ITINERIS

Advances in ocean science from autonomous gliders

Underwater gliders

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Laboratorio di Oceanografia
Università Politecnica delle Marche

Autonomous Instruments in Oceanography
Università degli Studi di Napoli Parthenope
10-14 February 2025

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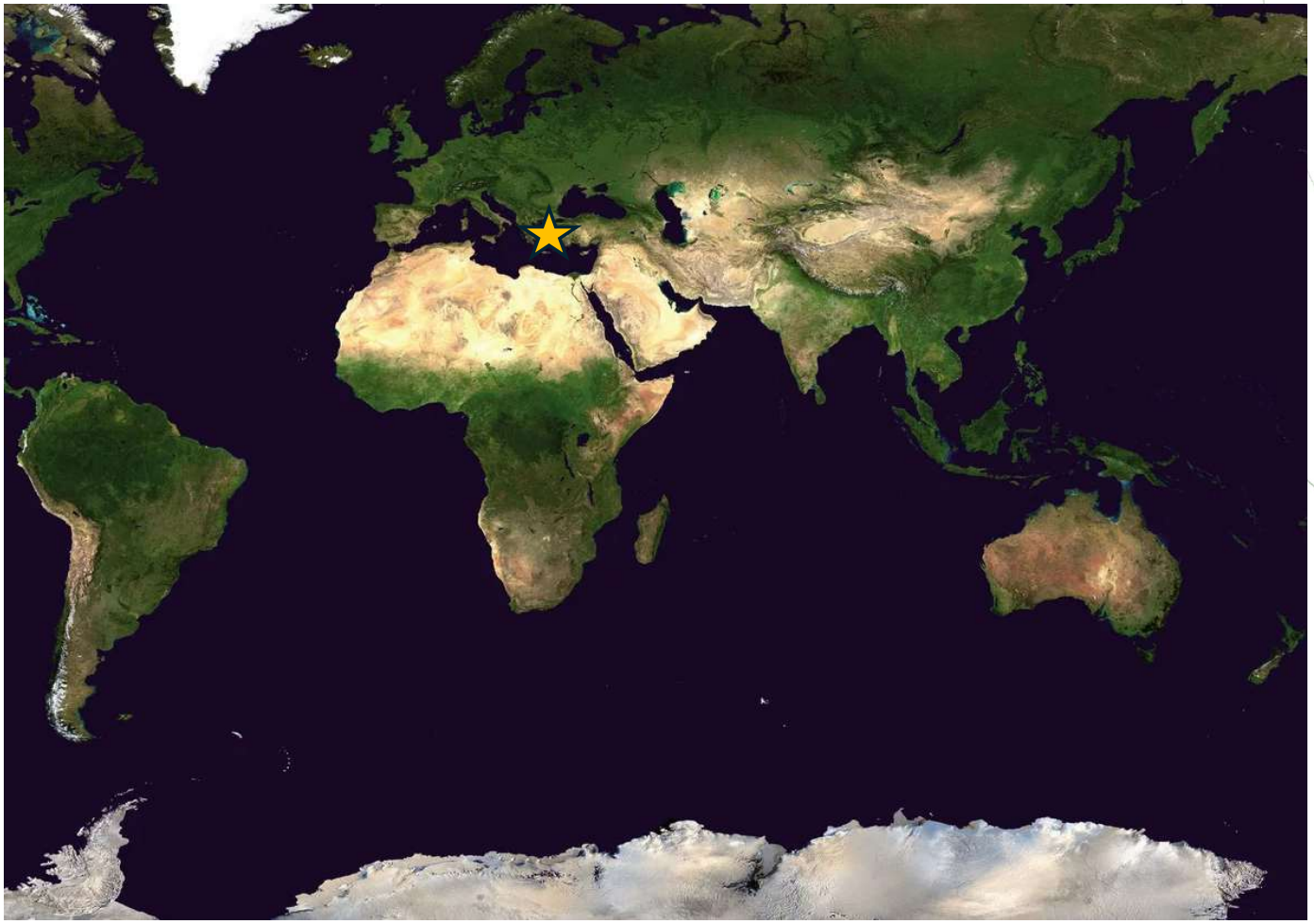
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 "Education and Research" - Component 2: "From research to business" - Investment 3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Introductions

Introductions: my journey with autonomous instruments



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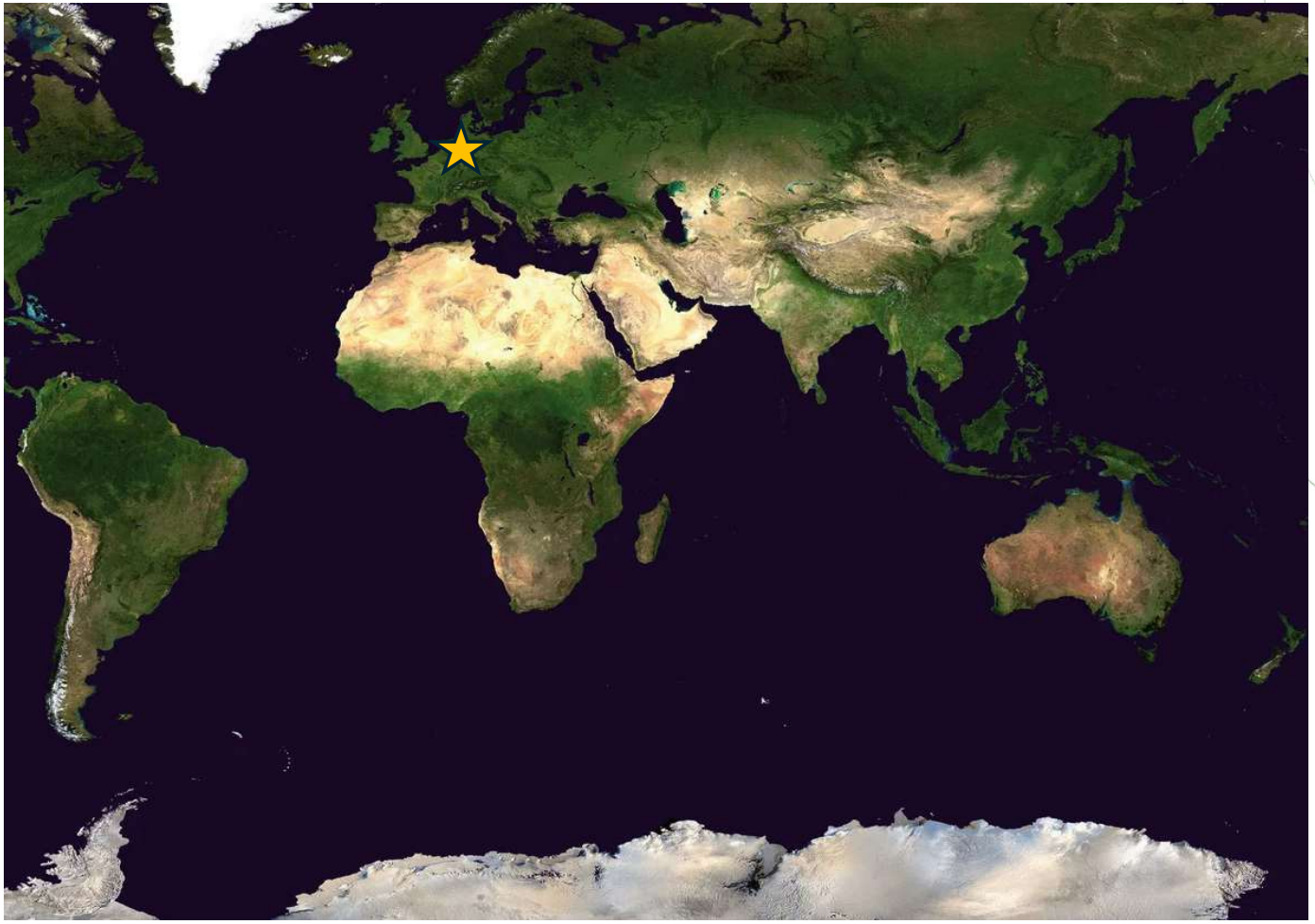

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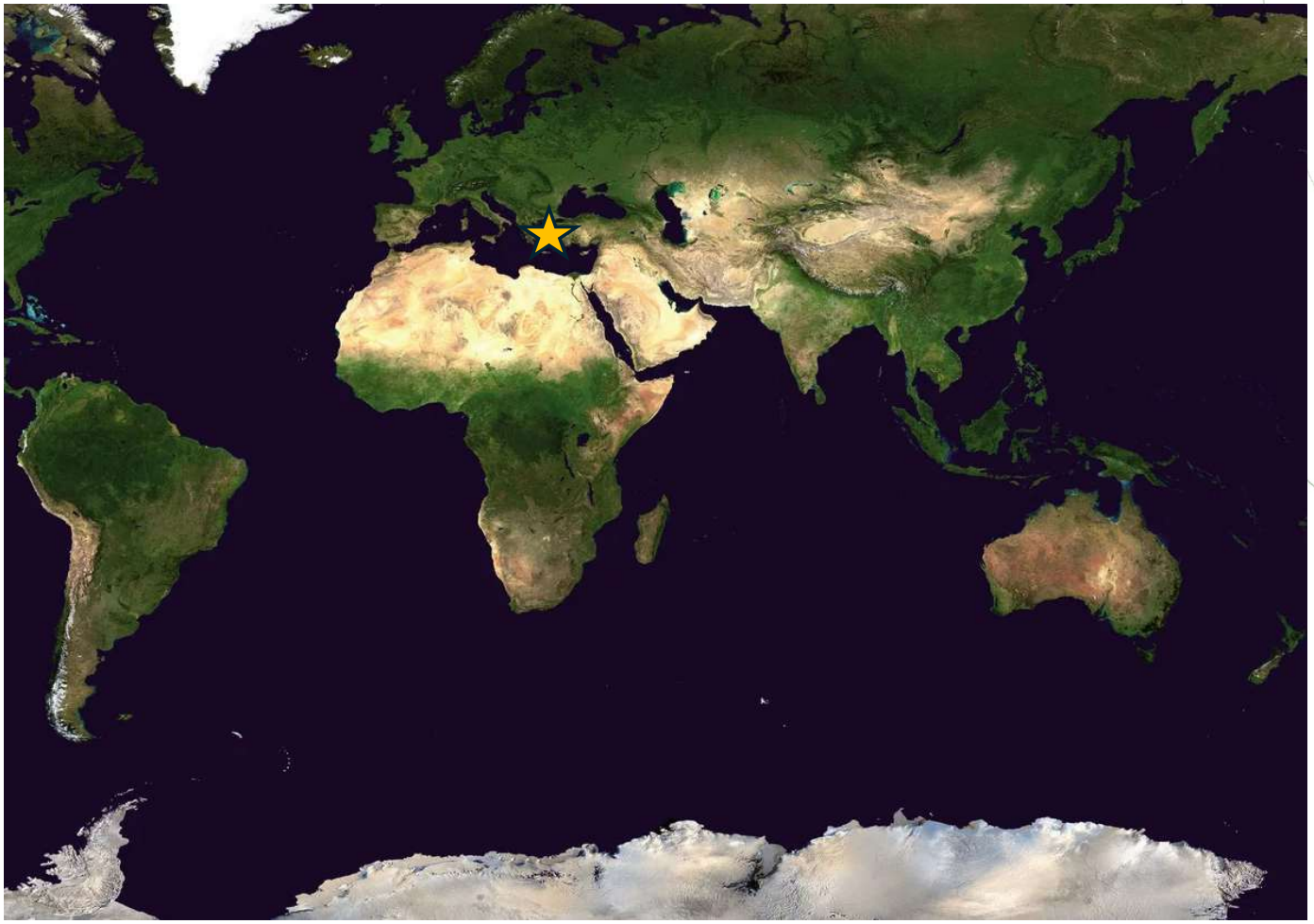

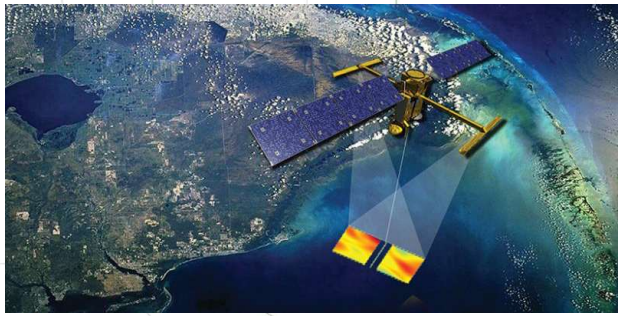

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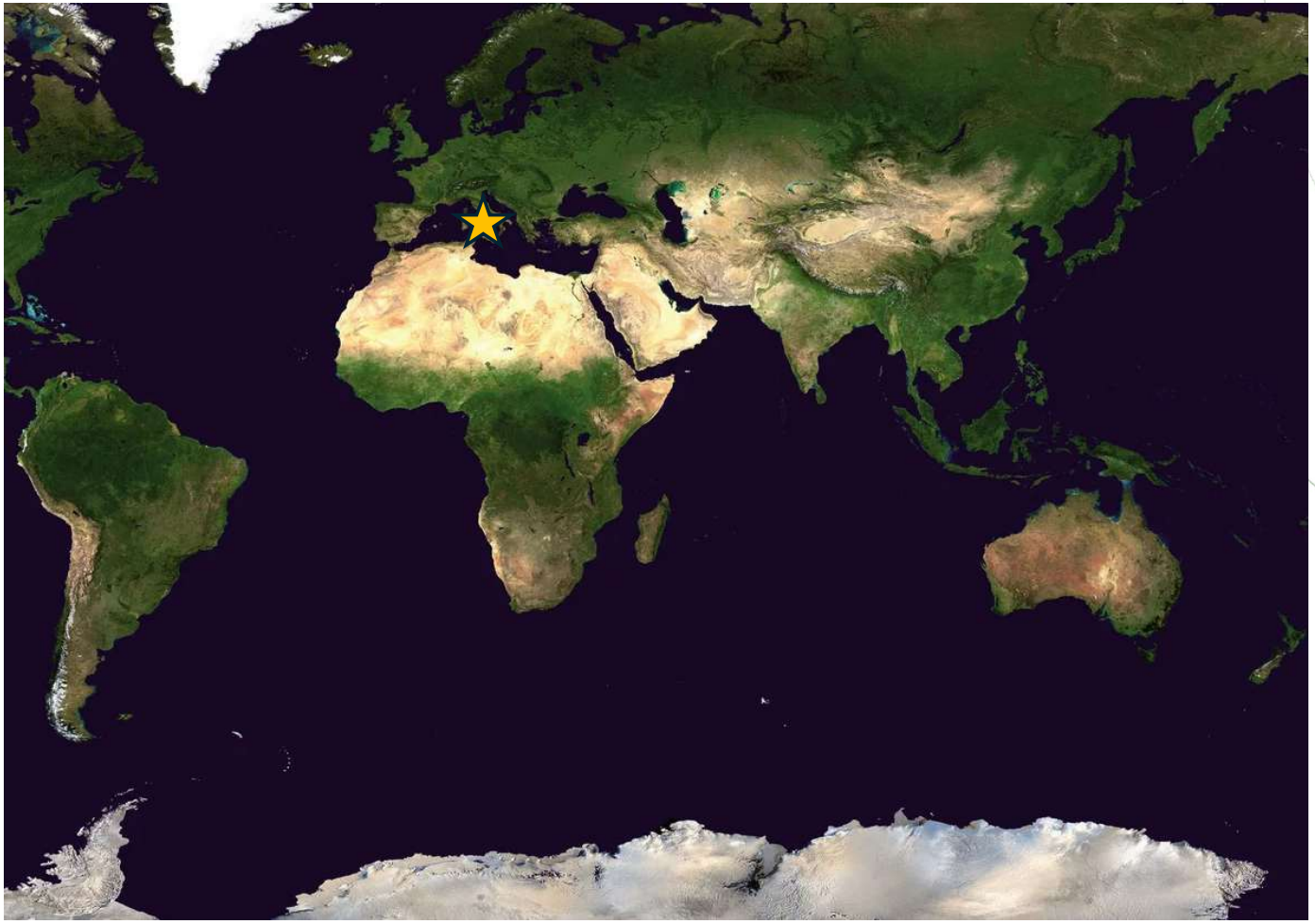

