OERA Research Project
Final Report

Going With the Flow 2:
Use of drifters to address uncertainties in the spatial variability of tidal flows

Project start date: October 15, 2017

Luna Ocean Consulting Ltd.
Dalhousie Ocean Acoustics Laboratory
Acadia Tidal Energy Institute

December 10, 2018

Executive Summary

Drifters are one of the oldest, simplest, and most reliable methods for measuring ocean currents, and also provide a simple and low risk platform from which to gather acoustic information along flow streamlines (drift tracks). In the context of tidal energy developments, drifters provide flow speed information needed for evaluating resource, engineering designing, and supporting marine operations.

With previous funding support from OERA the project team has developed:

- Instrumentation, methodology, and software for using several low-profile Global Positioning System (GPS) based drifters concurrently to map surface flows (SF drifters) at several tidal energy sites in Southwest Nova Scotia, with recent demonstration and application in the Minas Passage.
- A prototype Acoustic Doppler Current Profiler (ADCP) drifter, including demonstration in the Minas Passage.
- Drones and Drifters methodology and software for calculating flow speeds and trajectories of biodegradable drifters using aerial images collected by Unmanned Aerial Vehicles (UAVs a.k.a.drones).

The project plan for Going With the Flow 2 focuses on:

- Comprehensive characterization of Grand Passage (and to a lesser extent Petit Passage), as high quality demonstrations of flow field mapping that can now be applied to any site. The primary focus on one site allows for more advanced development and validation of the methods for data collection and analysis.
- ADCP drifter testing in Grand Passage and Petit Passage, with a focus on characterizing turbulence from a mobile platform.
- Analysis of our existing SF and ADCP drifter data sets (including Minas Passage)
- Data visualizations for information sharing

The approach includes use of:

1. The ADCP drifter to evaluate the along track:
    - vertical structure of the velocity,
    - vertical structure of turbulent dissipation rate, and
    - vorticity (at the surface).

2. Several SF drifters to evaluate spatial variation in flow speeds throughout the flood-ebb tidal cycle.

The project outcome is site characterization information useful for advancing research and micro-siting tidal turbines for testing, demonstrations, and/or commercial developments. The information has also be utilized by a) Dr. Alex Hay to advance research on turbulence in high-energy tidal environments, and b) Dr. Richard Karsten for calibration and validation of the FVCOM numerical model (FVCOM).

The surface flow measurements have been combined with existing data and updated images of surface flow-fields are available on-line with public access. A webinar providing an overview of flow speed measurements by drfiting platforms, and how they are used for site assessment and marine operations planning is avaiable at https://vimeo.com/285279452.

Example videos of flow field progression through tide time are avaiable at:

- Petit Passage https://vimeo.com/lunaocean/driftpp
- Grand Passage https://https://vimeo.com/lunaocean/gpsouth
- Minas Channel and Minas Passage https://vimeo.com/lunaocean/driftmp

For turbulence analysis, on the whole, the results are very encouraging, and clearly demonstrate that the ADCP drifter is a valuable tool for investigating large-scale turbulent structures in high-flow tidal channels. Especially noteworthy, one might even say revelatory, is the evidence for water-depth scale flow features with 1 m/s vertical velocities persisting along-track for time scales of minutes.

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1 Introduction and Objectives

Drifters are one of the oldest, simplest, and most reliable methods for measuring ocean currents, and also provide a simple and low risk platform from which to gather acoustic information along flow streamlines (drift tracks). In the context of tidal energy developments, drifters provide flow speed information needed for evaluating resource, engineering designing, and supporting marine operations.

With previous funding support from OERA the project team has developed:

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The original project objective was to reduce uncertainty in the spatial variation in flow speeds (including turbulence) within the Minas Passage (focus on the FORCE site), Grand Passage, and Petit Passage.

The proposed project plan for the Minas Passage was to collect data prior to and following deployment of the OpenHydro turbine (Berth D), and of use for planning an array of Tocardo turbines and at Berth A. However, the redeployment of the OpenHydro turbine was delayed, then access complicated by external factors. Also, the technology choice for Berth A became uncertain due to financial difficulties for Tocardo, and there has been a significant technology change for the Black Rock Tidal project. With consideration of the activities at FORCE, and other opportunities to work there in 2019, we adjusted the plan to focus efforts on:

- Comprehensive characterization of Grand Passage (and to a lesser extent Petit Passage), as high quality demonstrations of flow field mapping that can now be applied to any site. The primary focus on one site allows for more advanced development and validation of the methods for data collection and analysis.
- ADCP drifter testing in Grand Passage and Petit Passage, with a focus on characterizing turbulence from a mobile platform.
- Analysis of our existing SF and ADCP drifter data sets (including Minas Passage)
- Data visualizations for information sharing

2 Methodology and Results

The approach includes use of:

1. The ADCP drifter to evaluate the along track:
   - vertical structure of the velocity,
   - vertical structure of turbulent dissipation rate, and
   - vorticity (at the surface).
2. Several SF drifters to evaluate spatial variation in flow speeds throughout the flood-ebb tidal cycle.

2.1 Data Collection

The level of effort for data collection is provided on Table 1, where the * marks days where the ADCP drifter was used. Note that the budget includes only 3 days for data collection. The significant effort applied to mapping Grand Passage was accomplished due to proximity to the Luna Ocean office, a beautiful October 2017, and in-kind contributions from Luna Ocean to cover boat time (using the Puffin), professional time, and expenses (batteries and fuel) in order to utilize Grand Passage as an example of a world-class mapping effort. The Grand Passage surface flow data set has 478115 data points, with 347570 contributed by this research project. The Petit Passage data set has 140284 data points, with 84193 contributed by this research project.

Site	Date (2017)	Duration (hours)	Data points
Grand Passage	Oct 6	2.9	30329
Grand Passage	Oct 7	7.3	58826
Grand Passage	Oct 12	9.2	67707
Grand Passage	Oct 13	7.5	61211
Grand Passage	Oct 15	2.0	11317
Grand Passage*	Oct 28	7.9	69930
Grand Passage	Nov 2	3.4	48250
Petit Passage*	Nov 1	8.6	84193
Total		**48.8**	**431763**

Table 1: Summary of survey dates, duration, and surface flow data points collected. * marks days where the ADCP drifter was used.

