

MODULE 5 – PART A: SMART SENSING IN THE BLACK SEA OCEANOGRAPHY



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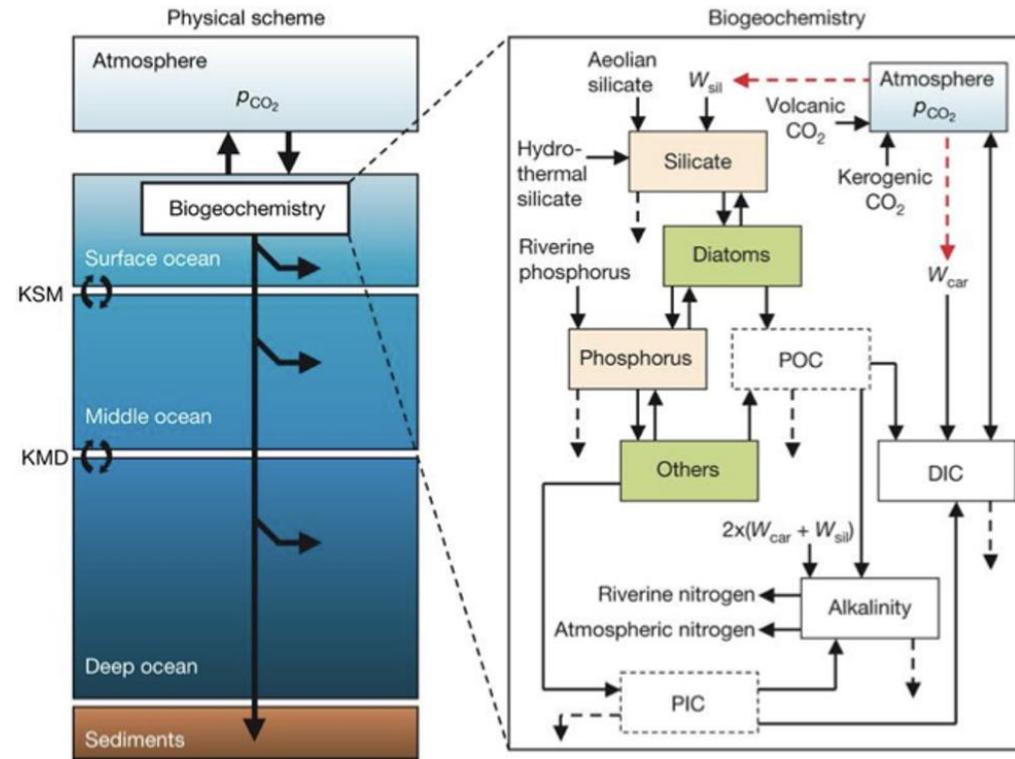
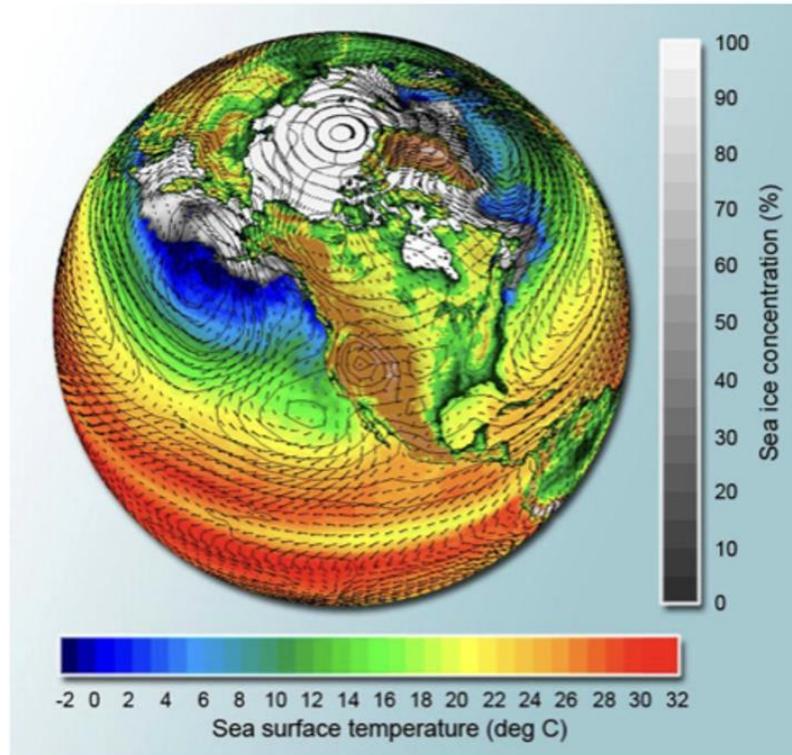
METU Institute of Marine Sciences



*This project has received funding from the European Union's Horizon 2020
Research and Innovation Programme under Grant Agreement No:101000240.*

- WHY IN SITU AND SMART MONITORING OF MULTI-STRESSORS?
- BASIC PRINCIPLES OF IN SITU SENSING
- EXAMPLE RECENT TECHNOLOGIES
- HOW BRIDGE-BS ADVANCED SMART TECHNOLOGIES IN THE BLACK SEA?

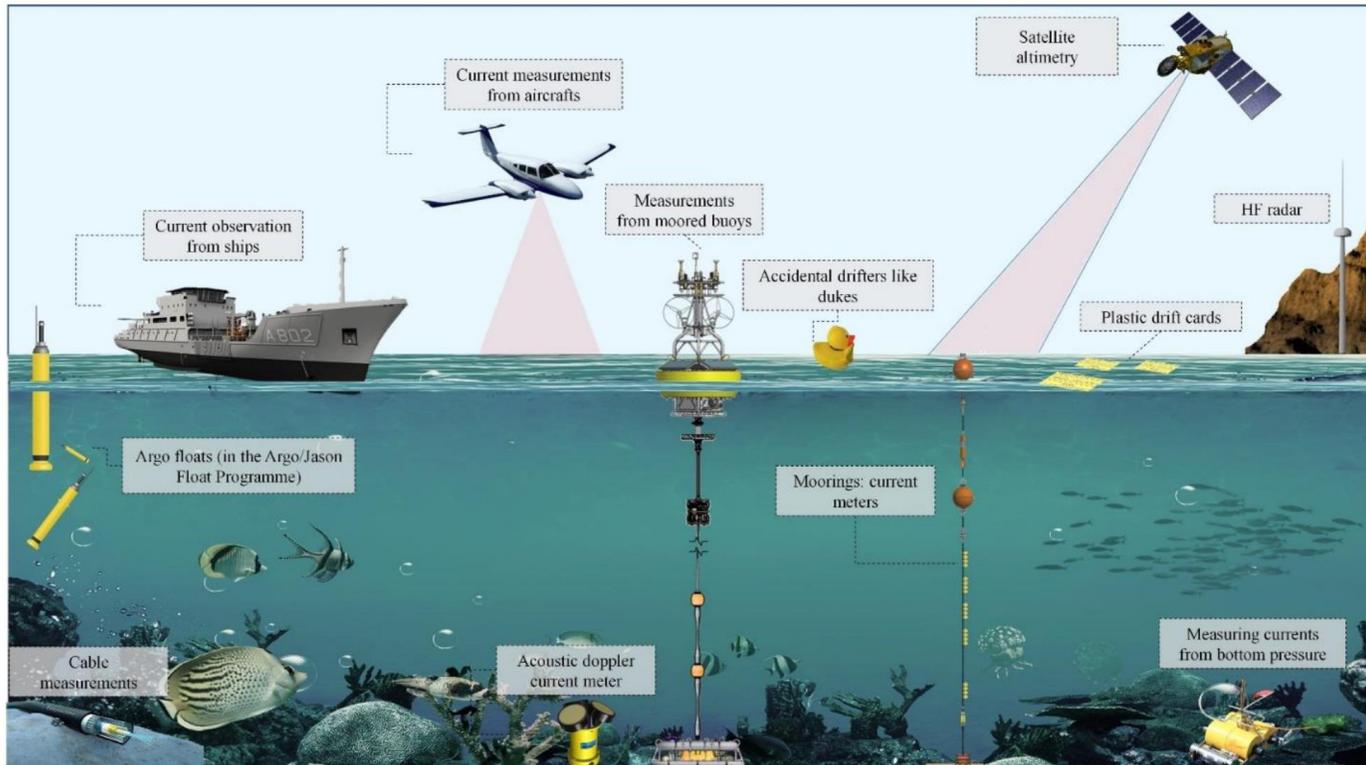
WHY IN SITU AND SMART MONITORING OF MULTI-STRESSORS?



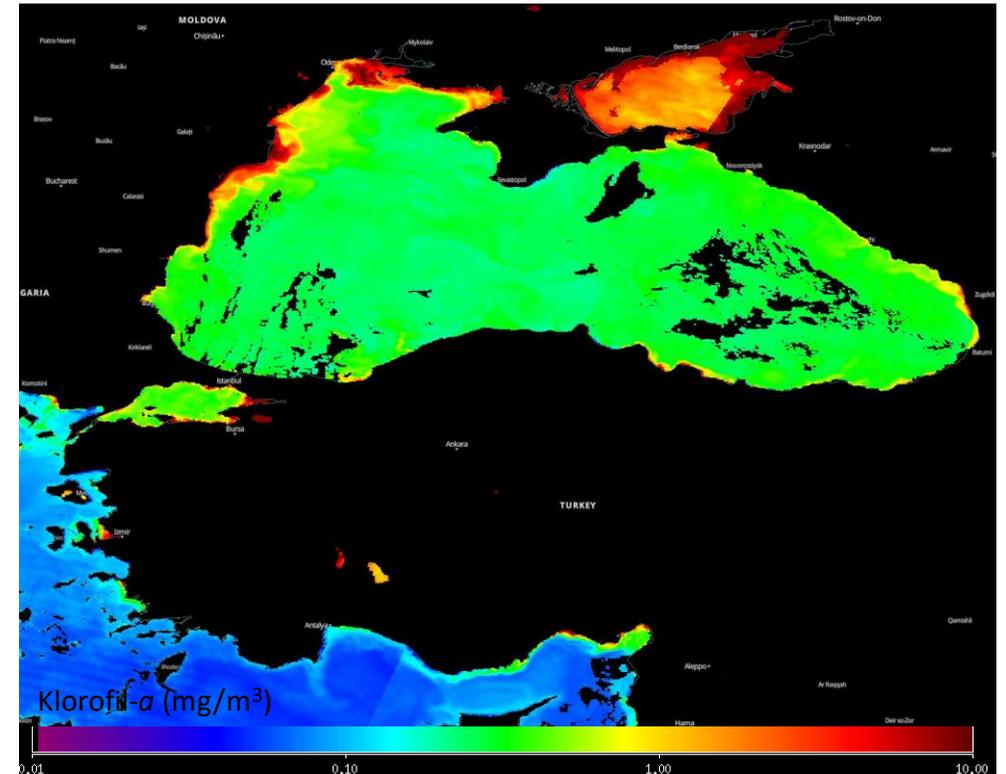
- Seas are often perceived in **2D** because of the ‘map representation’.
- Depth (**the 3rd D**) is often counter-intuitive so often neglected in public and policy opinion.
- Ocean interiors are under-observed due to challenging conditions but they are vital for **element cycles**, represent a **large habitat**, **storage of carbon**, **recycling of pollutants**.

WHY IN SITU AND SMART MONITORING OF MULTI-STRESSORS?

- Great deal of progress in surface ocean monitoring by surface-deployed and remote sensing tools
- Remote sensing can see **top 2m** but average ocean is **3800m deep**
- Black sea is **2200m deep!** Need **underwater tools** capable of withstanding specific **Black Sea conditions!**



Amani et al. 2022



TEMPORAL AND SPATIAL SCALES OF PROCESSES ARE VAST!

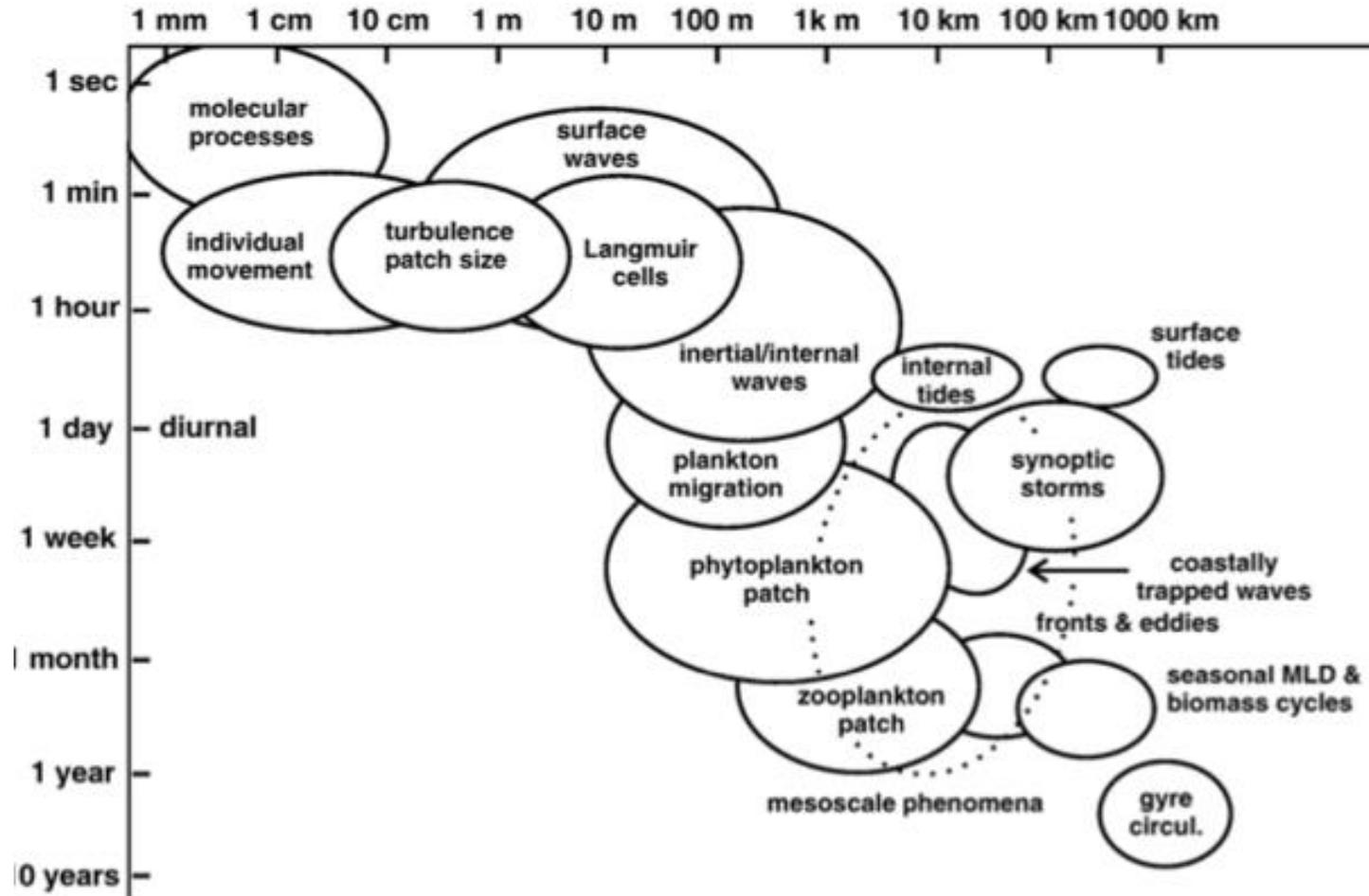


Fig. 1. Temporal and spatial scales of ocean processes. Modified after Dickey (2001).

