

EfxINNOs

Black Sea Blue Growth Workshop Series on “Advanced Marine Monitoring for the Sustainable Blue Economy of the Black Sea”

”Underwater drones: AUVs component, planning, operation, data processing and interpretation for the rapid assessment of several MSFD Descriptors (D1-macroalgae, D6//D7 and D10). QA/QC procedures on the marine habitats/marine litter datasets, its harmonisation for submission within PanEuropean data infrastructures: EMODnet and CMEMS “

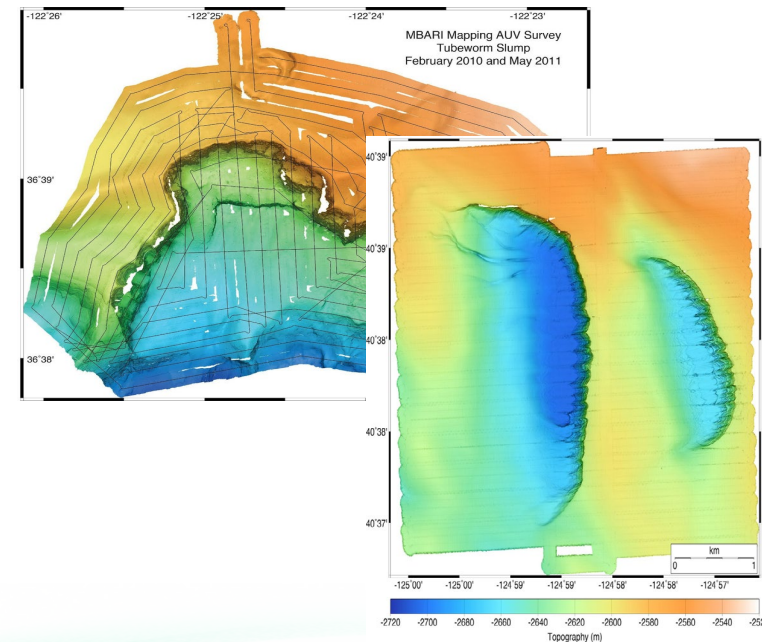
Razvan Mateescu

DATE: WEDNESDAY 17 APRIL 2026, ILIA STATE UNIVERSITY, TBILISI, **Online**

AUV – autonomous underwater vehicle

Application categories - What do AUVs do?

- **Access-limited environments**
- **Seafloor mapping** - Benthic and mapping
 - Multibeam sonar
 - Sub-bottom profiling sonar
 - Side-scan sonar
 - Synthetic Aperture Sonar
 - Digital camera
 - Chemical sensors: pH, O₂, CO₂, methane, etc
- **Spatiotemporal feature tracking** E.g. Blooms, plumes, fronts, spills
- **Shallow, coastal, or near structures, ...** Search and Salvage



Objectives – to respond to two questions

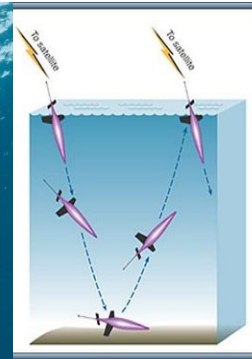
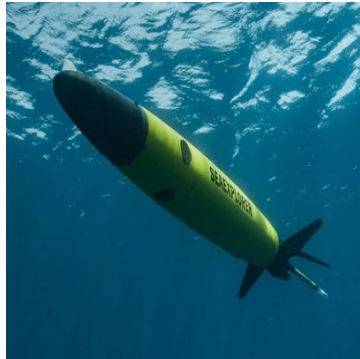
- What is your application of interest or area of work
- What's questions you're hoping to answer in AUVs uses

AUV type

- AUVs?: Floats and profilers



- AUVs ? : Gliders



- AUVs: Propeller-driven



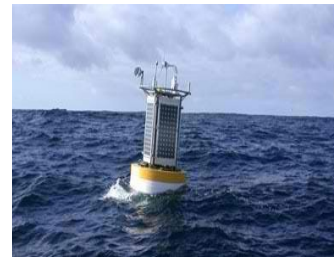
Why use an AUV?

Alternatives:

- Remote sensing - Ship-hull mounted sensors
- Cabled Towfish or ROV to capture episodic natural events
- Crewed Submersible
- Moored Platform

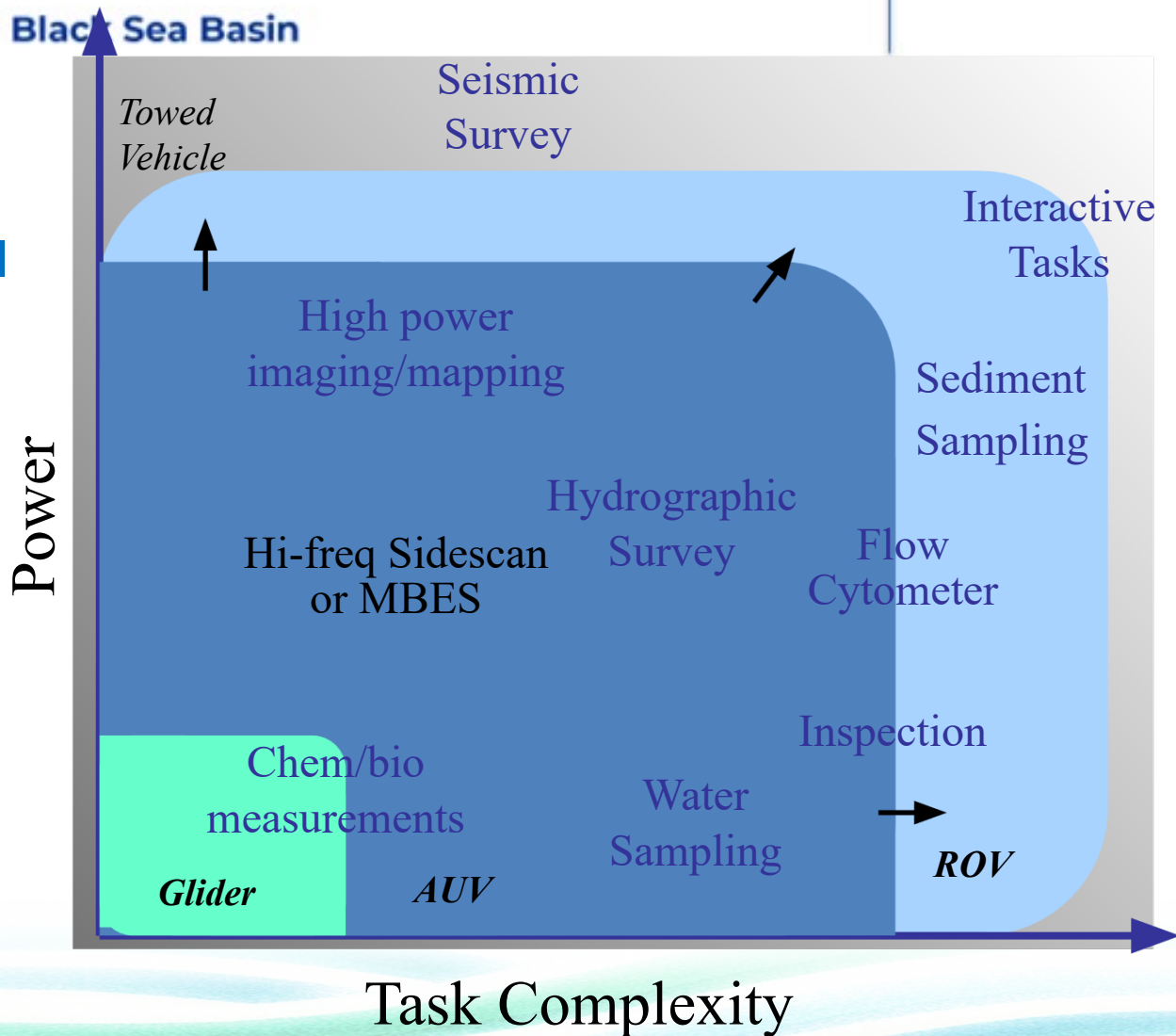
AUV Advantages:

- Less expensive AUV day rate: ~\$3k+
- Research vessel day rate: ~\$30k+
- Higher quality data, especially when deep
- Safer
- Mobile: Moorings have persistence, but are not mobile, Ships are mobile but not persistent