2.2 Flow Speed Analysis

For flow speed analysis, the GPS data were processed with Luna Ocean Data Analysis Software (LODAS) where the time series of position (latitude and longitude) are used to calculate velocities at a frequency of 1 Hz. QA/QC is manually applied, including inspecting each drift and removal of data from the start and end points to account for time with GPS on boat and initial acceleration and recovery. The non-dimensional tide time ($\hat{T}$) and tidal range ($\hat{R}$) paramaters were used to reference the data, where $\hat{T}$ is the position in time between two consecutive low waters (0 to 0.5 is flood and 0.5 to 1 is ebb), and $\hat{R}$ is the tidal range during data collection normalized by the 18.6 year maximum. These paramaters were introduced in *Trowse et al.* (2013), where $\hat{T}$ was referred to as α and $\hat{R}$ as β. . The LunaTide ”Phase-Learning” approach was then applied to generate tidal current forecasts for days of interest. LunaTide is under development with funding support from NRC-IRAP, with objective of having a prototype web-based system avaiable by Spring 2019.

A webinar providing an overview of flow speed measurements by drifting platforms, and how they are used for site assessment and marine operations planning is available at https://vimeo.com/285279452.

Surface flow filed maps for Grand Passage and Petit Passage are shown on Figures 1 and 2 for spring tide conditions. Example ADCP drifter data plots are shown on Figures 3 and 4.

Example videos of flow field progression through tide time are available at:

- Petit Passage https://vimeo.com/lunaocean/driftpp
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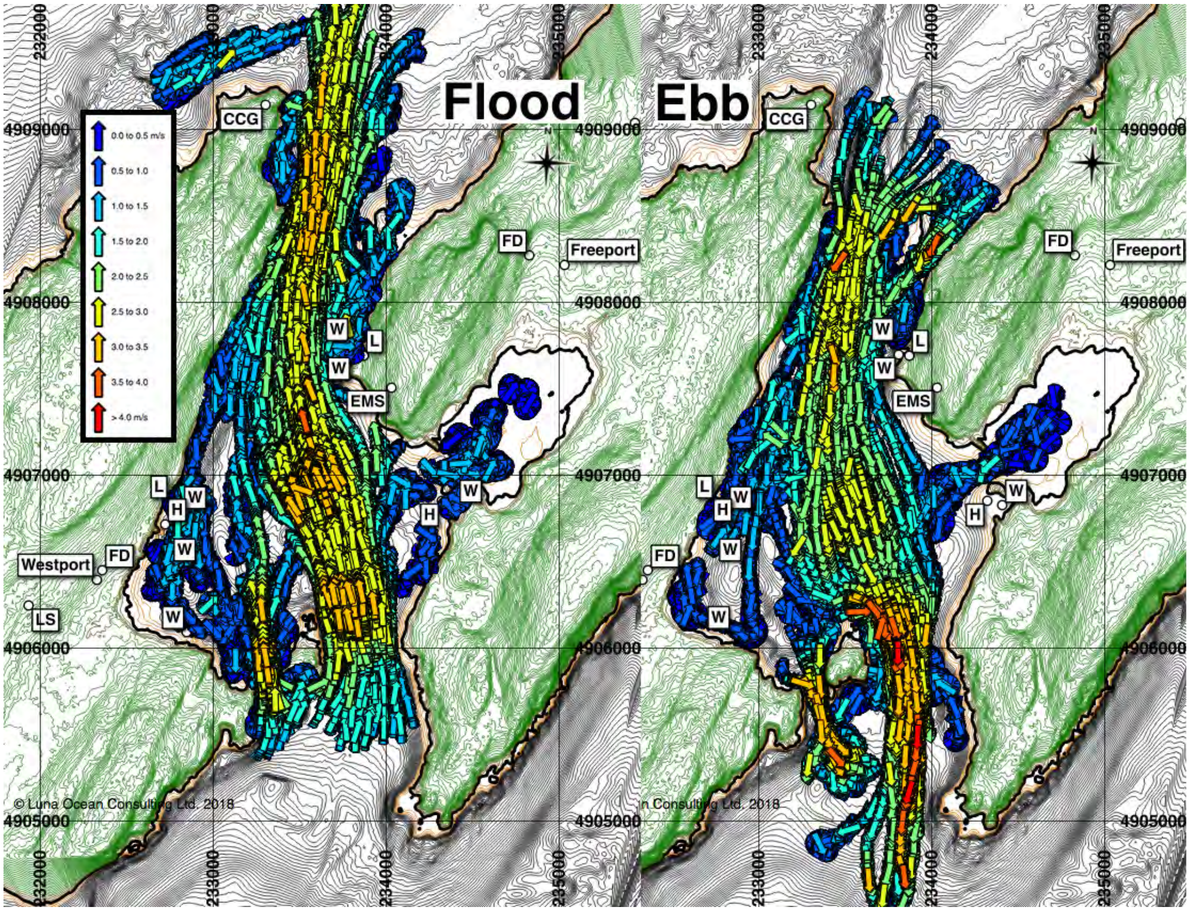

