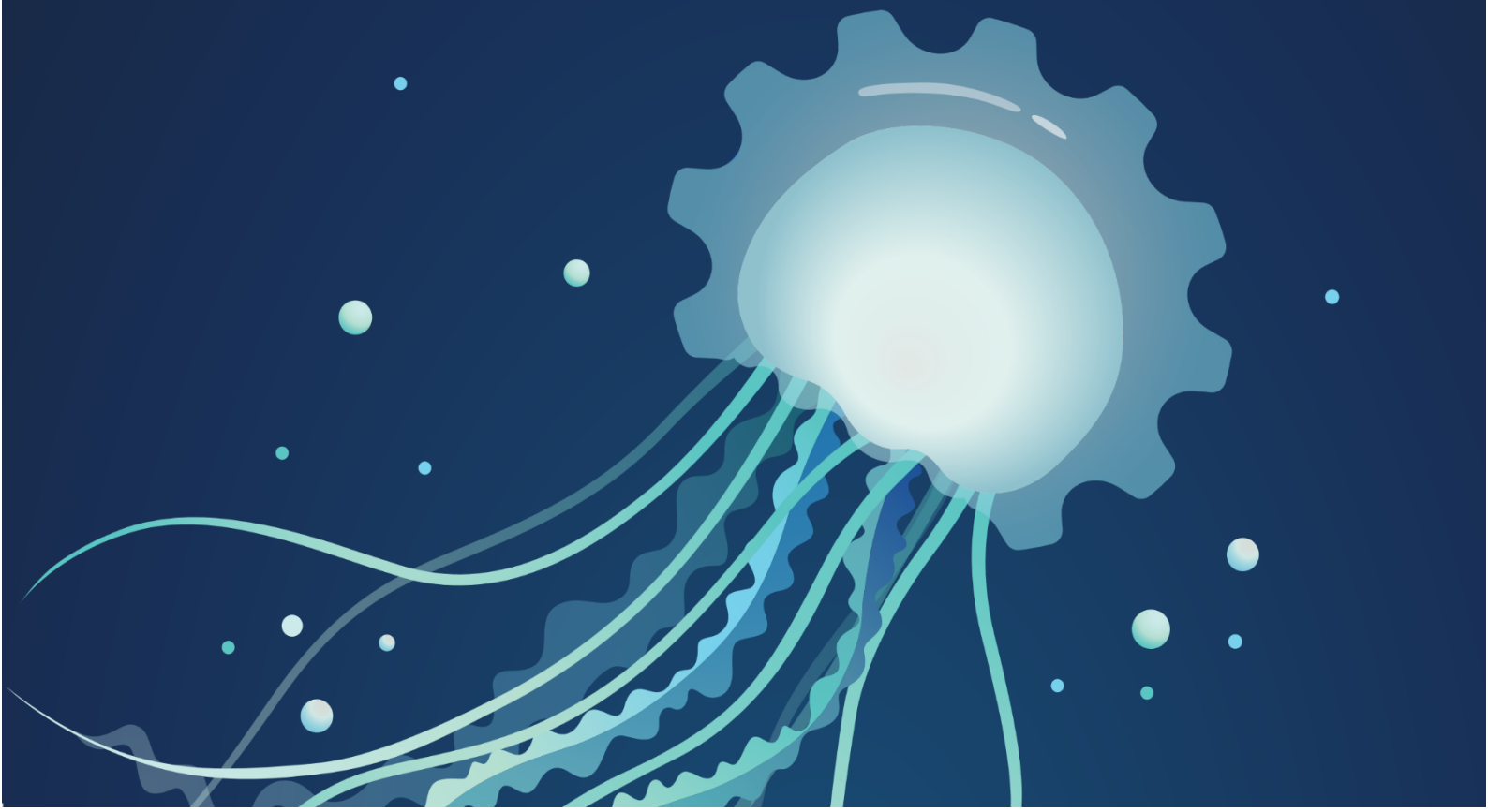
2022 25.09. - 2.10.
Biograd na Moru, Croatia

BREAKING THE SURFACE

14th INTERNATIONAL INTERDISCIPLINARY FIELD WORKSHOP OF MARITIME ROBOTICS AND APPLICATIONS



Breaking the Surface 2022

Biograd na Moru, Croatia

25th September-2nd October

PROCEEDINGS

1 CONTENTS

2 INTRODUCTION

The Breaking the Surface 2022 was held from 25th September until 2nd October in Biograd na Moru, Croatia and 200 people participated. It was a very successful post-pandemic edition of Breaking the Surface (BtS), the international interdisciplinary workshop on robotics and maritime innovations organized by the Faculty of Electrical and Computer Engineering (FER) of the University of Zagreb in collaboration with its MONUSEN and INNOVAMARE project partners. The programme was divided in four tracks (marine robotics, maritime archeology, marine biology, marine oceanography) and included 15 in-depth lectures, 8 tutorials, 6 demos and a full day workshop on Ocean Monitoring and Protection Technologies and Services in the Adriatic, co-organized with SeaCras and the Croatian Chamber of Economy and in partnership with the European Investment Bank, Mercator Ocean International and SOCIB.

Dates: 25th September – 2nd October 2022

Location: Biograd na Moru, Croatia

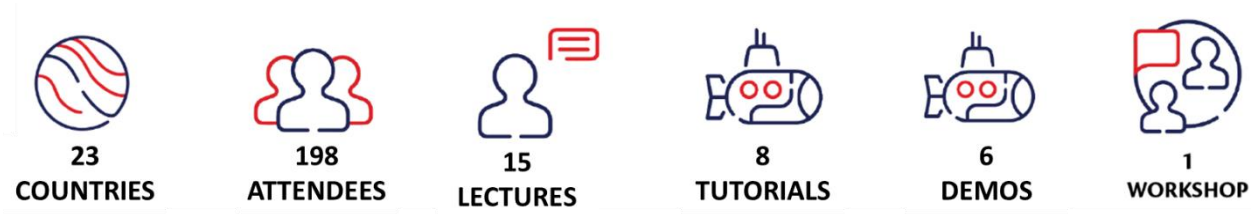
Website: http://bts.fer.hr/

3 ABOUT BREAKING THE SURFACE

Breaking the Surface - BtS summer school has been organized by UNIZG FER LABUST for the last 13 years – first three years as a part of FP7-REGPOT CURE project, while in the following years with Office of Naval Research Global and EU funded projects. This year's BTS was financed and supported by Interreg Italy-Croatia InnovaMare project, Horizon Europe MONUSEN, EU/Croatian funded-project DATACROSS and IEEE Oceanic Engineering Society. During the years, BtS served as a meeting place of experts and students of marine robotics and the marine robotics application areas such as marine biology, marine archaeology, marine security, oceanography, marine geology, and oceanology. This is the world's first successful, multi-year field training programme that combines academic topics in marine robotics and robotics application areas and hands-on working experience in the sea, doing remote sensing and sampling for various ocean sciences.

The program is organized in the form of plenary talks, hands-on tutorials and demonstrations of marine technologies, e.g., marine robotics (MAROB), marine biology and marine nature protection (MARBIO), maritime, nautical and ship archaeology (MARCH), oceanography (OCEAN), and company presentations.

BTS2022 IN NUMBERS:



4 ORGANIZERS

Breaking the Surface is organized under the European Union's Horizon Europe project MONUSEN – Montenegrin Centre for Underwater Sensor Networks (GA: 101060395), Interreg Italy-Croatia InnovaMare project (ID: 10248782), DATACROSS and IEEE Oceanic Engineering Society. The main organizers are University of Zagreb Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies and Centre for Underwater Systems and Technologies University of Zagreb Faculty of Electrical Engineering and Computing.

4.1 ORGANIZING BODIES

University of Zagreb

Faculty of Electrical Engineering and Computing

Laboratory for Underwater Systems and Technologies

Centre for Underwater Systems and Technologies

4.2 IN PARTNERSHIP WITH

University of Montenegro

National Research Council – Institute of Marine Engineering

Newcastle University

Croatian Chamber of Economy

Unioncamere del Veneto

University of Trieste

Agenzia regionale per la tecnologia e l'innovazione

National Research Council – Institute of Marine Science

MareFVG Technology Cluster

Communication Technology

National Oceanographic Institute

Ruđer Bošković Institute

University of Dubrovnik

University of Rijeka

Geomar

Institute for Systems and Computer Engineering, Technology and Science

Integrated Systems for Marine Enviroment

Norwegian University of Science and Technology

5 BREAKING THE SURFACE ORGANIZATION STRUCTURE

5.1 COMMITTEES CHAIRS

Prof. Dr. Sc. Zoran Vukić
General Chair

University of Zagreb, Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies

Prof. Dr. Sc. Nikola Mišković
Programme Committee Chair

University of Zagreb, Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies

Ana Golec,
Organizing Committee Chair

University of Zagreb, Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies

Igor Kvasić,
Technical Committee Chair

University of Zagreb, Faculty of Electrical Engineering and Computing, Laboratory for Underwater Systems and Technologies

5.2 PROGRAMME COMMITTEE

Bridget Buxton
University of Rhode Island
USA

Massimo Caccia
Italian National Research Council (CNR)
Italy

Fausto Ferreira
UNIZG FER
Croatia

Mateo Ivanac
Croatian Chamber of Economy
Croatia

Bill Kirkwood
Monterey Bay Aquarium Research Institute (MBARI)
USA

Jeff Neasham
Newcastle University, School of Engineering
United Kingdom

Irena Radić Rossi
University of Zadar
Croatia

Igor Radusinović
University of Montenegro, Faculty of Electrical Engineering,
Montenegro

5.3 ORGANIZING COMMITTEE

Ana Golec
UNIZG LABUST

COLLABORATORS AND VOLUNTEERS
Mak Gračić, Ena Džanko, Petra Kovačević, Fran Halambek, Lara Vdović, Maja Magdalenić and Hana Bilić

5.4 TECHNICAL COMMITTEE

Anja Babić, mag. ing.

UNIZG FER LABUST

Nadir Kapetanović, mag. ing.

UNIZG FER LABUST

Nikica Kokir

UNIZG FER LABUST

Ivan Lončar, mag. ing.

UNIZG FER LABUST

Igor Kvasić, mag. ing.

UNIZG FER LABUST

Doc. dr. sc. Đula Nađ

UNIZG FER LABUST

6 VENUE

Breaking the Surface 2022 was held for the tenth year in row in a unique location in Biograd na Moru, Croatia. All the participants are accommodated in Ilirija Resort hotels where all the workshop events are taking place and consists of three hotels that are within one minute of walk from each other:

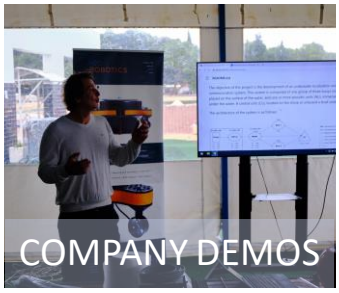
- Hotel Adriatic – conference hall and accommodation for participants
- Hotel Ilirija – conference restaurant and accommodation for participants
- Hotel Kornati – accommodation for participants

Surrounded by beautiful nature, sea and pine forests, the hotel has an ideal position - located by the sea, near the beach, but also next to the heart of the royal town of Biograd. In addition to direct access to the waterfront it features a 50 meters long Olympic seawater pool along a covered working area ideal for tutorials and demonstrations involving sea-deployed robots. Wellness centre, indoor and outdoor pools, à la carte restaurants, cocktail lounge bar, fully equipped conference halls, hotel marina and sports centre offer a rich entertainment program to the participants.

7 PROGRAMME

7.1 PROGRAMME STRUCTURE

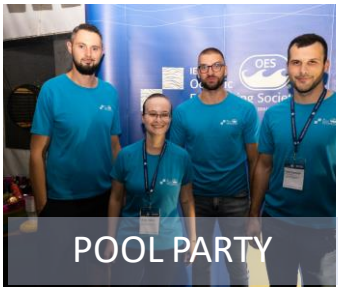
The workshop spanned over seven days with 15 lectures, 8 tutorials, and 6 demos in 4 different programme tracks. The mornings during the week were reserved for plenary talks, briefly interrupted by a coffee break and networking opportunity, while the afternoons were filled with hands-on tutorials, demos, and presentations from companies in the field of marine robotics and its applications. The evenings are when the ever-so-popular social events took place, putting an emphasis on socializing and interaction in a more casual atmosphere. The IEEE OES International Night, Women in Blue, an ocean sciences themed Pub Quiz and Karaoke Night were just some of the evening events participants could take part in. In combination with its highly interdisciplinary nature, it is exactly the many networking opportunities that make this event so special. The workshop was closed at a gala dinner on Friday, with ceremonial awarding of lecturers and contributors. Saturday was reserved for the traditional field trip to one of the local natural attractions, this year taking place in the beautiful city of Zadar.


COMPANY DEMOS


STUDENT
COMPETITIONS


SOCIAL EVENTS


EXPERIMENTS
AND TESTING


POOL PARTY


FIELD TRIP


From 20:30
Demo Pool
26.09.2022.
IEEE OES
UNIZG PARTY


From 20:30
Lavender bar
27.09.2022.
WOMEN IN
BLUE


From 20:30
Lavender bar
29.09.2022.
PUB QUIZ


From 21:00
Lavender bar
30.09.2022.
BTS KARAOKE
PARTY


19:30 - 21:00
Hotel Adriatic
30.09.2022.
CLOSING
CEREMONY
AND GALA
DINNER


09:00 - 16:00
Meeting spot: PARKING
1.10.2022.
FIELD TRIP

7.2 PROGRAMME ABSTRACTS AND AUTHOR BIOGRAPHIES

7.2.1 THE CHAGOS REMOTE OCEAN VOYAGER EXPEDITION (C-ROVE)

Bridget Buxton, University of Rhode Island, USA

We (Bridget Buxton, John Potter (NTNU), Casper Potter (NTNU)) present preliminary results from the 2021-22 C-Rove Expedition and the voyage of the 18m private sailing yacht Jocara to the Chagos Archipelago (British Indian Ocean territory). The 6-week project supported by OceanGate Foundation included oceanographic research activities such as water sampling for Environmental DNA analysis, underwater surveying and acoustic recording, in addition to terrestrial DNA sampling and wildlife observation (birds and mammals). We explore some of the challenges and lessons of conducting an extended remote ocean research expedition from a small sailing vessel, and share thoughts on the potential of this new marine research model. As underwater vehicles and their payloads become ever more capable and compact, crewed oceanographic research vessels have trended in the opposite direction: larger in size, fewer in number, and accessible to only a privileged few. Another irony is that so much of the world's oceanographic research undertaken with aspirations of environmental conservation and sustainability uses the least environmentally friendly platforms imaginable – a point noted by Greenpeace when they recently replaced their large diesel-burning MV Esperanza with a new smaller sailing vessel, the SY Witness. The question is no longer if, but when, oceanographic research will follow the maritime freight and cruise industries in pursuit of carbon neutrality. Our experiences on the C-Rove expedition show that this low-carbon model can be very efficient, economical and effective in the right circumstances and suggests design choices for small vehicles and sensor packages produced with this future in mind.

Dr. Bridget Buxton *is an underwater archaeologist and historian based at the university of Rhode Island, and chief archaeologist of the June-August 2021 Oceangate Titanic expedition. Bridget grew up in New Zealand and completed her PhD at Berkeley as a Fulbright scholar in ancient history and Mediterranean archaeology. She specializes in classical underwater archaeology and has been at the forefront of introducing new robotic technologies to underwater research. She has worked on and codirected archaeological expeditions all over the world, including the Mediterranean, Adriatic, black sea, and the south pacific, discovering and investigating dozens of historic shipwrecks and the two important ancient harbours of Akko and Caesarea in Israel.*

7.2.2 THE ROLE OF ACOUSTICS IN UNDERWATER ROBOTICS

Nuno Alexandre Cruz, INESC TEC, Portugal

Radio signals hardly propagate underwater, therefore radio-frequency based solutions that are routinely used above water (like GPS and other GNSS) are virtually useless in the underwater domain. On the other hand, sound waves propagate better in water than they do in air, therefore acoustics has been a major source of solutions to help solving the underwater localization challenges. In the domain of underwater robotics, the main task of the onboard navigation system is to estimate its own position and attitude in real time. This serves for the control system to make necessary corrections in trajectory, and, at the same time, it allows sensor data to be spatially tagged. A typical navigation system fuses together data from multiple sensors, like pressure sensors, digital compasses, IMUs, accelerometers, gyroscopes, and Doppler velocity meters. Even with the best of specs, these data alone produce position estimates with errors that grow in time due to continuous integration of biases. The use of acoustic signals to provide range and bearing to specific locations can provide absolute measurements and avoid divergence. The Center for Robotics and Autonomous System of INESC TEC in Porto, Portugal, has been involved in many R&D projects developing cutting-edge technology for the underwater environment. One example of specialization is underwater navigation,

a topic of active research for more than 20 years. This lecture will address some of the flagship projects of the Center in underwater robotics, with an emphasis on acoustic based devices and algorithms developed to maximize their usefulness in marine scenarios.

Nuno Alexandre Cruz *was born in Porto, Portugal, in 1970. He graduated in Electrical and Computer Engineering at the Faculty of Engineering of the University of Porto (FEUP), Portugal, in 1993. He received the MSc. in Digital Systems Engineering from UMIST, UK, in 1994, and the PhD in Electrical and Computer Engineering from the University of Porto in 2016. He is currently a Coordinator at the Centre for Robotics and Autonomous Systems of INESC TEC, in Portugal. He is also an Assistant Professor at FEUP, where he has been teaching for over 20 years, and serves as a member of the Department Council. His research interests include marine robotics, underwater navigation systems, and efficient use of autonomous vehicles at sea. Nuno Cruz has led and actively participated in numerous R&D projects, both national and international. He was the leader of the PISCES team, finalist of the Shell Ocean Discovery Xprize, in 2018, splitting the 1 million dollars prize. Under this effort, he led the development of DART, a portable deep water hovering AUV to map the ocean floor up to 4000 meters of depth, among other significant advances in collaborative robotics. He has been the author or co-author of more than 100 publications in international journals, book chapters, and proceedings of conferences, with regular presentations in top international conferences, such as the IEEE/MTS Oceans or IEEE UT. Nuno Cruz is a Senior Member of the IEEE Oceanic Engineering Society (a member since 1997), where he serves as an Associate Editor of the Journal of Oceanic Engineering, in the topics of AUV design, underwater navigation, acoustic navigation, and adaptive sampling. He is the Chair of the Portuguese Section of IEEE OES.*

7.2.3 AUTONOMOUS PLATFORMS FOR OCEANOGRAPHIC DATA COLLECTION

Riccardo Gerin, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS, Italy

In recent decades, technological developments and the miniaturisation of sensors have made the development of autonomous and unmanned remote sensing oceanographic platforms possible. These platforms can move through the water, provide long-term and real-time monitoring and, in addition, reduce costs compared to other traditional measurement approaches. They are very efficient and important tools to complement and extend conventional oceanographic observations.

Riccardo Gerin *obtained his MSc in Physics (2001) and a PhD in Environmental Sciences (2005) both from the University of Trieste. He works at OGS since 2005 and has a long experience in the technical aspects of autonomous instruments (drifters and gliders) and oceanographic instrumentation in general and in data processing and interpretation. He has also recently worked on low-cost platforms for developing countries and is currently coordinator of the OGS Centre for Oceanographic Calibration and Metrology (CTMO).*

7.2.4 LONGTERM DEPLOYMENT – DOES AUVS REALLY NEED TO SURFACE?

Antonio Vasilijević, Applied Underwater Robotics Laboratory, Norwegian University of Science and Technology, Norway

Present-day offshore operations rely almost exclusively on remotely operated vehicles deployed from support vessels. However, resident autonomous robotic systems that are docked and ready to operate at or near the offshore site, or towed docking units allowing charging and data transfer in

motion, have potential to become a game changer in offshore exploration and exploitation. The clear benefits are much shorter response time and significant reduction of cost and greenhouse gas emissions as support vessels are almost not needed. Nevertheless, there are still some challenges to be addressed before the concept becomes stateof-the-art. This talk will give an insight into NTNU's AURLab relevant results from various national and EU projects and touch upon some of these challenges such as subsea docking, residency, communication and USV-AUV integration. The talk will also present subsea part of the full scale OceanLab research infrastructure developed for remote experimentation, validation, and operation of underwater vehicles/technology from shoreside control room or any remote location.

Dr. Antonio Vasilijević *is a research project manager at the applied underwater robotics laboratory (AURLab), Norwegian University of Science and Technology where he is responsible for full lifecycle of research projects related to marine robotics as well as operation and further development of the Laboratory research infrastructure. He is a part of a team of engineers and researchers with vast experience in developing marine and autonomous technologies. Previously, Antonio acted as a Leading Researcher at the Laboratory of Underwater Systems and Technologies at University of Zagreb Croatia where he was project coordinator or key researcher in number of national or EU funded projects. Before returning back to academia in 2009, he worked on various engineering and senior positions in marine industry. His research interests cover broad area of marine robotics and marine technology in general and their applications.*

7.2.5 MOTION CAPTURE FOR UNDERWATER COMMUNICATION AND DIVER HEALTH MONITORING

Iain Anderson, Biomimetics Lab, Auckland Bioengineering Institute, New Zealand

SCUBA divers visit a world that is 1000 times denser than air, and that is often murky, with strong currents and other surprises. To mitigate risk divers are taught to go down in pairs, where each buddy looks out for the other. Yet many divers dive alone for a variety of reasons including buddy unavailability or accidental separation. The Diver Alert Network has reported that 86% of diving fatalities were alone when they died. For the buddy system to work well divers have developed gesture-based communications for hazard alerting, assessing each other's wellbeing and relaying intentions. Gesture based communication is line-of-sight and works well in clean non-murky water but can be hard to achieve when the water is murky and turbulent. And it is useless if the diver is alone or separated from a buddy. In collaboration with LABUST at the University of Zagreb we are using direct motion capture of fingers in a smart glove that processes gestures and turns them into commands that can be acoustically transmitted directly to a robot or a buddy that is out of sight. The motion-capture technology can also be used in a wetsuit to monitor diver breathing and movement. In this talk we describe the technology of the motion capture sensors and how they are well suited for the ocean environment. We demonstrate the glove, and relate our experimental results. Finally we report our preliminary work using wetsuit sensors for diver condition monitoring, demonstrating motion capture as a means for improving diver safety.

Iain Anderson *is Group Leader for the Biomimetics Laboratory of the Auckland Bioengineering Institute (www.abi.auckland.ac.nz/biomimetics (http://www.abi.auckland.ac.nz/biomimetics)). Iain completed his PhD (Engineering Science, University of Auckland) in 1996, and has worked as a whiteware product designer (Fisher and Paykel Ind.), a vibrations consulting engineer (NZ Department of Scientific and Industrial Research) and a research scientist associated with hip and knee implant design and surgery (Industrial*

Research Ltd., New Zealand). In 2000, Iain returned to the Department of Engineering Science as a staff member, and was one of the founding members of the Auckland Bioengineering Institute. Iain's interest in artificial muscles led to the formation of the Biomimetics Laboratory in 2004. The lab's research is currently focused on the control and self-sensing of electronic artificial muscles and the development of soft electroactive polymer sensors for underwater applications. Iain is involved in two Biomimetics Lab spin-out companies: StretchSense (2012) and PowerOn Ltd. (2019). StretchSense produces motion-capture gloves using soft elastomer dielectric elastomer sensors. PowerOn is commercializing the lab's electroactive polymer actuator technology. For his efforts in developing and commercializing electroactive polymer technology he was awarded the Royal Society of New Zealand's 2016 Pickering Medal.

7.2.6 MONITORING BIODIVERSITY WITH A WIRED UNDERWATER CAMERA

Neven Cukrov, Ruđer Bošković Institute, Croatia

Monitoring marine life and its biodiversity requires technological implementation to achieve the standards required for advanced ecosystem management in Marine Protected Areas (MPAs). We chose the Krka River Estuary Natura 2000 site in Croatia as a pilot area. A wired underwater surveillance camera is positioned at 5 m depth. The image acquisition is based on a motion sensing method with a self-developed software ("Fish Monitoring") running on a Windows OS environment. The images of mobile megafauna taken during daylight hours from 10th January to the end of April 2018 were selected for further processing. A total of 13808 images were analysed from which 136195 individual animals were identified. From 10026 images, a total of 16216 fish specimens belonging to 35 species were identified. These included 24 species of commercial interest, including the billfish Thunnus thynnus (Atlantic bluefin tuna) and animals of conservation interest such as the loggerhead turtle, Caretta caretta. The data collected in the time series showed an increase of fish biodiversity from winter to spring.

***Neven Cukrov** is a Senior Scientist at the Division for Marine and Environmental Research, Ruđer Bošković Institute from Zagreb and currently runs the Martinska marine station near Šibenik. He is also a full-time lecturer at the undergraduate and graduate studies of the University of Zadar, and at the doctoral study of oceanology, University of Zagreb. His field of research includes anthropogenic impact on recent sedimentation and precipitation of travertine, then research on biogeochemical processes of metals, natural and artificial radionuclides, and microplastics in aquatic systems (part sediment). In addition, he deals with development of automatic system for metals detection and biodiversity monitoring. His research area are water systems, including groundwater karst systems.*

7.2.7 CONTROL OF AUTONOMOUS UNDERWATER VEHICLES FOR HYDROBATICS

Ivan Stenius, Sriharsha Bhat, KTH Engineering Mechanics, Sweden

The term hydrobatics refers to the agile maneuvering of underwater vehicles. Hydrobatic capabilities can enable exciting new use cases for autonomous underwater vehicles (AUVs) in aquacultures, inspections, under-ice sensing, docking, and manipulation. These ideas are being explored at KTH within the Swedish Maritime Robotics Centre (SMaRC). Modeling the flight dynamics of such AUVs at high angles of attack is a key challenge – we use Simulink to perform real-time simulations of hydrobatic maneuvers. Furthermore, these robots are underactuated systems, making it more difficult to obtain elegant control strategies – we can use the Nonlinear Model Predictive Control toolbox to generate optimal controls. Finally, the controllers and simulation models developed can be tightly linked to SMaRC's AUVs and simulation environments through ROS.

Ivan Stenius *received his M.Sc. in Lightweight structures from the Royal Institute of Technology (KTH) in 2003 and a degree of Doctor in Technology KTH, Lightweight Structures on hydroelasticity and fluid structure interactions on high-speed craft in 2009. Stenius is currently full-time associate professor at the department of aeronautics and vehicle engineering at KTH. Stenius has expertise in underwater vehicle modelling design and construction. He has been PI for a number of research projects in collaboration with the Swedish Defence Material Administration, involving cross-disciplinary collaboration between the research groups – computer vision and perception, applied electrochemistry, and networked control at KTH. Stenius has in the recent years been involved in building up a research group in maritime robotics at KTH and he is now PI of the Swedish Maritime Robotics Centre (SMaRC) hosted by KTH that involves research on underwater robotics.*

Sriharsha Bhat *received a bachelor's degree in Mechanical Engineering from the National University of Singapore in 2013, and a master's degree in Vehicle Engineering from the Royal Institute of Technology (KTH), Stockholm, Sweden in 2016. He is currently a PhD student at KTH focusing on the control and simulation of underwater robots. From 2013-2014, he was a Research Engineer at the Singapore MIT Alliance for Research and Technology (SMART), Singapore focusing on aerial and underwater robotics; and from 2016-2018, he was a Technology Development Engineer at Continental, Hannover, Germany. His research interests include optimal and model predictive control, motion planning, reinforcement learning, simulation/modelling, and system identification for robots and autonomous vehicles in challenging field applications.*

7.2.8 DATA POLICY AND CHALLENGES FOR MARINE ROBOTICS

Roberta Ferretti, Simona Aracri, National Research Council of Italy - CNR, Italy

Data are a fundamental product of marine robotics. The growth of novel unconventional platforms gave rise to a new generation of data, for which there is no standardization and, hence, no coordination. The importance of codifying these data is twofold: robotic and observational. Sharing the platform performance data will aid novel technology in accelerating their commercialisation. Bringing new robotics platforms to the market is the crucial point of technological advancement, it is effectively the rite of passage that marks the difference between impactful robotics and base research. The global observational effort needs the unprecedented information gathered from state of the art robots. Therefore, the data protocols applied to these newborn environmental data have to match the quality of those applied to traditionally collected data. Ultimately, classifying robotic and environmental data feeds into the widely welcomed concept of fair and open science.

The lecture focuses on the meaning of self-describing data, i.e. minimum metadata required. It describes the difficulties that arise analysing non-standardised data and it highlights the best practices to be used to create a seamless data treatment approach, from acquisition to interpretation. Whilst in marine sciences data policies are relatively defined, in marine robotics this is an unexplored ground. The purpose of the lecture is to stimulate a discussion and to lay out a common path to define a set of metadata and shared vocabulary for the data gathered by novel robotic platforms.

Roberta Ferretti *is a researcher at the Italian National Research Council. She received her Master's Degree in Physics in 2008. After working at CERN as high energy physicist (2008-2010), in 2013 she joined the Institute of Marine Engineering in Genoa. Her activity dealt with the sensing capability of autonomous marine vehicles, focusing on data acquisition and analysis for the seabed characterization using automatic methods for the detection of Posidonia oceanica. During her Ph.D. (2017-2021) in cooperation with the Italian Navy Hydrographic Institute, she worked on the development of new approaches for the observation of transient phenomena in critical marine environments using autonomous marine vehicles for the data collection in different Arctic and Mediterranean field campaigns. Currently she is working on standardization of autonomous vehicles data acquisition for fair data management and open science.*

Simona Aracri, *is a permanent Researcher at the National Research Council of Italy – Institute of Marine Engineering. Previously Post-Doctoral Research Associate, University of Edinburgh, working on offshore robotic sensors. She holds Bachelor's and Master's degrees in Marine Engineering and Naval Architecture . She also holds a Ph.D. in Physical Oceanography from the National Oceanography Centre – University of Southampton. She has spent more than 6 months at sea on oceanographic sampling campaigns, in the Mediterranean Sea, Pacific Ocean and the North Sea. Her research interests encompass: the application of robotics for observational oceanography and environmental monitoring. She is interested in the entire process of data collections, from the device design to the deployment setting and, ultimately, in the resulting data.*

7.2.9 DEEP LEARNING COMPUTER VISION-BASED OBSTACLE DETECTION FOR AUTONOMOUS BOATS

Matej Kristan, Faculty of Computer and Information Science, University of Ljubljana, Slovenia

Autonomy is transforming most industries, and maritime robotics is no exception. With 90% of goods moved across the world in vessels, unmanned surface vehicles (USVs) present a considerable market opportunity. Small-sized USVs, in particular, present affordable devices for automated inspection of hazardous areas and periodic surveillance of coastal waters and have a strong potential for a wide-spread use. Apart from efficient control and high-level planning, safe and uninterrupted navigation relies on environment perception, in particular on obstacle detection and timely collision avoidance. The inherent dynamics of aquatic environment combined with a large variety of potential obstacles presents considerable challenges to computer vision systems, leaving robust obstacle detection an open research problem. In this talk an overview of recent work in the ViCoS laboratory (https://www.vicos.si/) on camera-based obstacle detection for USVs and the datasets created to facilitate the research in the USV obstacle detection will be given.

Matej Kristan *received a Ph.D. from the Faculty of Electrical Engineering, University of Ljubljana in 2008. He is a full professor in the Visual Cognitive Systems Laboratory (https://www.vicos.si) and a vice chair of the Department of artificial intelligence at the Faculty of Computer and Information Science, University of Ljubljana. He leads the Visual object tracking VOT initiative, is the president of the IAPR Slovenian pattern recognition society and Associate Editor of IJCV. He has co-organized over thirteen workshops and conferences, he received fourteen research excellence awards and four teaching excellence awards. His students regularly receive research excellence awards as well. His research interests include visual object tracking, anomaly detection and*

segmentation, perception methods for autonomous boats and machine-learning-based geophysics prediction models. According to Google scholar, his works have been cited over 8000 times, his h-index is 35.

7.2.10 DEVELOPMENT OF A SECURE, INTEROPERABLE AND HIGHLY SCALABLE STANDARD FOR UNDERWATER ACOUSTIC COMMUNICATIONS

Jeff Neasham, Newcastle University, UK

Since 2019, Newcastle University have worked, in collaboration with MoD/DSTL and Sonardyne international, to develop a open waveform standard for underwater acoustic communications. This is a highly scalable waveform capable of supporting everything from very short command/control messages up to streaming compressed voice between divers. It can also be used in a wide range of frequency bands to trade off data rate/packet duration versus maximum range. A key feature of the waveform is that it has been designed from the beginning with security in mind, including a number of physical layer security features which reduce probability of detection, interception and exploitation, in addition to more traditional data encryption techniques. This talk will describe the waveform design/capabilities, recent field testing results in UK waters and the Mediterranean, and potential application in the control and navigation of marine robots.

Jeff Neasham *received the B.Eng. degree in electronic engineering from Newcastle University, Newcastle upon Tyne, U.K., in 1994. He then worked at Newcastle University until 2007 as a Research Associate on research and commercial product development in underwater acoustic communication, sonar imaging, and wireless sensor networks, before taking up an academic post. He is currently a Professor of Acoustic Signal Processing with the School of Engineering, Newcastle University. He has published over 100 conference and journal publications and his work on underwater acoustic communication and positioning has been commercialised by 3 UK companies and 1 Italian company. His research interests are in underwater acoustic signal processing and device design, wireless communication networks and biomedical instrumentation.*

7.2.11 INTEGRATED OBSERVATIONS AND MONITORING SOLUTIONS FOR EXPLORATION AND SUSTAINABLE EXPLOITATION OF MARINE ABIOTIC RESOURCES

Marzia Rovere, Institute of Marine Sciences - CNR, Italy

Hydrocarbons are organic compounds that contain only carbon and hydrogen atoms. Marine environments are ideal for their formation, because organic matter rapidly undergoes anaerobic degradation while high and fast sedimentation rates, typical of marine settings such as the Adriatic Sea, favor rapid burial and decomposition of organic matter. Hydrocarbon generation can be either microbial or thermic, at different temperatures and depths. Hydrocarbons tend to migrate to shallower sedimentary horizons, giving rise to seafloor features such as pockmarks and mud volcanoes with varying scales. When the flow is sufficiently high, hydrocarbons escape the seabed and form gas plumes in the water column. The plumes can be detected as density anomalies by marine acoustic and geophysical sensors, that combined with geochemical and hydrological data, allow to quantify the upward flux of gas.

Hydrocarbon seepage is overlooked in the marine environment, mostly due to the lack of adequate space-time resolution environmental monitoring data that consider also the climate variability. This contribution is about the set-up of relocatable, customizable, scalable and cost-effective monitoring systems that can be operated from mobile platforms in the Adriatic Sea. Their applications include

monitoring of: coastal areas shifting water dynamics due to changing seasons; monitoring of leakage from abandoned or decommissioned wells/boreholes/sealines, reservoirs, shallow gas accumulations. Data and information collected with innovative and autonomous technology is essential to reduce uncertainties of offshore multi-hazards and can help strengthening the integrated, interoperable sharing of marine environmental information with decision makers, civil protection and the public.

Marzia Rovere *has a PhD in Earth Sciences and is researcher in marine geology at the Institute of Marine Sciences (ISMAR) of the National Research Council of Italy since 2009. Her scientific research deals with a variety of different topics related to seafloor and sub-seafloor mapping, including among others submarines landslides and their potential to trigger tsunamis, sediment transport in coastal areas, fluid flow along faults and the threads they pose to offshore installations. Her interests focus also on marine mineral resources, including aggregates on continental shelves, cold seep and hydrothermal habitats as unconventional sources of non-energy raw materials in the deep-sea through innovative recovery processes. Marzia participates in several EU projects, including EMODnet Bathymetry where she coordinates the public-access to ocean data of the Central Mediterranean, and is leading different national projects sponsored by public stakeholders. She is vice-chair of the joint IOC-IHO GEBCO Guiding Committee and participated in the establishment team of the GEBCO-NF Seabed 2030 project. She is the Italian alternate head of delegation to the works of the International Seabed Authority, where she served in the Legal and Technical Commission in 2015-2016. Marzia sailed in dozens of oceanographic cruises in the Mediterranean and Atlantic Ocean.*

7.2.12 DEVELOPING IMAGING TECHNOLOGIES TO SEARCH FOR, DISCOVER, AND UNDERSTAND LIFE IN THE DEEP SEA

Kakani Katija, Monterey Bay Aquarium Research Institute, USA

The ocean is a vast three-dimensional space that is poorly explored and understood, and harbours unobserved life and processes that are vital to ecosystem function. Ocean-going platforms are integrating high-resolution, multi-camera feeds for observation and navigation, producing a deluge of visual data. The volume and rate of this data collection can rapidly outpace researchers' abilities to process and analyse them. Additionally, to fully interrogate the space, novel algorithms and innovative robotic platforms are required to scale up our observational capacity. Two applications, locating animals of interest and conducting extended visual observations of animals in the water column, are particularly challenging objectives that require advances in imaging, robotic vehicles, and navigational algorithms. Here I will share collaborative advances that our group, the Bioinspiration Lab at MBARI, have been involved in to address imaging (DeepPIV, EyeRIS), vehicle (MiniROV, Mesobot, LRAUV), and algorithmic needs (FathomNet, ML-Tracking) to enable and sustain observations of life in the deep sea. Together, these efforts clearly demonstrate the potential that robotic platforms can have on exploration in unexplored environments and discovery of undiscovered life in our ocean.

Dr. Kakani Katija *is a Principal Engineer at the Monterey Bay Aquarium Research Institute, a Research Associate at the National Museum of Natural History (Smithsonian Institution), and a Visiting Associate Professor in Aerospace at the California Institute of Technology (Caltech). Originally an Aerospace Engineer (BSc from University of Washington and MSc from Caltech), Kakani received a PhD in Bioengineering from Caltech. As lead of the Bioinspiration Lab, Kakani and her group investigates ways that imaging can enable novel observations of life in the deep sea. By developing imaging and illumination tools (e.g., DeepPIV and*

EyeRIS), automating the classification of underwater visual data using artificial intelligence (FathomNet), and integrating algorithms on vehicles (MLTracking) for robotic vehicle missions (e.g. Mesobot, LRAUV) to consistently and persistently observe ocean life, her group's efforts will help increase access to biology and related phenomena in the deep sea. Kakani was named a National Geographic Emerging Explorer in 2011, a Kavli Research Fellow of the National Academy of Sciences in 2013, and a Frontiers of Engineering Fellow of the National Academy of Engineering in 2020. She has received generous funding support for the Bioinspiration Lab's work from a number of funding organisations including the Packard Foundation, National Geographic Society, NSF, NOAA, Schmidt Ocean Institute, and the Moore Foundation. In her spare time, Kakani, along with her husband and dog, like to roam the outdoors by foot and participate in random sporting events (e.g., figure skating, keg tossing, tobogganing, etc.).

7.2.13 FANTASTIC COLD – WATER CORALS AND WHERE TO FIND THEM

Johanna Järnegren, Norwegian Institute for Nature Research (NINA), Norway

The continental slope off the Norwegian coast have some of the most extensive cold-water coral reefs in the world. Offshore waters also intrude into the numerous deep fjords that incise the Norwegian coast, providing ideal conditions for deepwater species to colonise their steep rocky walls. Cold-water coral ecosystems are valuable, vulnerable and notoriously difficult to study. Their habitat is deep, with high currents making it challenging to navigate ROV and AUV, and sometimes dangerous due to entangled fishing lines and nets. During autumn 2022 we are mapping three marine protected areas in the Trondheimfjord to position cold-water corals. The main part of the corals are located on vertical walls where more traditional mapping methodology comes short. In our investigations we try to understand and implement the best and most (cost) efficient ways to do this, but are we succeeding? How can we best study these areas and what methods should be used? We invite to discussion!

***Johanna Järnegren** is a Senior scientist at the Norwegian institute for nature research (NINA). She is a marine biologist focusing on cold-water coral ecosystems with an emphasis on reproduction, anthropogenic effects from oil exploration, ocean acidification and aquaculture and mapping and monitoring of corals in coastal and fjord systems.*

7.2.14 AUVROVA-AUTONOMOUS LOW-COST RESIDENT INSPECTION UNDERWATER DRONE CONCEPT

Kjetil Eik, Norwegian Institute for Nature Research (NINA), Norway

Underwater inspections in the energy sector are typically costly, limiting what's inspected and the frequency. The value from inspections is in the collected data and application of that data. AUVROVA is a concept to create a fleet of low cost autonomous collaborative inspection drones enabling simultaneous monitoring of many assets spread over larger areas.

***Kjetil Eik** has worked in Norway's largest energy company, Equinor ASA since 1998 in various roles. For the last five years he has been embedded in the Emerging IT Sandbox team. A large part of this time has been devoted to supporting Equinor's various underwater robotics initiatives through building multi-disciplinary prototypes and one-off units to enable research and validation of internal concepts and vendor provided equipment and solutions.*

7.2.15 HETEROGENEOUS AUTONOMOUS ROBOTIC SYSTEM IN VITICULTURE AND MARICULTURE

Zdenko Kovačić, Nadir Kapetanović, University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

For millennia, viticulture and mariculture have been a component of human society. Both viticulture and mariculture are heavily reliant on human labour, with workers generally doing arduous, repetitive, sometimes even dangerous tasks for long periods of time. HEKTOR (Heterogeneous Autonomous Robotic System in Viticulture and Mariculture) project is looking for solutions to these issues. The main objective of the HEKTOR project is to realize a systematic solution for the coordination/cooperation of smart heterogeneous robots/vehicles (marine, land-based, and aerial vehicles) that are able to cooperate autonomously and assign tasks to each other in an open unstructured space. HEKTOR is designed as a modular and autonomous system, adapted for various missions in viticulture and mariculture with the foreseen possibility of human intervention during the performance of various inspection and intervention tasks. The lecture will cover the development and integration of various robotic platforms (all-terrain vehicle, autonomous catamaran, aerial drone, and remotely operated vehicle) and their cooperation enabling subsystems (landing platform, tether management system, and underwater acoustic localization). Furthermore, results of autonomous monitoring, spraying and suckering tasks in viticulture, and biofouling estimation in mariculture will be presented.

Zdenko Kovačić *is full professor at the Faculty of Electrical Engineering and Computing in Zagreb and head of the Laboratory for Robotics and Intelligent Control Systems (LARICS). In 1990/91 he was a visiting researcher at the Virginia Polytechnic Institute and the State University, Blacksburg, USA. For contributions to the fields of robotics, automation, and control, he received the University of Zagreb Award "Fran Bošnjaković" for the year 2013 and the Faculty of Electrical Engineering and Computing Award "Josip Lončar" for the year 2018. He was the principal researcher of more than 40 international and Croatian R&D projects including 3 ongoing ESF funded R&D projects and 3 R&D projects with industrial partners. He is the MC member of COST Action CA19104 Advancing Social inclusion through Technology and Empowerment (a- STEP). He is the author of 3 books in the fields of robotics, manufacturing systems and intelligent control. He is a member of the EuRobotics PhD Award Jury (2016-2022). He is the Senior Member of IEEE. He was president of Croatian Robotics Society 2005-2010. In the years 2012-2015 he was the elected president of Croatian Robotic Association. He is also a member of Croatian Society for Communication, Computer, Electronics, Measurement and Control. He is active in editorial boards of international journals and participated in the organization of numerous international conferences, workshops and academic seminars, and other events aimed at popularizing science.*

Nadir Kapetanović *(MSc, 2015) is a Ph.D. student and a researcher as a member of the Laboratory for Underwater Systems and Technologies (LABUST) at the University of Zagreb Faculty of Electrical Engineering and Computing. He is currently involved in ESIF project HEKTOR, and previously he was involved in research in Interreg Mediterranean co-funded project BLUEMED, NATO project MORUS, and several other EU and national funded projects. His research interests include model predictive control, path and coverage planning for underwater marine*

vehicles, and state estimation techniques. He is the Secretary of the IEEE Oceanic Engineering Society Student Branch Chapter of the University of Zagreb.

7.2.16 "WORK CLASS" ROVS FOR UNDERWATER OPERATIONS

Zdravko Eškinja,Ivo Kutleša, Marine Robotic Systems (MARS)

Underwater offshore operations are one of the most expensive tasks per day because it requires special equipment and deals with though working conditions. Companies are investing a huge effort to increase reliability of equipment and competence of operators, but this is hard to achieve, especially because machines have never been tested at certain conditions, and personnel have usually low experience with the machine. Logical solution is to build a simulator, perform software testing on it, and after all, do a professional training. One example of such approach will be shown here together with benefits and drawbacks.

7.2.17 UNDERWATER LOCALIZATION OF ACOUSTIC SOURCES – PRINCIPLES AND APPROACHES

Bruno Ferreira, INESC TEC, Portugal

This tutorial introduction will serve to provide foundation material that will be explored during the hands-on acoustic data processing and implementation of localization methods. The session will briefly describe some models of underwater acoustic propagation, together with the algorithms to estimate ranges and bearings between underwater devices. This will be followed by a comparison of different methods to estimate position with respect to geographic references, including Long Baseline and Ultra-short Baseline, for example. One typical application of these methods is the localization of underwater pingers, such as the ones of airplane black boxes. A similar example will be provided, with the description of the steps taken to determine the location of a sunk glider off the coast of Portugal in the autumn of 2021. The final part of the session will serve to announce the BTS underwater localization challenge, describing the characteristics of the deployed pinger, such as ping rate and frequency.

***Bruno Ferreira** (MSc 2009, Ph.D. 2014) is a researcher at the Center for Robotics and Autonomous Systems at INESC TEC and an Invited Assistant Professor at the Faculty of Engineering of the University of Porto. He holds a Ph.D. in Electrical and Computer Engineering from the Faculty of Engineering of the University of Porto. The focus of his work has been on autonomous underwater and surface vehicles, in the areas of control and estimation. He has 50+ peer-reviewed publications on these topics, in co-authorship with 84 researchers, 13 supervisions of M.Sc. theses, and he is currently supervising 3 Ph.D. theses. He made contributions to the development of marine vehicles such as TriMARES, SHAD, FLEXUS, leading the latter two. He has participated in 12 R&D projects. He is a guest editor and topic panel member for JMSE, and guest editor for Remote Sensing journal. Bruno is currently the vice-chair of the IEEE OES Portugal Chapter.*

7.2.18 GETTING STARTED WITH REEDS, THE WORLD'S LARGEST DATASET FOR PERCEPTION ALGORITHMS

Dr. Ola Benderius, Chalmers University of Technology, Sweden **Ted Sjöblom,** RISE - Research Institutes of Sweden, Sweden

Reeds is a new dataset for research and development of robot perception algorithms. The design goal of the dataset is to provide the most demanding dataset for perception algorithm benchmarking, both in terms of the involved vehicle motions and the amount of high quality data. The logging platform consists of an instrumented boat with six high-performance vision sensors, three high-fidelity lidars, a 360° radar, a 360° documentation camera system, as well as a three-antenna GNSS system and a fibre optic gyro IMU used for ground truth measurements. All sensors are calibrated into a single vehicle frame. The tutorial will introduce the dataset and give the participants hands-on experience on how to replay data into self-developed algorithms, with examples available in both Python and C++. The take-away is that participants easily can get started using the data in their own research and development, as well as getting insight into the capabilities of the latest sensors. Read more about the dataset here (currently being updated): https://reeds.opendata.chalmers.se

Dr. Ola Benderius *is Associate professor of Autonomous mobile systems at the Department of mechanics and maritime sciences at Chalmers University of Technology. His research focus is mainly on biologically inspired AI for mobile autonomous vehicles, both inspired by human driving and deep neural functions connected to self-motion and machine operation. He did in 2014 find the solution to a 70-year old mystery connected to human control and the so called remnant within control theory, by using inspiration from biological studies. In 2015 he was involved in forming the Chalmers vehicle research laboratory Revere, where he is currently leading research connected to autonomous driving, computer vision, software engineering in cyber-physical systems, and next generation HMI for both road and marine vehicles. He is one of the two architects behind the open-source software architecture OpenDLV for autonomous systems, the leader of Sweden's first autonomous racing team, and the initiator of Reeds, the world's largest dataset for fair benchmarking of robot perception algorithms.*

Ted Sjöblom *received a bachelor of Maritime captain, management and technology from Novia University in 2015, and in 2022 a Master's in Business, information system and a minor in Computer science from Åbo Akademi University, Finland. He is currently a Research and development engineer at RISE (Research Institutes of Sweden) in the department of Safety and transport and Maritime operations, focusing on the digitalization of sea transport. He has a background as a navigation officer on various ship types, from coastal tankers to cruise ships. From 2019 he worked with R&D within maritime digitalization in Finland and from 2021 in Sweden with task-related simulations, marine sensors, and navigation support tools.*

7.2.19 MULTIBEAM ECHOSOUNDER (MBES)

Matej Ćurić, Ivor Meštrović, Geomar, Croatia

The principle of Multibeam echosounder (MBES) work, technical characteristics and capabilities, problems arising from work, data processing principles and the final product. Practical Exercise to show MBES work with the help of a boat for a hydrographic measure (an 8-meter ship that optimally can accommodate 6 interested participants).

Matej Ćurić *MSc, geodetic engineer and hydrographer with 7 years of experience with MBES through various jobs like marine objects and infrastructure projects (3D models of seabed, plans and maps for designing, monitoring underwater constructions and excavating, surveying as-built state after works, detection of existing underwater installations, etc.)*

Ivor Meštrović *MSc, geodetic engineer and hydrographer with 10 years of experience with MBES through various jobs like marine objects and infrastructure projects (3D models of seabed, plans and maps for designing, monitoring underwater constructions and excavating, surveying as-built state after works, detection of existing underwater installations, etc).*

7.2.20 MARINE OBJECT DETECTION USING MARUS GENERATED DATASET

Ivan Lončar, Natko Kraševac, Juraj Obradović, University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

Simulators play a key role in the development of mobile robots. Simulating vehicle models and their environment without depending on actual hardware has proven beneficial for reducing cost and development time while facilitating safety during testing. One motivation for developing MARUS (https://github.com/MARUSimulator) was to have a simulator that can offer advanced capabilities of generating realistic environment allowing for closer-to-reality validation and verification (V&V) of applications developed for maritime vehicles. The simulator offers synthetic dataset generation with perfect annotations for various sensors (cameras, lidar, sonar) and allows for interaction with the environment for closed loop simulation. In this tutorial, we will show you how to train and validate deep neural network used for object detection in marine environment. You will learn how to generate an annotated dataset consisting of images from single or multiple cameras in MARUS. Generated dataset will be used to train a deep neural network for detecting and classifying chosen objects.

Ivan Lončar *received a MSc in Control Engineering and Automatization from the University of Zagreb Faculty of Electrical Engineering and Computing – UNIZG FER (Croatia). Even before graduation, he started working in Laboratory for Underwater Systems and Technologies – LABUST at UNIZG FER. As of 2017, Ivan is pursuing a PhD in Marine Robotics, specifically in Underwater localization. During his time in the laboratory, he was involved in multiple research projects including ONR NICOP Adriatic, H2020 subCULTron, H2020 EXCELLABUST, HrZZ project CroMarX. As of latest he is a project team leader working on development of an autonomous ship.*

Natko Kraševac *received a MSc in Computer Science from the University of Zagreb Faculty of Electrical Engineering and Computing – UNIZG FER in Zagreb (Croatia) in 2020. During the studies, his background was mainly computer vision, deep learning and AI with focus on application in autonomous driving. After graduation, Natko worked in web development field before diving into marine robotics. Since 2021. he started working in Laboratory for Underwater Systems and Technologies – LABUST at UNIZG FER where he is currently involved in a project developing an autonomous ship.*

Juraj Obradović *is a researcher in the Laboratory of Underwater Systems and Technologies (LABUST) at the University of Zagreb Faculty of Electrical Engineering and Computing (FER). He received his MSc in electrical engineering and information technology from FER in 2021 and joined LABUST right after graduation. During his time at college, he worked on various projects and developed an interest in SLAM, reinforcement learning, and formation control. He is currently enrolled in the development of an autonomous ship.*

7.2.21 LOCALIZATION CHALLENGE

Roee Diamant, University of Haifa, Israel

In this tutorial we will provide in-depth meetings with groups willing to take the localization challenge. We will introduce the acoustic equipment, go over the teams' plans for localization, and describe the procedure of the localization challenge. The tutorial will take place in small groups, with one-to-one feedback. This way, the groups could take advance of a peer-review for their localization methodology. The tutorial will also include demonstration of localization solutions, with analysis of real data. Challenges in acoustic localization will be highlights, and know-how solutions will be introduced.

Roee Diamant *received his PhD from the Department of Electrical and Computer Engineering, University of British Columbia, in 2013, and his B.Sc. and the M.Sc. degrees from the Technion, Israel Institute of Technology, in 2002 and 2007, respectively. From 2001 to 2009, he worked in Rafael Advanced Defense Systems, Israel, as a project manager and systems engineer, where he developed a commercial underwater modem with network capabilities. In 2015 and 2016, he was a visiting Prof. at the University of Padova, Italy. In 2009, he received the Israel Excellent Worker First Place Award from the Israeli Presidential Institute. In 2010, he received the NSERC Vanier Canada Graduate Scholarship. Prof. Diamant has received three Best Paper awards and serves as an associate editor for the IEEE Journal of Ocean Engineering. He is the coordinator of the EU H2020 project SYMBIOSIS (BG-14 track) and leads the underwater Acoustic and Navigation Laboratory (ANL) as an Associate Prof. at the Dept. of Marine Technologies, University of Haifa. His*

research interests include underwater acoustic communication, underwater localization and navigation, object detection and classification, and sonar signal processing.

7.2.22 GUIDANCE AND CONTROL OF UMVS

Massimo Caccia, CNR - Institute of Marine Engineering, Italy

The tutorial shows how guidance and control systems of Unmanned Marine Vehicles of CNR-INM are designed, implemented and tuned. Gain-scheduling PI velocity controller design and tuning is supported by basic model definition and identification experiments and allows easy design and implementation of guidance functions, heading control, line-following, path-following. Demonstration of the proposed approach will be available with SWAMP ASV.

Massimo Caccia *graduated in Electronic Engineering at the University of Genova in 1991. In the period October 16, 2013 – October 15, 2017 and October 16, 2017 – May 10, 2018 he served as Director and Acting Director, respectively, of the CNR Istituto di Studi sui Sistemi Intelligenti per l'Automazione (ISSIA-CNR). After joining CNR in 1993, his theoretical and applied research activities focused on marine robotics, mainly addressing the topics of modelling and identification, cooperative guidance and control, visionbased motion estimation and control, and embedded real-time platforms and architectures for Unmanned Marine Vehicles. He is among the European pioneer researchers in the field of unmanned surface vehicles and, with his research group, he developed pioneer research projects on the application of robotic technology to maritime safety. Research results, certified by more than 200 publications in international books, journals and conferences, led to the partnership in a number of EC, national and regional projects. He recently coordinated the projects Blue RoSES (EMFF), and MATRAC-ACP (Interreg Maritime Italy-France), and is coordinating the projects ARES (PON), and MODA (PNRM), that represent state-of-the-art R&D in the definition of guidelines and codes of practice for the operation of robotic vehicles in harbour waters and coastal water, and in the integration of shipbuilding and robotics according to the vision identified by Blue Italian Growth National Technology Cluster.*

7.2.23 STATIONARY H2ORBIT

Vladimir Djapic, H20 Robotics, Croatia

Founded in December 2017, H2O Robotics, Ltd. is a company specialized in maritime robotics, both underwater and surface, for different purposes and missions. Its flagship product is H2Omni-X, an USV capable of very low-power dynamic positioning, obstacle avoidance, autonomous operation and advanced communication capabilities under and above water. H2O Robotics, Ltd. provides services in maritime robotics, such as:

- manufacturing and selling H2Omni-X vehicle
- development of custom navigational algorithms
- adaptation of H2Omni-X for different use-cases
- development of custom vehicles
- R&D in the area of maritime technologies

H2Omni-X – smaller, lighter, smarter autonomous marine surface vehicle is an innovative robotic solution which outruns the current state of the market due to: high portability (easy operation and lightweight), high manoeuvrability (overactuated), long-term deployment capabilities (fault tolerant and energy efficient control), open source software architecture and competitive price. For marketing purposes, the vehicle is renamed to "H2Omni-X", conveying the message of omnidirectional vehicle, manufactured by H2O Robotics (name chosen for the company).

Base vehicle H2Omni-X, developed at LABUST/UNIZG-FER, was licensed to H2O Robotics company with a licensing fee which allows H2O Robotics to exploit, modify, improve, manufacture and sell vehicle to clients without any limitations.
Since the commercialization of H2Omni-X, H2O Robotics developed functional prototypes of 3 new products: 1) H2Orologio – an underwater pager, enables divers to communicate with other divers, topside (boat) units, other underwater or sea surface assets. We utilize a smart dive watch to accomplish the functionality of messaging underwater up to 1000 m;

2) H2Observe – small, low-cost, digital underwater modem. Our app runs on a smartphone and a dive boat can communicate with divers or other assets in the water, as well as track them;

3) H2Orbit – smaller version of H2Omni-X, dive flag buoy, tracks and trails underwater assets, enables Internet of Underwater Things.

This demo will include the demonstration of Stationary H2Orbit supporting several H2Observe systems as a type for Underwater localization & communication system. This system takes the form of one or more groups of three buoys, placed on the surface of the water, and one or more acoustic units, immersed under the water. A central unit, located on the shore or onboard a boat controls it.

Vladimir Djapic *received the B.S., M.S., and the Ph.D. degree from the University of California, in 2000, 2001 and 2009, respectively, all in electrical engineering. He is an accomplished manager and scientist with over 19 years of US and international experience (2 patents and over 50 publications) with a focus on advanced mapping, navigation, control, planning, and sensing methods for heterogeneous robotic systems. Since 2020 Dr. Djapic serves as a CEO of H2O Robotics. More recently, 2017-2020, Vladimir acted as a Mapping & Localization Manager and Technical Lead for Autonomous Driving Systems at American Haval Motor Technology (AHMT) whose mission was to design and develop a self-driving car capable of autonomous driving on public roads. From 2013 to 2017, Dr. Djapic was a Chief Scientist and a lead Principal Investigator (PI) for projects that utilize Maritime Autonomous Systems (air, surface, and subsurface), where he also led numerous international collaborative efforts.*

7.2.24 HYDROBATICS WITH UNDERACTUATED AUV

Kth Engineering Mechanics, Sweden

In this demo we plan to demonstrate hydrobatic manoeuvres with a slender underactuated AUV for the purpose of maximising the usability of the sensor suite on board. As an example one could think of a hybrid mission where the AUV is first doing a lawn mower pattern as part of a search mission and if the AUV identifies a target of interest the mission can be momentarily interrupted in order to perform a detailed inspection with cameras. During the detailed inspection the AUV hoovers around the object of interest and aims the cameras to collect a complete set of video/images. We will

demonstrated this close range hoovering and inspection manoeuvre and show how different control strategies can be utilised (classic PID control to more advanced methods such as LQR and MPC).

7.2.25 MDM TEAM

Vincenzo Calabrò, Lorenzo Marini, MDM Team, Italy

MDM Team is an Italian SME, founded in 2012 with core business focused on marine robotics. MDM Team combines several leading experts to support consultancy and designing for a large number of engineering applications, such as Design and prototyping of complex mechatronics systems, CAD design, FEM analysis, Development of mathematical models and software for real-time simulations, Homologation/certification of systems and components. MDM Team has a core team with many years of experience in prototyping of complex robotics systems, including underwater vehicle design and control (AUV/ROV), surface vehicle design and control (USV), inertial navigation systems and inertial measurement units (MRU), sensor fusion, human machine interface design, simulation of mathematical models, numerical optimization and systems architecture. The interest of MDM Team is focused on the development of proprietary platforms and the integration with third party applications and/or systems and our mission aims at delivering innovative mechatronics products and to support customer need through consultancy services and high-tech solutions.

Vincenzo Calabrò *is the chief technology officer (CTO) of MDM Team. He is a Ph.D. (class 2012 University of Pisa) in Robotics Automation and Bio-Engineering. In MDM Team he is technology roadmap responsible and follows Business development activities. Technically he leads activities on modelling, control and design of robotics systems and human interfaces. He has industrial background and international experience (Principal Engineer at Cybernetics Department in Kongsberg Maritime – Norway; Senior R&D Manager in Norwegian Subsea).*

Lorenzo Marini *is the chief executive officer (CEO) of MDM Team since 2016. He earned a Ph.D. in Industrial Engineering from University of Florence (class 2014). His background covers Vehicle Dynamics, Simulation, Mathematical Modeling and Mechanical Design. In MDM Team is the administrative responsible and follows Business development and sales activities supporting project goals definition and long terms corporate strategies. He has been the project Coordinator of ROMERO project – Robots fOr extreMe EnviROnment (GA ESMERA – GA 780265) (2020 -2022) funded by the Second Open Call of H2020 European SMEs Robotic Application.*

7.2.26 MULTIFUNCTIONAL SMART BUOYS AS PART OF A HETEROGENEOUS MARINE ROBOTIC SYSTEM ON A MONITORING MISSION

Anja Babić, University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

Long-term inspection and monitoring of harbours, marinas, and aquaculture ecosystems, including pollution mapping and marine litter detection, is a highly relevant problem in the area of marine robotics. This demonstration aims to showcase a heterogeneous multi-robot system tackling this issue. A set of complementary platforms with different capabilities and functionalities is featured, forming a single environmental monitoring and surveying system: autonomous catamaran-like surface vehicles SWAMP (CNR-GENOVA) and Korkyra (UNIZG-FER) with the Blueye Pro ROV tethered to it are integrated into the Multifunctional Smart Buoy (UNIZG-FER) system of surface and underwater sensor units. The agents form an ad-hoc communication network spanning both underwater acoustic channels and surface WiFi comms. Blueye ROV collects visual data of the

seafloor with an objective to find sea litter and other pollution factors, while acoustic sensor units monitor and report on water quality. ASV Korkyra is controlled to follow the ROV. Once sea litter is detected, its estimated georeferenced location is sent to the ASV SWAMP using the Smart Buoy as a relay, after which SWAMP moves to the given location. Besides serving as a hub transmitting relocation requests and points of interest, the buoy monitors the vehicles and sensor units during the entire length of the mission, collecting their telemetry, sensor, and status data over all communication channels, finally relaying it to be displayed on a user-friendly graphical IoT dashboard.

Anja Babić *is a researcher and PhD student at the University of Zagreb Faculty of Electrical Engineering and Computing and a member of the Laboratory for Underwater Systems and Technologies – LABUST. She is a senior researcher on the Multifunctional Smart Buoys project. Previously, she was involved in the EU H2020 project subCULTron – Submarine Cultures Perform Long-Term Robotic Exploration of Unconventional Environmental Niches. Other notable work includes implementing tasks for a robot-assisted autism spectrum disorder diagnostic protocol using the humanoid robot NAO for the HRZZ funded ADORE project and developing diver-focused sensing, data processing, and underwater communication as part of the FP7 project CADDY – Cognitive Autonomous Diving Buddy. Her research interests include evolutionary, neural, and bio-inspired robotics, emergent behaviour, task allocation and scheduling, formation control, and communication between both heterogeneous agents and members of a swarm, as applied to marine robotic platforms. She is the Chair of the IEEE Oceanic Engineering Society Student Branch Chapter of the University of Zagreb.*

7.2.27 AUTONOMOUS CATAMARAN AND TETHERED ROV AS PART OF A HETEROGENEOUS MARINE ROBOTIC SYSTEM ON A MONITORING MISSION

Nadir Kapetanović, University of Zagreb Faculty of Electrical Engineering and Computing, Croatia

Automating inspection and monitoring of harbours, marinas, and aquaculture ecosystems, including marine litter detection, is a highly relevant problem in the area of marine robotics. This demonstration aims to showcase a heterogeneous multirobot system tackling this issue. A set of complementary platforms with a different set of capabilities and functionalities is featured: autonomous catamaran-like surface vehicles SWAMP (CNR-GENOVA) and Korkyra (UNIZG-FER) with the Blueye Pro ROV tethered to it are integrated into the Multifunctional Smart Buoy system of surface and sensor units (UNIZG-FER). The autonomous surface vehicle (ASV) Korkyra is developed as a catamaran to provide better stability and hydrodynamic properties and is made of aluminium for increased robustness. It has a modular design allowing integration of various payloads such as Blueye Pro ROV. Furthermore, the autonomy of the ASV Korkyra is on average 10-11h allowing it to be used in intensive real-life inspection and monitoring missions. All agents from the above-mentioned heterogeneous robotic system form an ad-hoc communication network spanning both underwater acoustic channels and surface WiFi comms. Blueye ROV collects visual data of the seafloor with an objective to find sea litter and other pollution factors, while acoustic sensor units monitor and report on water quality. ASV Korkyra is controlled to follow the ROV. Once sea litter is detected, its estimated georeferenced location is sent to the ASV SWAMP using the Smart Buoy as a relay, after which SWAMP moves to the given location. The buoy monitors the vehicles during the entire length of the mission, displaying their telemetry and status data on a graphical dashboard.

Nadir Kapetanović *(MSc, 2015) is a Ph.D. student and a researcher as a member of the Laboratory for Underwater Systems and Technologies (LABUST) at the University of Zagreb Faculty of Electrical Engineering and Computing. He is currently involved in ESIF project HEKTOR, and previously he was involved in research in Interreg Mediterranean co-funded project BLUEMED, NATO project MORUS, and several other EU and national funded projects. His research interests include model predictive control, path and coverage planning for underwater marine vehicles, and state estimation techniques. He is the Secretary of the IEEE Oceanic Engineering Society Student Branch Chapter of the University of Zagreb.*

7.3 OCEAN MONITORING AND PROTECTION TECHNOLOGIES AND SERVICES IN THE ADRIATIC WORKSHOP (FRIDAY)

7.3.1 WELCOME AND INTRODUCTION

Mr. Nikola Mišković - Faculty of Electrical Engineering and Computing/Breaking the Surface - Vice-dean

Mrs. Sladjana Ćosić - European Investment Bank - Head of Croatian EIB Office

Mr. Šime Erlić - Ministry of Regional Development and EU funds - State Secretary

Mr. Josip Bilaver - Ministry of Maritime Affairs, Transport and Infrastructure - State secretary

7.3.2 KEYNOTE SPEAKERS

Mr. Nikola Mišković - Faculty of Electrical Engineering and Computing/Breaking the Surface - Vice-dean

Mrs. Sladjana Ćosić - European Investment Bank - Head of Croatian EIB Office

Mr. Šime Erlić - Ministry of Regional Development and EU funds - State Secretary

Mr. Josip Bilaver - Ministry of Maritime Affairs, Transport and Infrastructure - State secretary

7.3.3 OCEAN TECHNOLOGY FUNDING 1/2

Mrs. Antonella Calvia Goetz - European Investment Bank - Head of Division – Lead Advisor on Space and Ocean Technologies

Mrs. Renata Almeida Peloso - BlueInvest and PwC Luxembourg - Manager

Mr. Miguel Alves - European Investment Fund - Expert on Blue Investment

7.3.4 OCEAN TECHNOLOGY FUNDING 2/2

Mr. Ante Bobetko - Representative of Hamag-Bicro - Deputy General Manager

Representative of Ministry of Regional Development and EU funds

Ocean 14 - VC fund for Blue Economy

7.3.5 OCEAN OBSERVATION TECHNOLOGIES

Mr. Mario Špadina - SeaCras - CEO

Mr. Shep Smith - XOcean - CTO

Mrs. Chiara Petrioli / Mr. Claudio La Torre - W-sense - CEO/CFO

Mr. Tomislav Grubeša - Geolux - CEO

Mr. Josip Rukavina - Vectrino - CEO

Mr. Vladimir Djapić - H2O Robotics - CEO

Mrs. Marija Stupalo - Salonavar - CEO

Mr. Emanuel Rocco - Witted - CSO

Mr. Niccolo Rubini - River cleaning - BDO

7.3.6 PUBLIC, STAKEHOLDERS, USERS

Mrs. Tina Silovic - Mercator Ocean International

Mr. Mathieu Belbeoch - Ocean OPS, Manager

Mr. Christian Ferrarin - CMEMS, speaker from CNR ISMAR

Mrs. Daniela Iasillo - Planetek Italia

Mr. Joaquín Brito - The Oceanic Platform of the Canary Islands - Director

Mrs. Emma Reyes - SOCIB - Balearic Islands Coastal Observing and Forecasting System, Spain - Head of the HF Radar Facility

7.3.7 PANEL DISCUSSION

Mrs. Marina Dujmović Vuković - Regional development Agency Zadra Nova

Mr. Sandro Dujmović - NP Brijuni

Mrs. Sanja Slavica Matešić - Šibenik Knin County, temp. Head of Department

Mr. Stipe Lukin - SeaCras, CTO

Representative of the Italian Stakeholders

8 PARTICIPANTS

In 2022, 200 participants from 24 different countries and various fields joined Breaking the Surface.

1. Anja Babić
2. Nadir Kapetanović
3. Nikica Kokir
4. Senija Kokir
5. Kristijan Krčmar
6. Igor Kvasić
7. Ivan Lončar
8. Maja Markanović
9. Ana Golec
10. Marko Golec
11. Fausto Ferreira
12. Barbara Arbanas Ferreira
13. Vladimir Slošić
14. Martin Oreč
15. Luka Mandić
16. Natko Kraševac
17. Juraj Obradović
18. Nikola Mišković
19. Đula Nađ
20. Fran Penić
21. Ivo Kutleša
22. Zdravko Eškinja
23. Zoran Vukić
24. Vesna Vukić
25. Blanka Gott
26. Mak Gračić
27. Alexia Badi
28. Petra Kovačević
29. Fran Halambek
30. Hana Bilić
31. Ena Džanko
32. Mario Vražić
33. Dina Festetics Vražić
34. Goran Ranogajec
35. Davorka Mađerić
36. Emanuel Ranogajec
37. Iva Pesić
38. Luka Pesić
39. Ivan Petrović
40. Bernardina Petrović
41. Jelena Lončar
42. Slaven Lončar

43. Leon Lončar
44. Zdenko Kovačić
45. Hayat Hussein Rajani
46. Valerio Franchi
47. Rajat Agrawal
48. Prithvi Dibyendu Poddar
49. Lorenzo Marini
50. Vincenzo Calabrò
51. Niccolò Monni
52. Luyuan Peng
53. Pau Vial Serrat
54. Marta Real Vial
55. Greta Markfort
56. Thomas Glotzbach
57. Peter Weimar
58. Swetlana Fjodorow
59. Lukas Schmidt
60. Christine Kornmann
61. Kemal Delić
62. David Dörner
63. Nuno Cruz
64. Bruno Ferreira
65. Ivan Stenius
66. Martina Marić
67. Antonio Vasilijević
68. Sriharsha Bhat
69. Tim Hansen
70. Ola Benderius
71. Ted Sjöblom
72. Matthew Lock
73. Isabella Luppi
74. Koray Amico Kulbay
75. Roberto Francescon
76. Carl Ljung
77. Francesco Maurelli
78. Era Gërbeshi
79. Nayan Pradhan
80. Bogdan Belenis
81. Calin Clichici
82. Al-ameen Mawji
83. Marco Cella
84. Paolo Casari
85. Herman biørn Amundsen
86. Kjetil Eik
87. Ivar Bjørgo Saksvik
88. Johannes Marx
89. Ian Karez
90. Martin Kurowski
91. Sven Lack
92. Torsten Jeinsch
93. George Masters
94. Paul Randall
95. Tom Corner
96. Robert Shepherd
97. Giancarlo Troni
98. Juraj Dukić Hrvoić
99. Yiping Xie
100. Ignacio Torroba Balmori
101. Johanna Järnegren
102. Roee Diamant
103. Christopher Walker
104. Derek Orbaugh
105. Iain Anderson
106. Mathias Munkholm
107. Jacob Christensen
108. Nina Mahmoudian
109. Mo Rastgaar
110. Oscar Pizarro
111. Daniel Toal
112. Daniel Toal's wife
113. Maja Magdalenić
114. Lara Vdović
115. Matej Fabijanić
116. Allan Badian

117. Thomas Cimiega
118. Gherardo Liverani
119. Matej Kristan
120. Kakani Katija
121. Bridget Buxton
122. Željka Rajković
123. Valeria Patruno
124. Igor Radusinovic
125. Giulia Bologna
126. Francesca De Pascàlis
127. MARZIA ROVERE
128. Roberta Ferretti
129. Marco Bibuli
130. Jasna Pletikosić
131. Jeff Neasham
132. Gavin Lowes
133. Ben Sherlock
134. Željana Mikovčić
135. Ana Milošević
136. Žarko Zečević
137. Slavica Tomović
138. Luka Martinović
139. Luka Lazovic
140. Massimo Caccia
141. Fabrizio Ortolani
142. Petra Karanikic
143. Carlo Kraskovic
144. Jasmin Čantić
145. Aleksa Albijanić
146. Vladimir Novović
147. Corrado Motta
148. Lazar Ašanin
149. Stefano Küchler
150. Riccardo Gerin
151. Guido Bortoluzzi
152. Emanuele Rocco
153. Grazia Garlatti Costa
154. Tina Silovic
155. Simona Aracri
156. William Kirkwood
157. Bruno Crnički
158. Daniela Iasillo
159. Tomislav Radoš
160. Danijela Ćenan
161. Emma Reyes Reyes
162. Iain Shepherd
163. Neven Cukrov
164. Tomislav Stolar
165. Ivica Vilibić
166. Andrea Saiani
167. Mario Špadina
168. Stipe Lukin
169. Davor Blazencic
170. Shepard Smith
171. Sandro Dujmovic
172. Josip Rukavina
173. Marija Stupalo
174. Claudio La Torre
175. Antonella Calvia-Götz
176. Dragan Divjak
177. Vladimir Djapic
178. Miguel Alves
179. Mateo Ivanac
180. Raphaela Gutty
181. Christian Ferrarin
182. Luka Pensa
183. Matija Bilandzija
184. Šime Taraš
185. Morena Galesic
186. Marina Tavra
187. Andrej Obučina
188. Josip Bilaver
189. Ante Bobetko
190. Martina Vukašina

191. Sanja Slavica Matešić
192. Nela Rapinac
193. Sladjana Ćosić
194. Šime Erlić
195. Renata Almeida Peloso
196. Rita Sousa
197. Stephane Petti
198. Niccolo Rubini
199. Mathieu Belbeoch
200. Joaquín Brito

9 SCHEDULE

The table below summarizes the schedule available at https://bts.fer.hr/schedule-2022/

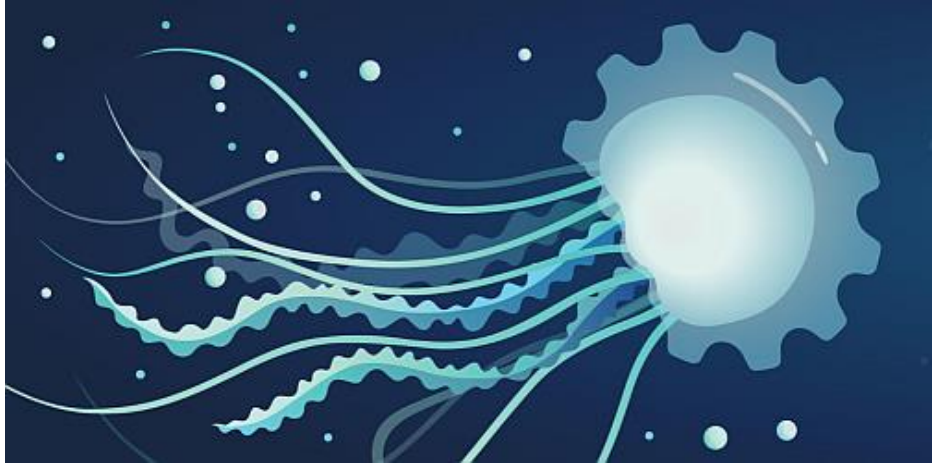
	SUNDAY, 25.09.	MONDAY, 26.09.			TUESDAY, 27.09.		
09:00 - 09:15		Opening session			Motion capture for underwater communication and diver health monitoring *Iain Anderson*		
09:15 - 09:30		The Chages Remote Ocean Voyager Expedition (C-Rove) *Bridget Buxton*					
09:30 - 09:45							
09:45 - 10:00		The role of acoustics in underwater robotics *Nuno Cruz*			Monitoring biodiversity with a wired underwater camera *Neven Cukrov*		
10:00 - 10:15							
10:15 - 10:30							
10:30 - 11:00		COFFEE BREAK			COFFEE BREAK		
11:00 - 11:15		Autonomous platforms for oceanographic data collection *Riccardo Genin*			Control of Autonomous Underwater Vehicles for Hydrobatics *Ivan Stenius, Sriharsha Bhat*		
11:15 - 11:30							
11:30 - 11:45							
11:45 - 12:00		Longterm deployment – does AUV really need to surface *Antonio Vasiljevic*			Data Policy and Challenges for Marine Robotics *Roberto Ferretti, Simona Aracri*		
12:00 - 12:15							
12:15 - 12:30							
12:30 - 13:00		LUNCH			LUNCH		
13:00 - 13:45							
13:45 - 14:00		T1 Intro - Getting started with Reads, the world's largest dataset for perception algorithms *Reads*			T3 Intro - "Work Class" ROVs for Underwater Operations *MARS*		
14:00 - 14:15							
14:15 - 14:30							
14:30 - 14:45		T2 Intro - Underwater localization of acoustic sources – principles and approaches *challange, INESC-TEC*			T4 Intro - Multibeam echosounder (MBES) *GEOMAR*		
14:45 - 15:00							
15:00 - 15:15							
15:15 - 15:30		BREAK			BREAK		
15:30 - 16:00		T1 *Reads*	T2 *INESC-TEC*	DEMO *H2O*	T3 *MARS*	T4 *GEOMAR*	DEMO *KTH*
16:00 - 16:30							
16:30 - 17:00							
17:00 - 17:30	REGISTRATION						
17:30 - 18:00							
18:00 - 18:30	WELCOME DRINK						
18:30 - 19:00							
19:30 - 20:30	DINNER	DINNER			DINNER		
20:30 - 21:00		IEEE OES UNIZG PARTY			WOMEN IN BLUE		
From 21:00							

WEDNESDAY, 28.09.	THURSDAY, 29.9.	FRIDAY, 30. 9.
Deep learning computer vision-based obstacle detection for autonomous boats *Matej Kristan*	**Developing imaging technologies to search for, discover, and understand life in the deep sea** *Kakani Katija*	**Welcome**
Development of a secure, interoperable and highly scalable standard for underwater acoustic communications *Jeff Neasham*	**Fantastic cold – water corals and where to find them** *Johanna Järnegren*	**Clean Ocean Mission** *Mr. Iain Shepherd* **Ocean Technology Funding 1/2**
COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
Integrated observations and monitoring solutions for exploration and sustainable exploitation of marine abiotic resources *Marzia Rovere*	**AUVROVA-autonomous low-cost resident inspection underwater drone concept** *Kjetil Eik*	**Ocean Technology Funding 2/2**
Company Presentation *MDM Team*	**Heterogeneous Autonomous Robotic System in Viticulture and Mariculture** *Zdenko Kovačić, Nadir Kapetanović*	**Ocean observation technologies** **Company pitches**
LUNCH	LUNCH	LUNCH
T5 Intro - Marine object detection using MARUS generated dataset *Ivan Lončar, Natko Kraševac, Juraj Obradović* **T6 Intro - Localization challenge** *challenge, University of Haifa*	**T7 Intro - Guidance and control of UMVs** *CNR, MONUSEN*	**Public, stakeholders, users presentations**
BREAK	BREAK	COFFEE BREAK
T5 *simulator, Ivan Lončar* **T6** *University of Haifa* **DEMO** *MDM Team*	**T7** *CNR* **DEMO** *Buoys* **DEMO** *ASV Korkyra*	**Panel discussion** **Challenge presentations**
DINNER	DINNER	GALA DINNER AND CLOSING CEREMONY
	PUB QUIZ	BTS KARAOKE NIGHT

10 SUPPORTERS

SUPPORTED AND FINANCED BY:

11 APPENDIX 1 – WORKSHOP LECTURE MATERIALS



Long-term deployment – does AUV really need to surface

Antonio Vasilijevic, Martin Ludvigsen - Applied Underwater Robotics Laboratory, NTNU

NTNU / Marin-technology dept. / AUR-Lab

Foto: Geir Mogen/Kommunikasjonsavd. NTNU

- Multidisciplinary profile

- AURLab founded in 2011
- Inter-faculty collaboration to promote
  - the application and use of underwater robotics
  - research across a wide variety of scientific disciplines and industries.
- AURLab is part of the Department of Marine Technology (IMT)

Long-term deployment

Common AUV deployment - few hours to several days

Implementation of autonomous underwater vehicles for persistent surveillance of the ocean

Stationary – with the place vehicle calls its home - residency

Dynamic – continuous scanning of larger areas.

Long-term deployment – needs and motivation

- Offshore operations
- Protection of cultural heritage
- Persistent Maritime Surveillance
- Monitoring and mapping the waterways

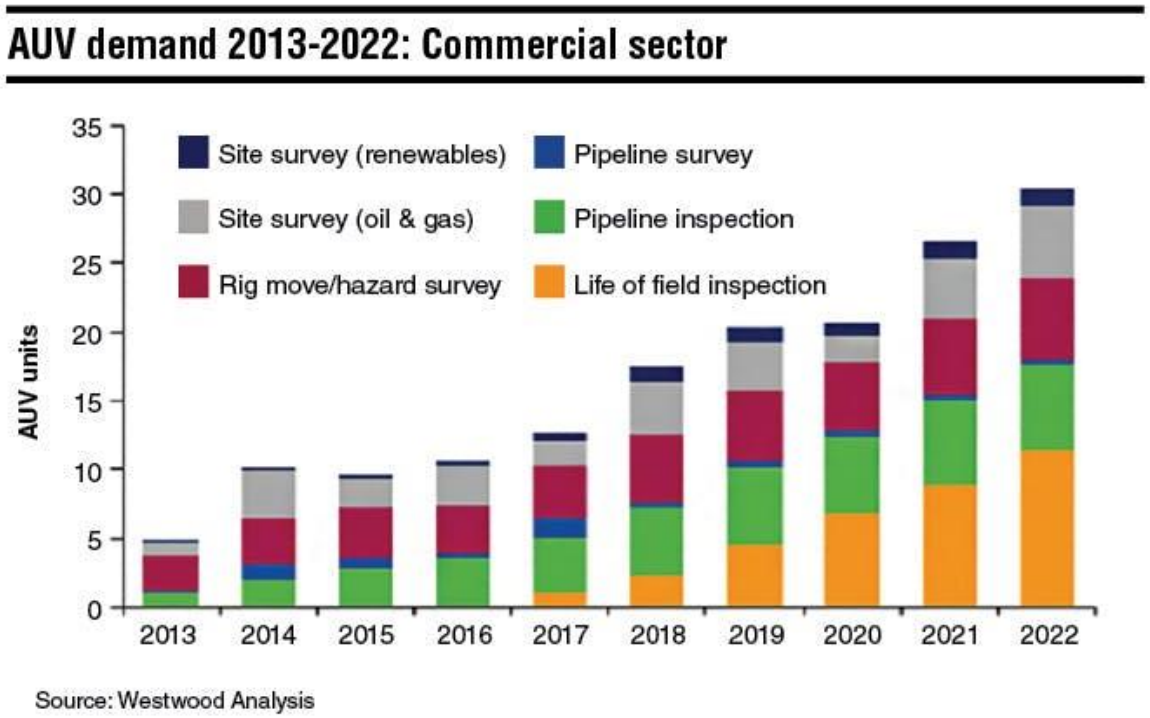
COST REDUCTION

INSPECTION FREQUENCY AND QUALITY

RESONSE TIME

ENVIRONMENT CO^2 EMISSION AND NOISE

Long-term deployment – needs and motivation



COST REDUCTION

INSPECTION FREQUENCY AND QUALITY

RESONSE TIME

ENVIRONMENT CO^2 EMISSION AND NOISE

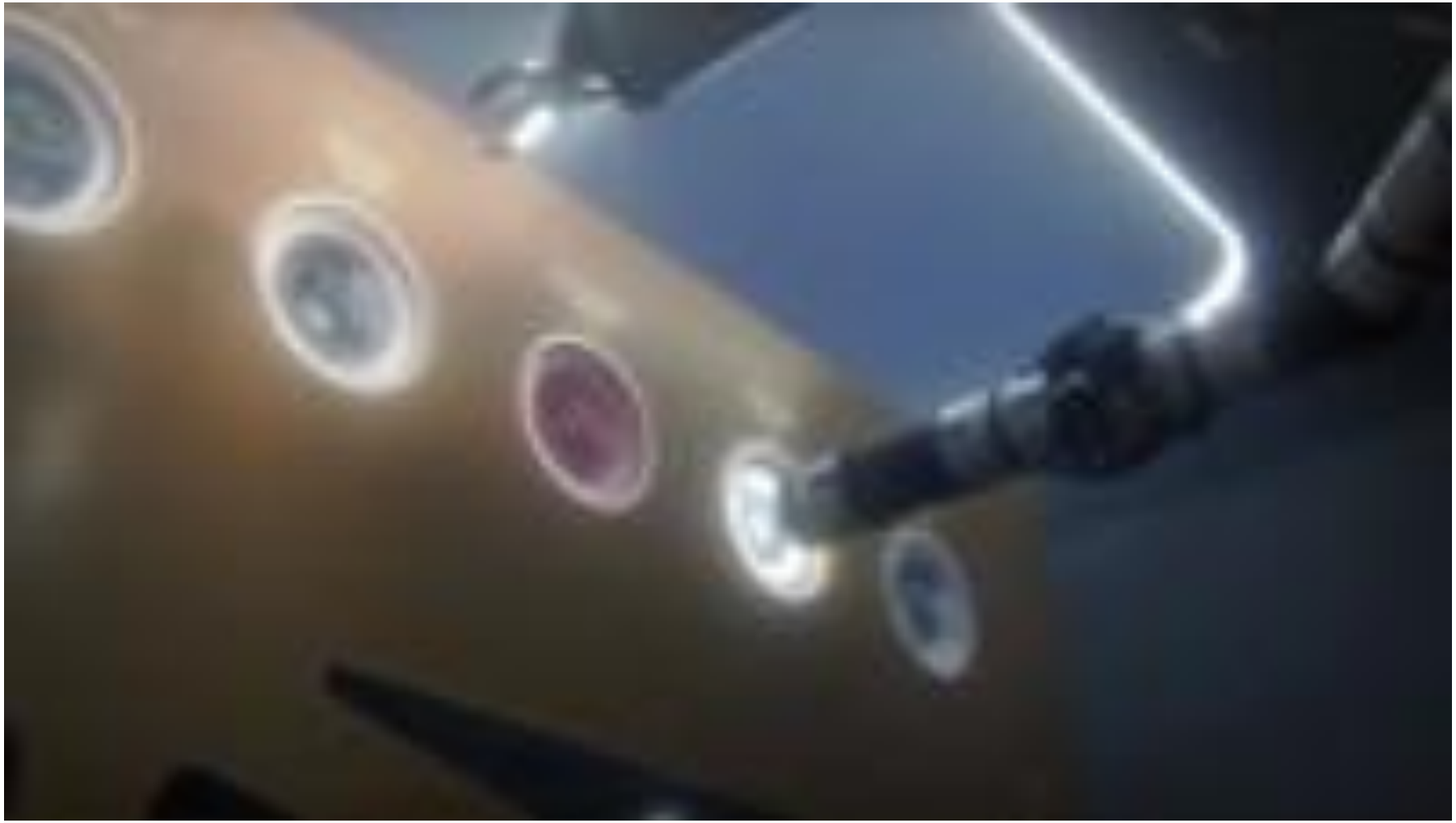
Long-term deployment – Challenges

- Endurance
- Positioning
- SA and decision making
- Communication

Long term deployment – Challenges

- Materials
- Biofouling
- Maintenance
- Sensors

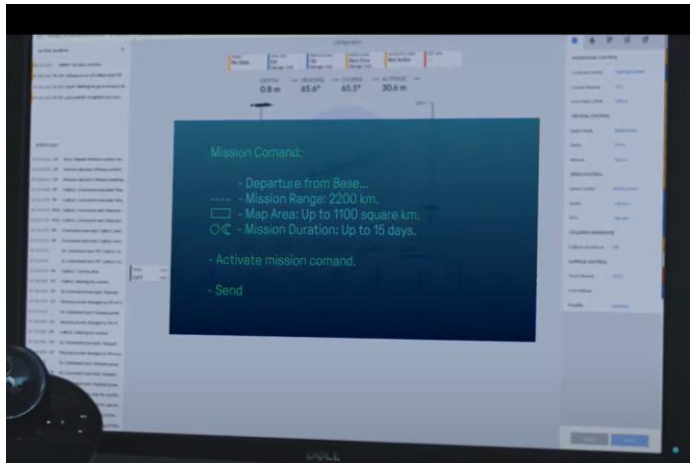
Motivation - Eelume movie



Longrange vehicles

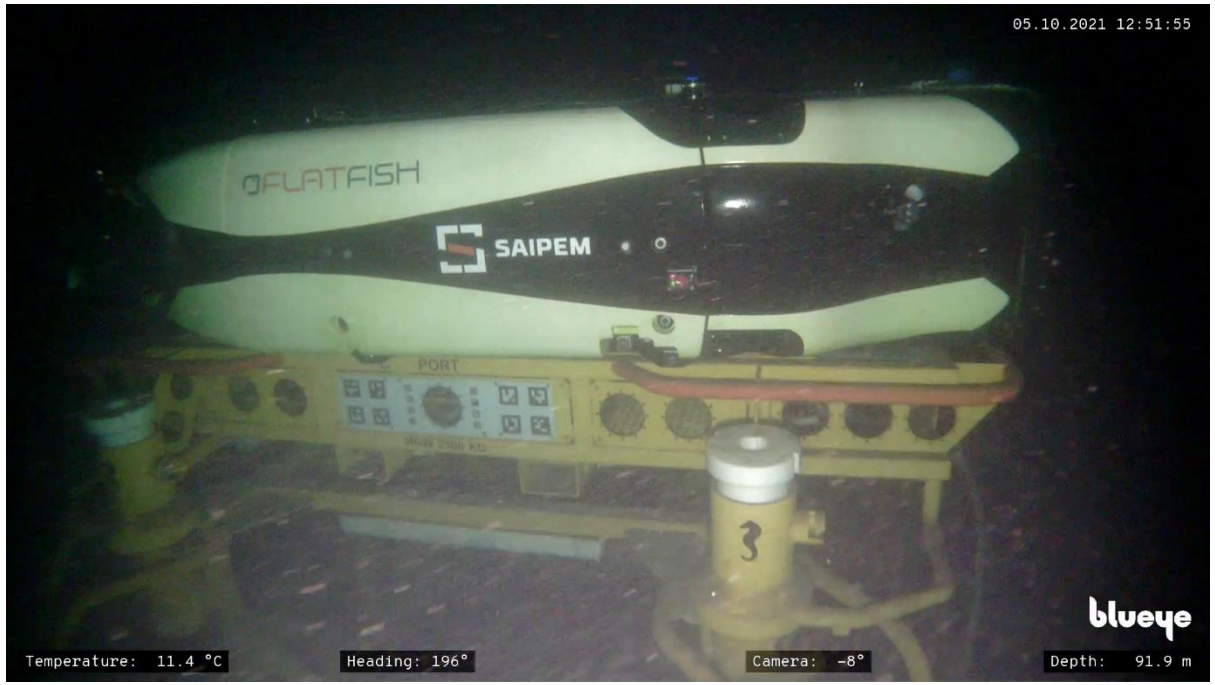
- HUGIN® Endurance - unsupervised shore-to-shore operations over long ranges

- NOC – Antarctica 12 months deployment



Resident Vehicle

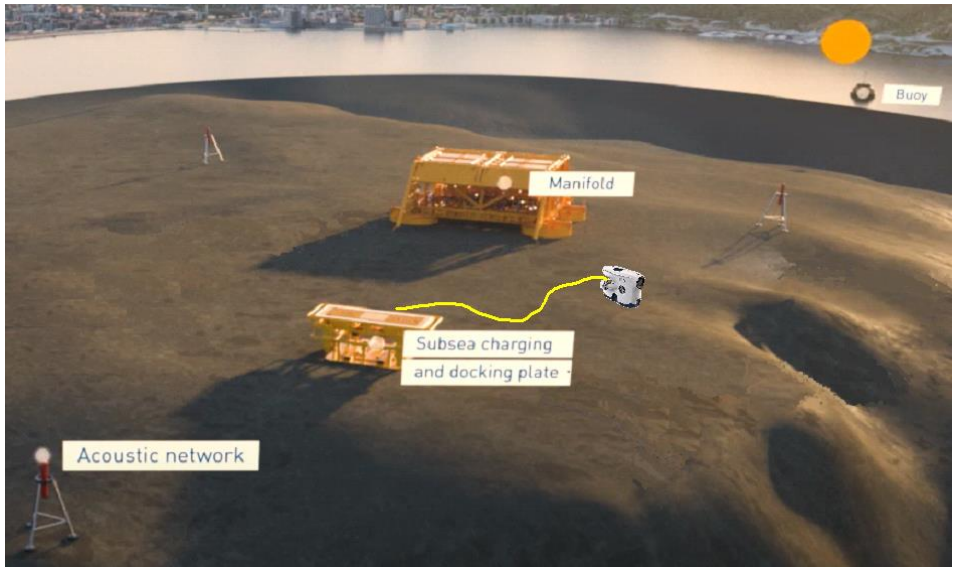
- Autonomous vehicle that performs unattended residence in the ocean for extended periods of time.
- Locate, observe and interact with underwater assets i.e., perform variety of inspection or/and intervention tasks.
- Upon task completion it returns to one of the nearby subsea docking stations for wireless charging and data transfer.
- The vehicle uploads the data collected and downloads new tasks or mission plans.
- Critical to realizing the potential of resident vehicle for offshore applications is reliable docking and communication in the area of the vehicle's "responsibility".

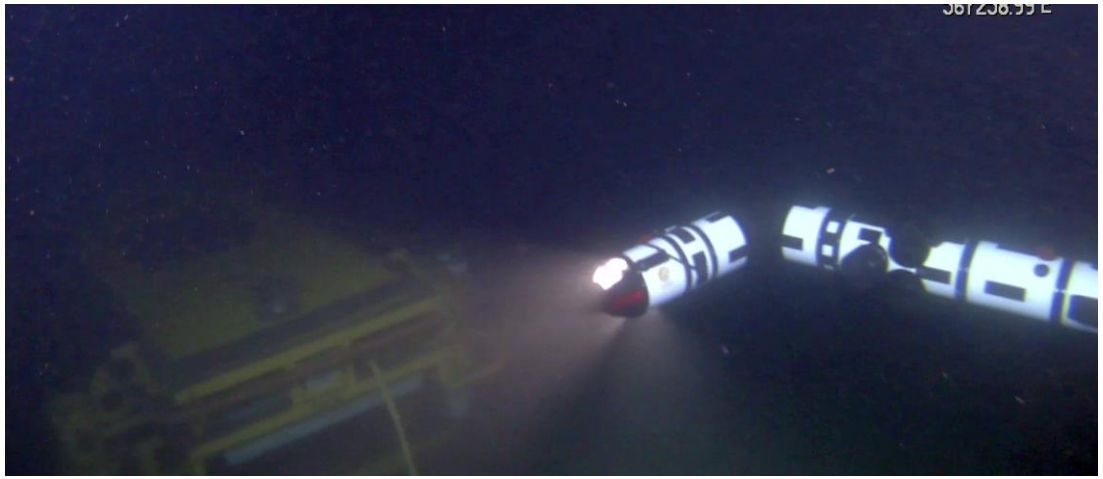


Resident Vehicle

- (Un)tethered vehicle:
  - remotely operated from ROC
  - autonomous

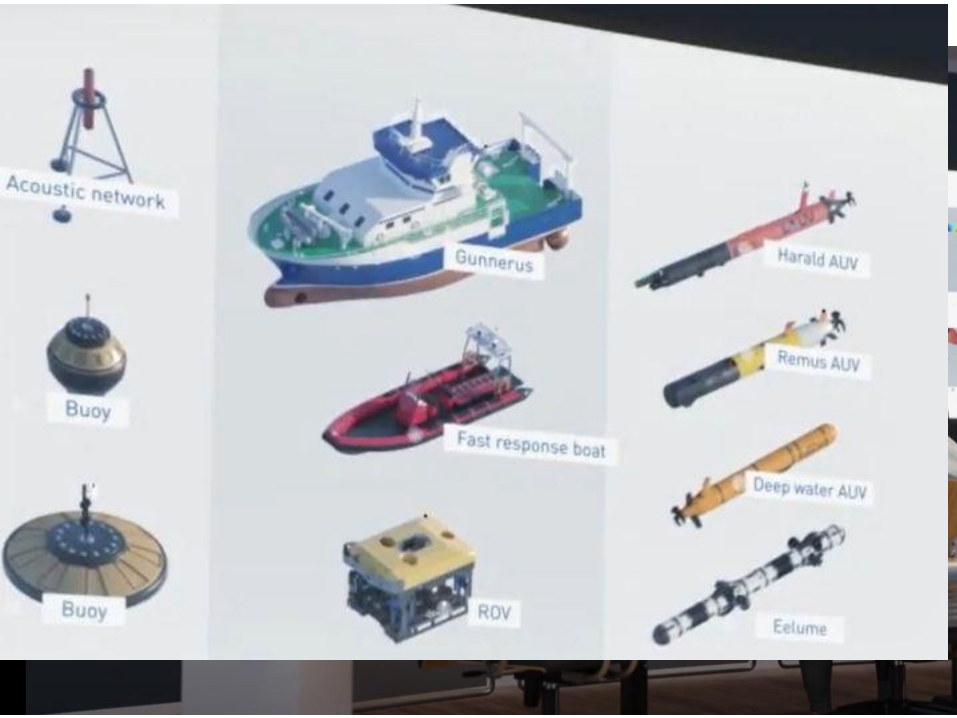
- From observation ROVs to long-range AUVs

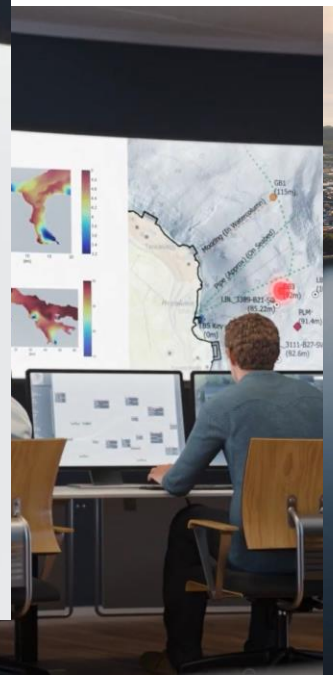


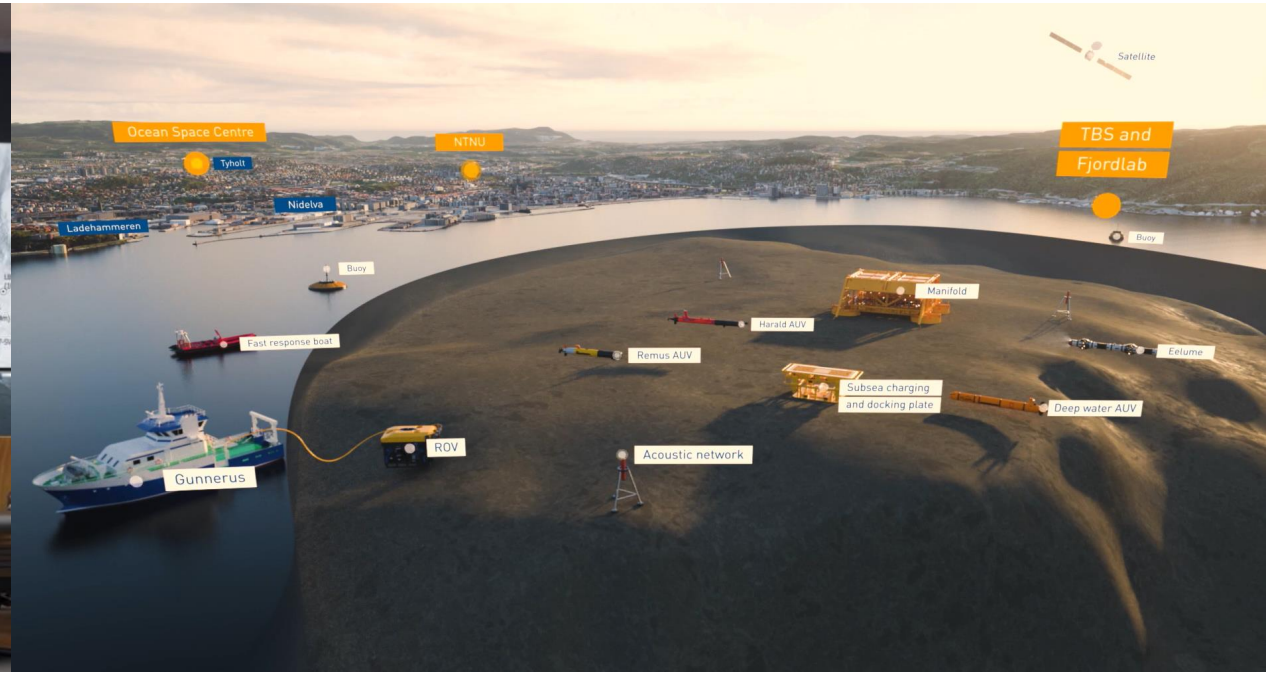


Trondheim fjord infrastructure

Control Room and Support Resources







OceanLab test site

A

Trondheim Biological Station (TBS)

- NTNU premises.
- Control room connected to Subsea instruments

B

Pigloop module (PLM)

- Installed at a depth of 90m

C

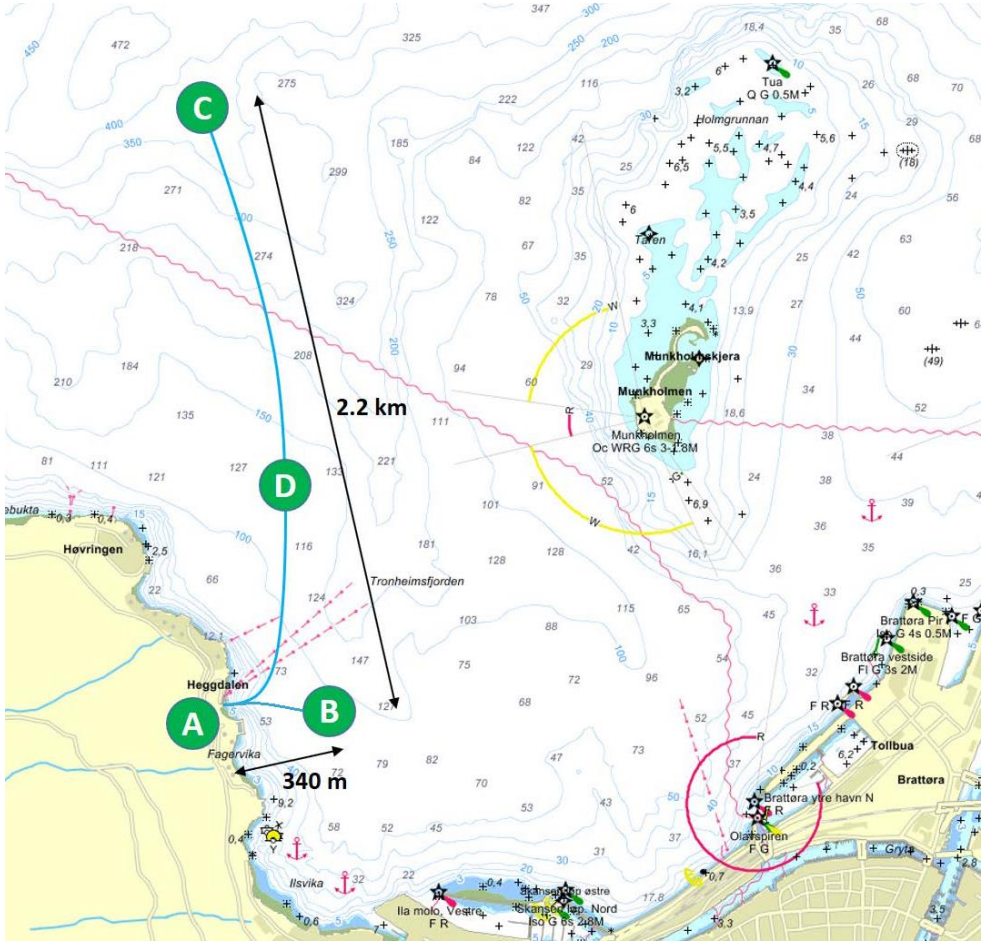
Subsea Docking Station

- Installed at a depth of 365m
- Under development by AURlab

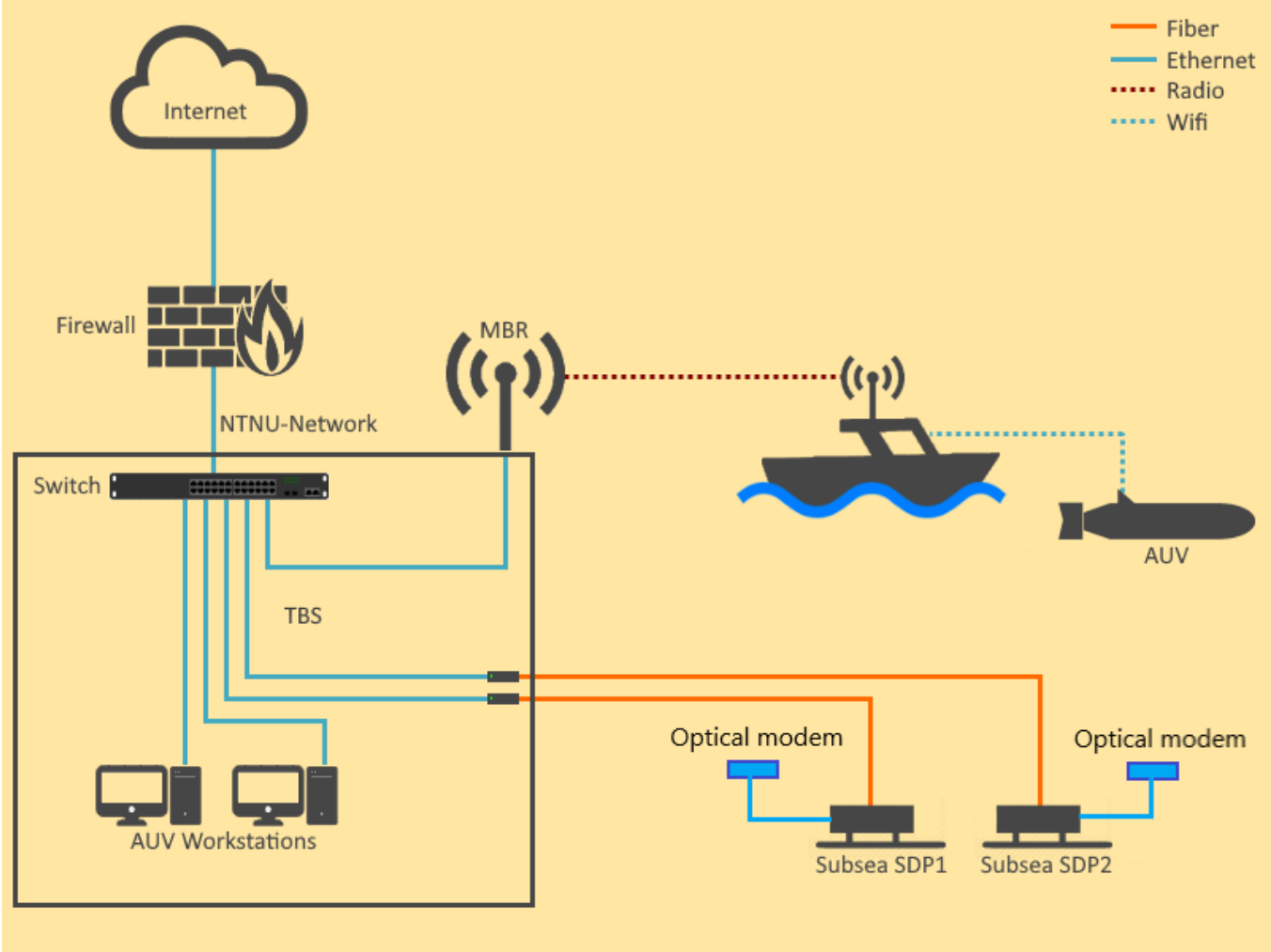
D

Seabed cables to SDS and PLM

- Supplies power and provides communication via optic fibers between land and subsea junction box



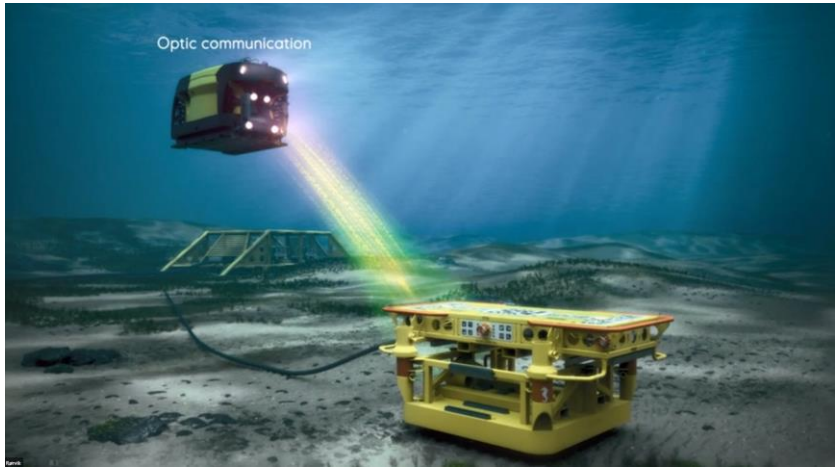
Communication

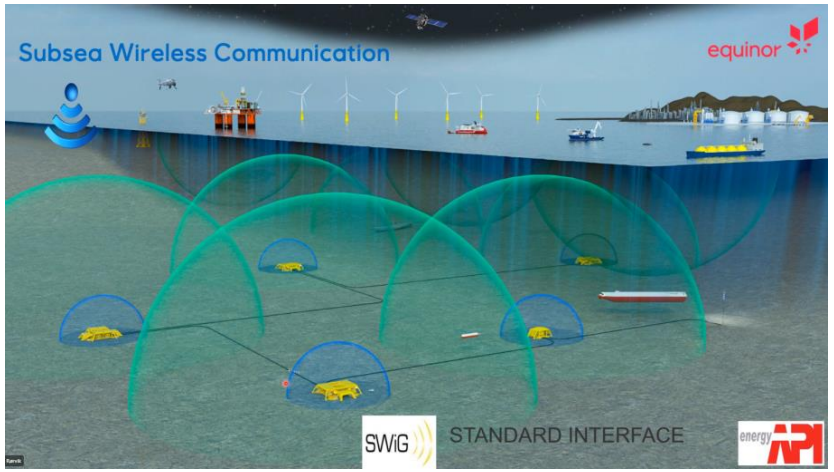


Charging and Wireless Subsea Communication Concept

Three-modal concept:

- Electromagnetic (Inductive) power and comm. while docked
  - Charging
  - Hi-bandwidth data transfer
- Optical - around SDS
  - Mid-bandwidth data 4-10Mbps
- Acoustics - larger area coverage
  - Low-bandwidth, essential and status data



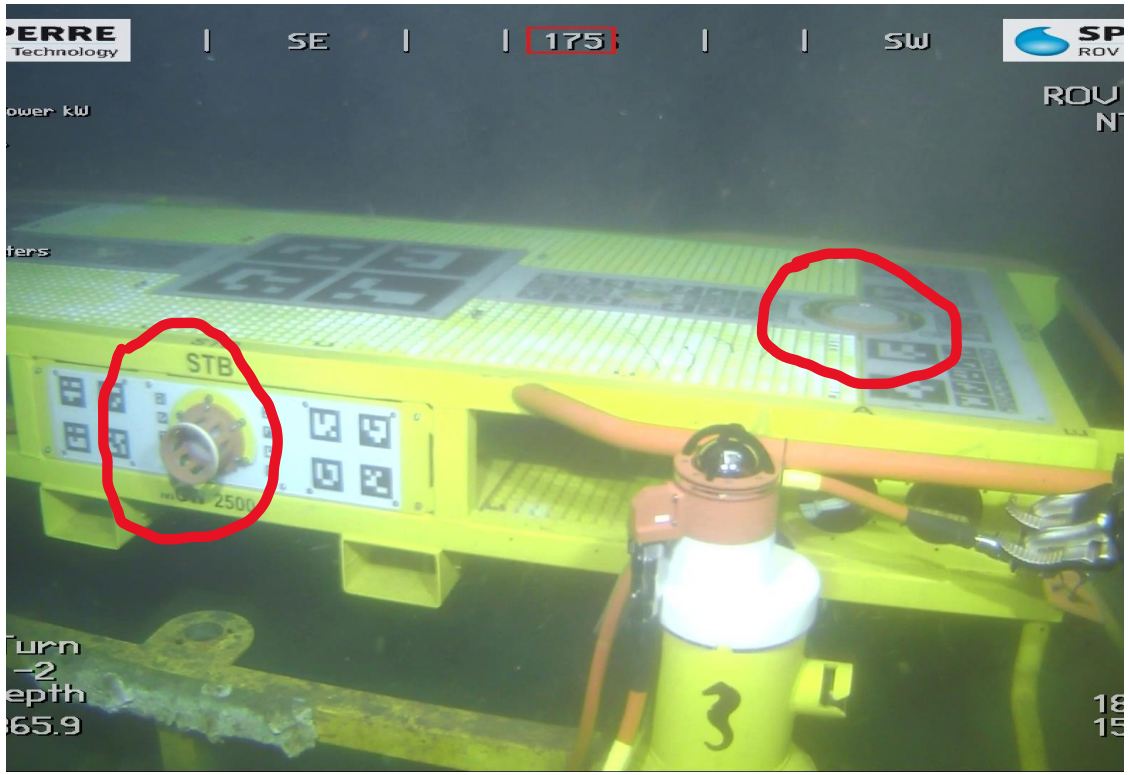


Courtesy of Equinor

Inductive connectors at SDS

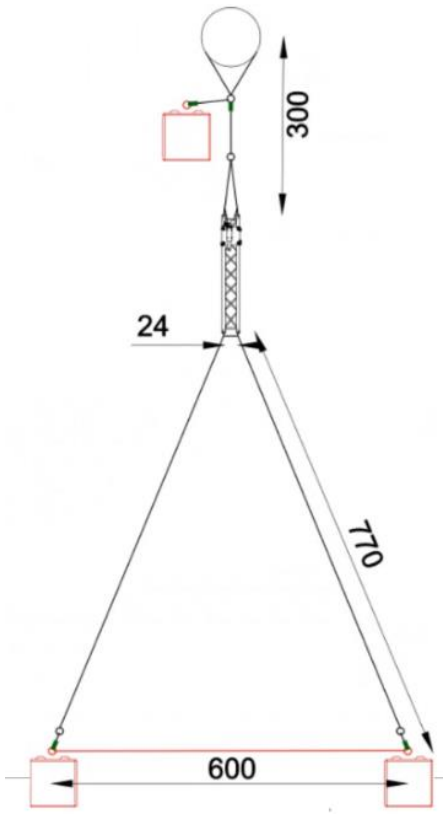
Inductive connectors:

- Close proximity
- Power 50W, 250W and 2kW
- Data: ethernet 80Mbps, serial

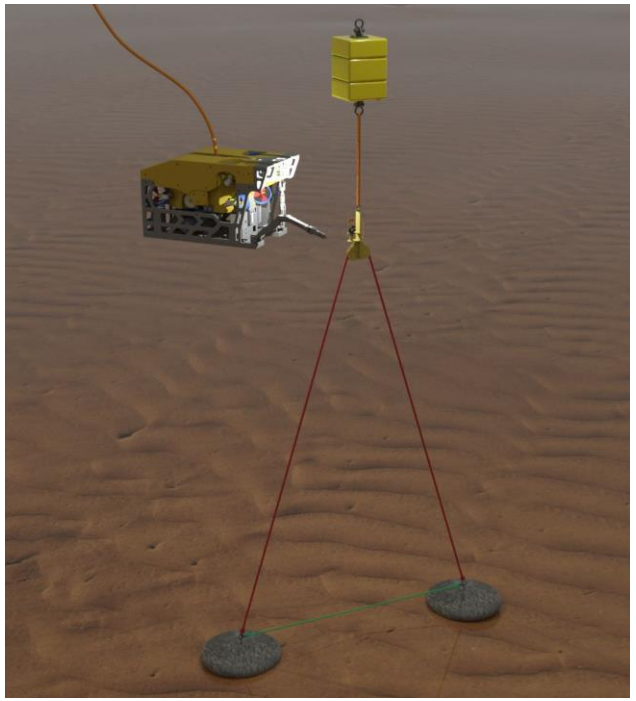


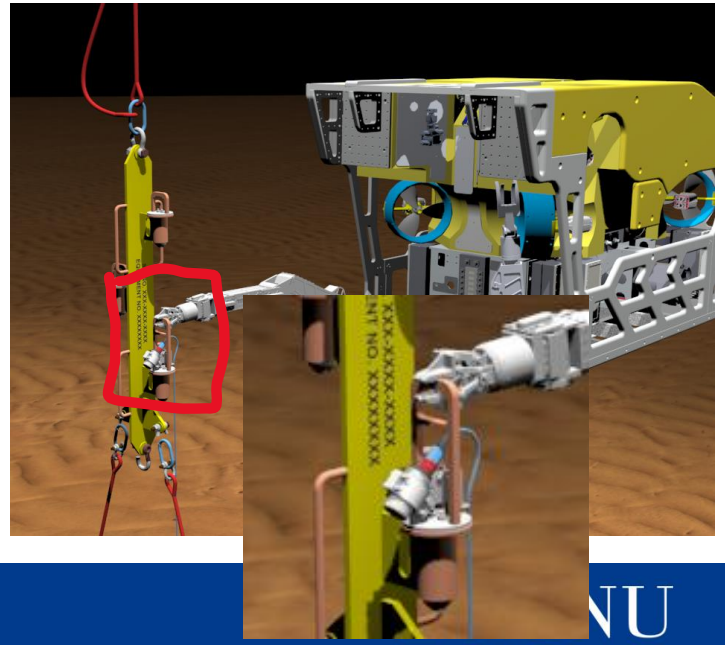
Åsgard SDS at OceanLab (365m depth) – docking plate, inductive connectors and camera

Communication tower FSO (optical) modem



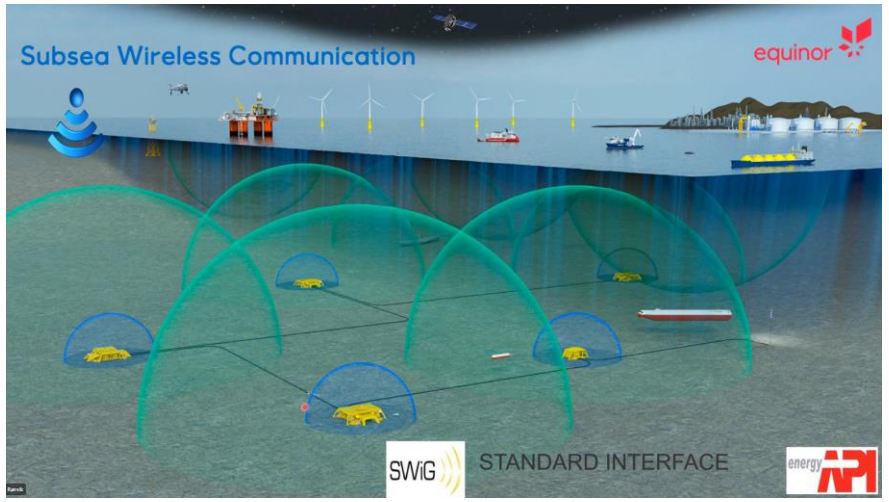
- Turbidity dependent
- Not omnidirectional, FoV 120 deg.
- Tower 13-15 meters high,
- Modem 10 meters above the seabed, tilted 45 deg





Acoustics

- 5 acoustic transponders for positioning
- Workboat with acoustics for communication with UID
- Offshore connected to the SDS
- Reliable, long-range solution