DISCRETE SAMPLING VS IN SITU MEASUREMENT

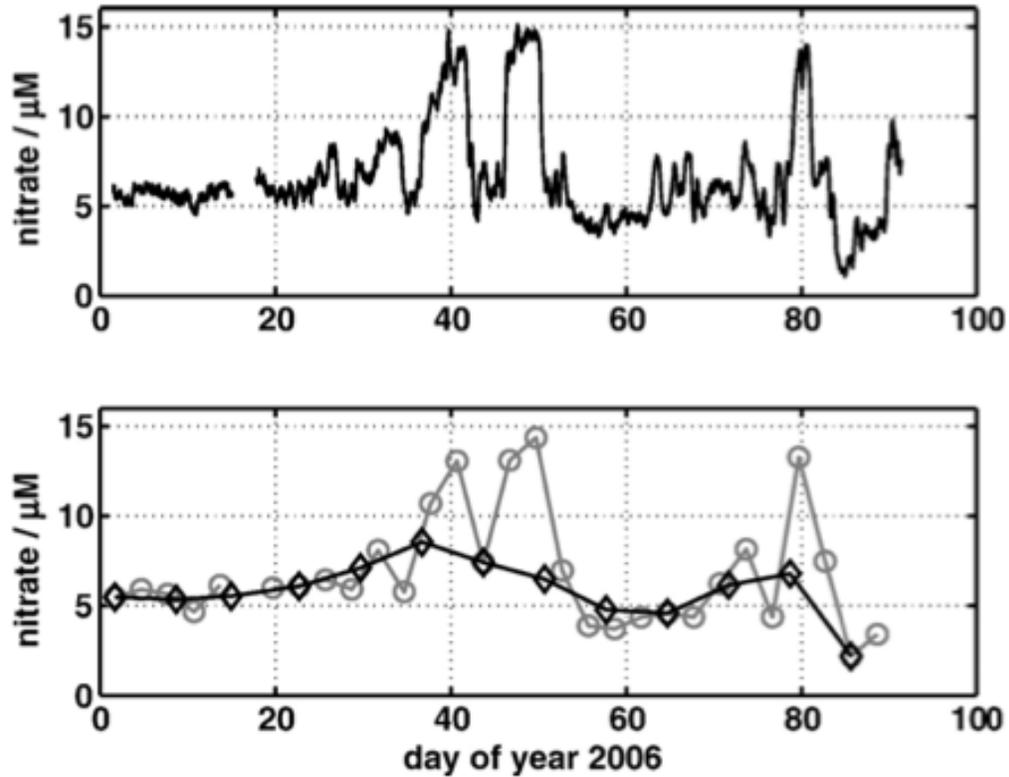
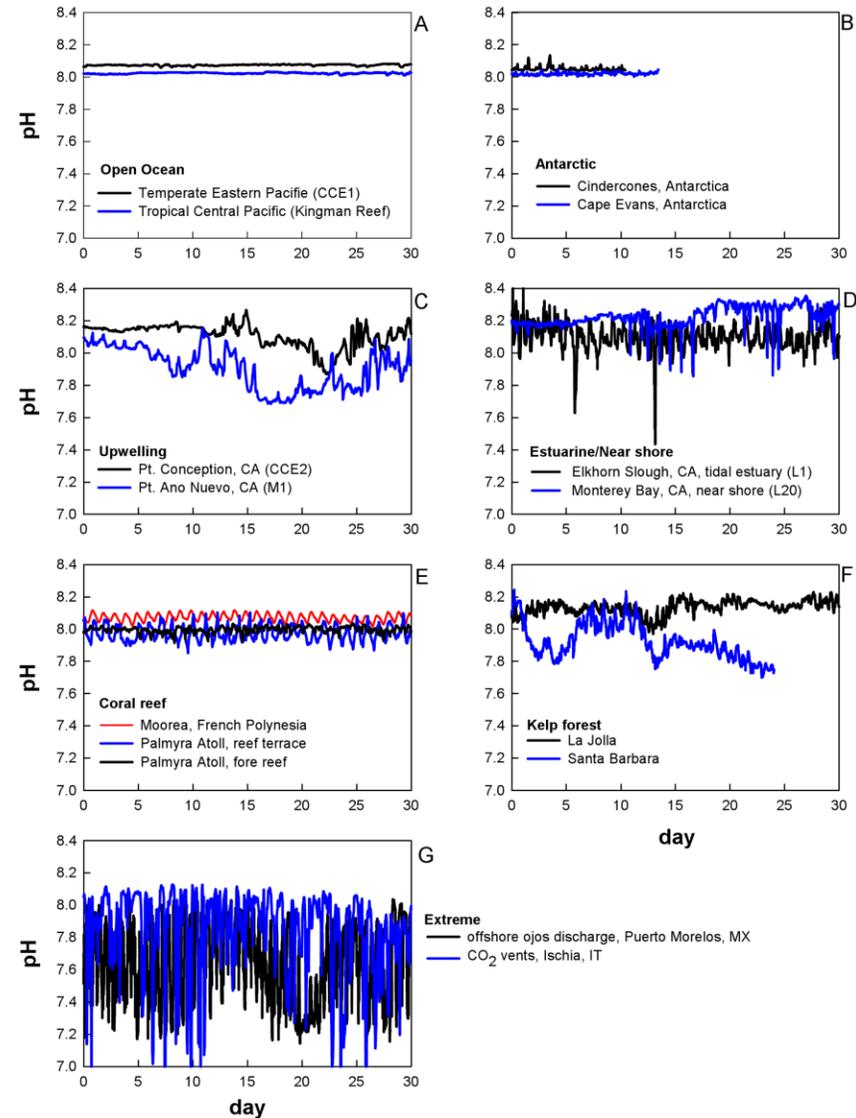
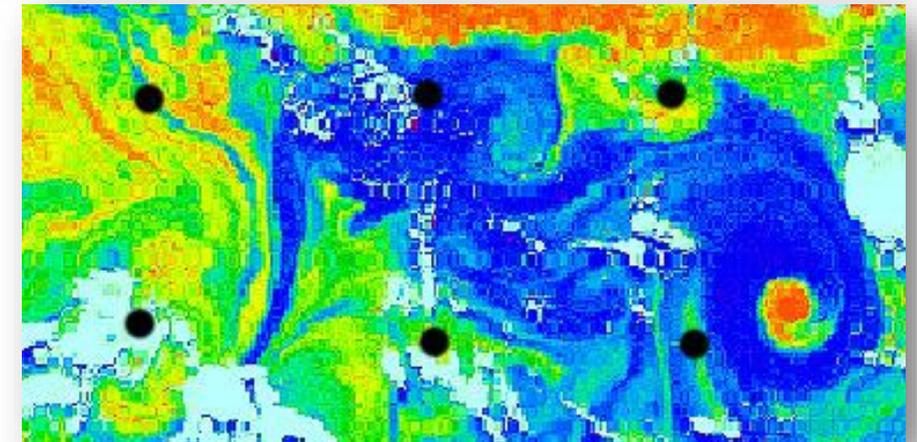


Fig. 2. Example for undersampling problem. Upper panel shows hourly nitrate data from MBARI mooring M1 as measured by the ISUS instrument for the first 91 days in 2006. Lower panel shows the same data sampled at 7 day intervals (black diamonds) and 3 day intervals (grey circles). Data downloaded from http://www2.mbari.org/coletti/m1_isus.cgi and used with permission.

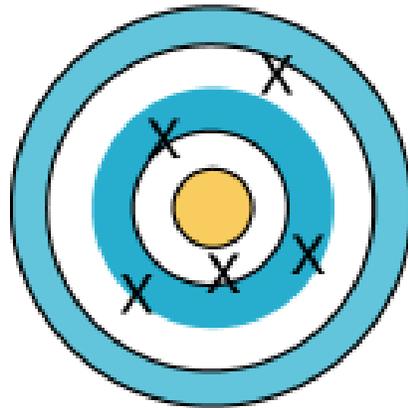


- Under-sampling leads to misleading distributions (time & space)
- Example of a chlorophyll survey in coastal waters
- Six measurements over about 200 square Km
- Real distribution from satellite is:

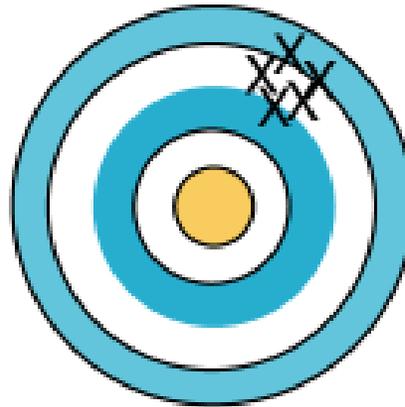
Further example is bacteria in natural water, higher concentrations close to a food source (mm to μm space scales). Typically take samples of hundreds of mL, so variability is lost!



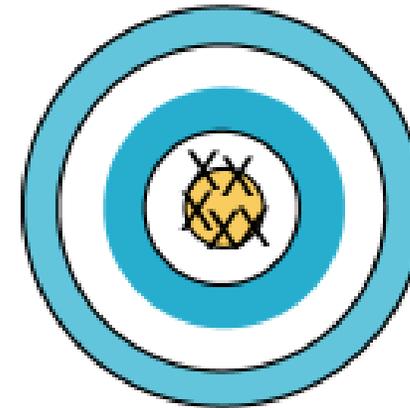
High precision and accuracy are what we aim to achieve in analytical measurements: an analogy with archery practice is useful, where the bulls-eye is the true value:



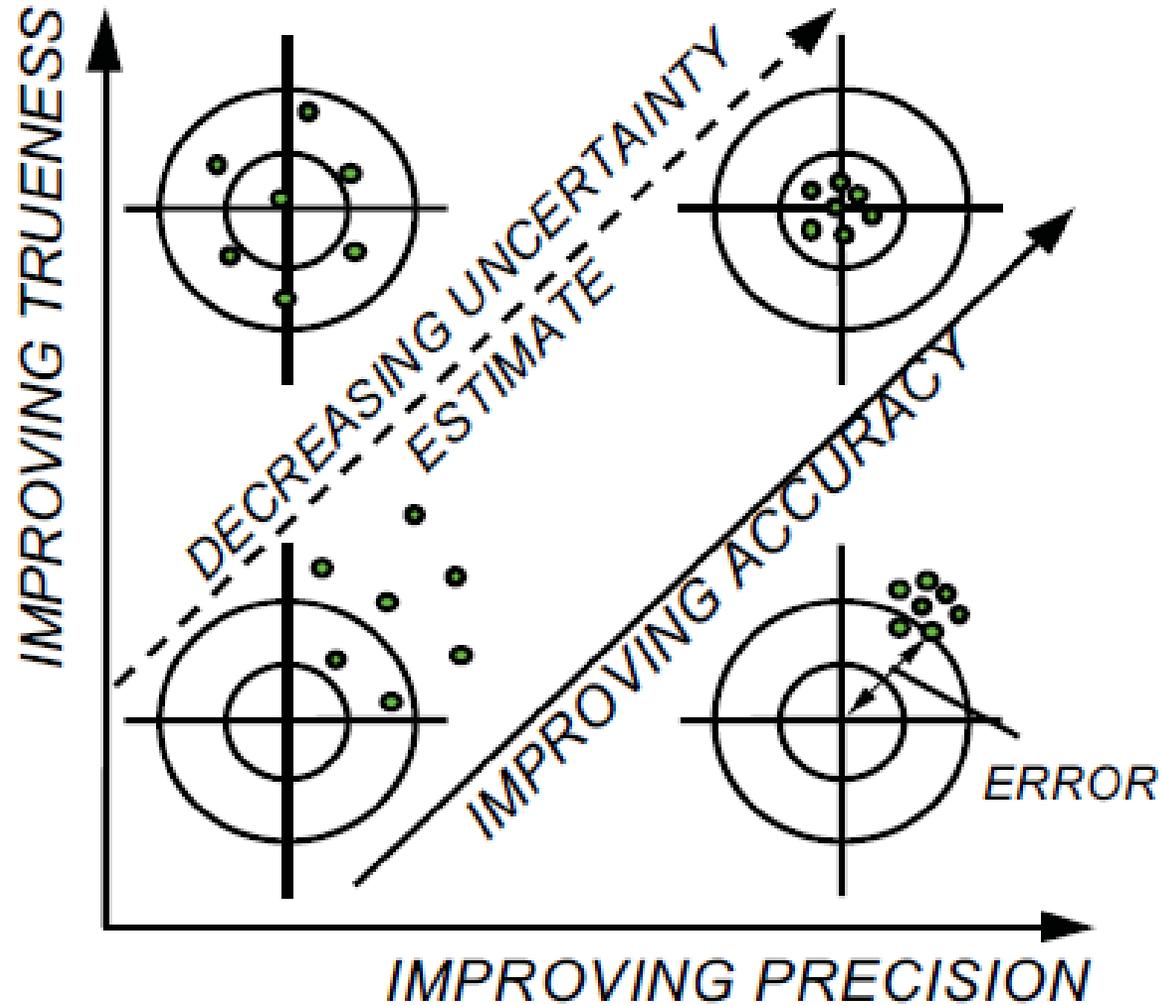
Accurate but
low precision



Precise but
inaccurate

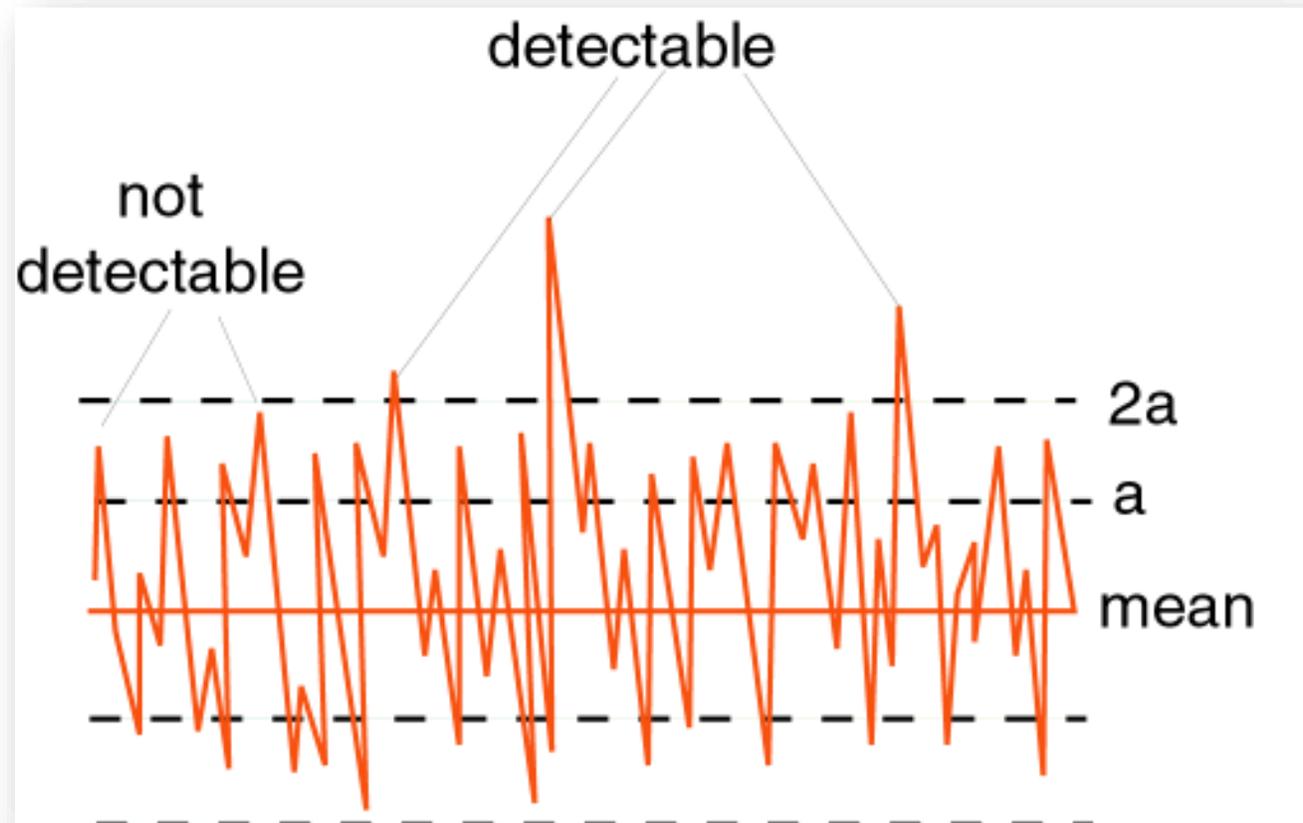


precise and
accurate



The DL= smallest amount of an analyte that can meaningfully be determined

- Essentially 'Signal to Noise' ratio- "Noise" includes instrumental variability plus changes in blank
- If instrumental noise major source of variability can use 2 times the baseline noise as a crude estimate of DL



