

Progetti ed applicazioni Underwater: la visione di Telespazio



Giuseppe Tomasicchio

Research, Digital & Innovation

Head of RDI System Engineering & Design Authority

Space Exploration & Space Station services Innovation Domain Manager



Marco Brancati

Senior Vice President of Research, Digital & Innovation

April 17th, 2024

SUMMARY

- Underwater Critical Infrastructures (UCIs) – [Overview](#)
- UCI PNT stakeholder needs and Key Performance Indicators (KPIs)
- Current Underwater technologies
- Current challenges in the underwater environment
- Underwater mission planning and operative challenges
- Conclusions





PULSAR

**PNT Unknown trends: a Long-term
key Sectors Assessment & Roadmap study**

ESA Frame Contract N° 4000132185/20/NL/GLC

PULSAR: Assessment of Technology Trend in Key PNT – Call for Order 2



The **main objectives** of the activity lead by **TELESPAZIO** (TPZ) have been:

- To assess with ESA the key PNT sectors with a view to identify the **main innovation trends** on each sector
- The identification of enabling actions for the identified technical innovation trends with the **aim of future possible injection into NAVISP**
- To **enhance cooperation between the industry and research institutions** on R&D subjects within PNT areas of common interest.

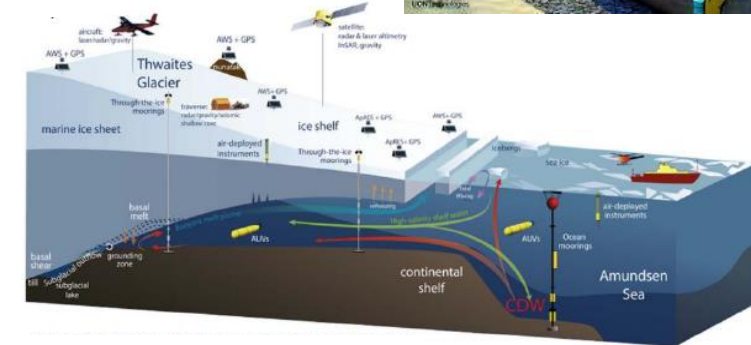
A team of **technical experts**, lead by TELESPAZIO supported the activities related to their field of proficiency and investigated in the [Call-Off Order 2 \(CoO-2\)](#) the following Work Item:

Underwater PNT (Positioning, Navigation & Timing) for a greener Earth

The team of expert also included the “**Centre for Maritime Research and Experimentation**” (CMRE) NATO institute in La Spezia (IT) and **SpaceExe srl**.

Within the project, TPZ as Consortium prime provided:

- a stakeholder needs and use cases analysis,
- a survey of the State-of-the-Art,
- an analysis of innovation beyond the State-of-the-Art and gap analysis
- a definition of the next steps to suggest with ESA for the definition of a technological roadmap for the Underwater PNT.



Underwater Critical Infrastructures (UCIs) – Overview (1/2)

Underwater Critical Infrastructures (UCIs), such as offshore platforms and windfarms, underwater oil/gas pipelines and fiber optic cables networks, represent undersea assets or systems which are essential for the maintenance of vital social functions.

The activities related to their **installation, operation and inspection** require instruments and vehicles that operate with a very high level of **Position Navigation and Timing (PNT) accuracy, below cm.**

The **Nord Stream 2 accident**, occurred on September 2022, strengthened the need for a rapid and accurate UCI monitoring and control processes, and the usage of Autonomous Underwater Vehicles (AUVs) became a key point.



Purpose: to give a detailed overview on how capabilities provided by **underwater PNT technologies** can evolve to improve the support in UCI Installation, Operation & Maintenance



Nord Stream 2 accident

Underwater Critical Infrastructures (UCIs) – Overview (2/2)

Most of the procedures followed by operators to install and maintain UCIs can be summarized in the following steps:

- **Pre-lay survey**
- **Beacons positioning**
- **Navigation and close inspection**
- **Intervention**

1. Survey step: performed almost **6 months** before the installation to verify and validate the geographical area of the seabed where the UCI will be deployed.

