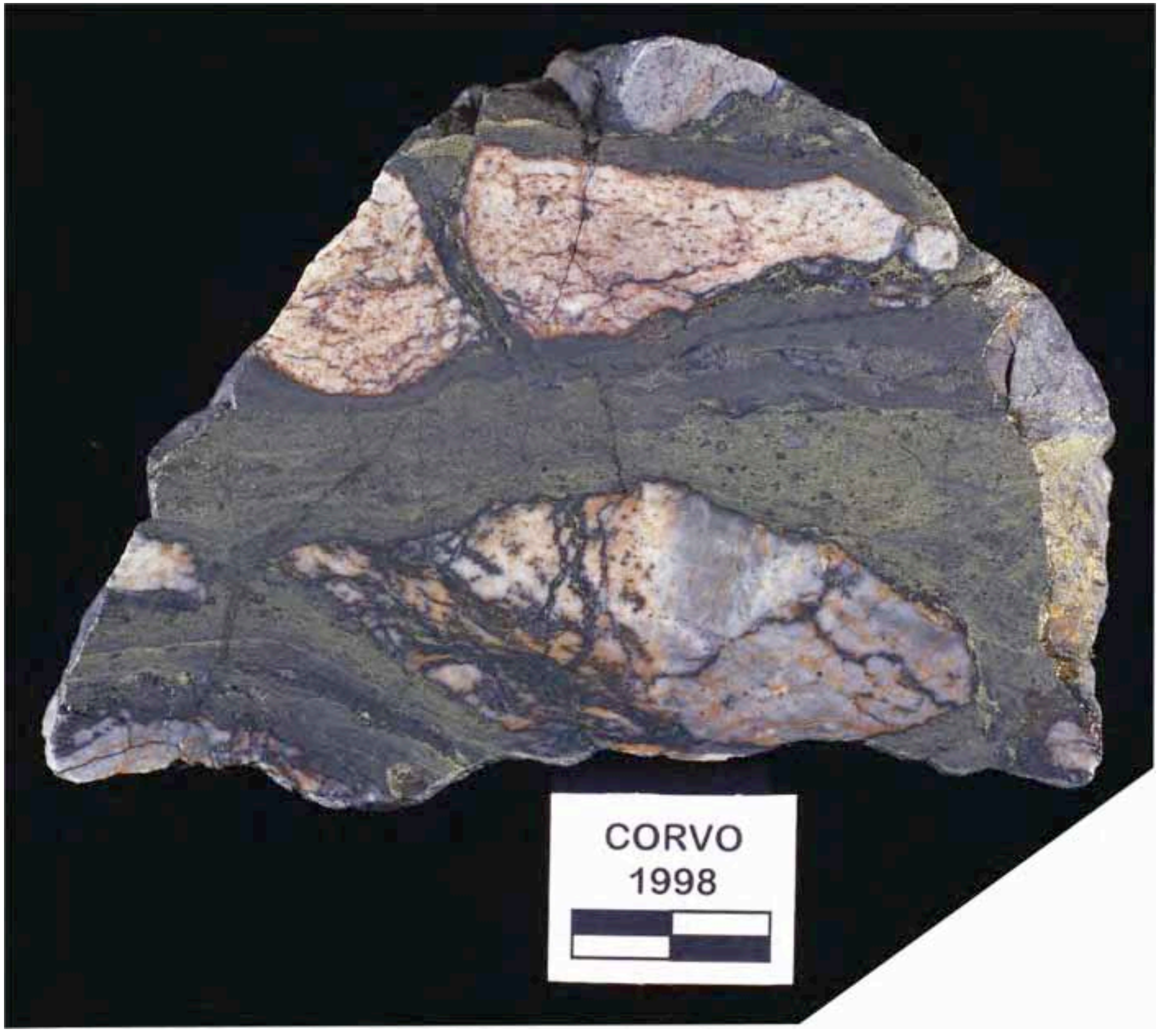
*Shallow subsurface replacement of coherent felsic volcanics

Textural evidence for replacement



*Shallow subsurface replacement of coherent felsic volcanics

Textural evidence for replacement

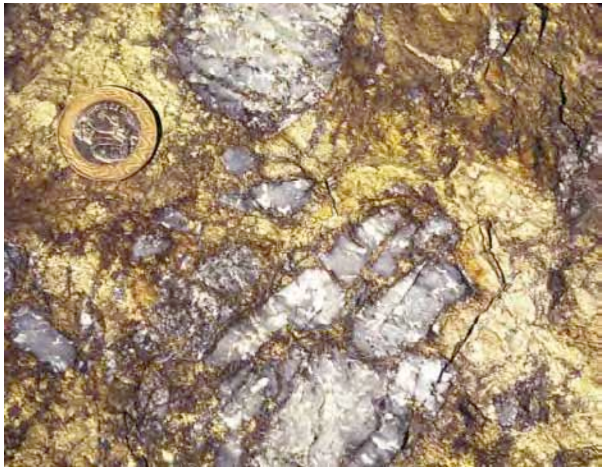


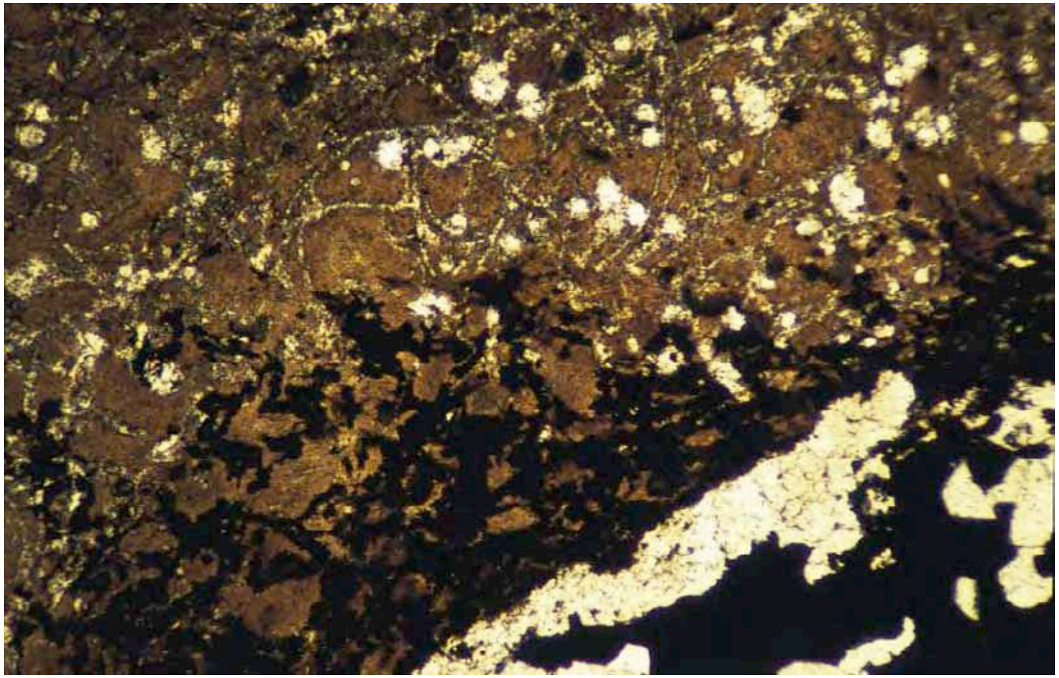
*Shallow subsurface replacement of coherent felsic volcanics

Textural evidence for replacement

*Shallow subsurface replacement of coherent felsic volcanics

Textural evidence for replacement



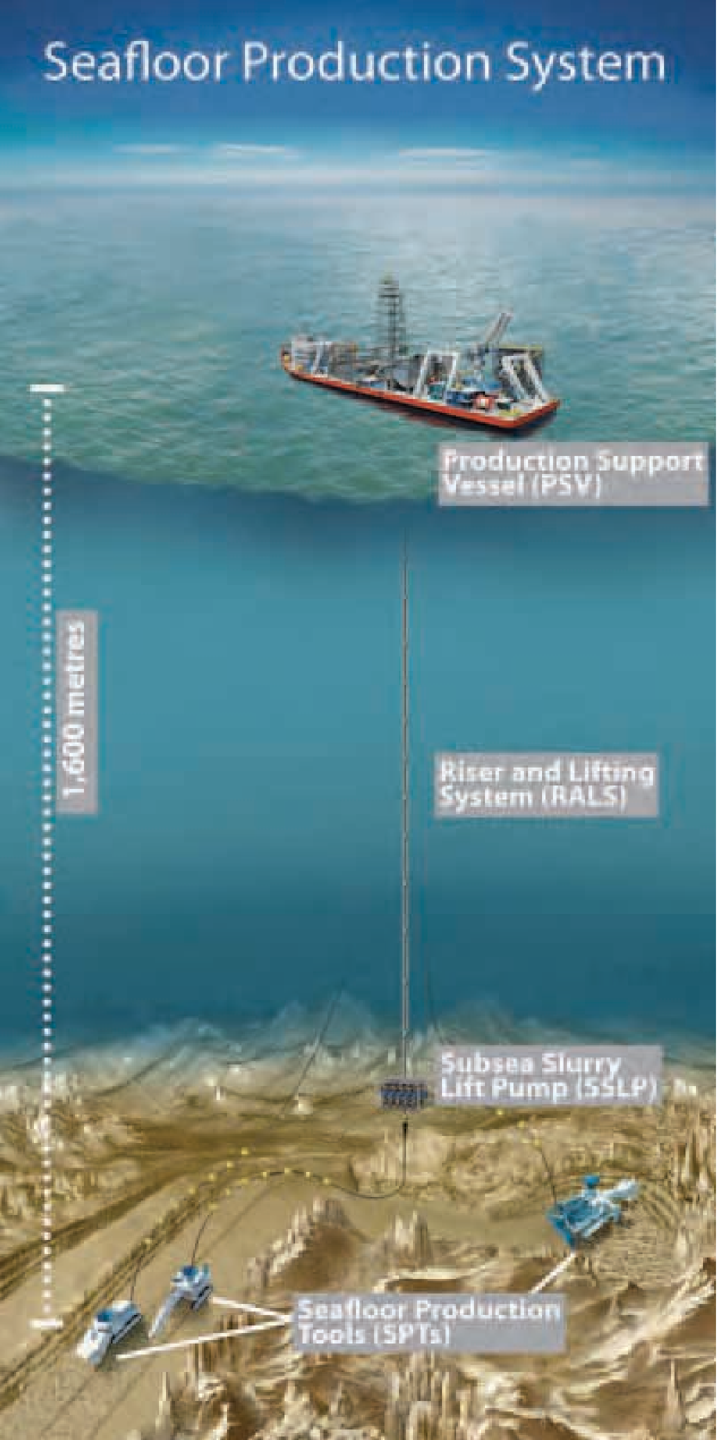


*Shallow subsurface replacement of coherent felsic volcanics

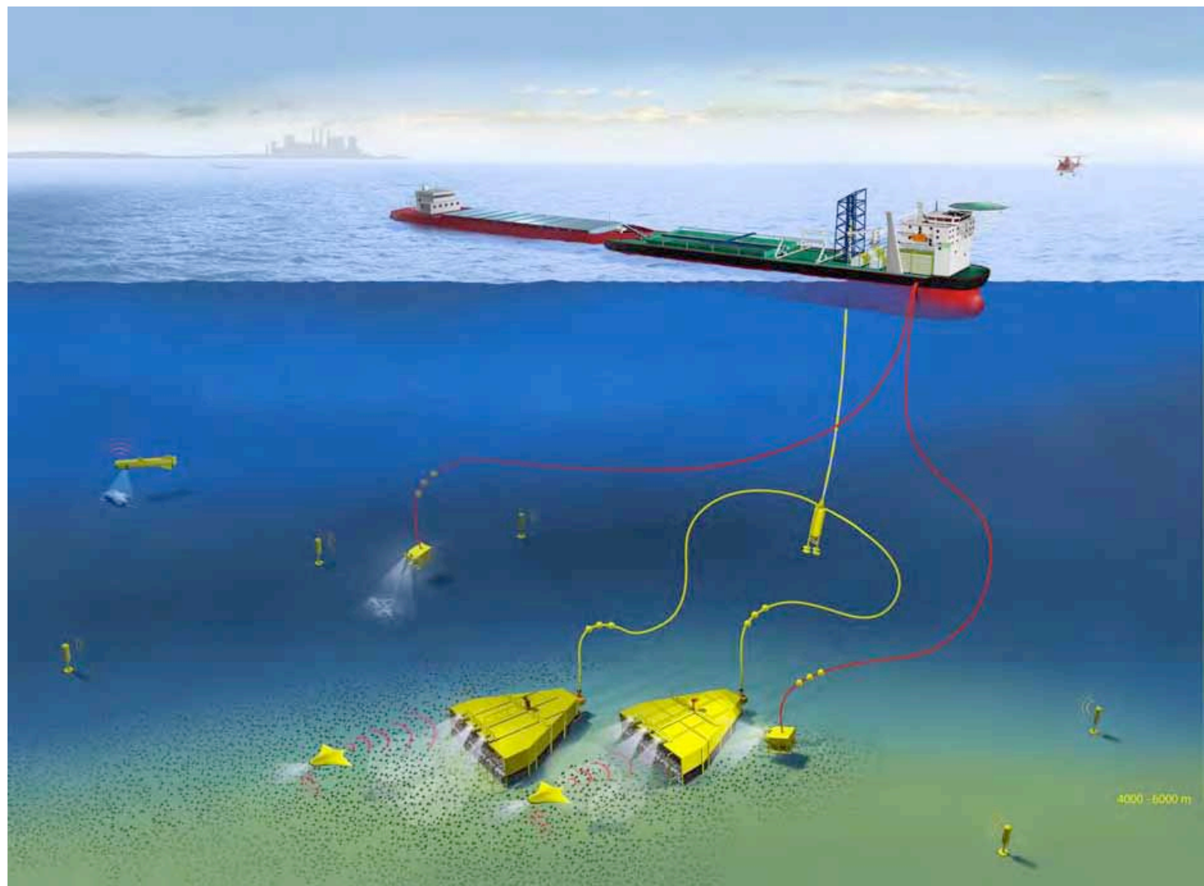
Eastern Manus Basin, PNG - Nautilus Concessions

Location	size/tonnage	N	Cu	Zn	Au	Ag	depth (m)
			wt.%		ppm		
Western Manus Basin							
Solwara 11	-	26	1.6	16.9	1.2	180	1390 - 1450
Solwara 18	-	2	0.3	19.6	0.2	110	1310
Central Manus Basin							
Vienna Woods, Solwara 2	-	215	1.2	21.0	10.0	355	2470 - 2500
Solwara 03	-	31	1.1	21.3	15.2	642	2560 - 2590
Solwara 10	-	12	7.7	15.2	2.5	165	2240
Solwara 14	-	14	1.4	19.2	3.3	97	2240
Solwara 16	-	6	2.1	18.6	2.8	105	2160
Eastern Manus Basin							
Suzette (Solwara 01)	90 000 m^2	250	9.7	5.4	15.0	174	1460
Suzette (Solwara 01)*	1 030 000 t	indicated	7.2	0.4	5.0	23	1460
Suzette (Solwara 01)*	1 540 000 t	inferred	8.1	0.9	6.4	34	1460
North Su	-	4	7.1	1.6	4.8	39	1183
South Su	-	4	7.4	9.2	6.8	191	1309
Solwara 05 (N of North Su)	30 000 m^2	12	6.0	8.3	14.6	282	1635 - 1680
Solwara 09 (west of North Su)	15 000 m^2	17	6.3	10.6	19.9	296	1680
PACMANUS	45 000 m^2	336	7.4	22.5	13.7	267	1650 - 1815
Solwara 12 (near Desmos)	-	10	7.0	22.6	13.7	425	1870
Solwara 12 (near Desmos)*	230 000 t	inferred	7.3	3.6	3.6	56	1870
Solwara 13 (Yuam Ridge)	30 000 m^2	7	9.1	30.7	4.7	546	2000

Nautilus Project



Yes, these are drawings

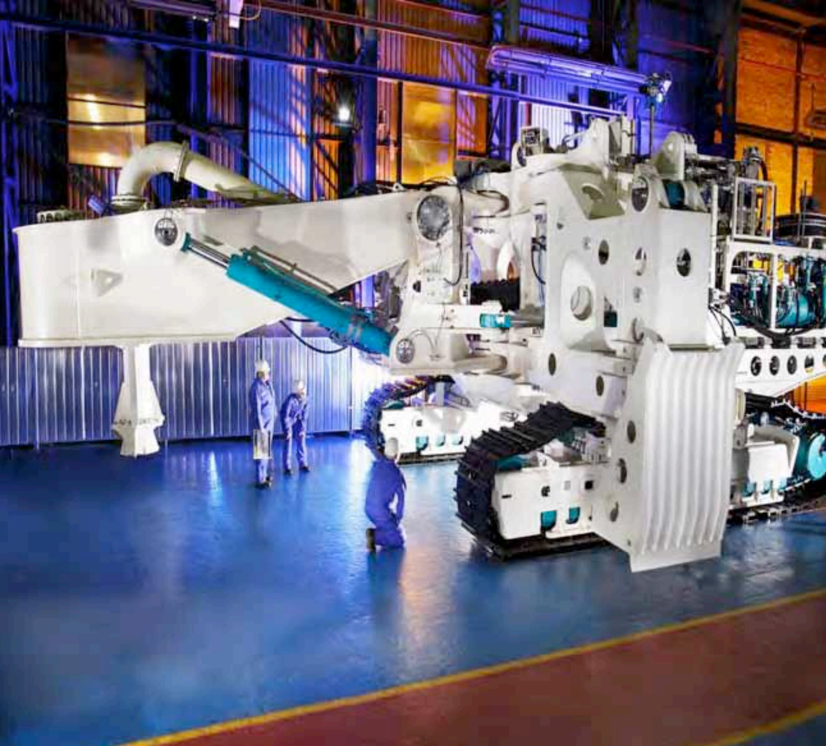





NAUTILUS

NAUTILUS


No, these are not drawings




S M D


REEF SUBSEA


CTCMARINE
RT-1 Rock Trencher
RT-1

Oceanic exploration is in its infancy!

Mineral exploration

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

Seafloor Sulfides: a Resource Perspective

- ✓ Applied research versus industrial activity
- ✓ Seafloor and sub-seafloor massive sulfides
- ✓ Inactive hydrothermal fields
- ✓ High potential, but must be demonstrated

Mining: a clean act

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

'Dirty' Mining is Past

Green Mining is Now

EMRA'15 workshop

Green Mining is Now

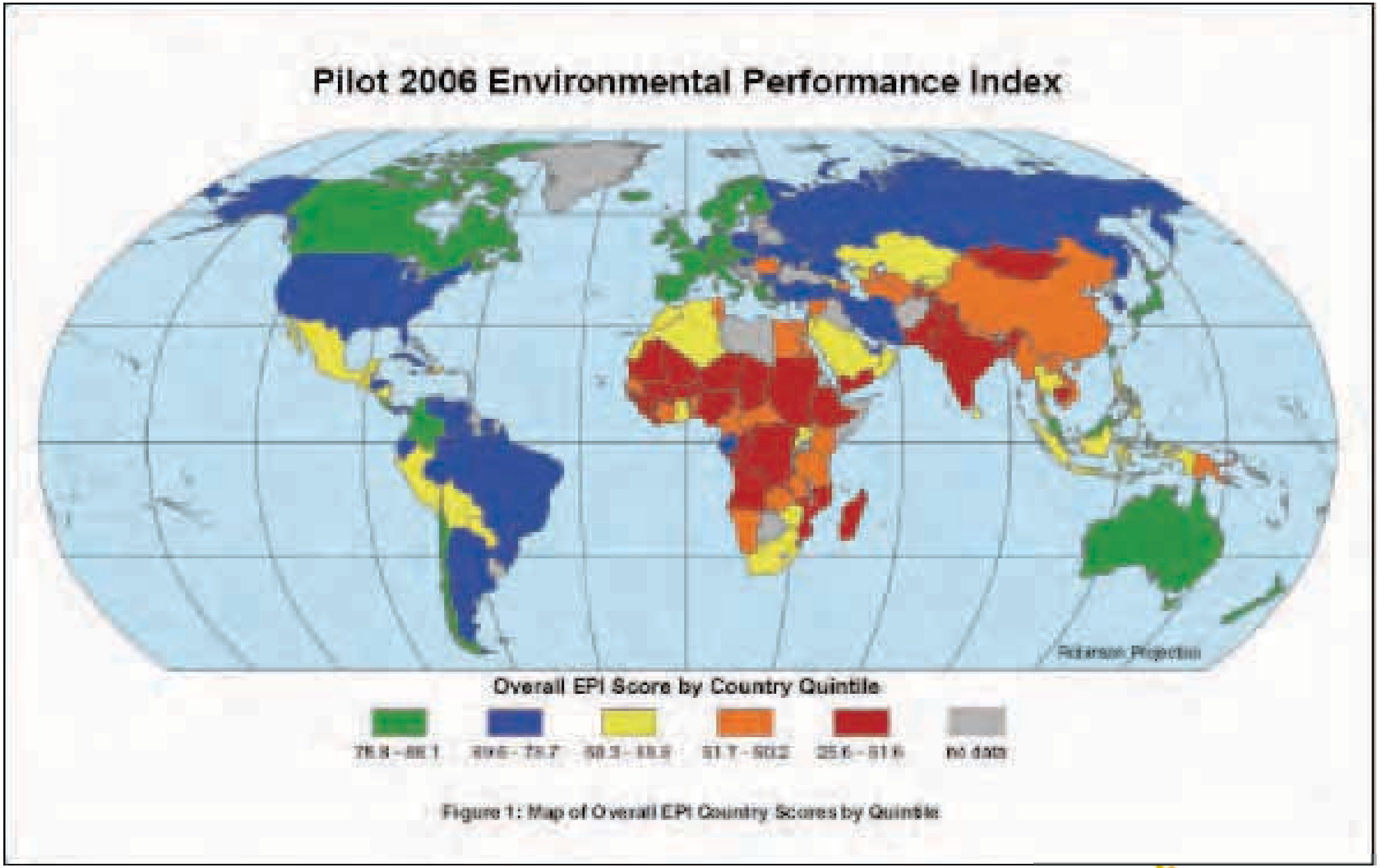
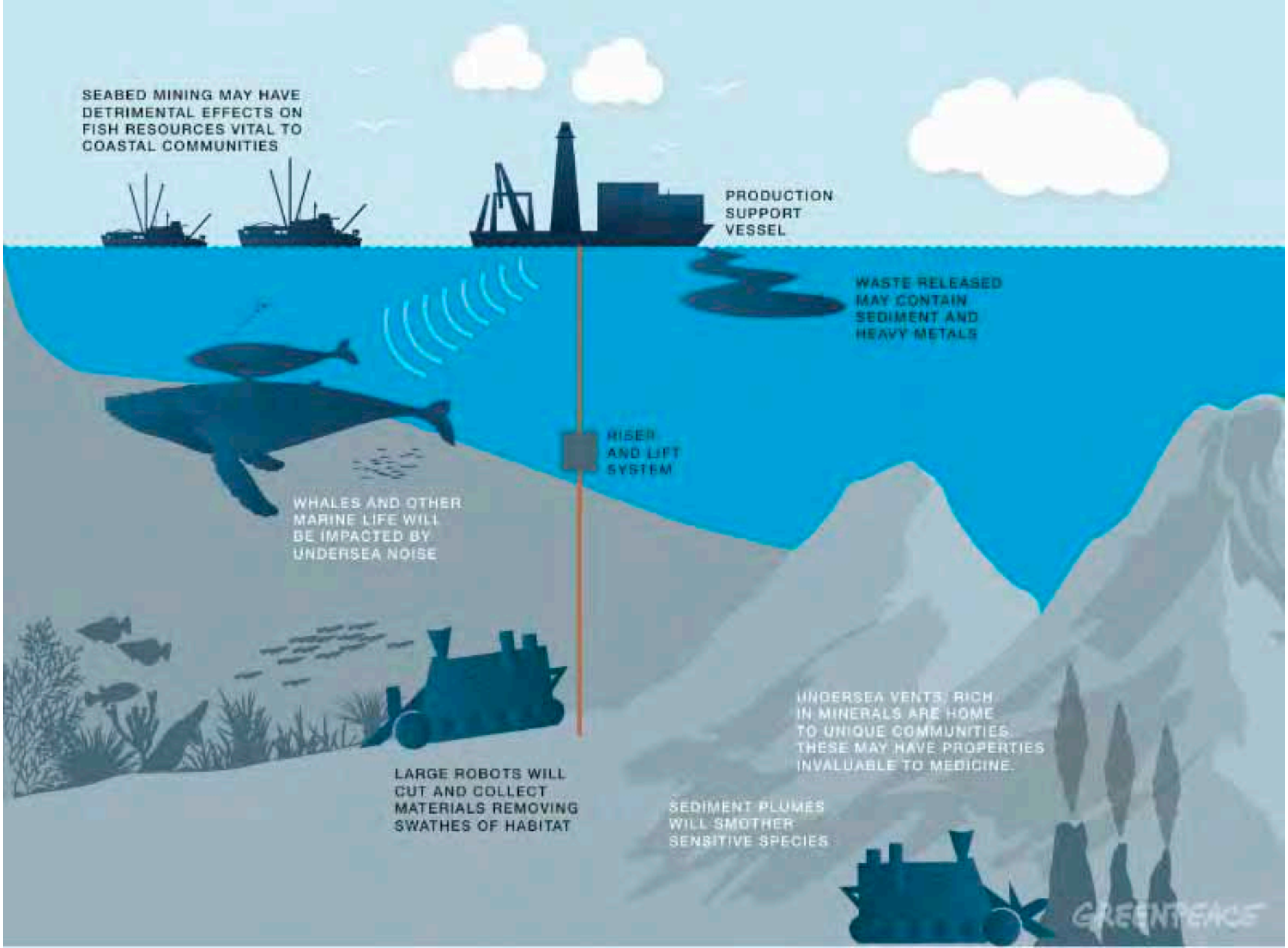


Figure 1: Map of Overall EPI Country Scores by Quintile

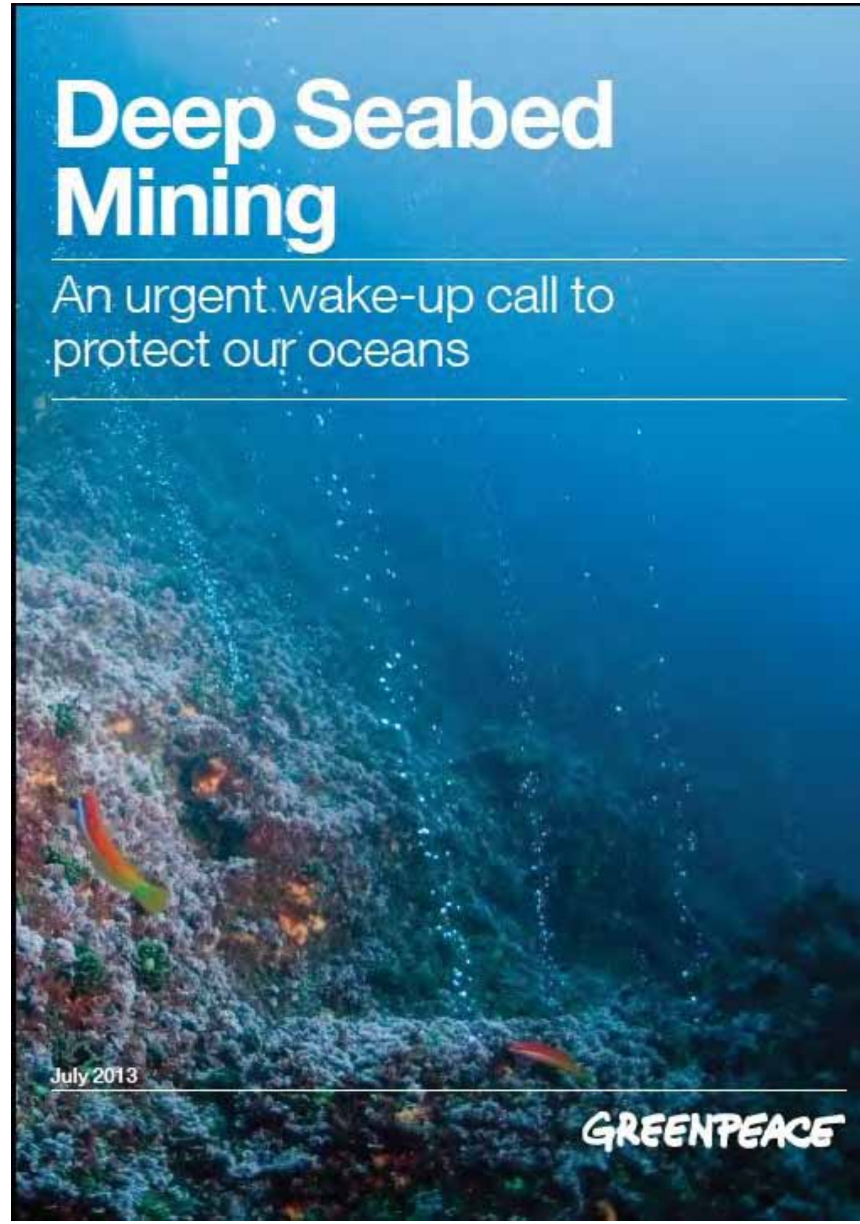
Marine ecosystems and environmental issues

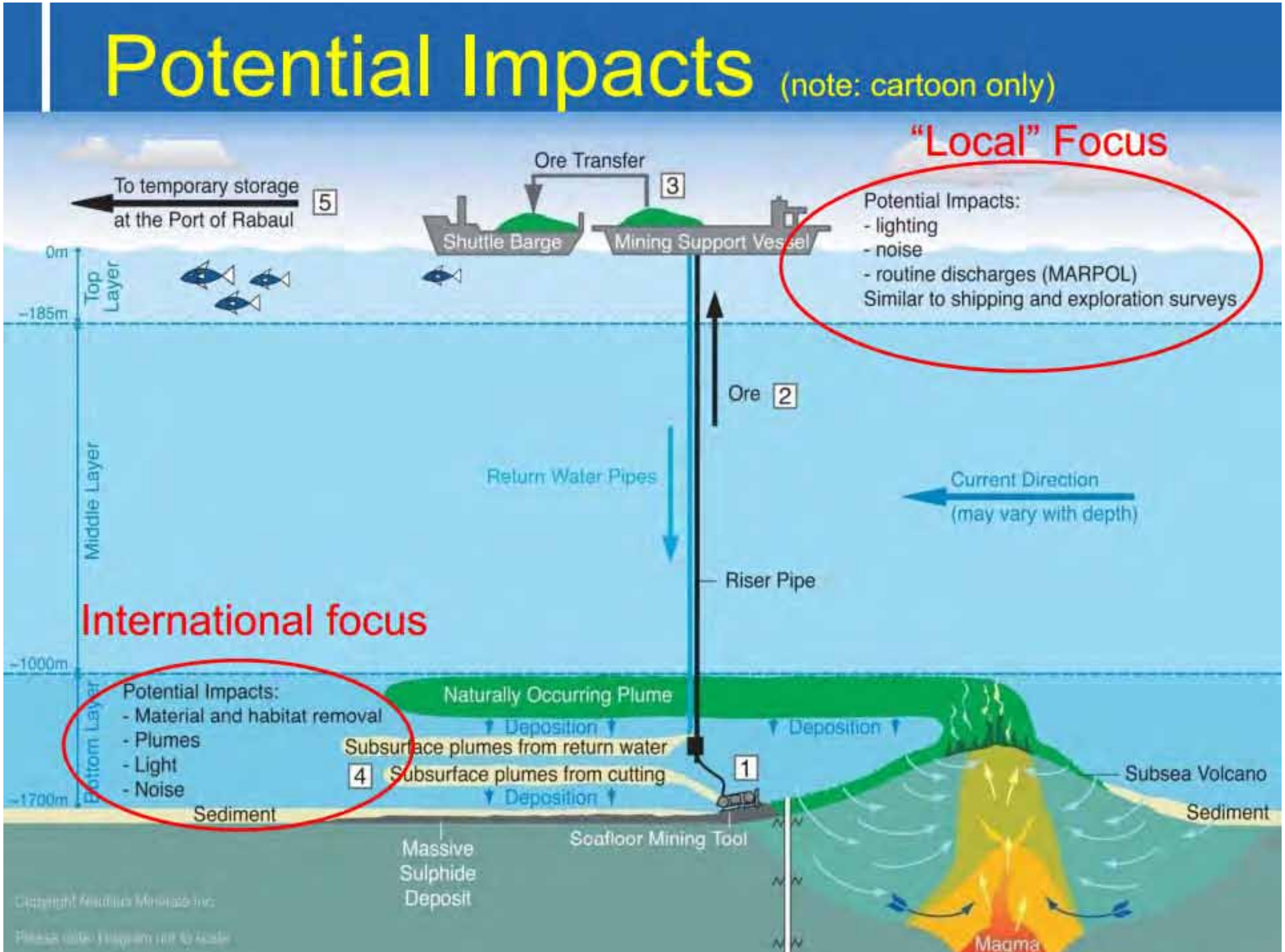


? P??BC?? ?


MARINE
RESERVES
NOW!
GREENPEACE

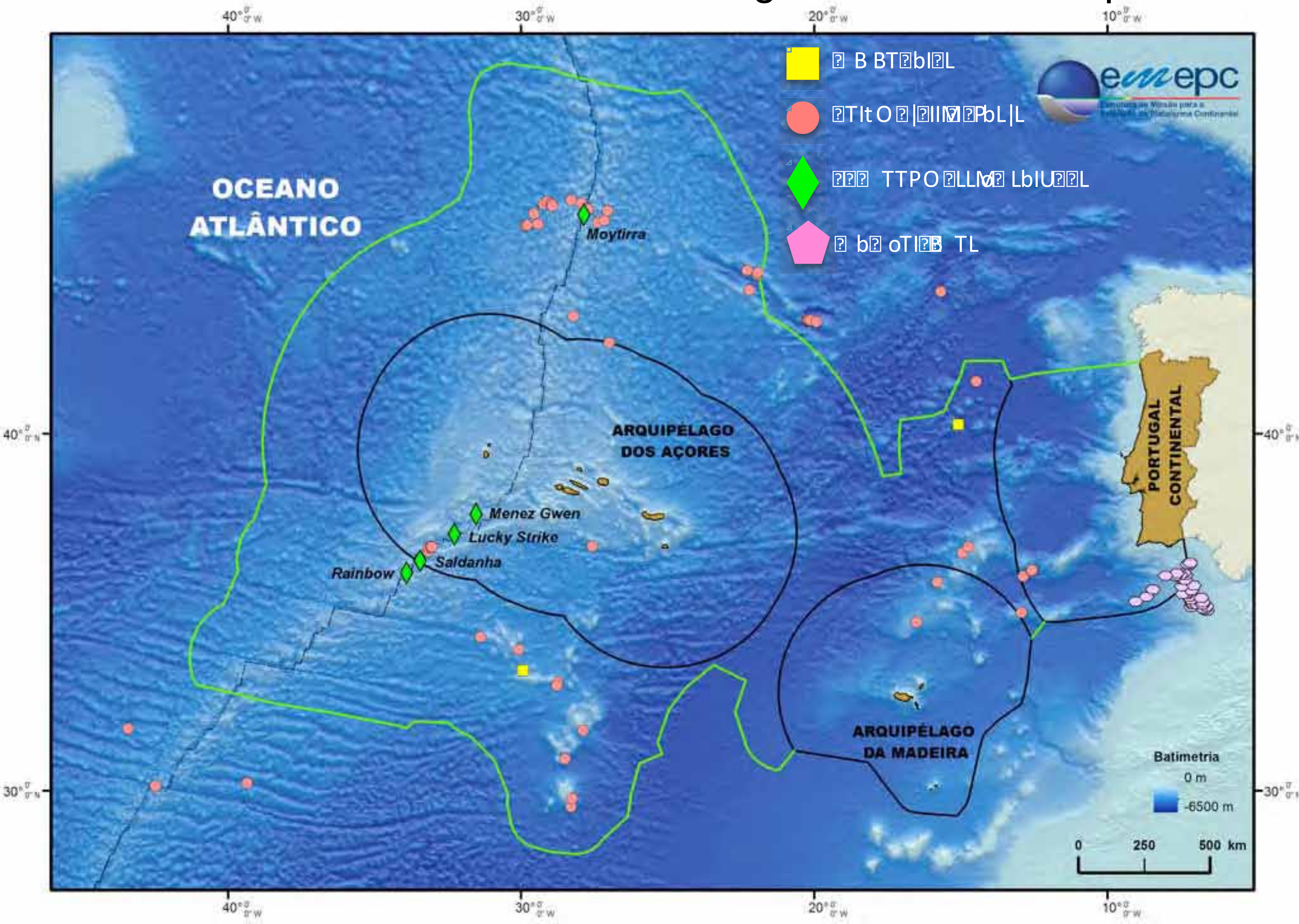

R.I.P. SEABED
SEABED
MINING
KILLS


Deep Seabed
Mining
An urgent wake-up call to
protect our oceans
July 2013
GREENPEACE


Potential Impacts (note: cartoon only)
"Local" Focus
Ore Transfer
To temporary storage
at the Port of Rabaul
5
3
Shuttle Barge
Mining Support Vessel
Potential Impacts:
- lighting
- noise
- routine discharges (MARPOL)
Similar to shipping and exploration surveys
0m
Top Layer
-185m
Ore
2
Middle Layer
Return Water Pipes
Current Direction
(may vary with depth)
Riser Pipe
International focus
-1000m
Potential Impacts:
- Material and habitat removal
- Plumes
- Light
- Noise
Naturally Occurring Plume
Deposition
Deposition
Subsurface plumes from return water
Subsurface plumes from cutting
4
1
Deposition
Bottom Layer
-1700m
Sediment
Subsea Volcano
Sediment
Massive
Sulphide
Deposit
Seafloor Mining Tool
Magma

Marine mineral resources at the Portuguese continental platform

RECURSOS MINERAIS DA PLATAFORMA CONTINENTAL PORTUGUESA



Submarine areas

Country	EEZ km2	Extended continental platform	Total jurisdiction	Land area	Ratio marine / land
USA	11 351 000		11 351 000	9 629 091	1,2
France	11 035 000		11 035 000	652 090	16,9
Australia	8 505 348	2 500 000	11 005 348	7 692 024	1,4
Russia	7 566 673		7 566 673	17 098 242	0,4
UK	6 805 586		6 805 586	242 900	28
NZ	6 682 503		6 682 503	270 467	24,7
Indonesia	6 159 032		6 159 032	1 910 931	3,2
Canada	5 599 077		5 599 077	9 984 670	0,6
Brazil	3 660 955	911 847	4 572 802	8 514 877	0,5
Japan	4 479 388		4 479 388	377 930	11,9
Portugal	**1 727 408**	**2 150 000**	**3 877 408**	**92 090**	**42,1**
Chile	3 681 989		3 681 989	756 102	4,9

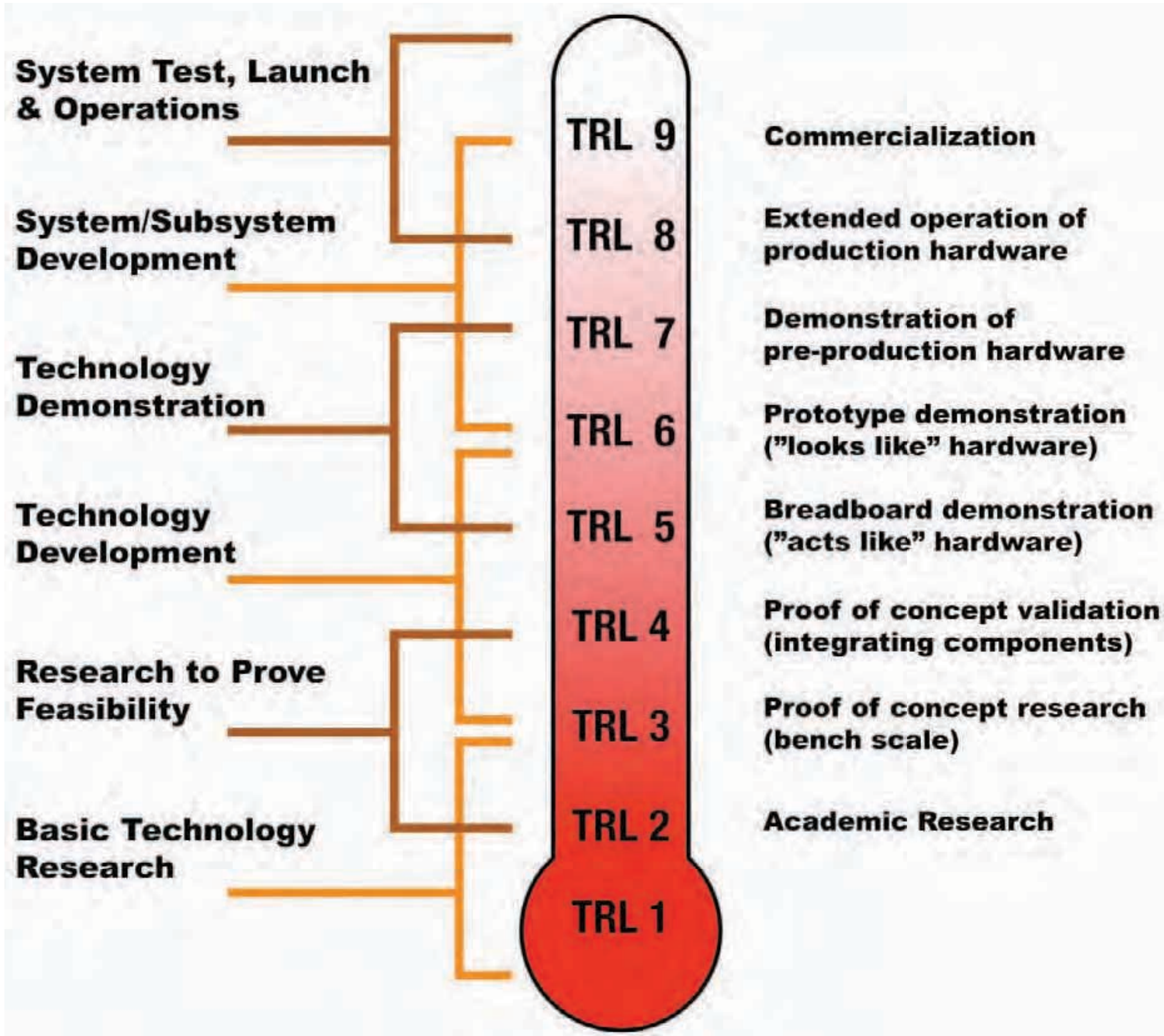
VMS Mineralization at the Modern Seafloor

FP7 NMP*

blue mining

: B TL MB L8BB T |DBTITNML8O | PM L tt Bn CPT b, TB |DBTITNML m H

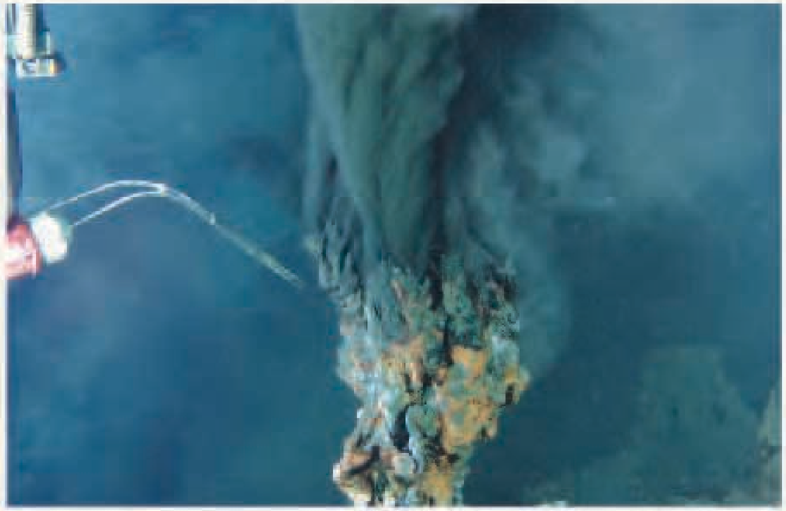
To Rise the Tech Readiness Levels



43RD CONFERENCE · UMI 2014 · PORTUGAL

UNDERWATER MINING INSTITUTE

ABSTRACTS



Harvesting Seabed Mineral Resources in Harmony with Nature

EDITED BY

James R. Hein, Fernando J.A.S. Barriga, and Charles L. Morgan

UMI 2014

September 21–28, 2014 • Lisbon, Portugal

EMRA'15 workshop

EMRA'15 workshop

euRathlon

EURATHLON
EU PROJECT

Gabriele Ferri and Fausto Ferreira,
CMRE, La Spezia, IT

euRathlon - an outdoor robotics challenge for land, sea and air

Gabriele Ferri,

Fausto Ferreira

NATO Centre for Maritime Research and Experimentation (CMRE) Viale San Bartolomeo 400, La Spezia, Italy

Funded by the European Union

FP7 Challenge 2 - Cognitive Systems and Robotics

euRathlon

Vision

- euRathlon is a research project funded by European Commission and coordinated by Prof. A. Winfield, University of the West of England
- To provide **real-world robotics challenges** that will test the intelligence and autonomy of outdoor robots in demanding mock disaster-response scenarios
- **Inspired by the 2011 Fukushima nuclear accident** we have been creating a competition that requires **autonomous flying, land and underwater robots** acting **together** to survey the disaster, collect environmental data, and identify critical hazards
- Leading up to this Grand Challenge in year 3, were directly related **land and underwater robot competitions** in years 1 (Berchtesgaden – Germany, 2013) and 2 (La Spezia – Italy, 2014), respectively

UWE BRISTOL University of the West of England
Fraunhofer FKIE
HERIOT WATT UNIVERSITY
PLOCAN consorcio
UNIVERSITY of OULU OULUN YLIOPISTO
CATEC CENTRO AVANZADO de TECNOLOGÍAS AEROESPACIALES
S&T organization Centre for Maritime Research & Experimentation

Bringing together expertise from the European Land Robotics challenge…

- ELROB
  - Established 2006

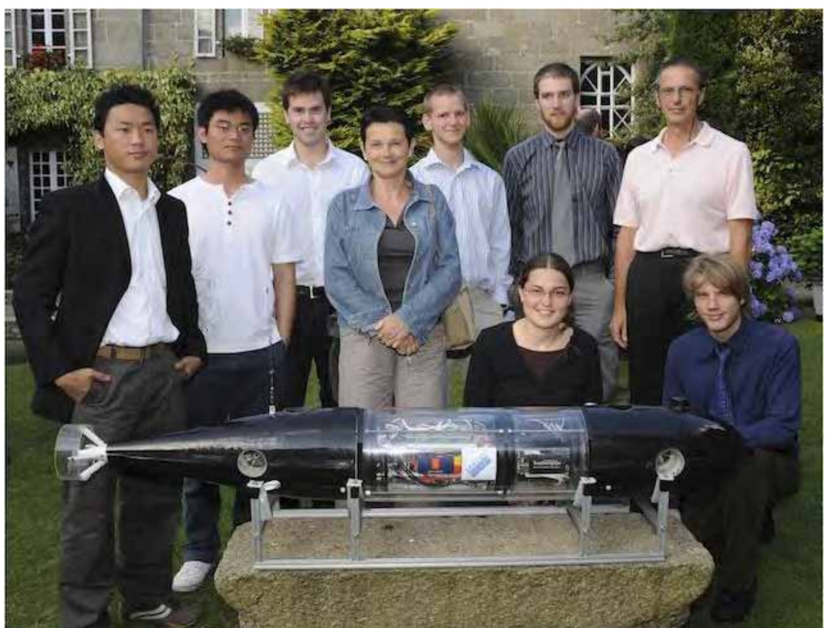
Scenes from C-ELROB 2011, Leuven Belgium

ELROB | The European Robot Trial

…the Student Autonomous Underwater Challenge – Europe

- SAUC-E
  - Established 2006
  - From 2010 organized by CMRE at CMRE water basin

Images from SAUC-E 2011, La Spezia, Italy



…and the workshop on Research Development and Education on Unmanned Aerial Systems (RED-UAS)

- Organized by FADA-CATEC, 2011
    - 150 participants, 12 countries

High level aims

- To spur advances in practical, usable real-world intelligent autonomous robots
  - The world's first competition which *combines ground, underwater and air robots*, that require intelligent autonomous robots to work together in disaster response scenarios
  - Pushing the state-of-the-art in *multi-robot collaboration, cooperation and shared situation awareness* to tackle real-world complex tasks in dynamic environments.
  - An open and user-led process of *defining the multi-robot competition scenarios, and related standards* for outdoor robotic vehicles
  - An open process for creating research, *industry and user-recognised benchmarks* for robot performance measurement and comparison
  - *Workshops* that foster a community of competitors
  - Imagination grabbing competitions

Year 1
euRathlon 2013

23-27 September

Berchtesgaden,

Germany

euRathlon 2013 winners

- ***Mobile for handling hazardous materials.***
  1st Telerob, 2nd ELP and 3rd SPACEAPPS

- ***Reconnaissance & Surveillance in urban structures (USAR).***
  1st ELP, 2nd Telerob, 3rd IMM-IAIR

- ***Search & Rescue in smoke-filled underground structure.***
  1st Telerob, 2nd ELP, 3rd ENSTABretagne

- ***Autonomous navigation.***
  1st MuCAR, 2nd RIS, 3rd NAMT

Additional awards:

- ***Novel Scientific Solution:*** RIS
- ***Creative Solution:*** NAMT
- ***Best Team Effort:*** E15

euRathlon 2014 marine robotics competition 29th September – 3rd October 2014, CMRE water basin, La Spezia, Italy

CMRE salt water basin

Participant teams

1) ENSTA Bretagne – SAUC'ISSE, France

2) ENSTA Bretagne – CISSAU , France

3) Scuola Superiore Sant'Anna – Shark, Italy

4) DFKI GmbH and University of Bremen – Avalon, Germany

5) Robdos/UPM – Robdos, Spain

6) University of Girona – Vicorob, Spain

euRathlon 2014 tasks (daily competitions)

1. Long distance underwater navigation - *reaching the disaster area*

2. Environmental survey of the accident area (mapping) – *understanding the effects of the disaster* (follow a wall, identify an anomaly and mapping some Objects of Potential Interest (OPIs))

3. Find the leaking source and inspect the pipeline – *localizing the leak* (tracking a plume composed of OPIs, inspect an underwater structure and localize a stopcock)

4. Underwater manipulation - *solving the issue* (manipulation of levers and interaction with underwater structures)

5. Combined scenario (to accomplish simplified versions of the cited tasks in sequence)





Some results… day 1, 29th September

Long range autonomous underwater navigation

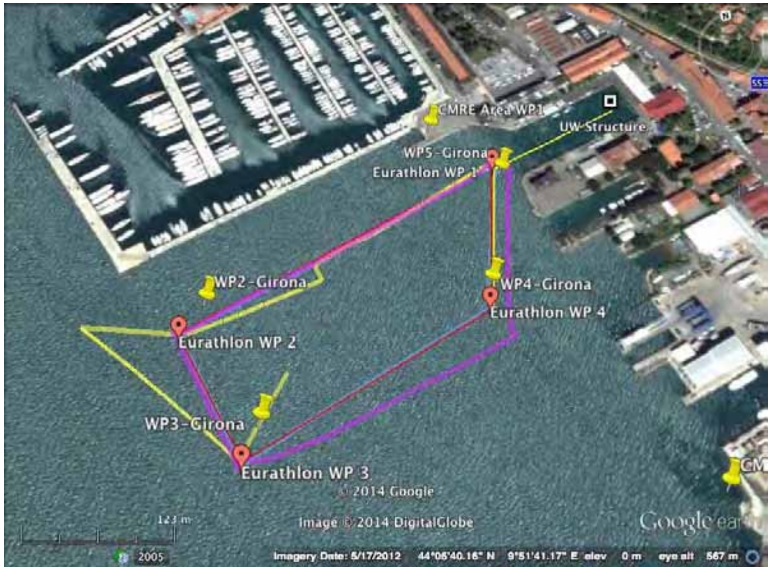
- ✓ 4 waypoints have to be reached outside the CMRE basin (1 km of distance to be covered)
- ✓ Cooperative navigation encouraged

Ranking:

1. University of Girona – 1 AUV
2. SAUC'ISSE - 1 AUV and 1 surface vehicle

Notes:

Good results by using cooperative navigation – SAUC'ISSE;
good performance with DVL-based navigation – Girona



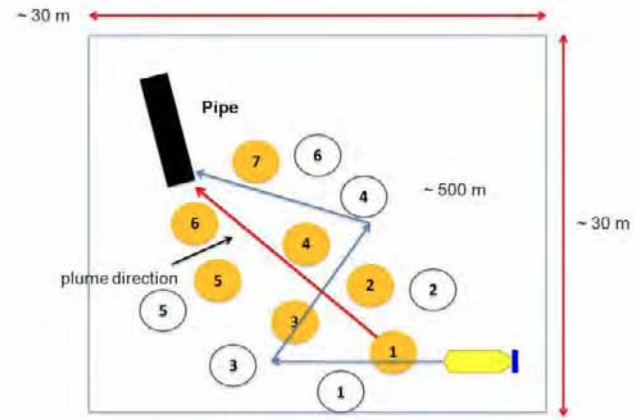
Navigation for the Girona team (blue) and the SAUCISSE team (yellow for AUV, purple for USV). The waypoints and the surfacing points of the Girona team are showed. Note that the ENSTA Bretagne AUV did well until contact was lost with the USV which finished its mission too quickly and stopped sending data after reaching the last waypoint (at that time, the AUV was still in transit between waypoints 1 & 2)

Results: day 2, 30th September

Leak localisation and structure inspection

✓ Simulated plume was to be followed by mapping/tracking the orange OPIs

✓ The underwater structure was to be imaged and mapped and the stopcock identified

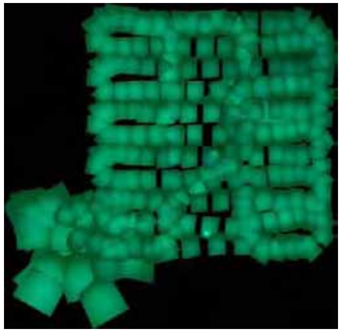


Ranking:

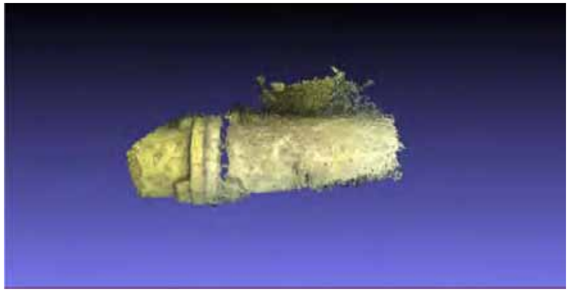
1. University of Girona
2. Avalon
3. SAUC'ISSE
4. CISSAU

Notes:

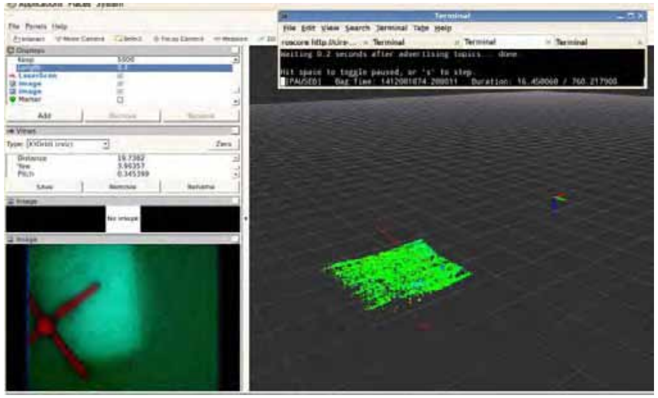
OPIs and structure detected and inspected; difficulties in detecting the number. The pipeline structure was mainly localized by mapping the area



Girona's optical mosaic



3D reconstruction via a camera of the structure (Avalon)



Girona multi-beam mapping and stopcock detection

Results: day 3, 1st October

Underwater manipulation

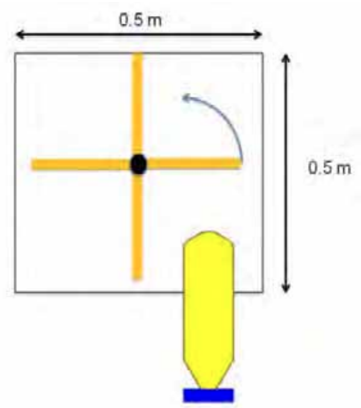
✓ Stay in touch with the pipe assembly structure, turning the valve and grabbing the pole+ring structure bringing it to the surface

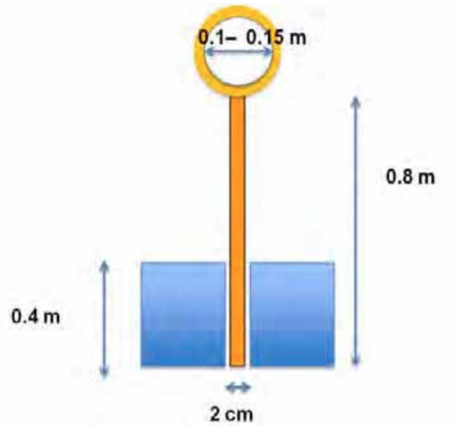
Ranking:

1. University of Girona
2. Avalon
3. CISSAU

Notes:

Girona and Avalon completed the tasks, tele-operation was used





Results: day 4, 2nd October

Environmental survey

✓ Follow the wall, find the anomaly (buoy with flashing light), area inspection to map orange OPIs

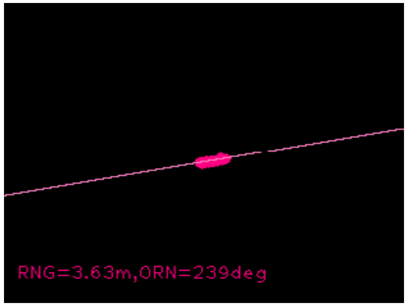
Ranking:

1. Avalon
2. University of Girona / SAUC'ISSE
4. CISSAU

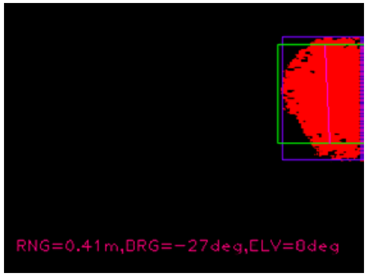
Notes:

The majority of teams succeeded in following the wall and detecting the OPIs.

Anomaly detected by CISSAU



Sonar wall tracking by SAUC'ISSE



OPI detected by SAUC'ISSE

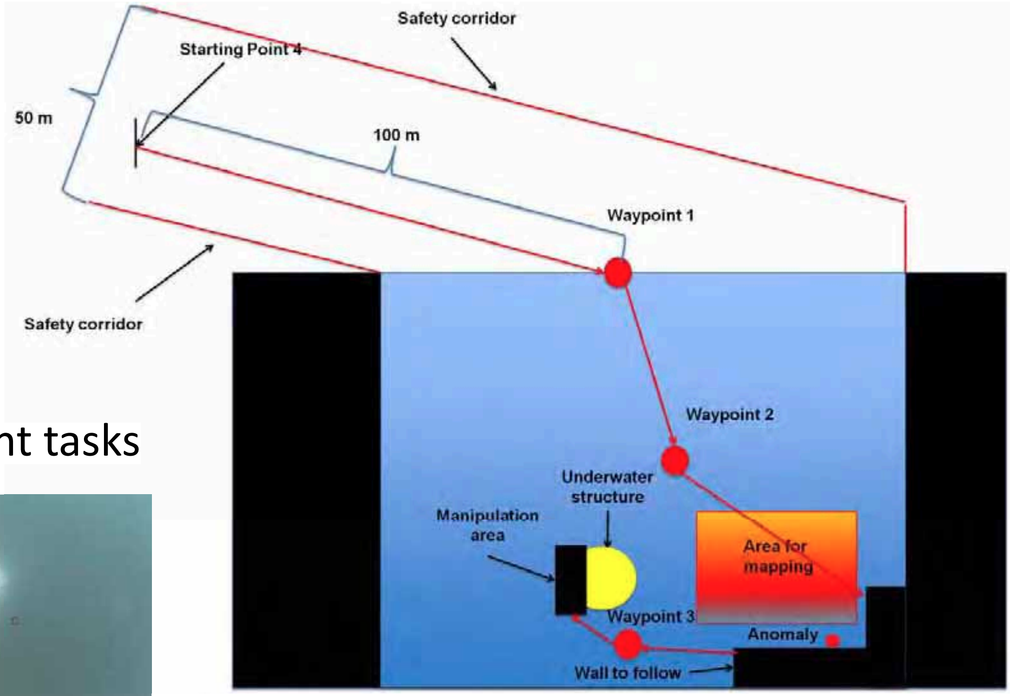
Results: day 5, 3rd October

Combined scenario

✓ Long range autonomous navigation to enter the area, wall following and area survey, pick and place task

Ranking:

1. University of Girona
2. SAUC'ISSE
3. Avalon
4. CISSAU



Notes:

First time a complex scenario with different tasks was presented

Avalon white OPI detection

Sponsors and supporters of euRathlon 2014

- ✓ *Office of Naval Research Global (ONRG)* sponsored the competition providing money for prizes and for the organization of the event
- ✓ Other direct sponsors/exhibitors were *BQ* (they sent two 3D printers as exhibition), *NIST* - exhibitor, *EC Managed*
- ✓ *Clearpath Robotics* was a supporter offering a strong discount for the purchase of their Kingfisher surface vehicle
- ✓ CSSN supported us during the organization of the event

euRathlon 2014 competition summary

- ✓ Good feedback in terms of interest by the community: SAUC-E/ euRathlon now are well-known brands
- ✓ Good results by some teams (especially Girona, Avalon and SAUC'ISSE). This showed the feasibility of 2015 scenarios. These teams are ready to face the 2015 Grand Challenge
- ✓ Growing interest in the (marine) robotics community
- ✓ As next step, more effort is needed in vehicle cooperation and autonomy (e.g. in manipulation)

euRathlon workshops

2013: Workshop euRathlon

Berchtesgaden, Germany, September, 2013

2014: Workshop euRathlon/ARCAS, Seville, Spain, May, 2014

2015: Workshop euRathlon/Sherpa, Oulu, Finland, June, 2015

Piombino, Italy, the euRathlon 2015 "Grand Challenge" venue

Partners/patrons

REGIONE TOSCANA

MINISTERO DELL'AMBIENTE E DELLA TUTELA DEL TERRITORIO E DEL MARE

Enel

Sponsors

Texas Instruments

EvoLogics

SBG SYSTEMS

Robotnik

OPTOFORCE SENSING FLEXIBILITY

euRathlon 2015 event areas: city locations

Castle:
workshop/invited talks

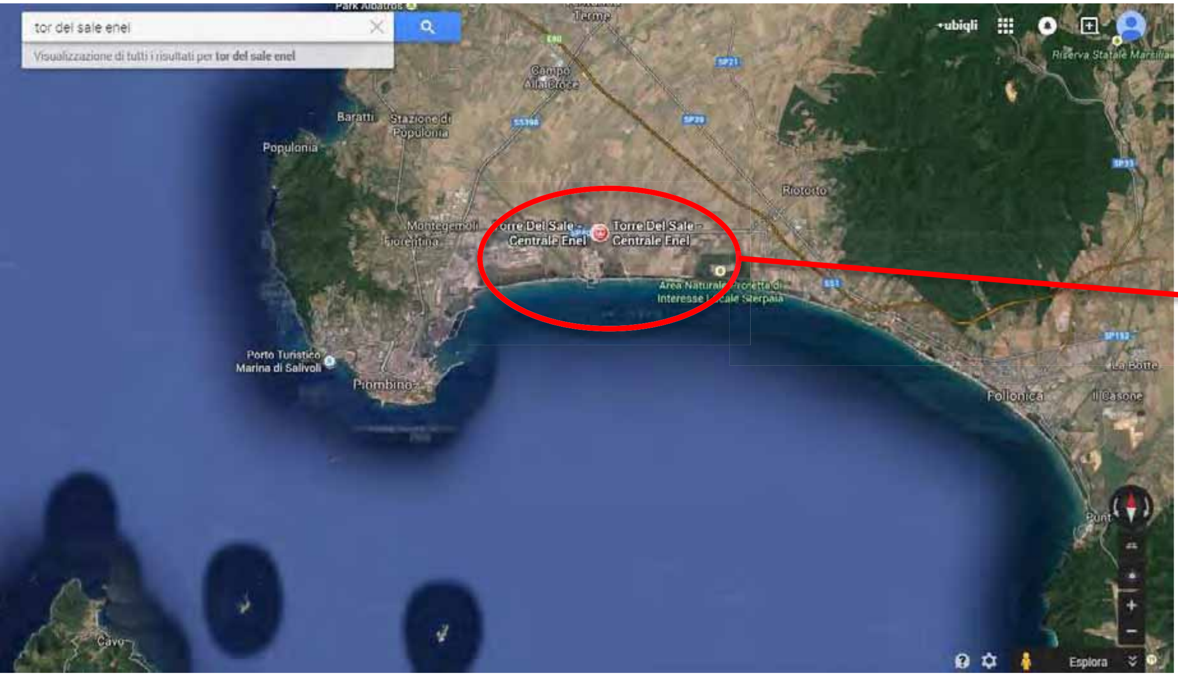
Bovio square:
Directional Centre, exhibitions

Scenarios inspired by the 2011 Fukushima-Daichi accident to prepare the 2015 Grand Challenge

An industrial devastated area and marine robots to intervene

euRathlon 2015 event areas: competition site

Area close to the ENEL-owned Tor del Sale electric plant



Competition area: surroundings of Tor del Sale electric power plant

- ✓ A building to simulate the reactor chamber; nearby land area for land robots
- ✓ Ease of flying robots
- ✓ Protected harbor for marine robots; availability of open waters for long range navigation
- ✓ Places for gazebos (for public and teams) in the ENEL area

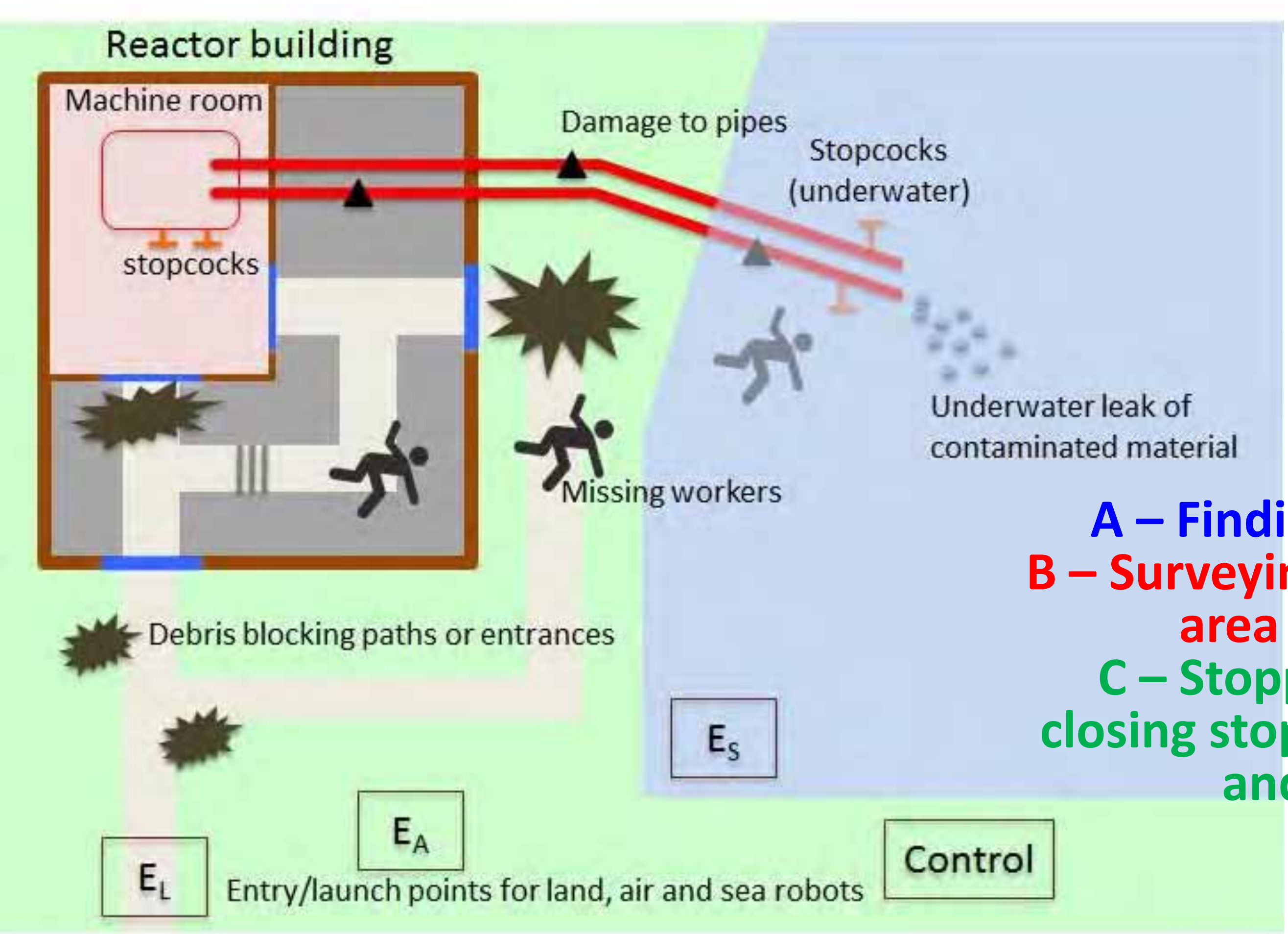
Area for gazebos (public and teams)

Flying robots area

Protected harbor area – marine robots

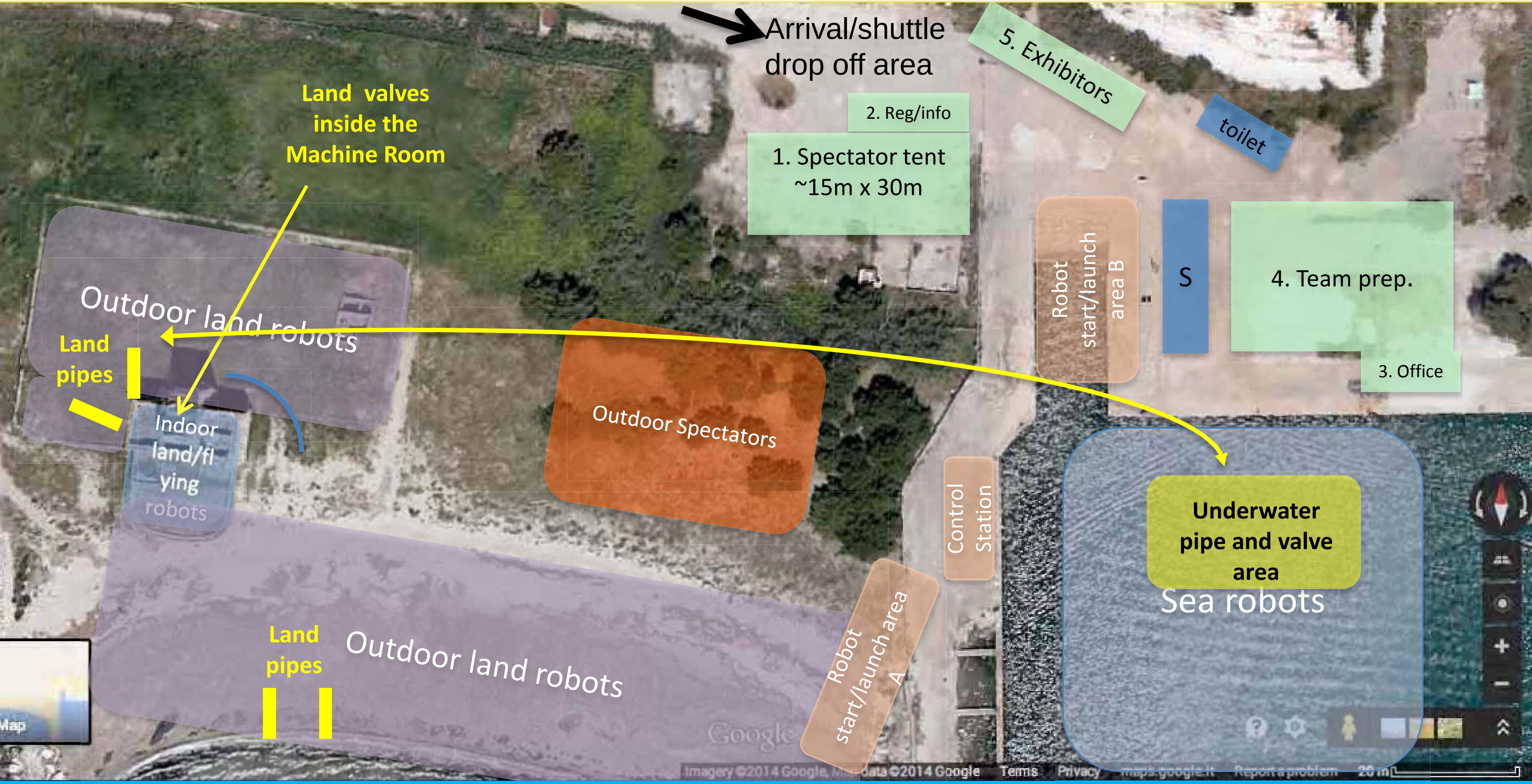
Building and surrounding areas – [redacted]bots

The euRathlon 2015 Grand Challenge



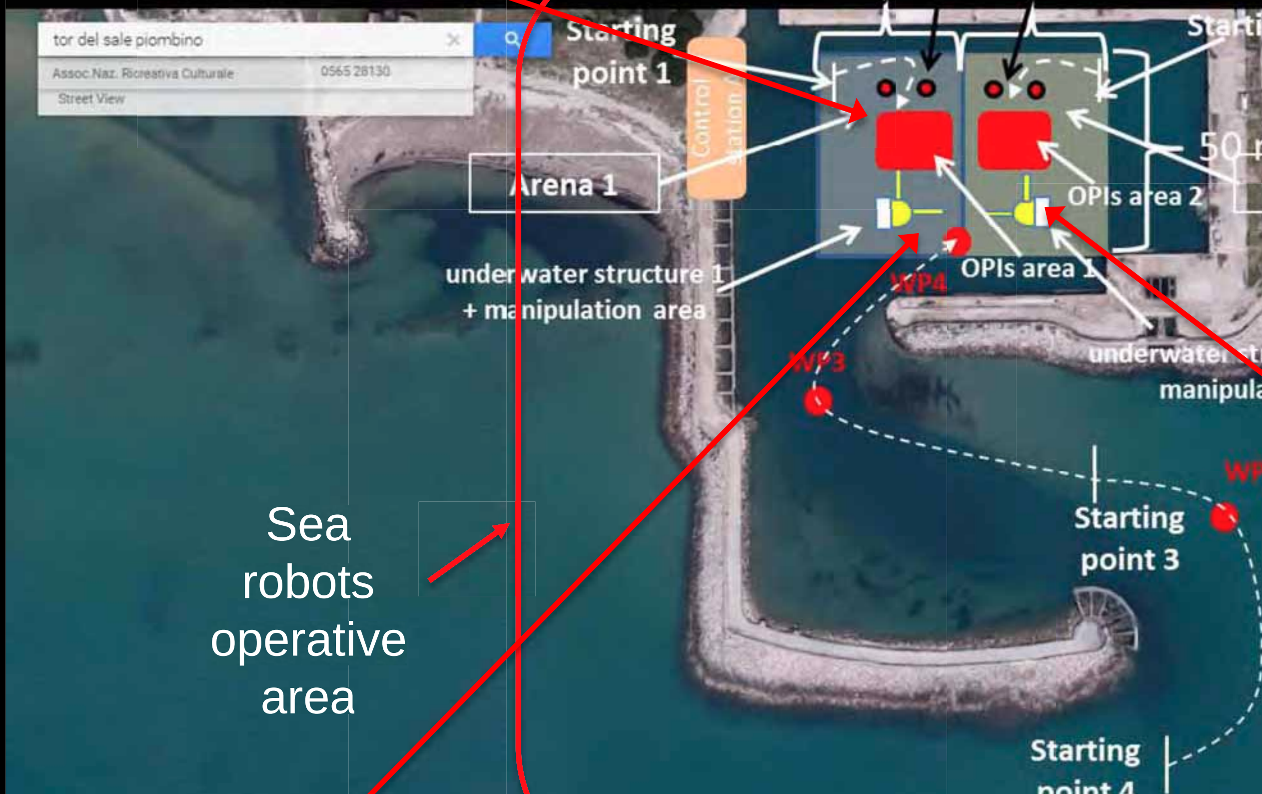
A – Finding missing workers
B – Surveying and monitoring the area of the accident
C – Stopping the leaking by closing stopcocks in the building and underwater

Plan for the Tor del Sale area



Tents (green)
1: Spectator tent, with seating, display screens and PA, and cafeteria, capacity ~400
2: Tent for registration, information and security
3: Tent for (a) euRathlon staff, (b) press office
4: Team preparation tent (pit lane)
5: (Optional) tent for exhibitors/sponsors

Indoor land/flying robot competition areas (pale blue)
Outdoor land robot competition areas (violet)
Outdoor spectator area and access path (orange)
Robot team control/launch areas and access paths (brick)
Metal structures (blue)
S: Secure storage for robots and equipment
Toilet/washroom trailer


tor del sale piombino
Assoc.Naz. Ricreativa Culturale
0565 28130
Street View
Starting point 1
Arena 1
Starting poin
50 m
Arena
OPIs area 2
OPIs area 1
underwater structure 1
+ manipulation area
underwater structure 2
manipulation
WP4
WP3
WP2
Starting point 3
Starting point 4
Esplora
Sea robots operative area

euRathlon 2015 Grand Challenge, Piombino, 17-25 September, 2005

Already ~20 teams registered (single and multi-domain) – team interest also from Dubai, Russia, India and Egypt – **13 marine teams**

Programme:

17 Sept. : Practice runs
18 Sept. : Practice runs
19 Sept. : Practice runs
20 Sept. : Single domain trials (different competitions for aerial, marine and land robots)
21 Sept. : Single domain trials (different competitions for aerial, marine and land robots)
22 Sept. : Subchallenges/Grand Challenge Qualifications
23 Sept. : Subchallenges/ Grand Challenge Qualifications - DARPA Robotics Challenge exhibition
24 Sept. : Grand Challenge Final
25 Sept. : Grand Challenge Final

Thanks for your kind attention!
We are waiting for you in Piombino!

contacts:

www.eurathlon.eu

Gabriele.Ferri@cmre.nato.int

Funded by the European Union

COOPERATION
FP7 Challenge 2 - Cognitive Systems and Robotics

EMRA'15 workshop

Session 2. Chair – Nikola Miskovic

14:00 **T2.1 - *UAVs for Marine Applications***
Francisco Almeida, TEKEVER, Lisbon, PT

14:30 **PANDORA (EU project)**

15:00 **T2.2 - *The future of autonomous marine vehicles in Ultra High Resolution Seismic reflection surveys (UHRS)***
Henrique Duarte, GEOSURVEYS, Aveiro, PT

15:30 **WiMUST (EU project)**

EMRA´15

ISR-IST Lisbon Portugal

EMRA'15 workshop

UAVs for Marine Applications

Francisco Almeida,
TEKEVER, Lisbon, PT

EU Funded Marine Robotics and Applications

UAVs for Marine Applications

Francisco Moitinho de Almeida

IST, Lisboa

18 June 2015, 15:00


Focus on PRODUCTS
Continuous INNOVATION
Passion for TECHNOLOGY

TEKEVER Worldwide

tekever

TEKEVER Markets

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INFORMATION TECHNOLOGY

Technological Areas

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AEROSPACE | DEFENSE | SECURITY

Technological Areas

tekever AUTONOMOUS SYSTEMS

Autonomous Multi-Mission Systems and Vehicles for Air, Land and Sea

tekever COMMUNICATION SYSTEMS

Advanced tactical communication systems for Civilian and Military Markets

tekever SPACE

Space Systems

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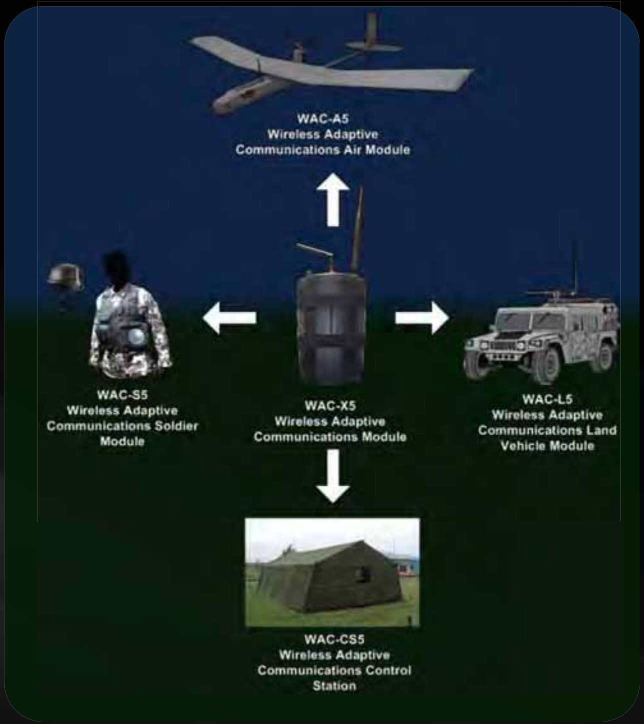
COMMUNICATION
SYSTEMS

Civilian and Military Tactical Communication Systems, based on advanced SDR technology
Fully compatible with all relevant NATO STANAG and other major international Standards



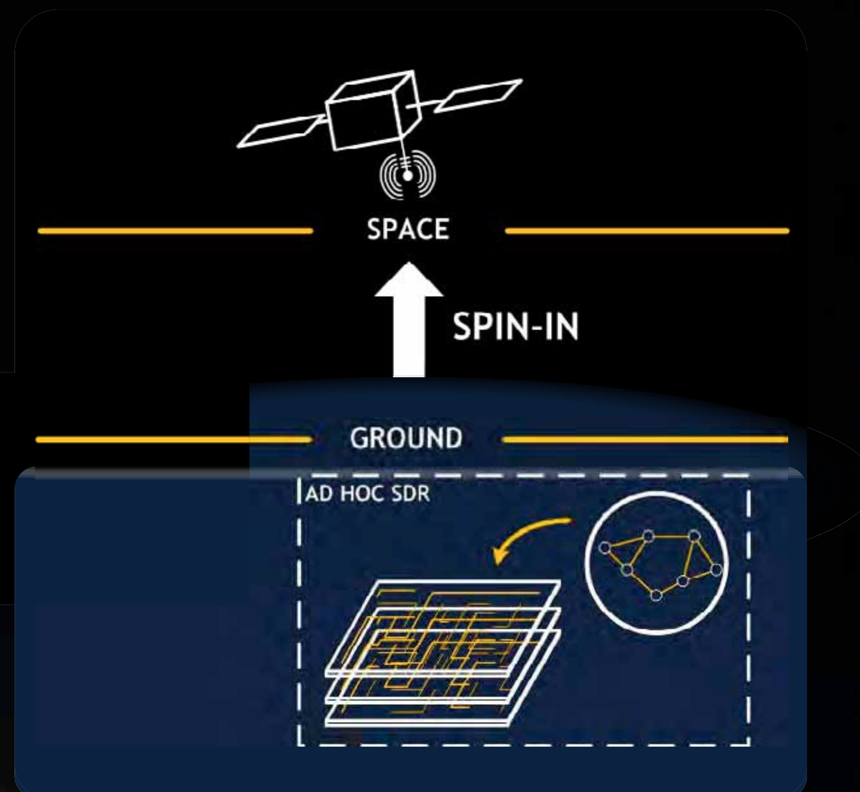
WAC Product Line
(Wireless Adaptive Communication System)

Develop, deliver and maintain products, solutions and technologies for the space segment.

GAMALINK: SDR platform for satellite datalinks with Ground Stations, GNSS and ISL

GAMASAT: 1st Portuguese built satellite (launch in 2016)

GAMANET: First space MANET, with 20+ nanosats in LEO (launch in 2016)



PROBA-3

A pair of probes to study the sun
With TEKEVER's communication technology

European Space Agency

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Portuguese entity with largest participation in European collaborative R&D Programs in the areas of Aerospace and Security:

- Volume of current projects exceeds 30M Euros
- TEKEVER leads 9 FP7 and 1 H2020 projects in Aeronautics, Space and Security, including partners like Thales, EADS, BAE, Selex Galileo, SAAB, DLR, FOI, among many others

Portuguese entity with largest participation in EDA projects

Technical reference in the area of Communications, participating in major NATO studies, and participating/coordinating ASD working groups

esa
European Space Agency

EUROPEAN DEFENCE AGENCY

HORIZON 2020

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AUTONOMOUS
SYSTEMS

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AUTONOMOUS
SYSTEMS

- Fixed wing mini UAS

- Designed for operation by Security Forces

- Validated and proven in partnership with Portuguese Police

- Commercially launched in Le Bourget 2013


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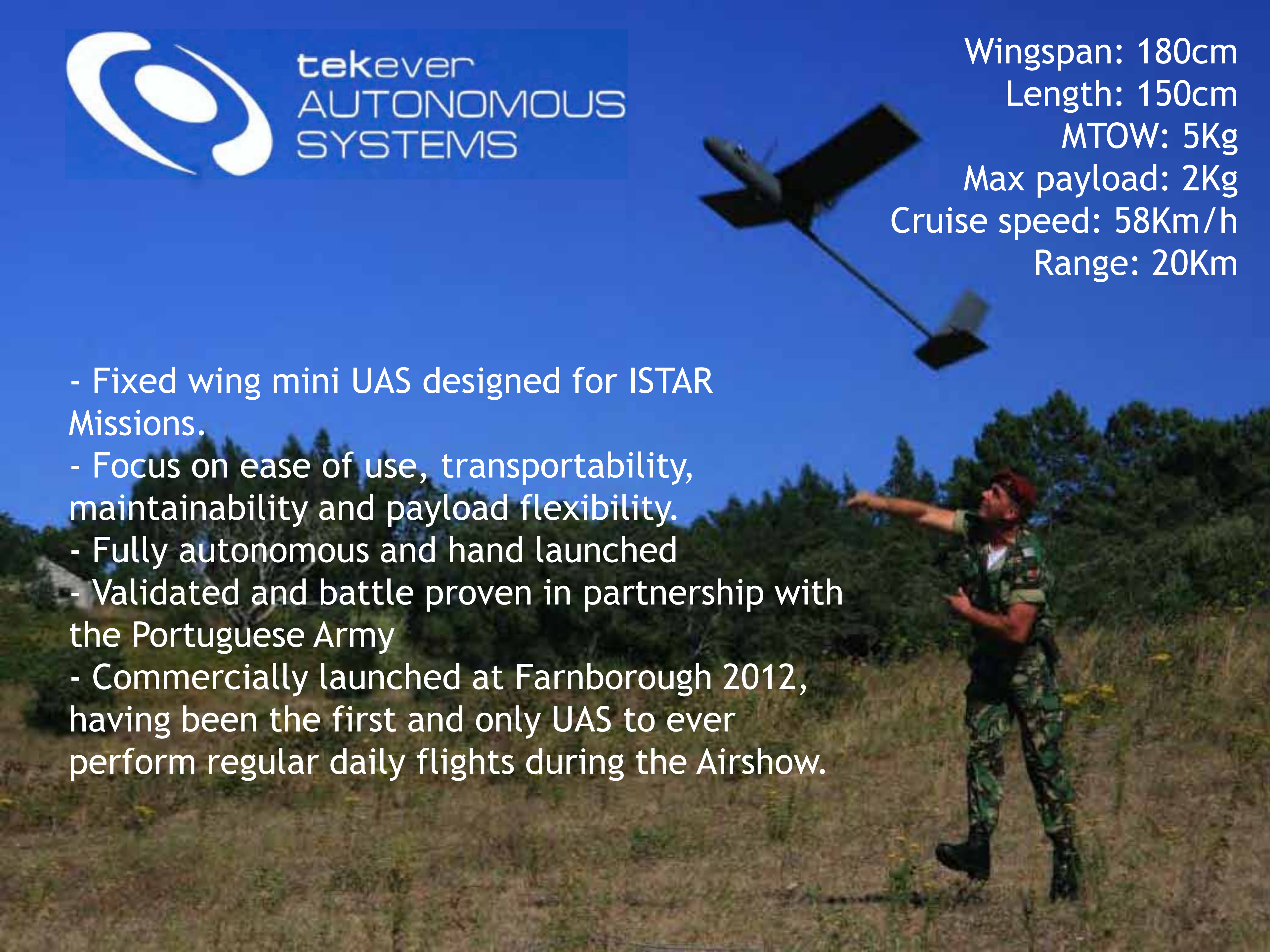
AUTONOMOUS
SYSTEMS
Designed to perform 4 to 10 hour missions
- EO, IR and LIDAR Sensors
- Hand or Catapult launched from land or sea
- Maritime and coastal surveillance missions operational extender for vessels
- Forest fire prevention
•with Portuguese Gendarme (GNR) at Parque Nacional Peneda-Gerês
Publicly presented at Le Bourget 2013



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AUTONOMOUS
SYSTEMS

Wingspan: 180cm
Length: 150cm
MTOW: 5Kg
Max payload: 2Kg
Cruise speed: 58Km/h
Range: 20Km

- Fixed wing mini UAS designed for ISTAR Missions.
- Focus on ease of use, transportability, maintainability and payload flexibility.
- Fully autonomous and hand launched
- Validated and battle proven in partnership with the Portuguese Army
- Commercially launched at Farnborough 2012, having been the first and only UAS to ever perform regular daily flights during the Airshow.

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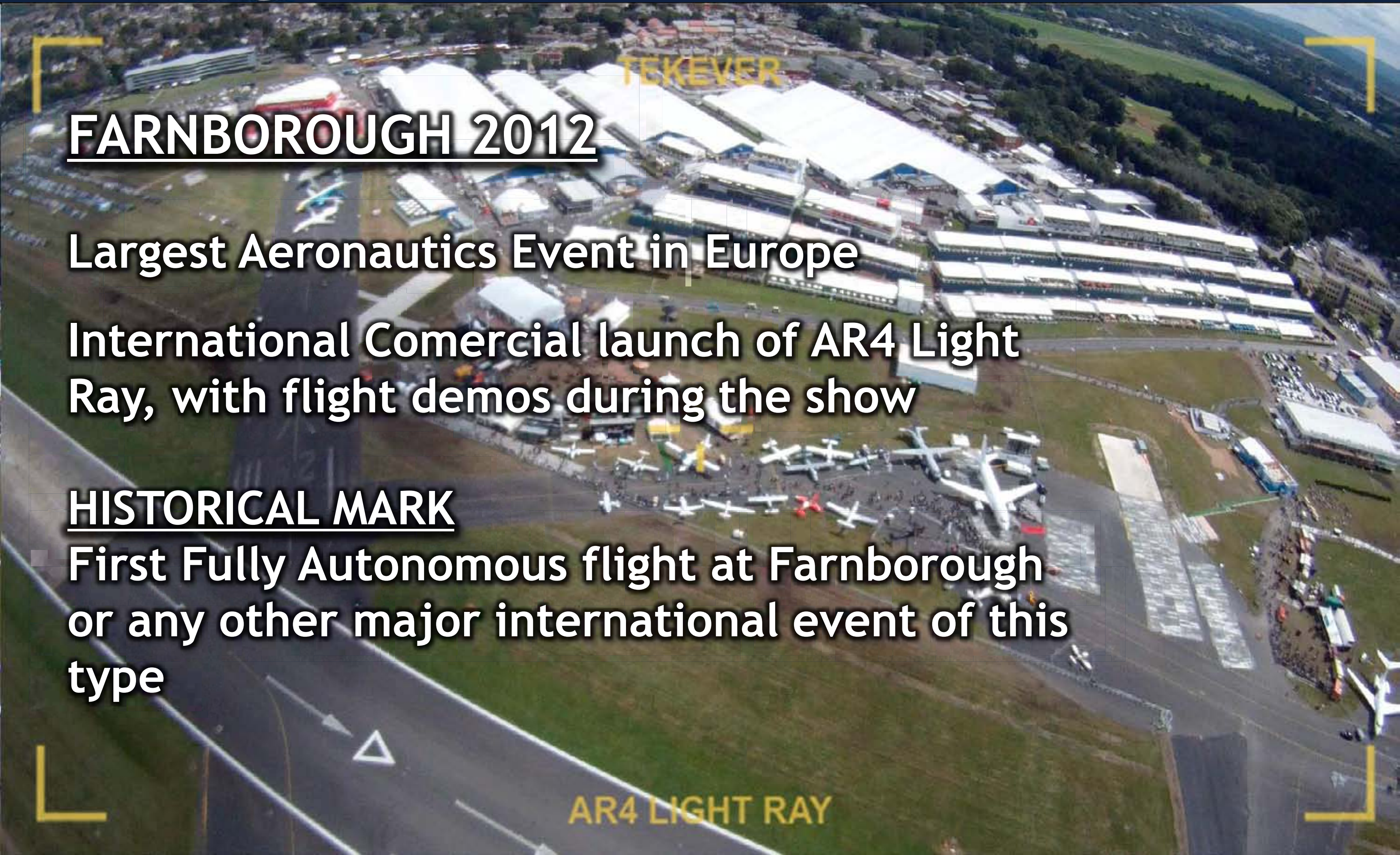
AUTONOMOUS
SYSTEMS



FARNBOROUGH 2012

Largest Aeronautics Event in Europe

International Comercial launch of AR4 Light Ray, with flight demos during the show

HISTORICAL MARK

First Fully Autonomous flight at Farnborough or any other major international event of this type


BBC - THE ONE SHOW
GALACTIC
Video retrieval
during the show
Prime Time, with
Virgin Galactic

AR4 Light Ray and AR2 Carcará performing 1st ever UAV autonomous formation flight at FIA 2014

tekever AUTONOMOUS SYSTEMS

•Designed to perform 15h+ missions
•EO, IR and SAR/SLAR Sensors
•Launched from short, unpaved air strips
•Flexibility in payloads and several range options
BLOS SATCOM Datalinks
•Presented in FIA 2014

UAVs for Marine Applications

Autonomous systems can support different types of missions at sea:

1. **Defence and security**
   Support to surveillance, control and menace combat actions
2. **Safety**
   Support to Search and Rescue actions in large areas
3. **Law enforcement**
   Controlling maritime traffic, protected areas, illegal fishing
4. **Environment**
   Prevention, detection and mitigation of hydrocarbon pollution, plastic pollution, among others

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Defence and Security

Using UAVs to extend the surveillance and operational range of naval platforms

Increasing line-of-sight and situational awareness in coastal guard and navy vessels

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Safety

Supporting dangerous and repetitive Search & Rescue tasks and patterns in large areas. Portugal is responsible for SAR in 6 million square kilometers

Performing surveillance and identifing persons and vessels in danger

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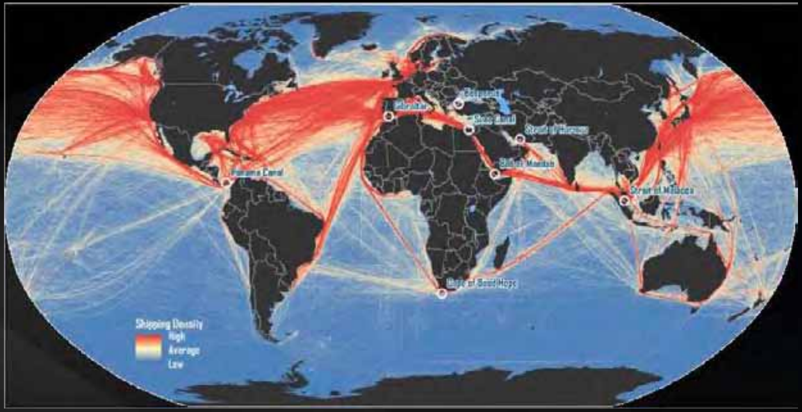
Law enforcement

Detecting and identifying illegal, unreported and unregulated fishing in territorial areas and high sea



Monitoring and controlling high density maritime traffic and surveying protect areas

Environment

Detecting and monitoring small and large oil spills from accidents, negligent and criminal acts, enabling a faster response

Monitoring the evolution and mitigation of hydrocarbon pollution, e.g via application of dispersant

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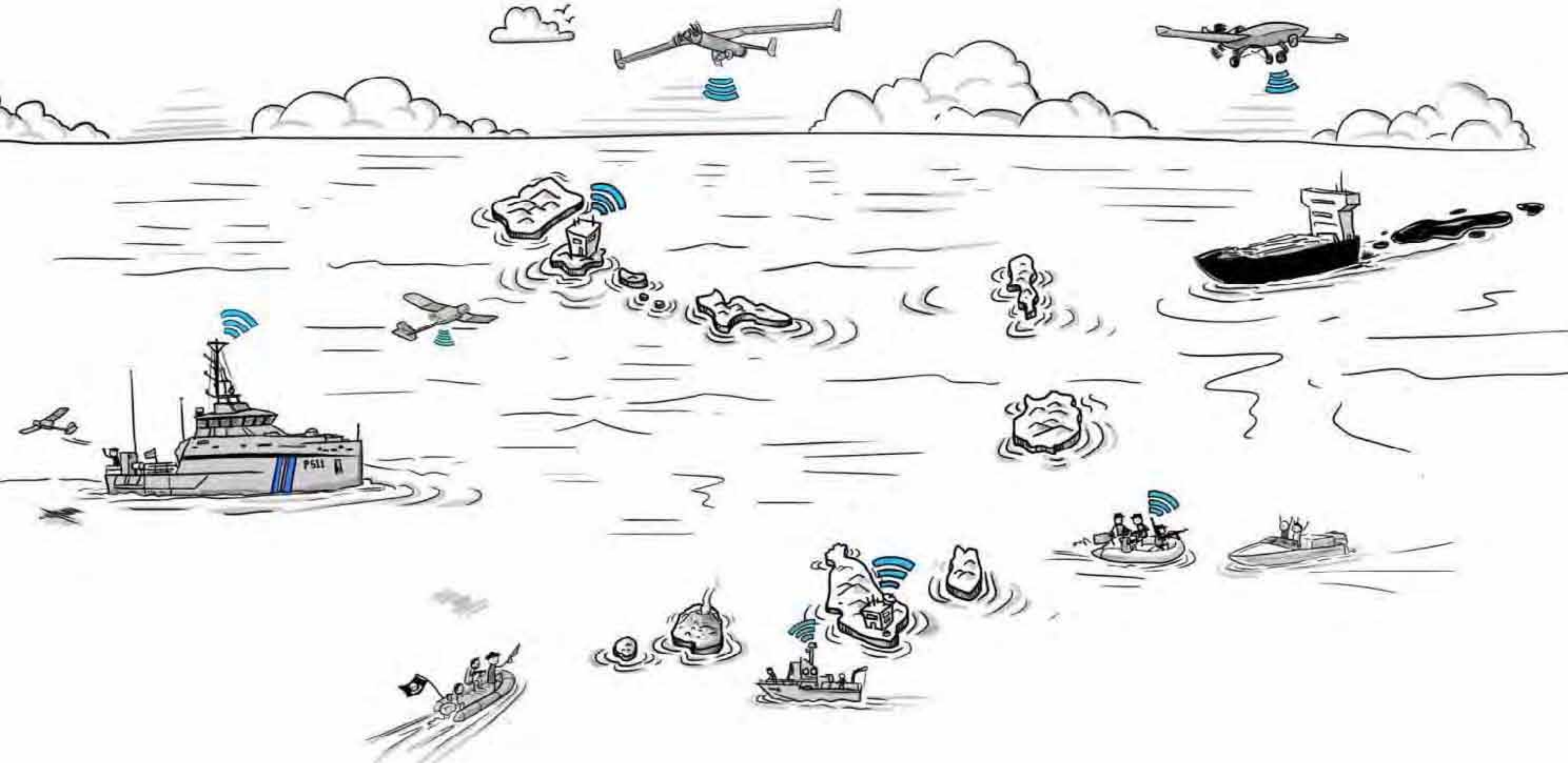
tekever AUTONOMOUS SYSTEMS

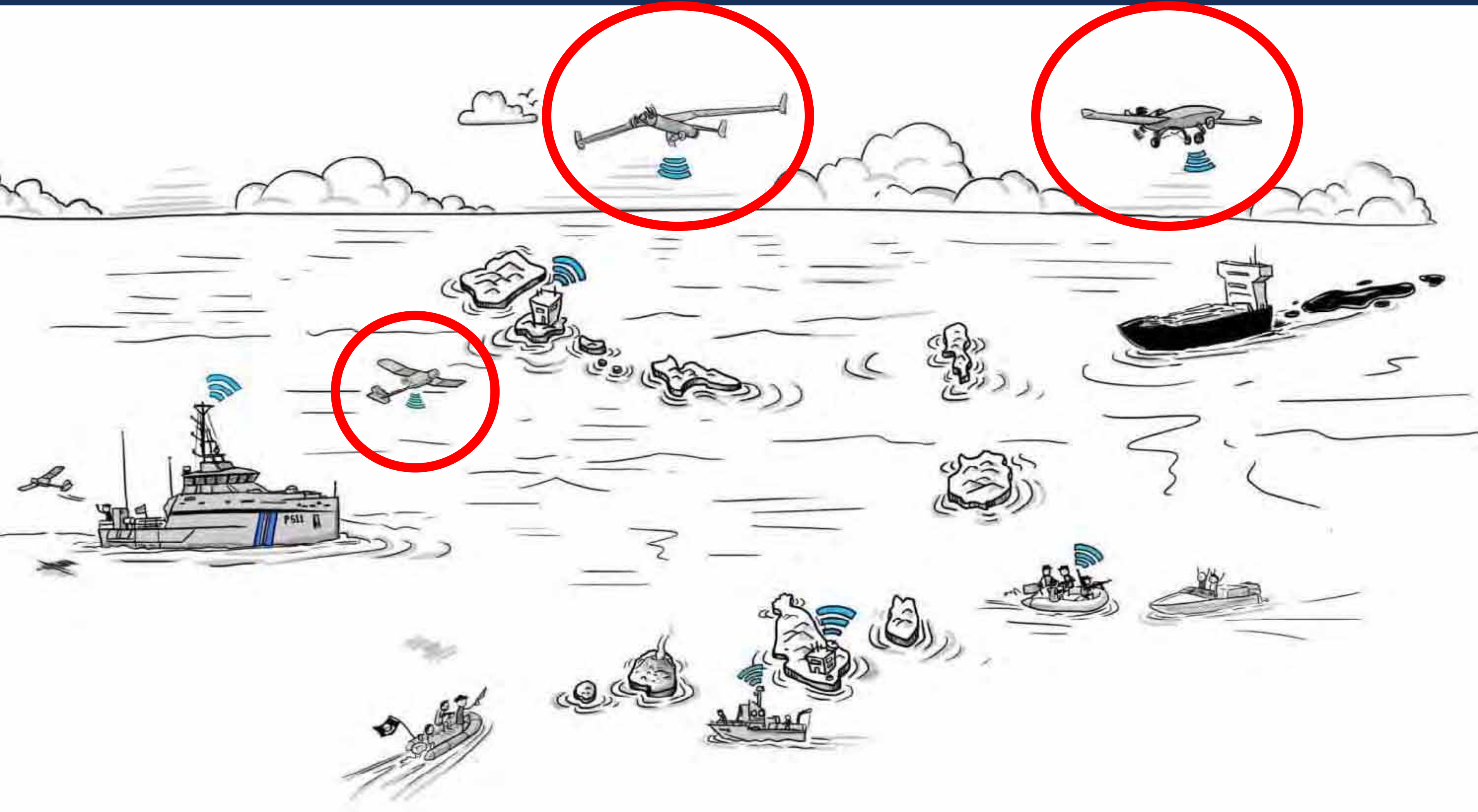
IN THE (NEAR?) FUTURE

UAVs for Marine Applications

tekever AUTONOMOUS SYSTEMS

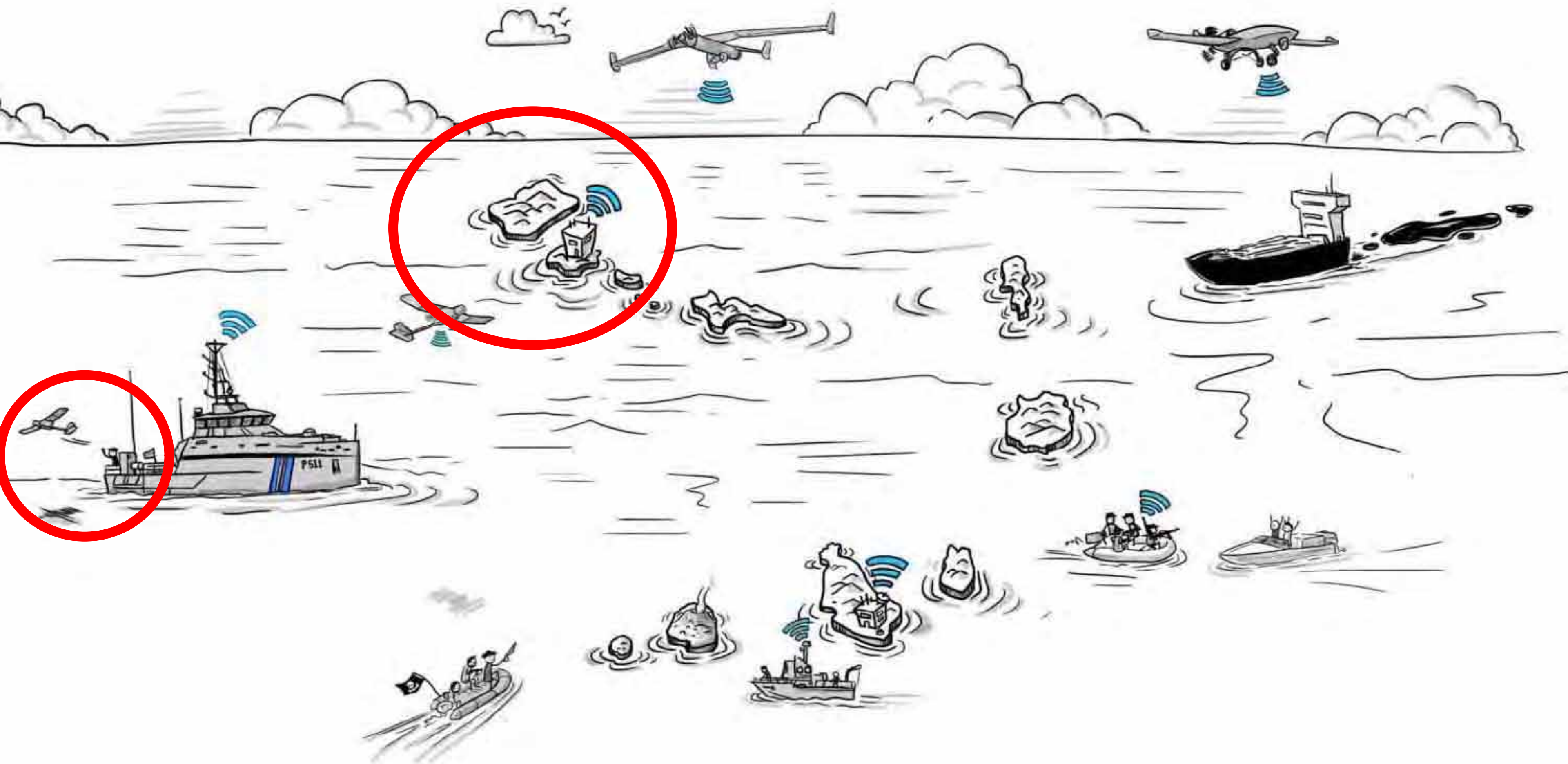


Heterogenous platform use

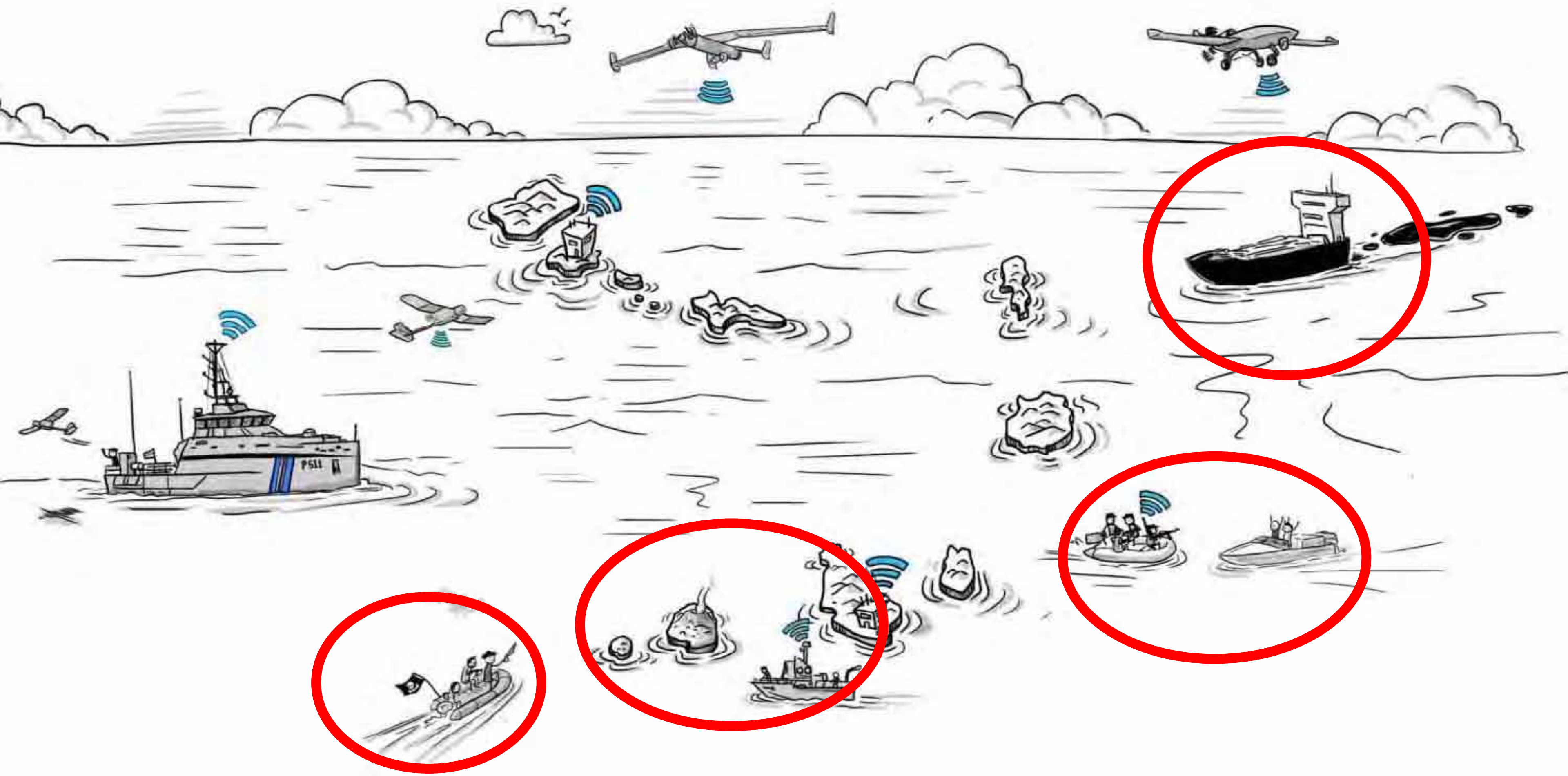


tekever AUTONOMOUS SYSTEMS

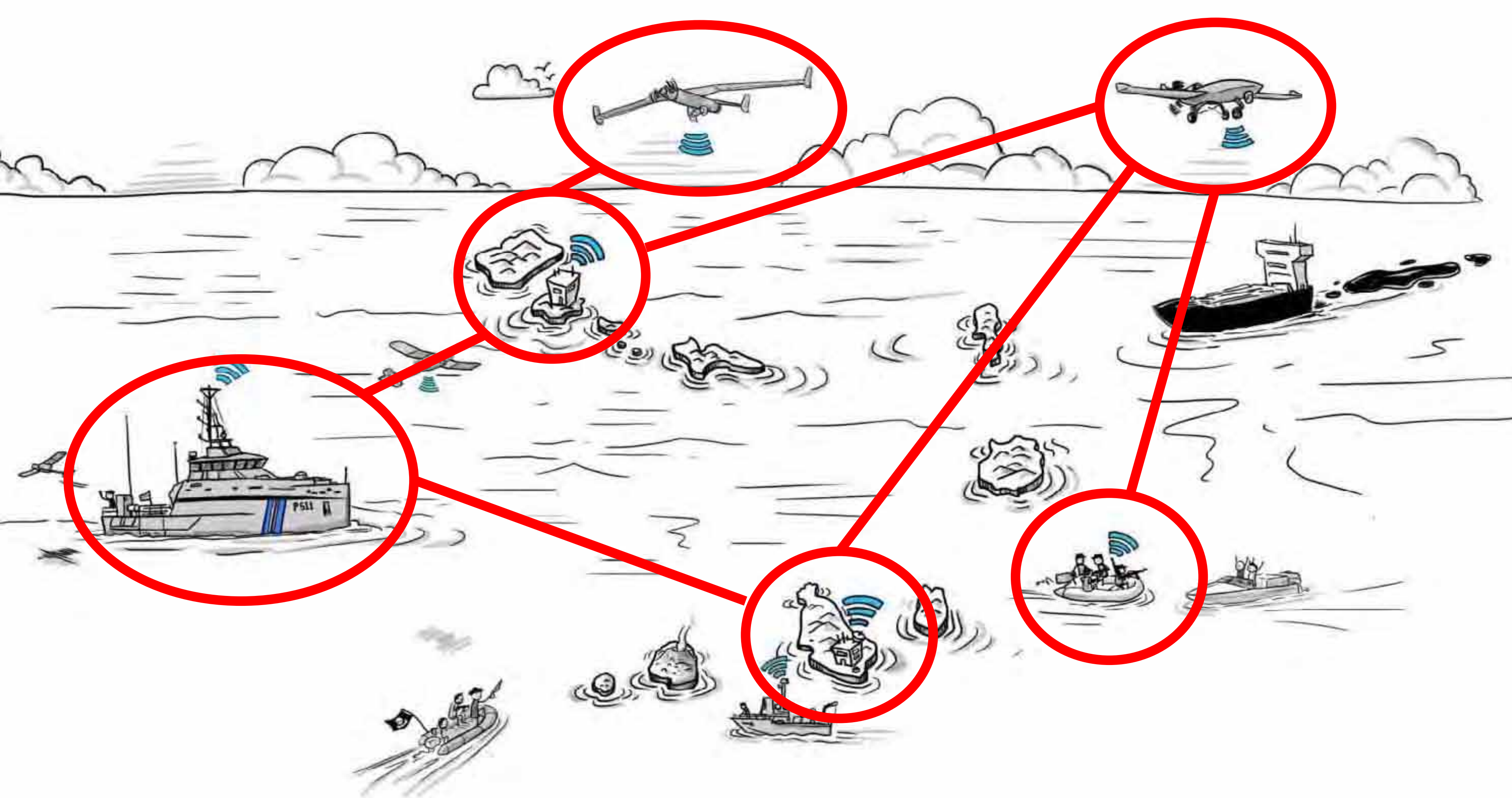
Launched from sea and land

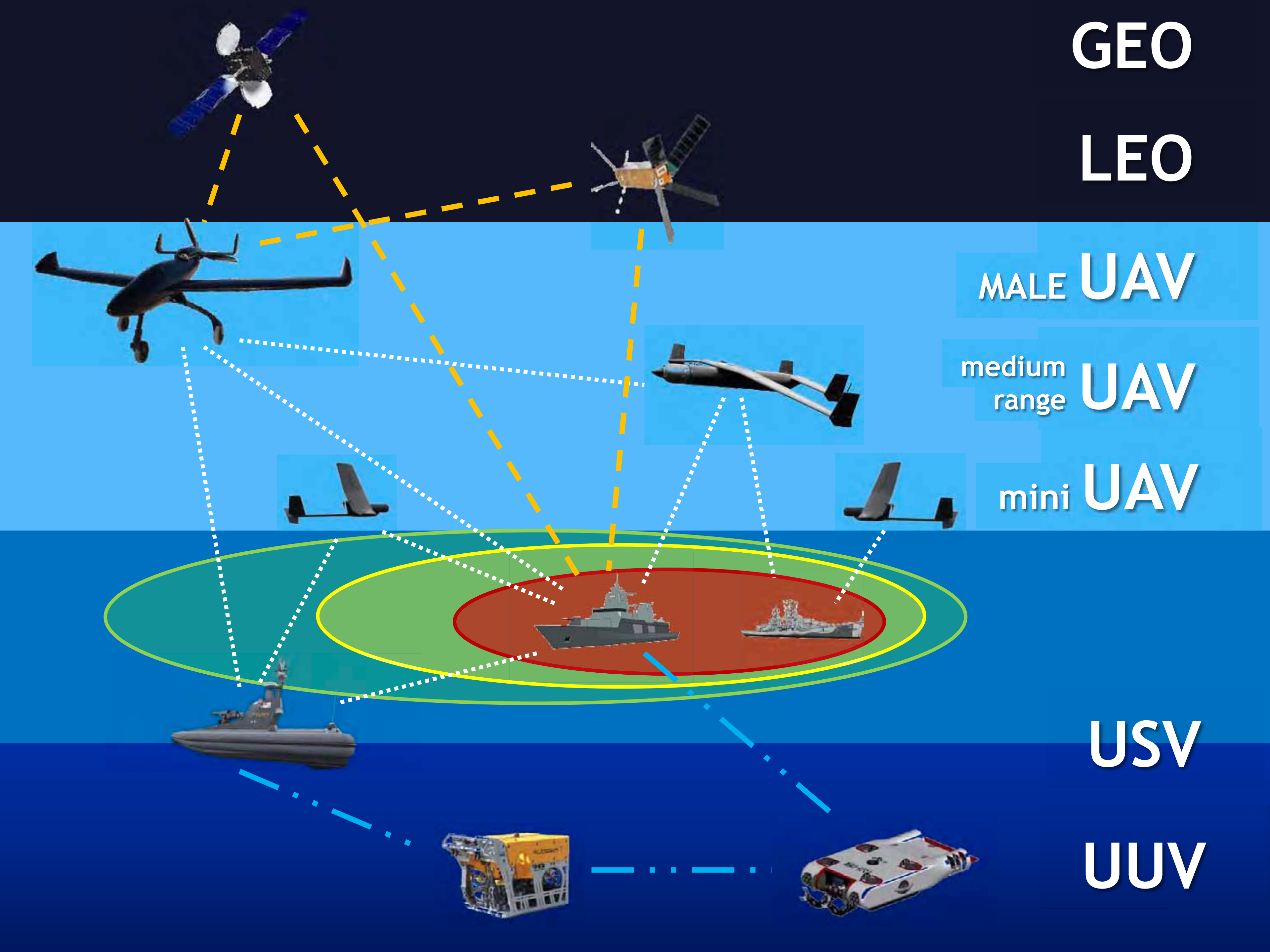


Different missions in land, coast and sea



Integration, readiness, efficience and operational capability





GEO
LEO
MALE UAV
medium range UAV
mini UAV
USV
UUV

Challenges in Maritime Applications

- **Performance**: endurance, altitude and range
- **Communications**
  - **Air-to-air**:
    - LOS: Data rate and reliability
    - BLOS: SATCOM in small UAVs
  - **Air-to-water**: relaying UAV-UUV comms
- **Autonomy**: decrease human-dependency
- **Cooperation**: task distribution in homogeneous and heterogeneous networks of autonomous vehicles
- **Sizeability, adaptability and flexibility**

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Relevant Projects & Collaboration

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RAPSODY

"Remote Airborne Platform with Satellite Oversight Dependency"

Financed by esa

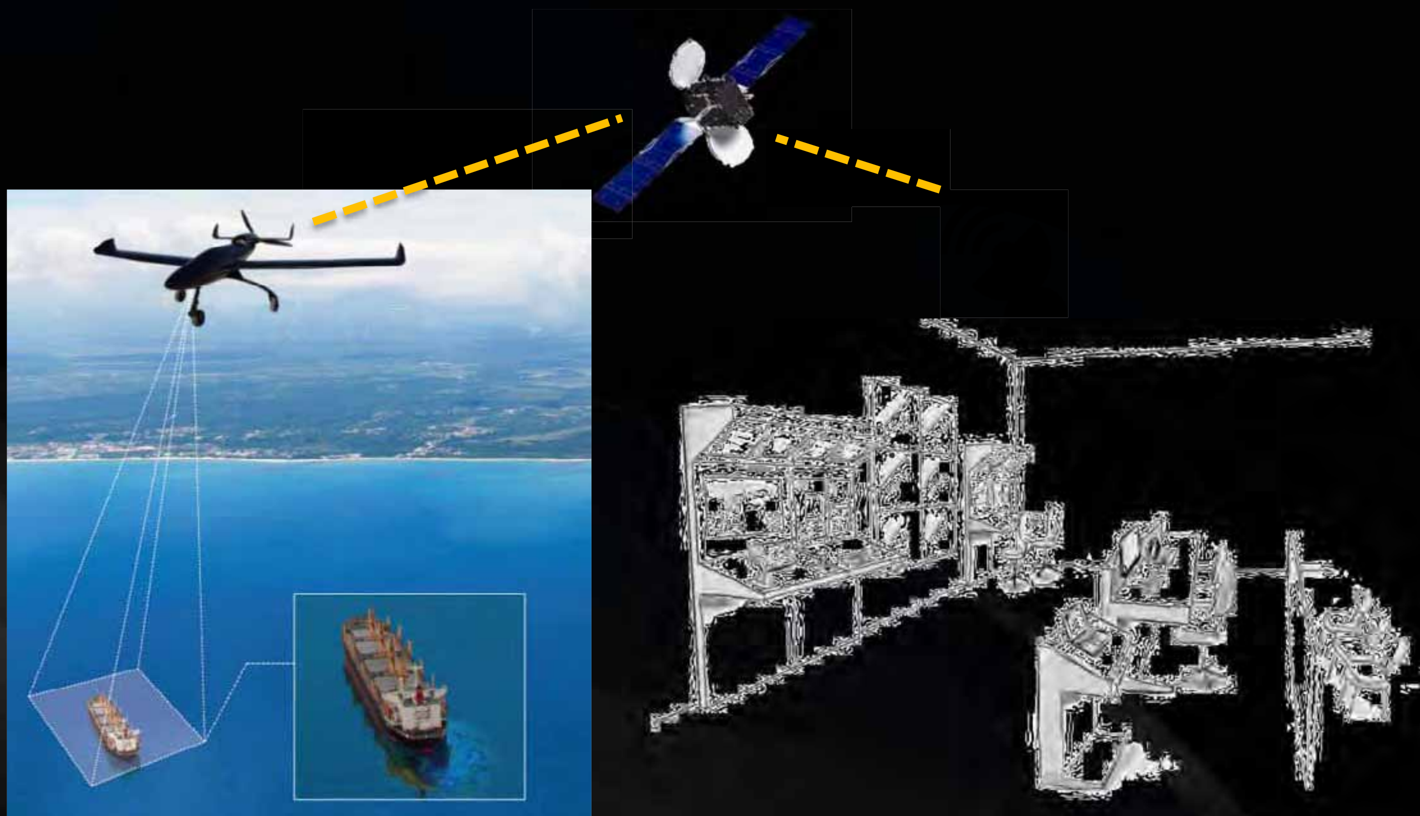
Partners:

European Maritime Safety Agency
Bond Air Services
TEKEVER UK
DSI

Portuguese Maritime Authority
Netherlands Coastguard
Malta Maritime Authority

RAPSODY

- **Demonstrate the use of UAVs in:**
- Search-and-Rescue Operations
- Maritime pollution monitoring and combat operations



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RAPSODY

Objectives

•Providing UAVs with a set of sensors for the realisation of operations such as:

a) Hidrocarbons detection and maritime pollution monitoring

b) Search and Rescue

•Develop an integrated sensor platform and embedded algorithms for automatic detection

•Exploiting satellite communication to operate UAVs beyond line-of-sight (BLOS)

•Demonstrating RAPSODY:

-Atlantic Ocean

-North Sea

-Mediterranean Sea

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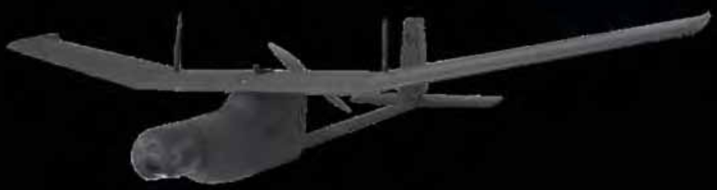
Automatic Landing on Vessels

AUTOLAND

Demonstrated the use of UAVs totally operated from vessels



AR4 Light Ray

AR3 Net Ray

Objectives

- Providing UAVs with the capability of executing every flight stage, from take-off to landing, from vessels (e.g. warships, frigates, patrol ships)

- Develop the necessary support systems to launch and collect UAVs

- Develop algorithms to launch and land the platforms automatically

- Demonstrate in a realistic environment

Collaboration with Portuguese Navy

TEKEVER has been cooperating with the navy in two large areas:

- **R&D Activities**

- **Operations**
  - -Extension of naval platforms with UAVs
  - -ISTAR missions (Intelligence, surveillance, target acquisition, and reconnaissance)
  - -Increased situational awareness

Collaboration with Portuguese Navy

The portuguese Navy will test TEKEVER technology in FRONTEX missions (European Agency for the Management of Operational Cooperation at the External Borders of the Member States of the EU) **in the context of the Mediterranean immigration crisis**

Collaboration with PT Naval Authorities

TEKEVER participated in a simulation of maritime pollution by the port of Leixões: SIMULACRO ANÉMONA 2015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EMRA'15 workshop

Pandora
Persistently Autonomous Robots

PANDORA
EU PROJECT

David Lane, HW University,
Scotland, UK

-

David Lane FREng FRSE

Professor of Autonomous Systems Engineering

Heriot-Watt University, Edinburgh, Scotland, UK

Edinburgh Centre for Robotics

A £35M Joint Venture between Heriot-Watt & Edinburgh Universities











Field Systems: Interaction Spaces : MOBOTARIUM : Enablers

edinburgh-robotics.org d.m.lane@hw.ac.uk

EPSRC Pioneering research and skills

Distinctly Ambitious www.hw.ac.uk

ECR

The Edinburgh Centre for Robotics and Autonomous Systems

- Multidisciplinary ecosystem – 27 core + 27 assoc. PIs across Engineering and Informatics disciplines

  Machine learning, AI, microsystems, neural computation, photonics, dependable systems, language cognition, human-robot interaction, image processing, control, manufacture research, ocean systems …

- Technical focus – 'Interaction'

  Environment: Multi-Robot: People: Self: Enablers

- 'Innovation Ready' postgraduates

  Populate the innovation pipeline. Create new businesses and models.

- Cross sector exploitation

  Offshore energy, search & rescue, medical, rehabilitation, ageing, manufacturing, space, nuclear, defence, aerospace, environment monitoring, transport, education, entertainment ..

- 38 company sponsors, EPSRC, £35M (so far ..)

  Schlumberger, Baker Hughes, Balfour Beatty, Renishaw, Honda, Network Rail, Selex, Thales, BAe, BP, Pelamis, Aquamarine Power, SciSys, Shadow Robot, SeeByte, Touch Bionics, Marza, OC Robotics …

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EDINBURGH CENTRE FOR ROBOTICS

Innovation Ready
Spin outs and licensing

-

EDINBURGH CENTRE FOR ROBOTICS
Innovation Ready

seebyte

touch bionics

HYDRASON solutions

Coda Octopus
Sound Underwater Intelligence

IceRobotics
DATA KNOWLEDGE INSIGHT

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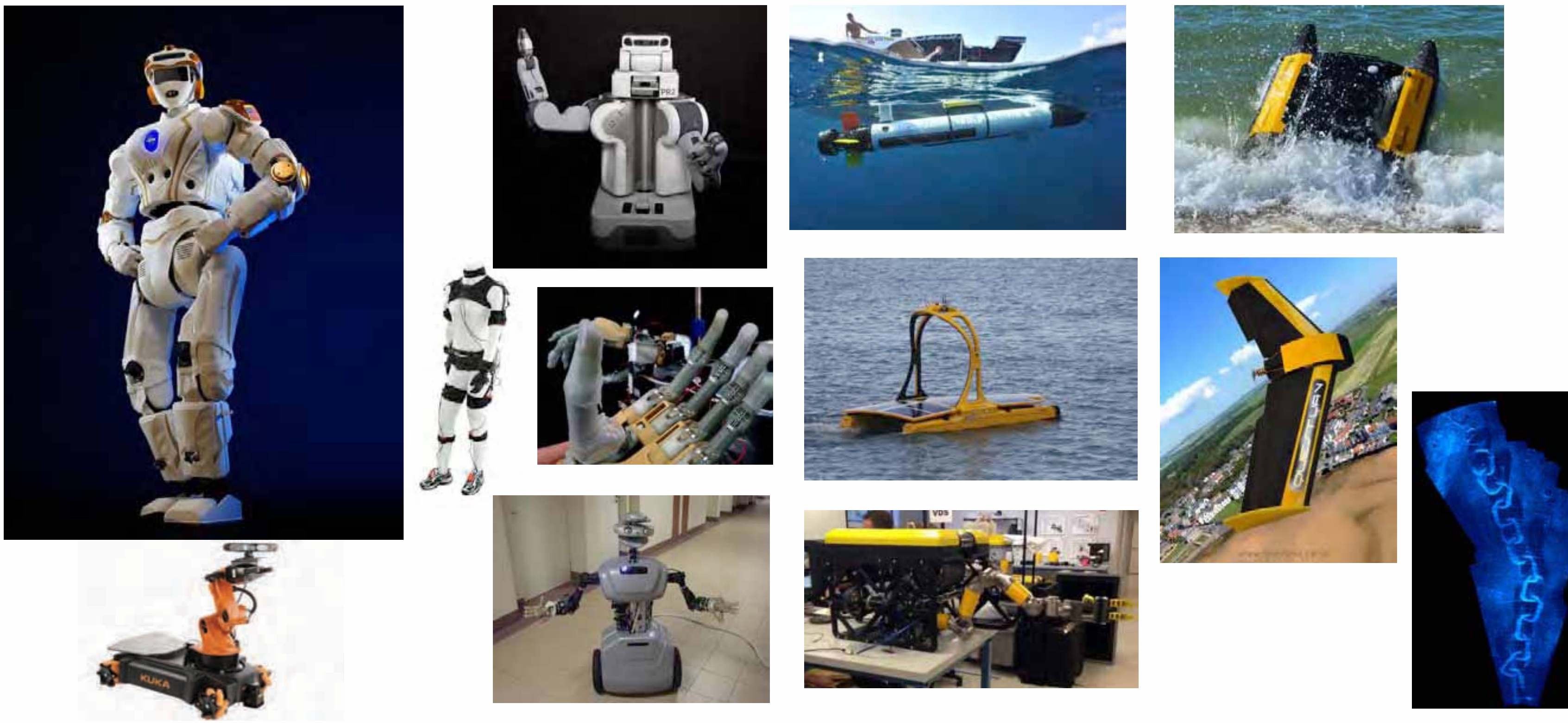
A National UK Facility for Research into the Interactions amongst Robots, Environments, People and Autonomous Systems



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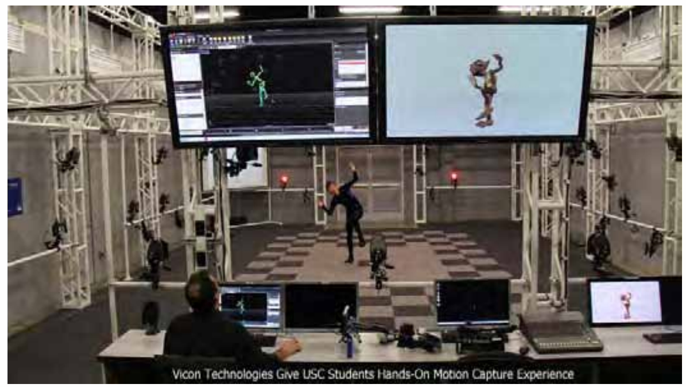

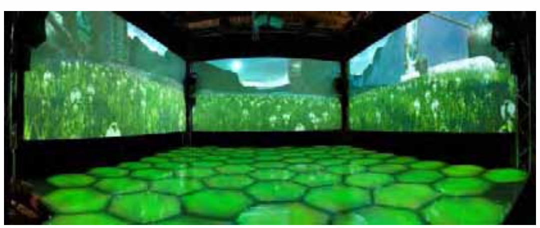

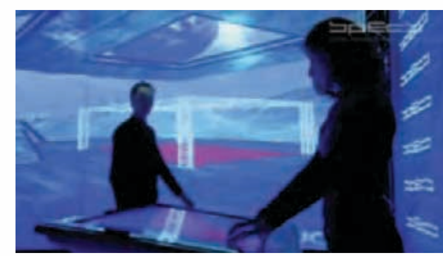

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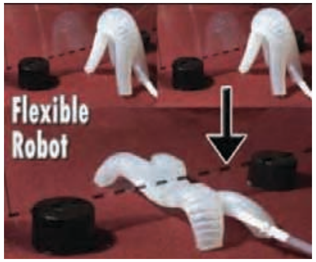

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ECR

The Edinburgh Centre for Robotics and Autonomous Systems

-

- 80+ PhD Students over 5 years
- I Year MRes followed by 3 Year PhD
- Industrial Sponsors and Secondments
- ‘**Innovation Ready**’ postgraduates (jobs and growth)
- ***#Cauldron* Training** - Creativity, Morals and the Machine, Innovation. Retreats, Sandpits, Conference. MIT Sloan School of Management and Cambridge ‘Ignite’
- **Competitions**: SAUC-E, ROBOCUP, EURATHLON, DARPA
- **Outreach**: Edinburgh Science Festival, EU Robotics Week
- **Enterprise Fund** leading to RAEng/RSE Enterprise Fellowships, Converge Challenge BizPlan, SE Proof of Concept Fund, Equity Investors

PANDORA

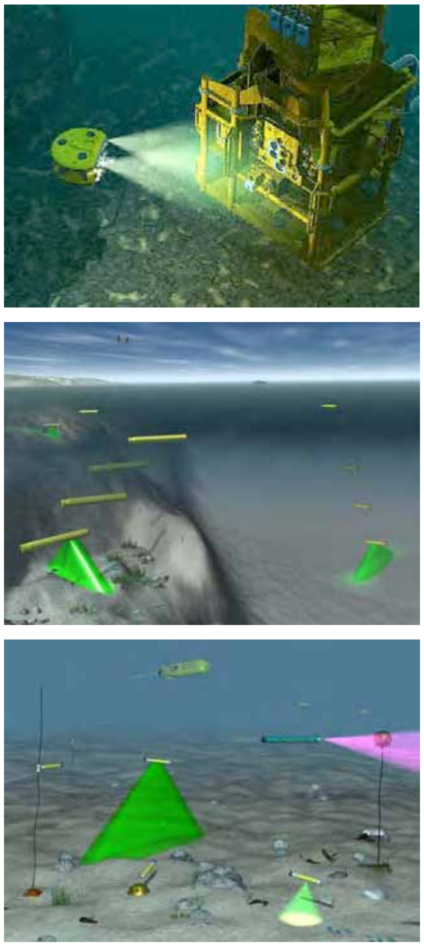
Persistent **A**uto**N**omy through learning a**D**aption **O**bservation and Repl**A**nning

UdG Girona 500

HWU Nessie V

PANDORA PROJECT – FP7-ICT-2011-7 Ref. 288273
www.persistentautonomy.com ·

Persistent Autonomy



- operate successfully while unsupervised and without recourse to a human operator
- for extended lengths of time
- in environments that are not completely known
- adapting purpose in response to unexpected events and disturbances
- on different scales in space and time
- whilst interacting with the environment
- and recovering from errors in task execution.

2003: ALIVE Autonomous Light Intervention Vehicle

FP5: Cybernetix, Ifremer, HWU, JRC, HiTec

EDINBURGH CENTRE FOR ROBOTICS

ECR: The Edinburgh Centre for Robotics

Innovation Impact

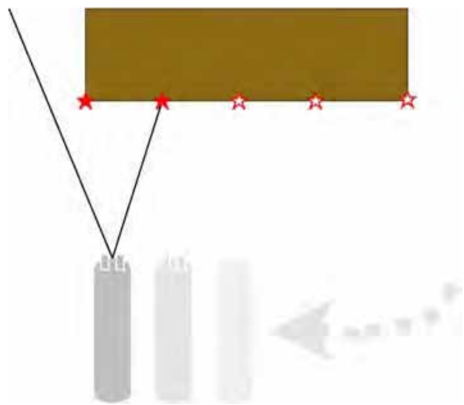
subsea 7

seebyte
Awareness Made Easy

AIV: **A**utonomous (underwater) **I**nspection **V**ehicle

Scenarios

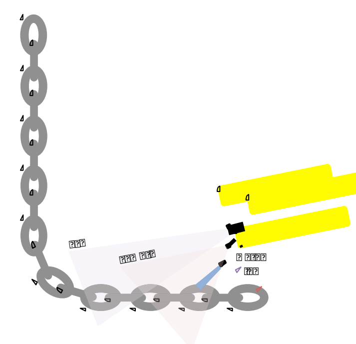
A. STRUCTURE INSPECTION



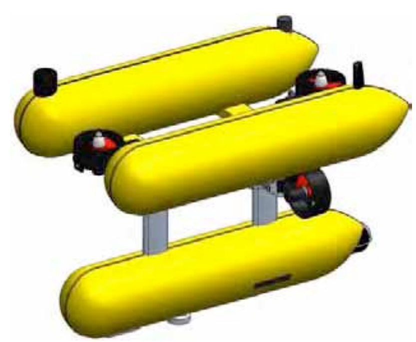
HWU, Fort William

Nessie VI AUV

B. CHAIN CLEANING AND INSPECTION

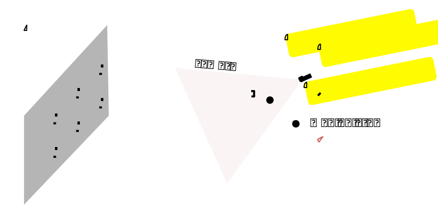


UdG, CIRS water tank

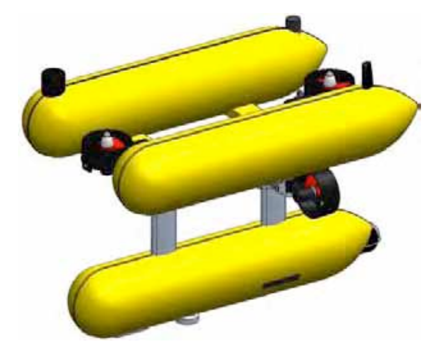


Girona 500 AUV

C.VALVE TURNING

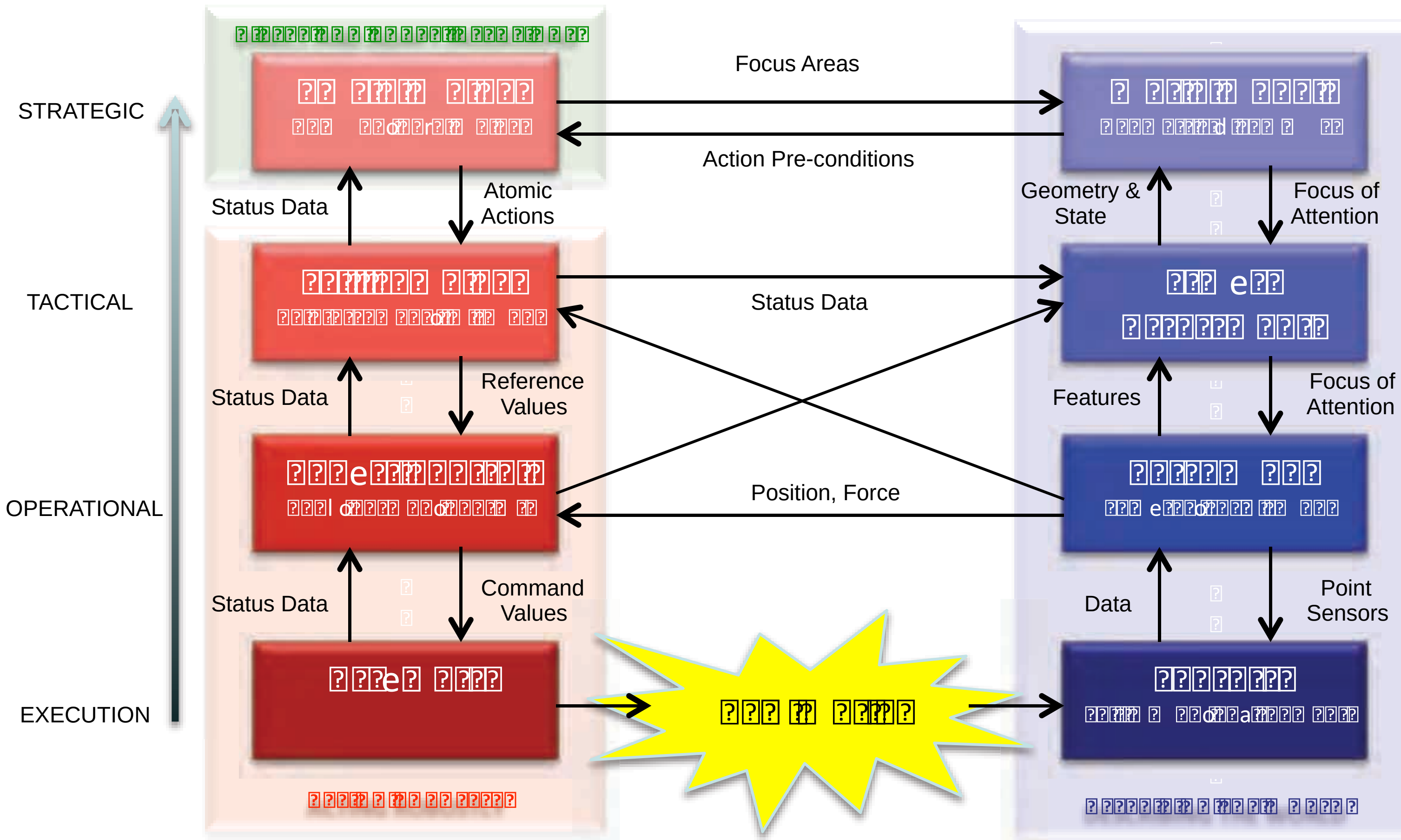


UdG, CIRS water tank



Girona 500 AUV

System Architecture



Themes

A. Describing the World will develop new probabilistic semantic representations of the environment and the state of task execution, driven by feature based localisation and world model update from sensors, and by focus of attention mechanisms. This will detect failure of task execution and its context.

B. Directing and Adapting Intentions will investigate planning and plan adaption under resource constraint and uncertainty in response to goals and the changing world above. This will enable the robot to respond strategically to action failure(s)

C. Acting Robustly will investigate the interface between re-enforcement/ imitation learning methods and robust control to make action execution indifferent to unwanted motion of target or self.

Describing The World

- Semantic world modelling:

- uncertainty and probability update tested post-processing sonar data and integrated in the vehicle architecture
- link with planning - queries the ontology for the problem instantiation and to acquire useful information

- SLAM Based Navigation Around Structures

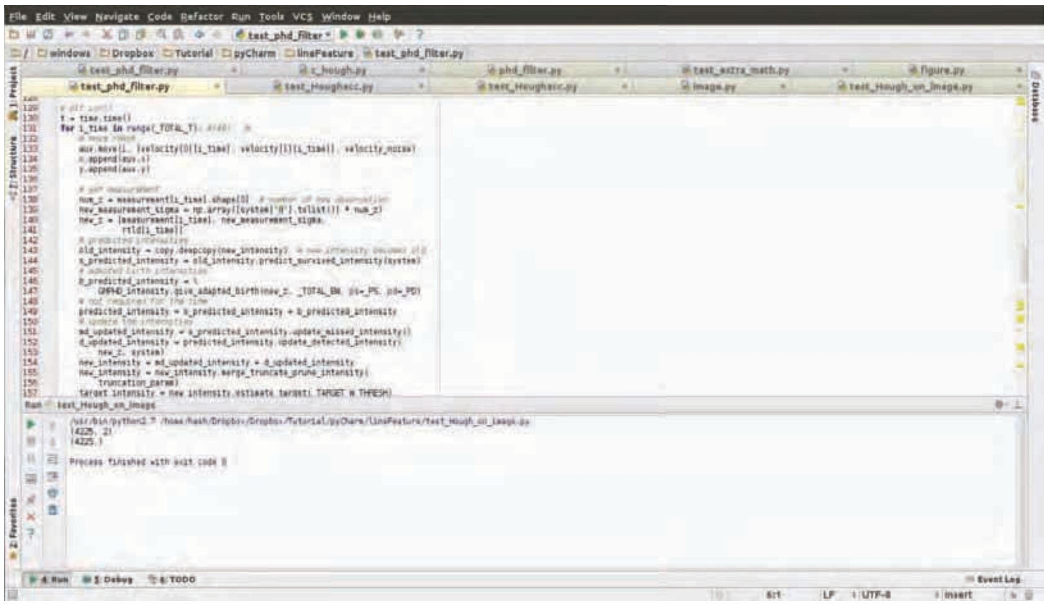
- Vision-based and sonar-based PHD mapping developed, showing robustness against outliers
- two types of SLAM developed; sonar-based Octomap developed, fully integrated and successfully tested embedded in *Nessie*^{AUV}

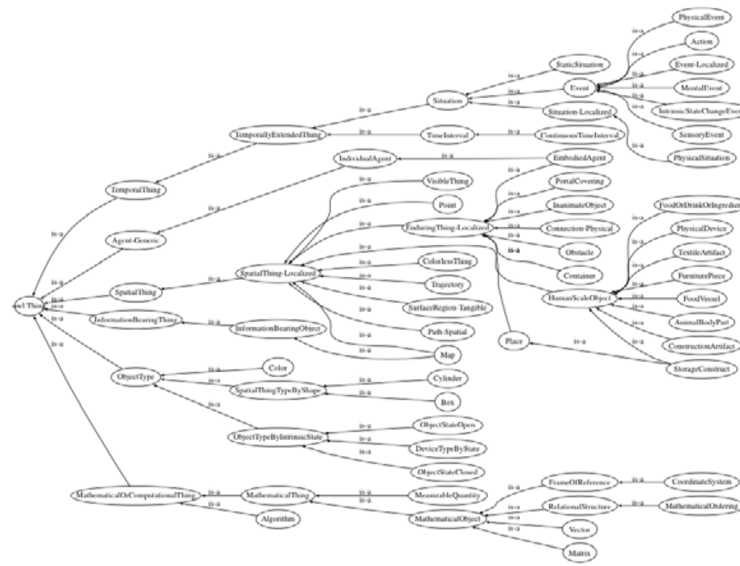
- Focus of sensor attention

- System designed with BV P900 and BV MB 2250 mounted on a pan&tilt, in *Nessie*^{AUV}; implementation started.

Ontology

Semantic Relation Modeling





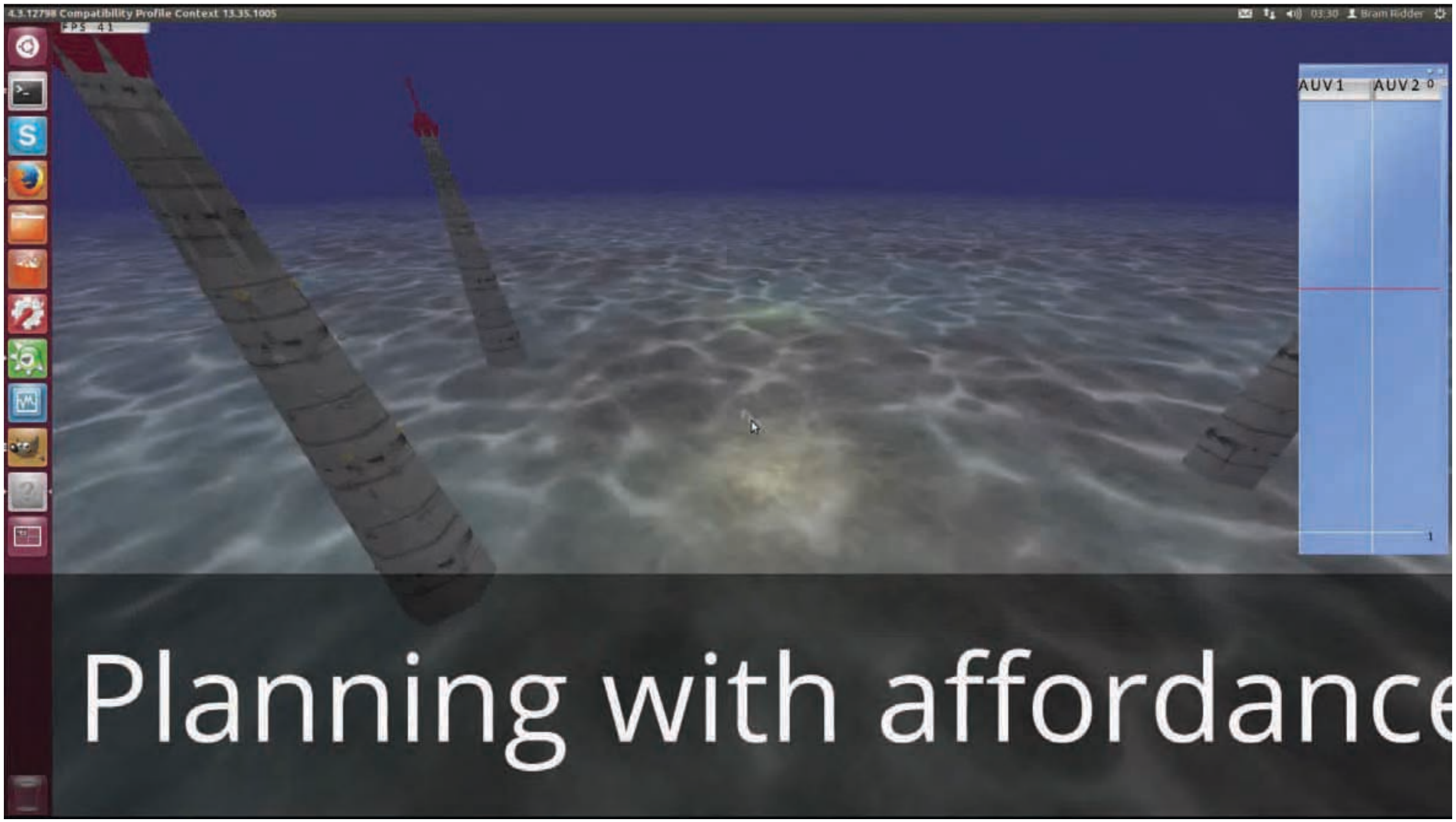
Signal to Symbol

PHD SLAM. Markov Logic Networks

Directing & Adapting Intentions

- Discovery-led temporal planning: plan execution interleaved with discovery, model update and re-planning
- Search-based planning using a reward discounting method for belief-tracking
- New algorithm for time-efficient 3-D motion planning
- Robust integration of generic temporal planning with ontology, path-planner and controllers, through ROS interface

Directing & Adapting Intentions



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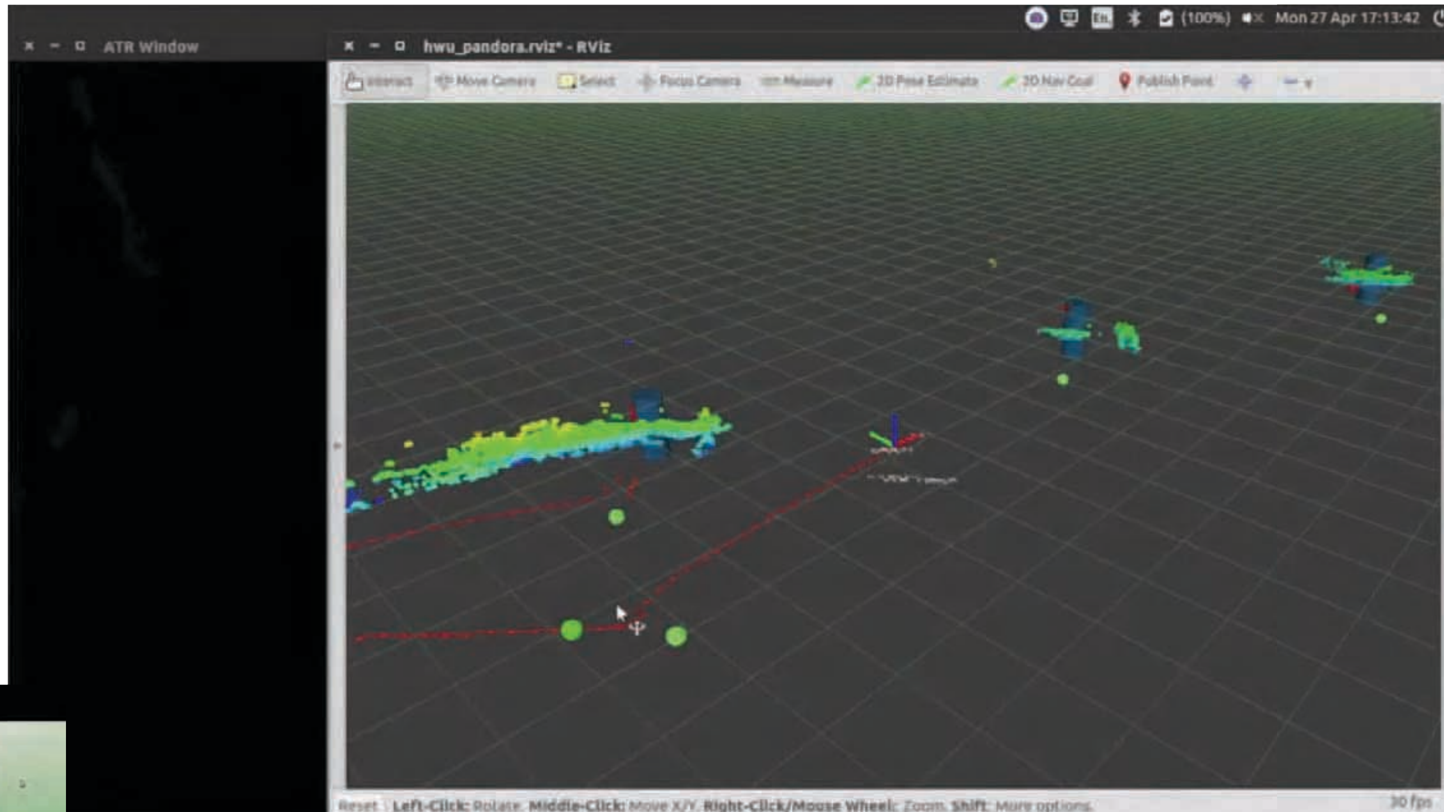
Directing & Adapting Intentions

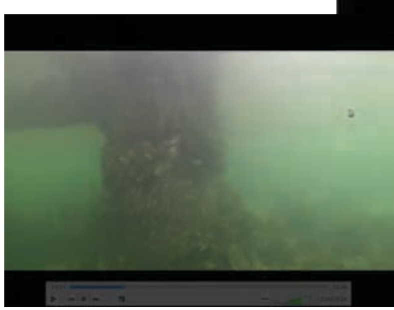
Fort William, Scotland, UK. 27 April 2015

Directing & Adapting Intentions

Pier inspection trials at the Underwater Centre

Directing & Adapting Intentions





Nessie AIV adapts inspection plan as the pier geometry is discovered

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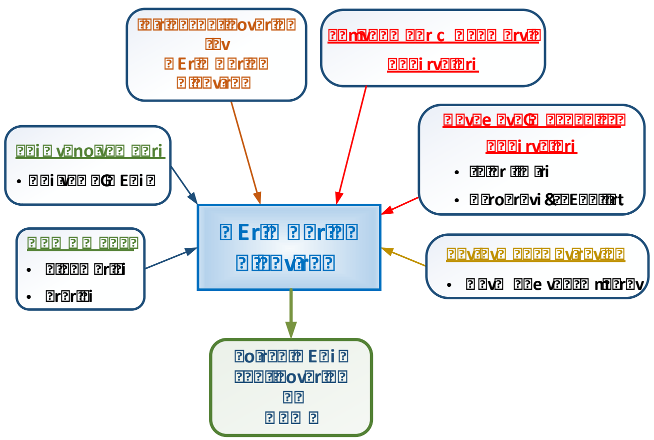
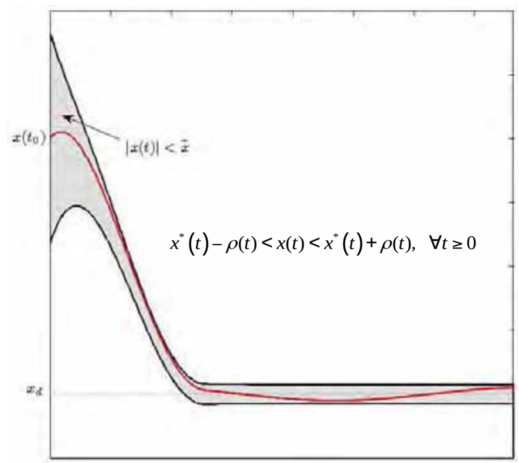
Robust Control Strategies

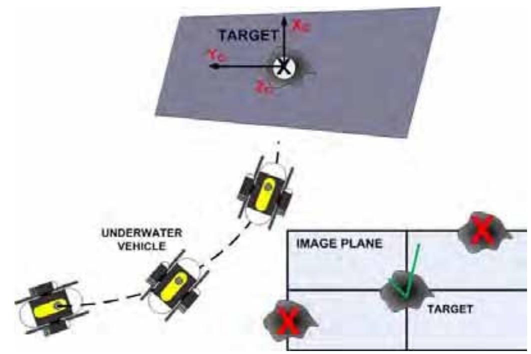
1. Task-specific grasp configuration.

2. Performance control in anchor chain inspection.

3. Extending the AUV operating envelope.



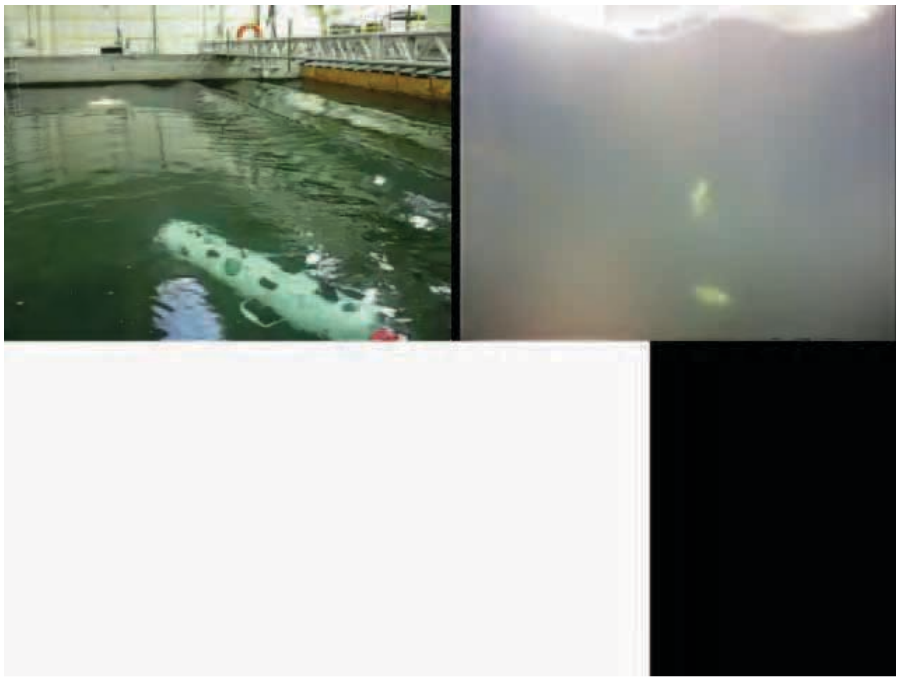




Future Work

- Force Control during Valve Turning. **(UdG & IIT)**
- Integration of Control Schemes with Planning Algorithms for Inspection. **(KCL)**
- Integration of Control Schemes with Skill Learning. **(IIT)**
- Integration towards extending the operating envelope of Nessie VI. **(HWU)**

Robust Control Strategies

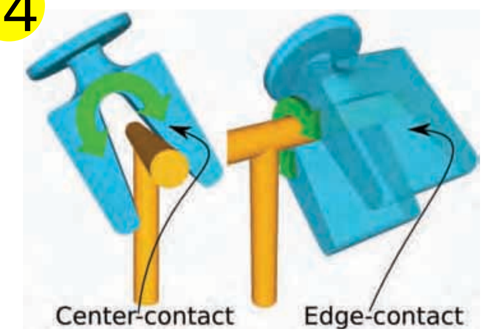


Skill Learning

1) Online Recovery from Thruster Failure
2) Covariance Analysis for Reinforcement Learning
3) Learning by Demonstration for AUV valve turning
4) Contact State Estimation for valve turning
5) Improving the Energy Efficiency of AUVs

3

4



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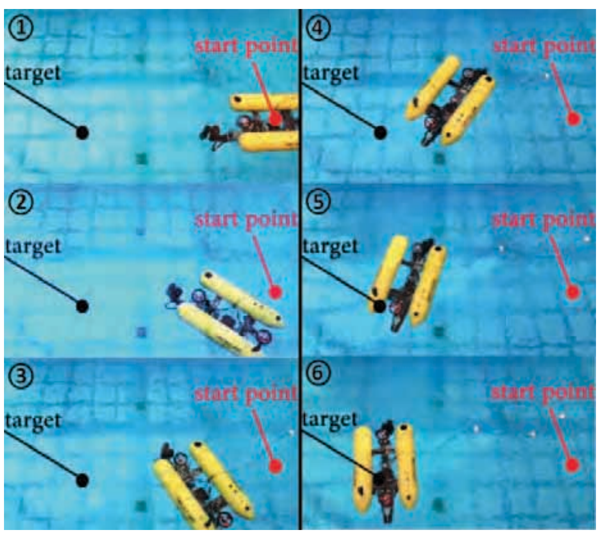

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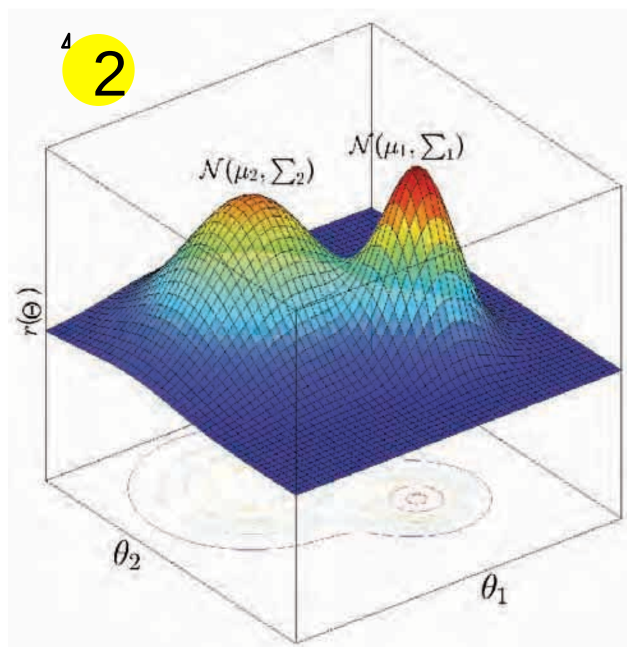

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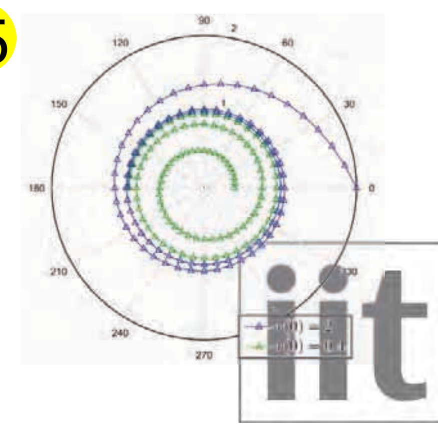
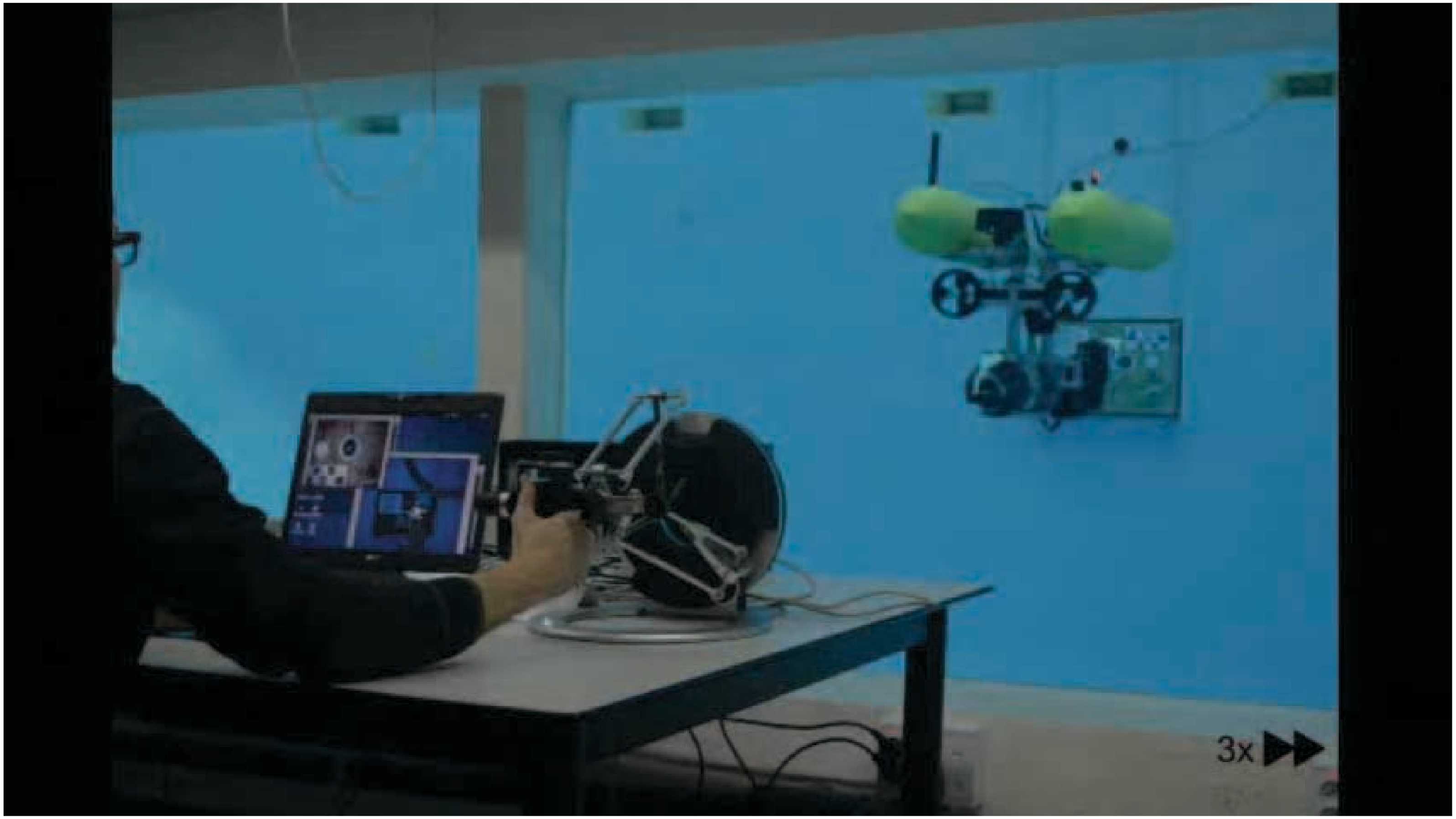


Skill Learning

-



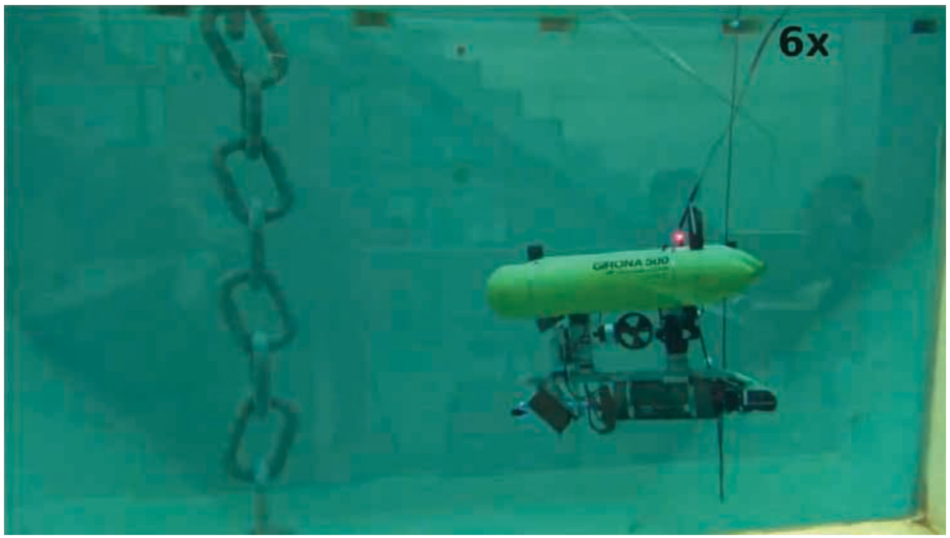
Valve Turning

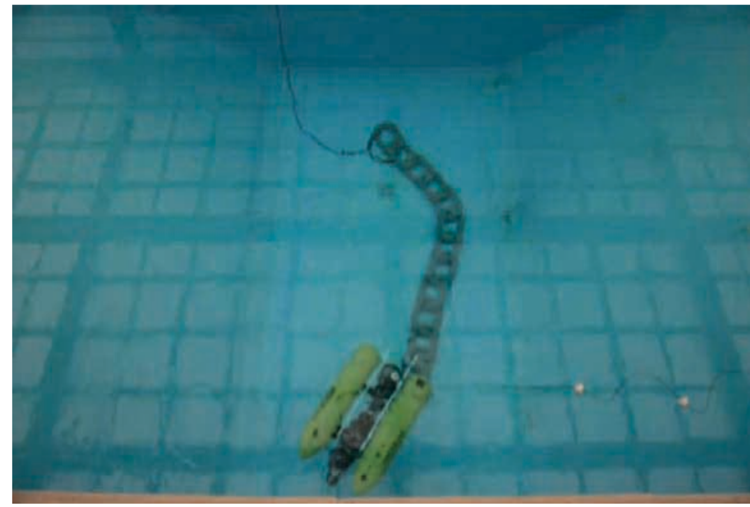
Pandora
Persistently Autonomous Robots

Skill Learning

EDINBURGH CENTRE FOR
ROBOTICS
Innovation Ready

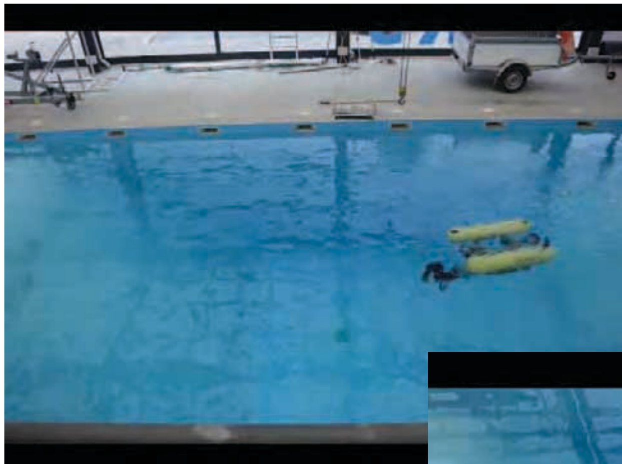
-



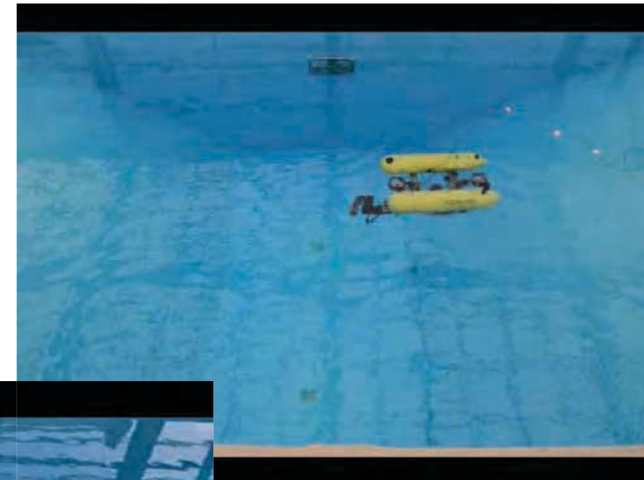


Chain Cleaning & Inspection

Skill Learning



Normal



Failed Thruster

Recovery

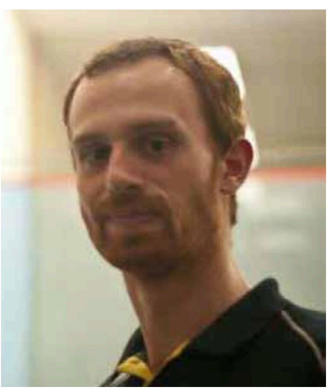
Heriot Watt University: HWU

D. M. Lane

F. Maurelli

T. Larkworthy

Z. Saigol



G. Frost

N. Tsiogkas

G. Papadimitriou

H. Kemal

V. de Carolis

University of Girona: UdG

Quim Salvi
Professor | PI

Marc Carreras
Associate Professor

Narcís Palomeras
Post Doc | WP5

Sharad Nagappa
Post Doc | WP1&5

Arnau Carrera
PhD Student | WP3

Natàlia Hurtós
PhD Student | WP5

Chee Sing
PhD Student | WP1

Joseta Roca
Project Mangement

Istituto Italiano di Tecnologia: IIT

Prof. Darwin Caldwell
(Project steering)

Petar Kormushev
(PI)

Sylvain Calinon
(co-PI)

Matteo Leonetti
(Post-doc)

Nawid Jamali
(Post-doc)

Reza Ahmadzadeh
(PhD student)

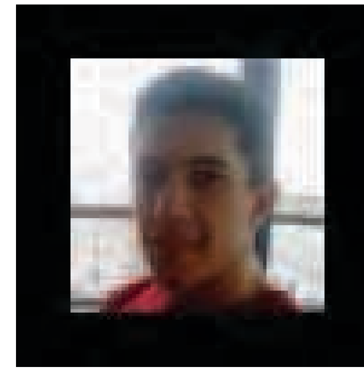
Rodrigo Jamisola
(Post-doc)

Kings College London: KCL


Maria Fox


Derek Long


Dan Magazzeni


Michael Cashmore

Experts in planning applications, domain modelling, temporal and resource constrained planning, plan validation and planning with continuous processes

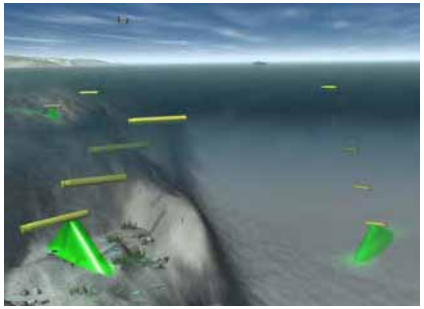
Planners - Crikey, CoLin, POPF, Optic, LPRPG
Validation – VAL
Planning under uncertainty – Plan-based policy learning, BATMAN

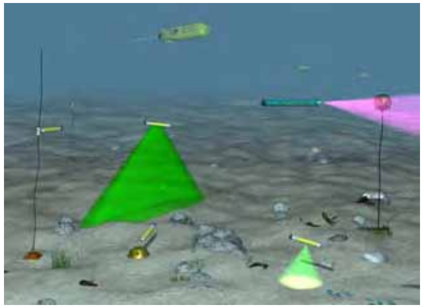
National Technical University of Athens: NTUA

Pandora
Persistently Autonomous Robots

Persistent Autonomy

EDINBURGH CENTRE FOR ROBOTICS
Innovation Ready

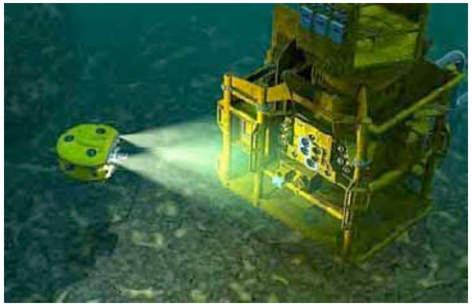


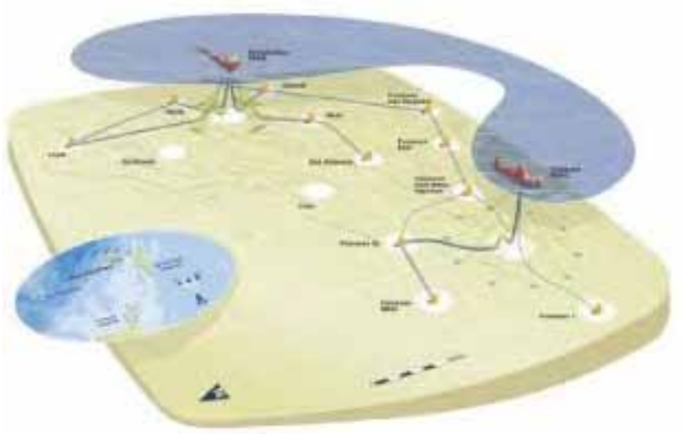


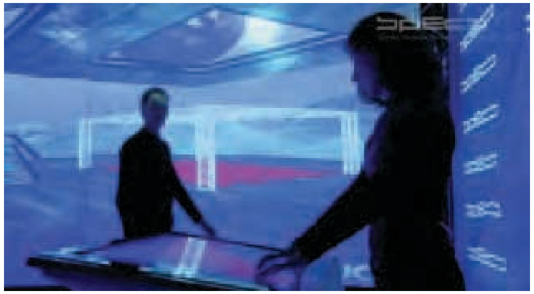
- operate successfully while unsupervised and without recourse to a human operator
- for extended lengths of time
- in environments that are not completely known
- adapting purpose in response to unexpected events and disturbances
- on different scales in space and time
- whilst interacting with the environment
- and recovering from errors in task execution.

HERIOT WATT UNIVERSITY

Where next? : Future FPSO : Oilfield as a Smart Space







Interaction between people, data, robots.

