OERA Research Project
Project Completion Report

Going With the Flow:
Advancement of drifting platforms for use in tidal energy site assessment and environmental monitoring

Project start date: March 19, 2017

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Executive Summary

Going with the flow, through use of drifters, is a cost-effective approach for obtaining valuable information on the flow field and sound scape in high-energy tidal environments.

Applying a simple and cost-effective philosophy to ocean observation, an inexpensive low-profile surface flow drifter (SF drifter) was developed in 2012 for initial assessment of potential tidal energy development opportunities as part of the OERA funded "Southwest Nova Scotia Tidal Energy Resource Assessment". The SF drifters provide a cost-effective approach for obtaining information on the flow field needed for initial site selection and for planning next steps in detailed site characterization. The drifters have also been used to supply information for "micro-siting" turbine berth locations and numerical model validation as part of the NRCan ecoEII project, "Reducing the cost of in-stream tidal energy generation through comprehensive hydrodynamic site assessment" (ecoEII project).

The GWTF project built upon previous success by the Project Team, and addressed limitations in drifter design by increasing functionality and making them useful at large scale sites such as the Minas Passage, including the FORCE site. Drifter development included adapting the platform to increase payload capacity enabling the drifters to carry a tracking device and an ADCP. Proof of concept testing was carried out in the Digby Region, followed demonstration and commercial application in the Minas Passage.

In addition to sensor development, research was conducted to advance data processing and assessment techniques. The calculation of surface flow speeds from GPS drifter data is relatively straight forward. However, the amount of measurements collected in surface flow field mapping requires smart and robust methods for data collection, processing, and analysis. To help streamline data processing, Luna Ocean developed a drifter data processing module as part of the Luna Ocean Data Analysis Software (LODAS).

The tide time ($\hat{T}$) and relative tidal range ($\hat{R}$) parameters are useful for data analysis. The surface flow speed data are organized by $\hat{T}$ and indexed by $\hat{R}$, then used to generate flow field maps that highlight areas of potential development for tidal energy projects, provide information for designing tidal power systems, and a means for testing (and improving) the spatial and temporal accuracy of numerical models. The surface flow measurements are also useful for combining with concurrent bottom mounted ADCP data collection to fill near surface gaps in ADCP data sets. A summary of surface flow assessments to date for Grand Passage is provided in short videos available at https://vimeo.com/lunaocean/driftgp and https://vimeo.com/lunaocean/driftgp2.

The ADCP drifter has undergone successful proof-of-concept level development, including deign, build, deploy, and data processing. Luna Ocean is continuing to work with the Dalhousie Ocean Acoustics Laboratory on ADCP drifter design and data processing and analysis software. With funding support from the GWTF project the Nortek Signature 500 kHz ADCP has received an upgrade to the heading, pitch, and roll sensors that will allow us to conduct research focused on evaluating the spatial variability in turbulence, including the vertical structure of turbulent dissipation rate, and vorticity at the surface.

Comparison of measurements from the SF drifters to FVCOM (the Model) simulations of tidal flows through Grand Passage show: a) the majority of Model predictions to be within 0.5 m/s of the SF drifter measurements, with several locations within 0.1 m/s, and b) spatial and temporal variation in the performance of the Model with a tendency for the model to be a bit faster than measurements in most locations in Grand Passage, a known model issue. Luna Ocean is continuing to conduct research with Acadia University on calibration of the Model using surface flow measurements. A draft video showing Minas Passage SF drifter data compared to flow speed predictions from the Model is available at https://vimeo.com/lunaocean/driftmp.

Recommendations for further GWTF research and development focus on use of the SF drifters and upgraded ADCP drifter 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, including:

- The ADCP drifter to evaluate the along track: a) vertical structure of the velocity, b) vertical structure of turbulent dissipation rate, and c) vorticity (at the surface).
- Several SF drifters to evaluate spatial variation in flow speeds throughout the flood-ebb tidal cycle, with a focus on filling spatial and temporal data gaps in the existing data sets including areas that are challenging for accurate modelling (such as eddies).
- Further investigation on the use of tide time ($\hat{T}$) and relative tidal range ($\hat{R}$) to predict flow speeds.

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1 Introduction and Objectives

Applying a simple and cost-effective philosophy to ocean observation, an inexpensive low-profile surface flow drifter (SF drifter) was developed in 2012 for initial assessment of potential tidal energy development opportunities as part of the OERA funded “Southwest Nova Scotia Tidal Energy Resource Assessment”. The SF drifters provide a cost-effective approach for obtaining information on the flow field needed for initial site selection and for planning next steps in detailed site characterization. The drifters have also been used to supply information for “micro-siting” turbine berth locations and numerical model validation as part of the NRCan ecoEII project, “Reducing the cost of in-stream tidal energy generation through comprehensive hydrodynamic site assessment” (ecoEII project).

The Going With the Flow (GWTF) project built upon previous success and addressed limitations in drifter design by increasing functionality and making them useful at larger-scale sites such as the Minas Passage. Drifter development included adapting the platform to increase payload capacity enabling the drifters to carry a tracking device and an ADCP. Proof of concept testing was carried out in the Digby Region, followed demonstration and commercial application in the Minas Passage. In addition to sensor development, research was conducted to advance data processing and assessment techniques.

A SF drifter and ADCP drifter is shown on Figures 1 and 2.

Figure 1: ADCP drifter (left) and surface flow drifter (right) - View 1. A small flag or streamer can be added to increase visibility, with consideration of maintaining minimal windage.

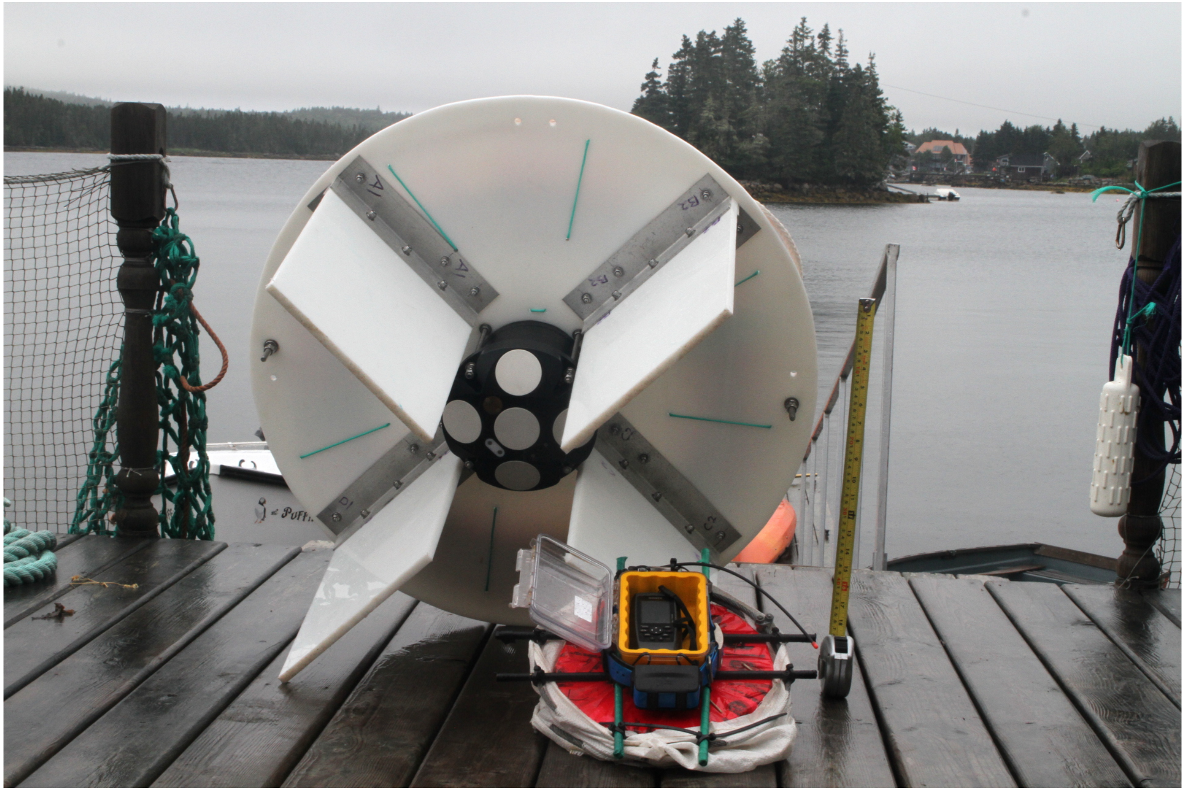

Figure 2: ADCP drifter and surface flow drifter - View 2

1.1 Background

In March 2015, OERA awarded funding to Fundy Tidal Inc. (FTI) to support further development of low-profile surface flow drifters for use in tidal energy site assessment and environmental monitoring. The project was led by Greg Trowse, and included collaboration with Dr. Alex Hay's group at Dalhousie University and Dr. Richard Karsten's group at Acadia University (the Project Team). Project objectives included:

- Increase payload capacity through modified design and use of a VHF tracking system, including addition of a hydrophone and/or ADCP.
- Conduct field trials in Grand Passage, Petit Passage, and/or Digby Gut including data collection for flow speeds and ambient noise.
- Advancing data processing methods including evaluating the relationship between flow speeds, tide time ($\hat{T}$), and relative tidal range ($\hat{R}$).
- Advance numerical model validation schemes using drifter measured flow fields.

- Characterize the ambient noise field at and in the vicinity of a proposed turbine site as a function of tidal current speed and time of day.

An interim report was submitted to OERA on November 30, 2015, and work on the GWTF project continued with OERA funding support until completion of the ecoEII site assessment project at the end of March 2016. Following completion of the ecoEII project Greg Trowse resigned from his position with FTI and incorporated Luna Ocean Consulting Ltd. (Luna Ocean). FTI did not advanced the GWTF project; however, Luna Ocean continued to develop low profile surface flow drifters through alignment with other field activities, and by conducting field tests at cost to Luna Ocean.

In March 2017 OERA awarded funding to Luna Ocean to continue the GWTF research in collaboration with the Project Team. At that time the research status was as follows:

- The VHF tracking system had been tested and utilized for data collection with up to 7 drifters simultaneously at several locations, including Grand Passage, Minas Passage (outside of the FORCE area), and Prince Edward Island (PEI). The most robust data set was collected in Grand Passage for strong spring tide ebb and flood conditions in conjunction with deployment of the ecoSpray tidal test platform, with concurrent measurements from a) 2 bottom mounted ADCPs and b) a Modular Acoustic Velocity Sensor (MAVS) mounted to the ecoSpray. Data analysis conducted to date had been limited to initial quality control procedures. The Minas Passage and PEI data collection was conducted for preliminary site assessment. Basic results had been provided to clients without advancing research objectives.

- Working in collaboration with Cascadia Coast Research (CCR), initial testing of an Inertial Measurement Unit (IMU) for drifter-based waves measurement was conducted in Grand Passage. Preliminary data analysis had been conducted. This was not included in original scope work, but was conducted due to alignment of research interests including an opportunity to collaborate with CCR.

- A prototype ADCP drifter was designed and built with assistance from students in the NSCC Ocean Technology program. A brief field test was conducted in Grand Passage (summer 2016) where the ADCP drifter was deployed by kayak. The ADCP drifter floated well. The ADCP data had not been analyzed. Design modifications and development of data processing code were required.

- Kody Crowell (Acadia Undergrad student) had focused his honours thesis on comparison of drifter flow speed measurements to predictions from the Finite Volume Community Ocean Model (FVCOM), including statistical comparison.