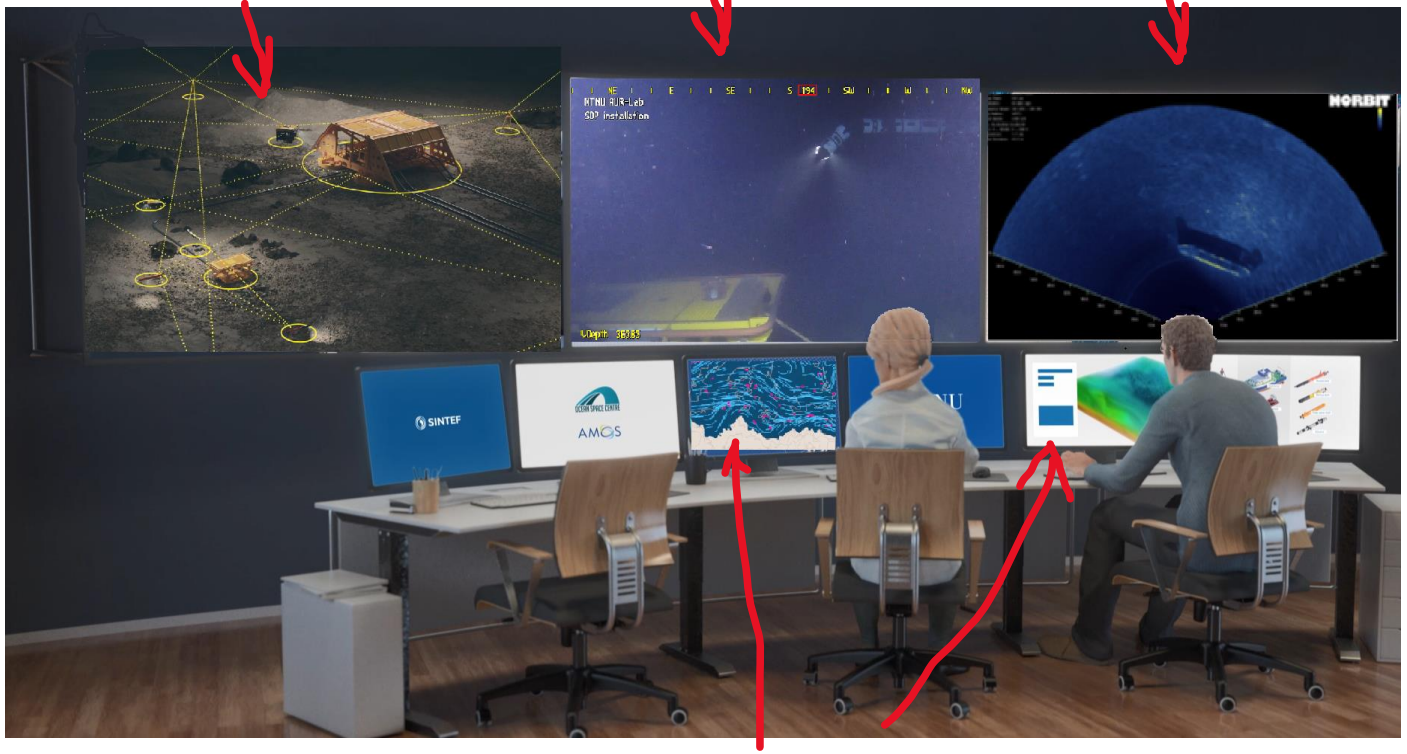


2022 - On-site observation

Situational Awareness

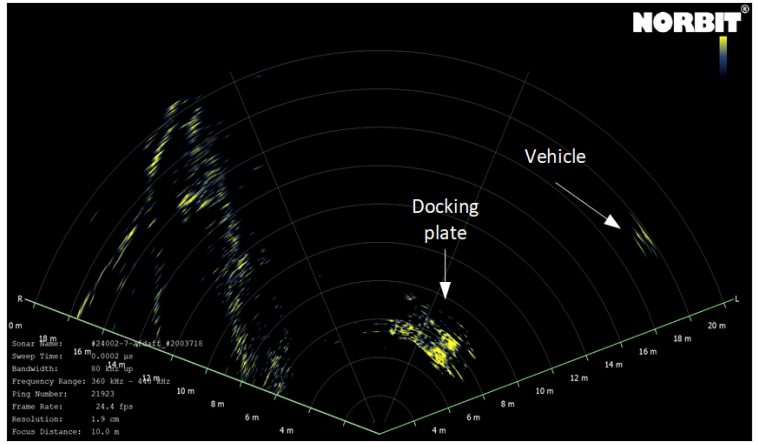
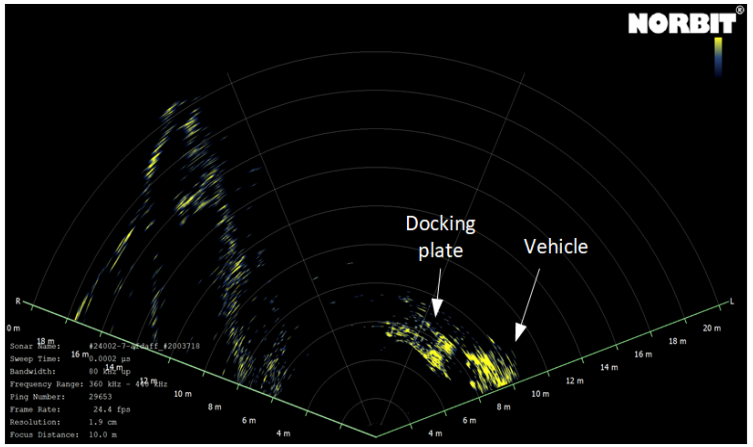
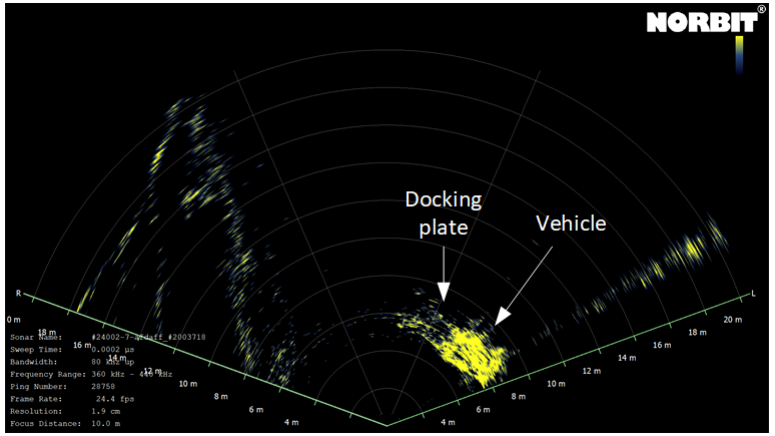
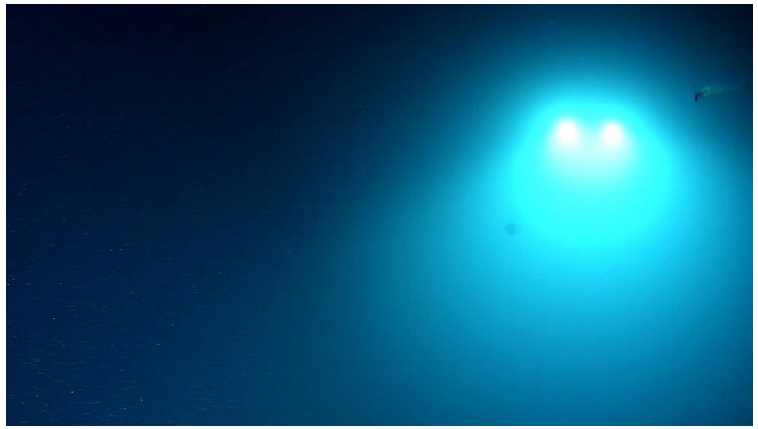
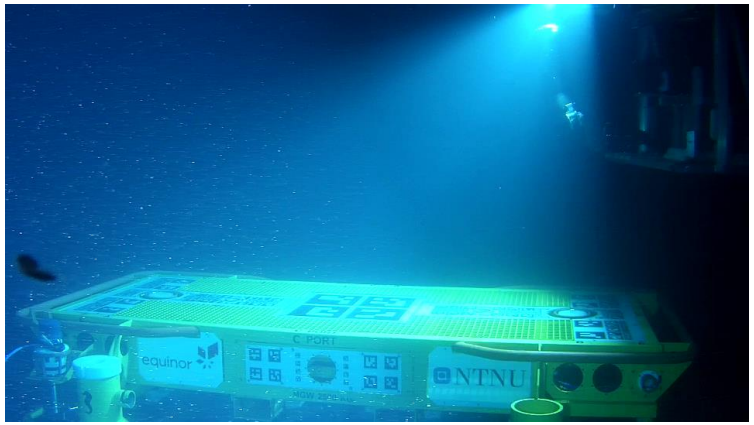
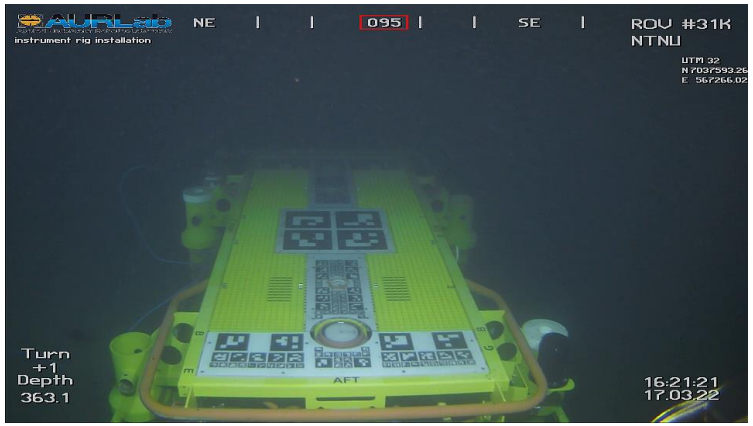
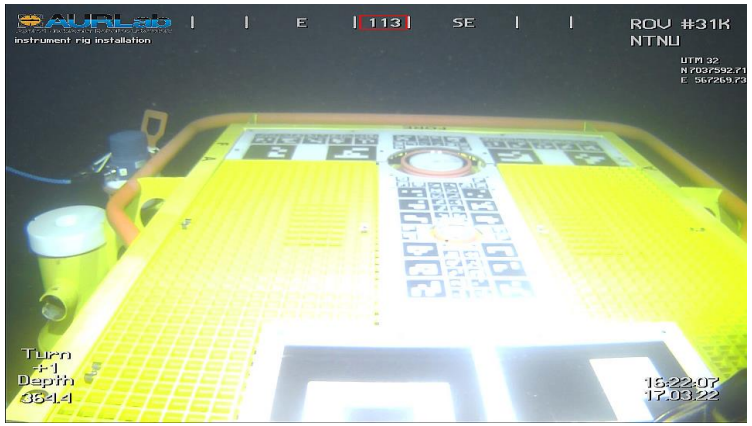
Visual monitoring

Sonar



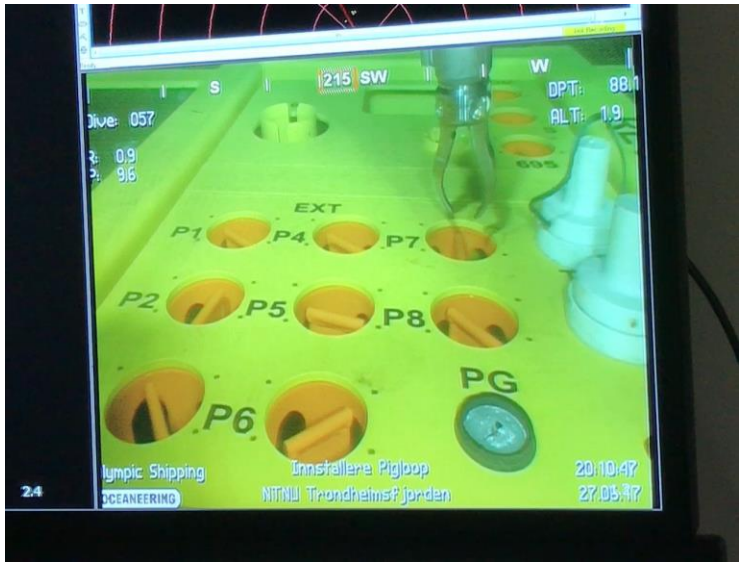
Environmental data

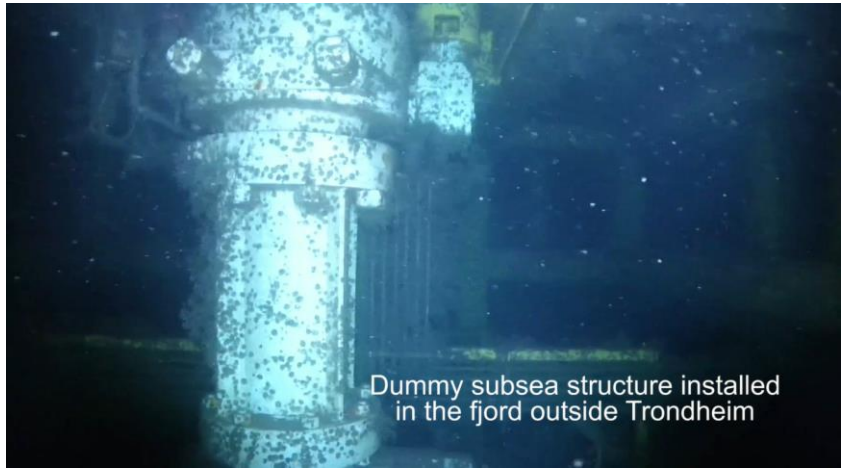
Observation: Camera, sonar, environmental data

	Approach	Lending	Docked
Sonar view			
Camera view			
ROV camera view			

Underwater Inspection/intervention testbed

- Realistic environment for inspection/intervention scenarios
- SDP - docking and residency (charging and data transfer)
- PLM – inspection installation
- PLM includes a dummy ROV panel with marking
- 3-modal communication and precise acoustic localization available around the site
- Environmental data from instrument rig





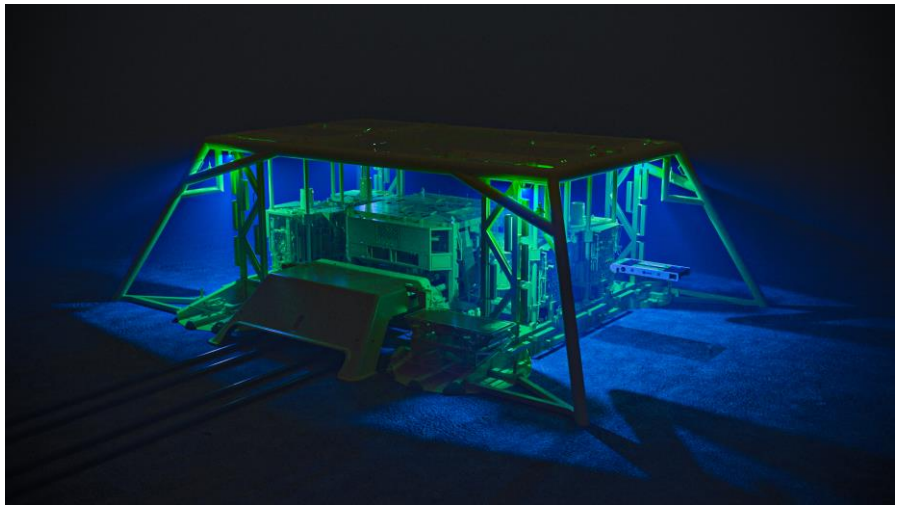
Pipeline

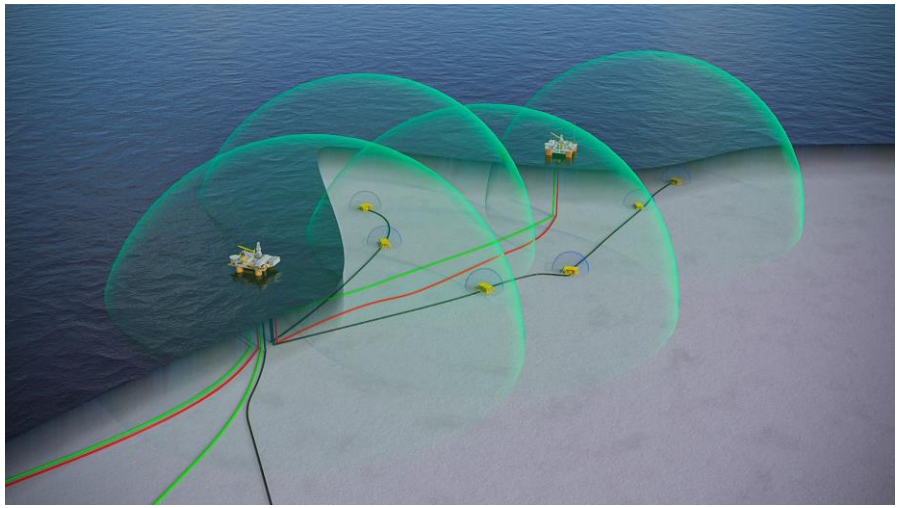
- Seawater pipeline for TBS close to PLM site
- Intake on 100 meters depth
- Convenient for pipeline tracking and inspection
- Or leak detection

Shoreside control room

OceanLab - Equinor UID validation

- Validation of UIDs
- Inshore testing of Subsea Docking Stations (SDS) before offshore installation (Åsgard and J.Sverdrup)
- Testing of Equinor offshore communication concept for future resident vehicle





Program for qualification of UID vehicles

Program sections:

- Basic, medium to advanced level manoeuvring
- Docking and residency
- Non-intrusive UID tasks (inspection)
- Intrusive UID tasks (intervention)
- UID endurance capacities
- UID communication

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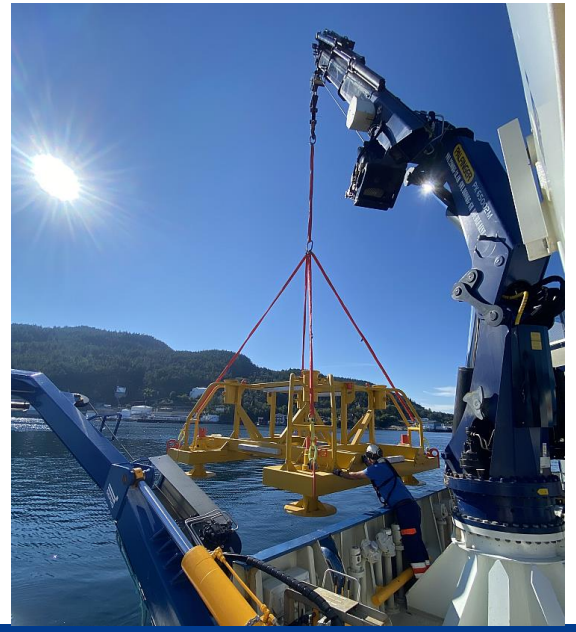
Qualification of UID

At NTNU OceanLab

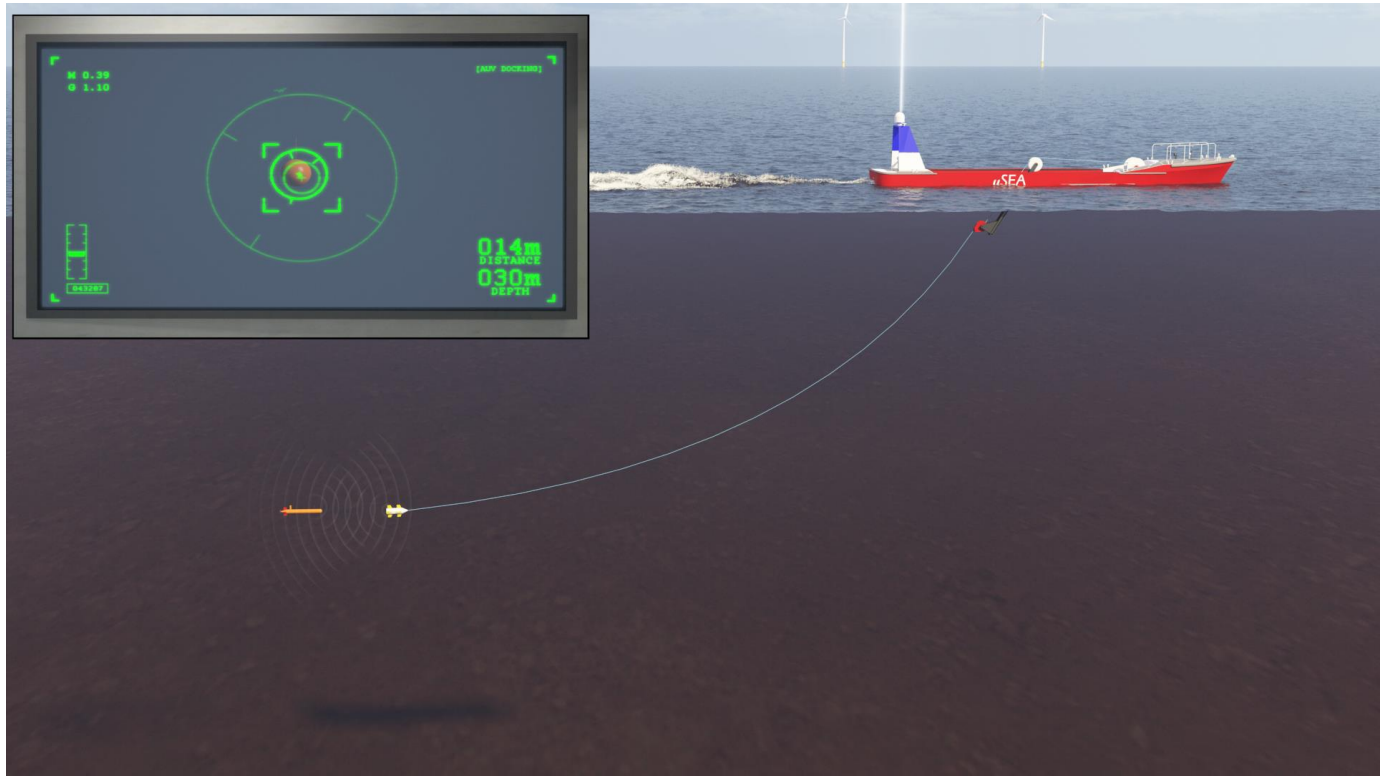
Installation phase June-September 2021

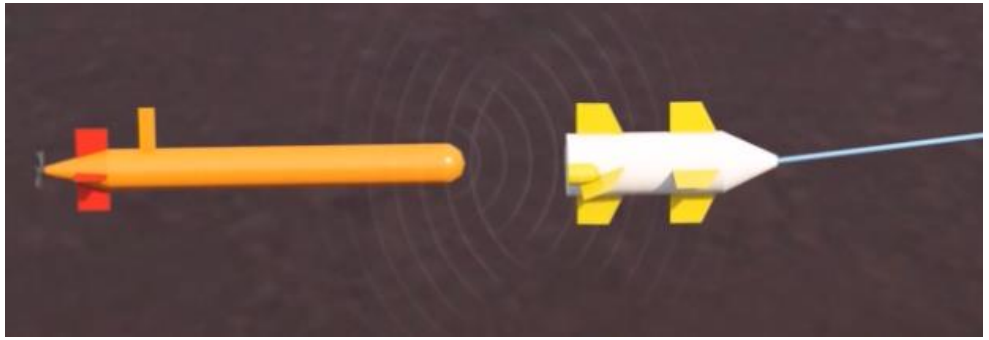
Qualification September-October 2021



Access AUV project

- System for long-term operation not fixed to the specific location
- Concept combines operation of AUVs with Small unmanned offshore vessel
- Development of uLARS™ Towhead system
- Docking of AUV, using USV and actively controlled Towhead





Project motivation

Cleaner

Cheaper

Safer

Project participants and partners

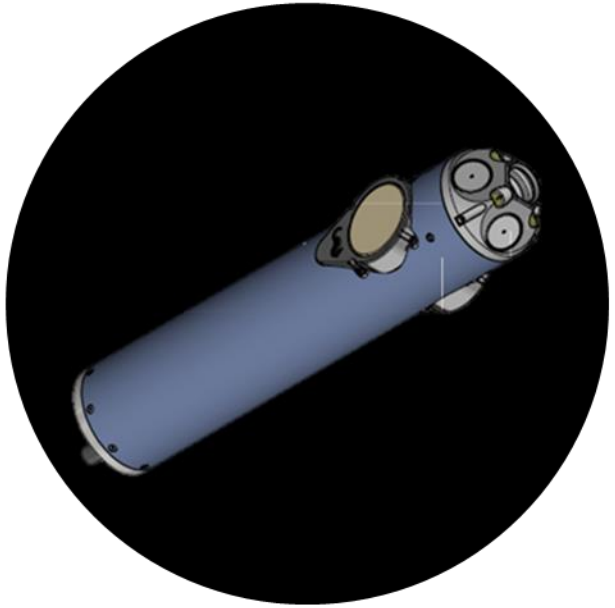
- ACCESS AUV project supported by Forskningsrådet (Research Council of Norway)

- Industry partners
  - uSEA Ocean Data (project owner)
  - Blue Logic

- Research partners
  - NTNU
  - Sintef
  - Norce

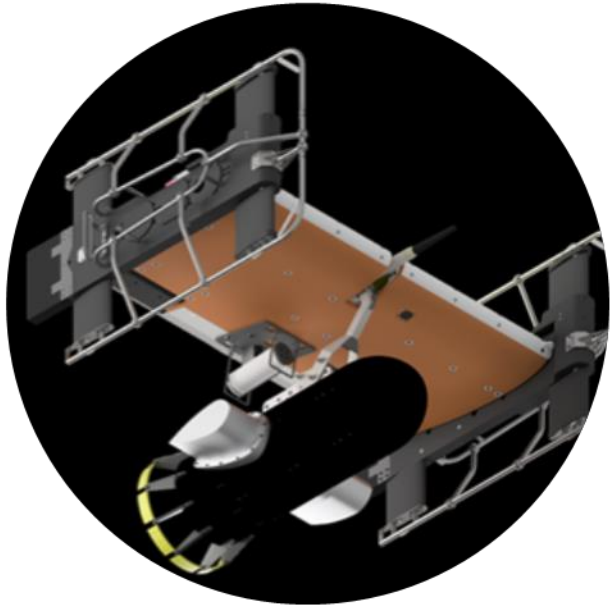
Systems

AUV



- Modified nose section
- Acoustic positioning transponder

Towhead



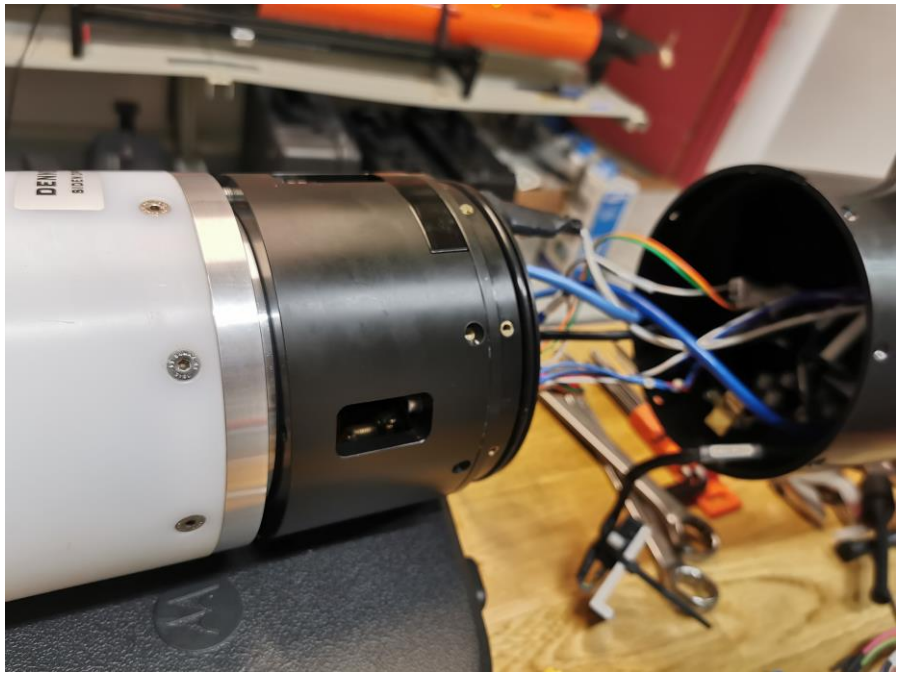
- Hydrodynamic wing and steering based on ElVA ScanFish
- Towhead docking funnel for AUV interfacing
- Towhead topside control unit
- Winch

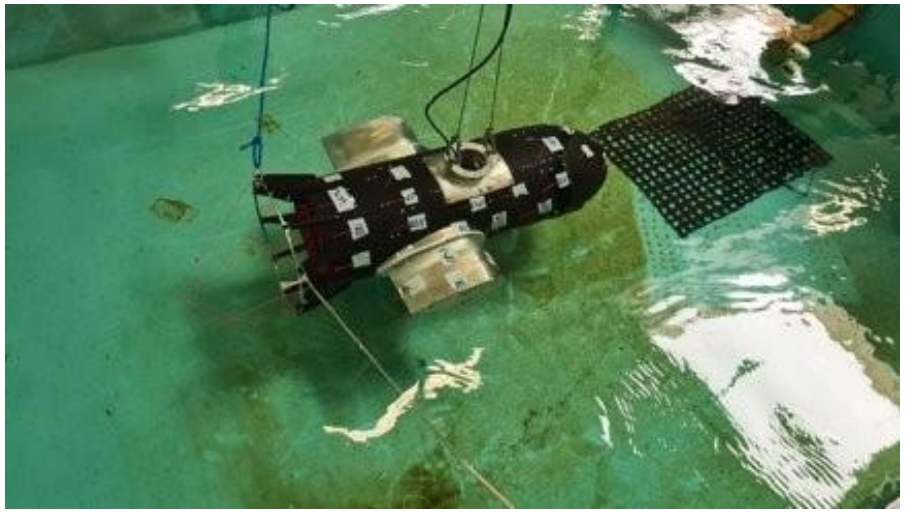
Vessel

- Communication system to shore
- USBL

System development

- AUV
  - Modified nosecone
    - Inductive power and data
    - Mechanical latching interface
    - LEDs
  - Integrated battery management system (BMS)
- Towhead
  - Hydrodynamic wings and control fins
  - Control algorithm
    - USBL, cameras and sonar
  - Alignment funnel
  - Structure for holding AUV and connectors
  - Inductive data and power transfer
    - 2x250W & 1Gbps
  - Latching mechanism



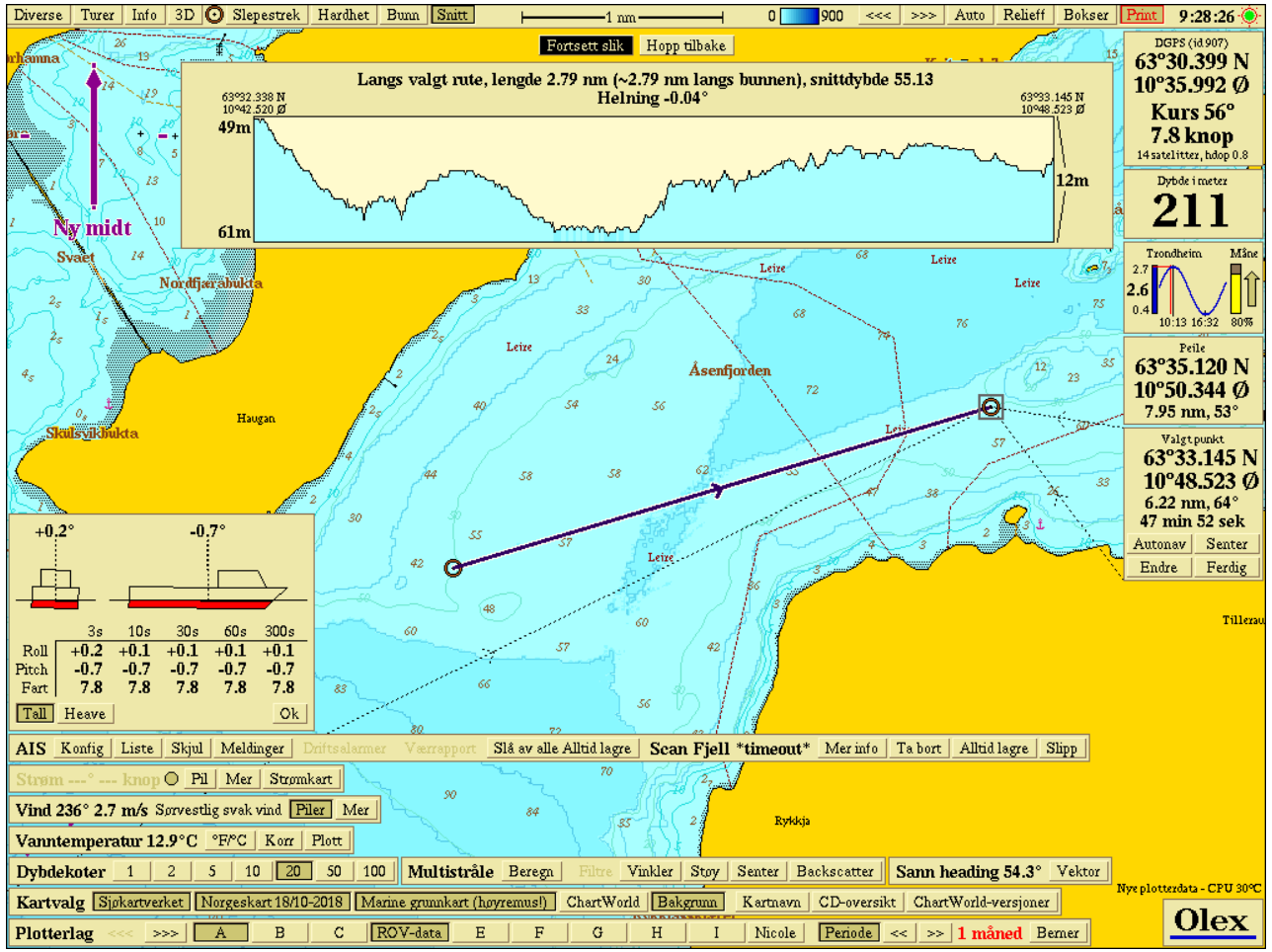


Project demonstration

- Full system test on deck
  - Data communication to and from AUV
  - Battery charging AUV
  - Latching AUV to Towhead

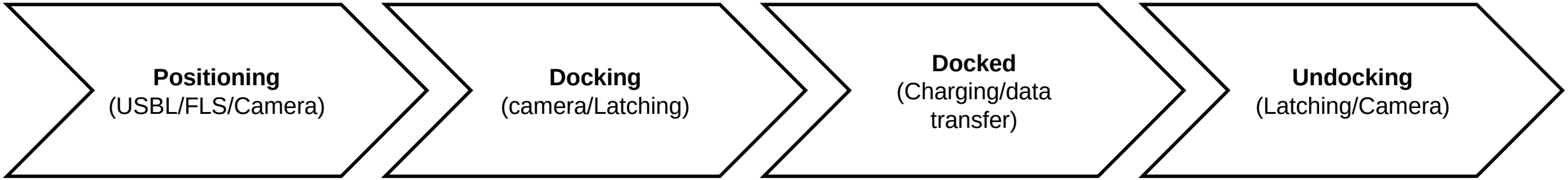
Project demonstration

- Trondheim fjord - Åsenfjorden
  - Average depth 55m
  - Run line ~ 2,8nm



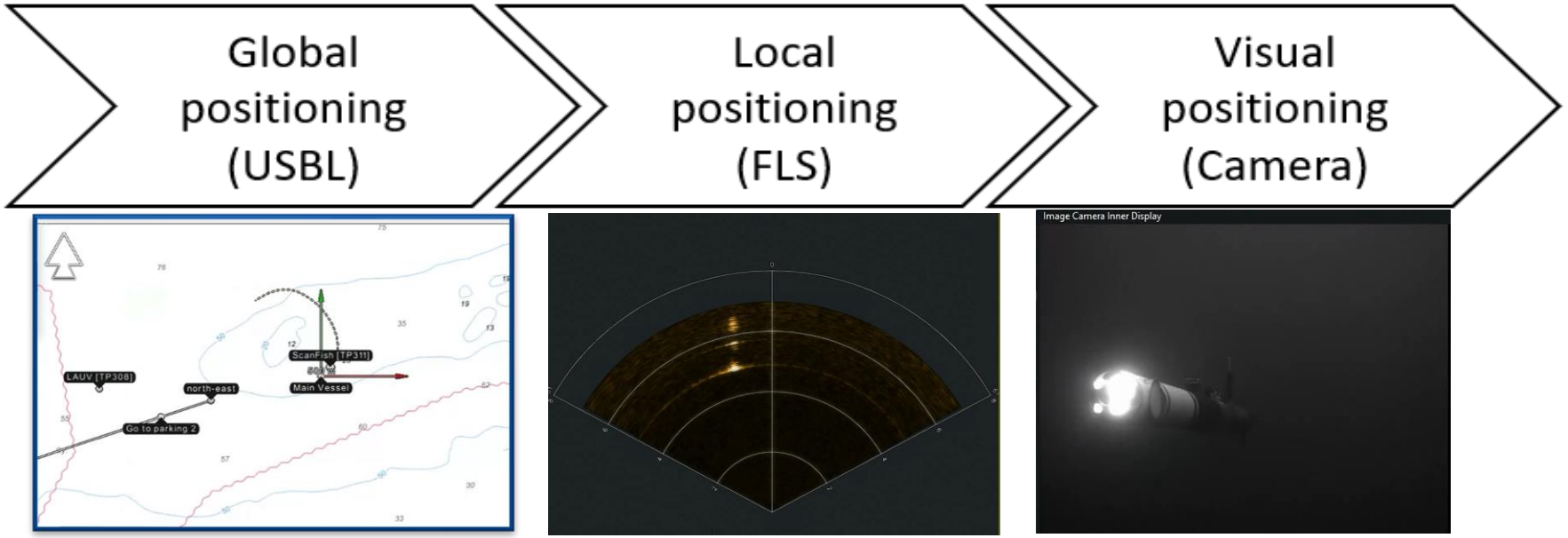
NTNU

Project demonstration



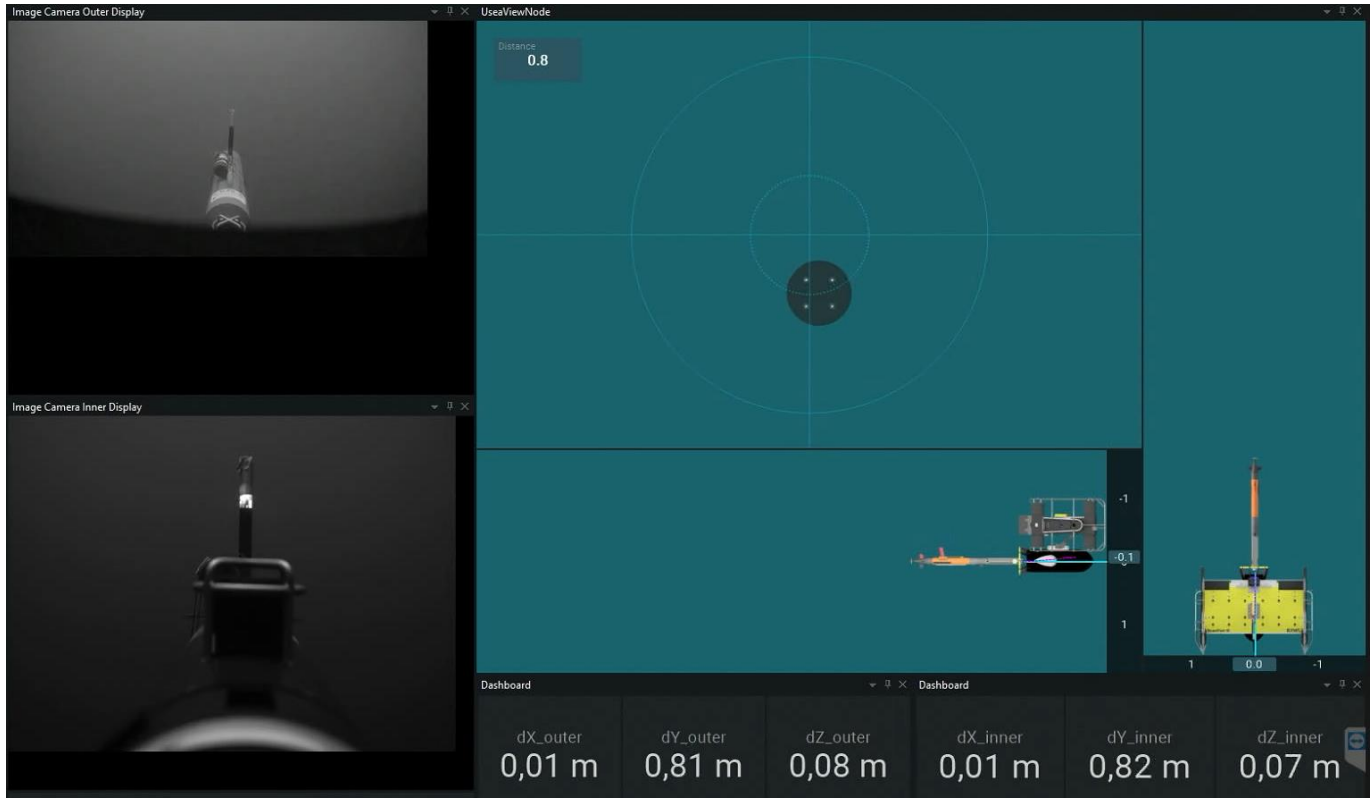
Project demonstration

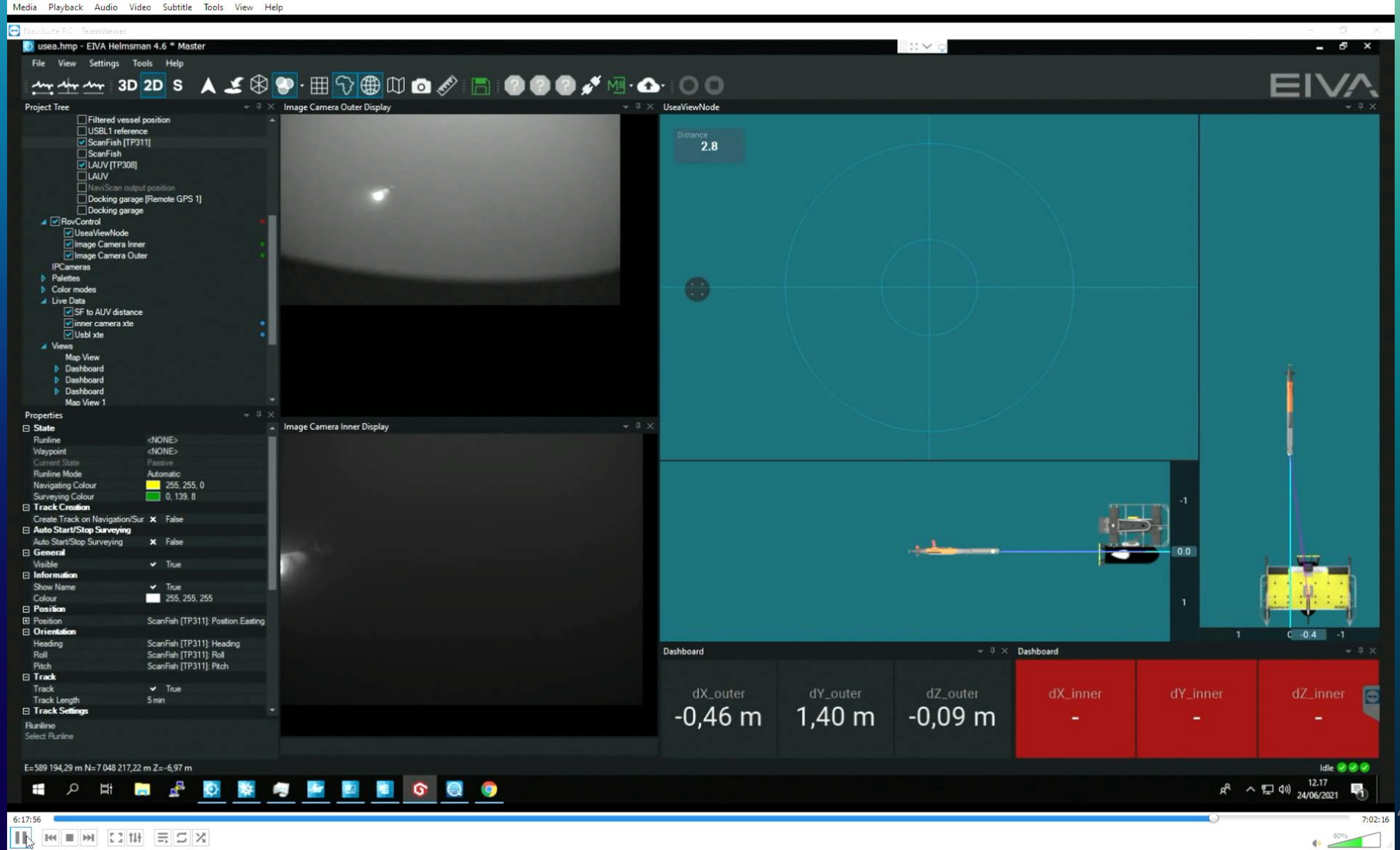
- Sensor transition on approach to docking
- Sensor evaluation
- Input correlation with sensor fusion
- Algorithm control / Alerts for human intervention
- Robust handling of failures in sensor input



Project demonstration

- User interface
  - Sensor view
  - Sensor interpretation view
  - Distance estimation
- Manual control
- Automated control
- Remote access for **operators** on shore
  - Remote monitoring and remote configuration

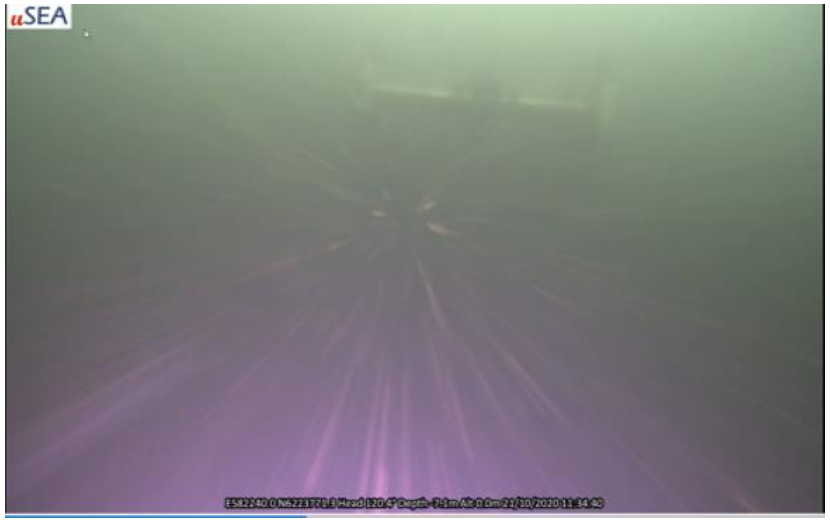



usea.hmp - EIVA Helmsman 4.6 * Master
File View Settings Tools Help
3D 2D S
EIVA
Project Tree
Filtered vessel position
USBL1 reference
ScanFish [TP311]
ScanFish
LAUV [TP308]
LAUV
NaviScan output position
Docking garage [Remote GPS 1]
Docking garage
RovControl
UseaViewNode
Image Camera Inner
Image Camera Outer
IPCameras
Palettes
Color modes
Live Data
SF to AUV distance
inner camera xte
Usbl xte
Views
Map View
Dashboard
Dashboard
Dashboard
Map View 1
Image Camera Outer Display
UseaViewNode
Distance
2.8
Properties
State
Runline <NONE>
Waypoint <NONE>
Current State Passive
Runline Mode Automatic
Navigating Colour 255, 255, 0
Surveying Colour 0, 139, 8
Track Creation
Create Track on Navigation/Sur False
Auto Start/Stop Surveying
Auto Start/Stop Surveying False
General
Visible True
Information
Show Name True
Colour 255, 255, 255
Position
Position ScanFish [TP311]: Position.Easting
Orientation
Heading ScanFish [TP311]: Heading
Roll ScanFish [TP311]: Roll
Pitch ScanFish [TP311]: Pitch
Track
Track True
Track Length 5 min
Track Settings
Runline
Select Runline
Image Camera Inner Display
Dashboard
dX_outer
-0,46 m
dY_outer
1,40 m
dZ_outer
-0,09 m
Dashboard
dX_inner
-
dY_inner
-
dZ_inner
-
E=589 194,29 m N=7 048 217,22 m Z=-6,97 m
Idle
12.17
24/06/2021
6:17:56
7:02:16

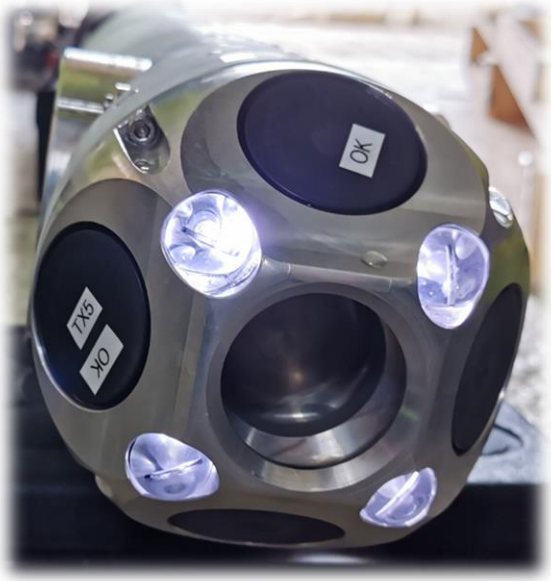
Lessons learned

Lessons learned

- Light pollution for image recognition
- Light patterns
- Stability between systems (AUV-Towhead)



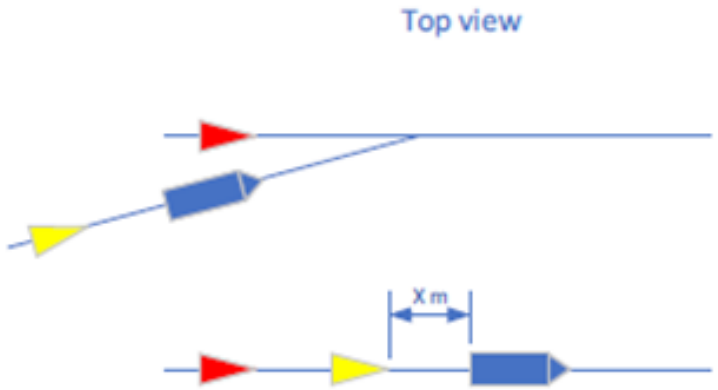
Depth	Sea state 3-4
7	X
13	X
20	X
30	X



Lessons learned

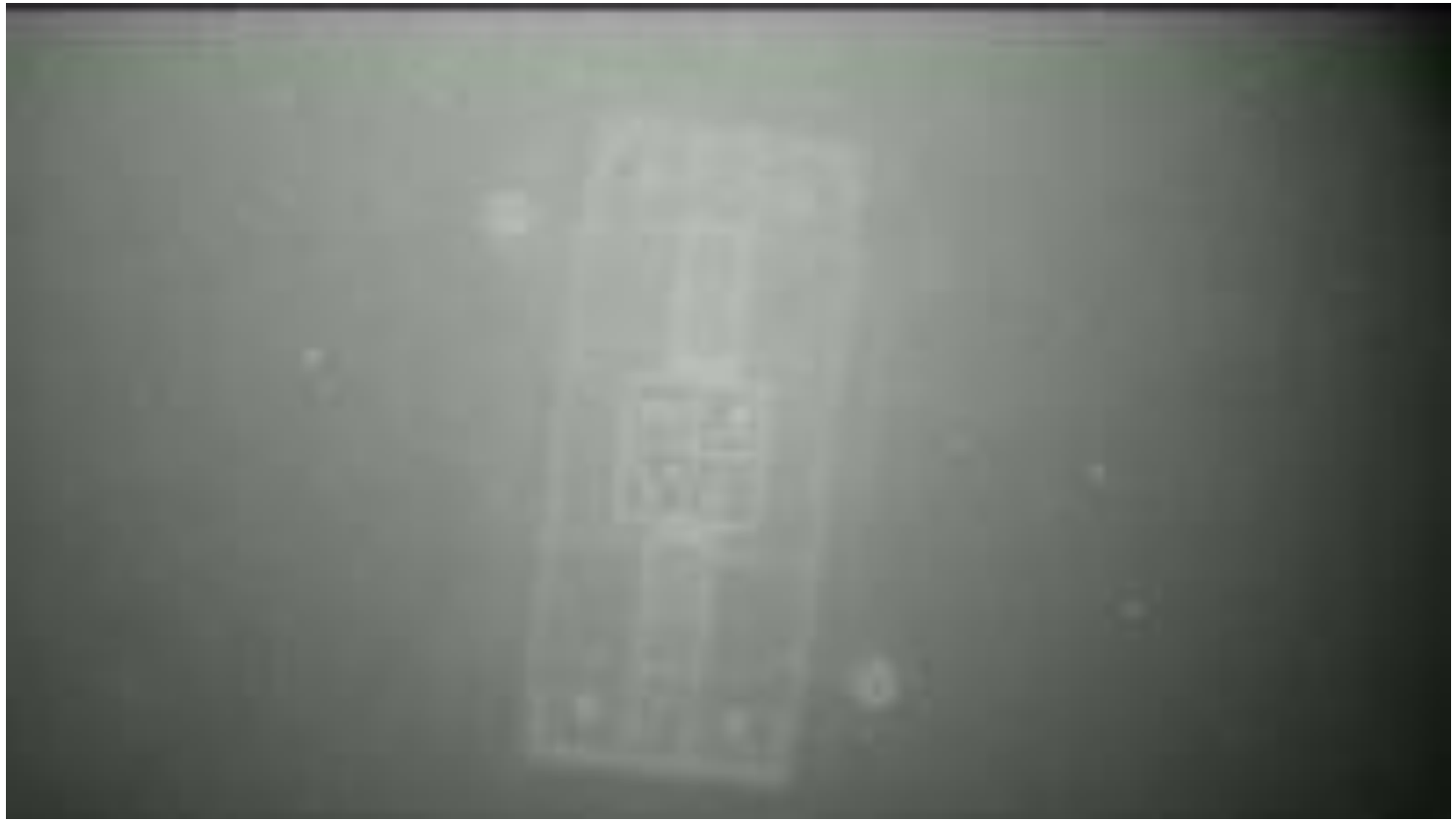
- Local USBL is redundant with global USBL and sonar
- Tuning of control algorithm
- Heat production from BMS integrated in AUV
- Heat production in inductive power transfer elements

- Vessel and Towhead not to operate above AUV
  - Overtake on the side
  - Close in by reducing speed and increasing layback



Autonomous Docking- visual*

- The experimental results of the Visual pose estimation



* Thomas Rannestad master thesis

Autonomous Docking- visual*

* Thomas Rannestad master thesis

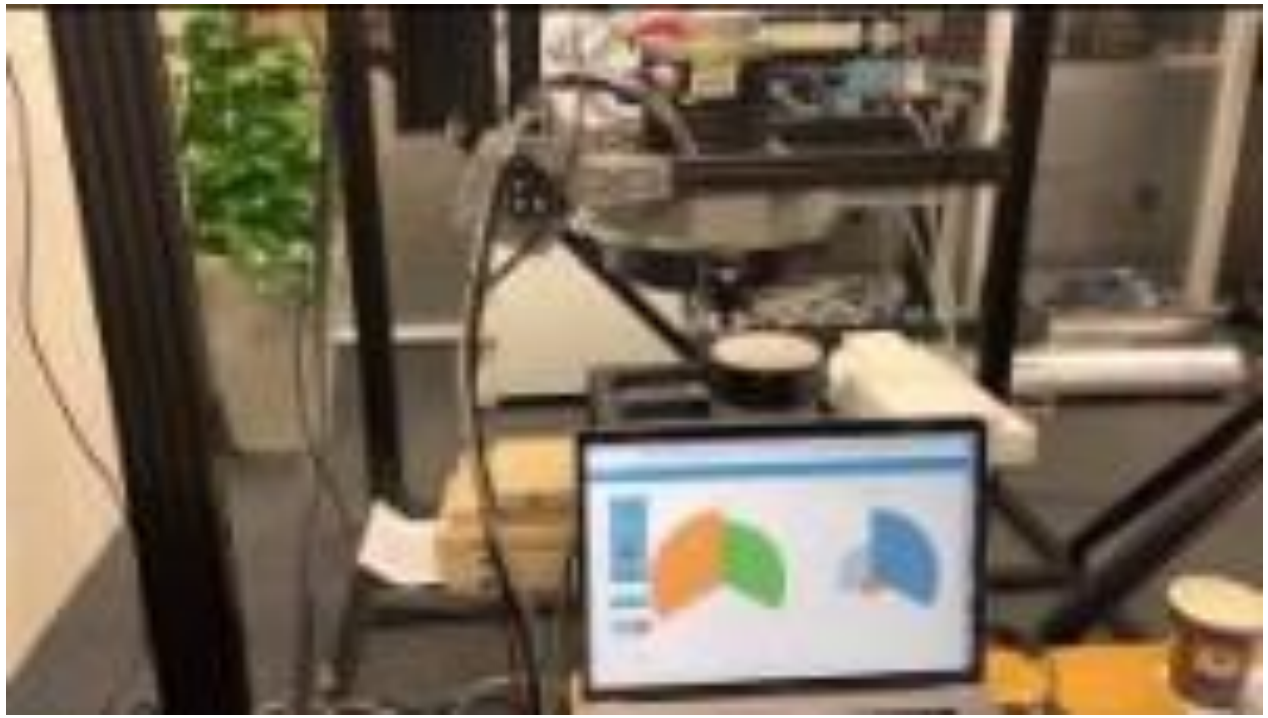
Autonomous Docking- visual*

- The occlusion docking experiment https://youtu.be/QDVo7W8UN_s

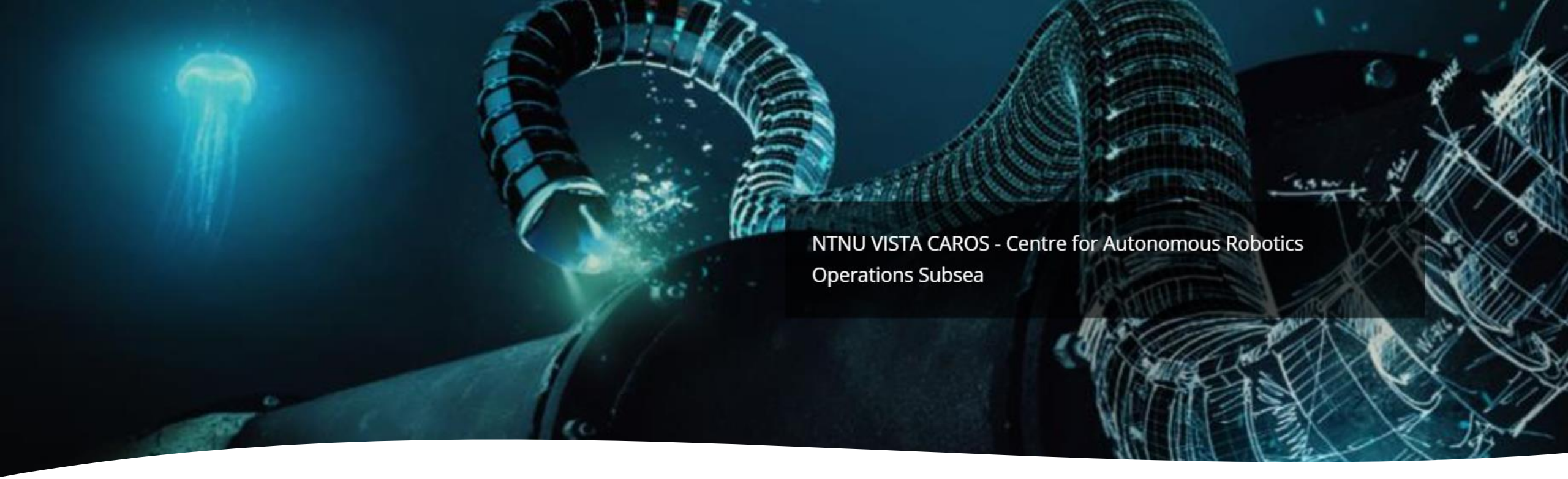
* Thomas Rannestad master thesis

Autonomous Docking final touch down –inductive*

- Final touch down – docking is hard to achieve with visual methods
- Markers are out of the camera field of view when close to the target (connector)
- Inductive method is used instead
  - Coil has 3/4 segments that can be used for “perfect” alignment



- Courtesy of:
- Bluelogic and Kjetil Eik - Equinor

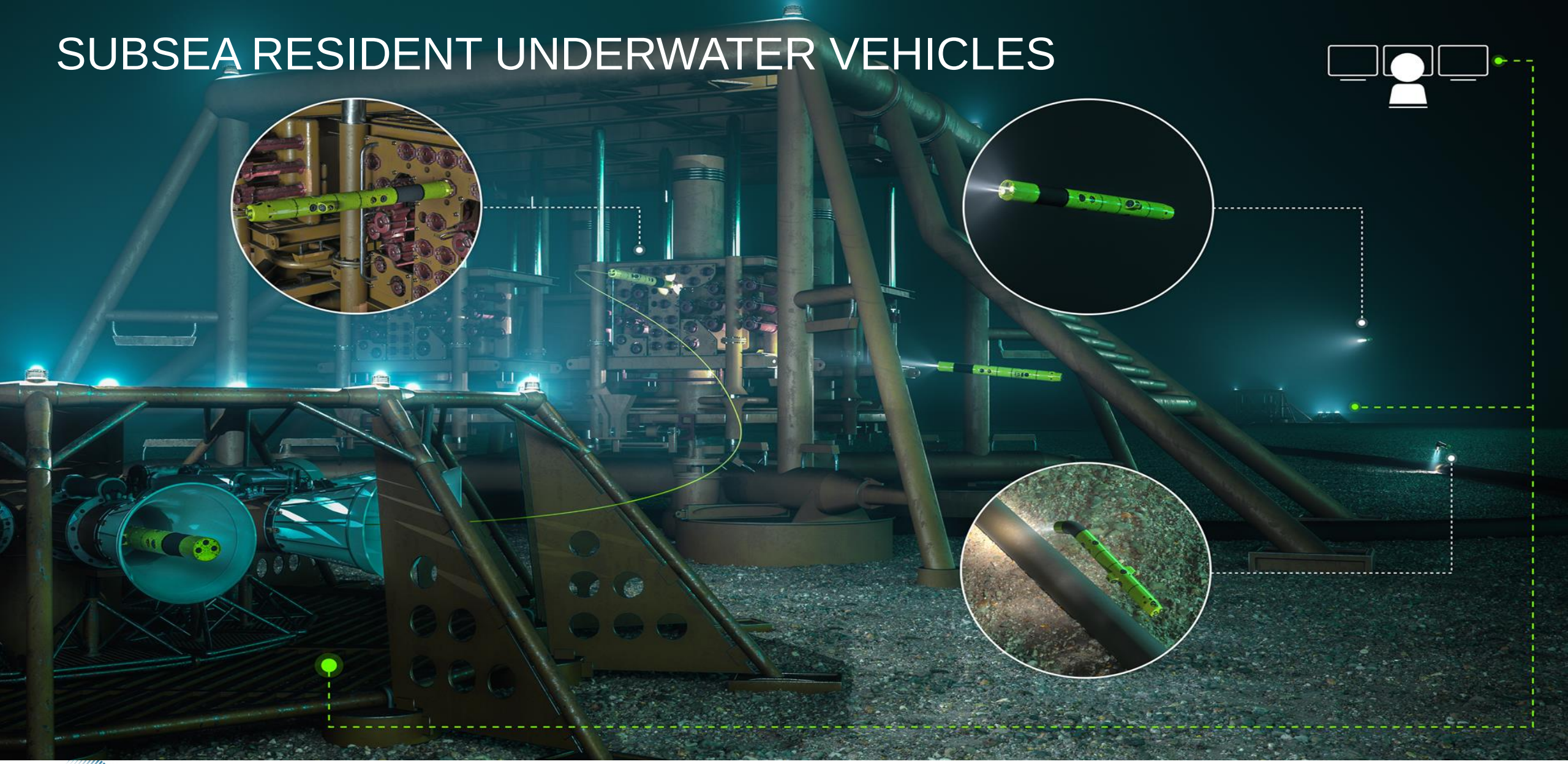


Research Industry

Caros - Equinor funded VISTA project

- Autonomous underwater robotic operations with focus on resident and collaborating AUVs supported by subsea docking systems for energy charging and communication.
- Autonomous docking and intervention operations, Coordinated control, Mission planning, Situation awareness, Testing and verification

SUBSEA RESIDENT UNDERWATER VEHICLES



VISTA

NTNU-VISTA Centre for Autonomous Robotic Operations Subsea (CAROS)

Det Norske Videnskaps-Akademi
The Norwegian Academy of Science and Letters

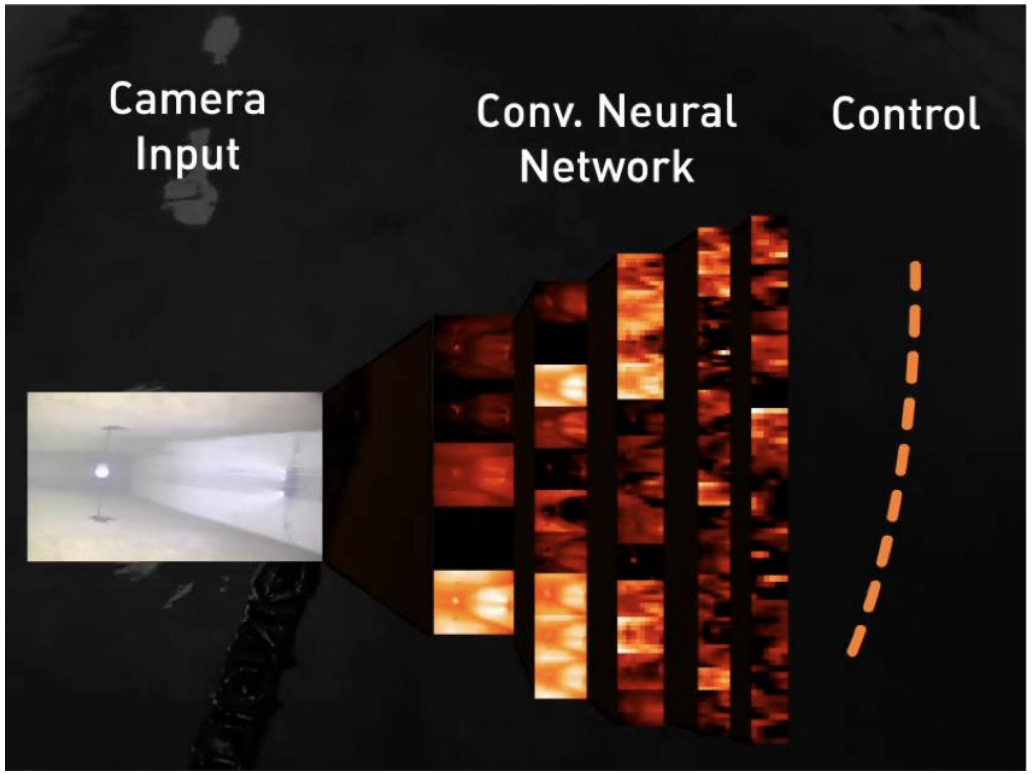
equinor

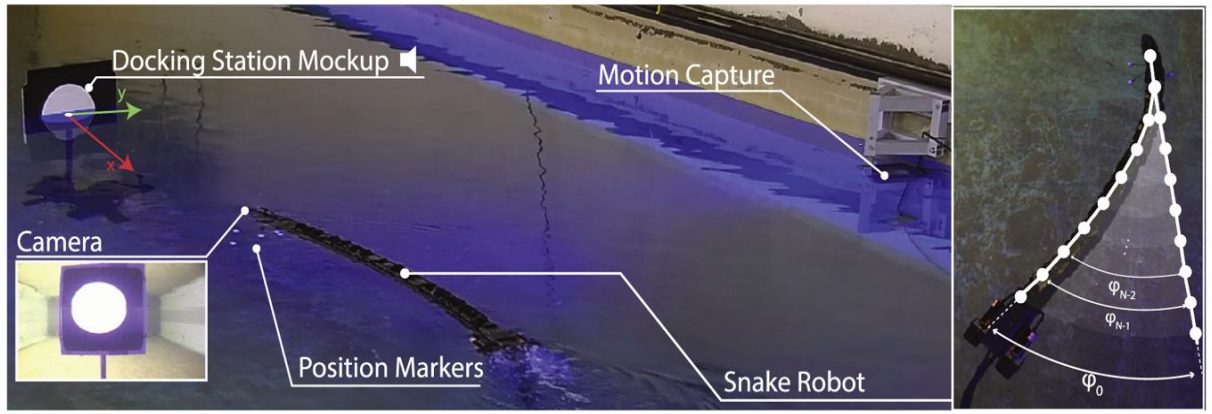
NTNU
Norwegian University of Science and Technology

DOCKING AN AUV USING A CNN

WP1 Autonomous docking and intervention operations

Project manager: Professor Kristin Y. Pettersen





Preliminary results:

A. Sans-Muntadas, E. Kelasidi, K.Y. Pettersen and E. Brekke, "AUV guidance and docking using a convolutional neural network", IFAC Journal of Systems and Control, Vol. 8, June 2019.

VISTA

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The Norwegian Academy of Science and Letters

equinor

NTNU
Norwegian University of Science and Technology

Relevance for the conference

- Residency and docking are essential functionalities for long-term deploy.
- Convenient easy-to-access testing polygon for variety of inspection or intervention tasks and technology testing at relevant depths in controlled in-shore environment
- State-of-the-art Remot Oper. Center for real-time monitoring of activities
- Affordable access - infrastructure development supported by Equinor and RCN and operated by NTNU

OceanLab Subsea site:

- Antonio Vasilijevic antonio.vasilijevic@ntnu.no
- Martin Ludvigsen martin.ludvigsen@ntnu.no

Thank you!

AURLab
Applied Underwater Robotics Laboratory

AMOS NTNU OCEAN SPACE CENTRE equinor

Development of a secure, interoperable and highly scalable standard for underwater acoustic communications

Prof Jeff Neasham, Tom Corner, Dr Ben Sherlock, Newcastle University

Dr Jon Davies, Paul Randall, Sonardyne

Alex Hamilton, Jack Barnett, Amy-Mae Hobbs, DSTL

Overview of presentation

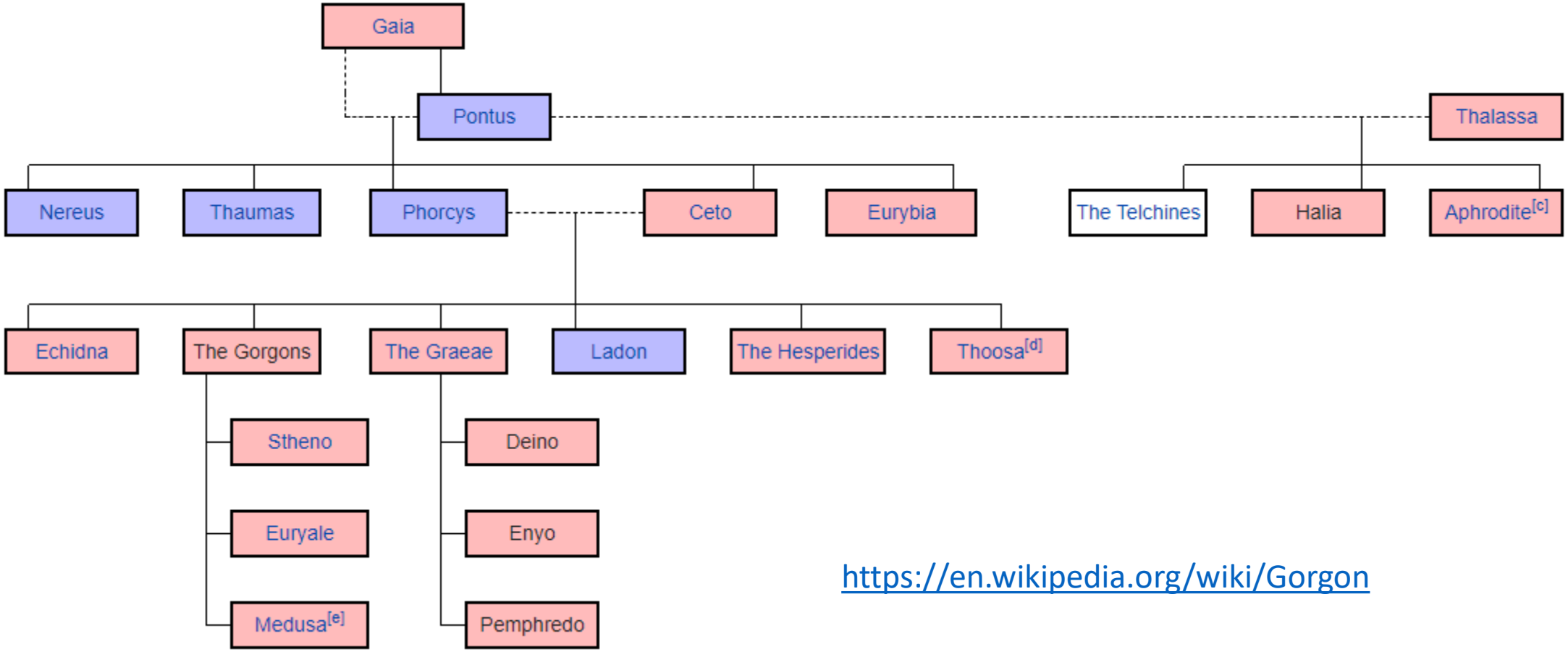
- Motivation and requirements.
- PhorcysV0 waveform architecture and design.
- Development of MATLAB reference chain.
- Development of enhanced receiver with adaptive space-time processing.
- Field test results in 3 frequency bands/ranges:
  - 20 – 28 kHz band for short range (Plymouth Sound)
  - 20 – 28 kHz and 8-12 kHz for short and medium range (North Sea)
  - 800 – 1500 Hz for long range (Mediterranean).
- Applications in marine robotics

Phorcys - overall motivation and philosophy

- Interoperability via an open standard - building on the JANUS philosophy (https://www.januswiki.com/).
- Waveform and protocols to meet UK MoD requirements:
  - High scalability in frequency, range, message size, modem size, weight and power (SWAP).
  - In-built security via waveform (TRANSEC) and data encryption (COMMSEC).
  - Must support high tempo comms and positioning/situational awareness.
- Avoid reliance on any one company's proprietary technology.
- Encourage competition and innovation among suppliers.

PHORCYS

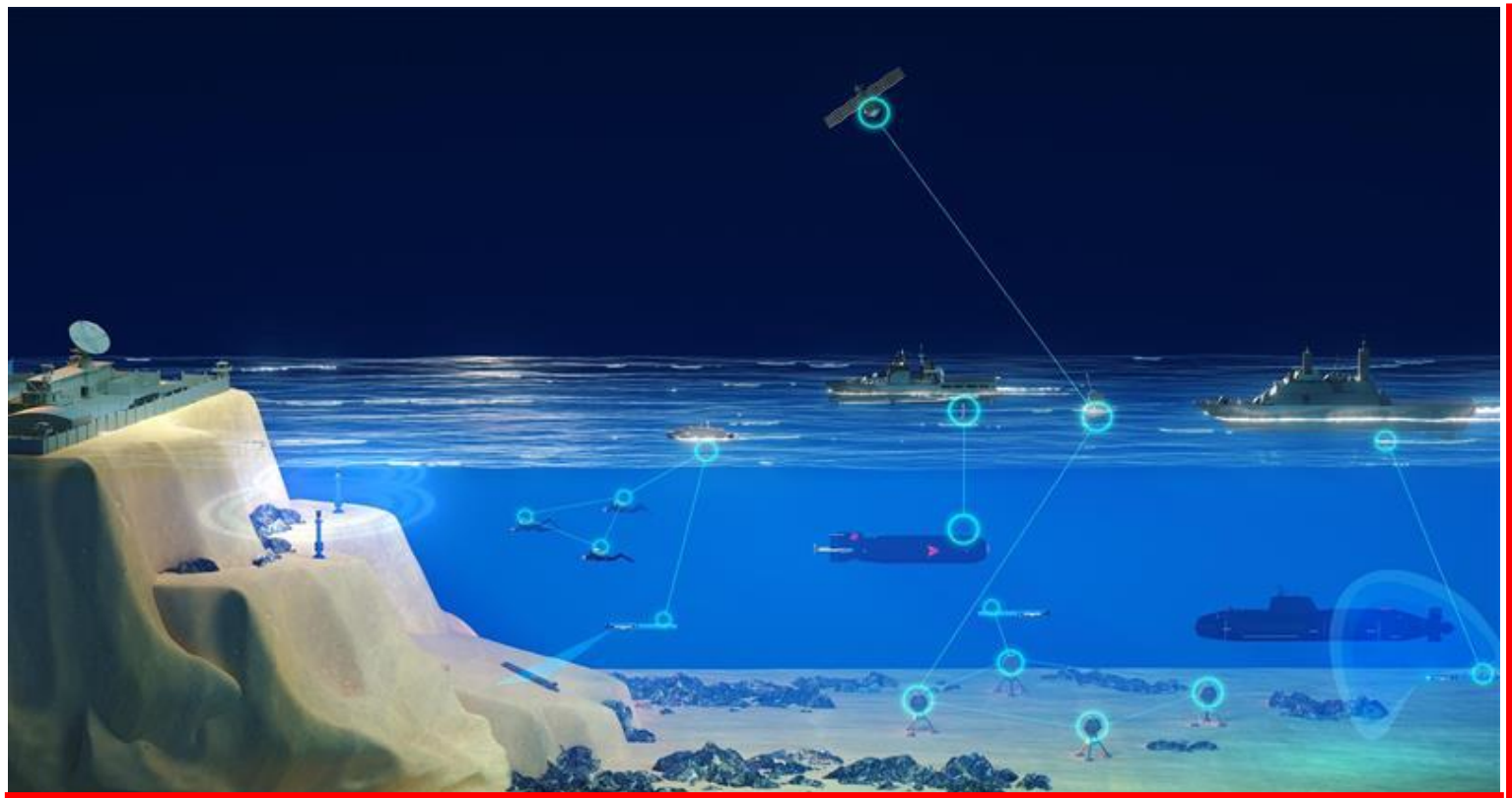
In case you're wondering….



https://en.wikipedia.org/wiki/Gorgon

PHORCYS

Defence Tactical ACOMMS - Challenges & Enablers



KEY Enablers

OPEN MULTIBAND SECURE WAVEFORMS ARCHITECTURES & PROTOCOLS

SOFTWARE DEFINED MODEM TECHNOLOGY (SDM)

C3 Challenges

Physics!

Information Security!

Platform Diversity

- Surface Ship, Submarine [**LARGE-Multibeam**]
- XLUUV, UUV,
- USV,
- ROV,
- Seabed Systems,
- Divers [**SMALL-Omni**]

Competing End User Requirements

- SWAP - Size /Weight/Power vs RANGE
- Data Rate / Networking / Multi-user
- Situational awareness (TEL + NAV)
- LPD/LPI/LPE - "Covertness"

PHORCYS

Phorcys Waveform Design Aims

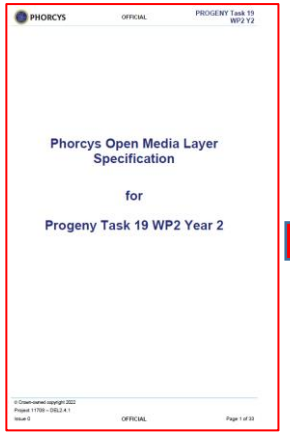
	Progeny Task19 Output		In development
Requirement	**Stheno**	**Eurayle**	**Medusa**
Range	Up to 3 NM	2 – 15 NM	20-100 NM
Environment	Shallow littoral (Less than 20m depth)	Littoral (less than 200m)	Deep-Littoral
#Nodes	Up to 40	Up to 10	Less than 10
Data rate	1-500bps 1200bps	1-250 bps 500bps	TBC (< 10bps)
Centre frequency	24 kHz	10 kHz	TBC (< 2kHz)
Bandwidth	8 kHz	4 kHz	TBC (< 1kHz)
Latency	< 1 minute	< 1 minute	TBC
H/W Complexity / SWAP	Low	Medium	Large DI Arrays
Message Types	Pre-canned Messaging. Arbitrary binary data packets (e.g., pre-formatted text, free text, highly compressed voice)		Pre-canned Messaging, Tactical Paging, Limited Text
Source level	180 dBre1μPa @1m (Diver limited)	190-195dBre1μPa@1m	TBC
Transducer directivity	Up to 6 dB (vertical plane only)	10-15 dB on large platforms	TBC
Modulation	Coherent MOS-PSK[1]	Coherent MOS-PSK	Incoherent MOS TBC
Secure	Yes (PCIS[2])	Yes (PCIS)	Yes (PCIS)

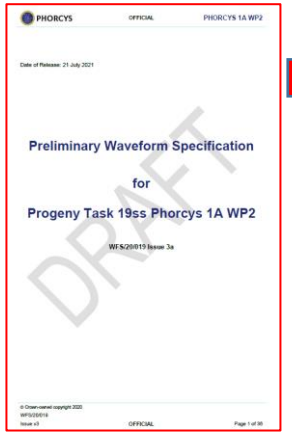
1 Mary Orthogonal Signalling – Phase Shift Keying
2 Phorcys Cryptographic Interoperability Standard

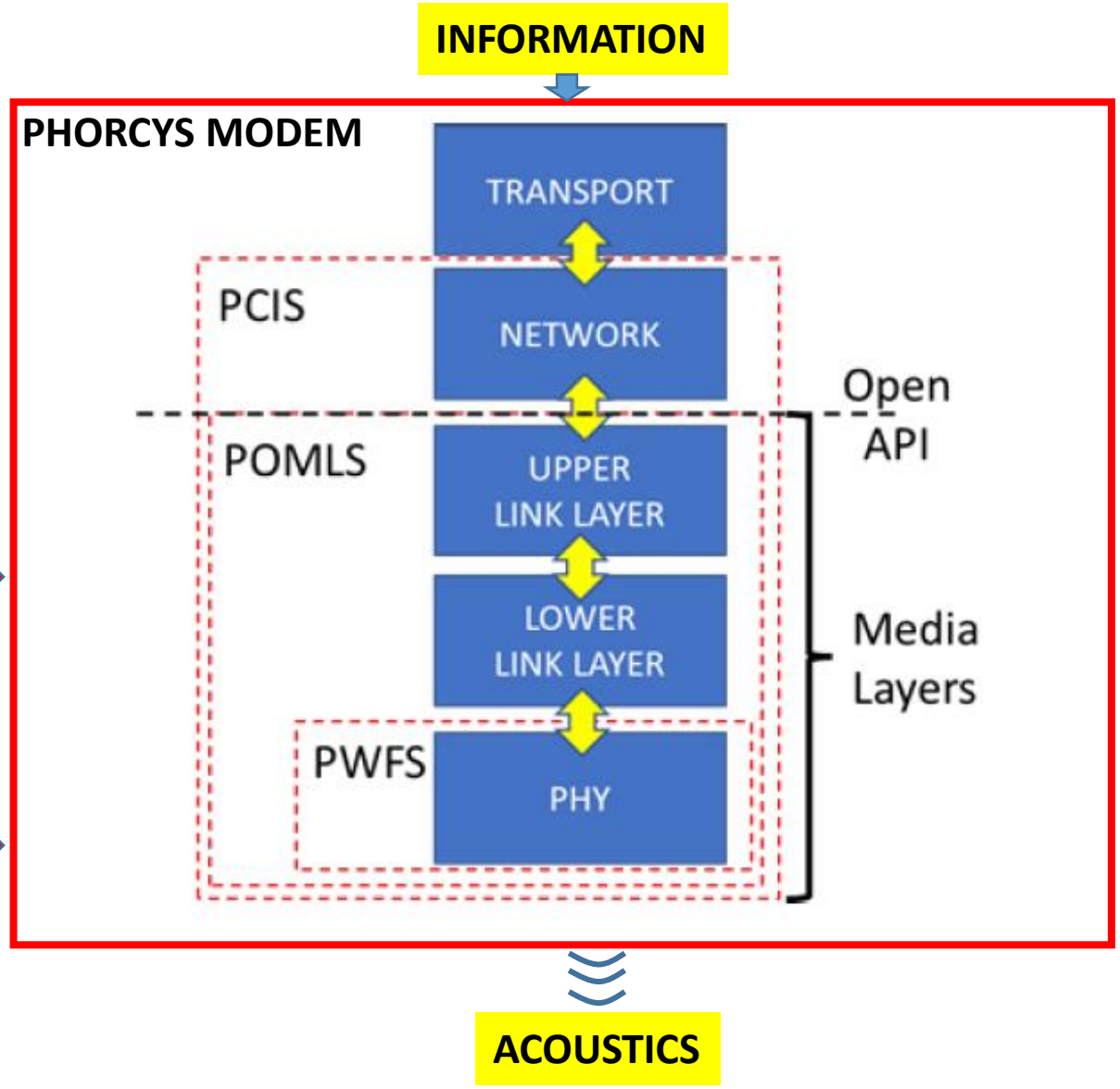
- **Multi-band (SWAP vs range)**
  - LF (MEDUSA)
  - MF (EURYALE)
  - HF (STHENO)
- **Open Waveforms & Protocols**
  - **Coherent** (Stheno/Euryale)
    - DSSS-CDMA addressing (efficiency/flexibility)
    - DSSS-MOS Modulation (performance/efficiency)
    - Adaptive receiver structures (performance)
  - **Incoherent** (Medusa)
    - Detection at v low SNR (Energy integration)
    - Reduced Complexity (Doppler & beam search)
- **Waveform future Scalability**
  - Future bandwidth efficient modulation and coding technologies (MPSK/OFDM)
  - Future adaptive LINK protocols

PHORCYS

Phorcys Waveform Design & Open Architecture





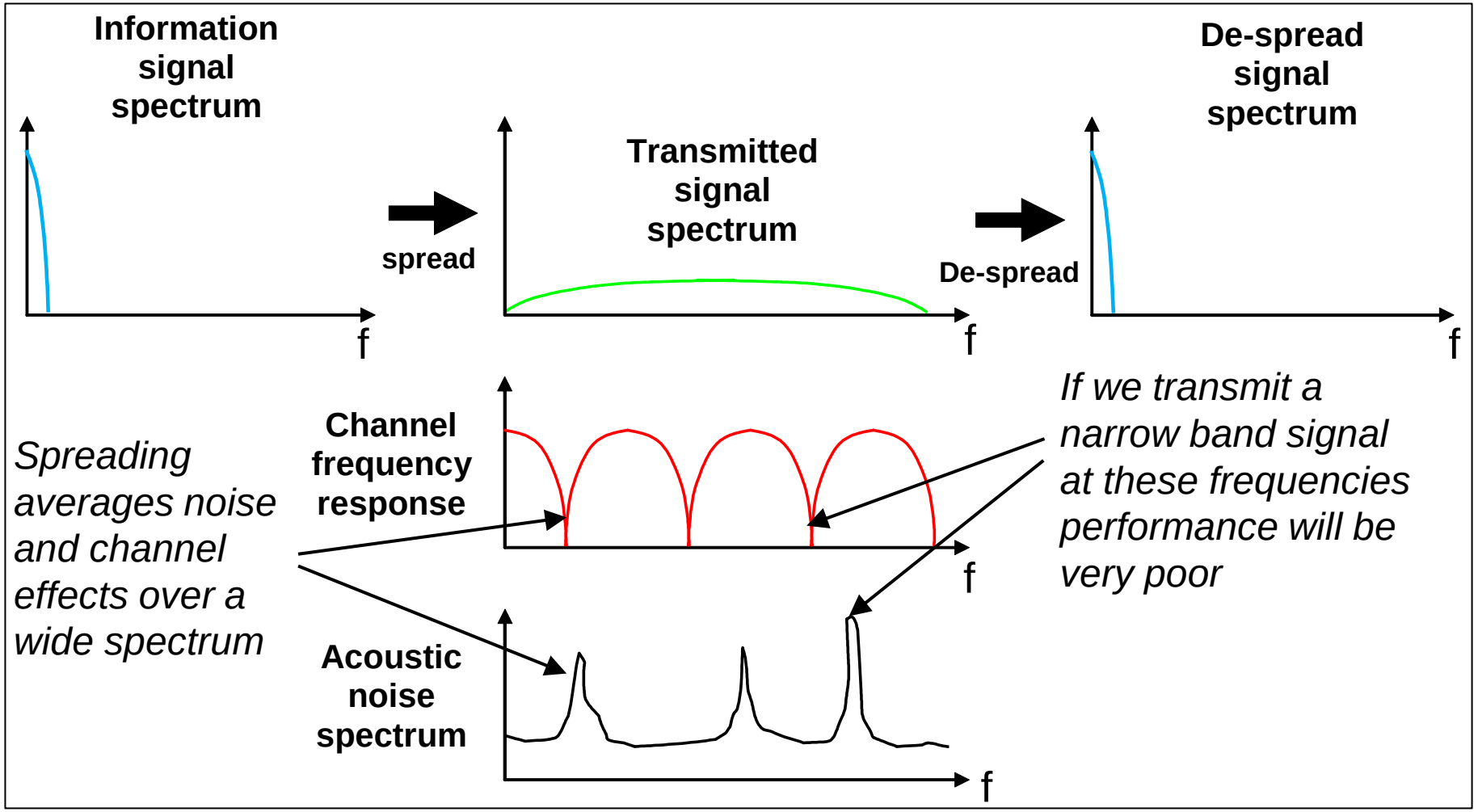


- Open (UK MOD owned)
  - PWFS
  - POMLS
  - PCIS
- Secure
- Extensible Waveforms
  - Flexible waveform architecture (PWFS)
- Extensible protocols
  - Open architecture (POMLS)
  - Open interfaces

Phorcys 1A - OFFICIAL

PHORCYS

Some spread spectrum communication theory



- Common spreading methods:
  - Pseudo random codes (DSSS)
  - Frequency hopping
  - Frequency sweep (chirp)
- All aim to decorrelate/reject multipath (echoes)
- Phorcys uses DSSS for noise like character.

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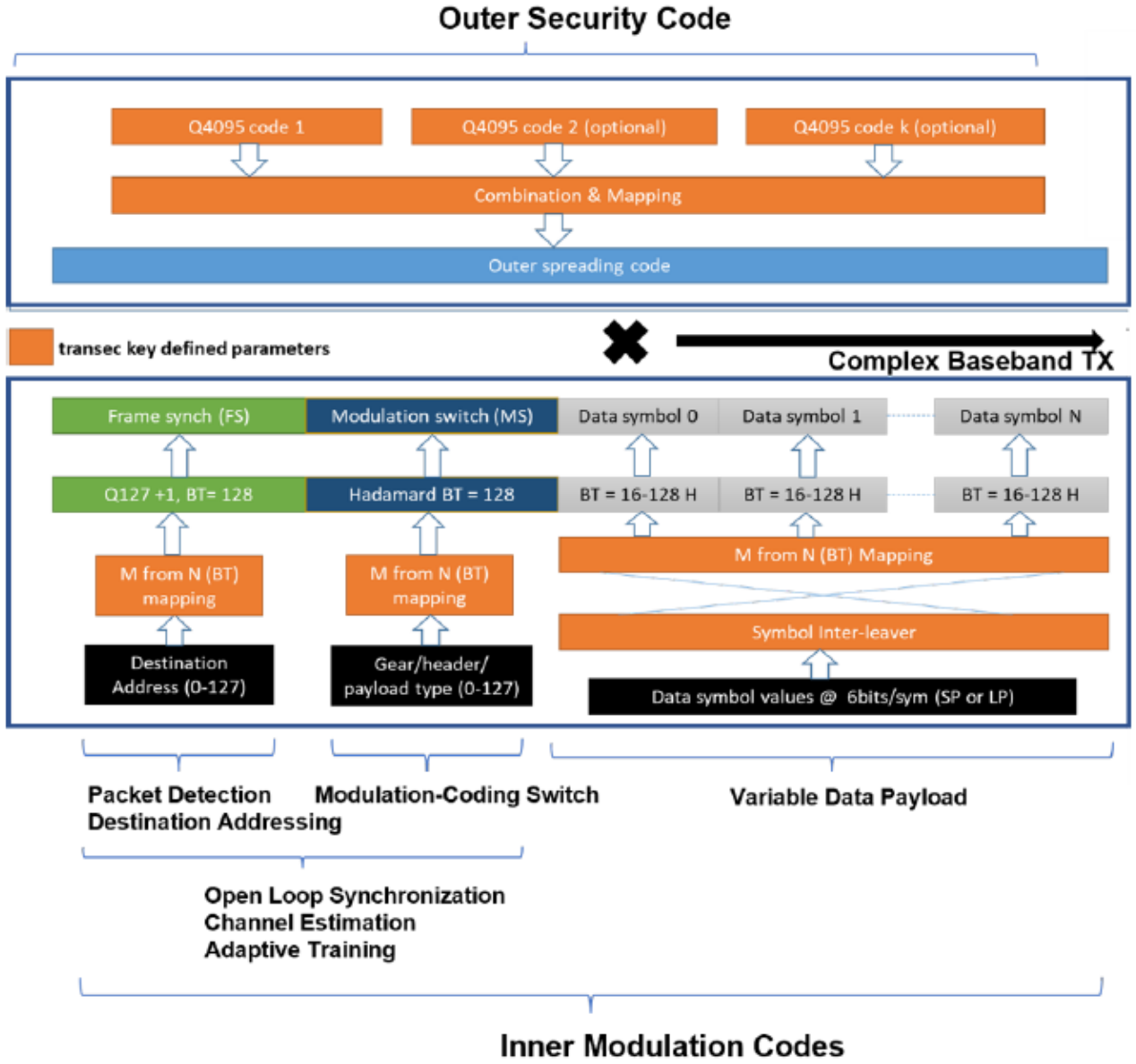
Phorcys MOS Coherent Packet Structure (Phorcysv0)



- **Coherent M-ary orthogonal signalling**
  - Common baseband waveform architecture
  - Scalable to multiple bands
- **Detection/Frame Synchronisation (FS)**
  - Waveform level addressing via 128 quadriphase codes.
  - Unicast, multicast and broadcast addressing.
  - Enables high precision TOA / DOA estimation (nav).
- **Modulation Switch (MS)**
  - 128 orthogonal Hadamard codes (7 bits)
  - Proven reliability
  - Switches modulation and data payload at receiver.
- **Flexible Data Payload (DP)**
  - 64-MOS-PSK (6 bits per code) modulation with variable spreading ratio (BT) from 16 – 128.
  - Future high data rate modes (e.g. M-PSK,OFDM)
- **Outer spreading/security code (OSC)**
  - Quadriphase code de-correlates multipath.
  - Scrambles waveform – hard to exploit without knowing spreading code.

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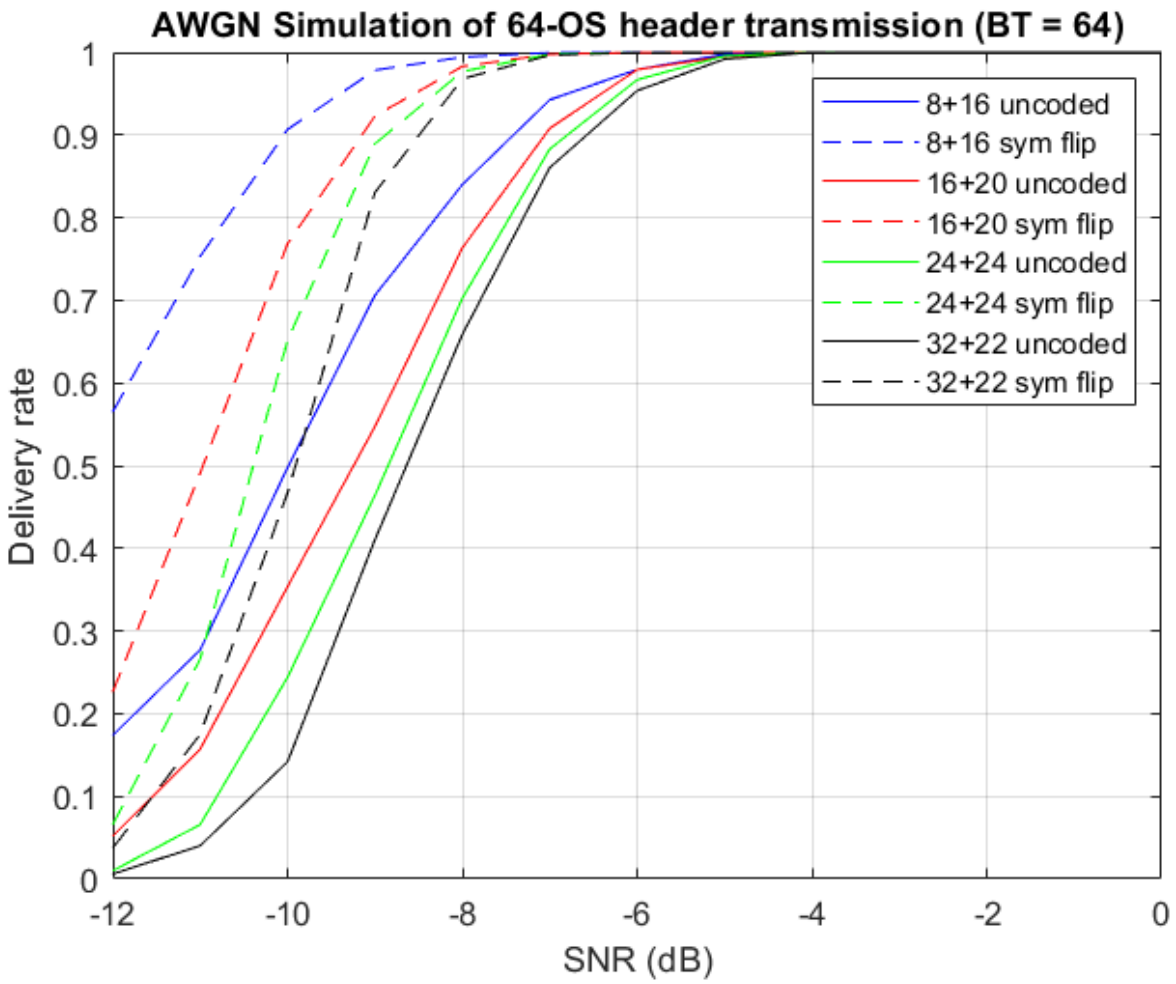
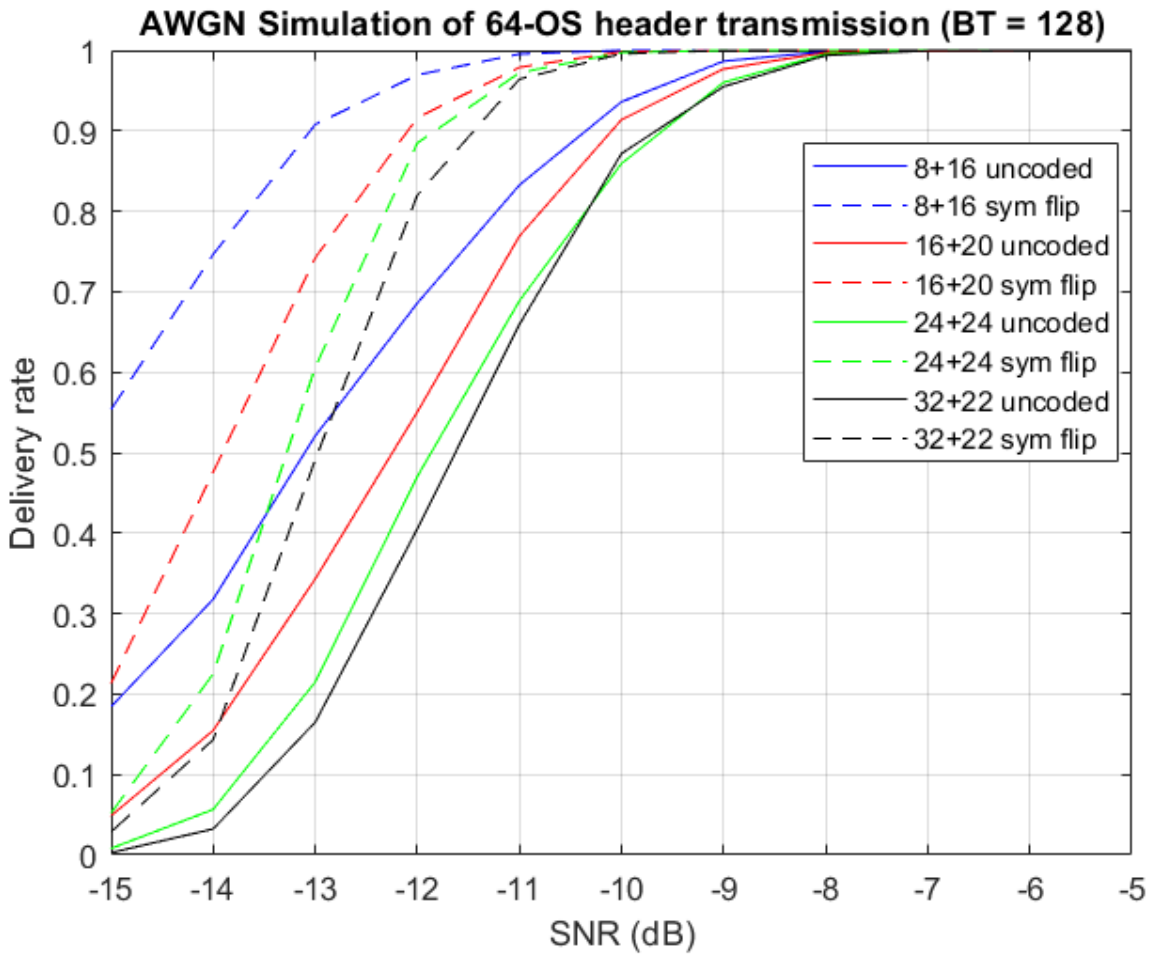
Example simulation - 64-OS short packets



64-OS, BT = 64 (750 bps)



64-OS, BT = 128 (375 bps)

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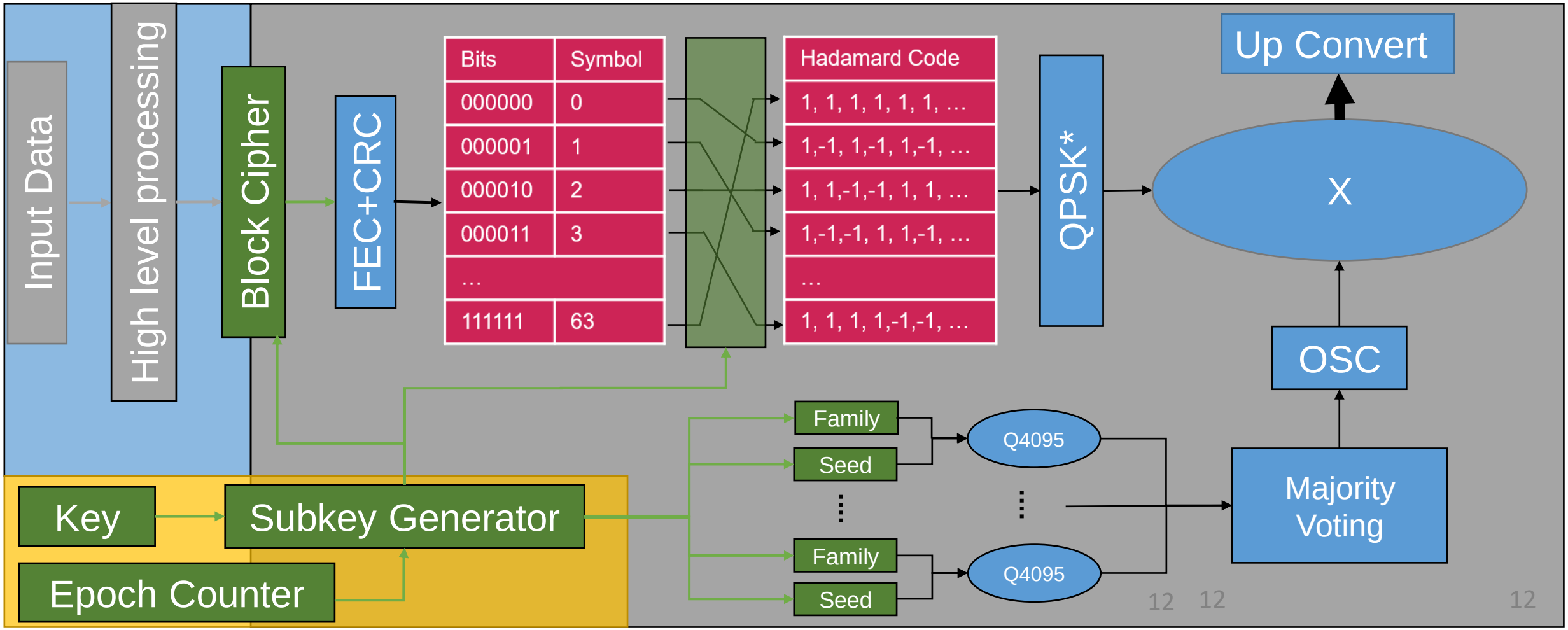
Defined packet/data rate values

- 32 out of 128 MS values are currently defined in Phorcys V0
  - 4 short packet (SP) formats – 2, 3, 4 and 7 payload bytes
  - 4 long packet (LP) formats – 16, 32, 64 and 128 payload bytes
- 4 spreading ratio (BT) values of 16, 32, 64 and 128
  - Trade off data rate/packet duration for reliability in sever channels.
- Data throughput up to 1620 bps on 32 byte packets.
- Packet durations as short as 44 ms for 2 byte packet (brevity is also good for security!)

PCIS – providing ~256 bits of security

Data Layer (COMMSEC)

Physical Layer (TRANSEC)



+ → Phorcys Cryptographic Interoperability Specification (PCIS)

+ → Phorcys V0 waveform specification

Phorcys 1A - OFFICIAL

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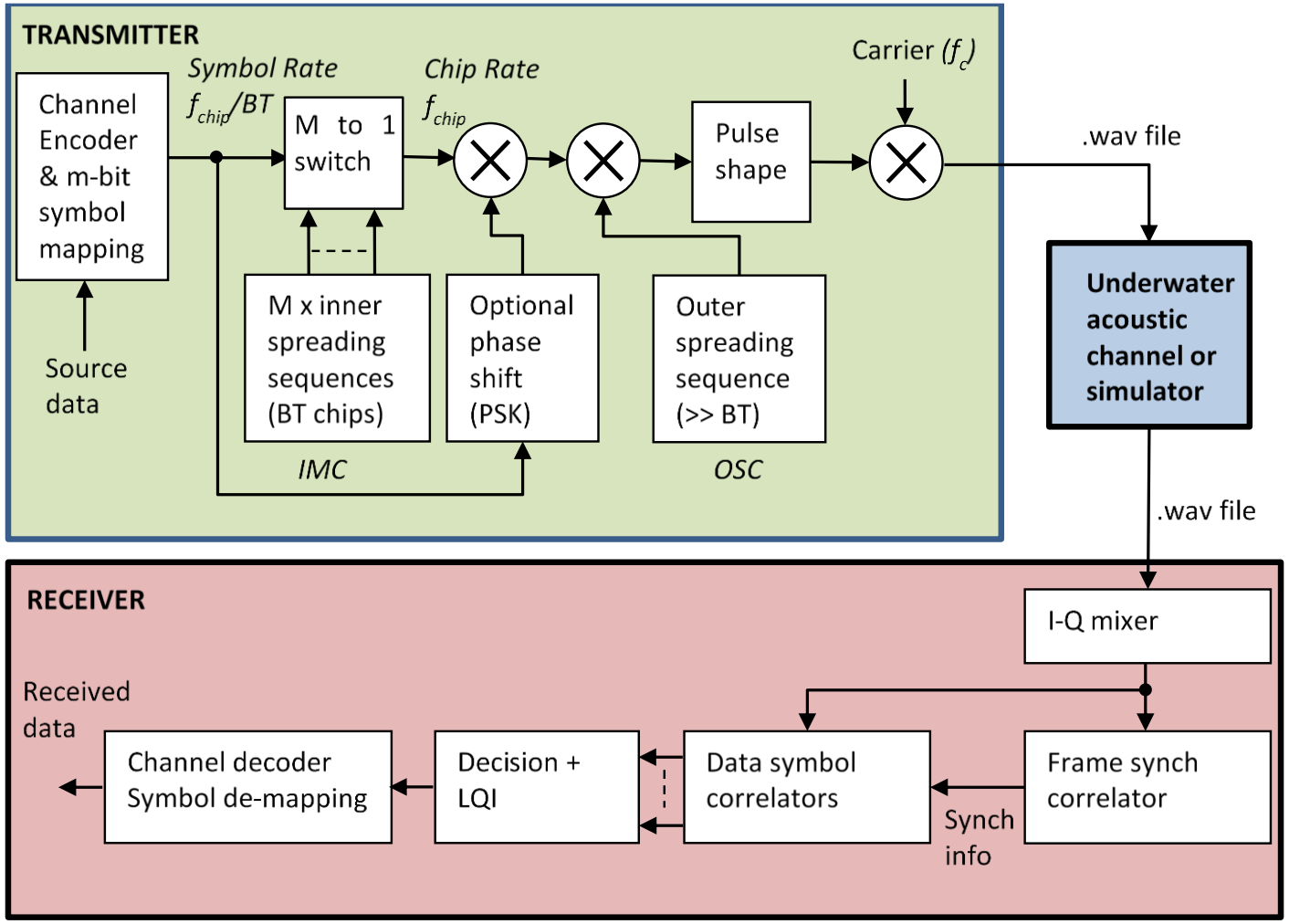
PhorcysV0 Reference chain



- Simplest possible Rx structure for Phorcys.
- Developed as MATLAB and C++ reference code.
- Real-time Tx/Rx demonstrated by C++ code running on Sonardyne hardware.
- Also ported to 3rd party modems (e.g. Popoto).
- Very effective at high BT but has limitations for low BT and severe channels.

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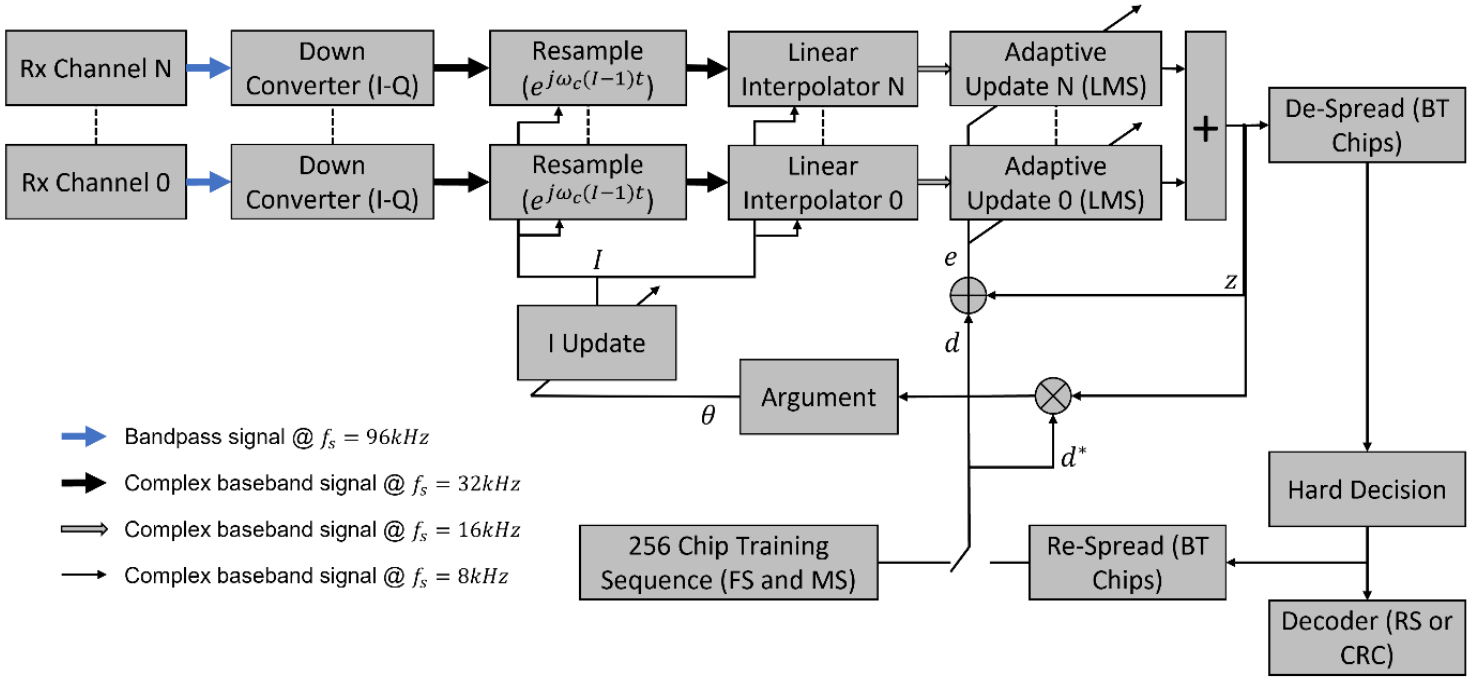
Enhanced adaptive receiver



- Adaptive equalisation combines short delay multipath energy before dispreading.
- Multichannel option for beamforming / diversity arrays.
- Closed-loop Doppler compensation by resampling.
- Uses existing FS + MS for training sequence.

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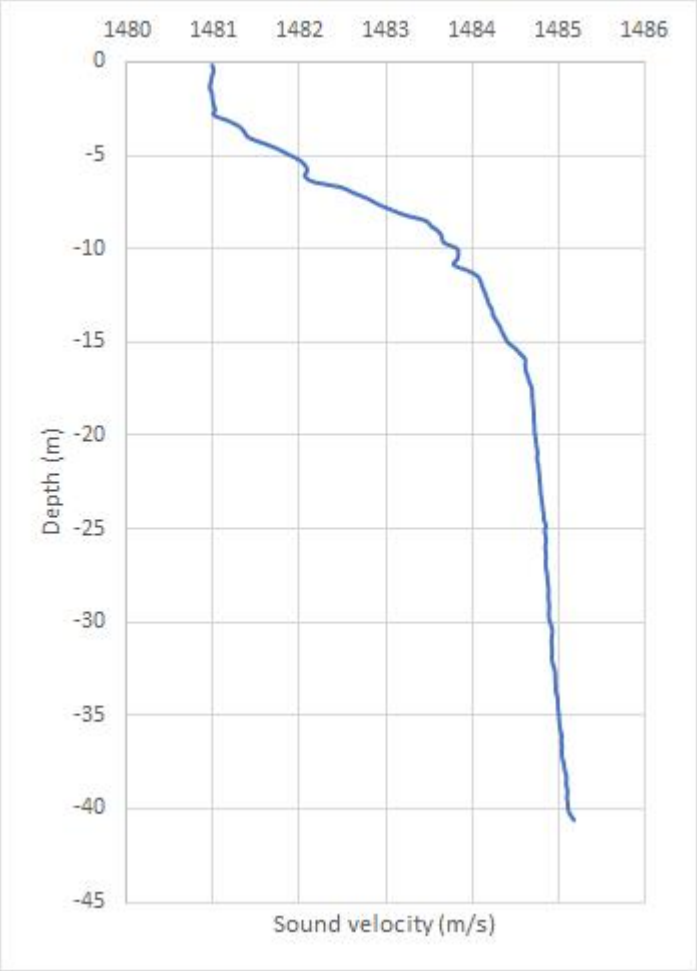
Test signal parameters

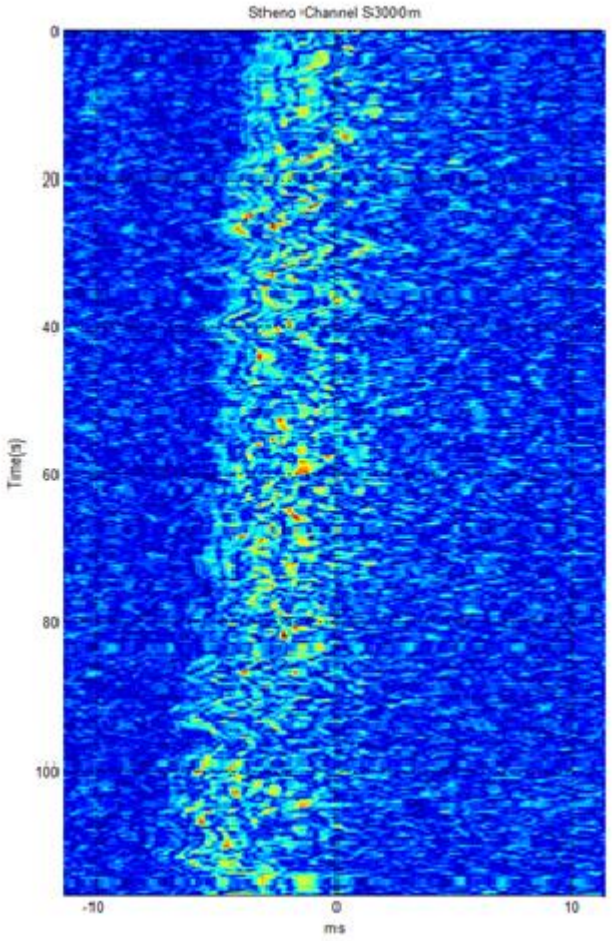
- Short packets of 3 data bytes with duration from 48 ms (Stheno) to 1.8 s (Medusa)
- Long packets of 32 bytes with duration 0.158 s to 11.89 s.
- Maximum throughput = 1620 bps (compressed speech?)

MS	BT	d	Stheno T/bps	Eurayle T/bps	Medusa T/bps
8	16	3	0.048 / 500	0.096 / 250	0.549 / 44
9	32	3	0.064 / 375	0.128 / 188	0.731 / 32.8
10	64	3	0.096 / 250	0.192 / 125	1.097 / 21.9
11	128	3	0.16 / 150	0.32 / 75	1.829 / 13.1
20	16	32	0.158 / 1620	0.316 / 810	1.806 / 142
21	32	32	0.284 / 901	0.568 / 451	3.211 / 78.8
22	64	32	0.536 / 478	1.072 / 239	6.126 / 41.8
23	128	32	1.04 / 246	2.08 / 123	11.89 / 21.5

North Sea Trial (January 2021)

- Omnidirectional Tx, omnidirectional Rx at 6m submersion.
- 30 - 60 m water depth
- 2 frequency bands:
  - Stheno: 20-28 kHz, SPL = 180 dB (8 W), range up to 5 km, Tx @ 7 m depth
  - Euryale: 8-12 kHz, SPL = 185 dB (26 W), range up to 20 km, Tx @ 14 m depth
- Upward refracting propagation with severe time varying multipath and low channel coherence.
- Packet delivery rate compared with detected packets (upper bound) for simple reference receiver (std) and enhanced adaptive receiver (AE).