Condition monitoring as part of Life of Field asset integrity

Robots are the arms and legs of Big Data

David Lane FREng FRSE

Professor of Autonomous Systems Engineering

Heriot-Watt University, Edinburgh, Scotland, UK

edinburgh-robotics.org d.m.lane@hw.ac.uk

EMRA´15

ISR-IST Lisbon Portugal

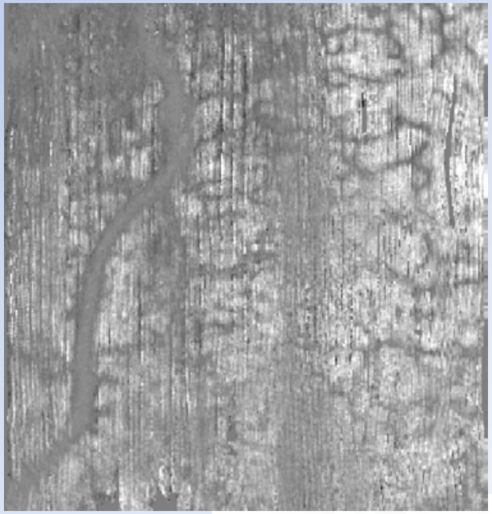
EMRA'15 workshop

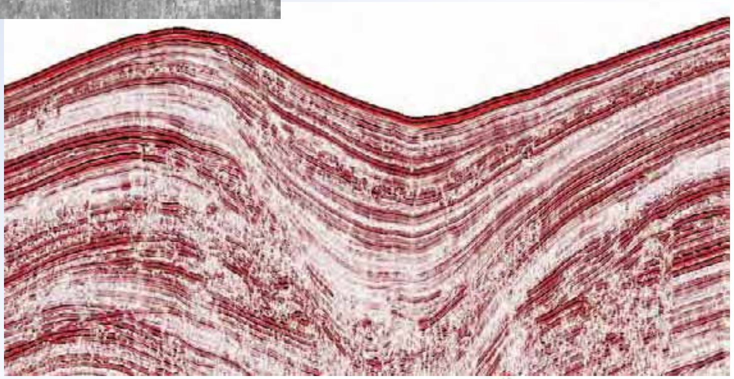
The future of autonomous marine vehicles in ultra high-resolution seismic reflection surveys (URHS)

Henrique Duarte,
Geosurveys, Aveiro, PT

The future of autonomous marine vehicles in Ultra High Resolution Seismic reflection surveys (UHRS)

Henrique Duarte, Geosurveys Geophysical Consultants





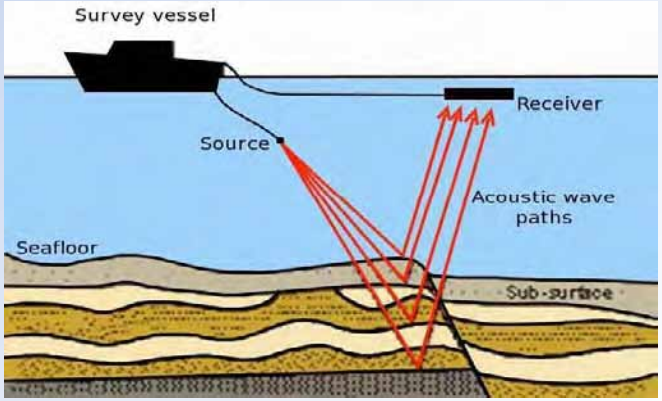
GeoSurveys geophysical consultants

Outline

- **UHRS surveying**
  - **Geophysical Method**
  - **Main markets**
- **Using AUVS in UHRS (WIMUST PROJECT)**
- **The marine windfarm projects**
- **Long term view**

Ultra High Resolution Seismic (UHRS)

- **Industry designation for a 2D / 3D marine seismic reflection survey method**
  - **Horizontal resolution < 1.5 m**
  - **Vertical resolution < 0.5 m**
  - **Water depths down to 3000 m**
  - **Image the upper 100 m below the seabed**
  - **Survey sites from 1 km^2 to 100 km^2**

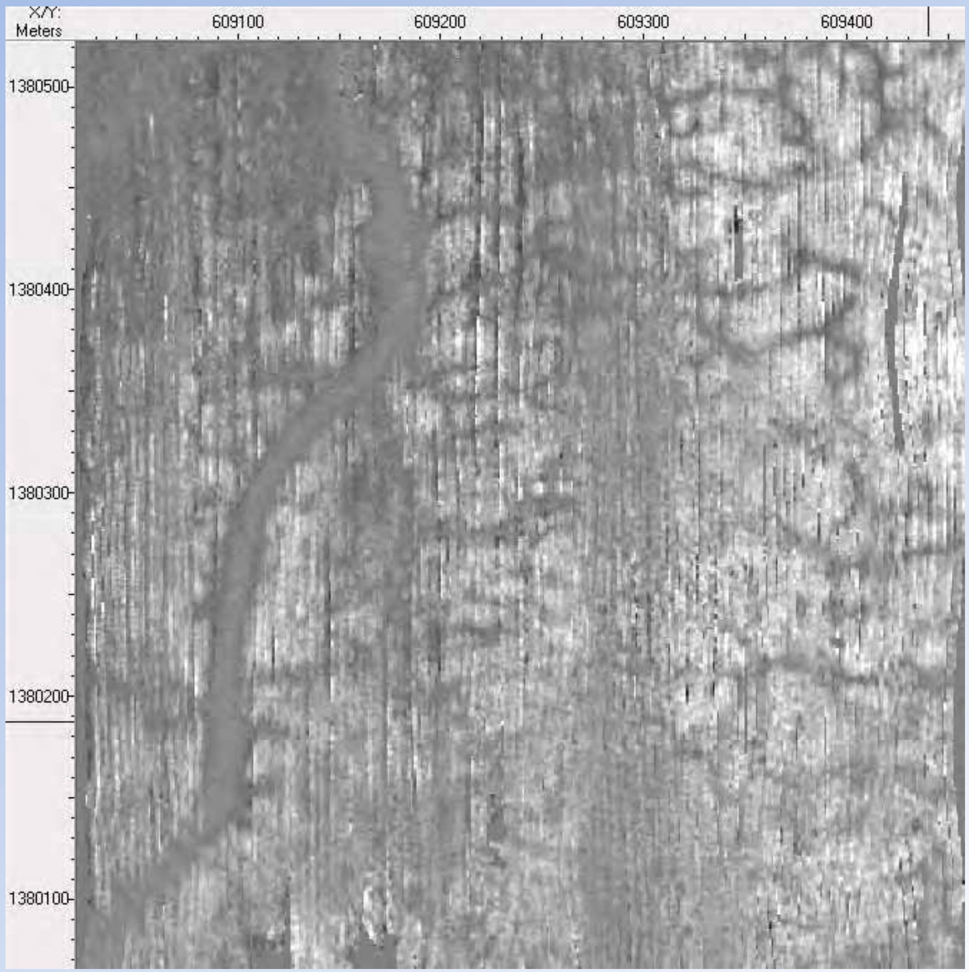


- **UHRS spread**
  - **Typical source frequency bandwidth – 100 Hz to 2000 Hz**
  - **Source and receiver array towed from vessels**
  - **Multi-channel receiver array up to 150 m long**
- **Main application for marine geotechnical engineering purposes**
  - **Design of foundations for overwater and subsea structures and anchors**
  - **Assessment of burial performance for pipelines and cables**

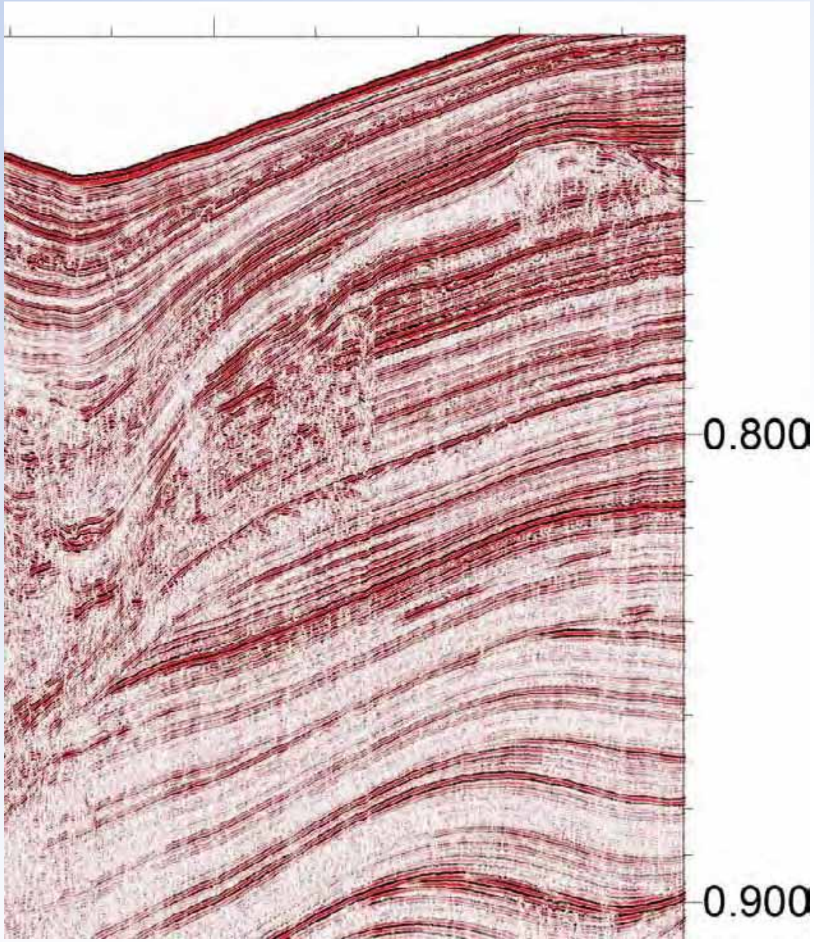
GeoSurveys geophysical consultants

Ultra High Resolution Seismic (UHRS)

3D time slice



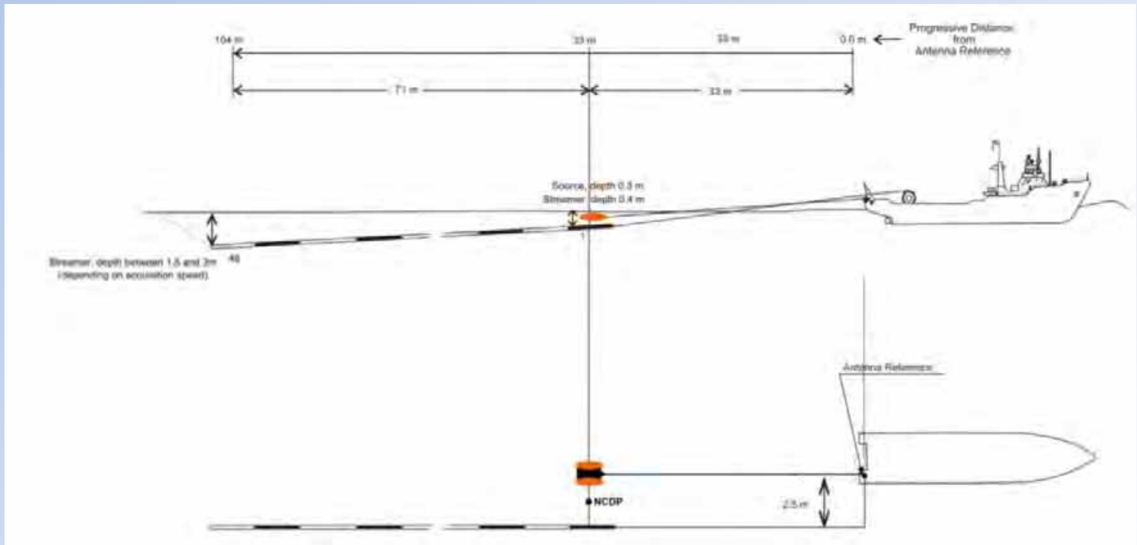
2D profile



GeoSurveys geophysical consultants

Ultra High Resolution Seismic (UHRS)

- **2D Configuration**
  - **1 source point**
  - **linear array of hydrophones**



- **3D Configuration**
  - **2 source points**
  - **multiple arrays of hydrophones**

GeoSurveys geophysical consultants

Ultra High Resolution Seismic (UHRS)

Ultra High Resolution Seismic (UHRS)

Operations

- Preferred 24 h operations on vessel > 25 m length

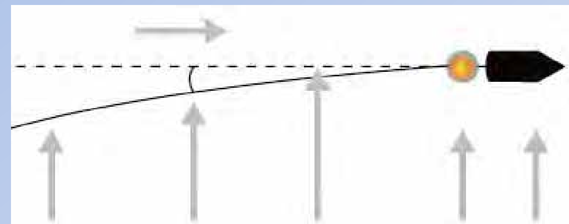
- North sea vessels > 45 m long

- 10 – 45 days of survey operations + weather / equipment downtime

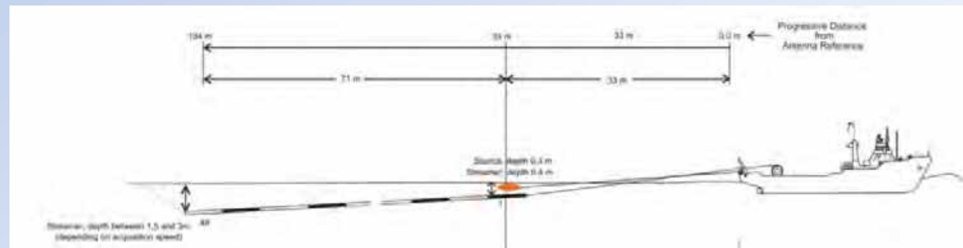
Ultra High Resolution Seismic (UHRS)

Major issues

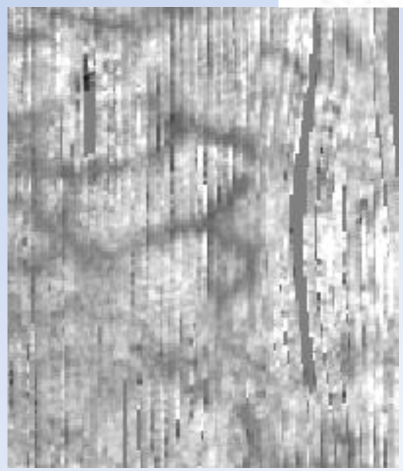
- **Currents & Feathering**



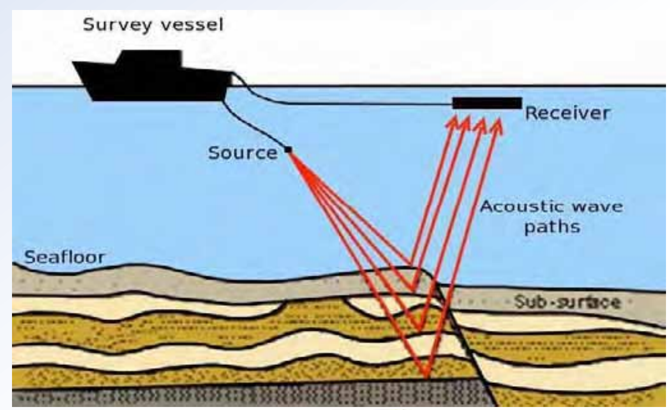
- **Towing limitations on the spread's geometry**



- **Line keeping and survey efficiency**



- **Achieving raypath coverage**



GeoSurveys geophysical consultants

Major markets

- **pipelines & cables**

- **Rig moves**

- **Marine windfarm foundations & cables**

GeoSurveys geophysical consultants

Roles for AUVs (WIMUST)

Multiple cooperating vehicles with hydrophone arrays and sources (> 7 vehicles)

Will significantly improve imaging quality

Geometrical liberty by decoupling seismic spread from the survey vessel

- Minimizing feathering
- Reliable line keeping
- Improved raypath coverage

Low noise survey conditions

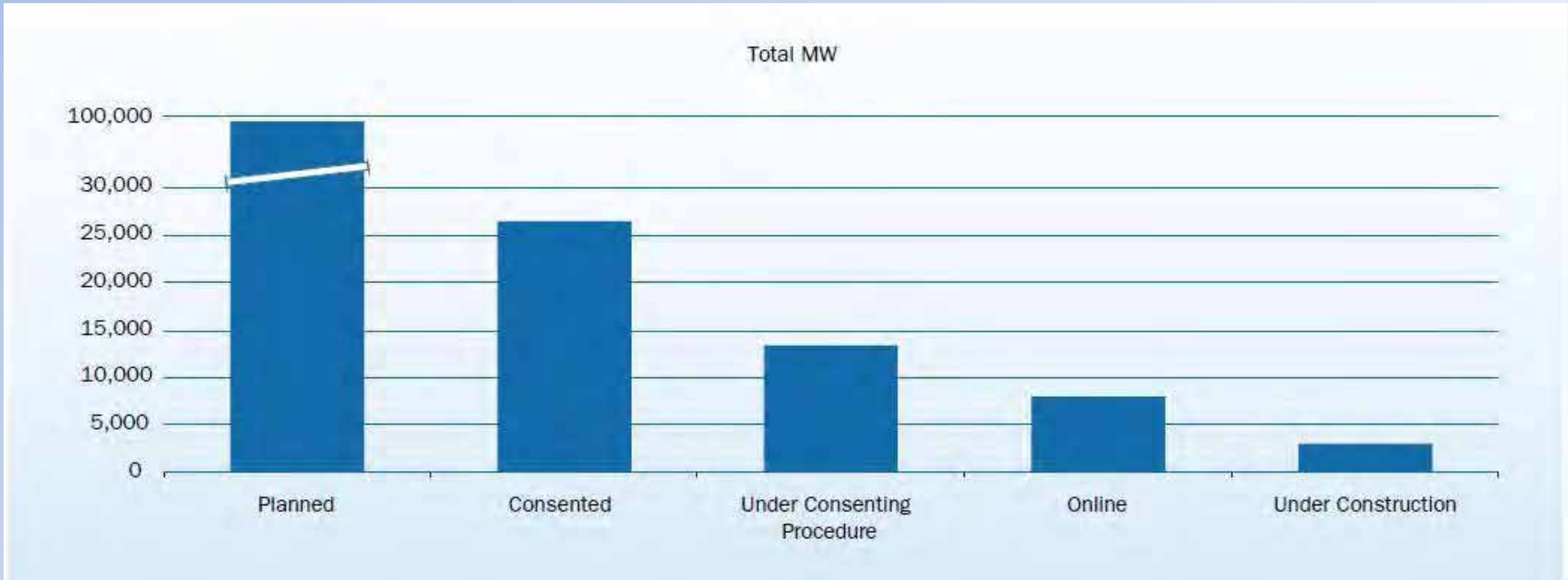
- Distance from vessel
- Can deploy at depth

Will Improve the reliability of survey budgeting

No rerun requirements due to poor vessel performance (feathering and line keeping)

GeoSurveys geophysical consultants

Growth in marine windfarm projects

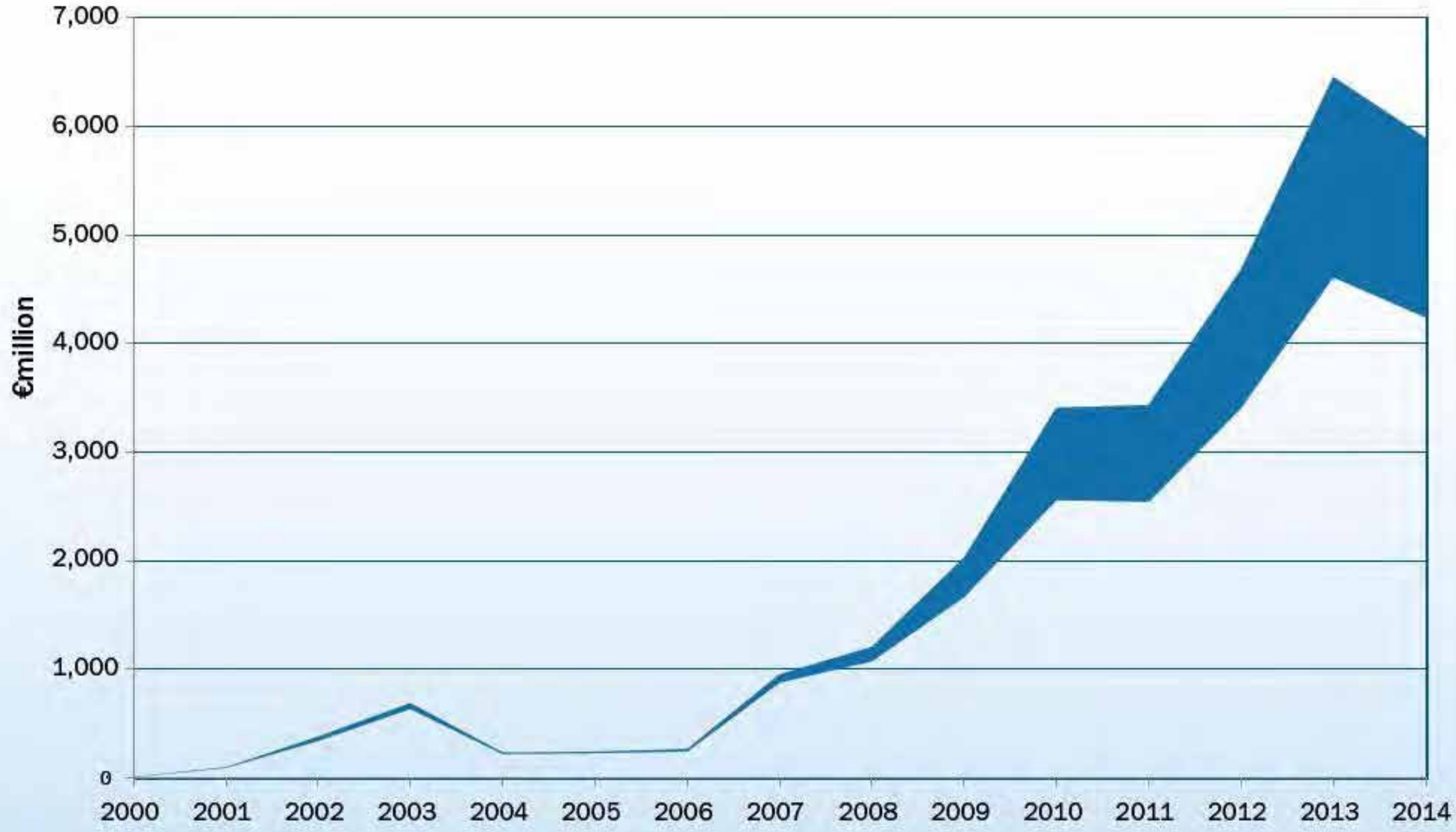


From EWEA-European-Offshore-Statistics-2014

GeoSurveys geophysical consultants

Captial depth in marine windfarm projects

FIG. 32: RANGE OF ANNUAL INVESTMENTS IN OFFSHORE WIND FARMS



From EWEA-European-Offshore-Statistics-2014

Potential of marine windfarm projects

- **UHRS survey costs per site 500 k – 5 million euros**
- **Hundreds of sites planned in the North sea for the next 10-20 years**
- **Historically each site was surveyed 1 -3 times with UHRS methods during project development**
- **Opportunity to mature AUV technology under Industry contractual requirements and demanding sea conditions**

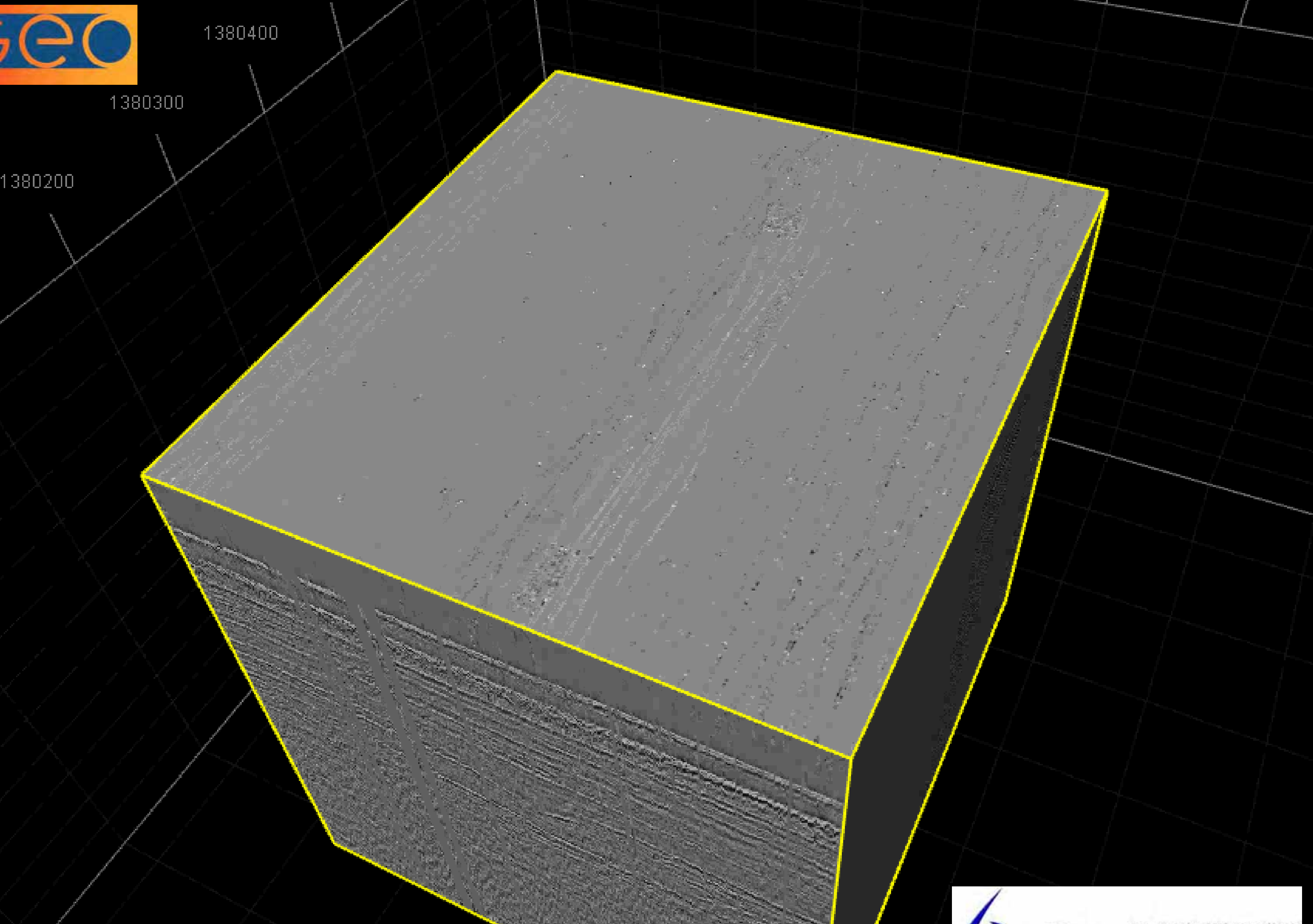
Potential of marine windfarm projects

- **AUV application to UHRS allows for a progressive development funded through commercial activities**
  - **Surface operations mimicking towed operations**
  - **Partial deployment of the spread on AUVs (low energy requirements)**
  - **Deep deployment of acquisition component**
  - **Full deployment of the spread**

- **Will open the door to other geophysical applications with cooperating AUVS:**
  - **Windfarm MBES surveying**
  - **UXO magnetometer surveying**

Long Term

- **UHRS Surveying is a small scale application of a traditional Oil & Gas Geophysical exploration method**
- **Fundamental principles scale up.**
- **UHRS requires tens of cooperating vehicles**
- **3D Marine Seismic Exploration will require thousands of cooperating vehicles…**


1380400
1380300
1380200

WiMUST
EU PROJECT

Giovanni Indiveri, Univ. Salento, IT

The H2020 project WiMUST: Widely scalable Mobile Underwater Sonar Technology. An overview.

Speaker: Giovanni Indiveri
Dipartimento Ingegneria Innovazione
Università del Salento, Lecce - ISME node

Lisbon, 18th June 2015

EMRA'15 workshop

Integrated Systems for Marine Environment

WiMUST
Widely scalable Mobile
Underwater Sonar Technology

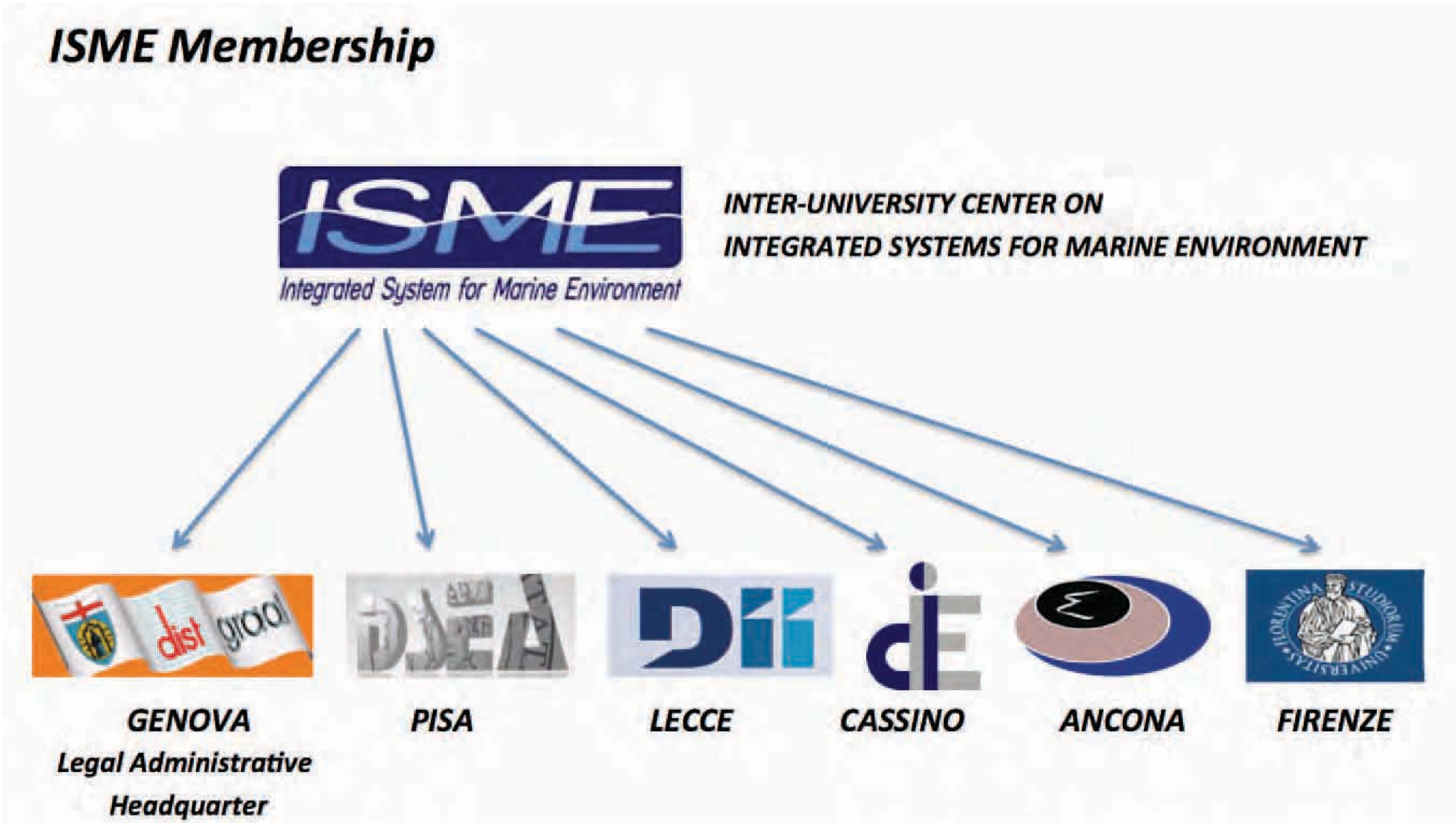
WiMUST Principle Investigators:

Gianluca Antonelli, Andrea Caffaz, Andrea Caiti, Giuseppe Casalino, Ivan Bielic de Jong, Henrique Duarte, Jonathan Grimsdale, Giovanni Indiveri, Sergio Jesus, Konstantin Kebkal, Antonio Pascoal and Daniel Polani

Outline

- The inter-university center ISME (Integrated Systems for the Marine Environment): an overview
- WiMUST: Widely scalable Mobile Underwater Sonar Technology. An H2020 project
- A few (very) preliminary results
- Concluding remarks

The ISME Network

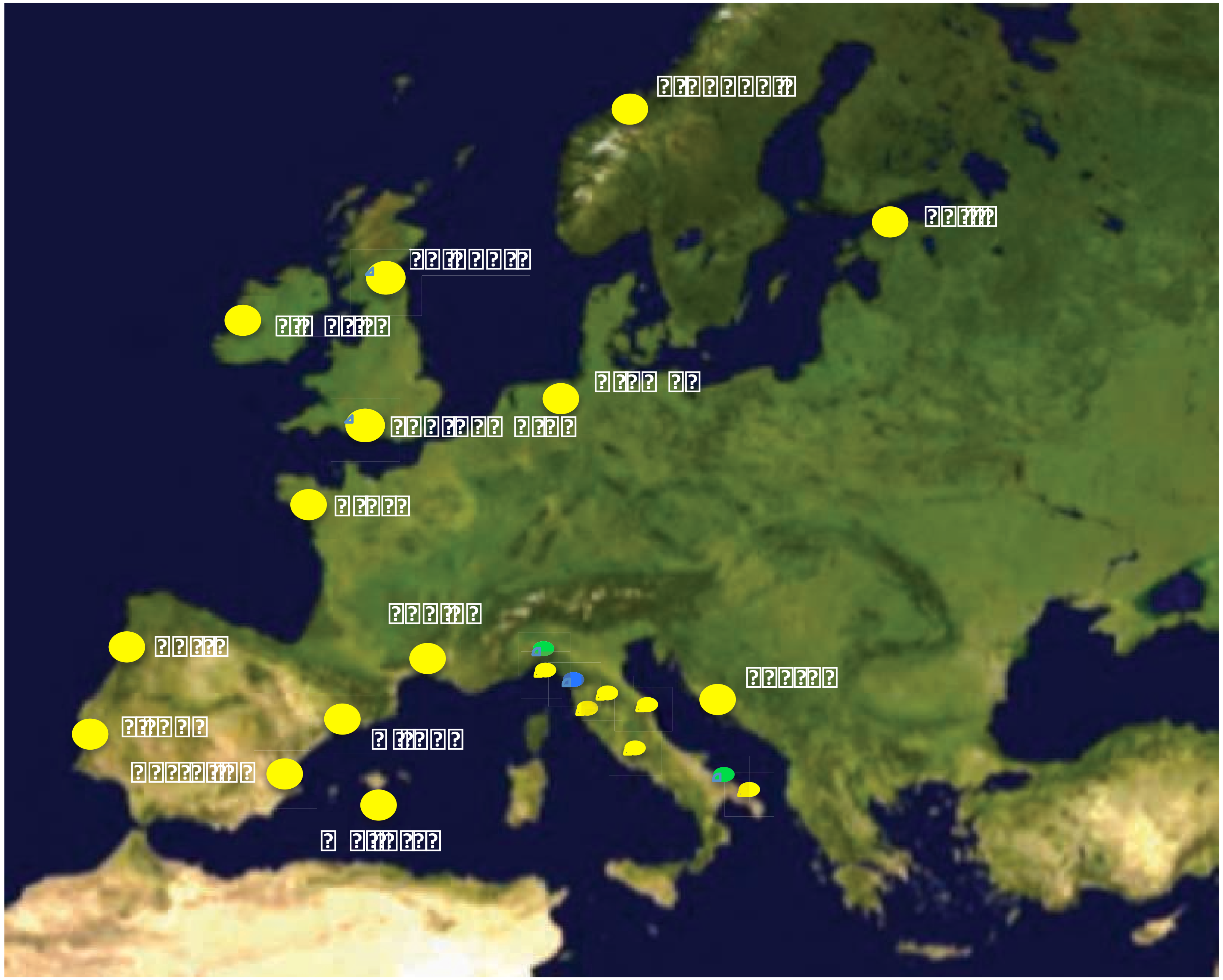


WiMUST
Widely scalable Mobile
Underwater Sonar Technology

Marine Robotics in Italy

- ISME
- CNR-ISSIA
- NATO-CMRE

WiMUST
Widely scalable Mobile Underwater Sonar Technology



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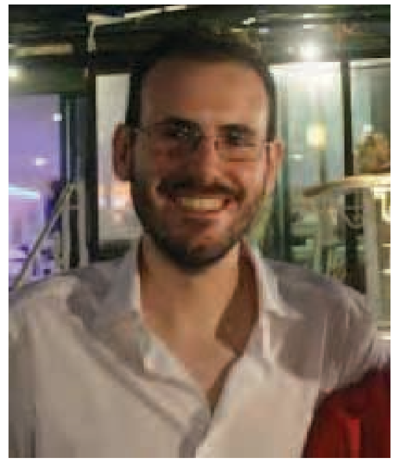
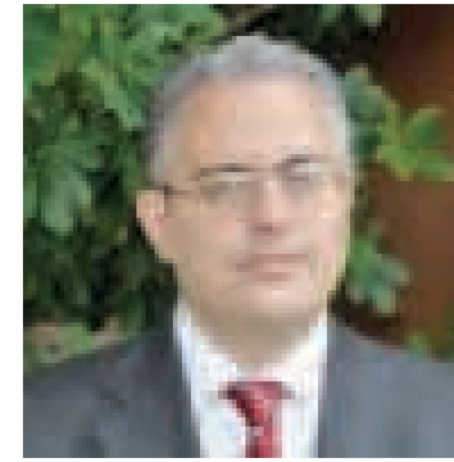
Ifremer

UIB

6/34

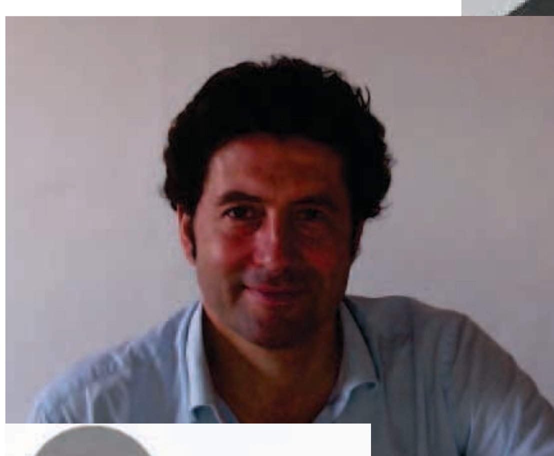
The ISME Crew

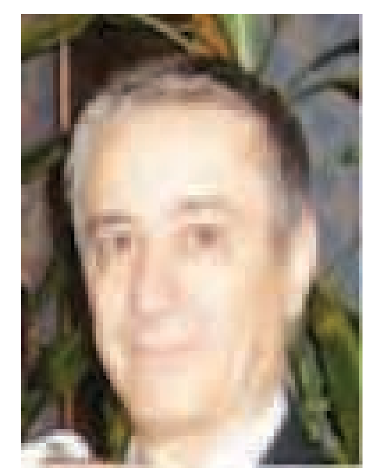














ISME Funding and Resources

- ISME does not receive any institutional funding for its operation
- All ISME research is funded by contracts with agencies, industries, third parties
- Resources from any participating lab are available to ISME
- ISME-owned resources are available to any participating lab
- Total Human resources available: more than 35 structured researchers and more than 15 non-structured young researchers
- Strong emphasis is given to applied research and field activities
- Pointing toward unifying frameworks encompassing most of the applications is constantly encouraged
- Average Budget per year: 550 K-Euro (last 5 years average)

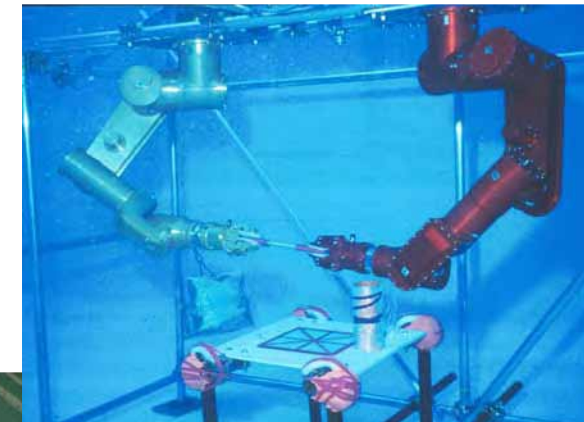
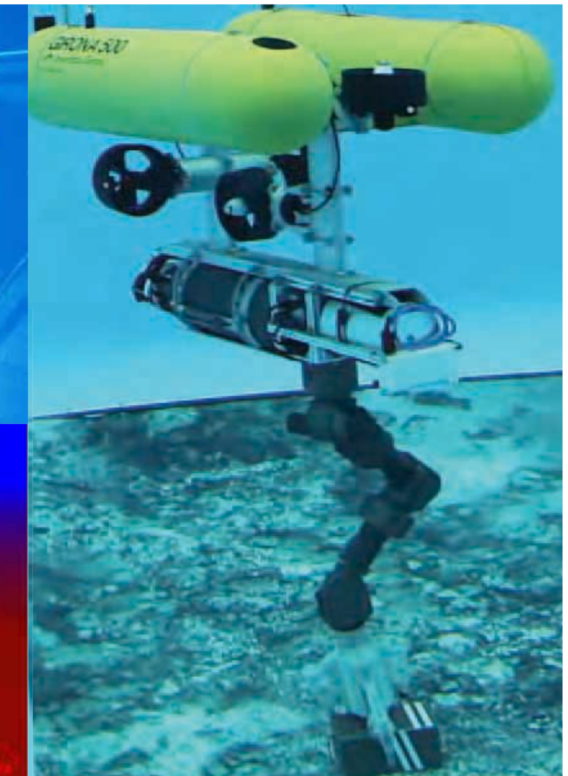
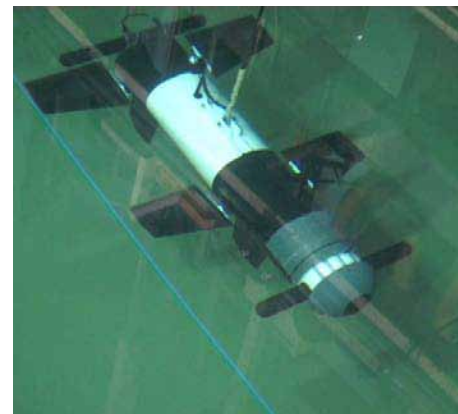
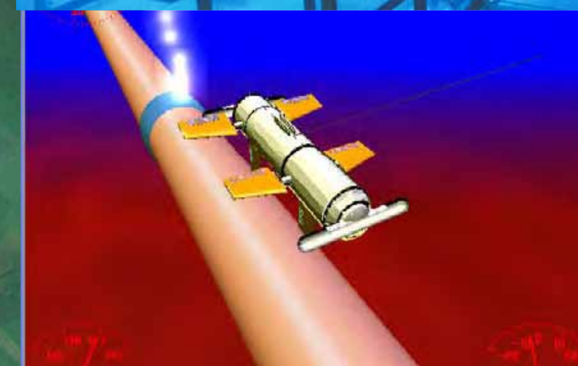
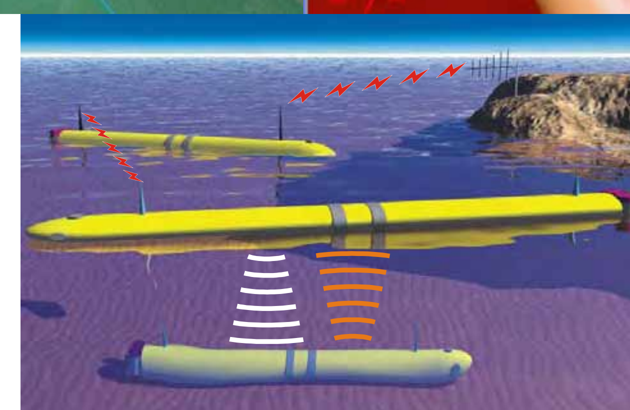
Wi MUST
Widely scalable Mobile Underwater Sonar Technology

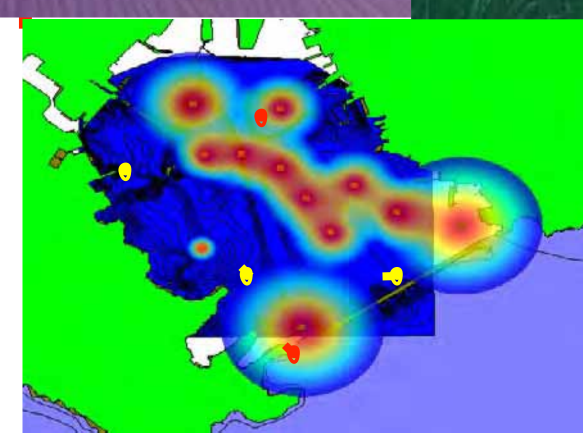
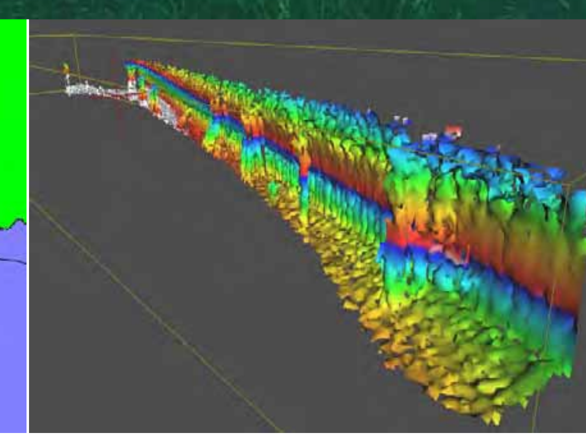
- Robotics
- - Underwater manipulation systems
- - Guidance and control of AUV's and ROV's
- - Distributed coordination and control of AUV's team
- - Mission planning and control

- Underwater acoustics
- - Acoustic localization
- - Acoustic communications
- - Underwater optical communications,
- - Acoustic Imaging and Tomography
- - Seafloor acoustics
- - Sonar systems

- Signal Processing and data acquisition
- - Distributed data acquisition
- - Geographical information systems
- - Decision support systems
- - Classification and data fusion

- Applications:
- - Surface and underwater security systems
- - Distributed underwater environmental monitoring
- - Underwater archaeology
- - Underwater infrastructures inspection
- - Sea surface remote sensing

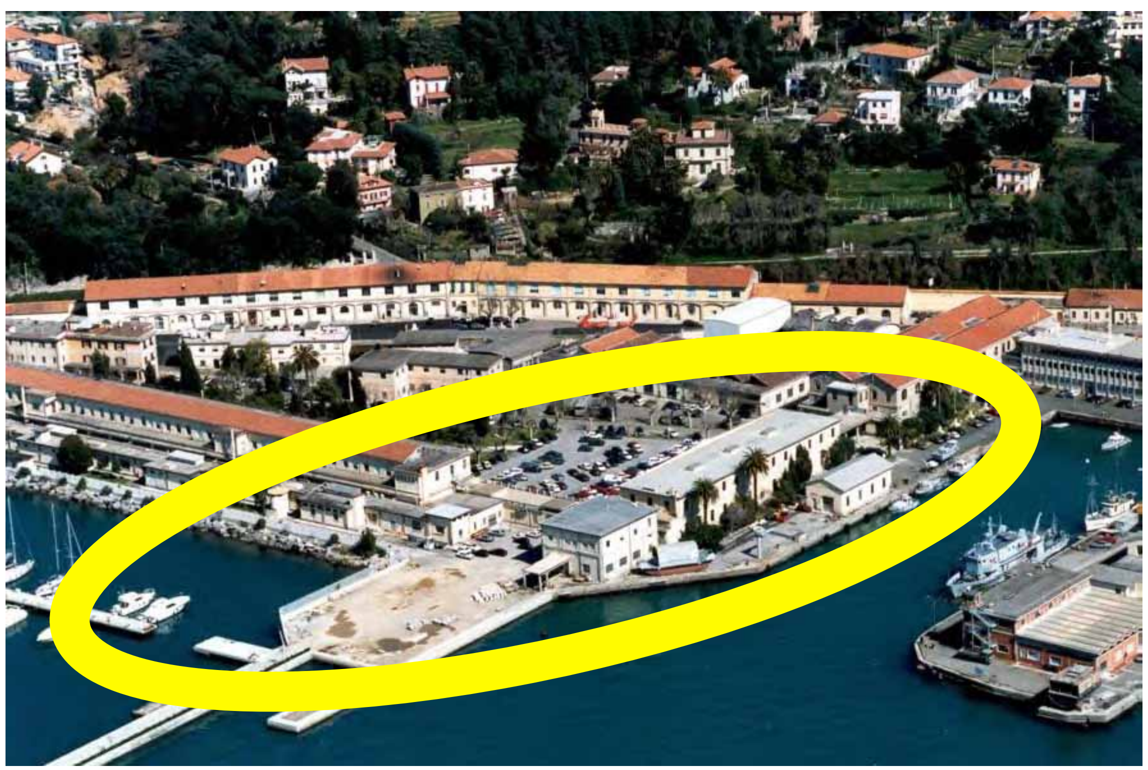






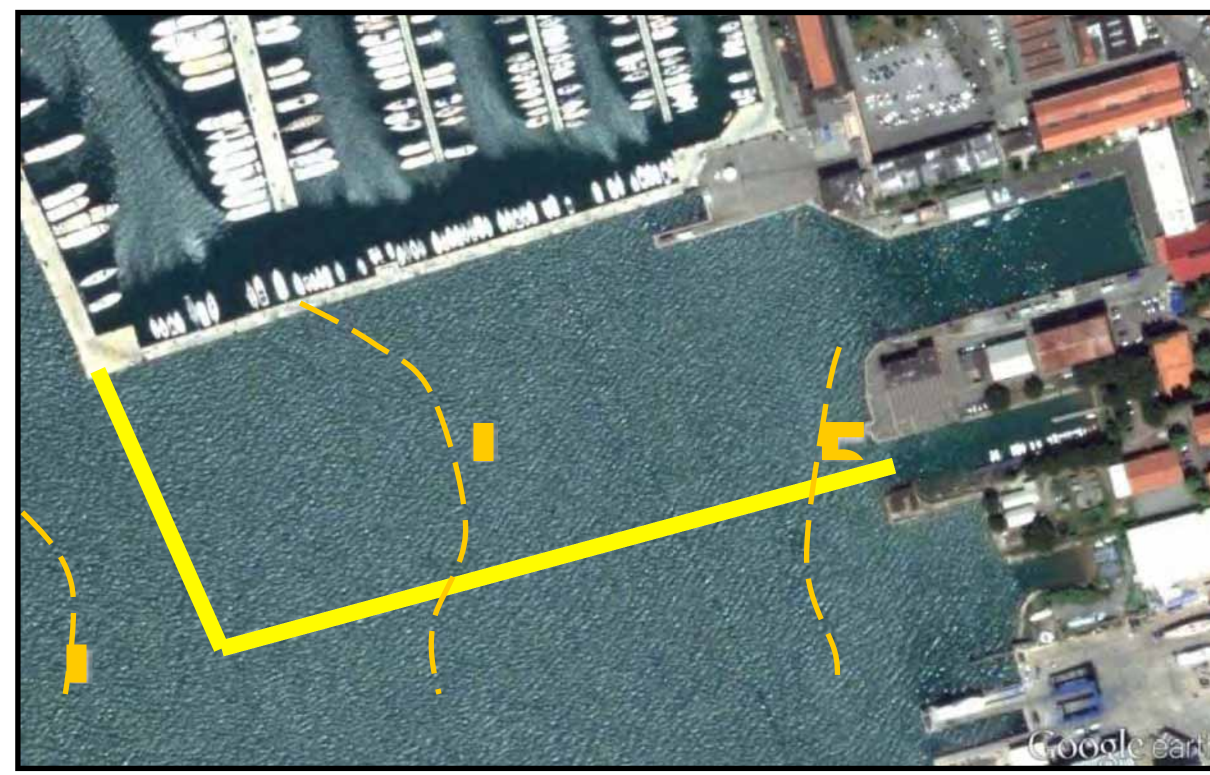



CENTRO SUPPORTO
CSSN
SPERIMENTAZIONE NAVALE

EA-Lab

ISME
Integrated Systems for Marine Environment





WiMUST - Widely scalable Mobile Underwater Sonar Technology

Grant agreement no: 645141

H2020 ICT-23-2014: Robotics

Started on February 1st, 2015

Duration 36 months

Maximum grant amount is EUR 3,970,081.25

Action Overview

ISME (UNIVERSITA' DEGLI STUDI DI GENOVA) – IT

ASSOCIACAO DO INSTITUTO SUPERIOR TECNICO PARA A INVESTIGACAO E DESENVOLVIMENTO – PT

CINTAL – CENTRO INVESTIGACAO TECNOLOGICA DO ALGARVE – PT

THE UNIVERSITY OF HERTFORDSHIRE HIGHER EDUCATION CORPORATION – UK

EVOLOGICS GMBH – DE

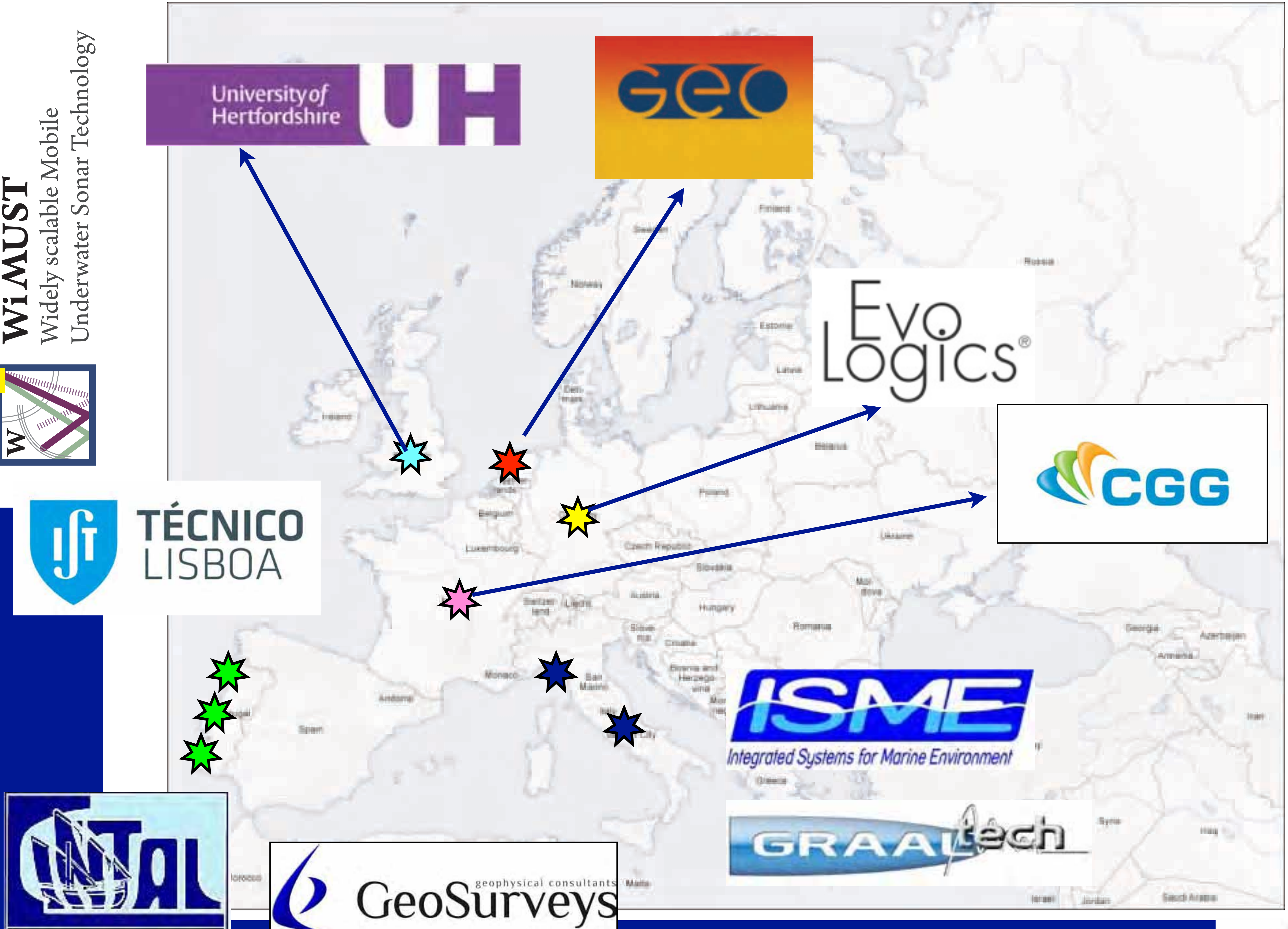
GRAAL TECH SRL – IT

CGGVERITAS SERVICES SA – FR

GEO MARINE SURVEY SYSTEMS BV – NL

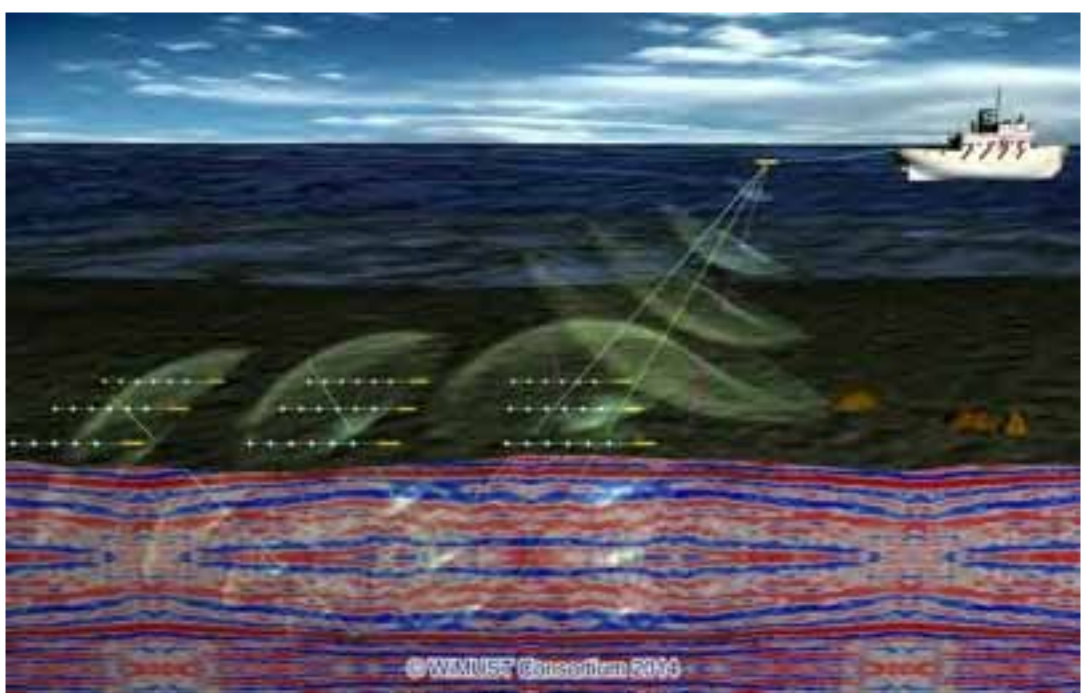
GEOSURVEYS – CONSULTORES EM GEOFISICA LDA – PT

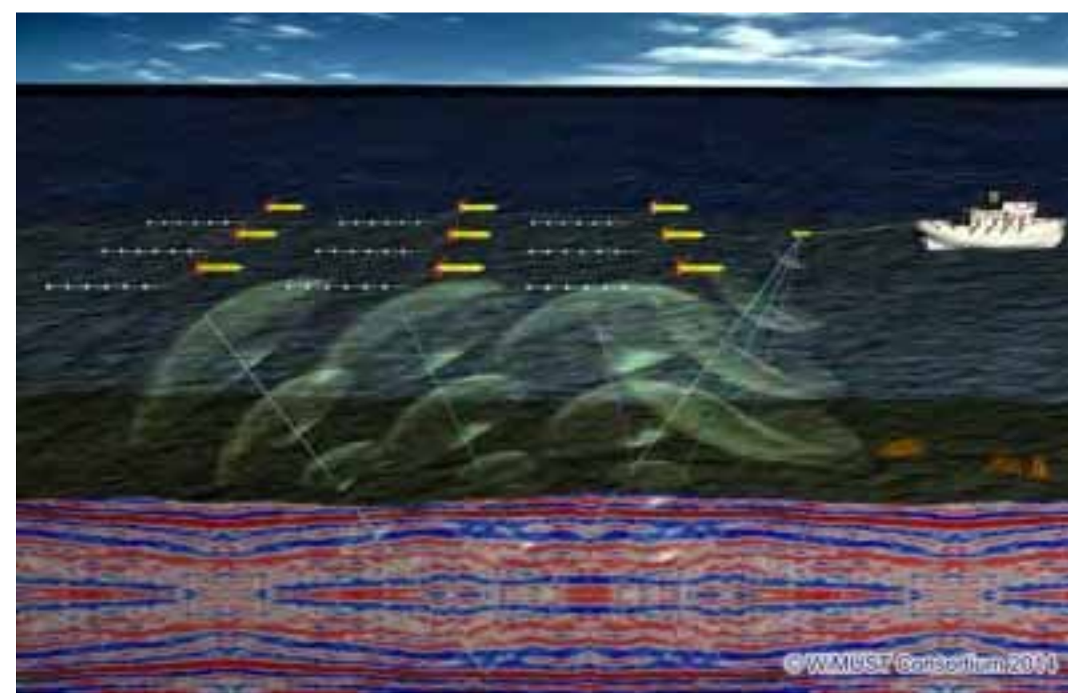
Wi MUST
Widely scalable Mobile
Underwater Sonar Technology

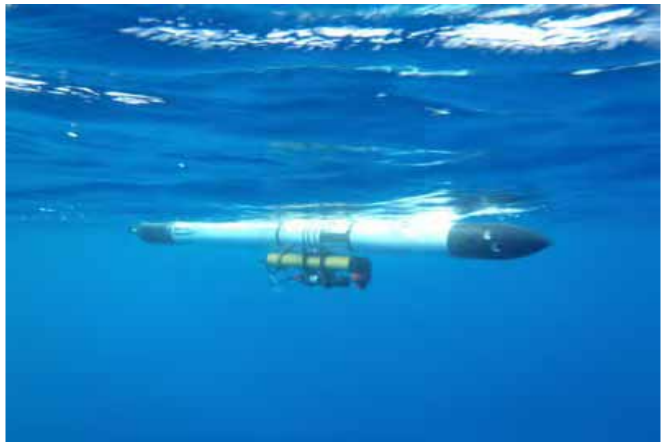


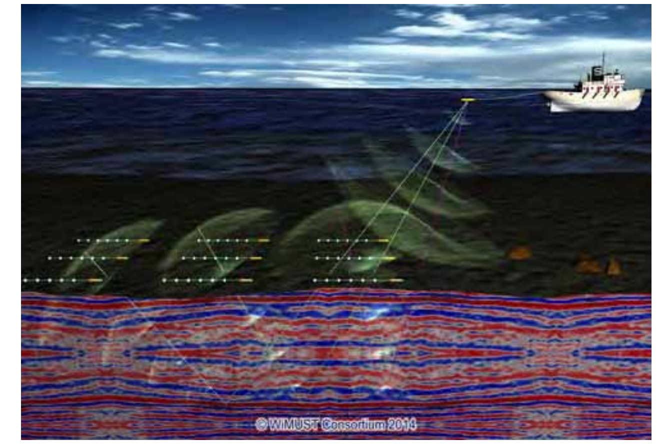
Wi MUST
Widely scalable Mobile
Underwater Sonar Technology

The Big Picture



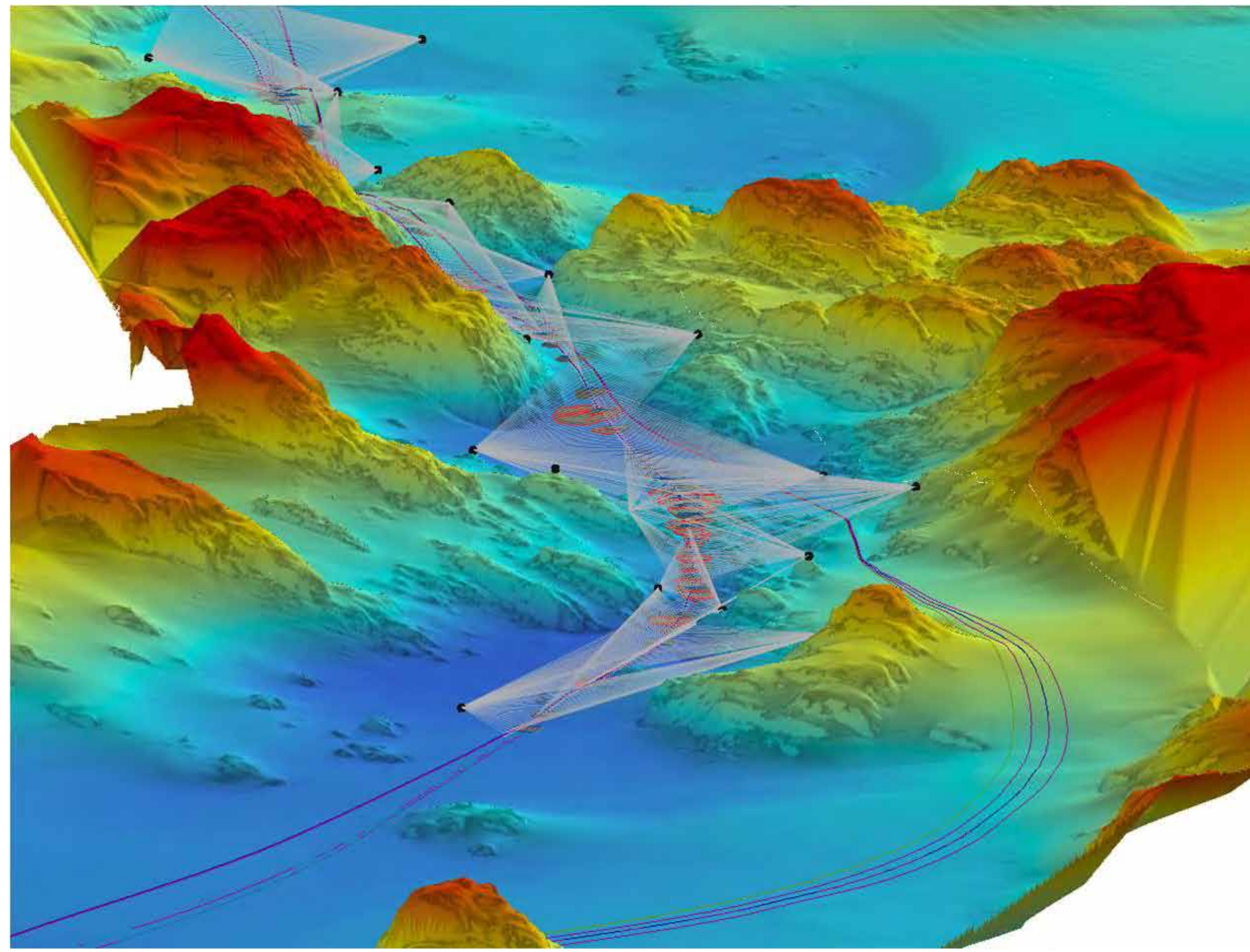






Market domain:
Marine Robotics (Civil & Commercial)

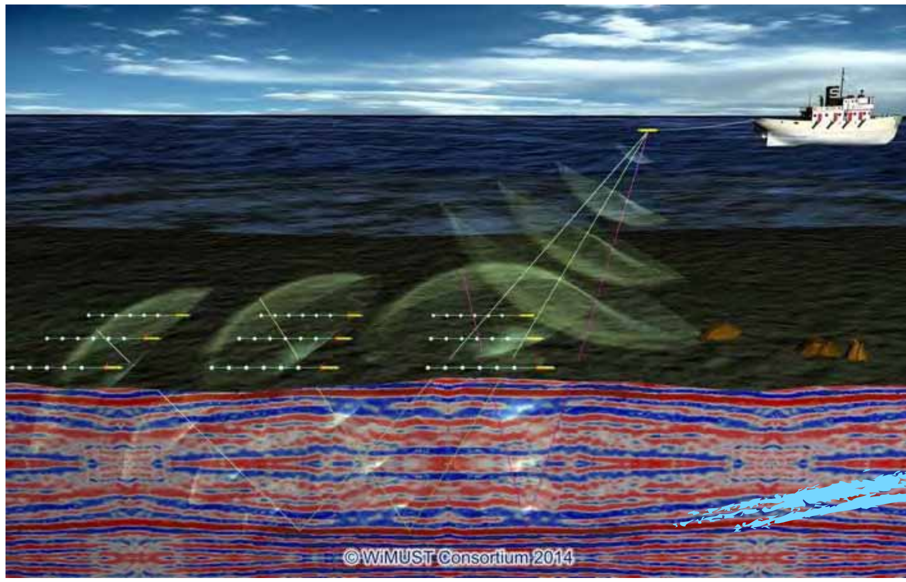
- Geotechnical Surveying
- Distributed Sensor Array
- Geophysical Surveying
- Monitoring



Achieve reliable cooperative operations of 10 or more marine robots for a demanding challenge in terms of navigation, guidance, control, mission planning, acoustic communications and data acquisition for geotechincal applications.

WiMUST
Widely scalable Mobile
Underwater Sonar Technology

Main challenges



European Commission

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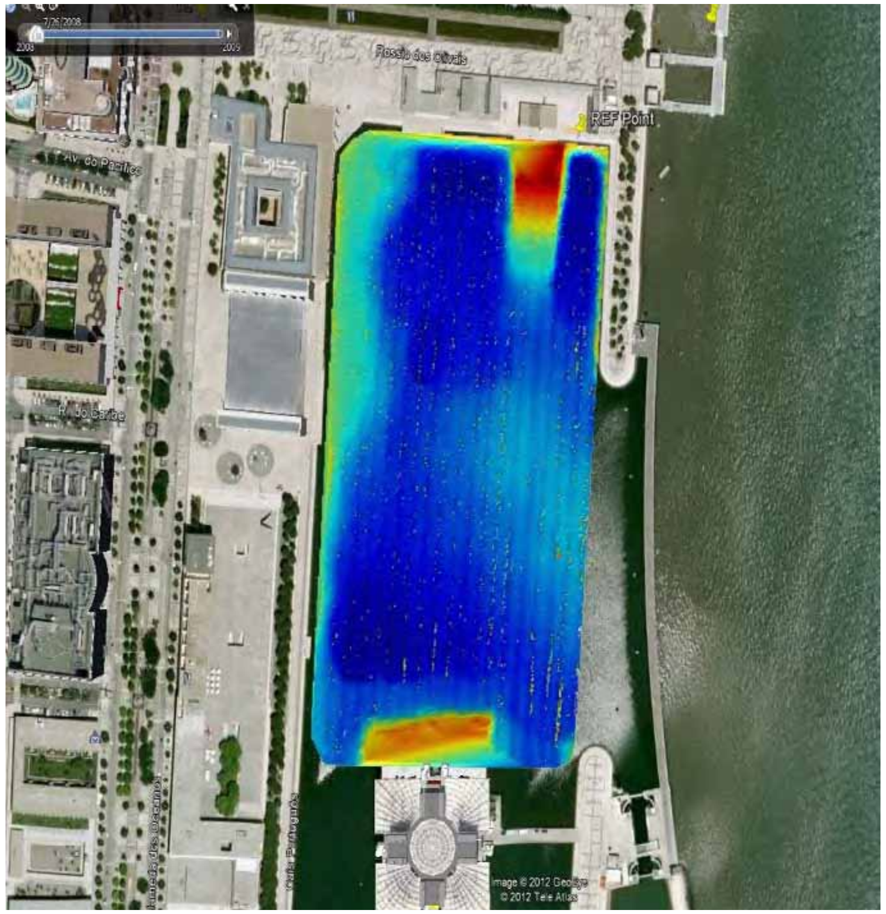
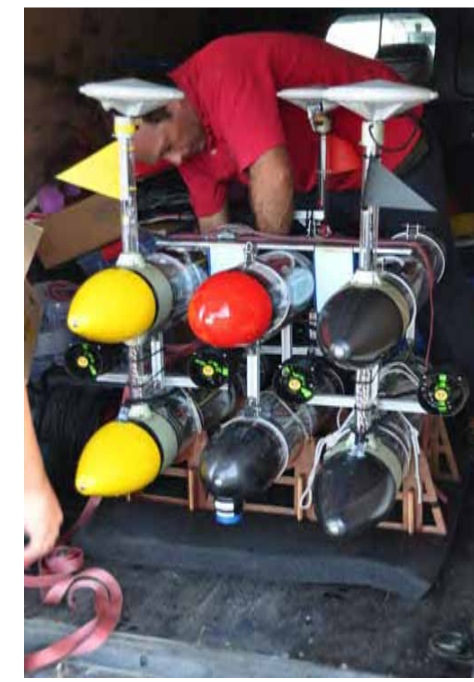
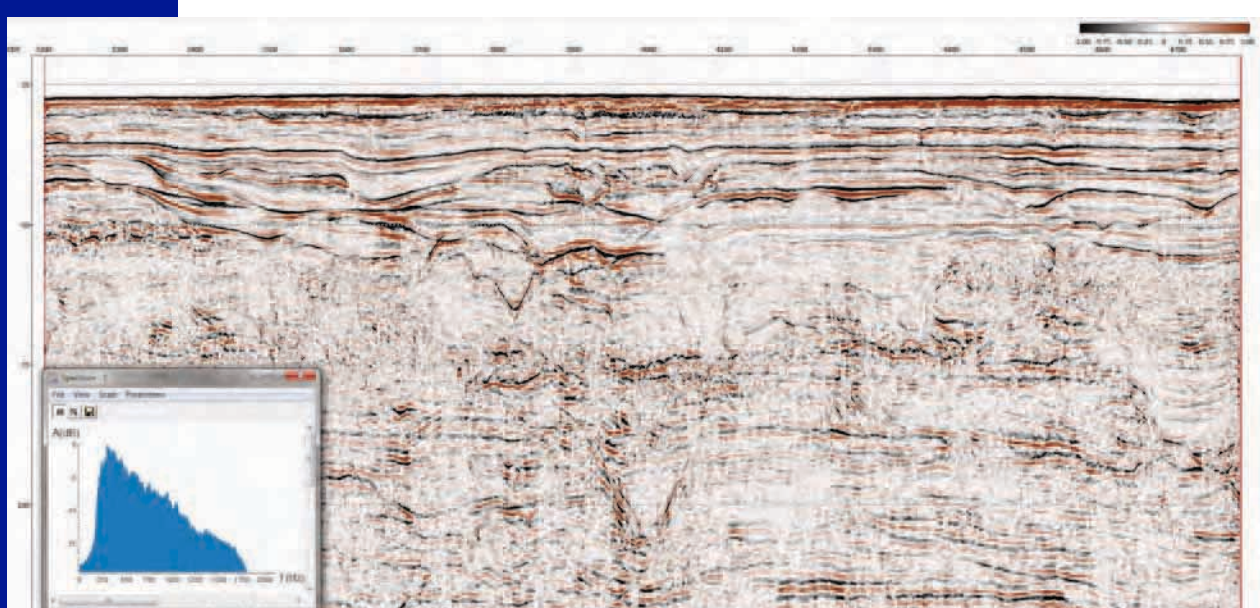
Underwater Sonar Technology







Main challenges

- Acoustic Distributed Sensor Array;
- Communications (short and long range);
- Geotechnical surveying and Geophysical characterization;
- Clock synchronization (below 50 mu sec);
- Cooperative Navigation and Motion Control: accurate formation control;
- HW integration of the acoustic acquisition system with the navigation one;

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NGC Related Activities at the ISME node in Lecce

Single range localization (SRL): observability

Outlier robust state estimation

SRL: team navigation

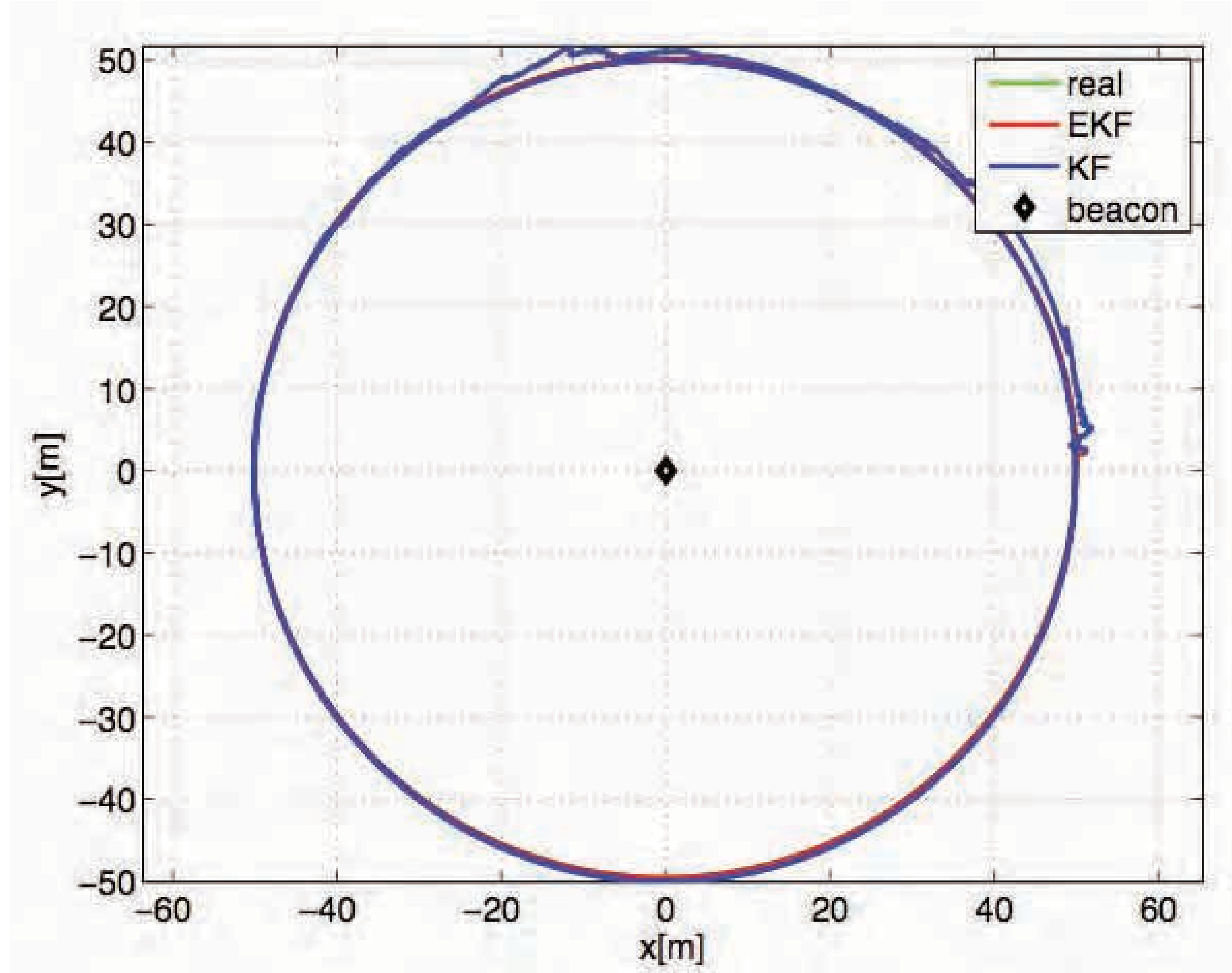
AUV motion control

Single range localization (SRL): observability

$$\dot{\mathbf{p}} = \mathbf{v}$$

$$\dot{\mathbf{v}} = \mathbf{u}$$

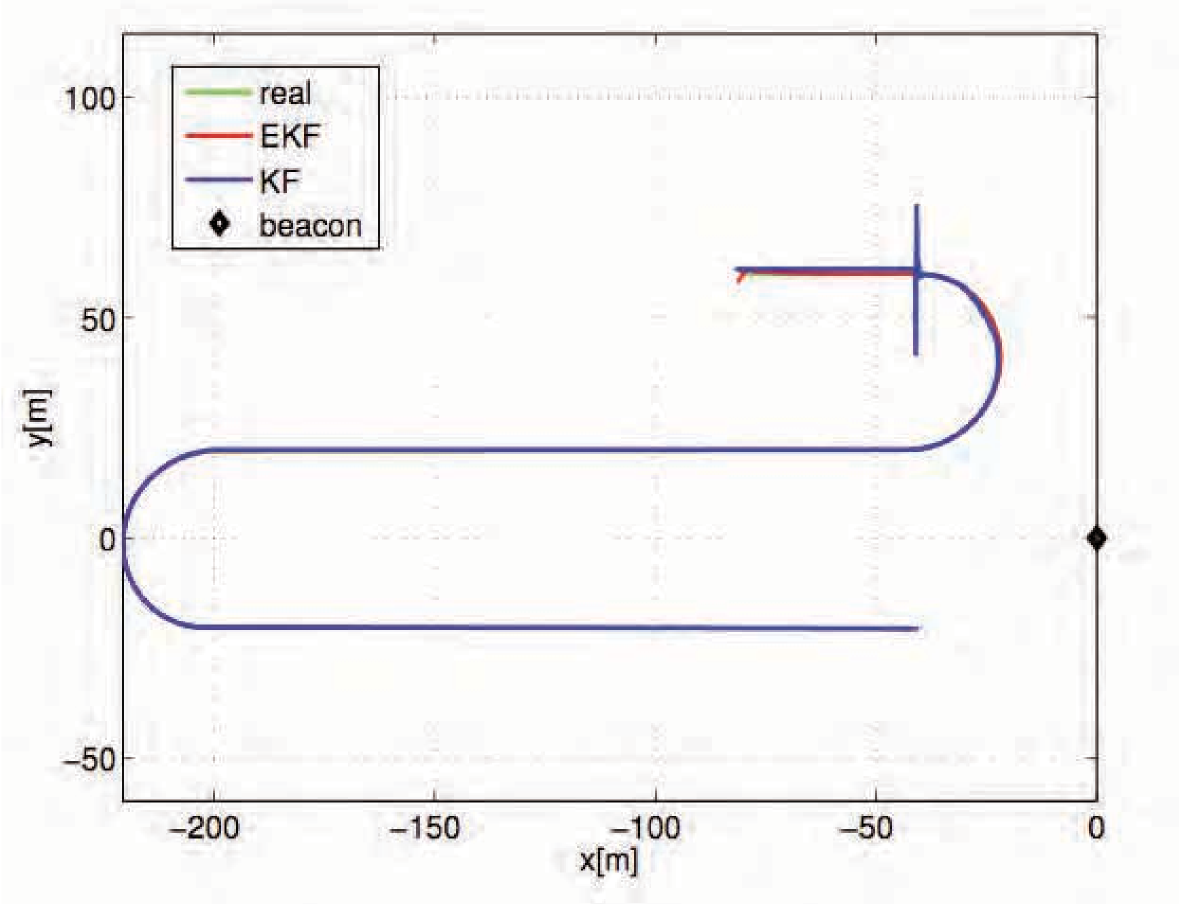
$$y = \frac{1}{2}\mathbf{p}^\top \mathbf{p} = \frac{1}{2}\|\mathbf{p}\|^2$$

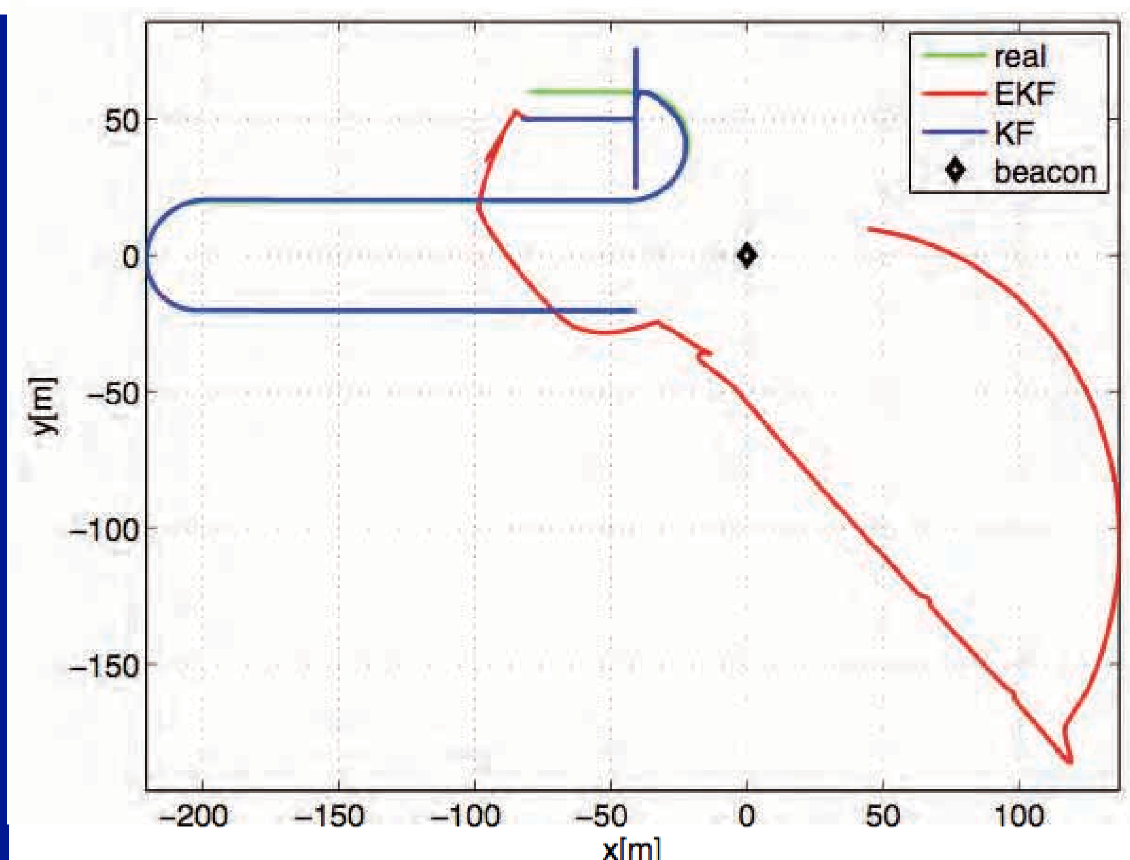


Observability analysis for single range localization

Filippo Arrichiello*, Daniela De Palma†, Giovanni Indiveri† and Gianfranco Parlangeli†
* Dipartimento di Ingegneria Elettrica e dell'Informazione
Università degli Studi di Cassino e del Lazio Meridionale (ISME node), Via G. Di Biasio 43, 03043 Cassino (FR), Italy
Email: f.arrichiello@unicas.it
† Dipartimento di Ingegneria dell'Innovazione
Università del Salento (ISME node), Via Monteroni, 73100, Lecce, Italy
Email: firstname.lastname@unisalento.it

MTS|IEEE OCEANS'15 Genova


real
EKF
KF
beacon
100
50
0
-50
-200
-150
-100
-50
0
x[m]
y[m]


real
EKF
KF
beacon
50
0
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-150
-200
-150
-100
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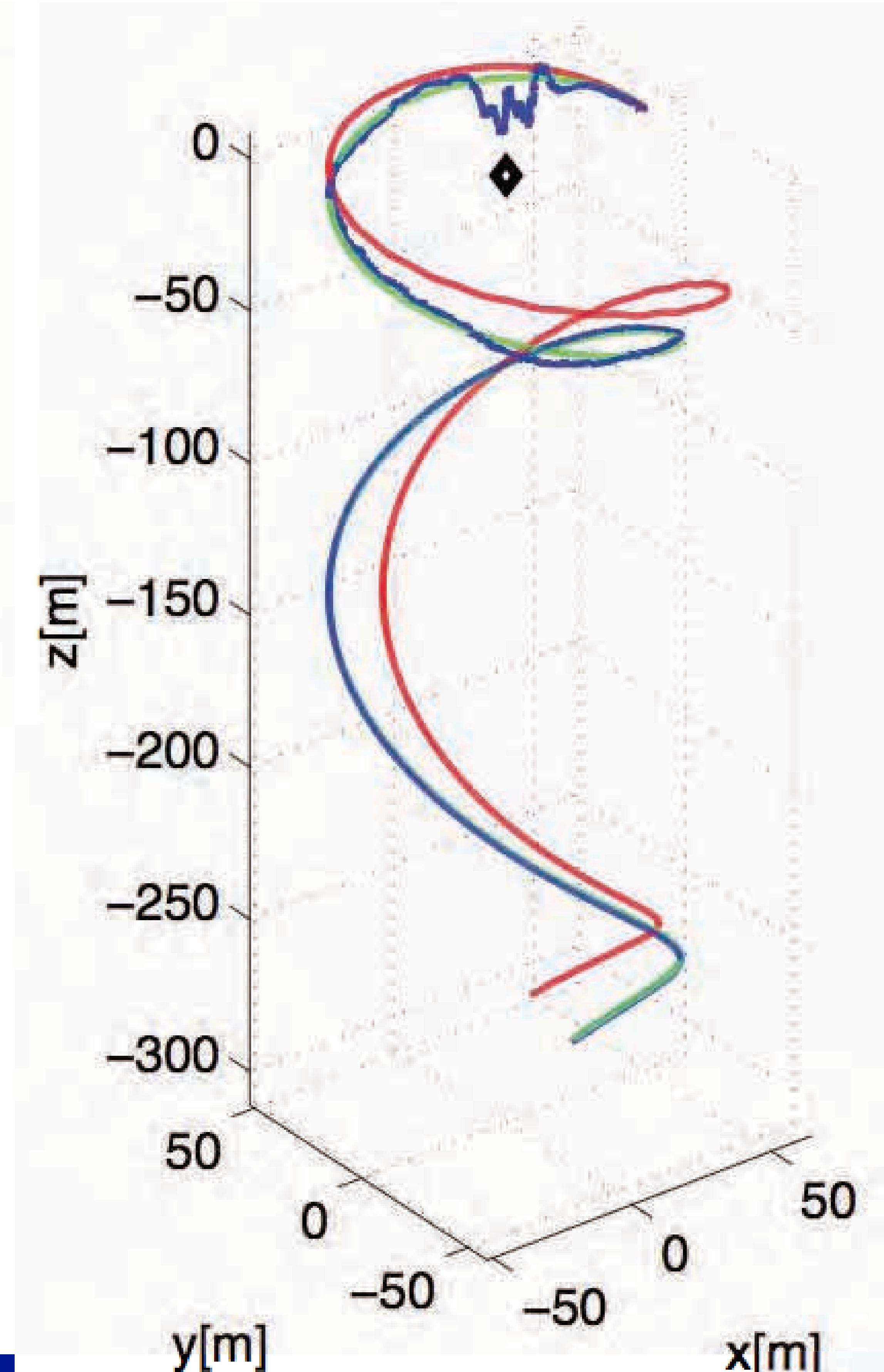
0
50
100
x[m]
y[m]


0
-50
-100
-150
-200
-250
-300
z[m]
50
0
-50
y[m]
50
0
-50
x[m]

Motion control while performing SRL

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AUV
motion
control

INTERNATIONAL FEDERATION
OF AUTOMATIC CONTROL

10th IFAC Conference on
Manoeuvring and Control of Marine Craft
MCMC 2015
August 24 – 26, 2015, Copenhagen Denmark

A Null-Space-Based Behavioral Approach to Single Range Underwater Positioning ⋆

Daniela De Palma *, Giovanni Indiveri * and Antonio Pascoal **,***

European Commission

Motion control while performing SRL

A Null-Space-Based Behavioral Approach to Single Range Underwater Positioning ⋆

Daniela De Palma *, Giovanni Indiveri * and Antonio Pascoal **,***

$$\dot{\mathbf{p}} = \mathbf{u}$$

$$r = h(\mathbf{p}) + \epsilon$$

e position error (distance to target)

$$\mathbf{u} = \underbrace{-K\mathbf{e}}_{\mathbf{u}_1} + \underbrace{N_{\mathbf{e}}\mathbf{v}}_{\mathbf{u}_2}$$

$$N_{\mathbf{e}} := I_{n\times n} - \frac{\mathbf{e}\,\mathbf{e}^\top}{\|\mathbf{e}\|^2}$$

$$\begin{cases} \mathbf{v}_k = \arg\max_{\bar{\mathbf{v}}_k} \min_{\mathbf{p}_0 \in \bar{\mathcal{U}}} \lambda_{min}(FIM_{k+1}(\mathbf{p}_0, \mathbf{u}_k)) \\ \mathbf{p}_{k+1} = \mathbf{p}_0 + \sum_{i=0}^{k} T_s \mathbf{u}_i \\ \mathbf{u}_k = -K\mathbf{e}_k + N_{\mathbf{e}_k} \bar{\mathbf{v}}_k \end{cases}$$

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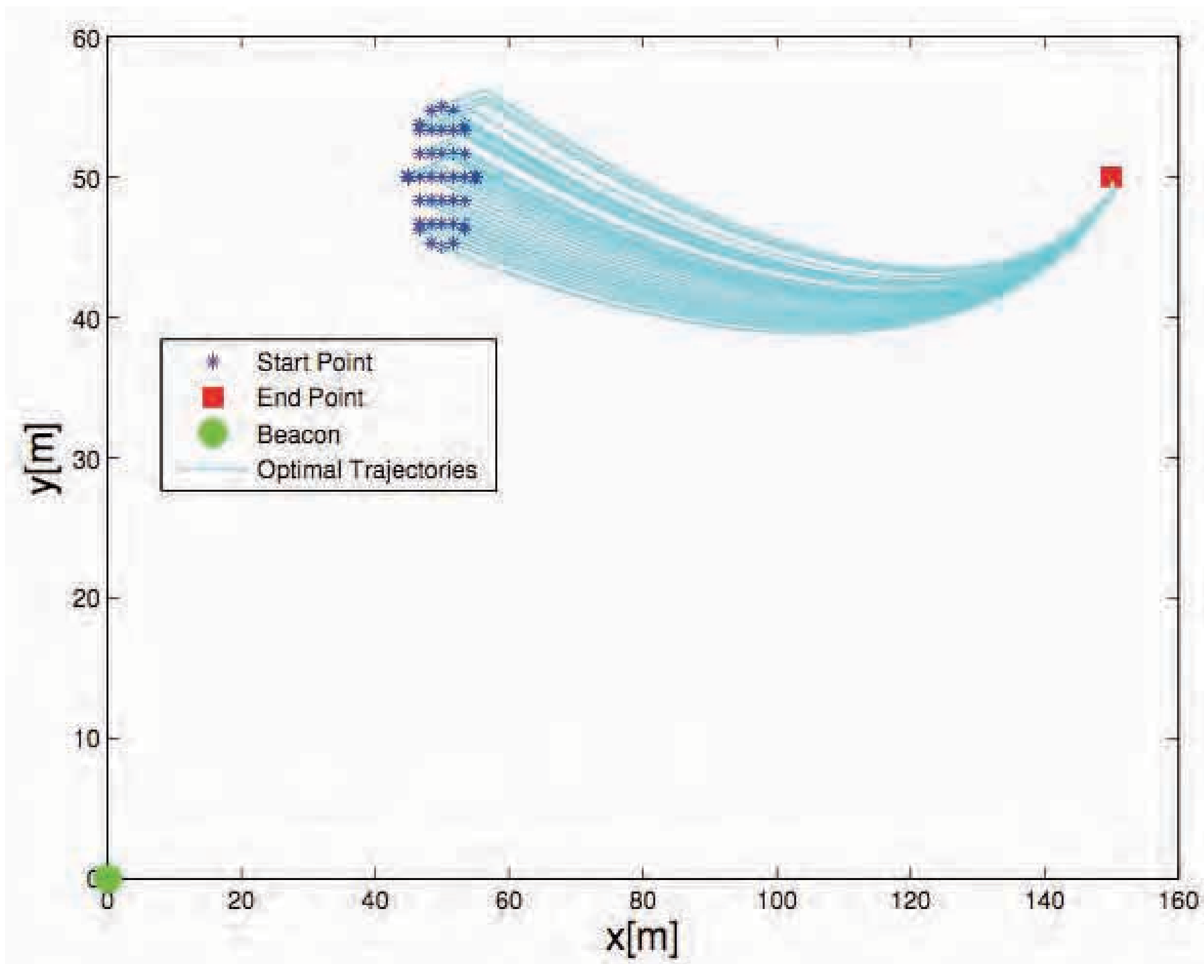
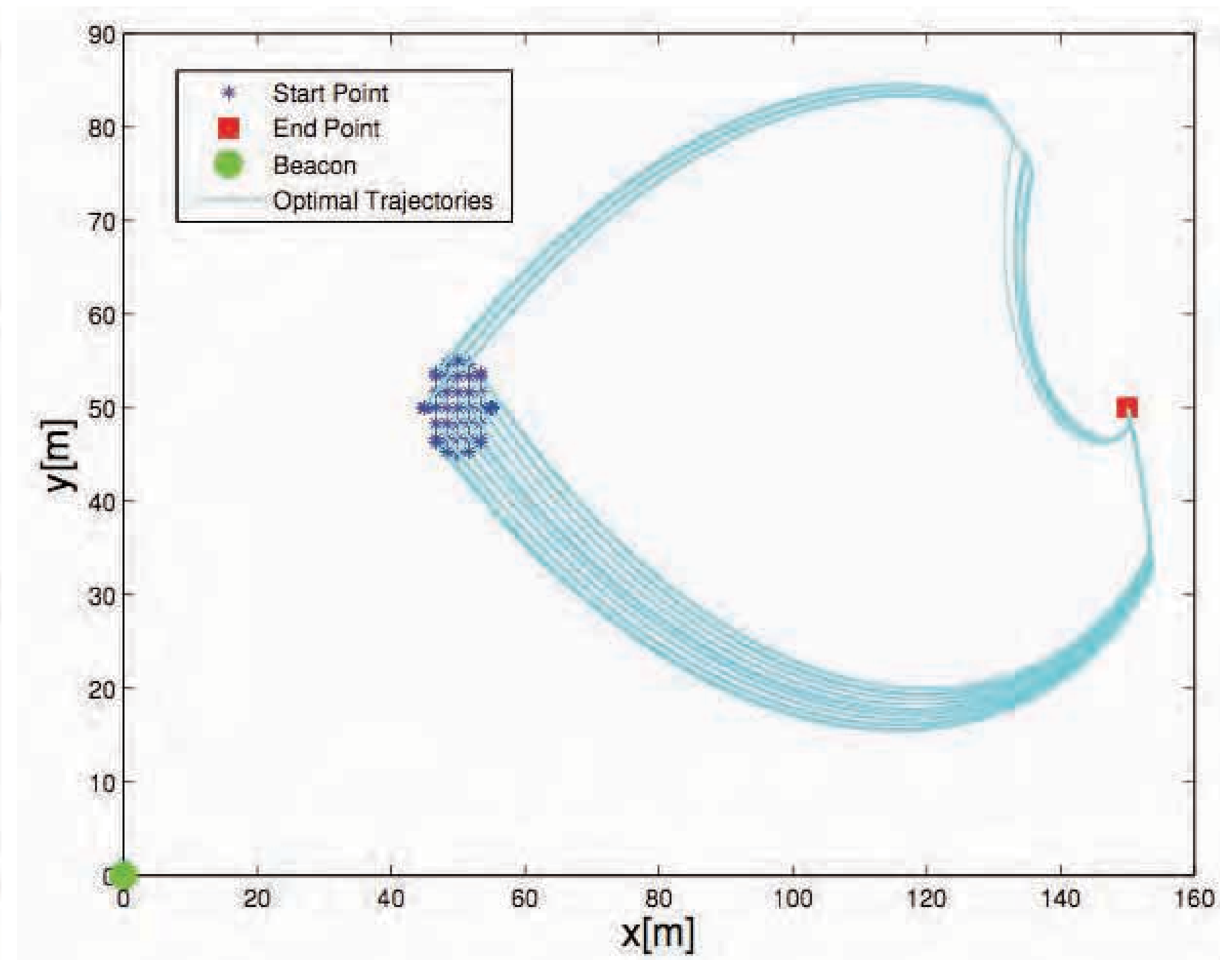
Underwater Sonar Technology

Motion control while performing SRL

A Null-Space-Based Behavioral Approach to Single Range Underwater Positioning *

Daniela De Palma *, Giovanni Indiveri * and Antonio Pascoal **,***





Single Vehicle Control

AUV
motion
control

Robotica: page 1 of 18. © Cambridge University Press 2015
doi:10.1017/S0263574715000119

Complementary control for robots with actuator redundancy: an underwater vehicle application

Giovanni Indiveri* and Alessandro Malerba

Dipartimento Ingegneria Innovazione, Università del Salento, via Monteroni, 73100 Lecce, Italy

(Accepted February 9, 2015)

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Widely scalable Mobile Underwater Sonar Technology

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Complementary control for robots with actuator redundancy: an underwater vehicle application

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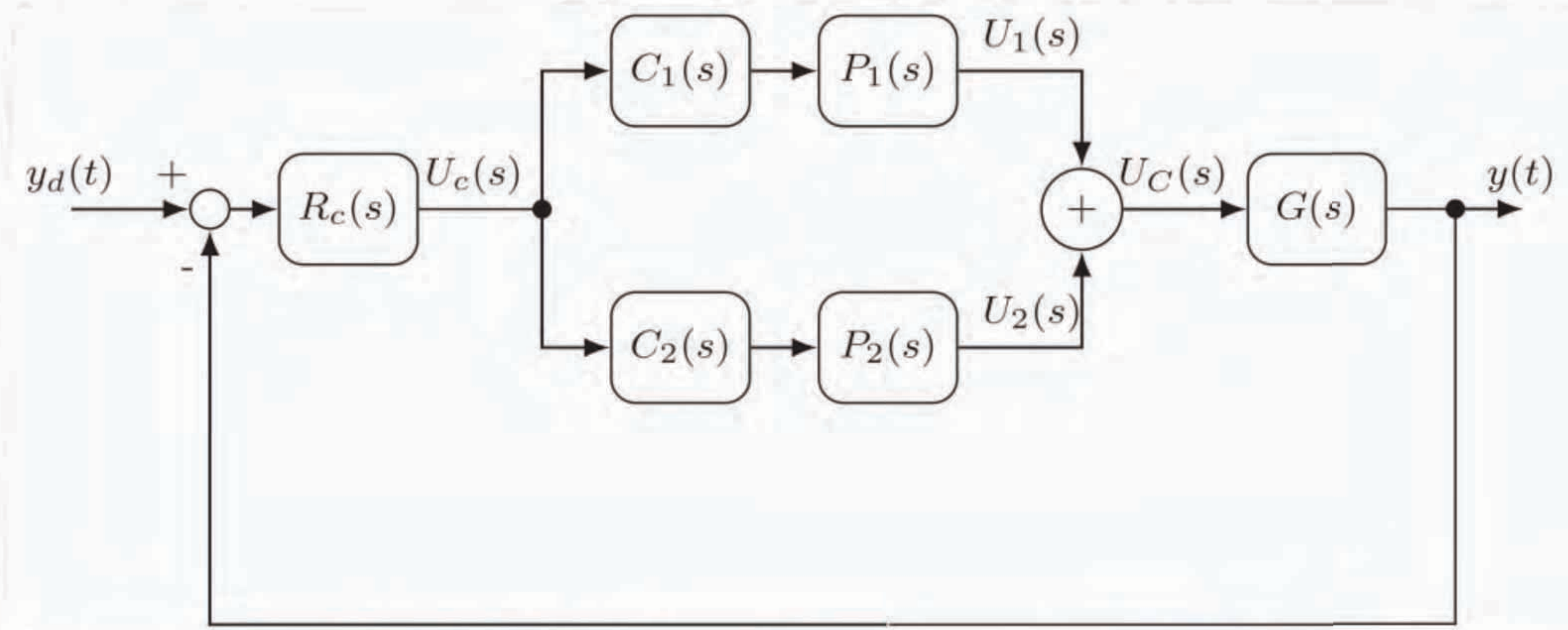


SRL: team navigation

Multi-vehicle relative localization based on single range measurements★

Daniela De Palma, Giovanni Indiveri and Gianfranco Parlangeli

3rd IFAC Workshop on Multivehicle Systems MVS 2015

IFAC INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

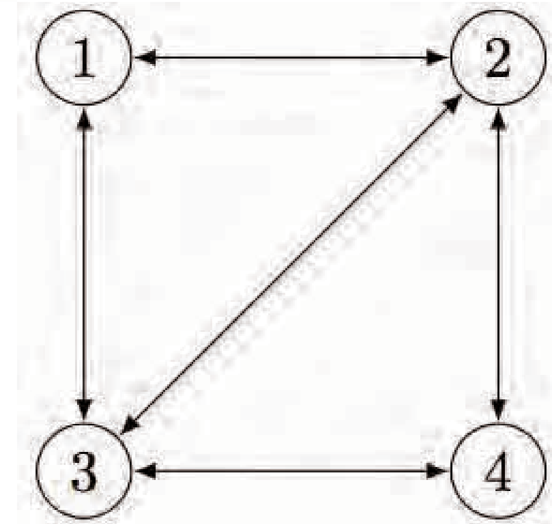
$$\dot{\mathbf{x}}_i = \mathbf{v}_i \quad : \quad i = 1, 2, \ldots, n$$

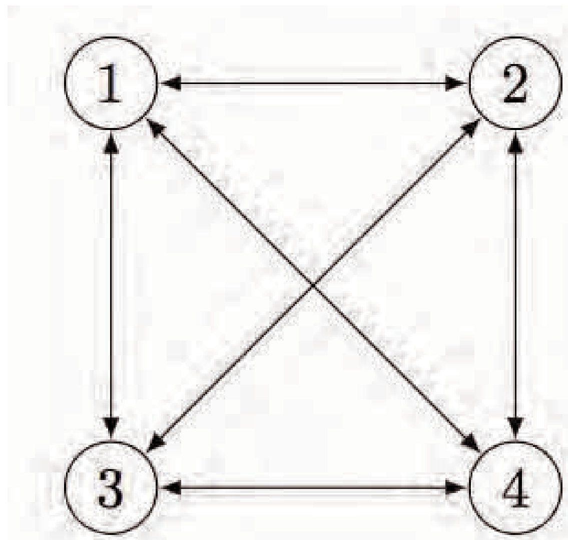
$$\mathbf{z}_{ij} := \mathbf{x}_i - \mathbf{x}_j$$

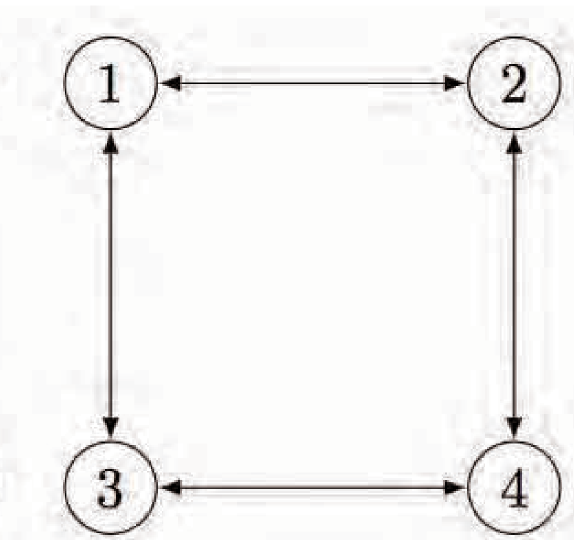
$$\mathbf{v}_{ij} := \mathbf{v}_i - \mathbf{v}_j$$

$$\dot{\mathbf{z}}_{ij} = \mathbf{v}_{ij}$$

$$y_{ij} = \|\mathbf{z}_{ij}\|^2$$



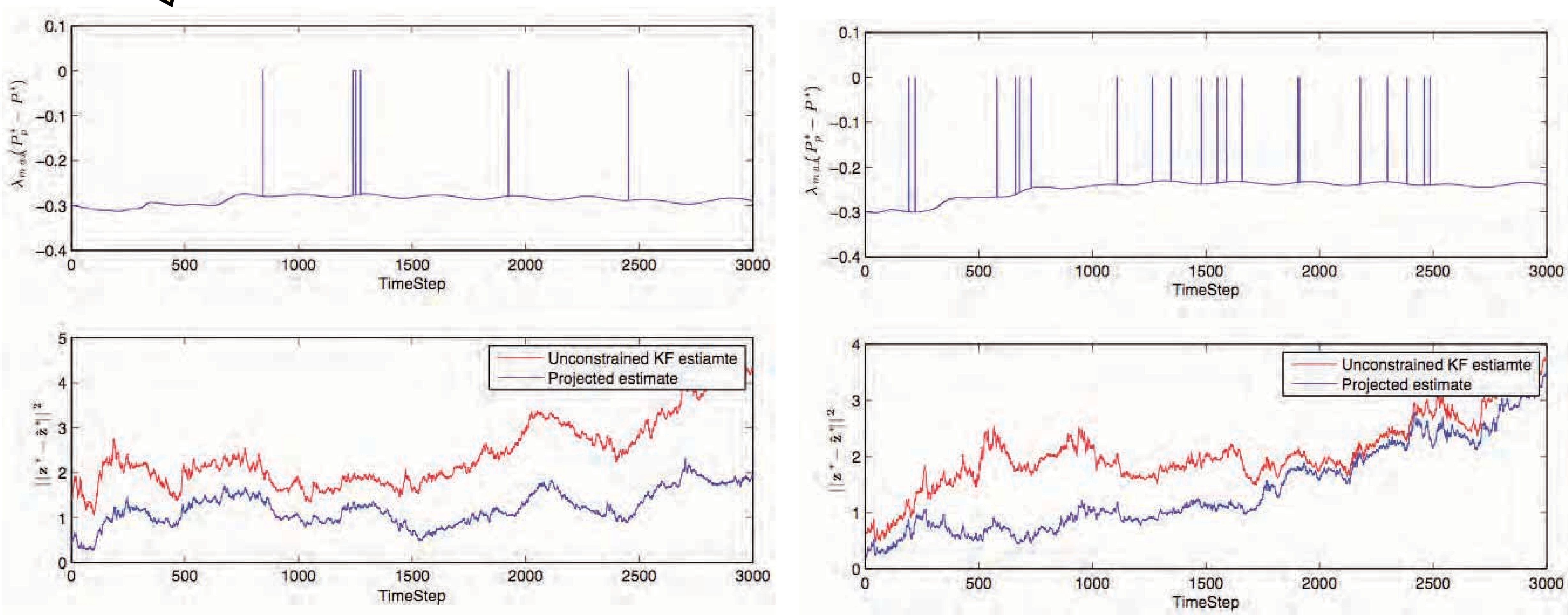




SRL: team navigation

Multi-vehicle relative localization based on single range measurements ⋆

Daniela De Palma, Giovanni Indiveri and Gianfranco Parlangeli



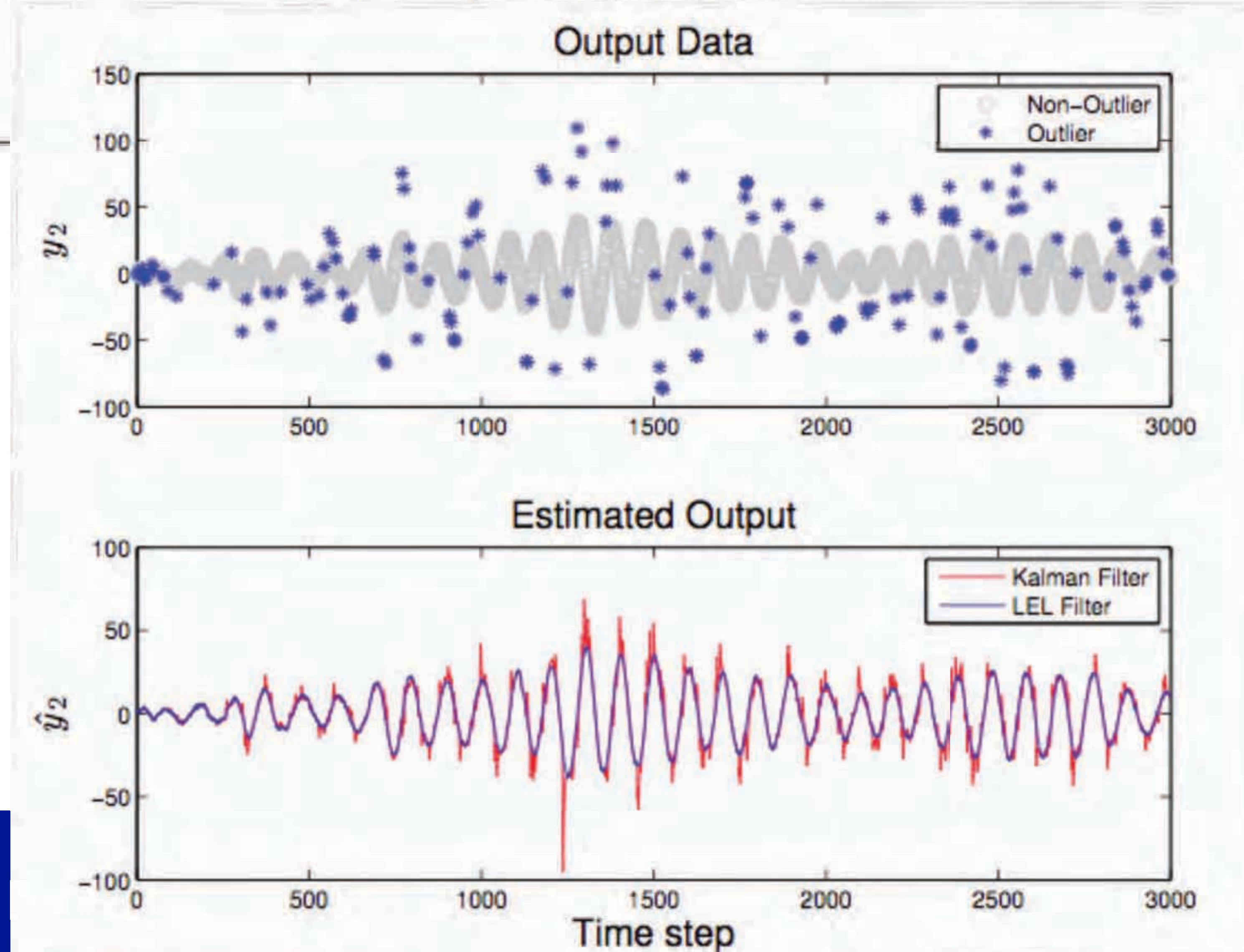
INTERNATIONAL JOURNAL OF ADAPTIVE CONTROL AND SIGNAL PROCESSING
Int. J. Adapt. Control Signal Process. 0000; **00**:1–39
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/acs

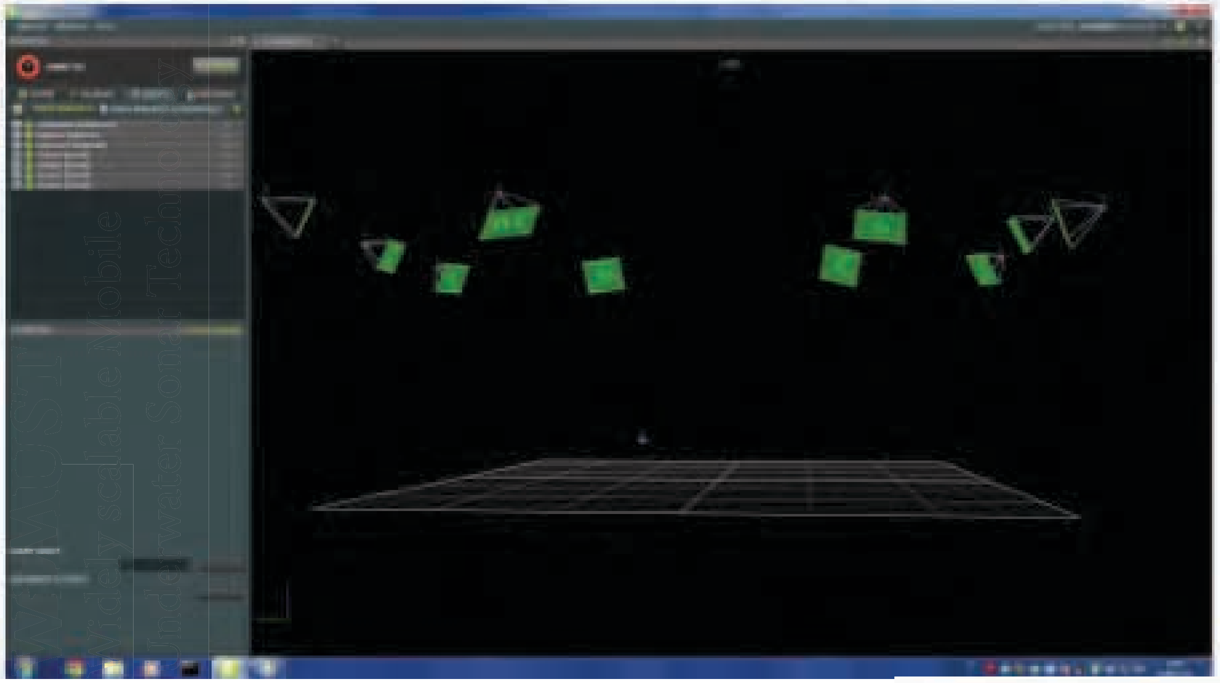
Output Outlier Robust State Estimation

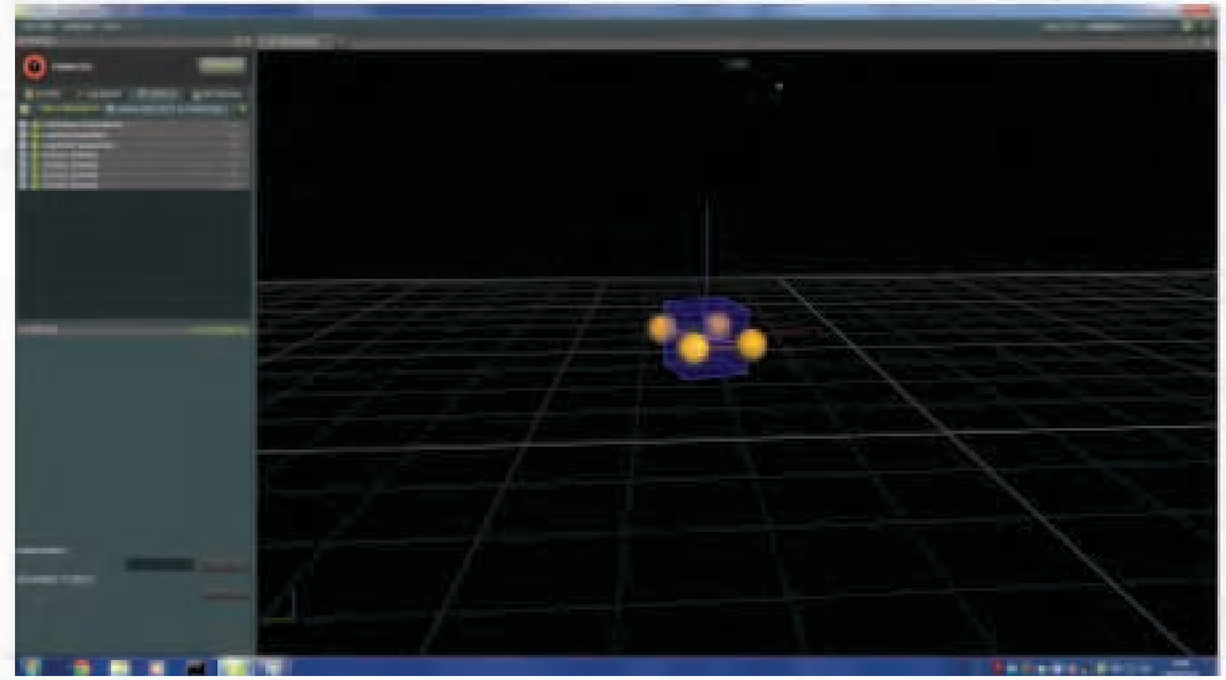
Daniela De Palma and Giovanni Indiveri*

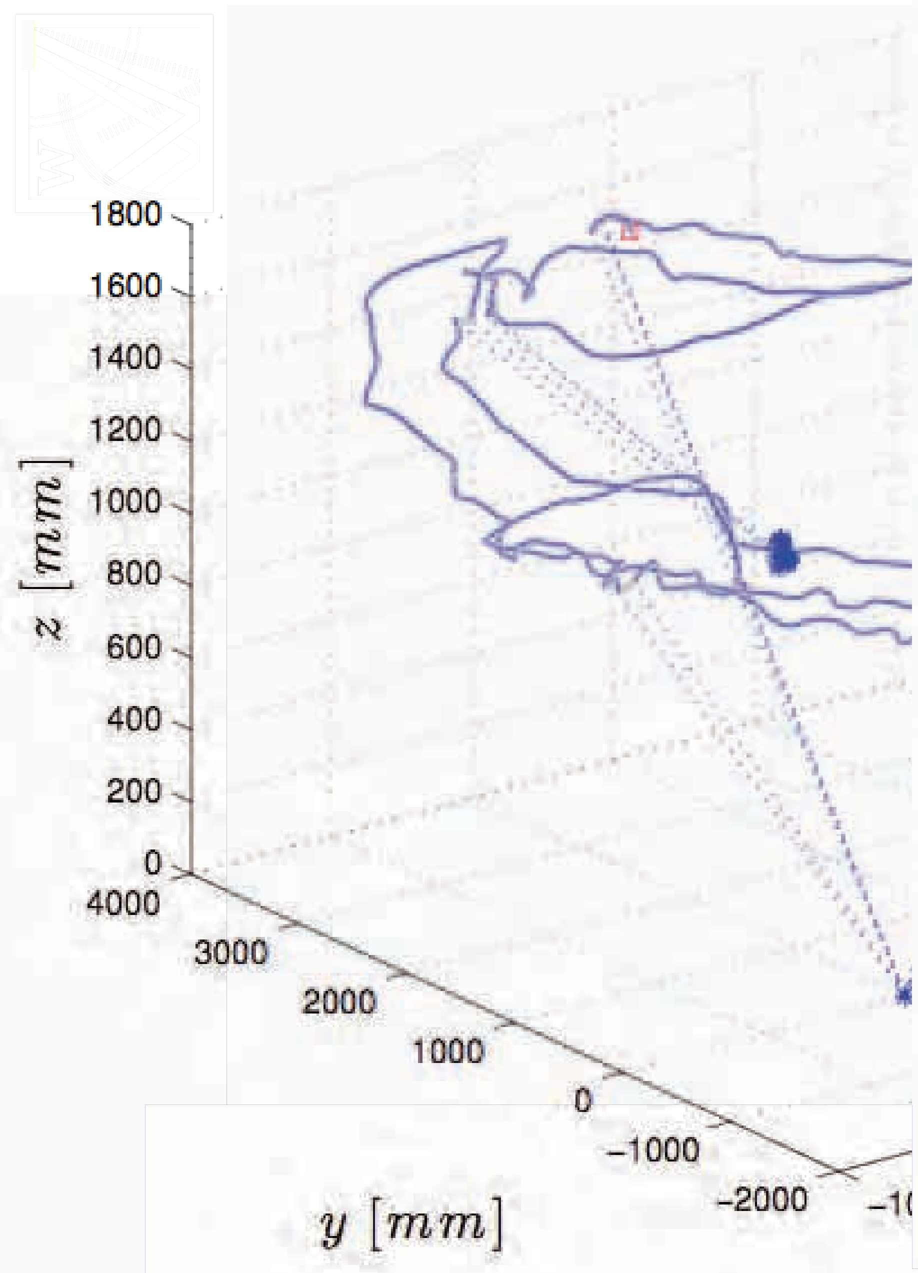
Dipartimento Ingegneria Innovazione - ISME node - Università del Salento, via Monteroni, 73100 Lecce - Italy.

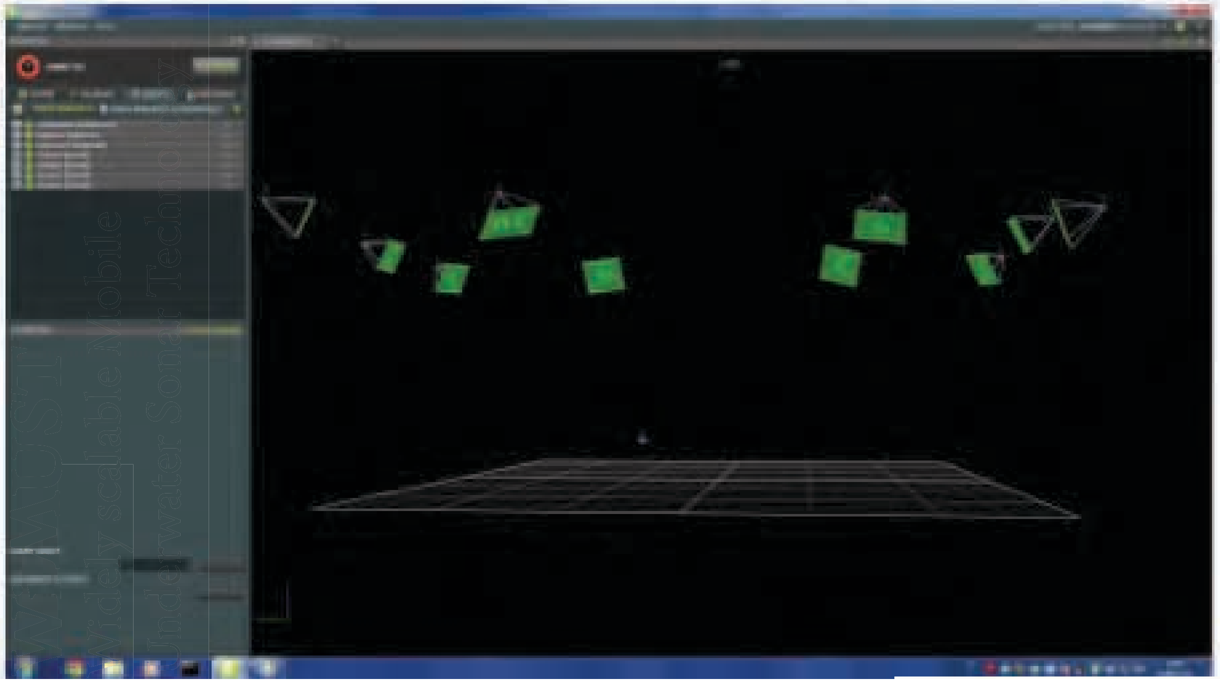
Outlier robust state estimation

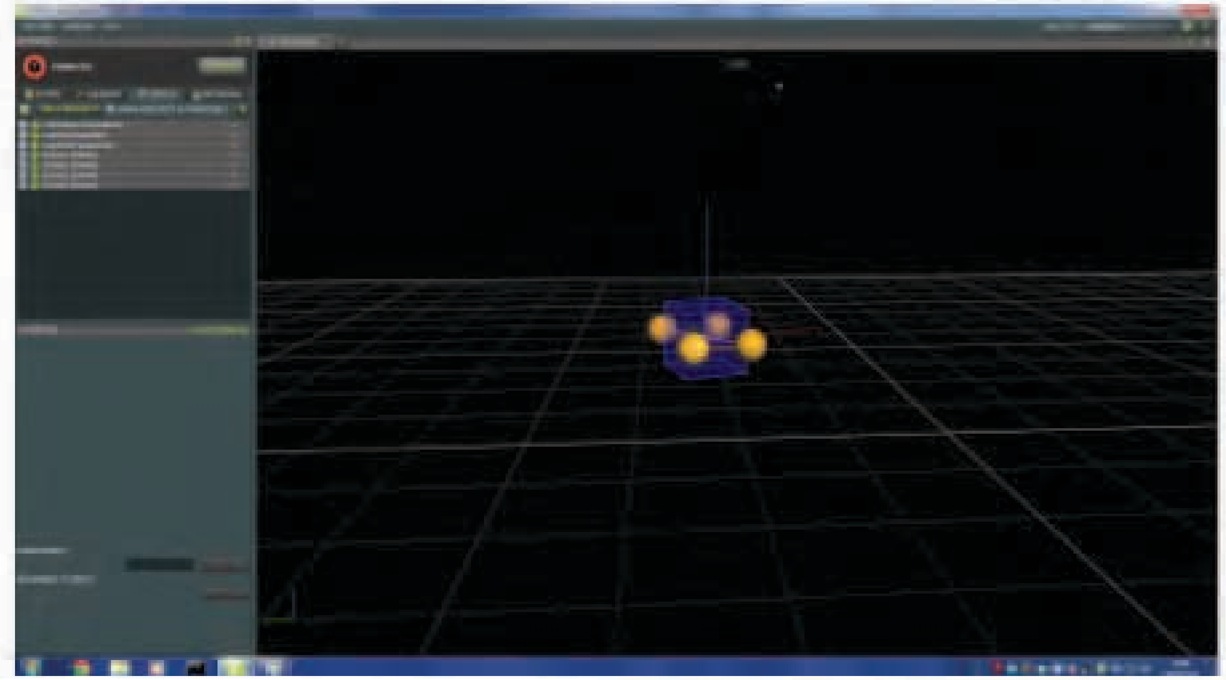


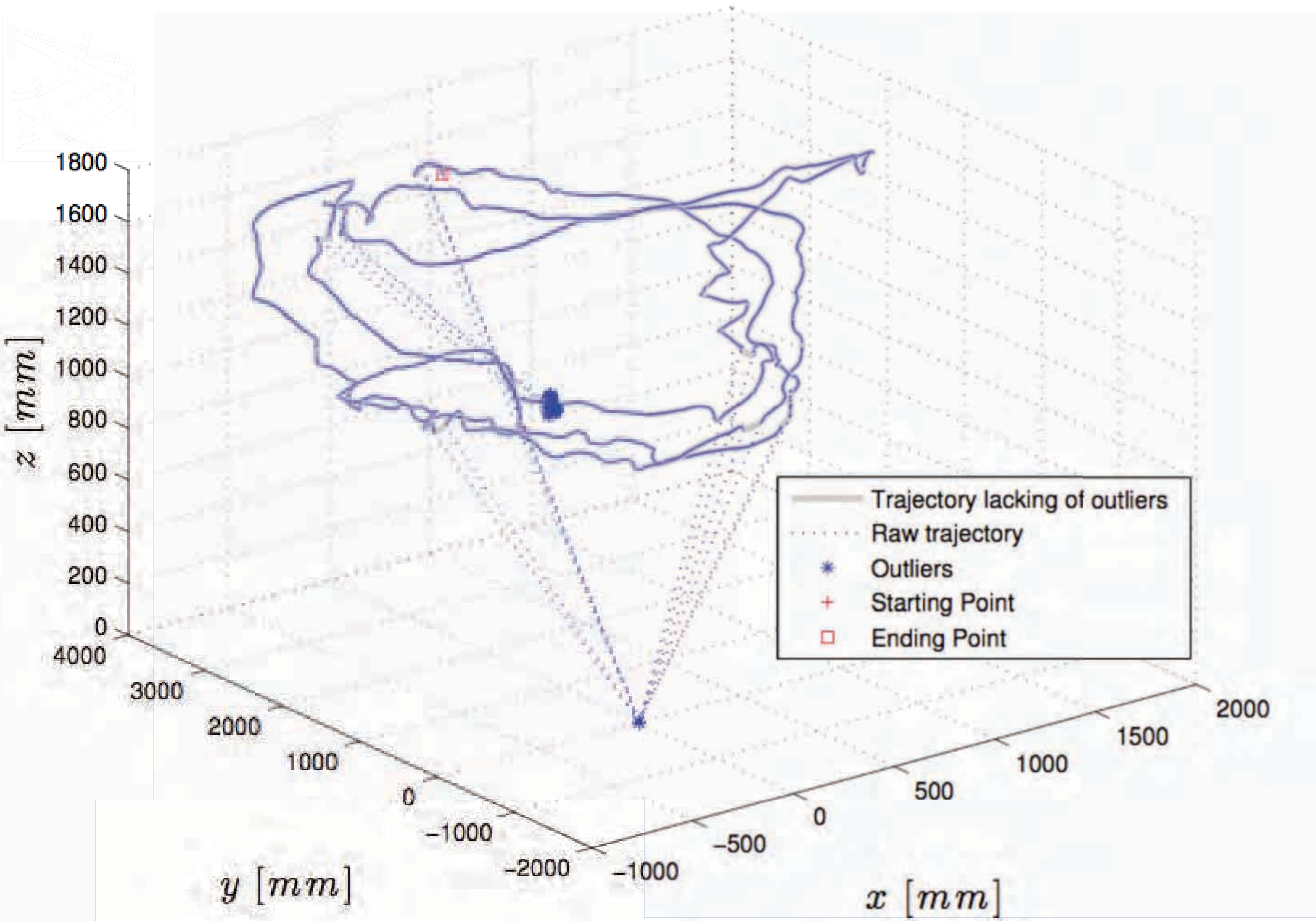




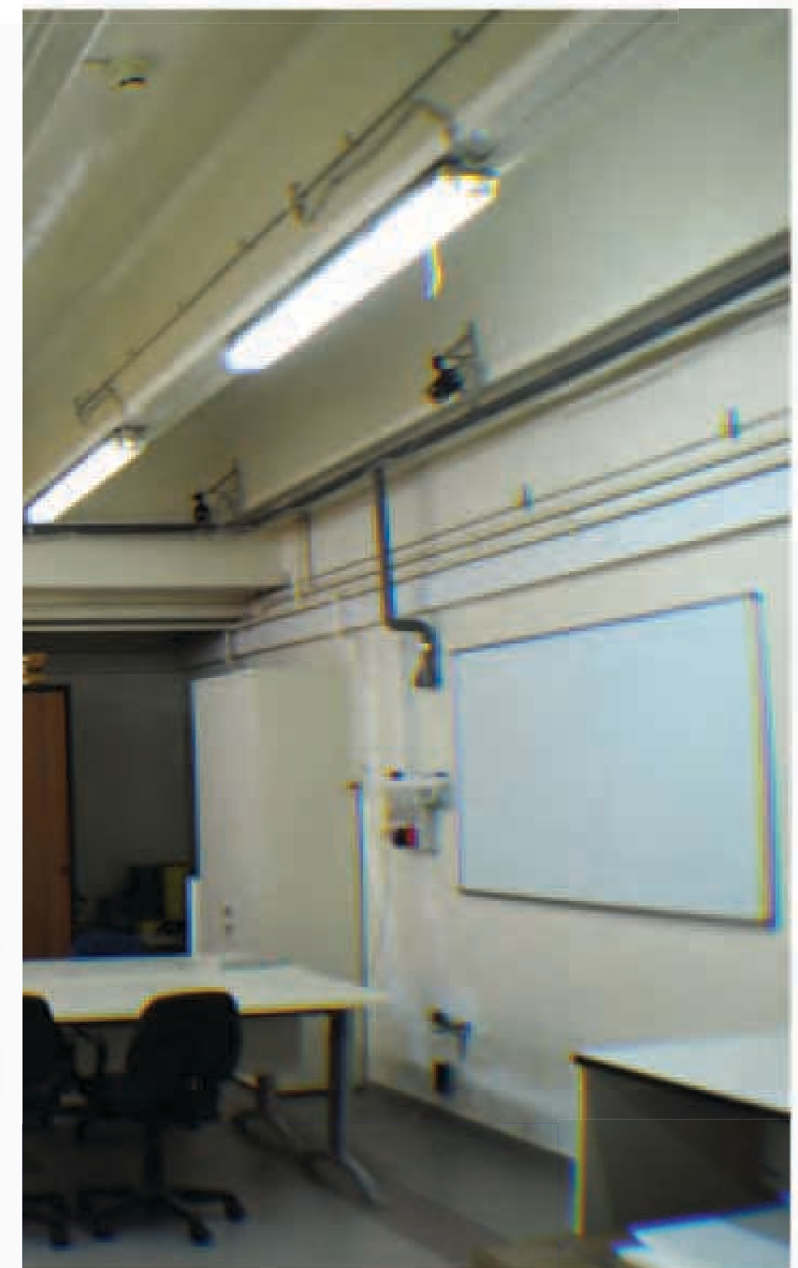

1800
1600
1400
1200
1000
800
600
400
200
0
z [mm]
4000
3000
2000
1000
0
−1000
−2000
y [mm]

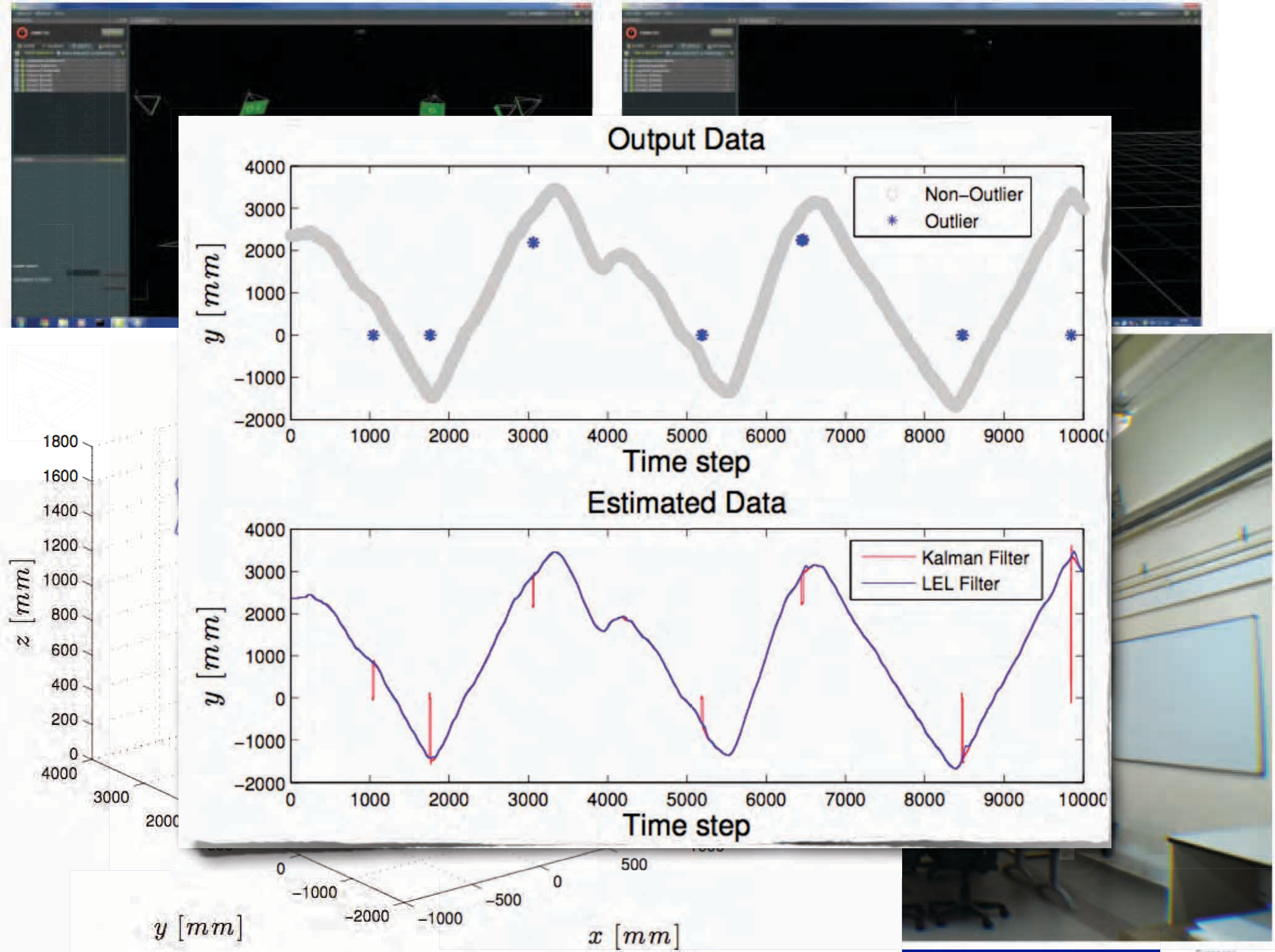






Trajectory lacking of outliers
Raw trajectory
Outliers
Starting Point
Ending Point
z [mm]
y [mm]
x [mm]
1800
1600
1400
1200
1000
800
600
400
200
0
4000
3000
2000
1000
0
−1000
−2000
−1000
−500
0
500
1000
1500
2000





Output Data
Non–Outlier
Outlier
y [mm]
Time step
Estimated Data
Kalman Filter
LEL Filter
y [mm]
Time step
z [mm]
y [mm]
x [mm]

Conclusions

- There is high potential for new achievements in the area of geotechnical surveying and geophysical exploration;
- Both fundamental and applied research is on our WiMUST agenda: stay tuned for updates.

http://www.wimust.eu

Thank you!

EMRA'15 workshop

Question Time

giovanni.indiveri@unisalento.it

EMRA'15 workshop

Session 3. Chair – Giovanni Indiveri

16:30 **T2.3 - *Easily deployable autonomous hydro-acoustic assets for highly mobile and flexible arrangements (underwater sensor networks, testbeds, and integrated USV and AUV robotic components)***
Konstantin and Oleksiy Kebkal, EVOLOGICS, Berlin, DE

17:00 **T2.4 - *Marine Megafauna Telemetry Systems***
Pedro Afonso, IMAR/DOP, Horta, Faial, Azores, PT

17:30 **T2.5 - *SPARC: Report from the EURobotics Board, Future Possibilities in H2020 Robotics PPP***
David Lane, Edinburgh Centre for Robotics and Ocean Systems Laboratory, Heriot-Watt University (EURobotics Board Member 2013-15)

Easily deployable autonomous hydro-acoustic assets for highly mobile and flexible arrangements (underwater sensor networks, testbeds, and integrated USV and AUV robotic components)

Konstantin Kebkal, Evologics, Berlin, DE

Easily Deployable Autonomous Hydro-Acoustic Assets for Highly Mobile Arrangements

(underwater sensor networks, testbeds, and integrated robotic components)

Konstantin Kebkal,
Oleksiy Kebkal,
Evologics, Berlin

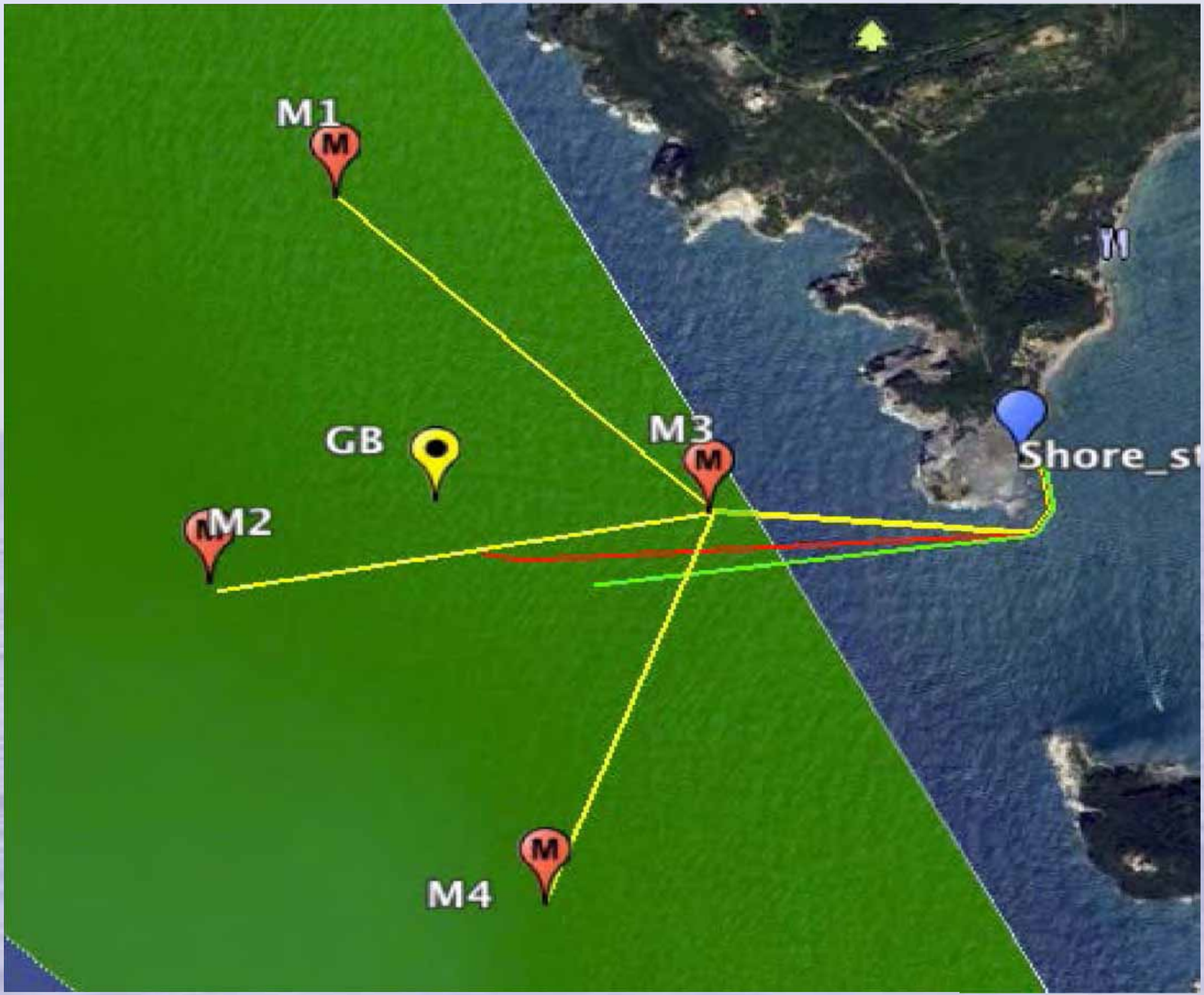
EMRA‘15 Workshop,
IST, Lisbon, 18-19 June 2015

Content:

- Intro,
- Smart UWA Nodes (Network, LBL, USBL),
- Smart USV (Sonobot),
- Low cost LBL Deployment,
- Unmanned/remote geo-referencing with USV Sonobot,
- Demo in Genova, May 2015.
- Light, low cost marine robitics

Intro

CMER LOON: location of Assets



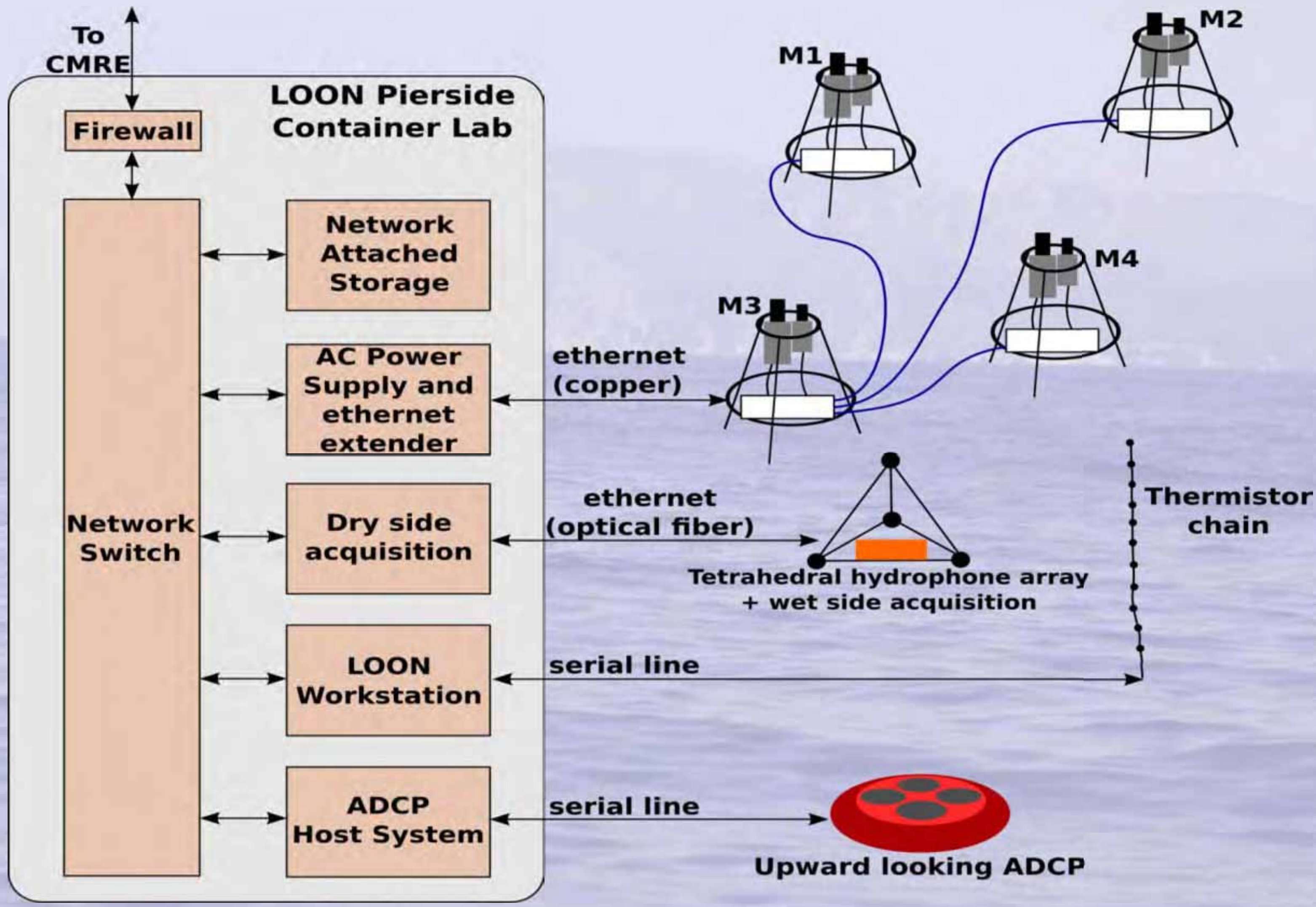
Picture by Joao Alves, CMRE

CMER LOON: location of Assets

Picture by Joao Alves, CMRE

LOON components comprising a testbed for experimenting with UAComms, networking

LOON: testbed diagram



Picture by Joao Alves, CMRE

Logictics for the LOON deployment and maintanence

LOON: tripods and cables

State of the art-testbeds:

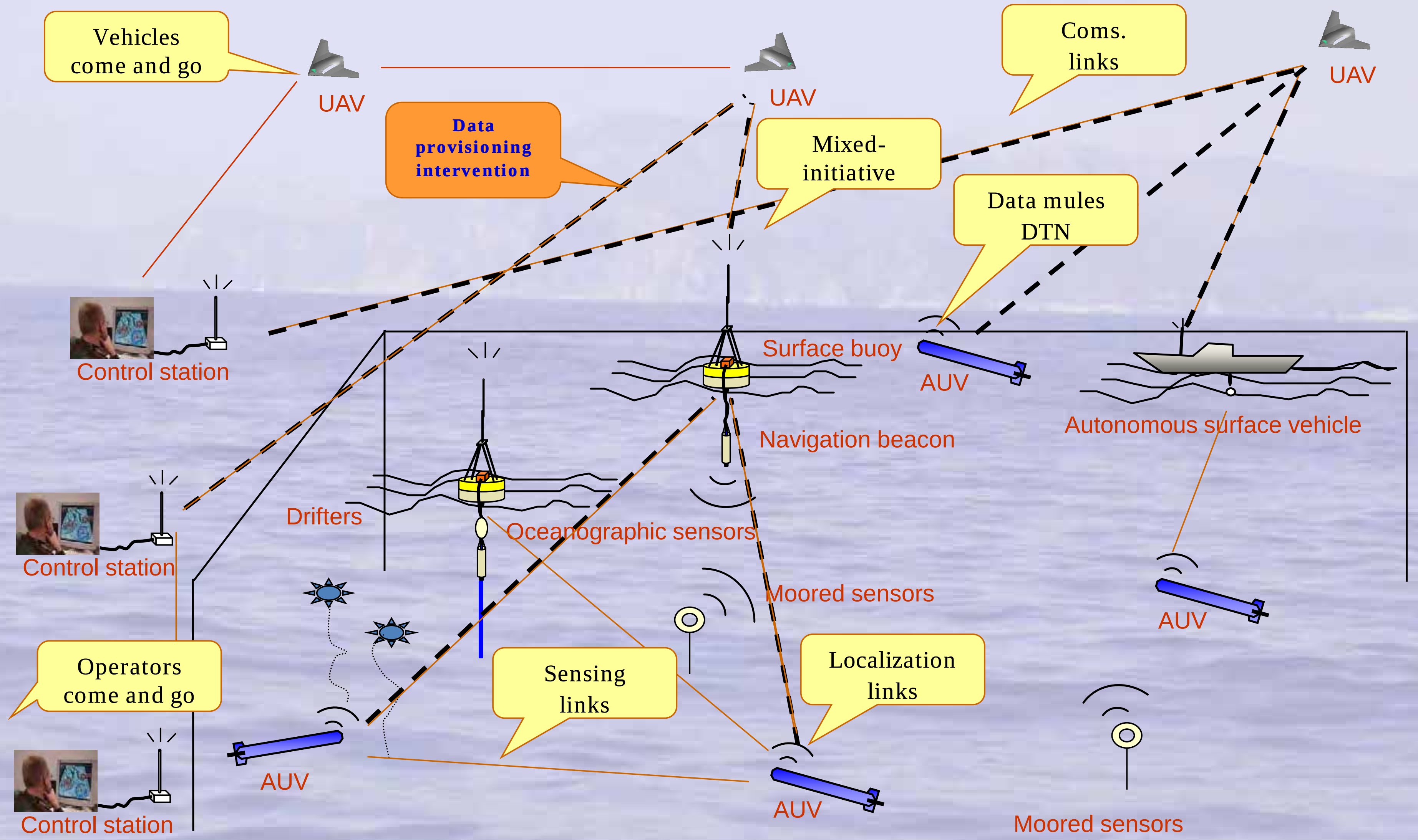
- **time consuming and very expensive deployment, recovery, maintanenence**

- **not flexible infrastructure**

Alternative:

Porto Testbed:
components are based on mobile devices (drifting platforms, AUVs, USVs)

Porto network testbed



Alternative:

Evologics light and easily deployable UWA and robotic assets to build

- **Testbeds (sensors fields, PHY, MAC, NET protocols development),**
- **LBL antennas,**
- **UWA networks.**

The idea was to develope a «Drop-And-Play» unit:

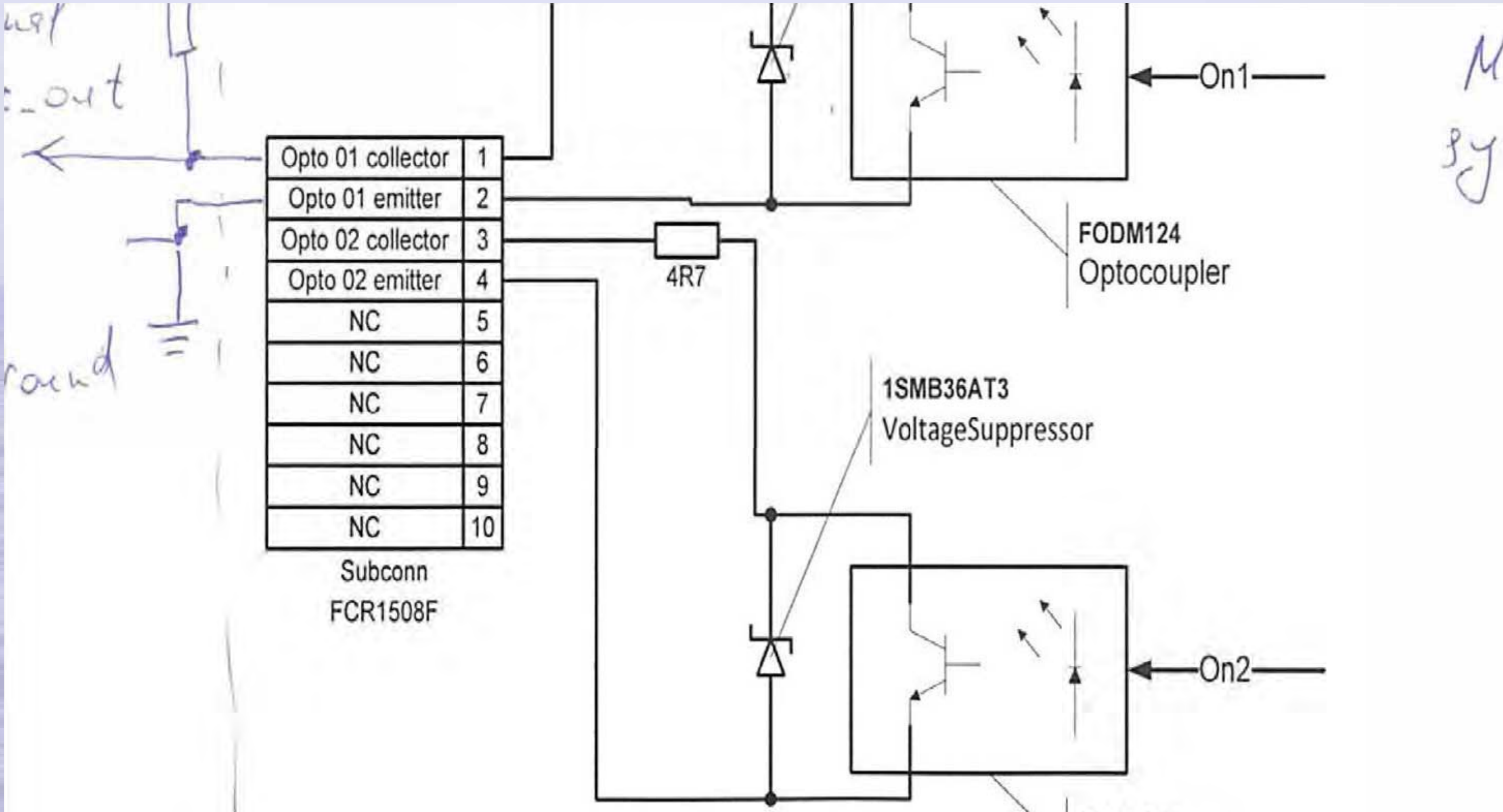
- **autonomous underwater module, containing UWA modem, integrated battery, floating coat and releaser,**
- **with a small size and weight of appr. 25 kg,**
- **capable to operate up to the depth of 1000 m (optionally 6000 m),**
- **equipped with a software for LBL operation, for UWA networking, operations as USBL transponder.**

UWA «Drop-And-Play» Hardware

«Drop-And-Play» unit (v. 1000 m)

Integrated releaser (controlled via S2C modem)

Integrated releaser: via optocouplers controlled by the modem



Deep water syntactic floaters

«Drop-And-Play» unit
(v. 6000 m)

UWA «Drop-And-Play» Software

UASN frameworks

- UANT[1]
- SUNSET[2]
- DESERT[3]
- UNetStack[4]

---

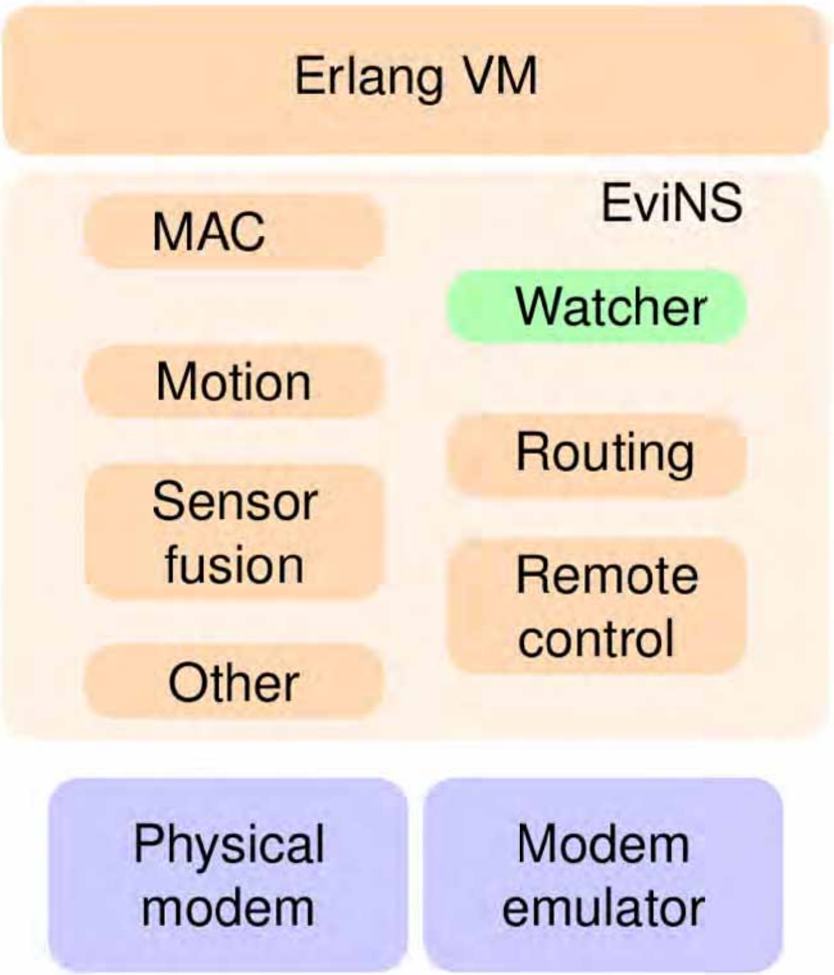
[1] Torrese, D *et al* “Software-defined Underwater Acoustic Networking Platform”, WUWNet’09

[2] Petrioli, C *et al* “The SUNSET framework for simulation, emulation and at-sea testing of underwater wireless sensor networks”, Ad Hoc Networks

[3] Masiero, R. *et al* “DESERT Underwater: An NS-Miracle-based framework to design, simulate, emulate and realize test-beds for underwater network protocols”, Oceans’12, Yeosu

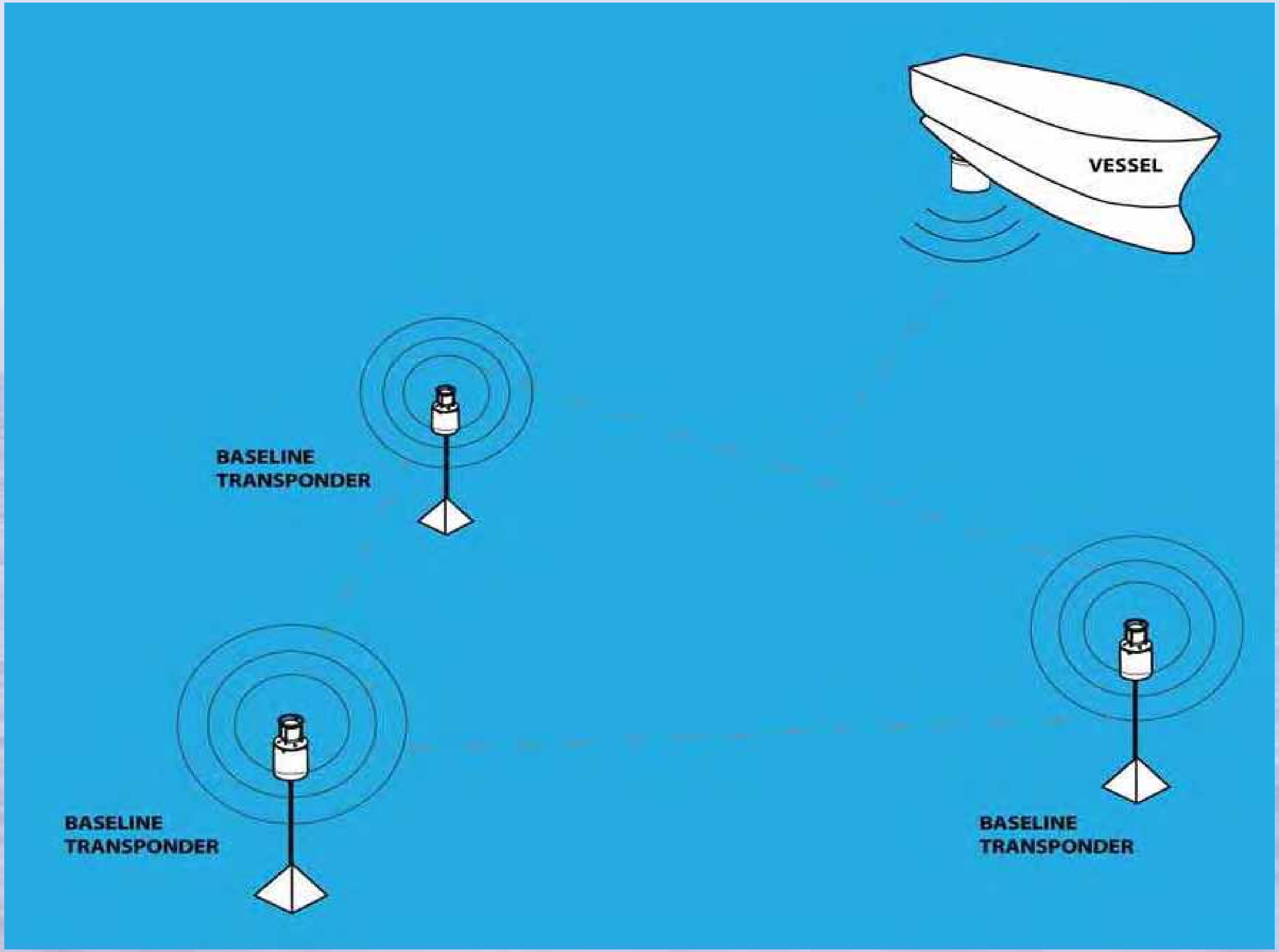
[4] Chitre, M. *et al* “UnetStack: An agent-based software stack and simulator for underwater networks”, Oceans’14, St. John’s

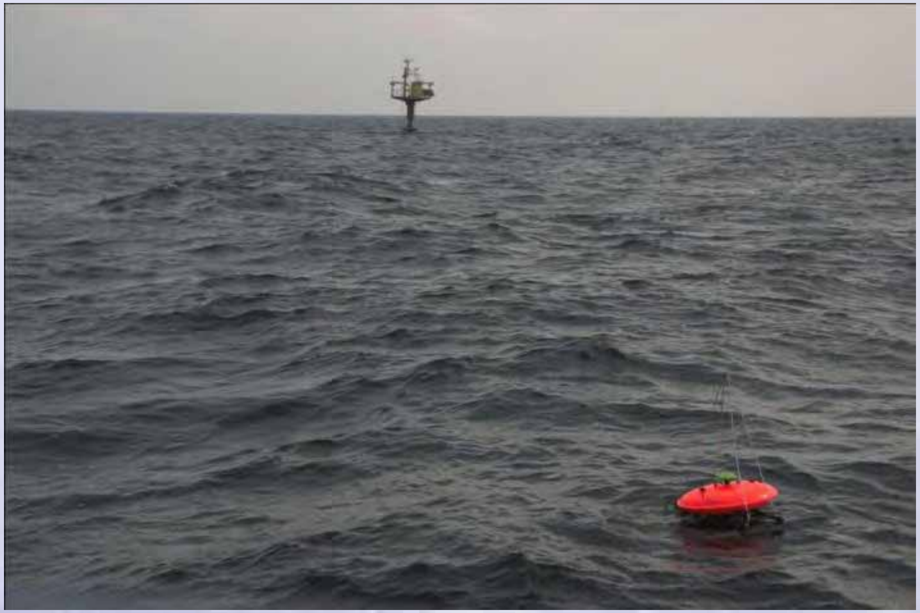
EviNS framework architecture



Evo
Logics®
Evo
Logics.de

LBL arrangement





D-GPS, WLAN, GPRS, Radio Control, Autopilot, Obstacle Avoidance

Vessel Transceiver with

Modem with all functionallities

Integrated AHRS (Attitude and Heading Reference System)

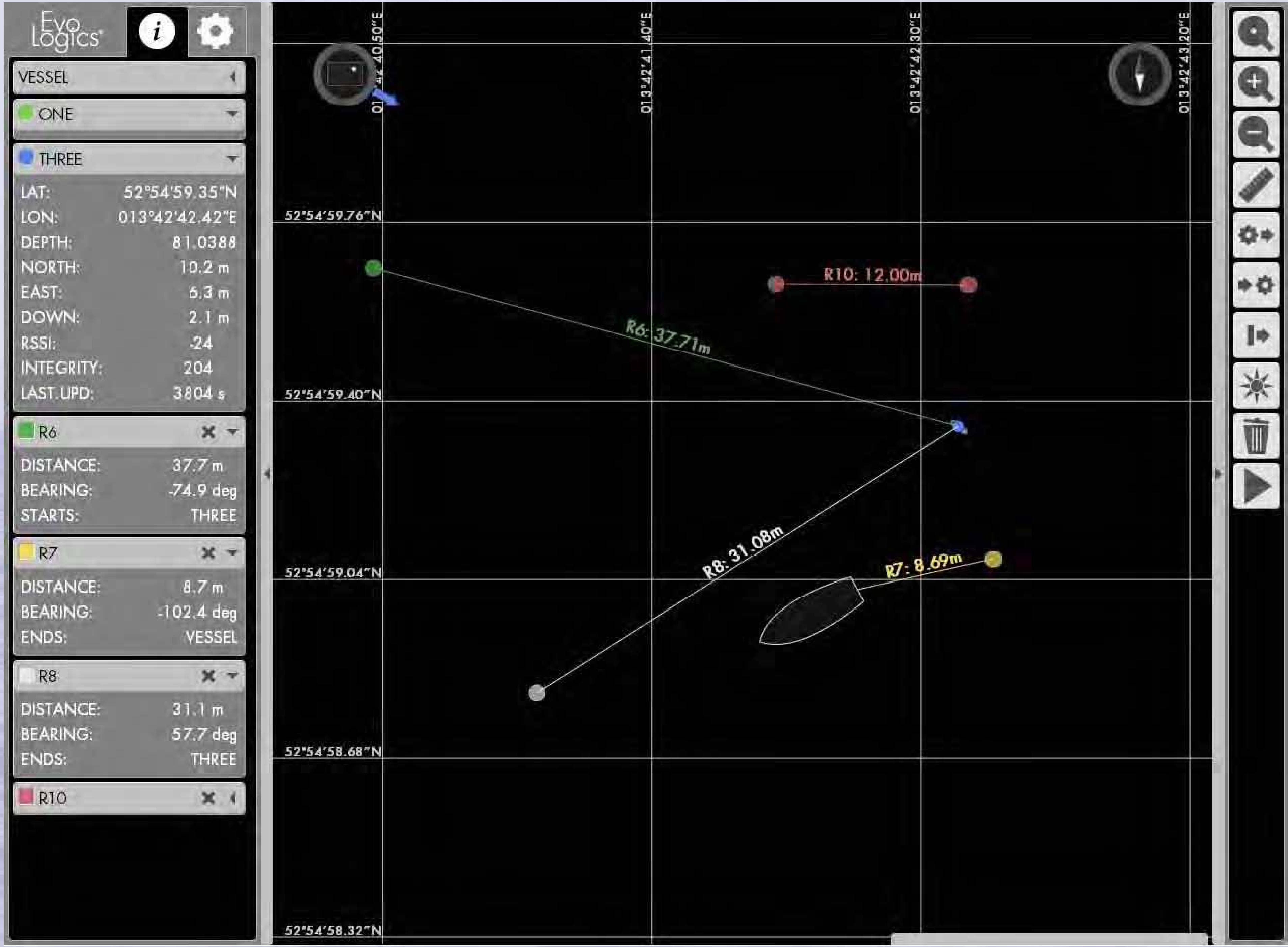
Integrated pressure sensor

Mounting frame for easier installation on the vessel

SiNAPS server: installed on the navigation computer interfaced with the vessel transceiver and other external instruments. SiNAPS server receives, processes and stores data from the transceiver and external instruments, and performs all the necessary calculations to display this information on-screen.

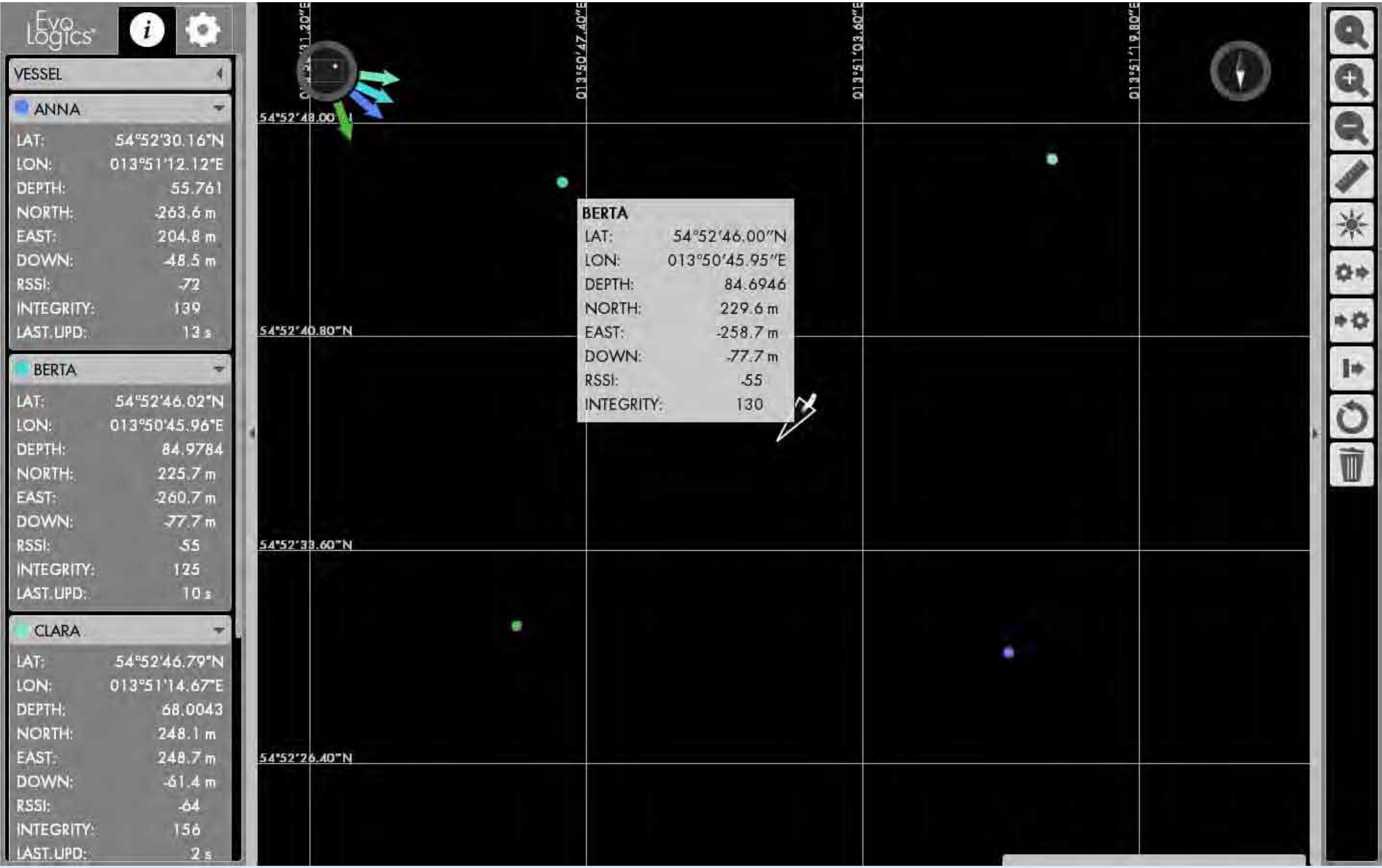
SiNAPS client: web-based user interface of the positioning system. It displays real-time information about the positions of the vessel and the targets, provides access to data management tools and system configuration settings.

User interface can be opened in most current web-browsers on any device in the local computer network, to access SiNAPS UI one must simply navigate the web-browser to the correct address. It is possible to open SiNAPS clients on multiple devices at once.

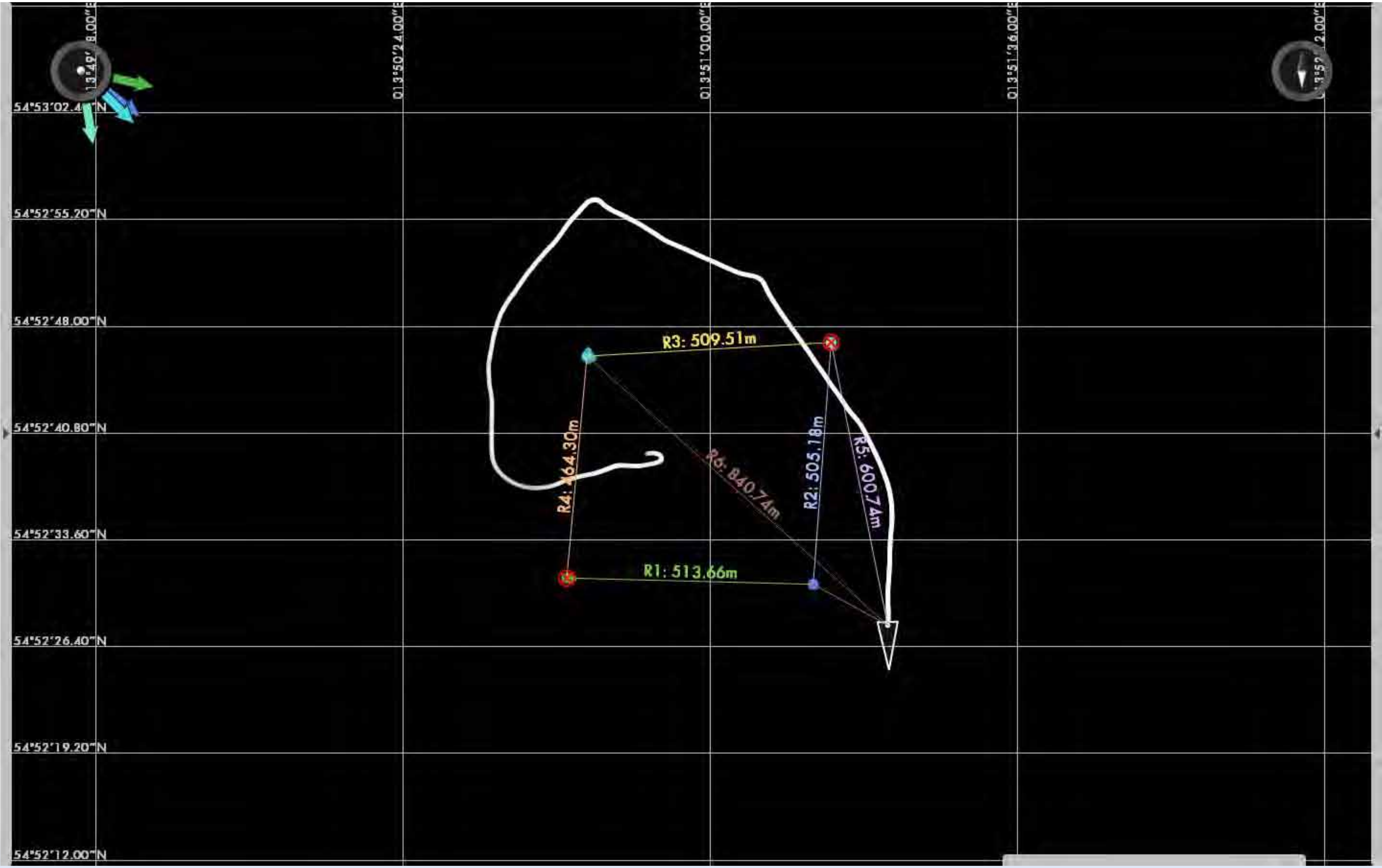

Evo Logics
VESSEL
ONE
THREE
LAT: 52°54'59.35"N
LON: 013°42'42.42"E
DEPTH: 81.0388
NORTH: 10.2 m
EAST: 6.3 m
DOWN: 2.1 m
RSSI: -24
INTEGRITY: 204
LAST.UPD: 3804 s
R6
DISTANCE: 37.7 m
BEARING: -74.9 deg
STARTS: THREE
R7
DISTANCE: 8.7 m
BEARING: -102.4 deg
ENDS: VESSEL
R8
DISTANCE: 31.1 m
BEARING: 57.7 deg
ENDS: THREE
R10
013°42'41.40"E
013°42'42.30"E
013°42'43.20"E
52°54'59.76"N
52°54'59.40"N
52°54'59.04"N
52°54'58.68"N
52°54'58.32"N
R10: 12.00m
R6: 37.71m
R8: 31.08m
R7: 8.69m

Demo in Genova, May 2015:

Low cost deployment of the LBL antenna



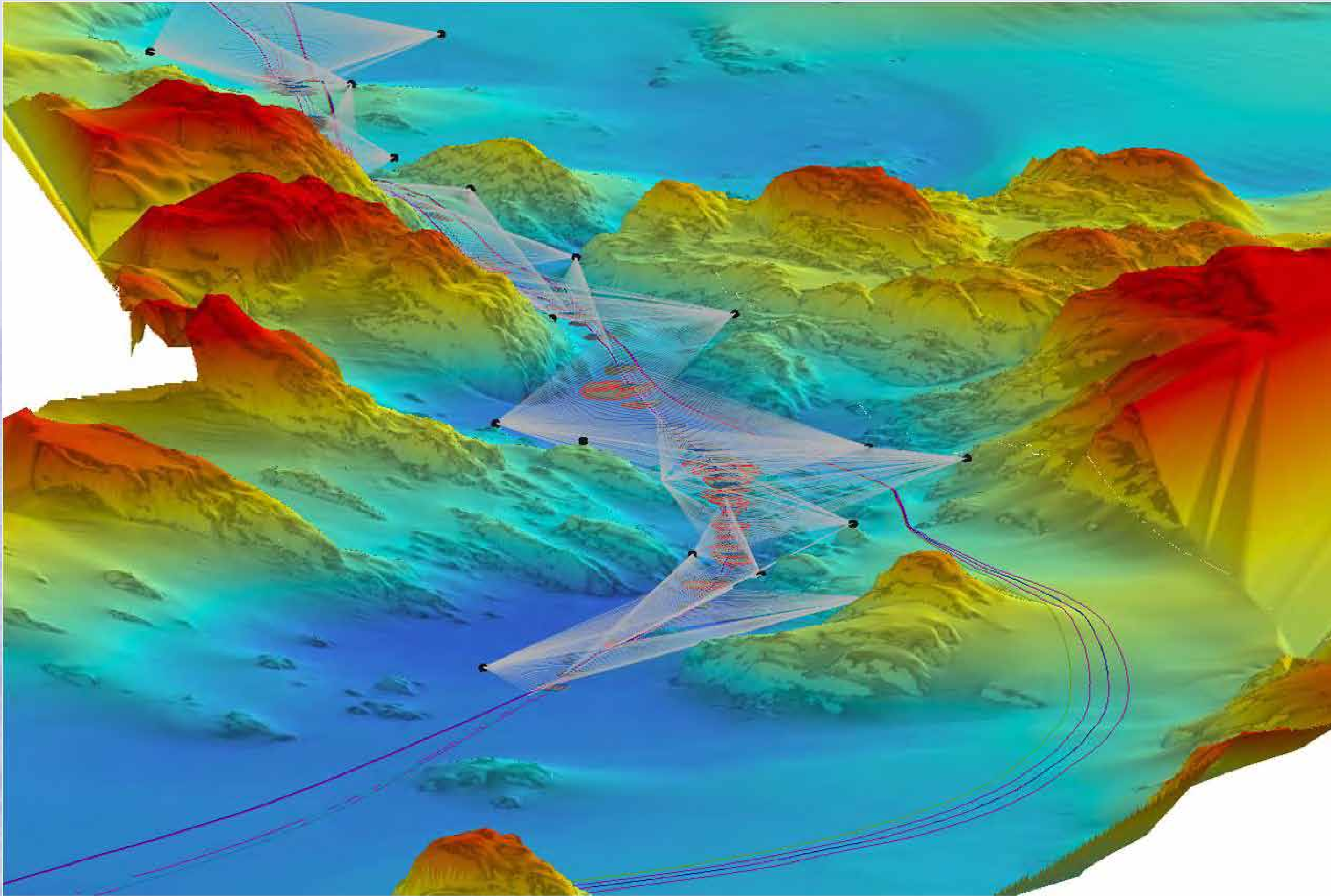
Example of a practical application (Screenshots from SiNAPS software)



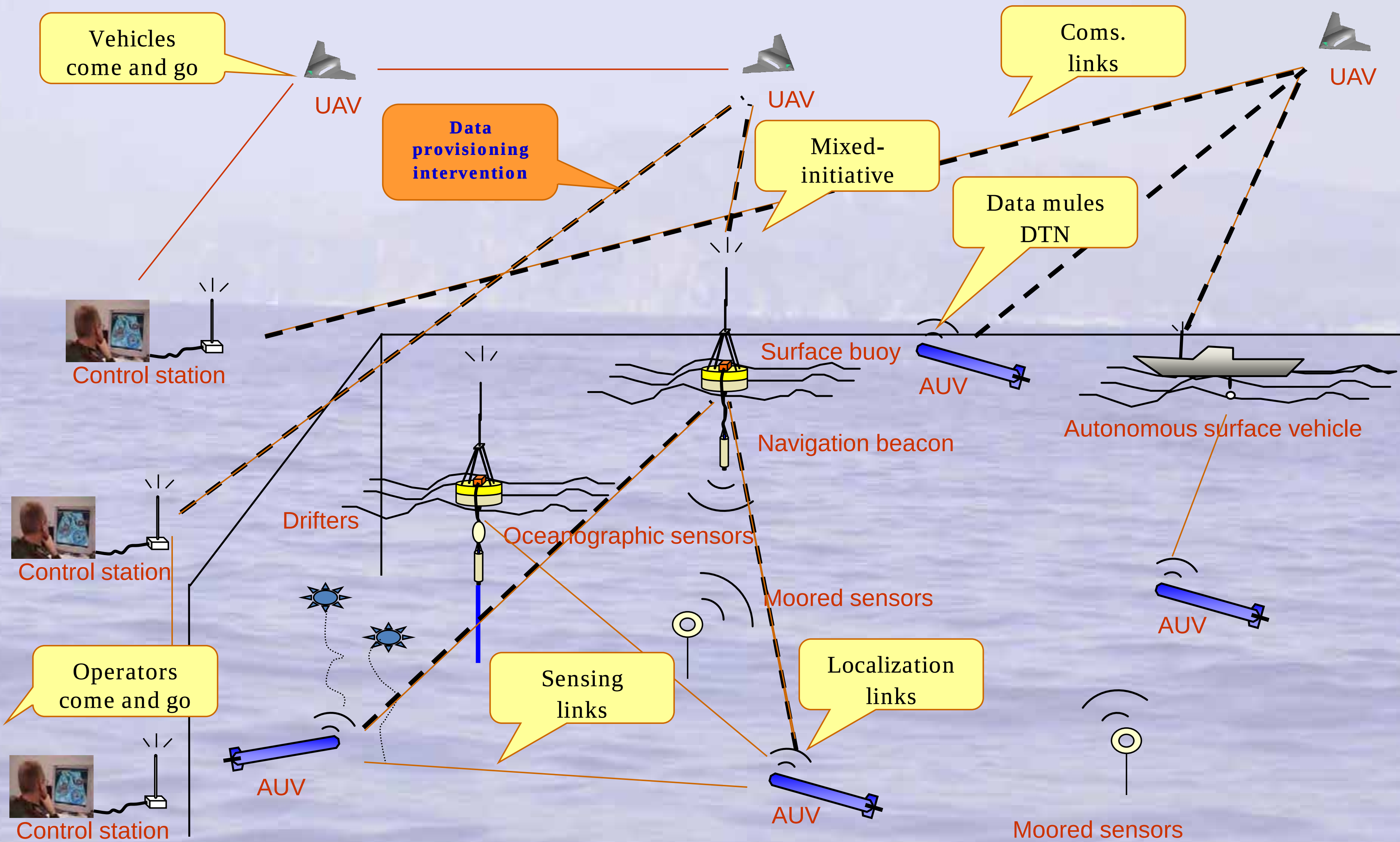
Example of a practical application (Screenshots from SiNAPS software)

Underwater Acoustic Networks

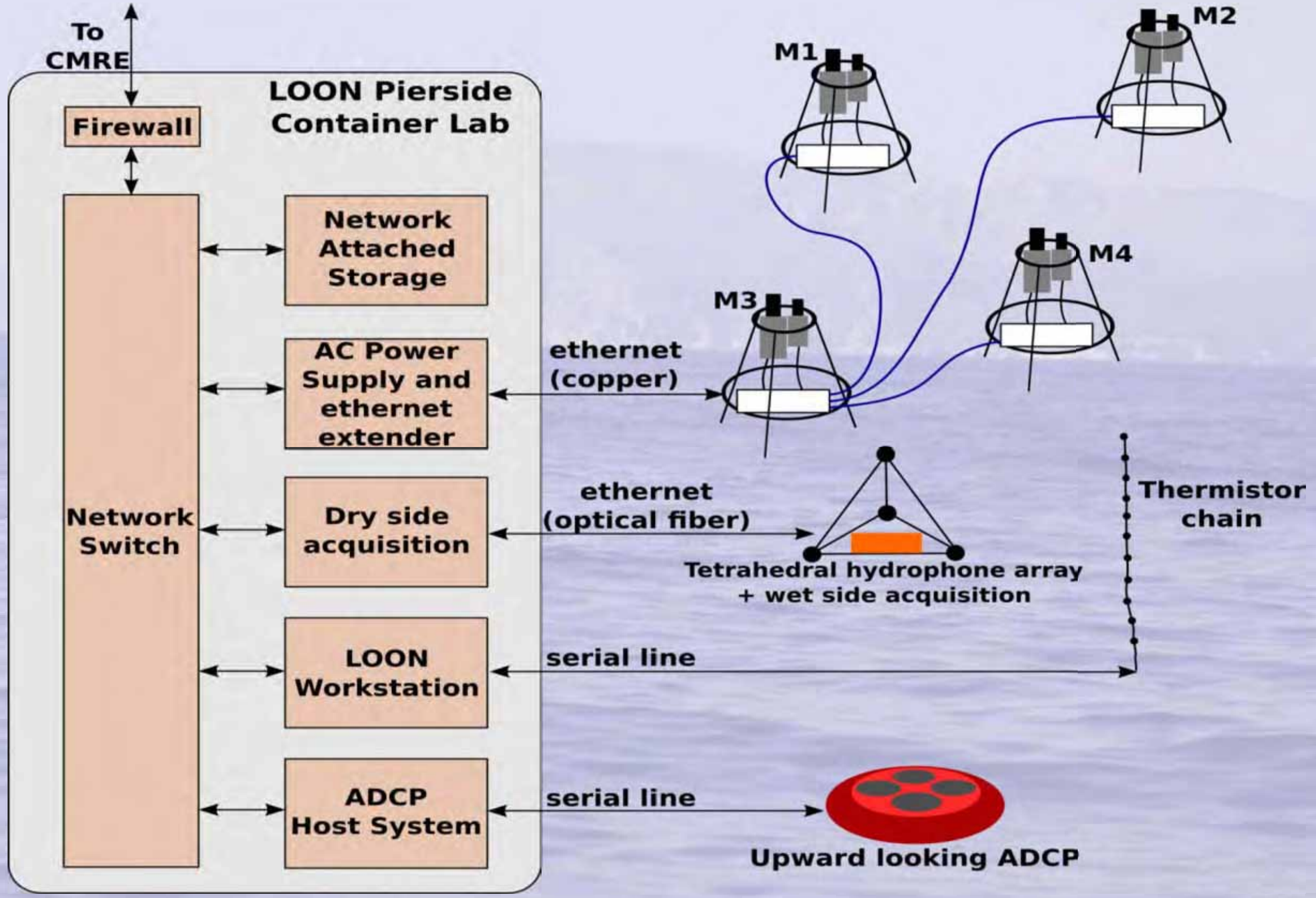
The equipment can be used independently as Underwater Communication & Navigation Networks



Evologics Testbed/Network can be used as an Extension of the Porto Testbed



Evologics Testbed/Network can be used as an Extension of the LOON testbed



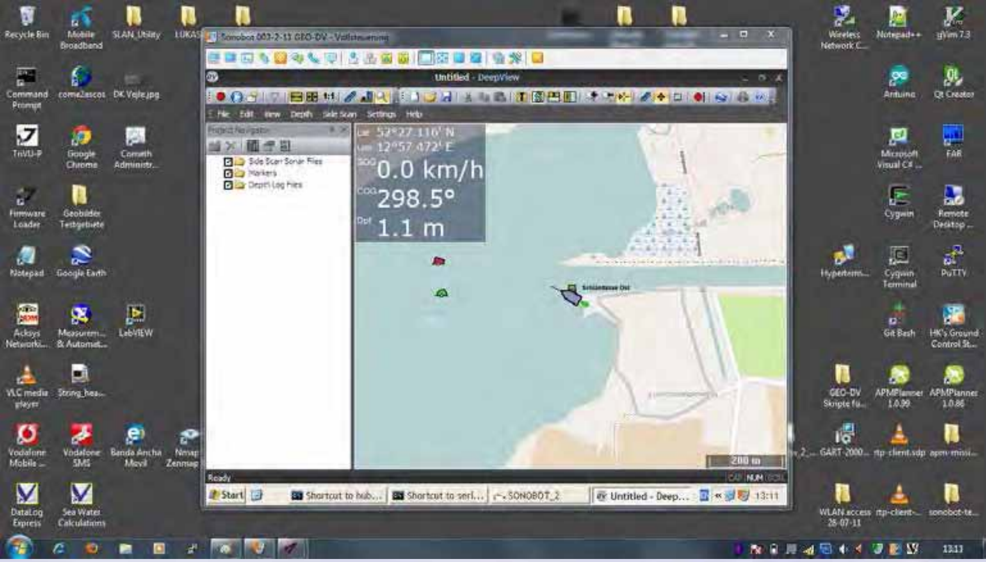
Picture by Joao Alves, CMRE

Marine Robotics:
USV Sonobot

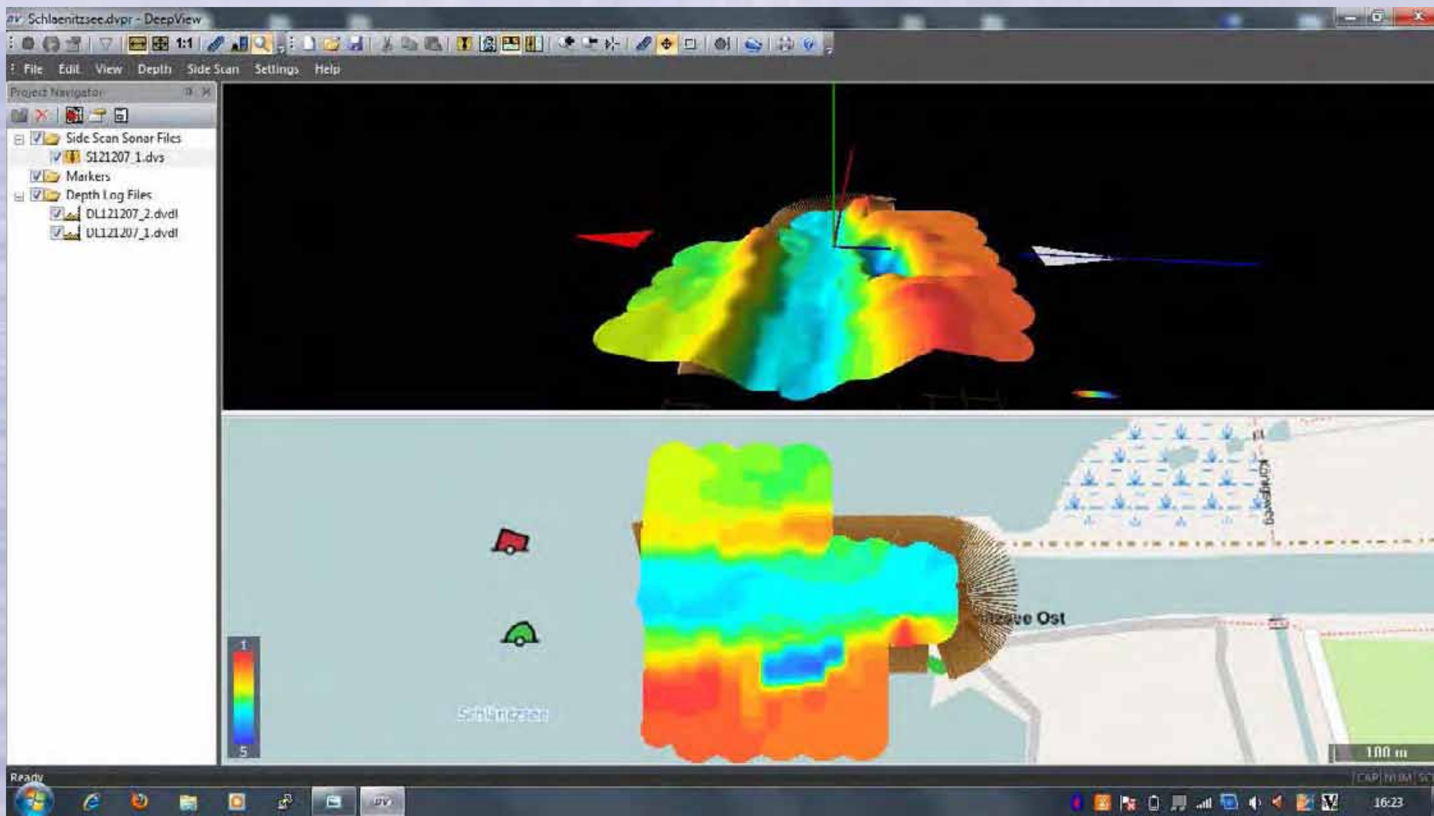
USV Sonobot basic

USV Sonobot advanced: obstacle avoidance capability


Stena Line


Untitled - DeepView
File Edit View Depth Side Scan Settings Help
Project Navigator
Side Scan Sonar Files
Markers
Depth Log Files
52°27.116' N
12°57.472' E
0.0 km/h
298.5°
1.1 m
Ready
Start
Untitled - Deep...
13:11


4.3 km/h
359.9°
1.7 m
Evologics Sonobot
DURABOOK


Schlaenitzsee.dvpr - DeepView
File Edit View Depth Side Scan Settings Help
Project Navigator
Side Scan Sonar Files
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Markers
Depth Log Files
DL121207_2.dvdl
DL121207_1.dvdl
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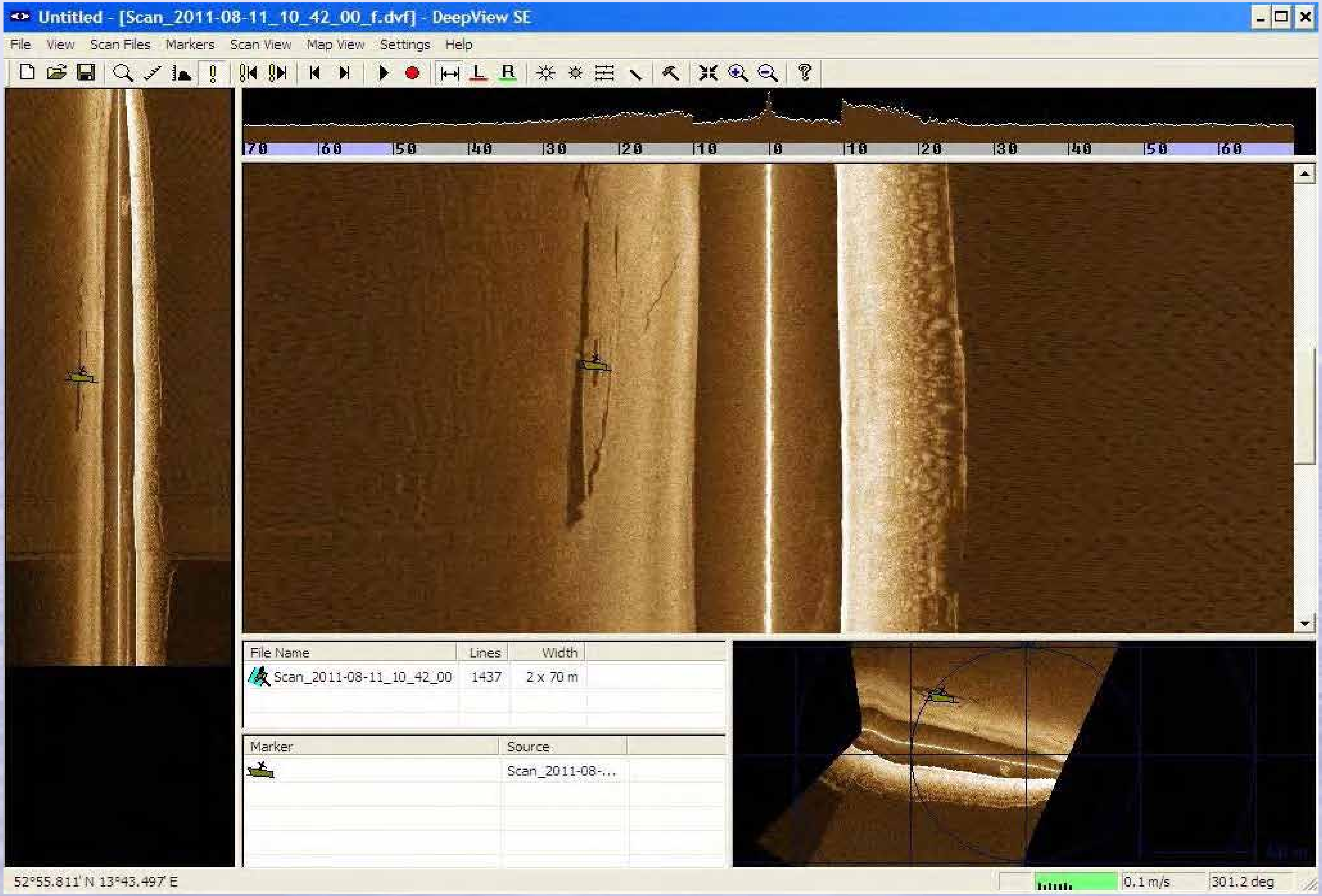
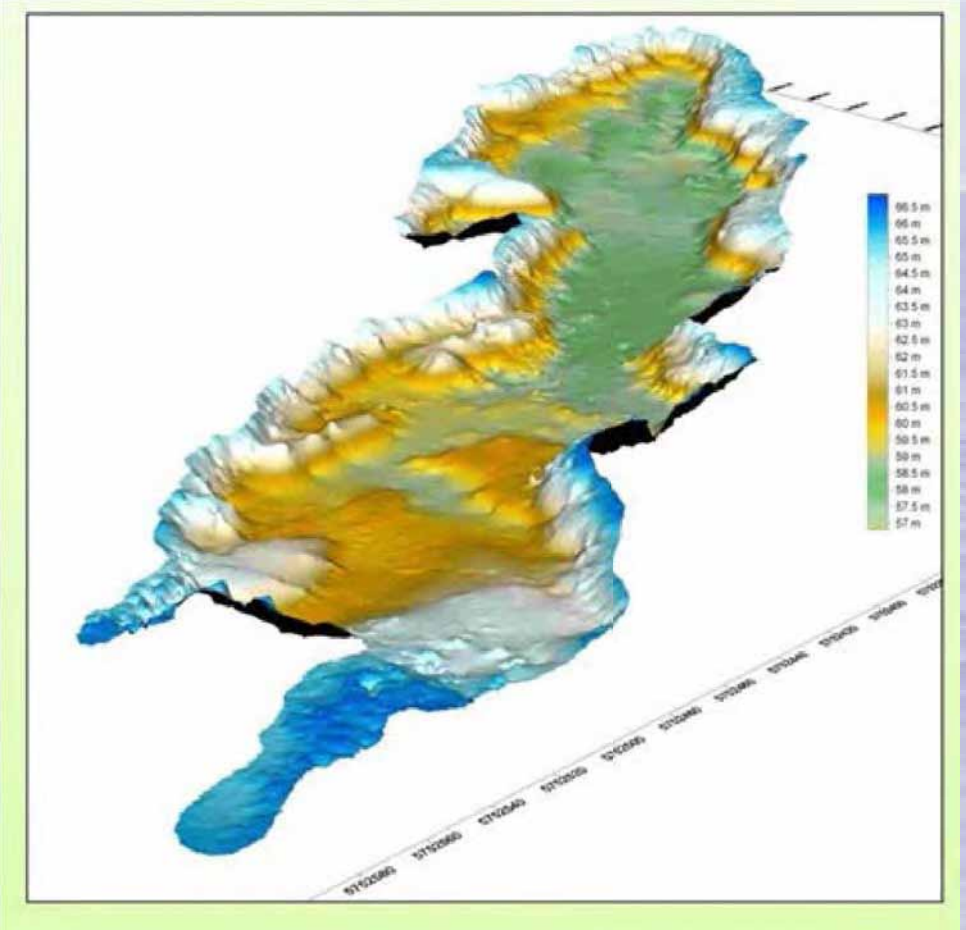
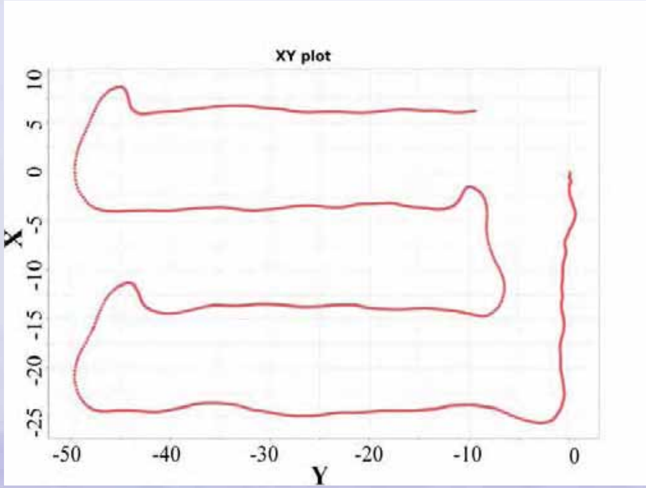
Side Scan Sonar

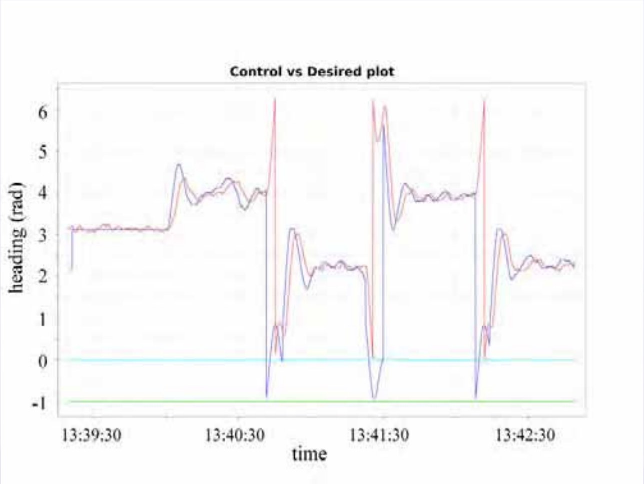


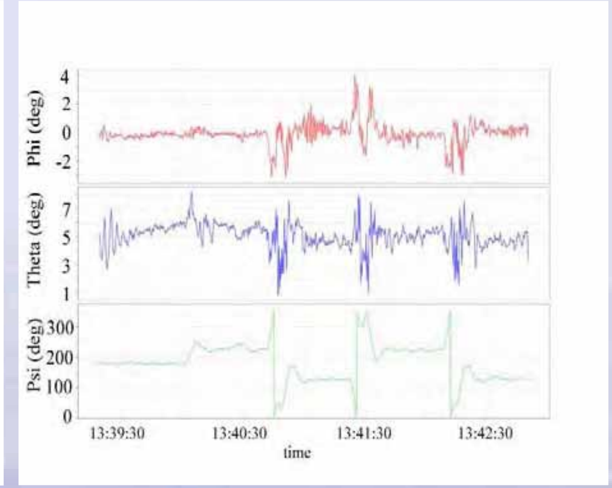


3D map of a water reservoire (Karlssee lake near Förderstedt, Germany)

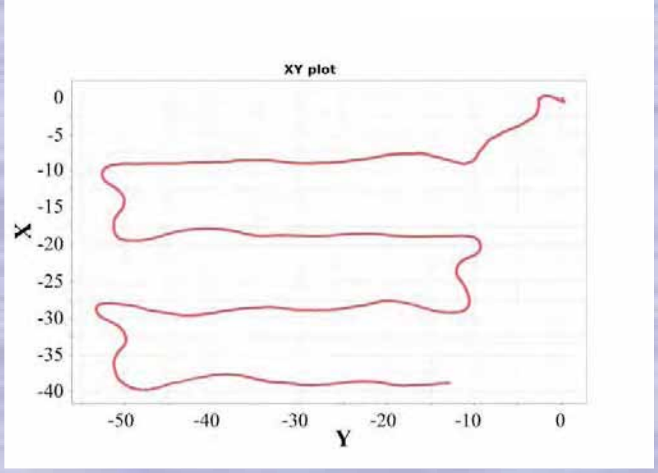
Autopilot functionality:
scans proceed **downwards** the river flow

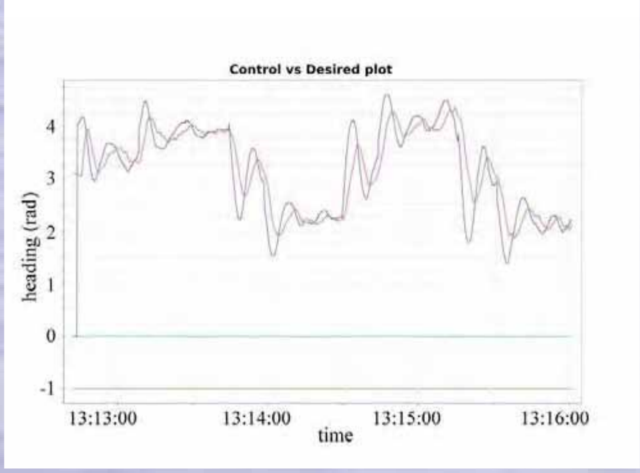


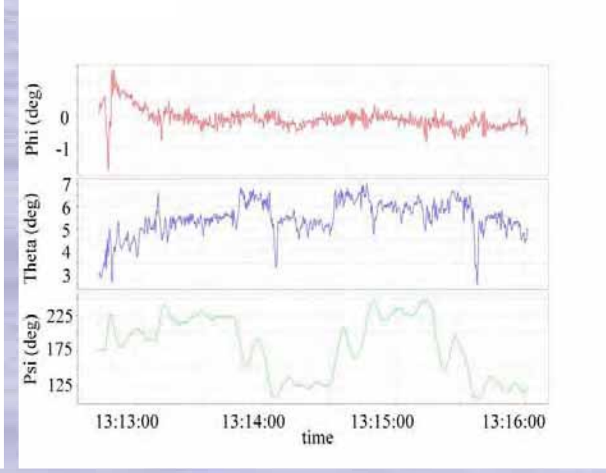




Autopilot functionality:
scans proceed **upwards** the river flow







Marine Robotics:
AUV Manta

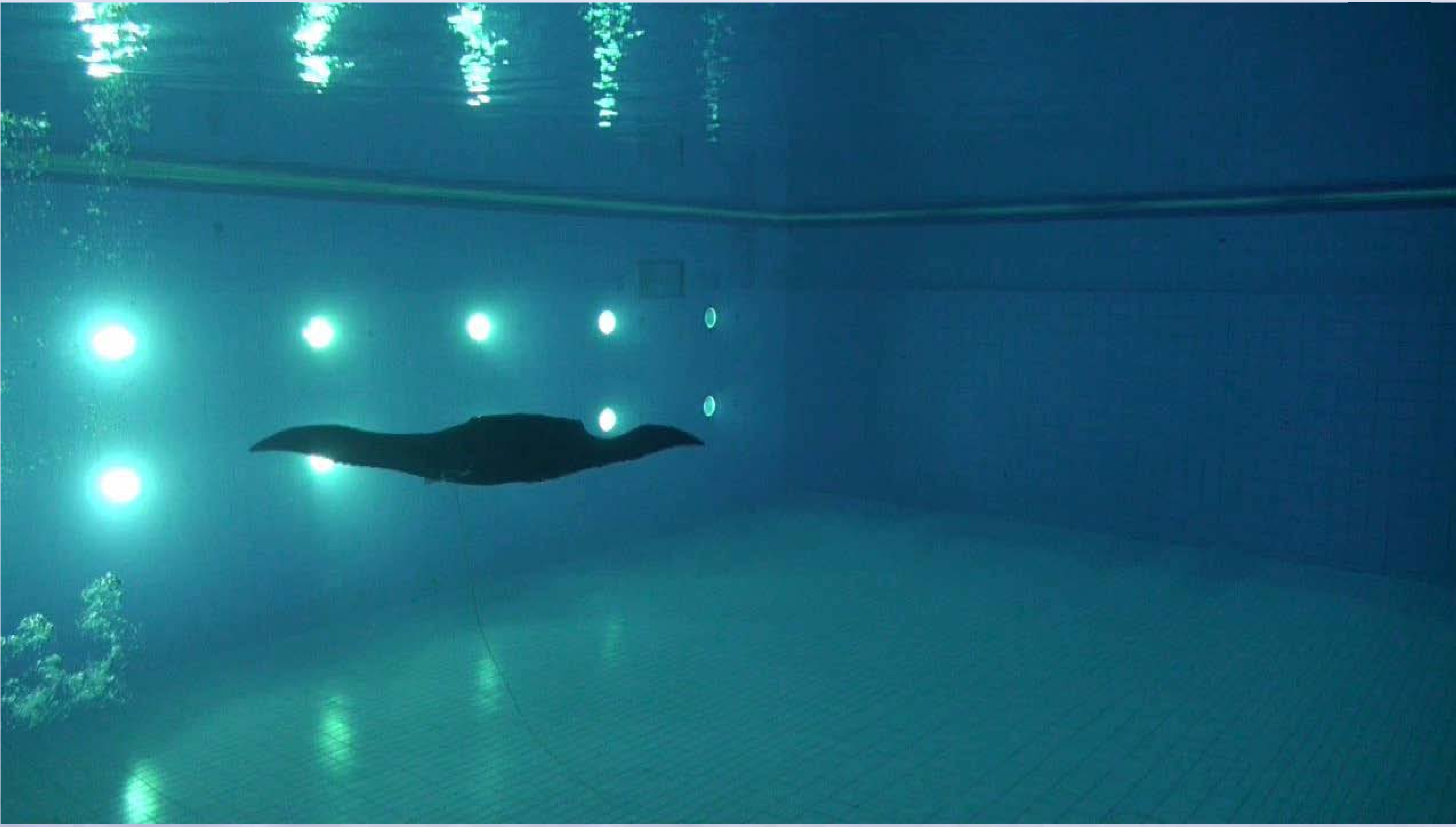
AUV Manta: sommer 2014

AUV Manta: first pool tests, September 2014

AUV Manta: depth keeping, November 2014

AUV Manta: free flight, November 2014

AUV Manta:
BOSS - Bionic Observation and Survey System, Dec. 2014



Review:

1. Creation of low cost, easily deployable autonomous hydro-acoustic and robotic assets for highly mobile open-water arrangements is not only an achievable objective, but within short time such assets/arrangements become "State-Of-The-Art":

- **acoustic part is already well developed,**
- **light and smart surface vehicles (USVs) exist, well developed and their number increases (one of them is Sonobot),**
- **light and smart underwater vehicles (AUVs) exist, well developed and their number increases (one of them is Manta)**

2. Still necessary to integrate different systems by means of unified communication protocols and navigation environments.

