High Resolution Doppler Profiler Measurements of Turbulence from a Moving Body

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Motivation

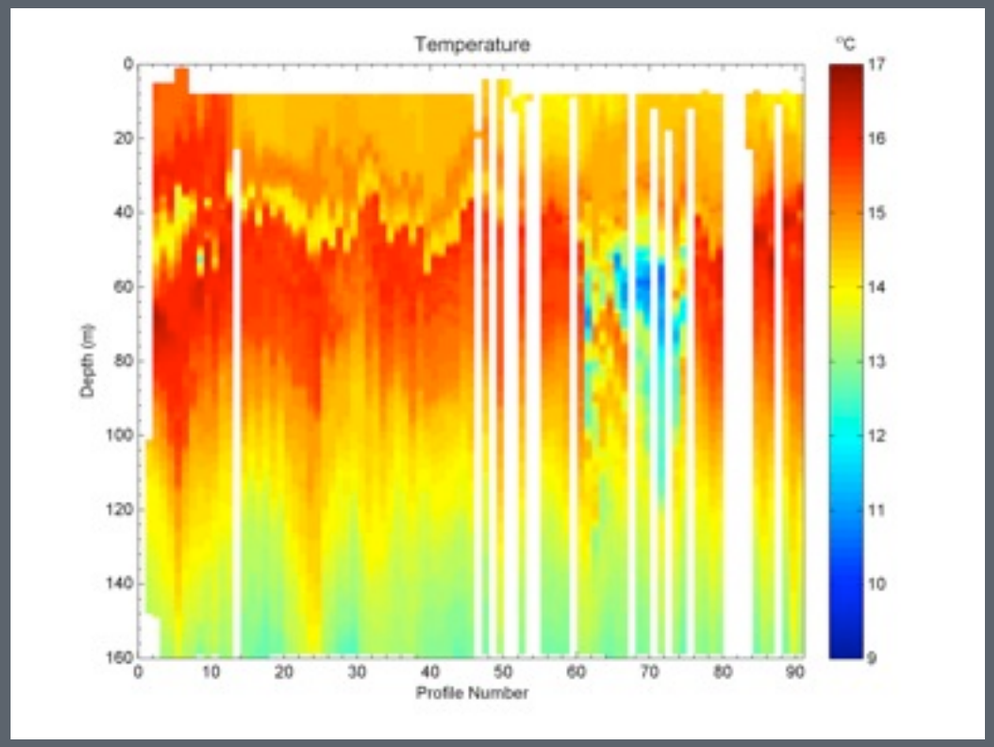
- Measuring high vertical resolution profiles over long mooring lines is impossible using single point sensors due to the cost and complexity.

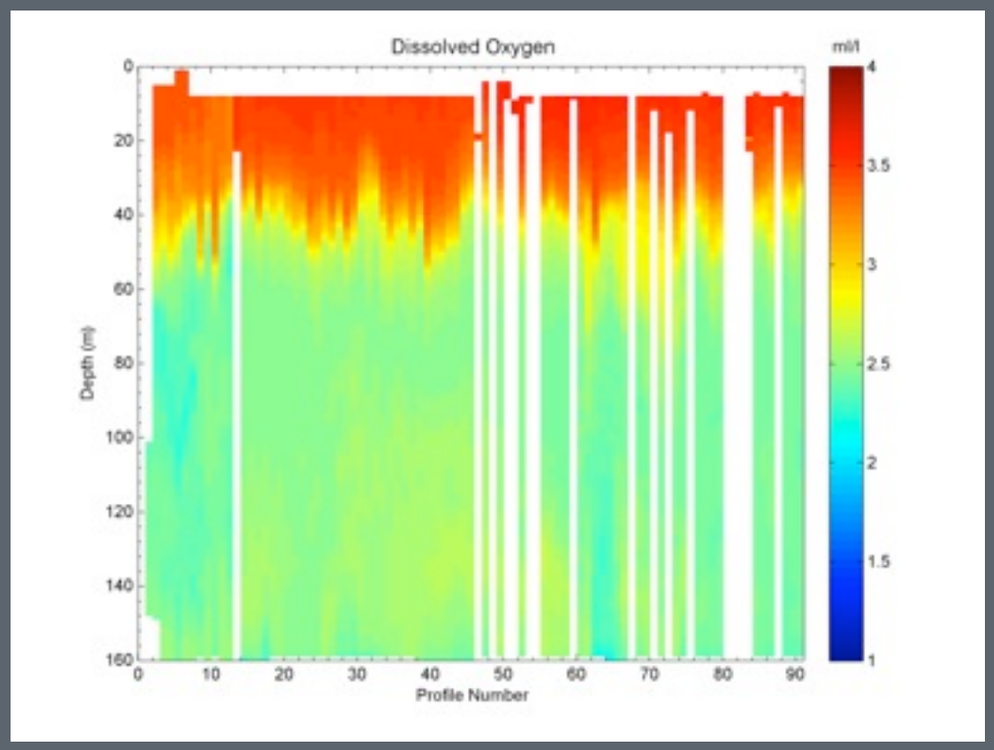
- Moored profilers support multiple data streams at a single location for long durations. This leads to a richer dataset.

- An important component missing from current instrumentation is the ability to resolve turbulent velocities and generate higher order turbulent statistics.

- A single moored profiling instrument (e.g. an ADCP) has limited profiling range, higher noise, and much coarser vertical resolution on the order of several meters.

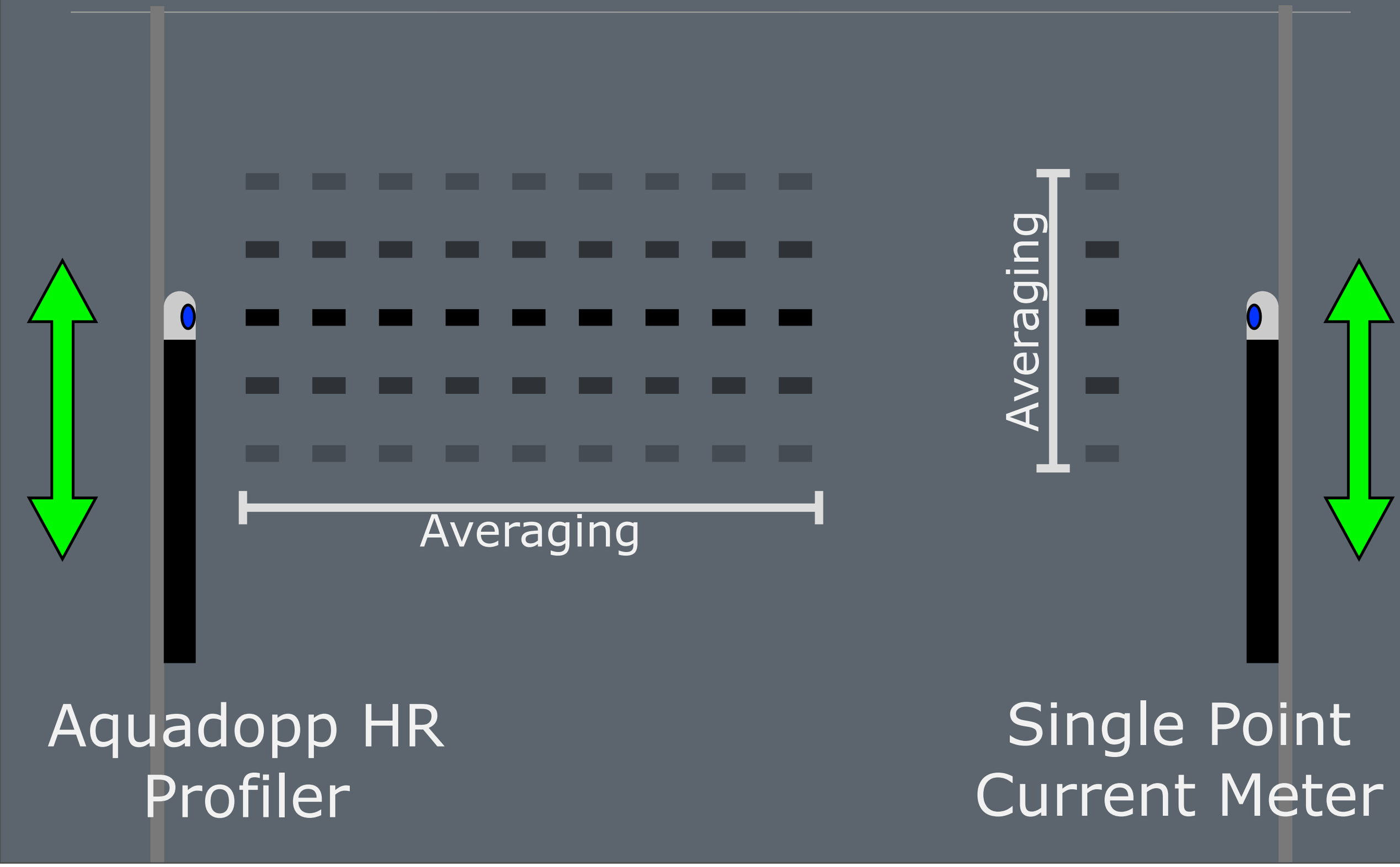
The importance of vertical resolution





- Averaging vertically obscures structure within the water column.
- Averaging removes variance (turbulence) from the signal.
- Homogeneous vertical segments will vary in size and amount of data. They are also arbitrarily defined.

Minimizing vertical averaging by using a Doppler profiler

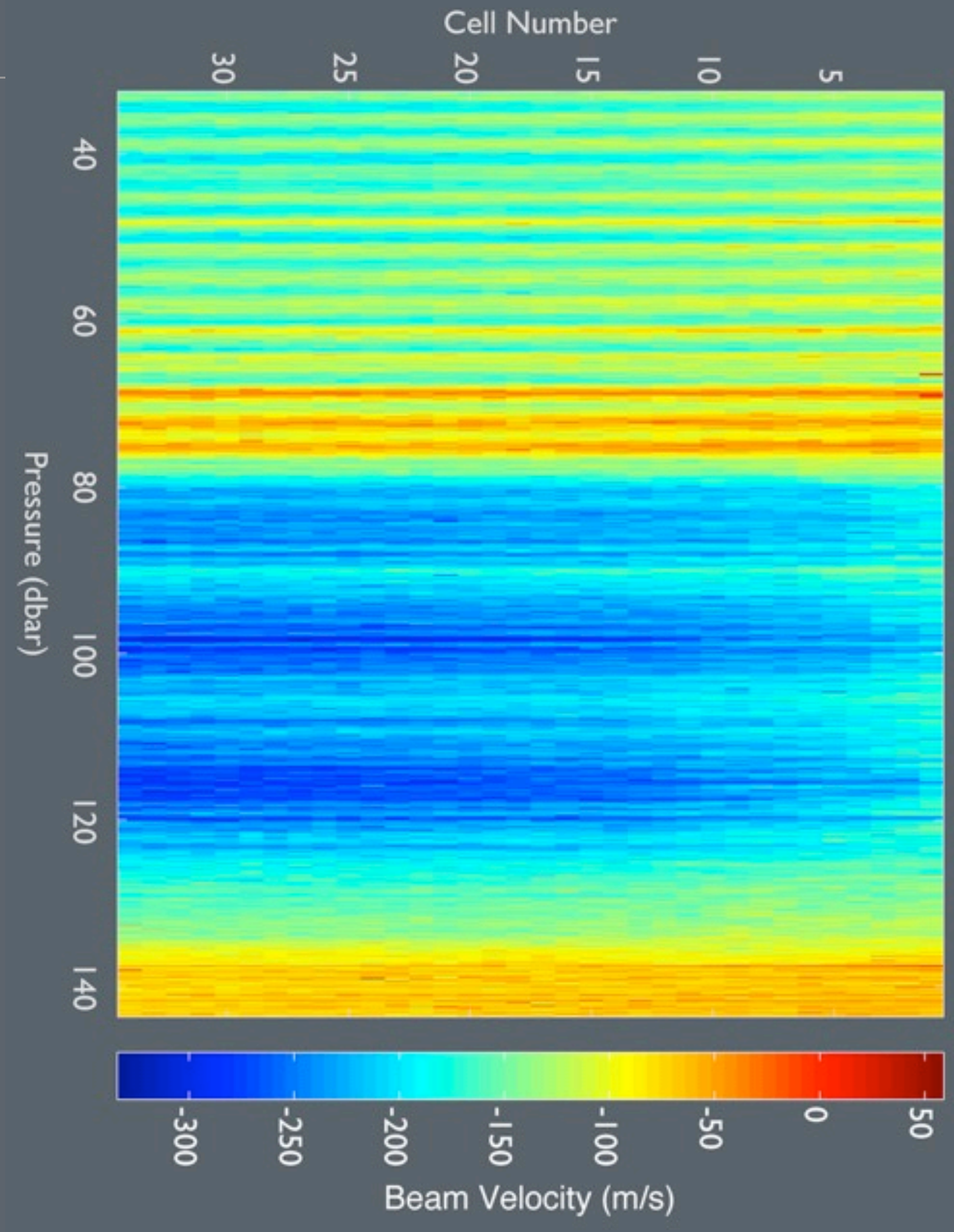


The Application

Mount a Nortek Aquadopp HR Profiler on a moored profiler.