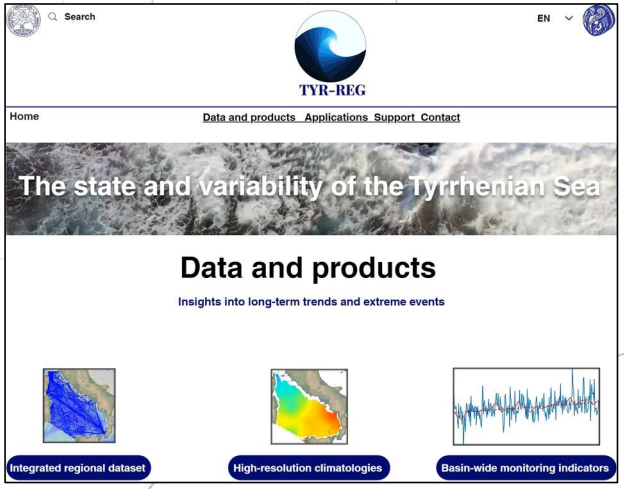

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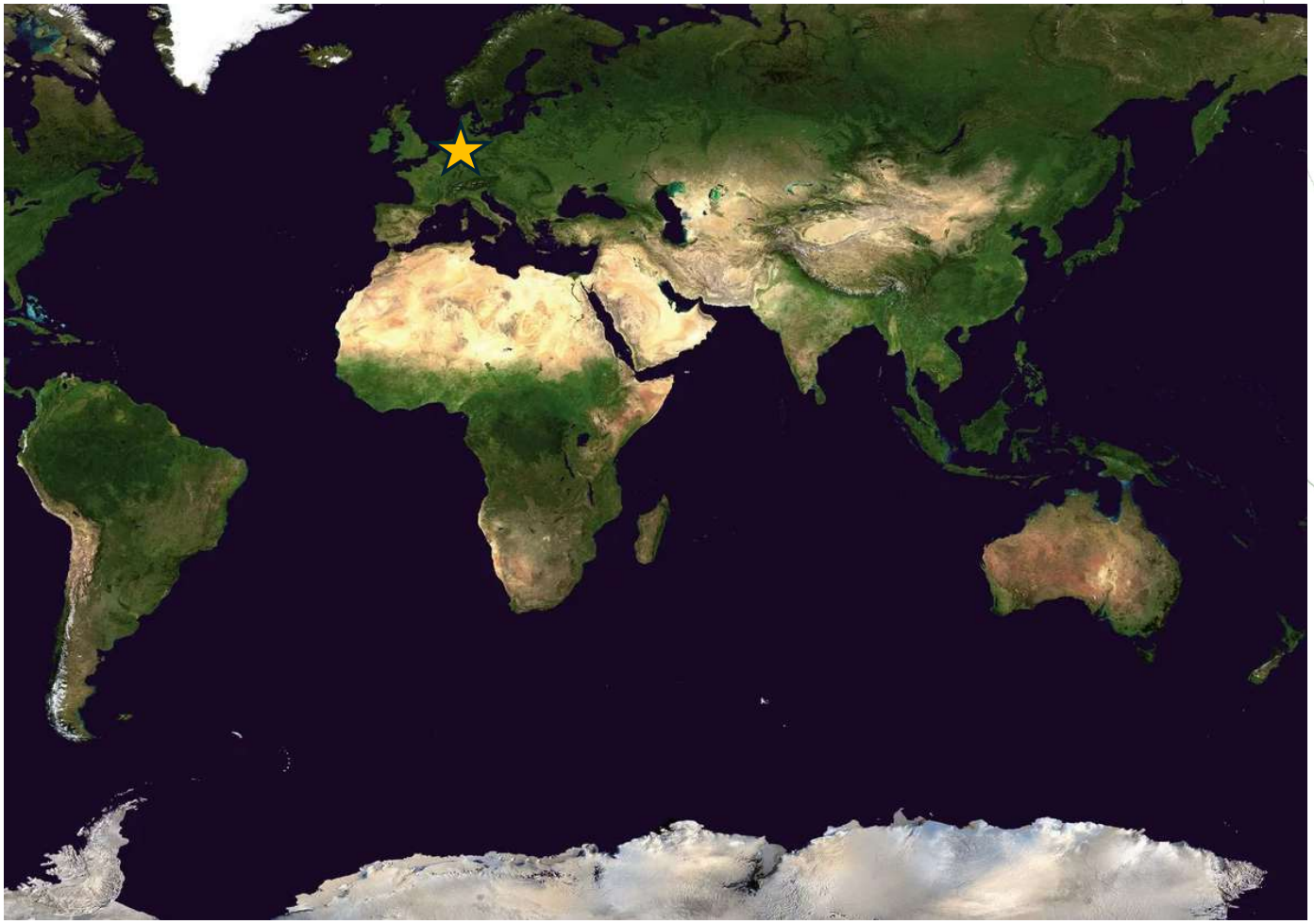

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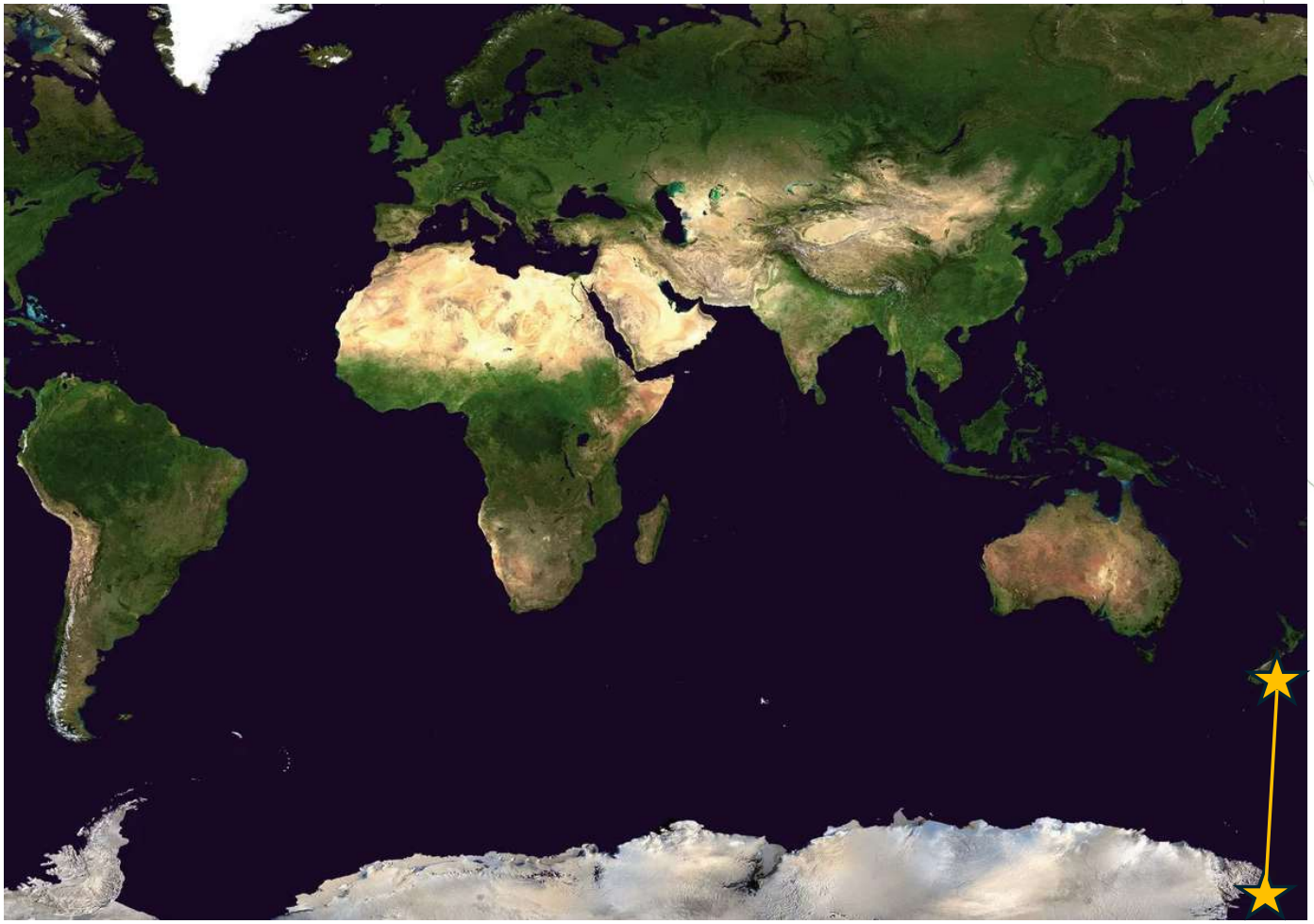
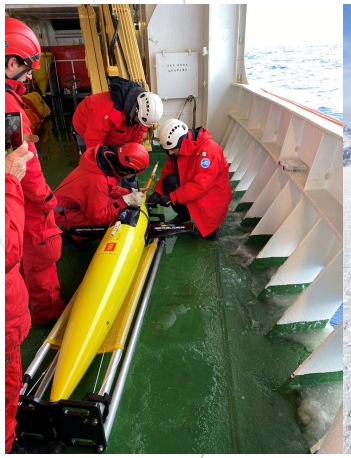
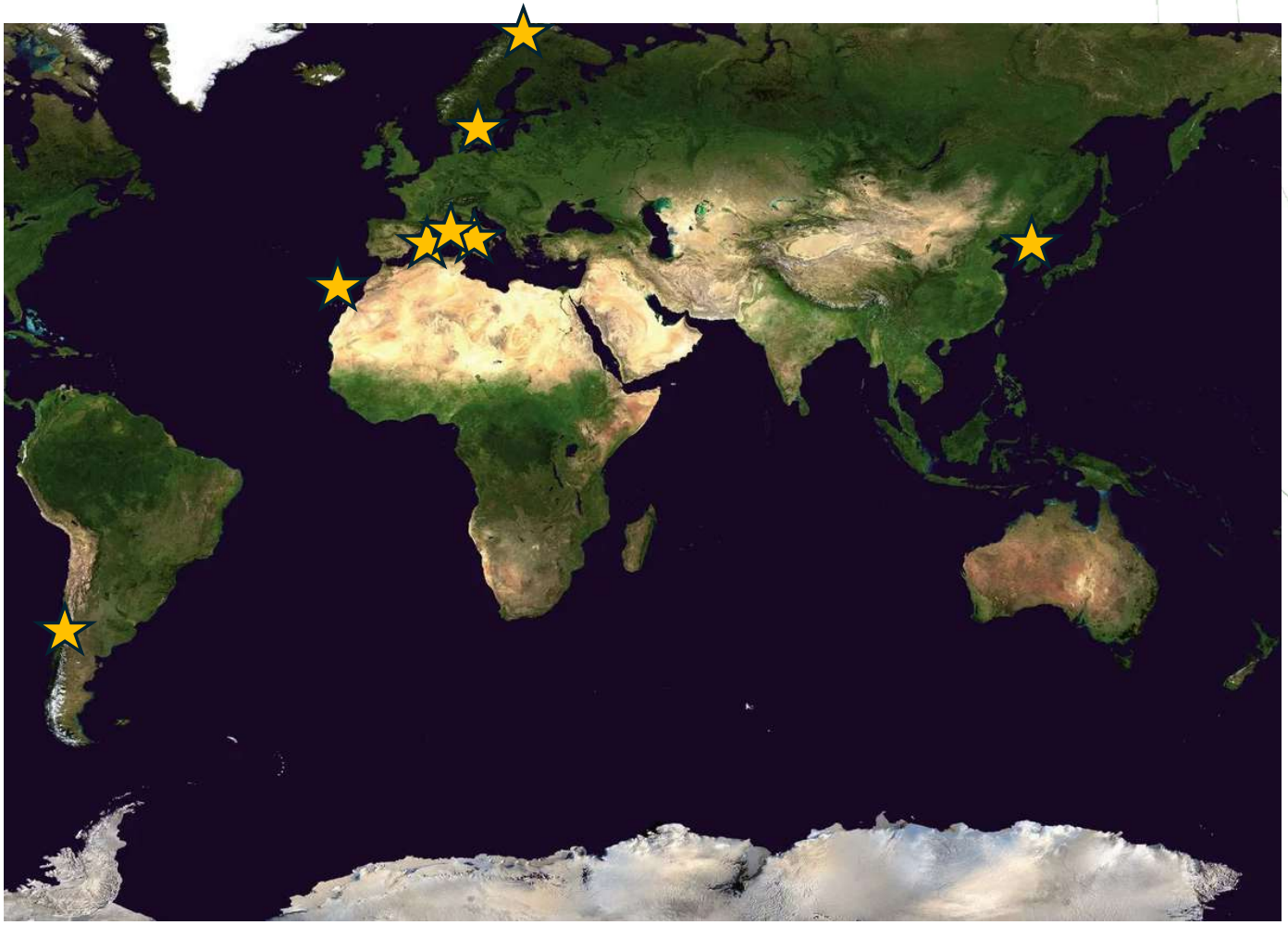