NEXT Black Sea Basin

AUV
Operational
Domain



NEXT Black Sea Basin

Choose Your AUV characteristics

Max depth:

Size:

Battery:

Max payload power:

Deployment length:

Speed:

Typical surface interval: Deployment

Deployment distance:

Comms:

Terrain avoidance:

Stability:

Maneuverability:

Person-portable:

Ship needed:

Data before recovery



AUV Operational Overview

- Operational Scenarios: Vehicle/ship support, infrastructure support
- Operational Scenarios: People/responsibility and control
- AUV Operations



AUV Operations

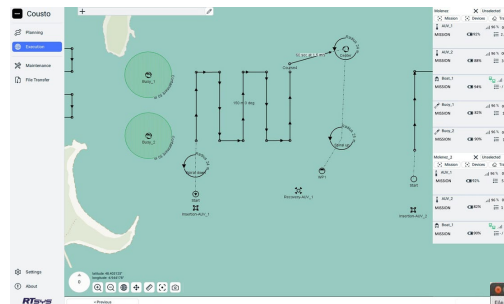
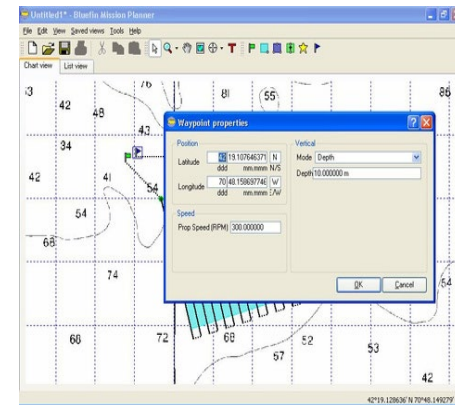
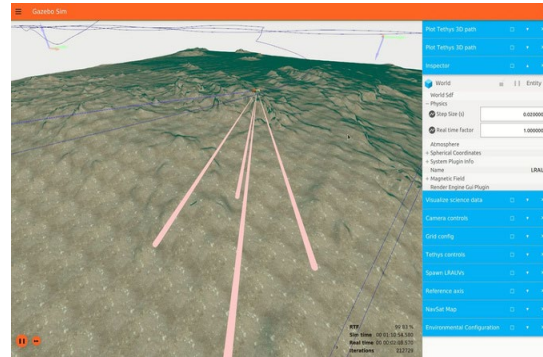
- **Vehicle preparation**
- Charge batteries
- Configure payload
- Close pressure vessels and check for leaks
- Complete close-out checklists
- Ballast and trim if necessary
- Vehicle self-test



AUV Operations

Mission Planning

- Describe CONOP
- Determine routes (waypoints, depth, etc) and/or behaviors (patch tracking, pipeline following, etc)
- Alter mission-level safety envelopes as needed (min altitude, max depth, exclusion zones, etc)
- Run simulation



Vehicle Software

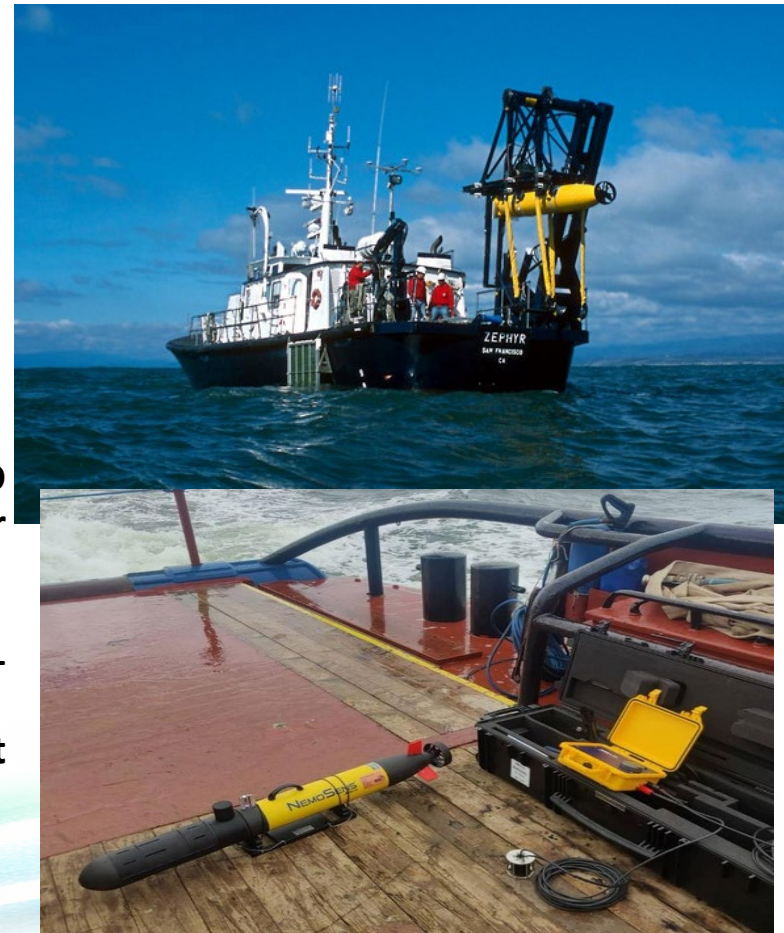
- Configure for payload
- Load necessary missions
- Alter vehicle-level safety thresholds (e.g. abort depth)
- Complete pre-deployment checklists
- Run vehicle self-test



AUV Operations

Vehicle Launch

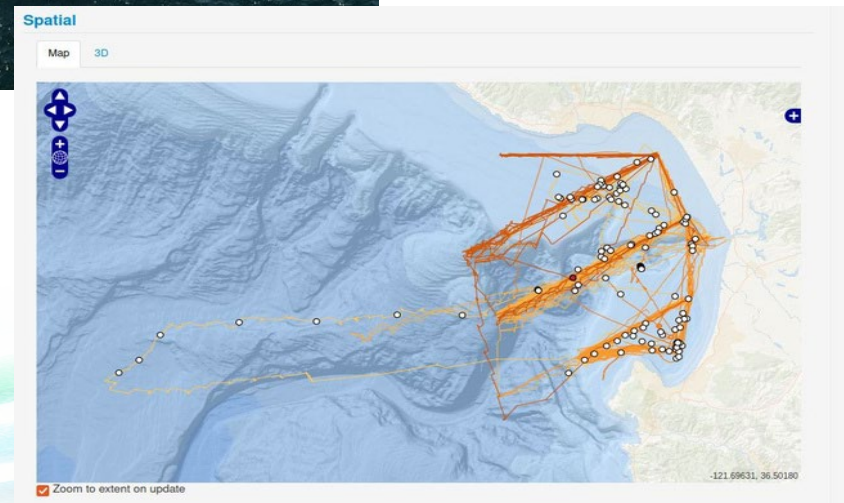
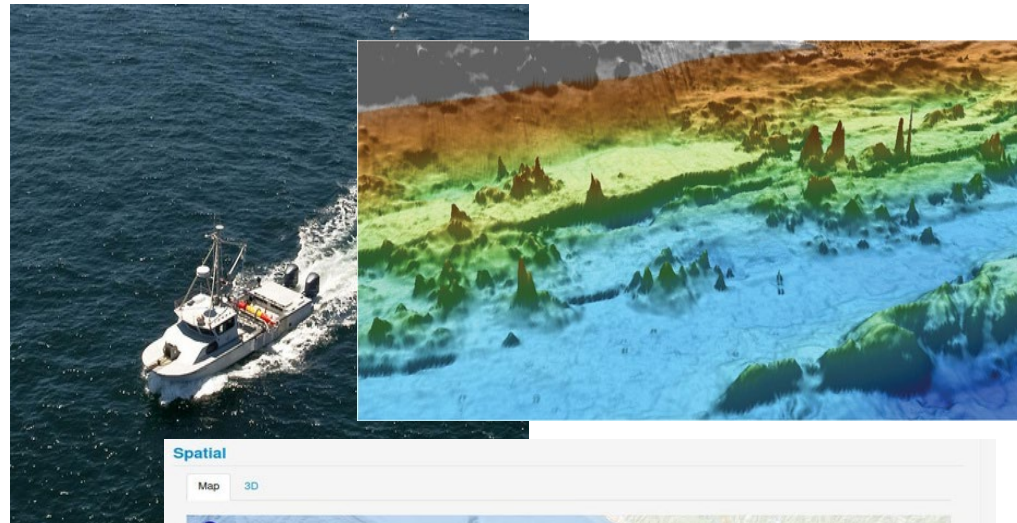
- Verify two-way communications
- Verify backup location systems Launch vehicle
- Check for leaks once in water (e.g. ground fault scan, humidity, etc)
- Start mission via communication with vehicle
- User interactions with vehicle: track, monitor from shore, adjust missions...
- Establish RF telemetry or exchange E-mails with SBD attachment to/from Iridium modem when on surface, or acoustics underwater
- User interface for “real time” data review
- Vehicle configuration can be changed in event of sub-system failure
- New missions can be loaded or modified as deployment requirements evolve.
- Notifications to inform operator of progress and errors



