Challenges in networked vehicle systems for ocean monitoring and surveillance

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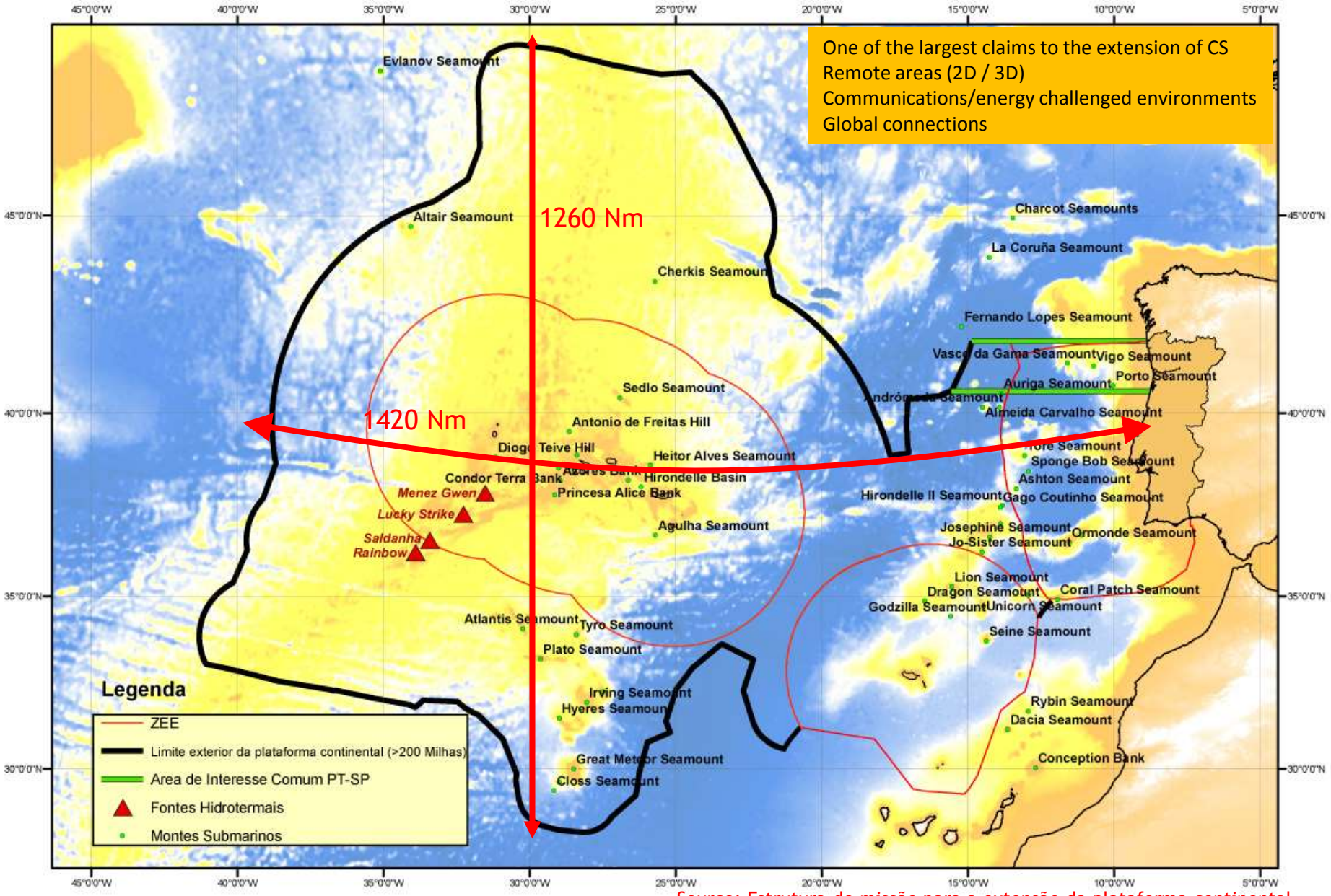
Portuguese challenges



Source: Estrutura de missão para a extensão da plataforma continental

Outline

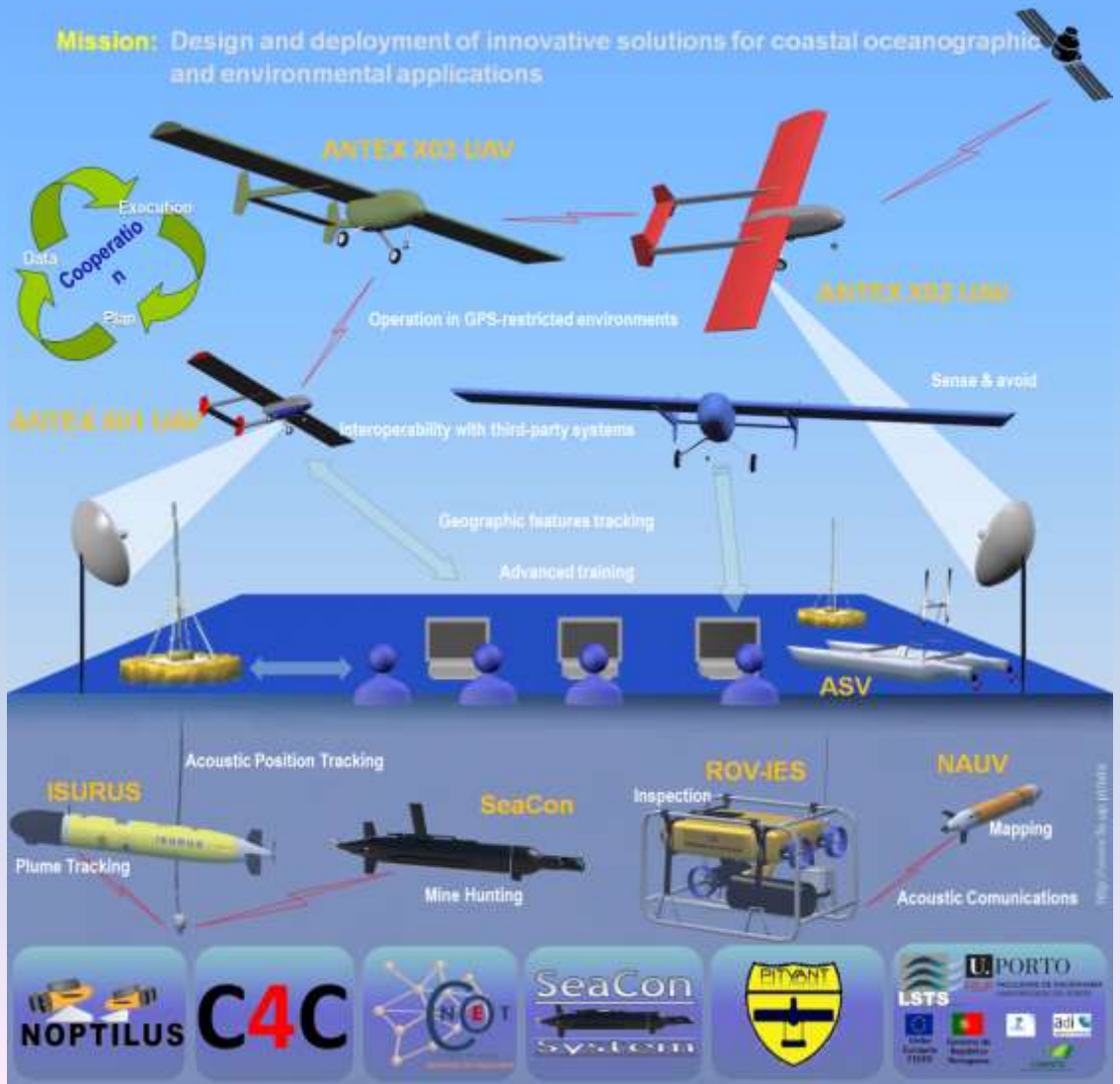
- Lab overview
- Operations
- Some challenges …
- Conclusions

LSTS-FEUP

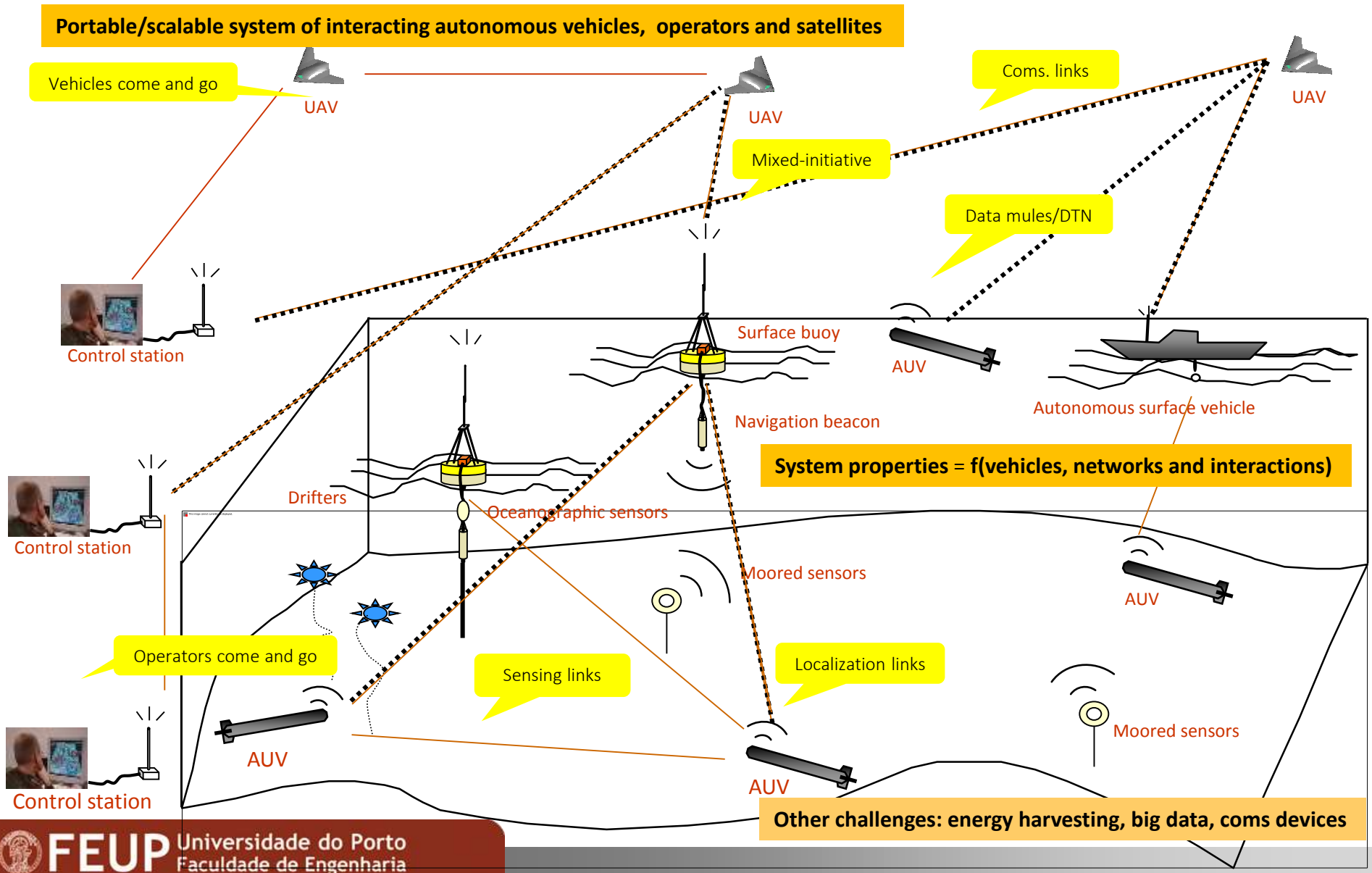
LABORATÓRIO DE SISTEMAS E TECNOLOGIA SUBAQUÁTICAS

UNMANNED VEHICLE SYSTEMS FOR A SUSTAINED PRESENCE IN THE OCEAN

Mission: Design and deployment of innovative solutions for coastal oceanographic and environmental applications



Vision


Portable/scalable system of interacting autonomous vehicles, operators and satellites
Vehicles come and go
UAV
UAV
Coms. links
UAV
Mixed-initiative
Data mules/DTN
Control station
Surface buoy
AUV
Autonomous surface vehicle
Navigation beacon
System properties = f(vehicles, networks and interactions)
Drifters
Oceanographic sensors
Control station
Moored sensors
AUV
Operators come and go
Sensing links
Localization links
AUV
Moored sensors
Control station
AUV
Other challenges: energy harvesting, big data, coms devices

Connecting the Dots

Networking Maritime Fleets of Autonomous Systems for Science & Surveillance

By
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João Borges de Sousa, Dept. Electrical & Computer Engineering, Univ. Porto, Portugal;
Ricardo Martins, Underwater Systems & Technology Lab, Univ. Porto, Portugal

A network of national observatories is being coordinated to provide ocean data for the Global Ocean Observing System (GOOS, http://www.ioc.goos.org). Many observatories are surface or sea-floor moorings with sensor arrays. Where moorings are cabled to shore for power, a few observatories include buoyancy gliders as observing system components. Discussions have been underway to further develop Integrated Ocean Observing Systems (IOOS) which also include propeller-driven autonomous underwater vehicles (AUVs), autonomous surface vessels (ASVs), and autonomous or unmanned aircraft systems (UAS).

This is a logical approach for IOOS because these autonomous technologies together provide greater spatial and temporal sampling than fixed observatories and do so more cost-effectively than manned ships or aircraft. Propeller-driven AUVs and ASVs can also sample in shallow waters, at spatially limited features (like oceanographic fronts), and areas of high current velocity where buoyancy-propelled gliders have limitations. Additionally, by combining sub-surface, surface, and airborne sampling platforms, collection of data on air-sea gas, heat and moisture fluxes is possible for studies of climate dynamics and ocean acidification. Finally, autonomous system networks can be cost-effective for maritime surveillance in search and rescue (SAR) cases, to monitor illegal fishing, or to respond to ship groundings or oil spills without risks to human health and safety.

DTN Communications Enable Near Real-Time Control of Autonomous Observing Systems

In making networks of autonomous systems effective ocean observing systems (OOS) components, several capabilities are required. The first requirement for using multiple autonomous vessels in an OOS is a reliable communications system across vehicles underwater, at the surface and in the air. Delay/Disruption Tolerant Networking (DTN) communication protocols have been adopted by ocean scientists. DTN communications protocols know when links are disrupted, and resume transmitting data when the communication link is re-established. This DTN functionality is important for large file transfers in communications-challenged maritime environments.

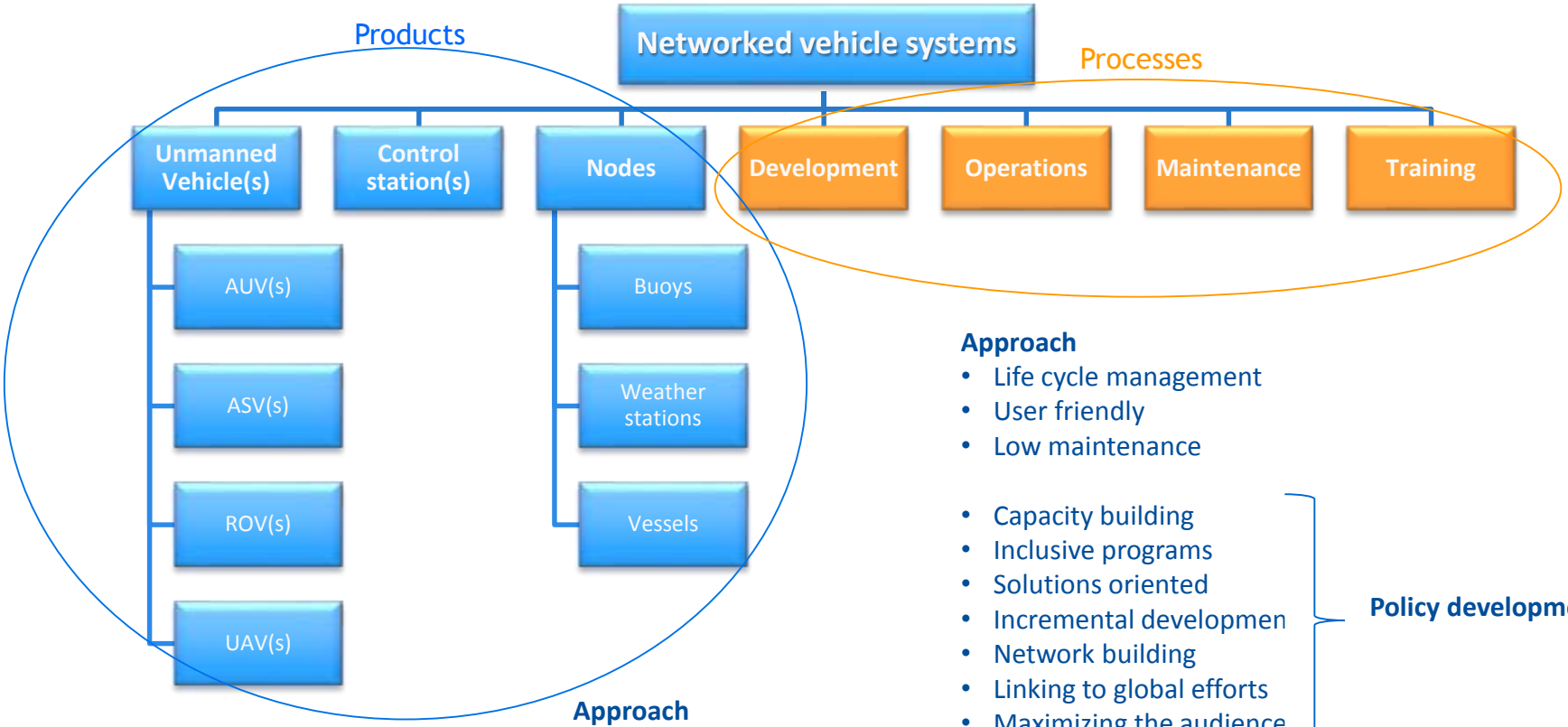
A series of ocean field exercises coordinated by the Portuguese Navy and the University of Porto, called REP (Rapid Environmental Picture), have focused on demonstrating Delay/Disruption Tolerant Networking communications between ships, AUVs, ASVs and UAS. This has allowed near real-time control and data exchange among platforms to coordinate control and inter-vehicle interaction for an optimally-employed autonomous OOS network.