- Anne Lombardi (Dalhousie M.Sc. student) had utilized hydrophone drifter data collected from Grand Passage and Digby Gut in her thesis work, including characterization of the ambient noise field. Anne successfully defended her thesis in December 2016. One publication has arisen from her research for far. The acoustic component of the project was complete, with details in *Lombardi et al.* (2016).

1.2 Work Plan

The work plan for completion of the GWTF project was as follows:

- WP1 - Advancement of SF drifter data processing using the Grand Passage data set collected in conjunction with the ecoSpray deployment, including a) direct comparison of drifter to ADCP measurements, and b) evaluation of relationships between flow speeds with tide time ($\hat{T}$) and relative tidal range ($\hat{R}$).

- WP2 - Preliminary proof-of-concept level data analysis of the drifter IMU data for waves measurements, including comparison to ADCP waves measurements.
- WP3 - Development of data processing code for the ADCP drifter (assisted by with existing financial support from Innovacorp) and preliminary proof-of-concept level data analysis. Design modifications (led by Dr. Hay's group), followed by a field experiment to test the modified design and collect a more robust data set.
- WP4 - Advancement of drifter to FVCOM comparisons through a) Kody Crowell's honours thesis work with supervision by Dr. Karsten and assistance by Greg Trowse, and b) Dr. Karsten and Greg Trowse conducting drifter to FVCOM comparisons using the data set from WP1.

Due to timelines for Dalhousie student research work, the Grand Passage ADCP waves data is not yet available. WP2 requires these data for validation of the IMU based waves measurements, and as such, WP2 has not yet been advanced. Research activities focused on WP1, WP3, and WP4 plus a demonstration in the Minas Passage with the SF drifters and ADCP drifter. Details are presented in the following sections.

2 Methodology and Results

2.1 Advancement of Drifter Data Processing

The calculation of surface flow speeds from GPS drifter data is relatively straight forward. First, a standard oceanographic MATLAB script ("sw_dist.m") is used to calculate the distance and bearing between each set of two subsequent latitude and longitude coordinates. Each distance traveled by the drifter is then divided by the corresponding time step between the measurements to calculate speeds, which are referenced to the center points in space and time between the 2 measurements. However, the amount of measurements collected in surface flow field mapping requires smart and robust methods for data collection, processing, and analysis. For example, on March 10, 2016, 165 drifts were collected in 8 hours from 1 boat with 2 crew (Reid Gillis and Greg Trowse) using 7 surface flow drifters yielding 41,810 good data points. During data collection the crew were careful to start and stop GPS data collection on each drifter within approximately 15 seconds of placing it in and out of the water.

To help streamline data processing, Luna Ocean developed a drifter data processing module as part of the Luna Ocean Data Analysis Software (LODAS). The code identifies individual drifts, and includes a user specified duration of "automatic data trimming" to remove the majority of out of water GPS data from the data set. This "auto_trim" value is set to correspond with the out of water data collection (e.g. 15 seconds in the example above), and the bad data points at the start and end of each drift are replaced with NaN values. The software then cycles through each drift and allows further "manual data trimming" at the start, end, and/or middle of each drift. For this purpose, the user is shown the drift track, speed, north velocity, and east velocity and prompted to identify any sections of the data that should be removed due to disturbance by the boat or other factors (such as entanglement with debris). A moving average is also applied (with user input for the window size) to smooth out any "jumpy" GPS data, while also retaining the raw speed values. LODAS also includes functions for visualizing the processed data and exporting as a CSV file for easy import to GIS software. This software has greatly reduced the time required to process large volumes of drifter data, while maintaining user review and visual data checks (e.g. not automating too much, as it is important to carefully review each drift track).

For data analysis, Luna Ocean is developing tools (software) focused on displaying spatial variability and accounting for differences related to temporal variation. Temporal variability in tidal flows exits at scales ranging from 1 second (and less) associated with turbulence and waves, to long-term variation applicable to changes in Annual Energy Production (AEP) over the duration of Power Purchase Agreements that range form 15 to 20 years in Nova Scotia. Improved quantification of flow speed variations due to turbulence and waves, combined with better understanding of turbine system response is important for resolving uncertainties and improving the accuracy of energy estimates, but is beyond the current state of science and standards. The GWTF project research focused on temporal variability over a) 12.42 hr flood-ebb tidal cycles and b) over the long-term (18.6 year) cycle.

Consistent with *Trowse et al.* (2013), analysis of temporal variation is aided through use of two dimensionless parameters, one representing the position in the M2 tidal period (tide time $\hat{T}$), the other the tidal range during the period of interest relative to the maximum range at the site (relative tidal range $\hat{R}$). $\hat{T}$ and $\hat{R}$ are described in Equations 1 and 2 below.

$$\hat{T} = \frac{t - t_0}{T_{M2}} \tag{1}$$

$$\hat{R} = \frac{R}{R^{max}} \tag{2}$$

where t is the time of the data point of interest, t_0 is the time of low water occurring prior to the data point of interest, T is the time between two low waters (typically 12.42 hours consistent with the M2 tidal constituent period), R is the tidal range to be evaluated, and R^{max} is the maximum tidal range over the 18.6 year tidal cycle. $\hat{R}$ is evaluated separately for ebb and flood tides to account diurnal inequality.

The effect of organizing flow speed measurements from a bottom mounted ADCP by tide time are shown on Figure 3.

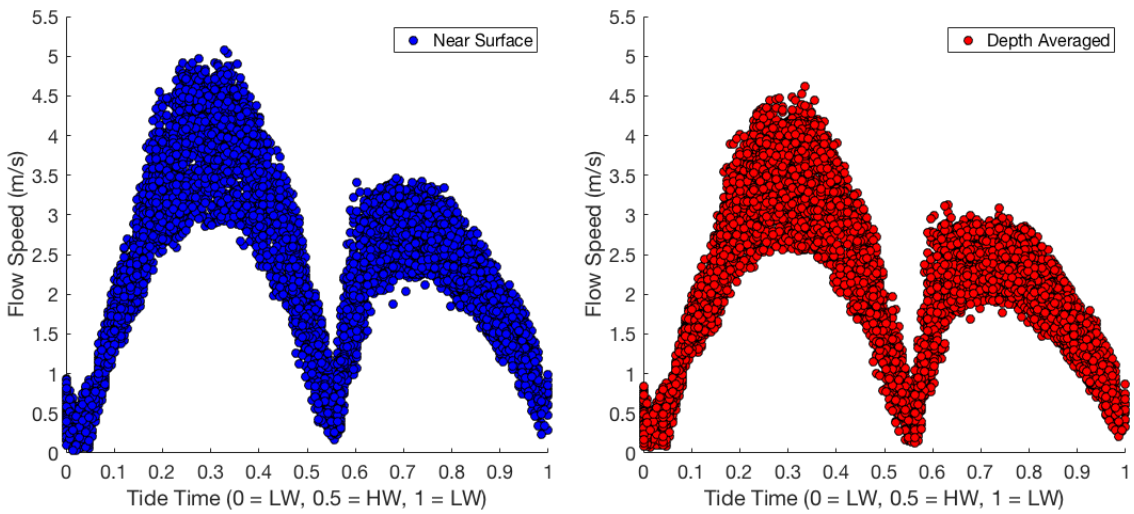

Figure 3: Tide time ($\hat{T}$) applied to ADCP data

By the definition of $\hat{T}$, flood tide (rising water level) is $0 \geq \hat{T} \leq 0.5$ and ebb tide (falling water level) is $0.5 \geq \hat{T} \leq 1$. Figure 3 shows data from the Minas Passage, and common to ADCP data collected at many tidal channels it reveals: a) a slight shift between the changing of water levels and flow directions, b) asymmetry between flood and ebb flow speeds (extreme in this case, where the flood tide is significantly faster than the ebb), and c) variation in the magnitude of flow speeds at each value of $\hat{T}$ as a result of temporal variation (spring/neap cycle). These data have been temporally averaged to 25 min, which reduces/removes the effect of turbulence. As such, the variation shown is primarily related to changes in tidal forcing. Over the 46 day deployment, the maximum depth averaged flow speed on a spring tide is approximately 4.5 m/s, and this is reduced to approximately 2.5 m/s on a neap tide. As shown on Figure 4, this variation is accounted for by evaluating the flow speeds based on the relative tidal range ($\hat{R}$). The maximum and minimum $\hat{R}$ values for this deployment are 0.92 (strong spring tide) and 0.55 (weak neap tide), and a tight relationship is shown between $\hat{R}$ and the maximum and mean flow speeds measured during flood and ebb tides (evaluated separately).

Use of the $\hat{R}$ parameter shows promise for predicting flow speeds, however additional research is required using measured and predicted flow speeds from several sites. At present, in the context of the drifter measurements, $\hat{R}$ is used to index flow speeds, where data can be collected on a low $\hat{R}$ day to measure spatial variation for a weak neap tide, a high $\hat{R}$ day to measure spatial variation on a strong spring, and several $\hat{R}$ values in between depending on research interest and industry needs.

The SF drifter data collected in March 10, 2016 in Grand Passage has been evaluated in conjunction with a

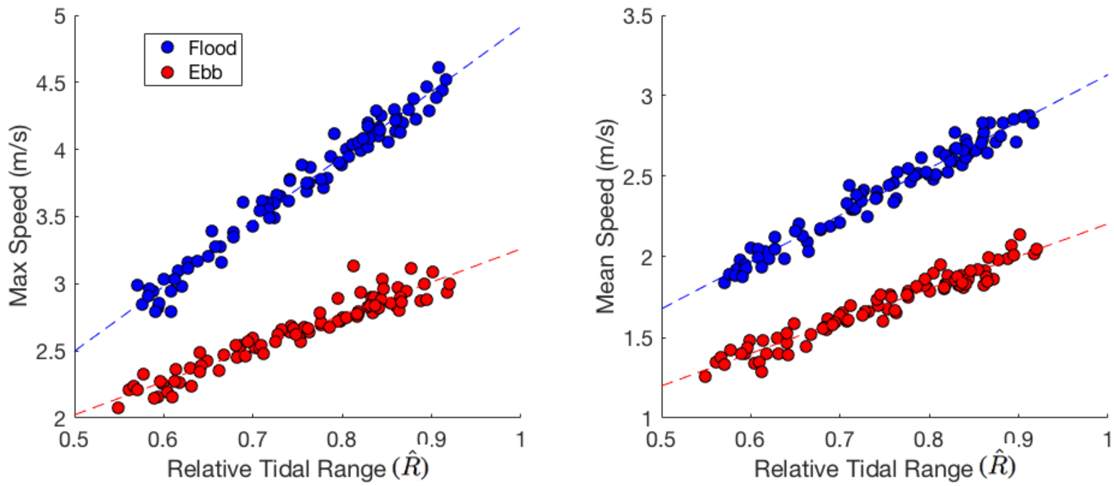

Figure 4: Relative tidal range ($\hat{R}$) applied to ADCP data.

bottom mounted ADCP that was deployed concurrently. A direct comparison is not possible, because SF drifters fill a gap in data availability from ADCPs. Bottom mount moorings for upward looking ADCPs are designed to minimize movement, and are preferably deployed on seabed with slope less than 5 degrees. The transducers used in ADCP instruments have a beam pattern that has side lobes. These are areas separate from the main beam where there is acoustic sensitivity. The side lobes are oriented such that it is possible for the surface echo from the side lobe beam to be received before the actual surface echo from the main beam. When this occurs the data in a profile from around the side lobe echo and further in range are questionable. Side lobe contamination limits the effectiveness of ADCPs for accurately measuring the water velocity close to the surface. A range threshold of 85% to 90% of the water column from the bin closest to the ADCP to surface is typically applied to remove side lobe contamination observed in the near surface flow speeds.

