An Integrated Approach to Characterization of Full-Spectrum Turbulence Near Current Tidal Energy Devices

Presented by Brett Prairie of Rockland Scientific at the Marine and Hydrokinetic Technology and Environmental Instrumentation, Measurement & Computer Modeling Workshop

Broomfield, Colorado
July 9 - 11, 2012

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Presentation Agenda

1. Introduction & Background
2. The importance of full-spectrum turbulence characterization for current tidal energy project development
3. How non-acoustic measurements can characterize small-scale turbulence near current tidal energy devices
4. Development of a continuous monitoring system to measure full-spectrum turbulence for the National Renewable Energy Laboratory
5. Conclusions and Q & A

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1. Rockland Scientific Inc. (RSI) – An Introduction

- Marine Turbulence Experts
  - Specialize in non-acoustic measurement techniques & Instrumentation
  - Utilize acoustic measurement technology for integrated systems

- RSI Two Principle Scientists with combined:
  - 40 years experience in oceanographic turbulence research
  - 25 Years in instrumentation
  - 60 + publications

- *"Instruments for Oceanographers by Oceanographers"*

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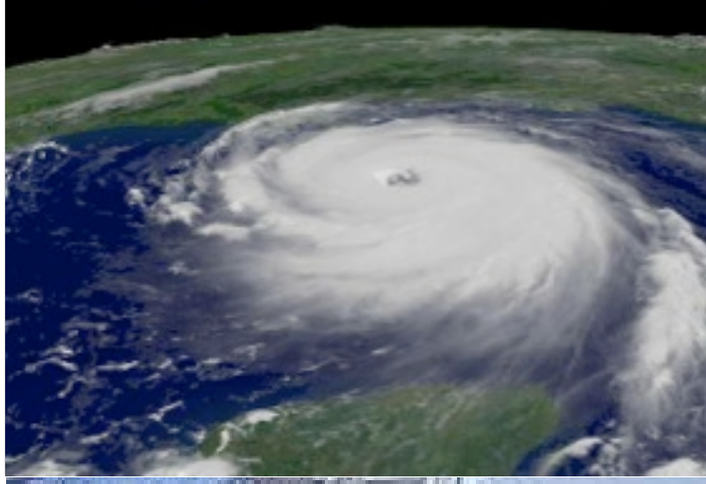
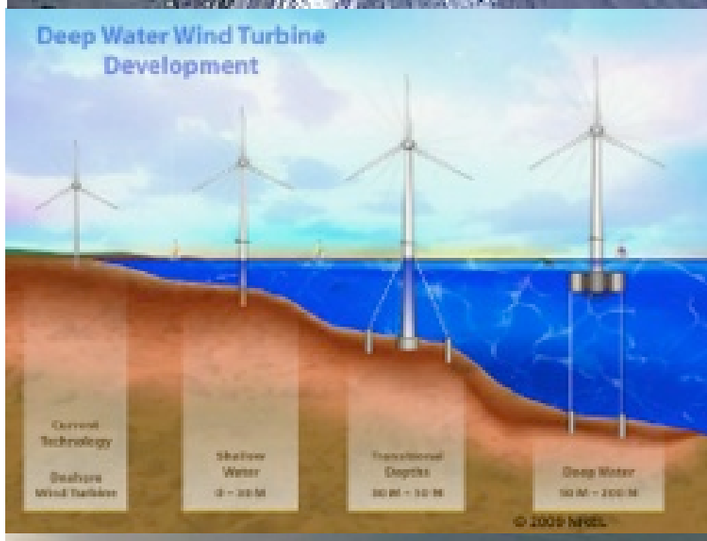
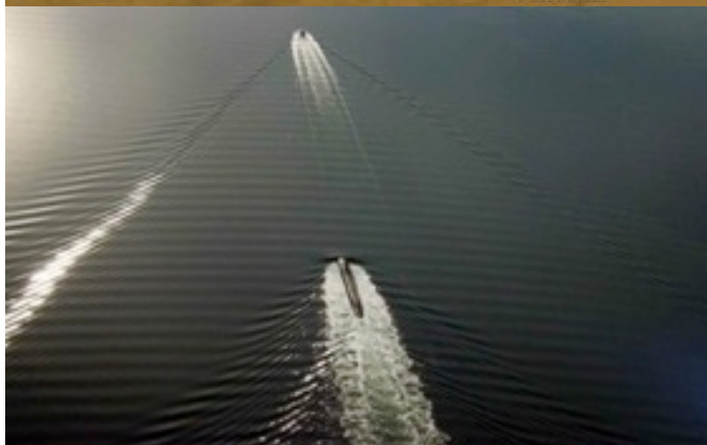
1. Traditional Applications

- Climate Research
  - Air-sea interaction
  - Deep-ocean circulation
- Coastal Management
  - Coastal erosion
  - Environmental impact
- Fisheries
  - Bio-physical interaction
- Security
  - Wake detection
  - Acoustic model refinement







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1. Customer Examples

Canada	Memorial University University of Quebec University of Victoria Fisheries and Oceans Canada
USA	Woods Hole Oceanographic Institution Texas A&M University National Research Lab Stennis Scripps UCSD etc.
UK	National Oceanography Centre Proudman Oceanographic Laboratory British Antarctic Survey University of Wales
France	IFREMER University Paris UPMC French Naval R&D Centre
Germany	IFM GEOMAR Kiel Institute of Baltic Research
Norway Sweden Switzerland	University of Bergen
Australia New Zealand	CSIRO University of Western Australia
China Taiwan Japan	Ocean University China

1. RSI Instruments - Deployment Options

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2. Characterizing Full-Spectrum Turbulence at Current Tidal Energy Devices

definition

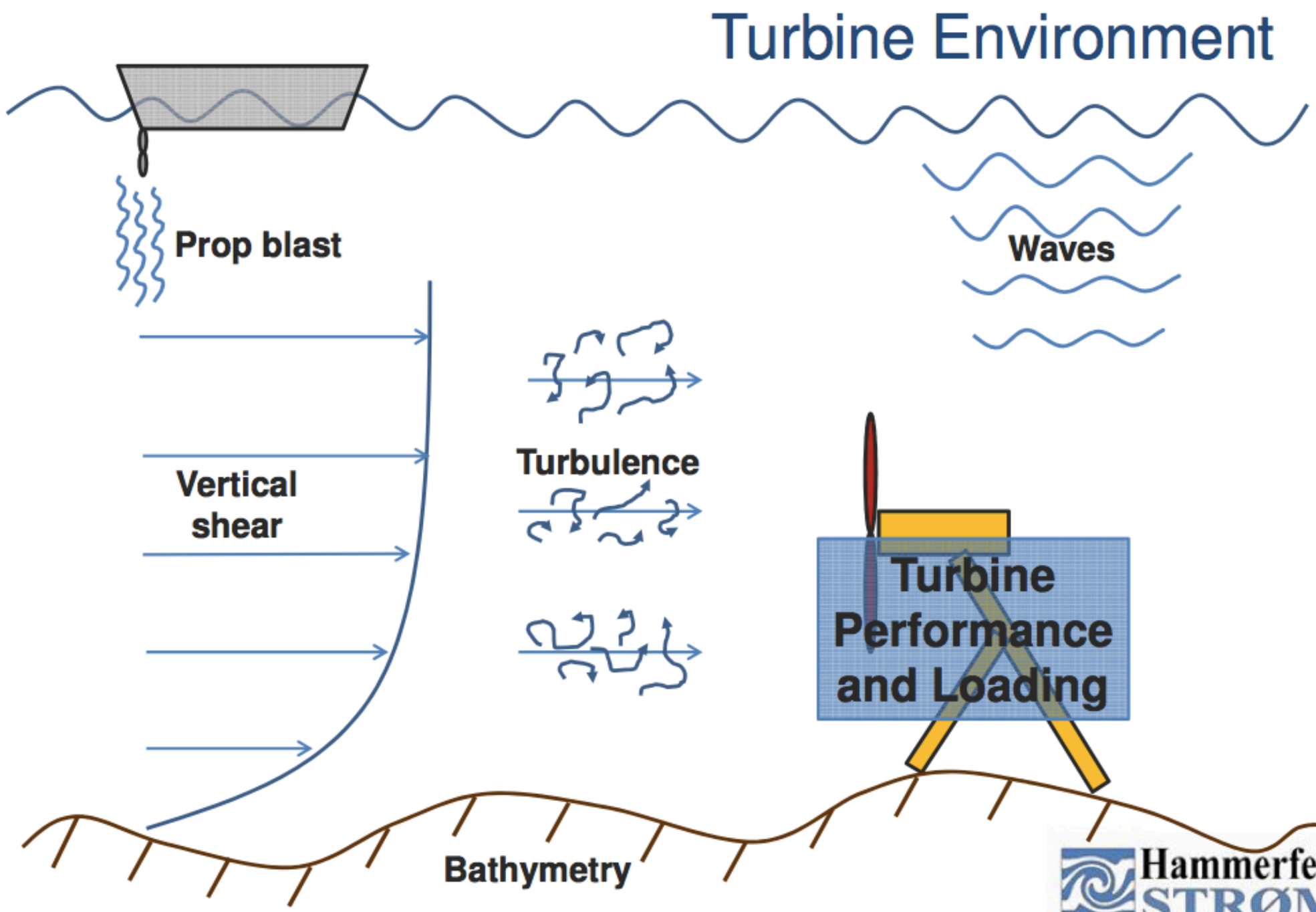
Full-Spectrum Turbulence. *The full range of environmental turbulence at a tidal energy site - from energy containing to dissipation scales.*