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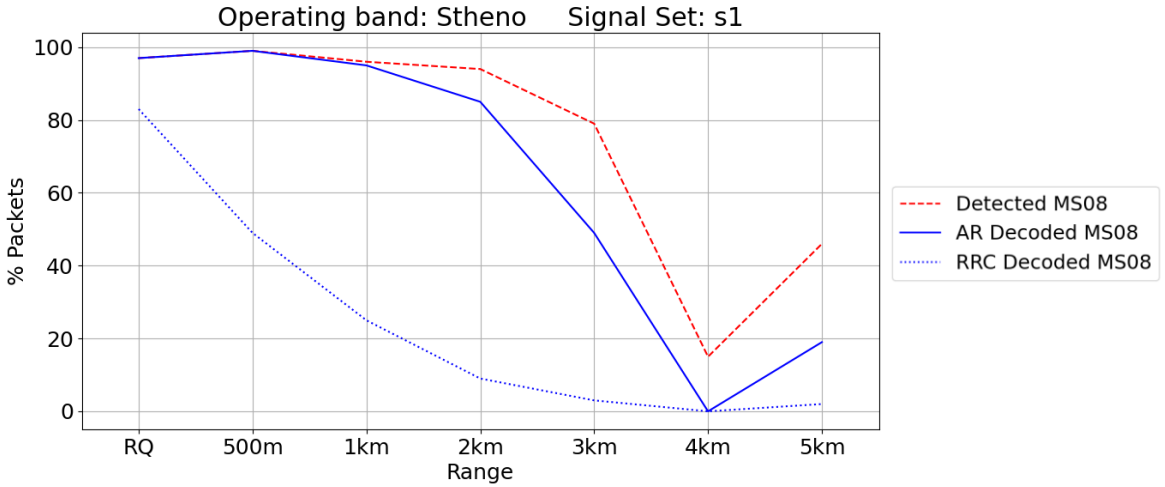
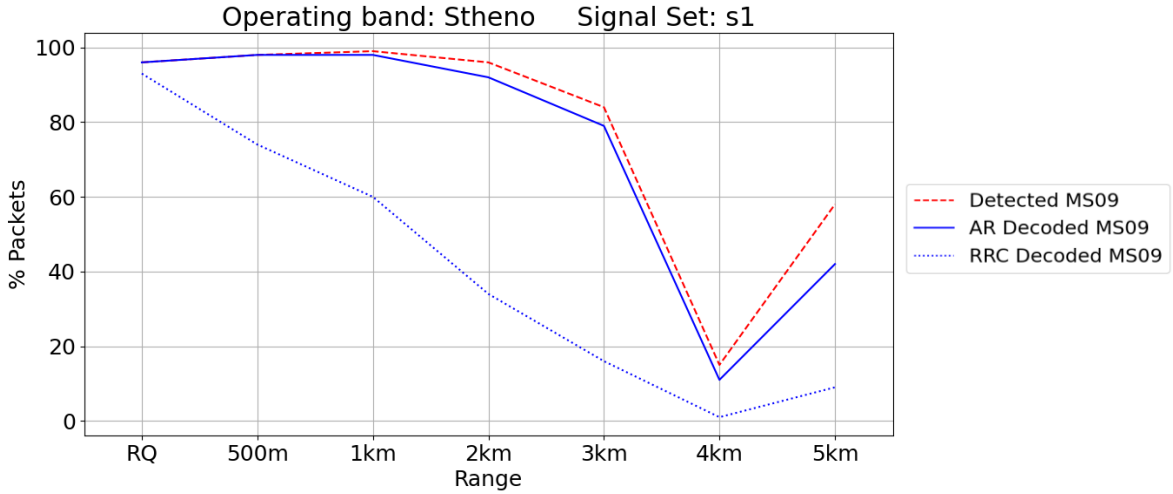
North Sea trial Data (Stheno band 20-28 kHz)

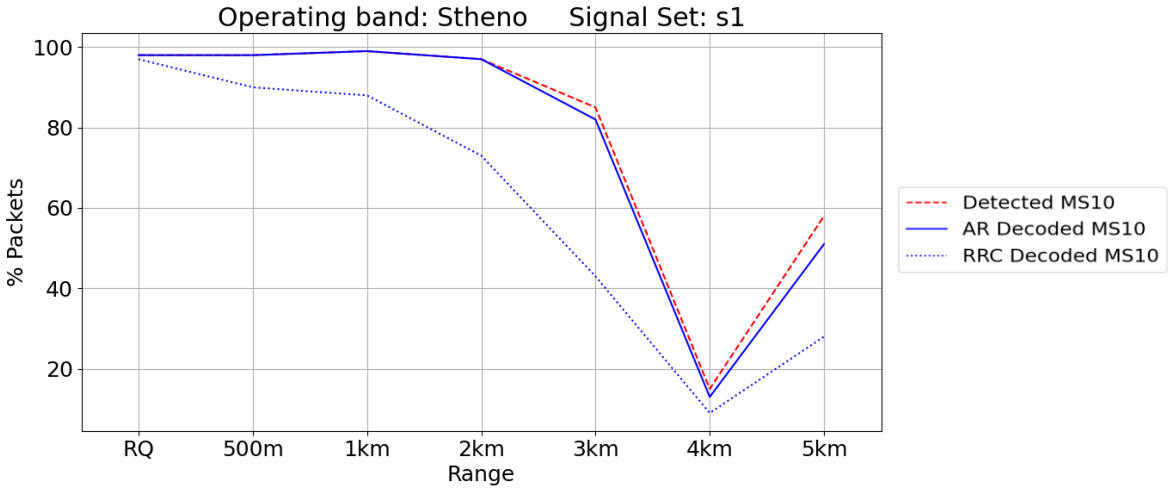
3 byte payload, 48 ms, 500 bps throughput



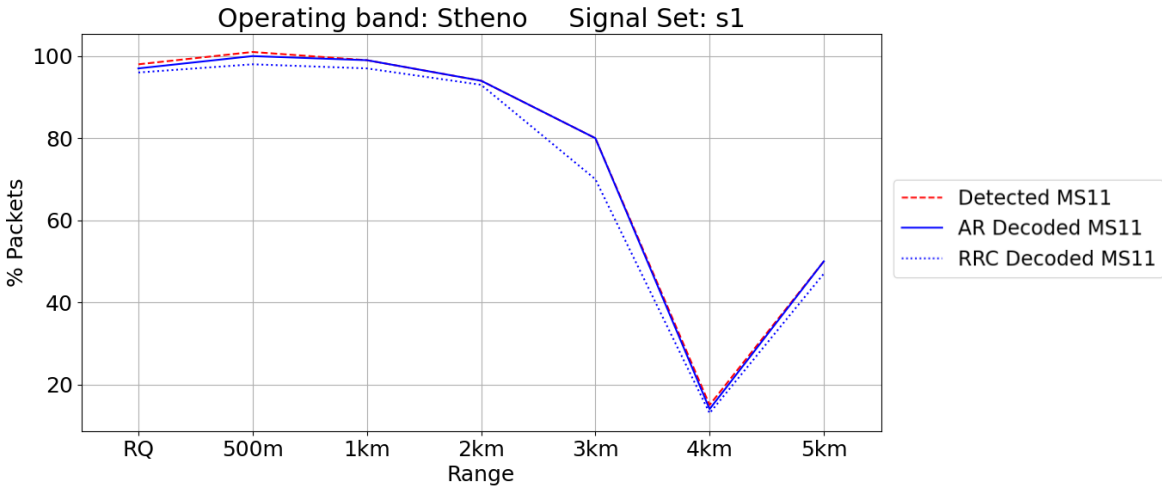
3 byte payload, 64 ms, 375 bps throughput



3 byte payload, 96 ms, 250 bps throughput



3 byte payload, 160 ms, 150 bps throughput



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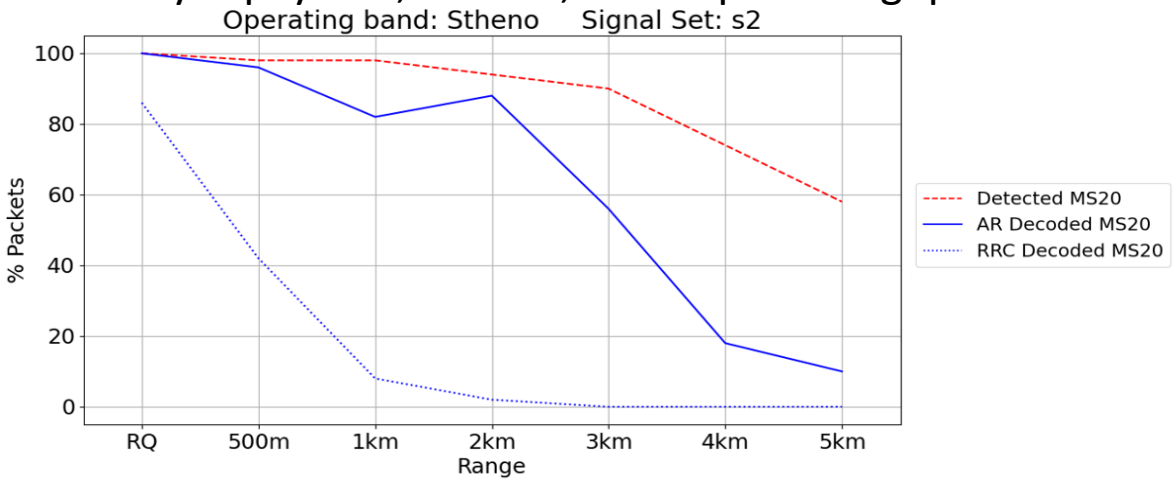
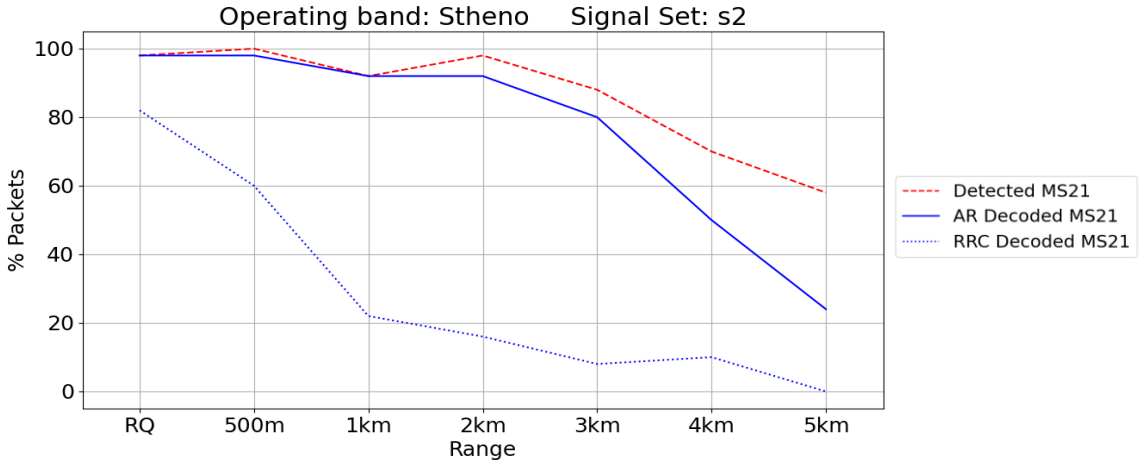
North Sea trial Data (Stheno band 20-28 kHz)

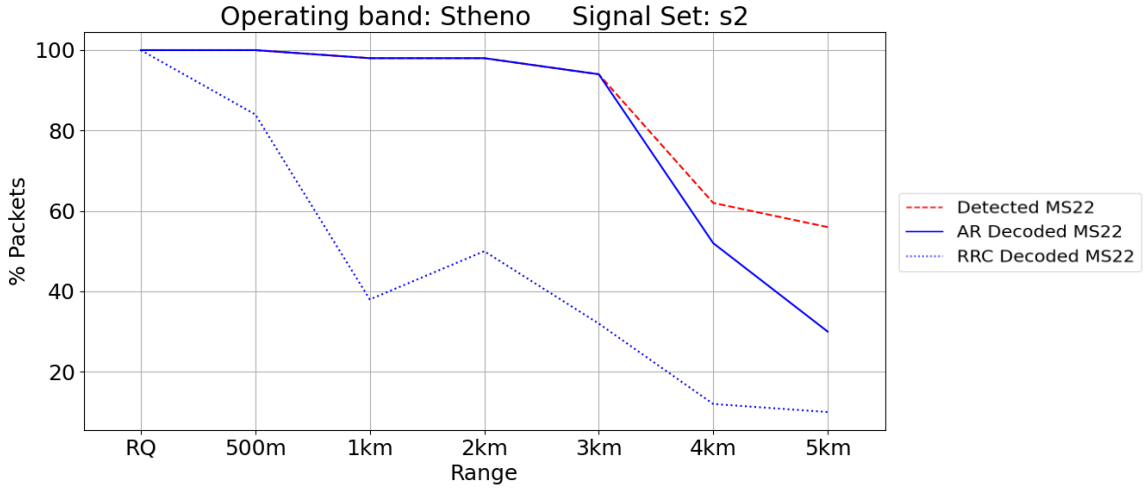
32 byte payload, 158 ms, 1620 bps throughput



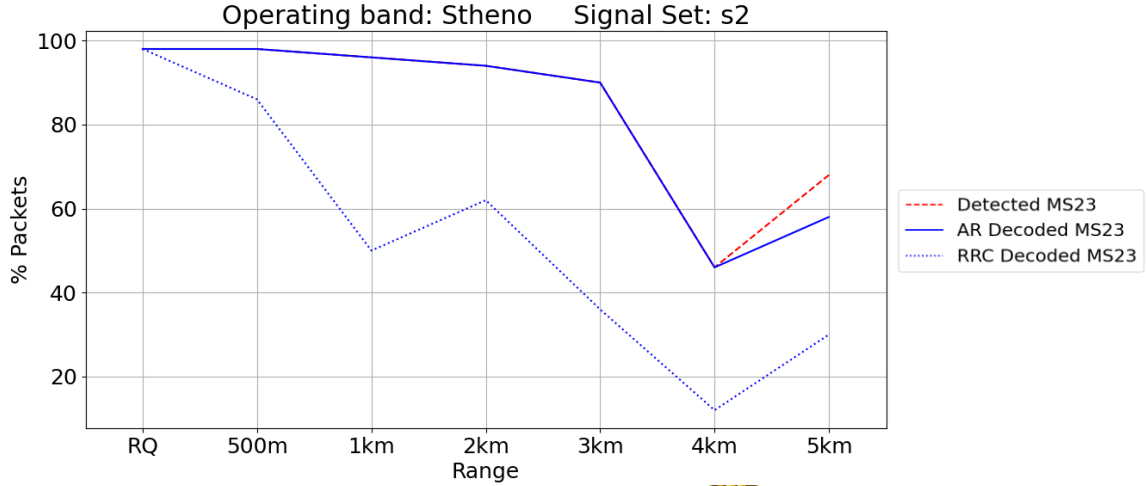
32 byte payload, 284 ms, 901 bps throughput



32 byte payload, 536 ms, 478 bps throughput



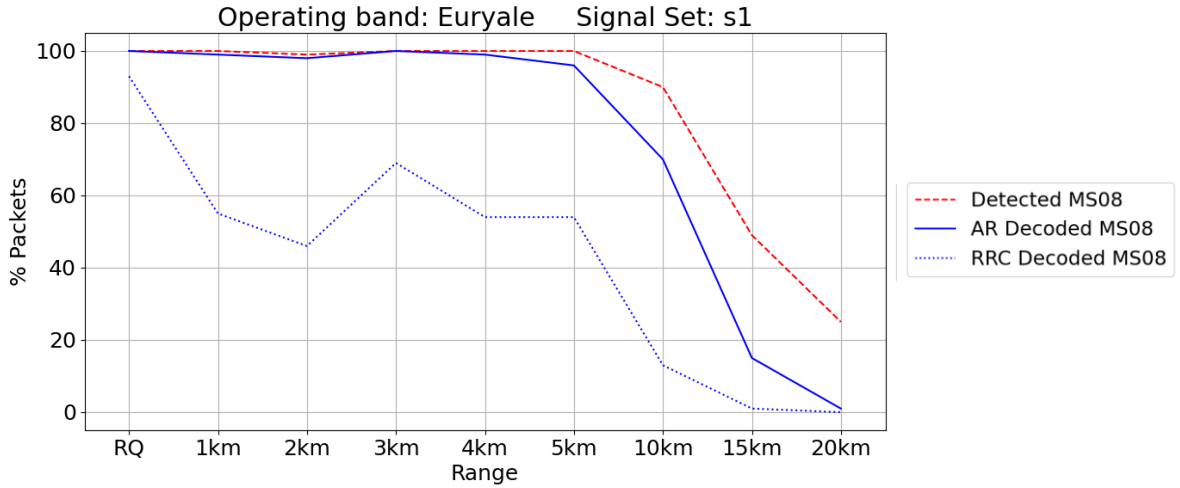
32 byte payload, 1040 ms, 246 bps throughput



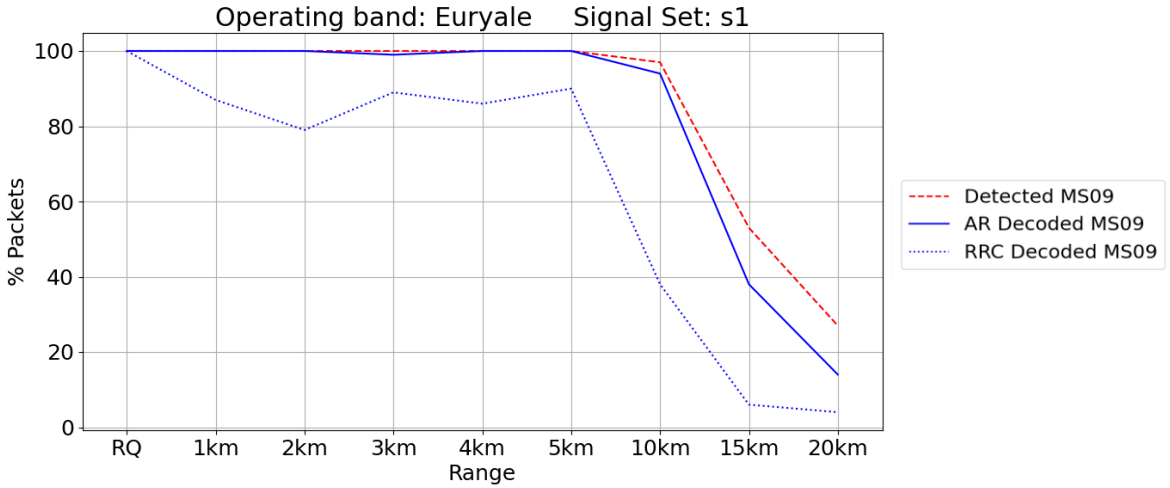
PHORCYS

North Sea trial Data (Euryale band 8-12 kHz)

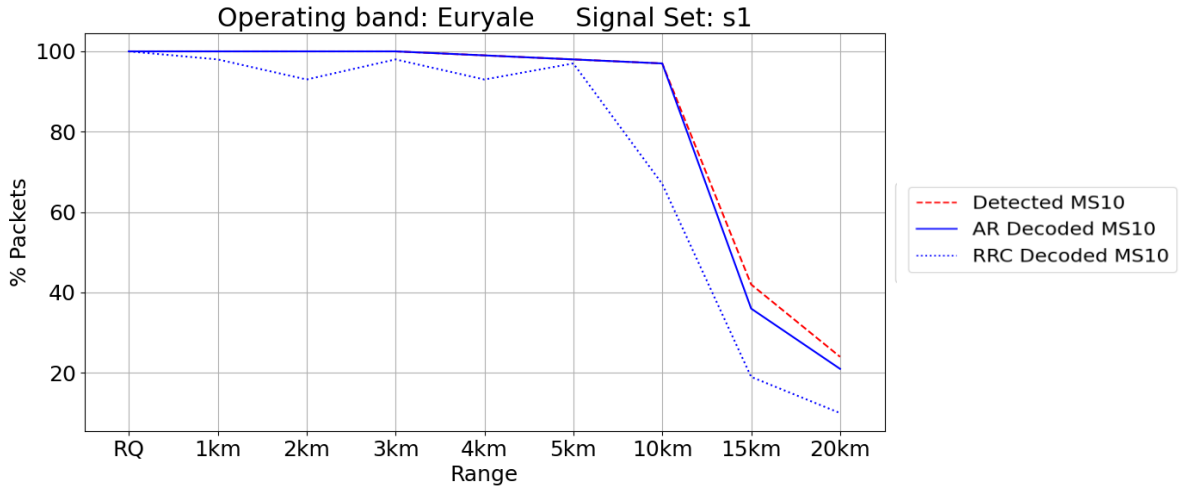
3 byte payload, 96 ms, 250 bps throughput



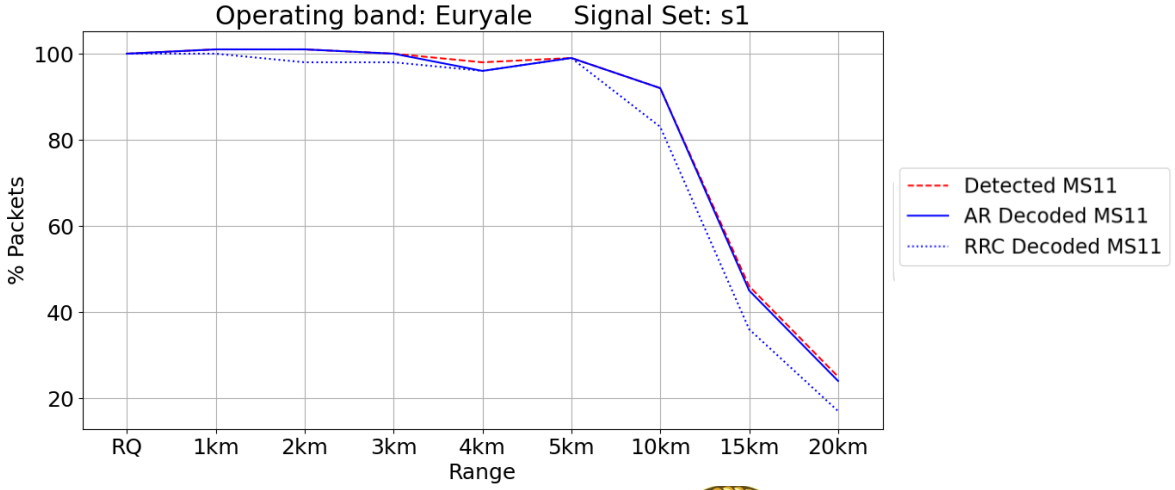
3 byte payload, 128 ms, 188 bps throughput



3 byte payload, 192 ms, 125 bps throughput



3 byte payload, 320 ms, 75 bps throughput



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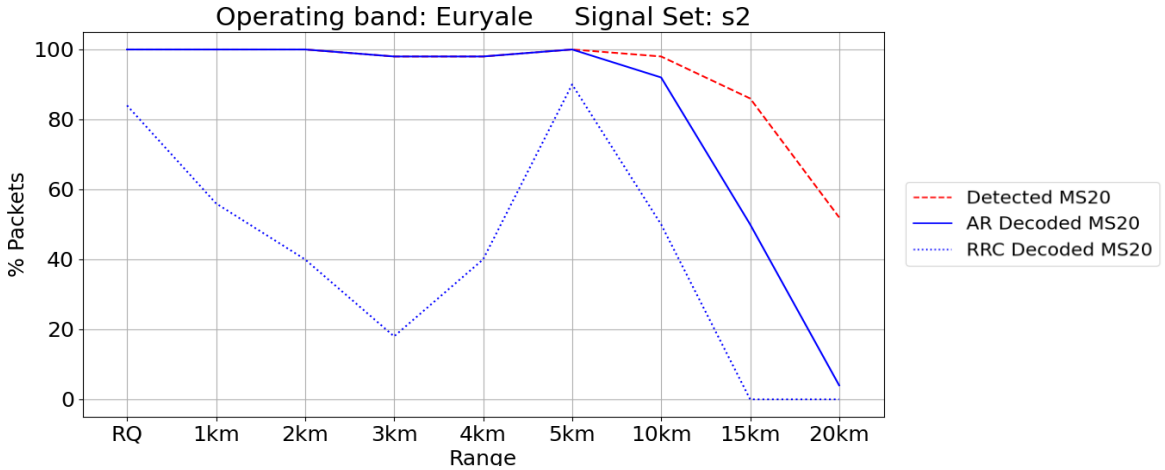
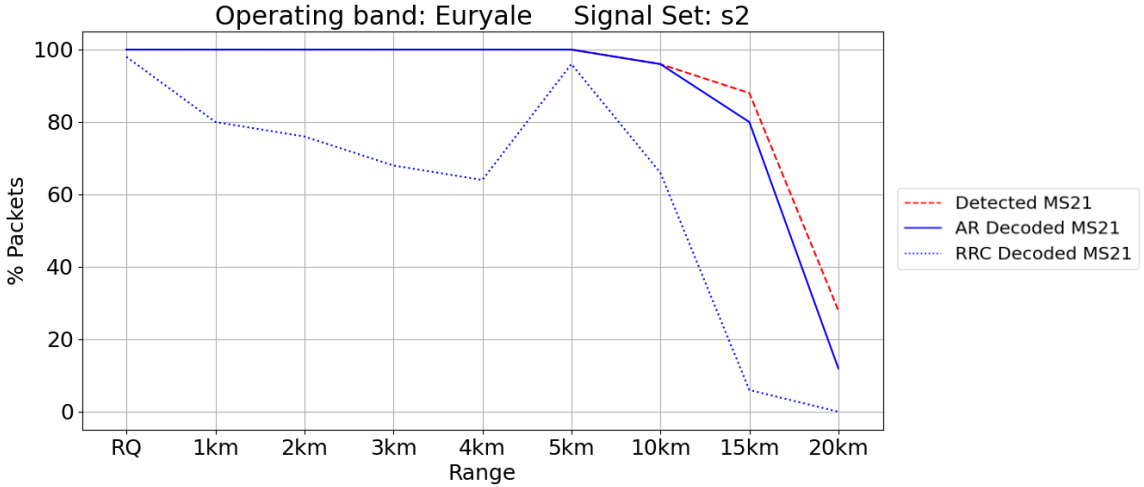
North Sea trial Data (Euryale band 8-12 kHz)

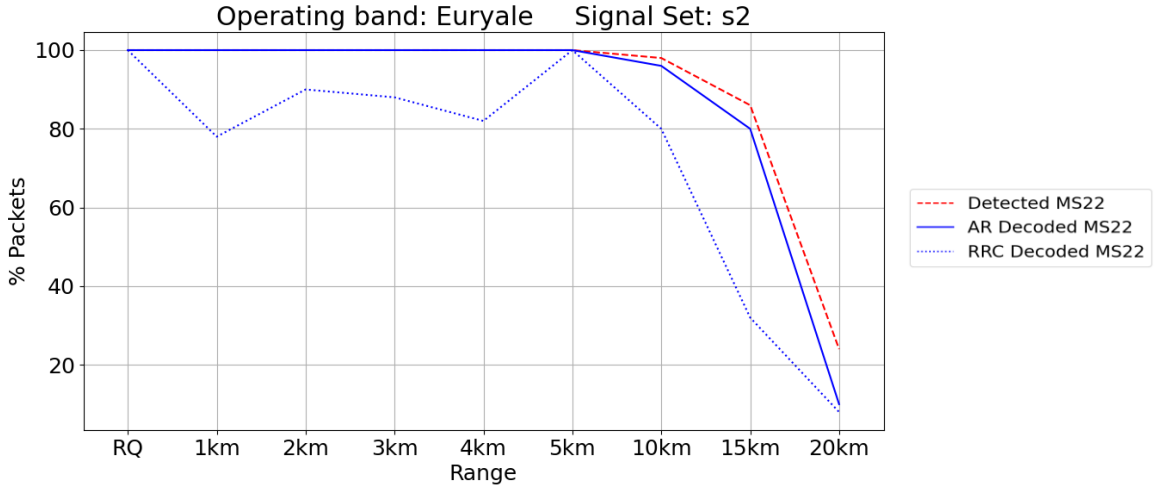
32 byte payload, 316 ms, 810 bps throughput



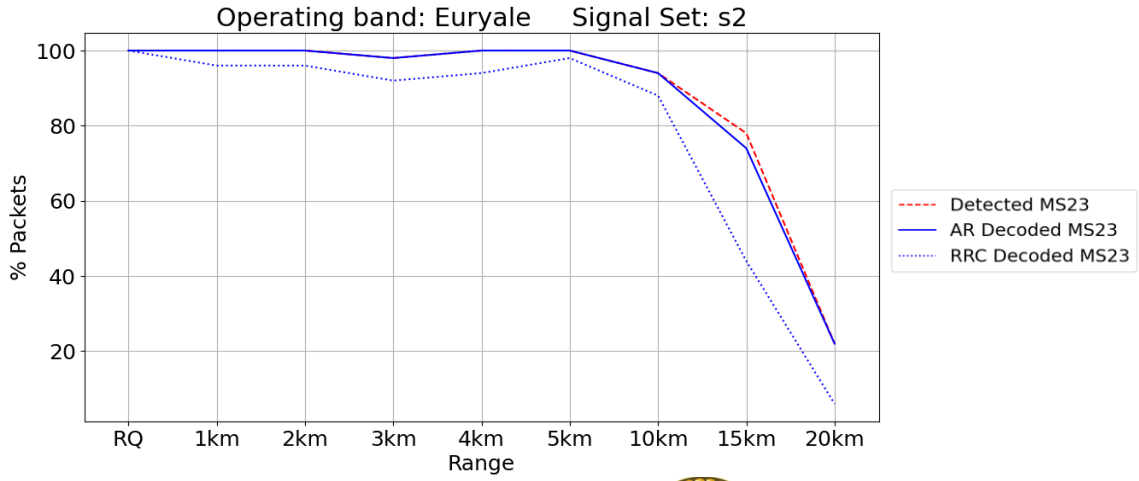
32 byte payload, 568 ms, 451 bps throughput



32 byte payload, 1072 ms, 239 bps throughput



32 byte payload, 2080 ms, 123 bps throughput



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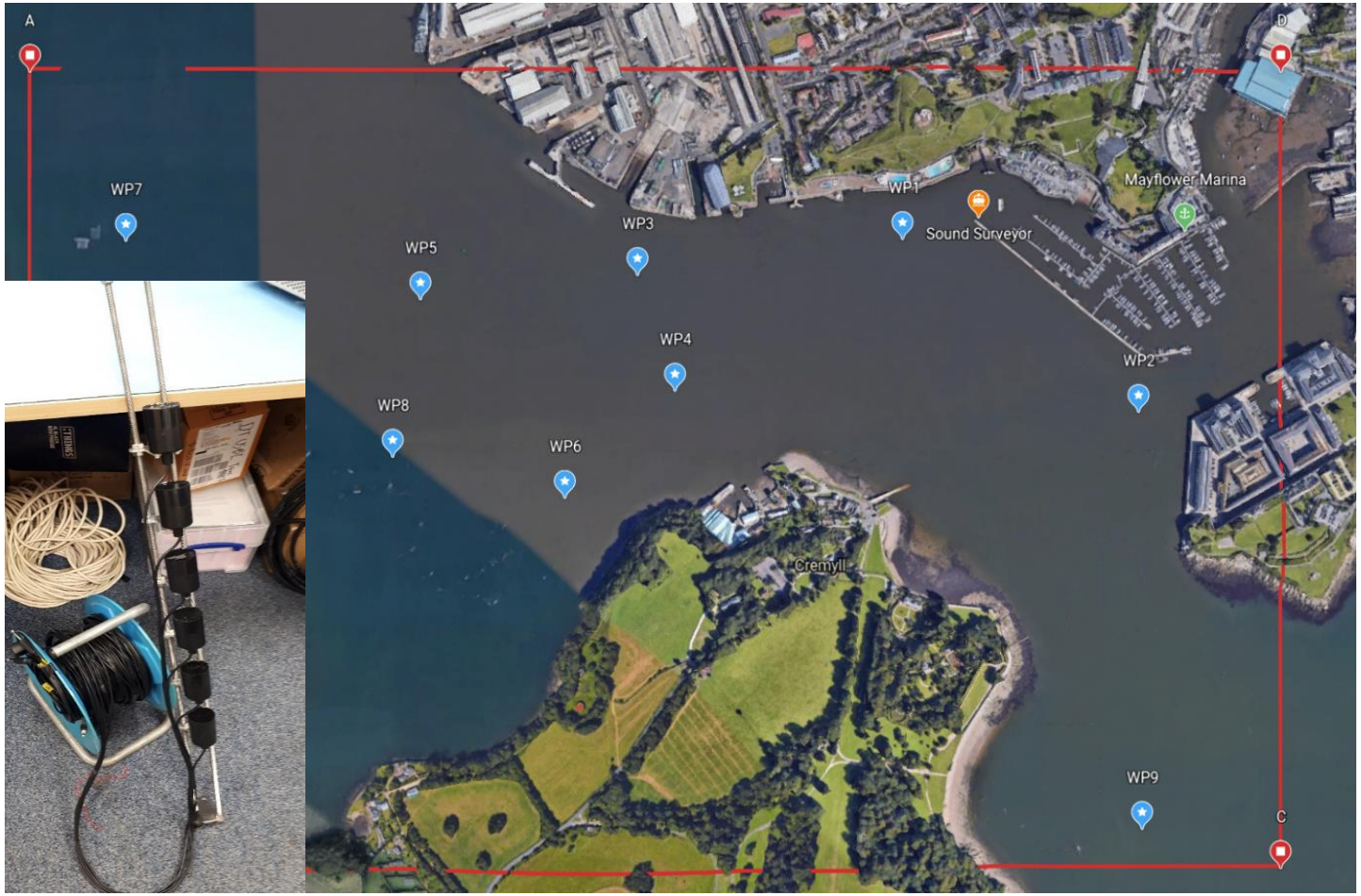
Trials in Plymouth Sound (August 2021 & March 2022)

- Shorter range tests up to 1.5km including from transmission between modem hardware.
- Complex 3D environment with freshwater mixing, strong tidal currents and frequent vessel traffic.
- Static and dynamic transmissions up to 4kts relative velocity.
- 6 element vertical line array added for 2nd trial (0.1 m or 1 m spacing)



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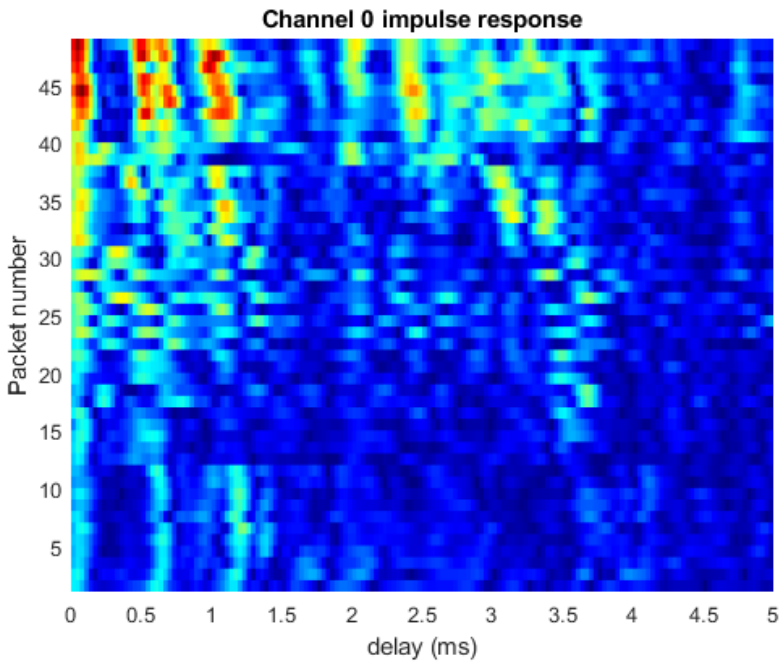
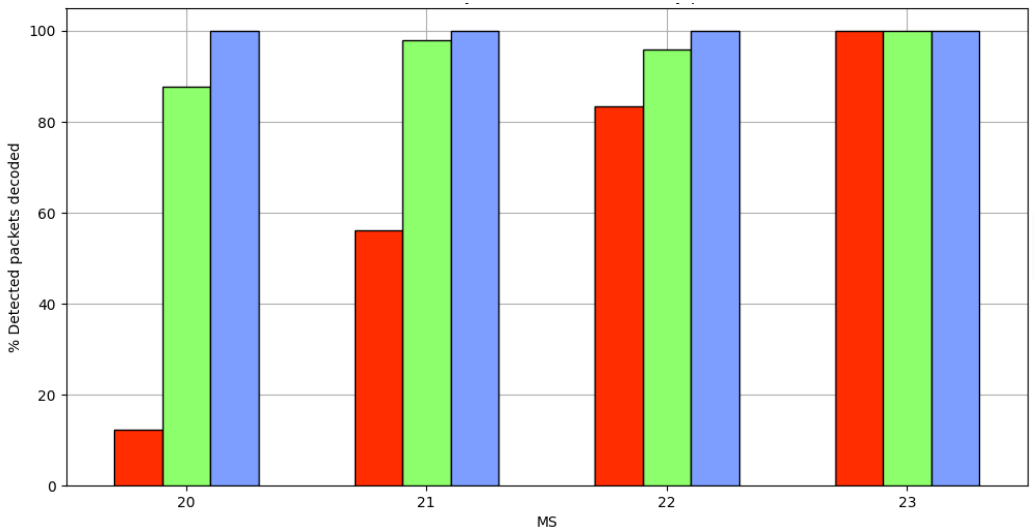
Multichannel adaptive receiver performance (Stheno)

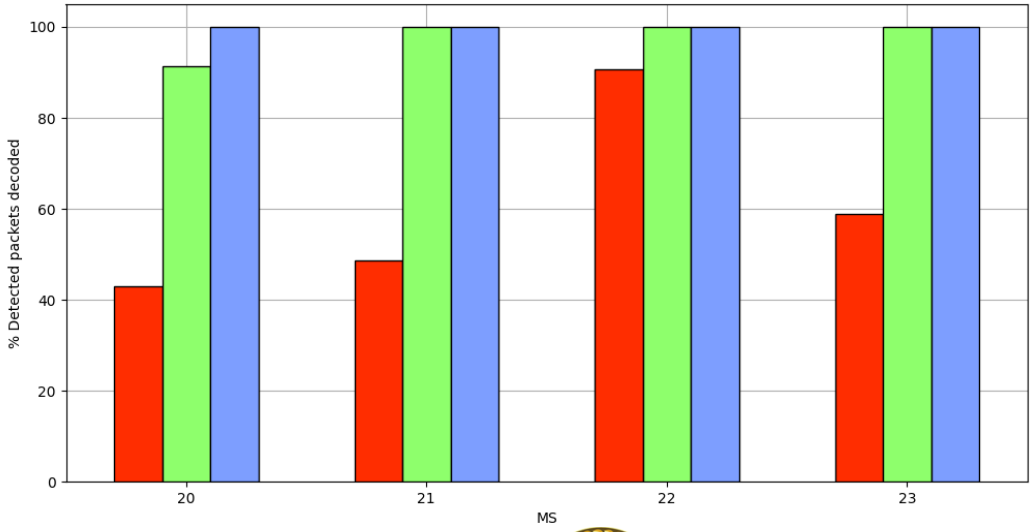
- Adaptive receiver (green) vastly improves packet delivery compared to RRC (red). 100% delivery with adaptive Rx array (blue).
- Sustained throughput up to 1.6 kbps in challenging environment.



Static transmission at WP7



Dynamic transmission from WP7 @ ~ 4kts.



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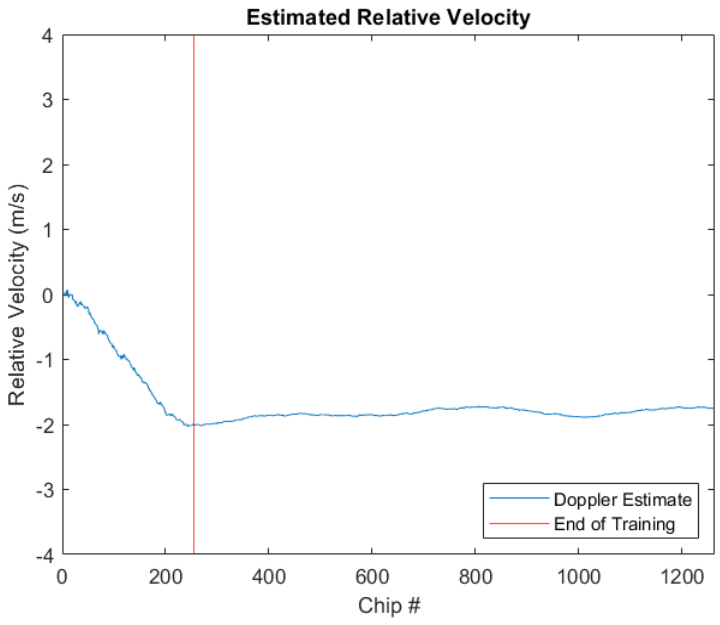
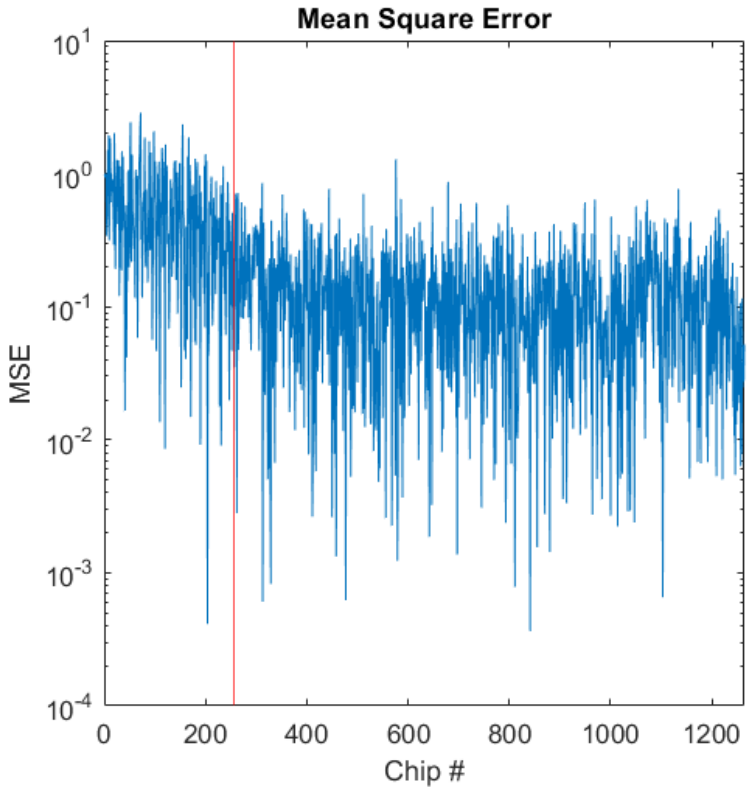
Adaptive receiver operation

- Metrics shown for single packet of dynamic data set from Plymouth.
- Estimated velocity plot shows algorithm converges to relative velocity within training period.
- Mean square error plot shows convergence of LMS algorithm during training, maintaining a steady state during data reception.





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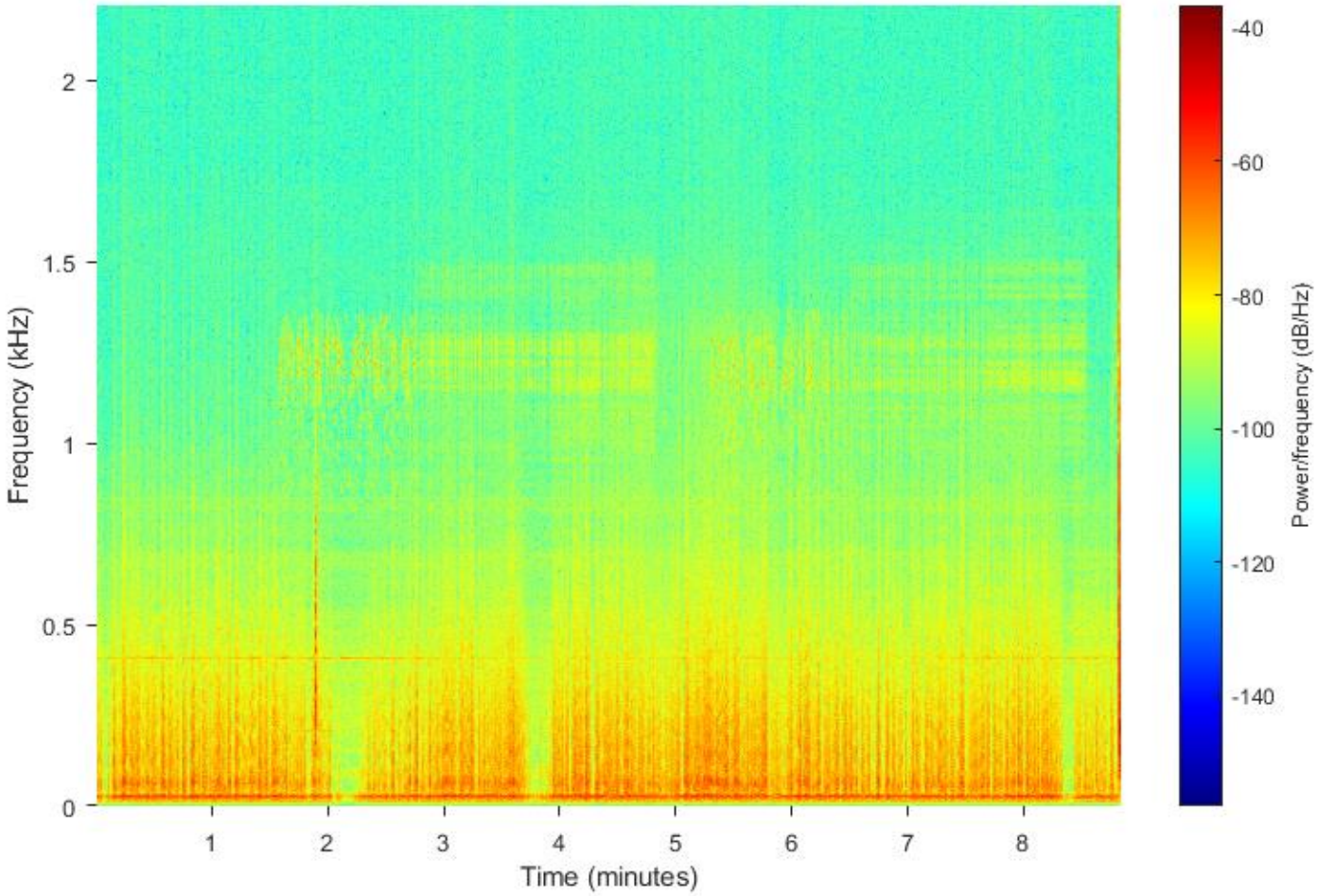
Long range transmission (Medusa band)

- PhorcysV0 waveform scaled to 0.8 – 1.5 kHz for long range transmission in Eastern Mediterranean*.
- Omnidirectional transmission at SPL = 200 dB.
- Omni directional receiver at ranges up to 200 km. Tx and Rx above SOFAR channel so propagation is sub-optimal.

90 km Range, Tx 40 m, Rx 100m



** Thanks to Roee Diamant and the University of Haifa team for collecting this data.*

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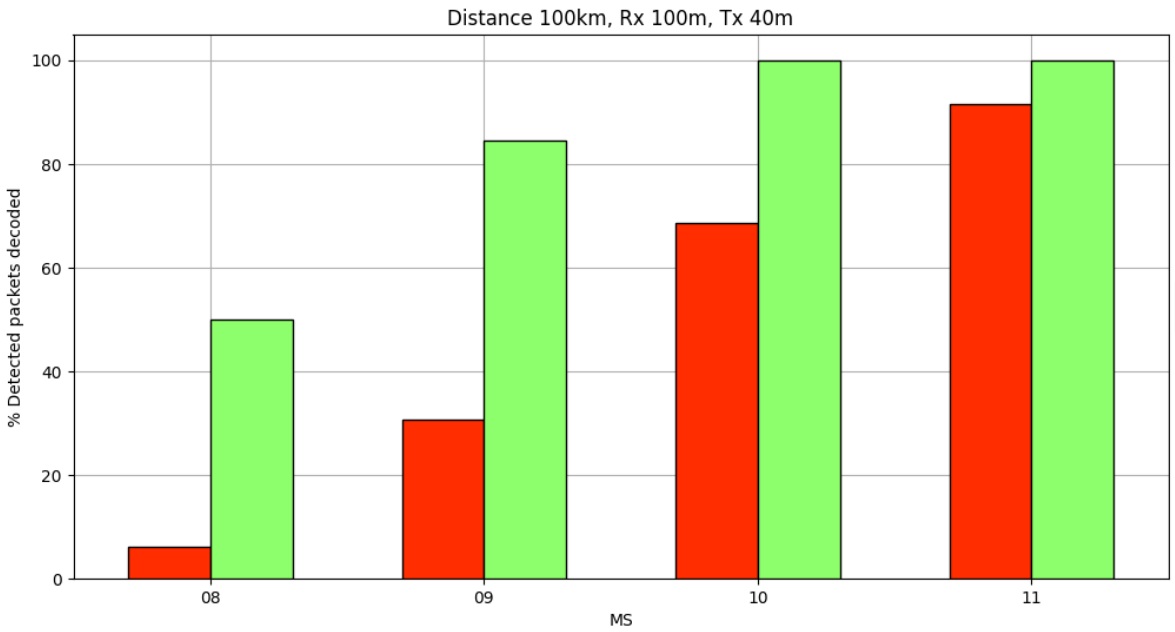
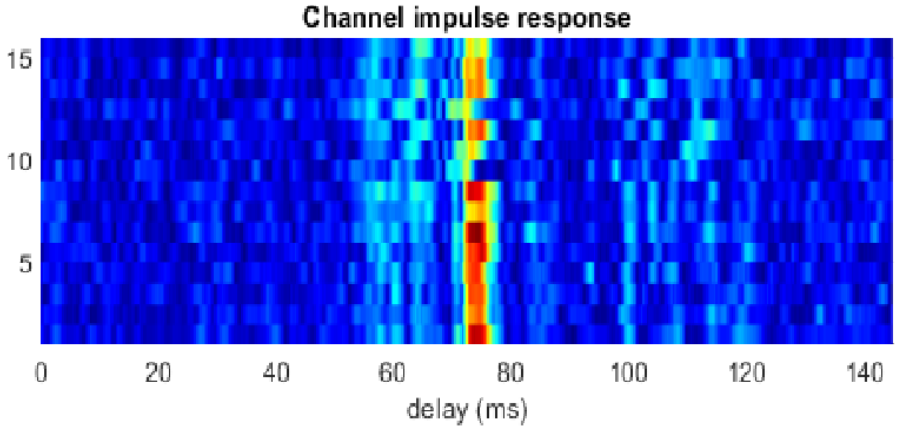
Long range transmission (Medusa band)

- Very promising results on transmission of 3 byte (SP) packets up to 100km range.
- Further benefits from adaptive receiver structure (single channel).
- 100% delivery over 90 km with Rx at 300 m (improved channel).
- Promising results on detection of prototype non-coherent (frequency hopping) signal up to 200km.





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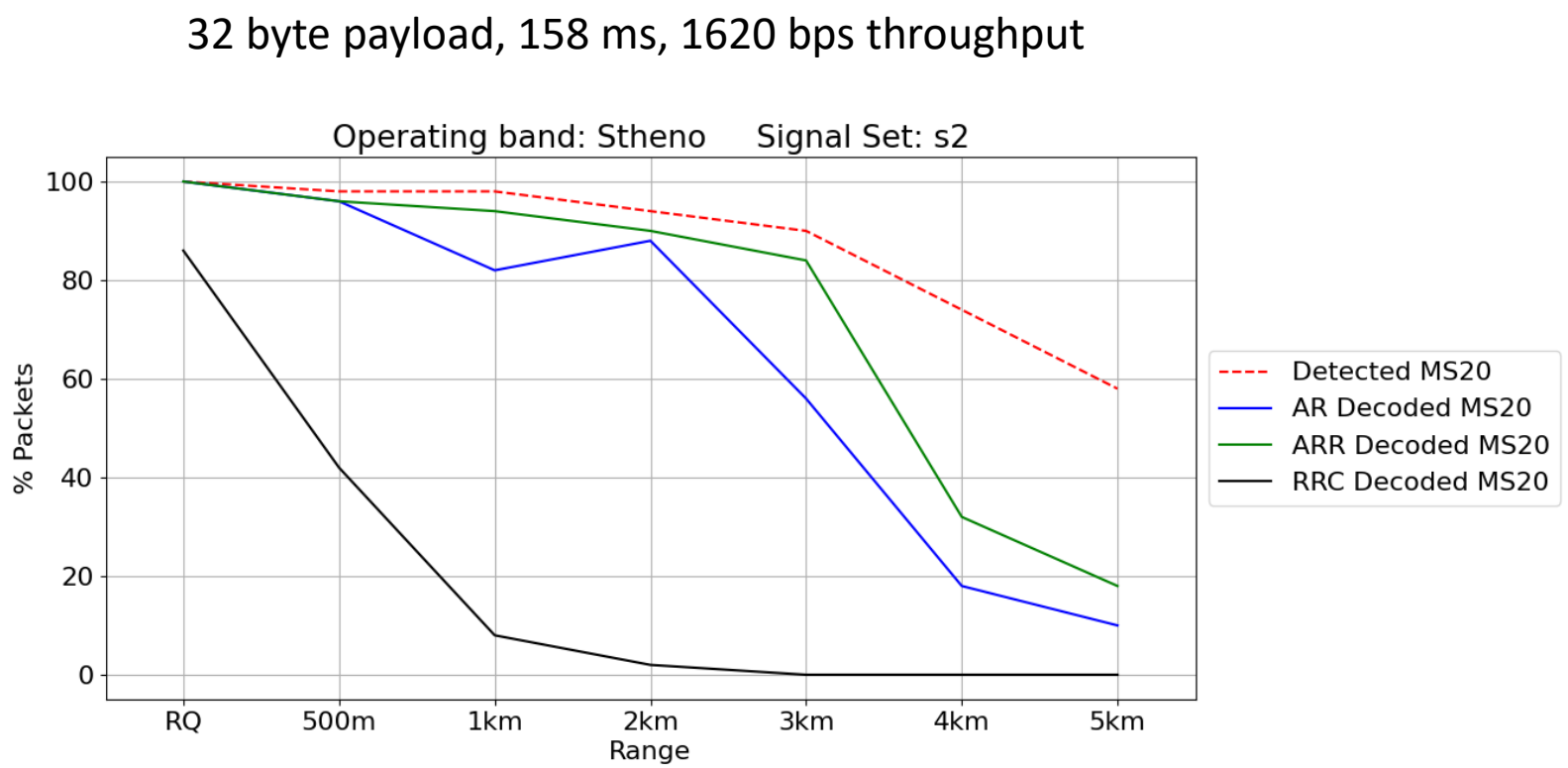
Adaptive Rake Receiver

- Further structures being investigated such as adaptive rake receiver (ARR).
- Uses 2 adaptive filters locked onto 2 largest paths detected.
- Initial results are promising, more research required to determine optimal parameters.



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Conclusions & further work

- The PhorcysV0 waveform was developed to meet tactical comms requirements in UK defence but its **properties** are highly desirable for **industrial and scientific** applications.
- **Security and interoperability** have been designed into the waveform from inception.
- The **scalability** of the waveform has been demonstrated, from short packets of a few bytes and <50 ms duration to sustained throughput at 1.6 kbps.
- The modulation (BT) gearing provides an effective route to maintaining **reliable packet delivery in variable channel conditions**. Work is ongoing to develop effective strategies for automatic gear switching.
- The waveform has been **successfully validated** in a wide variety of environments and frequency bands.
- The simple reference receiver is effective, especially at high BT, but there are substantial benefits to more capable **adaptive receivers**.
- Work is ongoing to further optimise the adaptive receiver to fully exploit **spatial/temporal diversity**, both for decoding performance and FS detection in hostile channels.

Potential applications in Marine Robotics

Stheno band (20 -28 kHz)

Low SWAP modems for micro AUVs, cooperative swarm robotics, diver-robot cooperation and navigation (< 3km).

Euryale band (8-12 kHz)

Medium-long range command/control and navigation (<20 km) for larger AUVs, deep water operations.

Medusa band (< 2 kHz)

Very long range (<200 km) navigation, command and control for high endurance AUVs (e.g. under ice).

PHORCYS

Thank you for listening

Questions?

jeff.neasham@ncl.ac.uk

PHORCYS

Reeds

Breaking The Surface 2022

Ola Benderius, Chalmers University
Ted Sjöblom, RISE

Reeds Project

Reeds is a novel dataset for research and development of robot perception algorithms. The design goal of the dataset was to provide the most demanding dataset for perception algorithm benchmarking, both in terms of the involved vehicle motions and the amount of high quality data.

CHALMERS
UNIVERSITY OF TECHNOLOGY

SWEDISH MARITIME ADMINISTRATION

UNIVERSITY OF GOTHENBURG

RI. SE

TRAFIKVERKET

Datasets for benchmarking

Benchmarking of perception algorithms is a big thing:

- Comparing different approaches
- To push research and state-of-the-art
- Common and accepted datasets are needed
- Difficult to establish a new dataset: Ever heard of Kitti?
- Reeds is trying to be different enough

Reeds Plattform, **Seahorse**

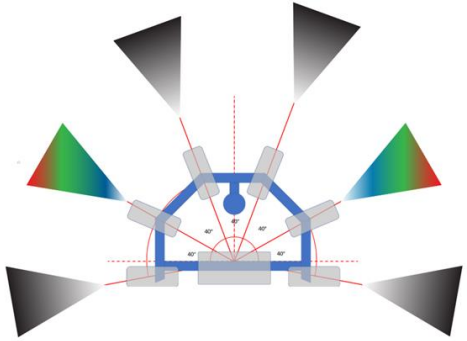
Ockelbo B16AL

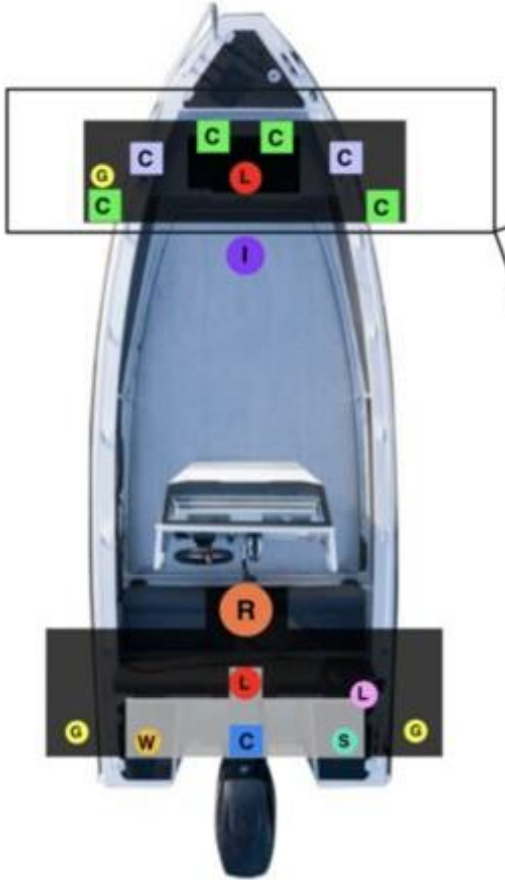
LOA: 5m
WOA: 2m
Draft 0.5m
Engine: 60hk
Weight: 500kg

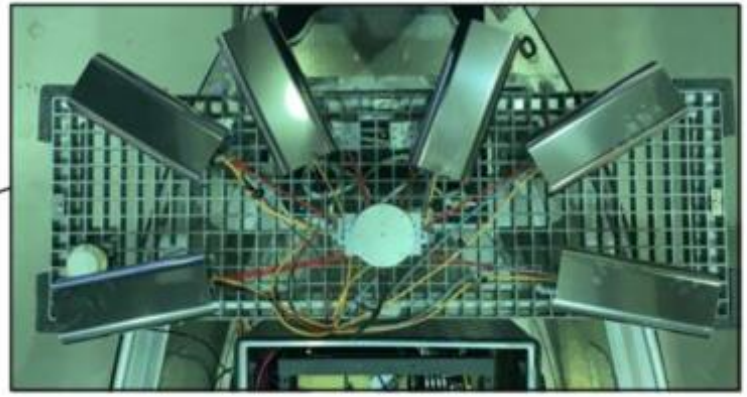
Onboard Sensors

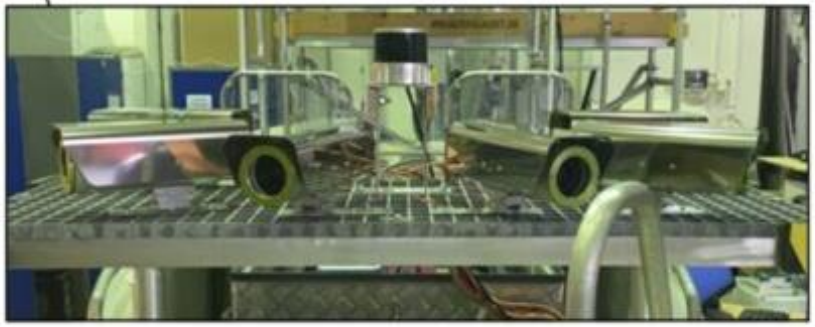
At the BOW

Cameras
FLIR Oryx 10GigE
Color x2 and Mono x4
4K at 12-bit +60(112)fps
16mm (H 43-47°)
275GB/min **(10bits/90fps)**









Onboard Sensors

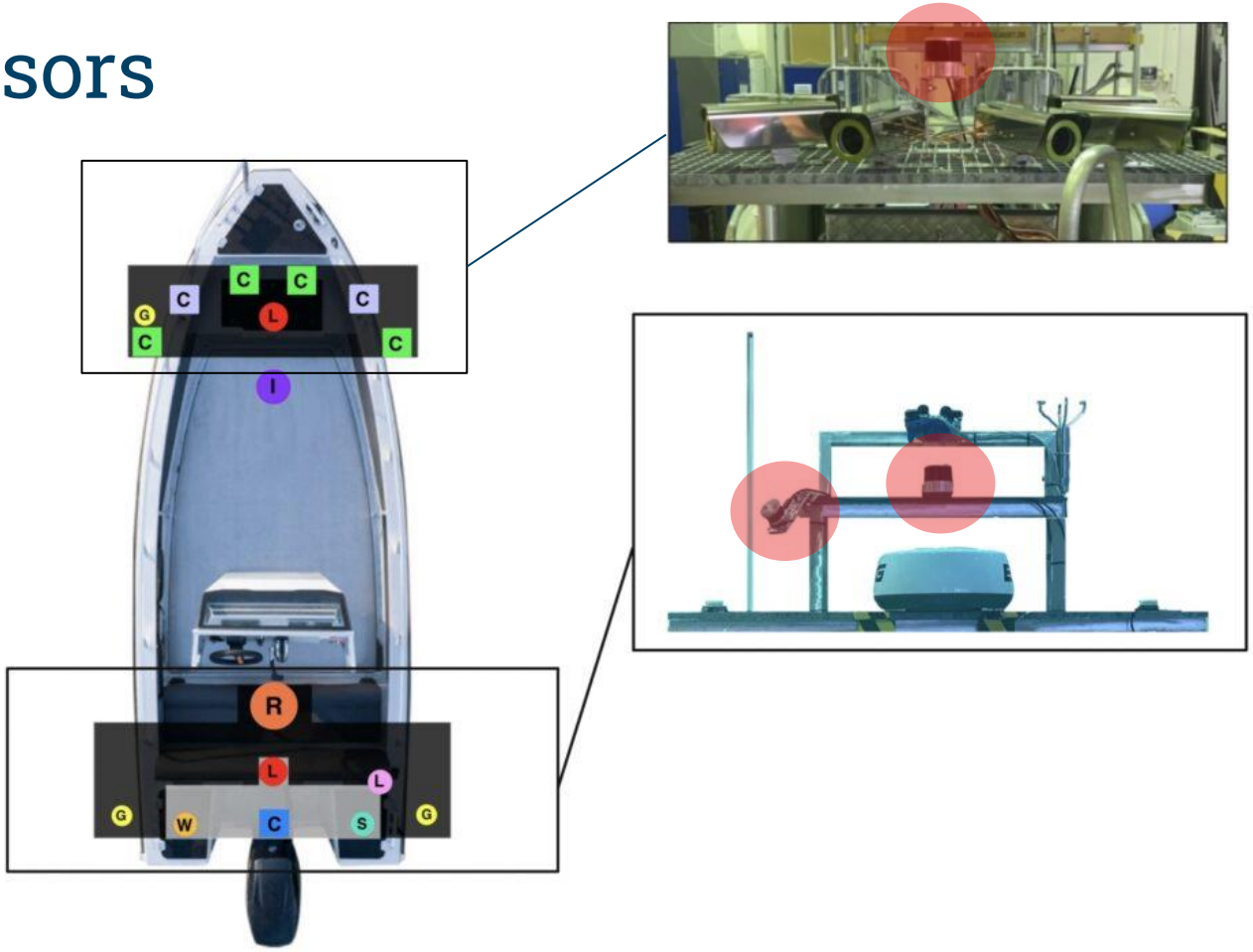
At the BOW & AFT

LIDAR
OUSTER OS1 x1
H 360° / V 45°
Range 120 meters
+/- 0.7-5 cm

OUSTER OS2 x2
H 360° / V 22.5°
Range 200+ meters
+/- 2.5-8 cm

128 Vertical beams
2.6M points per second

3 LIDARS
7.8M points/sec
14GB/min

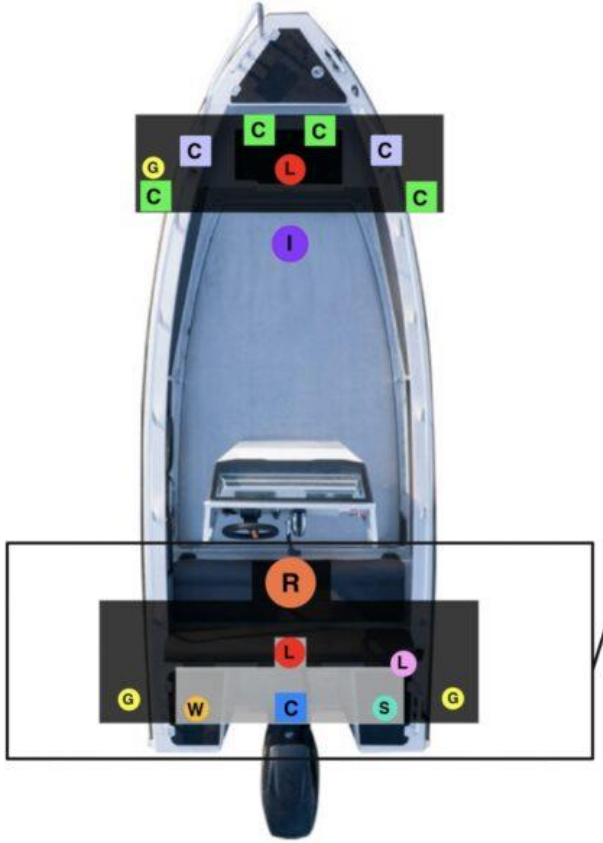


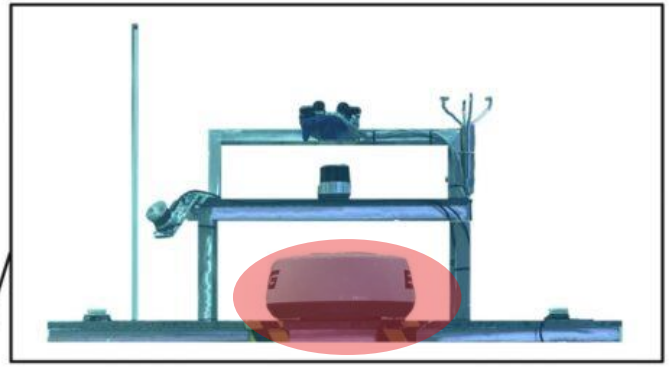
Onboard Sensors

At the AFT

Radar
NAVICO Halo20+
Solidstate + Doppler
X-band 9.4-9.5GHz
Beam width 2.5-4.9°
H 360° / V 25°
20-60 rpm

Range 36nm



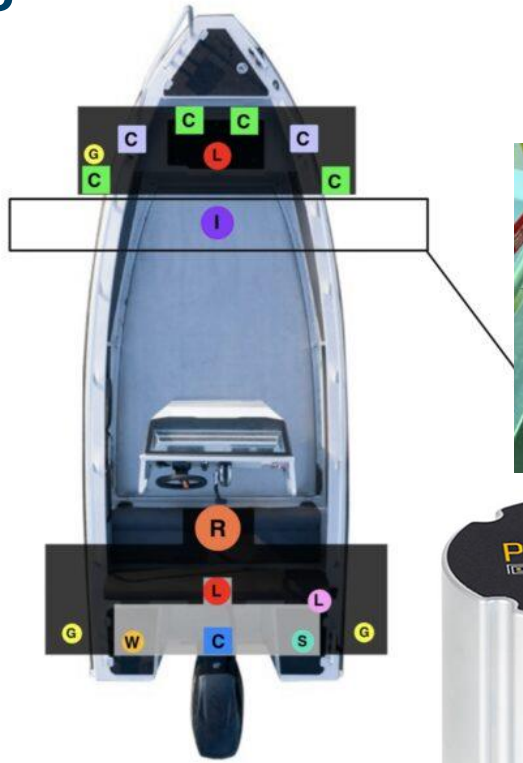


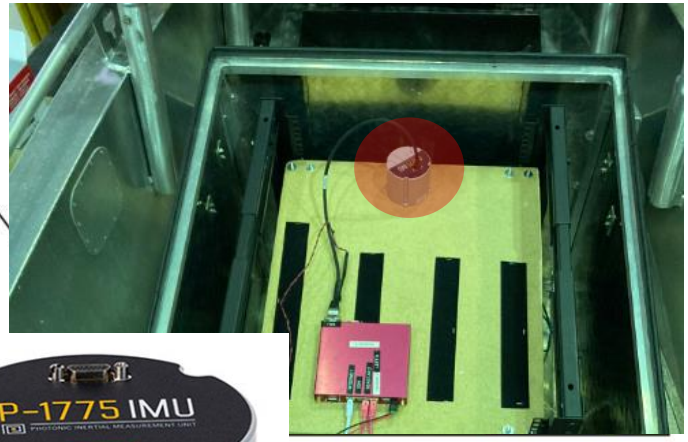
Onboard Sensors

At the Center (isch)

IMU - KVH P-1775
Up to 5 000Hz data rate
3-axis magnetometer for magnetic compensation

Currently the highest performing IMU from KVH





Onboard Sensors

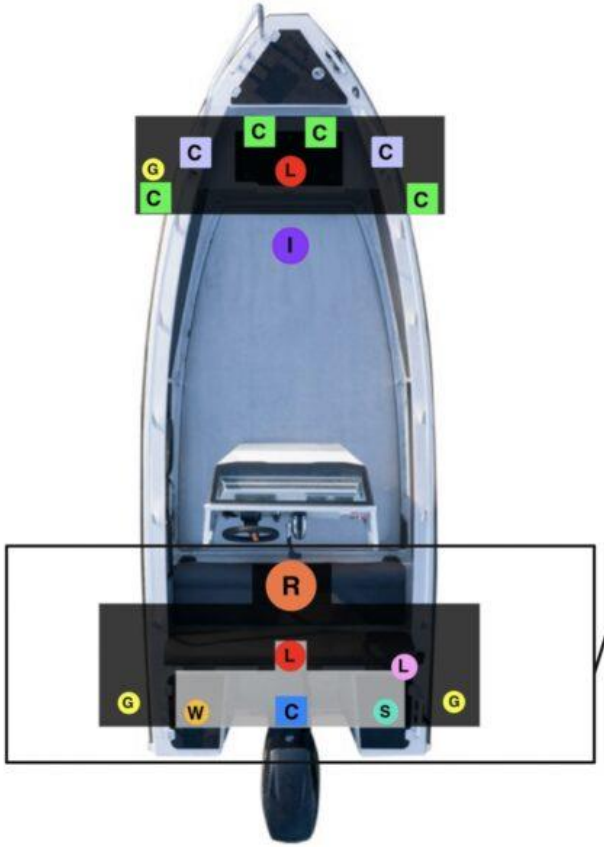
At the AFT

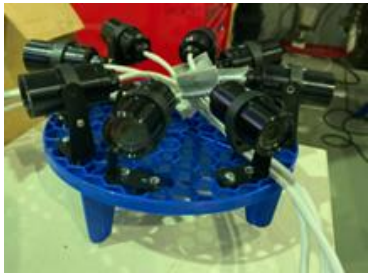
GNSS - 3 Antennas
ANAVS MSRTK (5cm)

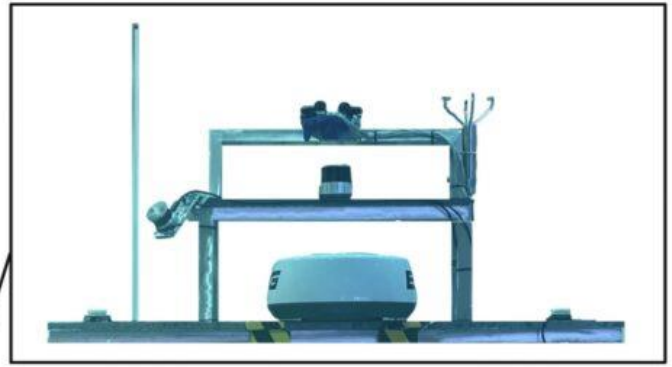
Ultrasonic Anemometer
WindObserver 65

HD-Cameras 360
AXIS F Series

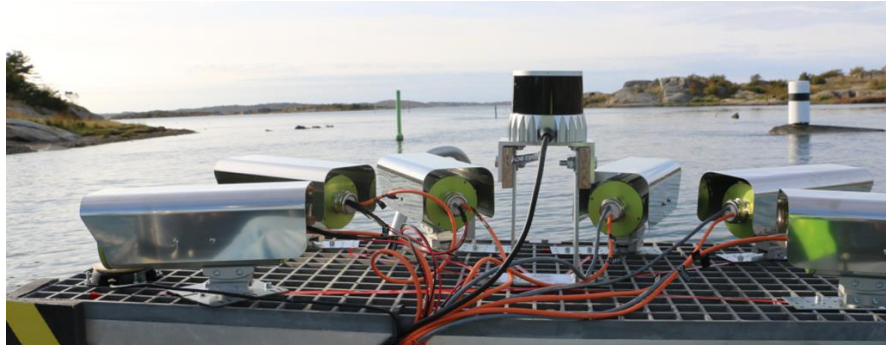
AIS & VHF
RTL-SDR





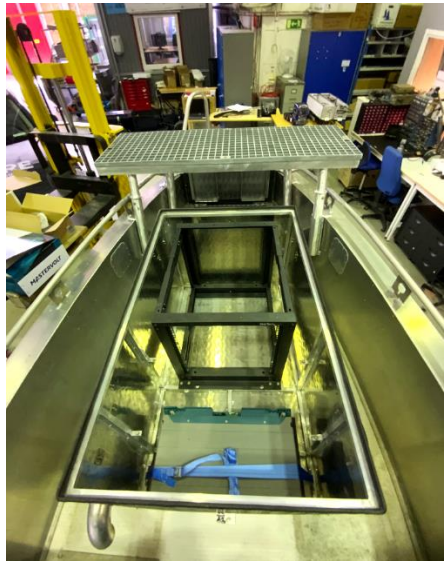


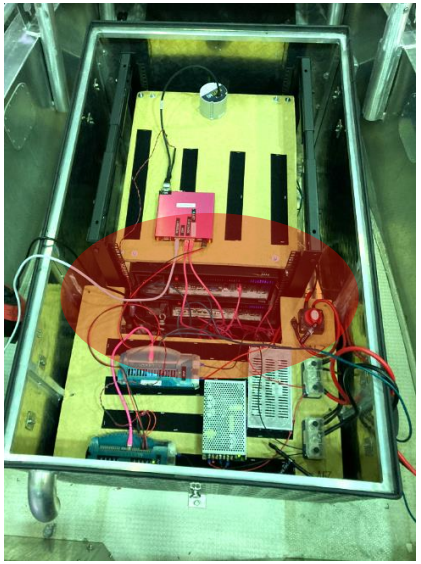
Logging HW



Two data center servers each has:

- Two AMD EPYC 7352 CPUs
- 128 GB RAM
- Seagate Exos SATA disk drives (~40TB)
- Micron 9300 NVMe U.2 SSD (3.5 GB/s, 15TB)
- Samsung 980 PRO NVMe M.2 SSD (5.1 GB/s, 1TB)
- One Nvidia GeForce RTX 2080
- One Nvidia Quadro RTX 4000.






B&G
HONDA
Ockelbo

The worlds largest benchmarking dataset

Perception algorithms (for example):

- Stereo vision and depth perception
- Optic and scene flow
- Odometry, localization, and mapping (SLAM)
- Object detection, classification, and tracking
- Semantic segmentation
- Scene and agent predictions

Challenges and leaderboards

Competing with algorithms:

- Public leaderboards
- Performance estimation
- Published algorithms
- Open to everyone

Fair comparison

Systematic benchmarking for reproducibility of computer vision algorithms for real-time systems: The example of optic flow estimation

Björnborg Nguyen[1], Christian Berger[2], and Ola Benderius[1]

***Abstract*— Until now there have been few formalized methods for conducting systematic benchmarking aiming at reproducible results when it comes to computer vision algorithms. This is evident from lists of algorithms submitted to prominent datasets, authors of a novel method in many cases primarily state the performance of their algorithms in relation to a shallow description of the hardware system where it was evaluated. There are significant problems linked to this non-systematic approach of reporting performance, especially when comparing different approaches and when it comes to the reproducibility of claimed results. Furthermore how to conduct retrospective performance analysis such as an algorithm's suitability for embedded real-time systems over time with underlying hardware and software changes in place. This paper proposes and demonstrates a systematic way of addressing such challenges by adopting containerization of software aiming at formalization and reproducibility of benchmarks. Our results show maintainers of broadly accepted datasets in the computer vision community to strive for systematic comparison and reproducibility of submissions to increase the value and adoption of computer vision algorithms in the future.**

benchmarks adopting de facto standards based on the work of Barron *et al.* [6].

B. Problem domain and motivation

To make optic flow estimation algorithms applicable in real-time critical applications, there are several hard constraints imposed on the estimator such as accuracy, robustness, and execution time. Much of the focus of the early works have been on benchmarking just on the first of which. Since there is a trade-off between computational cost and measurement performance, many algorithms are optimized for the latter. This has led to a general trend for algorithms depreciating computational costs and run-time aspects of such algorithms resulting in being unfit for real-time critical applications. This can be seen for example in the entries of *KITTI optical flow evaluation 2015* dataset [3], where benchmarks of optic flow accuracy along with their run-time vary from few milliseconds to several hours to compute a single frame.

Nguyen, B., Berger, C., & Benderius, O. (2019, November). Systematic benchmarking for reproducibility of computer vision algorithms for real-time systems: The example of optic flow estimation. In 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 5264-5269). IEEE.

Two problems, one solution

How can we solve:

- Massive dataset (not easy to move)
- Fair comparison (difference in computational hardware)

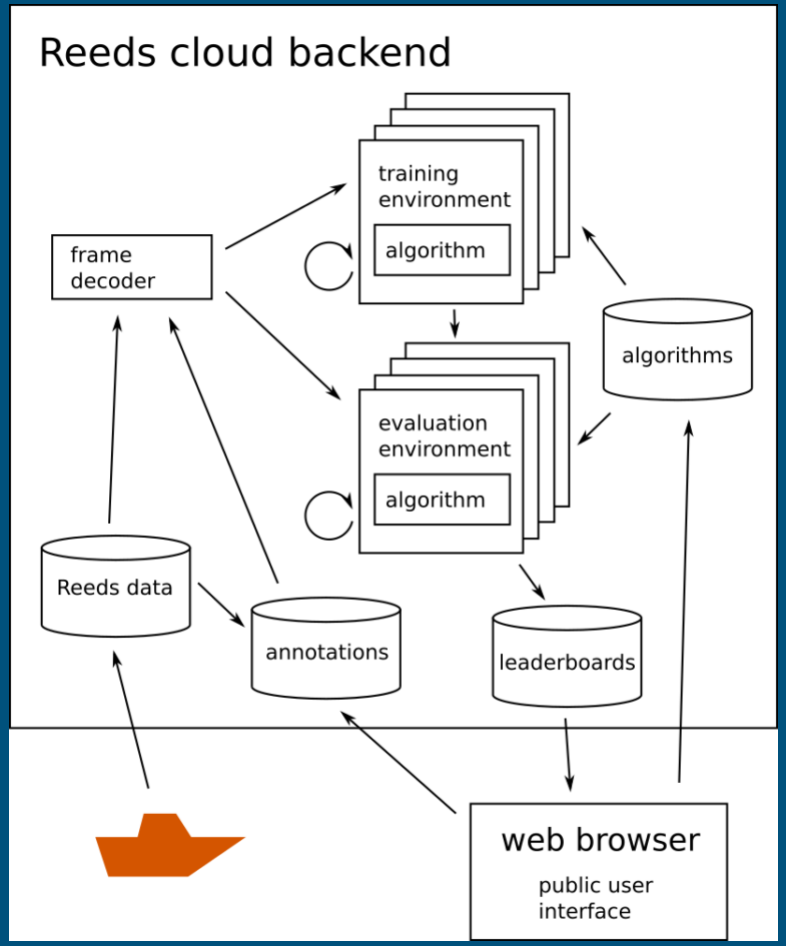
The Reeds web platform

A cloud-based evaluation platform:

- Easier to move software than data
- The same computational hardware is used for everything
- CPU and GPU
- Directly connected to automatic leaderboards

Added benefit:

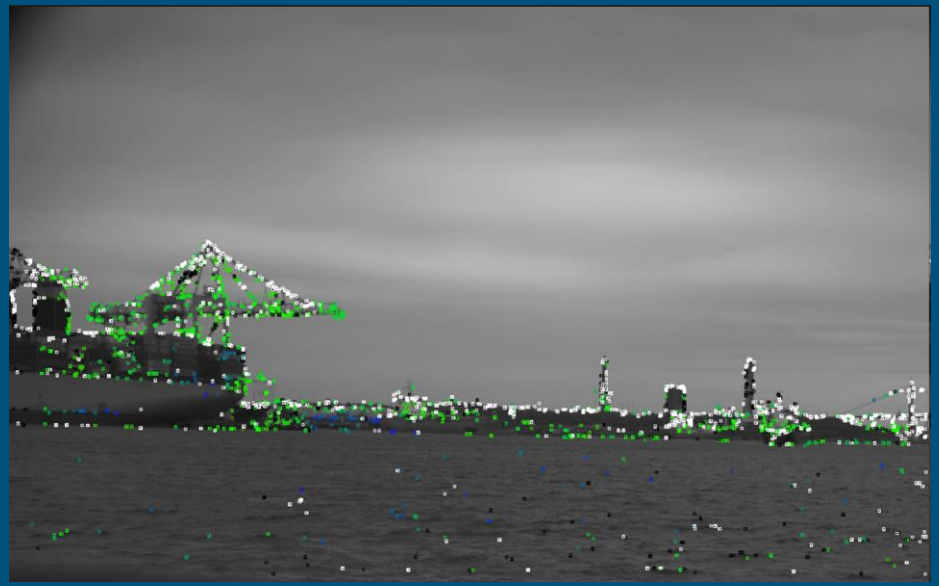
- Annotation tool
- Automated re-evaluation



Reference algorithms

Algorithms in different categories were tested:

- Evaluate the concept
- Validate sensors
- Provide initial scores
- Showcase



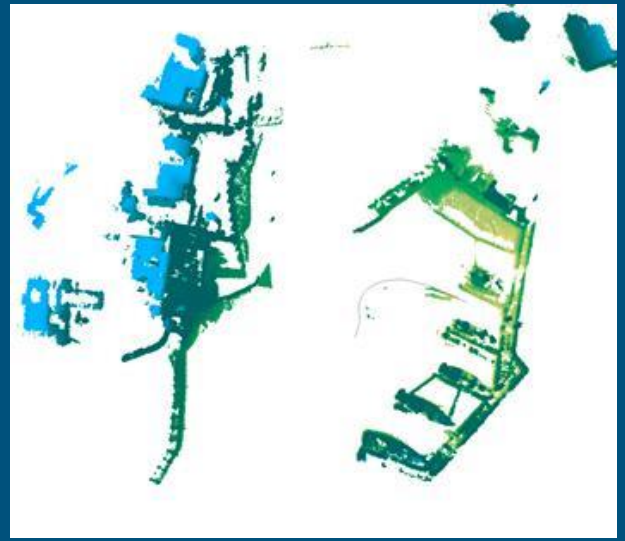
Master thesis projects

Localization:

- Petersson, A. (2021). Vision-based state estimation of autonomous boats.
- Wang, L., & Ganapati Hegde, V. (2021). Mapping and 3D reconstruction based on lidar.
- Engström, A., & Geiseler, D. (2022). Lidar-based simultaneous localisation and mapping in marine vehicles: Handling the complex motions in a marine setting.

Object detection:

- Rofalis, A. (2021). Detection and classification of marine vehicles.
- Sophonpattanakit, J. (2022). GAN-based water droplets removal.



Peer-reviewed papers

Localization:

- Engström, A., Geiseler, D., Blanch, K., Benderius, O., & García Daza, I. (2022). A lidar-only SLAM algorithm for marine vessels and autonomous surface vehicles. IFAC CAMS.
- Nguyen, B., Blanch, K., Petersson, A., Benderius, O., & Berger. C. (2022). Application and evaluation of direct sparse visual odometry in marine vessels. IFAC CAMS.

The Reeds community is growing

We are an active community interested in Reeds:

- Representing 16 countries (Europe, Asia, North America)
- We are getting close to go public

If you want to join, please fill in the form at reeds.opendata.chalmers.se and we will keep you up to date!

The tutorial this afternoon

Proof-of-concept

- Working with over 600 GB of data (18 min of logging)
- Only using a web browser

Hope to see you there!

Any questions?

Reeds

Breaking The Surface 2022

Ola Benderius, Chalmers University
Ted Sjöblom, RISE

Introduction

As we talked about before:

- This benchmarking data is to large to realistically move over the Internet
- We want to enforce a fair comparison between evaluations

Data format

We use the following formats in the Reeds data:

- GNSS, IMU, lidar, weather, AIS, VHF: libcluon/opendlv
- Documentation cameras: libcluon/opendlv packed as h264 compressed frames
- Monochrome logging cameras: Mono10p, 10 bits per pixel, 3208x2160
- RGB logging cameras: BayerRG10p, 10 bits per channel, 3208x2160

Note: Uniquely, we do not do any processing of Bayer patterns by default. The used can choose.

For today

We collected some data:

- 18 min
- 675 GB

Let's work with the data

Access a demo environment at **https://benderius.se** and follow the instructions.

The functionality of this environment will of course be expanded over time, but you will get the idea.

Wrapping up

Questions or comments?

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CNR
www.cnr.it

DSSTTA
www.dta.cnr.it

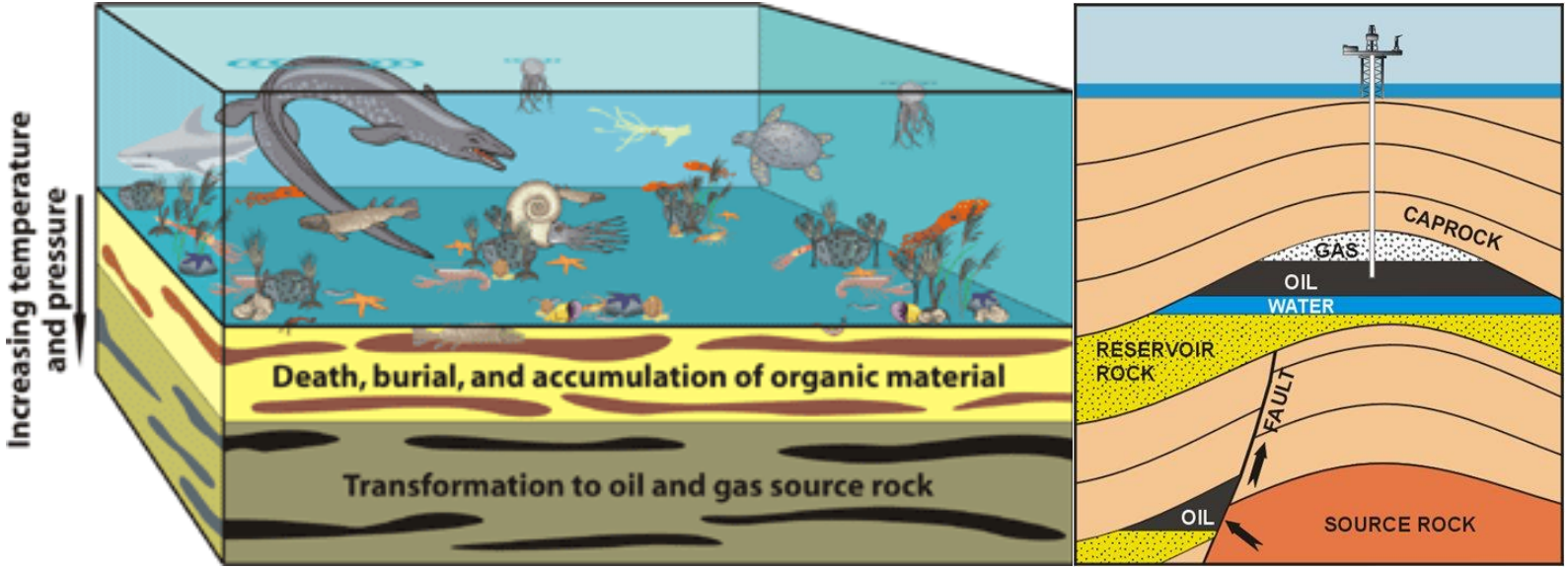
ISMAR – IAS – IRBIM
www.ricercamarina.it

Integrated Observations and Monitoring Solutions for Exploration and Sustainable Exploitation of Marine Abiotic Resources

Marzia Rovere

CNR ISMAR
ISTITUTO DI SCIENZE MARINE

How oil and gas [Hydrocarbons] form in marine sediment?



Methanogenesis → microbic / thermic

Biogenic gas

1. Acetic acid fermentation: $CH_3COOH \leftrightarrow CH_4 + CO_2$, chiefly subaerial environments (Whiticar et al., 1986)
2. CO_2 reduction by hydrogenotrophic methanogens:

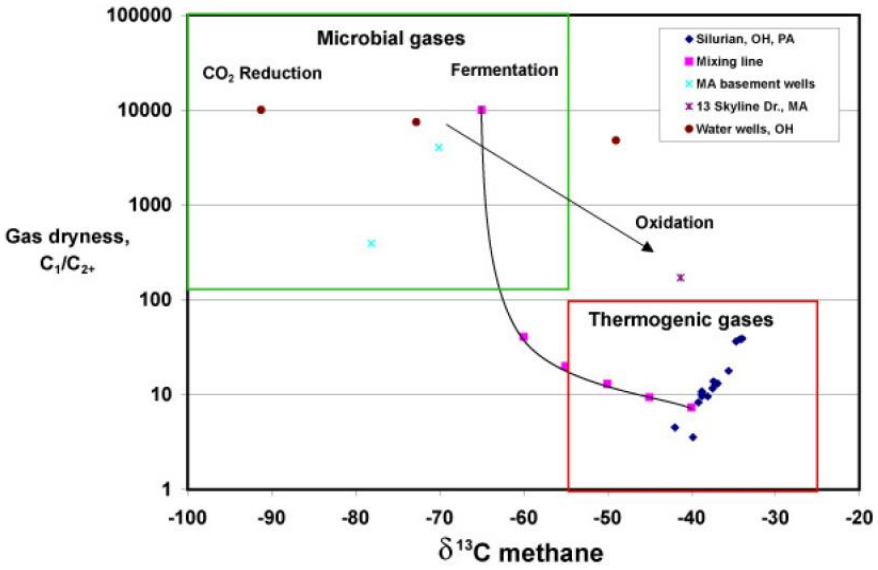
$CO_2 + 4\ H_2 \leftrightarrow CH_4 + 2H_2O$ (Whiticar et al., 1986) < 50°C

Thermogenic gas

1. kerogene cracking > 150-160° C = primary thermogenic gas
2. Oil cracking << 150-160 °C = secondary thermogenic gas (Stolper et al., 2014)

Abiogenic gas

1. In hydrothermal vents and deep in the Earth's crust, extremophiles thrive in env. oxygen, nitrate, ferric iron, and sulfate depleted $C + 2\ H_2O \leftrightarrow CH_4 + O_2$



Hydrocarbon seepage

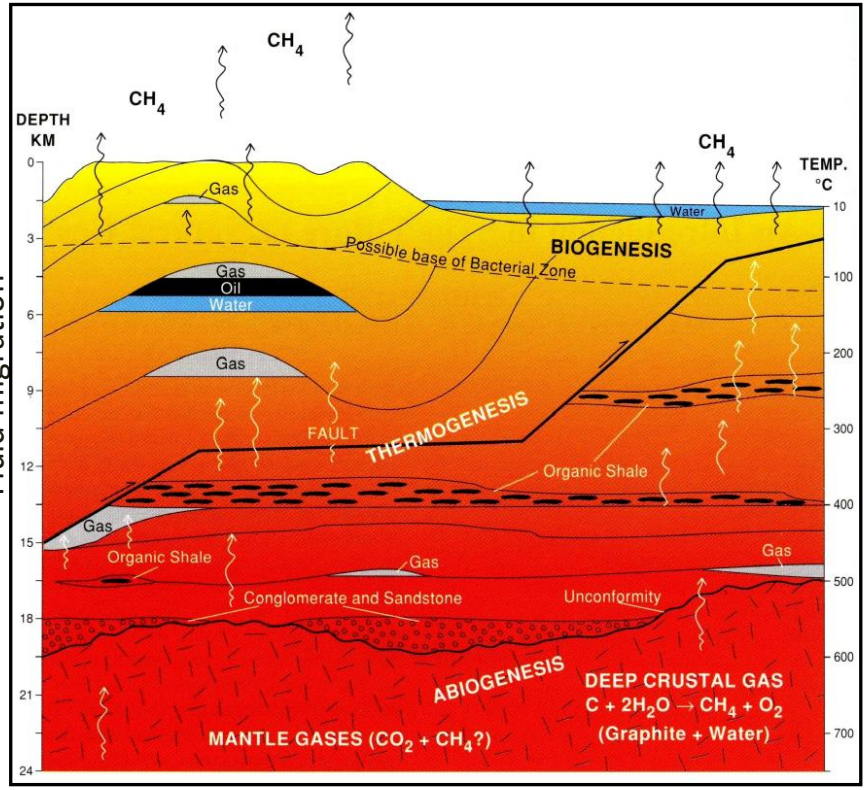
Fluide escapes from the seabed to form gas plumes

Hydrocarbons may pierce the seabed

Hydrocarbons tend to migrate by buoyancy

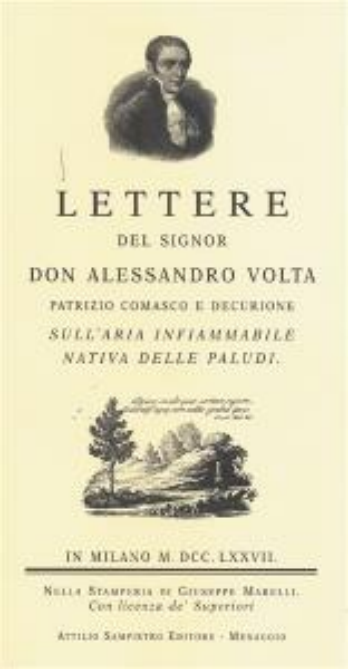
Deeply-trapped hydrocarbons

Fluid migration



methanogenesis

Howell et al., 1993

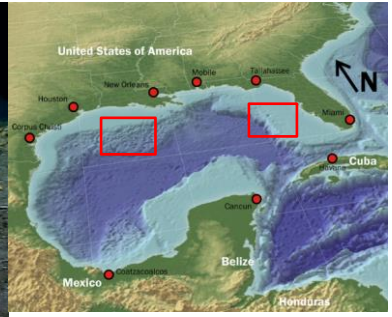

LETTERE
DEL SIGNOR
DON ALESSANDRO VOLTA
PATRIZIO COMASCO E DECURIONE
SULL'ARIA INFIAMMABILE
NATIVA DELLE PALUDI.

IN MILANO M. DCC. LXXVII.

NELLA STAMPERIA DI GIUSEPPE MARELLI.
Con licenza de' Superiori

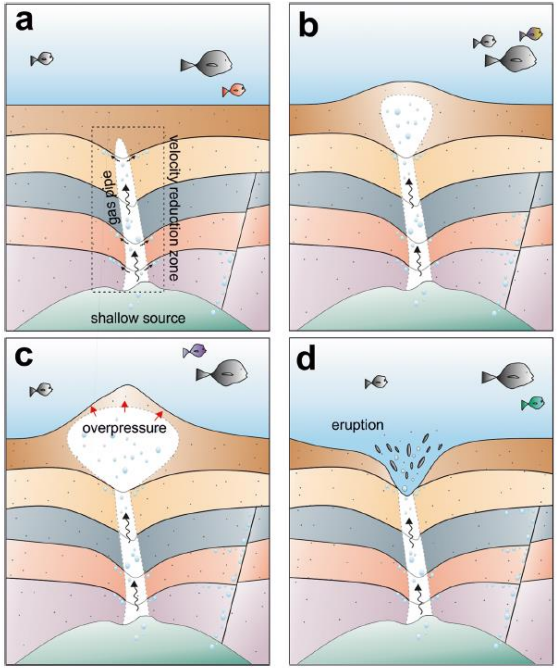
ATTILIO SAMPIETRO EDITORE - MENAGGIO

Methane seepage was first observed by Alessandro Volta in the lake beds of Lago Maggiore, northern Italy, in 1776, he noted gas bubbles and the inflammability of the gas “gas di palude”



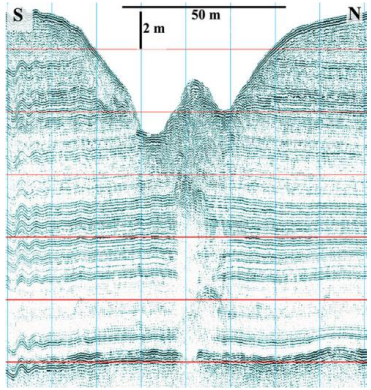
First discovery in the deep sea: Gulf of Mexico, Florida (Paull et al., 1984) and Lousiana (Kennicutt et al., 1985) continental slope with ROV

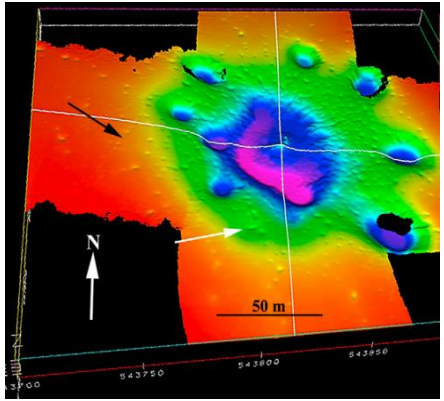
Morphological expressions of seepage: pockmarks



Sarıtaş et al., 2018

ROV video image of a 4-m-diameter pockmark at 1300 m depth NW Pacific Ocean. Monterey Bay Acquarium MBARI, 2009





CHIRP seismic profile (left) and multibeam bathymetry (right) of a pockmark (Hovland et al., 2010)

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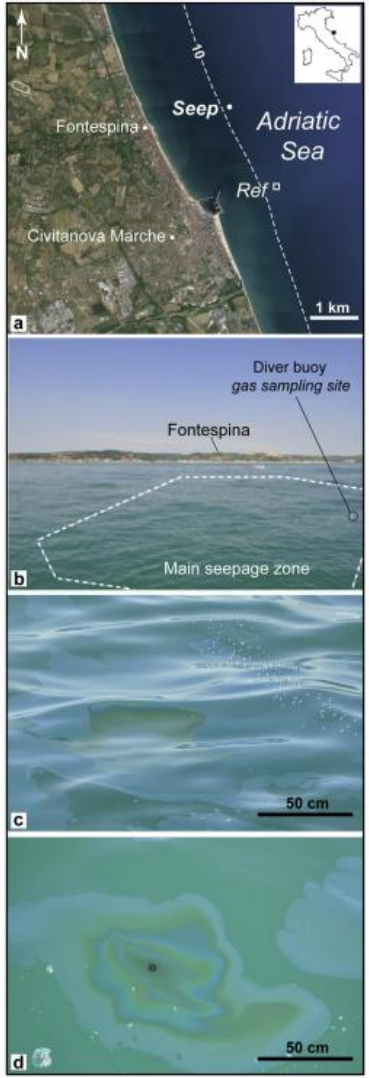
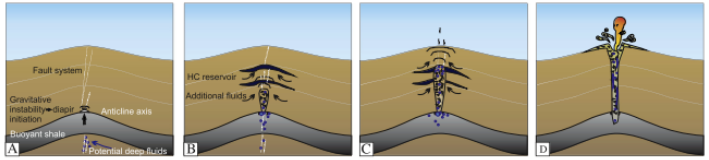
Morphological expressions of seepage: oil seeps

Asphalt volcano discovered in 2007 offshore Santa Barbara, California.
Image courtesy MARUM - Center for Marine Environmental Sciences



Offshore Fontespina, Adriatic Sea (Etiope et al., 2014)

Morphological expressions of seepage: mud volcanoes



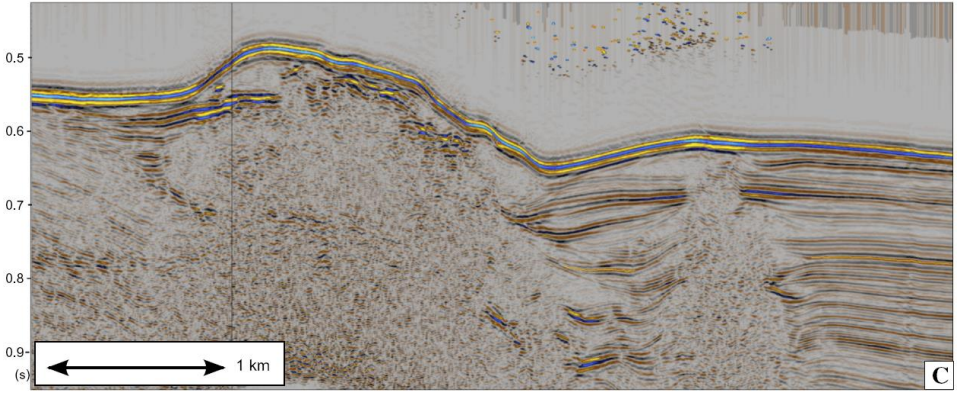
Diapir initiation in buoyant shales with potential deep fluids migration along structural highs (e.g. anticline axes) or fault networks

Fluids migration from different units and overpressure increase, diapiric structure development and brecciation during its growth

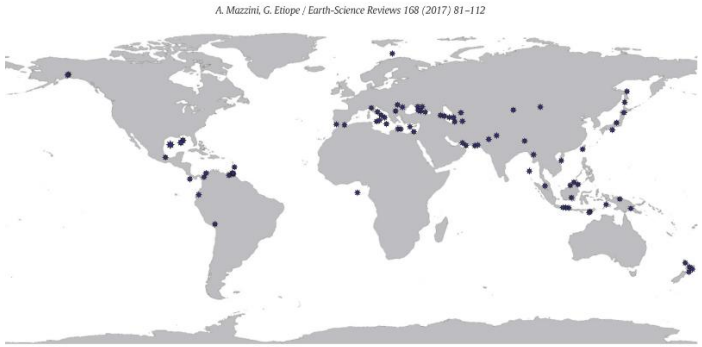
Overpressured diapir reaches critical depth. Overburden cannot contain fluids rich diapir. System in unstable conditions ready for triggering

Blast of gas. The sudden pressure release allows large amount of fluidized and gas saturated sediments to reach the surface

1 m^2 – 4 km diameter (terrestrial)) up to 12 km offshore (Orange et al., 2009)

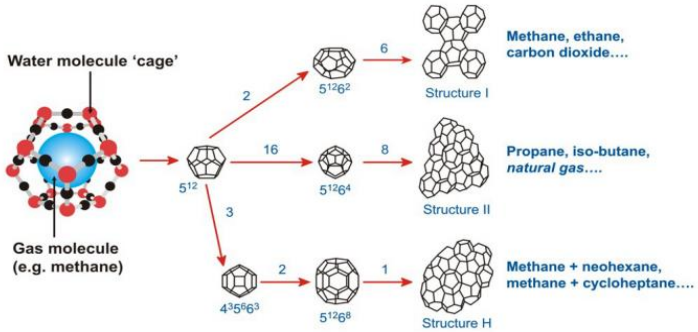


MCS seismic profile of a mud volcano (Mazzini and Etiope, 2017)

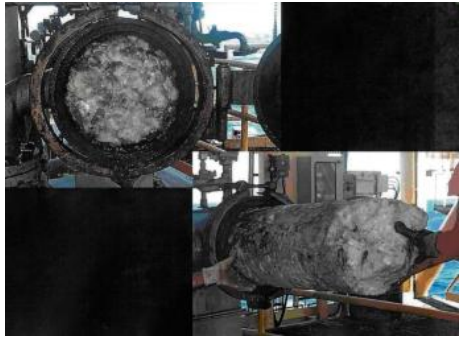


Global distribution of mud volcanoes (Mazzini and Etiope, 2017)

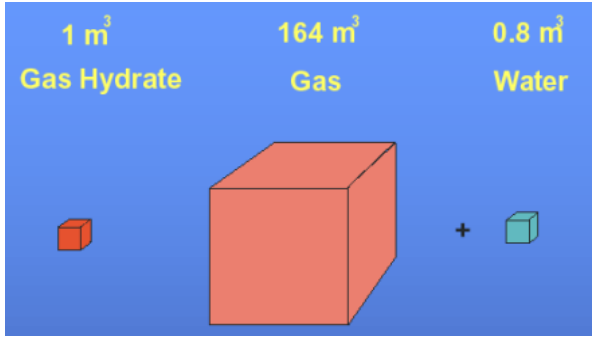
Gas hydrate pingoes



Gas hydrates are a crystalline solid formed of water and gas and look and act like ice, but they contain huge amounts of methane, not stable at normal sea-level pressures and temperatures (gas-hydrate stability zone), therefore represent either an hazard and a resource



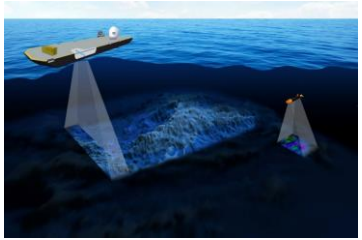
Gas hydrates clog a gas pipe

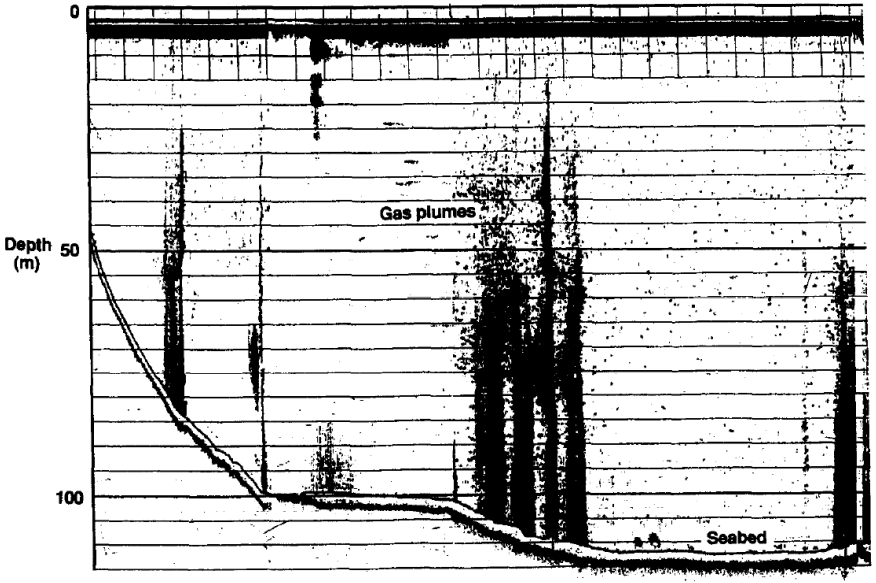


Gas hydrates methane potential

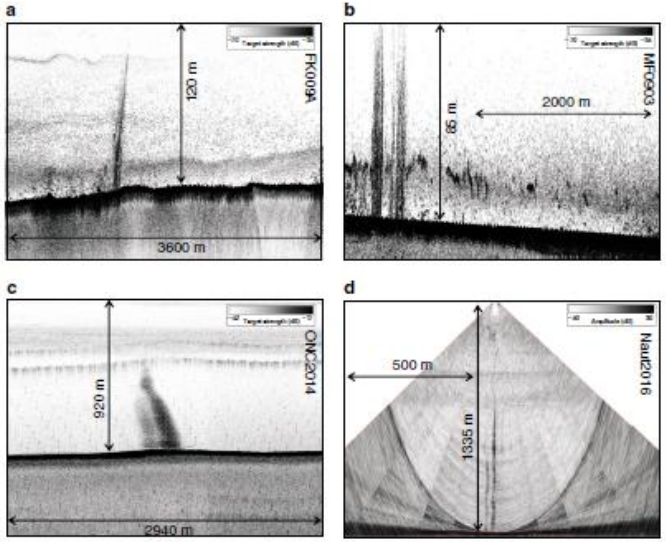
At the seafloor, when gas hydrate concentrate form pingoes (Judd and Hovland, 2007; Serié et al., 2012) often inside pockmarks. Offshore Norway, this pingo is covered with bacteria mat and vestimentiferan worms (Hovland and Svensen, 2006)

Gas flares in the water column





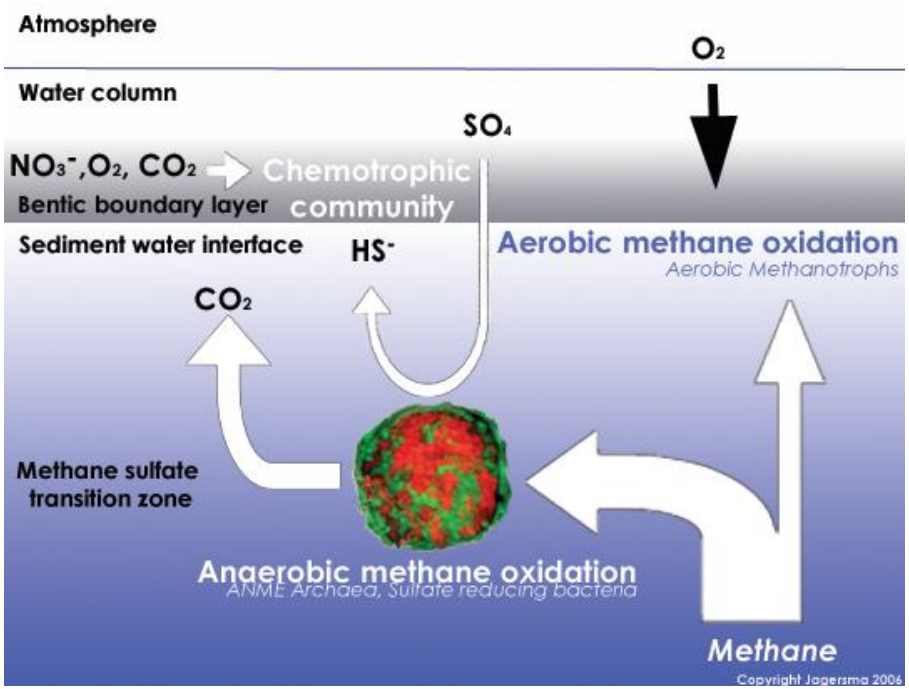
First images of hydrothermal gas plumes in the water column near Milo Island, Greece, from paper print of a ship echosounder, Dando et al. (1995)

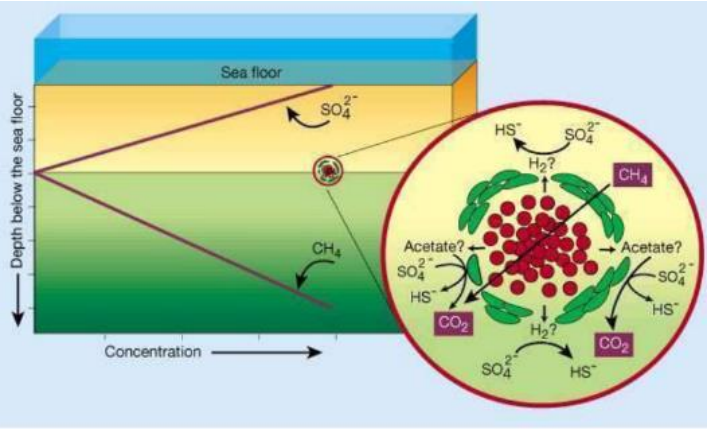


Evolution of marine geophysical techniques for detecting gas flares in the water column: from fish finders to multibeam systems that have increased the spatial and temporal resolution and accuracy in the detection of acoustic impedance contrast in the reflectivity (signal strenght return) of the water column. From Riedel et al. (2018)

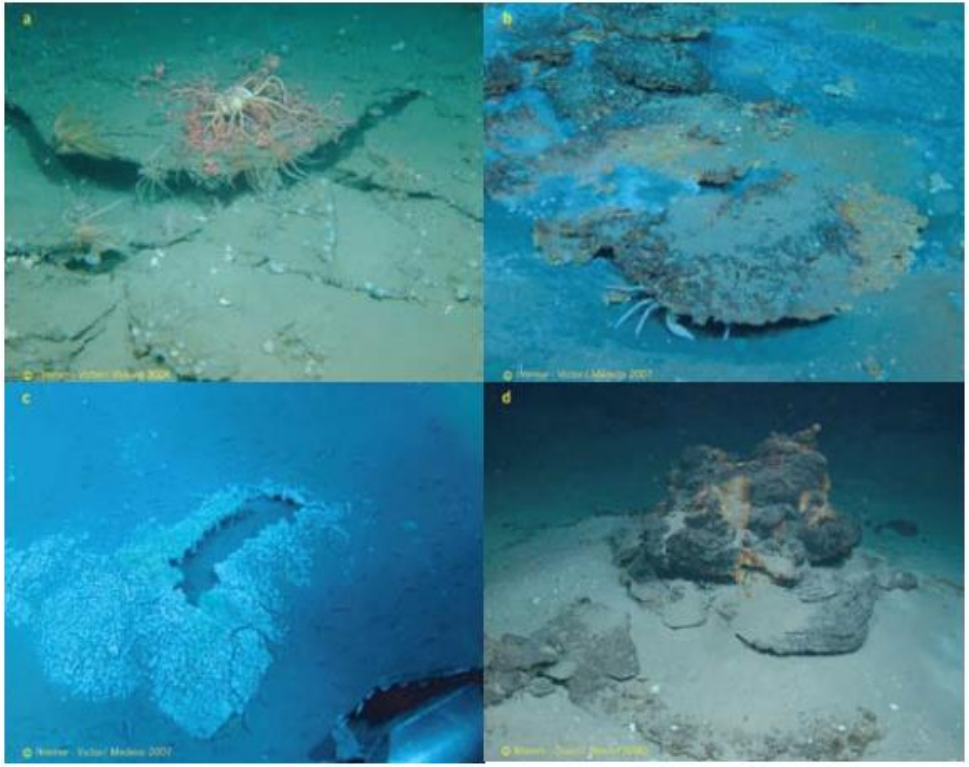
Methane can be consumed and converted into CO_2 by methane-oxidizing bacteria through a process called **Anaerobic Oxidation of Methane** (AOM) in the methane sulfate transition zone, few meters below the seafloor (Coleman et al., 1981).

Consortia of Archaea and sulphate-reducing bacteria (Hoehler et al., 1994: Hinrichs et al., 1999), which reduce sulfates contained in the pore waters, make it possible the AOM (Boetius et al., 2000).