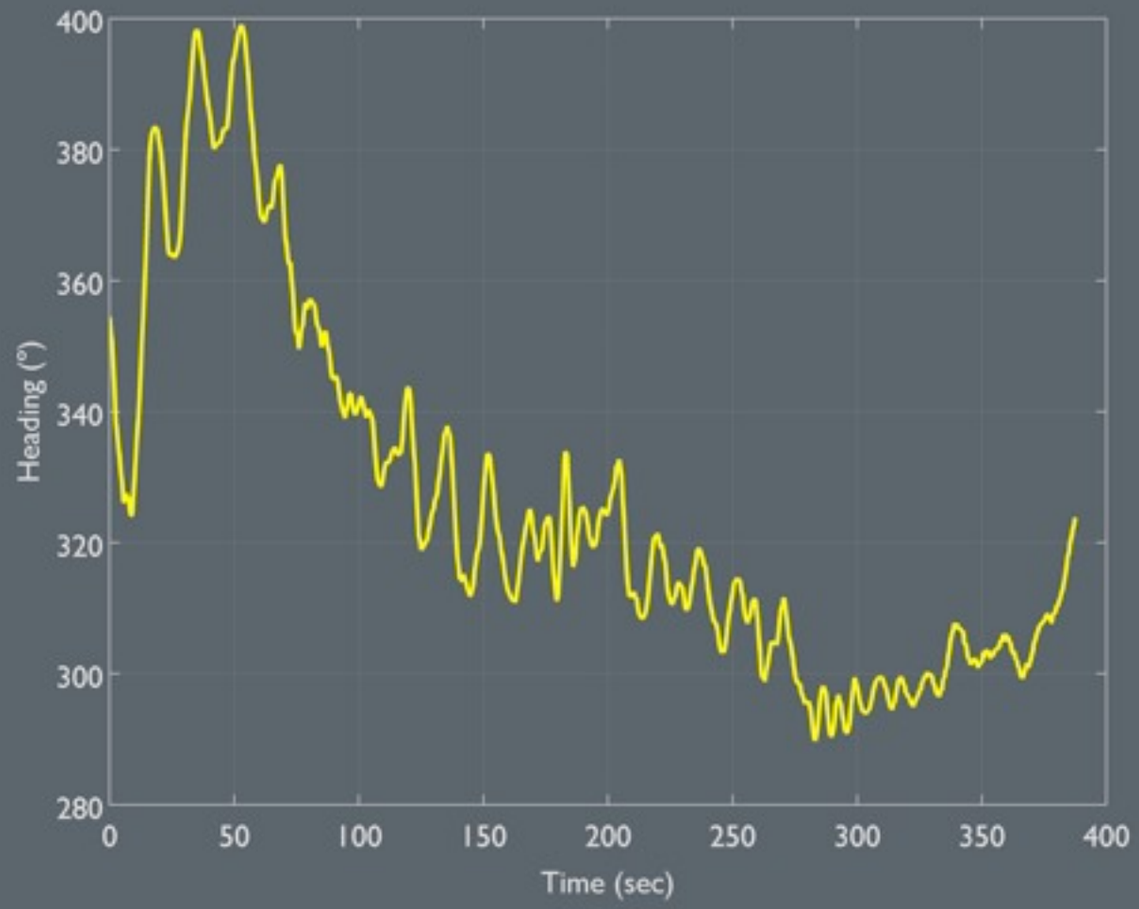
Instrument Configuration

- Sample rate: 2 Hz
- Cell Size: 0.01 m
- Profile Range: 0.44 m
- Ambiguity Velocity (w/ EVR): 0.69 m/s
- Maximum expected velocities at the site: 0.50 m/s



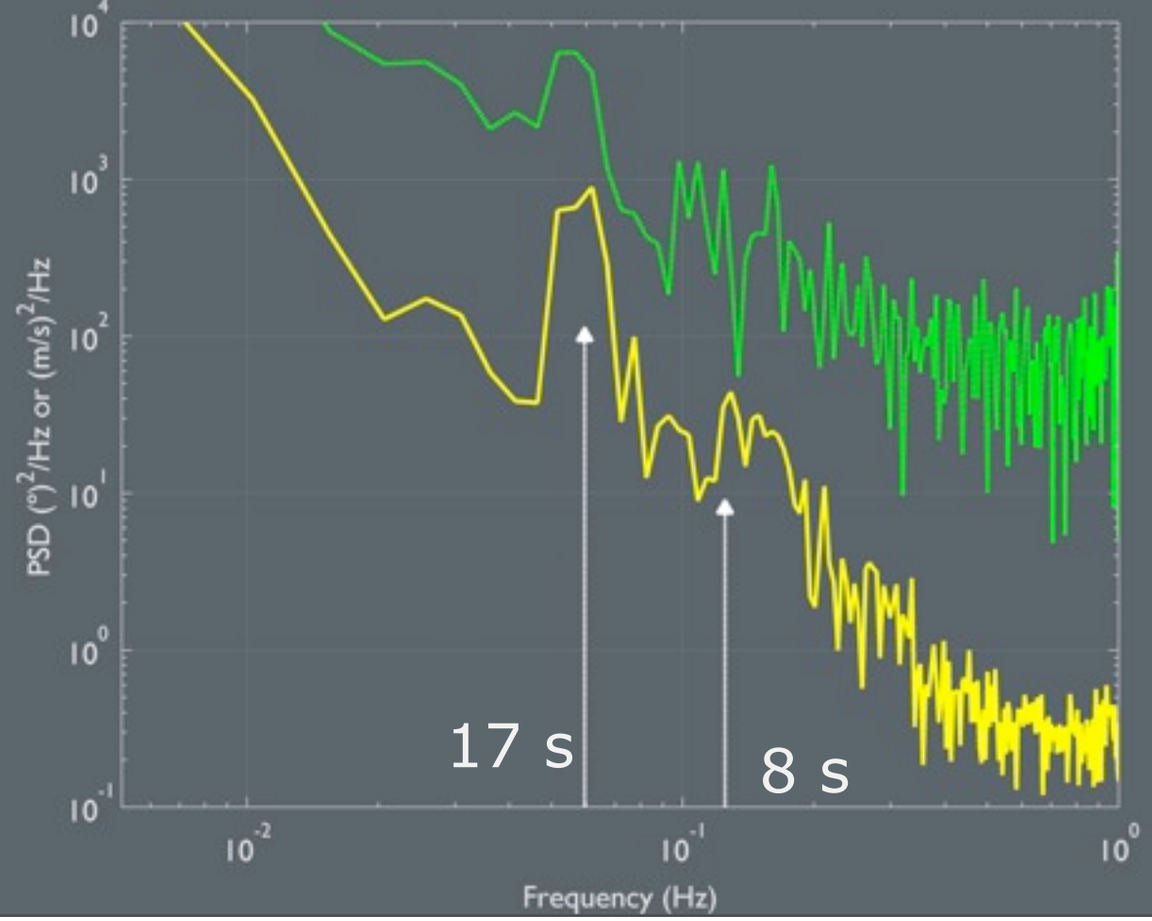
A complication

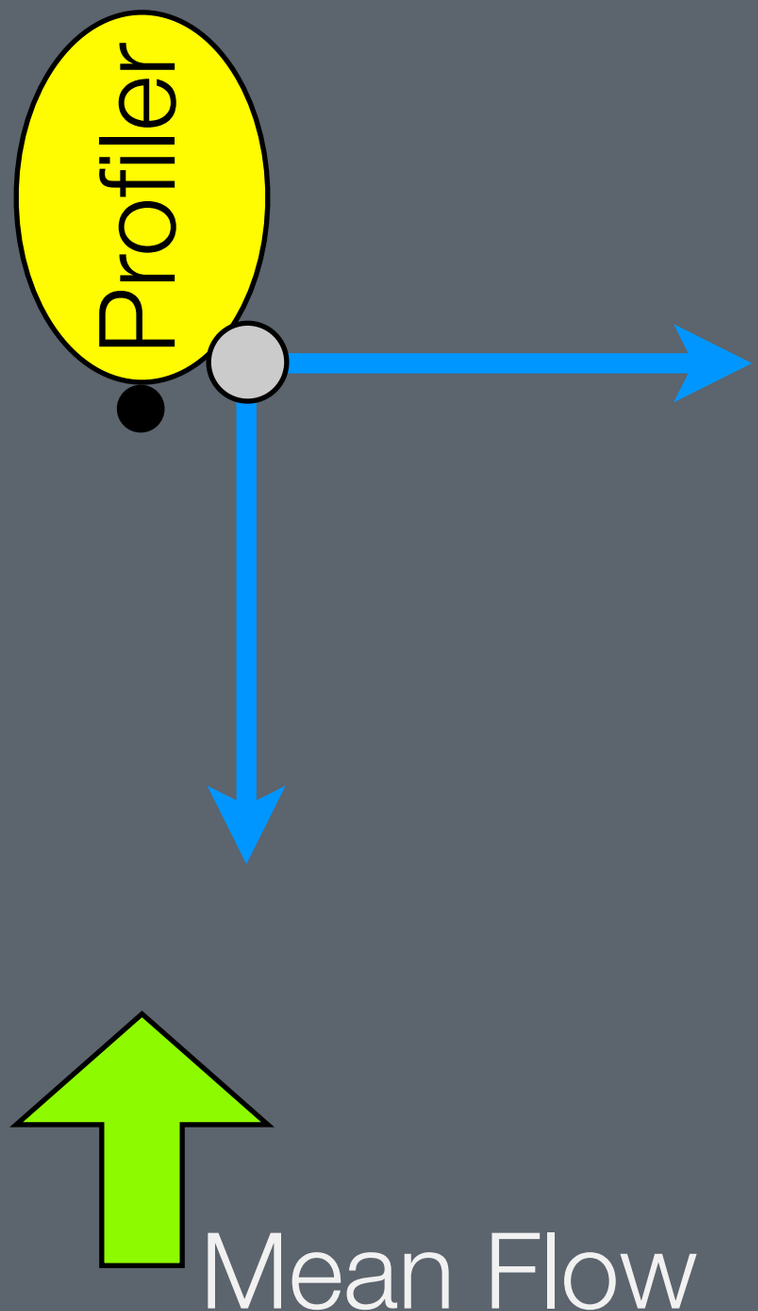
- The profiler body moves through the water column. The HR Profiler measures this motion along with the water velocity.

