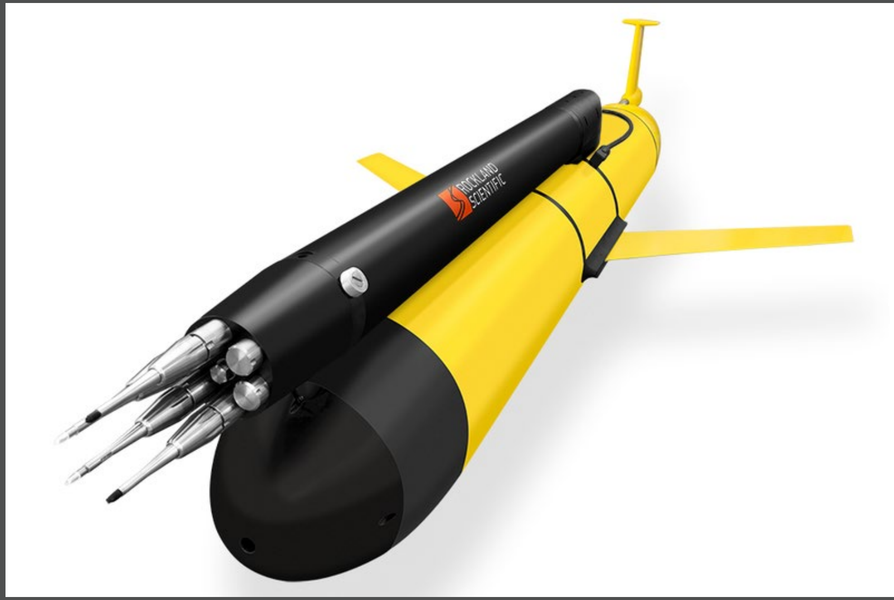
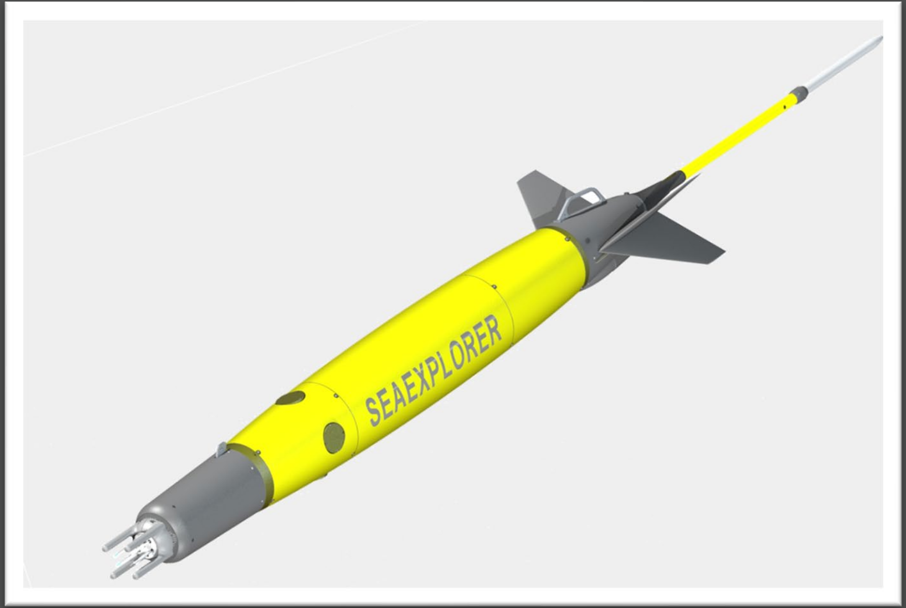
Mesures de Turbulence à l'aide de Gliders

Journées Nationales Glider

MIO Marseille | 08 Décembre 2023





Par Romain Tricarico - Sales & Support Manager EIMEA (Europe, India, Middle East & Africa) |contact: romain@rocklandscientific.com

Experts in Marine Turbulence Measurements

EXPERIENCE & MARKET

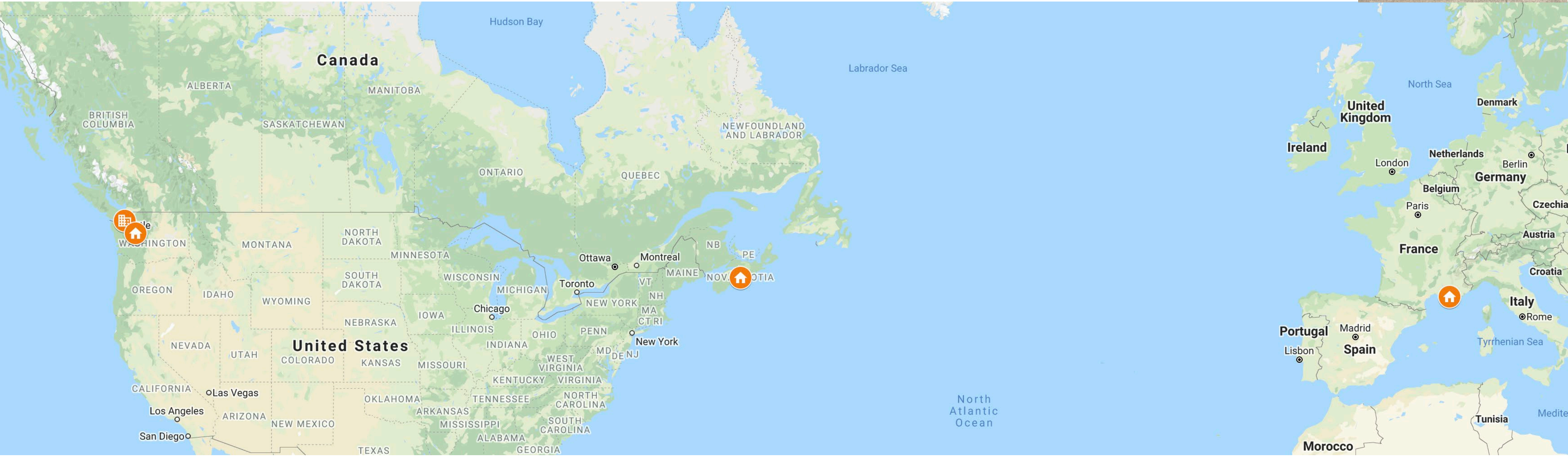
- Turbulence instrumentation for oceanography & limnology, since 2005
- Team of 25+ technical & scientific staff
  Incl.: 3 PhD, 4 MSc., 3 B.Eng
- End-users in academic and governmental research
- 480+ instruments operating in 30+ countries
  e.g.: USA, Canada, UK, Spain, Norway, Germany, Japan, India, Chile, New Zealand…
- Established partnerships with platform integrators
  e.g.: Teledyne, Alseamar, Kongsberg/HII/CSCS, NKE, MRV, DMO, etc.

ABOUT ROCKLAND SCIENTIFIC

Experts in Marine Turbulence Measurements

LOCATIONS

- Victoria, BC (HQ) | Halifax, NS | Seattle, USA | Aix-en-Provence, France



KEY PRODUCTS & SERVICES

ROCKLAND SCIENTIFIC

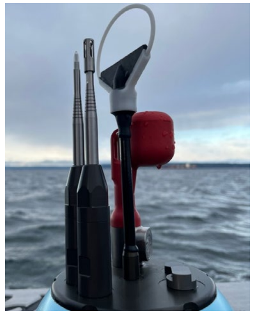
VERTICAL MICROSTRUCTURE PROFILERS (VMP)

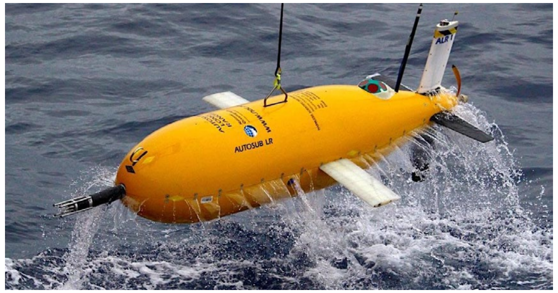
- Water column turbulence profilers for ship deployments
- Tethered or non-tethered operations
- From Lakes/Coastal ocean (100m) to Deep-sea applications (11,000m)




MODULAR SENSORS (MICRORIDER)

- Autonomous instruments for turbulence measurements from AUVs, **gliders**, moorings, floats, etc.
- Self-recording and fit for long-term deployments
- In-situ data processing capabilities **(ISDP)**





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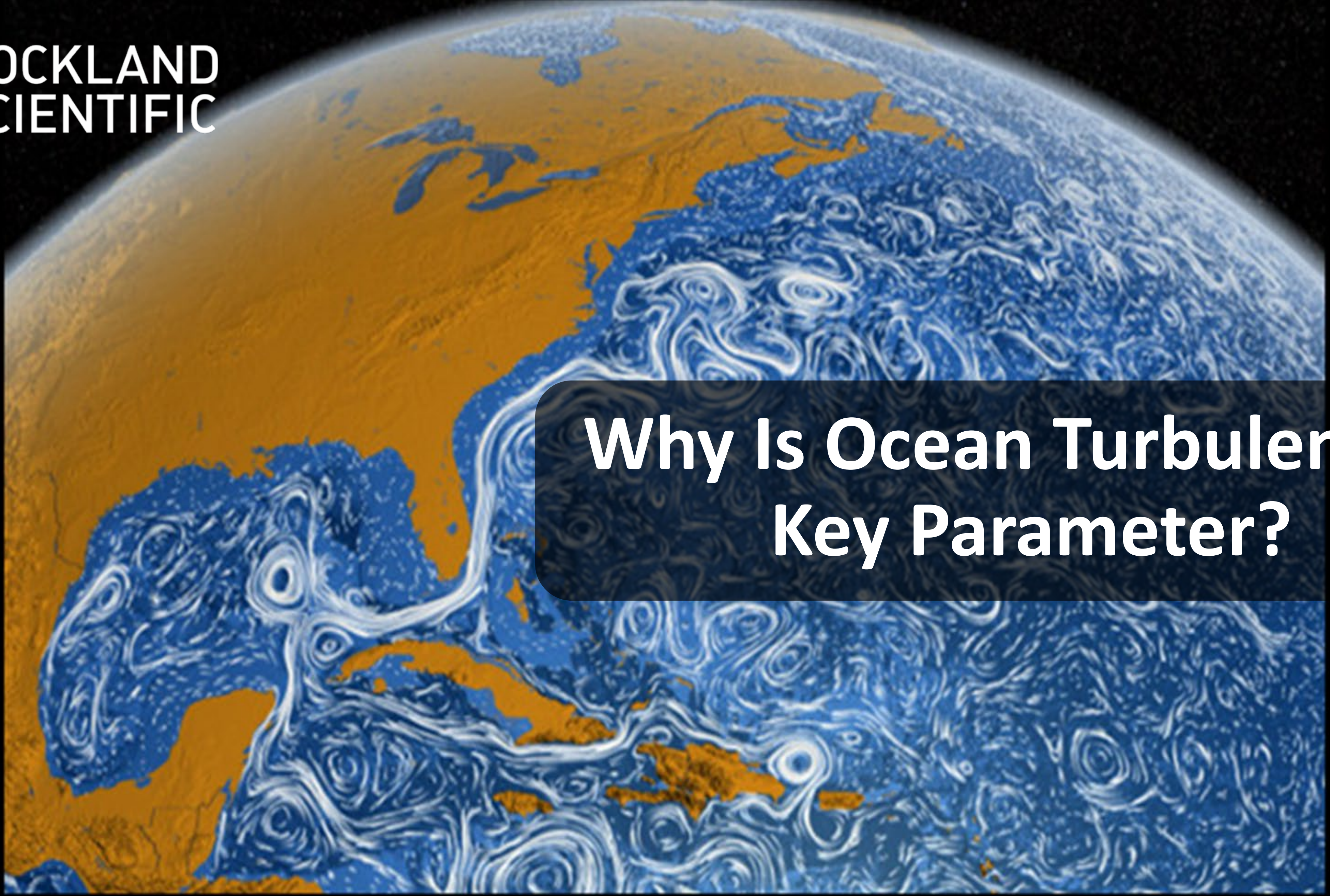
Why Is Ocean Turbulence a Key Parameter?



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WHAT IS TURBULENCE?

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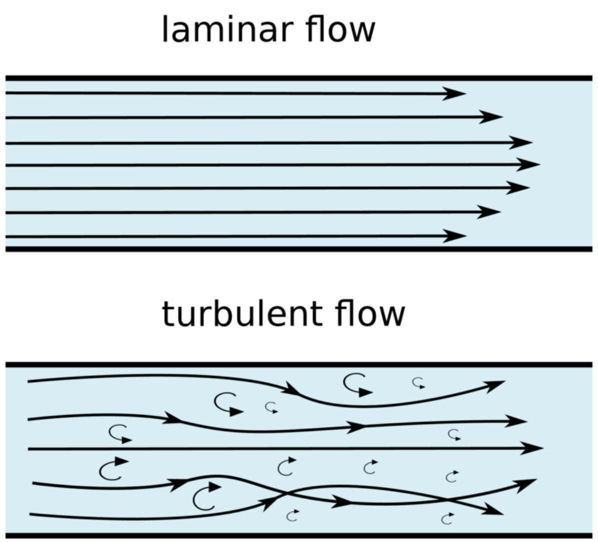
- Violent or unsteady movement of a fluid (air, water, etc.).
- Fluid motion characterized by **chaotic changes** in pressure and flow velocity.
- ≠ Laminar flow (when a fluid flows in parallel layers, with no disruption between those layers).



DIFFUSION

TURBULENT MIXING

TURBULENT KINETIC **ENERGY** (TKE)

- Turbulence is a process that causes **homogenization**.
- Turbulence **mixes** (i.e. homogenizes) tracers more rapidly than diffusion.

https://www.youtube.com/watch?v=KJ-yKOzNcL4

HOW IS TURBULENCE GENERATED?