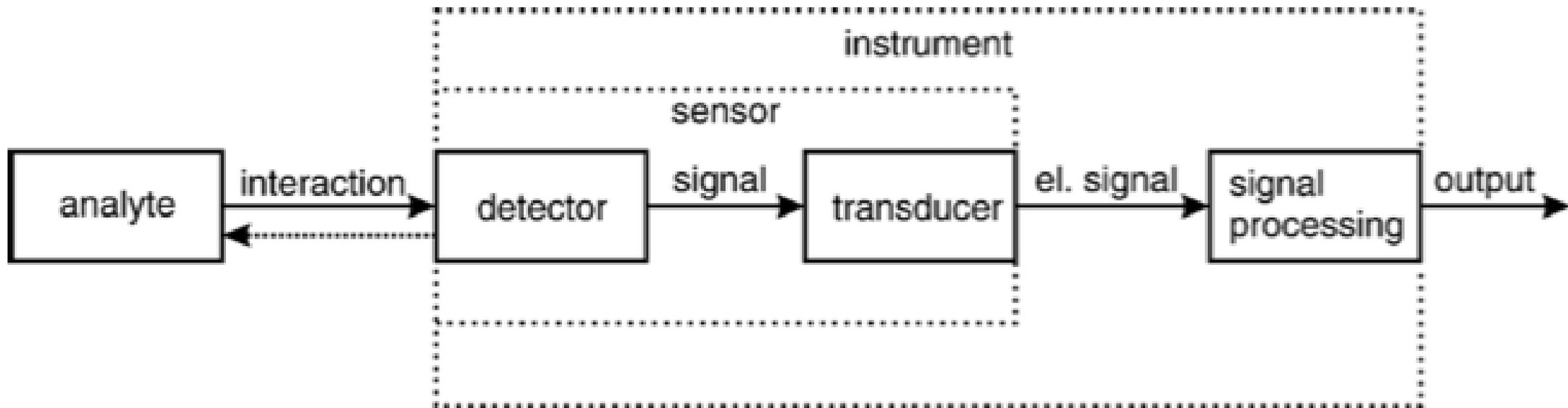


Table 1 Technology readiness levels (from [3])

1	Basic principles of technology observed & reported
2	Technology Concept and/or Application Formulated
3	Analytical and Laboratory Studies to validate analytical predictions
4	Component and/or basic sub-system technology valid in lab environment
5	Component and/or basic sub-system technology valid in relevant environment
6	System/sub-system technology model or prototype demo in relevant environment
7	System technology prototype demo in an operational environment
8	System technology qualified through test & demonstration
9	System technology 'qualified' through successful mission operations

Parameter	Sensor Technology	Status	Trends
Salinity	1) Conductivity, temperature and pressure 2) Refractive index	1) Mature, widely used 2) Proof of concept complete	1) Miniaturisation, cost reduction, mass deployment
Water velocity	1) Current meter 2) Acoustic Doppler Current Profiler	Mature	Miniaturisation, deployment on vehicles
Bathymetry	Sonar	Mature	Improved resolution
Optical properties	Optical sensor	Mature	Costs and size reduction, multispectral
Animal abundance	1) Sonar 2) Passive acoustics	Mature	Improved resolution and range, cost reduction, miniaturisation
Micro organisms	1) Fluorescence 2) Cytometer 3) Nucleic acid analyser	1) Mature 2) Mature but large 3) Mature but very large	1) multispectral, time resolved (physiology) All: miniaturisation

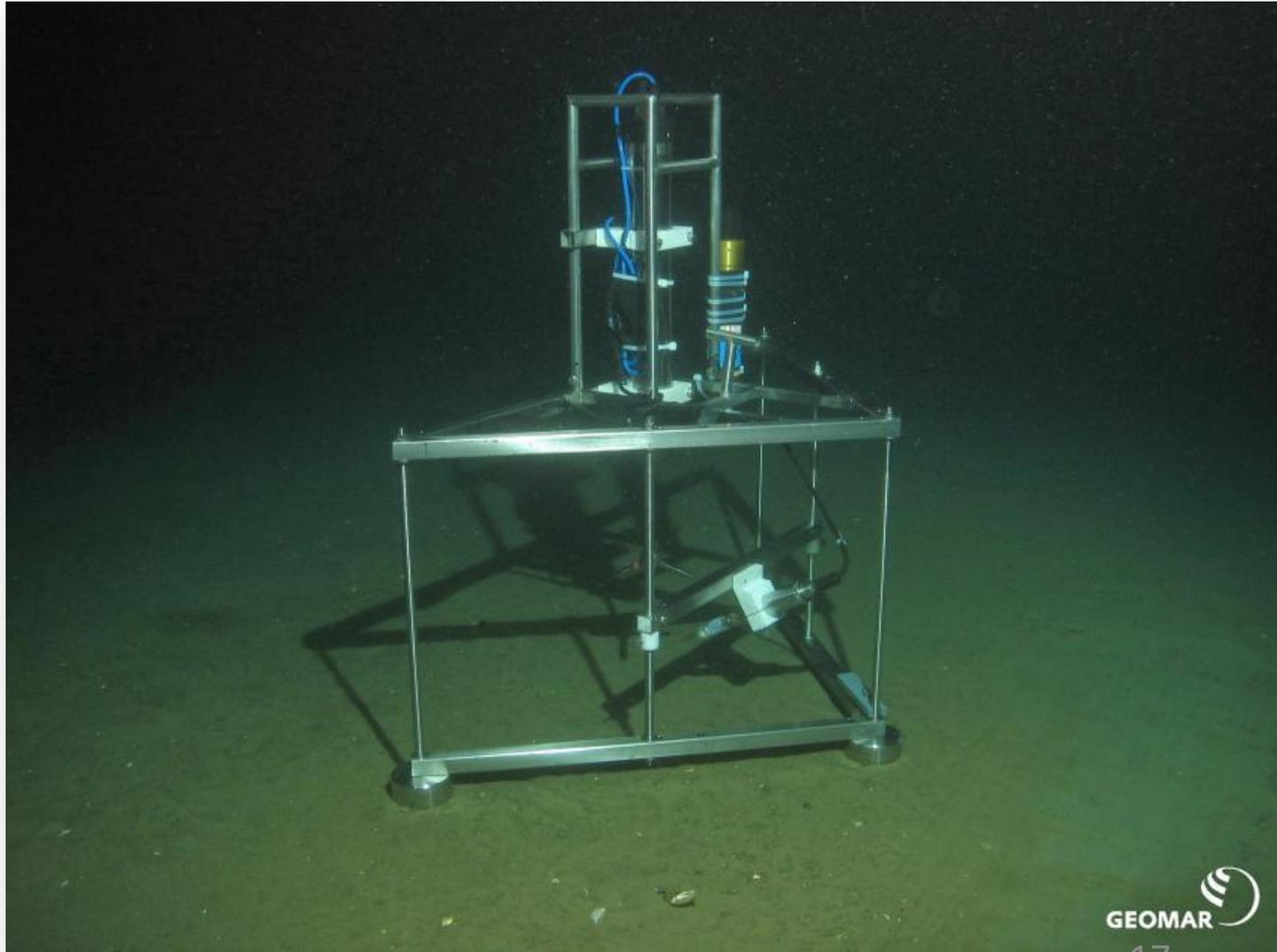
Parameter	Sensor Technology	Status	Trends
Inorganic chemistry	<ol style="list-style-type: none"> 1) Spectroscopy 2) Optodes 3) Reagent based analysers 4) Electrochemistry 	<ol style="list-style-type: none"> 1) Only nitrate mature (LOD ~400nM) 2) pH and ammonia developing 3) Mature but large, expensive and complex 4) Mature – esp. Metals and sulfur. Poor stability 	<ol style="list-style-type: none"> 1) Widespread deployment 2) Improved performance 3) Miniaturisation e.g. Lab on a chip technologies 4) In situ calibration, reagent free detection
Organic chemistry	<ol style="list-style-type: none"> 1) Fluorescence 2) Biosensing 3) In situ mass spec 	<ol style="list-style-type: none"> 1) Mature, subject to cross sensitivity 2) Prototype 3) Mature but large and ~100W, small molecules 	<ol style="list-style-type: none"> 1) Miniaturisation, multispectral 2) In situ, aptamers 3) Miniaturisation, inlet systems
Gases	<ol style="list-style-type: none"> 1) Optodes 2) Electrochemistry 3) In situ gas phase spectroscopy 4) In situ mass spec 	<ol style="list-style-type: none"> 1) O₂ mature, CO₂ in development 2) O₂ H₂ mature 3) CH₄ and CO₂ mature 4) Mature but large and ~100 W 	<ol style="list-style-type: none"> 1) Further analytes, improvement in performance 2) Further analytes, stability 3) Performance, miniaturisation 4) miniaturisation

Table 1 Examples of power requirements for oceanographic sensors and communication devices

Instrument	Manufacturer	Voltage/V	Power requirement/mW
Turbidity meter	Seapoint Sensors, Inc.	7–20	24.5 avg, 42 peak
Chlorophyll-a fluorometer	Seapoint Sensors, Inc.	8–20	120 avg, 216 peak
Conductivity, temperature and depth	Ocean Sensors, Inc.	6	1.2 sleep mode, 420 peak
Backscattering meter	Wetlabs, Inc.	7–15	0.6 sleep mode, 560 peak
Wireless temperature probe/transmitter	Madgetech, Inc.	3.3	49.5
Acoustic receiver	Sonotronics, Inc.	3.5	14 standby, 28 peak
Acoustic modem	Teledyne Benthos	14–28	12 standby, 500 active, 20 W transmit



MEASUREMENT OF EXCHANGES AT SEAFLOOR, SAME APPROACH



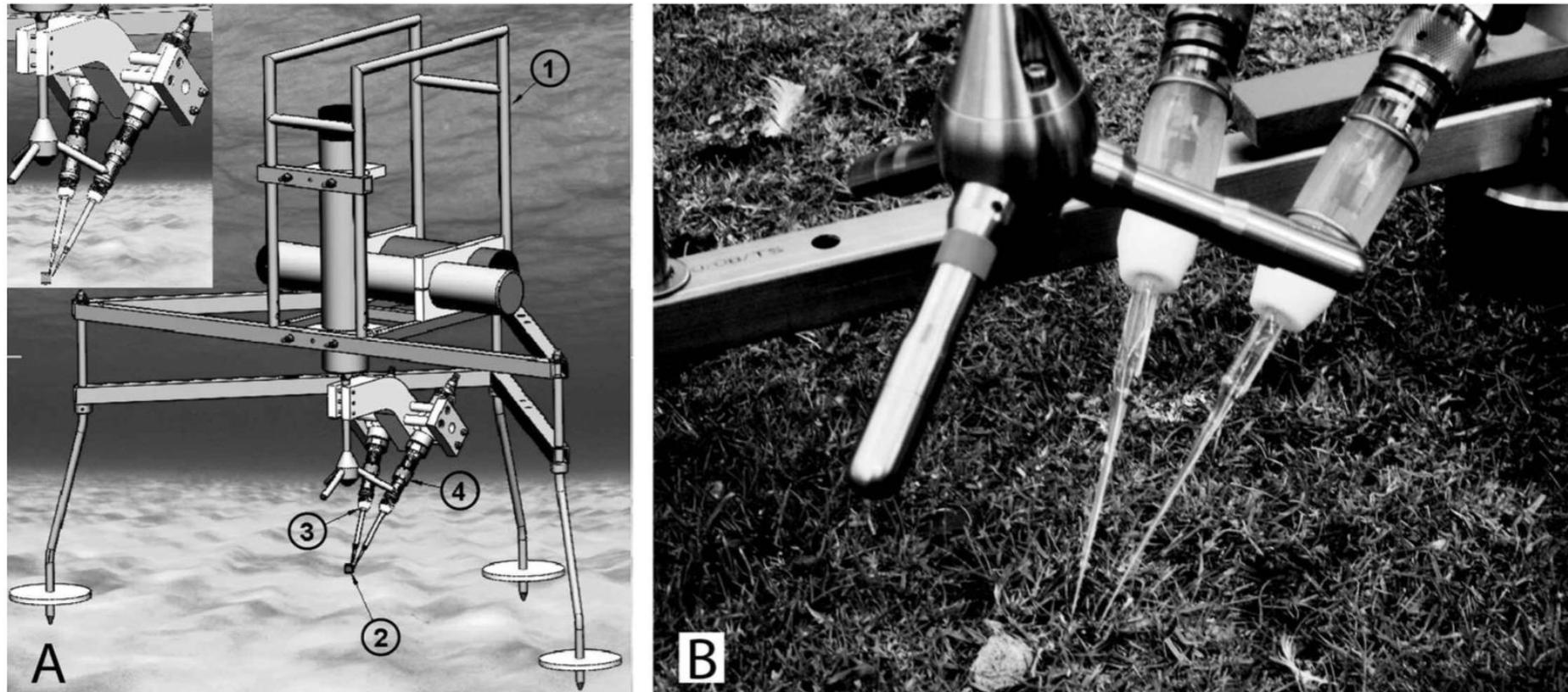
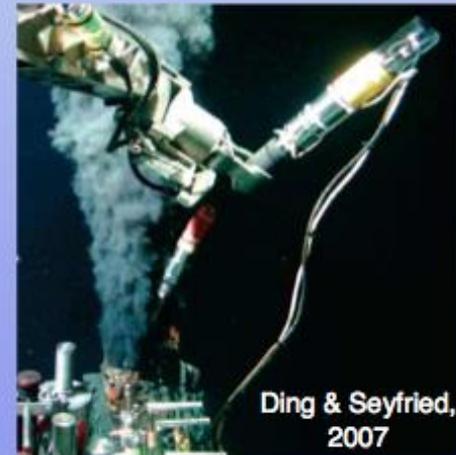
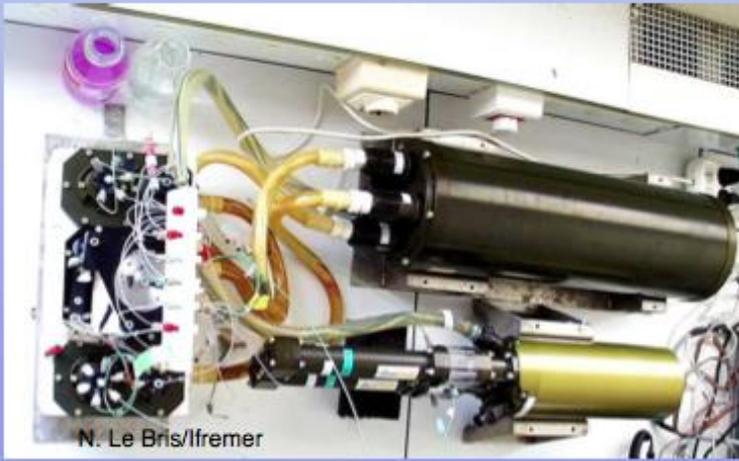
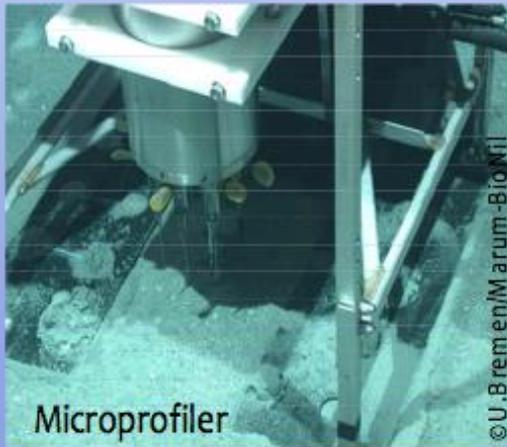
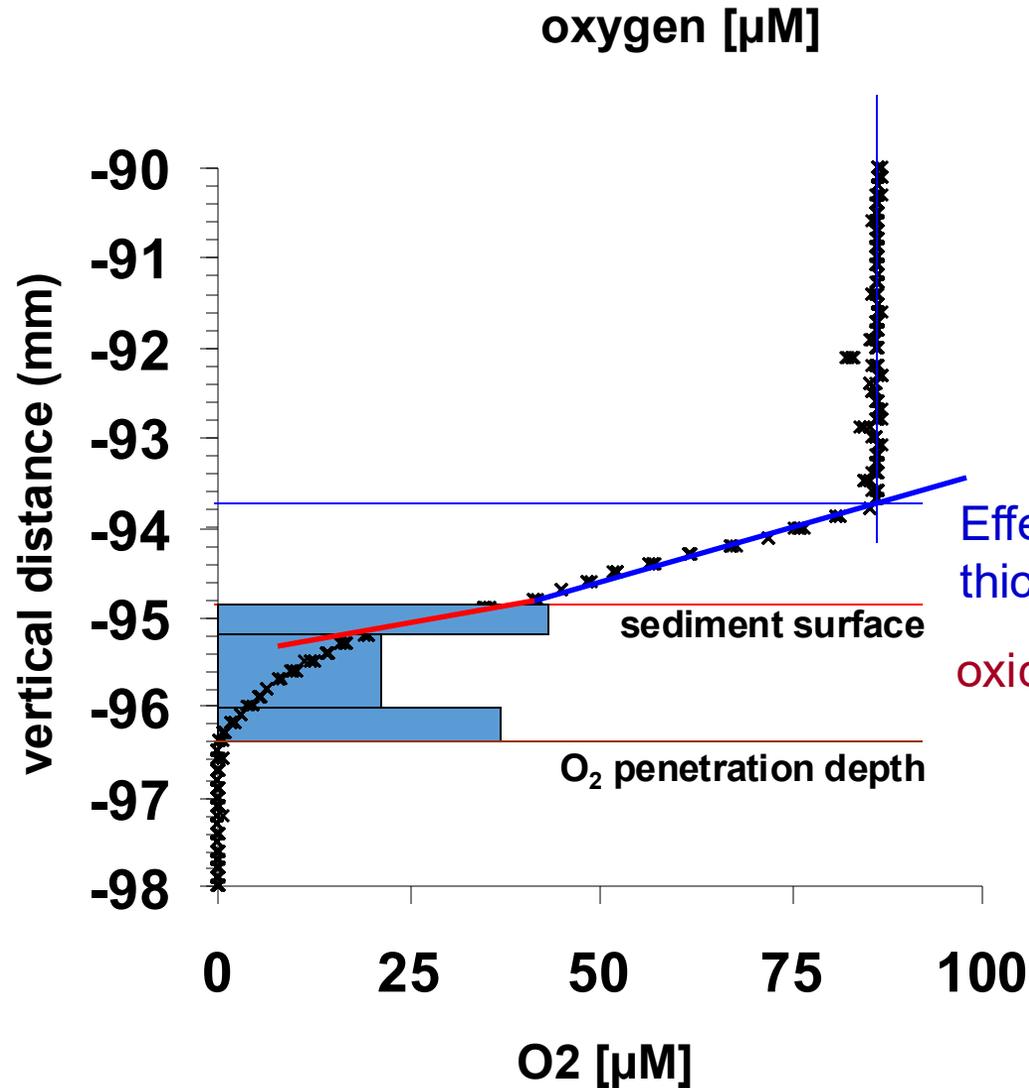