Approach

- Systems engineering/thinking
  - Methodological framework to develop systems
- Vehicles systems designed for interactions
  - Uniform control architecture
- Experimentation @ sea
  - Conops / Operational know-how / Reliable vehicle systems
- Strategic partnerships
  - Portuguese Navy / PO Air Force / Extension of the Continental Shelf
- International networking for S&T development
  - Controls, communication, computation, autonomy, HCI
- User-inspired basic research (Pasteur's quadrant)

Donald Stokes, **Pasteurs Quadrant: Basic Science and Technological Innovation**, Brookings Inst, 1998

Systems thinking



Approach
- Life cycle management
- User friendly
- Low maintenance

- Capacity building
- Inclusive programs
- Solutions oriented
- Incremental developmen
- Network building
- Linking to global efforts
- Maximizing the audience

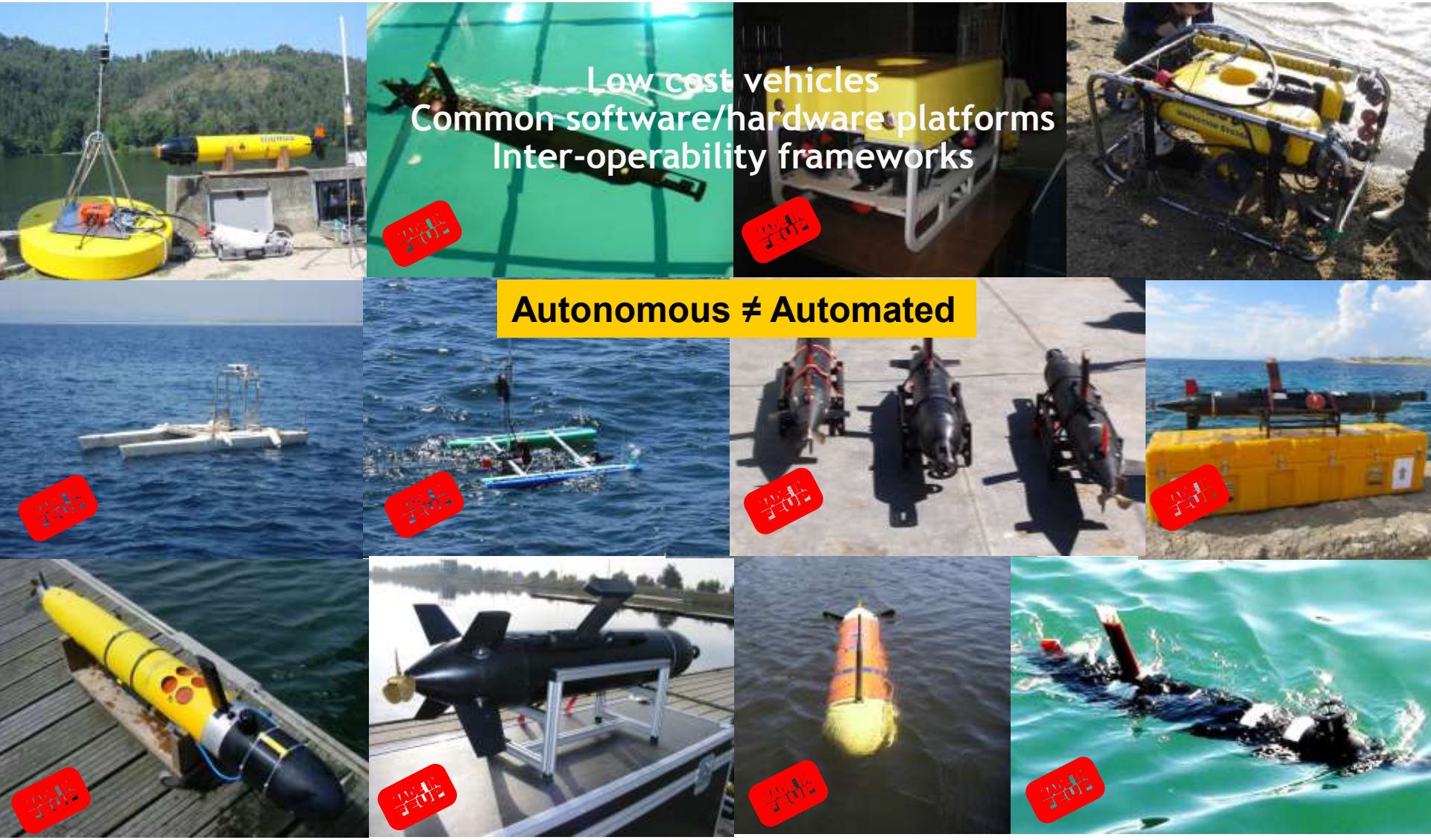
Policy development

Approach
- Open systems
- Low cost
- Modular software/hardware
- Designed for interactions
- Easy to replicate / scalable
- Multi role systems

AnnaLee Saxenian, **The New Argonauts: Regional Advantage in a Global Economy**, Harvard University Press, 2006

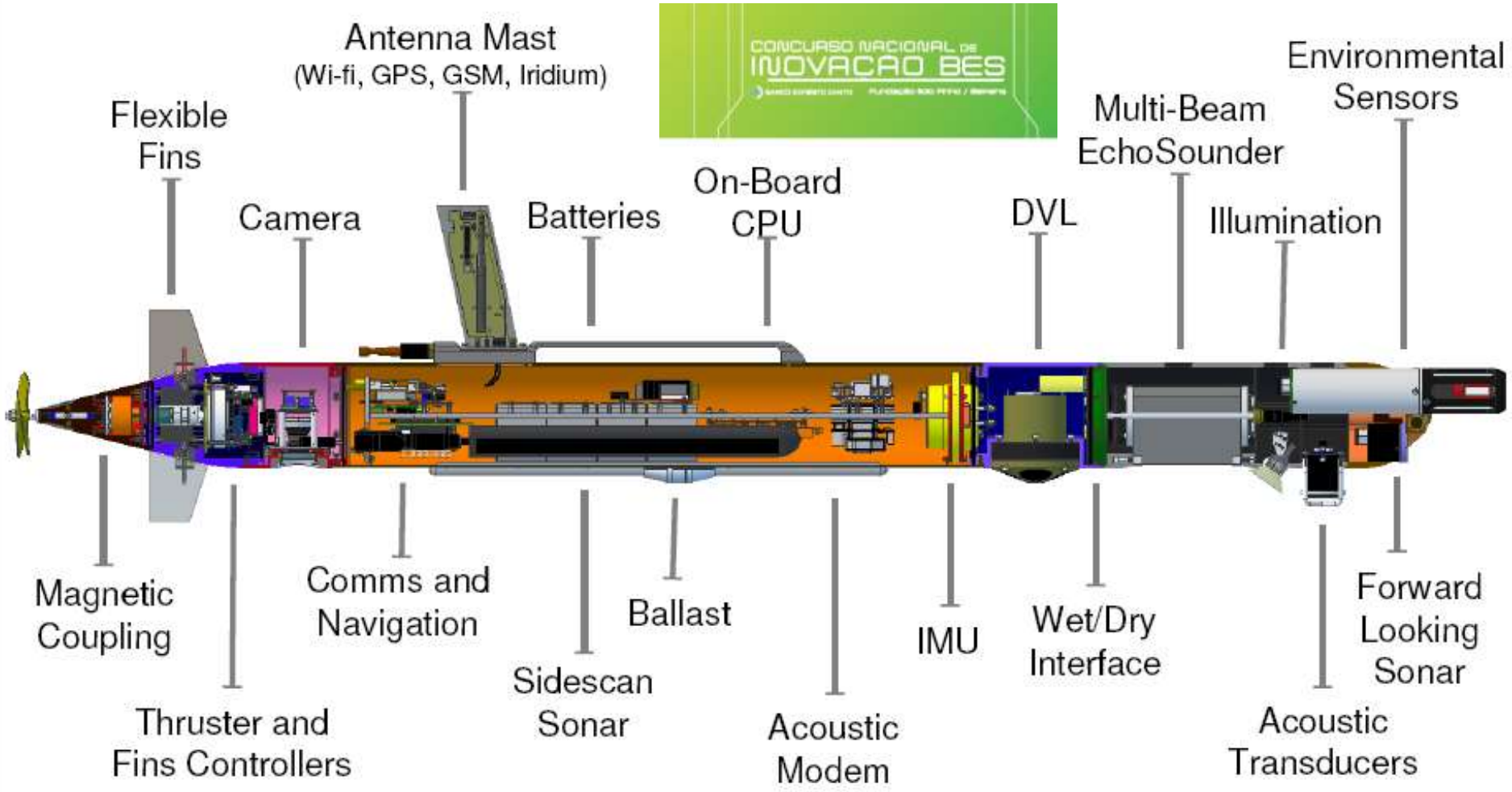
Daron Acemoglu and James Robinson, **Why Nations Fail: The Origins of Power, Prosperity, and Poverty**, Crown Business, 2012

Ocean vehicles



Light AUV (LAUV)

Designed for interactions – networked behavior



IEEE Standard for Application and Management of the Systems Engineering Process, 2011
MIL-HDBK-881 Department of Defense Handbook Workbreakdown Structure. Department of Defense, 2011.

AUV operations

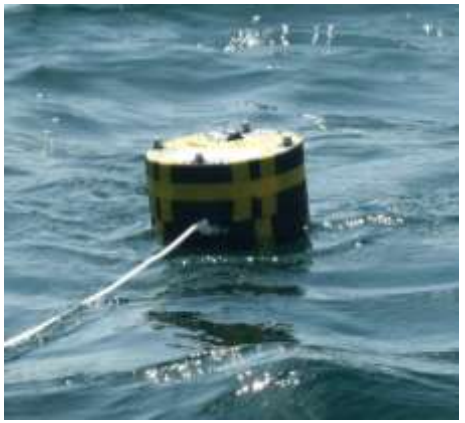
Making L&R simple

Coms gateways, *data loggers, drifters, fish tags*

Communications gateway

High performance data logger

Light data logger

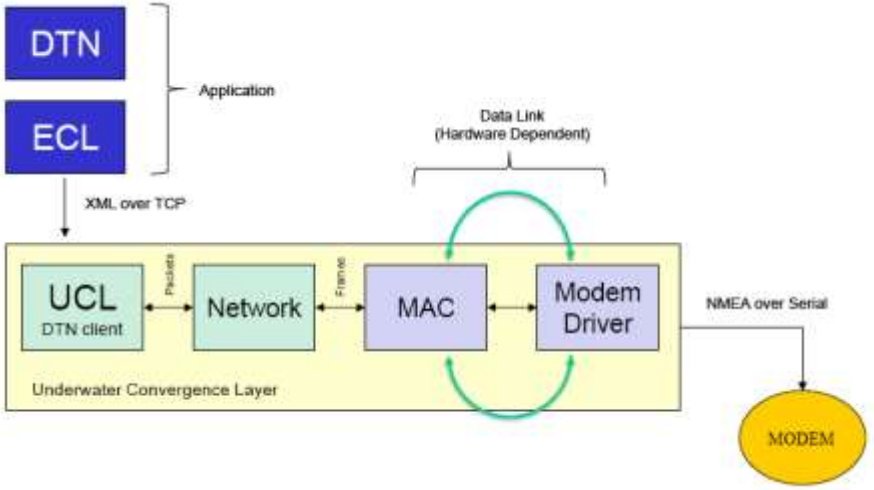


Drifter

Common hardware and software platforms

Drifters

Fish tags



Aerial vehicles

- PITVANT project – cooperation with POAF (MOD 2009-15)
  - Unmanned vehicle systems
    - 3 ANTEX01 (6.5 m wingspan)
    - 3 ANTEX02E (3.6m wingspan)
    - 8 ANTEX02 (2.4m wingspan)
    - 2 small wingspans
  - Stats
    - > 1000 autonomous flights
    - Day / night operations
  - Priority: flights over the ocean
    - Surveillance (fishing, polution, etc)
    - Long duration (> 8hours)

Common hardware and software platforms

UAS

UAV system

- Flight time: 1h
- Range: 10Km (video feed)
- Hand launched or catapult launch
- Fully autonomous (soon: no pilot required)

X8 based UAV (1.400 €)

- RC model based platform
- Autopilot
- Onboard computer for autonomy
- WiFi coms (up to 10Km range)
- IP video camera
- HD digital camera or IR camera
- DUNE on-board software
- IMC command and control protocol
- Battery powered

Ground station

- Laptop & antennas
- Neptus command and control software
- IMC command and control protocol
- Multi-vehicle control
- Internet enabled

Data vizualization/storage

Applications

- Maritime surveillance
- Aerial photography/mapping
- Biological studies
- Search and rescue
- Fisheries
- Incident response (floods)
- Inspection of power lines
- Ilegal hunting

Maximizing the audience

UAS operations

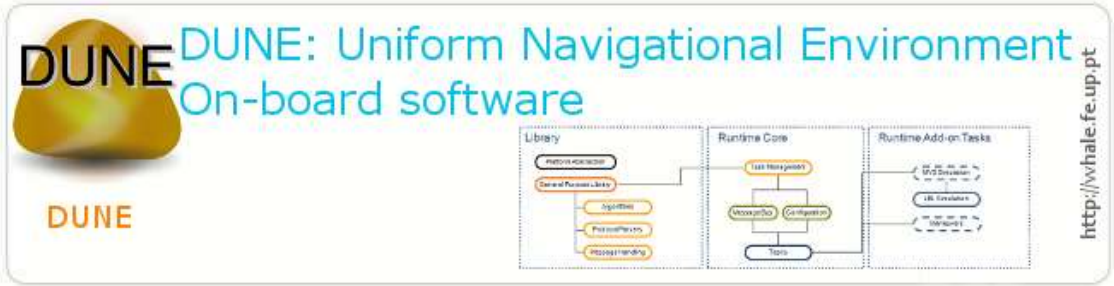
Software tool chain

Support for heterogeneous vehicles, inter-operability and communications challenged networks