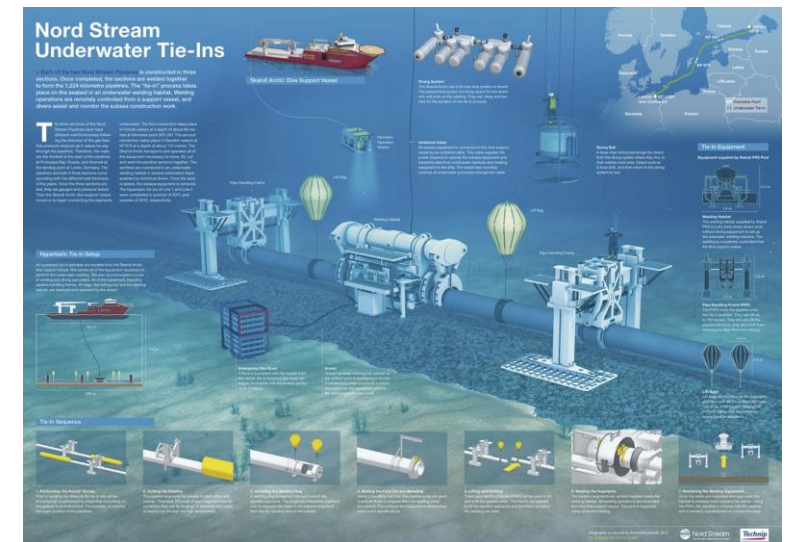
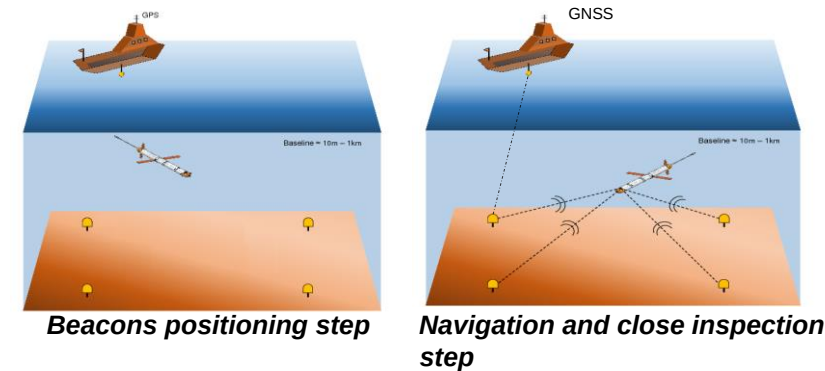
2. Beacons positioning step: **AUVs** autonomously reach the desired position, **Beacons** (i.e. Long Base Line – LBL) are continuously linked to a GNSS reference and their position on the seabed is geo-referenced.

3. Navigation and close inspection step: the **AUVs** autonomously reach the area delimited by the beacons, perform **autonomous navigation**, accurate **seafloor mapping** and **data acquisition**.

4. Intervention step: a vehicle repairs the identified damage through **manipulators**, remaining extremely stable during the operation.

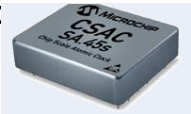
Assets & instruments

- AUV
- Sensors
- Actuators



UCI PNT stakeholder needs and Key Performance Indicators (KPIs) (1/3)

In the context of PULSAR Project [2] , funded by European Space Agency, has been performed a detailed assessment from June 2022 to May 2023 about Underwater PNT technologies.

Step	Needs and PNT KPI	Available PNT Technologies
<u>1. Preliminary survey</u>	- IMO Requirements [6] - Absolute Horiz. Accuracy: 10 m - Alert limit: 25 m - Time to alarm: 10 s - Availability: 99.8% per 30 days - Long Base Lines – distance precision (cm) up to 10000m range	- Mother-ship (DP 2 or 3) plus UUV - GNSS/DGNSS - Pipetracker - Magnetometer (Shallow water) - Subsea camera for unburied cable (deep water) - LBL 0.02m accuracy (@Kongsberg)
<u>2. Beacons Positioning</u>	- Beacon-GNSS ref. connection - Coverage: max distance from GNSS reference depends on depth (shallow/deep) - H/V accuracy: 5 m at max range from mothership	- USBL acoustic positioning (@iXblue) - Op. Range: 1000 m or 4000 m - H/V accuracy: 0.5% range (5 m) or 0.1% range (4 m) Min. operating temperature: -5°C
	High precision time synchronization  <i>* Chip Scale Atomic Clock</i>	- Chip Scale Atomic Clock* (CSAC, @Microchip) - at T=25°C at shipment ▪ $\pm 5.0E-11$ maximum frequency offset ▪ Short-term stability <10-11 @1000s - Minimum operating temperature: -10°C (over extended time period may yield unpredictable aging performance)