Figure 1: Grand Passage spring tide surface flow field

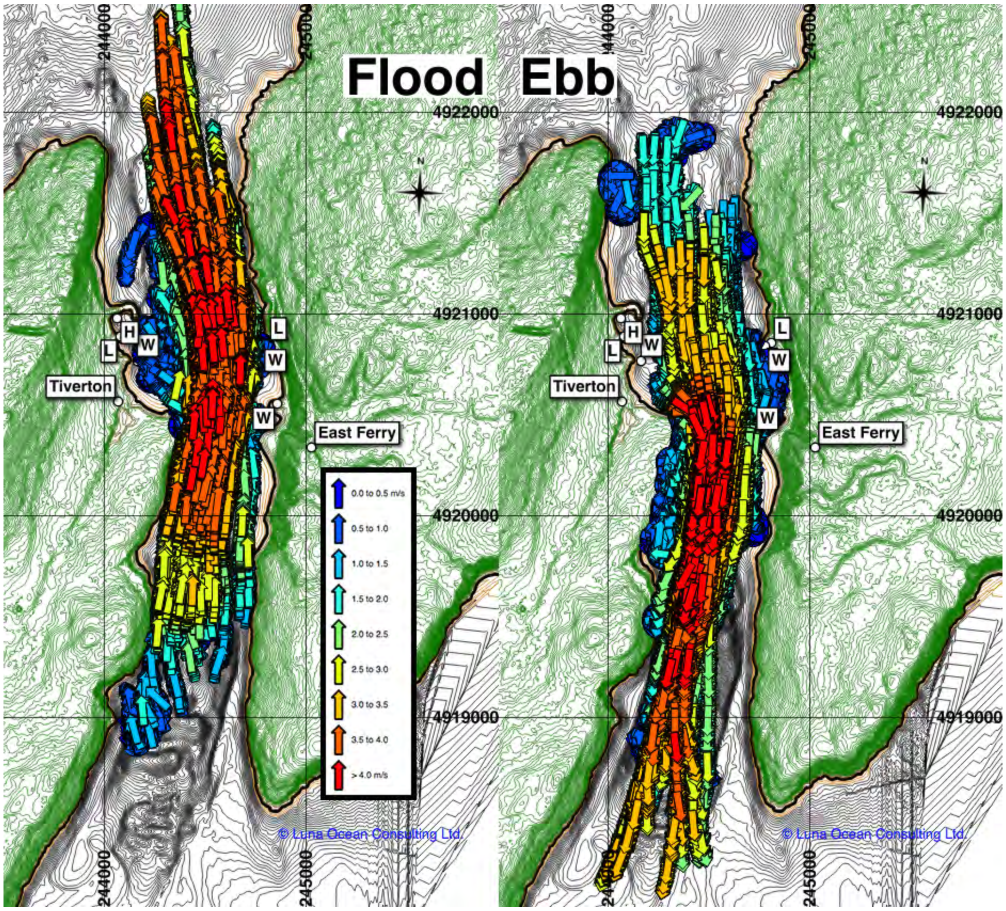

Figure 2: Petit Passage spring tide surface flow field

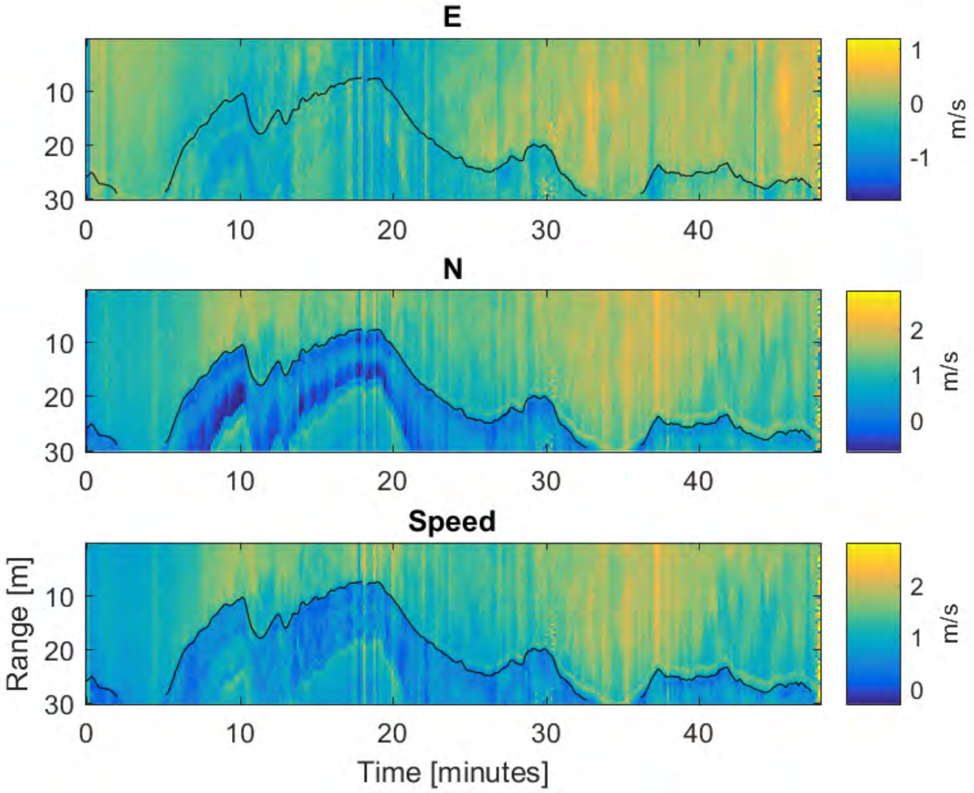

Figure 3: Grand Passage example ADCP drifter data plot (10 second averaged data)

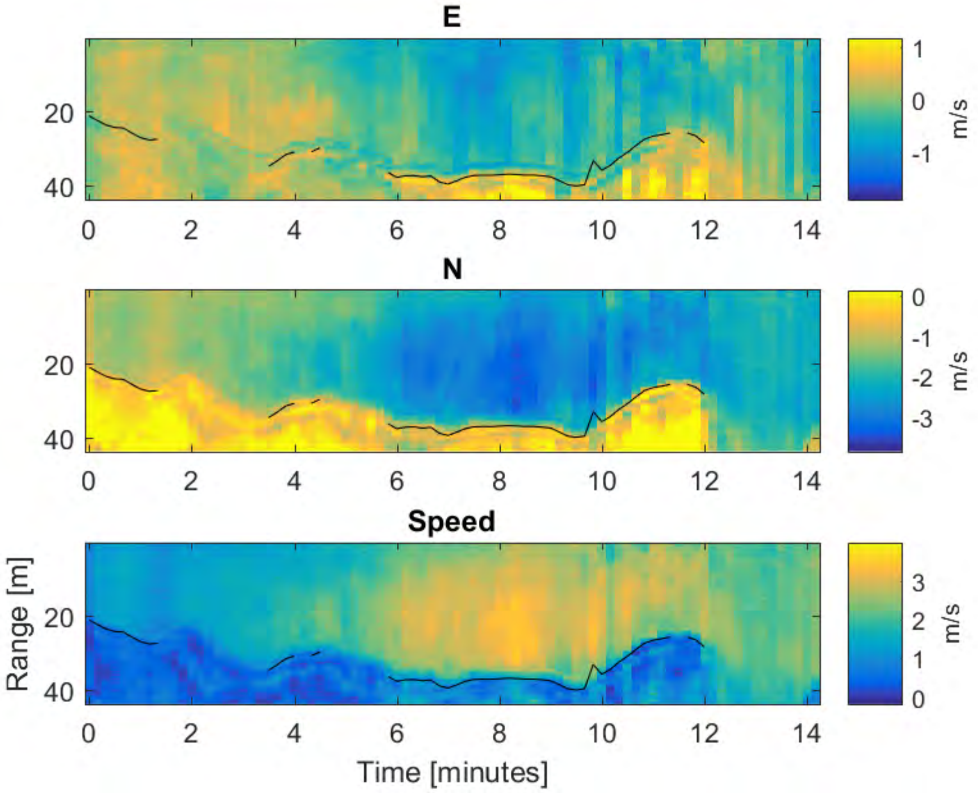

Figure 4: Petit Passage example ADCP drifter data plot (10 second averaged data)

2.3 Turbulence Analysis

2.3.1 Processing

Since the objective of the project is to determine the feasibility of obtaining turbulence measurements from the drifting ADCP in high-flow tidal passages, the analysis focused on the data from the vertical beam, since it is least affected by the drifter motion. No motion correction was applied. The velocities from the centre beam are nominally vertical, and here are treated as being identically vertical: i.e. equal to the actual vertical velocity, w.

