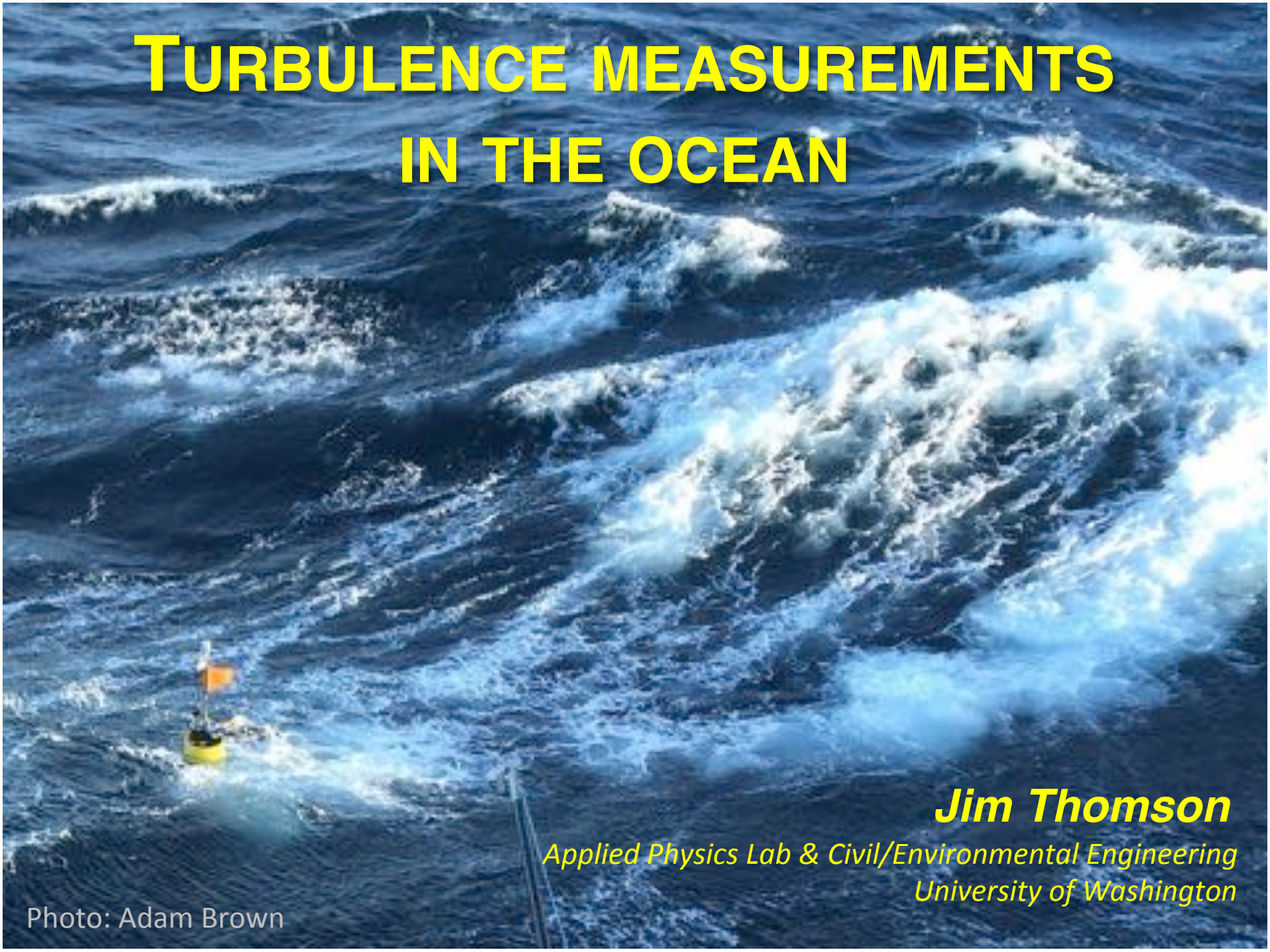
TURBULENCE MEASUREMENTS IN THE OCEAN

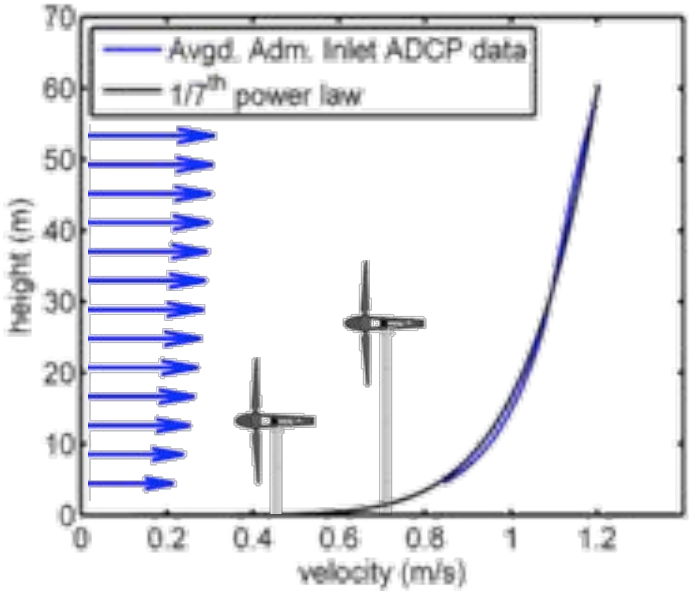


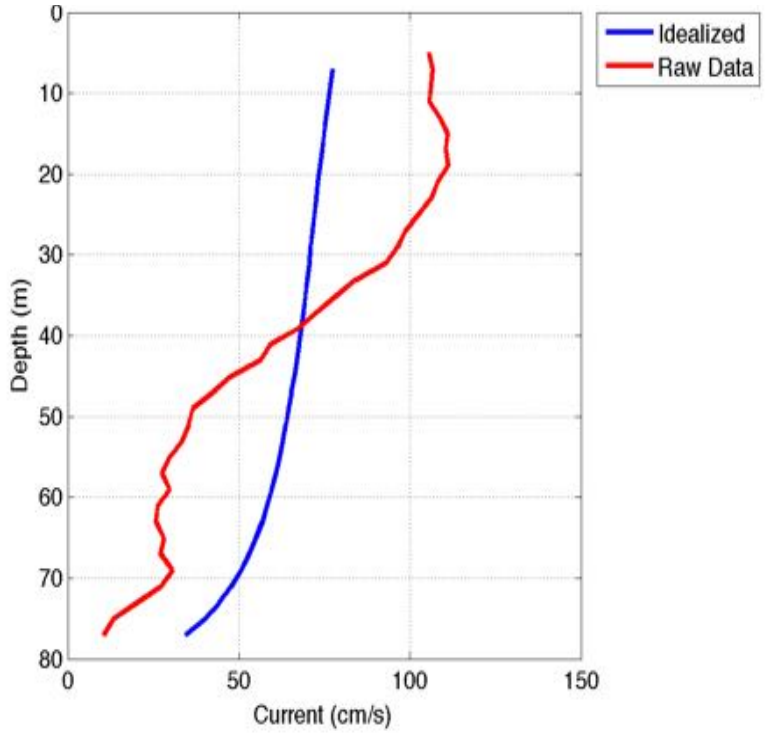
Jim Thomson

Applied Physics Lab & Civil/Environmental Engineering
University of Washington

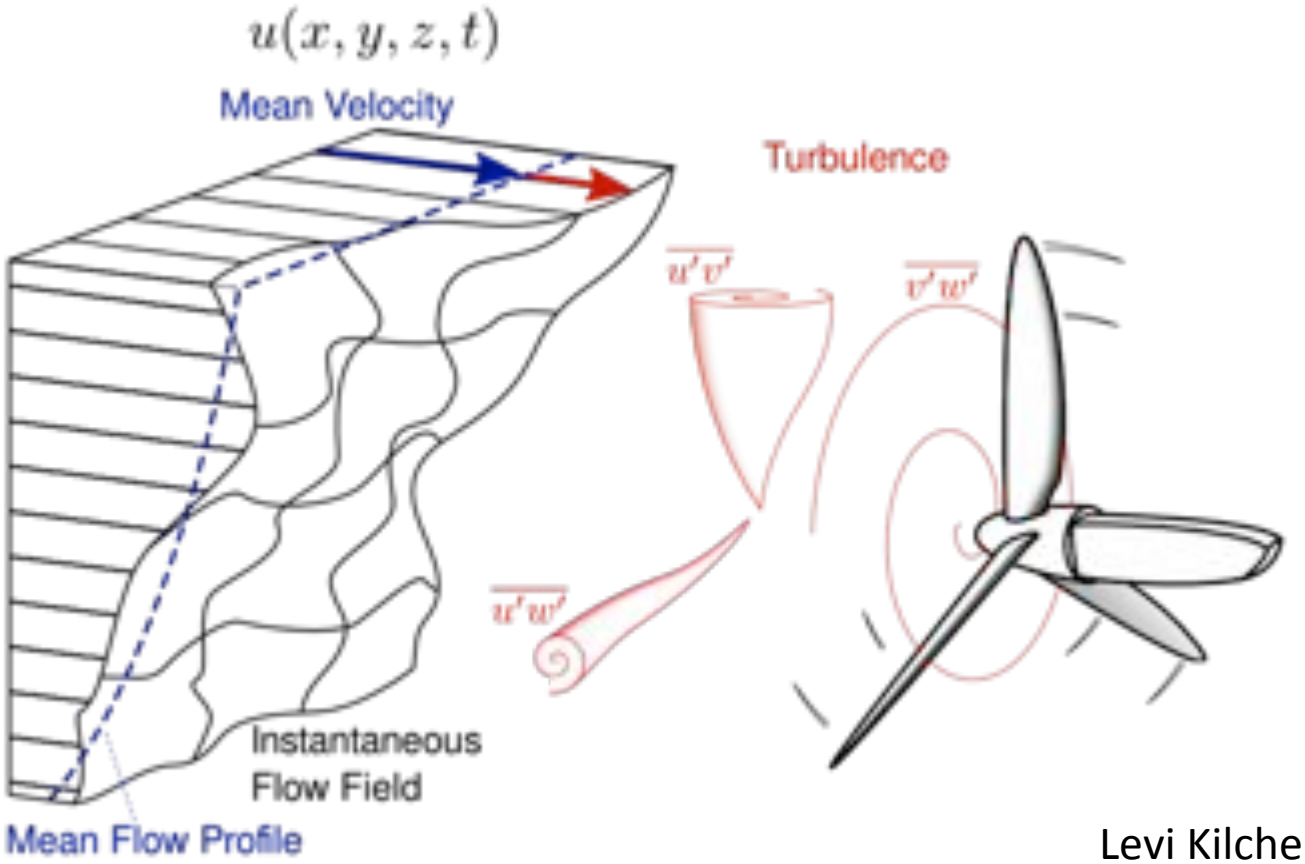
Photo: Adam Brown

The cartoon is wrong





The reality



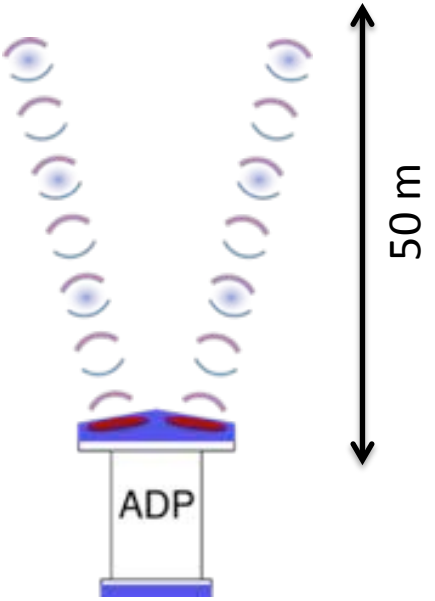
Levi Kilcher (NREL)

What do we want to know?

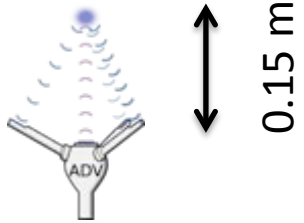
- Turbulence intensity, $I_u = \frac{\sigma_u}{\langle u \rangle}$
- Turbulence spectra, *TKE(f)*
- Coherence and instantaneous shear
- Extreme values
- Anisotropy

What can we measure?

- Acoustic Doppler Current Profilers (ADCP)
  - Poor precision: temporal noise & spatial aliasing
  - Deployment conveniences (profile from bottom)

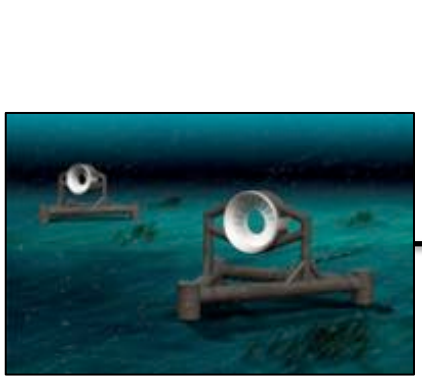


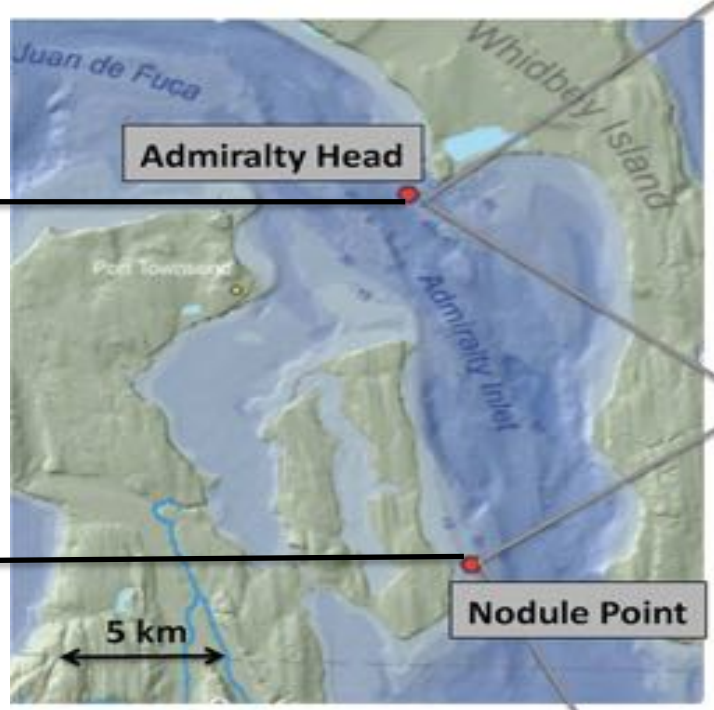
- Acoustic Doppler Velocimeters (ADVs)
  - Excellent precision (coherent pulses)
  - Deployment challenges (must position at hub height)