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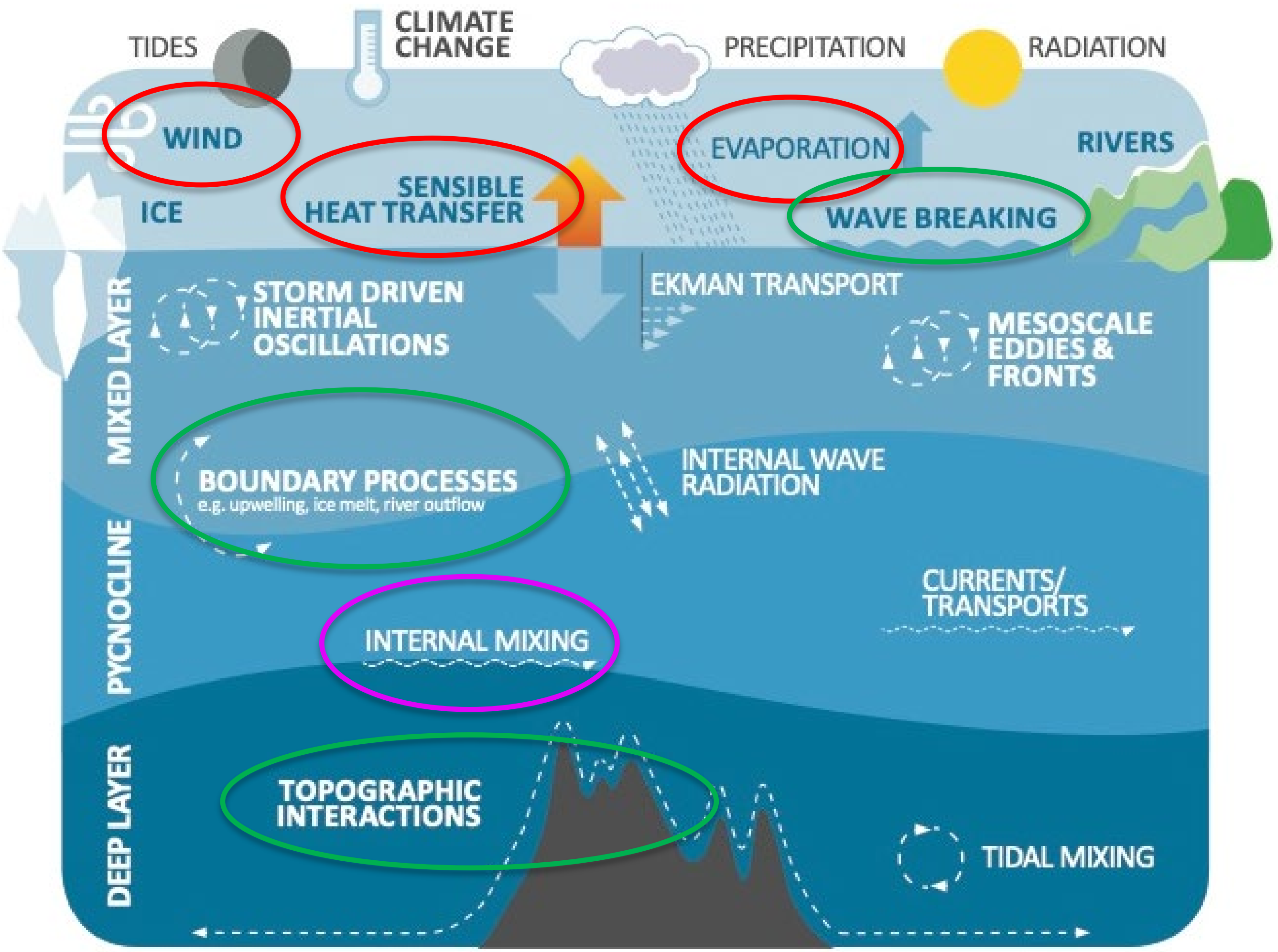
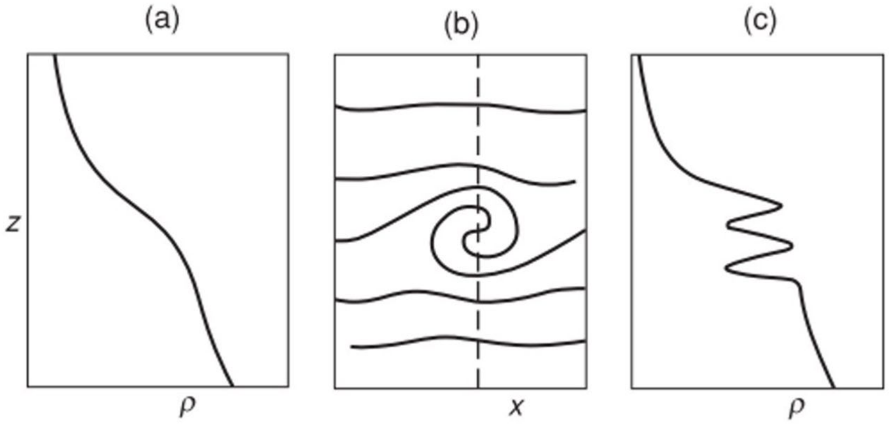
- Different Environmental Processes:
    1) Air-Sea Interactions
    2) Interior Mixing
    3) Boundary Friction



WHY MEASURING TURBULENCE?



- Ocean mixing is driven by small-scale (1cm - 10m) 3-dimensional turbulent eddies, which produce density overturns.
- Turbulence is the dominant force in the mixing of flow properties across gradients (diapycnal mixing).
- These **micro-scale gradients** are then eroded by molecular diffusion, causing mixing.

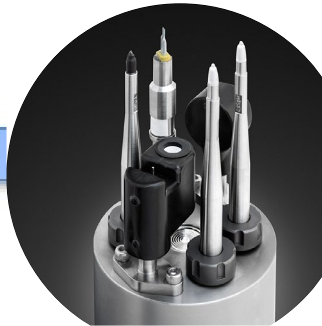
- **Vertical diffusivity (Kv)** is related to **ε**, the flux Richardson number (Rf), and the buoyancy frequency (N2) as:

$$Kv = \frac{R_f \ \varepsilon}{(1 - R_f)\, N^2}$$

Where:

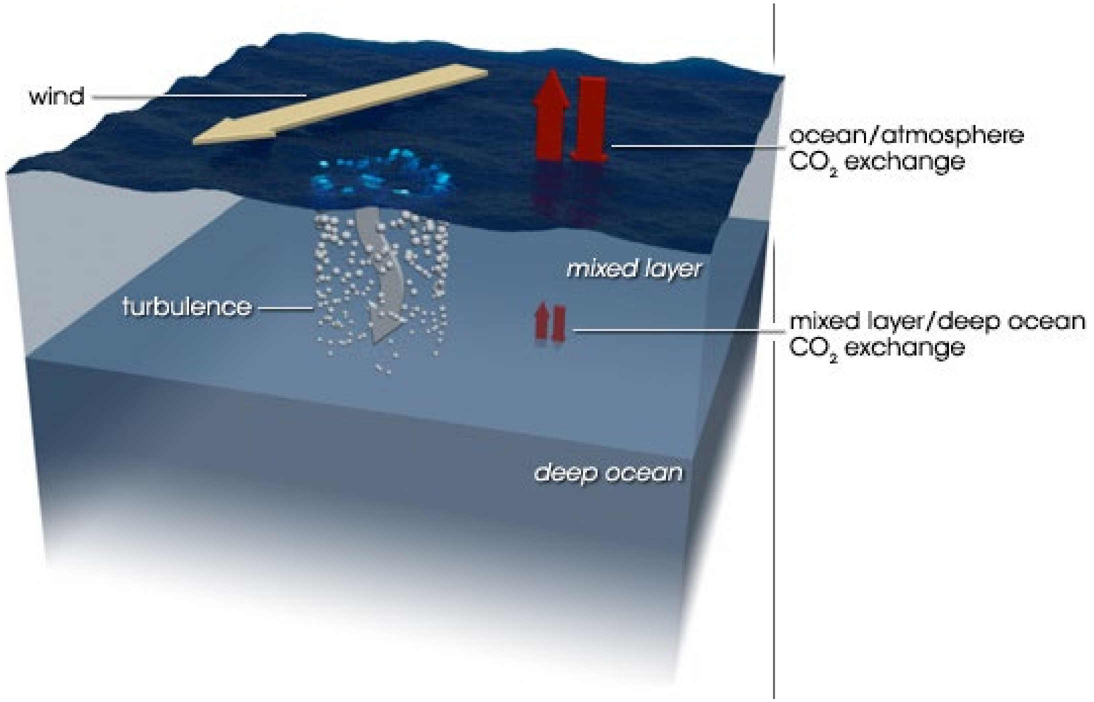
- the ratio Rf / (1 - Rf) has been experimentally determined to be ~0.2 (e.g. Osborn, 1980)
- N2 is a measure of density stratification computed from the glider CTD
- **ε is the dissipation rate of turbulent kinetic energy (TKE)**, calculated from the vertical shear

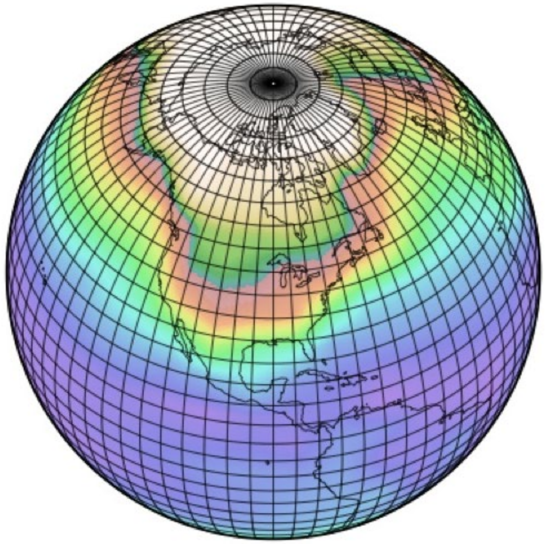
What ROCKLAND sensors are measuring

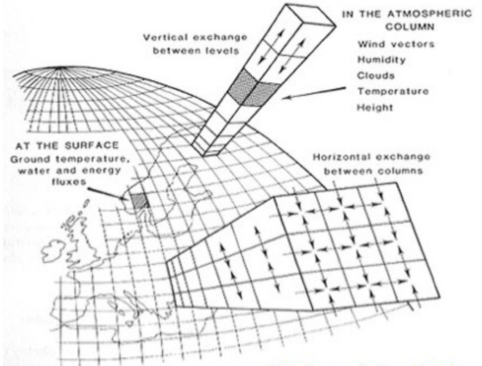


WHY MEASURING TURBULENCE?

- Turbulence controls **mixing** of anything that is in the ocean or enters the ocean (heat, salt, energy, nutrients, chemicals, etc.) **=> Allow direct flux measurements**.
- Turbulence explains local variations in sea currents, but these processes occur at scales much smaller than **climate model grid scale** **=> need for in-situ measurements** to parameterize climate simulations.







(Henderson-Sellers, 1985)

WHY MEASURING TURBULENCE?

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- Turbulence is increasingly recognized to be a key factor in the climate system:

Front. Mar. Sci., 28 November 2023
Sec. Physical Oceanography
Volume 10 - 2023 | https://doi.org/10.3389/fmars.2023.1241023

Turbulent diapycnal fluxes as a pilot Essential Ocean Variable

Arnaud Le Boyer[1*] Nicole Couto[1*] Matthew H. Alford[1] Henri F. Drake[2] Cynthia E. Bluteau[3] Kenneth G. Hughes[4] Alberto C. Naveira Garabato[5] Aurélie J. Moulin[6] Thomas Peacock[7] Elizabeth C. Fine[1] Ali Mashayek[8] Laura Cimoli[9] Michael P. Meredith[10] Angelique Melet[11] Ilker Fer[12] Marcus Dengler[13] Craig L. Stevens[14,15]

https://doi.org/10.3389/fmars.2023.1241023

How Do Rockland Sensors Measure Turbulence?

HOW TO MEASURE TURBULENCE?

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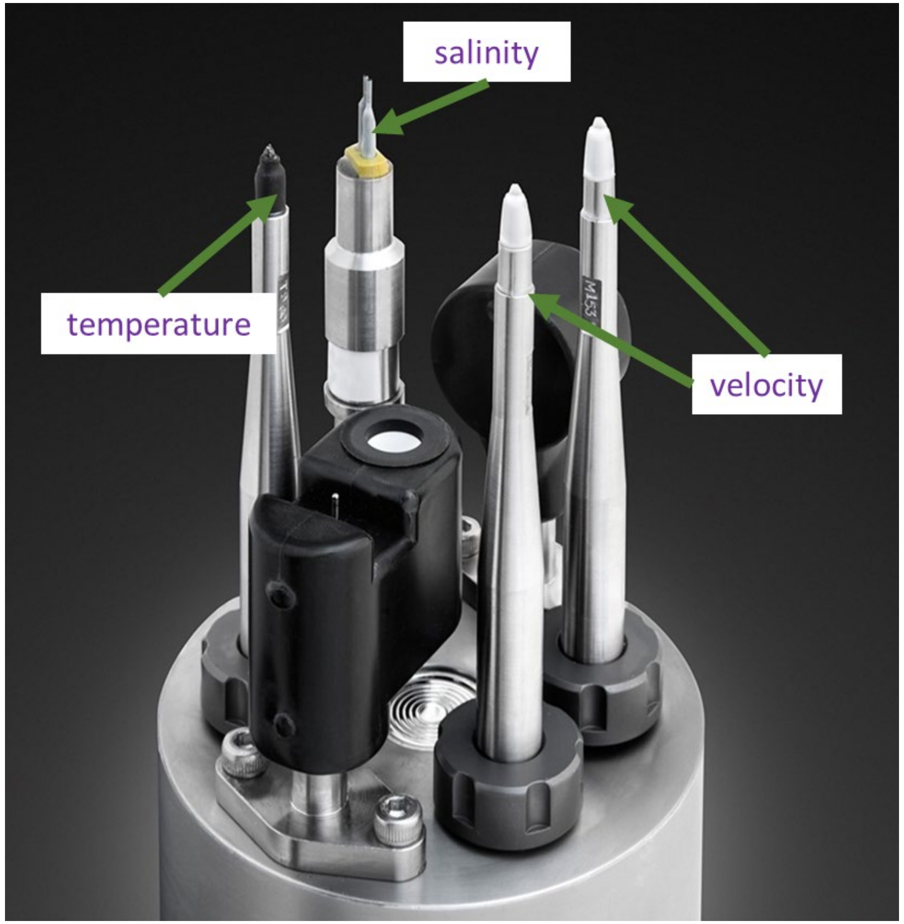
➢ What do we need to measure the whorls?

1. A sensor or probe that **detects the physical parameter of interest**, excluding (as much as possible) all other parameters.
2. Electronic circuitry that **amplifies** and alters the signal produced by a probe, and **records this signal** for later analysis.
3. A platform that **moves the sensor smoothly** through the ocean to produce a space series of the parameter of interest, i.e. a profile.

Flow



Small (and fragile) sensors to measure whorls on millimeter scales

HOW TO MEASURE TURBULENCE?

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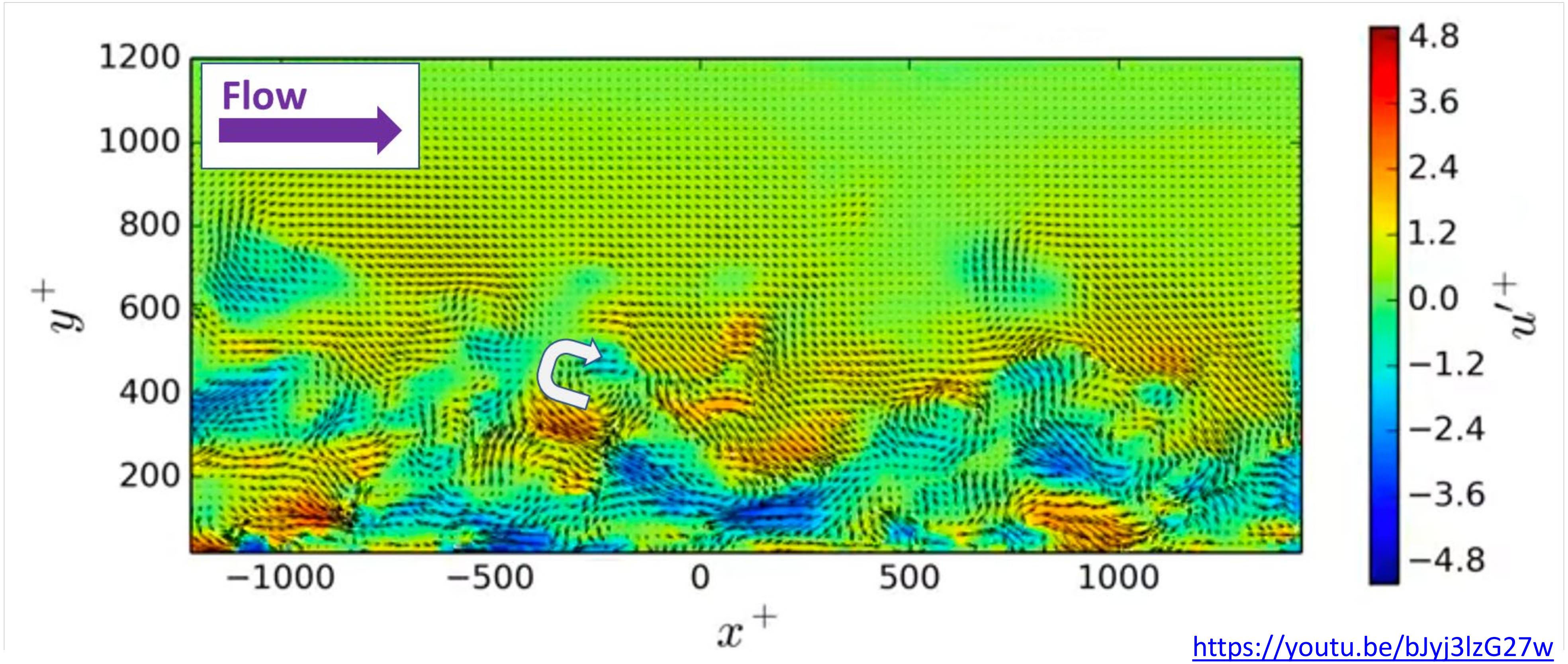
- What properties of the whorls can be measured?

1. **Velocity (Direct Measurement):**



https://youtu.be/bJyj3lzG27w

SHEAR PROBES

HOW TO MEASURE TURBULENCE?