AUV Operations

Deployment End

- Locate vehicle if unattended
- Recover vehicle on-board ship/shore
- Download and review full resolution data (Science and Engineering)
- Note failures or large deviations from simulation and adjust
- Prepare for next mission:
- charge/change batteries,
- clean sensors



AUV Operations

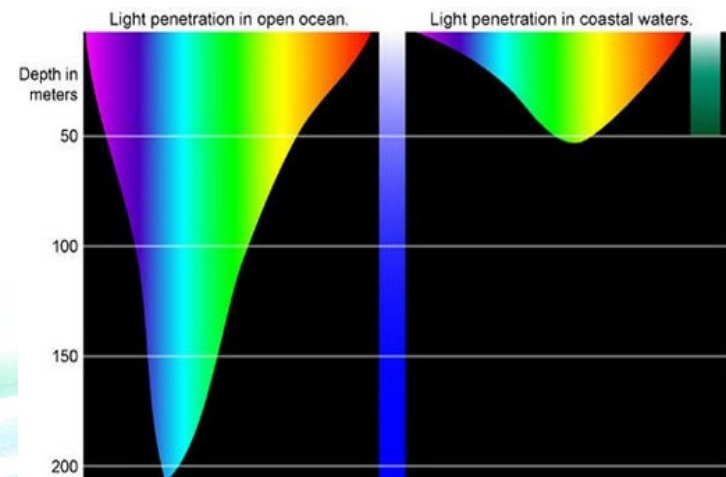
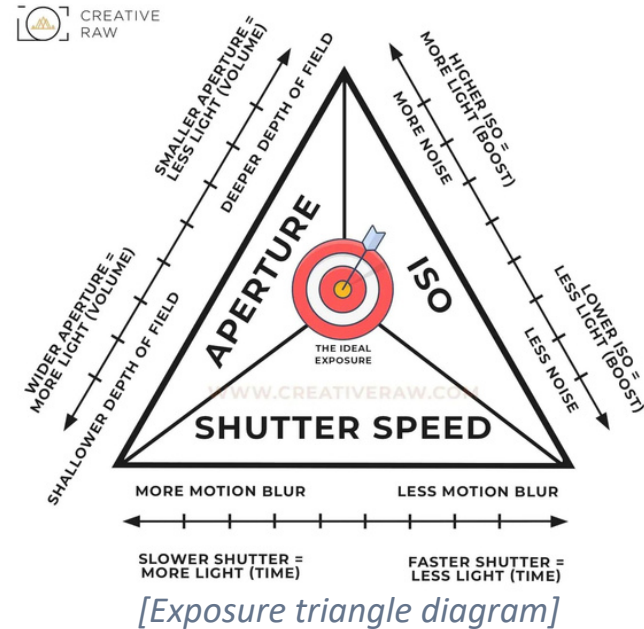
Underwater imagery

Optical imaging: Just add lights?

- High power requirements
- Might impact phenomena or measurements of interest
- Vehicle dynamics impact imaging

Light penetration varies by water clarity
Camera lenses and water cause refraction,
absorption, scattering

Lights cause brightness variation Vehicle
orientation and motion distorts image



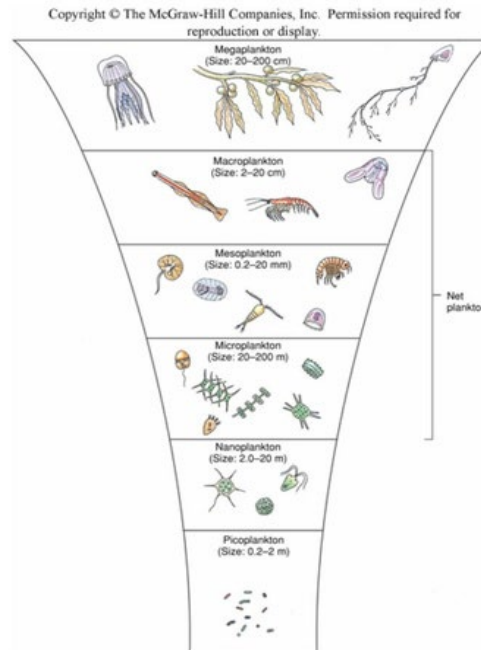
UNDERWATER IMAGERY

➤ Microimaging

➤ Macroimaging

Usecases:

- Behavioral ecology
- Habitat mapping
- Change detection
- Infrastructure inspection

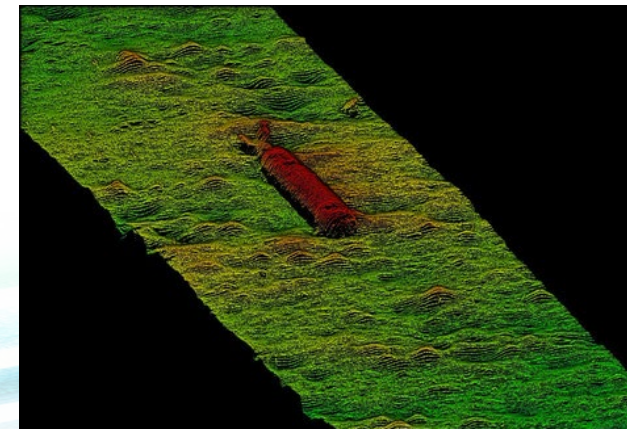
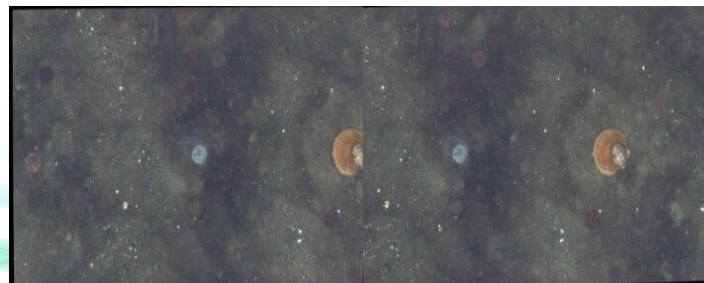


ROV, I2MAP,
Acoustics,
Piscivore

Chiton / ISIIS

Planktivore,
Zooglider

Backscatter /
Biolum /
Fluorescence

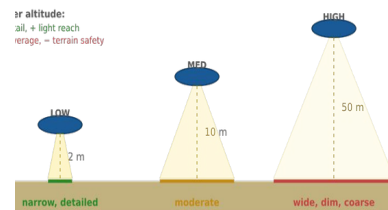
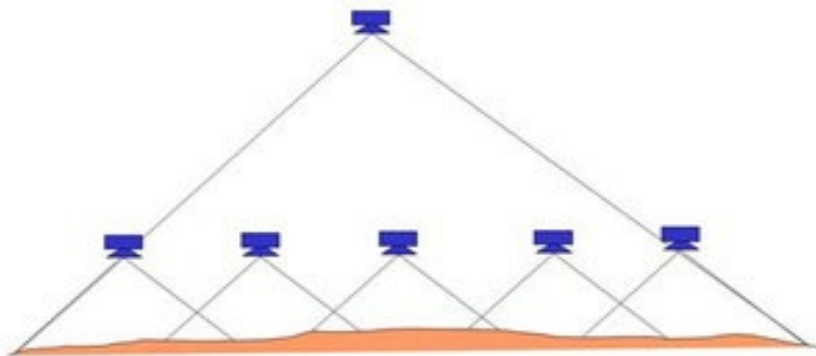


