Quantifying Turbulence for Tidal Power Applications

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Motivation

- Turbine performance
- Turbine fatigue
- Environmental effects
Objectives

- Field measurements from an actual tidal power site
- Evaluation of metrics:
  - Turbulent intensity, \( I = \sigma_v / <v> \)
  - Turbulent dissipation rate, \( \varepsilon \)
  - Coherence, \( <v'_x v'_y> \)
- Best practices:
  - Sampling schemes
  - Rigorous treatment of errors
Instruments and sampling

- Acoustic Doppler Current Profiler (ADCP):
  - volume sampling
  - **beam coordinates**
  - 64 s @ 2 Hz = 128 points, every 30 min

- Acoustic Doppler Velocimeter (ADV):
  - point precision
  - 64 s @ 32 Hz = 2048 pts, every 10 min

5 m tripod deployed in 22 m water depth
Mean velocities

ADCP (Acoustic Doppler Current Profiler)

<\nu> [m/s]

Height [m]

05/07 05/14

0 1 1.5

ADV (Acoustic Doppler Velocimeter)

<\nu> [m/s]

0 0.1 0.2

4.6 m above seabed

NNMREC
Raw velocity fluctuations

Raw ADCP data is noisy!

Corrected velocity std deviation is

$$\sigma_{v,c} = \sqrt{\sigma_v^2 - n^2}$$
Corrected results

- ADV vs ADCP
- \( \langle v \rangle \) [m/s]
- \( \sigma_{v,c} \) [m/s]
- \( I_c \) [%]

Graphs showing time series data from 05/07 to 05/14 with blue and red lines for ADV and ADCP, respectively. The graph for \( \sigma_{v,c} \) shows variability over time. The graph for \( I_c \) indicates a range from 0 to 50% with a label showing \( I \approx 10\% \).
Stationarity (stable mean)

Short, but not too short, records (“bursts”) are necessary for robust statistics…

...see Polagye et al (in prep)
Dissipation rate

- Frequency spectra from ADV
- Inertial sub-range shows cascade of energy to small scales,
- Slope is rate of energy loss

06–May–2010 01:30

- Inertial sub-range
  - Horizontal noise
  - Vertical noise

$S \text{ [m}^2\text{/s}^2\text{/Hz]}$

$f \text{ [Hz]}$
Dissipation rate

- Spatial structure from ADCP
- Inertial sub-range shows cascade of energy to small scales,
- Slope is rate of energy loss

06–May–2010 01:30:00, z = 4.71 m, v = 0.8 m/s

Inertial sub-range noise (along beam)
Combined results
Vertical dependence
Coherent Turbulent Kinetic Energy (eddies)
Conclusions

- Turbulent intensity $\approx 10\%$

- Doppler measurement error ("noise") can heavily bias observed velocity variance and **must be removed**.

- Dissipation rate has more dynamic range than turbulent intensity, but operational significance unknown.

- Coherent TKE shows time-space scales of eddies.
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Tripod motion?

04–May–2010

Acceleration [g]

v [m/s]

12:00 15:00 18:00

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8