$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$$



Secondary effect of AOM = precipitation of authigenic carbonates (Ritger et al., 1987) for supersaturation of $CaCO_3$ and authigenic sulfides such as pyrite (Konhauser, 1988) on the seafloor

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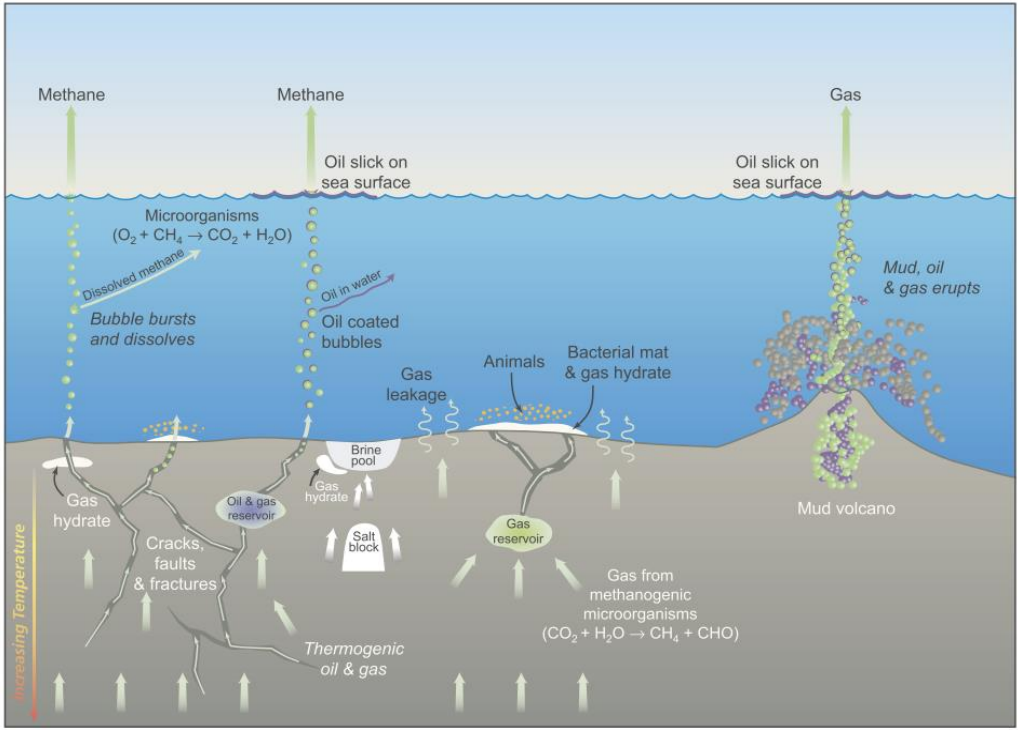
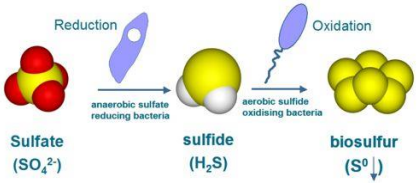


$$2H_2S + O_2 \rightarrow 2S^0 + 2H_2O$$



Sulfides sustain complex ecosystems that relay on the symbiosis with sulfide-oxidizing bacteria (e.g. Beggiatoa sp.) that convert the sulfides into energy for several animal species

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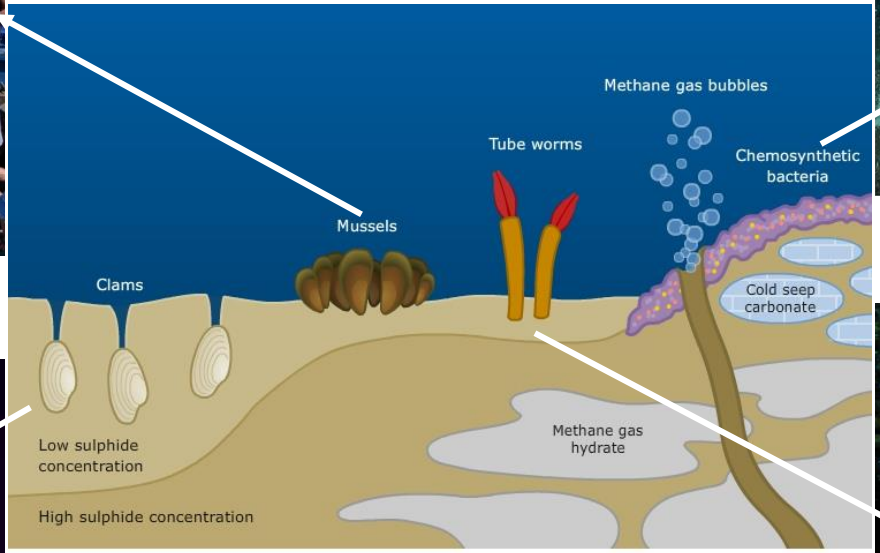
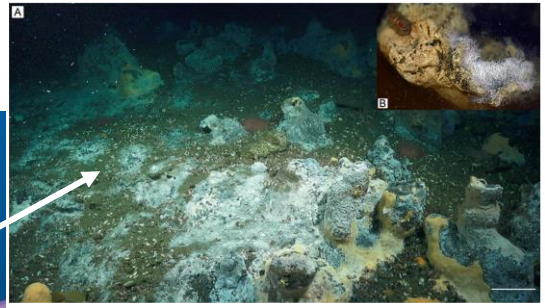
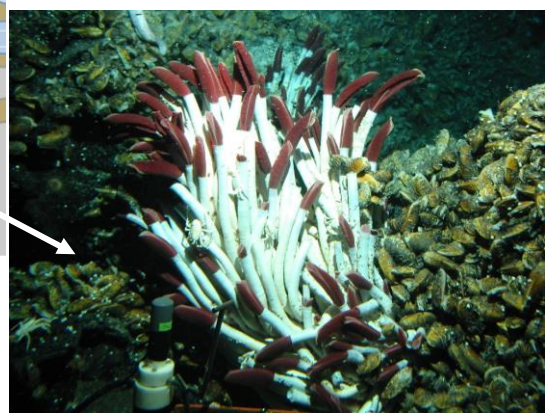
Acharax family Solemyidae (mussels)

Calyptogena family Vesicomyidae (clams)





Beggiatoaceae, bacteria
Leprich et al., 2021



Polichets family Siboglinidae (worms)

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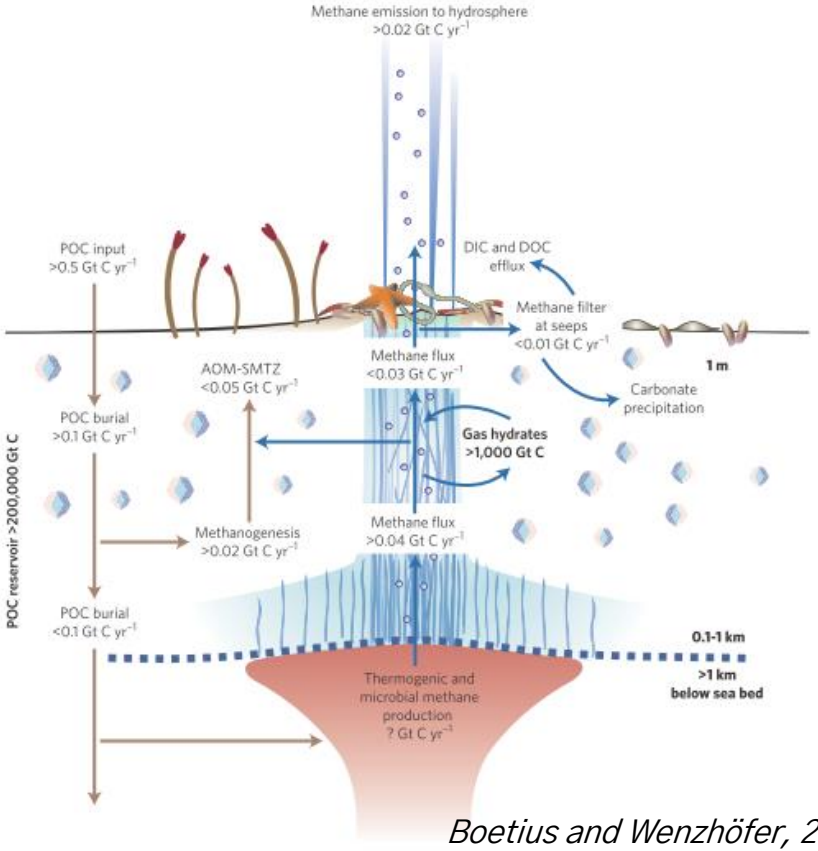
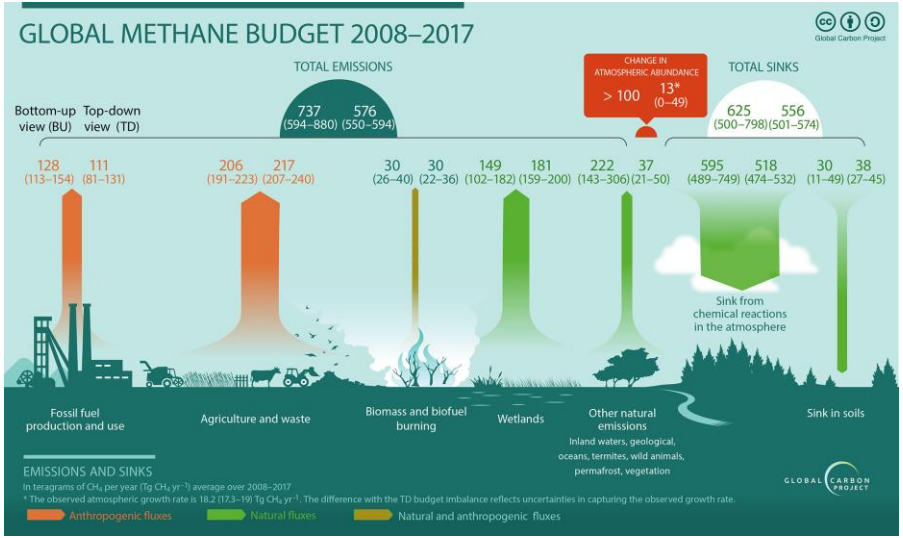


Boetius and Wenzhöfer, 2013



Saunois et al., 2020

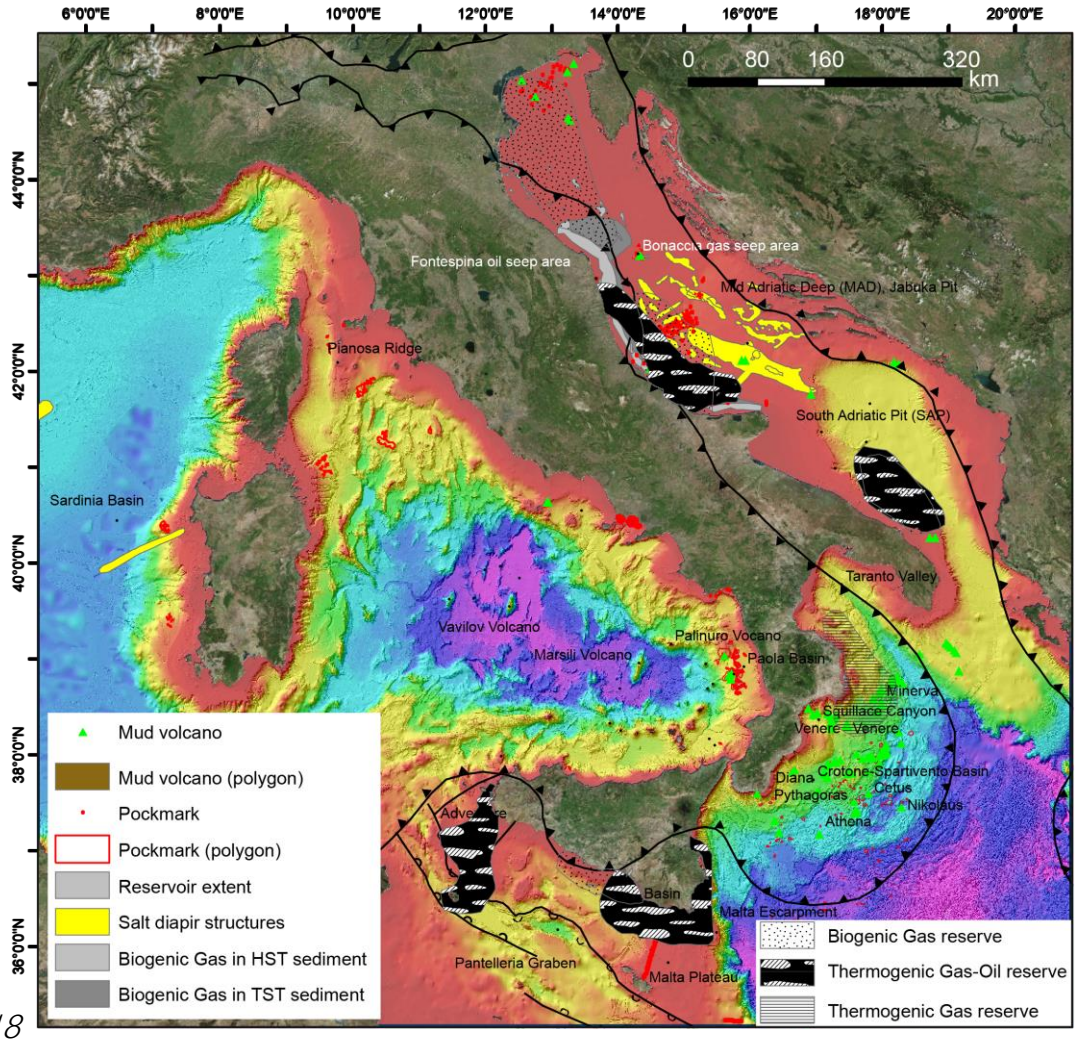
Global estimate for marine geological emissions in the atmosphere: 0.005–0.01 Gt CH_4 yr^{-1}

Mapping the natural seepage in the Central Med

Hydrocarbon seepage and fluid migration are overlooked in the marine environment

This is due to high costs, lack of high-resolution exploration data, adequate smart equipment

There is need for an integrated, multidisciplinary investigation



Rovere et al., 2018

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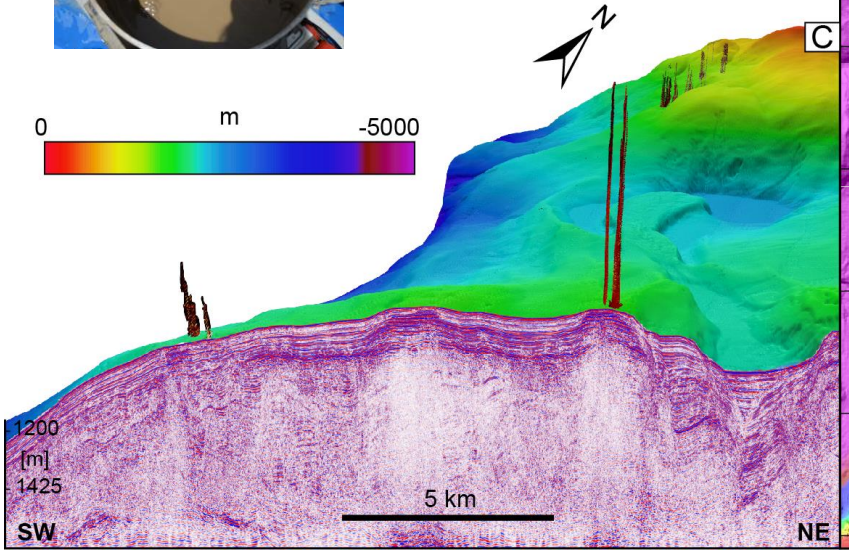
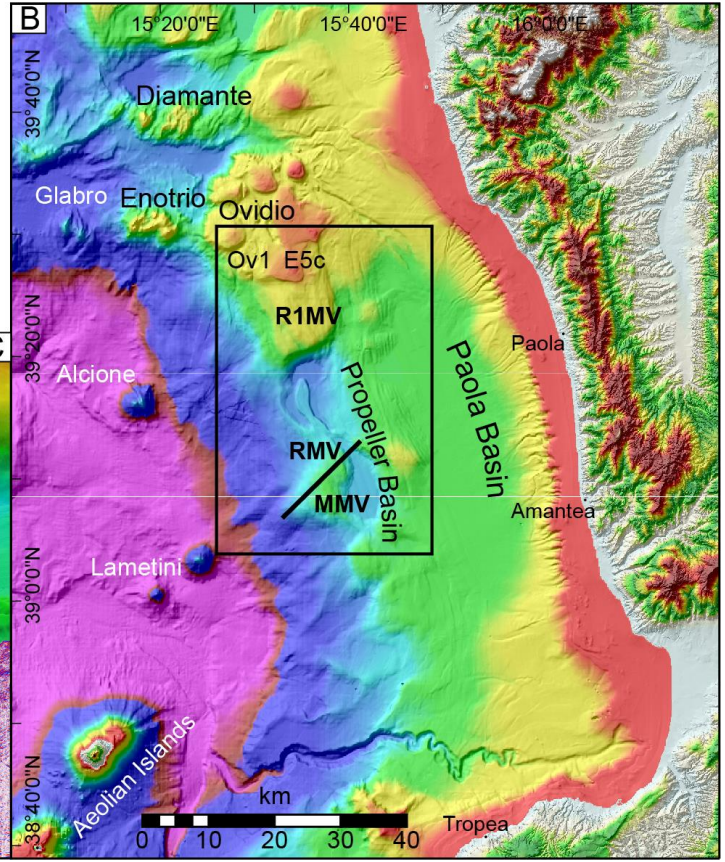
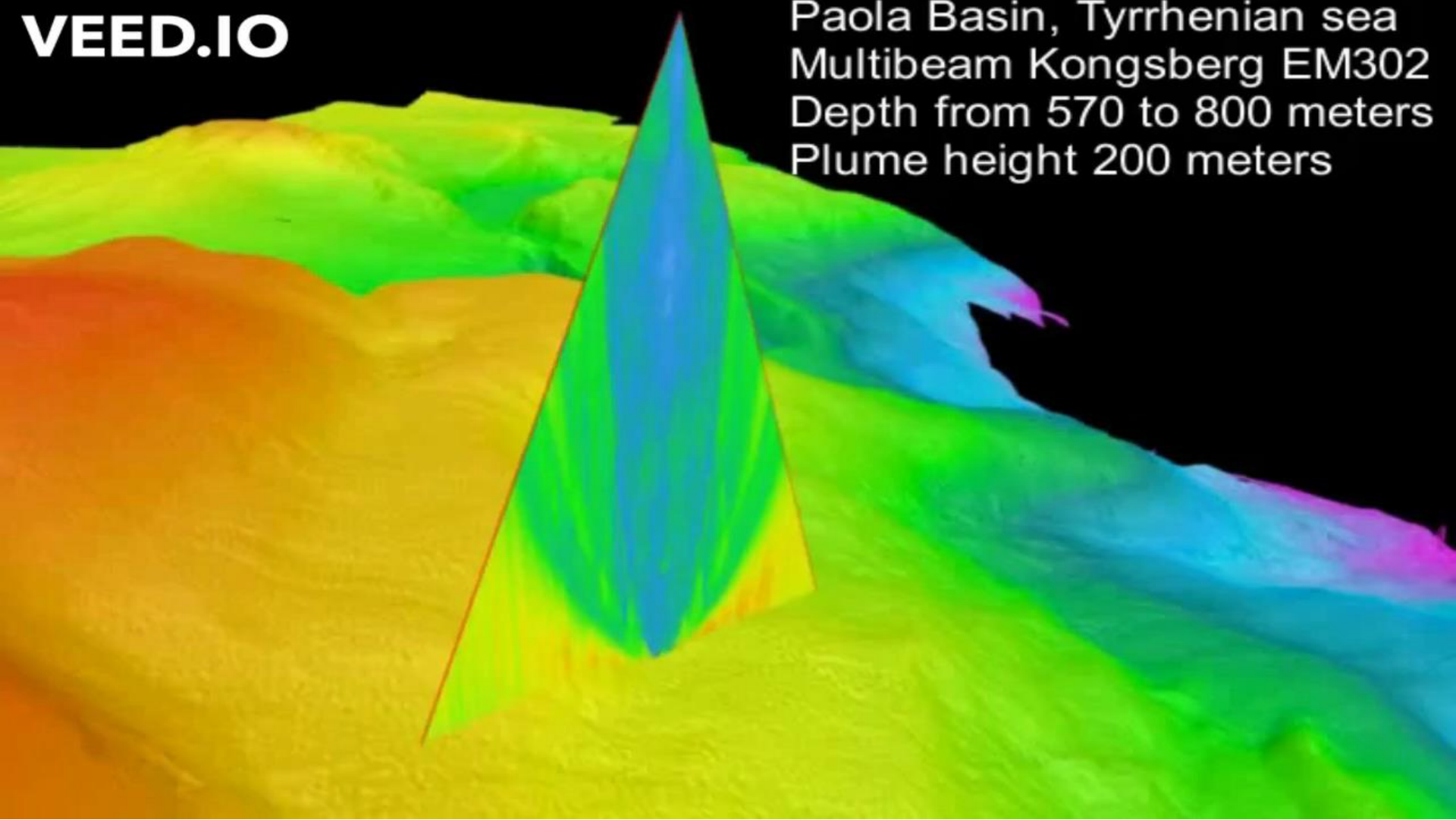
Sampling station	CO_2 (%)	N_2 (%)	O_2 (%)	Ar (%)	CH_4 (%)	$\delta^{13}C_{CO_2}$ (‰)
MB14 BC05	98.73	1.08	0.11	0.026	0.056	-1.1
MB14 BC09	98.61	1.26	0.053	0.031	0.051	-1.8

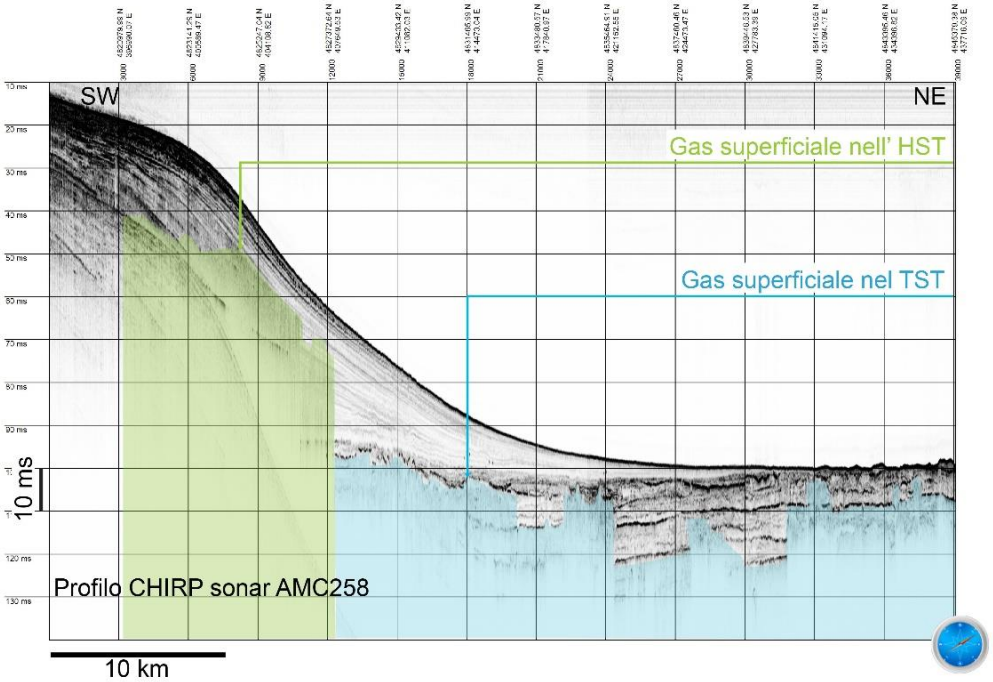


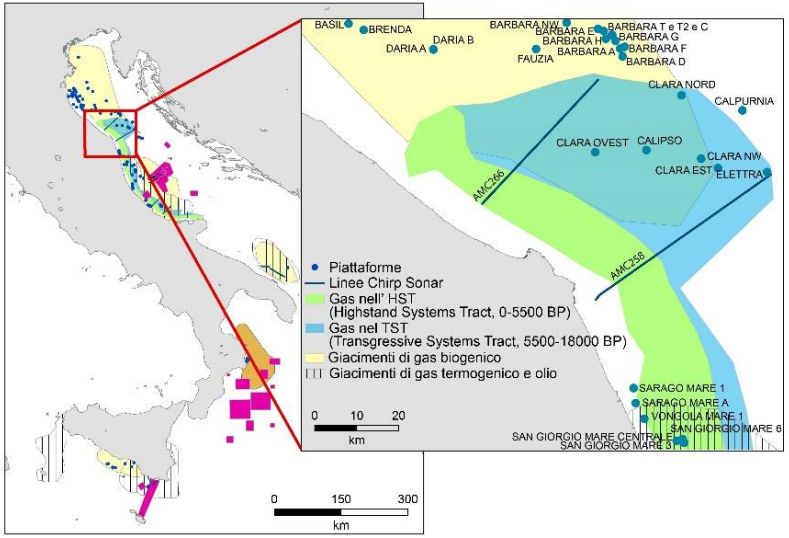


Rovere et al., 2022


VEED.IO
Paola Basin, Tyrrhenian sea
Multibeam Kongsberg EM302
Depth from 570 to 800 meters
Plume height 200 meters

Seepage in the Adriatic Sea





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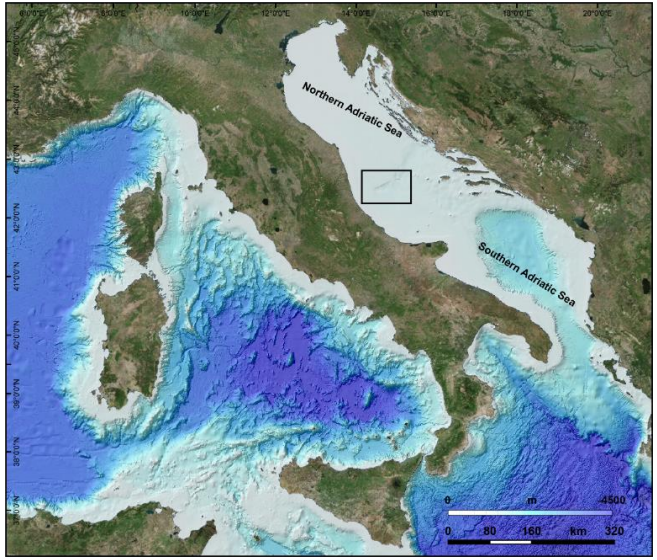
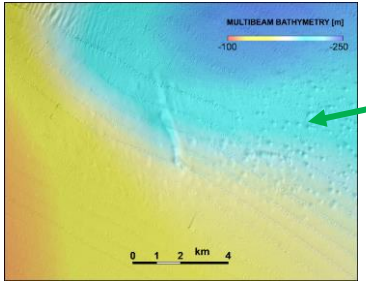
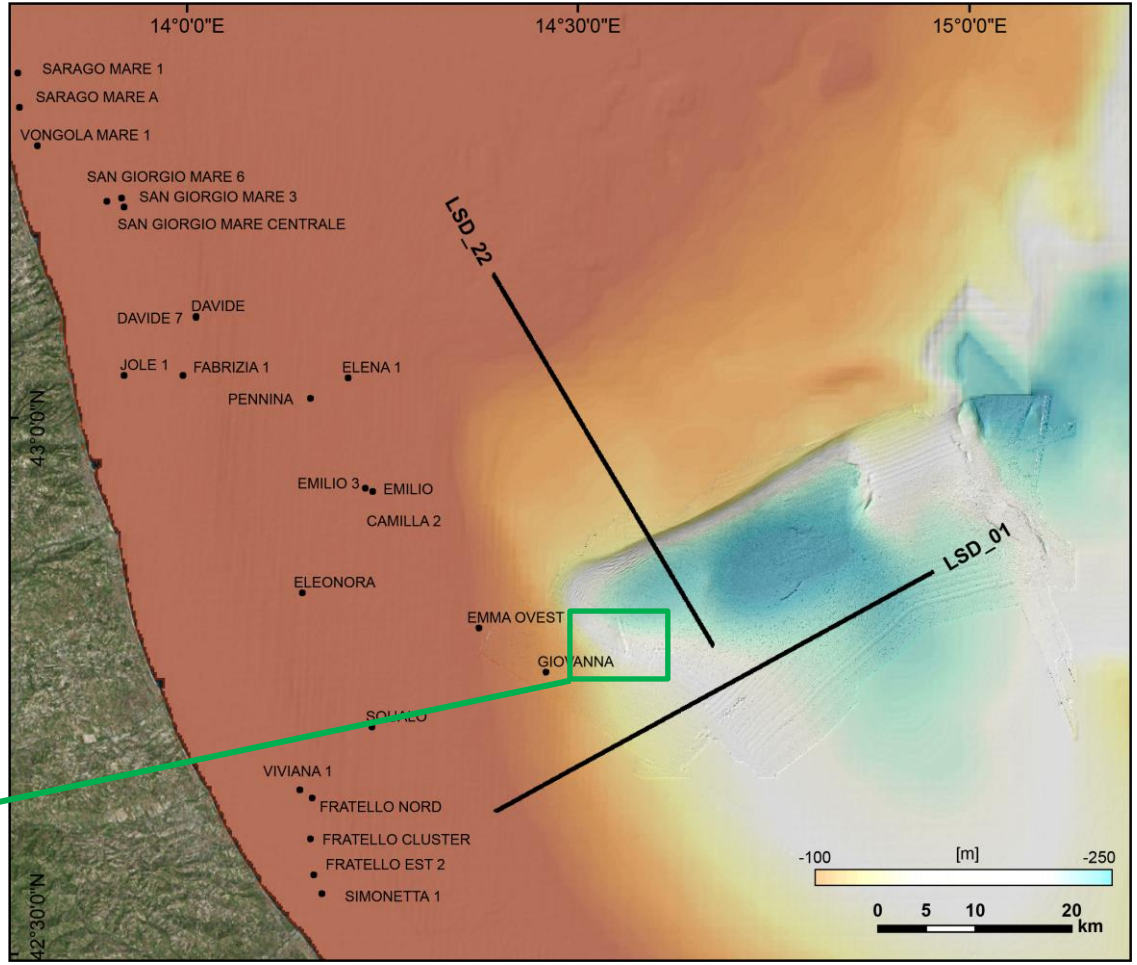




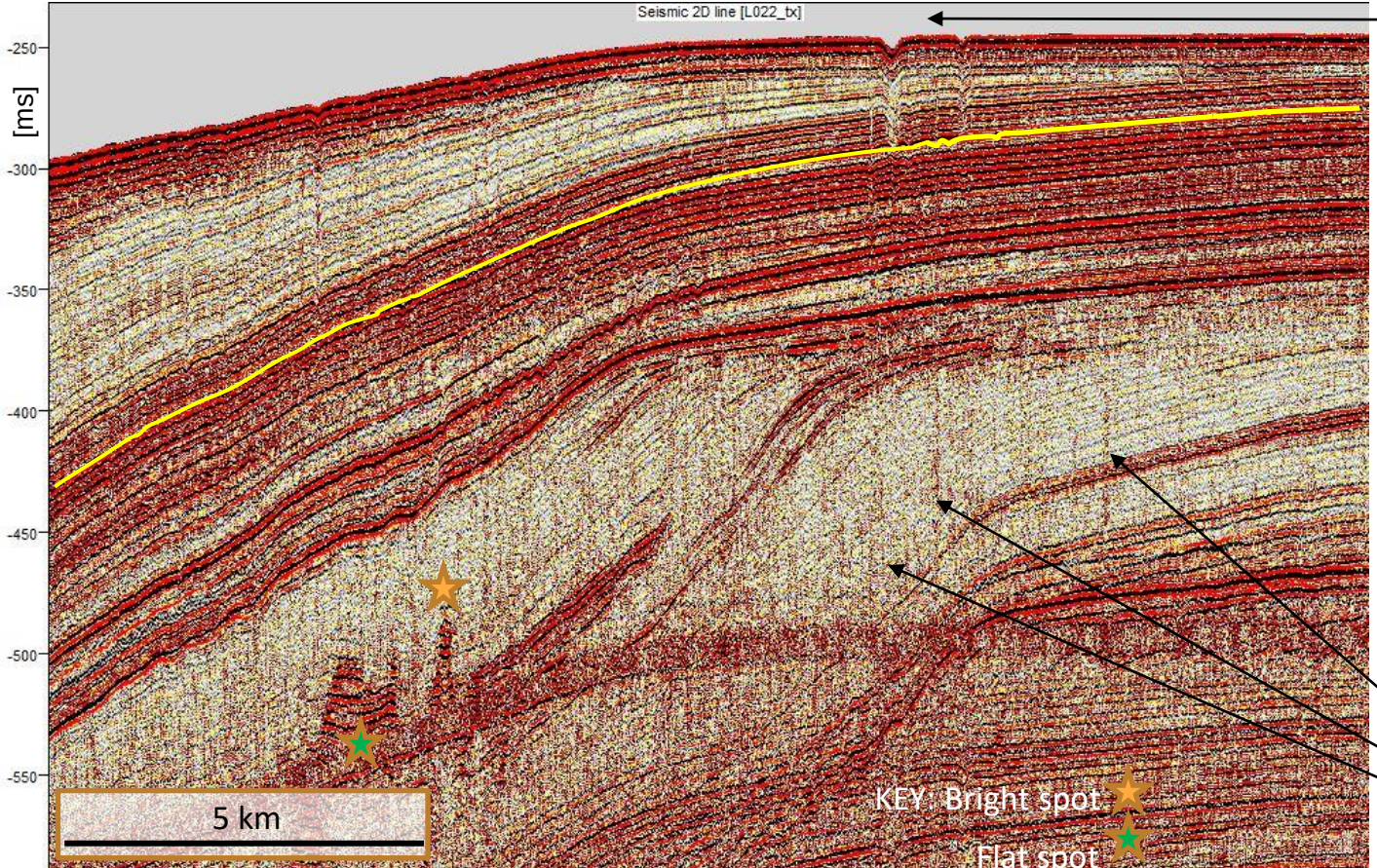


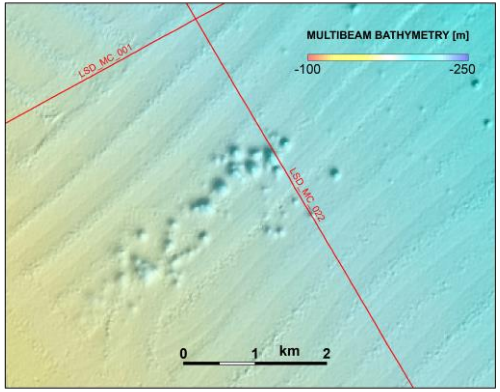
MCS line LSD_22

NW

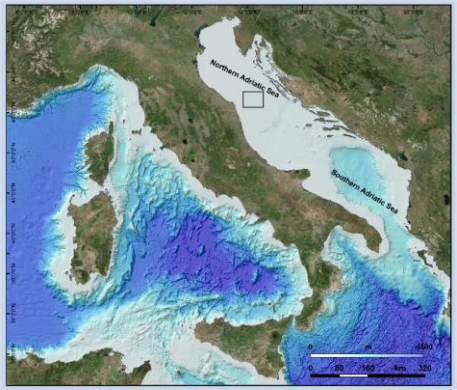
SE

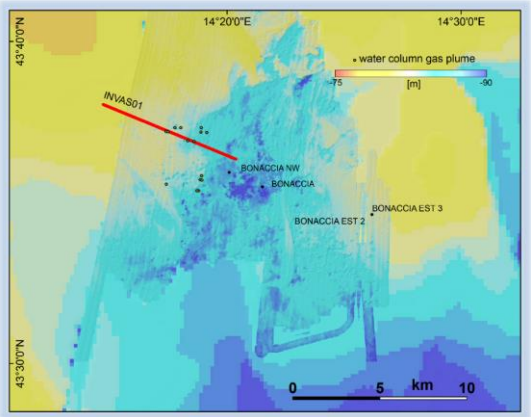
Pockmark with a marked morphology above the yellow reflection (60 ky BP)

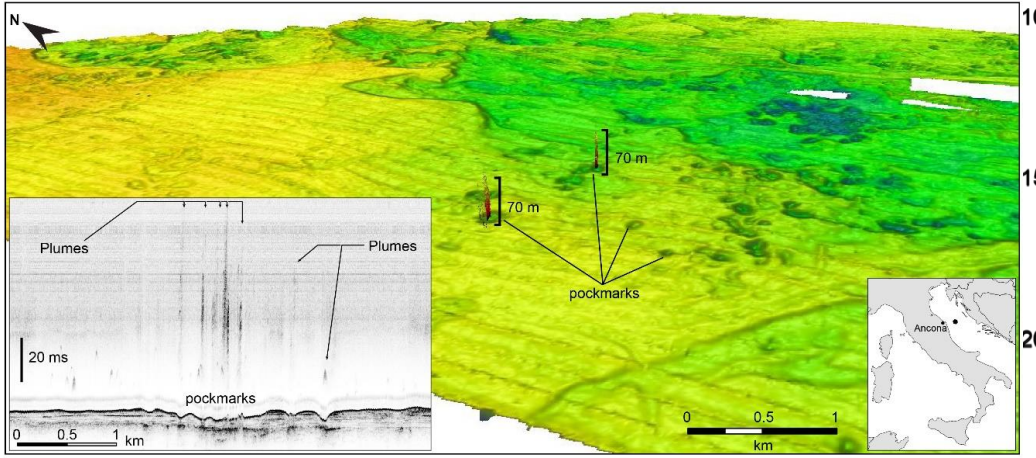


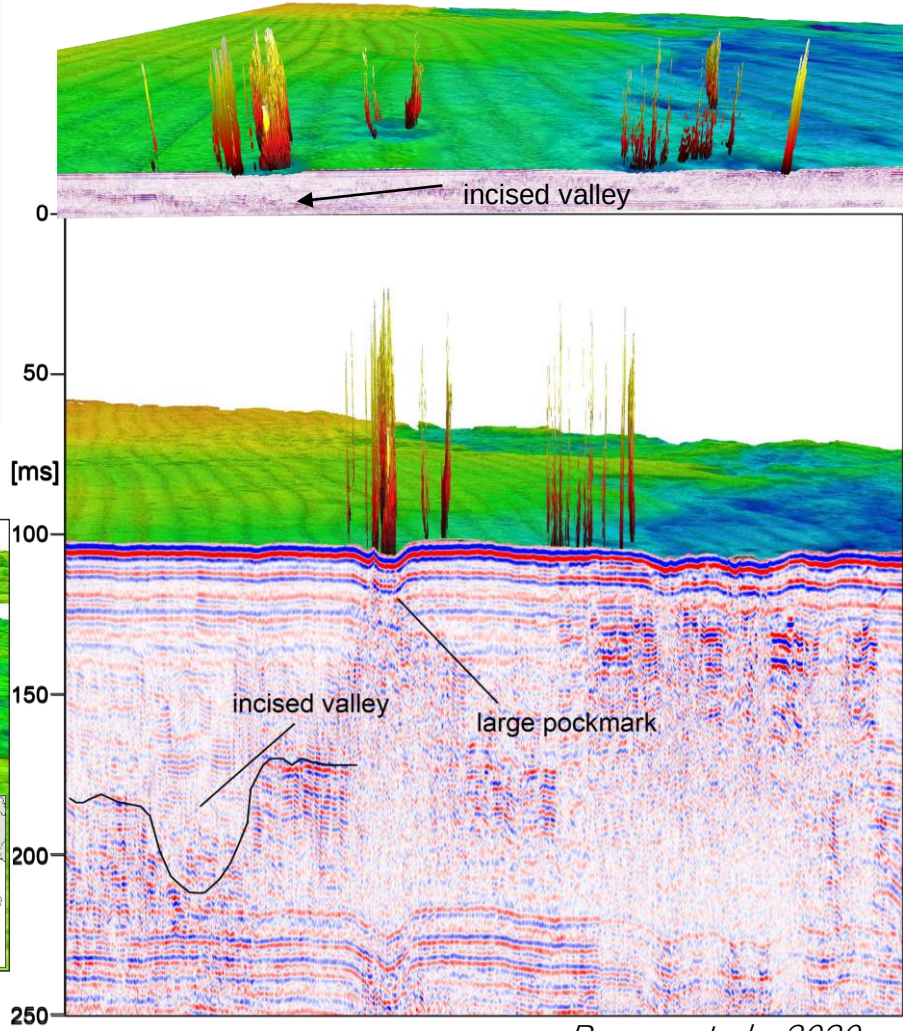


Local change in seismic amplitude









Rovere et al., 2020

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Why monitoring of seepage

- Understanding the transport processes of hydrocarbons from the sub-seabed to the hydrosphere and potentially the atmosphere is important to better quantify the **global carbon budget**.

- Understanding the migration of hydrocarbons in the subsurface is of primary importance for oil and gas exploration. Fluid migration structures on reflection seismic data are difficult to map manually and subtle features that are related to hydrocarbon migration are often overlooked.

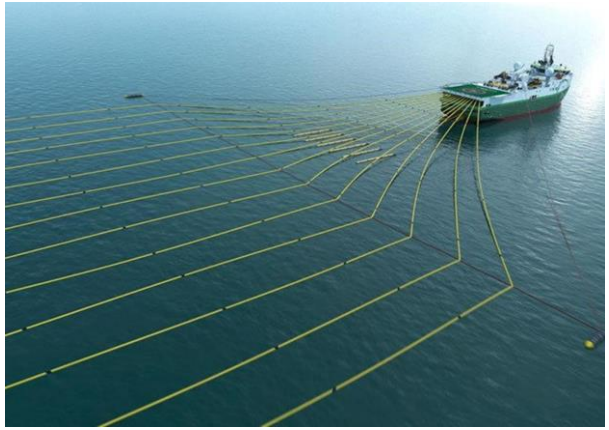
Main questions

- How much of the methane released from the seafloor reaches the upper water column and/or the atmosphere?
- What is the variability of the methane release and what are the processes involved?
- What are the interactions between the physical, chemical and biological processes that affect methane transport?
- How much natural methane seeps contribute to the atmospheric compared to leakage from offshore exploitation?

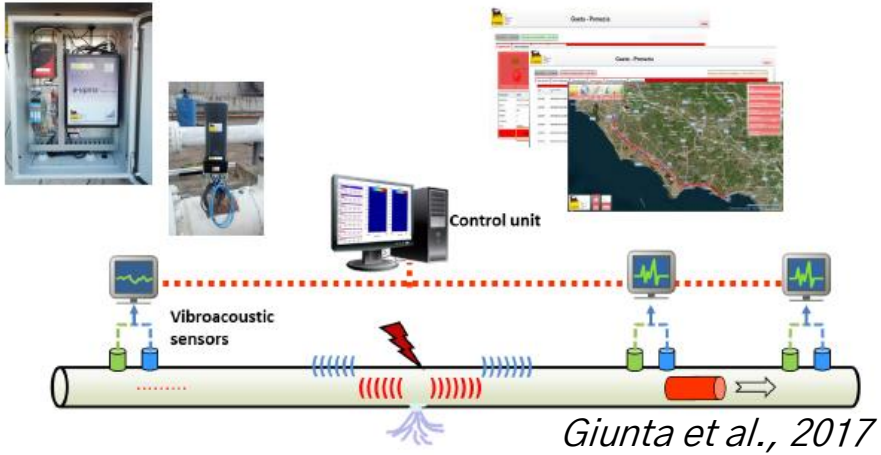
Exploration and monitoring by industry

- Large-scale investment and projects
- High environmental impact
- Slow response
- Restricted applicability

3D seismics



Advanced Vibroacoustic Pipeline Monitoring



Giunta et al., 2017

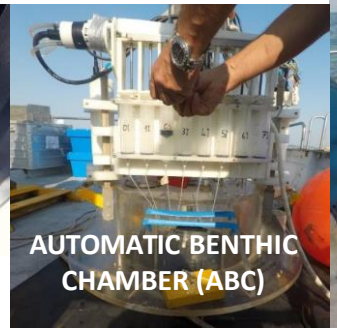
Monitoring integrated solutions

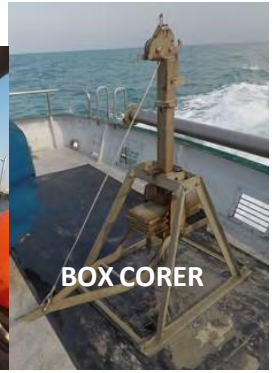
REMO: cost–effective and **RE**locatable **MO**nitoring

Multidisciplinary

It is the combination of the geophysical, geochemical and sedimentological methods

Multi instrument





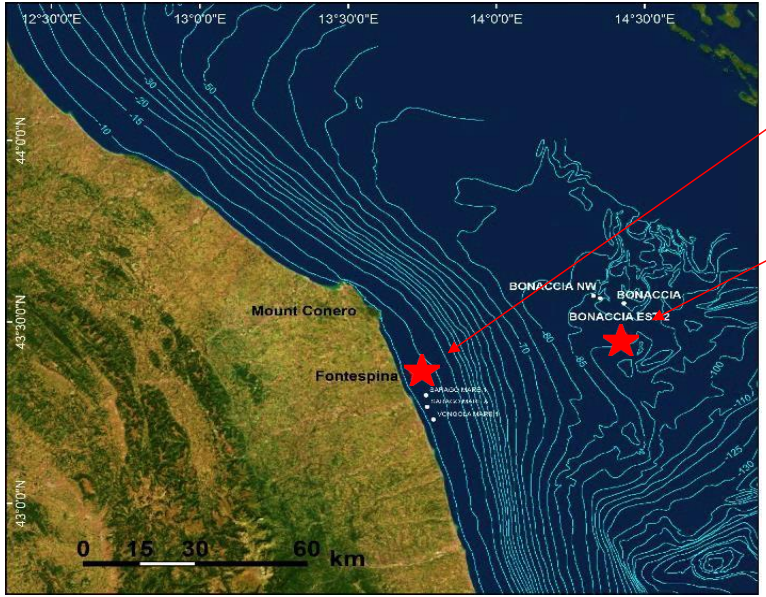
Cost-effective

It has been designed thanks to techniques and know-how developed by CNR – ISMAR, CNR – IRBIM and Ministry of Economic Development (DGS – UNIMIG – DIV. V)

Relocatable

Depending on the area in which it is applied it is able to identify, characterize and monitor seepage

Where has REMO been tested?



FONTESPINA SITE

OFFSHORE Mt CONERO SITE

Fontespina	**11 m**	**Coast**	**thermogenic**	**The only natural offshore oil spill known in Italy**
Offshore Mt. Conero	**84 m**	**offshore**	**biogenic**	**Near the Bonaccia cluster of gas exploitation platforms**

Multibeam system

The EM2040 system is a dual head large swath coverage [140-200°] shallow water multibeam echo sounder mounted on the keel of R/V Tecnopesca II with operating frequency range 200-400 kHz. For the water column survey, an optimized frequency between 250 and 300 kHz was used.

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Automatic Benthic Chamber

ABC is a cylindrical Plexiglas device.

Multiparameter probe to record continuously T, S, O_2, pH and depth.

Equipped with a system to collect water samples.

IN THE REMO method

- To collect water samples for geochemical analyses(hydrocarbons).

-To measure the dissolved benthic fluxes (O_2 , DIC, pH) in the sediment-water interface.

Box Corer

Box-corer (17 x 10 x 24.5 cm)

IN THE REMO method

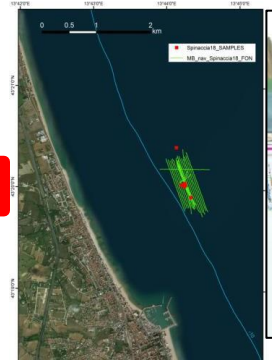
- To collect sediment samples nearby hydrocarbon seepages (n = 6 for each site) for geochemical analyses and characterization of sediments (PAHs, metals, major and trace elements)

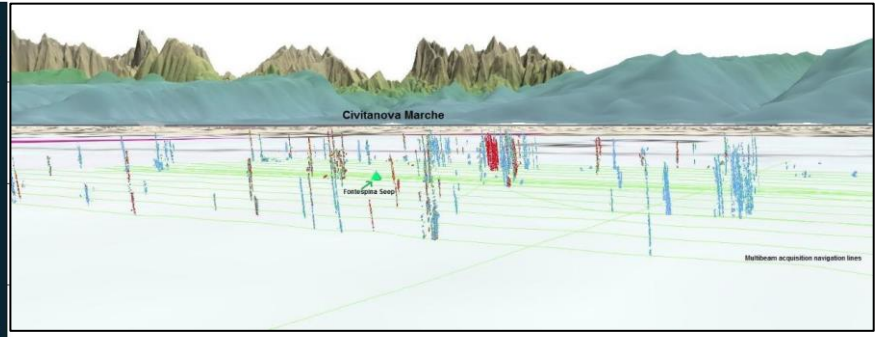
Fontespina oil spill site

RESULTS

FONTESPINA SITE

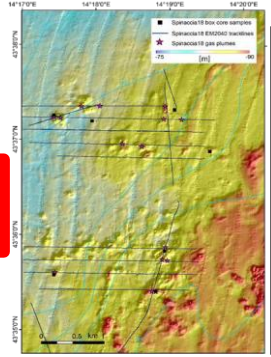
110 gas plumes

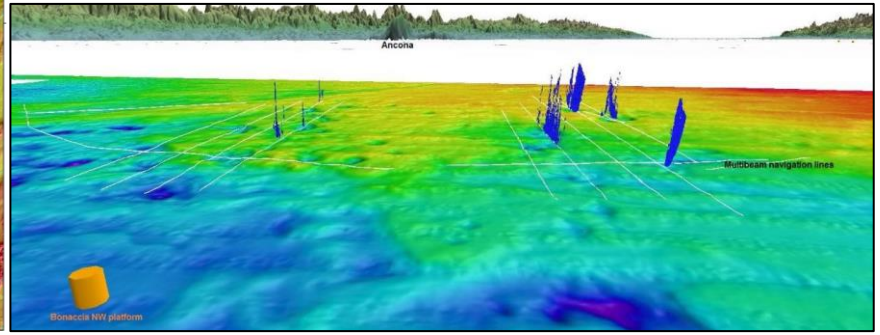




OFFSHORE Mt. CONERO SITE

31 gas plumes





Gas plumes in 3D in the water column, acquired by the Multibeam

RESULTS

The multiparameter probe recorded stable values of depth (11.04 ± 0.05 m), temperature (27.7 ± 0.01 °C) and salinity (37.4 ± 0.01).

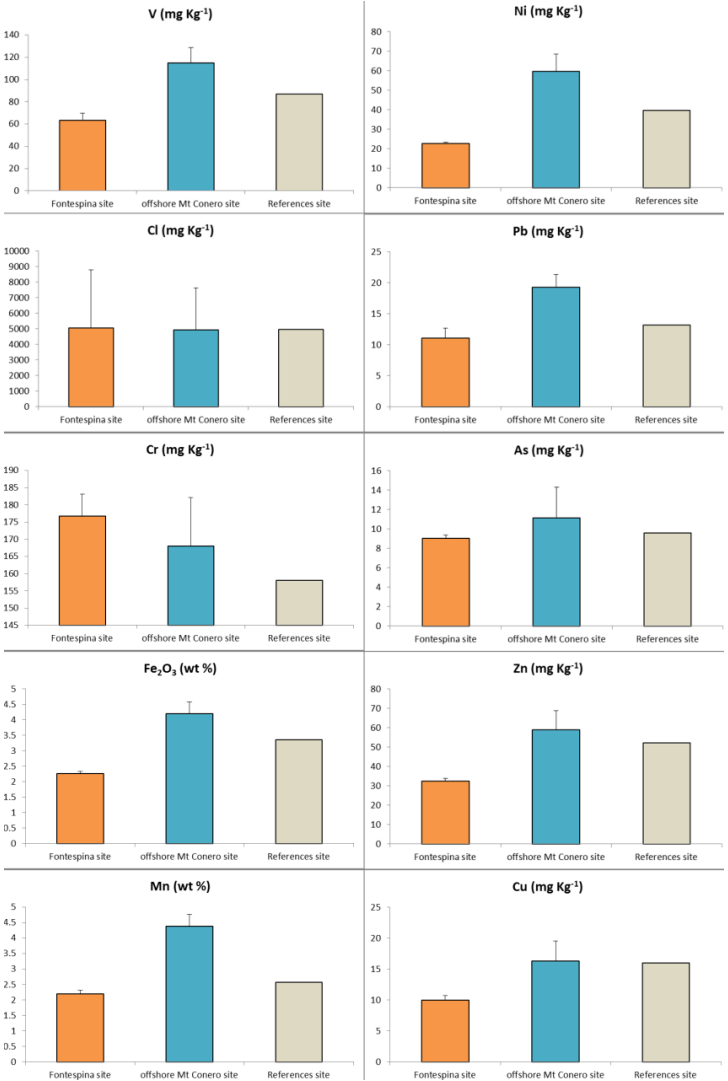
Presence of a higher content of reactive organic matter and/or older and thermogenic organic substances. This is possibly due to natural hydrocarbon seepage contributions coming from deeper sediments.

Automatic Benthic Chamber deployed on the seabed (9 working hours)

Dissolved benthic fluxes (mmol/m²*d)			
	Oxigen	**Dissolved Organic Carbon**	**H^+**
Fontespina	**-51**	**42**	**2e-0.7**
Reference site*	**-39**	**9,4**	**n.d.**

* Central Adriatic Sea (*Spagnoli et al., 2010*)

RESULTS

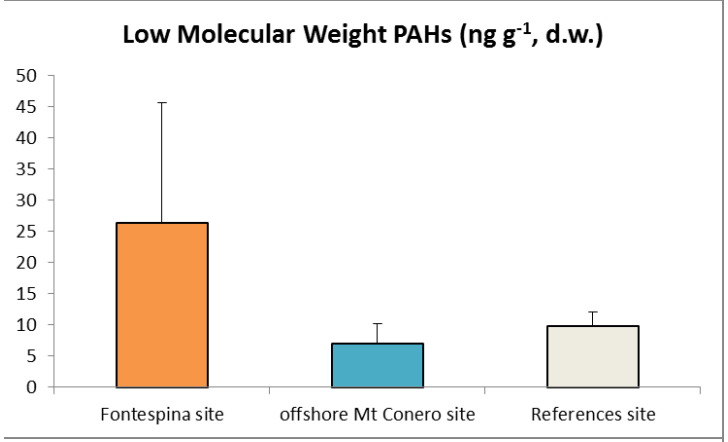


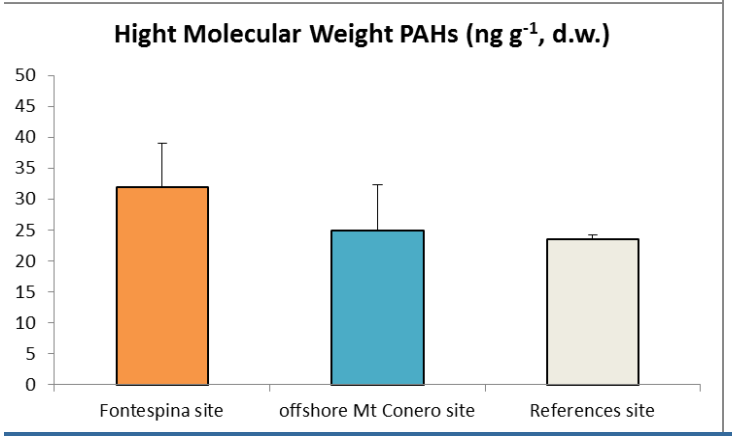
Fontespina site
Offshore Mt Conero site
Reference site

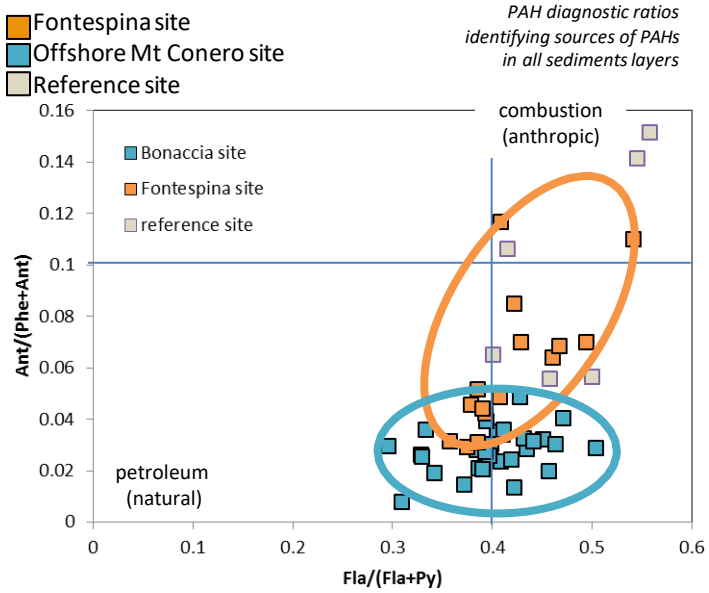
Metal, major and trace elements in sediment samples showed a distinct chemical composition between two sampling sites.

Higher values were observed in the Offshore Mt. Conero site than in the other one, suggesting deeper-sourced fluid contribution to the mineralization of the sediments around the site.

RESULTS







A greater concentration of Low Molecular Weight hydrocarbons was recorded in the Fontespina site, underlining a presence of natural and thermogenic sources in this site.

In the PAH sources cross-plot, the Fontespina site showed a wide variability in PAH sources than in the other one, suggesting an influence due to its proximity to the coast.

RESULTS

Metal composition by ICP-OES

Values (mg/L)							
Metal species	0 I	1 I	3 I	4 I	5 I	6 I	7 I
Al	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Cd	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Cr	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Cu	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Pb	< D.L.	< D.L.	0.0468	< D.L.	0.0190	0.0228	< D.L.
Mn	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
As	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
B	4.1744	5.3180	4.5720	3.8472	5.2658	5.3828	4.1482
Ba	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Be	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Co	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Fe	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Ni	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Se	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.	< D.L.
Sn	0.0636	0.0632	0.0632	0.0632	0.0632	0.0632	0.0632

Gas composition by static headspace gas chromatography

C10–C40	
Sample	mg/L
0 I	28.6
1 I	36.9
3 I	< L.R
4 I	0.56
5 I	2.47
6 I	2.03
7 I	< L.R

7 water samples, collected with the benthic chamber in Fontespina, show that major gas compounds are: nitrogen, oxygen and only in some samples, traces of carbon dioxide and methane. Regarding the metal composition, the results show a typical sea water composition and no evidence of hydrocarbon or heavy metal/trace metal contamination

REMO: Advantages and Limits

It is easy to use and cost-effective.

It avoids the use of divers, complex exploration instruments, a large vessel and expensive analyses.

It is versatile and deployable in different environments.

Can be used only up to 200 m water depth.

The sea must be extremely calm and the boat must be capable of maintaining the same position during monitoring.

Needs several improvements (gas sampling; video camera for real-time monitoring; methane sensors; automatic deployment and recovery).

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Robotic solutions

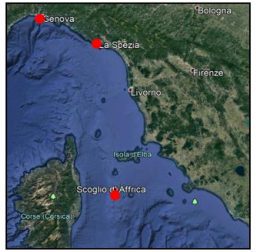
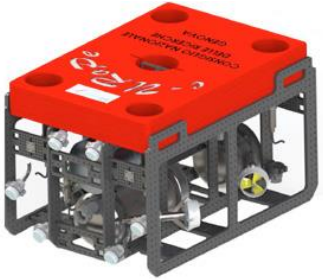
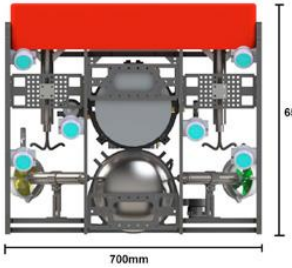
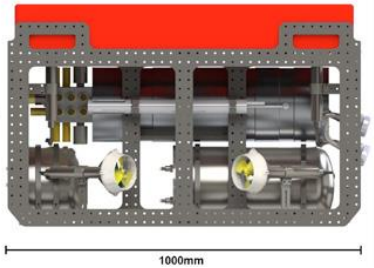


Table 1. e-URoPe characteristics

Main Characteristics			
Type	Open Frame Hydrid AUV/ROV		
		Vehicle	**Tool Sled**
Length L	$[mm]$	1000	1000
Breadth B	$[mm]$	700	700
Height H	$[mm]$	650	400
Weight	$[kg]$	100	50
Maximum Depth	$[m]$	250	
Rated Speed	$[m/s]$ at$200[m]$	0.5	
Single Propeller Thrust	$[N]$	38	
Vertical Thruster	nr	4	
Horizontal Thrusters	nr	4	
Power and Electronics			
ROV Communication	2GBit - Fiber Optic Ethernet		
AUV Communication	Acoustic Modems		
Power	$[W]$	900	
AUV Autonomy	$[h]$	1	+2
Native Payload			
CTD Probe	nr	1	
Echo Sounder	nr	2	
LED Lights	nr	4	+4
Video Camera	nr	2	+2
IMU		1	

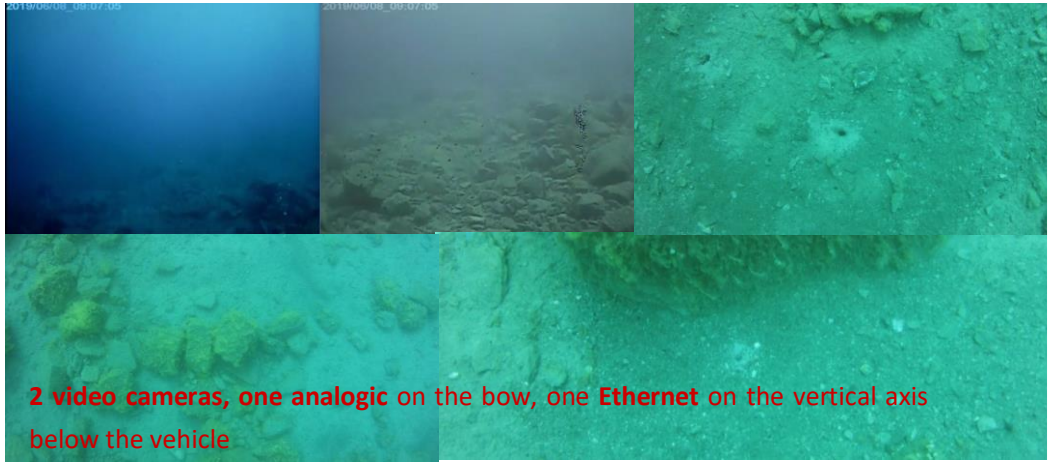


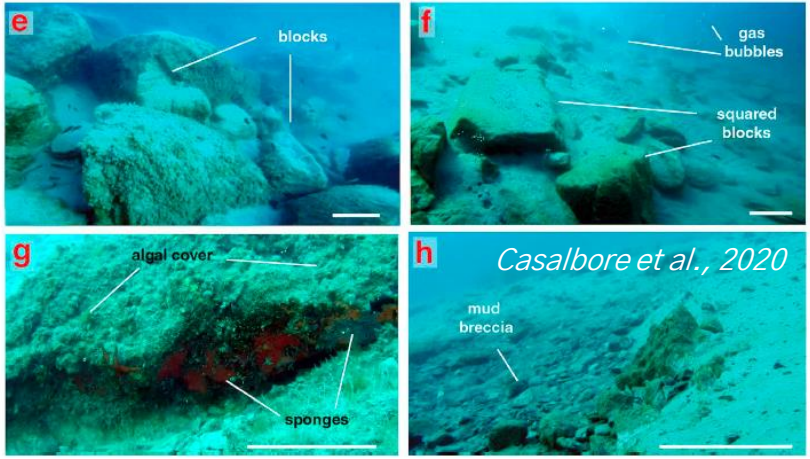




INM INSTITUTE OF MARINE ENGINEERING

off Montecristo Island





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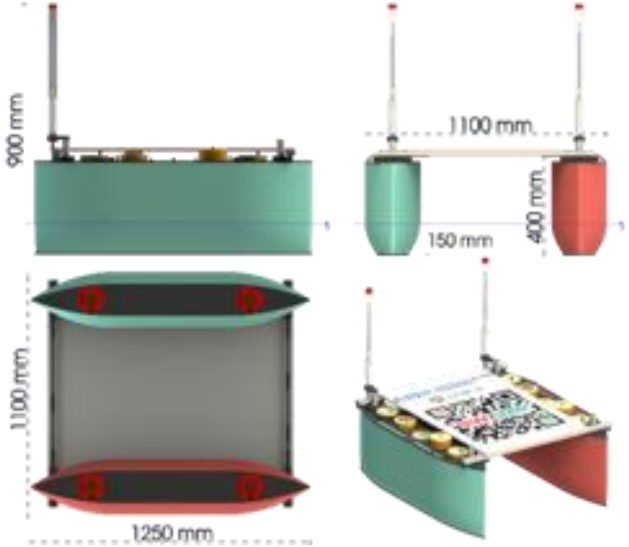
Equipping robotic solutions with multibeam echosounders

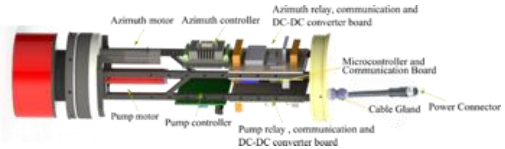
Specifications	2020
Selectable Frequencies	**200-400kHz** **700kHz (option)**
Beam Width	**1°** x 1° @700kHz **2°** x 2° @400kHz 4° x 4° @ 200kHz
Selectable Swath	10° to 130°
Sounding Depth	**100m**
Number Soundings	Selectable 256/1024*
Immersion Depth	100m/4000m
Power Consumption	20W
Size /weight	15x15cm, 4kg

Interreg Italy - Croatia InnovaMare
European Regional Development Fund
EUROPEAN UNION

Single components of MBES installation, from left to right: sonar head, I2NS, MRU, mini SVP

SWAMP (Shallow Water Autonomous Multipurpose Platform)

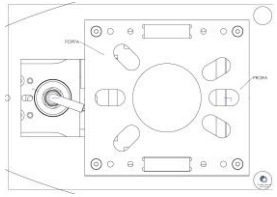


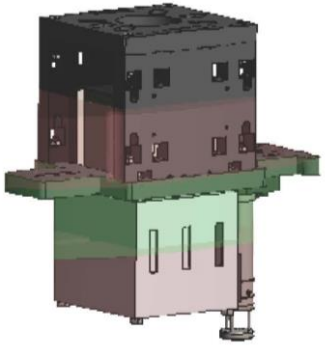


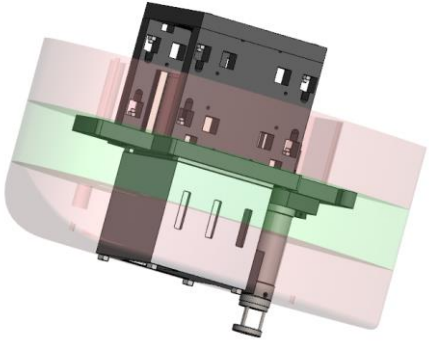
Pump-Jet thrusters flush with the hull, produce 12.25 N at 1200 RPM and a Power consumption of 90 W

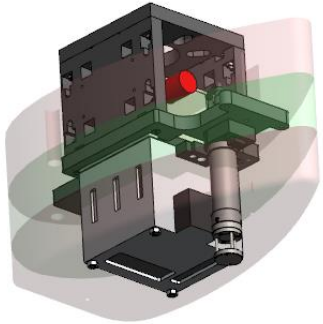
- Full-electric Catamaran 1.23 m long, 1.1 m high while antenna equipped, breadth 0.7 m - 1.25 m
- Lightweight 38 kg, Draft 0.1 m, Maximum payload 20 kg – draft 0.14 m
- Each hull is a single vehicle with its propulsion, navigation, guidance and control (NGC) and power system from battery
- Each monohull results to be an ASV and, thanks to the azimuth thrusters, is highly controllable
- Max speed in deep waters 1.6 m/s, in extremely shallow waters 1 m/s
- The basic NGC package of each hull is composed by an IMU and a GPS
- SWAMP architecture is based on an onboard WiFi using the 192.168.29.0 network

Fitting complex sensors such as multibeams









PE-FOAM (closed cell polyethylene foam) and HDPE (High Density Polyethylene) mounting frame created by CNR-INM to protect MBES and easily mounted on a pole or SWAMP

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R2Sonic 2020 in a pole-mounted configuration

R2Sonic 2020 in the SWAMP configuration

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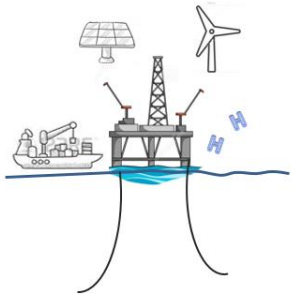
European Regional Development Fund
EUROPEAN UNION

START-UP ACTION

SEALINES

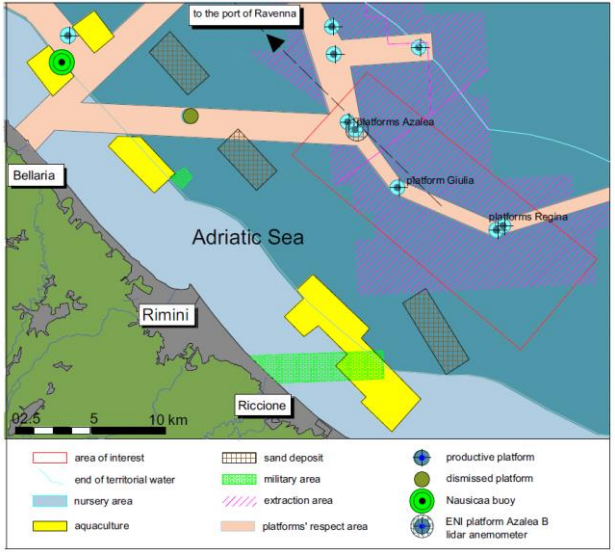
An action project that investigated the feasibility of sustainable repurposing of hydrocarbon sealines – that ended their life cycle (decommissioning) – into hydrogen transport



Feasibility study for a scientific research hub in an integrated green energy system

I. Antoncecchi, G. Rossi, M. Bevilacqua, R. Cianella, G. Vico, M. Pacini, N. Mondelli, M. Rovere, M. Bibuli, N. Barkas, V. Veniček, D. Dobrinić, Mounir Ghribi ,
S. Ceramicola, Mounir Ghribi, S. Ferrero, D. Di Battista, D. Vittorini

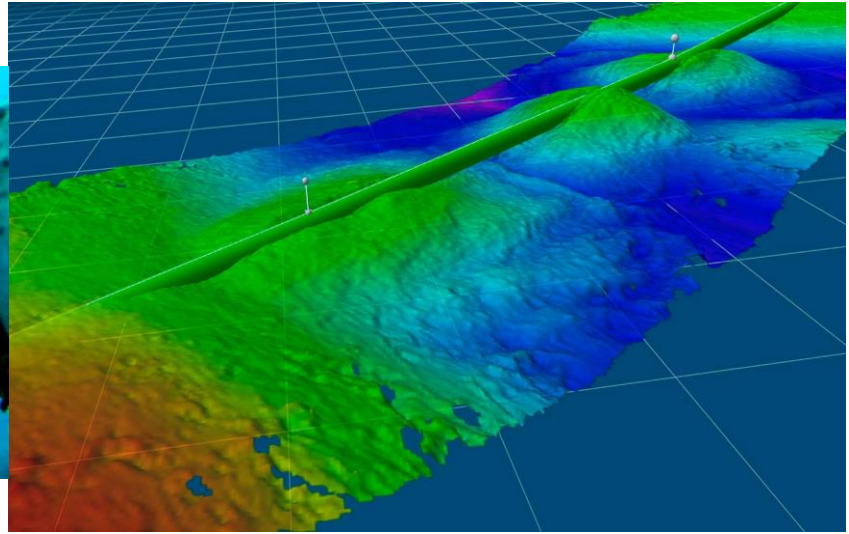
AZALEA A – Technical CHARACTERISTICS



- Adriatic Sea, within 12 nm
- bitubular (19 x 4 m) installed in 1984 by ENI S.p.A.
- gas extraction platform, 16 km from the coastline
- height above sea level: 17 meters
- depth: 19 meters
- connected to the Rubicone central (Forlì-Cesena, Italy)
- pipe material: API 5LX52 (yield strength= 359 MPa)

Sealine	*start point*	*end point*	*Type*	*Fluid*	*Year*	*offshore length (km)*	*Nominal diameter (“)*	*Thickness (mm)*
Azalea 1-2 - Anemone Cluster	44°10’16.229” 12°42’52.329”	44°12’43.694 12°42’19.862	Rigid	GLICOLE	1978	4.58	3	4.78
Azalea 1-2 - Anemone Cluster	44°10’16.229” 12°42’52.329”	44°12’43.694 12°42’19.862	Rigid	GAS	1978	4.58	6	10.97

Repeatable observations over space and time



Sealine maintenance and monitoring using an in-house ROV or SAV integrated with sensor-based measurements, gas, water and sediment sampling. Low-cost first response inspection (e.g. 26th Sept. 2022 sudden Northstream 1&2 pressure drop in the Baltic Sea).

- Reconstruction and comprehensive knowledge of the underwater environment and sealine
- Customized gas bubble sampling device
- Gas gauge detectors
- Sediment sampling devices for environmental and biological parameters

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Monitoring applications for robotic solutions

1. Imagery data from high resolution cameras coupled with multi-beam echo-sounder acoustic data (water column and seafloor)
2. Reconstruction and comprehensive knowledge of underwater environment and marine infrastructures → real-case history (Azalea platform)
3. Repeatable observations over space and time
4. Cost-effective

- Monitoring discharge and vertical methane and oil migration in coastal areas
- Monitoring the seasonally shifting of water dynamics and how control vertical methane and oil migration
- Monitoring leakage from abandoned or decomissioned wells/sealines and other offshore infrastructures
- Fast detection of migration of biogenic CH_4 along the boreholes originating from shallow gas pockets
- Detecting hydrocarbon reservoir leakage without expensive 3D seismic acquisition and re-processing
- Monitoring of PAHs pollution in harbour areas

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ISMAR
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DI SCIENZE
MARINE

Thank you!

Marine Robotics Unity Simulator - MARUS

Ivan Lončar, Natko Kraševac, Juraj Obradović, Fausto Ferreira, Ivan Petrović
Faculty of Electrical Engineering and Computing
University of Zagreb, Croatia

@BTS2022, Biograd na Moru, Croatia

Europska unija
Zajedno do fondova EU

Operativni program KONKURENTNOST I KOHEZIJA

EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

This work was co-funded by the European Union through the European Regional Development Fund.

Contents

- Motivation
- MARUS –what it offers
- Tutorial outline

Motivation

Ongoing projects

- BROD – Autonomous ship project (IRI2 ERDF)
- ROADMAP (ONR NICOP)
- CUV-ME2 (ONR + Croatian Navy)
- EUMarineRobots (H2020-INFRAIA)
- HEKTOR (ESI ERDF)
- InnovaMare (Interreg)
- MARI-Sense (ERDF)
- Multifunctional smart buoys(ESI ERDF)
- MONUSEN (HORIZON)

roadmap
Robot-Aided Diver Navigation in Mapped Environments

EUMR

HEKTOR

Interreg
Italy - Croatia
InnovaMare

EUROPEAN UNION

MARI-Sense

MONUSEN
~ MONtenegrin center for Underwater SEnsor Networks ~

MULTIFUNCTIONAL
SMART BUOYS

BROD – Autonomous ship project

- „Povećanje razvoja novih proizvoda i usluga koji proizlaze iz aktivnosti istraživanja i razvoja (IRI) – faza II“ – Croatian tender
- Financed by European Regional Development Fund (ERDF)
- 55 mil. HRK ~ 7 mil. EUR
- 2-year project
- Fire Fighting boat
- 4 person team from LABUST

Europska unija
Zajedno do fondova EU

Operativni program KONKURENTNOST I KOHEZIJA

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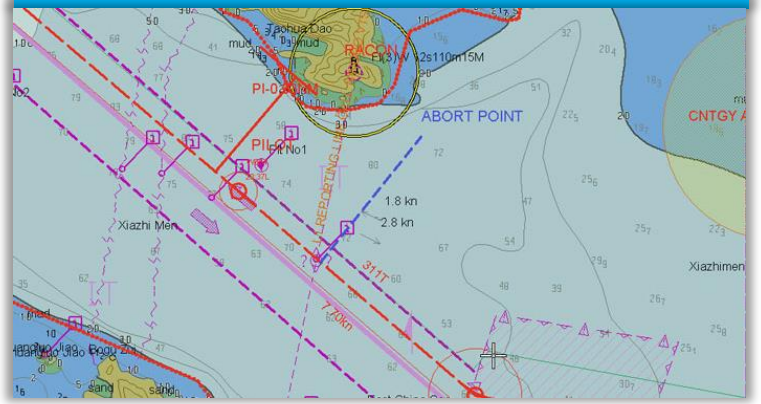
BROD – Autonomous ship project

- The ship
  - LOA = 23,95 m
  - LWL = 23,4 m
  - BOA = 6,5 m
  - H = 3,06 m
  - DISP. = 72 t
  - CREW= 1
  - POWER = 2 x 1081 kW @ 2300 rpm
  - FIFI PUMP - 2 x 1365 m3/h, 140m
  - FIFI MONITOR - 2 x 1200m3/h , 140m
  - PROPULSION - 2 x JET DRIVE
  - BOW THRUSTER - 1 x 45kw, fi 400 mm

BROD – Autonomous ship project

LABUST

Autonomous navigation



Situational awareness

Remote control center

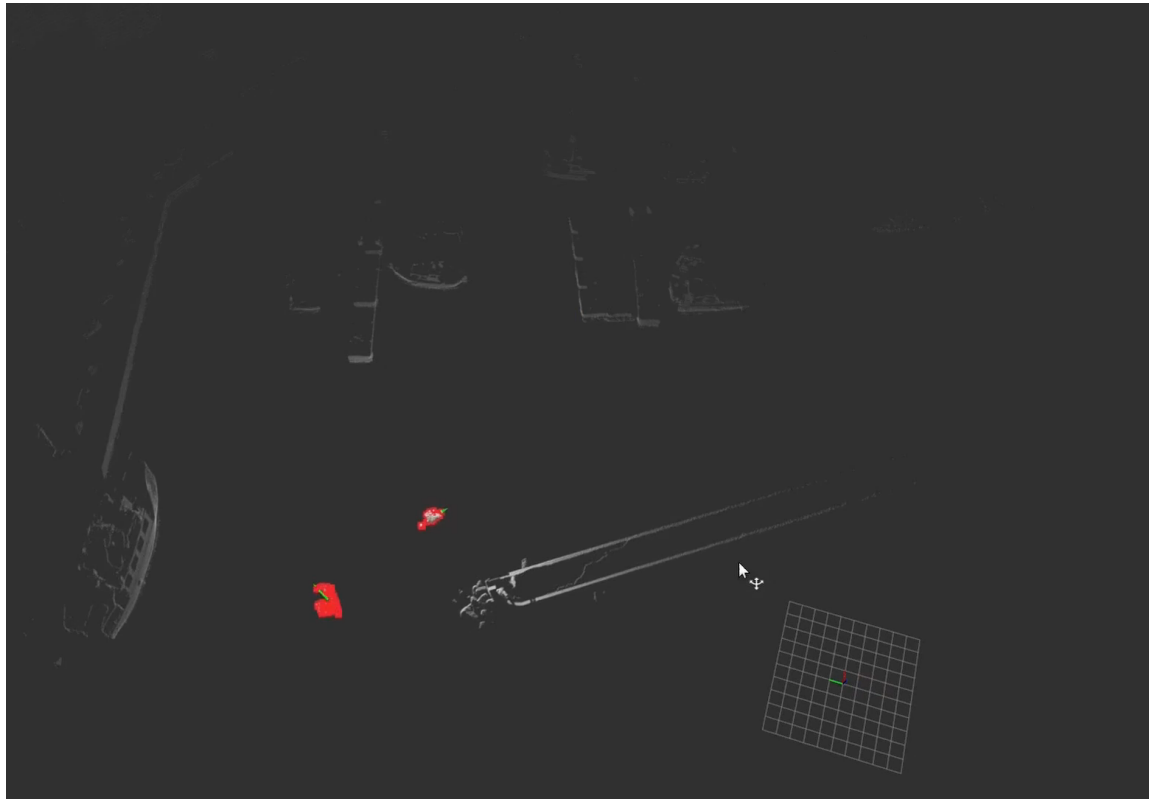
Cyber security

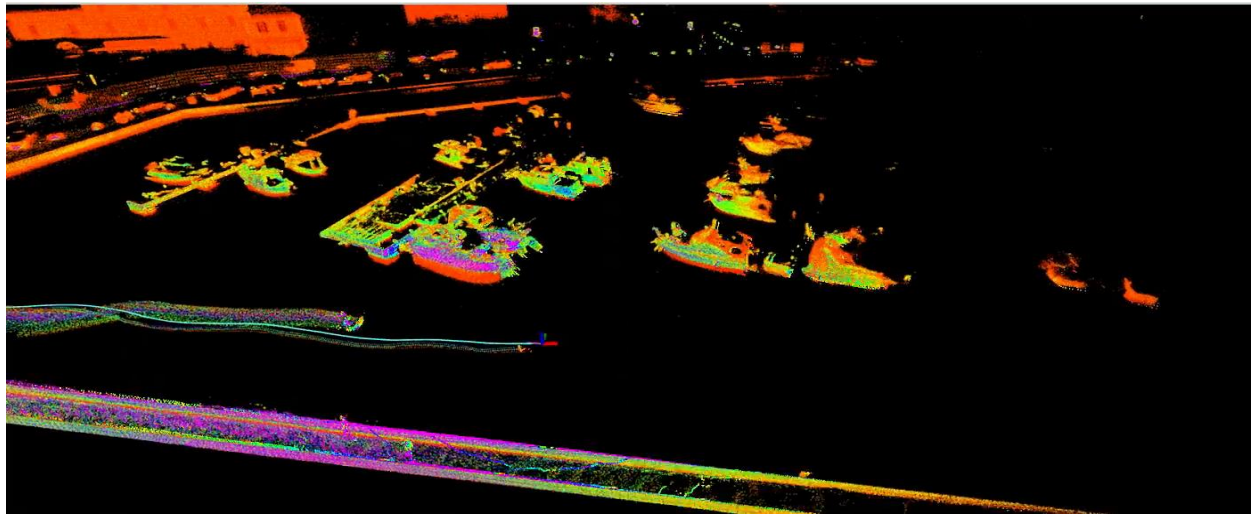
BROD – Autonomous ship project

- ASV Korkyra
  - Test vehicle
- Preliminary data collection
  - Lidar
  - Camera

BROD – Autonomous ship project

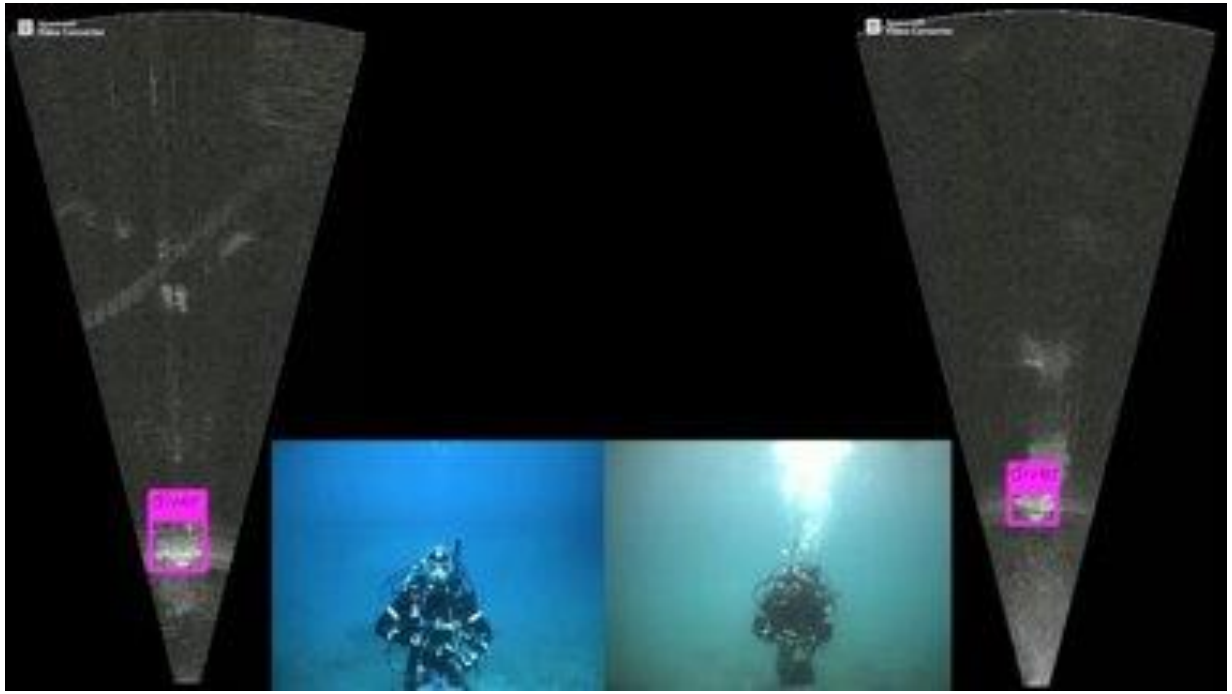
- Limited data collected

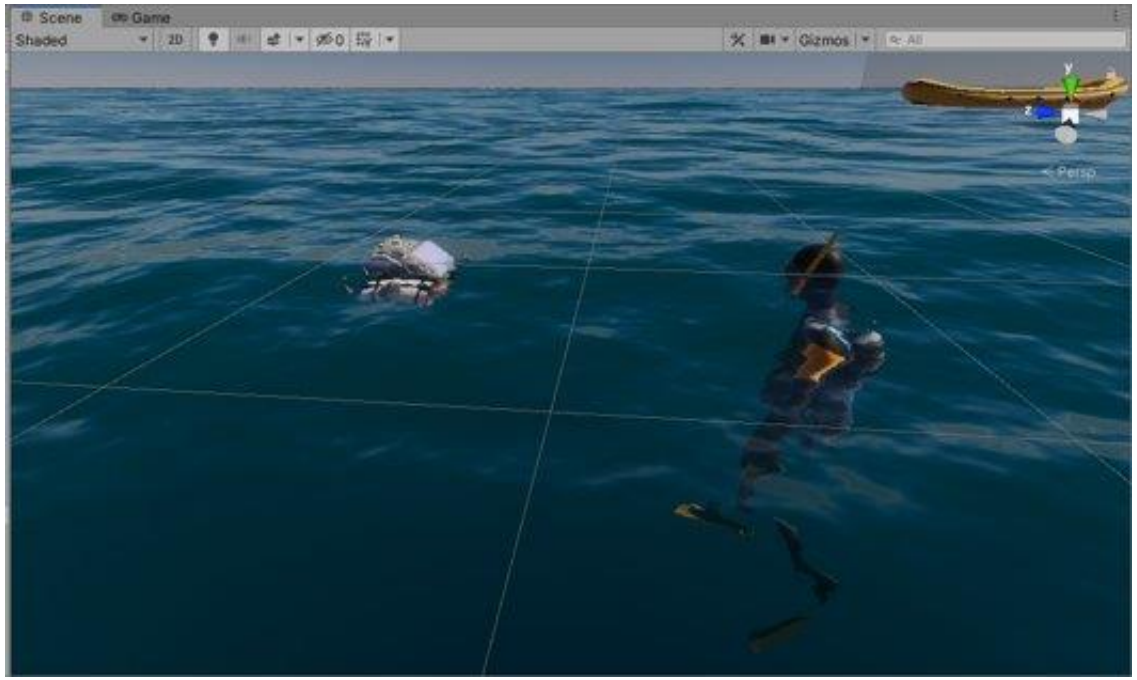




ROADMAP – Short recap

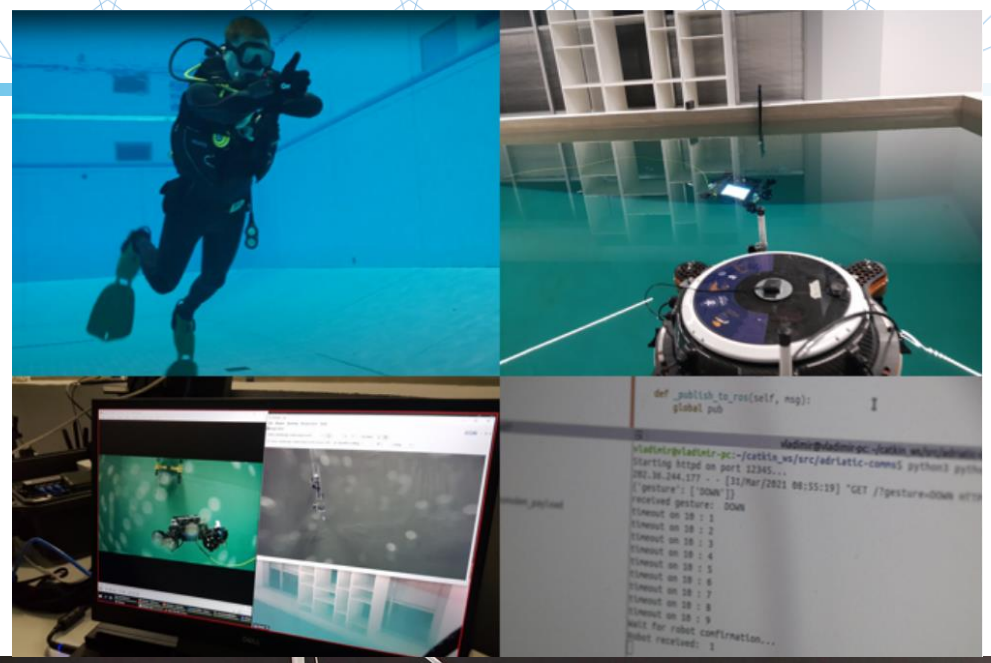
- Human robot interaction (VR)
- Tracking diver
  - sonar
  - camera



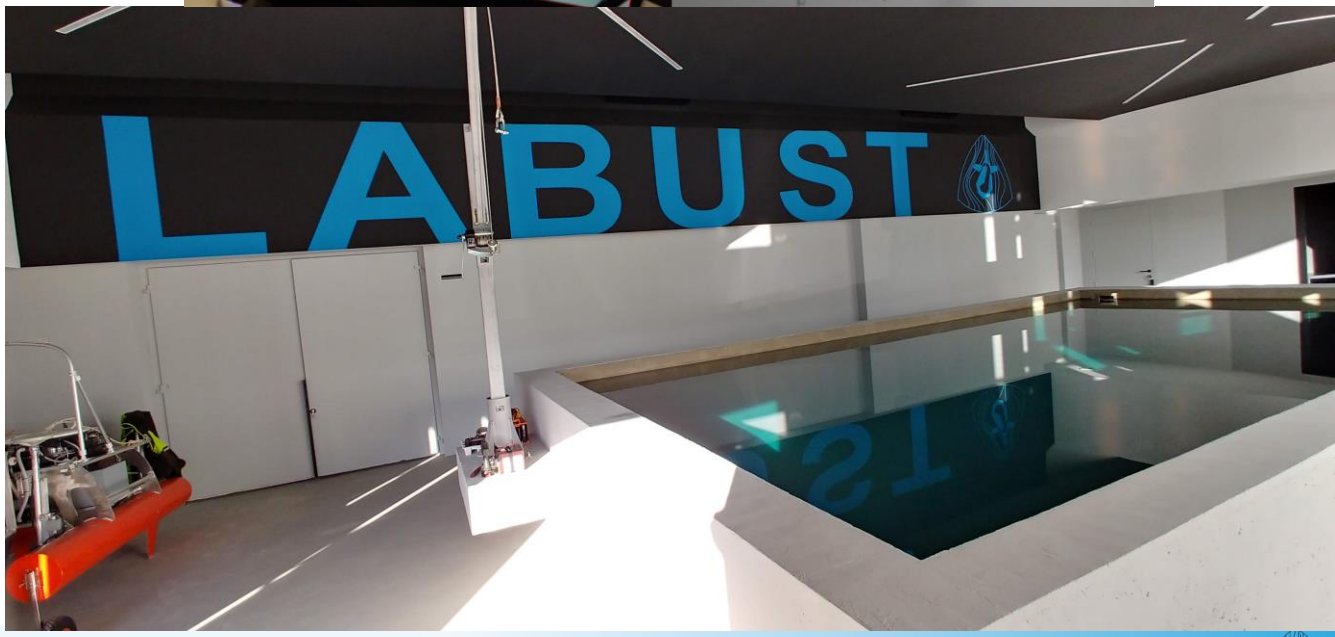


LABUST facilities

- Located in Zagreb (continental Croatia)
- Indoor pool
  - 4m x 8m x 3m (L x W x D)
  - Birdseye camera view
  - Indoor UWB localization system (Pozyx)
  - Underwater camera system



- Jarun lake „near”



Marine datasets

LABUST

Real datasets

- Difficult to collect
  - Manual annotations
- Maritime perception datasets available
  - Annotations hit and miss
  - Low variability in scenes

Synthetic datasets

- Speeding up development
  - Reducing cost
- Translating to real world?
- Single simulator for all LABUST research projects
  - maritime and underwater

Marine datasets

Real datasets

VS

Synthetic datasets

MARUS - Marine Robotics Unity Simulator

https://github.com/MARUSimulator

Open-source simulators

Categories	MARUS	UUVSimulator	UWSim	ZeroSim	IsaacSim	UwRobotics Simulator	URSim	Gemini	HoloOcean
Good visuals	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Robotics domain	Marine	Underwater	Marine	General*	General*	Underwater	Underwater	Maritime	Underwater
Acoustic comms	Yes	No	No	No	No	No	Yes	No	Yes
Backend	ROS1/2	ROS1	MATLAB/ ROS1	ROS1/2	Various	ROS1/2	ROS1	ROS1	-
Linux/Win	Yes/Yes	Yes/No	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes	Yes/Yes
Dataset annotation	Yes	No	No	Yes	Yes	No	No	No	No
Maintained	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes
Base framework	Unity3D	Gazebo	OpenSceneGraph	Unity3D	Unity3D	Unity3D	Unity3D	Unity3D	Unreal Engine 4

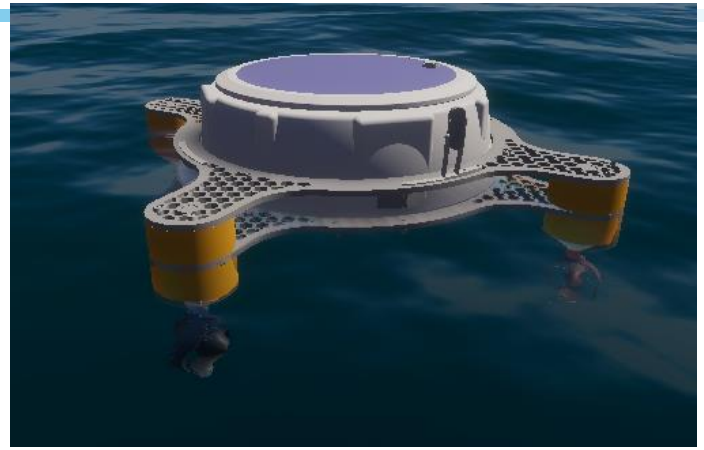
* General describes general purpose mobile robotics simulators (ground, manipulators, aerial) not including marine robotics

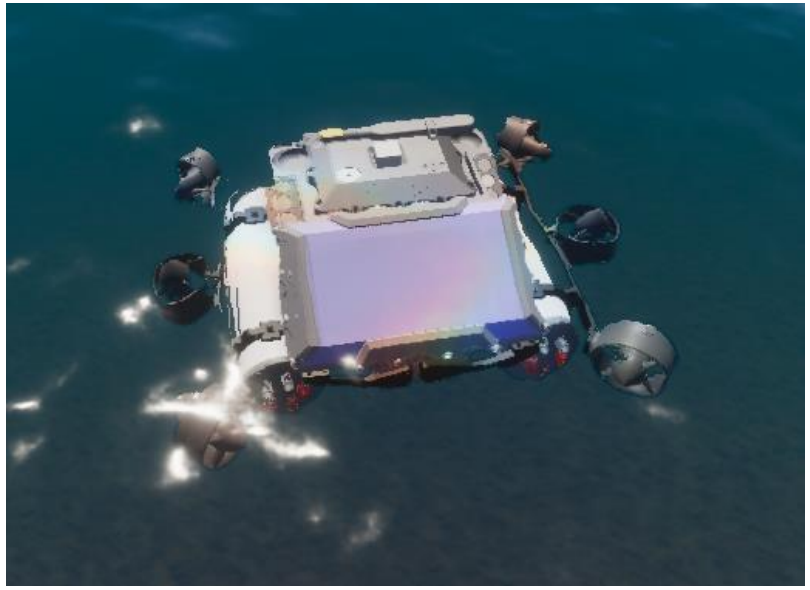
I. Lončar, J. Obradović, N. Kraševac, L. Mandić, I. Kvasić, F. Ferreira, V. Slošić, Đ. Nađ, N. Mišković, “MARUS - A Marine Robotics Simulator” in OCEANS 2022 - MTS/IEEE Hampton Roads, accepted for publication, 2022.

Unity + ROS(2)

- Game engine
- Large community
  - User built assets (free and paid)
- Easy scene generation
  - Adding objects, environment, lighting, ...
- Visualization on advanced level
  - Parallelization using GPU shaders for sensors
- Cross-platform (linux, Windows, Android, iOS)

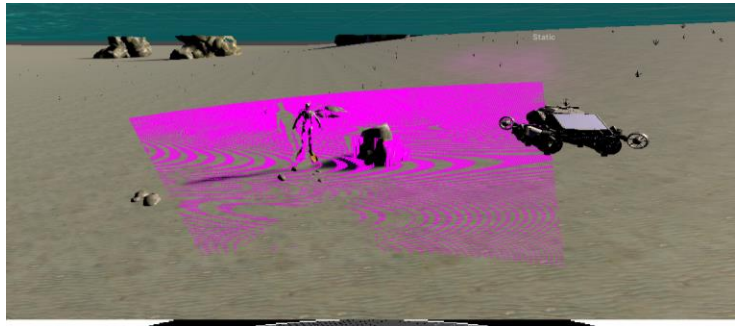
MARUS – 3D assets

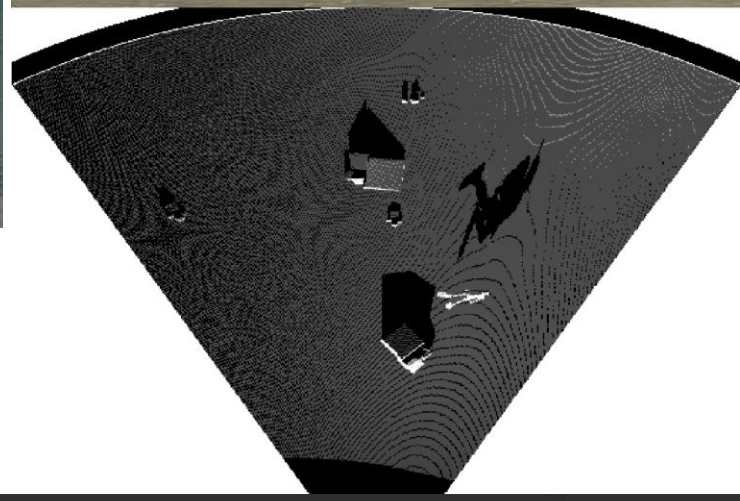


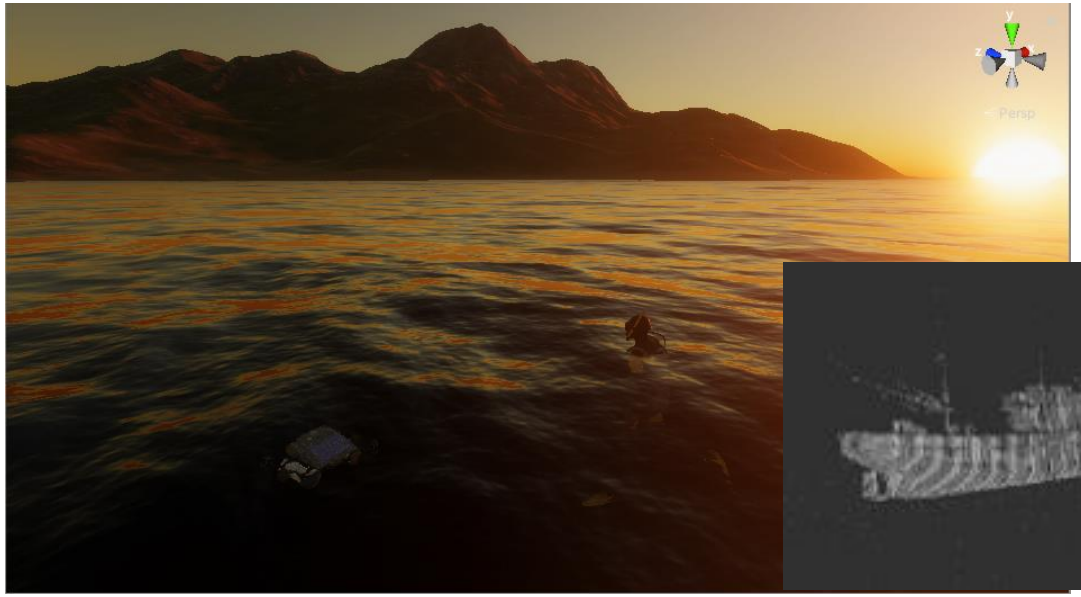


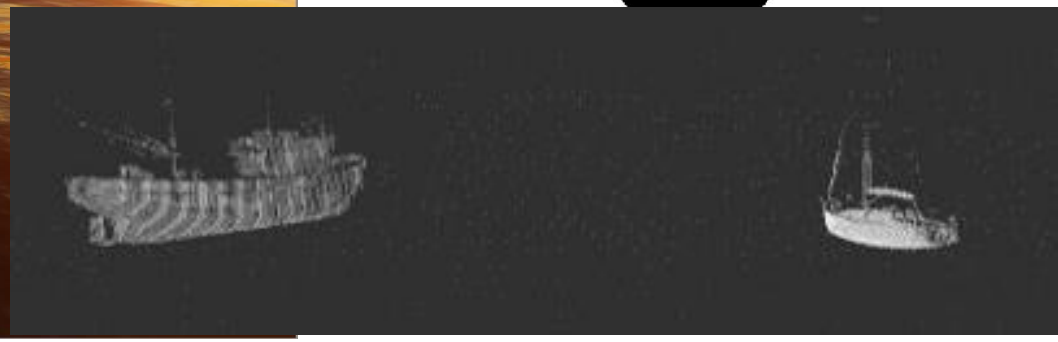
MARUS - Sensors

- **Lidar**
- **Sonar**
- **Camera (native)**
- IMU
- GNSS
- Ranging (native)
- Depth
- Acoustic modem
- AIS



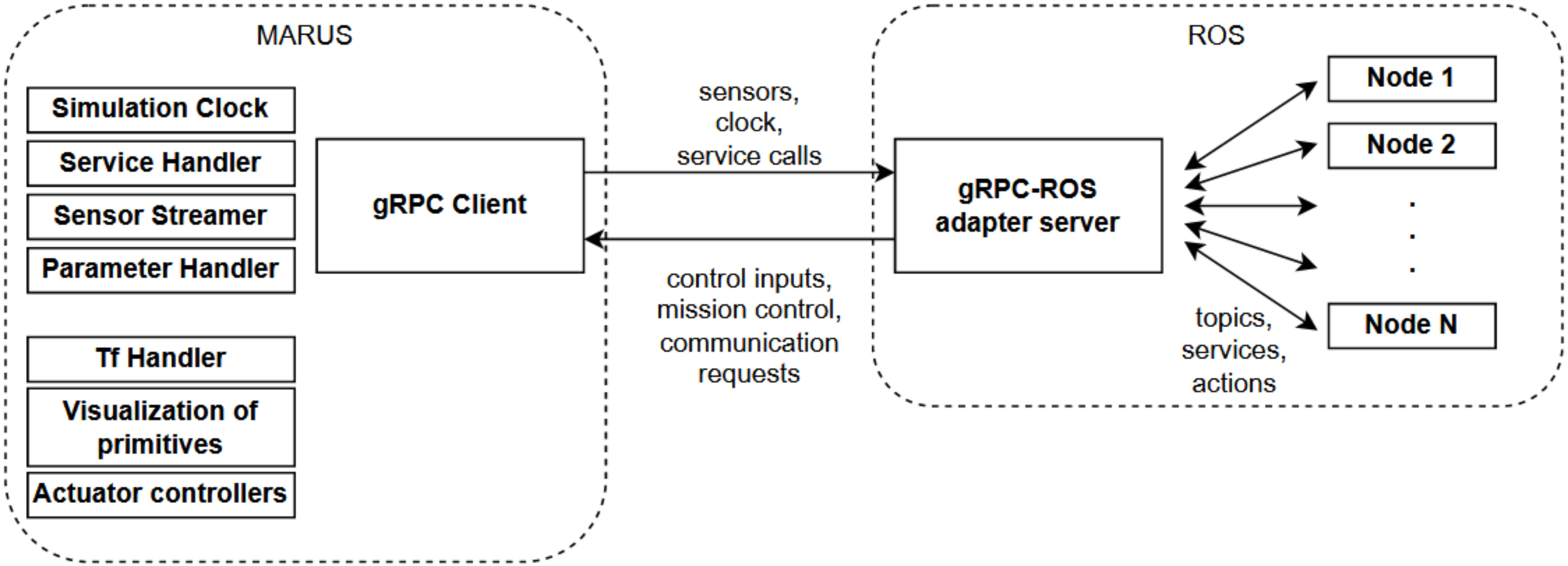






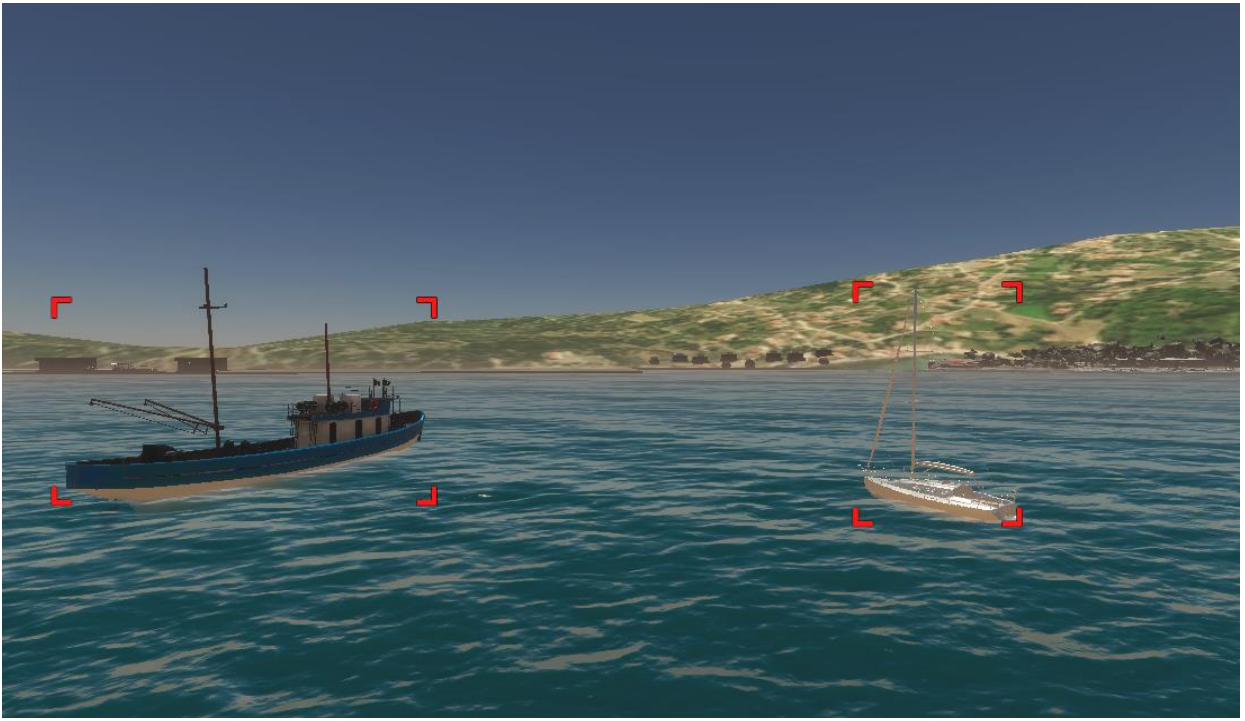
MARUS - Middleware connector (e.g. ROS(2))

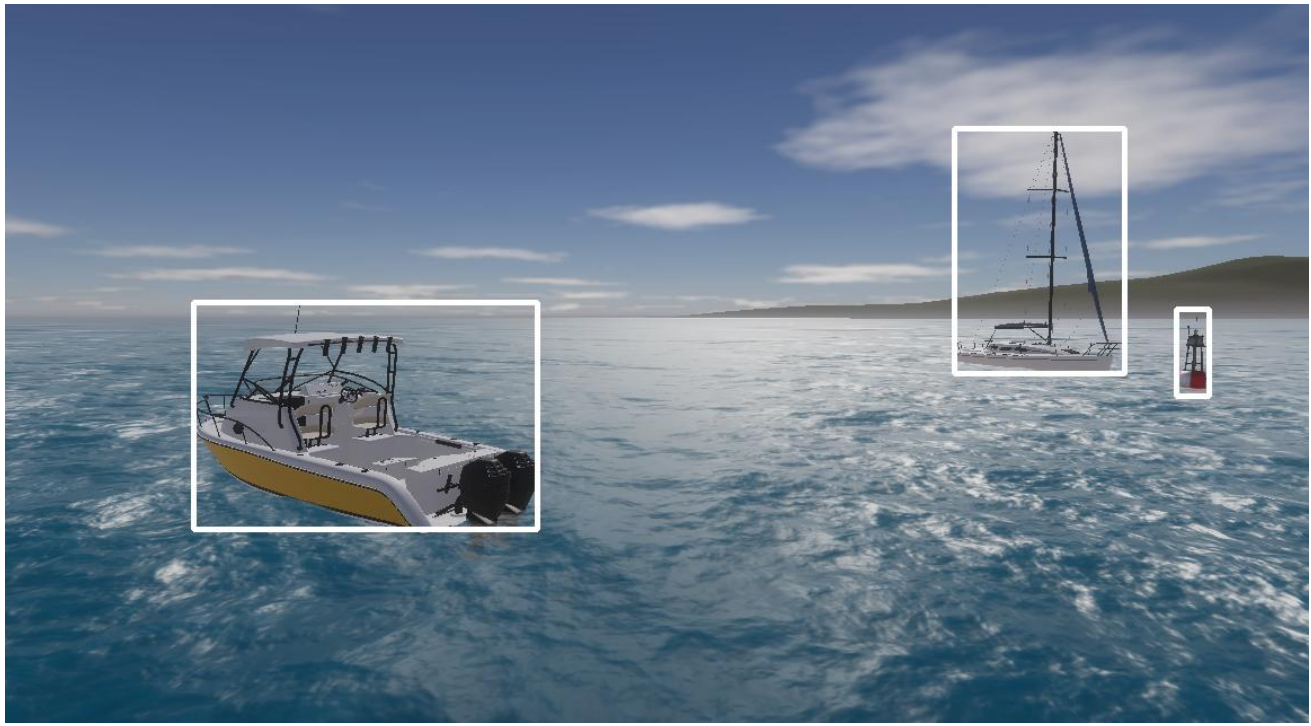
- gRPC - Remote Procedure Call (RPC) framework



MARUS – Dataset generation

- Camera annotations
  - Classification
  - Segmentation (Soon)
  - Saved in YoloV5 format (easily convertible)

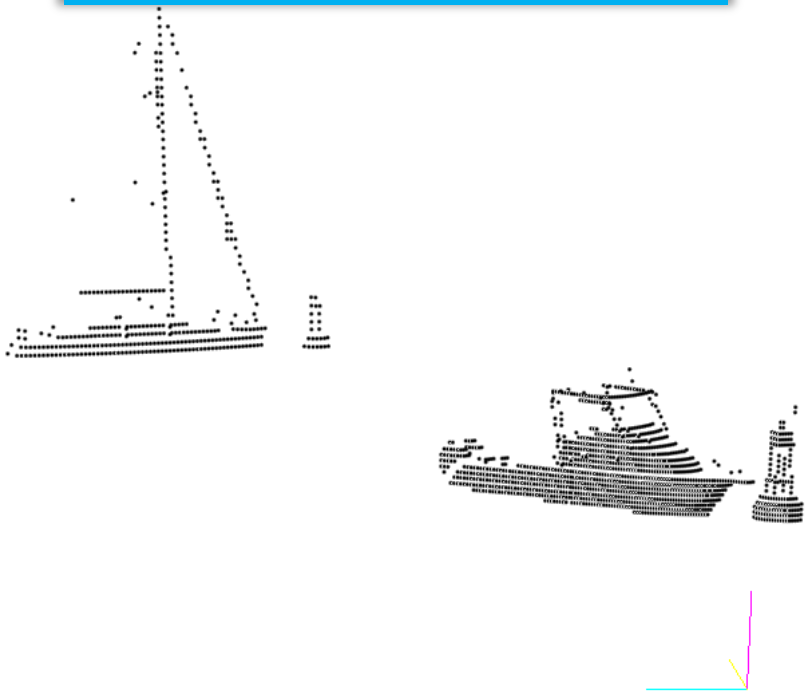




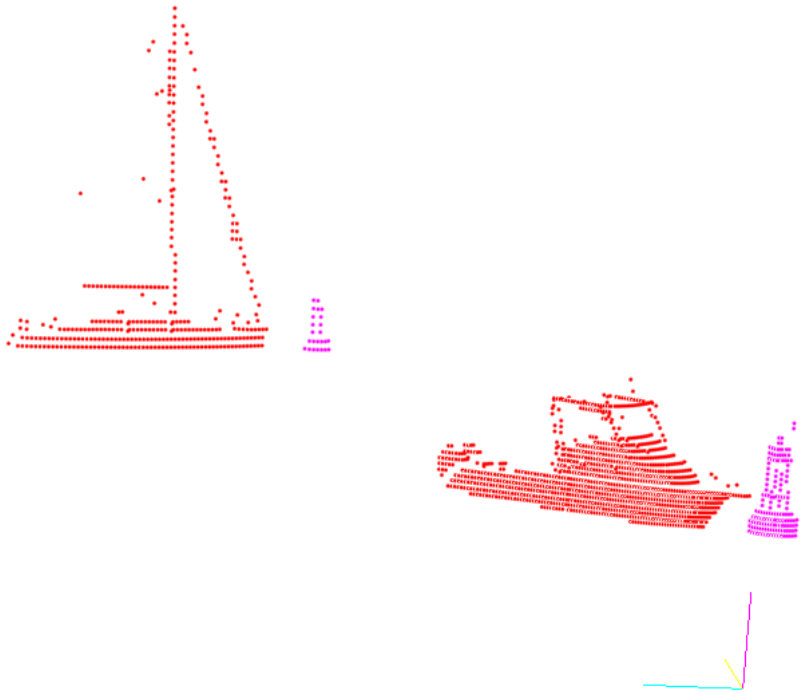
MARUS – Dataset generation

- Lidar annotations (in pointcloud2 format)
  - Classification
  - Instance segmentation

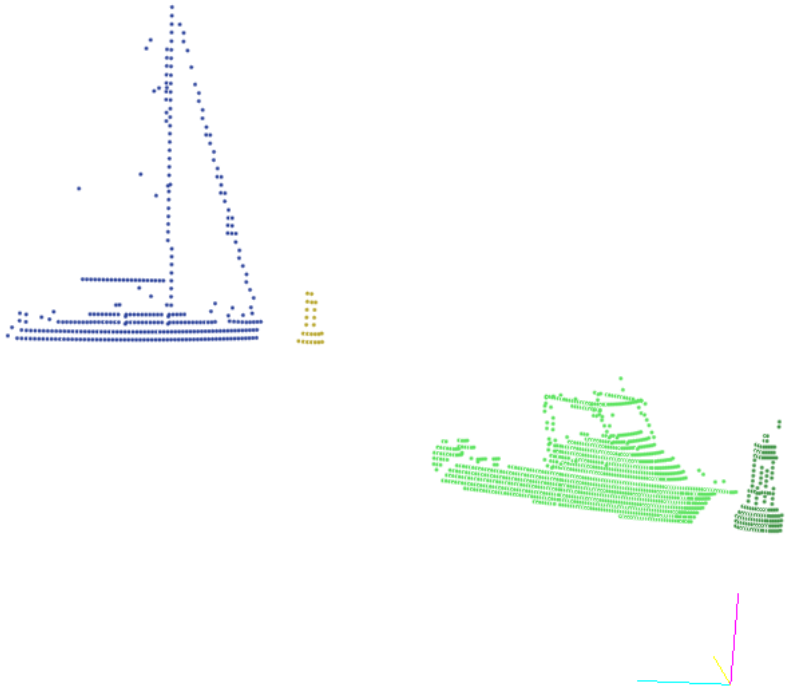
Raw



Classes

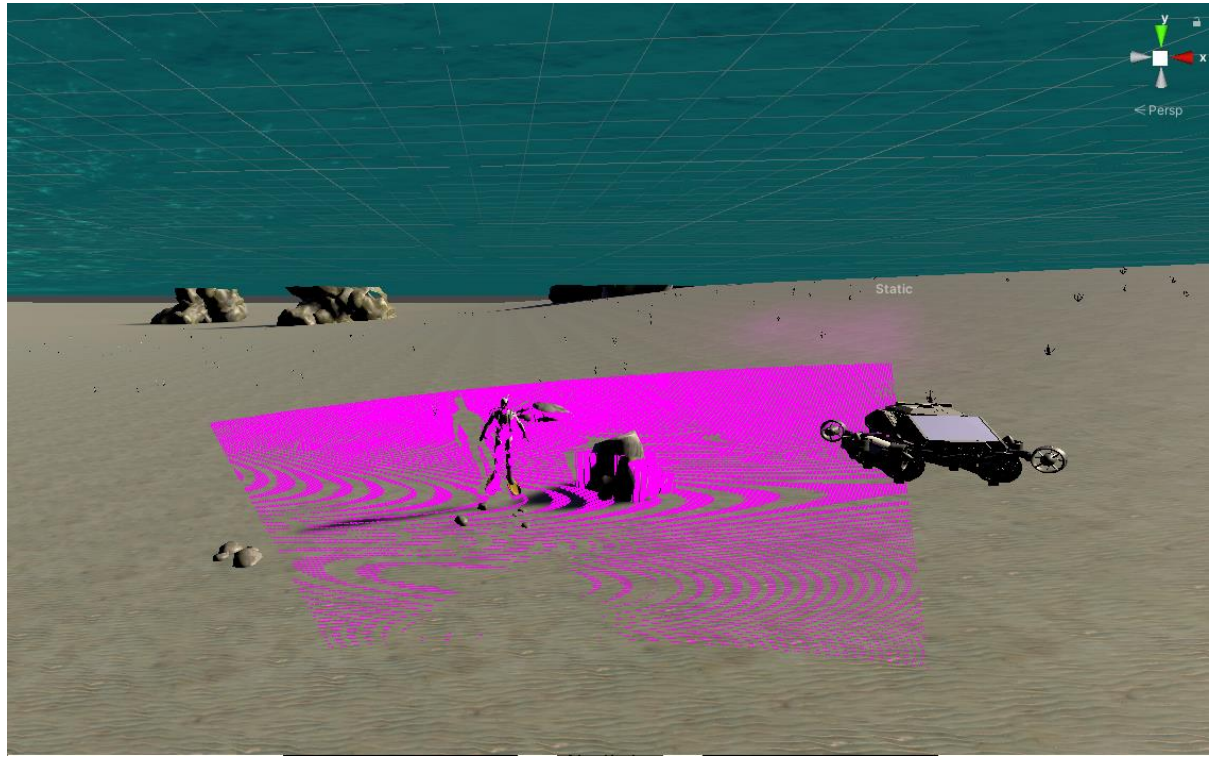


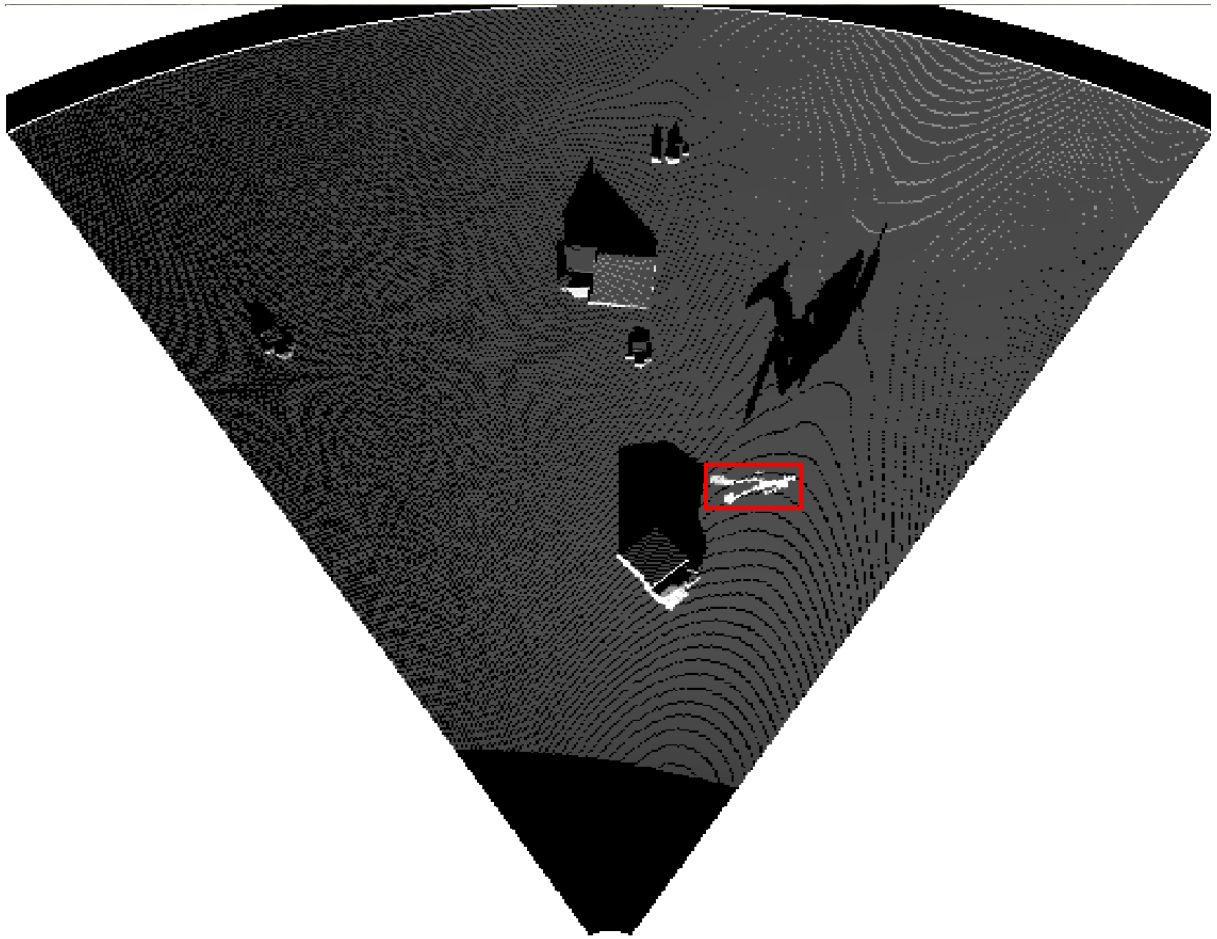
Instances



MARUS – Dataset generation

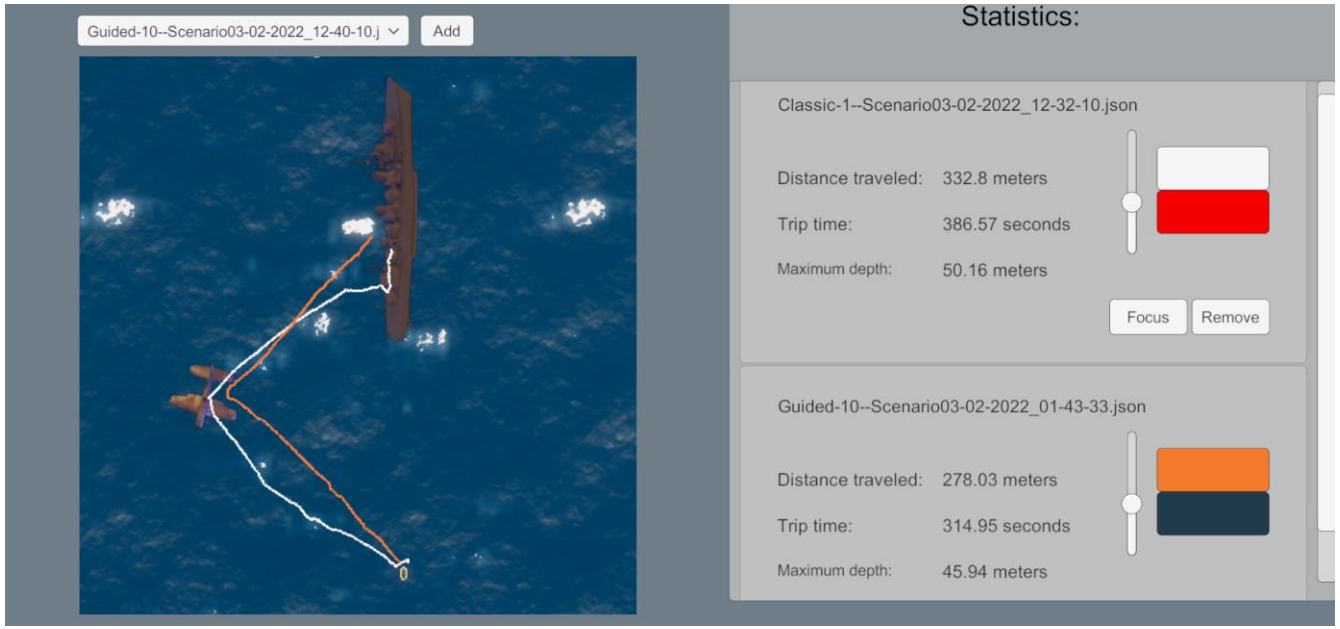
- Sonar annotation
  - Bounding box
  - Segmentation (Soon)