SF drifter data that were collected within 2 m of the ADCP deployment location were plotted with a) the vertical flow profile measured by the ADCP at the nearest time to the drifter crossing (t_0), and b) the ADCP measurements at the nearest to surface good data bin for 10 seconds prior to and following the drifter crossing ($t_0 \pm 10$seconds). The data compare favourably, with the drifter measurements extending the ADCP measured vertical flow profile to surface. The closest passing (0.55 m) is shown on Figure 5.

For the Marine Renewable Energy Areas (MREAs) in the Digby Region of Nova Scotia, including all data collection to date, surface flow data have been collected from:

- Grand Passage with 340 drifts including 130,585 surface flow measurements collected using up to 7 SF drifters deployed by kayak and rigid hull inflatable boat (RHIB) prior to and following implementing the VHF tracking system, including 3 drifts contributed by Chloe Malinka and 12 drifts contributed by Anne Lombardi that were collected during drifting hydrophone studies,
- Petit Passage with 136 drifts including 56,091 surface flow measurements collected using up to 3 SF drifters deployed by kayak and RHIB prior to implementing the VHF tracking system, and
- Digby Gut with 181 drifts including 57,300 surface flow measurements collected using 3 SF drifters deployed by RHIB prior to implementing the VHF tracking system.

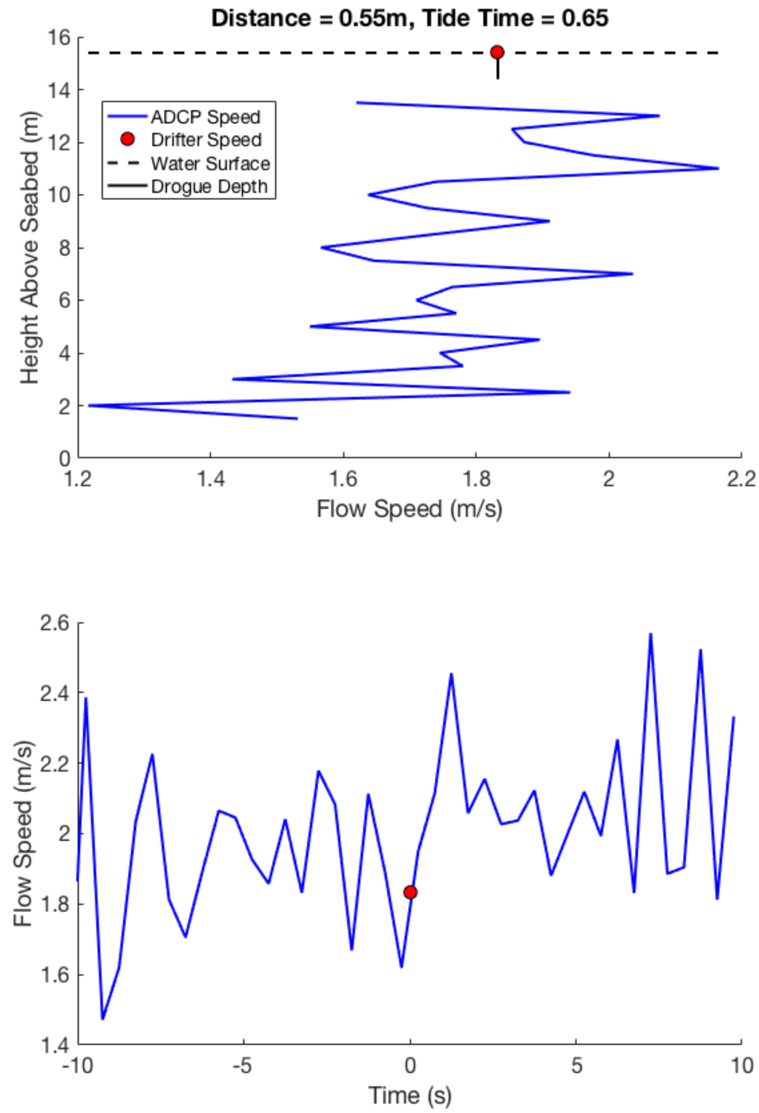

Figure 5: Concurrent flow measurements using bottom mounted ADCP and surface flow drifter. The lower sub-plot shows the nearest to surface ADCP flow speed measurements with a range threshold of 85% applied to remove surface (side-lobe) contamination. The sampling rates were 2 Hz for the ADCP and 1 Hz for the SF drifter.

Photos from data collection in each of these tidal channels are shown on Figures 6 through 8. An example speed profile from a single drift in Grand Passage is shown on Figure 9.

Figure 6: Grand Passage drifter data collection concurrent with testing of the ecoSpray platform

The tide time parameter has been used to combine all SF drifter measurements collected to date. Figures 10 through 15 show these data binned by $\hat{T}/2$, thus separating the data into flood and ebb tide, where the majority of data collection has occurred in the faster areas of the channels to align with interests for tidal energy development. There is (of course temporal) variation throughout the flood and ebb tides. The data have been rendered such that the fastest flow speed measurements are brought forward to highlight the areas of most interest for potential tidal energy development, which were used to help define Marine Renewable Energy Areas (MREAs) for the three passages. For more advanced analysis these data are typically binned by $\hat{T}/24$ (approximately 30 minutes) or less, to evaluate temporal variation through the flood-ebb tidal cycle. Examples for Grand Passage are provided in short videos available at https://vimeo.com/lunaocean/driftgp and https://vimeo.com/lunaocean/driftgp2, with the former including background information on the use of drifters and latter showing drifter visualizations with $\hat{T}/746$ (approximately 1 min time bins).

Figure 7: Petit Passage drifter data collection

Figure 8: Digby Gut drifter data collection

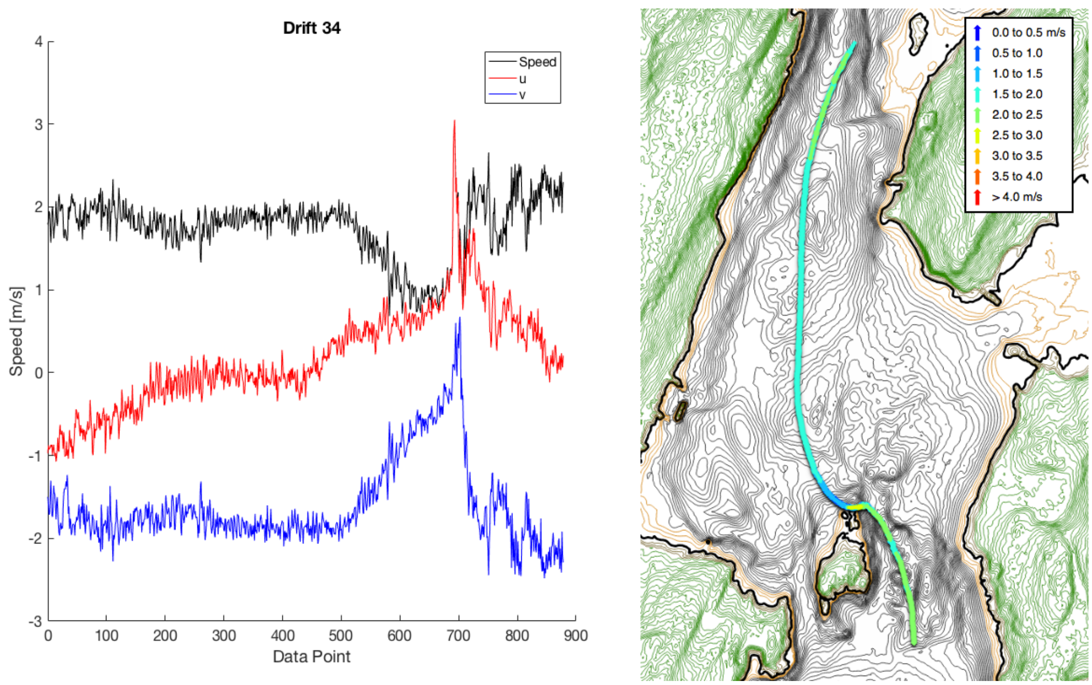

Figure 9: Grand Passage drifter speed profile. Ebb tide, starting at the northern end of the passage

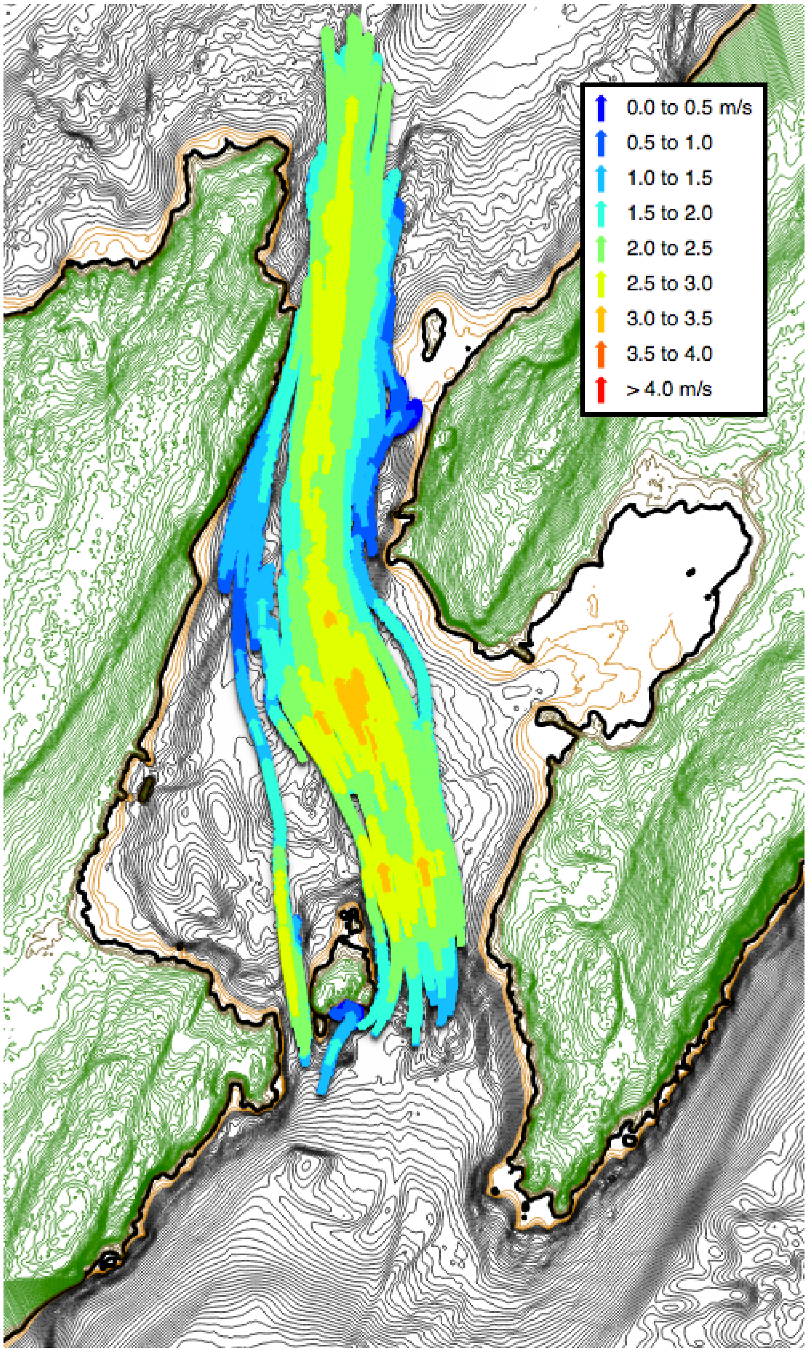

Figure 10: Grand Passage flood tide surface flow drifter measurements ($\hat{T} \leq 0.5$, north up)