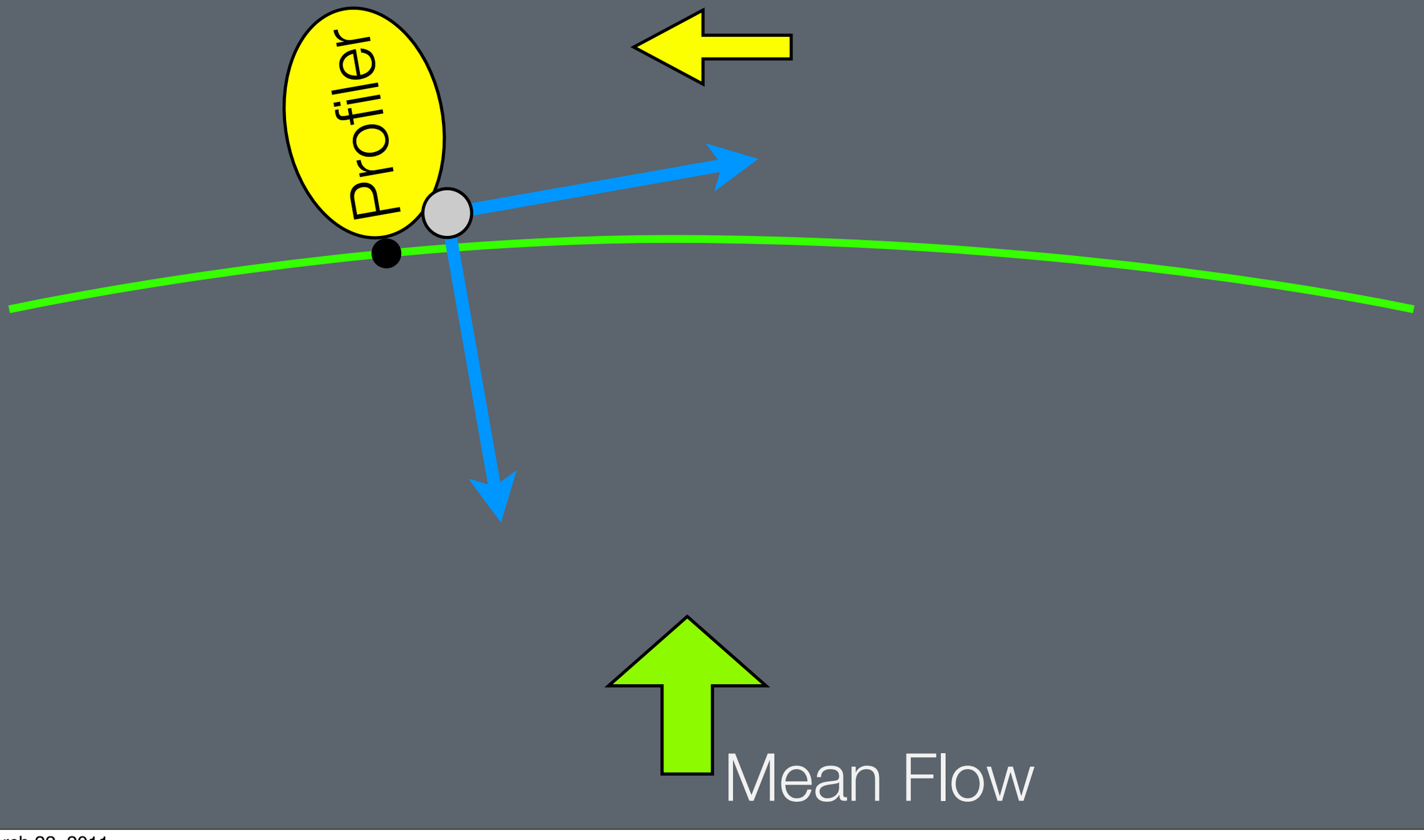


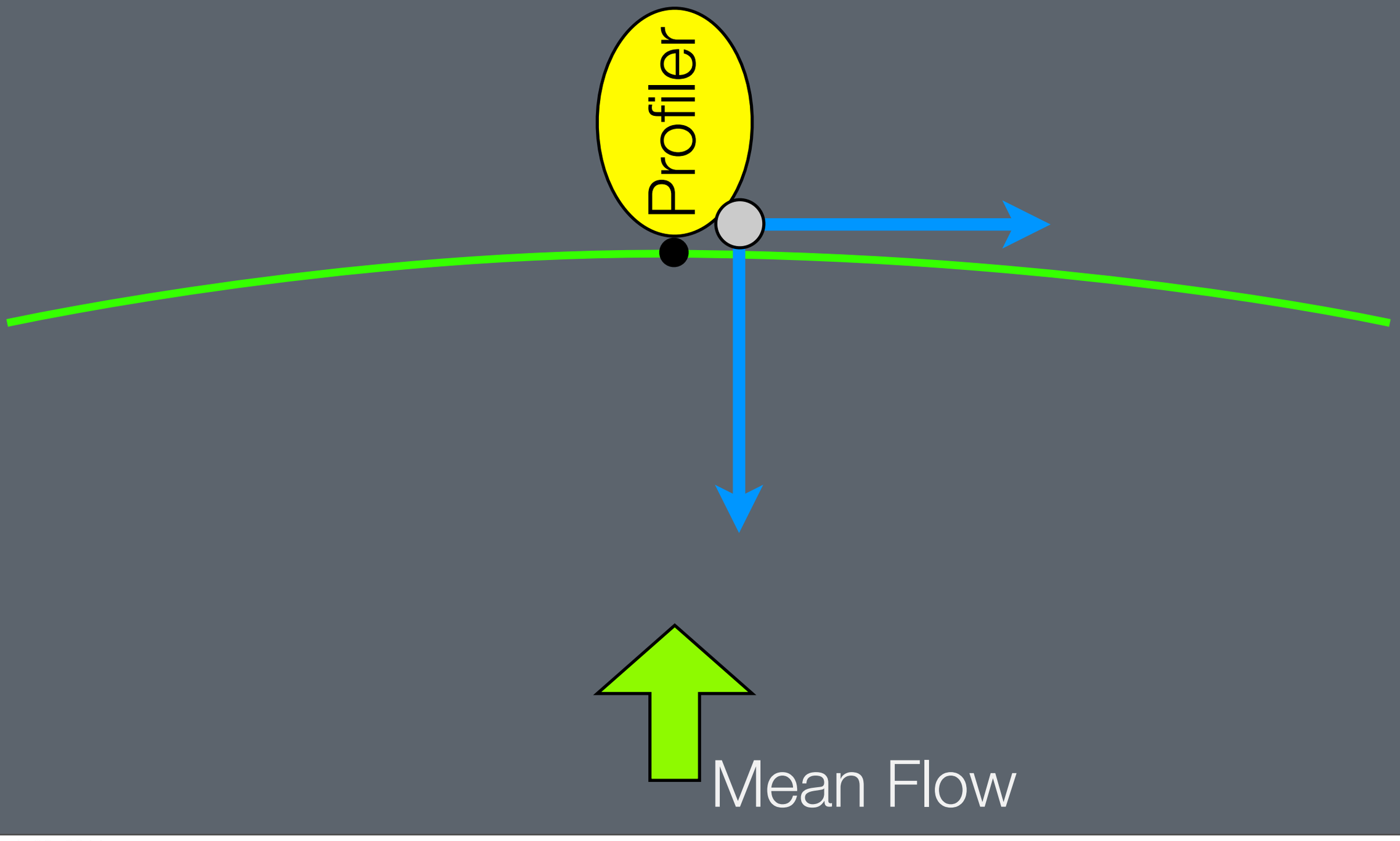
- Ideally, we want to know all three components the instrument is measuring to minimize bias and other errors.

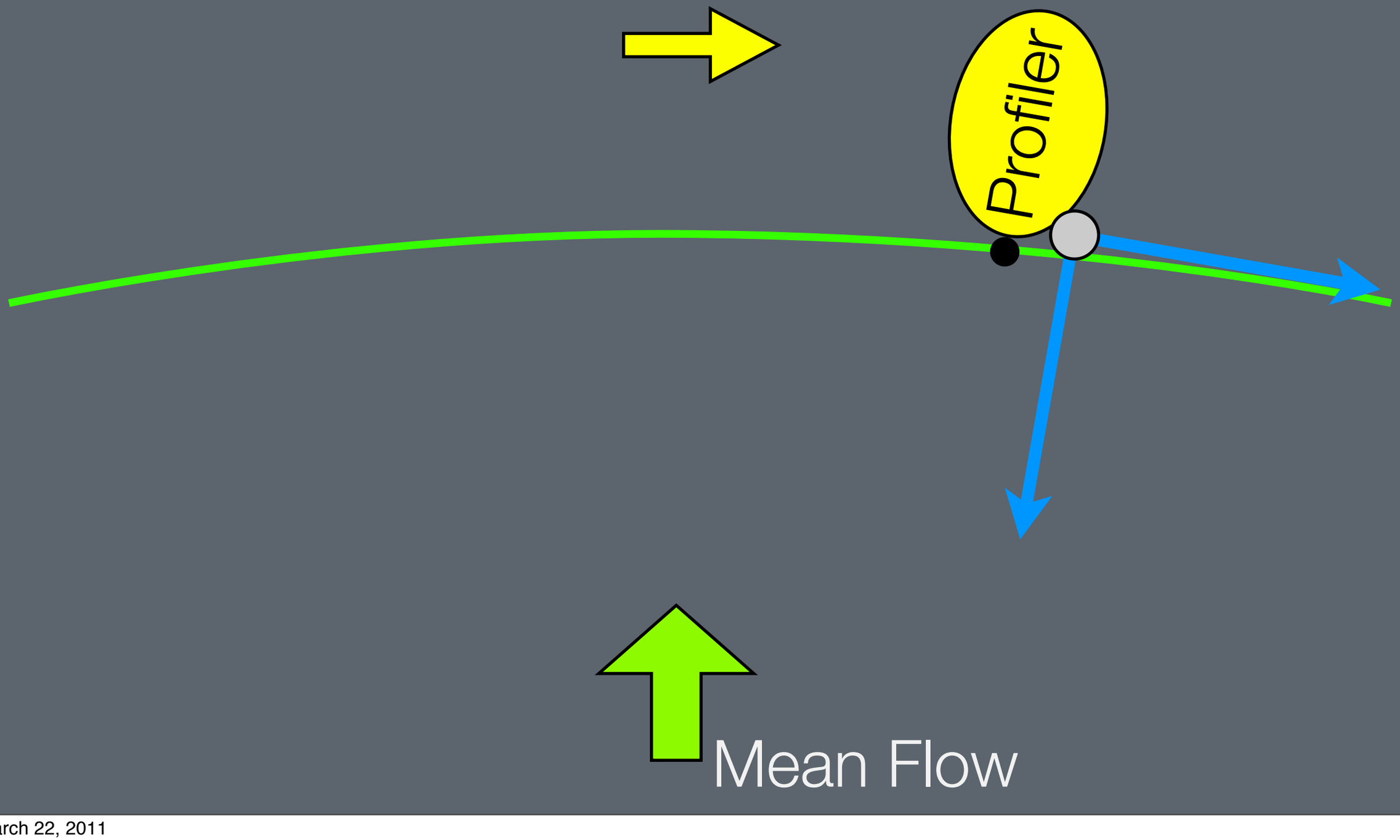
- There are a variety of techniques available to perform this decomposition.