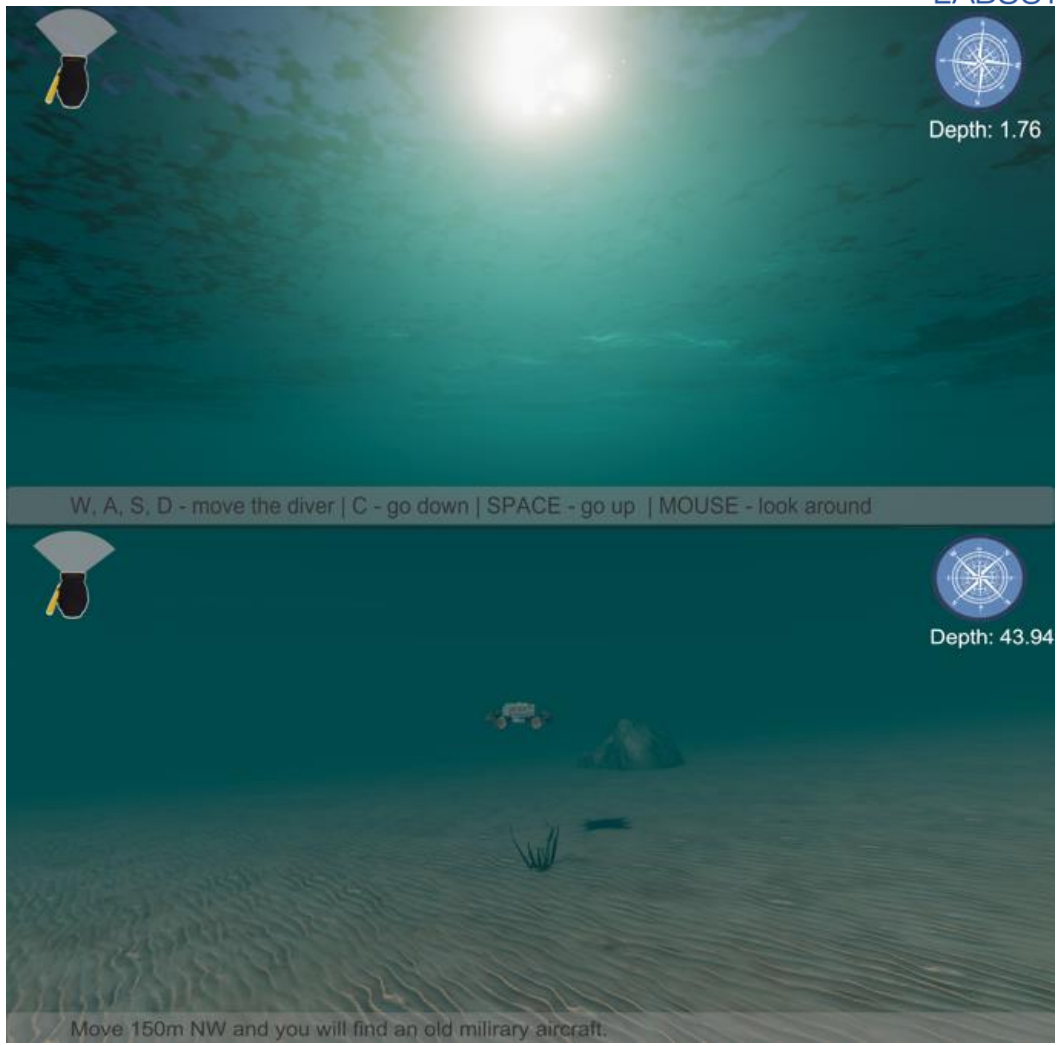




MARUS – Recent perception applications

- Survey @ BTS21
  - aiding diver navigation using D2
  - only self-navigation gadgets
- 26 participants

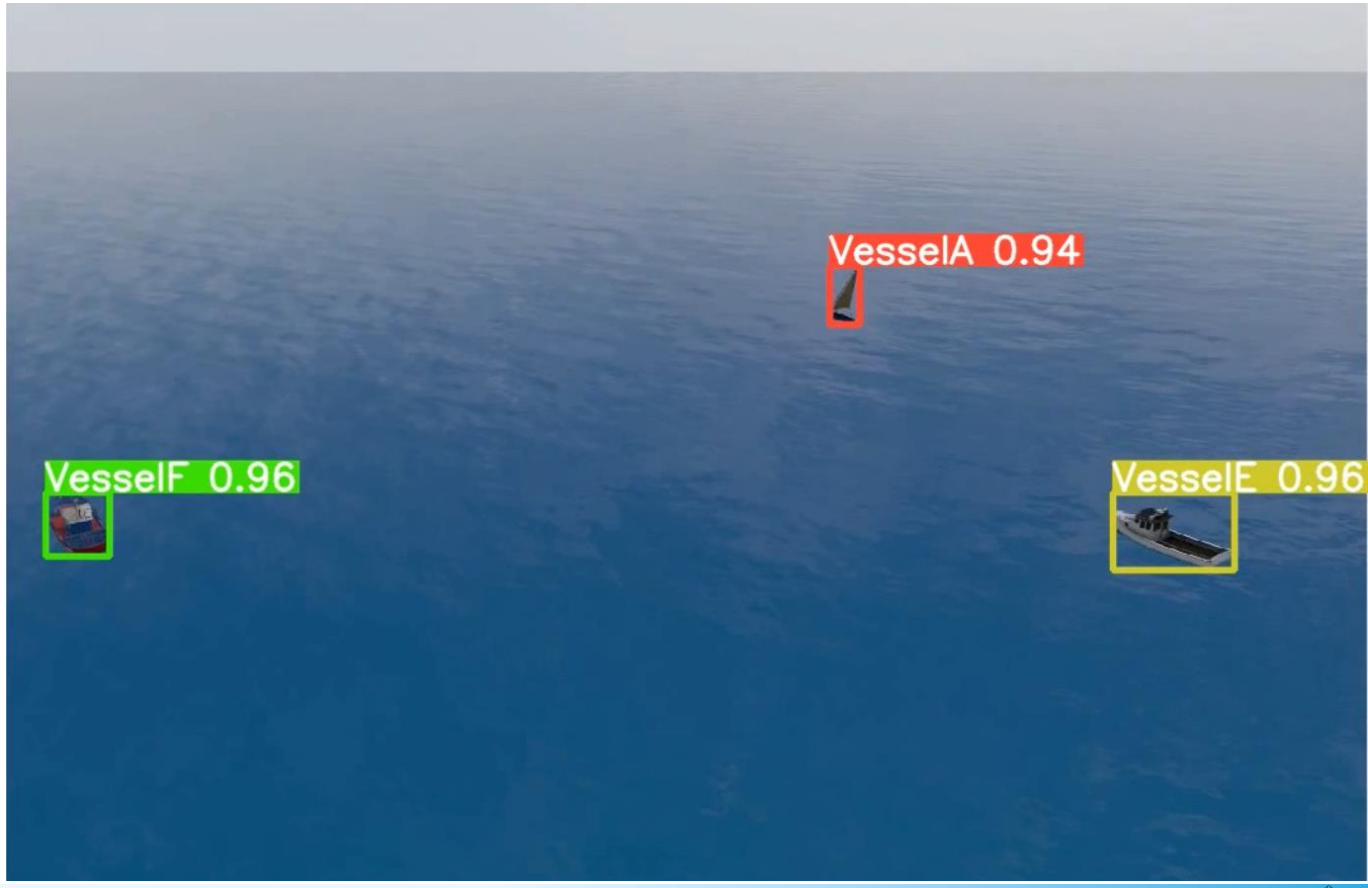




I. Kvasić, Đ. Nađ, I. Lončar, L. Mandić, N. Kraševac, J. Obradović, and N. Mišković, “Aided diver navigation using autonomous vehicles in simulated underwater environment,” CAMS 2022, accepted for publication

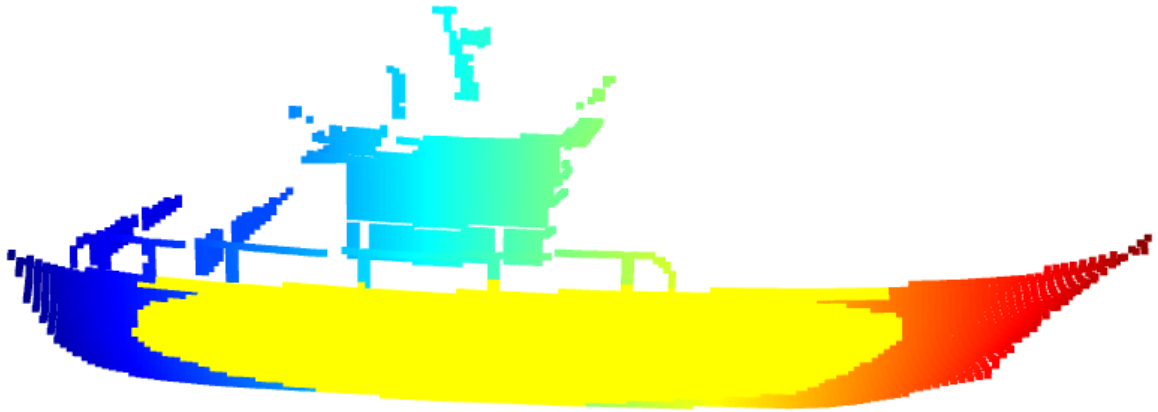
MARUS – Recent perception applications

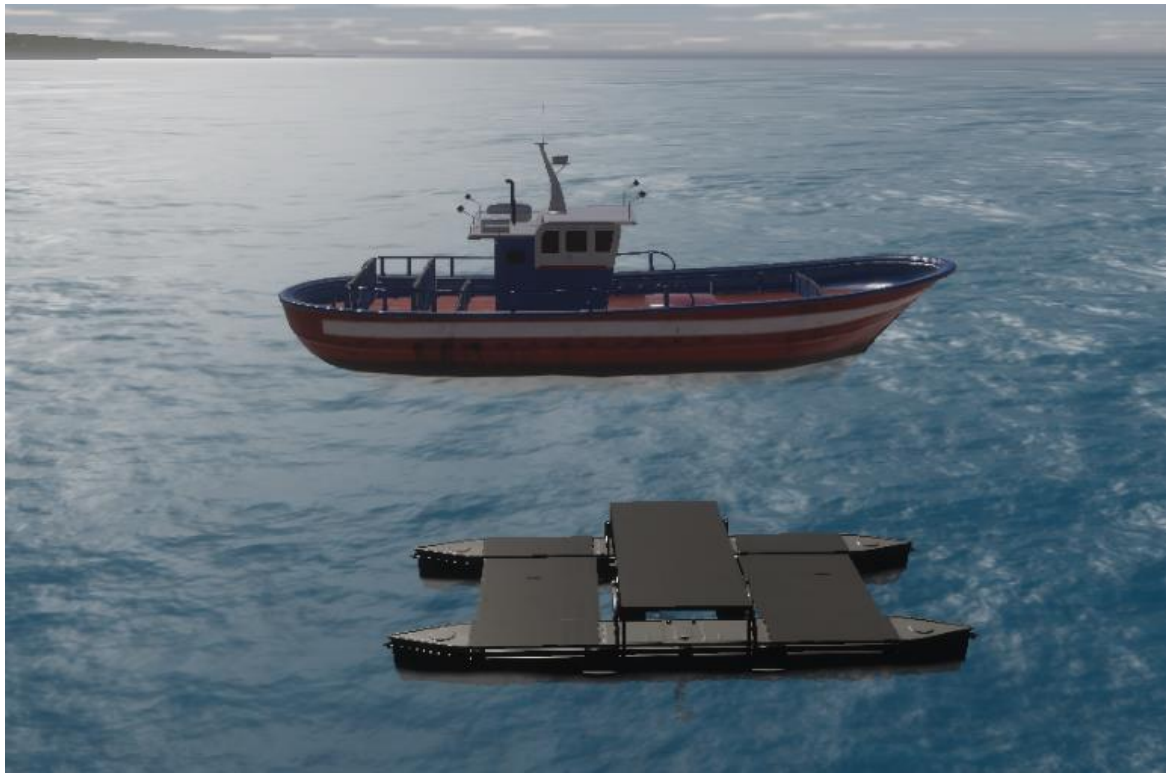
- MBZIRC 2023 competition
  - Reduced MARUS fidelity to match Gazebo
  - **Collected annotated dataset** for object detection in MARUS
  - **Validated** in Gazebo



MARUS – Recent perception applications

- MBZIRC 2023 competition
  - Lidar placement prototyping in MARUS
  - Algorithm tested before moving to Gazebo





F. Ferreira, N. Kraševac, J. Obradovi ć, R. Milijaš, I. Lončar, S. Bogdan, and N. Mišković, “LIDAR-based USV close approach to vessels for manipulation purposes,” in OCEANS 2022 - MTS/IEEE Hampton Roads, 2022, accepted for publication

Summary

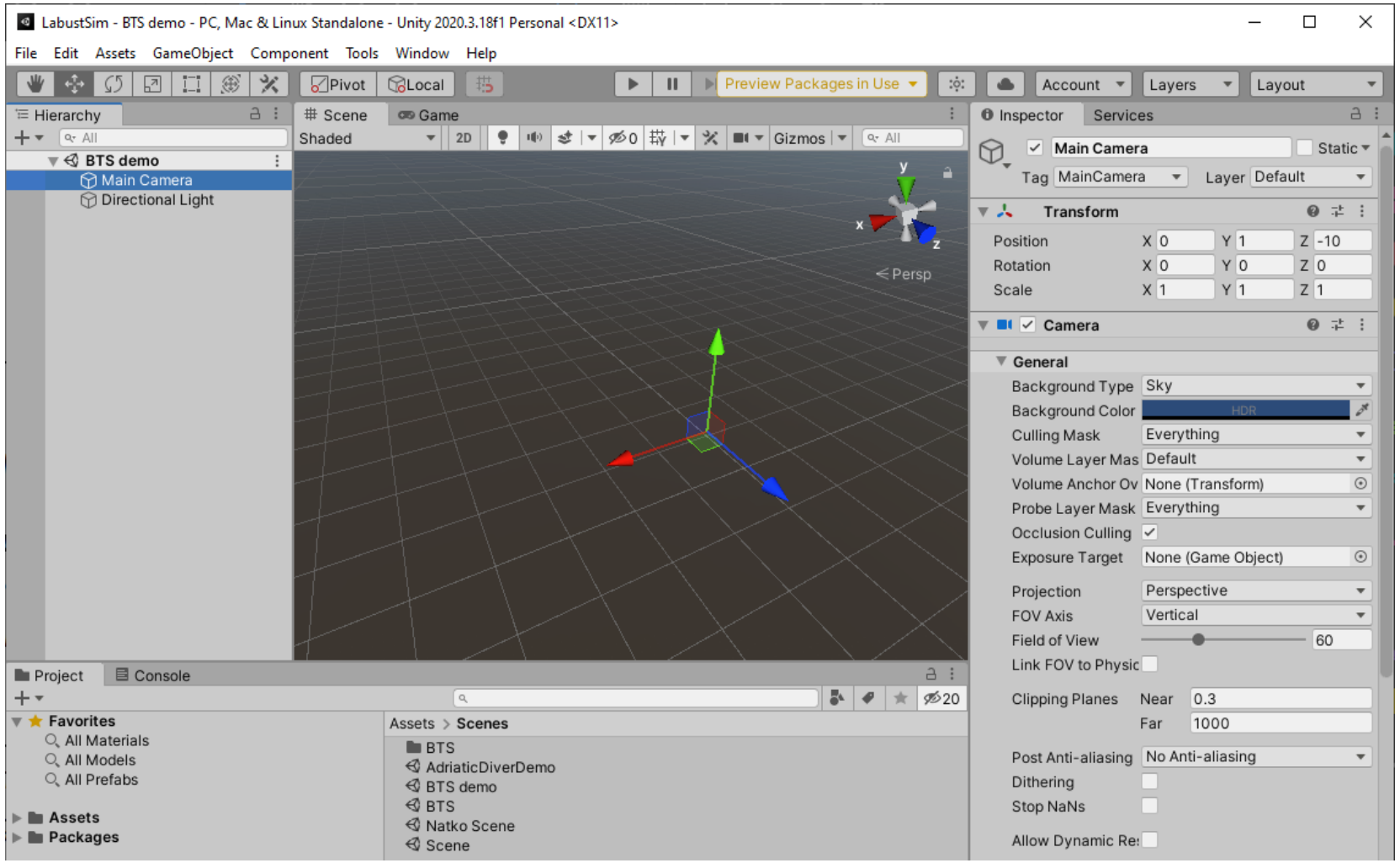
- Quality perception datasets hard to come by
- Field work expensive
- Simulation prefered in early stages of development

- MARUS tries to address current simulators drawbacks
  - High visual fidelity
  - Annotation tools
  - Lot’s of sensors

Tutorial:
Marine object detection using MARUS generated dataset

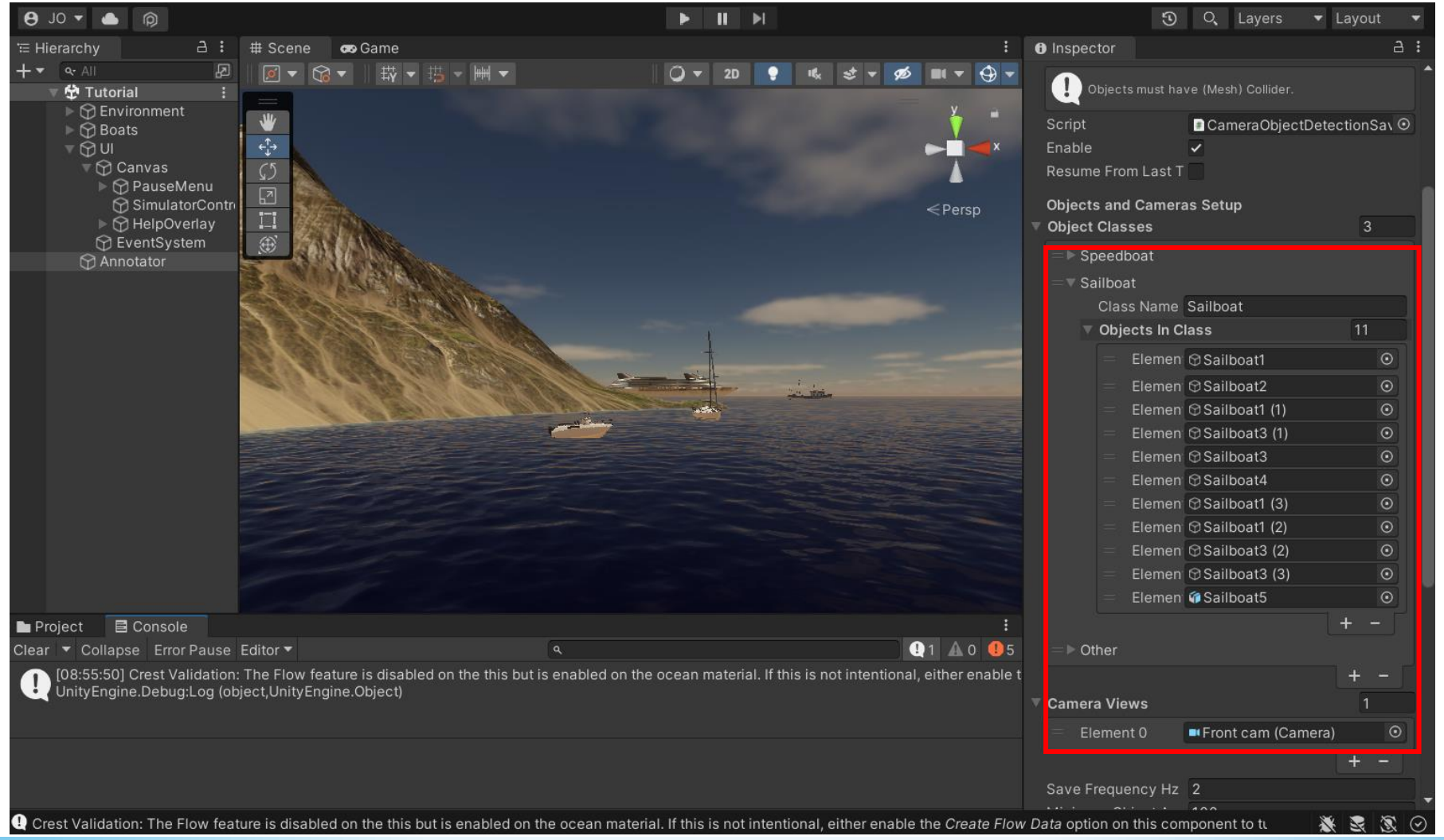
Tutorial – learn basics

- Familiarize with MARUS/Unity



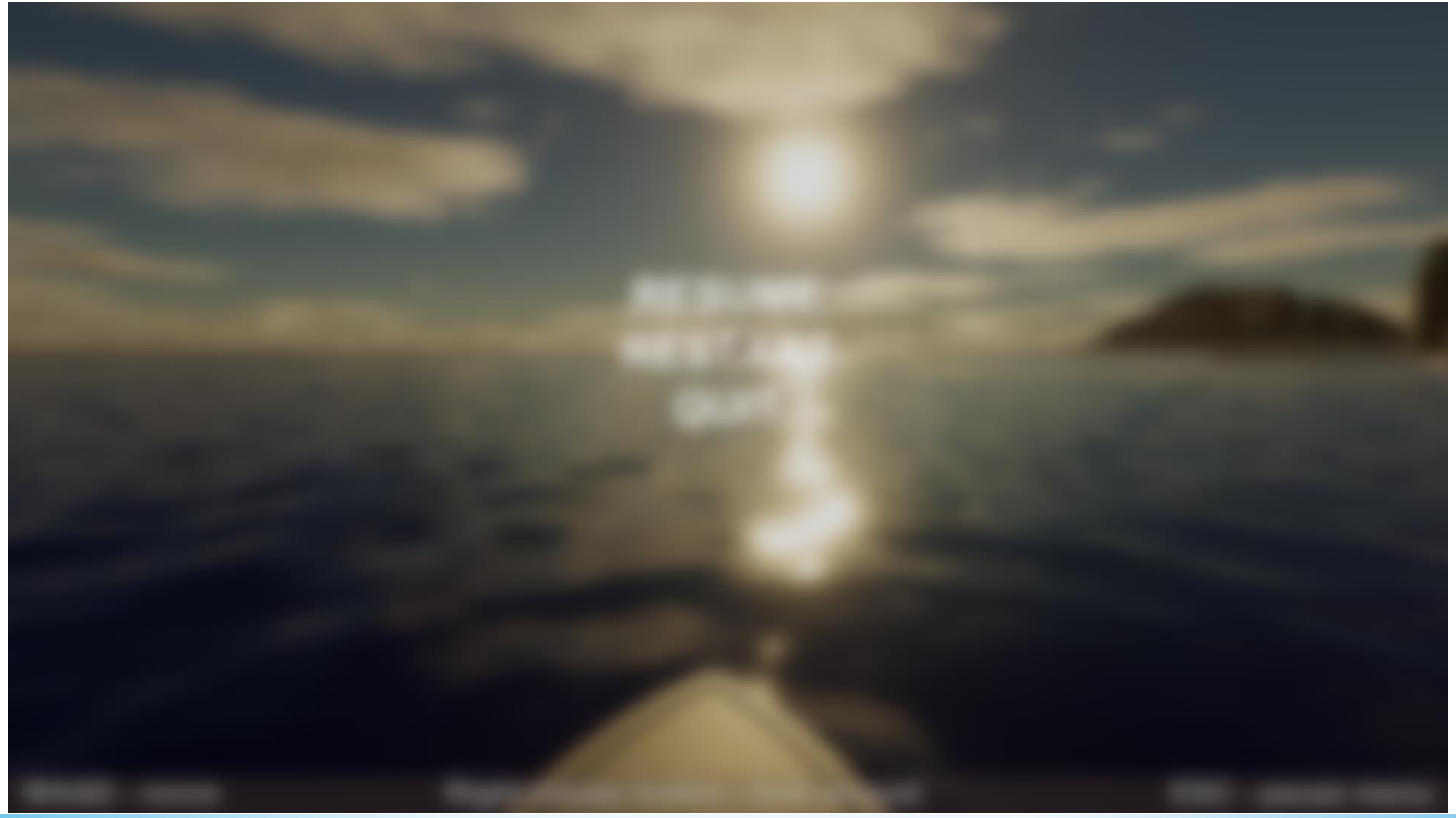
Tutorial – play around

- Play with simulation scene



Tutorial – Drive around („collect dataset”)

- Collect camera image dataset with annotated objects

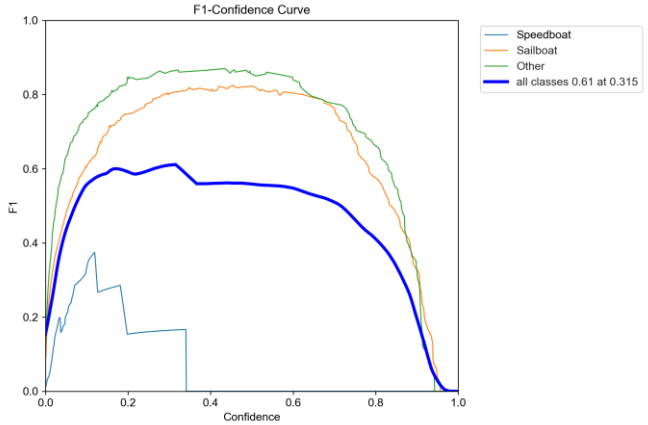


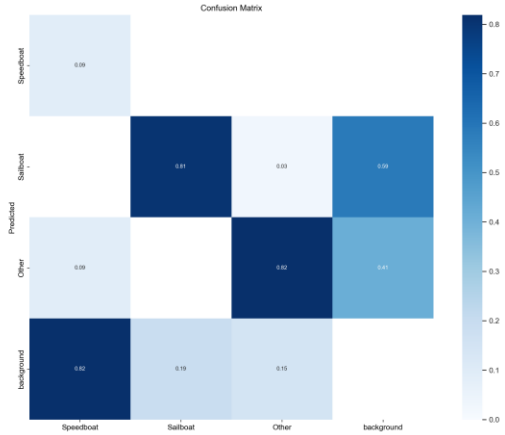
Tutorial – training neural network

- Train a small YOLOv5 CNN for object detection and classification
- PyTorch

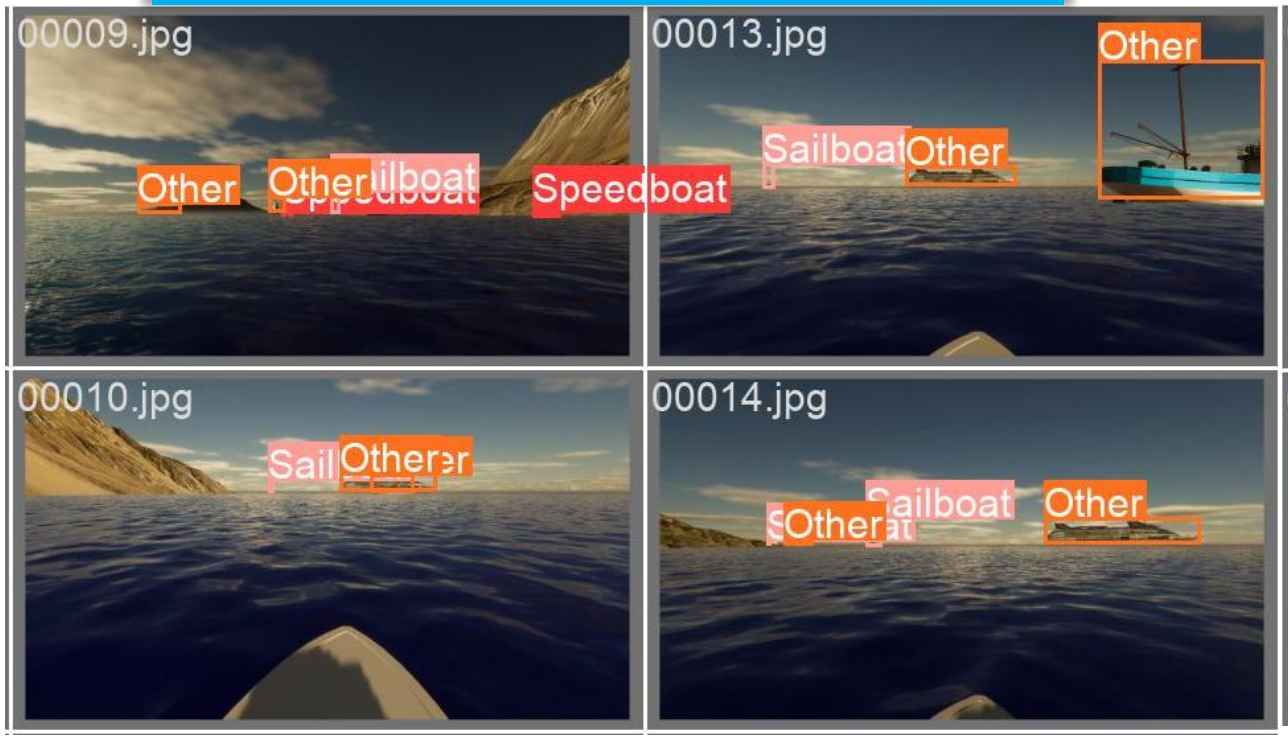
```
     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     23/99      2.39G    0.07098     0.0255    0.01187         19        640: 100%|██████████| 5/5 [00:01<00:00,  2.53it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 11.40it/s]
                 all          4         11      0.674      0.429       0.21     0.0466

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     24/99      2.39G    0.07865    0.02401    0.01038         20        640: 100%|██████████| 5/5 [00:01<00:00,  2.62it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 12.08it/s]
                 all          4         11      0.647      0.143      0.149     0.0666

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     25/99      2.39G    0.07519     0.0227   0.009931         14        640: 100%|██████████| 5/5 [00:01<00:00,  2.62it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 11.94it/s]
                 all          4         11      0.747      0.429      0.344     0.0844

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     26/99      2.39G     0.0729    0.02362    0.00903         13        640: 100%|██████████| 5/5 [00:01<00:00,  2.60it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 12.05it/s]
                 all          4         11      0.644      0.429      0.195      0.047

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     27/99      2.39G    0.06586    0.02717   0.008756         37        640: 100%|██████████| 5/5 [00:01<00:00,  2.58it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 12.83it/s]
                 all          4         11      0.107      0.429      0.148     0.0353

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     28/99      2.39G    0.07554    0.02171   0.007847         11        640: 100%|██████████| 5/5 [00:01<00:00,  2.61it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 11.55it/s]
                 all          4         11      0.783      0.429      0.436      0.157

     Epoch    GPU_mem   box_loss   obj_loss   cls_loss  Instances       Size
     29/99      2.39G    0.06411     0.0226    0.00785         25        640: 100%|██████████| 5/5 [00:01<00:00,  2.56it/s]
               Class     Images  Instances          P          R      mAP50   mAP50-95: 100%|██████████| 1/1 [00:00<00:00, 10.55it/s]
                 all          4         11      0.263      0.625      0.375      0.153
```

Tutorial - evaluation





Ground truth



Prediction

Thank you for your attention

Supported by the project "Razvoj autonomnog besposadnog višenamjenskog broda" project (KK.01.2.1.02.0342) co-financed by the European Union from the European Regional Development Fund within the Operational Program "Competitiveness and Cohesion 2014-2020".

Deep learning computer vision-based obstacle detection for autonomous boats

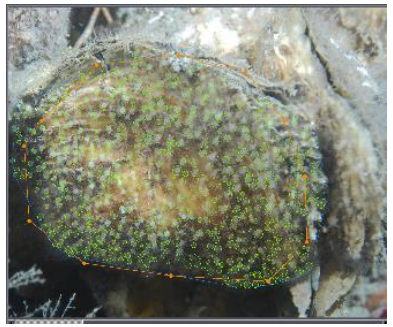
Matej Kristan

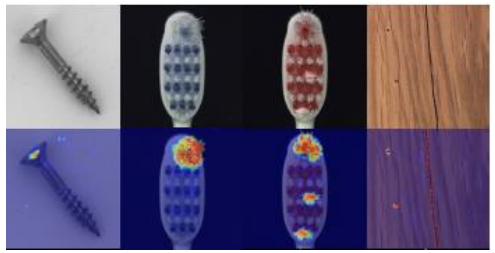
Visual Cognitive Systems Laboratory
Faculty of computer and information science
University of Ljubljana, Slovenia

Breaking the Surface, September 2022

ViCoS research

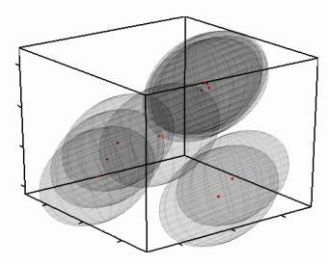
1. Anomaly detection & counting

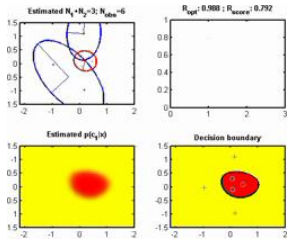


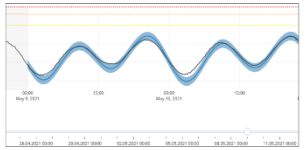


ECCV2022,ICCV2021, PR2021, AAI2020, JSR2018

2. Forecasting and online learning

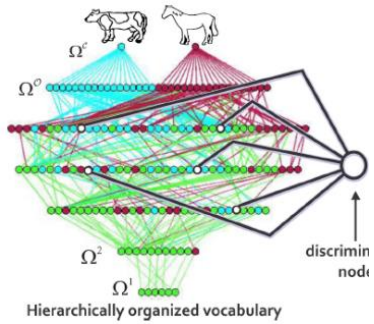






GMD2021, VC2017, SMCB2013, PR2011, IVC2009

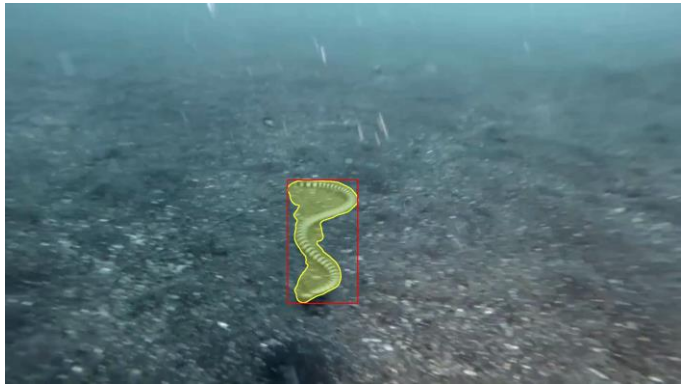
3. Deep structured networks



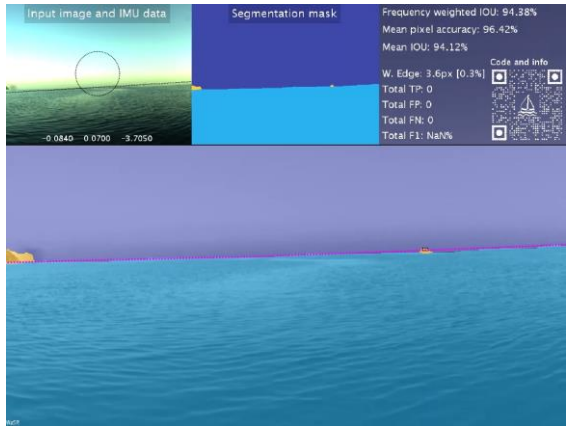
IJCV2020, CVPR2018, ICPR2016, CVIU2015, SCIA2013, ICVS2013, ICPR2012

4. Visual object tracking

TPAMI2021, TCyb2020, CVPR2020, ICCV2019, CVPR2019, ACCV2018, IJCV2018, ICCV2017, CVPR2017, TCyb2017, TPAMI2016, TIP2016, WACV2016, TPAMI2013, SMCB2010, PR2009, CVIU2009, ICCV-W(2013,2015,2017,2019, 2021), ECCV-W(2014,2016,2018, 2020,2022)



5. Robotic vision



IROS2022, WACV2021, TCyb2021, ICRA2020, JOE2019, IROS2019, RAS2018, IROS2018, RAS2017, IJRR2017, ISPA2017, ICRA2016b, ICRA2016a, IEEE TCyb2016, IJRAS2013, IMAVIS2013, IROS2012, EPIROB2010

Unmanned surface vehicles (USV)

- Maritime automation presents a large market opportunity
- 90% of all goods transported by water, presenting >$40bn annual expense
- Not just goods, consider passengers, automated delivery, etc.

Cargo ships

Ferries

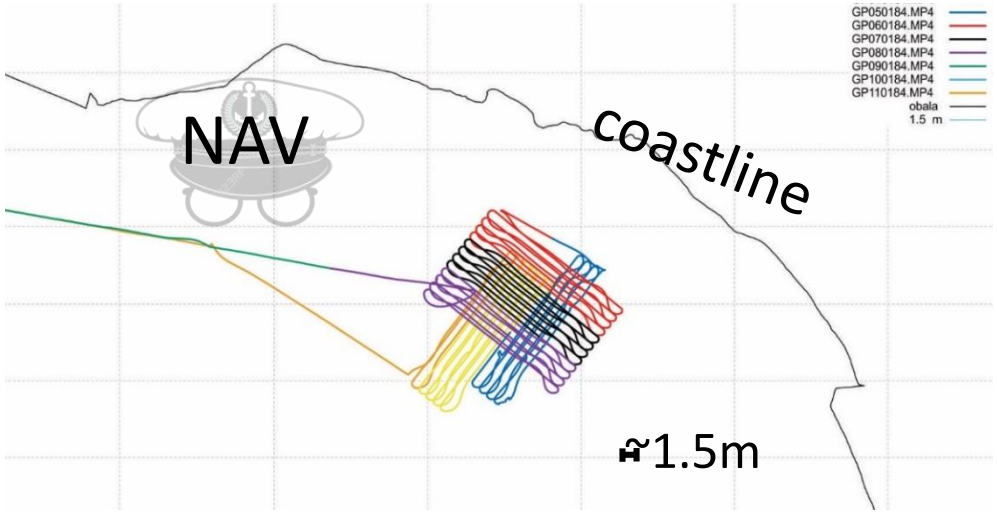
Waste collection

Coastal water USVs

- Small (~2m) portable boats for automating a broad range of applications:
  - Coastal water surveillance
  - Hydroelectric plants maintenance
  - Bathymetry, etc.

Coastal water USVs

- Significant effort invested in hardware, control & high-level planning



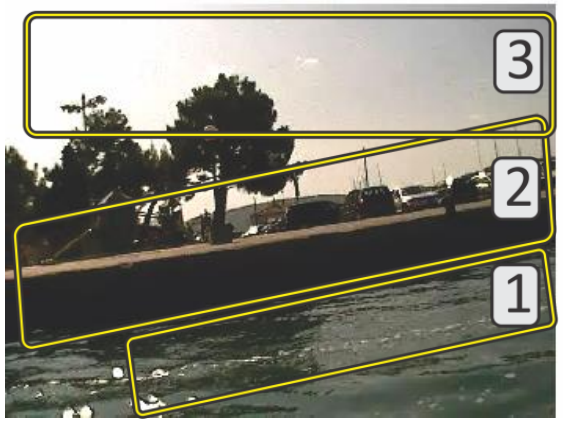
- Safe navigation requires robust obstacle detection
- Cameras: information rich & low cost
- Projects: TPMIR (~2010), ViAMaRo (2017-2020), DaViMaR (2020-2023)
  (joint work with the Faculty of electrical engineering UL & Sirio d.o.o.)

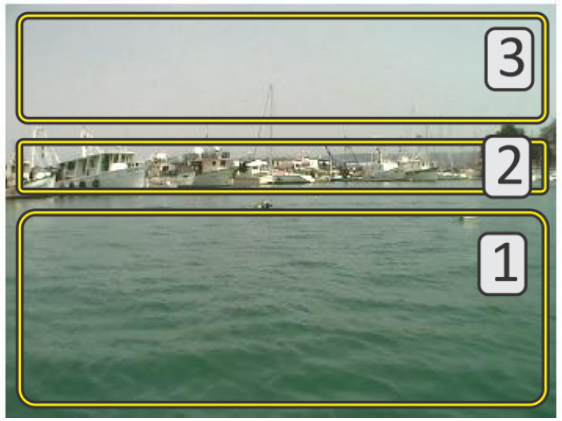
What makes an obstacle




- Common to all obstacles: Surrounded (or floating on) by water
- Issues: water appearance varies

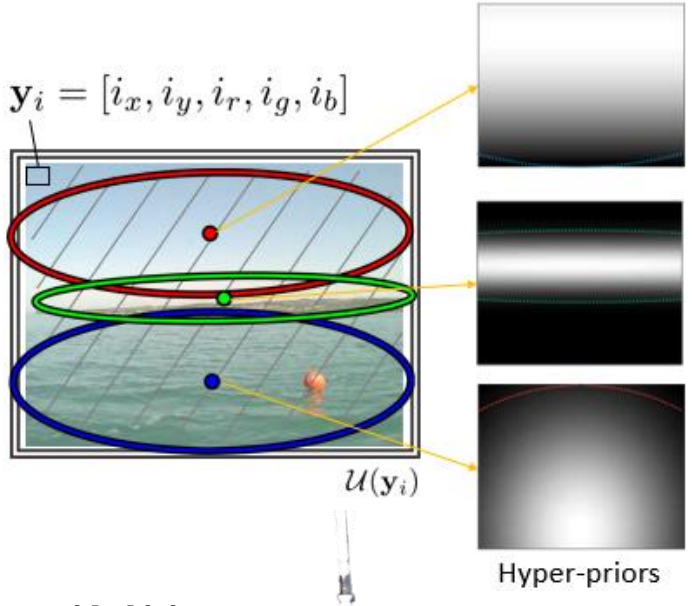
Three semantic regions.
Bottom region is water.

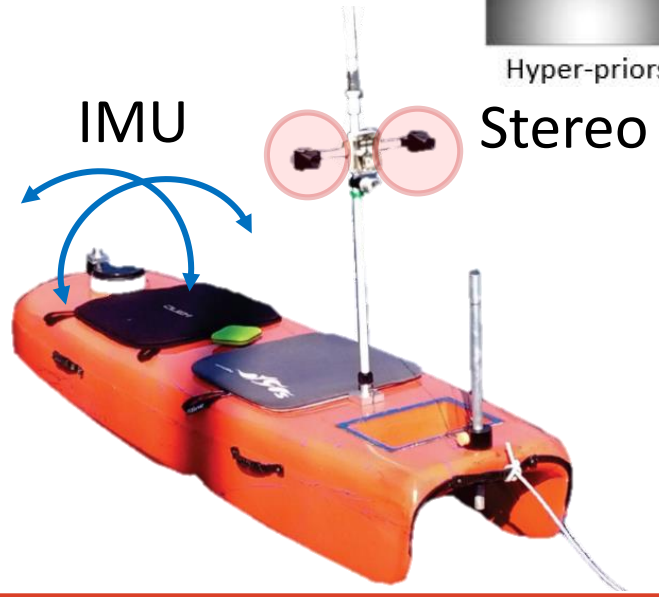




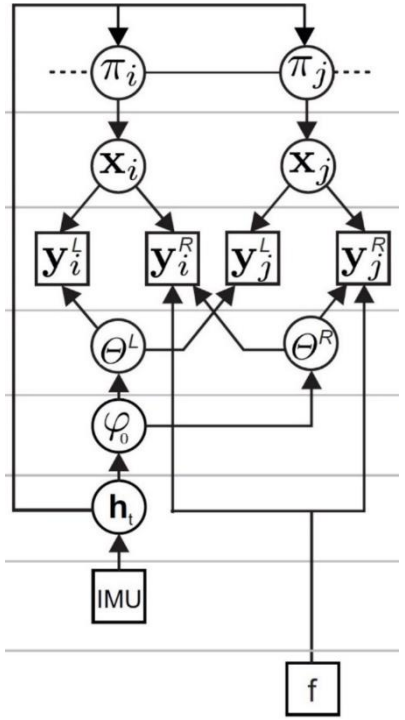
Semantic segmentation graphical model (SSM)

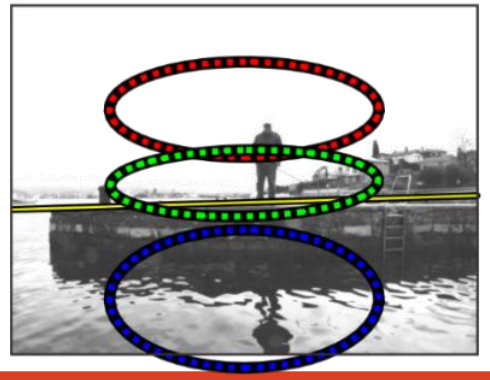
Monocular[1]



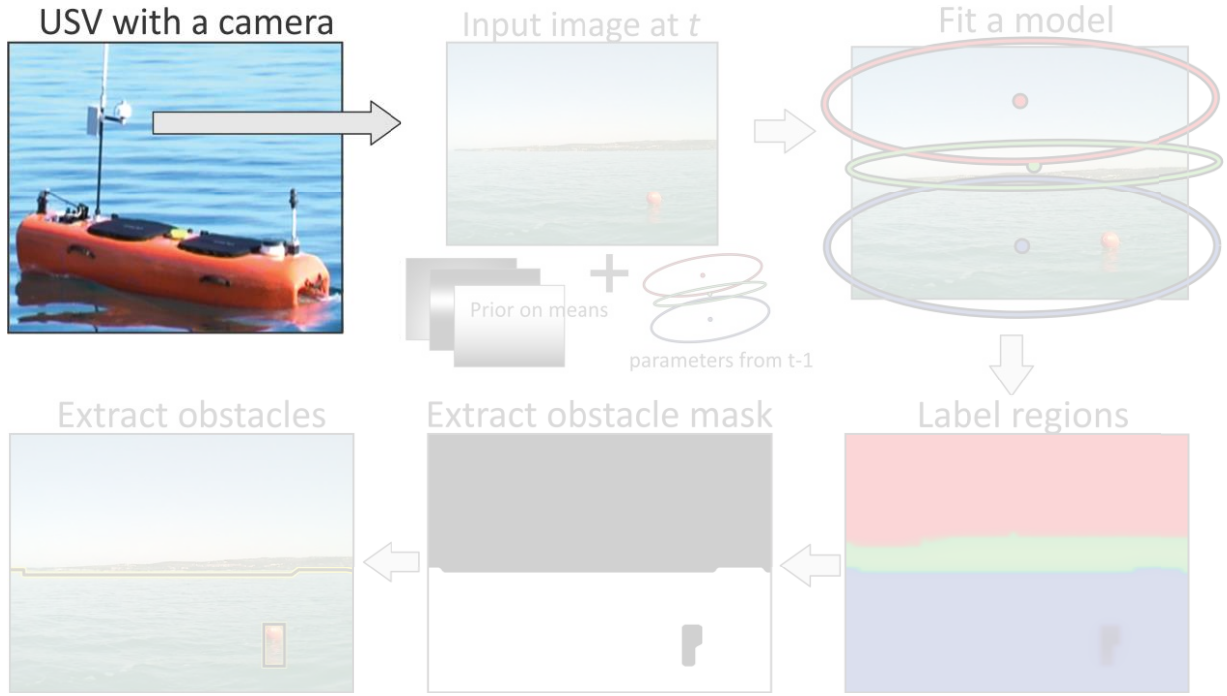


Stereo&IMU[2]





General detection approach



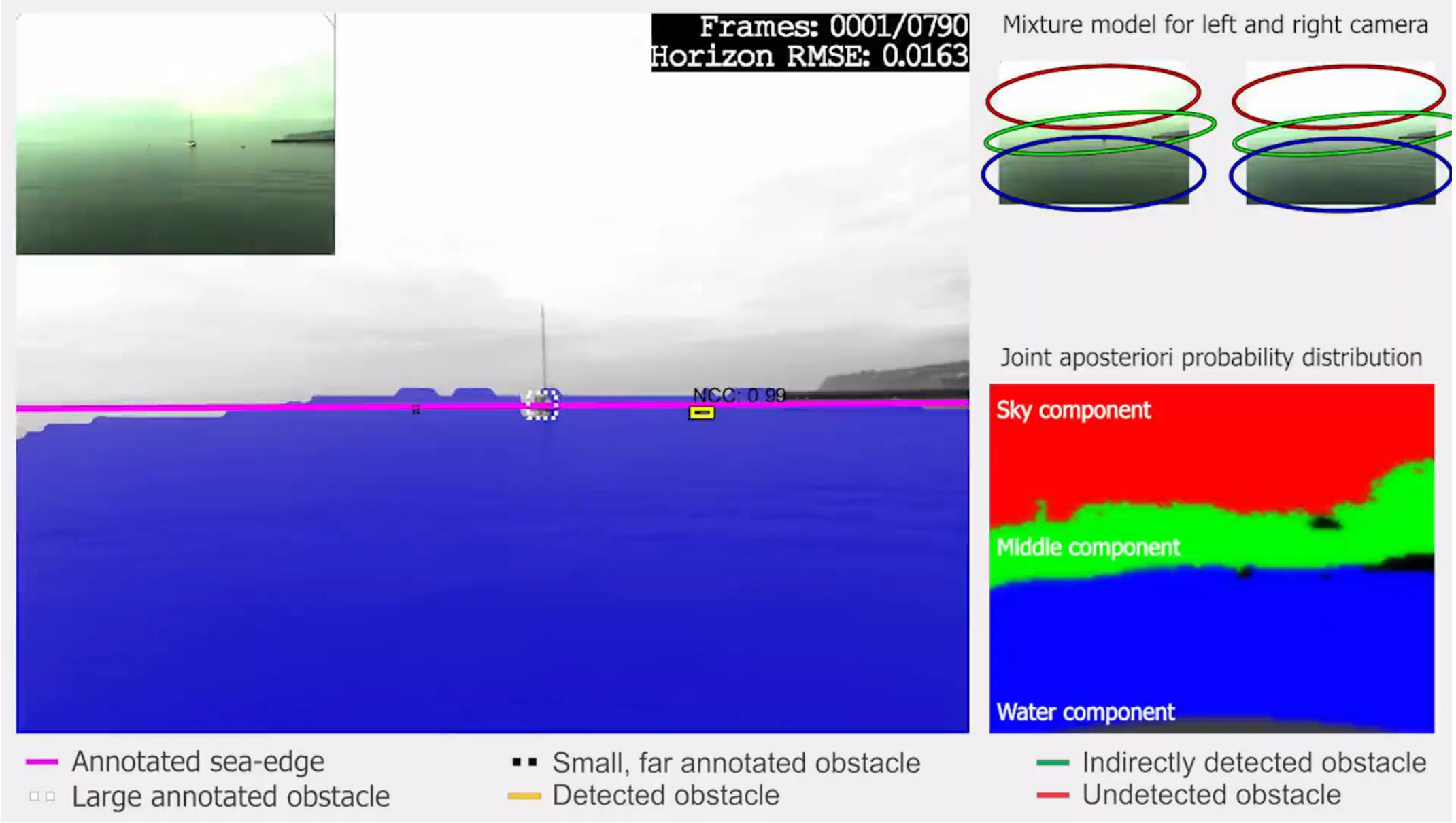
CPU Core i7 single thread: 70 fps in Matlab

[1]Kristan et al., CVWW2013 / IEEE TCyb 2016

[2]Bovcon et al., ISPA2017/IROS 2018/RAS2018

IeSSM visualization

[Bovcon and Kristan, IROS 2018]



Evaluation of general segmentation CNNs

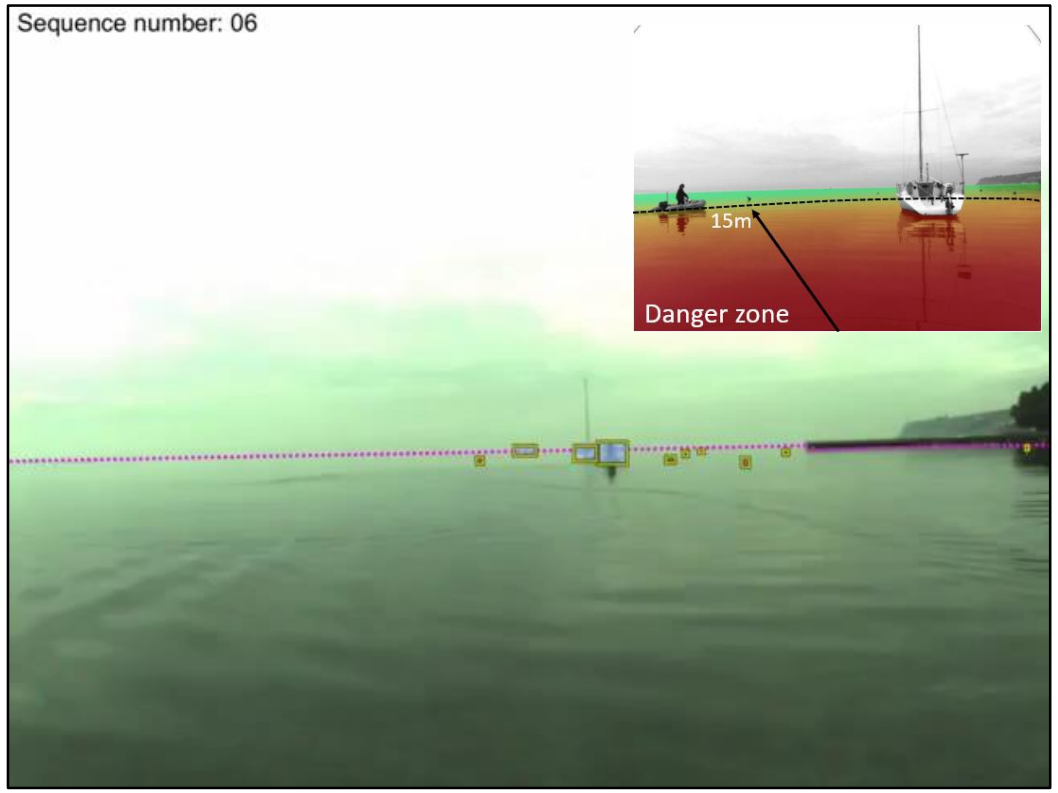
Train: MaSTr1325

[Bovcon et al., IROS2019]

- 1325 images (1278x958 res) from 50h footage taken over 2 years
- Diverse weather conditions
- Manually segmented (water, obstacle, sky)

Test: MODD2

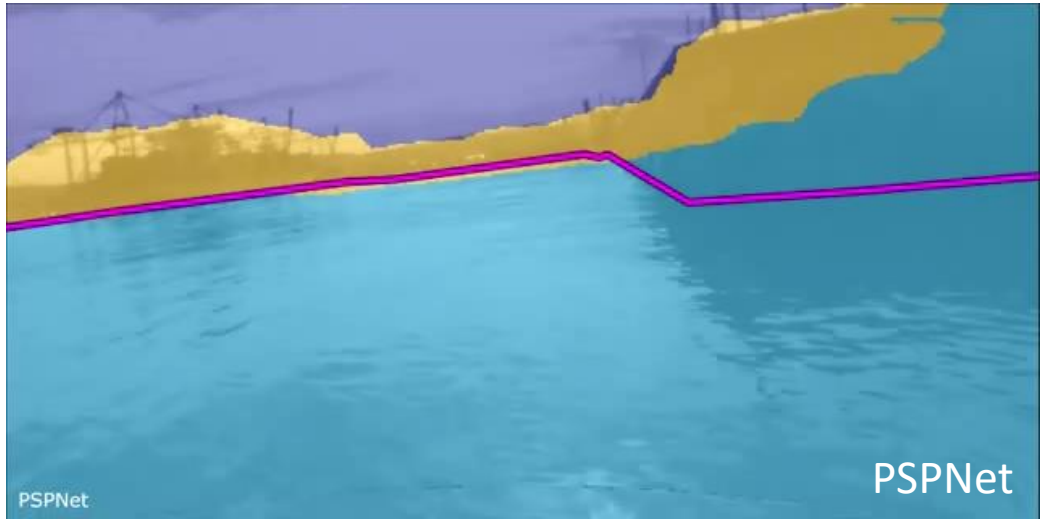
[Bovcon et al., RAS2018]

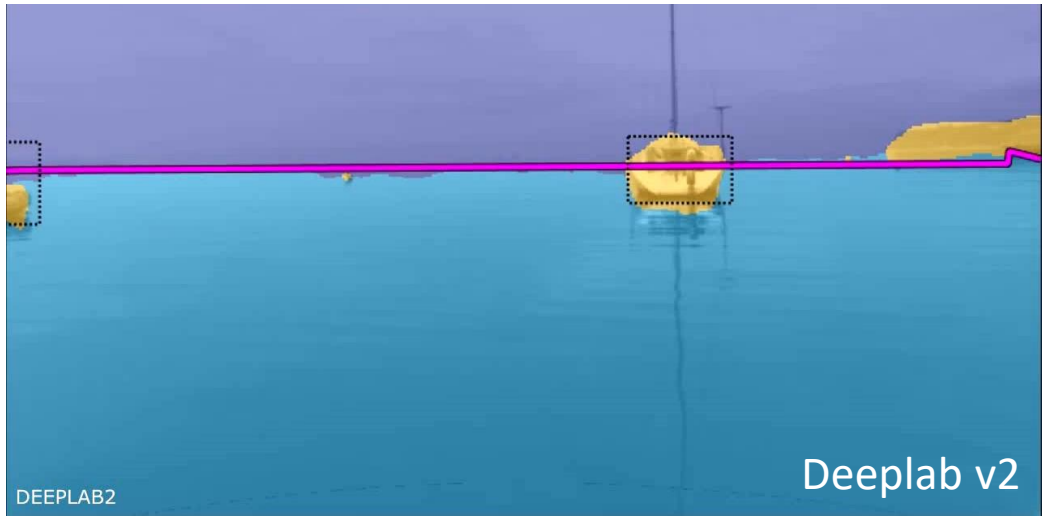


- 28 stereo sequences (~12k images, 1278×958)
- Obstacle bounding boxes + water edge
- Danger zone 15m
  (farthest point reachable in 10s at speed 1.5m/s)

Evaluation of general segmentation CNNs

	μ_{edg}	Pr[dz]	Re[dz]	F1[dz]	FPS
U-Net	18.8	13.8[5.9]	87.2[82.9]	23.8[11.0]	15.4
PSPNet	40.0	86.5[76.4]	51.0[50.2]	64.1[60.6]	17.2
DeepLab	16.6	77.4[82.3]	54.3[66.5]	63.8[73.6]	1.6
DeepLab$_{\neg CRF}$	16.0	81.6[70.0]	64.2[74.5]	71.9[72.2]	17.2

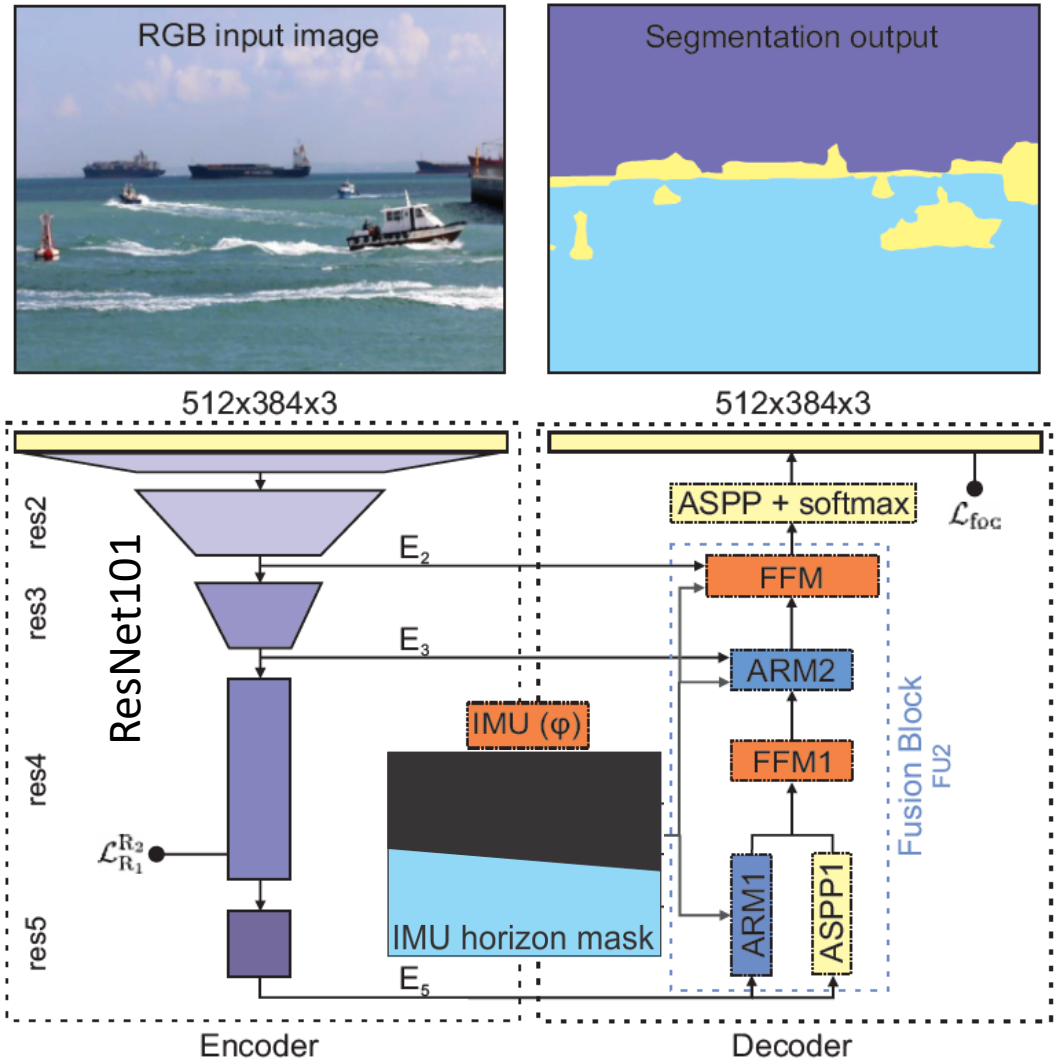




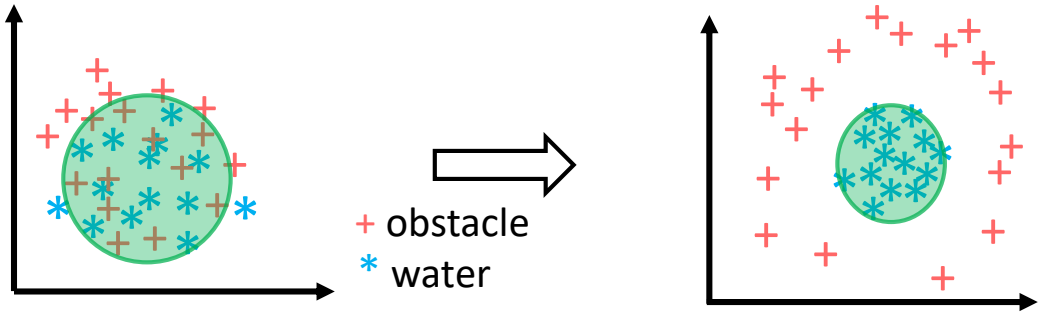
- Vanilla DeepLab architecture fast, best trade-off between TP/FP

[Bovcon et al., IROS2019]

WaSR (water-obstacle separation and refinement network)



- Focal loss for training
- Various water appearances should cluster in encoder embedding and be different from obstacle features
- A new water-separation loss:



[Bovcon et al., ICRA2020 ; Bovcon et al., IEEE TCyb 2021]

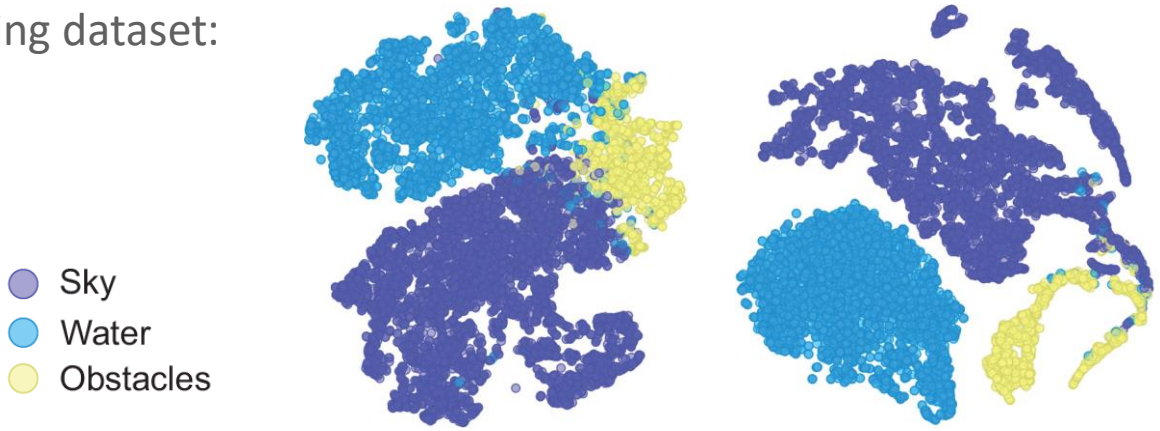
WaSR tested on MODD2

Architecture	μ_{edg}	Pr	Re	TPr	FPr	F1
$\text{WaSR}_{\text{NOSL}}$	11.0	91.7	92.1	49.7	4.5	91.9
WaSR	**10.5**	**94.6**	**96.5**	**52.1**	**3.0**	**95.5**

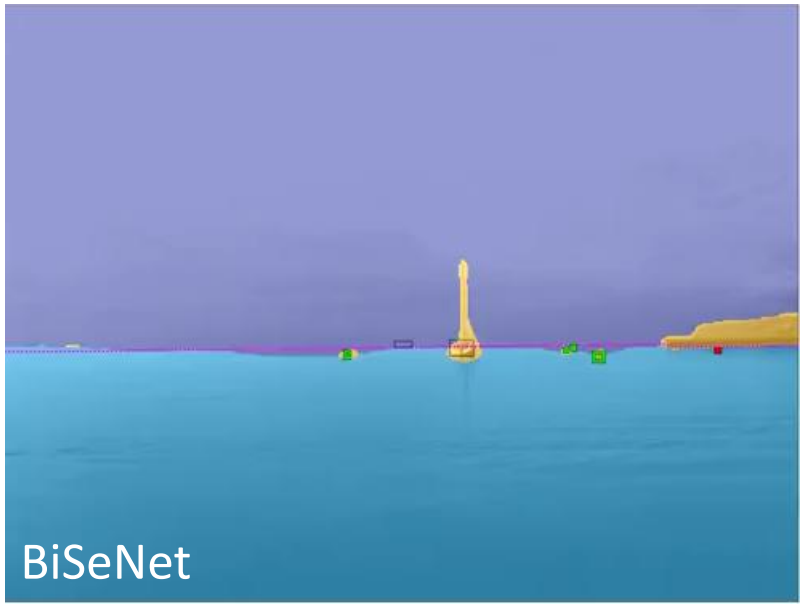
T-SNE visualization of encoder features on training dataset:

wo. separation loss

with separation loss



Architecture	μ_{edg}	Pr	Re	TPr	FPr	F1
PSPNet [11]	13.5	56.8	93.2	50.3	38.2	70.6
SegNet [34]	13.2	74.3	92.5	49.9	17.2	82.4
$\text{DeepLab2}_{\text{NOCRF}}$ [38]	12.5	94.5	62.6	33.8	**2.0**	75.3
DeepLab3+ [14]	13.8	64.9	84.2	45.4	24.6	73.3
BiSeNet [13]	12.0	77.1	90.4	48.4	14.5	83.2
RefineNet [12]	14.4	90.2	92.7	50.0	5.4	91.4
WaSR	**10.5**	**94.6**	**96.5**	**52.1**	3.0	**95.5**
FC-DenseNet56 [52]	14.5	74.5	91.4	49.3	16.9	82.1
100-Layer Tiramisu [52]	13.1	73.0	89.2	48.2	17.9	80.3
MobileUNet [53]	13.8	54.5	89.2	48.1	40.1	67.7
$\text{IntCatch}_{\text{full}}$ [56]	20.4	52.8	82.7	44.6	39.8	64.5

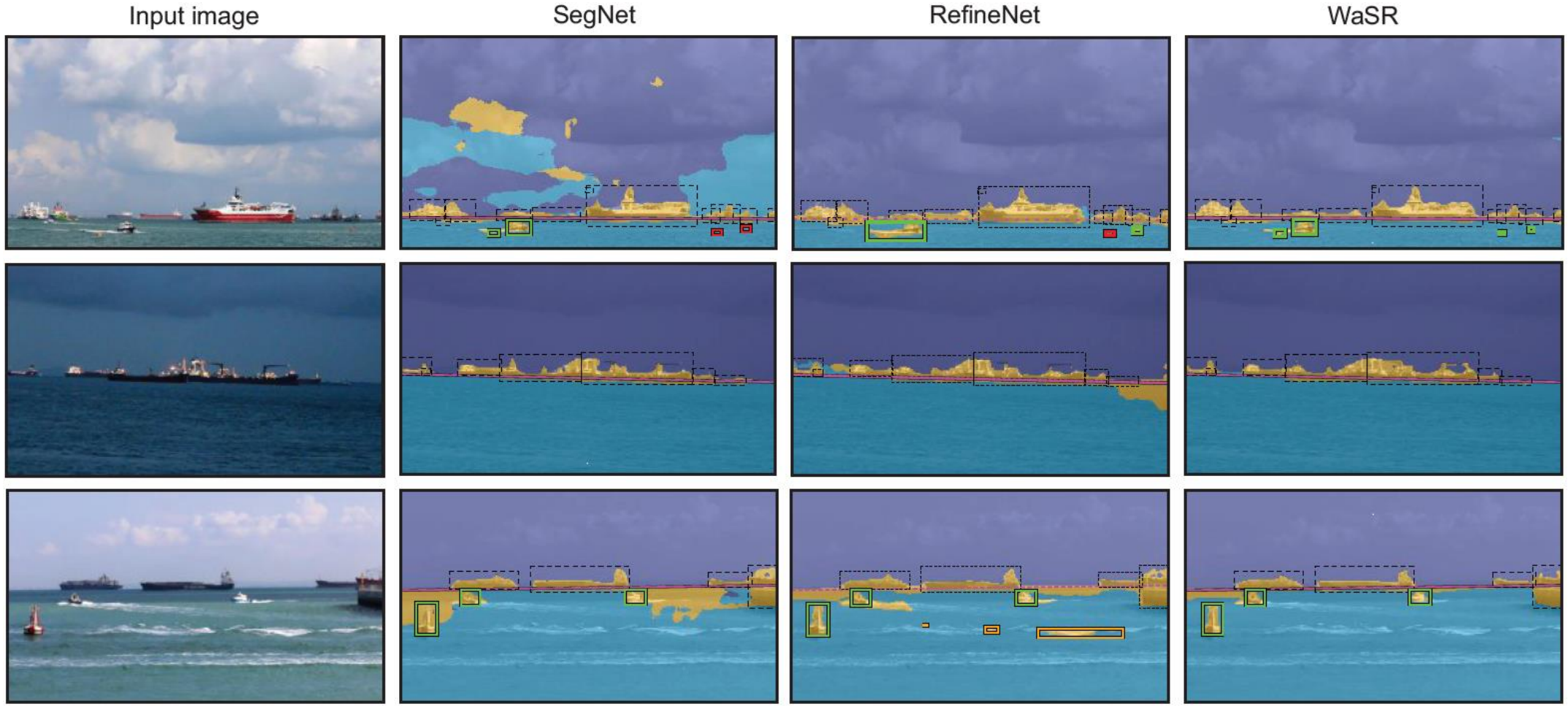


WaSR tested on SMD[1]

[1][Prasad et al. IEEE T-ITS 2017]

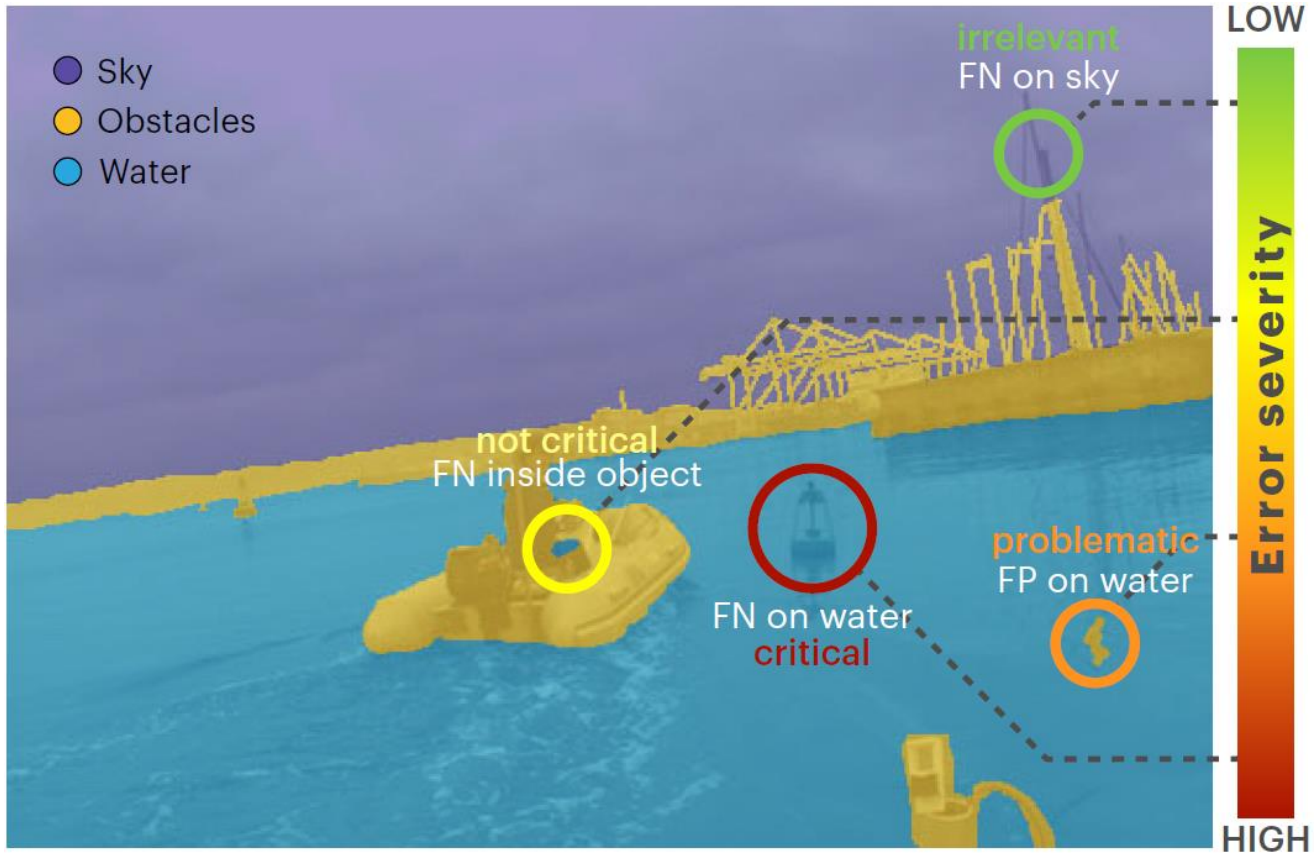
- 12 sequences (dusk, night, light rain)
- No re-training (trained on MaSTr)

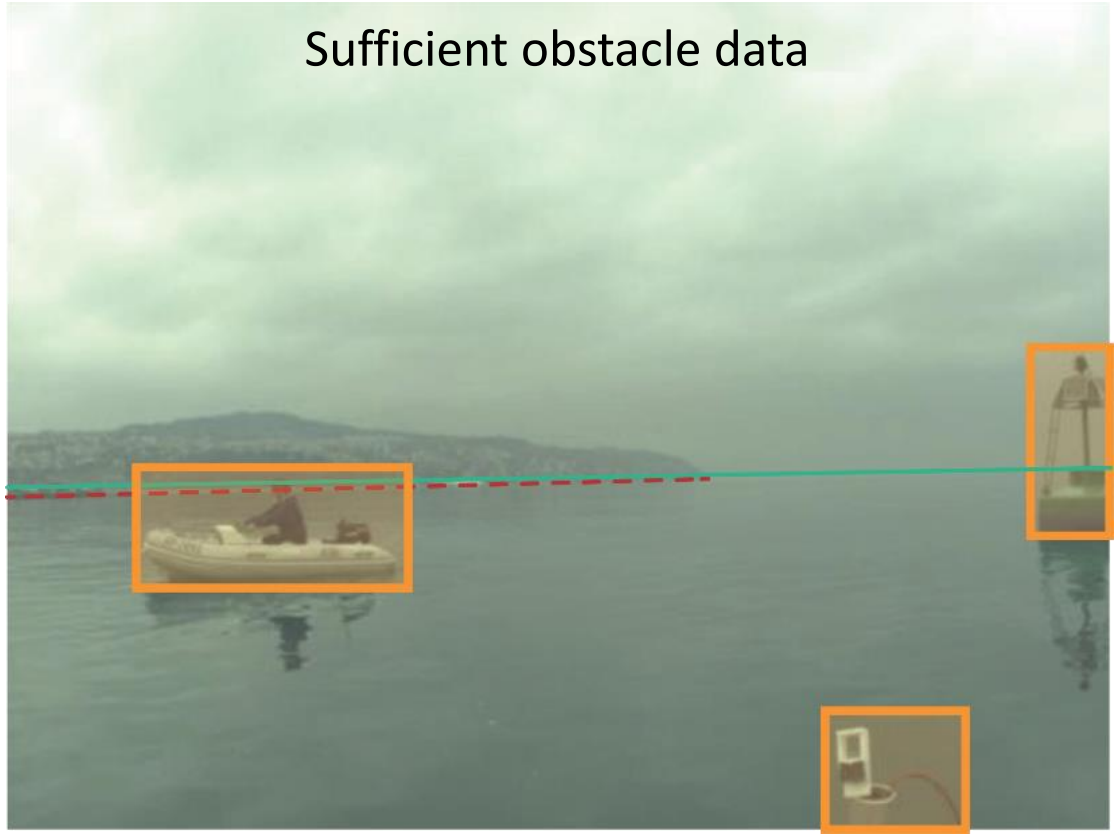
Architecture	μ_{edg}	Pr	Re	TPr	FPr	F1	vs. MODD2
SegNet	31.0	31.2	76.3	74.0	163.2	44.3	-46.2%
BiSeNet	28.9	15.9	88.6	85.9	452.7	27.0	-67.6%
RefineNet	24.8	49.2	79.7	77.3	79.9	60.8	-33.5%
WaSR	**16.0**	**77.0**	**94.1**	**91.2**	**27.2**	**84.7**	**-11.3%**



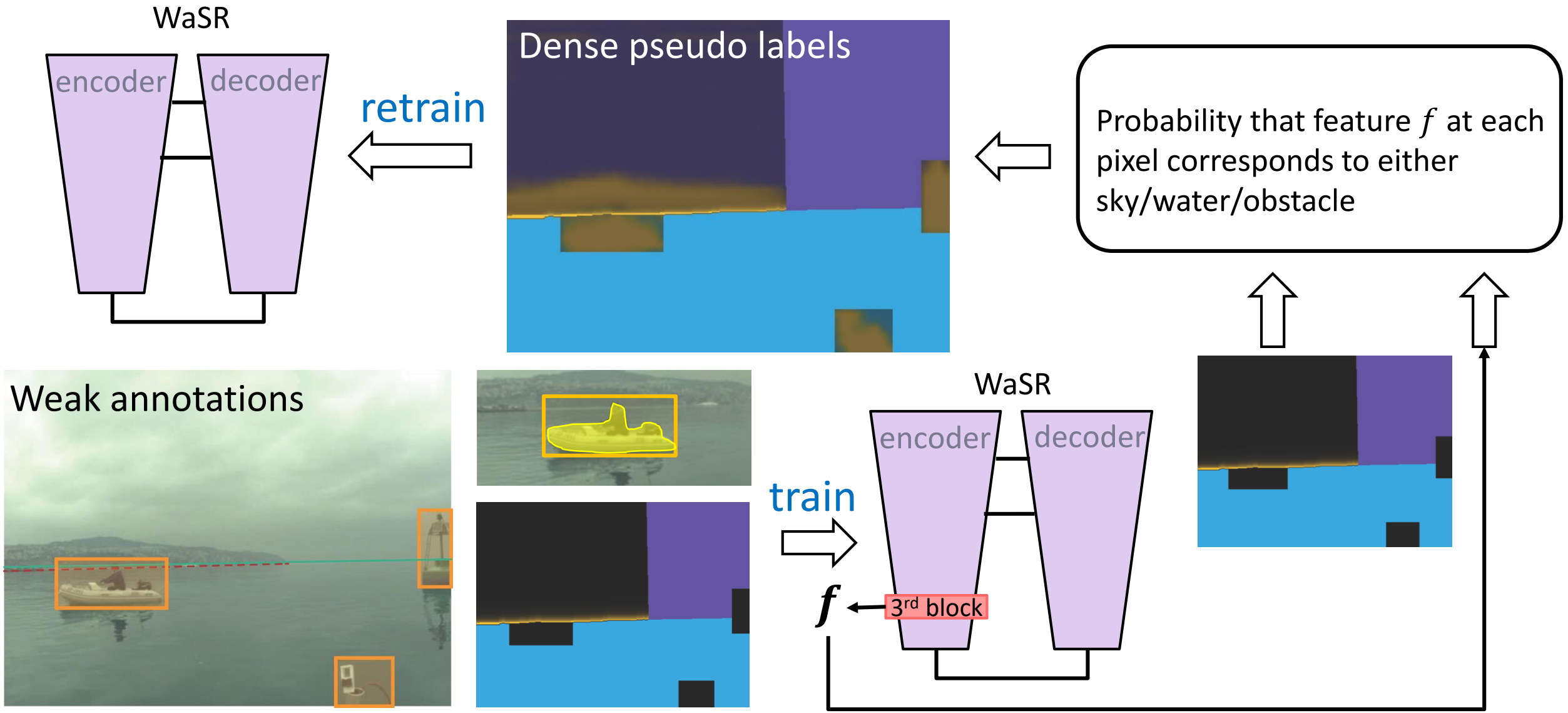
Towards training with minimal annotation

- Training data annotation for segmentation methods is laborious
- Segmentation accuracy is not equally important for all regions





Scaffolded learning regime (SLR)

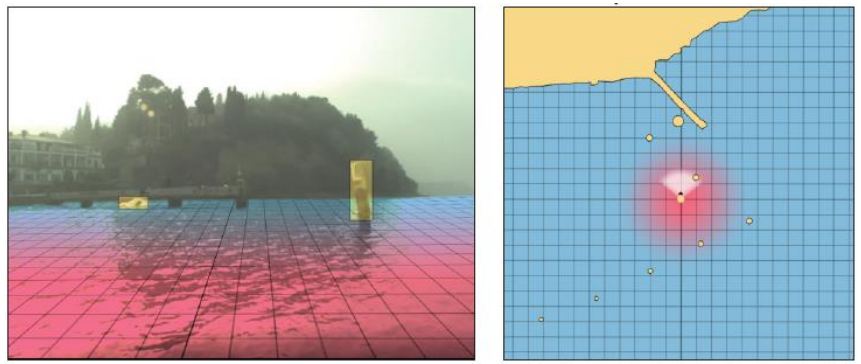


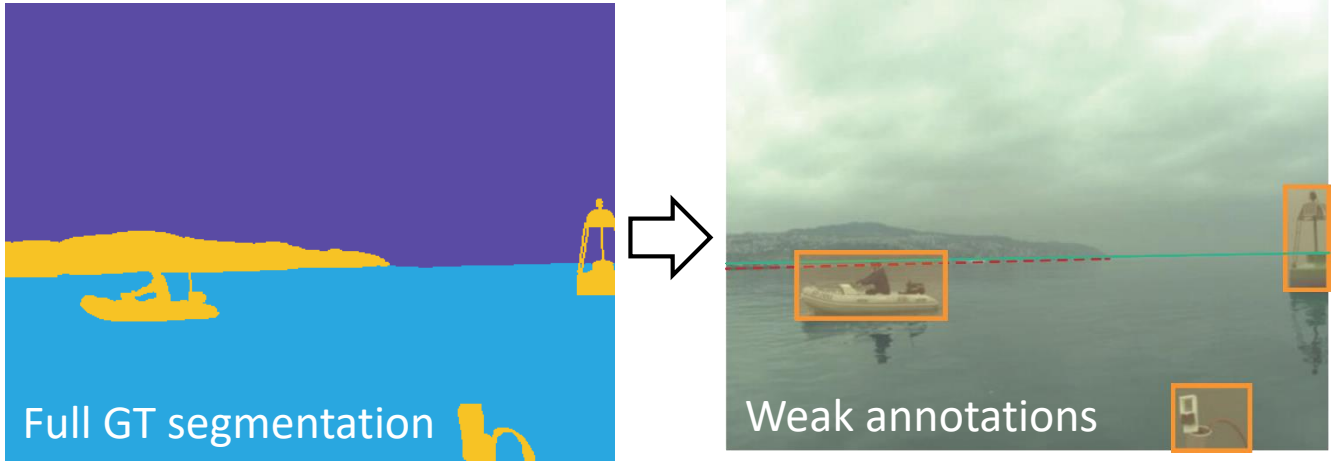
Žust and Kristan, Learning Maritime Obstacle Detection from Weak Annotations by Scaffolding, WACV 2022

Evaluation of SLR

[1]Bovcon et al., IROS2019
[2]Bovcon et al., IEEE T-ITS2021

- Trained on MaSTr1325[1] (weak annotations)
- Tested on MODS[2]
  - 94 sequences
  - 81k stereo images & IMU
  - 60k objects annotated
  - 15m danger zone annotation

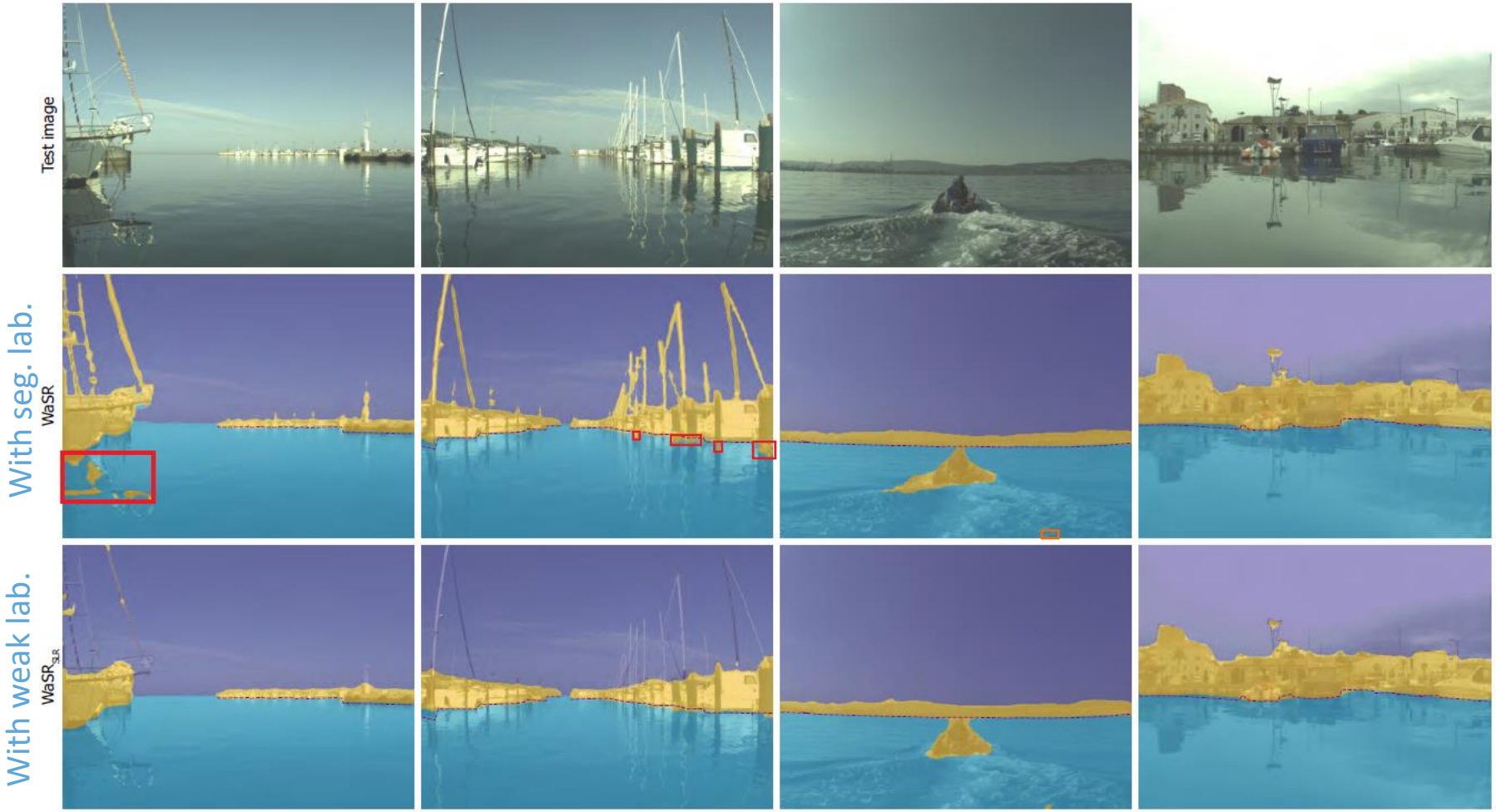




Results (SLR)

		Overall		
		Pr	Re	F1
seg.	RefineNet	89.0	93.0	91.0
	DeepLabV3	80.1	92.7	86.0
	BiSeNet	90.5	89.9	90.2
	WaSR	95.4	91.7	93.5
weak	$\text{DeepLabV3}_{\text{SLR}}$	94.3	89.4	91.8 (+5.8)
	WaSR_{SLR}	**96.7**	**93.1**	**94.9** (+1.4)

		Danger zone (<15m)		
		Pr	Re	F1
seg.	RefineNet	45.1	98.1	61.8
	DeepLabV3	18.6	**98.4**	31.3
	BiSeNet	53.7	97.0	69.1
	WaSR	82.3	96.1	88.6
weak	$\text{DeepLabV3}_{\text{SLR}}$	85.5	95.5	90.3 (+59.0)
	WaSR_{SLR}	**91.5**	96.0	**93.7** (+5.1)



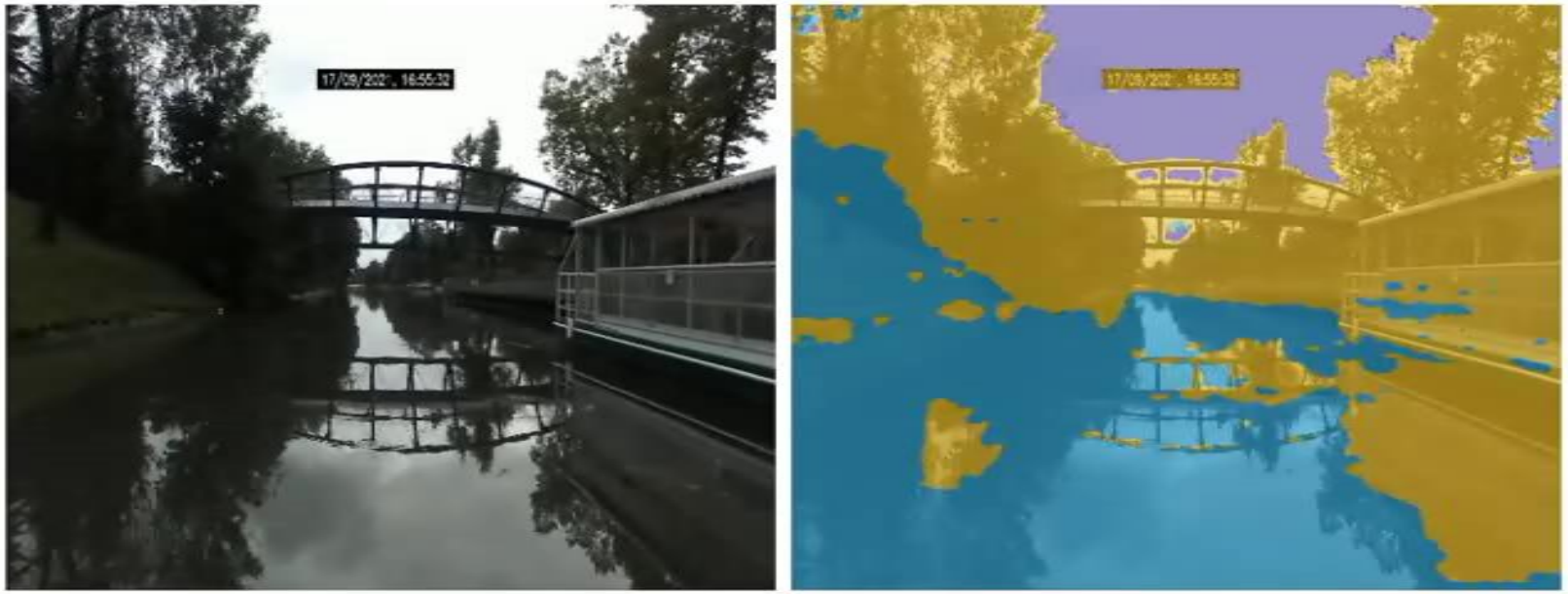
- SLR on weak labels slightly *outperforms* training on segmentation labels!

Žust and Kristan, Learning Maritime Obstacle Detection from Weak Annotations by Scaffolding, WACV2022

Issues with reflections and mirroring

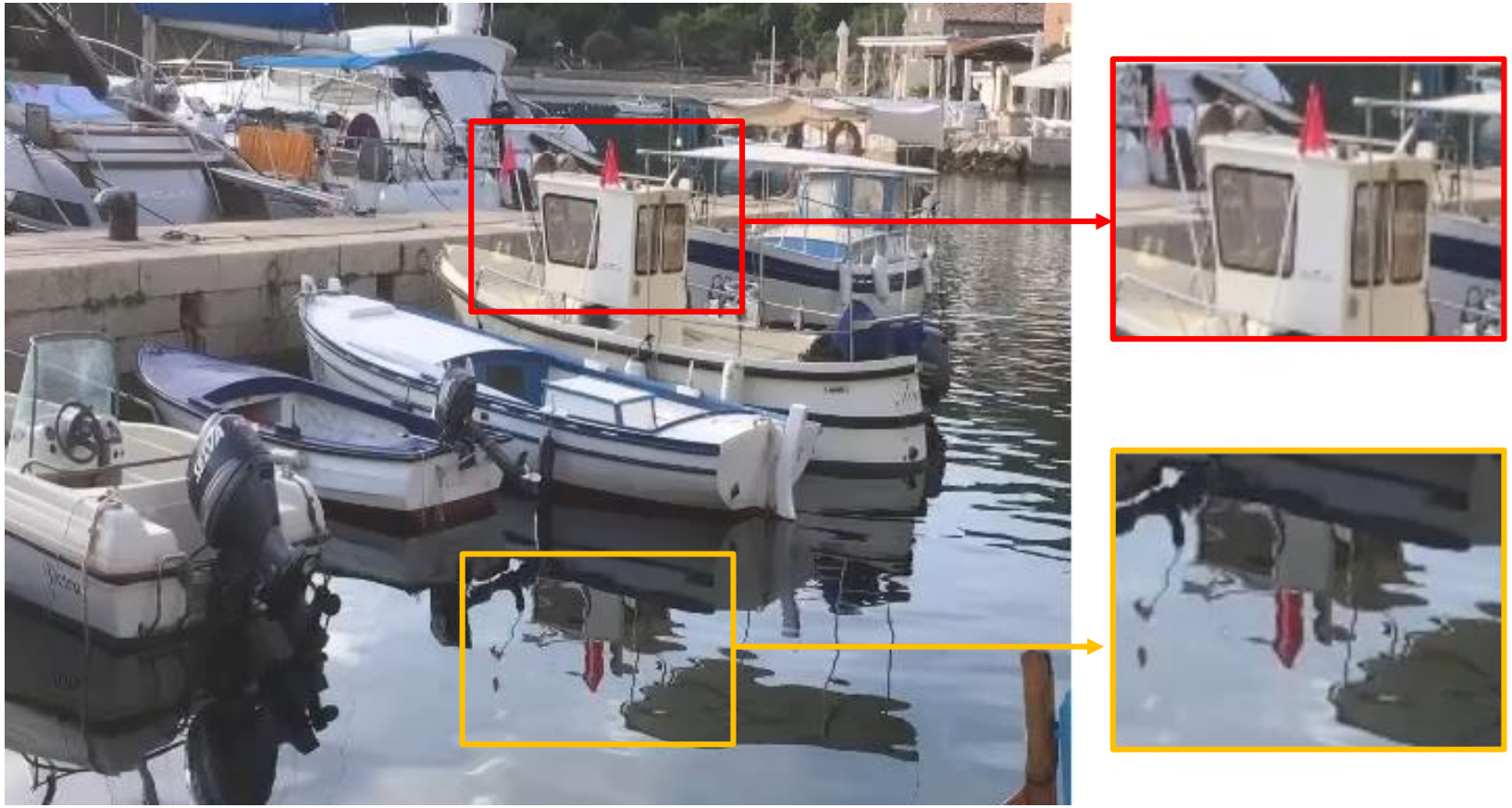
- Water surface highly reflective

WaSR
[Bovcon et al., TCyb2021]



- State-of-the-art fails with false detections on glitter and mirroring

Exploiting appearance dynamics

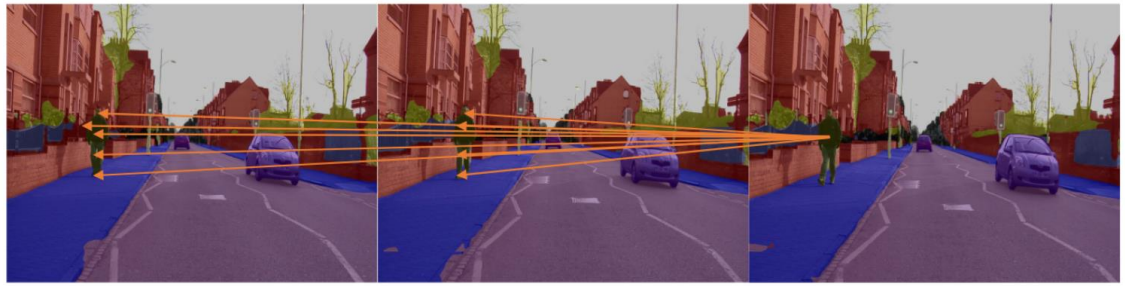


Reflections ambiguous *at a single frame*

- Water surface motion affects reflection appearance dynamics
- Solution: Exploit temporal appearance dynamics

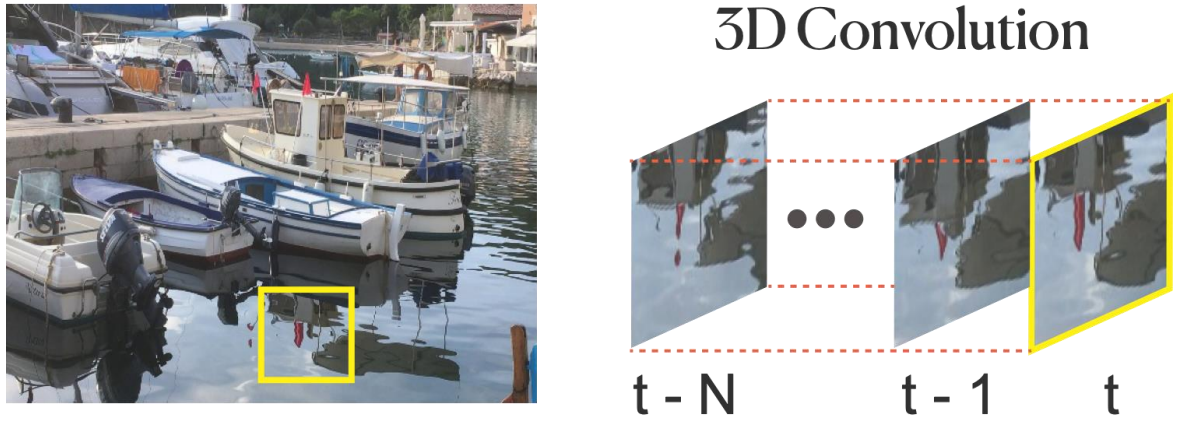
Exploiting appearance dynamics

UGV sota:



- Aggregate information from semantically similar regions in past images
- Use global attention [2,3] over temporal features

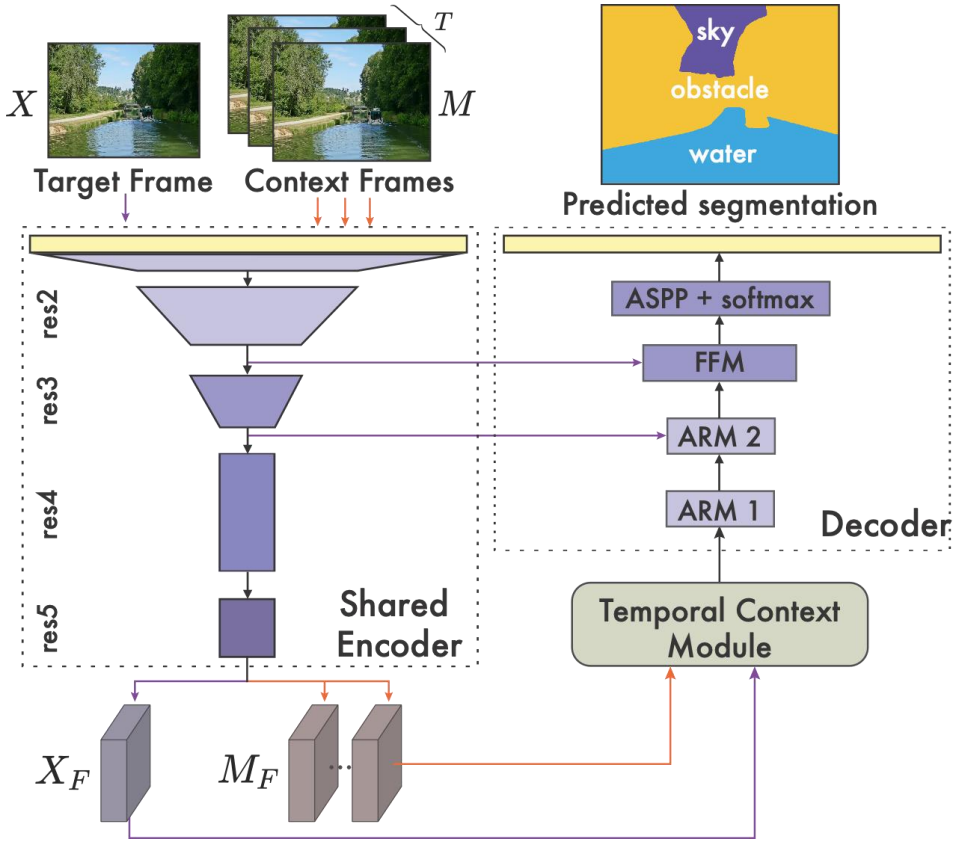
Our approach:

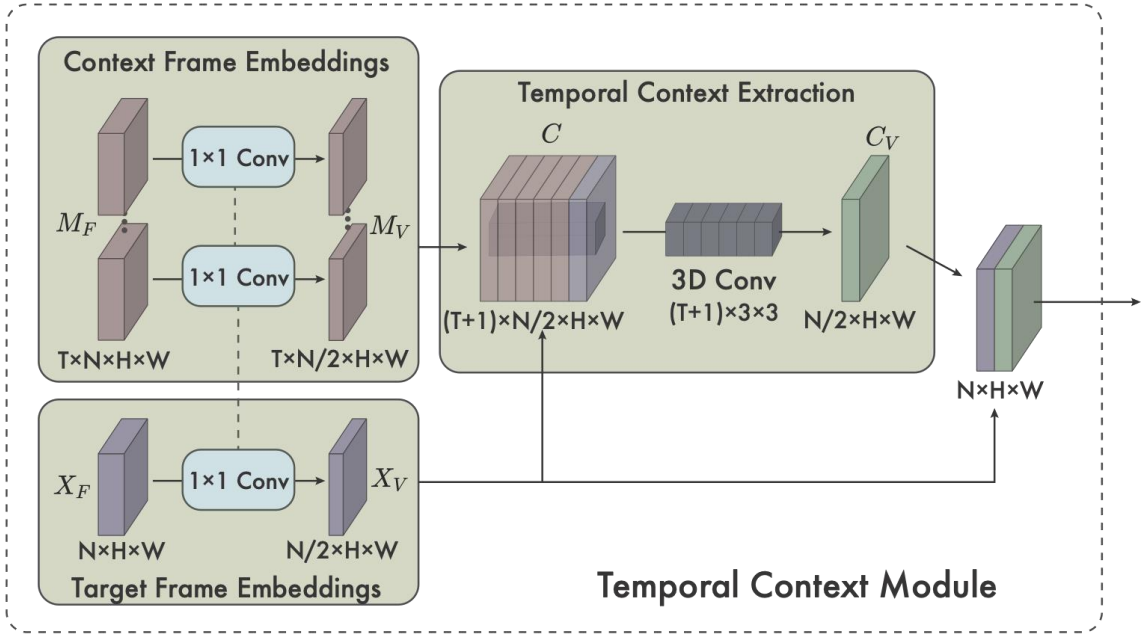


- Capture discriminative local texture changes
- Local 3D convolution over temporal features

[2] Wang, Hao, et al. “Temporal Memory Attention for Video Semantic Segmentation.” ICIP 2021
[3] Oh et al.: Video Object Segmentation using Space-Time Memory Networks, CVPR 2019

Temporal WaSR: WaSR-T





- Enrich encoder features with temporal context (computed using 3D Conv)
- Combine target frame features and temporal context features and pass to decoder

Žust & Kristan, Temporal Context for Robust Maritime Obstacle Detection, IROS2022

WaSR-T Results

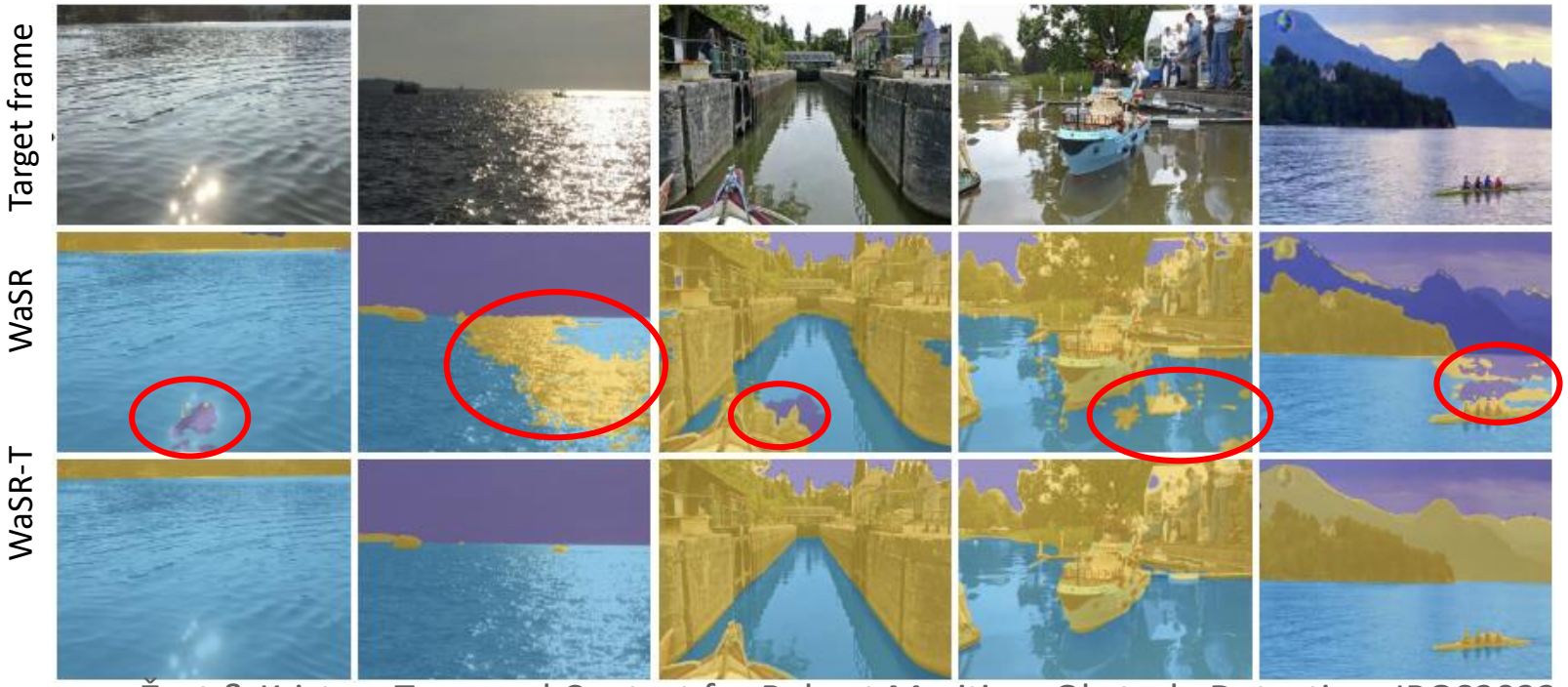
- Extended MaSTr1325[1] with temporal data (T=5) and additional scenes (~150)
- WaSR-T evaluated on MODS[2] benchmark for maritime obstacle detection
- Surpasses existing single-frame methods as well as temporal methods

Results on MODS benchmark

	method	F1
Single frame	DeepLabV3	86.0 (31.3)
	BiSeNet	90.2 (69.1)
	RefineNet	91.0 (61.8)
	WaSR	93.5 (87.6)
Temporal	TMANet	90.4 (91.5)
	STM	**94.4** (91.0)
	WaSR-T	**94.4** (**93.6**)

[1]Bovcon et al., IROS2019
[2]Bovcon et al., IEEE T-ITS2021

Qualitative results on hard examples (web images)



Žust & Kristan, Temporal Context for Robust Maritime Obstacle Detection, IROS2022

WaSR-T performance

Qualitative results

Žust & Kristan, Temporal Context for Robust Maritime Obstacle Detection, IROS2022

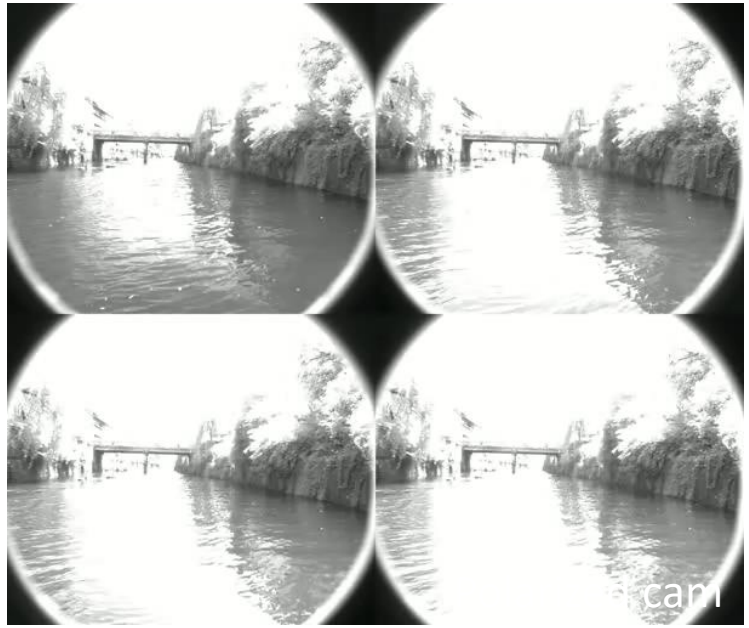
- Significant improvement on reflections and even on static obstacles
- Further work required to improve computational efficiency

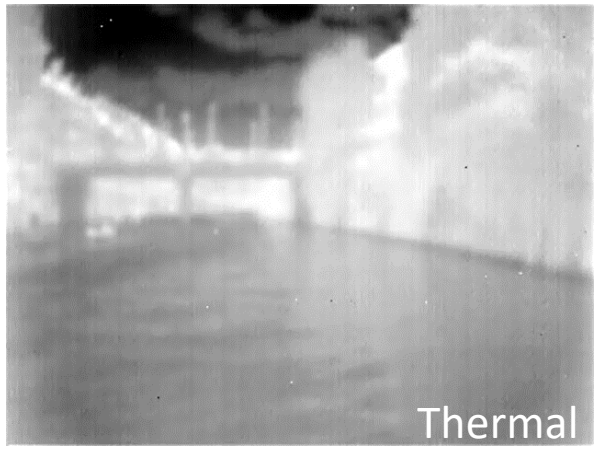
Ongoing efforts

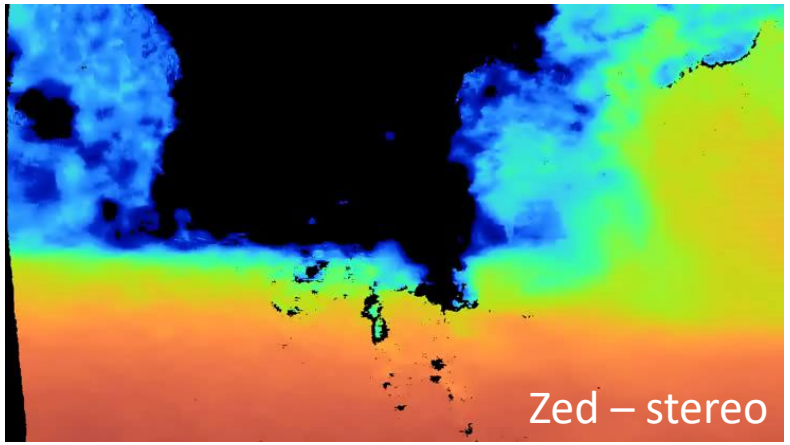
- Consider multimodal networks – record a new dataset first

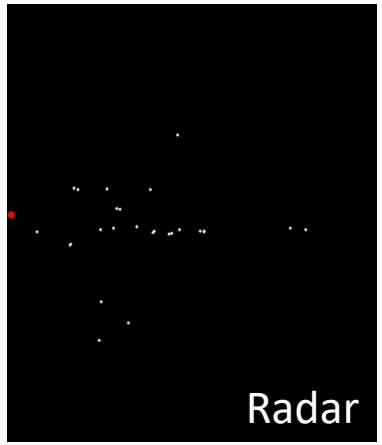
  (i) 2x Stereo RGB cameras, (ii) polarized light gray-scale camera, (iii) thermal camera, (iv) LIDAR, (v) Radar , (iv)? IR 970nm? ; Environments: Lakes, Rivers, Coastal sea

A new multimodal dataset in acquisition





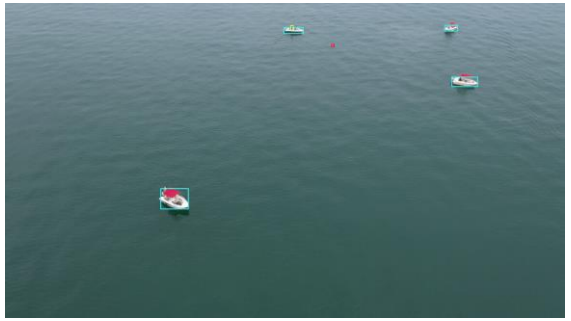




1st Workshop on Maritime Computer Vision MaCVi2023

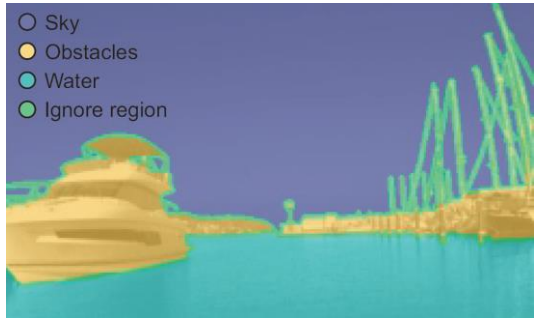
- In conjunction with WACV2023 (Hawaii)
- 4 challenges:

Detection (UAV)

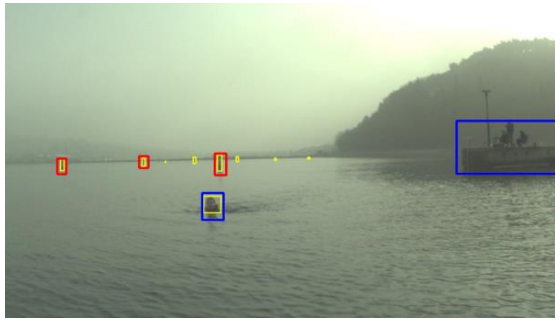


Tracking (UAV)

Segmentation (USV)



Detection(USV)

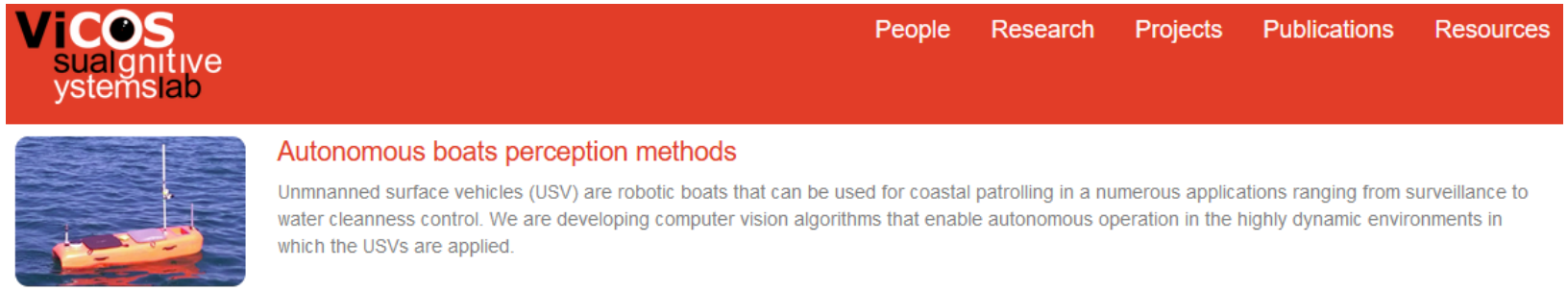


- Best research papers invited to submit to Sensors journal
  - Paper submission: 25.10.2022
  - Challenges close: 25.10.2022
  - MaCVi2023: 3.1.2023

https://seadronessee.cs.uni-tuebingen.de/wacv23

Conclusion

- Obstacle detection by segmentation
- WaSR: visual + IMU , copes well with slight domain shifts
- Temporal appearance improves segmentation
- Segmentation networks may be trained from weak annotations
- Multimodal dataset being acquired
- Community building: Maritime challenges planned



https://www.vicos.si/research/autonomous-boats

Datasets: MODD, MODD2, MODS, MaSTr1325

Code: WaSR, MODx evaluation toolkits, Camera-IMU calibration tools, etc.

Thanks

The ViAMaRo/DaViMaR core vision team

Matej Kristan

Janez Perš

Borja Bovcon

Jon Natanael Muhovič

Lojze Žust

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Rok Mandeljc, Mozetič Dean, Duško Vranac, Aljoša Žerjal, Stanislav Kovačič, Vildana Sulić

ARRS program P2-0214 and project J2-2506

Slovenian Research Agency

Work Class ROV in Underwater Operations

Presentation by:

Zdravko Eškinja, Phd
Ivo Kutleša, mag. Ing. el.
Marine Robotics and Systems

September 27, 2022.