2. Characterizing Full-Spectrum Turbulence at Current Tidal Energy Devices

The tidal energy industry has concluded that:

- turbulence measurements are a key requirement in optimizing designs of tidal-current turbines
- Environmental turbulence significantly impacts the loading on turbines and their performance
- In-situ turbulence measurements with a spatial resolution of 0.01-1m (i.e., the scale of the turbine blades) are needed
- The limitations of the existing measurement methodologies may impact the technical and economic viability of tidal energy projects

2. Site Characterization – Biggest Challenge for Tidal Energy Industry: Measuring Unsteady Loading



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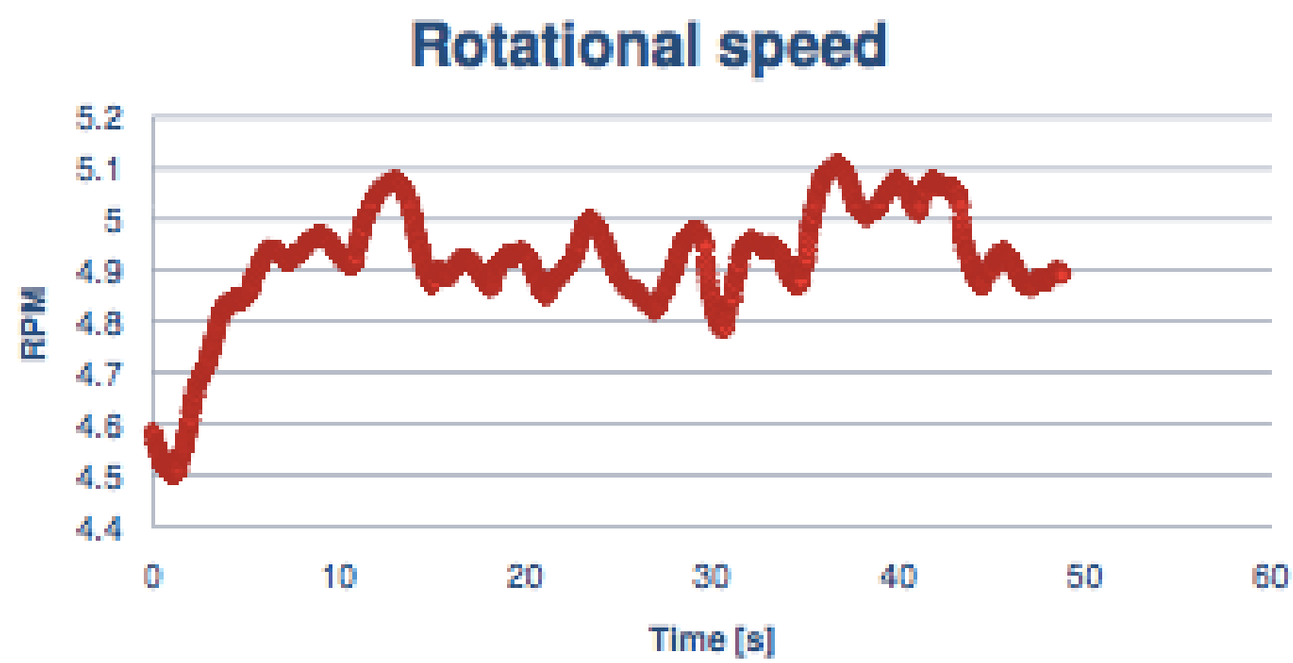
2. Site Characterization: Turbulence Measurement Challenges

Characterizing unsteady loading on turbine



Perceived challenges using conventional turbulence measurement instrumentation (acoustic)

- Standard deviation of data similar size to turbulence intensities
  - Adds uncertainty to Energy yield predictions. This impacts project economics
  - Large variation in loading on rotors affects safety factors and cost in design of turbines

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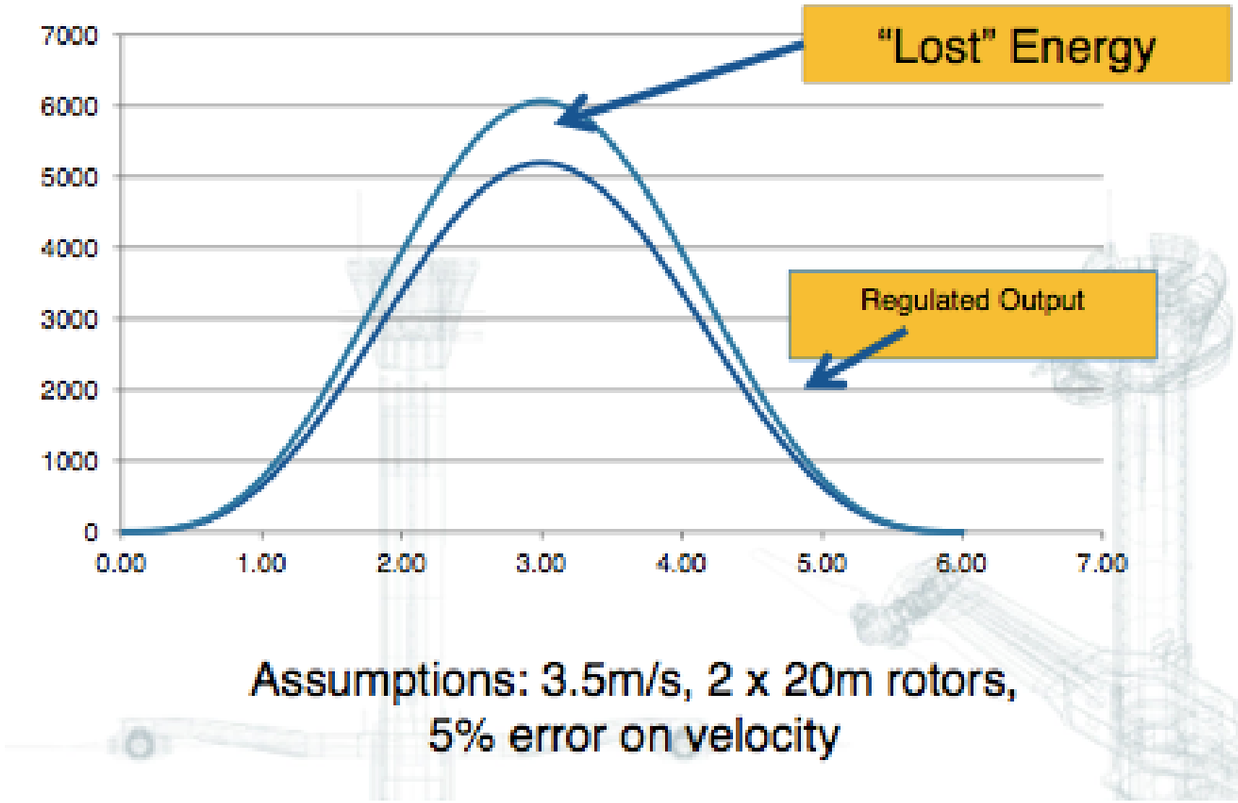
2. Site Characterization: Turbulence Measurement Challenges