ANTA 2019-2020

Introductions: my journey with autonomous instruments



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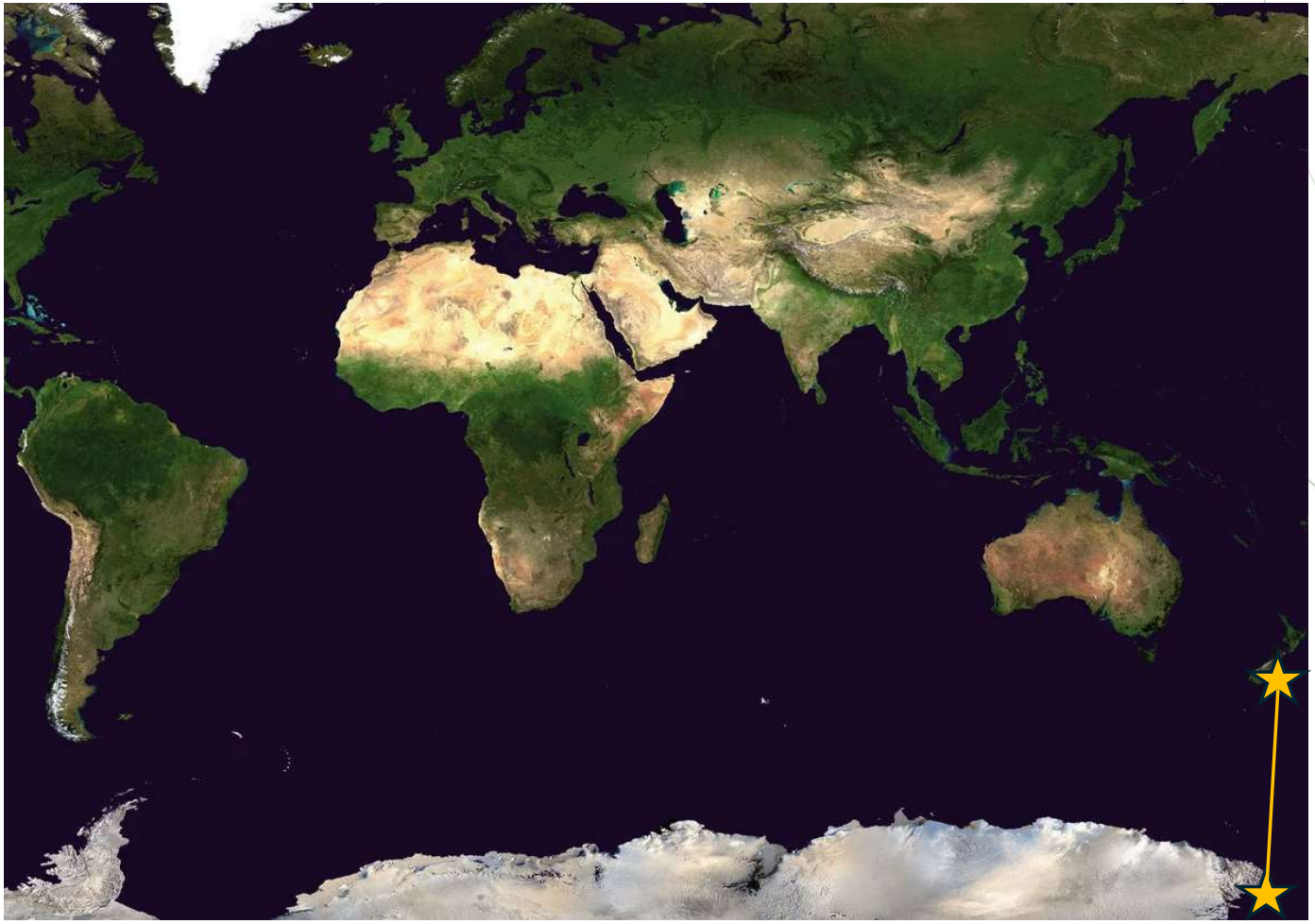

ANTA 2023-2024

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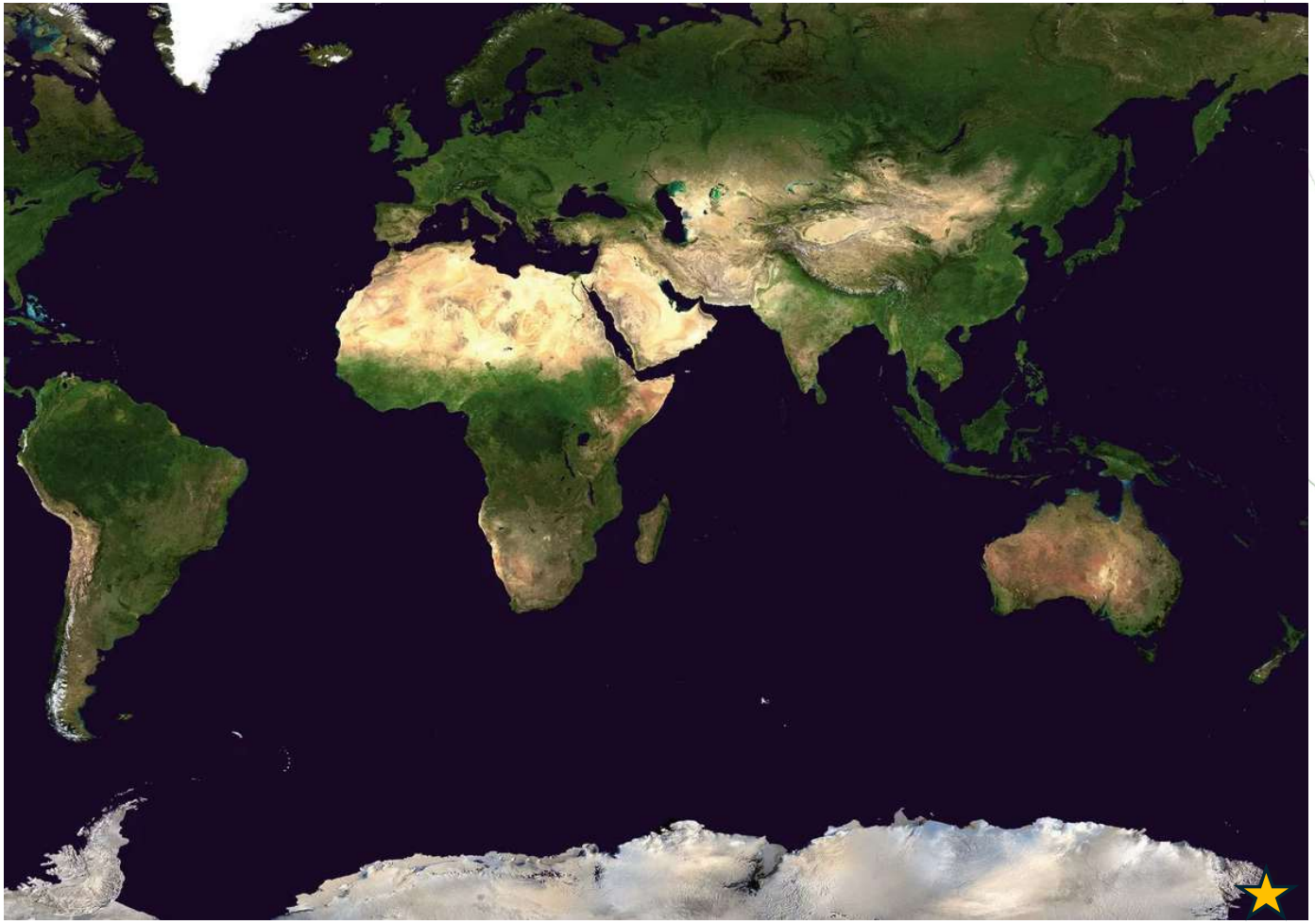
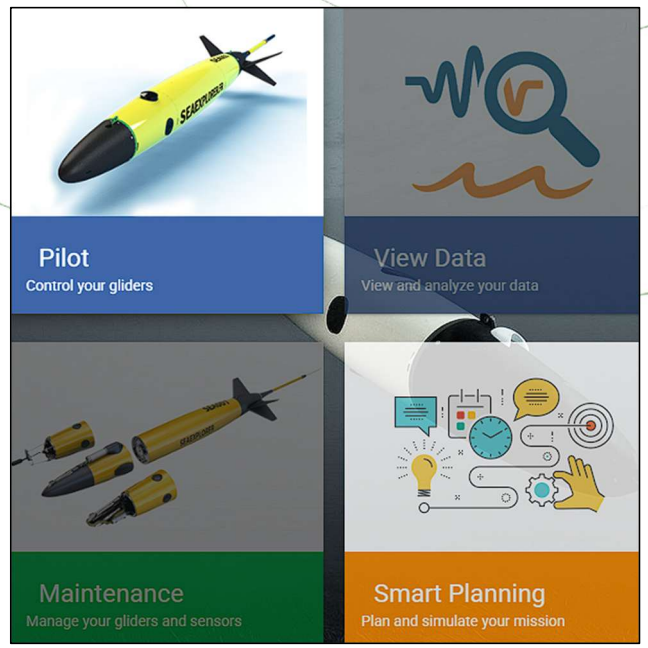
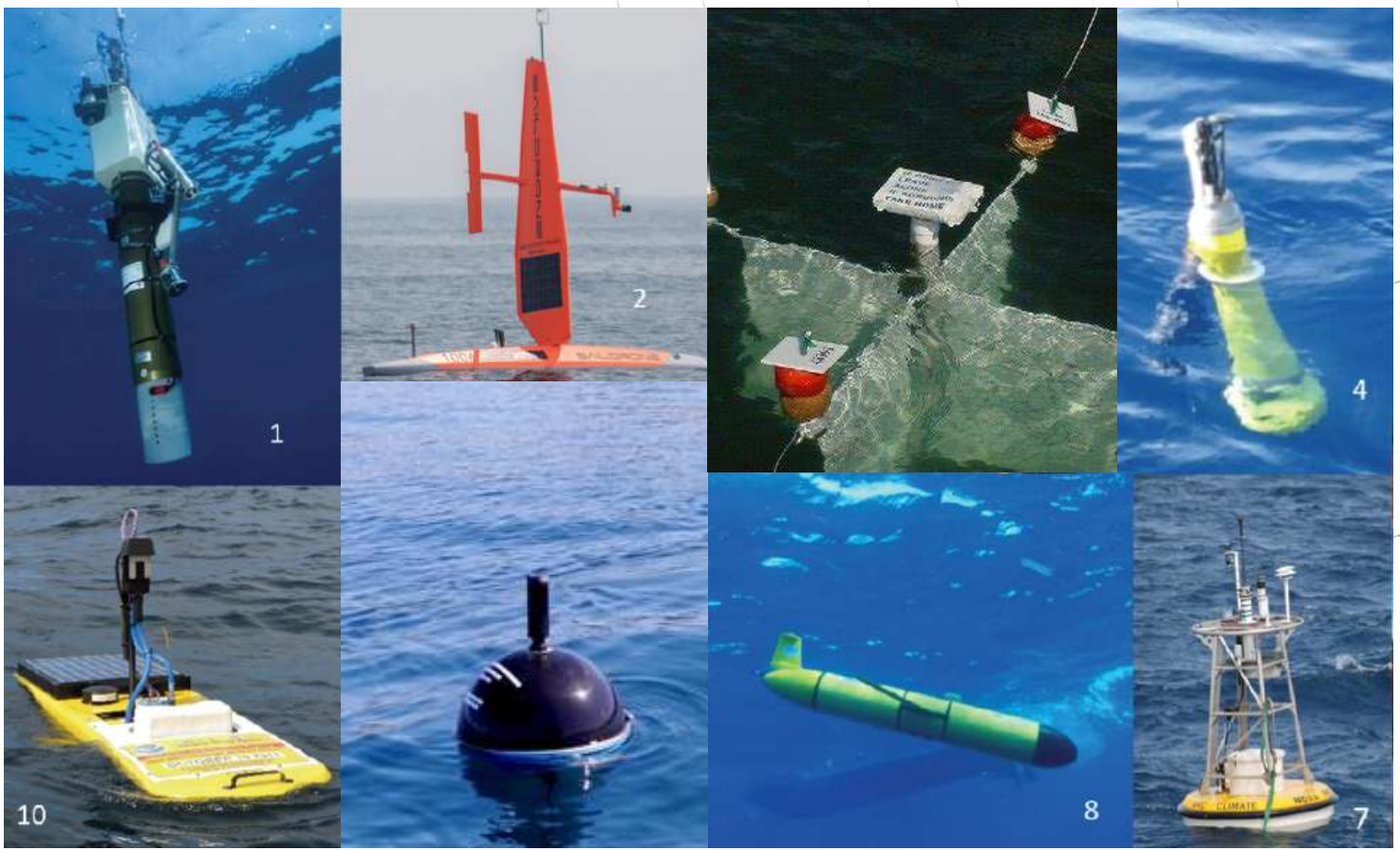


ANTA 2024-2025



What about you?



Contents

1) Introduction to underwater gliders

Overview, history, design

Principles of operation

2) Technical aspects and instrumentation

Energy efficiency, communication & navigation system and scientific sensors

3) Real-life applications and usages in different disciplines

Capabilities and insight into diverse glider operations

Exercise on realistic mission planning with the GLIMPSE simulation software

4) Glider data analysis and interpretation

Data output, existing processing tools and community efforts

Practical session with sample data from recent missions

5) Challenges, innovations and future perspectives

Current limitations and challenges, tips and tricks

Ongoing innovations and future directions in glider technology

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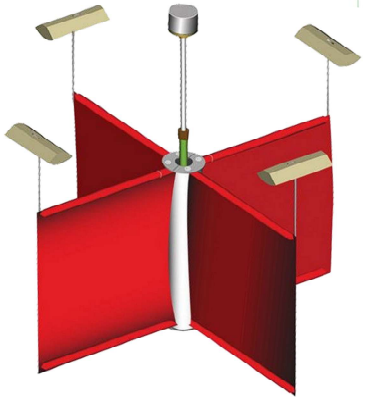
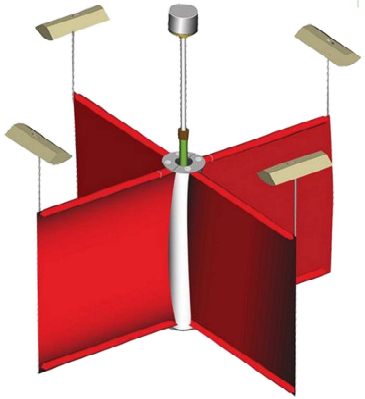
Introduction to underwater gliders

Drifters...



Difference among autonomous instruments

Drifters... **drift!**



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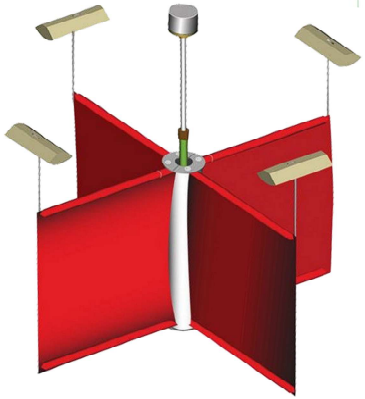
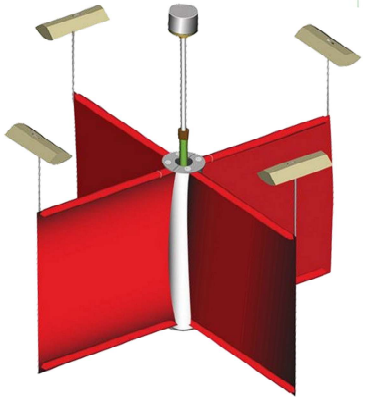


Floats...