Outline

- Introduction
  - Testing Auto-Functionalities in Work Class ROV
  - Operator Training
- Machines and Challanges
  - Heavy trancher machine with cutter
  - Jetting ROV
  - Compact ROV
  - Other machines
- Data analysis
- Simulation in testing
- Simulation in education
- Conclusion

Introduction

Underwater offshore operations are demanding and highly customised, but all all machine operations have some common characteristics:

- Trials are very expensive and very rear
- There are too many elements in the chain that can fail

TM05

TM05

Length (O.A vehicle only) : **7.90 m**

Width O.A : **7.20 m**

Height O.A : **5 m**

Weight in air : **47.5 tons**

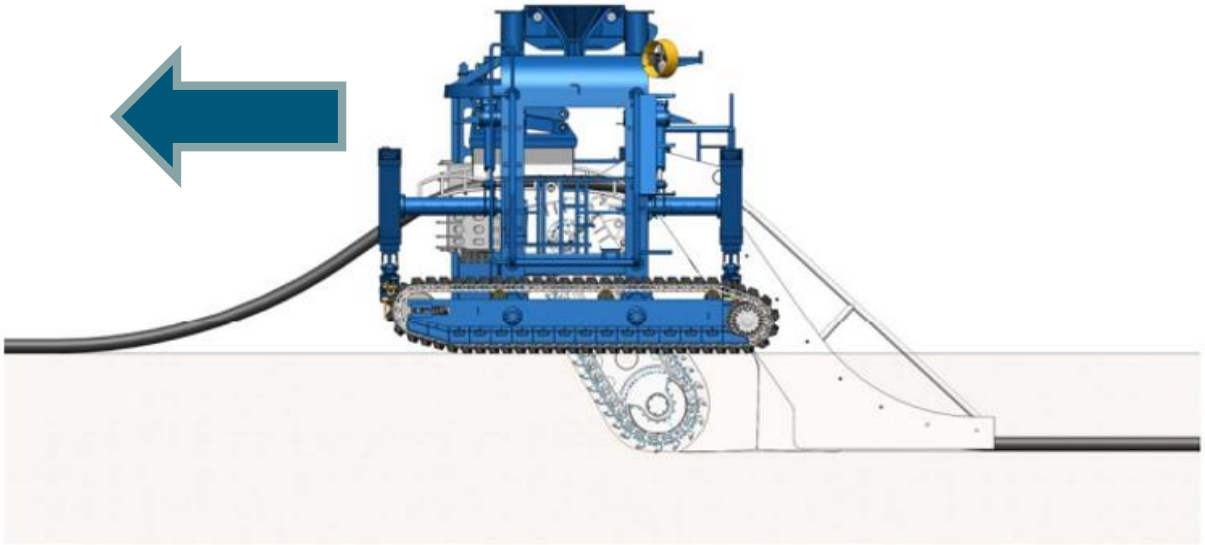
Weight in water : **38 tons**

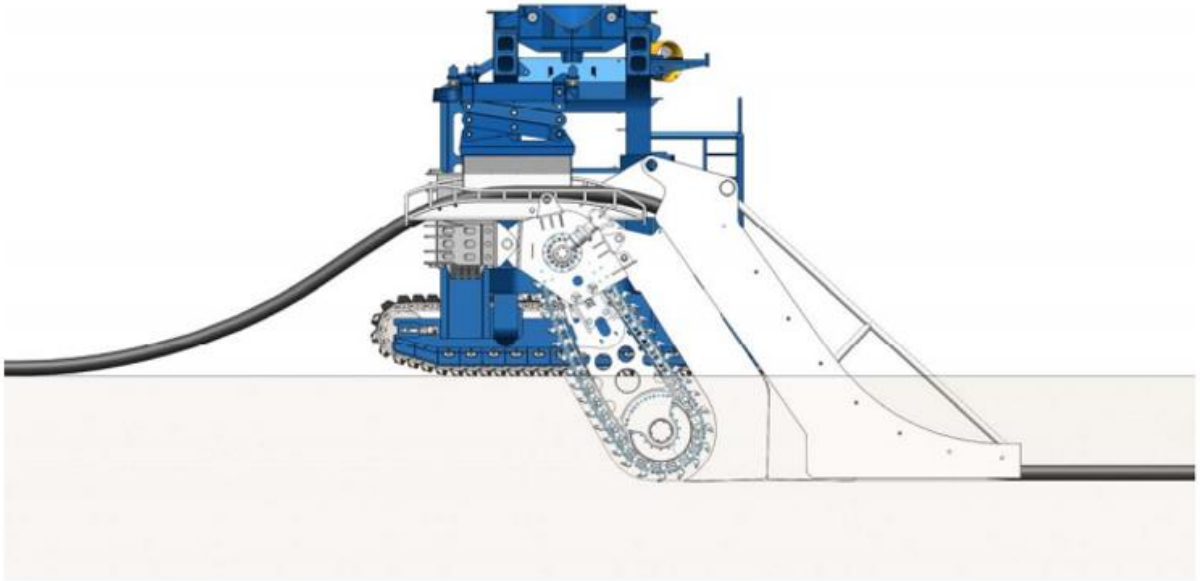
Power : **1310 HP**

Max water depth :**150 m**

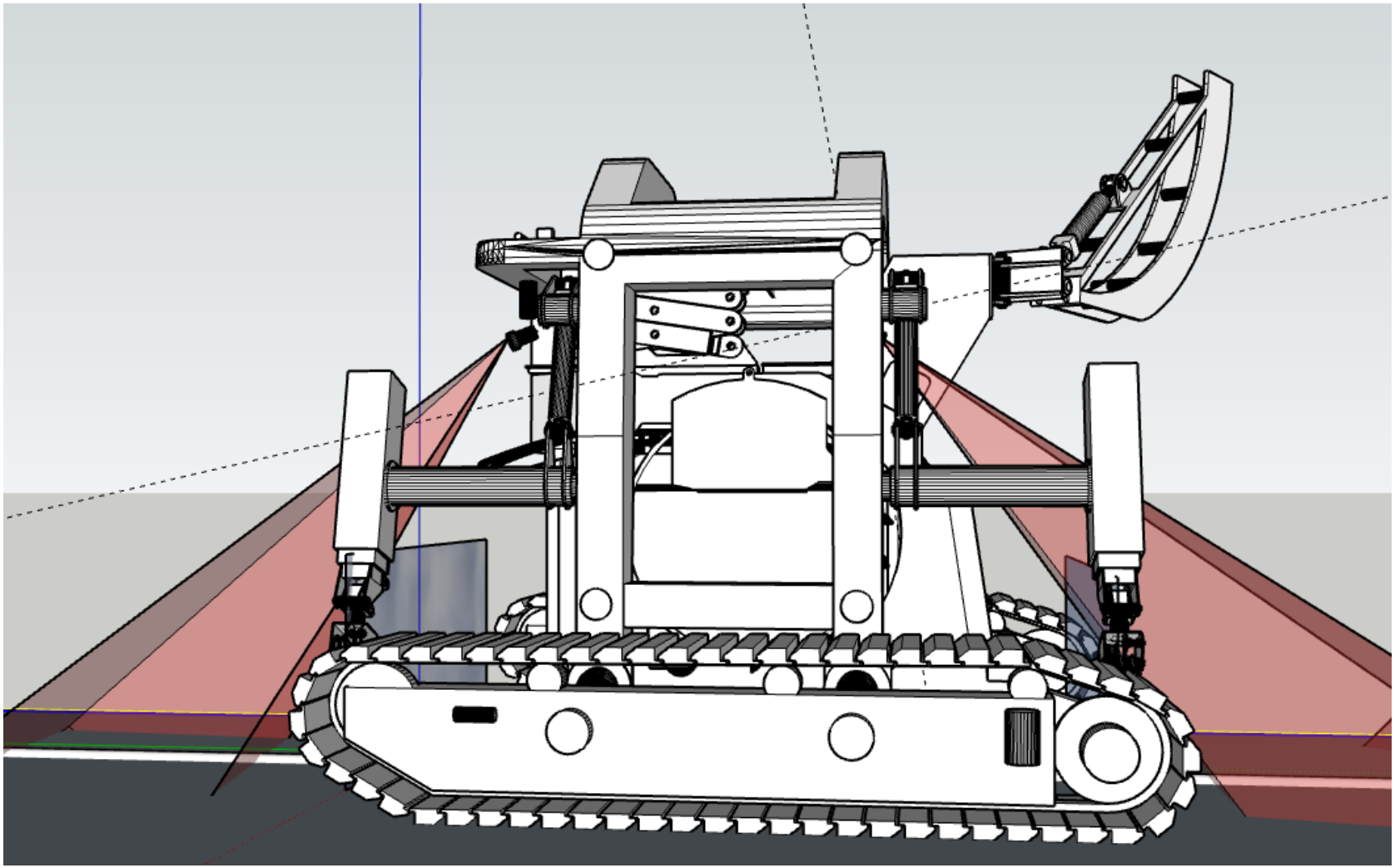
TM05

TM05 - How it works





How to operate?

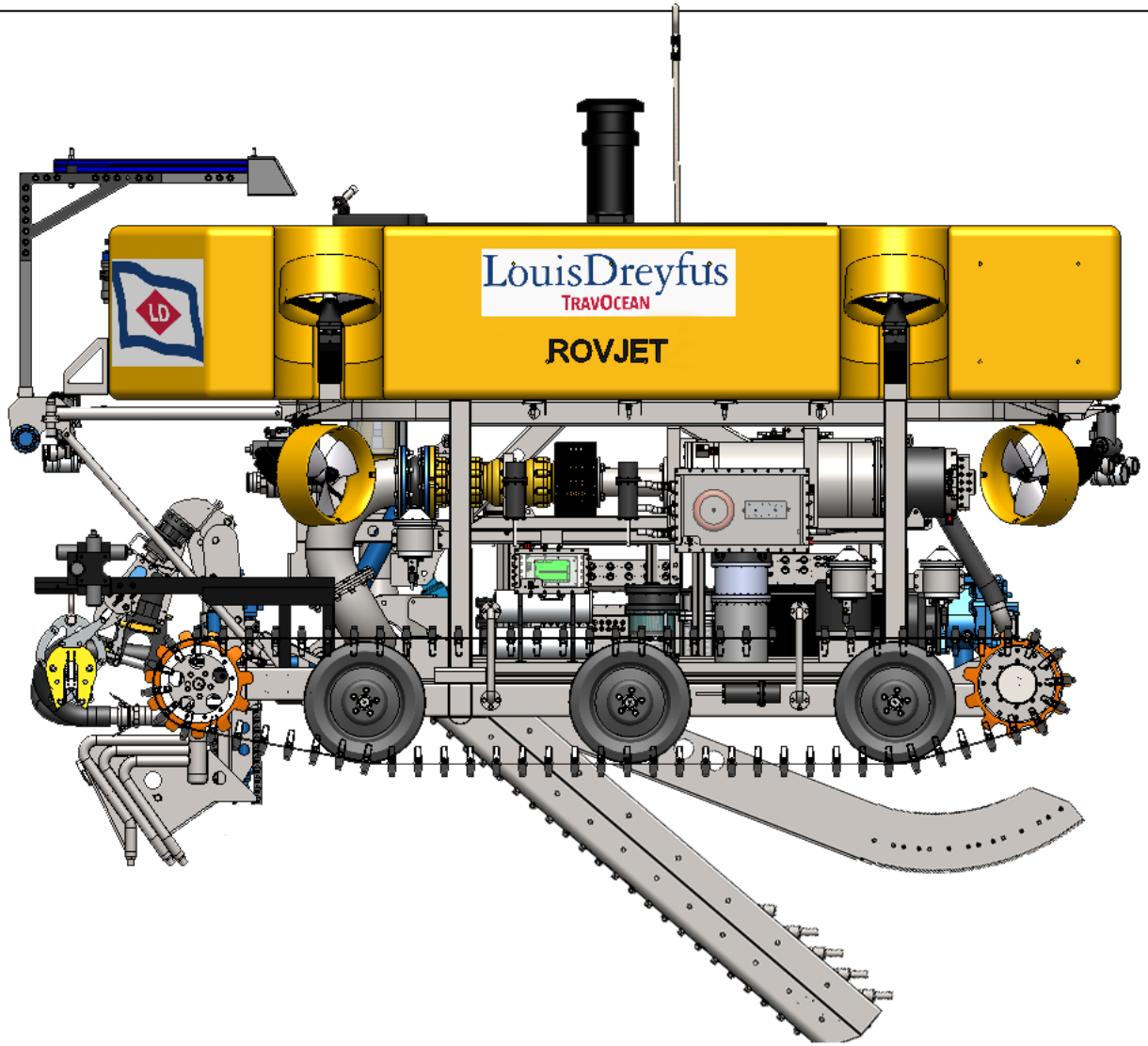


ROVJET

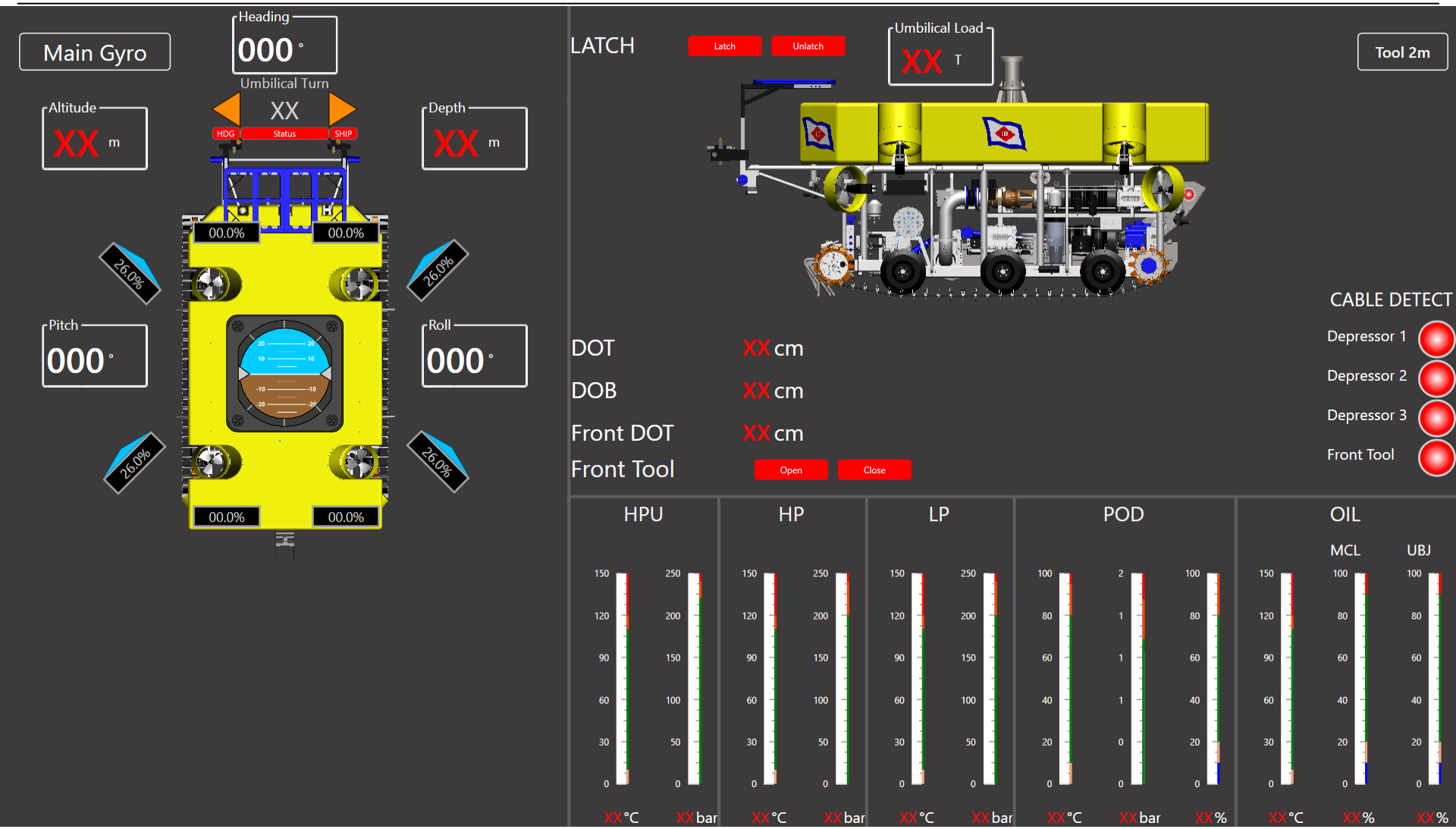
ROVJET 400

Length (O.A.) : **5.80 m**
Width (O.A. with tracks) : **3.40 m**
Height (O.A.) : **2.50 m**
Weight in air : **10 tons**
Trench depth : up to **2.00 m**
Trench width : up to **340 mm**
Total power : **300 kW (400 HP)**
Max. rating depth : **2,500 m**
Speed on tracks : **2,500 m/h**

ROVJET



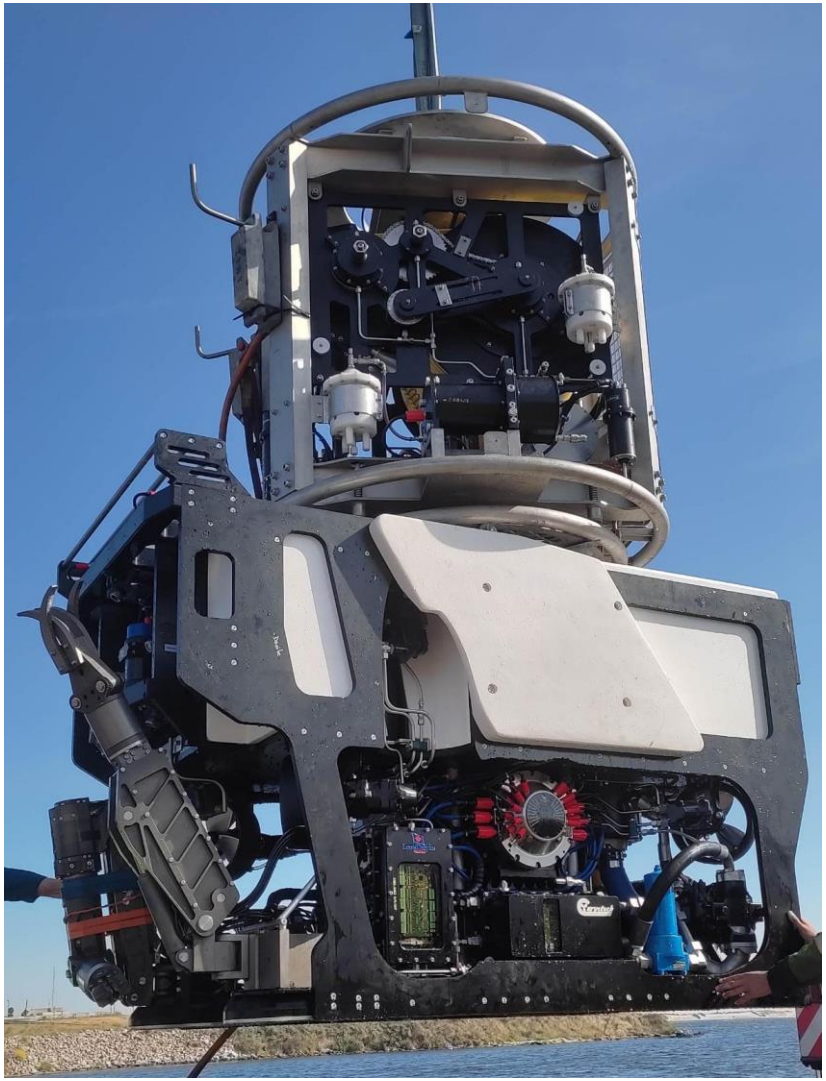
ROVJET PILOT SCREEN



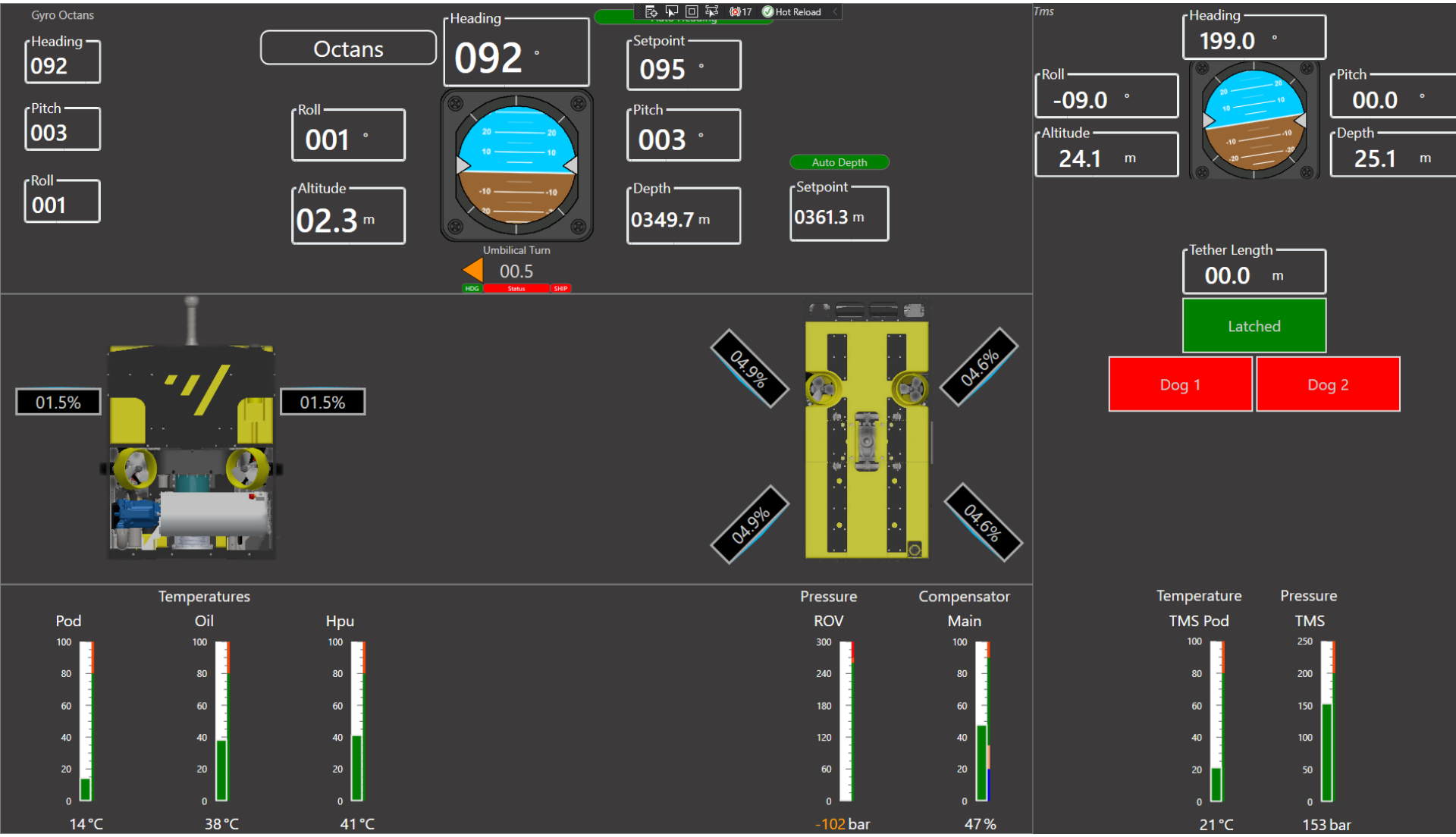
ROVC

MAIN SPECIFICATIONS

Length (O.A.)	2.70 m
Width (O.A.)	1.54 m
Height (O.A.)	1.70 m
Weight in air	2700 kg
Payload	150 kg
Total power	100 HP
Max. rating depth	1000 m
Depth	4000 m



ROVC

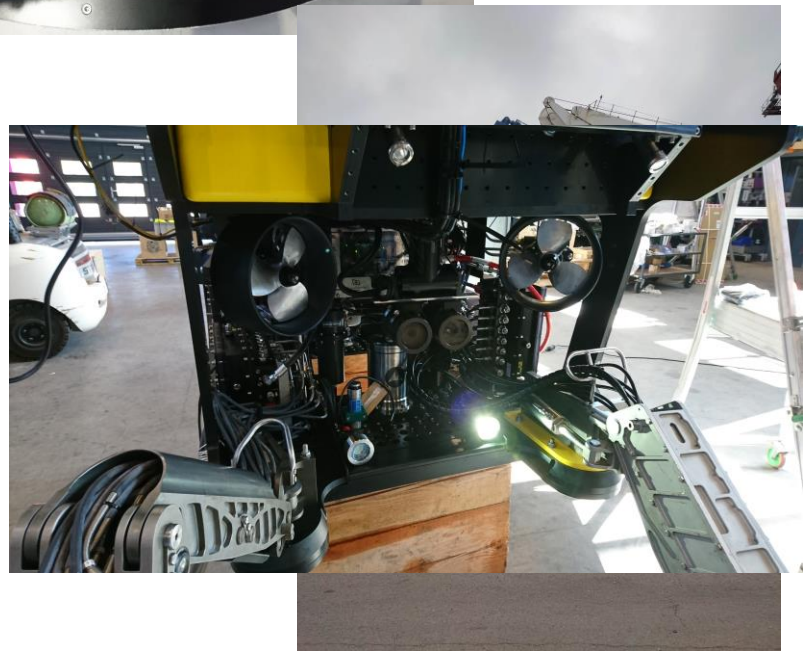

Gyro Octans
Heading
092
Pitch
003
Roll
001
Octans
Heading
092 °
Roll
001 °
Altitude
02.3 m
Umbilical Turn
00.5
HDG
Status
SHIP
Hot Reload
Setpoint
095 °
Pitch
003 °
Depth
0349.7 m
Auto Depth
Setpoint
0361.3 m
Tms
Heading
199.0 °
Roll
-09.0 °
Altitude
24.1 m
Pitch
00.0 °
Depth
25.1 m
Tether Length
00.0 m
Latched
Dog 1
Dog 2
01.5%
01.5%
04.9%
04.6%
04.9%
04.6%
Temperatures
Pod
Oil
Hpu
14 °C
38 °C
41 °C
Pressure
ROV
-102 bar
Compensator
Main
47 %
Temperature
TMS Pod
21 °C
Pressure
TMS
153 bar

Operating Machines

ROVc

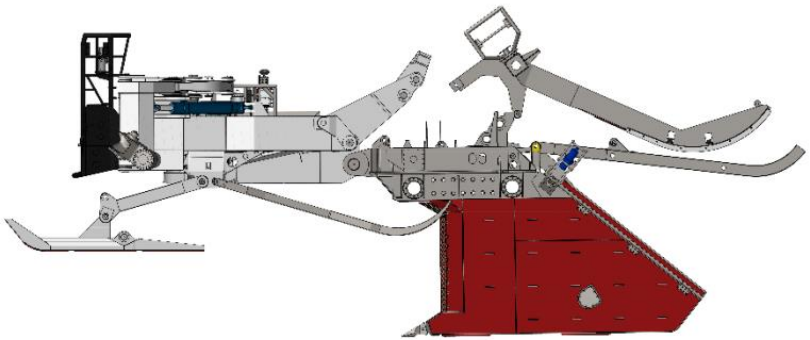

THRUSTER ENABLE
POWER
ROLL
LIGHT CHANNEL
DEPTH
Auto DEPTH
PAN/TILT
GAIN/TRIM
PRIMARY FLIGHT
LouisDreyfus
TRANSOCEAN


Dive n° 008 HOOK CONNECT
15/10/2020
18:52:55
Alt: 0 meter
Kp: 5.638
E005 36.50
N59 45.849

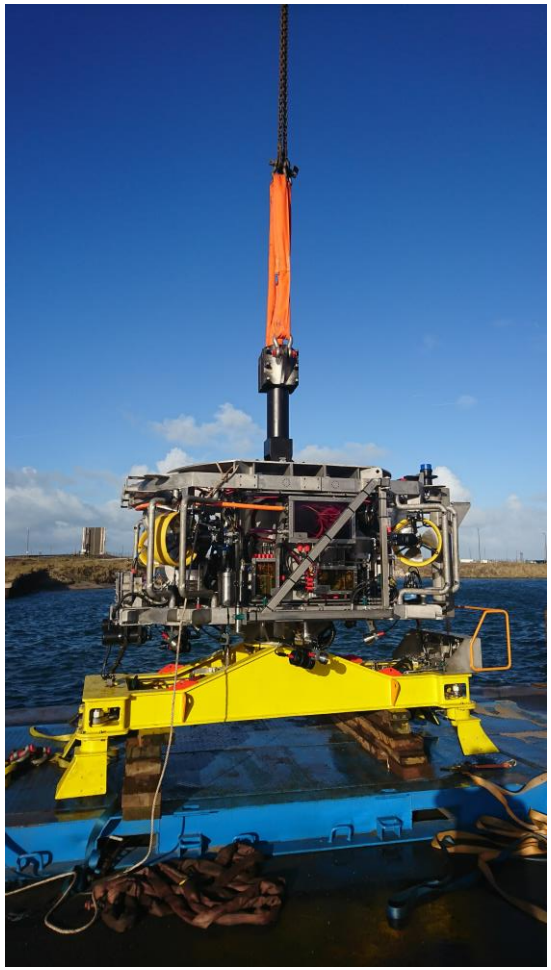


Other machines

Plough

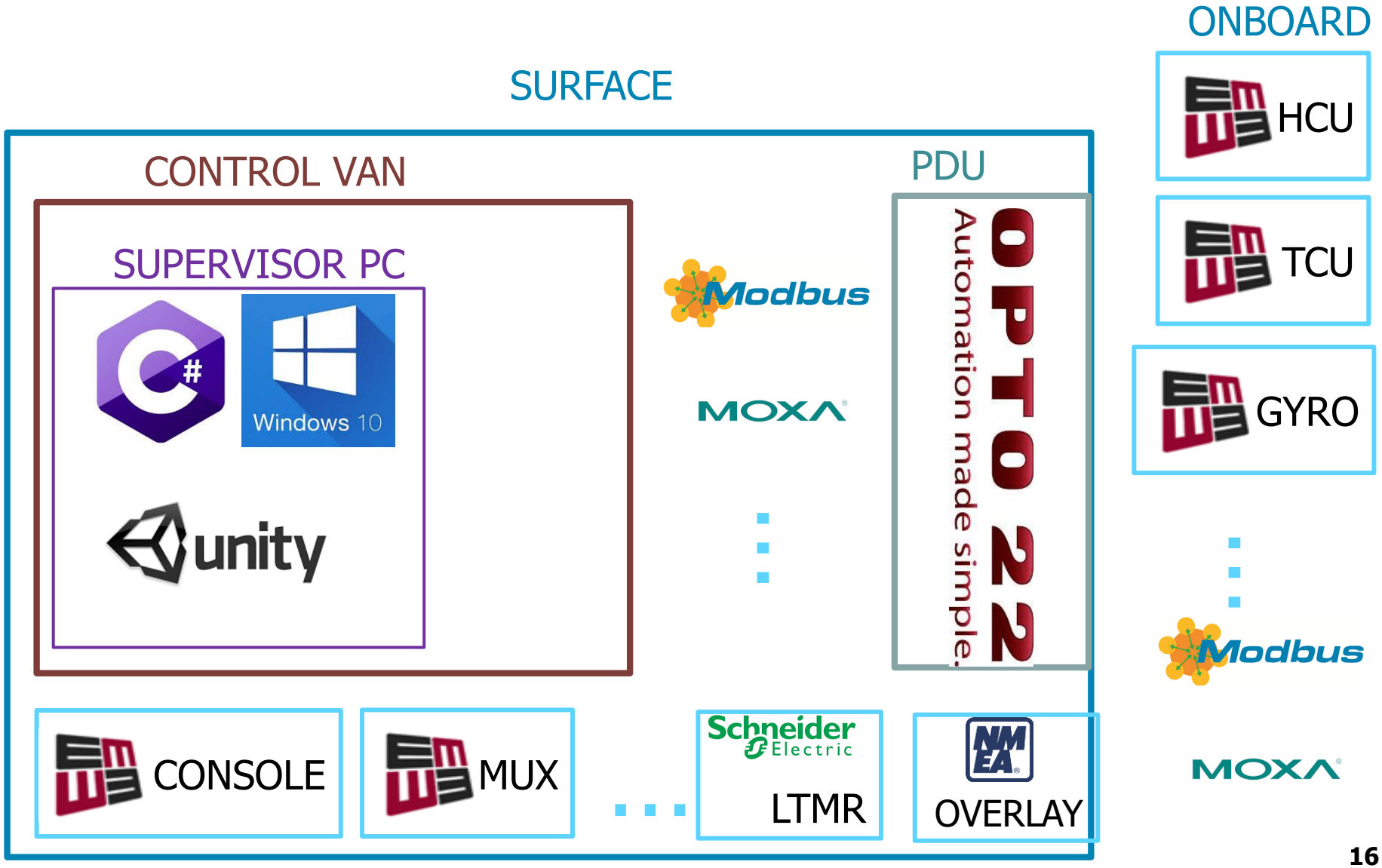


Universal Spreader System



Touch Down Monitor

Arhitecture

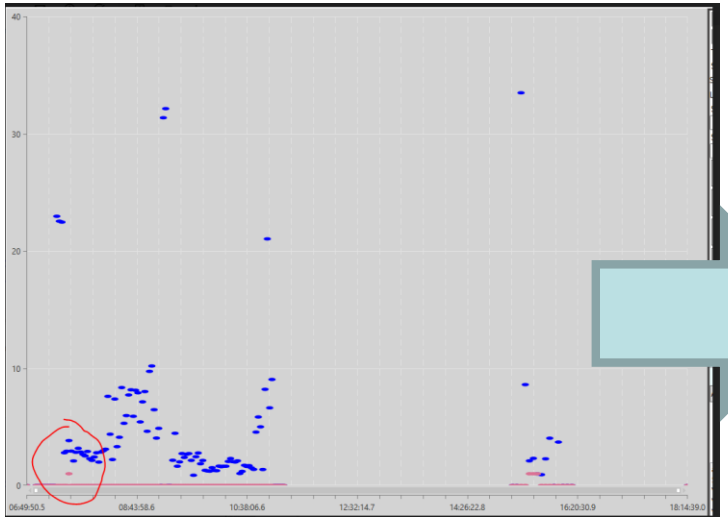


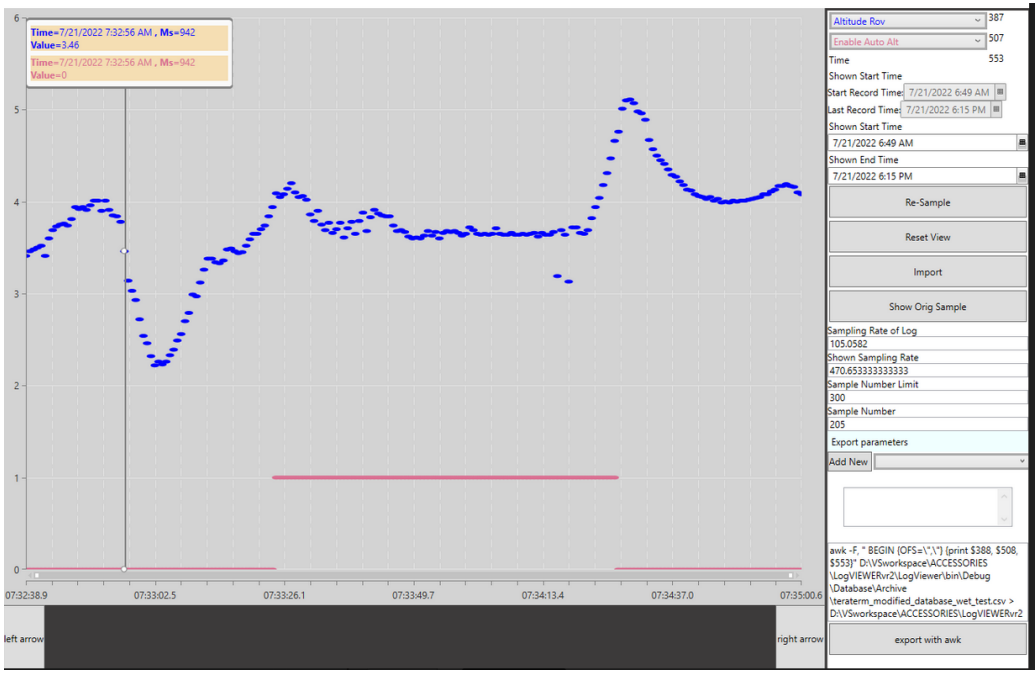
Testing

- Testing Conditon
  - Only few meter depth
  - Limited manovers
  - Short time

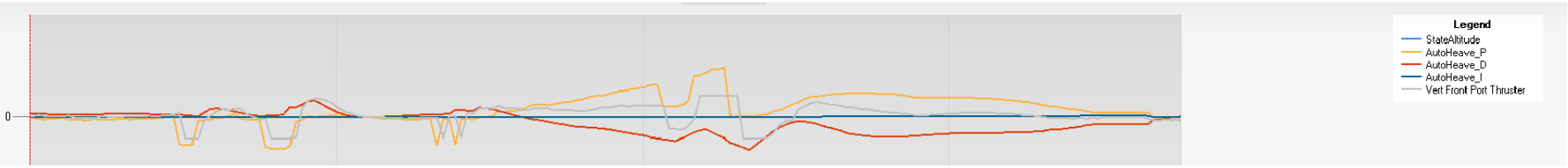
- Working condition on board
  - Restarting software is not safe under water
  - Sometimes few hours to retreive machine on deck
  - Noise and signal (or power) disturbance are very common

Data Analysis





Gigabyte of data in 24 hours



Simulation

- **Operator training**
- **Software testing**
- Unity – real-time development platform used mainly for video games, but also for movie animations, architecture…

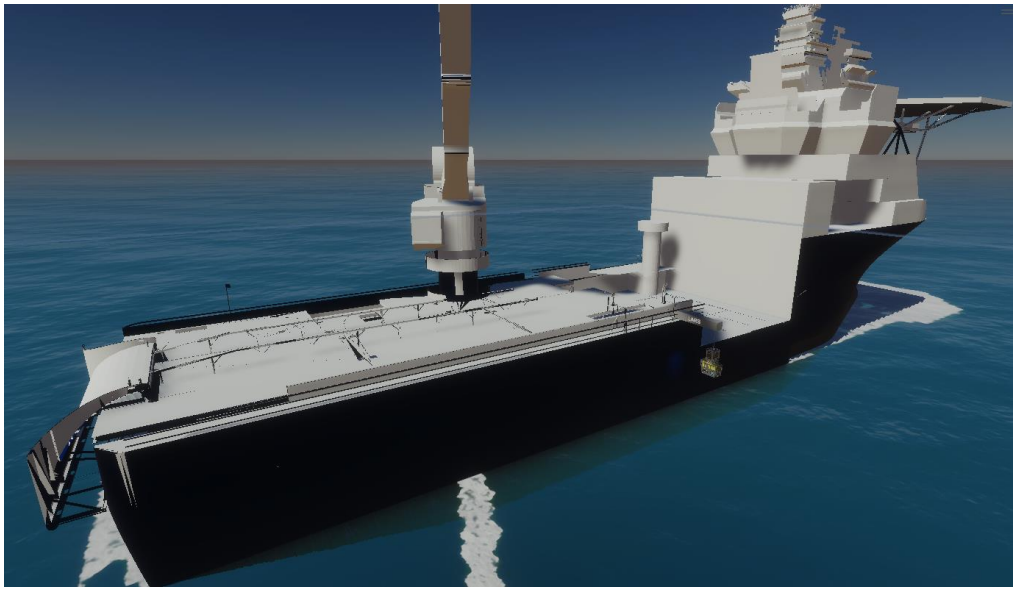
Unity

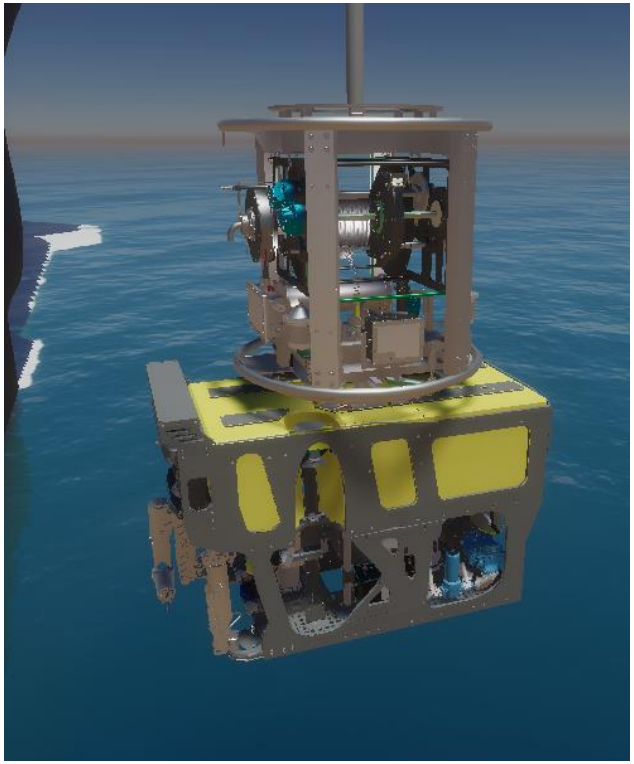
- C# scripting
- Physics engine
- Graphics visualization
- Simulating rigidbody interactions, ocean/sea (hydrodynamics), tether (rope), light…

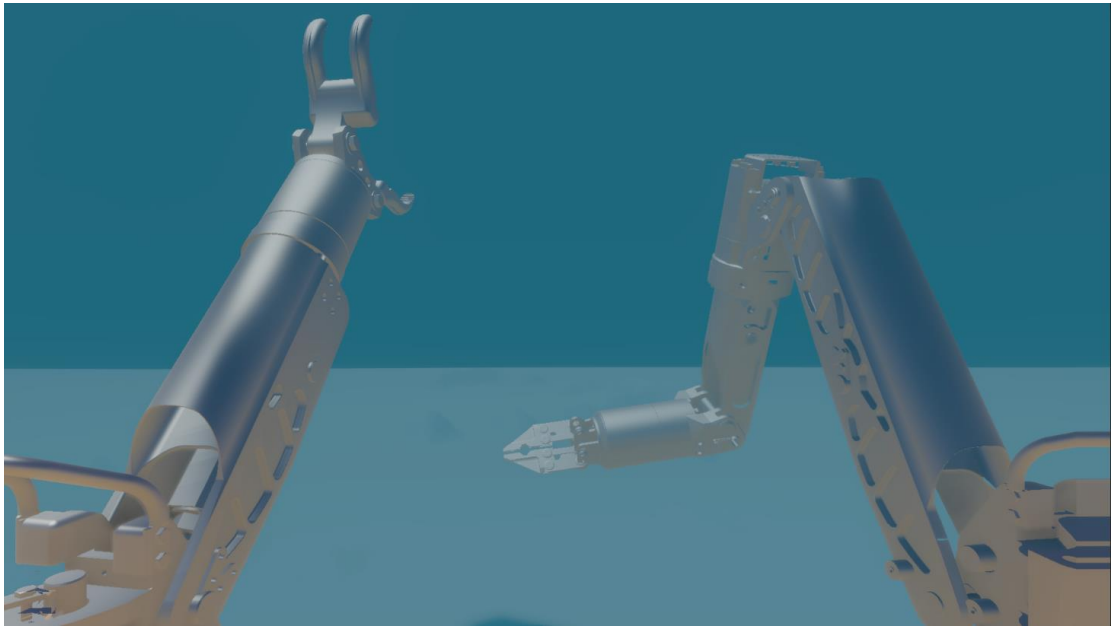
Unity editor

Supervisor’s controll view

Unity simulation







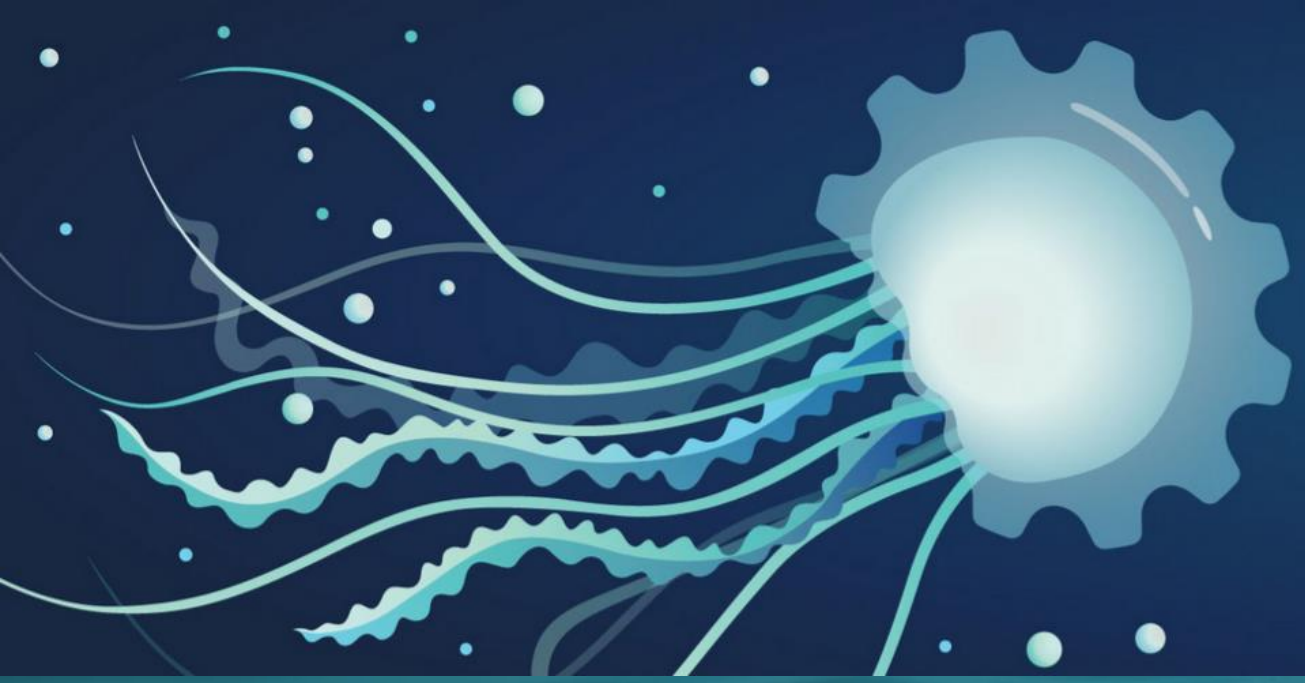
Conclusion

How to deal with hard conditions described above:

- increase reliability of equipment
- increas competence of operators

Steps:

- building a simulator
- perform software testing
- professional training



2022 25.09. - 2.10.
Biograd na Moru, Croatia

BREAKING THE SURFACE

14th INTERNATIONAL INTERDISCIPLINARY FIELD WORKSHOP OF MARITIME ROBOTICS AND APPLICATIONS

Data Policy and Challenges for Marine Robotics

R. Ferretti and S. Aracri
National Research Council – INstitute of Marine engineering

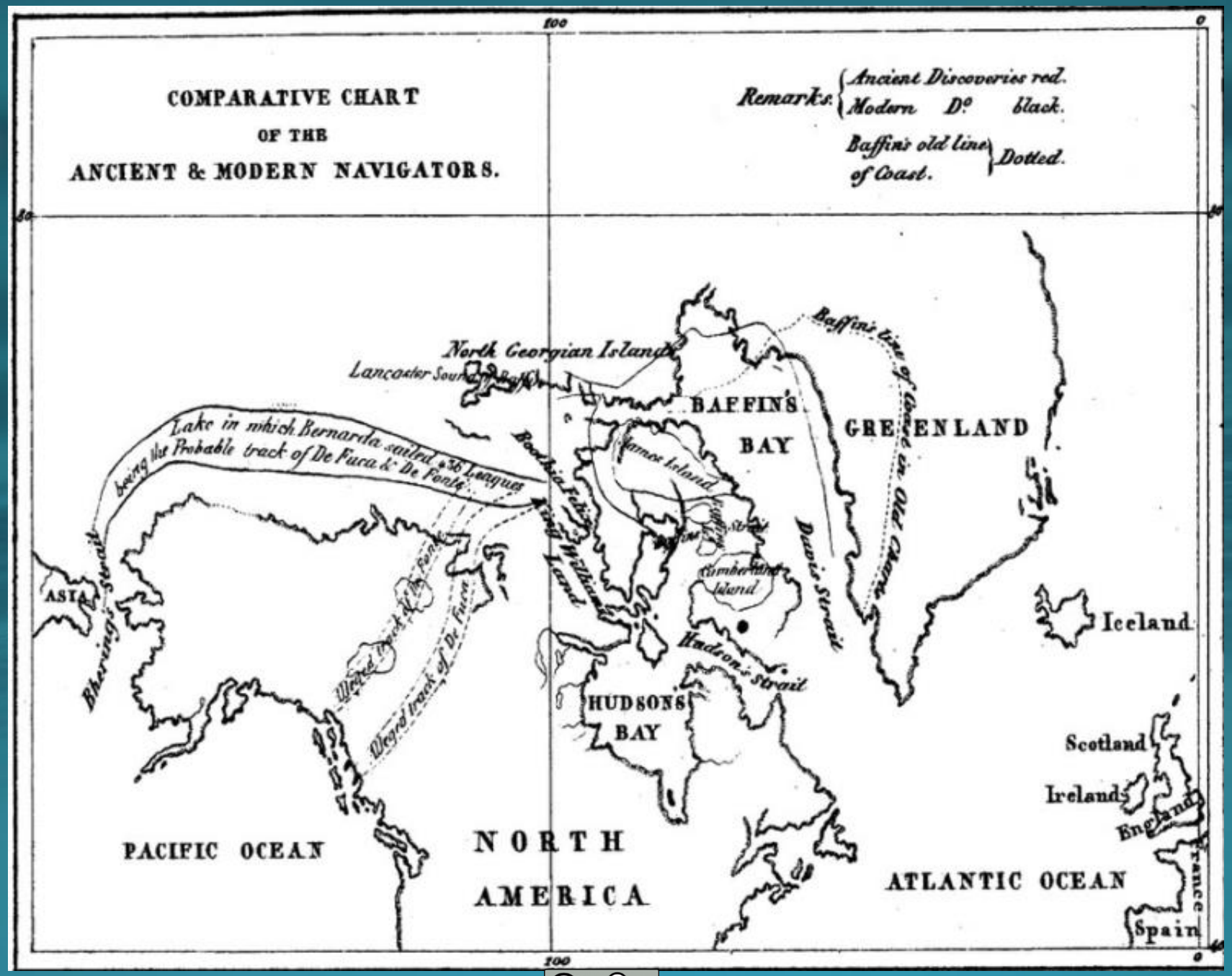
Interreg Italy - Croatia InnovaMare

EUROPEAN UNION

INM

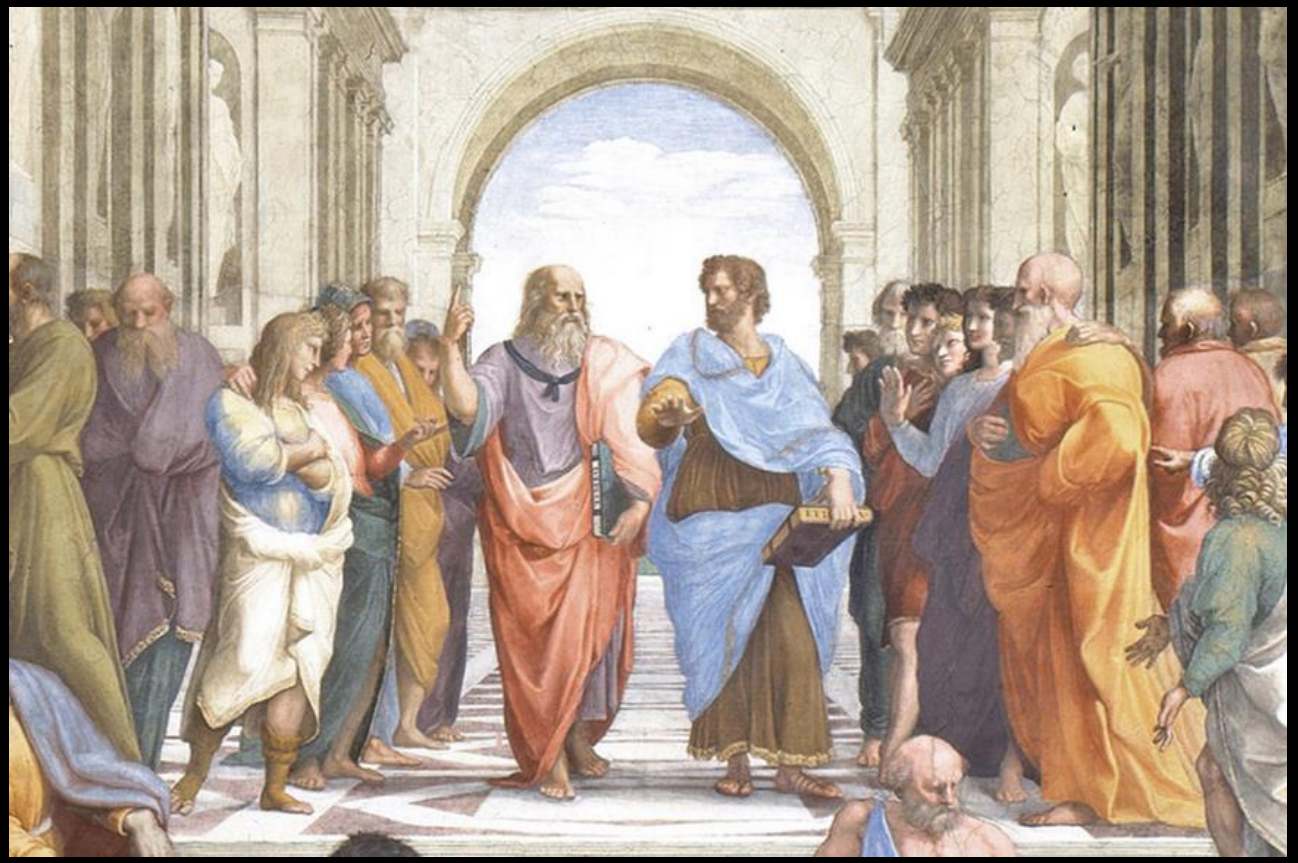
Oceanographic Observations

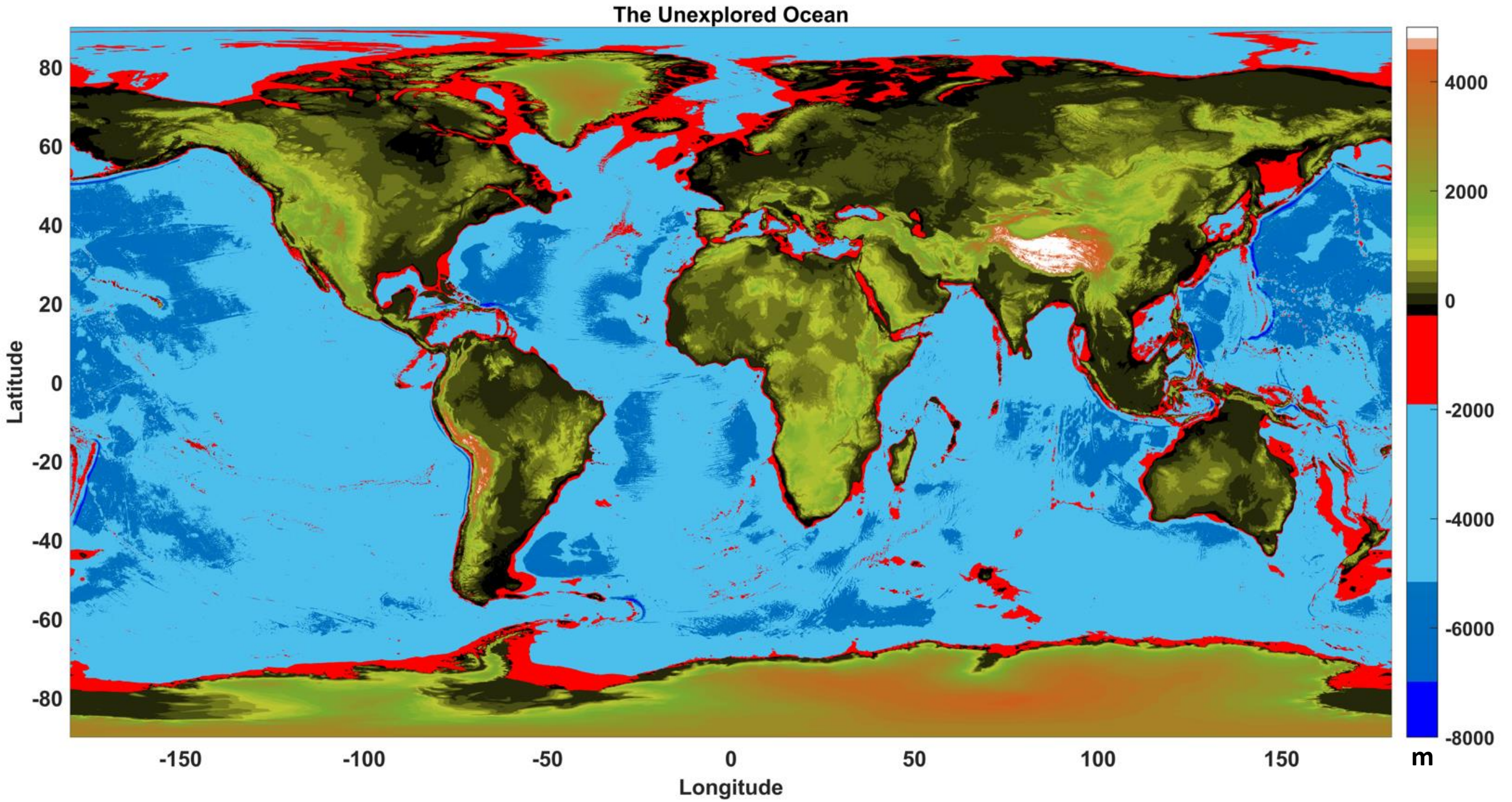
The possible location of the north-west passage from the Atlantic to the Pacific in the book of John Ross (1835)



Ocean Science Data Collection, Management, Networking and Services Manzella and Novellino 2022 https://doi.org/10.1016/C2019-0-05509-4

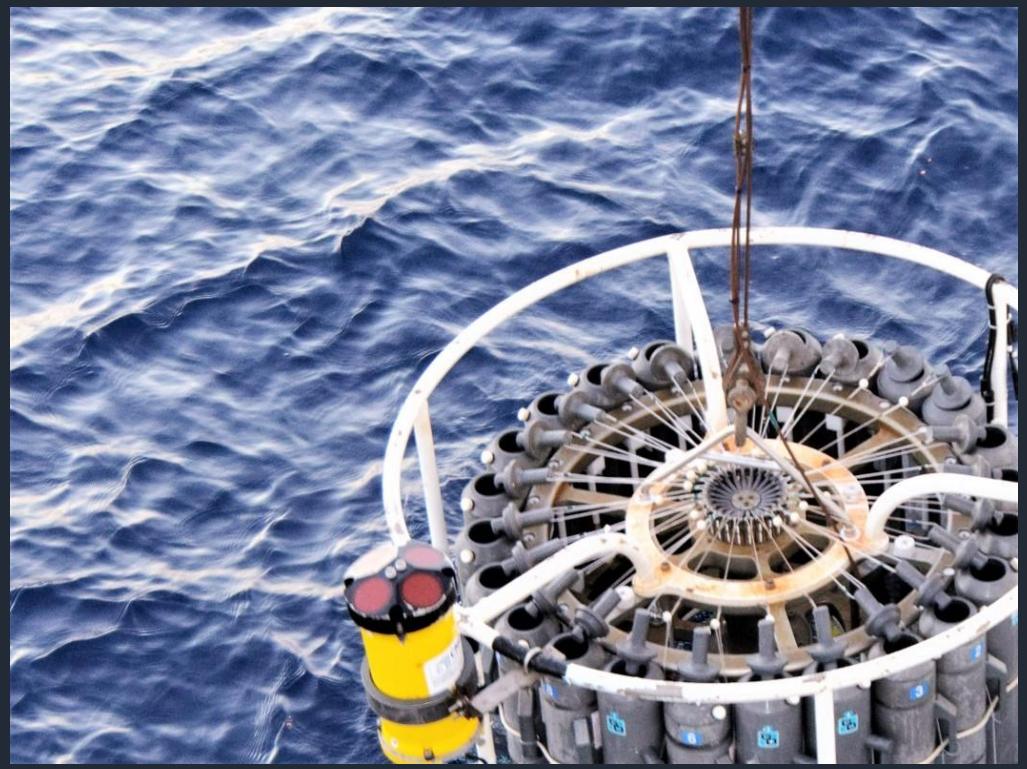
«Diligent Observations»





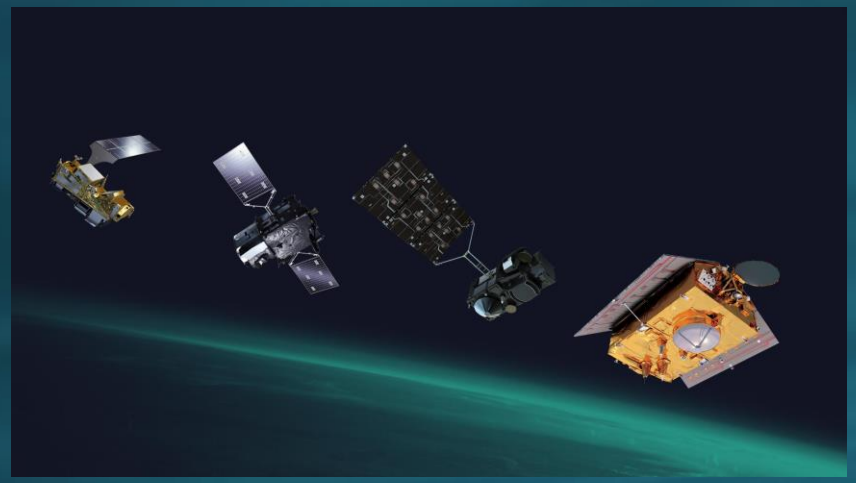
https://doi.org/10.1089/soro.2020.0011

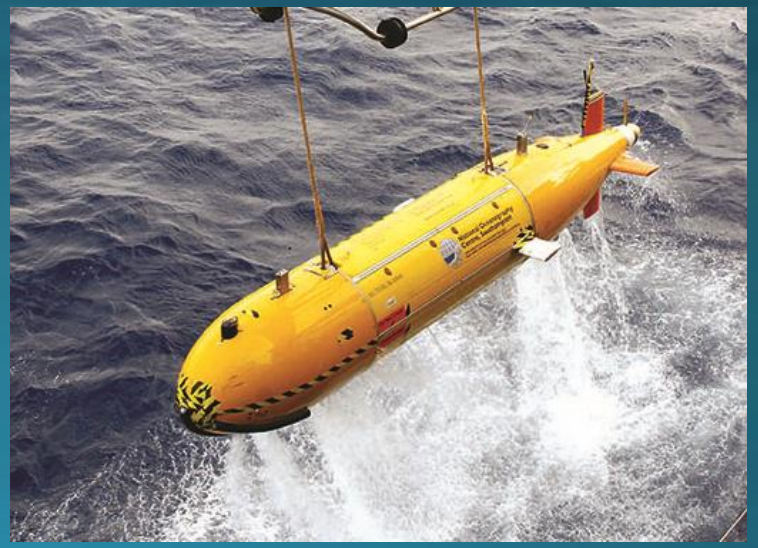
SONNE Cruise – Panama Basin 2014

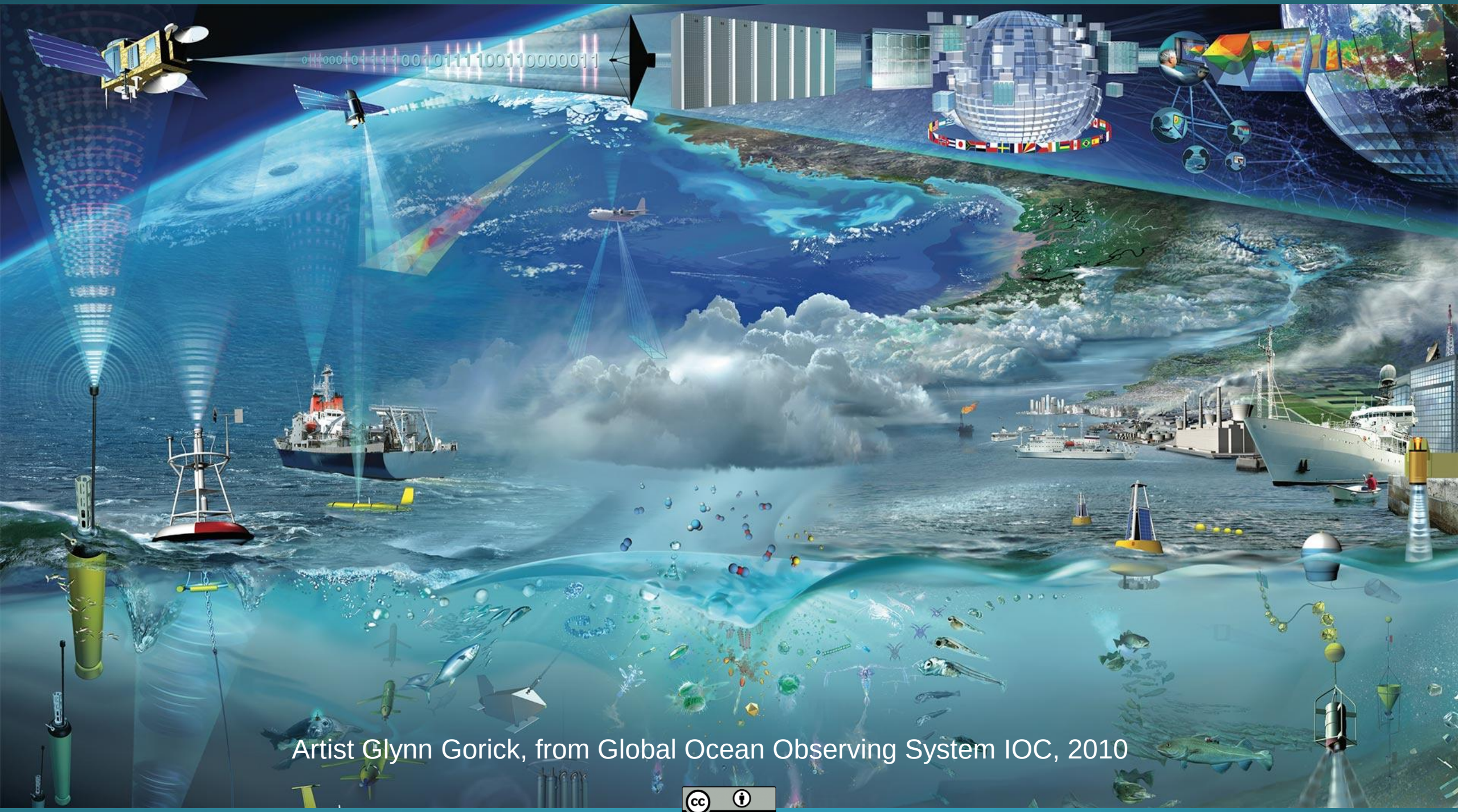


Niskin bottle (1894 - Nansen – 1966)

Traditional Marine data collection methods

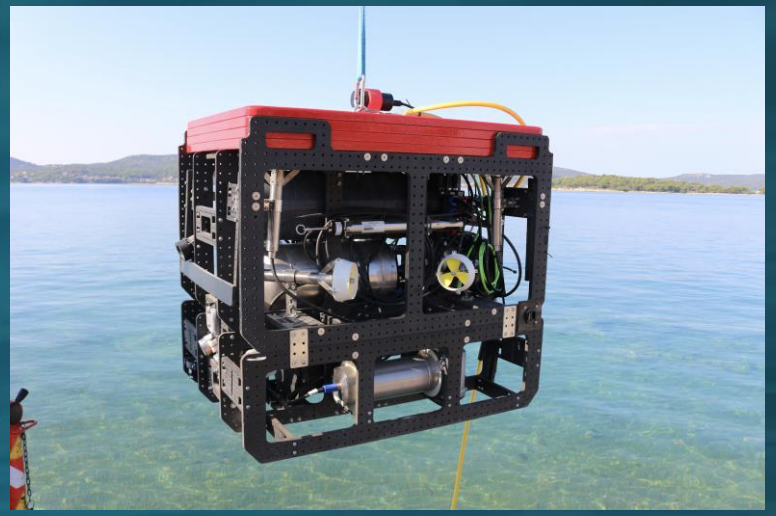






Artist Glynn Gorick, from Global Ocean Observing System IOC, 2010

Emerging robotic platforms for Marine data collection



eOOS Technology Forum 2022

THINKING AHEAD: THE TECHNOLOGY OF THE SCIENCE WE WILL NEED FOR THE OCEAN WE WANT

EuroGOOS Office - Intergovernmental Oceanographic Commission of UNESCO

Progresses in Marine observation and bottle necks

- Under-sampling in some remote areas - high logistical costs
- Make data acquisition more efficient and less costly
- Enhance Industry involvement and engagement
- Implementation of ocean communication technology (e.g. Internet of Things (IoT)
- Improve knowledge transfer
- Innovative materials to minimise the environmental impact
- Low-cost sensors and high automation and user-friendly
- Self-sustaining technology (e.g., auto-calibrating sensors)
- Maximising the marketability of products
- Liaise with technology developers
- More funding needed for achieving long-term goals
- Replace expensive sampling (ships) with autonomous systems when possible
- Increasing collaboration within and across sectors
- Giving Ocean issues major visibility to society

Macro groups of marine observations

Hydrographic Profiles
(CTD, gliders, Argos, AUVs, animal tagging, etc...)

SWAMP

Surface Drifters

LAGRANGIAN

Satellites

REMOTE SENSING

Moorings

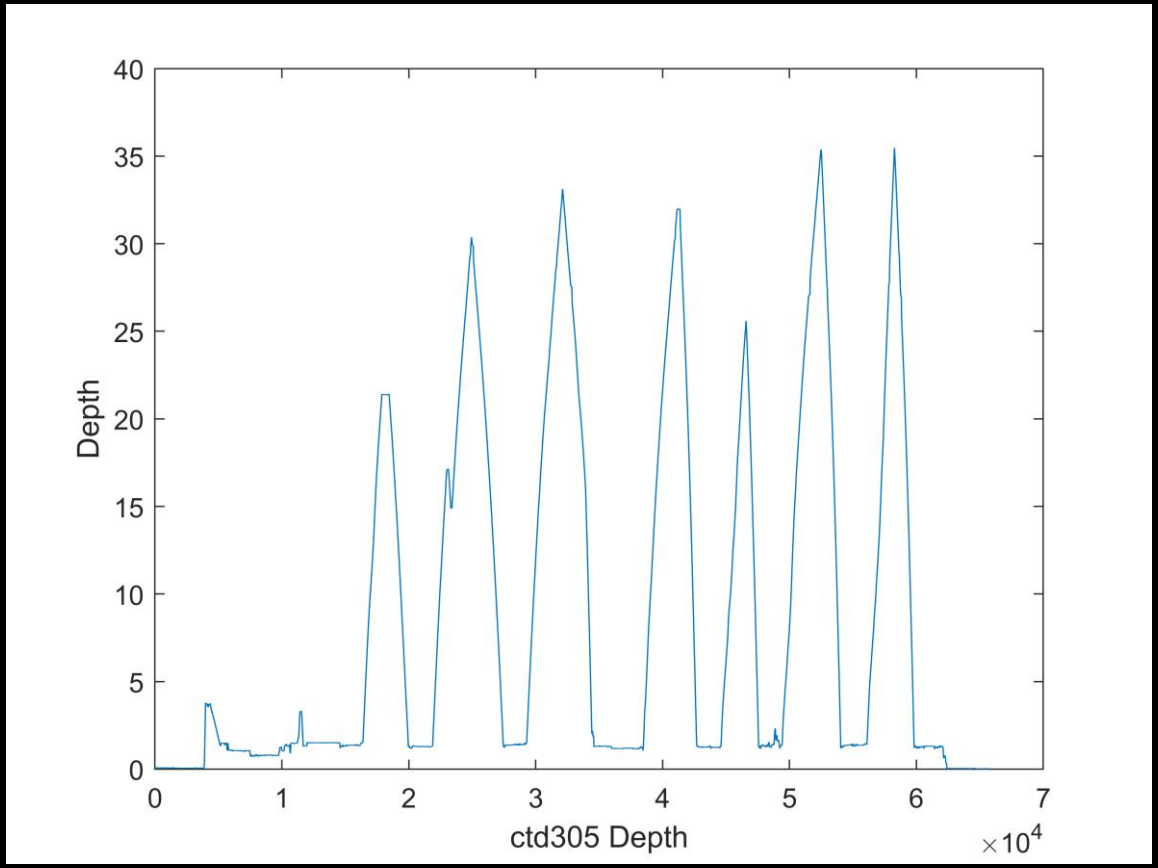
EULERIAN

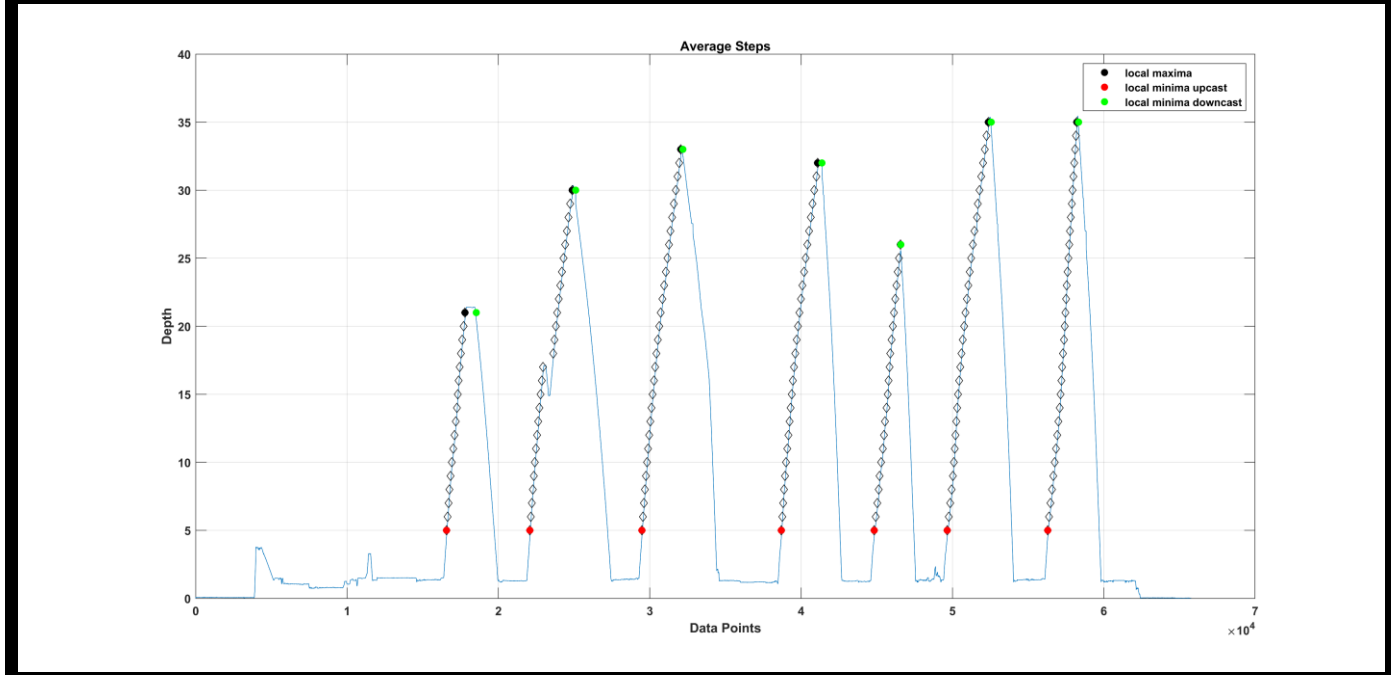
National Oceanography Centre
British Oceanographic Data Centre BODC

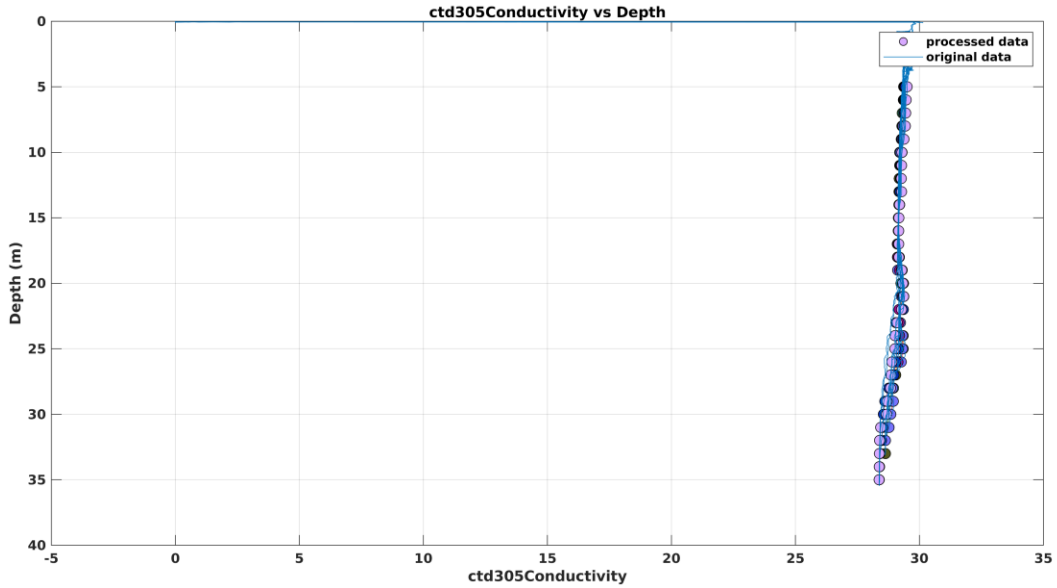
Data description and format

Data standard (downcast, bottle firing info, quality check,…)

Minimum Metadata (collection details, instrument details, sample data — for calibration purposes, calibrations, data sampling, data processing)


Depth
ctd305 Depth
×10^4


Average Steps
local maxima
local minima upcast
local minima downcast
Depth
Data Points
×10^4


ctd305Conductivity vs Depth
processed data
original data
Depth (m)
ctd305Conductivity
0
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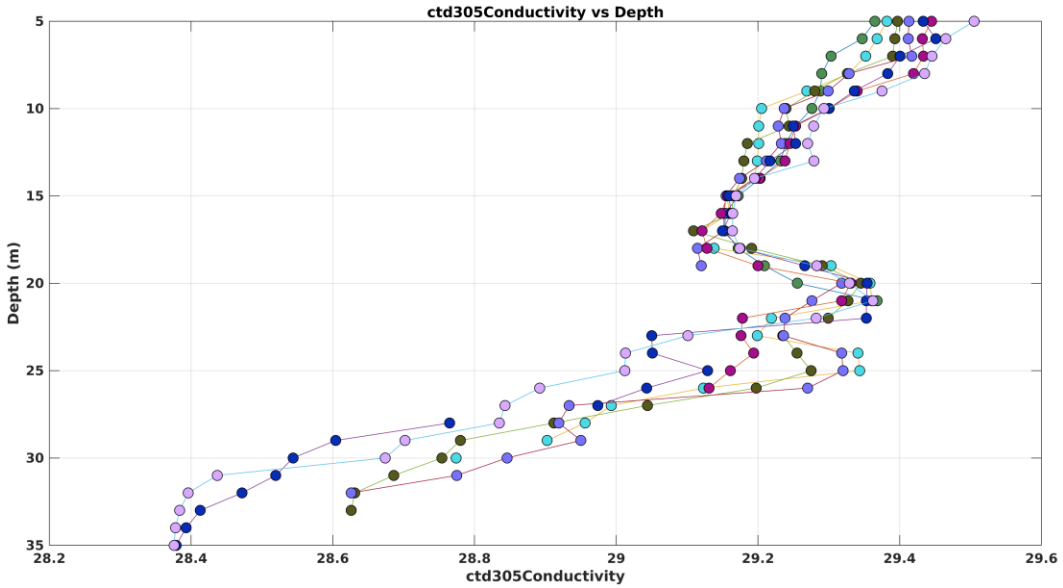
ctd305Conductivity vs Depth
Depth (m)
ctd305Conductivity
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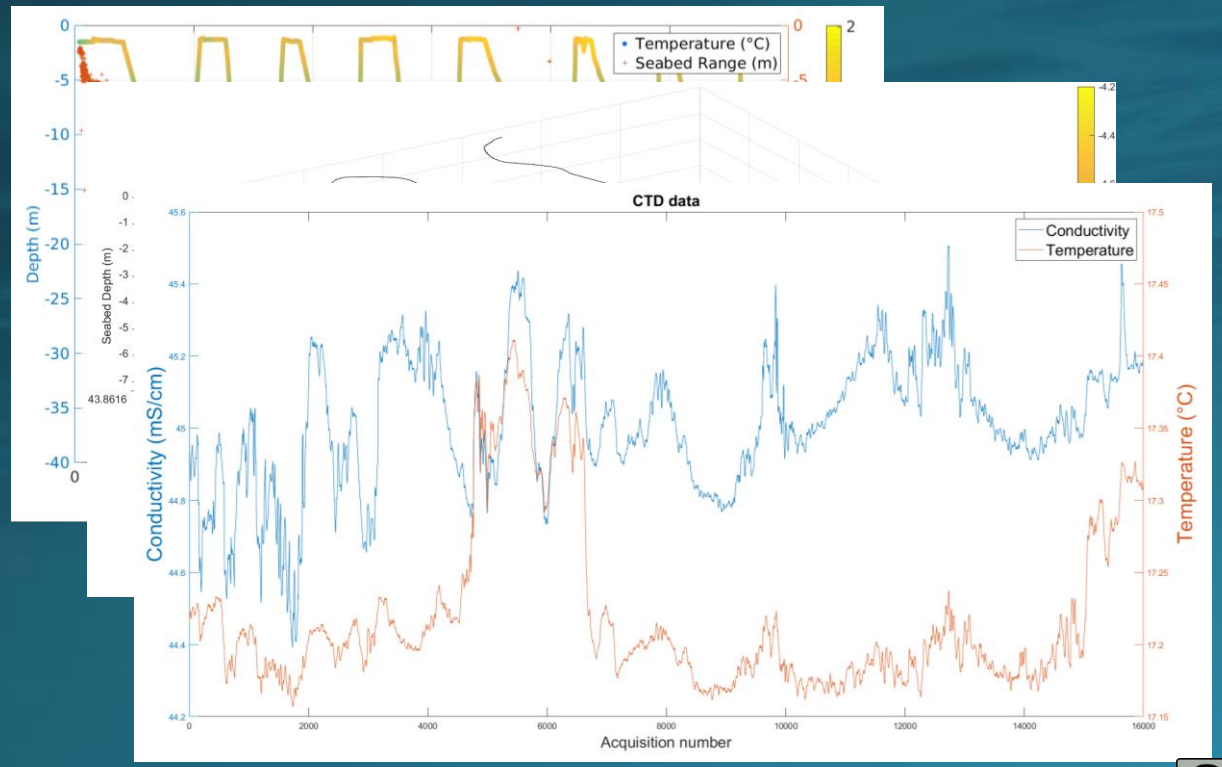
35
28.2
28.4
28.6
28.8
29
29.2
29.4
29.6

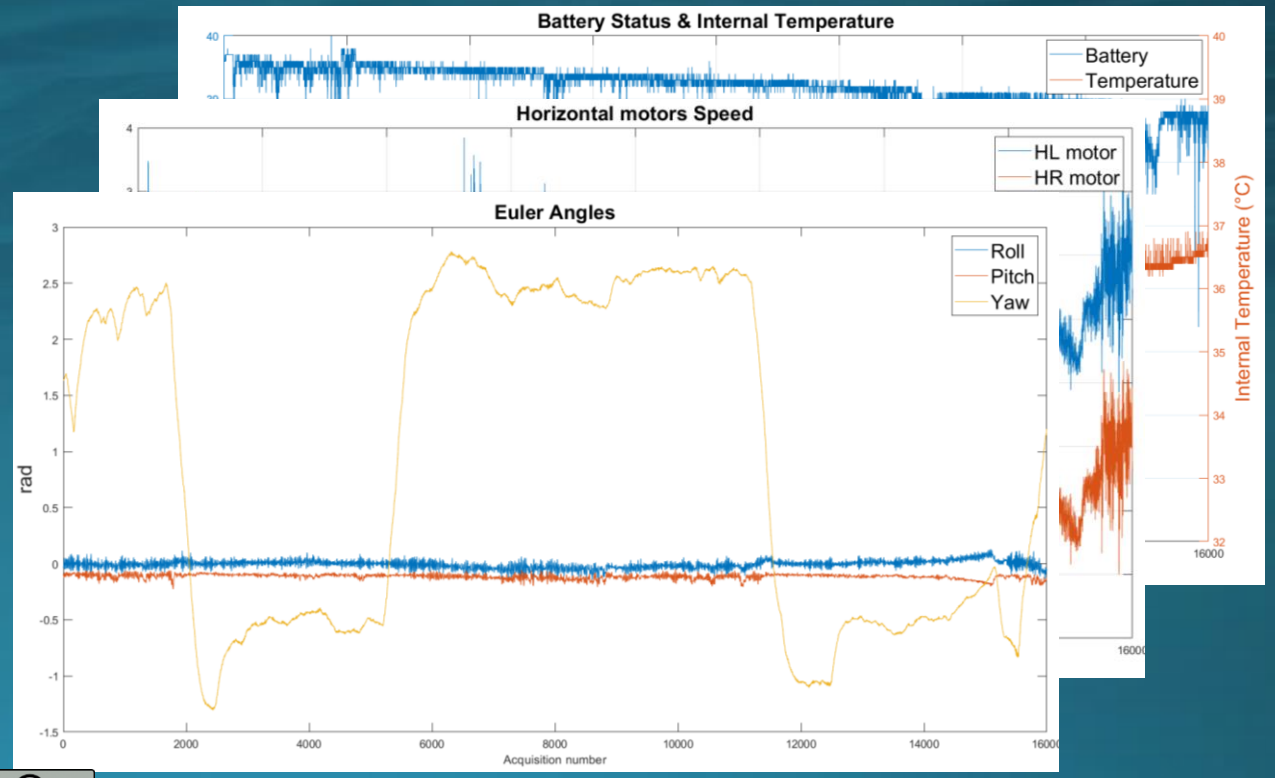
FAIR data in marine robotics

Emerging robotic platforms for Marine data collection

Marine Environmental data

Marine Robotic data





Emerging robotic platforms for Marine data collection

Marine Environmental data

Marine Robotic data

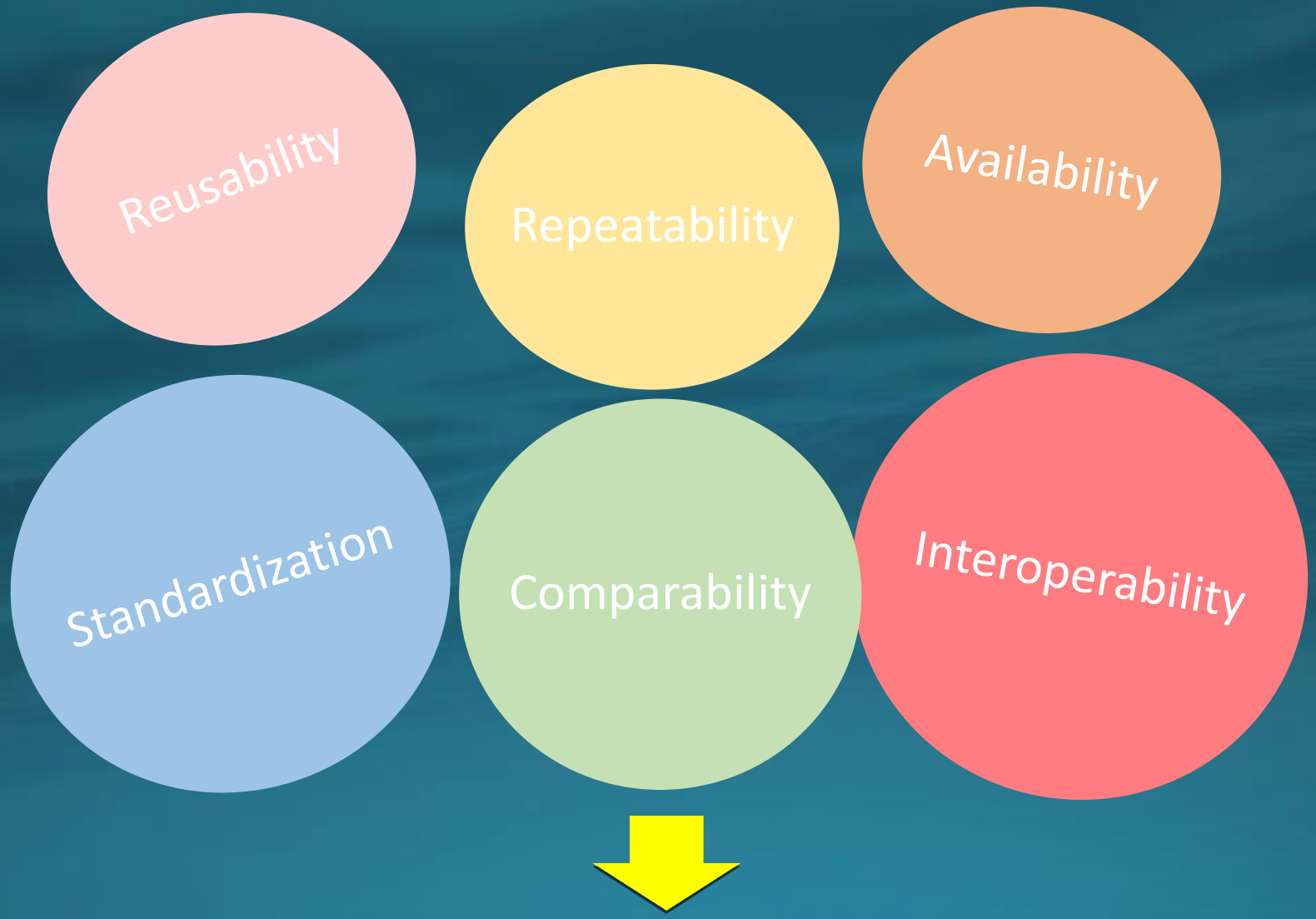
- Enhancement in the development of innovative robotics platforms
- Allow experiment repeatability and results comparability as well as availability of data set for GNC algorithms testing and validation
- Contribute to the global ocean observing effort

https://www.eoos-ocean.eu/wp-content/uploads/2022/08/EOOS-Tech-Forum-report-2022.pdf

The Global Ocean Observing System

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

FAIR Marine robotic data



FAIR marine robotic data

FAIR Marine robotic data

The FAIR Principles in a nutshell

Apr. 27, 2021

Findable
- Globally unique, resolvable, and persistent identifiers
  - *To retrieve and connect data*

Accessible
- Community defined descriptive metadata
  - *To enhance discoverability*

Interoperable
- Common terminologies
  - *To use the same term mean the same thing*

Reusable
- Detailed provenance
  - *To contextualize the data and facilitate reproducibility*
- Terms of access
  - *Open as possible, closed as necessary*
- Terms of use
  - *Clear licences, ideally to enable innovation and reuse*

SCIENTIFIC DATA

We'd like to understand how you use our websites in order to imp

FAIR guide, Nature, March 2016

Open Access | Published: 15 March 2016

The FAIR Guiding Principles for scientific data management and stewardship

Mark D. Wilkinson, Michel Dumontier, [...] Barend Mons

Designed to support knowledge discovery and innovation both by **humans** and **machines**

FAIR - Findable

- Metadata are data providing information about data that make them findable, trackable and (re)usable.
- **Descriptive metadata** usually includes info such as title, author, subjects, keywords, publisher, urls, etc. They are mainly **domain agnostic**.
- Several standards exists:

Dublin Core

ISO 19115

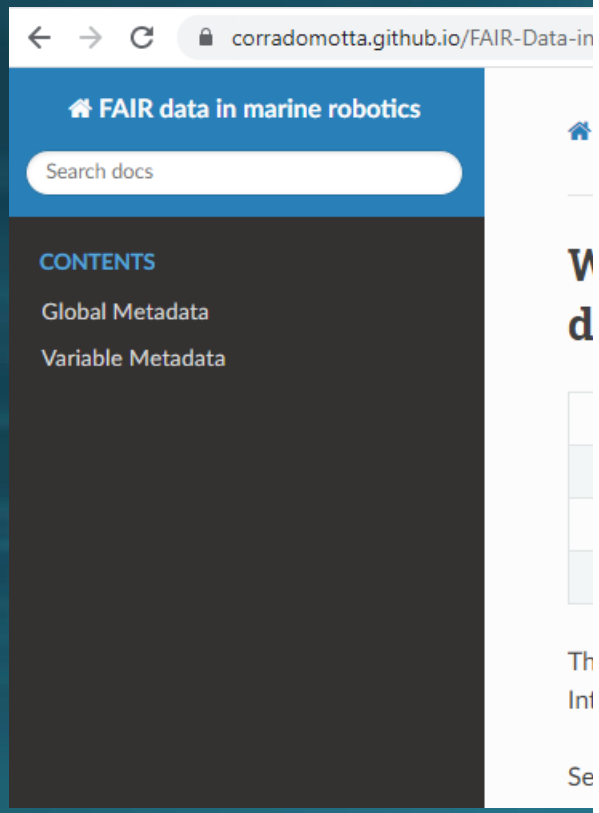
DataCite

Global Metadata is the term used to identify descriptive metadata in the NetCDF files.

The **ACDD** convention (Attribute for Climate and Data Discovery) can be used to populate the global attributes.

FAIR - Findable

We agreed upon a set of minimum **mandatory and optional global attributes** to be used in our datasets.



xarray.Dataset

- Dimensions: (**index**: 65756)
- Coordinates: (1)
- Data variables: (23)
- Attributes:

title :	Raw Data Svalbard 2019
summary :	Data collected during the Svalbard mission in 2019.
keywords :	ctd,depth,svalbard
conventions :	ACDD-1.3,CF-1.6
creator_name :	Motta, Corrado
creator_email :	mail@cnr
institution :	CNR-INM
date_created :	2022-08-22T09:49:00+02:00
platform :	satellite
license :	None
standard_name_...	NetCDF Climate and Forecast (CF) Metadata Convention Standard Name Table v79
creator_url :	https://www.cnr.it/
project :	INNOVAMARE

https://corradomotta.github.io/FAIR-Data-in-Marine-Robotics/html/index.html

FAIR - Findable

A **persistent identifier** (PID) is a long-lasting reference to a resource. That resource might be a publication, dataset or person

There are different PID types for different kinds of resources: **DOI** for objects (publications, data, software) and **ORCIDs** for people (researchers, authors, contributors).

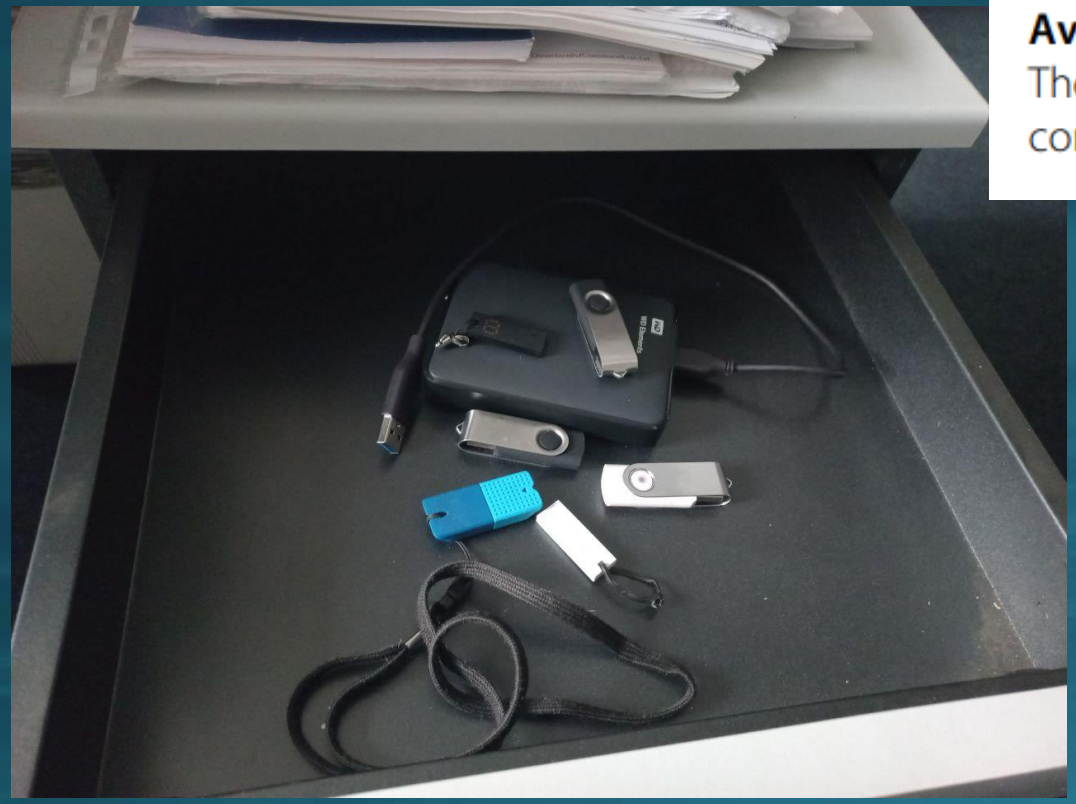
Many repositories will assign a PID of the former type when an object is deposited.

What is a DOI?

DOI stands for digital object identifier and is an alphanumeric code providing a unique and persistent link to specific electronically published content (compliance with the ISO 26324 standard).

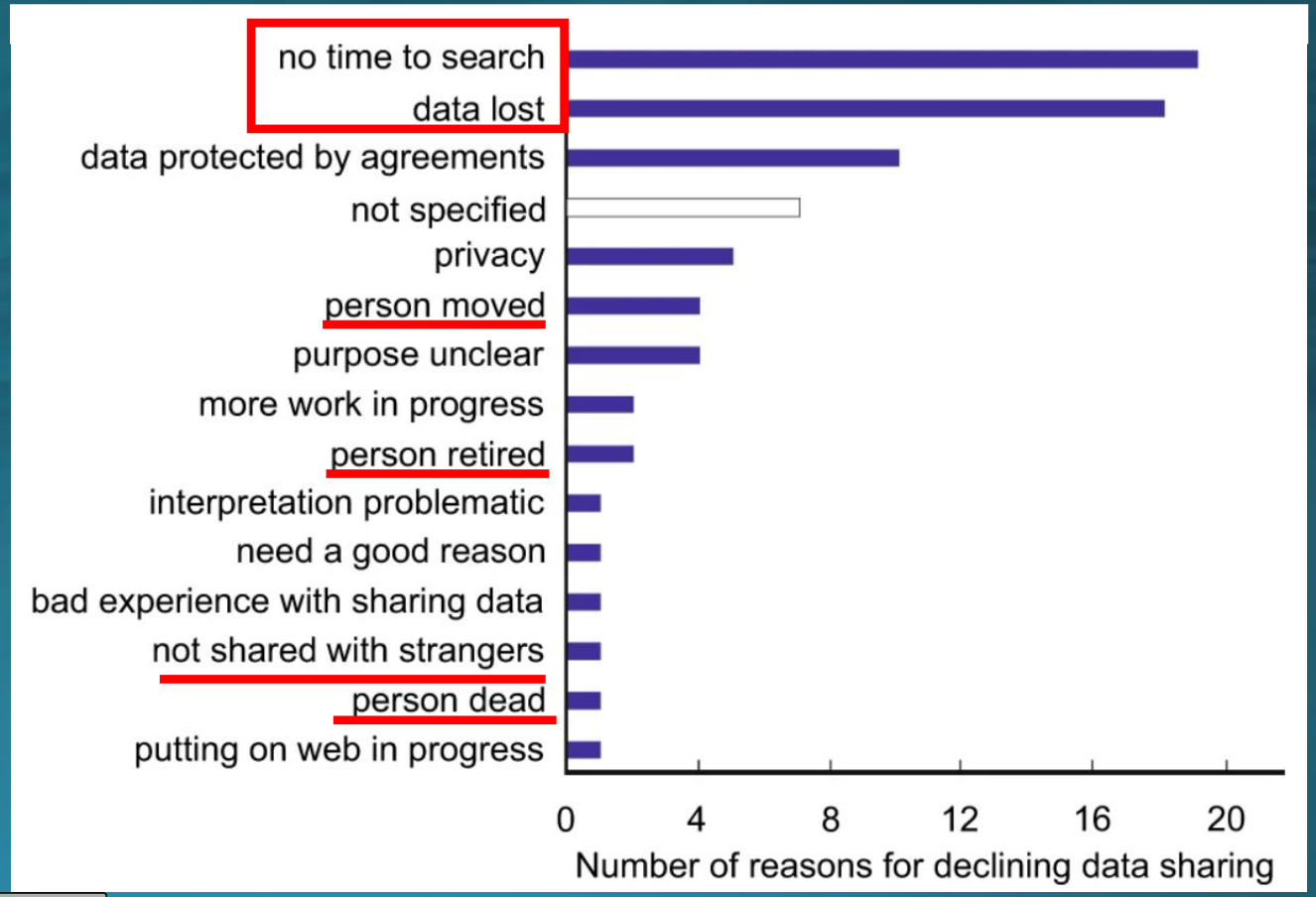
The DOI for a digital object remains fixed over the lifetime of the object.

FAIR - Accessible



Availability of data and materials

The datasets generated or analyzed during our survey are available from the corresponding author upon reasonable request.



Let's try to ask the authors to provide the data

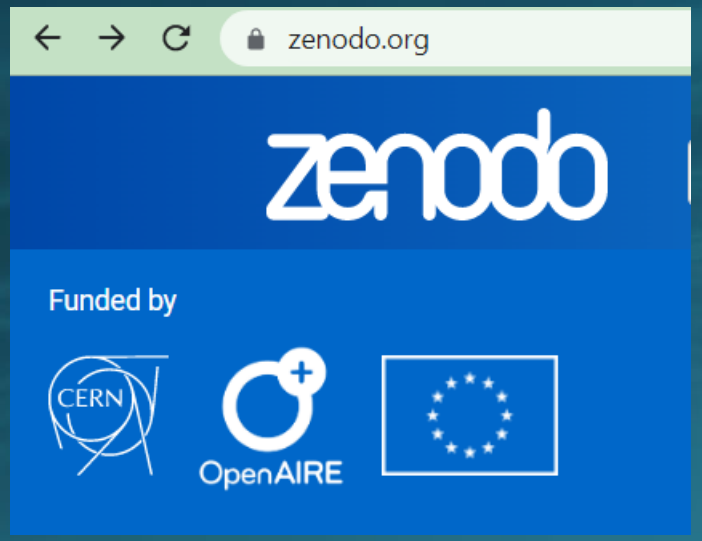
Data requests to authors are successful in about **40%** of cases but…

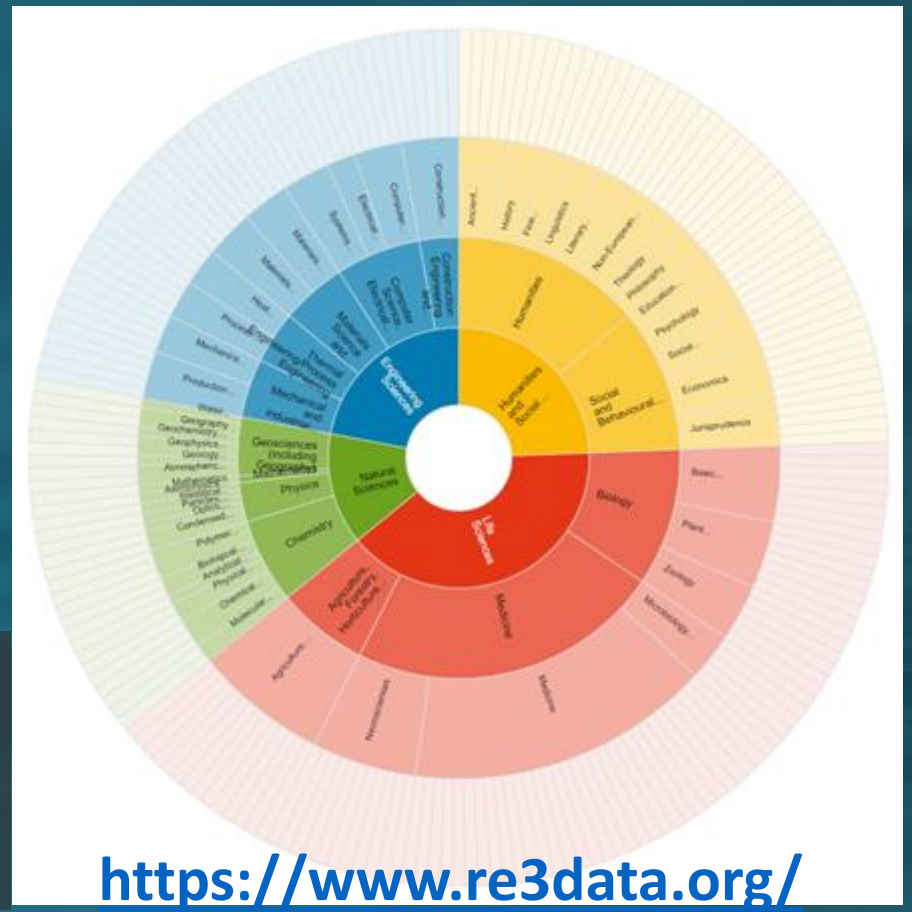
DOI https://doi.org/10.1038/s41597-021-00981-0

FAIR - Accessible

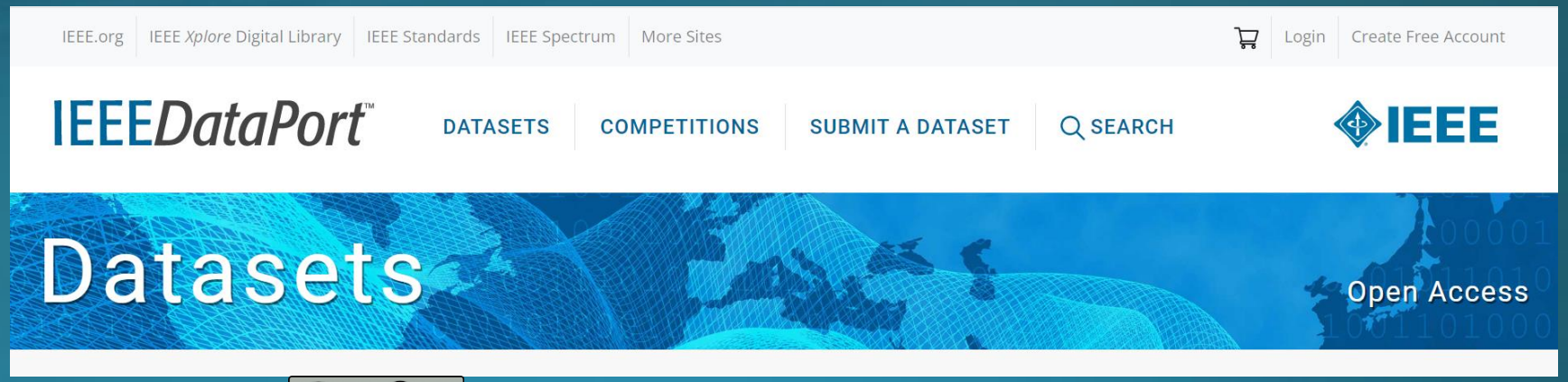
Deposit the data in a **trusted repository** or in a **data journal**

No Repository for Robotic Data found!!



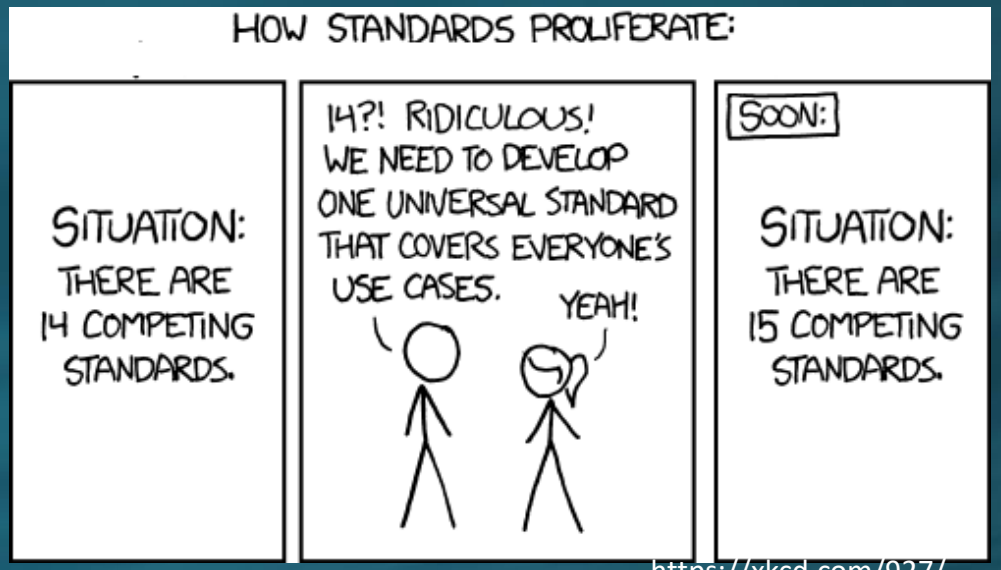


https://www.re3data.org/



FAIR - Interoperable

Interoperability both on the **syntactic** and the **semantic** levels is assured by the use of **standard**



https://xkcd.com/927/

Syntactic interoperability: two or more systems to communicate and exchange data

>>> **Open** and **Self describing** data format (i.e. NetCDF – CF, rosbag, others?)

netCDF

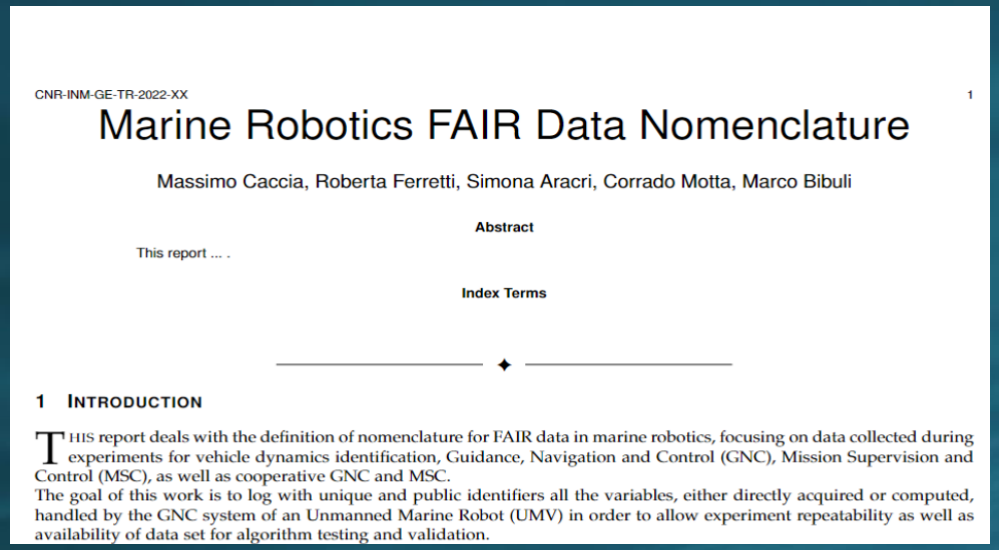
ROS

Semantic interoperability: the data is not only exchanged between two or more systems but also understood by each of them

>>> **Controlled vocabulary** (collection of commonly agreed terms searchable online) and **ontology** (specifications of conceptualizations that document the types of entities that exist in a domain and their relationships)

FAIR - Interoperable

First attempt to define an internal shared vocabulary for **data in marine robotics**



CNR-INM-GE-TR-2022-XX 1

Marine Robotics FAIR Data Nomenclature

Massimo Caccia, Roberta Ferretti, Simona Aracri, Corrado Motta, Marco Bibuli

Abstract

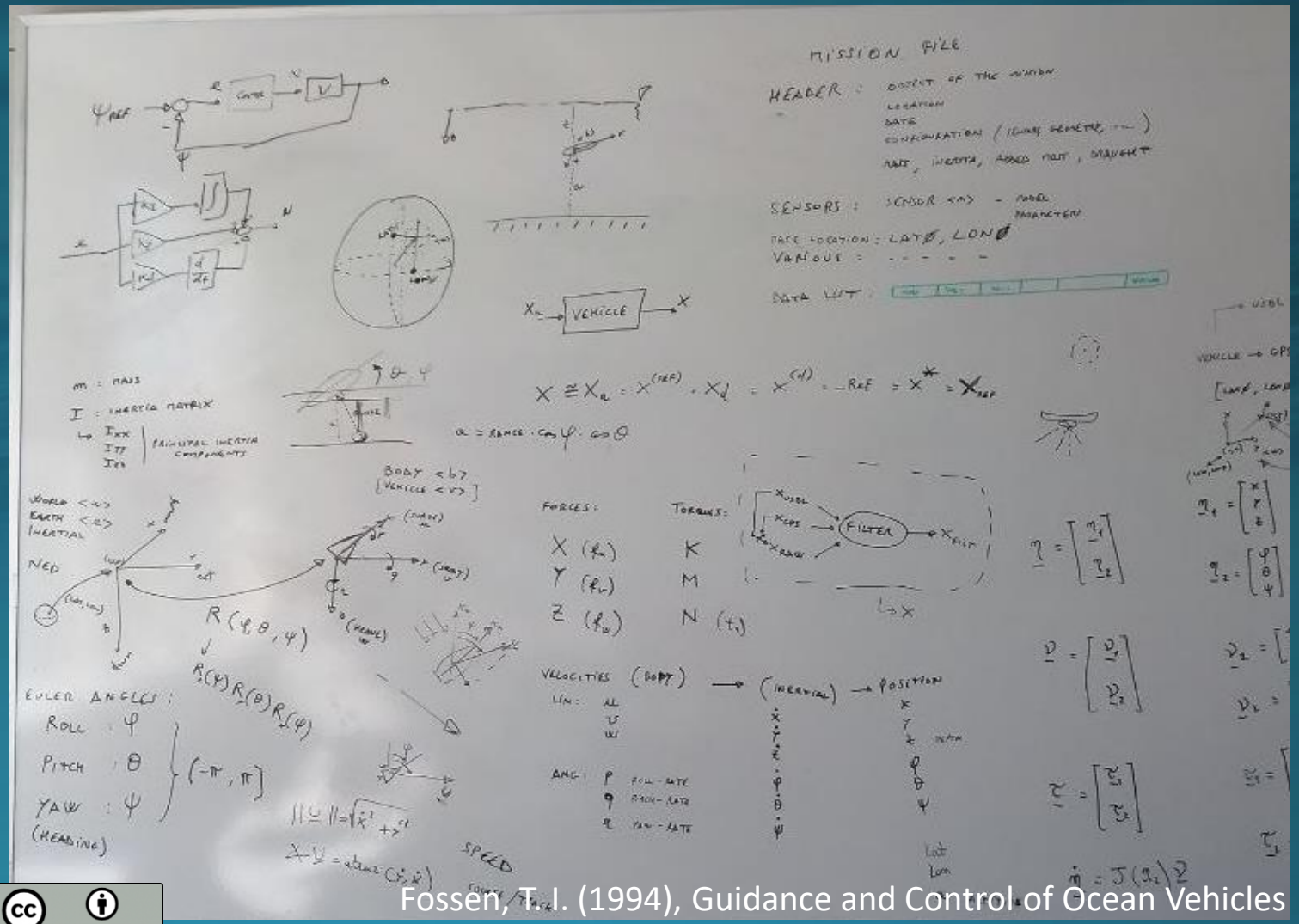
This report ... .

Index Terms

1 Introduction

This report deals with the definition of nomenclature for FAIR data in marine robotics, focusing on data collected during experiments for vehicle dynamics identification, Guidance, Navigation and Control (GNC), Mission Supervision and Control (MSC), as well as cooperative GNC and MSC.
The goal of this work is to log with unique and public identifiers all the variables, either directly acquired or computed, handled by the GNC system of an Unmanned Marine Robot (UMV) in order to allow experiment repeatability as well as availability of data set for algorithm testing and validation.

Starting point: data collected during experiments for vehicle dynamics identification, Guidance, Navigation and Control (GNC), Mission Supervision and Control (MSC)



Fossen, T.I. (1994), Guidance and Control of Ocean Vehicles

FAIR - Reusable

FAIR

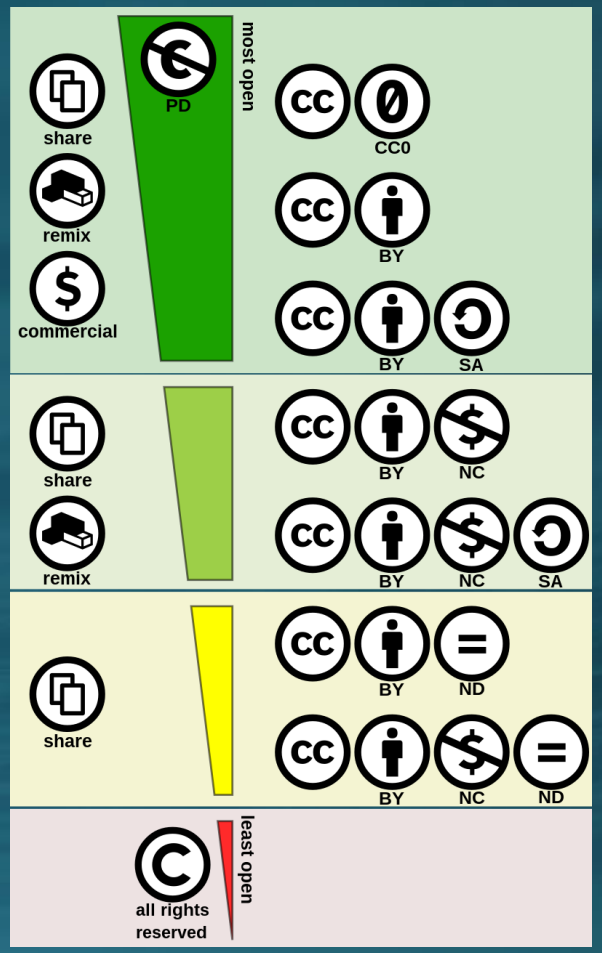
≠

OPEN

Reuse is enabled by

- a clear statement of licence of use

«as open as possible, as close as necessary»



- «use metadata» : clear description of the actual content of data using standard naming conventions for variables, units, missing values, etc…

Use metadata are **domain specific**

Use metadata for robotic variables ?

FAIR - Reusable

Use metadata for marine robotic data is a particularly critical argument open to discussion.

We are working to identify a minimum set of **use metadata** that are necessary and sufficient to clearly describe the marine robotic data, enabling the use of these data by potential stakeholders and avoiding a “bad use” due to misunderstanding

NGC_latitude	(index) float64	45.44 45.44 45.44 ... 400.4 400.4
long_name :	latitude	
standard_name :	latitude	
units :	degree_north	
coverage_conten...	physicalMeasurement	
comments :	Latitude measured by GPS	

https://corradomotta.github.io/FAIR-Data-in-Marine-Robotics/html/variable_metadata.html

Final goal: marine robotics data «FAIR by default»

Develop a structured **Data Management Plan** covering all the **data life cycle** steps

A new way of thinking to our research activities from a **data perspective**

First example of implementation of the **workflow for metadata:** ITTC maneuverability test with SWAMP in Venice

https://dynamics.folio3.com/blog/what-are-the-three-main-goals-of-data-lifecycle-management-dlm/

Interreg Italy - Croatia InnovaMare

Final goal: marine robotics data «FAIR by default»

Schema of the **workflow for metadata and data "FAIR by default"**

HCI

Conf.ini
(global metadata)

SWAMP

Log&Trace.csv
(telemetry)

PY PY

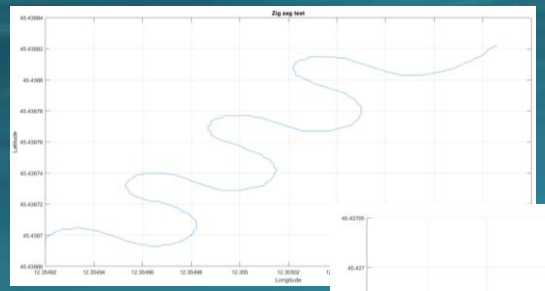
Scripts
(Python)

Database for global and variable metadata (JSON)

NetCDF - CF and ACDD Compliant

XML

ISO 19115



	A	B	C	D	E	F
1	date	time	latitude	longitude	projection_x_coordinate	projection_y_coordinate
2	date	time	latitude	longitude	projection_x_coordinate	projection_y_coordinate
3	20220915	75849250	45.43682500	12.35510700	-57.23	31.66
4	20220915	75849250	45.43682500	12.35510700	-57.23	31.66
5	20220915	75849500	45.43682400	12.35510500	-57.34	31.50
6	20220915	75849500	45.43682400	12.35510500	-57.34	31.50
7	20220915	75849500	45.43682400	12.35510500	-57.34	31.50
8	20220915	75849500	45.43682400	12.35510500	-57.34	31.50
9	20220915	75849500	45.43682400	12.35510500	-57.34	31.50
				2.35510000	-57.79	31.11
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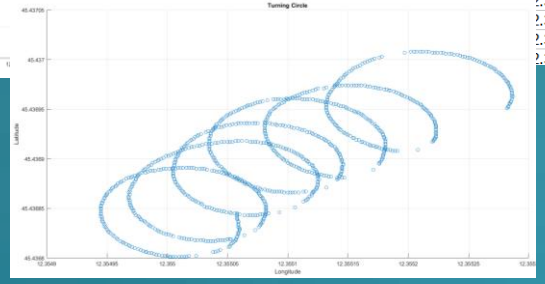
				2.35510000	-57.79	31.11



ITTC maneuverability test

global_metadata.json

variable_metadata.json

https://github.com/CorradoMotta/FAIR-Data-in-Marine-Robotics

Interreg Italy - Croatia InnovaMare
EUROPEAN UNION

Open questions and discussion

- Trusted Repository: where should I publish the marine robotics data?

- Use metadata: which are the variables of interest, and which are the minimum set of metadata needed to describe them comprehensively?

- Shared vocabulary / ontology: how do I define the names of the variables of interest? (CF Convention, …)

- Standard data format for robotic data: NetCDF ? Rosbag? Others?

Thank you for your ~~attention~~ collaboration!!!