Fig. 1. A) Eddy correlation system shown on an ROV-deployable frame. 1) frame, 2) measurement volume, 3) sensor and sensor holder and 4) amplifier housing and connector. B) Dual O₂ sensor deployed on the same ADV.

- Colorimetry (water, fluids)
- Amperometry (sediments, microbial mats)
- Potentiometry (sediments, mats, water, rock/animal interfaces...)
- Au amalgam voltammetry (sediments, mats, water, rock/animal interfaces...)



80 cm



NOTE

Microsensors perturb DBL thickness (δ_{DBL}) measurements resulting in a 25 – 45 % compression. Hence microsensor derived δ_{DBL} - measurements should be considered as minimum values.

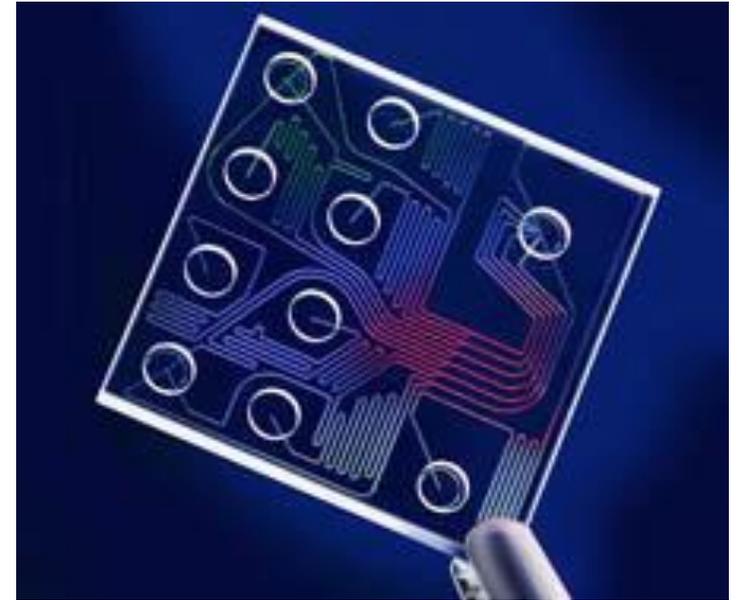
$$\text{DOU} = D_o \frac{dC}{dz}$$

$$\text{DOU} = D_s \frac{dC}{dz}$$

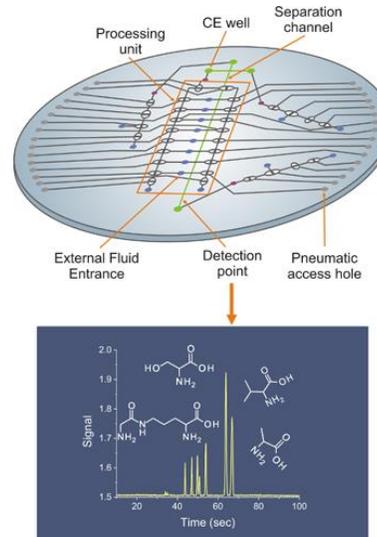
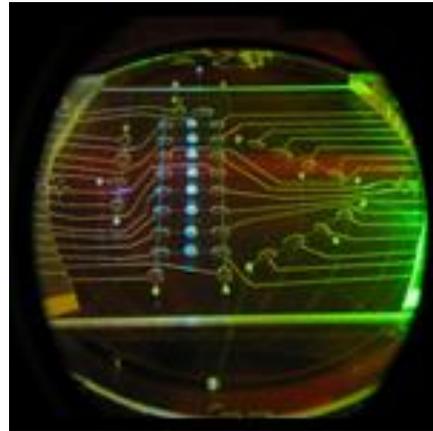
MINIATURIZATION IS THE FUTURE: LAB ON CHIP TECHNOLOGY



*Miniaturization
Autonomy
Integration*



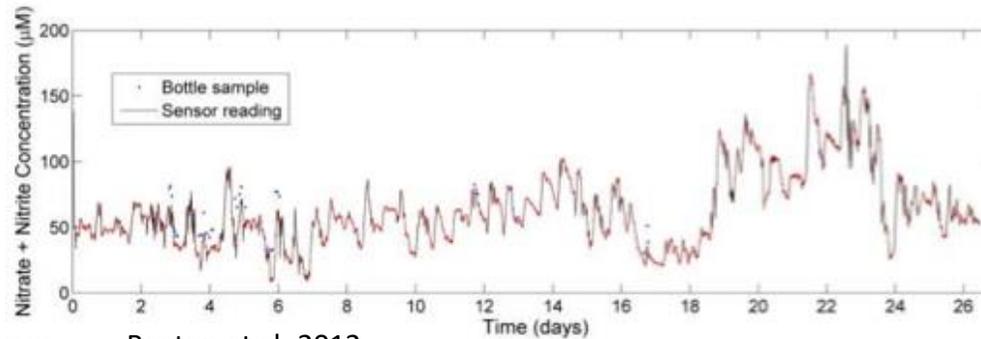
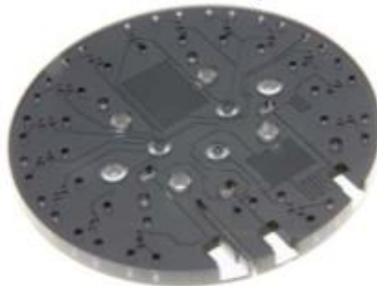
Agilent Tech., Inc.



On-chip capillary electrophoresis

Skelley et al. 2005

Lab on a chip



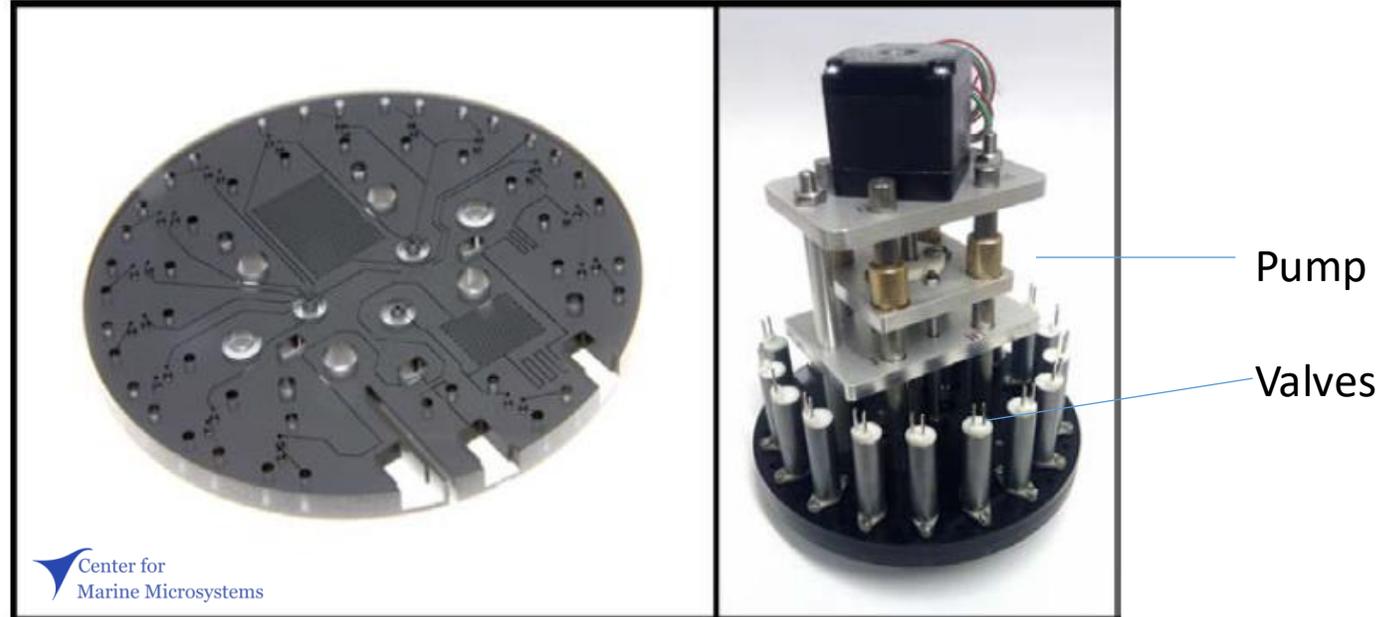
Beaton et al. 2012

Center for Marine Microsystems

National Oceanography Centre
NOC Southampton

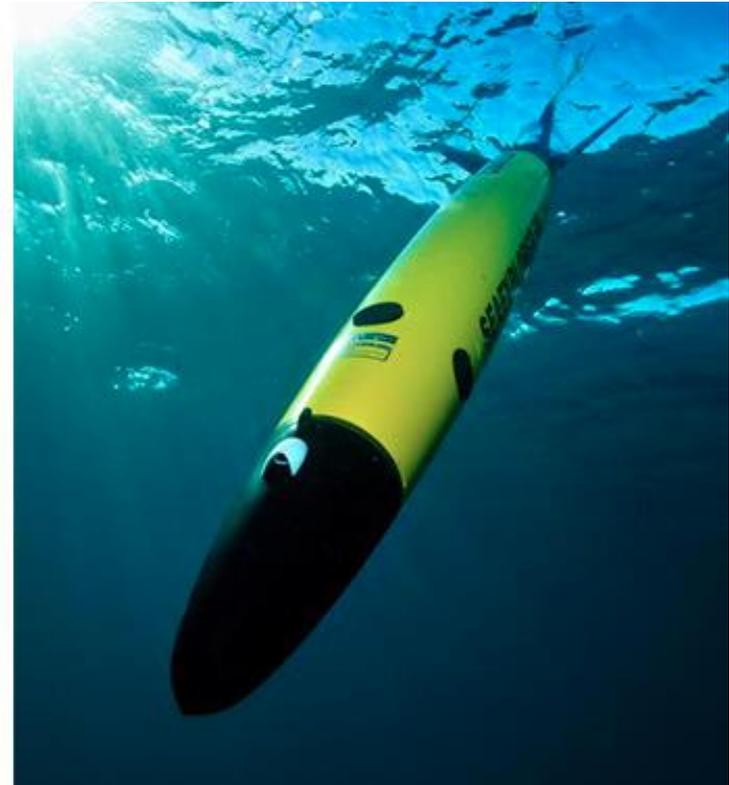
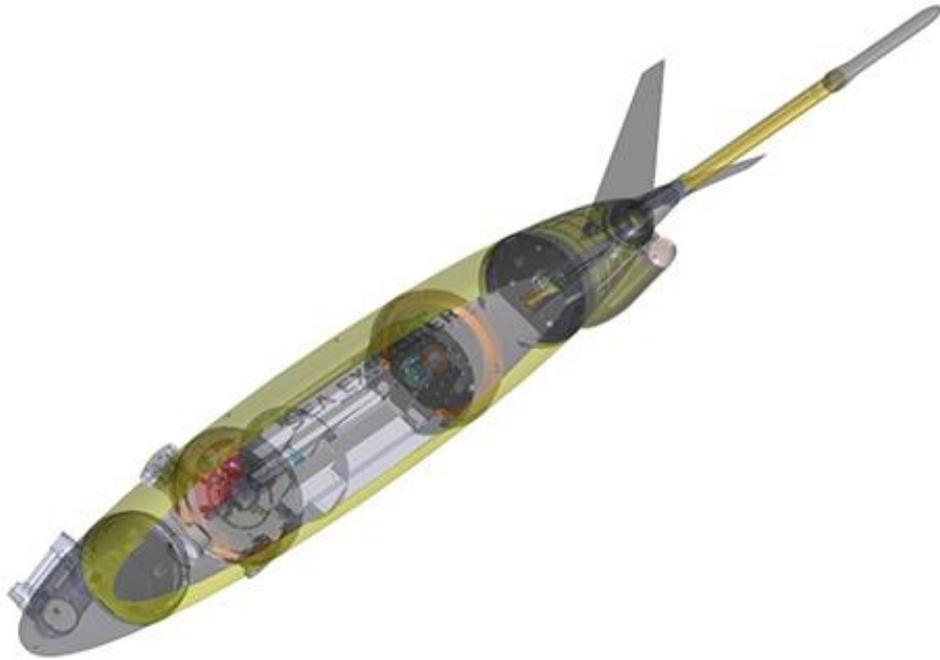