UNDERWATER IMAGERY:

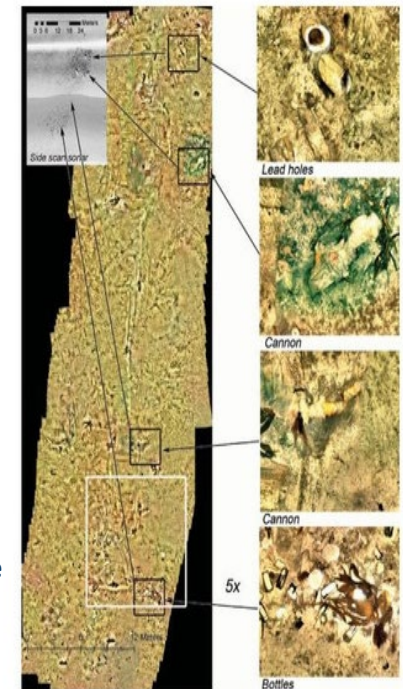
➤ Photo-mosaicking/stitching/composite images

- ✓ Can be seafloor, vertical walls, structures, organisms
- ✓ May or may not be georeferenced
- ✓ 2D panorama or input to 3D reconstruction (SfM) Often merged with sonar or other data

- A few high altitude photographs to define positions of objects
- Lots of low altitude photographs to capture detail
- Use the high altitude photo to help position the low altitude ones



Resolution depends on sensor and altitude
Huge variation! cm - m/px



Requirements

Survey planning for resolution and overlap
Vehicle telemetry and substantial postprocessing

Payload Considerations for AUV Applications

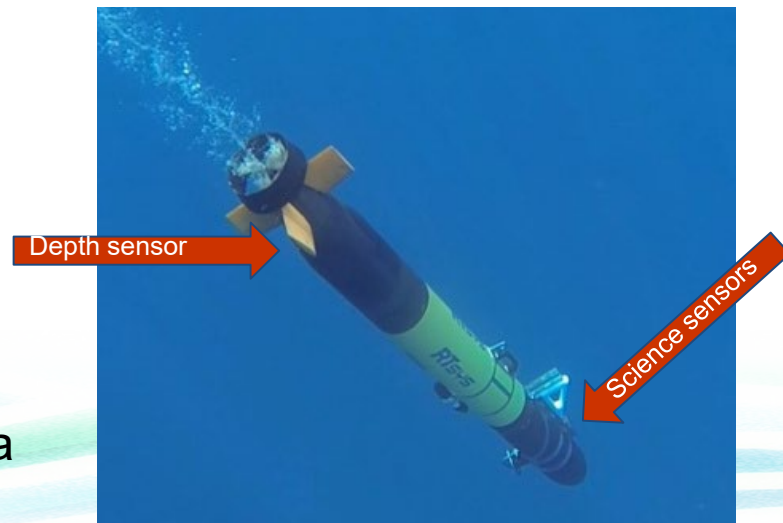
Geometry and motion affect when and where measurements are taken:

When

- Delays create spatial smearing
- Flow paths, sensor settling, high-volume data transmission
- **Matters for:** Pumped flows, optodes, etc
- **Example:**
 - CTD data with 1s flow path
 - Vehicle travelling at 1 m/s = 1 m smear

Where

- Sensor locations matter relative to navigation reference
-
- Vehicle attitude affects true sensor position
- **Example:** 30° pitch with sensors 2m apart = **1m vertical error**

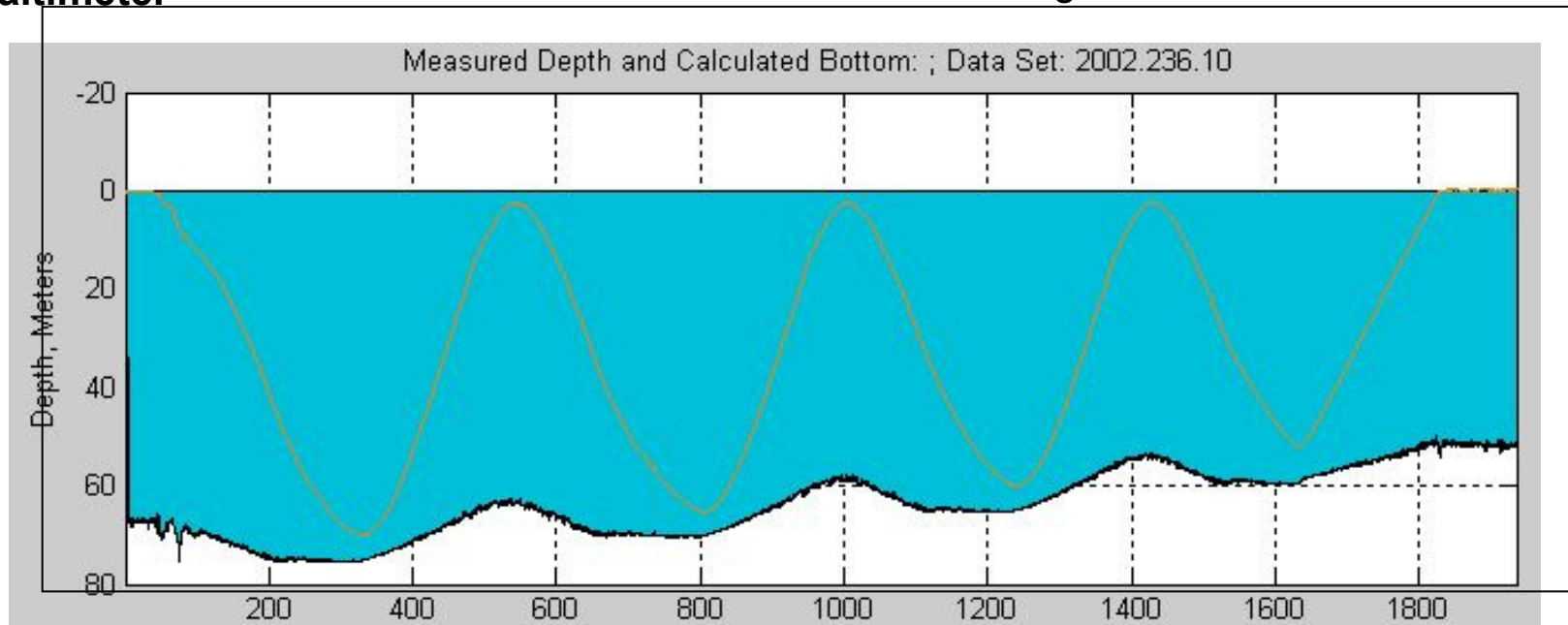


Flow around vehicle can affect the data

Payload Considerations for AUV Applications

Example: bathymetry from
altimeter

Vehicles skid and drift in turns
Sensor orientation changes with vehicle attitude

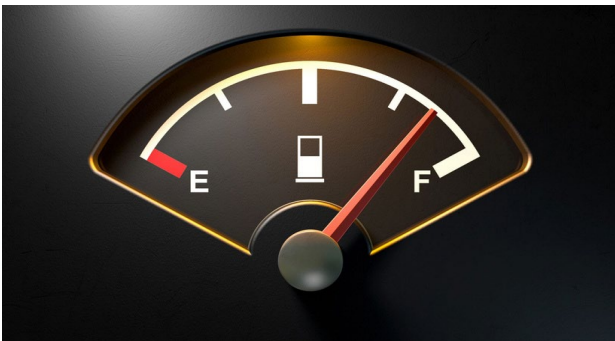


- When vehicle pitches down, altimeter reads closer; when pitching up, reads farther
- Smooth, sloped seafloor appears to have artificial "ripples"
- **Collect all raw vehicle and raw science data for post processing and analysis**

Power Budget Fundamentals

Power and Endurance

How far can
you go? How
long can you
run? What
can you do?