The objective of the analysis of the data so far has been to determine the energy spectral density of the vertical velocity fluctuations, $S_{ww}(k)$, where k is the vertical wavenumber and from these spectra after correcting for Doppler noise to estimate the variance σw^2 (i.e. the w contribution to the turbulence kinetic energy) as a function of flow speed (i.e. the drifter speed over ground).

The ADCP acquired data at 4 Hz in either 0.5 or 1 m range cells, out to a maximum range of 45 m. To obtain spectral density estimates at wavenumbers as low as possible, data segments were selected from each drift for which the minimum water depth was 20 m. To suppress Doppler noise while maintaining high spatio-temporal resolution, 10-ping ensembles were averaged prior to computing the spectrum: i.e. a 2.5 s time average, corresponding to a 10 m spatial average for a drift speed of 4 m/s. The resulting ensemble-averaged w profiles where demeaned, and Hanning-windowed over the full depth of the profile, prior to computing the spectrum.

For the above ADCP settings, the manufacturers setup software indicates an expected error between about 6 cm/s and 14 cm/s, the exact values vary with maximum range, which varied a little for different deployment days, for 1 and 0.5 m cell sizes respectively. Thus, for 10-ping ensembles, the Doppler noise spectral density is expected be 0.0010 and 0.0020 m3/s2 for 1 and 0.5 m range cells, respectively.Turbulence energy dissipation rate was estimated using the second-order structure function, as outlined in *McMillan and Hay* (2017).

2.3.2 Results

Results for a representative drift are presented in Figure 5. The data in Figure 5 are from Minas Passage for a mean flow speed 3 m/s. Many of the figures in this report are in the same format. The top panel, a, shows the ensemble-average w profiles. Panel c shows the 10-ping ensemble acoustic backscatter profiles, uncorrected for attenuation and spreading. The 10-ping ensemble w spectra were averaged in 2-minute blocks, and are shown in Panel b. Panel d shows the drifter track. The coordinates x and y are the east-west (positive eastward) and north-south (positive northward) positions relative to the overall mean along-track position. Each point is a 10-ping ensemble position, the colours represent the 2-minute intervals, the repeating temporal sequence in time being black, blue, green etc. ending with magenta (the same colour scheme is used in panel b). The white dots represent the mean position in each 2-min segment. Panels e and d show the mean speeds and RMS vertical velocity (i.e. the square root of σw^2).

The data in Figure 5a exhibit vertical structure on 10-m scales, varying with time on 1-min time scales. The variability is roughly the same over the full 13-min duration of the drift, and is reflected

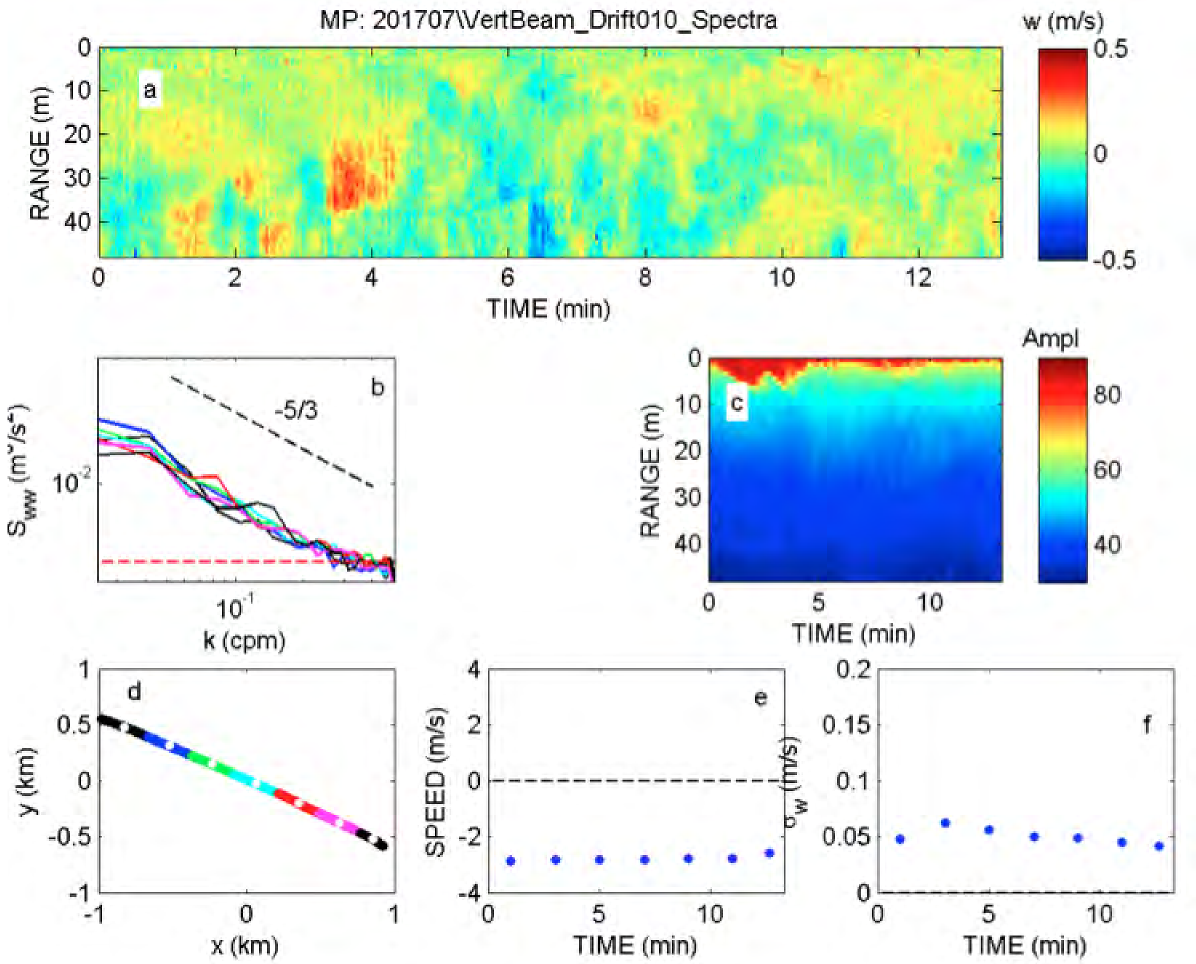

Figure 5: Turbulence Analysis - Representative Drift 1

in the fact that the average spectra in the 2-min segments are very similar (Figure 5b). These spectra all exhibit the -5/3 slope expected for fully-developed turbulence, indicated by the dashed red line. At the smallest resolved scales (highest wavenumbers), they also tend to asymptote to the expected Doppler noise level, indicated by the dashed red line. Figure 6 shows a similar set of results, also from Minas Passage, but for a much weaker mean flow. The spectra are all very near the Doppler noise level. Together, these data provide clear evidence that the ADCPdrifter is able to measure turbulence along-track to water depths exceeding 40 m.