Field tested in thousands of operations with air and ocean vehicles

Off-board command, control and communications

Communication protocols for command and control of heterogeneous systems

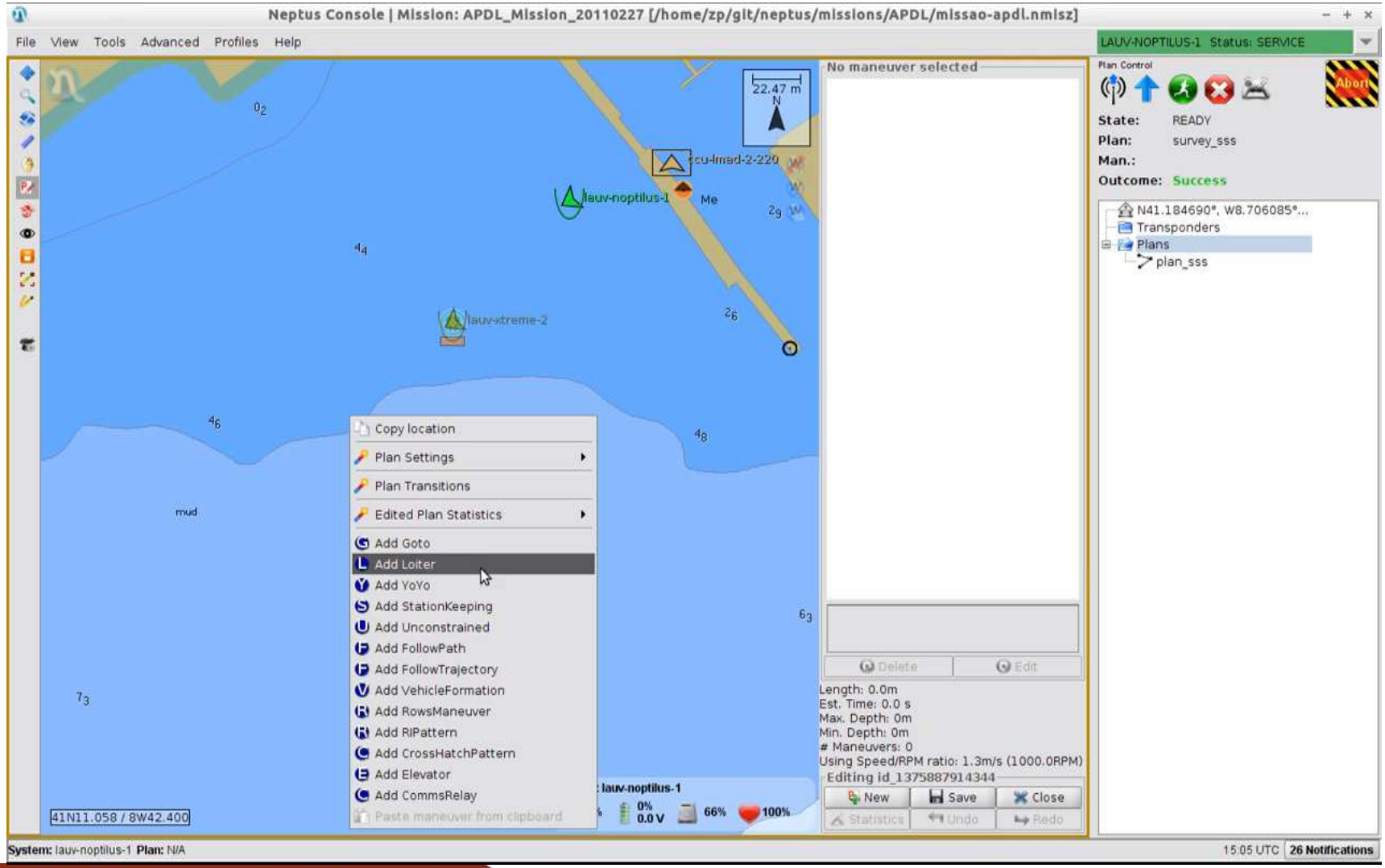


Onboard software (vehicles, buoys, data loggers)

User group: PT, US, NL, NOR, SWE, SP, FR, UK, DE, GR, IN

neptus

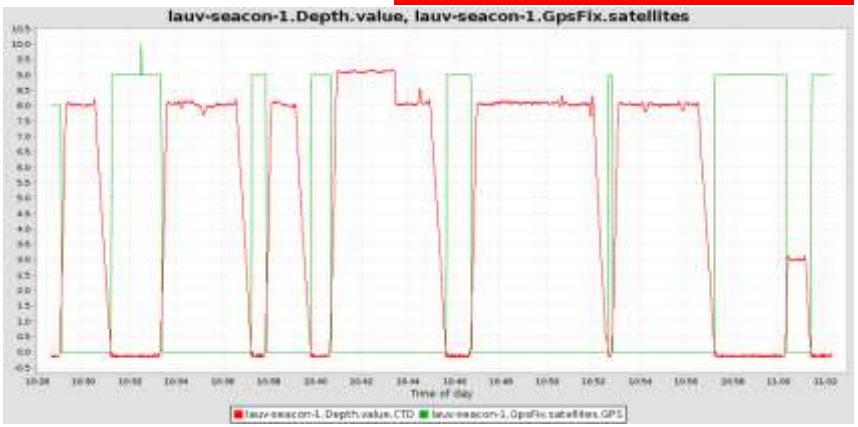
User-orientation and mixed-initiative interactions

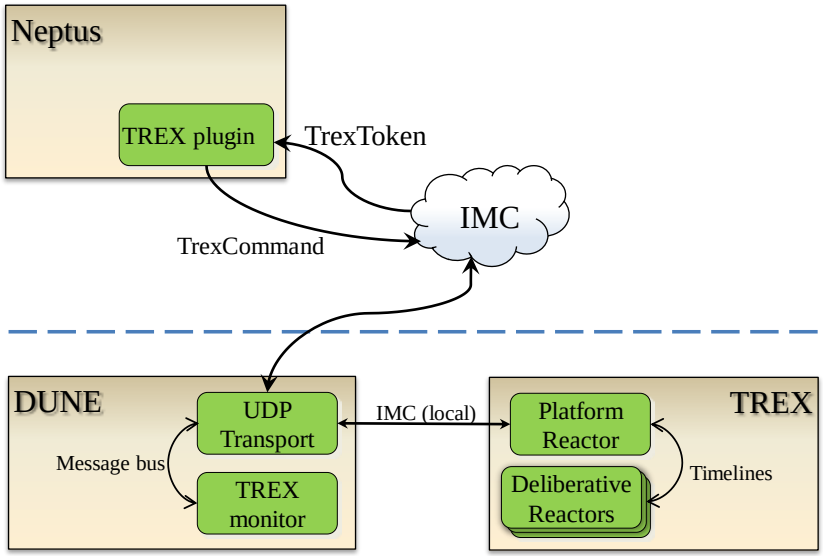


Autonomy (T-REX)

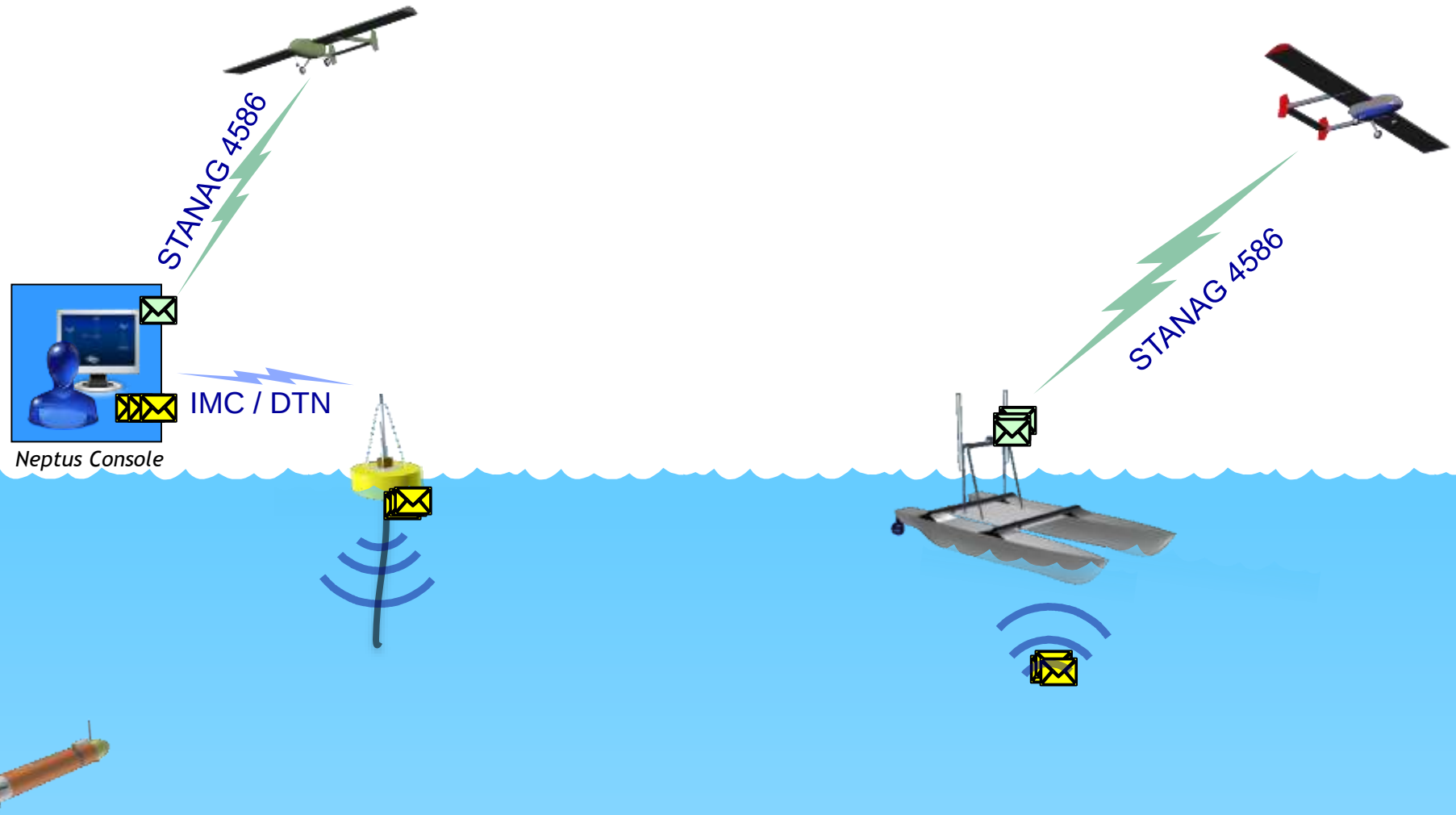
On-board deliberative planning

- Plans generated onboard
- Safety and time constraints
- High-level objectives
- Replanning in face of unpredicted events

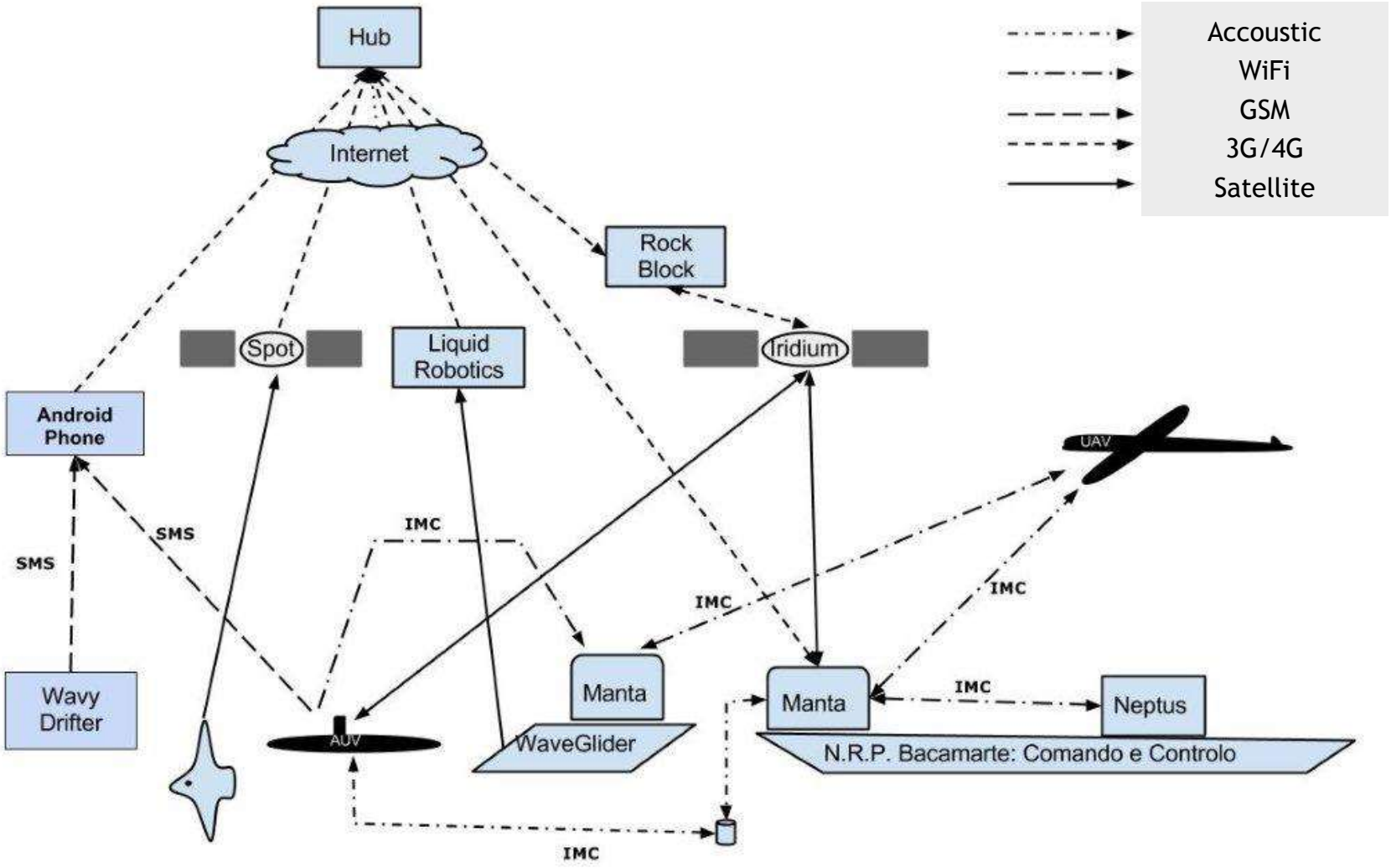




Operations under intermittent connectivity

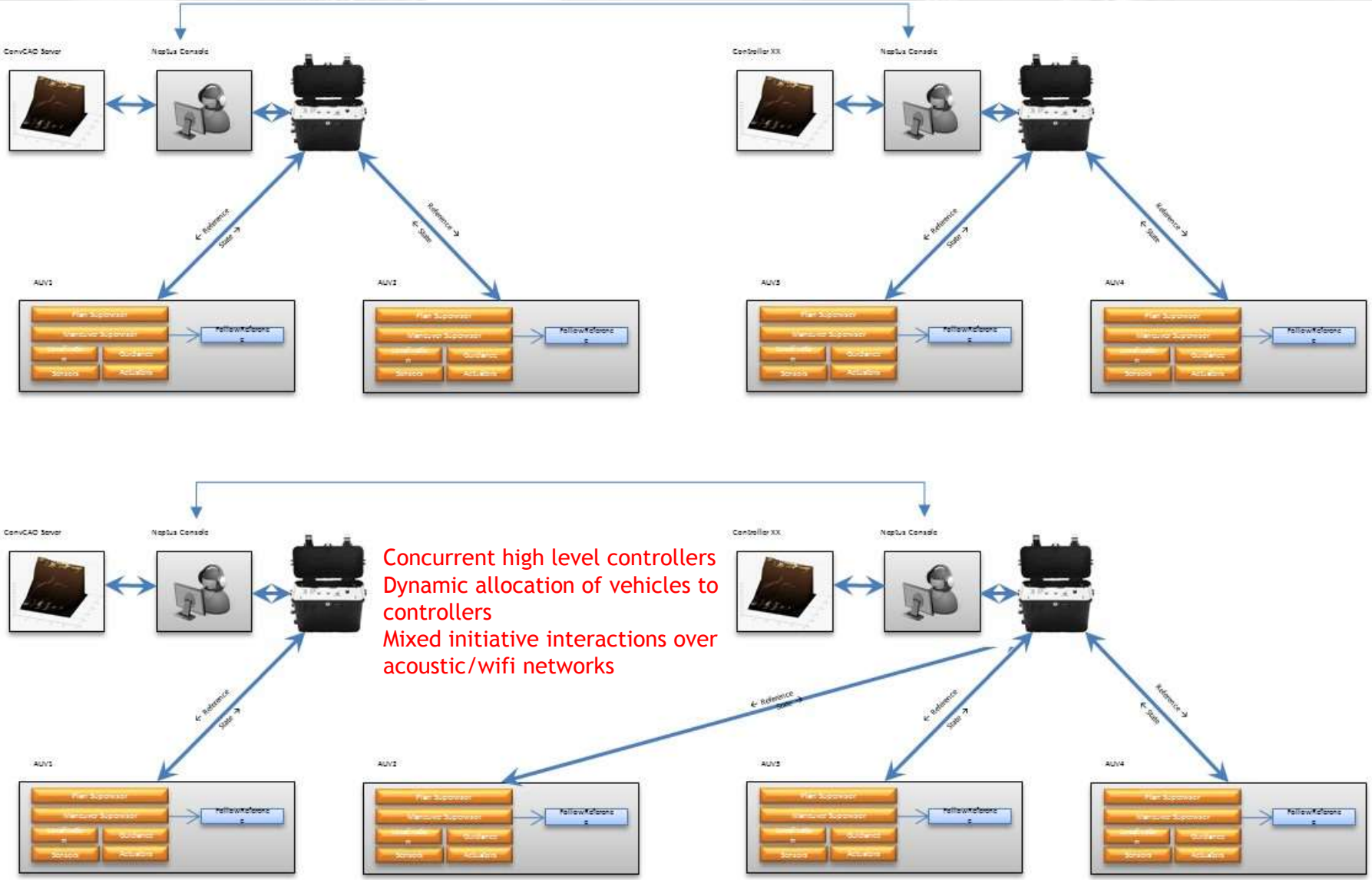


Situational awareness



Multi-vehicle systems

Flexible control architecture designed for continuous evolution



Operations

Large scale exercises
Simultaneous ops in the Pacific, Atlantic and Adriatic
Deployments from shore or from ship/submarine
Over 100 days of ops per year