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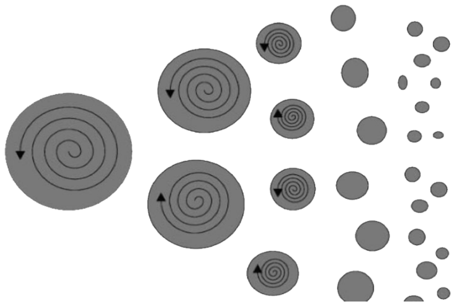
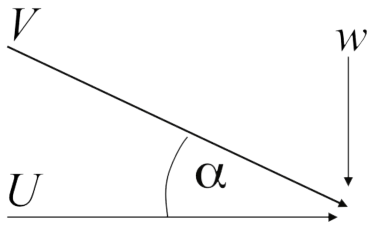
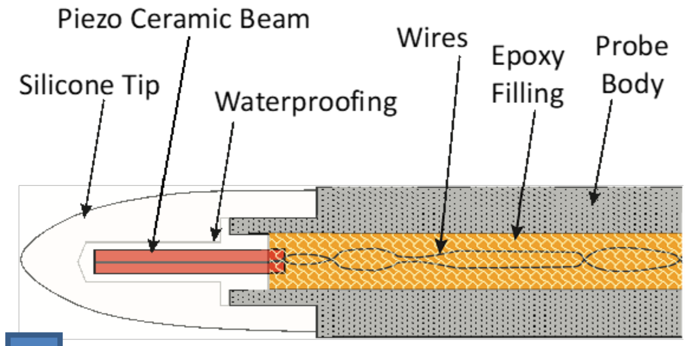
➢ THE SHEAR PROBE:

- The piezo-ceramic beam **only responds to fluctuations** and produces no mean signal (i.e. an AC-sensor).
- Actually sampling the **rate of change of velocity** (typically sampling at 512 Hz).
- The beam is only sensitive to the **broadside component** (u) of the velocity (similar to a diving board).
- There must **be an axial mean flow to generate lift** (sensor must move through the water).







Lift force generated by flow

piezo ceramic beam bends microscopically → voltage generated $E \propto SUw$ → compute shear and spectrum $\frac{\partial w}{\partial x}, \Phi(k)$ → Compute dissipation rate $\varepsilon = 7.5\nu \int \Phi \, dk$

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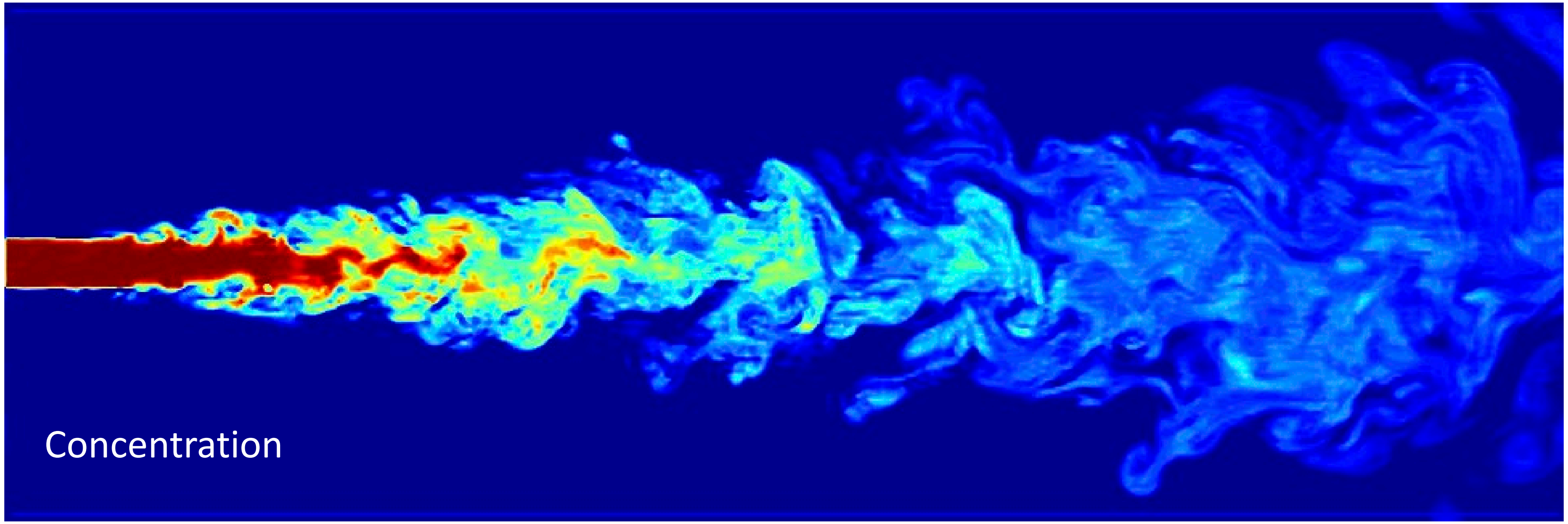
HOW TO MEASURE TURBULENCE?

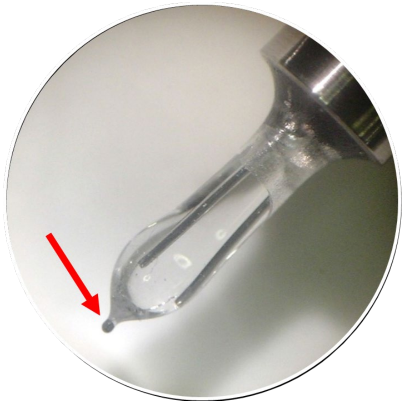
- What properties of the whorls can be measured?

2. Scalars (Indirect Measurements: Heat, Salt):

FAST THERMISTORS (FP07)



http://people.duke.edu/~jda4h/research.html.old



HOW TO MEASURE TURBULENCE?

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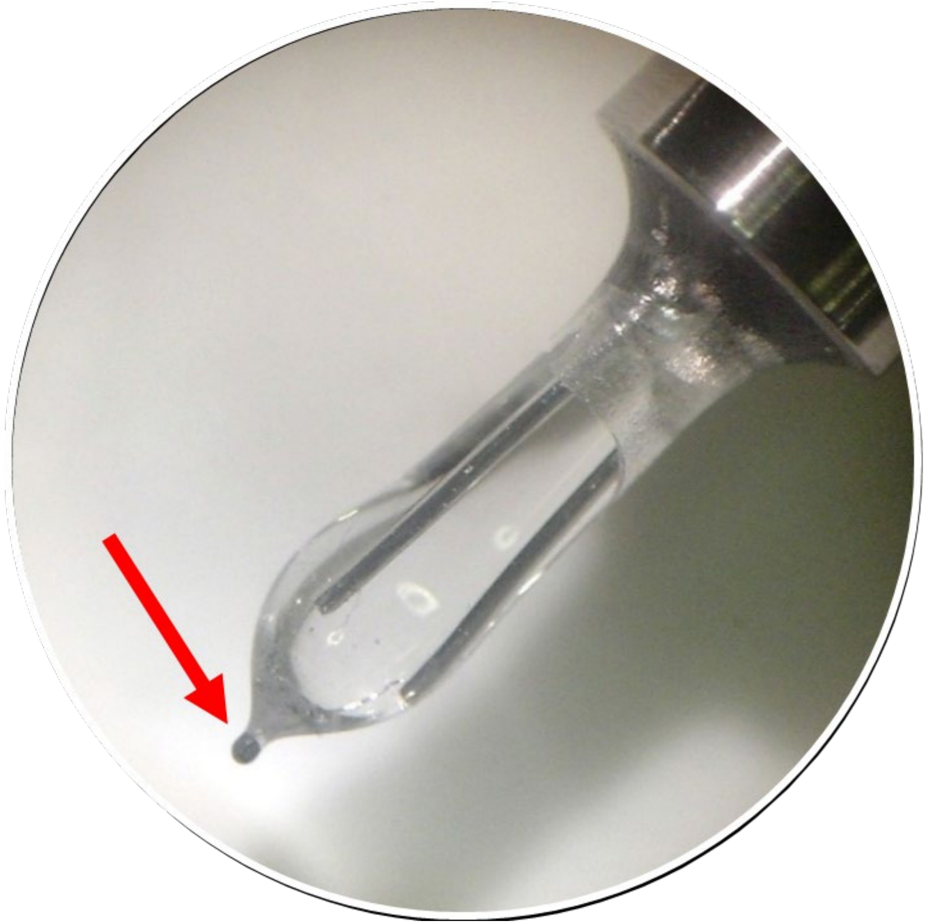
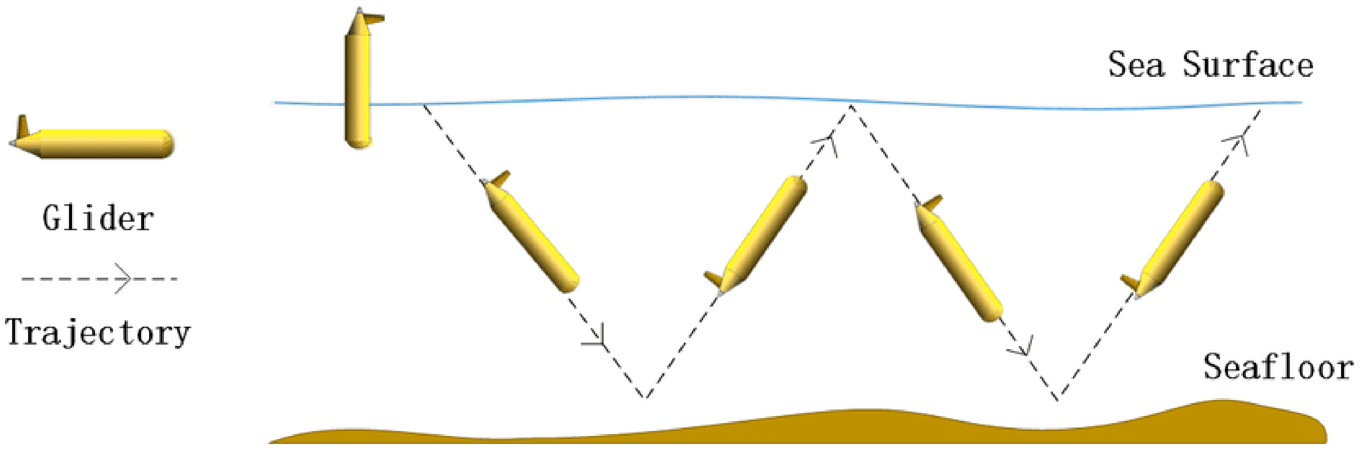
➢ **THE FAST THERMISTOR (FP07):**

- A metal-oxide **resistor**
- A large temperature-dependent negative coefficient of resistance **(The higher the temperature, the lower the resistance)**
- The FP07 thermistor is the smallest **(0.2 mm)**, and fastest thermistor-type temperature sensor



THE PLATFORM: UNDERWATER GLIDERS

- Gliders are “quiet” platforms, driven only by buoyancy => **low vibrations**
- Adequate endurance for process studies (weeks to months) => **greater spatial & temporal resolutions**
- Several glider platforms are available for turbulence measurements:
  - **Slocum** (Teledyne Webb)
  - **SeaGlider** (Kongsberg/HII)
  - **SeaExplorer** (Alseamar)



UNDERWATER GLIDERS

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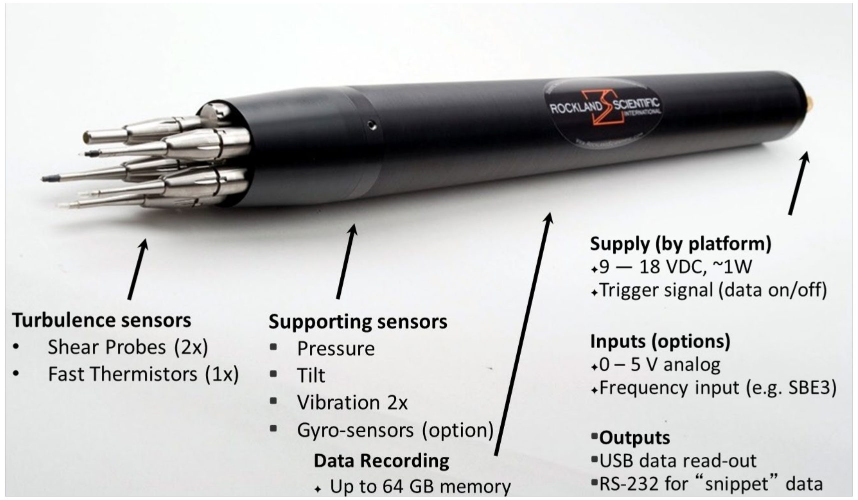
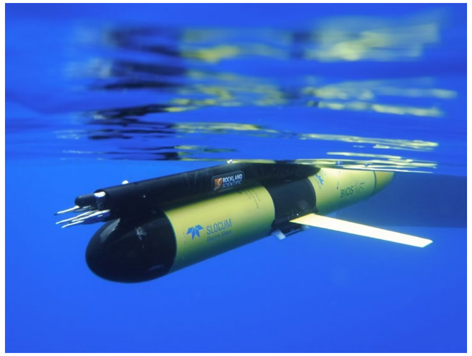
➢ **Different turbulence sensor packages available, depending on the glider:**



MicroRider-1000 (Slocum)

MicroRider-1000-G (SeaExplorer)

MicroPod system (Seaglider)



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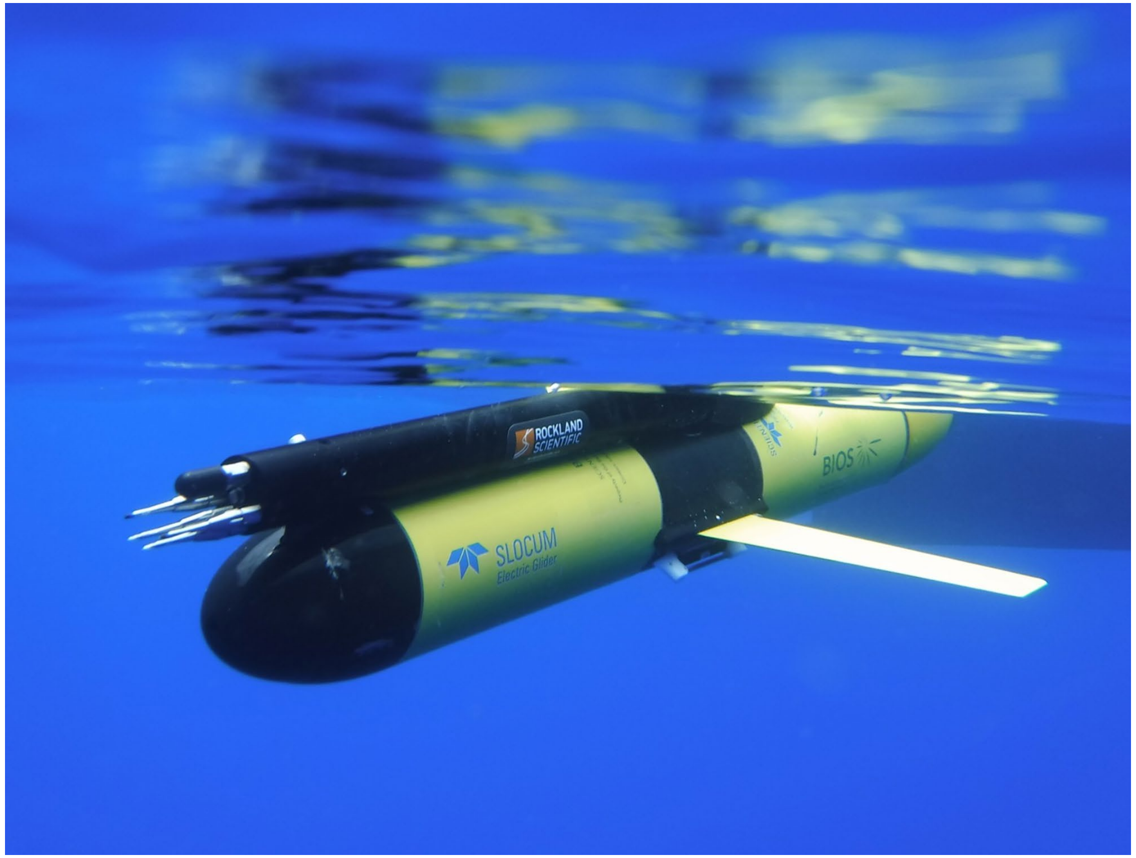
UNDERWATER GLIDERS