More power consumption → shorter mission (duration or distance)

Total Power

P_{total}

=

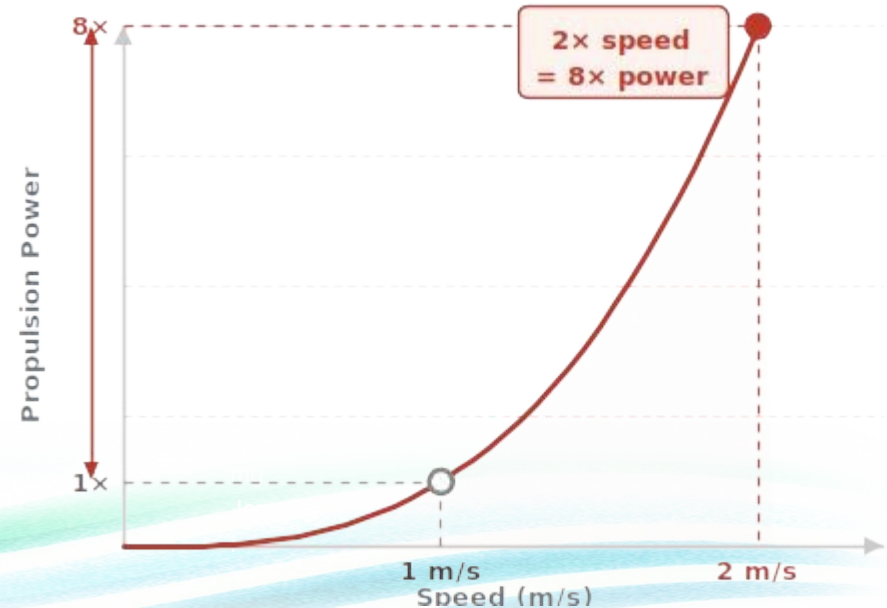
water

$P_{\text{propulsion}}$

+

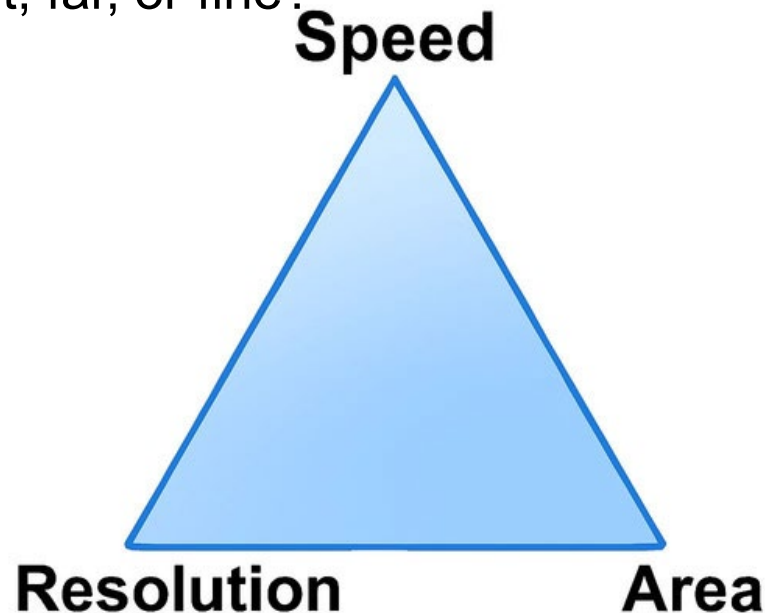
“Hotel load” + payload

$P_{\text{electronics}}$



Mission Planning Triangle

“Fast, far, or fine?”



Changing one parameter affects the other two

Can optimize for:

Speed

Fastsurvey: maximize distance covered/time

Area

Widecoverage: maximize spatial extent

Resolution

Tighttrackspacing: maximize data density

For max coverage, find the speed “sweet spot” balancing propulsion vs. electronics power

Selective Sensor Operation

Running high-power payloads only when necessary, increases range and duration



Example: Harmful Algae Bloom Detection

- Transit mode: Prop+ CTD +Fluorometer only
- Look for bloom signatures
- Detection mode: Add flow cytometer + imaging (3x power)
- Only when fluorescence threshold exceeded
- Precise species identification and counting
- Candidate blooms 10% of mission? 1%?



Power Impact:

- 10% detection time: **3× range improvement** vs always-on
- 1% detection time: **4× range improvement** vs always-on

SENSOR SELECTION

Example of mission:

Parameters:

Area: 200km²

Duration: 72 hours

Battery: 20 kWh

:Find aircraft wreckage

Available sensors:

- Navigation suite: 35W (required)
- Sidescan sonar: 45W
- Camera system: 40W
- Magnetometer: 8W
- Chemical sensors: 15W
- Acoustic transponder and modem: 15W

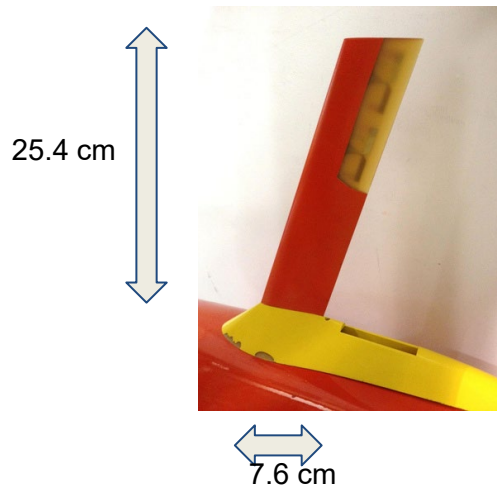
What sensors do you choose and why?



Img. Blueye Robotics

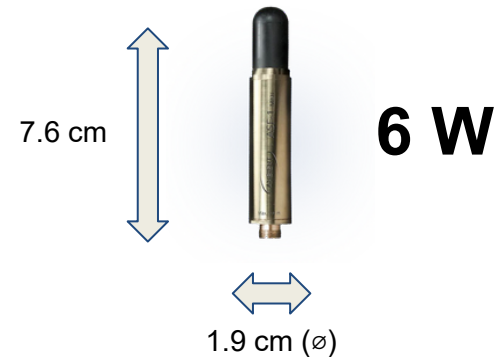
Which of these two shapes requires less energy? How much less?

Antenna: 25.4 cm airfoil

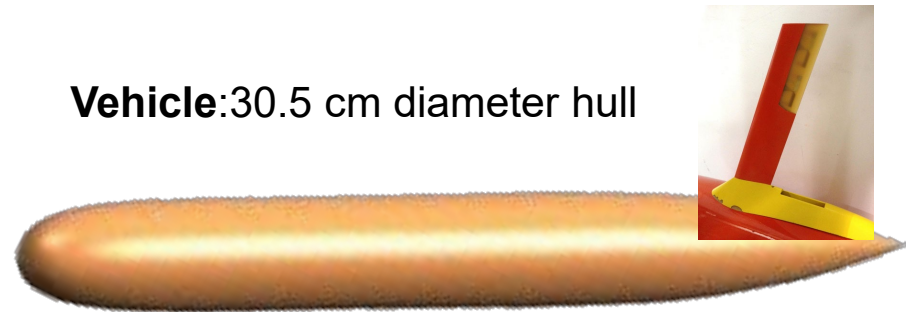


1.3 W

Hydrophone: 7.6 cm cylinder



Vehicle: 30.5 cm diameter hull



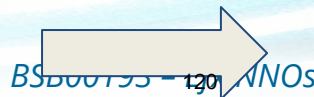
10 W Vehicle

6 W Hydrophone

1.3 W Antenna

**35% of the power just to
propel the hydrophone**

10 W
20% less survey time!



Underwater navigation

Requirements:

- How deep does GPS penetrate into freshwater? Seawater?
- A) 100 meters
 - B) 10 meters
 - C) 1 meter
 - D) Less than 0.5 meter

About your study theme/science:

How accurately and precisely must you know where each measurement was made? Will you return to these locations in future missions?

Are you correlating with other georeferenced datasets?

Do you need real-time positioning during your mission?

About your site/AOI:

Operating depth? Operating altitude?

Ship support?

Surface and subsea hazards? Wind, currents, shipping lanes, obstacles, etc.

Possibility of deploying fixed infrastructure?

Is bathymetry available?