Under Predicted Energy

- Economics poor – investment challenge
- Structure & Foundations could be under designed
- Impacts on installation & operations

Over Predicted Energy

- Lower yield may lead to financial penalties
- Structure & Foundations could be overdesigned
- Installation method/vessels could be over specified

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3. Non-acoustic Measurements to Characterize Small-scale Turbulence Near Current Tidal Energy Devices

- The standard method for the measurement of ocean turbulence is with the shear-probe sensor.

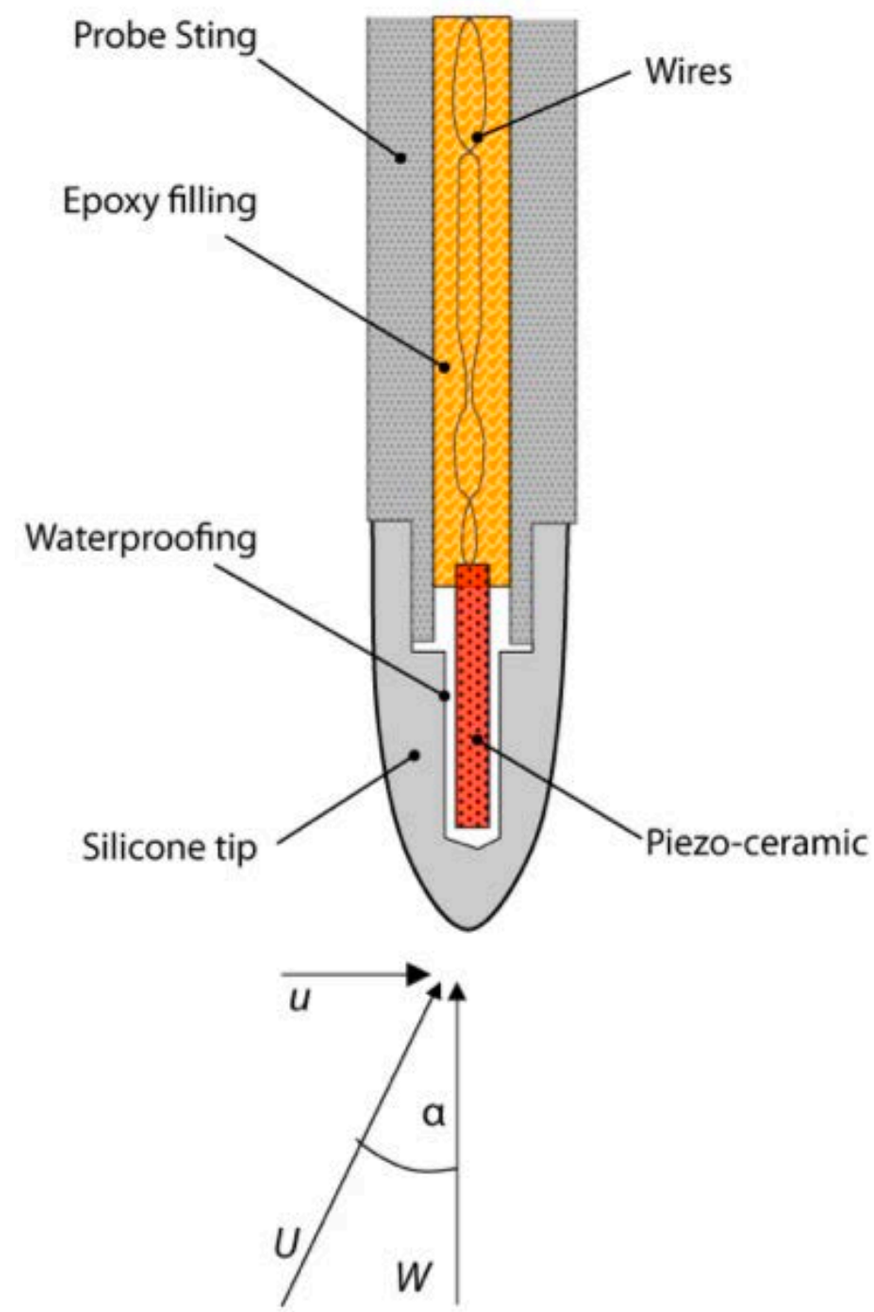
- Shear probes are mounted on the nose of a VMP (profiler pointed downward).