UCI PNT stakeholder needs and Key Performance Indicators (KPIs) (2/3)

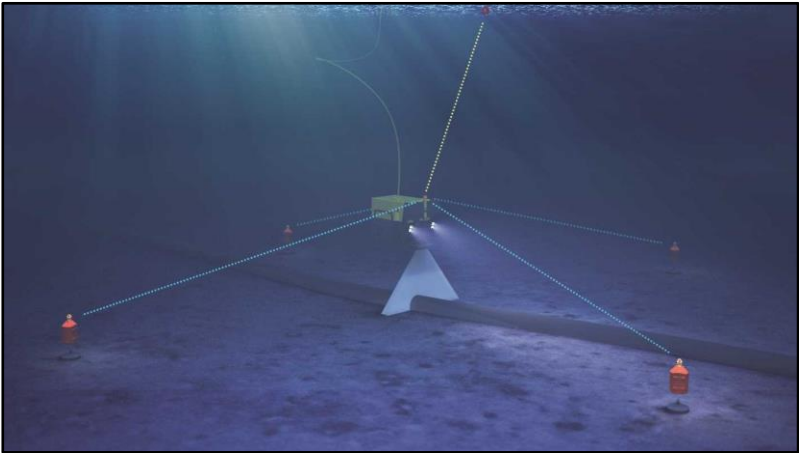
Step	Needs and PNT KPI	Available PNT Technologies
<u>3. Navigation and close inspection</u>	• AUVs LBL positioning - H/V position accuracy: 30 cm at max range - H/V velocity accuracy: Range/Coverage: 100 m – 1 km	• LBL acoustic positioning (@EvoLogics) - Typical static accuracy: 0.05% of R_{max} 50 cm at 1 km - Frequency Range: 8 kHz – 16 kHz - Range: max 8 km (hemispherical, 40W, 7-17 kHz) - max 6 km (120° pattern, 65W, 15-27 kHz) - Minimum operating temperature: 0°C
	• High precision time synchronization	• Chip Scale Atomic Clock as in beacon Positioning step
	• Cable area mapping - Accuracy: tens of cm - Continuity: 99.5% over 3 hours	• Magnetometer (Shallow water) • Subsea camera for unburied cable (deep water) • Downward-looking Multibeam Echosounder (MBES, @Kongsberg) - Swath coverage sector: 140 deg - Range resolution: 1 cm - Min. operating temperature: - 2° - Continuity: % over 3 hours
	• Collision avoidance from obstacles - Horizontal Accuracy: 1 m - Integrity Alert Limit: 25 m - Time to alarm: 10 s - Continuity: 99.9% over 3 hours	• Forward-Looking Sonar (FLS, @Kongsberg) - Depth rating: 4000 m - Range: 0.2 m to 200 m - Coverage: 200 deg - Range Resolution: 1 cm - Angular Resolution: 2 deg - Min. operating temperature: -2°C



UCI PNT stakeholder needs and Key Performance Indicators (KPIs) (3/3)

Step	Needs and PNT KPI	Available PNT Technologies
4. Intervention	• High precision intervention capabilities (IMO): - H/V accuracy in vehicle's position w.r.t. the cable damage's position: 10 cm - Alert limit: 25 cm - Time to alarm: 5 s - Continuity: 99.9% over 3 hours	• LBL acoustic positioning of the vehicle (@iXblue) - Op. Range: 1000 m or 4000 m - H/V accuracy: 0.5% range (5 m) or 0.1% range (4 m) - Min. operating temperature: -5°C • Industries are starting using resident ROVs with docking station

Note: Table results from questionnaires, interviews, mail exchanges and discussions occurred within the PULSAR project Credits to Kongsberg, DRASS, GEOTEAM and other relevant global stakeholders for their availability.