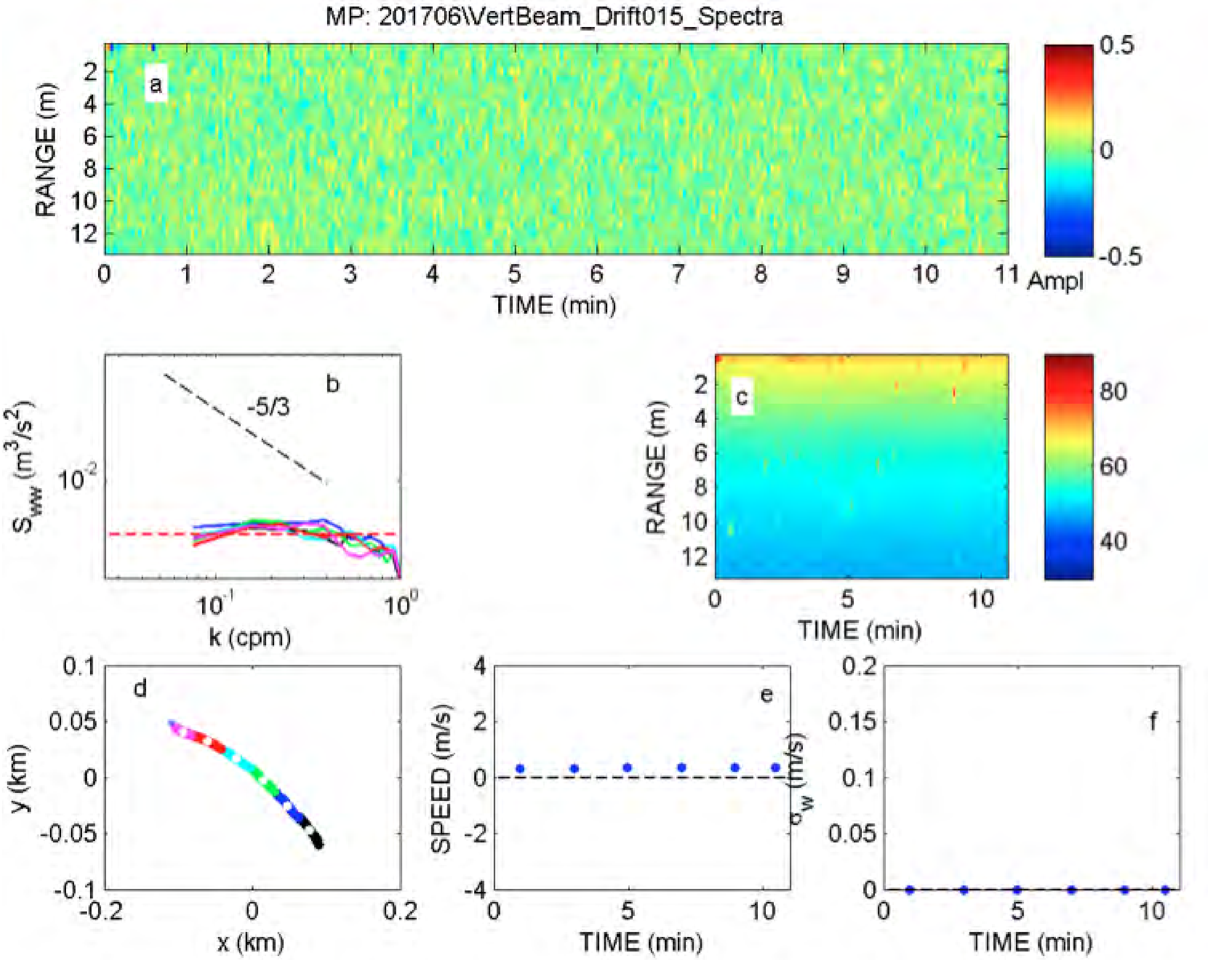

Figure 6: Turbulence Analysis - Representative Drift 2

In one instance, the drifter was captured by a whirlpool during one of the drifts in Minas Passage and sucked beneath the water surface. Beam 5 did not return useful data while the drifter was in the whirlpool, likely due to the presence of air also trapped within the vortex tube penetrating the water column beneath the drifter carried. However, as shown in Figures 7 and 8, the data during the time prior to capture and after release, are of high quality.