Difference among autonomous instruments

Drifters... **drift!**

Floats... **float!**



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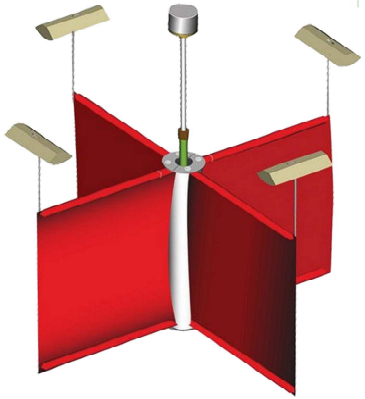

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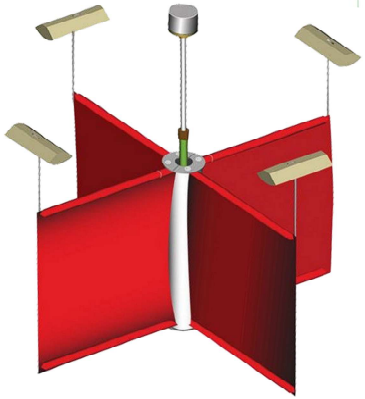
Gliders....

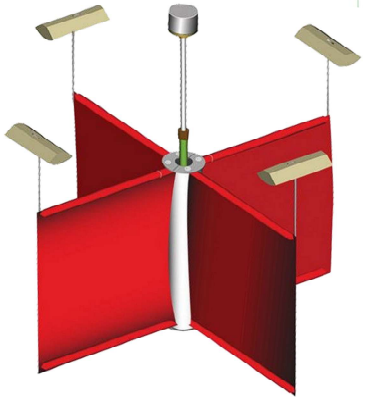


Difference among autonomous instruments

Drifters... **drift!**

Floats... **float!**

Gliders.... **glide!**



Difference among autonomous instruments

Drifters... **drift!**

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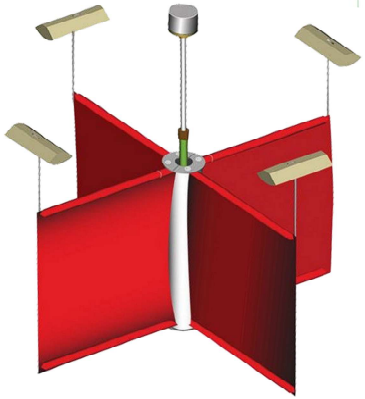
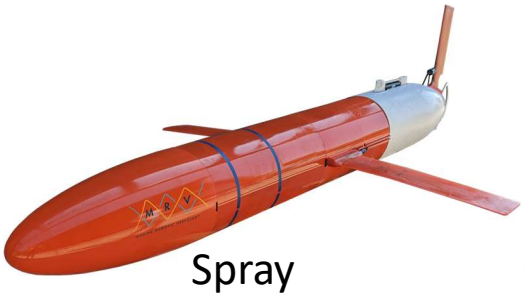
Gliders.... **glide!**



What is an underwater glider?

Slocum



Spray

Seaglider

SeaExplorer

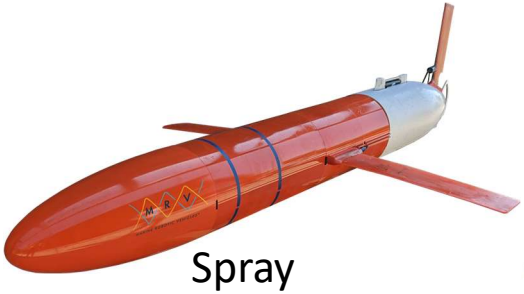
1.50-2 m long & 50-70 kg depending on model and payload

2-6 km between surfacing when diving to 1km depth

What is an underwater glider?

“A unique class of <u>autonomous sampling vehicles</u> that don’t rely on traditional propeller propulsion...”

Slocum



Spray

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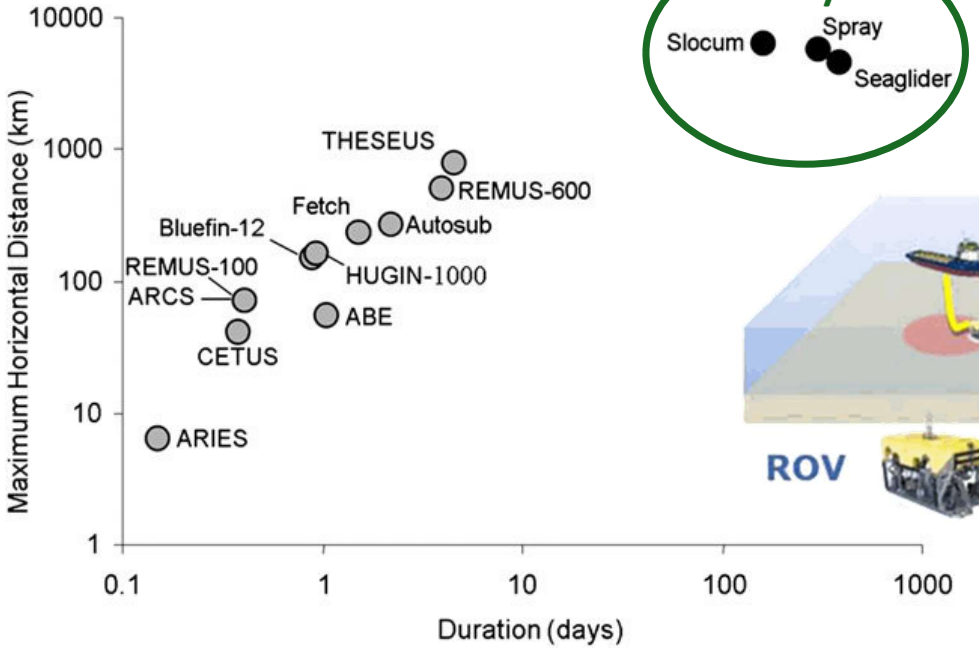
Autonomous underwater vehicles

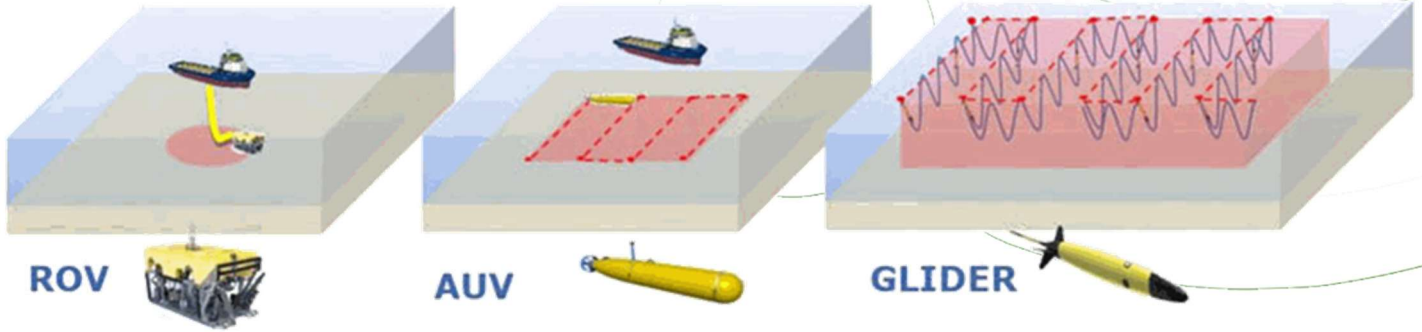
AUVs

Moline et al., 2009 (http://dx.doi.org/10.1175/2009JTECHO666.1)

Unique class of autonomous underwater vehicles



temporal & spatial scales unattainable by powered AUVs

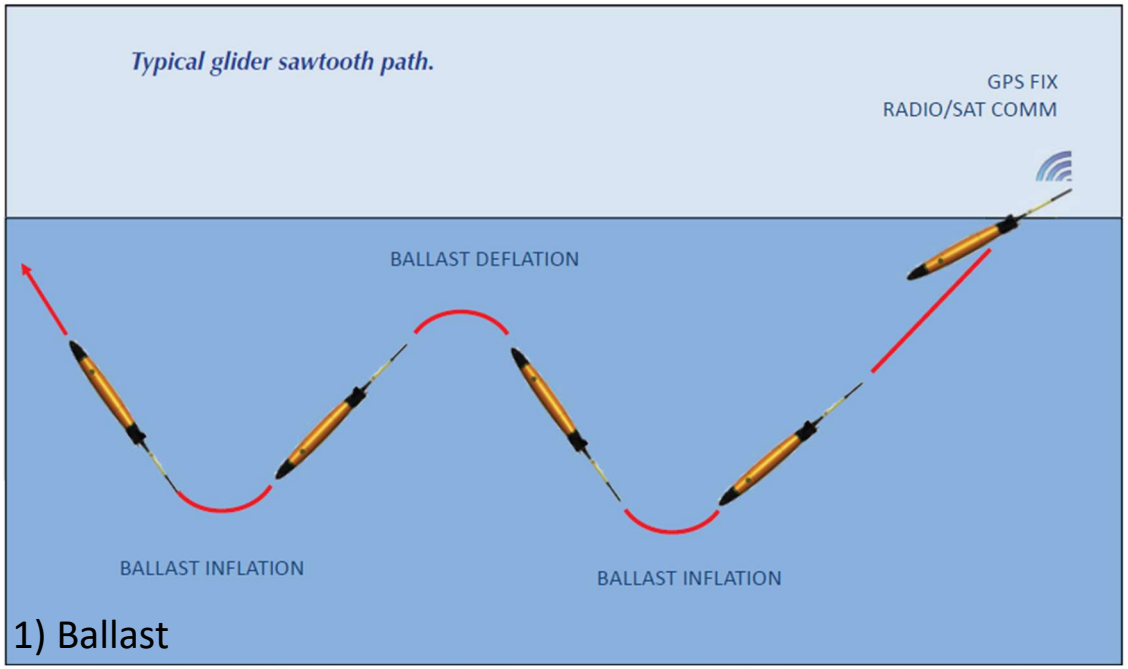


Moline et al., 2009 (http://dx.doi.org/10.1175/2009JTECHO666.1)

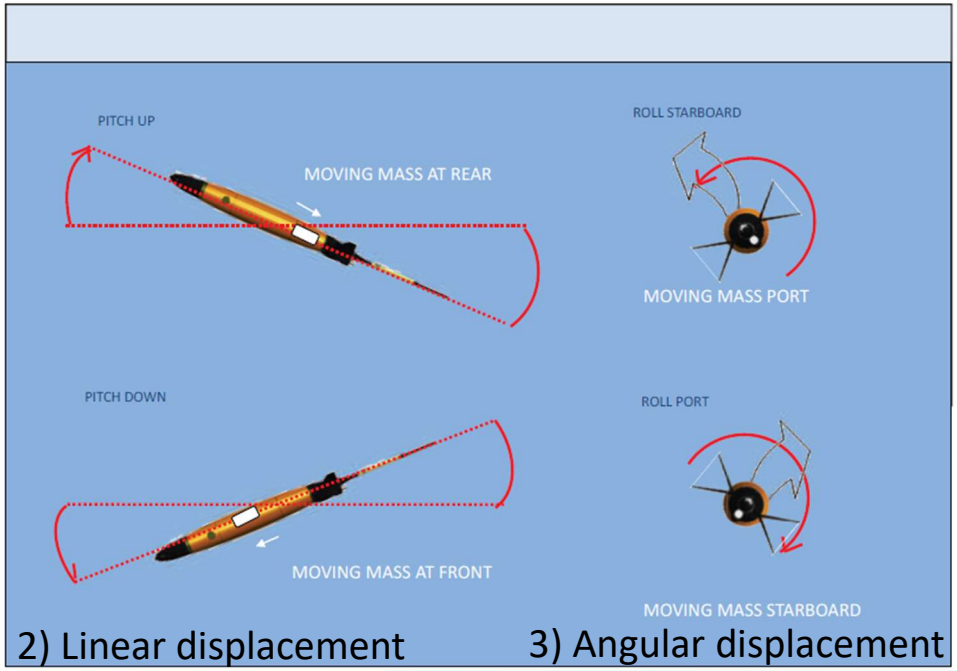
Levaché et al., 2019 (https://doi.org/10.3997/2214-4609.201902859)

Introduction

“A unique class of sampling vehicles that don’t rely on traditional propeller propulsion…”



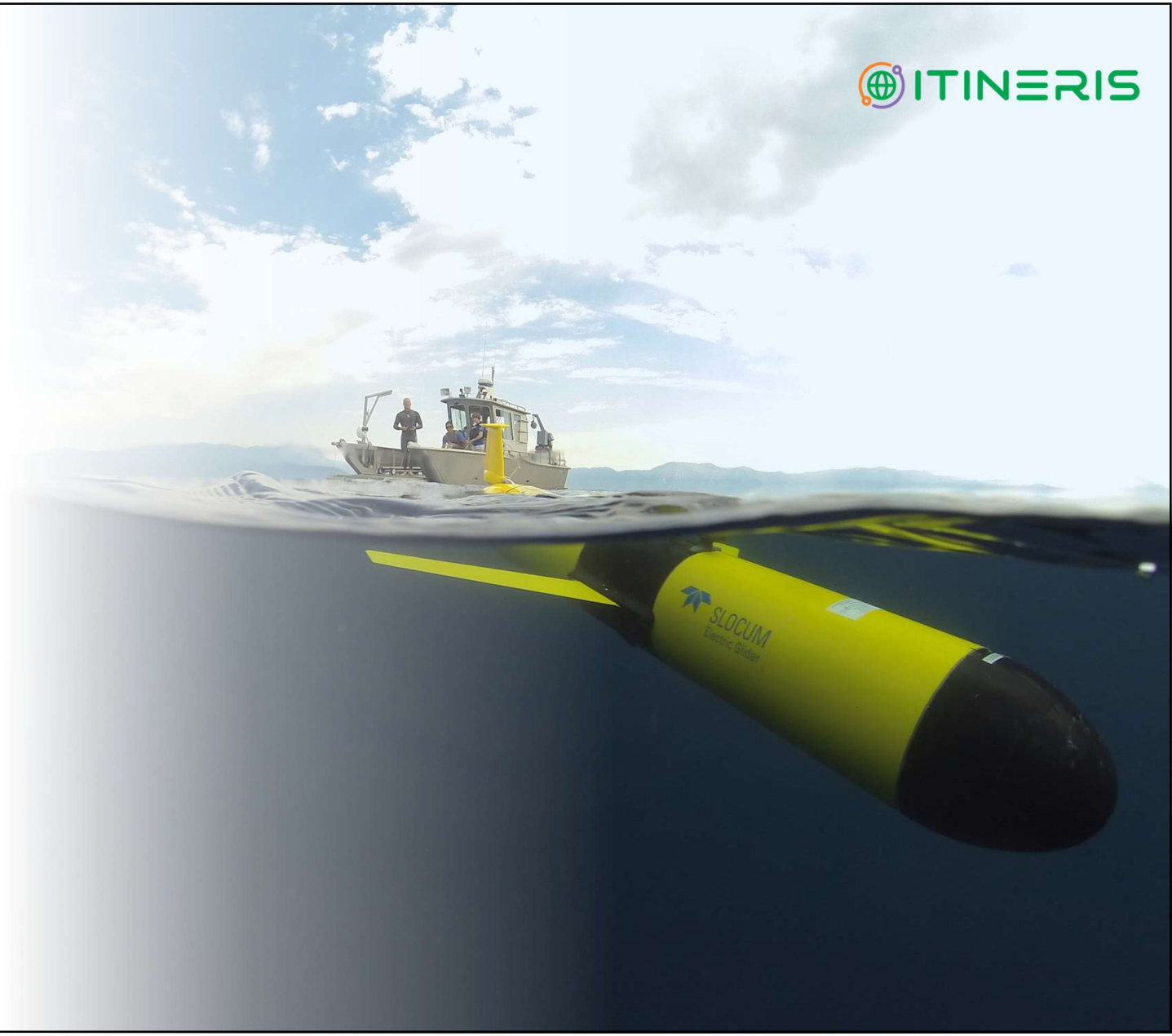
1) Ballast



2) Linear displacement

3) Angular displacement

Underwater glider history



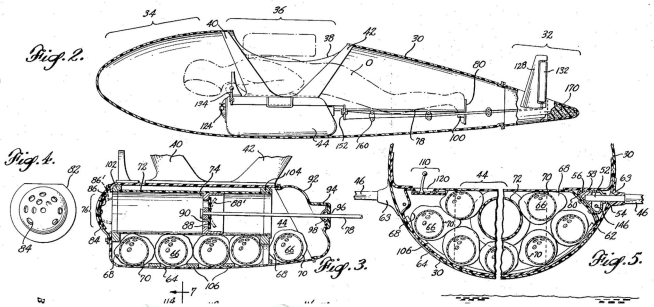
The original idea

early 1960s

Concept Whisper: prototype swimmer delivery vehicle

&

Hydroglider patent: buoyancy engine powered by a swimmer-passenger (Ewan Fallon)