Underwater Close inspection and Intervention Drone

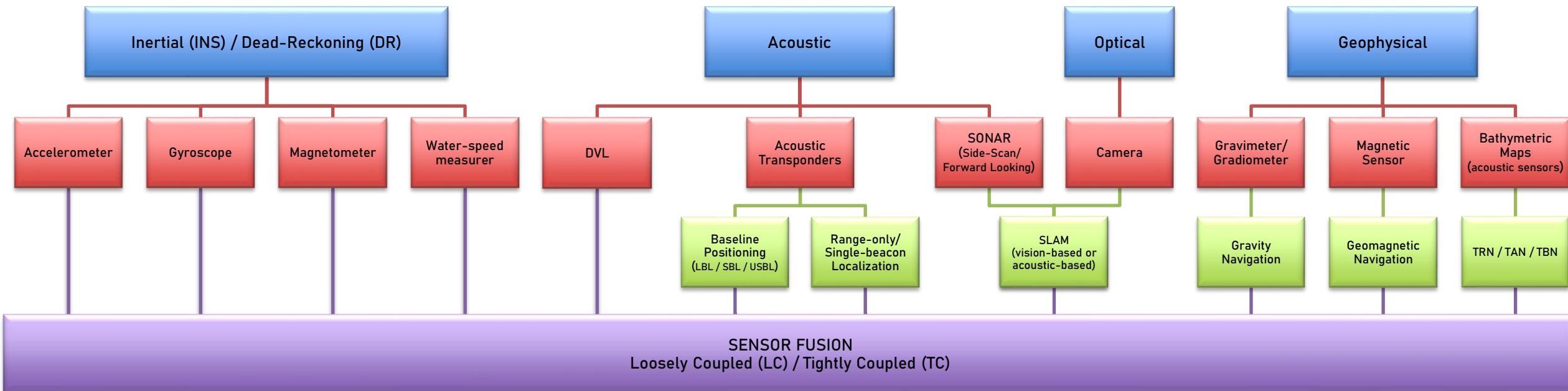


Current Underwater technologies: sensors and instrumentations (1/2)

- Primary Challenge of the Underwater Environment: **GNSS Unavailability**

Underwater positioning is comparable to indoor localization

- Inertial sensors: precise DR for short periods, then position error grows.
- Acoustic sensors: good IMU (Inertial Movement Unit) -aid, but resolution decreases with range.
- Optical sensors: good resolution, but range is extremely short and drastically reduces with depth (light availability issue).
- Magnetic sensors: performance not affected by depth, but an accurate map of the local magnetic field is needed to navigate.



Current Underwater technologies (2/2)

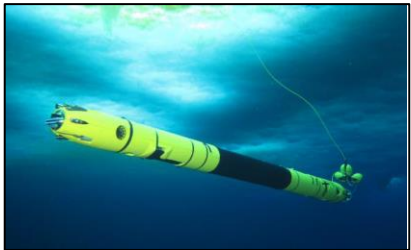
Sensing devices based on **optics**, **acoustics**, and **electromagnetics** are used including:

- Seafloor mapping (Single-Beam, Multi-Beam and Side-Scan sonar)
- Resource exploration (Sub-bottom profiler)
- Location and navigation (Inertial/Dead-Reckoning, Acoustic, Geophysical), where Inertial can be classified as IMU and INS
- Communication (Fiber Optic, Acoustic, RF, Visible Light)

Other technologies: Inertial Navigation Sensors (INSSs), Doppler Velocity Log (DVL), Side Scan Sonar, MultiBeam Synthetic Aperture Sonar, Pipetrackers, Long/Short/UltraShort Base Lines.

Limitation: usage of the **Global Navigation Satellite System (GNSS)**, due to the physics of the marine environment, that cannot be exploited underwater due to electromagnetic wave dissipation.

Several Underwater assets are the (X-L)**UUVs/AUVs**, **ROVs**, **UIDs**, **MUMs** both experimental and available on the market.



Autonomous Underwater Vehicle (AUV):
(Credit: Rob Robbins/NSF)



Large Unmanned Underwater Vehicle
(LUUV) (Credits by DRASS)



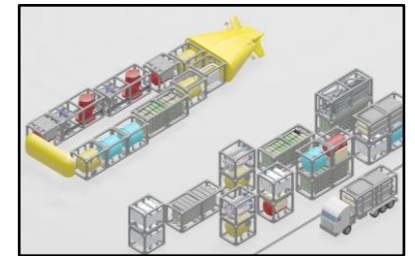
Hydrone ROV/AUV underwater
vehicle (Credits by SAIPEM)