3. Evologics uses DUNE for integration of its robotics systems. Converters DUNE-ROS feasible.

4. Evologics developed hydro-acoustic modems with and open-source framework EviNS for development of networking and positioning applications.

5. The opportunity for combining different assets of different manufactures becomes possible.

Thank you!

EMRA´15

ISR-IST Lisbon Portugal

EMRA'15 workshop

Marine Megafauna Telemetry Systems

Pedro Afonso,
IMAR/DOP, Univ. Azores, PT

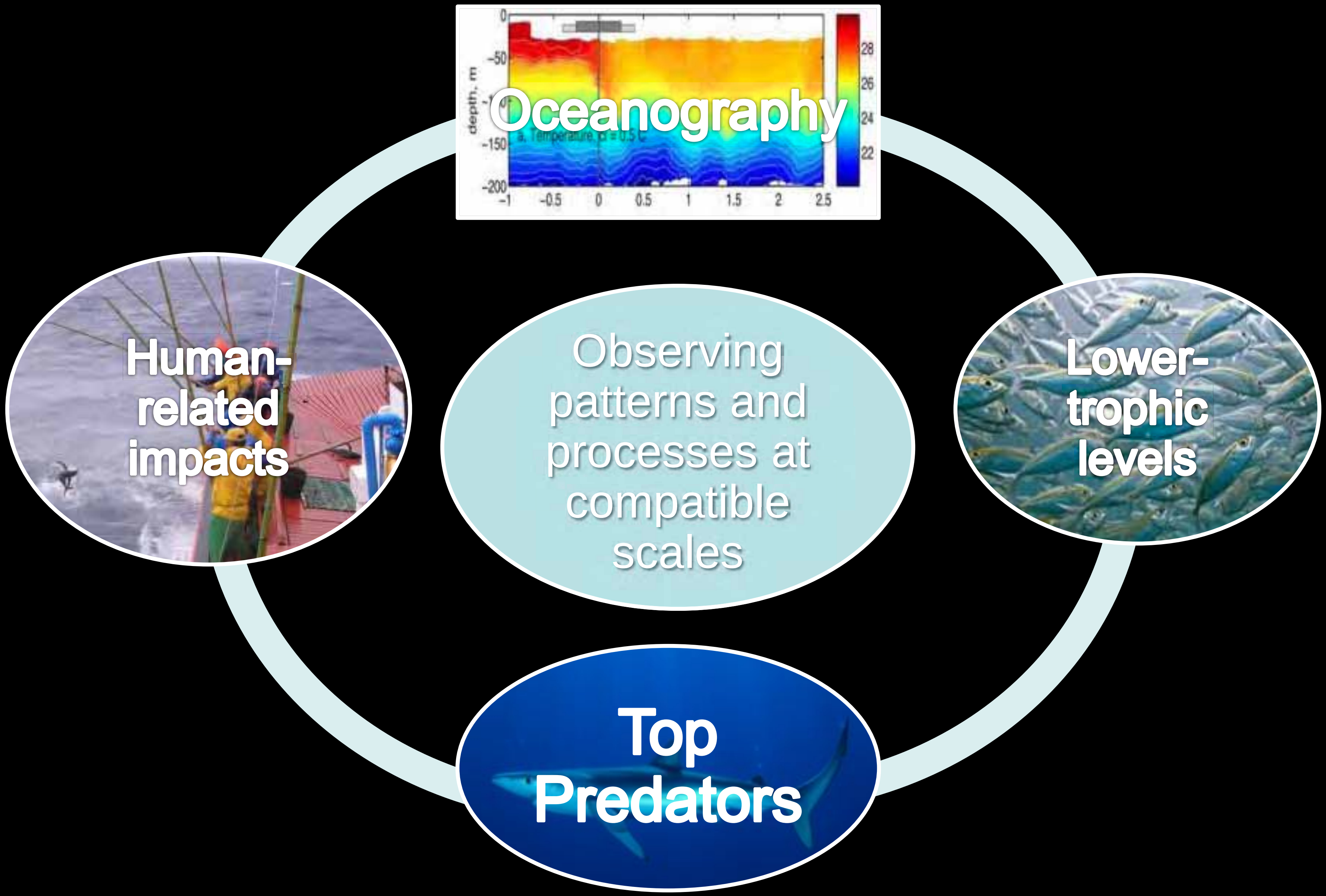
Marine robotics and the biotelemetry of Marine Megafauna

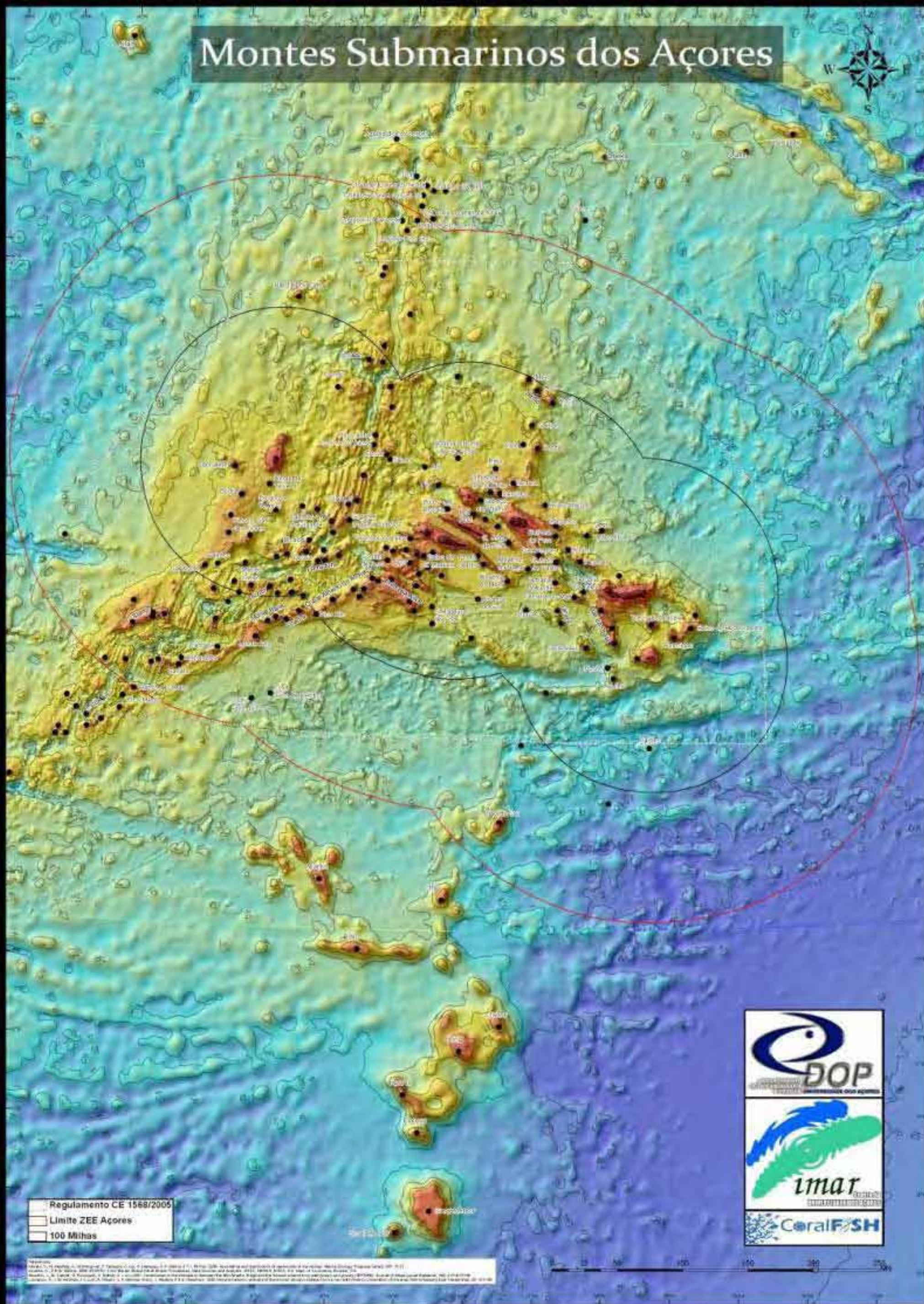
Pedro Afonso,
Jorge Fontes, Mónica Silva

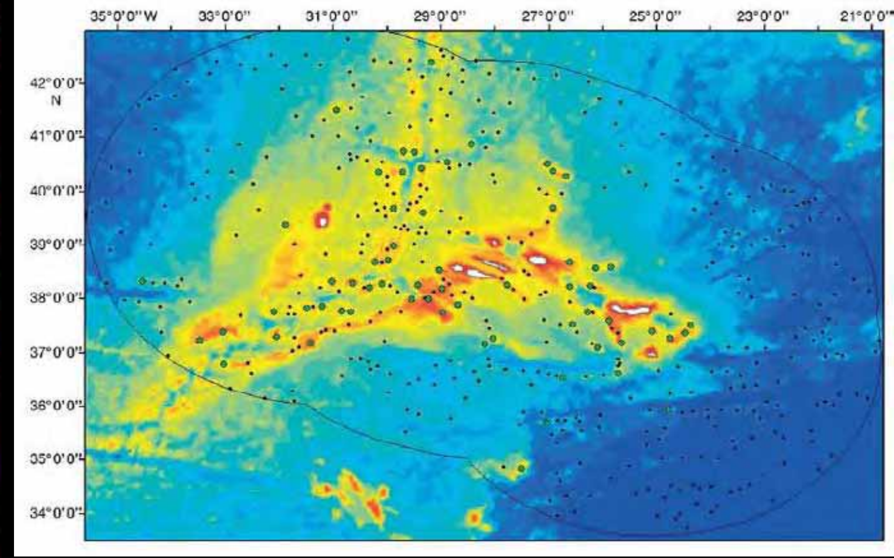
EMRA, IST - June 2015


澳洲
$128元

Goal: Drivers of predator distribution & behaviour







Azores seamounts
ca. 434

Vol. 357: 17–21, 2008
doi: 10.3354/meps07268

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published April 7

Abundance and distribution of seamounts in the Azores

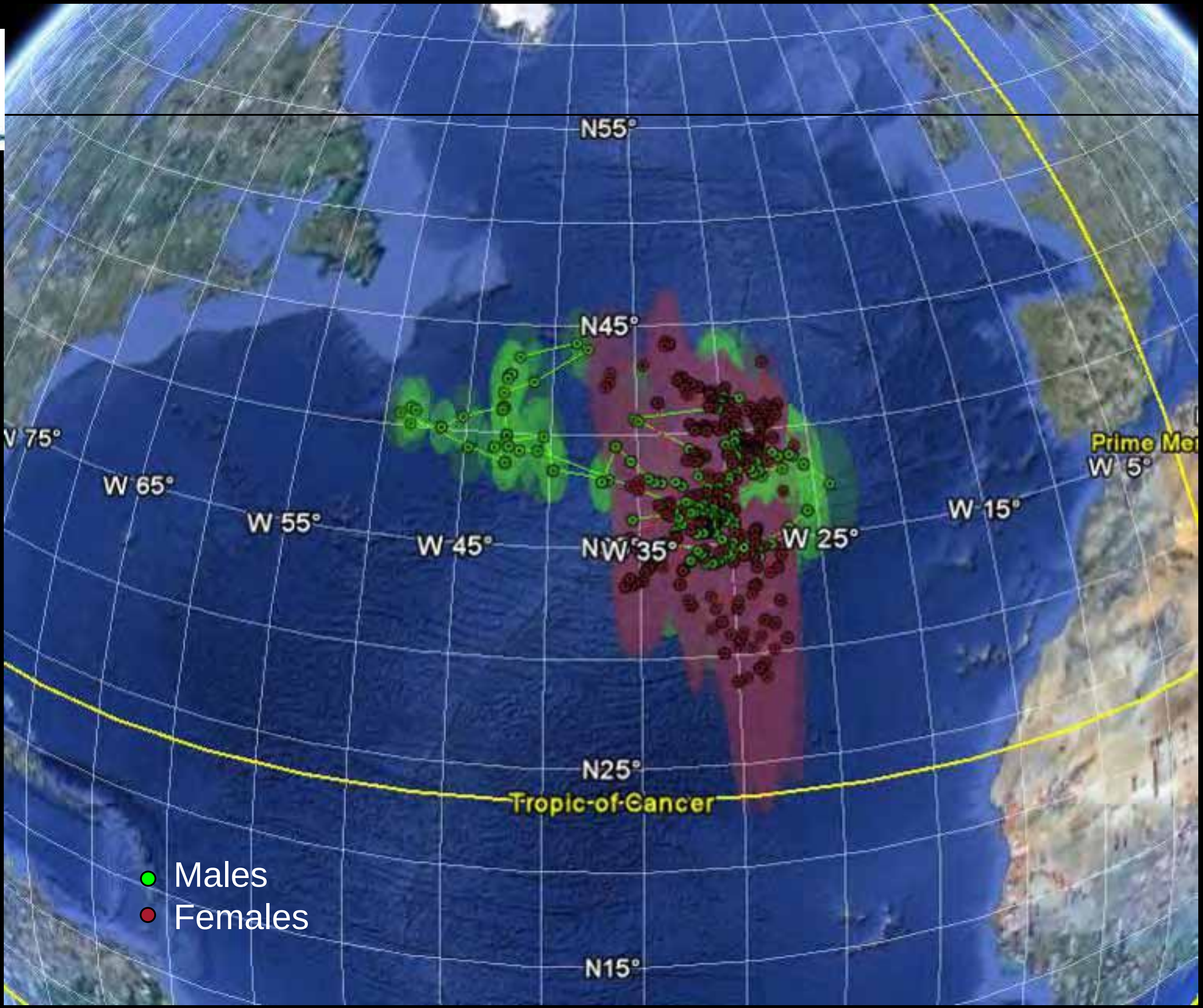
Telmo Morato[1,2,*], Miguel Machete[1], Adrian Kitchingman[2], Fernando Tempera[1], Sherman Lai[2], Gui Menezes[1], Tony J. Pitcher[2], Ricardo S. Santos[1]

[1]Departamento de Oceanografia e Pescas, Universidade dos Açores, 9901-862, Horta, Portugal
[2]Fisheries Centre, Aquatic Ecosystems Research Laboratory, 2202 Main Mall, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada

Biotelemetry - *Archival satellite tags*

(light based geolocations + vertical behaviour)

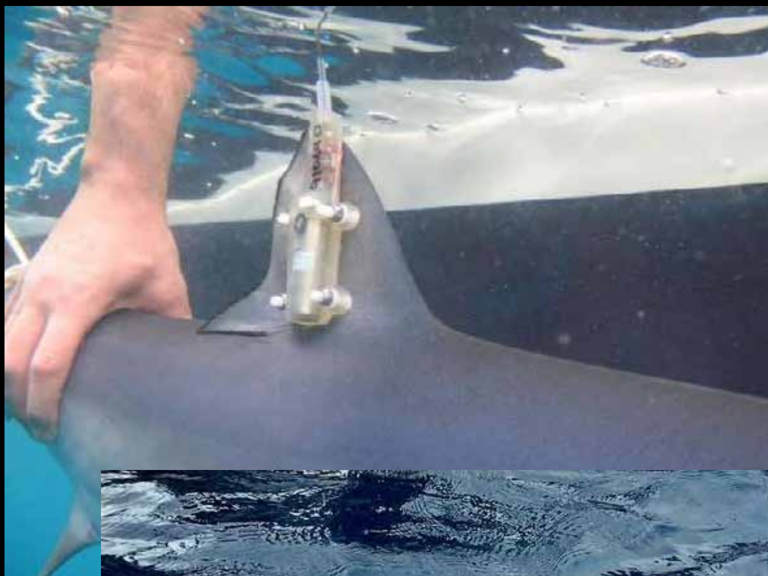
Biotelemetry - Archival satellite tags
(light based geolocations + vertical behaviour)



Geolocation error from PATs:

Only good for large scale questions

Biotelemetry - SPOT satellite tags
(Argos positions only)

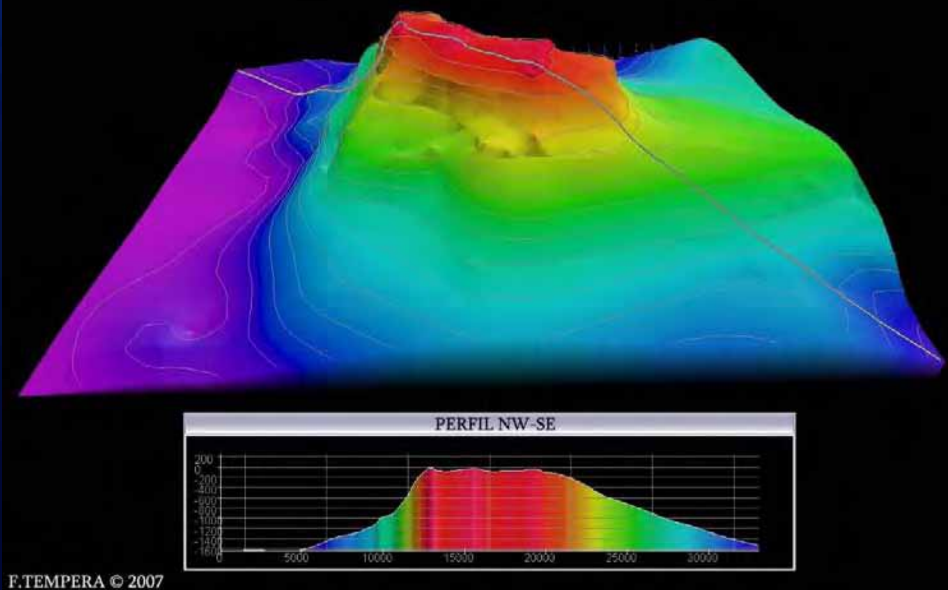


Requires air transmission and fixing:

Only good for restrainable and surfacing animals

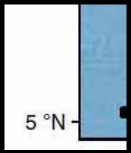
Devilray aggregations at seamounts

Tracking them out



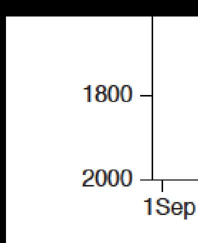
Devilray aggregations at seamounts

Azores as EFH for N Atlantic population

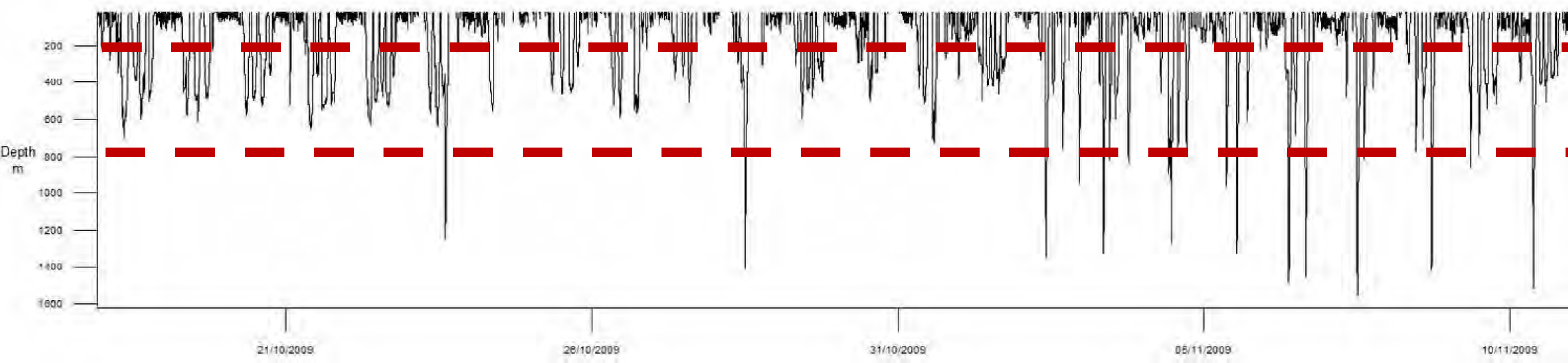


Thorrold et al (2014) *Nature communications*

Gregory

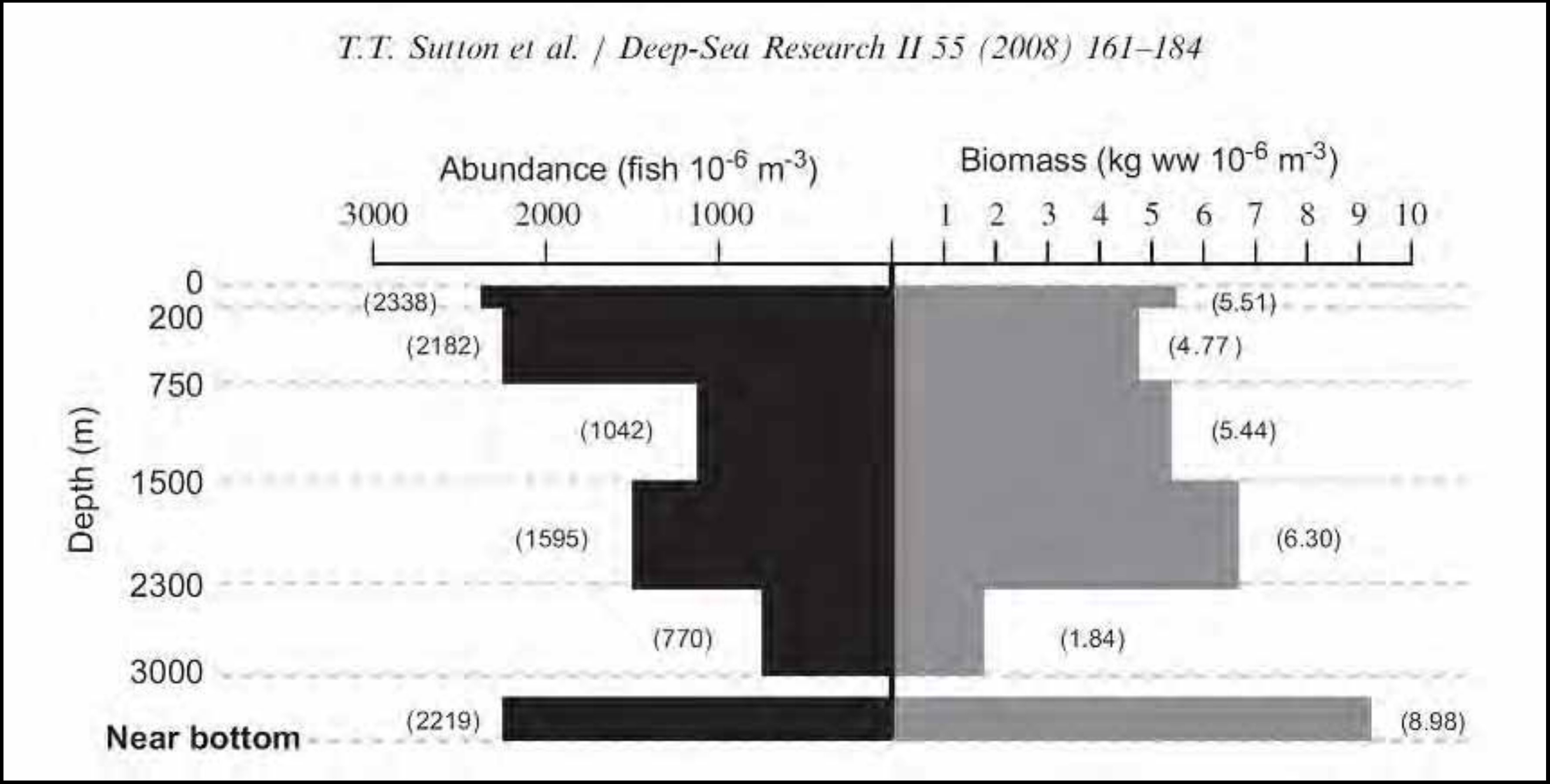


Deep diving behaviour of blue shark



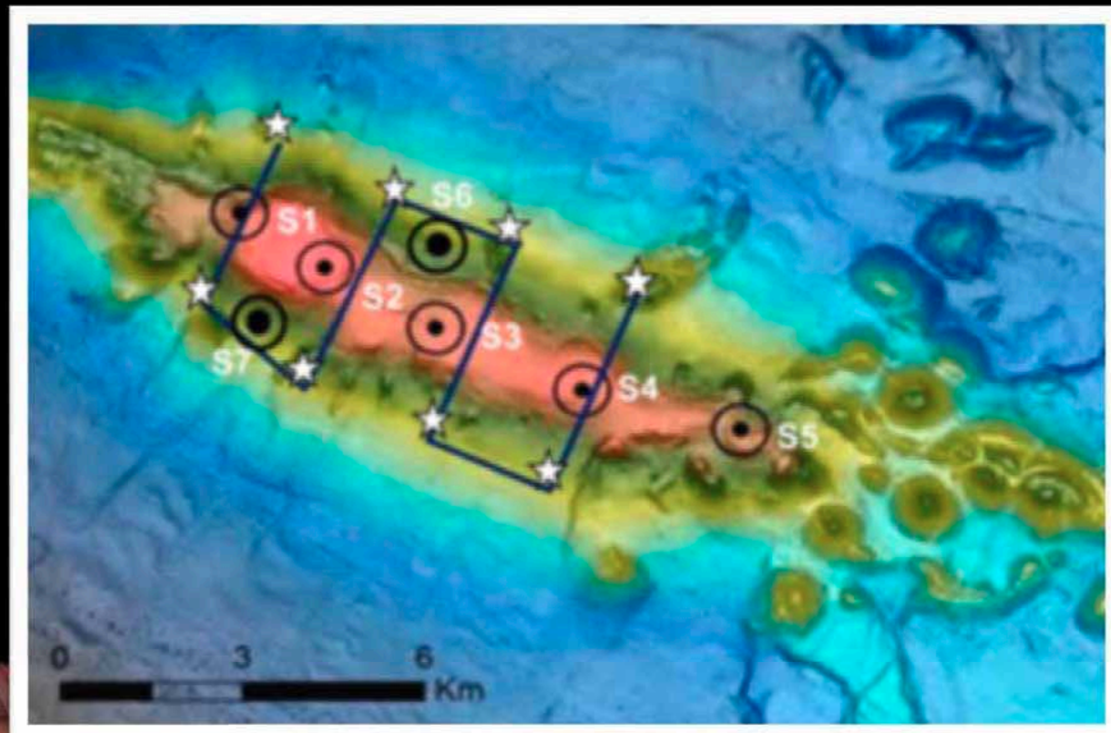
Why deep diving? Some hypotheses

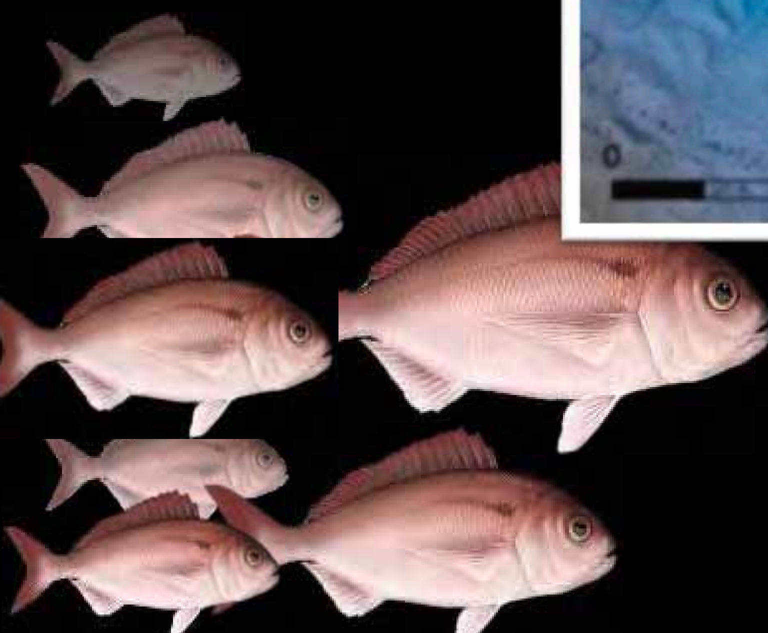
- Feeding (on DSL deeper components)



Estimates may need to be revised 1 order of magnitude! (Irigoien et al 2014)

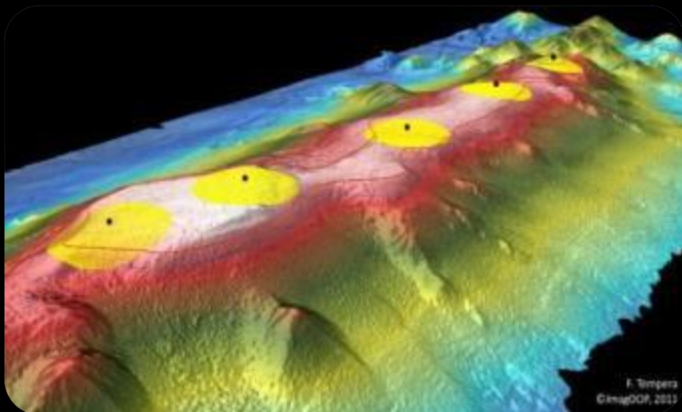
Active acoustic tracking:
Synoptic observation fish 3D behavior vs. its food

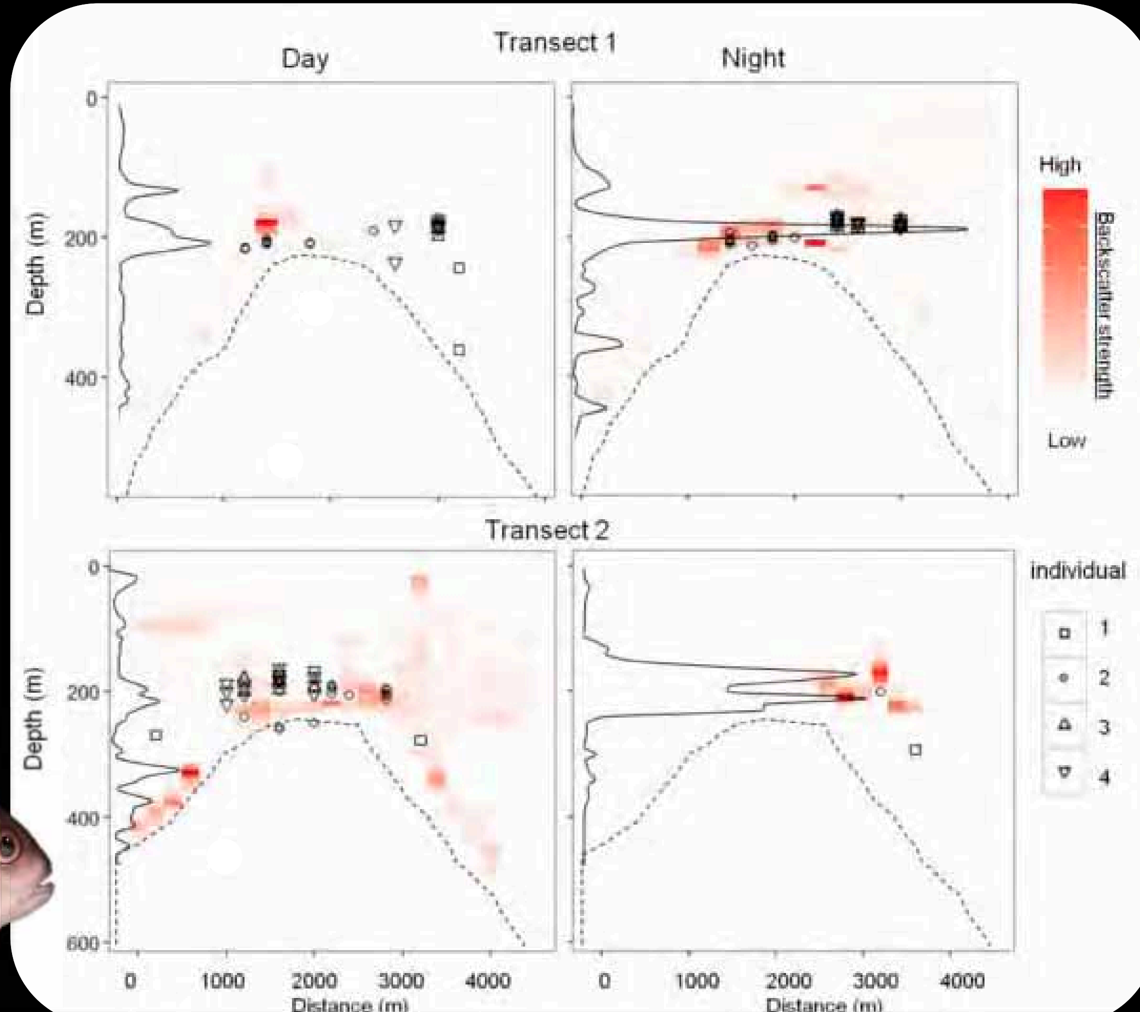




Afonso et al (2014) *PLoS ONE*

Active acoustic tracking:
Synoptic observation fish 3D behavior vs. its food



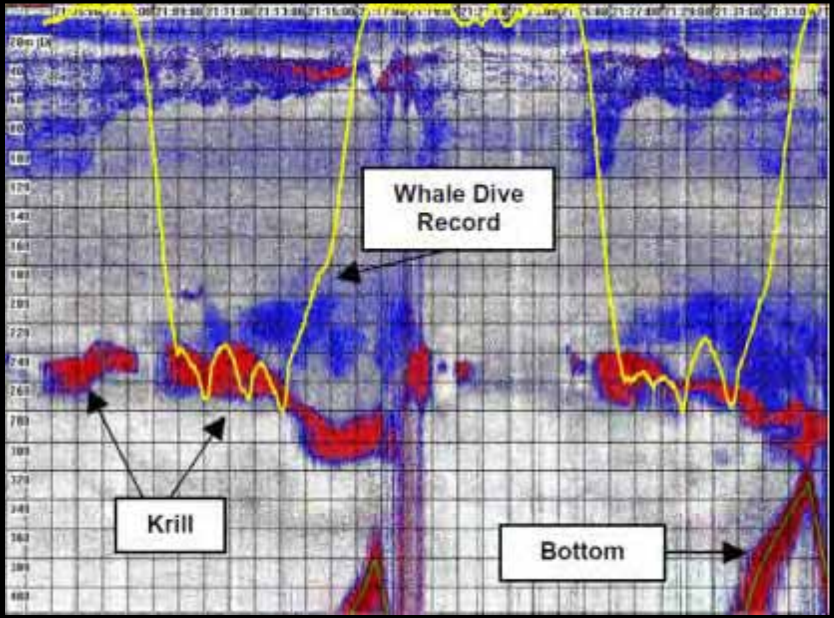


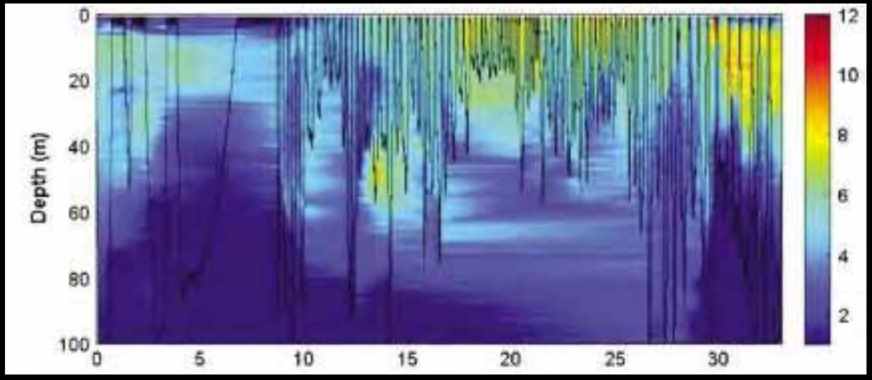
Afonso et al (2014) *PLoS ONE*

Tracking more and better - Robotic Vehicles?

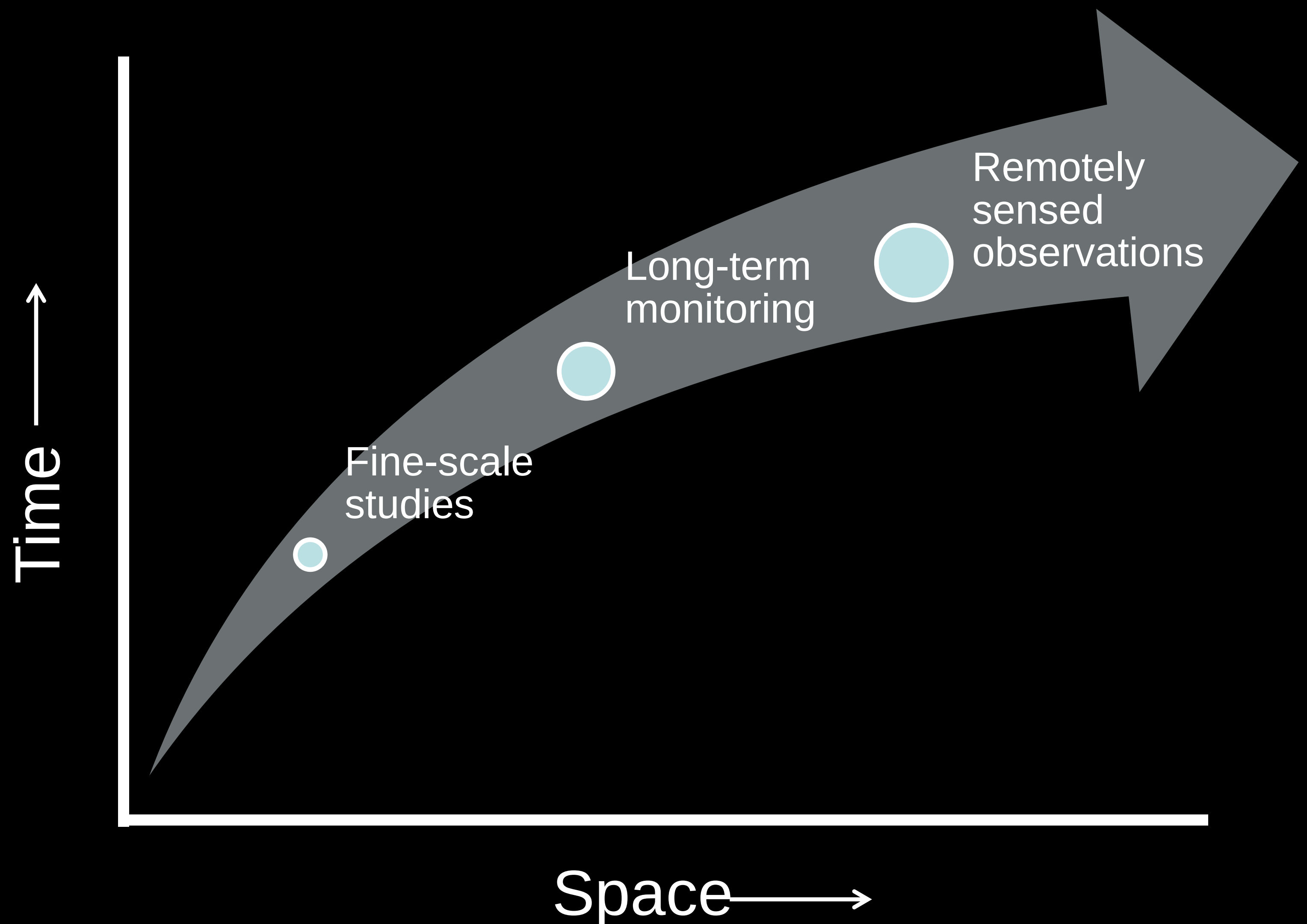
Challenges:
real time 4D animal tracking & environmental sampling

Providing a mechanistic understanding of ocean processes driving animal behaviour

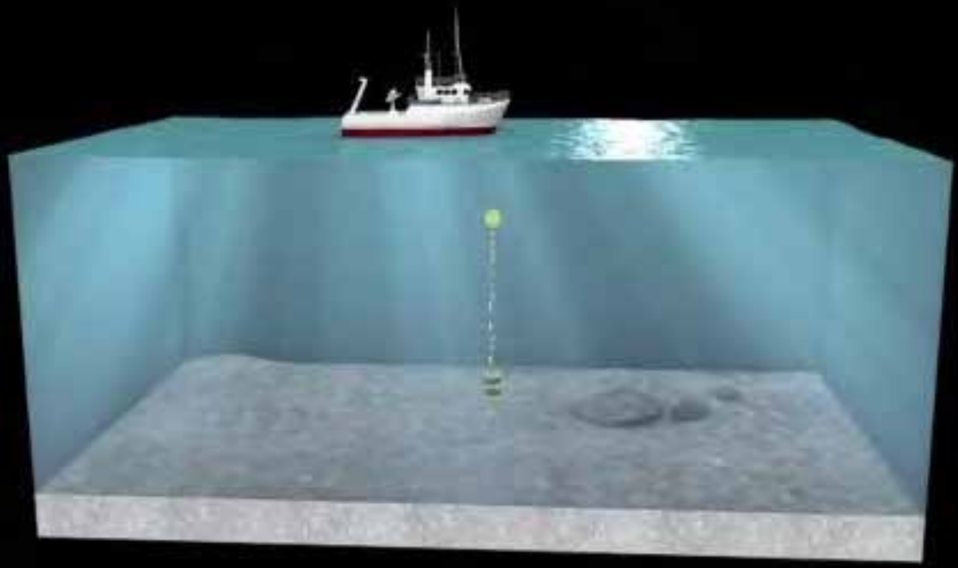




The Goal:
Understanding drivers of oceanic predator distribution & behaviour



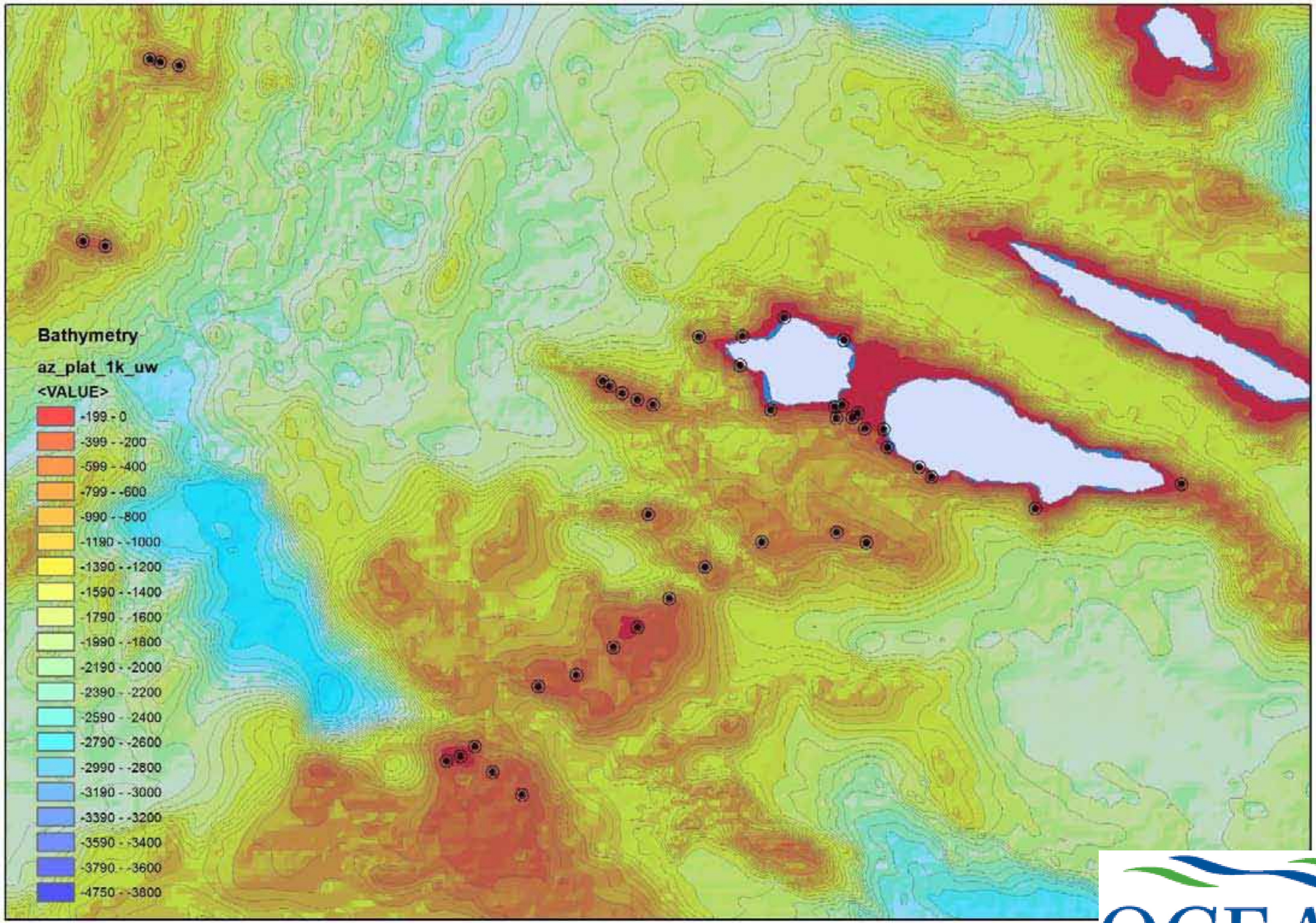
Migrações de grandes baleias e habitat oceânico



Problem:
Need for longer time series of data

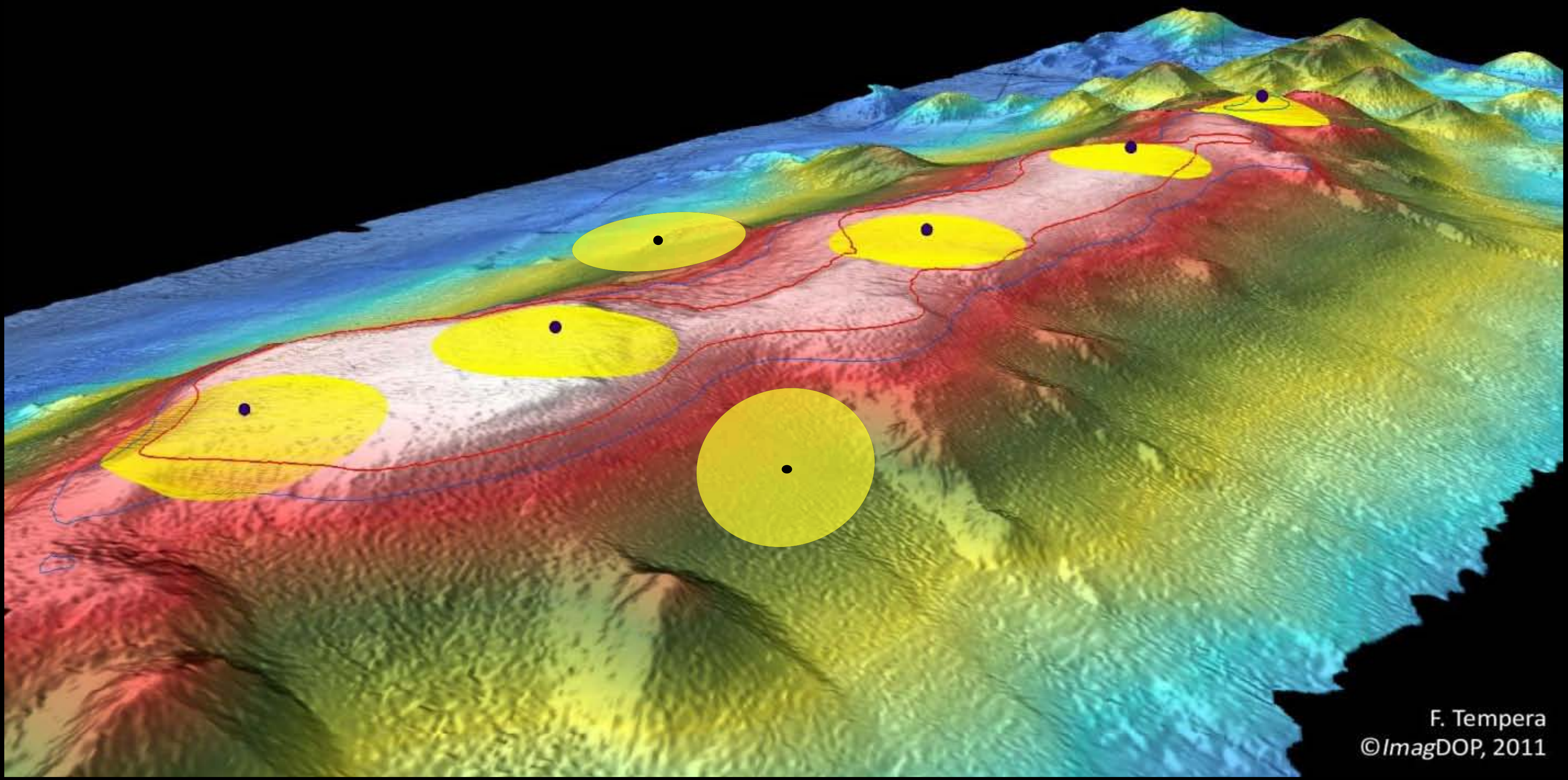
Moored oceanographic instruments / Ocean observatories

The Azores line: a network for passive acoustic telemetry

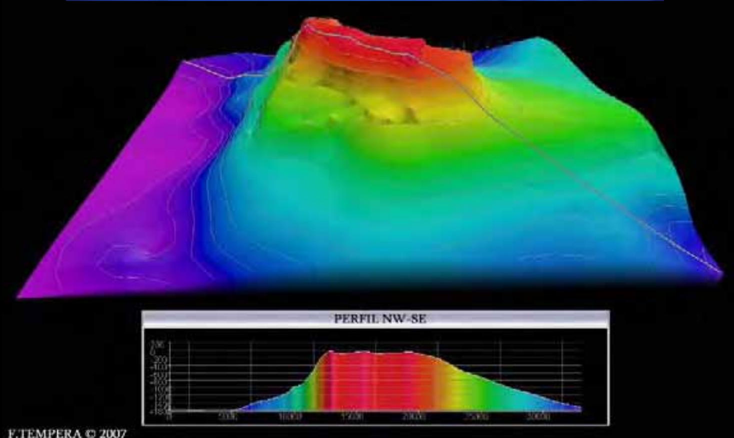


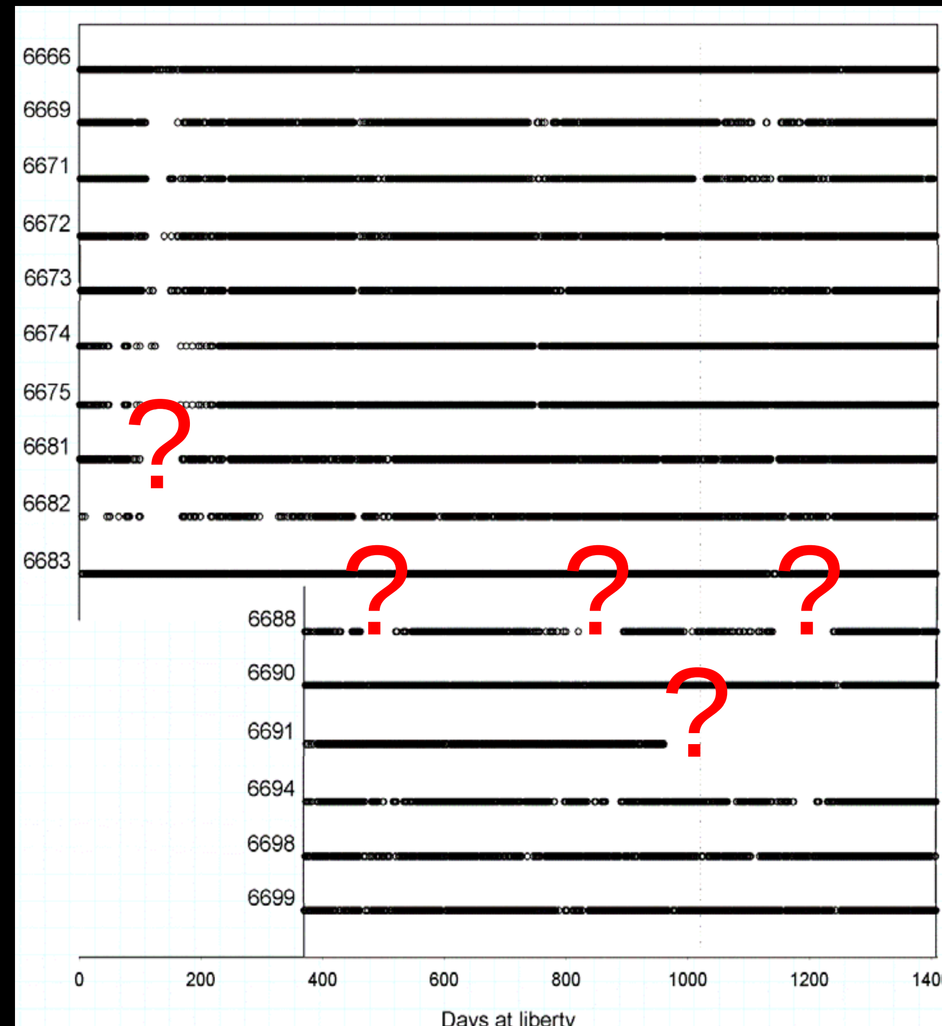
OCEAN TRACKING NETWORK

The Azores line: a network for passive acoustic telemetry



Acoustic telemetry at seamounts: long term residency of pelagic predators





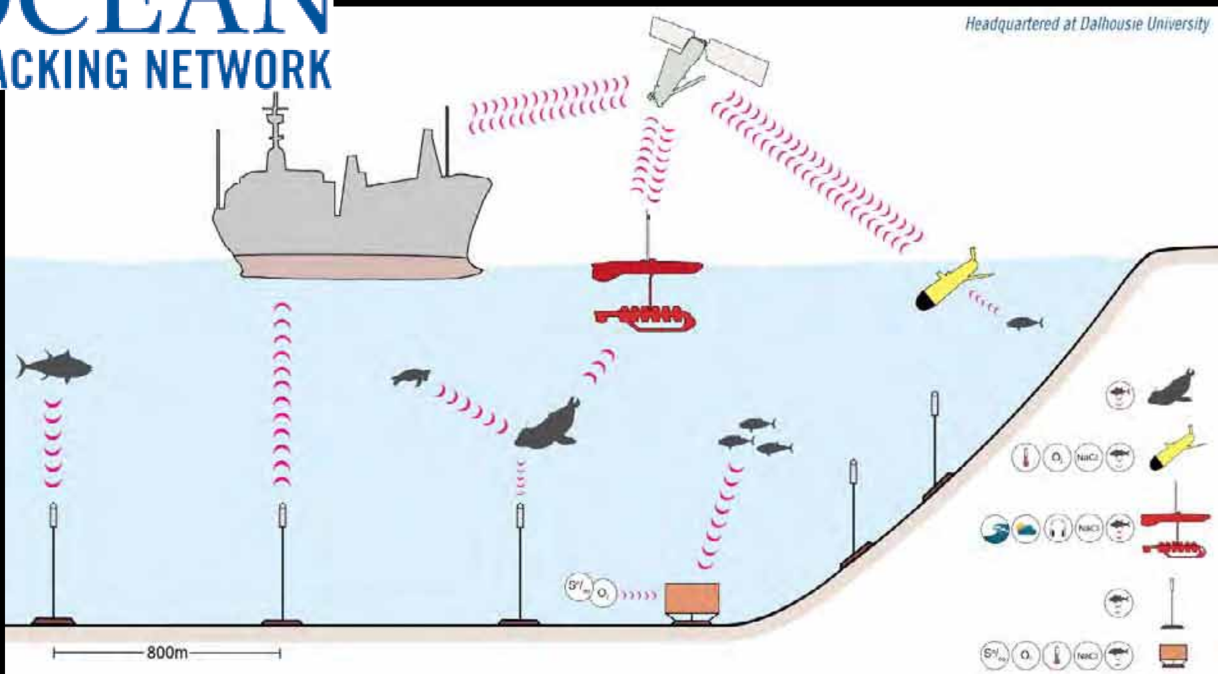
Fontes et al (2014) *Marine Biology*

Glider mounted receiver download

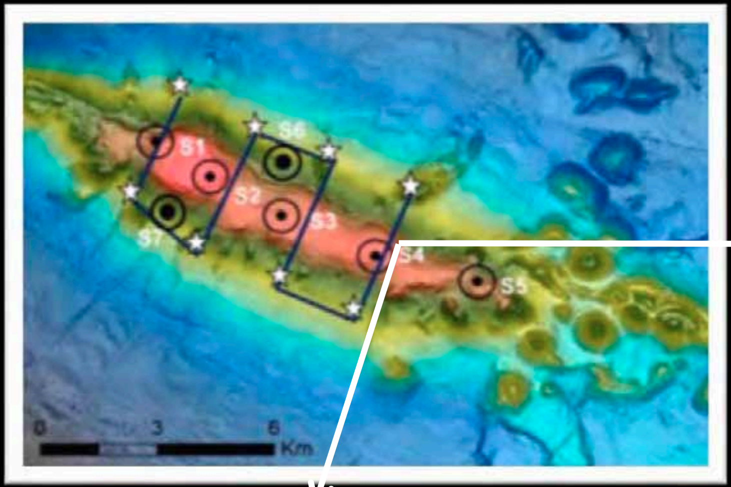
OCEAN TRACKING NETWORK

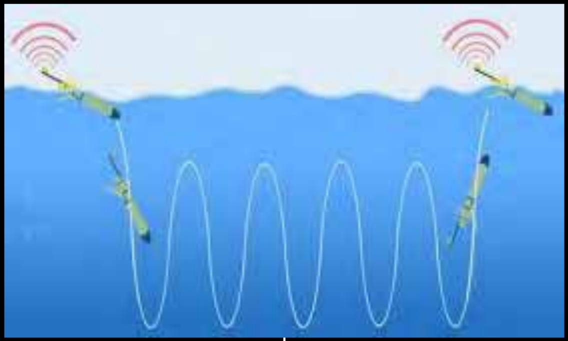
OTN- Electronic tags to track aquatic animals

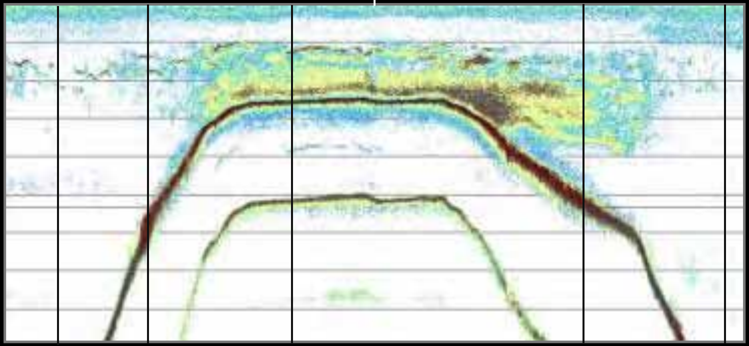
OCEAN
TRACKING NETWORK

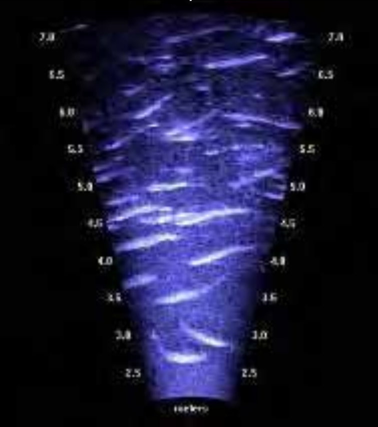


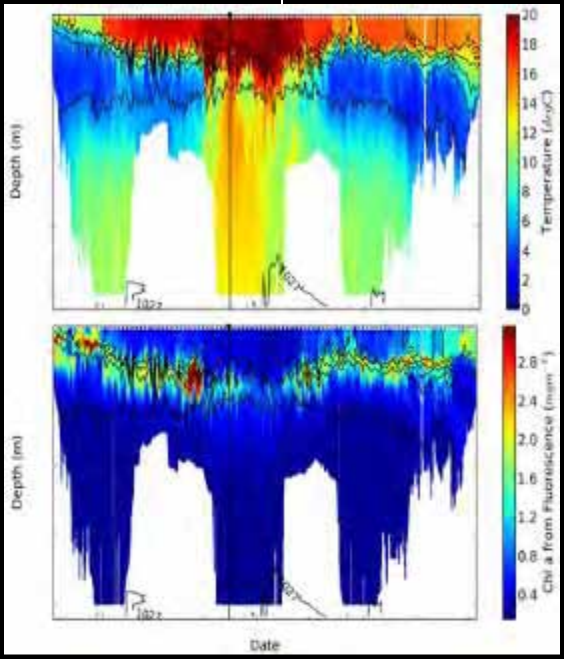
Challenges: coordination among vehicles and fixed sensors



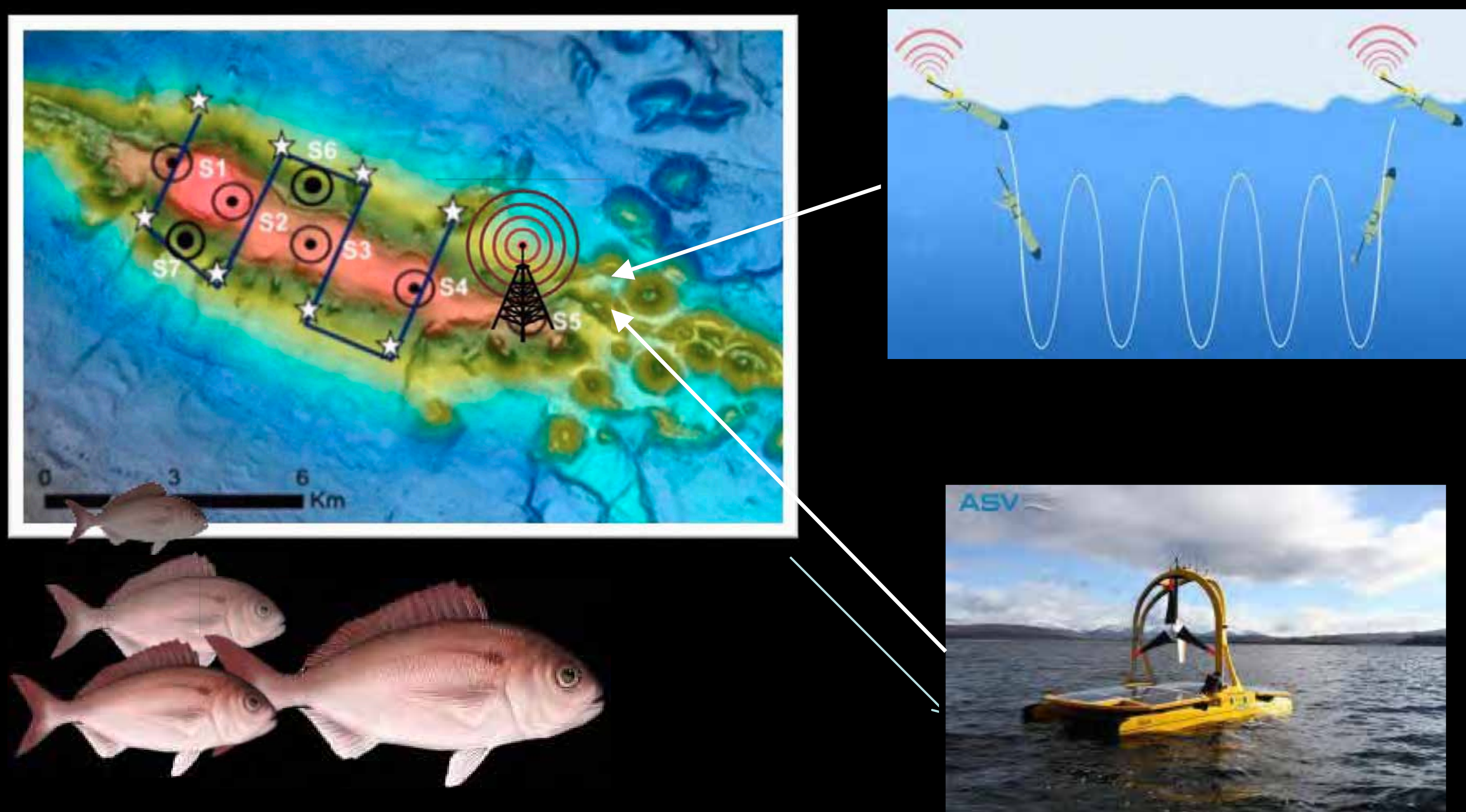






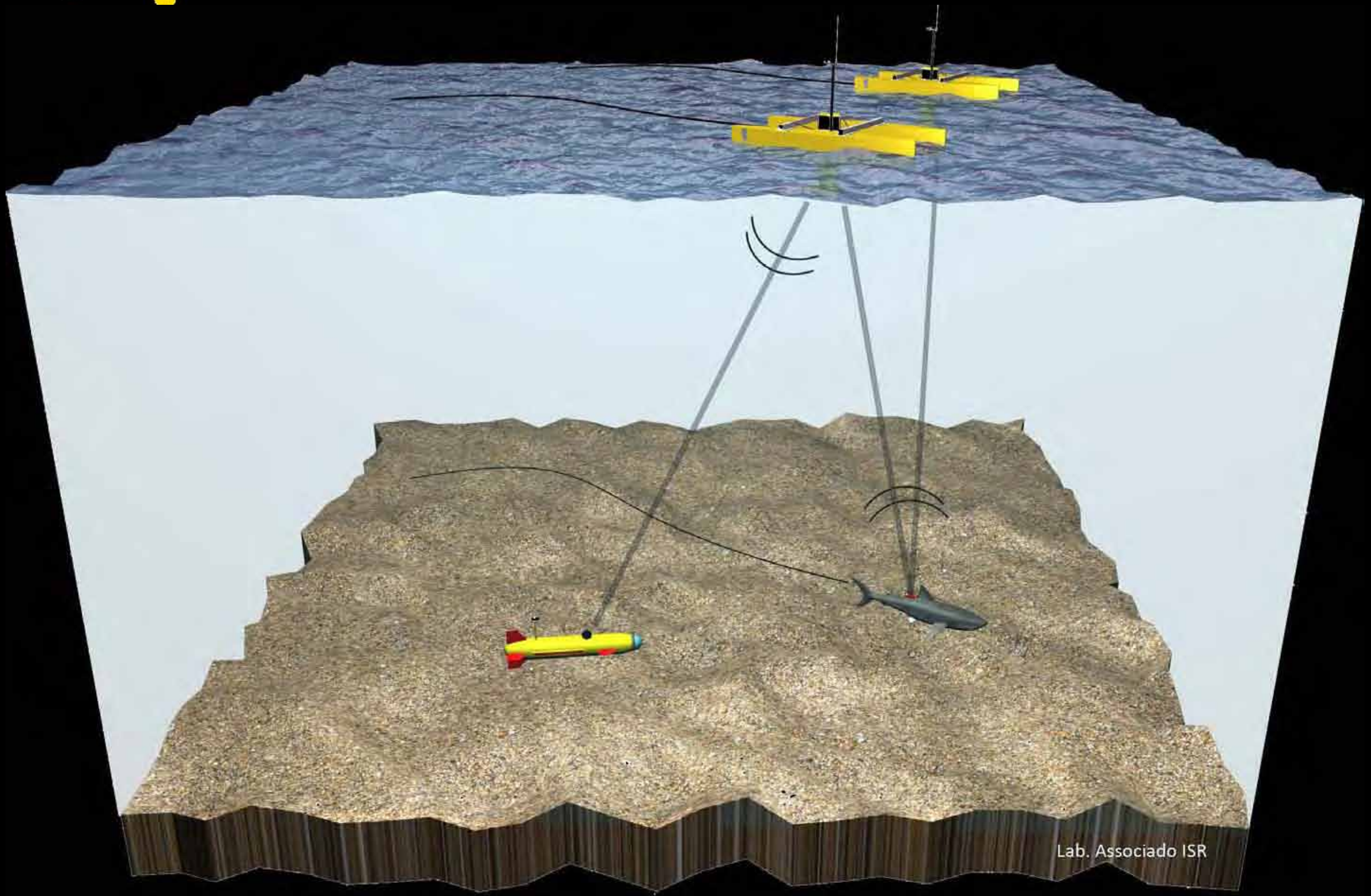


Challenges: event response triggered multi-sampling



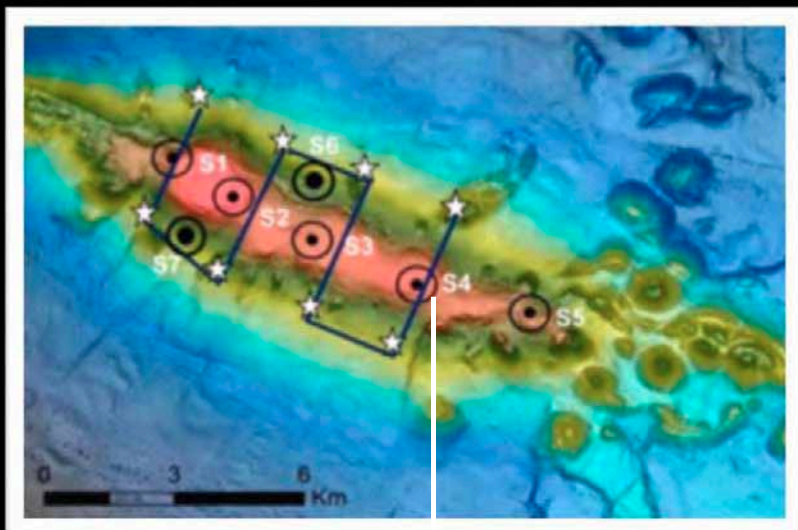
GREX

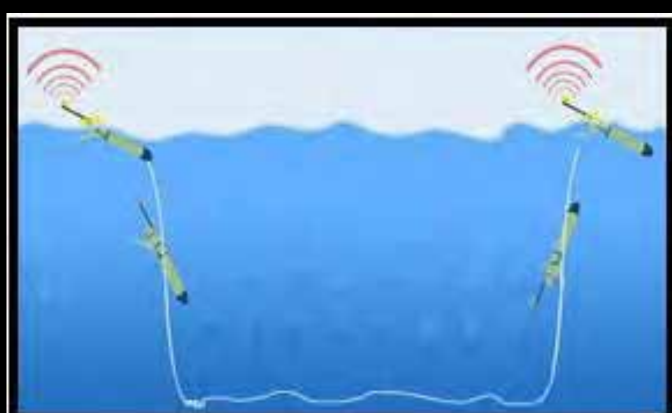
The fish tracking scenario



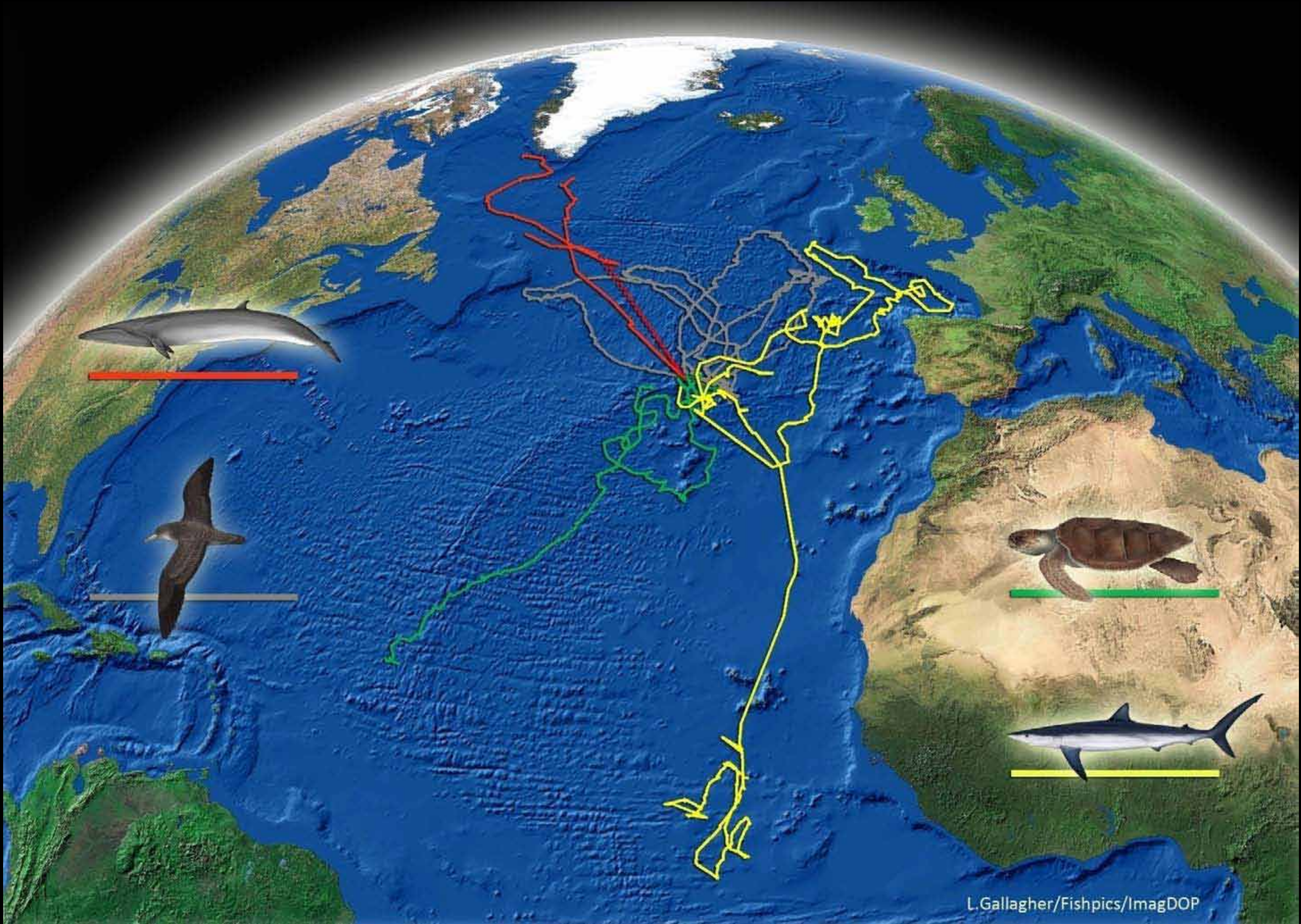
Challenges: multiple goal oriented sampling designs

(multiples resolutions are needed over space and time)



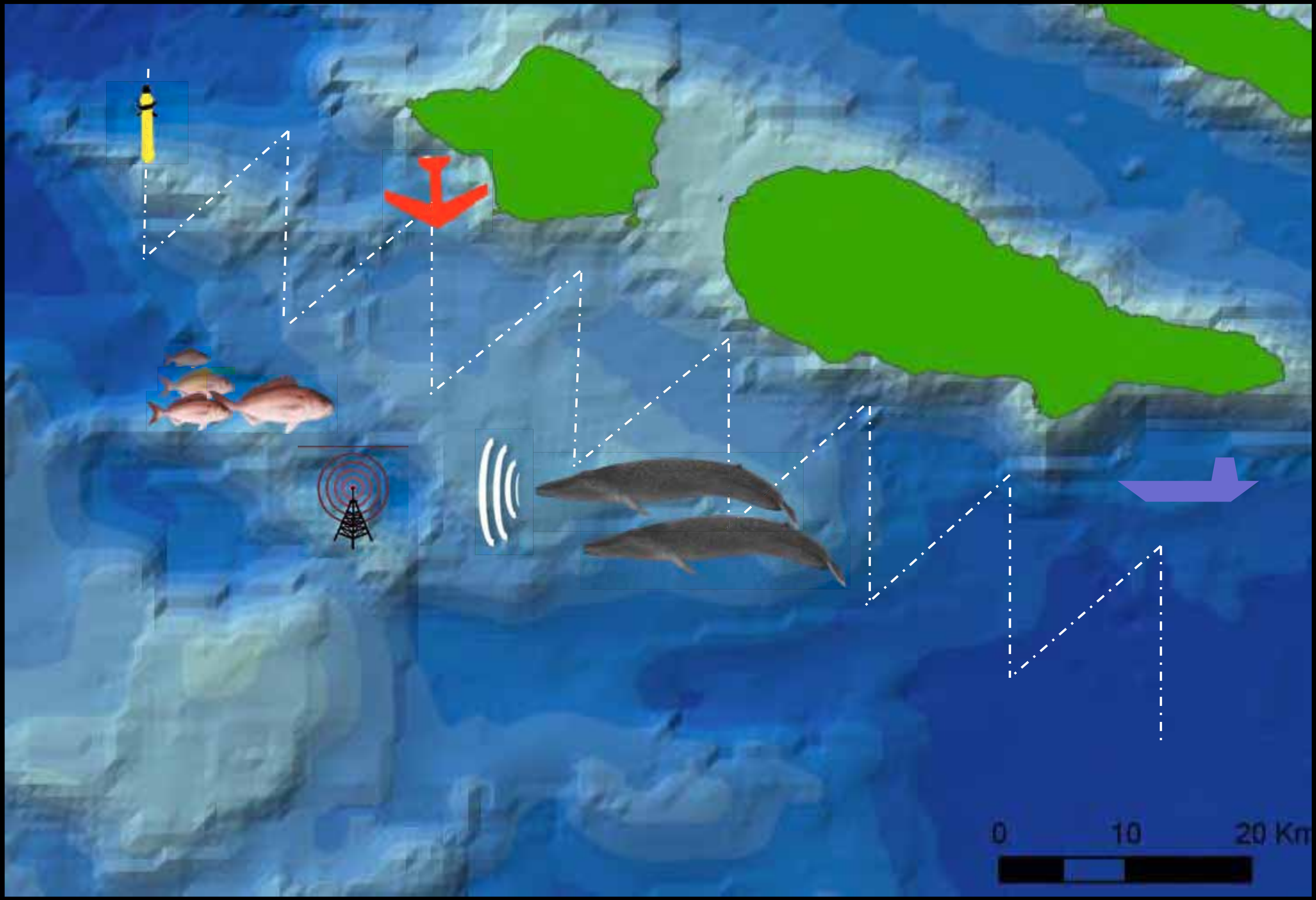


Multispecies Essential Habitat Hotspot?



Objective: monitoring animals & environment over time

Capturing ecossystem variability and human pressures across diel, monthly, annual and decadal cycles



Challenges to Marine Technology

- Intelligent vehicles for real-time interaction with environment:
  - Detection of animals using acoustic, optical, electromagnetic, DNA cues (eg. Mimic guided military torpedoes)
  - Detection of oceanographic structures using gradients in temperature, Chl a, pH, oxygen

Innovative sensors: acoustic, optical, chemical, molecular, particle imaging systems

Increased autonomy, speed, depth rating

Challenges to Marine Technology

- Interactive network of autonomous and fixed platforms:
  - Bi-directional, real time communication (acoustics, satellite, radio…)
  - Coordinated surveying
  - Dynamic configuration

Flexible, interactive comm network

Complex and adaptive mission control

- ‘Animal-borne’ vehicles:
  - “Pilot-fish/remora” robot (Similar to CADDY Prj.)
  - Parasite robots

The real challenge

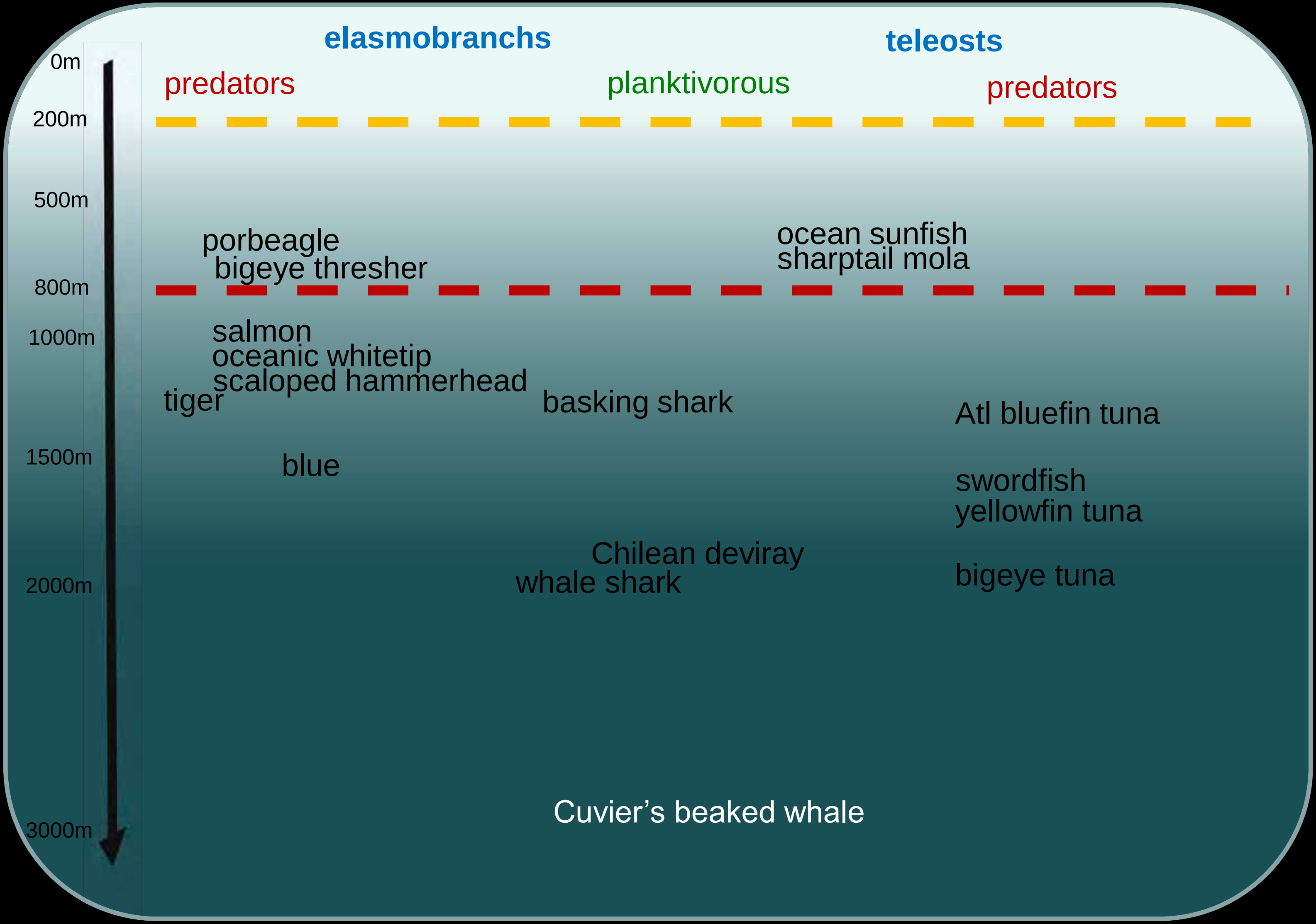
Most researchers deeply focused in their own fields of research

Merging science & technology: cross-disciplinarity

OBRIGADO

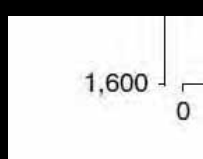

POPH
POTENCIAL HUMANO
QREN
QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
FCT
Fundação para a Ciência e a Tecnologia
SEVENTH FRAMEWORK PROGRAMME
eea grants
OCEAN
TRACKING NETWORK

Who deep (?) dives(?)

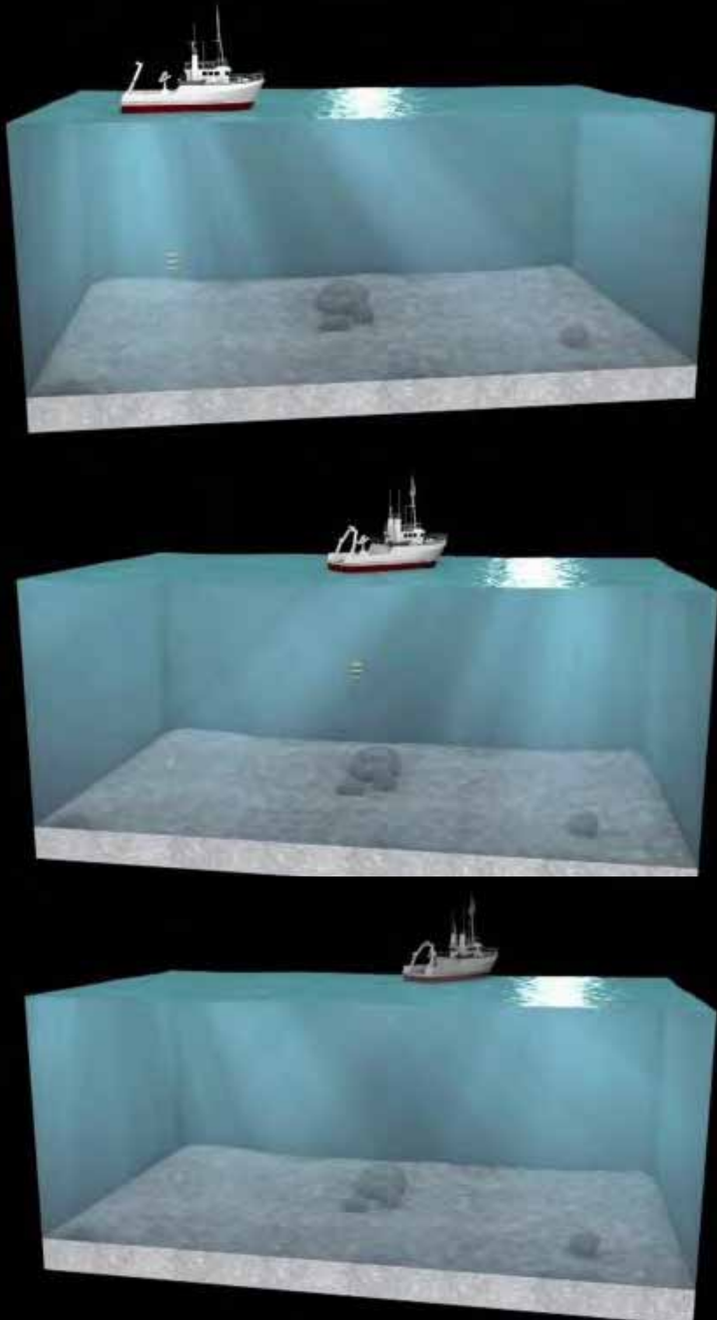


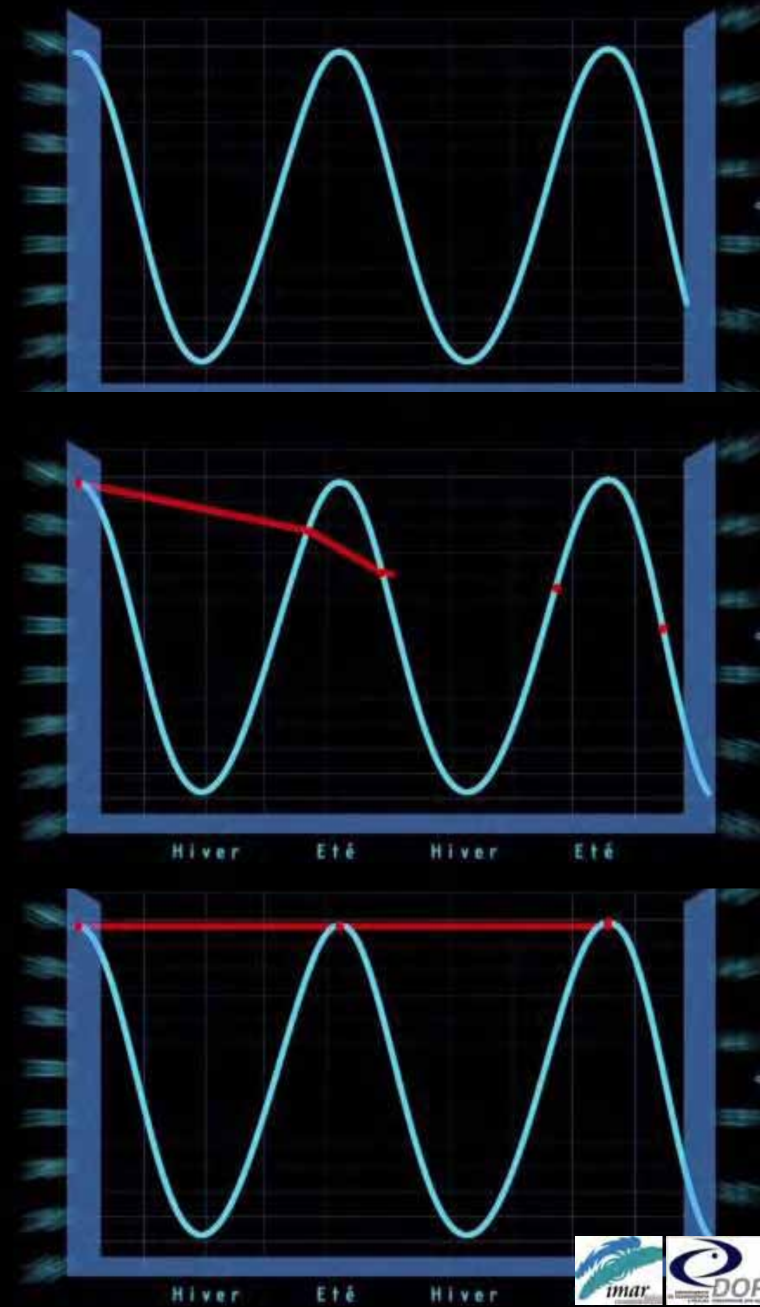
- 30 (+ 5) studies post 2002; 8 elasmobranchs, 4 teleosts

Devilray vertical behavior



Thorrold et al (2014) *Nature communications*





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EMRA'15 workshop

Strategic Research Agenda For Robotics in Europe 2014-2020

SPARC The Partnership for Robotics in Europe

SPARC: Report from the EURobotics Board, Future Possibilities in H2020 PPP

David Lane
Heriot-Watt Univ. , Edinburgh, Scotland, UK

EDINBURGH CENTRE FOR ROBOTICS

-

David Lane

Professor of Autonomous Systems Engineering
Heriot-Watt University, Edinburgh, Scotland, UK

EURobotics Board Member 2013-2015

EDINBURGH CENTRE FOR ROBOTICS

THE UNIVERSITY of EDINBURGH

HERIOT WATT UNIVERSITY

edinburgh-robotics.org   d.m.lane@hw.ac.uk

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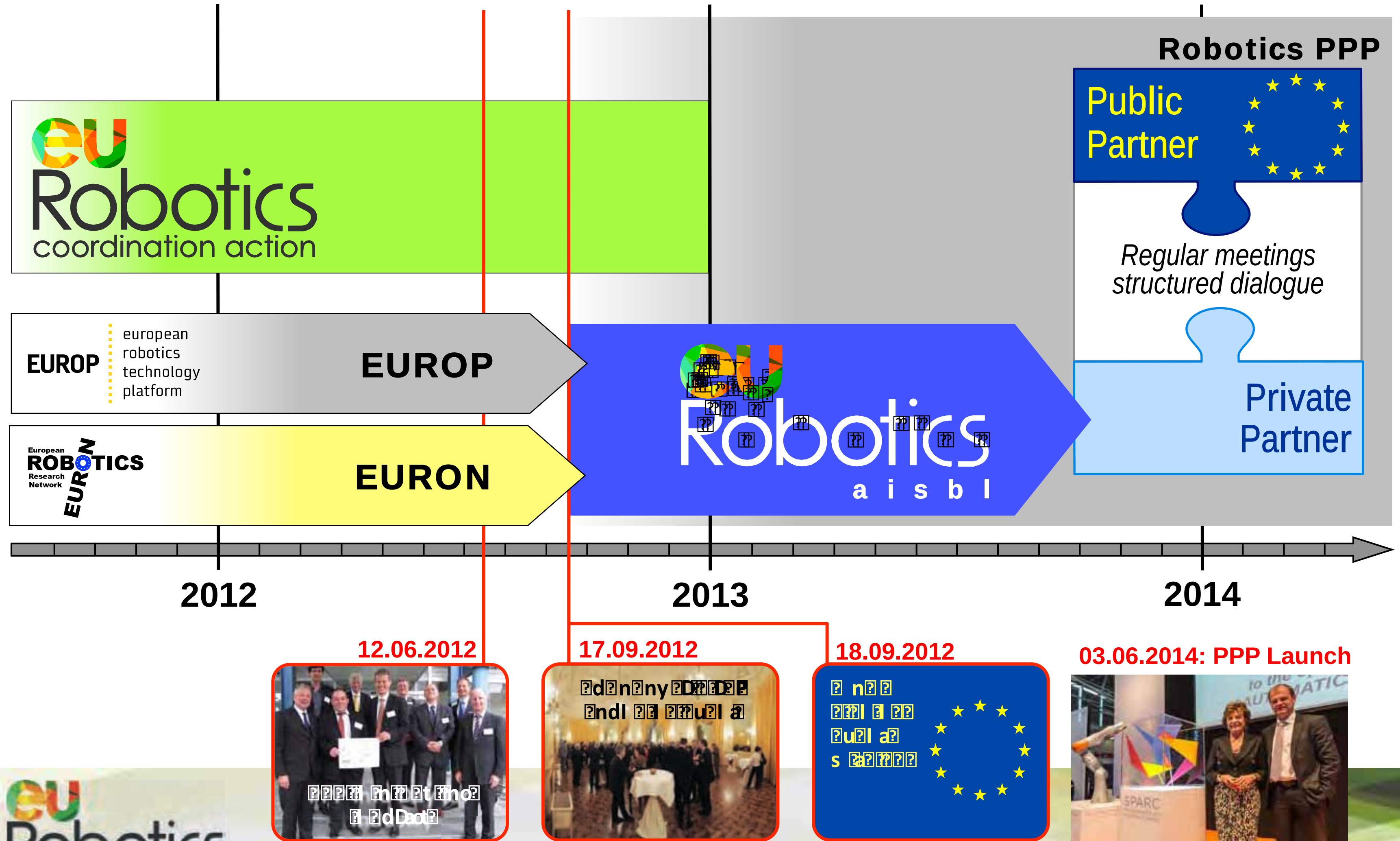
The way towards the Robotics PPP



euRobotics aisbl

1.develop **strategic goals** of European robotics and foster their implementation

2.improve **industrial competitiveness** of Europe through innovative robotic technologies

3.position robotic products and services as key enablers for **solving Europe‘s societal challenges**

4.strengthen **networking activities** of the European robotics community

5.promote European robotics

6.reach out to existing and new **users** and markets

7.contribute to **policy development** and addressing ELS issues

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SRA = High level document

- wide readership
- overview of status
- sets terminology

MAR = Technical detail

- updated each year
- tracks trends
- please contribute!

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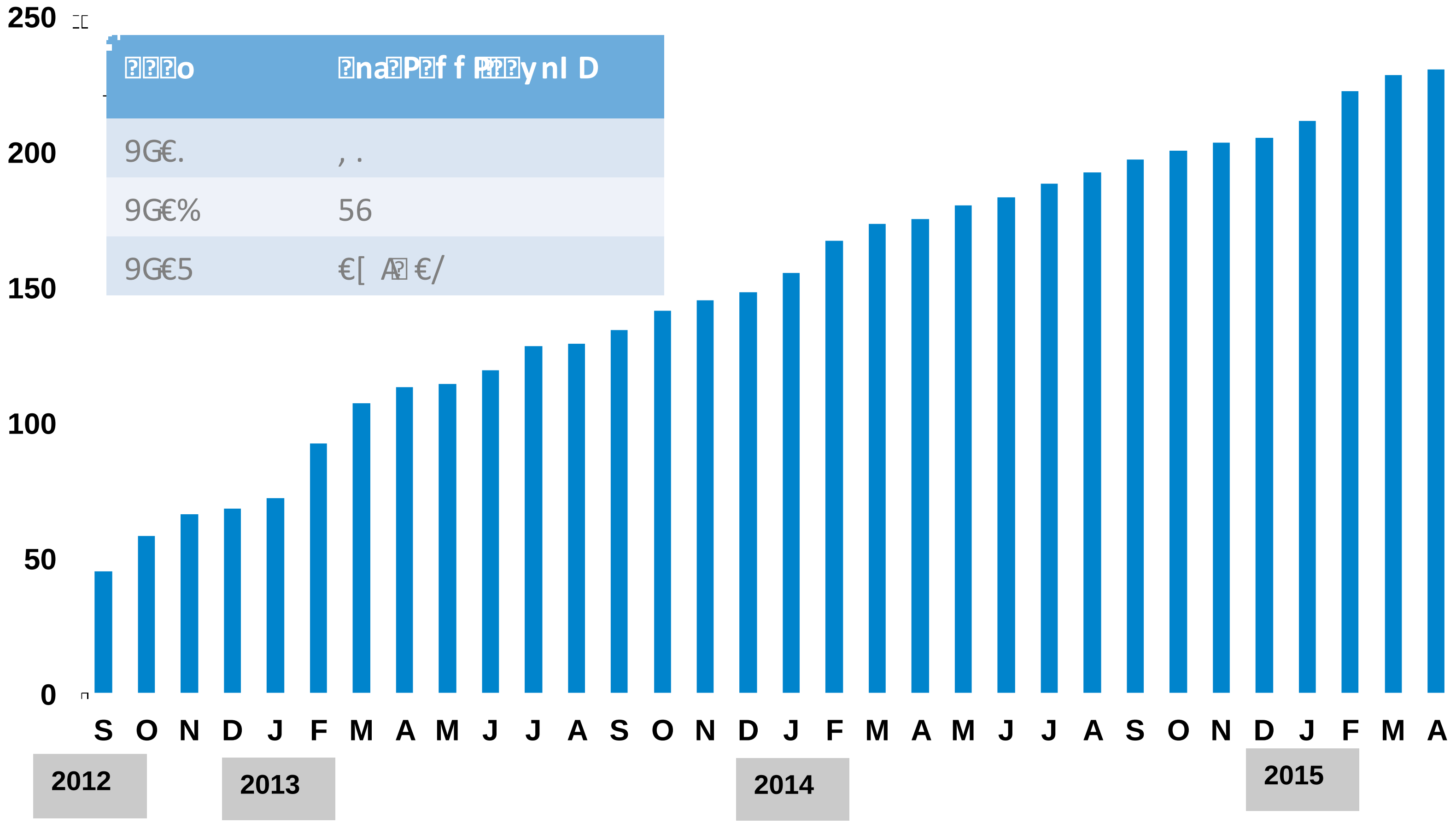

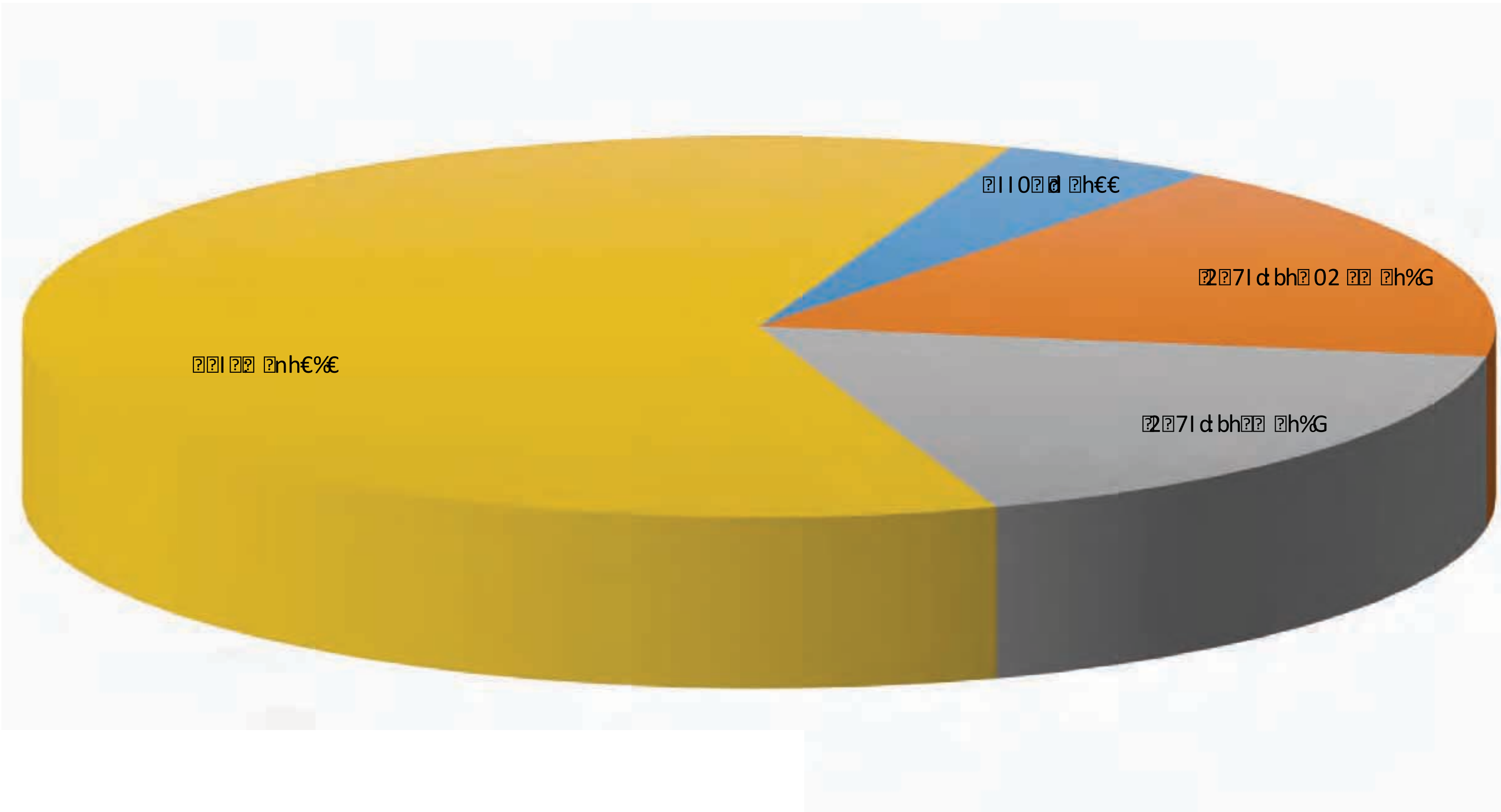

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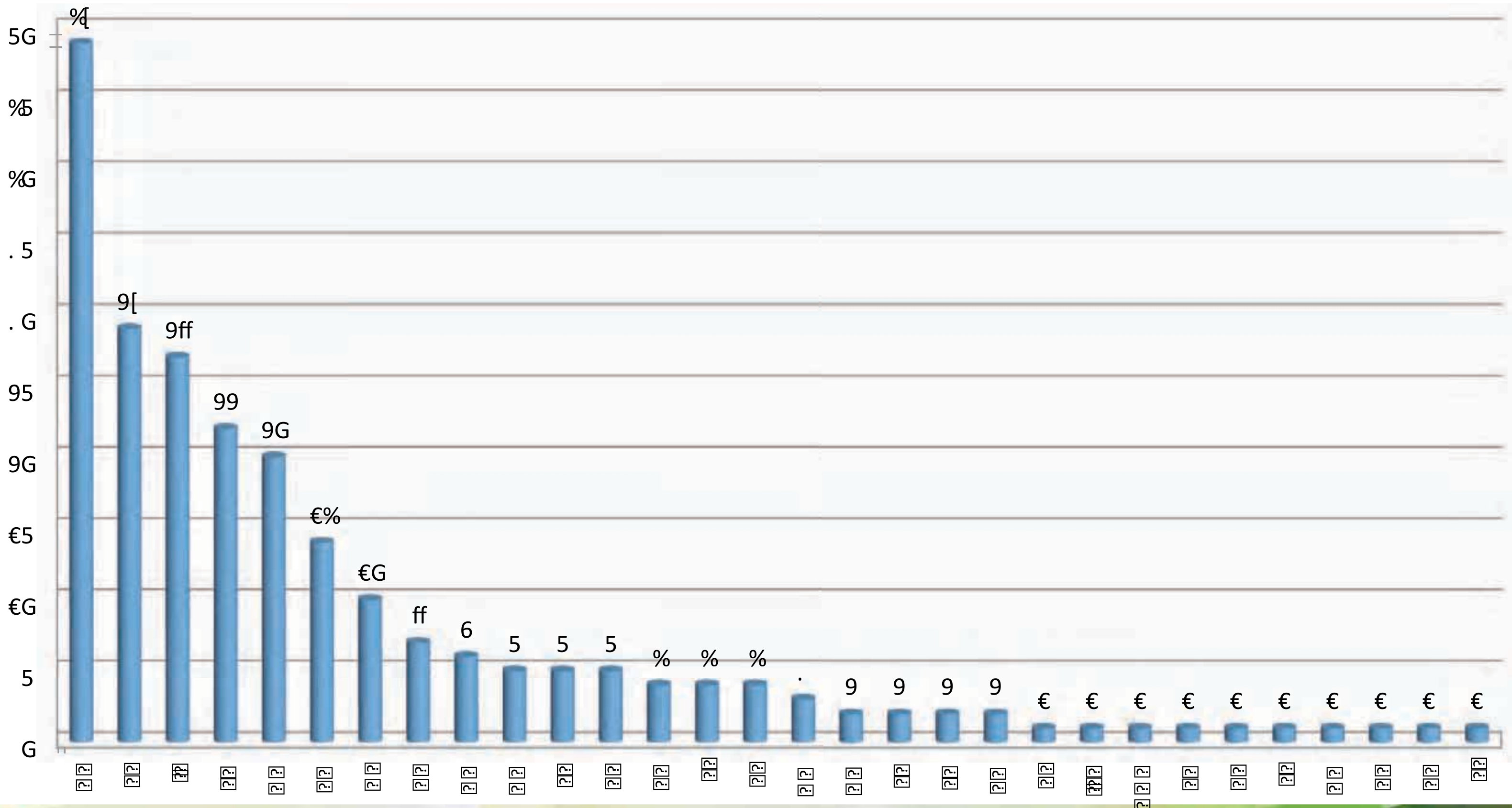

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	euRobotics	RockEU	TOTAL
INCOME	**365000**	563000	928000
PERSONNEL EXPENSES	153000	181000	**335000**
TOTAL EXPENSES	305000	563000	868000

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Session 4. Chair – Benedetto Allotta

09:00 **MORPH (EU project)**

09:30 **T3.1 - *Marine Technology: Challenges and Opportunities in relation to Marine Renewable Energy***
António Sarmento, WavEC, Lisbon, Portugal

10:00 **CADDY (EU project)**

MORPH

EU PROJECT

Joerg Kalwa, ATLAS Elektronik,
Bremen, DE

The Project MORPH in context of a business perspective

Joerg Kalwa
Coordinator

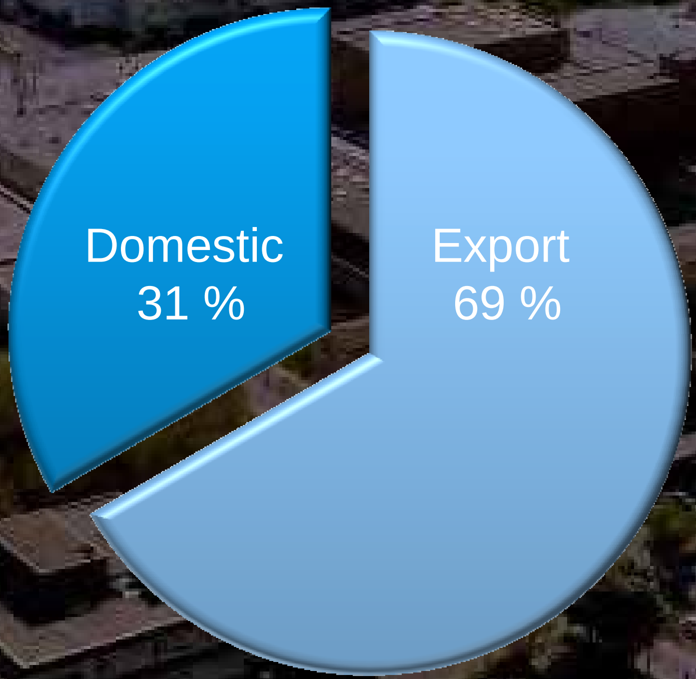
based on contribution of all partners

… a sound decision

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and Airbus DS

ATLAS ELEKTRONIK Group
Turnover and Employees

Annual Turnover: 440 Mio. €



1970 employees worldwide

approx. 1300 in Bremen (approx. 1600 in Germany)

Graduate Engineers	**49 %**
Commercial	**16 %**
Skilled Workers	**12 %**
Technicians	**23 %**

ATLAS ELEKTRONIK

Locations
World-wide

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and EADS
Bremen (Headquarter), Wedel, Wilhelmshaven

ATLAS ELEKTRONIK UK
A company of the ATLAS ELEKTRONIK Group
United Kingdom: Winfrith; Newport

ATLAS ELEKTRONIK CANADA
Canada: Victoria BC

ATLAS NORTH AMERICA
USA: Norfolk, Virginia

ATLAS MARIDAN
Denmark: Hørsholm

ATLAS ELEKTRONIK FINLAND
A company of the ATLAS ELEKTRONIK Group
Finland: Helsinki

SONARTECH ATLAS
Australia: Macquarie Park

ATLAS ELEKTRONIK UAE
UAE: Abu Dhabi

ANEC KOREA
Korea: Chungbu-Dong

ATLAS ELEKTRONIK INDIA
A company of the ATLAS ELEKTRONIK Group
India: New Delhi

CybiCOM ATLAS Defence (Pty) Ltd
South Africa: Simon's Town

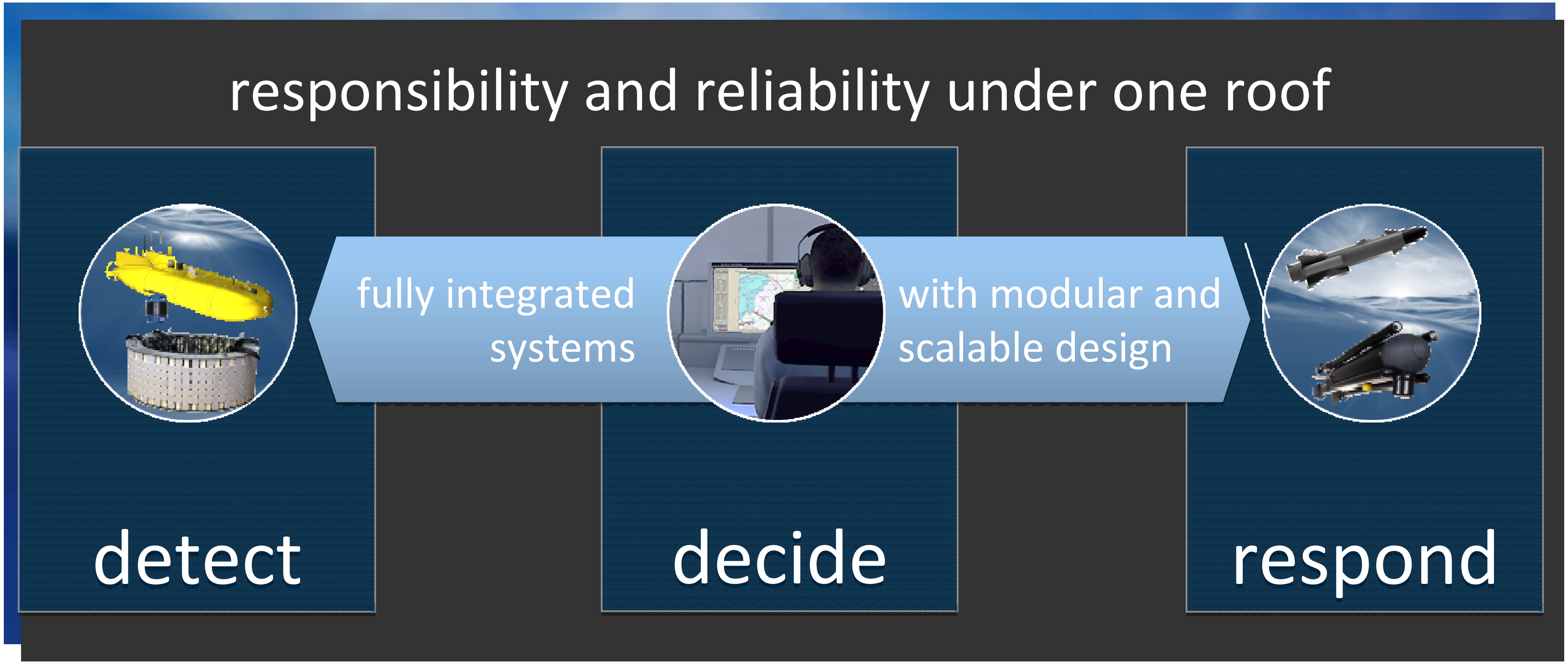
ATLAS Naval Support Centre Ltd
Thailand: Bangkok

Advanced Lithium Systems Europe
Defence Applications S.A.
Greece: Athen

ATLAS ELEKTRONIK Group
at a glance

ATLAS Systems and Products

… a sound decision



ATLAS ELEKTRONIK

History of the ATLAS ELEKTRONIK
Experience makes the difference

ATLAS WERKE

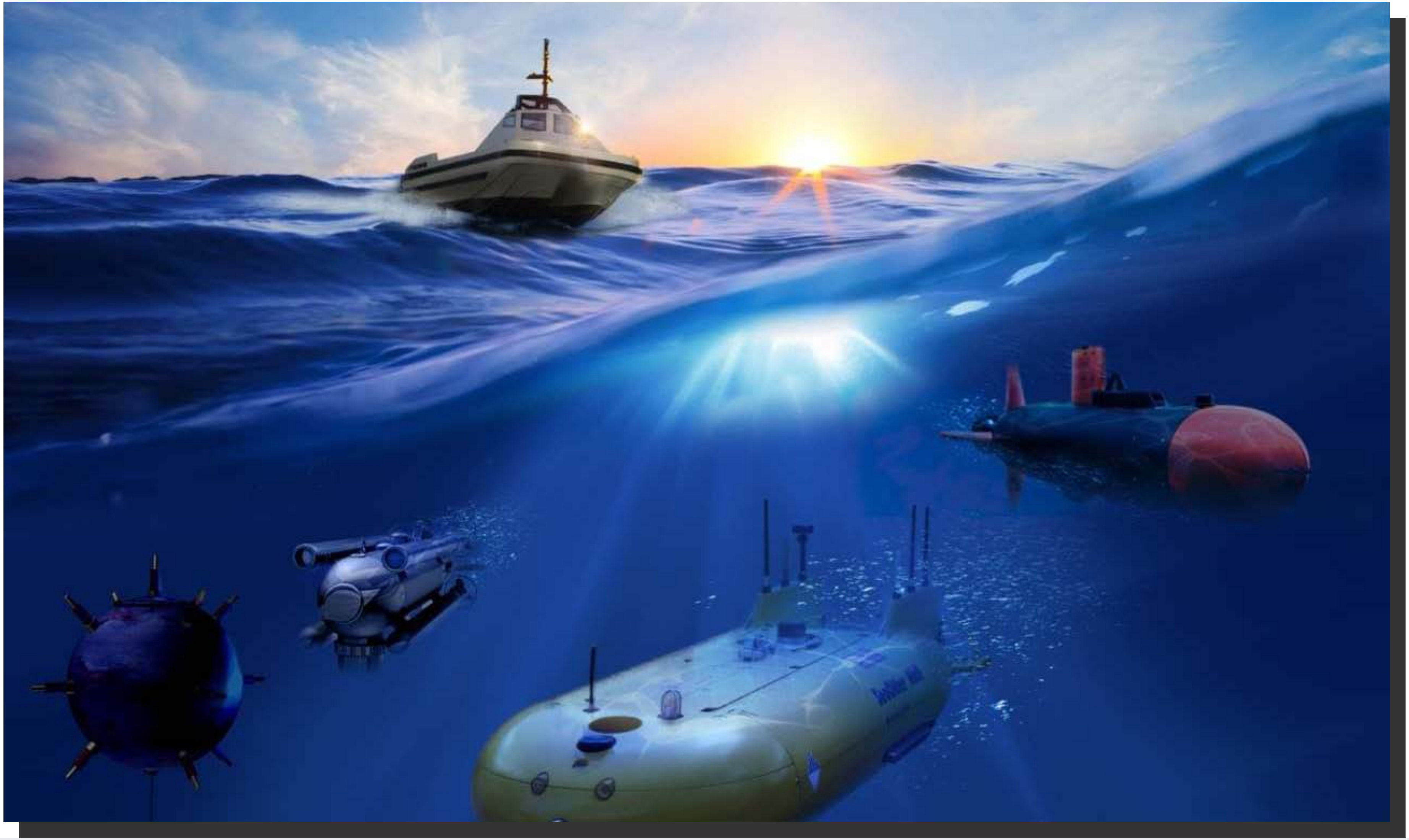
Developing the Future

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and Airbus DS

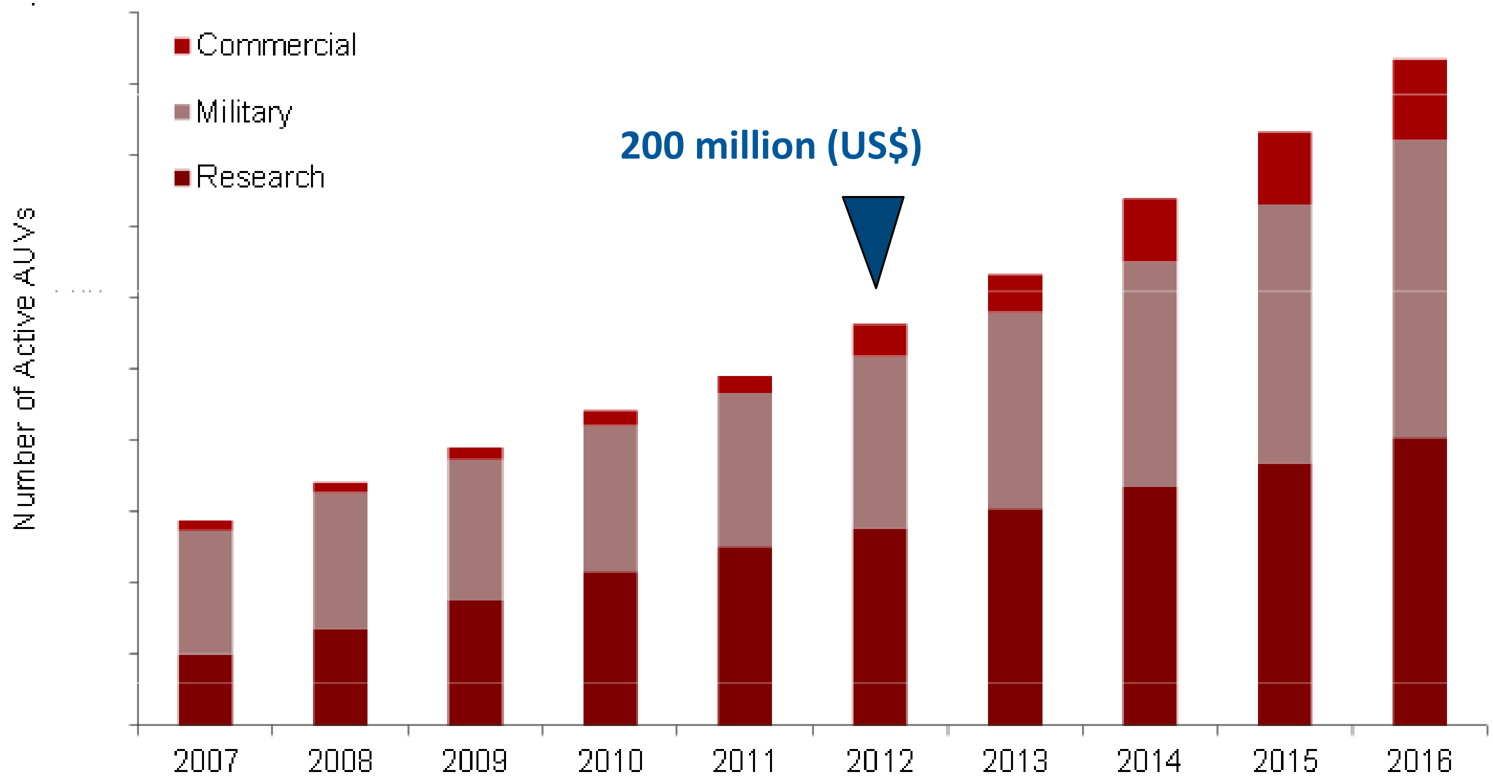
- 1902 – Norddeutsche Maschinen- und Armaturfabrik GmbH
- 1911 – Atlas Werke
- 1966 – Fried. Krupp GmbH
- 1983 – Krupp Atlas Elektronik GmbH
- 1991 – Atlas Elektronik GmbH
- 1994 – STN ATLAS Elektronik GmbH
- 1997 – STN ATLAS Elektronik GmbH
- 2003 – ATLAS ELEKTRONIK GmbH
- since 2006

ATLAS ELEKTRONIK

ATLAS ELEKTRONIK
Unmanned systems will play a key role



Autonomous Underwater Vehicles
A market prospect



UUV OI, London. 13 Mar 2012, John Westwood: Military & research AUVs to total 89%

Autonomous Underwater Vehicles
A market prospect

Small, man portable AUVs (< 50 kg)

Midsize, coasta water AUVs (< 600 kg)

Ocean size AUVs (> 600 kg)

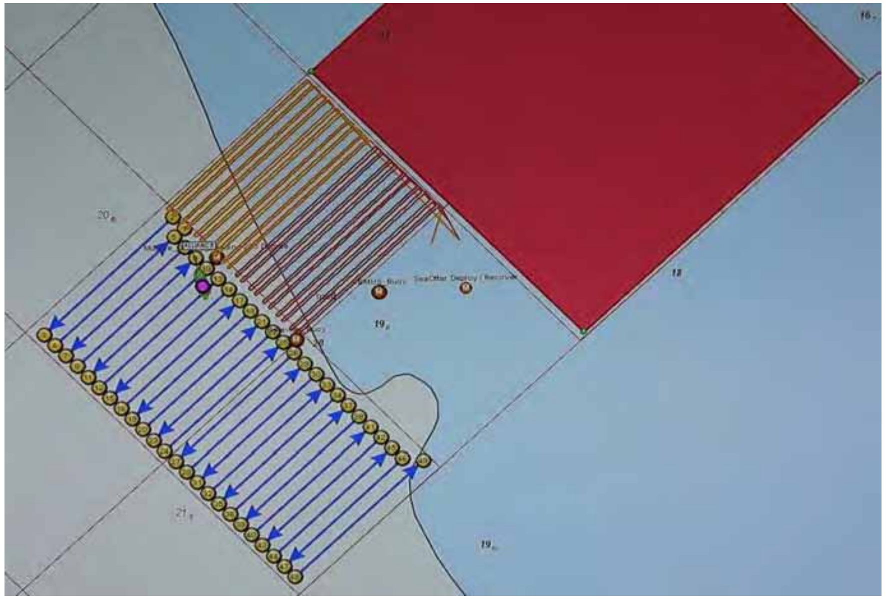
Where are multiple AUVs?

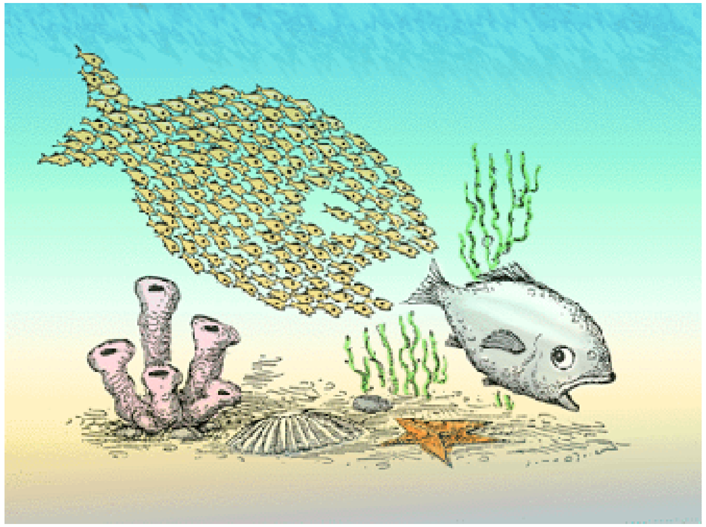
ATLAS ELEKTRONIK

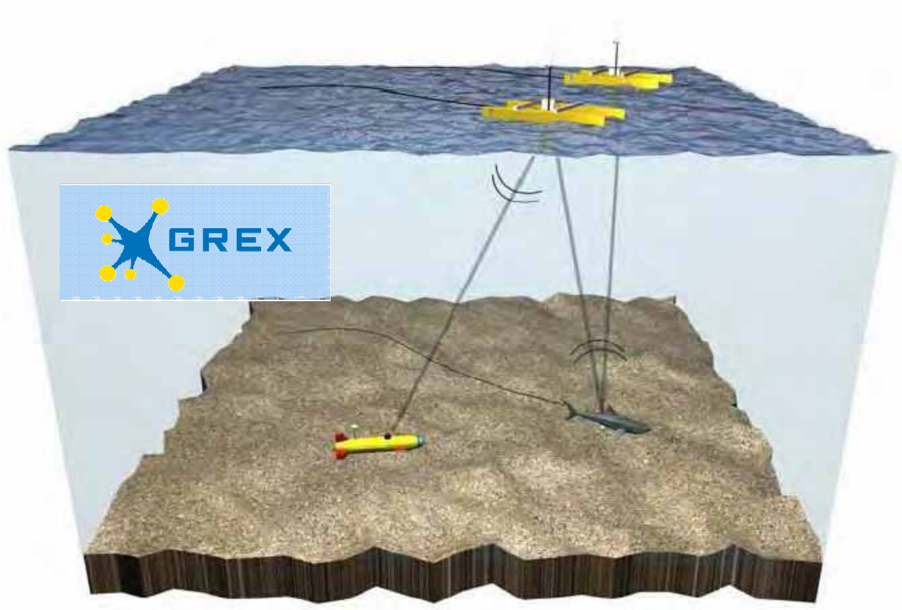
Why multiple vehicles?

Boost Efficiency by…

- Parallelisation
- Cooperation
- Optimisation of sensor placement
- Redundancy
- Emergence

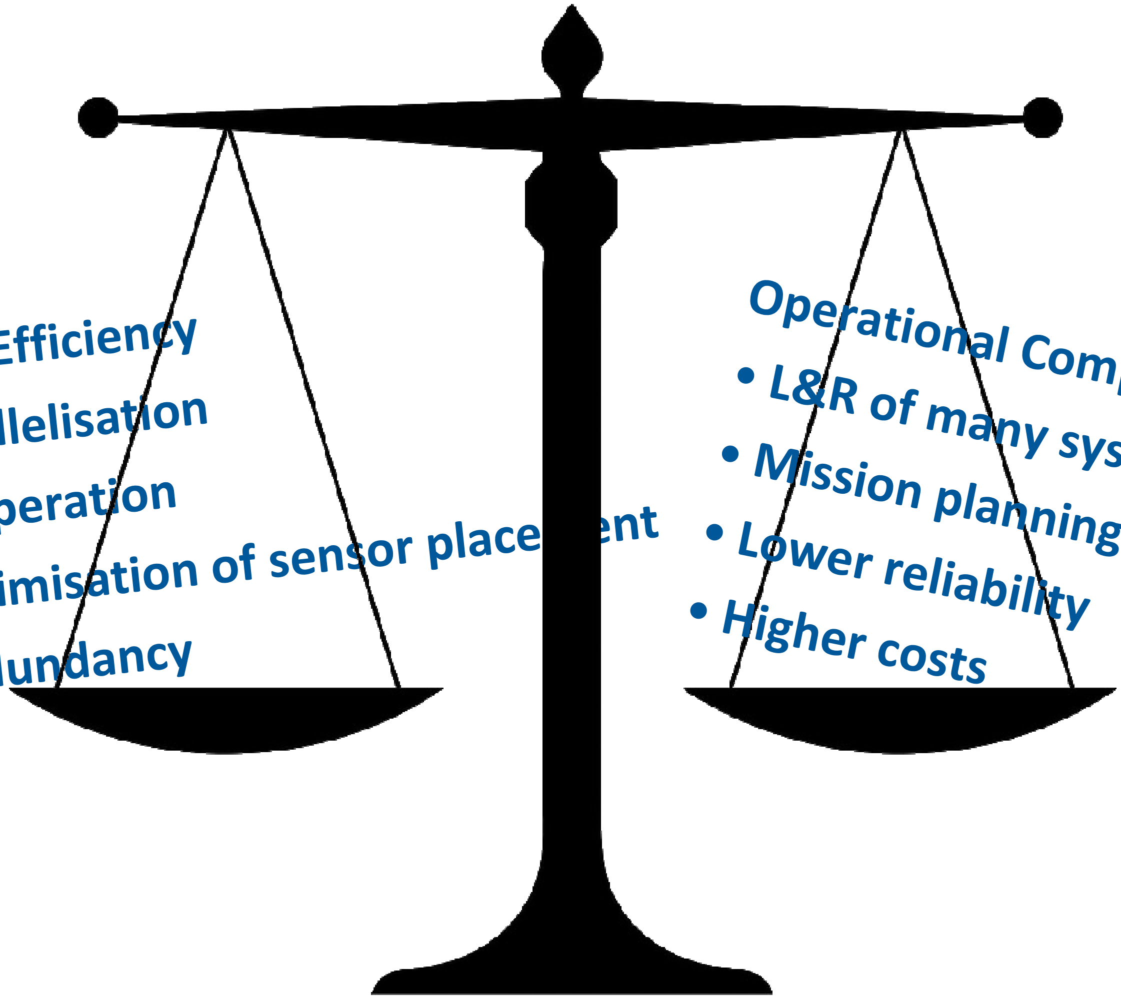






ATLAS ELEKTRONIK

Multiple Unmanned Vehicles
efficiency vs complexity



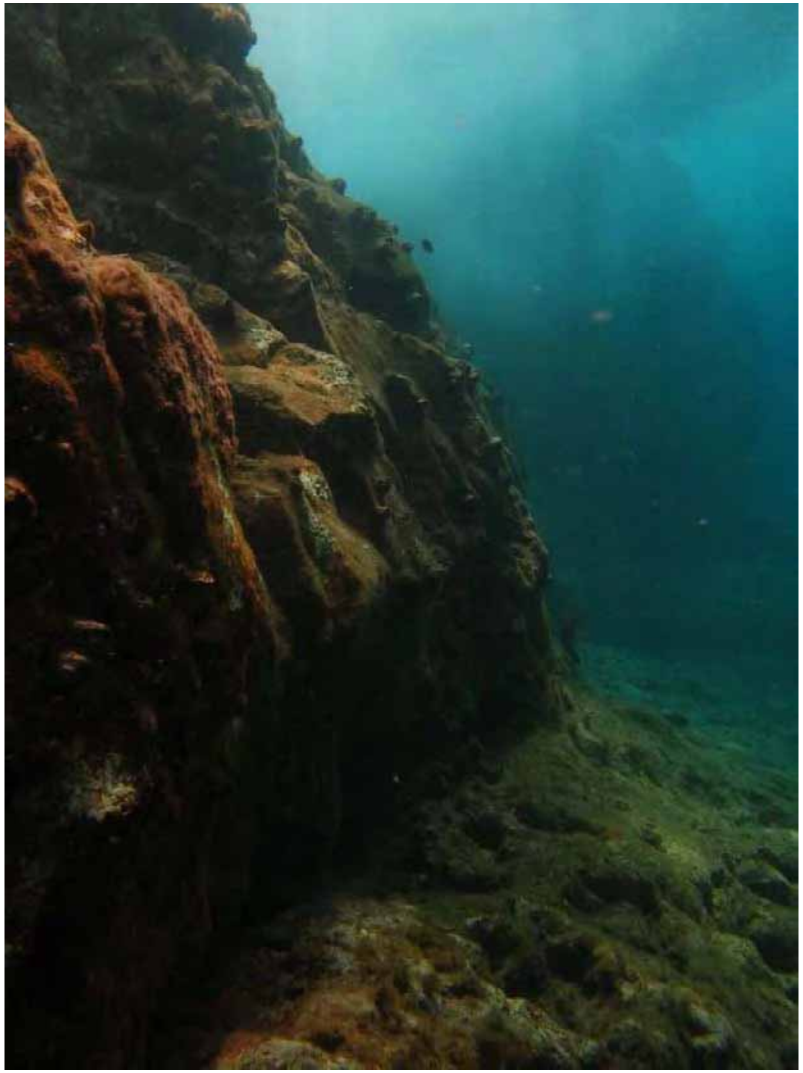
Boost Efficiency
- Parallelisation
- Cooperation
- Optimisation of sensor placement
- Redundancy

Operational Complexity
- L&R of many systems
- Mission planning and supervision
- Lower reliability
- Higher costs

Multiple Unmanned Vehicles
Research pushes technology

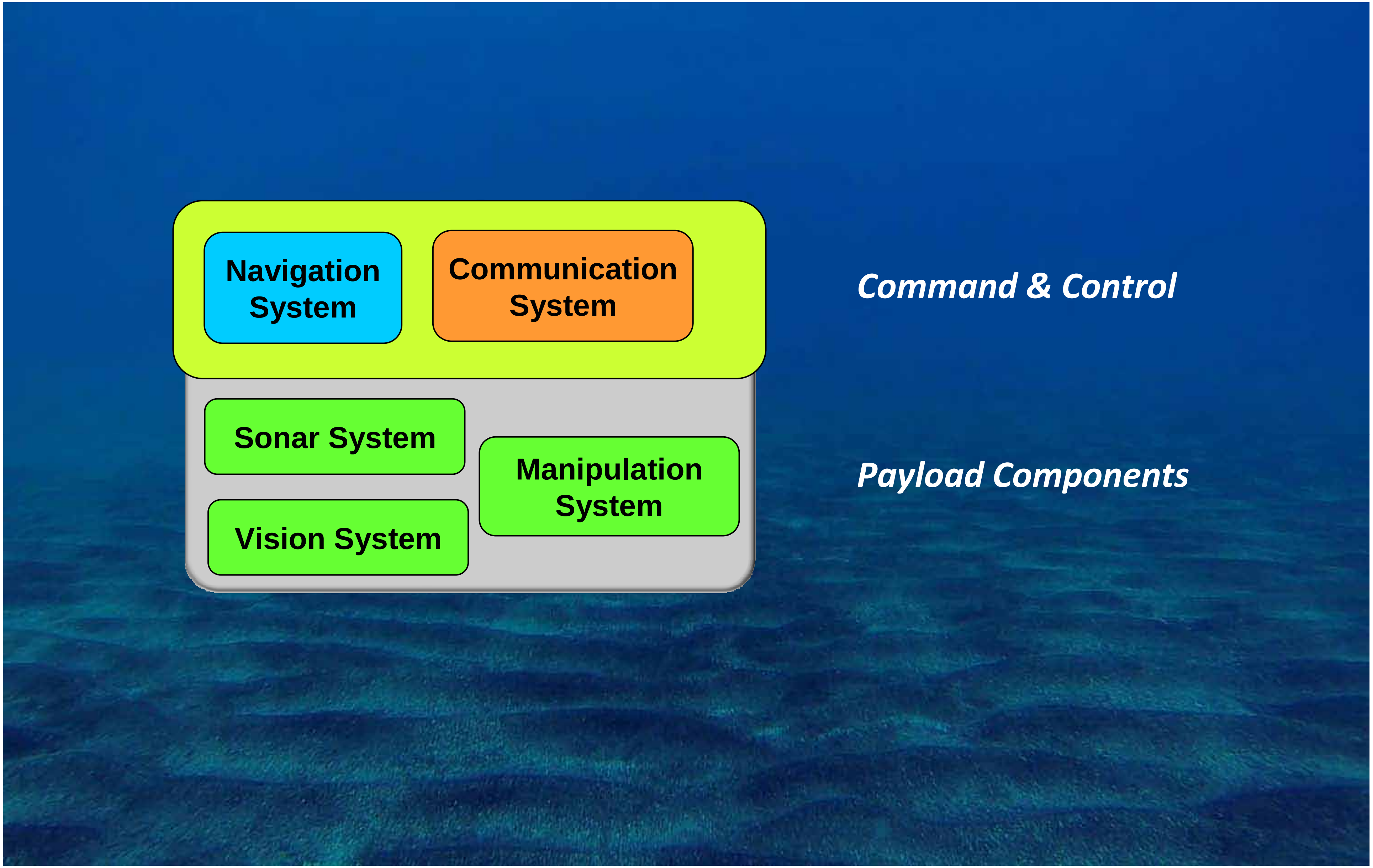
Multiple Unmanned Vehicles

Coorperative mapping of rugged terrain



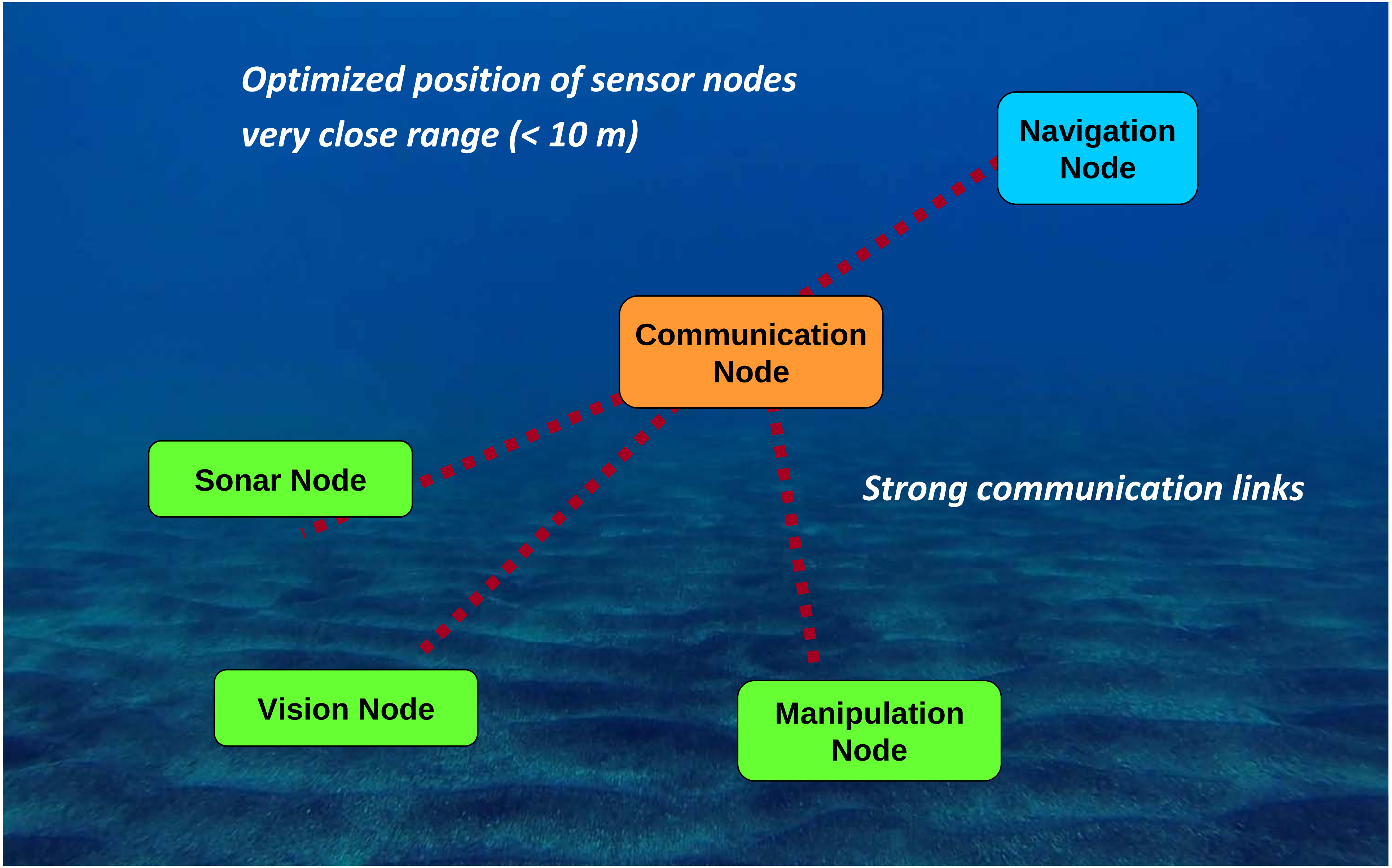
Multiple Unmanned Vehicles

A possible approach: a virtual supra vehicle made of self driven components

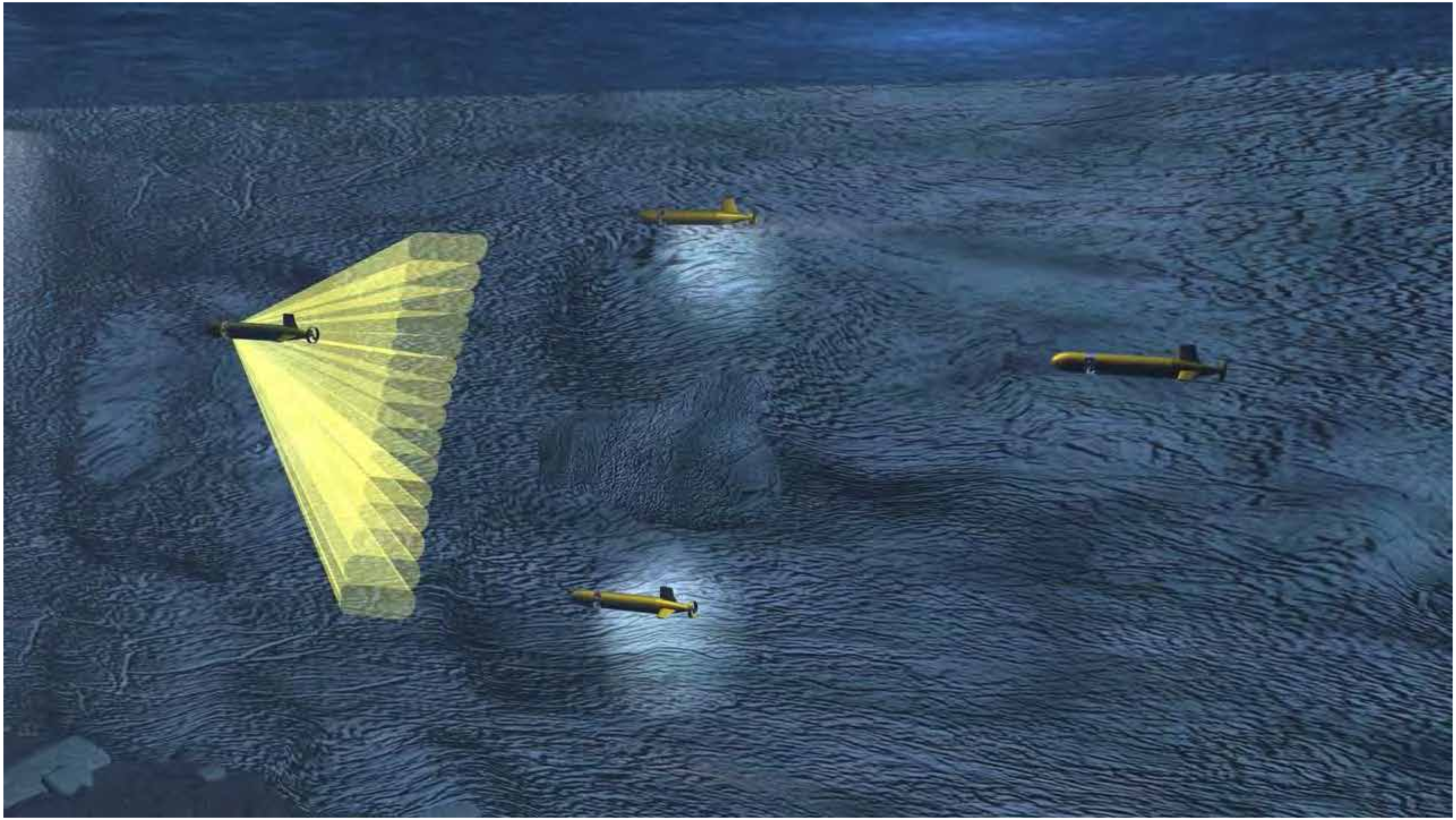


Multiple Unmanned Vehicles

A possible approach: a virtual supra vehicle made of self driven components



The basic MORPH idea:
a virtual supra vehicle made of self driven components



MORPH partners
overview

MORPH

Marine Robotic System of Self-Organizing, Logically Linked Physical Nodes

02/2012 – 01/2016

ATLAS ELEKTRONIK (Germany)

CNR - Consiglio Nazionale delle Ricerche - Istituto di studi sui sistemi intelligenti per l'automazione, (Italy)

IFREMER - Institut français de recherche pour l'exploitation de la mer (France)

Jacobs University (Germany)

IST/ISR - Instituto Superior Tecnico / Institute for Systems and Robotics (Portugal)

IUT - Ilmenau University of Technology (Germany)

CMRE - Centre for Maritime Research and Experimentation (Italy)

UDG - Universitat de Girona (Spain)

IMAR - Institute of Marine Research (Portugal)

WHOI - *Woods Hole Oceanographic Institution (USA)*

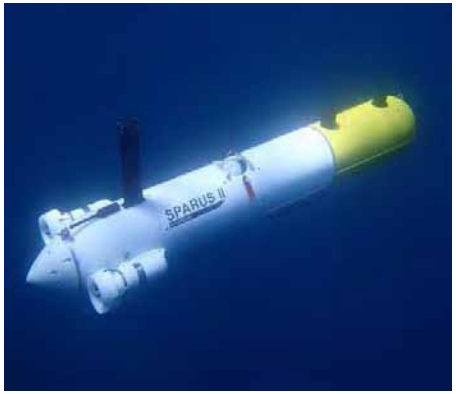
European Commission

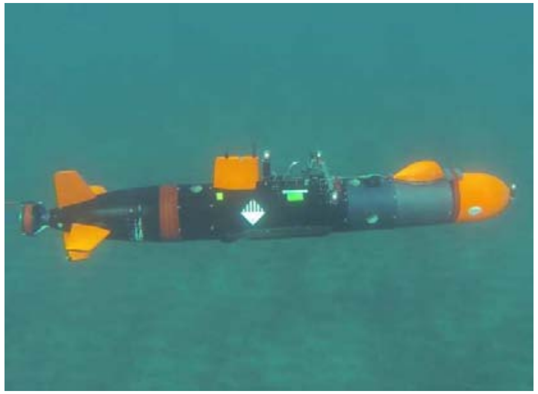
RESEARCH & INNOVATION

FP7

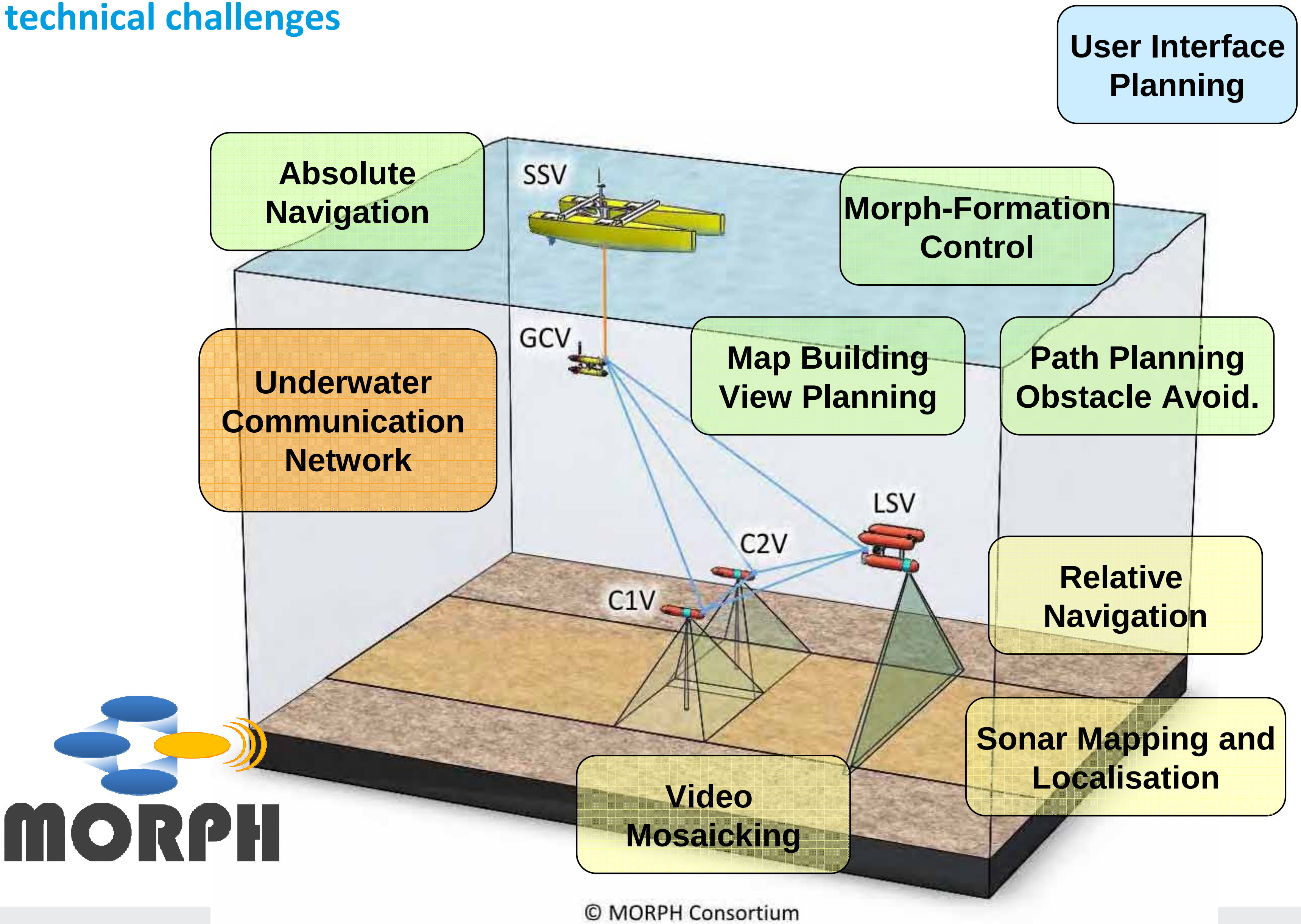
ATLAS ELEKTRONIK

The MORPH project
Vehicles in the project



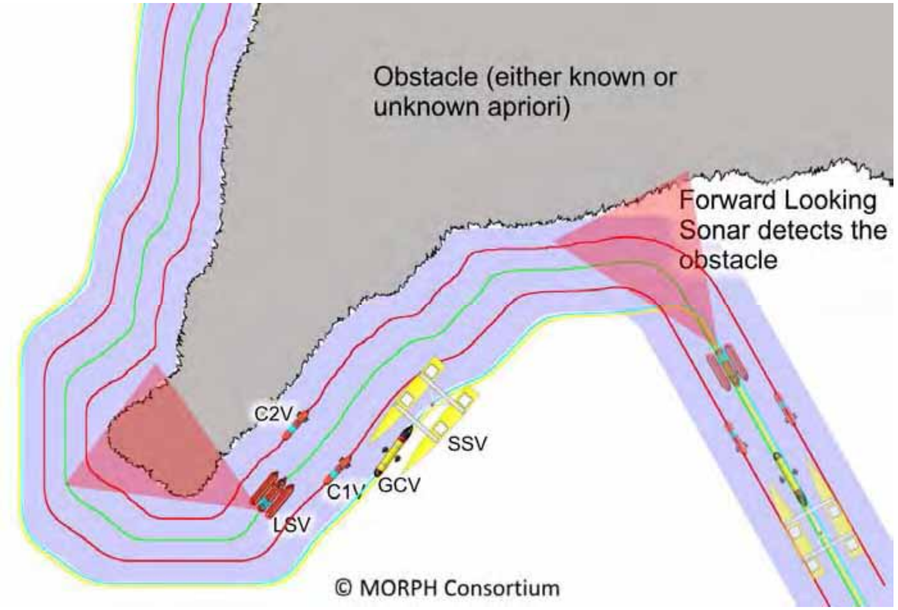


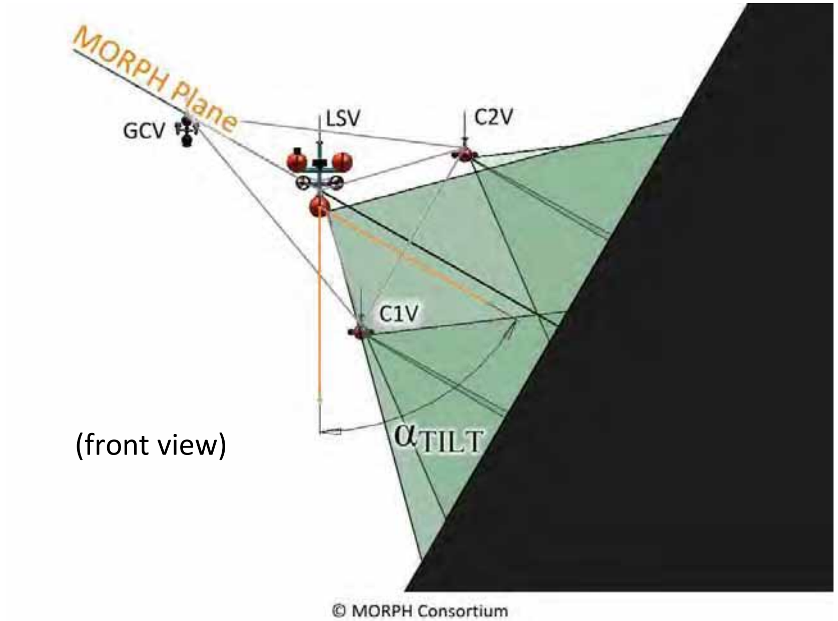
The MORPH project
technical challenges

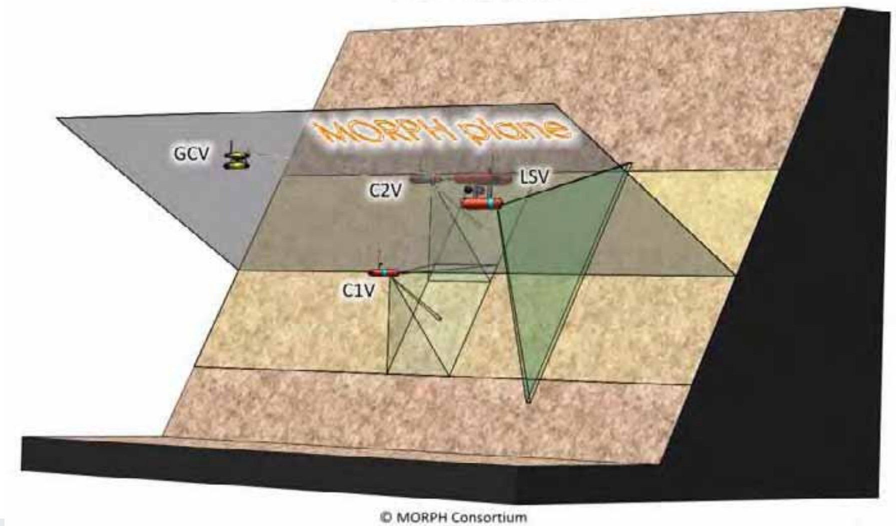


ATLAS ELEKTRONIK

The MORPH project
Path planning

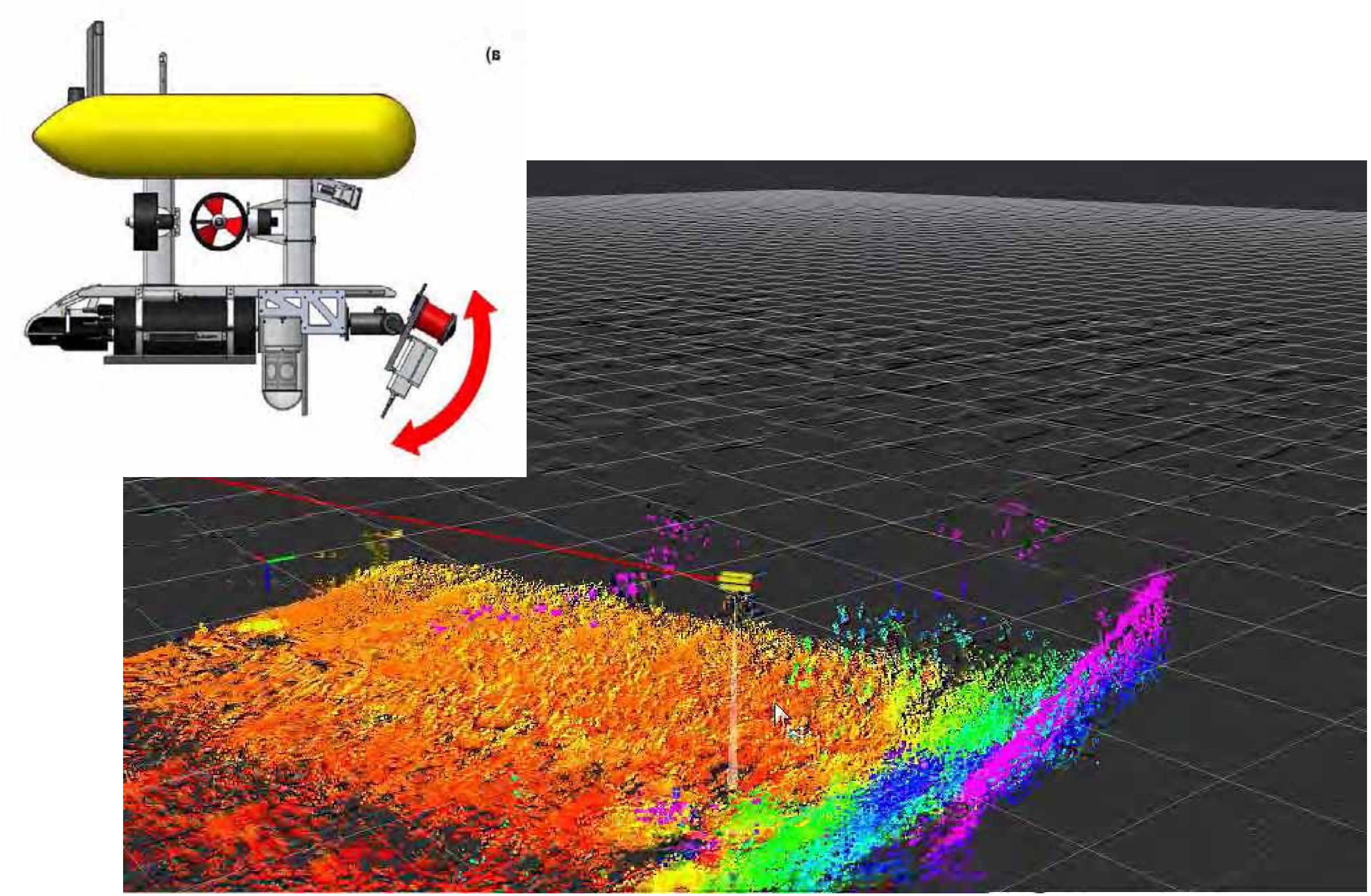






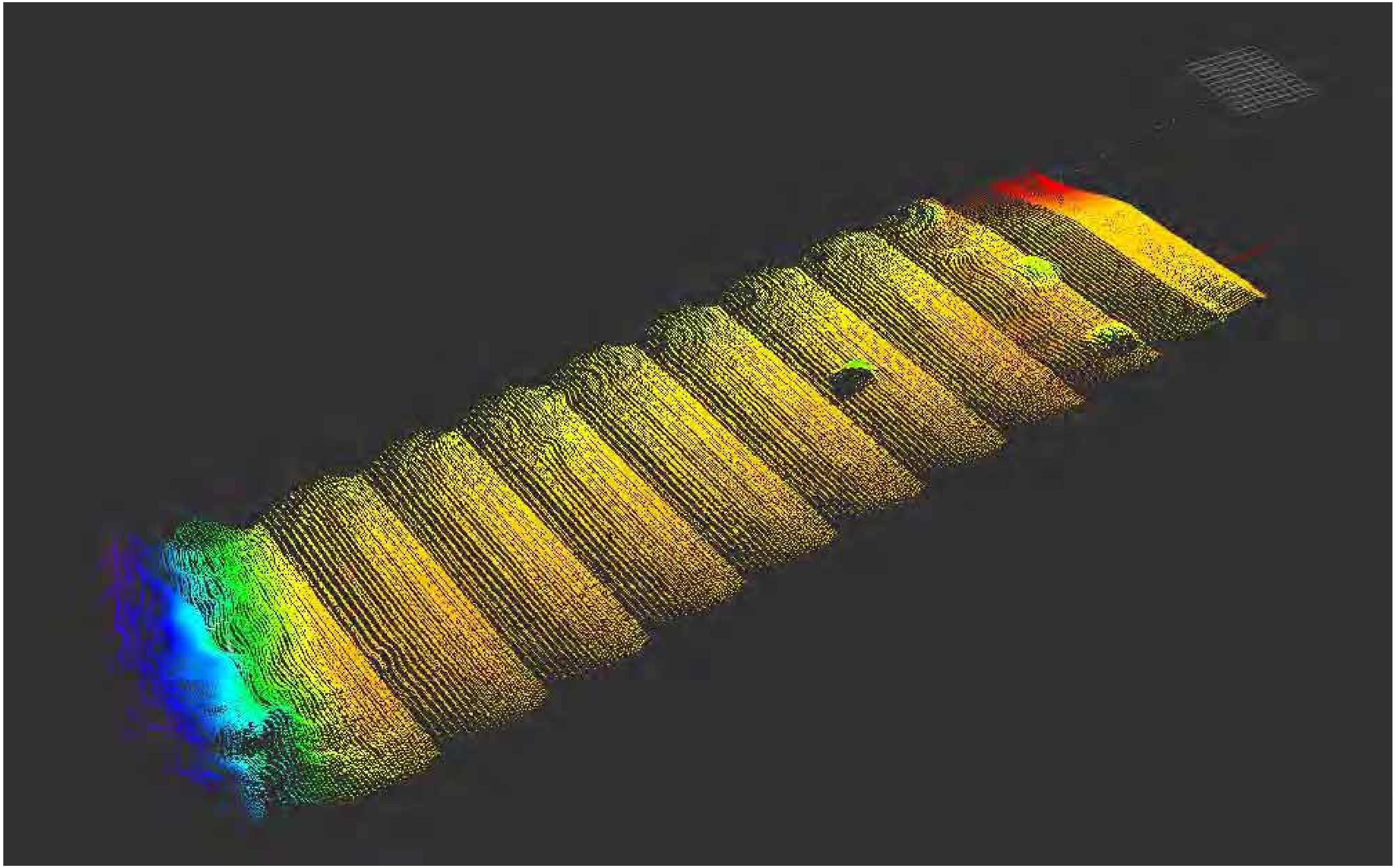
ATLAS ELEKTRONIK

MORPH challenges
Path Planning and Obstacle Avoidance



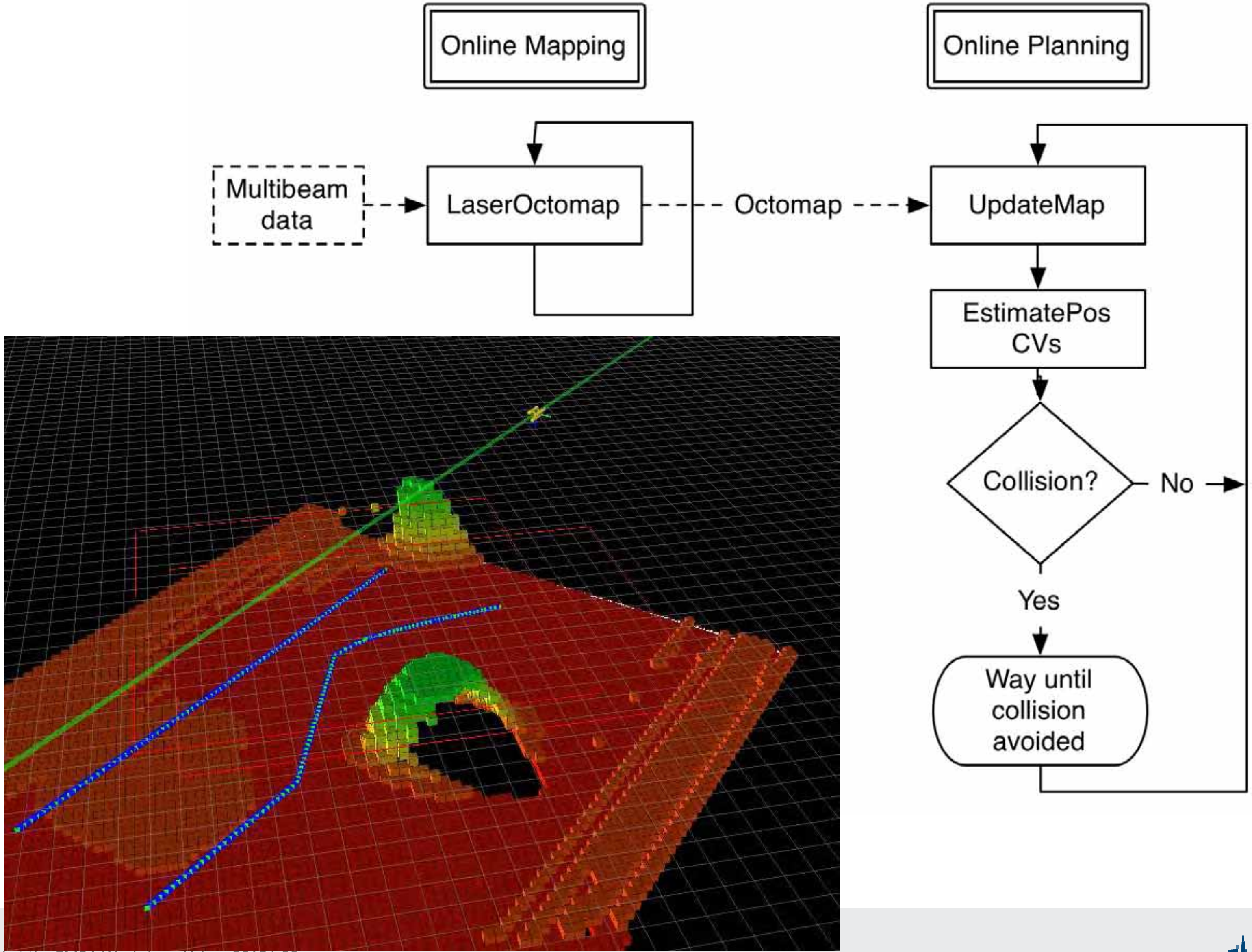
MORPH challenges

Path Planning and Obstacle Avoidance

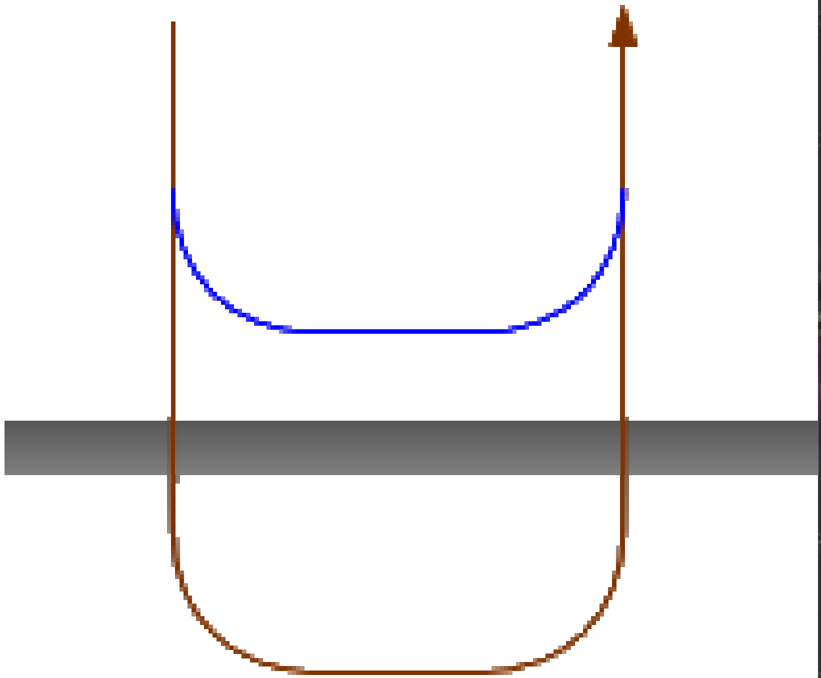


MORPH challenges

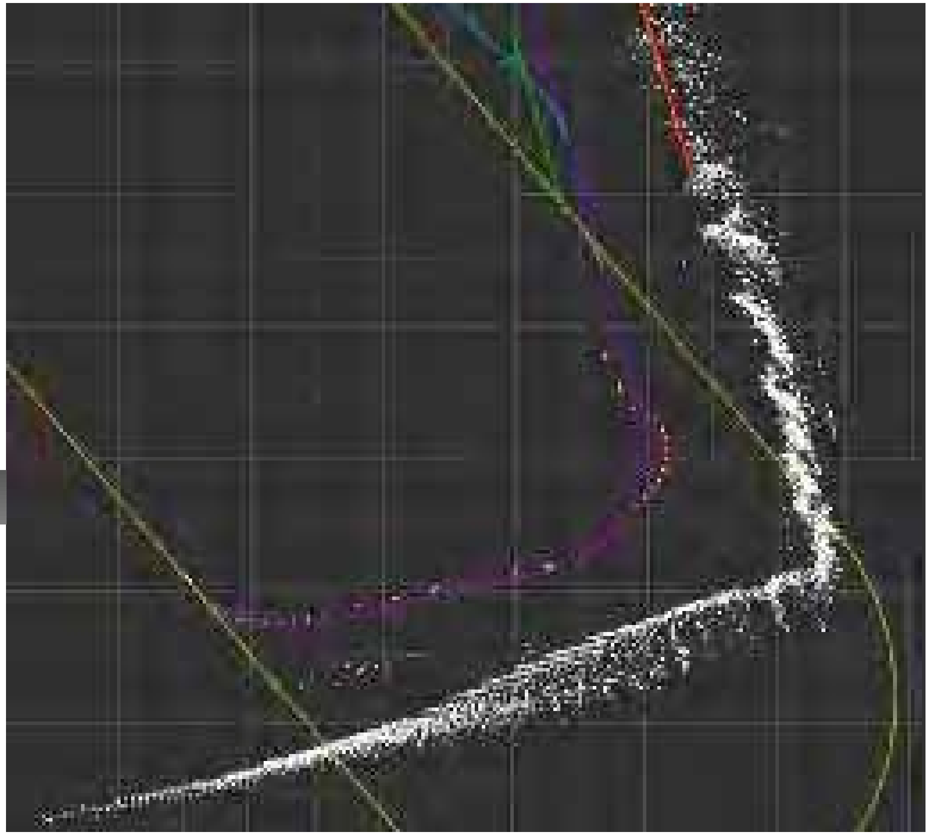
Path Planning and Obstacle Avoidance



Challenge: follow a wall

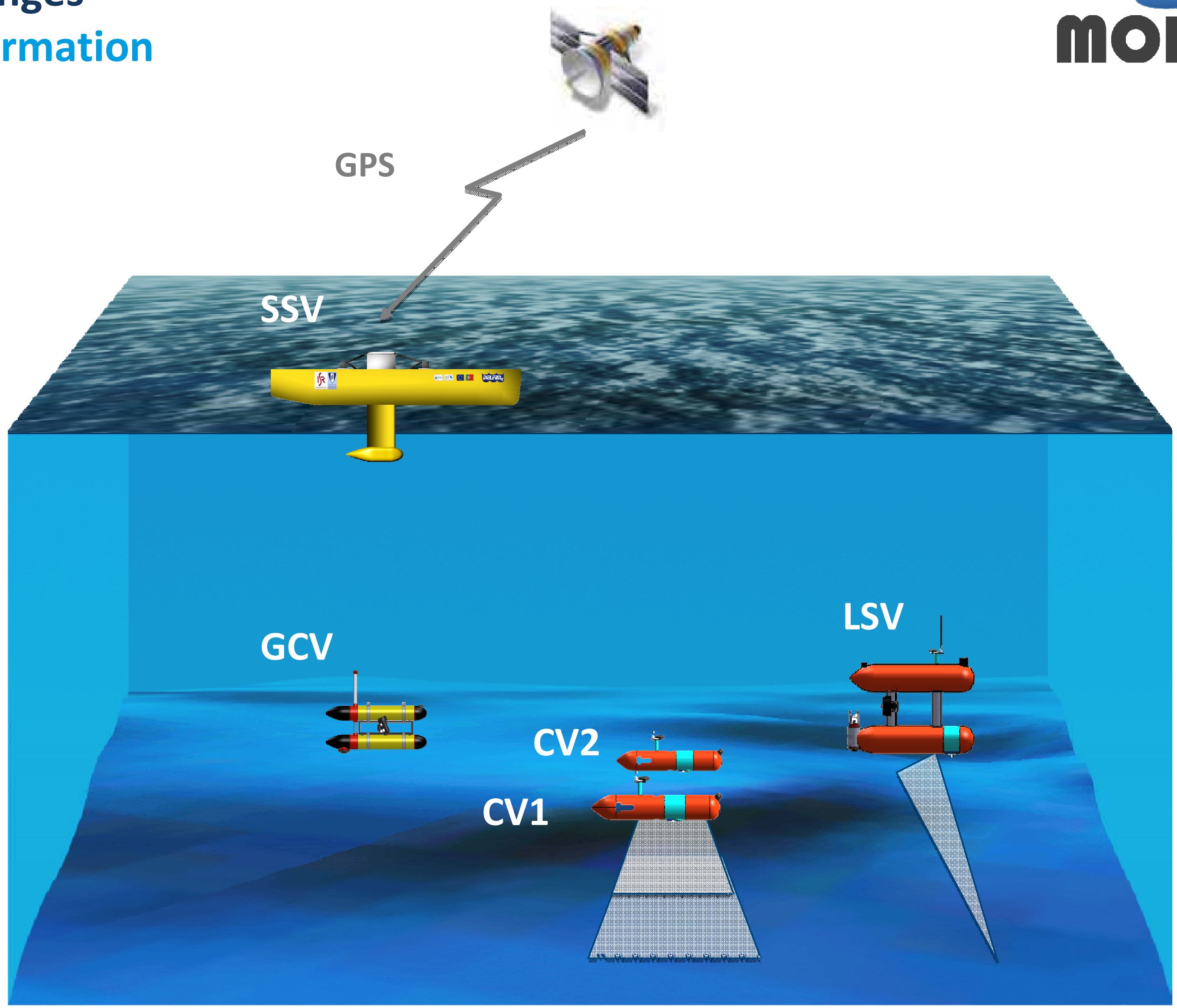


scheme



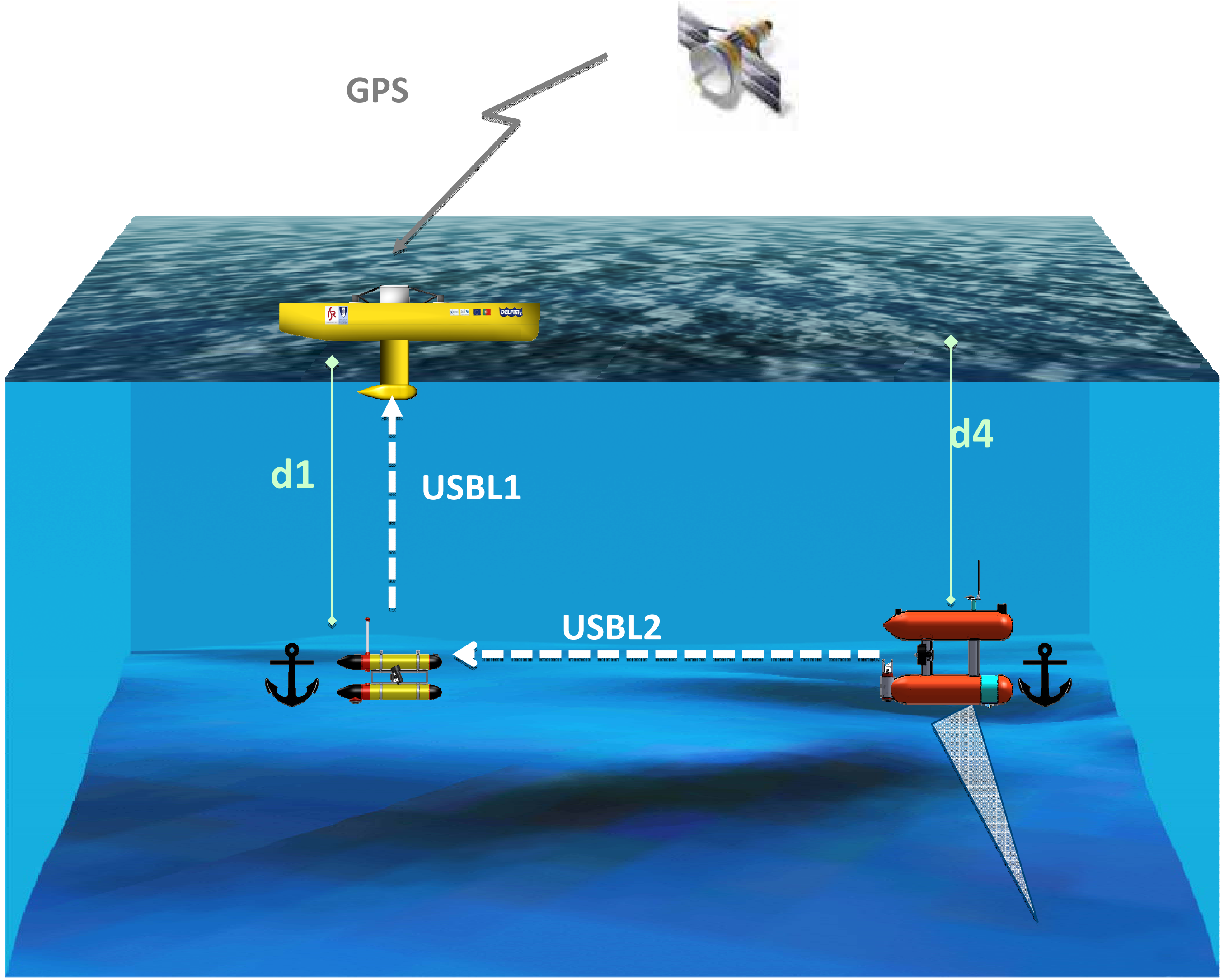
initial tests of UDG 500 vehicle

MORPH challenges
Keeping the formation

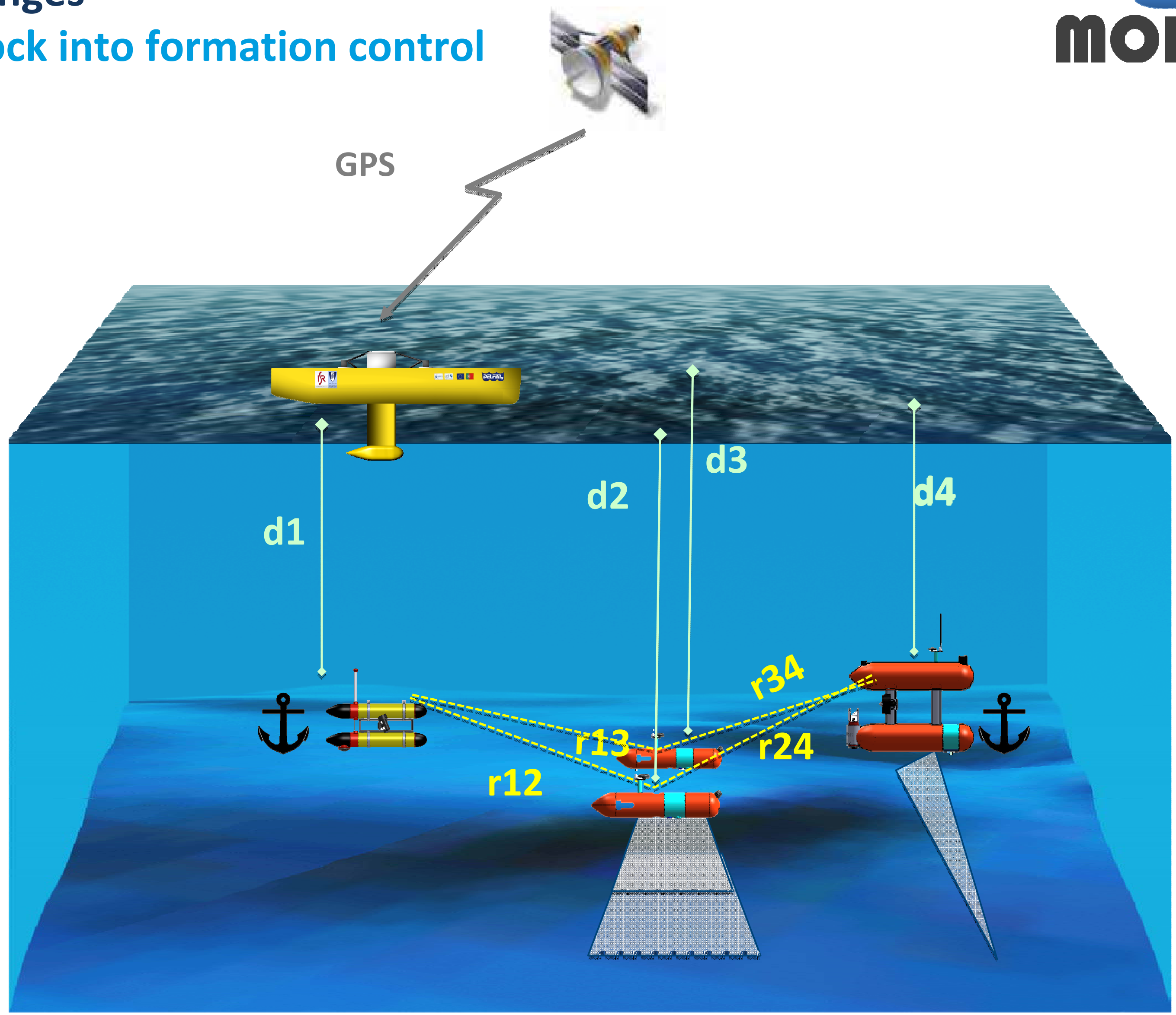


ATLAS ELEKTRONIK

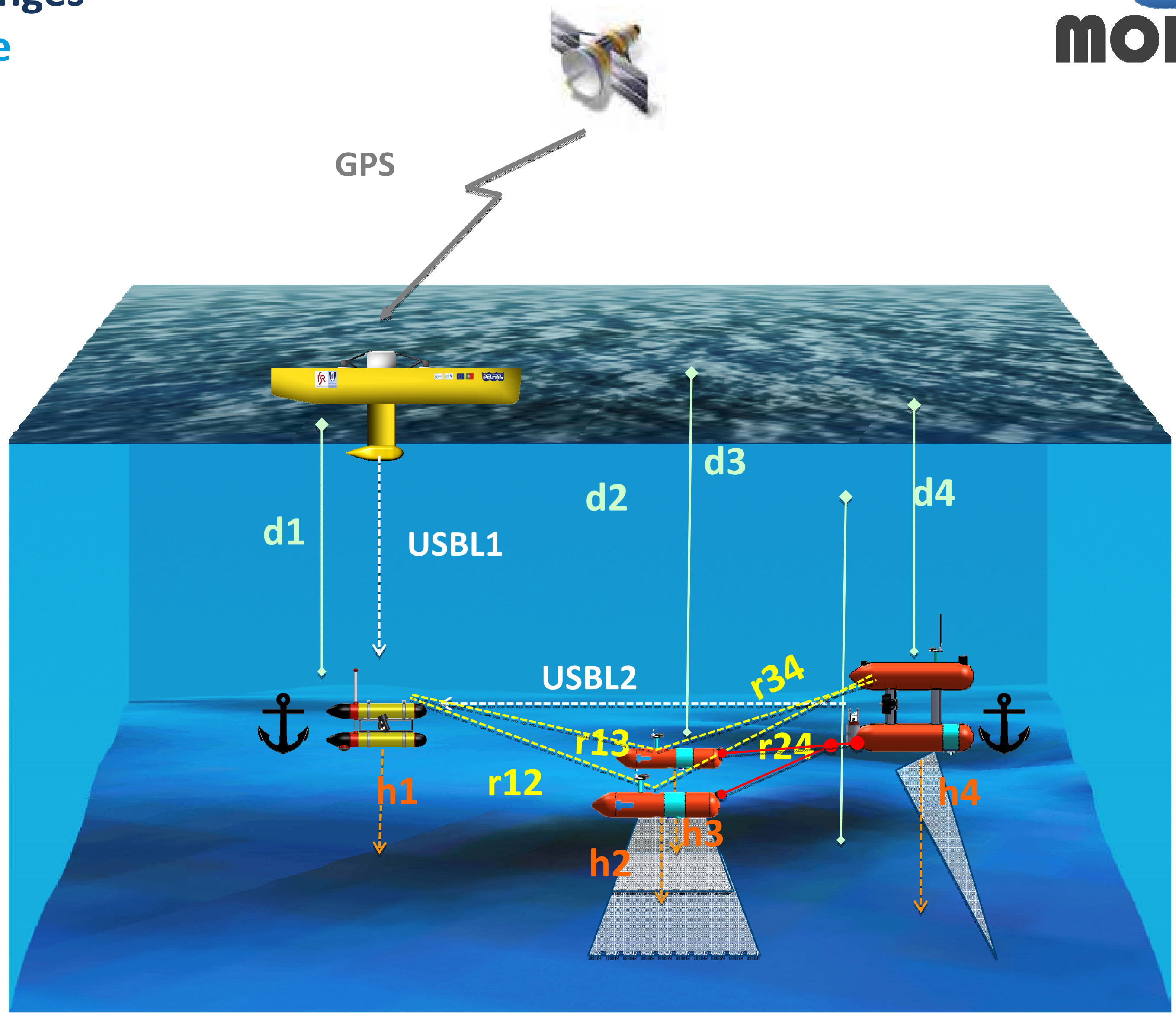
MORPH challenges
Global navigation & geo-referencing of the anchore vehicels