W = apparent vertical velocity due to profiling or movement into relative flow

u = horizontal velocity fluctuation due to turbulence

U = total velocity

α = angle of attack



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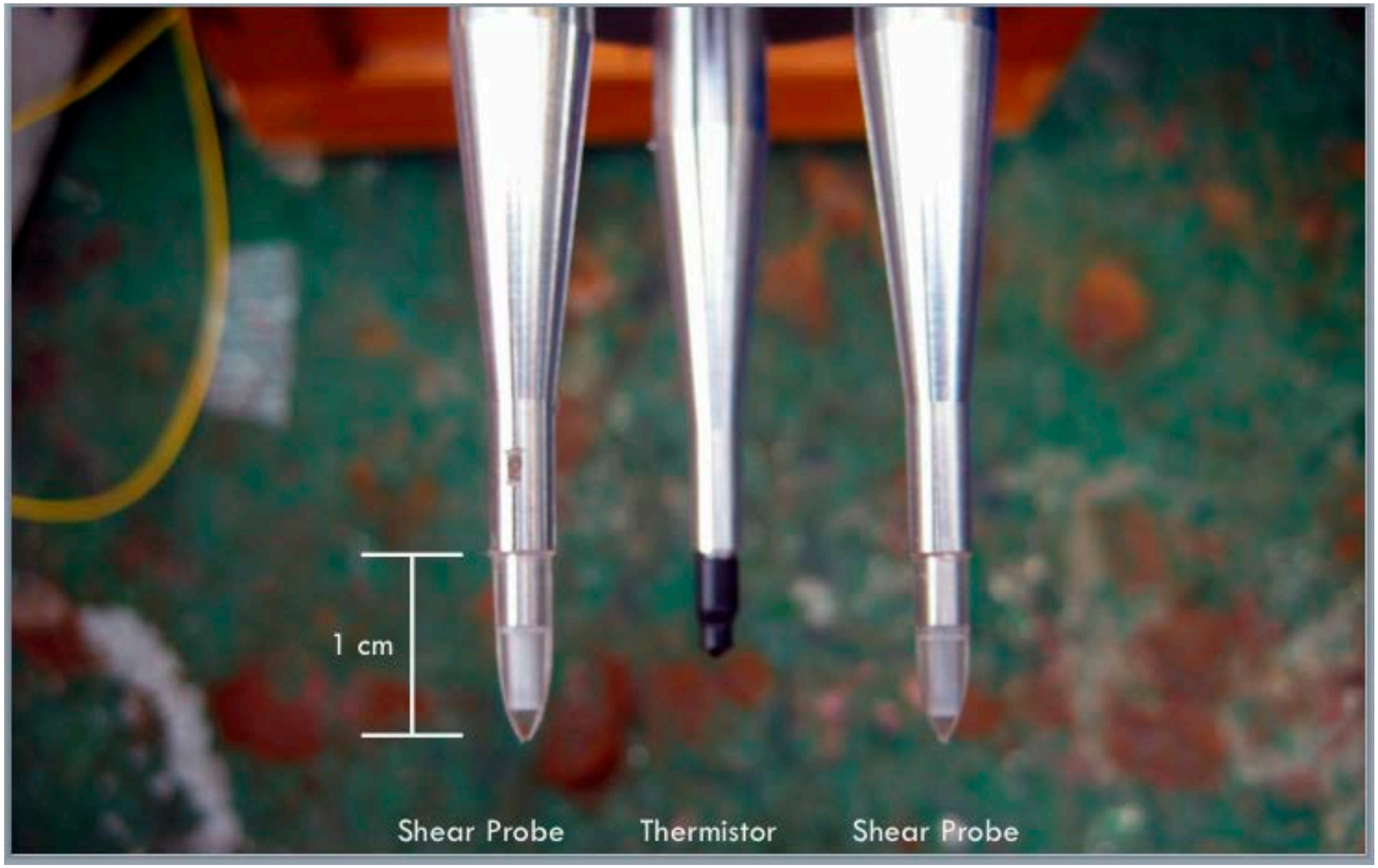
3. Non-acoustic Measurements to Characterize Small-scale Turbulence Near Current Tidal Energy Devices



- The smallest spatial scale scale resolved by the shear probe is determined, to first order, by the length of the probe tip, which is approximately 1cm.

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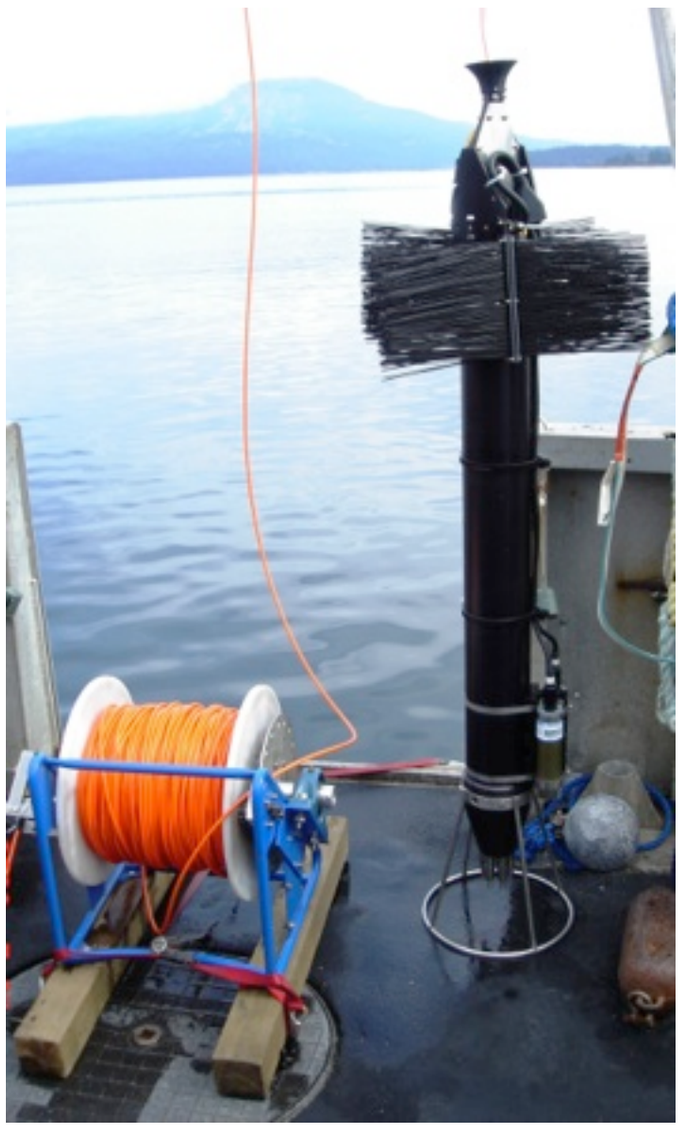
3. Vertical Turbulence Profiler

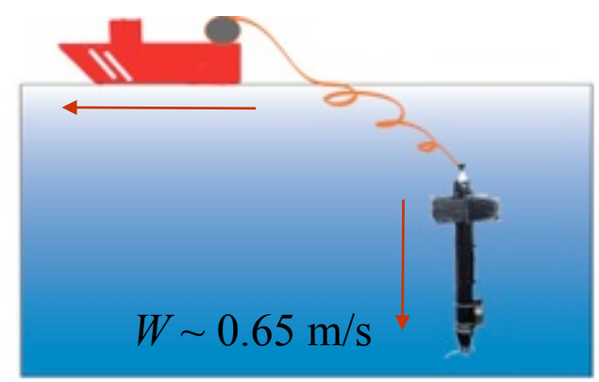


Sensors:

- Velocity Shear Probe
- Fast Thermistor
- Micro-conductivity probe

- Pressure sensor
- Accelerometers x, y, z

- Fluorometer
- Conductivity & Temperature



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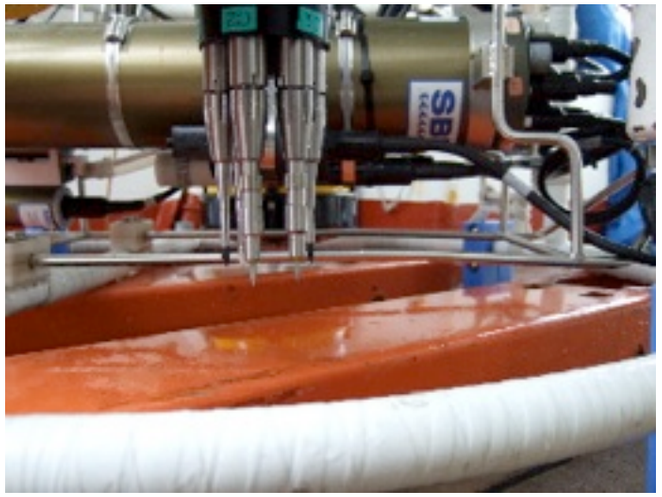
3. MicroRider - Glider Deployments