Integrated on-chip valves and custom-designed microfluidics pump:
Peripheral sensor components are still large and need to be smaller



Beaton et al. 2012

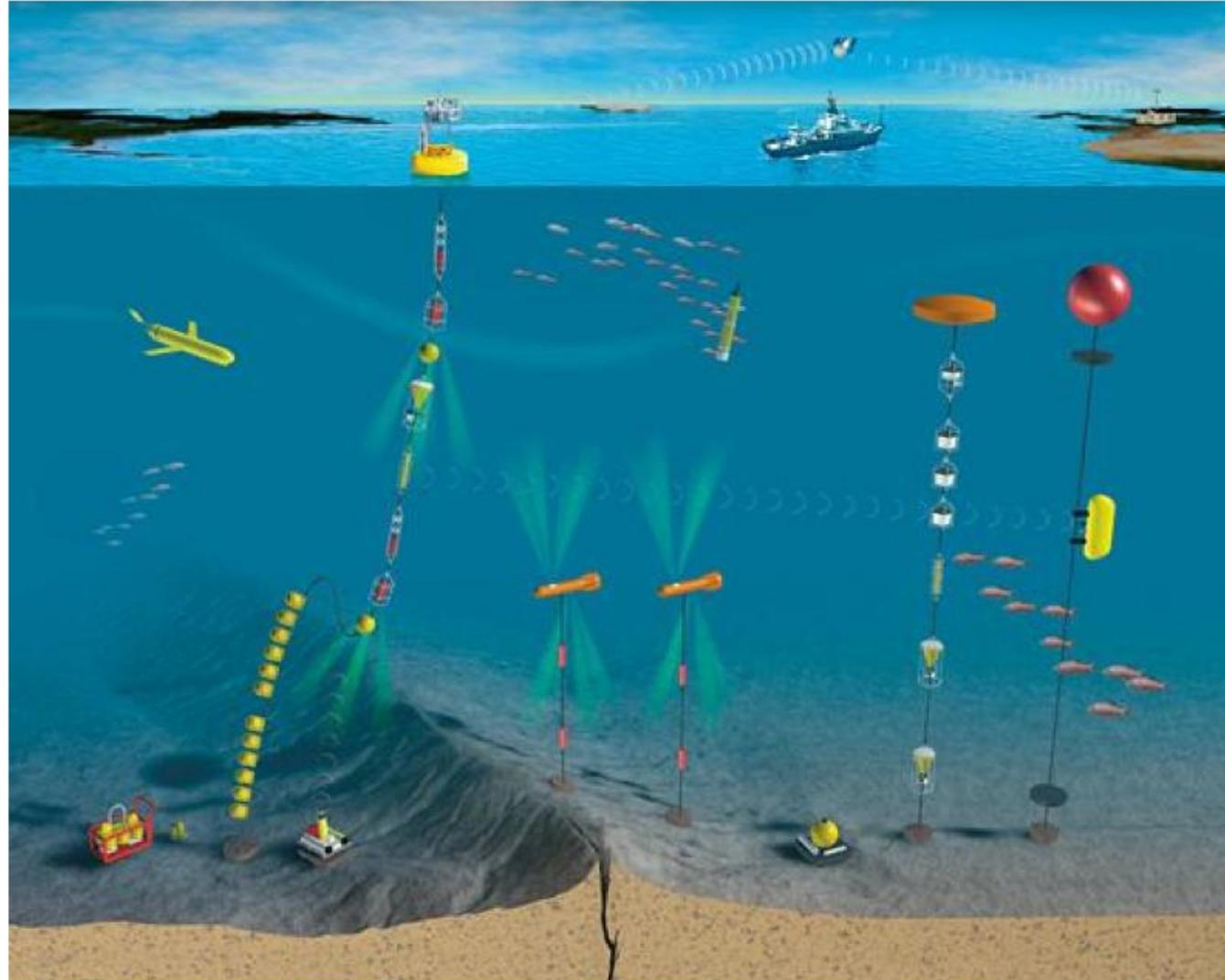
SENSORS: WHERE DO WE GO FROM HERE?



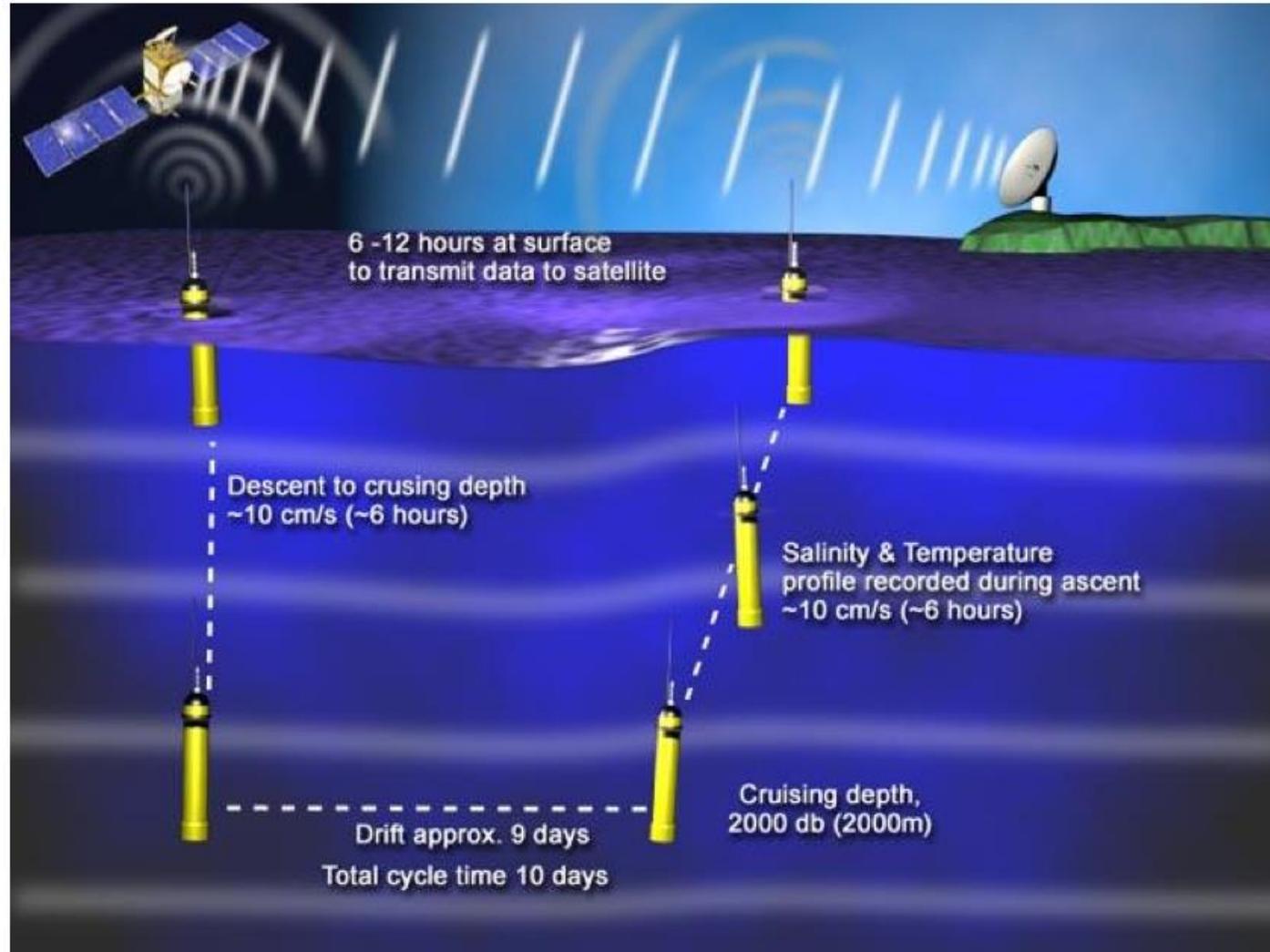
SENSORS: WHERE DO WE GO FROM HERE? AUTONOMOUS PLATFORMS: ARGO/APEX FLOATS

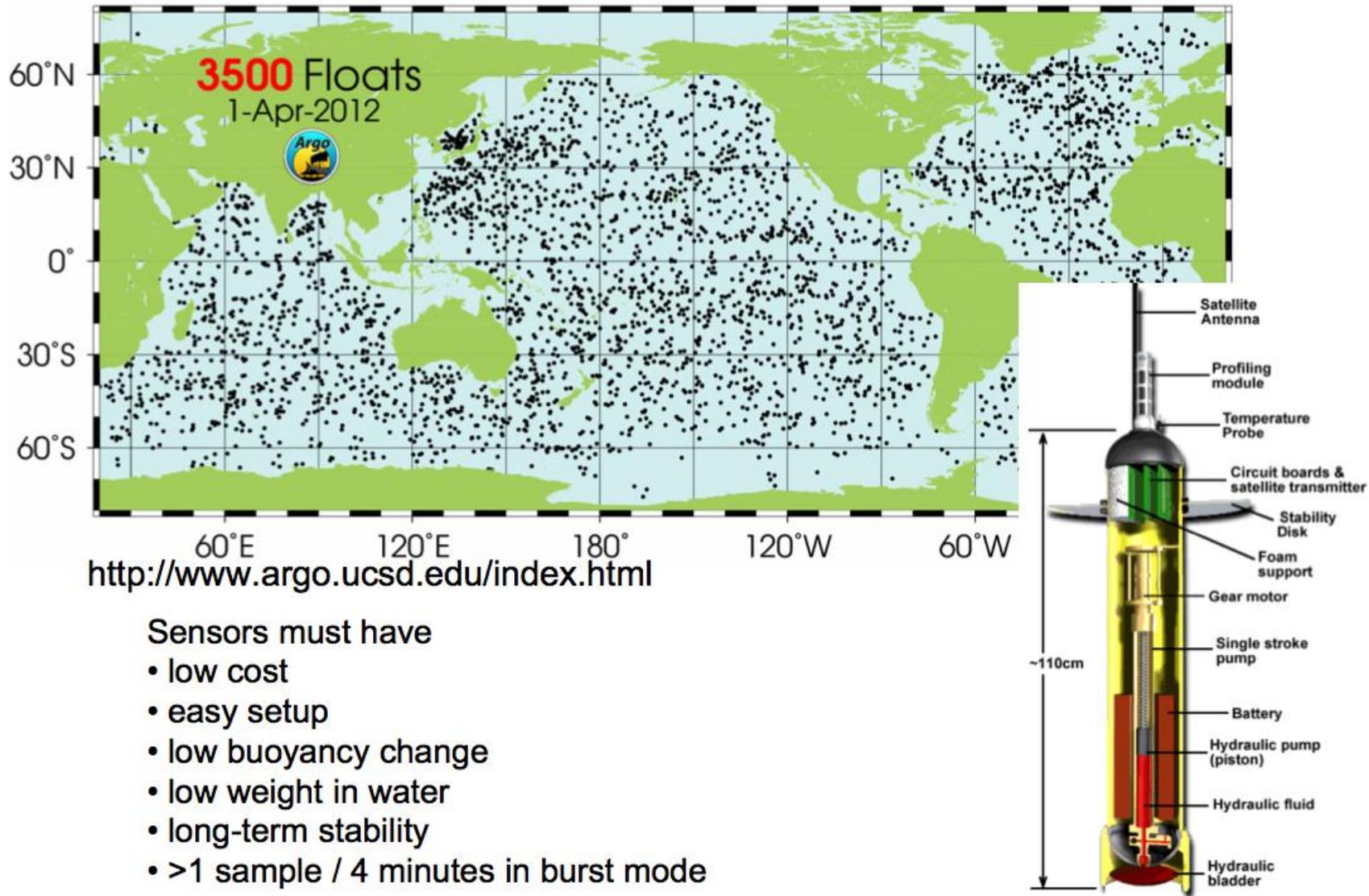


SENSORS: WHERE DO WE GO FROM HERE? OBSERVATION SYSTEMS



A Target platform: Argo – global reach and impact

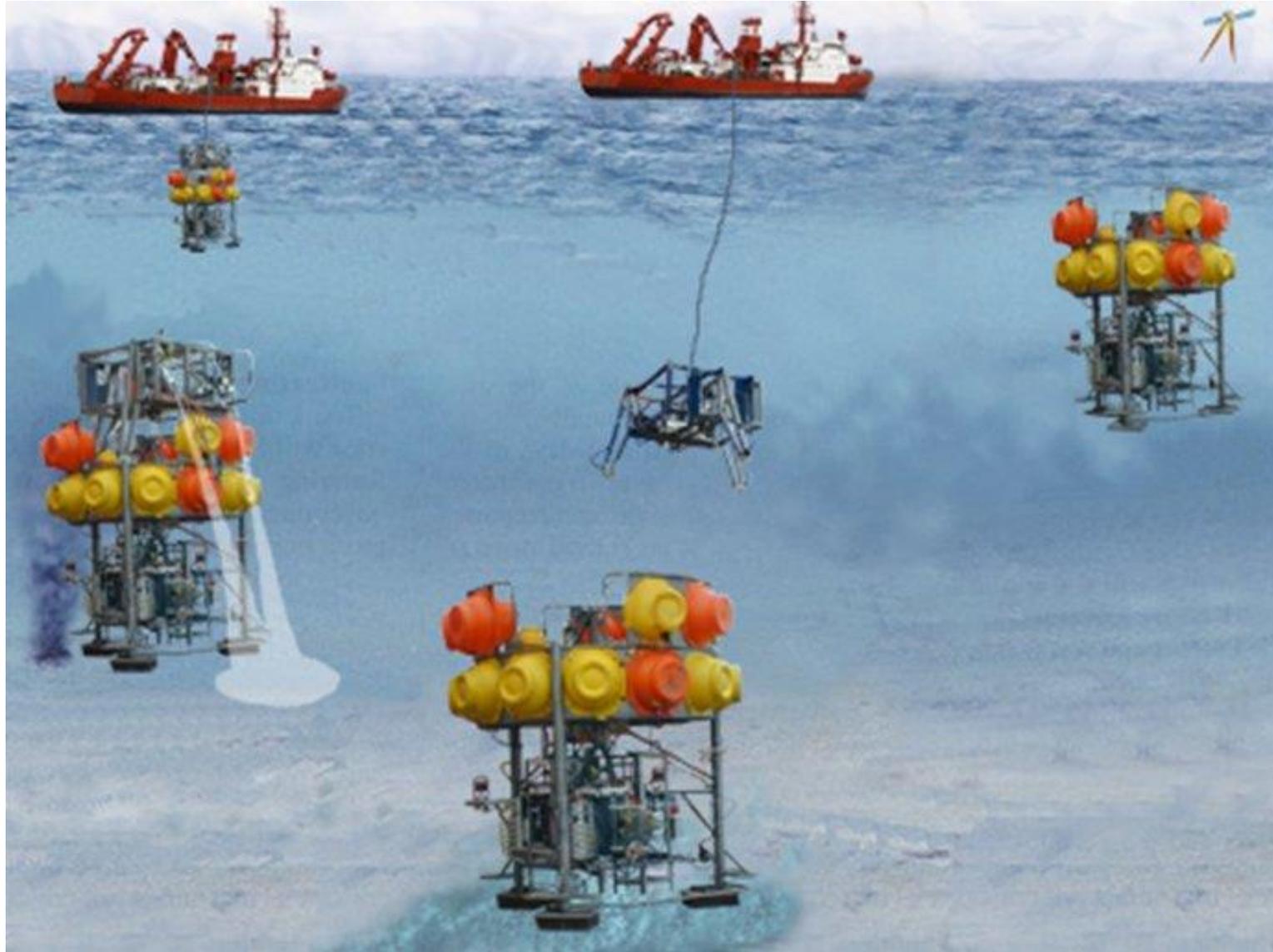




Sensors must have

- low cost
- easy setup
- low buoyancy change
- low weight in water
- long-term stability
- >1 sample / 4 minutes in burst mode

SENSORS: WHERE DO WE GO FROM HERE? AUTONOMOUS PLATFORMS: BENTHIC OBSERVATORIES



SENSORS: WHERE DO WE GO FROM HERE?