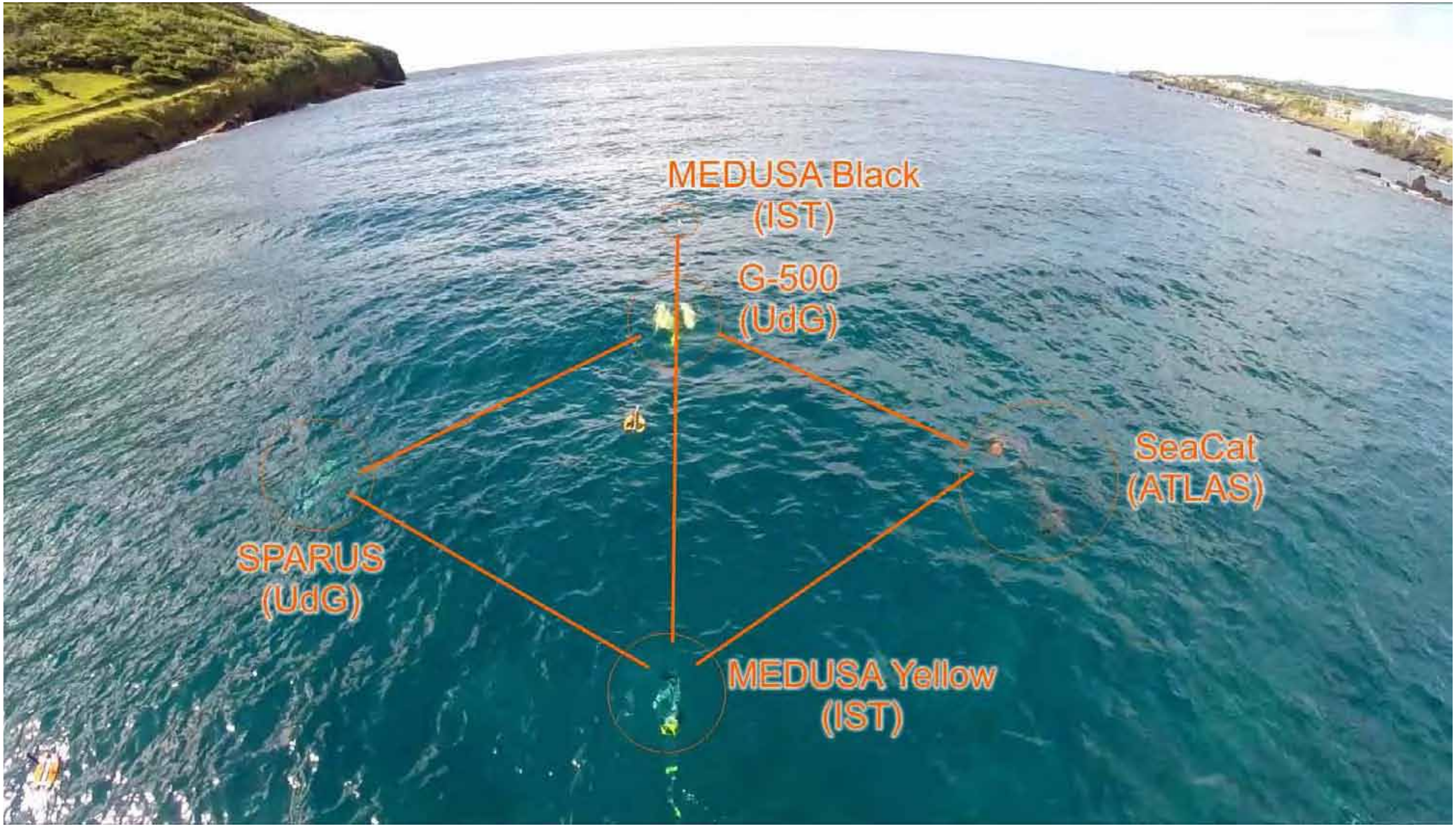
MORPH challenges
CVx vehicles lock into formation control



MORPH challenges
The full picture

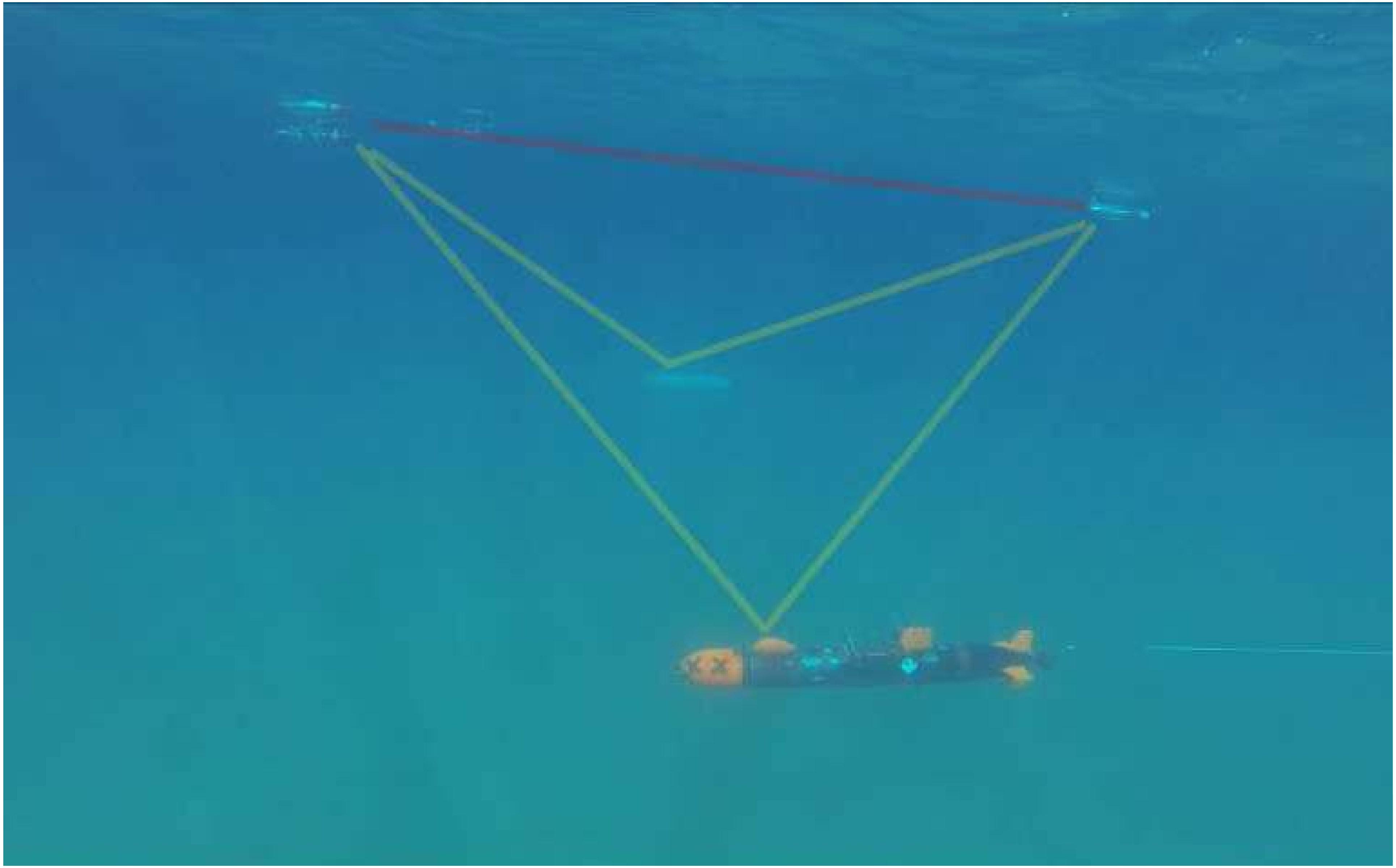


MORPH challenges
Formation control

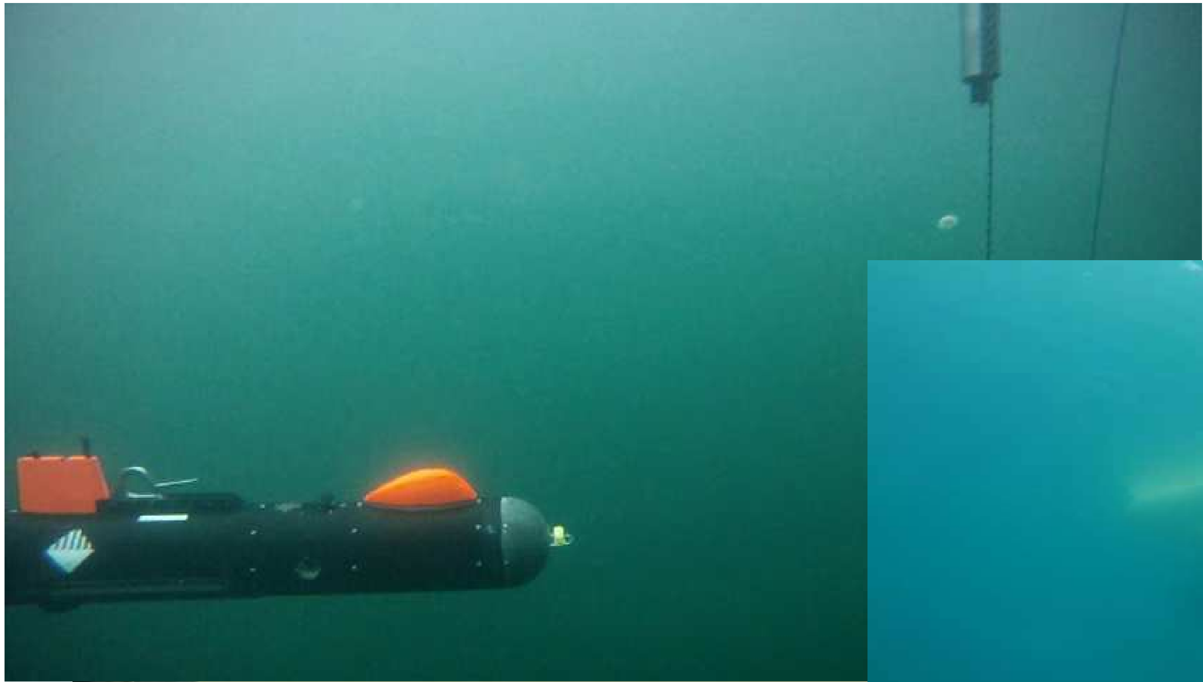


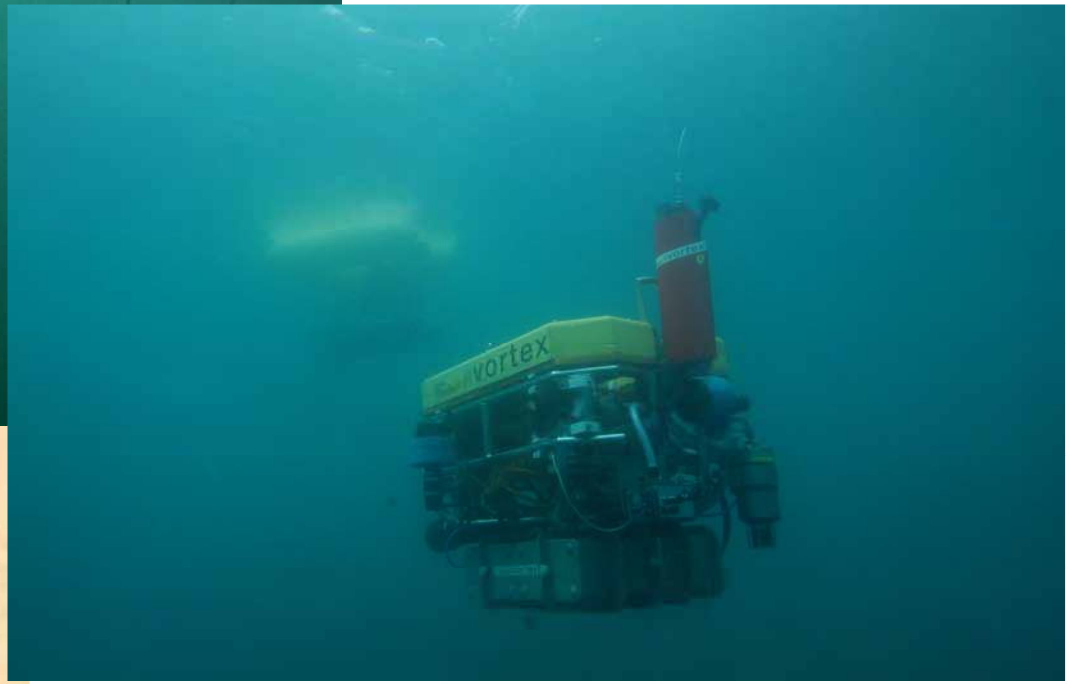
MORPH challenges

Formation control



MORPH challenges: Acoustic Communication
One slide on hardware





MORPH challenges: Acoustic Communication
Combined data + location awareness with full network integration

Two typical approaches:

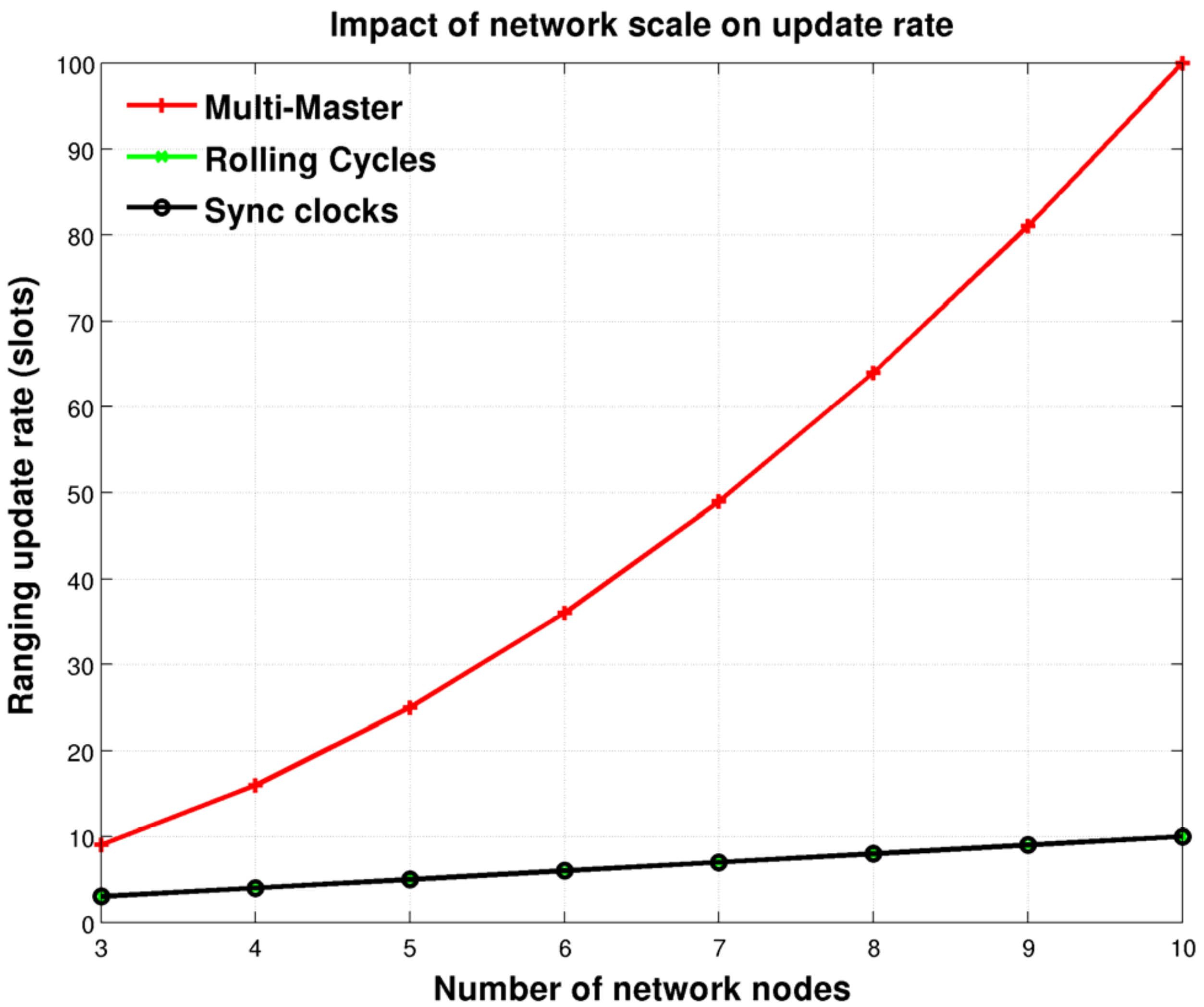
- Extensive round-robin of all-to-all query and reply cycles to get round trip TOFs, in "Multi-Master" fashion.
- Precisely synchronized clocks, Time Of Flight measured from one-way transmissions.

Two specific features of the EvoLogics modem that we are using in MORPH allow us to explore something different…

- The modem has precise time tagging in local DSP clock of beginning of transmission and reception of packets.
- The modem allows the application to specify when to reply to a query message.

This way a node can listen to N-1 queries (N being the number of nodes in the network), register their time of arrival and in convenient time answer in one packet with all time lapses between receptions and transmission. At the same time this packet also works as a query for all the other nodes.

MORPH challenges: Acoustic Communication
Combined data + location awareness with full network integration



MORPH challenges: Acoustic Communication
Combined data + location awareness with full network integration

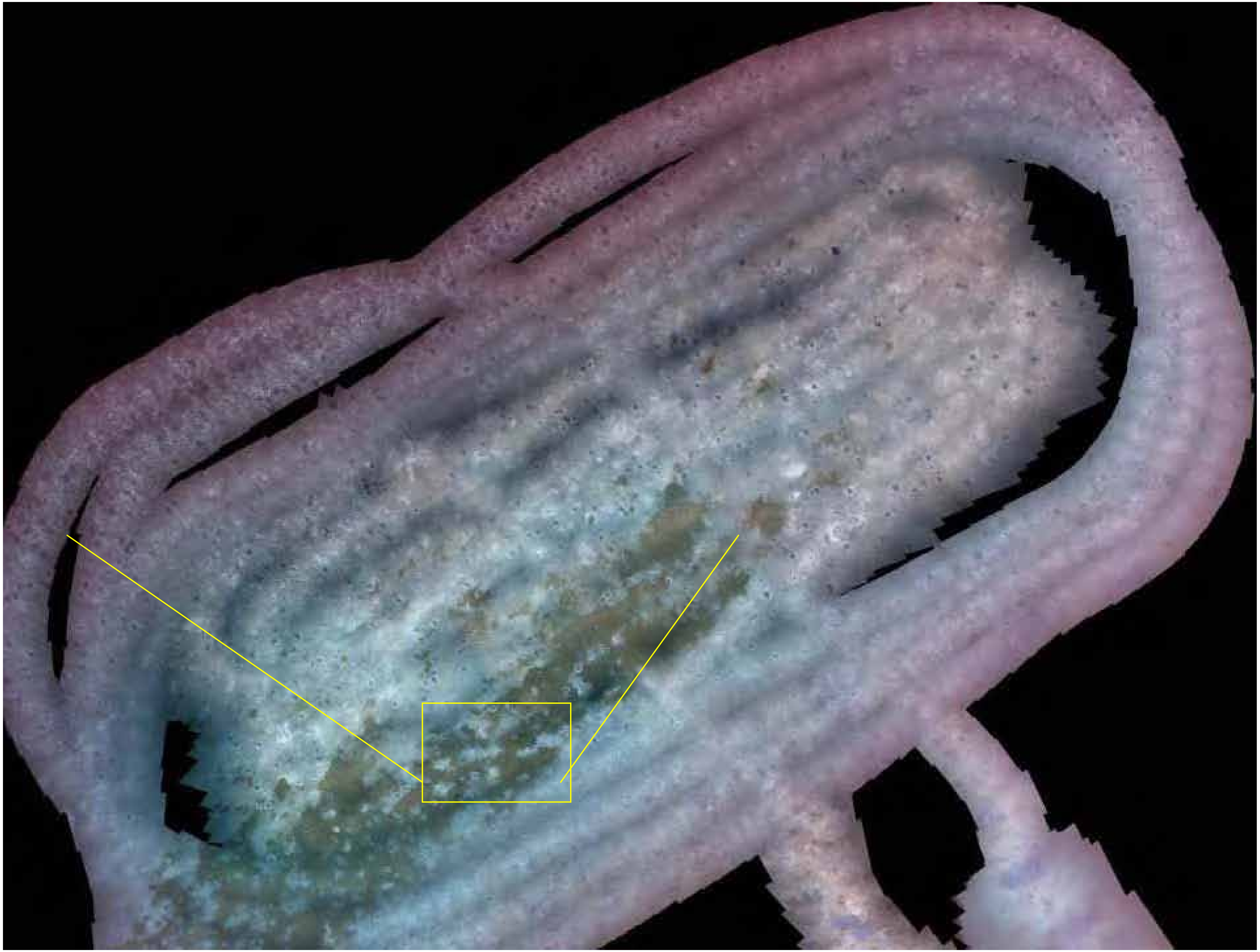
Communication Module Functionality

Provides the basic rolling cycles query scheme to extract ranges, using 3 (N-1) bytes of the available payload for this functionality.

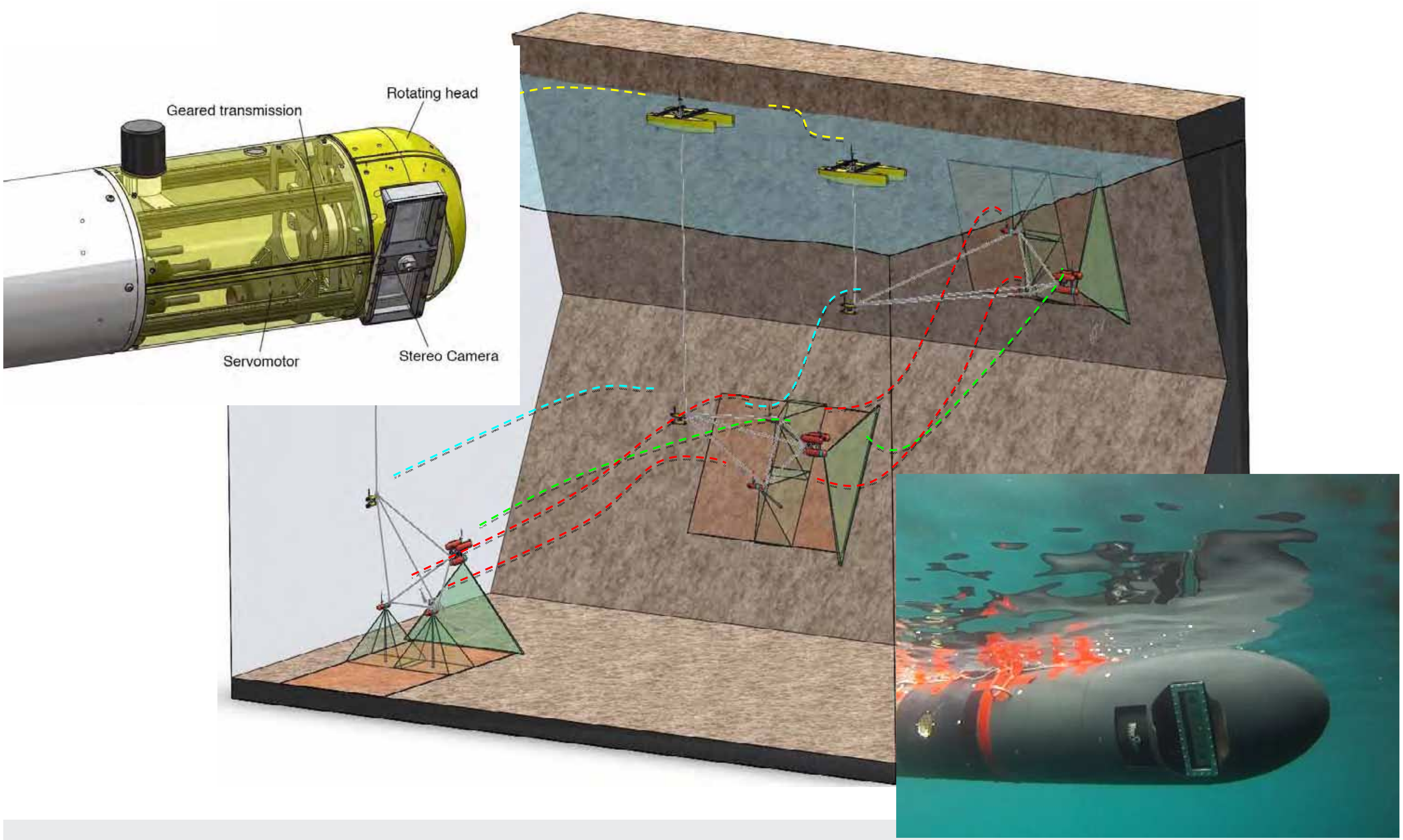
Users may exchange data through the communication module in abstraction from the localization functionality.

The user data to be passed are piggybacked on the location packets

MORPH Trial: Horta, Azores 2014

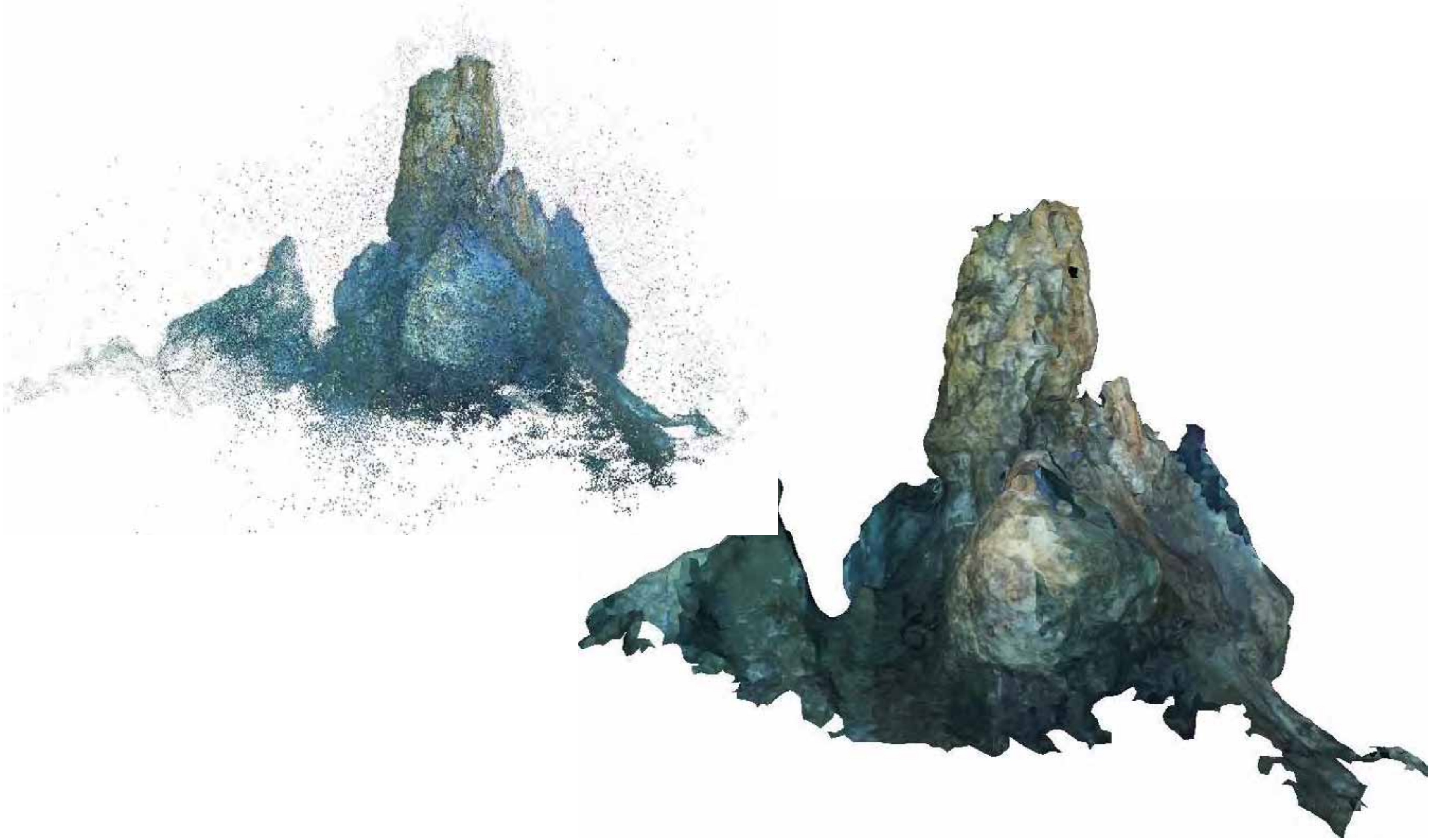


The goal 2015:
mapping of vertical structures using rotatable sensors



MORPH Challenges

3D reconstruction



MORPH
Some personal impressions

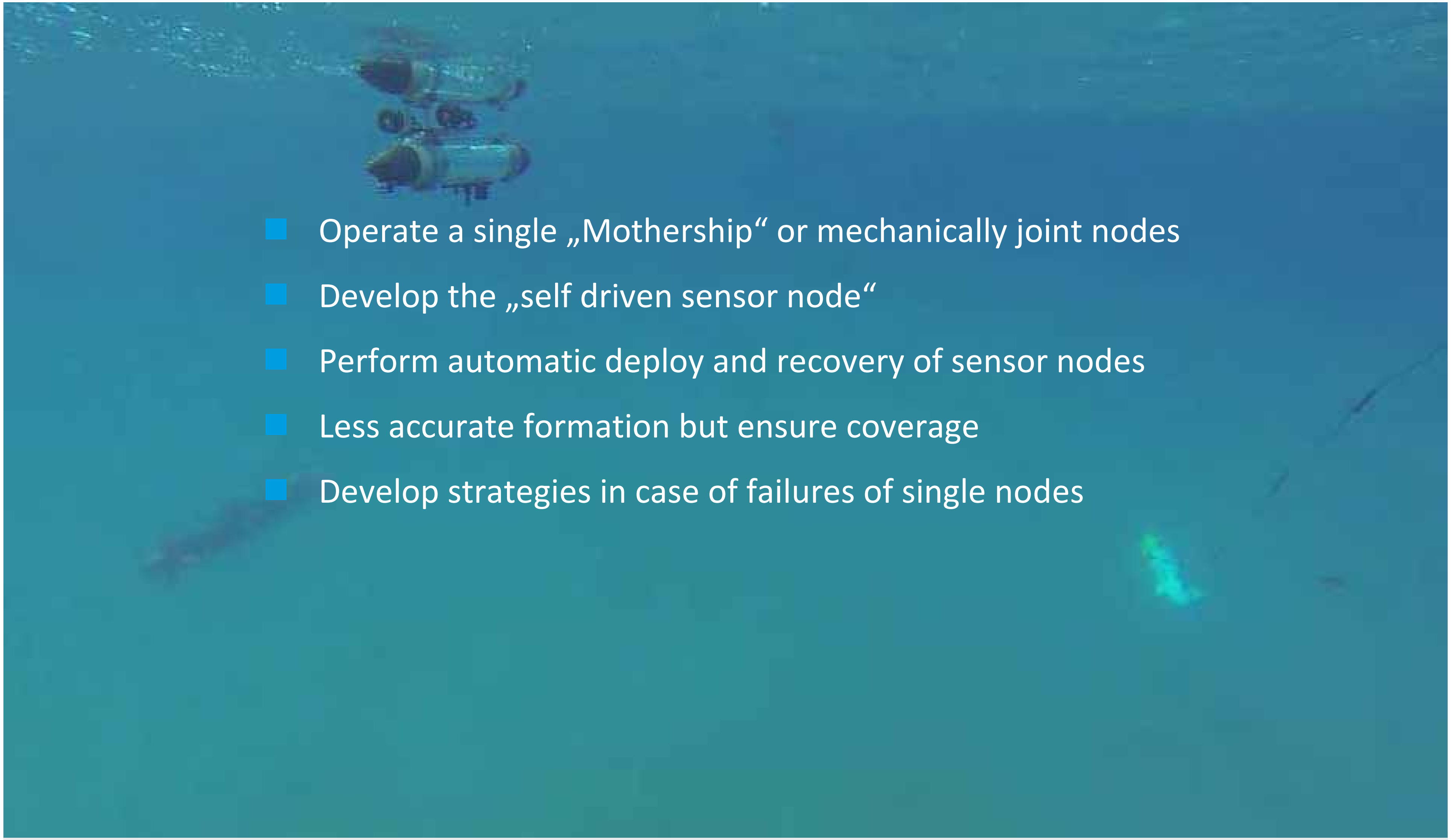
MORPH is pushing the frontiers of technology in terms of

- Proof of concept of a supra vehicle with deployed sensors
- Investigated control techniques w/o expensive navigation
- Realized an efficient communication and navigation network
- Investigated rotational and panoramic sensors
- Developed mapping and modeling techniques

but

- Far away from robustness
- Operation of multiple nodes still complex
- Operation in sheltered area from shore
- Application got too less attention
- Distributed knowledge makes it difficult to provide a system to potential customers
- Huge investment necessary to build an operational Supra Vehicle

Operation Multiple Vehicles
A Vision



- Operate a single „Mothership“ or mechanically joint nodes
- Develop the „self driven sensor node“
- Perform automatic deploy and recovery of sensor nodes
- Less accurate formation but ensure coverage
- Develop strategies in case of failures of single nodes

ATLAS ELEKTRONIK

MORPH

Many thanks for attention on behalf of the whole team

Contact

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www.atlas-elektronik.com

ATLAS ELEKTRONIK
A joint company of ThyssenKrupp and Airbus DS

EMRA'15 workshop

Marine Technology: Challenges and Opportunities in relation to Marine Renewable Energy

António Sarmento
WavEC, Lisbon, PT

WavEC
Offshore Renewables

MARINE TECHNOLOGY

CHALLENGES AND OPPORTUNITIES IN RELATION TO MARINE RENEWABLE ENERGY

ANTÓNIO SARMENTO

2015-06-19

SUMMARY

- WavEC Offshore Renewables
- Overview of Marine Renewable Energy.
- Challenges and opportunities for Marine Technology


MCT Seagen 1.2 MW, Northern Ireland (2008)


Monitoring buoy


WindFloat prototype

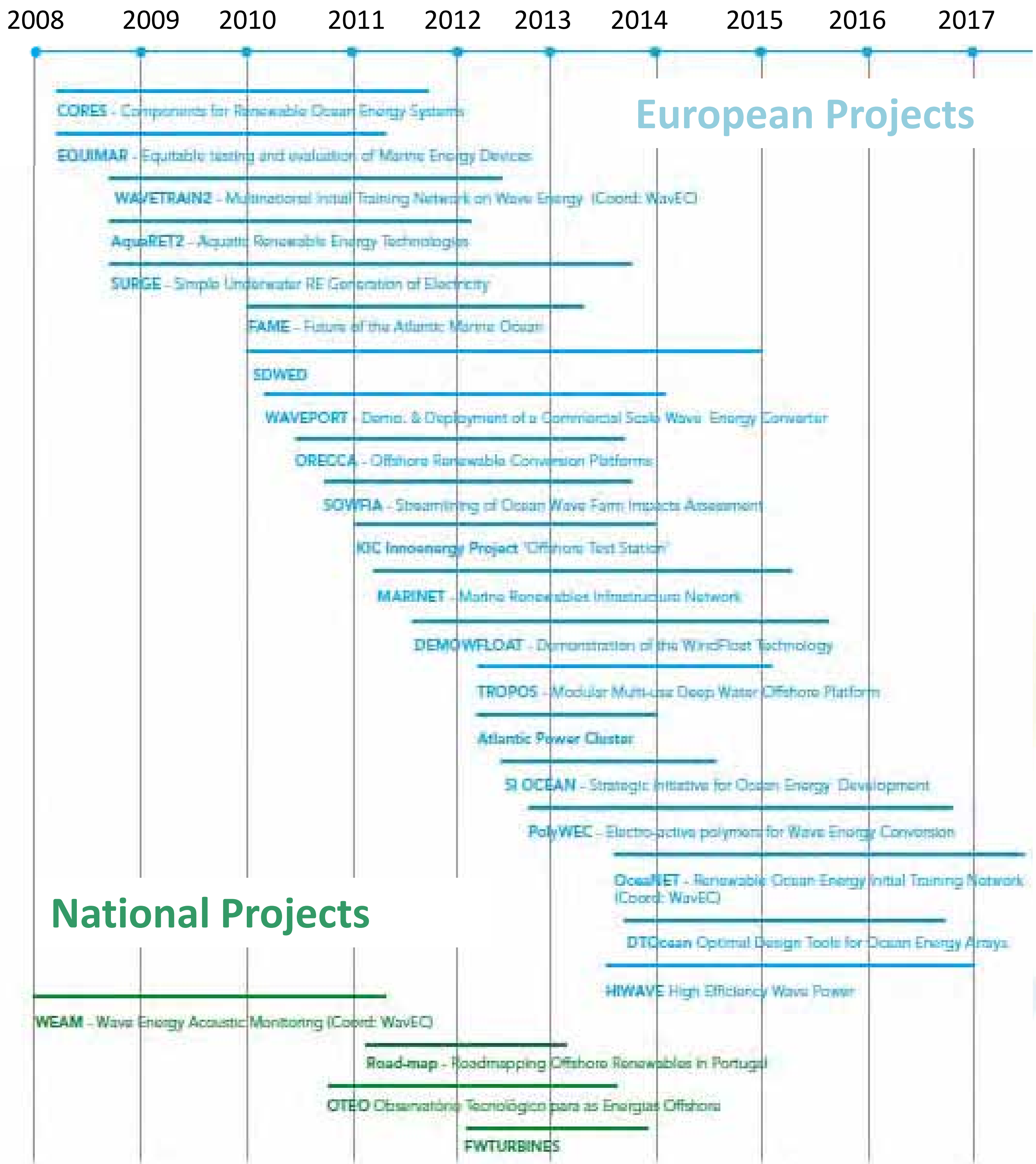

Waveroller, Peniche, 2011

WAVEC OFFSHORE RENEWABLES

- Private non-for-profit
- Markets
  - **Wave energy**
  - **Offshore wind**
  - **Ocean technology**
- Funded through:
  - **Consultancy - 25%**
  - **R&D projects (EC) – 50%**
  - **New products and services – 25%**

KEEPING TRACK OF MULTIPLE R&D PROJECTS

- *A broad spectrum of activities*
- *Added value for the development of new products and new services*
- *More then 100 international partners*



PROVIDING SERVICES AROUND THE WORLD

eit Knowledge & Innovation Community
KIC InnoEnergy

JRC
EUROPEAN COMMISSION

IDB
Inter-American Development Bank

OES OCEAN ENERGY SYSTEMS
An IEA Technology Initiative

ENERGYIN
PÓLO DE COMPETITIVIDADE E TECNOLOGIA DA ENERGIA

IBERDROLA

[redacted]

gasNatural fenosa

REN

KRISO

edp

ice

Pacific Northwest NATIONAL LABORATORY

TEAMWORK TECHNOLOGY

WAVEROLLER® by AW-Energy

wedge

CORPOWER OCEAN

Ciemat
PLATAFORMA SOLAR DE ALMERÍA

Global Renewable Solutions

DEX

CEiiA

OCEANTEC

[redacted]

smalle Technologies
Devices that generate electricity from oscilation

PRINCIPLE
renewable energy delivered

www.wavec.org

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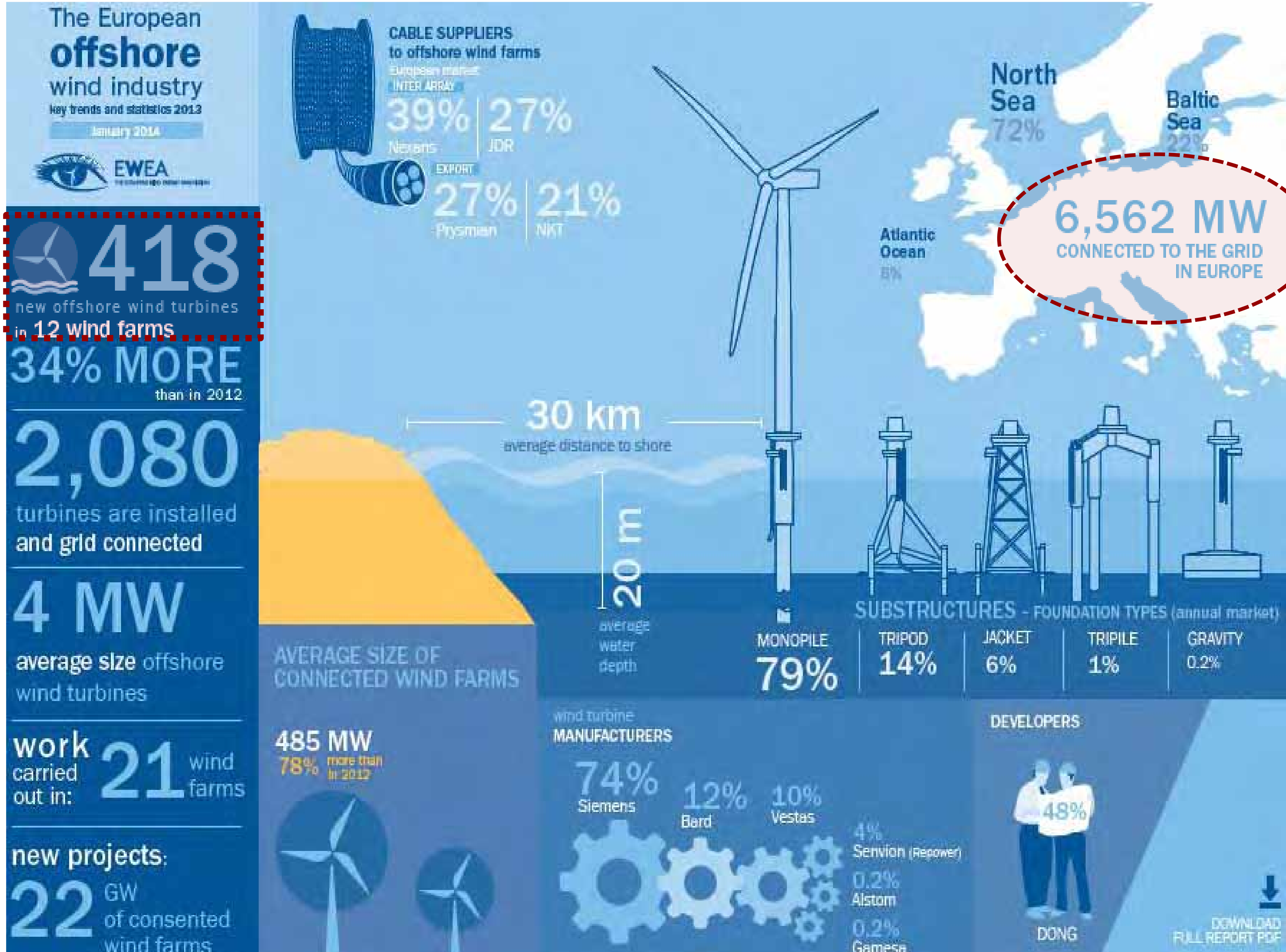
Pico wave energy plant
(1999 – 2015...)

Monitoring buoy

WindFloat prototype

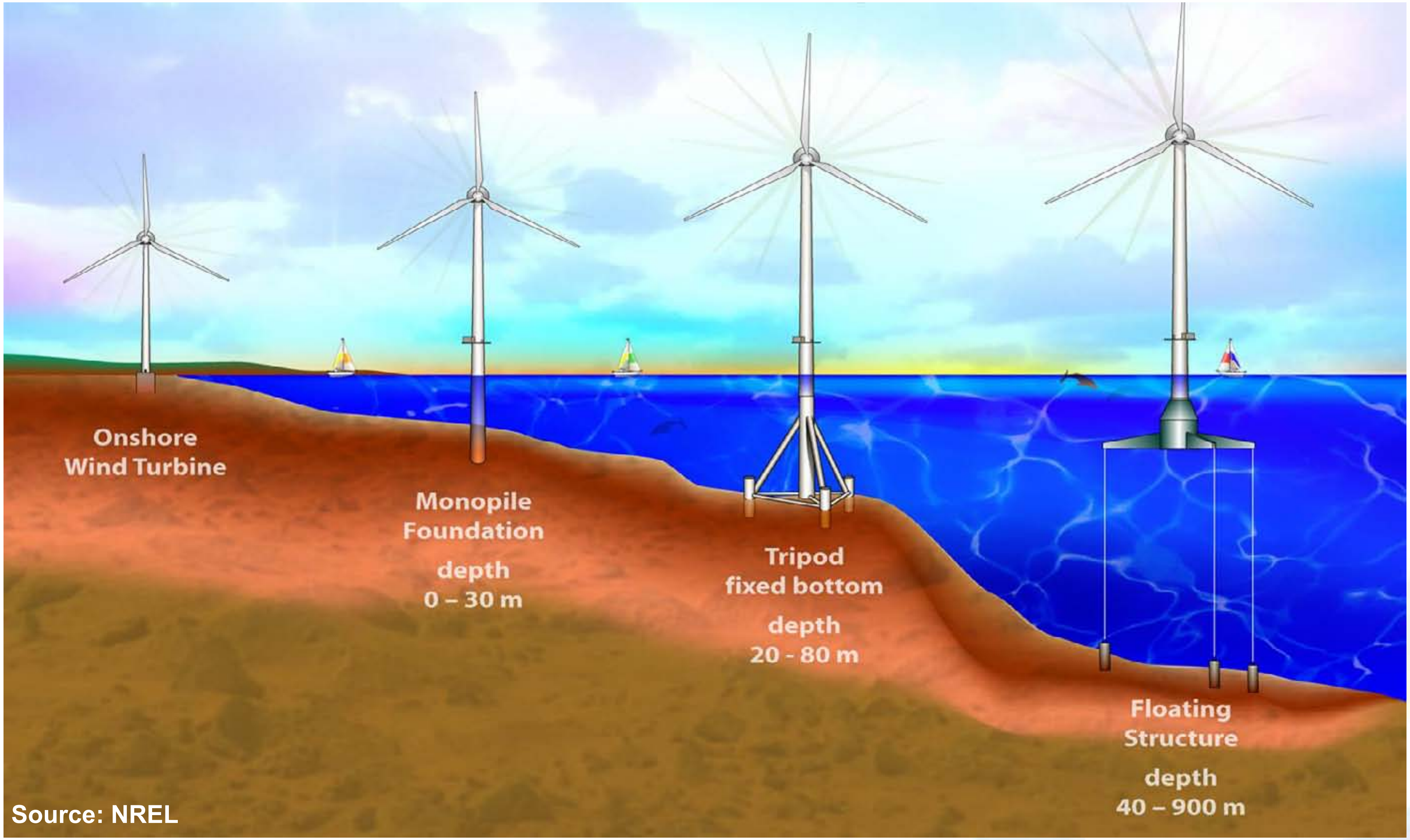
Underwater inspection at the WindFloat

2013 European Offshore Wind Statistics

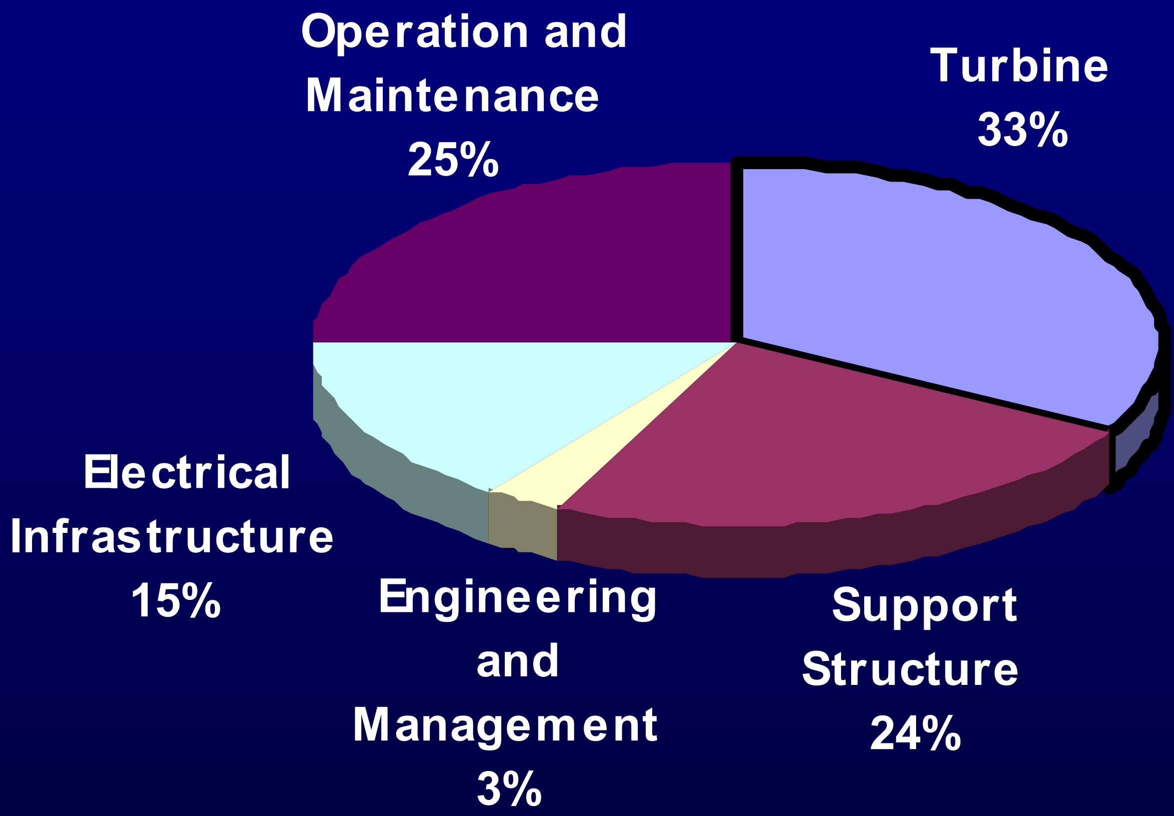


…avec.org

Progressing to deeper waters: Floating!



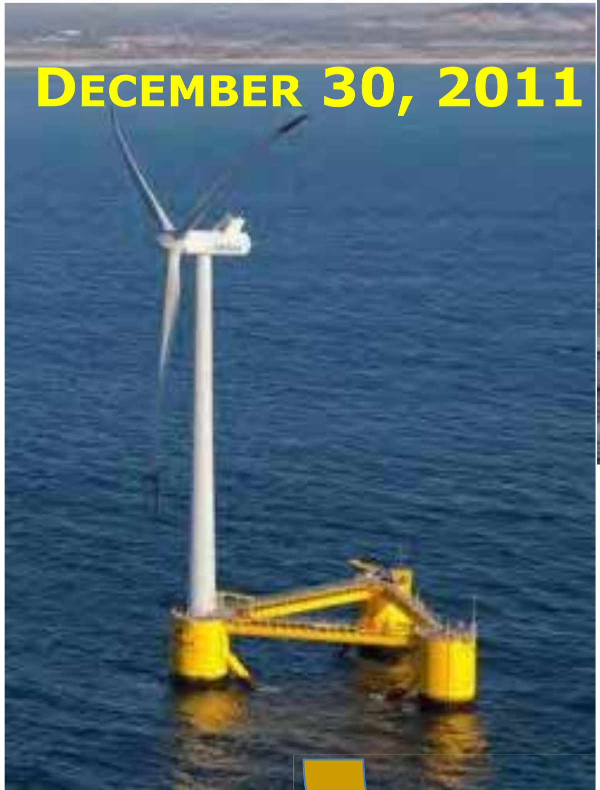
COST BREAKDOWN OF FIXED OFFSHORE WIND ENERGY



The WindFloat

- **EDP, ASM, REPSOL**
- **Principle Power**
- **WavEC**

- 400 MW farm:
  - 50 x 8 MW turbines
  - 50 floating platforms
  - 75 km of mooring lines
  - 50 km of underwater electrical cables



TIDAL STREAM TURBINES

Prototype testing since 2004

3+ of continuous operation

Two 10 MW farms announced in 2015

SR 250, EMEC (2011)

AK-1000 at EM

6x30kW FreeFlow 5m deployed at NY (2006)

Clean Current turbine (Alstom Hydro), Race Rocks (2006)

1MW OpenHydro turbine, Bay of Fundy (2010)

ORPC 60kW Beta TGU, Cobscook Bay (2010)

PS 100, Humber Estuary (2009)

Minesto Deep-Gen concept

WAVE ENERGY

© 2008 AQUARET
2008 AQUARET
© 2008 AQUARET
© 2008 AQUARET
OWC
Oscillating bodies
Overtopping
Deformable bodies
Prototype sea trials since 2004
Diversity of concepts
Inconsistent energy production

SUMMARY

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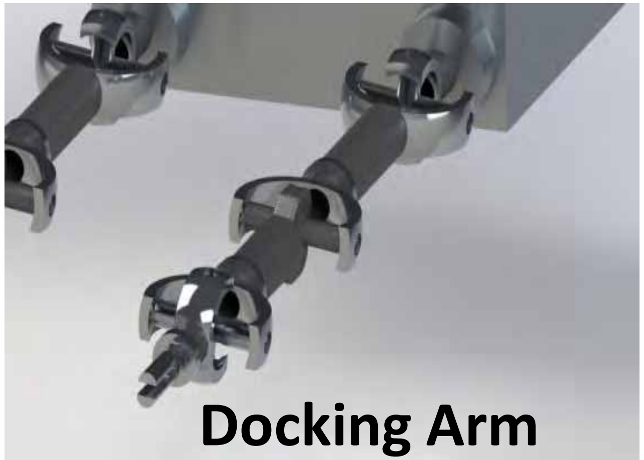
TECHNOLOGICAL CHALLENGES & OPPORTUNITIES

- ✓ Increasing turbine (wind and tidal) size and power: ⇨ mechanical fatigue
- ✓ Reducing deployment and O&M costs (25% of energy cost):
  - Inspection of mooring lines and underwater electrical cables and connectors & turbine blades
  - Condition based maintenance
  - Underwater operations
  - Station keeping at high tidal stream velocities and energetic waves

Empowering small ROVs

Funding

Kraken – As easy as moving your own arm

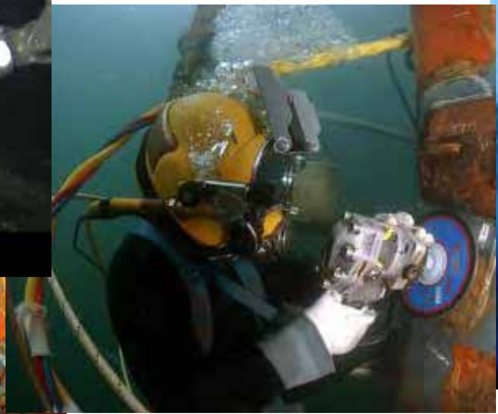

Docking Arm


Manipulator Arm


“Sleeve” Interface

Challenge: A marketable product by 2018 requiring no specialized operator

Empowering small ROVs



Sacrificial Anode Replacement

Biofouling Cleaning

NDT Surveys

Valves Operation

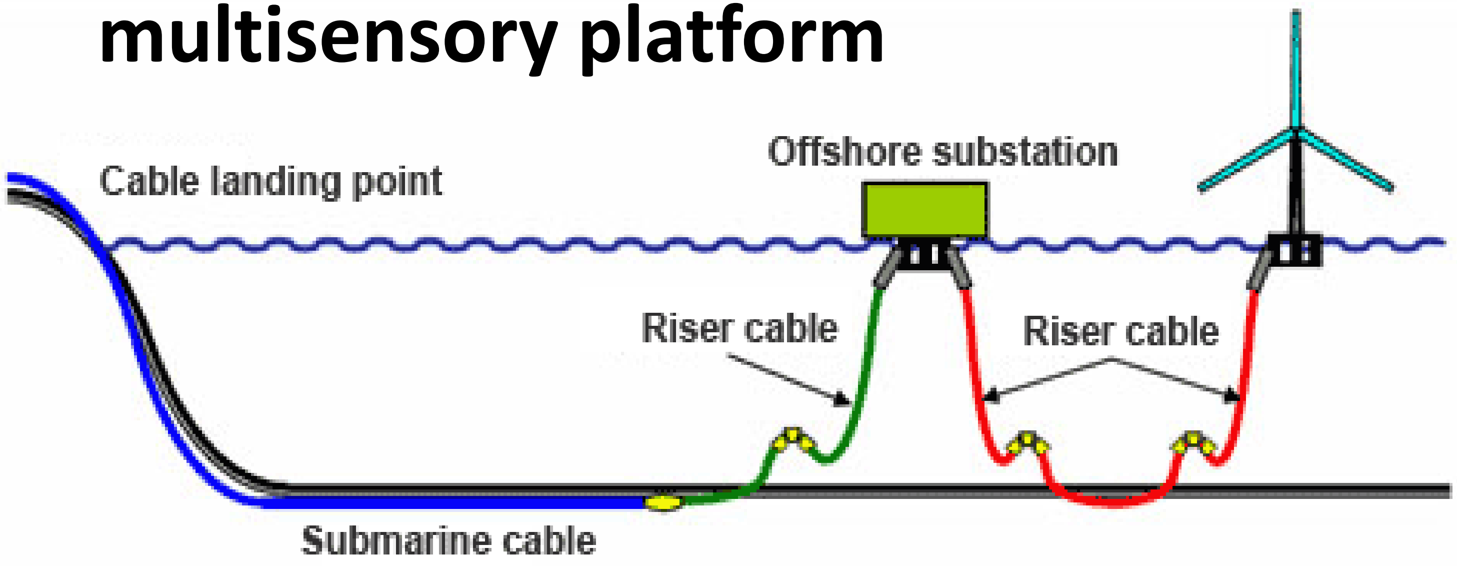
Environmental Surveys and Sampling

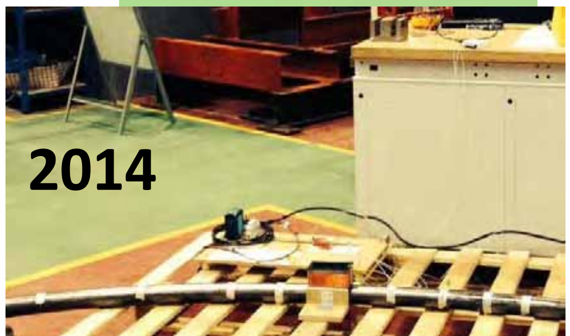
Underwater Explosives

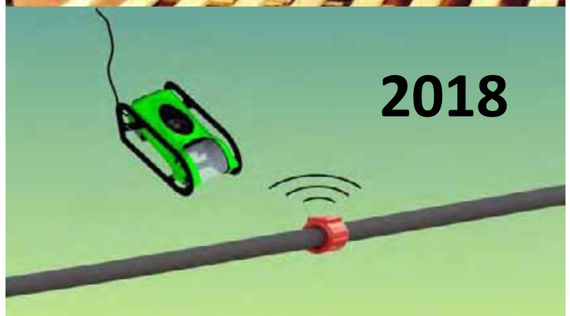
Visual Inspection and Survey

Symbiotracker: Monitoring underwater power cables & more

Autonomous induction-powered multisensory platform







- Partial Discharge Detection
- Cable Stress Measurement
- Environmental Monitoring
- Cable Locator

Challenge: A marketable product by 2020

UAV for offshore platforms inspection

PARTNERS

uavision

UAV Manufacturer

8.2

Inspection Contractor

Sensor specialist

eit KIC InnoEnergy

PRO DRONE

Onshore Wind Turbines (2015)

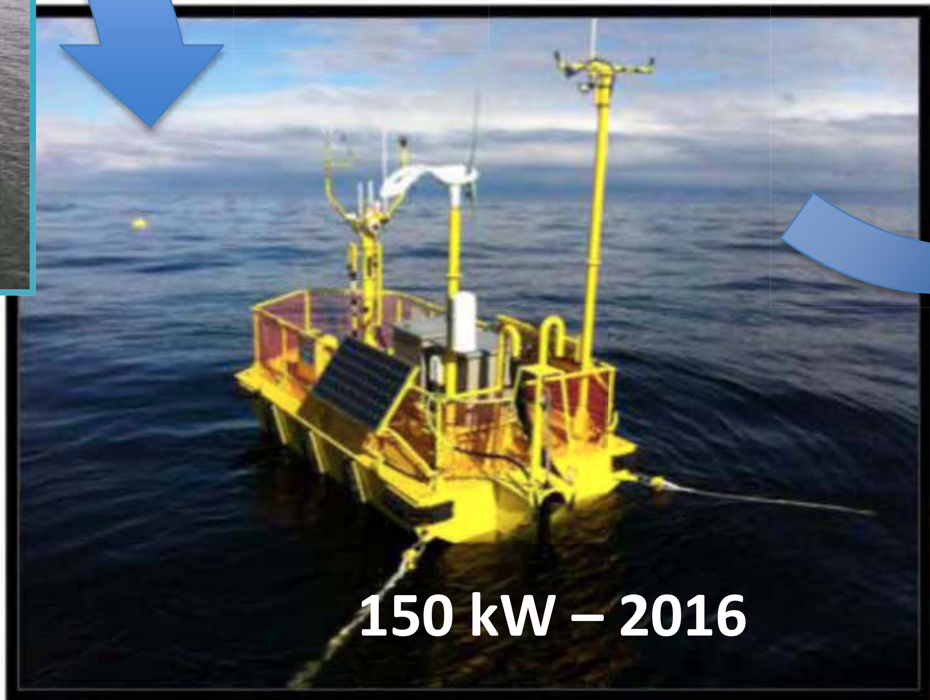
Offshore Wind Turbines (2018)

Offshore O&G (2020)

Oceanic Monitoring Buoys

Partners

Auto-positioned (2018)
Resident UAV (2018)
Network integration (2020)



Challenge: Network of 15 buoys by 2020 in the Portuguese EEZ

THANKS

WavEC
Offshore Renewables

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www.wavec.org

EMRA'15 workshop

CADDY
Cognitive
Autonomous
Diving
Buddy

CADDY
EU PROJECT

Nikola Miskovic, Univ. Zagreb, HR

learning, interpreting, and adapting to the
diver's behaviour and physical state

CADDY

Cognitive Autonomous Diving Buddy

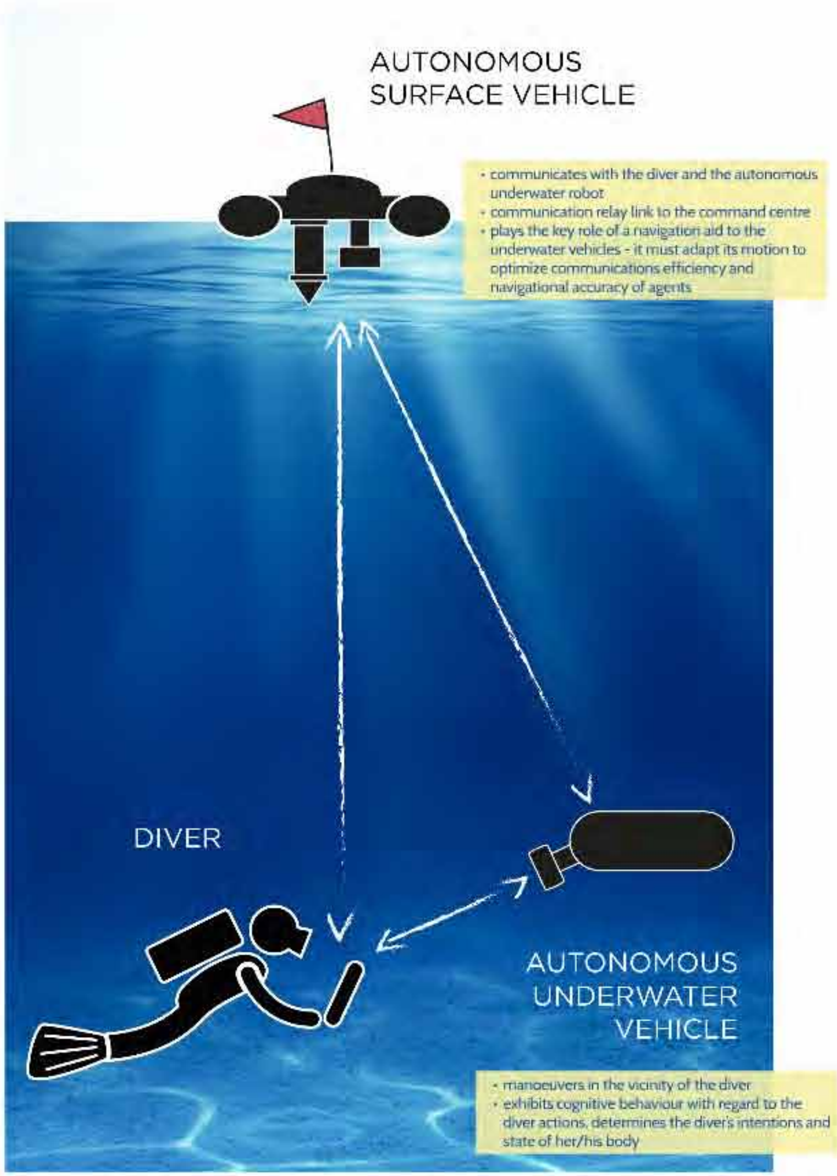
SEVENTH FRAMEWORK PROGRAMME

http://www.caddy-fp7.eu/

Key facts:
FP7-ICT Cognitive Robotics STREP with 7 partners
EU contribution: €3,7 million
Duration: 36 months, starting 01/01/2014
Coordinator: UNIZG-FER

FER
Consiglio Nazionale delle Ricerche
ISR LISBOA
JACOBS UNIVERSITY
universität wien
Newcastle University
DAN EUROPE

- ~1 fix per second



What?

Set up symbiotic links between a human diver and a set of companion autonomous robots (underwater and surface).

How?

By developing a multicomponent, highly cognitive robotic system capable of learning, interpreting, and adapting to the diver's behaviour and physical state

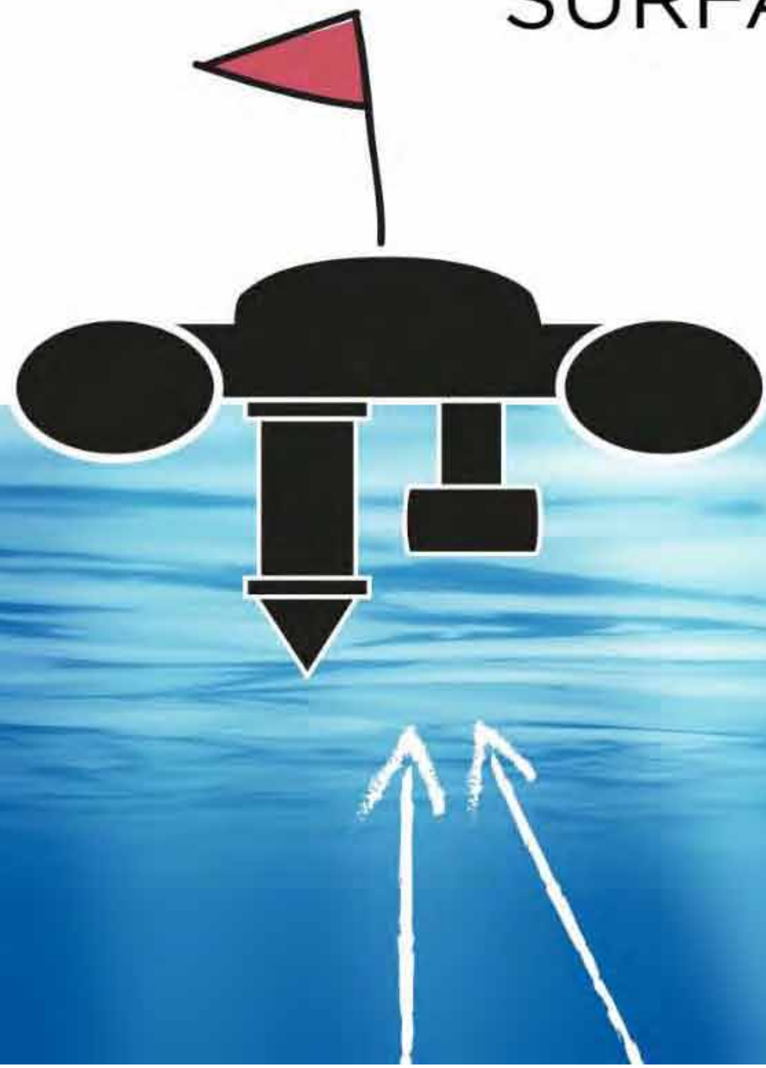
CADDY

Cognitive Autonomous Diving Buddy

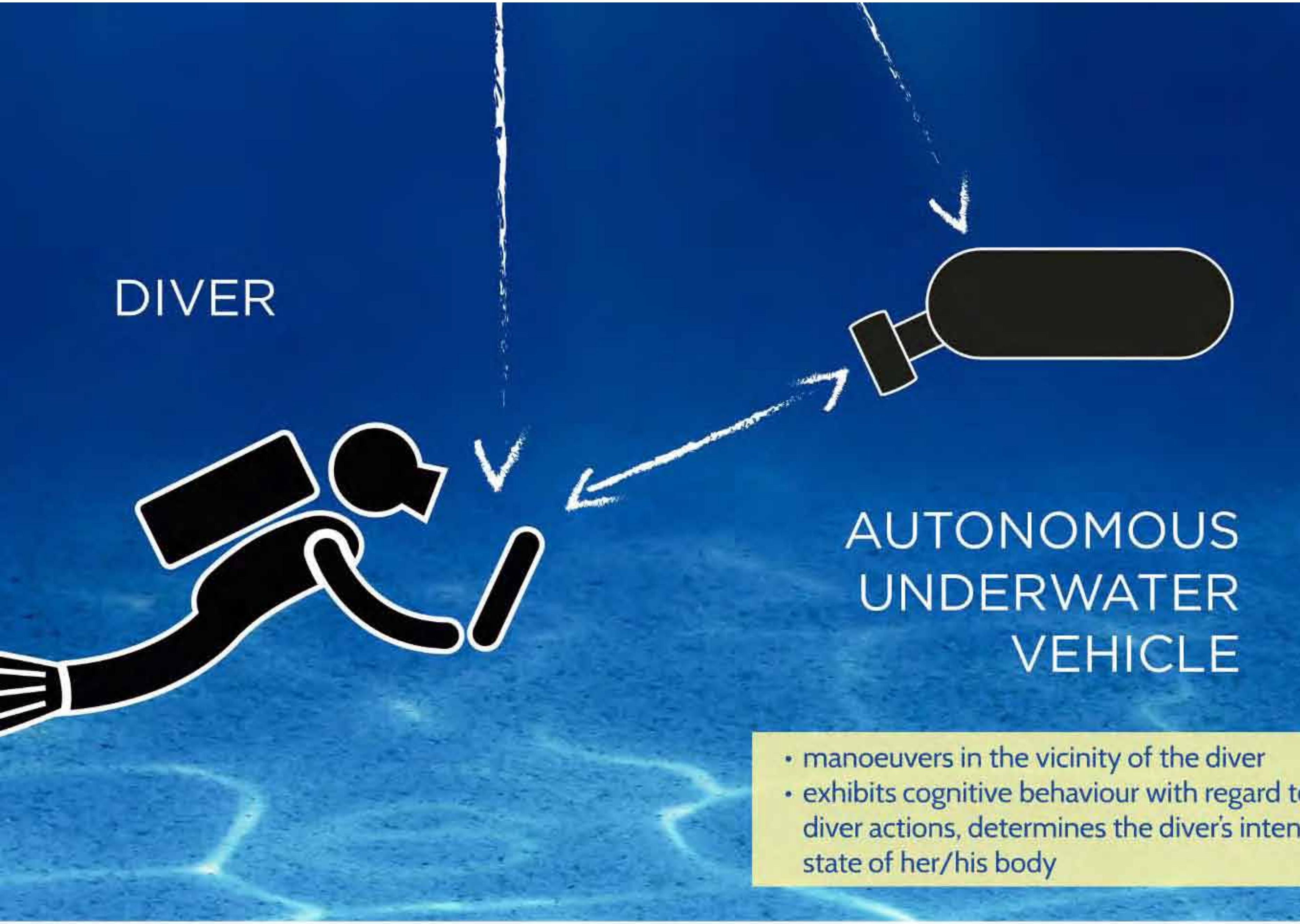
Key facts:

FP7-ICT Cognitive Robotics STREP with 7 partners

AUTONOMOUS SURFACE VEHICLE

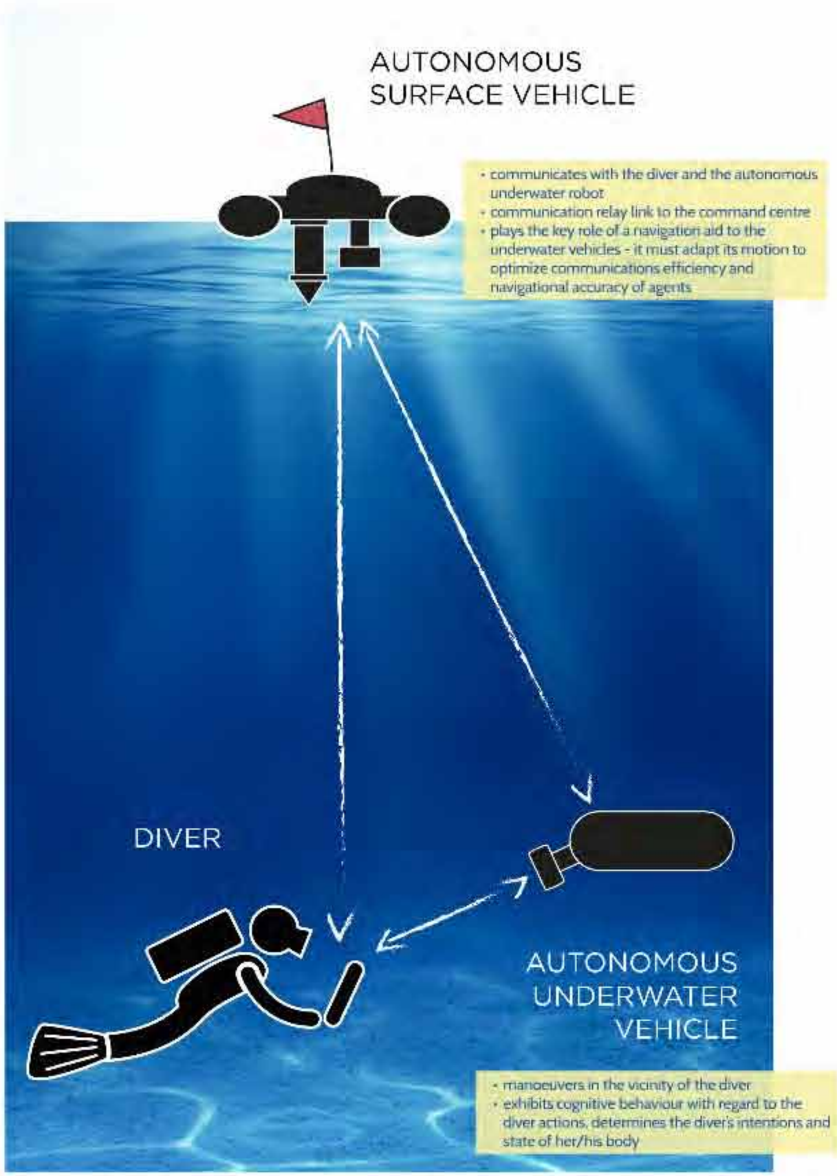


- communicates with the diver and the autonomous underwater robot
- communication relay link to the command centre
- plays the key role of a navigation aid to the underwater vehicles - it must adapt its motion to optimize communications efficiency and navigational accuracy of agents



- manoeuvers in the vicinity of the diver
- exhibits cognitive behaviour with regard to the diver actions, determines the diver's intentions and state of her/his body

- ~1 fix per second



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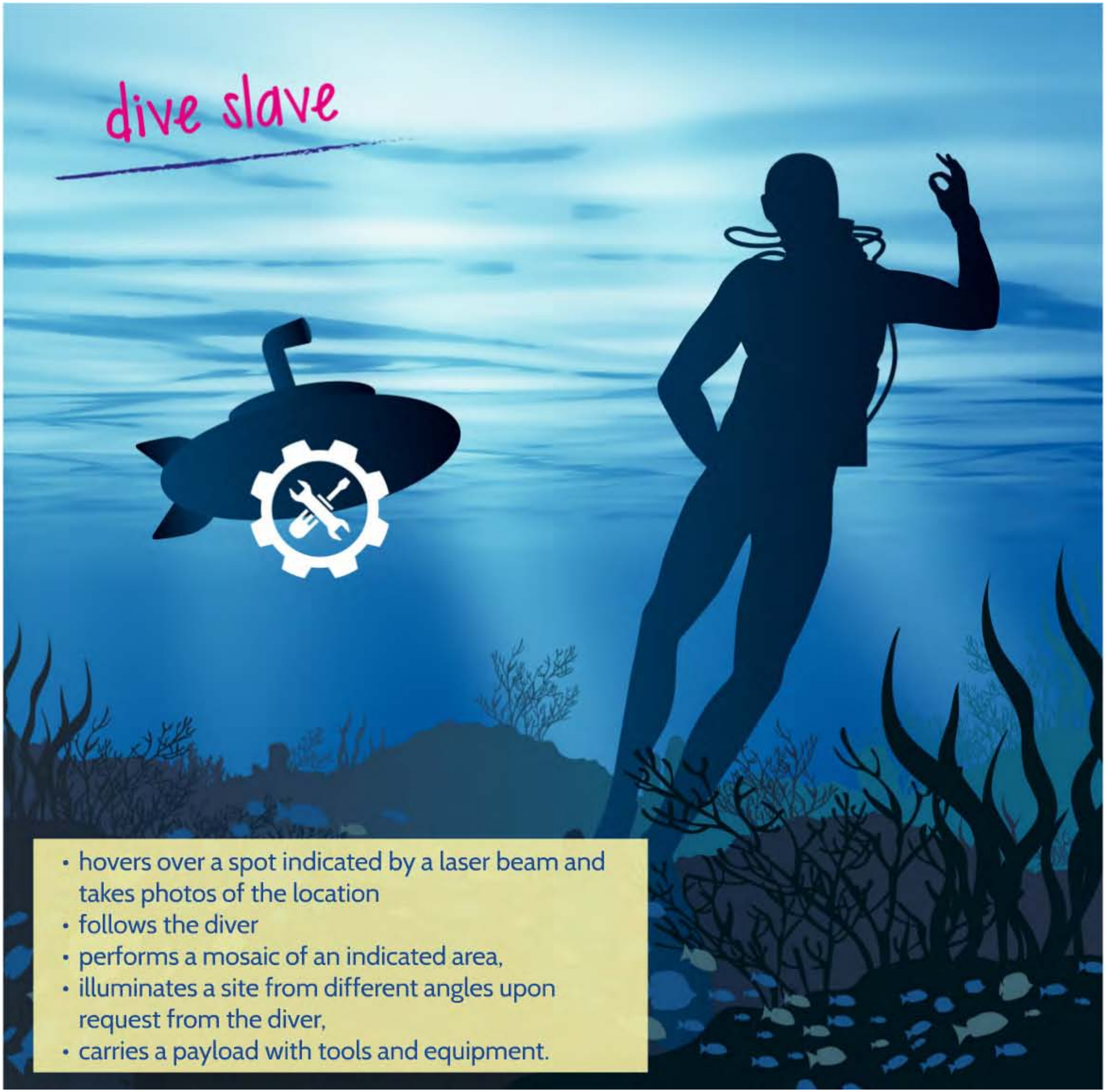
CADDY

Cognitive Autonomous Diving Buddy

Key facts:
FP7-ICT Cognitive Robotics STREP with 7 partners


dive guide
• guides (upon request) the diver from one spot to another, along a predefined search path,
• steers the diver safely to an appropriate point at the surface
• acts as an intelligent communication router in situations where the diver loses line-of-sight to the surface vessel.

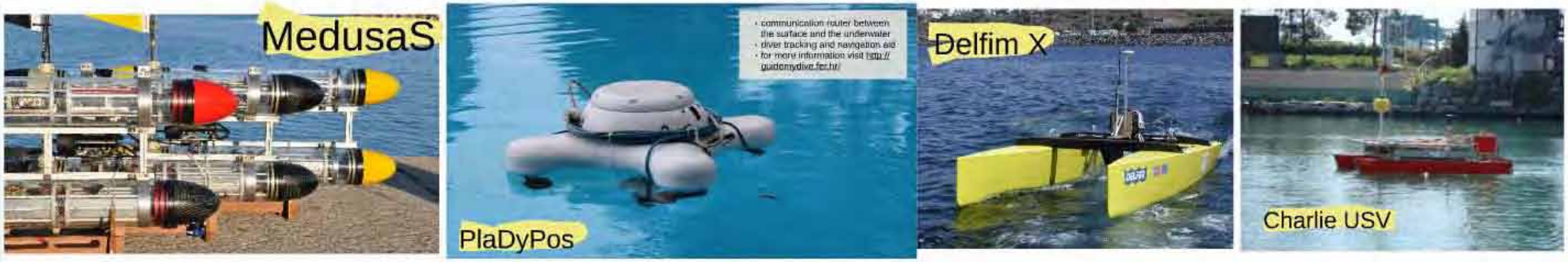

dive observer
• observes the diver at all times
• interprets diver's behaviour and symbolic gestures communicated by the diver.
• manoeuvres safely around the diver in order to assume the best viewpoint for observation;



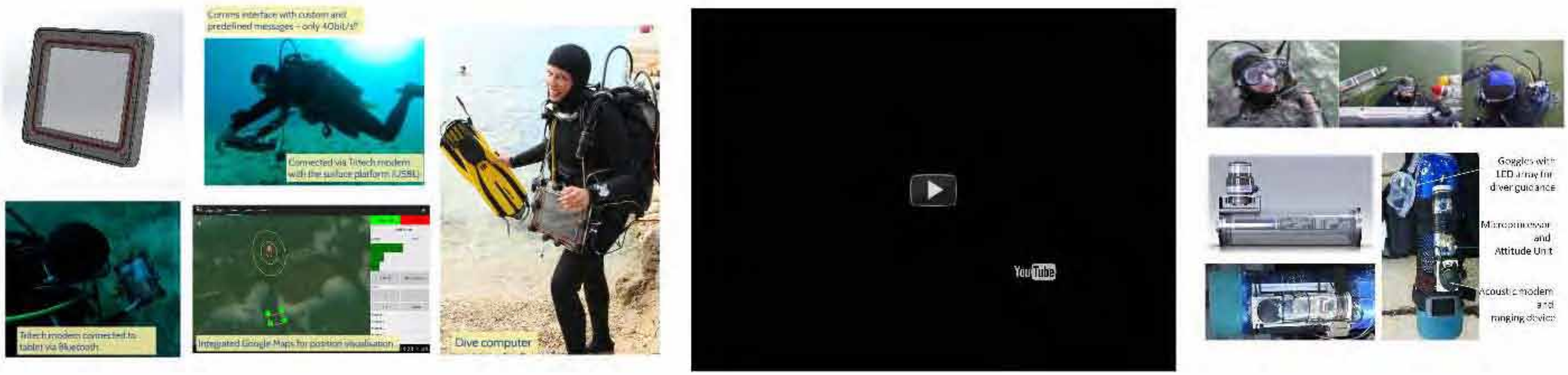
dive slave

- hovers over a spot indicated by a laser beam and takes photos of the location
- follows the diver
- performs a mosaic of an indicated area,
- illuminates a site from different angles upon request from the diver,
- carries a payload with tools and equipment.

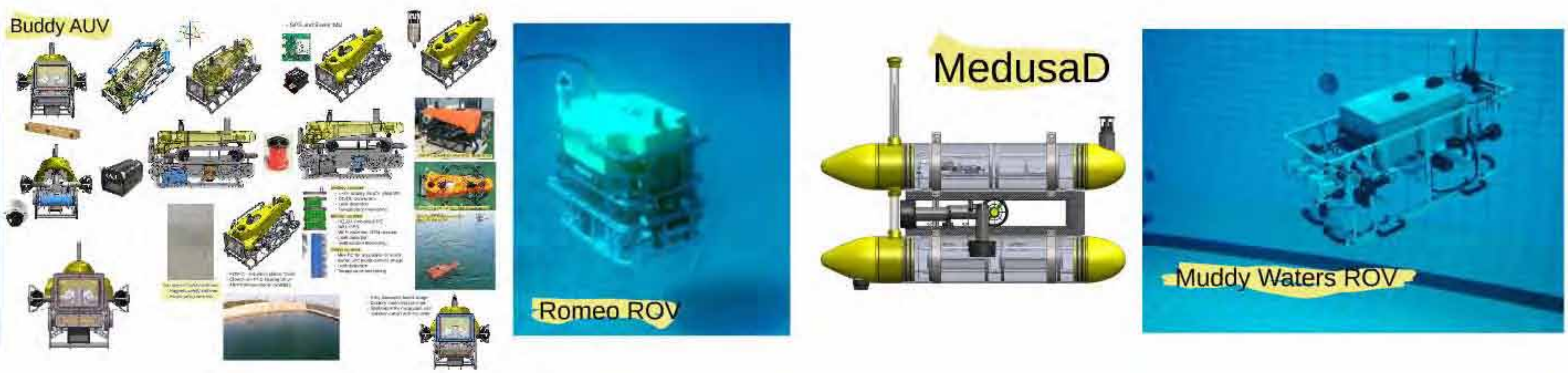
Surface segment

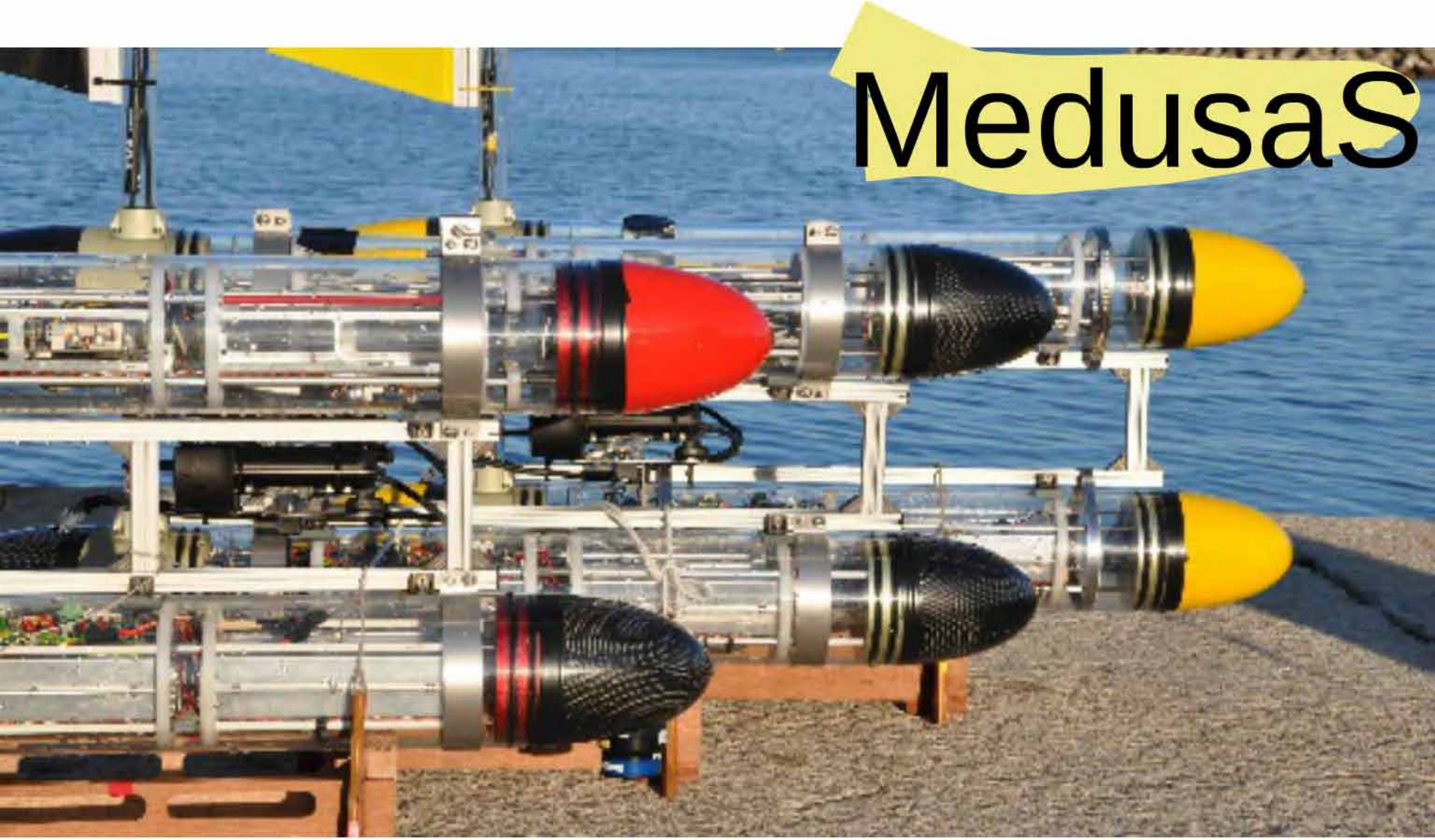


Linking the diver

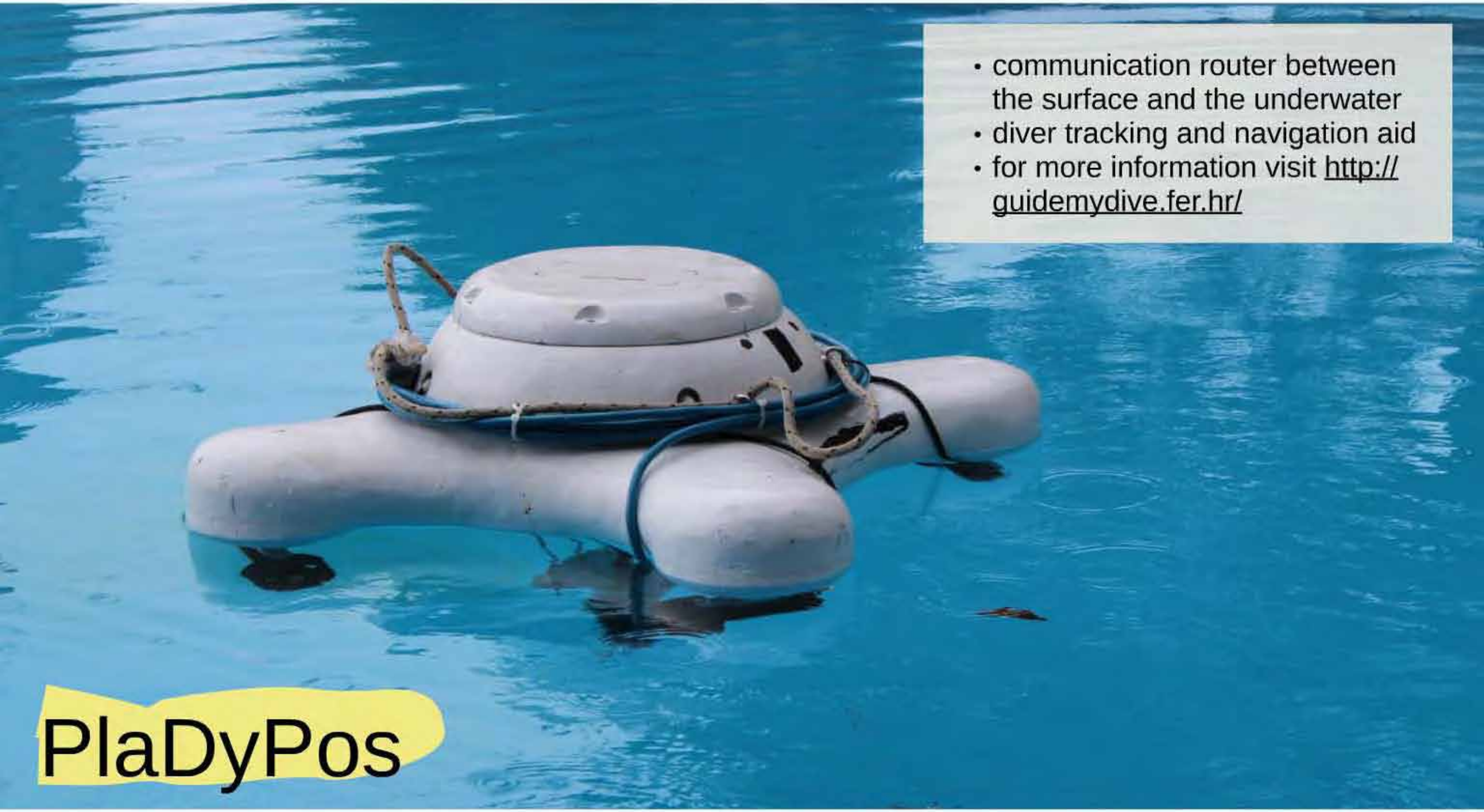


Underwater segment

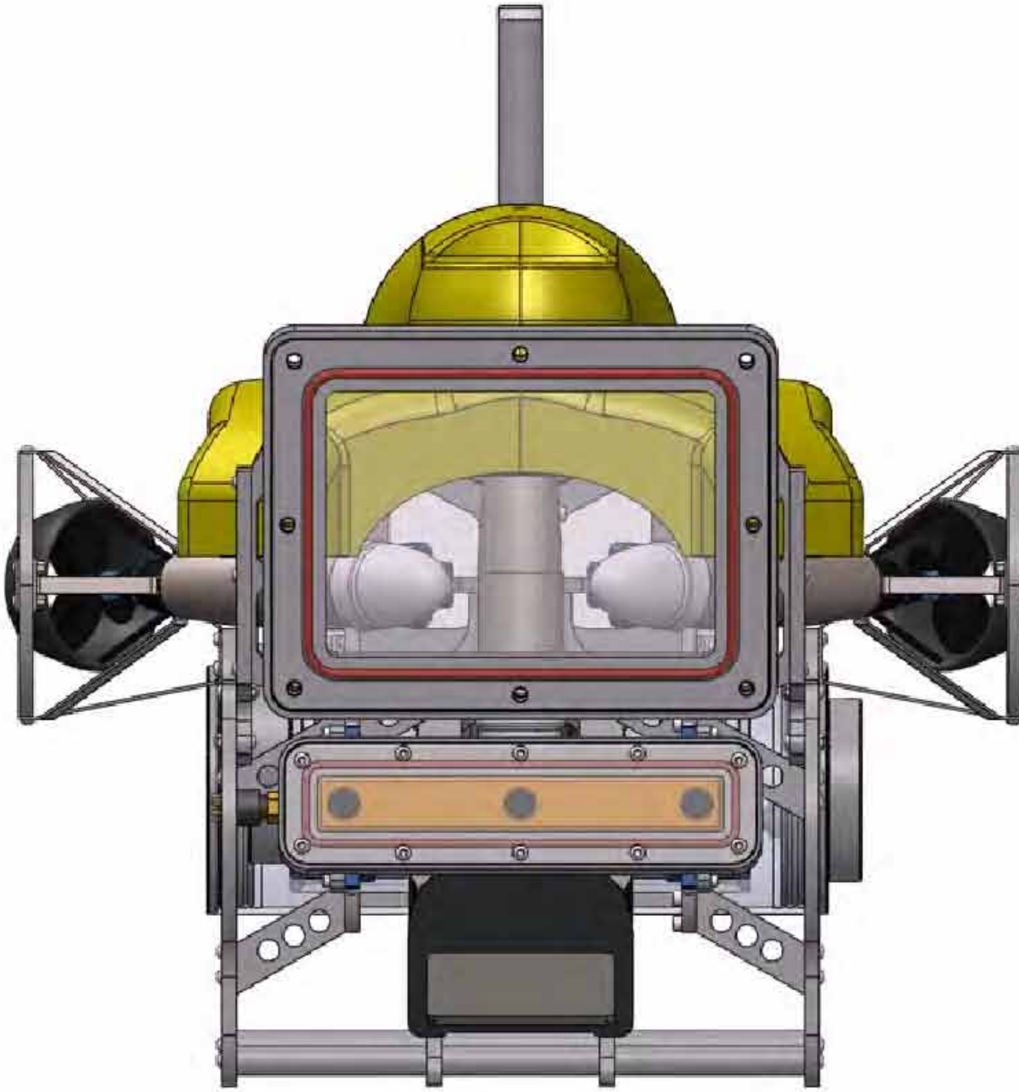



MedusaS

PlaDyPos



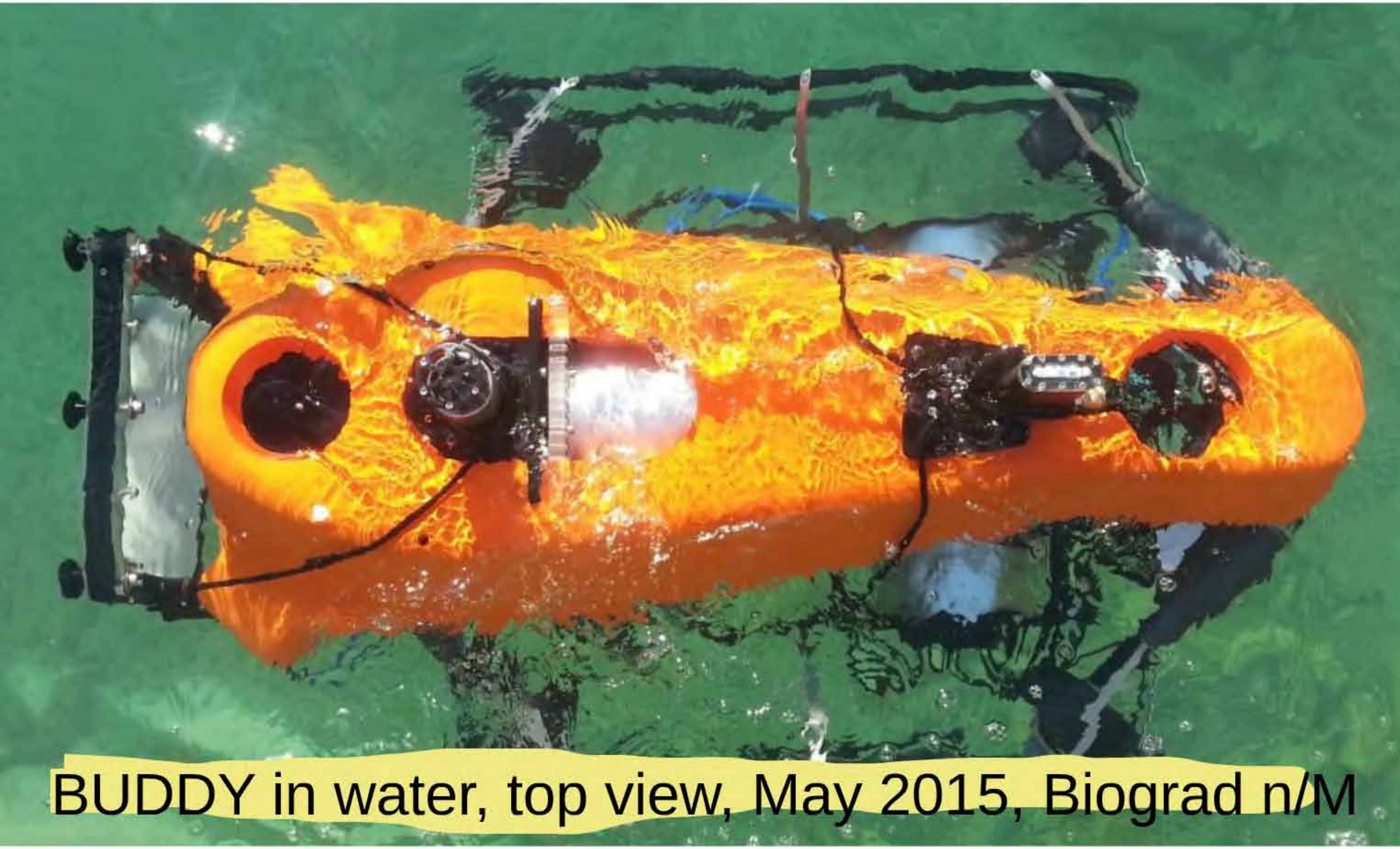
- communication router between the surface and the underwater
- diver tracking and navigation aid
- for more information visit http://guidemydive.fer.hr/



Two types o
- Magneti
- Haptic s

BUDDY assembled, May 2015, Biograd n/M

BUDDY assembled, May 2015, Biograd n/M

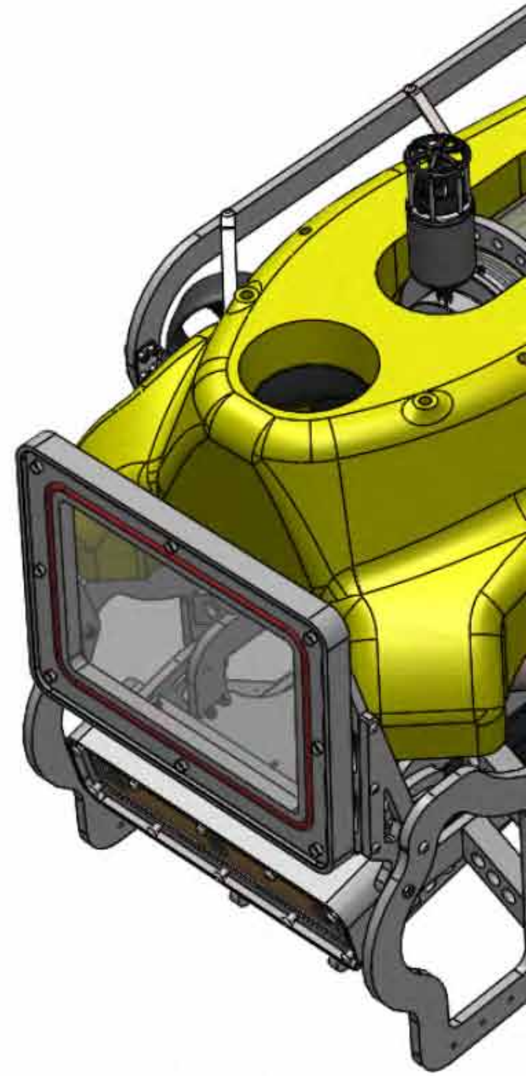


BUDDY in water, top view, May 2015, Biograd n/M

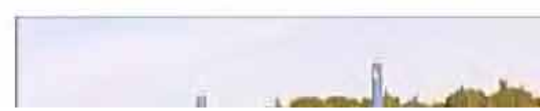
BUDDY and PlaDyPos cooperating,

BUDDY and PlaDyPos cooperating,
May 2015, Biograd n/M

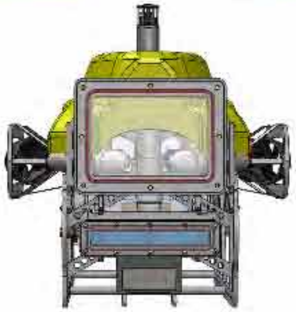
Two types of safety switches:
- Magnetic safety switches
- Haptic safety switches

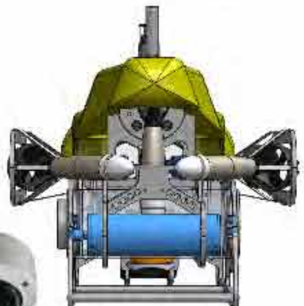


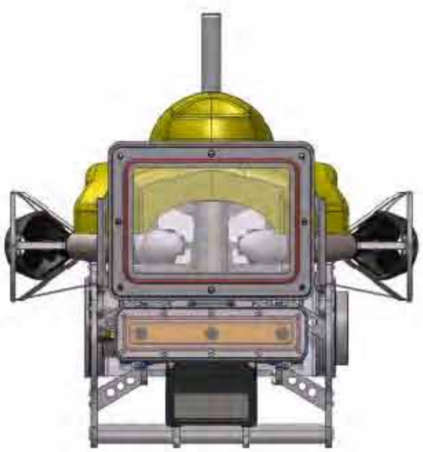
- POM-C - ind
- Closed-cell F
- Aluminum el

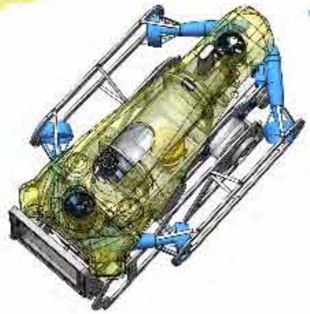


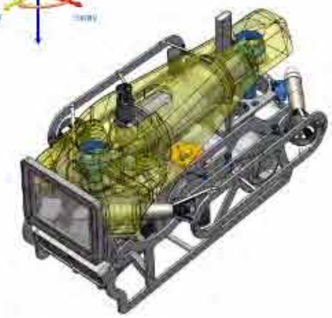
Buddy AUV



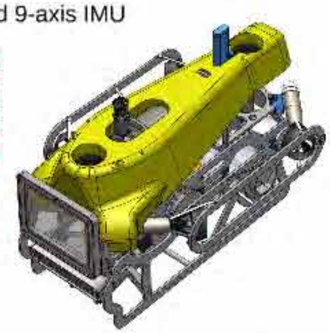


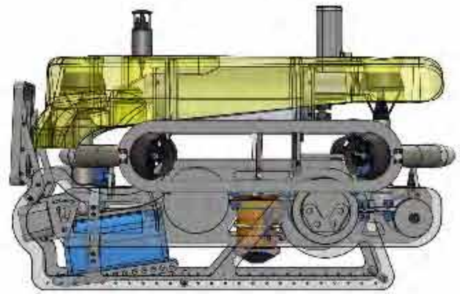


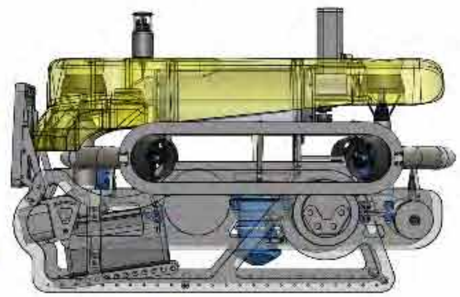




- GPS and 9-axis IMU







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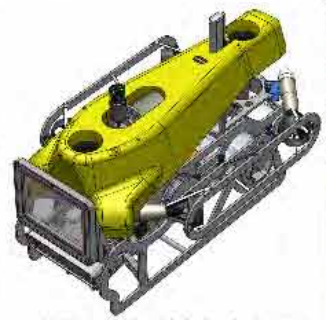


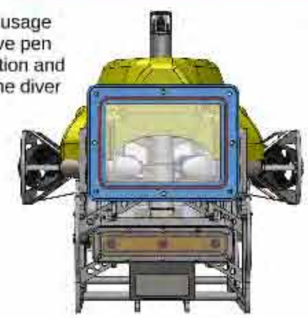
- POM-C - industrial plastic frame
- Closed-cell PVC floating block
- Aluminum electronic canisters

Battery canister
- Li-ion battery 46.8 V, 1160 Wh
- DC/DC converters
- Leak detection
- Temperature monitoring

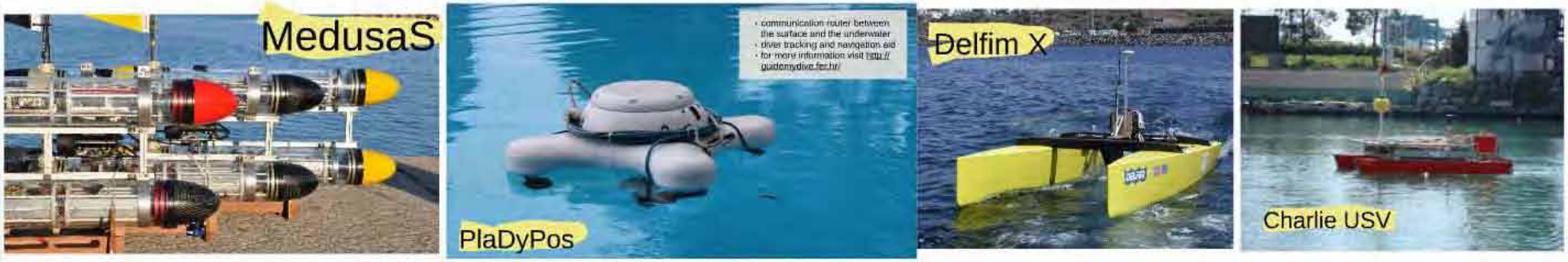
Master canister
- PC104 embedded PC
- IMU, GPS
- Wi-Fi antenna, GSM module
- Leak detection
- Temperature monitoring

Vision canister
- Mini PC for acquisition of sonar, stereo and mono camera image
- Leak detection
- Temperature monitoring

- Fully functional tablet usage
- Custom made inductive pen
- Application for navigation and communication with the diver



Surface segment



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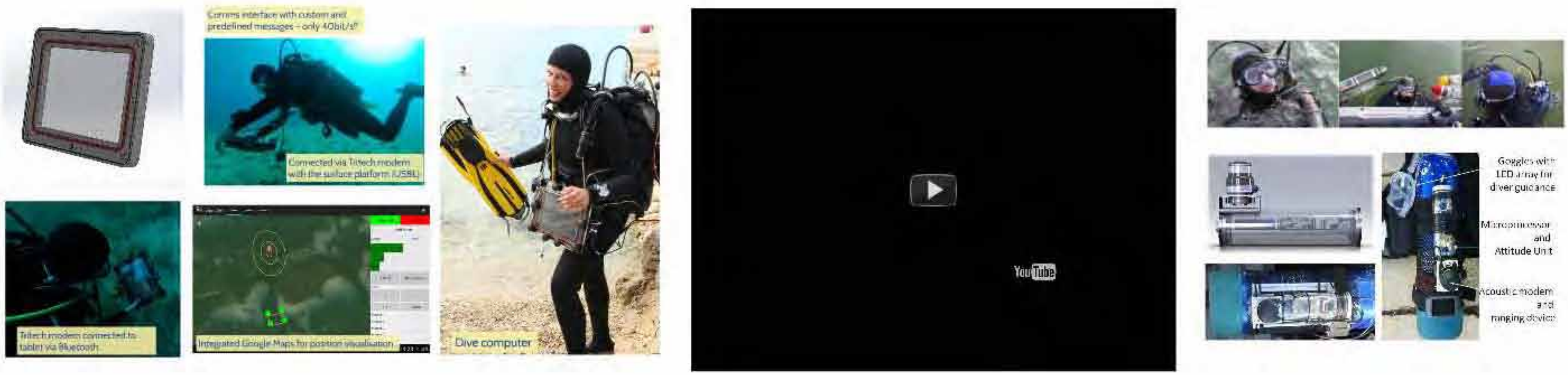
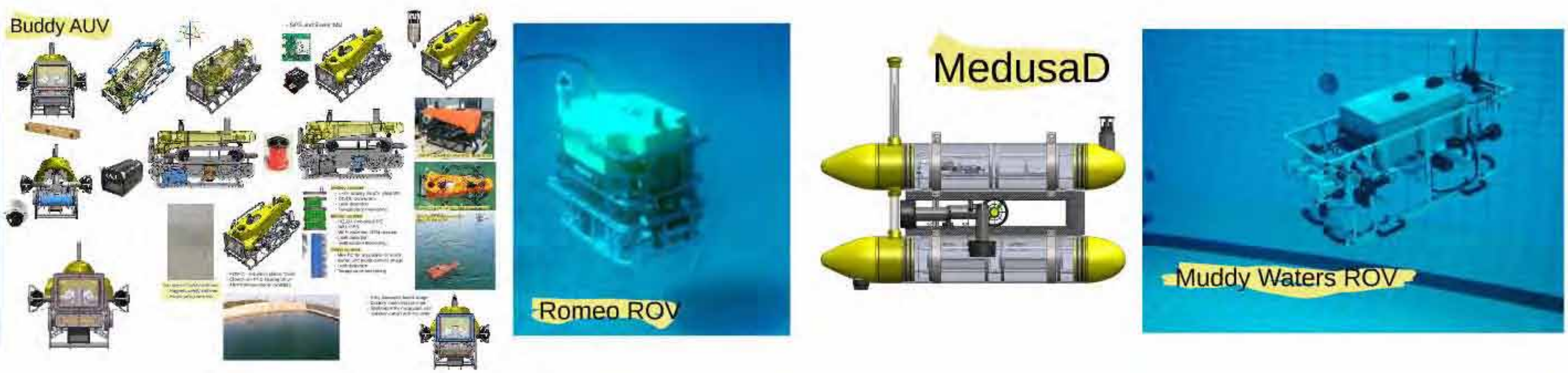


Underwater segment



New miniature modem/USBL

- 100bps data rate
- USBL positioning integrated in all units

Tank tests

- USBL fix repeatability assessed (<< 1 deg).
- Range repeatability <10cm.
- ~1 fix per second

WP1 Multicomponent system

New miniature modem/USBL
- 100bps data rate
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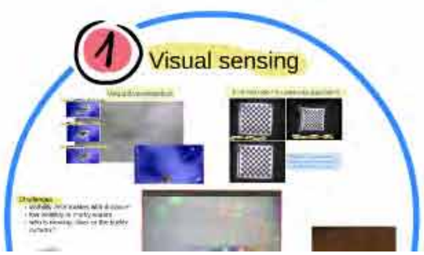
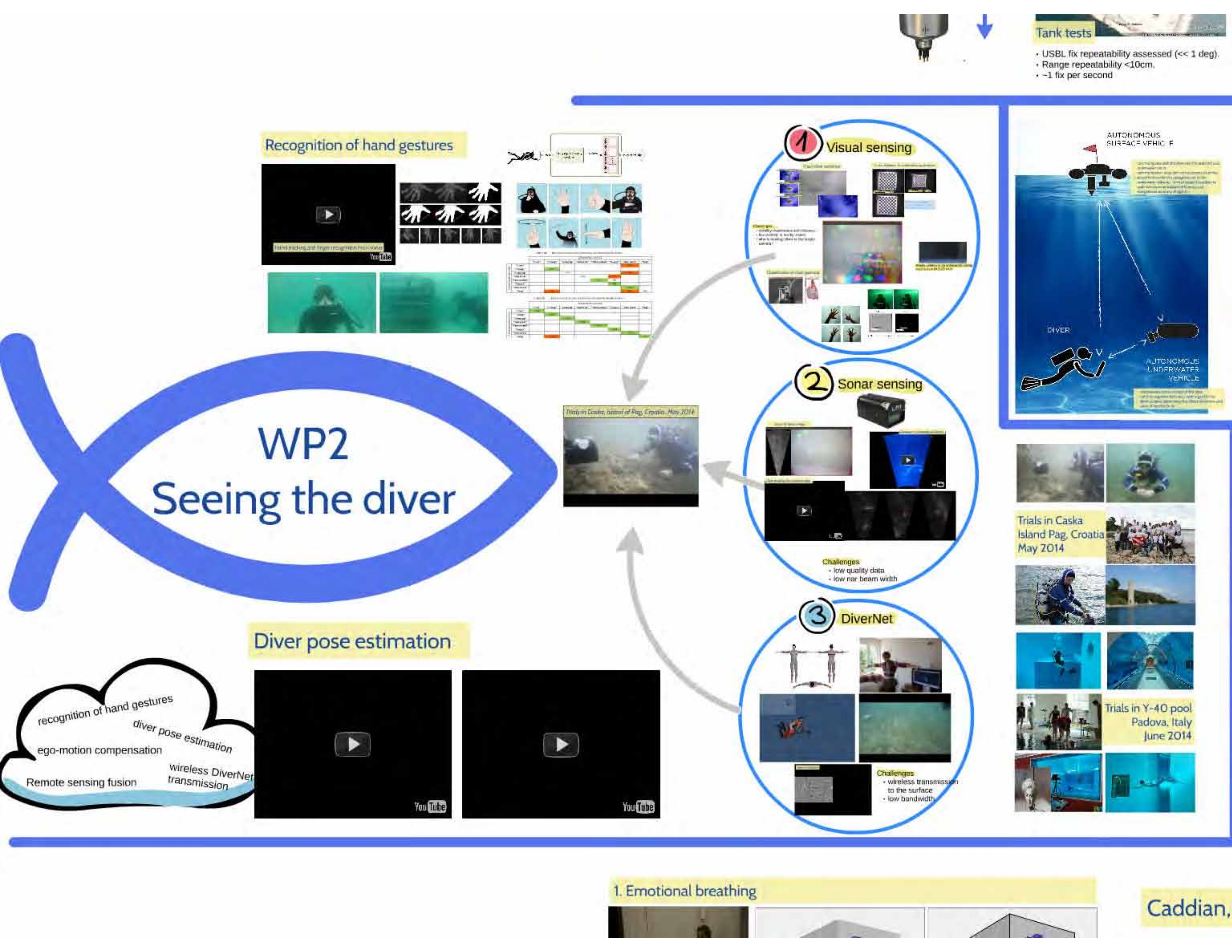


What?
Set up symbiotic links between a human diver and a set of companion autonomous robots (underwater and surface).

How?
By developing a multicomponent, highly cognitive robotic system capable of



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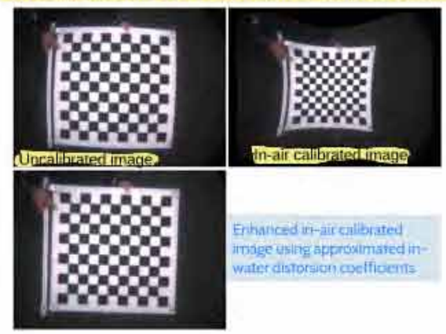
• ~1 fix per second
Recognition of hand gestures
AUTONOMOUS SURFACE VEHICLE
DIVER
AUTONOMOUS UNDERWATER VEHICLE
1 Visual sensing
2 Sonar sensing
Challenges
• low quality data
• low nar beam width
3 DiverNet
Challenges
• wireless transmission to the surface
• low bandwidth
Trials in Caska, Island of Pag, Croatia, May 2014
WP2
Seeing the diver
Trials in Caska
Island Pag, Croatia
May 2014
Trials in Y-40 pool
Padova, Italy
June 2014
Diver pose estimation
recognition of hand gestures
diver pose estimation
ego-motion compensation
wireless DiverNet transmission
Remote sensing fusion
1. Emotional breathing
Caddian,

1 Visual sensing

Visual diver detection

In-air calibration for underwater applications

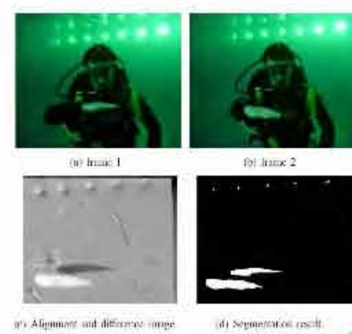


Challenges

- visibility deteriorates with distance
- low visibility in murky waters
- who is moving: diver or the buddy camera?

Stereo camera in an underwater casing mounted on BUDDY AUV

Classification of diver gestures



Visual diver detection

Stereo camera in an underwater casing mounted on BUDDY AUV

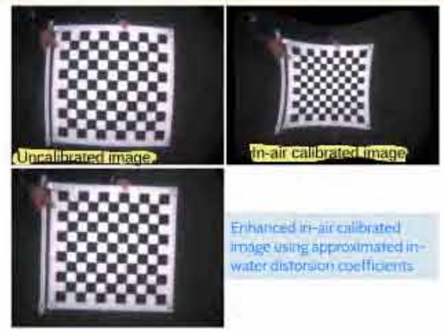

/camera/image_raw

Diver pose estimation

Visual sensing

Visual diver detection

In-air calibration for underwater applications



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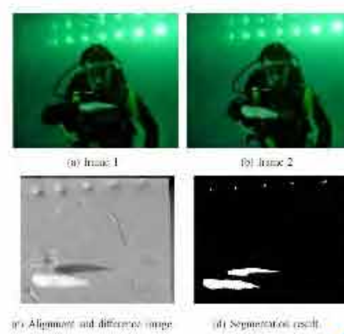
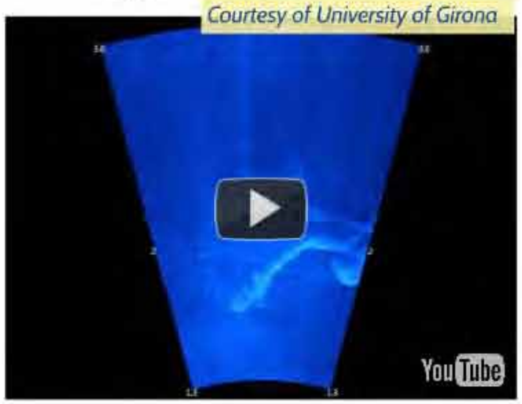
Classification of diver gestures



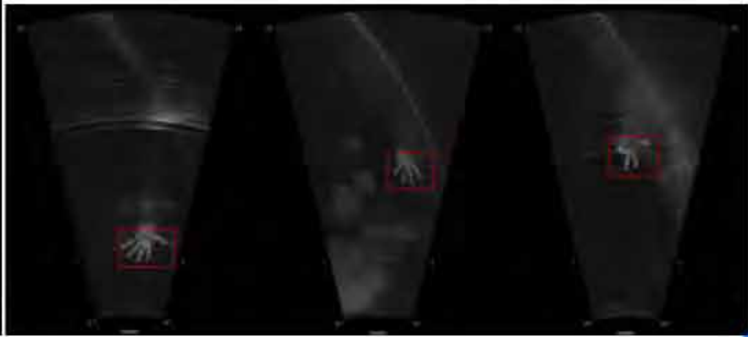
2 Sonar sensing

Sonar vs stereo image

Courtesy of University of Girona



Diver tracking from sonar image

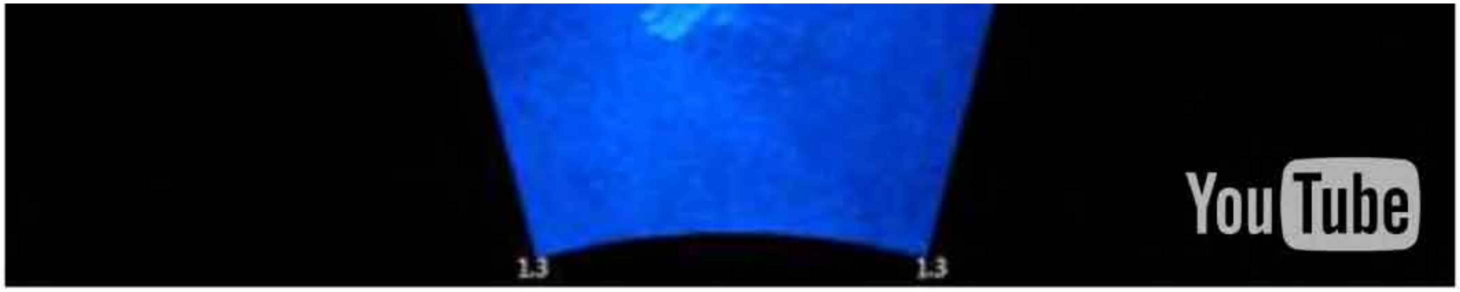


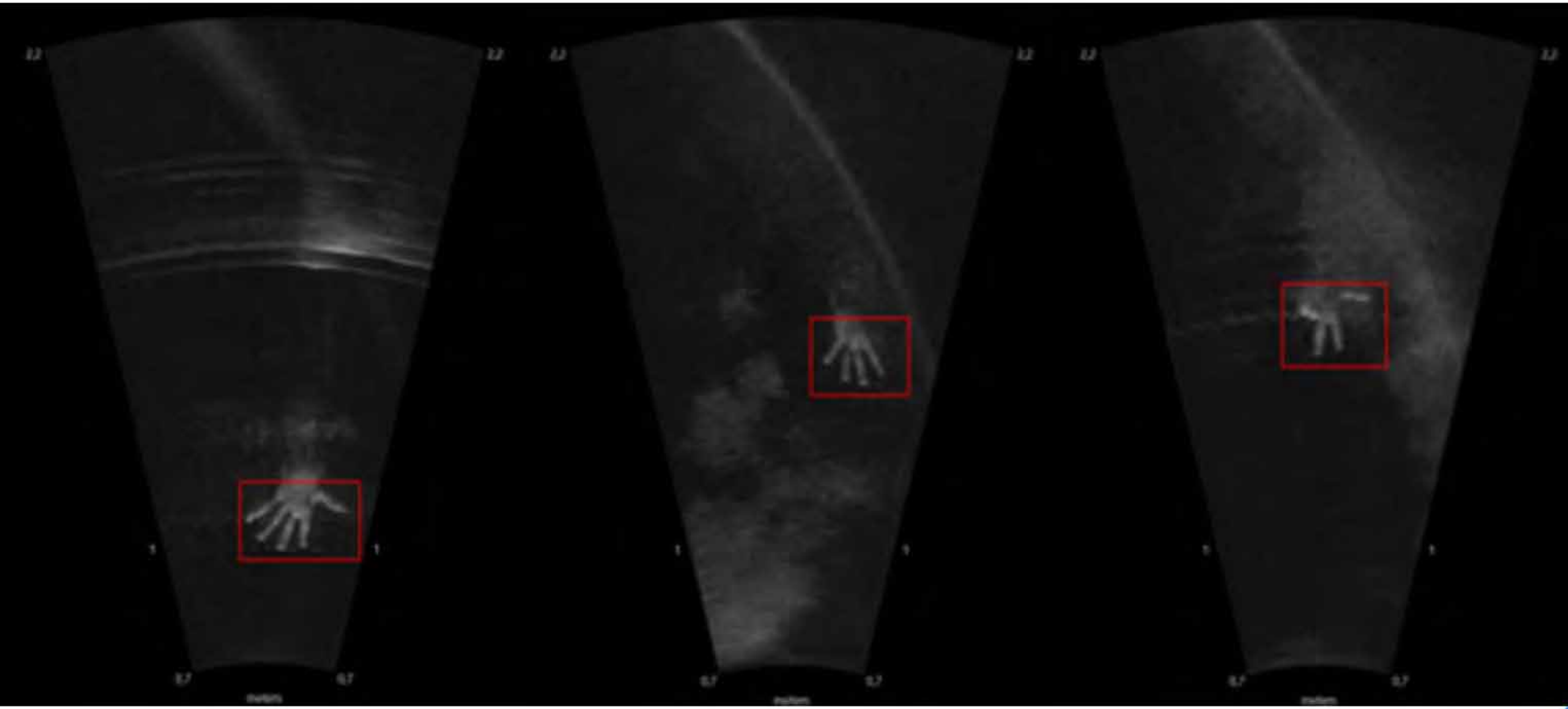
Challenges

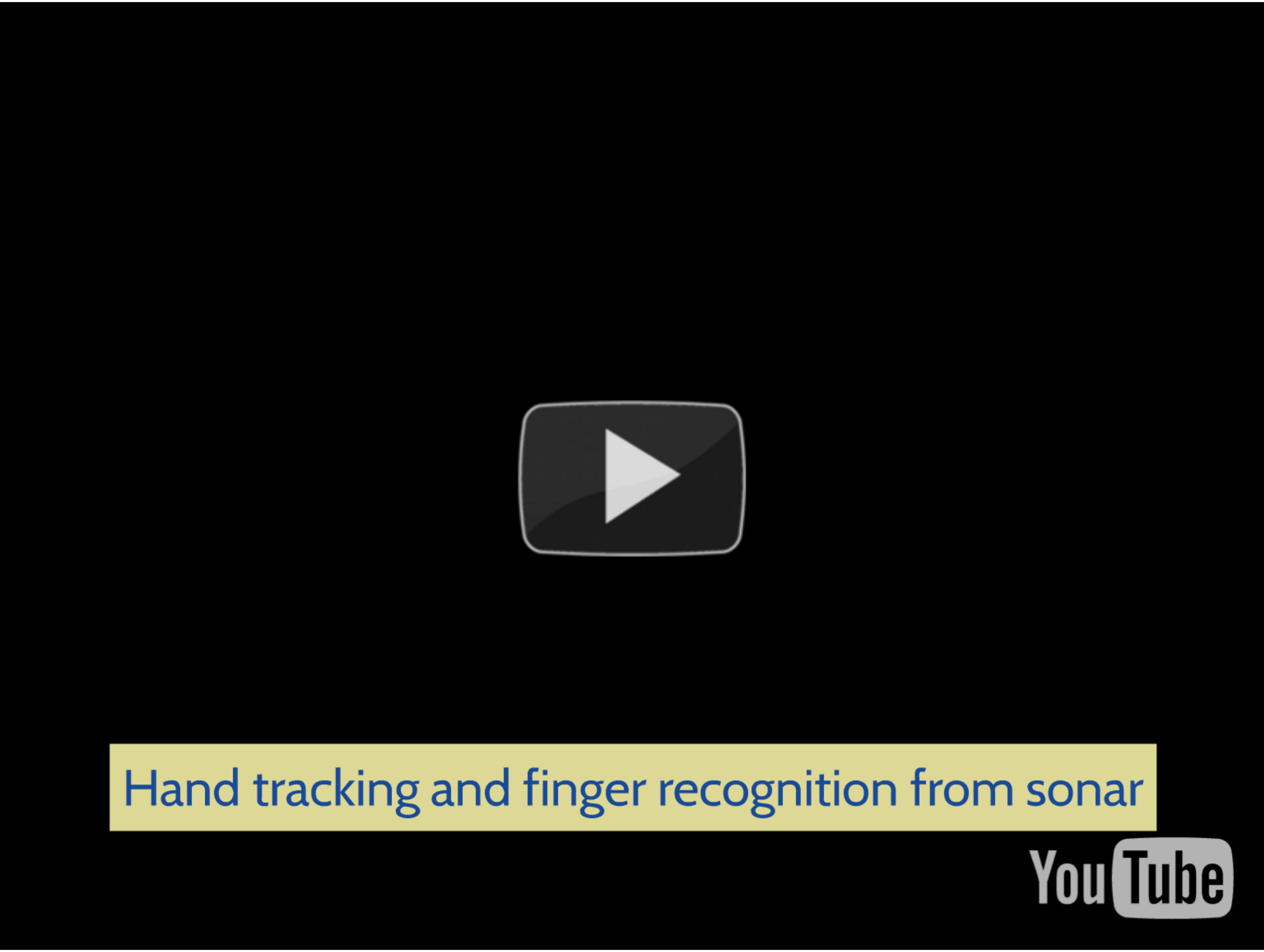
- low quality data
- low nar beam width

Sonar vs stereo image

Diver tracking from sonar image

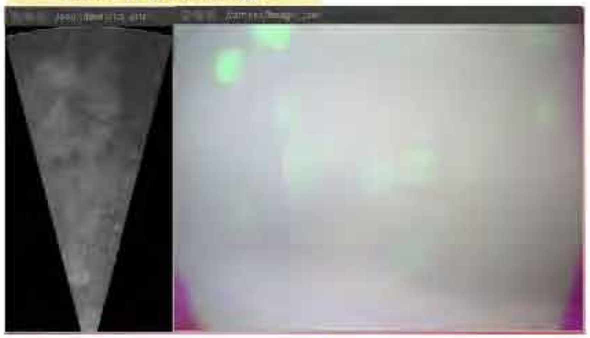

1.3
1.3



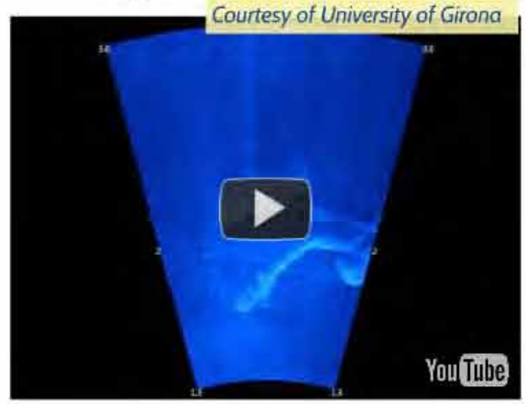

Hand tracking and finger recognition from sonar

(2) Sonar sensing

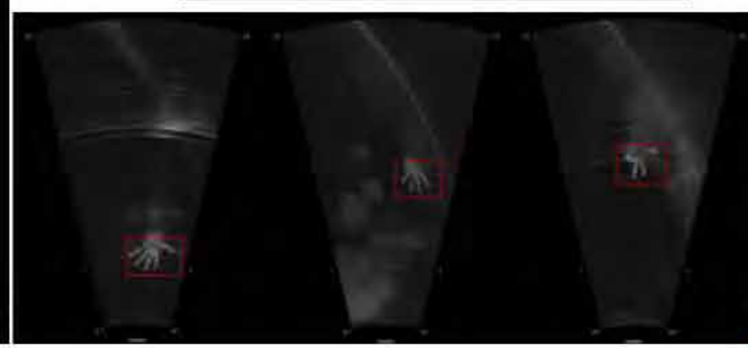
Sonar vs stereo image



Courtesy of University of Girona



Diver tracking from sonar image

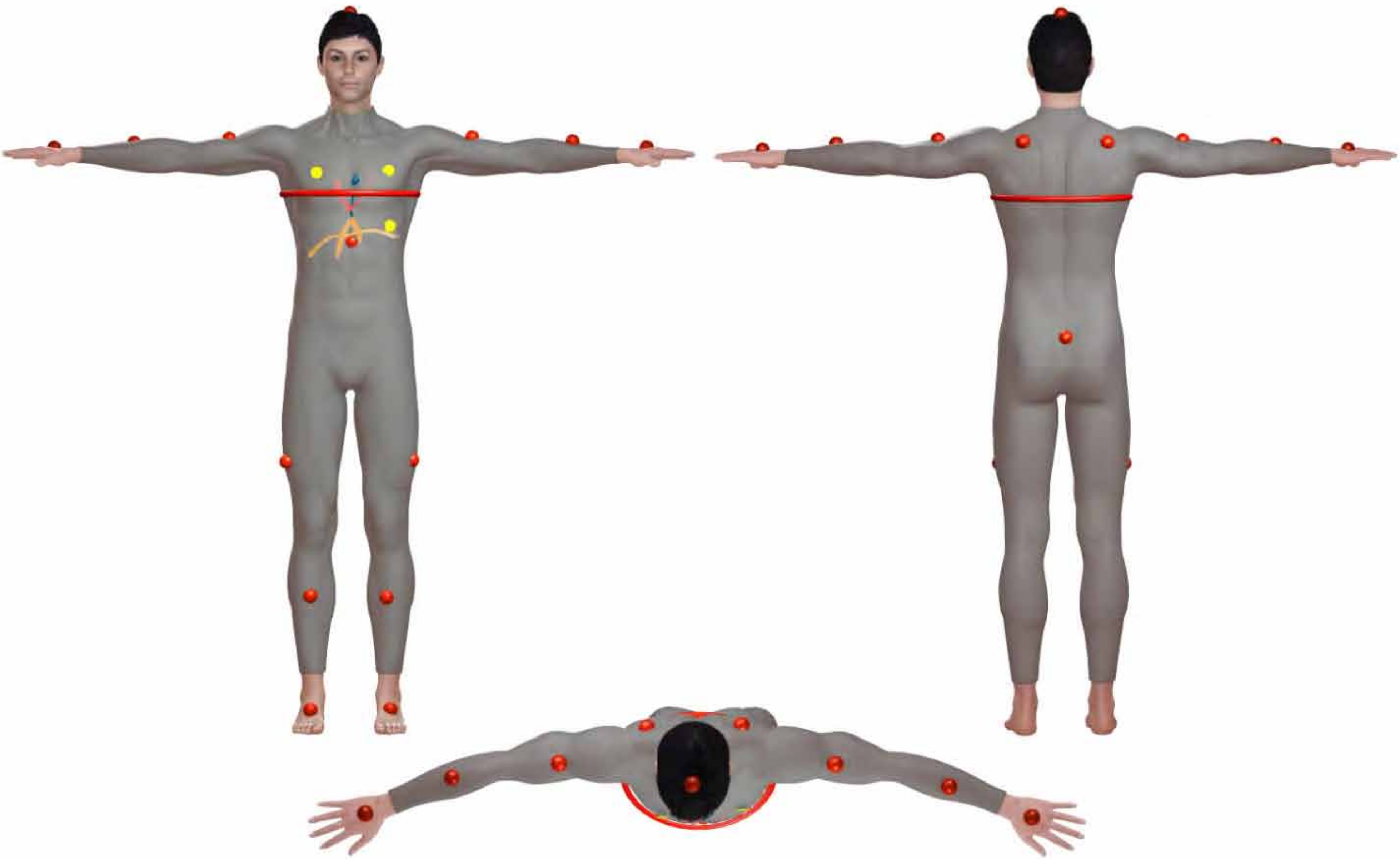


Challenges
- low quality data
- low nar beam width

3 DiverNet

Challenges

- wireless transmission to the surface
- low bandwidth



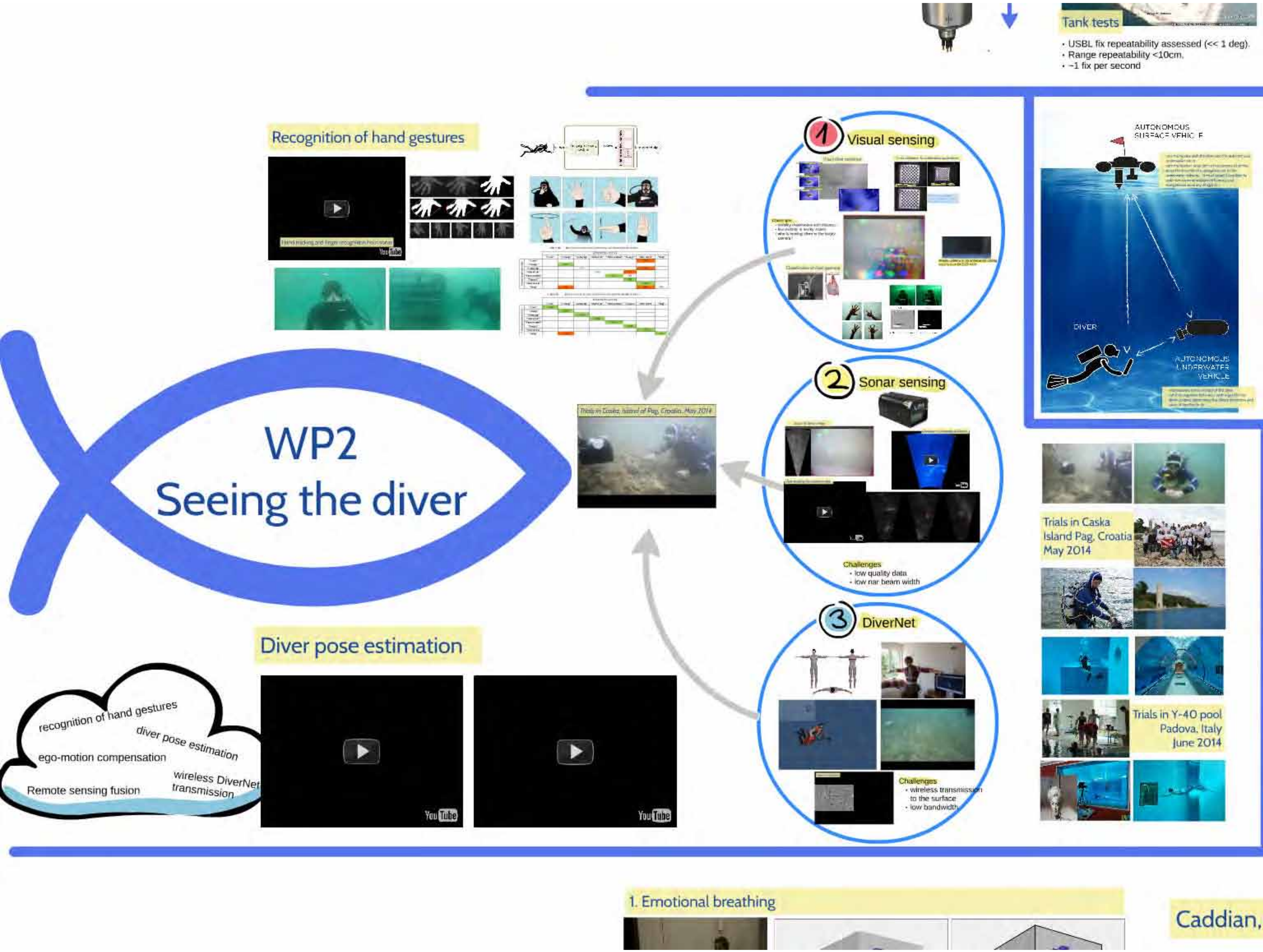

CADDY

DiverNet calibration

3 DiverNet

Challenges

- wireless transmission to the surface
- low bandwidth



Tank tests
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DIVER
AUTONOMOUS UNDERWATER VEHICLE
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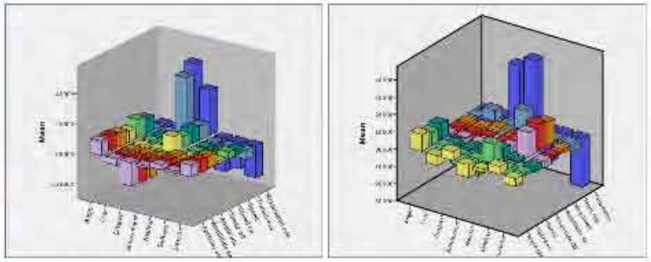
ego-motion compensation
wireless DiverNet transmission
Remote sensing fusion
1. Emotional breathing
Caddian,

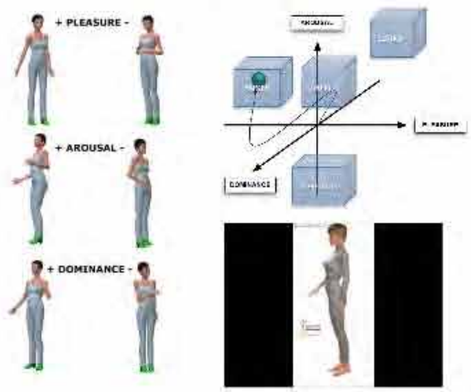
1. Emotional breathing



Parameters	Anger	Fear	Disgust	Amusement	Sadness	Surprise
Respiration rate	→	→	↑	↑	→	→
Resp. Turbulence	↓	→	↑	↑	→	→
Heart rate	↓	→	↓	→	→	↓
Heart Turbulence	→	→	↑	↑	→	→

2. Breathing through regulator

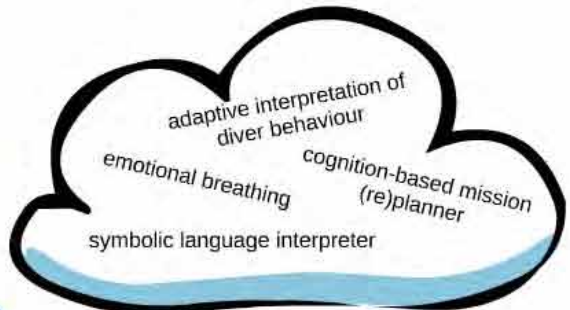
3. Internal states and posture



Caddian, the diver-robot language

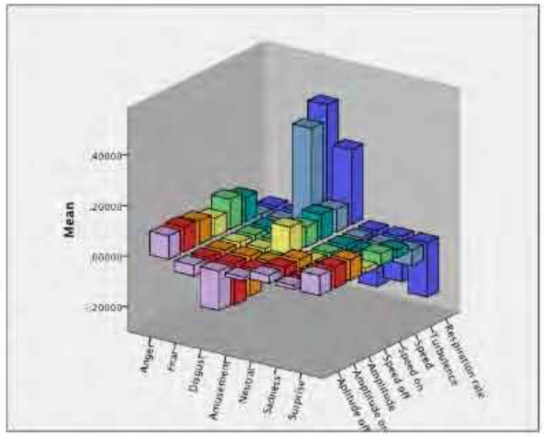
"I follow you" (i.e. You lead) ↔ A I F Y ∀

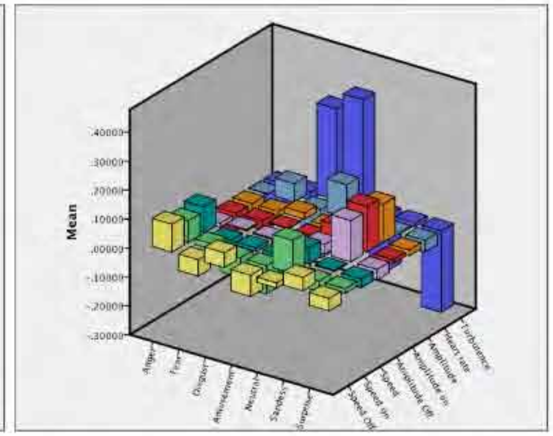
SYNTAX	A	I	F	Y	∀
GESTURES					
SEMANTICS	I follow you				



WP3 Understanding the diver

1. Emotional breathing

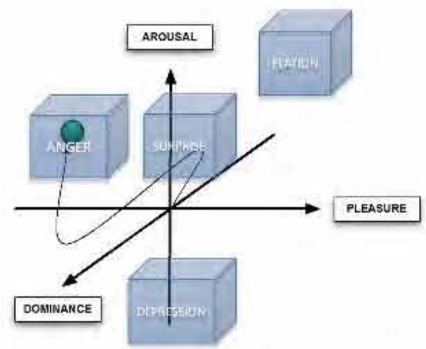




Parameters	Anger	Fear	Disgust	Amusement	Sadness	Surprise
Respiration rate	→	→	↑	↑	→	→
Resp. Turbulence	↓	→	↑	↑	→	→
Heart rate	↓	→	↓	→	→	↓
Heart Turbulence	→	→	↑	↑	→	→

2. Breathing through regulator

3. Internal states and posture

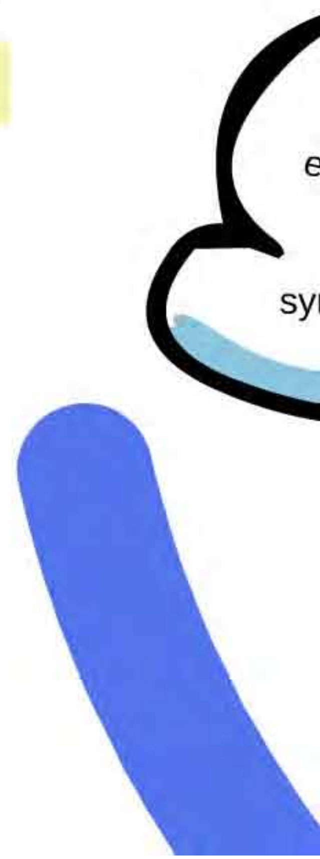


Cado

SYNTAX

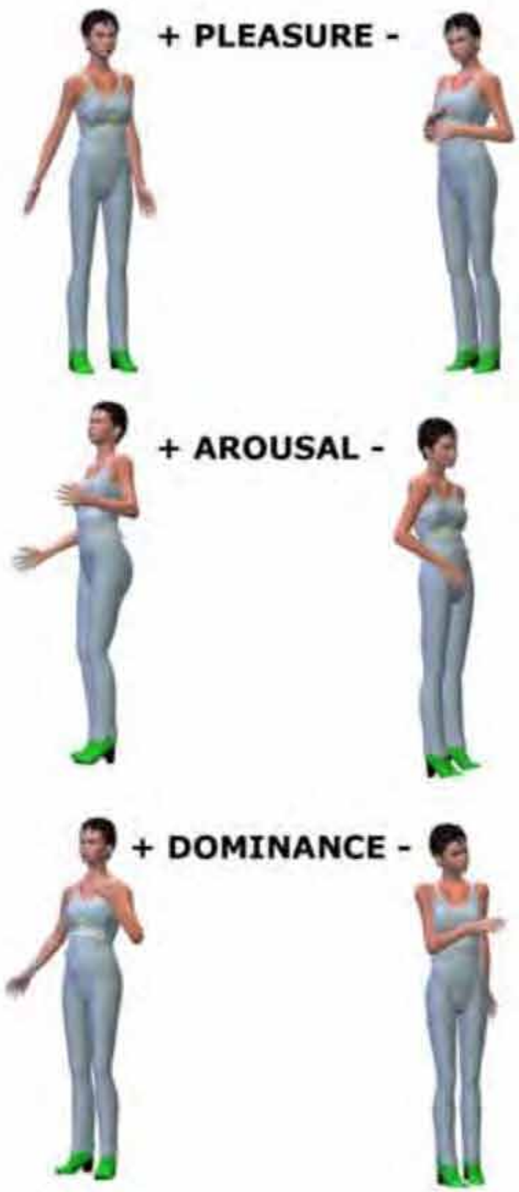
GESTURE

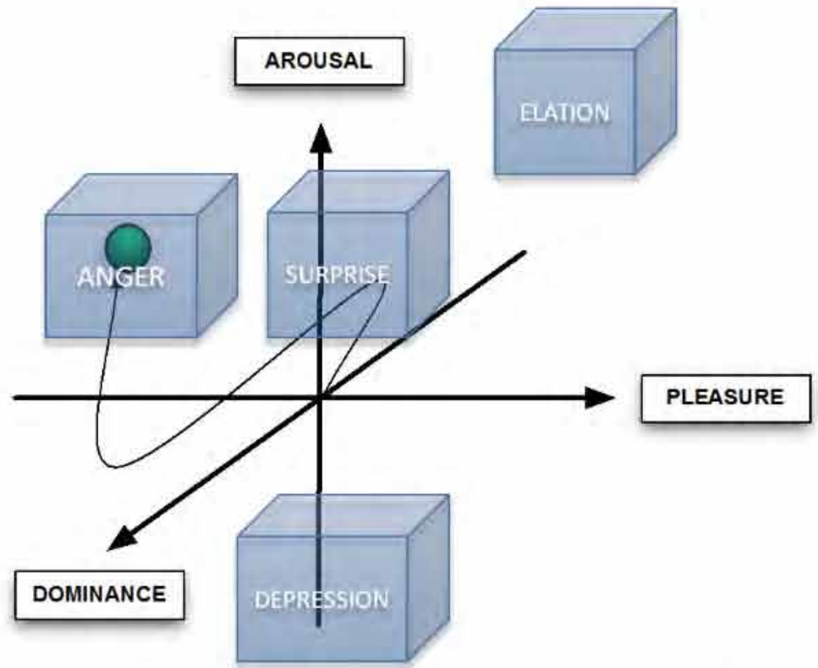
SEMANT



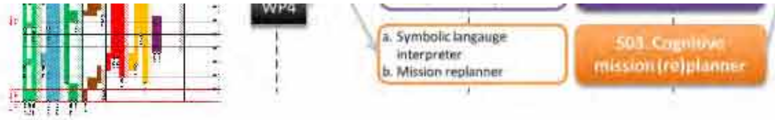
or

3. Internal states and posture






p_-1_a_-1_d_-1
Department of
Anthropology

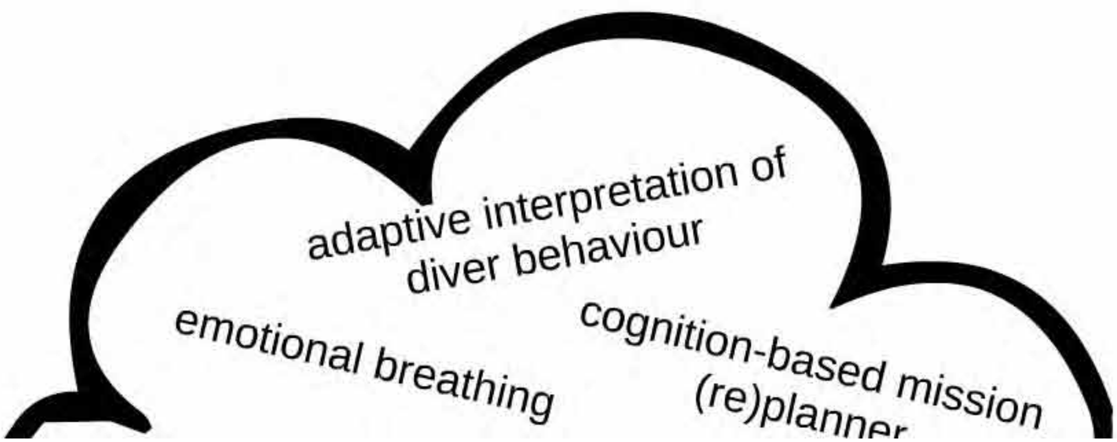


- Interprets command
- executes (photo s, v
- Reports m

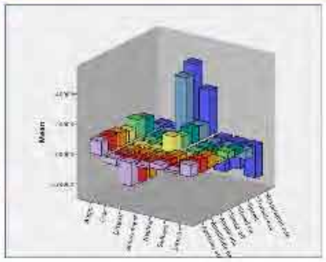
Caddian, the diver-robot language

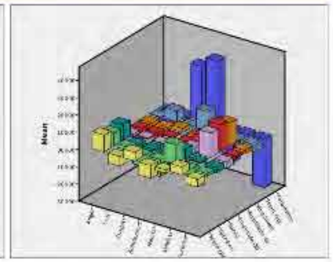
"I follow you" (i.e. You lead) ↔ A I F Y ∀

SYNTAX	**A**	**I**	**F**	**Y**	**∀**
GESTURES					
SEMANTICS	**I follow you**				



1. Emotional breathing

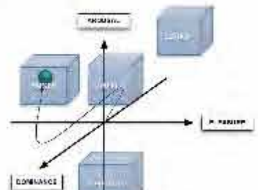




Parameters	Anger	Fear	Disgust	Amusement	Sadness	Surprise
Respiration rate	→	→	↑	↑	→	→
Resp. Turbulence	↓	→	↑	↑	→	→
Heart rate	↓	→	↓	→	→	↓
Heart Turbulence	→	→	↑	↑	→	→

2. Breathing through regulator

3. Internal states and posture



Caddian, the diver-robot language

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SYNTAX	A	I	F	Y	∀
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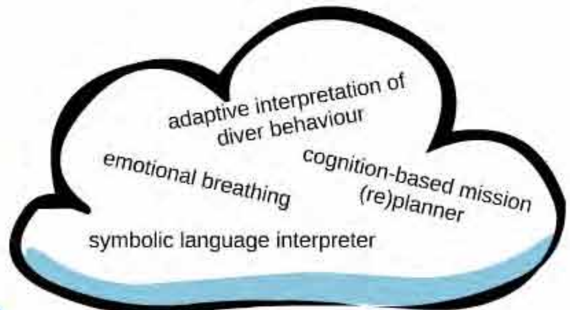
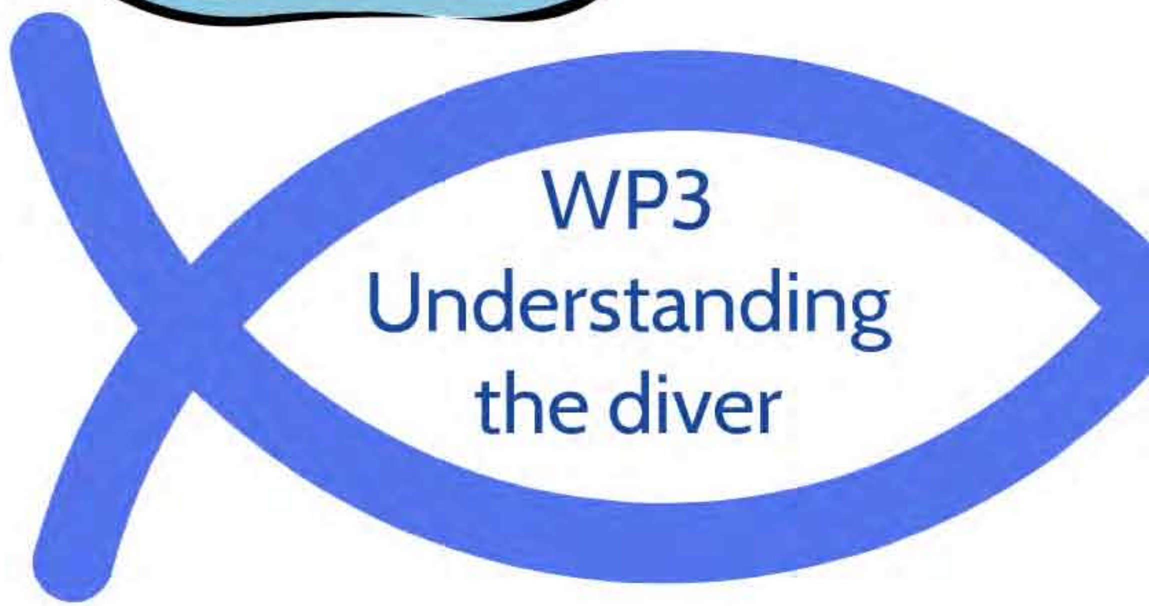
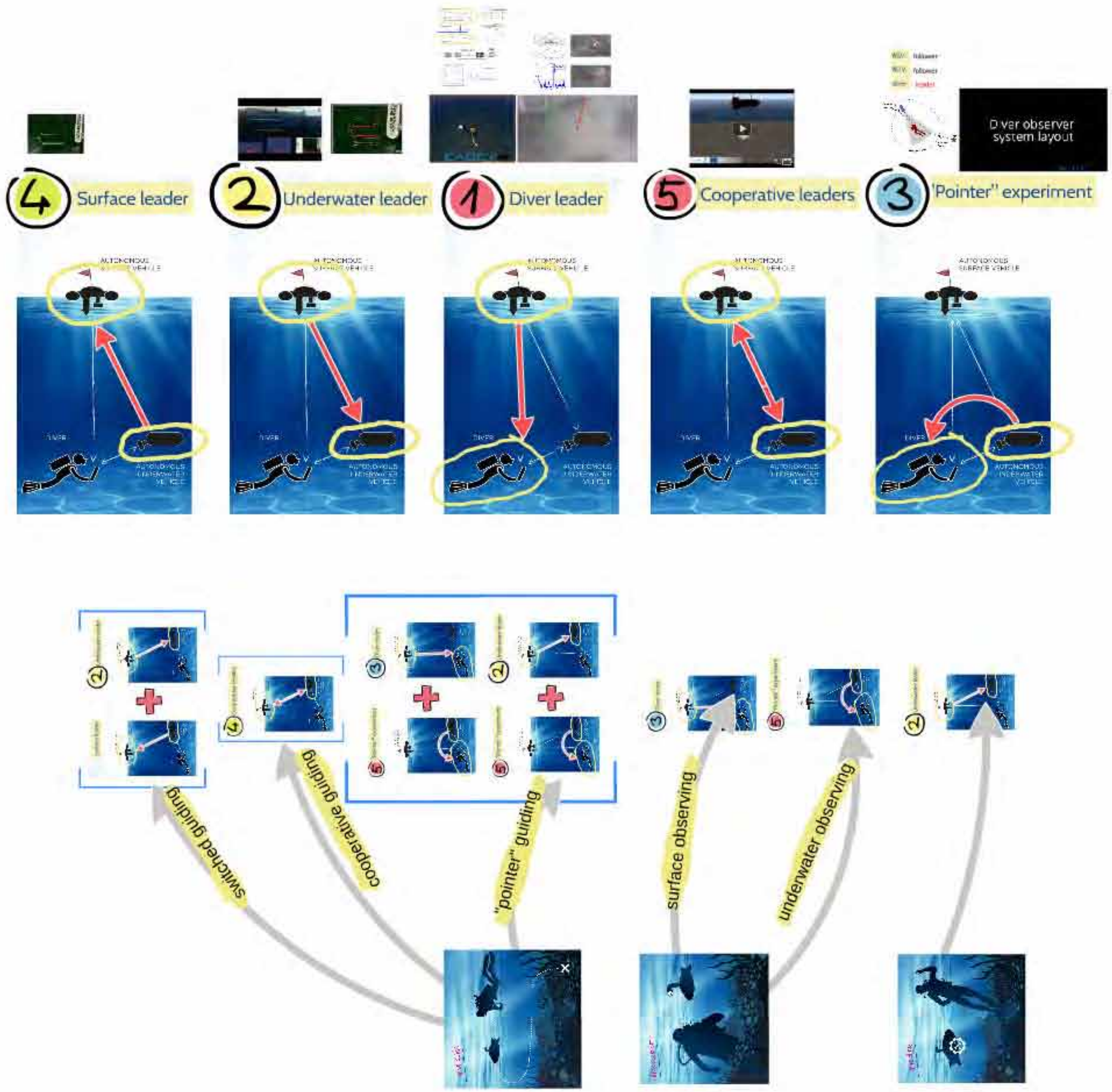
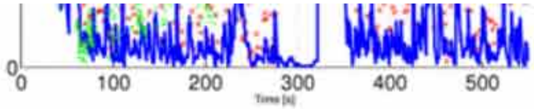




Cooperative control and optimal formation keeping



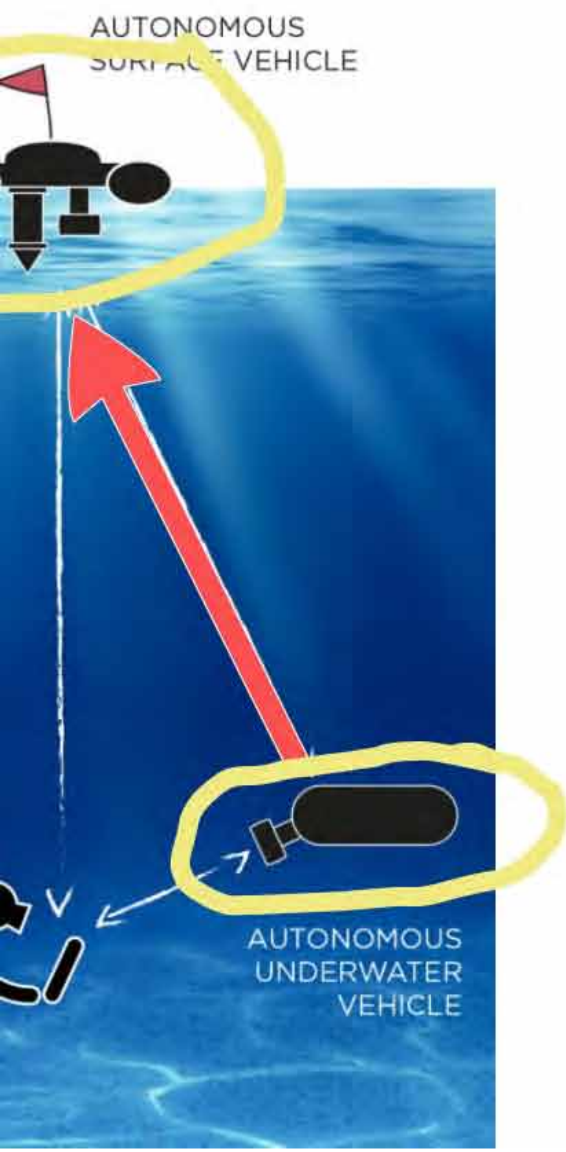
Underwater leader
AUTONOMOUS SURFACE VEHICLE
AUTONOMOUS UNDERWATER VEHICLE
1
Diver leader
AUTONOMOUS SURFACE VEHICLE
DIVER
AUTONOMOUS UNDERWATER VEHICLE
5
Cooper
DIVER


0
0
100
200
300
400
500
Time [s]

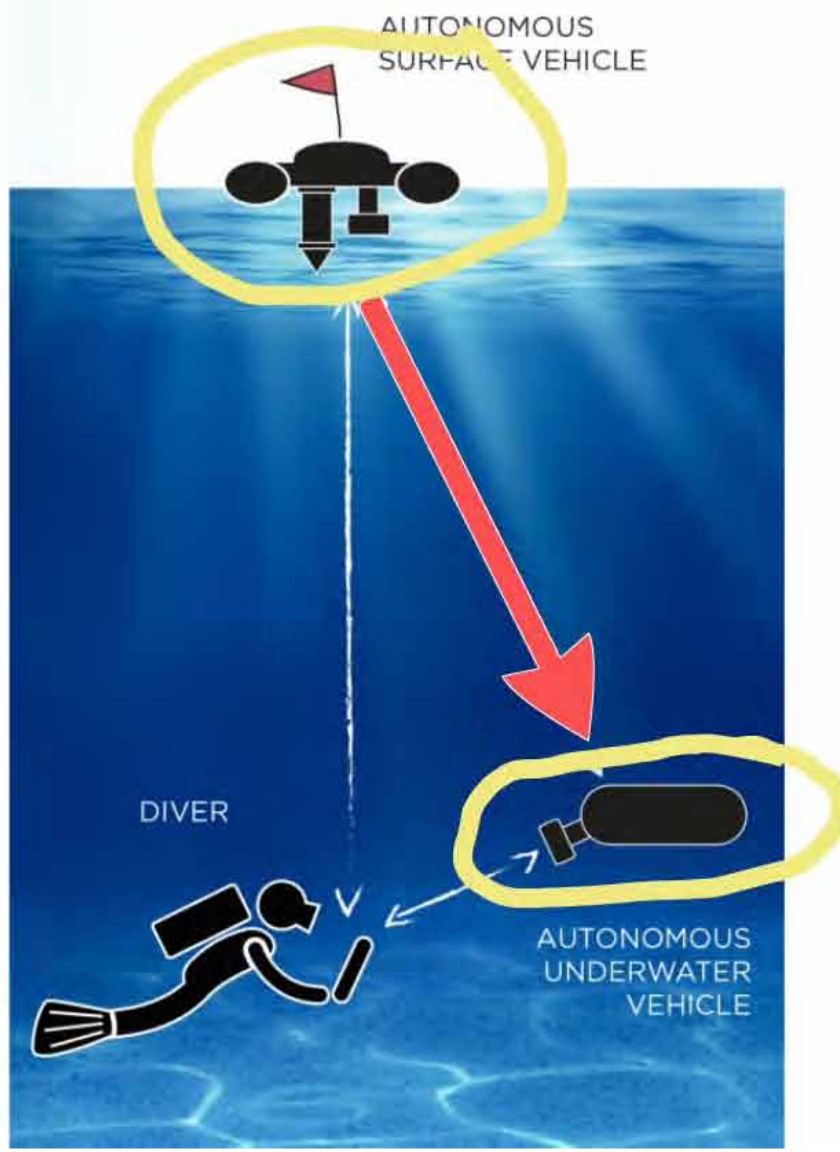

CADDY

[redacted]

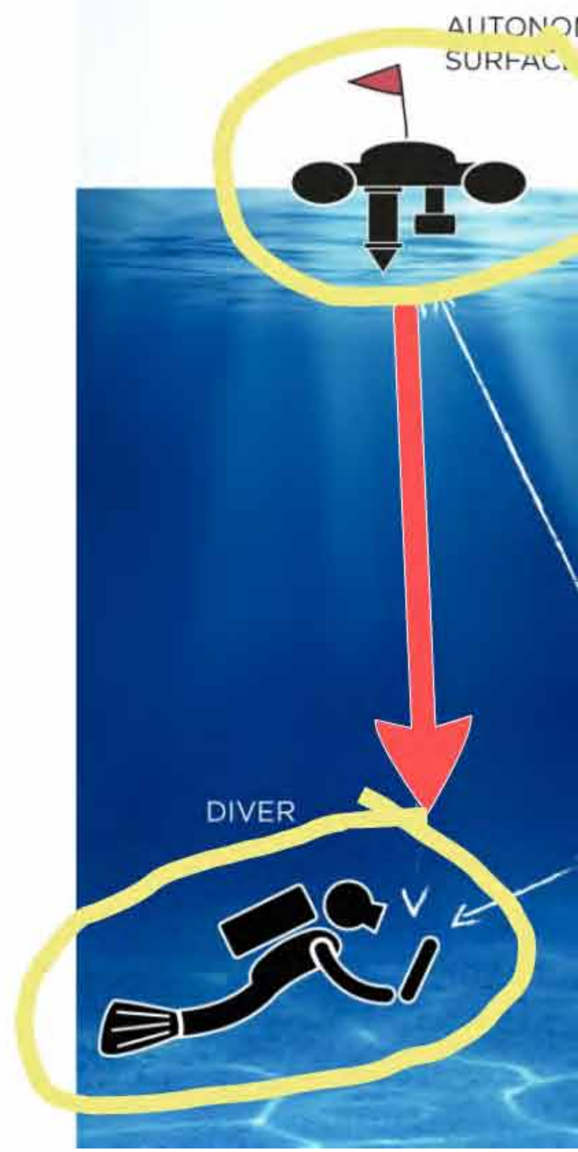
Surface leader

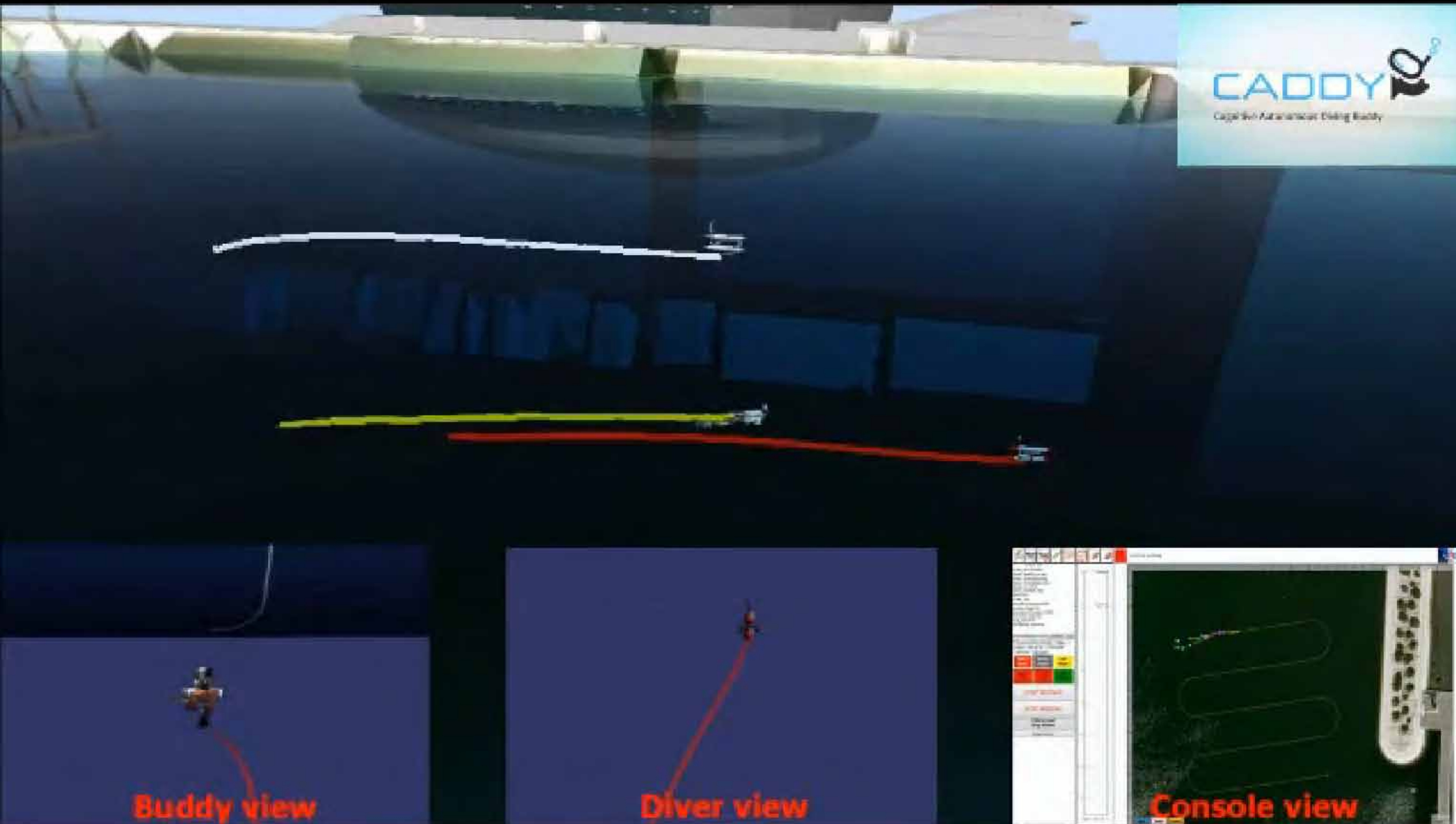


2 Underwater leader



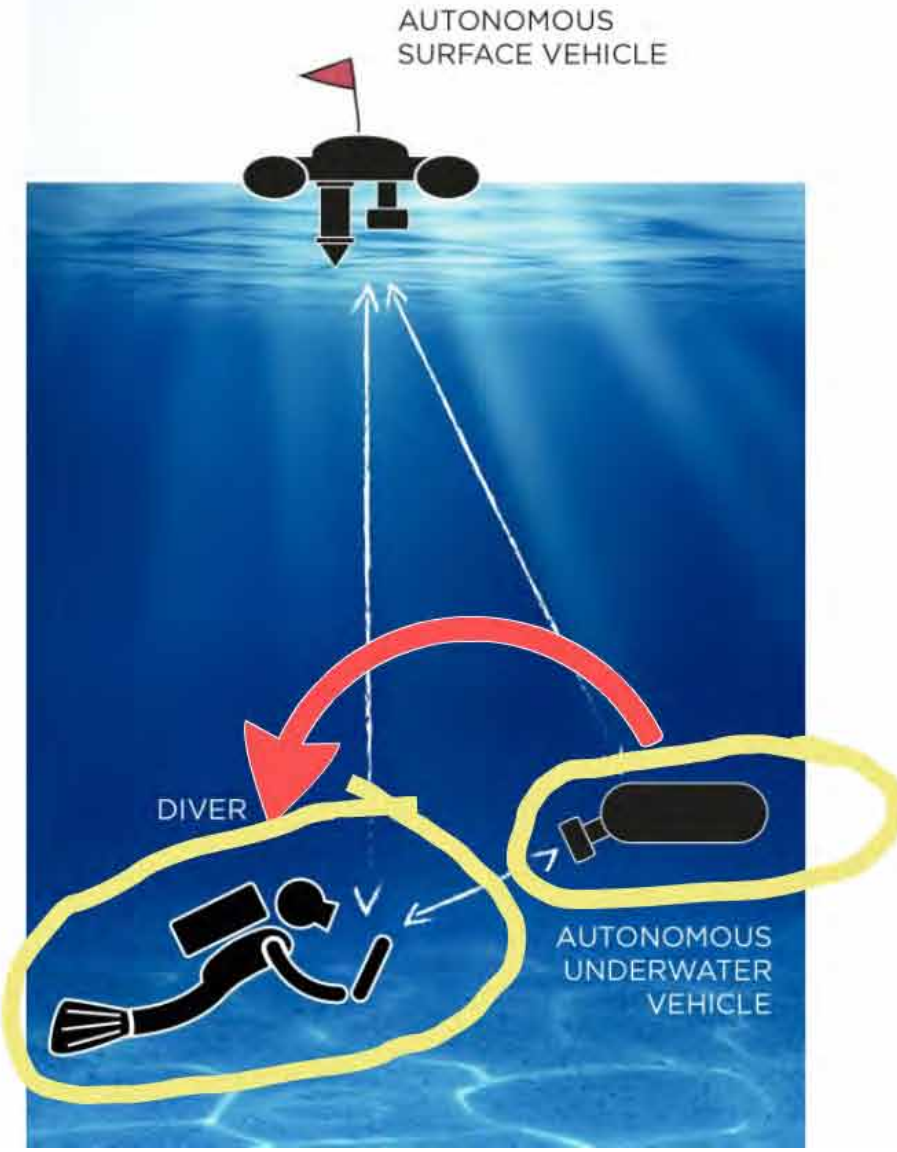
1 Diver l

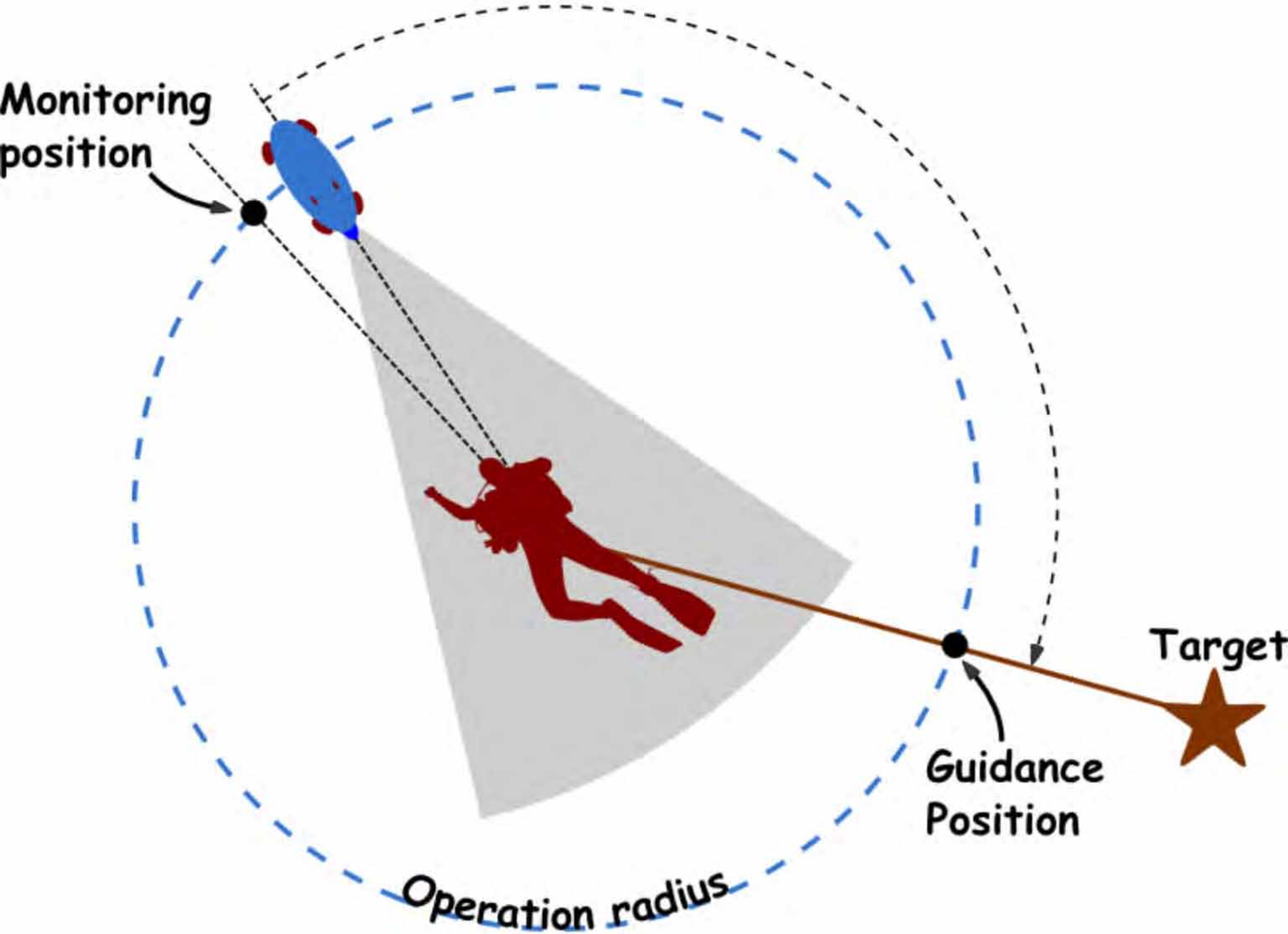



CADDY
Buddy view
Diver view
Console view

erative leaders

'Pointer'' experiment



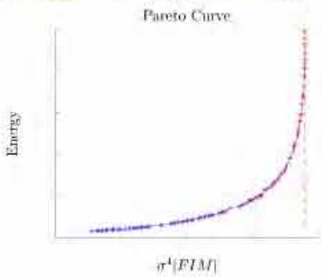

Monitoring position
Target
Guidance Position
Operation radius

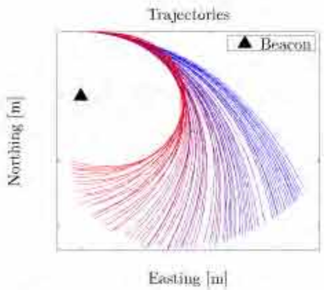
Diver observer system layout

CADDY

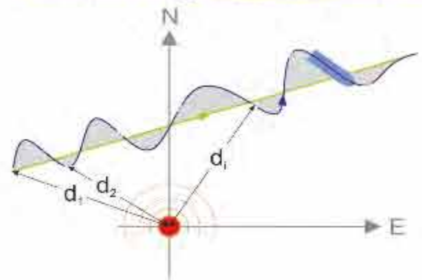
Range-based target localization

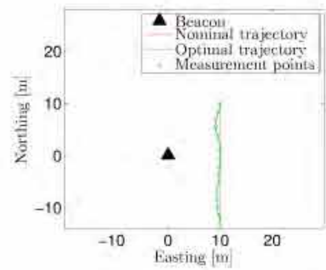
Minimizing energy

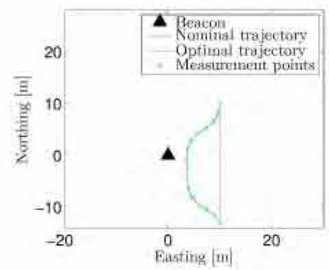




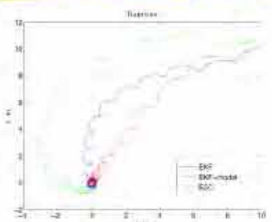
Minimizing deviation from nominal trajectory

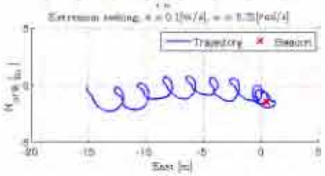


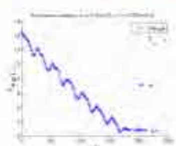


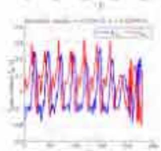


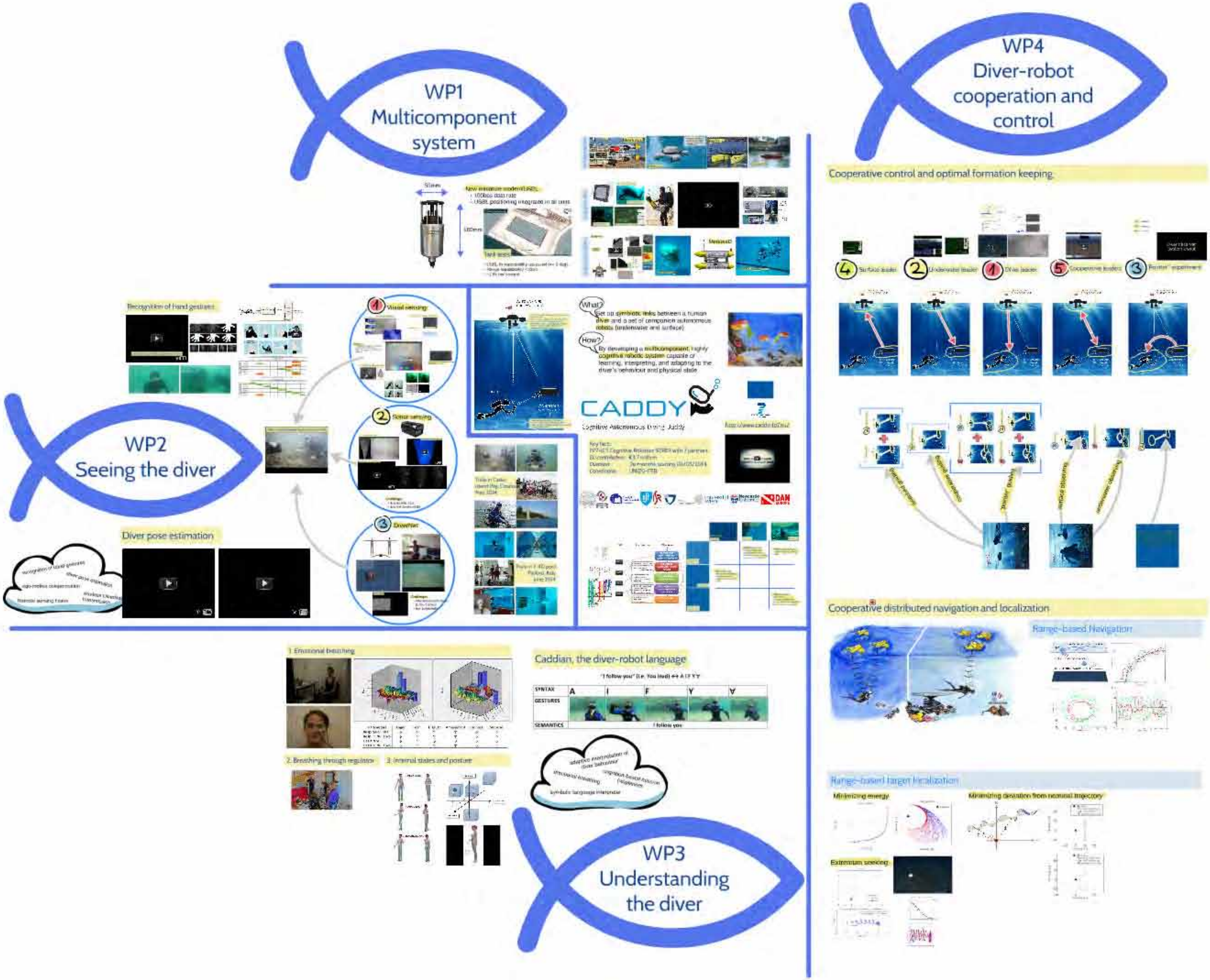
Extremum seeking





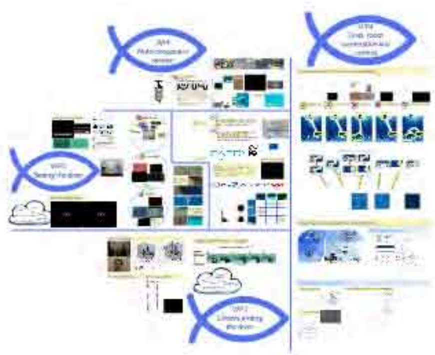





WP1
Multicomponent
system
WP4
Diver-robot
cooperation and
control
Cooperative control and optimal formation keeping
Recognition of hand gestures
WP2
Seeing the diver
Diver pose estimation
What?
How?
CADDY
Cooperative distributed navigation and localization
Range-based Navigation
Range-based target localization
Minimizing energy
Minimizing deviation from nominal trajectory
Extremum seeking
1. Emotional breathing
2. Breathing through regulator
3. Internal states and posture
Caddian, the diver-robot language
SYNTAX
GESTURES
SEMANTICS
I follow you
WP3
Understanding
the diver

www.caddy-fp7.eu

CADDY FP7 project



Thank you!