EELUME ROBOT
(Credits by Kongsberg)



Underwater Intervention Drone – UID
(Oceaneering® - Stinger®)

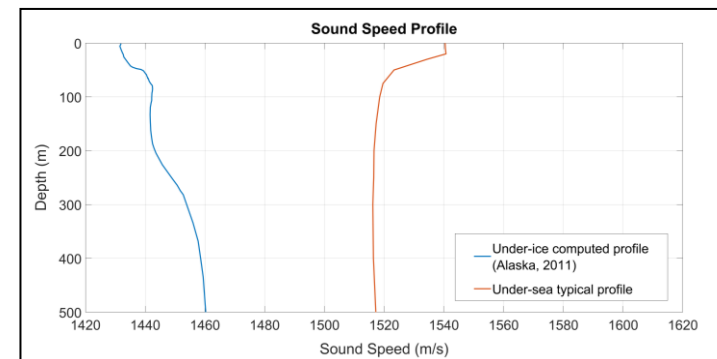


MUM base and mission modules
(©thyssenkrupp)

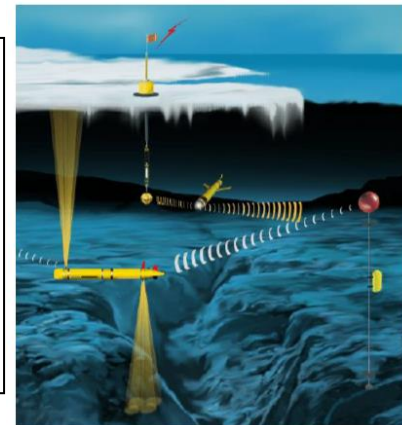


Current challenges in the underwater environment

- **GNSS unavailability under-water:** AUV dependence from a support vessel, both in terms of navigation and battery life.
- Usage of solutions having an impact on the maritime ecosystem and disturbance to marine fauna.
- Expensive and polluting motherships
- The **range of Long BaseLine (LBL)** systems is significantly less than the desired one;
- The **accuracy of LBL systems** is significantly less than the desired one, especially in case of close intervention. So, the intervention of a support vessel is still required and necessary;
- The **availability of support vessel** (due to legal frameworks, raise costs) is subjected to market conditions;
- **Magnetometers** are not good for depth of burial;
- Dead-reckoning (DR) **position drift** estimated at 8 mt/4000sec
- Ice rapid change and movement in arctic areas
- Different sound speed profiles with depth & under-sea/ice scenario
- There is a **PNT reliability** problem → Often AUV/UUV get lost.