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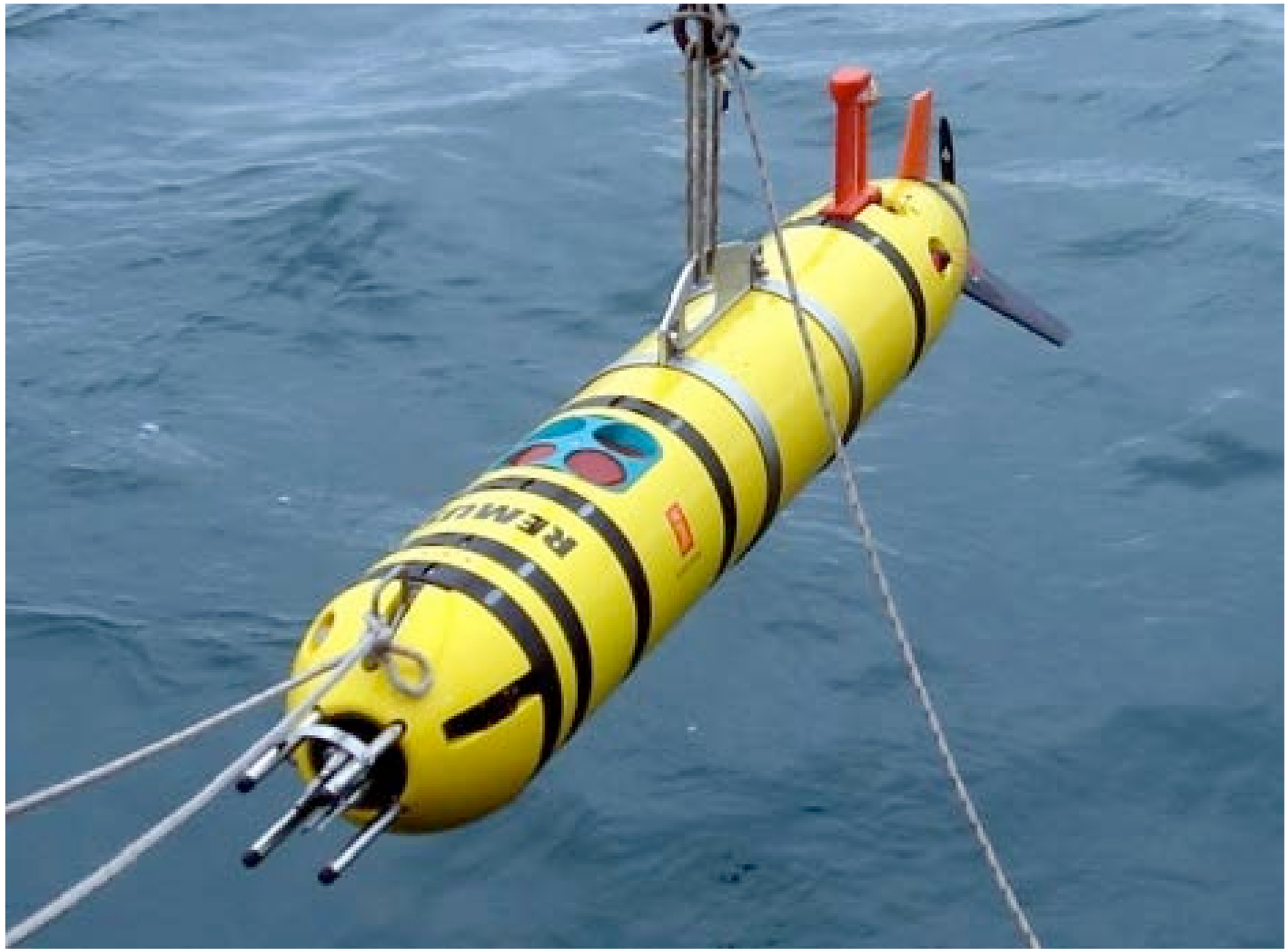
3. AUV Deployment



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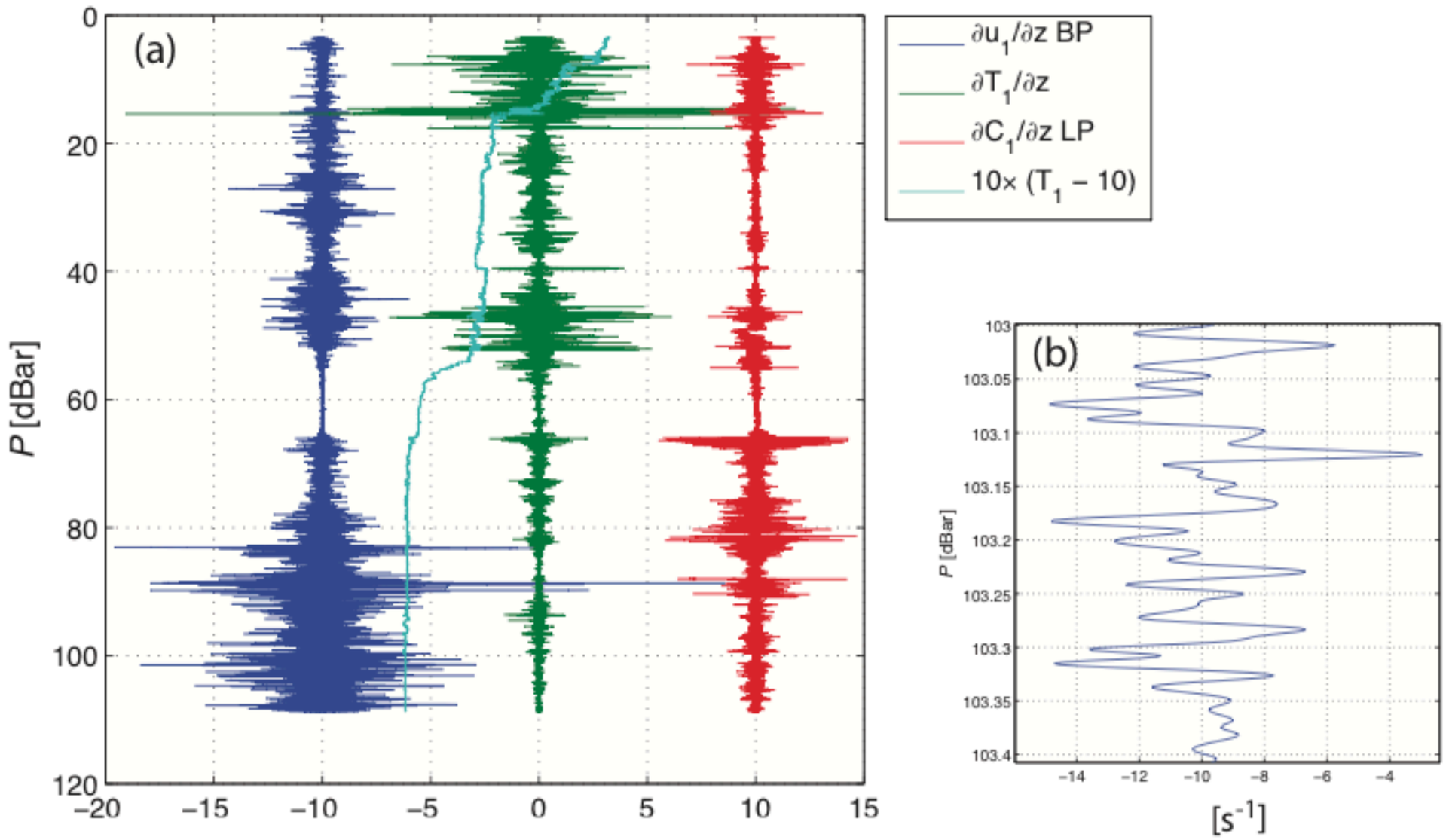
3. Non-acoustic Measurements: Data Examples from Tidal Channels



(a) Profiles of shear (blue) and the vertical gradients of temperature (green) and conductivity (red). *The data are band-pass filtered between 0.4 and 50 Hz for display purposes only. A scaled version of the temperature profile (cyan) is shown for reference. The shear and the conductivity gradients have been shifting left & right by 10 units for clarity.*

(b) A 40cm detail of the shear starting at 103m depth highlights the centimeter-scale variations resolved by the shear probe.