CADDY
Cognitive Autonomous Diving Buddy
This project has received funding from the
European Union's Seventh Framework Programme
for research, technological development and demonstration
under grant agreement no. 611373
YouTube

EMRA´15

Session 5. Chair – Paulo Oliveira

11:00 **T3.2 – *Developments in robust acoustic positioning and communications***
Robin Sharphouse, Blueprint, Ulverston, UK
Jeff Neasham, Newcastle University, UK

11:30 **T3.3 – *The Light Autonomous Underwater Vehicle***
Ricardo Martins, Oceanscan, Porto, PT

12:00 DexROV (EU project)

12:30 **T3.4 – *Intervention AUVs: Experiences and Challenges***
Pere Ridao, Univ. Girona, Girona, ES

ISR-IST Lisbon Portugal

EMRA'15 workshop

Developments in Robust Acoustic Positioning and Communications

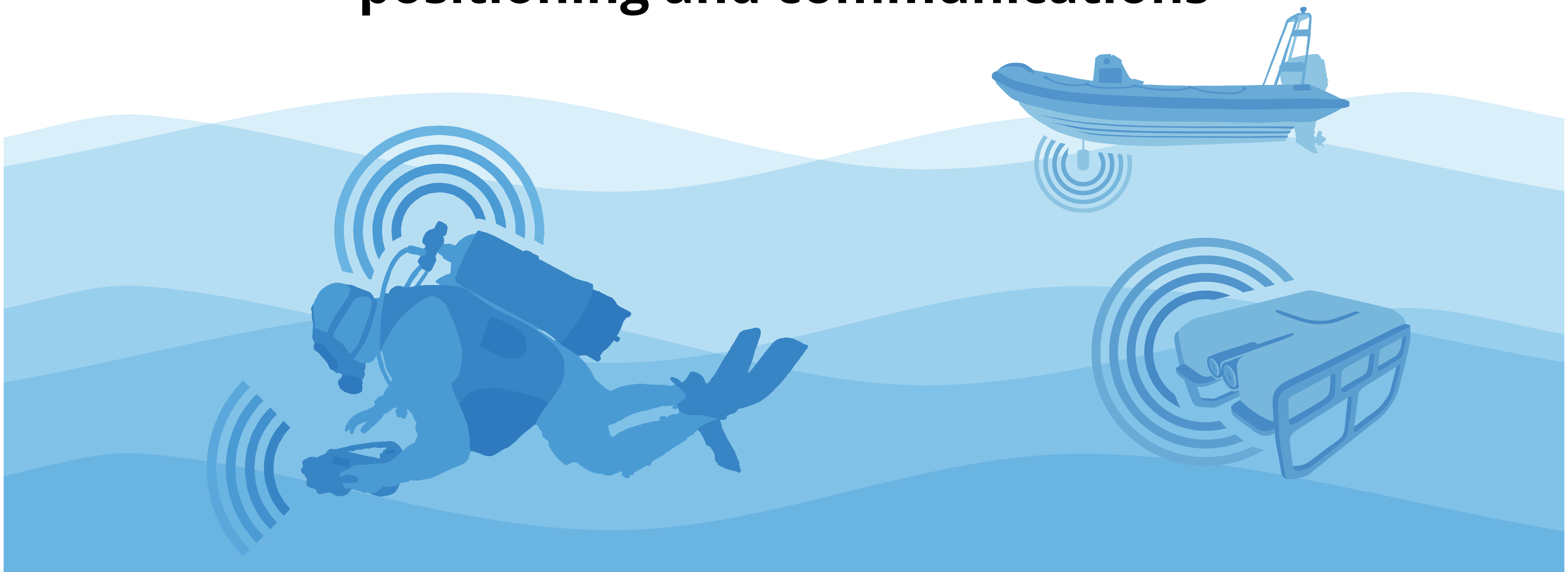
Robin Sharphouse, Blueprint, Ulverston
Jeff Neasham, Newcastle University
UK

blueprint subsea
Robin Sharphouse

Newcastle University
Jeff Neasham

CADDY
Cognitive Autonomous Diving Buddy

Developments in robust acoustic positioning and communications

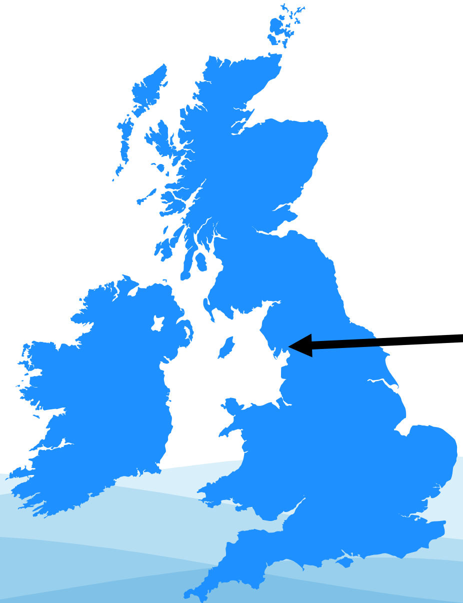


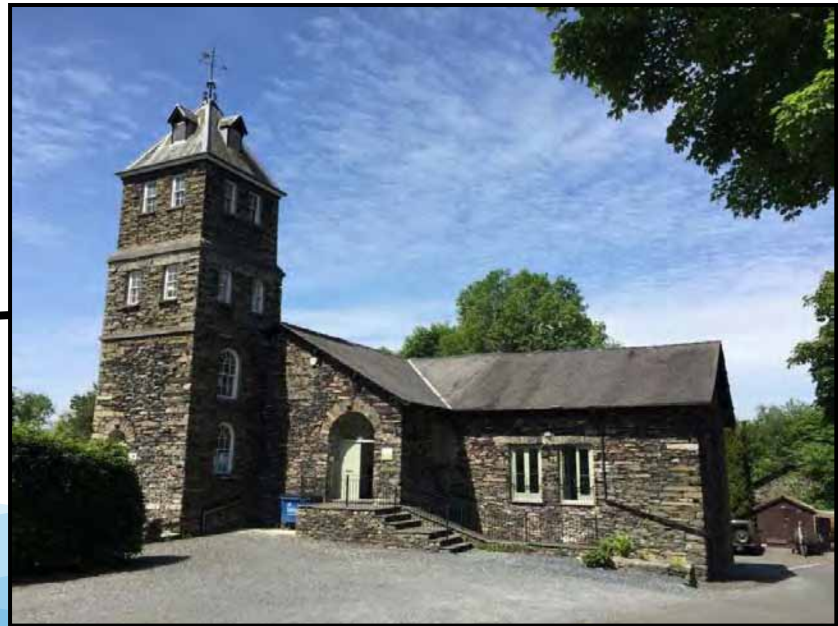
www.blueprintsubsea.com

About Blueprint Subsea

- Since 2006, Blueprint Subsea have designed and manufactured a range of sonar and navigation products for the subsea, search-and-rescue and commercial diving markets.

- Offices and production based near Lake Windermere in the English Lake District.



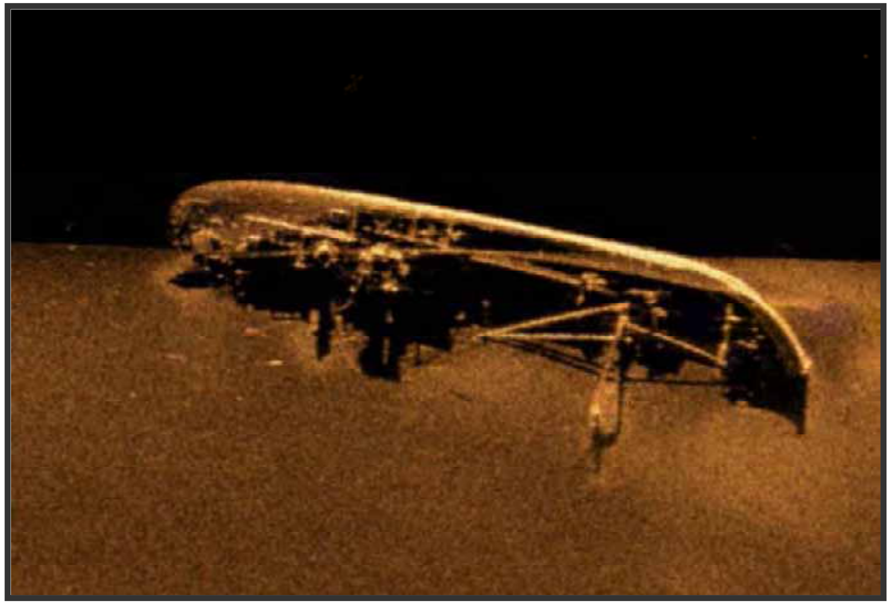


About Blueprint Subsea

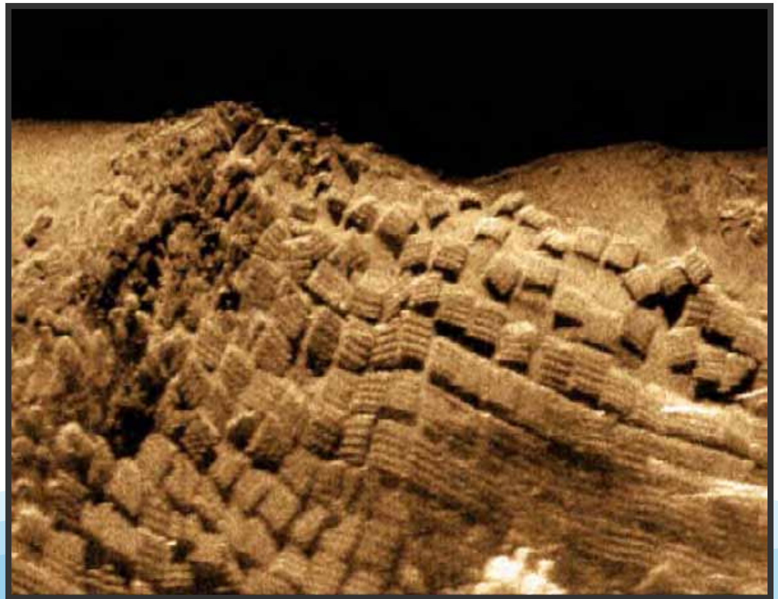
Our product range includes:

- StarFish - a range of small, affordable and portable sidescan sonar systems.
- Artemis – a handheld diver console with integrated sonar and navigation.
- RovTools - small to medium sized ROV tooling solutions.
- SeaTrac – acoustic data modems and USBL positioning transponders.

StarFish 452 Sonar



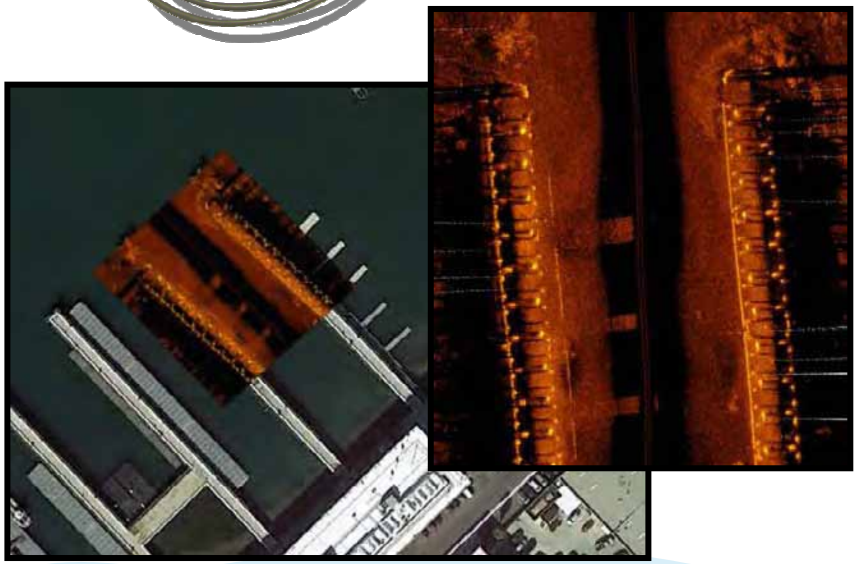
Steamship in the Gulf of Finland at a depth of 33 metres - courtesy of Ari Kapenen, Deeptech.

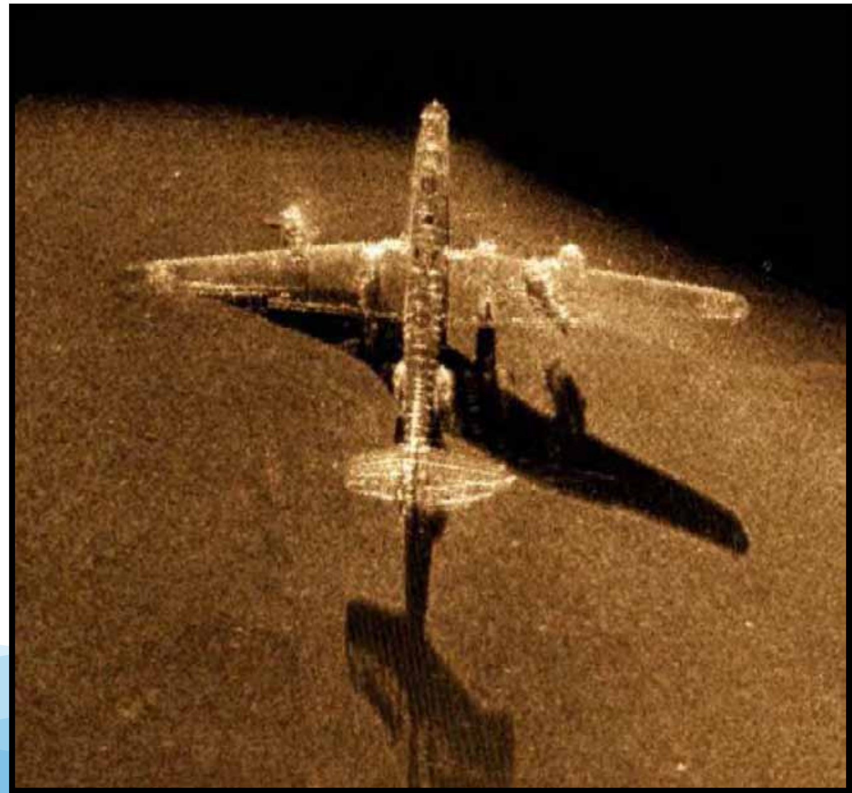


Concrete mattress beneath a harbour berth - courtesy of Marek Szatan, Hydrograf.

StarFish 453OEM Sonar

Wreck of a PB4Y Privateer bomber in Lake Washington at a depth of 53 metres.





Mosaic of Dock Survey using an Oceanserver Iver2 AUV.
(image produced using Oceanserver's mosaicing software)

Artemis Diver Console

blueprint subsea

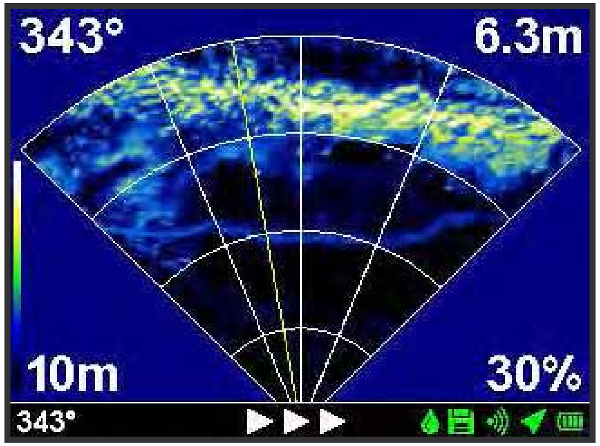
Newcastle University

A handheld underwater computer incorporating target detection sonar and GPS navigation.

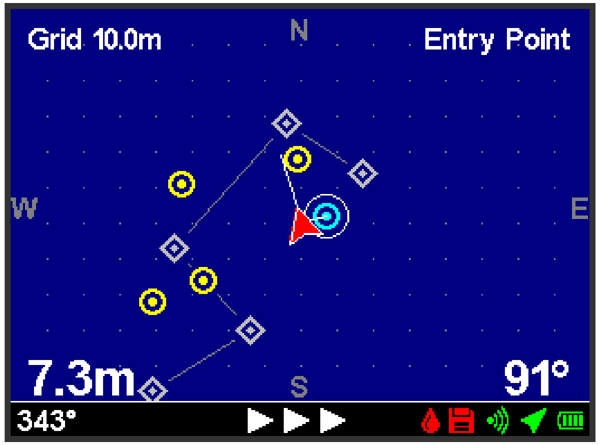
- Unexploded ordnance.
- Seabed infrastructure
- Missing persons, lost property, vehicles, aircraft, wrecks etc.
- Seabed / lakebed antiquities.

Artemis Diver Console

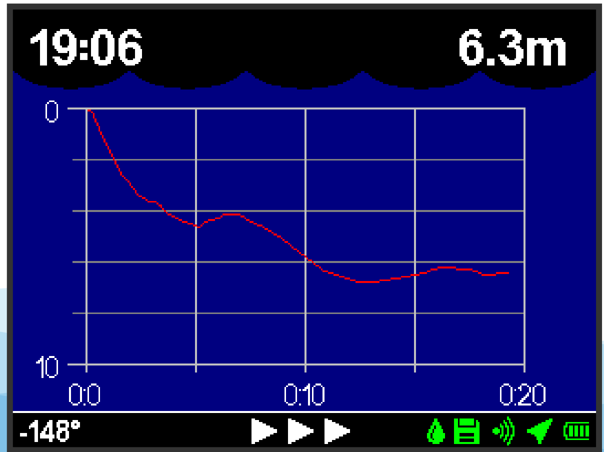
Sonar



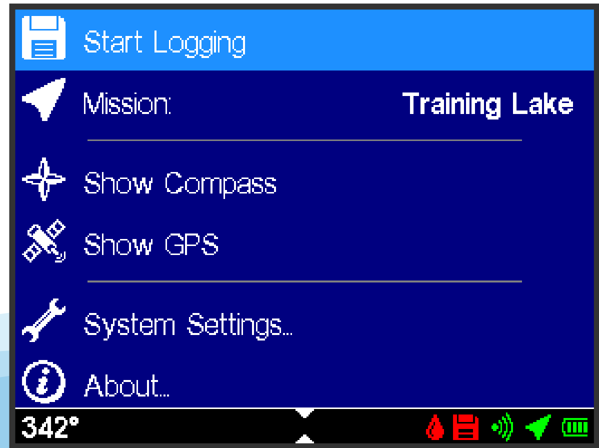
Navigation



Dive Profile



Settings



SeaTrac Modems

blueprint subsea
Newcastle University

SeaTrac X150

All-in-one USBL tracking receiver and data modem.

SeaTrac X110

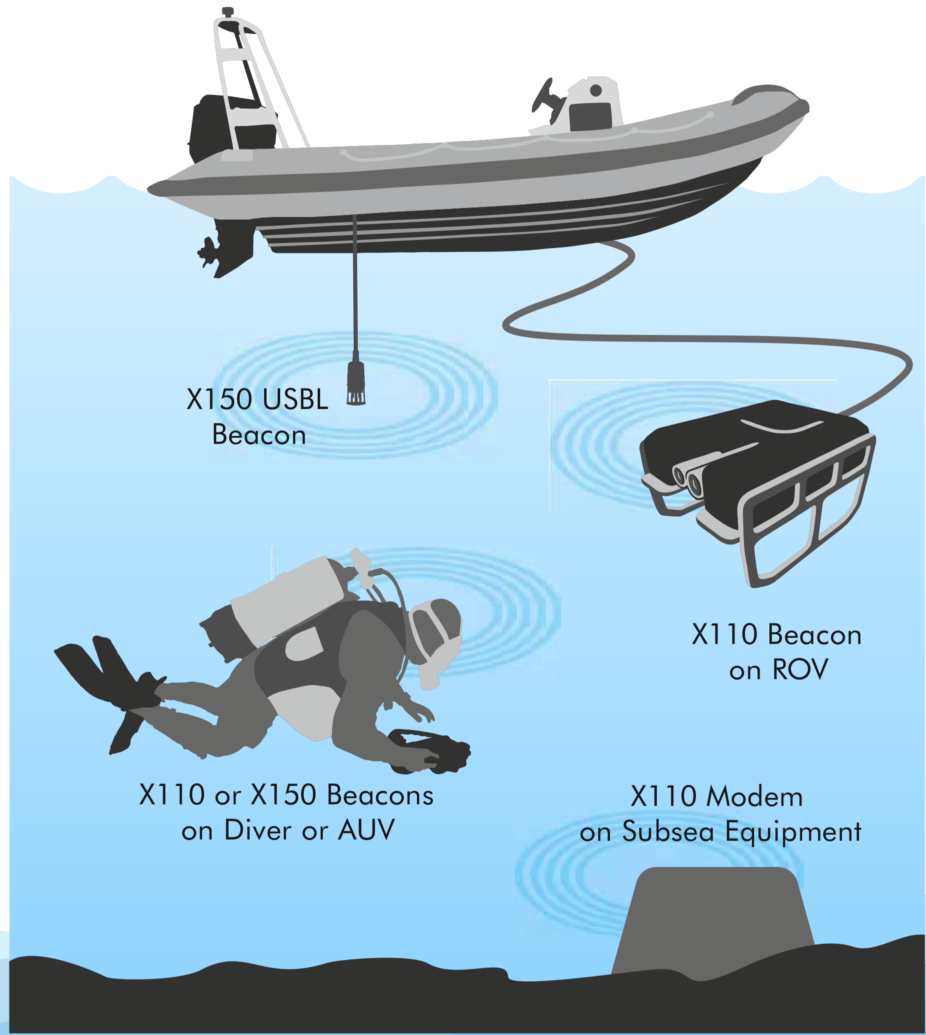
Transponder beacon and data modem.

blueprint subsea

Newcastle University

SeaTrac Design Goals

- Miniature transponders (no additional hardware outside the transceiver housing).
- Simultaneous positioning with data exchange.
- Data exchanged between addressable transponders, or broadcast to all.
- Inverted USBL (iUSBL) operation for diver-to-diver or AUV-to-AUV positioning.



SeaTrac Design Goals

- Position update period of less than 2s.
- Efficient protocols for short messages (allowing closed loop operations).
- Acoustic frequency >20kHz for compatibility with Diver operations.
- Reliable operation to at least 1km range, including very shallow water horizontal channels.
- Immunity to complex acoustic multi-path and Doppler effects.
- 100bps initial data rate, increasing to 1kbps+ for later missions (firmware update under development).

SeaTrac Applications

- Typical surface based tracking of single or multiple assets.
- Control, status monitoring and relocation of seabed based equipment.
- Mixed platform operations : Surface, Diver, ROV and AUV combined operations.
- Diver-to-Diver or AUV-to-AUV (swarm) positioning & communications.

Hardware Platform

Pressure and Water Temperature sensor.
Auto-calculates VOS (based on given salinity)

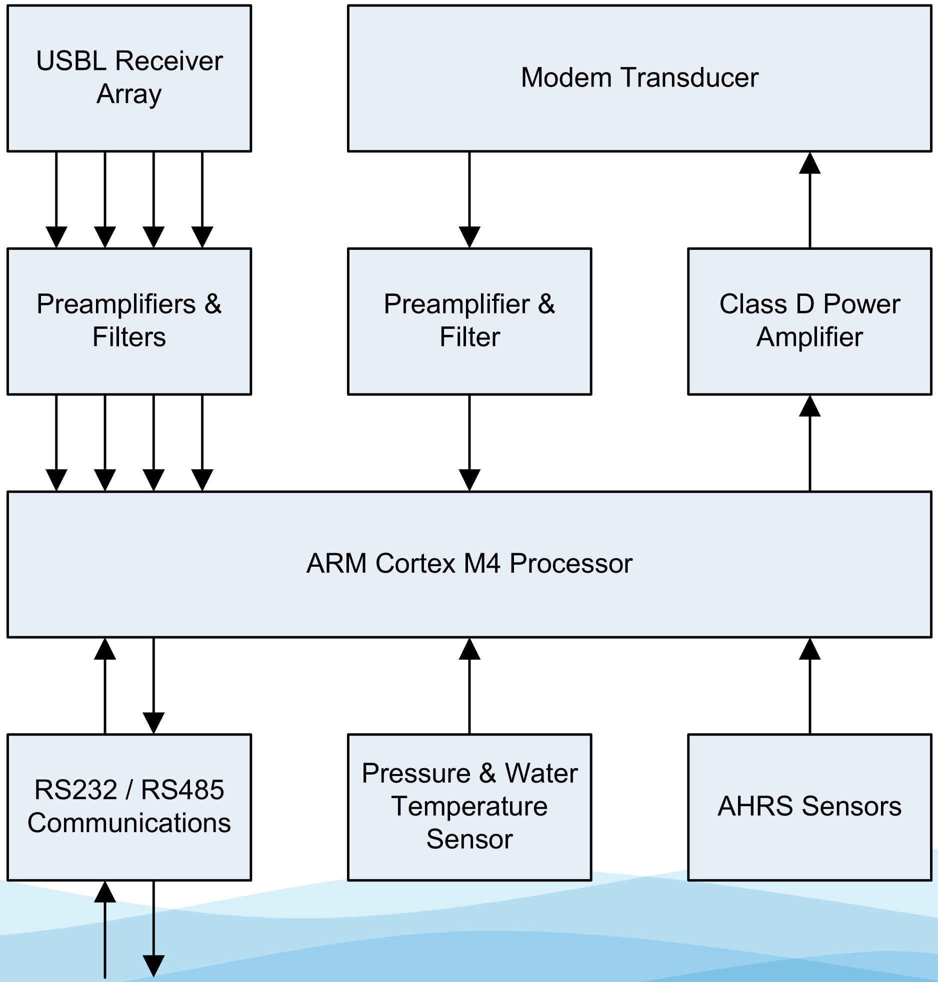
150MHz Processor

4 channel USBL Array.
16-bit ADC sampling.

Main modem transmitter
Source Level <176dB.
Frequency 24 to 32kHz

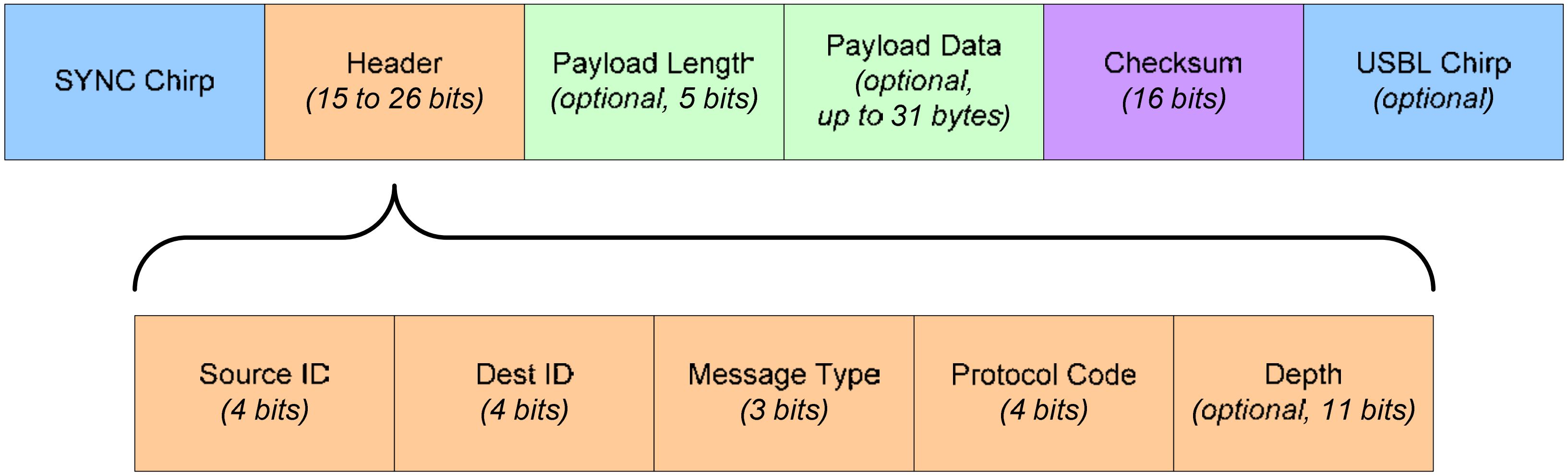
AHRS Sensors
(Accelerometer, Magnetomerer Rate-Gyro's)

Hardware Platform



Acoustic modem link Layer

Message format…



Source and Dest ID bits allow…

- Targeted delivery
- Identification of responder
- Broadcast to all

Message Types…

- One-Way (Broadcast)
- Request / Respond
- Request / Respond USBL
- Request / Respond Enhanced

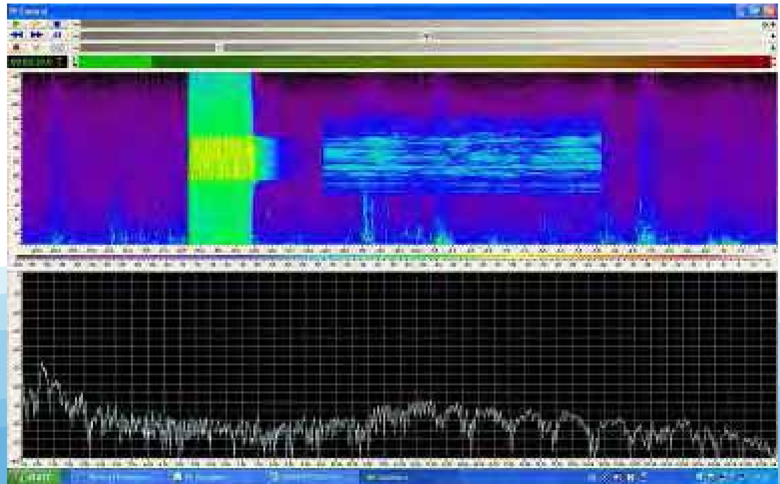
Protocol Layer

PING	Specified transponder responds Position computed Shortest message at 31 bits (410ms total)
ECHO	Specified transponder responds with transmitted payload. Useful to testing acoustic link
NAV	Navigation and tracking functions – allows remote interrogation of depth, heading, attitude, supply etc.
DAT	Datagram protocol – UDP like, allows simple data exchange up to 31 bytes per packet.
DEX	Data Exchange protocol – TCP like, allows buffered 'sockets' with missing packet tracking and recovery.

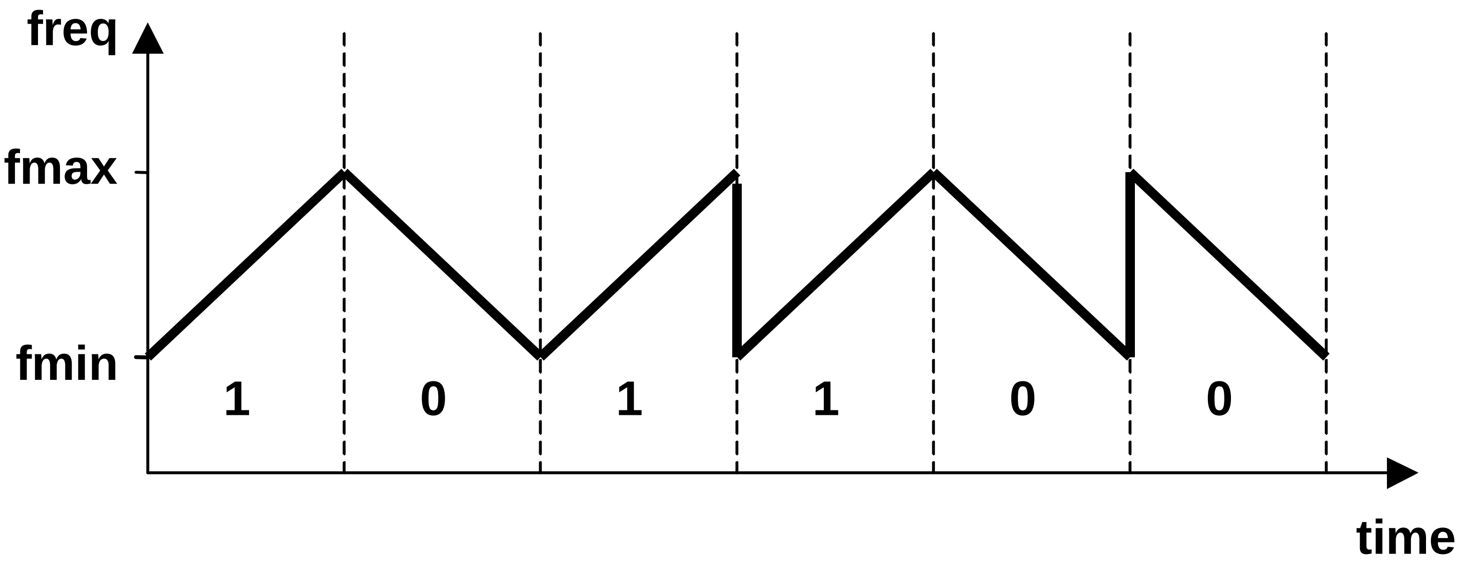
Serial commands available for each protocol for application control.

Acoustics at Newcastle

- 20+ years research in underwater acoustic comms & imaging
- Anechoic water tank, range of acoustic instrumentation, ROVs
- Several commercially available products.
- 3 academic staff, 3 research staff + 6 PhD

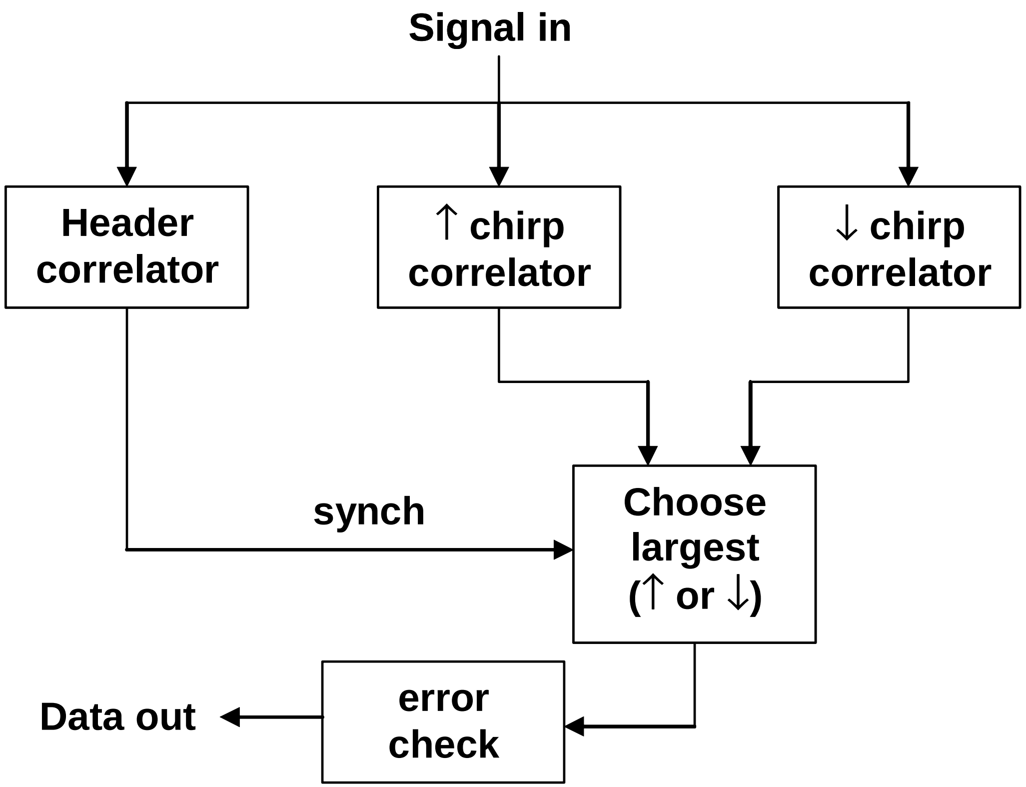


Physical Layer (100bps)



- Low bit rate spread spectrum signalling used for robust data transfer.
- 100bps (raw data rate) = 10ms symbols
- F_{min} = 24kHz, F_{max} = 32kHz
- Special case 50ms symbols used for Sync and USBL positioning.

Physical Layer



- SYNC chirp : 26dB processing gain
- DATA chirps: 19dB processing gain
- CHIRP signalling has inherent Doppler tolerance – but adaptive decoding algorithm used.

USBL Positioning

- USBL uses a 4 element tetrahedral array with 20mm spacing.
- Uses same signalling scheme to enable simultaneous positioning and data exchange
- Recursive optimisation algorithm finds best fit for azimuth and elevation.

USBL Positioning

- Range resolution is governed by the signal bandwidth – approx 10cm.
- Azimuth and Elevation angles are combined with heading, attitude, acoustic range and VOS (from pressure and water temperature) to determine final relative position.
- ‘Enhanced’ mode USBL responses contain the remote transponder depth to 1m accuracy – improves position solution (especially with refraction)

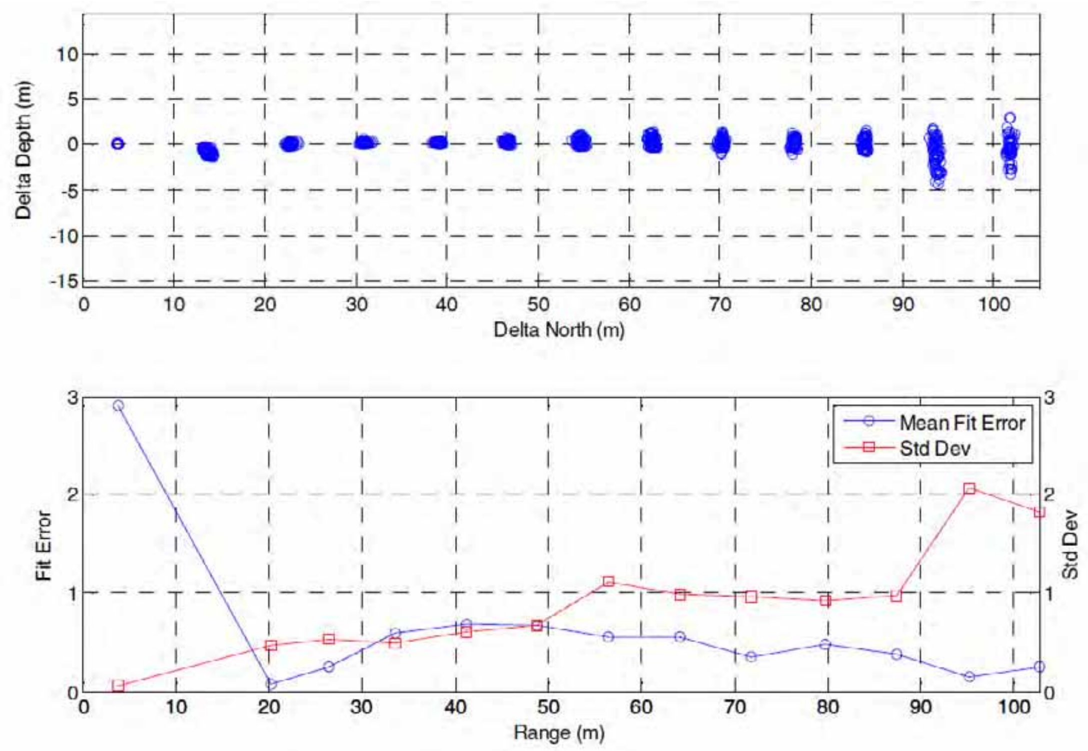
Performance Testing

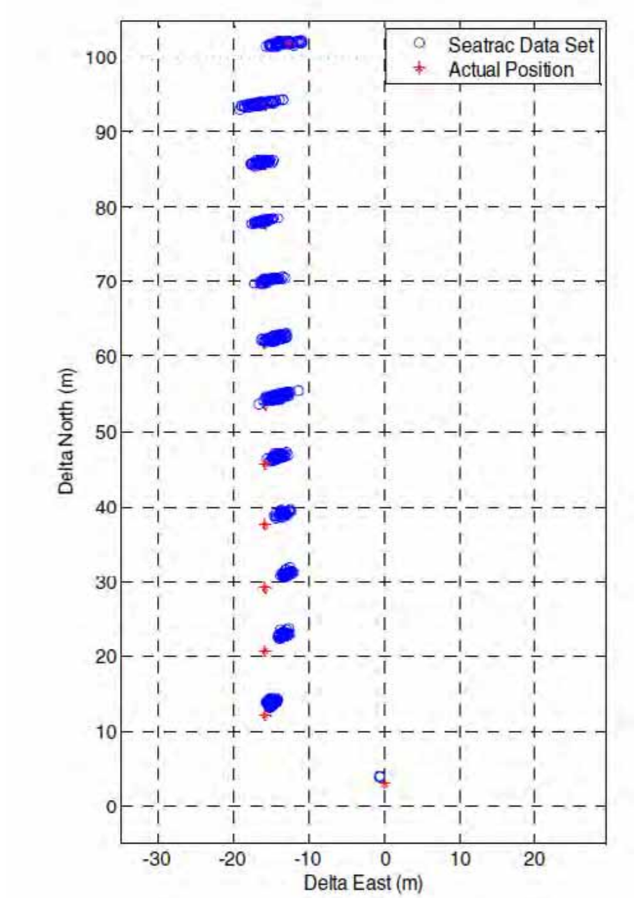
Marina complex

8-10m deep

375m x 165m

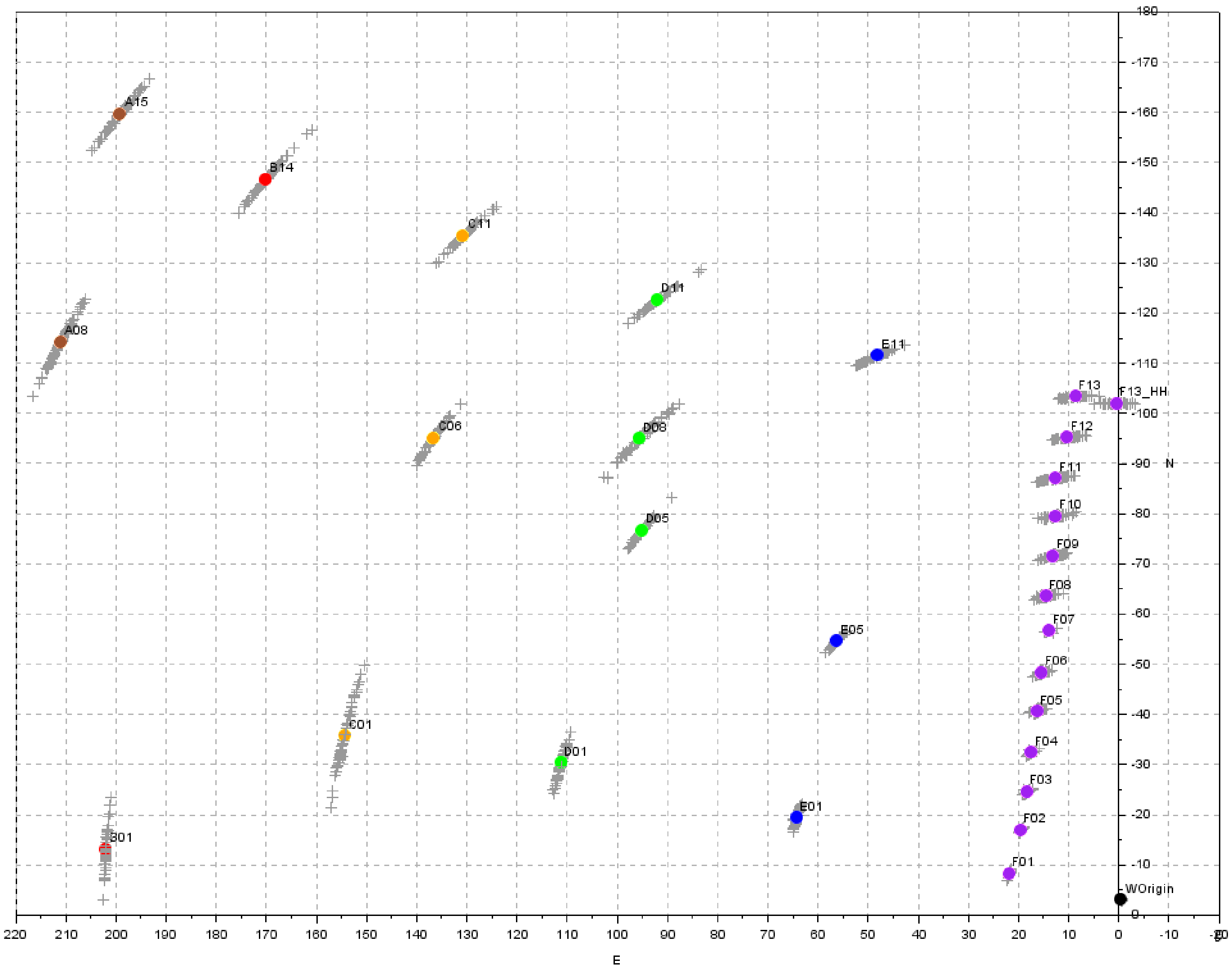
Performance Testing





- >95% packet delivery at ranges up to 1.5km.
- SD of <2% of range over wide variety of environments.
- <2s position update achieved with CADDY vehicles.

Performance Testing



2610 Fixes (47 groups)

Range SD: 0.099m

Azimuth SD: 0.95°

Elevation SD: 0.51°

AHRS Yaw SD: 1.0°

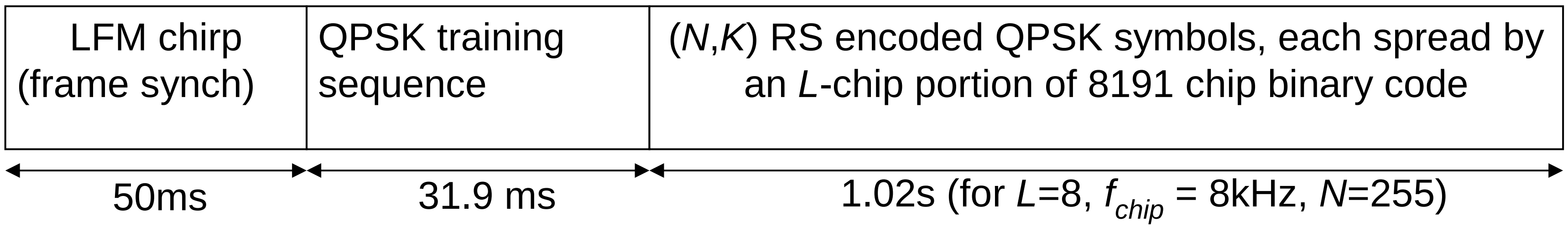
AHRS P/R SD: 0.12°

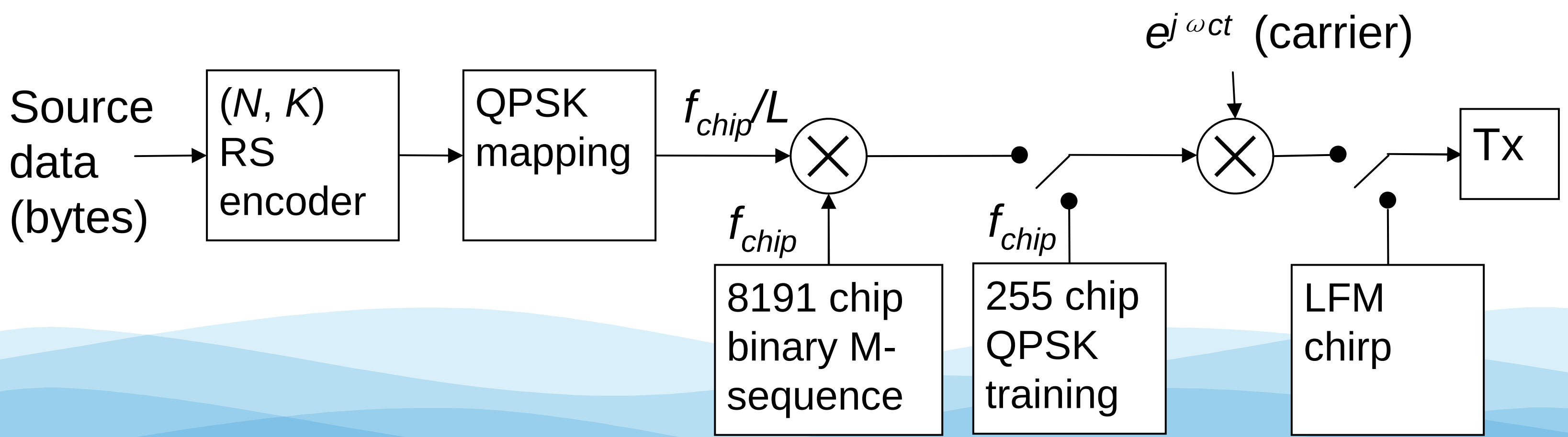
Performance Testing

- Very challenging multi-path due to concrete walls and bedrock floor (channel time spread ~1s)

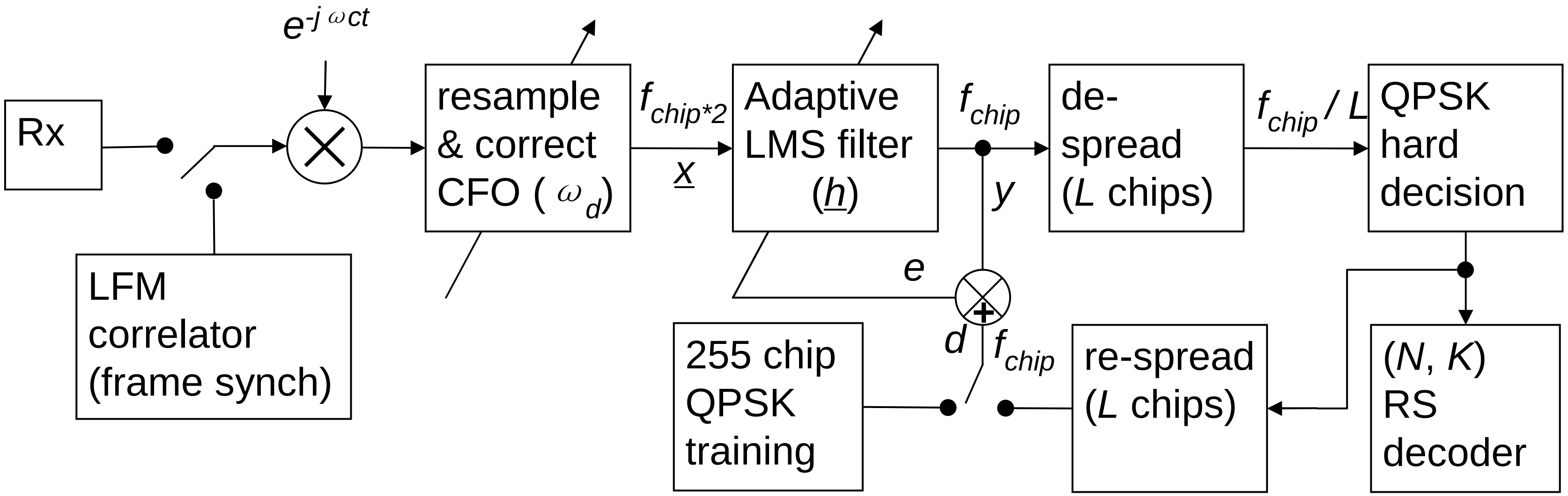
DSSS Scheme for 1.4kbps

- Firmware upgrade to introduce Direct Sequence Spread Spectrum (DSSS) processing





DSSS Receiver Structure



$$y[i] = \underline{h}^T[i]\underline{x}[i]$$

$$\theta_e[i] = \arg\left(y[i].d^*[i]\right)$$

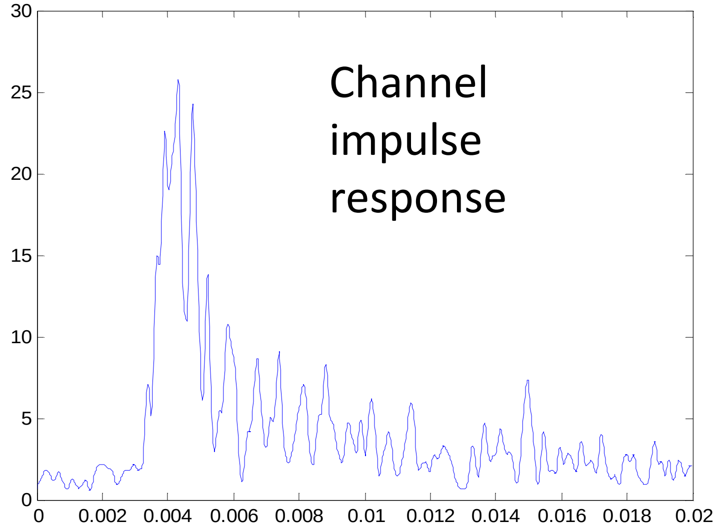
$$e[i] = d[i] - y[i]$$

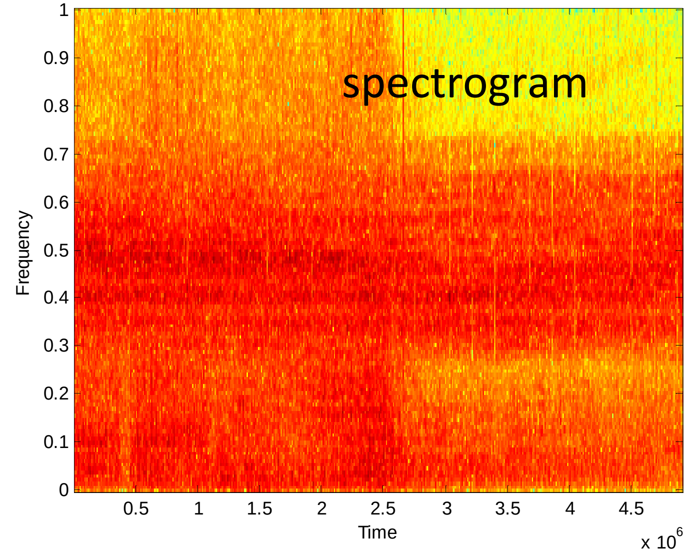
$$R[i+1] = R[i] + k_p\theta_e[i]$$

$$\underline{h}[i+1] = \underline{h}[i] + \mu e[i]\underline{x}^*[i]$$

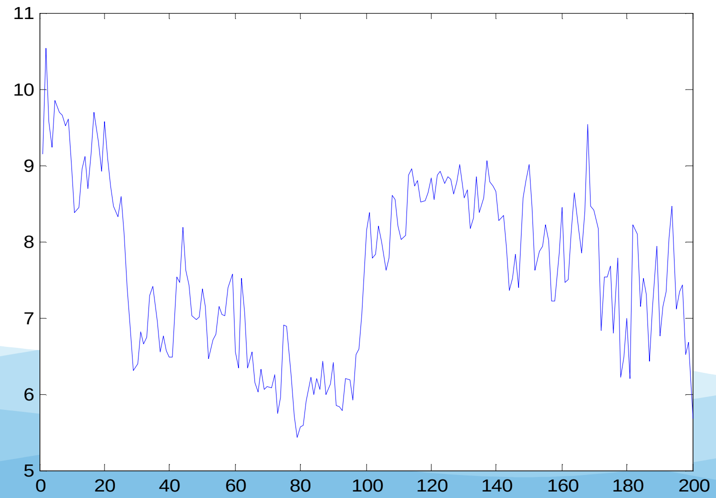
$$\omega_d = \omega_c\left(R[i]-1\right)$$

DSSS in 1.5km Estuary Channel

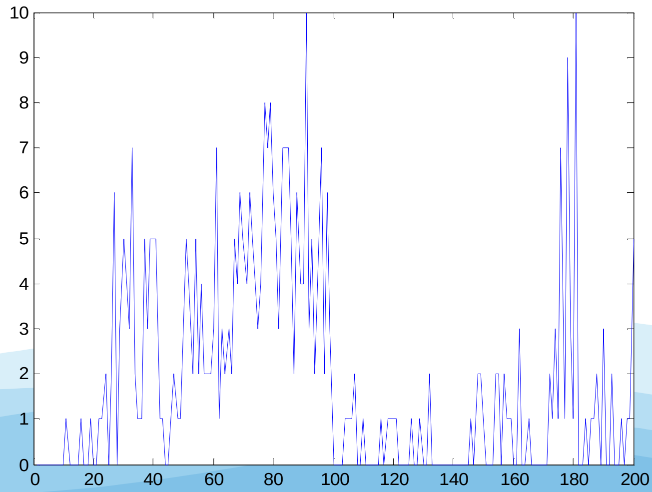




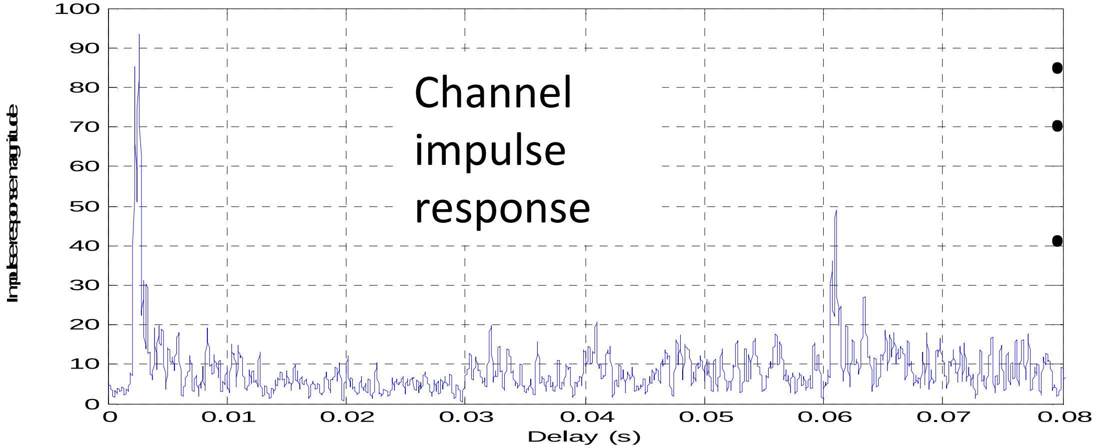
Output SINR (dB)



Errors in 2000 bit packet

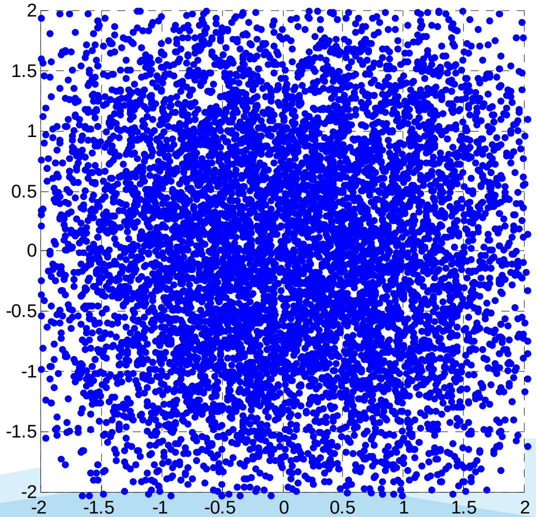


DSSS in 100m Dock Channel

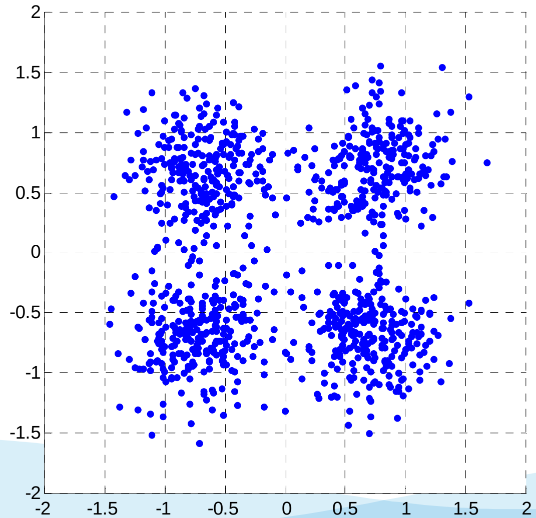


Channel impulse response

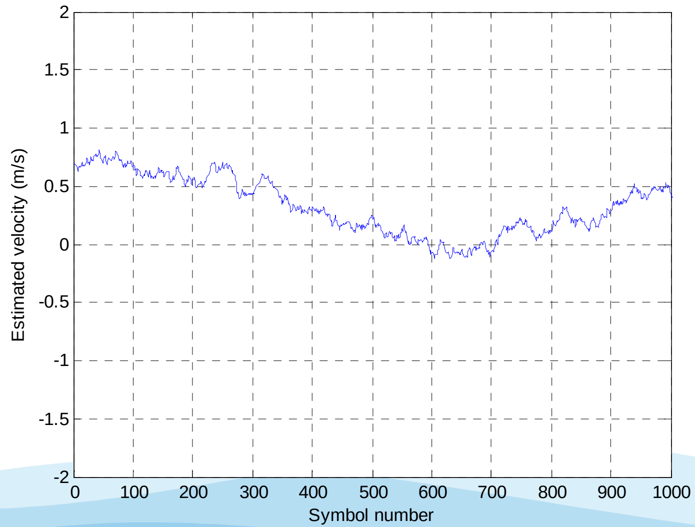
- Severe delay spread >100ms.
- Platform motions induced to simulate CADDY vehicles.
- 96% of packets decoded compared to 27% without Doppler correction.



Constellation before de-spreading



Constellation after de-spreading



Estimated velocity from Doppler correction

Conclusions & Future Work

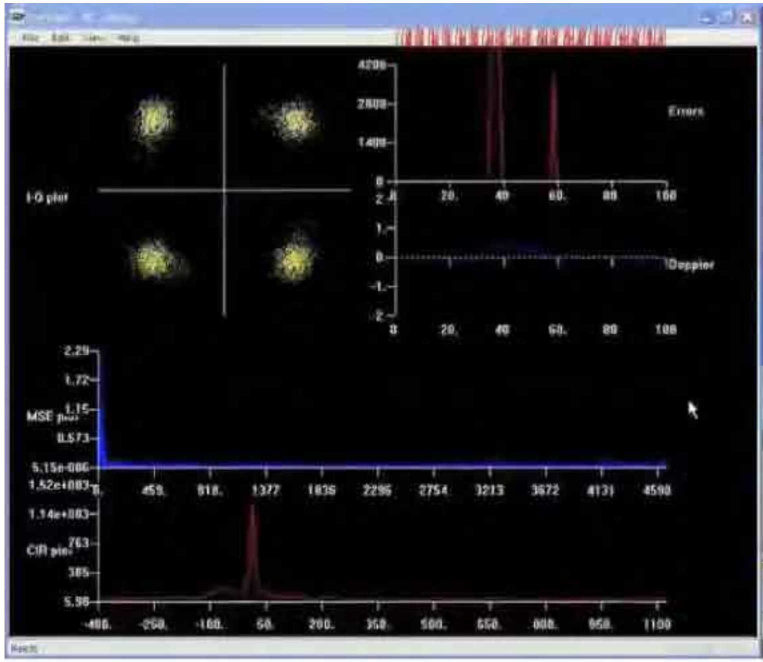
- The miniature transceiver design has proven effective and reliable and is entering volume production by Blueprint Subsea.

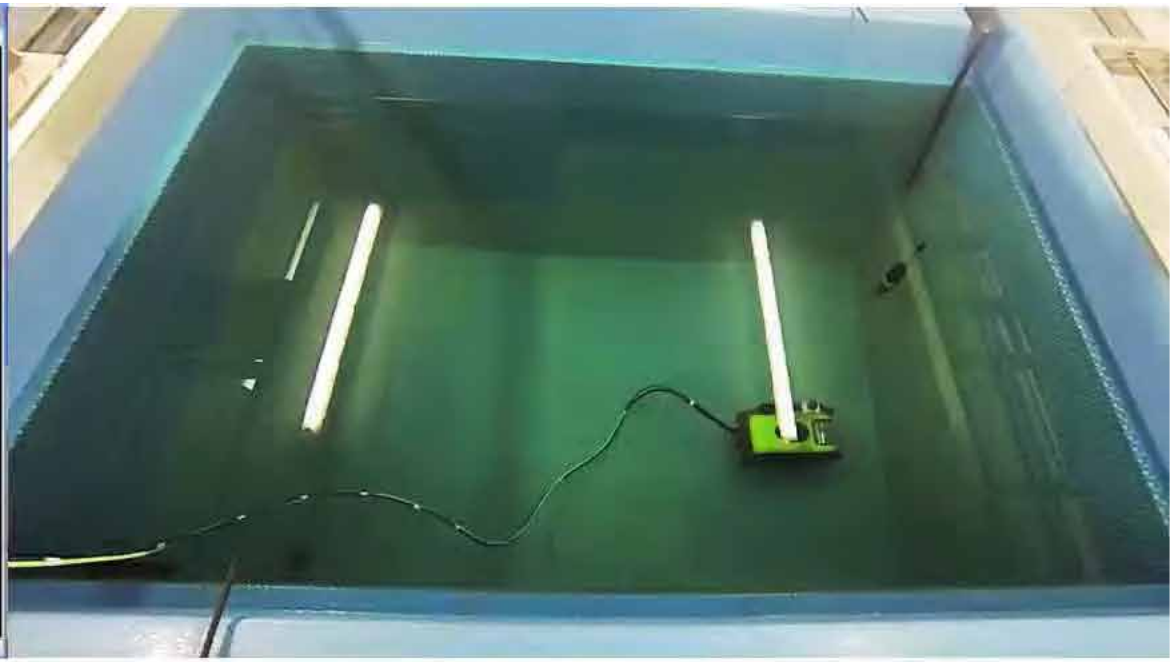
- The miniature integrated USBL array provides positioning with standard deviation of around 2% of range.

- 100bps spread spectrum mode has proven highly reliable on CADDY vehicles but will be replaced by 1.4kbps DSSS scheme for higher throughput.

- Future work will focus on high rate (>20kbps) QPSK transmission modes and diver adaptive scheduling.

20-80kbits/s transmission with adaptive modulation and coding





Thank You

EMRA'15 workshop

The Light Autonomous Underwater Vehicle

Ricardo Martins
Oceanscan, Porto, PT

OCEANSCAN

Marine Systems & Technology

The Light Autonomous Underwater Vehicle
Past, Present & Future

Ricardo Martins
rasm@oceanscan-mst.com

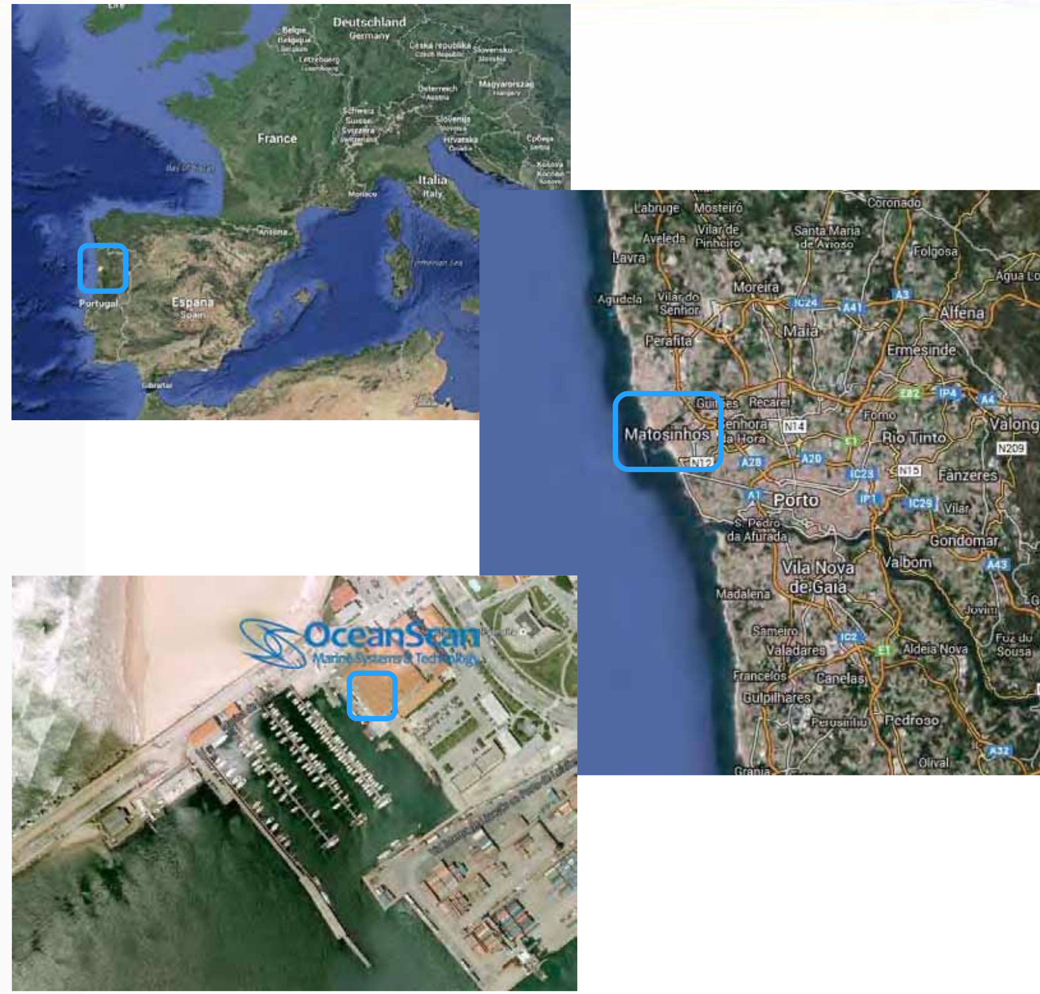
OceanScan
Marine Systems & Technology

OceanScan
Marine Systems & Technology

Provides Innovative Solutions for
Hydrographic, Research and
Security & Surveillance Surveys

Overview

- Established in 2008
- Porto University Spin-off
- Strategic partnership with the "Underwater Systems & Technology Laboratory" (LSTS)
- Headquarters in the Leixões Harbour complex



LSTS

U.PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

UPTEC

CONCURSO NACIONAL DE INOVAÇÃO BES
BANCO ESPIRITO SANTO

A BIT OF HISTORY

- LSTS was established
- REMUS AUV Purchased

1997

- Development of First AUV Prototype

2000

- Development of New Lightweight, Low cost AUV

2004

- Portuguese BES Innovation Award

2006

- OceanScan Established

2008

2014

2008

2009

2010

2013

2014

VISION & APPROACH

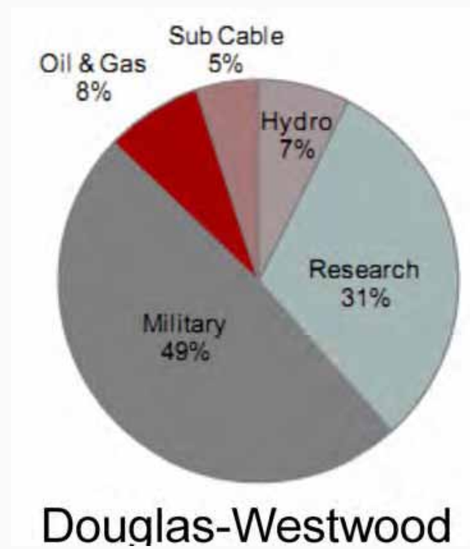
- Lead the AUV industry in driving costs lower
- World class payload and navigation solutions
- Flexible vehicle design to allow a wide range of applications
- Increasing capabilities/acceptance of autonomous systems – particularly by the military
- Highly operational tools for ocean demanding applications (Compact size, reliability, …)
- Open system
- Continuous technological integration
- Co-develop solutions and create operational experience with users

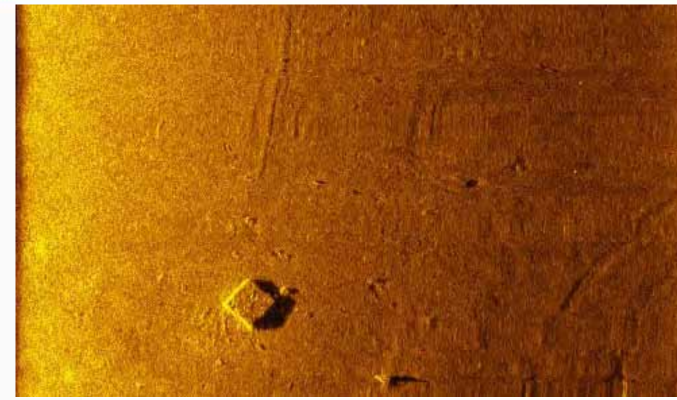
ACTIVITY

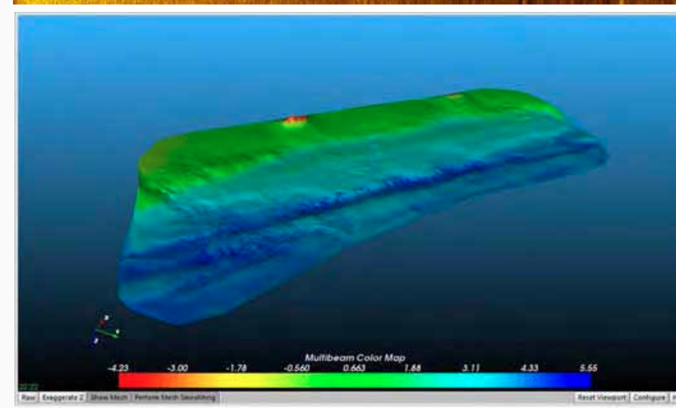
- Production and marketing of the LAUV system
- Research and development
  - Internal product development
  - Special projects and systems
- Customer support
  - Maintenance and repairs
- Survey Services
- Demonstrations

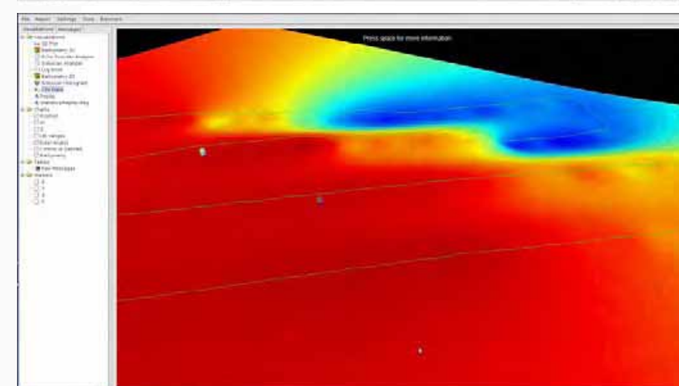
MARKET & APPLICATIONS

- **Defense**
  - Mine Warfare (MCM)
  - Rapid Environmental Assessment (REA)
  - Search & Rescue (SAR)
- **Research/Academic**
  - Environment & Oceanography
  - Underwater Archaeology
  - Robotics
- **Hydrography**
  - Bathymetry
  - Dredging Support
  - Environmental Mapping
- **Next Step: Oil & gas**
  - Increase depth rating up to 500m
  - Pipeline Inspection
  - High resolution and precision Bathymetry
  - Sub-Bottom Profiling









COLLABORATION - R&D

LSTS

U.PORTO

Marinha

hidrográfico
marinha·portugal

emepc
Estrutura de Missão para a Extensão da Plataforma Continental

MBARI

NPS
PRAESTANTIA PER SCIENTIAM
1909

Imperial College London

COLLABORATION - MARKET

Spain

INNOVA oceanografia litoral

France

VIRTUALDIVE

Italy

INSTALL
Marine Survey Genuine Solutions

Benelux

CLEMACO

Oi oceanology international 2014
11-13 MARCH 2014, LONDON, EXCEL
Join us at Oceanology International 2014
The global ocean forum

ocean business 15
14-16 April 2015 • Southampton, UK
The hands-on ocean technology exhibition and training forum

China

北京大洋经略科技有限公司
Beijing OceanEco Technology Co. Ltd.

Baltic Sea

emma technologies

Russia

PRO

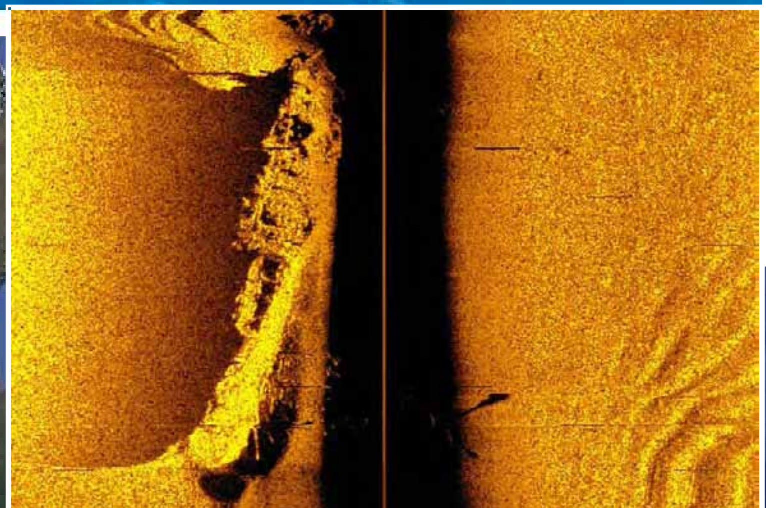
Romania

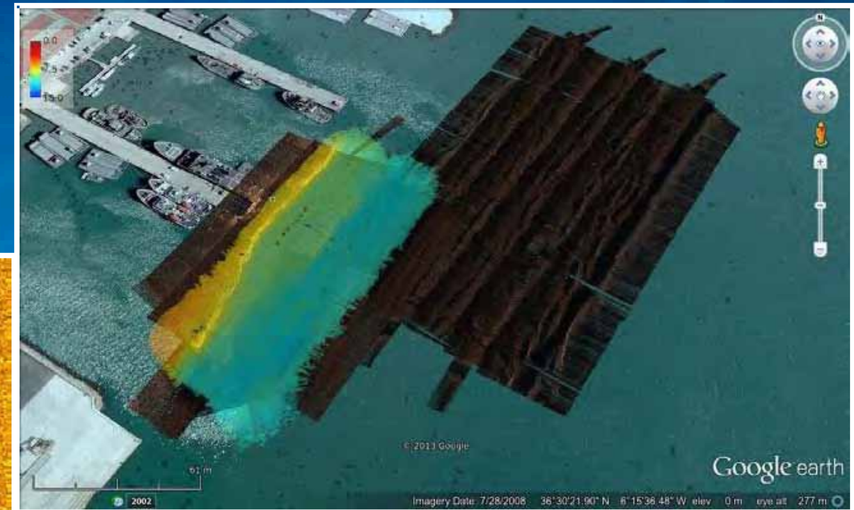
MARINE RESEARCH

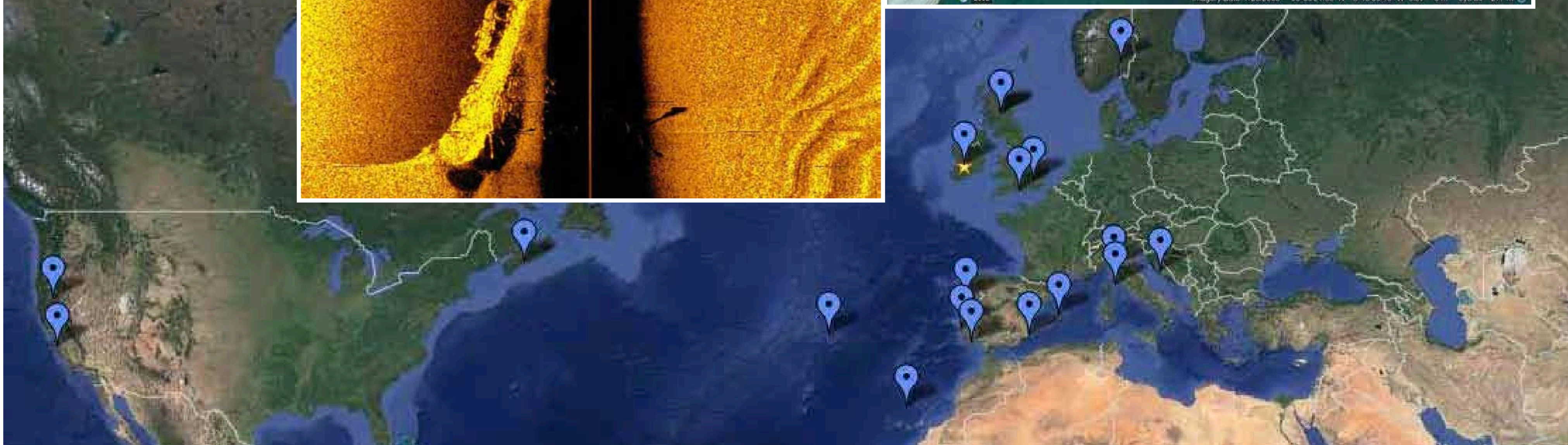
Brazil

AMBIPETRO

OPS & CLIENTS



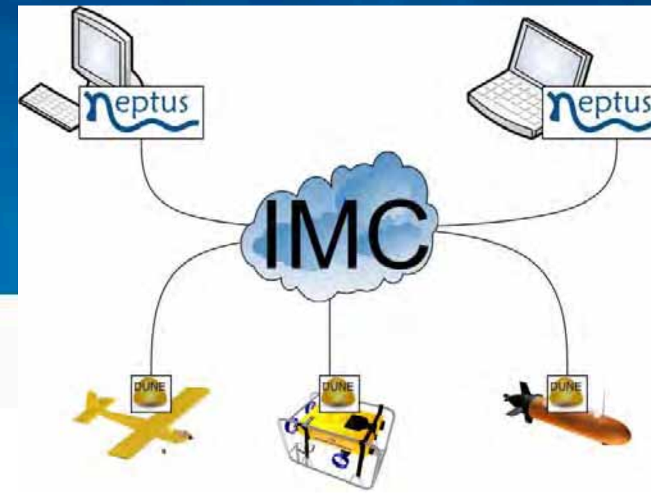


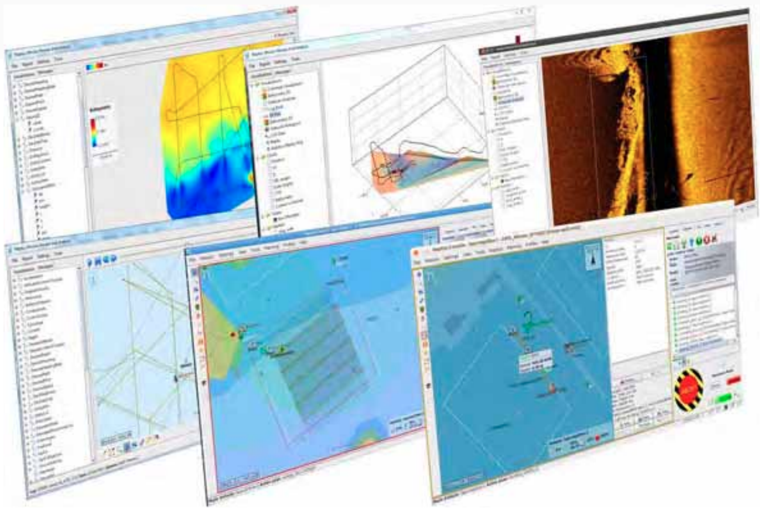


THE CONCEPT
Continuous and sustained presence in the Ocean

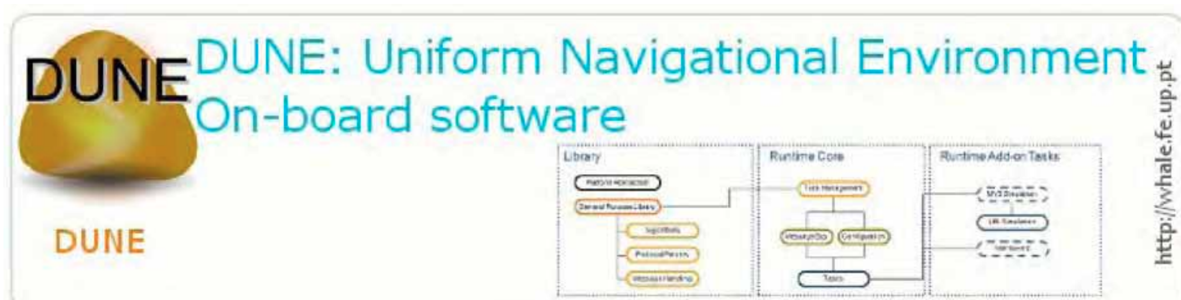
- Lightweight/small size
- Affordable
- Robust & Reliable
- Low logistics
- Modular design
- Open system

SOFTWARE FRAMEWORK





- Open source software toolchain for autonomous vehicles developed by Porto University
- Covers all the different stages of the mission life cycle: configuration, planning, simulation, execution and post-mission analysis.

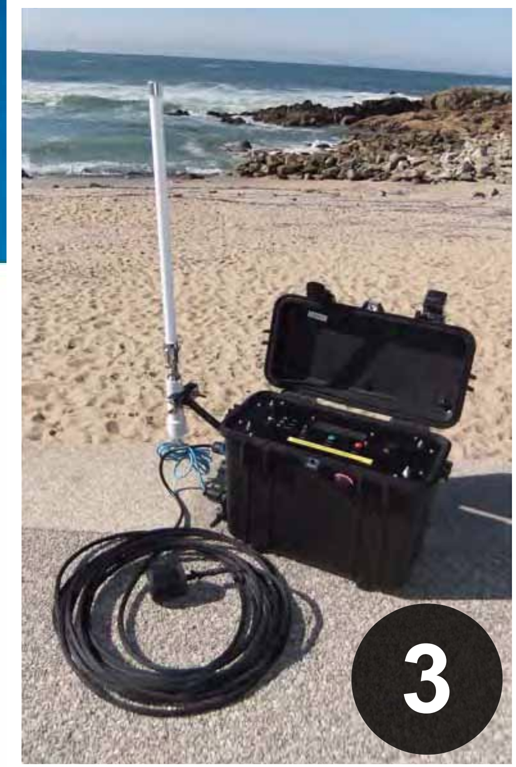


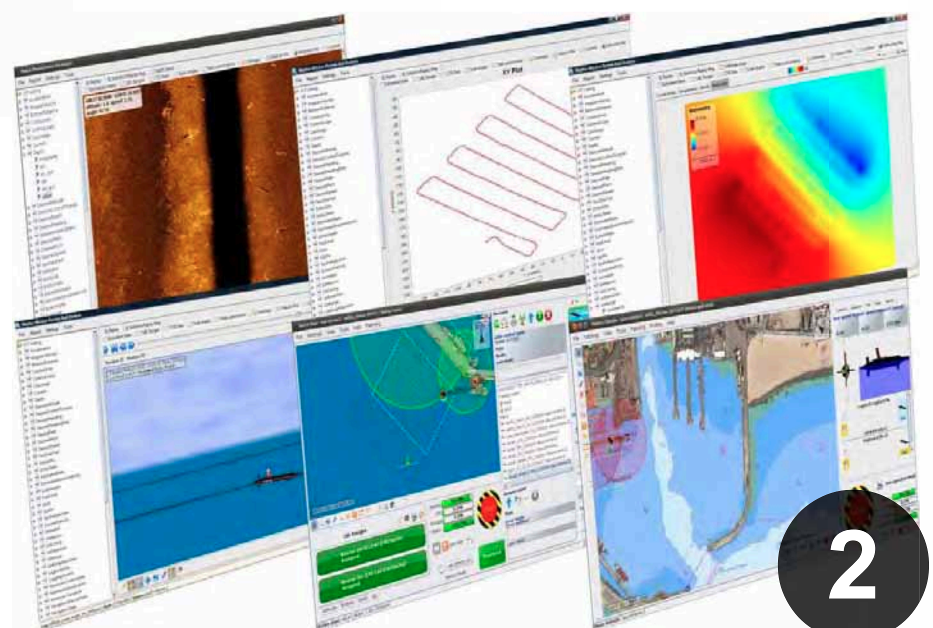
SYSTEM OVERVIEW

(1) LAUV

(2) Command and Control Unit

(3) Communications Gateway





SYSTEM OVERVIEW


Down the Memory Lane

LAUV BLUE (2006-2008)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University

Two Units

Decommissioned in 2008

- **Length:** 110 cm
- **Diameter:** 15 cm
- **Endurance:** 4 hours
- **Weight:** 12 Kg
- **Depth Rating:** 25 m
- **Steering:** 3 Servo Controlled Fins
- **Thrust:** 60W Motor
- **Comms:** 802.11b, GSM
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Custom Narrow Band LBL
- **Payload Sensors:** CTD

LAUV GREEN (2007-2008)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University

One Unit

Decommissioned in 2008

- **Length:** 60 cm
- **Diameter:** 15 cm
- **Endurance:** 4 hours
- **Weight:** 8 Kg
- **Depth Rating:** 50 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 60W Motor
- **Comms:** 802.11g, GSM
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Custom Narrow Band LBL
- **Payload Sensors:** CTD

LAUV XTREME 1 (2008-2011)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

One Unit

Decommissioned in 2011

- **Length:** 110 cm
- **Diameter:** 15 cm
- **Endurance:** 6 hours
- **Weight:** 14 Kg
- **Depth Rating:** 50 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 60W Motor
- **Comms:** 802.11g, GSM, Acoustic Modem
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem LBL
- **Payload Sensors:** CTD, Echo Sounder

LAUV SEACON (2010-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University, OceanScan-MST, and the Portuguese Navy

Four Units

2 Upgrades

- **Length:** 137-185 cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 17-22 Kg
- **Depth Rating:** 50 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem, DVL, RLG IMU
- **Payload Sensors:** CTD, Sidescan, Camera, Echo Sounder

LAUV XTREME 2 (2011-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

One Unit

3 Upgrades

- **Length:** 186 cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 25 Kg
- **Depth Rating:** 50-100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM,Acoustic Modem
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem LBL, DVL, RLG IMU
- **Payload Sensors:** CTD, Sidescan, Camera, Echo Sounder

LAUV NOPTILUS (2012-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

Three Units

1 Upgrade

- **Length:** 186 cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 25 Kg
- **Depth Rating:** 50-100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM, Acoustic Modem
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem LBL, DVL, RLG IMU
- **Payload Sensors:** CTD, Sidescan, Camera, Echo Sounder, Multibeam

LAUV DOLPHIN (2013-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

Three Units

- **Length:** 185-208 cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 28-30 Kg
- **Depth Rating:** 100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM, Acoustic Modem
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem LBL, DVL, FOG IMU
- **Payload Sensors:** CTD, Sidescan, Camera, Echo Sounder

LAUV XPLORE (2013-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

Two Units

- **Length:** 186 cm
- **Diameter:** 15 cm
- **Endurance:** 32 hours
- **Weight:** 25 Kg
- **Depth Rating:** 100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM, Acoustic Modem, Iridium SBD
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem LBL
- **Payload Sensors:** CTD, Rhodamine, Refined and Crude Oils Sensor

LAUV LUPIS (2014-Present)

Developed by the Underwater Systems and Technology Laboratory (LSTS) of Porto University and OceanScan-MST

Three Units

- **Length:** 150 cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 25 Kg
- **Depth Rating:** 100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM, Iridium SBD
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, DVL
- **Payload Sensors:** CTD

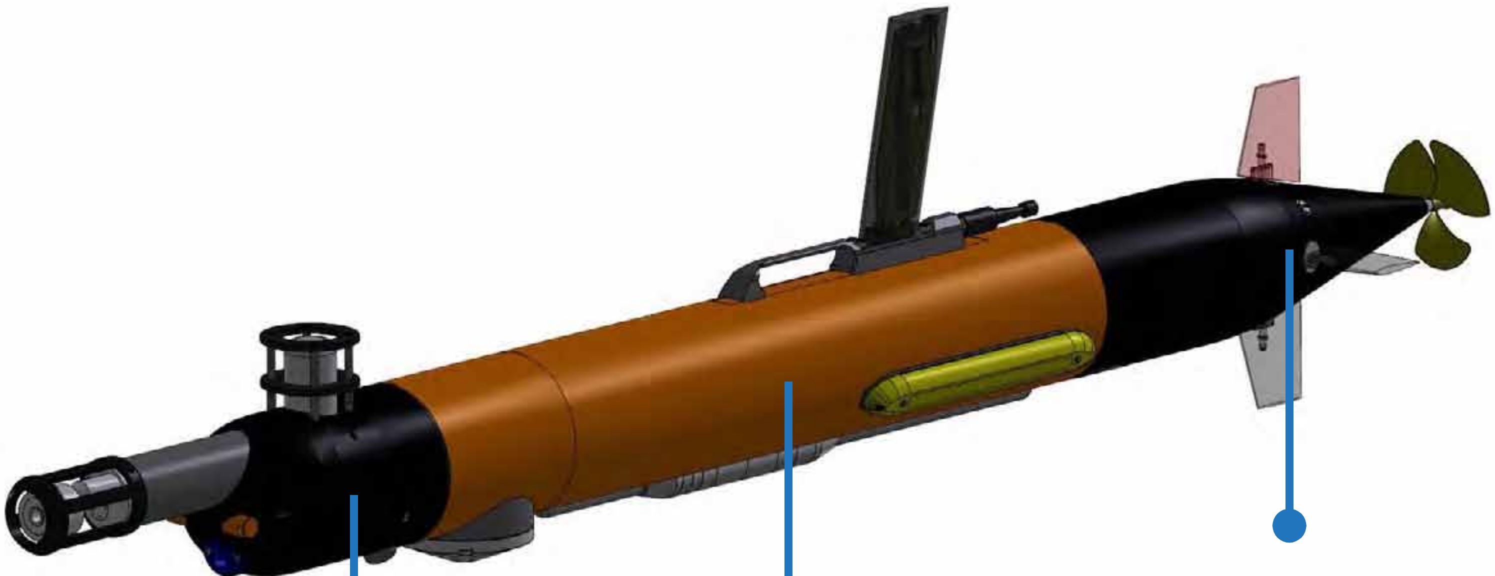
LAUV LT (2014-Present)

Developed by OceanScan-MST, the Underwater Systems and Technology Laboratory (LSTS) of Porto University, and EMMA Technologies

Three Units

- **Length:** 186-214- cm
- **Diameter:** 15 cm
- **Endurance:** 8 hours
- **Weight:** 30-33 Kg
- **Depth Rating:** 100 m
- **Steering:** 4 Servo Controlled Fins
- **Thrust:** 90W Motor
- **Comms:** 802.11n, GSM
- **Navigation:** GPS, MEMS AHRS, Pressure Sensor, Acoustic Modem, DVL, RLG IMU
- **Payload Sensors:** CTD, Sidescan, Camera, Echo Sounder, Multibeam

SECTIONS

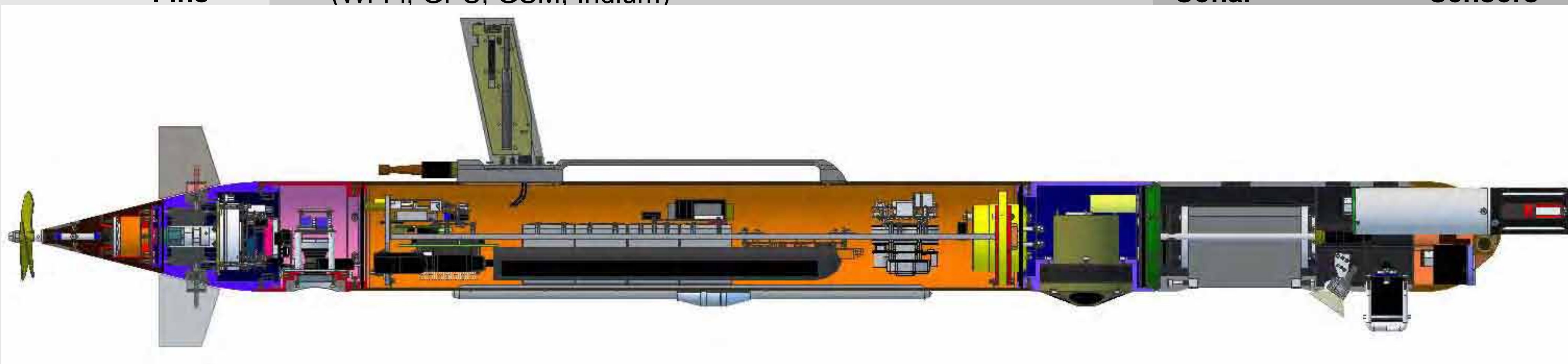


Nose Section
(Flooded)
WQ Sensors
Acoustic Txd

Main Section
(Dry)
Electronics
Batteries

Tail Section
(Dry)
Servos+Motor
Drivers

INTERNAL VIEW



www.oceanscan-mst.com

OceanScan – Marine Systems & Technology Lda

NAVIGATION INSTRUMENTS

- GPS, AHRS, Depth Sensor
- DVL (LinkQuest, Teledyne RDI)
- LBL (WHOI, Teledyne Benthos, EvoLogics)
- USBL (EvoLogics, Blueprint Subsea*)
- IMU (Honeywell, iMAR)

SONARS AND IMAGING

EdgeTech 2205 Series

HD SSS | 400/900kHz | 150/75m

L-3 Klein UUV 3500 Series

HD SSS | 455/900KHz | 150/75m

Optional Bathymetry 450kHz

Marine Sonics

Sea Scan HDS Embedded

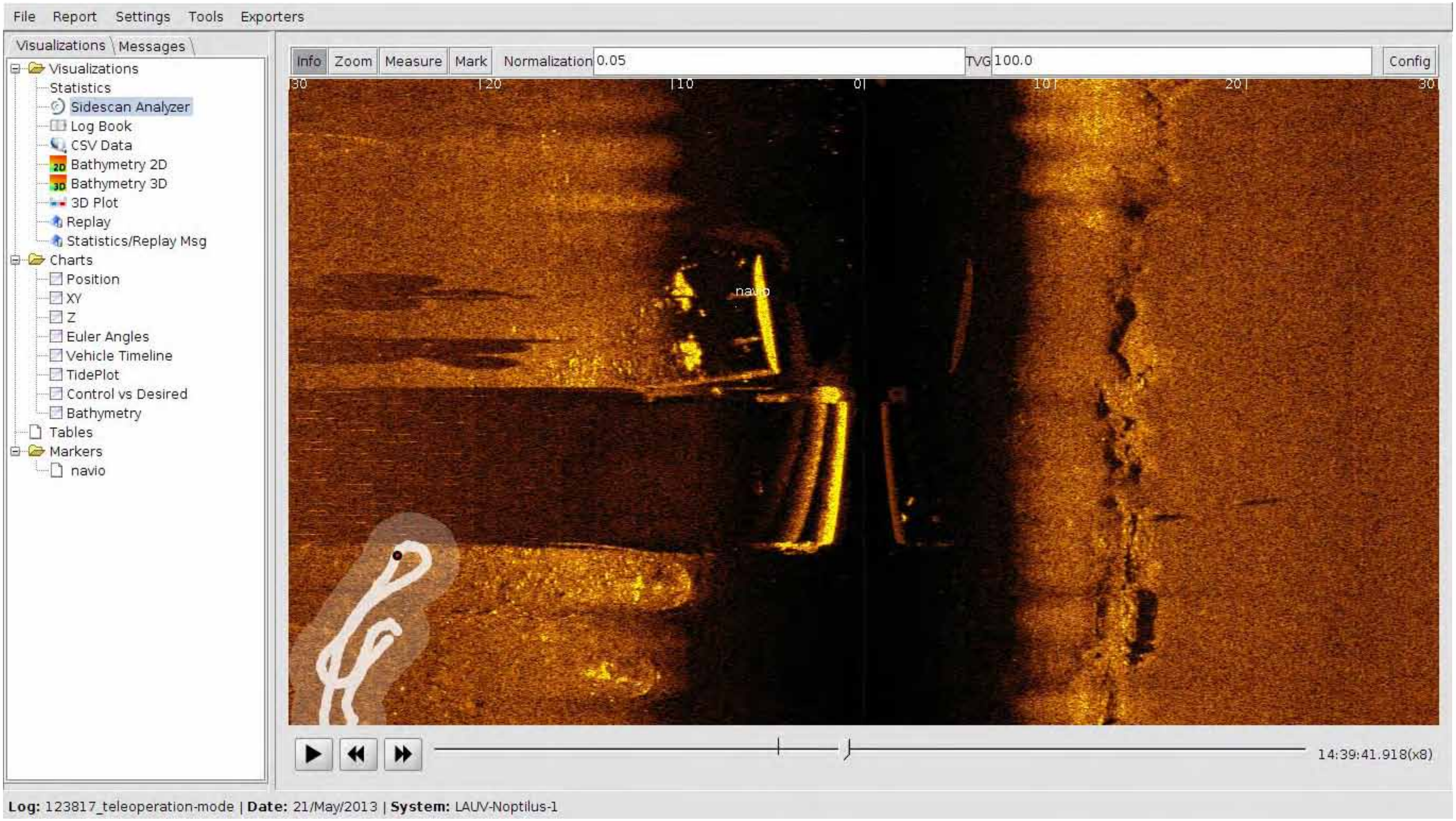
Imagenex Yellow Fin

SSS | 260/330/800kHz

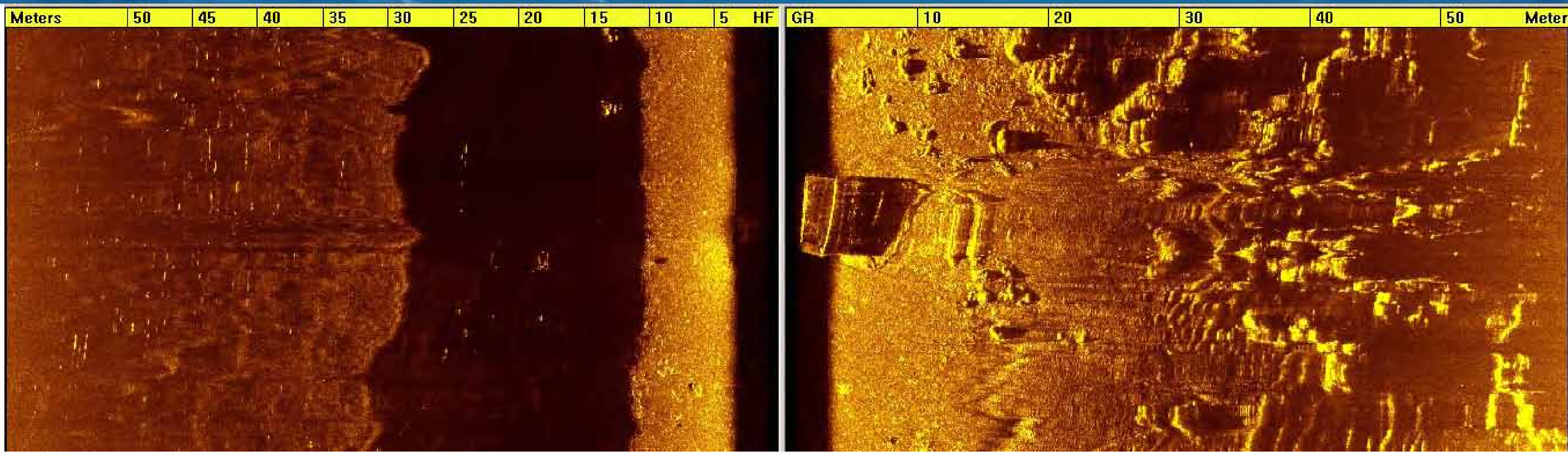
BlueView MB2250-W

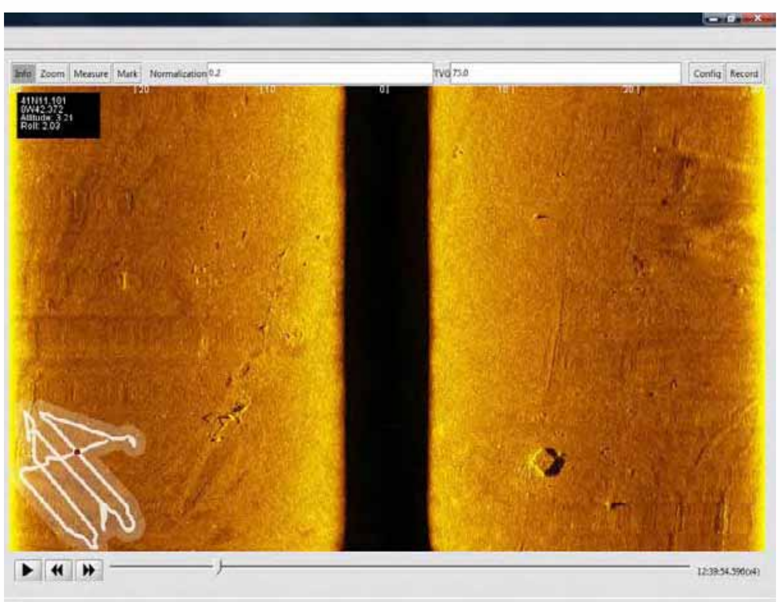
MB | 2.25 MHz

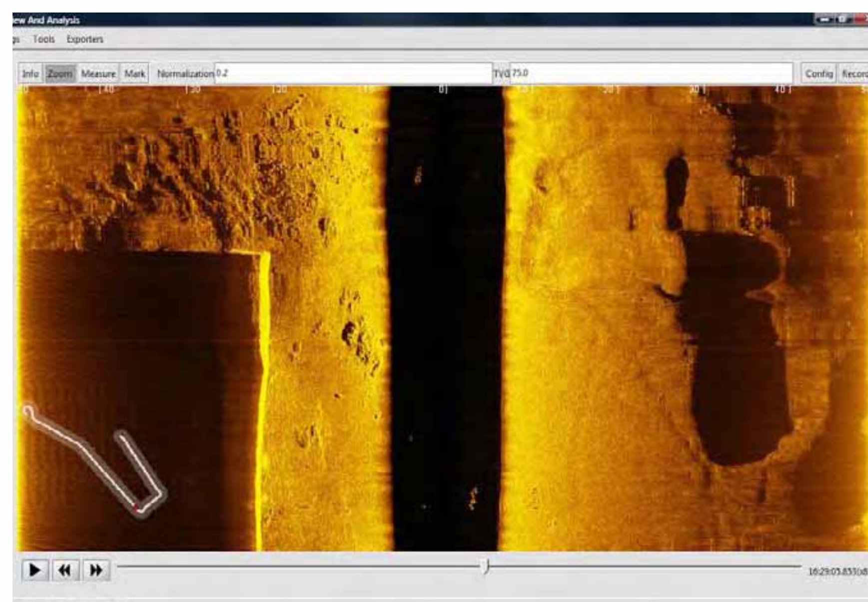
Imagenex SSS
Harbour Survey | Cadiz, Spain



Edgetech HD SSS
Harbour Survey | Porto, Portugal

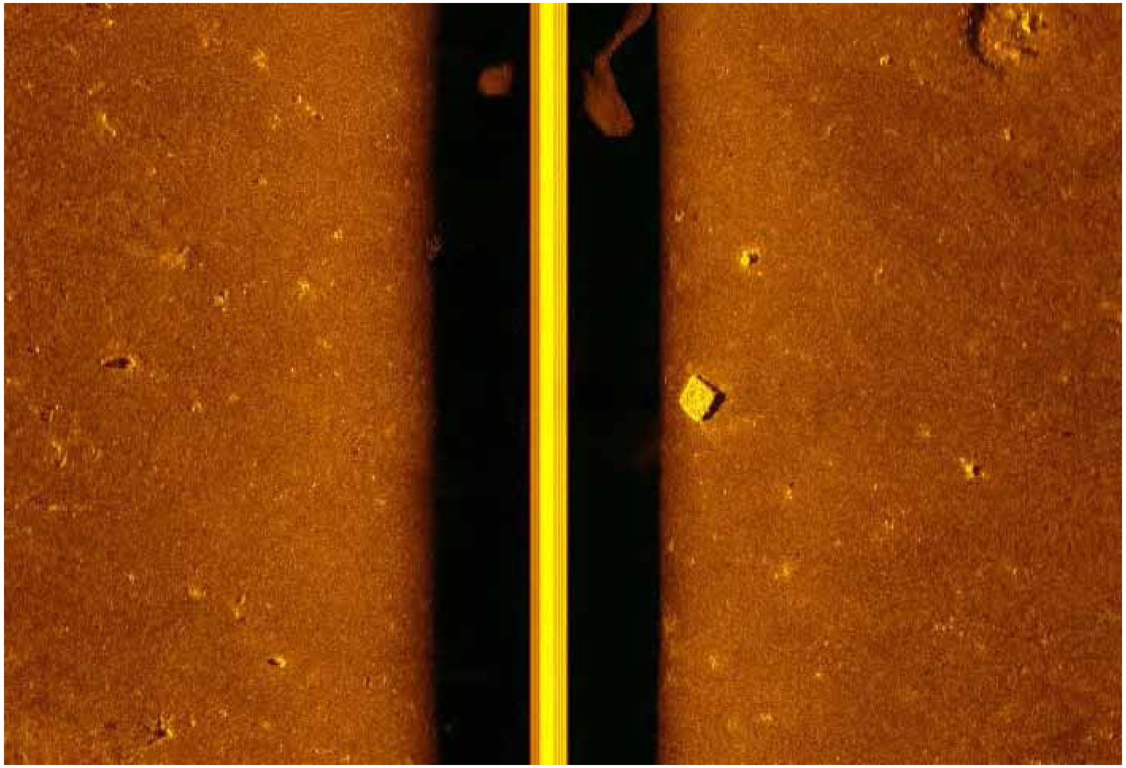


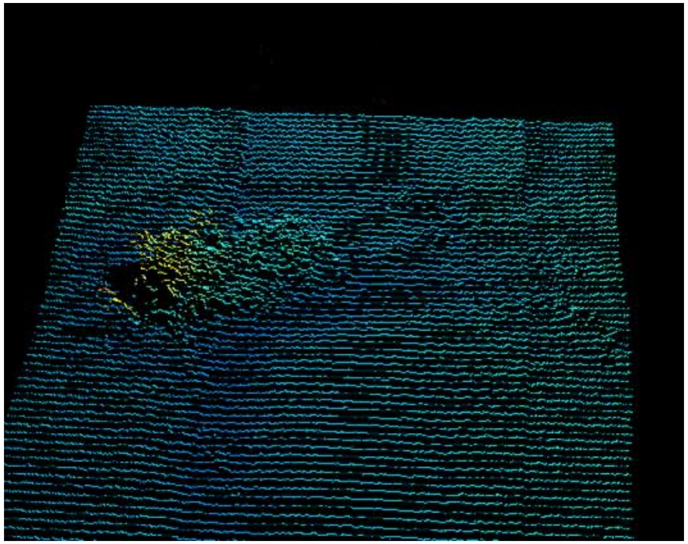


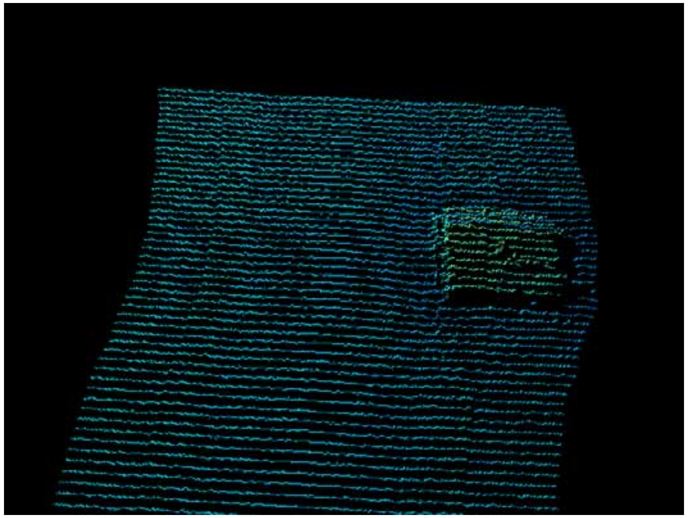


SONARS

- BlueView MB2250-W
- Klein UUV 3500







SONARS

Imagenex DeltaT

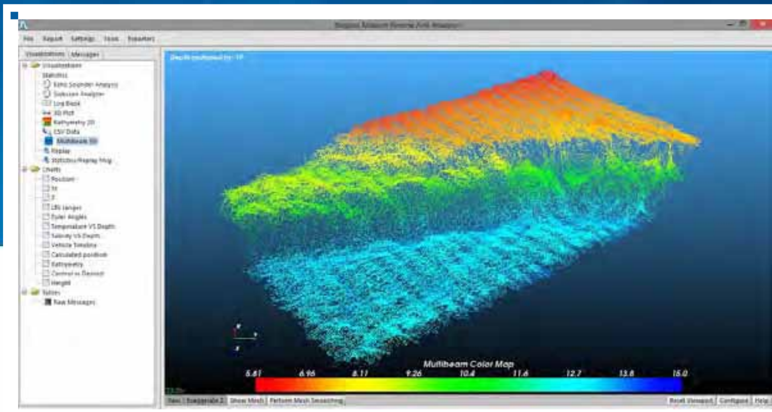
Frequency: 260kHz

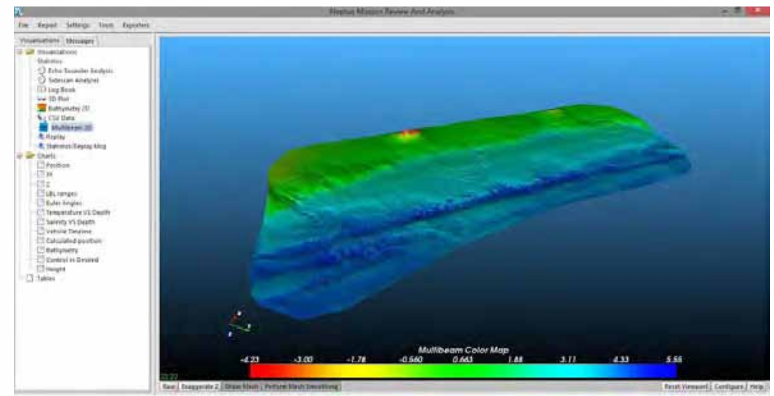
Swath: 120x3 deg

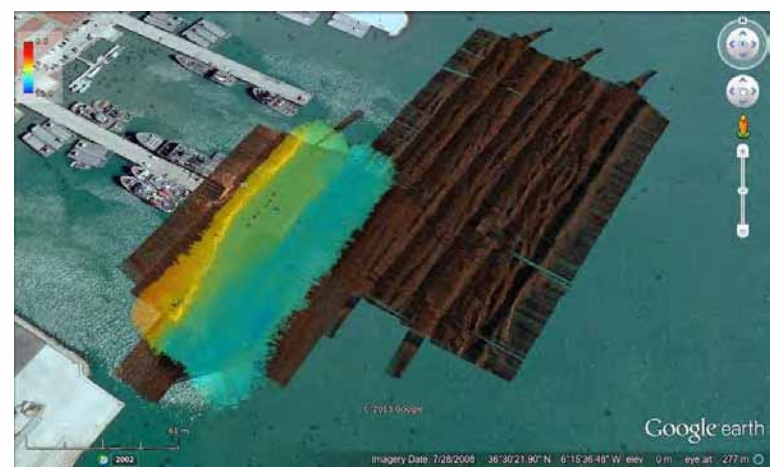
Number of beams: 480

Maximum Slant Range: 100m

IMAGENEX

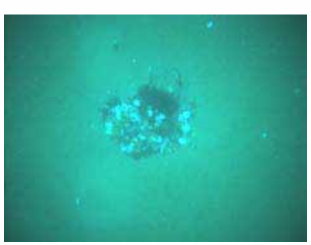


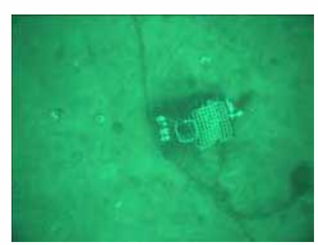




CAMERA

- Industrial Video Camera
- High sensitivity 1.4 MP CCD
- Resolution: 1376x1032
- Maximum Frame Rate: 15
- 4400lm LED illumination module





ENVIRONMENTAL SENSORS

- **Sound Velocity**
- **CTD**
  Conductivity, Temperature, and Depth
- **Dissolved Oxygen**
- **Optical Sensors**
  Turbidity and a wide range of fluorescence parameters
- **pH**
- **Other environmental and oceanographic sensors**

THE NEAR FUTURE

- Integration of more payload sensors (different brands and models)
- Increase the vehicle's diameter
- Increase the depth rating to 200 m and then 500 m
- Improve visualization tools


OCEANSCAN – MARINE SYSTEMS & TECHNOLOGY
Engineering the future for a sustained presence in the ocean
www.oceanscan-mst.com | info@oceanscan-mst.com | +351 220301576

DexROV
EU PROJECT

Diego Urbina,
Space Application Services
Zaventem, BE

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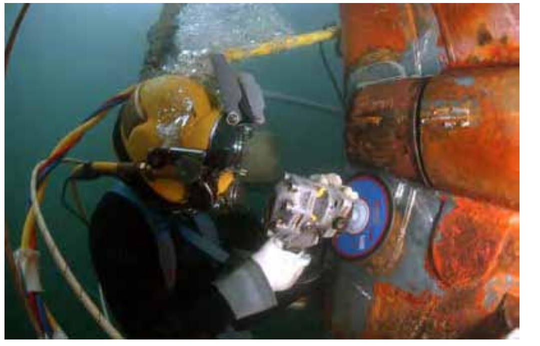

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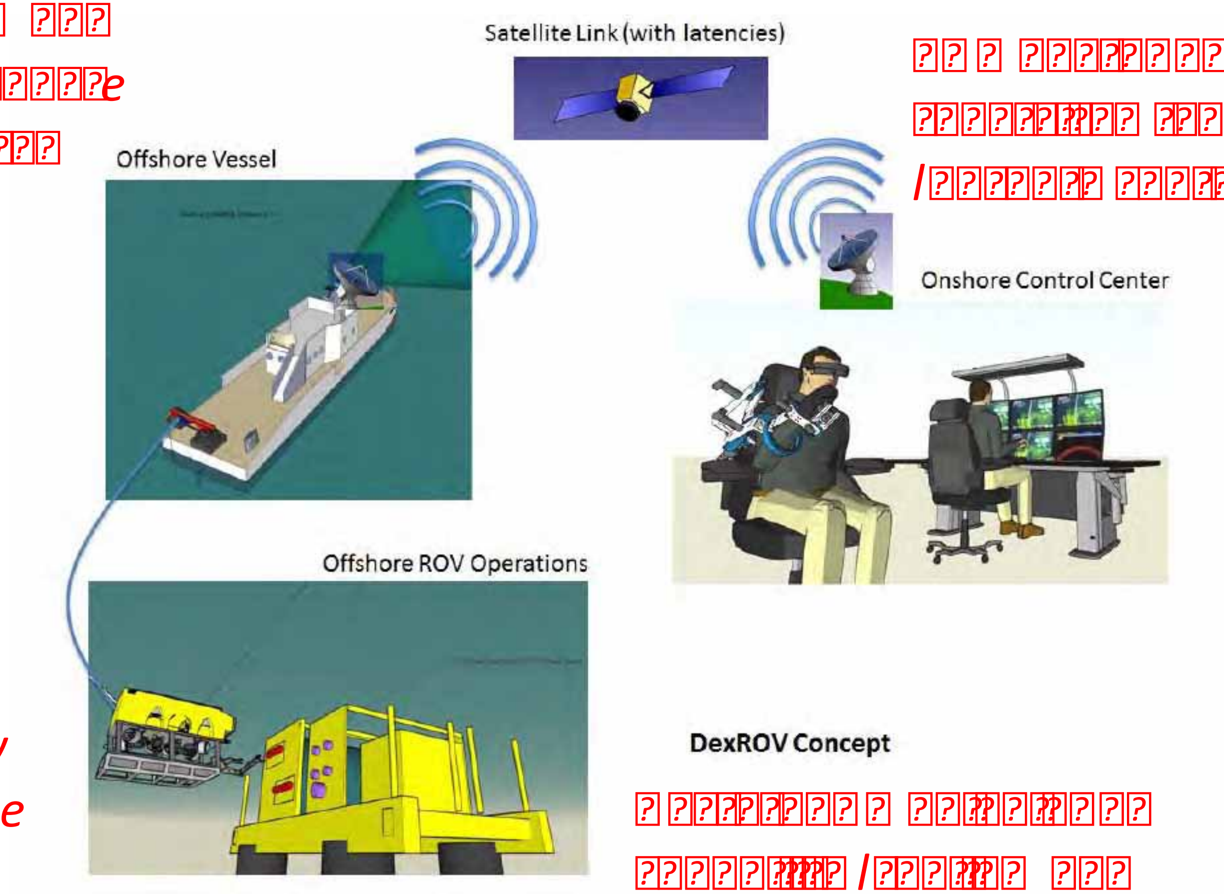
Satellite Link (with latencies)
Offshore Vessel
Onshore Control Center
Offshore ROV Operations
DexROV Concept

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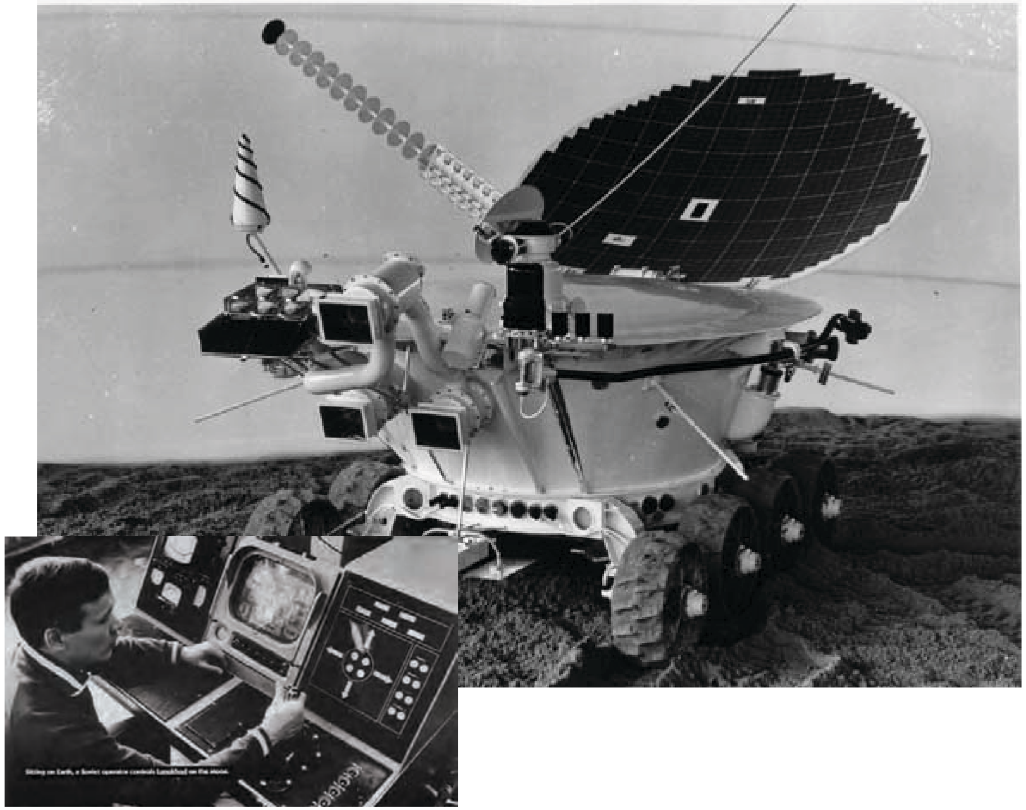

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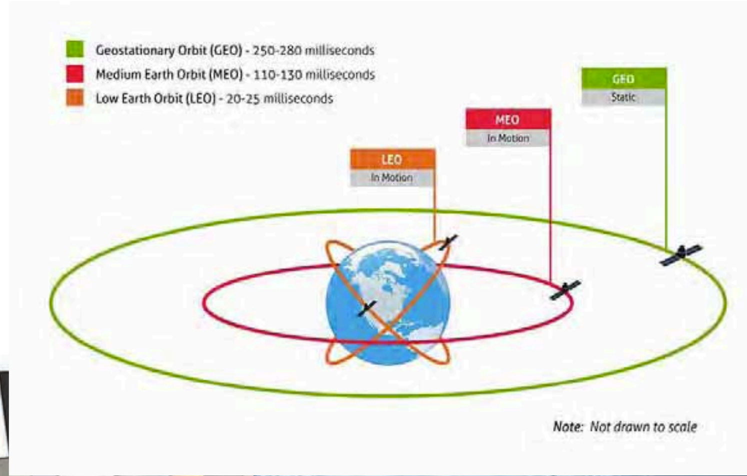

Geostationary Orbit (GEO) - 250-280 milliseconds
Medium Earth Orbit (MEO) - 110-130 milliseconds
Low Earth Orbit (LEO) - 20-25 milliseconds
GEO
Static
MEO
In Motion
LEO
In Motion
Note: Not drawn to scale

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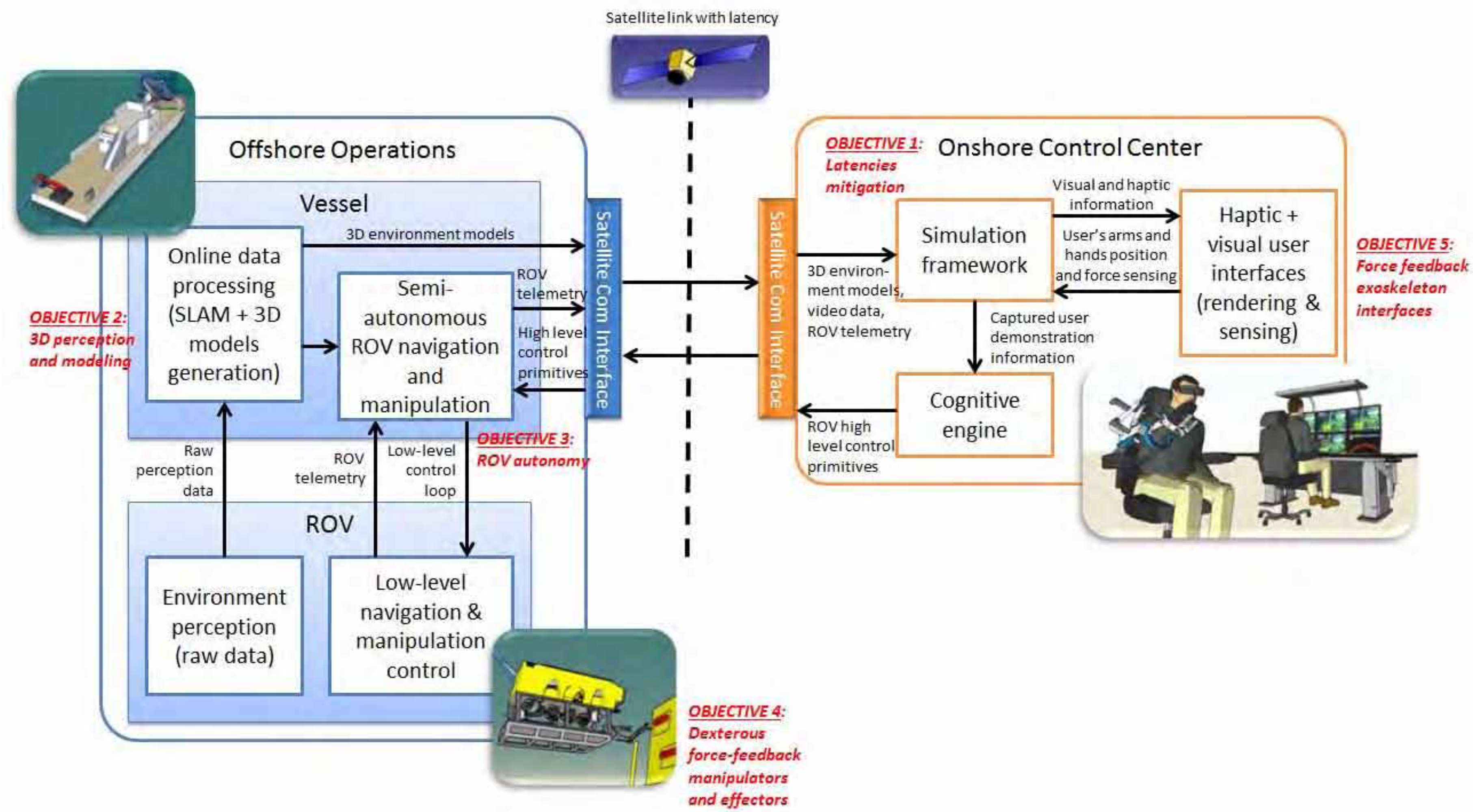

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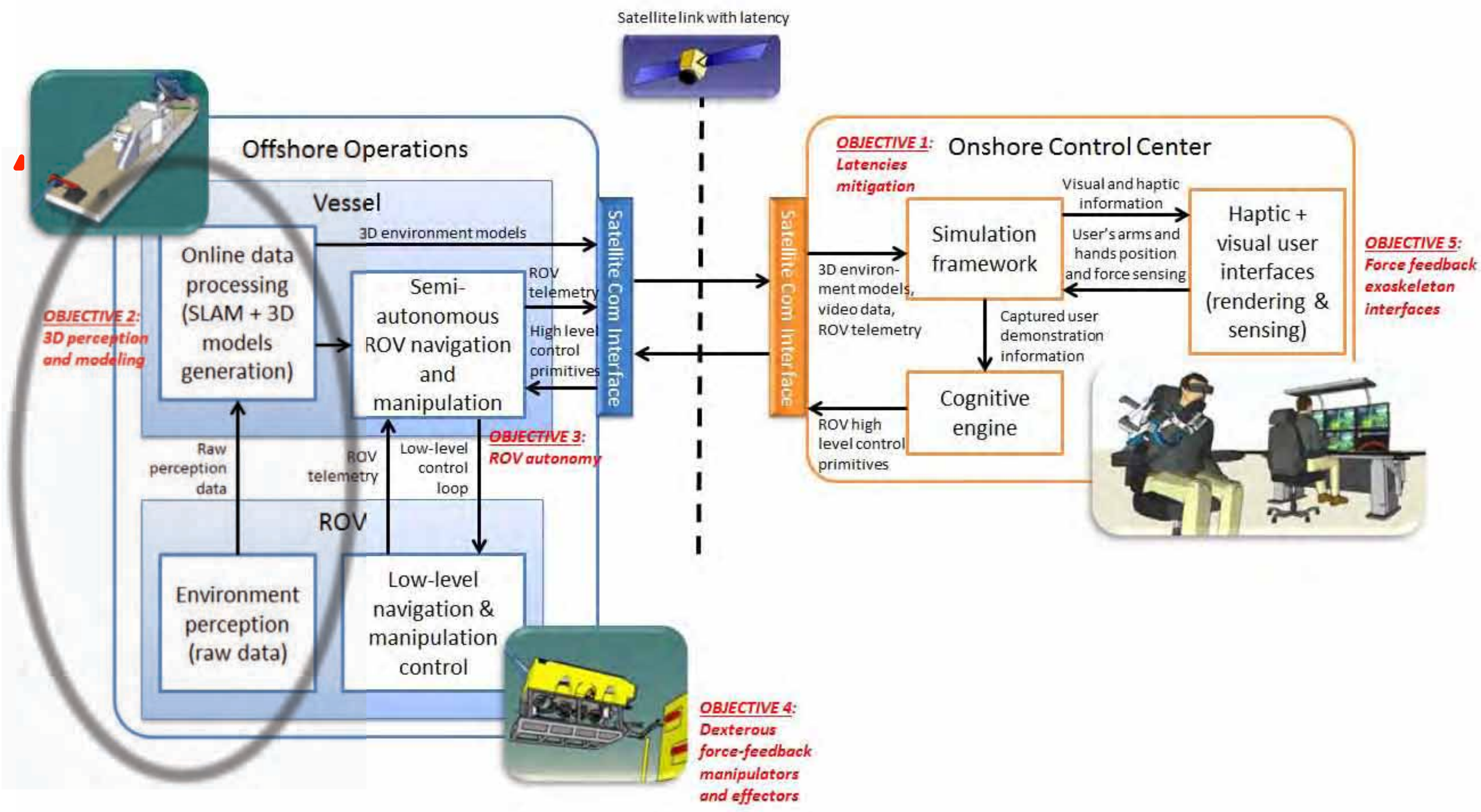

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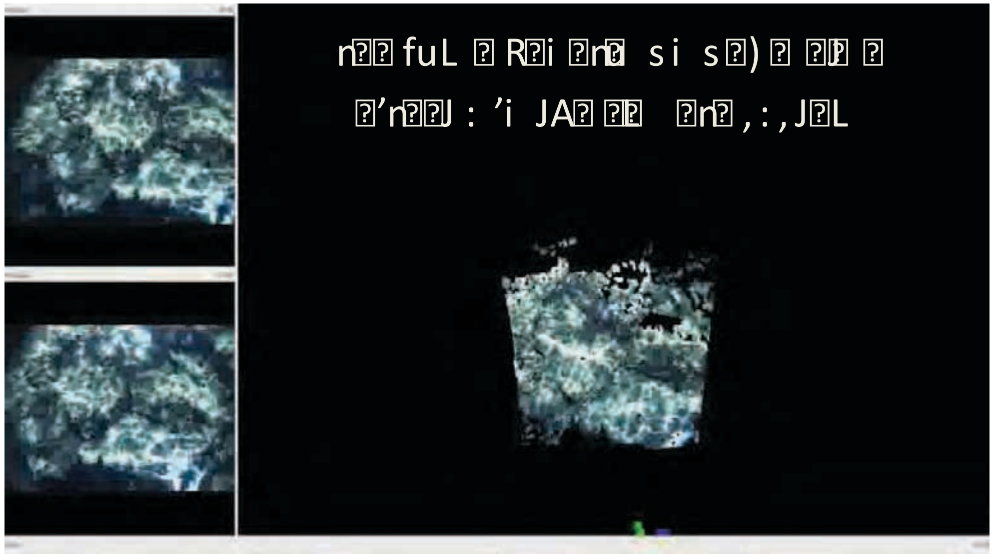

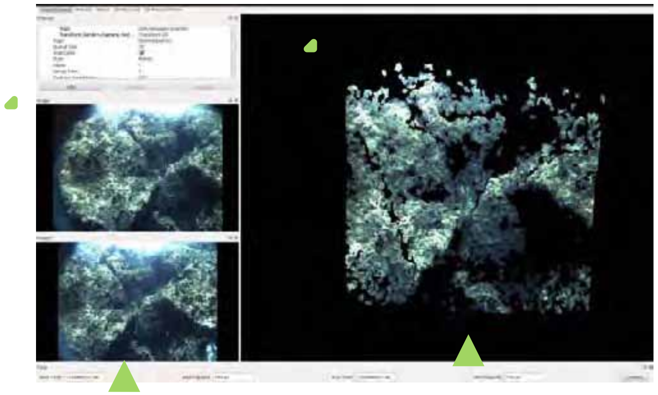

stereo
2D images

3D colored
point cloud

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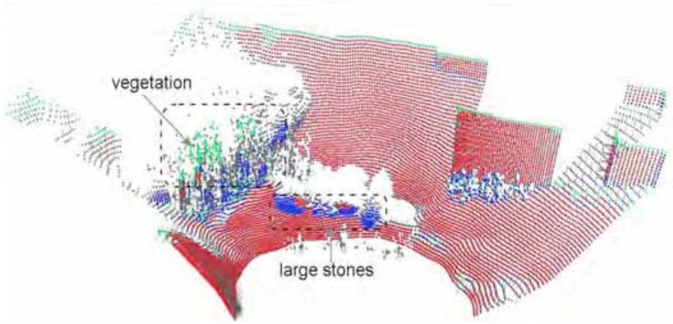

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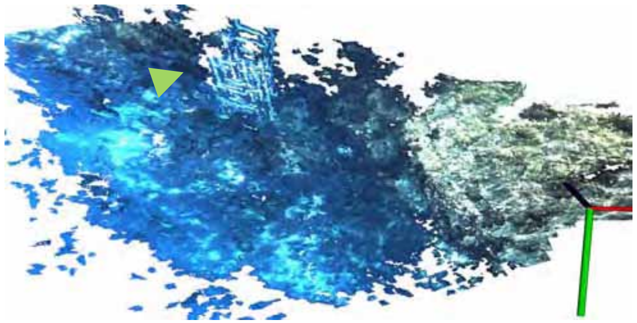
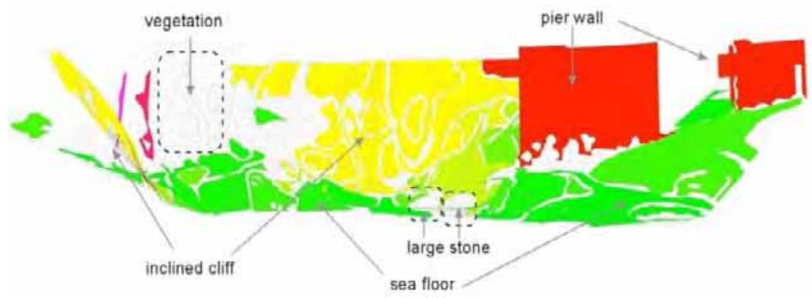
, ?oD?i ?? s ?) Sv n?R',J?n?? bs'i J ?s D?, nsi : ?x?n: (v^JA ?n? ?, As Oi G

ladder as "ground truth", approx. 25cm drift over 15m motion





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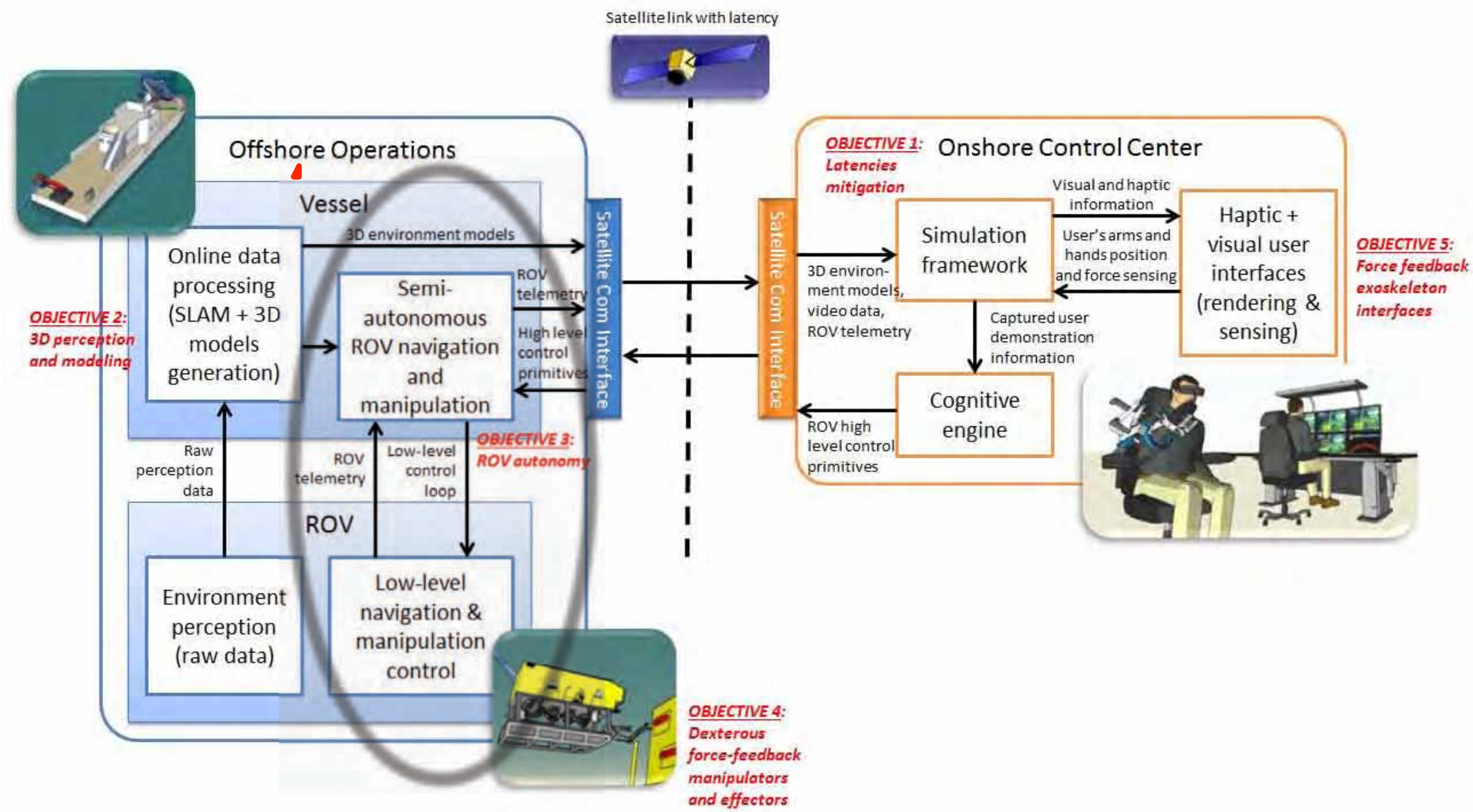

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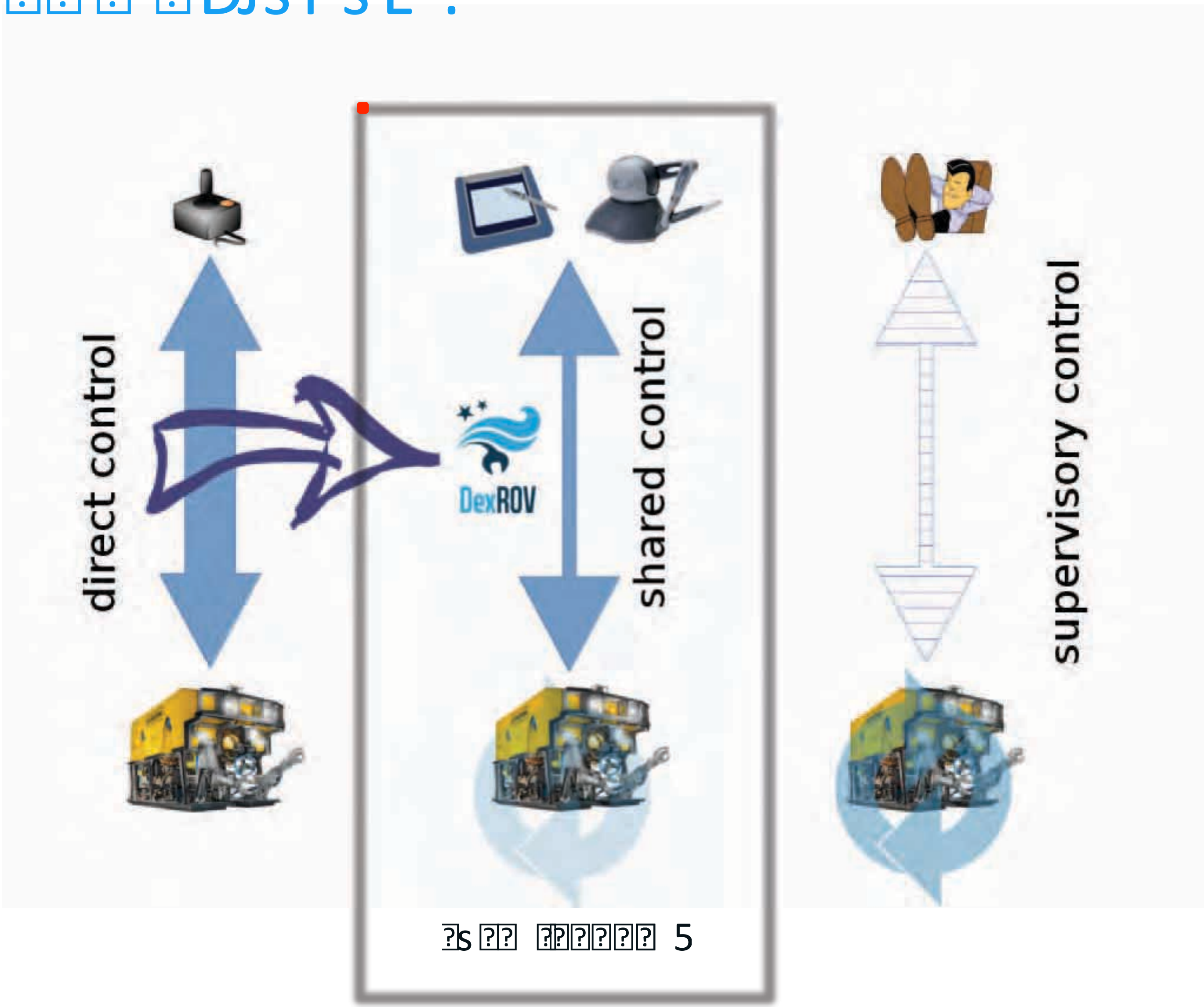
direct control
DexROV
shared control
supervisory control

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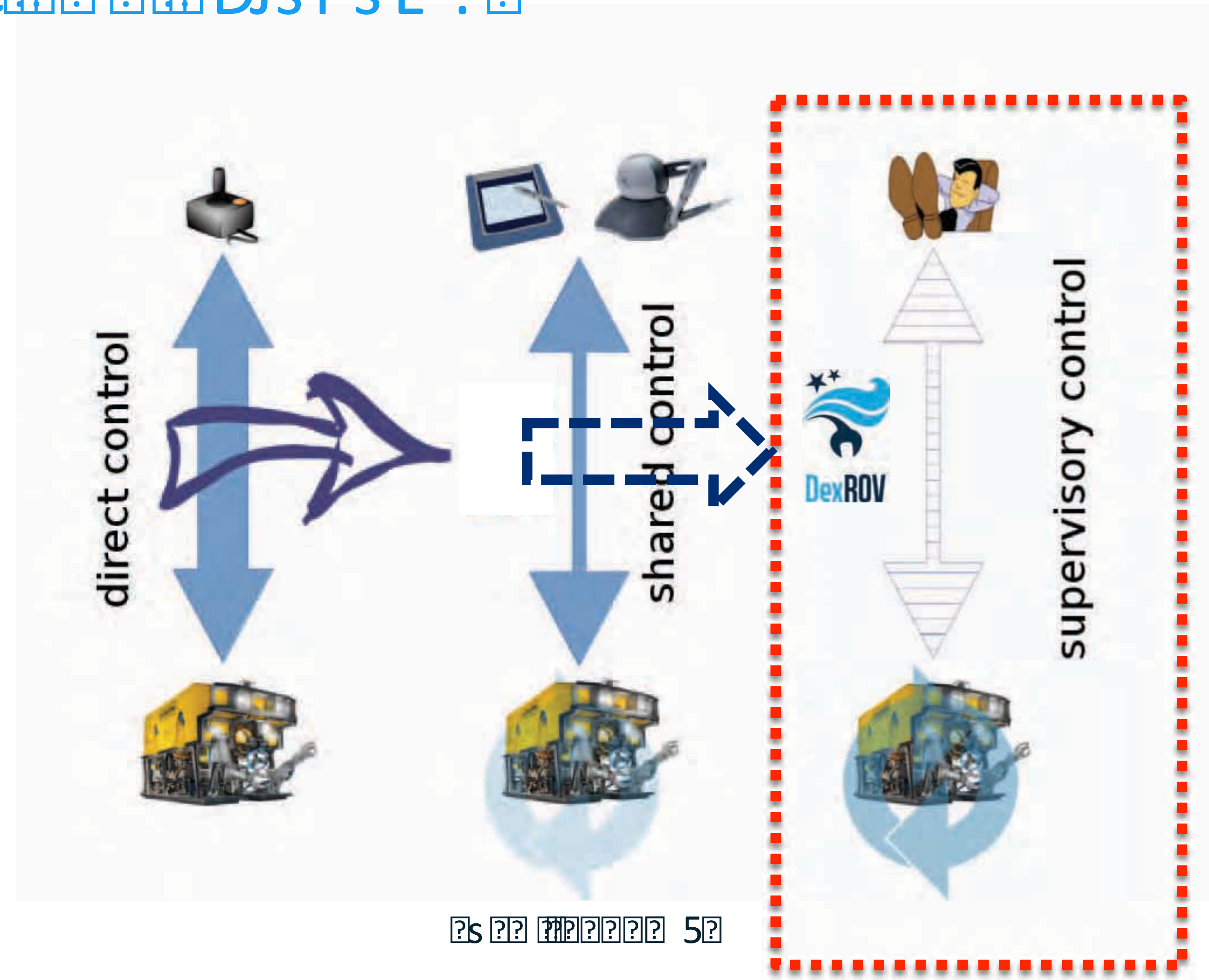
nsGC??? ??DJsisL :?



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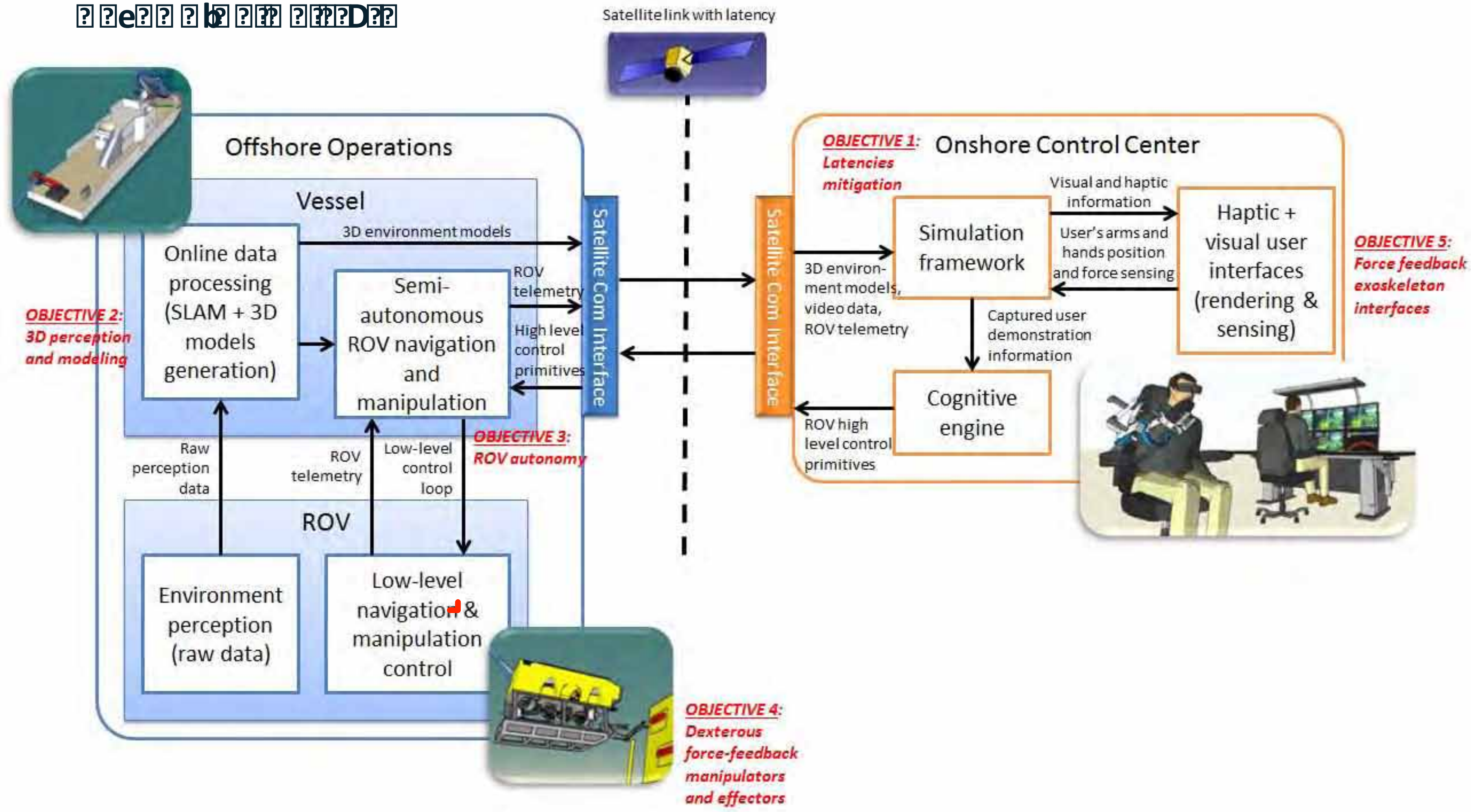

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  - S □□VJ□ms D, mX Js B □s□GL □ 'bD□ sn, O'JA □s n□□ ,□i ,'i R □□ □ ''J:
  -) f□i R□n□□ Rn'bb□n, mS □ ux□ □s□, □□ AdE□V'si P□VJ□i ,'si □ □ □ □D□usi P□ □D□usi GO'JA □s n□□ ,□i ,'i R □□ □ ''J:
  - □ ,5'□ □s n'i J□Rn□ i R JA□ L □ 'bD□ sn, si Js JA□ □□ □ m'RAJPL '□ 'i J□nx□i usi □,□ ,d□b□ A□ SFvvG

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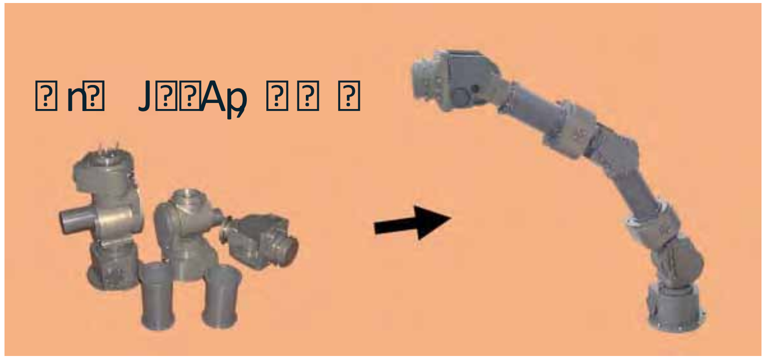

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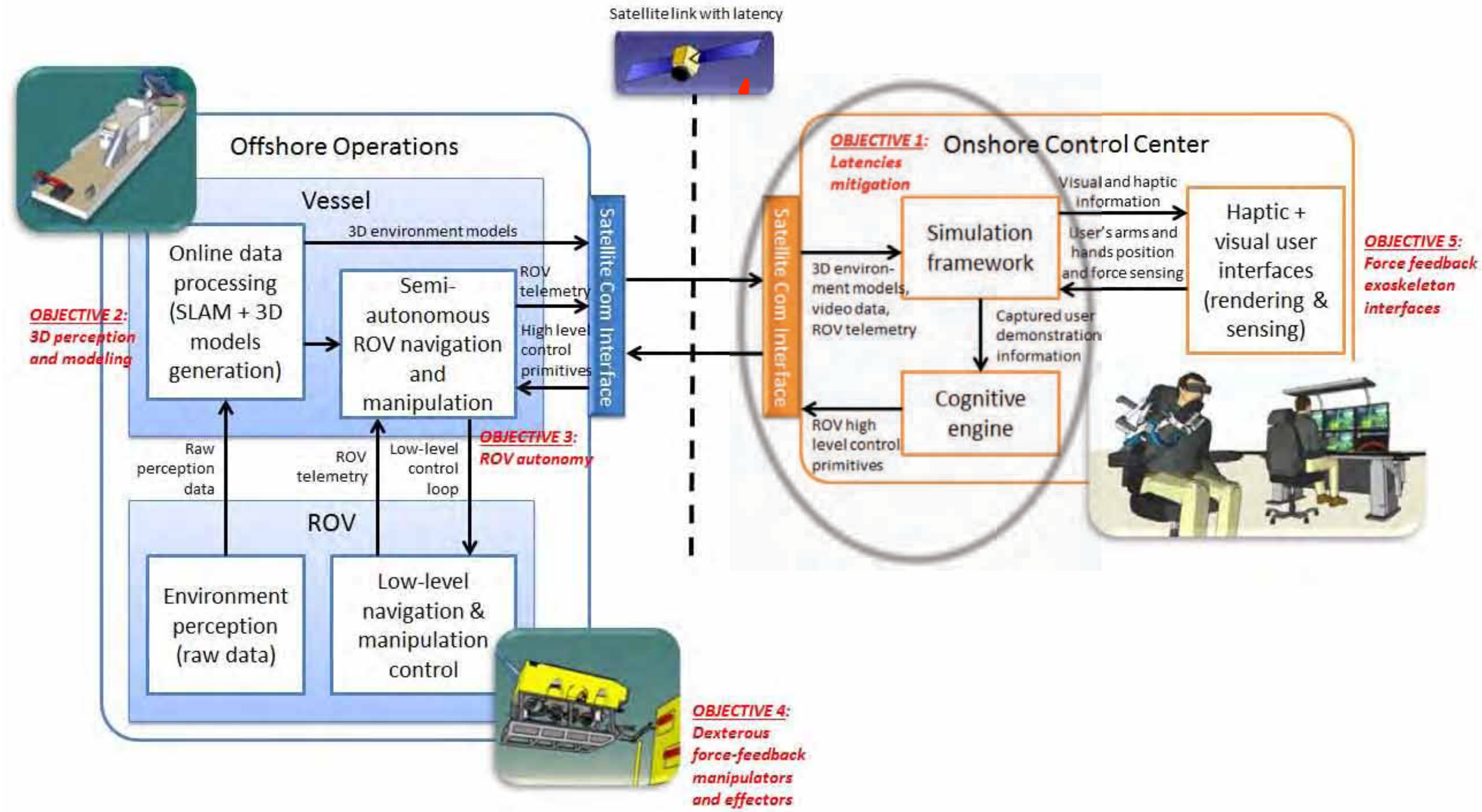

Satellite link with latency
Offshore Operations
Vessel
3D environment models
Online data processing (SLAM + 3D models generation)
Semi-autonomous ROV navigation and manipulation
ROV telemetry
High level control primitives
Satellite Com Interface
OBJECTIVE 2: 3D perception and modeling
Raw perception data
ROV telemetry
Low-level control loop
OBJECTIVE 3: ROV autonomy
ROV
Environment perception (raw data)
Low-level navigation & manipulation control
OBJECTIVE 4: Dexterous force-feedback manipulators and effectors
OBJECTIVE 1: Latencies mitigation
Onshore Control Center
Satellite Com Interface
3D environ-ment models, video data, ROV telemetry
Simulation framework
Visual and haptic information
User's arms and hands position and force sensing
Haptic + visual user interfaces (rendering & sensing)
Captured user demonstration information
Cognitive engine
ROV high level control primitives
OBJECTIVE 5: Force feedback exoskeleton interfaces

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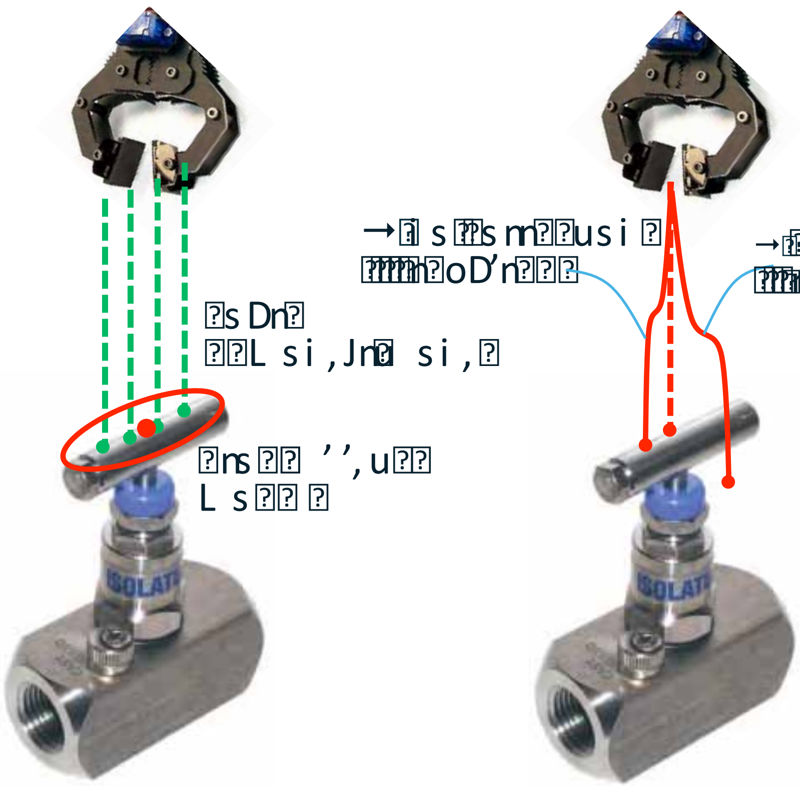

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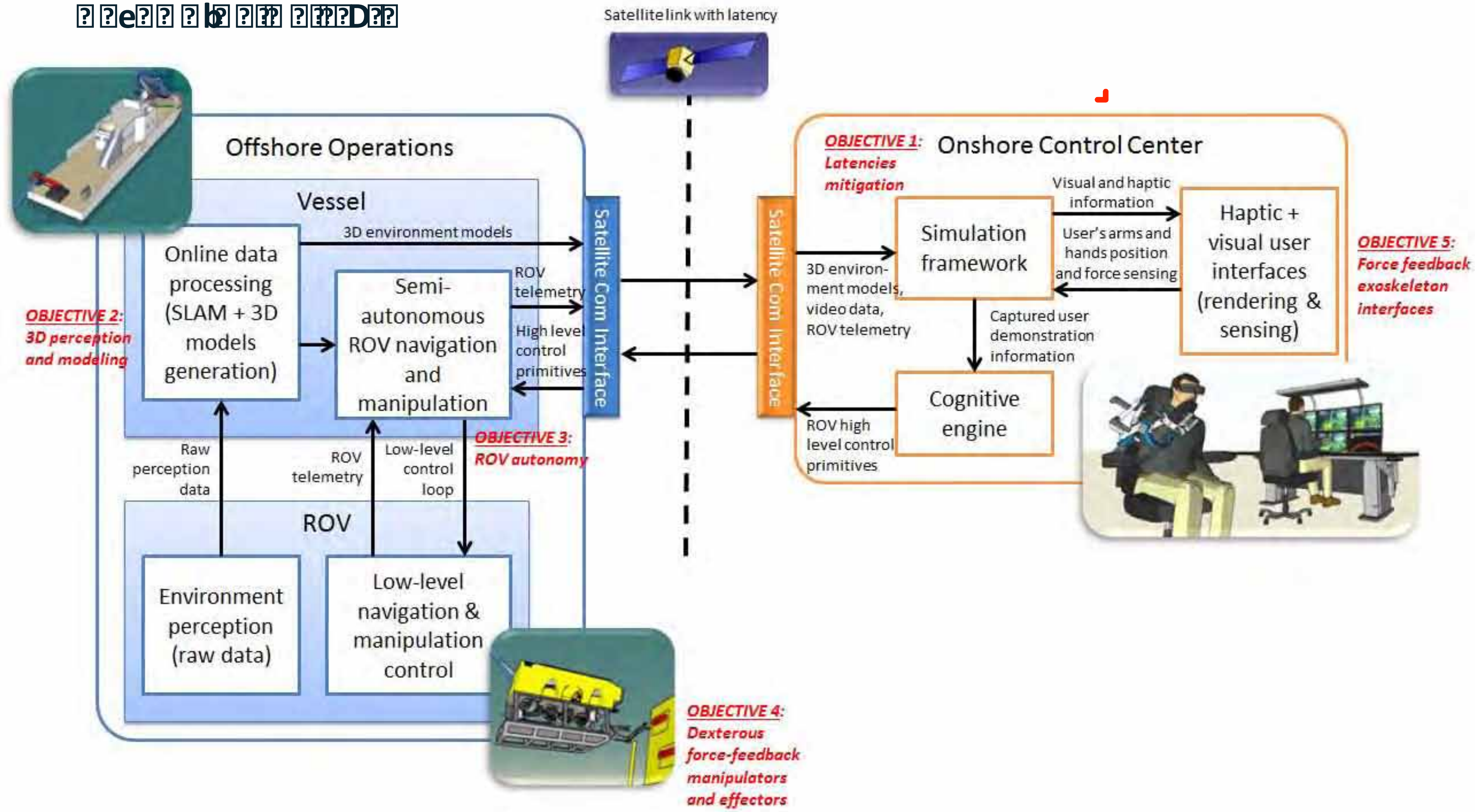
UWSim: Prats, M.; Perez, J.; Fernandez, J.J.; Sanz, P.J., "An open source tool for simulation and supervision of underwater intervention missions", 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2577-2582, 7-12 Oct. 2012



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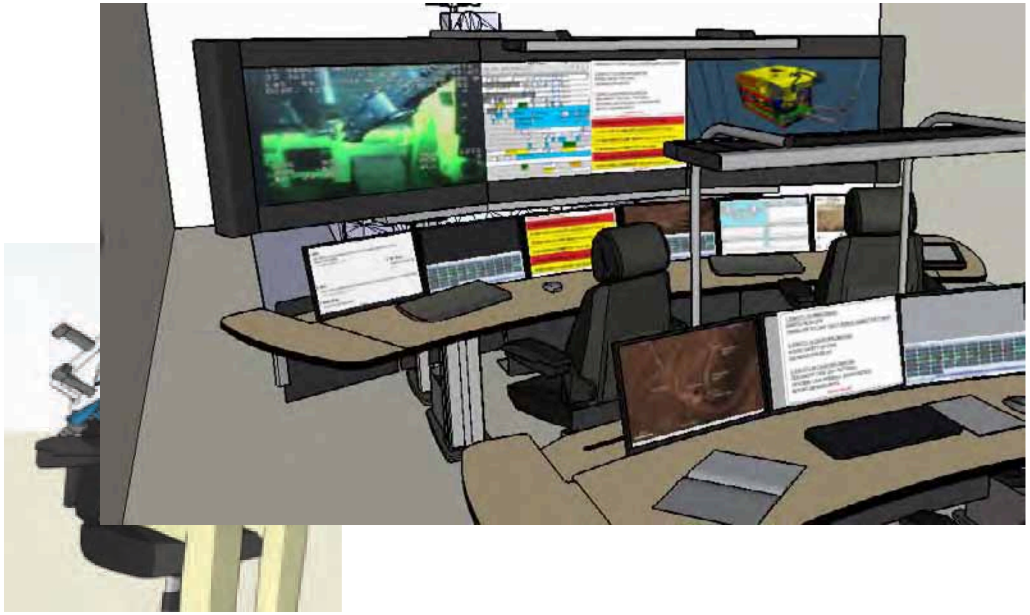
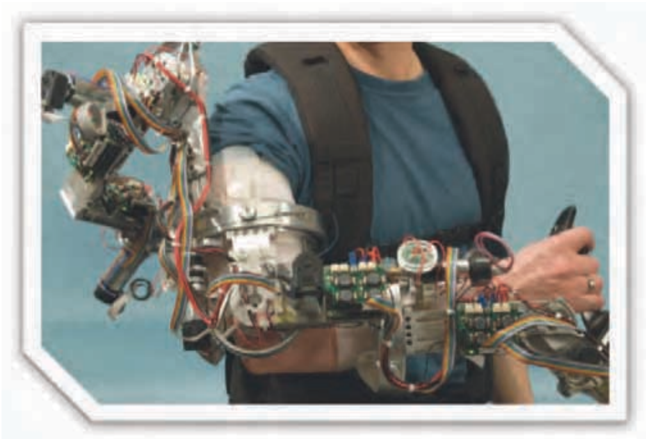
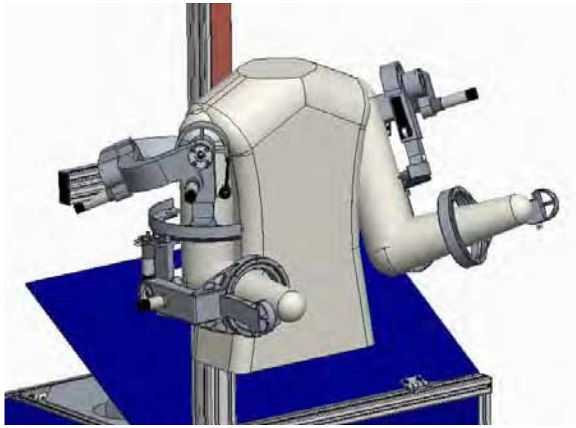
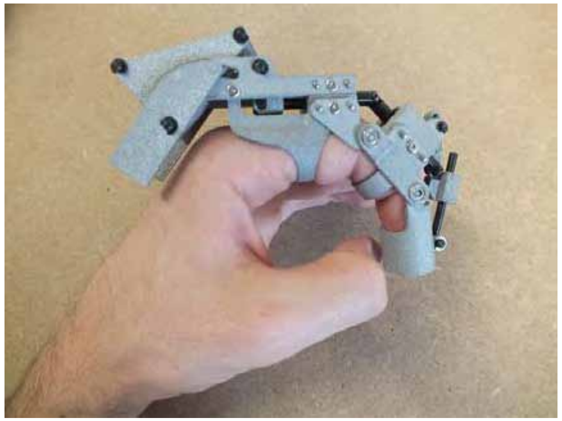
Onshore Control Center
Satellite Com Interface
3D environment models, video data, ROV telemetry
Simulation framework
Visual and haptic information
User's arms and hands position and force sensing
Haptic + visual user interfaces (rendering & sensing)
Captured user demonstration information
Cognitive engine
ROV high level control primitives
OBJECTIVE 5: Force feedback exoskeleton interfaces



DexROV





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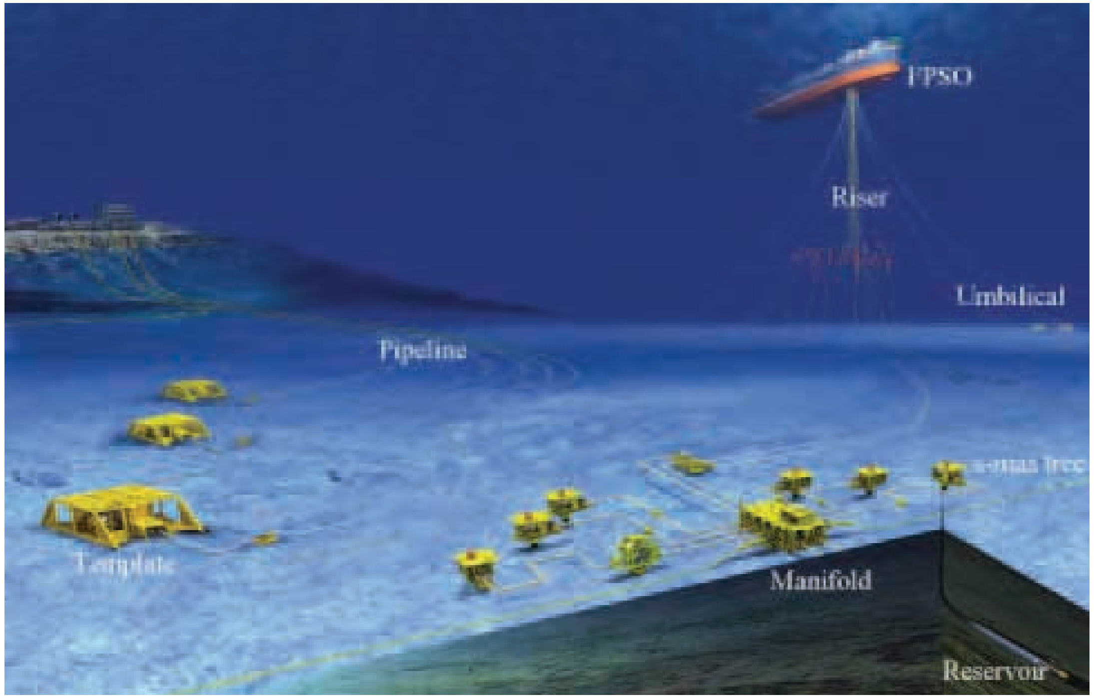
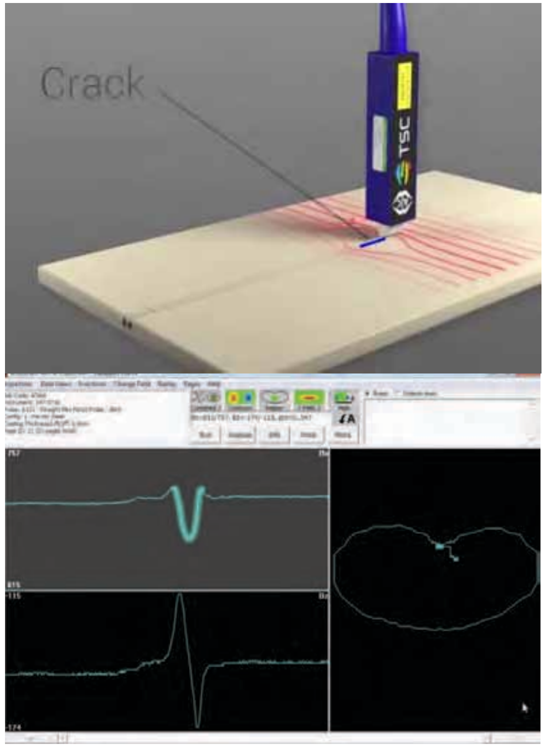


FPSO
Riser
Umbilical
Pipeline
Template
Manifold
Reservoir



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GEOMAR

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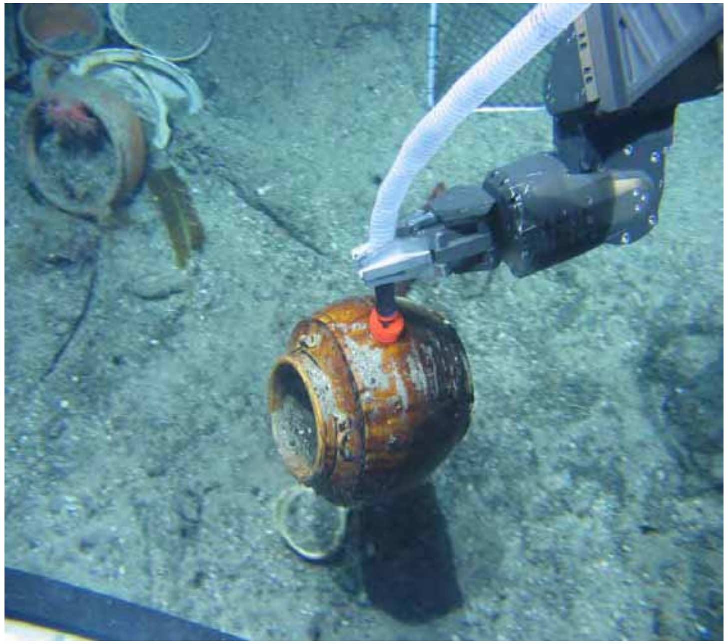

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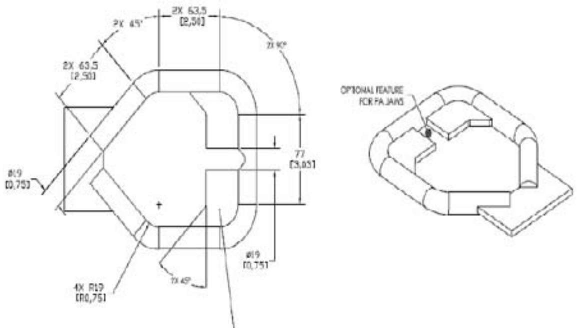

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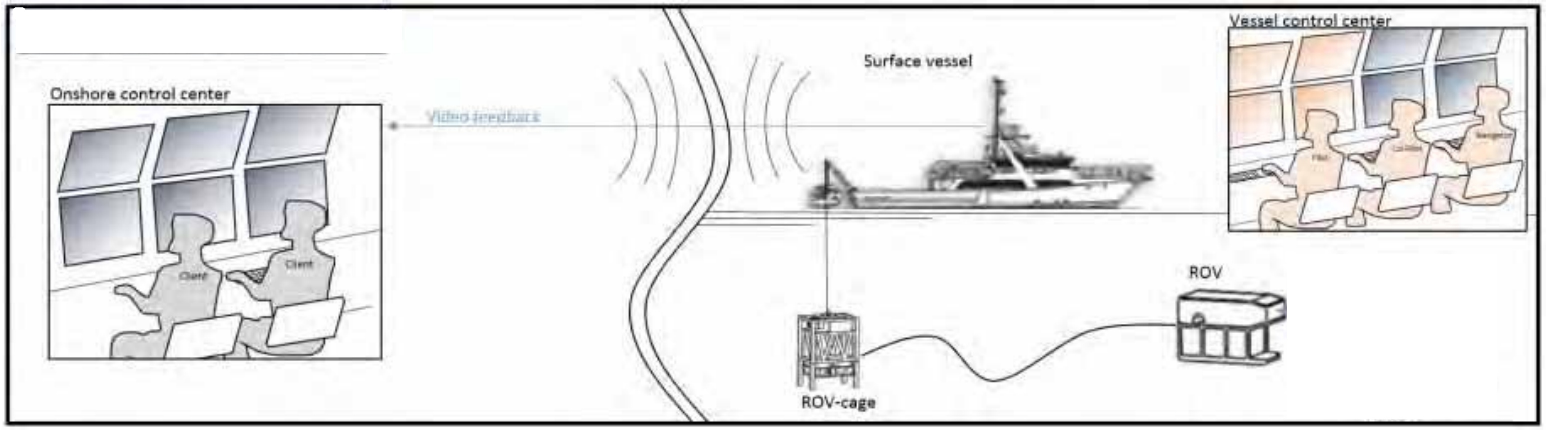
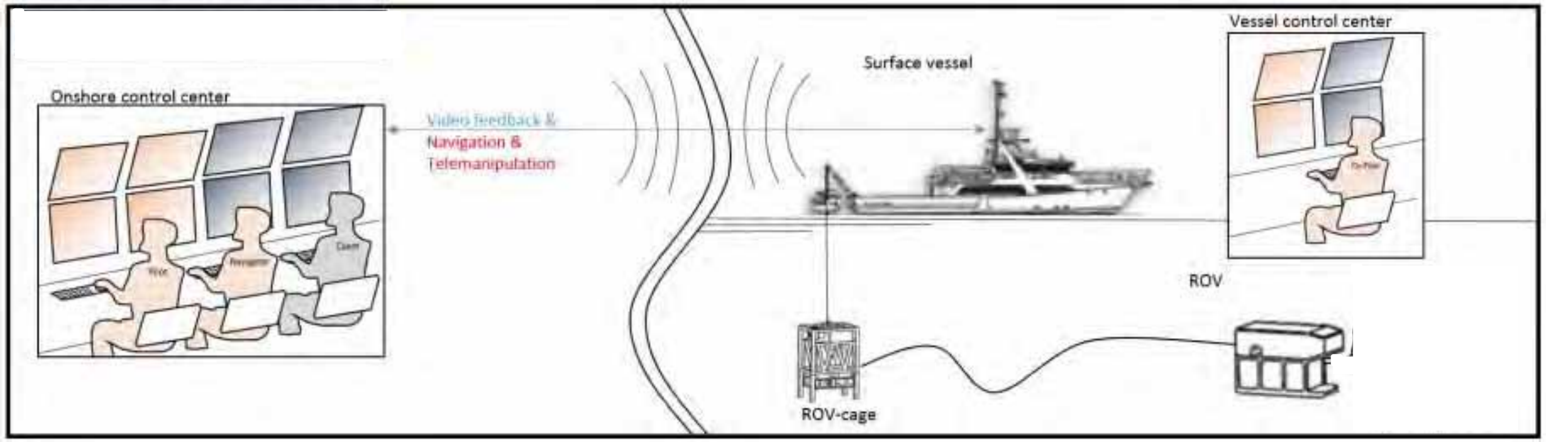
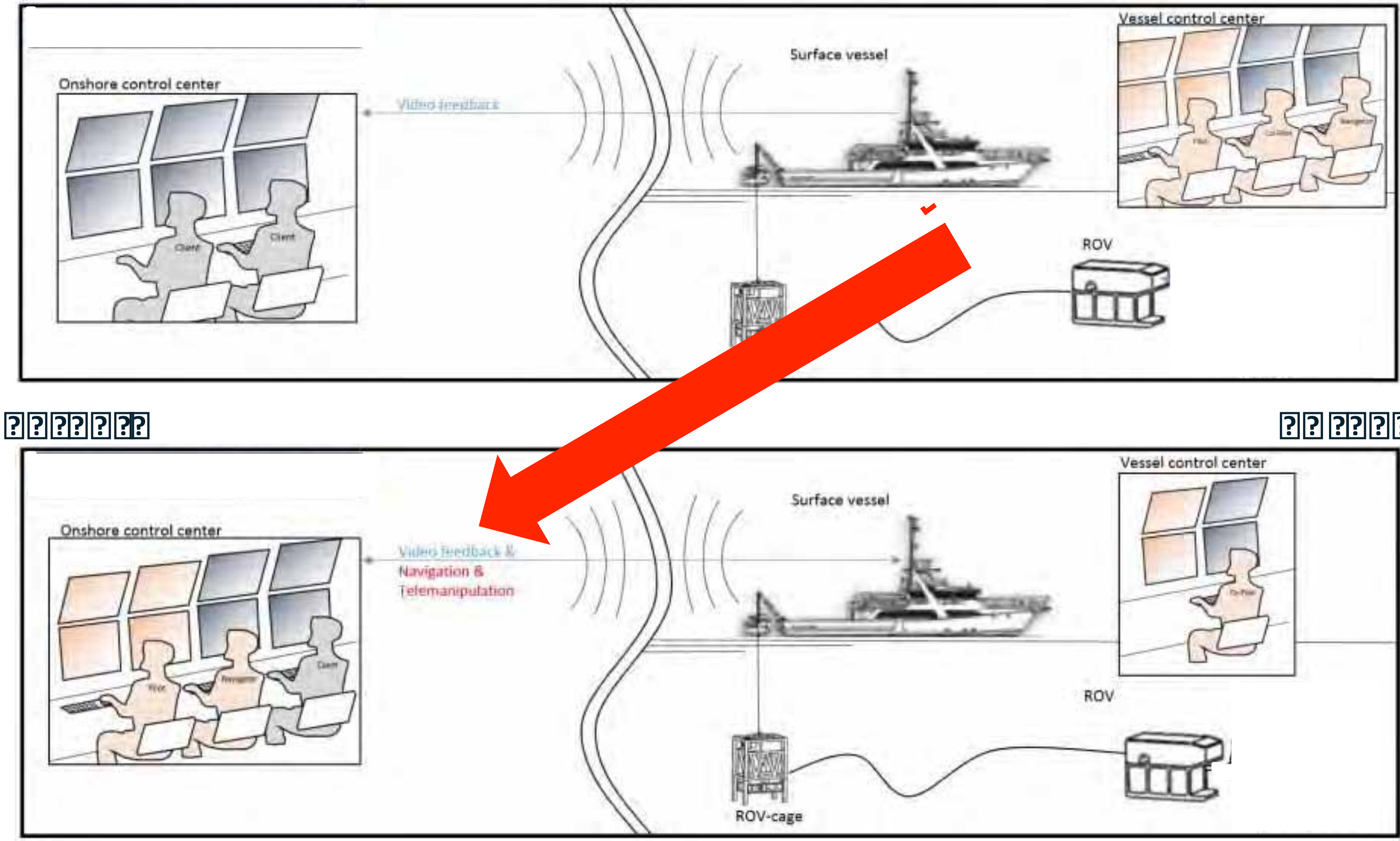
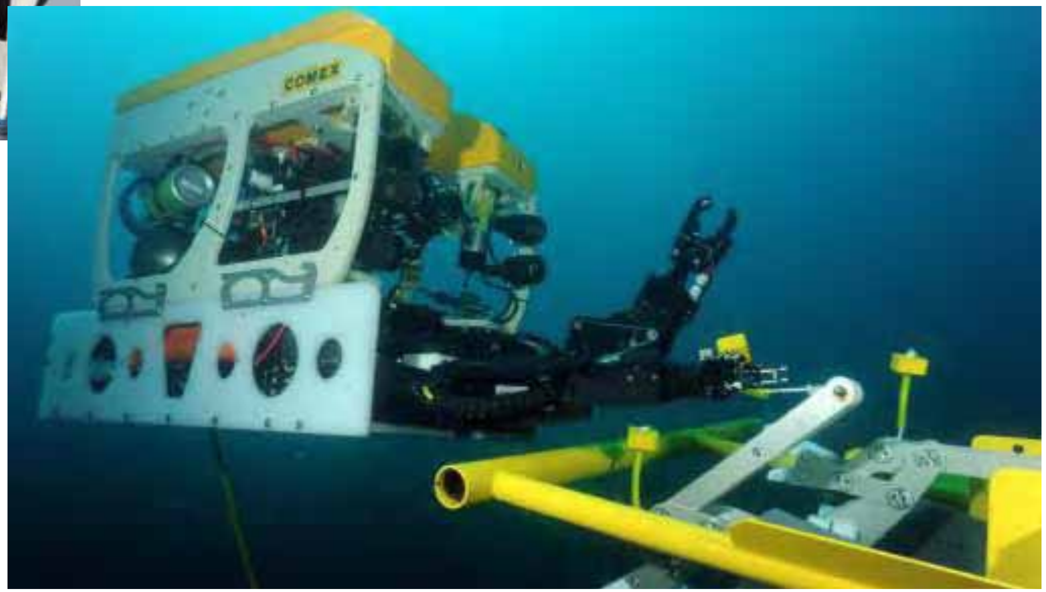

Onshore control center
Video feedback
Surface vessel
Vessel control center
ROV
ROV-cage

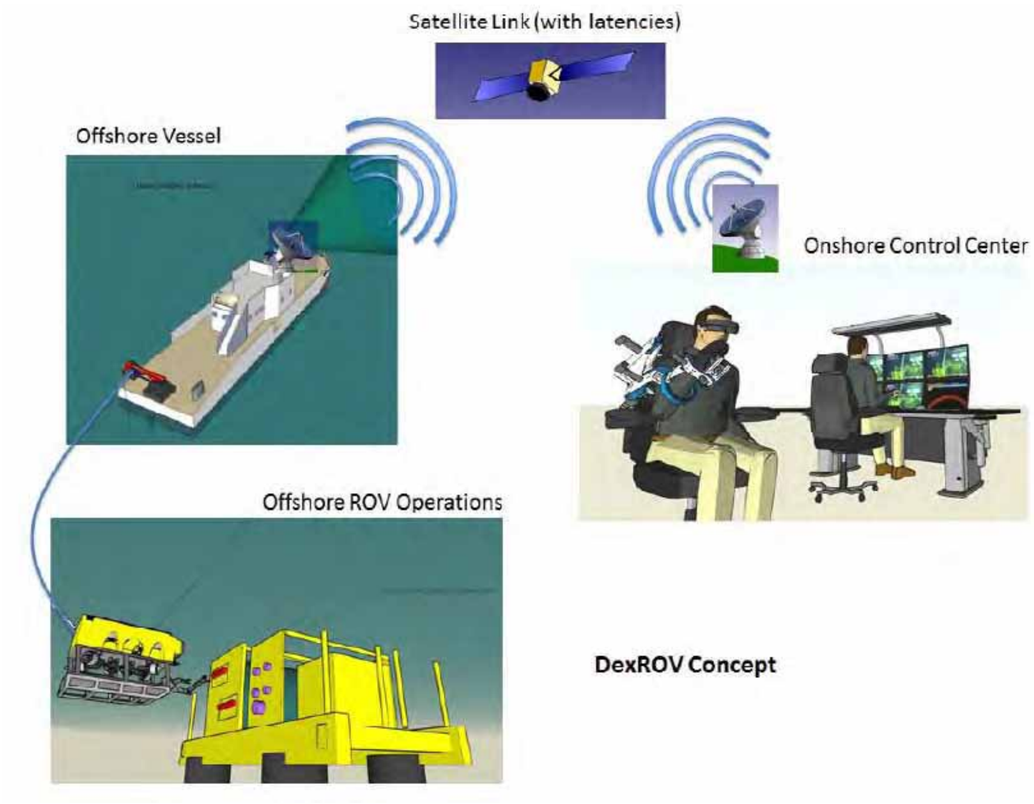

Onshore control center
Video feedback &
Navigation &
Telemanipulation
Surface vessel
Vessel control center
ROV
ROV-cage


Onshore control center
Video feedback
Surface vessel
Vessel control center
ROV
Onshore control center
Video feedback &
Navigation &
Telemanipulation
Surface vessel
Vessel control center
ROV
ROV-cage


comex


COMEX

DexROV



DexROV Concept

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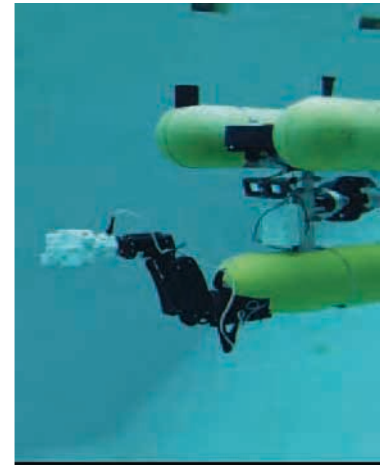
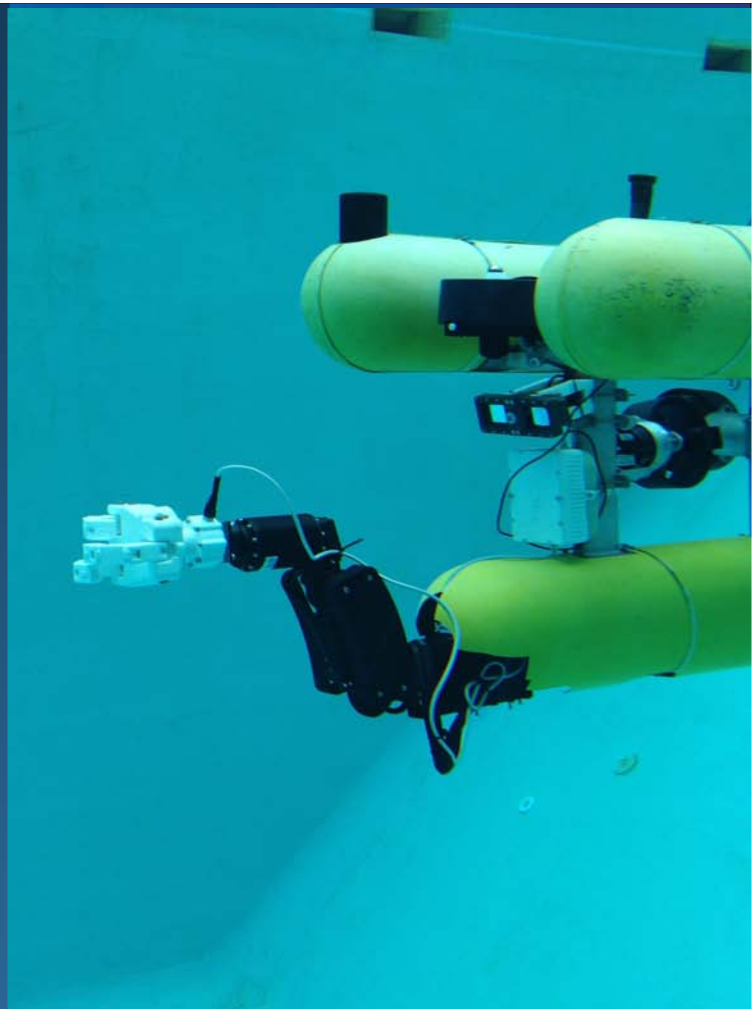
EMRA'15 workshop



Intervention AUVs: Experiences and Challenges

Pere Ridao, Univ. Girona, ES

Universitat de Girona
Computer Vision and Robotics Group



Intervention AUVs
Experiences and Challenges

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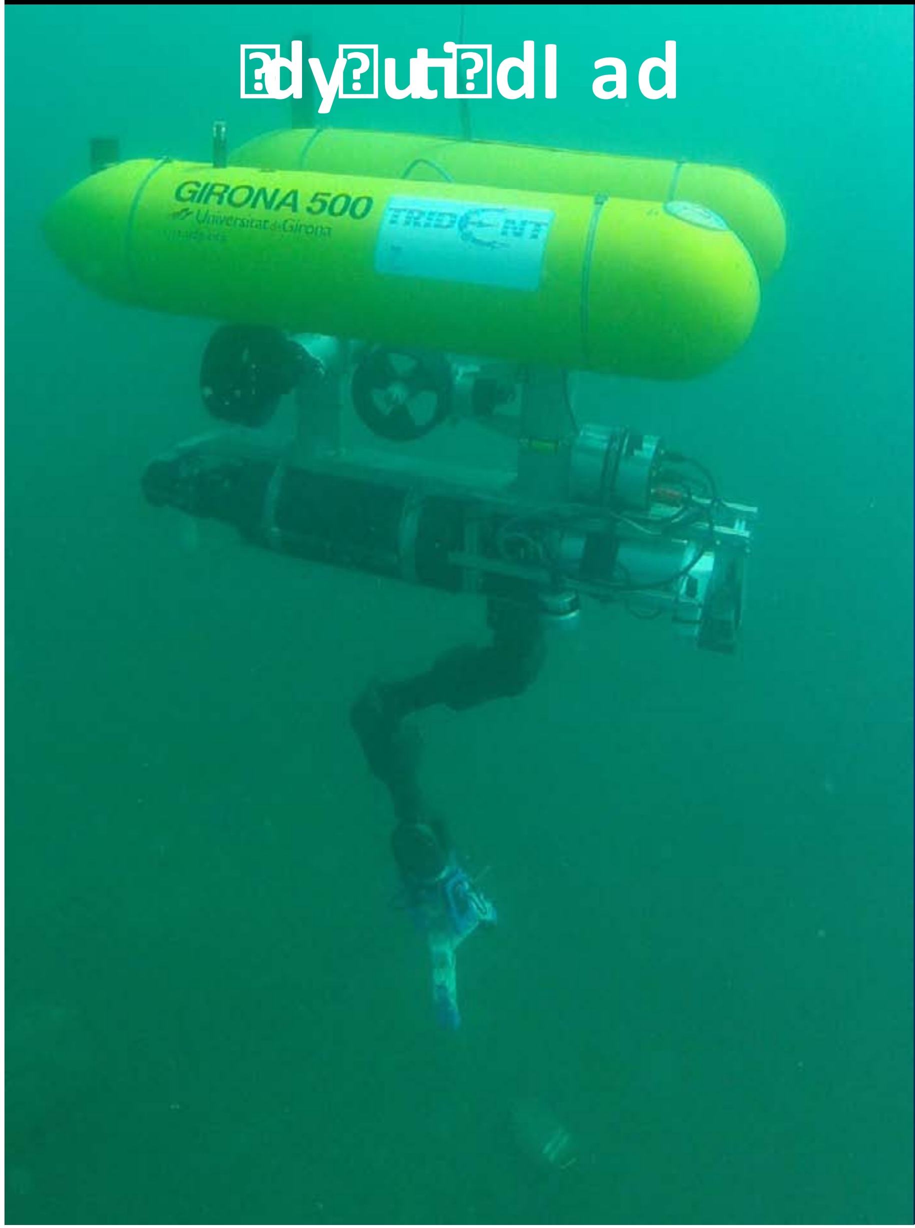
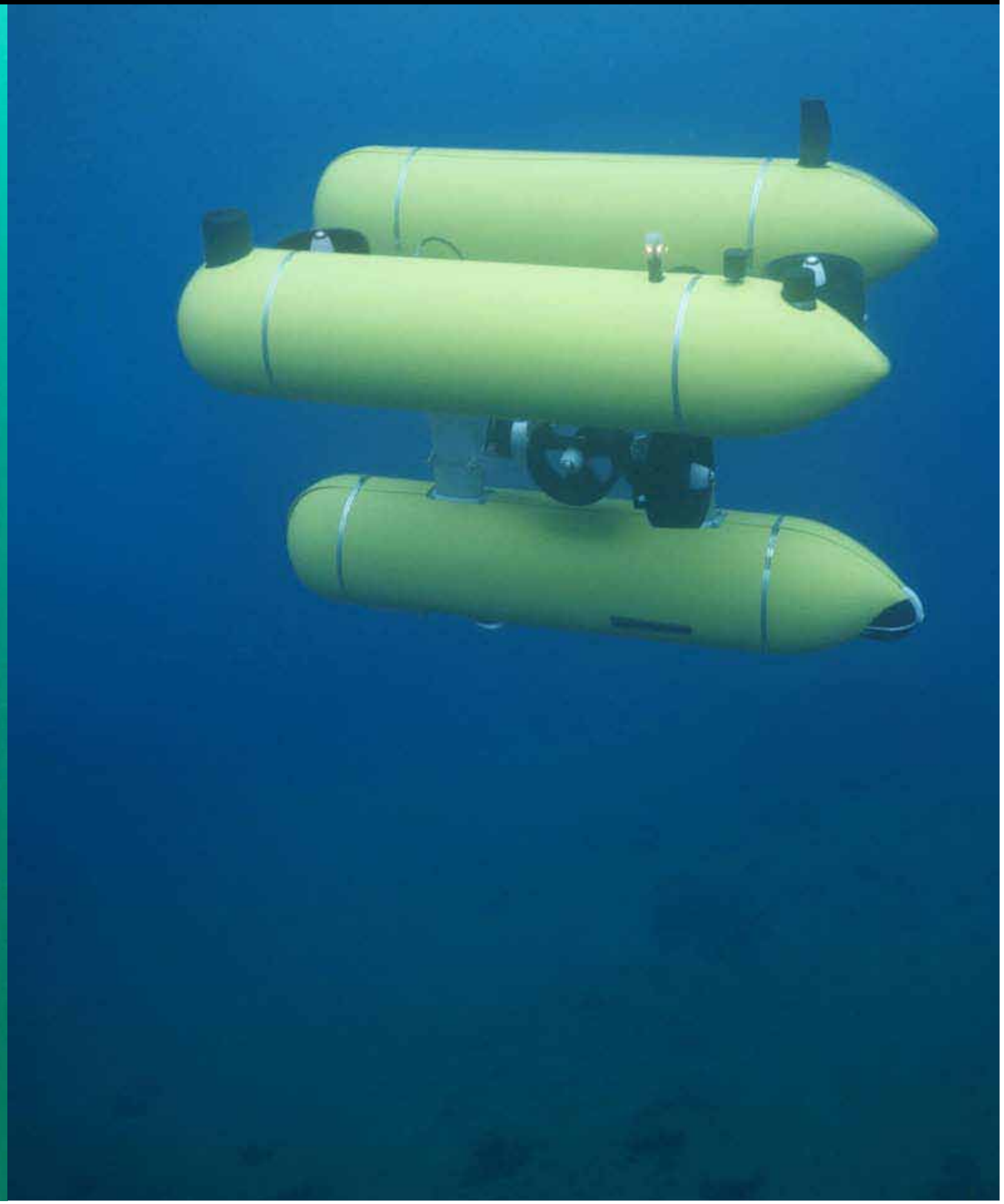

GIRONA 500
Universitat de Girona
TRIDENT



Intervention AUVs

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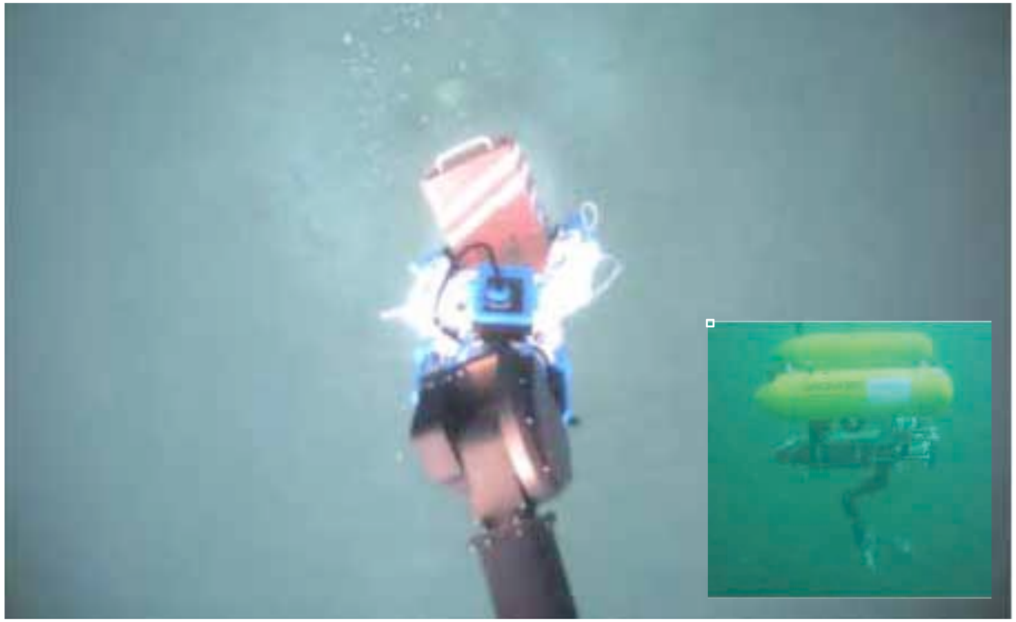


❑ SAUVIM USA PROJECT

- 6 Ton I-AUV.
- 6000 m. Depth rated.
- Pasive Arm for object localization.
- 7 DOF arm for object manipulation.
- Free Floating Manipulation.
- Task Priority Redundancy Control.