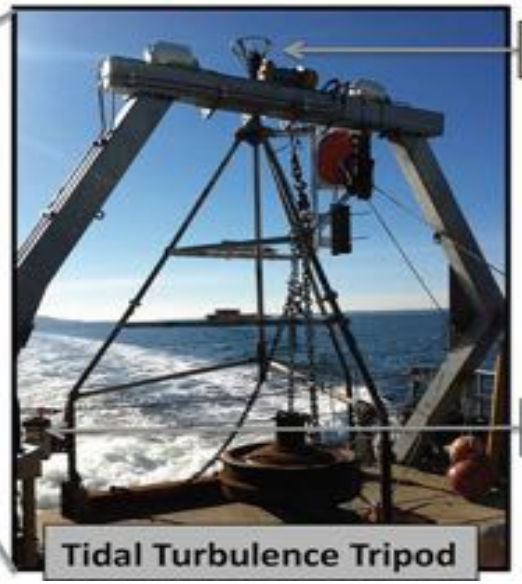


Admiralty Inlet tripod measurements

Thomson et al, JOE, 2012







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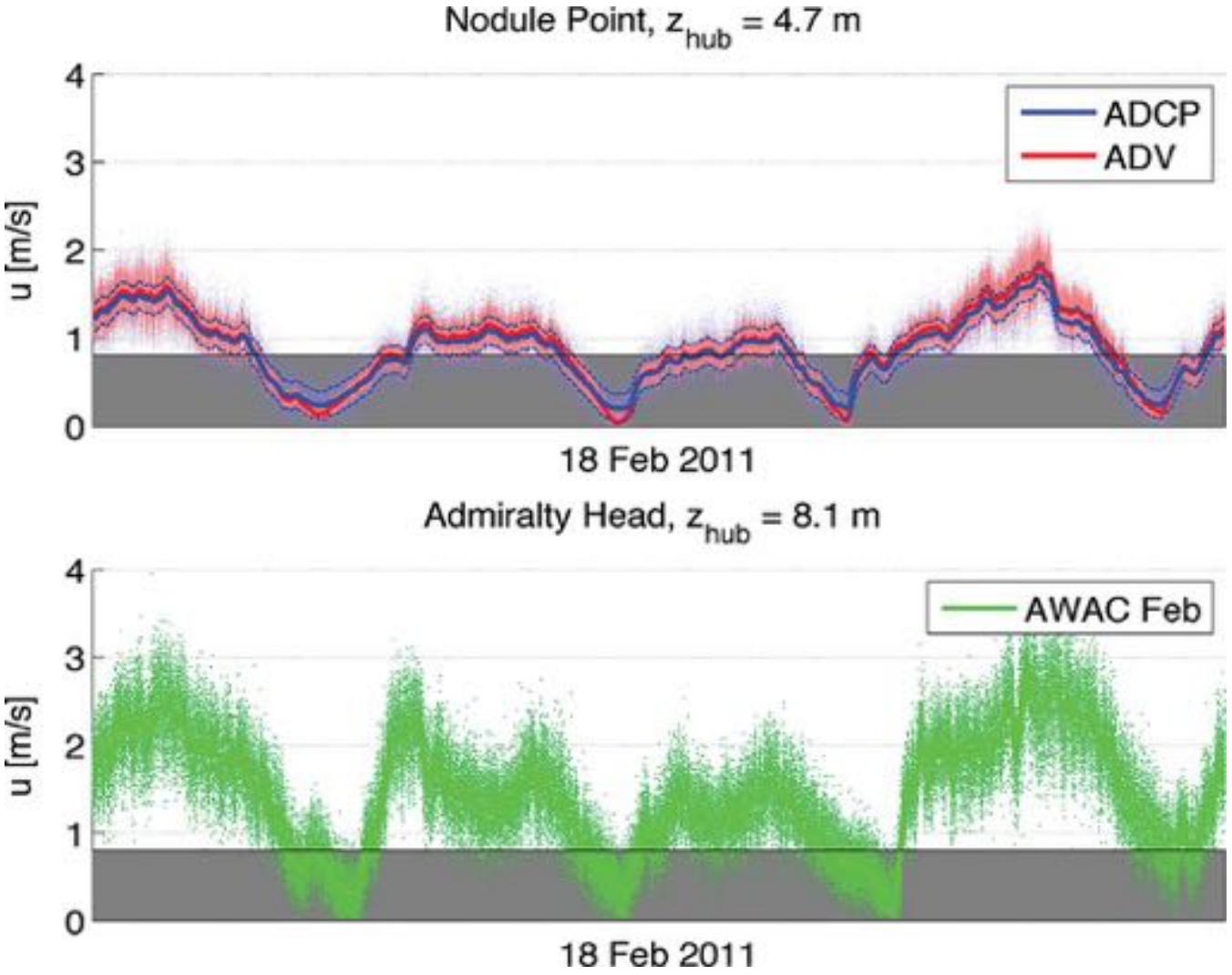
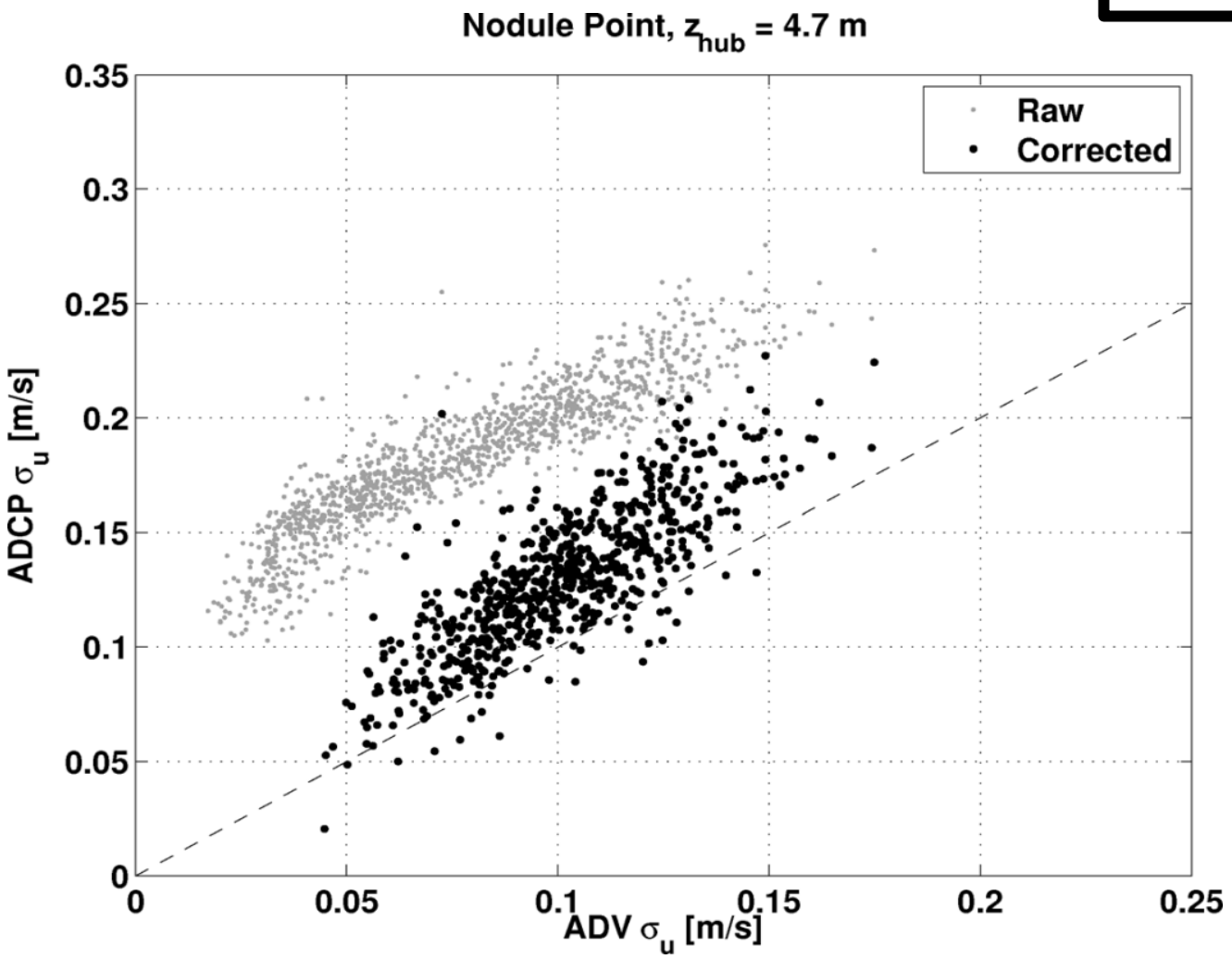
Tripod time series



ADCP vs ADV

$$I_u = \frac{\sigma_u}{\langle u \rangle} = \frac{\sqrt{\langle u'^2 \rangle - n^2}}{\bar{u}}$$



Noise can be half of the signal from an ADCP!

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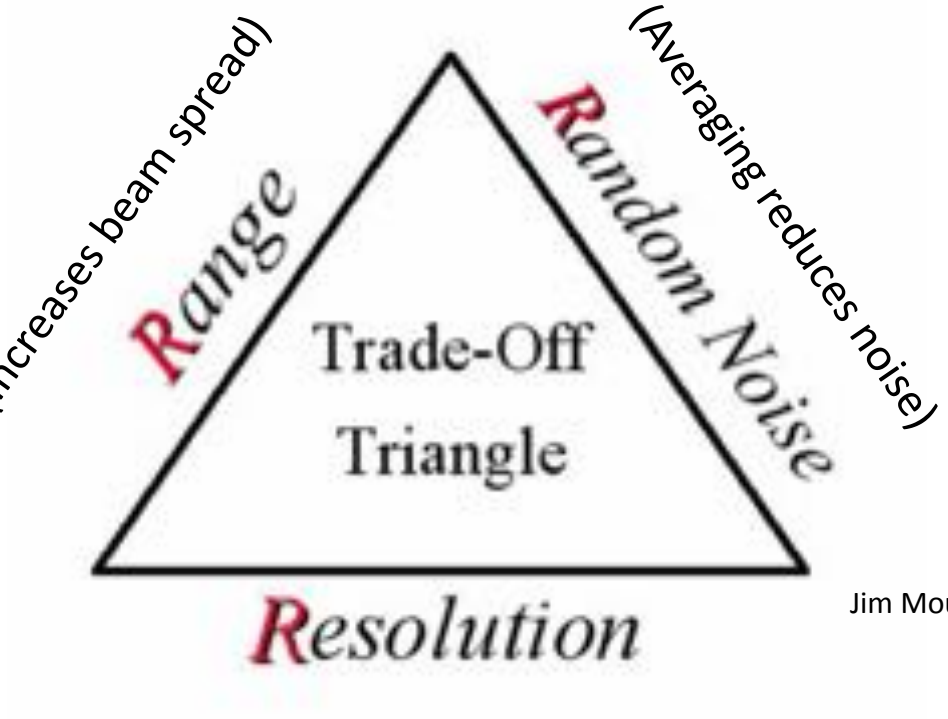
Tradeoffs in configuring Doppler profilers



Jim Moum (OSU)

(Smaller bins have more noise)

Recipe: sample as fast as possible at f_s and set the bins size to be no smaller than the advective length scale $L = U/f_s$, then check if noise variance will be greater than true variance.
Make no three-dimensional inferences at scales smaller than the beam spread.

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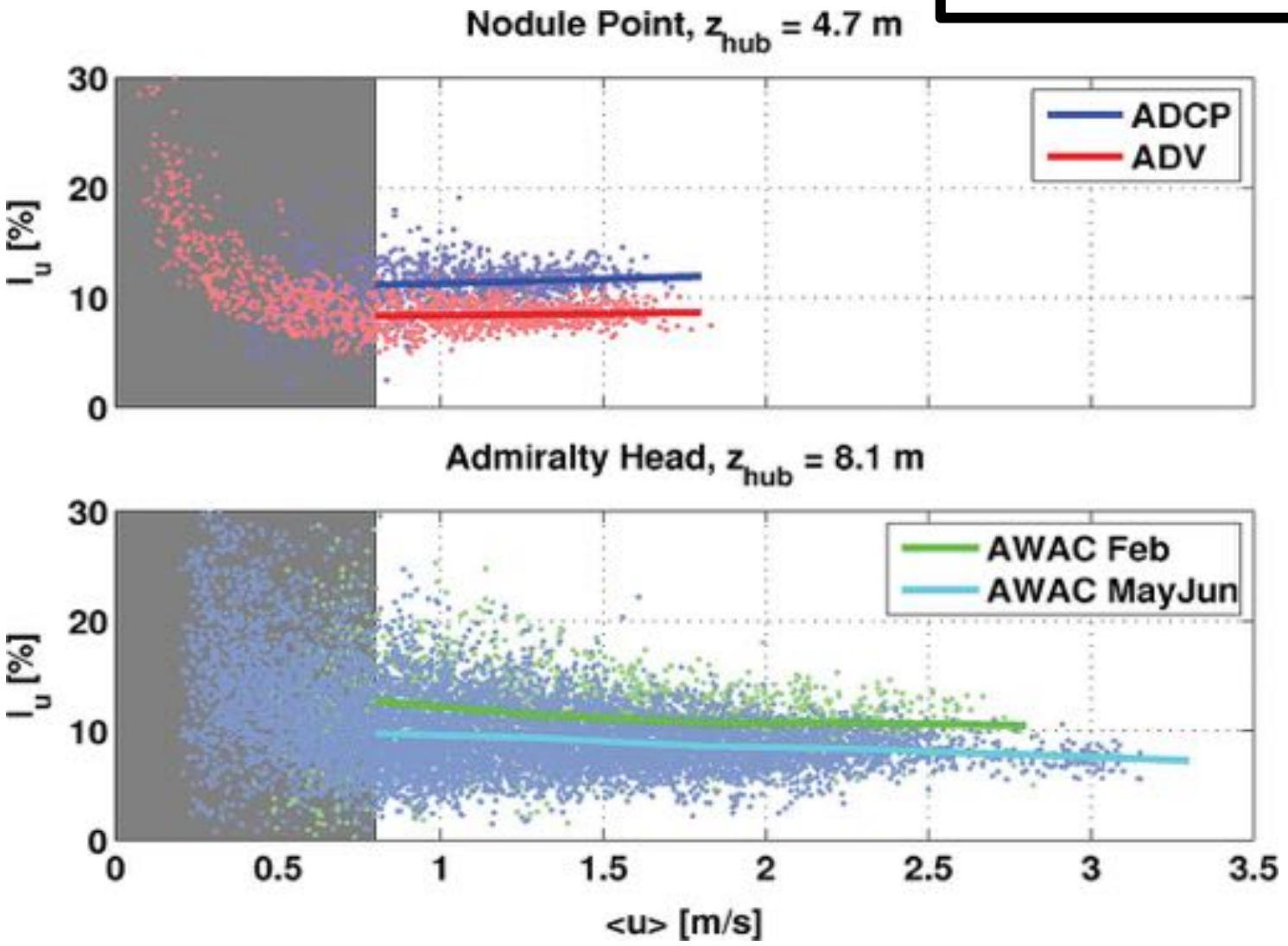
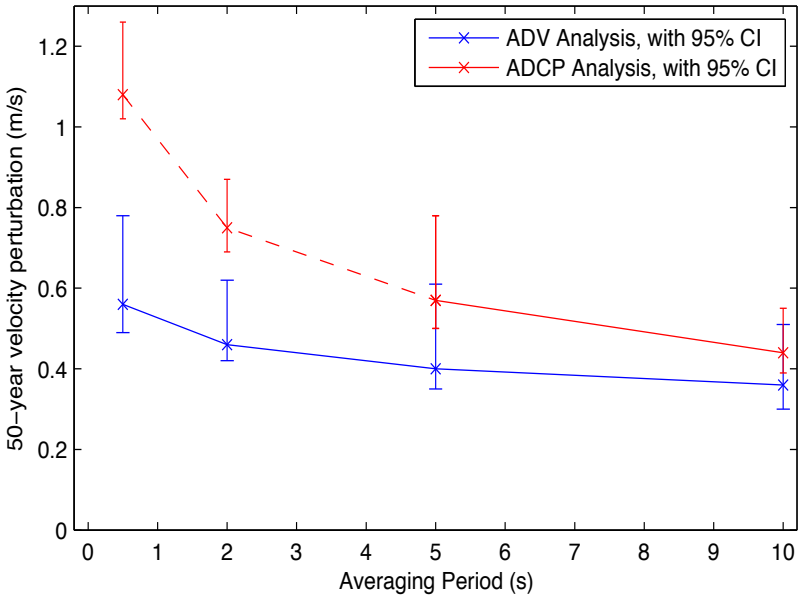
Turbulence intensity