The first glider concept

early 1960s

Concept Whisper: prototype swimmer delivery vehicle

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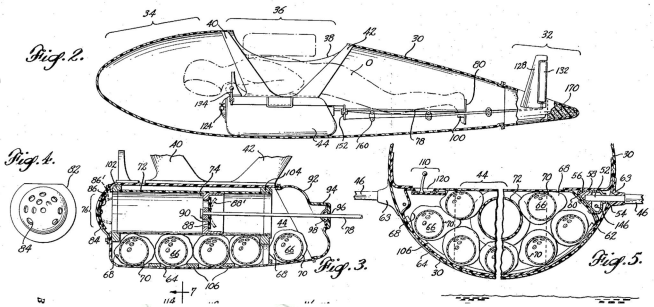
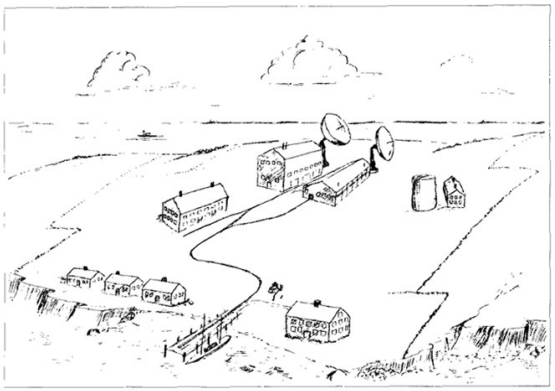
Hydroglider patent: buoyancy engine powered by a swimmer-passenger (Ewan Fallon)



1989



The Slocum Mission Control Center on Nonamesset Island.

Each Slocum reports into Mission Control via satellite about six times a day.

Slocum Mission: glider <u>concept</u> with a buoyancy engine powered by a heat exchanger (article in Oceanus by by Henry Stommel)

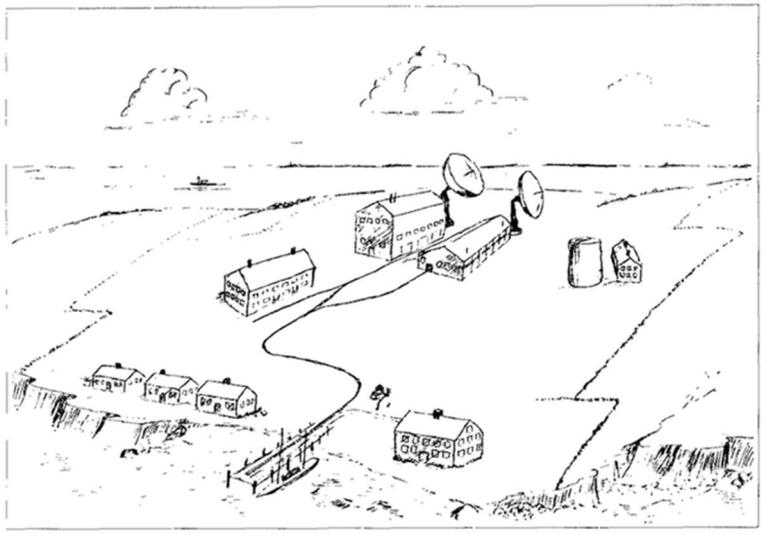
Science fiction at the time !

The thermal glider concept

FEATURE

THE SLOCUM MISSION

Narrative and Illustration
By Henry Stommel



The Slocum Mission Control Center on Nonamesset Island.

The payoff in increase of knowledge often is greatest the more unconventional the idea, especially when it conflicts with collective wisdom.

Each Slocum reports into Mission Control via satellite about six times a day.

https://tos.org/oceanography/assets/docs/2-1_stommel.pdf

Henry (Hank) Stommel

The thermal glider concept

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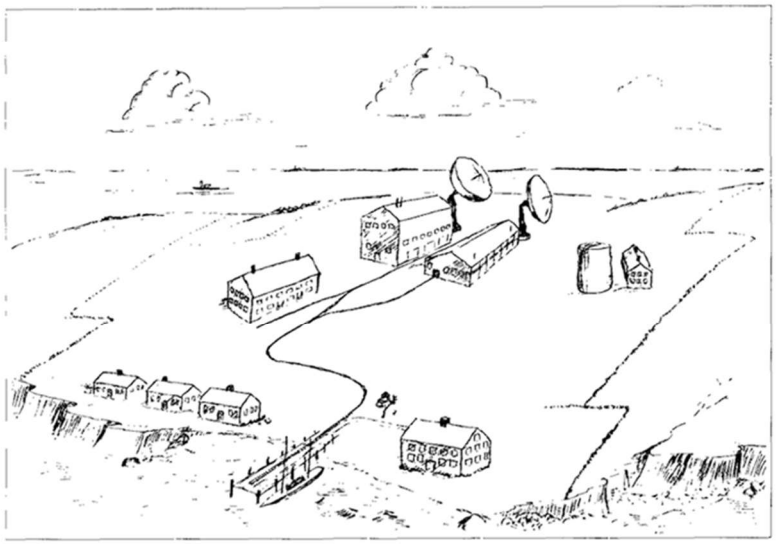

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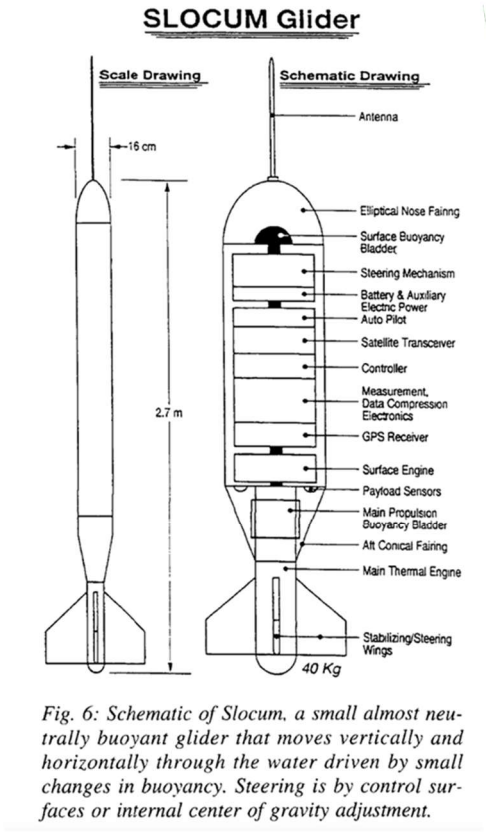

Fig. 6: Schematic of Slocum, a small almost neutrally buoyant glider that moves vertically and horizontally through the water driven by small changes in buoyancy. Steering is by control surfaces or internal center of gravity adjustment.

Doug Webb: the real-life "pioneering ocean engineer"

question. But a pioneering ocean engineer had a different vision of how to garner a harvest of data on a deep-ocean global basis, and this led, after a few vicissitudes, to the Department of the Environment's determination to support the Slocum Mission and the present deployment of Slocums throughout the world.

The thermal glider

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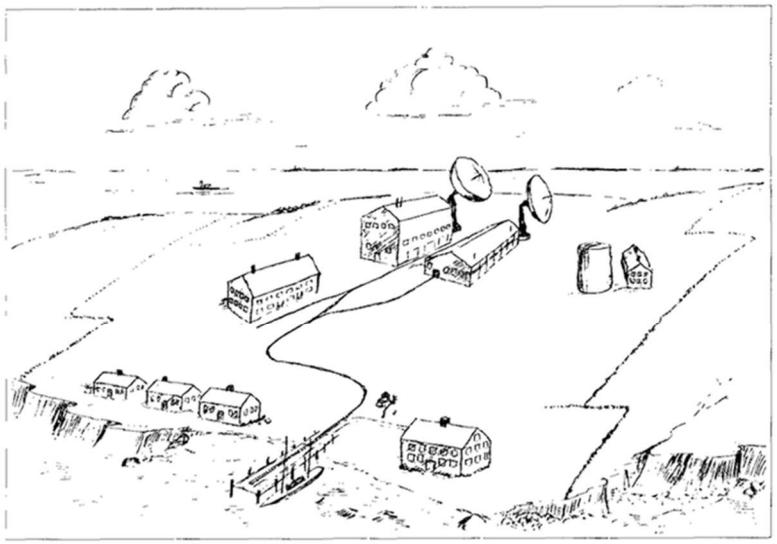
THE SLOCUM MISSION

Narrative and Illustration
By Henry Stommel



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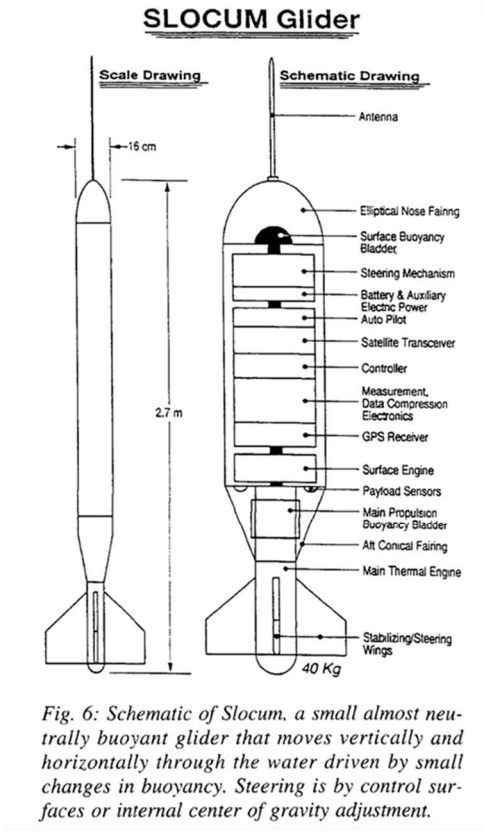


Fig. 6: Schematic of Slocum, a small almost neutrally buoyant glider that moves vertically and horizontally through the water driven by small changes in buoyancy. Steering is by control surfaces or internal center of gravity adjustment.

Slocum Thermal
by Webb Research (2001)

2003 Reality !

The electric glider

Electric Slocum

Teledyne Webb Research

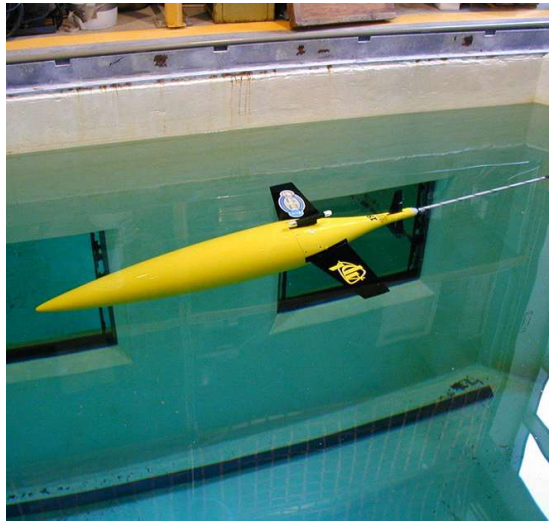
Transatlantic Crossing!