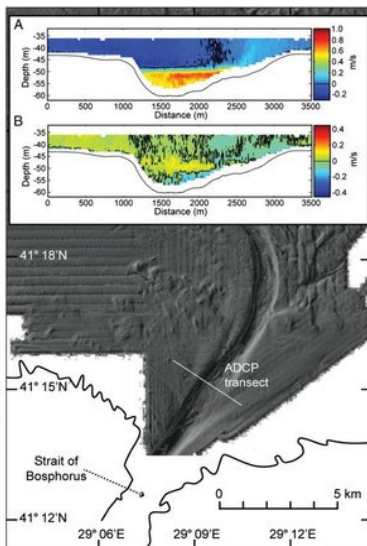
Navigation quality

More demanding applications

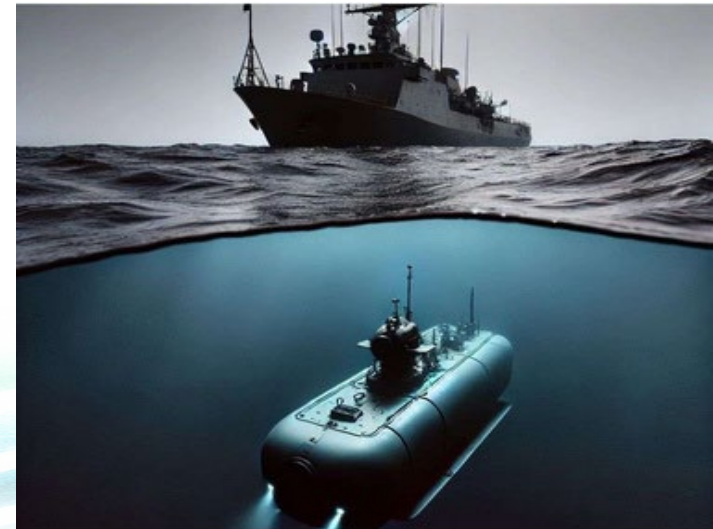
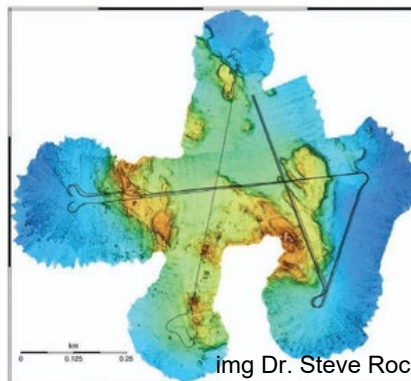
- Sitemonitoring and change detection (returning to exact locations over months or years)
- Georeferenced mapping
- Spatial correlations (relating measurements to geographic features)
- Multilatform operations (coordinating with ships, moorings, other AUVs)
- Working near boundaries (avoiding obstacles, staying within study area)

Less demanding applications

- Basin-scale oceanography (large-scale processes)
- Water-referenced measurements (adaptive tracking, following dynamic features)
- Opportunistic sampling



Nav precision or nav accuracy?



NEXT Black Sea Basin**The reference****GPS on the surface**

- Easy, inexpensive, accurate
- Interrupts mission
- Surface is dangerous
- Weather/sea state dependent

Short missions, long-distance missions, shallow water

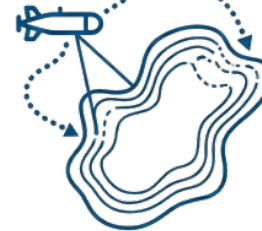
**Features of known terrain (TRN)**

- Match sensors to known maps
- No infrastructure needed
- Very accurate, continuous reference
- Requires maps, distinctive terrain, good view of bottom, lots of computation

**Acoustic beacons or ship**

- Accurate (cm to meters)
- Requires infrastructure or ship
- Complex, expensive, affected by site specifics

Fixed sites, ship-supported ops, very deep water

**Features of unknown terrain (SLAM)**

- Create map as you navigate
- Requires distinctive terrain, but no prior maps
- High sensing/compute requirement
- Emerging technology

Between Fixes: Dead Reckoning

Navigate by estimating your motion since the last known position

What do we need to navigate?

- Know where we're pointed. (Heading/Attitude)
- Know how fast we're moving (Speed)
- Apply motion to reference to know where we are (Position)

Why isn't this perfect?

- Compass error $\pm 1-2^\circ$
- How to know about water motion?
- Small errors compound over time



AHRS
SparionM2

Unaided DR $\rightarrow$ 5-10% distance travelled
1.5 hrs at 1 m/s $\rightarrow$ ~500 m error!

How to improve accuracy?

Add a DVL (Doppler Velocity Log)

- Acoustic instrument
- Measures velocity relative to seafloor (like a radar speed gun pointing down)
- Error: ~0.1-1% of distance traveled
- Limitation: needs to "see" the seafloor (altitude typically < 300m)



img Nortek
Nortek DVL 500



img Nortek

NORTEK

Add an INS (Inertial Navigation System)

- "Smart DR": accel + gyro + fancy math to get a really good motion estimate
- Best combined with DVL: ~0.05-0.1% error
- Trade-off: expensive (\$10K-\$100K+), more power (~15-20W)



INS
IxBlue PHINS

These methods still accumulate error, just more slowly!

Nav comparison

Error Rate

Power

Cost

Notes

~5-10% of distance

<~2W

\$

DVL-aided Dead Reckoning

Addspeed-over-groundfrom seafloor

~0.1-1% of distance

~10W

\$\$

DVL needs altitude
<~300m

INS (Inertial Navigation)

"SmartDR":fusewithaccelerometers +
gyros

~0.05-0.1% of distance

~15-20W

\$\$\$

Best when
combined with DVL

TRN / SLAM

Continuous terrain/feature matching

Not determined by
distance

Varies

Varies

Computation/terrain
requirements



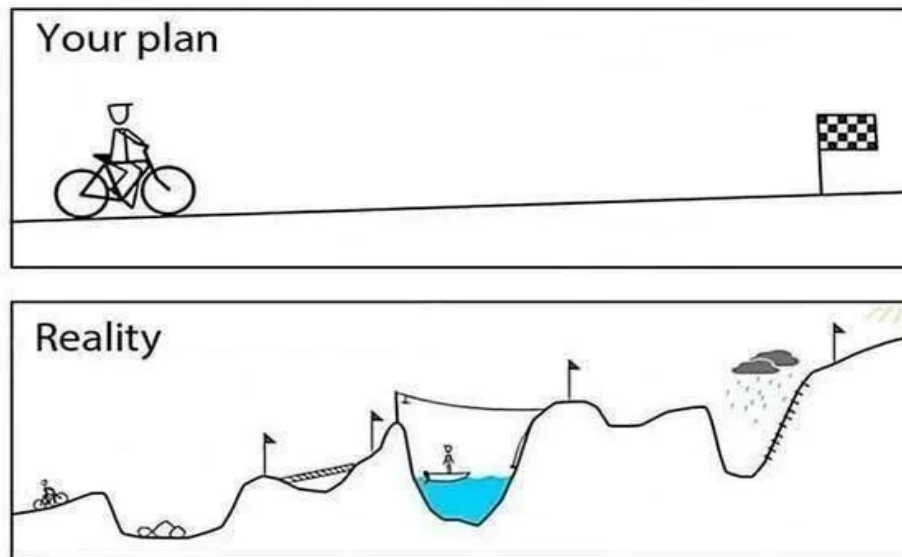
- Fast, high-quality fix at the surface
- Surfacing frequency drives mission design



- Frequent positioning without surfacing
- Infrastructure cost is high

PATH PLANNING AND OBSTACLE AVOIDANCE

How to do things → what to do



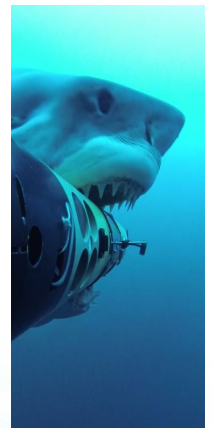
Manual control → Waypoint following → Path planning → Adaptive autonomy

- Obstacle avoidance
- Multi-objective optimization [BSB00193 - EfxINNOs](#)
- Dynamic replanning
- Collaborative planning

NEXT Black Sea Basin

AUV Hazards at sea

- . Entrapment
 - _ Fishing nets
 - _ Under rocks or ledges
- . Entanglement
 - _ Kelp
- . Flooding
 - Vulnerable on the Surface
 - Seals
- . Implosion
 - _ GPS position updates and radio communications
 - _ Rendezvous for recovery
 - _ Antenna damage, or worse
 - _ Liability – was the boat or people injured?
 - _ Stolen
- . Communications Failure



AUV Operations – When your vehicle is overdue

- What kind of search is needed? Is it on the surface, bottom, midwater?
- What is the wind/current? Estimate search area
- Act quickly. Know what assets you can call upon before they're needed. Have established relationships.
- For surface searches, aerial assets are best
- For underwater searches, long range acoustics are best.
- Midwater (drifting) searches are the hardest
- Understand the behavior of your AUV. What will it be doing?
- Practice ahead of time!