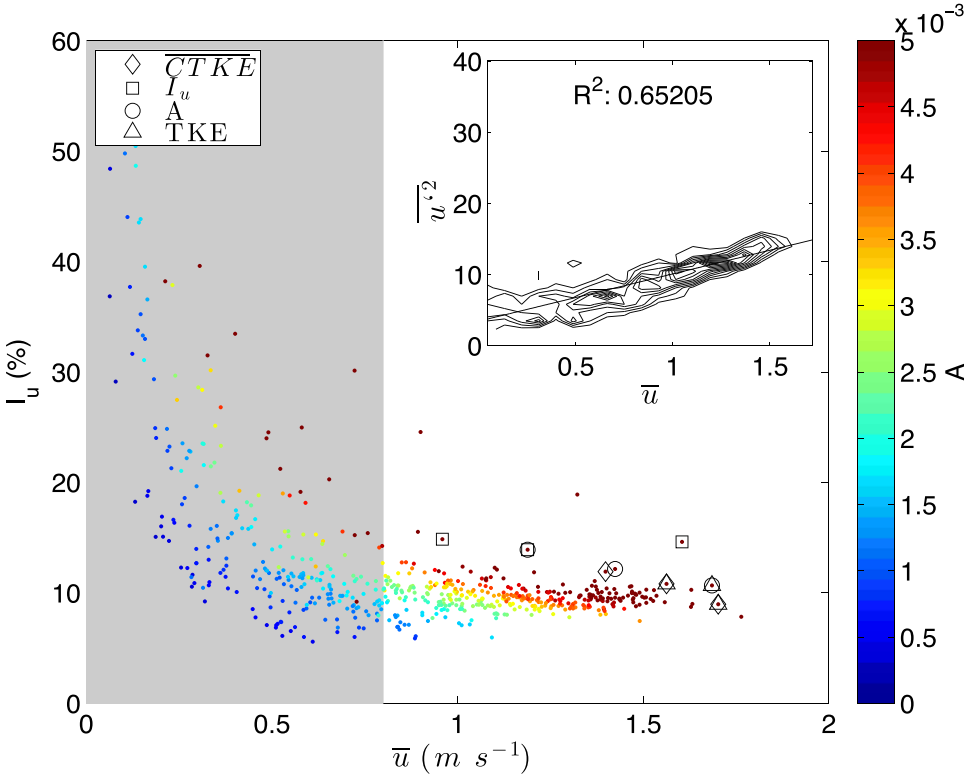
$$I_u = \frac{\sigma_u}{\langle u \rangle} = \frac{\sqrt{\langle u'^2 \rangle - n^2}}{\bar{u}}$$



Extreme values and anisotropy



Harding et al, EWTEC 2011



McCaffery et al, Renew. Energy, 2015

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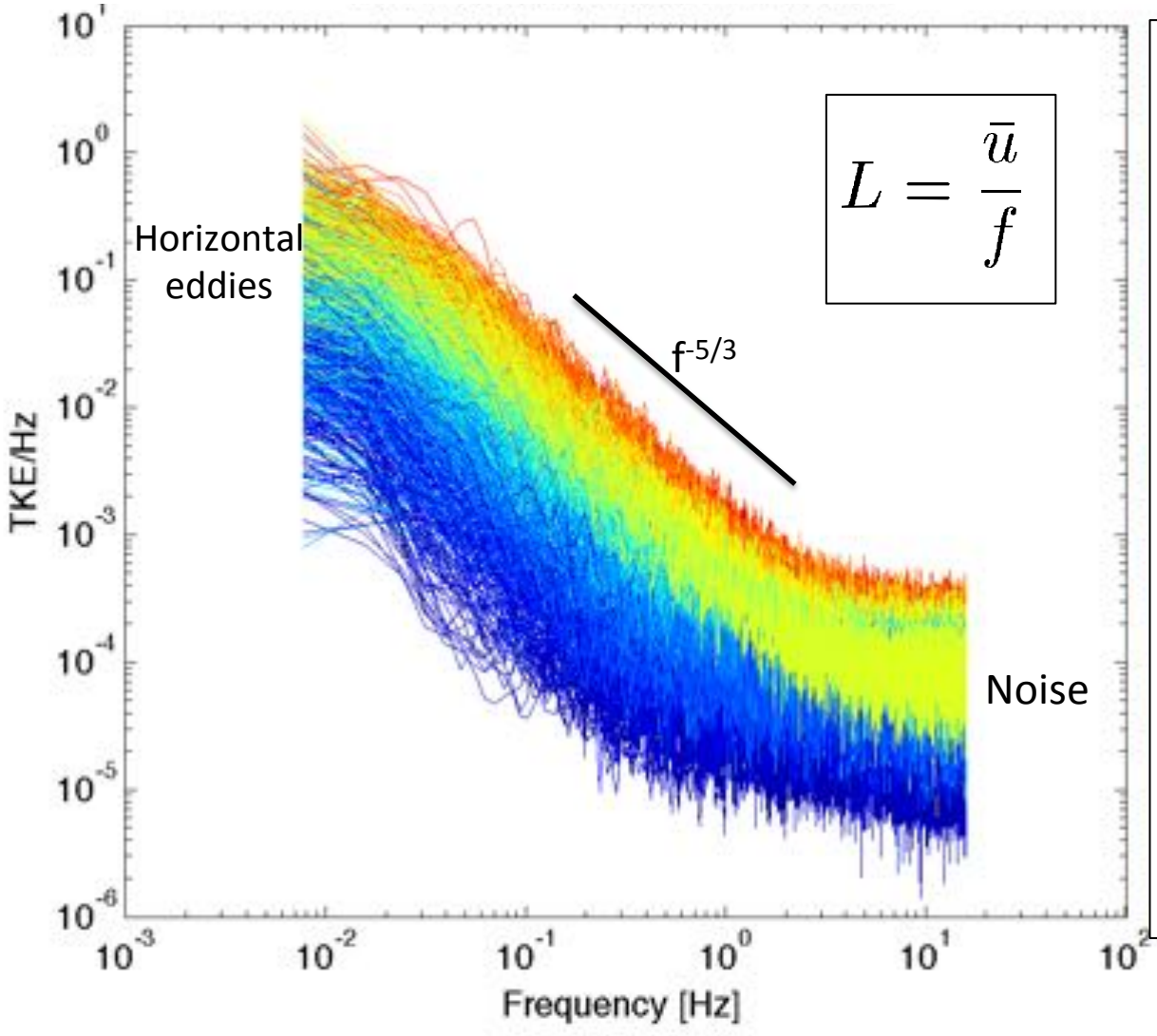
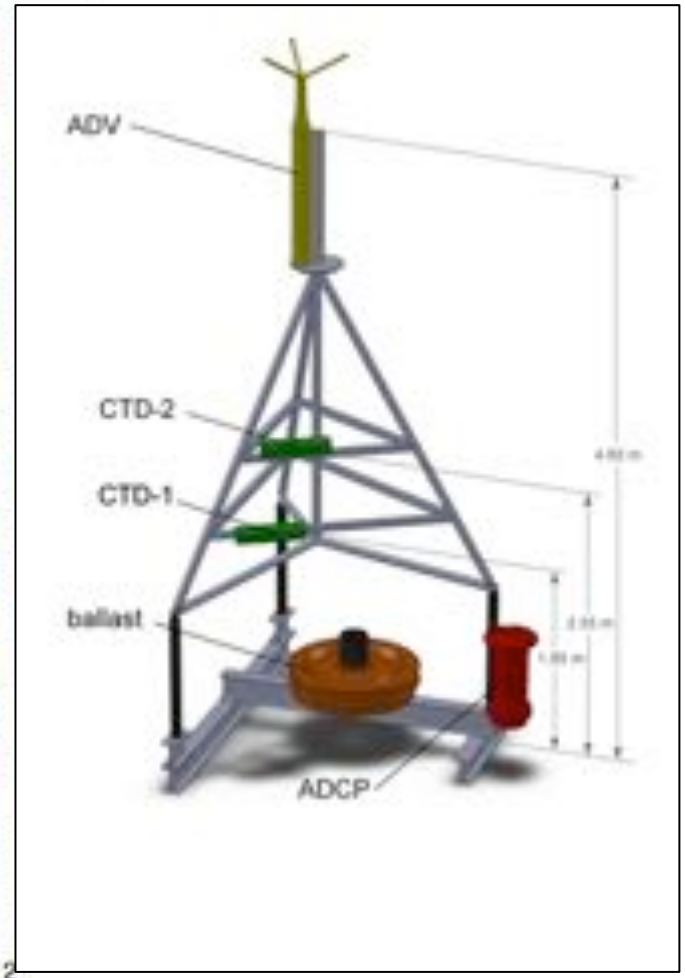
Turbulence spectra

Tripod makes this "easy"





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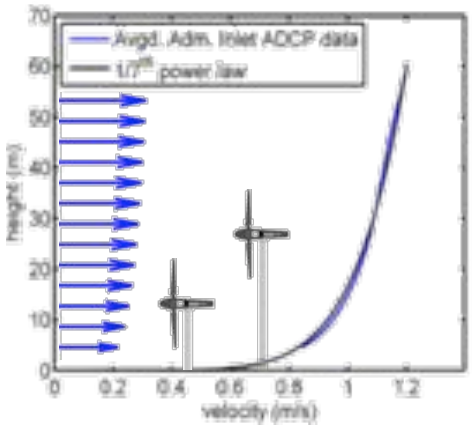
Tidal Turbulence Mooring

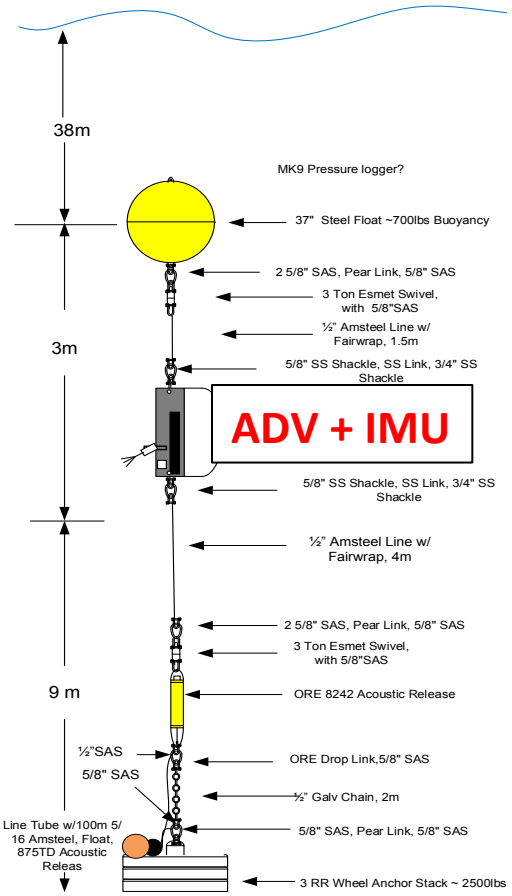


Problem: ADCPs measurements are poor (b/c noise and beam spread)

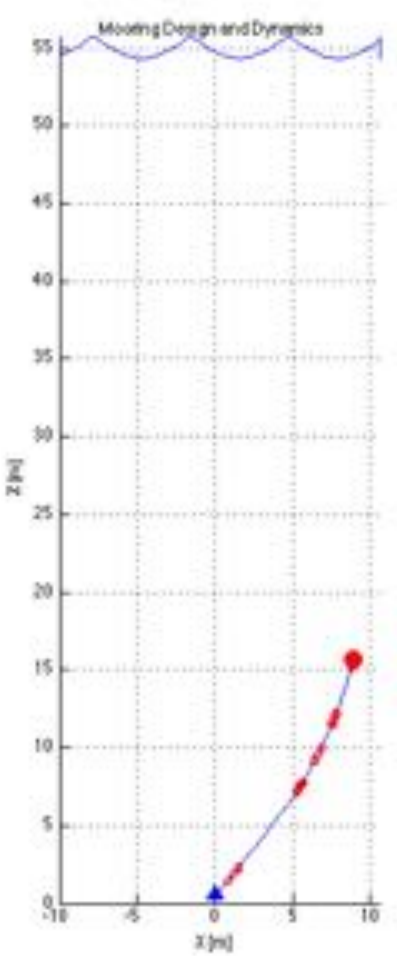
Solution: moor ADVs far above seabed

Challenges:

- Potential for mooring 'blow down'
- Potential for anchor drag
- Potential for motion contamination



Surface



Seabed

Thomson et al, METS 2013, Kilcher et al METS 2014, Thomson et al, ICOE 2014

Mooring deployments

June & Sept 2012

Feb 2013

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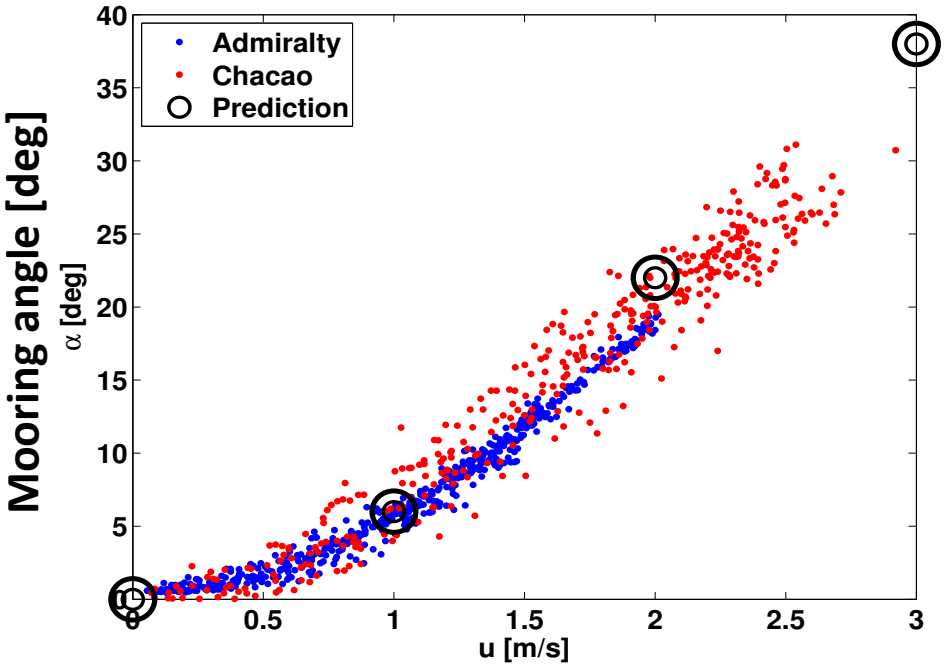
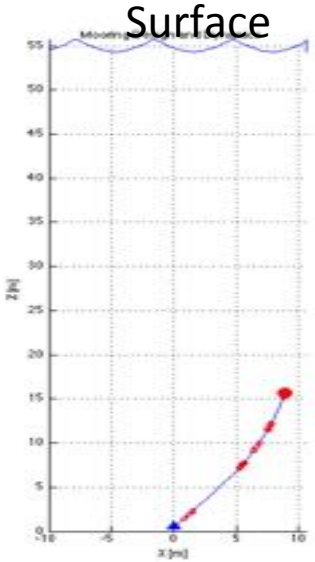
Mooring performance