Rutgers University

Different types of commercial electric gliders

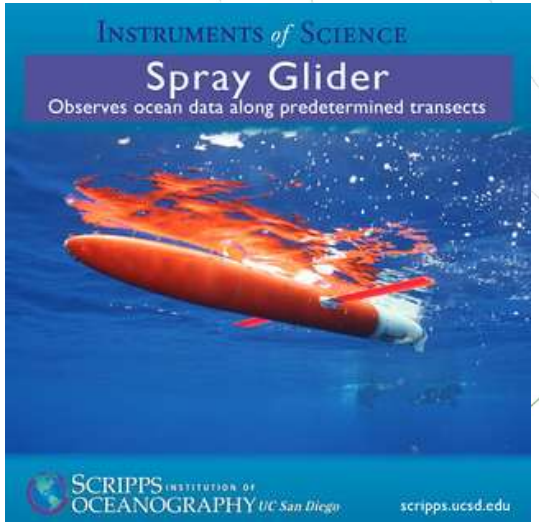
Slocum

Teledyne Webb Research



Seaglider

University of Washington



Spray

Scripps Institution of Oceanography

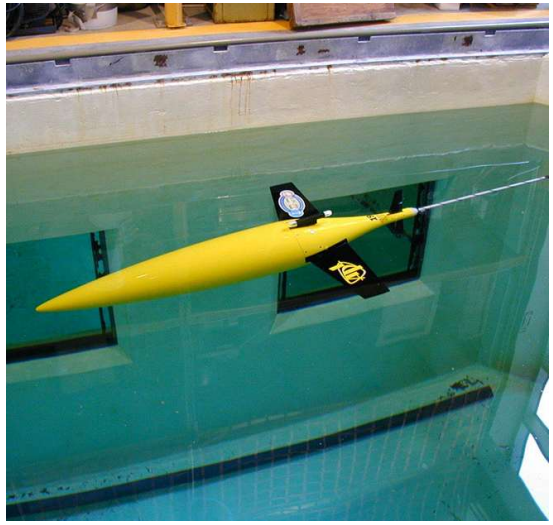
SeaExplorer

ACSA & ACRI, CNRS, IFREMER

Differences among commercial gliders

Slocum

Teledyne Webb Research



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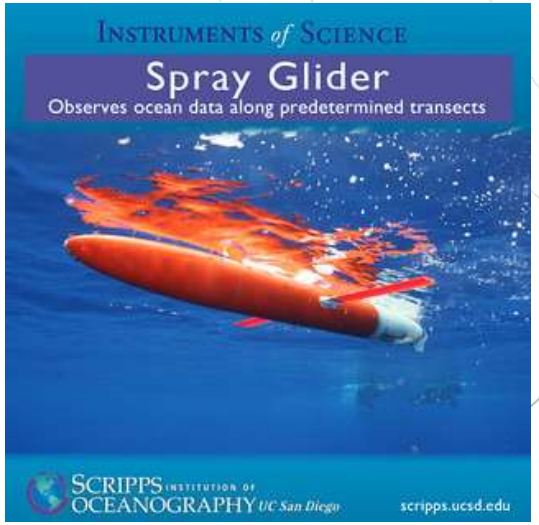

Spray

Scripps Institution of Oceanography

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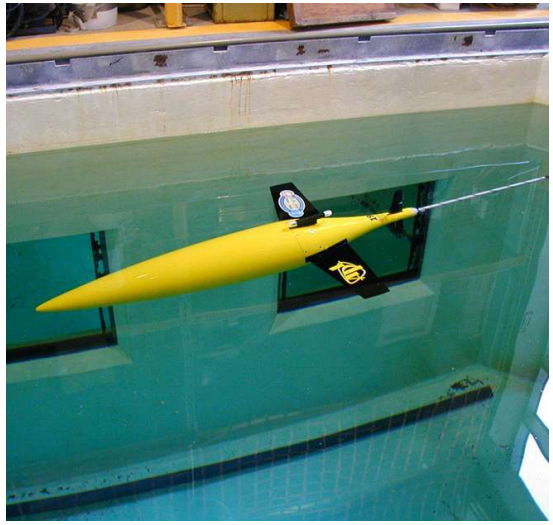
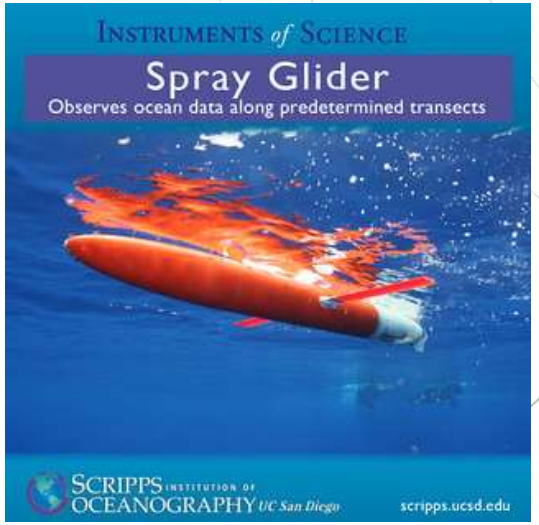
In what ways are these gliders different?

Differences among commercial gliders





Slocum

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Spray

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ACSA & ACRI, CNRS, IFREMER

Wings ?

How they work ?

Antenna ?

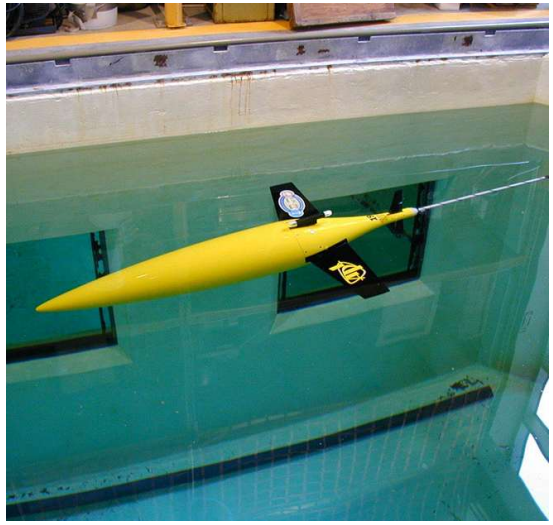
In what ways are these gliders different?

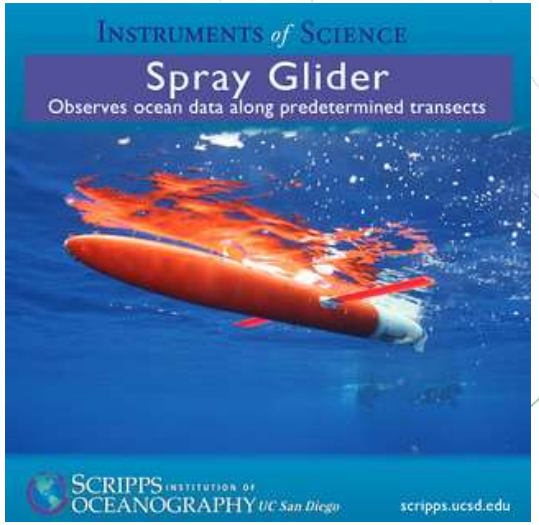
Rudder ?

Torpedo shape ?

Size ?

Differences among commercial gliders





Slocum	**Seaglider**	**Spray**	**SeaExplorer**
Wings	Wings	Wings	*Wingless*
Steering Rudder	Fixed Rudder	Fixed Rudder	Fixed Rudders
Fin Antenna	*Foldable Antenna*	Fin Antenna	*Foldable Antenna*

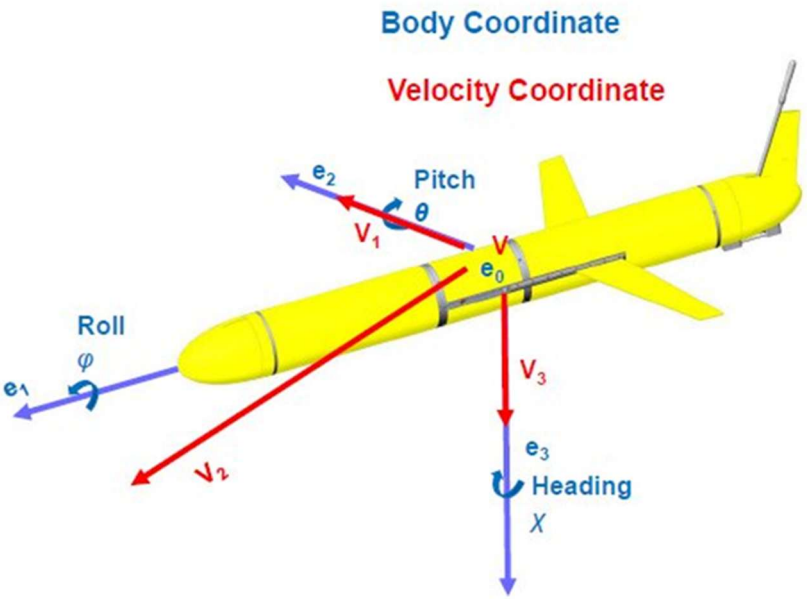
Functional differences among models

Key components controlling movement

Buoyancy

Pitch

Roll



Functional differences among models

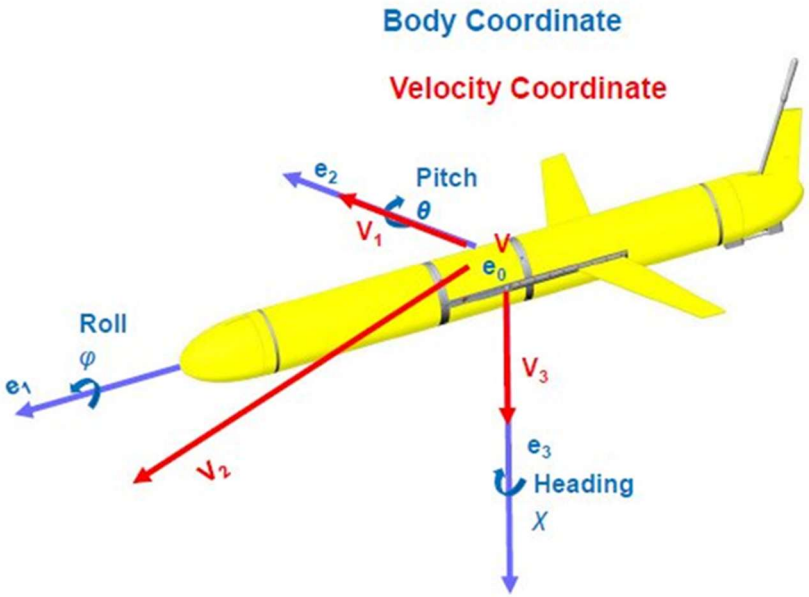
Key components controlling movement

Buoyancy

Pitch

Roll

How can they be controlled?



Functional differences among models

Key components controlling movement

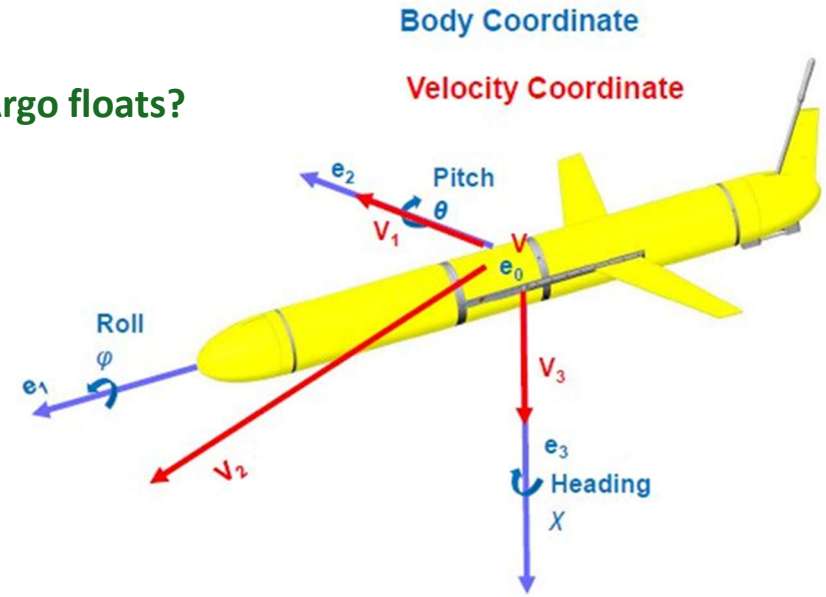
Buoyancy

Do you remember the buoyancy control in Argo floats?

Pitch

Roll

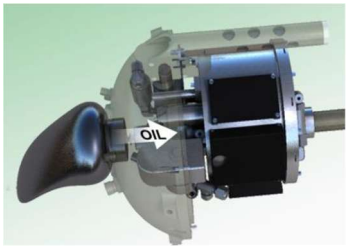
How can they be controlled?



Functional differences among models

Key components controlling movement

Buoyancy



Pump moves oil in/out of an external bladder

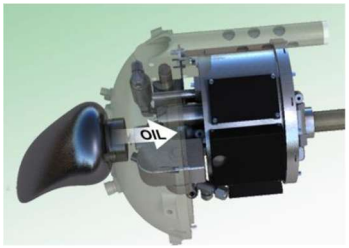
Pitch

Roll

Functional differences among models

Key components controlling movement

Buoyancy



Pump moves oil in/out of an external bladder

V ↗ → B ↗

Pitch

Roll

Functional differences among models

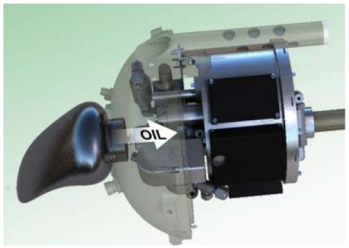
Key components controlling movement

Buoyancy

Pitch

Roll

Why oil and not air?



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Functional differences among models

Key components controlling movement

Buoyancy

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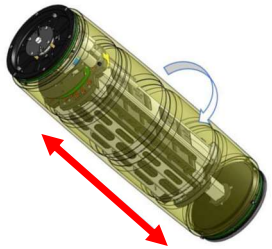


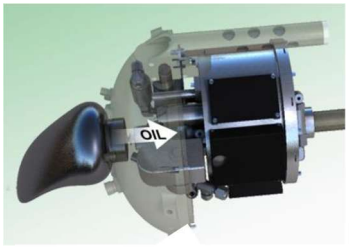
Moving the pitch battery does not change the volume of vehicle!

Roll

Functional differences among models

Key components controlling movement

Buoyancy



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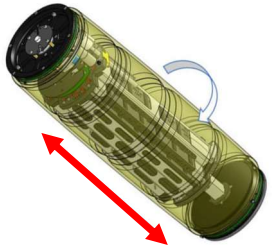
V ↗ → B ↗

Pitch



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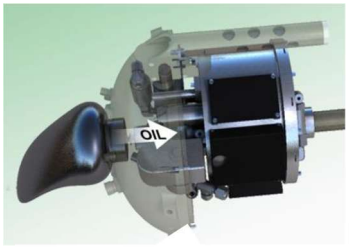
Shift forward → Pitch down

Roll

Functional differences among models

Key components controlling movement

Buoyancy



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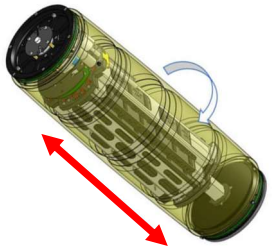
Pitch



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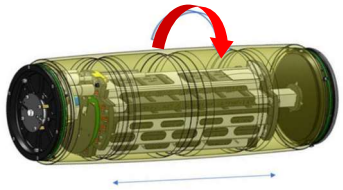

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Key components controlling movement

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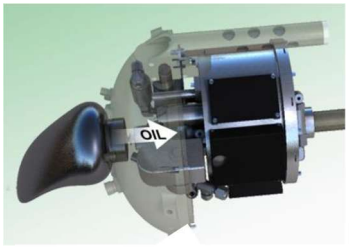

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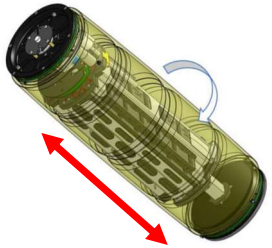

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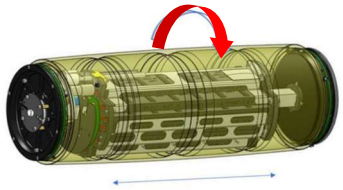
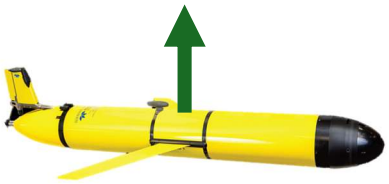