- SLOCUM => MICRORIDER-1000



- **SEAEXPLORER => MICRORIDER-1000-G**

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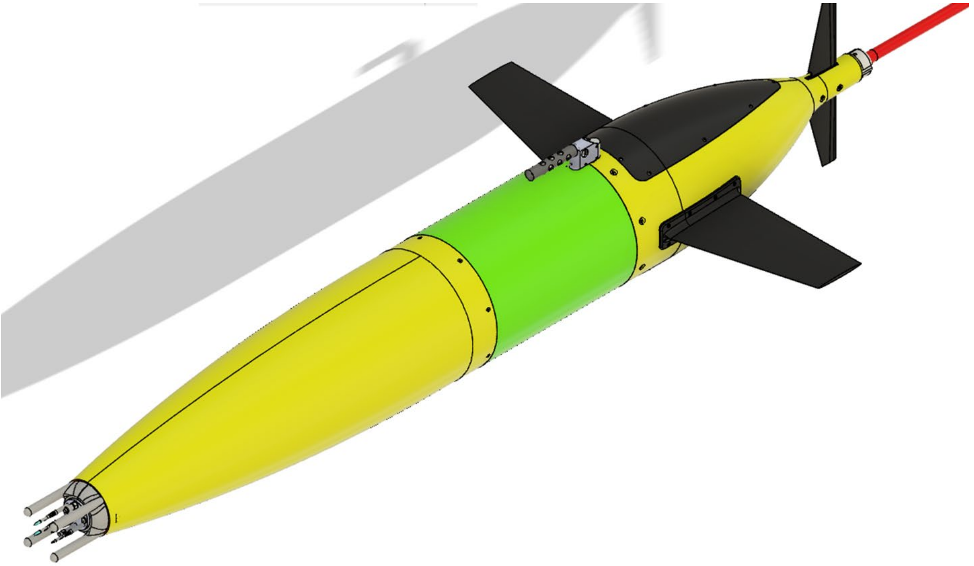
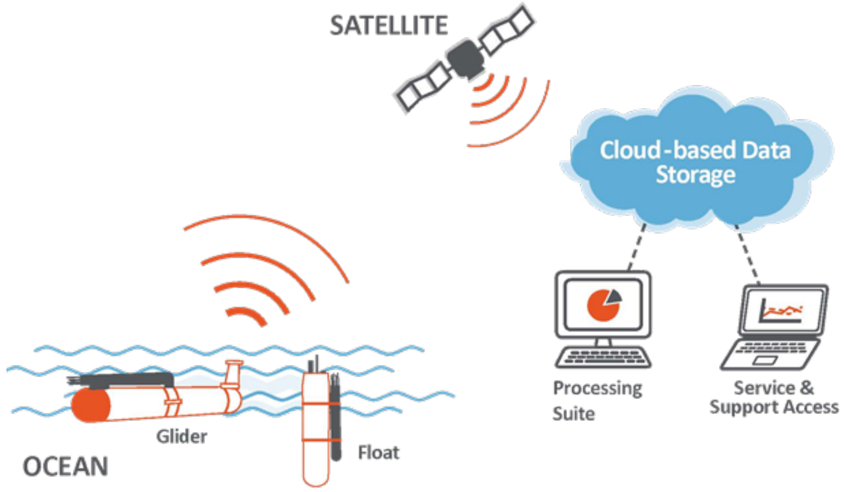
- SEAGLIDER => MICROPOD-SYSTEM (+ On-going integration of MICRORIDER-1000-G)

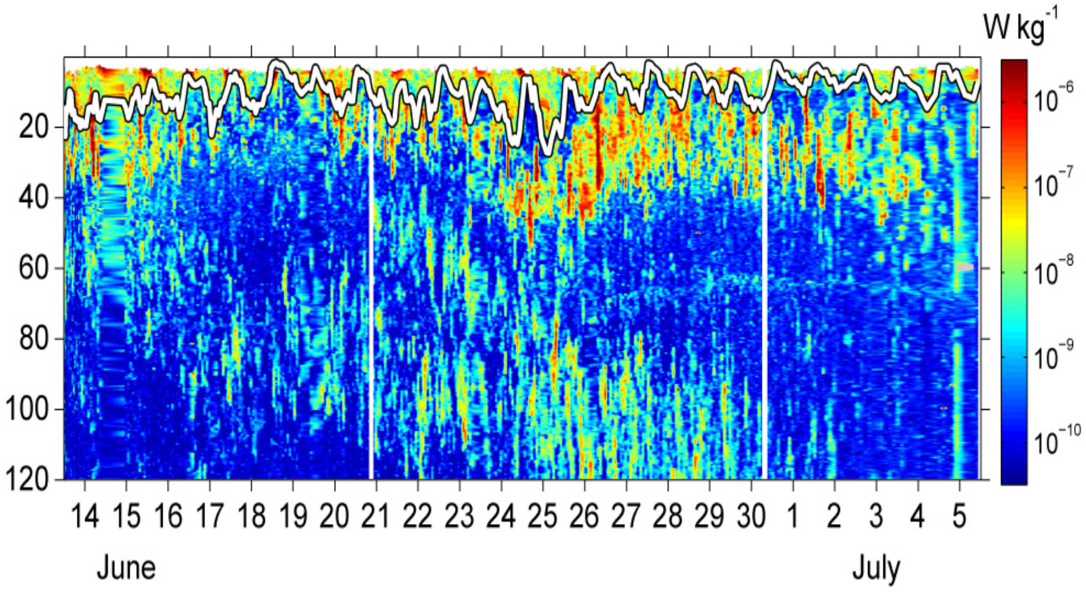


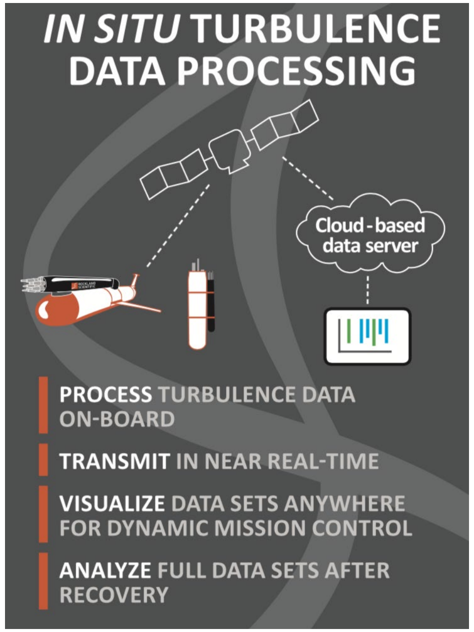
➢ New IN-SITU DATA PROCESSING (ISDP) capability:

- Recent improvements (new Linux-based datalogger replacing old CF2 Persistor) have enabled the development of ISDP algorithms (also implemented on profiling floats).

- On-board data processing and reduction (> 99% data reduction ratio) now allows the transmission of **ε estimates** (dissipation rate of the TKE) **in near real-time** via Iridium!







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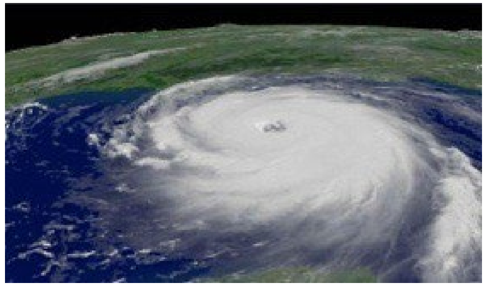
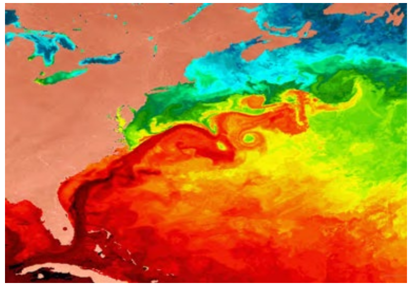
APPLICATION EXAMPLES

APPLICATIONS?





➢ RESEARCH

- Climate Research (climate change, air-sea interactions, deep-ocean circulation)
- Fisheries Management (nutrients transport, bio-physical interactions)
- Coastal Engineering (erosion, environmental impacts)

➢ RESOURCE EXTRACTION

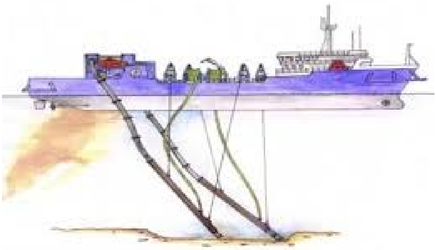
- Oil & Gas (pollution propagation measurement & modelling)
- Offshore Mining (manganese nodules extraction, tailings disposal)
- Tidal Energy (array layout optimization, environmental impact)

➢ DEFENSE / SECURITY

- Anti-submarine warfare (ASW): wake detection, UUV signature

EXAMPLES:

- Mixing processes affect the exchange of heat, salt, nutrients, momentum, etc.
- Vertical diffusivity affects ocean-atmosphere exchange processes (-> CO_2 absorption)
- Turbulence affects rates of ice melt (-> sea level rise)
- Local changes to water stratification affect wildlife and fisheries



CUSTOMERS APPLICATIONS

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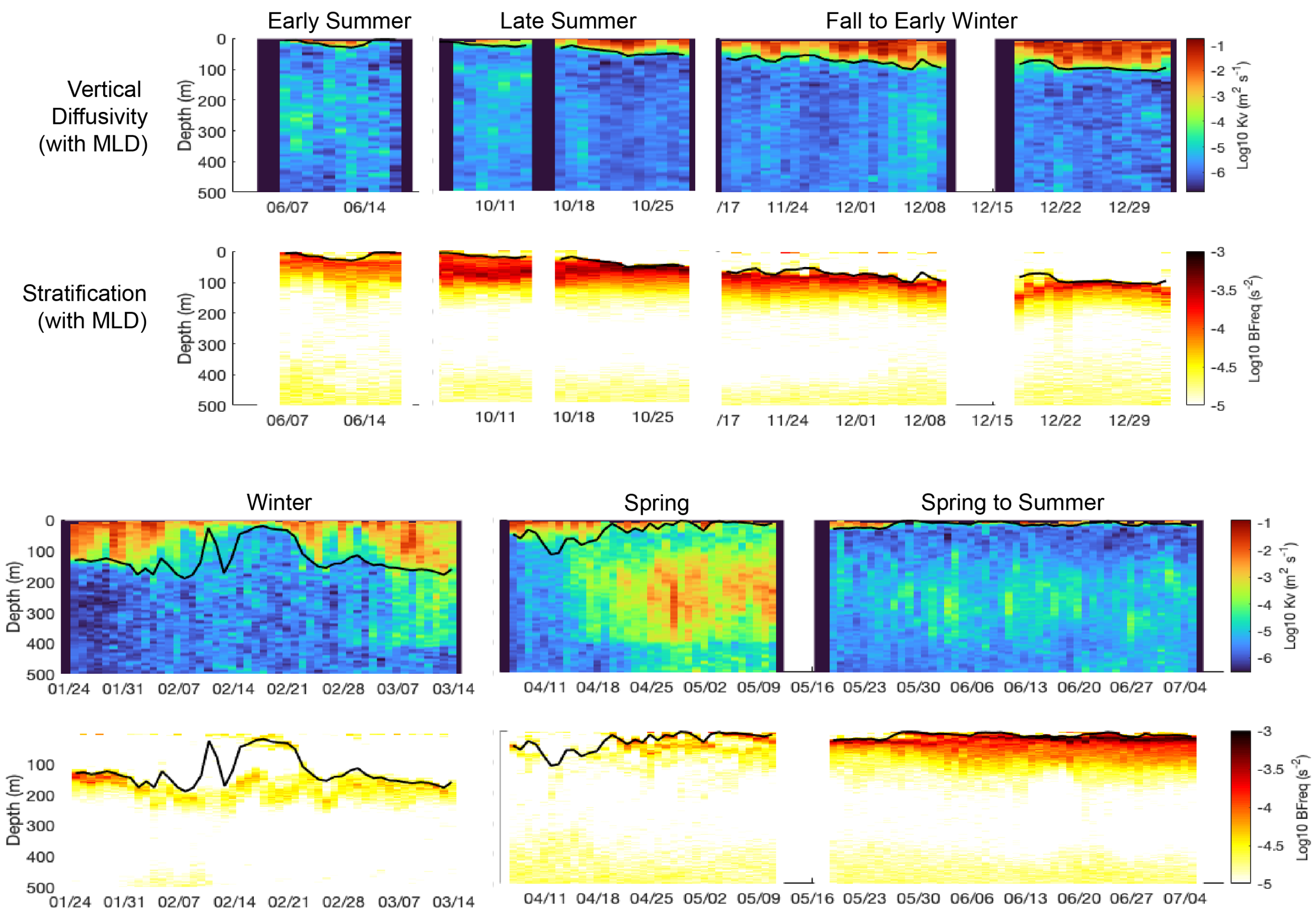
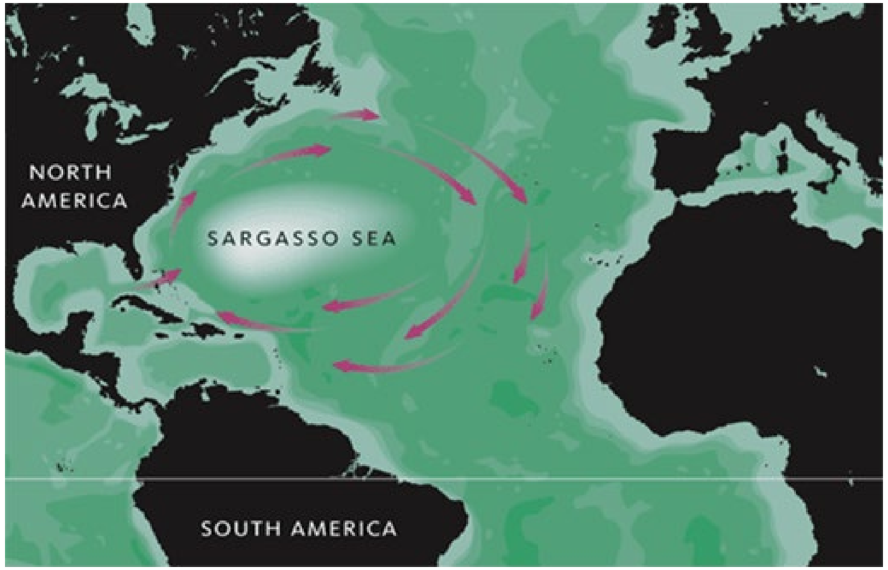
- **Biologically Enhanced Turbulent Mixing in the Sargasso Sea (R. Curry, BIOS, 2021):**