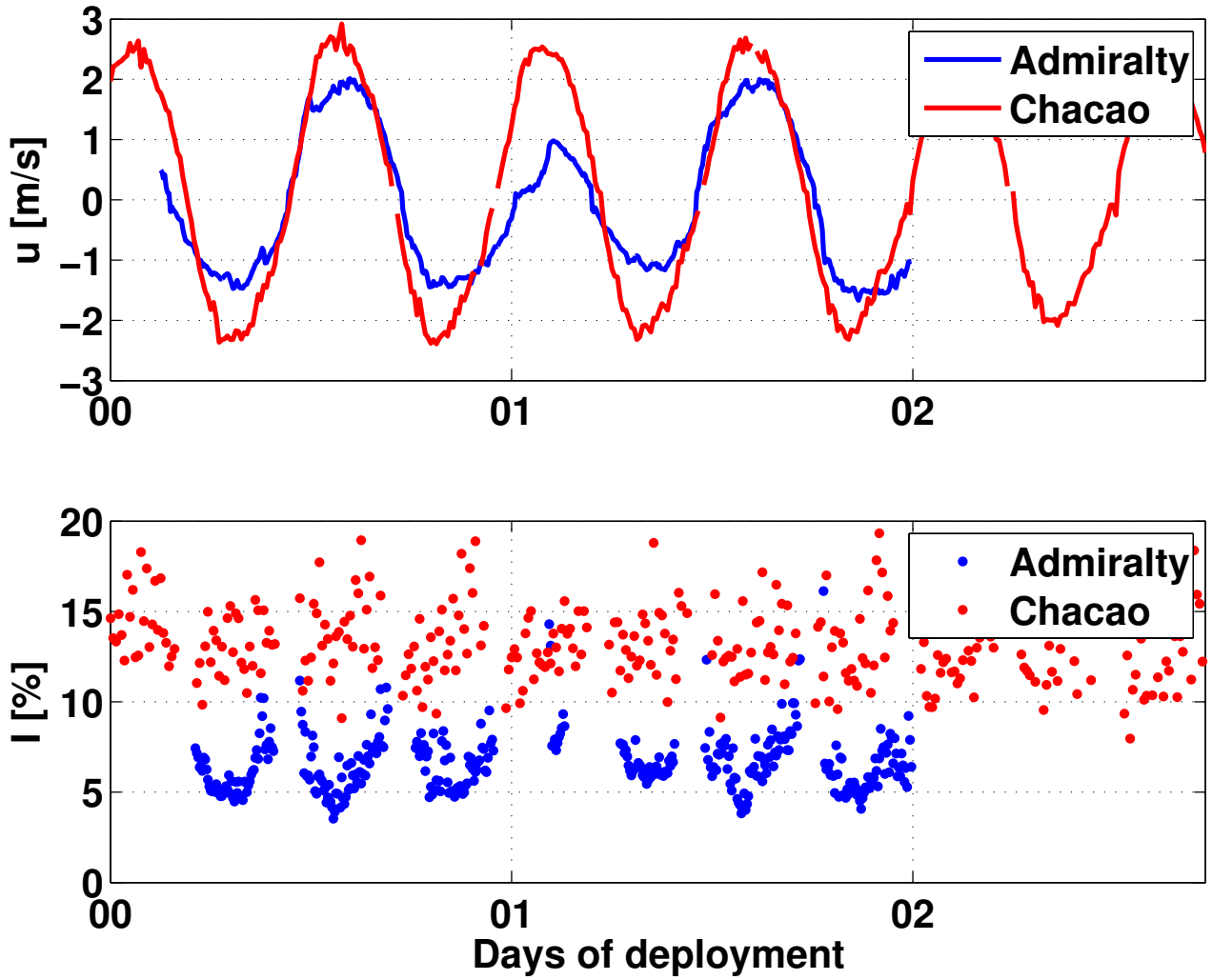




Tidal current [m/s]

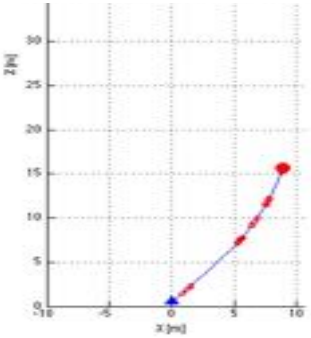
Northwest National Marine Renewable Energy Center

Mooring time series



Motion correction and TKE spect

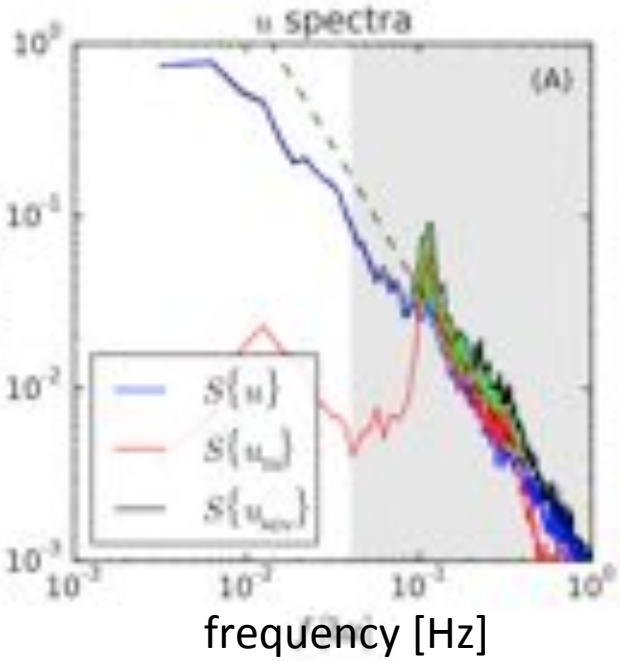
$$\vec{u} = \vec{u}_{ADV} - \vec{u}_m$$



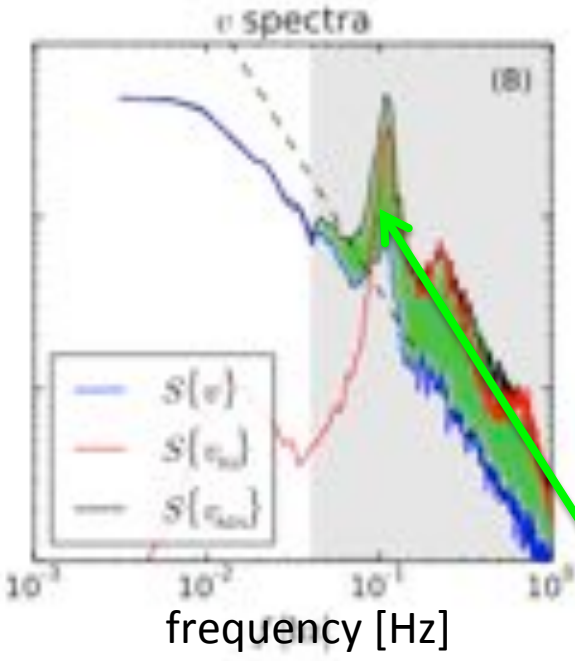
Seabed

Components:

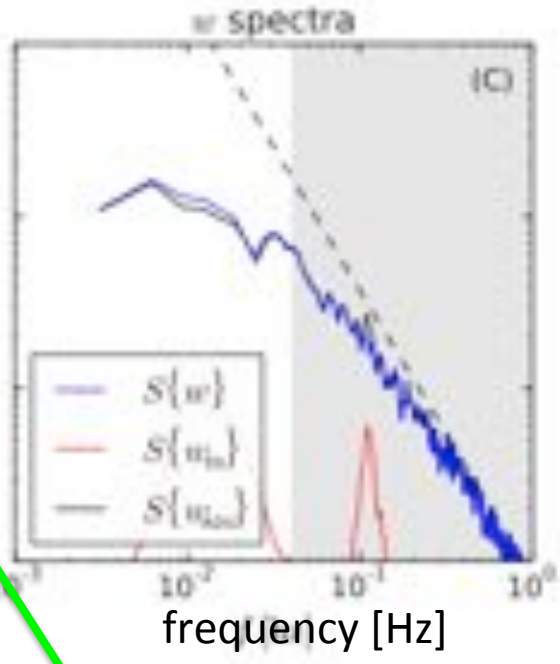
streamwise (u)



cross-stream (v)



vertical (w)



Cross-stream has fatal motion contamination, other components are successfully recovered

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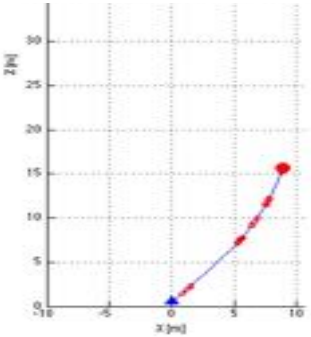
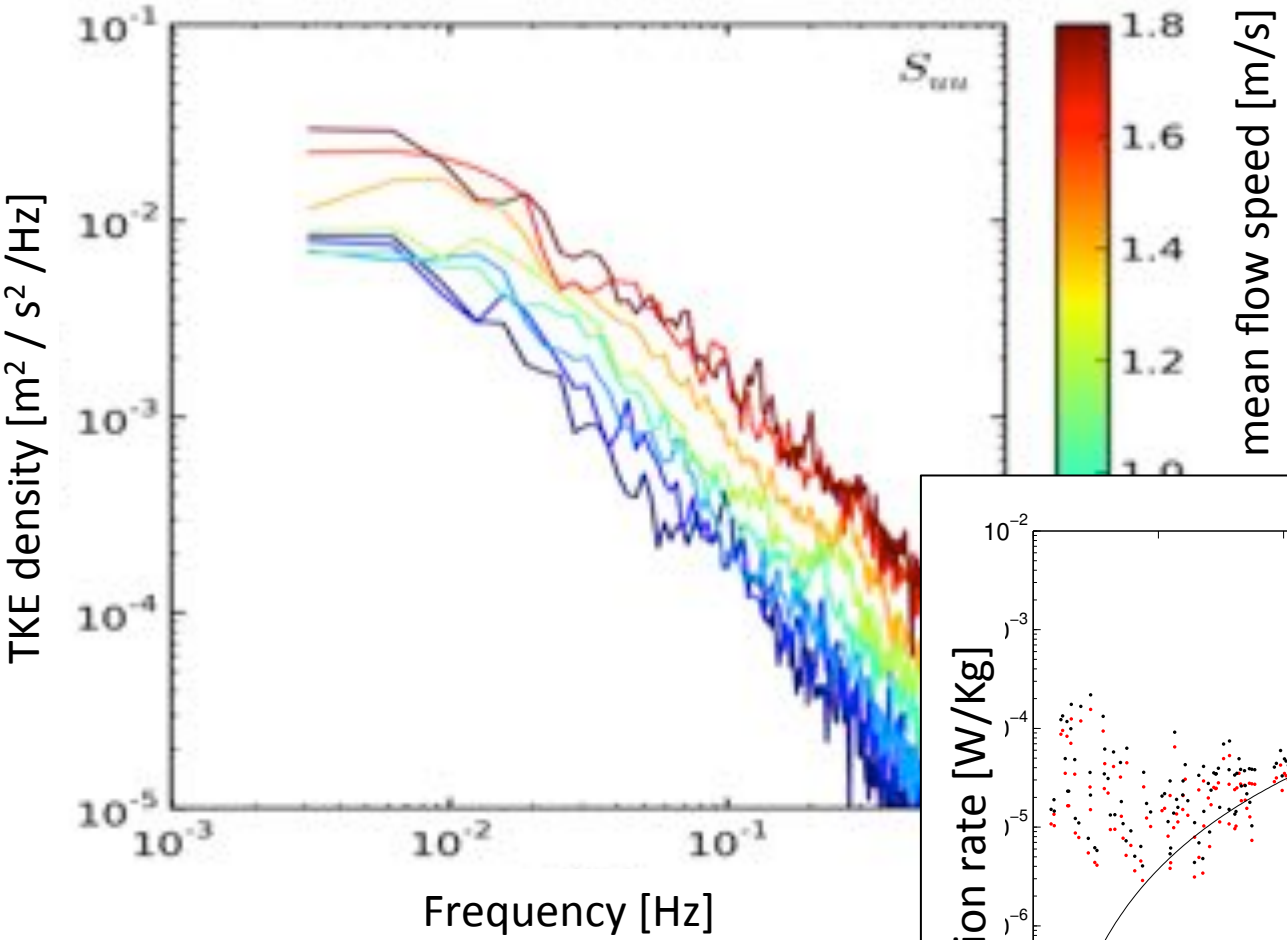
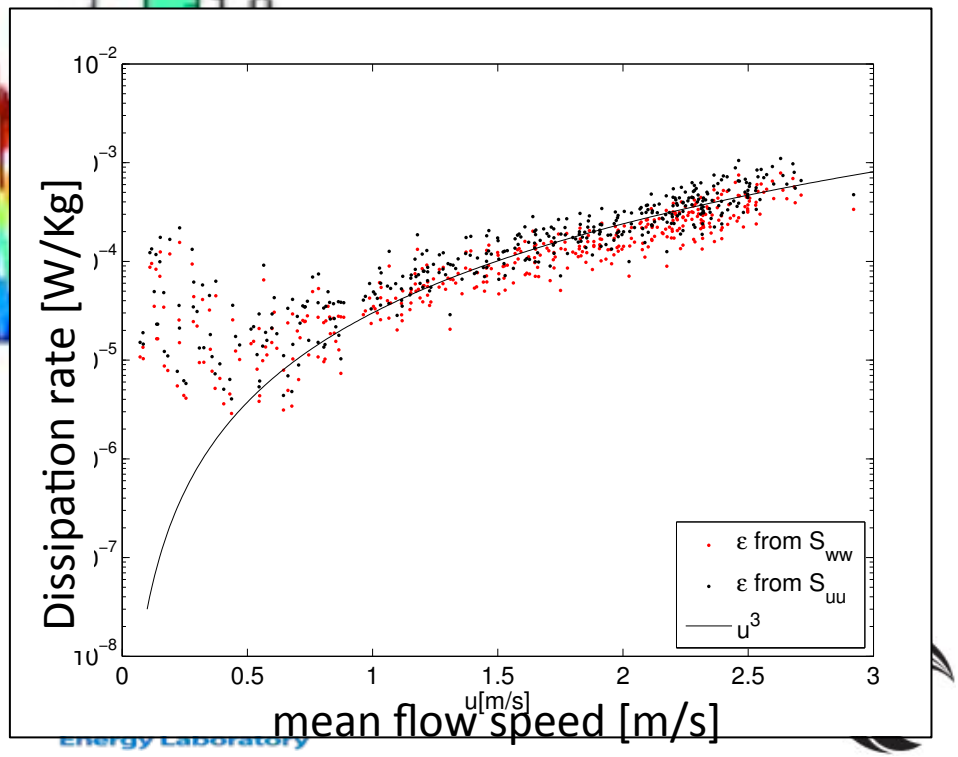
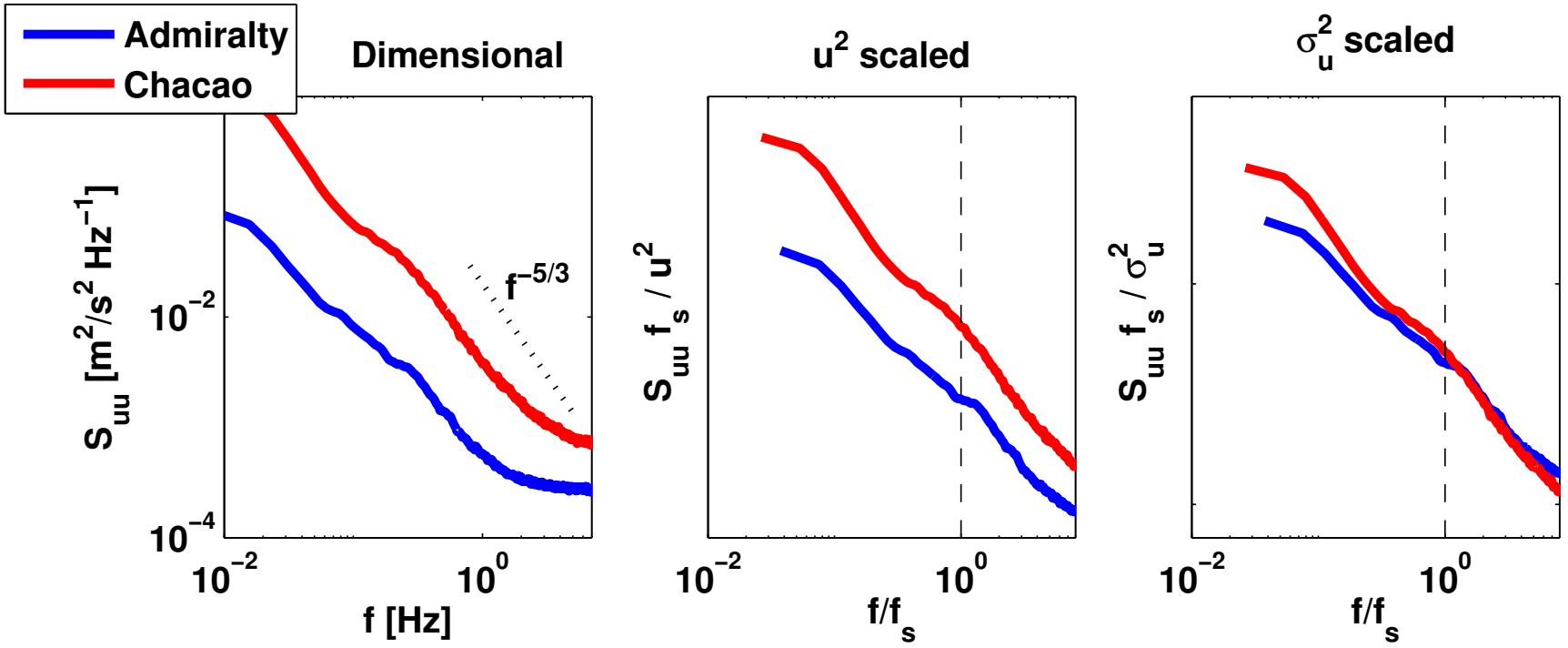
Scaled TKE spectra