References

- Manzella and Novellino, Ocean Science Data Collection, Management, Networking and Services, 2022, https://doi.org/10.1016/C2019-0-05509-4
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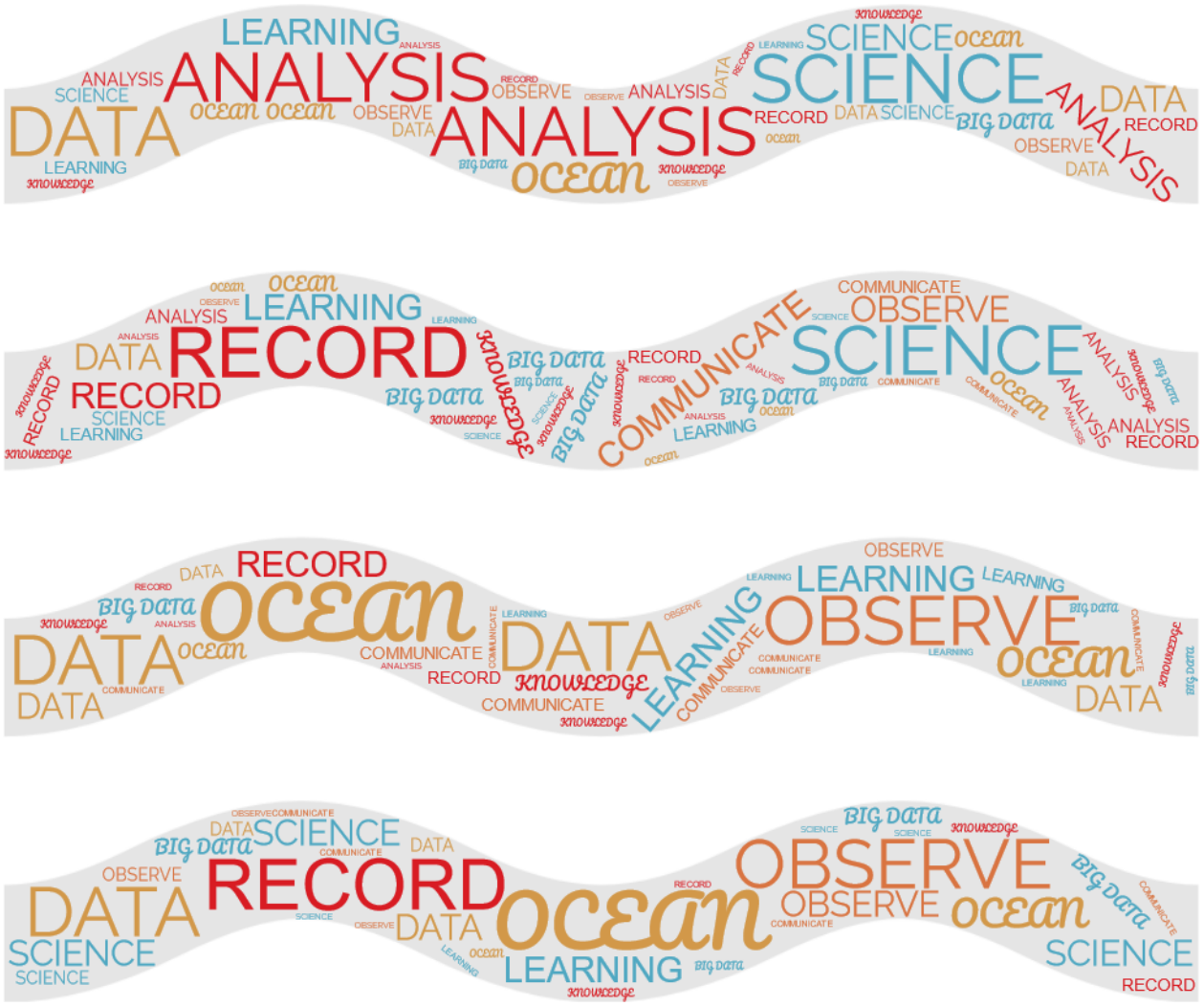
- DOI https://doi.org/10.1038/s41597-021-00981-0
- https://corradomotta.github.io/FAIR-Data-in-Marine-Robotics/html/index.html
- https://www.nature.com/articles/sdata201618
- Ferretti, R.; Caccia, M.; Coltorti, M.; Ivaldi, R. New Approaches for the Observation of Transient Phenomena in Critical Marine Environment. J. Mar. Sci. Eng. 2021, 9, 578. https://doi.org/10.3390/jmse9060578

Back up slides


LEARNING
ANALYSIS
SCIENCE
DATA
ocean
OBSERVE
RECORD
knowledge
BIG DATA
COMMUNICATE

FAIR - Accessible

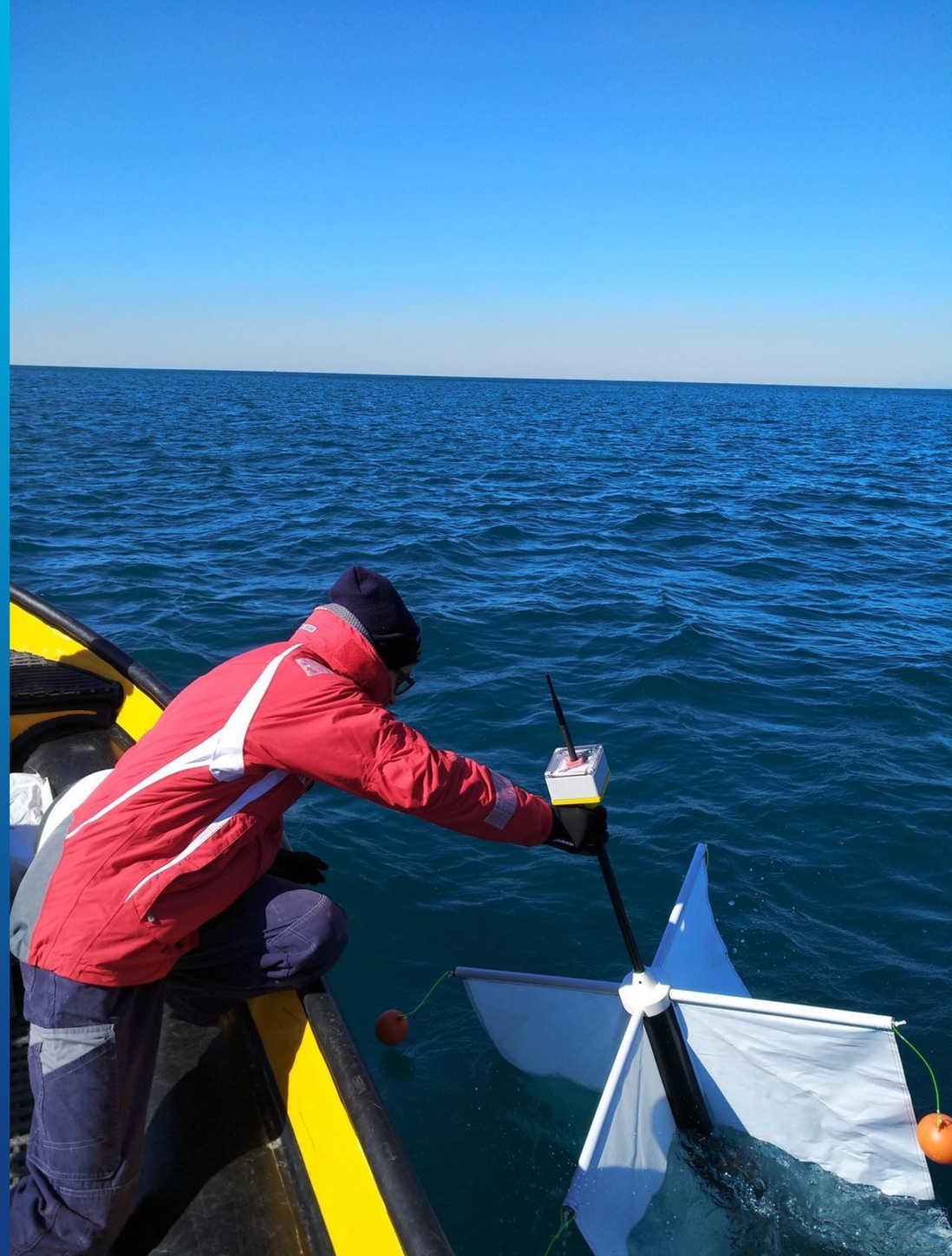
OPeNDAP – Open-source Project for a Network Data Access Protocol

Simply the integration and combination of data from various data centers
Support data access, combining multiple physical files to a single virtual dataset
Removes the step of downloading data prior to analysis

OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Autonomous platforms for oceanographic data collection

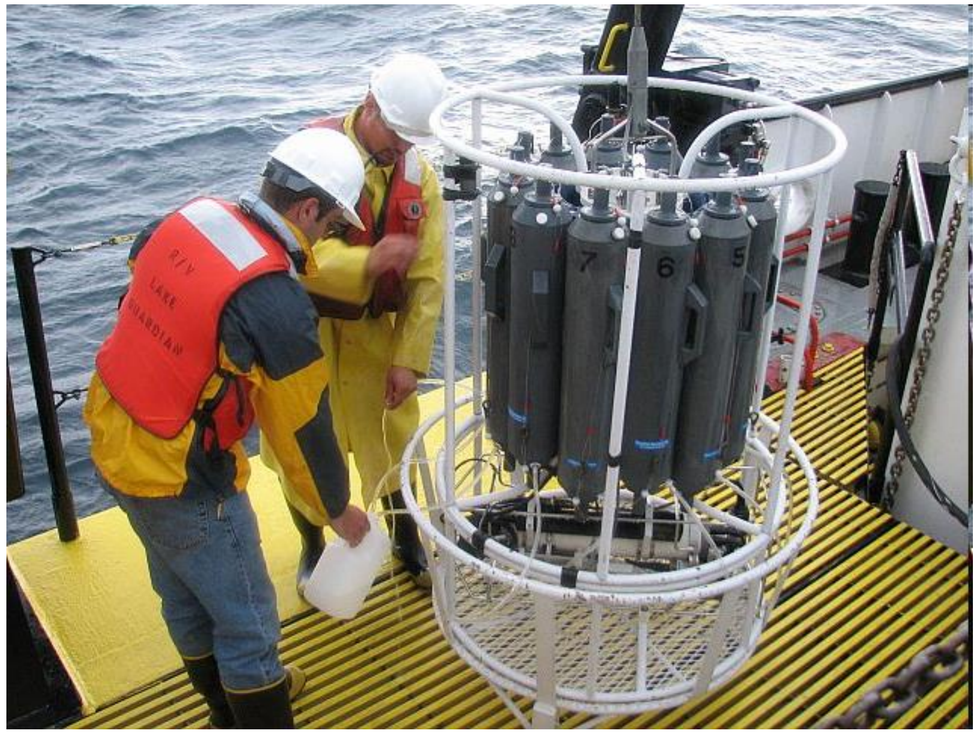
Riccardo Gerin & TEC, MAOS and CTMO groups
rgerin@inogs.it

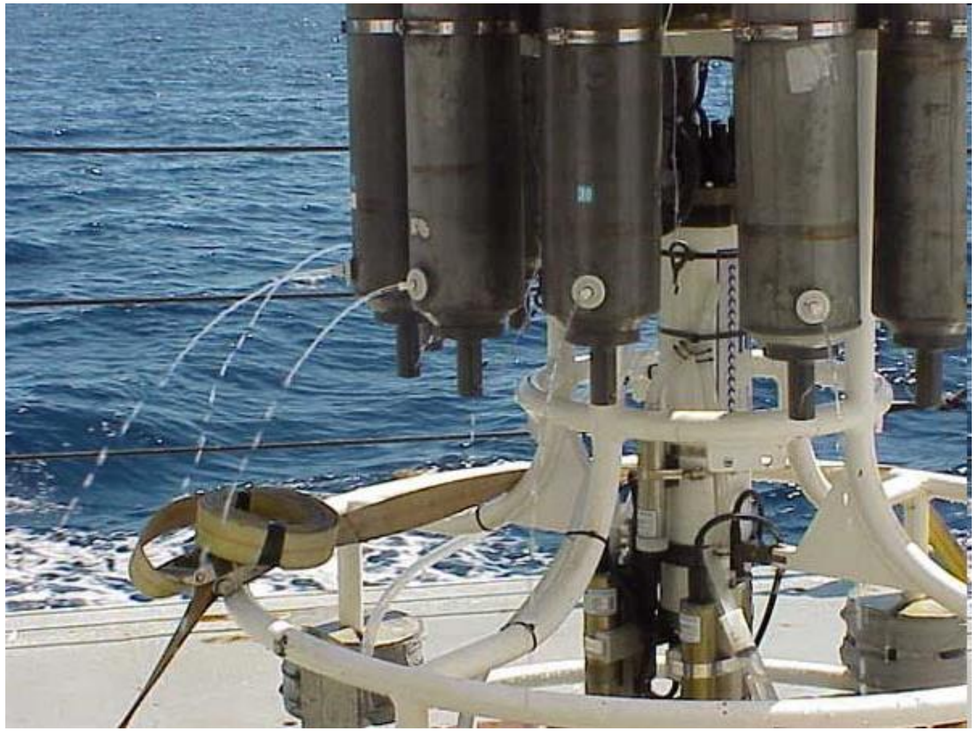


Autonomous platforms and oceanography

In recent decades, technological developments and the miniaturization of sensors have made the development of autonomous and unmanned remote sensing oceanographic platforms possible. These platforms can move through the water, provide long-term and real-time monitoring and, in addition, reduce costs compared to other traditional measurement approaches. They are very efficient and important tools to complement and extend conventional oceanographic observations.

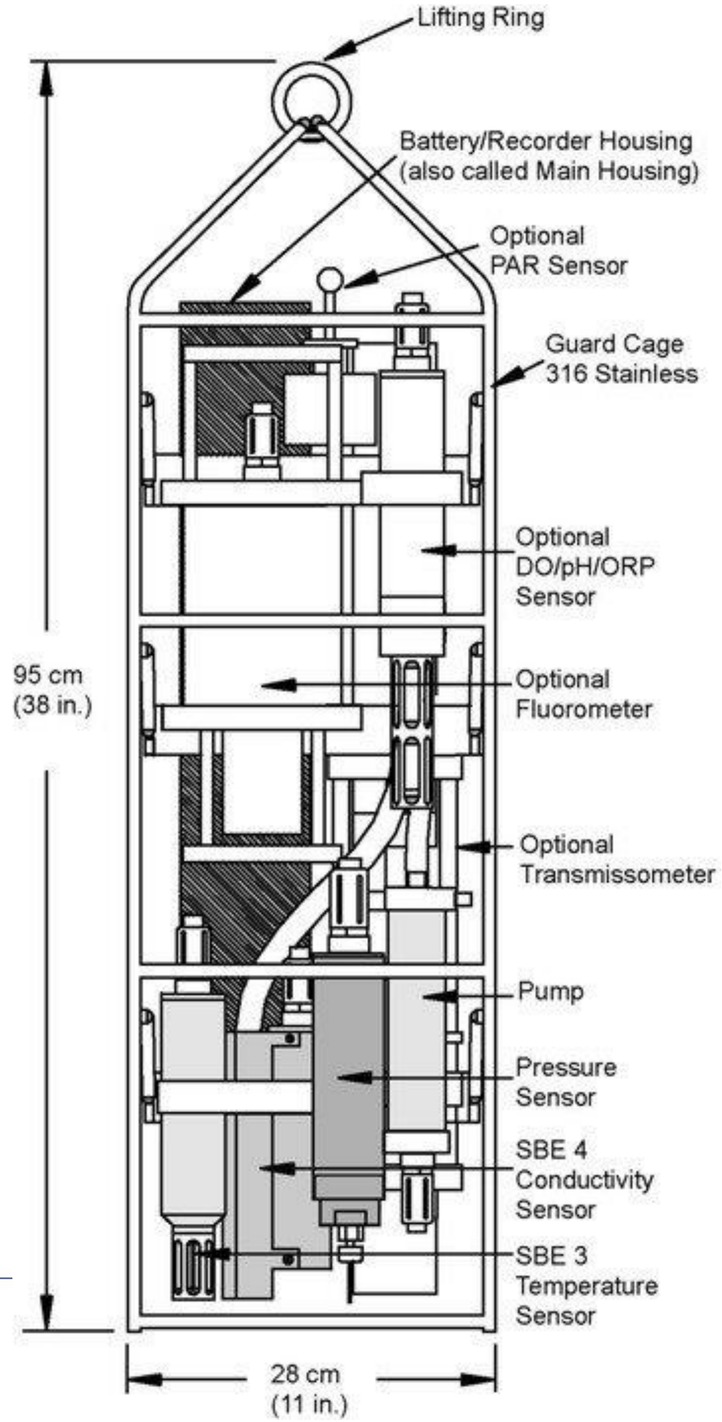
On board a research vessel
Water sampling : Rosette





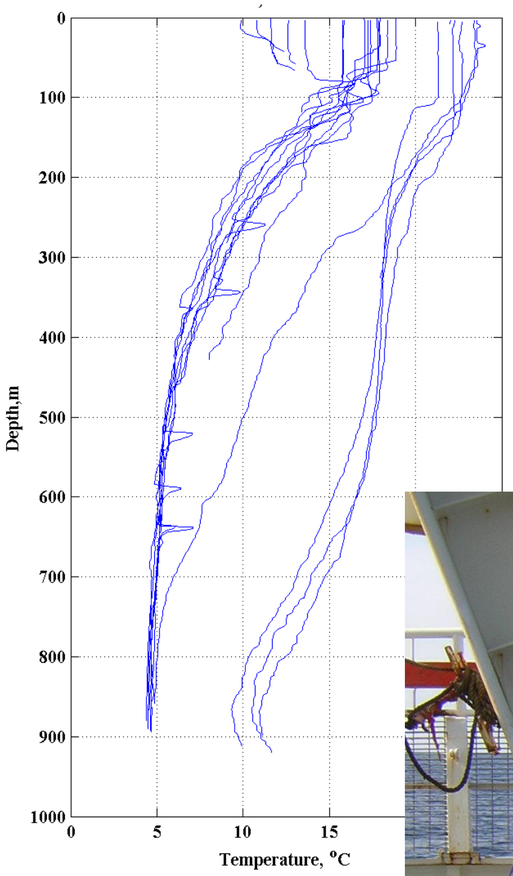
On board a research vessel

CTD: Conductivity, Temperature and Depth



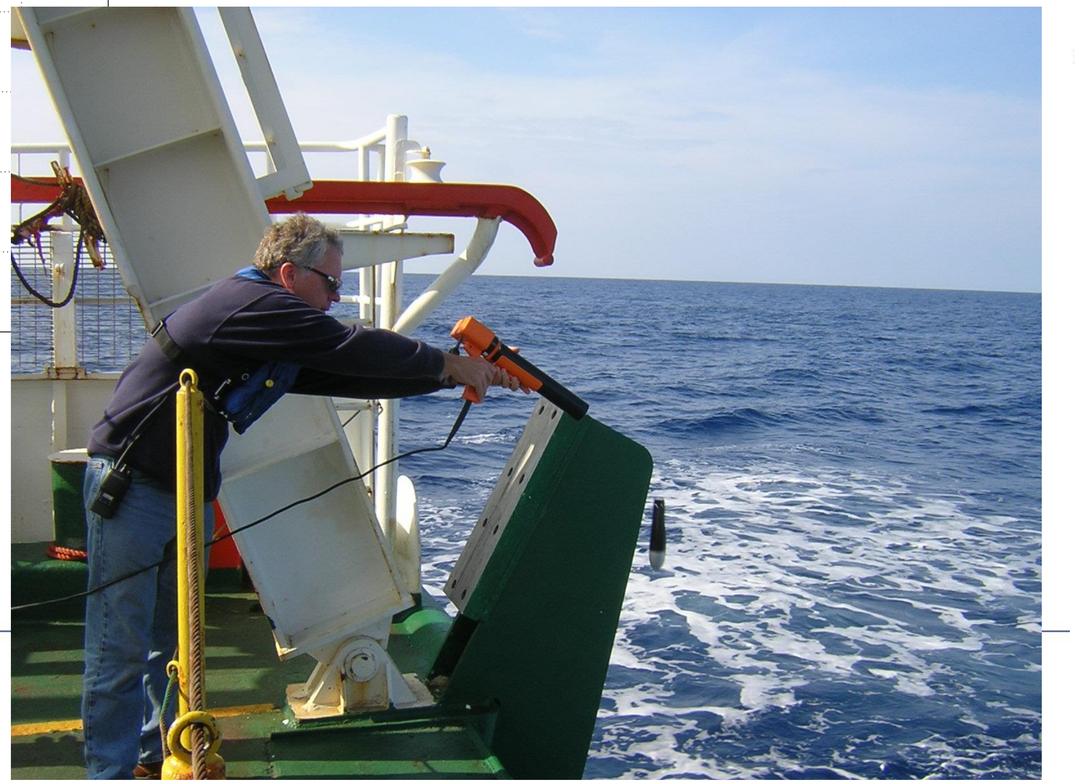
OGS

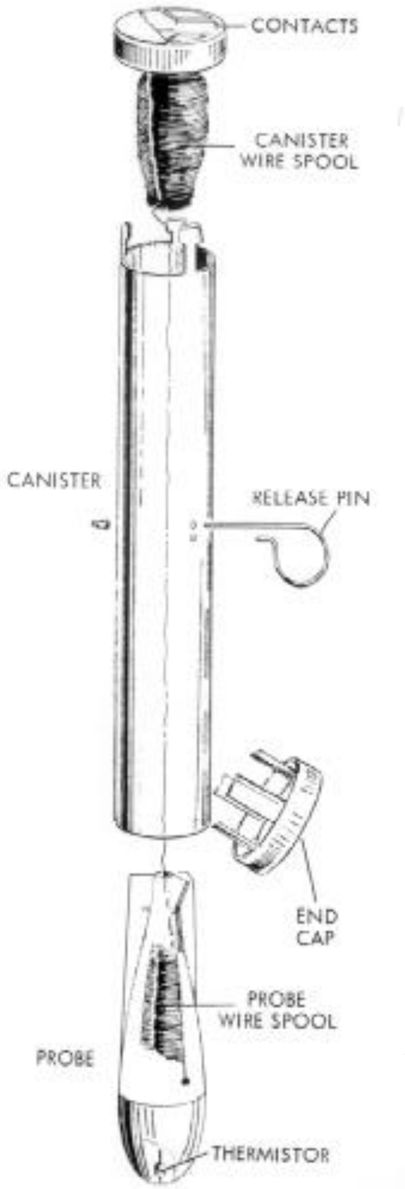
On board a research vessel



XBT: eXpandable

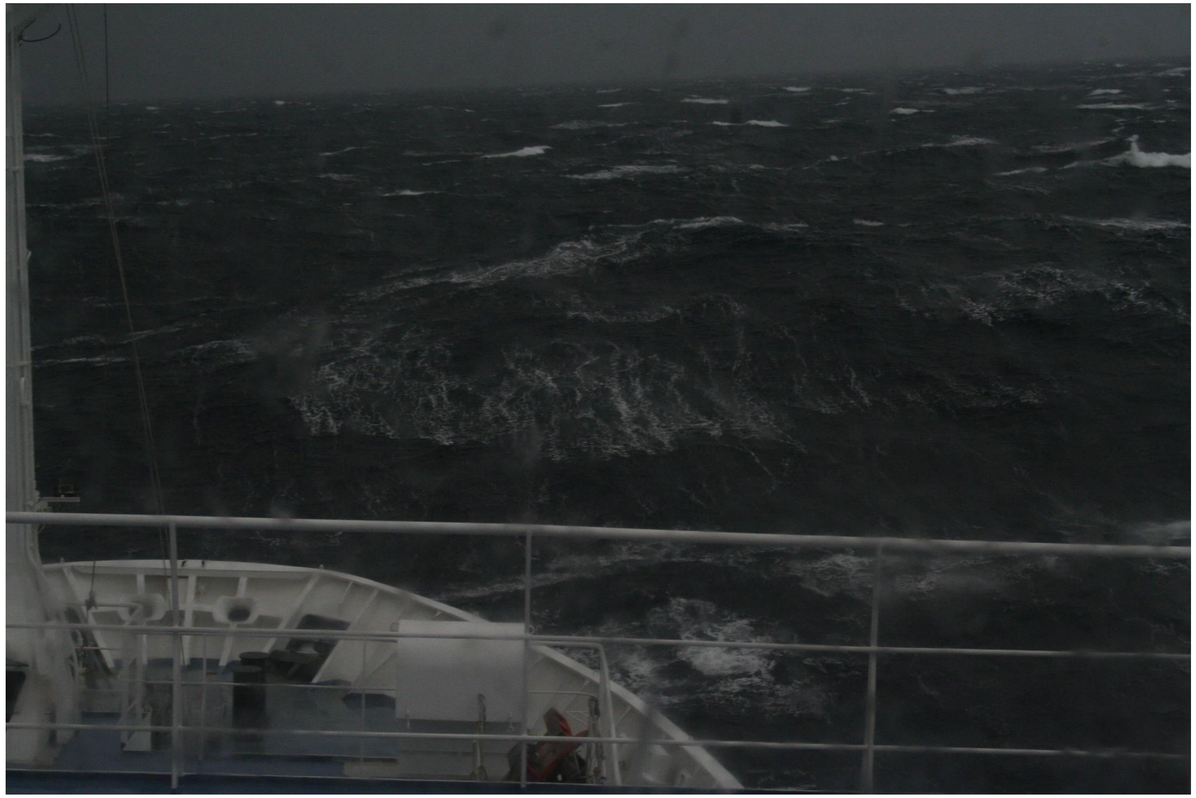
BathyThermograph

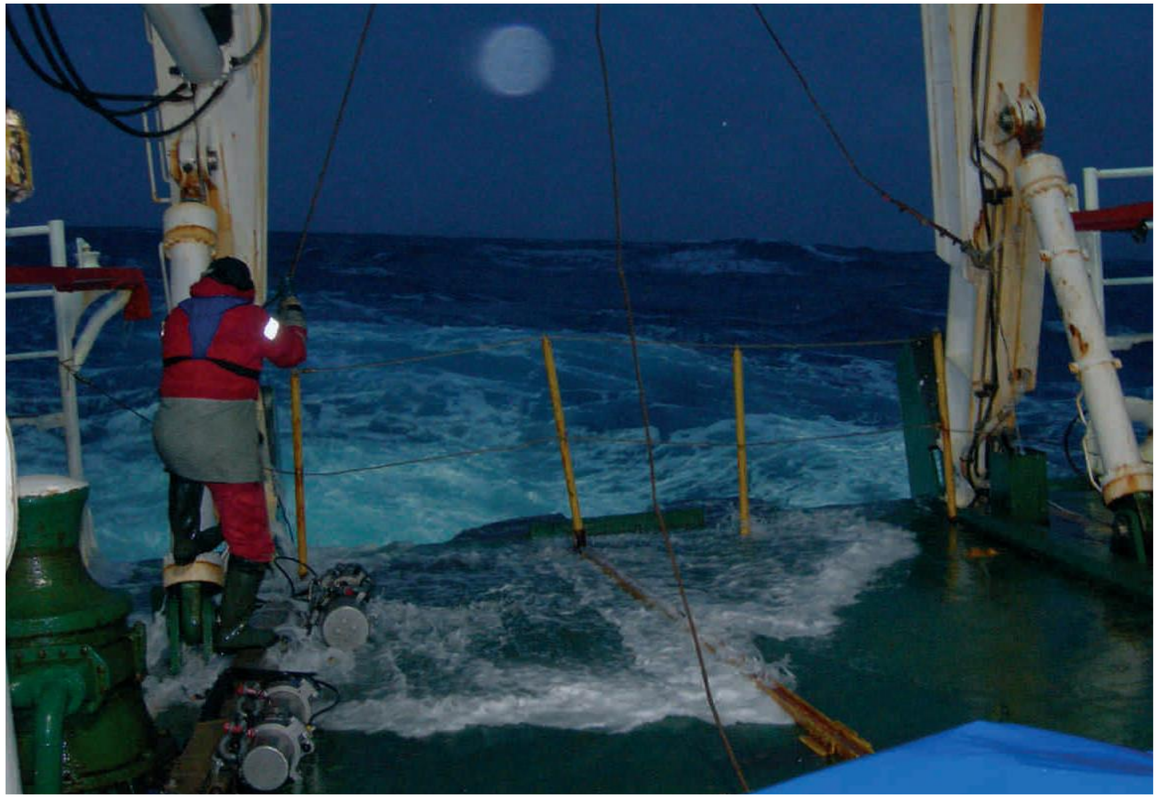




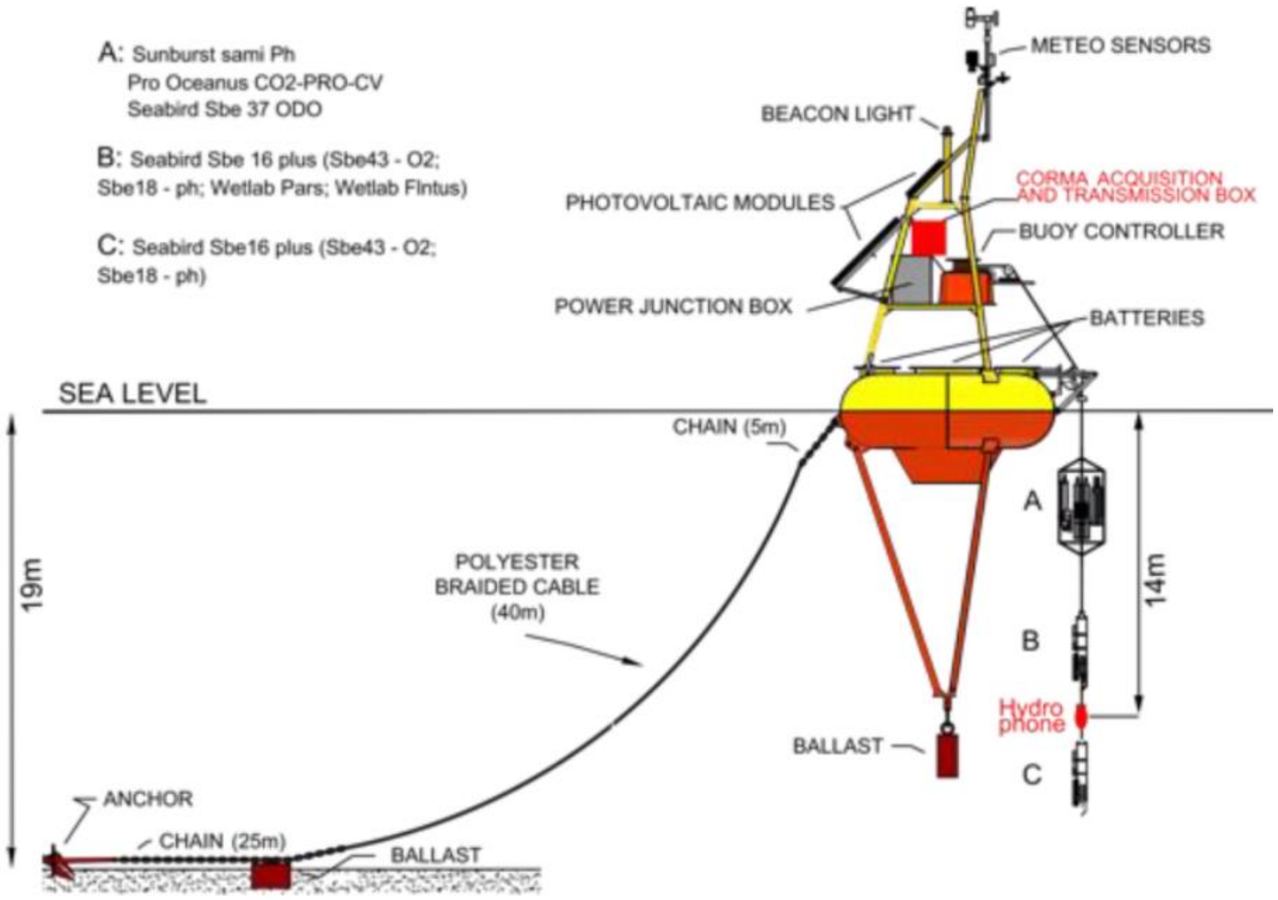
OGS

… it is not always easy …

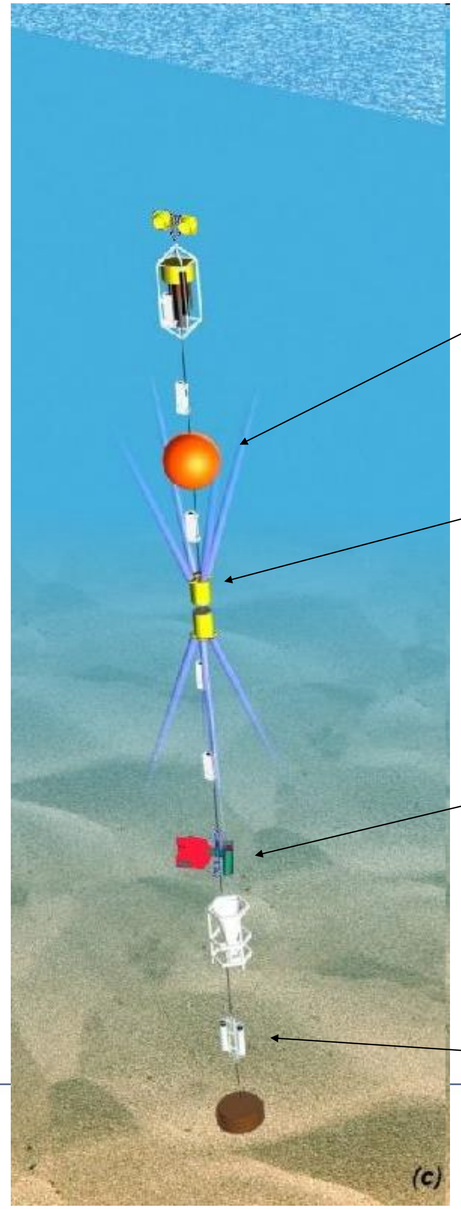




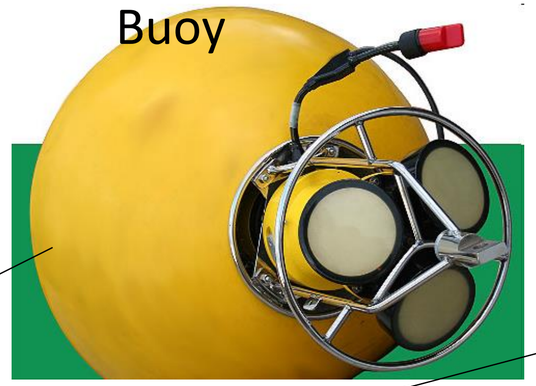
Fixed buoy


A: Sunburst sami Ph
Pro Oceanus CO2-PRO-CV
Seabird Sbe 37 ODO
B: Seabird Sbe 16 plus (Sbe43 - O2; Sbe18 - ph; Wetlab Pars; Wetlab Fintus)
C: Seabird Sbe16 plus (Sbe43 - O2; Sbe18 - ph)
METEO SENSORS
BEACON LIGHT
PHOTOVOLTAIC MODULES
CORMA ACQUISITION AND TRANSMISSION BOX
BUOY CONTROLLER
POWER JUNCTION BOX
BATTERIES
SEA LEVEL
CHAIN (5m)
19m
POLYESTER BRAIDED CABLE (40m)
A
B
C
14m
Hydro phone
BALLAST
ANCHOR
CHAIN (25m)
BALLAST

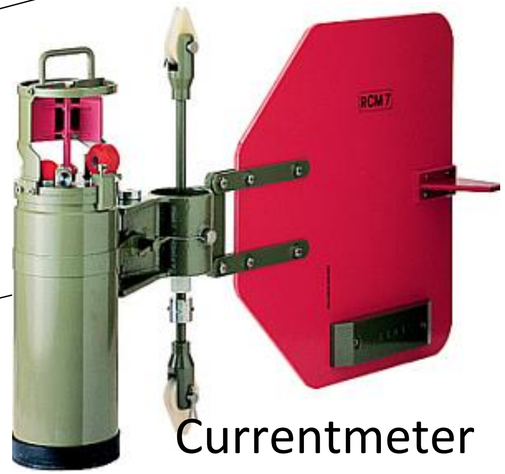
Fixed buoy



Buoy



ADCP: Acoustic Doppler Current Profiler

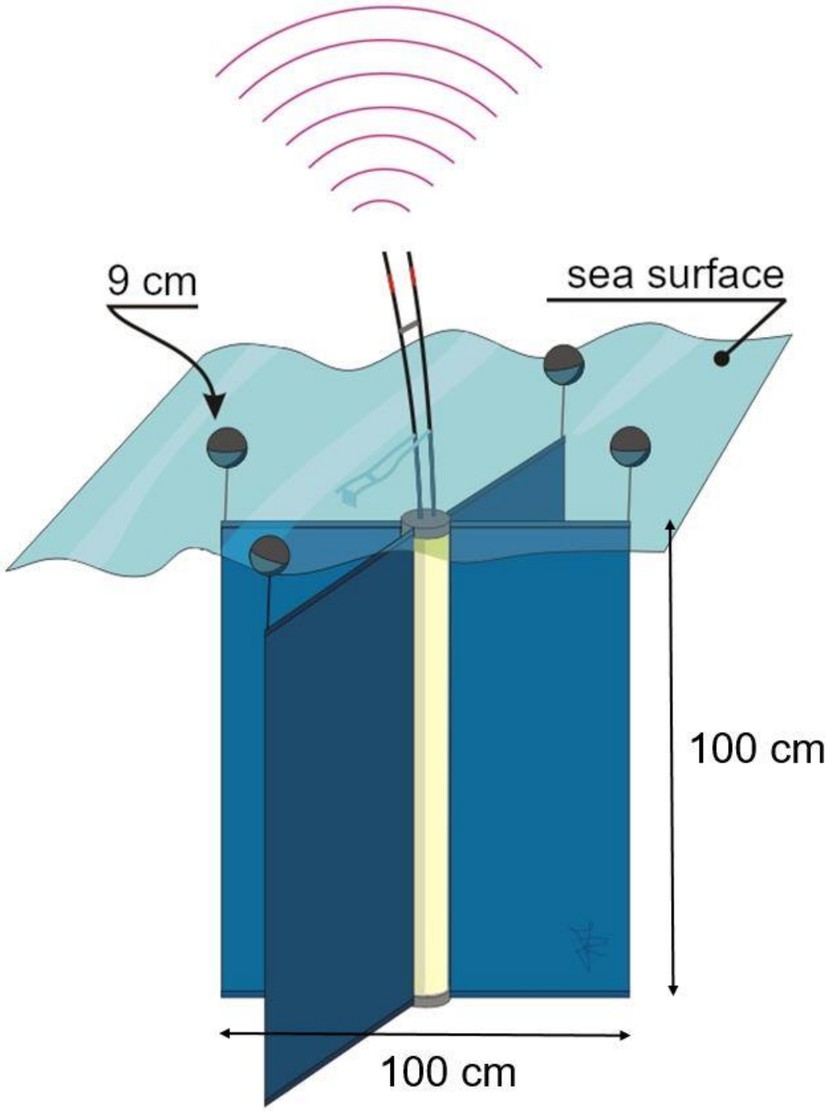


Currentmeter (AANDERAA)

Acoustic releaser

OGS

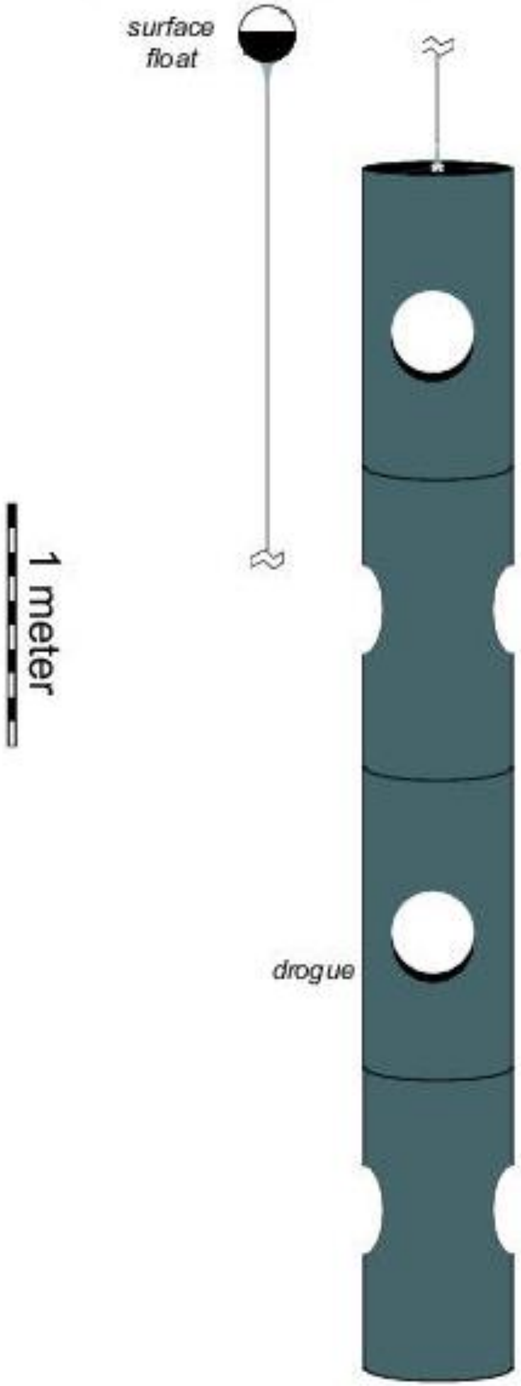
Drifter



CODE drifter
(Davis, 1985)

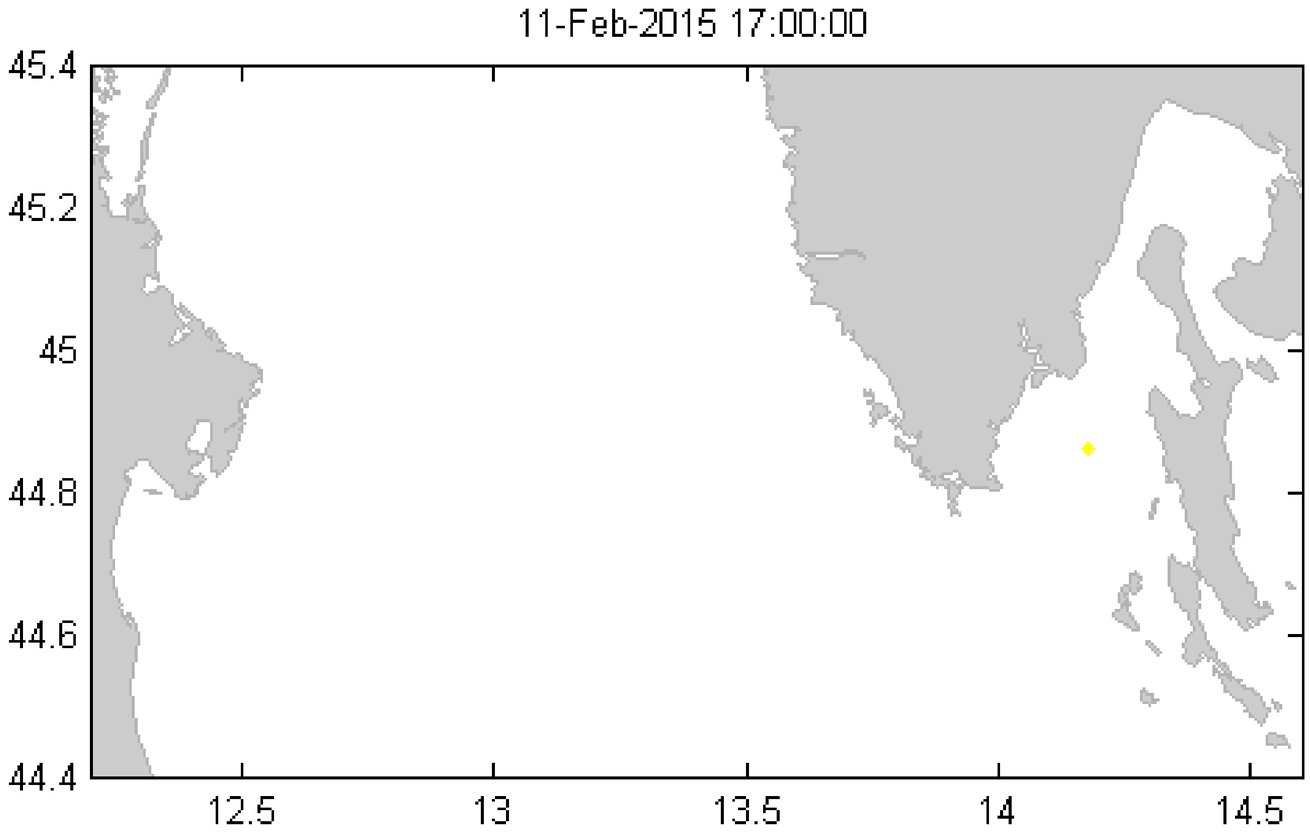
Drifter

SVP drifter
(Sybrandy and Niiler, 1992)

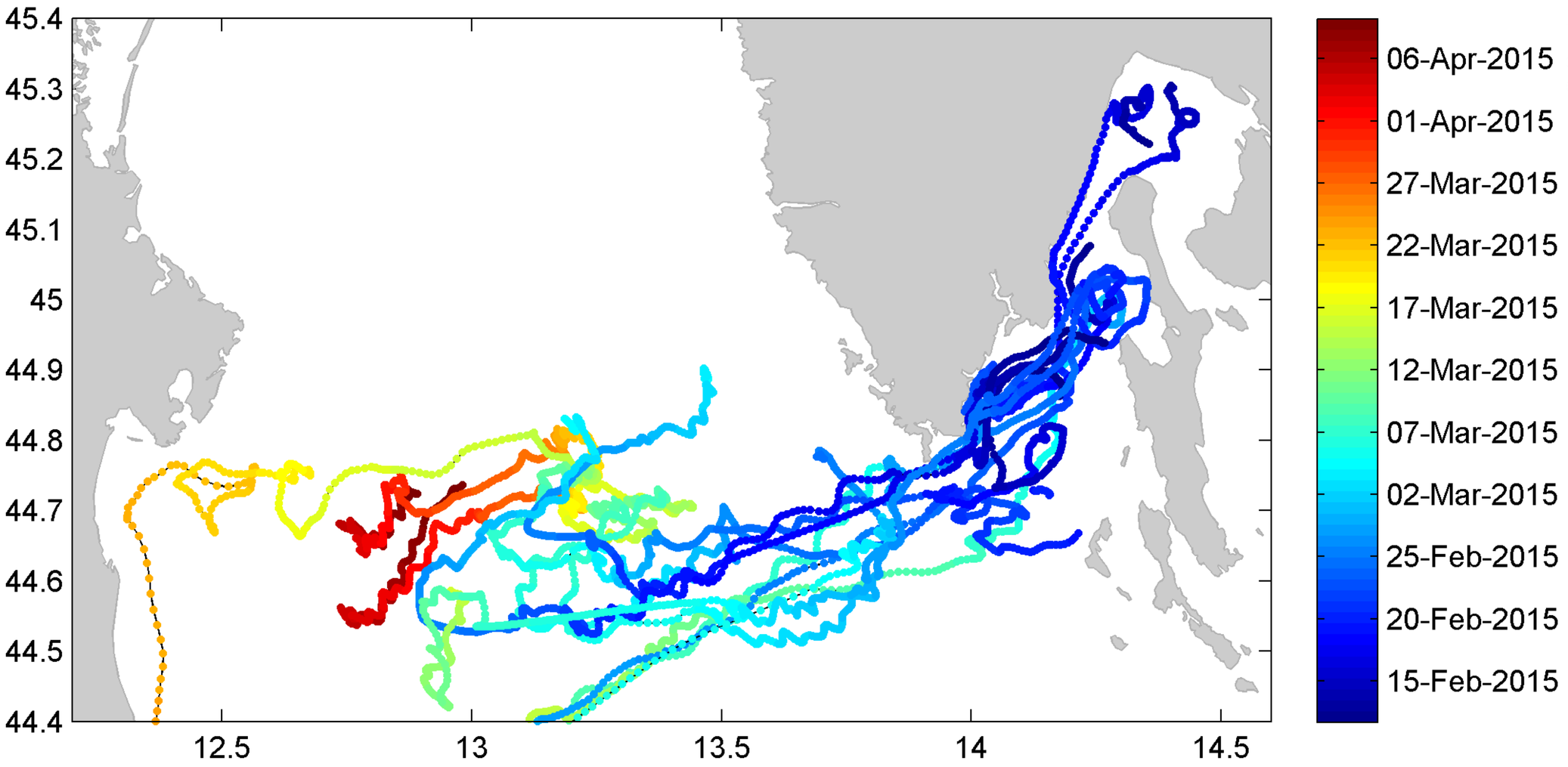


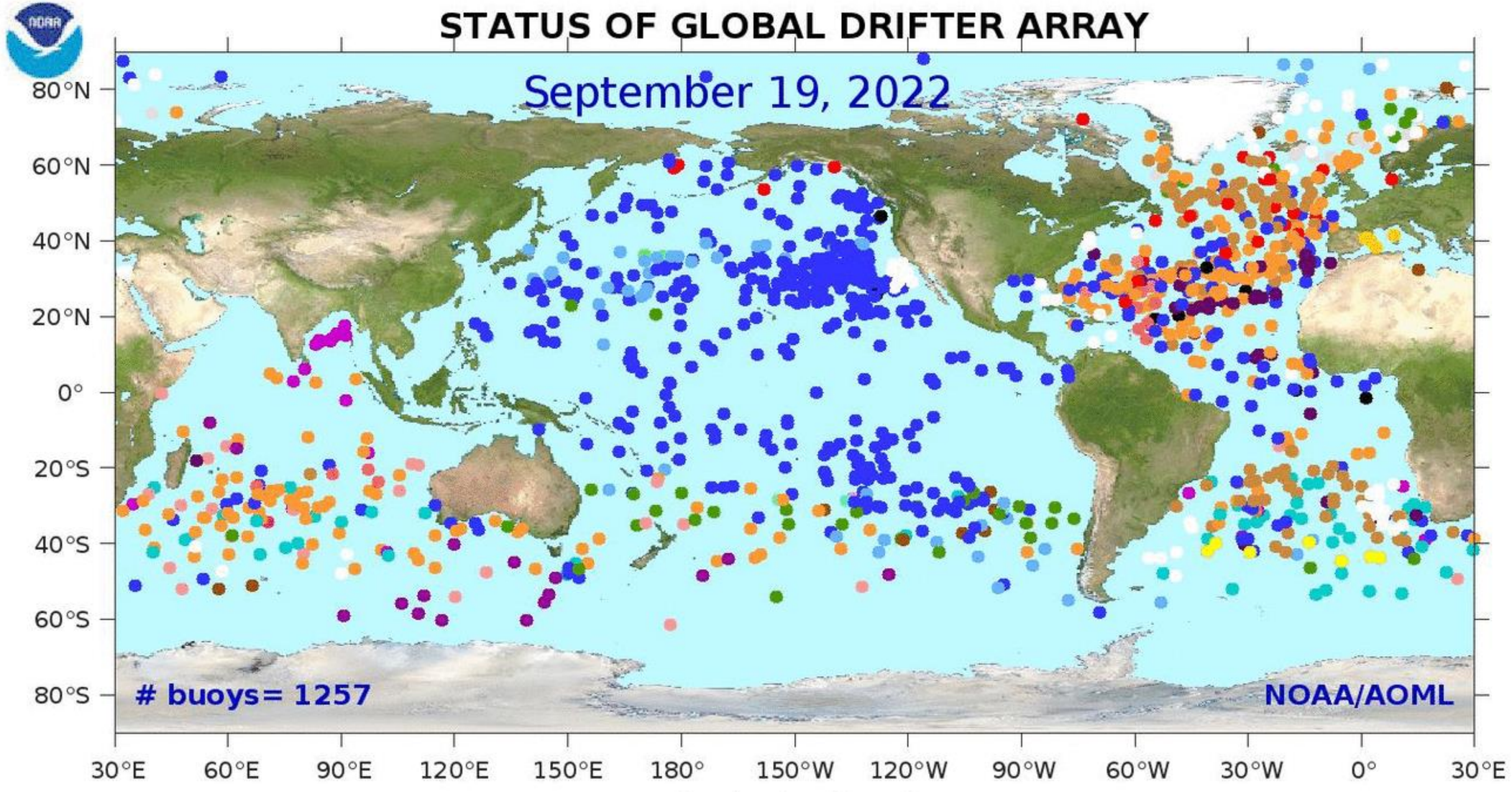
OGS

Drifter: North Adriatic Experiment 2015 in the Kvarner area



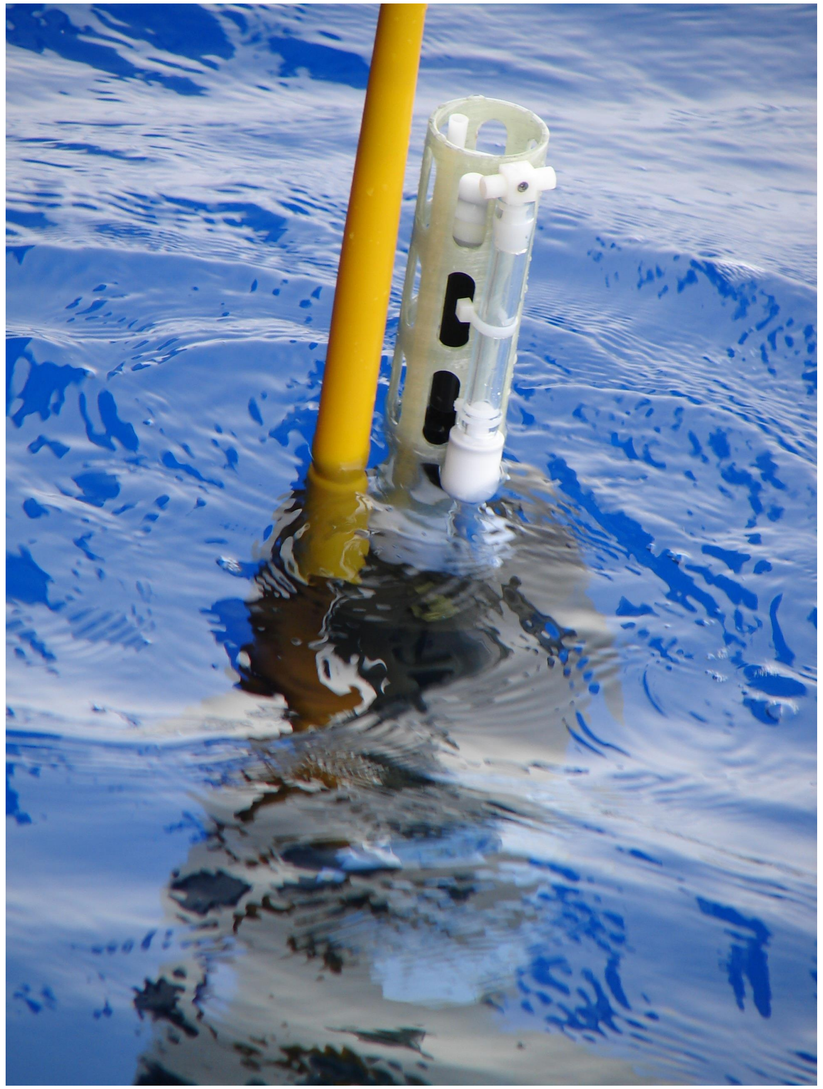
Drifter: North Adriatic Experiment 2015 in the Kvarner area

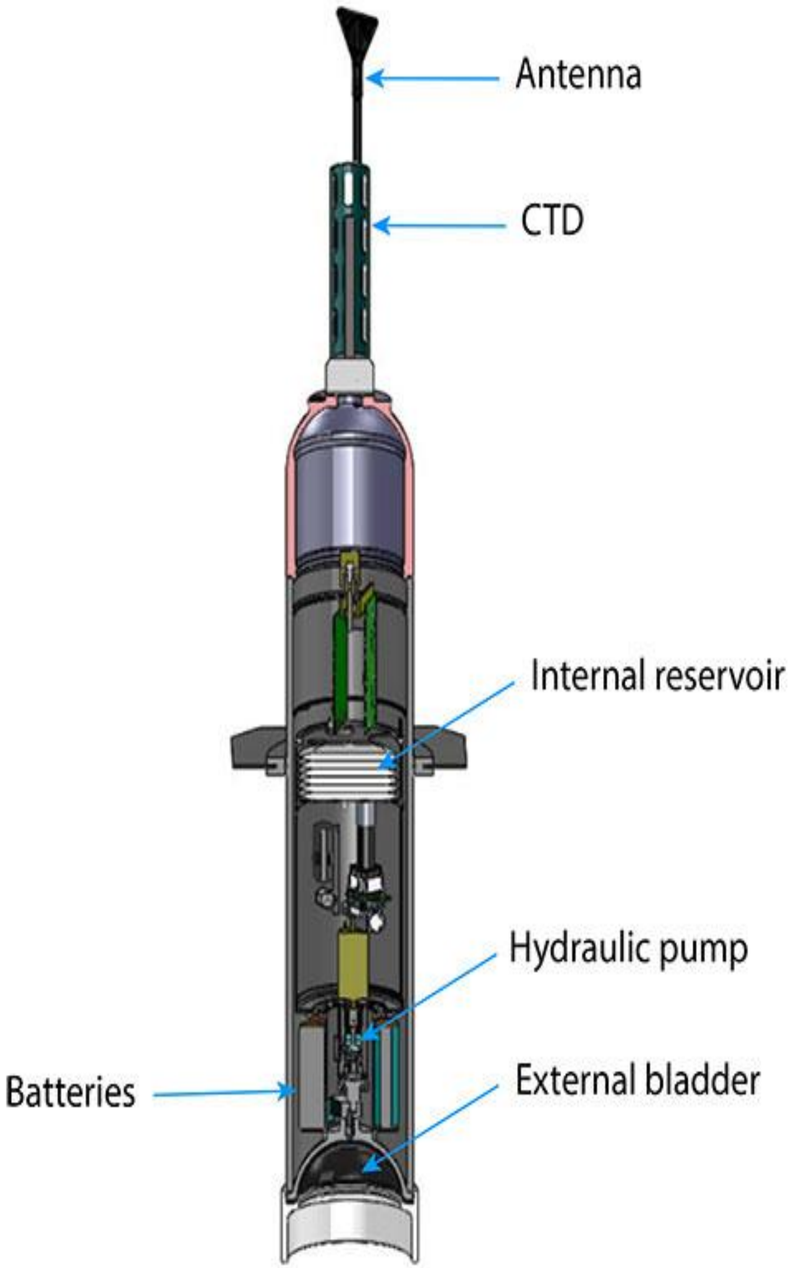



STATUS OF GLOBAL DRIFTER ARRAY
September 19, 2022
buoys= 1257
NOAA/AOML
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
30°E
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E

OGS

Float

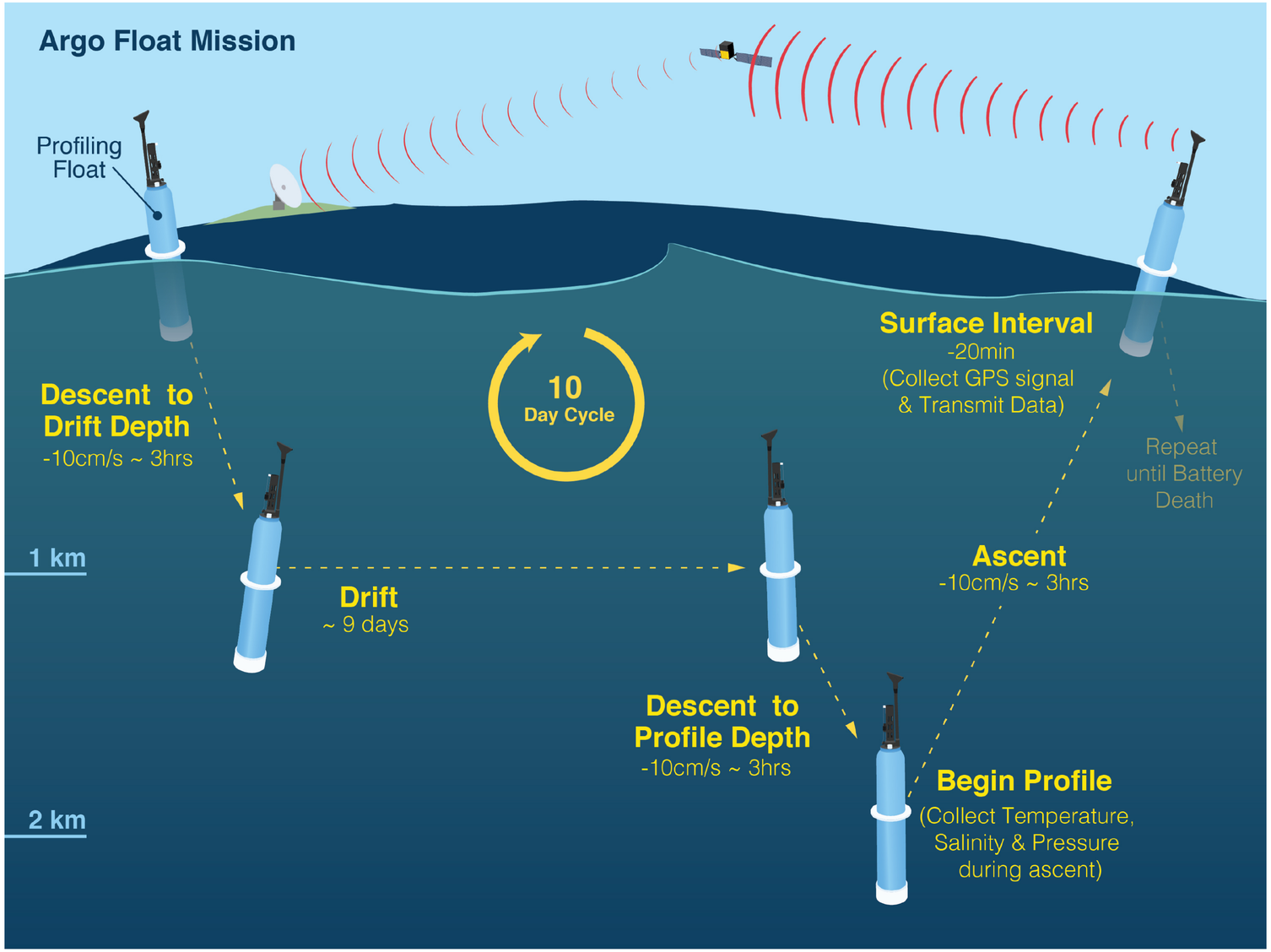




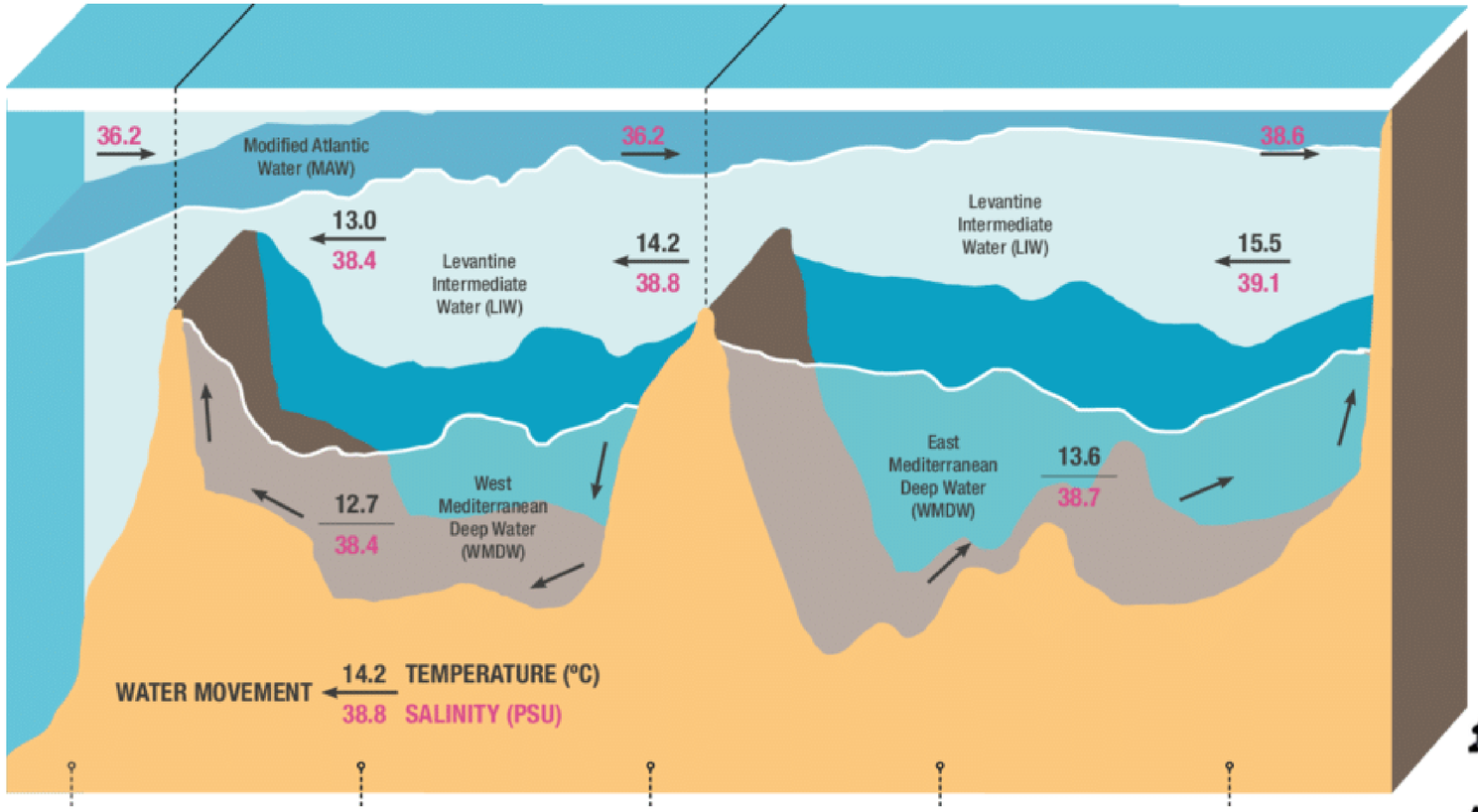
Credit: Michael McClune, Scripps Institution of Oceanography

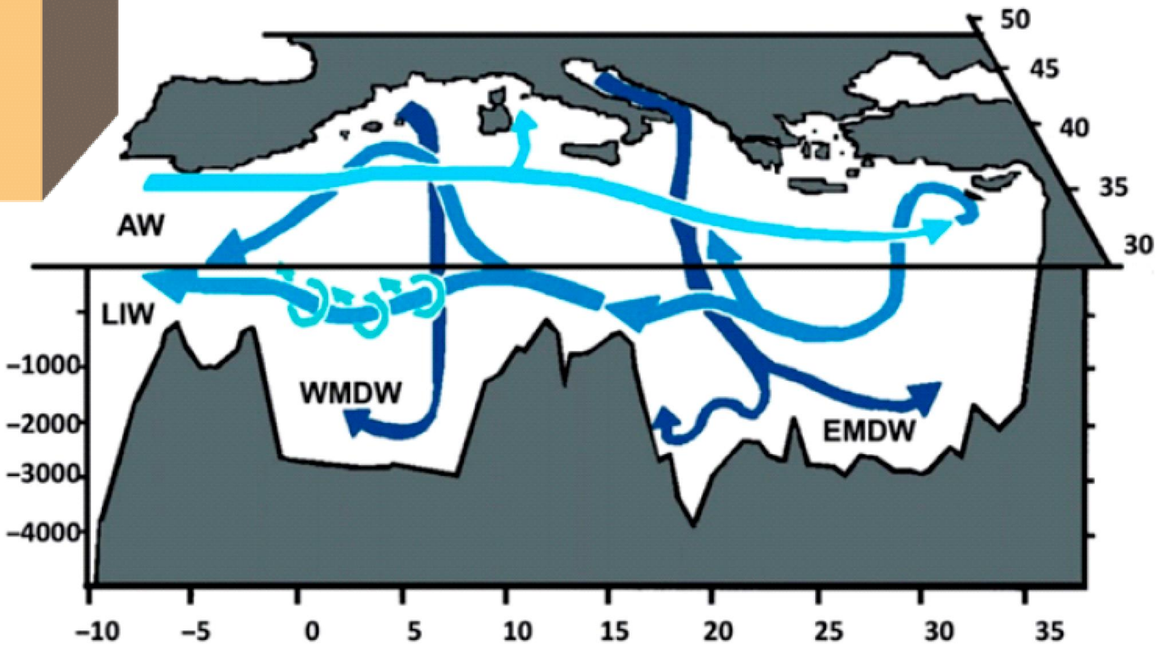
OGS

Float


Argo Float Mission
Profiling Float
Descent to Drift Depth
-10cm/s ~ 3hrs
10 Day Cycle
Surface Interval
-20min
(Collect GPS signal & Transmit Data)
Repeat until Battery Death
1 km
Drift
~ 9 days
Ascent
-10cm/s ~ 3hrs
Descent to Profile Depth
-10cm/s ~ 3hrs
Begin Profile
(Collect Temperature, Salinity & Pressure during ascent)
2 km

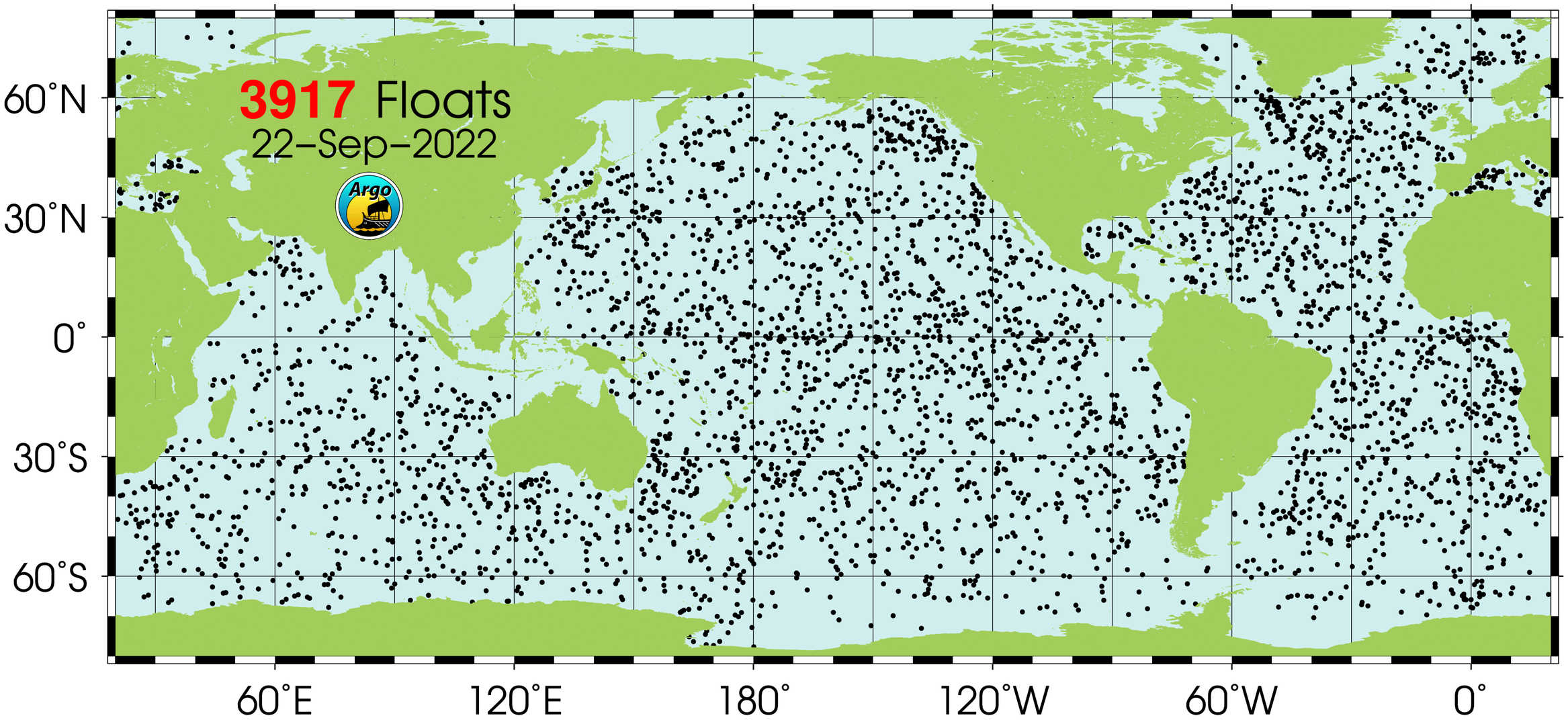
Mediterranean Circulation





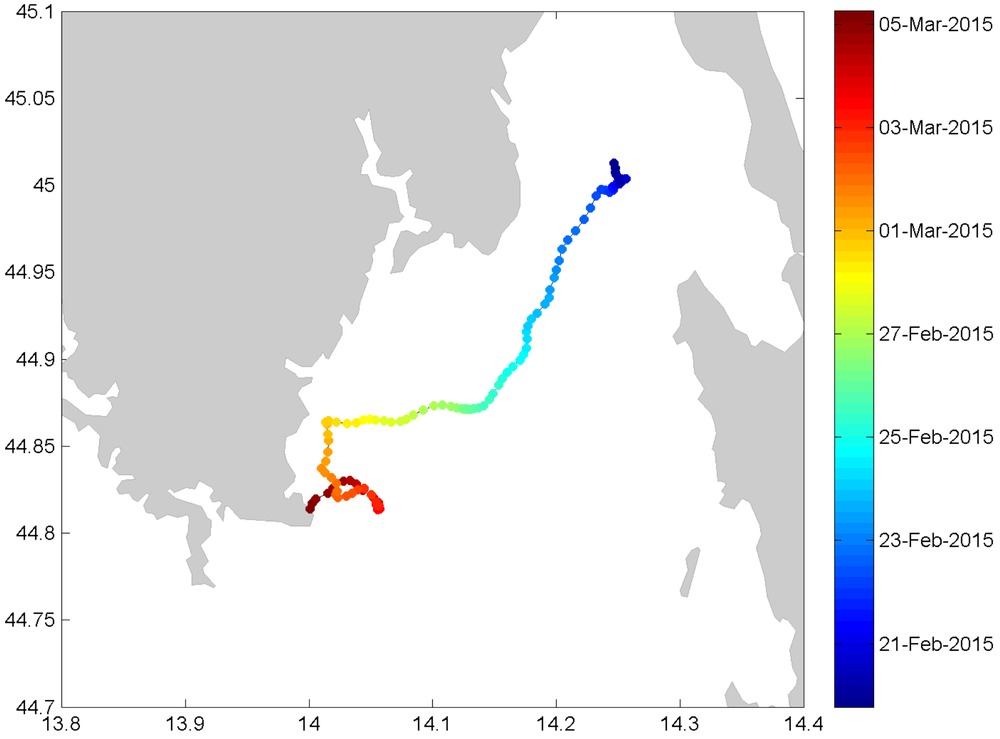
OGS

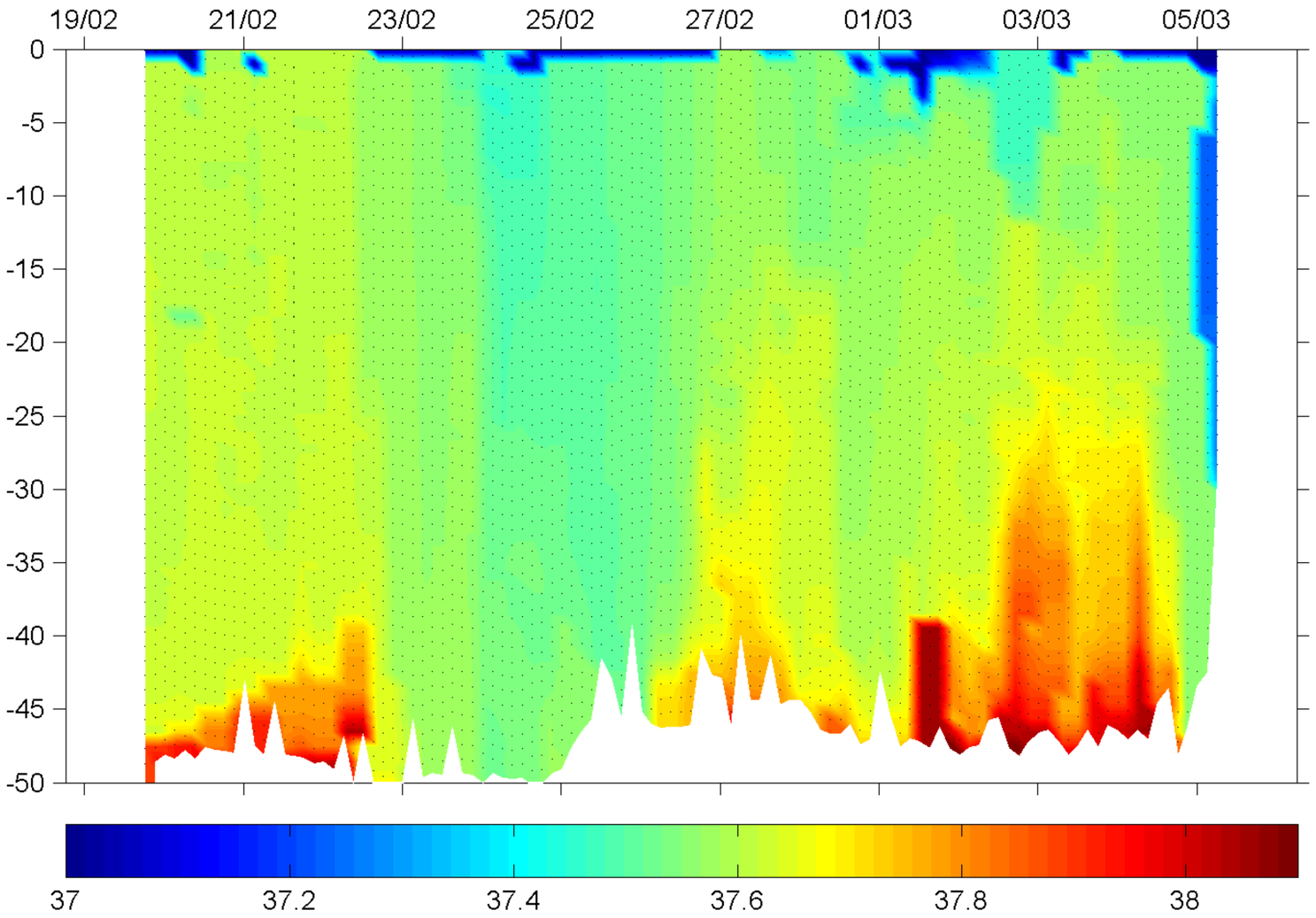
Float distribution



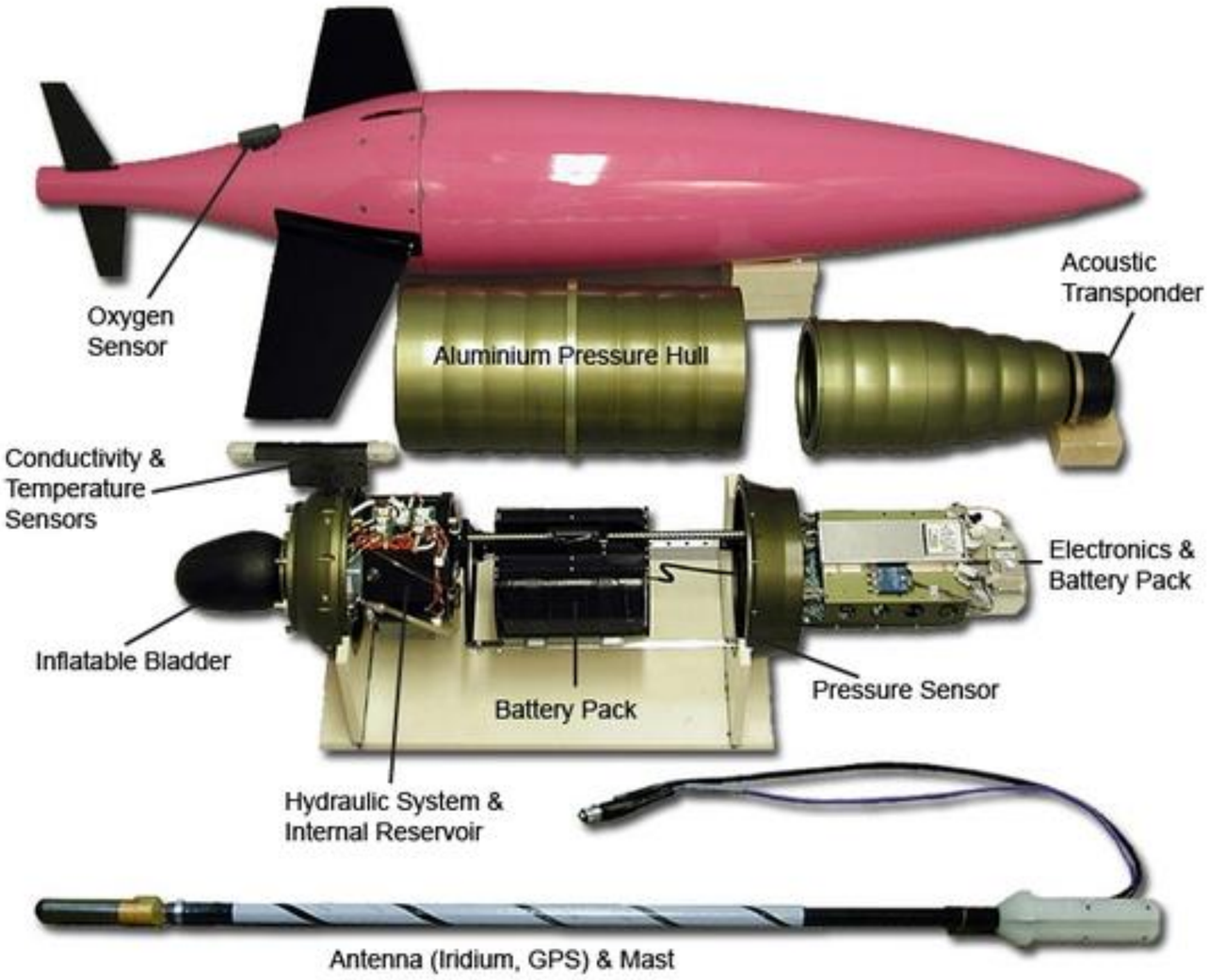
OGS

Float: North Adriatic Experiment 2015 in the Kvarner area





Glider

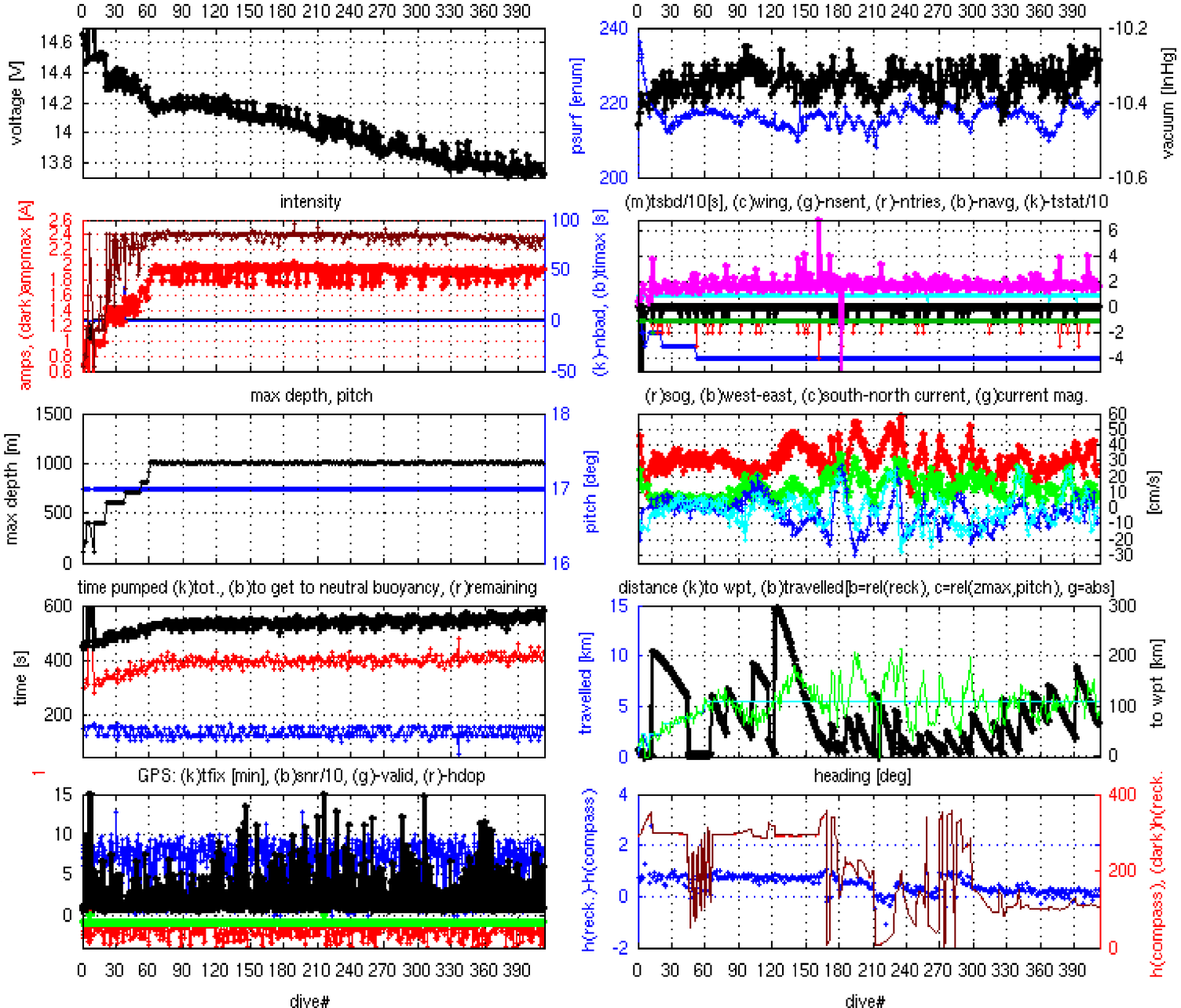

Oxygen Sensor
Aluminium Pressure Hull
Acoustic Transponder
Conductivity & Temperature Sensors
Electronics & Battery Pack
Inflatable Bladder
Battery Pack
Pressure Sensor
Hydraulic System & Internal Reservoir
Antenna (Iridium, GPS) & Mast

OGS

Glider

RutgersCOOL
Pubblicato il 26 set 2016

Glider

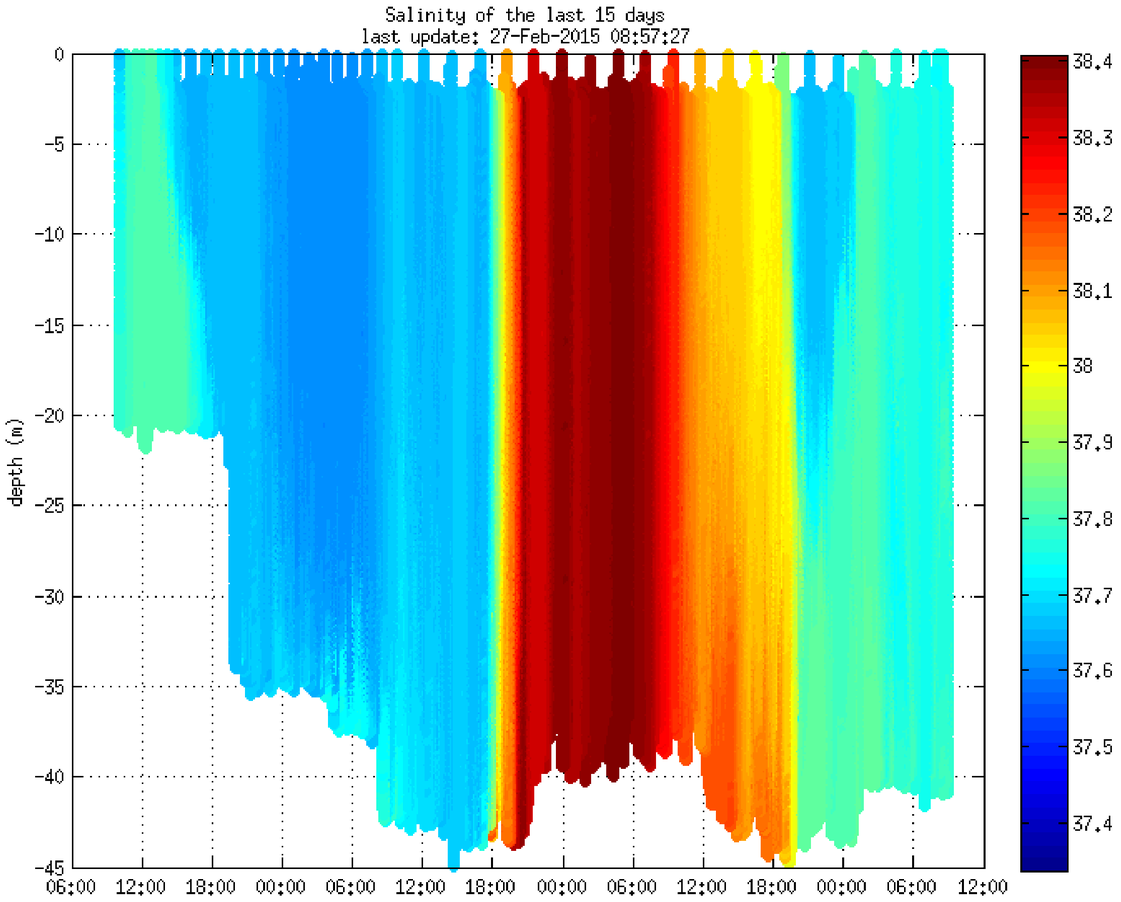


More than 3000 parameters

OGS

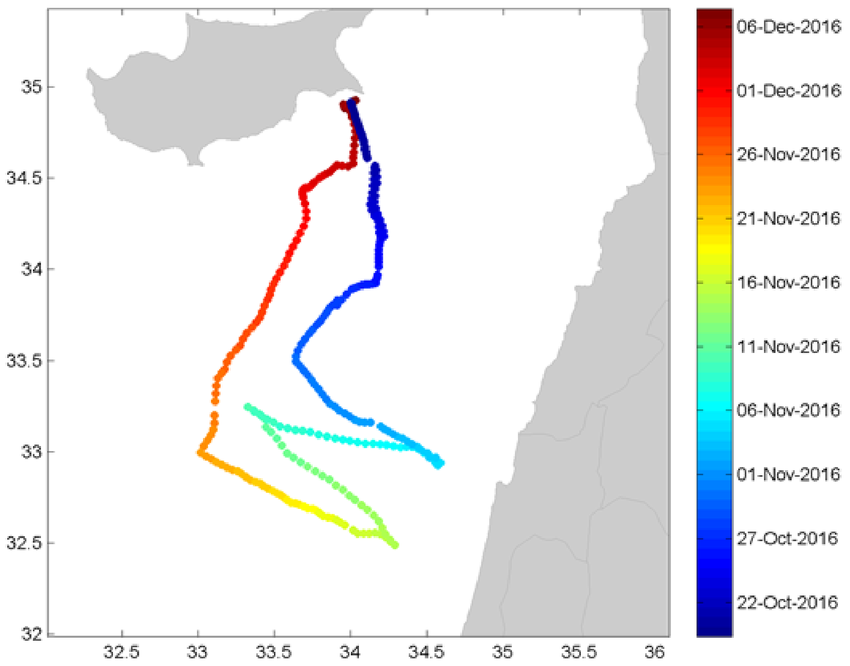
Glider: North Adriatic Experiment 2015 in the Kvarner area

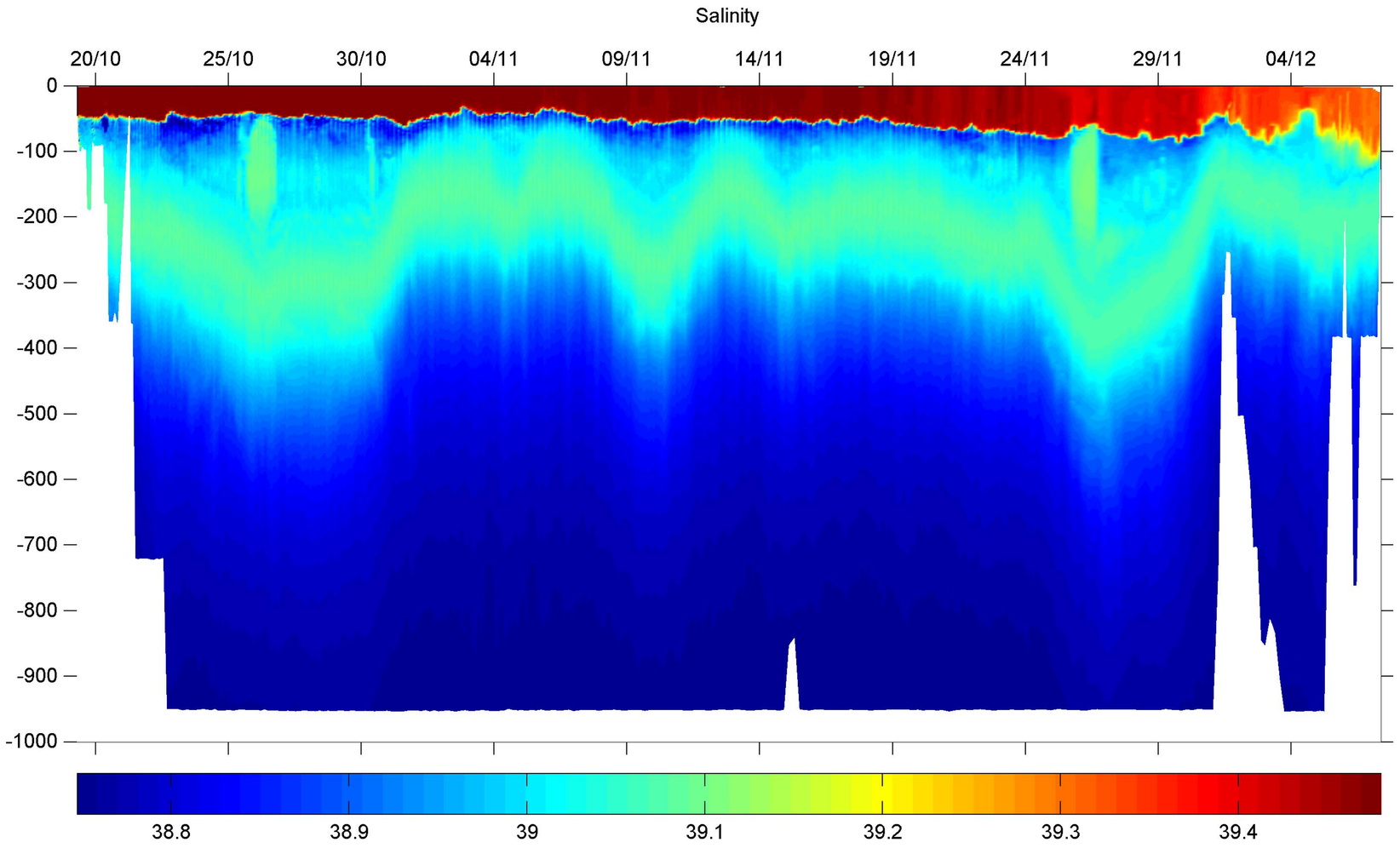
- deployed on 24 Feb 2015;
- recovered on 27 Mar 2015;
- max depth between 20 and 45 m;
- 90 surfacings, about 700 yos (double CTD profiles).



Kokkini Z., Gerin R., Poulain P.-M., Mauri E., Pasarić Z., Janecović I., Pasarić M., Mihanović H. and Vilibić H. (2017). A multiplatform investigation of Istrian Front dynamics (north Adriatic Sea) in winter 2015. Mediterranean Marine Science, 18/2, 344-354.

Glider: South of Cyprus Experiment 2016





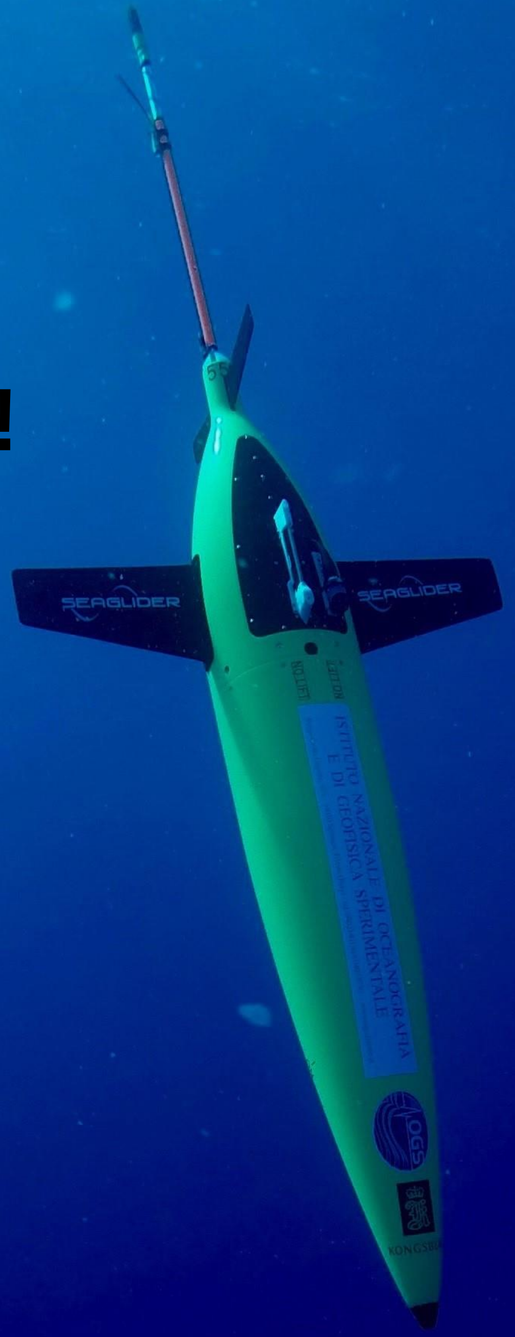
- about 1000 km;
- 48-day mission;
- 330 yos (double CTD profiles).

Find all OGS glider mission at:
http://nettuno.ogs.trieste.it/sire/glider/history.php

OGS

University of Cyprus

Thanks for your attention !



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101060395

Guidance and Control of Unmanned Marine Vehicles

Massimo Caccia

ISTITUTO DI INGEGNERIA DEL MARE
INSTITUTE OF MARINE ENGINEERING
massimo.caccia@cnr.it

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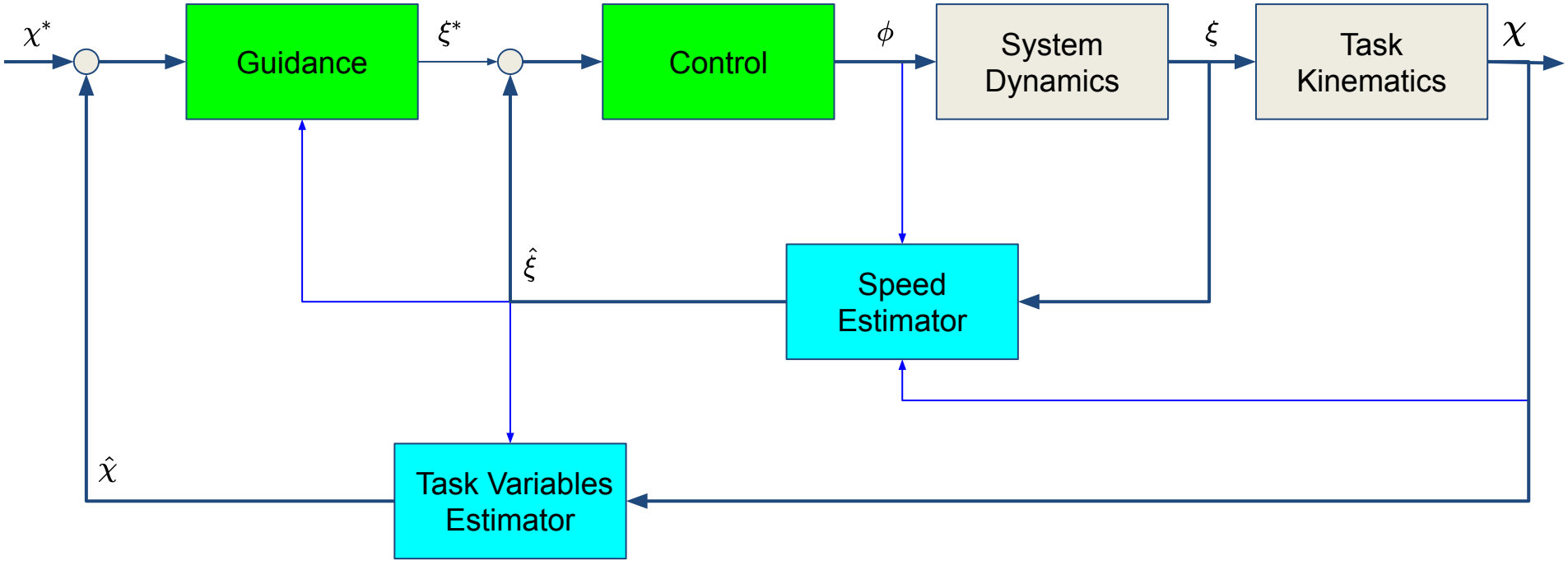
Dual loop Guidance and Control architecture



ISTITUTO DI INGEGNERIA DEL MARE
INSTITUTE OF MARINE ENGINEERING
massimo.caccia@cnr.it

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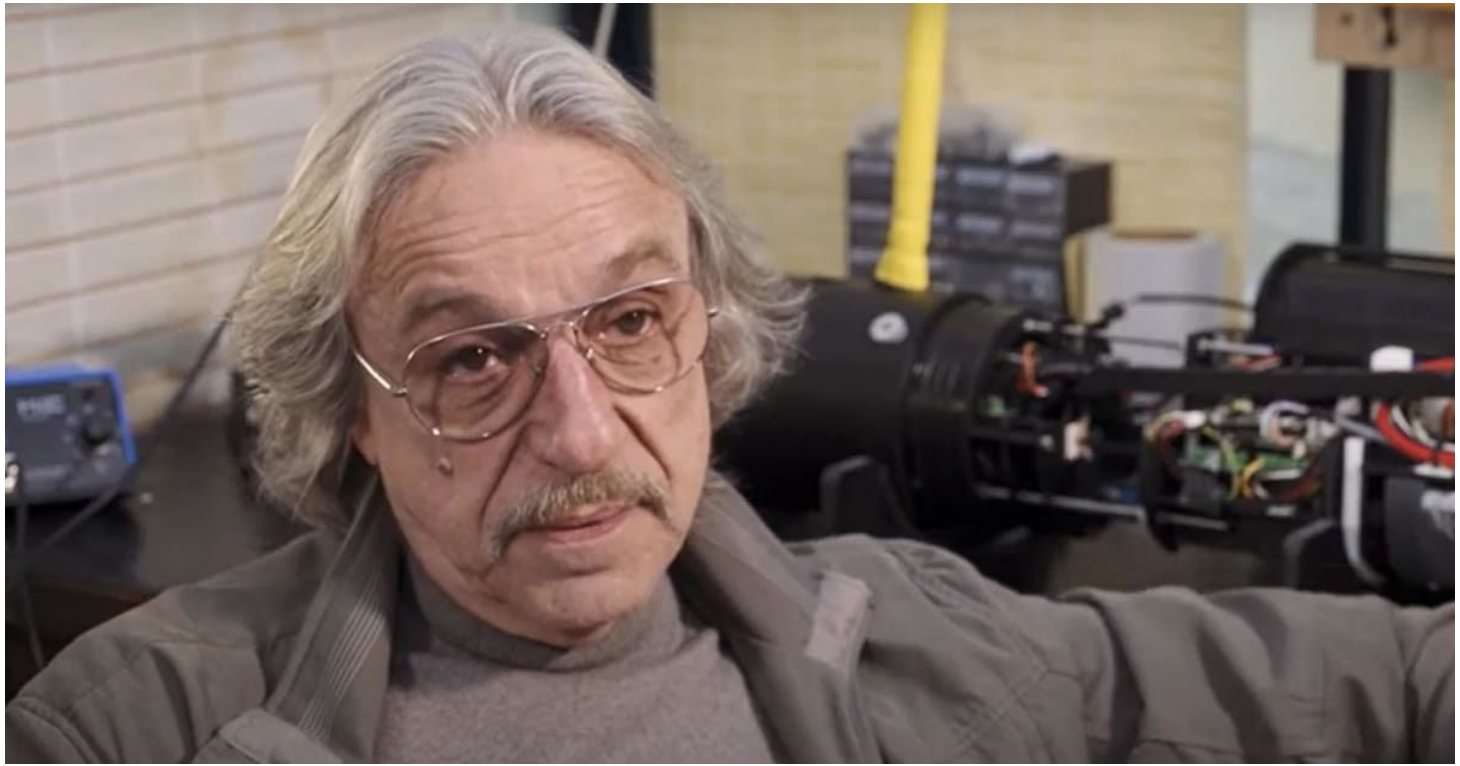
In memory of Prof. Giuseppe Casalino



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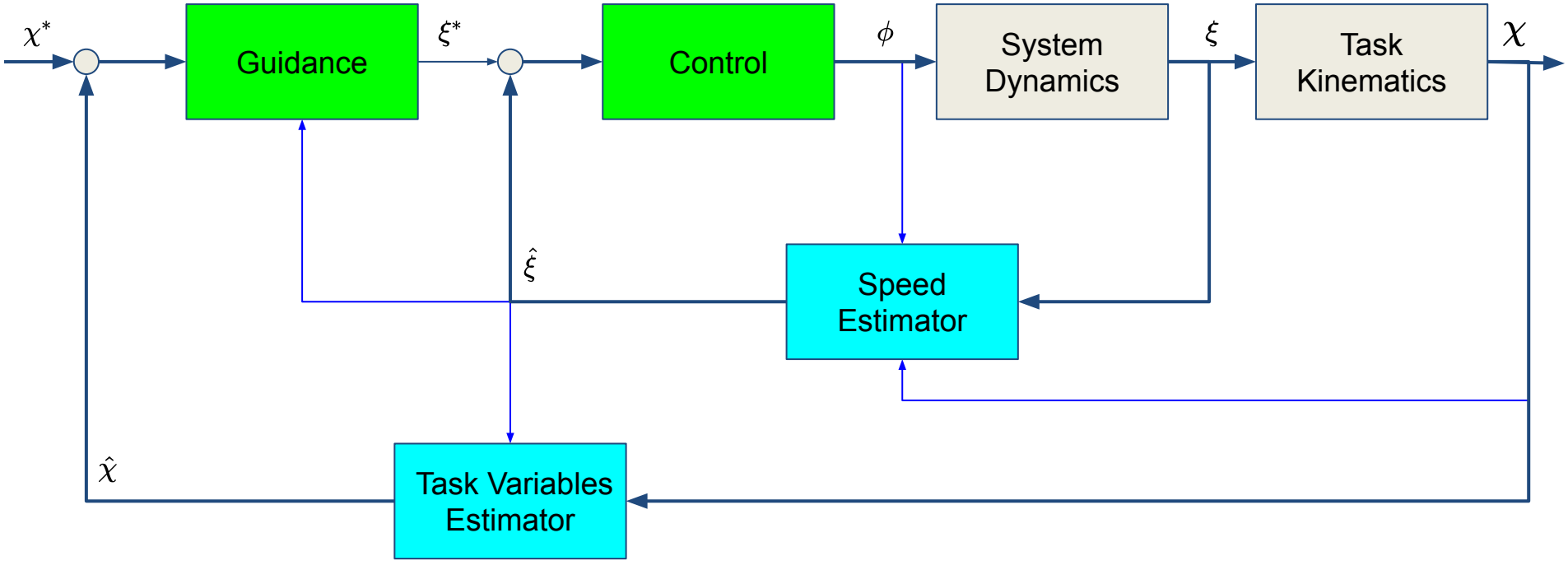
Dual loop Guidance and Control architecture



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INSTITUTE OF MARINE ENGINEERING
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System dynamics - Modeling

$$M_{RB}\dot{\nu} + C_{RB}(\nu)\nu = \tau_A + \tau_D + \tau_{WB} + \tau$$

$$(M_{RB} + M_A)\dot{\nu} + (C_{RB}(\nu) + C_A(\nu))\nu + (D_L + D_Q(\nu))\nu + g = \tau$$

$$\tau_{WB} = -g$$

$$M\dot{\nu} + C(\nu)\nu + (D_L + D_Q(\nu))\nu + g(\eta) = \tau$$

$$\dot{\eta} = J(\eta)\nu$$

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System dynamics - Modeling (simplified)

- Hp. 1 : the vehicle works at low speed and that the body-fixed reference frame coincides with the robot center of mass

$$r_G = [x_G \; y_G \; z_G]^T = [0 \; 0 \; 0]^T \qquad (C_{RB}(\nu) + C_A(\nu))\nu \; is \; negligible$$

- Hp. 2 : the vehicle is structurally stable in pitch and roll

$$\theta = 0 \; ; \; \phi = 0$$

$$\boxed{\begin{aligned} (M_{RB} + M_A)\dot{\nu} + (D_L + D_Q(\nu))\nu + g &= \tau \\ \tau_{WB} &= -g \end{aligned}}$$

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System dynamics (uncoupled model) & Kinematics

Dynamics

Surge $$(m + A_{11})\dot{u} = -k_u u - k_{|u|u}|u|u + X$$

Sway $$(m + A_{22})\dot{v} = -k_v v - k_{|v|v}|v|v + Y$$

Heave $$(m + A_{33})\dot{w} = -k_w w - k_{|w|w}|w|w + (B - W) + Z$$

Yaw $$(I_z + A_{66})\dot{r} = -k_r r - k_{|r|r}|r|r + N$$

Kinematics

Surge $$\dot{x} = u\cos\psi - v\sin\psi + \dot{x}_C$$

Sway $$\dot{y} = u\sin\psi + v\cos\psi + \dot{y}_C$$

Heave $$\dot{z} = w$$

Yaw $$\dot{\psi} = r$$

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System Dynamics - practical 1 d.o.f. uncoupled model

$$m\dot{\xi} = -k_\xi \xi - k_{\xi\|\xi\|}\xi\|\xi\| + \phi_\xi + \eta_\xi$$

$$m\dot{\xi} \approx -k_\xi \xi + \phi_\xi + \eta_\xi \ , \ at\ low\ speed$$

Linearised system dynamics

$$\dot{\xi}(\xi, \phi_\xi) \approx \dot{\xi}(\bar{\xi}, \bar{\phi}_\xi) + \frac{\partial \dot{\xi}}{\partial \xi}(\bar{\xi}, \bar{\phi}_\xi)(\xi - \bar{\xi}) + \frac{\partial \dot{\xi}}{\partial \phi_\xi}(\bar{\xi}, \bar{\phi}_\xi)(\phi_\xi - \bar{\phi}_\xi)$$

massimo.caccia@cnr.it

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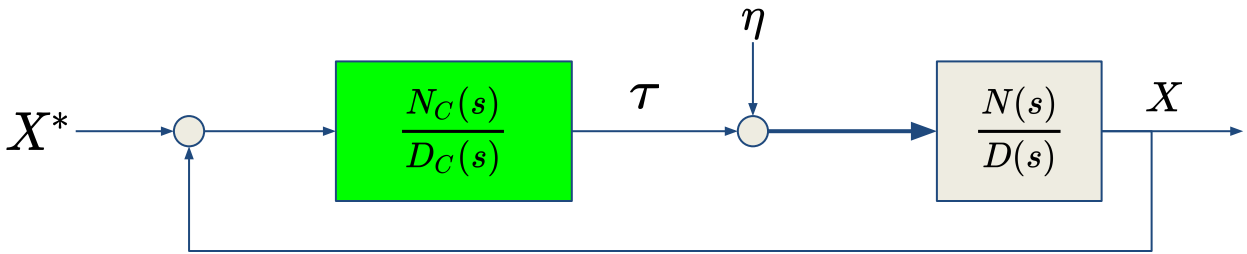
Disturbance compensation using Laplace transformation (1)



$$X(s) = \frac{N(s)}{D(s)}\eta(s) + \frac{N(s)}{D(s)}\frac{N_C(s)}{D_C(s)}(X^*(s) - X(s))$$

$$X(s) = \boxed{\frac{D_C(s)N(s)}{D(s)D_C(s)+N(s)N_C(s)}}\eta(s) + \frac{N_C(s)N(s)}{D(s)D_C(s)+N(s)N_C(s)}X^*(s)$$

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Disturbance compensation using Laplace transformation (2)

Final Value Theorem $\lim_{t\to\infty} x(t) = \lim_{s\to 0} sX(s)$

Step function input and noise $X(s) = \frac{X^*}{s}\ ,\ \eta(s) = \frac{\eta^*}{s}$

$$\lim_{s\to 0} sX(s) = \lim_{s\to 0} \frac{D_C(s)N(s)}{D(s)D_C(s)+N(s)N_C(s)} s\frac{\eta^*}{s} + \lim_{s\to 0} \frac{N_C(s)N(s)}{D(s)D_C(s)+N(s)N_C(s)} s\frac{X^*}{s}$$

$$D_C(s) = s\bar{D}_C(s)$$

$$\lim_{s\to 0} sX(s) = \lim_{s\to 0} \frac{s\bar{D}_C(s)N(s)}{D(s)s\bar{D}_C+N(s)N_C(s)} s\frac{\eta^*}{s} + \lim_{s\to 0} \frac{N_C(s)N(s)}{D(s)s\bar{D}_C+N(s)N_C(s)} s\frac{X^*}{s} = X^*$$

0

massimo.caccia@cnr.it

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System Dynamics - practical 1 d.o.f. uncoupled model

$$m_\xi \dot{\xi} = -k_\xi \xi - k_{\xi\|\xi\|} \xi \|\xi\| + \phi_\xi + \eta_\xi$$

$$m_\xi \dot{\xi} \approx -k_\xi \xi + \phi_\xi + \eta_\xi \ , \ at\ low\ speed$$

Linearised system dynamics

$$\dot{\xi}(\xi, \phi_\xi) \approx \dot{\xi}(\bar{\xi}, \bar{\phi}_\xi) + \frac{\partial \dot{\xi}}{\partial \xi}(\bar{\xi}, \bar{\phi}_\xi)(\xi - \bar{\xi}) + \frac{\partial \dot{\xi}}{\partial \phi_\xi}(\bar{\xi}, \bar{\phi}_\xi)(\phi_\xi - \bar{\phi}_\xi)$$

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Control system design - speed control

Given a constant operating point ξ^* the controller provides:

ϕ^* feed-forward constant control value yielding zero error

ϕ_δ feed-back control action, which assigns a desired characteristic equation to the closed-loop linearised system.

controller $\phi_\xi = \phi^* + \phi_\delta$

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Control system design - speed control

For every value of the reference speed ξ^* in the operating range,

a feed-forward control value $\phi^* = (k_\xi + k_{\xi\|\xi\|}\|\xi^*\|)\xi^*$ is applied,

and the nonlinear state equation is linearised about the desired operating point (ξ^*, ϕ^*),

obtaining the family of parameterized linear models

$$\dot{\xi}_\delta = -a(\xi^*)\,\xi_\delta + b\xi_\delta$$

$$a(\xi^*) = \frac{k_\xi + 2k_{\xi\|\xi\|}|\xi^*|}{m_\xi}\ ,\ b = \frac{1}{m_\xi}$$

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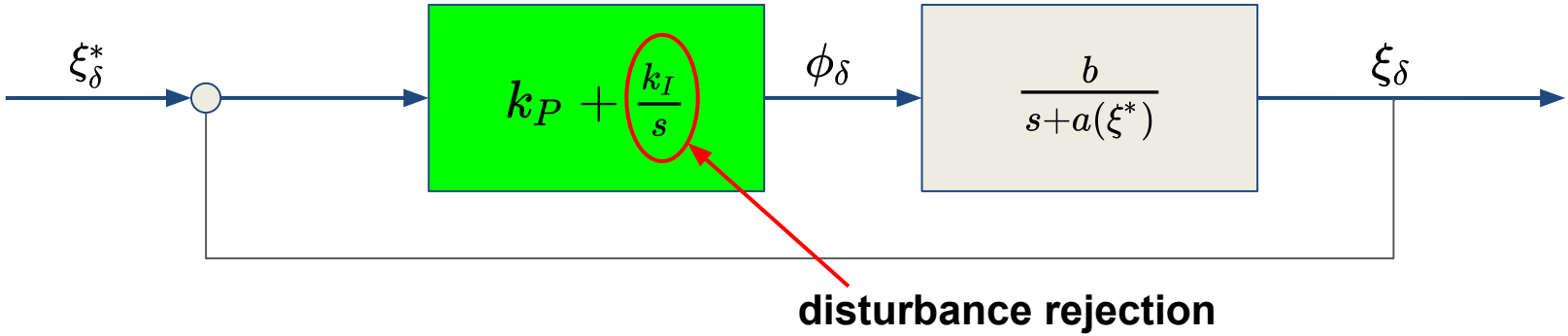
Control system design - speed control



closed-loop transfer function

$$\frac{bk_P s + bk_I}{s^2 + [a(\xi^*) + bk_P]s + bk_I}$$

closed-loop characteristic equation

$$s^2 + 2\sigma s + \sigma^2 + \omega_n^2 = 0$$

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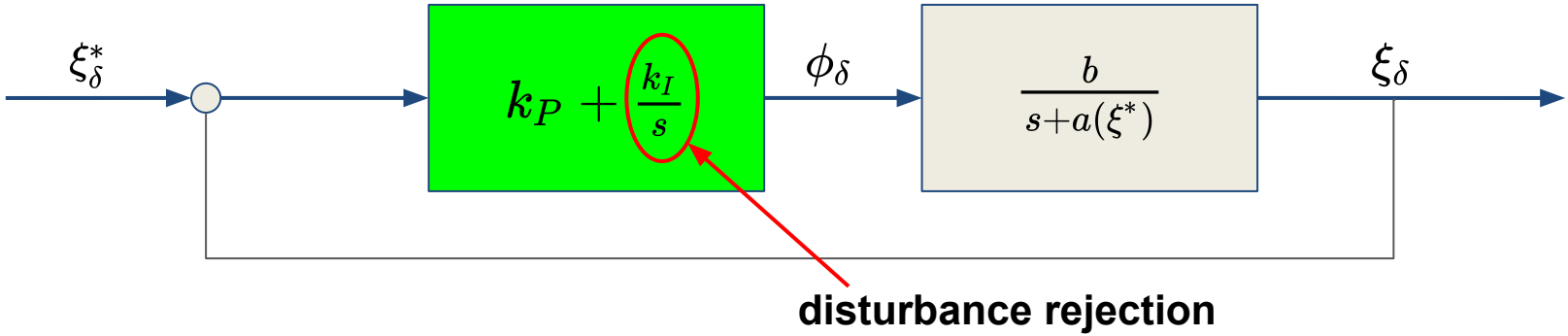
Control system design - speed control



$$\frac{bk_P s + bk_I}{s^2 + [a(\xi^*) + bk_P]s + bk_I}$$

$$s^2 + 2\sigma s + \sigma^2 + \omega_n^2 = 0$$

Gain-Scheduling controller

$$k_P = m_\xi \left[2\sigma - a(\xi^*)\right] = 2m_\xi - k_\xi - 2k_{\xi\|\xi\|}\left|\xi^*\right|$$

$$k_I = m_\xi \left(\sigma^2 + \omega_n^2\right)$$

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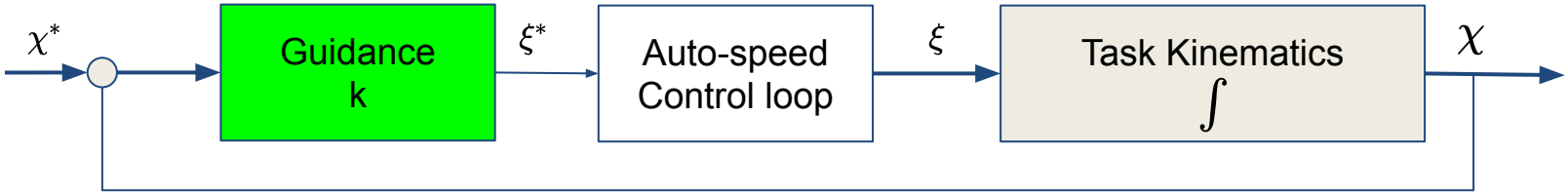
Guidance system design - position control



guidance transfer function $\frac{k}{s+k}$

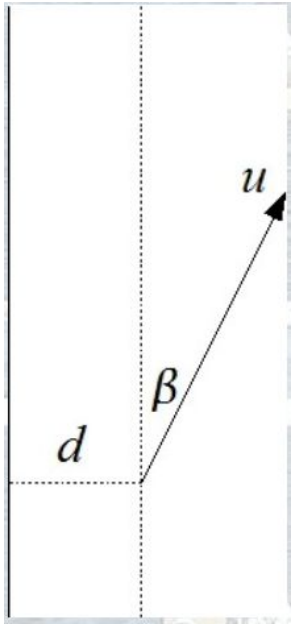
ideal guidance time constant $\tau = \frac{1}{k}$

- in practice, the auto-speed control loop has a finite dynamics
- the proportional gain of the position guidance task function is chosen such that its time constant is from 2 to 10 times slower than the inner loop dynamics

ISTITUTO DI INGEGNERIA DEL MARE
INSTITUTE OF MARINE ENGINEERING
massimo.caccia@cnr.it

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101060395

Guidance system design - straight line-following



$$\dot{d} = u \sin\beta + \eta \approx u\beta + \eta \,, \; u > 0$$
$$\dot{\beta} = r$$
$$\ddot{d} \approx \dot{u}\beta + u\dot{\beta} + \dot{\eta} = ur$$

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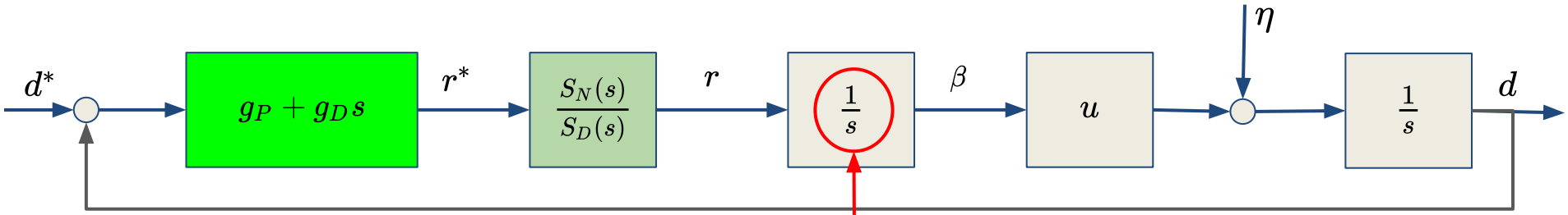

Closed-loop control $S_N(s) = p_1 s + p_0$

$$S_D(s) = q_2 s^2 + q_1 s + q_0$$

The integrator embedded in the system kinematics naturally compensate external disturbance

$$D = \frac{uS_N(s)(g_P+g_D s)}{s^2 S_D(s)+uS_N(s)(g_P+g_D s)} D^* + \frac{s S_D(s)}{s^2 S_D(s)+uS_N(s)(g_P+g_D s)} \eta$$

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System Dynamics - practical 1 d.o.f. uncoupled model

$$m\dot{\xi} = -k_{\xi}\xi - k_{\xi||\xi||}\xi||\xi|| + \phi_{\xi}$$

System Dynamics Identification

Onboard sensor measurements - Steady-state manoeuvres

$$-k_{\xi}\xi(i) - k_{\xi||\xi||}\xi(i)||\xi(i)||| + \phi_{\xi}(i)\ ,\ i = 1 \ldots N$$

Least Squares estimation of drag coefficients

Added Inertia is between 10% and 30% of the vehicle inertia

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System Dynamics Identification

Onboard sensor measurements - Steady-state manoeuvres

$$\begin{bmatrix} \xi(1) & \xi(1)\|\xi(1)\|| \\ \vdots & \vdots \\ \xi(i) & \xi(i)\|\xi(i)\|| \\ \vdots & \vdots \\ \xi(N) & \xi(N)\|\xi(N)\|| \end{bmatrix} \begin{bmatrix} k_{\xi\|\xi\|} \\ k_{\xi\|\xi\|} \end{bmatrix} = \begin{bmatrix} \phi_\xi(1) \\ \vdots \\ \phi_\xi(i) \\ \vdots \\ \phi_\xi(i) \end{bmatrix}$$

Least Squares estimation of drag coefficients

$$\hat{\mathbf{x}} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{b}$$

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System Dynamics Identification

Onboard sensor measurements - Steady-state manoeuvres

- Added Inertia is between 10% and 30% of the vehicle inertia
- Zig-zag manoeuvres

massimo.caccia@cnr.it

HEKTOR

Heterogeneous autonomous robotic system in viticulture and mariculture

Zdenko Kovačić, Nadir Kapetanović, Nikola Mišković

BTS 2022, September 29, 2022, Biograd na moru

EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

Outline

- Basic information about HEKTOR
- HEKTOR robots and subsystems
- Viticulture scenarios
- Mariculture scenarios
- Results
- Publications

Basic information about HEKTOR

Duration: 36 months (13.03.2020. – 31.03.2023.)