Cooperation

- Portugal
  - Marinha Portuguesa
  - Porto de Douro e Leixões
  - IPMA
  - DGPM
  - Força Aérea Portuguesa
  - Estrutura de Missão para a Extensão da Plataforma Continental
  - Oceanscan MST (spin-off)
- USA
  - US Coast Guard
  - MBARI
  - UC Berkeley
  - Naval Postgraduate School
  - Google
  - University of Michigan
  - Naval Undersea Warfare Center
- Europe
  - AMOS - NTNU (Norway)
  - Royal Institute of Technology (SWE)
  - Naval Undersea Research Center (NATO)
  - National Oceanography Center (UK)
  - Imperial College (UK)
  - Plocan (Spain)
  - Delft University (NL)
  - EU/NATO/EDA project partners
    - NOPTILUS - FP7
    - SUNRISE - FP7
    - NECSAVE - EDA
    - NETMAR - Interreg
    - SAFEPORT - NATO
    - PITVANT - PO MOD
    - UReady4OS - DG-ECHO
    - ITN – UAS – Marie Curie
- India

Indicators

National institutional impact	• Navy and Air Force unmanned vehicles programs • Supporting ops of deep sea ROV (extension of the continental shelf)
World firsts	• Underwater rendezvous between 2 AUVS (2006) • Lauch and recovery of AUV from U214 class submarine (2012) • Coordinated UAS-AUV coastal fronts observations (2013) • UAS supervising AUV with the help of a Wave Glider (2014)
Impact on the market	• Spin-off Ocean Scan Marine Systems and Technologies LDA • Evologics uses software tool chain for their ASV model • Community of users of software tool chain: over 12 countries
Operational highlights (last year)	• Atlantic and Pacific, Adriatic and Mediterranean • Over 1000km (AUVs) • Over 200 flights (UASs) • Longest AUV mission (24h)

OPERATIONS

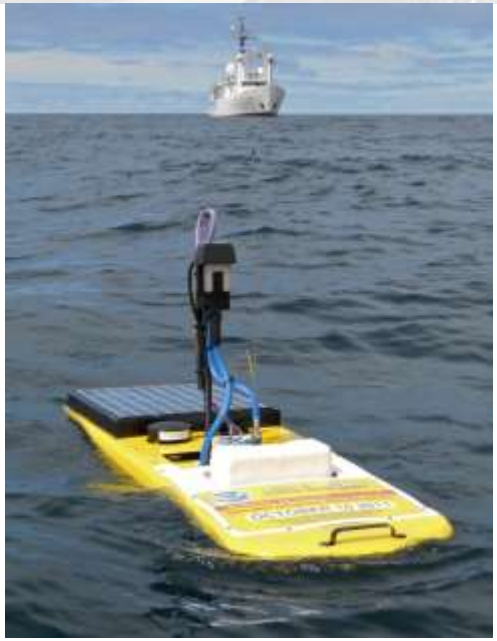
Cathach exercise *May 2013*

Integration with existing systems

Chasing hammerhead sharks *Aug 2013*

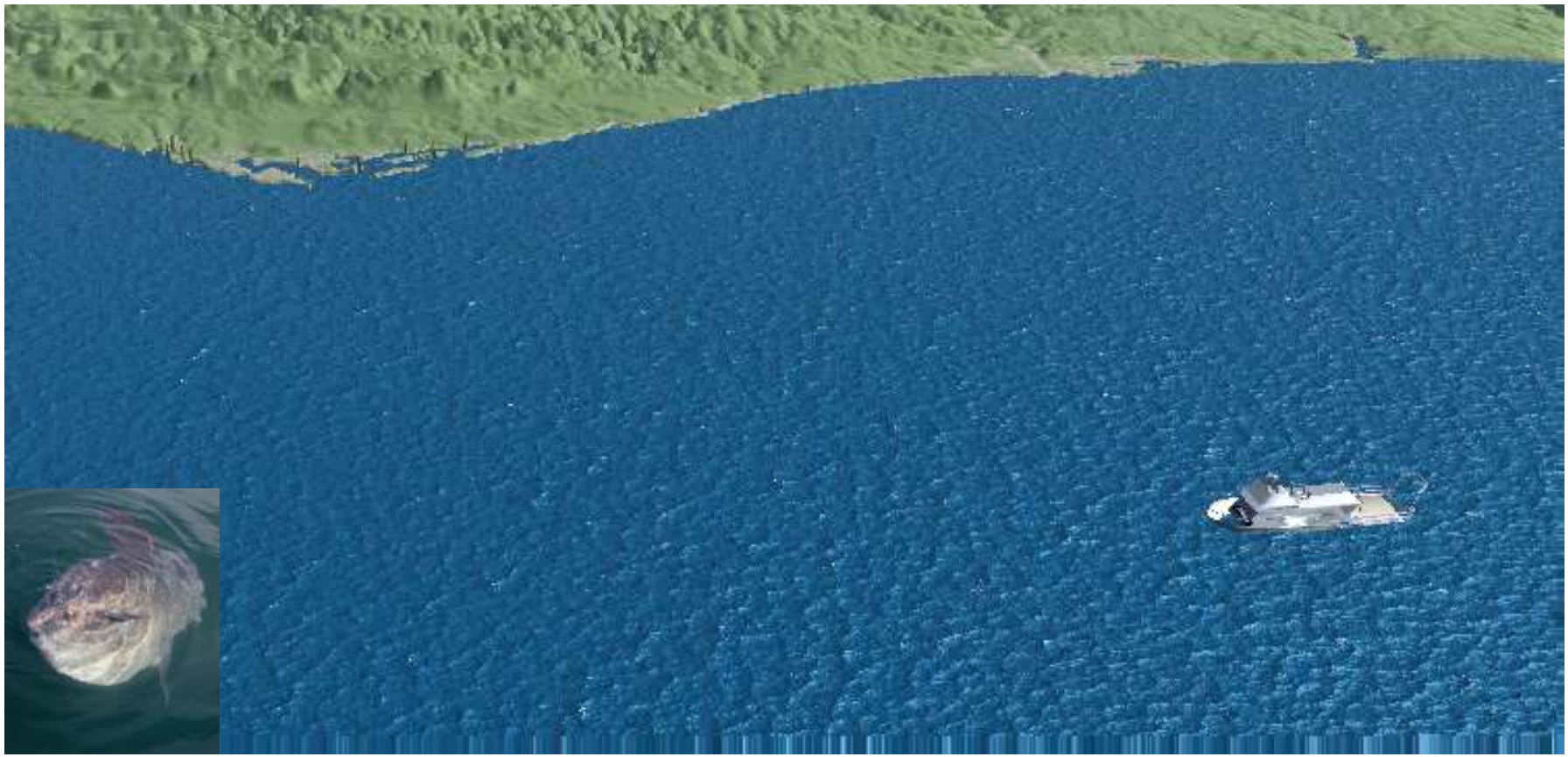
- Cooperation with the University of Açores

CANON experiment *Monterey 2013*



Mobile communications hotspot and rendezvous for communications

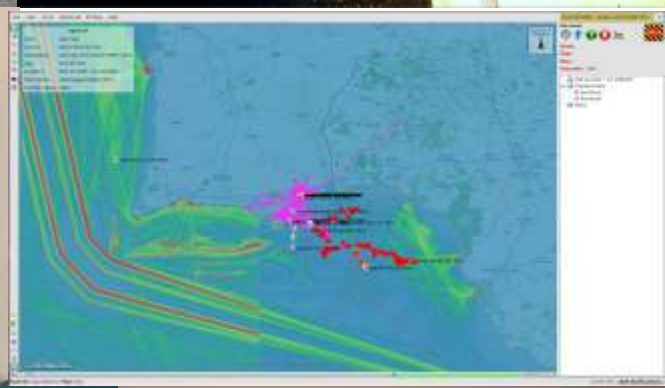
Sunfish tracking *May 2014*



Persistent tracking and learning of fish behavior



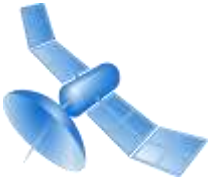




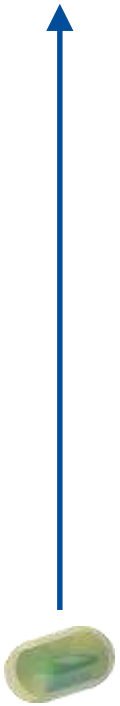

DO IT: interdisciplinary


LSTS

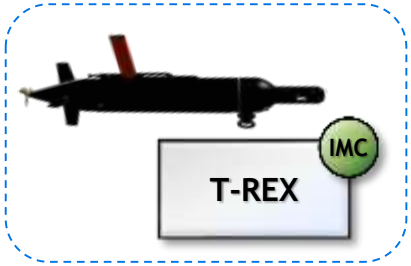


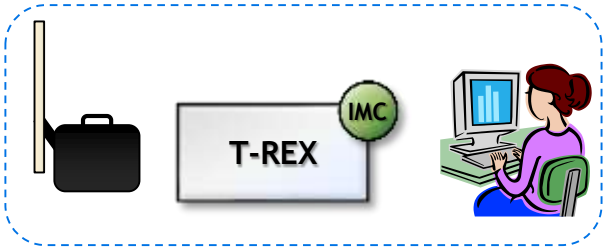
globalstar

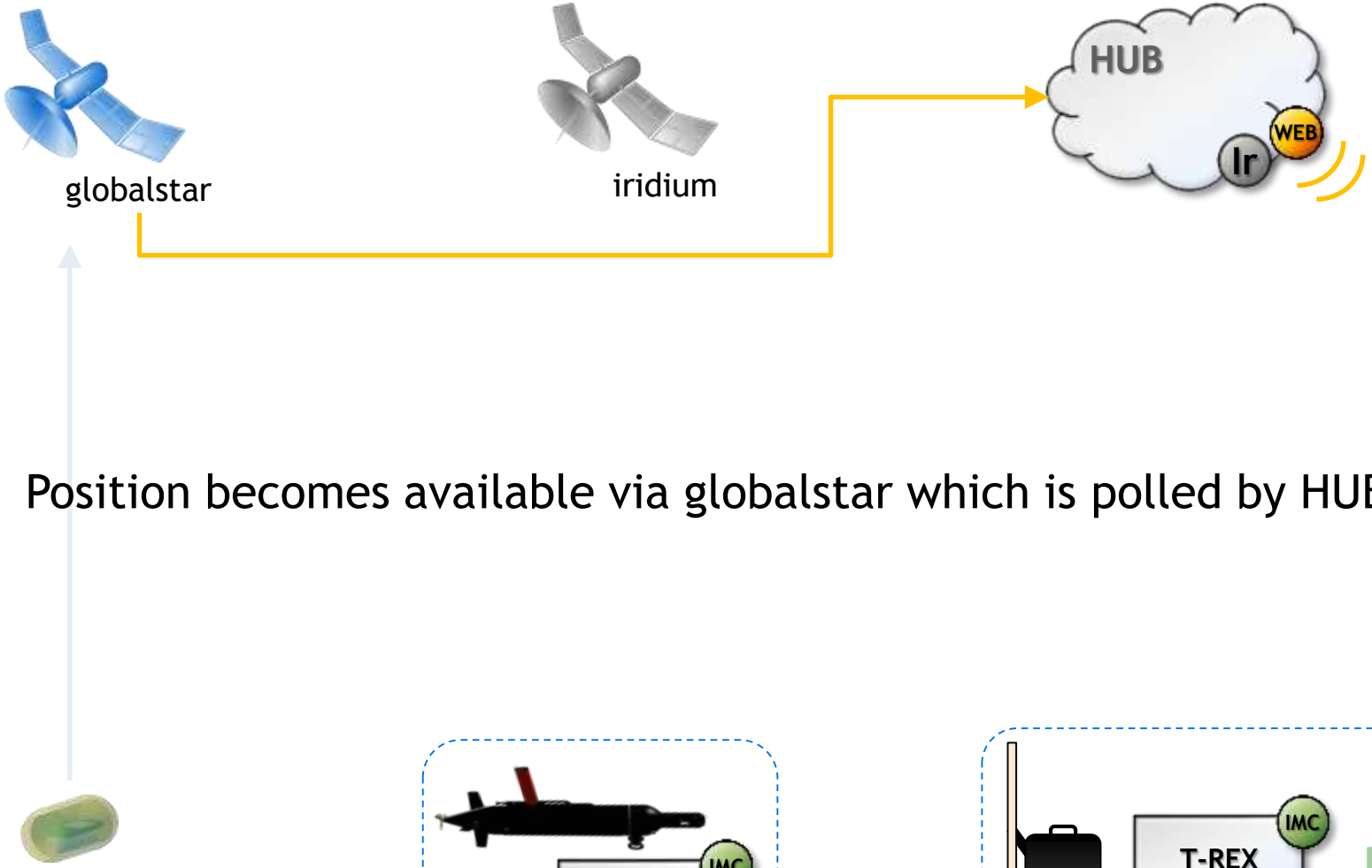
iridium

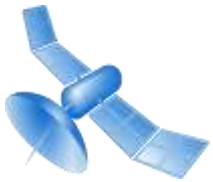


Sunfish tag sends position update





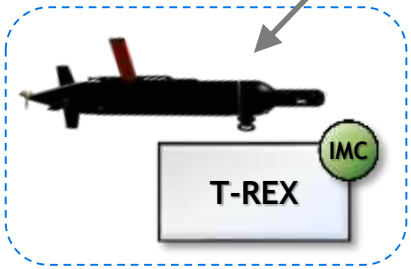

globalstar
iridium
HUB
WEB
Ir
Position becomes available via globalstar which is polled by HUB
IMC
T-REX
IMC
T-REX

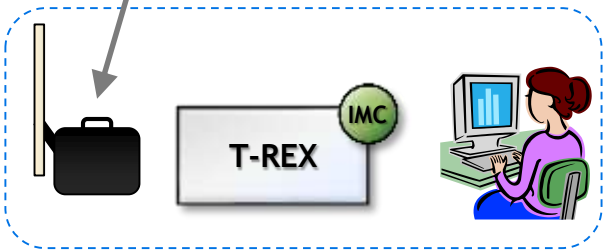


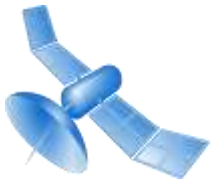
globalstar

iridium

HUB pushes new information to Iridium subscribers



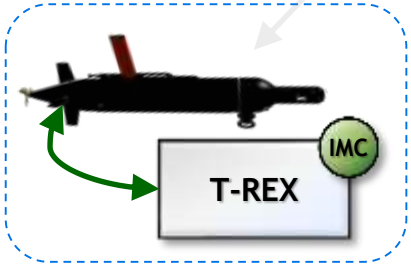


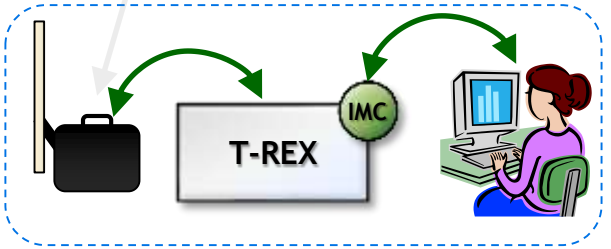


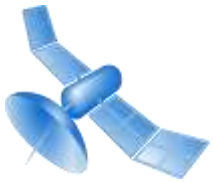
globalstar

iridium

Locally all data and commands use IMC







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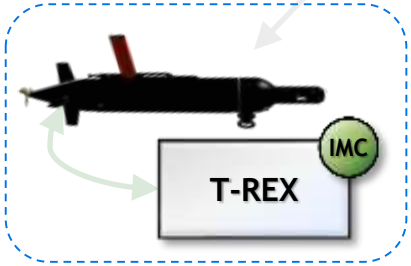
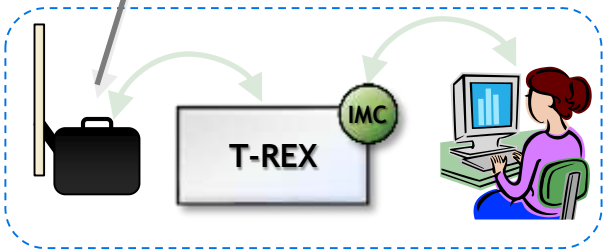
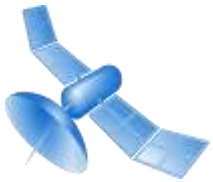
iridium