BIOS

CUSTOMERS APPLICATIONS

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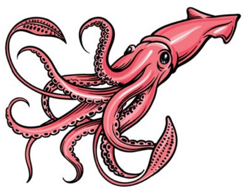
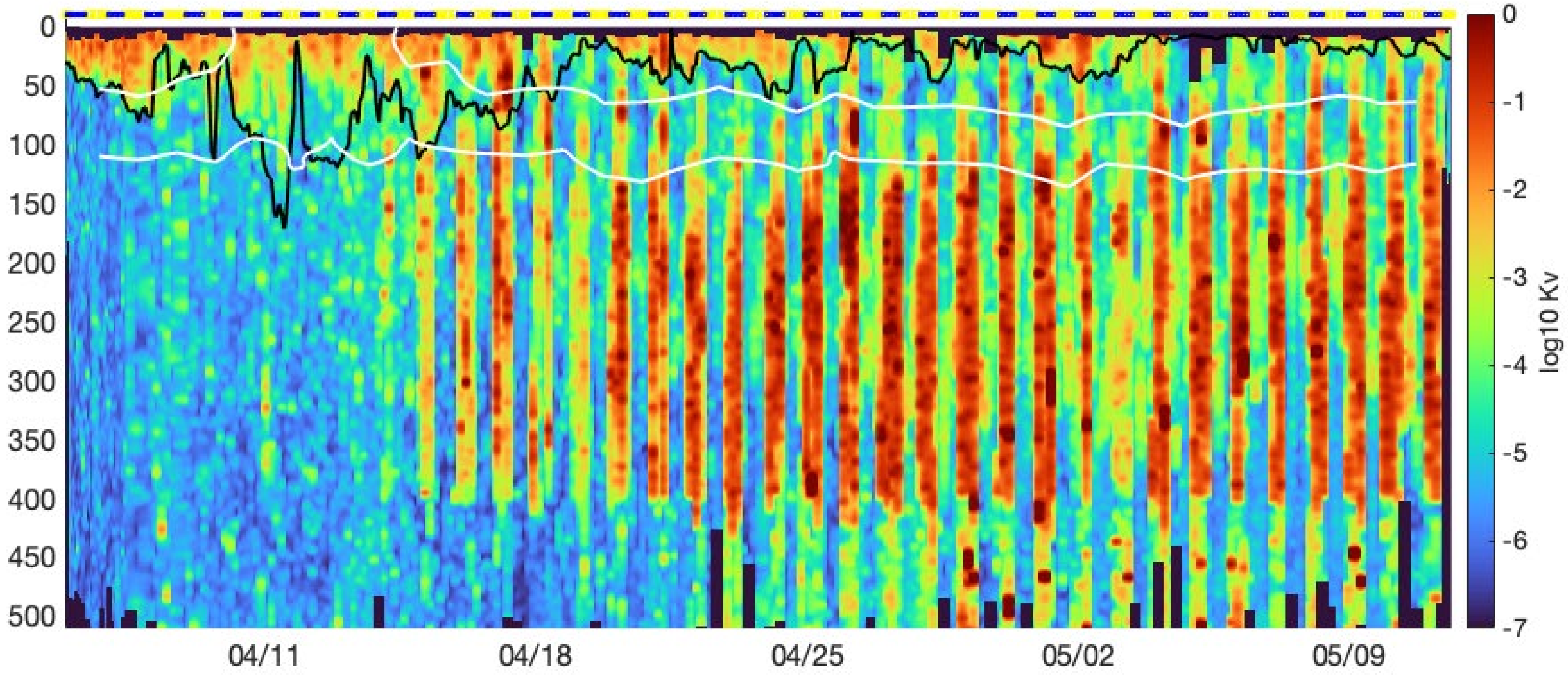
➢ Biologically Enhanced Turbulent Mixing in the Sargasso Sea (R. Curry, BIOS, 2021):

- The amplitude of turbulence & persistence throughout the night hours (and disappearance at sunrise) suggests diel migration of marine organisms (squids?)
- Significantly contribute to bringing nutrients up to the euphotic zone





CUSTOMERS APPLICATIONS

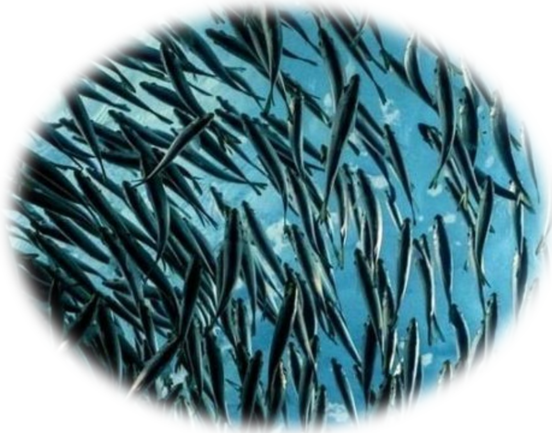
nature geoscience

ARTICLES

https://doi.org/10.1038/s41561-022-00916-3

Check for updates

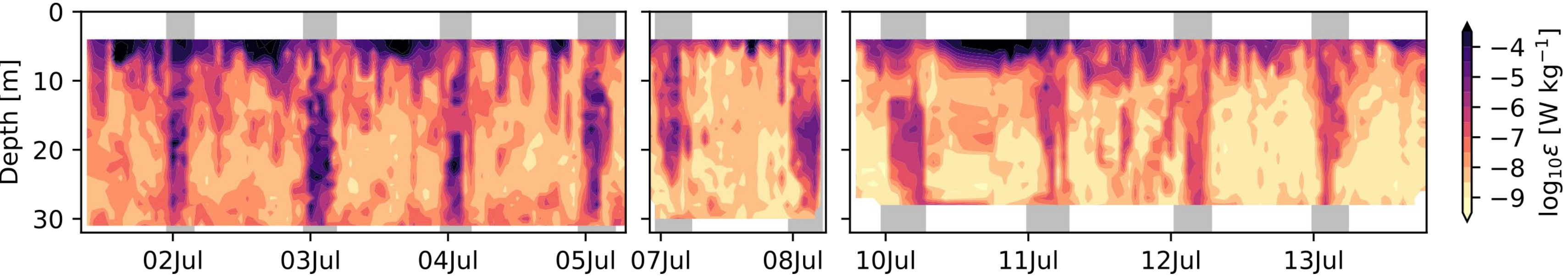
Published online: 7 April 2022

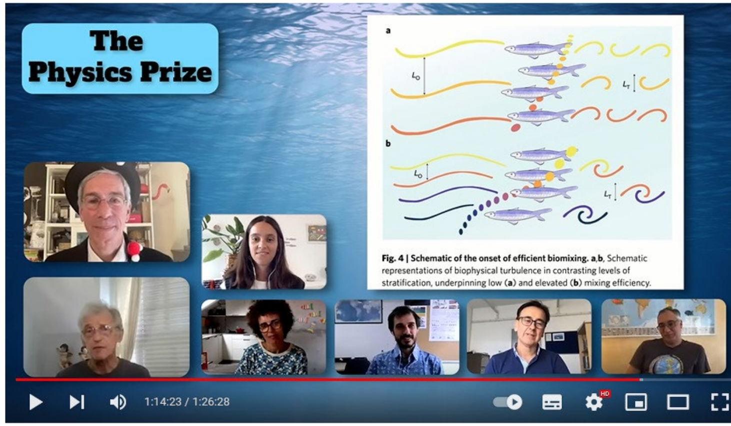


Ig Nobel

Intense upper ocean mixing due to large aggregations of spawning fish

Bieito Fernández Castro[1,2], Marian Peña[3], Enrique Nogueira[4], Miguel Gilcoto[2], Esperanza Broullón[5], Antonio Comesaña[5], Damien Bouffard[6], Alberto C. Naveira Garabato[1] and Beatriz Mouriño-Carballido[5]





Very strong night-time dissipation rates:

$\varepsilon \sim 10^{-6} - 10^{-5}$ W kg^{-1} (10x to 100x the daytime values)

https://www.youtube.com/watch?v=f-fosxKyzQ8

CUSTOMERS APPLICATIONS

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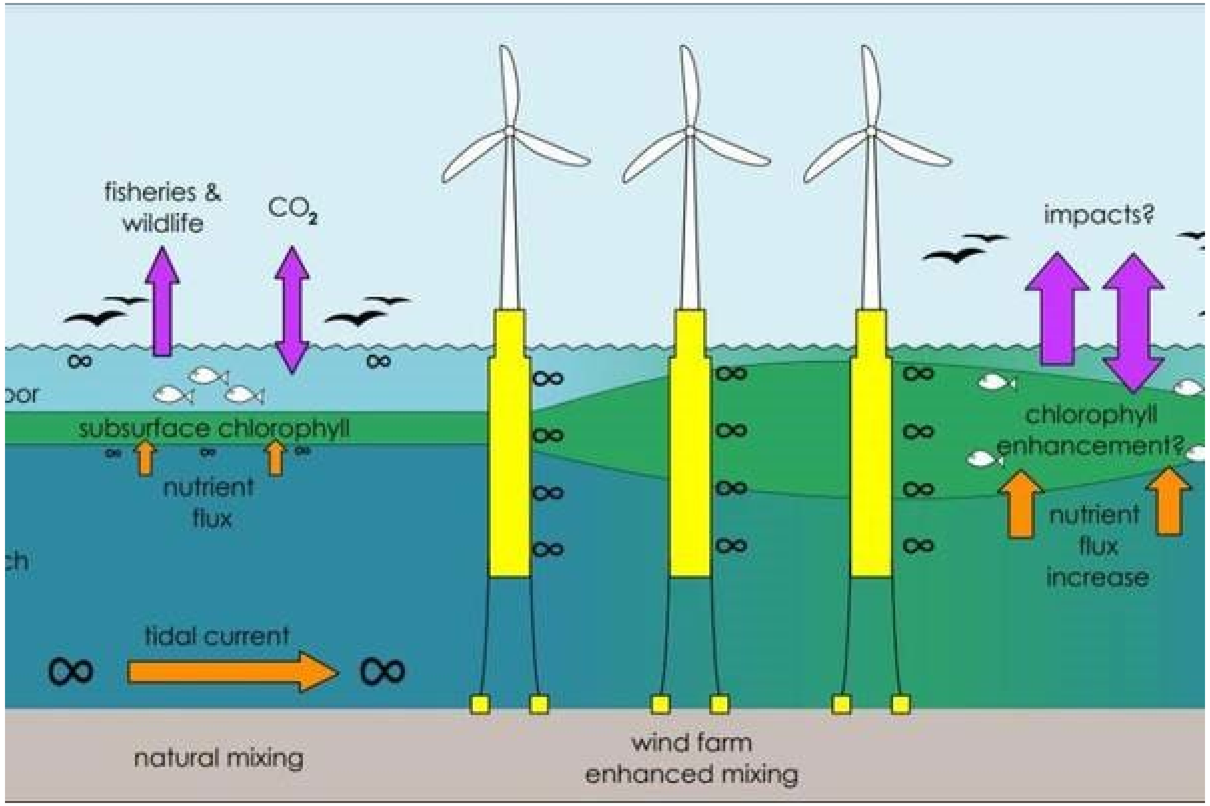
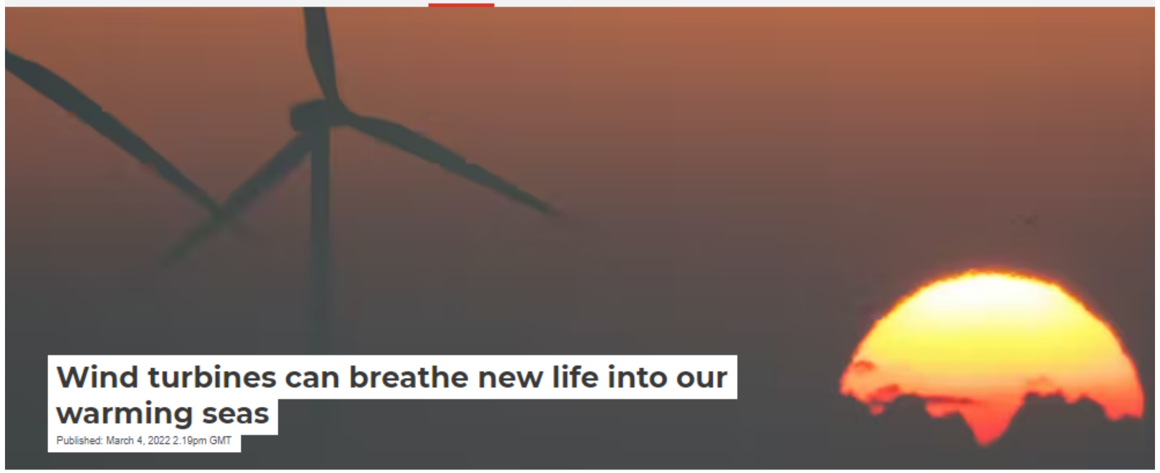
- Anthropogenic Mixing of Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure (R. Dorrell et al. 2021):




THE CONVERSATION

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Wind turbines can breathe new life into our warming seas

Published: March 4, 2022 2.19pm GMT

Ian Dyball / shutterstock

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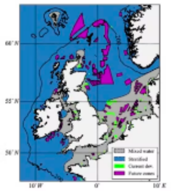
Offshore wind is set to move further and further from shore, as demand for renewable energy grows and new floating turbine technology makes deep-water expansion possible. However, for the first time, large areas of the UK continental shelf now open for development are "seasonally stratified". David Attenborough has described these seasonal seas as some of the most biologically productive on the planet. While they only cover 7% of the ocean, they are estimated to account for somewhere between 10% and 30% of the life at the bottom of the food web.

According to our new research, one byproduct of deep-sea wind farming is that the foundations of these floating turbines could help reverse the damaging effects of climate change on such seas.

In seasonally stratified seas, the water is completely mixed during winter, but separates into layers in the spring with warm sunlit water forming over the top of colder water below. The formation of this "stratification" during spring triggers a massive



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Disclosure statement

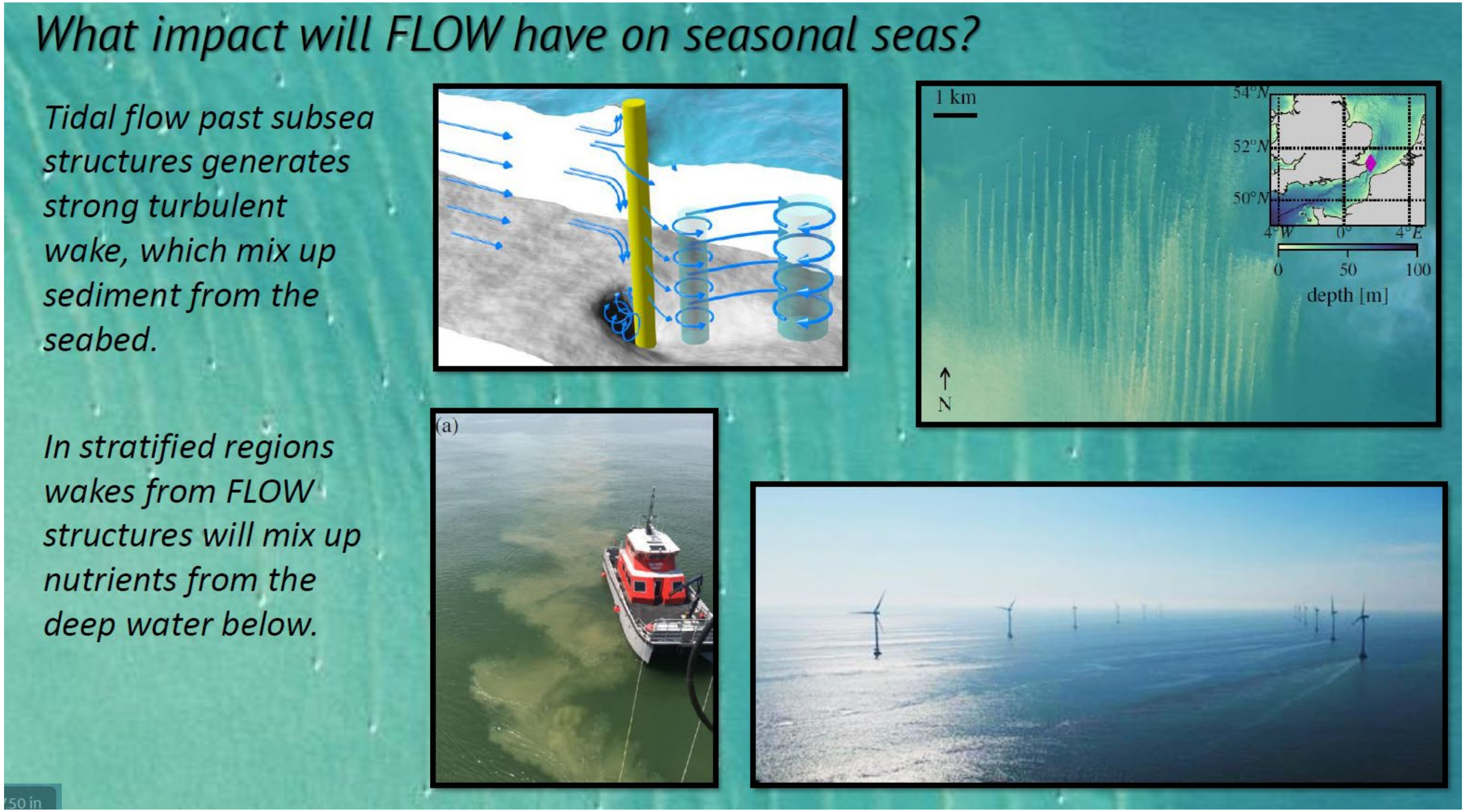
Ben Lincoln receives funding from the UK National Environmental Research Council, the European Union & Welsh Government.