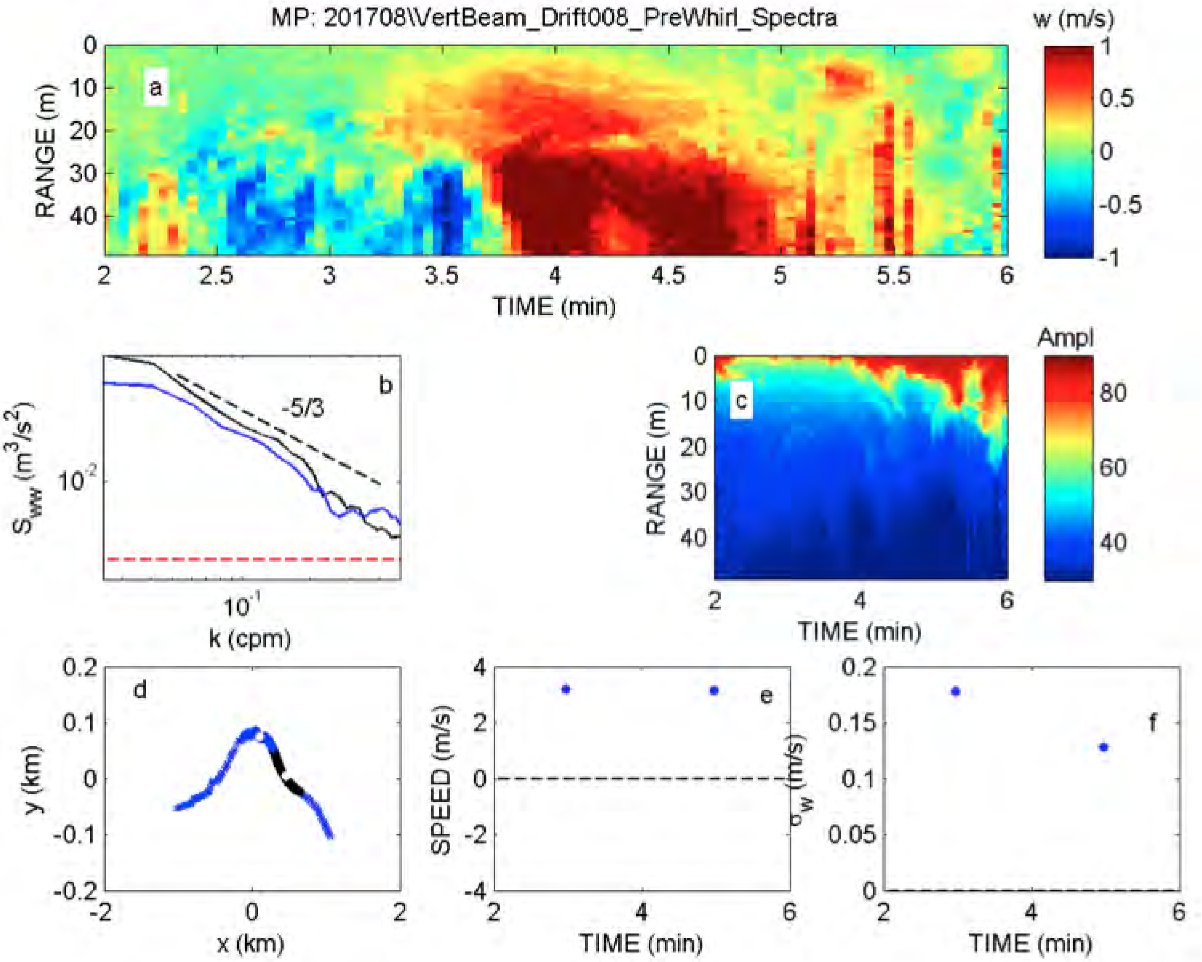

Figure 7: Turbulence Analysis - Pre-Whirlpool. Note the +/- 1 m/s scale in panel (a)

Furthermore, as might be expected given the conditions required for the formation of m-scale whirlpools at the sea surface, the corresponding spectral densities and values of w are significantly in these Figures than in Figure 5. Note as well the very high (> 1 m/s) vertical velocities in prior to the drifter being captured by the whirlpool (Figure 7a).

Results of comparable quality were obtained from the drifts in Petit Passage and Grand Passage. Figure 9 summarizes the results, showing the combined values of σ_w from the three passages plotted

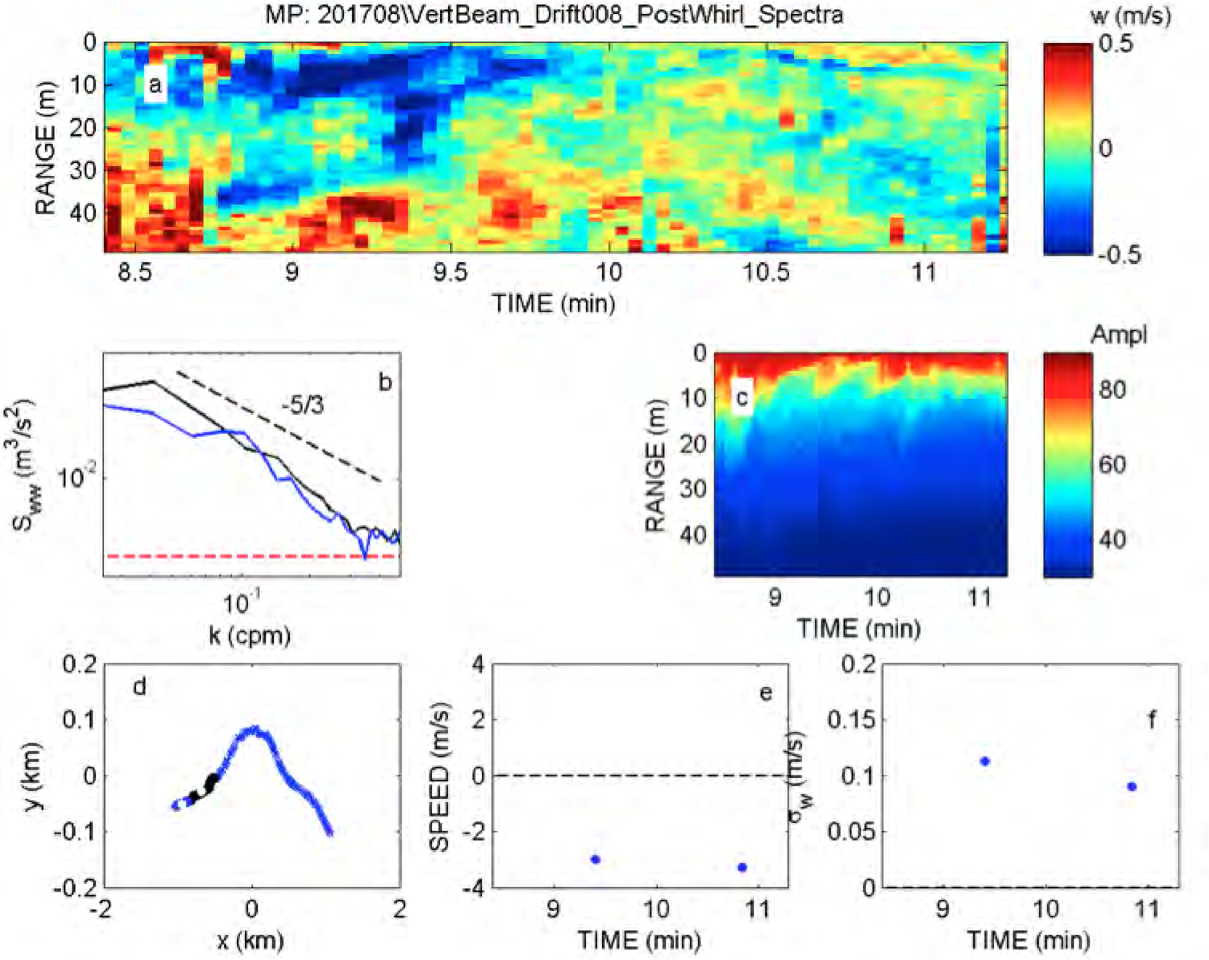

Figure 8: Turbulence Analysis - Post-Whirlpool

against the magnitude of the mean speed during the 2 min segments along each drift. There is a trend toward higher turbulence intensities with increasing drift speed. The fact that Minas Passage is more turbulent than Petit, and Petit moreso than Grand, is clearly indicated. However, the more striking feature of the results in Figure 9 is the high degree of scatter. This scatter is the result of along-track differences in turbulence intensities associated with pronounced bathymetric features and, in one case, a whirlpool.