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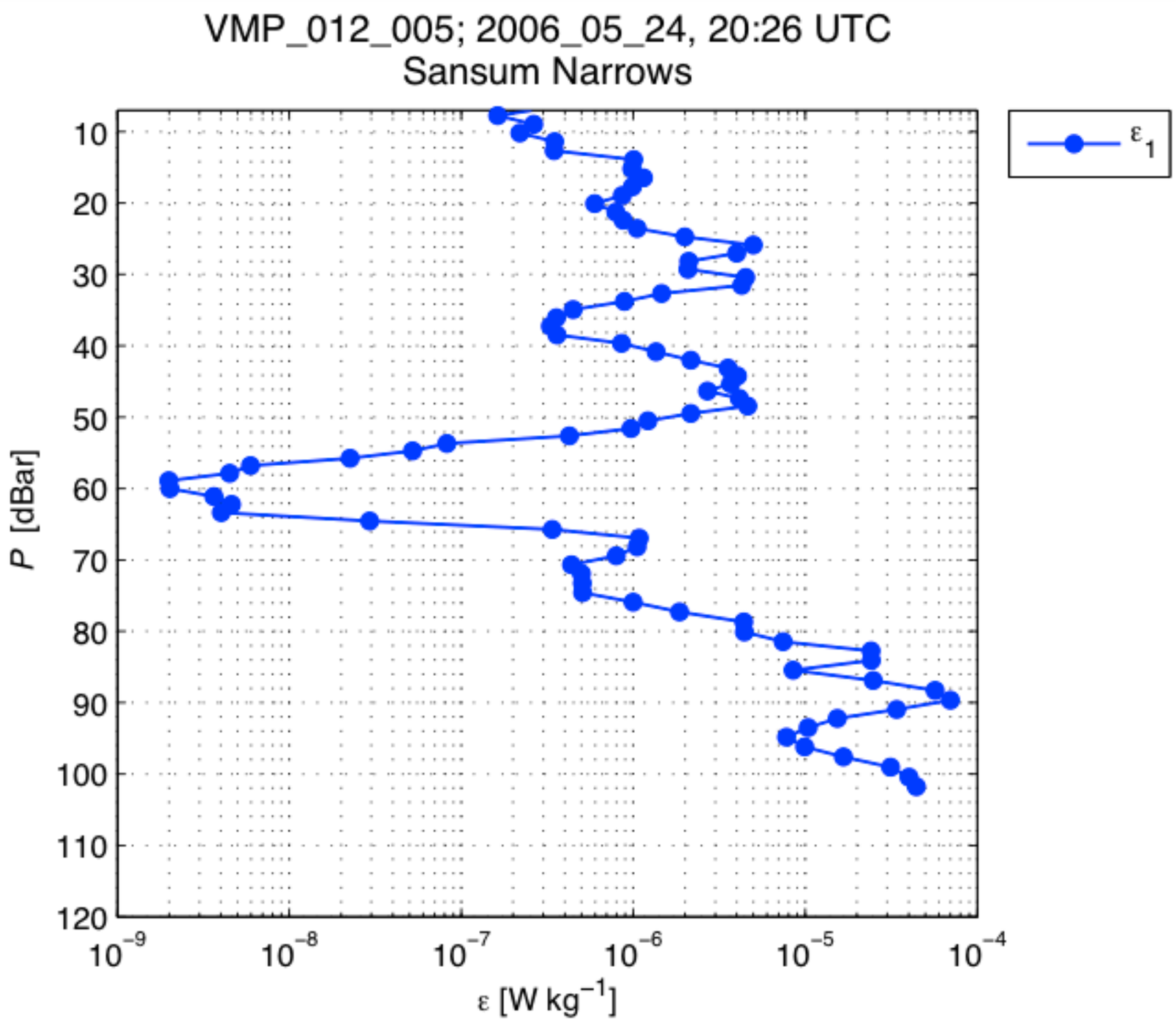
3. Non-acoustic Measurements: Data Examples from Tidal Channels

The vertical profile of the rate of dissipation of Turbulent Kinetic Energy. The estimates are spaced approximately 1.25 m vertically



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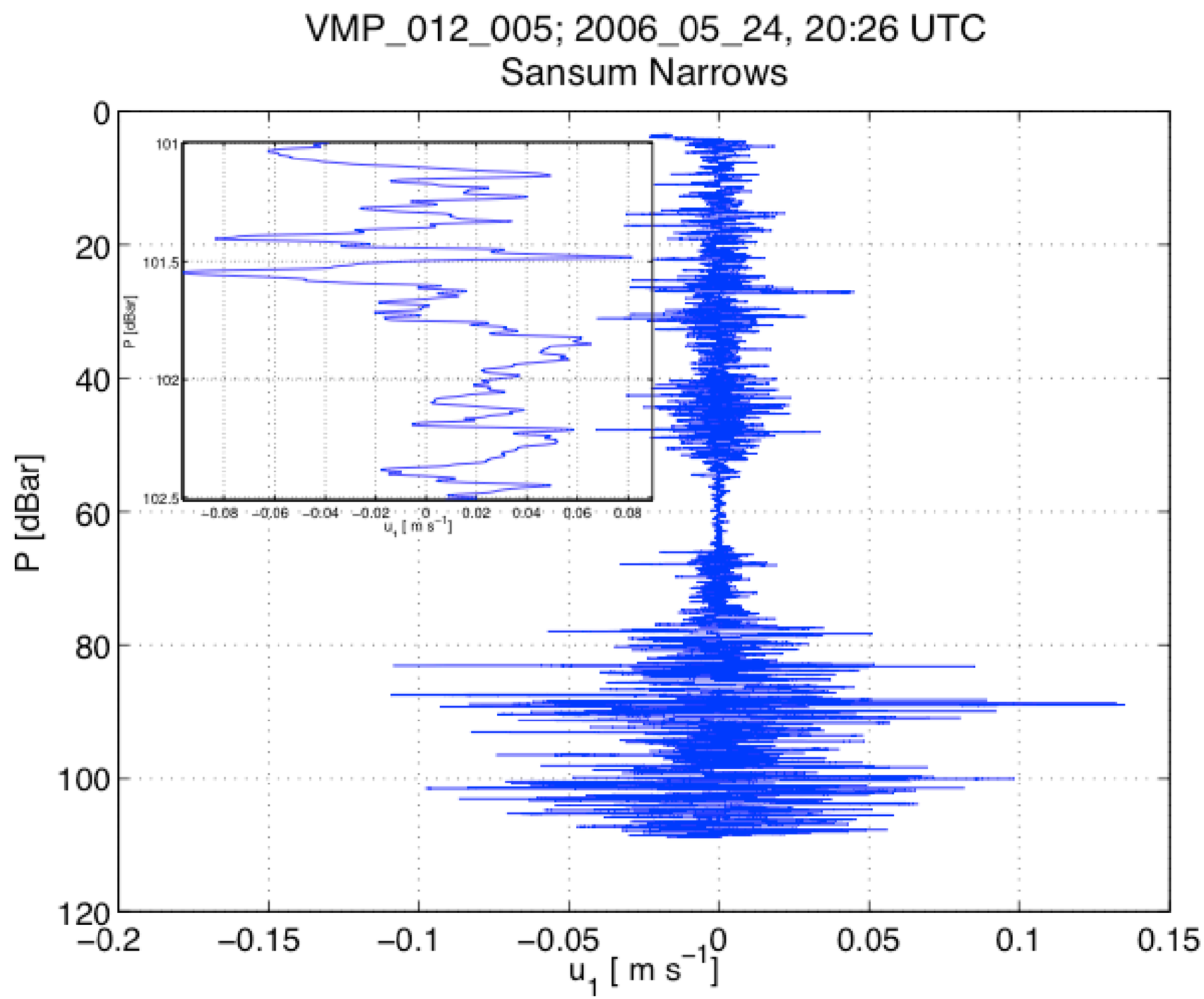
3. Non-acoustic Measurements: Data Examples from Tidal Channels

(a) Profiles of turbulent horizontal velocity computed by numerically integrating the vertical shear.