Robert Dorrell receives funding from the UK Natural Environment Research Council and the UK Engineering and Physical Sciences Research Council.

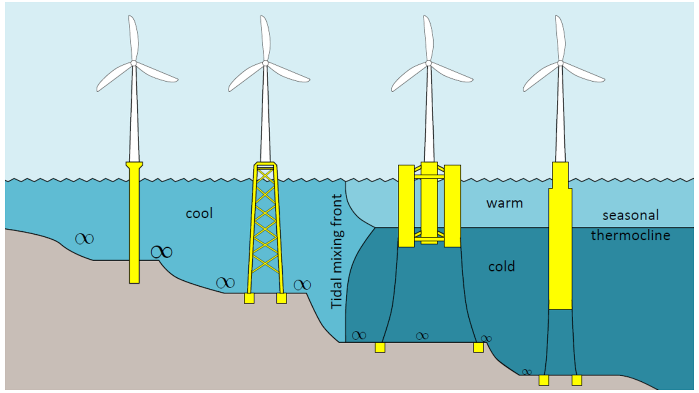
Tom Rippeth receives funding from the UKRI NERC and EPSRC. He is a volunteer for a Liberal Democrats and has campaigned again a new road scheme in North Wales.

CUSTOMERS APPLICATIONS

- **Anthropogenic Mixing of Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure (R. Dorrell et al. 2021):**



- The move from fixed to floating is not just a move to deeper waters…
- It’s a move from permanently mixed to seasonally stratified.



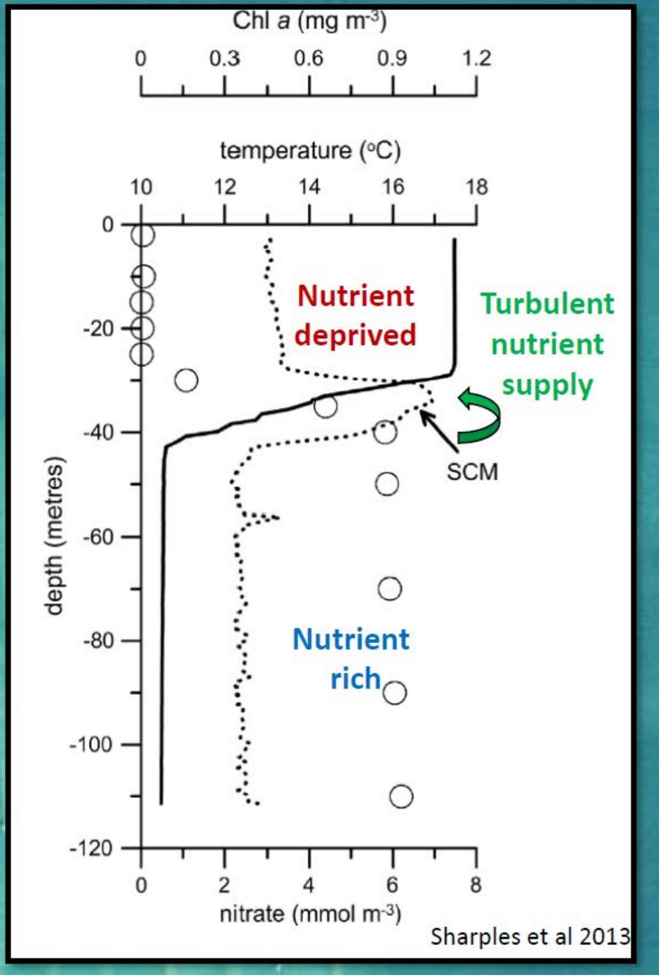
CUSTOMERS APPLICATIONS

ROCKLAND SCIENTIFIC

➢ **Anthropogenic Mixing of Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure (R. Dorrell et al. 2021):**

Primary productivity:
controlled by stratification
sustained by turbulent mixing

- 50% of primary production in spring bloom
- 50% of primary production occurs in a subsurface chlorophyl maximum (SCM)
- SCM sustained by a turbulent nutrient flux



➢ Fishing activity is strongly associated with regions of enhanced mixing

➢ How will wind farm induced mixing compare to natural rates?

CUSTOMERS APPLICATIONS

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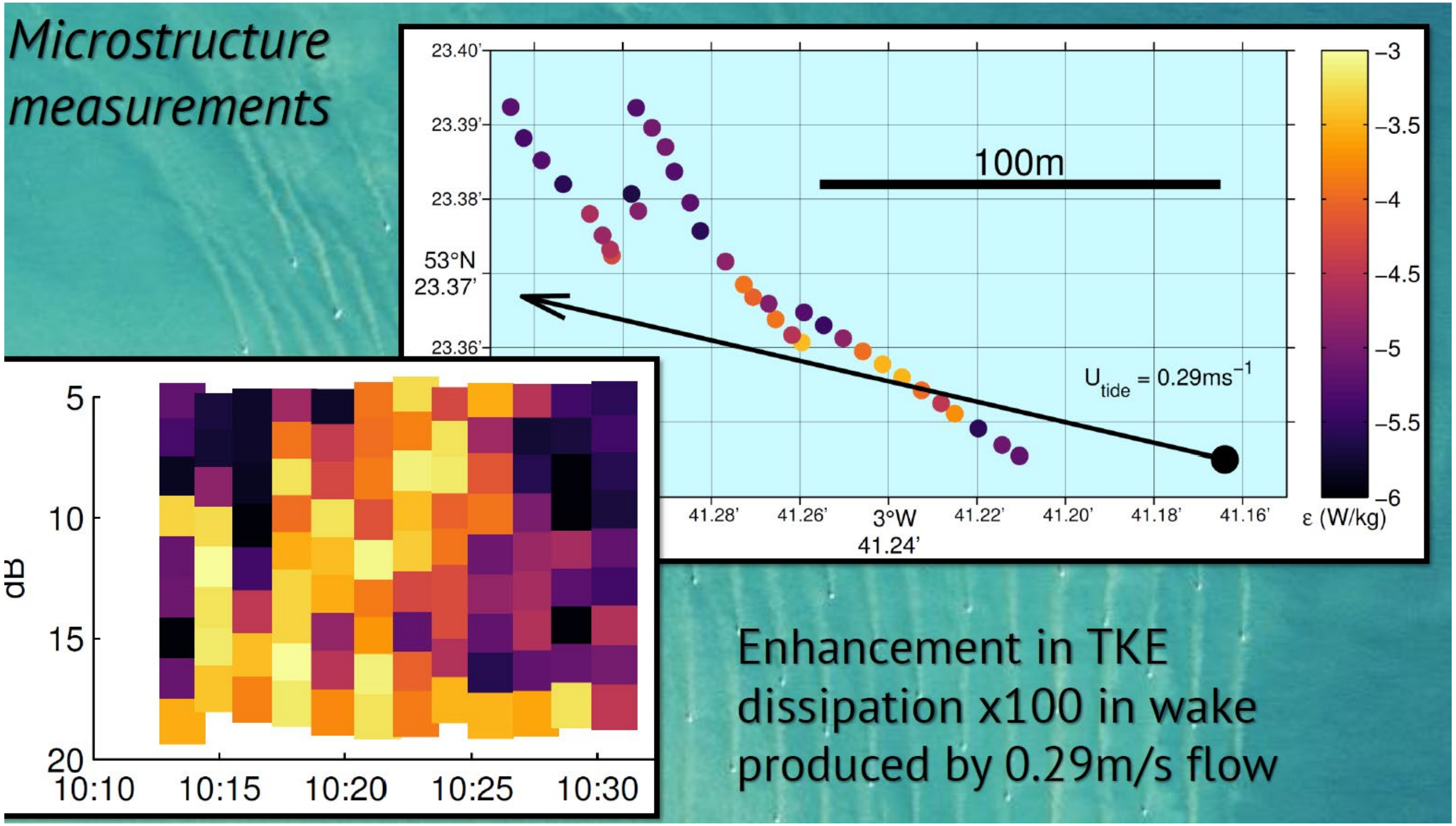
➢ **Anthropogenic Mixing of Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure (R. Dorrell et al. 2021):**



Preventing Negative Impacts

- Break down of stratification
- Delaying the spring bloom
- Movement of tidal mixing fronts
- Exhaustion of nutrient supply

Ensuring Positive impacts…

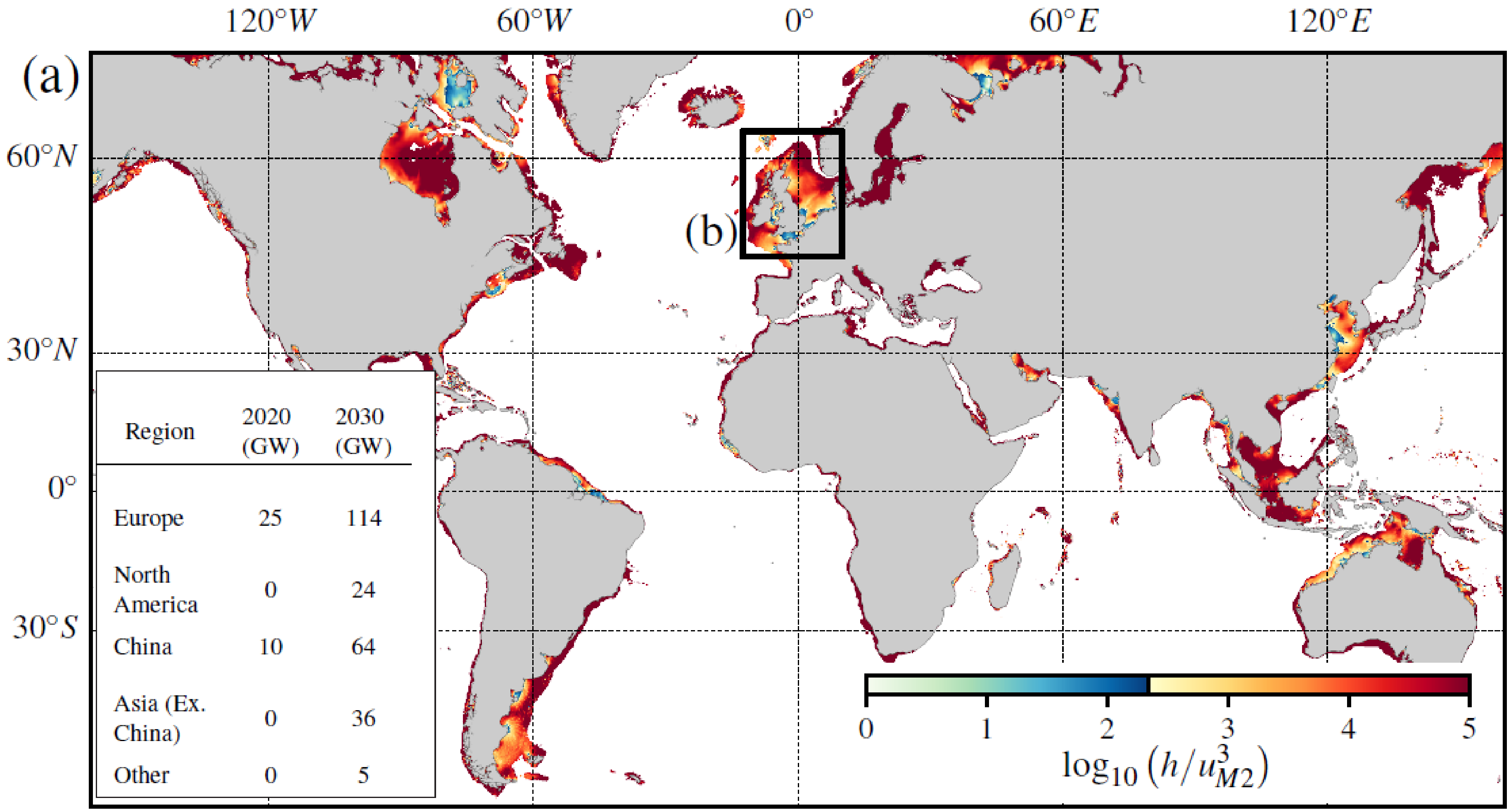
- Enhancement in productivity

Mitigating negative impacts?

- Climate change is increasing the strength of stratification

CUSTOMERS APPLICATIONS

➢ **Anthropogenic Mixing of Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure (R. Dorrell et al. 2021):**



Region	2020 (GW)	2030 (GW)
Europe	25	114
North America	0	24
China	10	64
Asia (Ex. China)	0	36
Other	0	5

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Detection and Tracking of Ultra-Quiet Robotic Submarines

The small size and stealth of modern unmanned underwater vehicles makes them nearly impossible to detect with conventional means.

This represents a growing threat in protecting harbors and choke-points and a growing disadvantage in modern-era asymmetrical warfare.

WISKER – Wake-Induced Signature from Kinetic Energy Radiation

- Enhanced **ASW detection & tracking** capabilities: Subsurface turbulent wakes from UUVs can persist for many hours & can be clearly distinguished in natural environments.
- AUV can possibly be characterized through turbulence data analysis (speed, size, time since passage)
- WISKER appeals to ASW as an alternative **non-acoustic method** to directly detect turbulent wakes generated by small and ultra-quiet UUVs against the background natural environment.

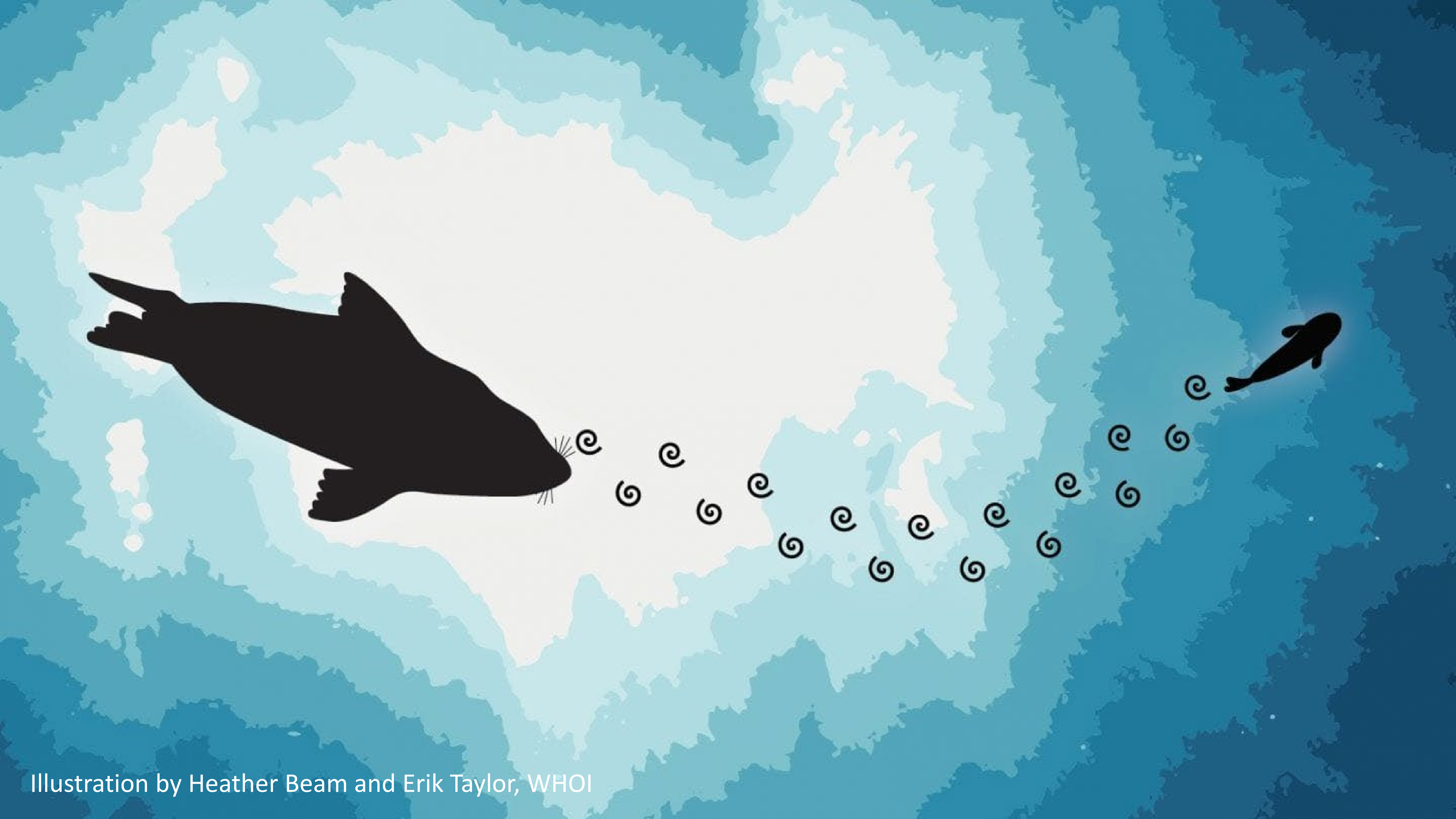
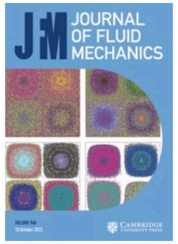


Illustration by Heather Beam and Erik Taylor, WHOI

Home > Journals > Journal of Fluid Mechanics > Volume 783 > Wake-induced 'slaloming' response explains exquisite...