Generated objectives are sent to HUB via Iridium







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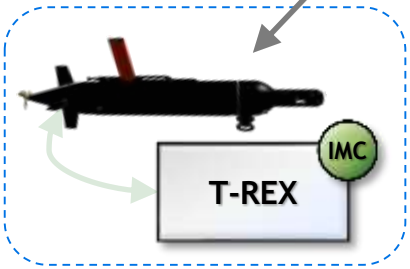
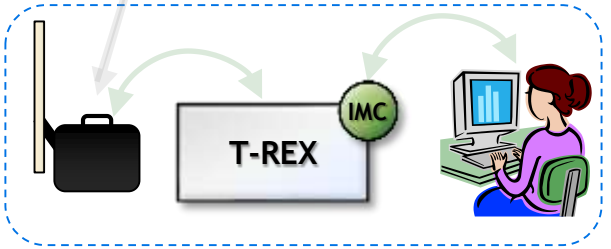
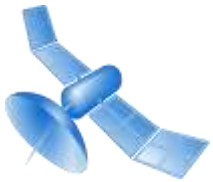
iridium

...And forwarded to the tasked vehicle







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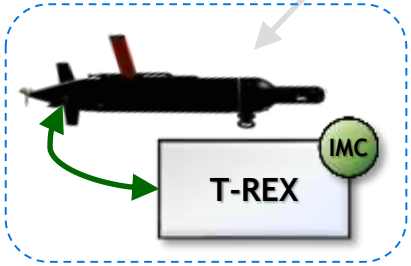
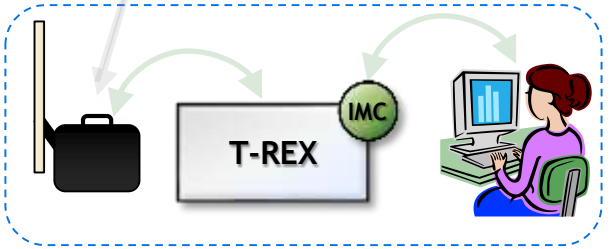
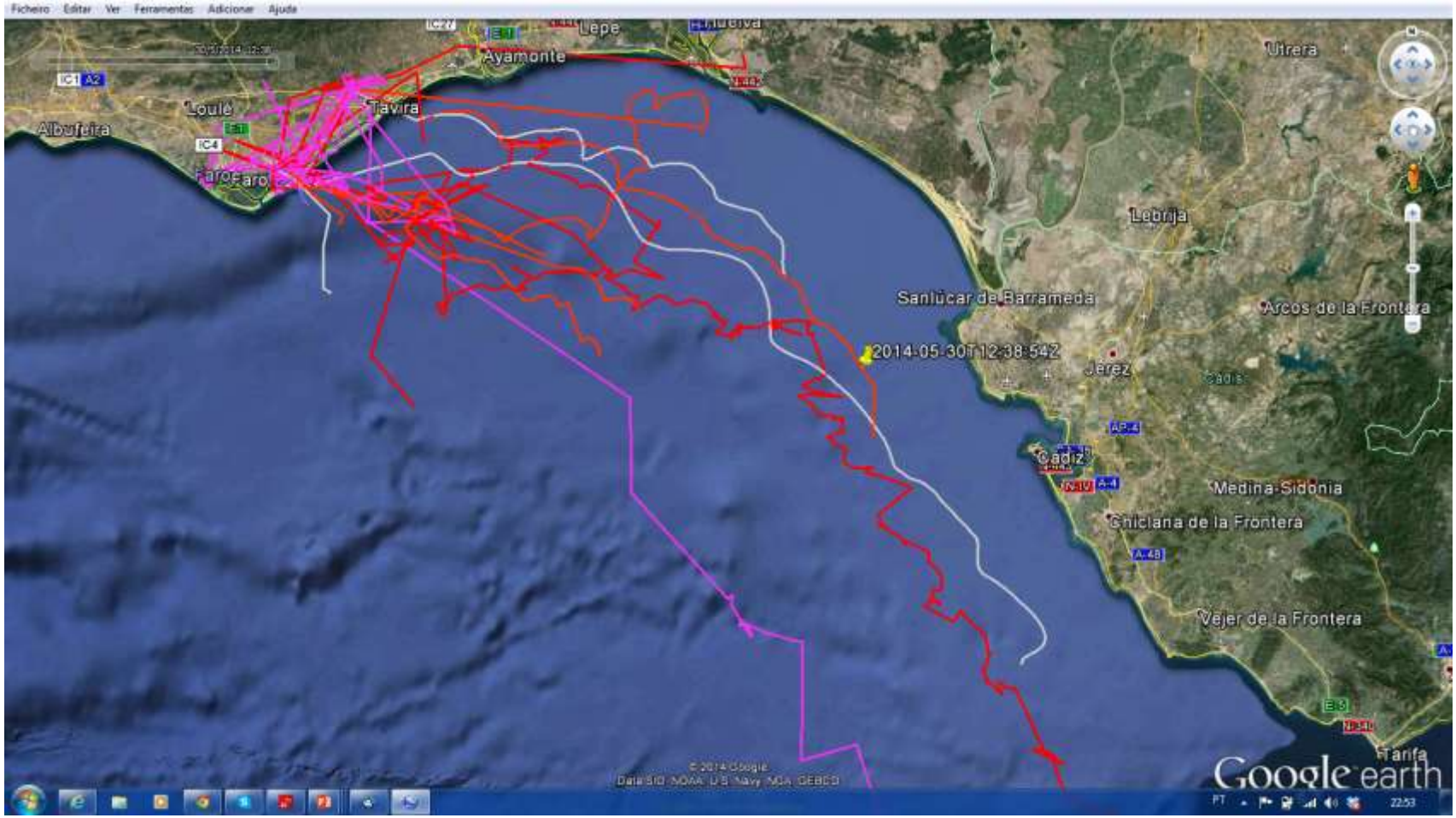
iridium

T-REX uses previously received information and objective to generate and execute new plan





Fish tracks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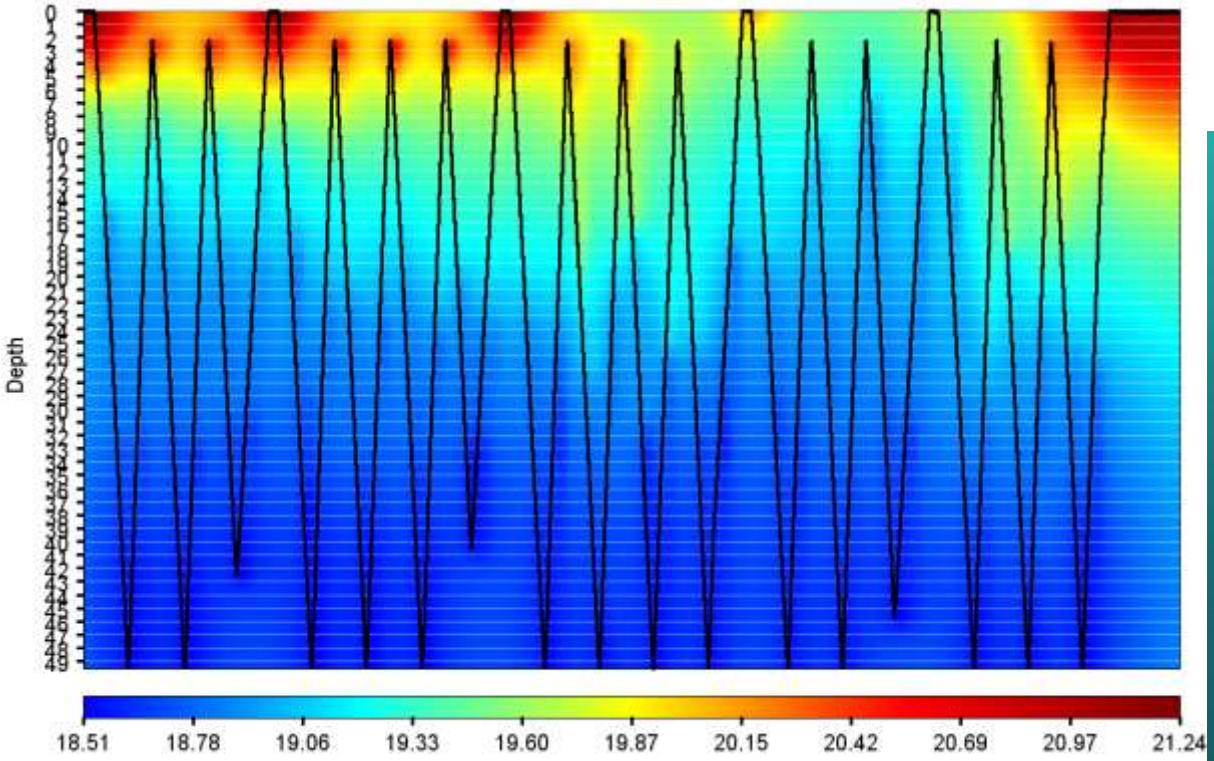
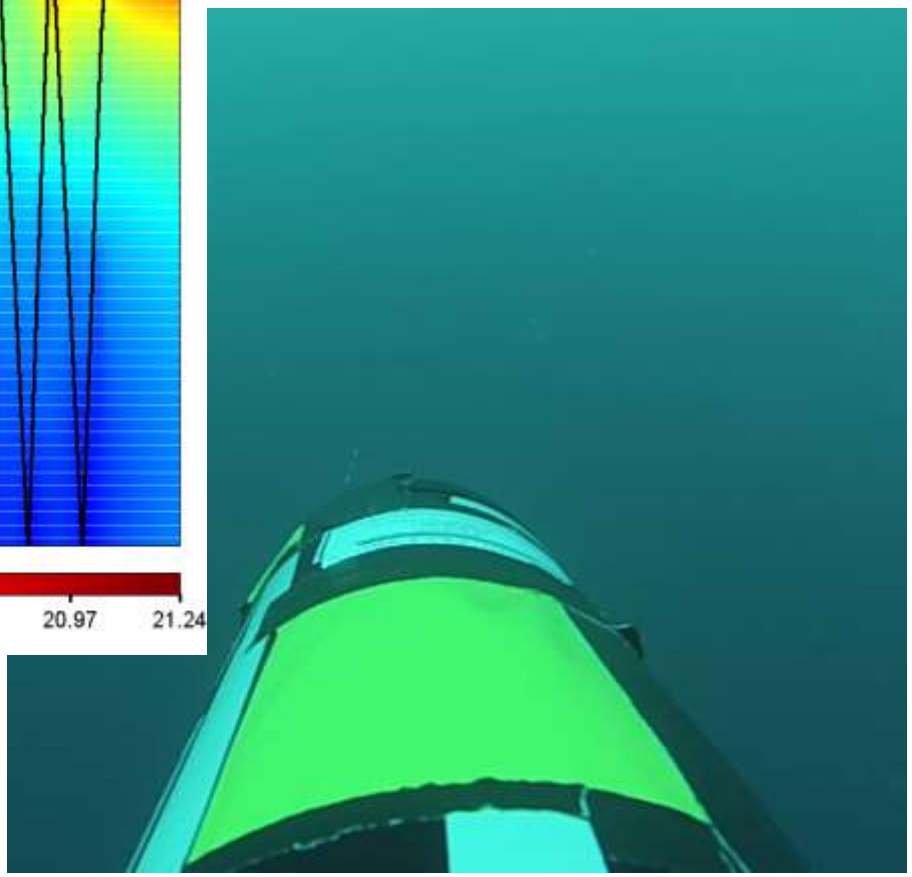
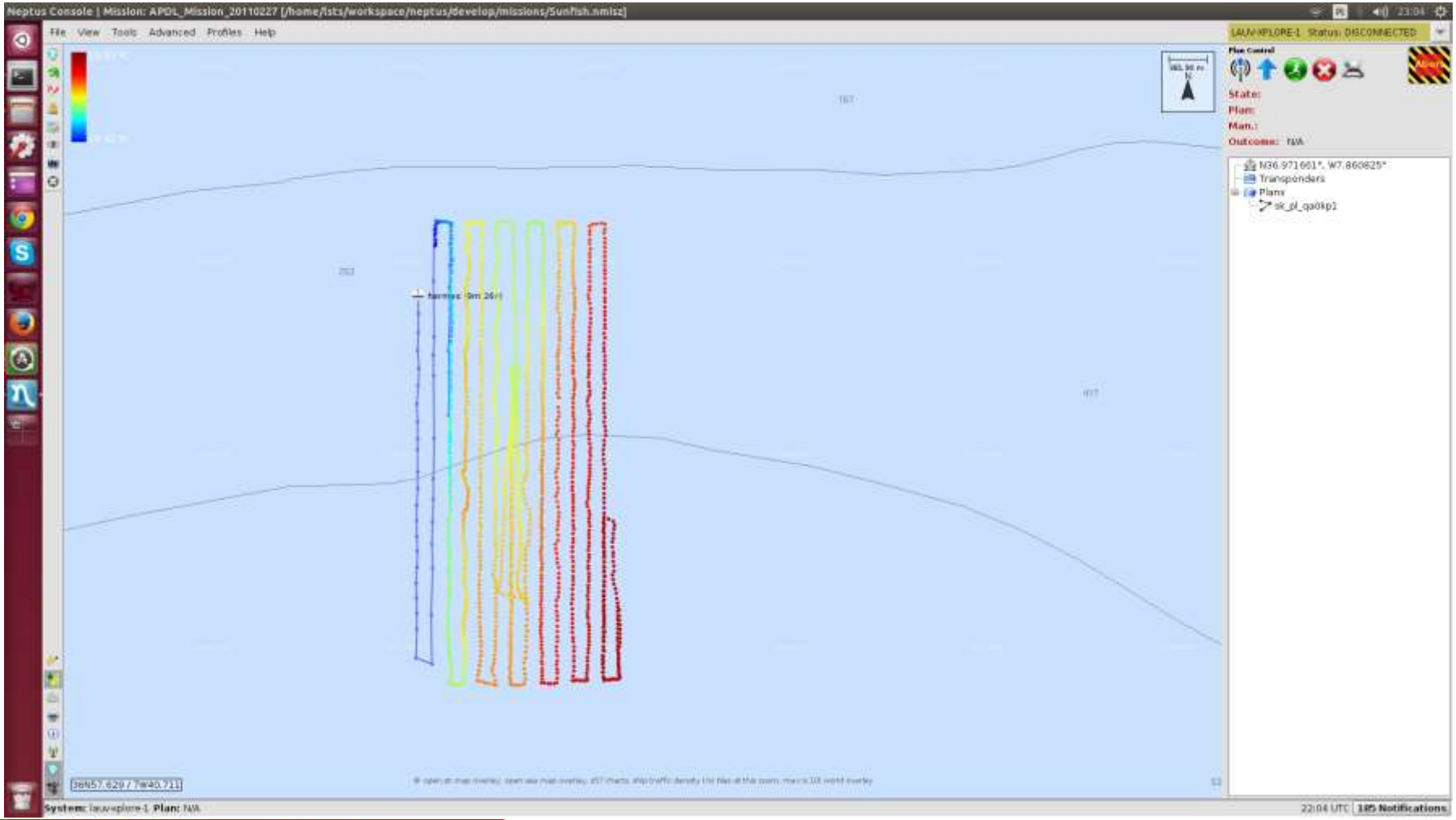
Google earth