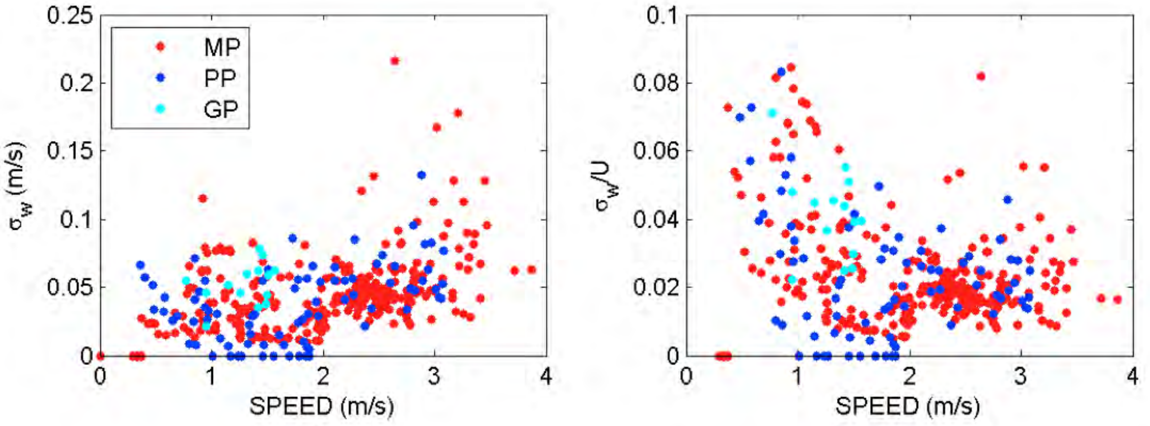

Figure 9: Turbulence Analysis - Comparison of σ_w for Three Tidal Channels

Figure 10 shows the vertical velocity and dissipation rates estimated using the 2nd-order structure function for a drift in Minas Passage. Note again the very high vertical velocities. As in Figure 7a, the $>$ 1m/s speeds persist for minutes and are preceded by pronounced vertical divergence in mid-water column. Panel (b) shows these same vertical velocities with the linear trend removed, emphasizing the zones of high vertical divergence (i.e. changes in the sign of w. Note that w is positive downward). Panel (c) shows the dissipation rate estimates. Importantly, (1) these estimates exhibit significant structure both vertically and as a function of time along the drifter track , (2) the spatial structure of the dissipation rates clearly mimics the pattern of vertical velocity divergence, and (3) the dissipation rates reach very high values ($>$ 0.01 W/kg).

Figure 11 shows the time series of 3-axis acceleration and ADCP attitude (pitch, roll, and heading) parameters during the same drift. The vertical velocities are also plotted, for ease of comparison to the results in Figure 10. It is clear from the heading time series that the drifter was either in an eddy, or a zone of high lateral shear, for ca. 3 min intervals both at the beginning and at the end of the drift.

The striking association of zones of high dissipation rate with zones of high vertical divergence at mid-depth bears further consideration. In particular, one has to ask whether the presence of persistent high divergence zones indicates that the assumption of local isotropy upon which the structure function analysis is based is being violated. There are two arguments suggesting that