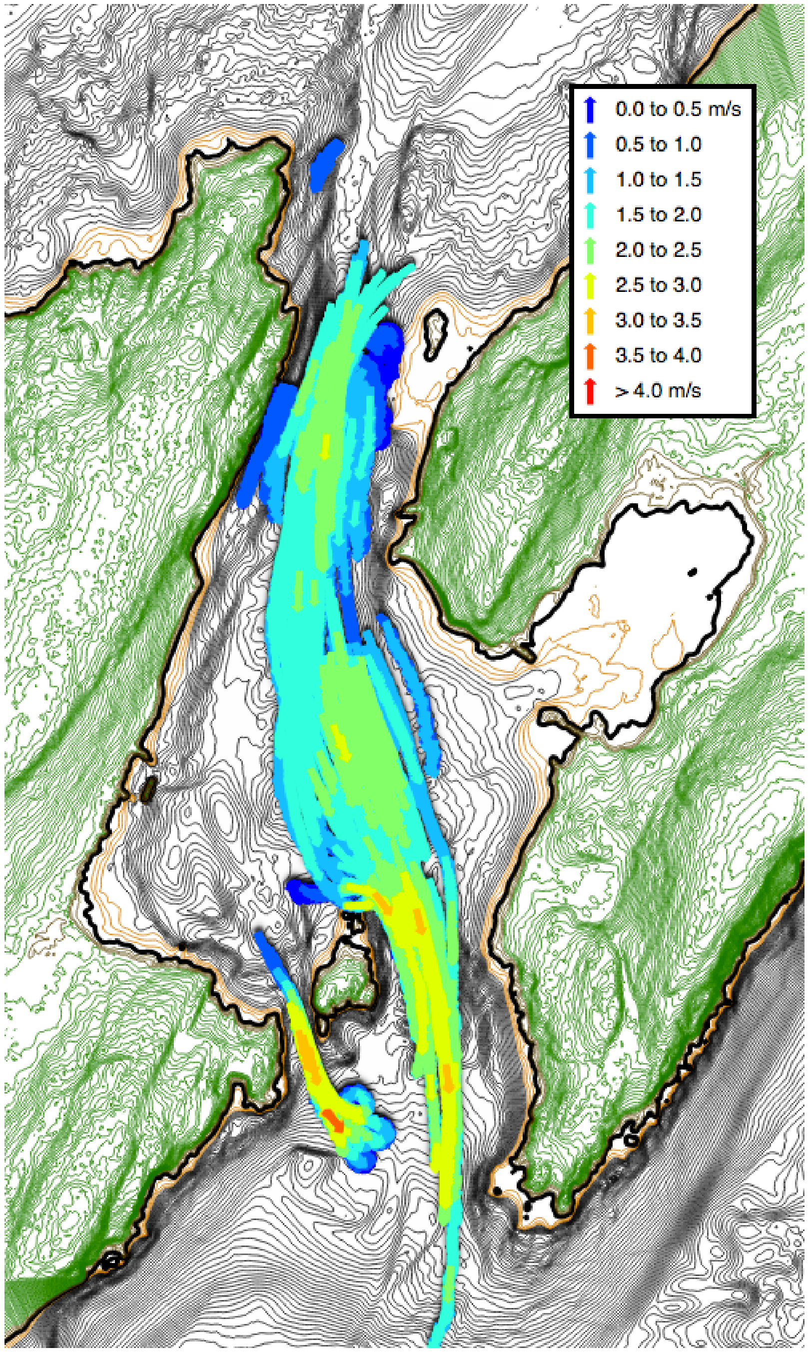

Figure 11: Grand Passage ebb tide surface flow drifter measurements ($\hat{T} \geq 0.5$, north up)

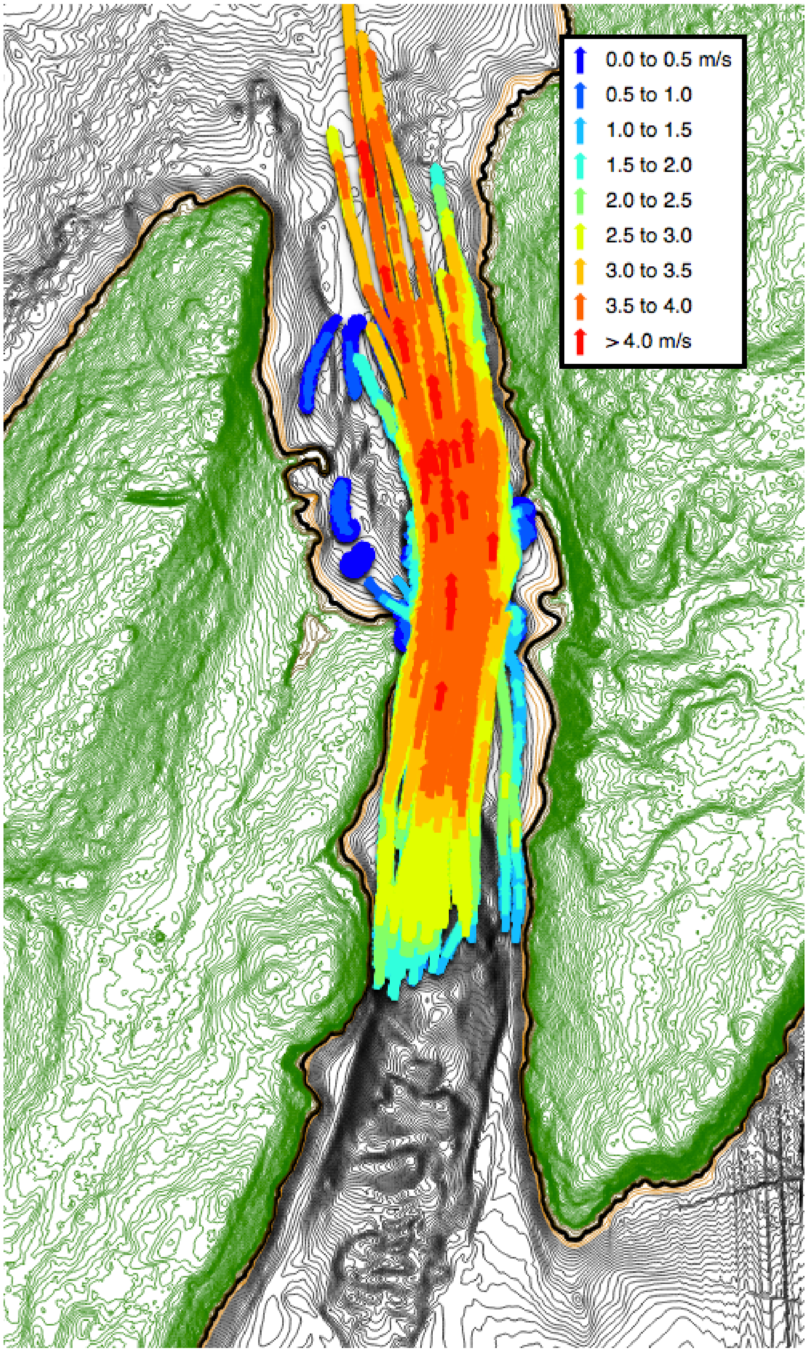

Figure 12: Petit Passage flood tide surface flow drifter measurements ($\hat{T} \leq 0.5$, north up)

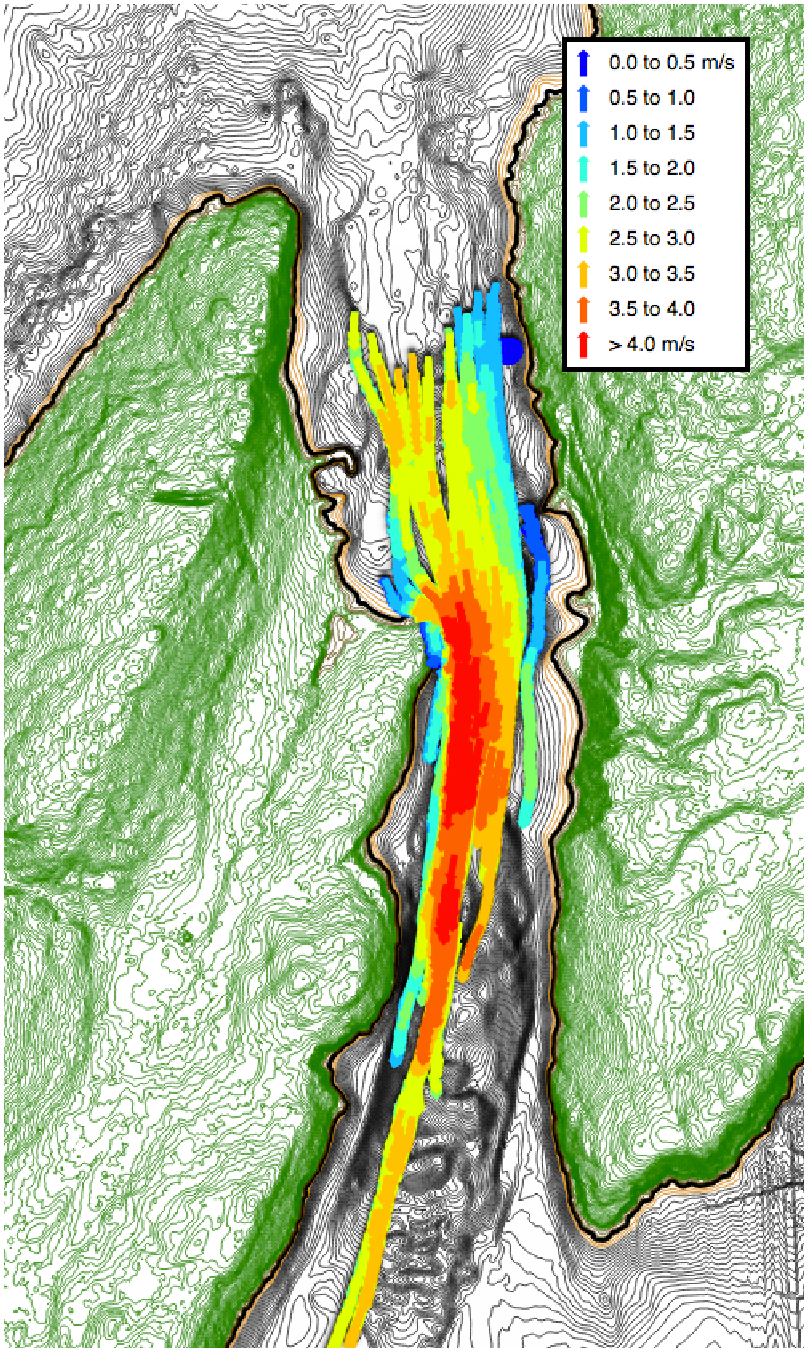

Figure 13: Petit Passage ebb tide surface flow drifter measurements ($\hat{T} \geq 0.5$, north up)