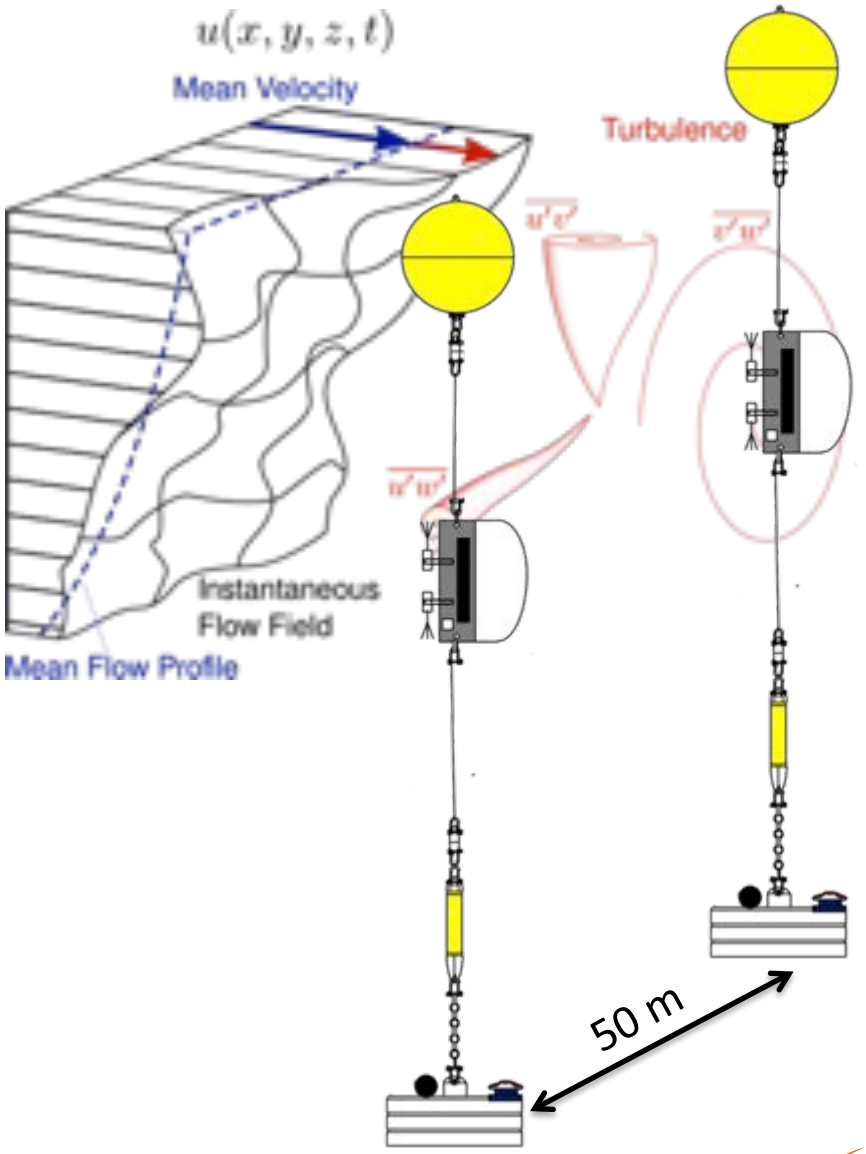


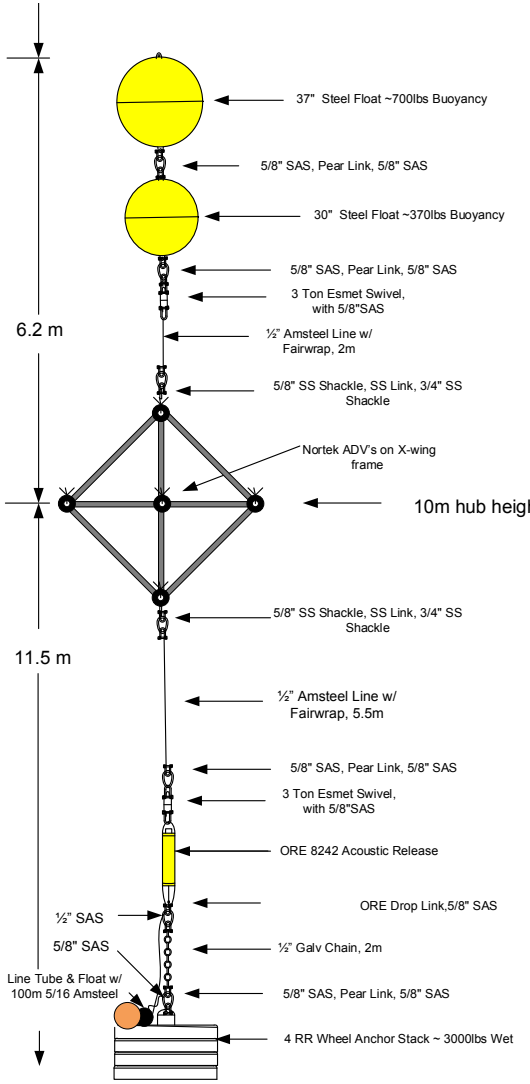
Normalized spectra



- Chacao is more turbulent, even scaled by energy.
- Difference is greatest at large scales (low frequencies),
- Turbulent cascade is similar, if scaled by total TKE (which is set a low frequencies)

Coherence measurements





"X-wing"

Note: Not To Scale

University of Washington Applied Physics Laboratory 1013 NE 40th St. Seattle, WA 98105	
X-Wing ADV Mooring	
Admiralty Inlet, WA	
Joe Talbert	Water Depth: 55M
Deploy:6/17/14	5/8/14

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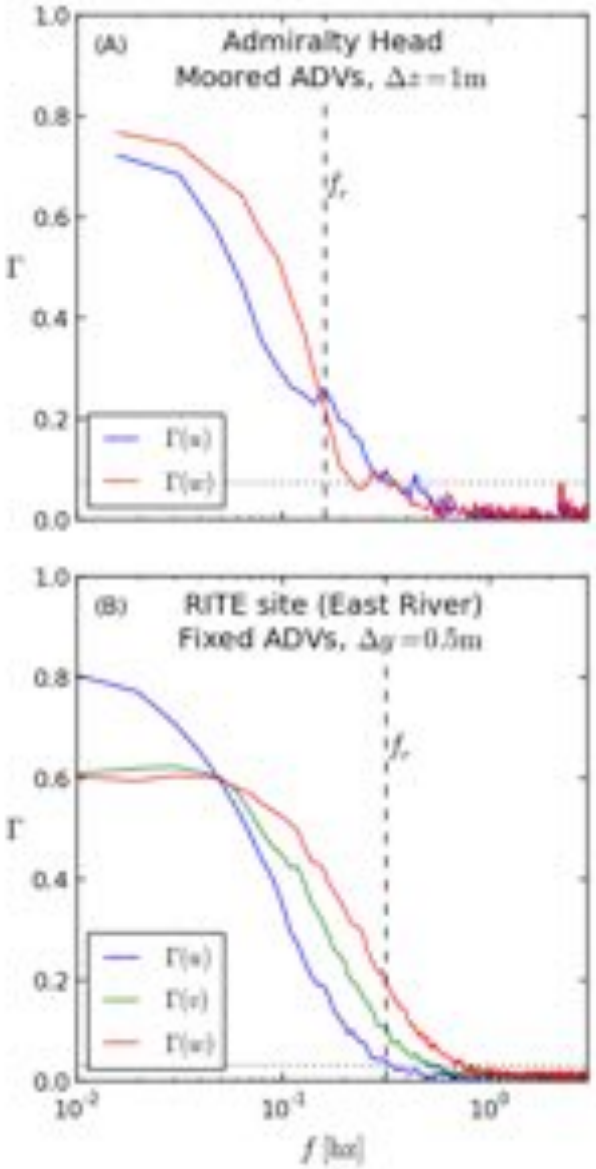
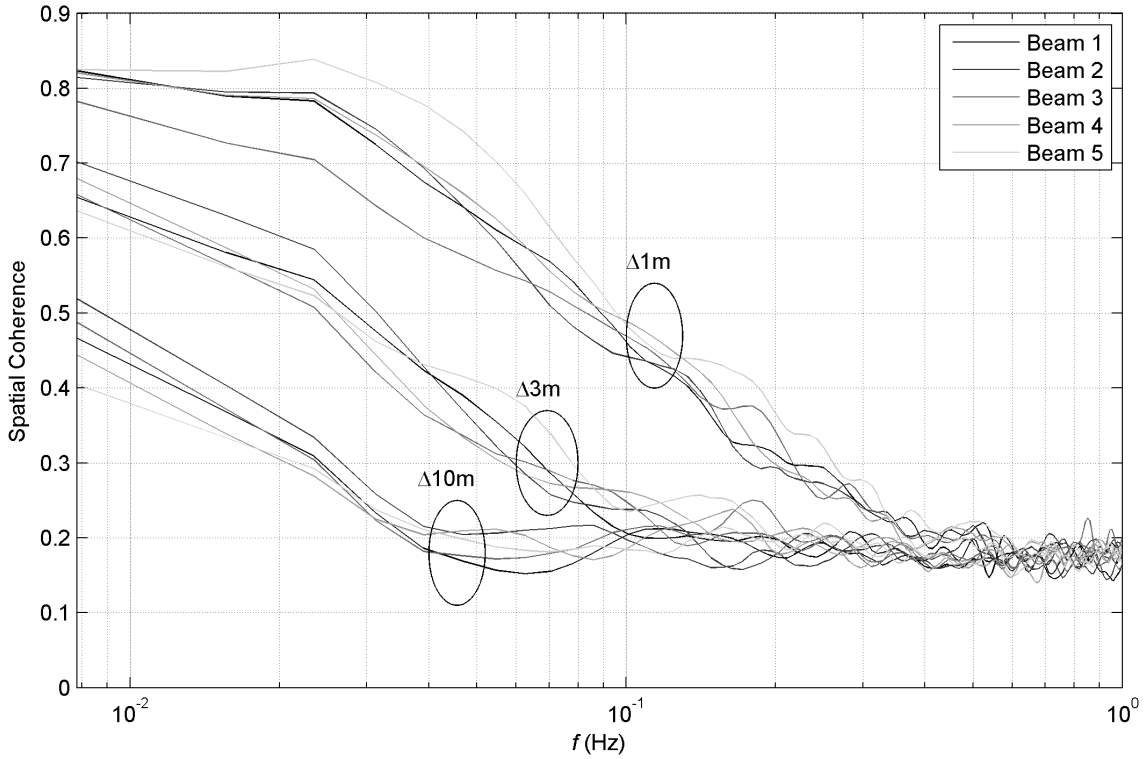
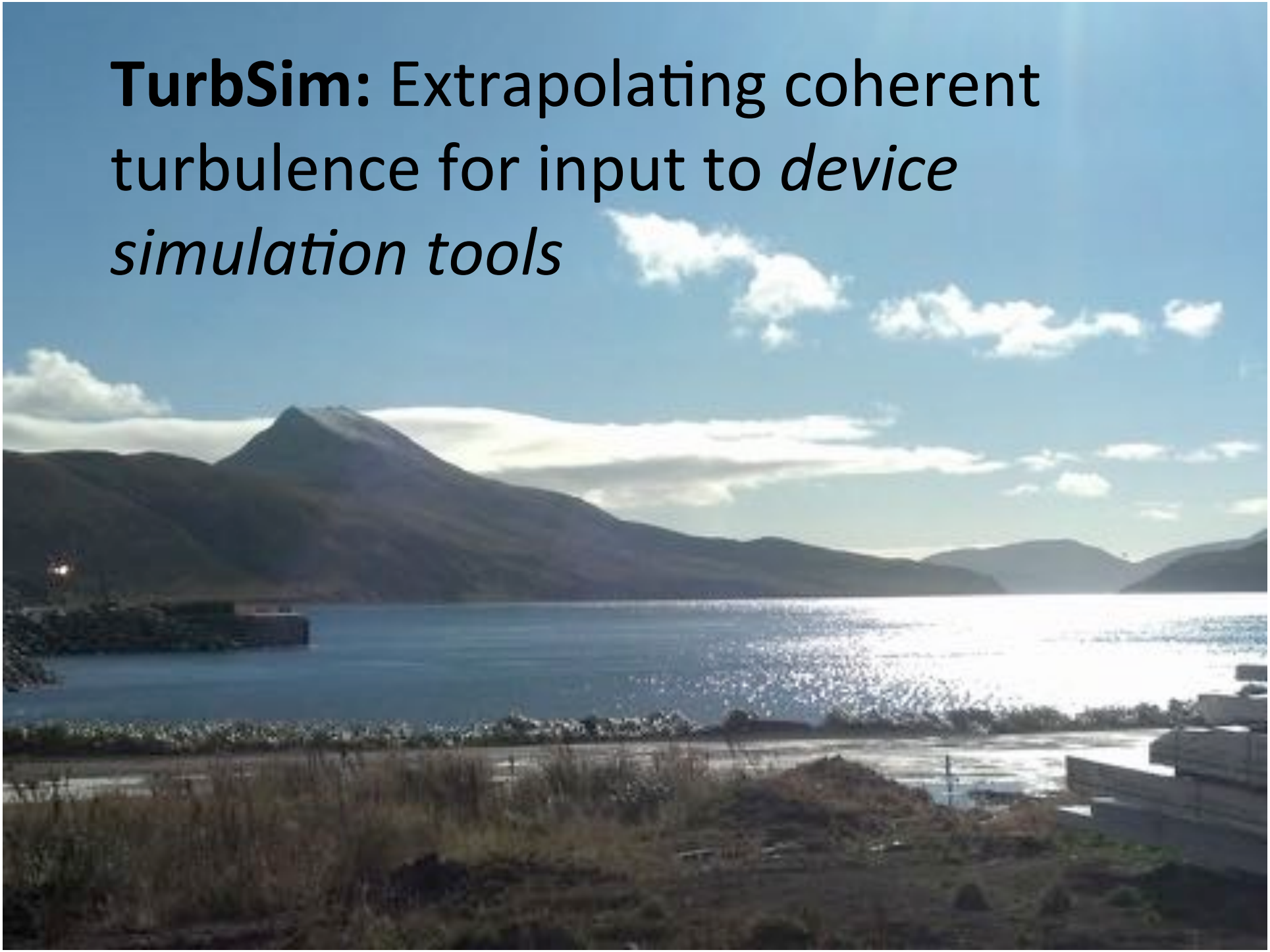
Coherence results and length scales