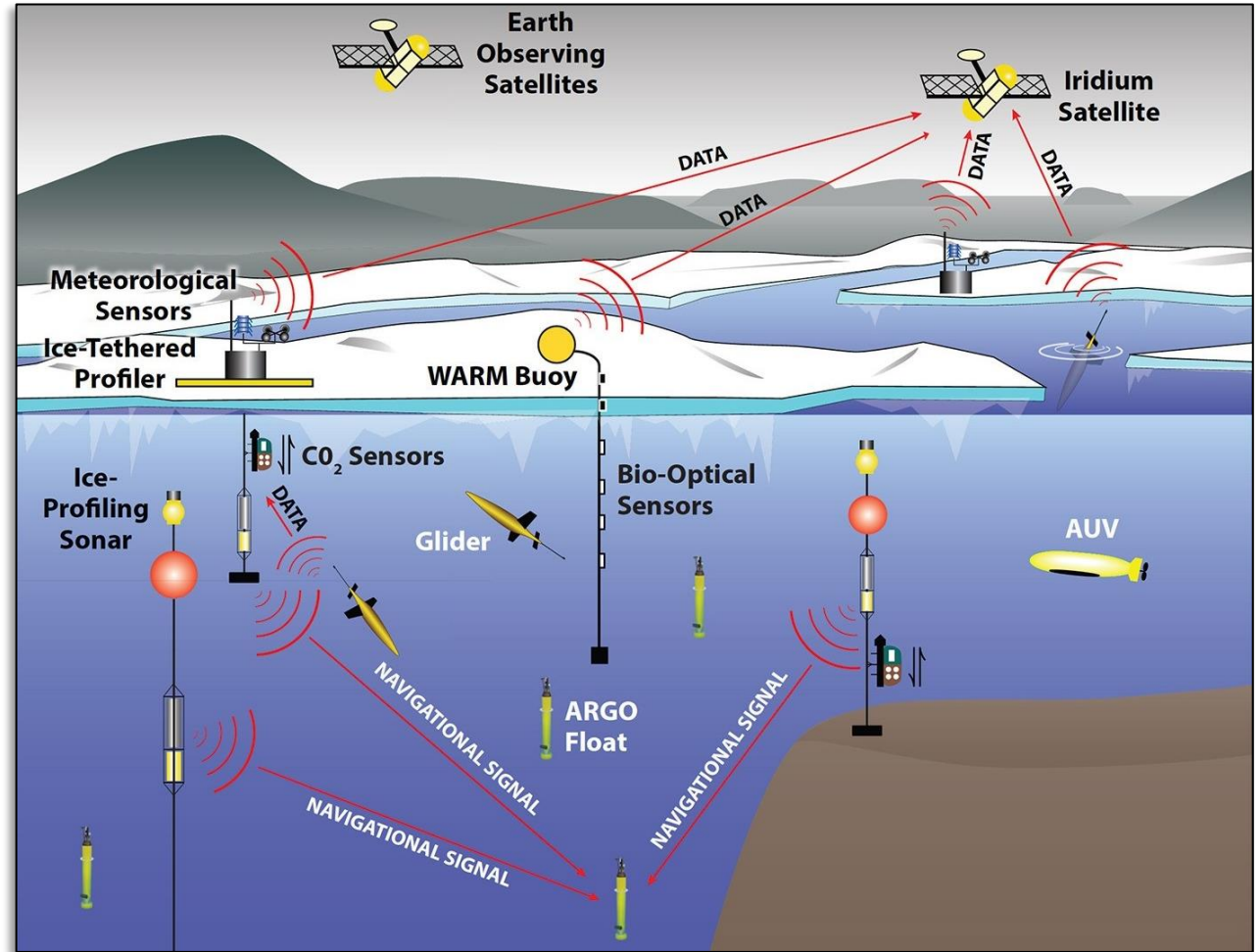


- Comparison between underwater (typical) and under-ice (ICEX11) sound speed profiles.



Underwater mission planning and operative challenges

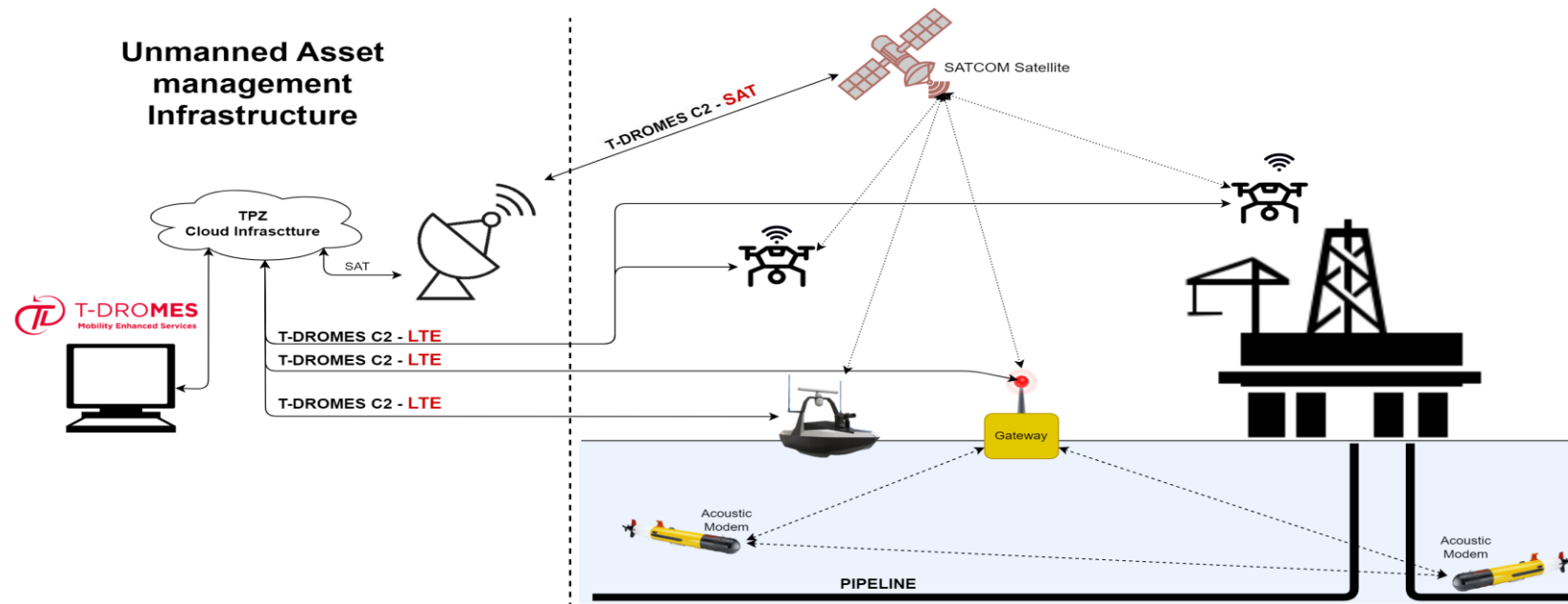
- The accurate knowledge of **ice morphology** is indispensable to perform safe operation, especially when a mothership is involved → usage of **EO satellites** (e.g., *Copernicus*).
- In order to cope with the EO revisit time & responsiveness, **Geo-information techniques** are able to exploit different EO Satellites and fuse different remote sensing imaging sources including also the ones collected by manned aircrafts and Unmanned Aerial Vehicles (UAVs) equipped with cameras, lidars, etc.
- The second fundamental role of satellite observations is namely **ranging observations**. Underwater assets exchange signals with each other. Some among them are characterized by a surface part, out of the water (e.g., the WARM buoy). There it is possible to get a data link with a satellite.