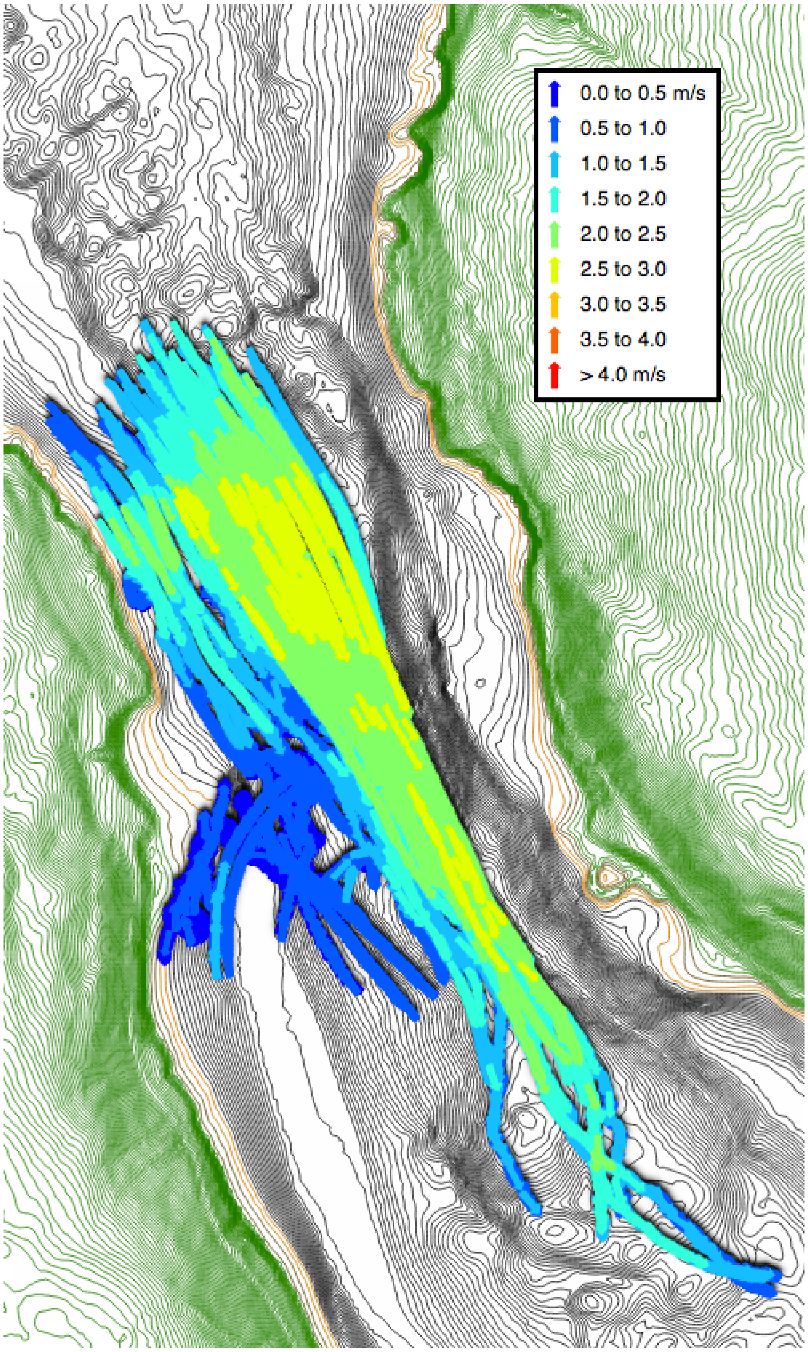

Figure 14: Digby Gut flood tide surface flow drifter measurements ($\hat{T} \leq 0.5$, north up)

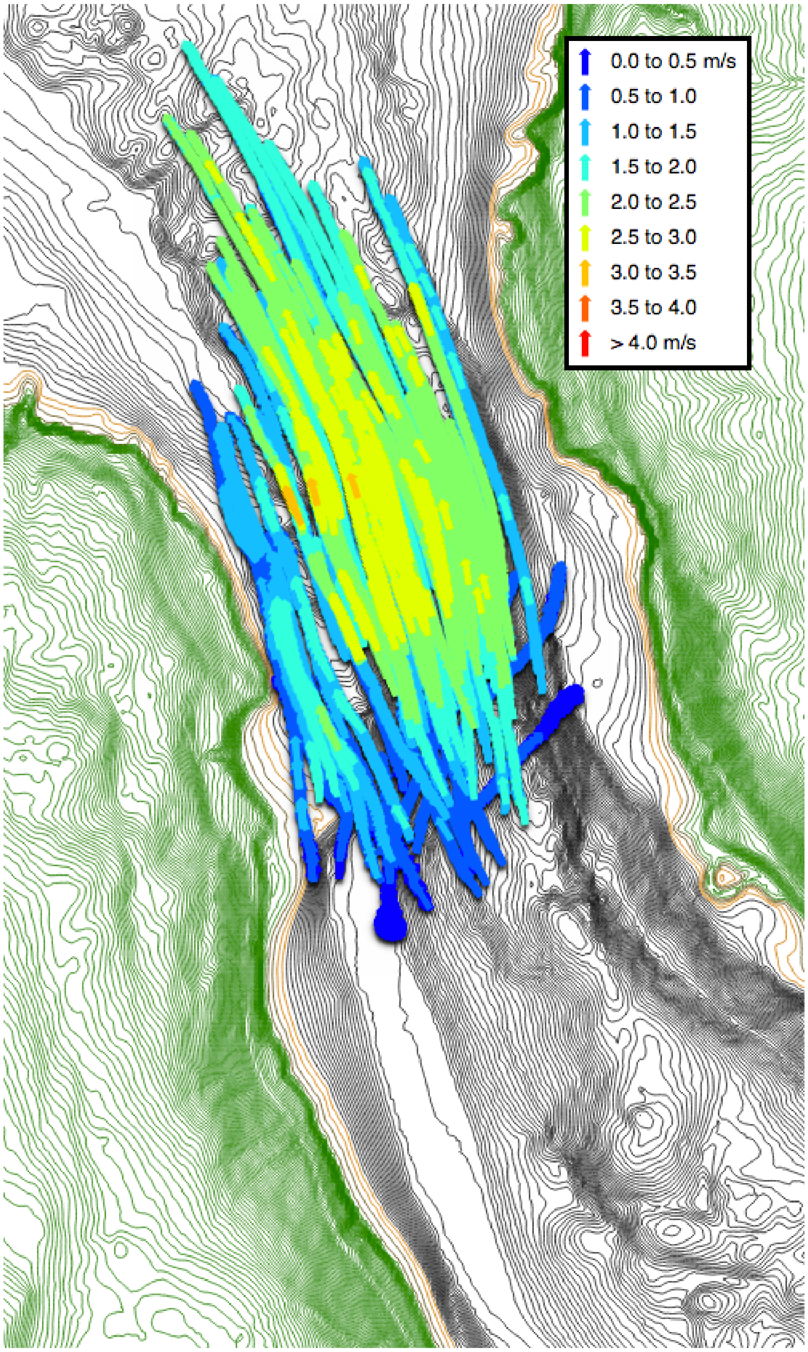

Figure 15: Digby Gut ebb tide surface flow drifter measurements ($\hat{T} \geq 0.5$, north up)

2.2 ADCP Drifter

As noted in Section 1, a prototype ADCP drifter was developed with assistance from students in the NSCC Ocean Technology program. Working in collaboration with Dr. Hay's group at Dalhousie University, the ADCP drifter design was modified to reduce weight allowing easier deploy and recovery from small vessels, while maintaining a rugged and reliable design. The ADCP drifter is shown on Figures 1, 2, 16, and in several of the photographs included in Section 2.4.

The ADCP drifter has been tested in the Minas Passage on three occasions (June 16, July 4, and August 18, 2017), once using funding from the GWTF project (June 16, 2017) and twice for site investigation purposes. 43 ADCP drifter tracks have been collected. The locations of data collection are shown on Figures 17 and 18. Sample plots of preliminary data processing for ADCP drifts that passed through the FORCE site are shown on Figures 19 and 20 for flood tide and Figures 21 and 22 for ebb tide. The data shown are 10 second averages of 4 Hz data.

These data are considered accurate at the proof-of-concept level for evaluating the spatial variability in flow speeds (vertical structure of the velocity) using a drifting ADCP. Luna Ocean is continuing to work with the Dalhousie Ocean Acoustics Laboratory on ADCP drifter design and data processing and analysis software. With funding support from the GWTF project the Nortek Signature 500 kHz ADCP has been sent to the manufacturer for an upgrade to the heading, pitch, and roll sensors that will allow us to conduct research focused on evaluating the spatial variability in turbulence, including the vertical structure of turbulent dissipation rate, and vorticity at the surface.

Figure 16: ADCP drifter in Minas Passage (near Cape Split)

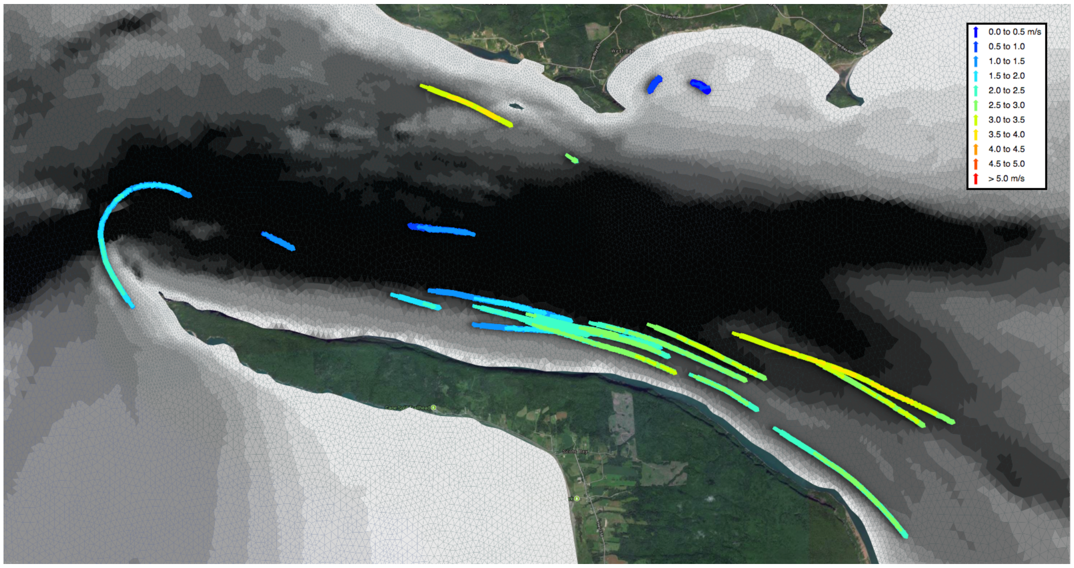

Figure 17: ADCP drifter Minas Passage flood tide data collection locations and associated surface flow speeds