Correlating measurements





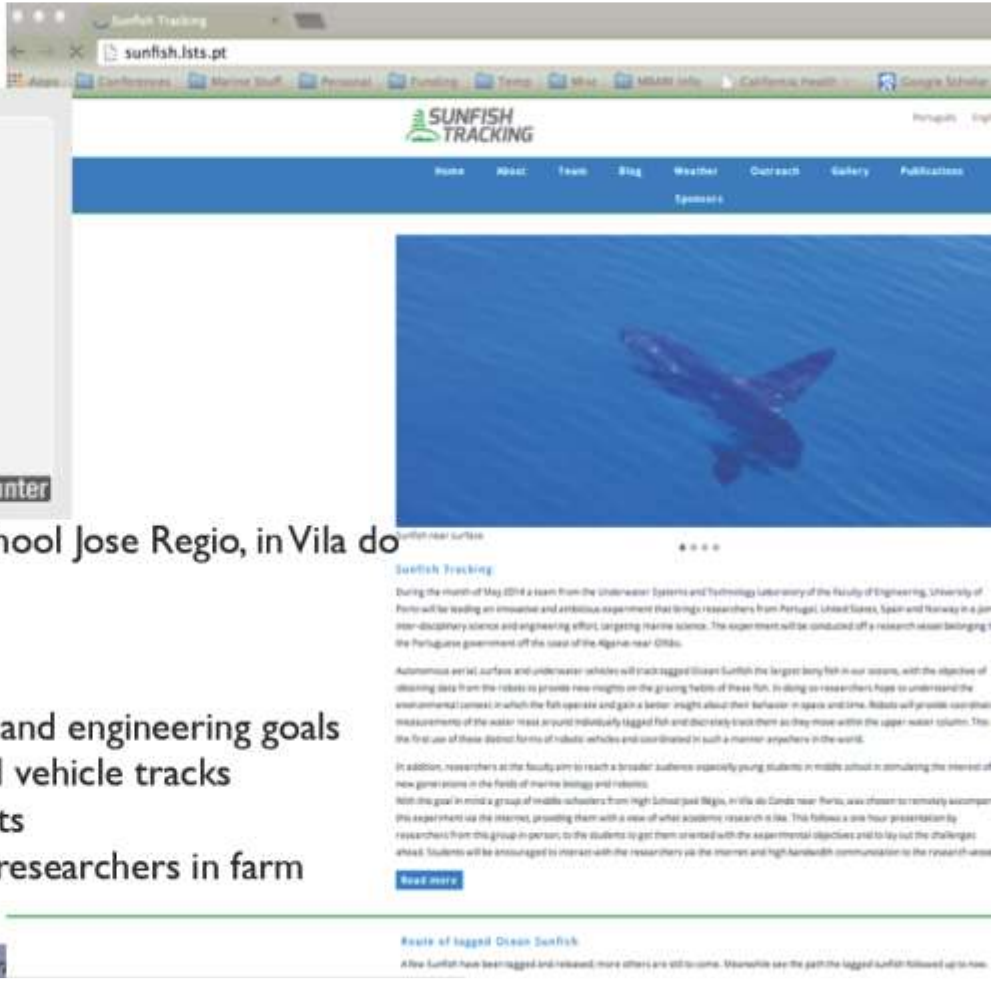
Wave Glider real-time CTD



Surface temperature profiles (IR camera)

Coordinated air and ocean observations

PERSISTS: outreach



Interaction with 8th grade students High School Jose Regio, in Vila do Conde near Porto

- Science class project on Mola's
- April 28th visit & presentation on science and engineering goals
- HUB web services for visualizing Mola and vehicle tracks
- Naming Mola's which are visible to students
- May 20th interaction including Q&A with researchers in farm house

Recognized Environmental Picture – Atlantic (REP 14)

Organized by

- PO Navy
- Porto University
- Centre for Maritime Research and Experimentation

Participants

- University of Rome
- Certh
- Royal Institute of Technology
- Evologics
- OceanScan

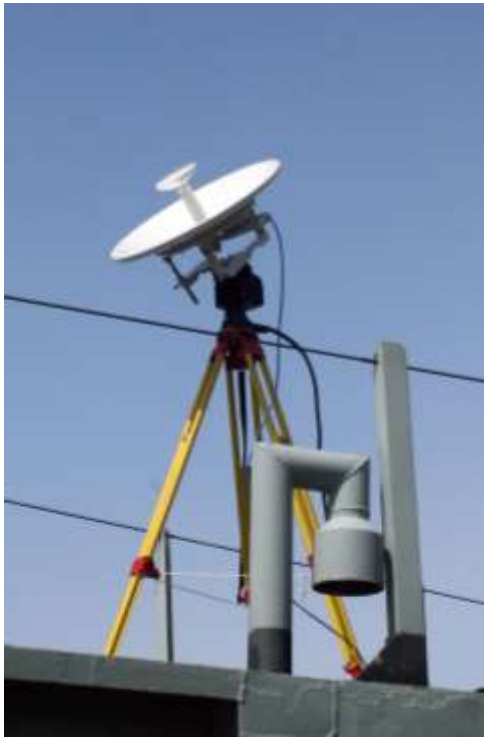
Areas

- Mine Warfare
- Harbour Protection
- Expeditionary Hidrography
- Search and Rescue
- Maritime Law Enforcement
- Environmental Monitoring

Large scale experimentation

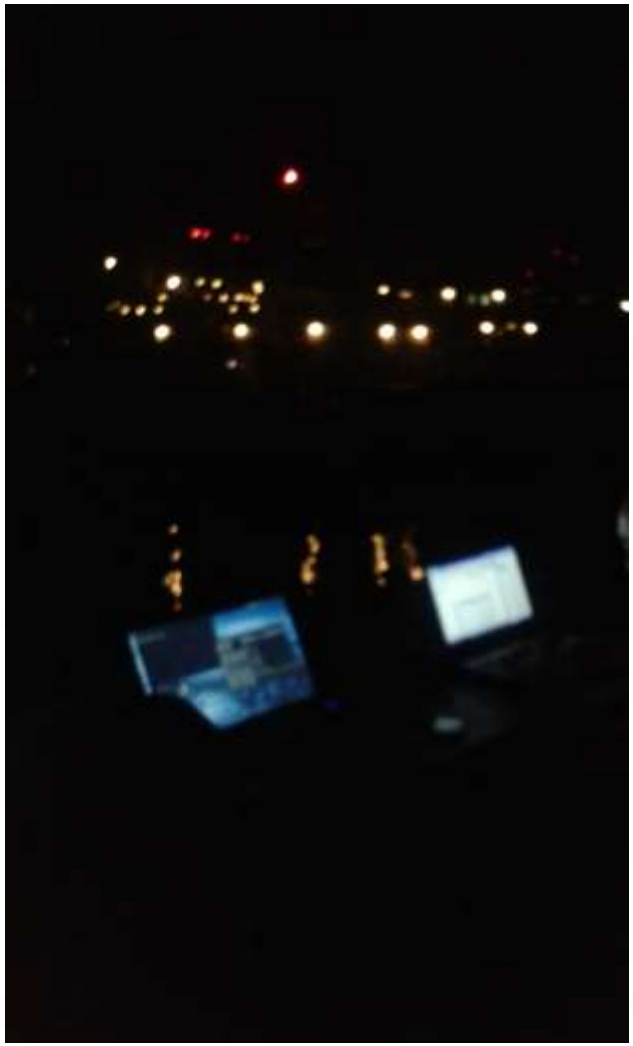
REP 14 – 4 ships

REP 14 – Vehicle systems



"Truly" autonomous UAV/AUV operations
Coordinated observations - coastal fronts
UAVs for "bent" LOS communications
Mixed initiative control ASVs, AUVs, UAVs

REP 14 – Night ops

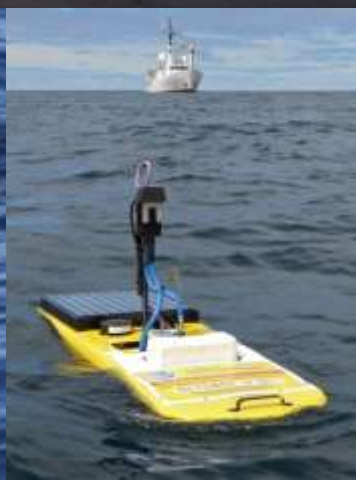


REP 14 – Estuary operations

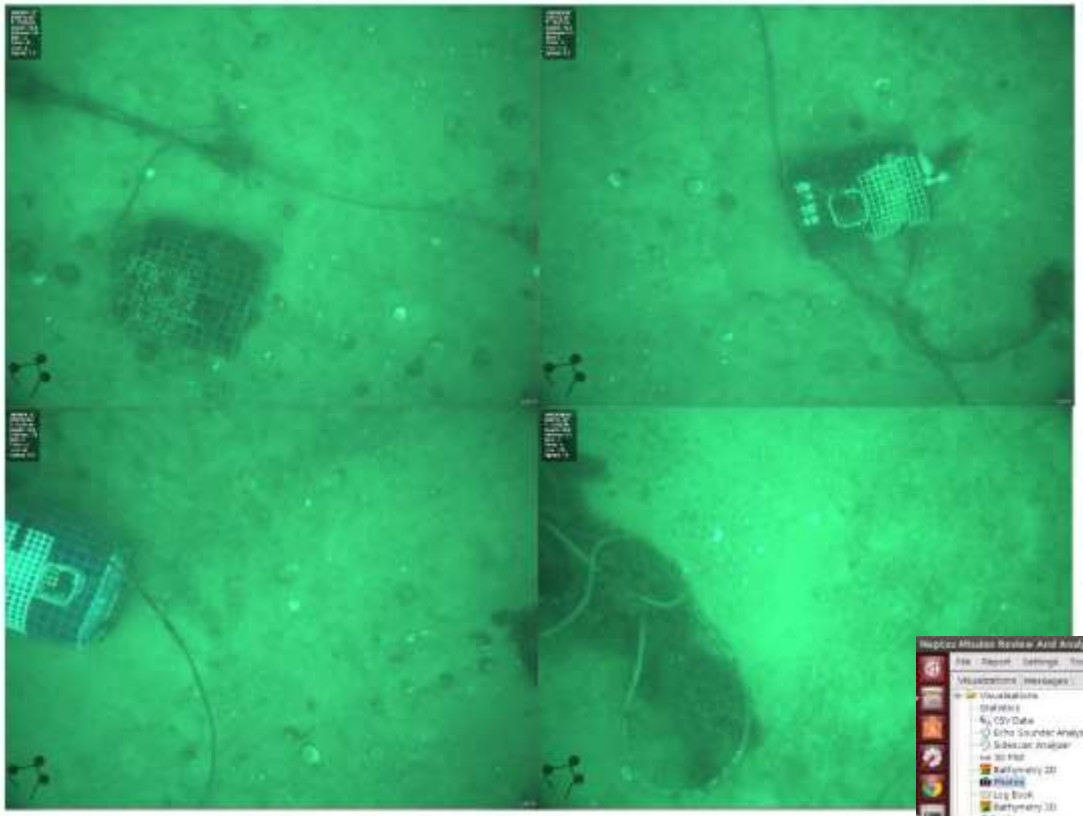
REP 14 – UAV/ASV/AUV coordination

World first: UAS controls (feedback) a submerged AUV with the help of a Wave Glider