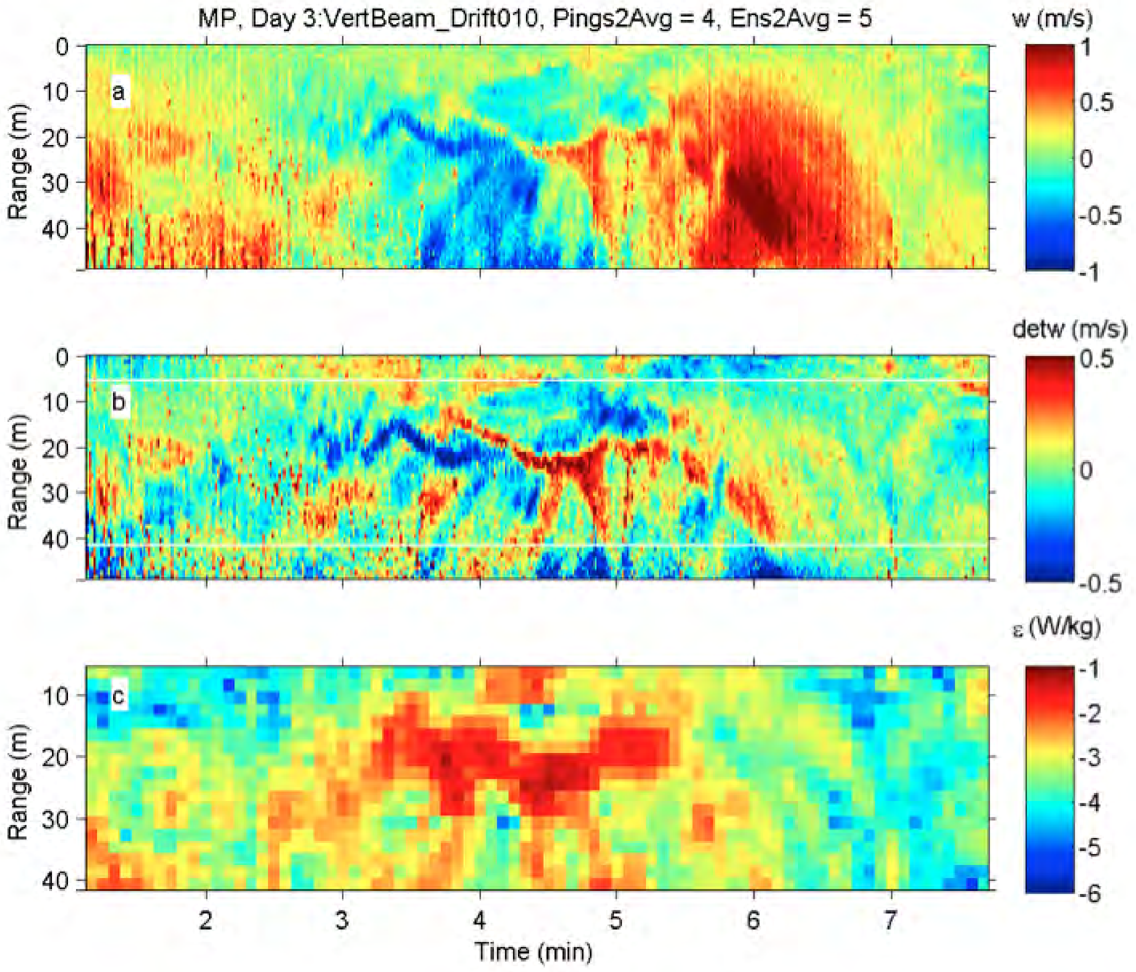

Figure 10: Turbulence Analysis - Vertical Velocity and Dissipation Rates. The white lines in (b) demarcate the vertical extent of the region over which the dissipation rates shown in (c) were estimated.

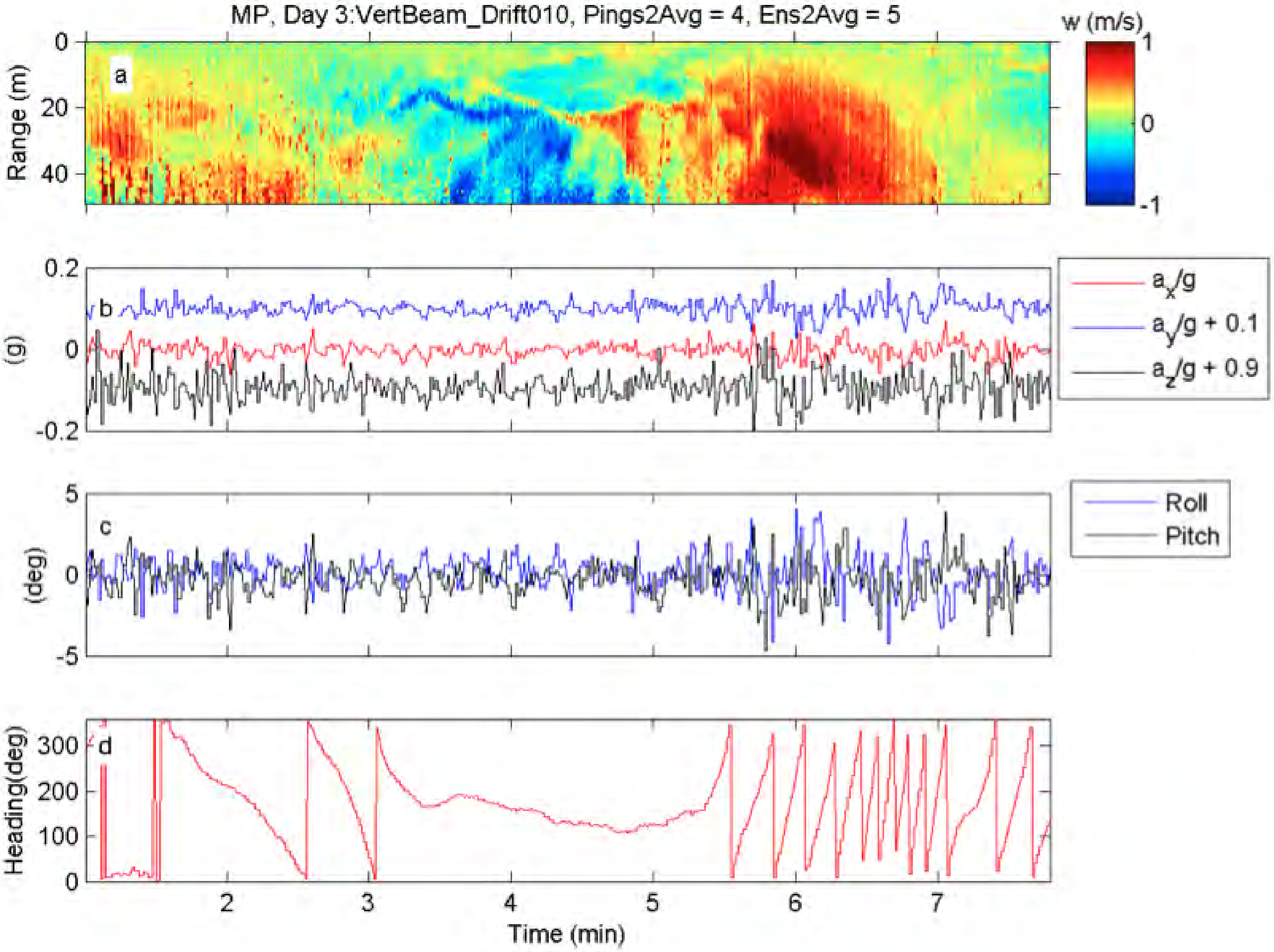

Figure 11: Turbulence Analysis - 3-Axis Acceleration and ADCP Attitude

this is not the case. The first is that dissipation rate estimate for different maximum values of the separation distance r in the structure function $D_{LL}(r)$ calculations yielded values both comparable in magnitude and with the same space-time structure as those in Figure 10, for which $max(r)$ = 5. In particular, the values and pattern remained the same for smaller values: specifically, $max(r)$ = 3 and 4 m. The second argument is based on the spectra which, for the more energetic conditions especially (see Appendix A) exhibit a clear inertial subrange for O(10 m) and smaller vertical scales.

3 Conclusions and Recommendations

The project outcome is site characterization information useful for advancing research and micro-siting tidal turbines for testing, demonstrations, and/or commercial developments. The information has also be utilized by a) Dr. Alex Hay to advance research on turbulence in high-energy tidal environments, and b) Dr. Richard Karsten for calibration and validation of the FVCOM numerical model (FVCOM).

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References

McMillan, J., and A. Hay, Spectral and Structure Function Estimates of Turbulence Dissipation Rates in a High-Flow Tidal Channel Using Broadband ADCPs, *Journal of Atmospheric and Ocean Technology*, 2017.

Trowse, G., R. Cheel, and A. Hay, Southwest Nova Scotia Tidal Energy Resource Assessment Volume 1: Tidal Energy Potential Reconnaissance, *Tech. rep.*, OERA, 2013.