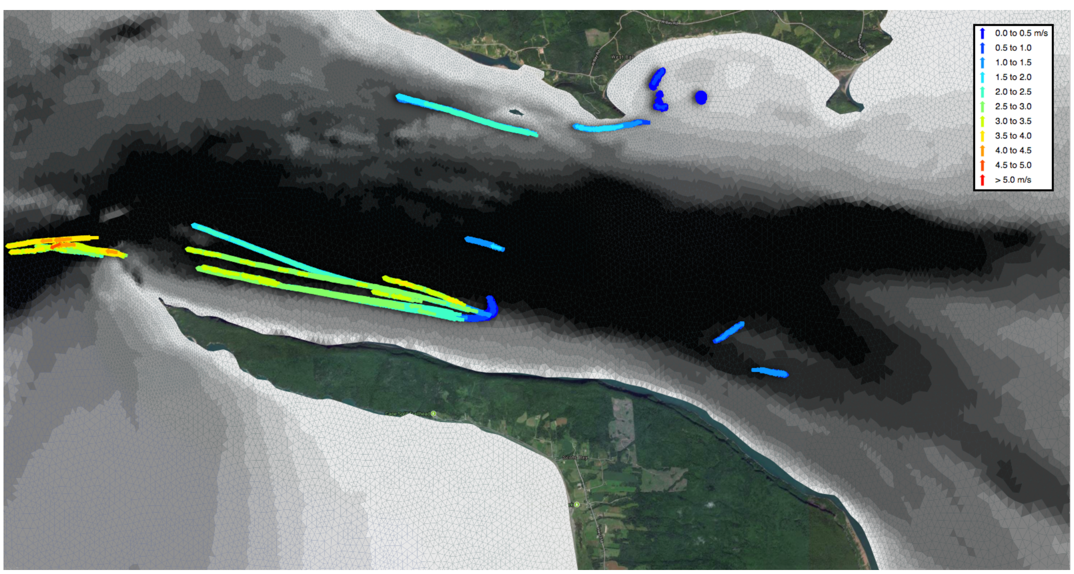

Figure 18: ADCP drifter Minas Passage ebb tide data collection locations and associated surface flow speeds

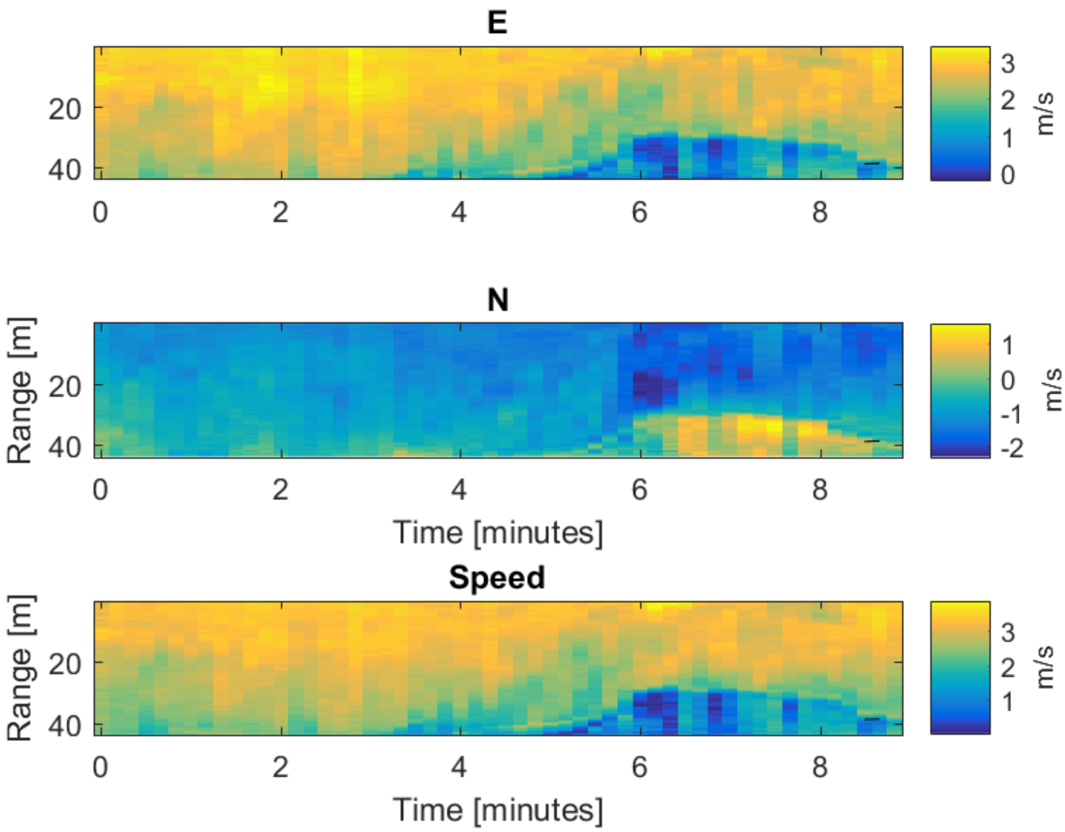

Figure 19: ADCP drifter preliminary along drift profile from FORCE site on flood tide. 10 second averages of 4 Hz data. Data from range bins beyond seabed not yet removed, which are evident from the abrupt change in velocities (range ≈ depth).

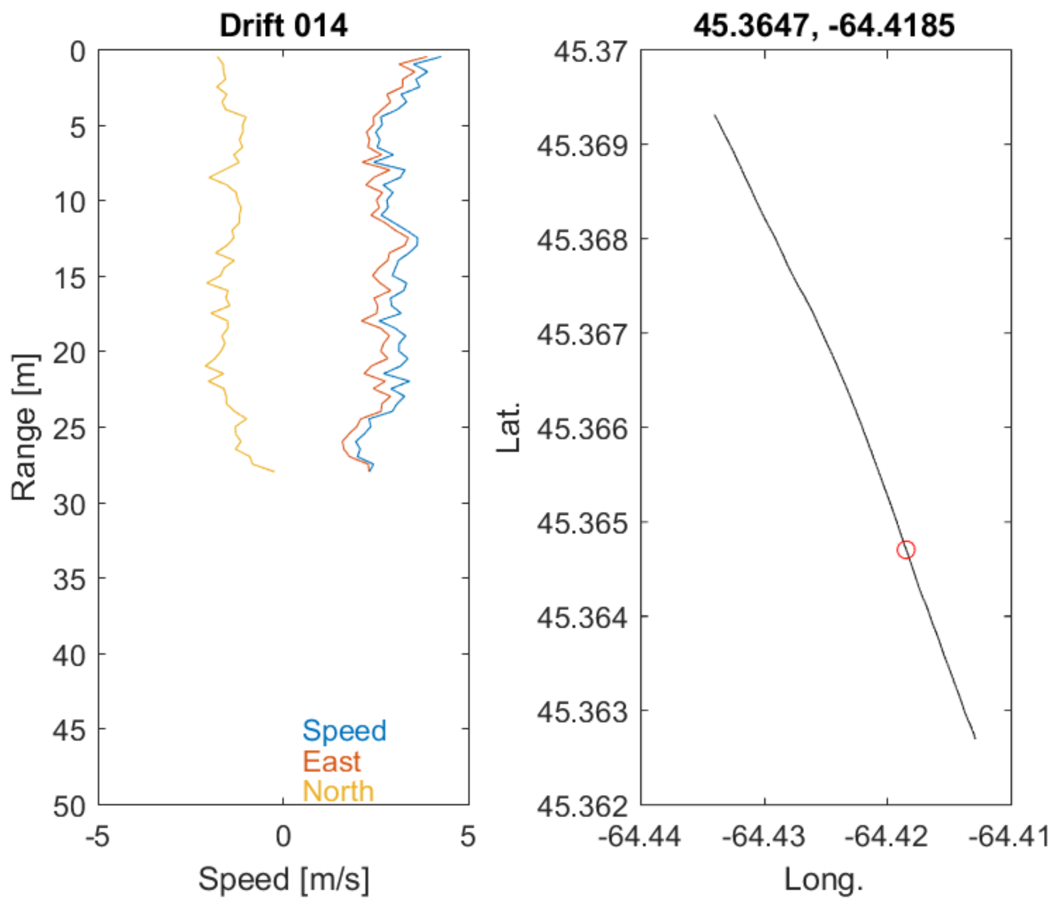

Figure 20: ADCP drifter preliminary single vertical profile from FORCE site on flood tide. 10 second averages of 4 Hz data. Data removed for range bins beyond seabed (range ≈ depth).

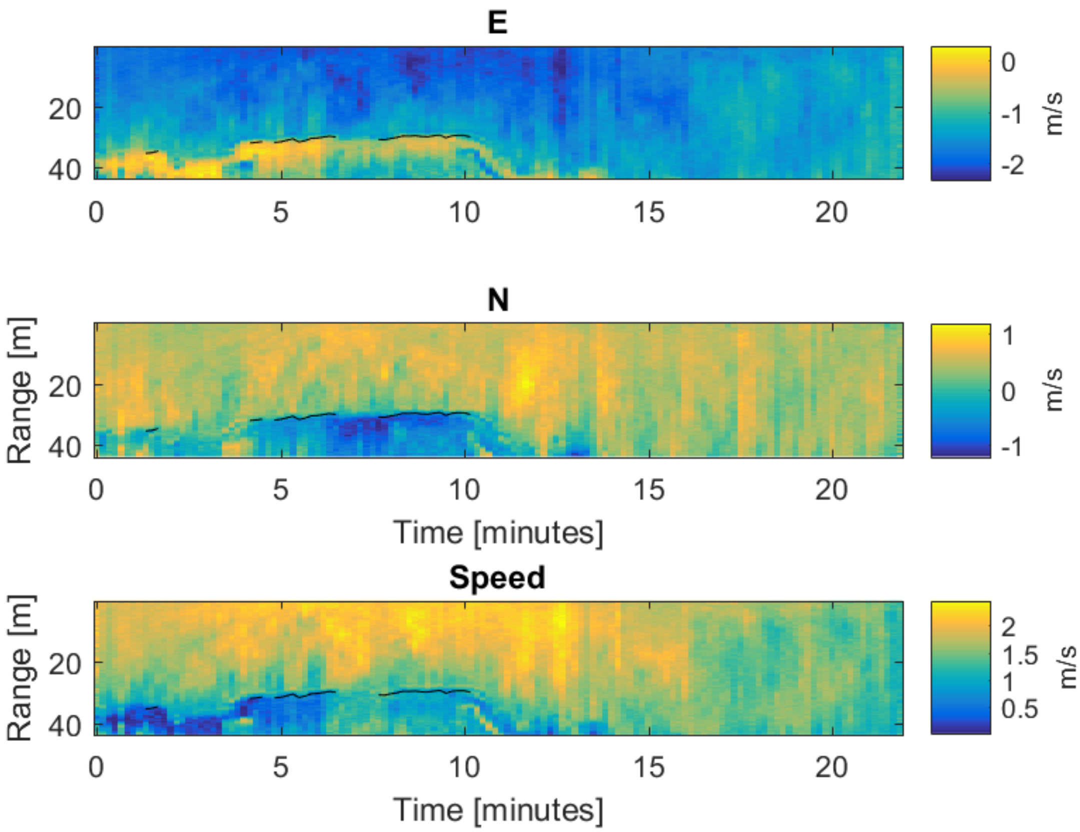

Figure 21: ADCP drifter preliminary along drift profile from FORCE site on ebb tide. 10 second averages of 4 Hz data. Data from range bins beyond seabed not yet removed, which are evident from the abrupt change in velocities (range ≈ depth). Initial results from implementing bottom detection shown by black lines.