Center of mass shifts starboard

↳ Roll to starboard

Functional differences among models

Key components controlling movement



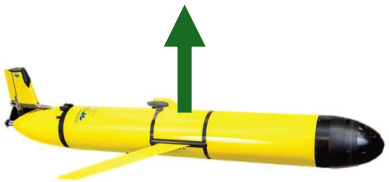
Buoyancy

Pitch

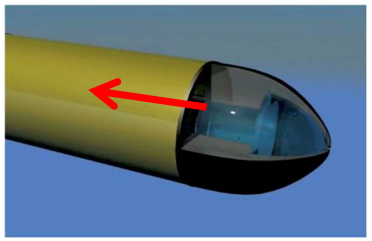
Roll

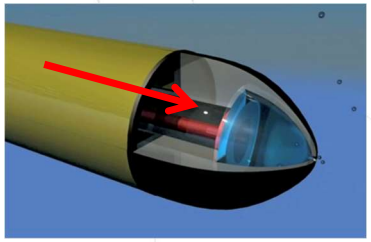
Functional differences among models

Key components controlling movement



Buoyancy



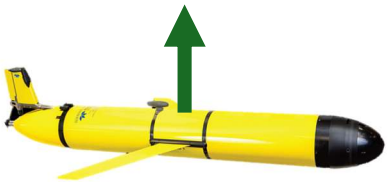


Pitch

Roll

Functional differences among models

Key components controlling movement



Buoyancy

Pitch

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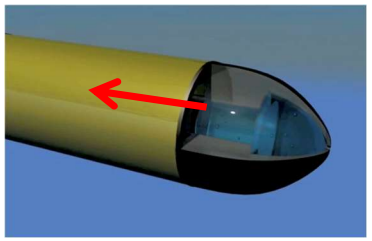
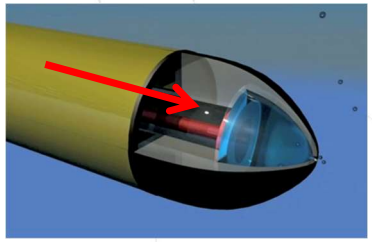


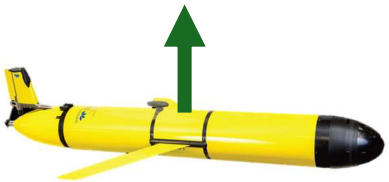


Piston empties/fills a compartment with seawater

$\rho \searrow \rightarrow B \nearrow$

Functional differences among models

Key components controlling movement



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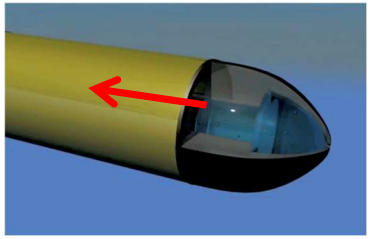

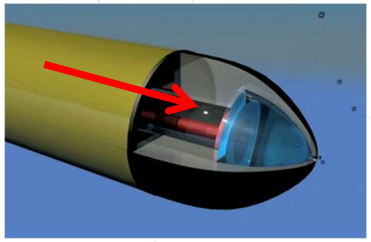

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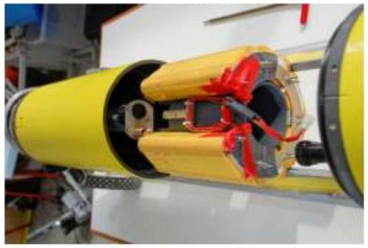
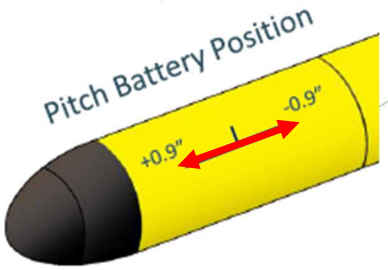
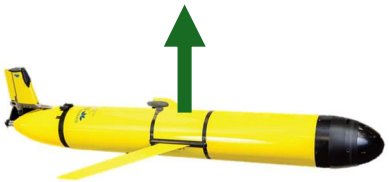




Roll

Functional differences among models

Key components controlling movement



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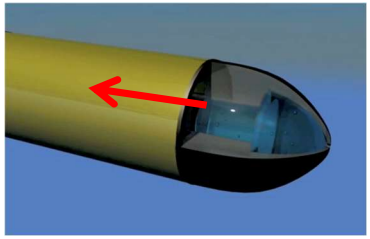

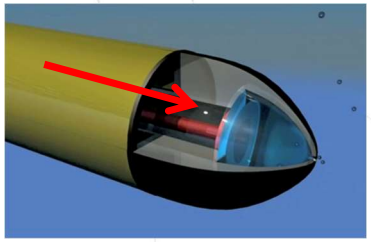

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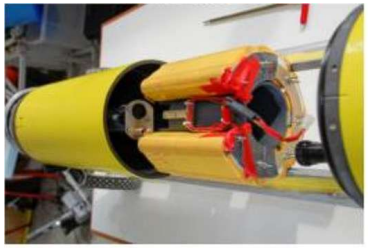
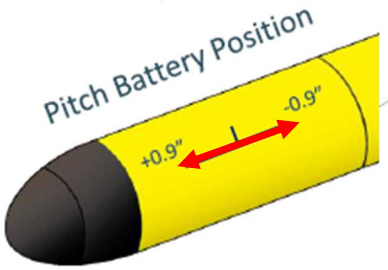




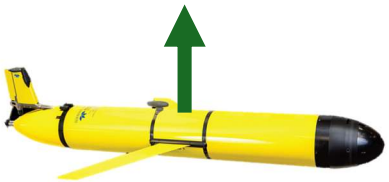
Moving the pitch battery does not change the volume of vehicle!

Shifts forward → Pitch down

Roll

Functional differences among models

Key components controlling movement



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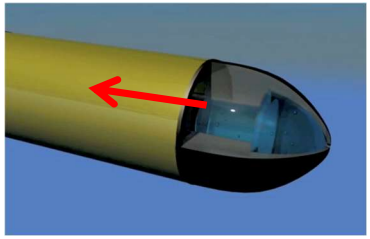

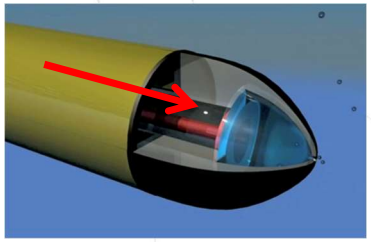

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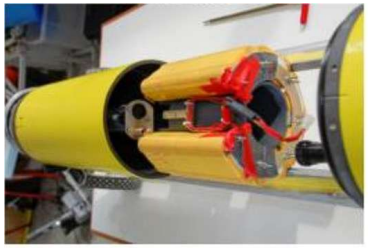

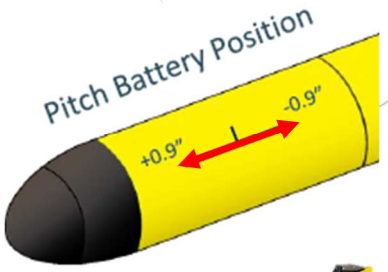

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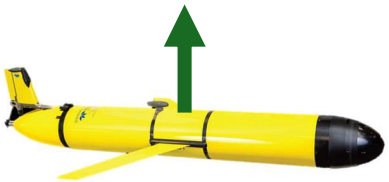
Shifts forward → Pitch down

Roll

Functional differences among models

Key components controlling movement



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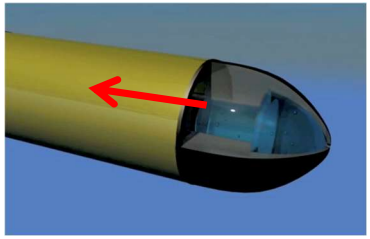

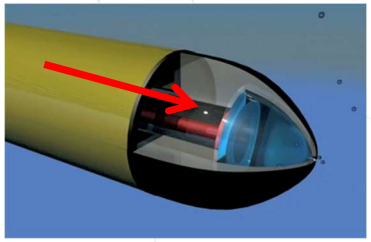

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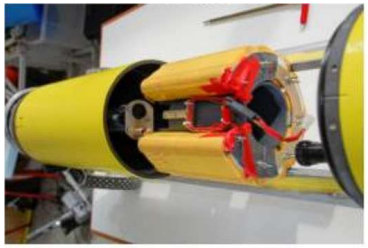

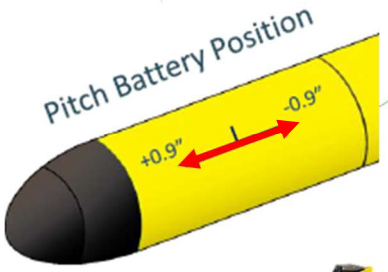

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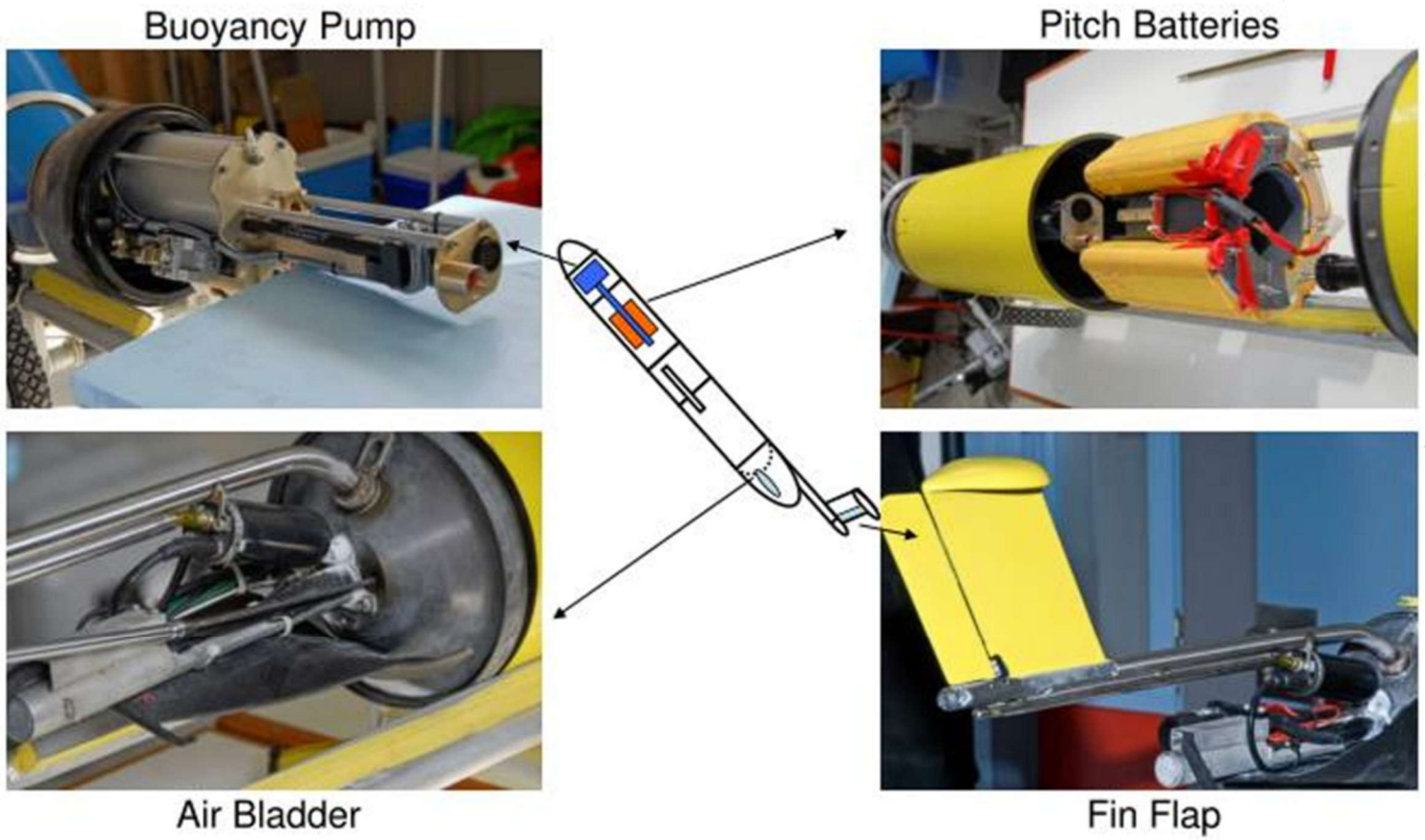
Shifts forward → Pitch down

Roll

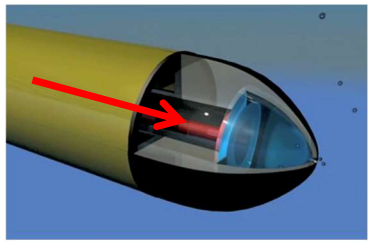
Center of mass shifts starboard

→ Roll to starboard

Notes on actuators



Notes on buoyancy propulsion



Advantages:
Simple, robust, and quick buoyancy adjustment.
For shallow waters & missions with frequent buoyancy changes.
Suited for rapid-response, dynamic environments.

Disadvantages:
Higher energy consumption.
Limited depth range with less precise buoyancy control at depth due to pressure variations.
Risk of seawater intake affecting reliability.

Advantages:
Energy-efficient, perfect for long missions (months-year).
Precise buoyancy control at great depths (up to 6000 m).
Sealed system, highly reliable and resistant to biofouling.

Disadvantages:
Slower buoyancy response.
More expensive and complex maintenance.
Less suitable for dynamic, shallow environments.

Notes on buoyancy propulsion

Buoyancy adjustments are (relatively) small ~500 cc

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Is that enough for a large glider (~2m) weighing 60-70kg ?