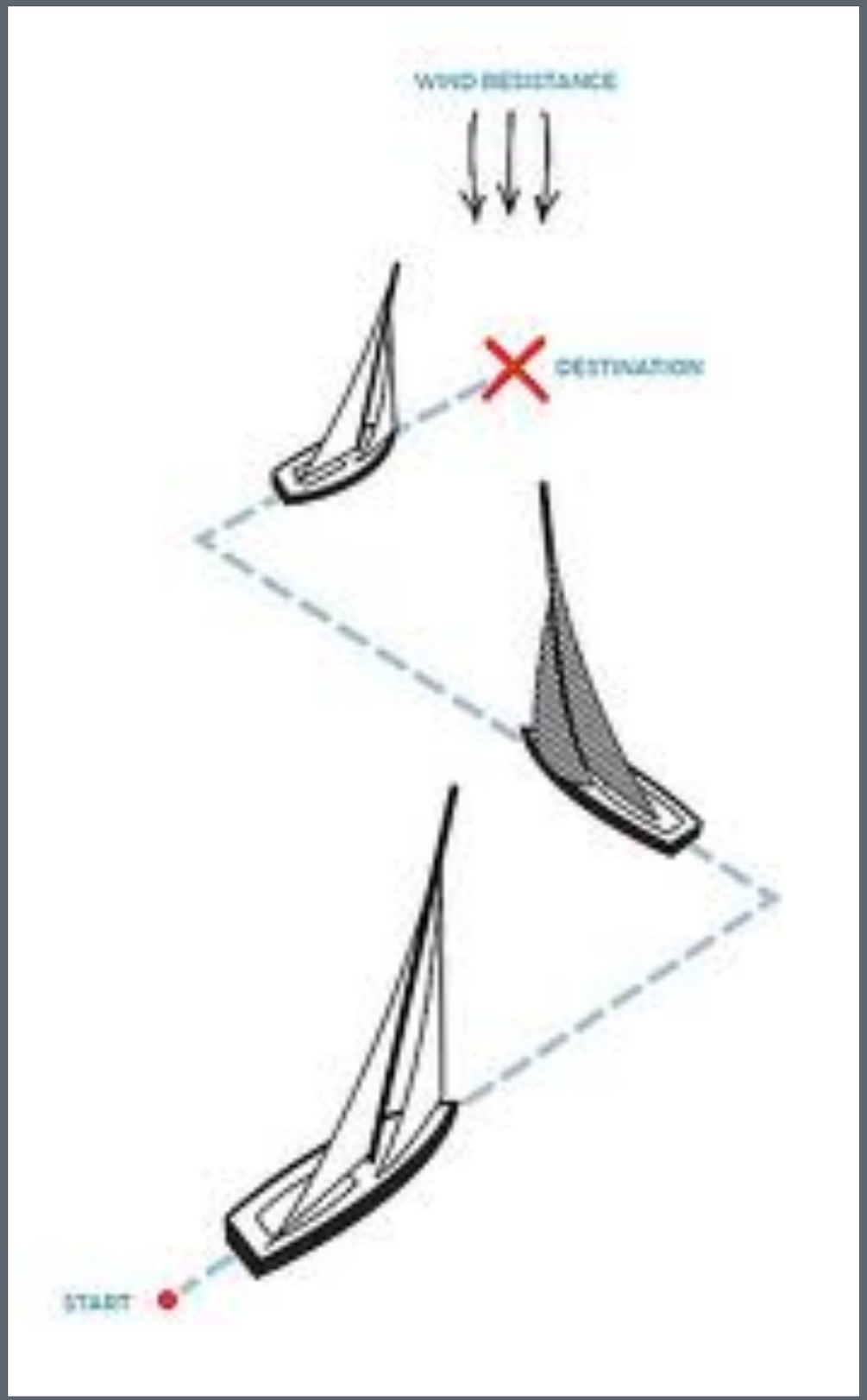


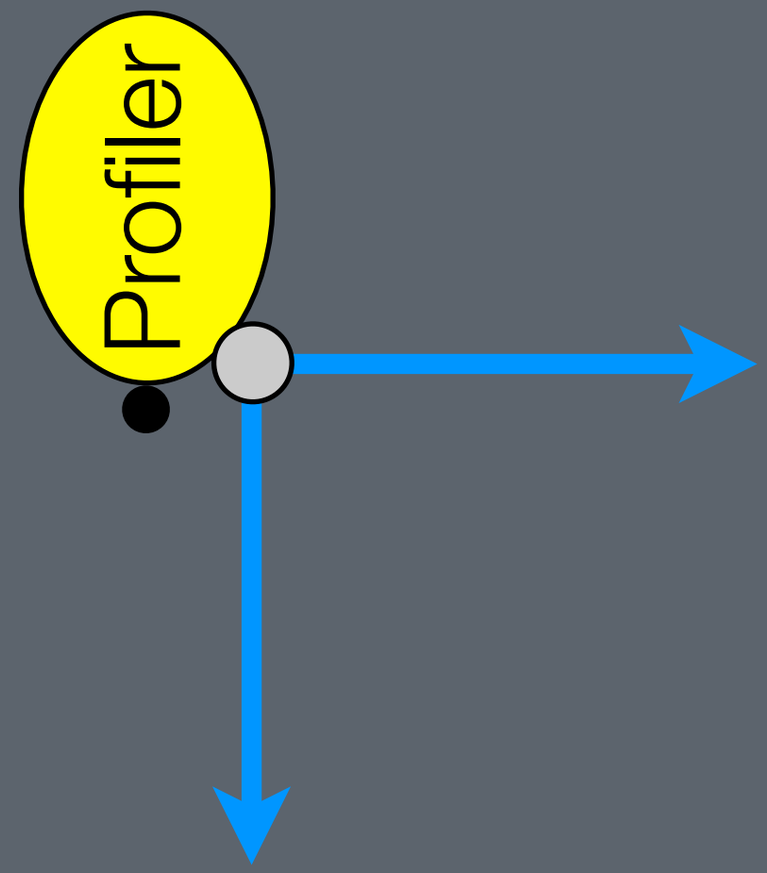

Profiler
Mean Flow


Profiler
Mean Flow

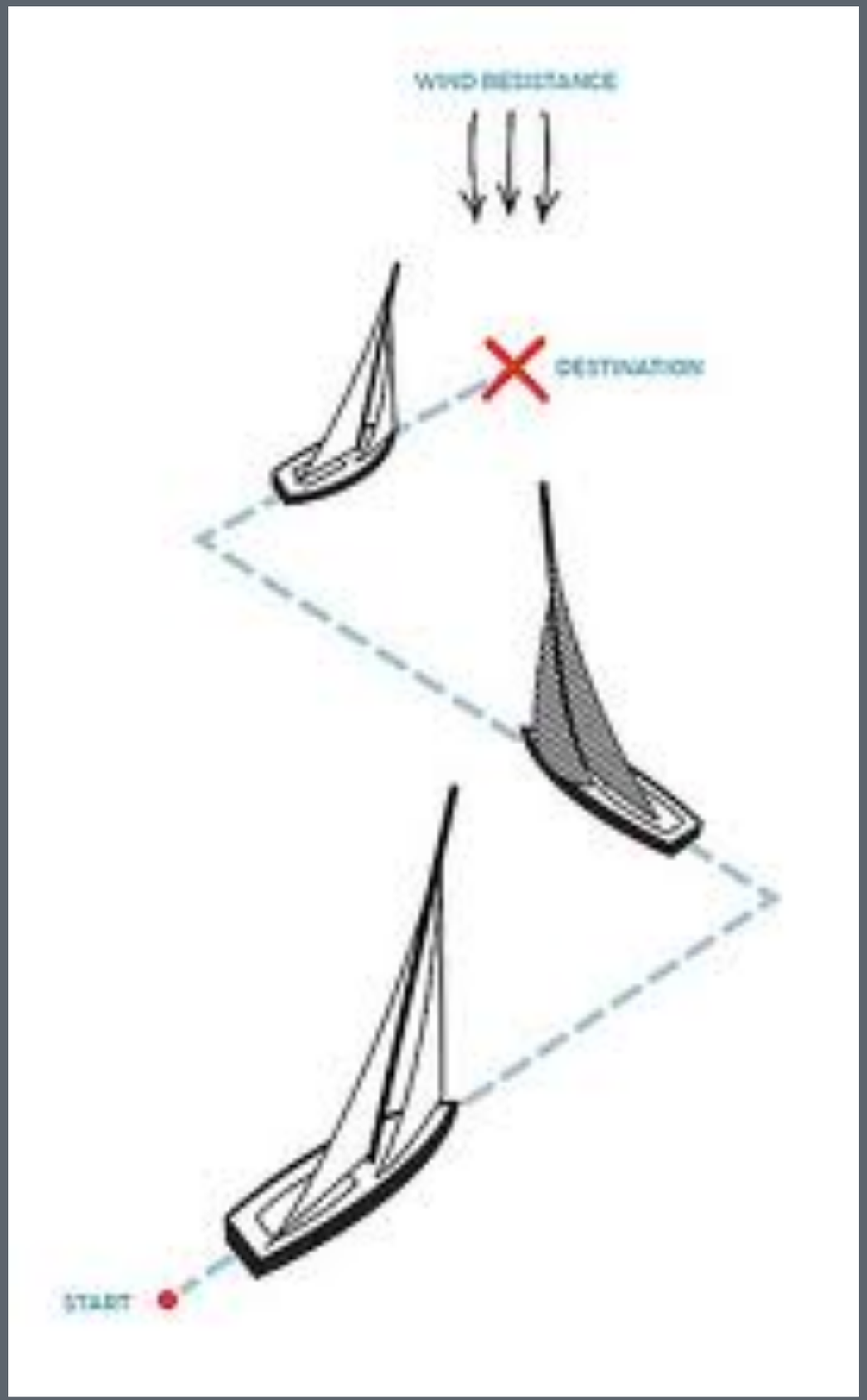

Profiler
Mean Flow

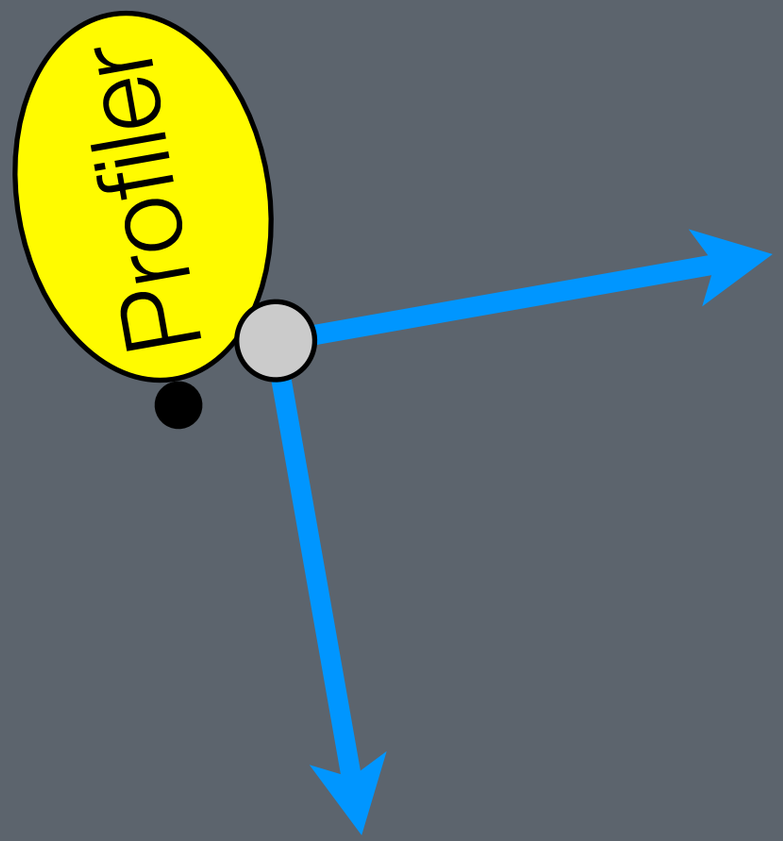

Profiler
Mean Flow



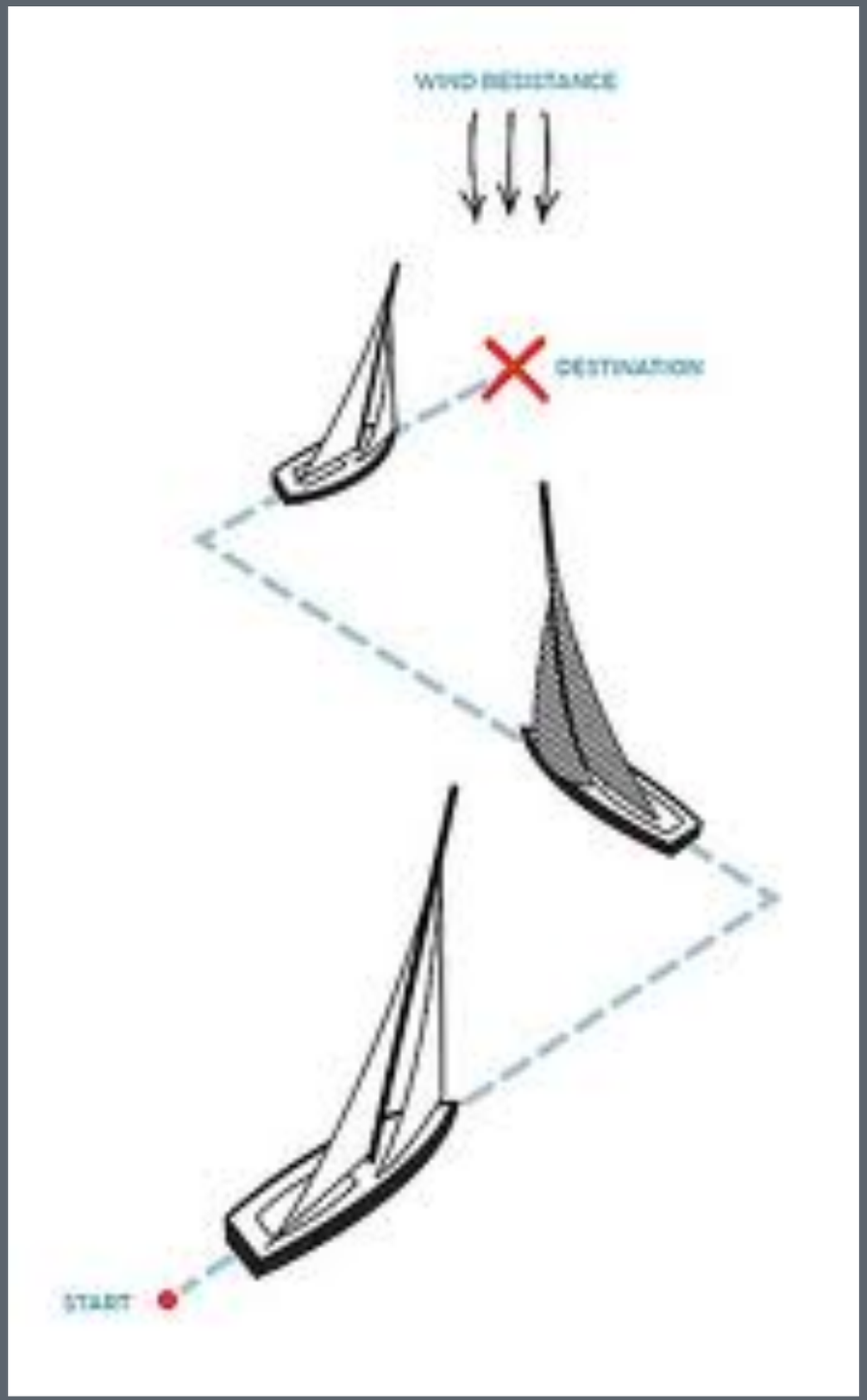


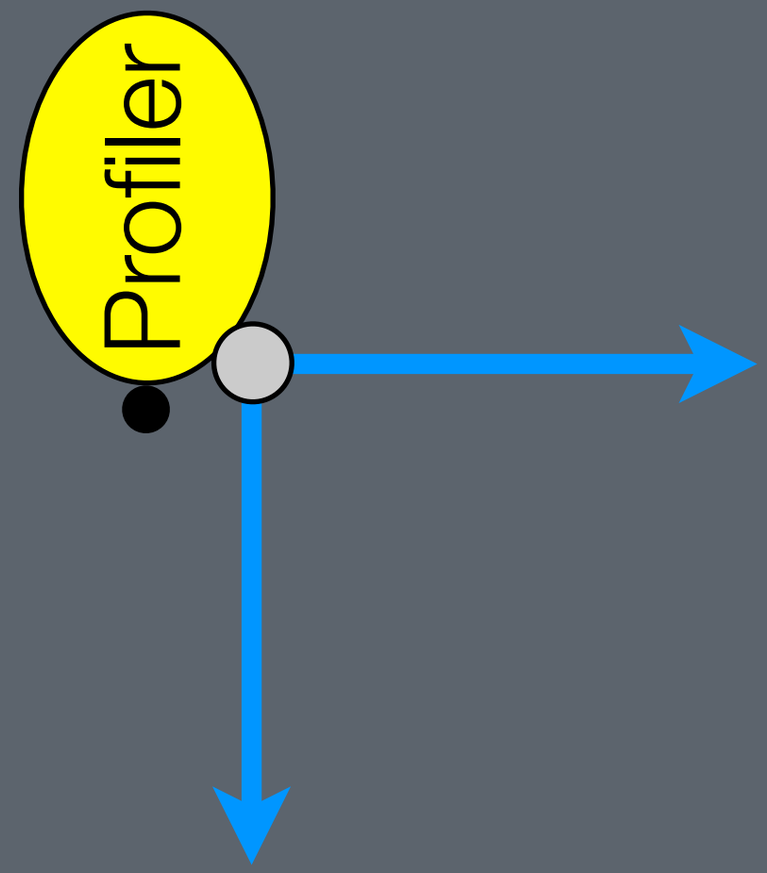
Mean Flow



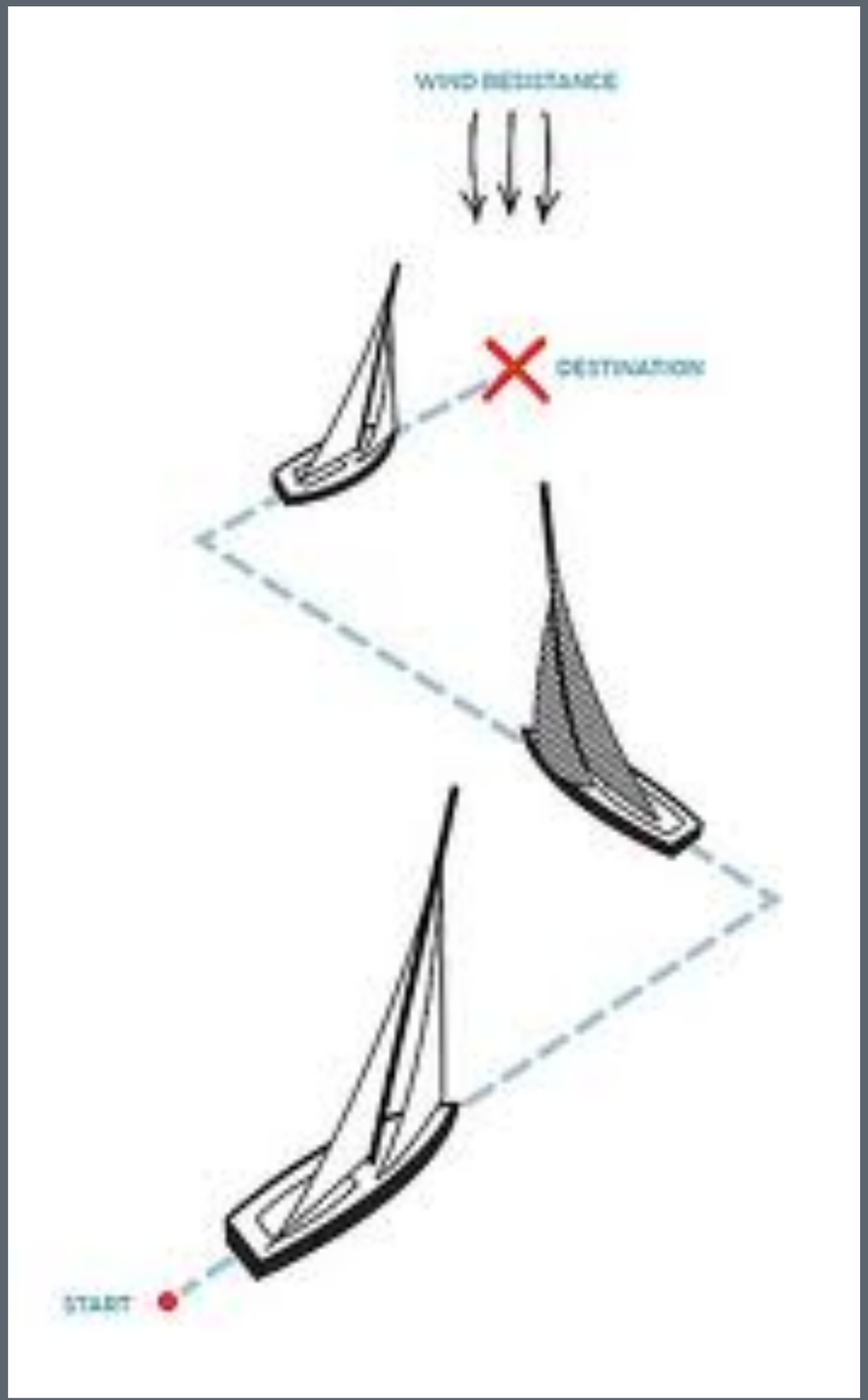


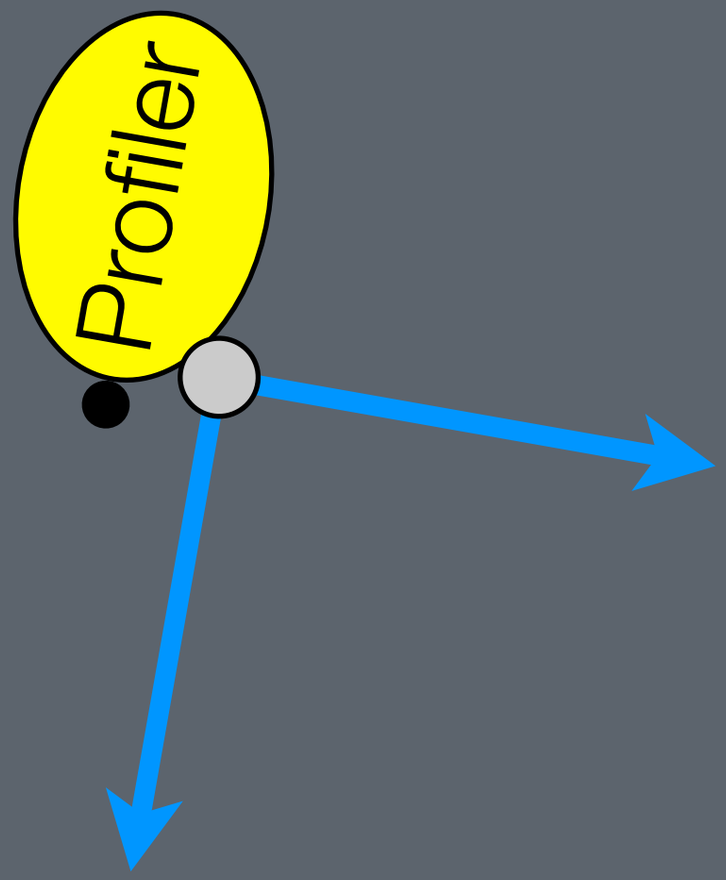
Mean Flow





Mean Flow





Mean Flow

Velocity decomposition and averaging

Profiler
Motion

$$u(t) = \overline{u} + \tilde{u} + u'(t)$$