Coherence is an exponential function of separation distance, and effectively zero for scales larger than the water depth

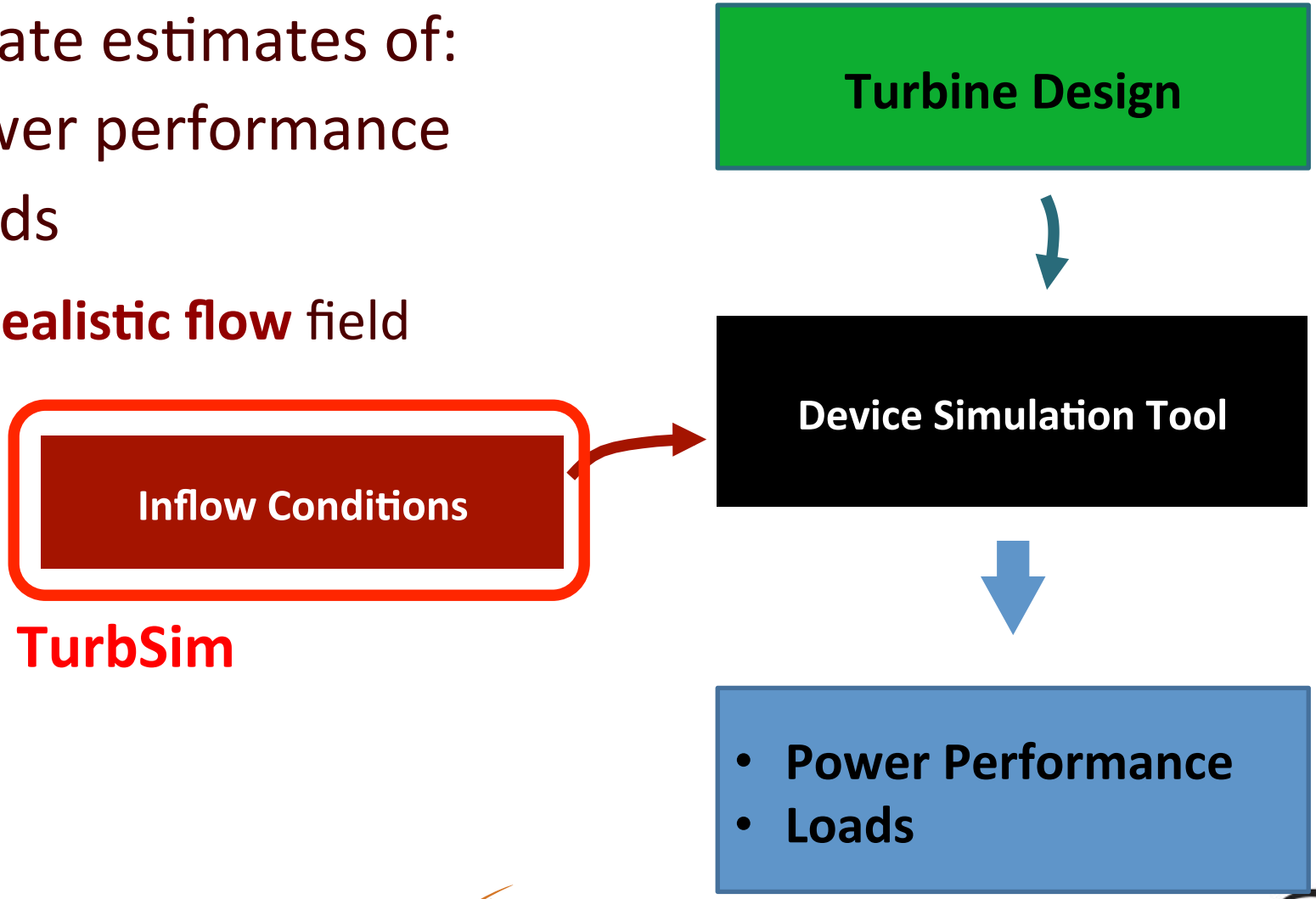

TurbSim: Extrapolating coherent turbulence for input to *device simulation tools*

Device Simulation: Goals

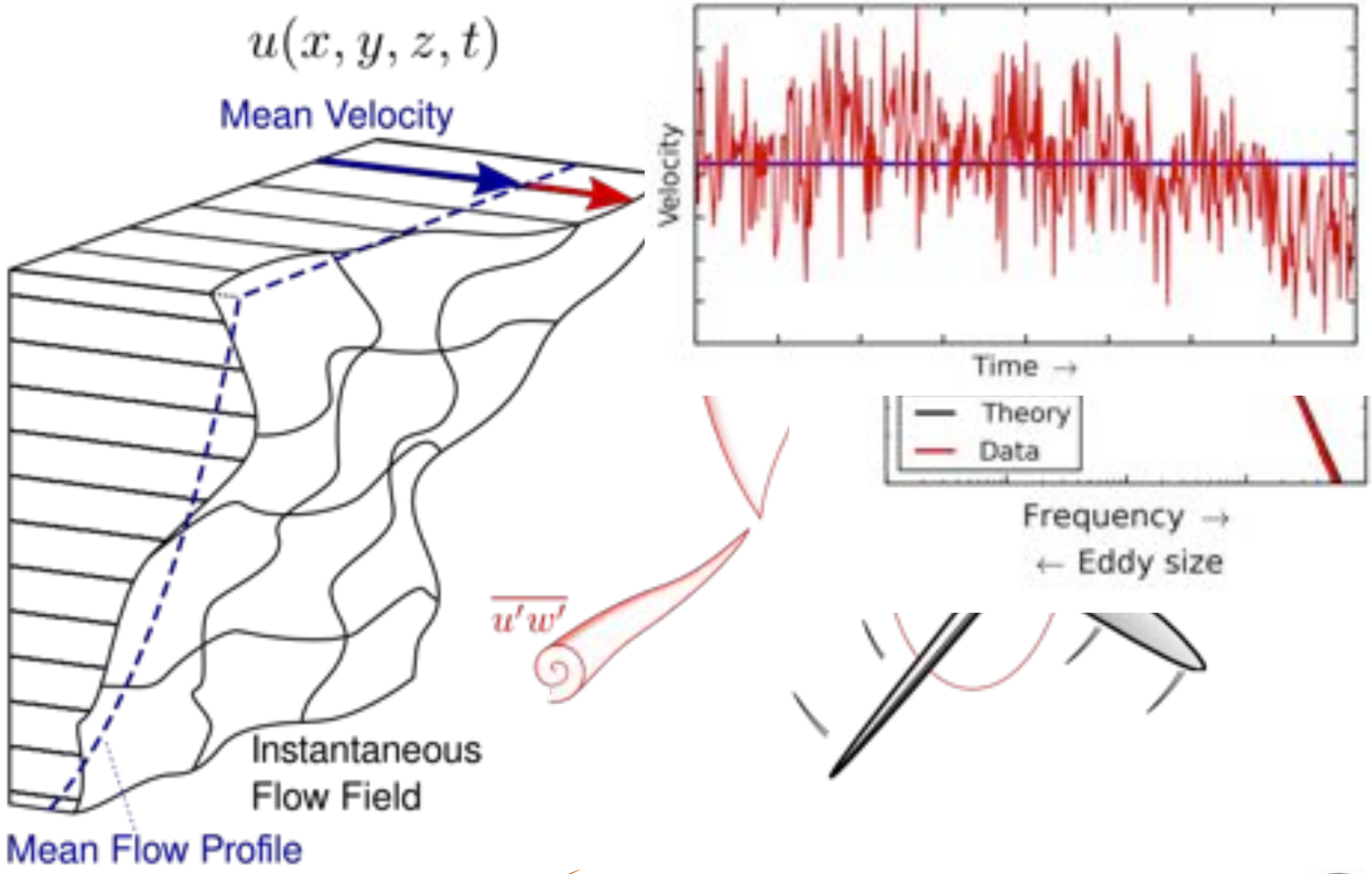
Accurate estimates of:

- Power performance
- Loads

in a **realistic flow** field



What is a ‘realistic flow field’?