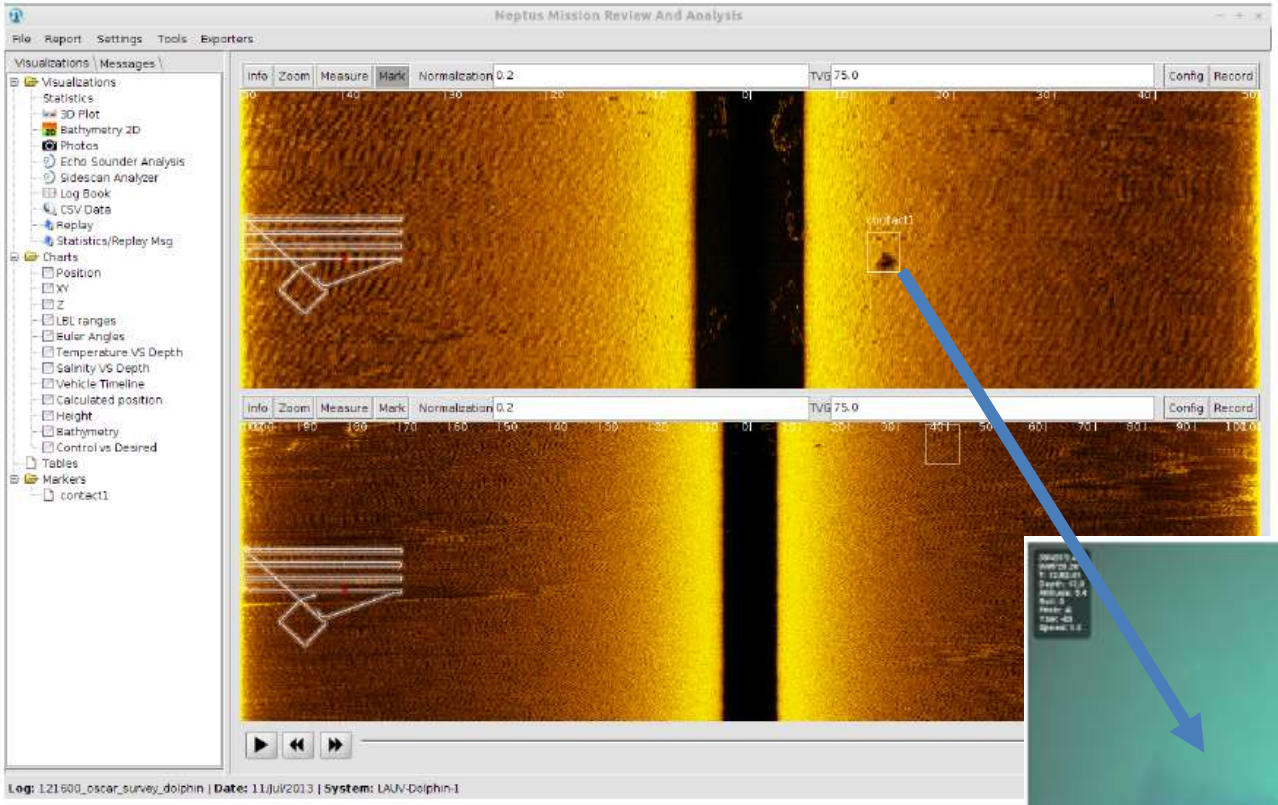
- Wi-Fi
- AComs
- Manta Gateway

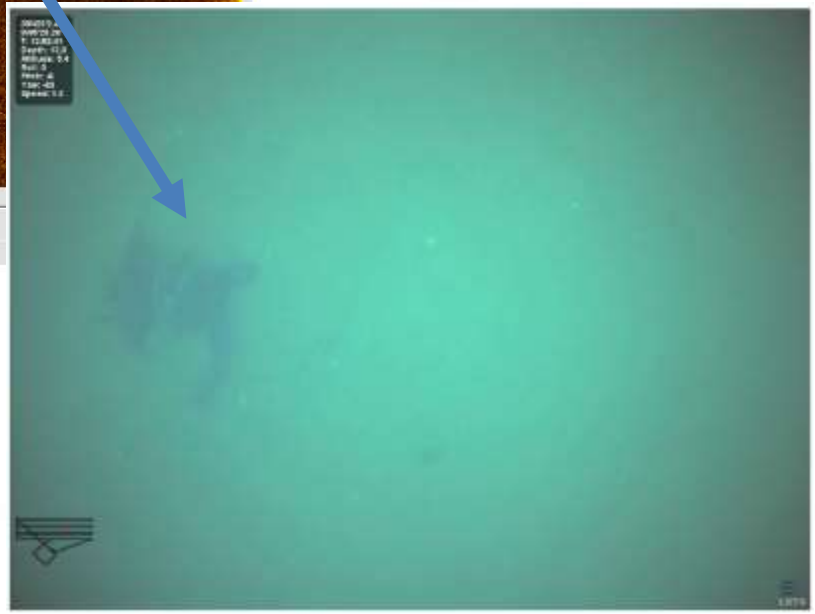


REP 14 – Data products

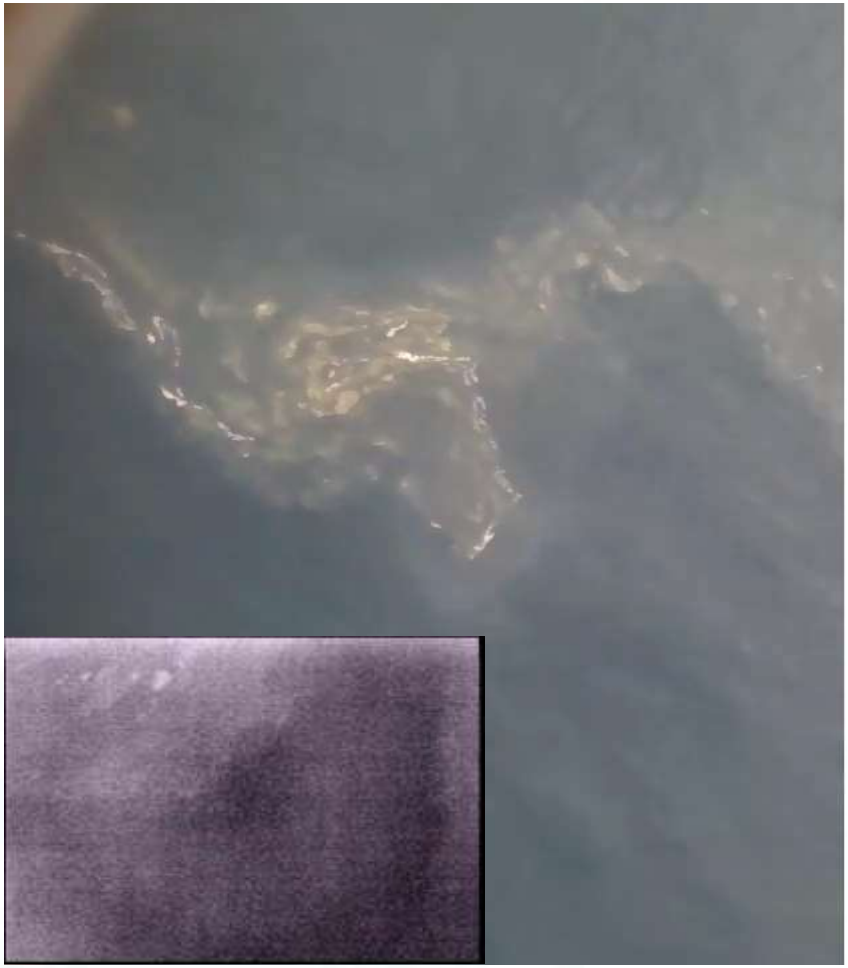


REP 14 – Data products

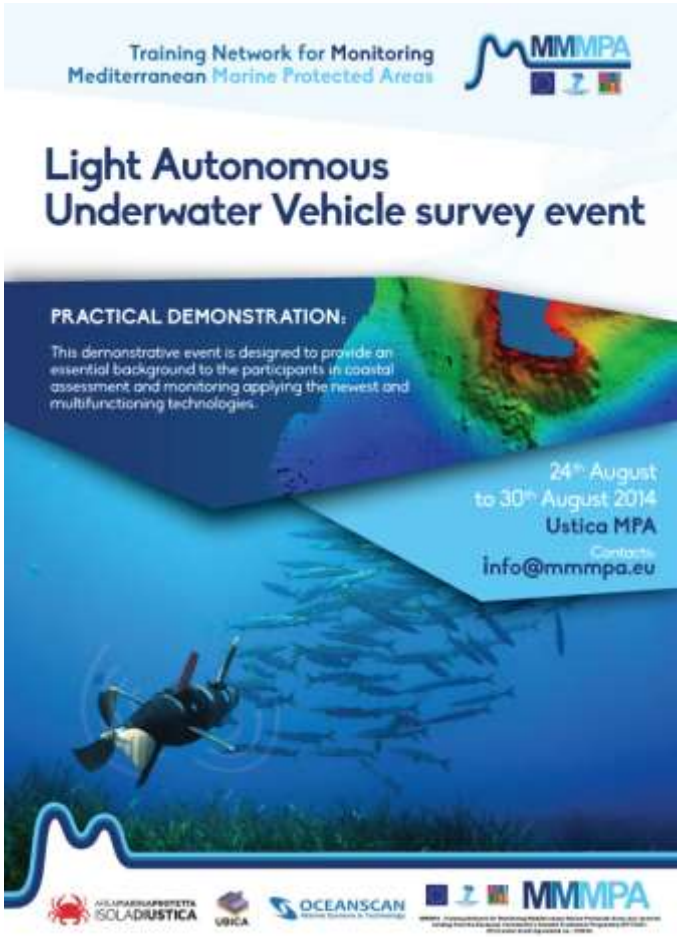


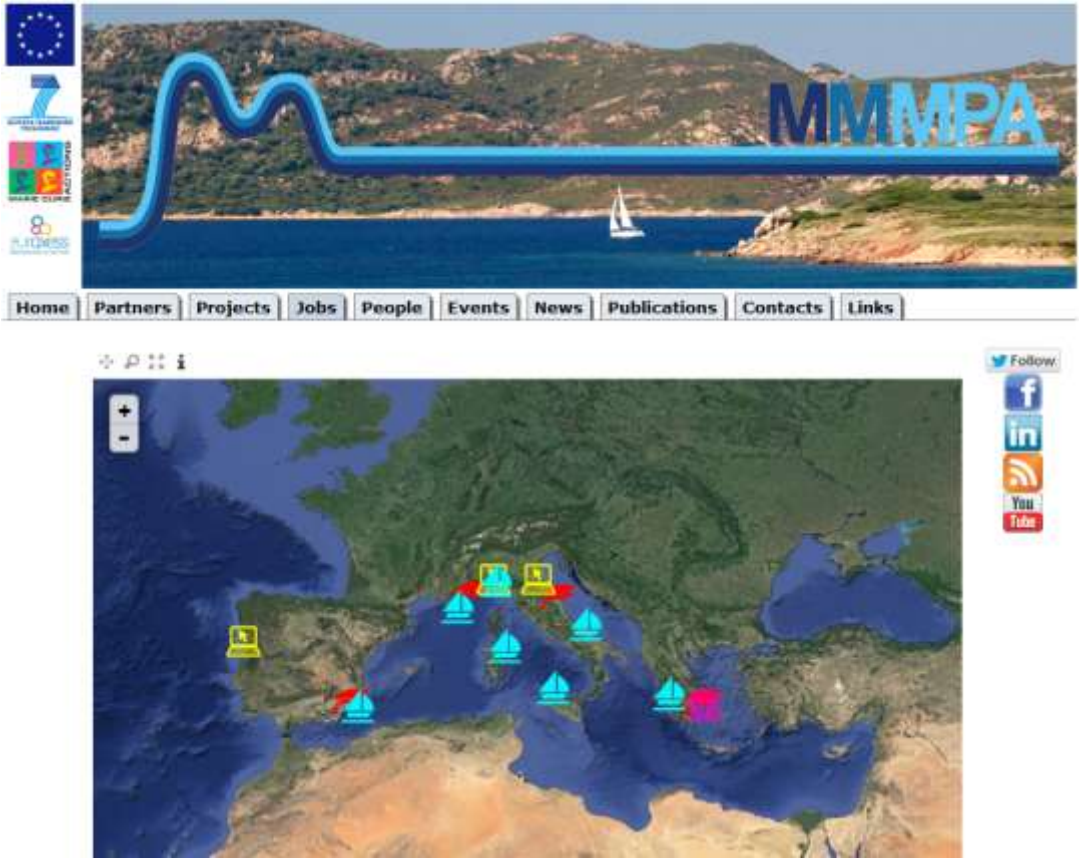


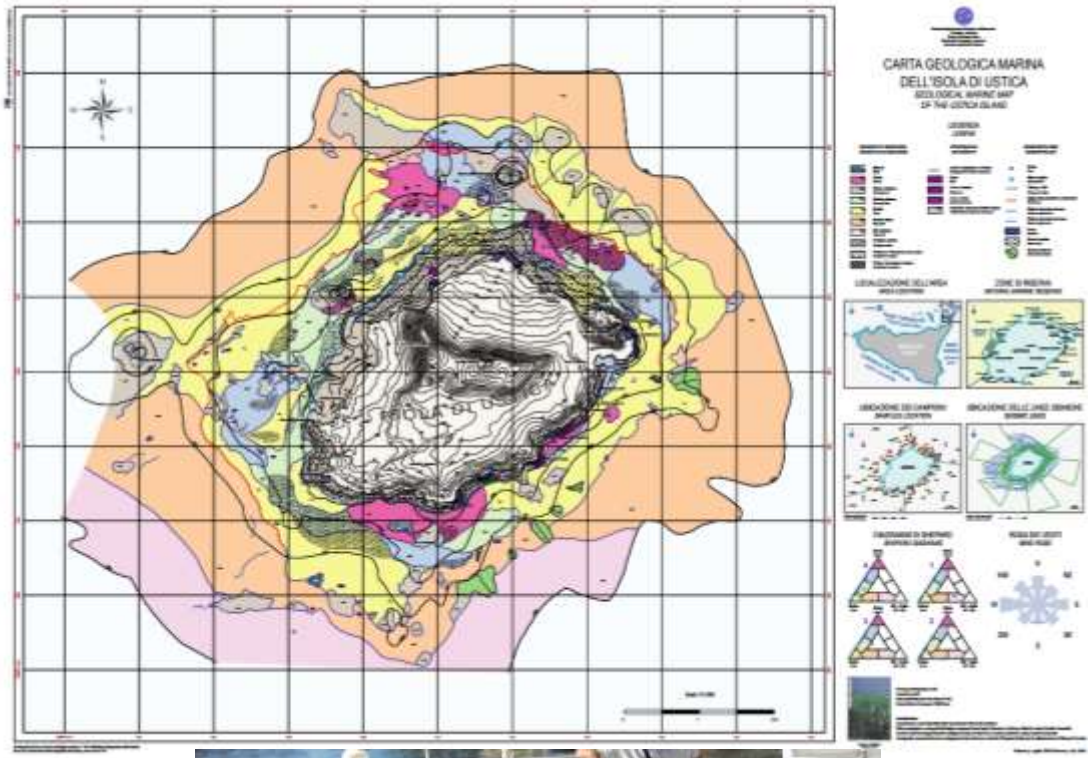
REP 14 – Data products

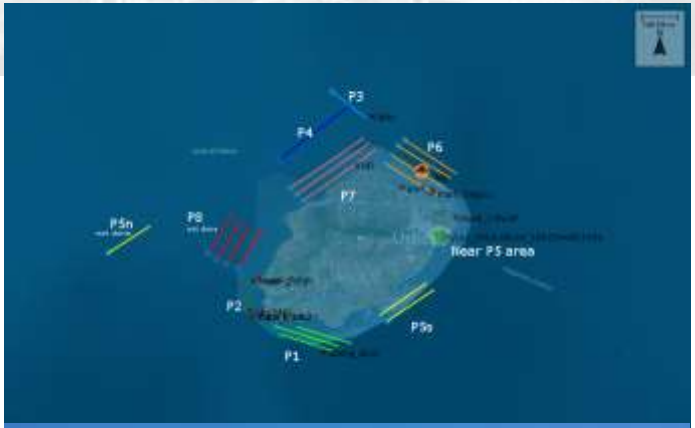


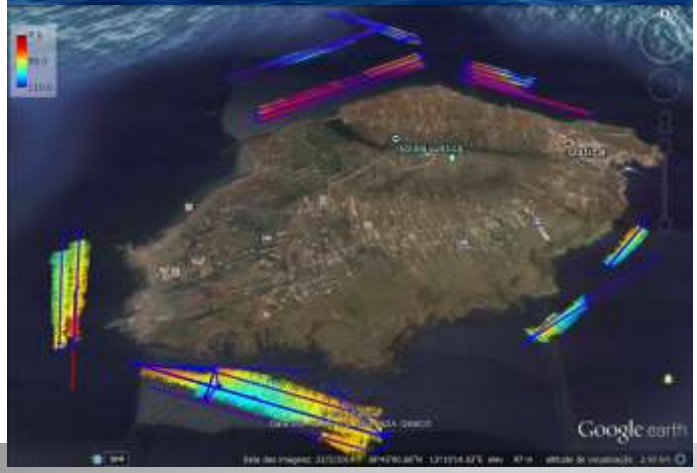
Ustica - mapping MPAS *Aug 2014*



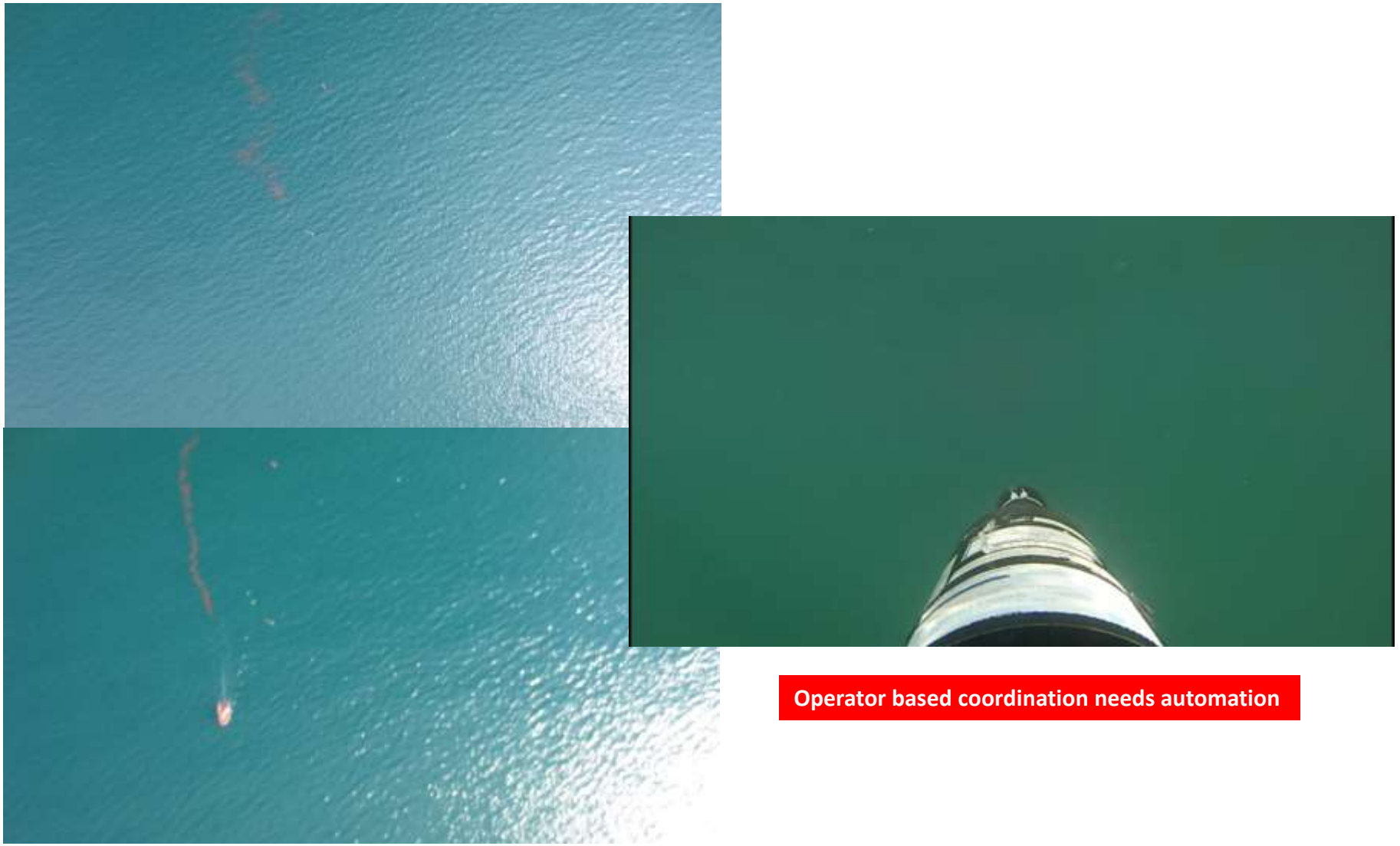



CARTA GEOLOGICA MARINA
DELL'ISOLA DI USTICA


P3
P4
P6
P7
P5n
P8
Near P5 area
P2
P5p
P1


Google earth

Coordinated air/ocean observations Split *Sept 2014*



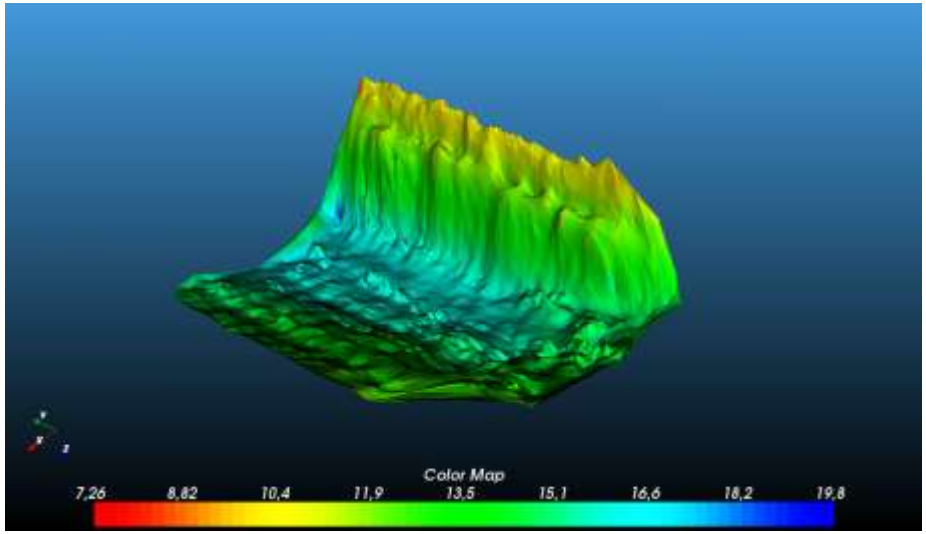
Operator based coordination needs automation