[Marani09].

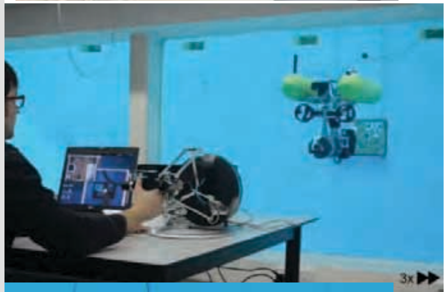
❑ TRIDENT EU PROJECT

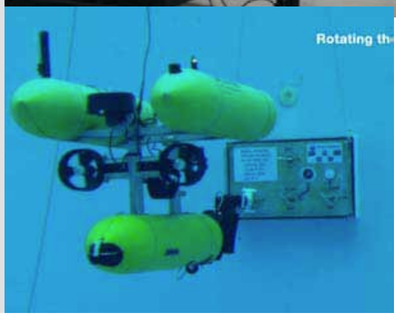
- 200 Kg I-AUV.
- 500 m. Depth rated.
- 7 DOF arm for object manipulation.
- Free Floating Manipulation.
- Agile Manipulation.
- Photomosaicing based object search.
- Multipurpose Grasping .
- Black Box Search & Recovery

[Sanz12].

DOCKING

FLOATING



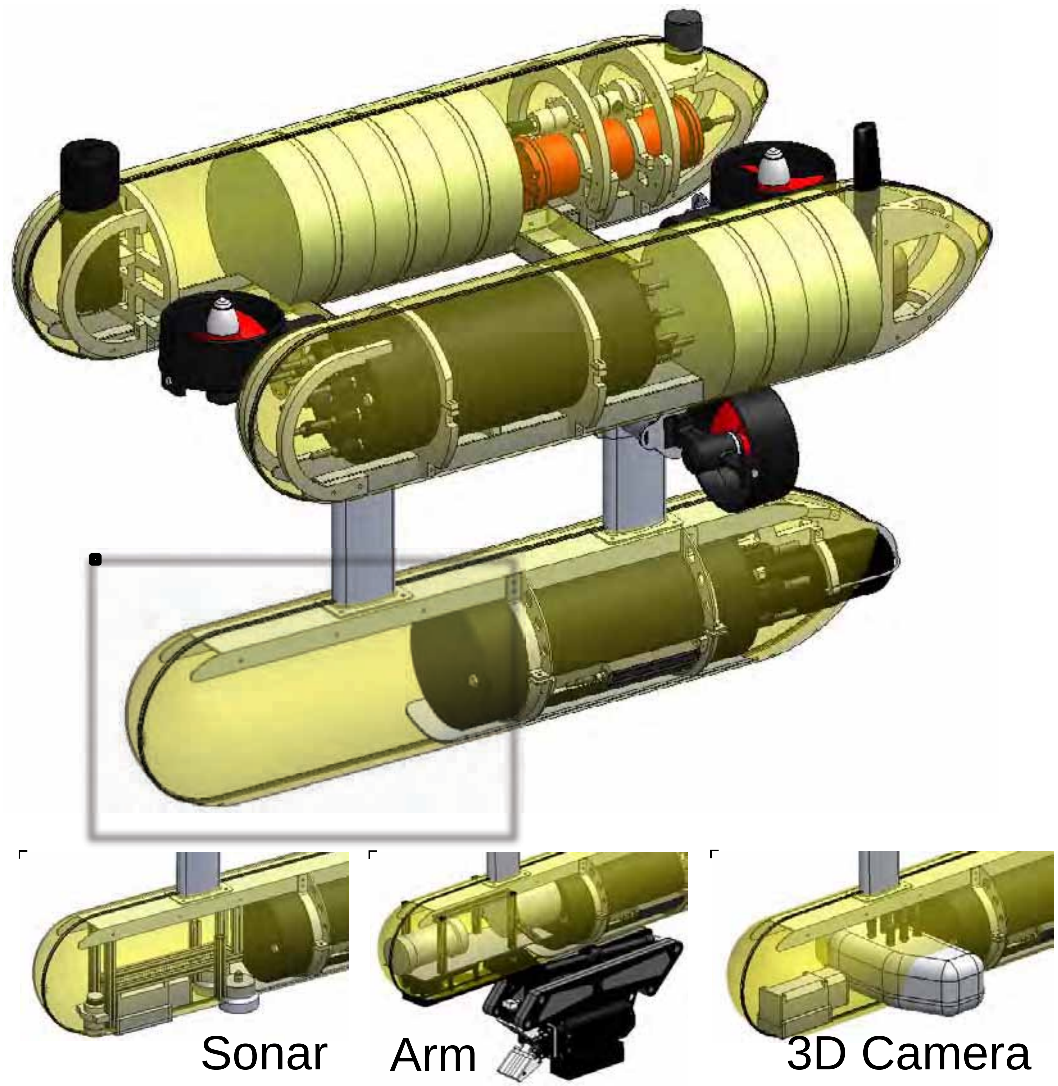


❑ **ALIVE EU Project** [Evans03]
- 2 hydraulic GRABS for docking
- 1 7DOF arm for manipulation
- Sonar/vision based docking to an underwater panel

❑ **TRITON Spanish Project** [Palomeras14]
- Funnel based Pasive Docking
- Range Only + Vision Navigation
- Valve Turning + Connector Un/Plugging

❑ **PANDORA FP7** [Carrera15]
- Learning by Demonstration
- Vision based Navigation
- Valve Turning

❑ **MERBOTS-ARCHROV** [Cieslak15]
- Task Priority Redundancy Control + Concurrence
- Vision based Navigation
- Valve Turning



GIRONA 500 AUV

Standard Sensors

- Doppler velocity log
- Attitude and heading reference system
- Fiber optic gyro (heading)
- GPS
- Ultra short base-line
- Dual frequency profiling sonar
- Sound velocity sensor
- Pressure gauge
- Sidescan sonar
- Video Camera system + LED lighting

Payload

- 35 liters volume available for mission specific equipment.
- Ethernet and RS - 232 interfaces with the vehicle
- Regulated 24V@10W and unregulated 14.4V@90W

Intervention AUVs

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GRAALtech 	[illegible]	[illegible]	[illegible]	[illegible]
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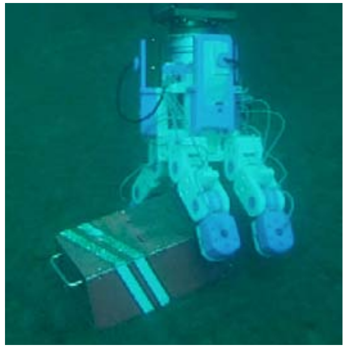

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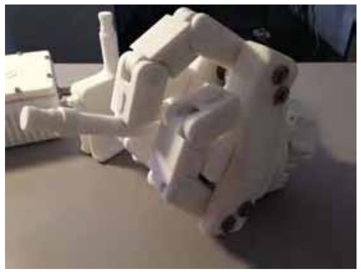

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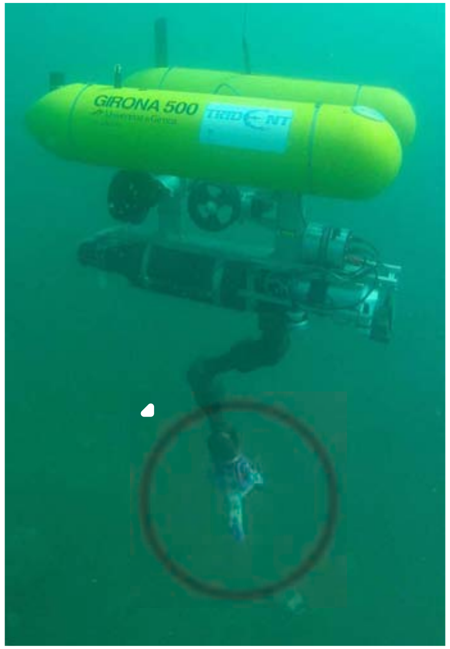
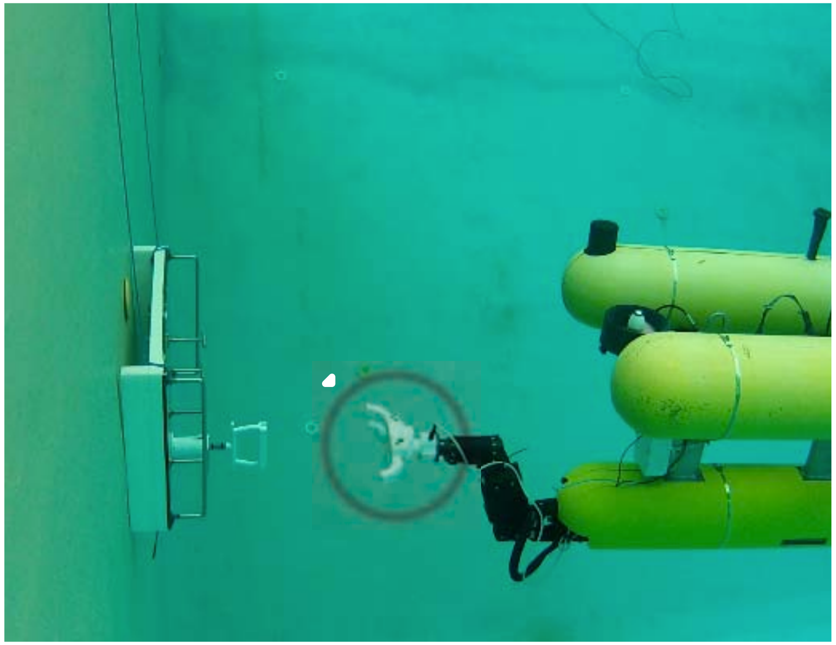


TRIDENT Project
G500 + GRAALTECH arm
(7DOF) + UNIBO Hand

RAUVI Project
G500 + ECA 4DOF (UJI)
Arm: rated for 300 m.
Lifting capacity 10 kg



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G500 + ECA 4DOF (UdG)
Arm: rated for 300 m. Lifting capacity 10 kg
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- 3 Different Robot manipulators (4 to 7 DOF) succesfully integrated.

ROS

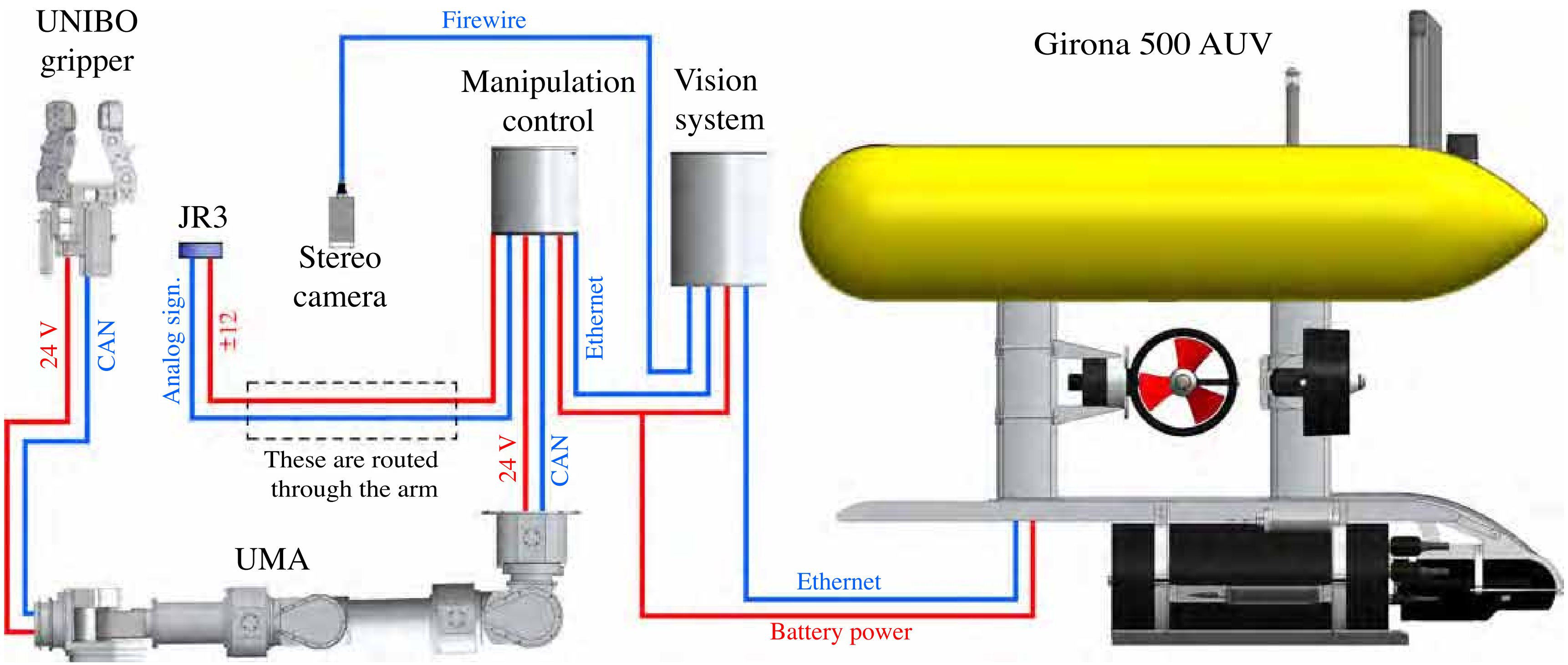
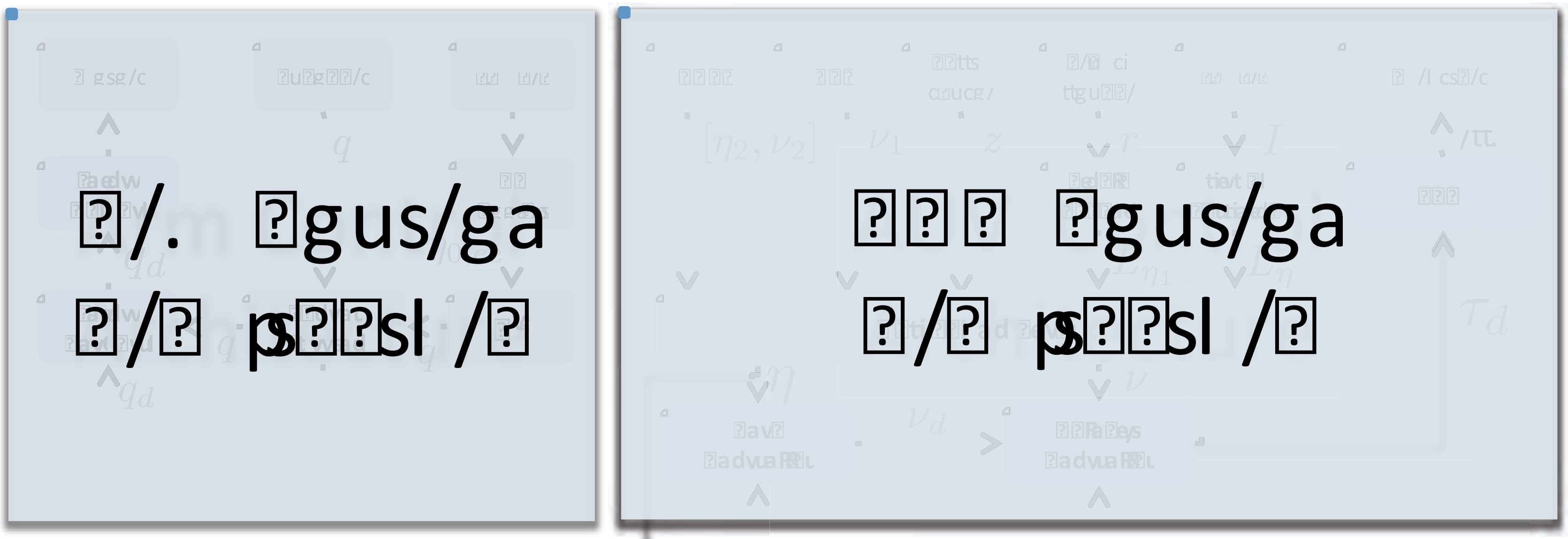


Fig. 8. Schematic showing the connections between the different subsystems



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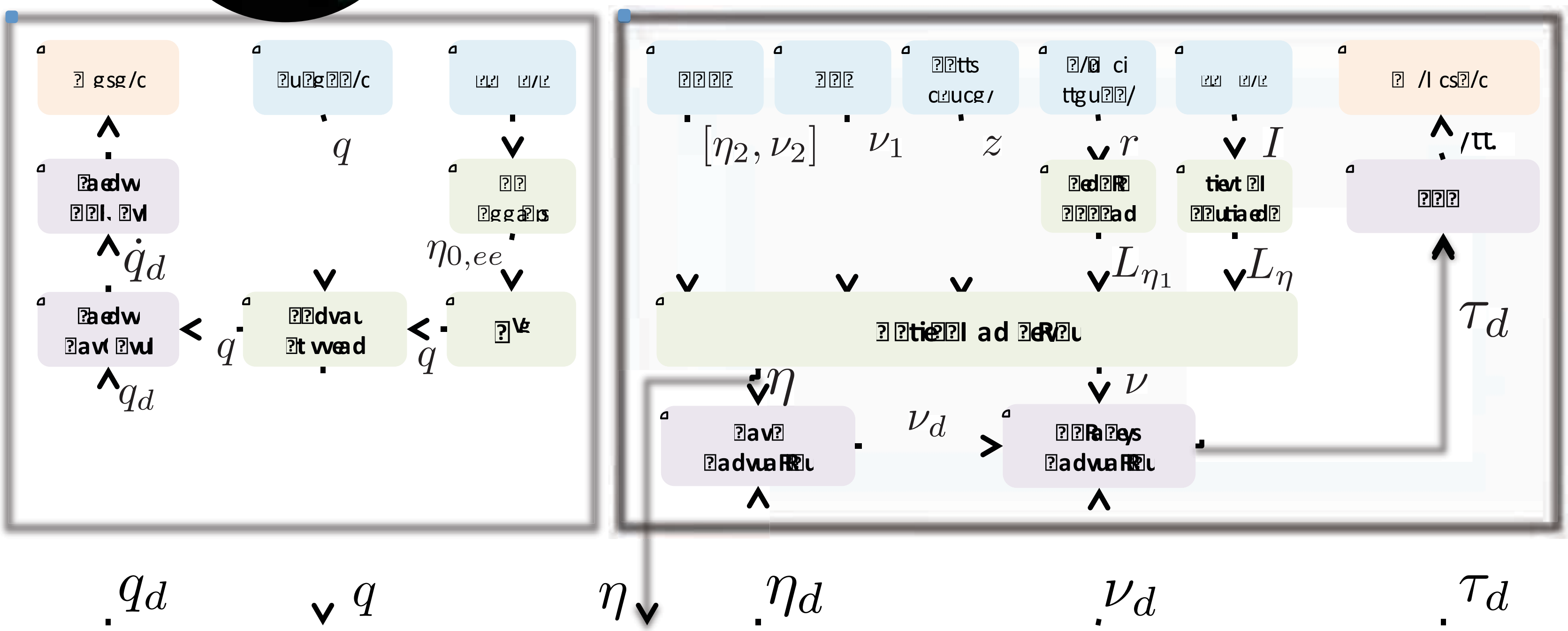
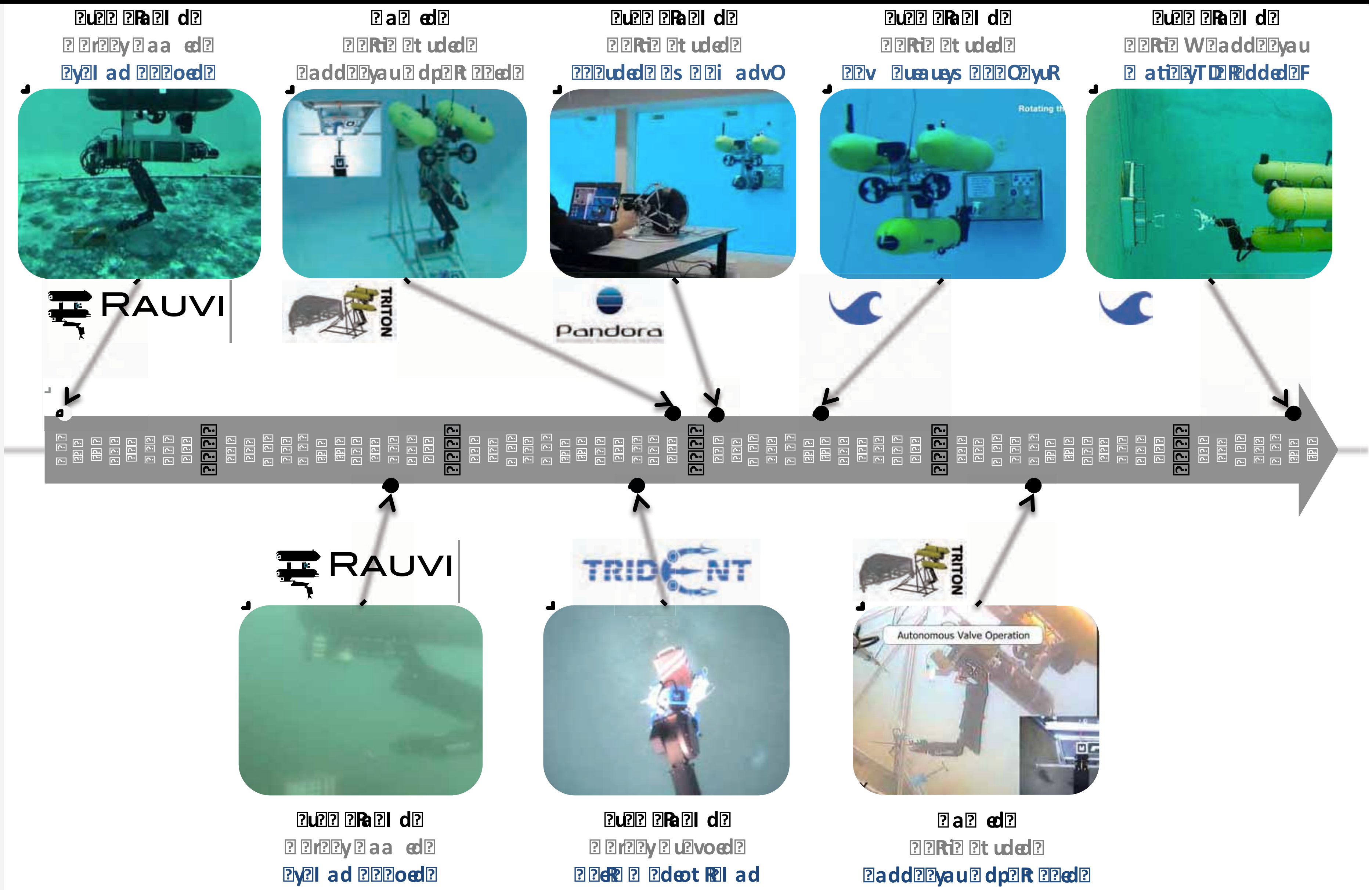
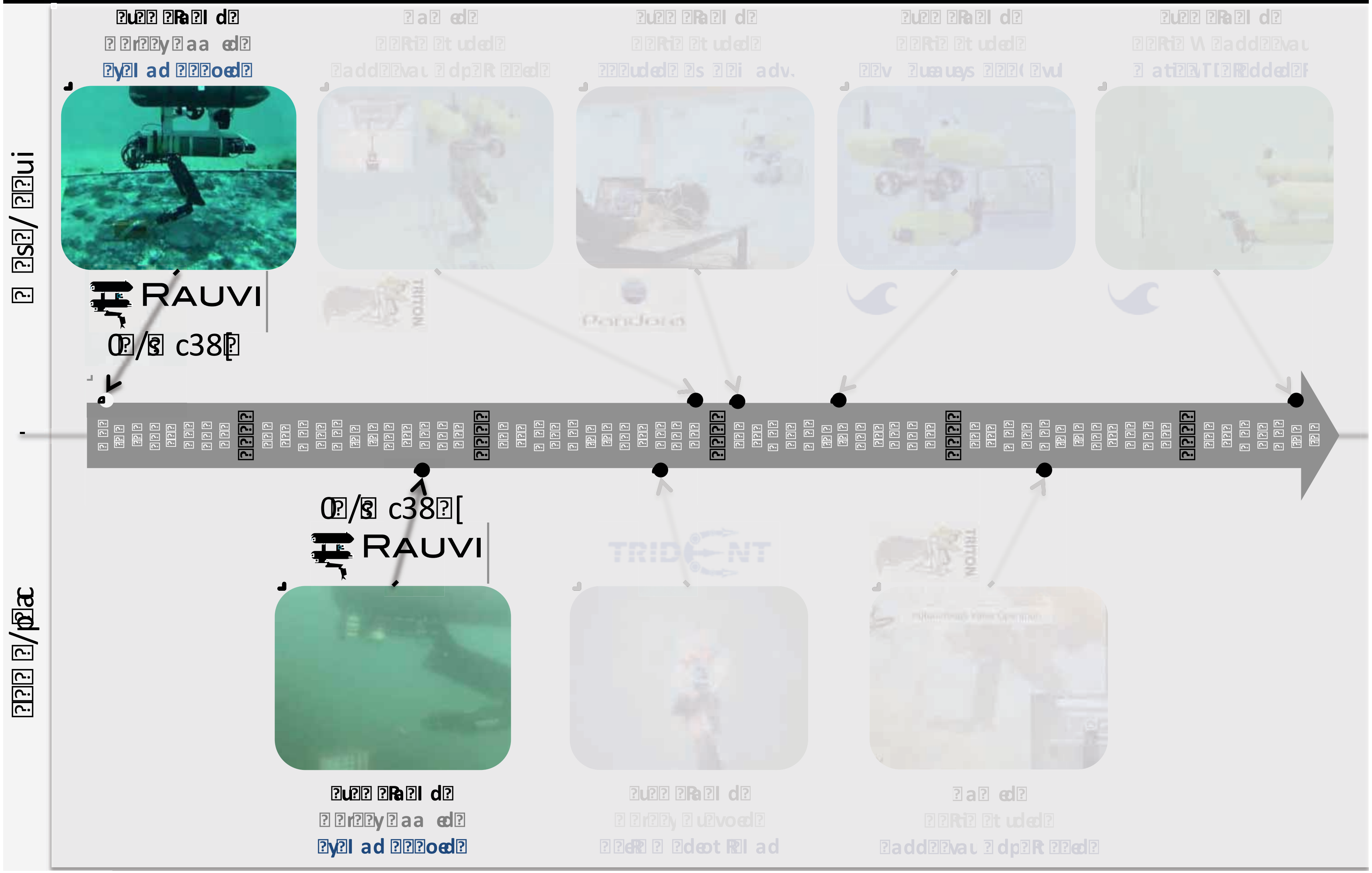
Intervention AUVs



Intervention AUVs



Intervention AUVs



Black Box Recovery Harbour Experiments

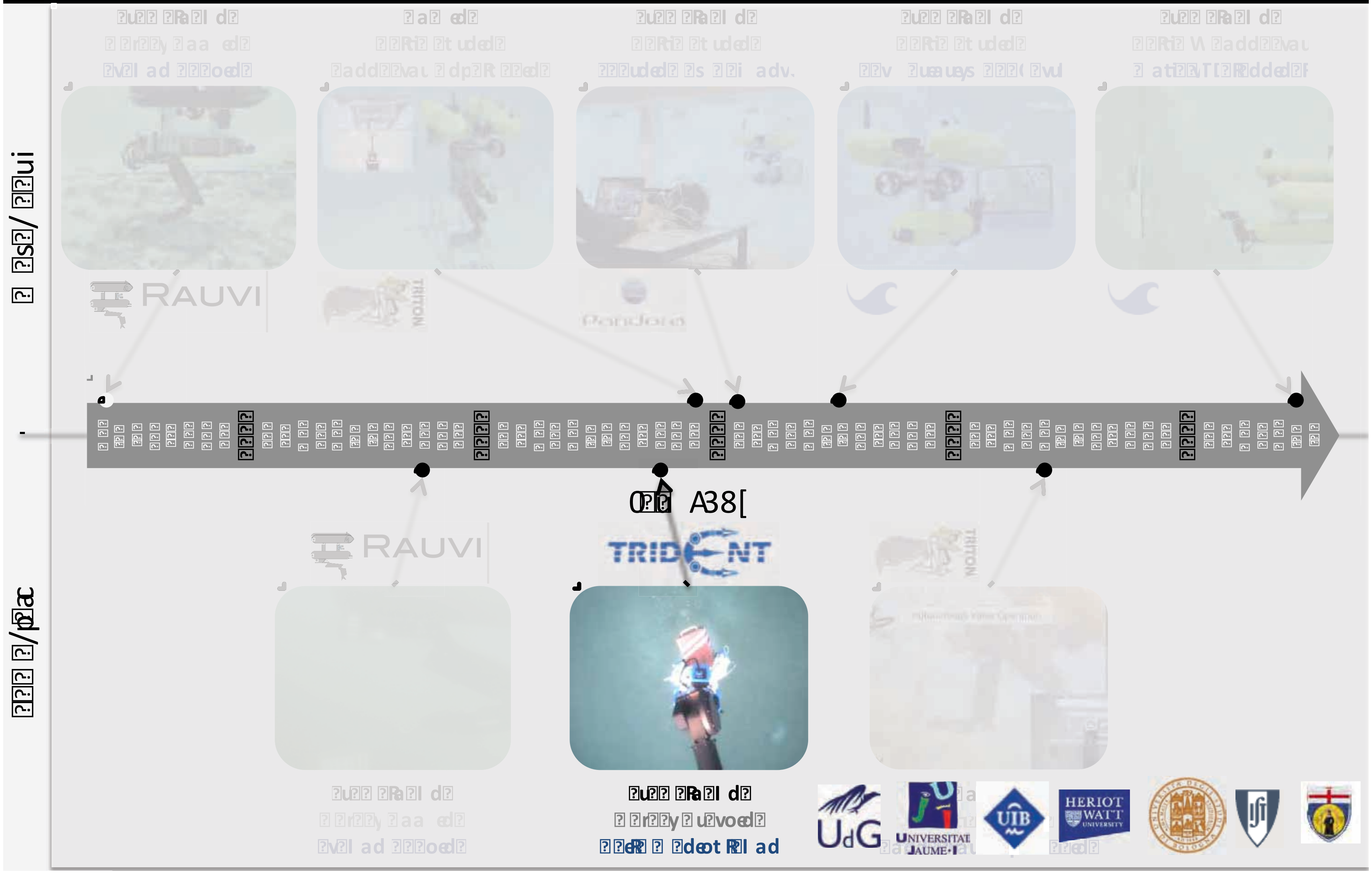
1st TRIDENT Fall School. Roses, Oct 2011

UNIVERSITAT JAUME·I

Universitat de Girona

UIB
Universitat de les Illes Balears

Intervention AUVs



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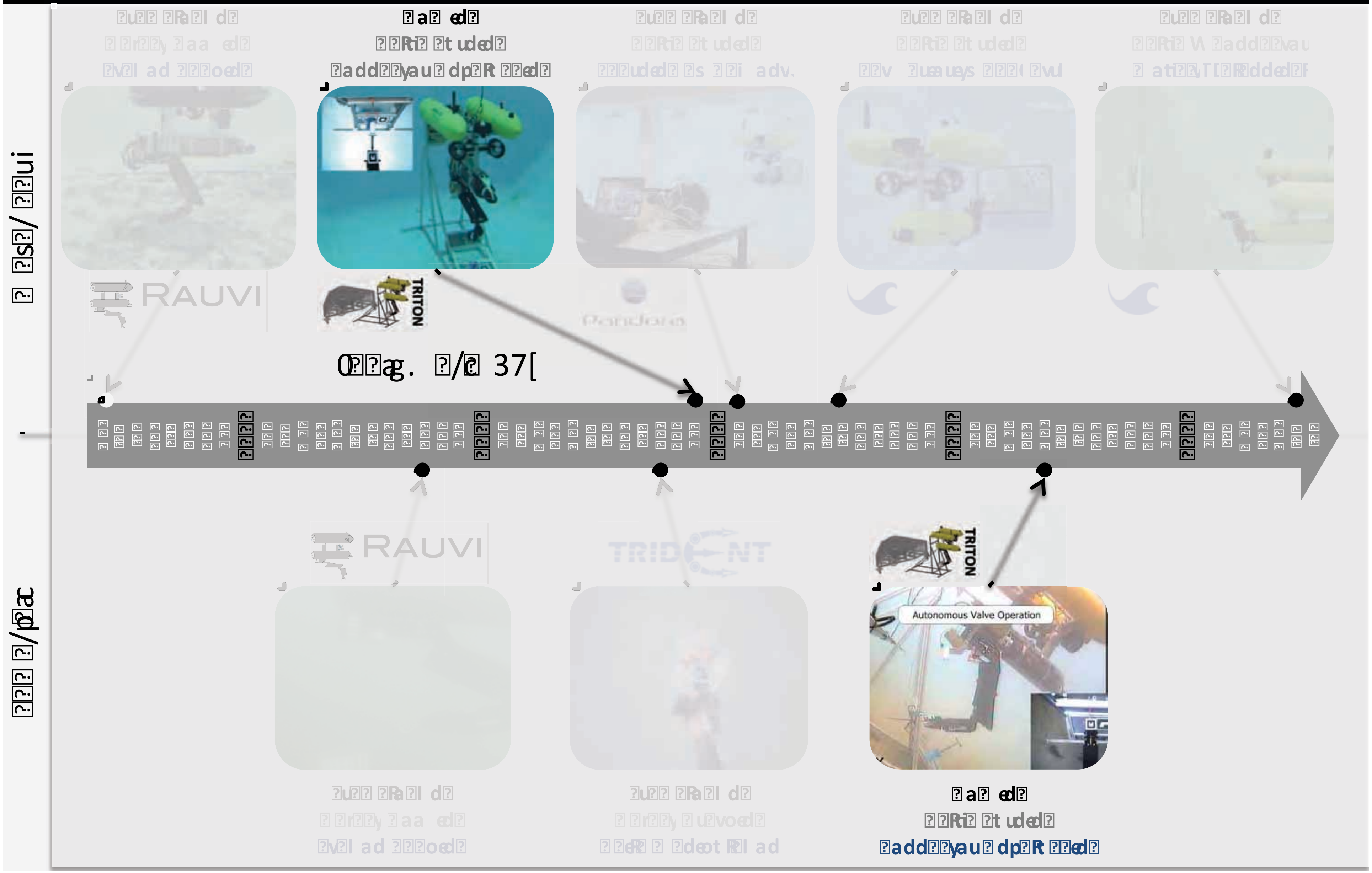
Intervention AUVs



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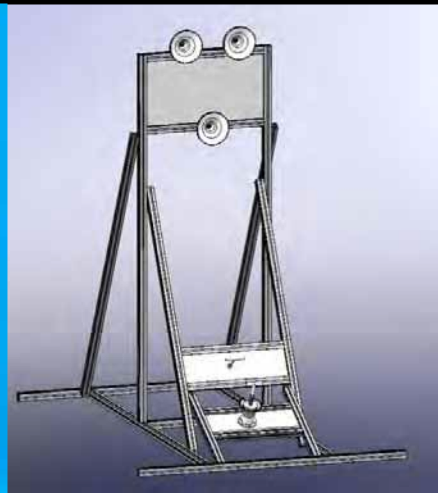

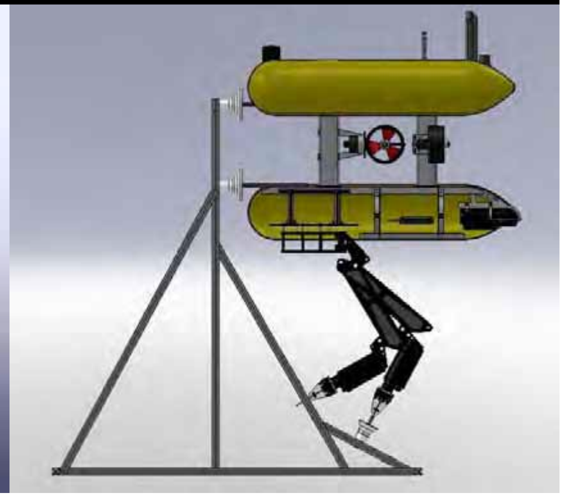

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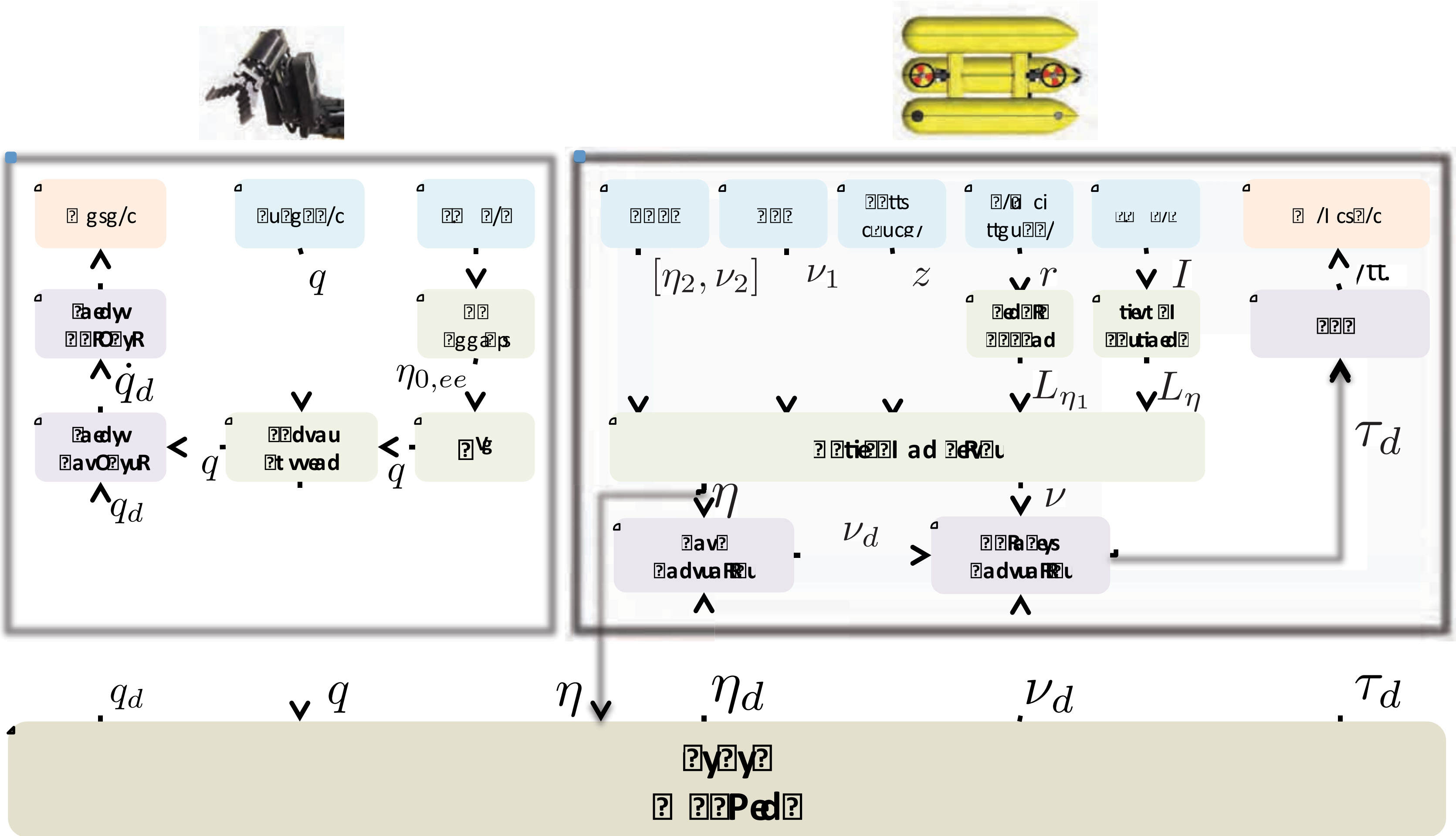

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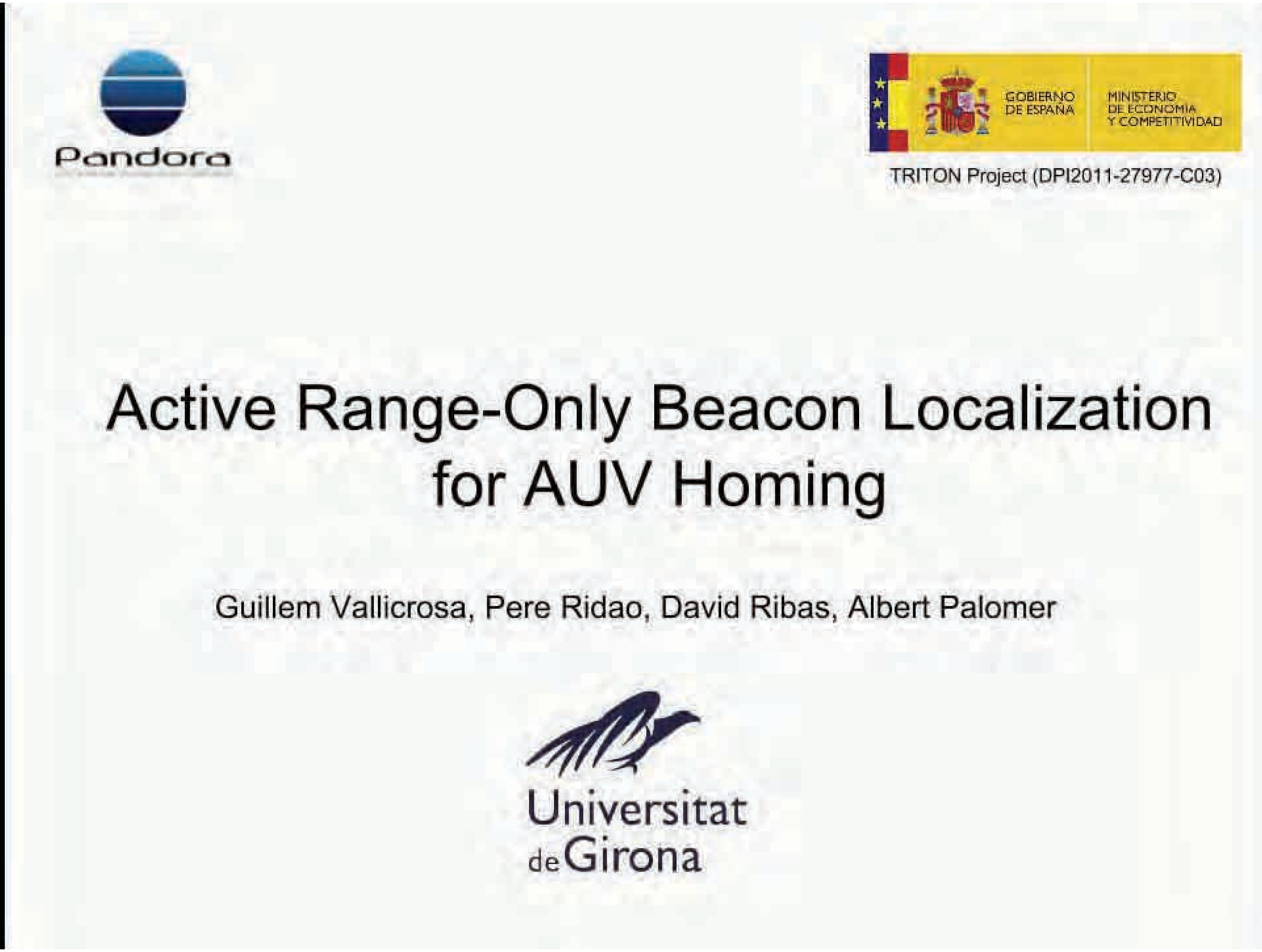

Pandora
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
TRITON Project (DPI2011-27977-C03)
Active Range-Only Beacon Localization for AUV Homing
Guillem Vallicrosa, Pere Ridao, David Ribas, Albert Palomer
Universitat de Girona

TRITON | Intervención Submarina mediante Robots Marinos Cooperativos y Percepción Multisensorial

AUTONOMOUS UNDERWATER INTERVENTION

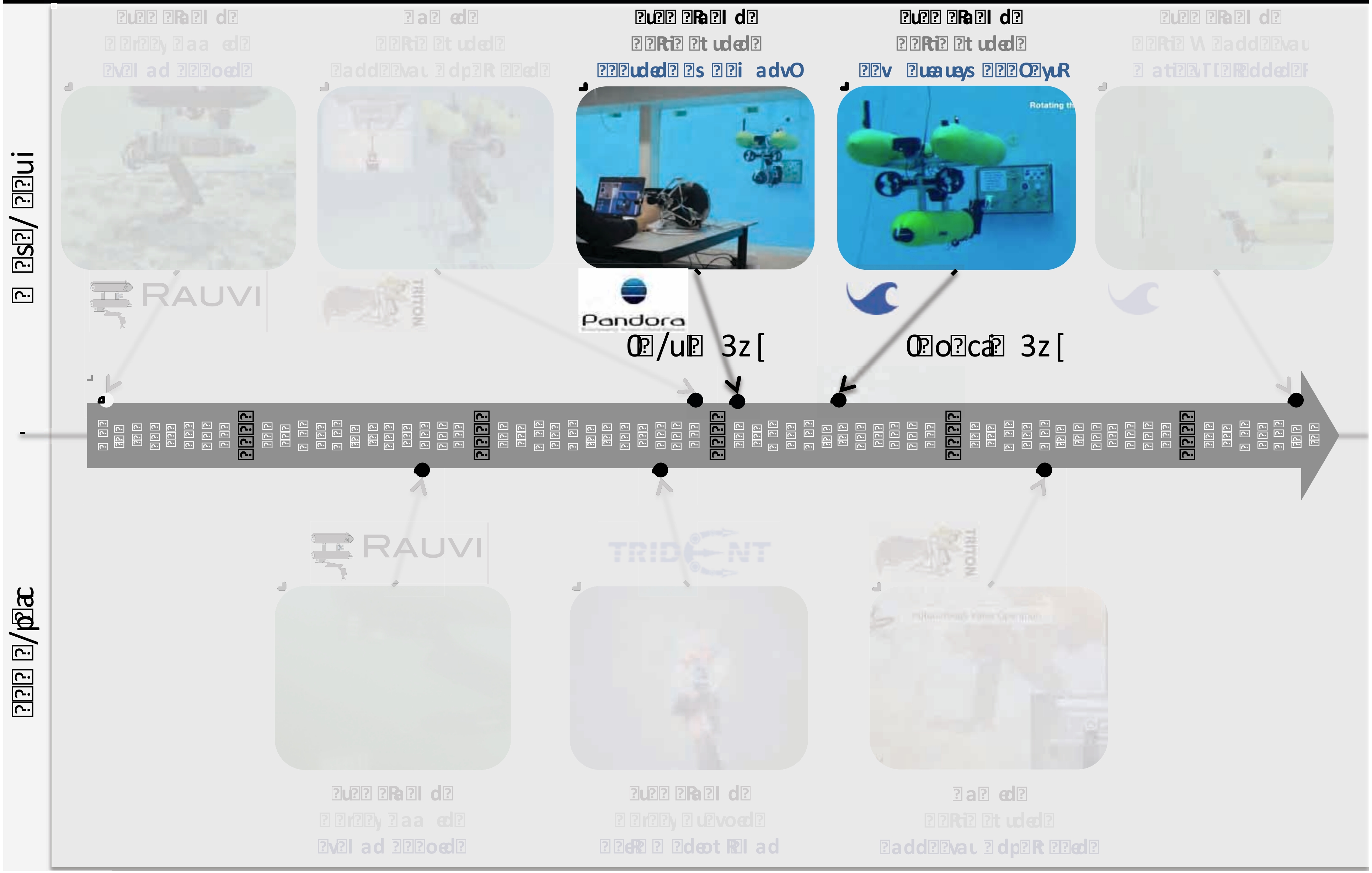
Docking & Intervention

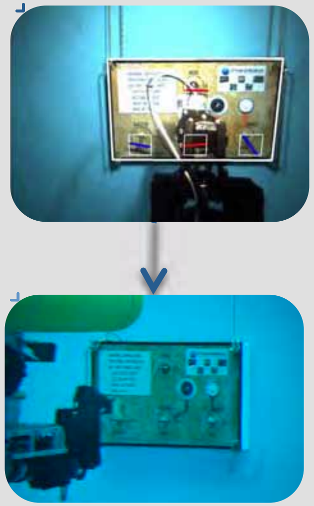
UNIVERSITAT JAUME·I

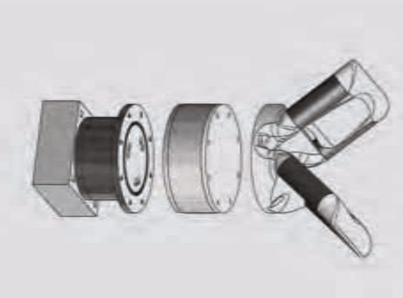
Universitat de Girona

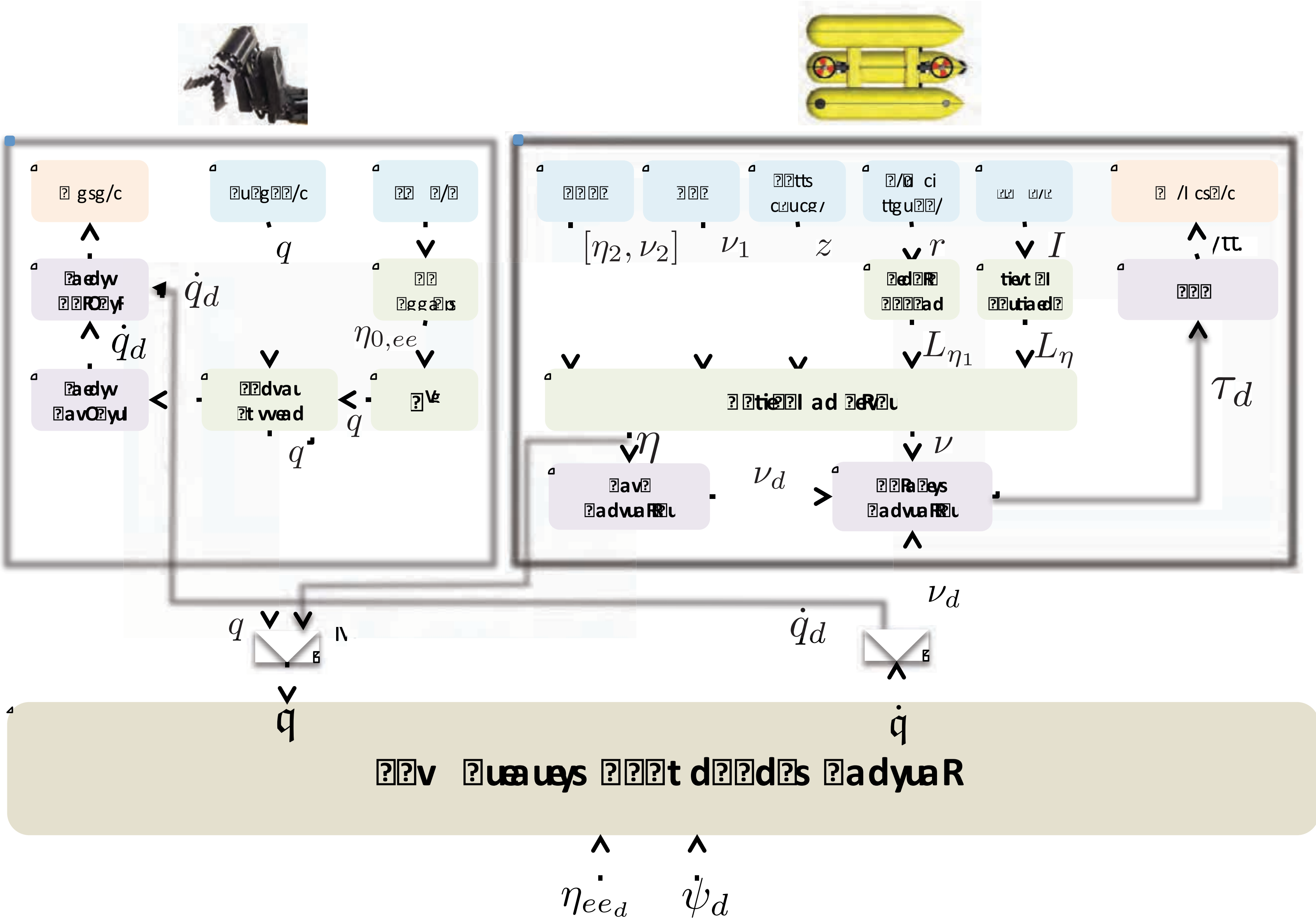
Universitat de les Illes Balears

Intervention AUVs









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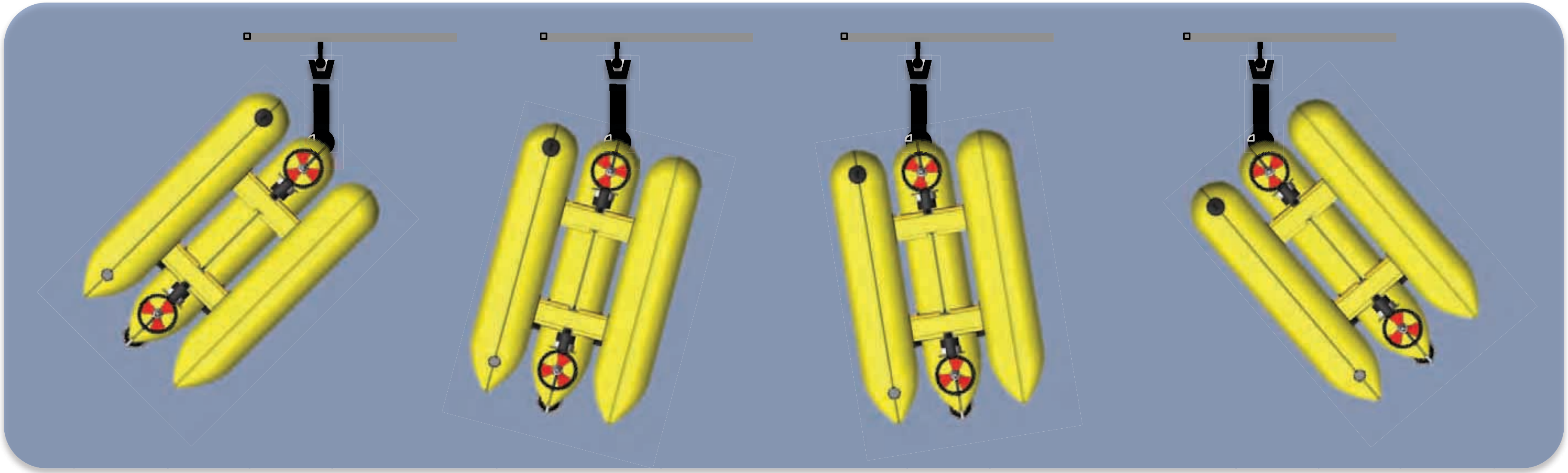

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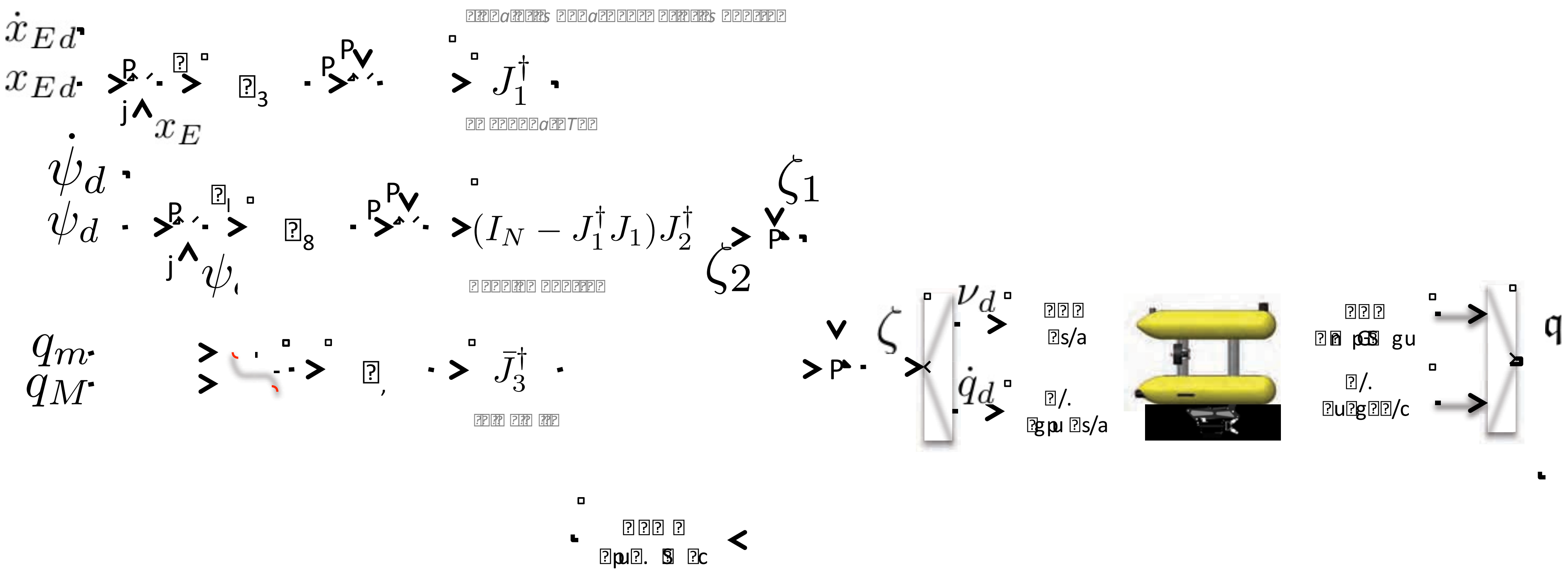

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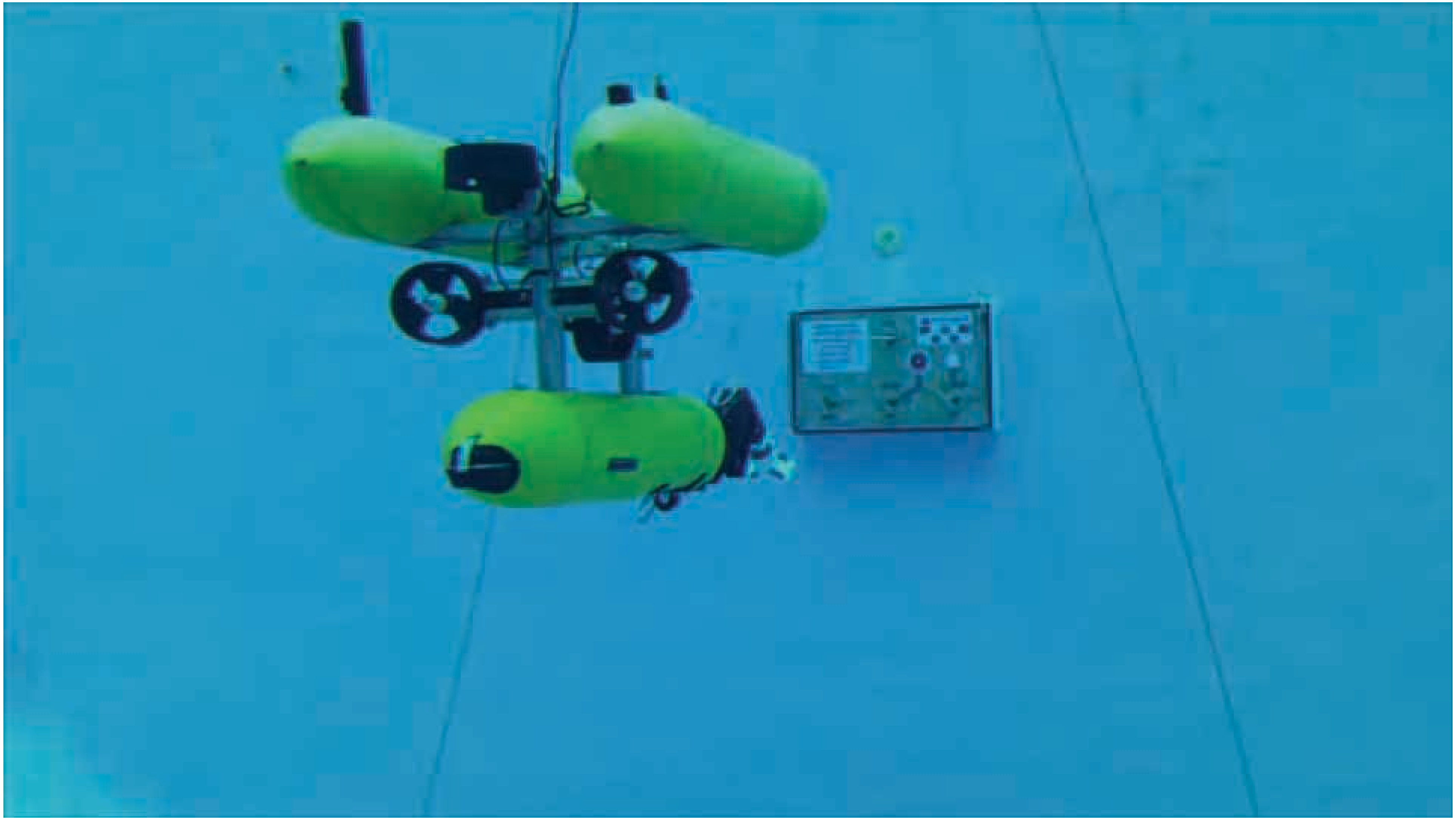
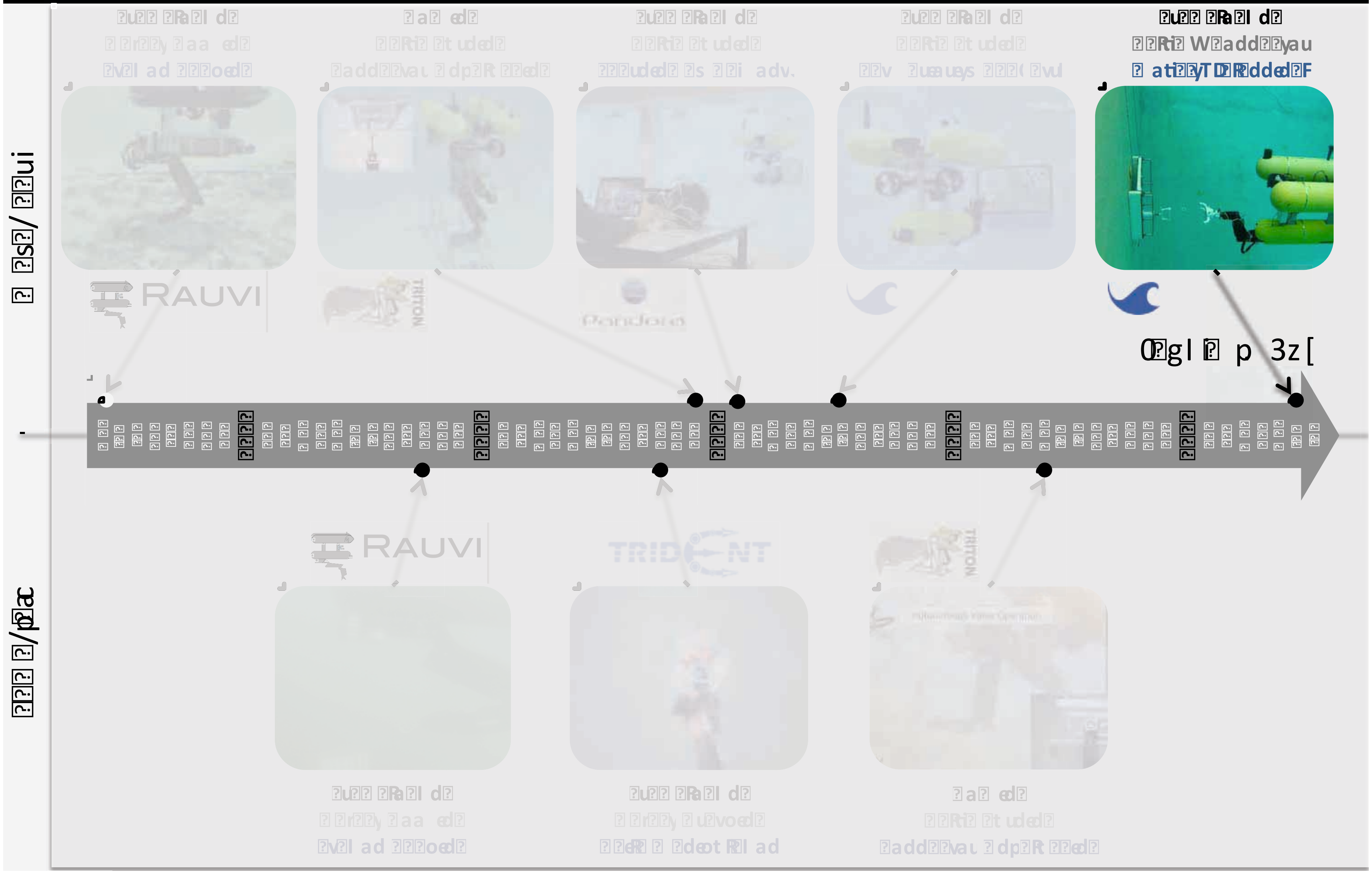


Intervention AUVs



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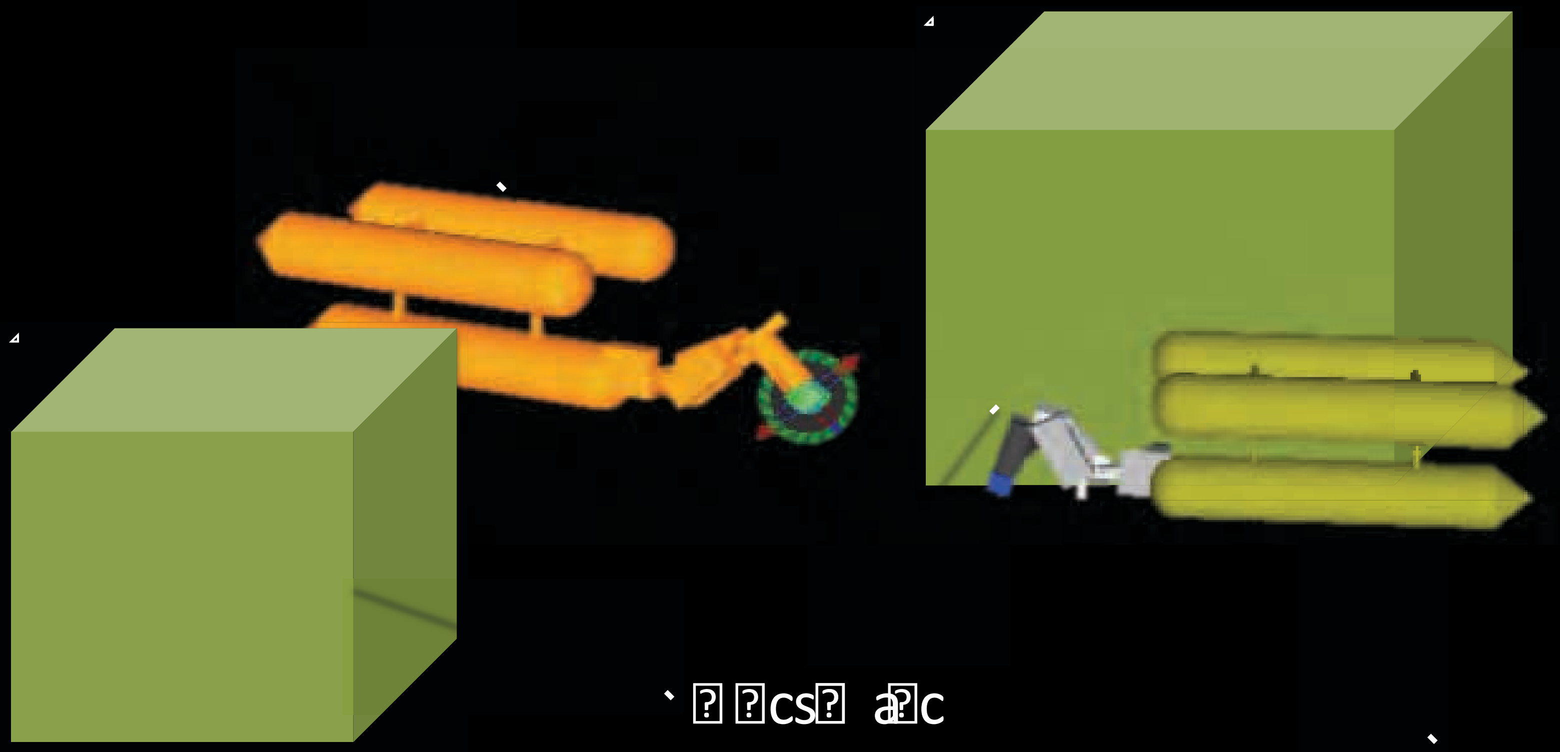
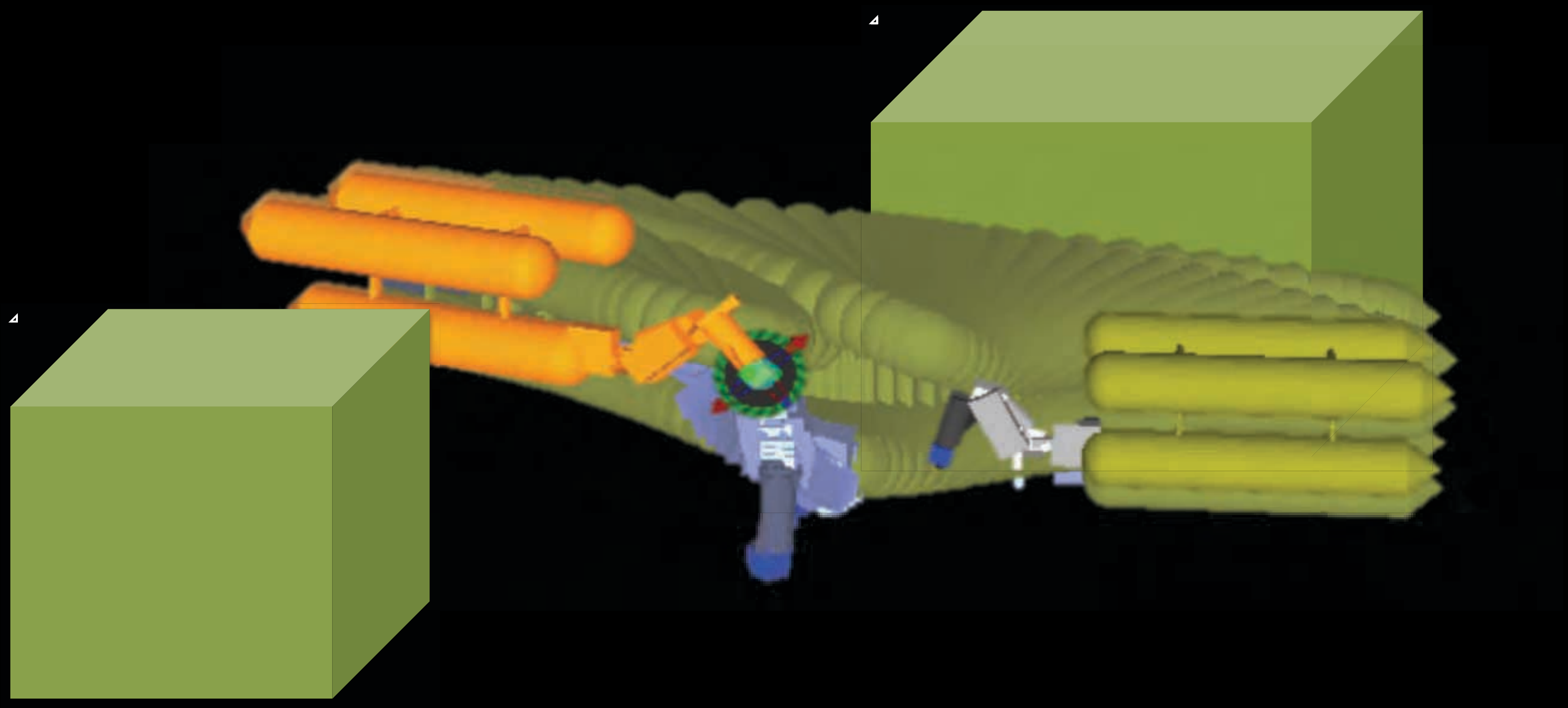
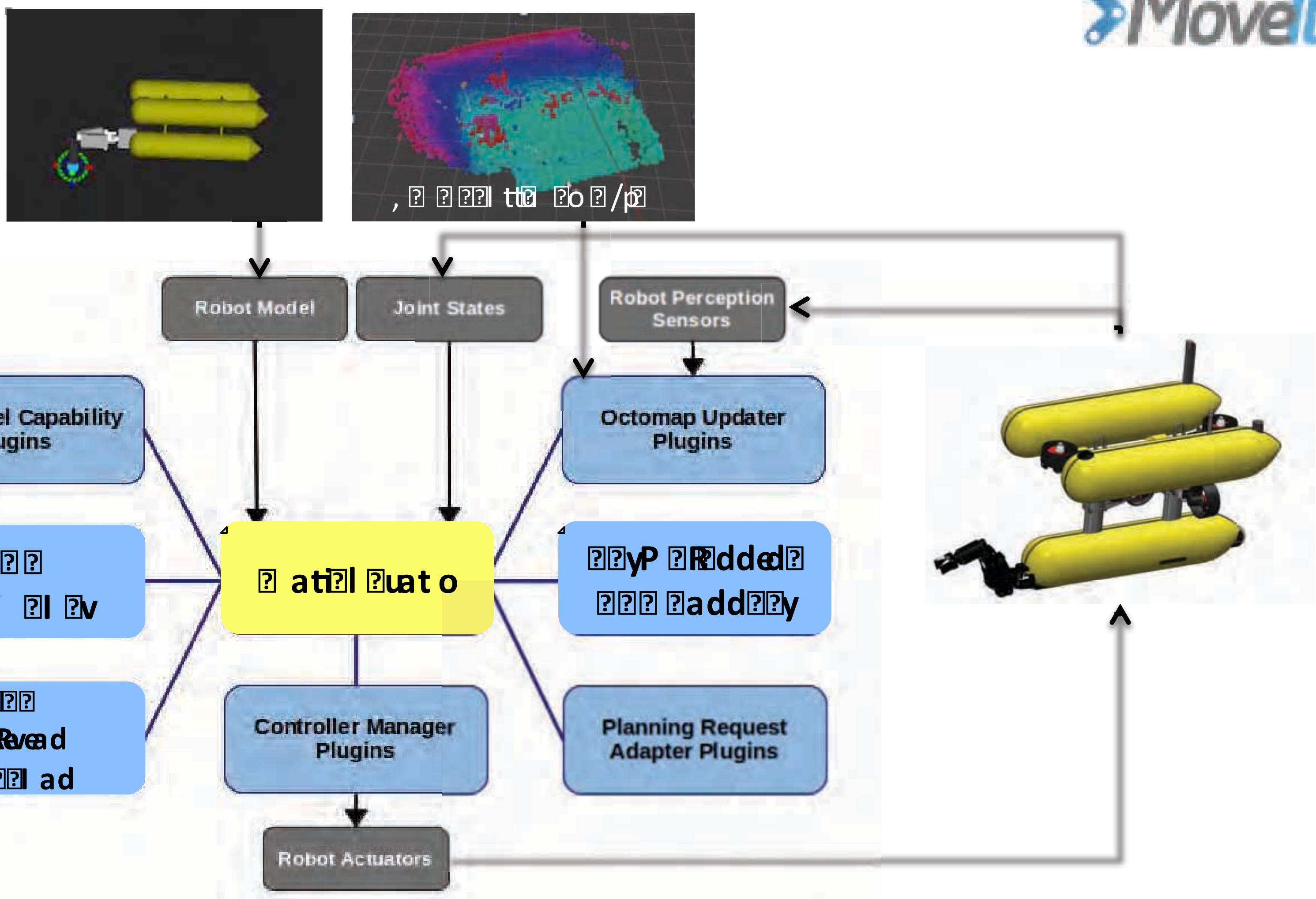
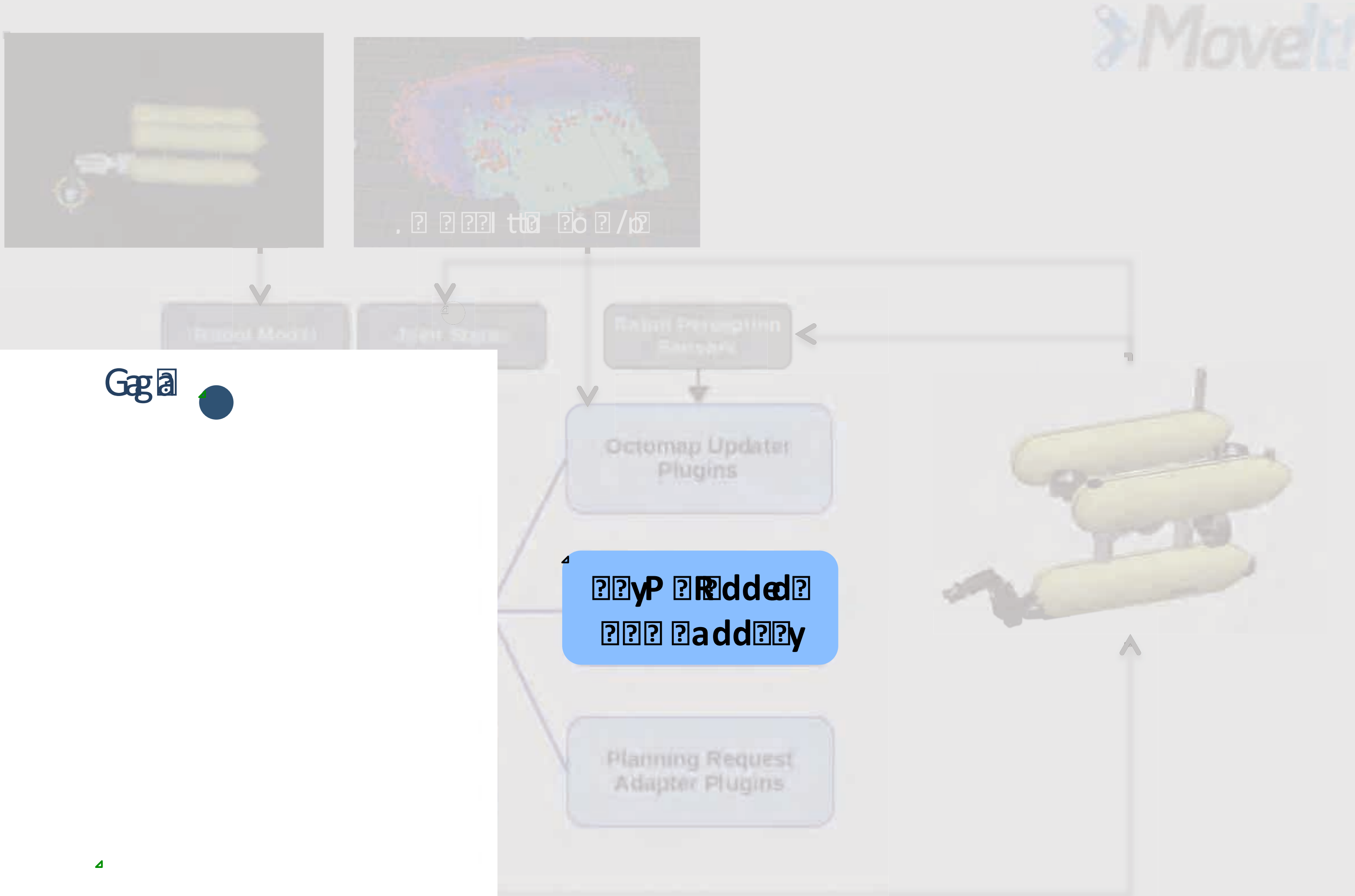
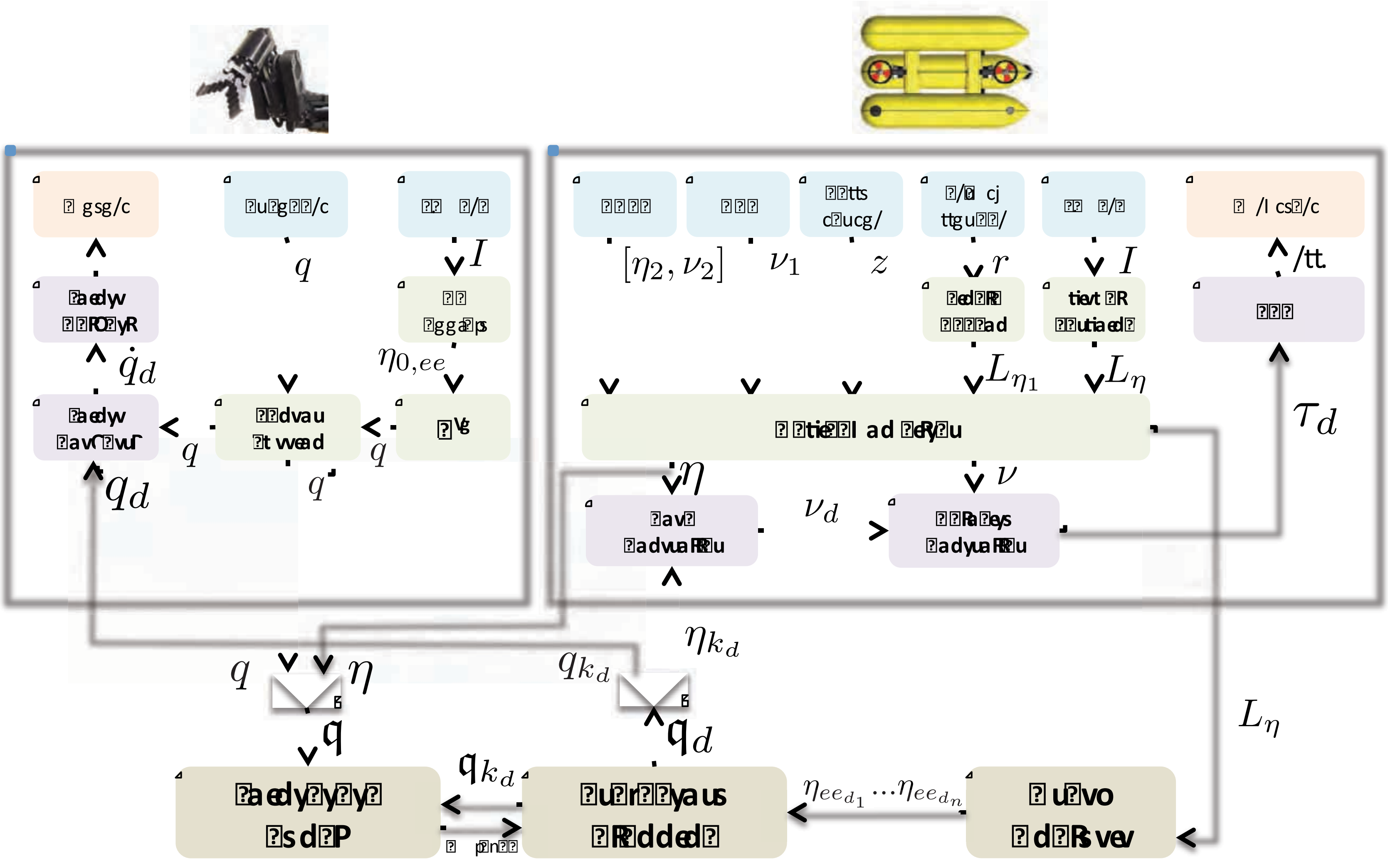





Robot Model
Joint States
Robot Perception Sensors
High Level Capability Plugins
Octomap Updater Plugins
Controller Manager Plugins
Planning Request Adapter Plugins
Robot Actuators

Intervention AUVs

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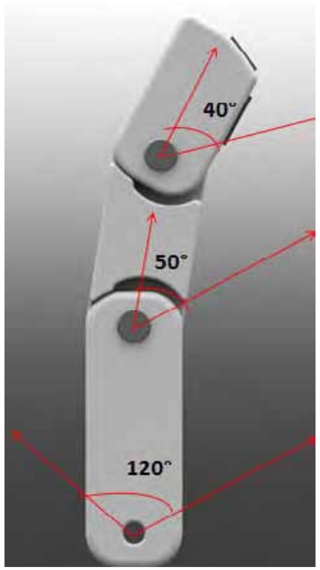
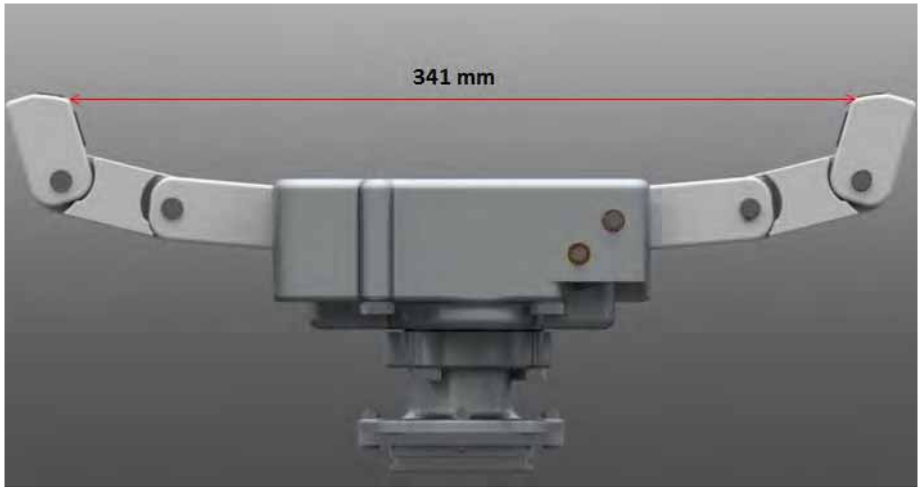
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
DPI2014-57746-C3-3-R
Free-Floating Autonomous Valve Turning
in Presence of Virtual Obstacles
(MoveIt!-based implementation)
Universitat de Girona


40°
50°
120°


13 mm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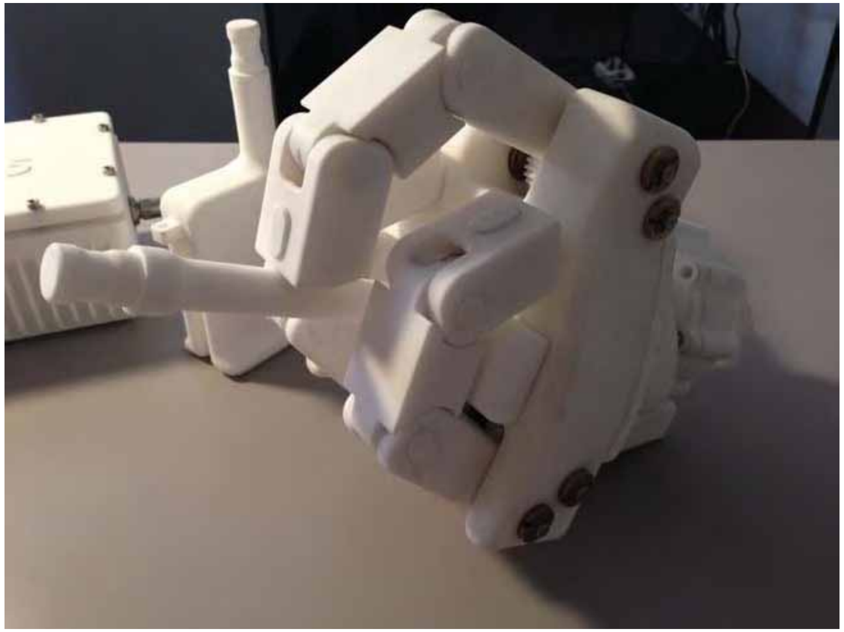

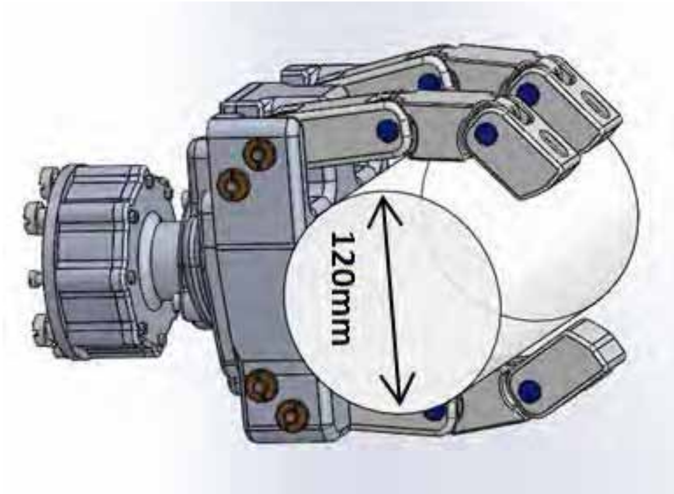
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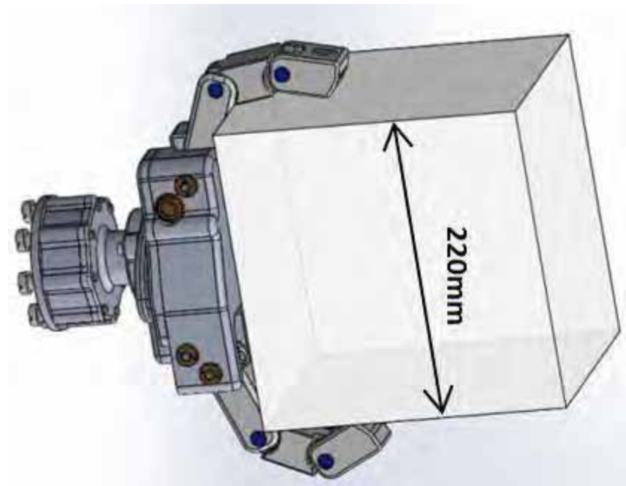
220mm

GOBIERNO DE ESPAÑA — MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
DPI2014-57746-C3-3-R

Free-Floating Autonomous Underwater Manipulation: Connector Plug/Unplug (MoveIt!-based implementation)

Universitat de Girona

Intervention AUVs

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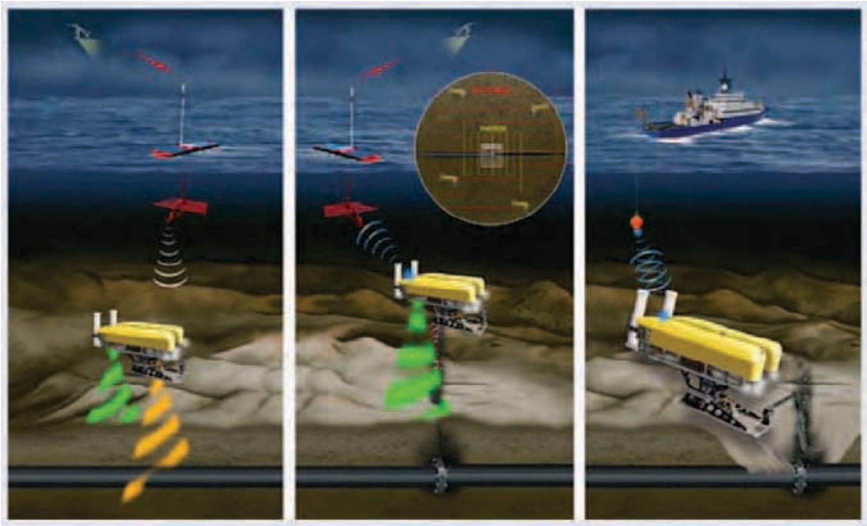

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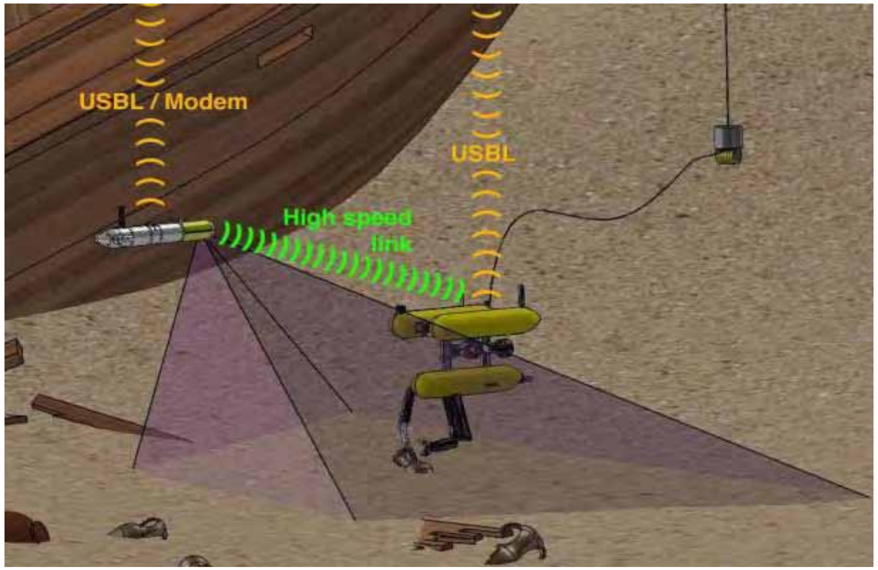
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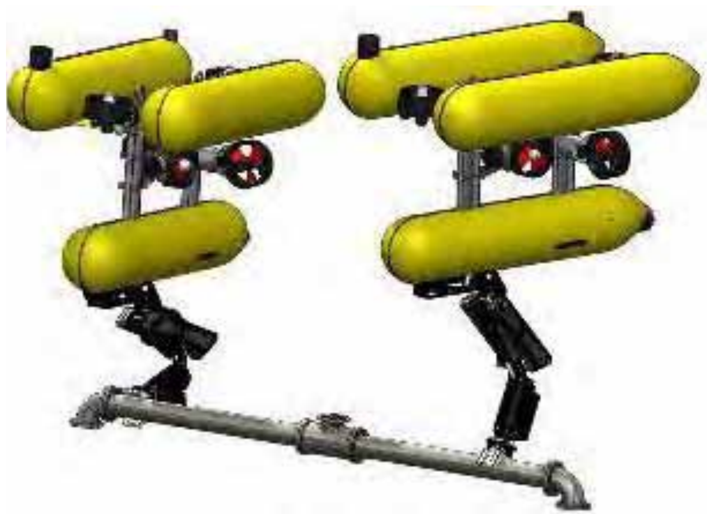

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[Marani *et al.* 09] Marani, G., Choi, S., and Yuh, J. (2009). Underwater Autonomous Manipulation for Intervention Missions. AUVs. Ocean Engineering. Special Issue: AUV, 36(1),15–23.

[Sanz *et al.* 12] Sanz, P.J.; Ridao, P.; Oliver, G.; Casalino, G.; Petillot, Y.; Silvestre, C.; Melchiorri, C.; Turetta, A., "TRIDENT An European project targeted to increase the autonomy levels for underwater intervention missions," Oceans - San Diego, 2013 , vol., no., pp.1,10, 23-27 Sept. 2013

[Evans *et al.* 03] Evans, J., Redmond, P., Plakas, C., Hamilton, K., and Lane, D. (2003). Autonomous docking for Intervention- AUVs using sonar and video-based real-time 3D pose estimation. OCEANS 2003, 4, 2201–2210.

[Palomeras *et al.* 14] [illegible]

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EMRA'15 workshop

Session 6. Chair – Joerg Kalwa

14:00 Marine UAS (EU project)

14:30 ARROWS (EU project)

15:00 **T4.1 – *AUV Technology: from concept to commercialization***
Alessio Turetta, GraalTech, Genova, IT

15:30 **T4.2 – *Measuring small island-induced processes: Tech-savvy approaches***
Rui Caldeira, CIIMAR, Porto, PT

EMRA'15 workshop

Marine UAS
EU PROJECT

Tor Johansen, NTNU, Trondheim, NO
António Pascoal, IST, Lisbon, PT

MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring

Tor Johansen, NTNU, Trondheim, NO

presented by Antonio Pascoal, IST, Lisbon, PT

Overview of presentation

- What is a Marie Curie Innovative Training Network?
- Background and motivation for MarineUAS
- Scientific and training objectives of MarineUAS
- Planned workshops and training events open for external participation

MARIE CURIE ACTIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642153.

MarineUAS

Innovative Training Network on Autonomous Unmanned Aerial Systems for Marine and Coastal Monitoring

European Training Network funded by H2020

- Project period 1.1.2015 – 31.12.2018
- 15 PhD scholarships funded
- 10 Beneficiaries – 5 Academic, 5 Industrial/Research
- 4 Associated Partner Organizations
- Coordinator is Professor Tor Arne Johansen, Norwegian Univ. Sci. Tech., Trondheim

What is a H2020 European/Innovative Training Network?

Part of the Marie Skłodowska-Curie actions: Keys are **PEOPLE** and **MOBILITY**

- *High quality* ***doctoral-level training*** *in and* ***outside academia:***

  Increased competitiveness of European industry

- *Innovative training networks bring together universities, research centres and companies from different countries worldwide to train a new generation of researchers.*
- *The funding boosts scientific excellence and business innovation, and* ***enhances researchers' career*** *prospects through developing their skills in* ***entrepreneurship, creativity, and innovation.***

What more?

The proposed research training or doctoral programme should respond to ***well-identified multi- and interdisciplinary needs*** in scientific and technological research areas, ***expose the researcher to different sectors***, and ***offer a comprehensive set of transferable skills (such as entrepreneurship and communication).***

Proposals should reflect existing or planned research cooperation among the partners, involving the researchers through ***individual, personalised research projects.***

MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring

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Doctoral Training Objectives

Expanding on the existing doctoral programs at the involved universities, MarineUAS combines

- Cutting edge training-by-research
- Complementary and transferable skills training
- Secondments/exchange among partners
- Hands-on UAS operator training
- Cross-disciplinary skillset and field testing experience
- Network-wide training events

Why MarineUAS?

European countries have vast coasts and economic zones that go far into the Atlantic and Arctic oceans and are challenging to monitor and manage.

The need to protect and manage the vulnerable natural environment and marine resources in a sustainable manner is an important policy that is manifested in European legislation such as the European Strategy for Marine and Maritime Research.

Why MarineUAS?

use of autonomous unmanned aerial vehicle systems (UAS) instead of manned aircraft and satellite-based remote sensing, oftentimes exploiting strong collaborative links with buoys, ships and autonomous marine vehicles for in-situ observations.

UAS offers potential advantages such as high endurance, reduced cost, increased flexibility and availability, rapid deployment, higher accuracy or resolution, and reduced risk for humans and negative impact on the environment.

Applications of UAS technology in marine and coastal monitoring are numerous…

Environmental monitoring

Example: Use of EO and infrared/thermal cameras to monitor oil spills (Maritime Robotics AS)

Iceberg surveillance

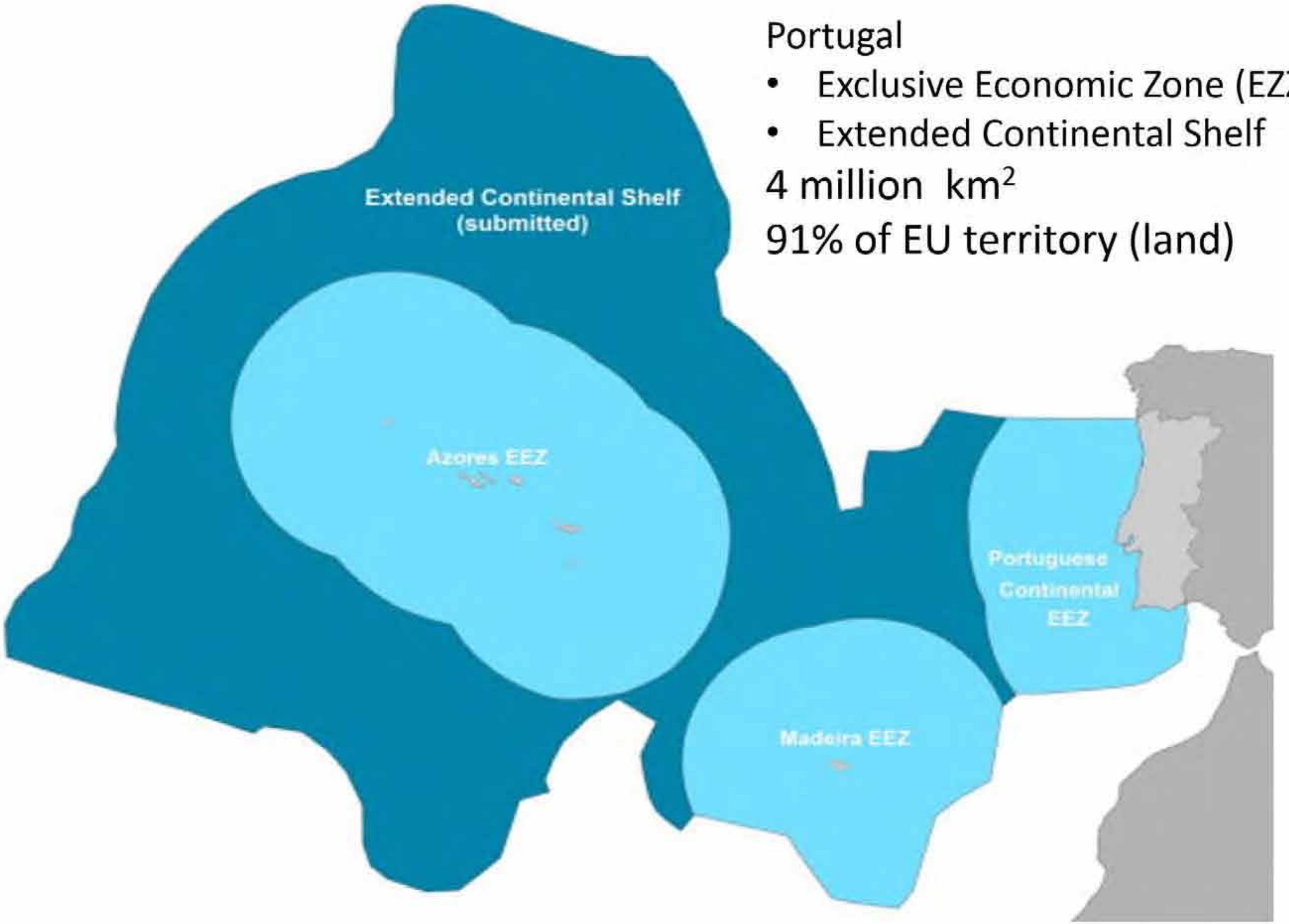
Northern sea routes are becoming attractive due to the climate change.
Exploration of minerals and petroleum is moving to the Arctic.
Protection of the ships from collision with icebergs and sea ice may depend on UAV surveillance.

Search and rescue

Example: Use of infrared/ thermal camera
(Univ. Porto and NTNU)

Management of Marine Resources, Oceanography and Security

- Fisheries
- Ship traffic
- Border control
- Pollution
- Environmental parameters
- Oceanography
- Marine biology



Portugal

- Exclusive Economic Zone (EZZ)
- Extended Continental Shelf

4 million km^2

91% of EU territory (land)

Maritime and Coastal UAS Scenarios

- Large distances (100’s km) and long endurance (>8 hours) Beyond-Line-of-Sight (BLOS) operations
- Very limited communication infrastructure in many areas (including arctic regions); satellite systems with small footprint are generally sparse, unreliable, expensive, and low capacity.
- Low risk for incidens involving third parties; little air/surface traffic, sparsely or not populated

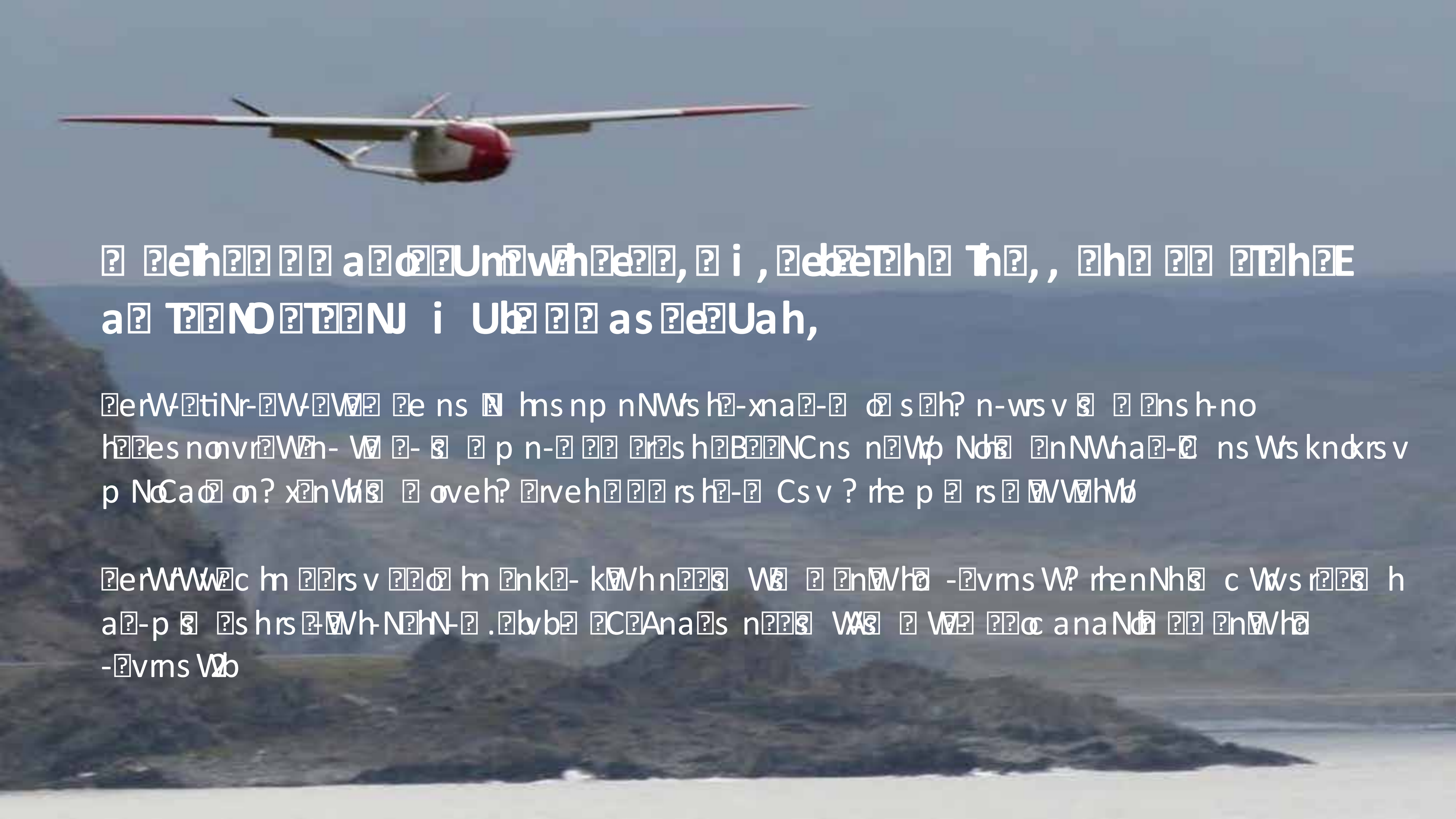
...or .... fog, darkness, rain, cloudy, windy, ...

MarineUAS objective:
Enabling safe UAS BLOS operation in non-segregated airspace

UAVs must be able to operate safely in airspace shared with other air traffic.

Autonomous control with fault tolerant control and key safety functions such as mid-air collision avoidance (detect and avoid) are essential to achieve this.

- SESAR 2020
  - One of the key topics of SESAR 2020 is to integrate RPASs into the Single European Sky environment
  - Honeywell wants to play a major role in areas of DAA and C2 link development for RPAS within SESAR 2020
- National rules by Civil Aviation Authorities
  - NORUT, Maritime Robotics and NTNU have licenses and experiences with BLOS operations in shared airspace in Norway



MarineUAS objective: Smarter and more efficient UAS with intelligent functions that adapt the UAS behavior and autonomously re-plan its mission in real-time in response to onboard sensors

This requires research on advanced real-time information processing, and real-time autonomous decision making that integrates the intelligence into autopilots and task execution.

This is essential in marine and coastal environments where large spaces lead to long distance communication that will usually not allow large amounts of data to be transmitted in real time.

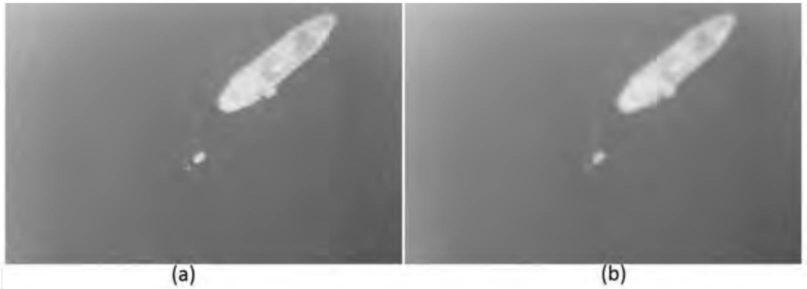
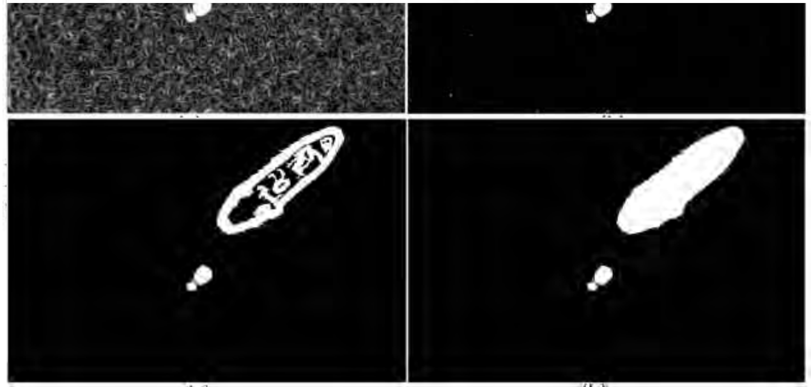


Figure 3. Before (a) and after (b) smoothing of the original image. The image is showing a large boat (length of 55m), a rigid-inflatable boat and a small buoy.



Tightly coordinated operations involving autonomous UAS in interaction with autonomous surface vessels (ASVs), autonomous underwater vehicles (AUVs), and sensor nodes are needed in missions where remote UAS sensors are not sufficient, and the ASVs and AUVs need aerial guidance in order to make measurements at the right locations.

Examples include

- determining the spatial and temporal extent of oil spills,
- fields of toxic algae, and
- plumes arising from pollutant discharges, as well as
- estimating the temporal and spatial distribution of scalar fields of which temperature, chlorophyll concentrations, and salinity are examples

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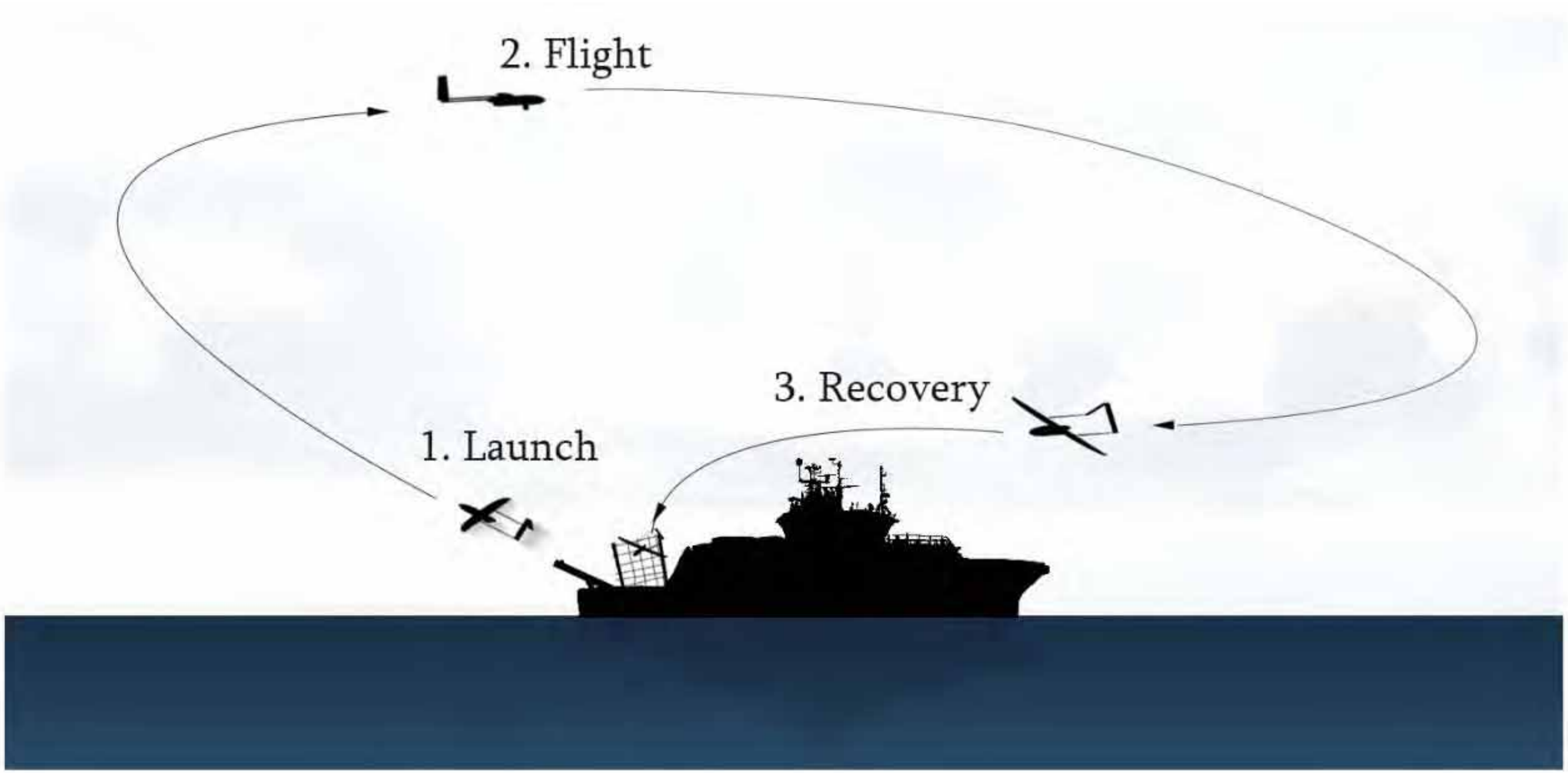
Demonstration of capabilities and benefits in challenging marine operations and science missions through field testing

… such as iceberg tracking in the Arctic, large area multi-vehicle monitoring and surveillance, take-off and landing of UAVs from ships in harsh weather conditions, and execution of complex missions in close collaboration with marine science end-users.



MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring

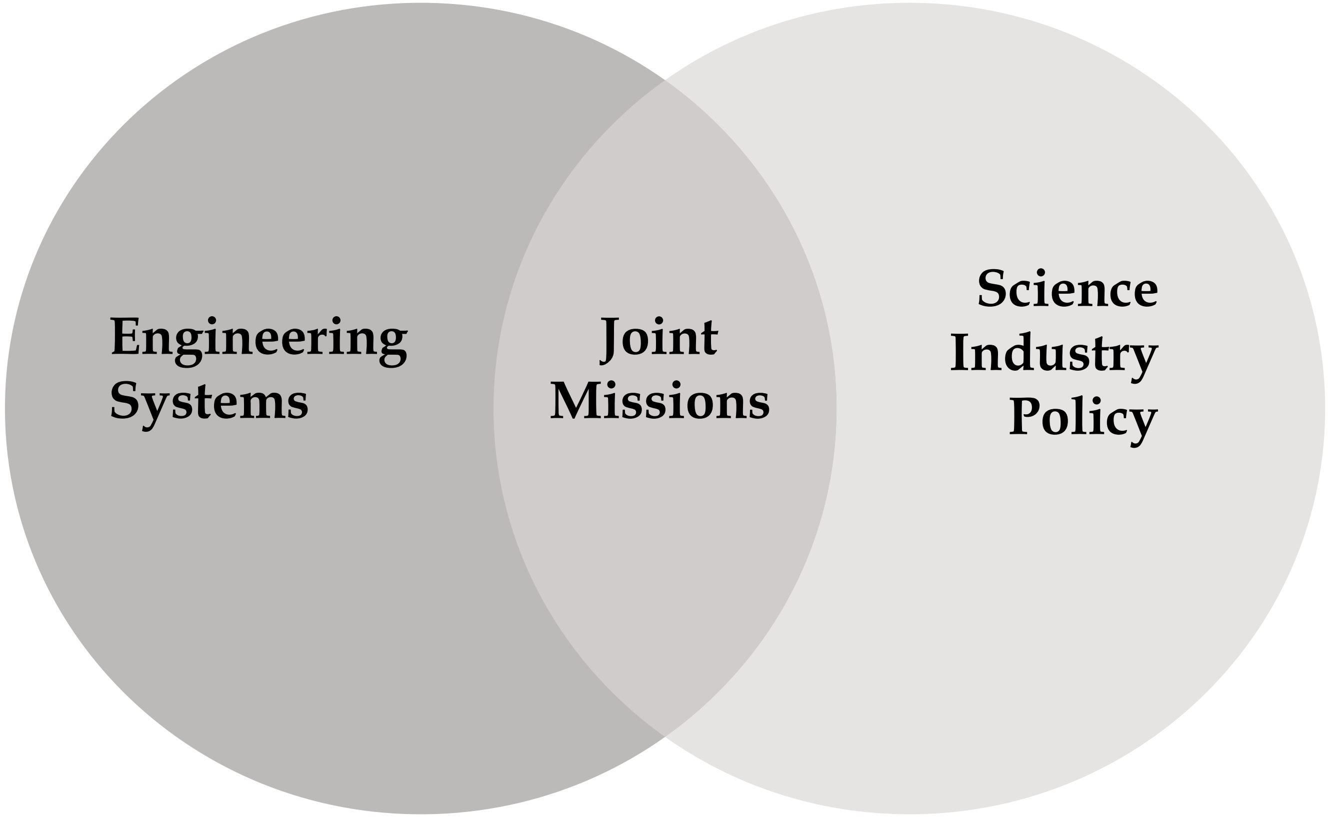
Marine UAS training program

- Some workshops and open for external participation
- Summer schools are generally open

More information at www.marineuas.eu

MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring



I - Engineering Systems
II - Science, Industry, and Policy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642153.


Basic PhD training
- Local doctoral programs
- Graduate courses
- Summer schools and conferences
- Transferable skills
- UAS technology workshop
- UAS operator training
- UAS airspace integration workshop
- Marine and coastal science workshop
- Marine and coastal surveillance workshop
Individual researsch
- Research under supervison
- Theories, methods and technologies
- Interaction with end-users
- Interaction with industry
- Collaboration and secondments
- Research reviews
- Publications
- Dissemination and outreach
Field experiments
- Demonstrators
- Validation and verification
- Case studies
- Interaction with end-users
- Interaction with industry
- Secondments
- Publications
- Dissemination and outreach
- Operational experience
- Hands-on skills

Marine and Coastal Surveillance Workshop

Hosted by Maritime Robotics in Norway Spring 2016

The objective of this three-day workshop is to give an introduction to typical marine and coastal inspection and surveillance missions, emphasizing the use of UAS.

The workshop will give an introduction to surveillance and inspection, search and rescue, sensor payload systems, and operational challenges such as harsh weather and lack of permanent infrastructure at sea.

We plan presentations to be given by experts from MR, NORUT, the Norwegian Coast Guard, Norwegian Clean Seas Association for Operating Companies, United States Coast Guard, MARINTEK, Sintef Fisheries and Aquaculture, and the Norwegian Coastal Administration.

UAS demonstrations will be performed, possibly at Agdenes microairfield near Trondheim.

MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring

Marine and Coastal Science Workshop

Hosted by IMAR and IST at the Azores in Portugal Summer 2016

The workshop will afford participants an introduction to environmental monitoring and mapping for sustainable management of the coasts and oceans, with due account for the required technological systems (cooperating air, surface, and underwater vehicles). Oceanography, and other applications of MarineUAS, are facing the "Big Data" challenge concerning observation systems and databases that could support end-users and service providers.

Leading experts in marine biology, oceanography, ecology, meteorology, UAS and coast guards will deliver lectures providing insights on various aspects of marine and coastal monitoring systems. Field demonstrations will be organized with surface, underwater, and aerial vehicles. The standards and requirements imposed by such systems and infrastructure needs to be taken into account in an integrated systems of systems approach.

In addition to experts from IST and the Partner Organizations IMAR, IPMA and CIIMAR, there will be presentations originating from UPORTO, the European Global Ocean Observing System (EuroGOOS), European Maritime Safety Agency (EMSA), and Monterey Bay Aquarium Research Institute, (MBARI).

MarineUAS

Innovative Training Network on Autonomous Unmanned Aerial Systems for Marine and Coastal Monitoring

RPAS Pilot and Operator Training and Certification

Basic course hosted by NORUT Tromsø, Norway

This course on UAS Operation includes planning, rules and regulations, legal and liability aspects, approval by aviation authorities, certification, pilot and operator responsibilities and tasks.

The MarineUAS doctoral fellows will follow a 12-month program that will give them competence and skills as UAS operators. The program will consists of lectures, e-course, exercises and practical training.

The intention of the course is that it can form the basis of formal certification of the ESRs as UAS operators for VLOS and Extended VLOS operations in certain European countries, having in mind the limitation that the UAS rules are not international or harmonized at this point. In any case, the course will give a comprehensive understanding of the operational aspects of UAS operation.

MarineUAS

Innovative Training Network on Autonomous Unmanned Aerial Systems for Marine and Coastal Monitoring

Workshop on integration of UAS into non-segregated airspace

The two-day workshop organized by Honeywell in Prague, Czech Republic, is planned for Winter 2016/17

It will focus on enabling technologies for UAS integration into non-segregated airspace, in particular detect and avoid (D&A), flight management, air traffic management (ATM), low workload ground stations, safe and secure command and control, and high integrity autonomous platforms.

Presentations will be given by experts from Honeywell, European aviation authorities, and the MarineUAS partners.

MarineUAS

Innovative Training Network on
Autonomous Unmanned Aerial Systems
for Marine and Coastal Monitoring

MarineUAS Summer School

Organized by IST, Portugal, Spring/Summer 2017

The two-week summer school will be a forum for the presentation and discussion of theoretical and practical issues pertaining to UAS, with a special focus on the interaction with autonomous surface and underwater vehicles, and other marine assets.

Presentations will be given on selected topics that include cooperative motion planning, navigation, and control, as well as mission planning with due account for navigational constraints.

The presentations will be followed by hands-on experiments. Tests will be carried out in a protected marine area using the fleet of autonomous surface and underwater vehicles that are property of IST and a group of small autonomous air vehicles. The objective is for the attendees to participate actively in the sequence of steps that go into cooperative mission planning, programming, and execution, effectively going from theory to practice. This will be made possible by using advanced software tools that allow for seamless algorithm implementation and hardware-in- the-loop simulation prior to multiple vehicle deployment in real operating conditions.

Winter School

Organized by University of Porto, Winter 2017/18

The two-week intensive summer school is intended mainly for external researchers, with mini-courses contributed by the MarineUAS network participants.

It will integrate technical topics and application case studies and demonstrations from the partners in the network, in particular an extensive set of presentations and field demonstration from UPORTO in collaboration with IMAR, IPMA and CIIMAR Particular emphasis is given on the NEPTUS/DUNE/IMC open source software environment and control architecture for networked multi-vehicle operations.

		Individual research projects
ESR1	UPORTO	Cooperative control of UAS for distributed monitoring with logic-based communication
ESR2	USE	Multi-UAS planning and trajectory generation for safe long duration missions
ESR3	IST	Cooperative compliant ASV/USV formation control for coastal area surveys under stringent communication constraints: Coordination with UAS
ESR4	USE	Distributed appraoches for coverage and tracking missions with multiple heterogeneous UAVs for coastal areas
ESR5	UPORTO	Coordinated control for UAS integration in maritime operations
ESR6	MR	Intelligent data acquisition in maritime UAS
ESR7	NTNU	Multi-UAS iceberg detection, tracking and motion prediction
ESR8	IST	Cooperative motion planning and adaptive ocean sampling strategies: Cooperation between air and marine vehicles
ESR9	NORUT	Sensor based formation flights with discontinuous sensor data applied to ice monitoring
ESR10	LiU	Tight integration of GNSS and IMU at high latitudes with ground radio support
ESR11	NTNU	UAV fault tolerant control and automatic de-icing
ESR12	CATEC	Autonomous operation of VTOL UAV on mobile platforms
ESR13	HON	Detect and avoid (D&A) for remotely piloted aircraft systems
ESR14	LiU	Model-based diagnosis for UAVs
ESR15	iTUBS	Multifunctional flight control and vehicle management

ARROWS
EU PROJECT

Benedetto Allotta
Univ. Florence, IT

UNIVERSITÀ DEGLI STUDI FIRENZE

ARROWS

ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

MDM LAB

The ARROWS Project: Adapting and Developing Robotics Technologies for Underwater Archaeology

Benedetto Allotta

DIEF - Dept. of Industrial Engineering, University of Florence
MDM Lab – Laboratory of Mechatronics and Dynamic Modelling

UNIVERSITÀ DEGLI STUDI FIRENZE

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

ISME

Integrated Systems for Marine Environment

ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 308724

Call: FP7-ENV-2012-one-stage, topic ENV.2012.6.2-6 *Development of advanced technologies and tools for mapping, diagnosing, excavating, and securing underwater and coastal archaeological sites*

Starting date: September 1st, 2012
Duration: 36 months
Number of partners: 10
EU [illegible]bout 3M€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UNIVERSITY
TWI
TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY
EESTI MEREMUUSEUM
ESTONIAN MARITIME MUSEUM
EDGE LAB
ISTI
FLORENTINA STUDIORUM UNIVERSITAS
NESNE
elektronik

ARROWS

ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

1. University of Florence, Italy
2. ISTI-CNR – Pisa, Italy
3. Tallinnaa Tehnikaulikool – Tallinn, Estonia
4. Heriot-Watt University – Edinburgh, UK
5. Edgelab S.R.L. – La Spezia, Italy
6. Albatros Marine Technologies S.L., Maiorca, Spain
7. Nesne Elektronik, Izmir, Turkey
8. TWI Ltd, Cambridge, UK
9. Regione Sicilia, Italy,
10. Eesti meremuuseum, Tallinn, Estonia

Goals

- Horizontal **surveys of large areas** using customized AUVs
- **High quality maps** thanks to localization abilities of AUVs
- **Modern shipwreck/submerged site penetration** by biomimetic vehicles
- Soft **cleaning tool**
- Mixed reality environments for **virtual exploration** of archaeological sites
- Mo[illegible]g of changes via **back-to-the-site missions**

Methodology

- Identification of the archaeologists' requirements – an ***Archaeological Advisory Group*** has been created. S. Tusa, U. Dresen, I. Radic, H.G. Martin, A. Zarattini, P. Gambogi, P. Lätti

- Identification of the technological problems

- Looking for solutions with technological readiness levels that predict their maturation for exploitation within 3-5 years

ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

AUVs for archaeologists? The challenge (1):

- **Small:**
  - ✓ fits in a bag
  - ✓ can penetrate modern wrecks
  - ✓ easy launch & recovery
- **Fast:**
  - ✓ can move rapidly among sites
  - ✓ can rapidly map large areas for discovery missions
- **Strong:**
  - ✓ can afford currents and waves
- **Long endurance:**
  - ✓ can work for at least 8 hours before recharging
- **Easy**:
  - ✓ can be operated without the help of a platoon of nerds
- **“… e … l Ti … ”:**
  - … pply processed data immediately, without need of hours of … cessing

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ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

AUVs for archaeologists? The challenge (2):

- **"Rich" payload:**
  - ✓ SSS for large surveys
  - ✓ Forward looking sonar for closer surveys of sites
  - ✓ Subbottom profiler
  - ✓ Magnetometer
  - ✓ Metal detector
  - ✓ Cameras for mosaicing, slam, 3D reconstruction
  - ✓ …
- **Precise positioning:**
  - ✓ "back to the site" missions within 1 m or less
  - ✓ Exact geo-referencing of images, sonograms, mosaics, [illegible]constructions

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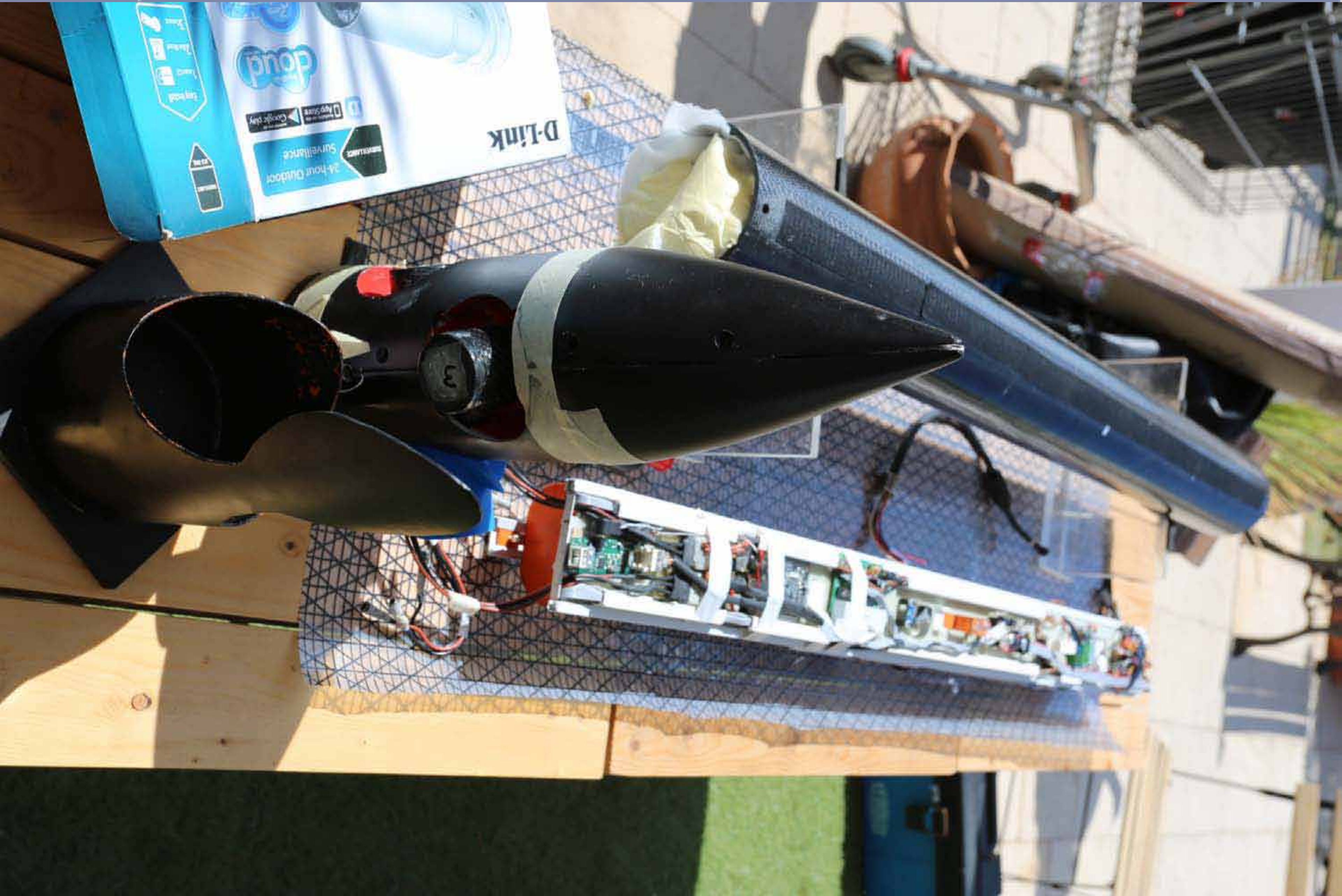
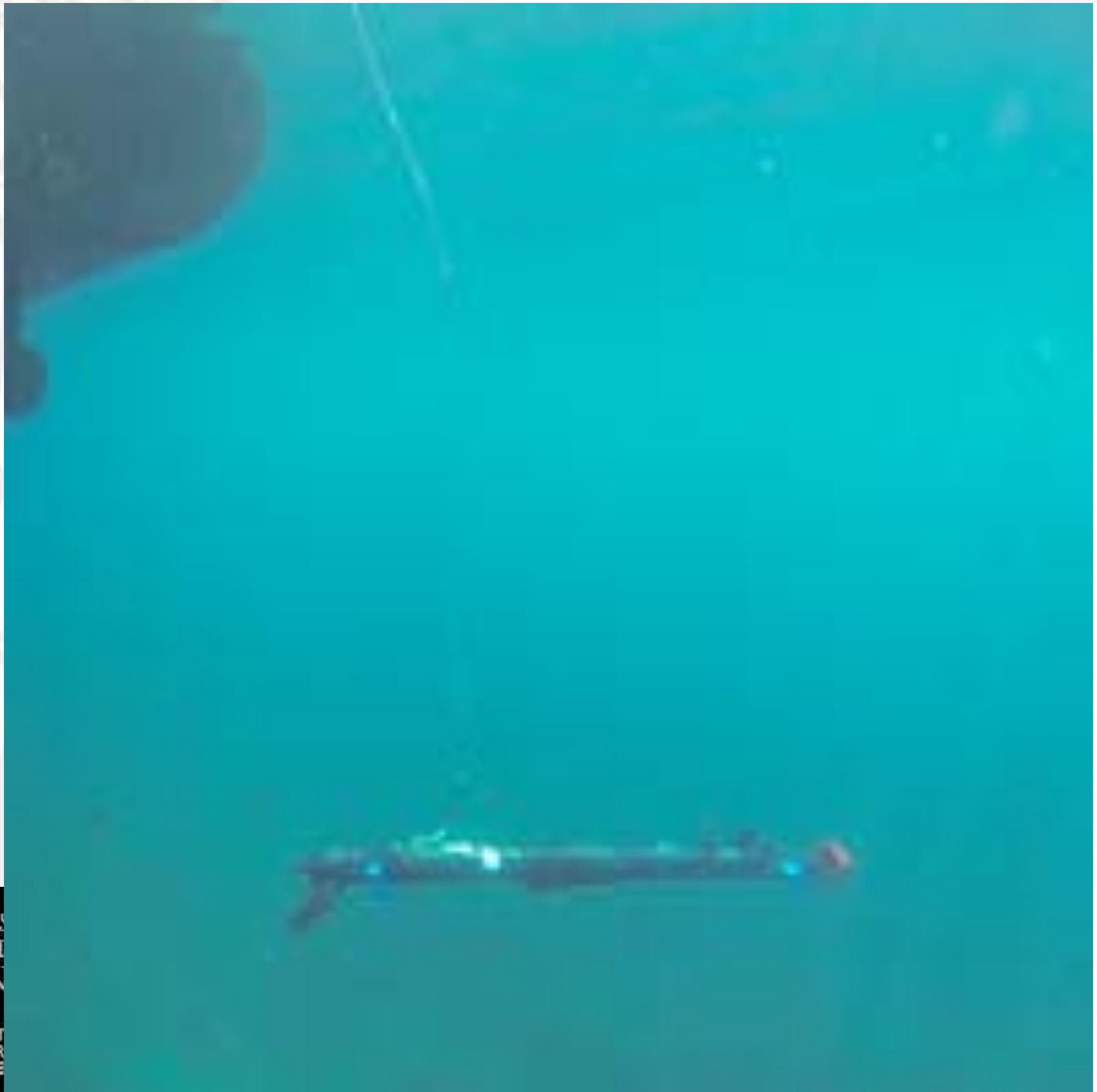
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

AUVs for archaeologists?
The challenge (3):

- **Cheap!!!**
- **Reliable:**
  - ✓ always comes back home…

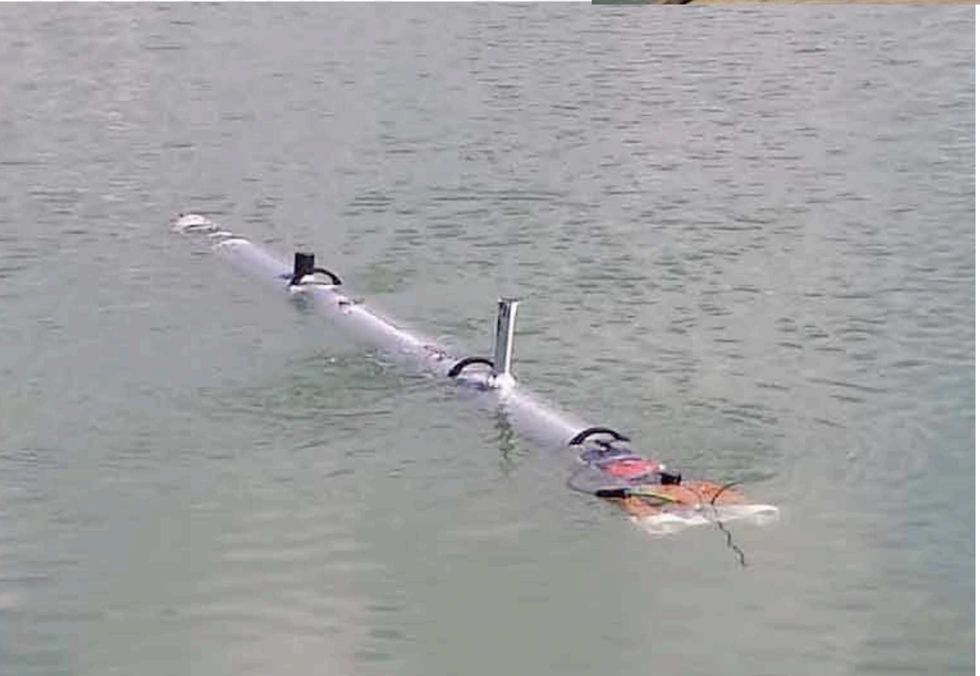

D-Link
24-hour Outdoor
Surveillance

New vehicles – A-Sized (Edgelab)



ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

New vehicles – MARTA (UNIFI)



New vehicles – MARTA (UNIFI)

Main Features

- Torpedo–shaped
- Hovering capability
- Maximum depth: 150 m
- Maximum speed: 4 knots
- Diameter: 177Ø mm
- Length: depending on configuration
- Energy: 1300 Wh
- Modularity: modules connected by Ethernet, CAN Bus + power supply
- Linux + ROS

Navigation and communication

- MEMS IMU + FOG
- DVL
- Depth sensor
- Altimeter
- GPS
- Radio modem
- WiFi
- Acoustic modems (2)

Payload

- Forward-looking MBES
- 2 cameras
- Laser + 4 leds

ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

New vehicles: U-CAT biomimetic robot (TUT)

h C2 6e U71e : A A A o T6- 0- o 64 : A 0 i C= t h 6a

UNIVERSITÀ DEGLI STUDI FIRENZE

ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

New vehicles: U-CAT biomimetic robot (TUT)

New vehicles – U-CAT Biomimetic Robot (TUT)

- Weight: less than 20 kg
- Material: Al - Anticorodal
- Maximum depth: 100 m
- Maximum speed: fins propulsion to be tested
- Size: 600 X 219Ø mm
- Power Supply: 29.6V DC X 620 Wh
- Linux + ROS

- 1 camera
- 2 LED illuminators
- IMU
- Depth sensor
- Custom made echo-sounders
- GPS
- Wi-Fi
- Acoustic modem

ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

MDM LAB

"Old" vehicles – Typhoons

THESAURUS

REGIONE TOSCANA

IN SUPREMÆ DIGNITATIS 1343

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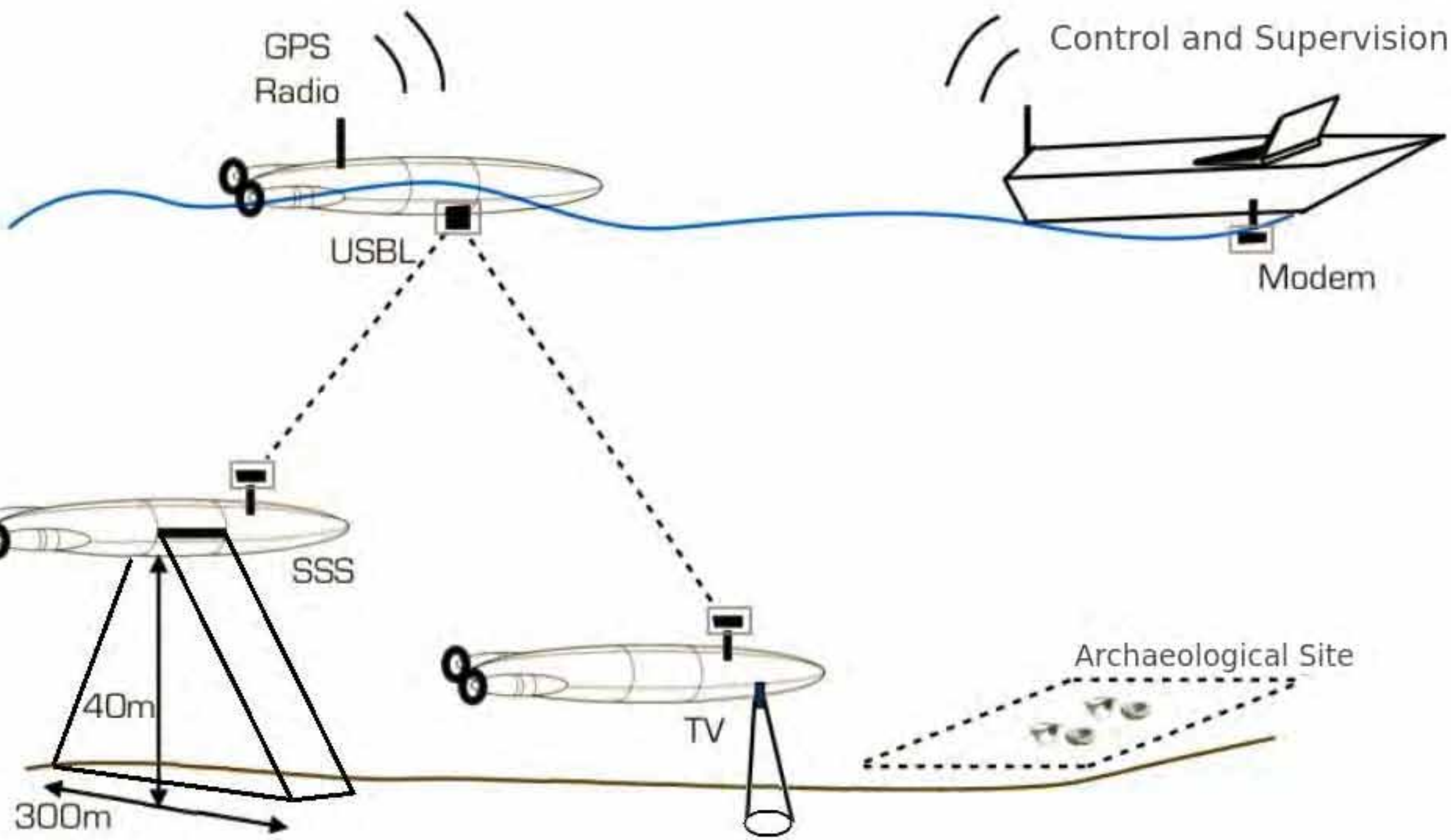
ARROWS ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

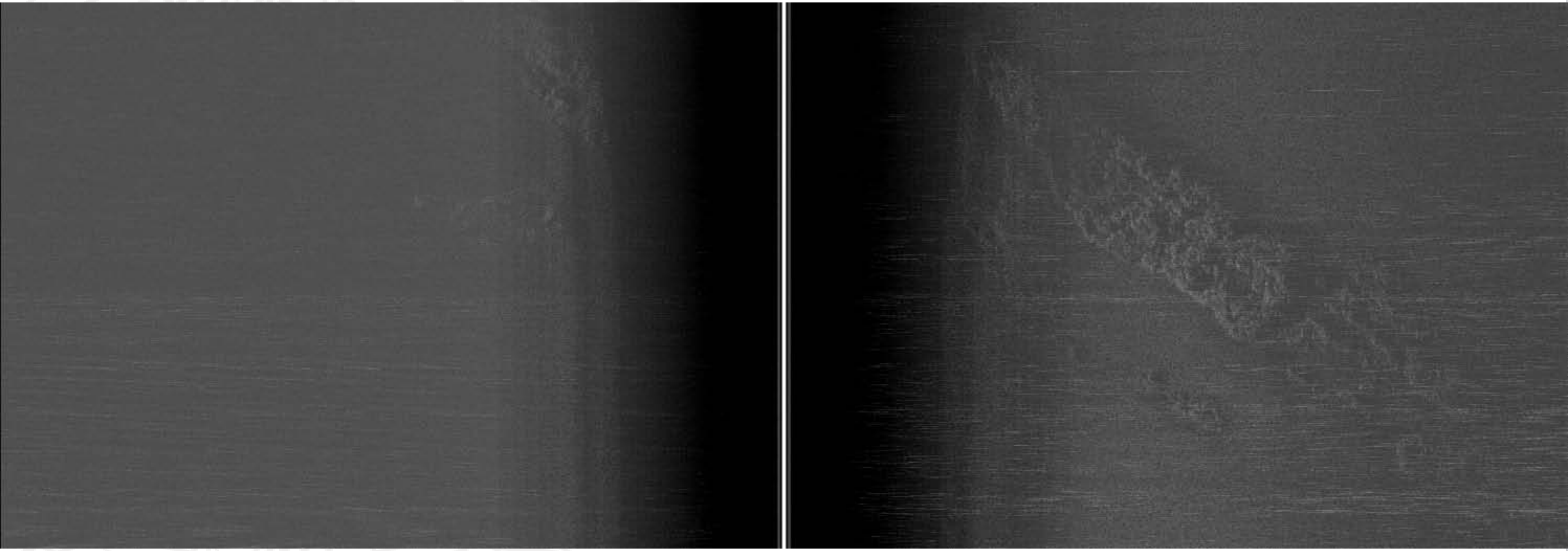
MDM LAB

Cleaning Tool (to be mounted on the Typhoon)

Robot system made of AUVs for underwater archaeology



Gulf of Baratti, July 28, 2014: SSS of the "Caligola" wreck



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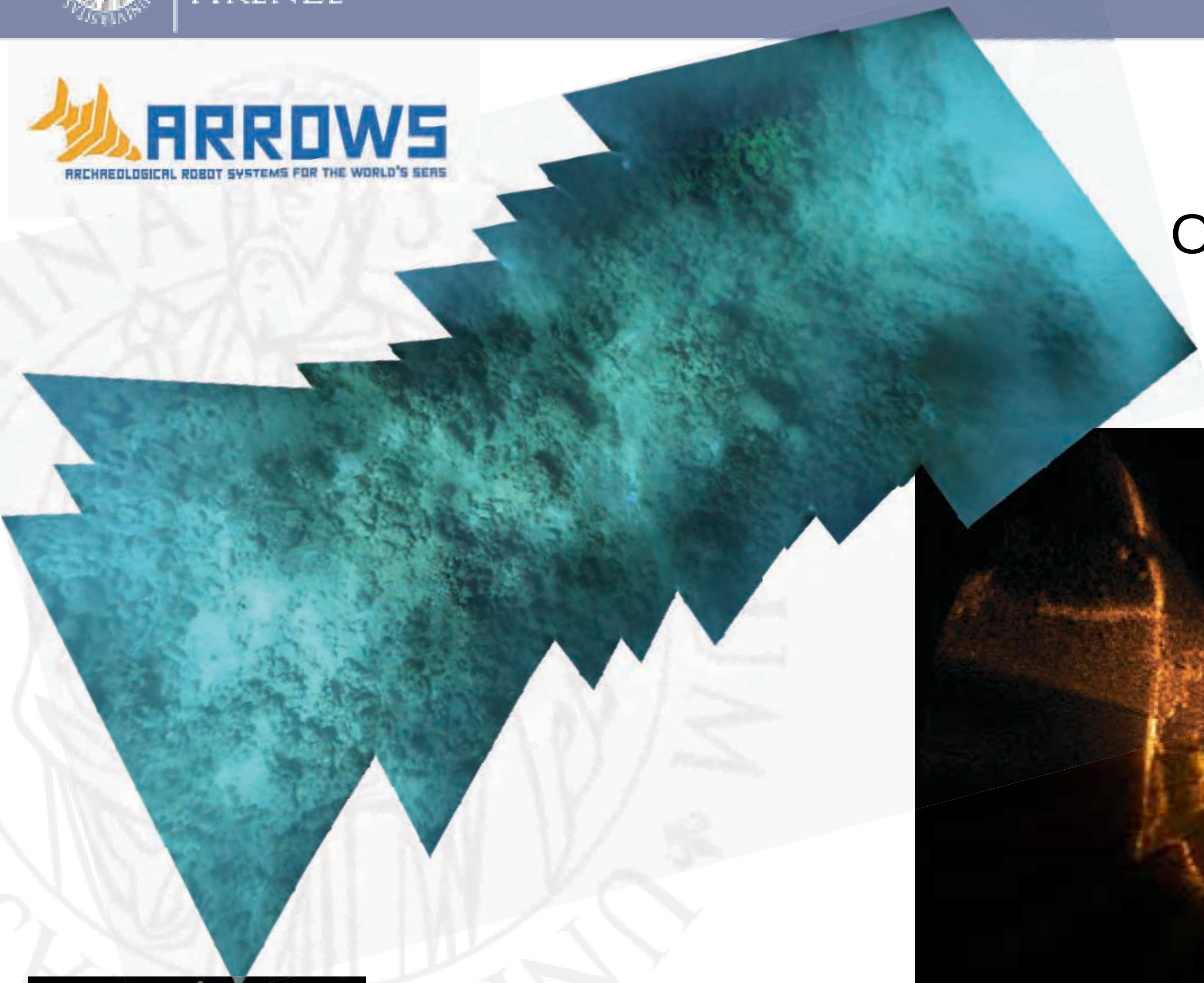
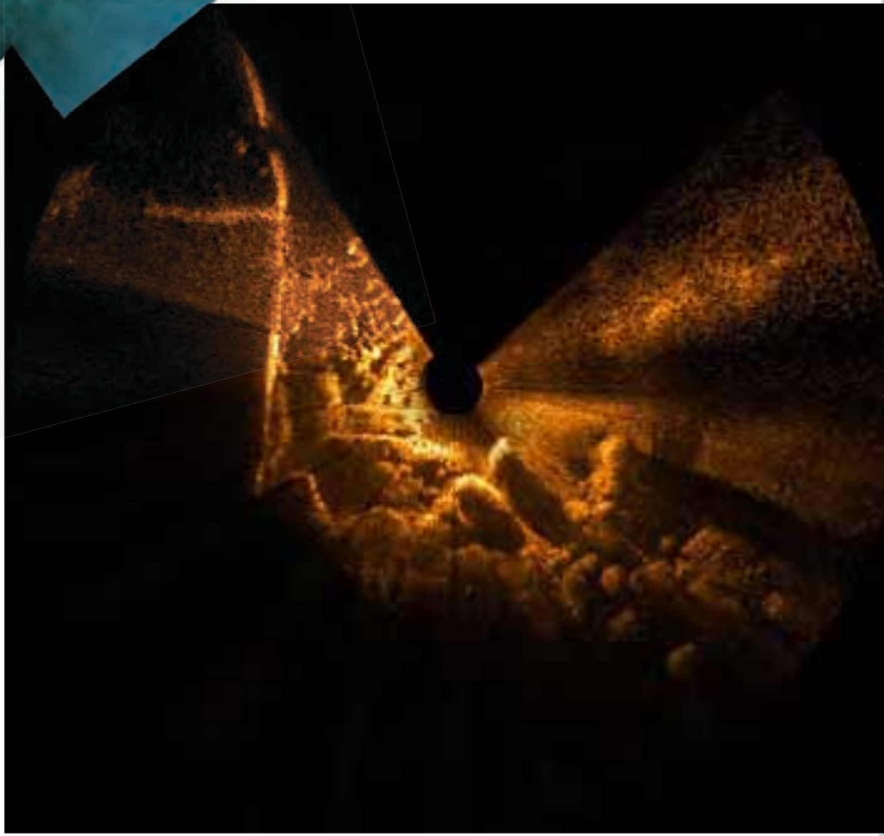
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

MDM LAB



Optical data



Acoustic data

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ISME
Integrated Systems for Marine Environment

CENTRO SUPPORTO CSSN SPERIMENTAZIONE NAVALE

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MARINA MILITARE


MARINA MILITARE

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FIRENZE

MARINA MILITARE

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ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

MDM LAB

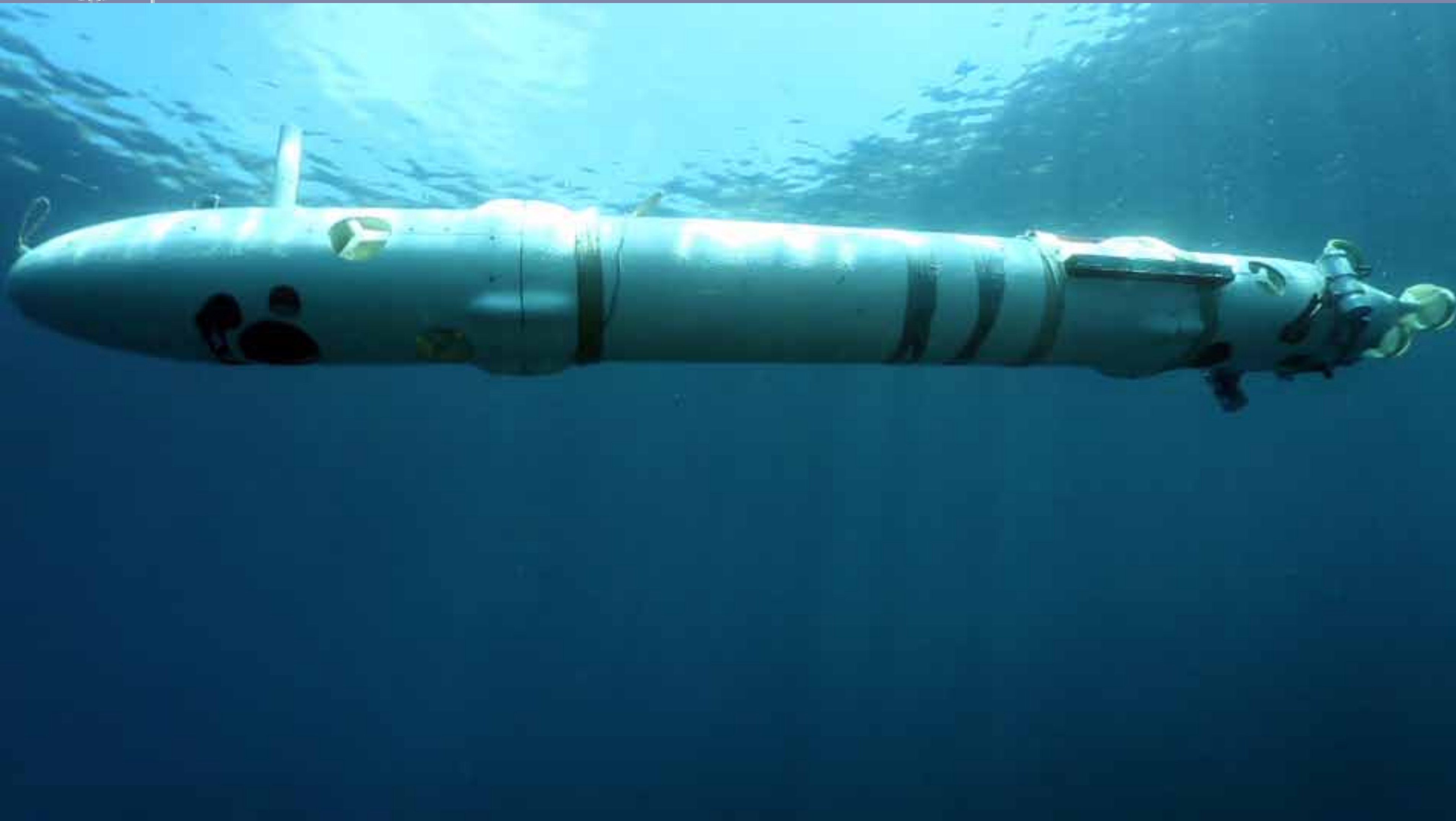
Demonstration 1:
May 26 – June 5, 2015

Sicily (Egadi Archipelago)

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

UW


GALLUZZO
PALLANUOTO



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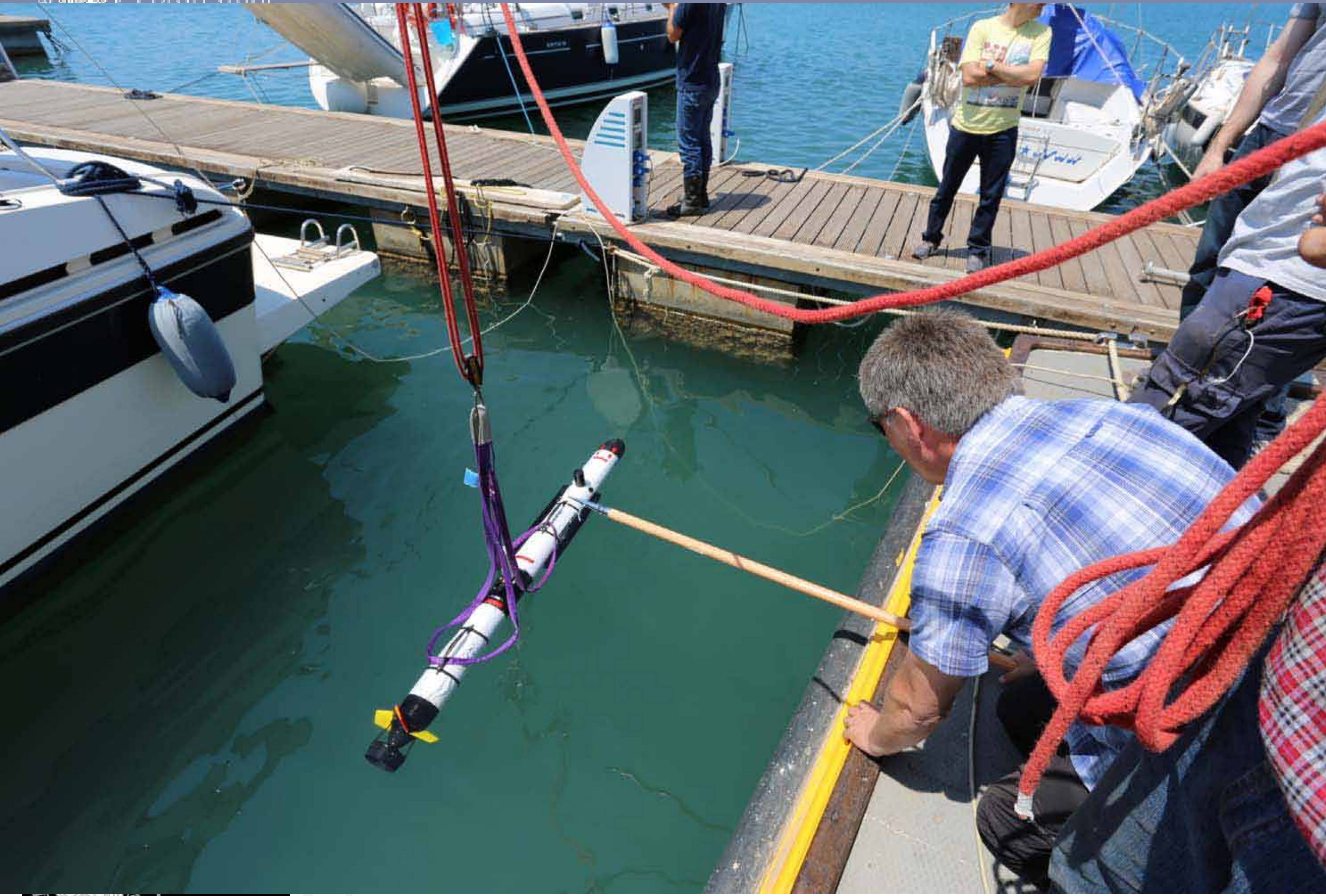

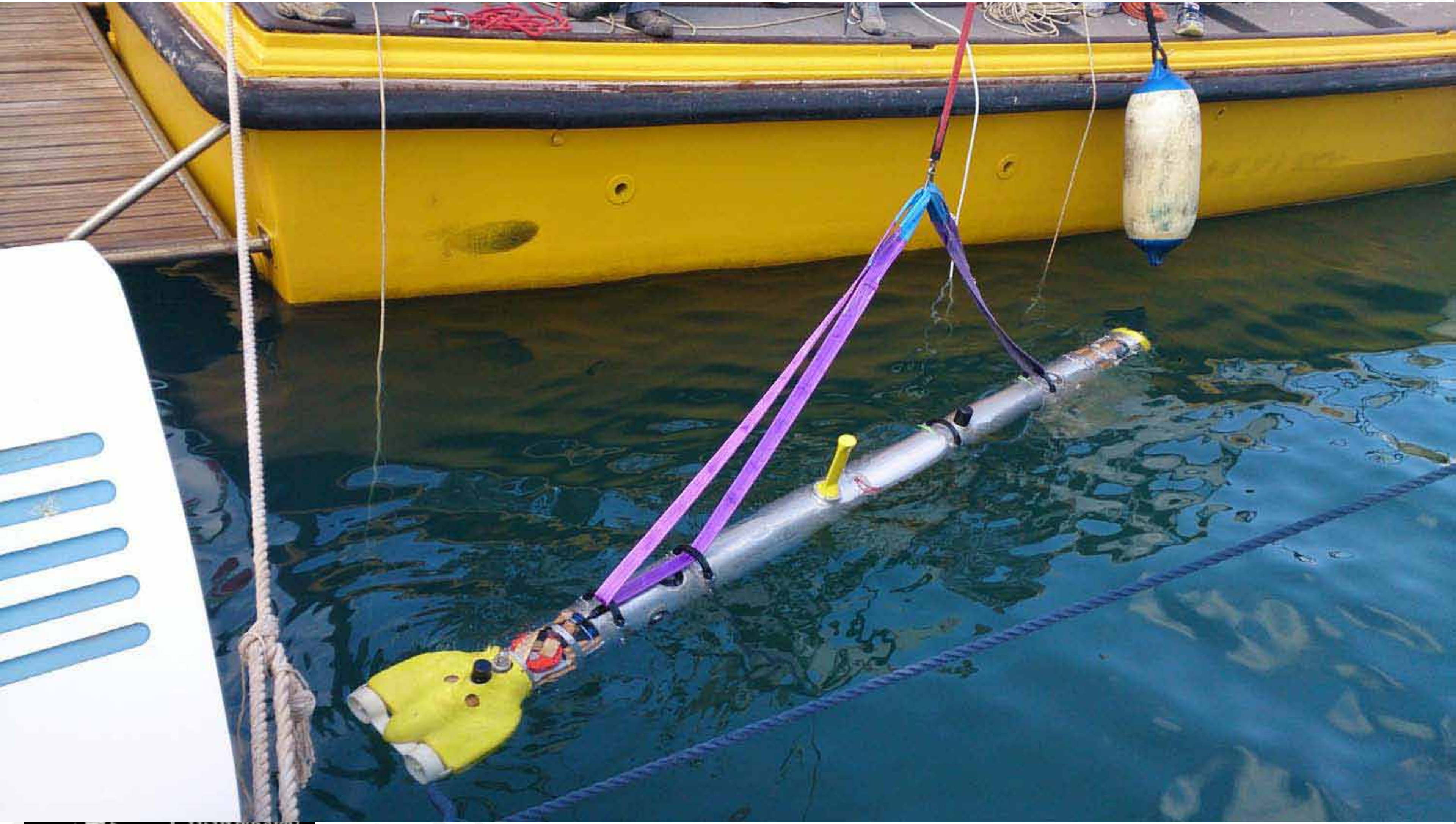

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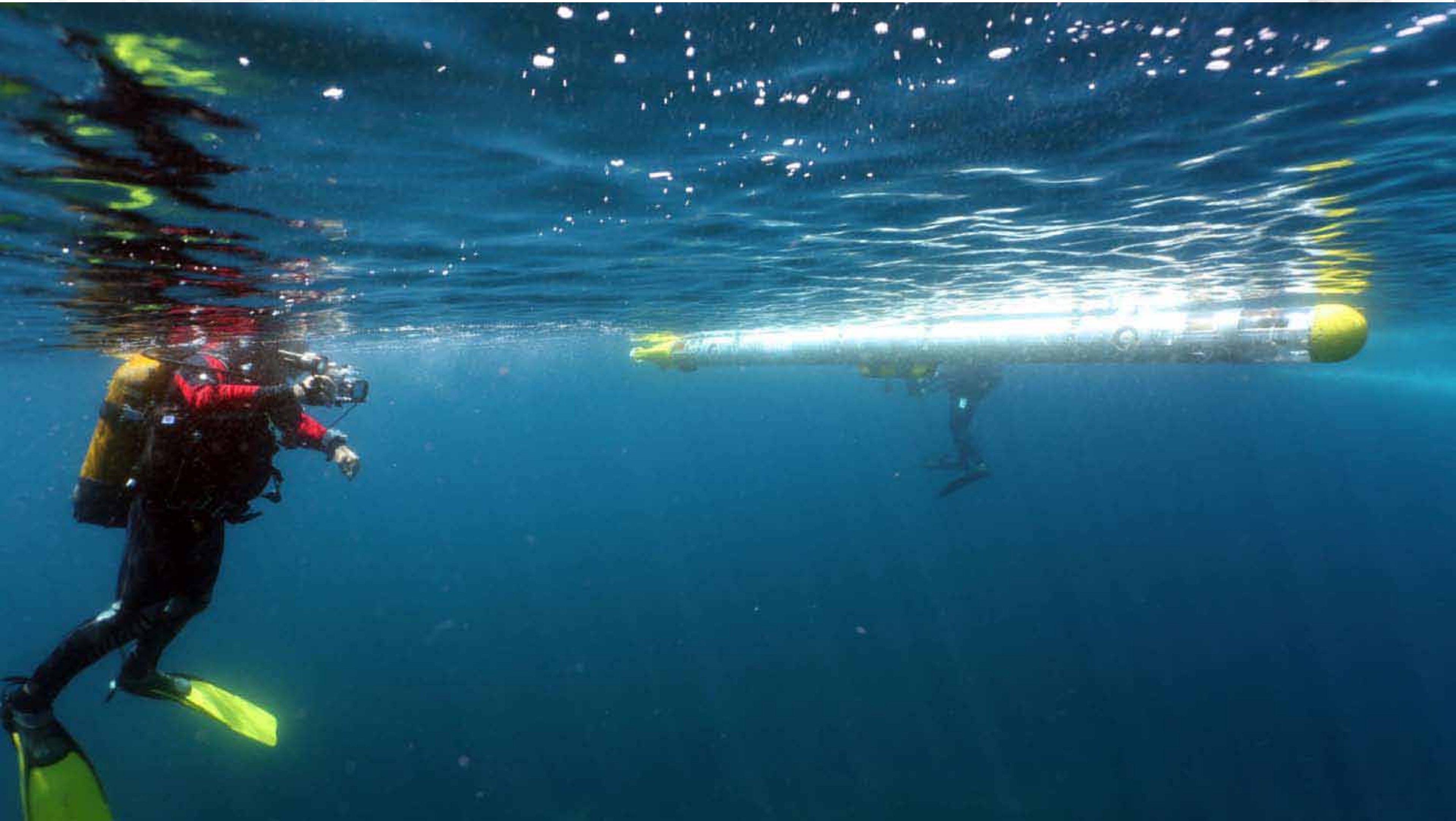