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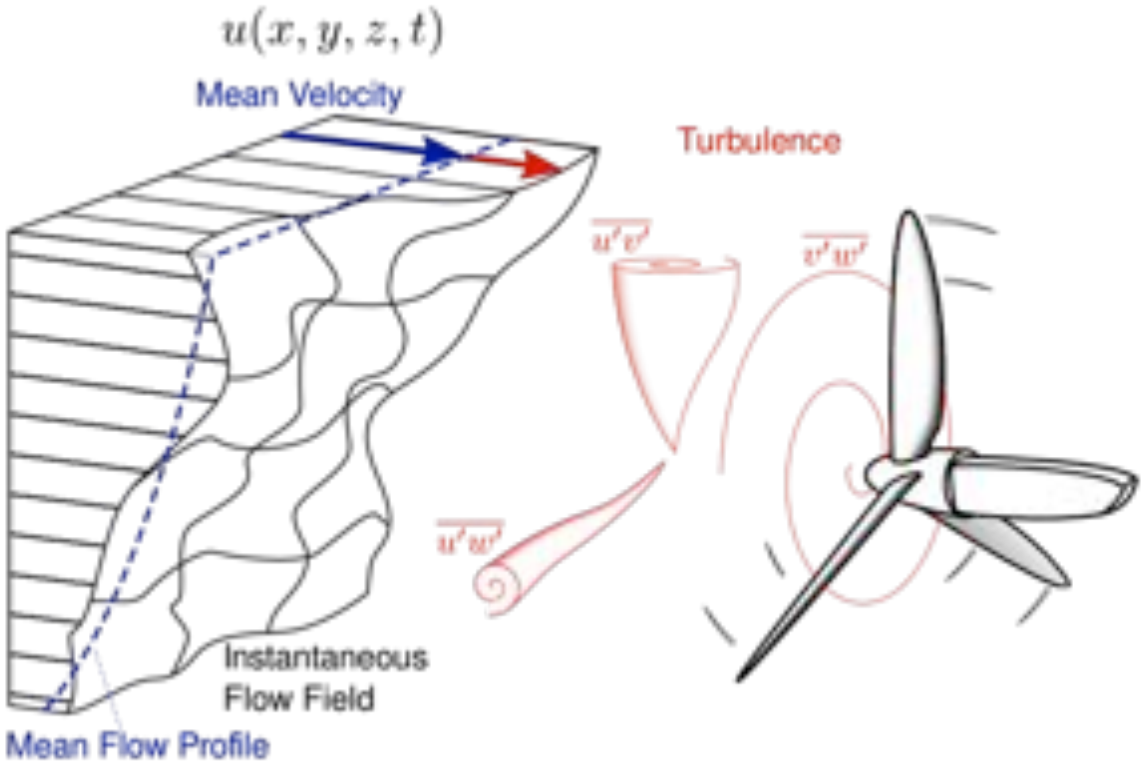
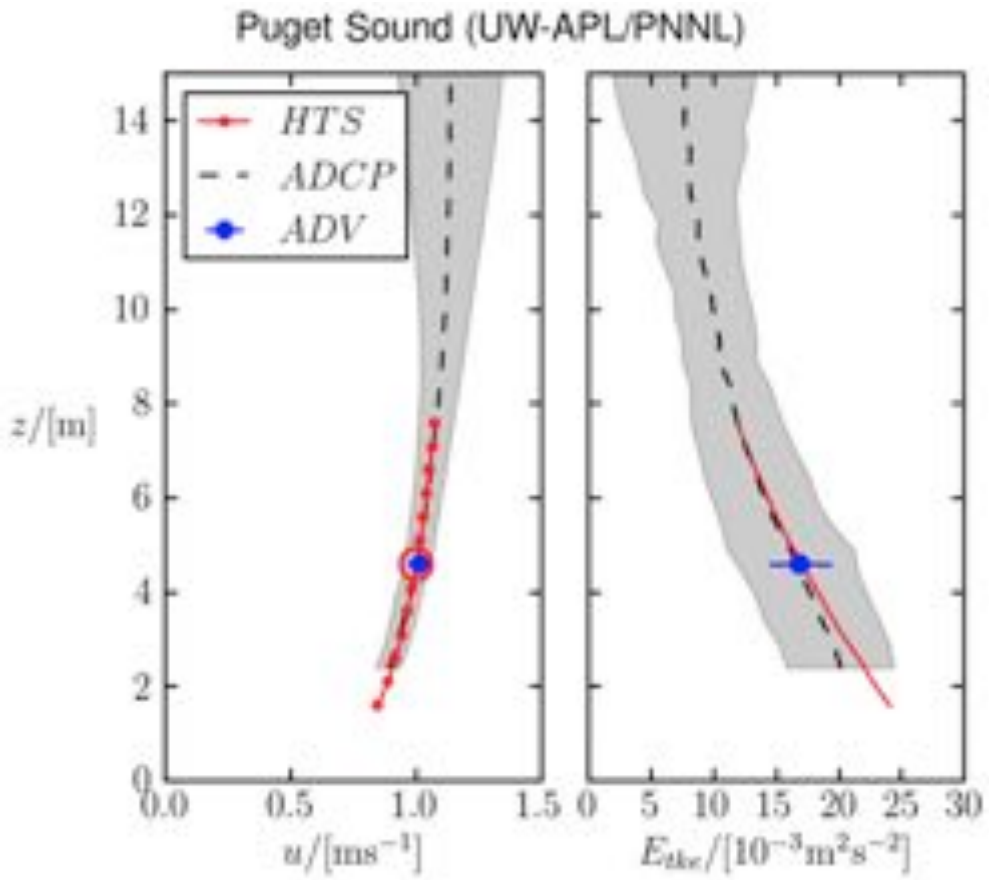
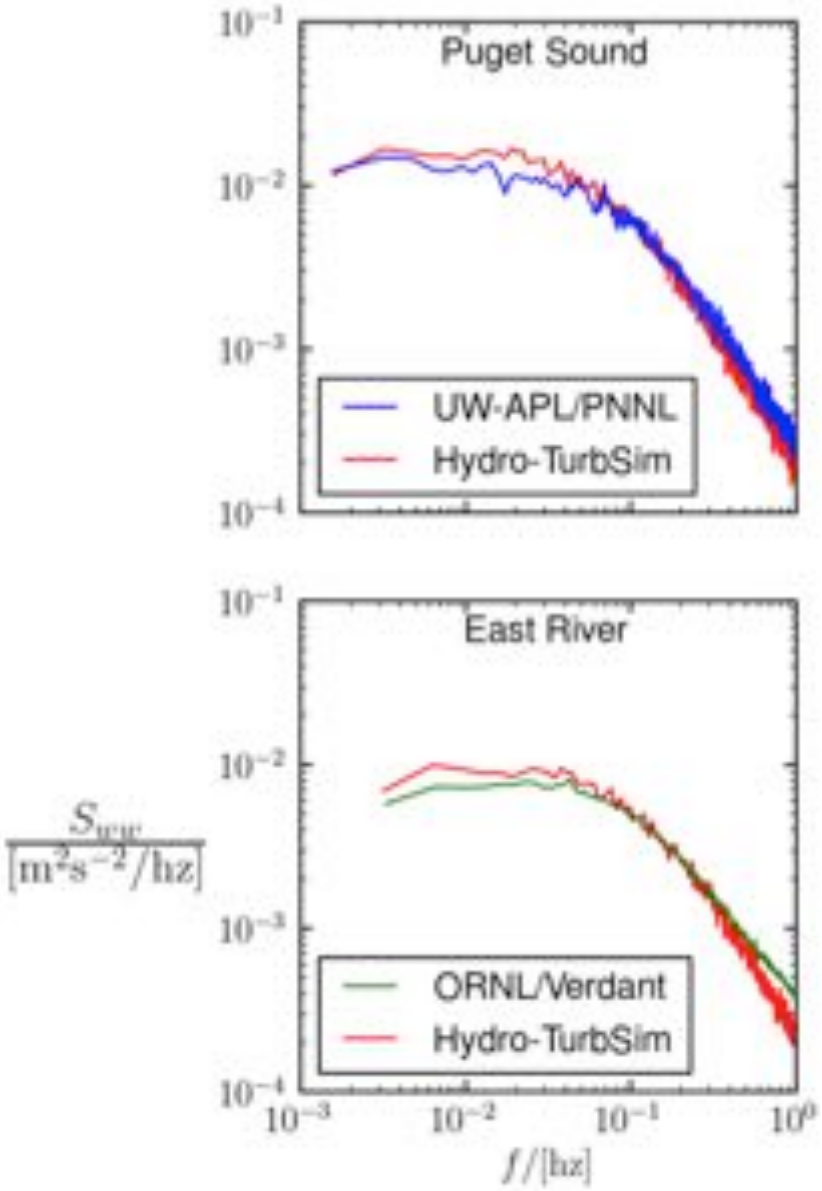
What do we need to measure/simulate?

- Mean velocity profile
- Turbulent Kinetic Energy (TKE)
  turbulence intensity
- Turbulence Spectrum
  timescales of turbulence
- Reynold's Stresses
- Spatial coherence
  length-scales of turbulence



Measurements





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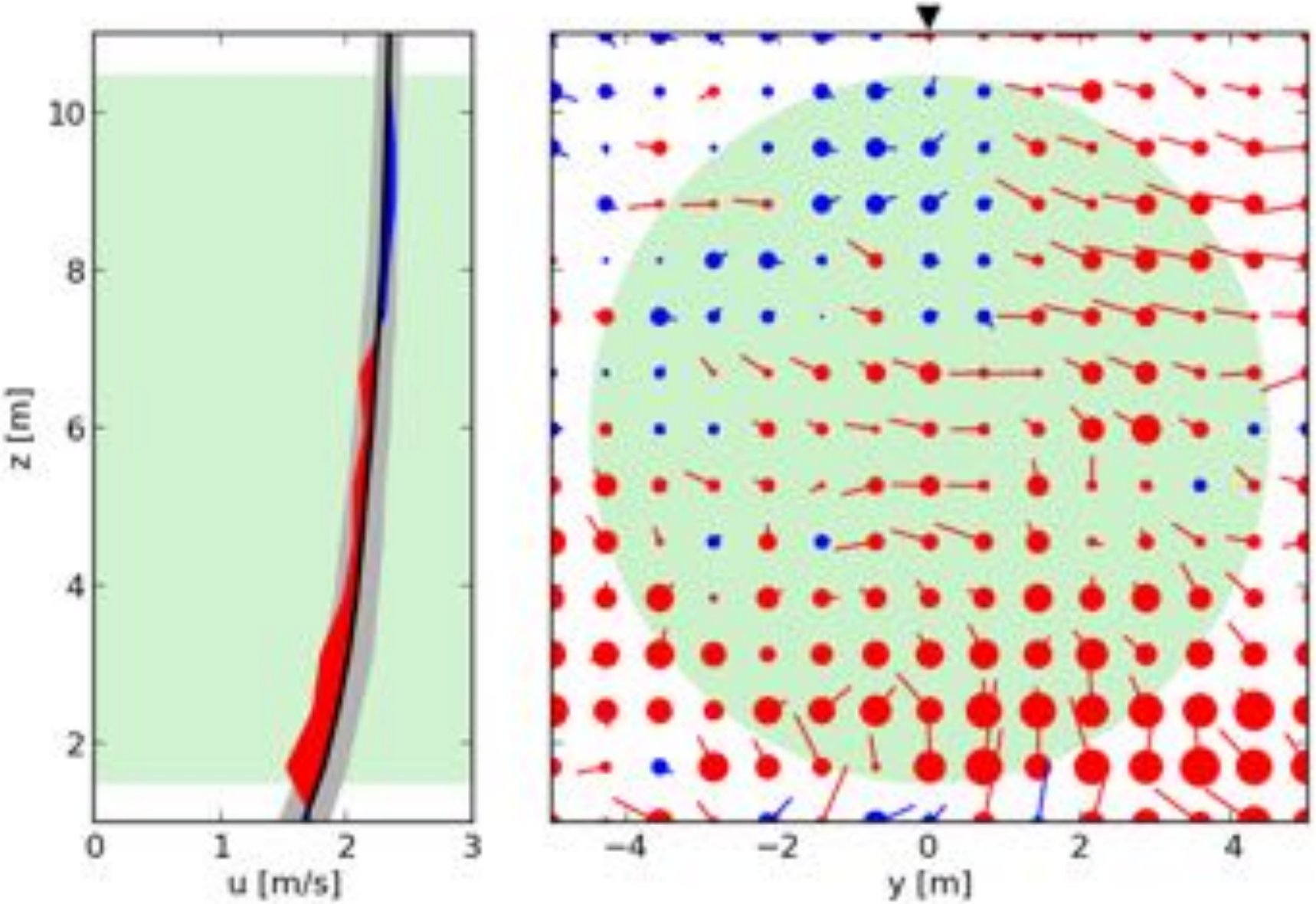

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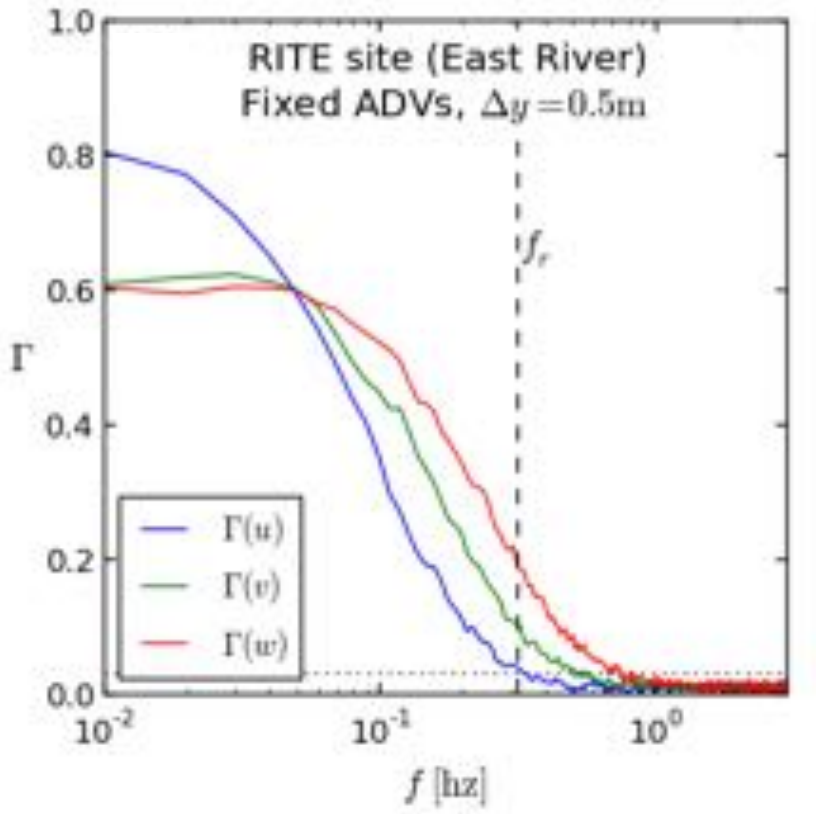
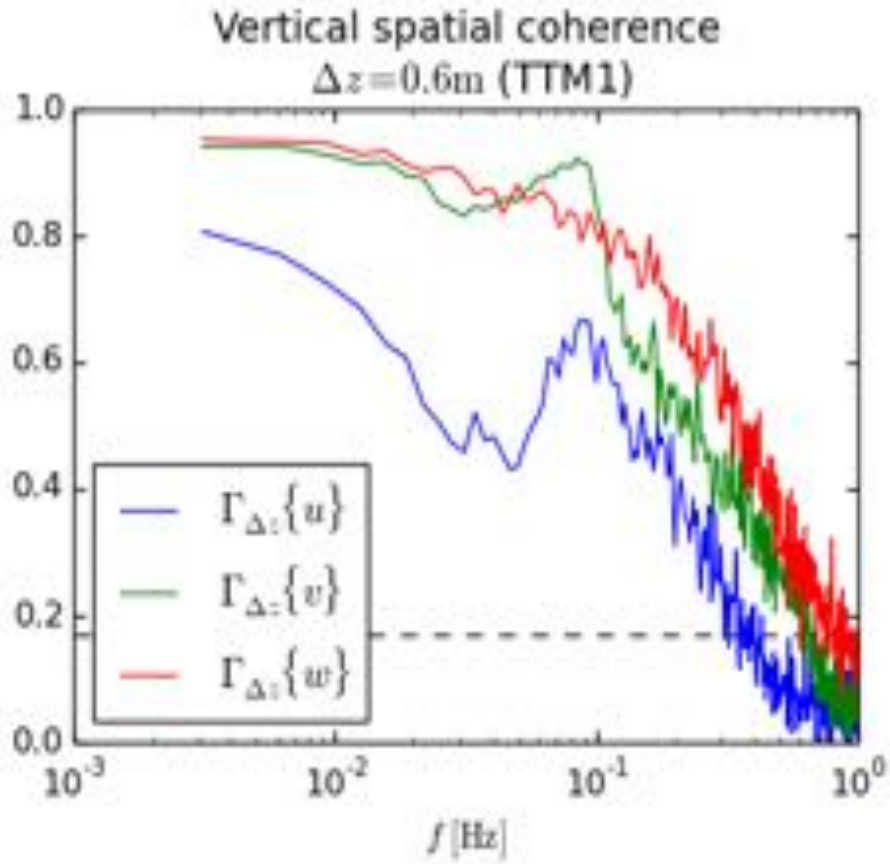
Spatial Coherence





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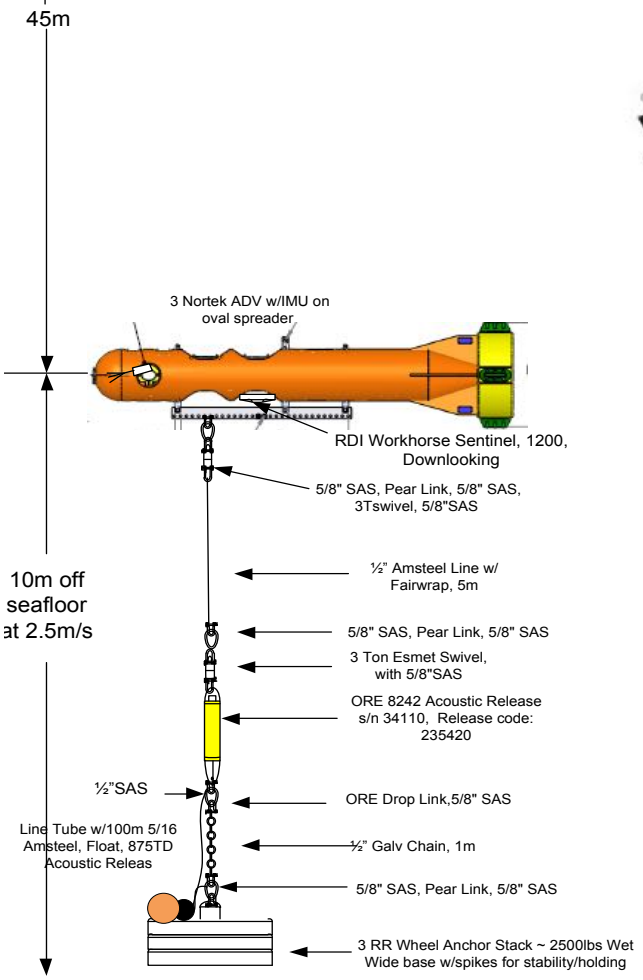
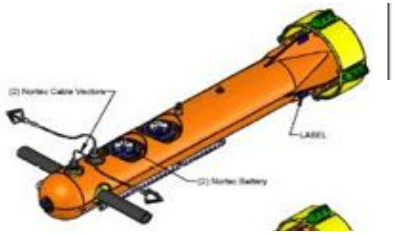
The next [big] thing: “stablemoor”





Deepwater Buoyancy StableMoor 400:
Weight: 650lbs
Buoyancay:
Length: 1
Width of spre
Dia. At Tail: 30"

Note: Not To Scale

University of Washington Applied Physics Laboratory 1013 NE 40th St. Seattle, WA 98105	
Stablemoor Turbulence Mooring	
Admiralty Inlet, WA	
Joe Talbert	Water Depth: 55M
Deploy:	Date: Feb 2015

Just tested on Tuesday
Deploying in
Admiralty Inlet next week

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Waves make turbulence too!