Madeira demonstration *Nov 2014*

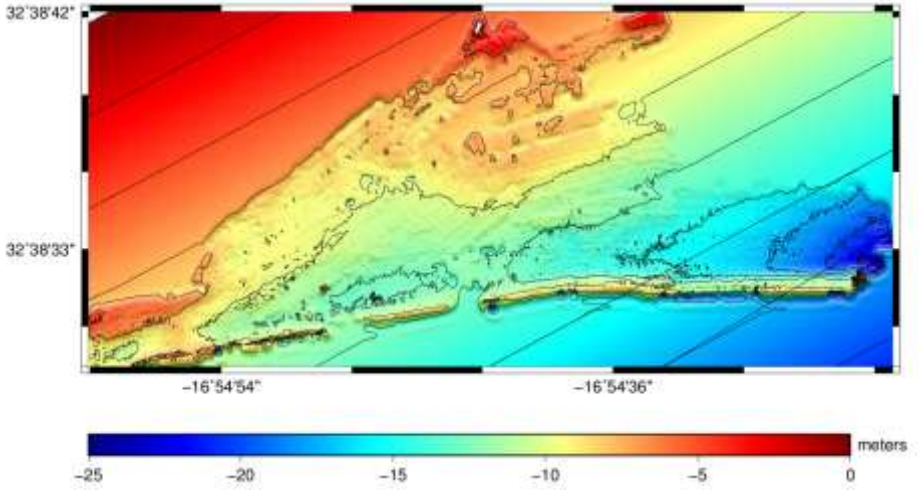
Marinha

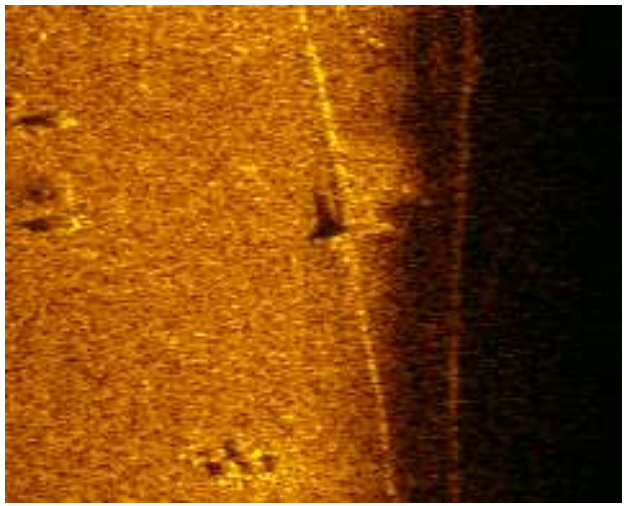
ciimar madeira

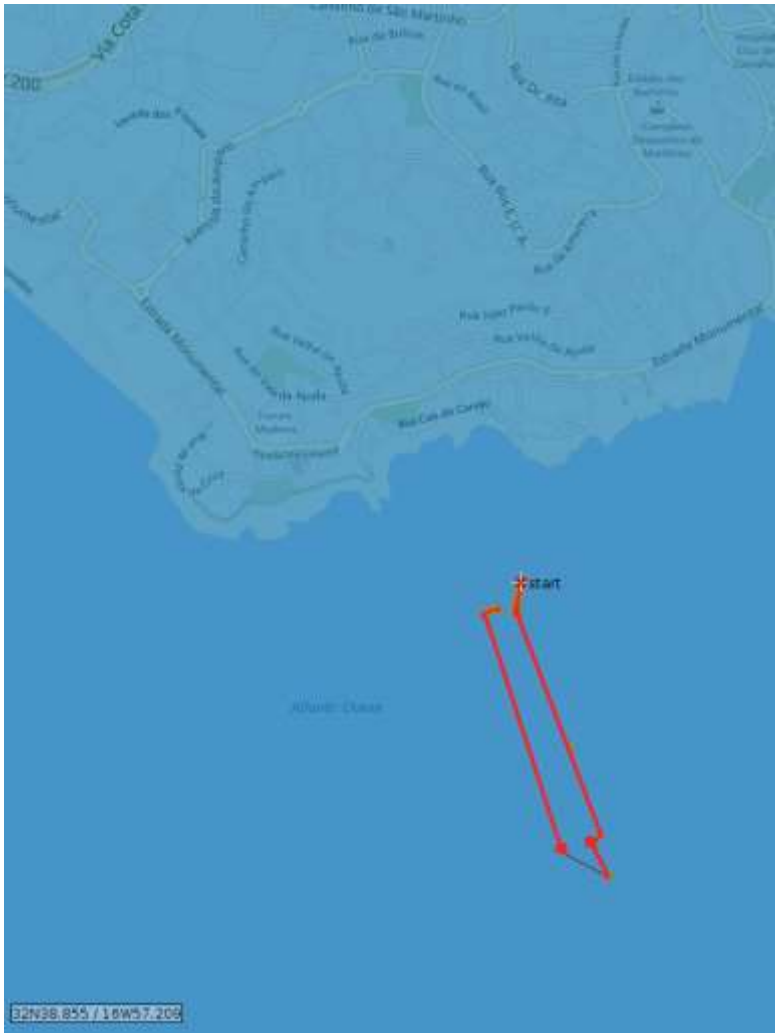
PORTOS DA MADEIRA

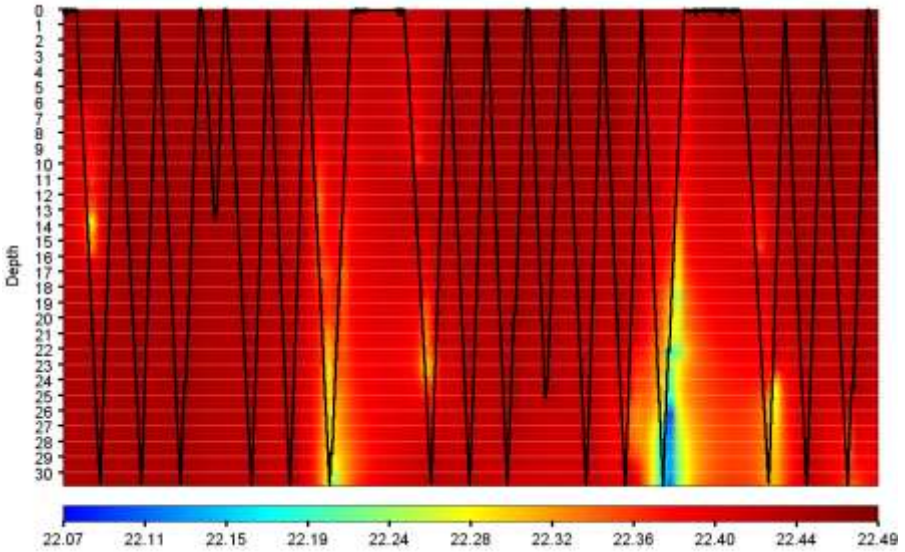

Color Map
7,26
8,82
10,4
11,9
13,5
15,1
16,6
18,2
19,8

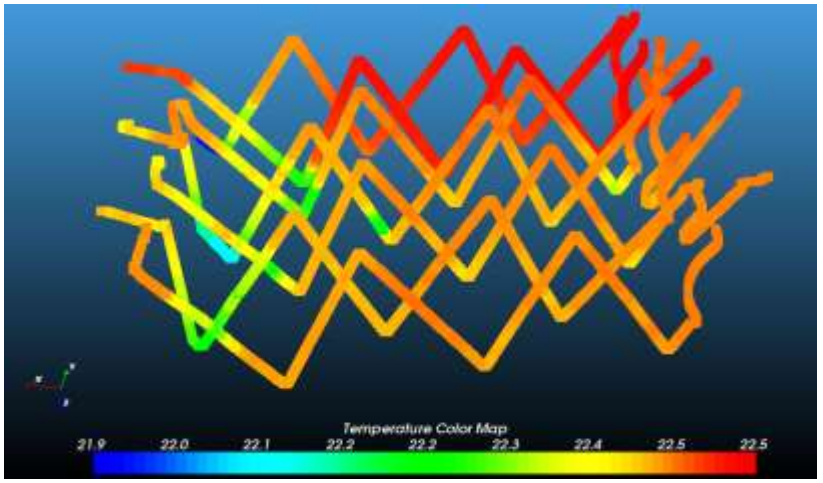

Avenida Francisco Sá Carneiro


32°38'42"
32°38'33"
-16°54'54"
-16°54'36"
meters
-25
-20
-15
-10
-5
0



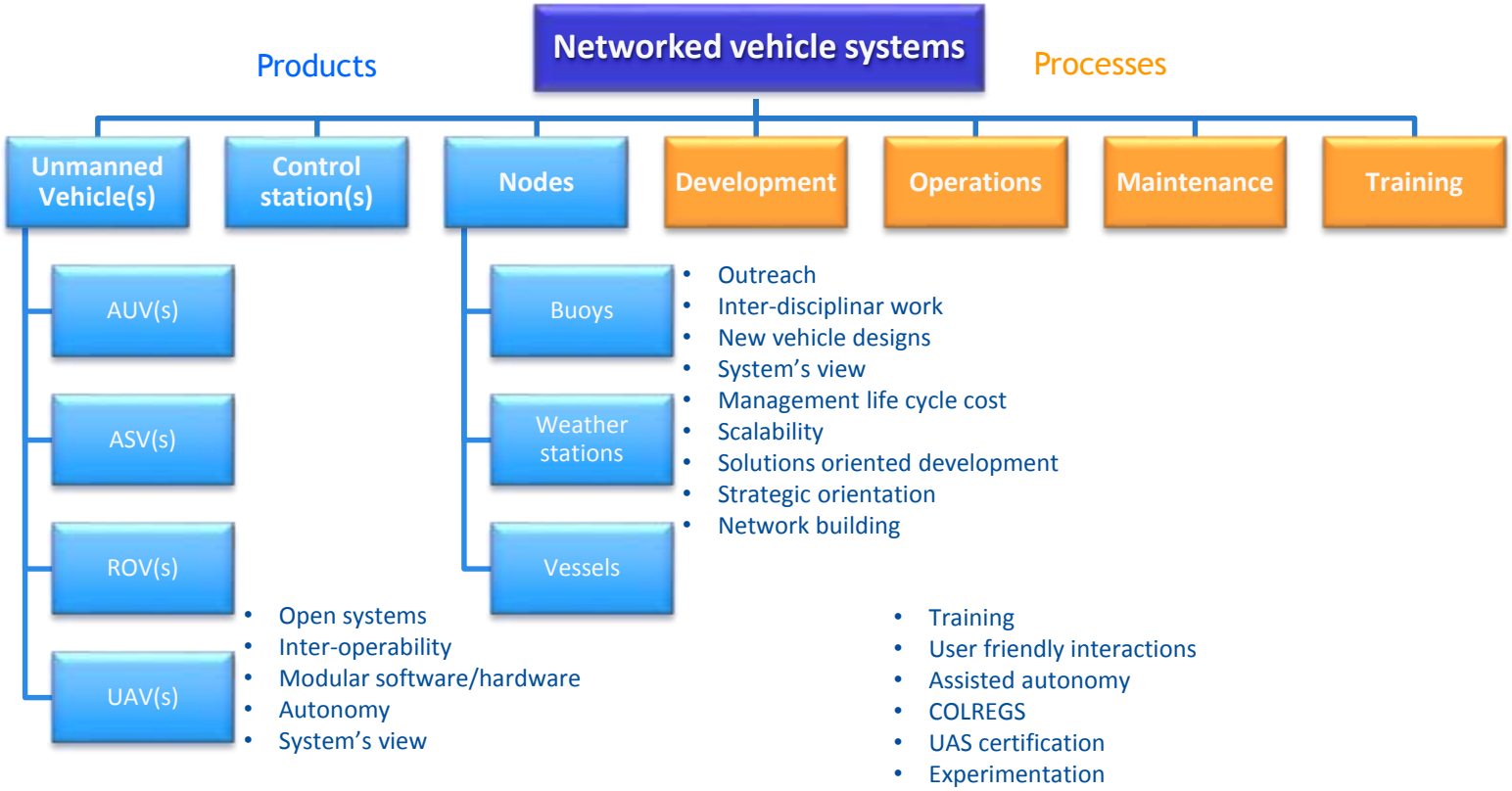

start


Depth
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
22.07
22.11
22.15
22.19
22.24
22.28
22.32
22.36
22.40
22.44
22.49


Temperature Color Map
21.9
22.0
22.1
22.2
22.3
22.4
22.5

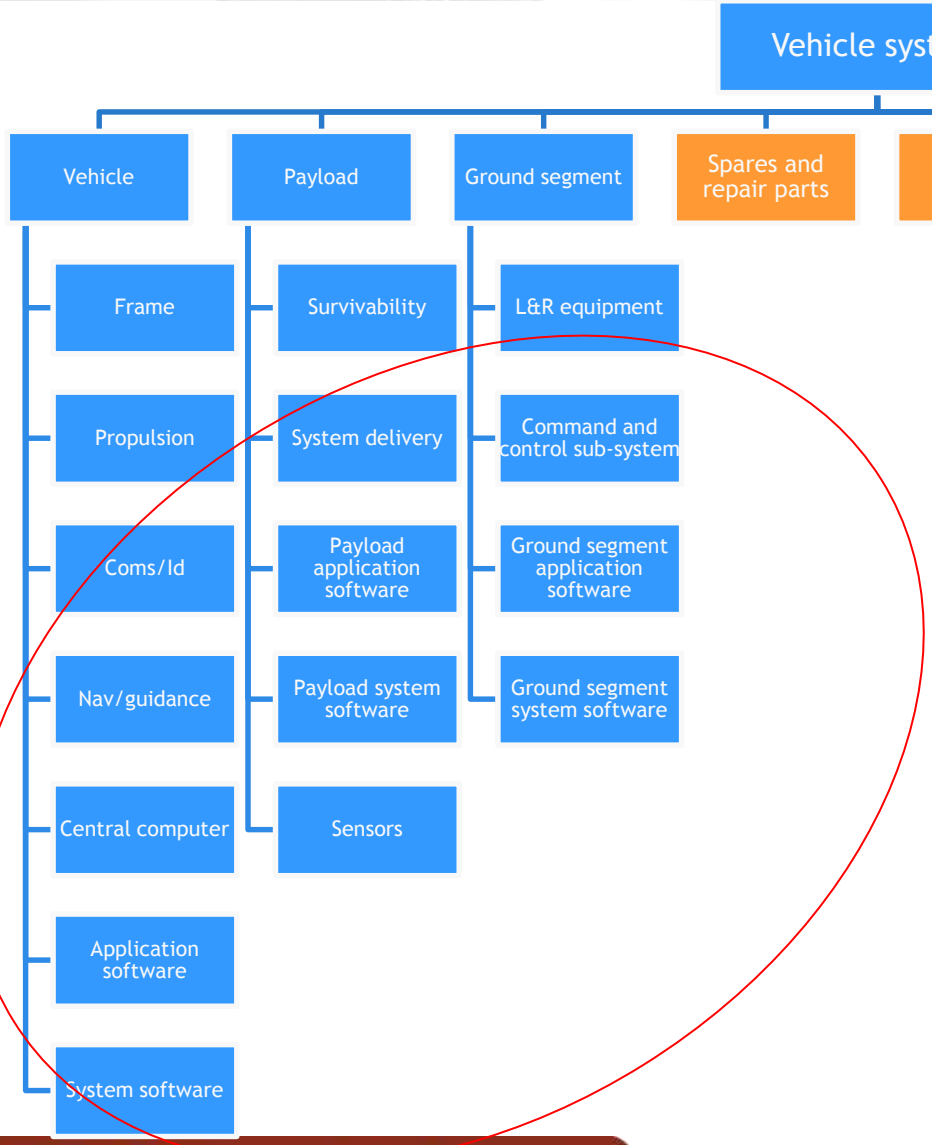
SOME CHALLENGES …

Systems thinking



"*The interoperability goal for Unmanned Systems is an ability to provide data, information, material, and services to and accept the same from other systems, units, or forces … and to use the exchanged data, information, material, and services to enable them to operate effectively together.*" DOD 2011.

Going deeper …



Technical focus but we need to consider the whole system

CONCLUSIONS

- MDA (and ocean observation) presents significant challenges
  - Connected natural and man-made systems
  - Multiple spatial and temporal scales
  - Region specific
- Networked vehicle systems are key to MDA
  - Vehicles designed for interactions
  - Development models targeted at scalability, inter-operability and open systems to minimize cost and facilitate replication
  - Co-evolve with developments in communications, energy harvesting, sensing and big data
  - Learn from experimentation
  - Establish networks of partnerships
  - Development of personnel

Friendly technologies