Project budget: 5.794.060,14 HRK

Funding source: ESIF (EFRR)

Full time young researchers: 4 (FER), 1 (UNIDU)

Coordinator: University of Zagreb Faculty of Electrical Engineering and Computing

Partners: University of Zagreb Faculty of Agronomy

University of Dubrovnik Institute for Marine and Coastal Research

Support: Cromaris Zadar

Vinarija Zure, Lumbarda

HEKTOR

Project team

prof. dr. sc. Zdenko Kovačić
voditelj projekta, član Upravnog odbora

prof. dr. sc. Stjepan Bogdan
istraživač

izv. prof. dr. sc. Matko Orsag
istraživač

Ivo Vatavuk
mladi istraživač

Ivan Hrabar
mladi istraživač

Asst. Prof. Tamara Petrović, Ph.D.

Ana Golec

prof. dr. sc. Bernard Kozina
istraživač, član Upravnog odbora

Marina Anić
istraživač

Jurica Goričanec
mladi istraživač

prof. dr. sc. Nikola Mišković
istraživač

prof. dr. sc. Gordan Gledec
istraživač, član Upravnog odbora

Nadir Kapetanović
mladi istraživač

doc. dr. sc. Nenad Antolović
istraživač

dr. sc. Jakša Bolotin
istraživač

dr. sc. Nikša Glavić
istraživač, član Upravnog odbora

dr. sc. Valter Kožul
istraživač

Antonia Kurtela
mladi istraživač

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HEKTOR

Main goals

- Autonomous coordination/cooperation of smart heterogeneous robots/vehicles (sea, land and air)
- Autonomous execution of various work, inspection and intervention missions in viticulture and mariculture with minimum human intervention
- Demonstration of innovative solutions that will replace human work in difficult conditions (large slopes, large areas of plantations, long-term diving at greater depths, unfavorable weather conditions, etc.)

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Phase 1: Industrial research (24 months)

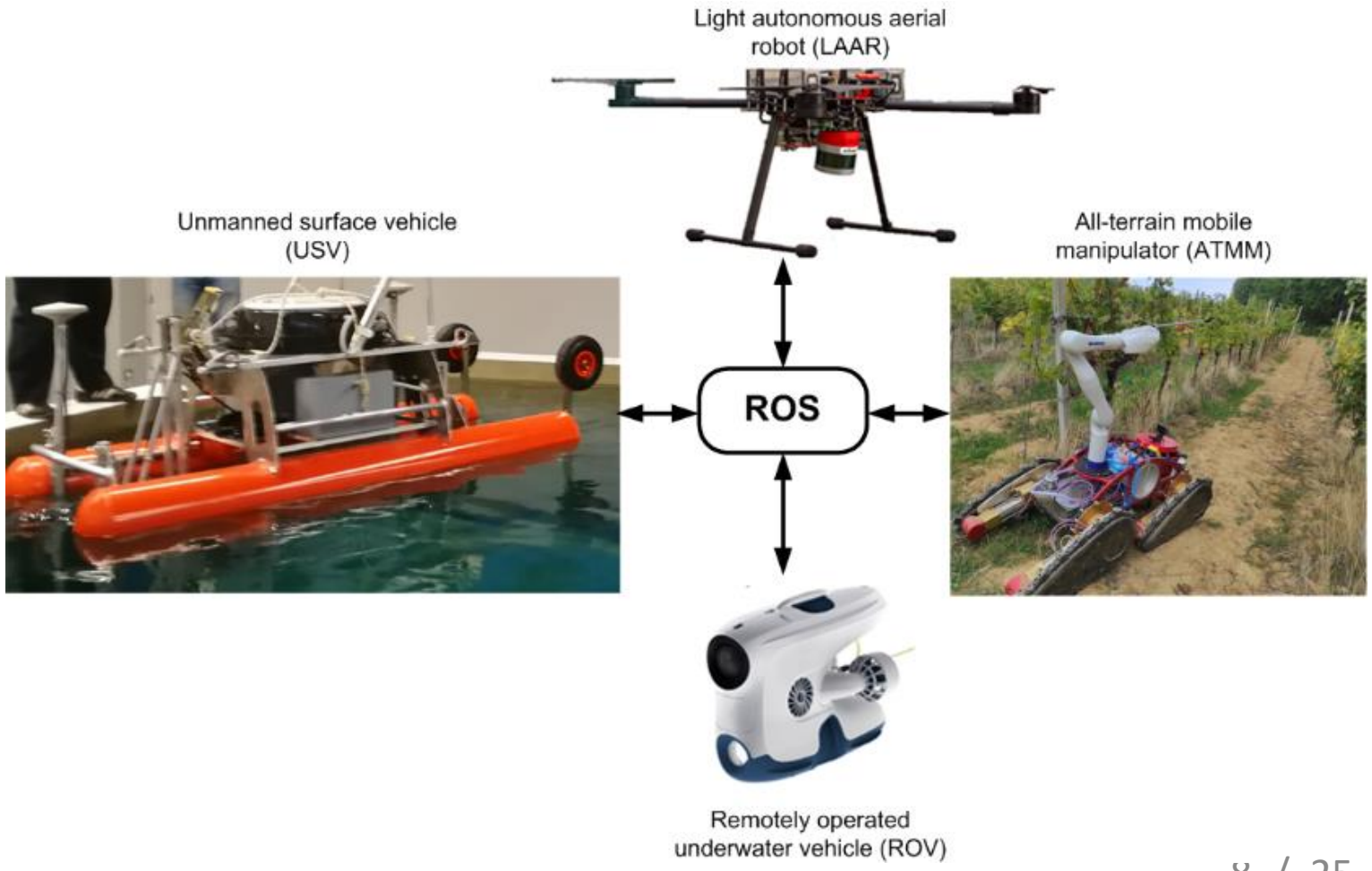
- A detailed analysis of existing procedures in the cultivation and care of vineyards and the procedures used in cage fish farming
- Upgrade/adjustment of the existing and newly acquired robotic platforms
- Examination of prototypes of robotic platforms in a laboratory environment
- Laboratory testing of the entire system

Phase 2: Experimental research (12 months)

- Demonstration activities in an environment that reflects operational conditions from real life
- Vineyards Jazbina in Zagreb and Zure in Lumbarda, island Korčula
- Cages for fish farming in Preko, island Ugljan from Cromaris Zadar
- After each conducted experiment
  - Analysis and new modifications for possible improvement
  - New experiments

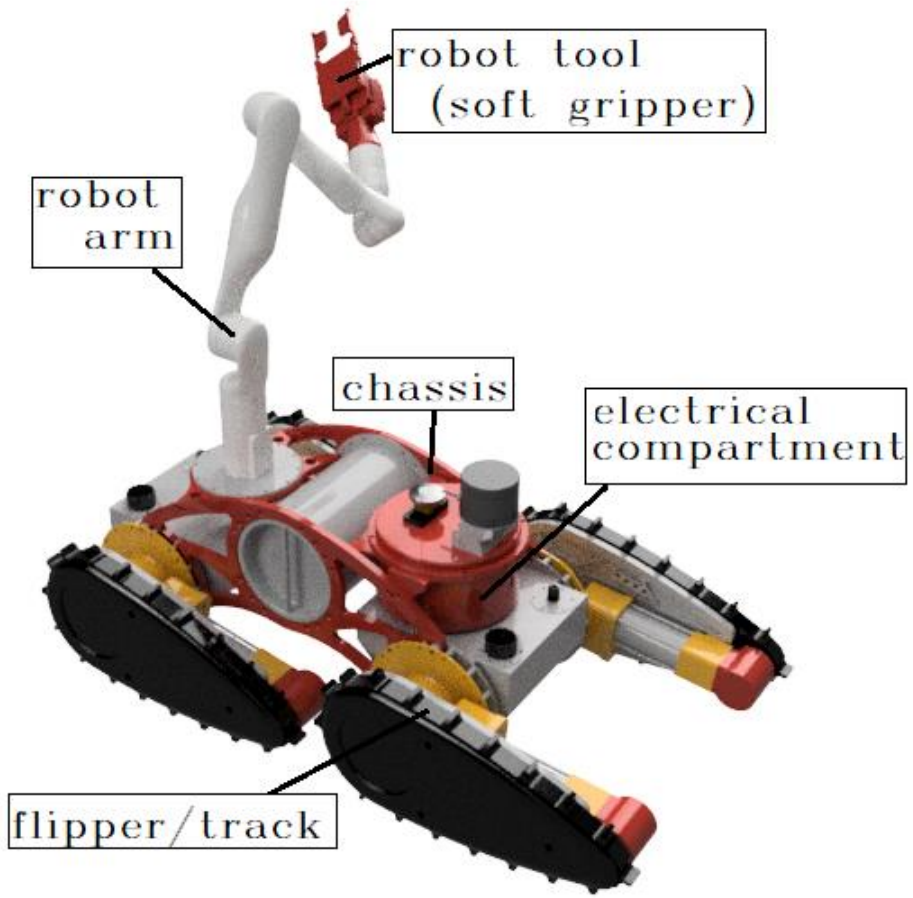
HEKTOR robots and subsystems

- ROS middleware
- ATMM – All-terrain mobile manipulator
- LAAR – Light autonomous aerial robot (UAV)
- USV – Unmanned surface vehicle (catamaran)
- ROV – Remotely operated underwater vehicle



All-terrain mobile manipulator

- Autonomous movement in vineyard
- Operations on the vine – spraying and bud rubbing
- 2 parts – mobile platform and Kinova Gen3 robotic manipulator
- LiDAR, stereo cameras and GPS
- Kinova Gen3 – 7-DoF, torque controlled

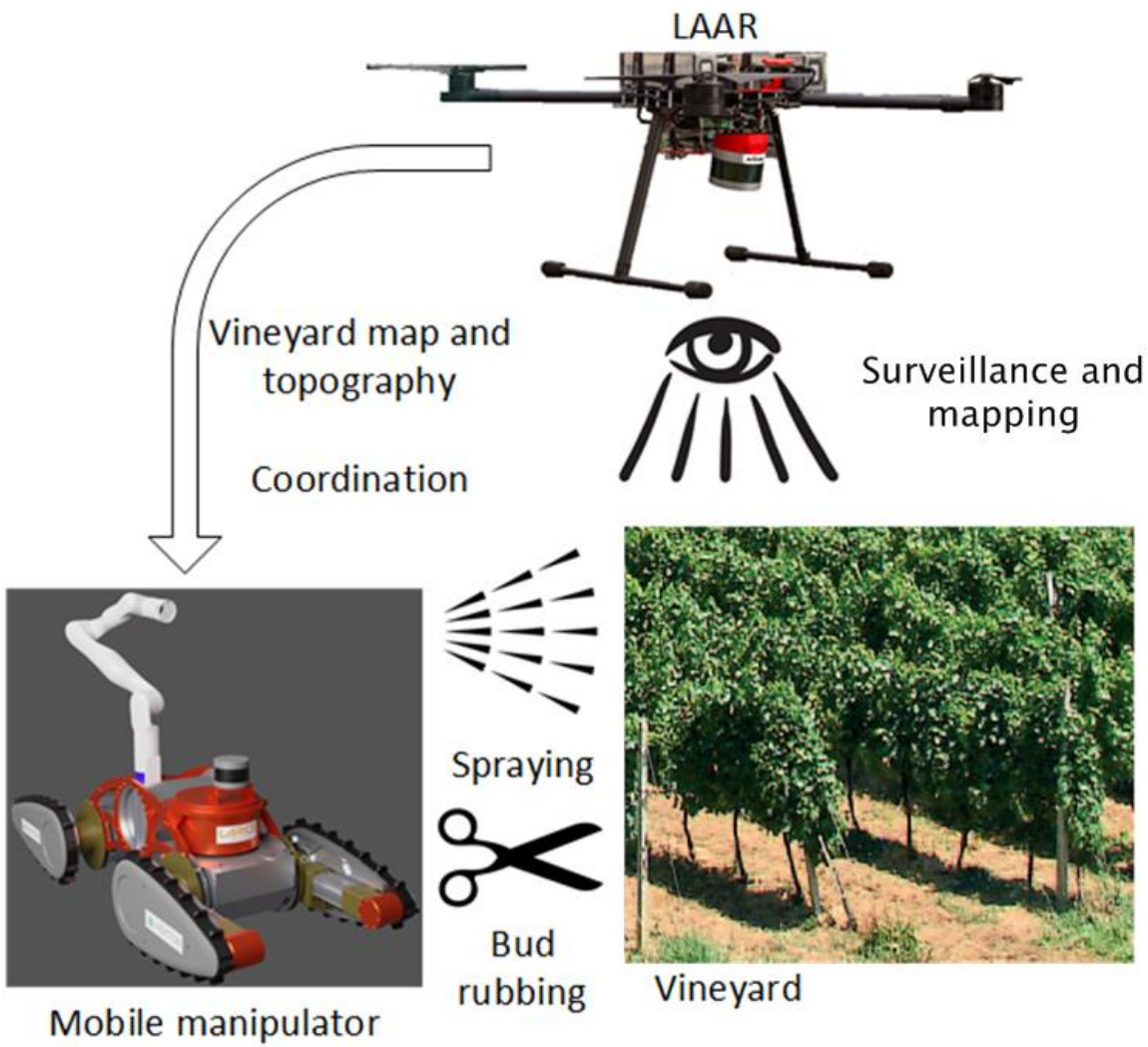


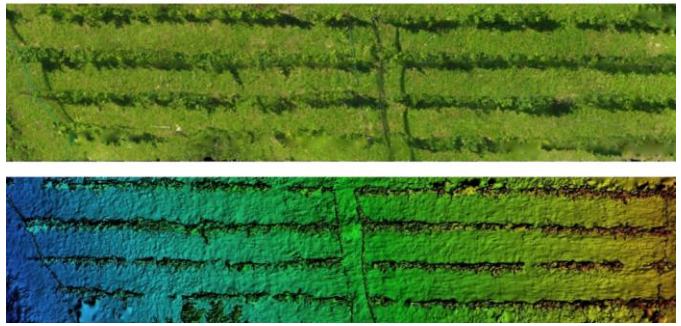
• Lightweight Autonomous Aerial Robot – LAAR

- Medium-scale carbon-fiber quadcopter
- Dim. – *1.2m x 1.2m x 0.45m, 8-10 kg*
- Pixhawk autopilot, Intel NUC on-board computer
- 30 min flight time
- *Velodyne* VLP-16 LiDAR sensor
- *Sony RX100* RGB camera
- Multispectral *MicaSense RedEdge-MX* sensor
- Thermal camera

Viticulture scenarios

- Vineyard monitoring
  - State of vines, existence of diseases and yield of grapes
  - Different map variants based on data from LAAR
  - Coordination between UAV and ground robot
  - Creation of point cloud and digital elevation model of vineyard
  - LiDAR or photogrammetry process

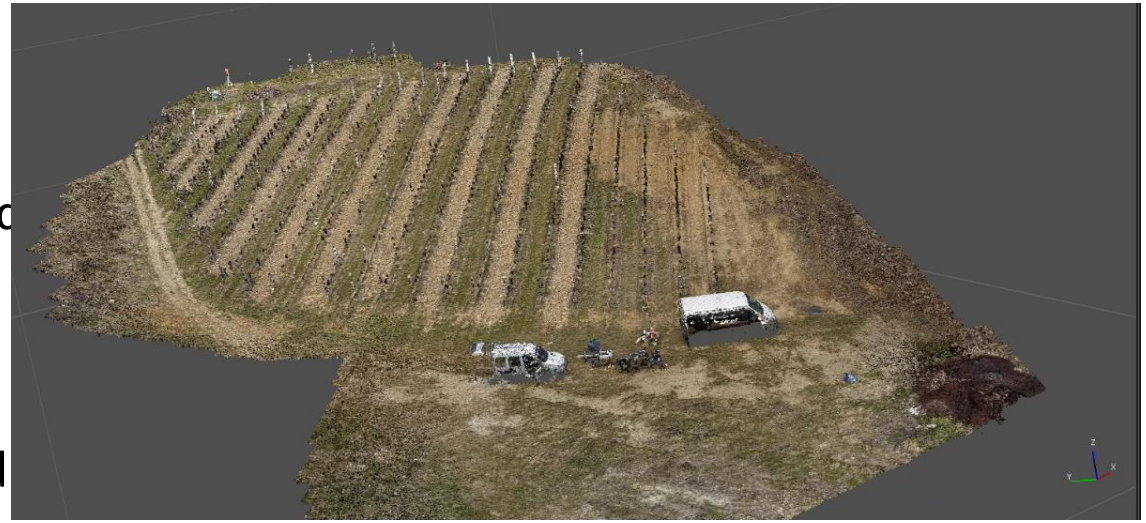




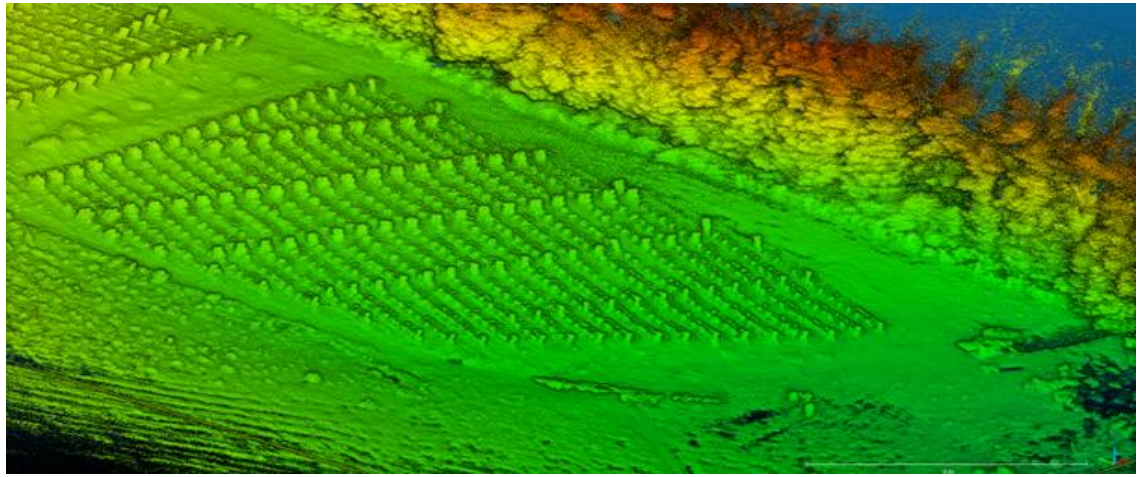
Viticulture scenarios

- Vineyard monitoring
  - State of vines, existence of diseases and yield of grapes
  - Different map variants based on data from LAAR
  - Coordination between UAV and ground robot
  - Creation of point cloud and digital elevation model of vineyard
  - LiDAR or photogrammetry process

The map of a vineyard created by photogrammetry

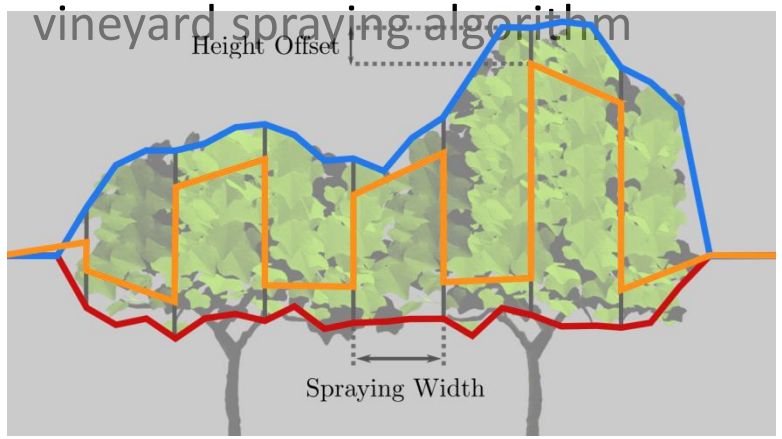


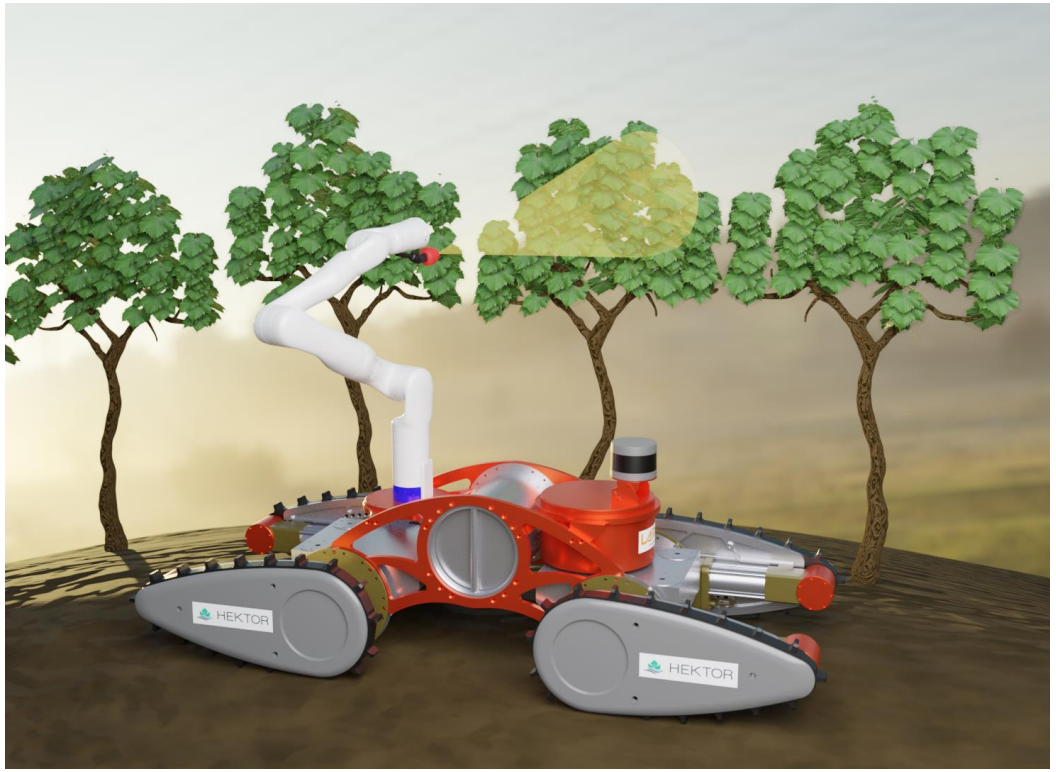
The map of a vineyard created from the LiDAR point cloud



Viticulture scenarios

- Vineyard spraying
  - Optimization of amount of used chemicals
  - Autonomous movement of a mobile manipulator through the rows of vineyard
  - Model predictive control (MPC) based vineyard spraying algorithm

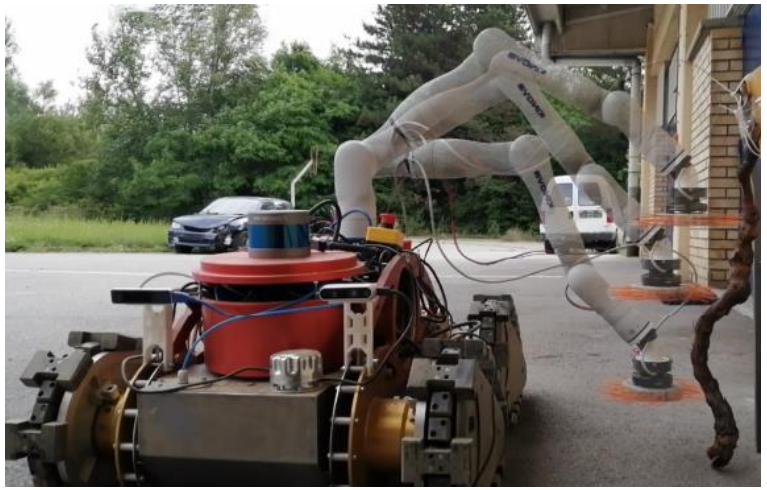




Viticulture scenarios

- Suckering
  - Removal of undesirable buds and shoots from grape trunks
  - Autonomous navigation and positioning of mobile manipulator
  - Detection and removal of buds and shoots without damaging the trunk
  - Generation of accurate 3D model

Torque controlled suckering tool



Compliant brush tool

Viticulture scenarios

- Suckering

(a) Before suckering on a vine $ID = 2$ - right side perspective.

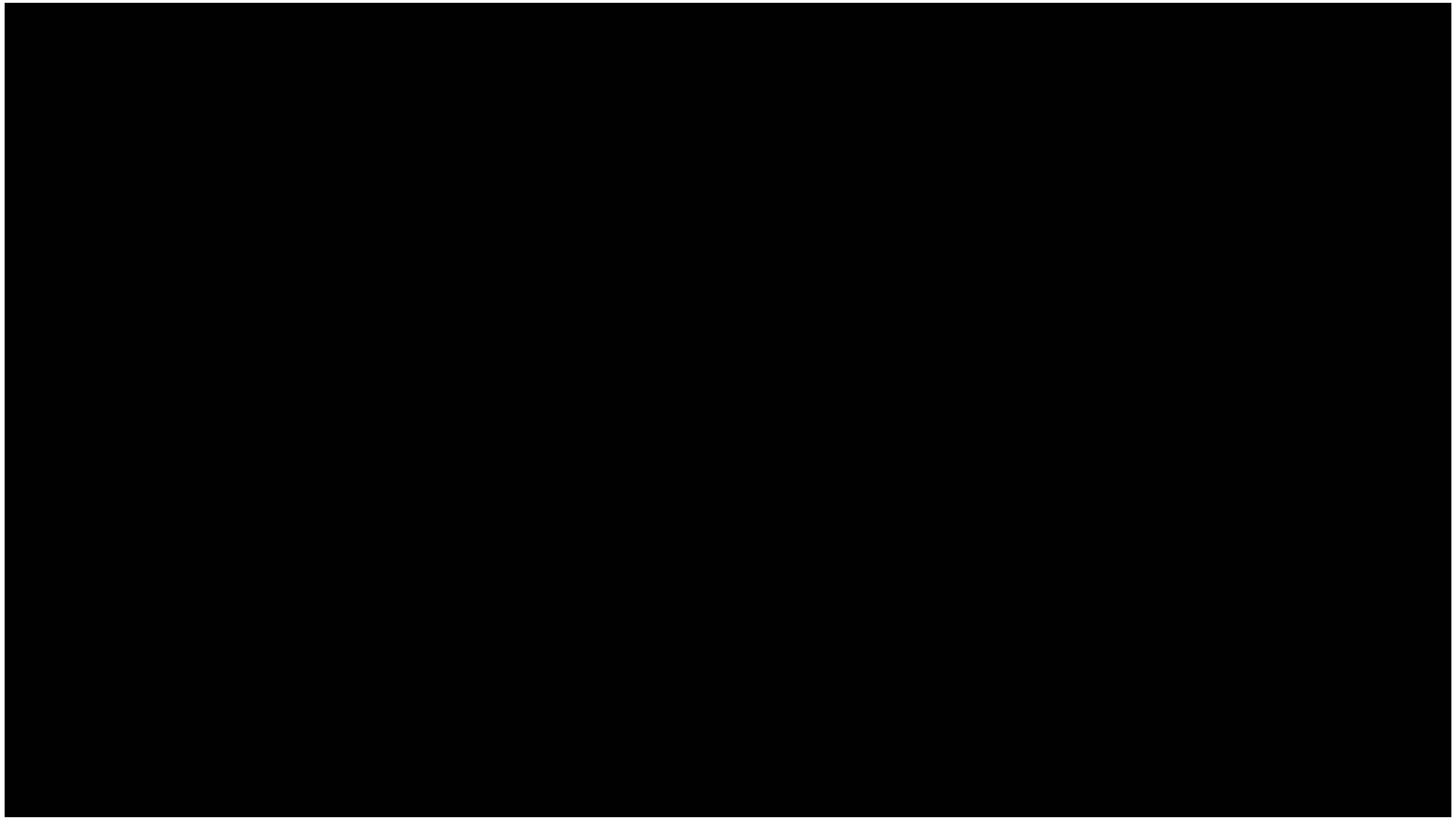
(b) Before suckering on a vine $ID = 2$ - left side perspective.

(c) After suckering on a vine $ID = 2$ - right side perspective.

(d) After suckering on a vine $ID = 2$ - left side perspective.

Experiments

- Controlled vineyard spraying



Experiments

- Suckering

Mariculture scenarios

HEKTOR

Overview

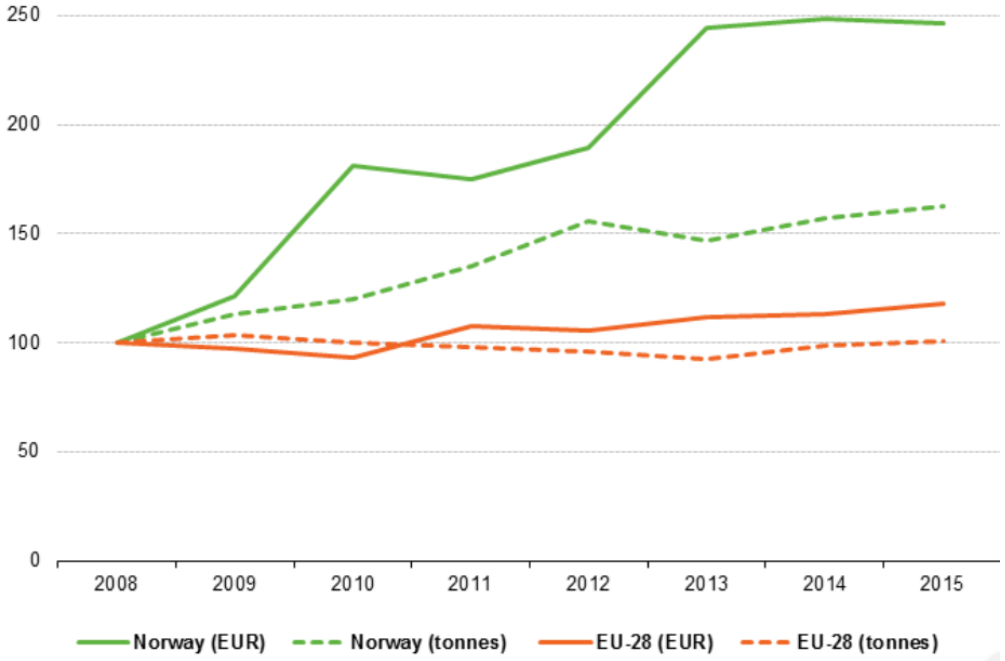
1. **About HEKTOR project mariculture use case**
2. Remotely Operated Vehicle (ROV) Blueye Pro
3. Autonomous Surface Vehicle (ASV) Korkyra
4. Landing platform
5. ROV acoustic localization: UWGPS G2 integration
6. Tether management system
7. Biofouling estimation
8. Seatrials
9. Conclusion

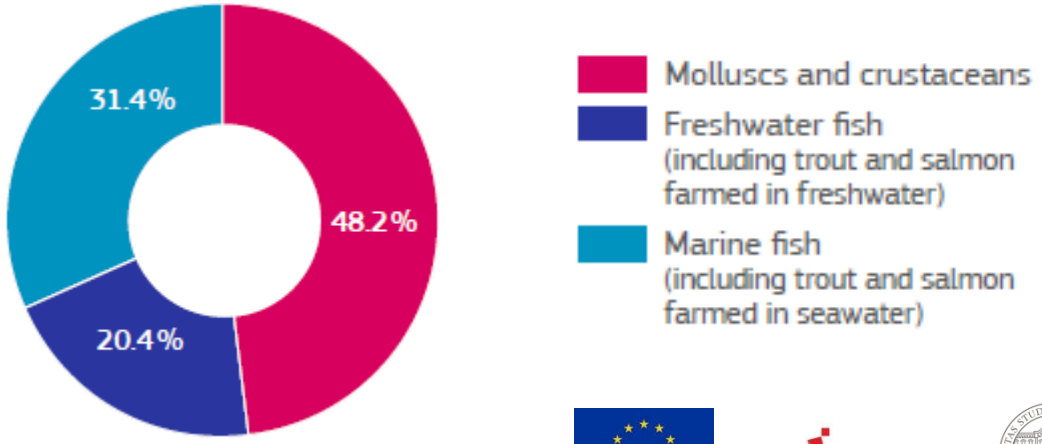
EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI
SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

HEKTOR

Motivation

- globally, **mariculture** is the fastest growing part of food industry
- 20% of fish stock in EU comes from aquaculture
- 80.000 employment around EU
- 21% of Croatia's fish stock is from aquaculture
- sector with a significant growth





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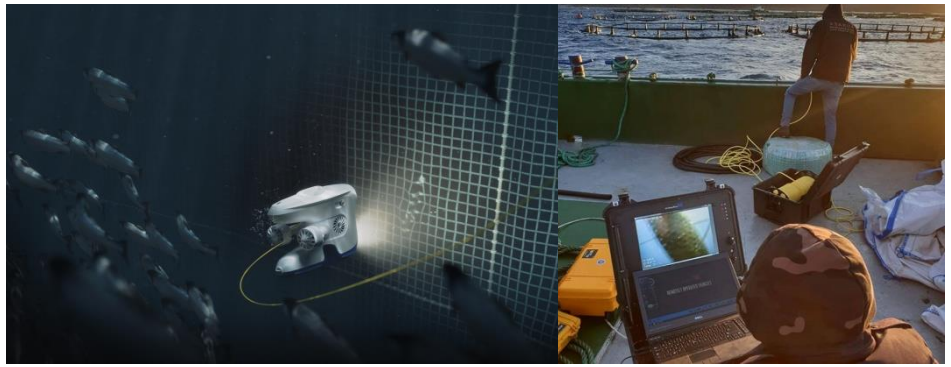
HEKTOR

Main objectives

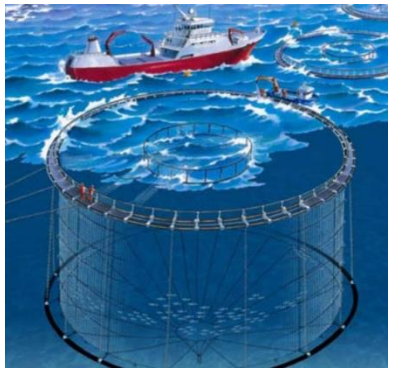
- analysis of procedures in viticulture and cage fish farming
- determine processes that robots can improve
- find invovative solutions which substitute human labor in harsh environments

fish stock inspection

net biofouling inspection



human-operated ROV inspections



long dives at bigger depths

unfavorable weather conditions

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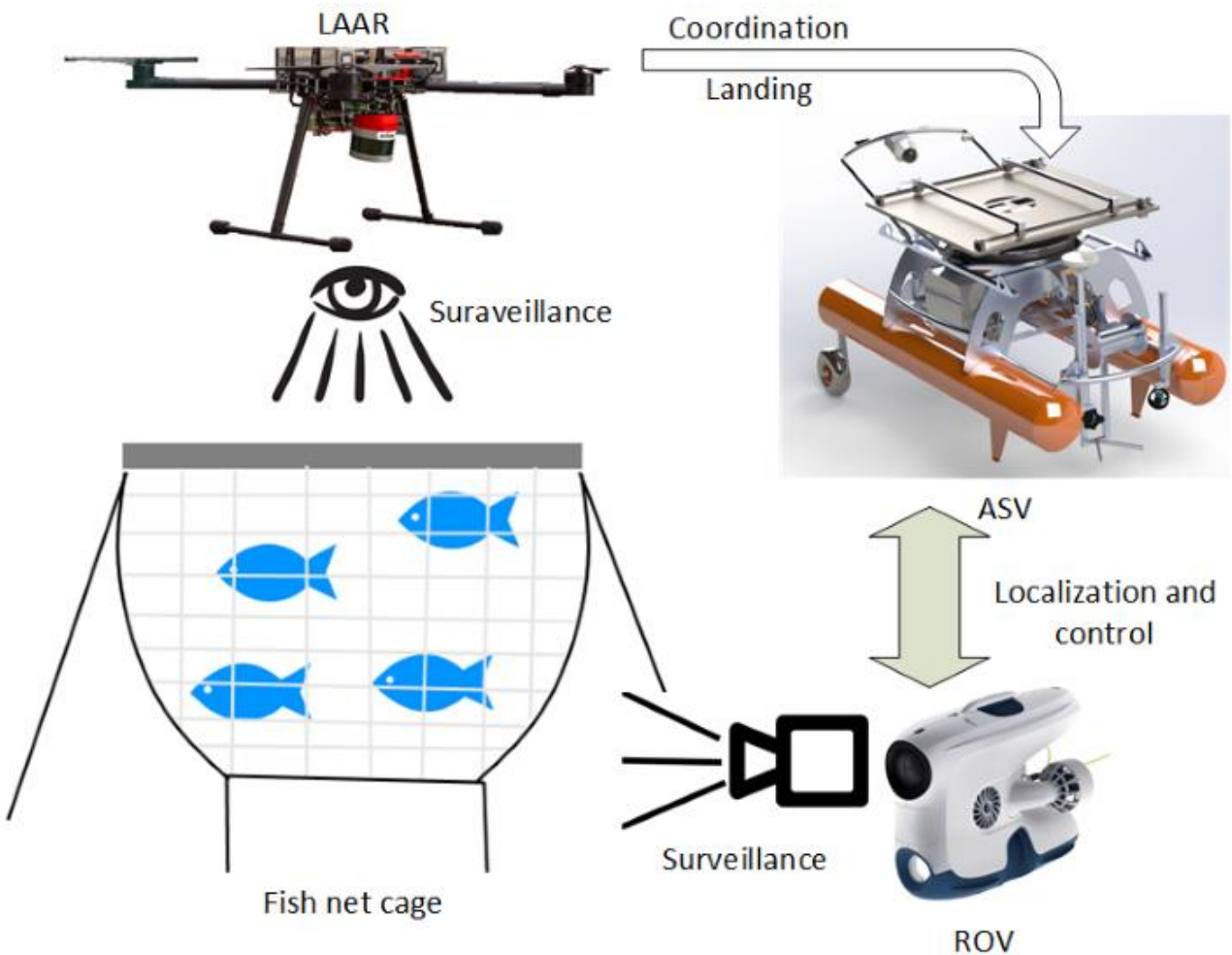
LABUST

HEKTOR



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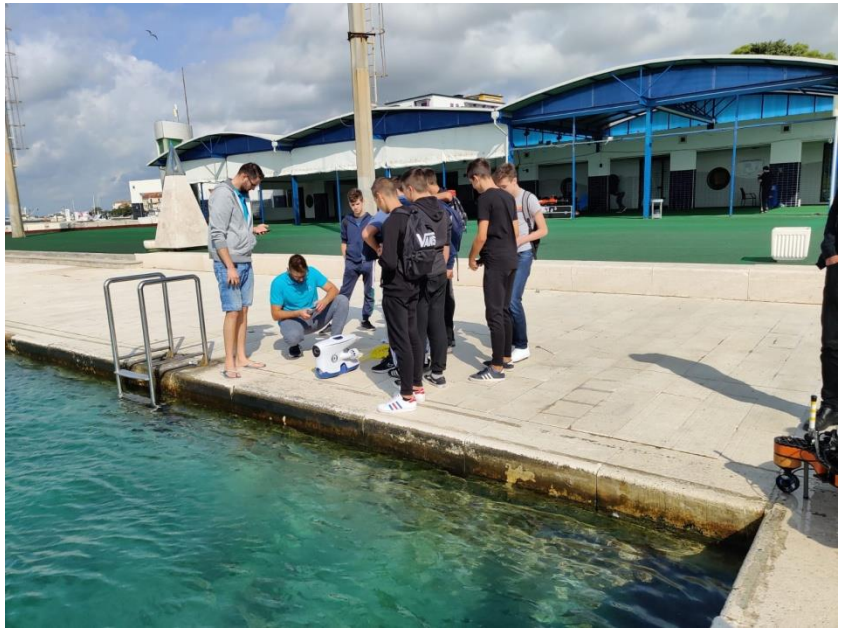
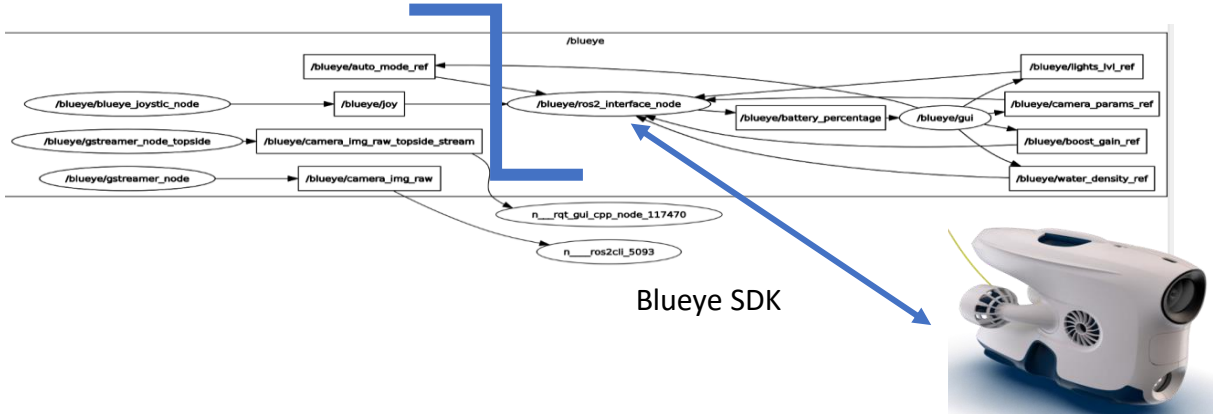
Blueye Pro ROV – ASV/ROS2 integration



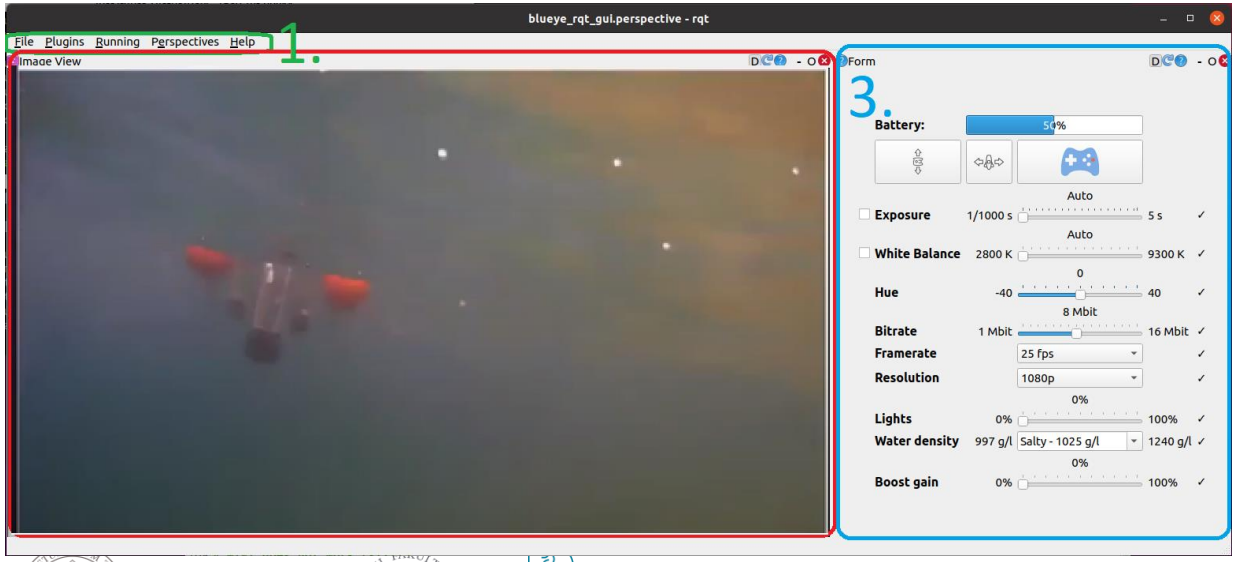
10/2020 state

Topside/operator PC

Bottomside/catamaran



Blueye SDK



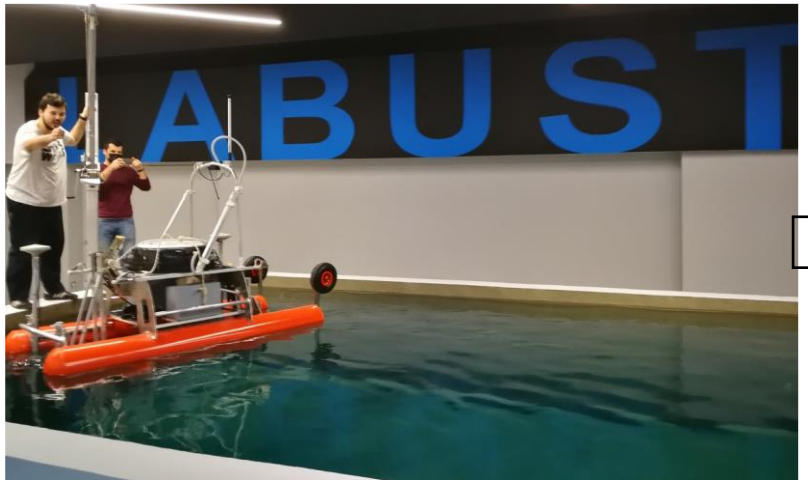
LABUST

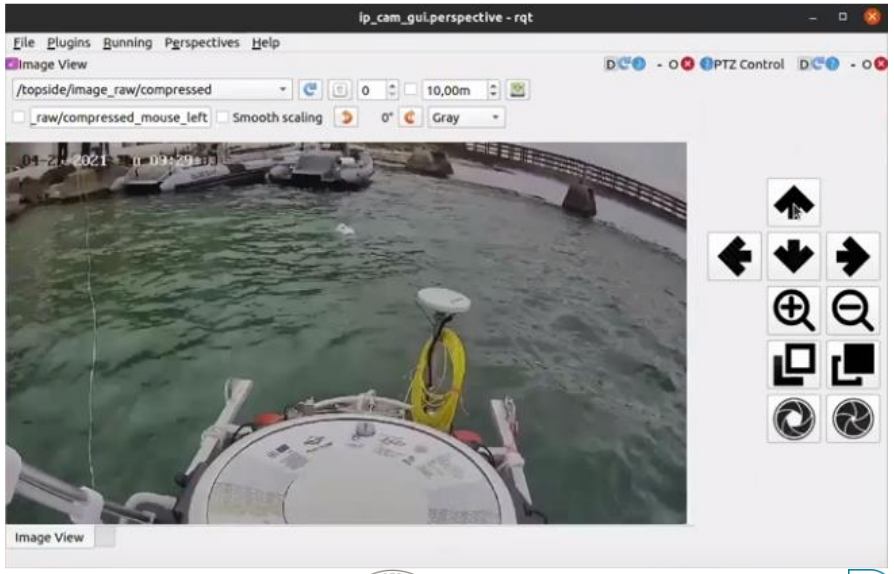
HEKTOR

ASV Korkyra

- 200 x 100 cm alluminium
- 50/100kg w/wo payload
- Minn Kota el. Boost motor
- 4 x T200 thrusters
- Continuity of ASV aPad design
- Top and bottom deck
- max. speed: 3-4 kn
- Autonomy: min. 4-20h
- payload: sonar,

ROV TMS, UAV platform, surveillence camera, ROV acoustic localization





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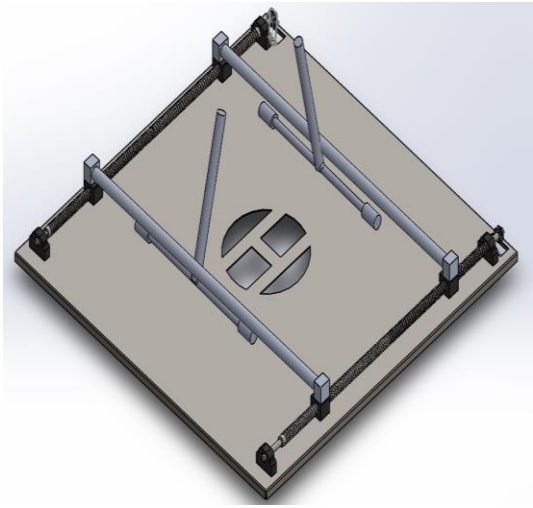
ASV Korkyra BtS2021 video

bts2021.mp4

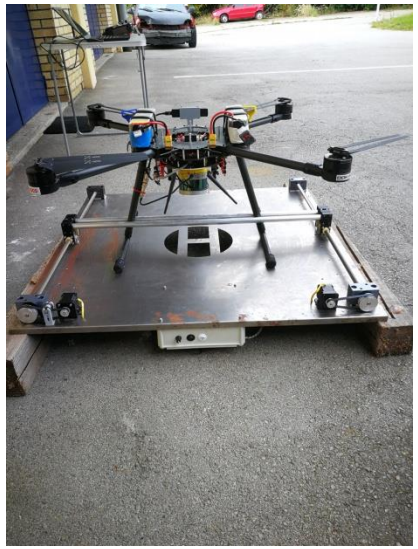
Landing platform v1



10/2020 state

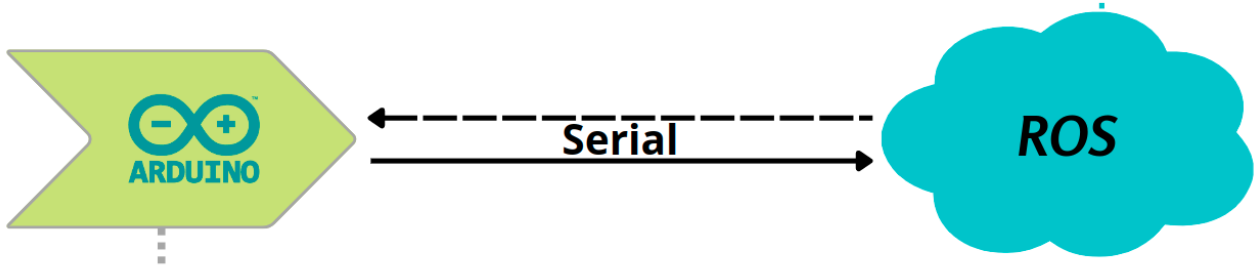
v.1 @ 10/2021

- 100x100cm ferous tin with Al mount
- controlled by Arduino Uno, integrated into ROS1
- lab. Dummy robustness tests, dry/BtS UAV tests,
- belt transmission **T_close=4.5s**



Landing platform v1

< MsgNum, CmdCode>



< MsgNum, CmdCode, Status>

CmdCode

- 0 - STOP,
- 1 – OPEN command,
- 2 - CLOSE command

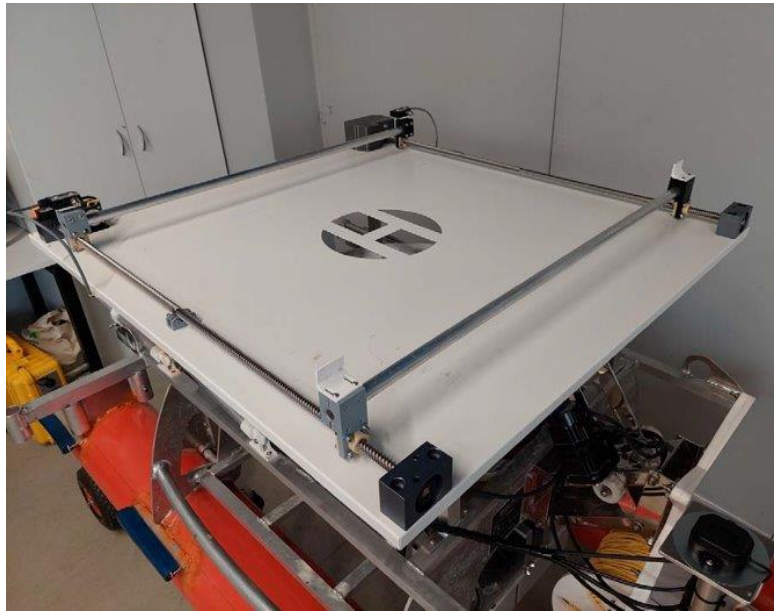
Status

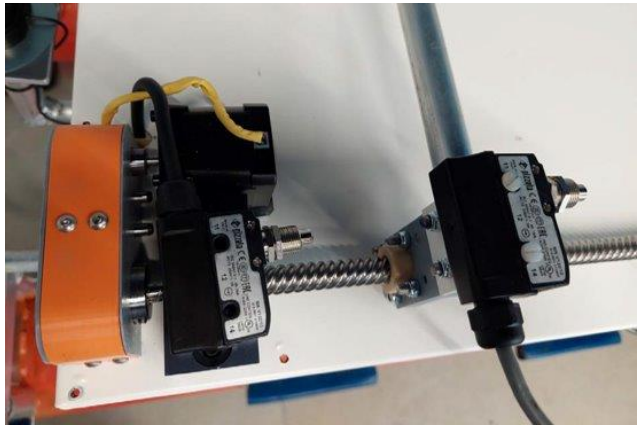
- 0 - Message received and parsed successfully
- 1 - Task started
- 2 - Task completed
- 3 - Error code

Landing platform v2

10/2021 state

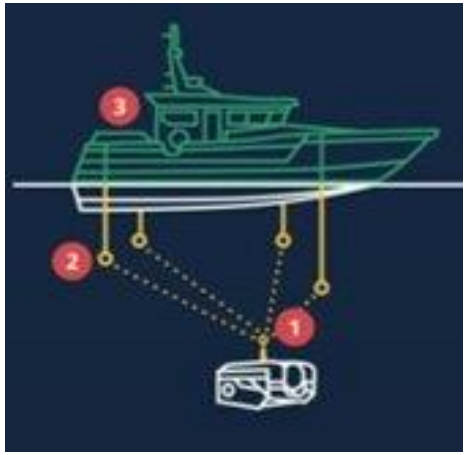
- **v.2 @ 04/2022**
- lab. Dummy robustness tests, dry UAV tests,
- 10 cm longer LP, 10cm higher underconstr.
- gearbox instead of a belt trans. **T_close=6.5s**

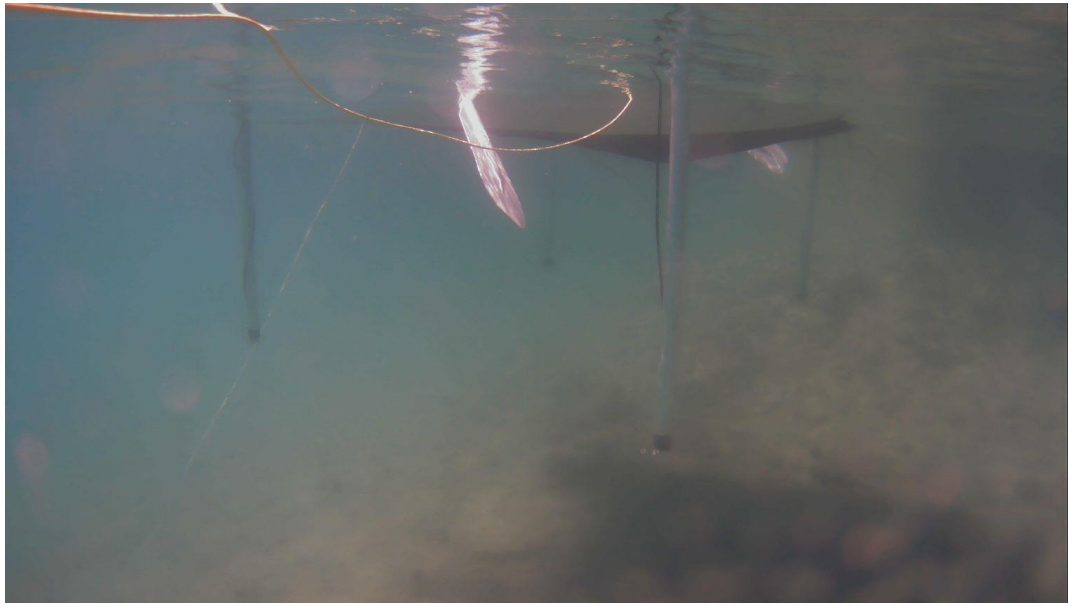




Water Linked UWGPS G2

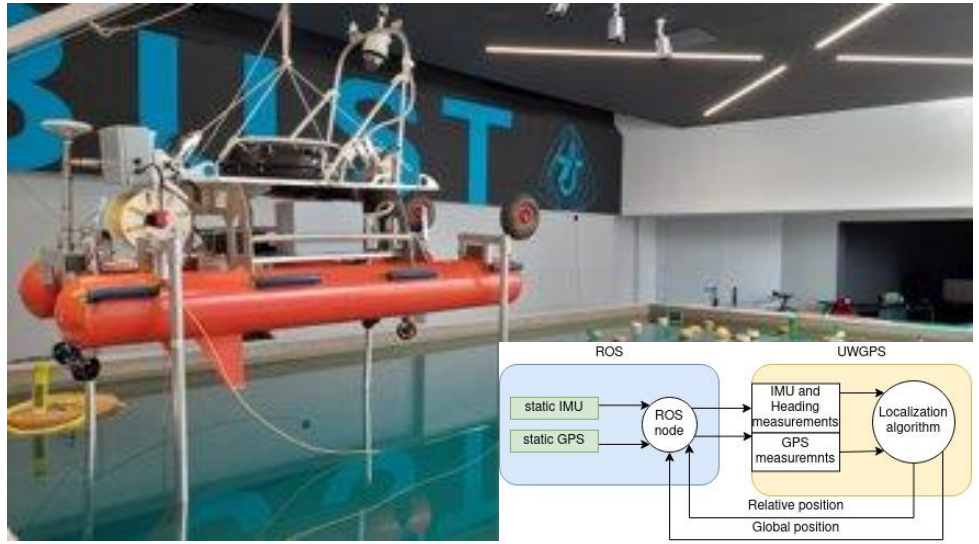
- SBL system
  - 4 topside antennas and one underwater locator
  - Localization using triangulation algorithm
  - Depth sensor on the locator
- Operational range: 100 m (up to 300m)
- Ping rate: 2 – 4 Hz
- Onboard computer in topside case
  - Collects GPS/IMU measurements
  - Launches local HTTP server
    - Calculation of the global or relative location
    - Communication



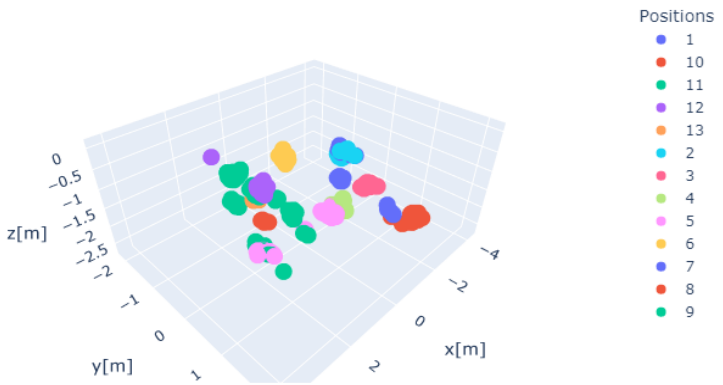


Pool testing of UWGPS G2 – ROS2 integration

- Pool dimensions: 8 x 4 x 3 m
- UWGPS Baseline dimensions: 2 x 2 m
- Locator was positioned at 13 different locations in the pool
- Multipath
- Measurement precision:
  - <0.1 m horizontal plane
  - < 0.01 m depth due to depth sensor correction
- Measurement accuracy:
  - <0.3 m in horizontal plane
  - <0.5 m in depth

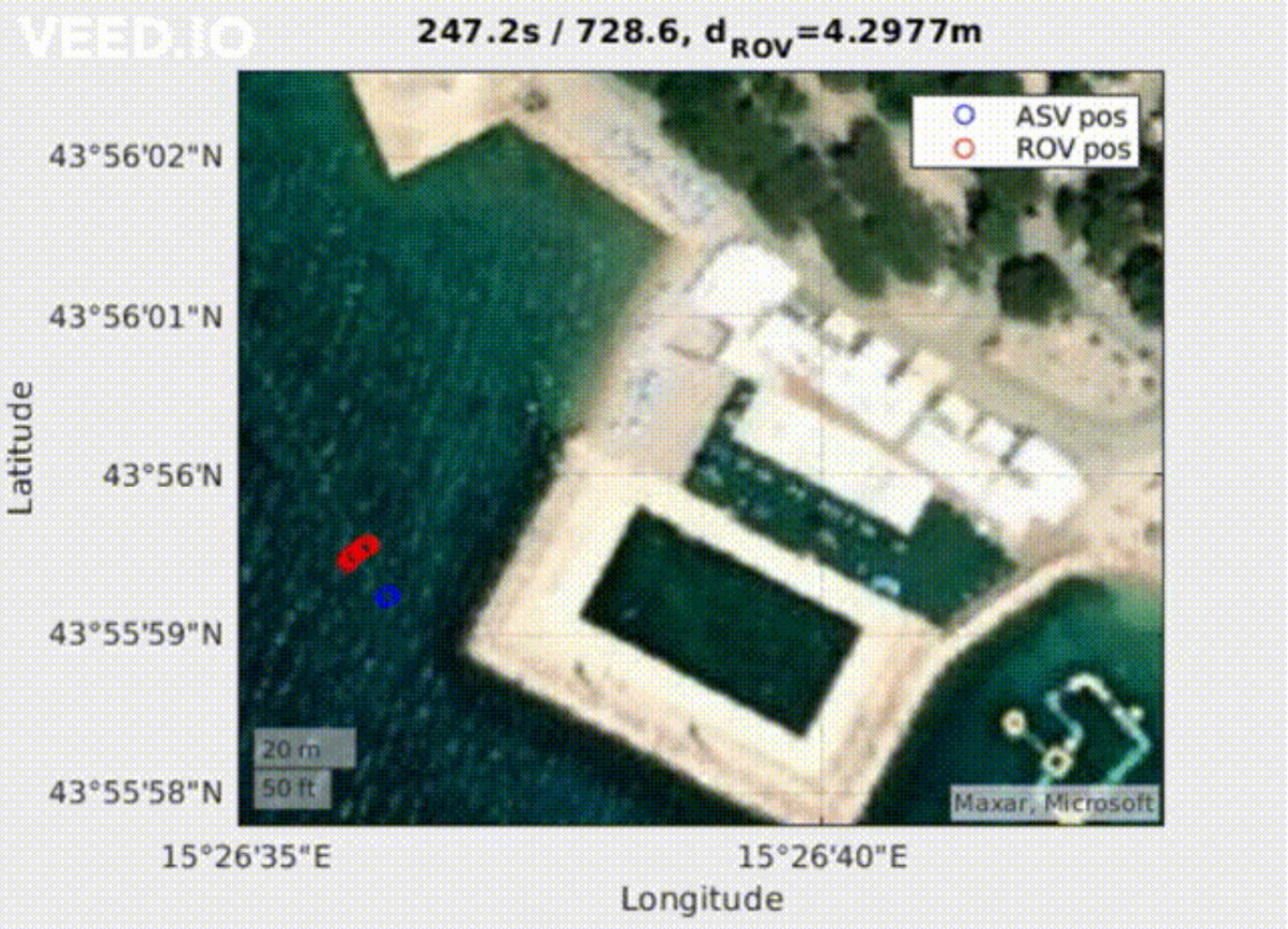


Visual representation of measured locator positions



Sea trials at BtS2021

- First testing of UWGPS in the real environment
- Outliers visible in shallow water



LABUST

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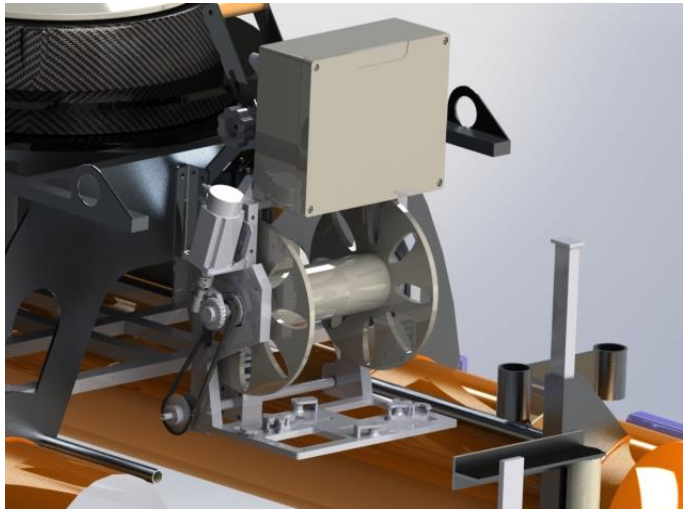
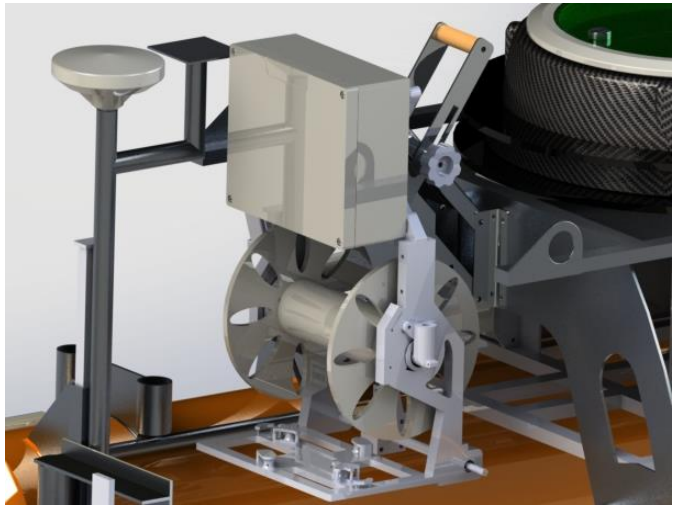
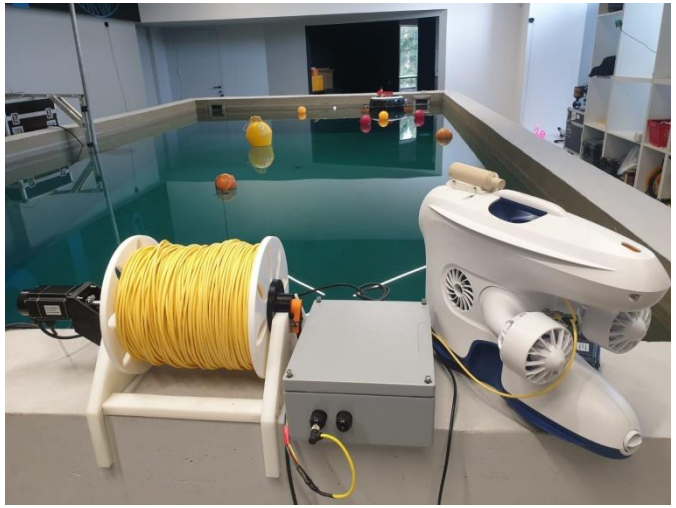
Mechanical design

- Tether: 400m long, D=4mm
- 16 layers, 59 windings/layer
- slipring
- wormgear transmission
- self-reversing screw + chain
- tether tension system
- aluminium IP67 "control" box
- pool and ASV mounts





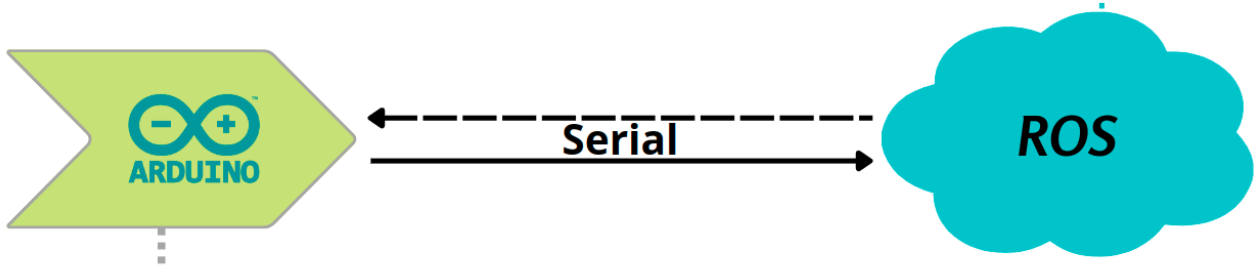


EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

Communication protocol

< MsgNum, CmdCode, d^{ROV}_{avg}, Tolerance >



< MsgNum, CmdCode, Status, $d^{ROV}_{adaptive}$, L^{TMS}_{unw}, v^*_{SPS}, v_{SPS} >

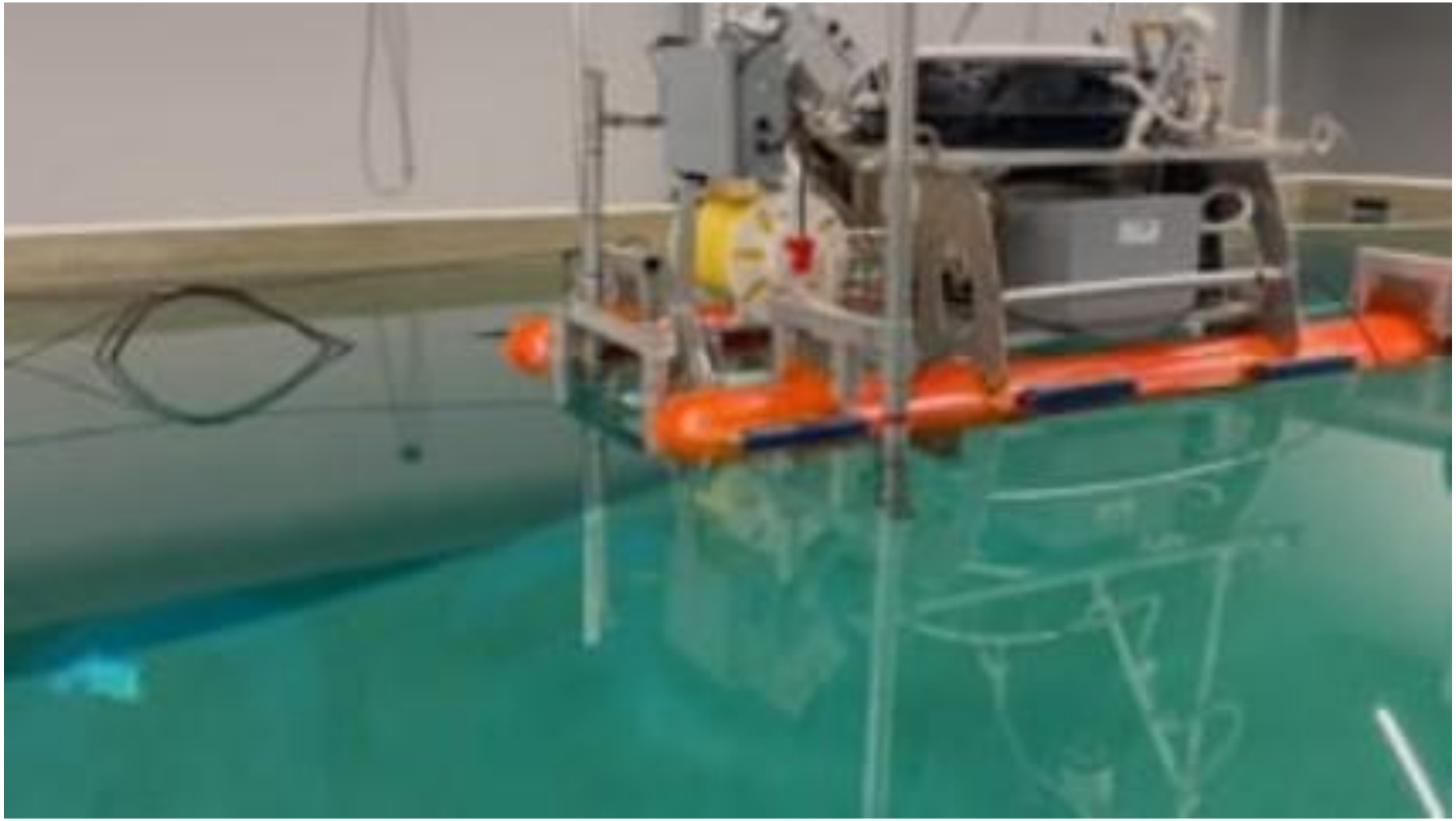
CmdCode

- 0 - STOP,
- 1 - UNWIND command,
- 2 - WIND command

Status

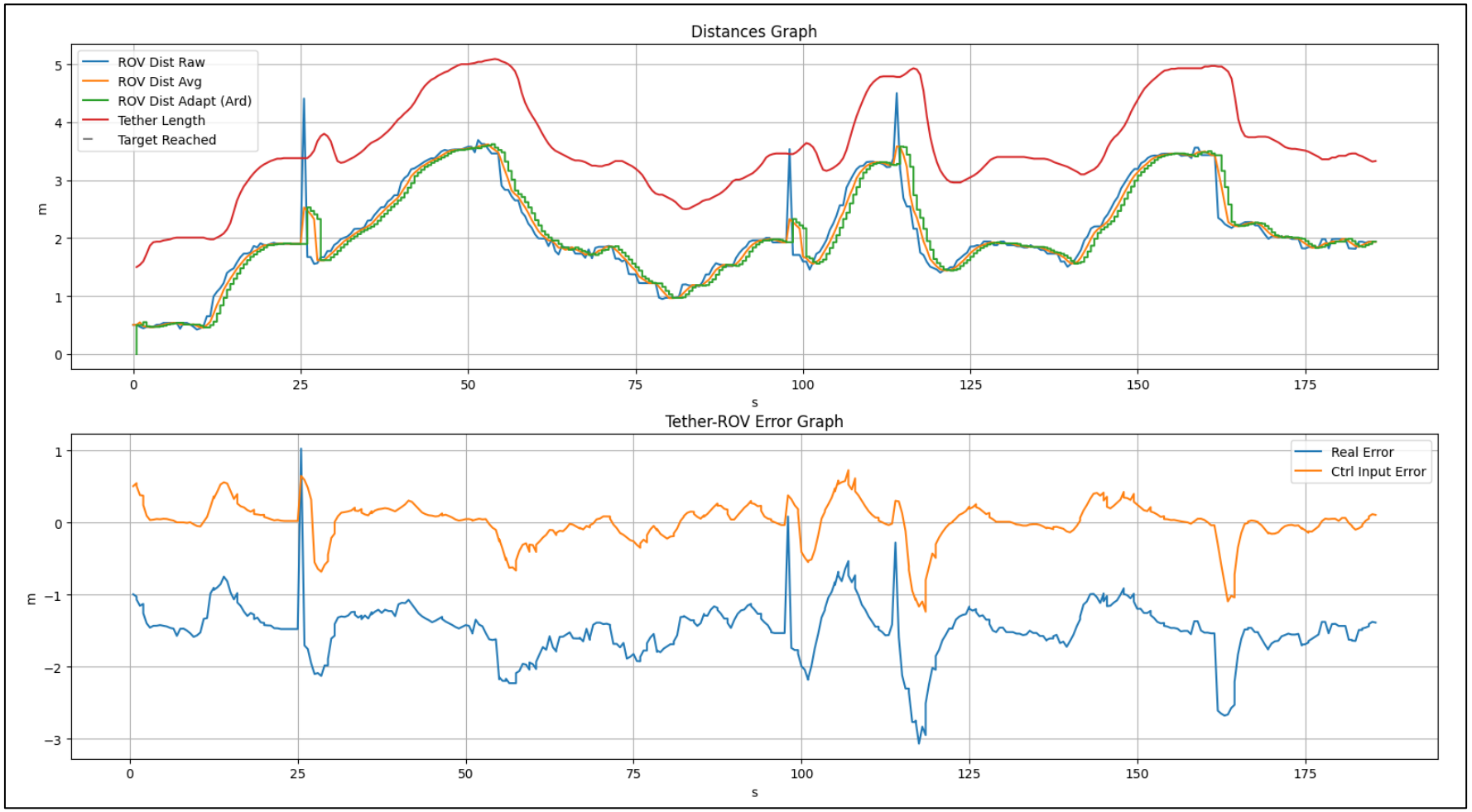
- 0 - Message received and parsed successfully
- 1 - Task started
- 2 - Task completed
- 3 - Error code

TMS Tests - Pool



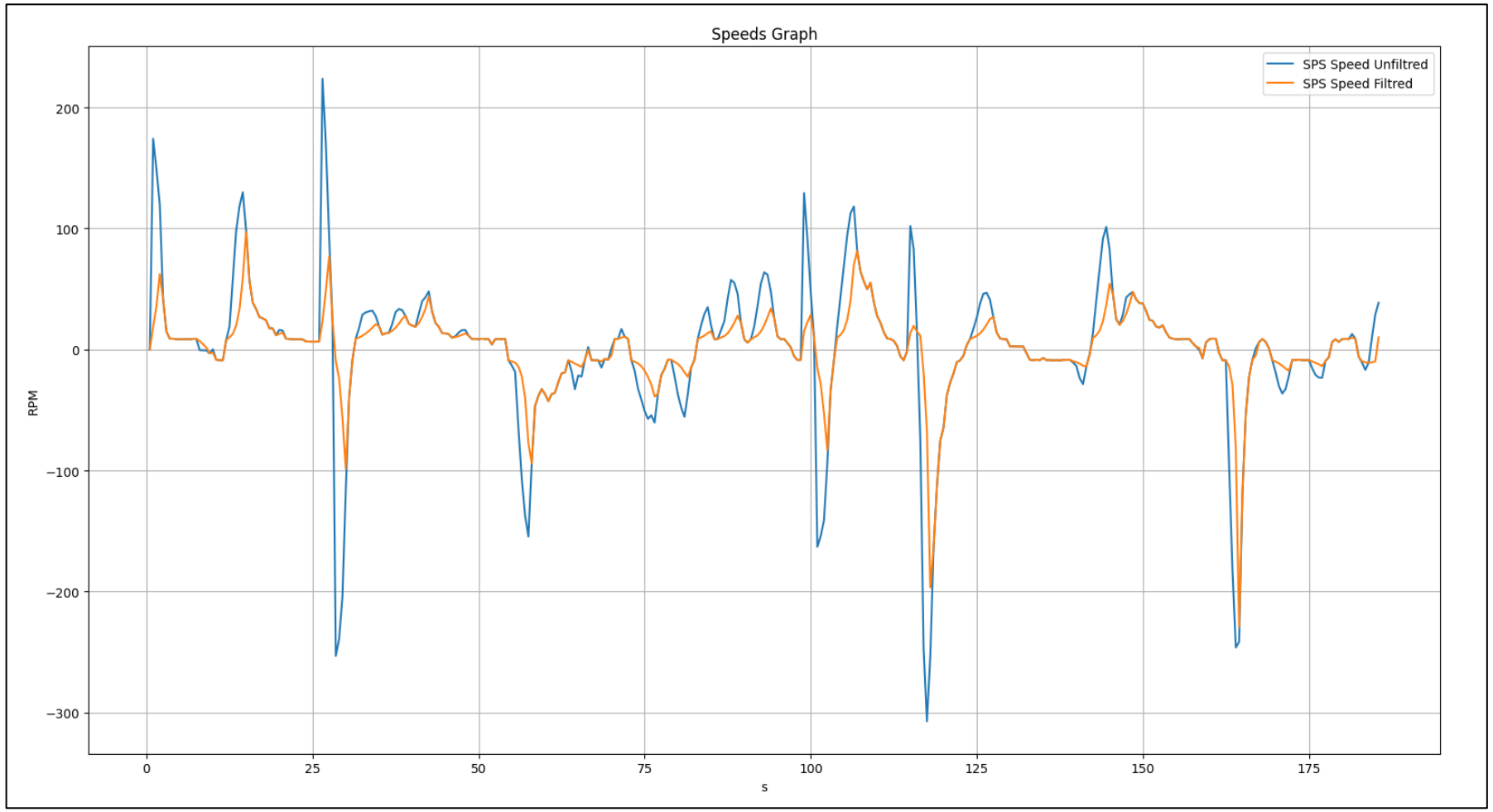
TMS Tests - Pool

- Setup
  - Tolerance = 1.5m
  - Δ = 0m



TMS Tests - Pool

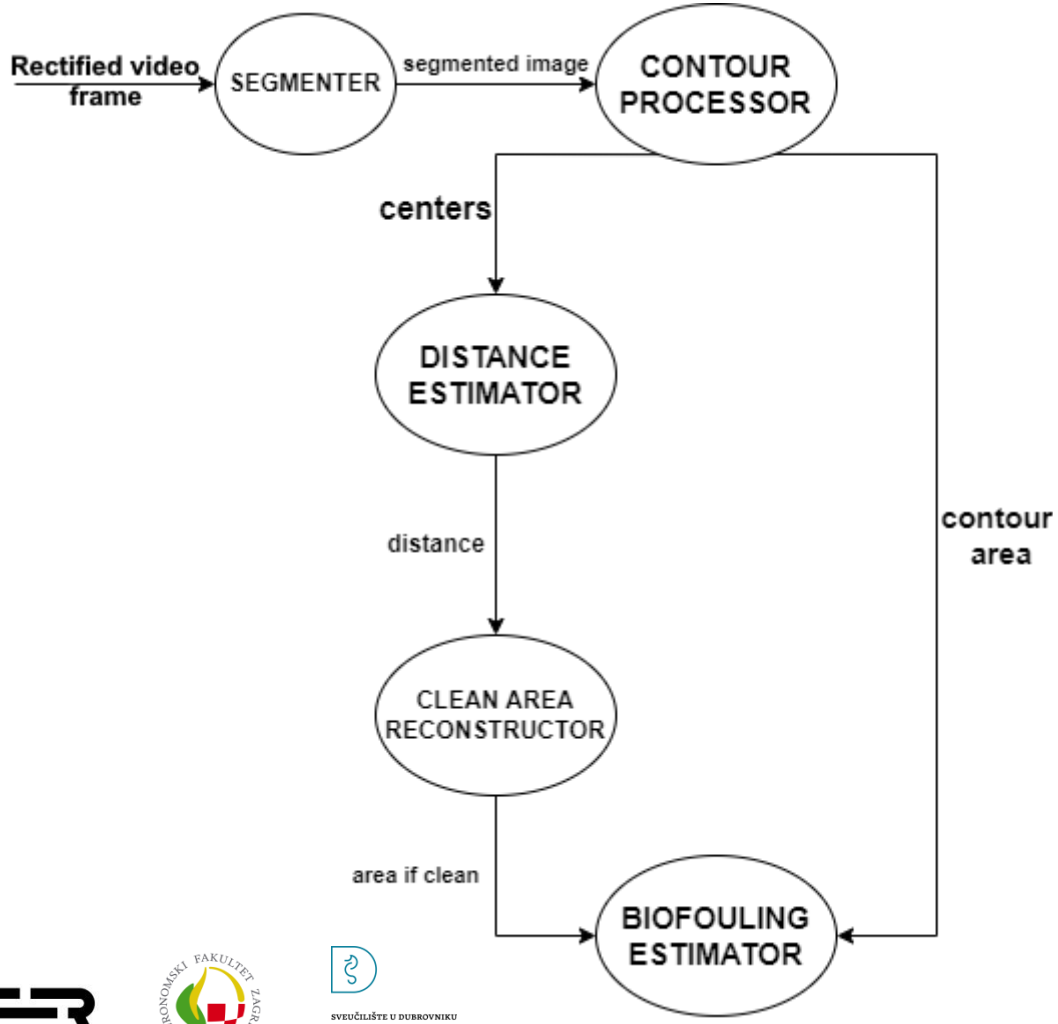
- Setup
  - Tolerance = 1.5m
  - Δ = 0m



HEKTOR

Biofouling estimation framework

- Complete solution from video stream
  to biofouling estimation percentage
- Implemented in Python and ROS2



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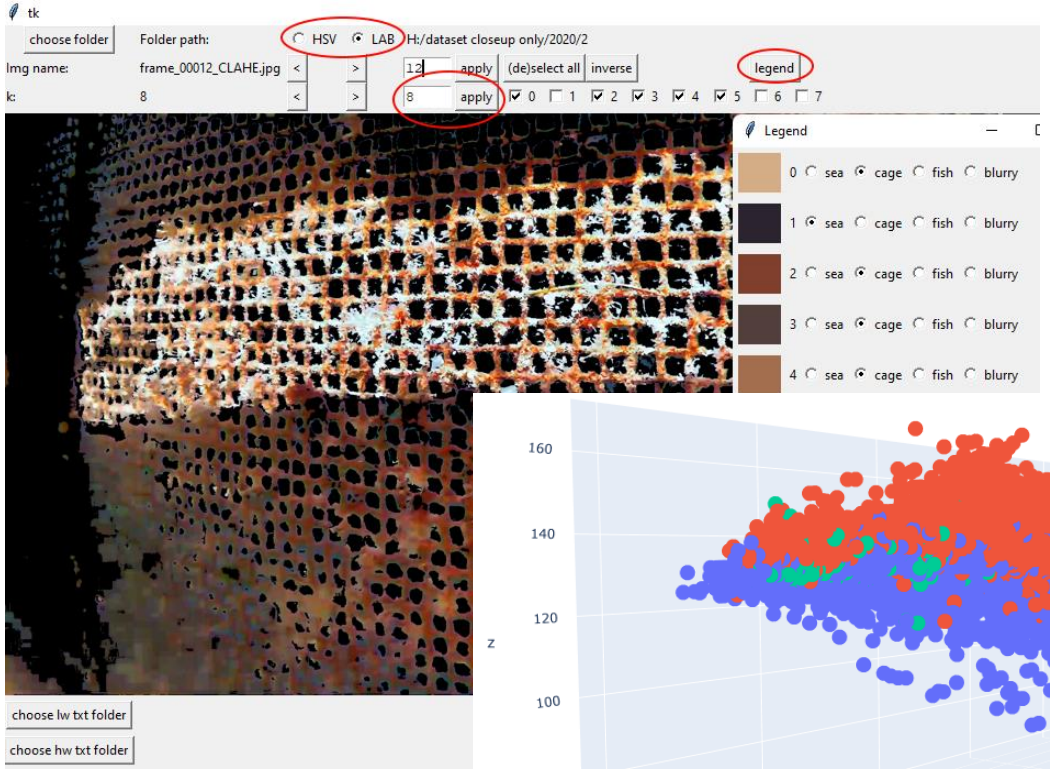
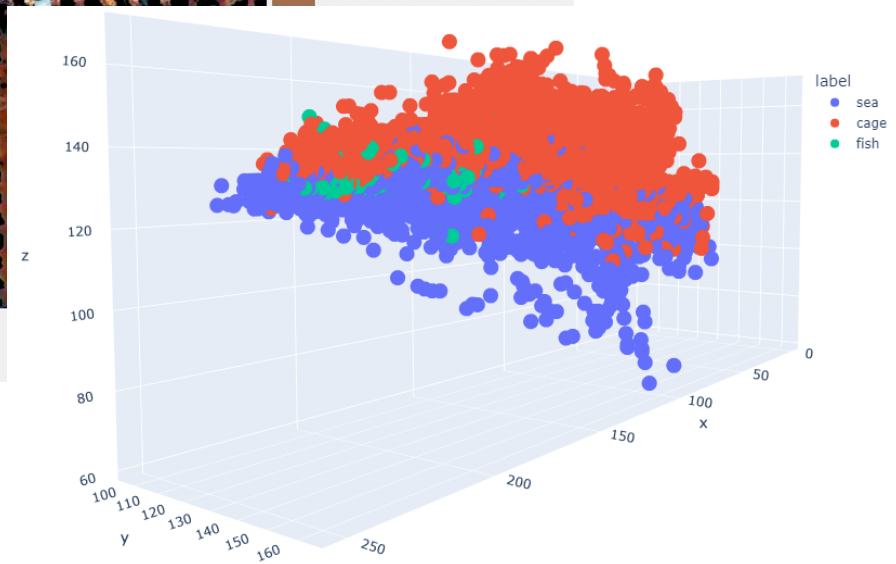
HEKTOR

Collected footage labeling and training

- CIELAB color space – Euclidean
  - Opponent pairs: red-green, blue-yellow
- Trained **logistic regression model**:
  - 1300 images
  - 80.88% train accuracy,
  - 80.62% test accuracy
  - 1080p prediction in under 1 s

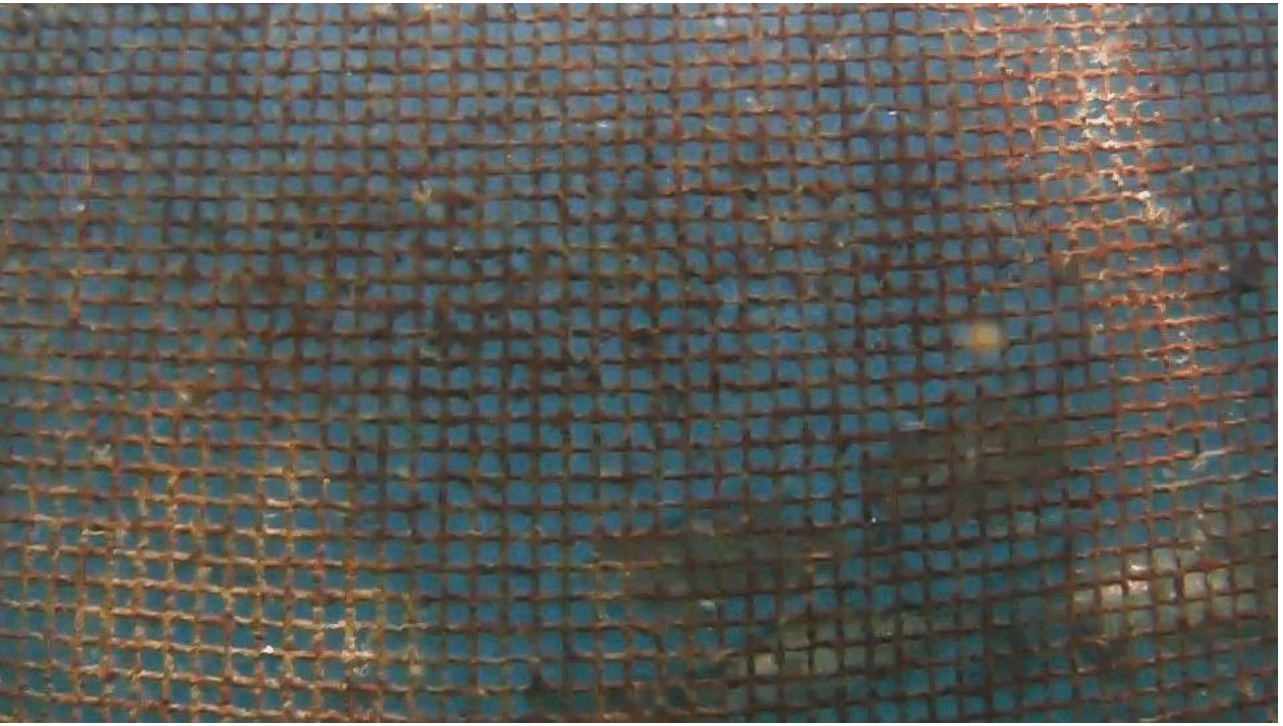


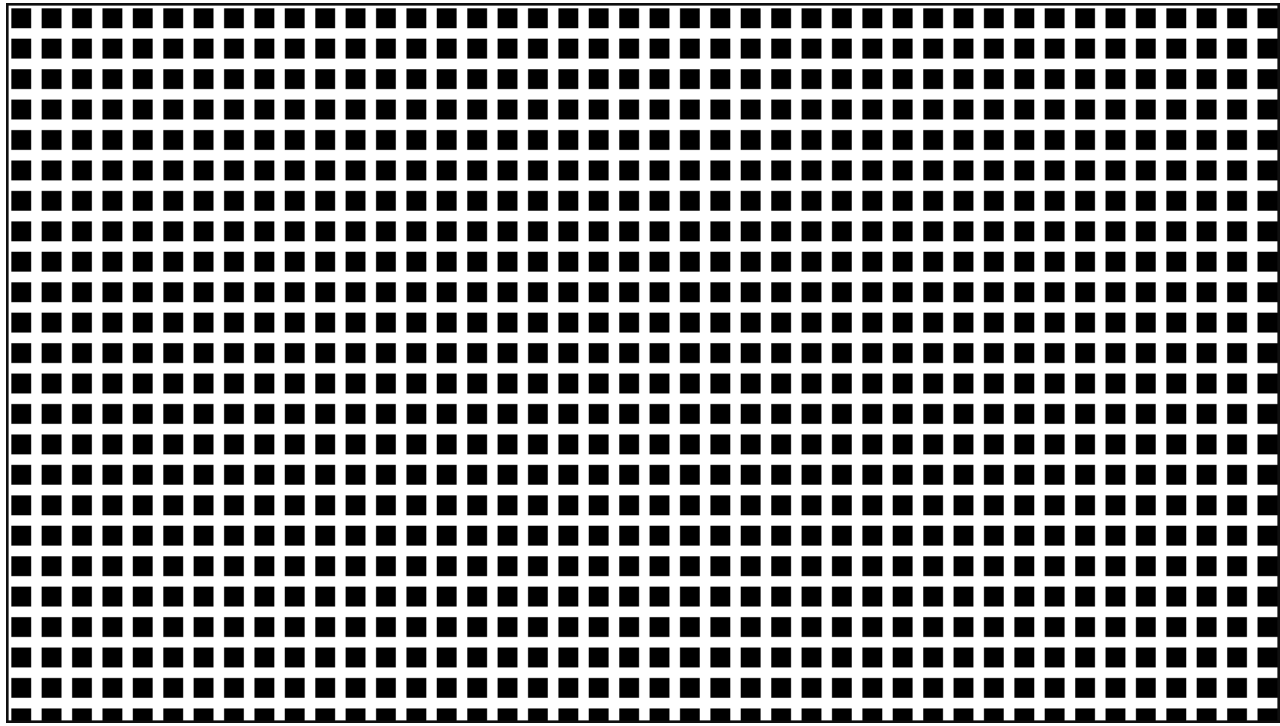


EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

HEKTOR



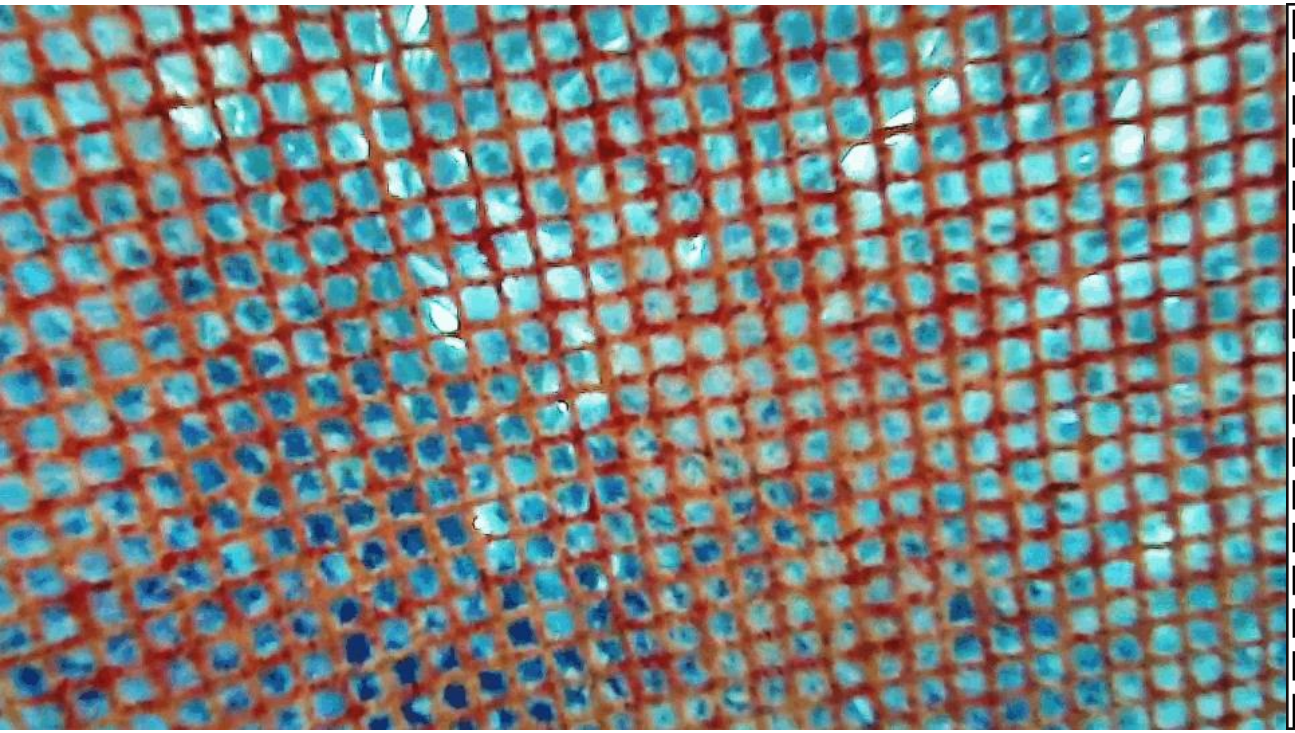


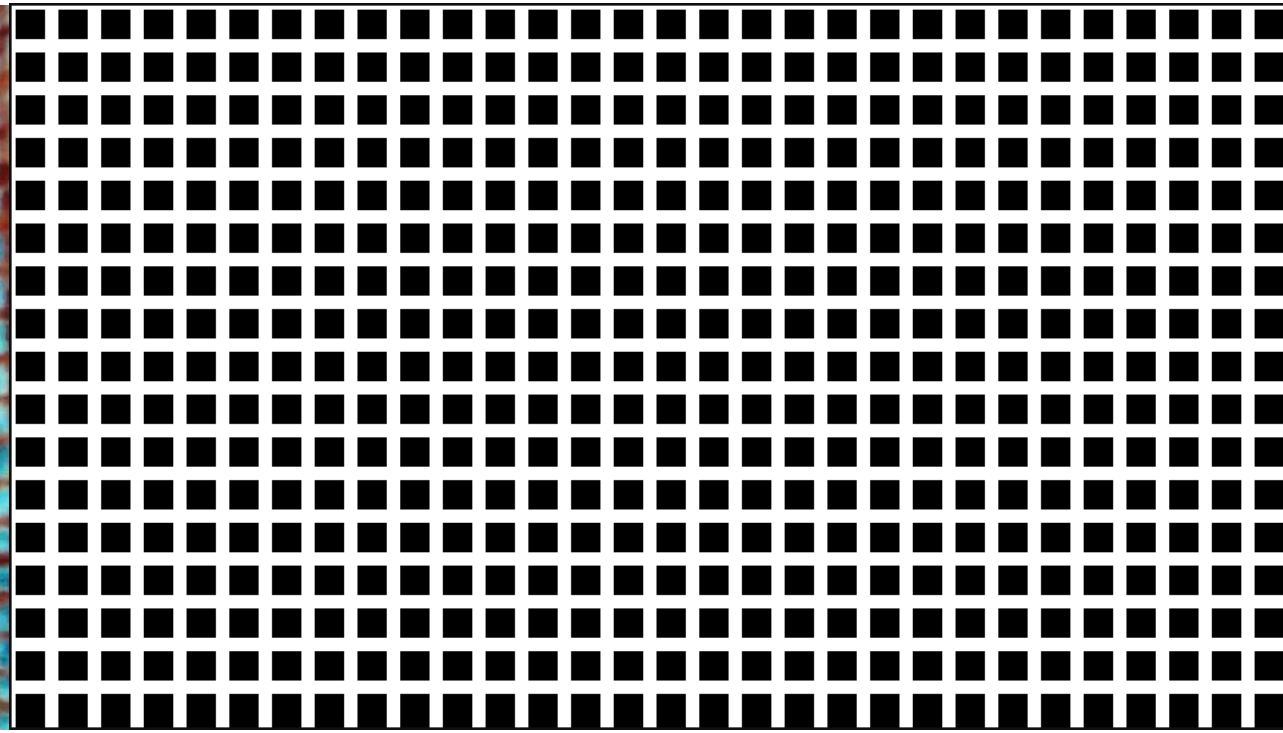
Contour area: 100609 px^2
Biofouling ratio: 1 – (100609 / 239522) =
= 1 – 0.42 = 58%

Contour area: 239522 px^2
Parameters: line width → 8 px
square size → 15 px

EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI
SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

HEKTOR





Contour area: 205898 px^2
Biofouling ratio: 1 – (205898 / 252960) =
= 1 – 0.814 = 18.60%

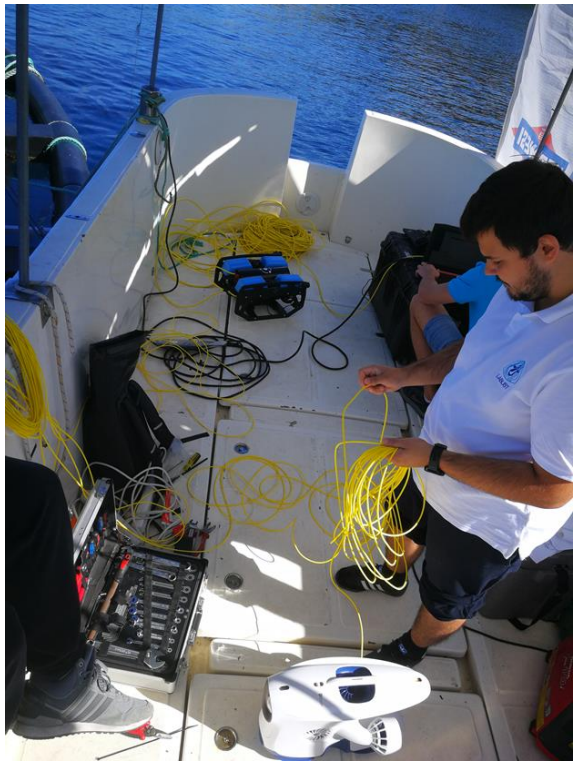
Contour area: 252960 px^2
Parameters: line width → 10 px
square size → 22 px

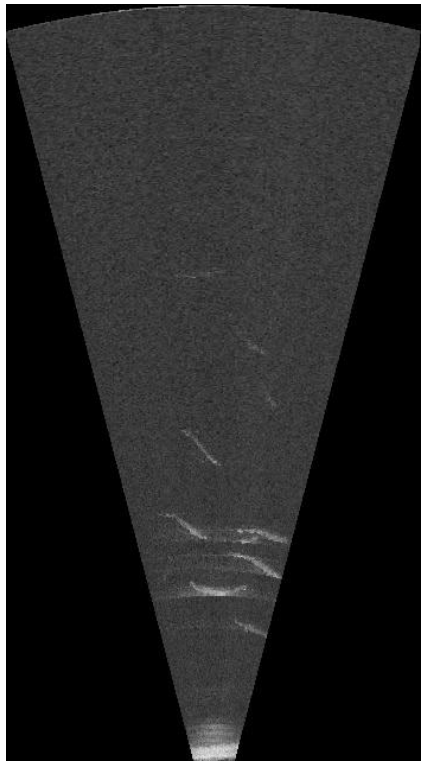
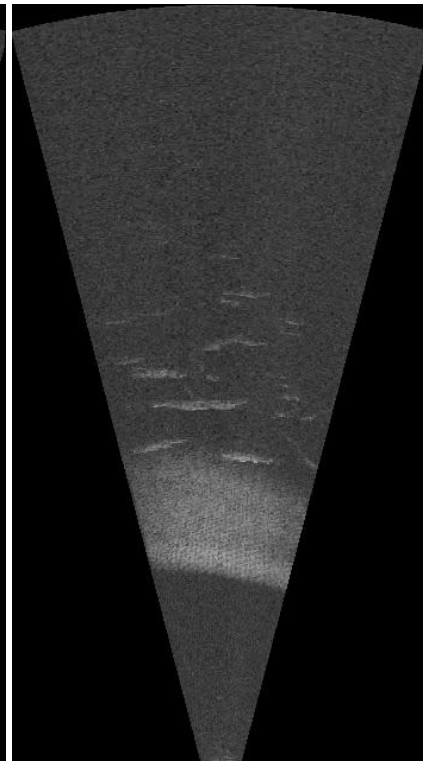
EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI
SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

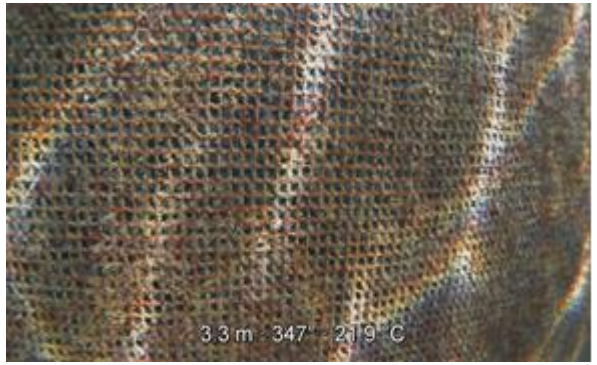
LABUST

HEKTOR

Seatrials





CROMARIS fishery @ Kali, Ugljan, Croatia, 10/2020

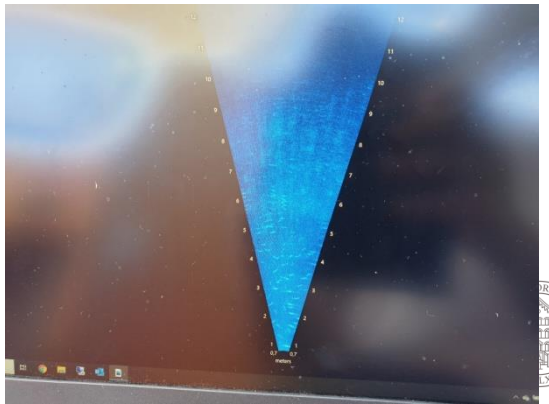
EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

SVEUČILIŠTE U DUBROVNIKU INSTITUT ZA MORE I PRIOBALJE

Seatrials

Split, 04/2021

Ugljan, 05/2021



BtS, 10/2021

Bistrina, 04/2022

Publications

1. Journal papers

1. Ivanovic A.; Orsag, M. "Parabolic Airdrop Trajectory Planning for Multirotor Unmanned Aerial Vehicles, IEEE Access, vol. 10, 36907-36923, 2022, https://doi.org/10.1109/ACCESS.2022.3164434 .
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4. Vatavuk, I.; Vasiljević, G.; Kovačić, Z.; Task Space Model Predictive Control for Selective Vineyard Spraying with a Mobile Manipulator. Agriculture, Vol. 12, no. 3, 3812022, https://doi.org/10.3390/agriculture12030381 .
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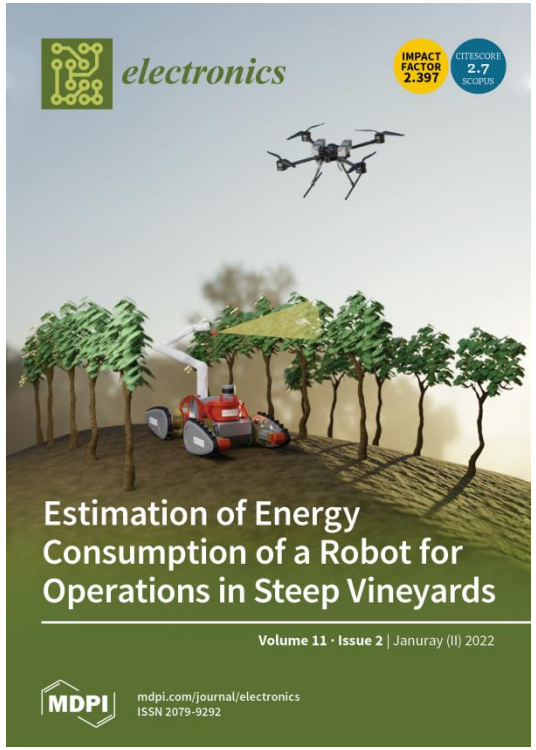
6. A. Batinovic, T. Petrovic, A. Ivanovic, F. Petric and S. Bogdan, A Multi-Resolution Frontier-Based Planner for Autonomous 3D Exploration, in IEEE Robotics and Automation Letters, vol. 6, no. 3, pp. 4528-4535, July 2021, https://doi.org/10.1109/LRA.2021.3068923 .
7. A. Batinovic, A. Ivanovic, T. Petrovic and S. Bogdan, A Shadowcasting-Based Next-Best-View Planner for Autonomous 3D Exploration," in IEEE Robotics and Automation Letters, https://doi.org/10.1109/LRA.2022.3146586
8. Kapetanović, N.; Vasilijević, A.; Nađ, Đ.; Zubčić, K.; Mišković, N. Marine Robots Mapping the Present and the Past: Unraveling the Secrets of the Deep, Remote Sensing, 2020, 12, 3902; https://doi.org/10.3390/rs12233902 .
9. Kapetanović, N.; Kordić, B.; Vasilijević, A.; Nađ, Đ.; Mišković, N. Autonomous Vehicles Mapping Plitvice Lakes National Park, Croatia, Remote Sensing, 2020, 12, 3683; https://doi.org/10.3390/rs12223683 .
10. Akram, W.; Casavola, A.; Kapetanović, N.; Mišković, N. A Visual Servoing Scheme for Autonomous Aquaculture Net Pens Inspection Using ROV. Sensors 2022, 22, 3525. https://doi.org/10.3390/s22093525 .



Publications

2. Conference papers

1. Kapetanović, N.; Nađ, Đ.; Mišković, N. Towards a Heterogeneous Robotic System for Autonomous Inspection in Mariculture, The IEEE/OES MTS Global OCEANS Conference and Exposition, San Diego, SAD, 2021.
2. Rezo, M., Čagalj K.-M., Ušljebrka I., Z. Kovačić, "Collecting Information for Biomass Estimation in Mariculture with a Heterogeneous Robotic System," 2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO), 2021, pp. 1125-1130, https://doi.org/10.23919/MIPRO52101.2021.9596683 .
3. Hrabar I., Goričanec J., Kovačić Z., "Towards Autonomous Navigation of a Mobile Robot in a Steep Slope Vineyard," 2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO), 2021, pp. 1119-1124, https://doi.org/10.23919/MIPRO52101.2021.9596997 .
4. Borković, Goran; Fabijanić, Matej; Magdalenić, Maja; Malobabić, Andro; Vuković, Jura; Zieliński, Igor; Kapetanović, Nadir; Kvasić, Igor; Babić, Anja; Mišković, Nikola, "Underwater ROV Software for Fish Cage Inspection," 2021 44th International Convention on Information, Communication and Electronic Technology (MIPRO), 2021, pp. 1747-1752, https://doi.org/10.23919/MIPRO52101.2021.9596823 .
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7. Kotarski, D.; Piljek, P.; Pranjić, M.; Kasač, J. Toward Modular Aerial Robotic System for Applications in Precision Agriculture, ICUAS 2022, Dubrovnik, Croatia, pp. 1530-1537, June 21-24, 2022. https://doi.org/10.1109/ICUAS54217.2022.9836108
8. Stuhne, D.; Tabak, J.; Polić, M.; Orsag, M. Design and Prototyping of Soft Finger AI-Enabled Hand (SofIA), 2022 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Royton Sapporo, Sapporo, Hokkaido, Japan, pp. 1581-1586, July 11-15, 2022. https://doi.org/10.1109/AIM52237.2022.9863338
9. Arbanas Ferreira, B.; Petrović, T.; Bogdan, S. Distributed Mission Planning of Complex Tasks for Heterogeneous Multi-Robot Systems, 2022 IEEE 18th International Conference on Automation Science and Engineering (CASE) Mexico City, Mexico, August 22-26, 2022.
10. Kapetanović, N.; Mišković, N.; Ferreira, F. Landing Platform for Autonomous Inspection Missions in Mariculture Using an ASV and a UAV, CAMS 2022, Kongens Lyngby, September 14-16, 2022.
11. Kapetanović, N.; Mišković, N.; Nađ, Đ. Tether Management System for Autonomous Inspection Missions in Mariculture Using an ASV and an ROV, CAMS 2022, Kongens Lyngby, September 14-16, 2022.
12. Lončar, I,; Mišković, N. Maximum likelihood based underwater localization algorithm aided with depth measurements. // IFAC CAMS. Kongens Lyngby, Danska, September 14-16, 2022.
13. Fabijanić, M.; Kapetanović, N.; Mišković, N. Biofouling Estimation in Mariculture. OCEANS Conference and Exposition, Hampton Roads, SAD, October 17-21, 2022.
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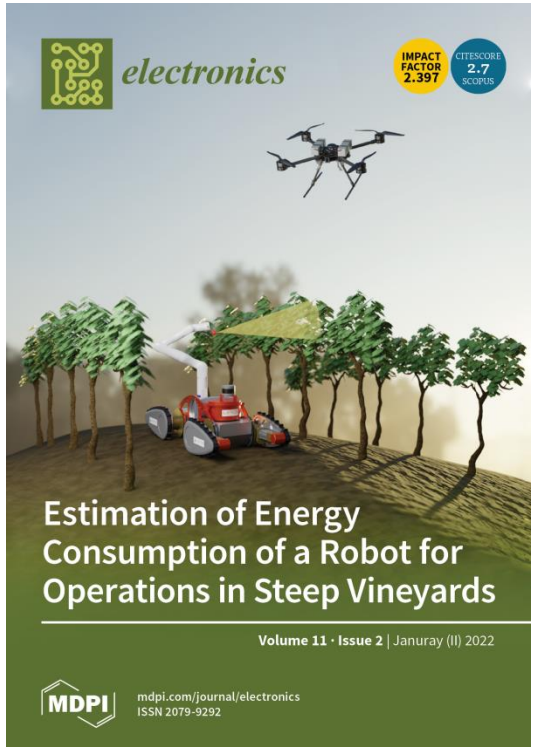

Innovations

Prelog, 13.-15.05.2022.

Autonomni katamaran za marikulturu

Autori inovacije: Nadir Kapetanović, Đula Nađ, Nikica Kokir, Martin Oreč, Kristijan Krčmar, Nikola Mišković

Autonomno površinsko plovilo dizajnirano je kao katamaran koji se koristi u marikulturi u misijama autonomne inspekcije mreža ribogojilišta. Napravljen je od aluminija i ima dimenzije 200x100 cm s trupovima promjera 24 cm i ukupne visine 140 cm tako da može raditi u uvjetima do stanja mora 2. Trenutno teži 100 kg i može primiti još 100 kg tereta. Katamaran je pogonjen sa 4 električna propulzora u X konfiguraciji tako da može postići omnidirekcionalno. Motor od 720 W postavljen na krmu omogućava kretanje u otvorenim morskim područjima. Za potrebe misija autonomne inspekcije prosječna autonomija traje 10-11 h. Katamaran je zamišljen kao modularna platforma koja omogućava autonomnu kooperaciju s letećim dronom I bespilotnom ronilicom za inspekciju mreža ribogojilišta iz zraka i pod morem. Time se katamaran transformira i u "garažu" za druga vozila pa su razvijene slijetna platforma za letjelicu i sustav za automatsko namatanje kabela ronilice.

Razvoj ove inovacije financirao je Europski fond za regionalni razvoj, Konkurentnost operativnog programa i kohezija 2014-2020, kroz projekt Heterogeni autonomni robotski sustav u vinogradarstvu i marikulturi (HEKTOR) - broj potpore KK.01.1.1.04.0041 (https://hektor.fer.hr)

Dodatne informacije o sustavu: https://doi.org/10.3390/s22082961

Prelog, 13.-15.05.2022.

Autonomni heterogeni robotski sustav za prskanje i uklanjanje mladica u strmim vinogradima

Autori inovacije: Ivo Vatavuk, Marko Cukon, Dario Stuhne, Ivan Hrabar, Jurica Goričanec, Zdenko Kovačić

Autonomni heterogeni robotski sustav za prskanje i uklanjanje mladica s trsova dizajniran je za rad u vrlo strmim vinogradima. Osnovu sustava čini mobilni robot s četiri kraka s gusjenicama. Robot prepoznaje prolaze između redova i kreće se duž njih vođen informacijama prikupljenim s bespilotne letjelice i vlastitih senzora. Za prskanje koristi se mobilni robotski manipulator s podsustavom za prskanje (slika lijevo). Za uklanjanje mladica robot locira trs, pozicionira se kraj njega i skida mladice pomoću robotskog manipulatora i podatnog alata ili s posebno dizajniranim dodatnim alatom (slika desno).

Razvoj ove inovacije financirao je Europski fond za regionalni razvoj, Konkurentnost operativnog programa i kohezija 2014-2020, kroz projekt Heterogeni autonomni robotski sustav u vinogradarstvu i marikulturi (HEKTOR) - broj potpore KK.01.1.1.04.0036 (https://hektor.fer.hr)

Dodatne informacije o sustavu: https://doi.org/10.3390/s22082961

HEKTOR

Thank you for your attention

Research work presented here has been financed by the European Union through the European Regional Development Fund-The Competitiveness and Cohesion Operational programme (KK.01.1.1.04.0036).