Dead Vehicle

- Following a deep dive:
 - _ Primary comms failed
 - _ Backup location beacon failed
- Vehicle drifted on surface for 16 days
- Picked up < 10km from where it started
- Worst circumstance is a dead vehicle drifting in the mid-water column

NEXT Black Sea Basin

AUV Operations – Launch and Recovery

Operational Location Devices

- GPS and Radio/Satellite
 - Transmit GPS position over VHF or Iridium satellite modem
- VHF beacon
 - Radio direction finder (RDF) on recovery ship
- Strobe light
 - Very effective at night
- Ultra-short baseline (USBL) tracking AUV from ship •
Acoustic Modem
 - AUV can tell ship where it is •
Ship can tell AUV what to do

Teledyne Benthos Acoustic
Modem

Applied Acoustics Easy Trac



WHOI Sentry

NEXT Black Sea Basin

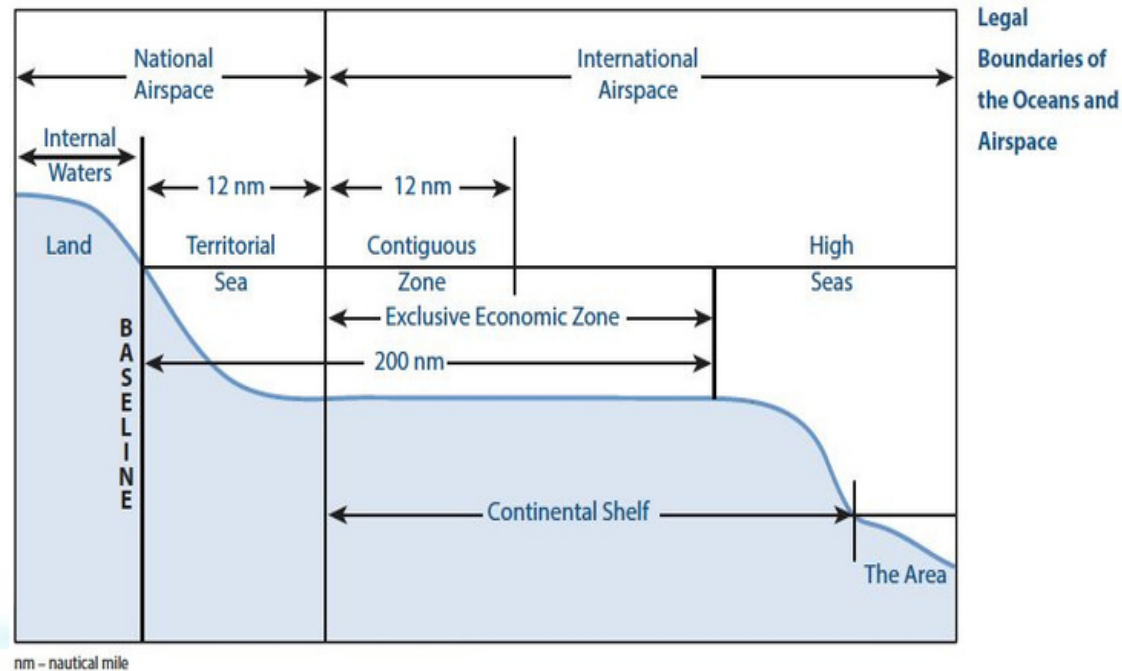
- Stay off the surface!
- Situational awareness (yours and others)
- Notice to mariners
- Labelling
- Contact info and resources
- Be visible
- Redundancy and mission planning
- Response: be prepared and practice

PREVENTION



REGULATION

- Evolving - everyone's making it up
 - Farther along with ASVs
 - Guidelines for ROVs
 - UNCLOS application fuzzy
 - Are AUVs vessels?
 - Marine protected areas
 - Export control
 - AIS
- What todo?
- Identify stakeholders
 - Cite similar operations



(img Tufts University)

Complementary data sources

AUV data gains context when combined with other platforms and sensors



CTD Casts

- Calibration/validation
- Full water column profiles
- Large-volume water samples



Physical samples

- Sediment/Substrate
- Organisms
- Particulate/dissolved gasses



Moorings/fixed platforms

- Time-series context
- Weather/current data



Satellite Data

- Broader spatial context
- Surface conditions
- Multi-scale analysis

Also useful for mission planning!

Data management

- How much data will we collect?
- Where will it live?
- What processing is needed before analysis? Who does that processing?

Low-Volume

MB to low GB

Sources:

- CTD sensors
- Basic biogeochem
- Vehicle telemetry

Formats:

Timeseries formats:
NetCDF, CSV, Matlab,
Etc

Requirements:

Standard analysis tools

Medium-Volume

10s-100s GB

Sources:

- Multibeam
- Sidescan
- Still imagery

Formats:

Often proprietary

Requirements:

Processing software,
storage plan

High-Volume

100s GB to TB

Sources:

- Video
- High-res imaging
- Acoustic backscatter

Formats:

Video, image, raw binary

Requirements:

Storage infrastructure,
processing pipeline
Consider subset strategy

Hi res video can easily approach! Determined by bitrate, framerate, resolution

TRENDS

Smarter & Smaller

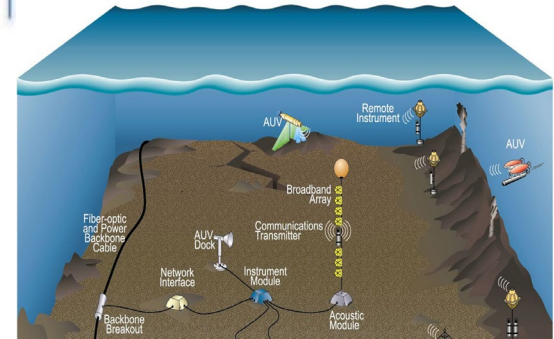
- Micro-AUVs; cheaper, smaller compute and sensing
- More, more-integrated onboard realtime AI and ML
- Automatic → autonomous

Persistent & Powerful

- Energyharvesting and advanced batteries
- Resident systems with months-long deployments
- Advancing sensing and control, e.g. real-time genomic analysis, precision hovering

Connected & Collaborative

- Multi-platform coordination (AUV-ASV-Observatory)
- Shared tasks and cooperative localization
- Swarm operations



NEXT Black Sea Basin

Trend: Onboard Processing & AI/ML Processing Strategies

Event-Triggered Recording

Record only when target detected (e.g., ML model identifies organisms)