Journal of Fluid Mechanics

Wake-induced 'slaloming' response explains exquisite sensitivity of seal whisker-like sensors

Published online by Cambridge University Press: 16 October 2015

Heather R. Beem and Michael S. Triantafyllou

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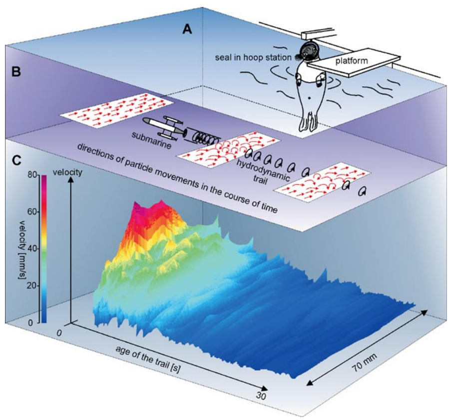
HOME > SCIENCE > VOL. 293, NO. 5527 > HYDRODYNAMIC TRAIL-FOLLOWING IN HARBOR SEALS (PHOCA VITULINA)

REPORTS

Hydrodynamic Trail-Following in Harbor Seals (*Phoca vitulina*)

GUIDO DEHNHARDT, BJÖRN MAUCK, WOLF HANKE, AND , HORST BLECKMANN Authors Info & Affiliations

SCIENCE • 6 Jul 2001 • Vol 293, Issue 5527 • pp. 102-104 • DOI: 10.1126/science.1060514



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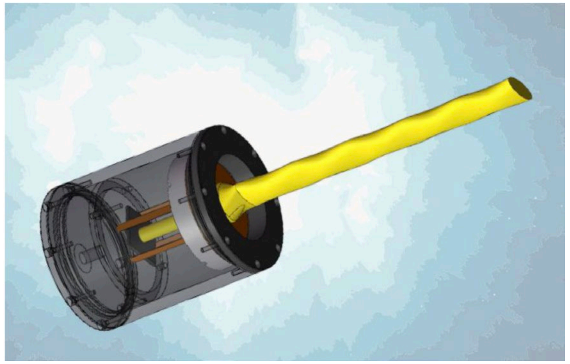
Published: 16 July 1998

Seal whiskers detect water movements

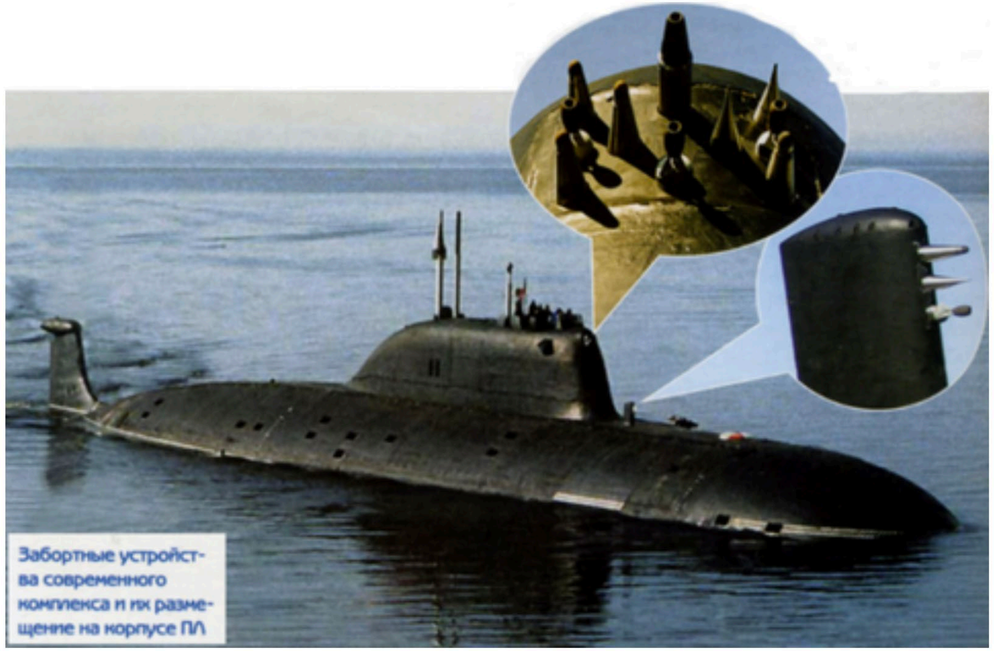
Guido Dehnhardt, Björn Mauck & Horst Bleckmann

Nature **394**, 235–236 (1998) | Cite this article



Previous technology: Russian SOKS System

- SOKS, stands for "System Obnarujenia Kilvaternovo Sleda" or "wake object detection system."
- This device, fitted to Russian attack submarines, tracks the wake a submarine leaves behind.
- SOKS is visible in photos of Russian subs as a series of spikes and cups mounted on external fins.



https://www.popularmechanics.com/military/navy-ships/a28724/submarine-sonar-soks/

DEFENSE APPLICATIONS

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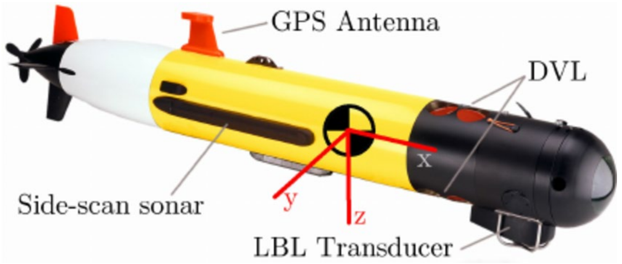
➢ **Royal Navy Submarine Appears In Gibraltar With Enhanced Wake Detection System:**

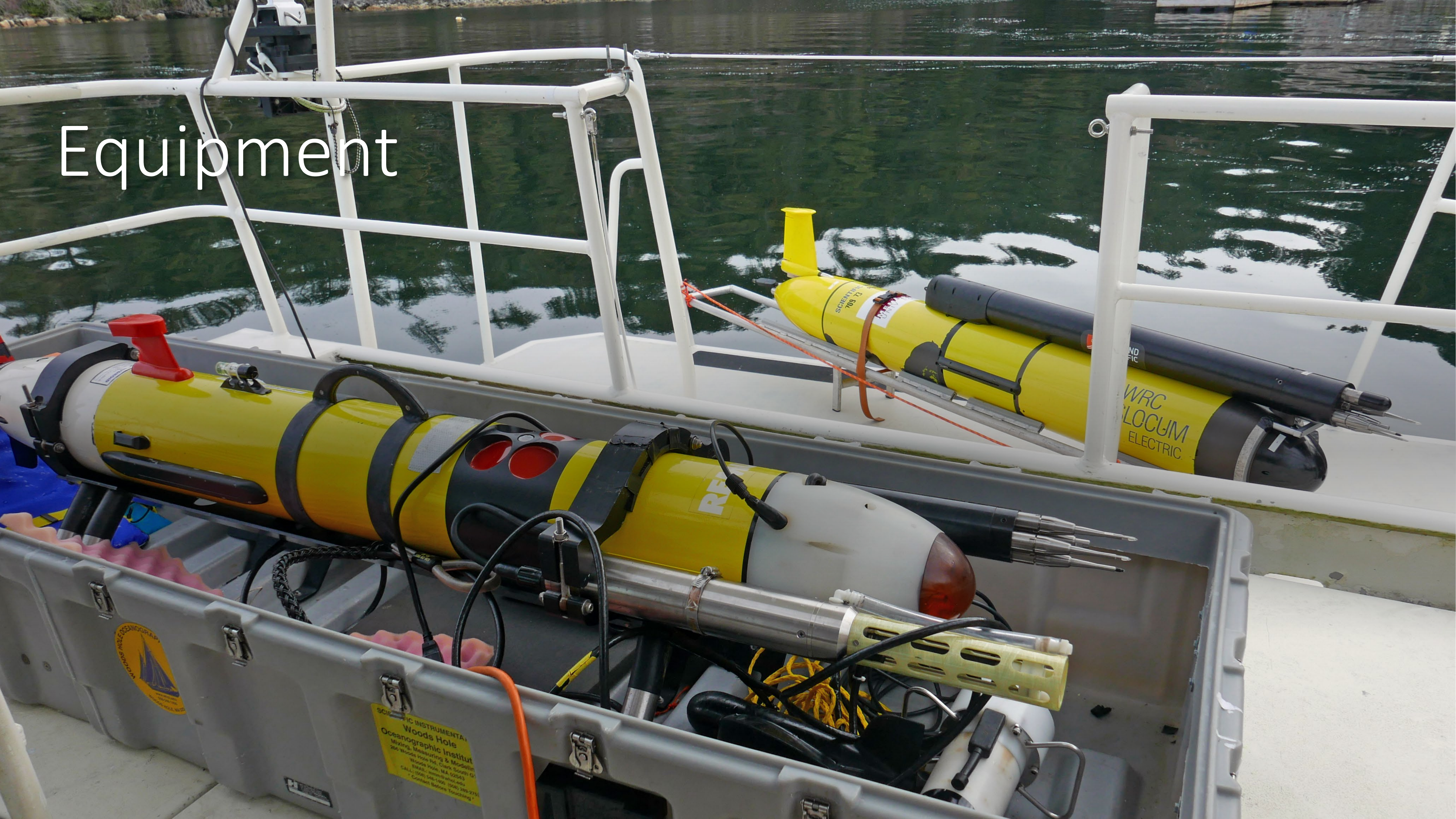
https://www.thedrive.com/the-war-zone/39055/new-wake-detection-sensor-spotted-on-royal-navy-submarine-as-it-pulls-ito-gibraltar

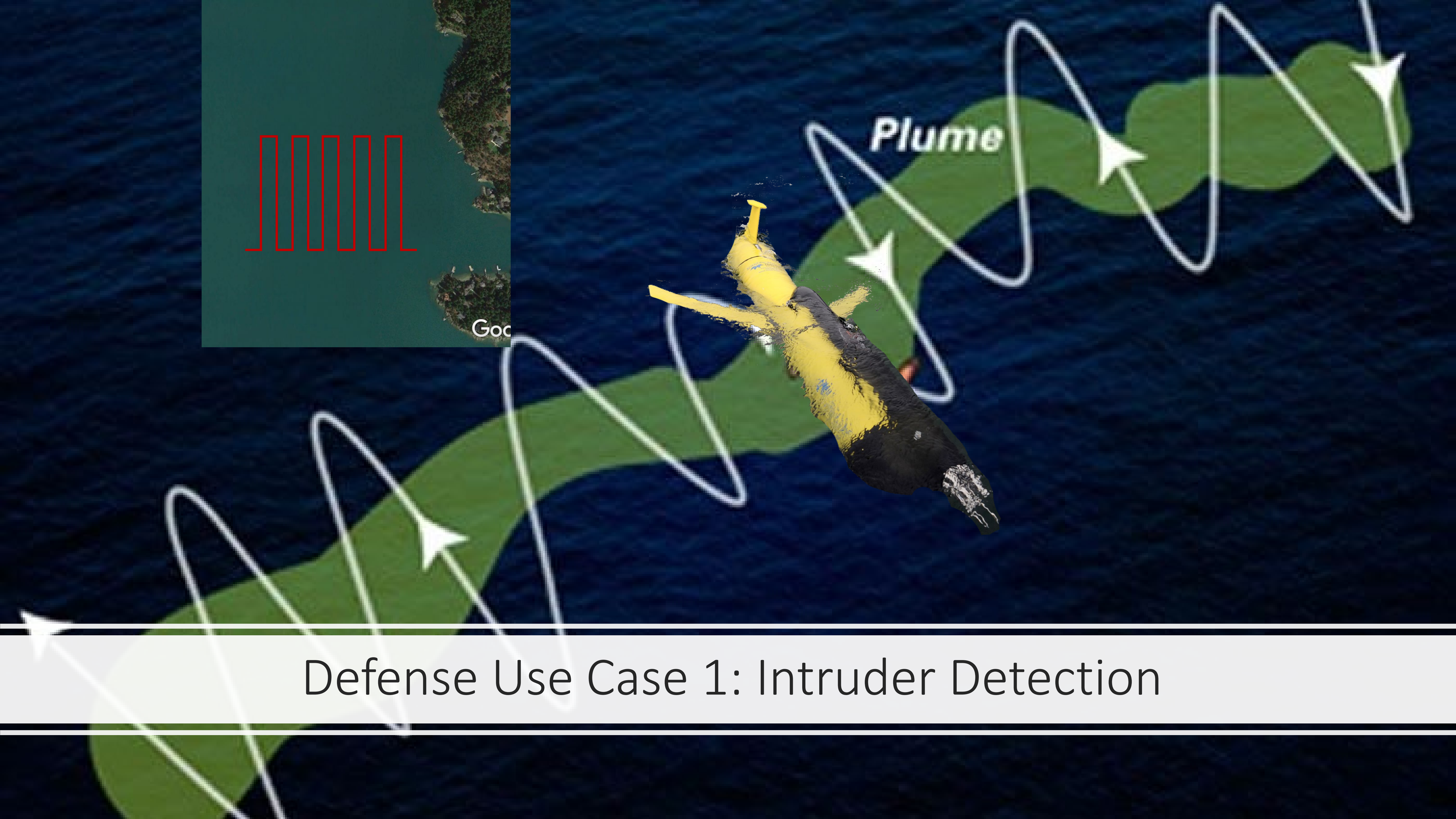
Demonstration project for AUV detection Saanich Inlet, BC, Canada

- Saanich Inlet is a fjord-like inlet near Victoria BC
- The hypothesis is that shear probes can detect the wake of a small AUV
- A Remus 100 was used to simulate a typical AUV reconnaissance pattern in front of a small harbour
- A *Slocum* glider carried shear probes and patrolled the area