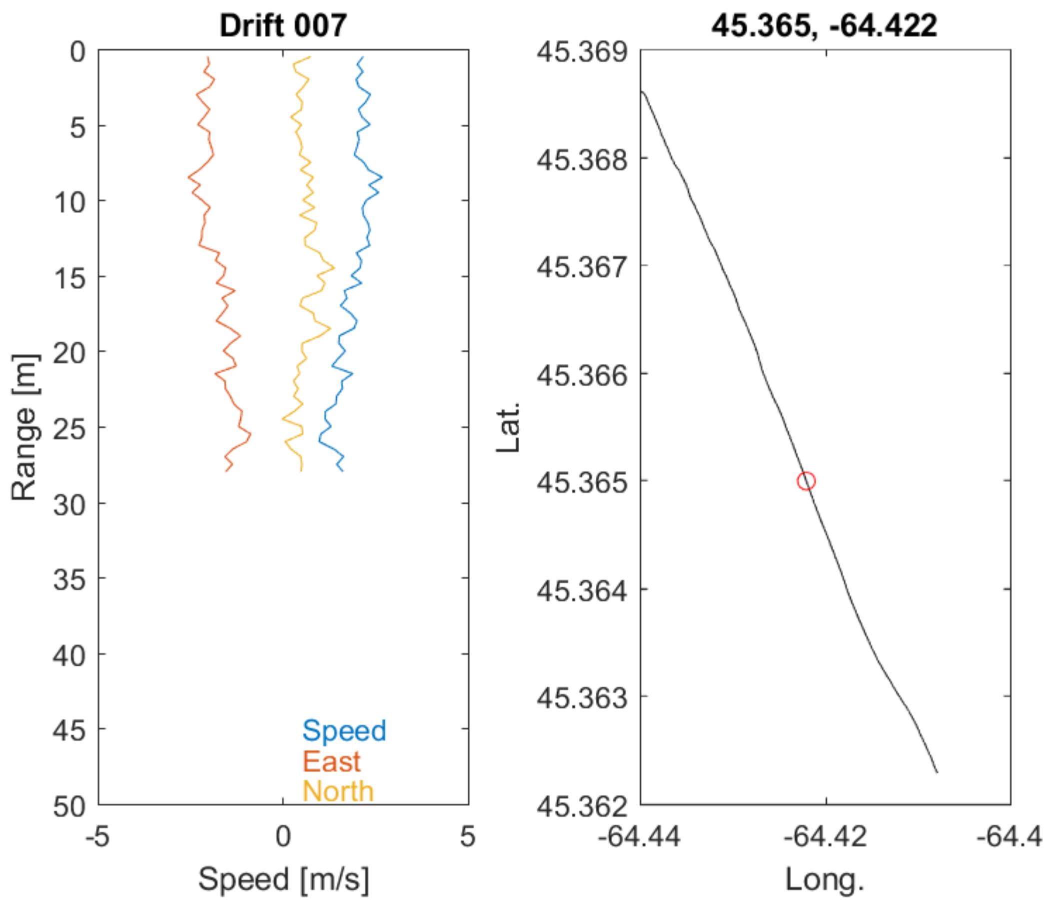

Figure 22: ADCP drifter preliminary single vertical profile from FORCE site on ebb tide. 10 second averages of 4 Hz data. Data removed for range bins beyond seabed (range ≈ depth).

2.3 FVCOM Comparisons

With funding support from the GWTF project and the Mitacs program, Luna Ocean took on an Acadia M.Sc. student intern (Jeremy Locke) for to assist with SF drifter data collection, and conduct research focused on further development of methods for validating and calibrating FVCOM (the Model) with measurements from SF drifters. Jeremy Locke had and internship from April through September 2017, and was co-supervised by Greg Trowse and Dr. Richard Karsten. His work builds upon initial comparisons of the Model to drifter flow speed measurements conducted as part of Kody Crowell's thesis (former Acadia Undergrad student), available at http://openarchive.acadiau.ca/cdm/singleitem/collection/HTheses/id/1372/rec/2.

A comparison of Model predicted flow speeds to SF drifter measurements collected in Grand Passage on March 10, 2016 is shown on Figures 23 (flood) and 24 (ebb), where the data points plotted are the absolute value of the speed difference. The locations with the largest speed difference are brought forward on the plots, and the counts for each bin of 0.1 m/s sped difference are included in the legend. Similar to the flow speed plots, for more advanced analysis these data are typically binned by $\hat{T}/24$ (approximately 30 minutes) or less to evaluate temporal variation through the flood-ebb tidal cycle. Histograms of the speed difference are provided on Figures 25 (flood) and 26 (ebb). A scatter plot of Model predicted vs SF drifter measured flow speeds is provided on Figure 27. The plots show a) the majority of Model predictions to be within 0.5 m/s of the SF drifter measurements, with several locations within 0.1 m/s, and b) spatial and temporal variation in the performance of the Model with a tendency for the model to be a bit faster than measurements in most locations, which is consistent with previous comparisons to ADCP measurements.

A rough draft of a video showing drifter to Model comparisons for the Minas Passage (binned by $\hat{T}/746$) is available at https://vimeo.com/lunaocean/driftmp with password "GWTF". The data visualization shows spatial and temporal variation in the performance of the Model. Luna Ocean is continuing to conduct research with Acadia University on calibration of the Model using surface flow measurements.

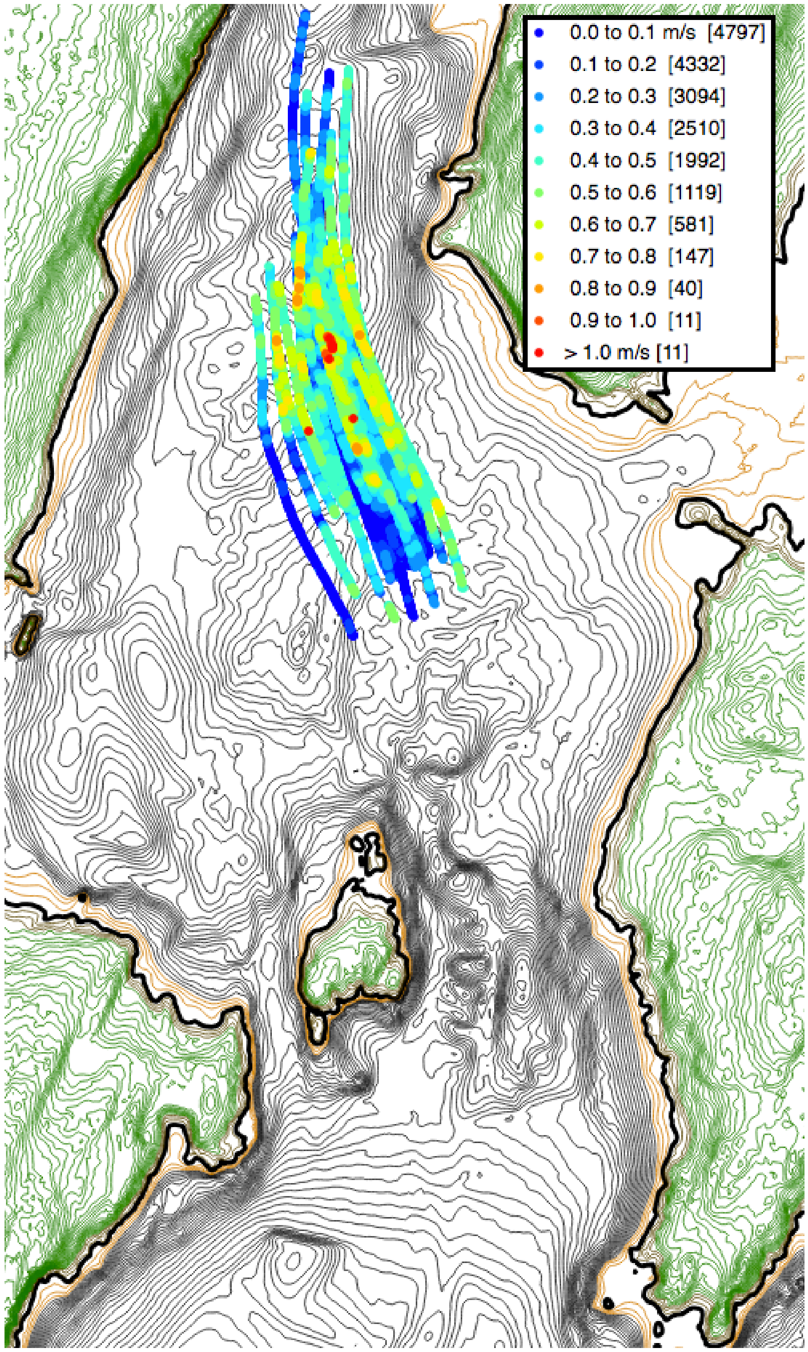

Figure 23: Spatial comparison of surface flow measurements to Model predictions for Grand Passage on flood tide for March 10, 2016.

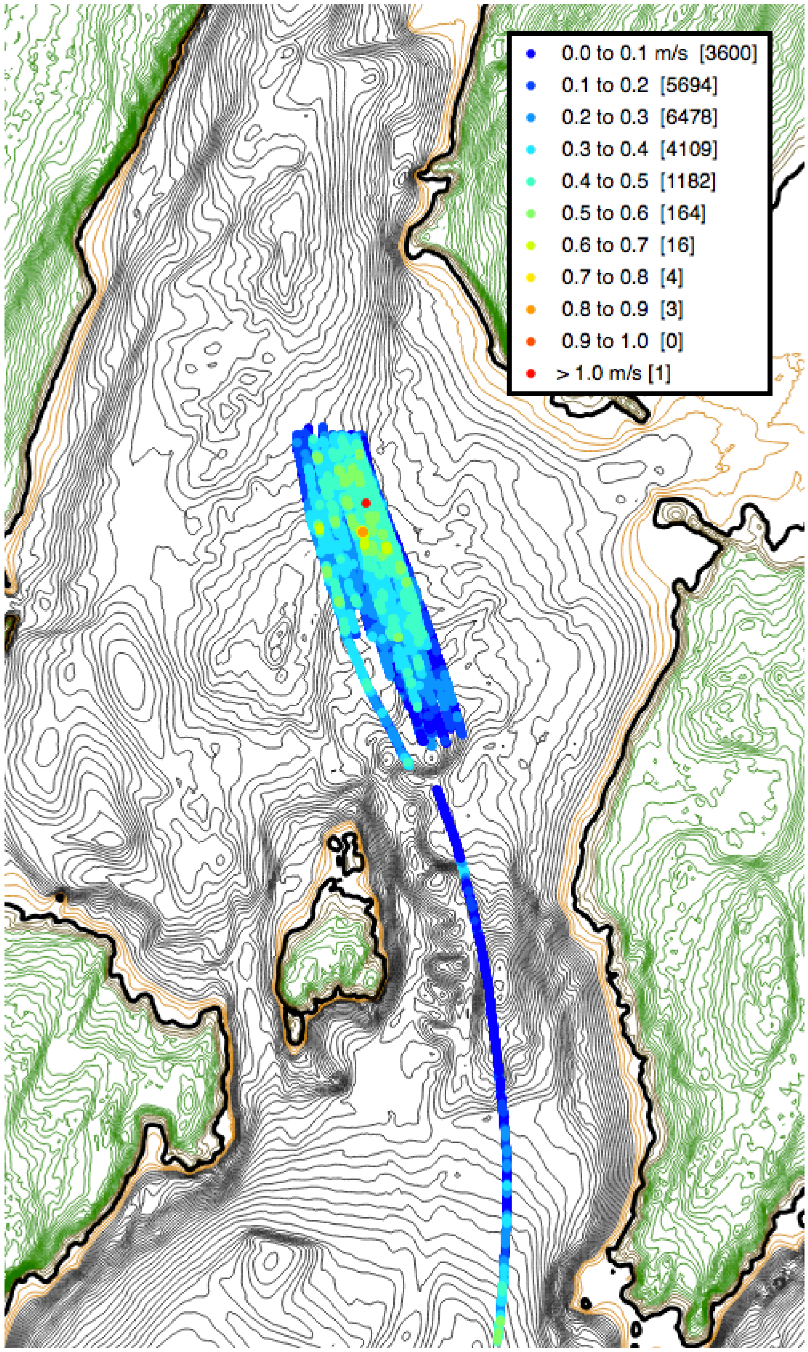

Figure 24: Spatial comparison of surface flow measurements to Model predictions for Grand Passage on ebb tide for March 10, 2016.