Adaptive Imaging Properties

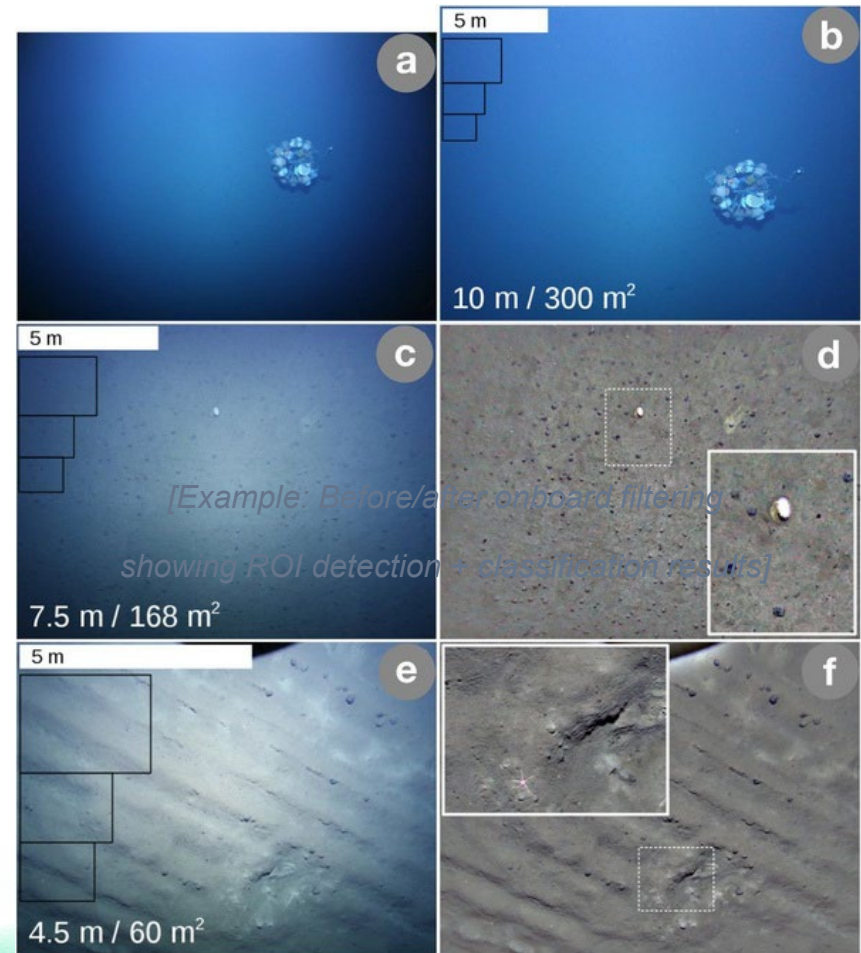
E.g. Adjust frame rate or bitrate

Onboard Classification

Store metadata, transmit ROIs only (e.g., taxa counts)

Compression & Summarization

Generate reduced representations (e.g., thumbnails + detection database)



Reducing data volume through intelligent selection

(img Hemholtz Association)

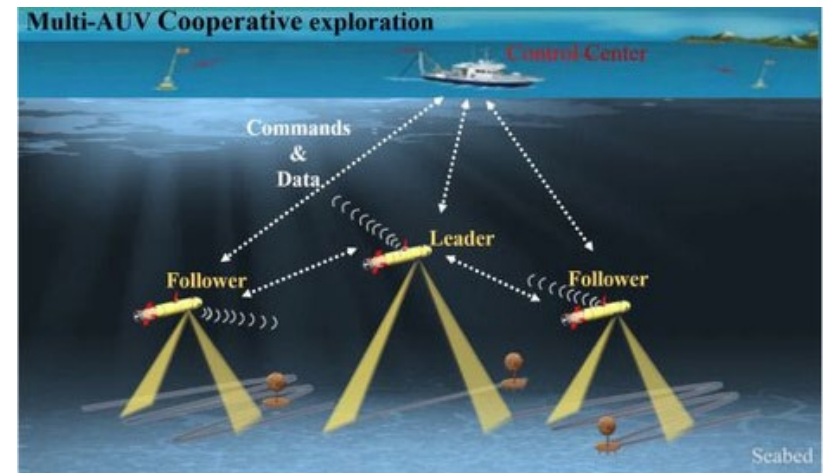
Multi-vehicle operations

Why Cooperate?

- **Coverage & Efficiency:** Survey larger areas faster than single vehicles
- **Redundancy:** Mission continues if one vehicle fails
- **Complementary Capabilities:** Different sensors, depths, or specializations working together
- **Simultaneous Multi-Point Operations:** Track moving targets, measure spatial gradients, or monitor multiple sites at once

Major Technical Challenges

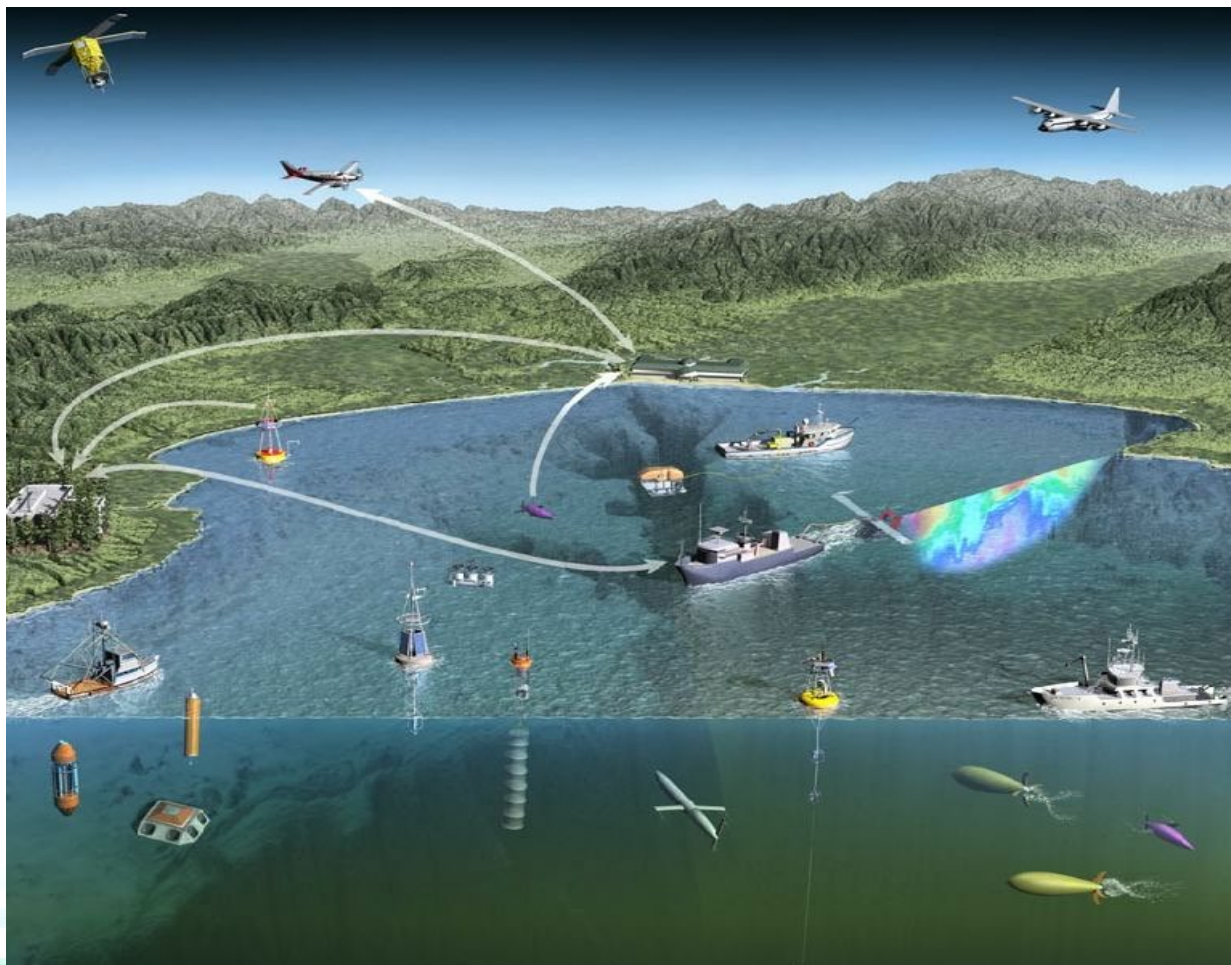
- **Communication constraints:** Limited bandwidth, intermittent connectivity
- **Coordination without central control:** Distributed decision making
- **Time synchronization:** Critical for data fusion and collision avoidance



Cooperation can be AUV-AUV or AUV-other platforms!

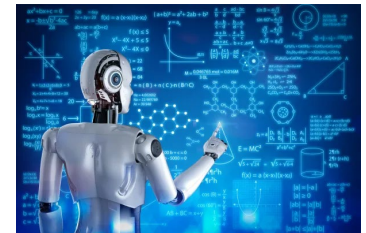
NEXT Black Sea Basin

Integrated Multiplatform Operations - AOSN



Important Questions

- What is your priority and why? (speed, resolution or area)
- Can your mission be split into a detection phase and a confirmation/characterization phase?
 - What sensors would each phase need?
 - What fraction of your survey area do you expect to contain what you're looking for?
 - What's your trigger for switching to confirmation mode?



Sources

- MBARI's AUV training OSM26, Glasgow
- RTSYS' NemoSENSE mAUV training – Constanta 2025



Thanks for your attention!