This project is co-funded by the European Union

COUSTEAU

WWW.COUSTEAU.ORG
CUSTODIAN OF THE SEA
SINCE 1943

ANOXIC LAYER OF THE BLACK SEA

THE DANGER OF ITS RISE

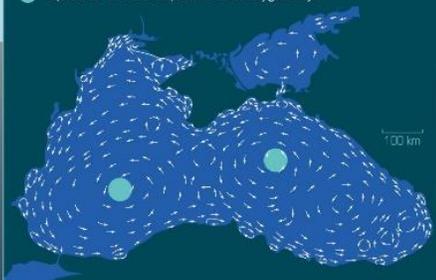
EMBLAS-Plus
Environmental Monitoring in the Black Sea



Map of the main currents of the Black Sea

The lowest depths of the oxygen layers (54 m) have been found in **the middle of the western and the eastern cyclonic gyres** in the open sea. The oxygen layer is thicker (160 m) near the coast.

● spots of lowest depths of the oxygen layer



87% of the Black Sea's volume is anoxic, which means without dissolved oxygen (O_2).

This anoxic zone is impregnated with hydrogen sulphide (H_2S) which is a highly toxic chemical compound. It is the largest anoxic water basin in the world

The Black Sea is a closed sea and the vertical currents are weak in its deep part. The consequence is that the deep waters do not mix with the upper oxygenated waters. This induces an increasingly large anoxic zone.

Between 1955 and 2017, toxic boundary shoaled from **140 m to 54 m deep***. This phenomenon is strengthened by eutrophication and global warming.

54 m

ANOXIC ZONE
oxygen free layer
contains H_2S



Consequences of the rise of the anoxic layer :



A compression of almost **40% of the habitable space** for oxygen dependent marine inhabitants (fish, shellfish, dolphins, algae and microorganisms). It threatens biodiversity.



The Black Sea is more vulnerable to **pollution and climate change**.



Microscopic observation of microorganisms belonging to the group *Lokiarchaeota*

160 m

2 km • maximum depth

Only a few microorganisms can live in the extreme conditions of the anoxic zone. Among them, the group *Lokiarchaeota* were found in the Black Sea. Discovered in 2015, this group is very interesting because it is a kind of 'missing link' between prokaryotes (organisms which do not have nucleus) and eukaryotes (ones which have nucleus, like animals and plants).

* According to the EMBLAS-II field data (2017). More information at http://emblasproject.org/wp-content/uploads/2019/07/EMBLAS-II_NPMS_UO6S_2017_ScReport_FinDraft2.pdf



There is ongoing research about the potential use of H_2S to **produce energy**. This could be an advantageous solution to combat the rise of the anoxic layer.



floating electrostation
oxygen-free zone
 H_2S hydrogen sulphide
Intake of bottom waters at 2 000 m of depth

WHAT CAN WE DO ABOUT IT?

We can all act to make things better!

As a citizen: Reduce your carbon footprint. Use as less energy as possible at home and at work. Prefer the use of public transports or bikes rather than cars when possible.

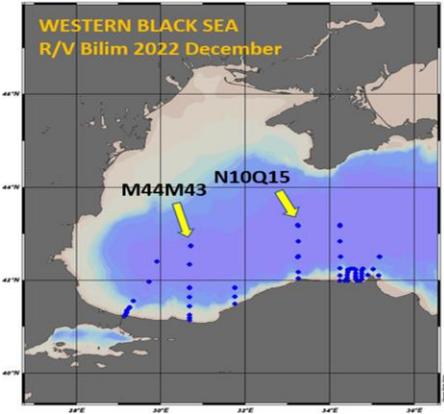
As a decision maker: Adopt measures and laws to limit air pollution and greenhouse gases. Join international agreements to fight climate change.

More information at emblasproject.org

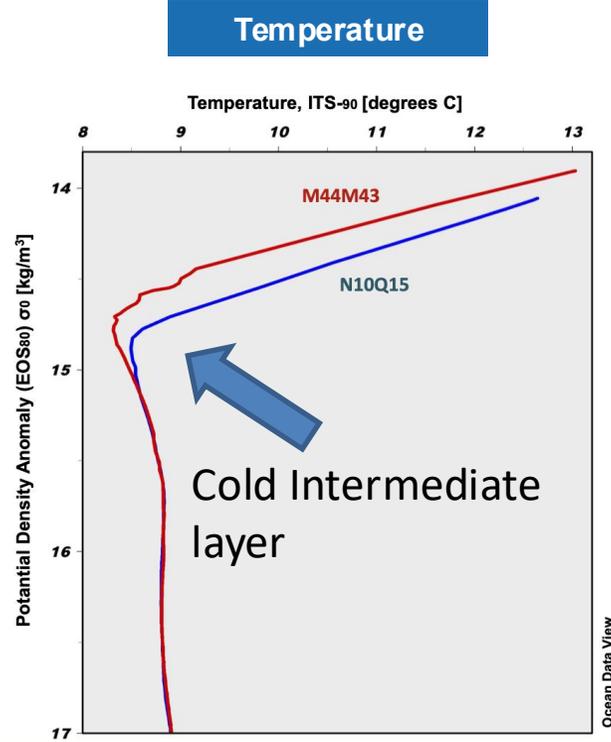
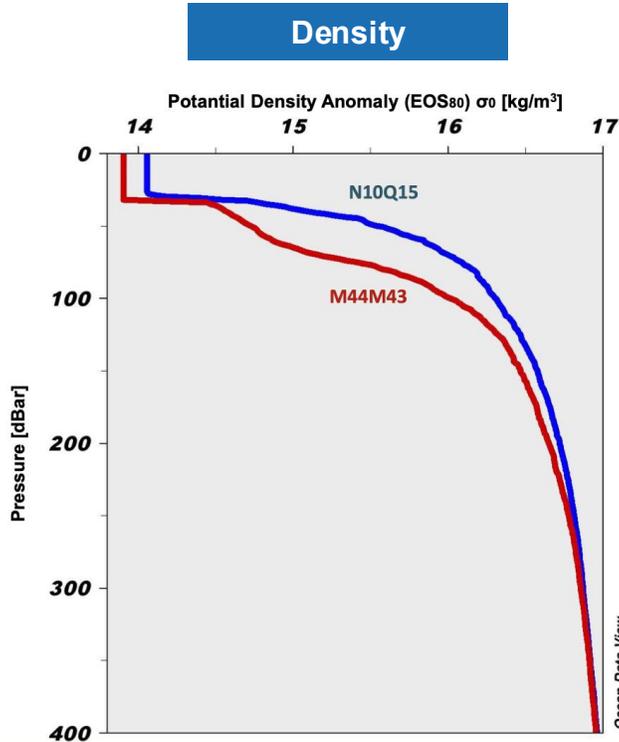




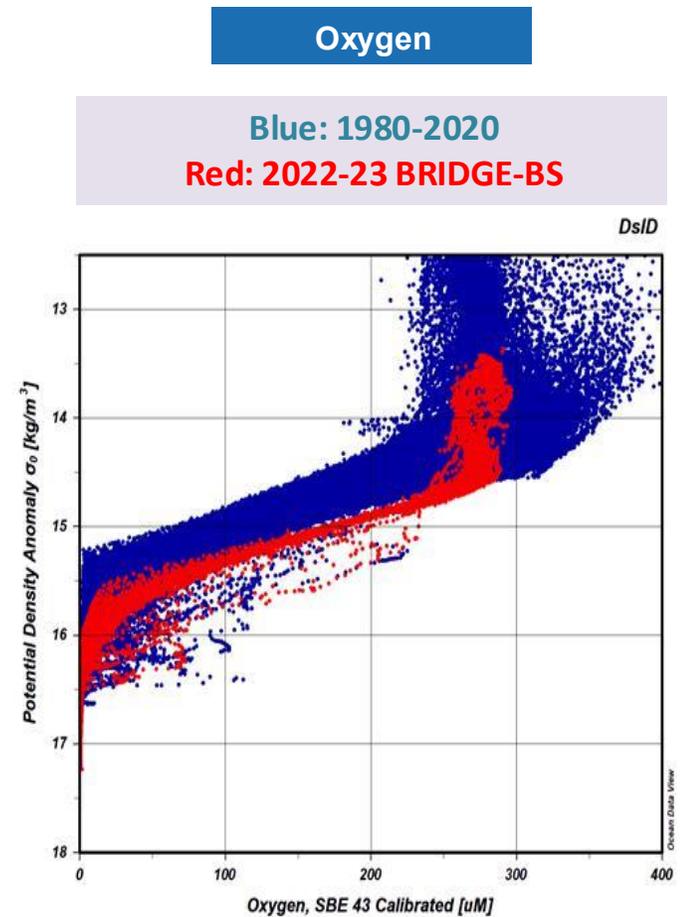
RECENT STATE: VERTICAL STRUCTURES OF DENSITY AND TEMPERATURE



Stations occupied by RV Bilim-2 in the eastern and central part of the Black Sea

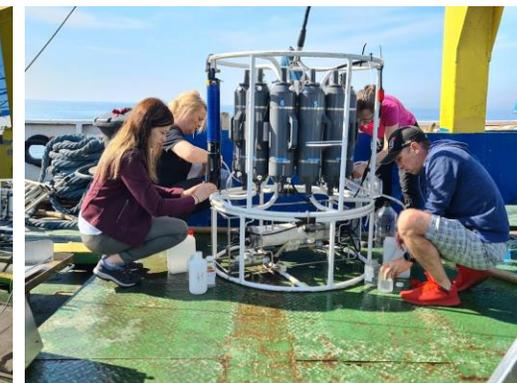


The upper layer of the western central station M44M43 was observed thicker and colder while the surface layer was thinner and warmer in the mid-central station N10Q15. Throughout December 2022, the sea surface was transitioning to winter conditions while maintaining above-average sea surface temperatures.



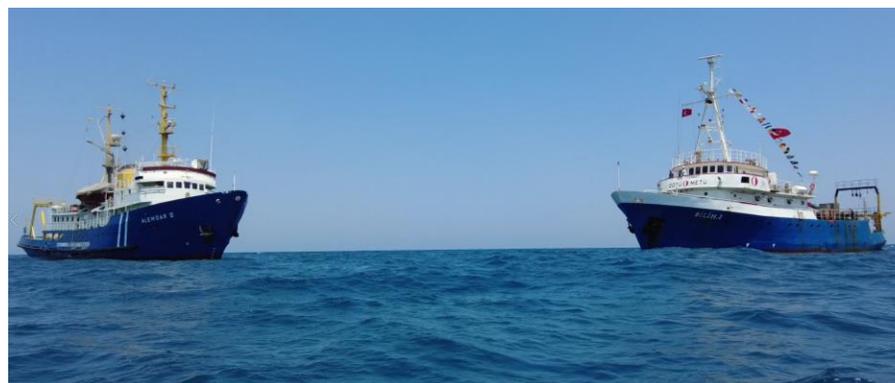
JOINT RESEARCH

BRIDGE-BS brings together **leading institutions** from across the Black Sea region and Europe to conduct **collaborative research** and **share expertise** to tackle the **multi-stressors** of the Black Sea.



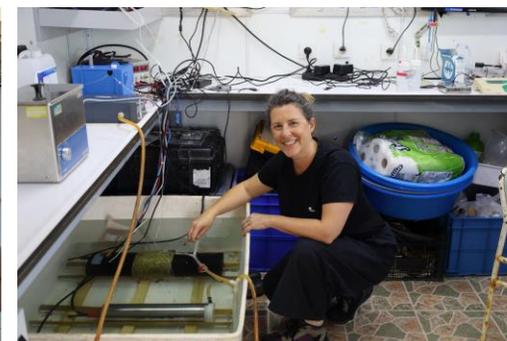
EXPERT COLLABORATION

From **co-designed methodologies** to **joint scientific cruises**, BRIDGE-BS partners work together to **generate knowledge**, **conduct fieldwork**, **harmonize methodologies**, and build long-term **research capacity**.



YOUNG SCIENTISTS ENGAGEMENT

Onboard collaborations among BRIDGE-BS partners strengthen **regional monitoring**, ensure **data comparability**, and promote transboundary **knowledge exchange**, while actively **engaging young scientists** in hands-on research and capacity building.



INNOVATIVE TECHNOLOGIES DRIVING BRIDGE-BS RESEARCH

AMONG THE FIRST IN THE BLACK SEA!

COLLABORATIVE RESEARCH CRUISES

- ✓ Harmonization of Methodologies
- ✓ Intercomparison of Results
- ✓ Temporal Data Comparison