Mean
Velocity

Turbulence

Velocity decomposition and averaging

$$u(t) = \overline{u} + \tilde{u} + u'(t)$$

Velocity decomposition and averaging

Average for a long time
to remove these
two components

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Velocity decomposition and averaging

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Average in space
to remove these
two components

Velocity decomposition and averaging

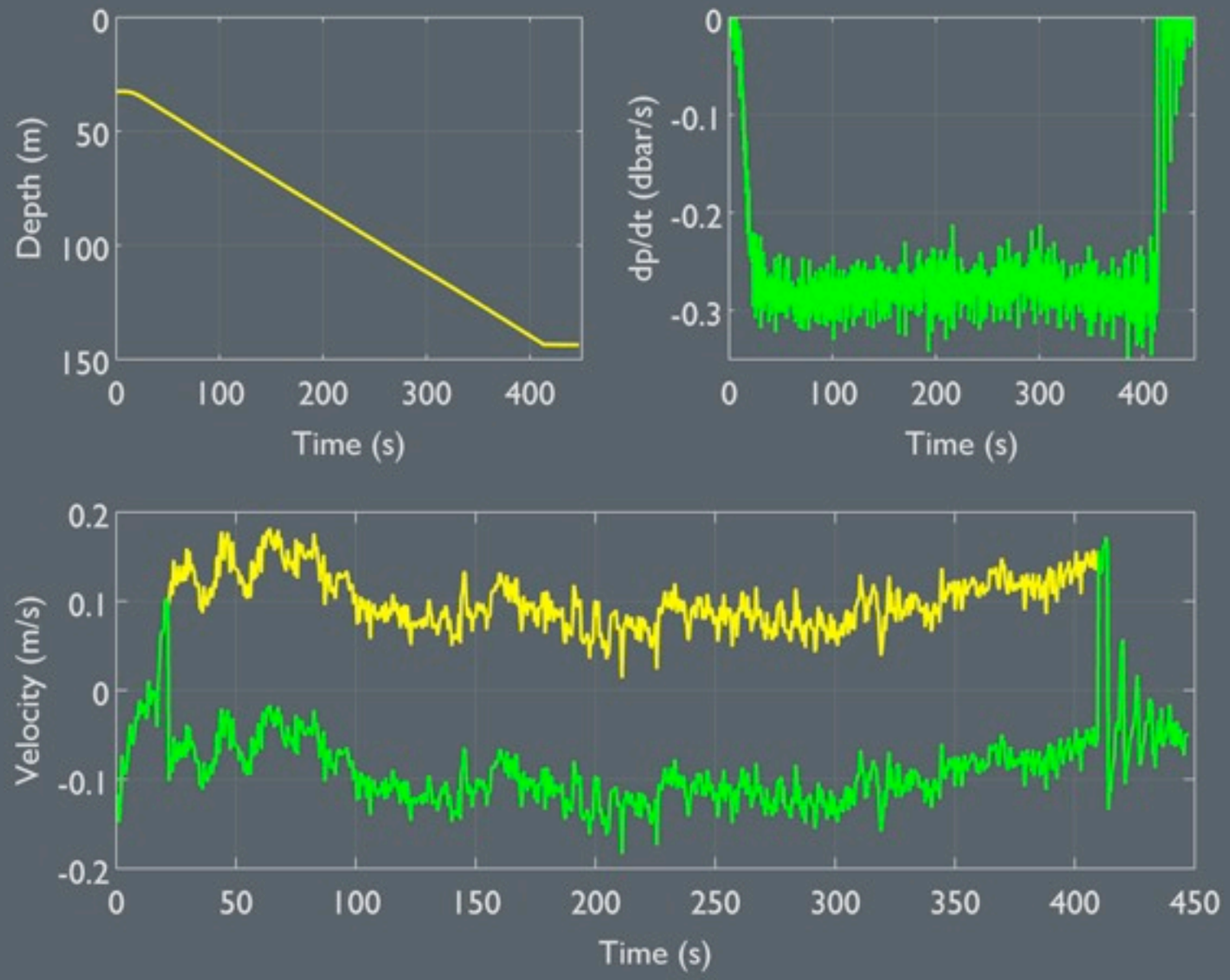
Average for a long time
to remove these
two components