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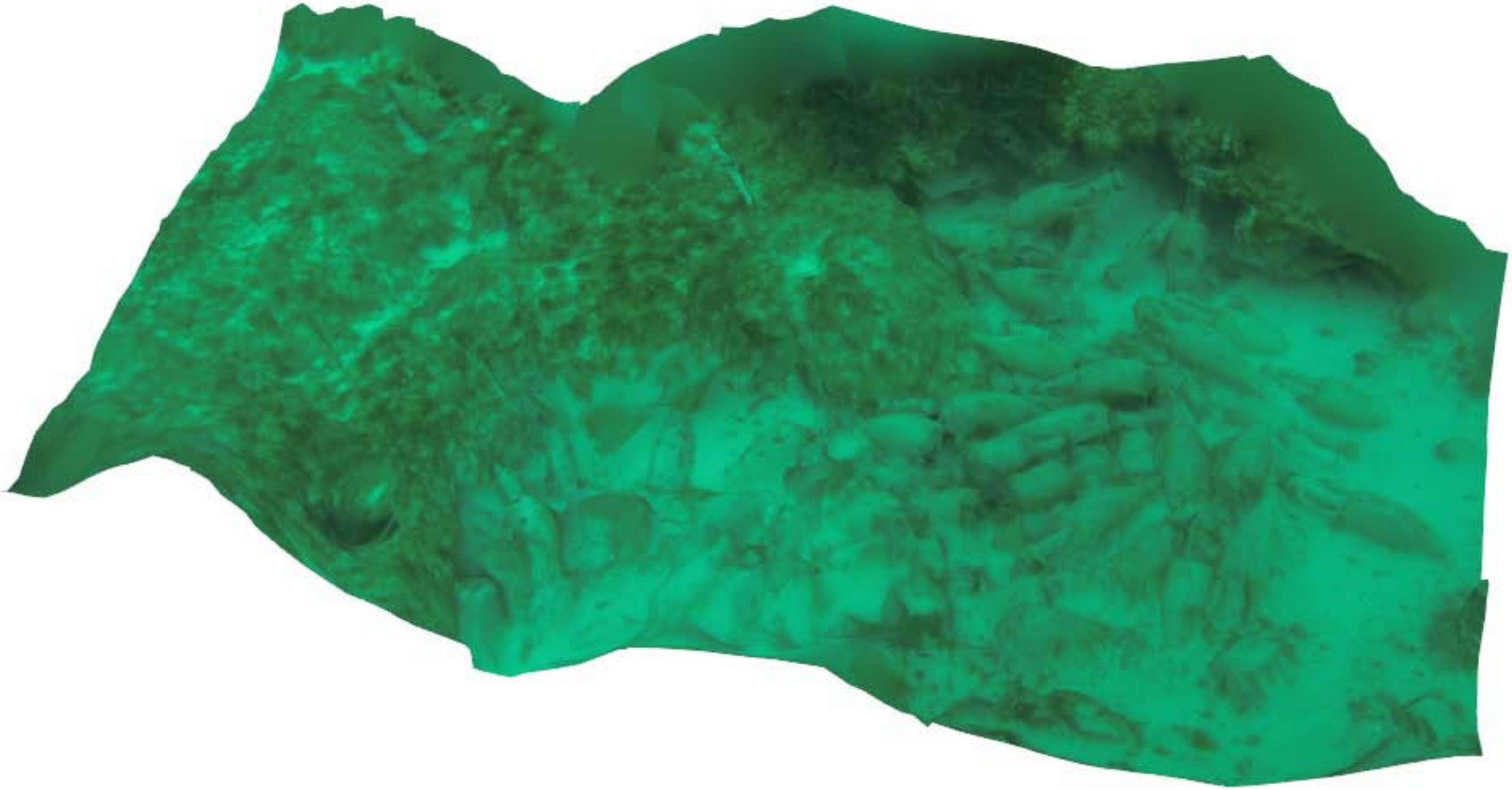

d.scaradozzi@univpm.it - 150530_Italy_Trapani_TestMarta

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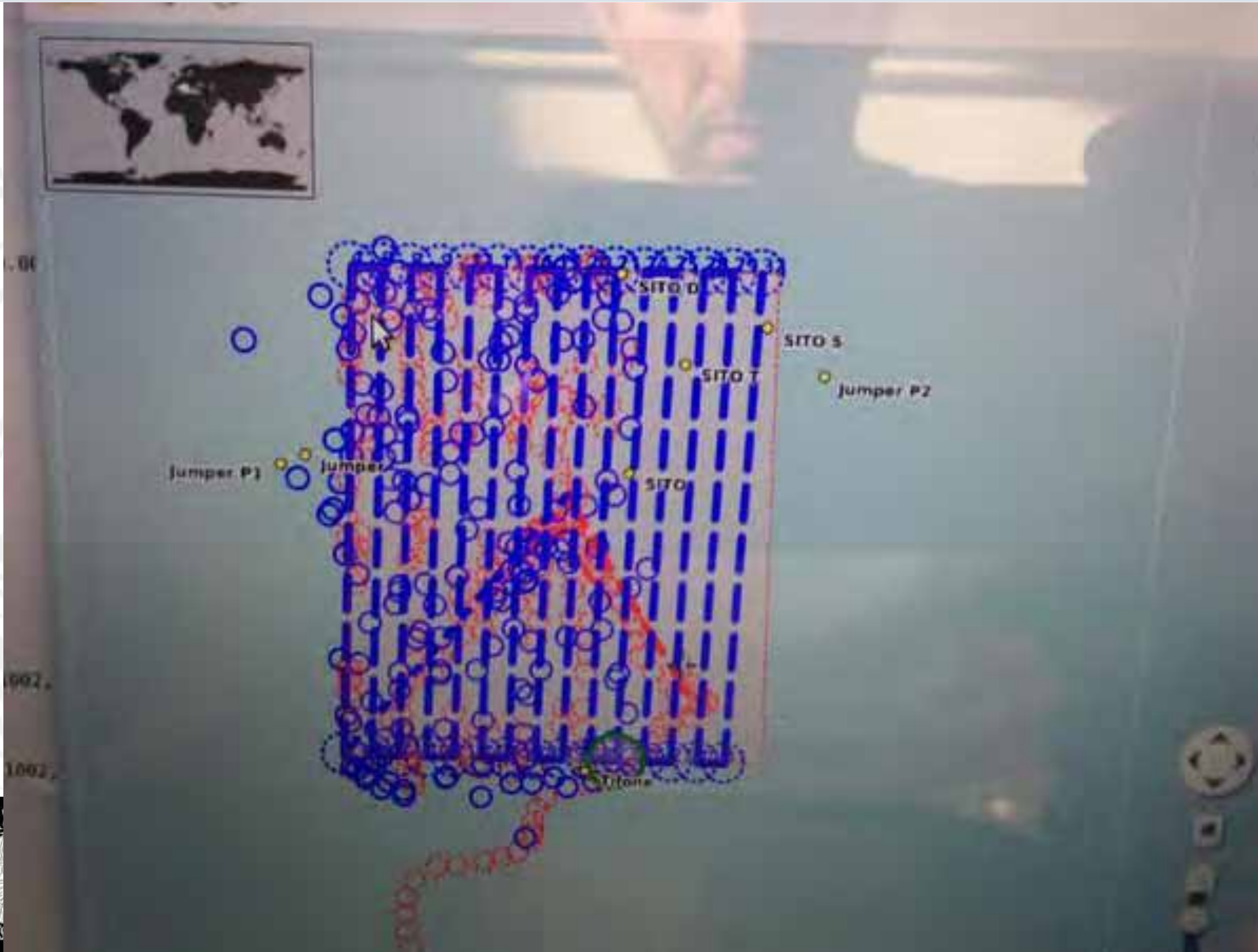
Marta
Tifone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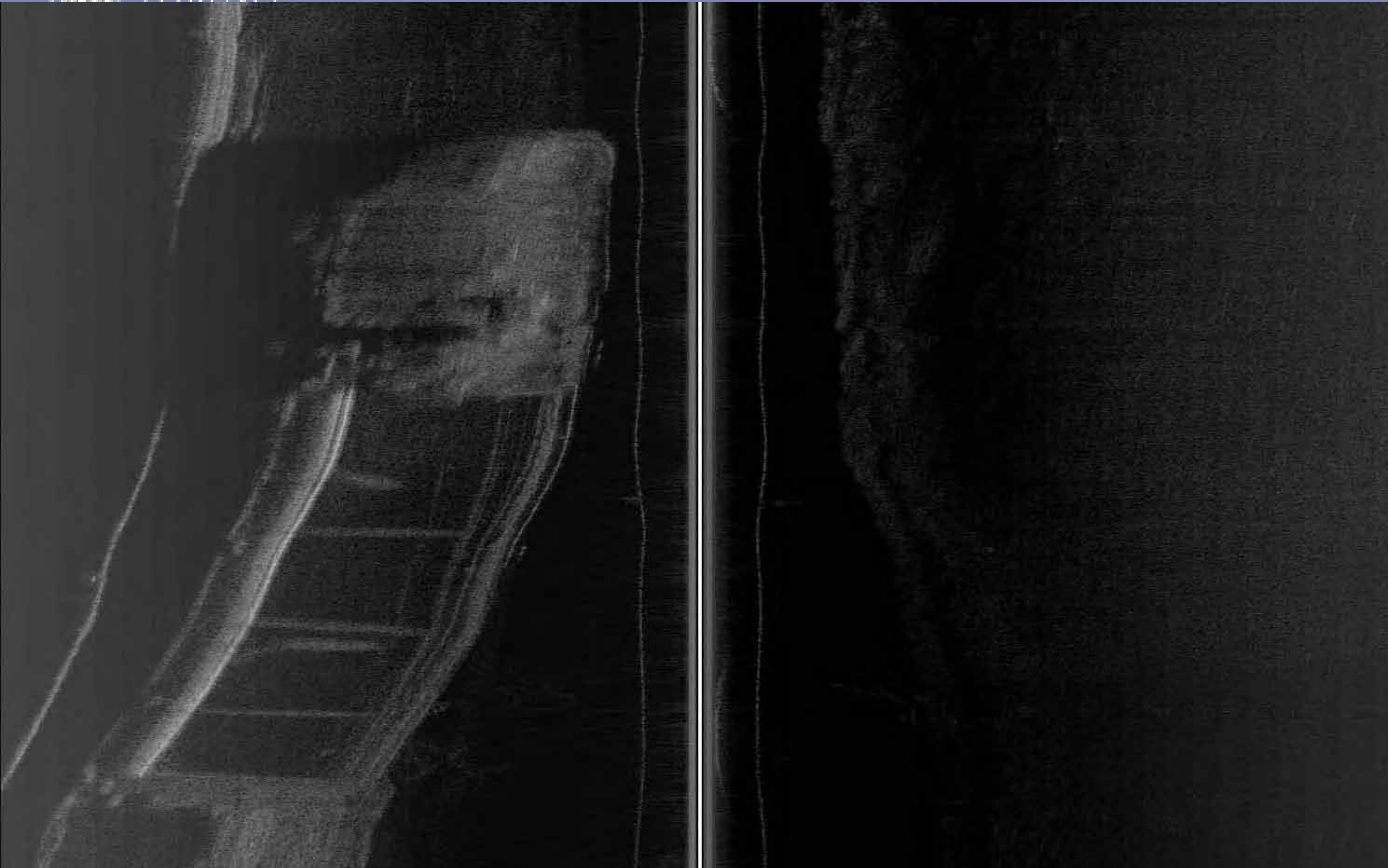
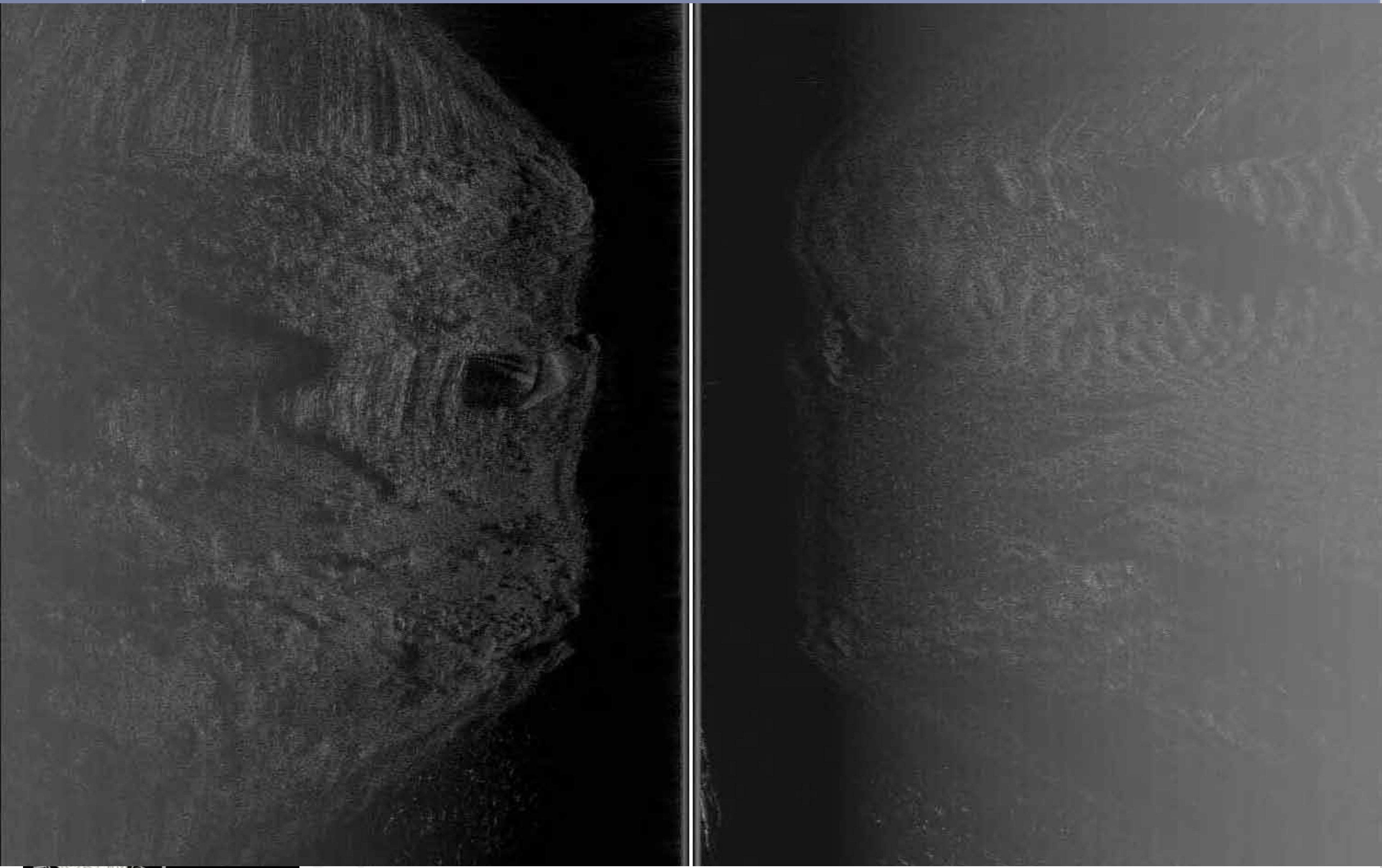
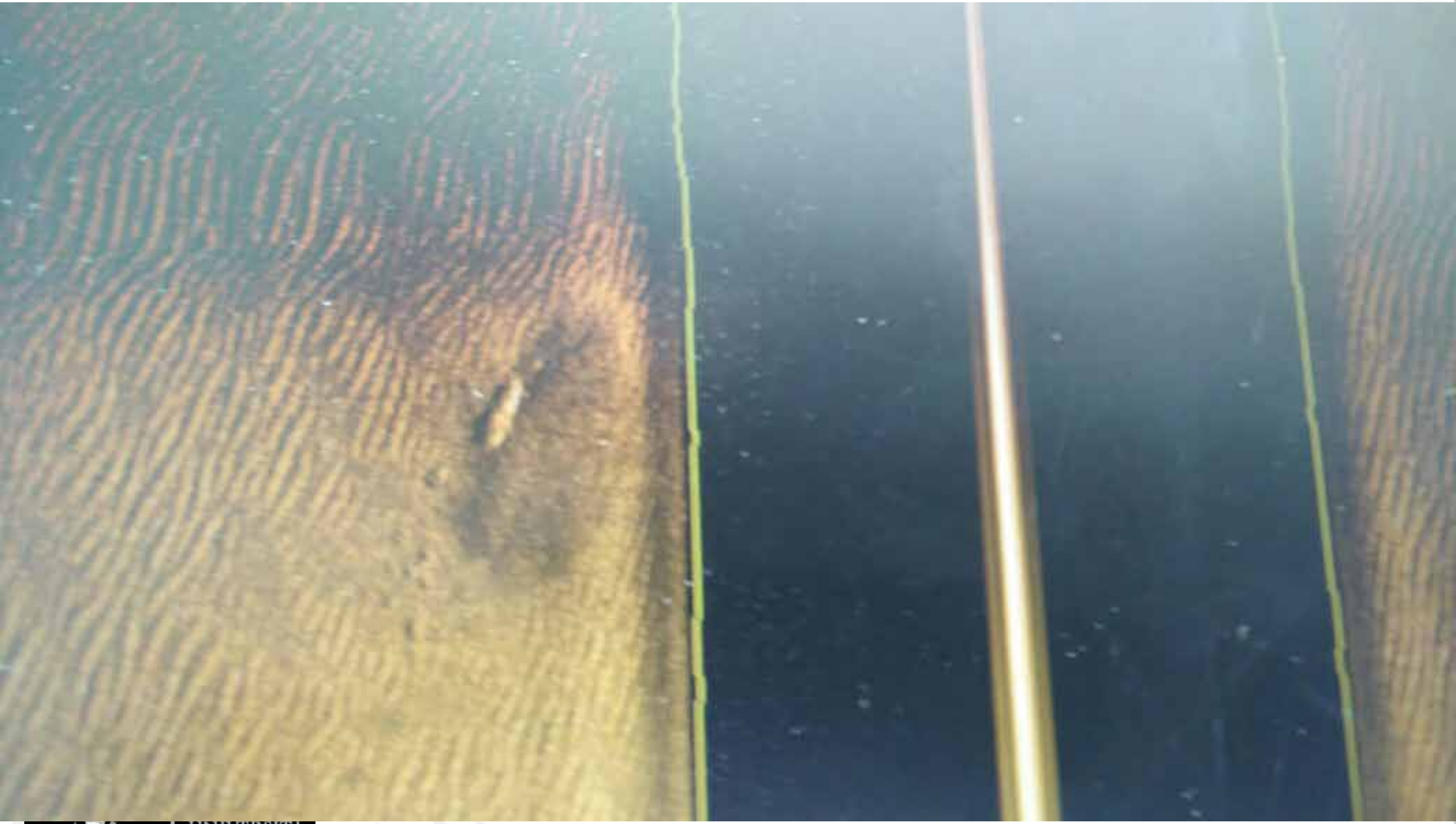
SITO 5
SITO T
Jumper P2
Jumper P1
Jumper
SITO







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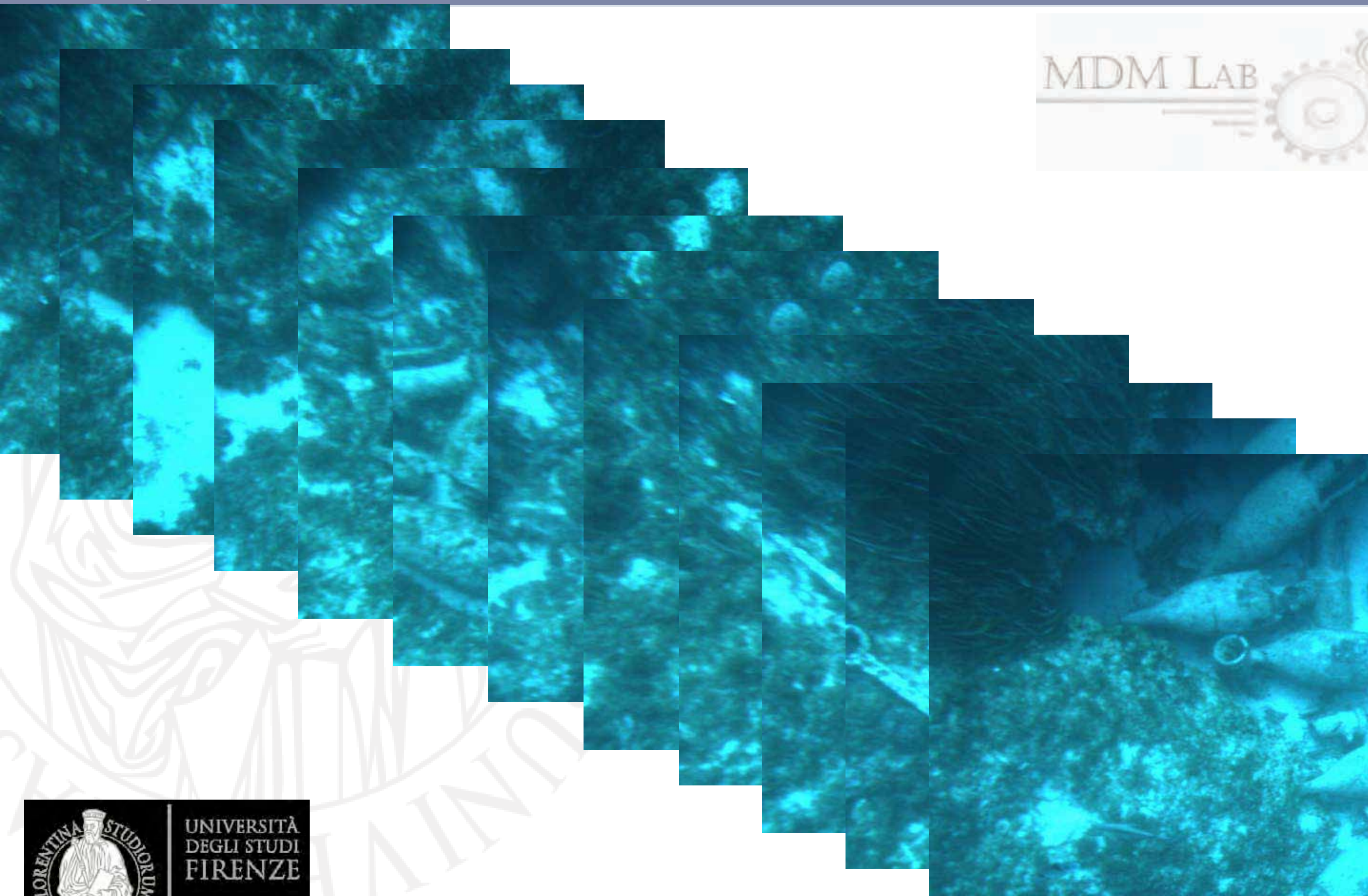

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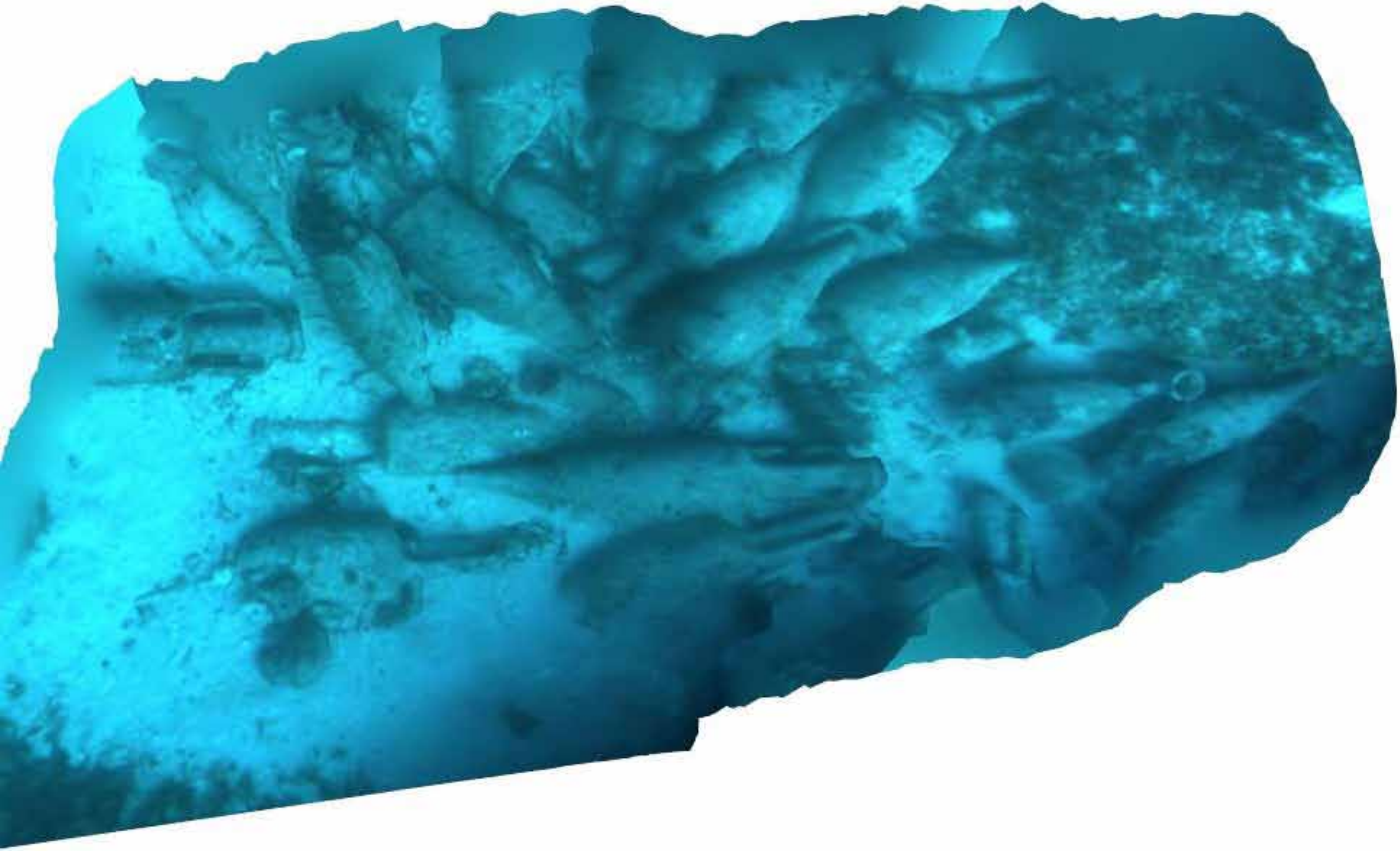
DI INGEGNERIA
INDUSTRIALE

by



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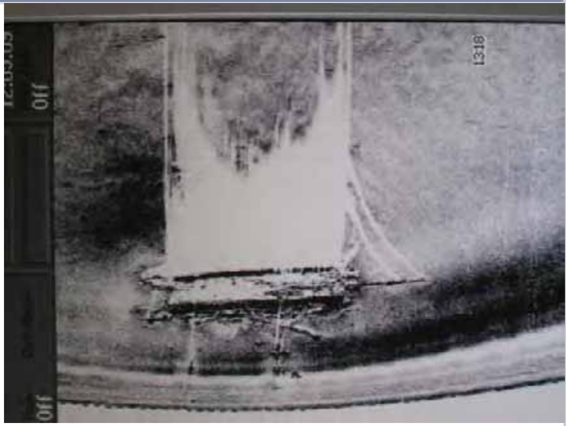
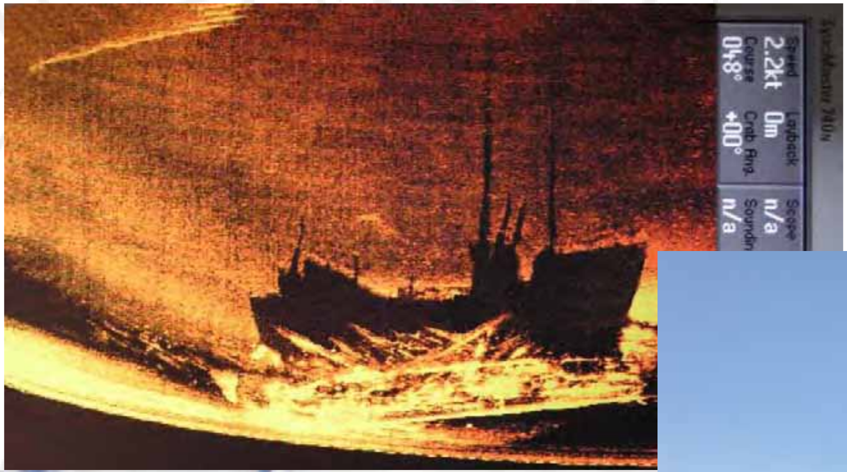
ARROWS
ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

Demonstration 2: July 17-23, 2015





Baltic Sea

bc

Publications (so far…)

1. B. Allotta et al., “THE ARROWS PROJECT FOR UNDERWATER ARCHAEOLOGY,” finalist at the Italian Heritage Award 2013, paper published in “Strategie e Programmazione della Conservazione e Trasmissibilità del Patrimonio Culturale,” Aleksandra Filipović and William Troiano Eds., Edizioni Scientifiche Fidei SIgna, 2013. ISBN 978-88-909158-8-8
2. B. Allotta, L. Pugi, F. Bartolini, A. Ridolfi, R. Costanzi, N. Monni, and J. Gelli, “Preliminary design and fast prototyping of an autonomous underwater vehicle propulsion system,” Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2014.
3. T. Salumäe et Al., “Design principle of a biomimetic underwater robot: U-CAT,” OCEANS'14 MTS/IEEE St. John's Oceans: Where Challenge Becomes Opportunity, Saint John's (Canada), 14-19 September 2014.
4. B. Allotta et al., “The ARROWS project: adapting and developing robotics technologies for underwater archaeology,” in IFAC Workshop on Navigation Guidance and Control of Underwater Vehicles (NGCUV 2015), 2015.
5. B. Allotta et al., “Development of a Navigation Algorithm for Autonomous Underwater Vehicles,” in IFAC Workshop on Navigation Guidance and Control of Underwater Vehicles (NGCUV 2015), 2015.
6. F. Bellavia et al., “Piecewise Planar Underwater Mosaicing,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.
7. B. Taner et al., “An Innovative Cleaning Tool for Underwater Soft Cleaning Operations,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.
8. F. Bellavia et al., “Piecewise Planar Underwater Mosaicing,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.
9. L. Pugi et al., “Design of a Modular Propulsion System for MARTA AUV,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.
10. D. Lane et al., “Facilitating Multi-AUV Collaboration for Marine Archaeology,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.
11. A. Ridolfi et Al., “Design of Modular Autonomous Underwater Vehicle for Archaeological Investigations,” Oceans’15 MTS/IEEE Conference, May 18-21, 2015, Genova, Italy.


2015


ACKET UNDER THE SEAT
TTI DI SALVATAGGIO SOTTO IL SEDILE
LIFEJACKET
ASUS

ARROWS

ARCHAEOLOGICAL ROBOT SYSTEMS FOR THE WORLD'S SEAS

www.arrowsproject.eu

benedetto.allotta@unifi.it

Thank you for your attention!

EMRA´15

ISR-IST Lisbon Portugal

EMRA'15 workshop

AUV Technology: from concept to commercialization

Alessio Turetta
GraalTech, Genova, IT

EMRA'15 workshop

June 18-19 2015, Lisbon, Portugal

AUV Technology: from concept to (*almost*) industrialization

alessio turetta

OUTLINE

- Company Introduction
- An industrial R&D program: the Spicerack® project
  - Application domain and motivations
  - Project vision
  - Preliminary de-risking phase
  - The roadmap to a new AUV: Safran

OUTLINE

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  - Application domain and motivations

  - Peoject vision

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  - The roadmap to a new AUV: Safran

FEW DETAILS

- Established in 1998 in Genova, Italy
- Engineering R&D SME (12 persons, 3 Ph.D.)
- Design and realization of mechatronic systems
- Expertises in:
  - Mechatronic design
  - Modeling, simulation and control
  - Real-time software and embedded systems
  - System integration and testing
  - Project management
- Focus on Marine Application since 2006

WHAT WE DO

Products

- Folaga
- UMA
- X-300

WHAT WE DO: PRODUCTS

Folaga – Autonomous Underwater Vehicle

WiMUST
Widely scalable Mobile
Underwater Sonar Technology

Length	2222 mm
Diameter	155 mm
Weight in air	31 kg (68 lb)
Weight in water	Variable -0.35/+0.35 kg (-0.77/+0.77 lb)
Max speed	2 knots (4 knots optional)
Min speed	0 knots
Max depth	80 msw
Navigation sensors	GPS, depth-meter, 3D inclinometer
Additional Sensors	Humidity, temperature, battery charge
Communication	Radio link on surface
	Acoustic modem (optional)
Batteries	NiMH - 12V -45 Ah
Endurance	6 hours at max speed in AUV mode
	Days in glider mode

WHAT WE DO: PRODUCTS

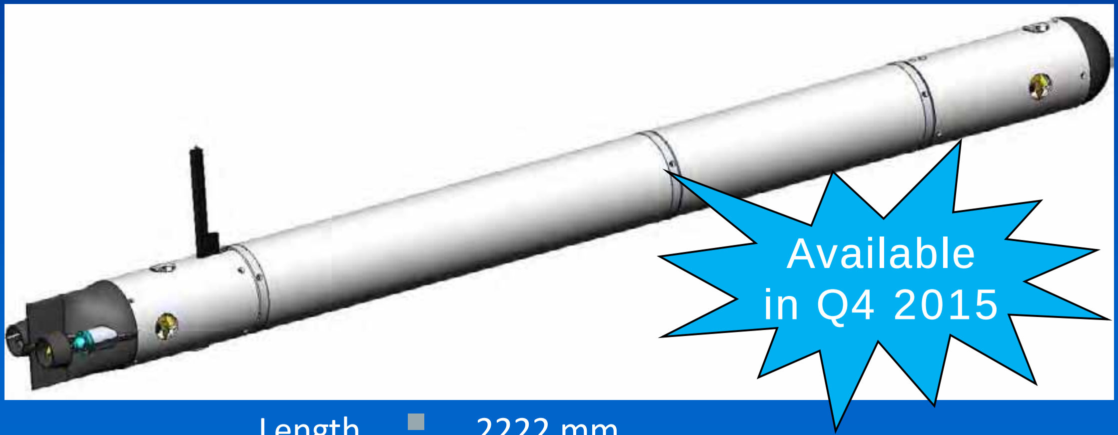
UMA - Underwater Modular Arm

Number of axis*	7
Length*	1 m
Weight in air*	28 kg (61.8 lbs)
Weight in water*	14 kg (30.9 lbs)
Max depth*	100 msw
Lifting capability*	10 kg (22 lbs) in air
Control system	Embedded servo boards with joint-level control at 200 Hz
Sensors	High-resolution joint positions
	6 axis force/torque (optional)
Batteries	camera on the wrist (optional)
Power	24 Volt
	200-500 Watt

* User selectable. Data refer to the system in the picture

NEW PRODUCT

X-300



Length	▪	2222 mm
Diameter	▪	155 mm
Weight in air	▪	29 kg (64 lb)
Weight in water	▪	Variable -0.35/+0.35 kg (-0.77/+0.77 lb)
Max speed	▪	5 knots
Min speed	▪	0 knots
Max depth	▪	300 msw
Navigation sensors	▪	GPS, depth-meter, 3D inclinometer
Additional Sensors	▪	Humidity, temperature, battery charge
Communication	▪	Radio link on surface
	▪	Acoustic modem (optional)
Batteries	▪	Li Ion 24V -1200 Wh
Endurance	▪	14 hours at max speed in AUV mode
	▪	Days in glider mode

WHAT WE DO

Products

- Folaga
- UMA
- X-300

Services

- AUV for different needs
- R&D Partnerships

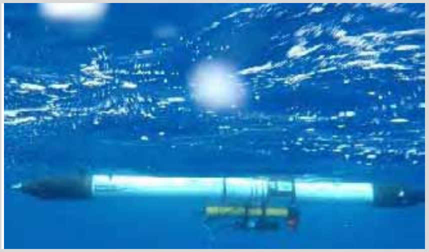
WHAT WE DO: SERVICES

AUVs for Your Needs

Graal Tech provides a customized access to the underwater world, to help clients collecting data from the marine environment, acquiring information from specific equipment, or performing ad-hoc missions.

Environmental Data Delivery

Underwater Equipment Assessment



AUVs for Customized Missions

AUVS FOR YOUR NEEDS

AUVs for Customized Missions

Provided Services

- Support in mission definition
- Support in payload definition
- Payload realization
- Support in mission execution
- Data extraction
- Data delivery

Target Clients

- Control researchers
- Project consortia for a demo
- Research teams for de-risking tests

WHAT WE DO: SERVICES

R&D Partnerships

Graal Tech helps organizations that care about innovation to reduce time and costs, while managing technical risks, in conceiving and realizing new mechatronic solutions, by combining its capabilities with the client assets and needs.

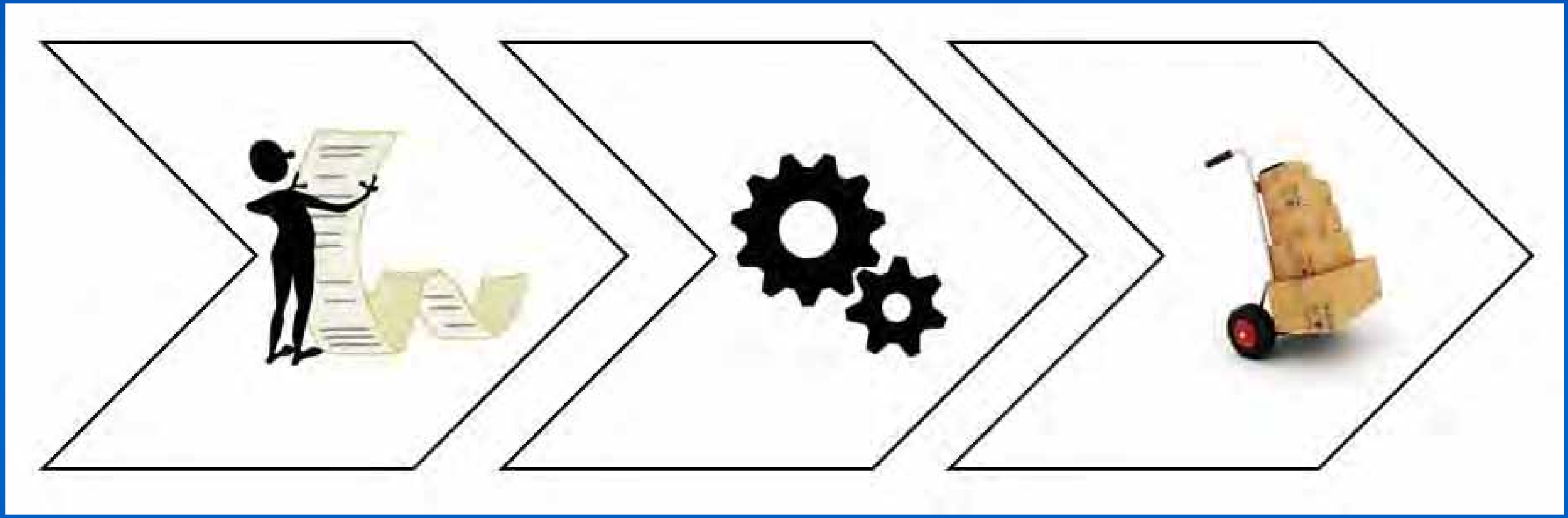
Prototype Realization

Beyond Prototyping

Public Funded Research Projects

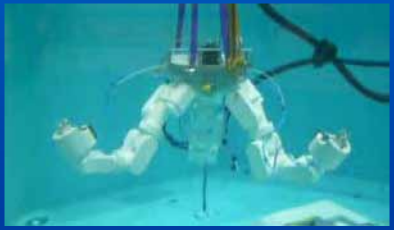
R&D PARTNERSHIPS

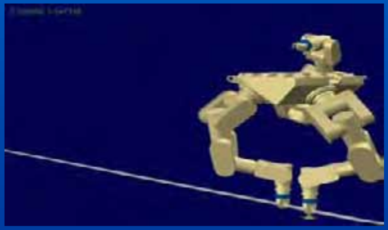
Prototype Realization



Example: EWM

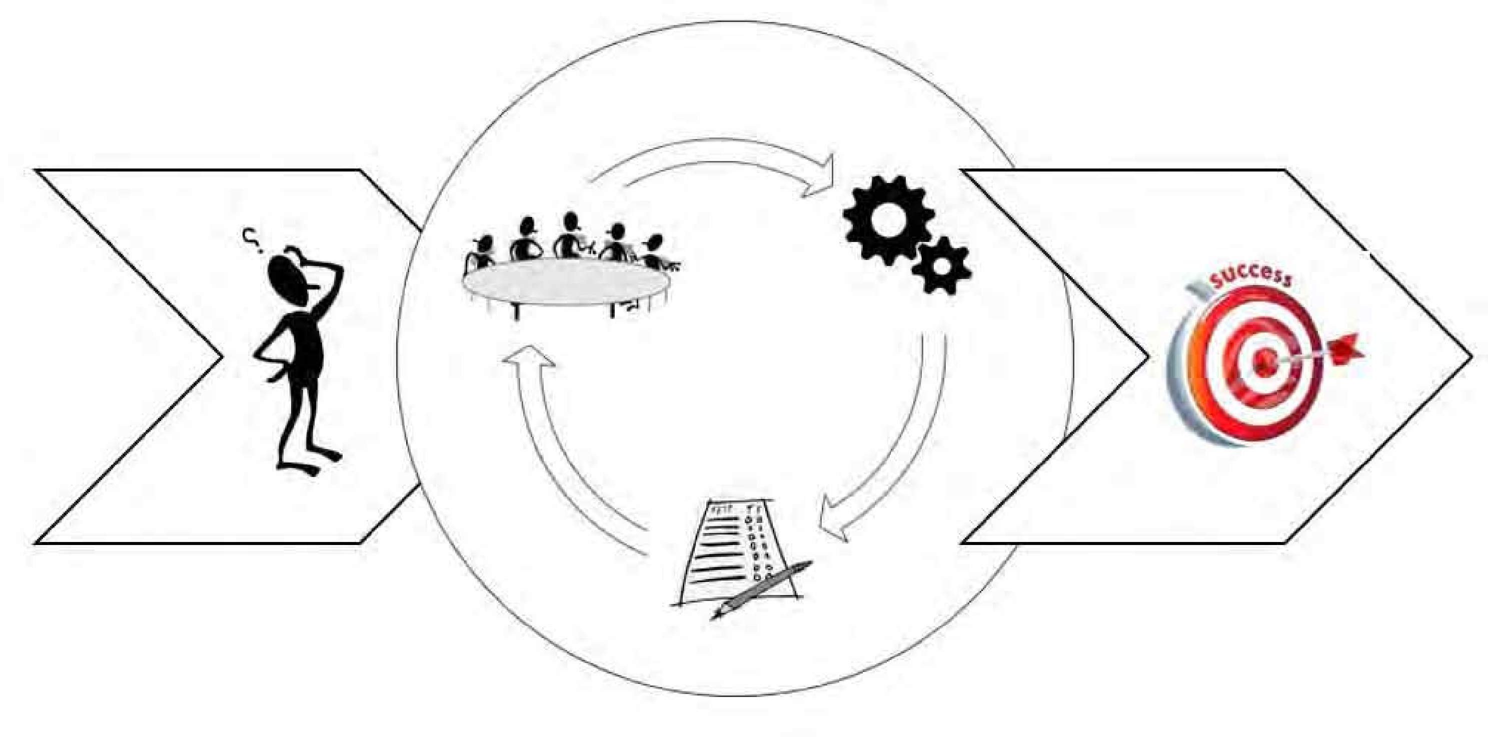
- Mechatronic design and development
- Control system design and simulation
- Software implementation
- System integration
- Validation tests





R&D PARTNERSHIPS

Beyond Prototyping



Example: Spicerack®

OUTLINE

- Company Introduction
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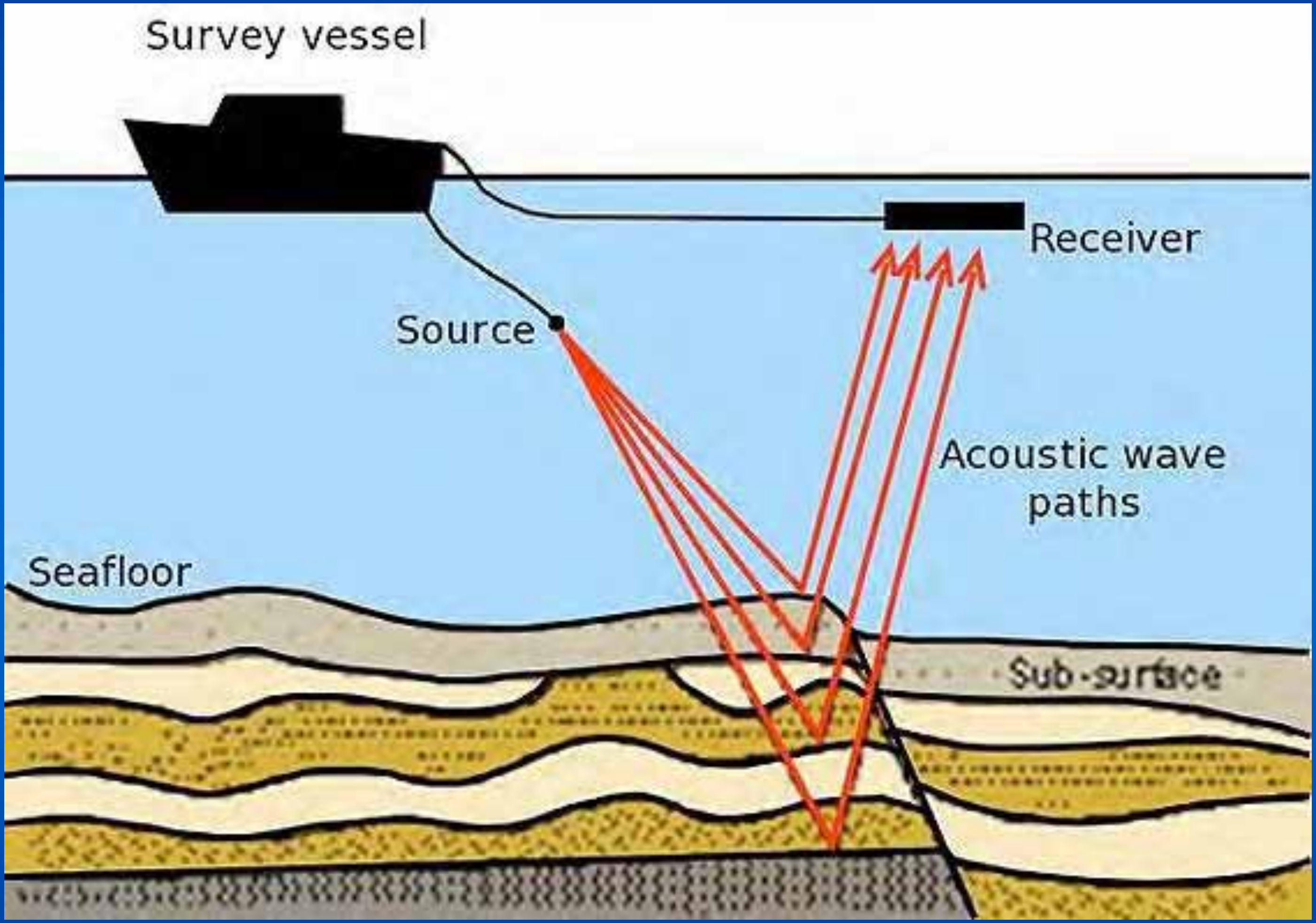
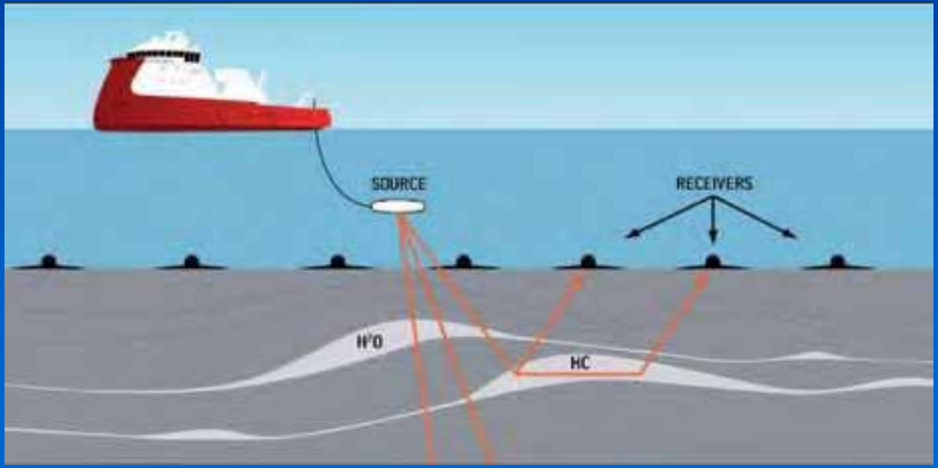
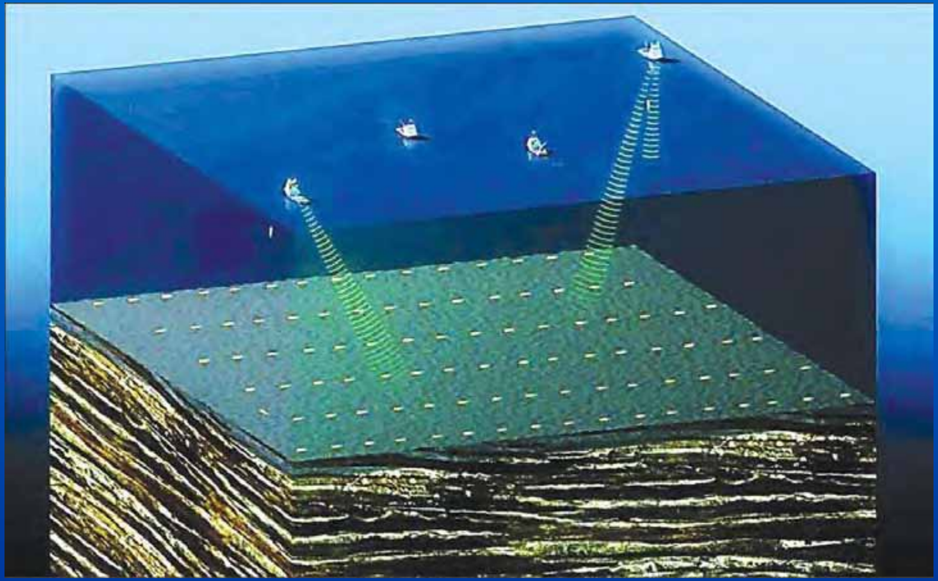
  - The roadmap to a new AUV: Safran

ANOTHER SEISMIC SURVEY…

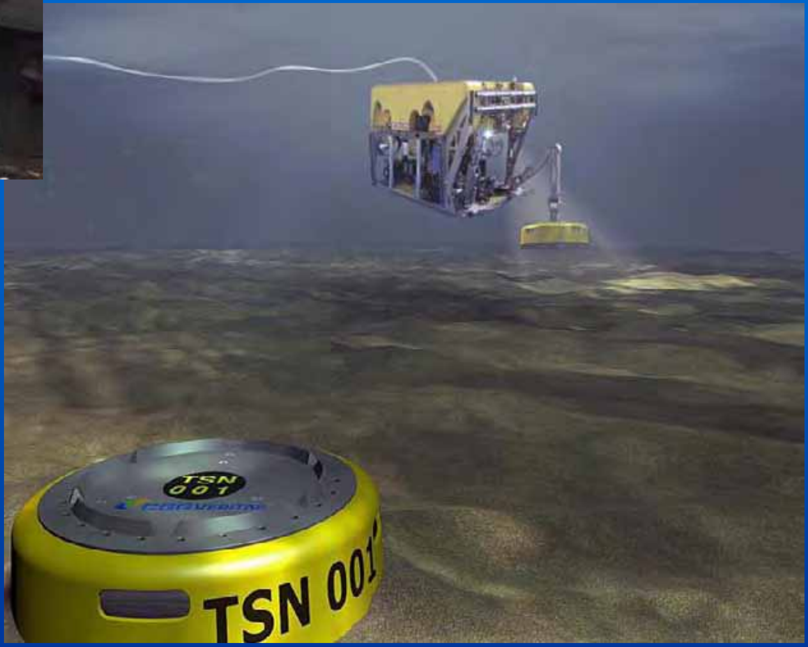


… BUT DIFFERENT THAN WiMUST





COSTLY DEPLOYMENT AND RECOVERY



OUTLINE

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SPICERACK® VISION

MAIN CHALLENGES

Target reaching	Ensure that every AUV will reach its target position and will land on it with the given precision (5 meters)
Sea bottom holding	Ensure that every AUV will keep for days its location on the seabed and will be able to take off when needed
Seismic coupling	Ensure that registered seismic data will have a quality at least equal to that of other ocean bottom nodes

OUTLINE

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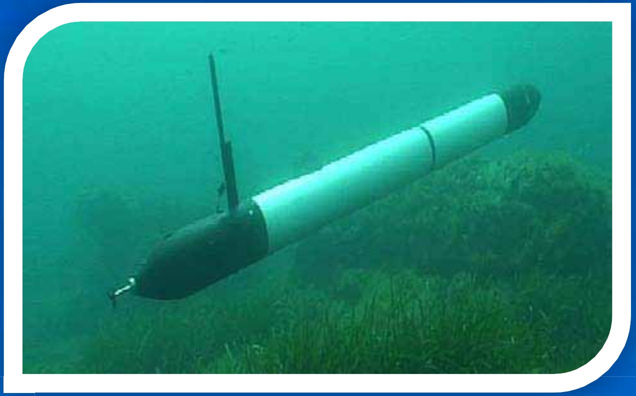
RISK ASSESSMENT PHASE: CINNAMON

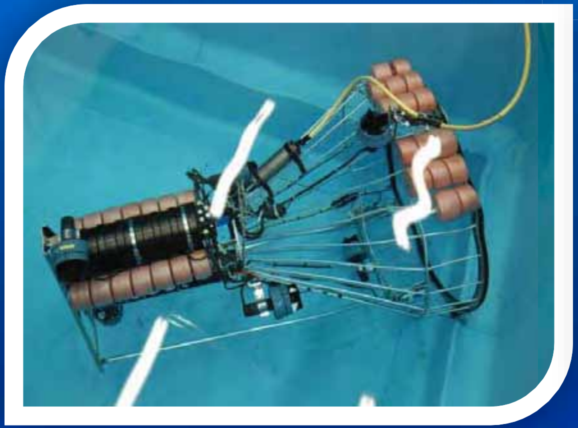


Goal of the project

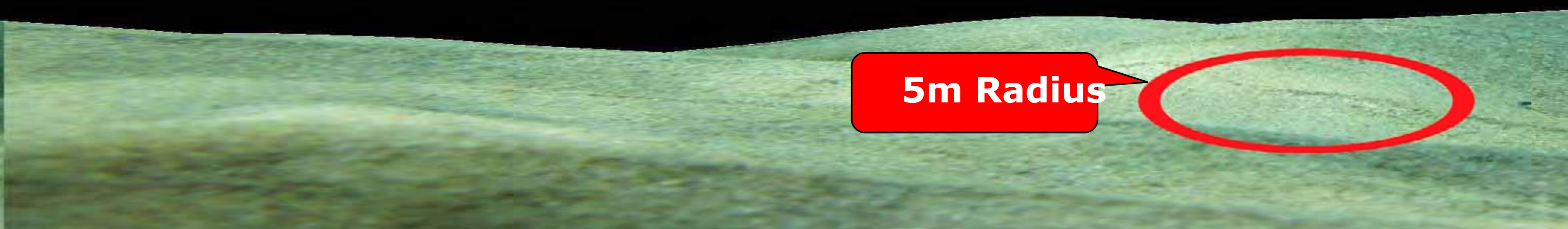
- To show the feasibility of the Spicerack concept

Actors:

- CGG Veritas
- CMRE
- Graal Tech



PROJECT GOAL



CUSTOMIZATION OF FOLAGA

- HiPAP transponder added
- Whoi Micromodem transducer in the nose
- Mission software developed

SEA TRIALS

TEST RESULTS: LANDING

TEST RESULTS: ENTERING IN THE BASKET

CELEBRATION !!! (March 2012)

OUTLINE

- Company Introduction
- An industrial R&D program: the Spicerack® project
  - Application domain
  - Motivations
  - Preliminary de-risking phase
  - The roadmap to the development of a new AUV

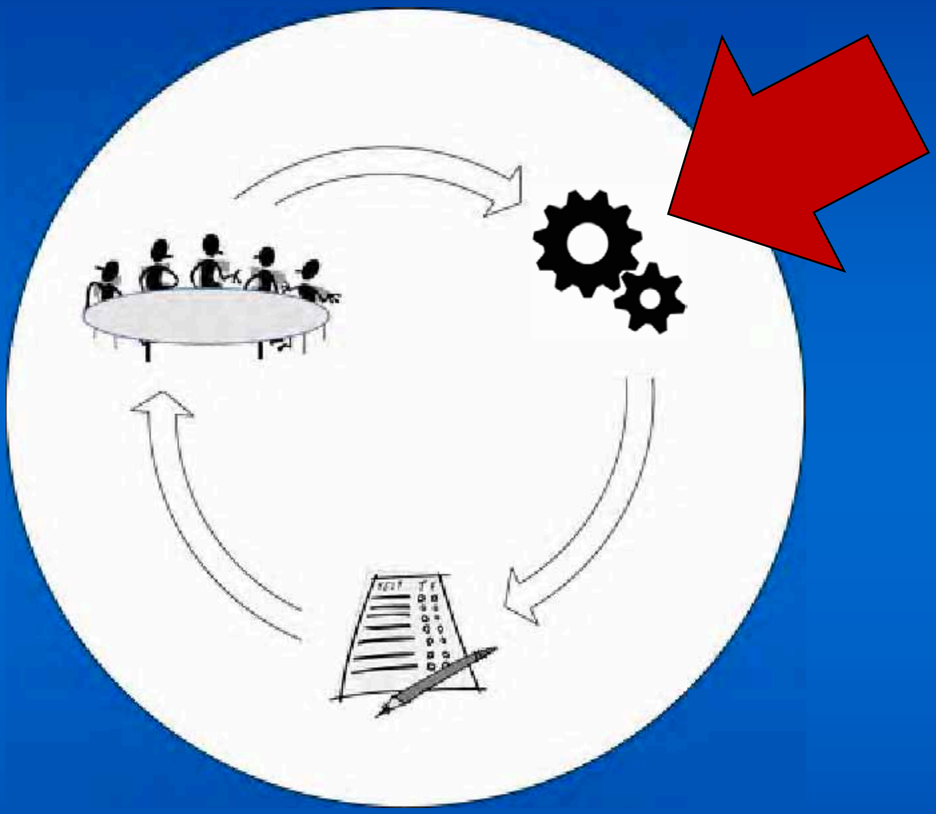
START OF ROAD TO SAFRAN (May 2012)

Goal

- PHASE 1 with 20 vehicles to be ready in 2014

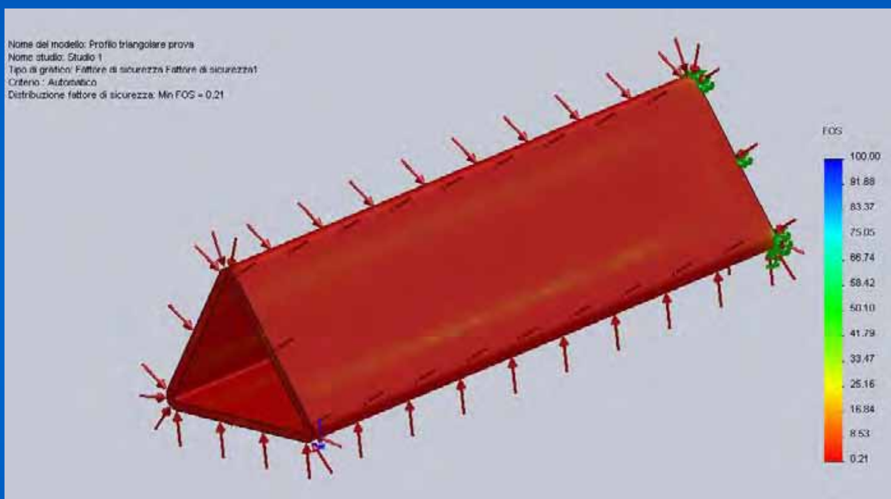
  (while keeping in mind PHASE 2 and 3…)

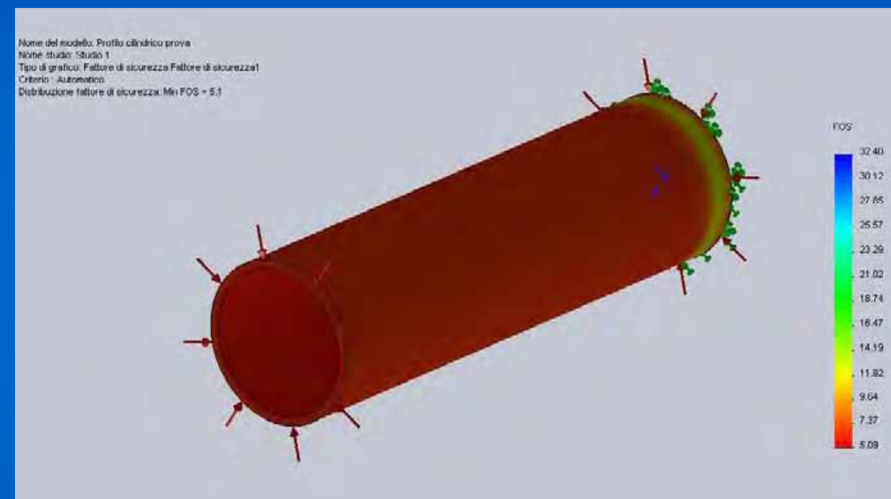
ENGINEERING PHASE



1st CHALLENGE – The Shape

An AUV or an underwater TOBLERONE?

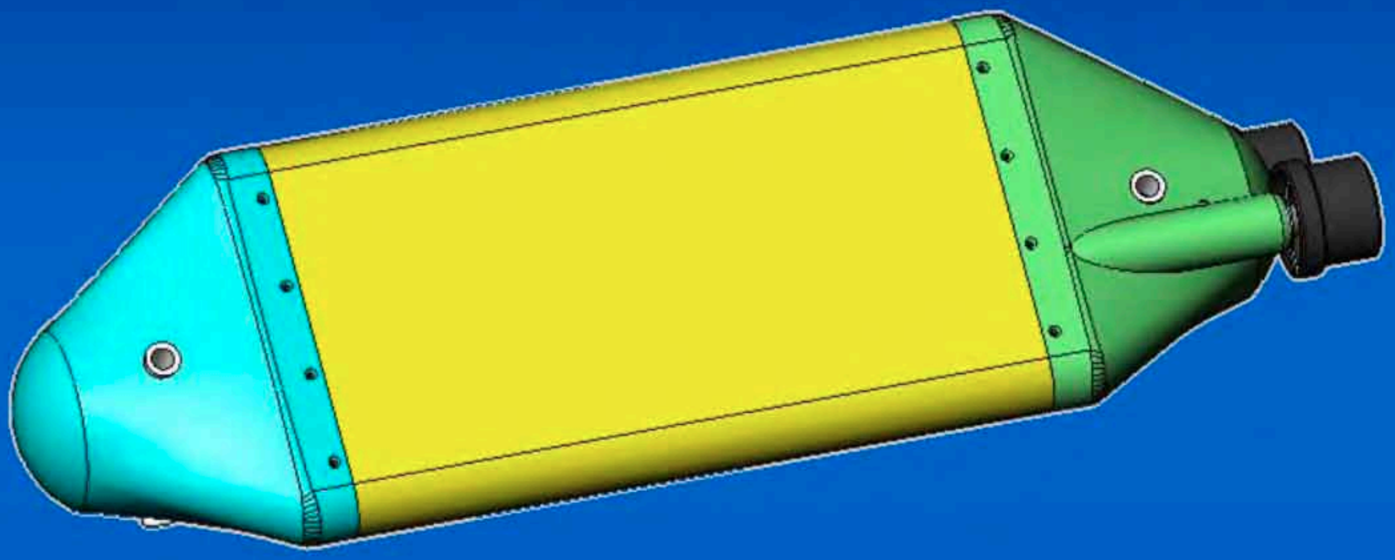




Under the same stress conditions the cylindrical shape is 20 time better than the triangular shape

TWO ALTERNATIVE CONCEPTS EXPLORED

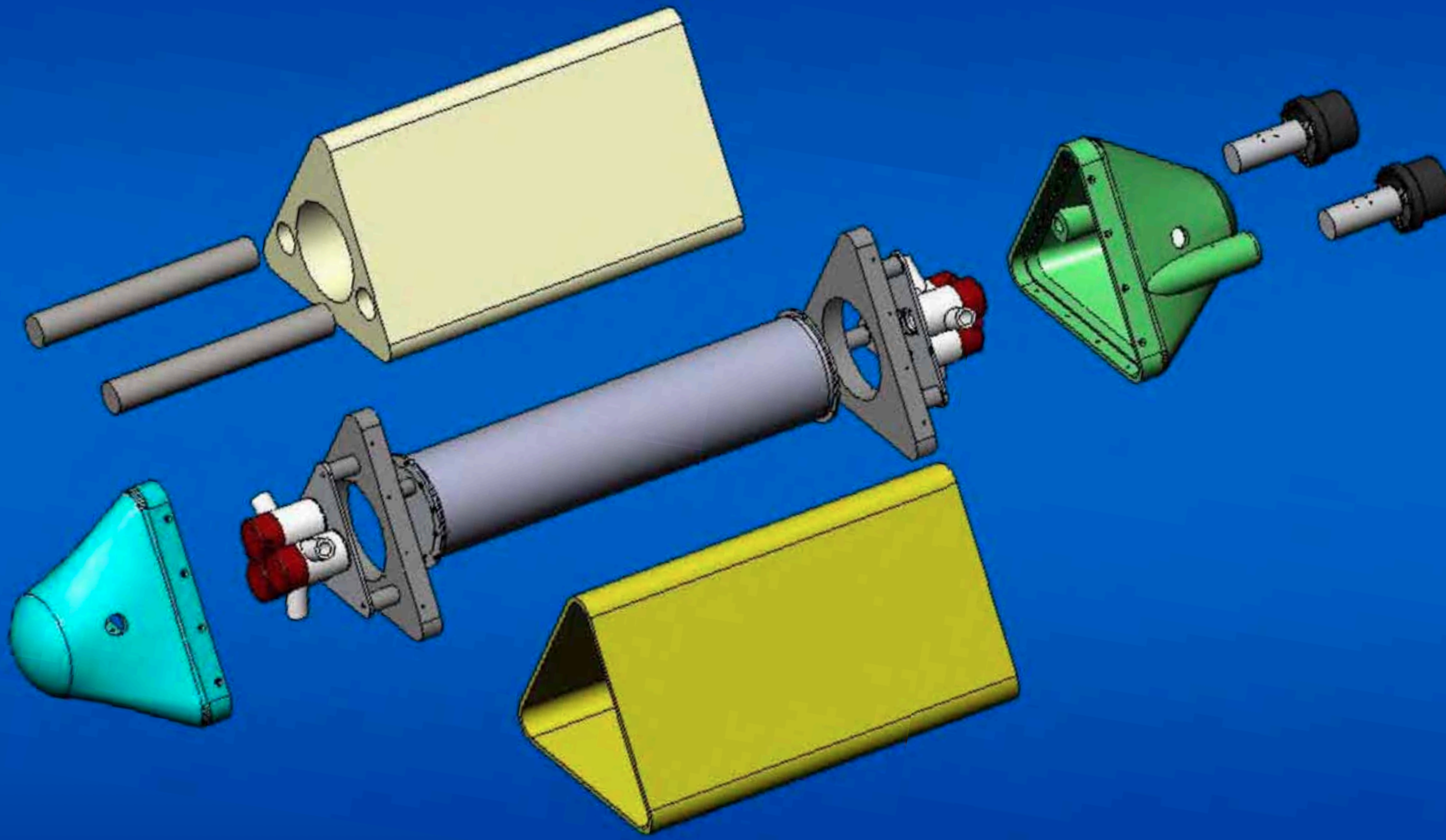
THE 1st CONCEPT: ALPHA



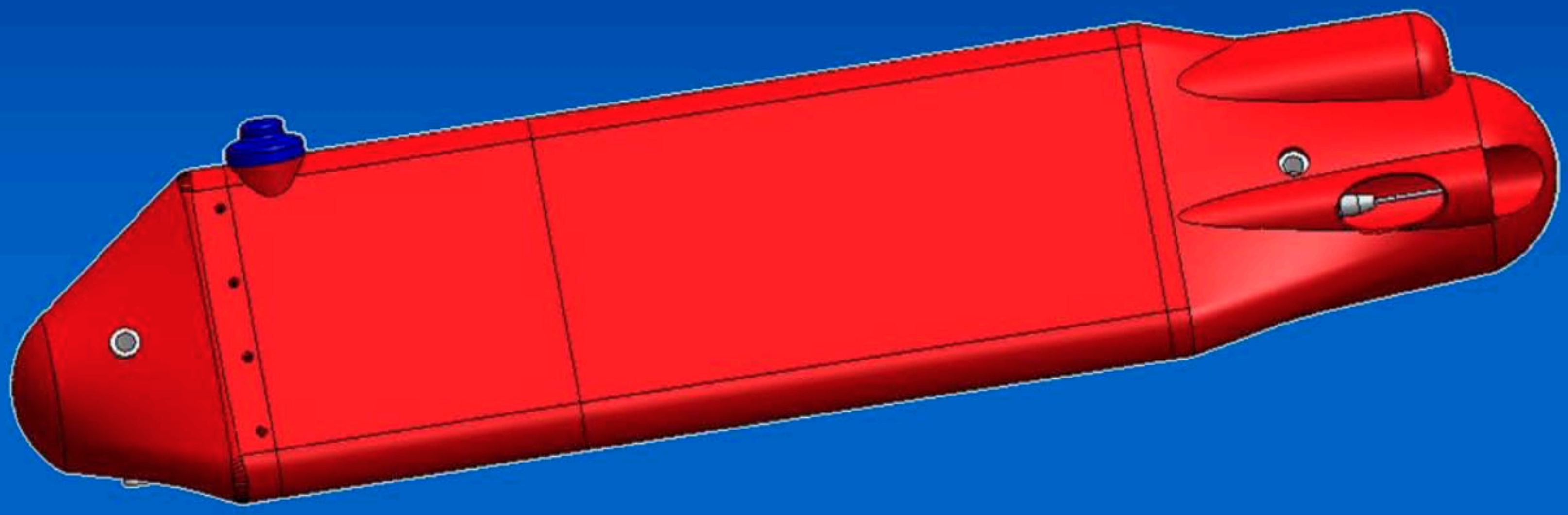
Main features

- Dry cylinder in a wet triangular central body
- Nose and tail wet sections

ALPHA – Internal structure



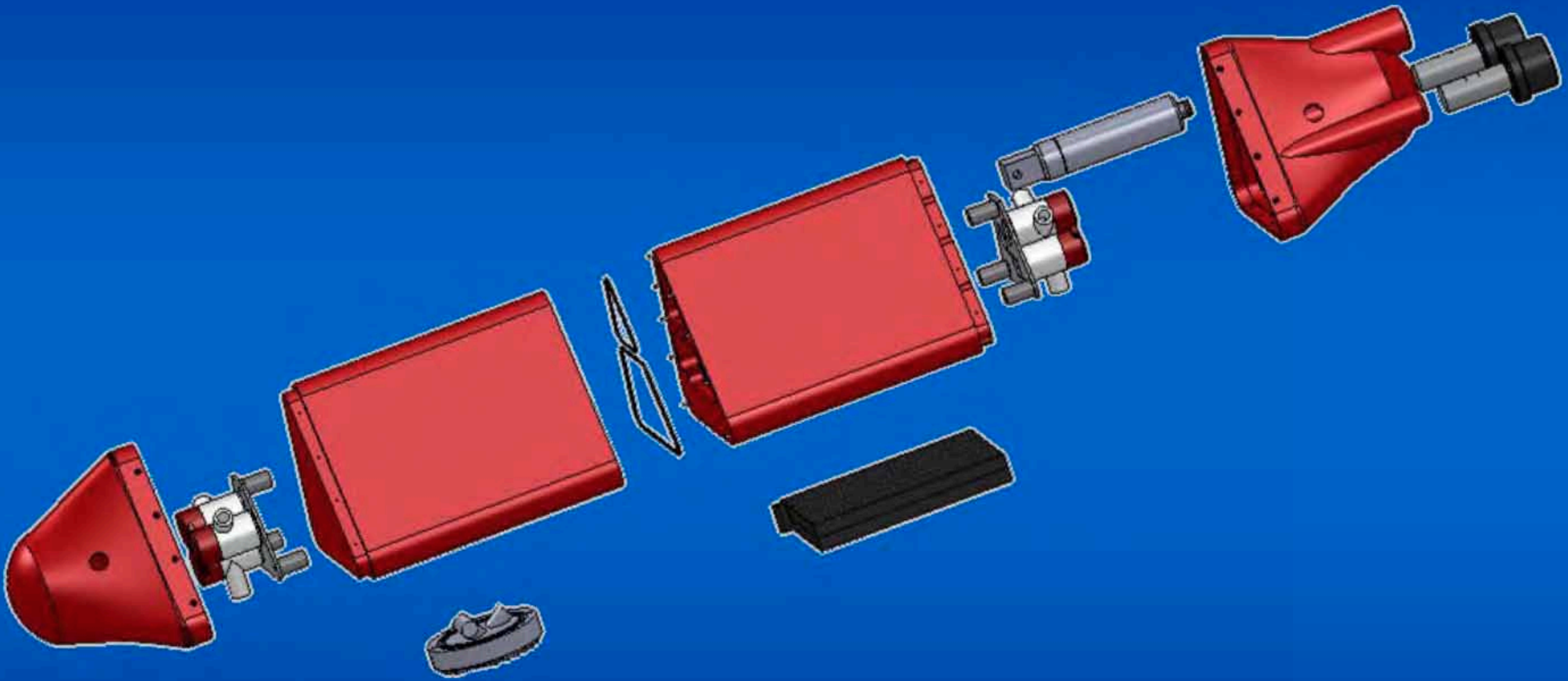
THE 2nd CONCEPT: BRAVO



Main features

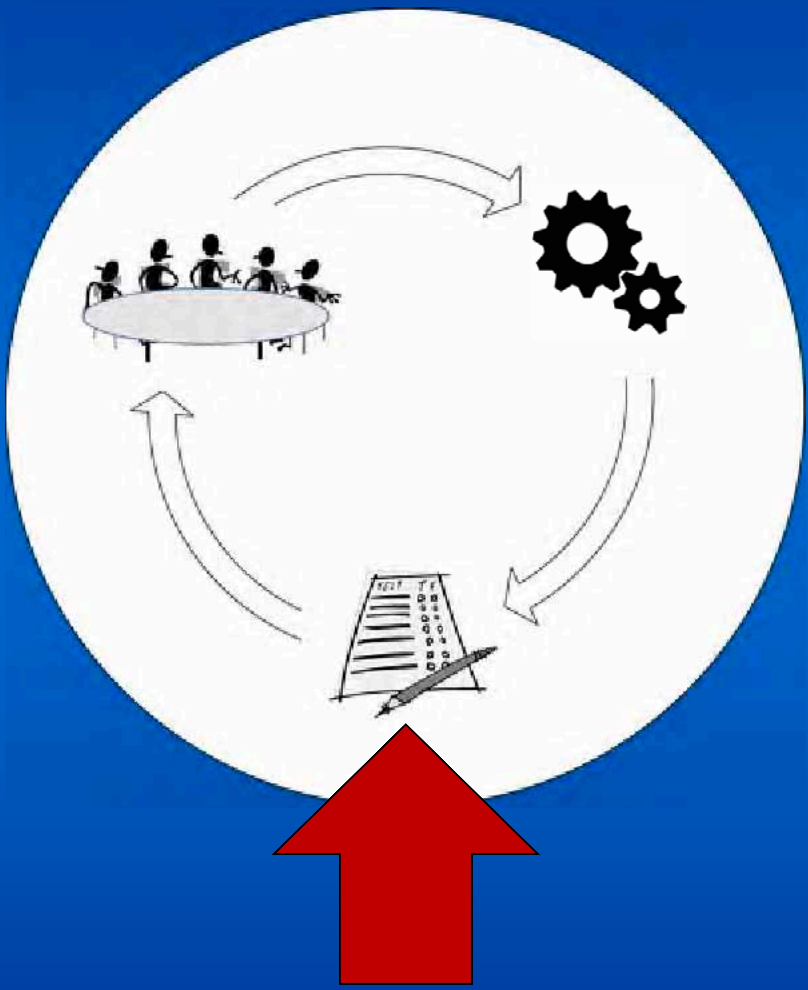
- Dry triangular central body
- Nose and tail wet sections

BRAVO – Internal structure



1st Realization: ALPHA Ver.1 (July 2012)

TESTING PHASE



ALPHA Ver.1 – Motion Tests @ pool (La Spezia)

Freestyle

Lateral shift

Pitch control

Turn on the spot

Verical dive

Spiral

ALPHA Ver.1 – Navigation Tests @ lake (Viareggio)

ALPHA Ver.1 – Navigation Tests @ lake (Viareggio)

- remotely operated mode through a WiFi link
- unstable hydrodynamic behaviour registered at high speed

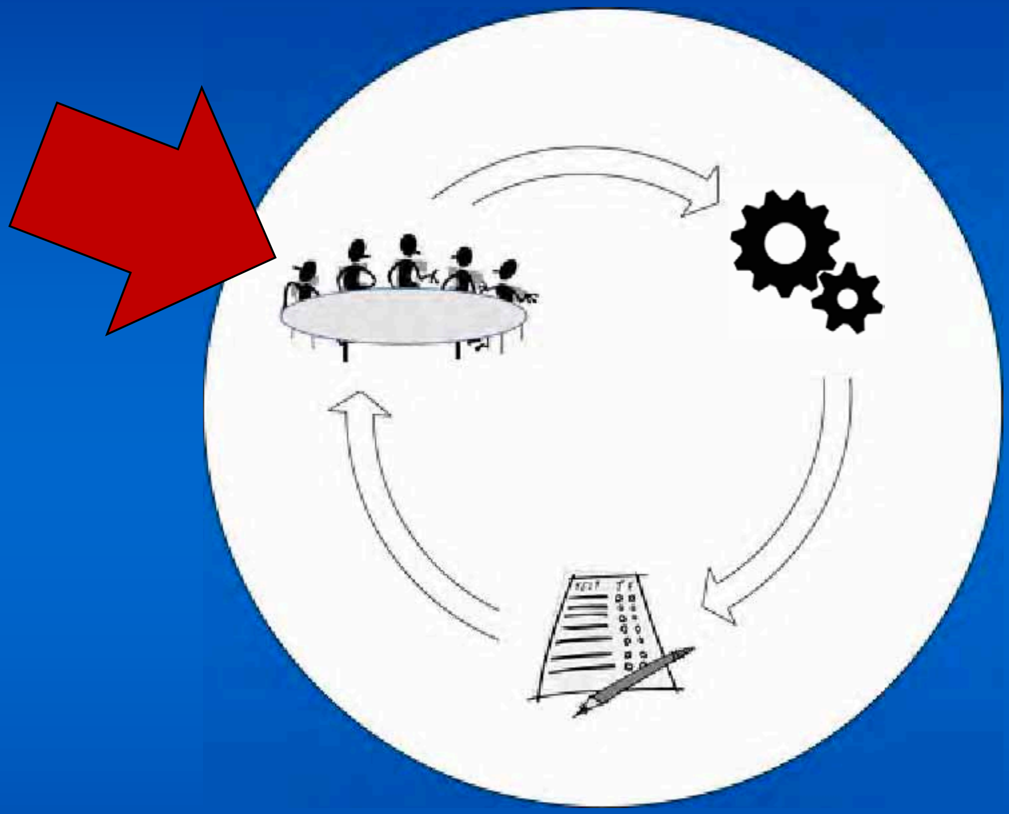
ALPHA Ver.1 – Bottom Holding Tests @ river (Ovada)

preliminary bottom holding capability test performed in river

ALPHA Ver.1 – Bottom Holding Tests @ river (Ovada)

- twisting maneuvre executed while pushing down
- some millimeters penetration into the sand achieved

TEST ANALYSIS AND NEXT STEPS PLANNING

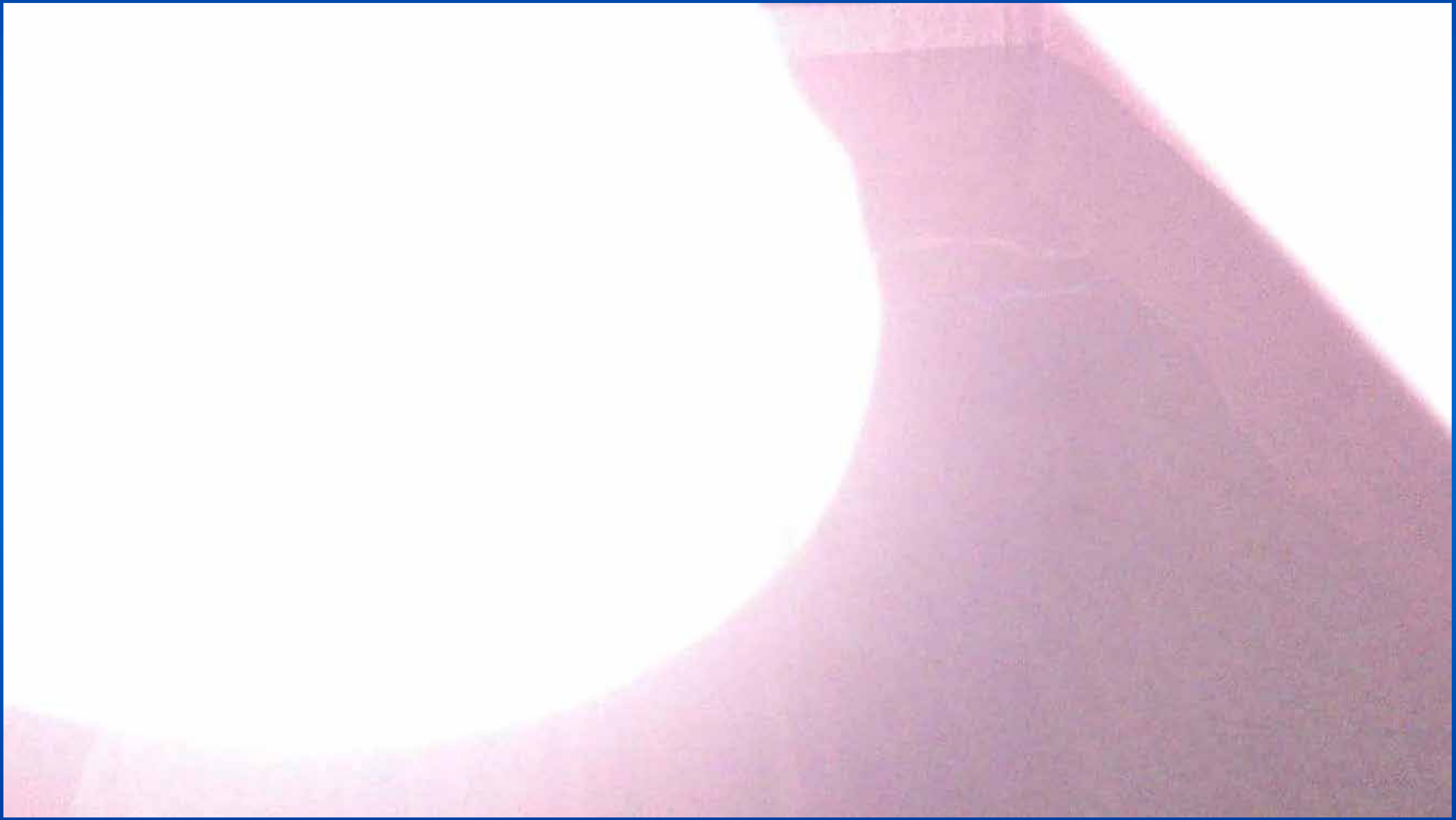


LEARNT LESSONS

Target reaching	Needs of hull with better hydrodynamic properties for a more stable and faster navigation → **ALPHA VER.2** and **.3**

ALPHA VER. 2 – New tails and noses

ALPHA VER. 2– Preliminary tests in the pool

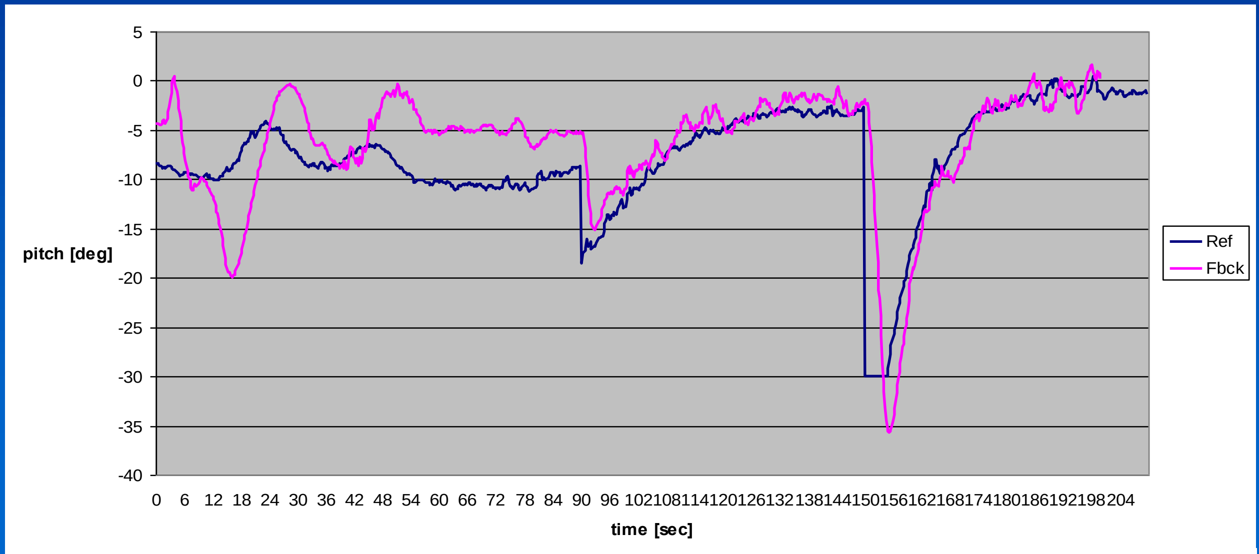


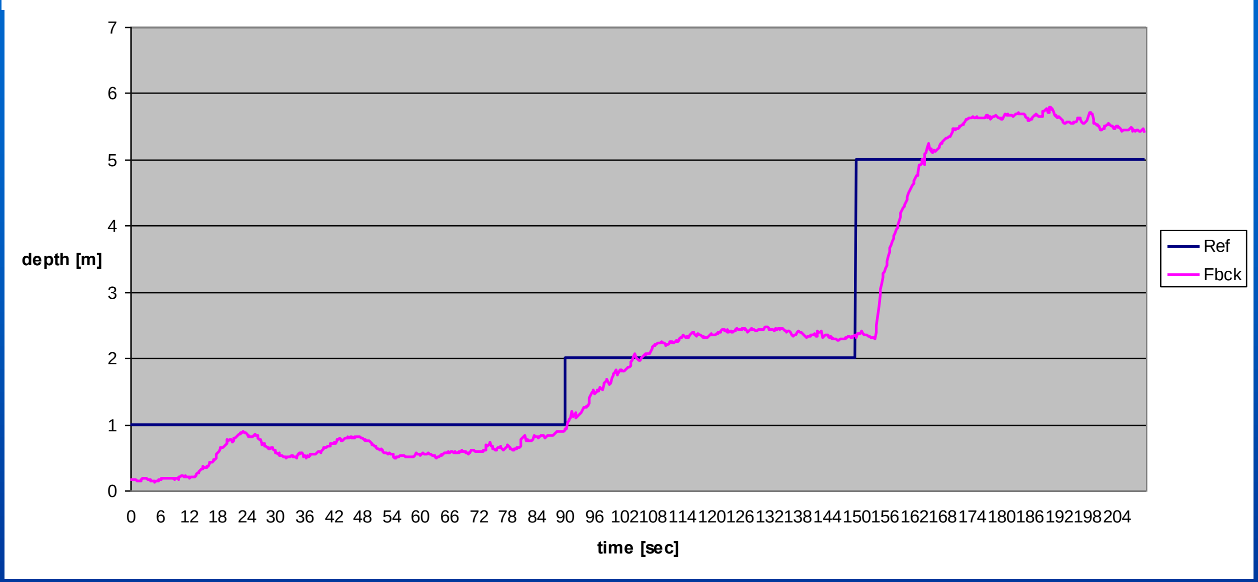
ALPHA VER. 2– Navigation tests @ lake

ALPHA VER. 2– Navigation tests @ lake

- autonomous mode
- mission commands received via WiFi

ALPHA VER. 2– Navigation tests @ lake



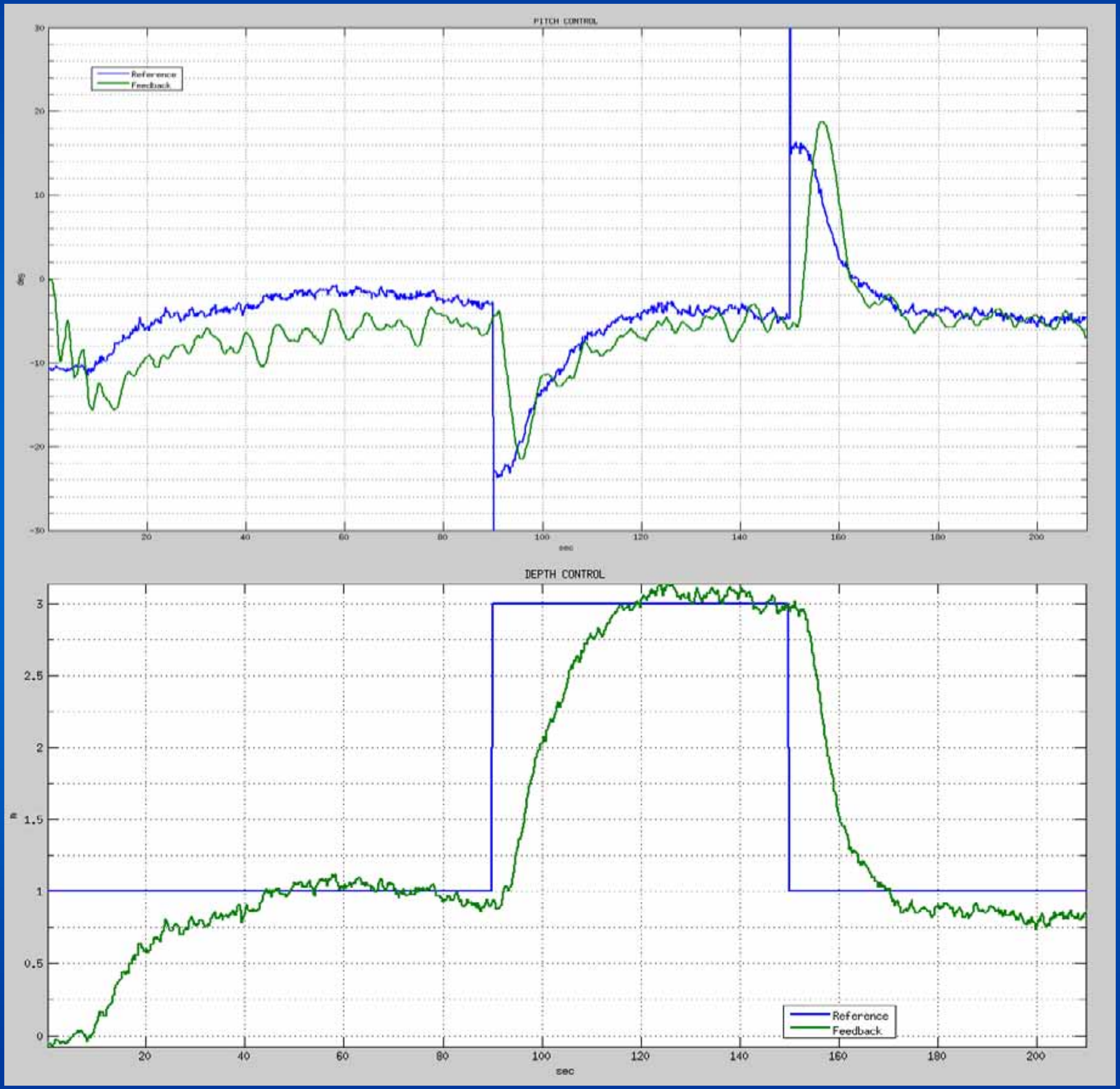


ALPHA VER. 3– New tail and 12 pumps

ALPHA VER. 3 – Navigation tests @ lake

- better behaviour obtained
- higher speeds achieved

ALPHA VER. 3 – Navigation tests @ lake



LEARNT LESSONS

Sea bottom holding	Needs of a more effective technique than a simple twisting maneuvre to obtain a better penetration inside the sea bottom → the concept of **MAGIC CARPET**

THE CONCEPT OF MAGIC CARPET

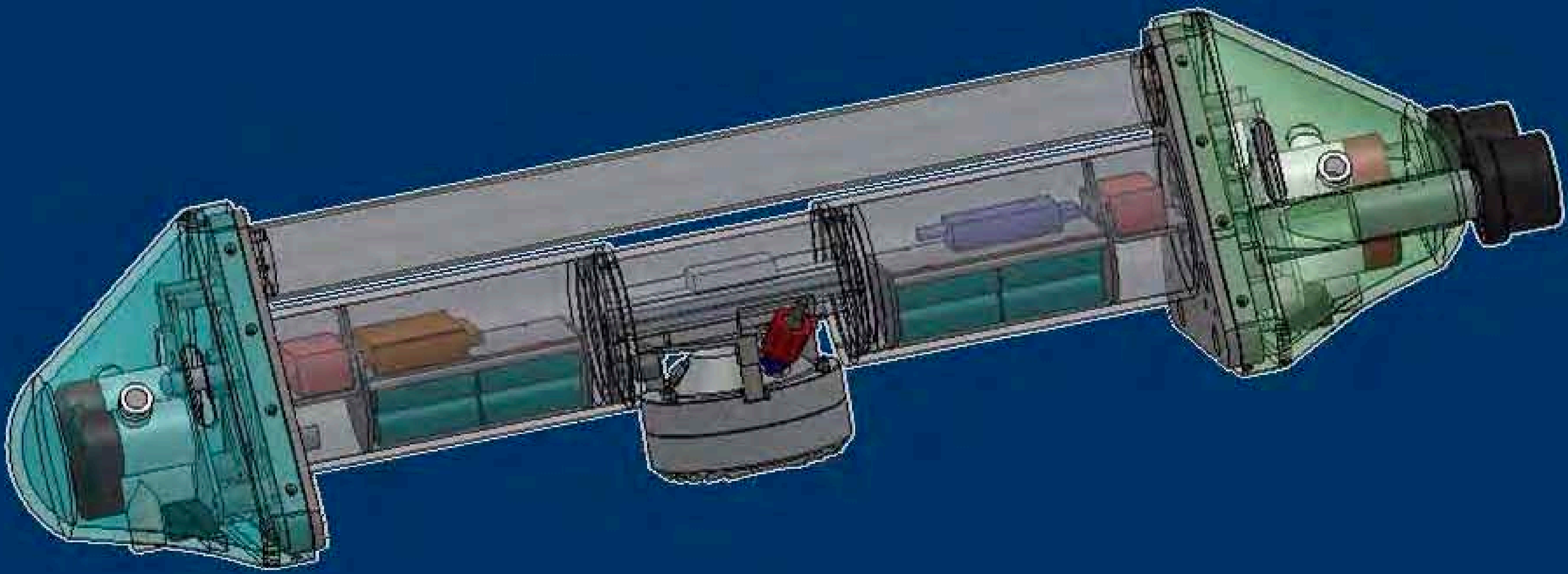
THE FIRST TESTED MOCKUP

- plexiglass mockup with ALPHA Ver.1 nose and tail
- 5 centimeters sand penetration obtained

LEARNT LESSONS

Seismic coupling	Needs of comparative tests to assess the quality of seismic data acquired → **CHARLIE** and **DELTA** AUVs

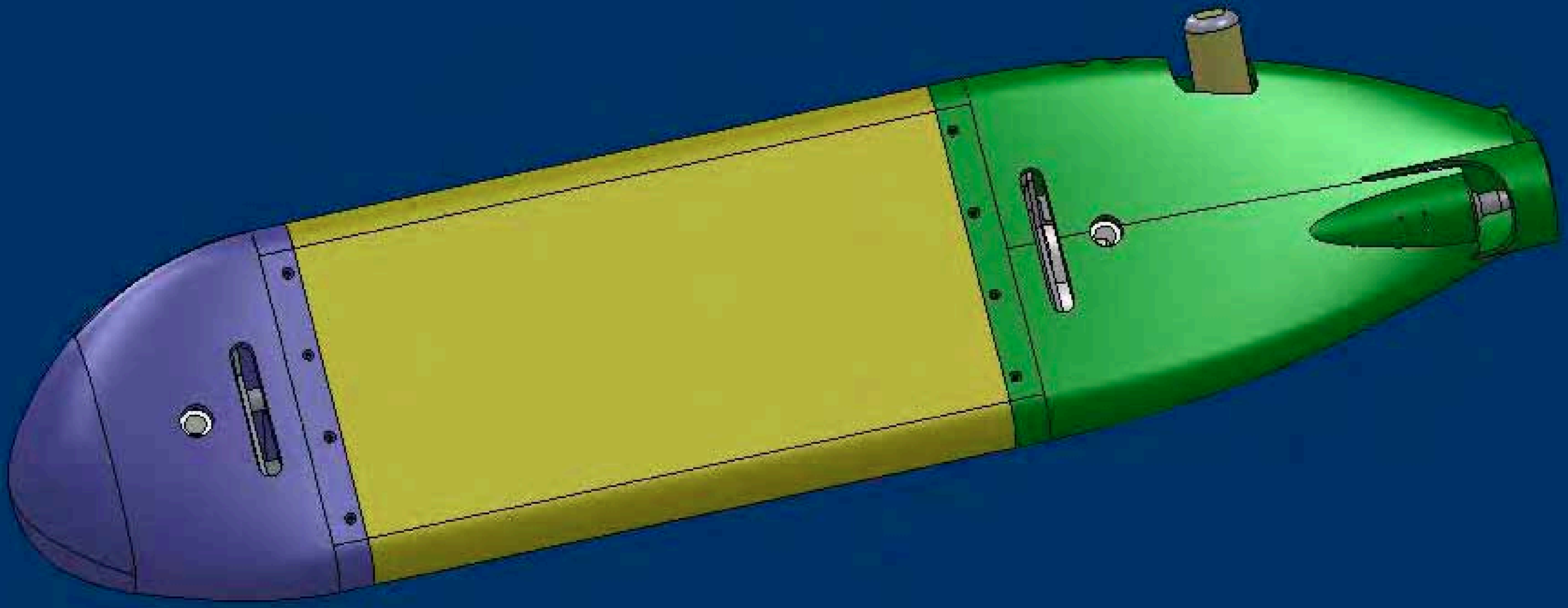
CHARLIE



Main features

- seismic Payload as it is in Trilobit (backup solution of DELTA)

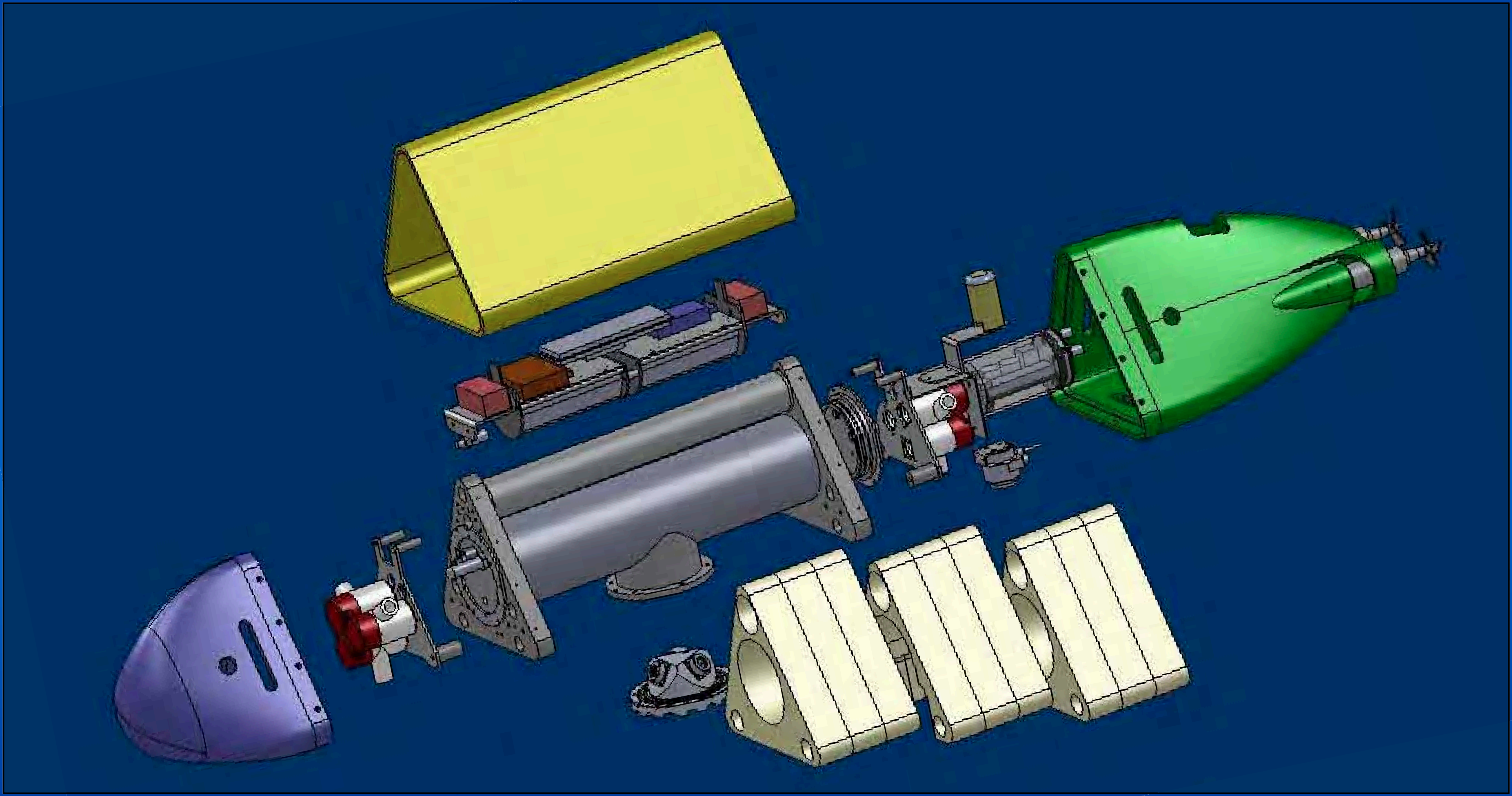
DELTA



Main features

- seismic Payload with the "Jim2" solution
- acoustic modem

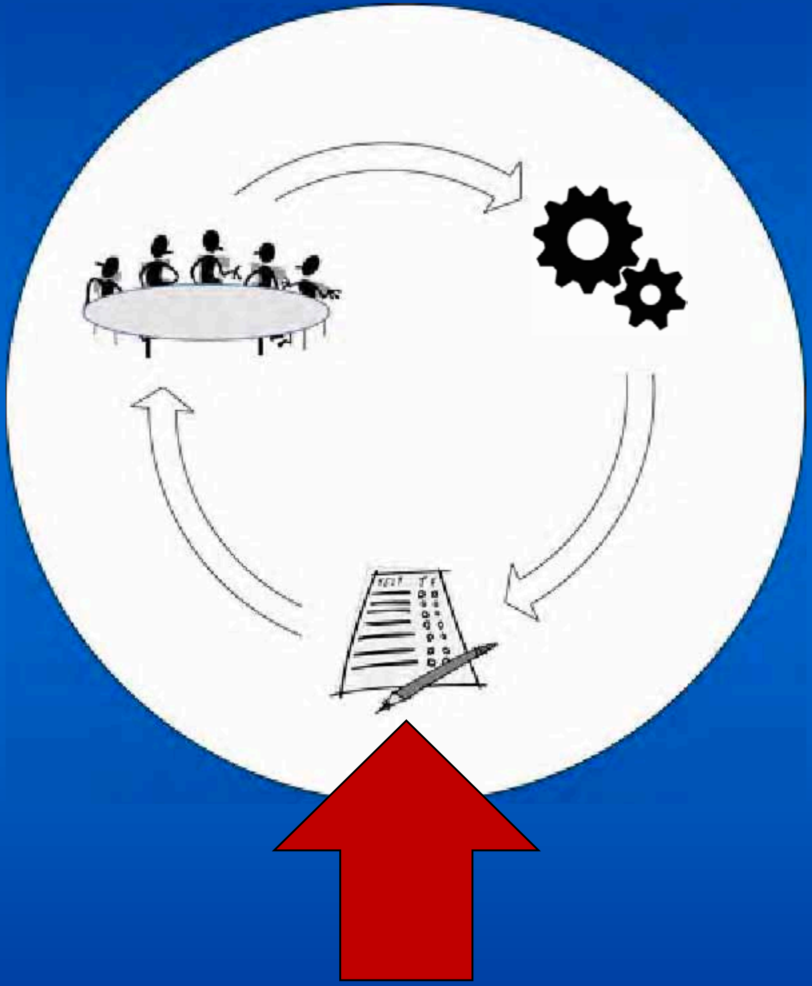
DELTA – Internal structure



DELTA Ver. 1 – Tests in tank – Quality of Data

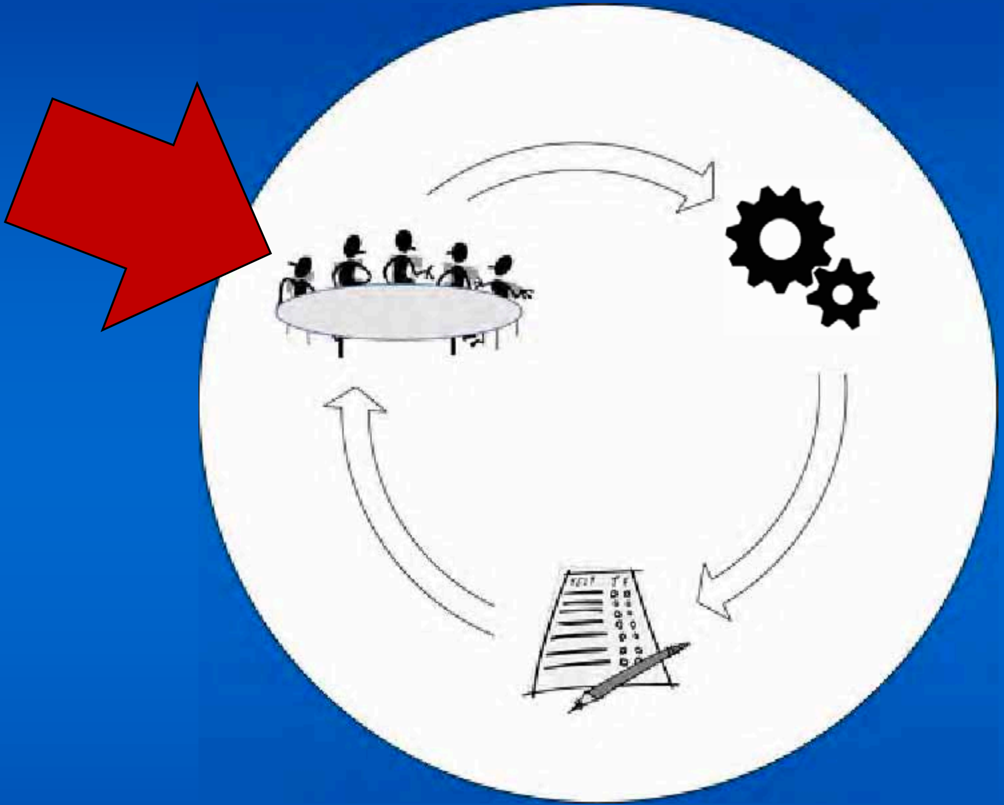
- comparative tests performed with Trilobit and Delta
- recorded seismic data evidenced good quality

TESTING PHASE



GRAALtech

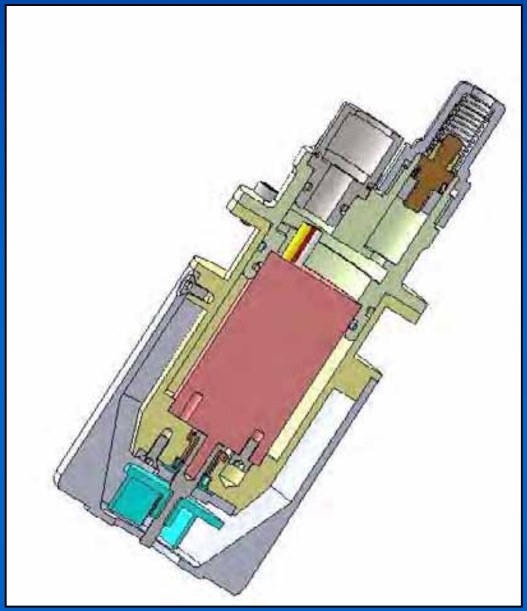
TEST ANALYSIS AND NEXT STEPS PLANNING

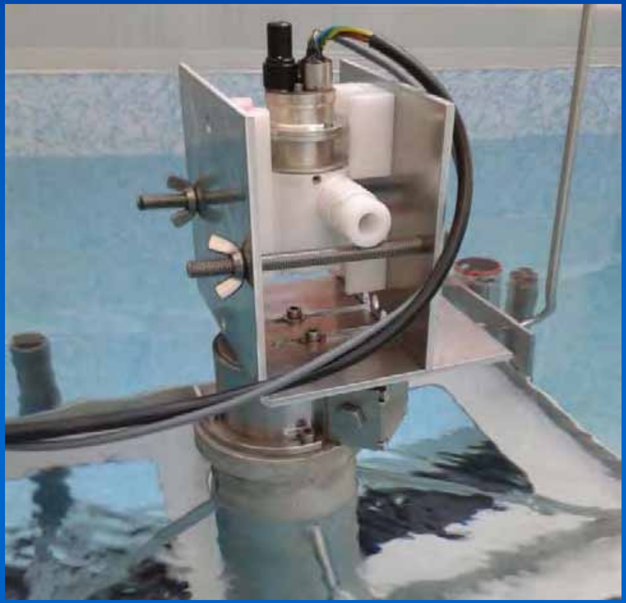


FURTHER IMPROVEMENTS

Target reaching	• More powerful actuators → **CUMIN, PAPRIKA** • Accurate position feedback → **ACOUSTIC GUIDANCE** • Stability without protruding surfaces → **ECHO**
Sea bottom holding	• More effective fluidification → **NEW MAGIC CARPET** • Feedback on the burying process → **BURIAL SENSOR** • **AUTOMATIC BURYING PROCEDURE**
Seismic coupling	• Good coupling with the new magic carpet → **NEW BODY**

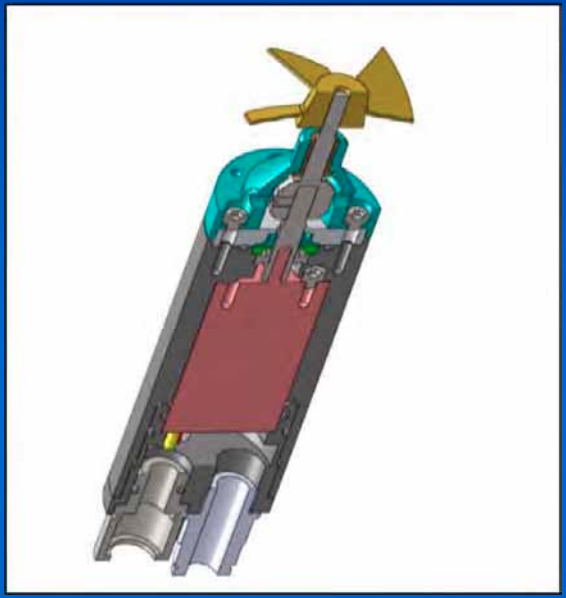
NEW JET-PUMP: CUMIN

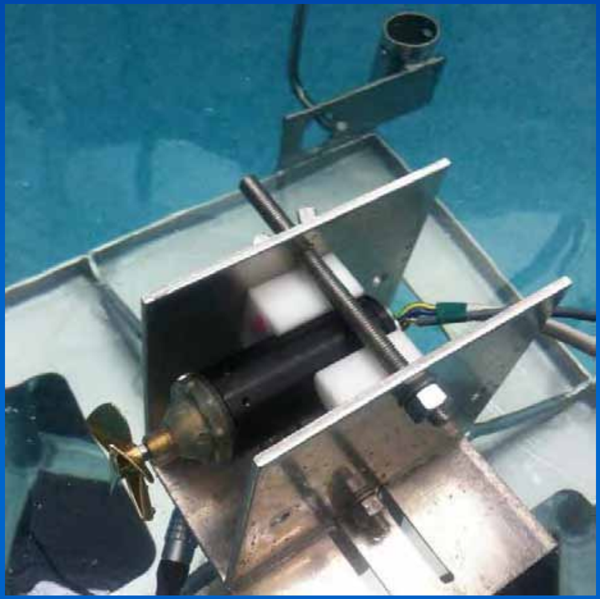




- Brushless motor inside
- Oil filled with pressure compensator
- Max force: 2ON @ 650W

NEW THRUSTER





- Brushless motor inside
- Oil filled with pressure compensator
- Max force: 30N @ 650W (with 50mm propeller)

NEW STEERING-THRUSTER: PAPRIKA

- Brushless motor inside
- Oil filled with pressure compensator
- Max force: 20N @ 400W (with 40mm propeller and 45mm tunnel)

ECHO

ECHO Ver. 1

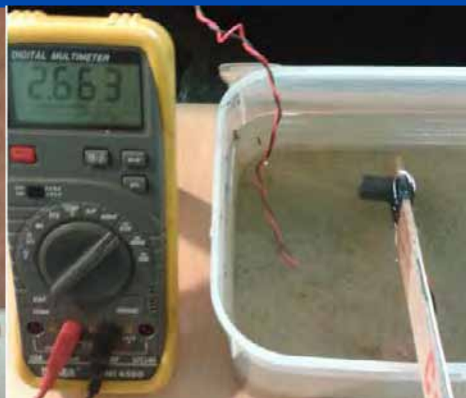
ECHO Ver. 2

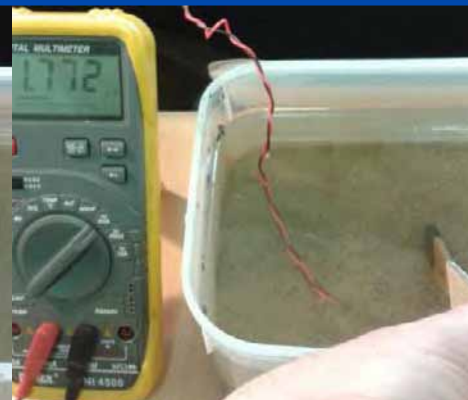
NEW MAGIC CARPET


- More holes
- Integrated in the hull

THE BURYING CHALLENGE

Custom sensor



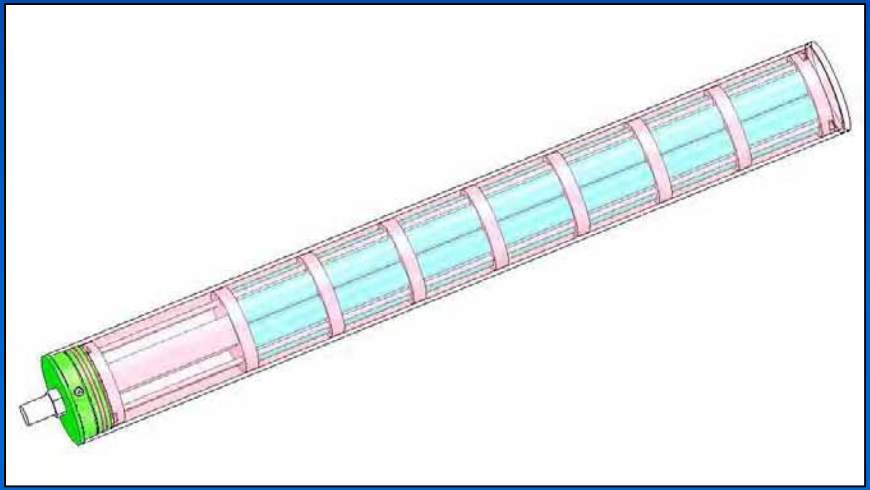

Automatic procedure



FURTHER ACHIEVEMENTS

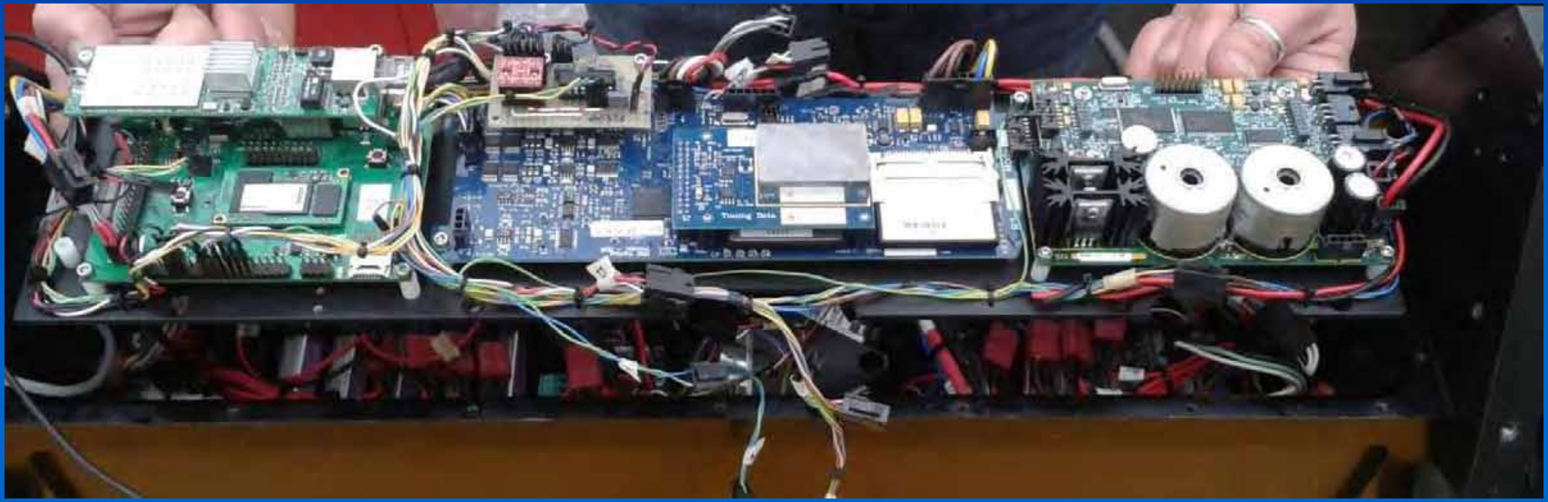
- Removable batteries
- Low-power avionics
- Real-time SW
- Multi-AUV GUI
- Navigation with negative buoyancy

REMOVABLE LI-ION BATTERIES



- Easily removable for fast substitution
- Tested at 150 msw
- Decoupled actuators and sensors
  - 340Wh @ 25.2V (30A max current)
  - 470Wh @ 7.2V (5A max current)

LOW-POWER LOW-COST AVIONICS



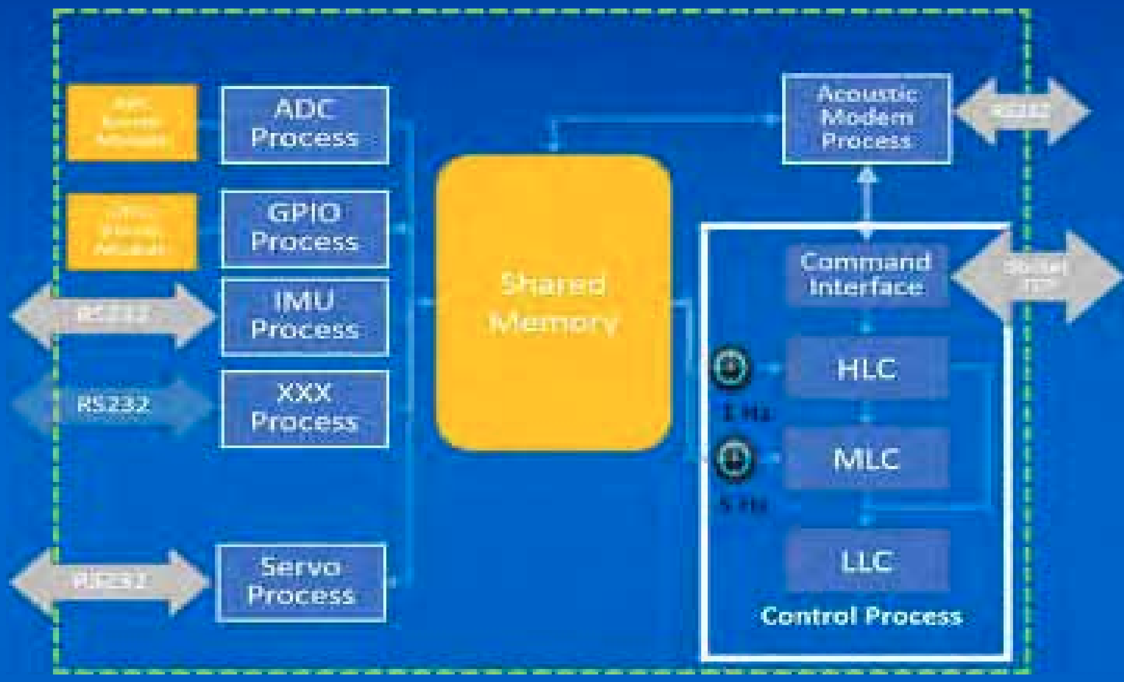
- Low cost arm-based CPU (115 €, 170mA)

- 18 channels serial driver board (40$)

- Low-cost 3D inclinometer (75$)

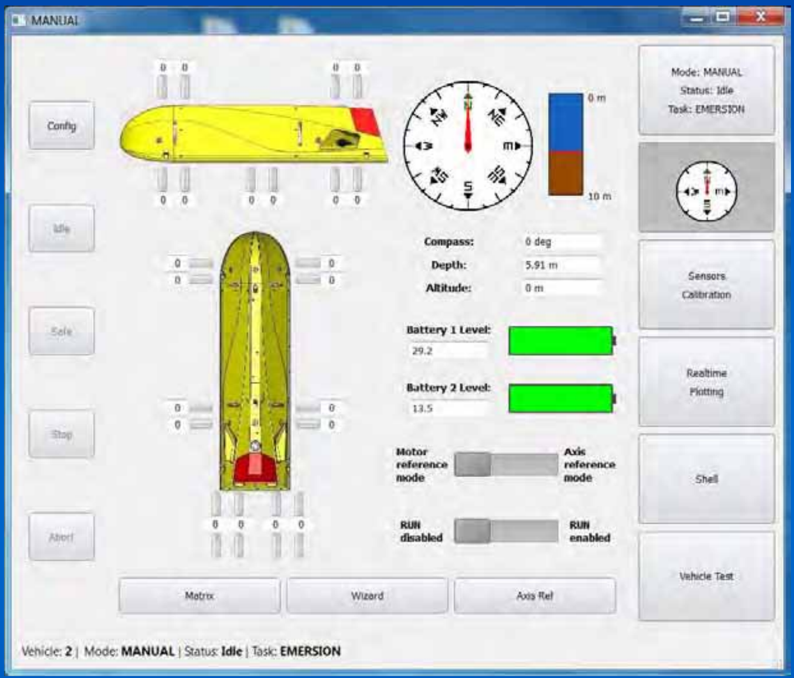
- ESC for jet-pumps and thruster (60-150)

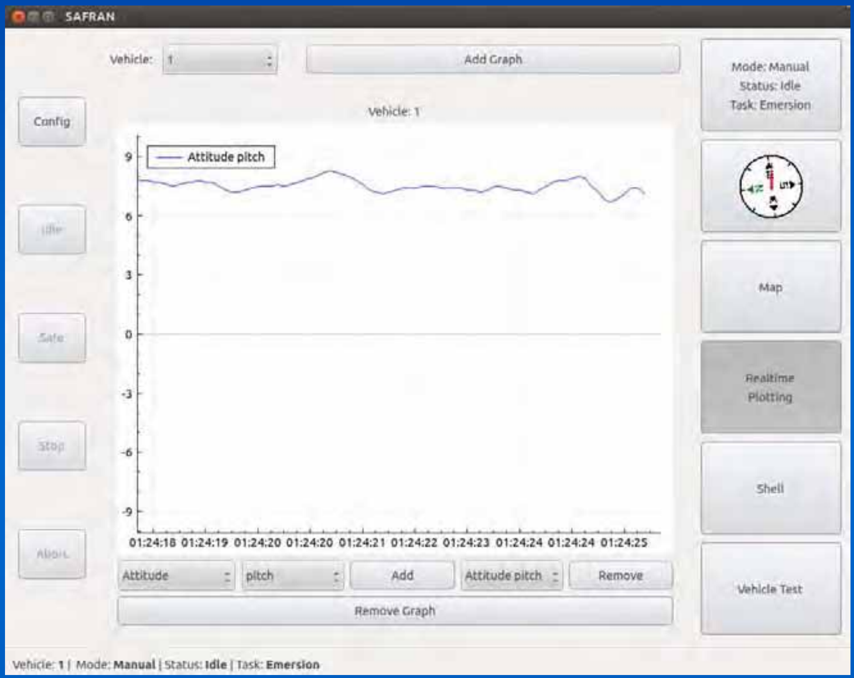
QT-BASED SOFTWARE ARCHITECTURE



- Object-based infrastructure easily scalable and reconfigurable
- XML-based settings of parameters-to-tune, commands, data-to-log
- Improved logging facility
- Nested control loops up to 10Hz

ADVANCED MULTI-AUV GUI



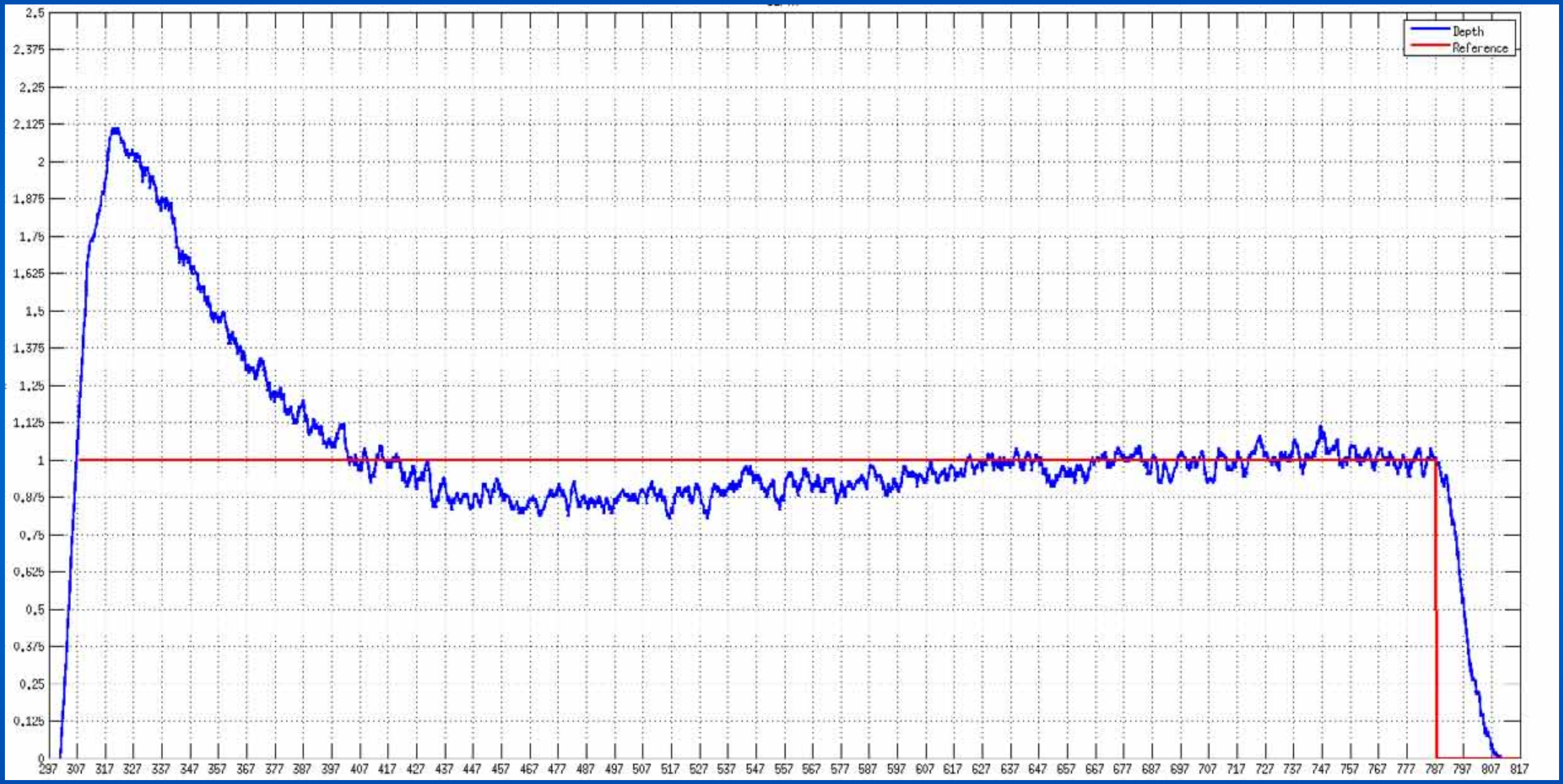


- OS independent
- Joystick and touchscreen integrated
- On-line graphical monitoring of variable of interest
- Multiple mode supported (Manual/TeleOperated/Mission/Calibration)

NAVIGATION WITH NEGATIVE BUOYANCY

<u>8 minutes run</u>: 2.5 knots @ -2kg buoyancy

depth



time

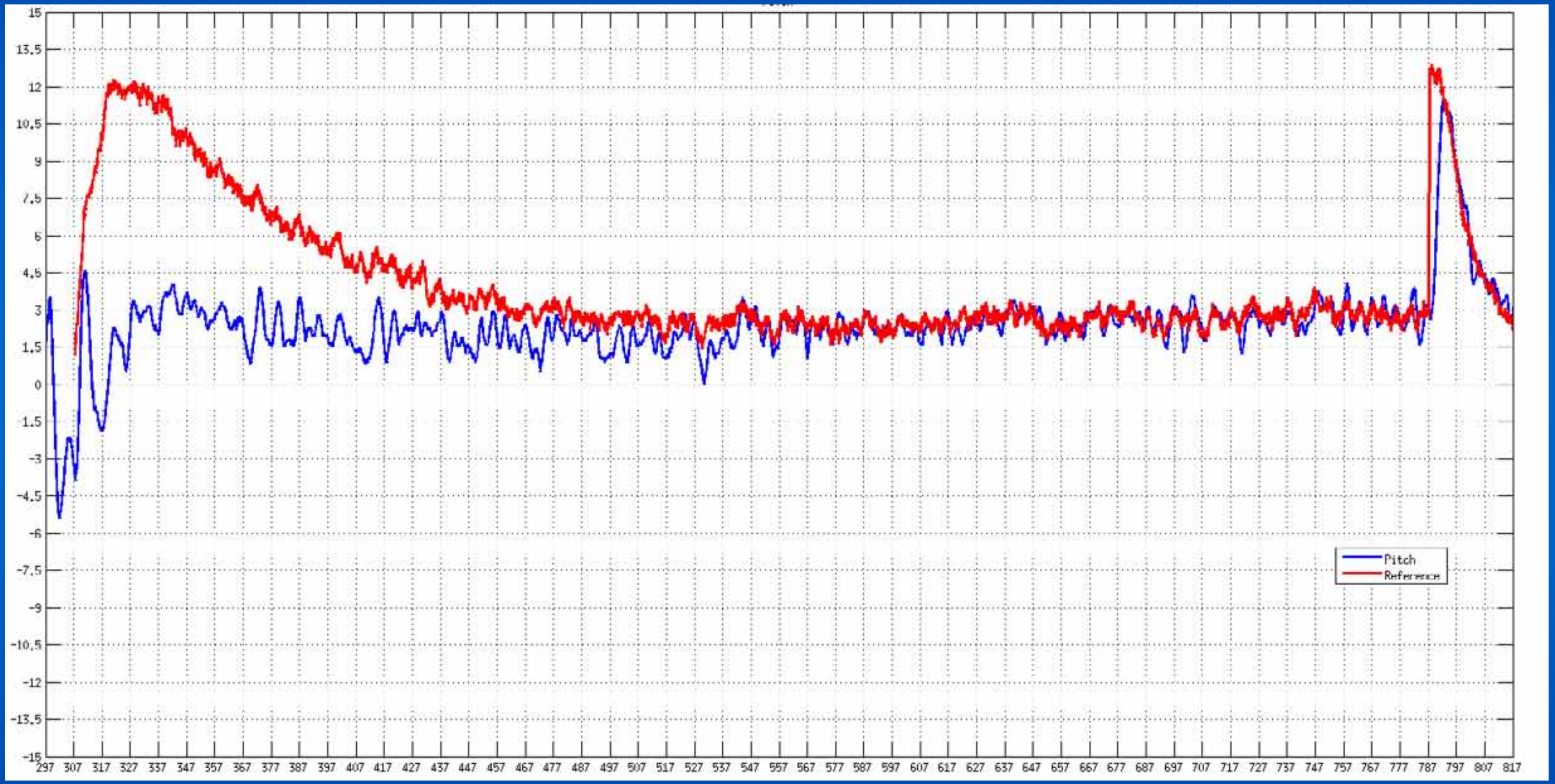
0.125 m

10 sec

NAVIGATION WITH NEGATIVE BUOYANCY

8 minutes run: 2.5 knots @ -2kg buoyancy

pitch



time

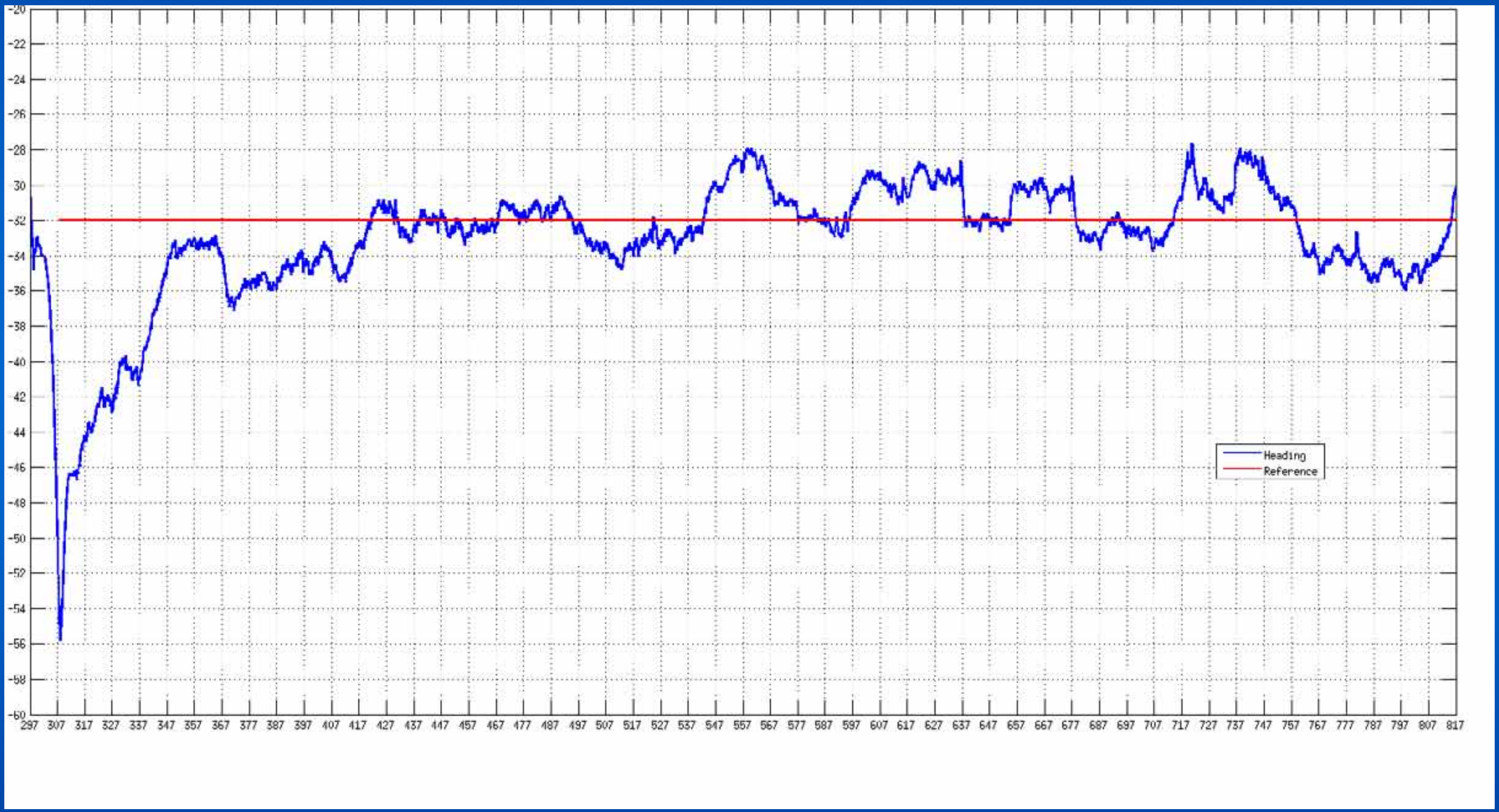
1.5 deg

10 sec

NAVIGATION WITH NEGATIVE BUOYANCY

<u>8 minutes run</u>: 2.5 knots @ -2kg buoyancy

heading



time

2 deg

10 sec

OUTLINE

- Company Introduction

- An industrial R&D program: the Spicerack® project
  - Application domain
  - Motivations
  - Preliminary de-risking phase
  - The roadmap to the development of a new AUV

GLOBAL MISSION AT SEA

NEED MORE INFO

www.graaltech.com alessio.turetta@graaltech.it

GLOABAL MISSION AT SEA

Safran - ECHO2

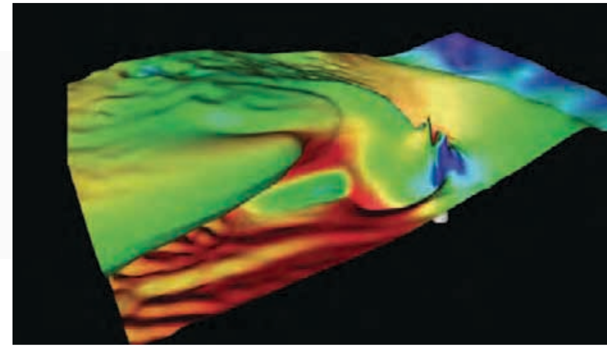
Orosei, October 2014

www.graaltech.com alessio.turetta@graaltech.it

EMRA´15

ISR-IST Lisbon Portugal

EMRA'15 workshop



Measuring small island-induced processes: Tech-savvy approaches

Rui Caldeira

CIIMAR, Porto, PT

Workshop

18 – 19 June
Lisbon

Measuring small island-induced processes: Tech-savvy approaches

Researcher @ CIIMAR
Lecturer @ ICBAS, U. Porto
Director of OOM

Outline

Island wakes: perturbing geophysical fluids

Laboratory studies: Dynamics

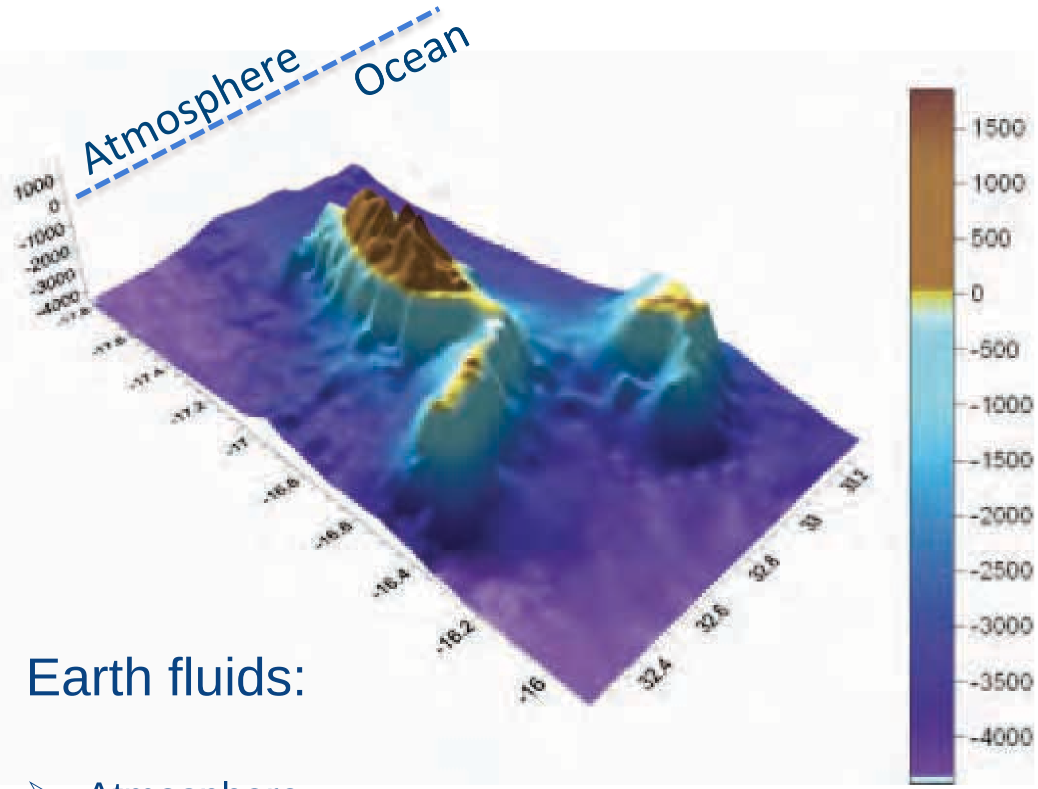
Airborne campaigns: Atmospheric wakes

Autonomous underwater vehicles: Ocean wakes

Search & Location

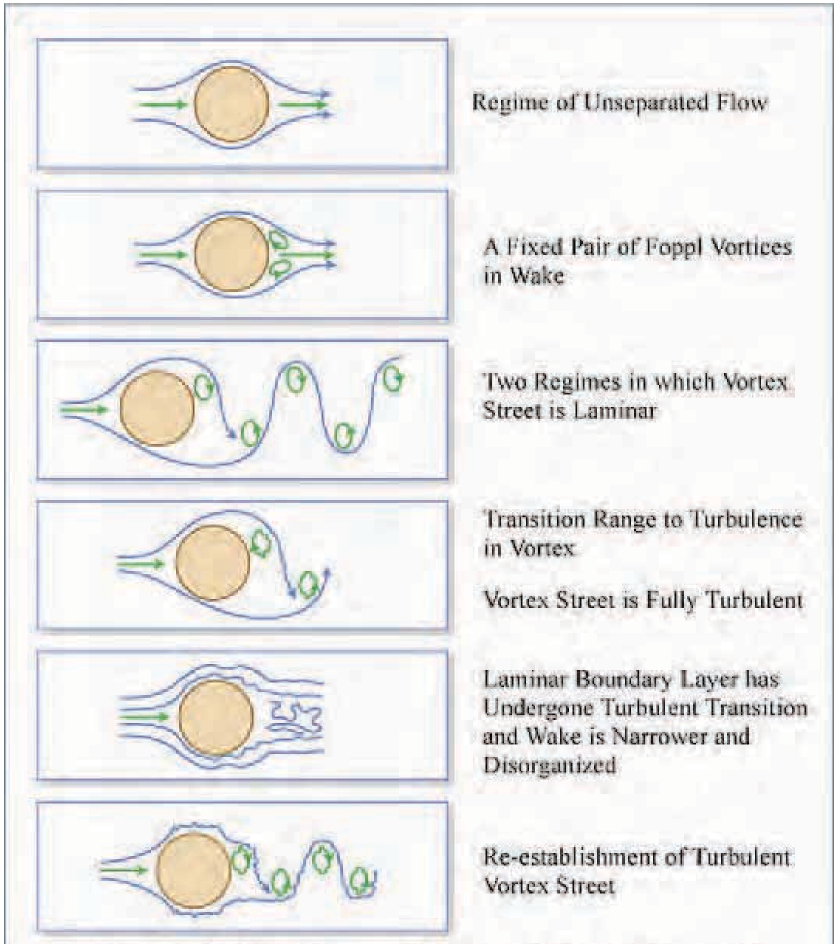
A vision for the future...

Island Wakes → Perturbing fluids



Earth fluids:

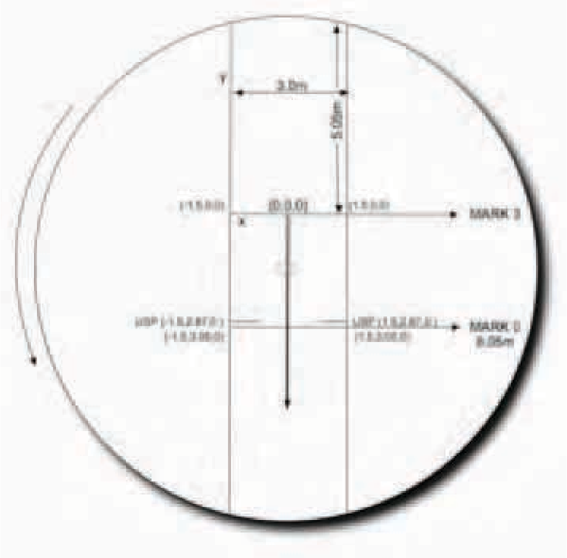
- Atmosphere
- Ocean

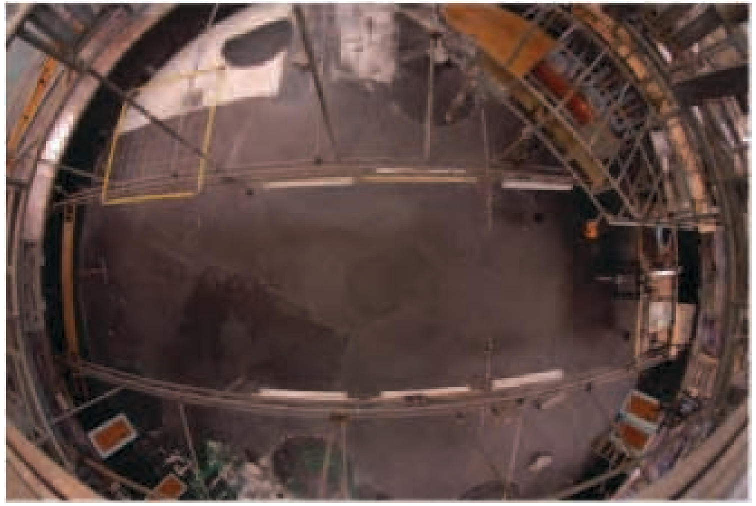


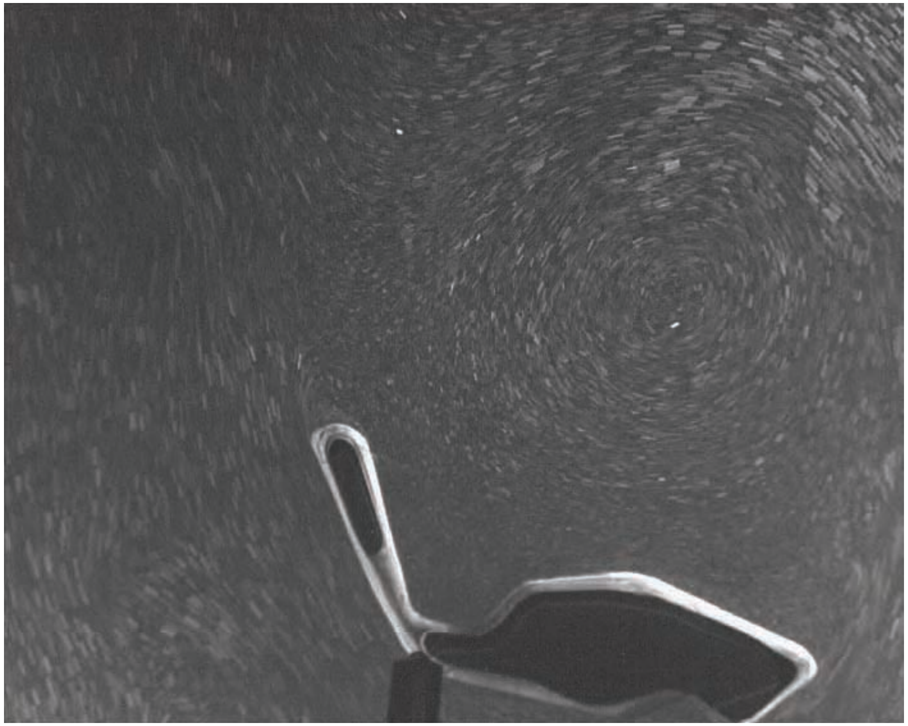
Regimes of fluid flow across smooth circular cylinders (Lienhard, 1966).

Coriolis platform 2008/2009

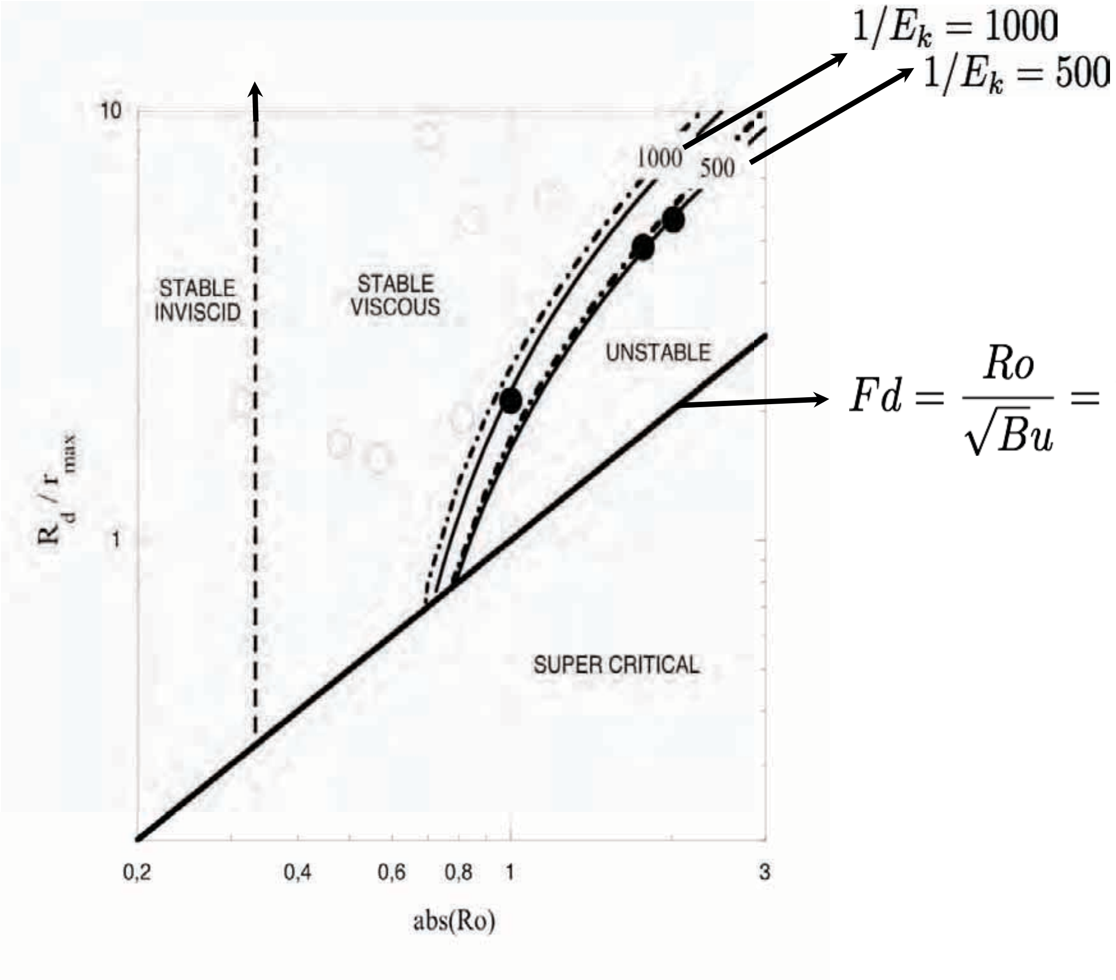
Coriolis platform





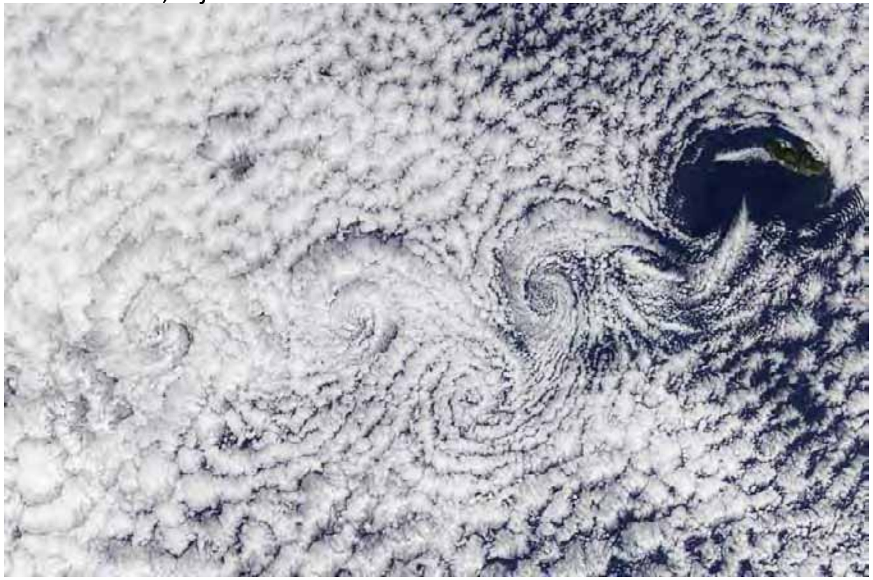


Laboratory studies: HYDRALAB III, FP6 / FP7

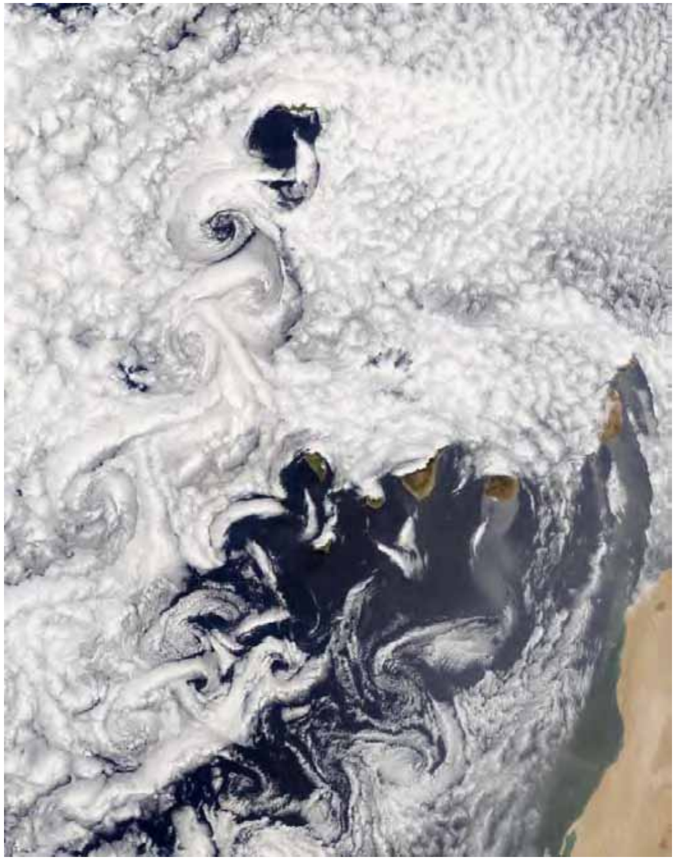


Wind Wake and VKS in the lee of Madeira Island

MODIS-terra, 1-jan-2002

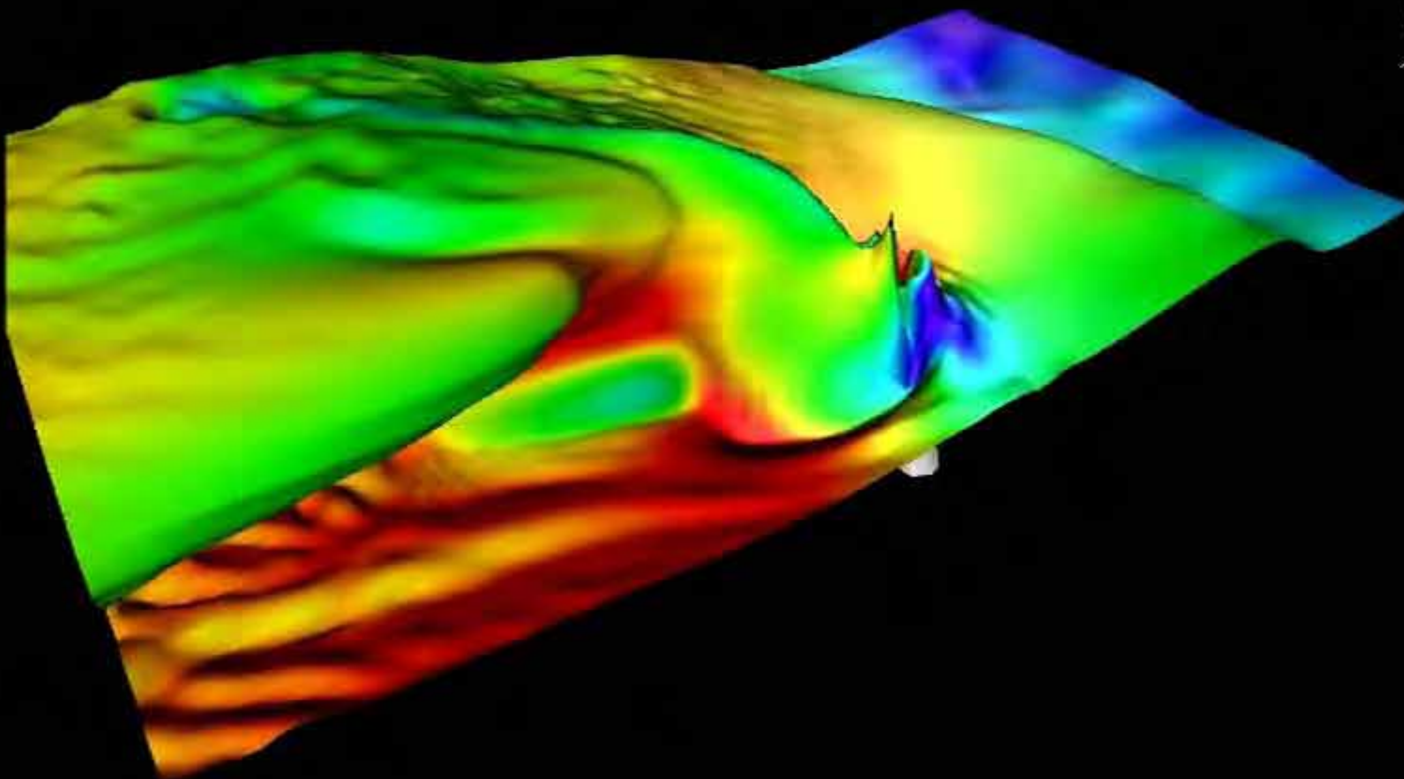


MODIS-terra. 5-July-2002.

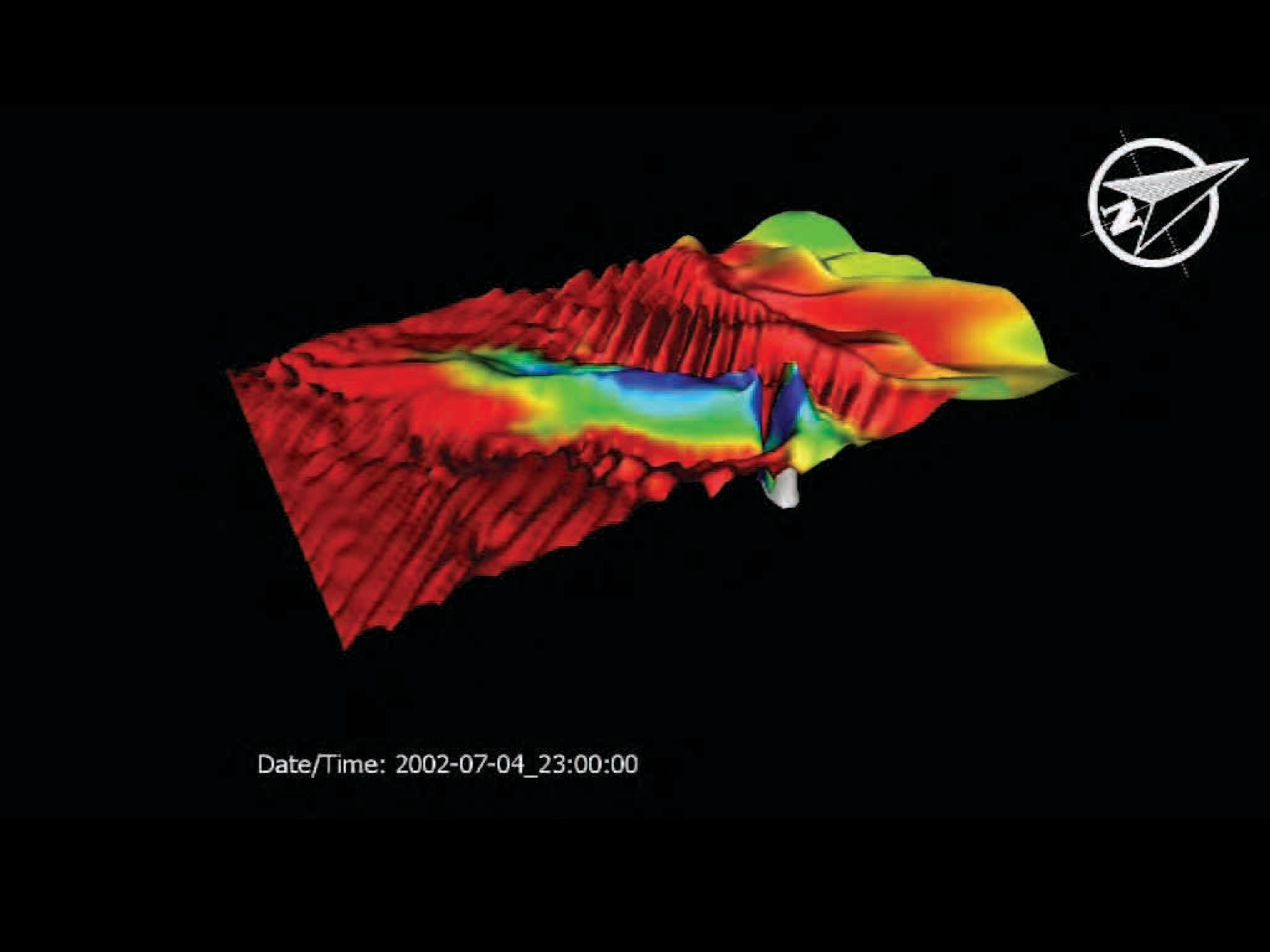


MODIS-terra, 28-Apr-2002

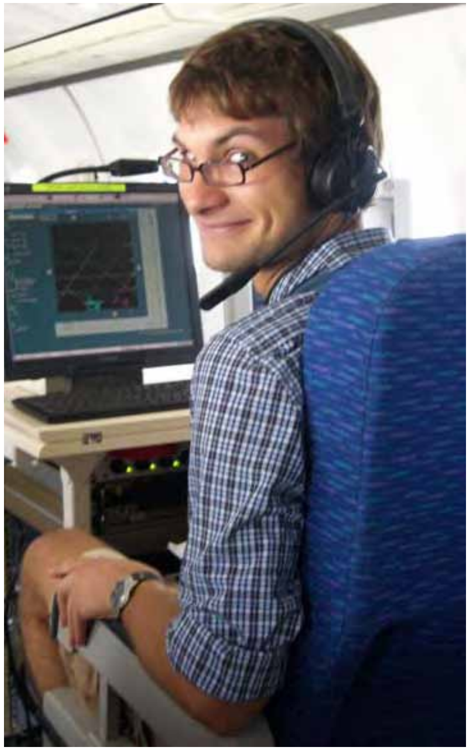
Credit: Jacques Descloitres, MODIS Land Rapid Response Team,
NASA/GSFC (http://visibleearth.nasa.gov/) .



Date/Time: 2002-07-03_19:00:00


Date/Time: 2002-07-04_23:00:00

I-WAKE



Madeira Wakes: Atmospheric

???Ducs ??gO?.?? ??

??s ?u ?r u O ??u??m?OqqD/Gs
???????mOGDN(s
? ?u? i ?r OqRDNGs

? ????m0??s i mT OCC LAAe?
? ? D??e ? ? ? OC/ (AAe?

?i ??? OCAA s t
Js ?u GAs t s ? CLR s t 2

Madeira Wakes: Atmospheric

•2 Pyrometers Kipp & Zonen CMP22 (visible) & CGR4 (Infra-red) (measuring upweling & downwelling radiances)

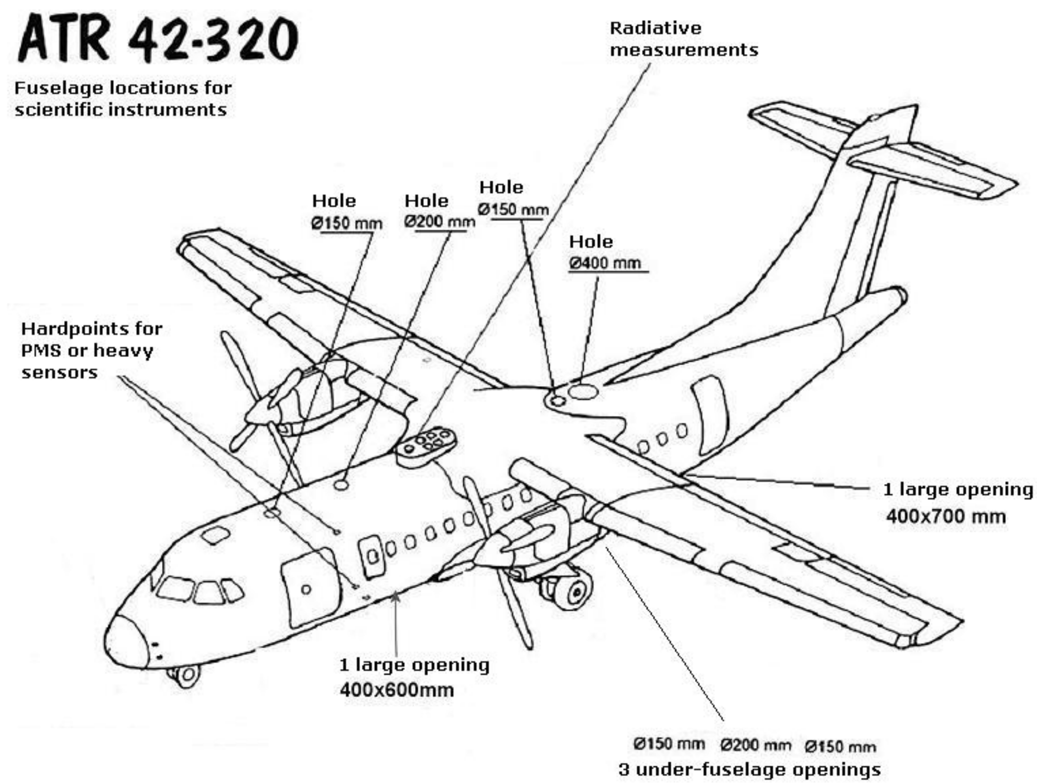
•“General Eastern” hygrometer (Dewpoint temperature range -75 -/+50°C);

•Rosemount 1201 & Rosemount 1221
static (0-1035 hPa) &
dynamic (0-85 hPa) pressure;

•CIMEL CLIMAT: Radiative temperature
3 wavelengths (-50; –400°C);

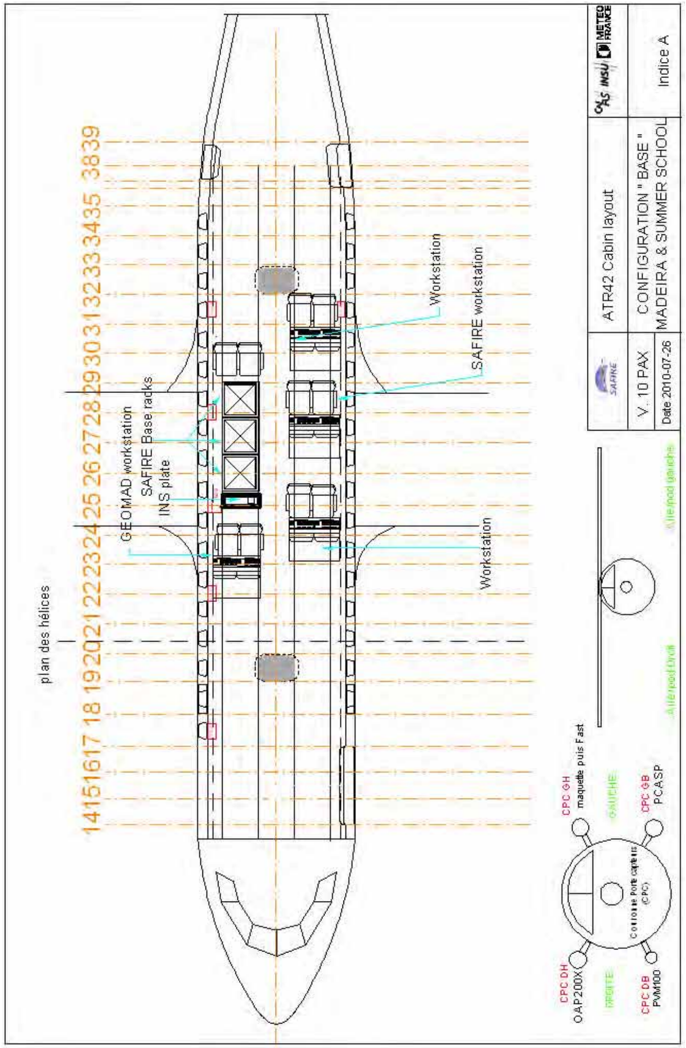
•5-port turbulence probe;
Wind: ± 256 kts ± 180 deg;

•Inertial Navigational System
& Global Positioning System



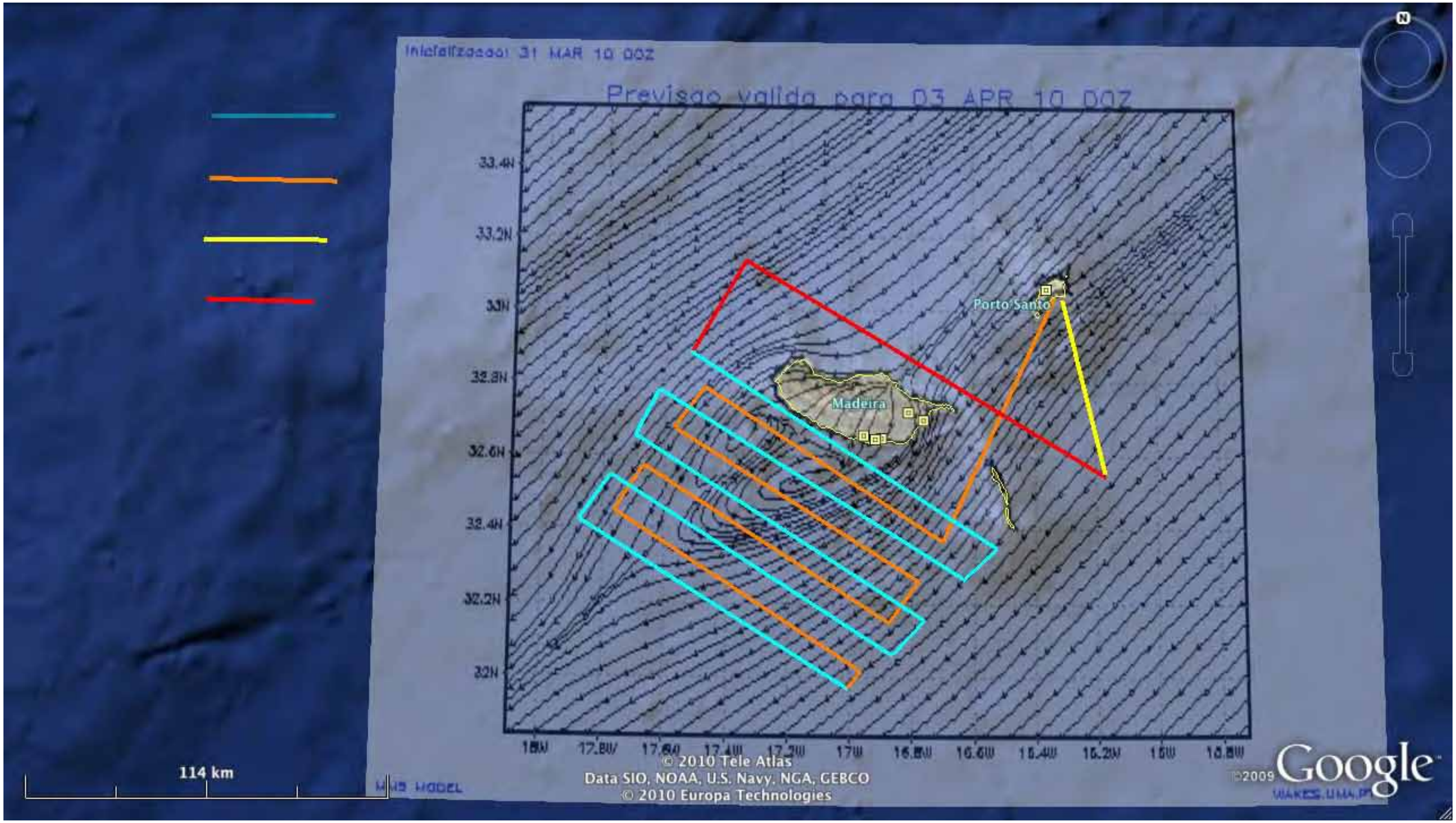
EUFAR European Facility For Airborne Research

Madeira Wakes: Atmospheric

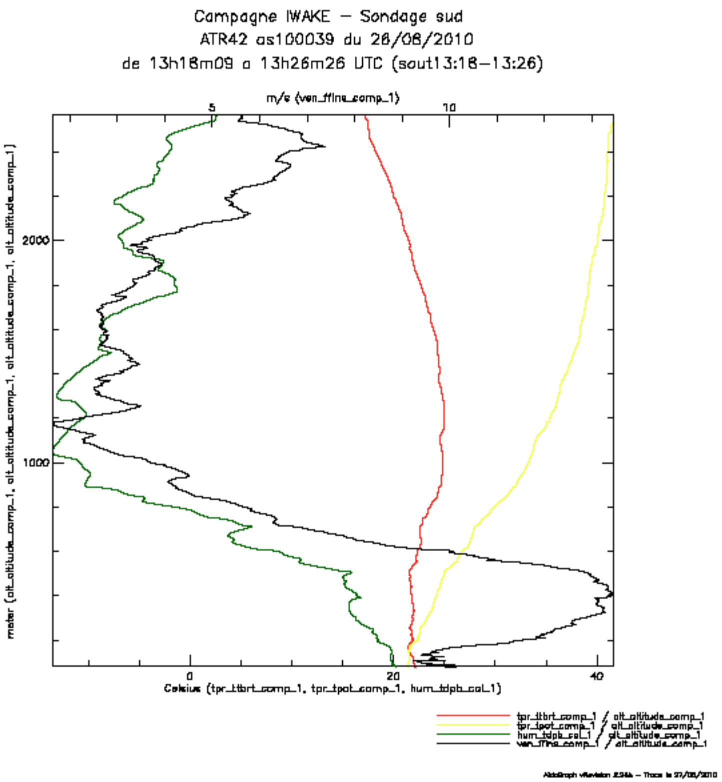


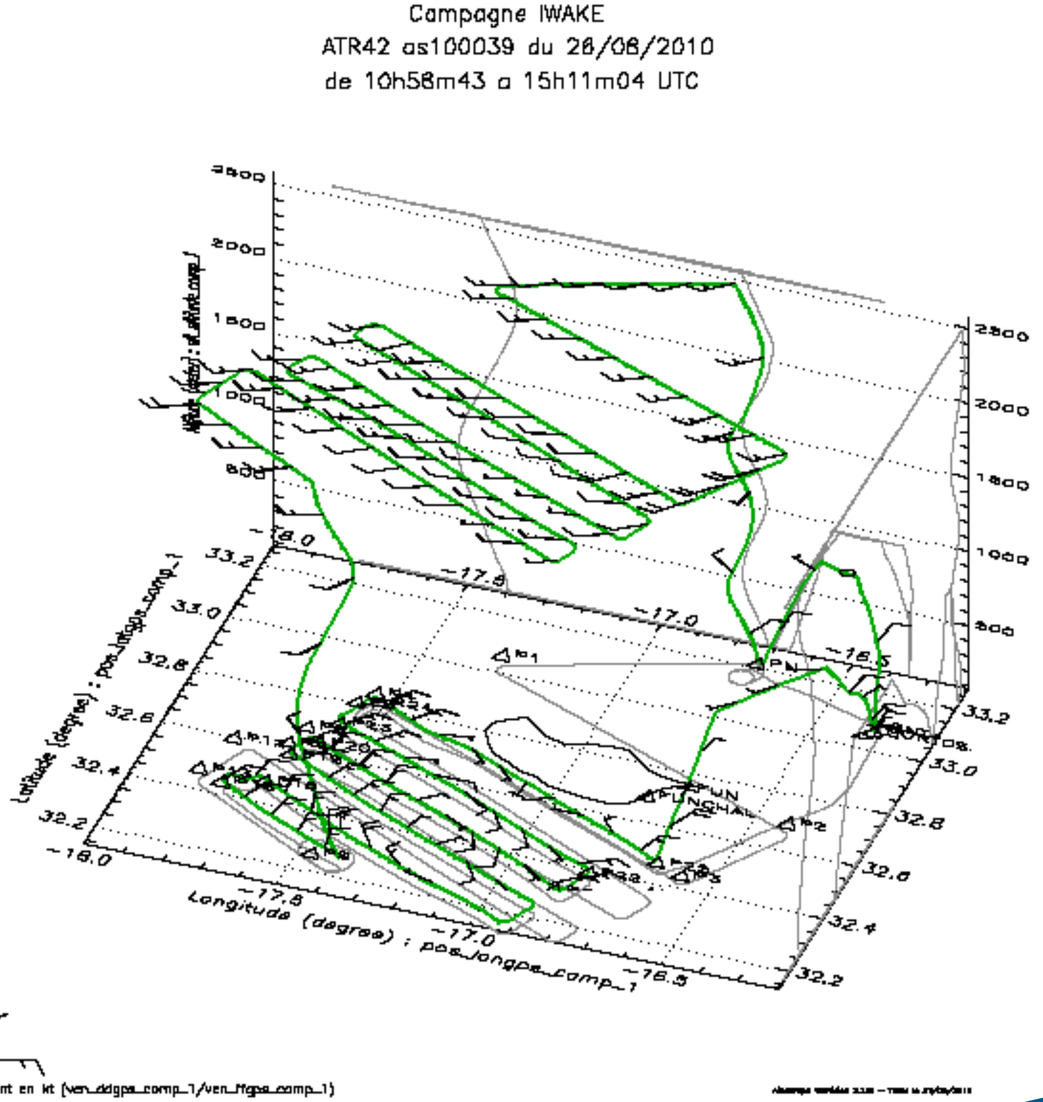
Madeira Wakes: Atmospheric

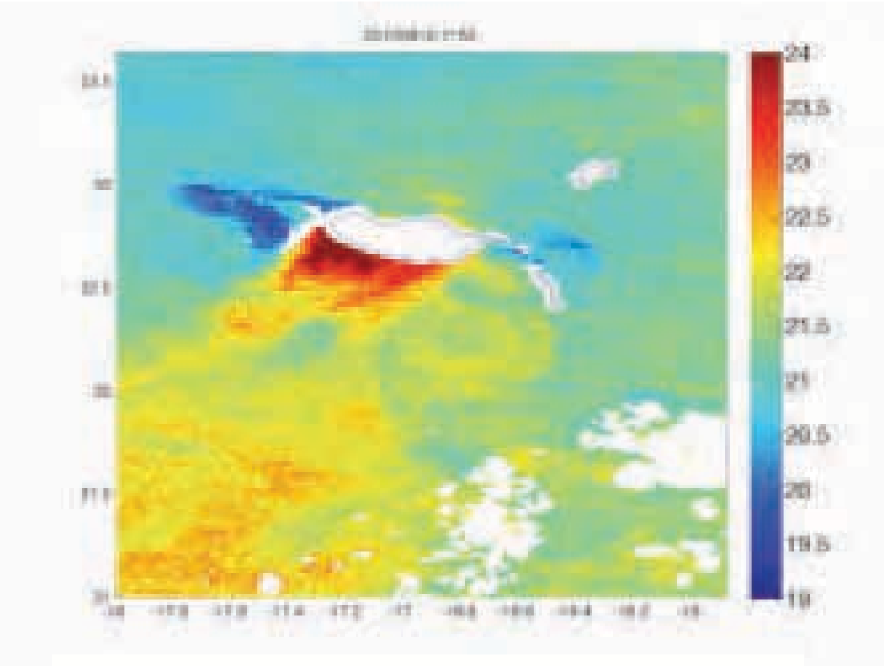
Total distance => ~700 NM = ~1300km



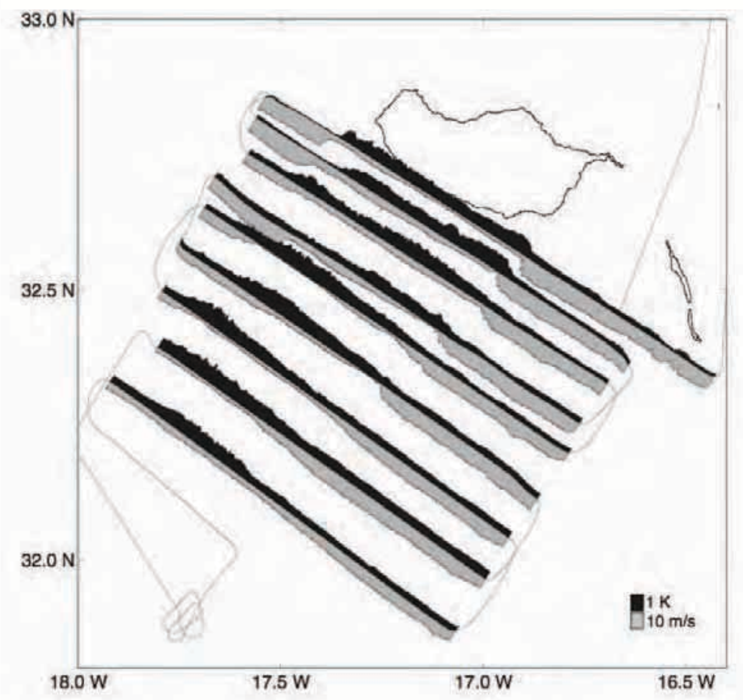
Madeira Wakes: Atmospheric

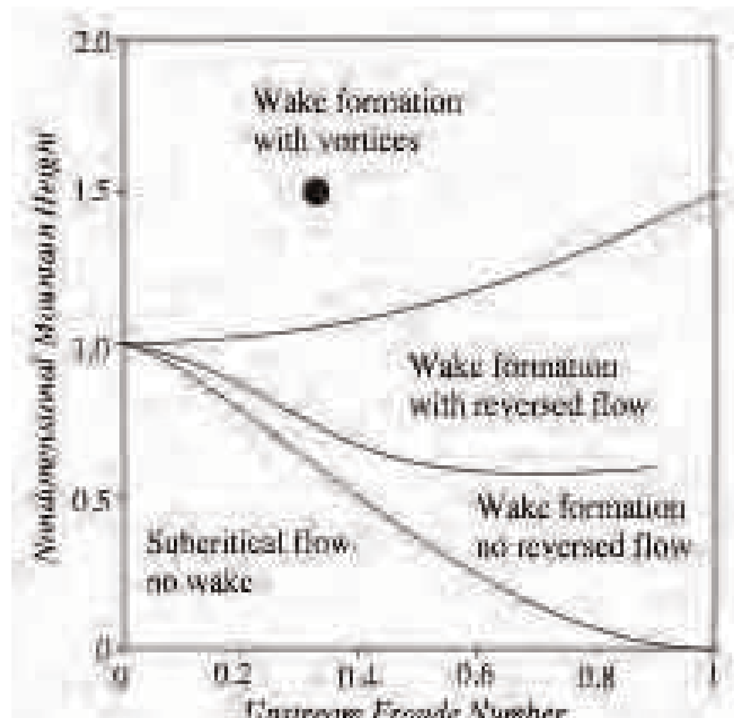


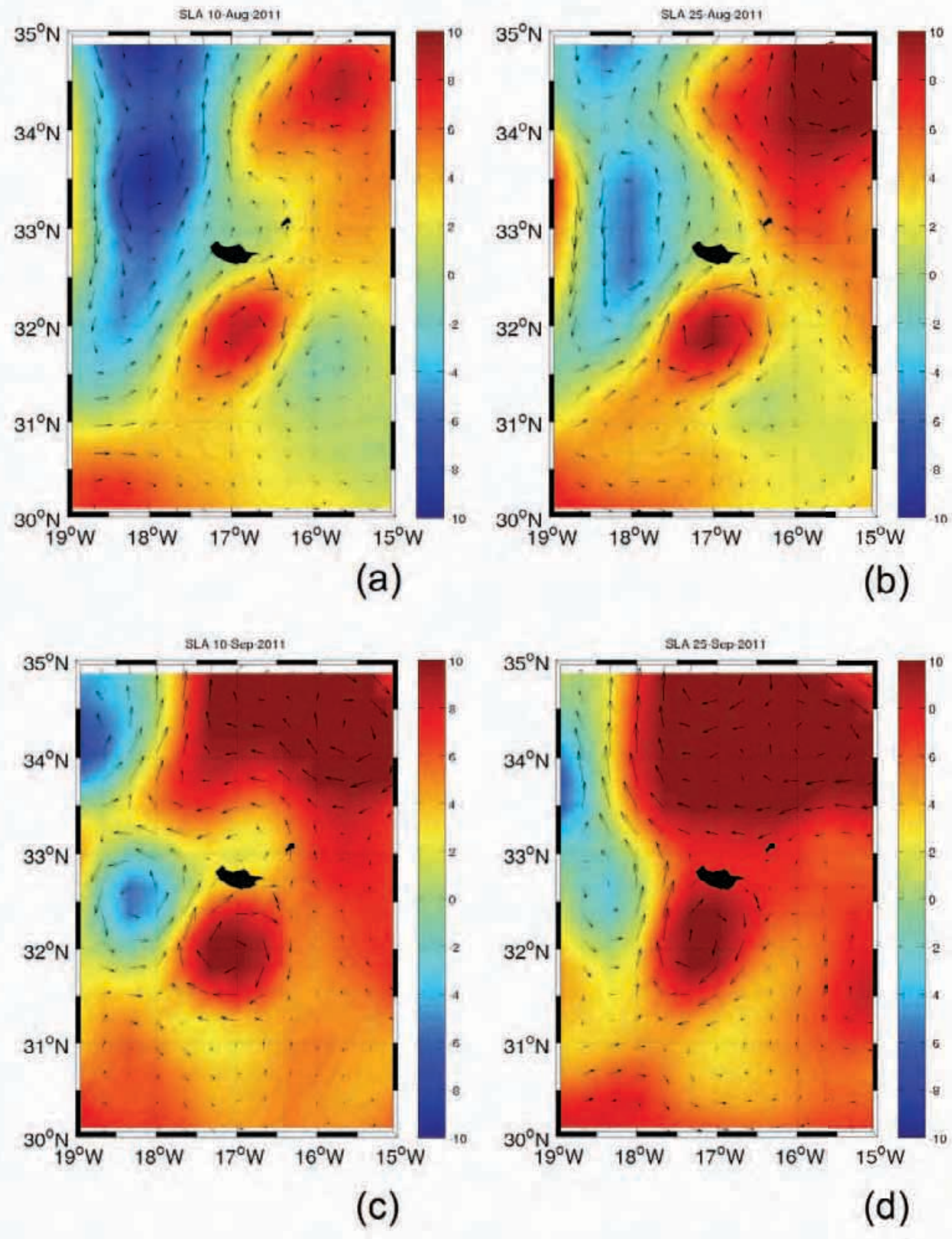



24
23.5
23
22.5
22
21.5
21
20.5
20
19.5
19


Journal of the Atmospheric Sciences

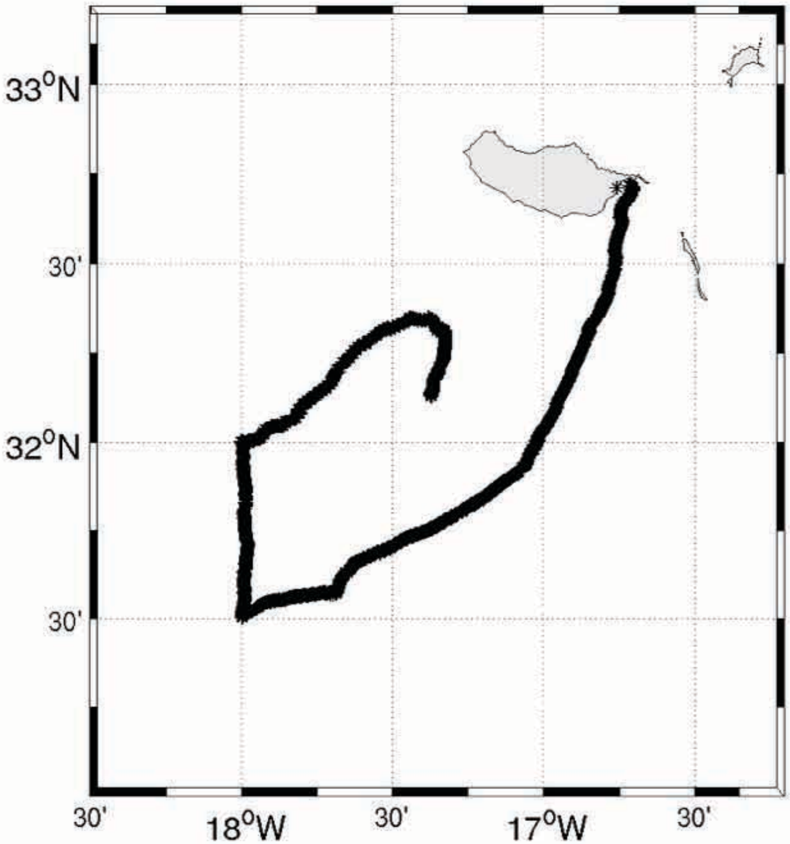

33.0 N
32.5 N
32.0 N
18.0 W
17.5 W
17.0 W
16.5 W
1 K
10 m/s


Wake formation with vortices
Wake formation with reversed flow
Wake formation no reversed flow
Subcritical flow no wake
Nondimensional Mountain Height
Upstream Froude Number
2.0
1.5
1.0
0.5
0
0
0.2
0.4
0.6
0.8
1

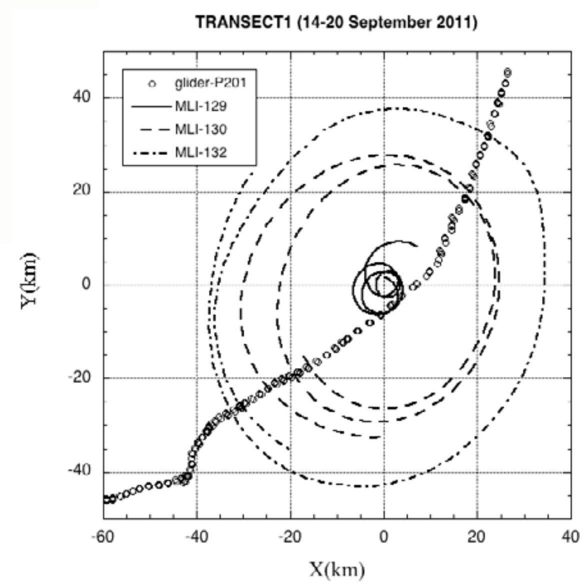


Madeira Wakes

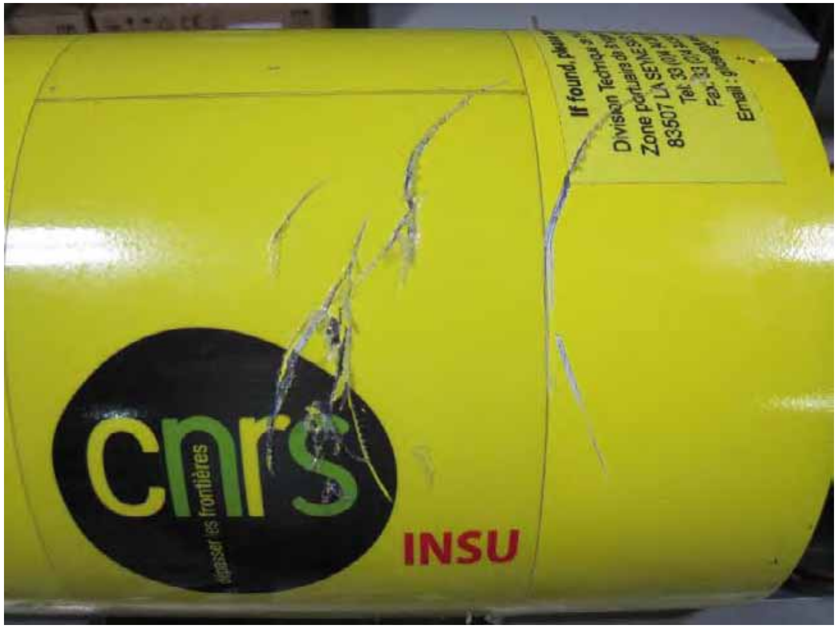
Oceanic

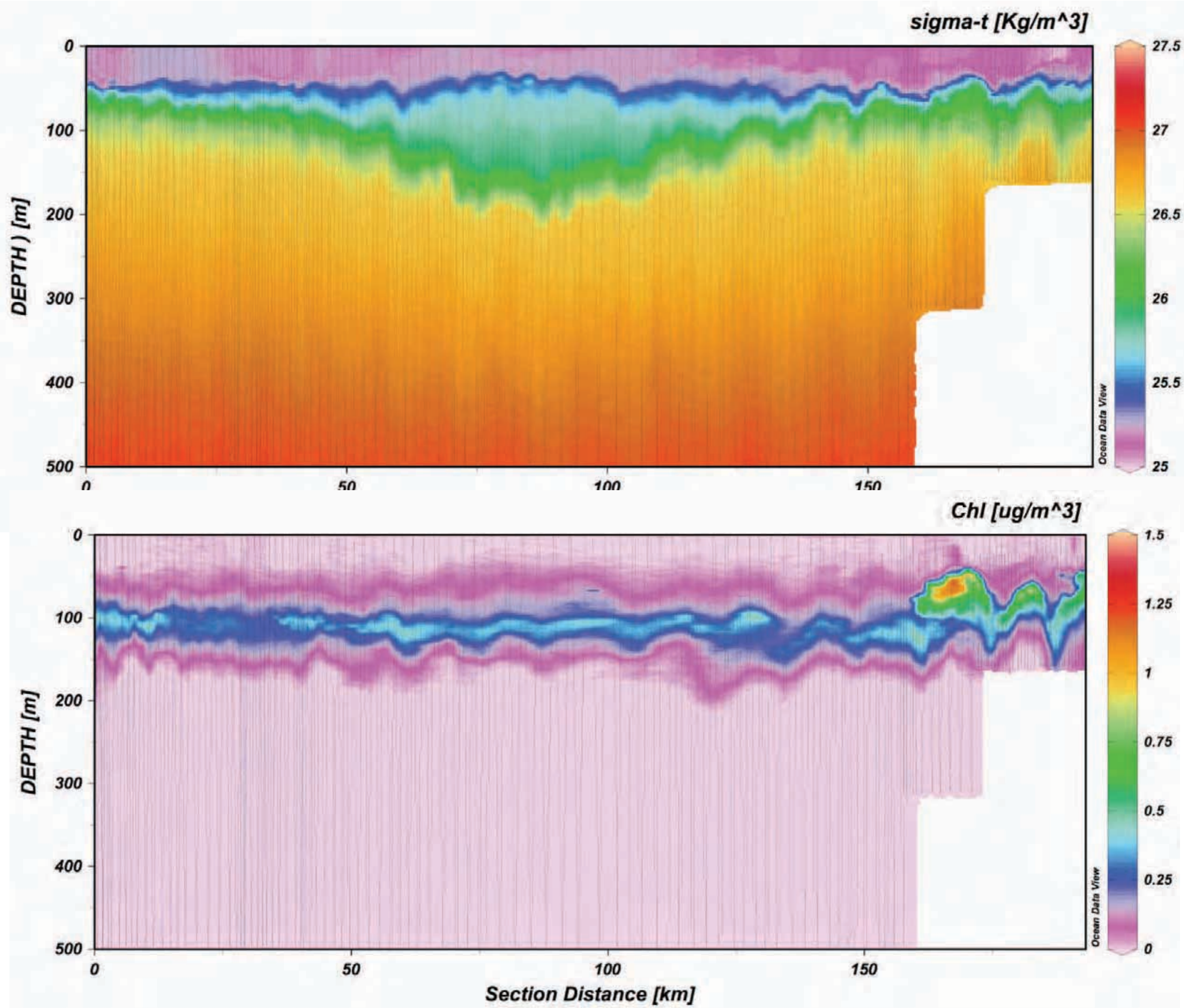

33°N
30'
32°N
30'
30'
18°W
30'
17°W
30'


TELEDYNE WEBB RESEARCH


TRANSECT1 (14-20 September 2011)
glider-P201
MLI-129
MLI-130
MLI-132
Y(km)
X(km)


0134


cnrs
INSU


sigma-t [Kg/m^3]
DEPTH) [m]
0
100
200
300
400
500
0
50
100
150
27.5
27
26.5
26
25.5
25
Ocean Data View
Chl [ug/m^3]
DEPTH [m]
0
100
200
300
400
500
0
50
100
150
Section Distance [km]
1.5
1.25
1
0.75
0.5
0.25
0
Ocean Data View

qACR

Observatório Oceânico da Madeira

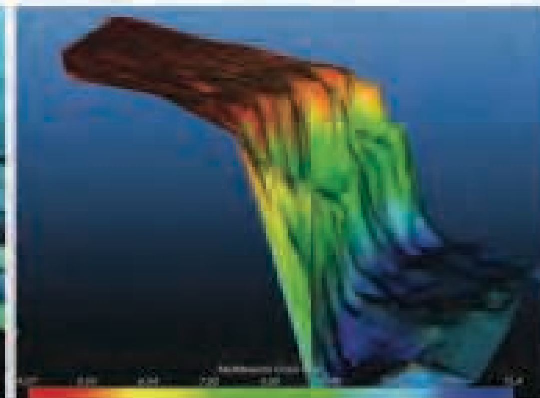
'DAMP – Demo AUV's Madeira Project'

'DAMP – Demo AUV's Madeira Project' é uma iniciativa multi-institucional e multi-disciplinar com o objetivo de testar e ensaiar veículos robóticos subaquáticos (autónomos) em ambientes portuários e costeiros. O projeto conta com a coordenação local do CIIMAR-Madeira em colaboração com a APRAM e com a participação do Laboratório de Sistemas e Tecnologias Subaquáticas (LSTS) da Faculdade de Engenharia da Universidade do Porto assim como da Marinha Portuguesa.