**UAVS FOR JELLYFISH
MONITORING**

SMART MONITORING SYSTEMS



GLIDER



SCANFISH



**BENTHIC
OBSERVING SYSTEMS**



**E-DNA
METABARCODING**



**ENZYMES
METAGENOMICS**

NEW SENSORS AND TOOLS



**DIGITAL LIBRARY FOR
PHYTOPLANKTON**



**PCO₂
MONITORING**



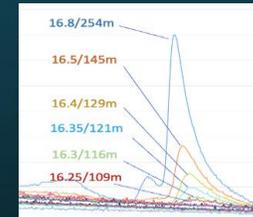
**ACOUSTIC
JELLYFISH DETECTOR**



**ACOUSTIC MARINE
MAMMAL OBSERVING**



IN-SITU pH SENSOR



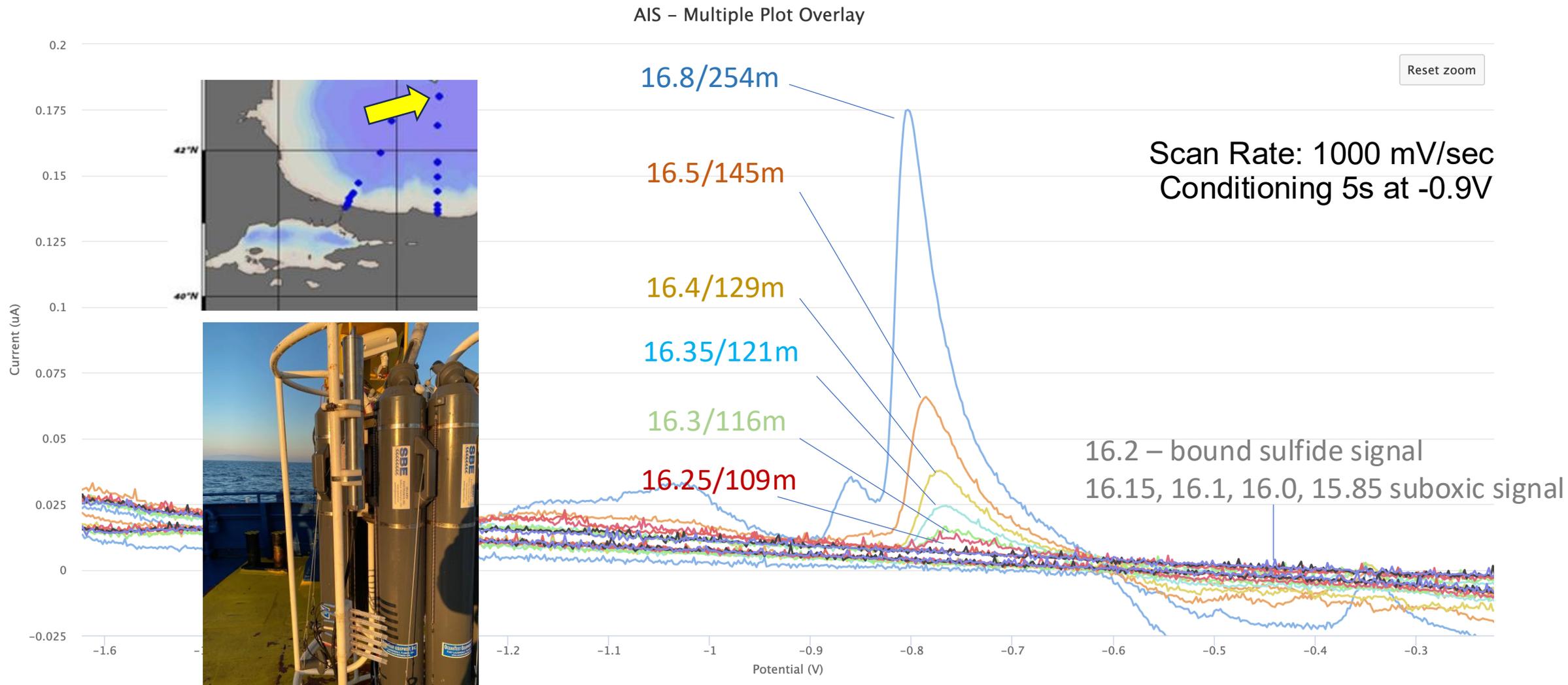
E-CHEM H₂S SENSOR



**RADIONUCLIDES
DETECTOR**



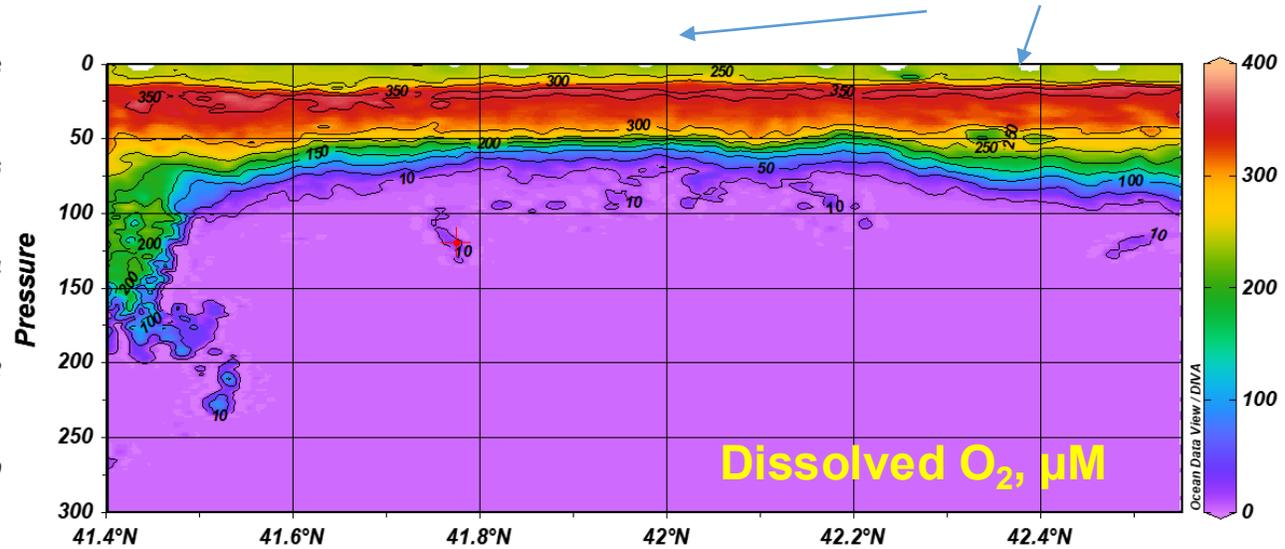
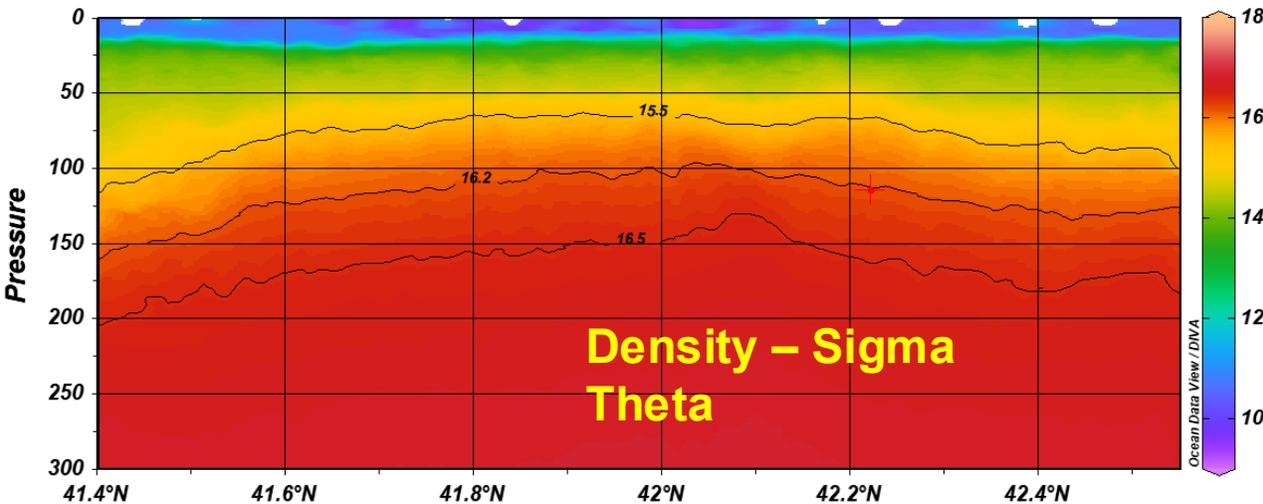
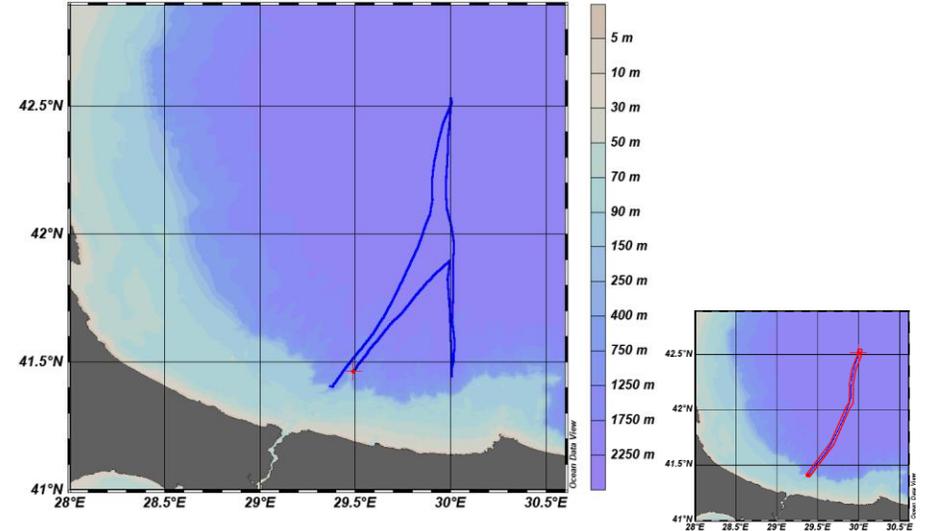
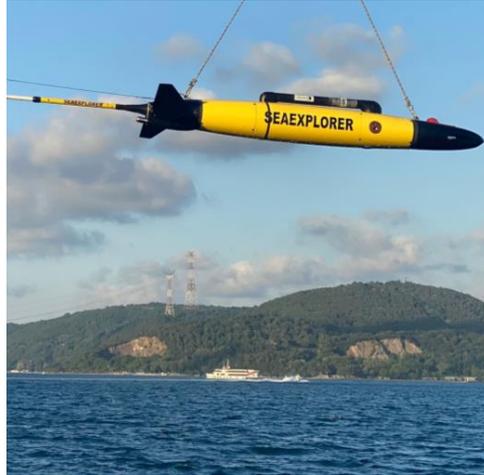
TOWARDS IN SITU HIGH RESOLUTION DETECTION OF HYDROGEN SULFIDE

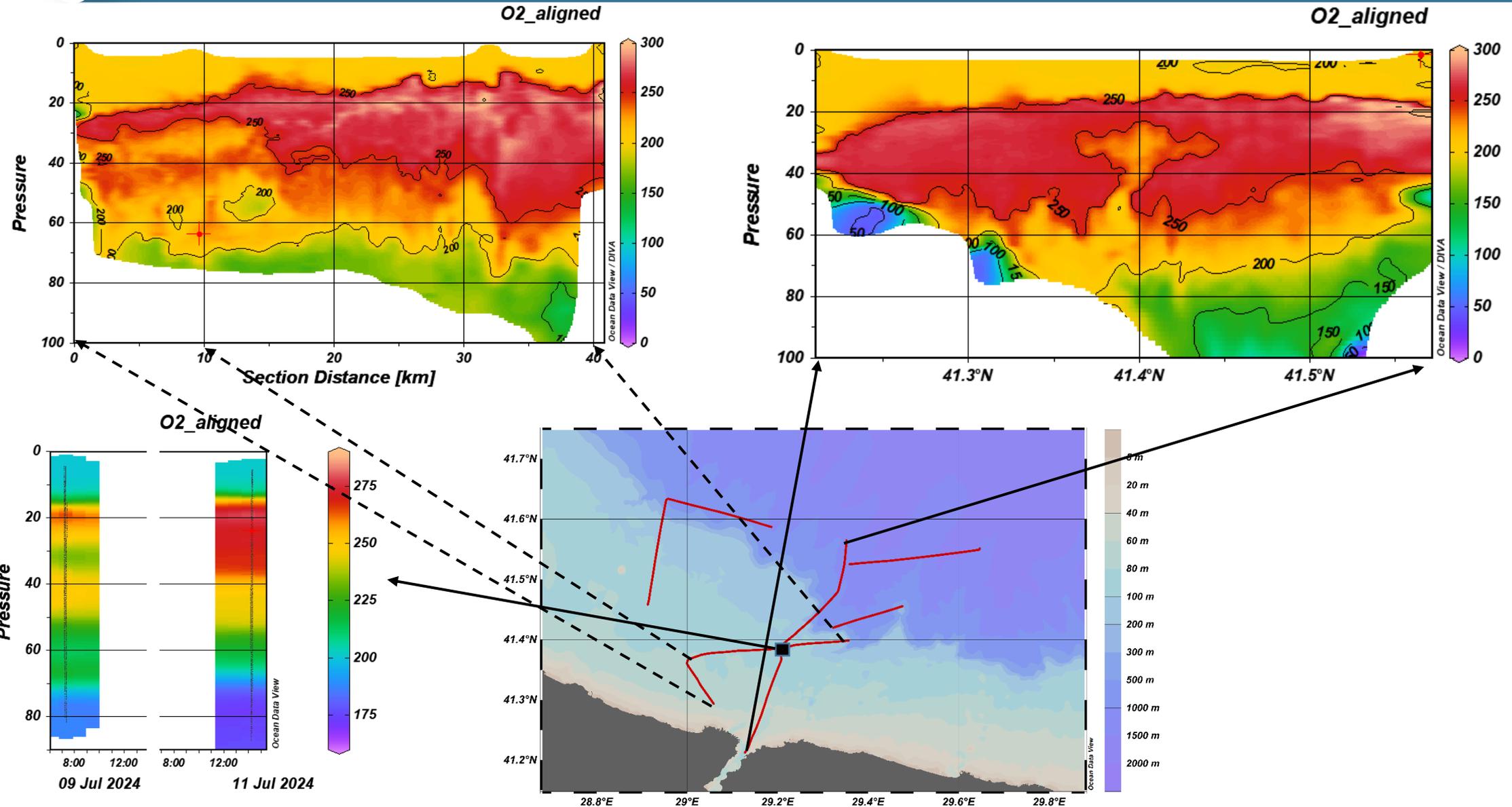


2024 July: Black Sea, M51M43 – Western Central – **H2S onset at 16.25 / 109 m**

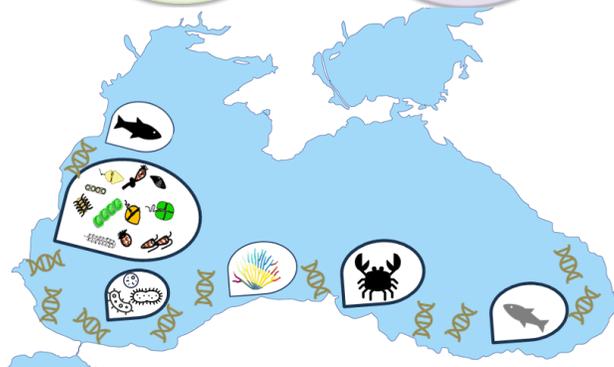
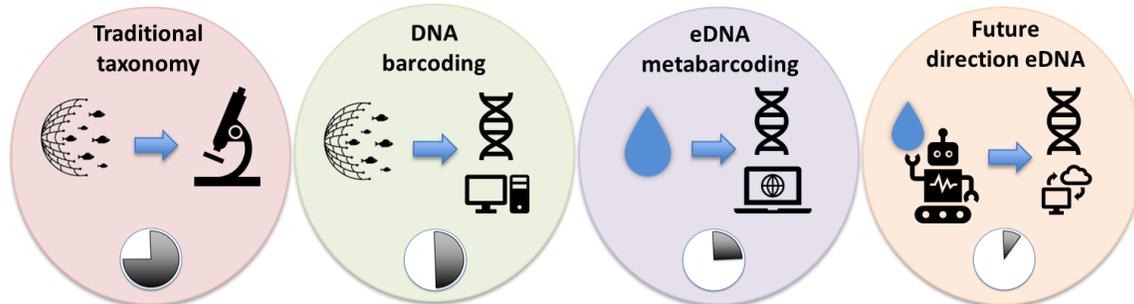
FIRST GLIDER OPERATION IN THE TURKISH EEZ.

11-22 July 375 km long transect
 ~1 km spatial resolution
 sampling (376 profiles) with
 CTD, O₂, Chl-a, Turbidity, SUNA
 (NO₂+NO₃).