$$u(t) = \overline{u} + \tilde{u} + u'(t)$$

Average in space
to remove these
two components

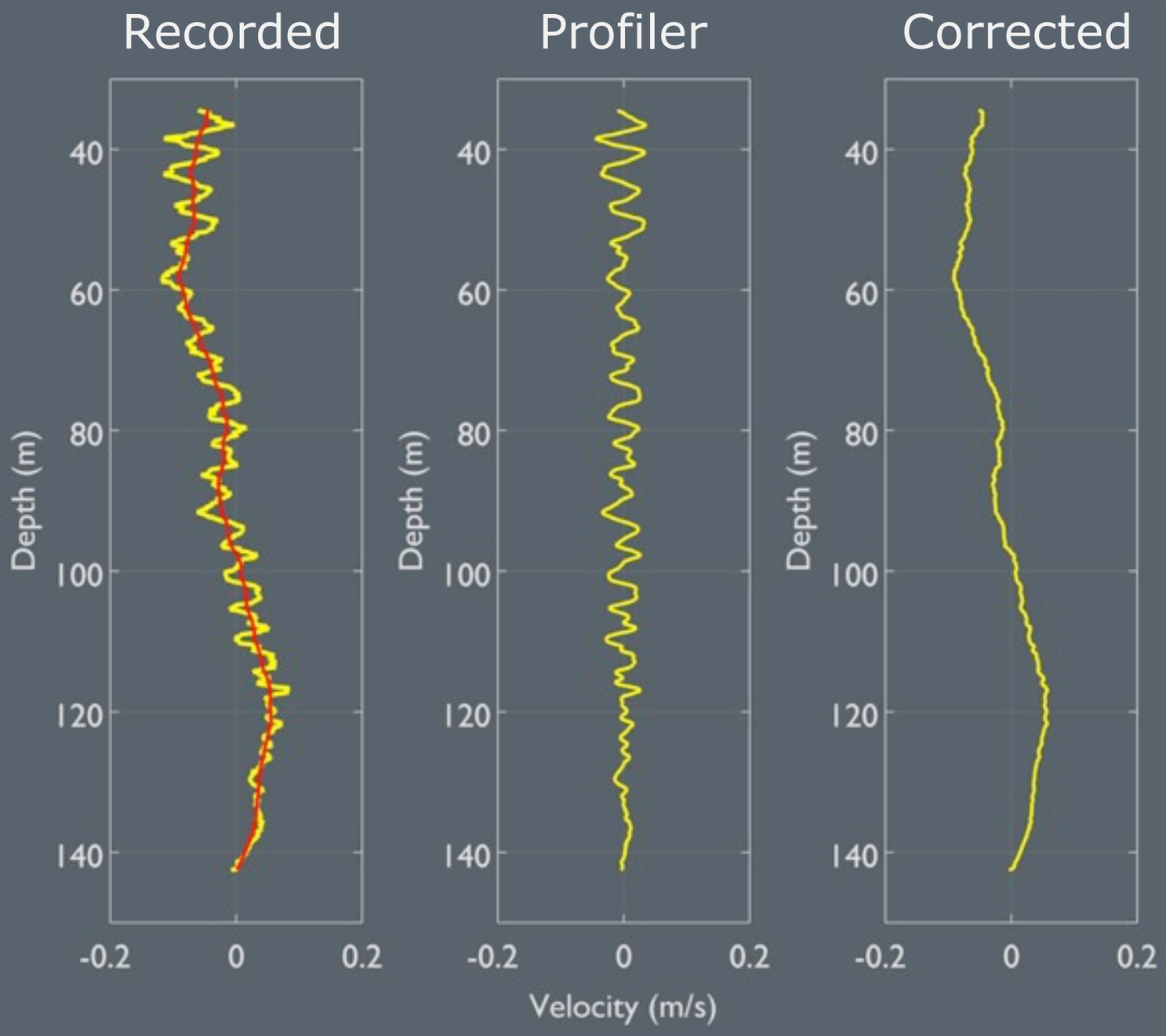
Average for a
short time
to remove (some of)
this component

Correcting for the profiler's vertical motion



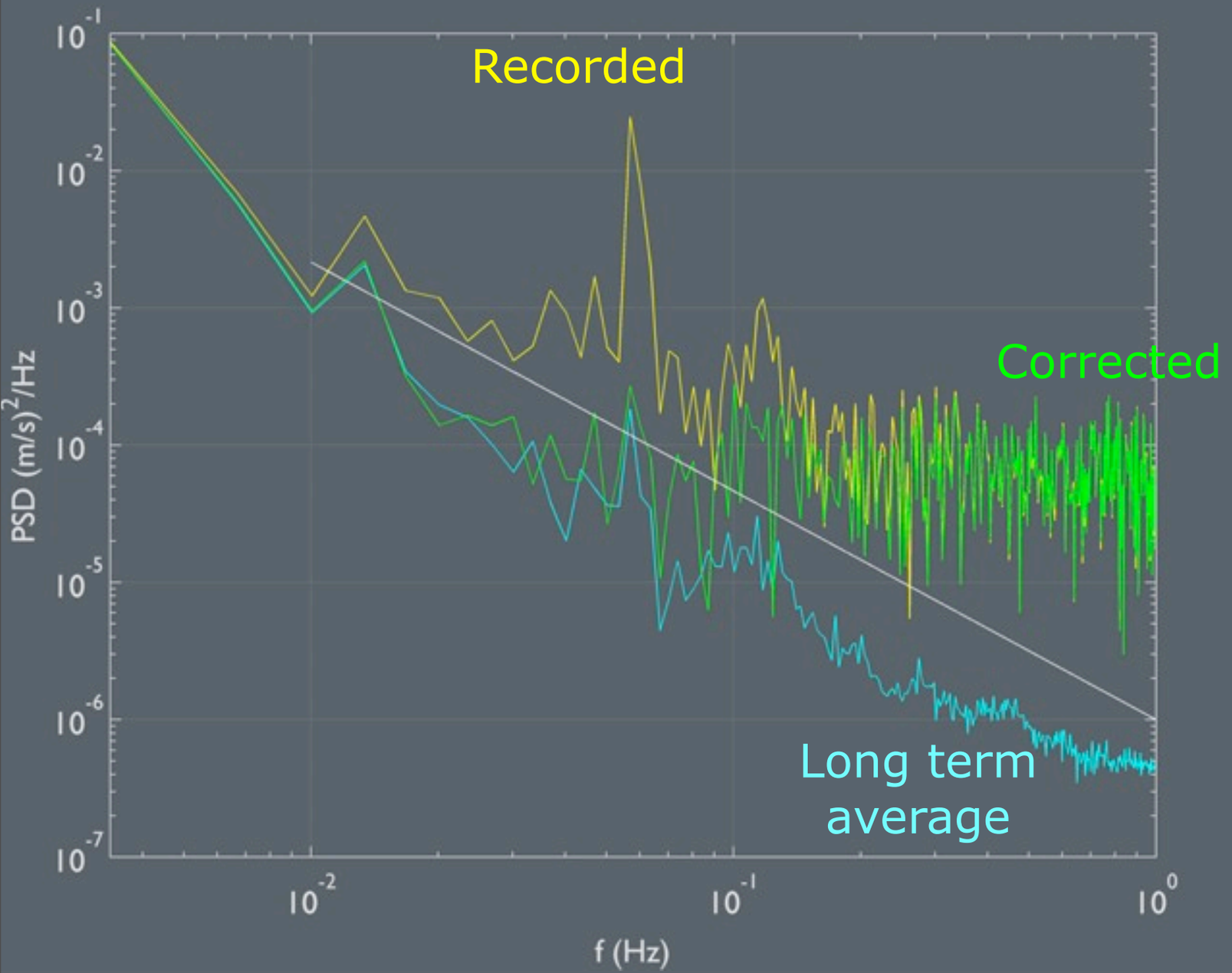
- Profiler vertical motion is estimated from pressure time series
- This is an independent measure of *w* relative to the free surface.
- Velocity correction is applied to the appropriate section of data
- Result matches values at the start and end of the profile.

Correcting for the profiler's horizontal motion



- Profiler velocity estimate obtained by differencing two different mean velocities.
- A better approach may be to use a linear filter (e.g. Shaw and Trowbridge)
- This is not an independent measure of the profiler velocity.

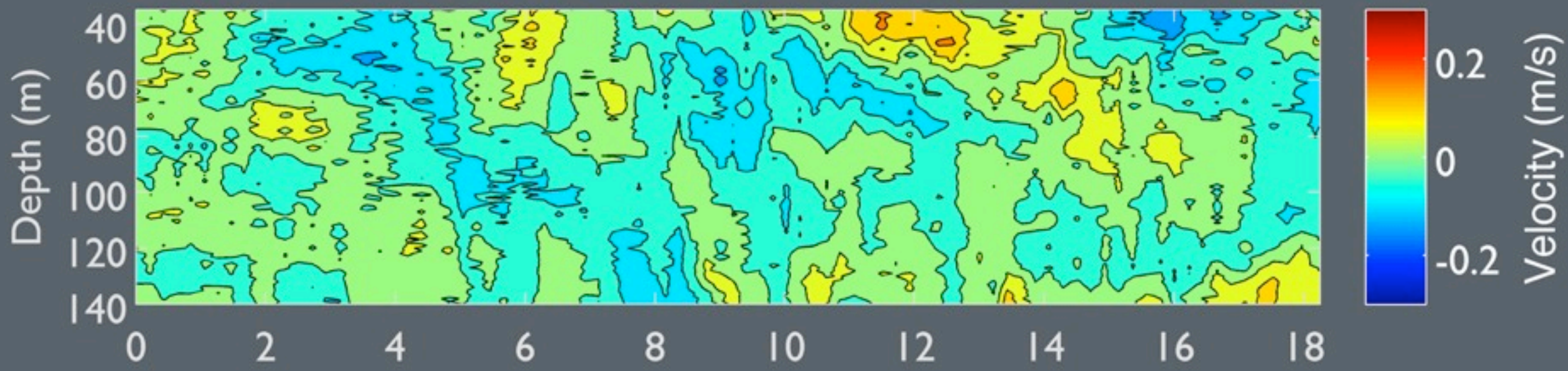
A somewhat successful correction



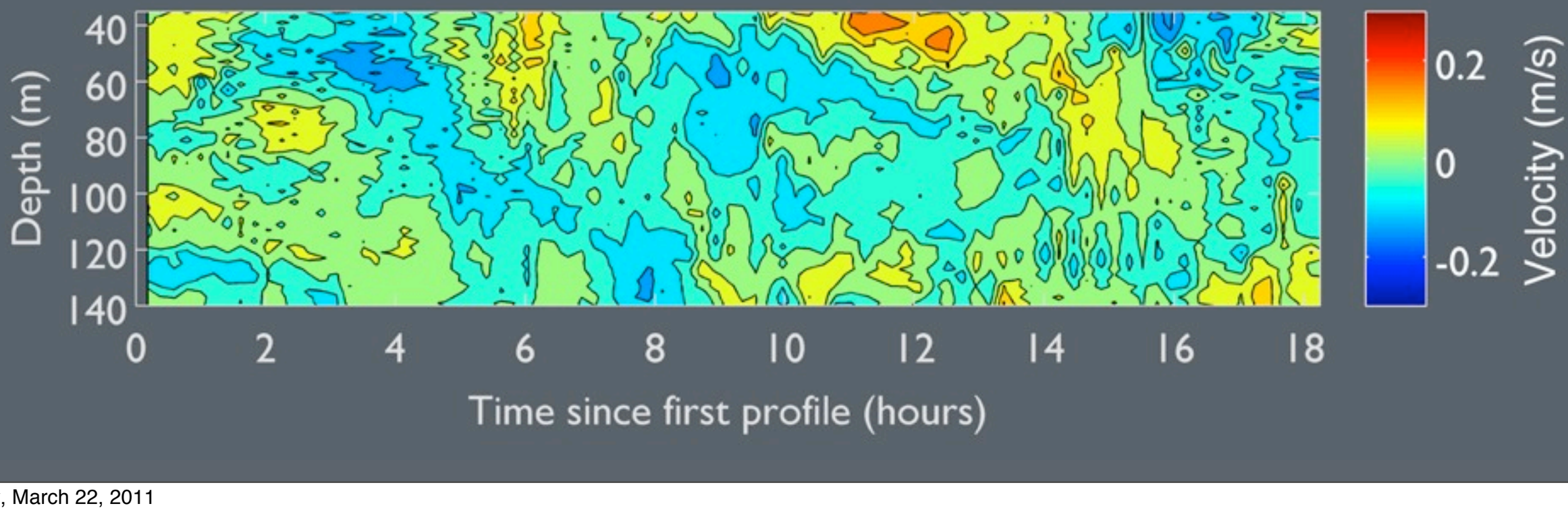
- A small amount of energy associated with the profiler motion survives.
- An independent measure of the horizontal motion will improve this correction.
- Again, we want to minimize vertical averaging to preserve structure.