(inset) A 1.50 m detail of the velocity starting at 101 m depth highlights the centimeter-scale variations resolved by the shear probe.



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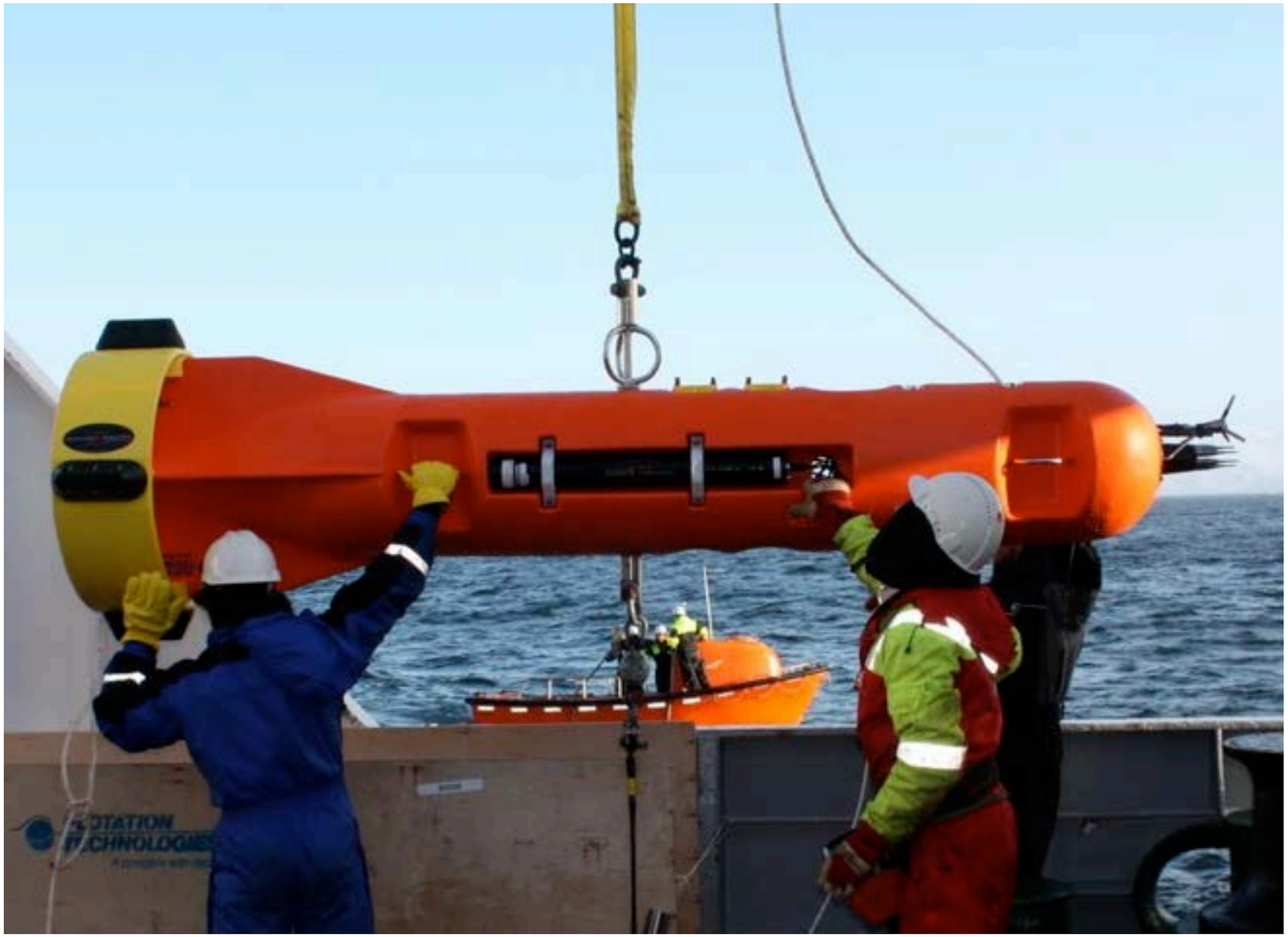
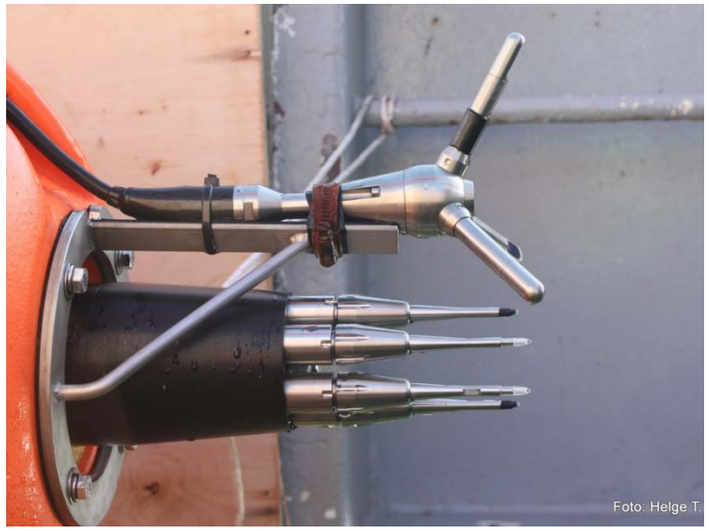
4. Development of a Continuous Monitoring System to Measure Full-Spectrum Turbulence with NREL





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4. Development of a Continuous Monitoring System to Measure Full-Spectrum Turbulence with NREL

- NREL designs conceptual system – subsurface smart mooring to continuously monitoring currents, turbulence & CT in high flow environments

- NREL identified needs for a motion compensation solution to back out the movement of the mooring for improved accuracy of ADV & ADCP

- Meanwhile RSI develops integrated non-acoustic/acoustic smart mooring system (U Bergen) - monitors full-spectrum turbulence at the ocean-atmosphere boundary layer near offshore wind sites.
    - *Includes motion compensation hardware and algorithms*

- NREL & RSI agree to combine expertise and partner in building a new version of the U Bergen system - goal to produce high-accuracy continuous full-spectrum turbulence measurements in the more challenging tidal energy operational environment.
    - *More challenging = variable and high flow rates (4 m/s)*

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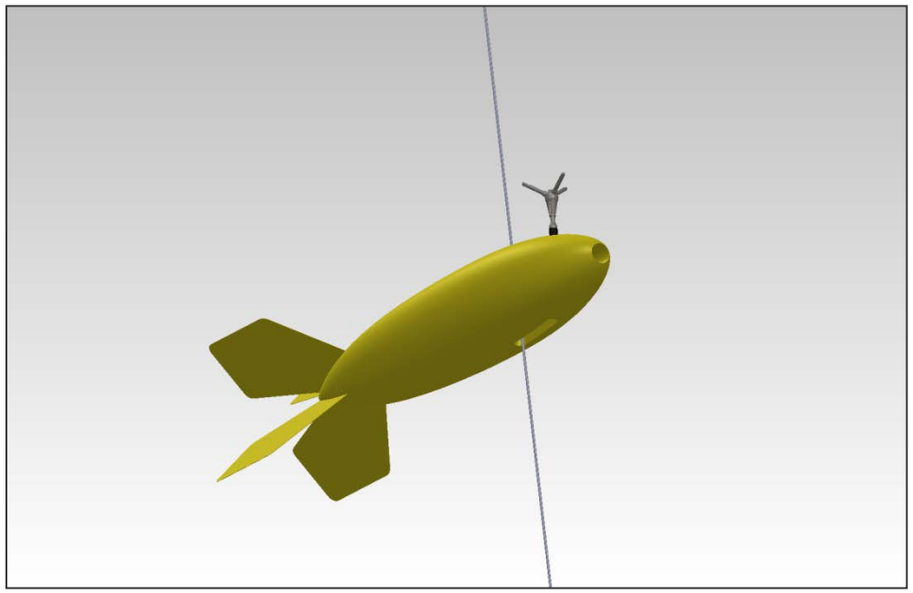
4. Design Considerations for Full-Spectrum Continuous Turbulence Mooring



1. Needs to perform autonomous measurements continuously, accounting for environmental & operational conditions over life cycle of tidal project. (4 m/s flows)
2. Mooring attachment point needs to be placed in the centre of mass and allow for swivel in pitch
3. Body of the mooring to be attached to line via swivel to ensure always pointing nose into flow
4. Mooring to orient itself dynamically into flow. Leave it free to pitch and free to yaw but rigid in roll.