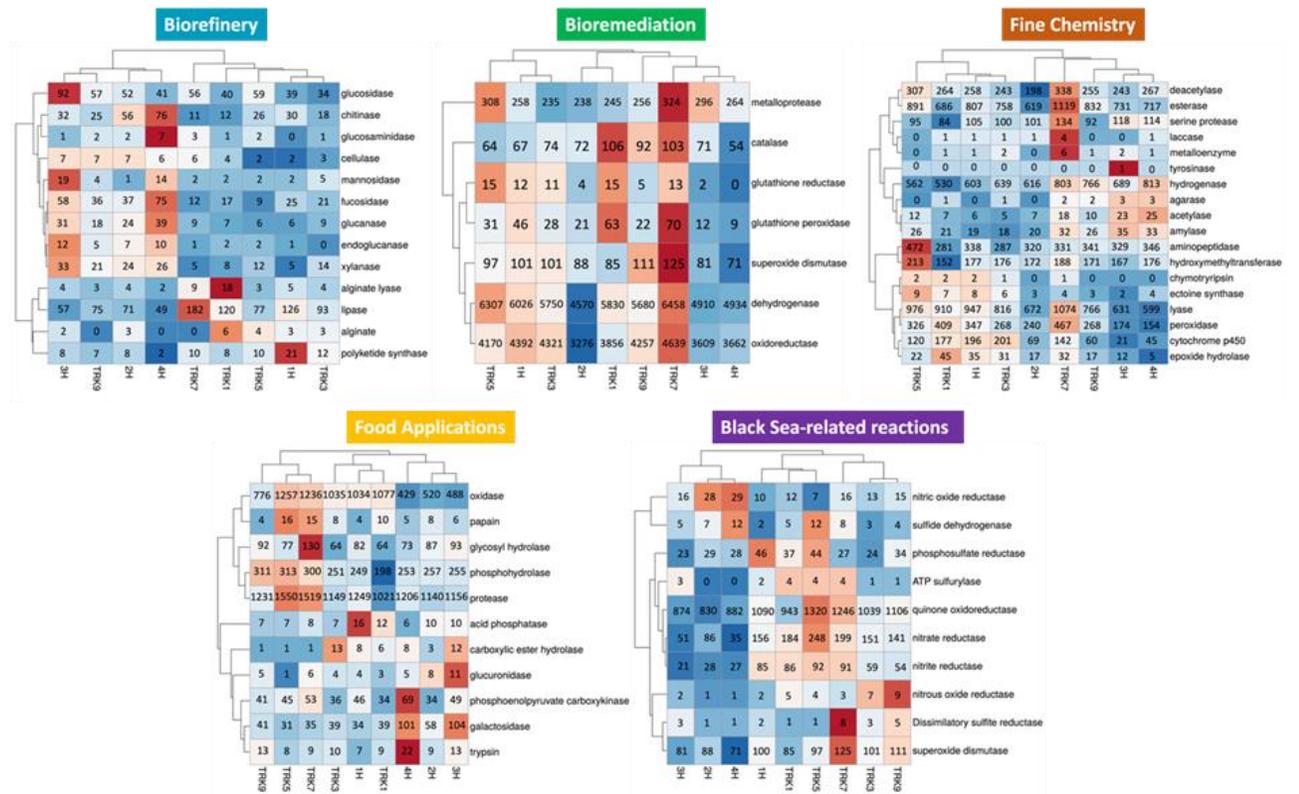


eDNA Metabarcoding

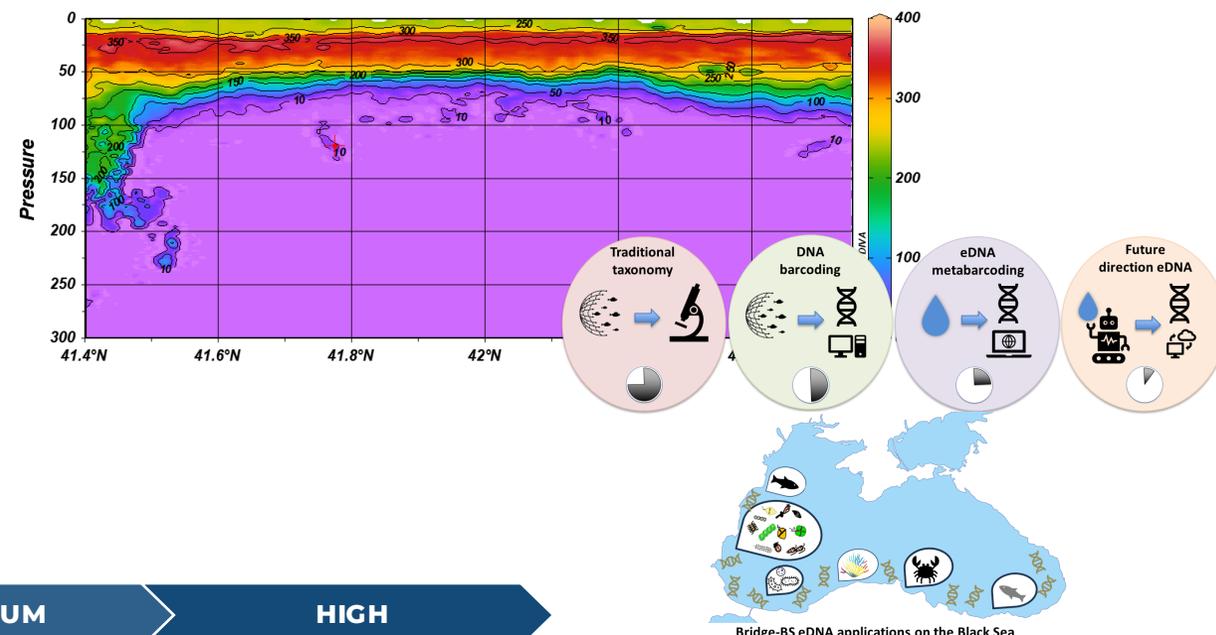
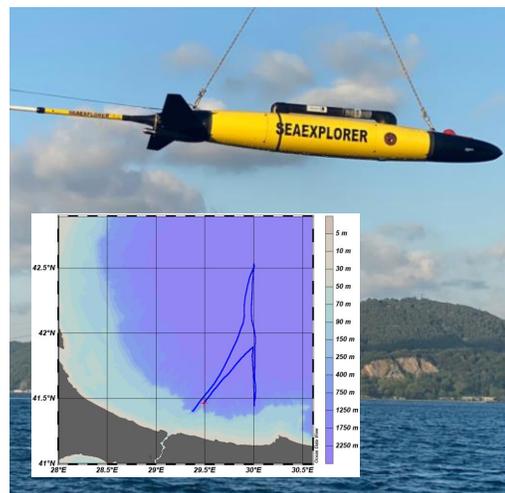
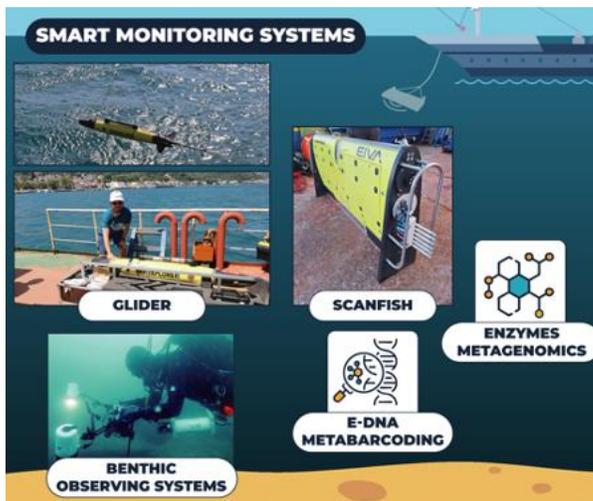


Bridge-BS eDNA applications on the Black Sea

Rapid Biomolecule Screening via Metagenomics



SMART MONITORING SYSTEMS: INCREASING LEVEL OF ADOPTION (LOA) IN THE BLACK SEA



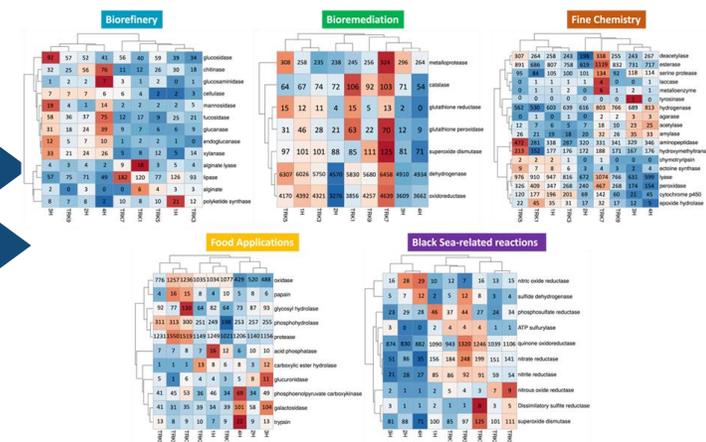
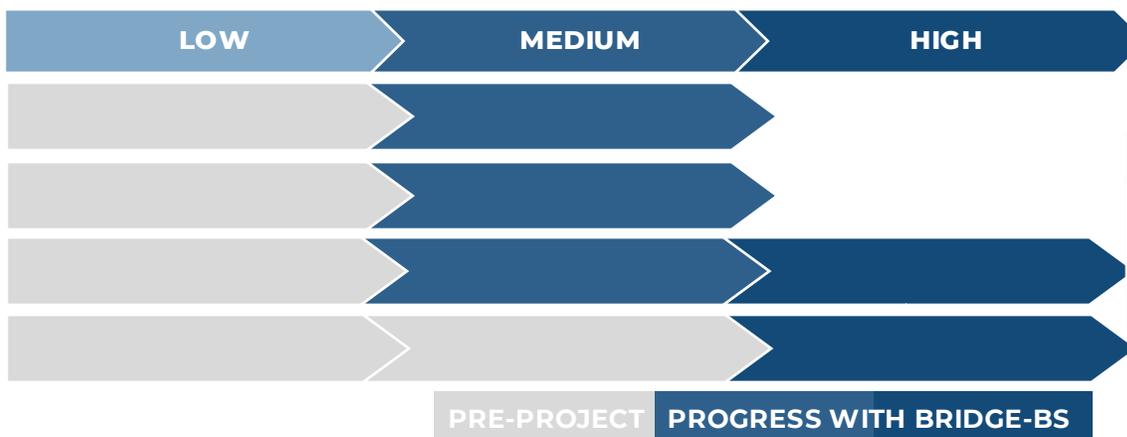
SMART MONITORING SYSTEMS

E-DNA METABARCODING FOR COST EFFICIENT BIO-MONITORING

FAST SCREENING OF NOVEL ENZYMES VIA METAGENOMICS

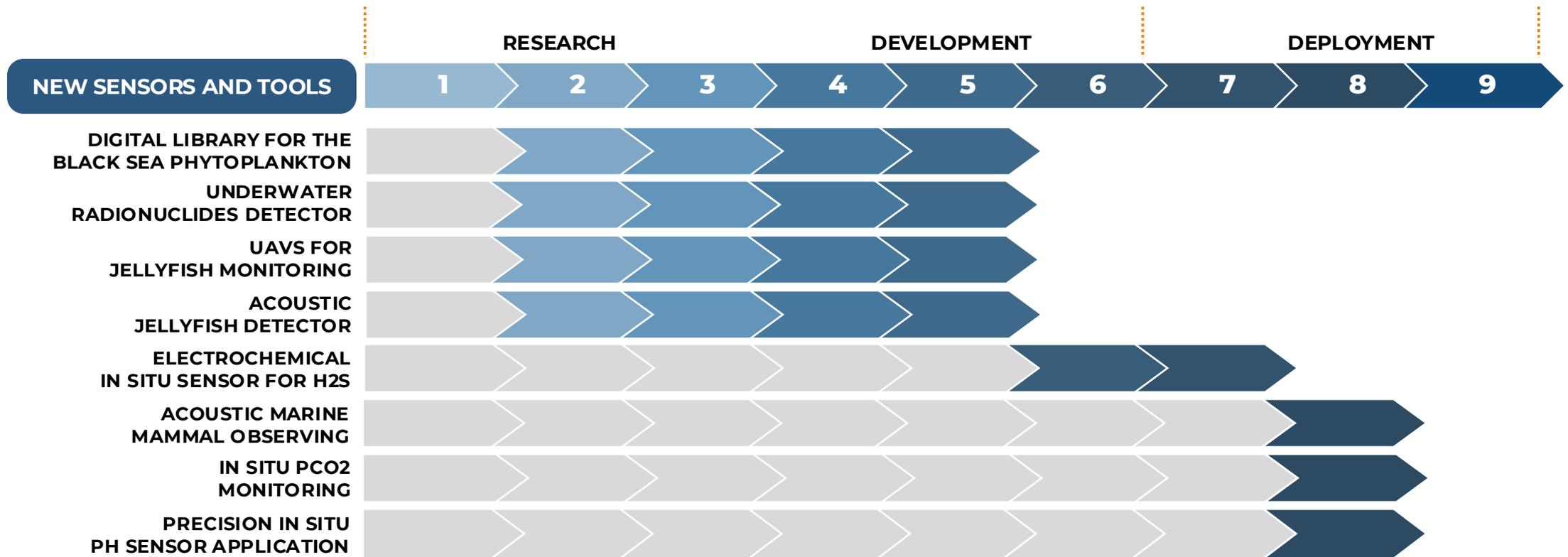
SMART OCEANOGRAPHIC SURVEYS WITH SCANFISH AND GLIDER

HIGH-RESOLUTION BENTHIC OBSERVING SYSTEMS





NEW SENSORS AND TOOLS: ELEVATING TECHNOLOGICAL READINESS LEVEL (TRL)

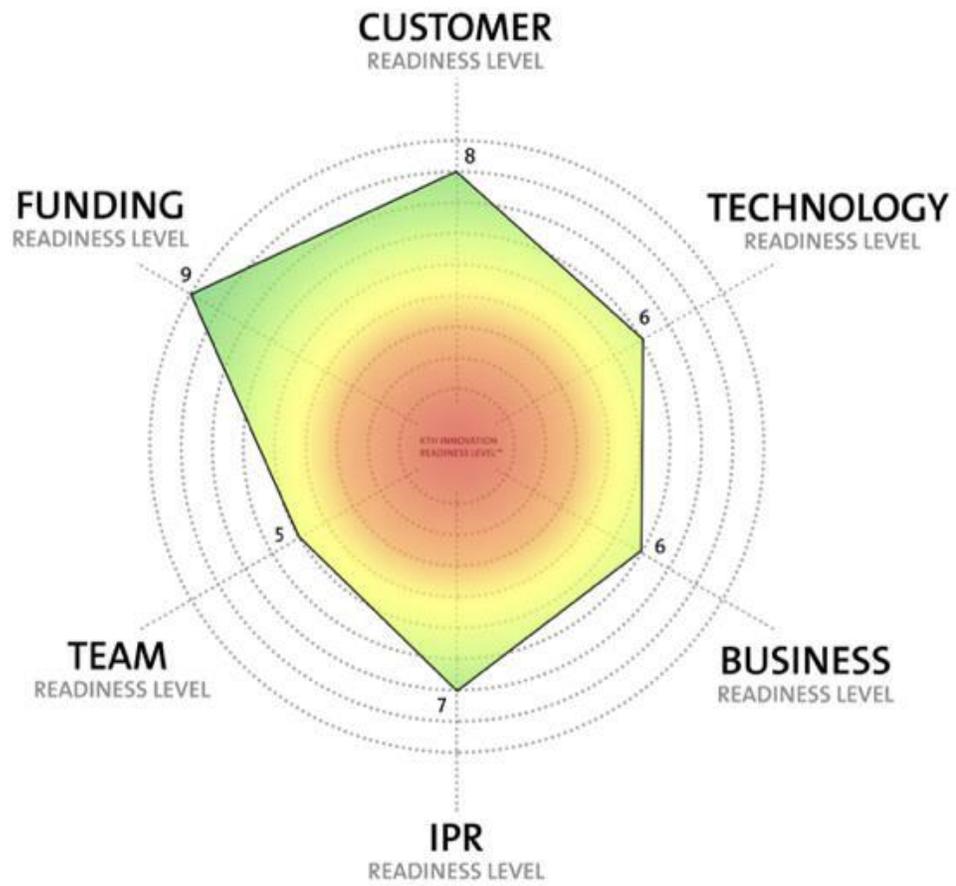


PRE-PROJECT PROGRESS WITH BRIDGE-BS



FROM PROOF OF IDEAS TO PROOF OF BUSINESSES (ACCELERATING 'INDUSTRY 4.0' BUSINESS MODELS)

How do we translate science into business opportunities?



PROOF OF IDEAS
(methods, technologies, services, models, etc.)



PROOF OF CONCEPTS
(how it works, is it relevant, is it needed, etc.)



PROOF OF BUSINESS
(how it works, is it relevant, is it needed, etc.)

- Ocean observations need to address 3D nature of seas.
- This is even more required for the vertically zonated Black Sea.
- A variety of technologies are reaching maturity but more work is needed on chemical sensors and biodiversity front.
- BRIDGE-BS advanced key sensing technologies in chemical and biodiversity monitoring.

SMART SENSING IN BLACK SEA OCEANOGRAPHY



Mustafa YÜCEL, BRIDGE-BS Co-Coordinator

Middle East Technical University

Institute of Marine Sciences



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