Comparison of mean East current

HR Profiler

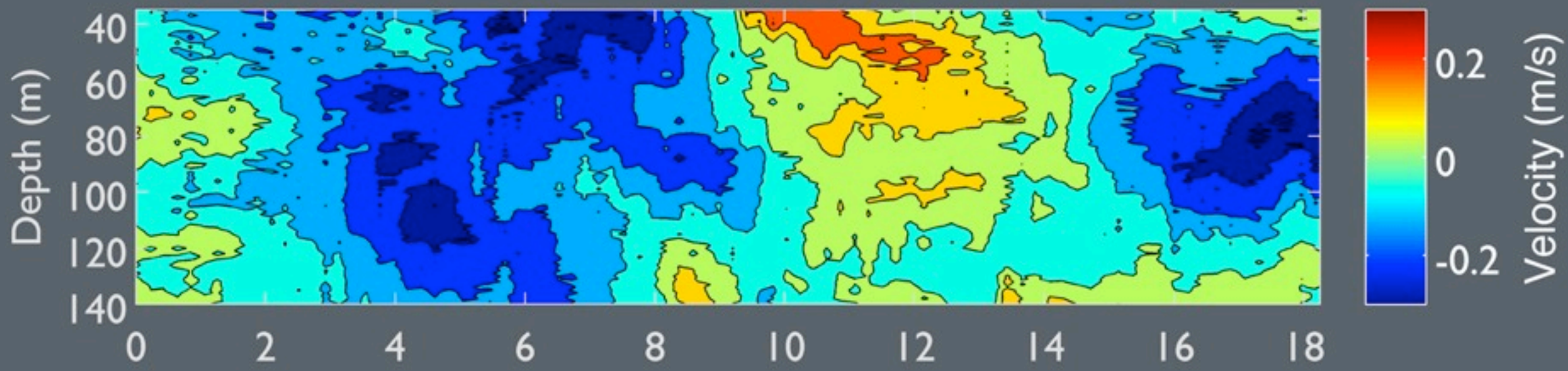


FSI Current Meter



Comparison of mean N current

HR Profiler



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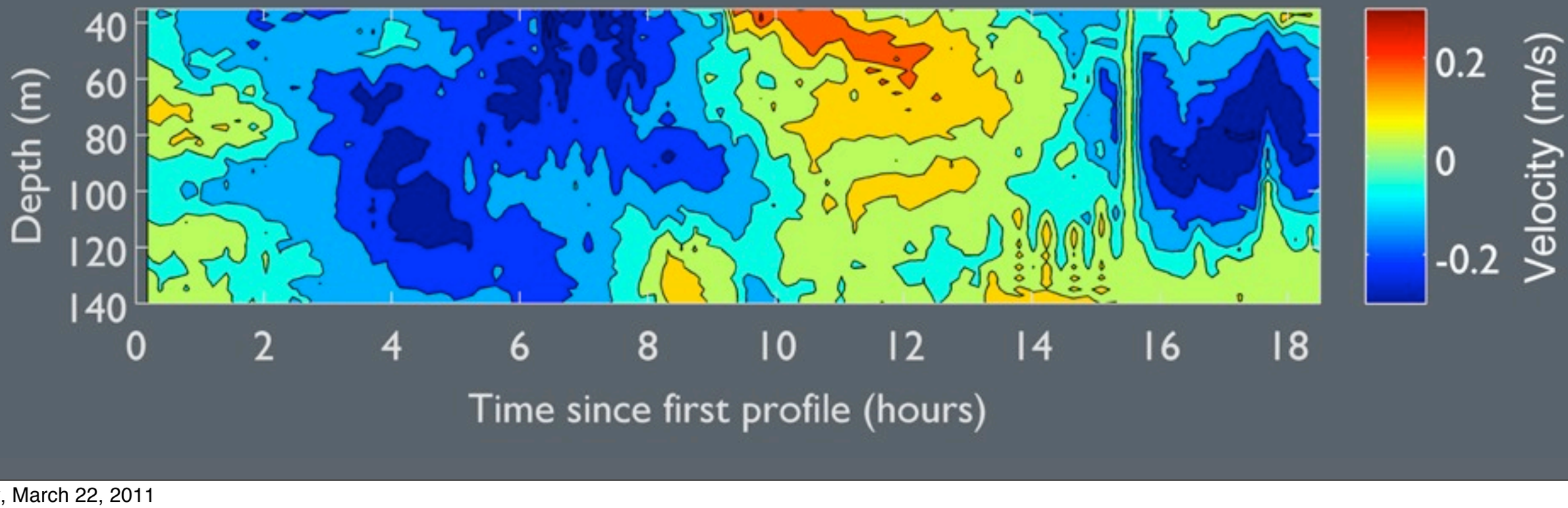
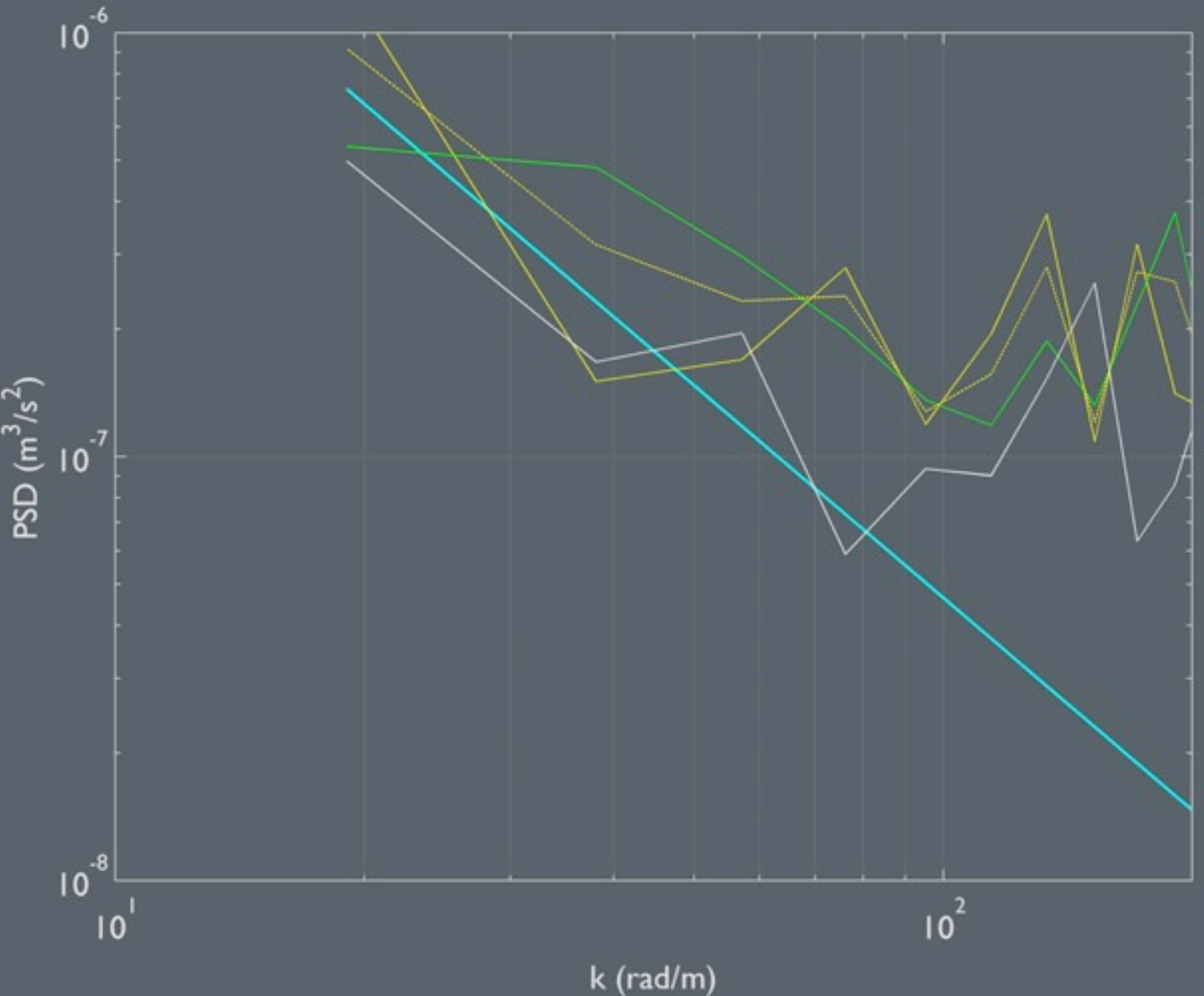
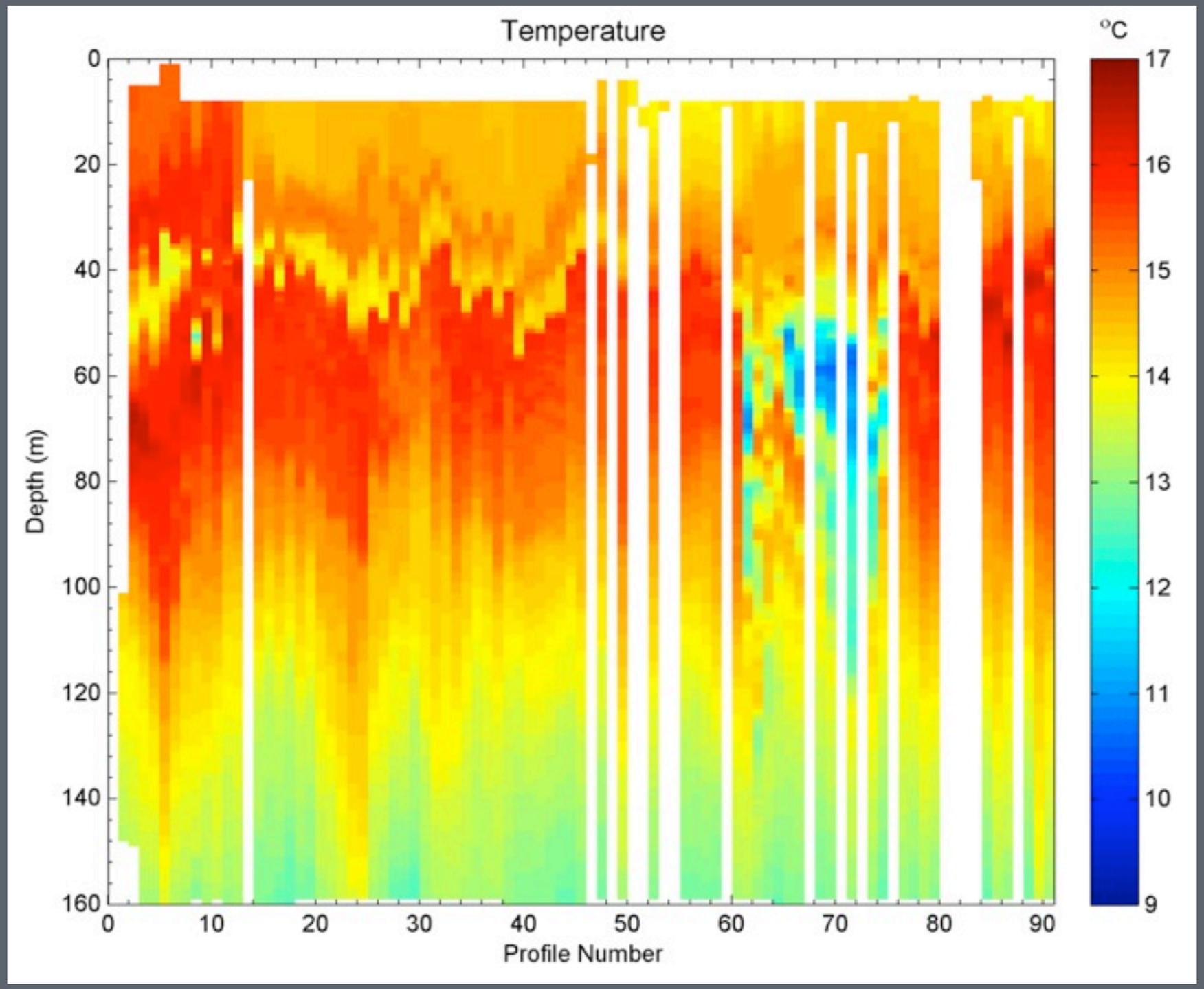