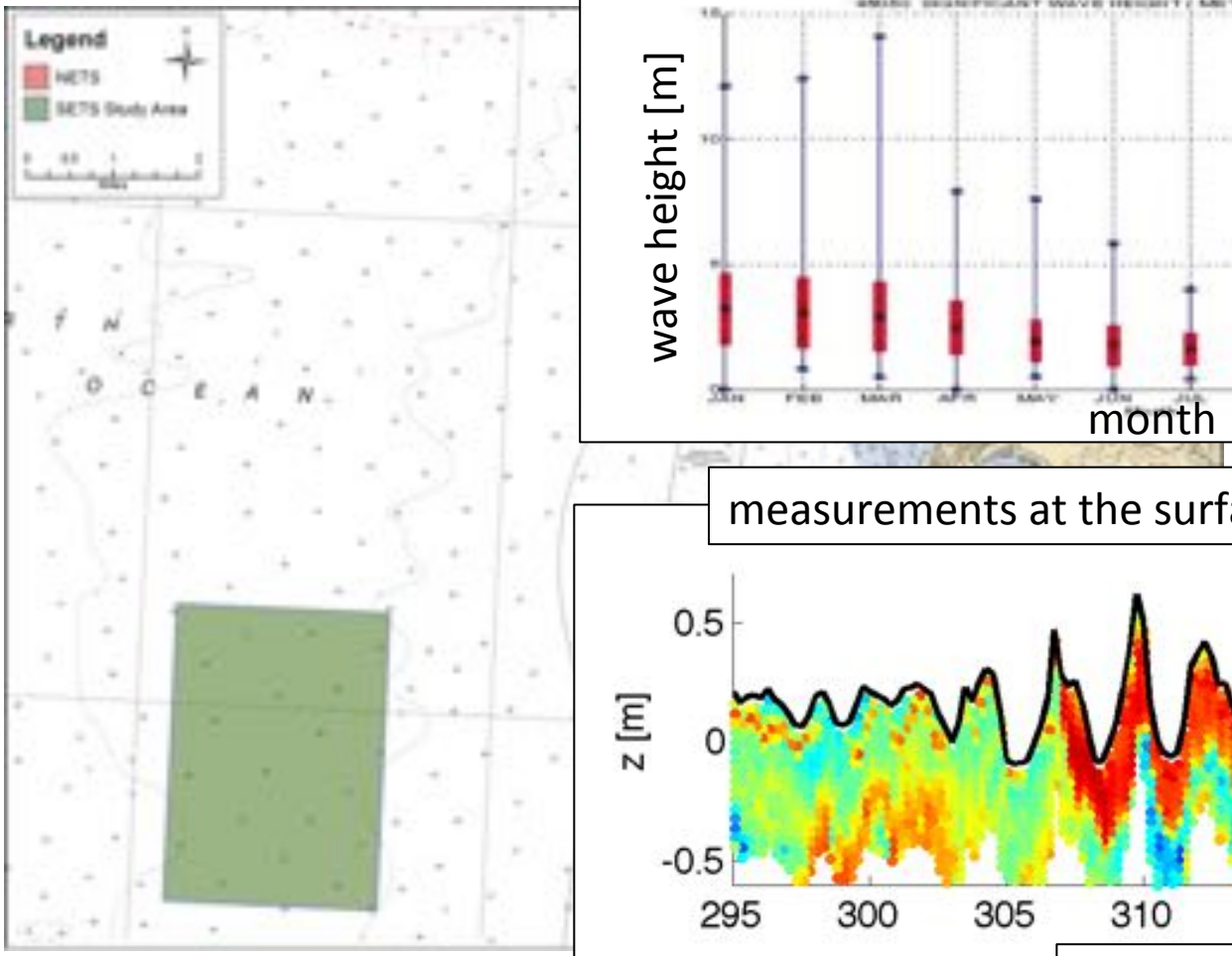
SWIFT: Surface Wave Instrument Float with Tracking

Thomson, J. *Journal of Atmospheric and Oceanic Technology,* ***29****, 2012.*

www.apl.uw.edu/swift

Hull	Anodized aluminum
Power	14 VDC, Alkaline or Lithium D cell packs
Weight	30 kg in air
Dimensions	1.25 m draft, 1.0 m mast, 0.35 m diameter
Shipping crate	1.65 m length, 0.5 m width, 0.5 m depth
Endurance	30 days (Alkaline), 90 days (Lithium)
Tracking (RF)	Garmin Astro DC40 collars (10 km range)
Tracking (Iridium)	Geoforce GT1 (global)
Telemetry	Iridium SBD
Processor	Sutron Xpert
Profiler	2 MHz Nortek Aquadopp HR
Met	Airmar PB200
IMU	Microstrain 3DM-GX3-35
CT	Aanderraa 4319
Camera	serial uCAM
Light	Yellow 1s flasher

Wave breaking at the Newport test site (winter 2016)



measurements at the surface (wave breaking)

time [s]

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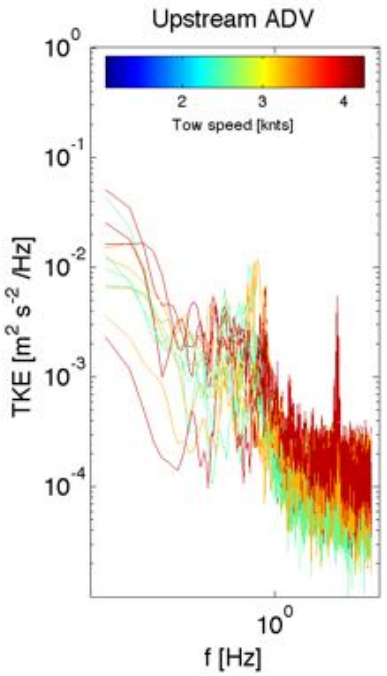
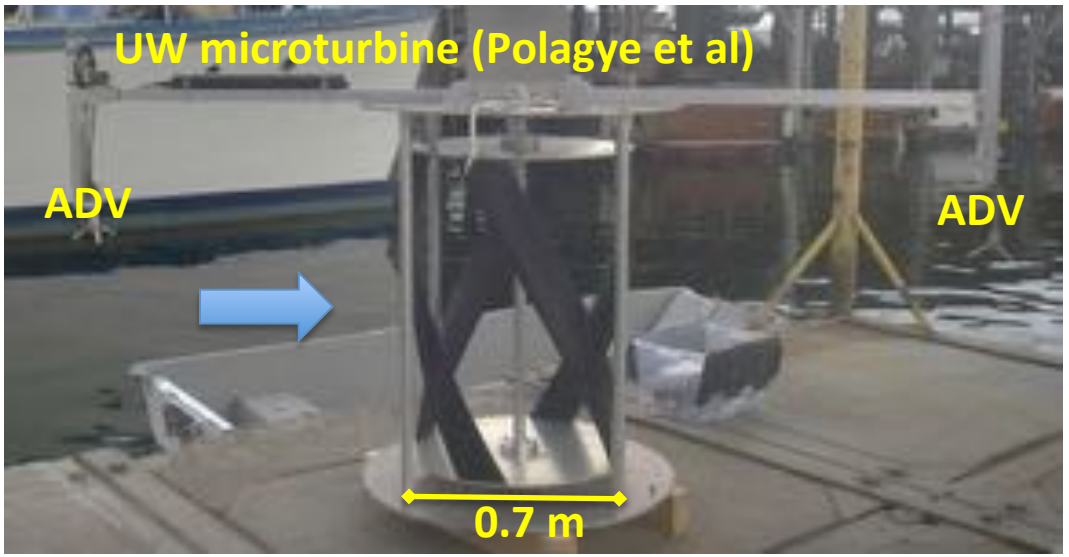
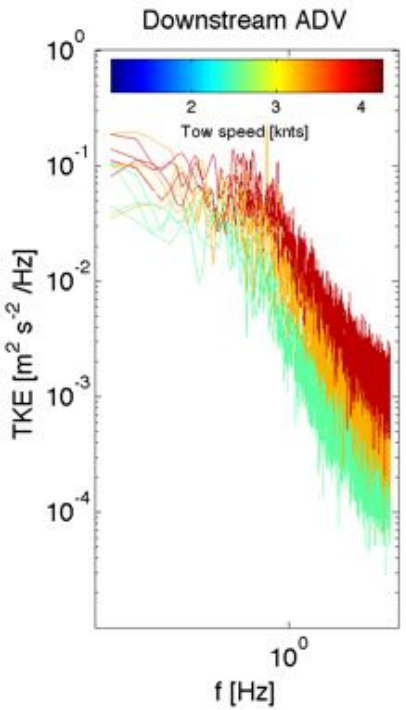
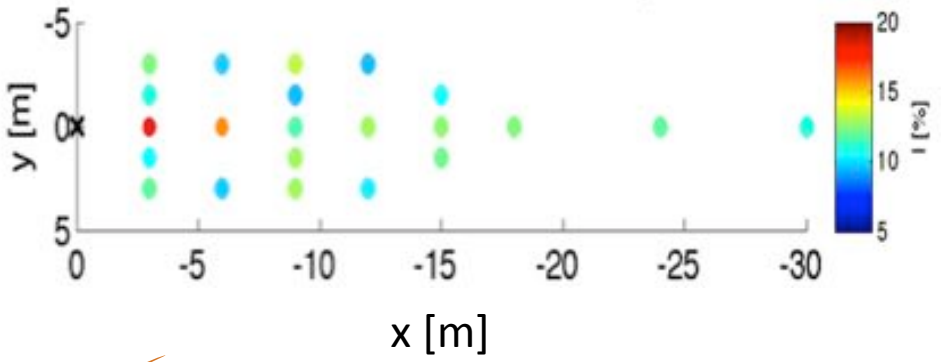
Beyond ambient turbulence: Wakes









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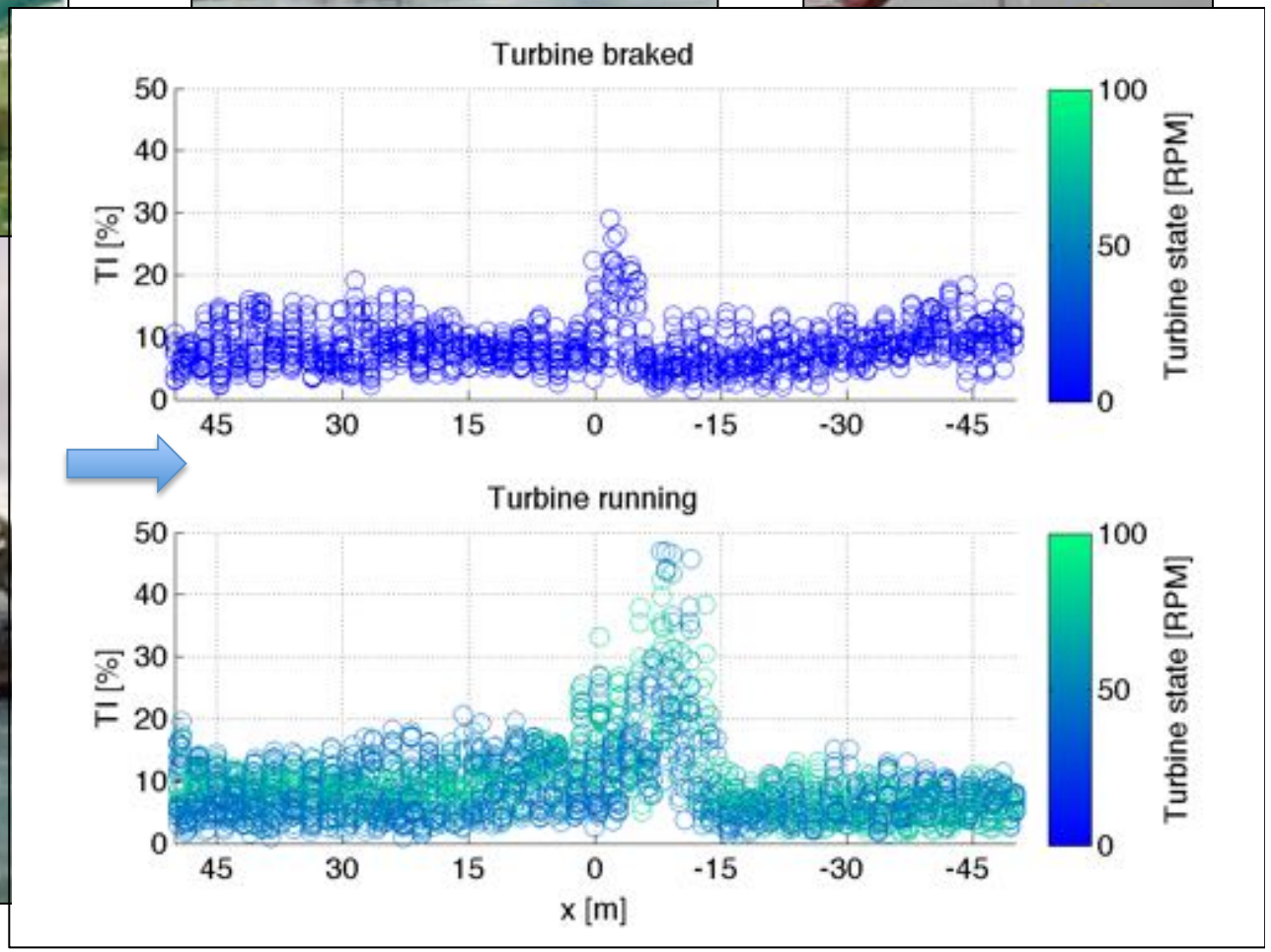
More wake measurements



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