Este projeto foi parcialmente financiado pela Agencia de Investigação das Canárias (Id. 2010/0062) atribuído à Divisão de Robótica e Oceanografia Computacional do Instituto de Investigação SIANI, da Universidade de Las Palmas de Gran Canária.

Quando e onde?
Dia 14 de novembro às 15h, no Porto do Funchal

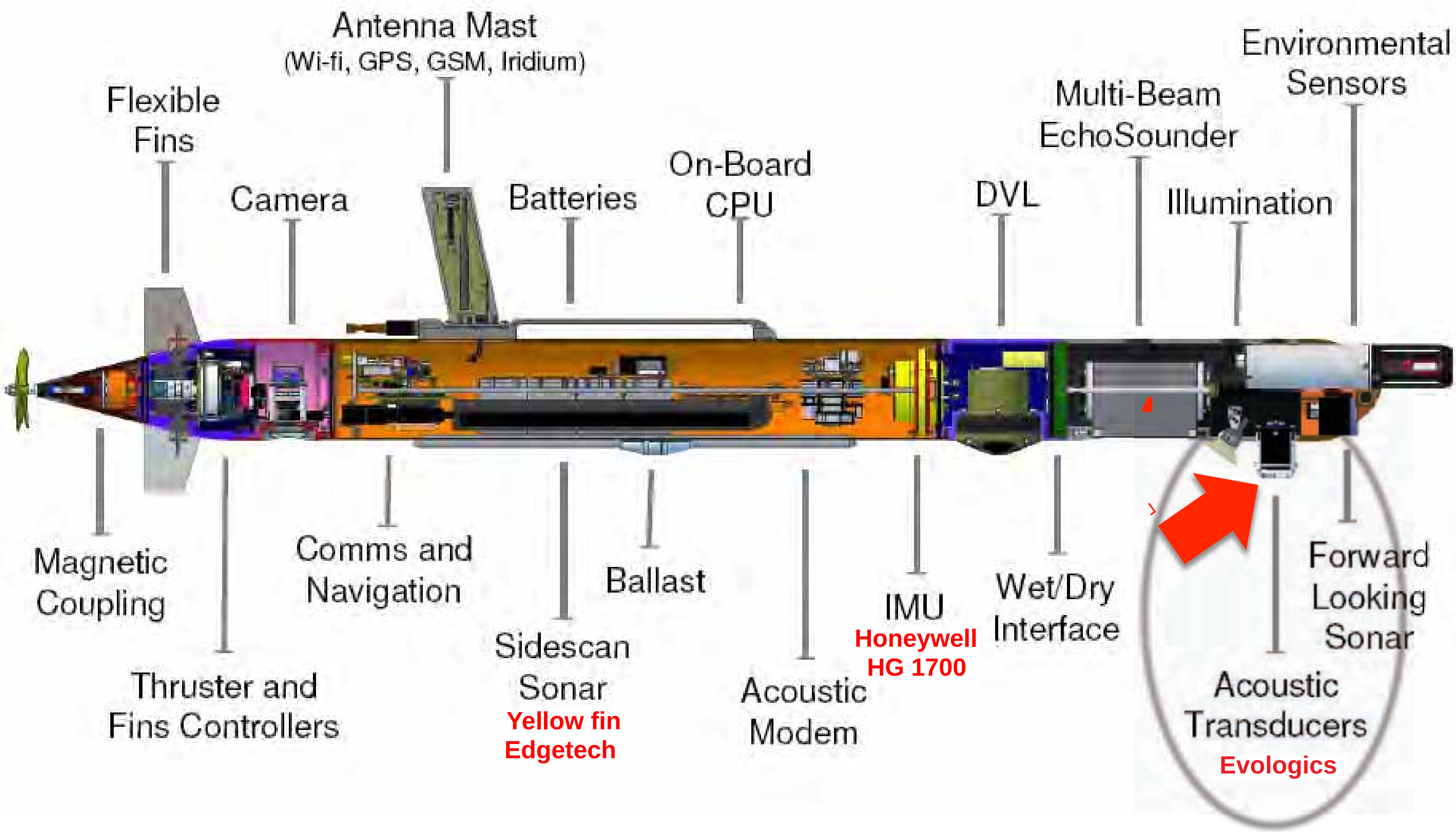
Como?
Robôs subaquáticos autónomos



Para que fim?
Recolha de dados sobre os fundos marinhos

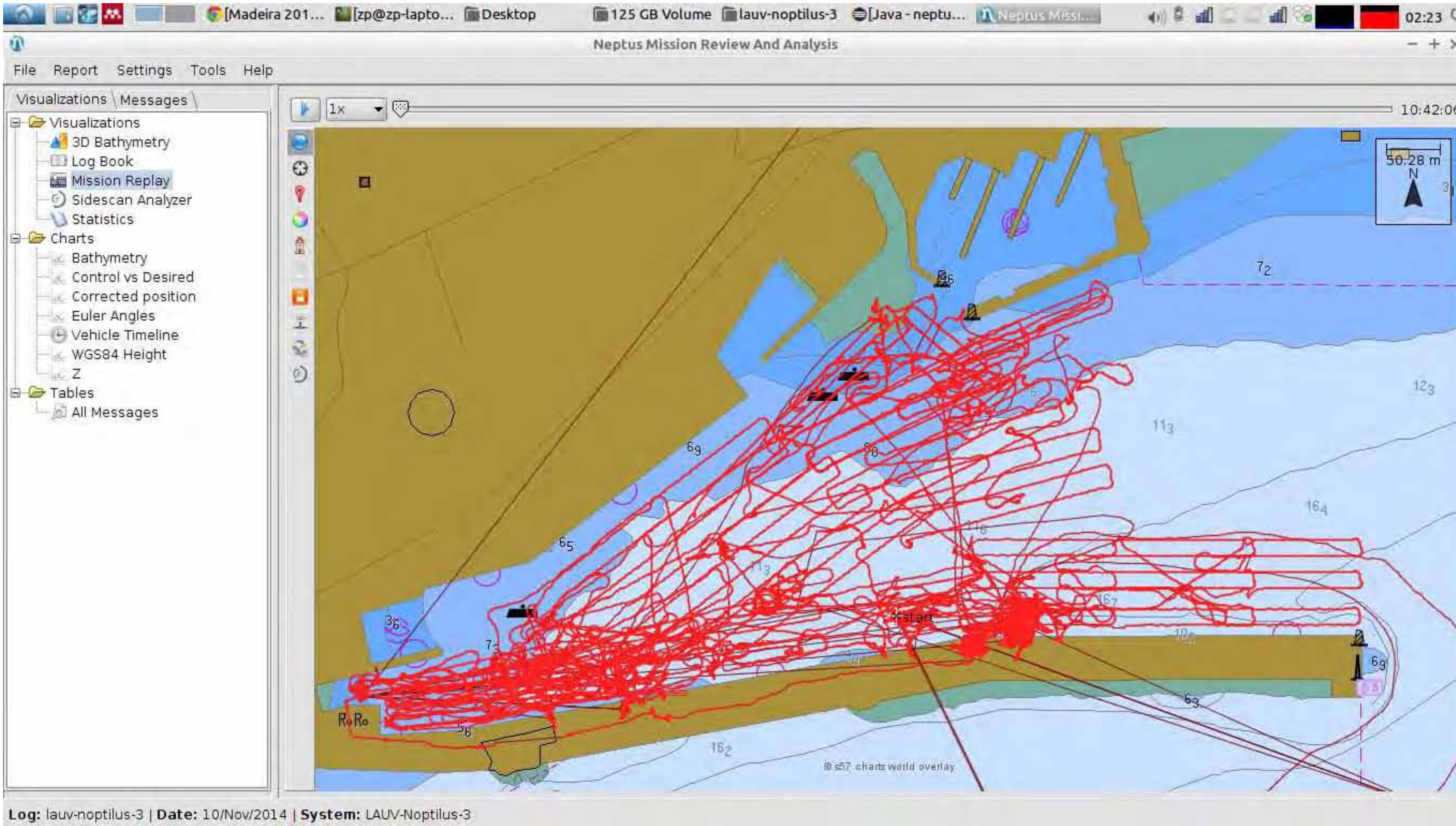
arditi ciimar madeira SIANI

Light-AUV

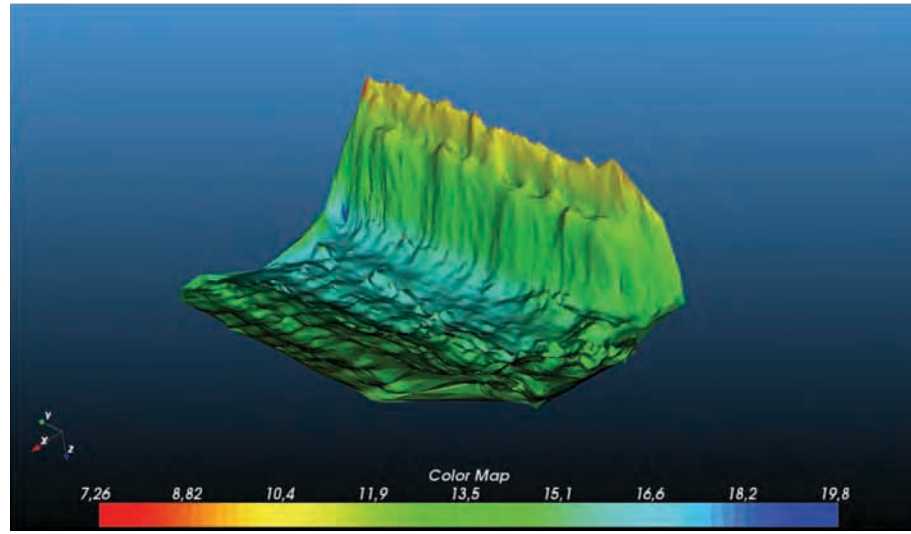


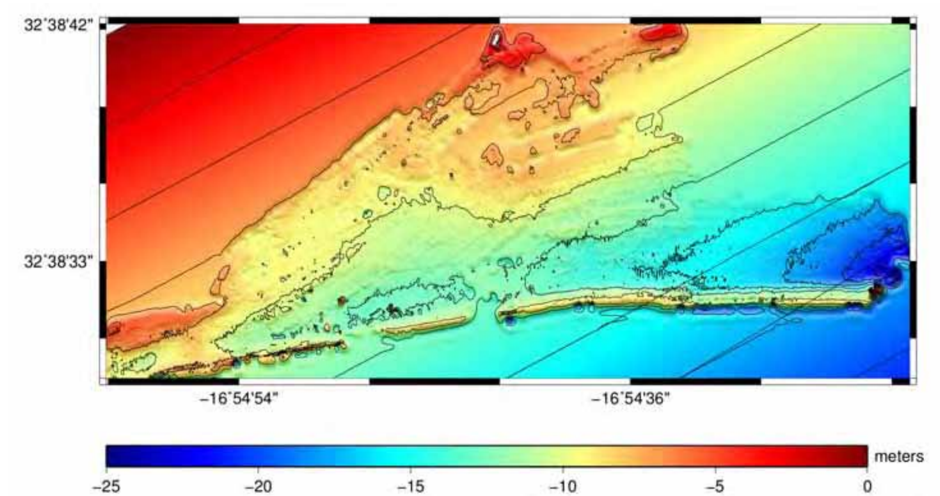
Antenna Mast
(Wi-fi, GPS, GSM, Iridium)
Flexible Fins
Camera
Batteries
On-Board CPU
DVL
Multi-Beam EchoSounder
Illumination
Environmental Sensors
Magnetic Coupling
Thruster and Fins Controllers
Comms and Navigation
Sidescan Sonar
Yellow fin Edgetech
Ballast
Acoustic Modem
IMU
Honeywell HG 1700
Wet/Dry Interface
Forward Looking Sonar
Acoustic Transducers
Evologics

MISSION-I: Bathymetry



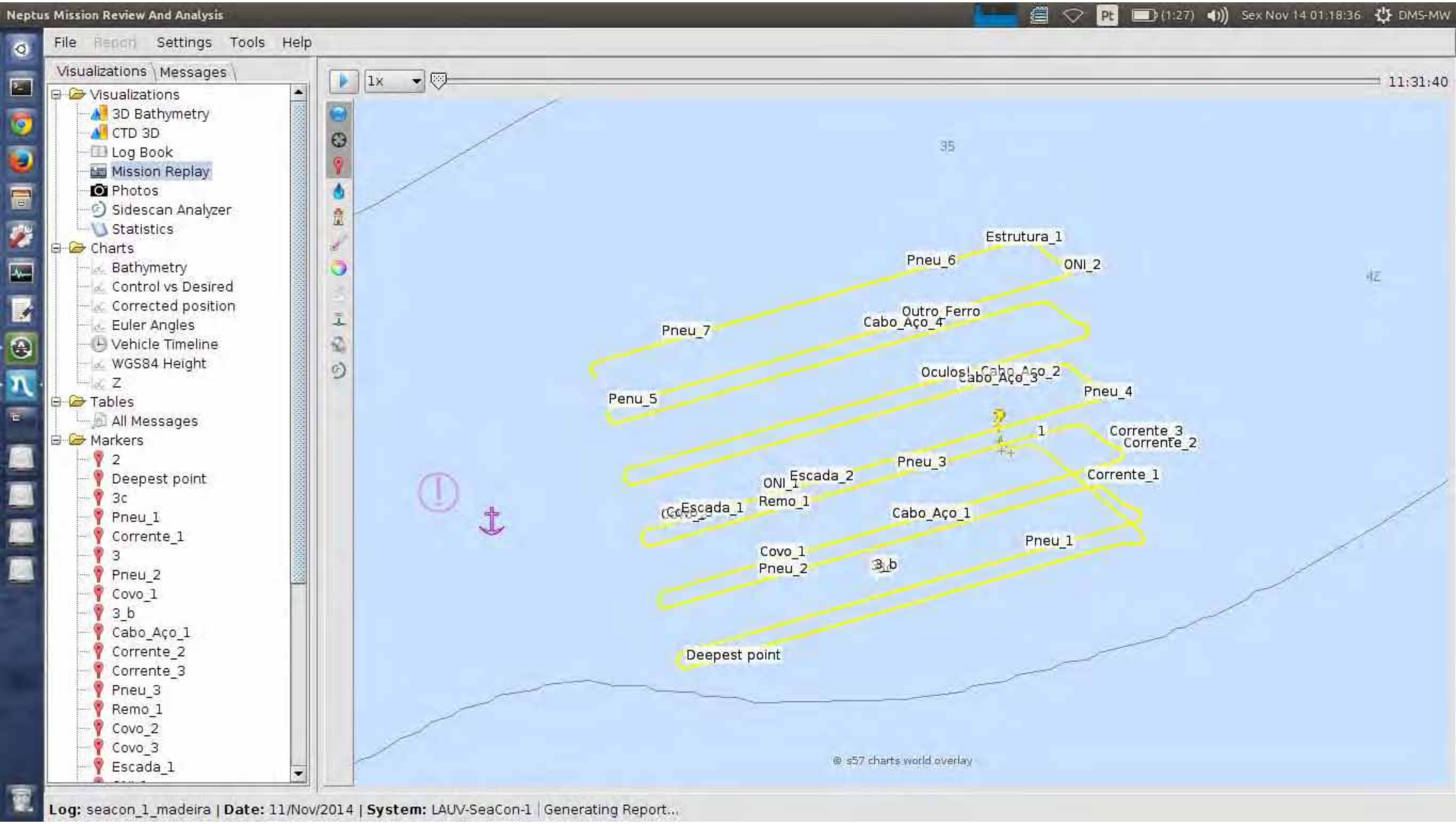
Funchal Harbor Bathymetry



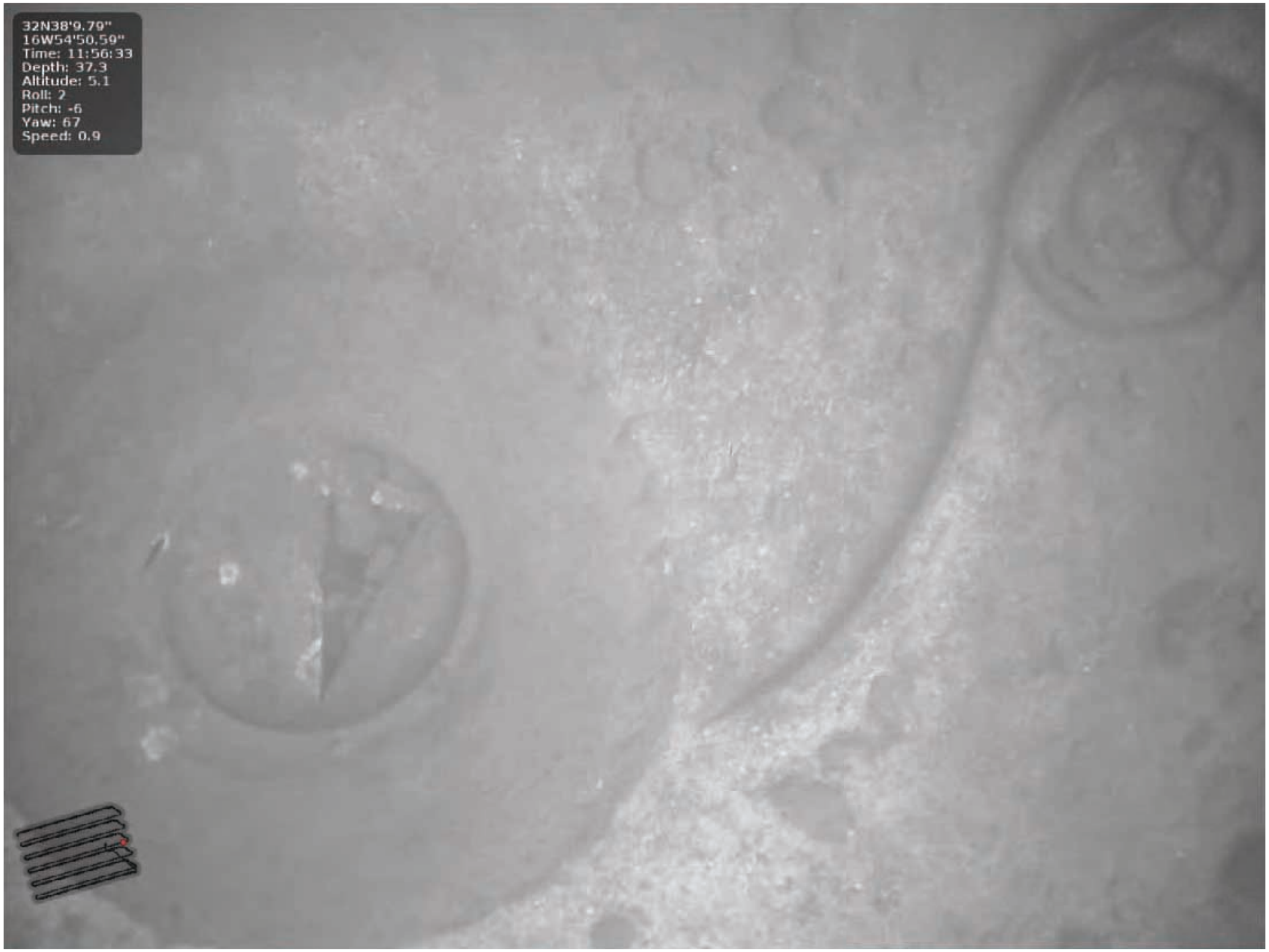


Mission-II: Search & Location

Mission-II: Search & Location

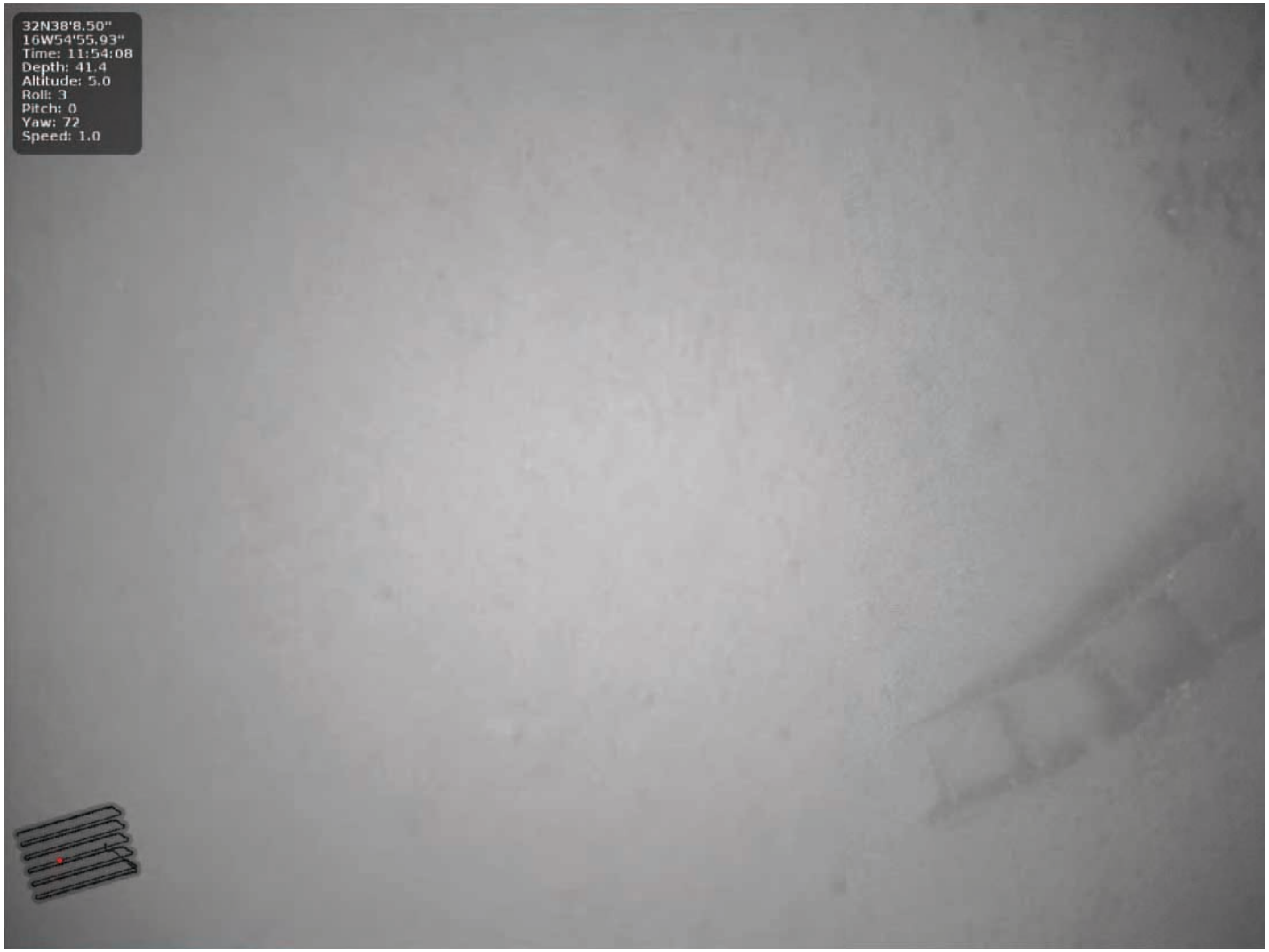


Mission-II: Search & Location



Mission-II: Search & Location

Mission-II: Search & Location



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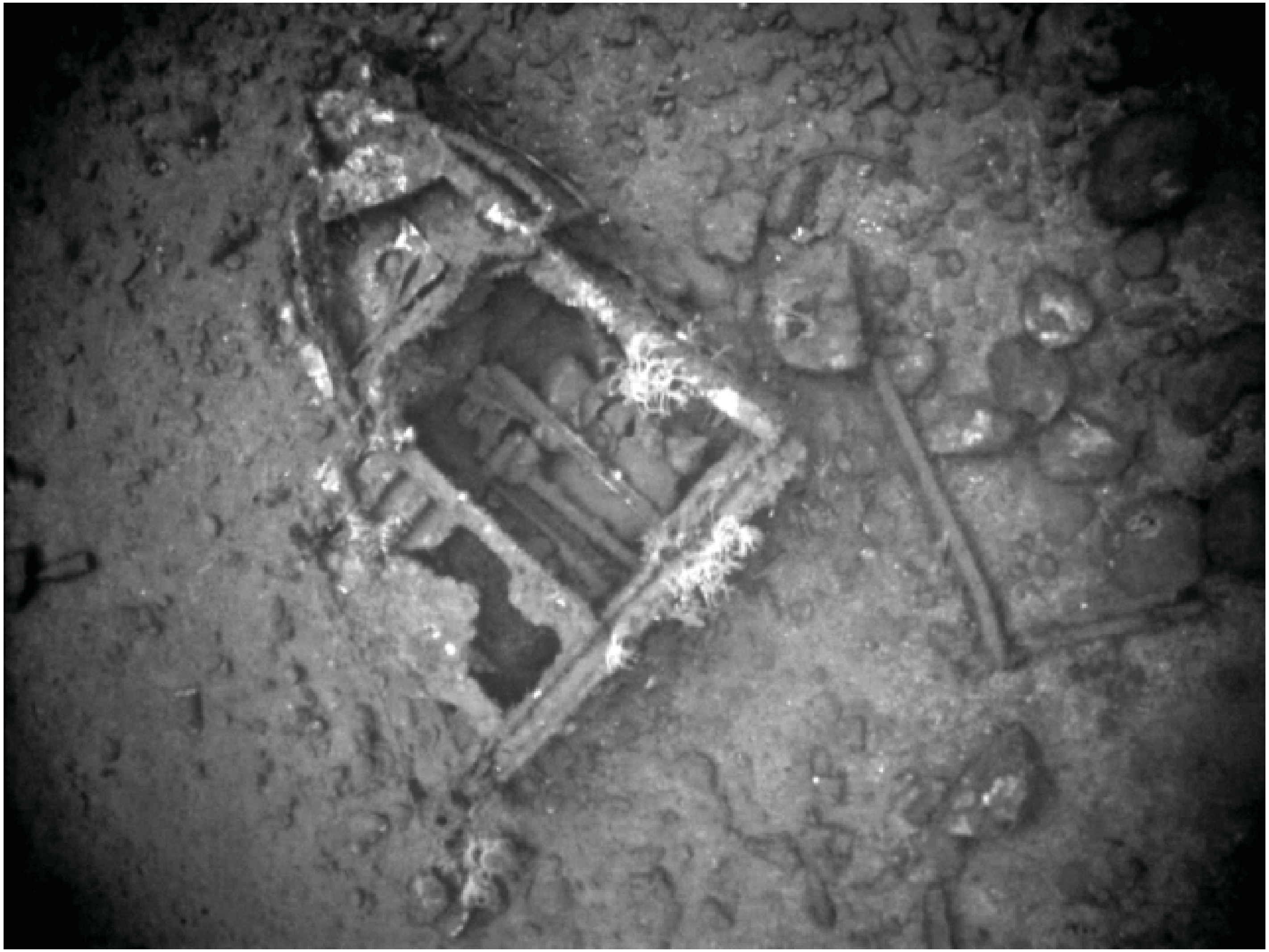

Mission-II: Search & Location

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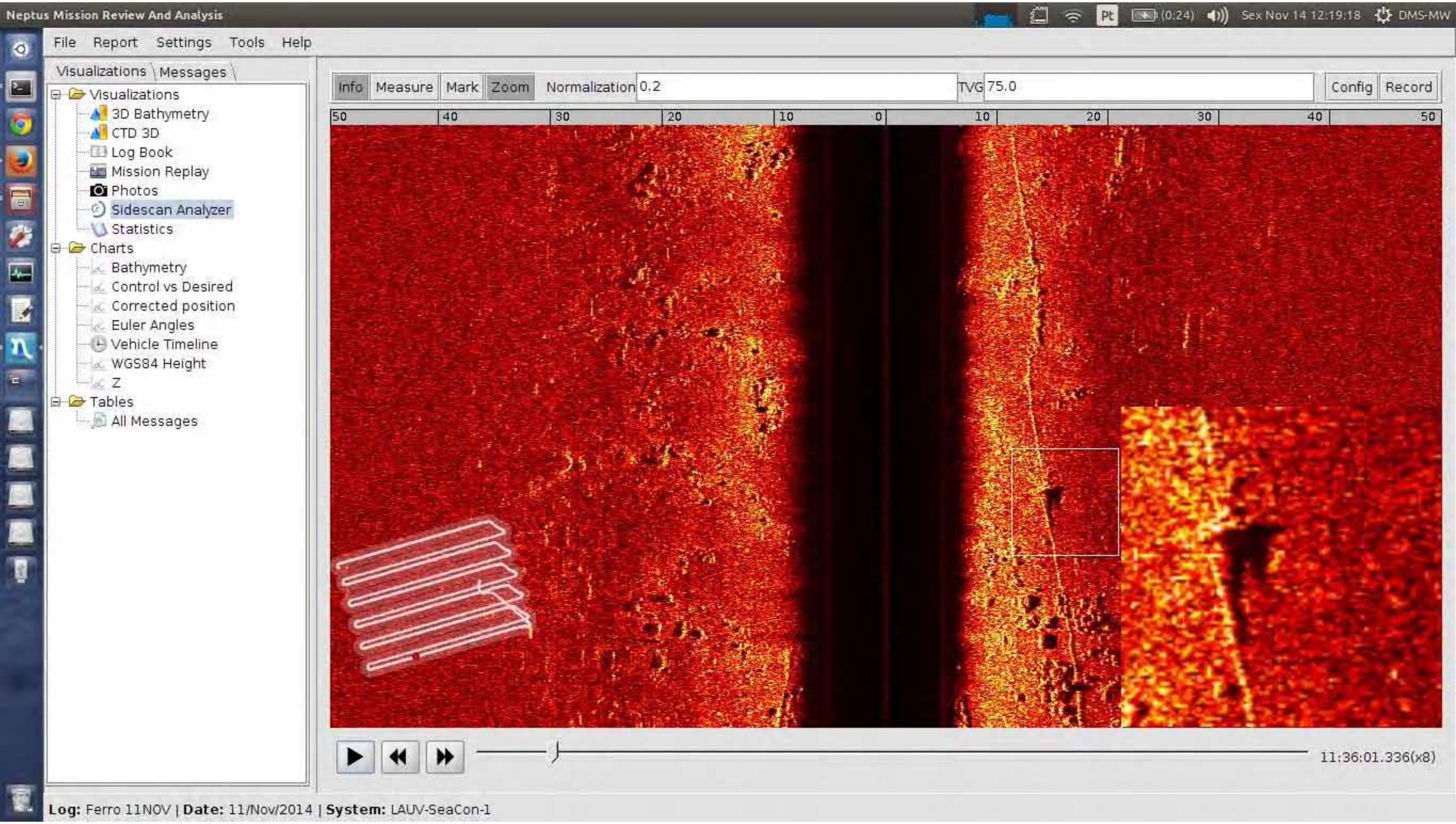

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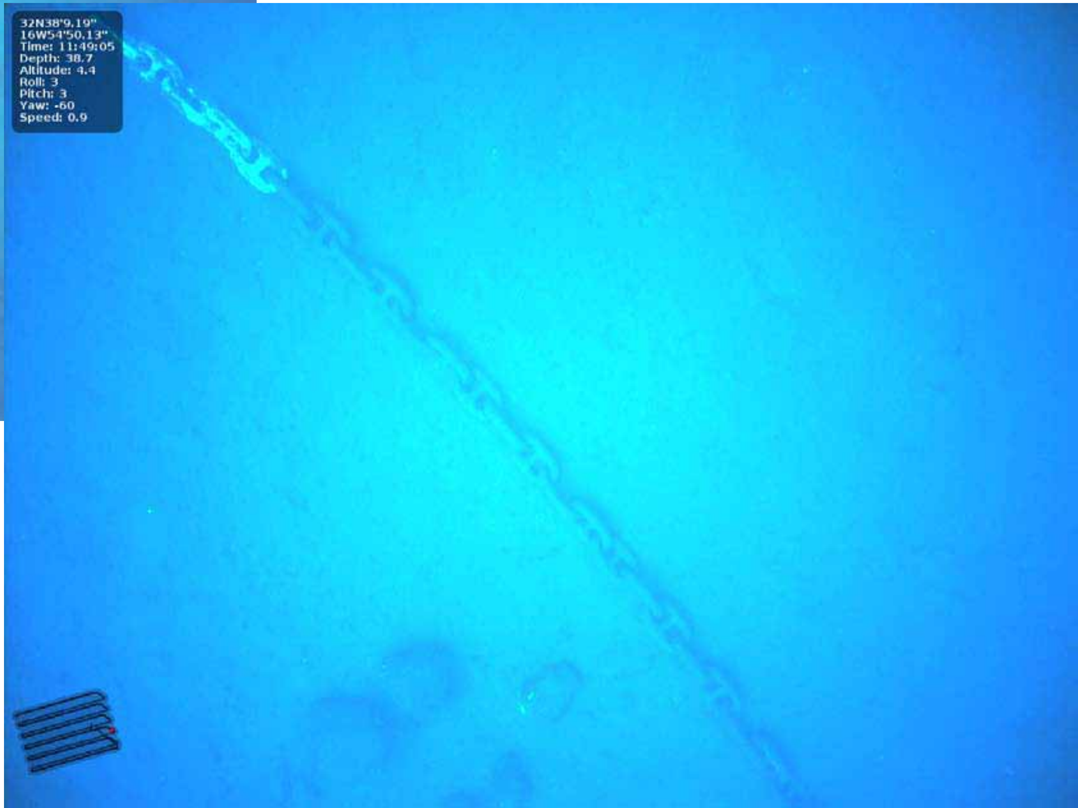
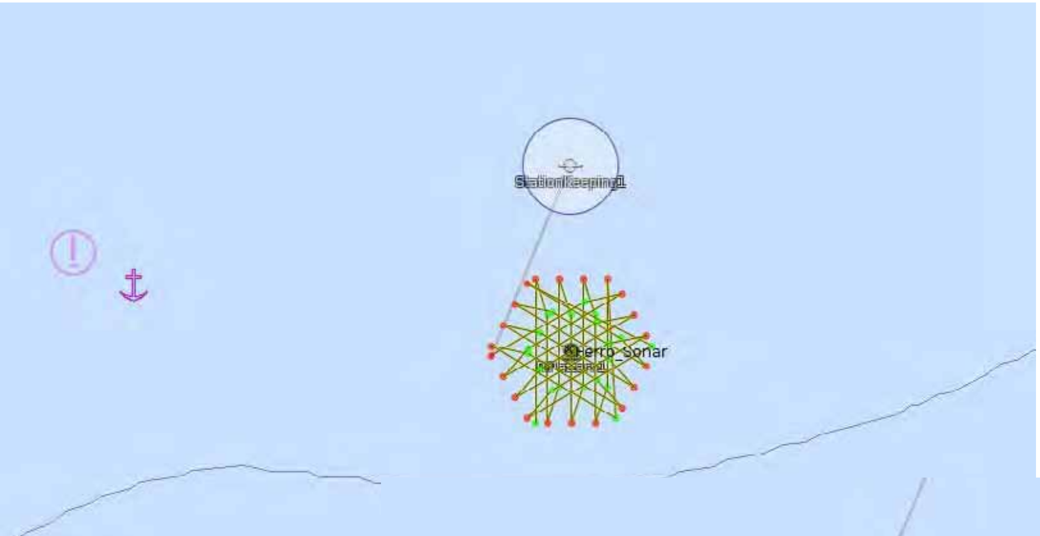
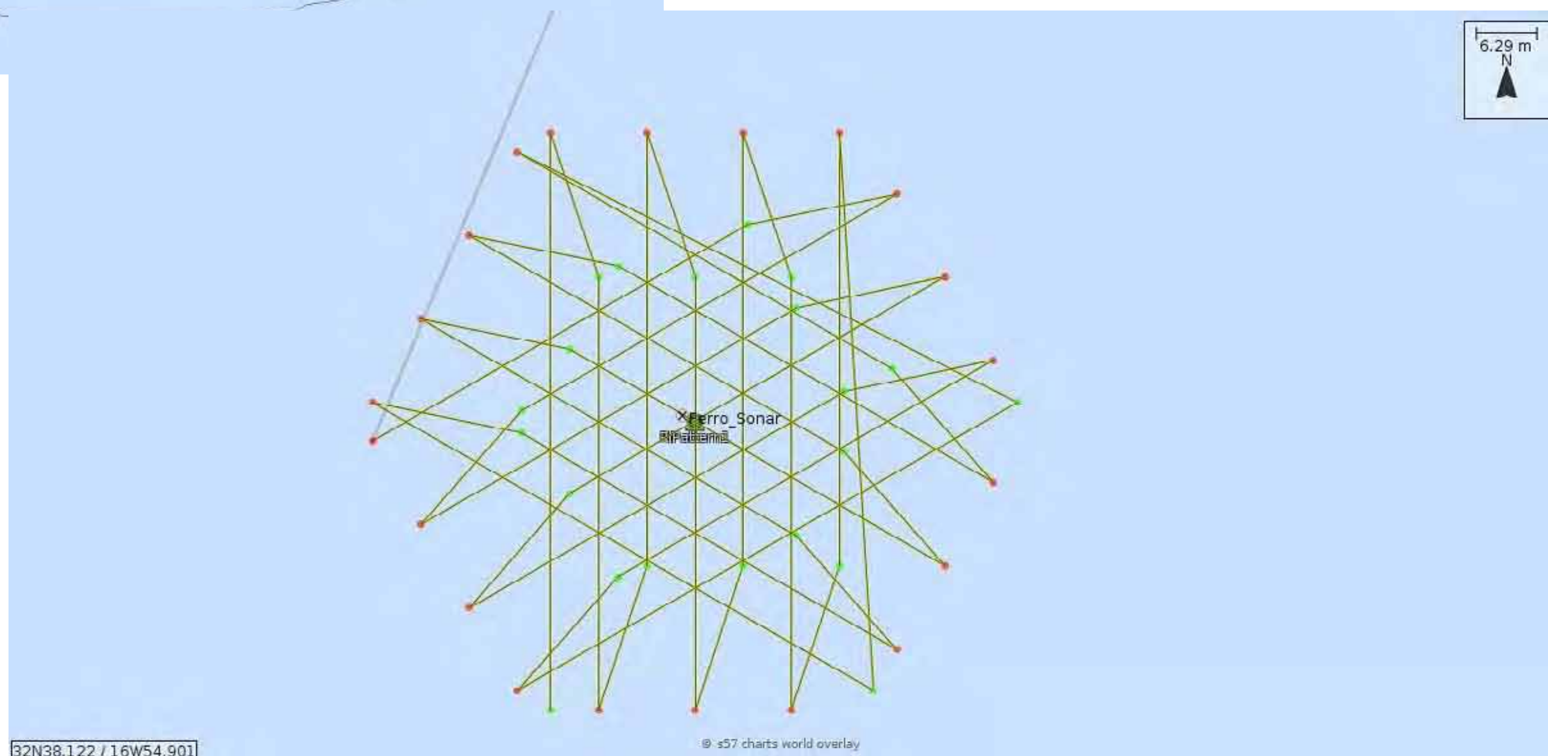
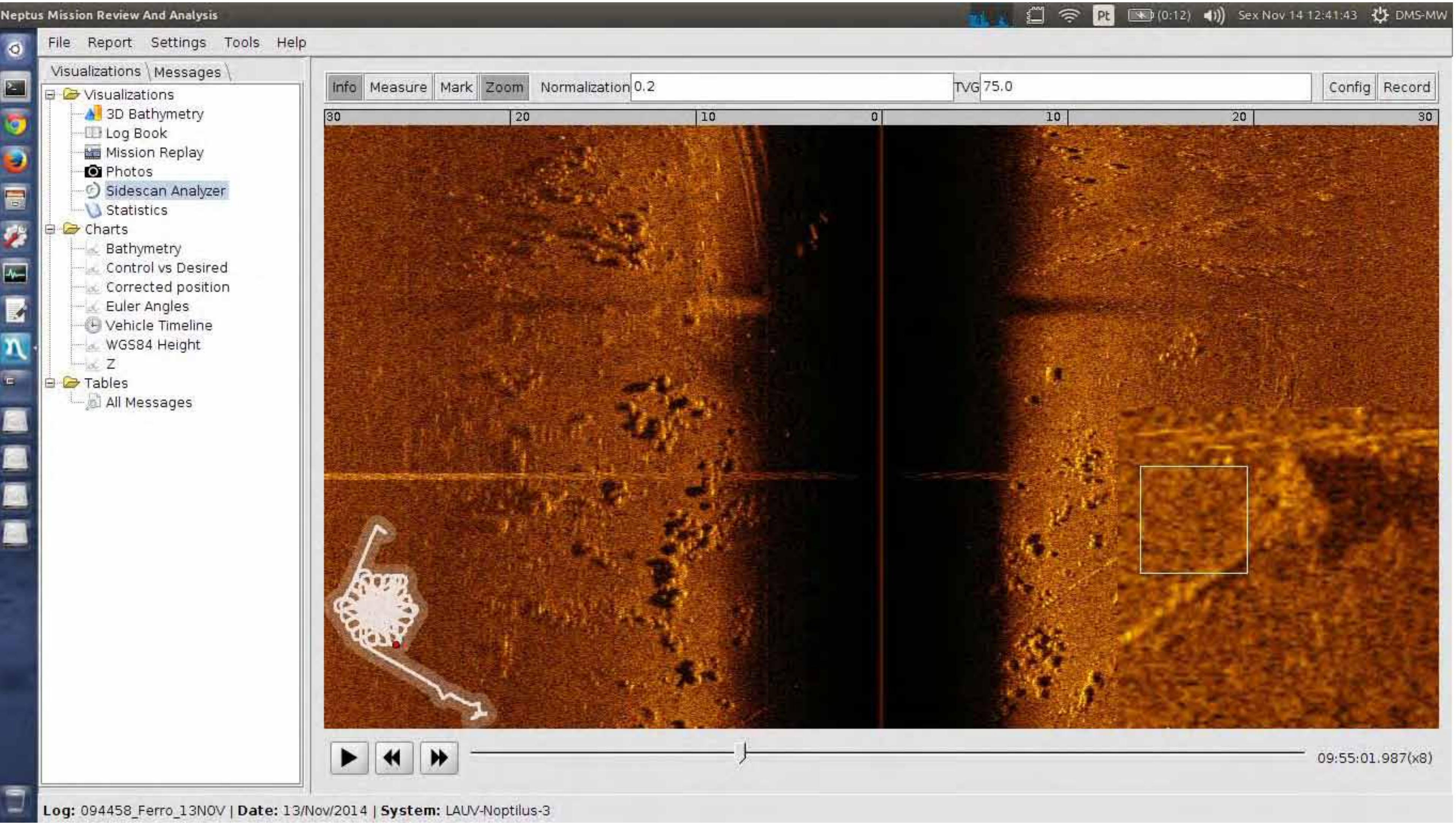


Mission-II: Search & Location

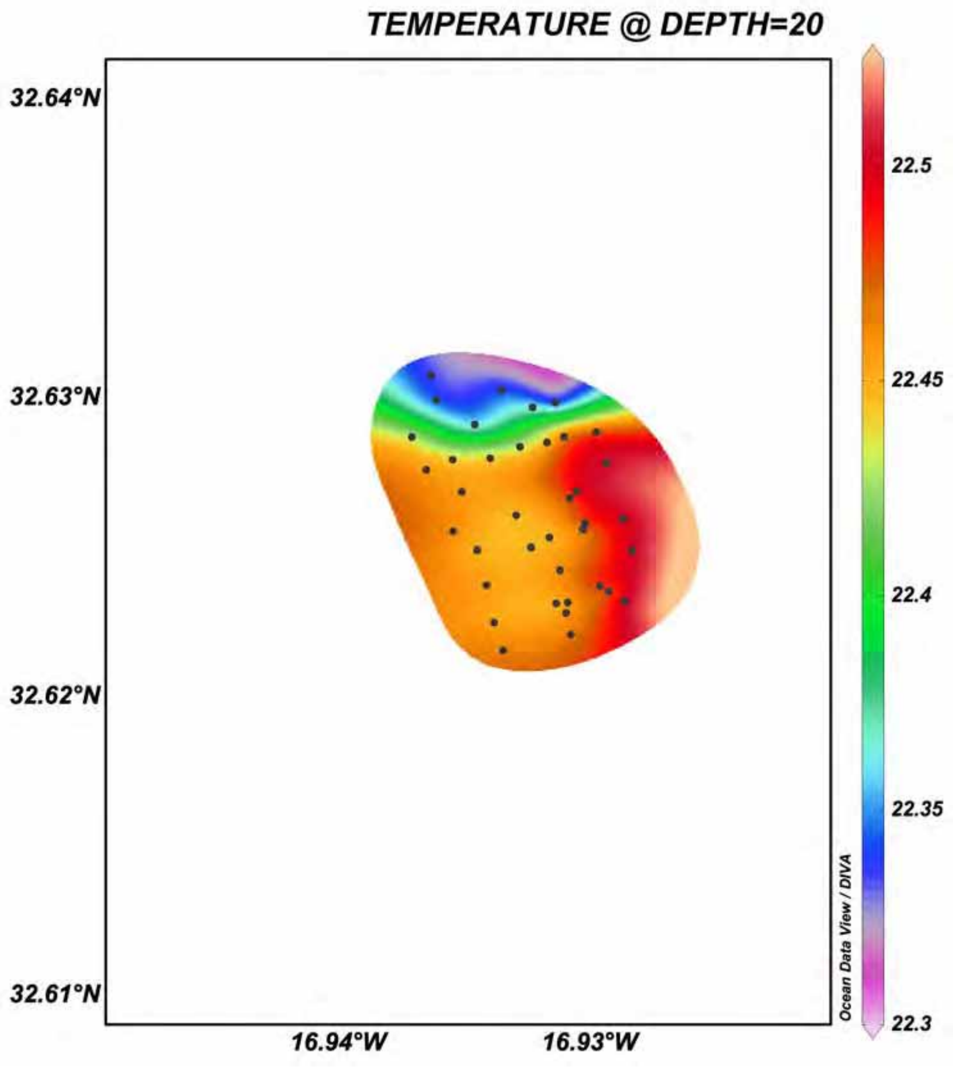


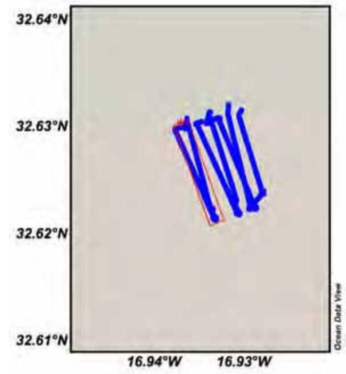


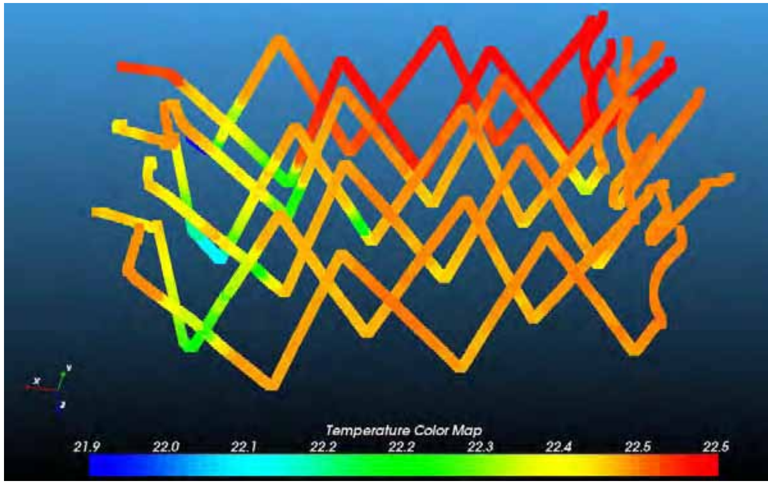
Mission-II: Search & Location



Mission-III: CTD

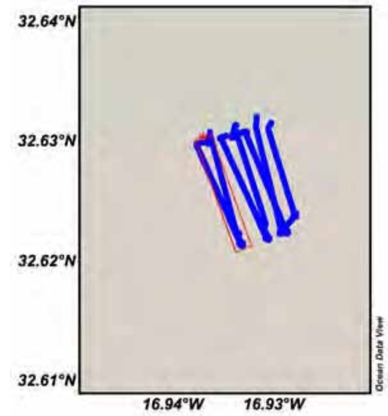


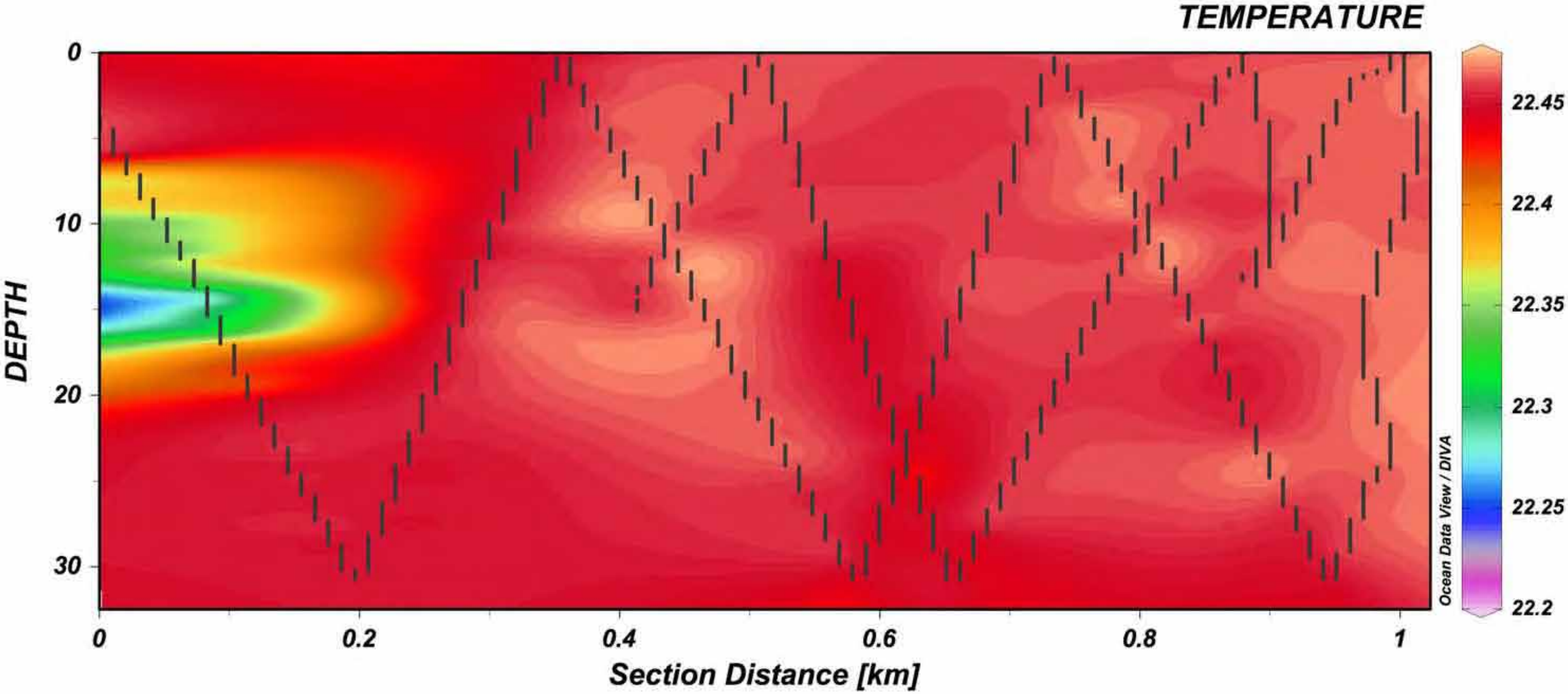




- LAUV: 2h @ ~1.2 m/s
- 22 perfis individuais com 1-navio ~5-6h

Mission-III: CTD





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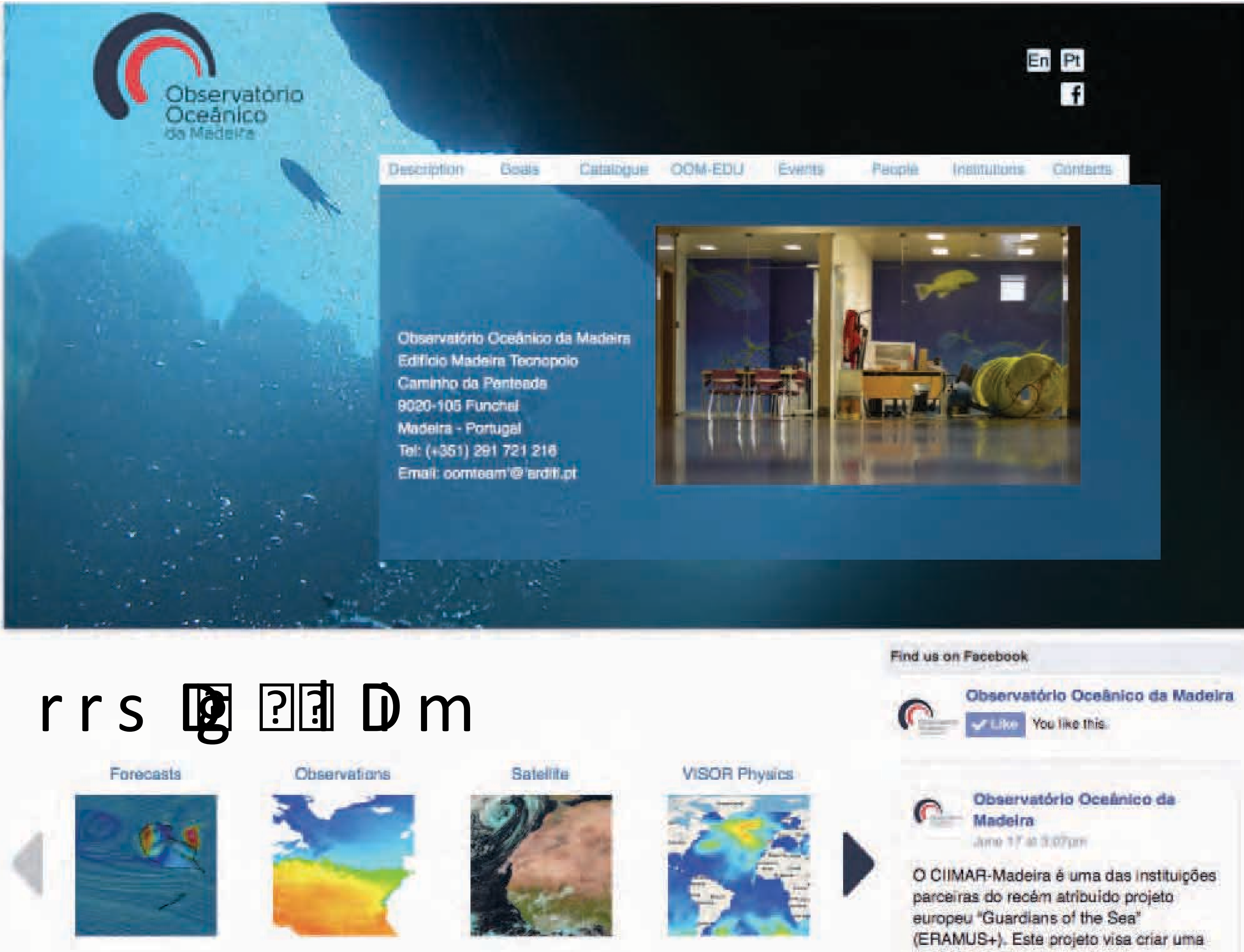
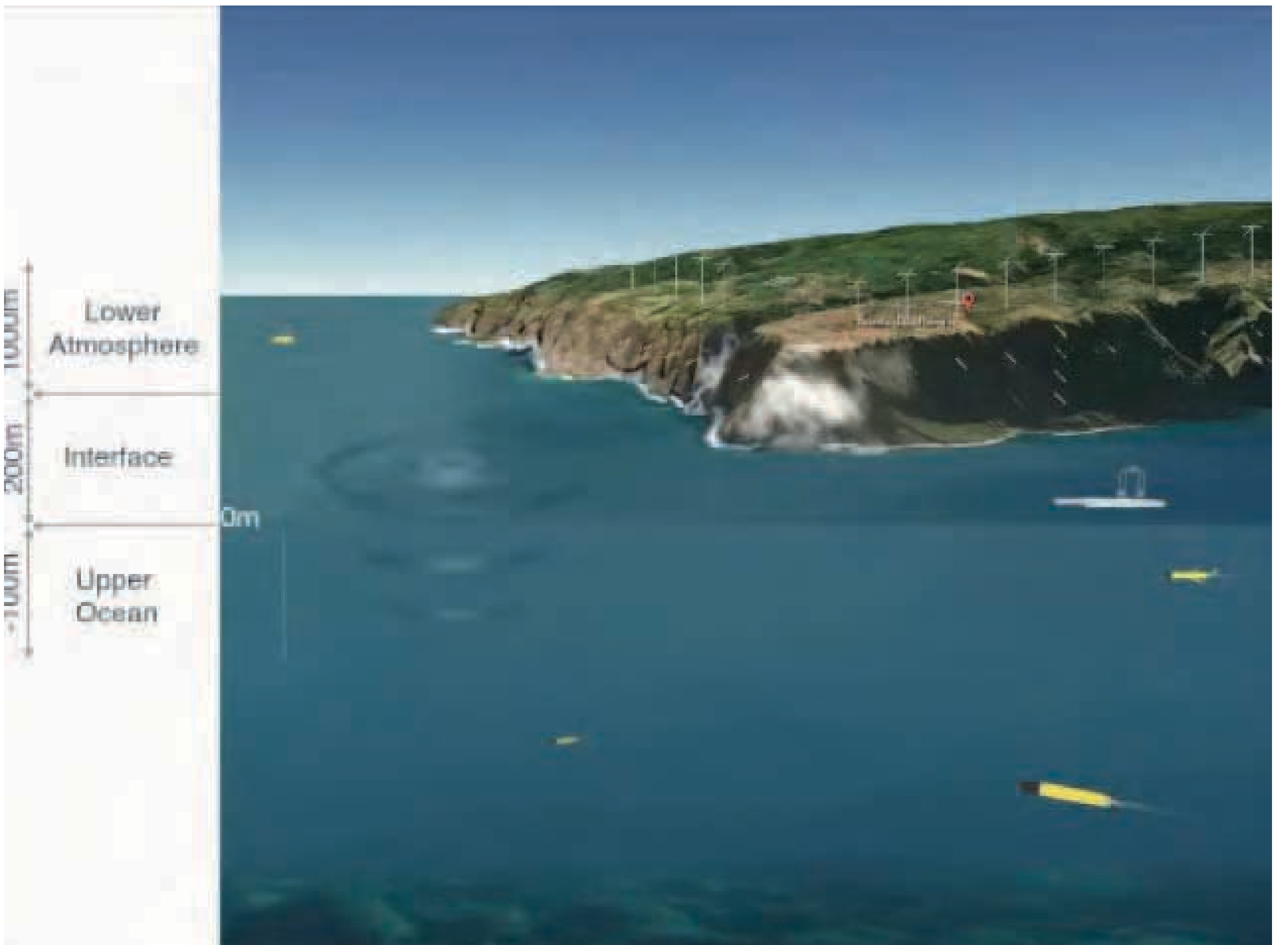
Observatório
Oceânico
da Madeira

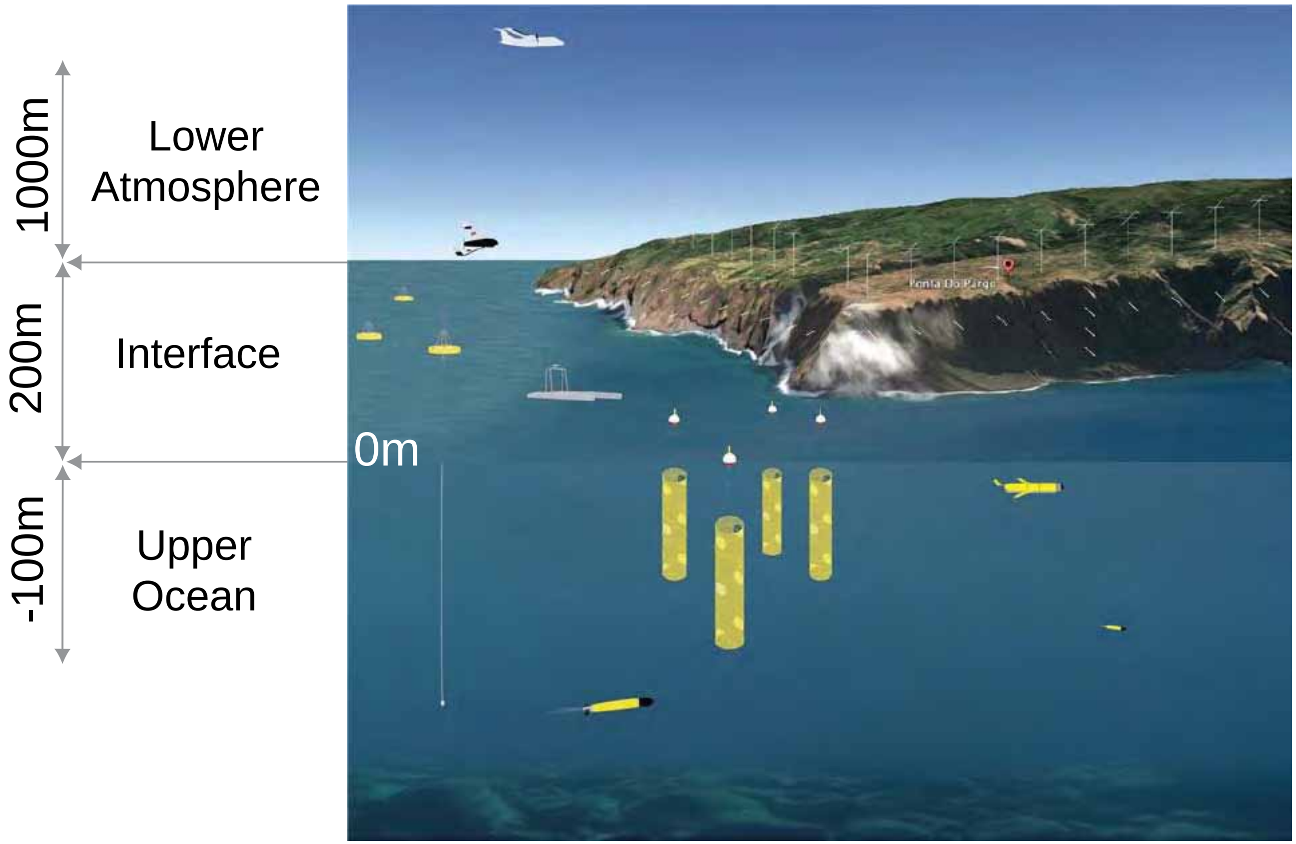


Observatório Oceânico da Madeira
En
Pt
Description
Goals
Catalogue
OOM-EDU
Events
People
Institutions
Contacts
Observatório Oceânico da Madeira
Edifício Madeira Tecnopolo
Caminho da Penteada
9020-105 Funchal
Madeira - Portugal
Tel: (+351) 291 721 216
Email: oomteam'@'arditi.pt
Find us on Facebook
Observatório Oceânico da Madeira
Like
You like this
Forecasts
Observations
Satellite
VISOR Physics
Observatório Oceânico da Madeira
O CIIMAR-Madeira é uma das instituições parceiras do recém atribuído projeto europeu "Guardians of the Sea" (ERAMUS+). Este projeto visa criar uma

[illegible] p[illegible] [illegible]r u[illegible]



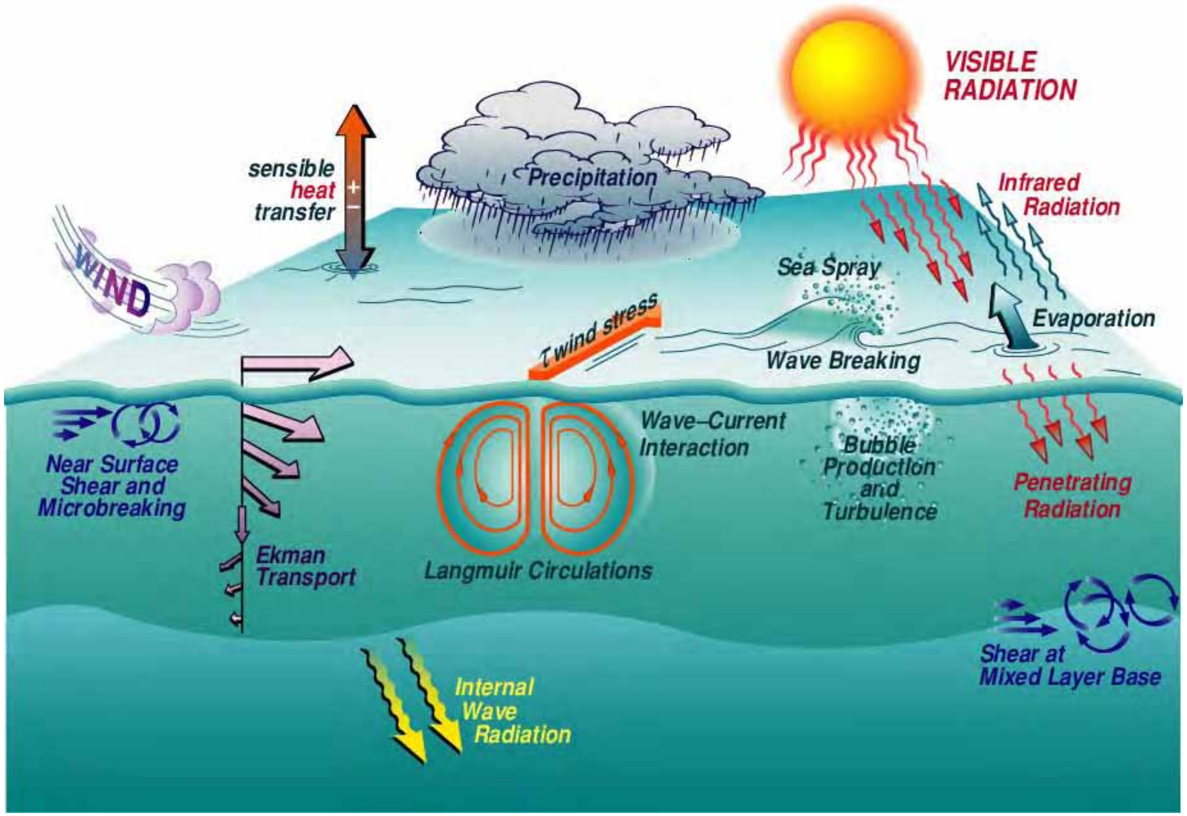
FUTURE: Madeira is an excellent system to study the air-sea interface



It is real!


Thank you!

Boundary layer interaction



Source: Coupled Boundary Layers Air-Sea Transfer Defense Research Initiative (CBLAST-DRI)

EMRA'15 workshop

Session 7. Chair – João Pedro Gomes

16:30 **SubCULTron(EU project)**

17:00 **T4.3 – *An Introduction to real-time data processing in autonomous survey operations***
Niels Nijhuis, CARIS EMEA, NL

EMRA´15

ISR-IST Lisbon Portugal

EMRA'15 workshop

SubCULTron
EU PROJECT

Thomas Schmickl
Univ. Graz, AT

subCULTron

[illegible]

[illegible]

[illegible]

[illegible]

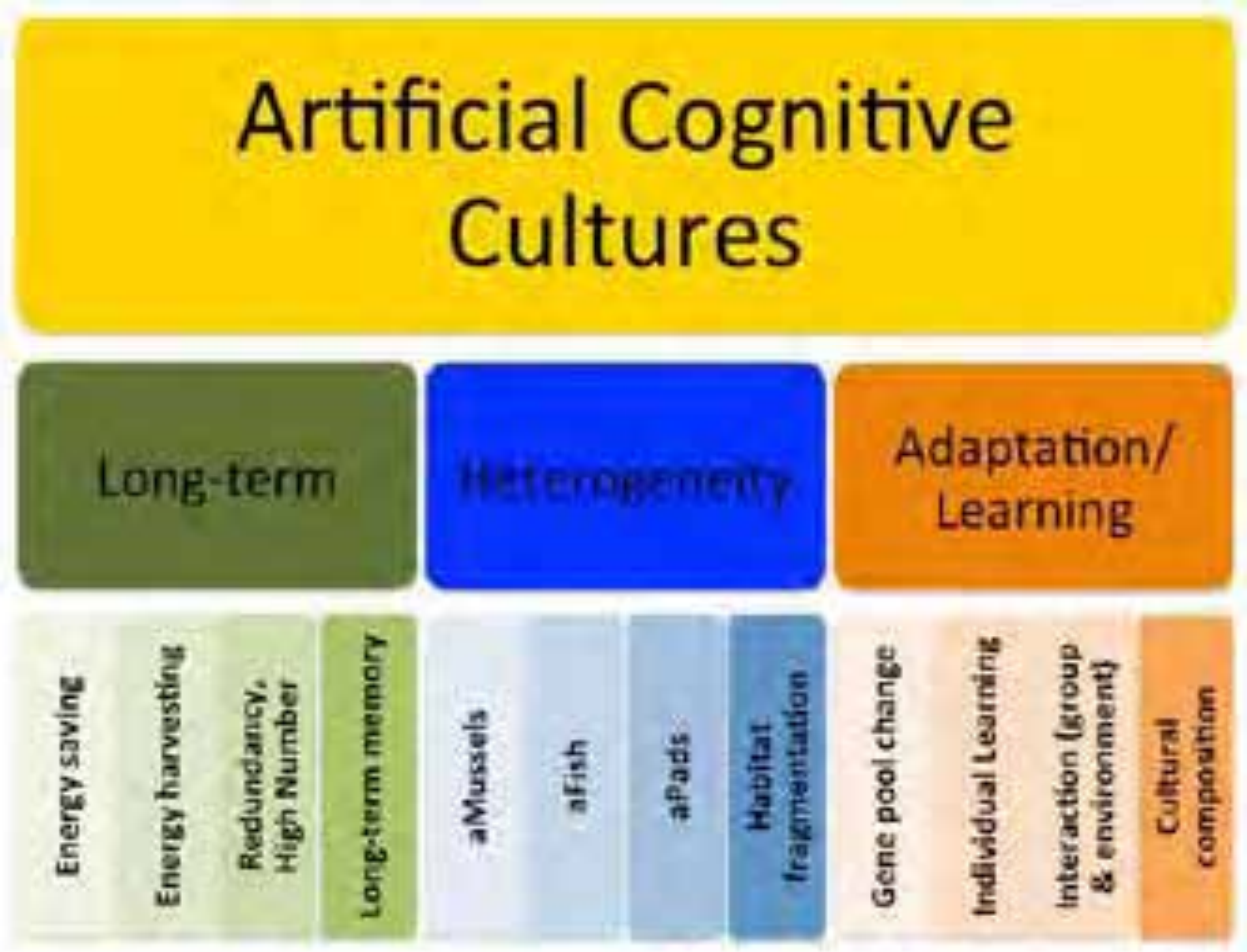
[illegible]

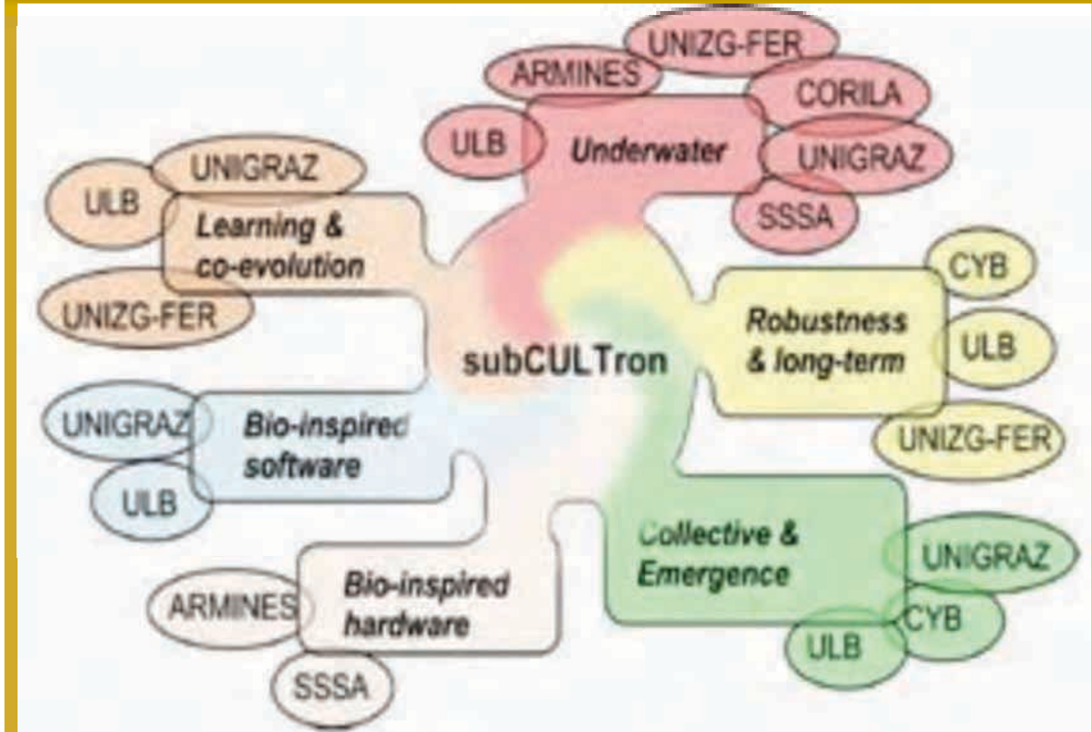

Two robots acting as
social agents

Swarms, heterog... ity

...phor...

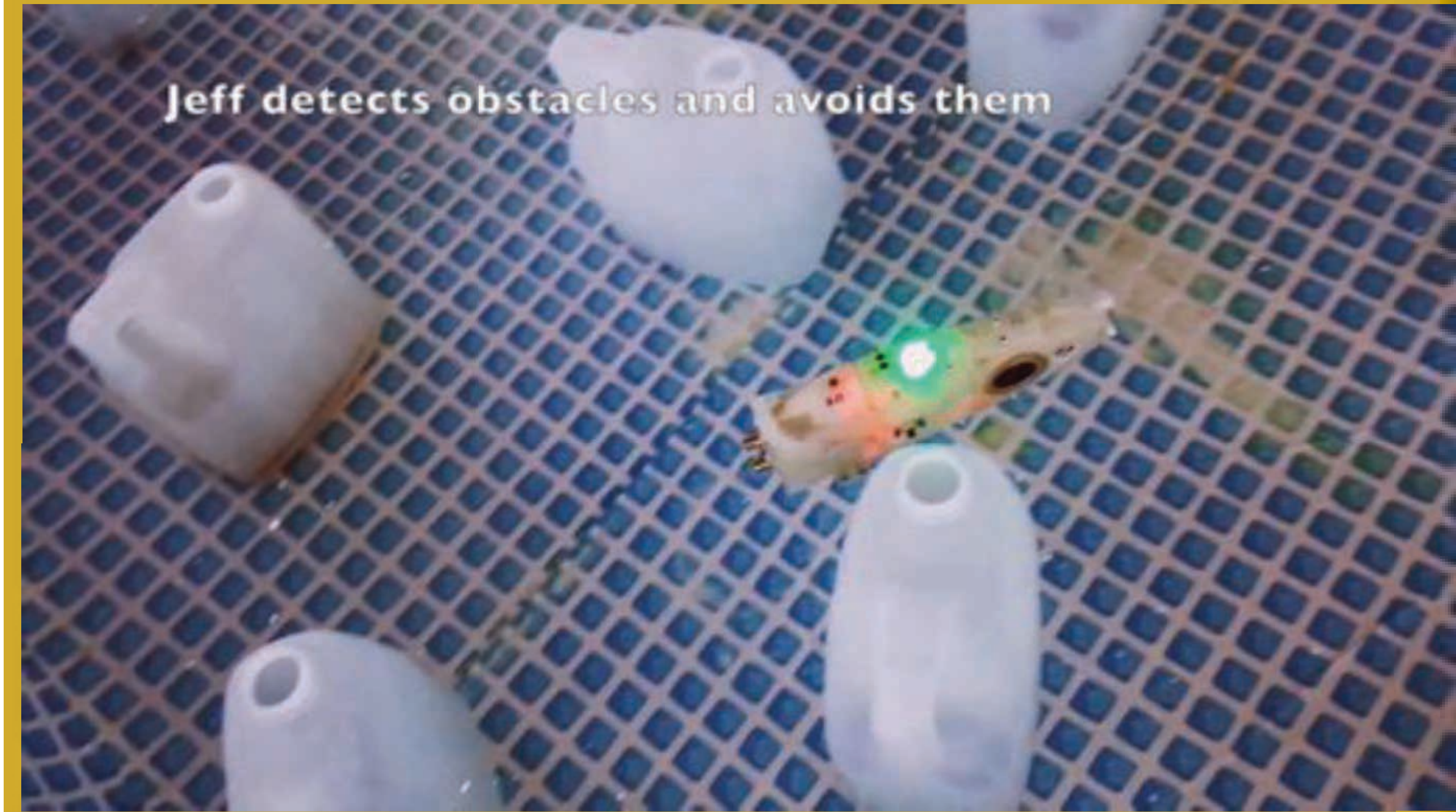
subCULTron


Artificial Cognitive Cultures
Long-term
Heterogeneity
Adaptation/ Learning
Energy saving
Energy harvesting
Redundancy, High Number
Long-term memory
aMussels
aFish
aPads
Habitat fragmentation
Gene pool change
Individual Learning
Interaction (group & environment)
Cultural composition



Partners:

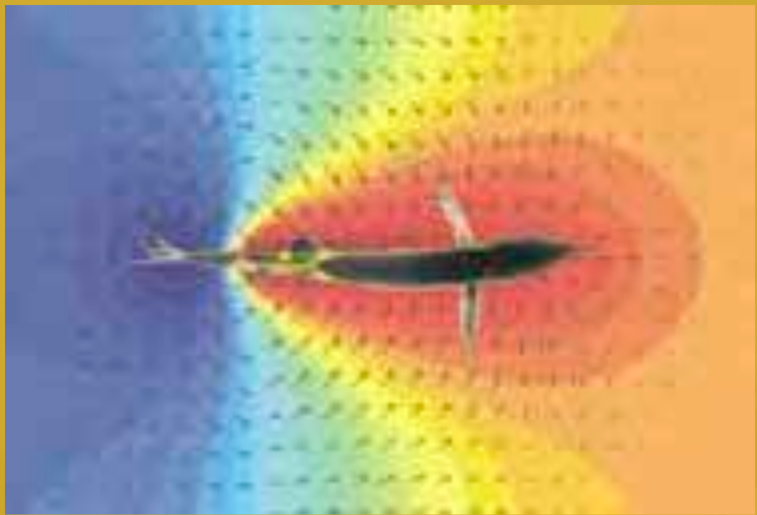
- University of Graz (UNIGRAZ)
- Scuola Superiore Sant'Anna (SSSA)
- Université libre de Bruxelles (ULB)
- University of Zagreb (UNIZG-FER)
- Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES)
- SME: Cybertronica Research (CYB)
- Consortium for coordination of research activities concerning the Venice lagoon system (CORILA)

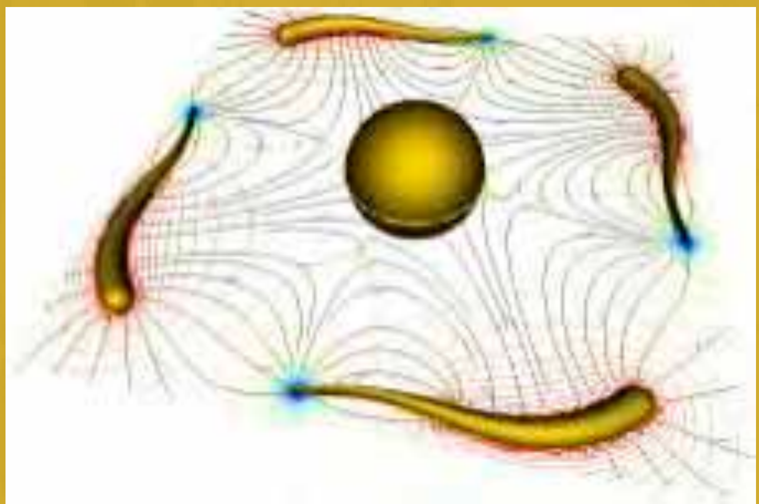

Jeff detects obstacles and avoids them

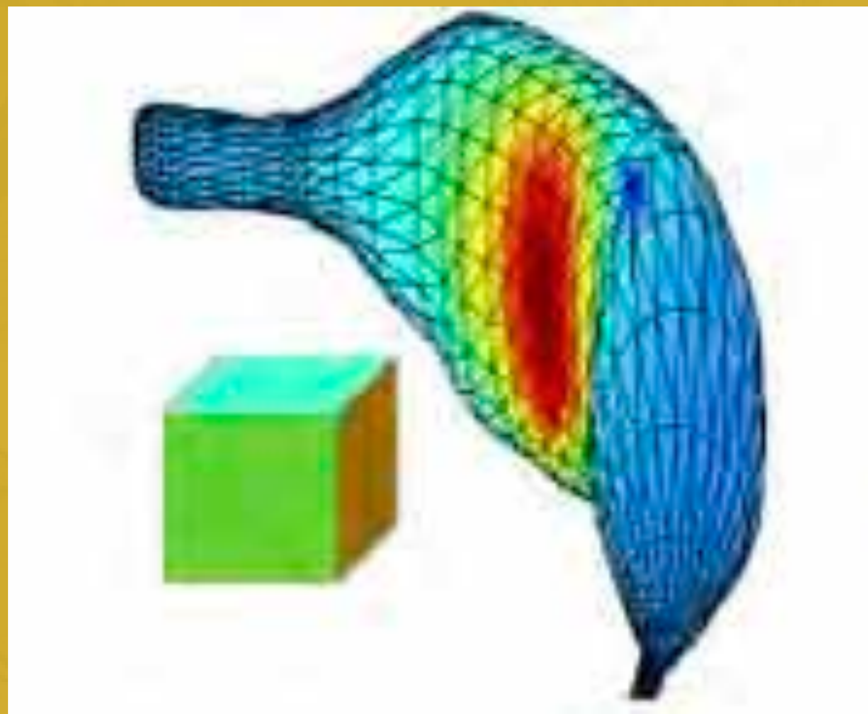
90??? ??-8 l?? ??1?ayA???8??R??t -8'???J?

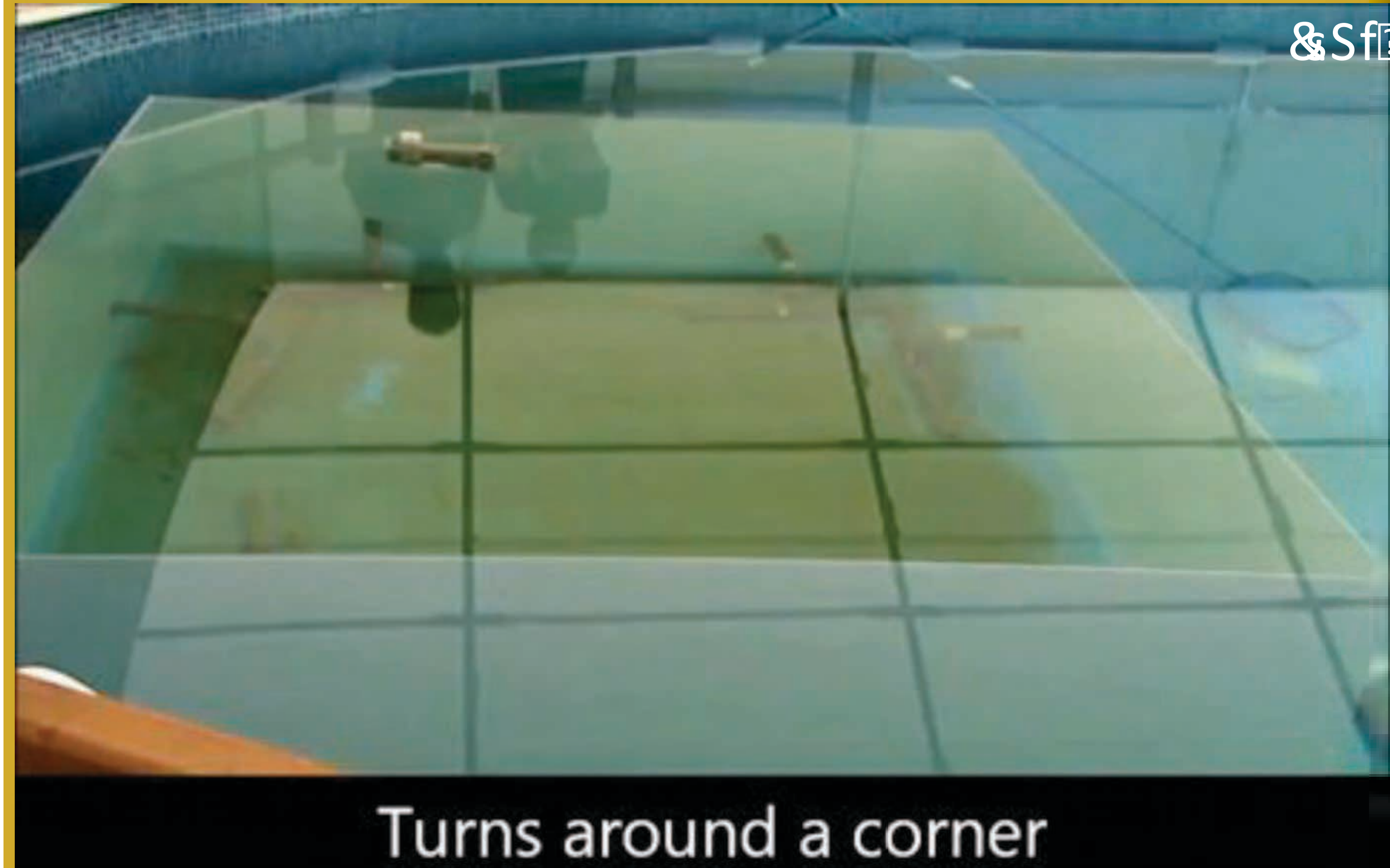
??NPK?DG?A?CE??NE?L J AO2?S ?I?APa?

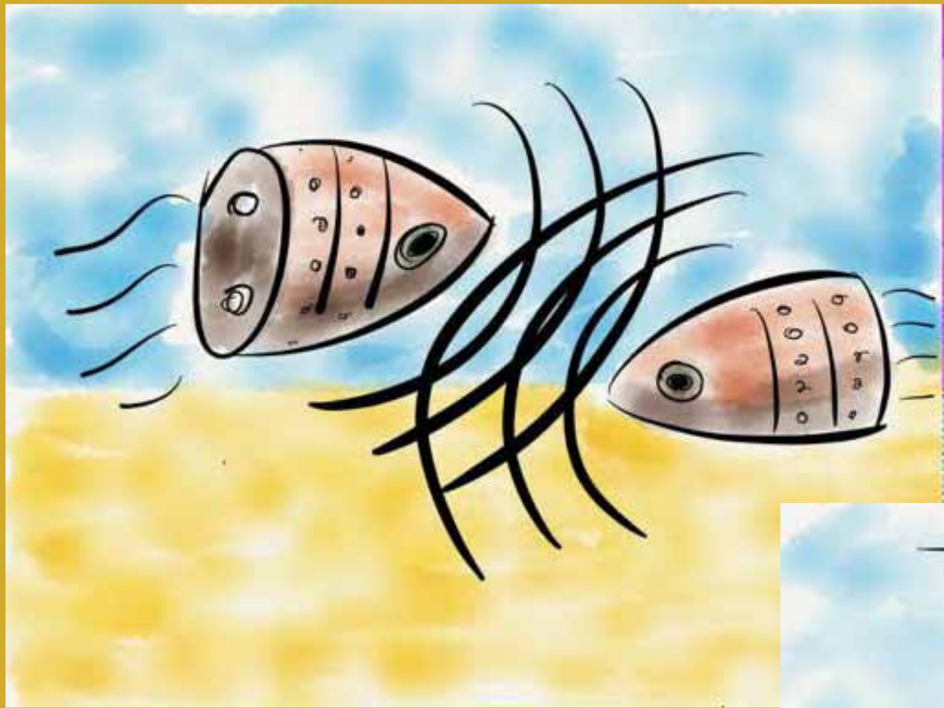
- ? 0-?8?8J9?? ??, ? ??8-?, 0-1a? J ?-9?&?5??J-A??9? 9?f?
- ?8?8J9??J-J R?-?18?5? ?9?ti?3M 88 9?&??t JR??i?9J-? MRf?
- ?a?-8y? ?809n?9?, AMRJ???? ?8t n8 ??0J? 8J? ARR? 9i ?, ?8??, ? a?8?8J9p?

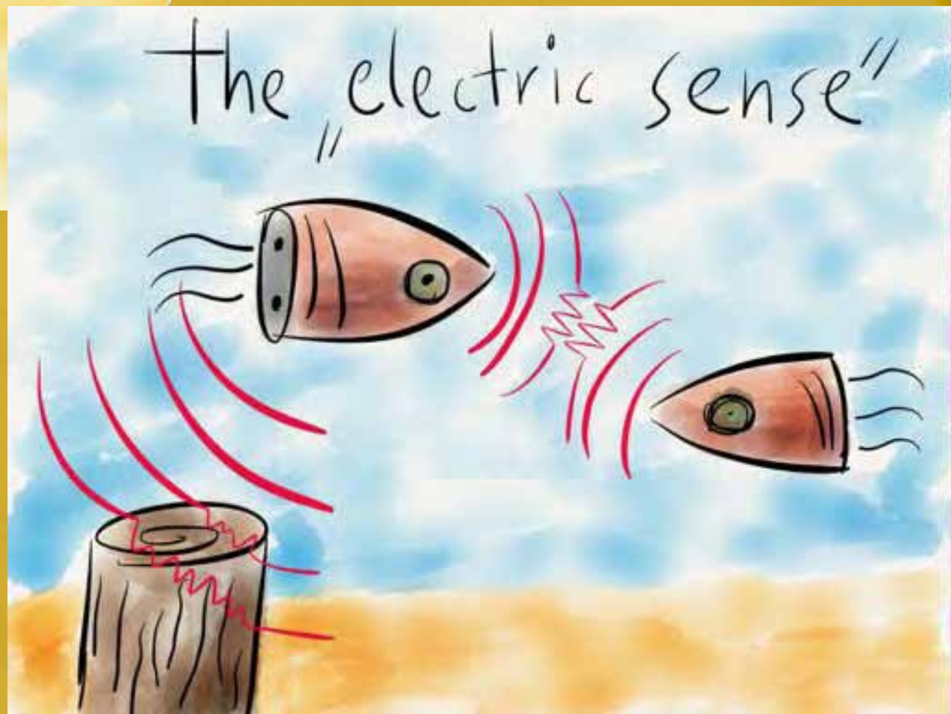







Turns around a corner

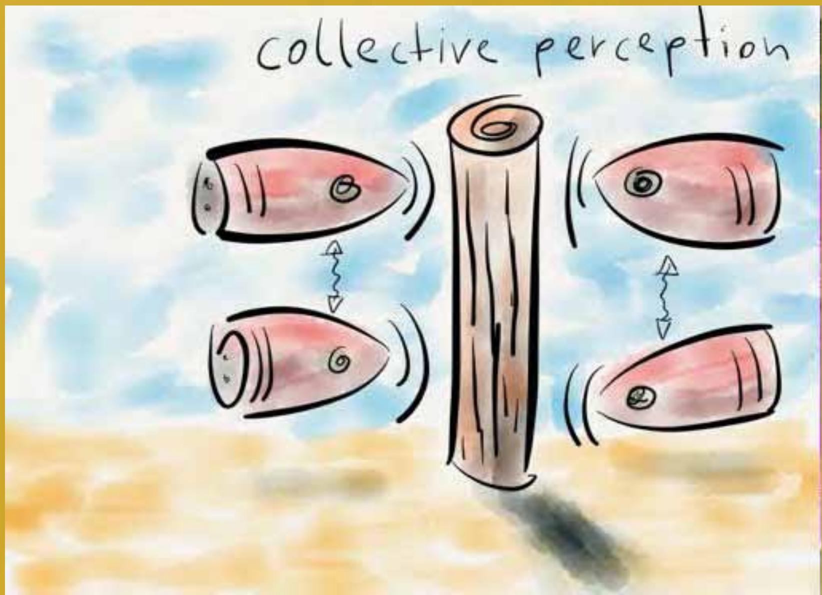


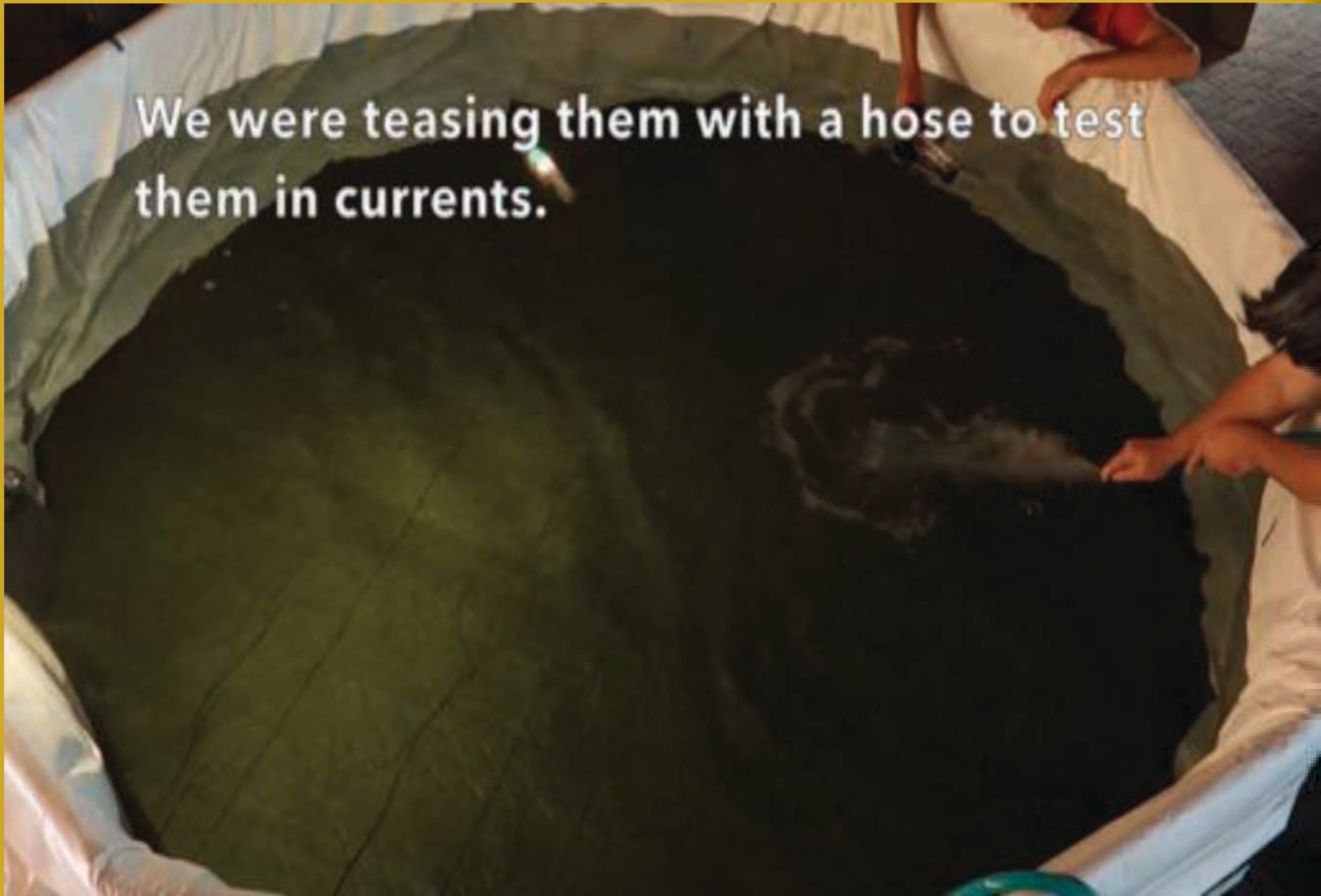

the „electric sense"

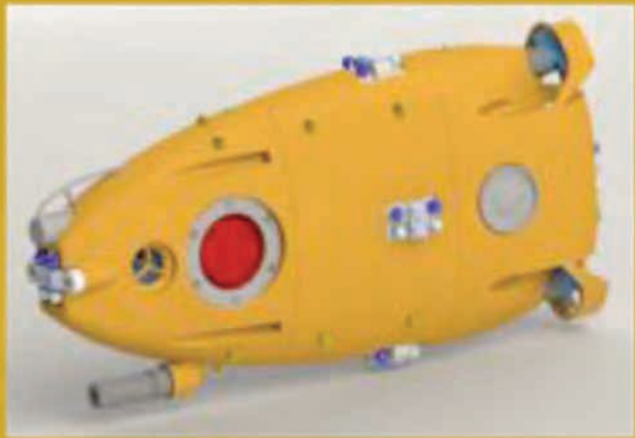
?85??nL??t ?-??t n8 ?

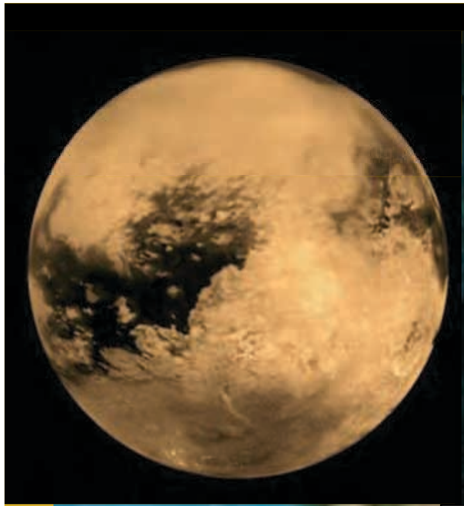
subCULTron

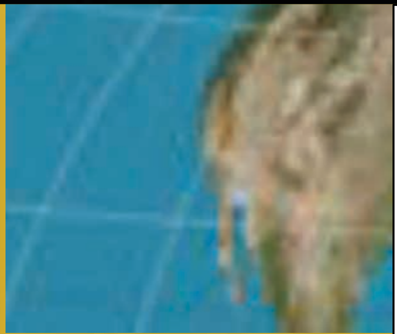
?A9?-A, A ?J??8?'??J?at ?9d9Ab?9d, J? ?-A5 9?




We were teasing them with a hose to test them in currents.

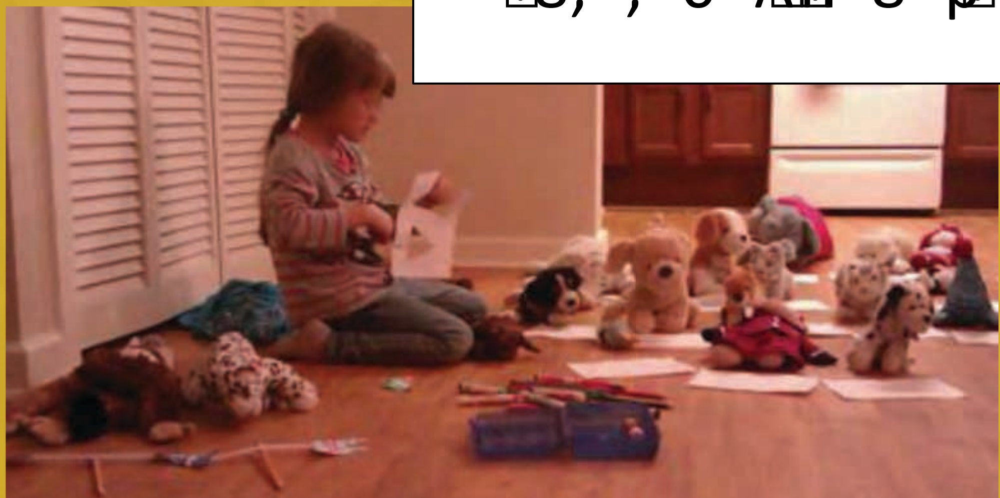




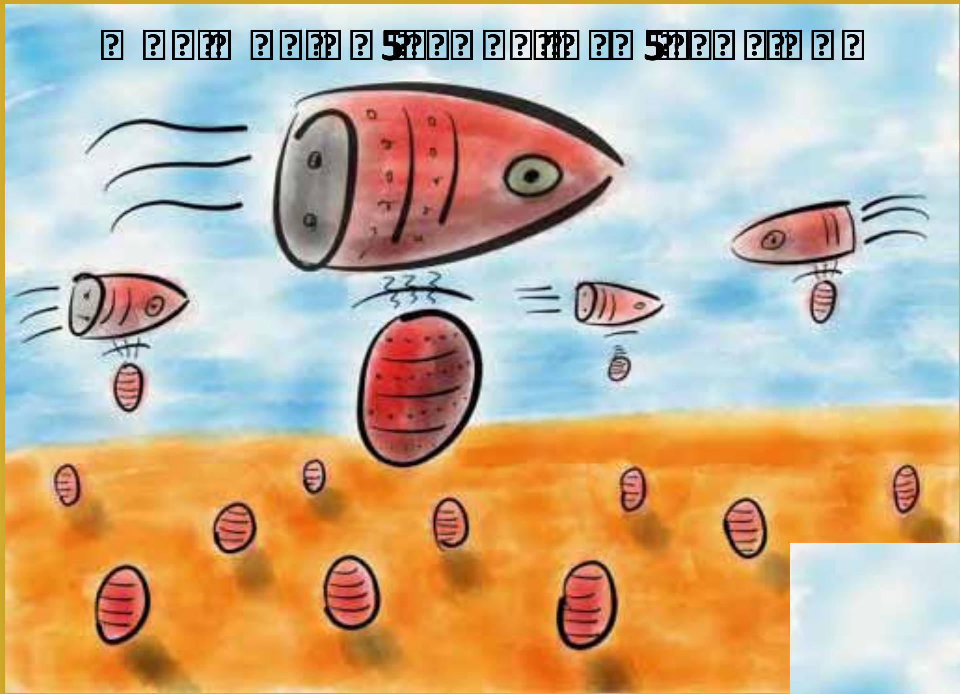
K I NPN DAAD DIP1

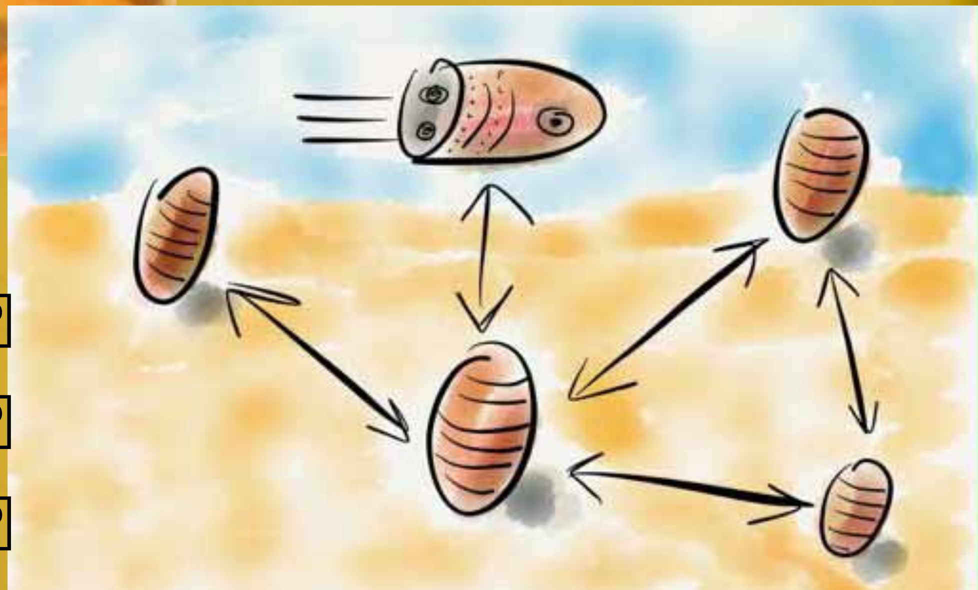
- 8 nLAa, 8 M-8 8J9A9-J R-5-8i
- 8 8J99J-0 J0- JR A8i R AJ
- 0A5 JR A8i A - 9J-0 J0- 8-
  8, , 0 An 8 p

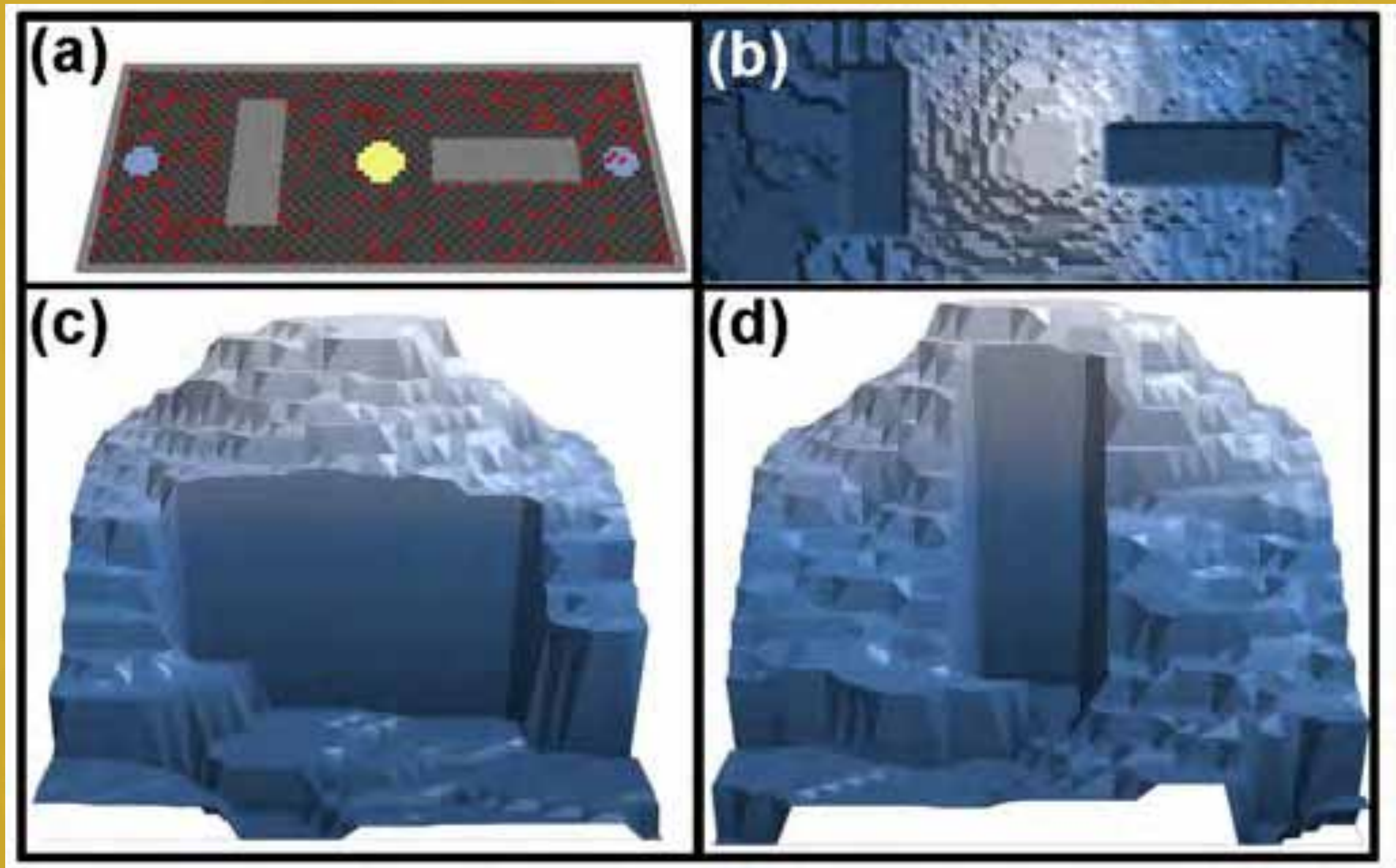



c Bg N y. F JR D Ow. Bg A9 8 g 8

subCULTron






(a)
(b)
(c)
(d)

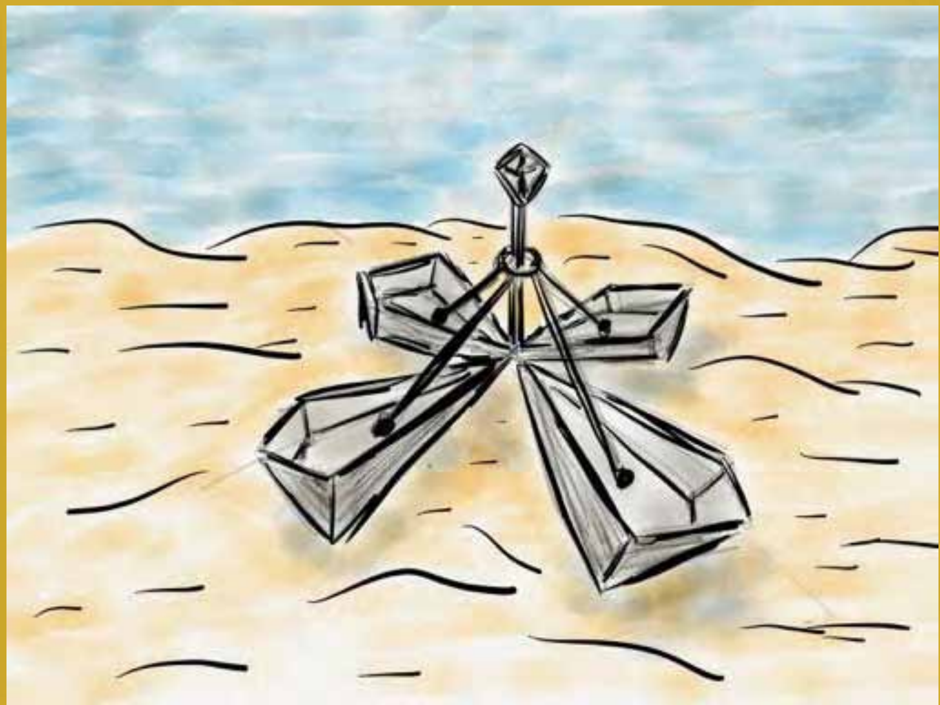
[illegible] 8JR[illegible]-[illegible]1[illegible]ayA[illegible]8[illegible]JR[illegible]t -8’[illegible]J[illegible]

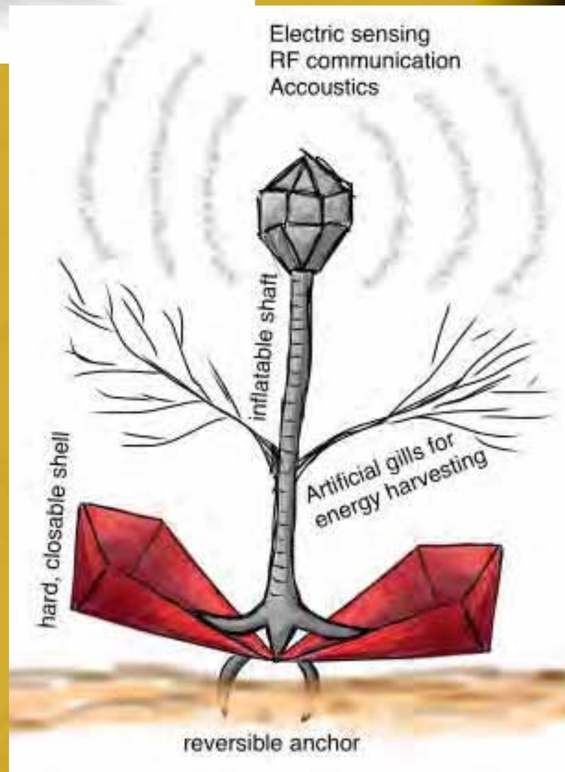
[illegible] J PP[illegible]Wa[illegible]

- [illegible]1[illegible]-a[illegible] [illegible]-May[illegible]E [illegible]A Jg5[illegible]8i [illegible]8, t 5[illegible]sAlag5[illegible]8 MyJ[illegible]-, [illegible] -0 A Mg5[illegible]8i y[illegible] J0[illegible] [illegible]gi [illegible]5yt -8J[illegible]J[illegible]-8[illegible]8Jp[illegible]
- [illegible]-8LA[illegible]A M[illegible] [illegible]0 [illegible]-i J [illegible]-[illegible], t[illegible] p[illegible]
- [illegible]-8LA[illegible]A M[illegible] [illegible]A9J-A[illegible]0J[illegible], [illegible], 8-a[illegible]&[illegible]-A f[illegible]8-[illegible]JR[illegible]9a9J[illegible], p[illegible]

[illegible] [illegible]c B[illegible] N[illegible]y. F[illegible]D [illegible]Ow. B[illegible]A9[illegible]8 g[illegible]8-JON5[illegible]

? 099?5?yy??-A 9J8-, AM?



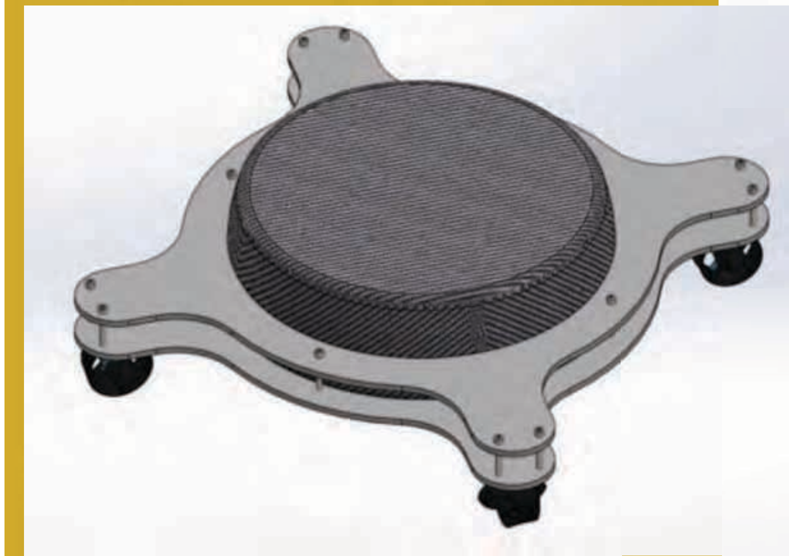


□ 8JR□-□1□ayA□□□□8□□JR□□t -8'□□□J□

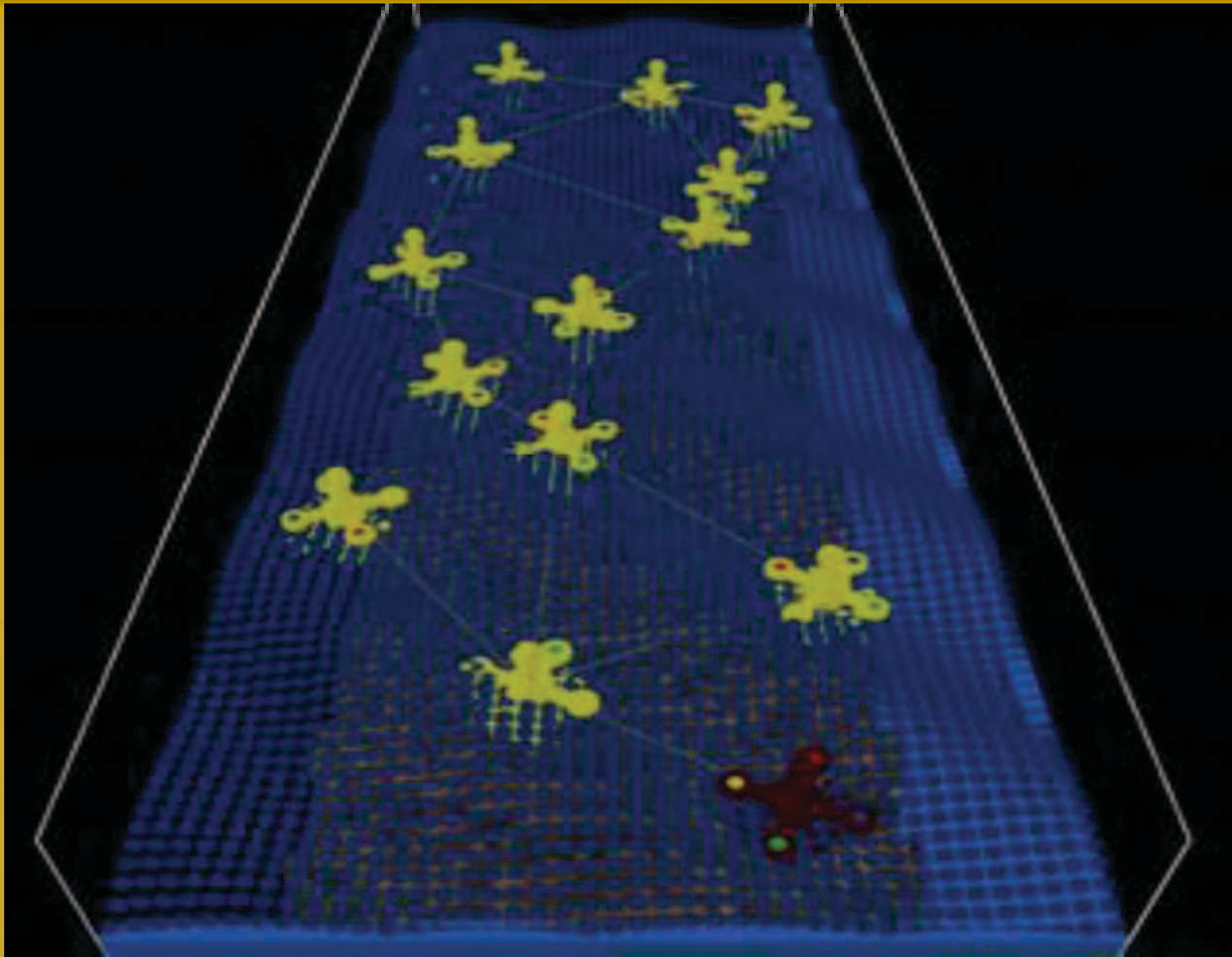
□□□□□P□S □I□A□P□i□NE PGMA□□□□□2□□NMG□□□Psa□

- □ 0□R□□□□2 □-□90-□□ □□9Jn 8 □JR□ □A □□8□□8□□8□
- □-8LA□A M□□ 5A 1□18□M8□□5 □□□J □ ti□R0, □ □98□□A□Ja□
- □-8LA□A M□□ □□ □-Ma□□□t 8J□□ □□□ □0 □□-i J □-□□ □□□

subCULTron



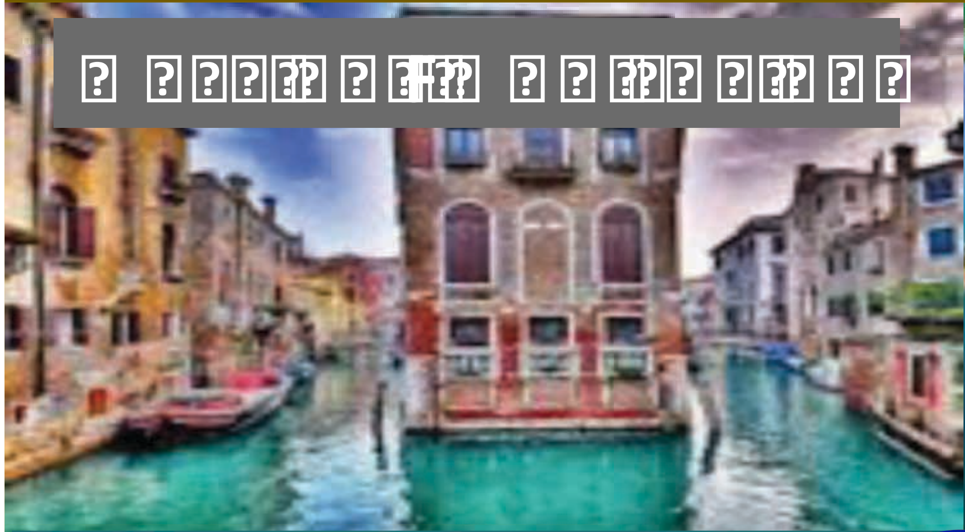
subCULTron

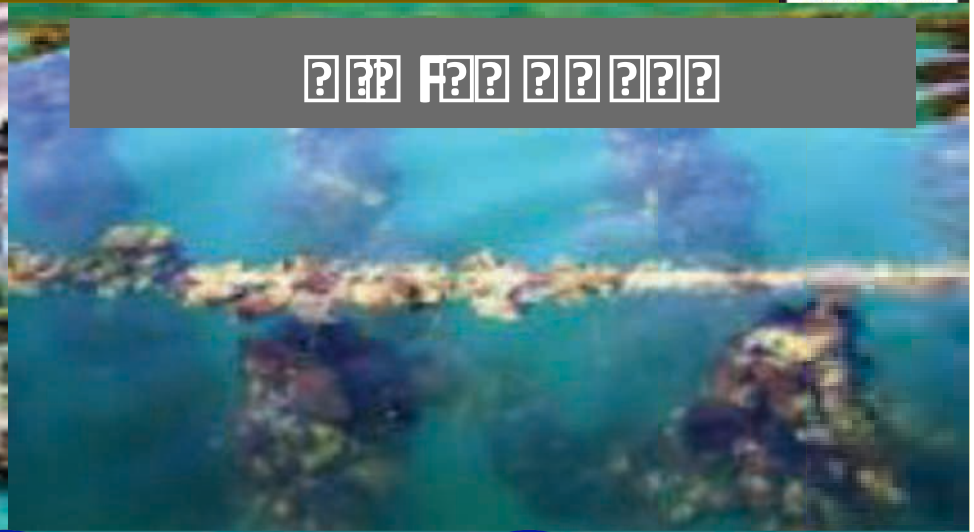


?JR?-95 98?R?L?90?R?A?9 ?

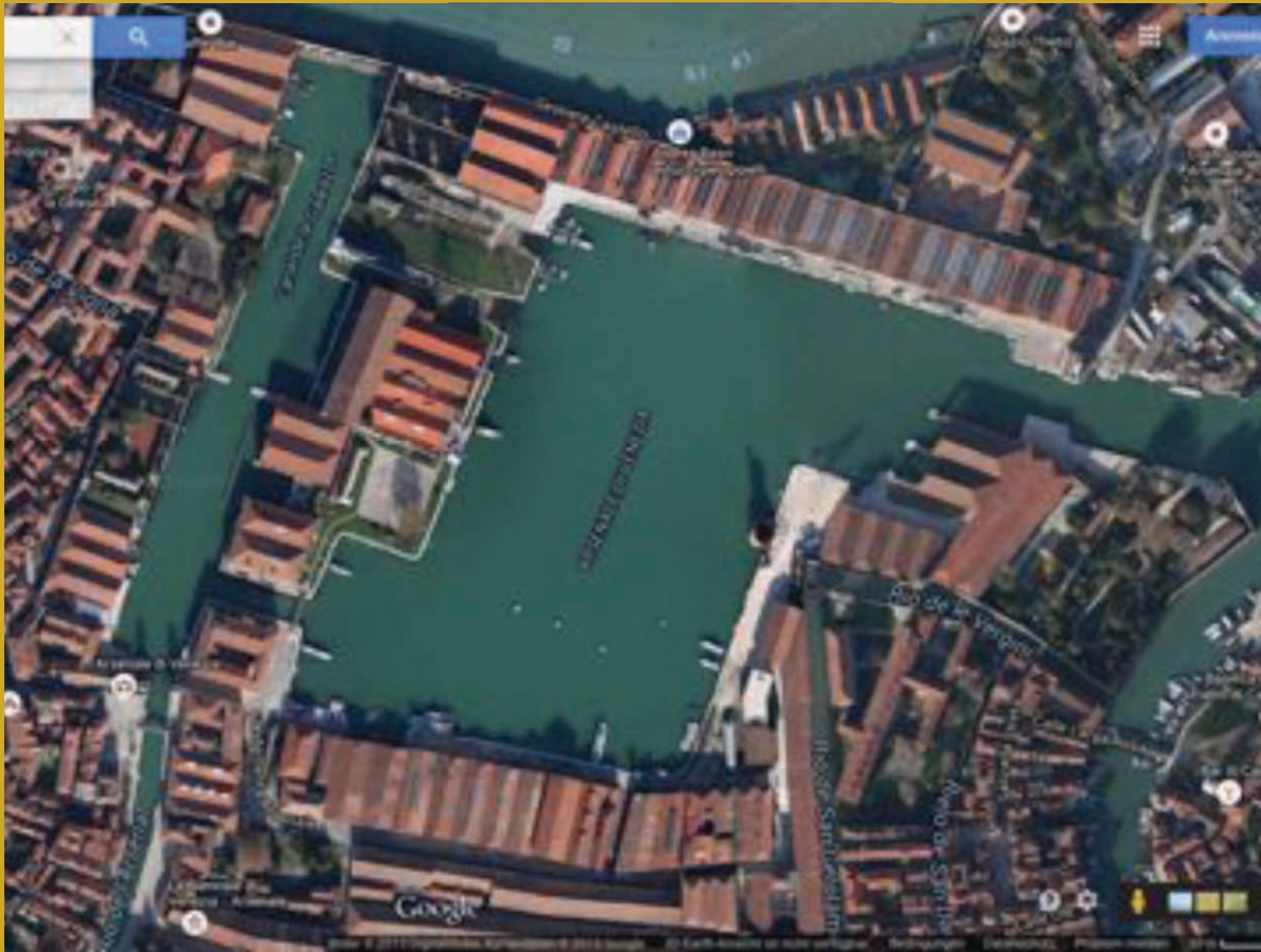
subCULTron

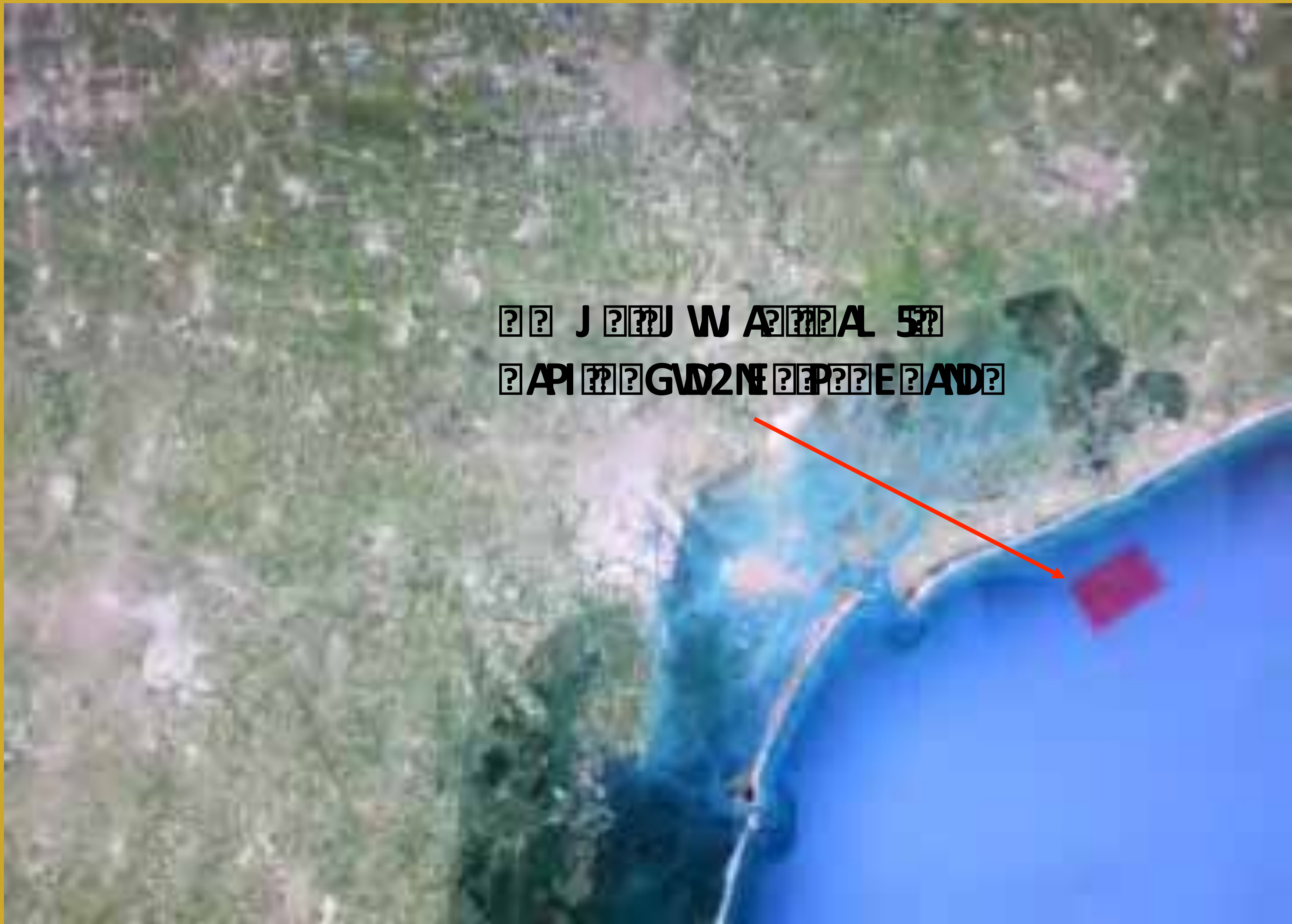
subCULTron






learn & evolve
long-term
complexify
subCULTron
electric sense
energy-harvesting
forming sub-cultures


Google



subCULTron

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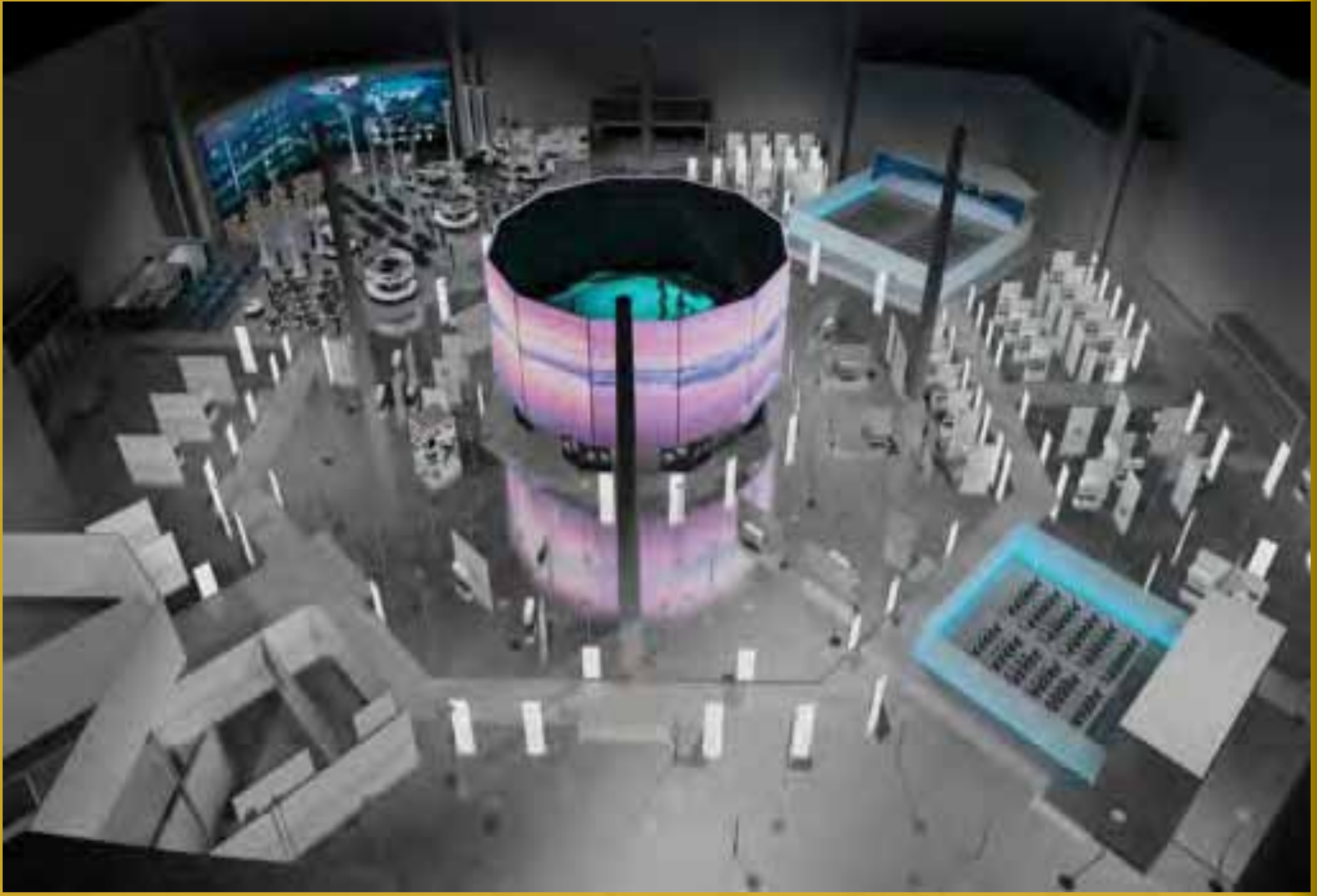


?R????-?8???8?8?8?t5a 59J?8 ?a80J0???&U??? ?f?

- BO?LA??89?A ?BO?i ??19?JR-80MR80J?Ow. B?
- ???lU??? ??A ?ji A2 ?-?
- ???-?R?8-?C?R????-?8???8?8?8x?8 ?a80J0???
- ? -?58818 ?-8?0R0?p8-Ml?

?R? 1?a80?

EMRA'15 workshop

An introduction to real-time data processing in autonomous survey operations

Niels Nijhuis
CARIS EMEA, NL

caris

Real-Time Data Processing in Autonomous Survey Operations

caris ONBOARD

Niels Nijhuis, CARIS

EMRA’15, 19th of June

Scope

- Introduction
- Autonomous platform market
- The Operational Requirement
- CARIS Onboard
- Proof of Concept
- Conclusion

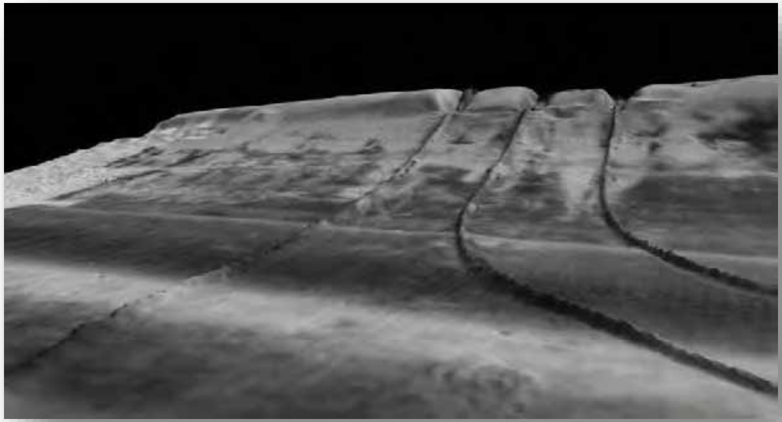
About

- 1979, Dr. Masry, UNB
- Canada, Netherlands, United States, Australia, United Kingdom
- CARIS Ping-to-Chart™

Processing **Analysis** **Production** **Distribution**

AUV Survey Overview

- Endurance
  - 8 hours to 72 hrs (not inc. gliders)
  - Size and payload dependent
  - Needs to be recovered or return to base
- Depth range
  - 30m, 200m, 3000m
  - 70% of AUVs sold < 200m water depth
    - *Source: Westwood 2010; Lukas C Brun 2012*
- Communications
  - Surface: Satellite, telemetry, wireless internet
  - Sub Surface: Low bandwith acoustic comms



AUV Survey Overview

- Data acquired by AUVs
  - Sonar
    - Sidescan
    - Multibeam
    - Interferometric
    - Synthetic Aperture Sonar (SAS)
  - ADCP
  - Oceanographic Sensors
  - Cameras

- Time stamped internally and files stored


Source: Kongsberg Maritime


Source: Hydroid

Introduction

- The volume of Autonomous Survey Operations have increased over the past 5 years

- Many platforms
  - Not only AUVs, but also ASVs

- More sensors

- Longer endurance

Autonomous Platform Market

Short - term

Mission Duration

Persistent

Sub Surface

Surface

Manned/Autonomous

Autonomous Platform Market

- Lower capital & operating costs, rapid deployment/recovery and the ability to work closer to the intended target
- Pre-defined mission and gather hydrographic data, to be stored internally until recovery when it would be processed
- As power sources improve operating times increase

The Operational Requirement

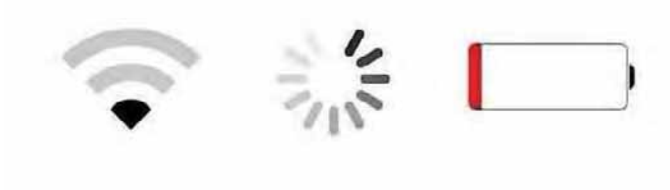
- Data volume increases

- Data bottleneck

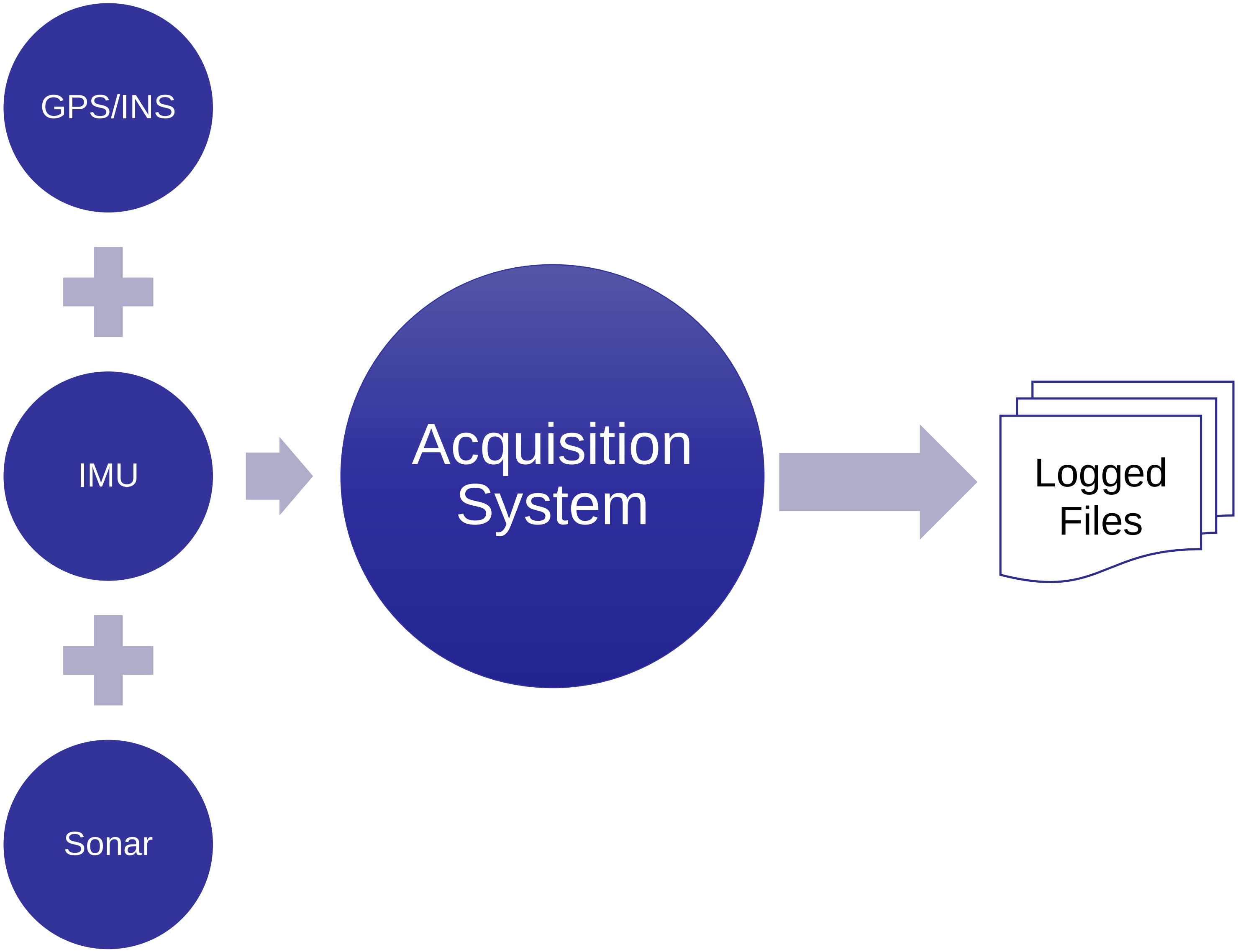
- Data deliverables may be slower
  - Data typically has to be processed after download at end of mission (small real-time communications bandwidth)

- Autonomous platforms often lack the ‘human control’ in the feedback loop

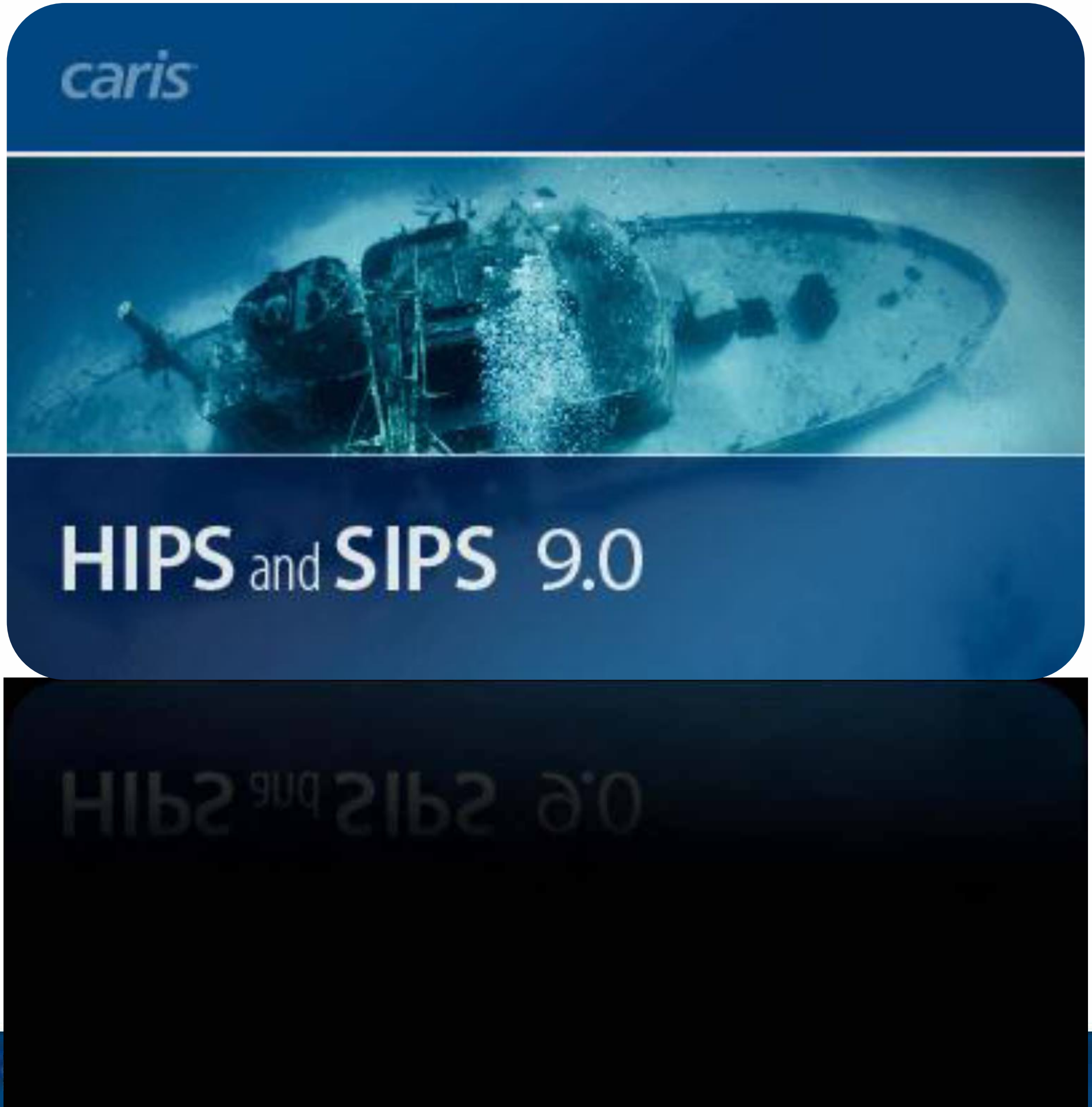
- Data deliverables may be slower
  – Data could be incorrectly acquired due to lack of surveyor interaction with platform (no feedback loop)



Traditional Autonomous Platform Workflow



Workflow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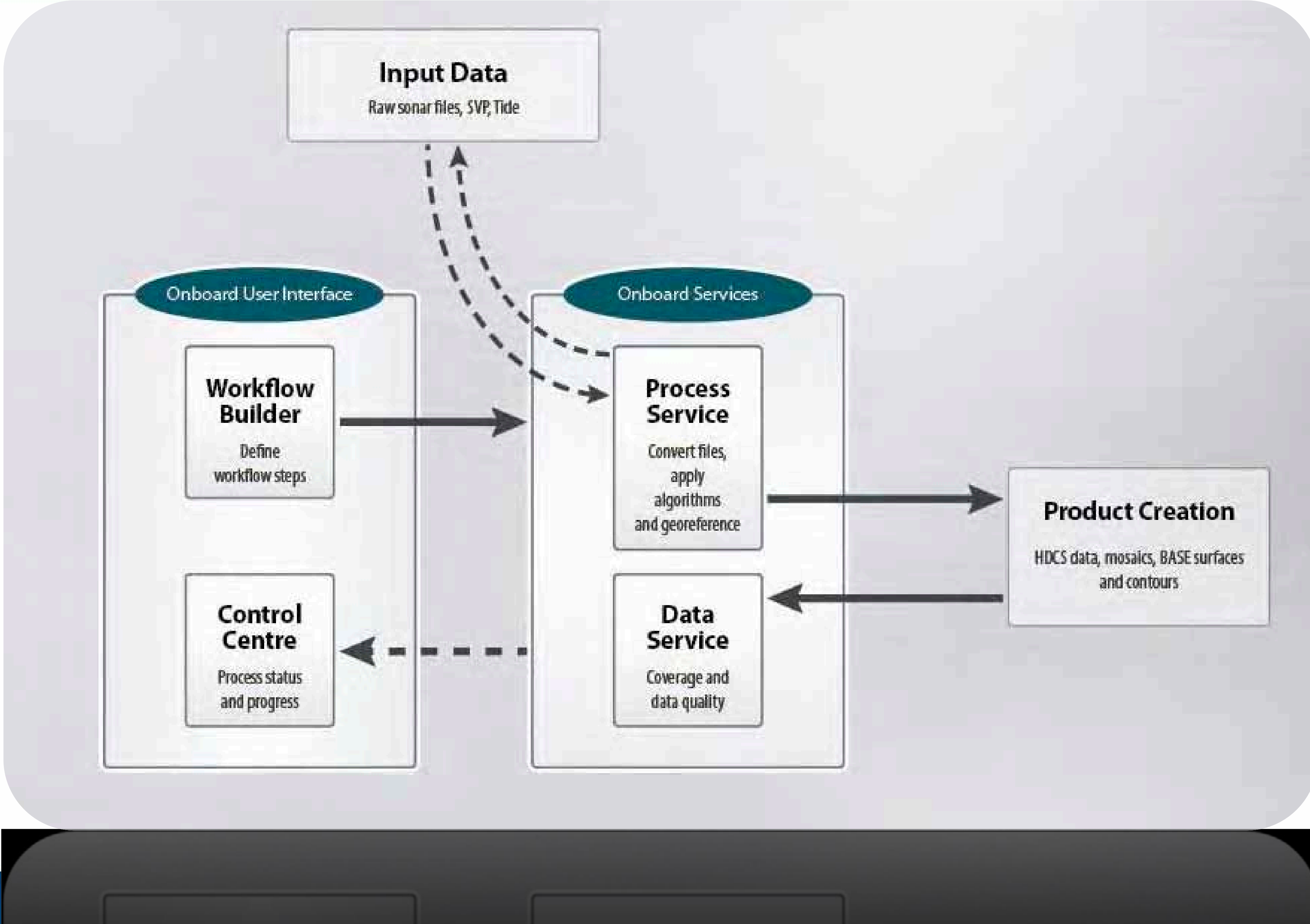
HIPS and SIPS 9.0

- The list of processes that can be built into a workflow is lengthy:

Conversion
Sound Velocity Correction
Load Tide
Load Auxiliary Data
Load Delta Draft
Merge
Apply Bathymetry Filters
Apply Attitude Filters
Surface Filter
Compute GPS Tide
Compute Total Propagated Uncertainty

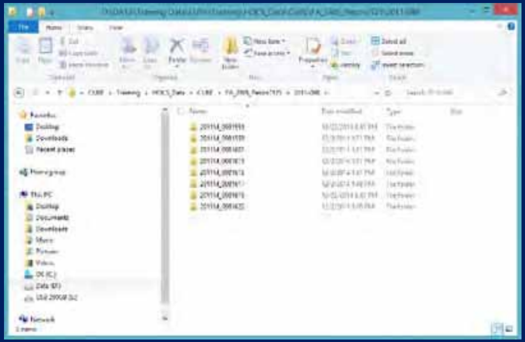
Recompute Towfish Navigation
Recompute Contact Positions
Regenerate Additional Bathymetry
Create Surface
Add to Surface
Recompute Surface
Finalize Surface
Combine Surface
Create Mosaic
Add to Mosaic
Export Surface to ASCII, GeoTiff etc.

Workflow in CARIS OnBoard

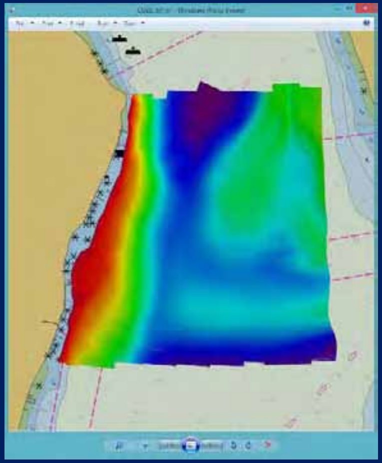


Examples of near real time products

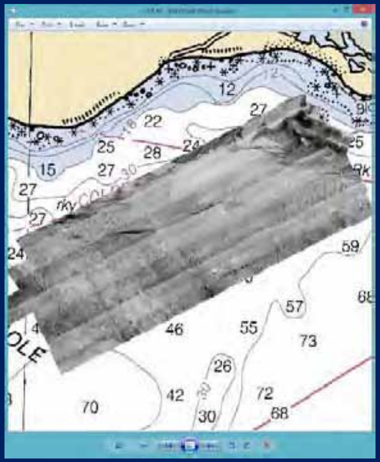
High Bandwidth



CARIS line files



GeoTiff

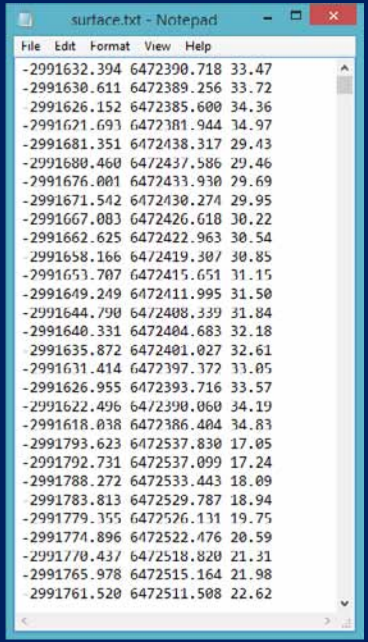


Sidescan Mosaic

Low Bandwidth

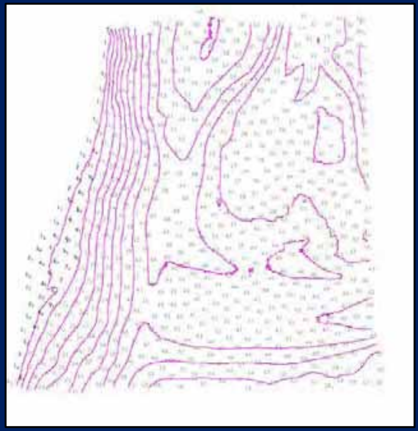
```
BASE Surface QC Report
-----------------------
Date and Time: 4/7/2015 1:31:11 PM
Surface: D:\DATA\HIPS\Session\CUBE_1m_FINAL.csar
Holiday layer created: No
Error values from: Standard Deviation

IHO S-44 Special Order:
     Range:  0.000 to 40.000
     Number of nodes considered: 709529
     Number of nodes within: 678139 (95.58%)
     Residual mean: -0.211
S-44 Order 1a:
     Range:  0.000 to 100.000
     Number of nodes considered: 1732082
     Number of nodes within: 1729638 (99.86%)
     Residual mean: -0.610
S-44 Order 1b:
     Range:  0.000 to 100.000
     Number of nodes considered: 1732082
     Number of nodes within: 1729638 (99.86%)
     Residual mean: -0.610
S-44 Order 2:
     Range: 100.000 to 5000.000
     No depths within the specified range
```

Bathymetry surface QC report



```
-2991632.394 6472390.718 33.47
-2991630.611 6472389.256 33.72
 2991626.152 6472385.600 34.36
-2991621.693 6472381.944 34.97
-2991681.351 6472438.317 29.43
-2991680.460 6472437.586 29.46
-2991676.001 6472433.930 29.69
-2991671.542 6472430.274 29.95
-2991667.083 6472426.618 30.22
-2991662.625 6472422.963 30.54
 2991658.166 6472419.307 30.85
-2991653.707 6472415.651 31.15
-2991649.249 6472411.995 31.50
-2991644.790 6472408.339 31.84
-2991640.331 6472404.683 32.18
 2991635.872 6472401.027 32.61
-2991631.414 6472397.372 33.05
-2991626.955 6472393.716 33.57
-2991622.496 6472390.060 34.19
-2991618.038 6472386.404 34.83
-2991793.623 6472537.830 17.05
-2991792.731 6472537.099 17.24
-2991788.272 6472533.443 18.09
 2991783.813 6472529.787 18.94
-2991779.355 6472526.131 19.75
-2991774.896 6472522.476 20.59
-2991770.437 6472518.820 21.31
-2991765.978 6472515.164 21.98
 2991761.520 6472511.508 22.62
```

ASCII depths



Sounding Surface

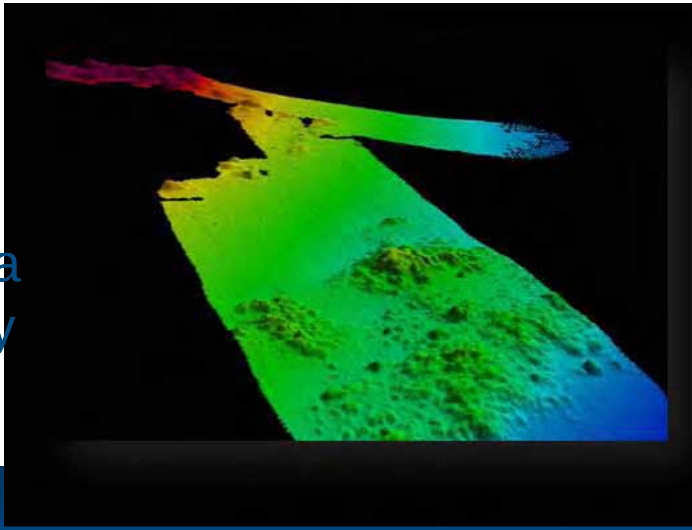
- By processing hydrographic data 'On Board', we can mitigate the data bottleneck

  - A processed dataset can be made available over limited bandwidth to the surveyor

  - Decisions can then be made as to how to proceed with the survey in the most time efficient manner

  - If no bandwidth is available, an almost final dataset can be quickly reviewed before redeployment of the vessel

  - For survey launches and manned vessels, a near-completed survey dataset is immediately available at the end of the survey



- Product deliverables scaled to support remote operations
  - AUV
  - ASV
  - Manned Platform remote supervision (survey launch/tenders)
  - Crowdsourced Bathymetry

Proof of Concept – 3 tier approach

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- In order to prove the concept, 3 platforms were identified:
  - Autonomous Surface Platforms
  - Autonomous Underwater Vehicles
  - Manned Survey Launches
- This allowed a scaled approach to proving the software with both the platform and sensors

Proof of Concept – Liquid Robotics & Teledyne

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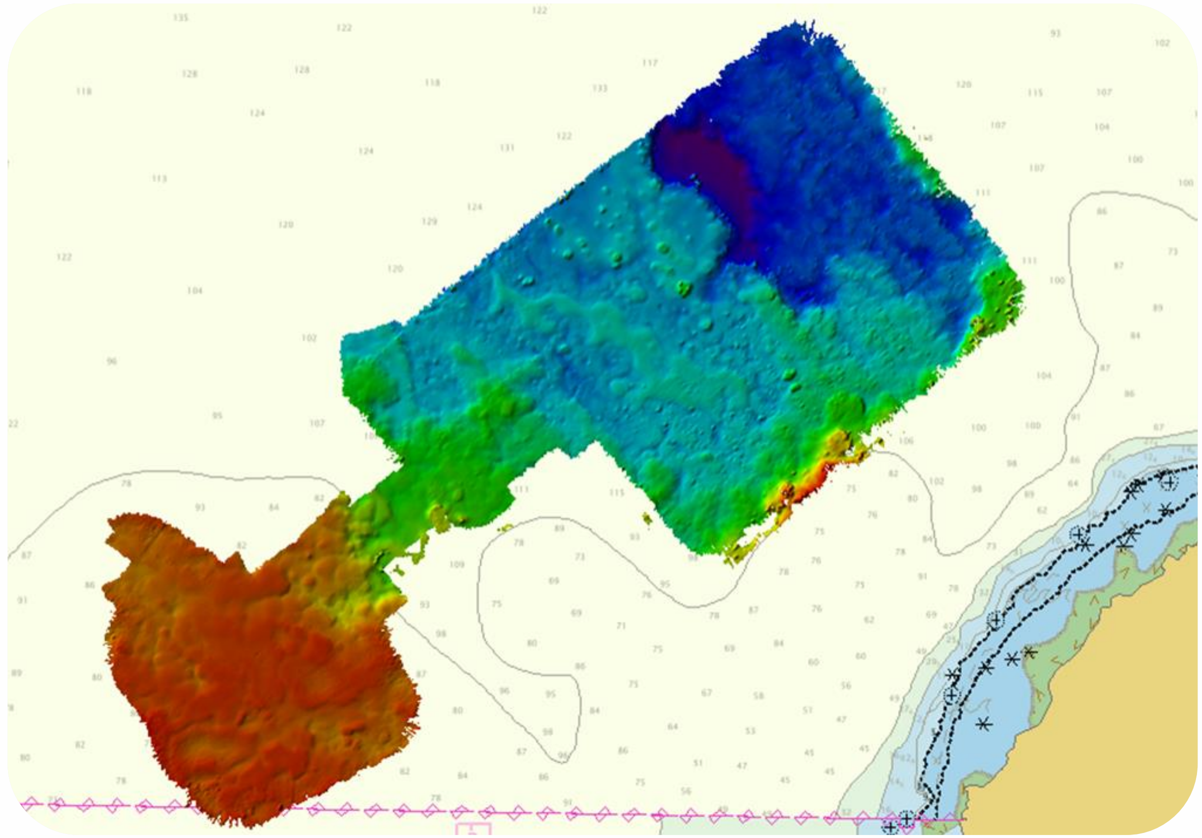
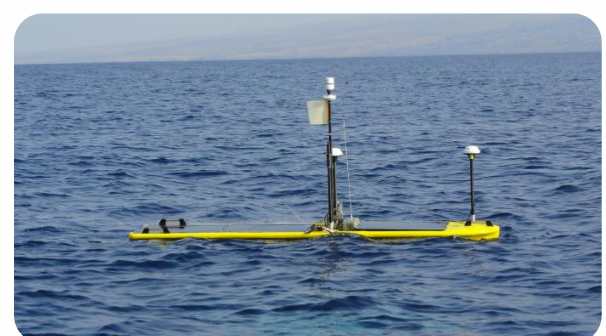
LIQUID ROBOTICS



TELEDYNE
ODOM HYDROGRAPHIC



Proof of Concept - Z Boat at US Hydro 2015

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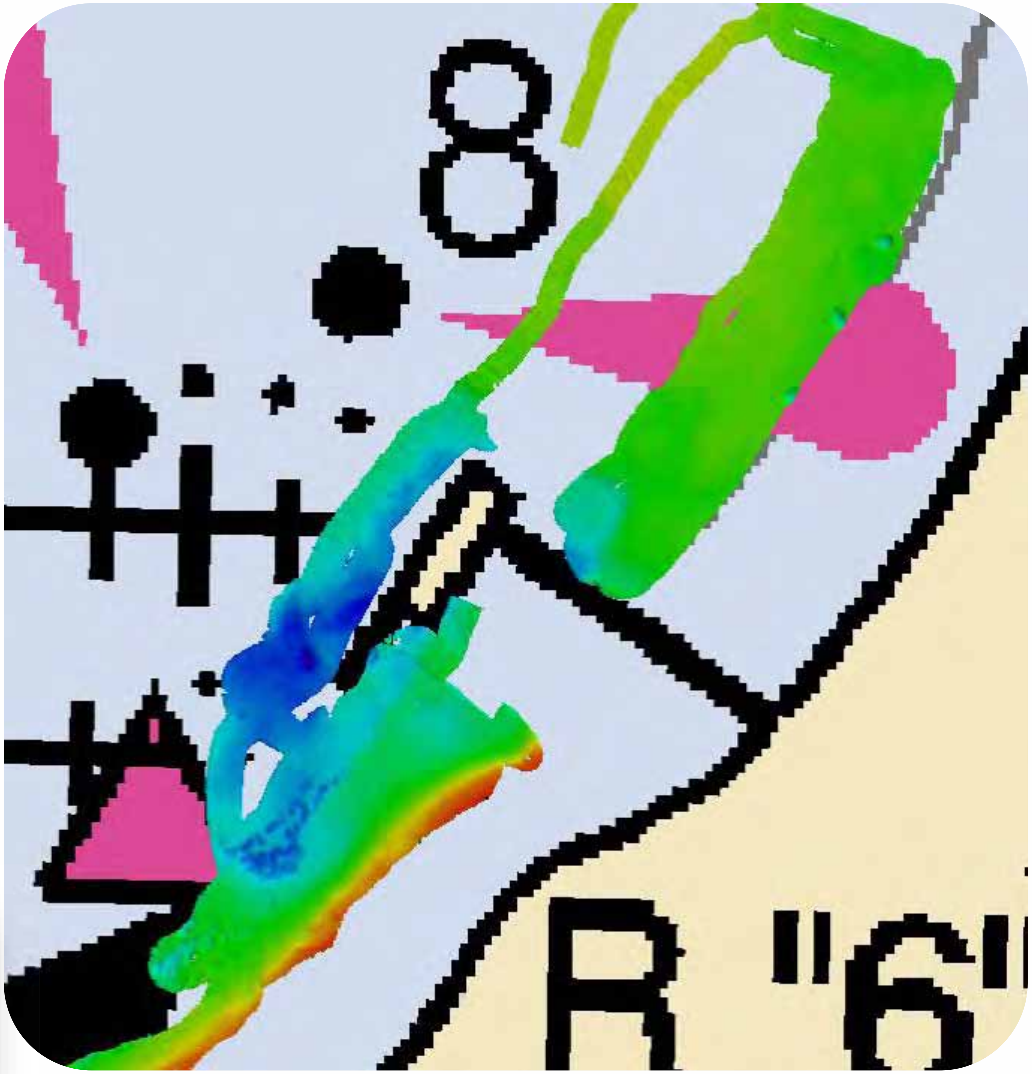
OCEANSCIENCE

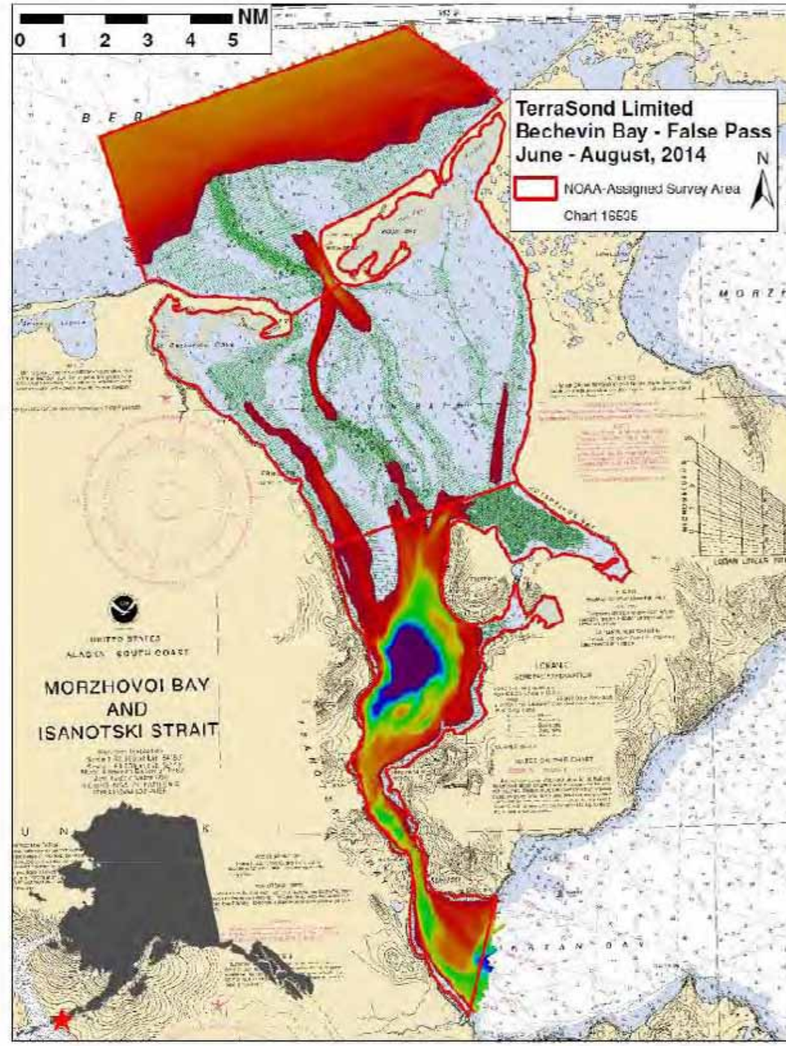


U.S. HYDRO 2015

March 16-19 · Gaylord Hotel · National Harbor, Maryland U.S.A.

Proof of Concept – NOAA Bay Hydro II & Terrasond

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION



TERRASOND
PRECISION GEOSPATIAL SOLUTIONS®

Proof of Concept – Hydroid Remus

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HYDROID
A KONGSBERG COMPANY

- Successful trial on Remus vehicle conducting trials in Boston, MA

Proof of Concept – Kraken SAS

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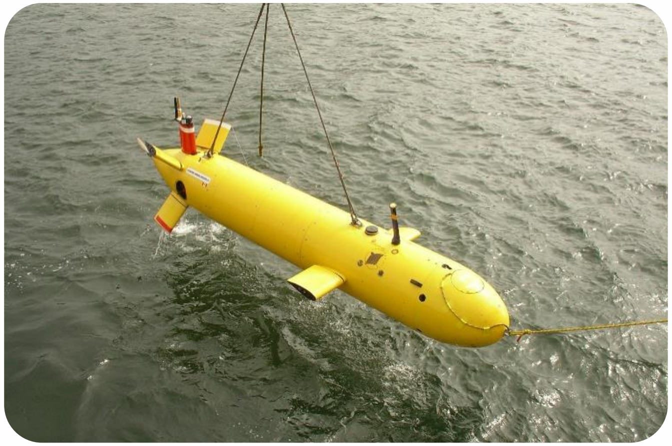
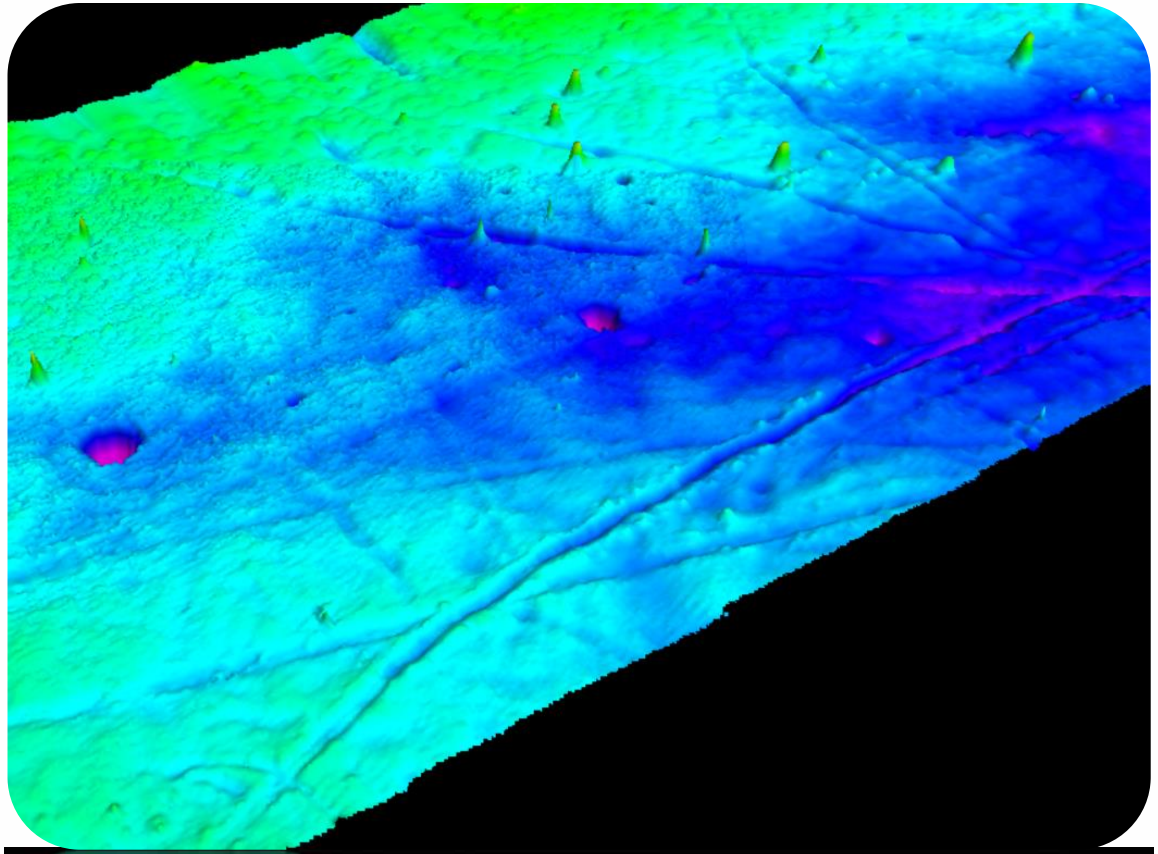
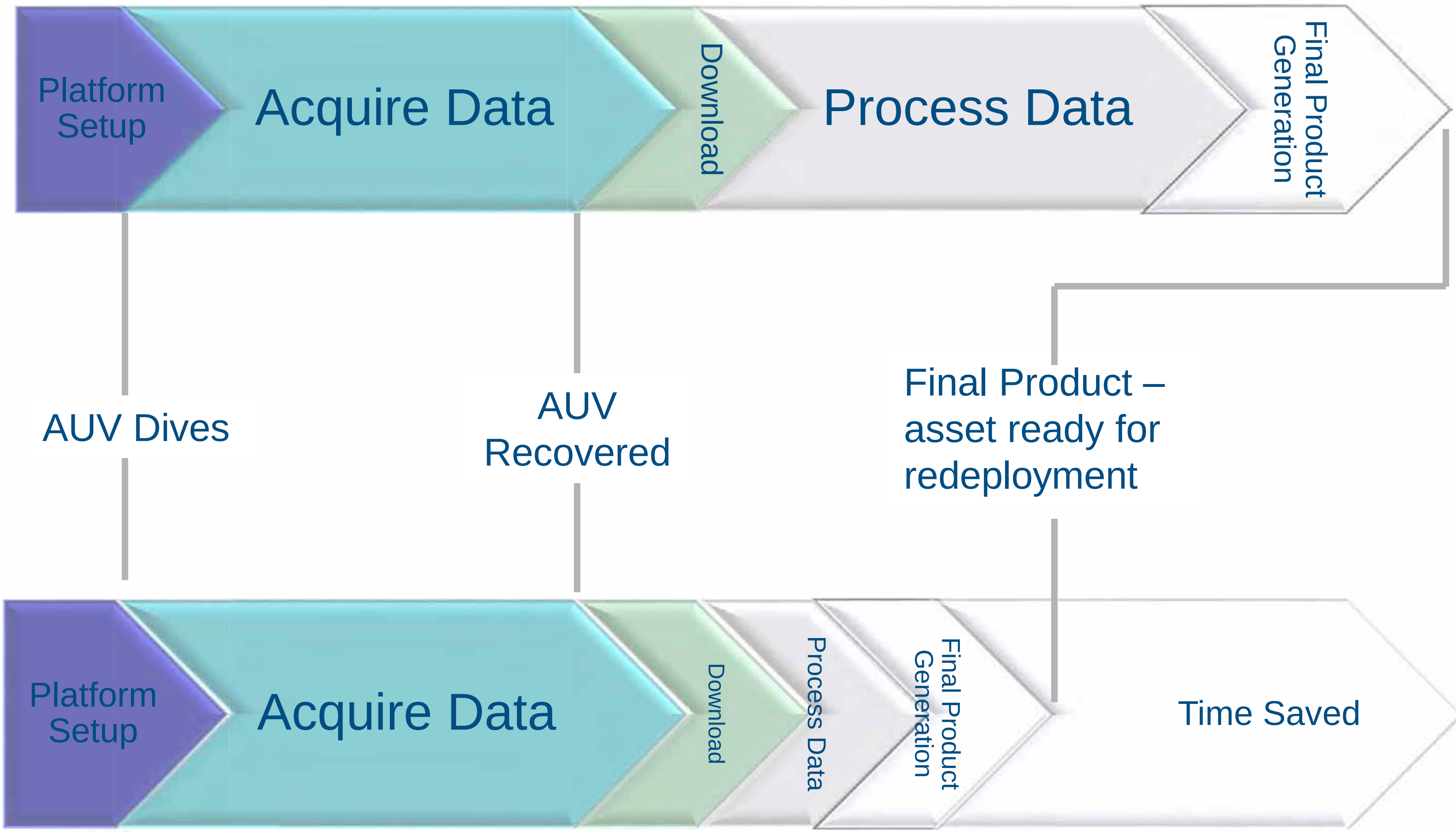


KRAKEN AquaPix®



Potential Time Savings

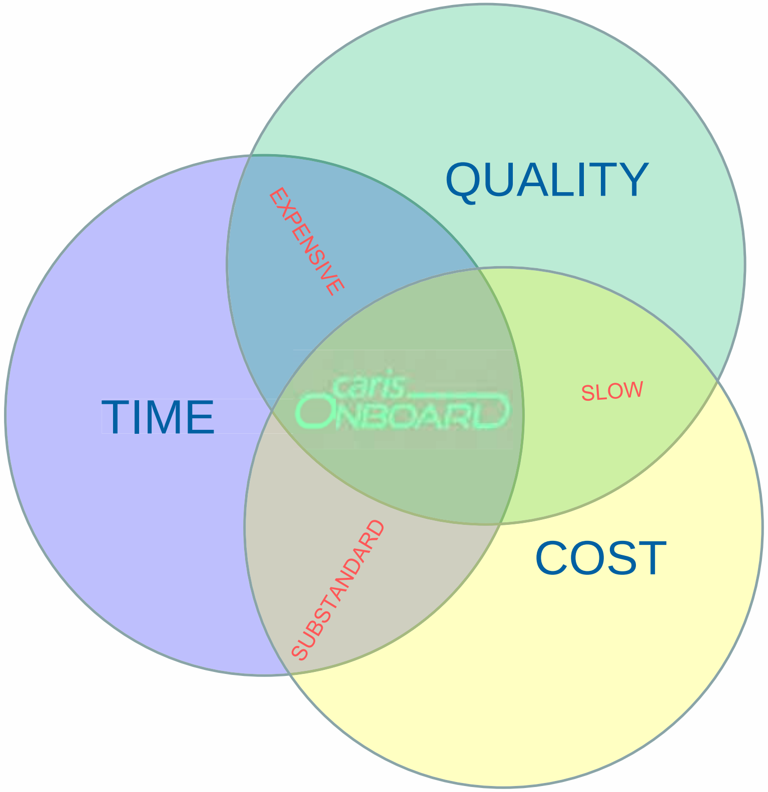
Traditional Workflow



caris ONBOARD **Workflow**

Conclusions

- Onboard data processing reduces overall ping to product time
- Allows for remote transfer of meaningful data from your survey platform, preventing costly errors in data acquisition and allowing effective management of remote assets
- Allows survey personnel to focus on higher level hydrographic tasking
- As part of the CARIS Ping-to-Chart™ solution, the data gathered can be processed in an optimal workflow to final product



Next Steps

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- Partnering with platform and sensor manufacturers
  - E.g: AUV, ASV, ROTV
- Full Windows/Linux package release in 3rd Quarter, 2015

- Brochure
- www.caris.com
- *sales@caris.nl*