Technologies for autonomous Arctic Ocean observing. Red lines mark examples of underwater acoustic navigation and communication paths and satellite telemetry for instruments on the surface. (C.M. Lee, et al. "Emerging technologies and approaches for in situ, autonomous observing in the Arctic", 2022)

Underwater mission planning and operative challenges: Telespazio Multi-modal unmanned Fleet Asset Management for UCI

- The involved unmanned assets require an integrated C2 (Command & Control) platform
- The necessity is to have a centralized architecture for manage the entire aerial and underwater unmanned drone formation in a **cooperative way**
- **TPZ T-DROMES** is a modular infrastructure platform, scenario independent that can be used to accommodate the **C2, Fleet management & Content delivery platform**
- Allow the infrastructure monitoring operator to plan automatic surveillance missions and real-time control all involved systems



Conclusions

- Installing, Operating, Inspecting/Monitoring activities in UCIs requires all the **enabling subsea technologies** like INS, DVL, Magnetometers, Side Scan Sonar, MultiBeam Synthetic Aperture Sonar, Pipetrackers, Long/Short/UltraShort Base Lines.
- **High cost of operation and** LBL network of beacons deployment; **optimization with continuous and raising adoption of AUVs** in many (not yet all) operational scenarios, so the development and improvement of ROVs and UIDs, Docking Stations along with increasing battery performance for higher endurance.
- Main aspects to tackle are the **PNT accuracy** in relative navigation provided **by the main sensors** above reported, that shall achieve **submeters performances of a few cm**, and undersea assets absolute navigation.
- To face all the challenges presented, e.g., GNSS under-ice unavailability and ice-movement and multipath, different solutions and technologies can be proposed also on-board the Autonomous Underwater Vehicles (AUV) with High precision clocks for internally stable and accurate time (short-term stability less than 10⁻¹¹ at 1000s with Chip Scale Atomic Clock (CSAC) to avoid high frequency periodic resurface.
- **TELESPAZIO** is working to improve the UCI solutions to reduce the AUV dependence from the Mother vessels both in terms of positioning and battery lifetime, involving space assets with reference **buoy or mobile gateways for SatNav/SatCom access**, so reducing the costs and green impact of involved support vessel.



THANK YOU
FOR YOUR ATTENTION

telespazio.com

Giuseppe Tomasicchio

Research, Digital & Innovation

Head of RDI System Engineering & Design Authority

Space Exploration & Space Station services Innovation Domain Manager

giuseppe.tomasicchio@telespazio.com

Marco Brancati

Senior Vice President of Research, Digital & Innovation

marco.brancati@telespazio.com