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↓

Neutral buoyancy: The glider's ballast must be adjusted before the start of a mission to achieve an overall vehicle density close to that of the water it will be deployed in

More on that later

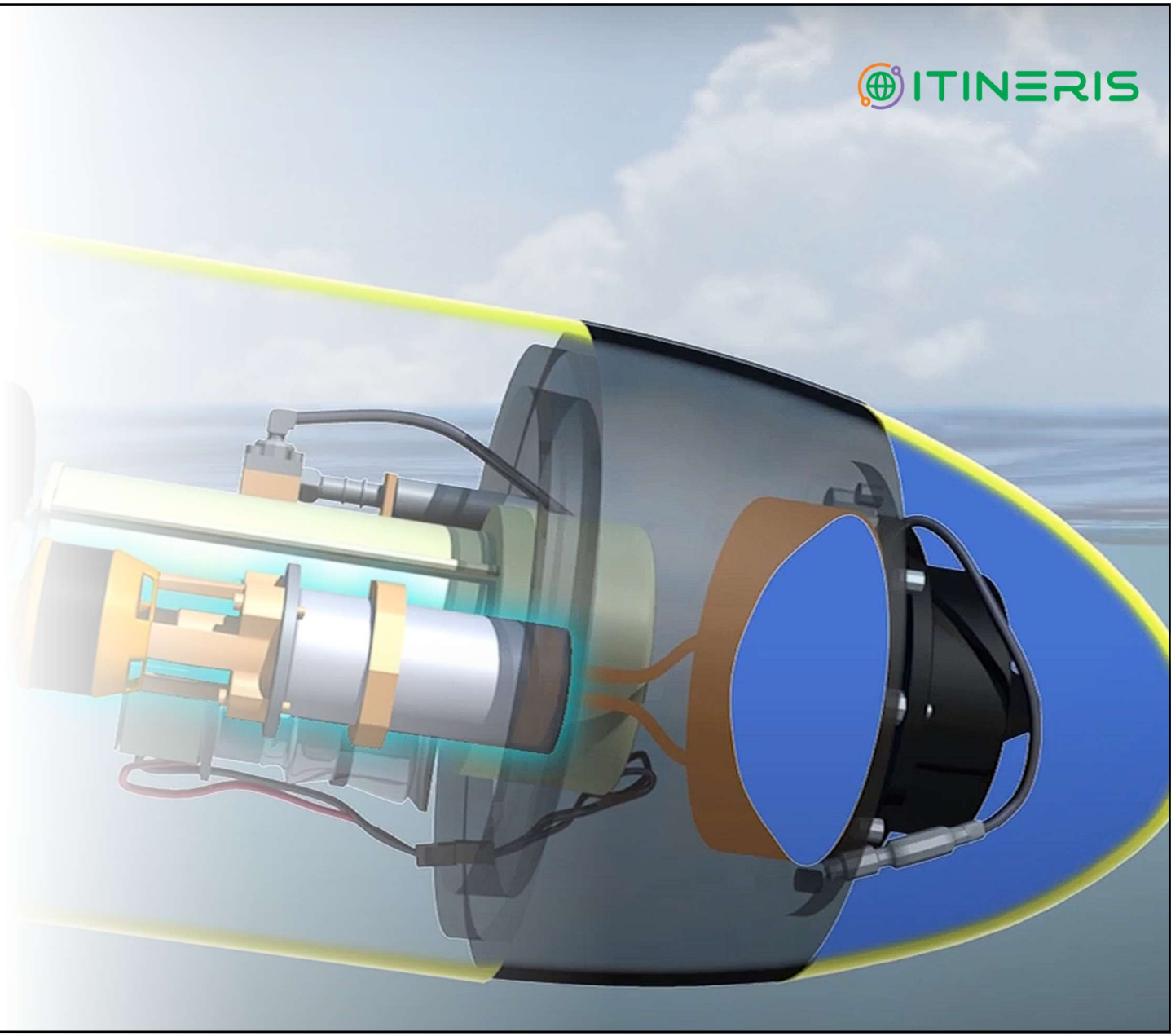
Questions?

Do you know how a glider works?

Time to try it out!

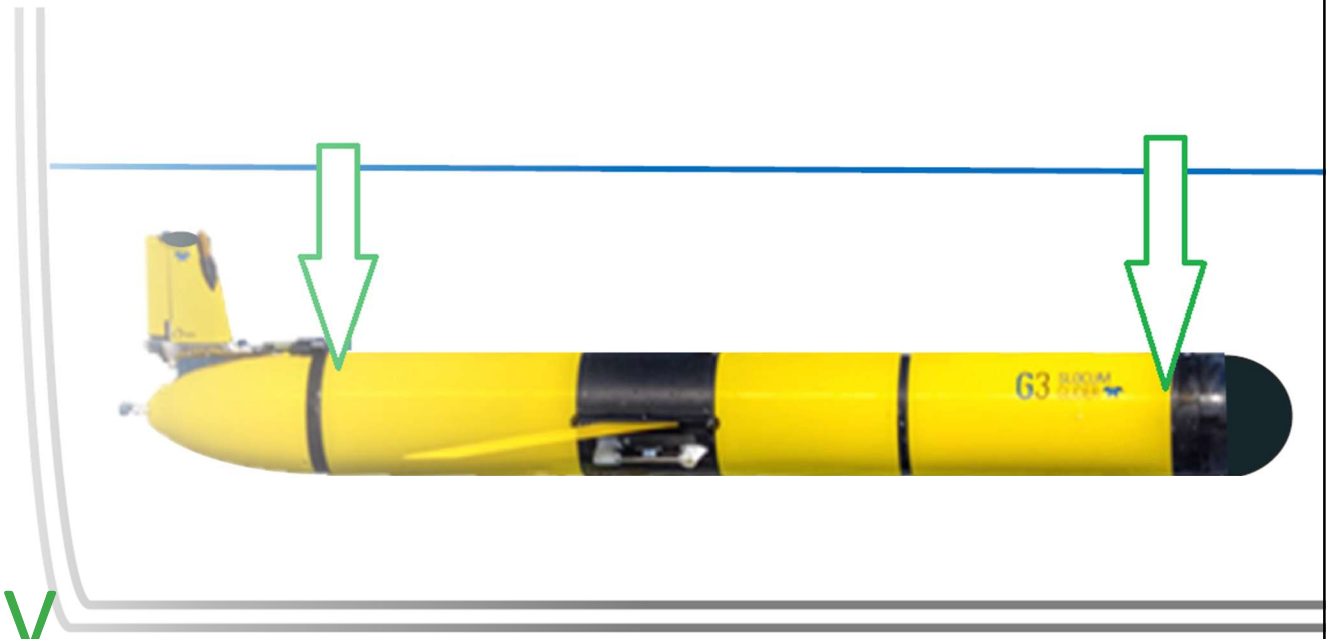
Group I
SeaExplorer

Group II
Slocum



Step I
Make your “glider” neutrally buoyant

Step II
Create a buoyancy engine for your “glider”



Advantages of autonomous gliders

•Energy efficiency
Buoyancy-driven propulsion allows missions lasting several months (depends on model, sensor load, mission parameters)

•Extended range without the need of ship presence
Piloting via satellite and long mission capability allows monitoring in remote areas

•Cost-effective autonomous operations
Lower operational costs than traditional shipboard observations

•High resolution water column sampling even in extreme conditions
Continuous “vertical” profiling is possible during storms, boundary currents and in polar regions

•Quiet operation
Minimal acoustic disturbance allows conducting reliable acoustic measurements

•Versatility with interchangable payload and quick adjustment options
Rapid sensor reconfiguration can be used to address a wide variety of ocean conditions and sampling requirements

bladder with 850 cc
up to 5000 km (10 months)
with a GPCTD-DO sampling at 10s

bladder with 1000 cc
up to 3200 km (~5 months)
with a GPCTD-DO, sampling at 4s

bladder with 900 cc
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up to 5000 km (10 months)
with a GPCTD-DO sampling at 10s

bladder with 1000 cc
up to 3200 km (~5 months)
with a GPCTD-DO, sampling at 4s

bladder with 900 cc
up to 3200 km (~5 months)
with a GPCTD-DO, sampling at 4s

Advantages of autonomous gliders

- **Energy efficiency**
  Buoyancy-driven propulsion allows missions lasting several months (depends on model, sensor load, mission parameters)

- **Extended range without the need of ship presence**
  Piloting via satellite and long mission capability allows monitoring in remote areas

- **Cost-effective autonomous operations**
  Lower operational costs than traditional shipboard observations

- **High resolution water column sampling even in extreme conditions**
  Continuous “vertical” profiling is possible during storms, boundary currents and in polar regions

- **Quiet operation**
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Value of underwater gliders

"Glider data help us to **better understand** and **characterize the oceanic variability**" through the assessment of "**physical and biogeochemical processes** at **large scale**, **mesoscale**, and **even submesoscale** (from ~1000km horiz. & ~1month to ~1km horiz. and ~1hour)"

EGO: Towards a global glider infrastructure for the benefit of marine research and operational oceanography

By Pierre Testor[1,2], Laurent Mortier[1], Johannes Karstensen[3], Elena Mauri[4], Karen Heywood[5], Dan Hayes[6], Pekka Alenius[7], Alberto Alvarez[8], Carlos Barrera[9], Laurent Beguery[2], Karim Bernardet[2], Laurent Bertino[10], Agnieszka Beszczynska-Möller[11], Thierry Carval[12], Francois Counillon[10], Estelle Dumont[13], Gwyn Griffiths[14], Peter M Haugan[10,15], Jan Kaiser[4], Dimitris Kassis[16], Gerd Krahmann[2], Octavio Llinas[9], Lucas Merckelbach[17], Baptiste Mourre[8], Kostas Nittis[16], Reiner Onken[17], Fabrizio D'Ortenzio[1], Sylvie Pouliquen[12], Alexander Proelss[18], Rolf Riethmüller[17], Simón Ruiz[19], Toby Sherwin[13], David Smeed[14], Lars Stemmann[1], Kimmo Tikka[6], Joaquin Tintoré[19]

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"there is now a general agreement that gliders can make us enter into a **new era in oceanography**"

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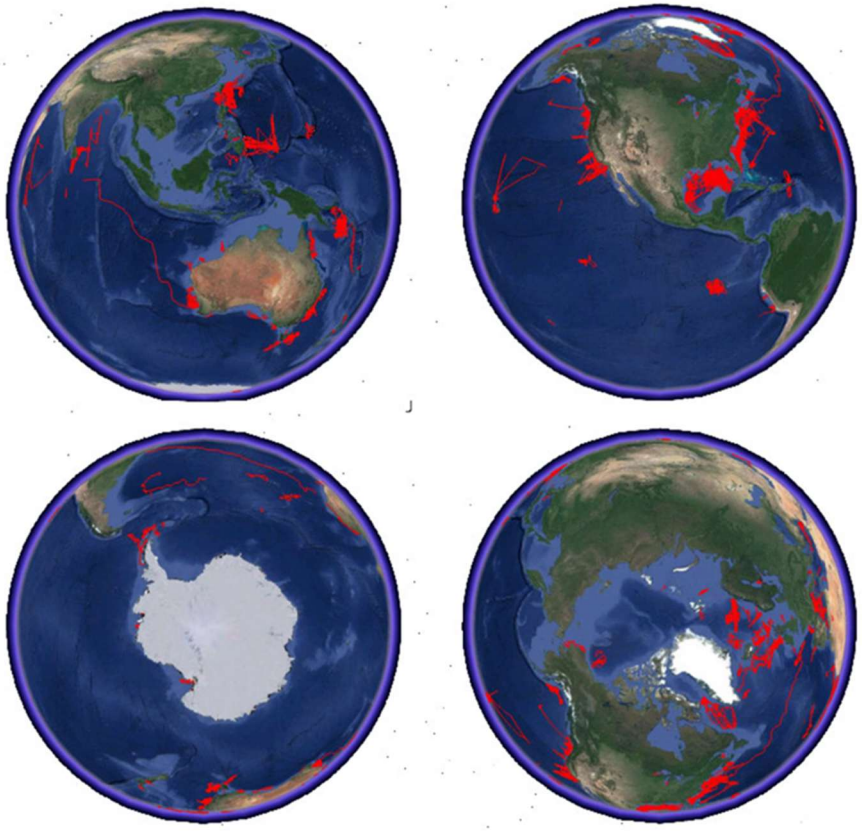
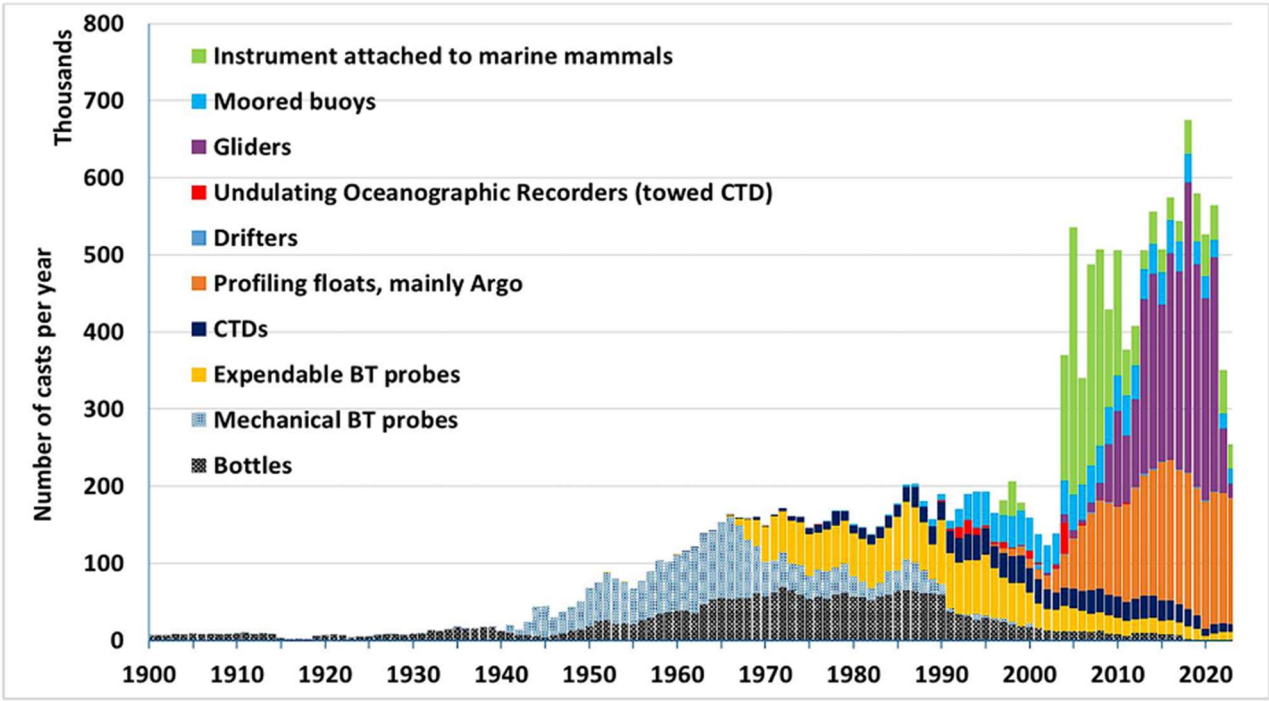
Global use of gliders



Changing methods of oceanographic data acquisition



~ 2600 glider missions (>1500 from 2019 to 2023)

>1.5 millions of profiles with >25 ocean variables

Questions?

Quiz 1

Are You QRious?

Mentimeter

https://www.menti.com/al2pkzjuc8vg

Offline quiz

What separates underwater gliders from other autonomous instruments like drifters, XBTs and Argo floats?
Select all correct answers.

a) Gliders can move both horizontally and vertically by adjusting buoyancy.

b) Underwater gliders are typically disposable after one mission.

c) The payload of gliders can easily be exchanged, and they can carry multiple sensors for physical, biogeochemical, and acoustic measurements.

d) Gliders are inefficient for long-duration missions due to high battery consumption.

e) Underwater gliders cannot operate in dynamic environments like boundary currents or storms.

f) Gliders can be pre-programmed and piloted remotely to adapt their trajectory during missions.

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Offline quiz

What characterizes the unique movement of underwater gliders?
Select all correct answers.

a) Underwater gliders move in a see-saw pattern made of so-called YOs.
b) Gliders glide forward using wings as they ascend and descend.
c) All underwater gliders use a motorized propeller to achieve a straightforward motion.
d) Underwater gliders change their pitch by shifting their battery forward or backward.
e) Underwater gliders roll by adjusting their center of mass through horizontal battery displacement.
f) The oil bladder/water piston allows gliders to adjust their buoyancy by inflating or deflating.

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