Turbulent velocity spectrum from along beam data



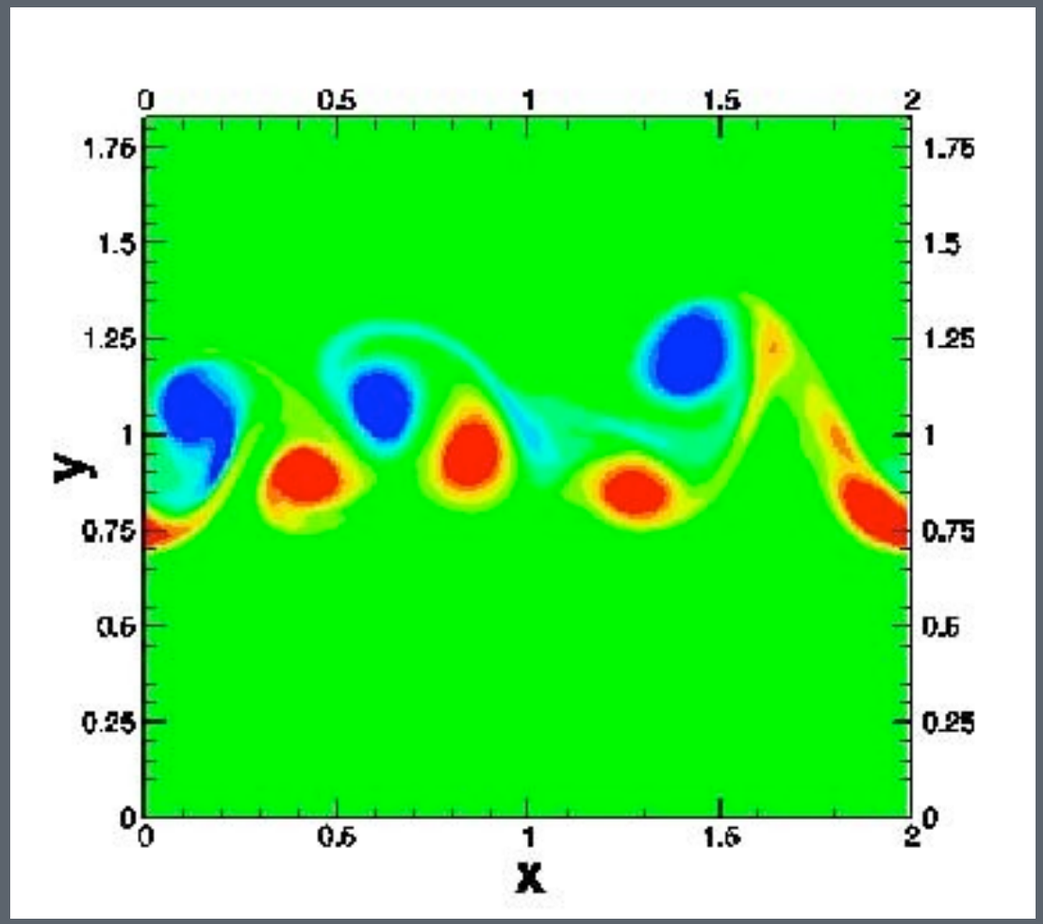
- While noisy, structure in the spatial velocity spectrum indicates we are measuring turbulence.
- This provides a means to estimate the turbulent dissipation rate (ε) and other higher order statistics.
- But what about stratification?

We have fairly strong, continuous stratification…



Stratified Turbulence

- Stratification will tend to suppress turbulent motions aligned with the density gradient (i.e. vertical).
- This results in thin layers of turbulence which maintain horizontal coherence but are potentially uncorrelated vertically.
- There are some scaling law estimates available for turbulent dissipation based on overturn Reynolds and Froude number analysis.



http://ae-www.usc.edu/research/fluid_mechanics/cfd.shtml

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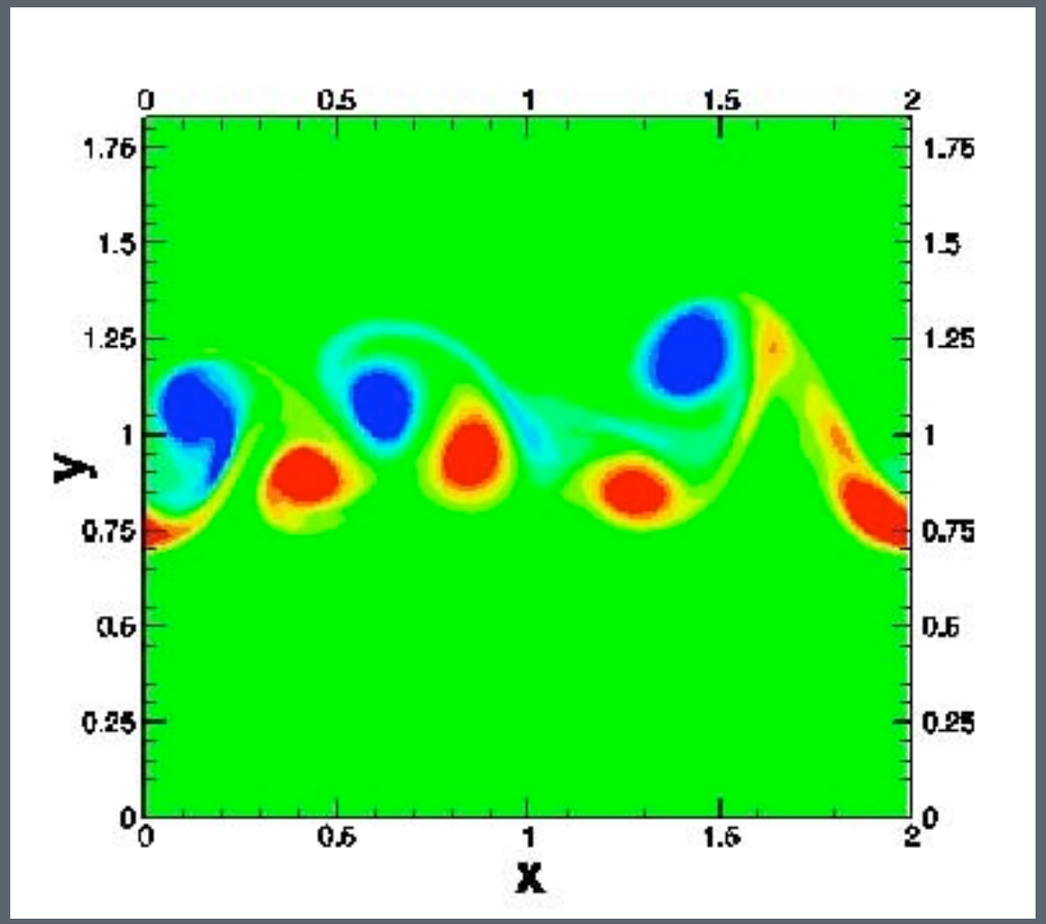
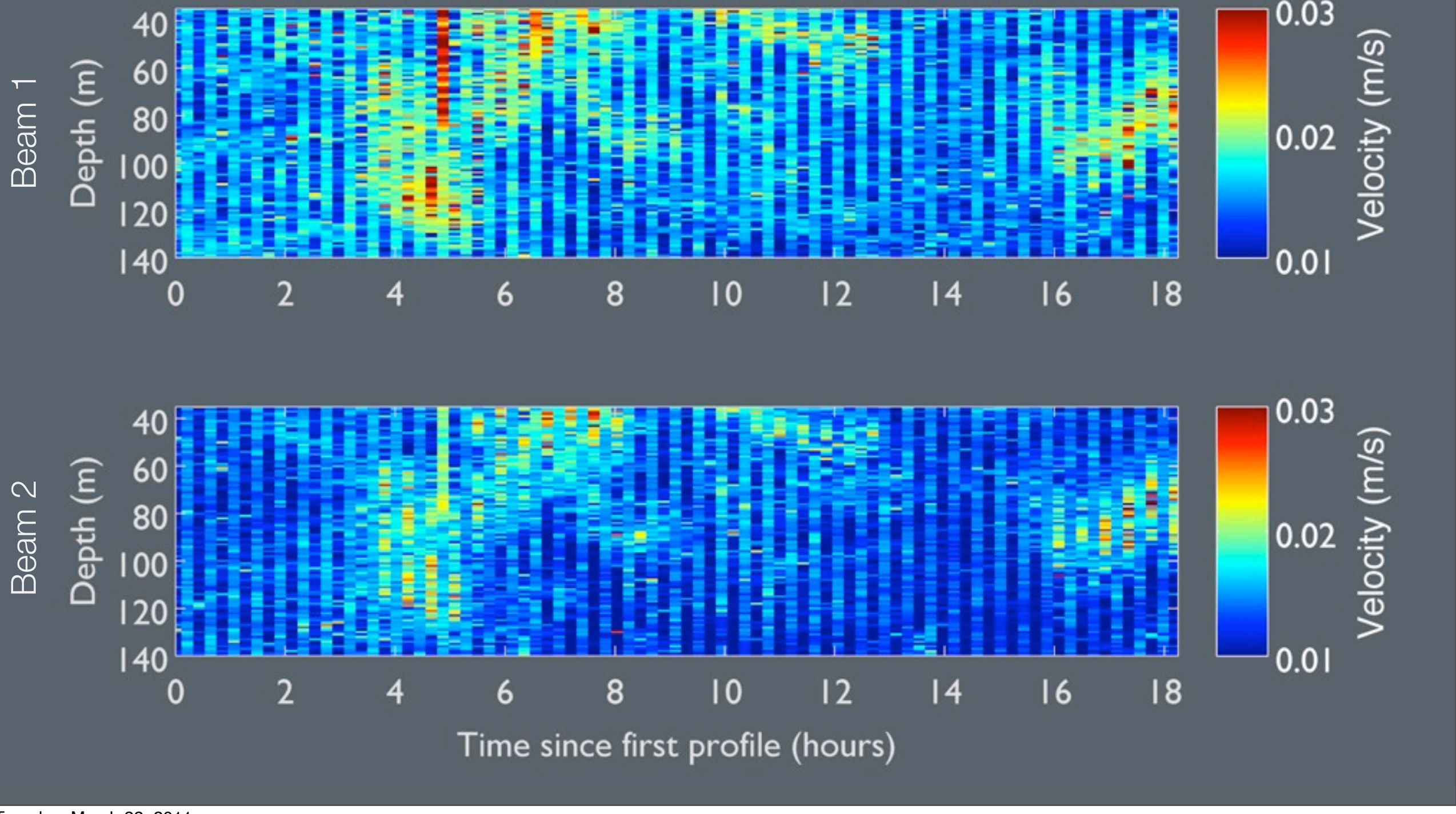


http://ae-www.usc.edu/research/fluid_mechanics/cfd.shtml

$\varepsilon \approx 10^{-9}$ W/kg

Turbulent intensities



Ongoing Work

- Integration of high resolution inertial measurement unit (IMU) with Aquadopp hardware to improve velocity corrections.
- Additional deployments and refinement of analysis procedures.
- Estimates of noise bias in various statistics.
- Validation of higher order turbulence statistics (effects of stratification, bias due to noise, etc.)

Thank you.
Questions?

If you'll be in Monterey you can see this talk again on Wednesday, March 23 between 10:40AM-12:30PM

Rusello, P.J., Alford, M.H., and Siegel, E. (2011), High Resolution Doppler Profiler Measurements of Turbulence from a Profiling Body (101013-001), Proceedings of 2011 IEEE/ OES Tenth Current, Waves and Turbulence, Measurement Workshop (CWTM)