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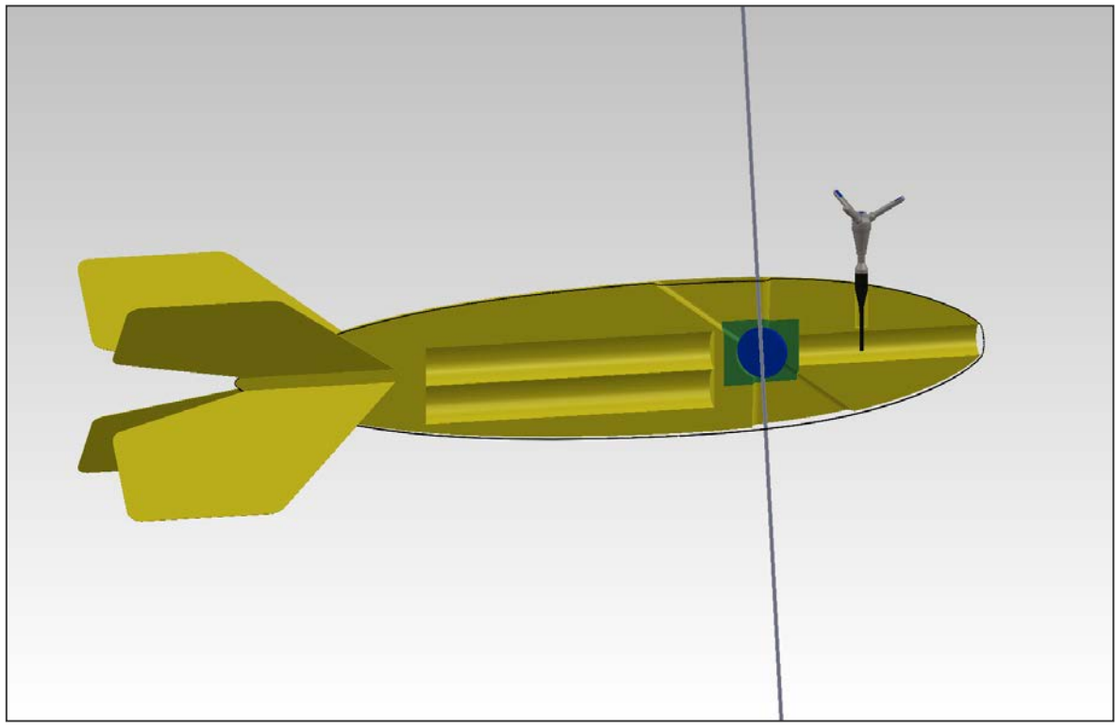
4. Development of Continuous Monitoring System to Measure Full-Spectrum Turbulence

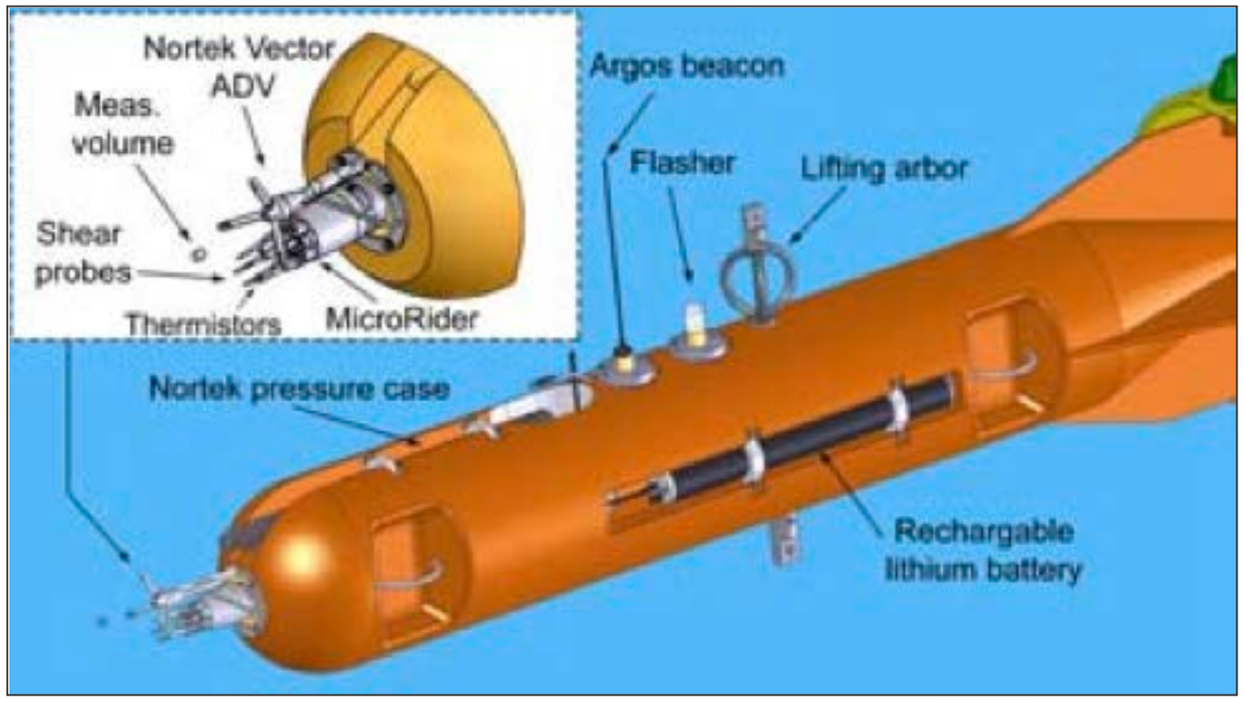
1. Fins used to ensure the system is pointed into the flow. The use of passive & neutral fin design (no active control) minimizes self-induced vibrations by eddies shed by fins.

2. Integrate both acoustic and non-acoustic turbulence measurement instruments. ADV & ADCP.

3. 6-degrees of freedom, motion compensation hardware integrated into MicroRider Instrument.

4. Ability to add additional sensing parameters such as a CTD.





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5. Conclusions

- Range of flow features within turbine environment affect the performance of & loading on turbine
- There is a demand for In-situ turbulence measurements with a spatial resolution of 0.01-1m.
- Full-spectrum turbulence measurements can be obtained using a combination of acoustic (i.e. ADV, ADCP) and non-acoustic methods (i.e. Shear Probe Method) on a variety of platforms (Flexibility)
- RSI has developed an integrated non-acoustic/acoustic smart mooring system capable of monitoring full-spectrum turbulence

Next steps:

- Tests with VMP in Scotland, August 2012
- Final design and build of NREL smart mooring system

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