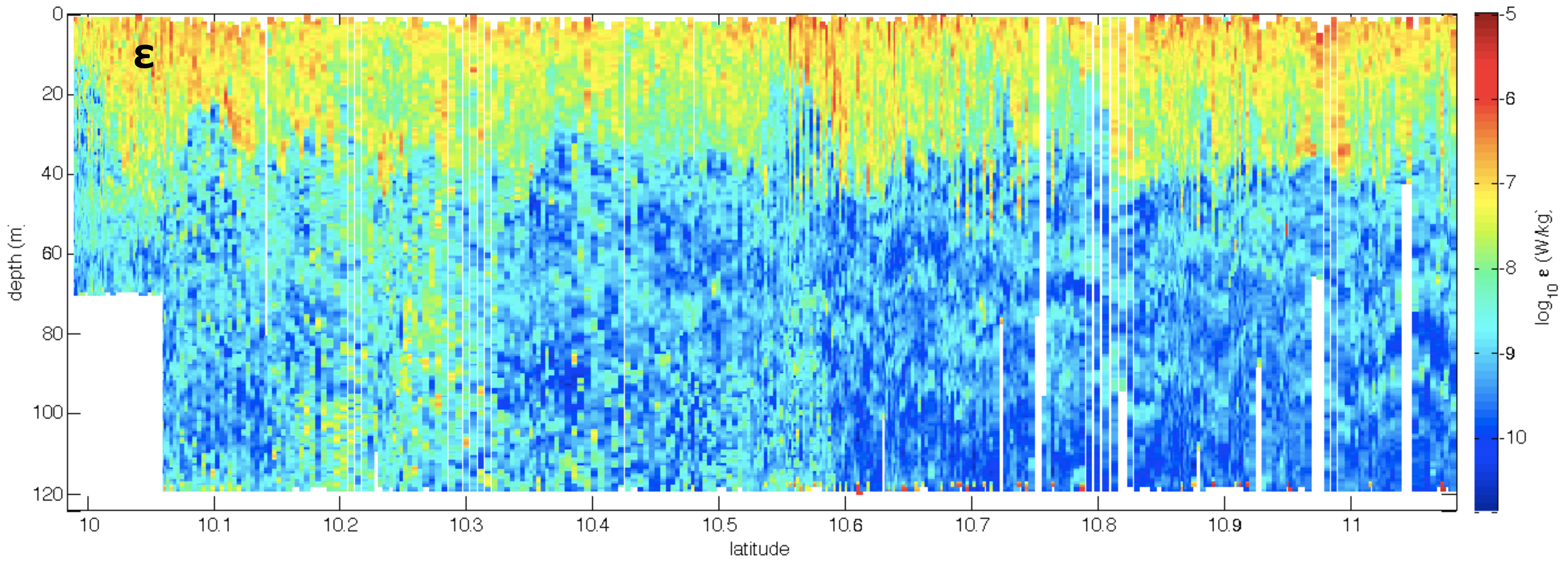
Equipment



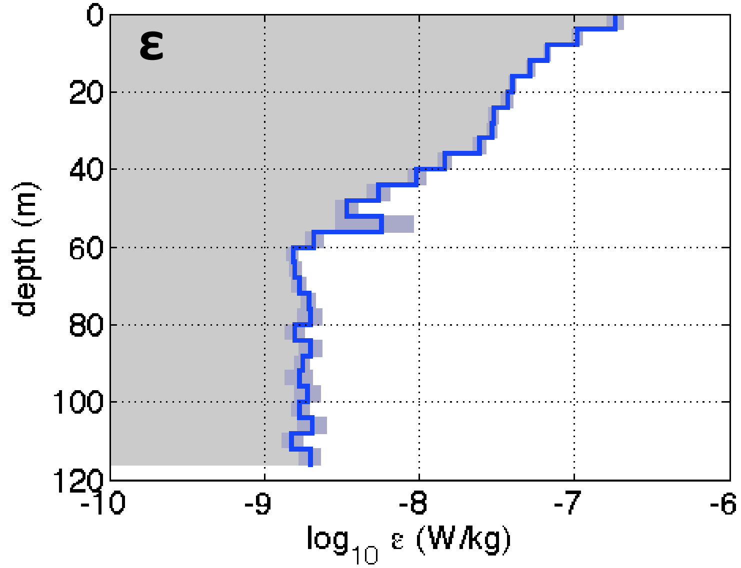


Defense Use Case 1: Intruder Detection

Turbulent Kinetic Energy dissipation rates from gliders



Environmental Baseline



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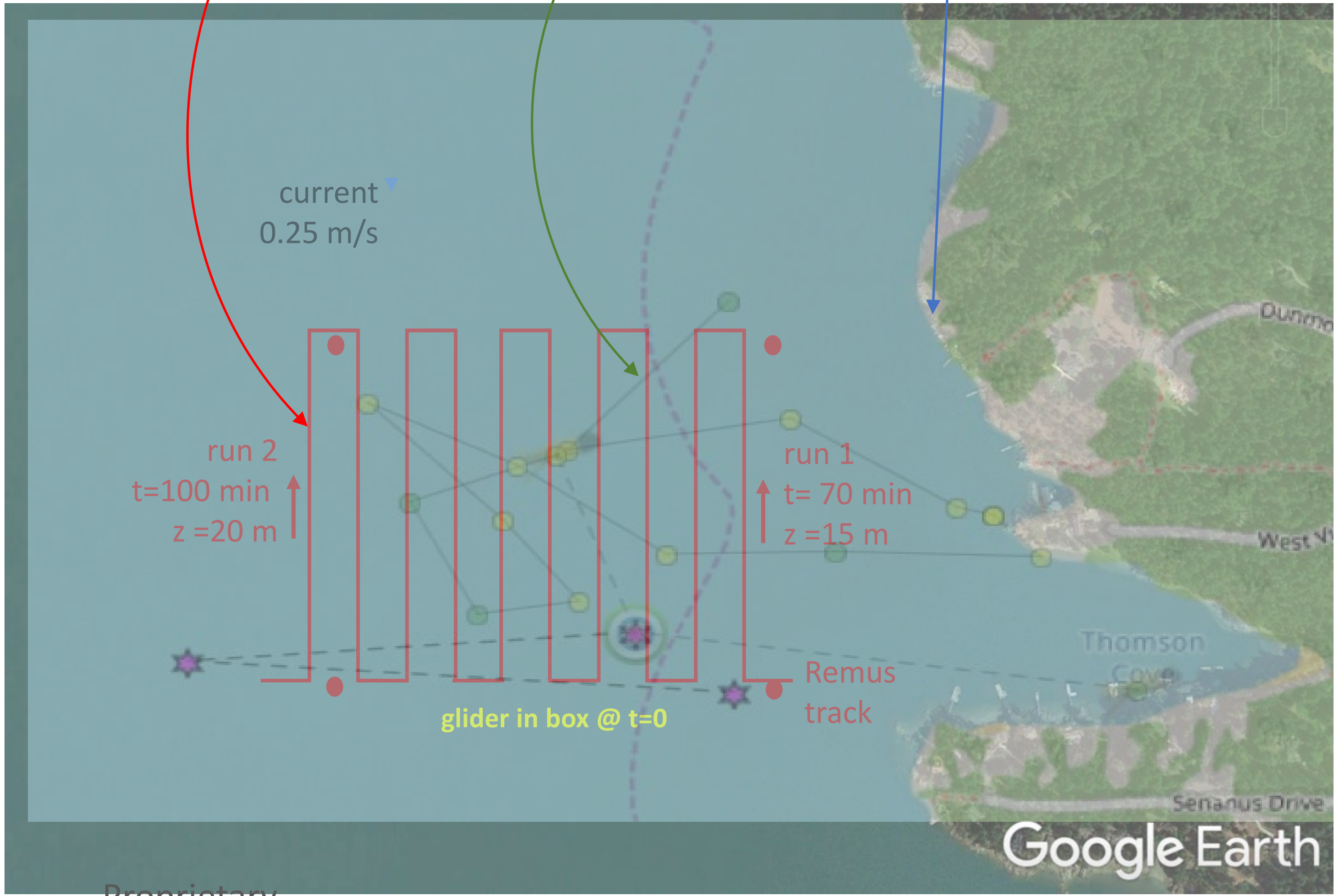
Test setup

Remus radiator pattern at 15 m , 20 m depth

Glider diving tracks, repeated dives along individual tracks

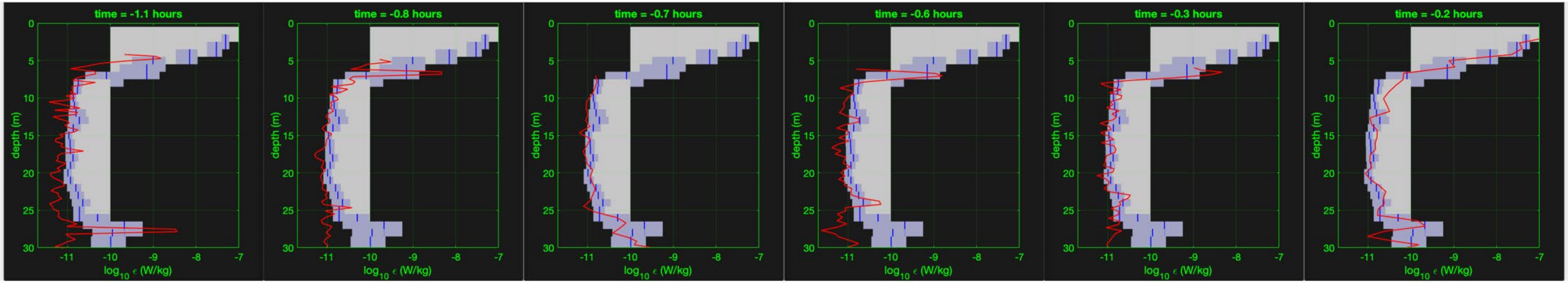


Proprietary

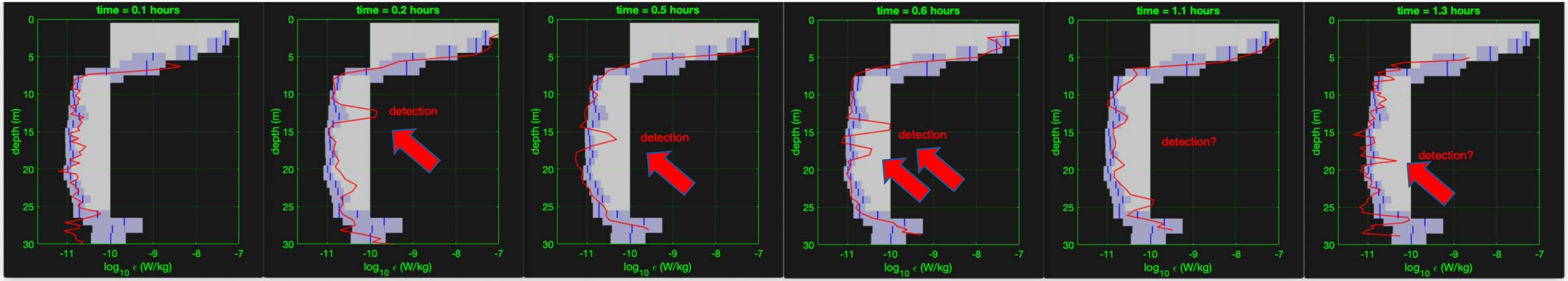
Turbulence detections

- Sequence shows a dozen glider profiles spanning 2.4 hours, from 1.1 hr before initial Remus run to 1.3 hours after
- Background image shows mean dissipation rate and 95% confidence intervals as calculation from bootstrap statistics

BEFORE Remus run



AFTER Remus run



KEY TAKE-AWAYS

- Turbulence controls **mixing** of anything that is in the ocean or enters the ocean

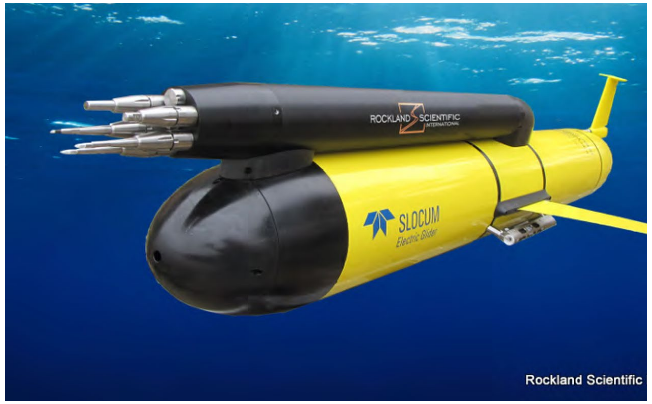
  => **Vertical diffusivity** of heat, salt, energy, nutrients, chemicals, etc.

- Turbulence processes occur at much smaller scales than climate model grid scales

  => **Strong need for in-situ measurements** to parameterize climate simulations.

- Gliders are excellent platforms for ocean turbulence measurements

  => Stable & quiet ($\varepsilon \sim 10^{-5}$ to 5×10^{-11} W/kg can be resolved)
  => High spatial & temporal resolution can reveal new physical processes
  => New ISDP algorithms now allowing transmission of **ε estimates in near real-time.**



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IMPORTANCE

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Underwater turbulence revealed as a key factor in climate change

Depositphotos

When someone mentions waves, we are most likely to think of the beach and surfers riding breaks to shore, not the waves deep beneath the ocean's surface. Now, new research has shed light on the important role underwater waves play in climate change.

On the Future of Argo: *A Global, Full-Depth, Multi-Disciplinary Array*

Dean Roemmich[1*†] Matthew H. Alford[1†] Hervé Claustre[2†] Kenneth Johnson

"Numerical experimentation over the last decade has shown that **key aspects of Earth's climate depend on accurate representation of turbulent mixing in the ocean**. In fact, the field has matured to a point where without better observational constraints on turbulent mixing it will be difficult to make further progress in understanding processes as diverse as abyssal circulation, tropical precipitation, the sea-surface, temperature cycle, or the extent of the oxygen minimum zones (…)."

(*Roemmich et al. 2019 On the Future of Argo*)

https://doi.org/10.3389/fmars.2019.00439

BONUS: TURBULENCE ON FLOATS

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- Collaboration with **MRV System**: integration on Alto float.

BONUS: TURBULENCE ON FLOATS

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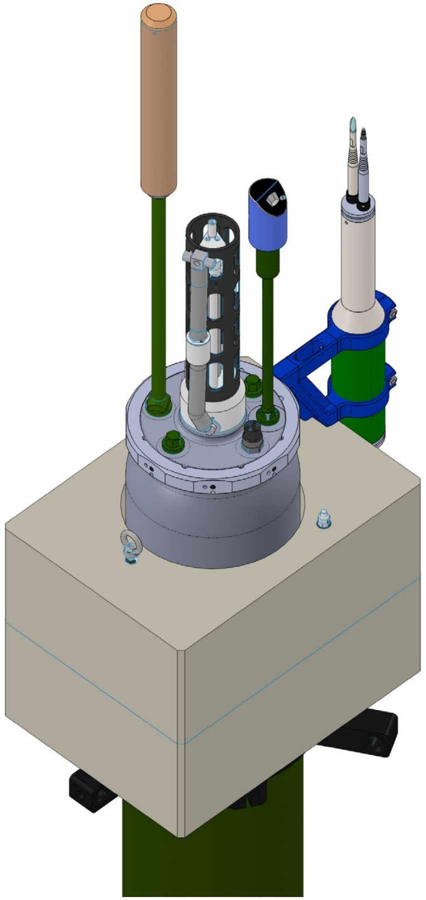
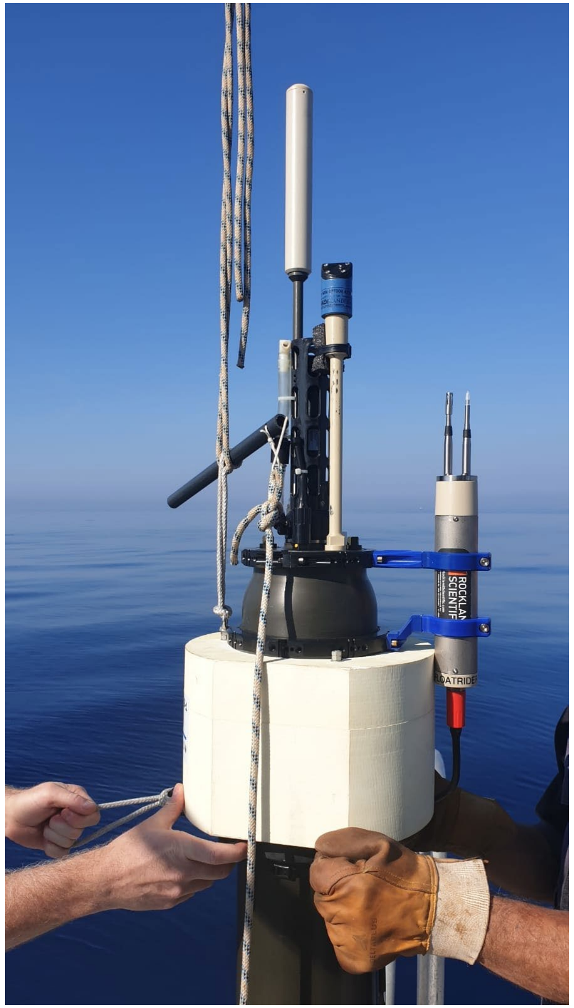
- Collaboration with **NKE Instrumentation**: integration on Provor CTS5 float.





QUESTIONS?

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