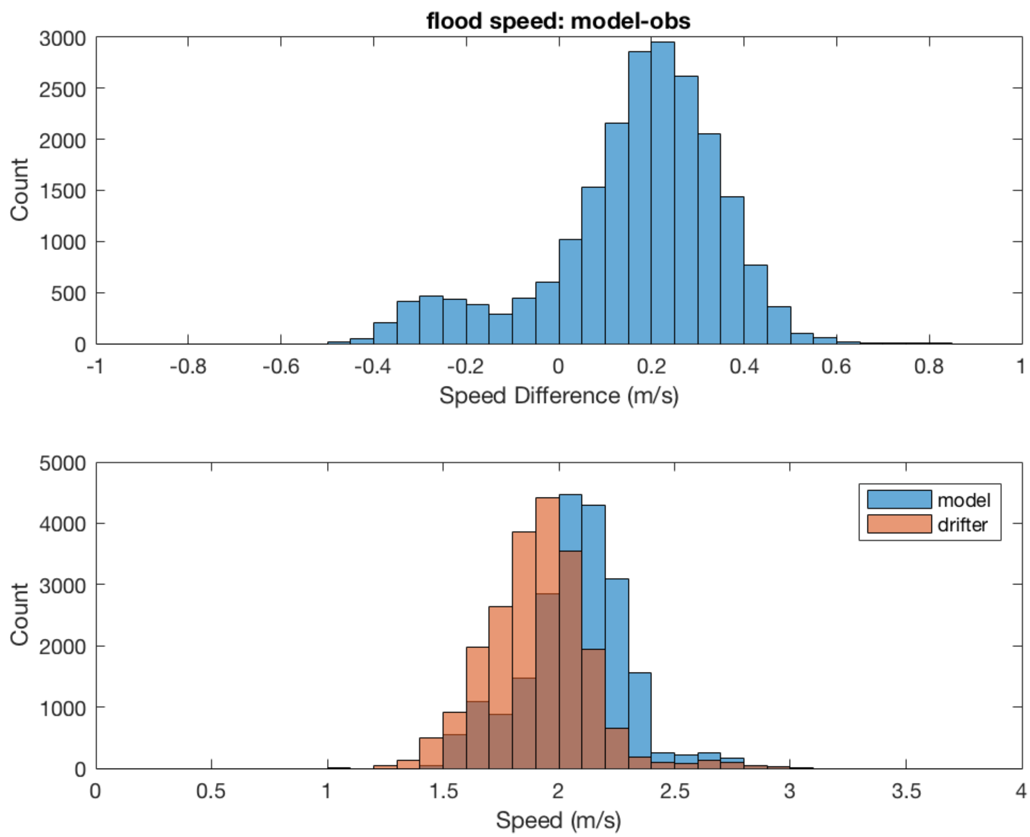

Figure 25: Histogram comparison of surface flow measurements to Model predictions for Grand Passage on flood tide for March 10, 2016.

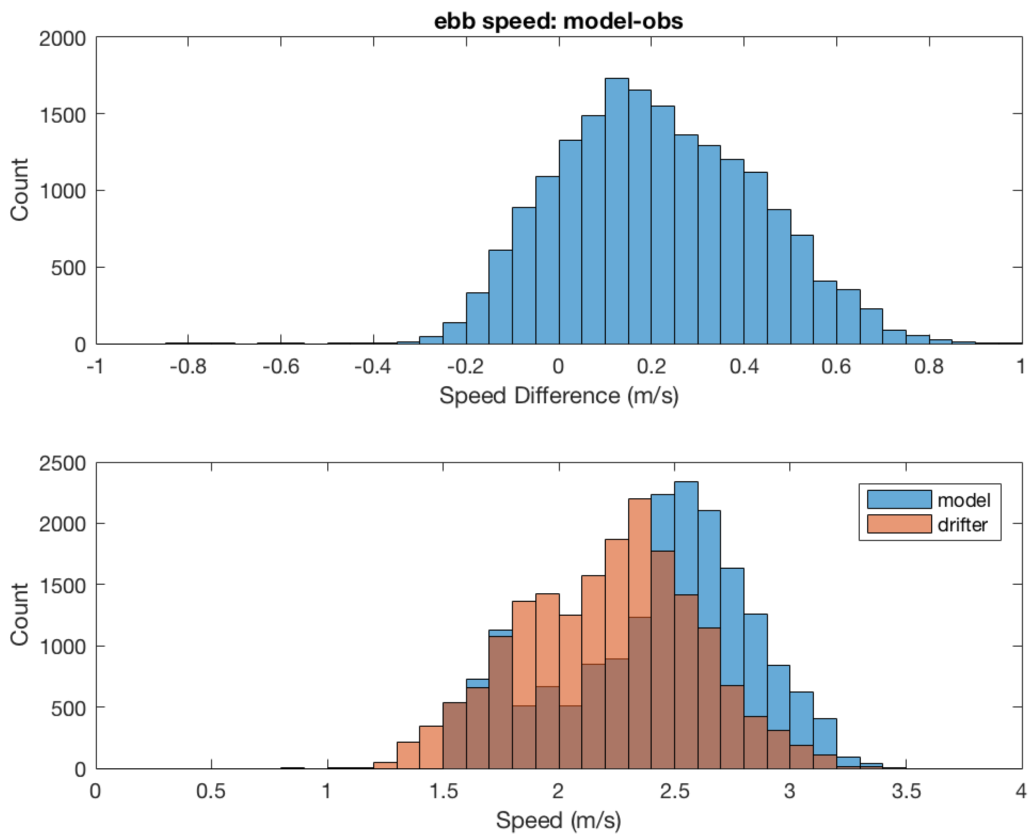

Figure 26: Histogram comparison of surface flow measurements to Model predictions for Grand Passage on ebb tide for March 10, 2016.

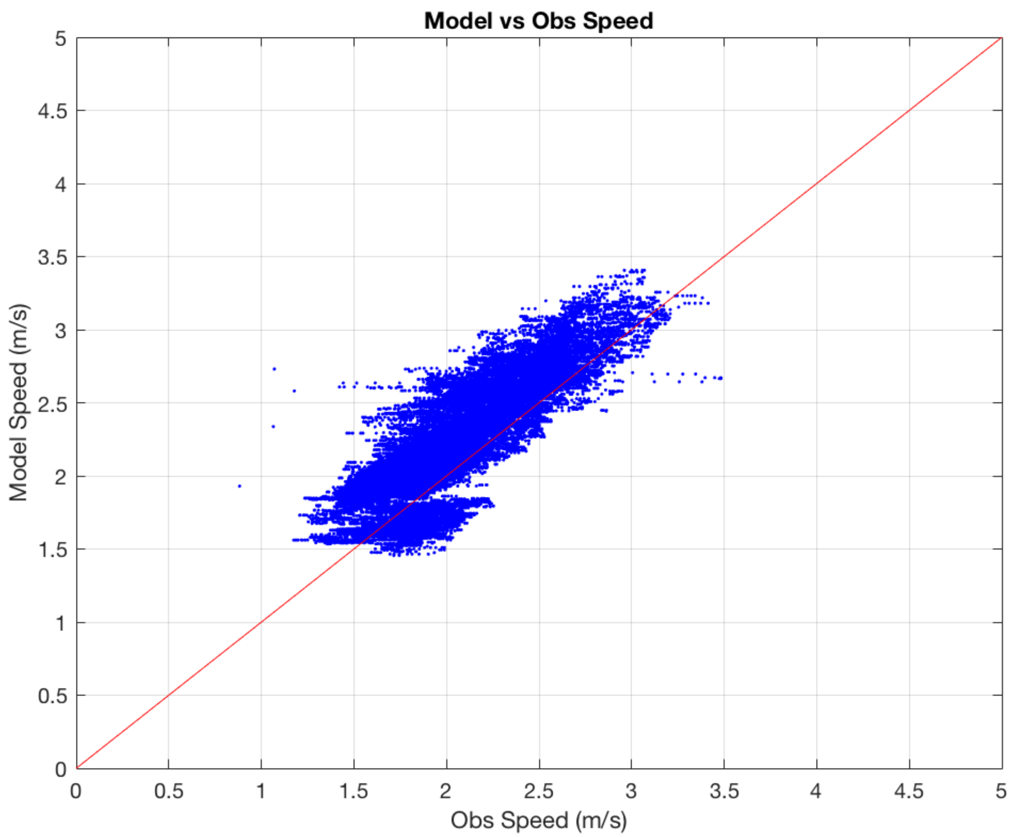

Figure 27: Scatter plot of Model predicted vs surface flow drifter measured flow speeds for Grand Passage on March 10, 2016.

2.4 Minas Passage Demonstration

The SF drifters and ADCP drifter have been used for preliminary investigation of the spatial variation of tidal currents throughout the Minas Passage. To date, three full days of data collection have been conducted. The initial day was June 16, 2017 supported by funding from the GWTF project. The second and third days were July 4 and August 18, 2017 supported by Big Moon Power (BMP) for site investigation and Model validation purposes. To date, LOCL has collected 308 drift tracks including 214,141 surface flow measurements from from West Bay, Cape Sharp, the FORCE site, Cape Split, Cape Blomidon and through the centre of Minas Passage. Photos from drifter data collection in the Minas Passage are provided on Figures 28 through 37.

Preliminary data from the ADCP drifter are shown previously on Figures 19 through 22.

Figures 38 and 39 show surface flow measurements binned by $\hat{T}/2$, thus separating the data into flood and ebb tide. As noted in the figures captions, some of the data are contributed by Dr. Brian Sanderson, Mike Adams, and Dr. Anna Redden of the Acadia Centre for Estuarine Research (ACER) including long drift tracks with 23,117 data points. The ACER GPS data was collected during drifting hydrophone studies of the Minas Passage and Minas Channel, then processed using the surface flow module of LODAS. The ACER data consist of long drifts with a single drifter sampling once every 5 seconds, grouped to the data set by referencing data points to tide time ($\hat{T}$). Including these data show usefulness of the $\hat{T}$ parameter, as well as the value of collaboration and data sharing for building flow field maps of large areas such as the Minas Passage. All of the long drifts, except the one that does loops in Scots Bay are were contributed by ACER. The "loopy drift" exited the Minas Passage past Cape Split during data collection for BMP. It traveled into an area of rough water and was not rot recovered when intended. It retuned to the Minas Passage with the flood tide and was picked up on the VHF tracking system and recovered near sunset. This was a good, unintended, test for the tracking system that also resulted in a very interesting drift track.

A rough draft of a video showing the data binned by $\hat{T}/746$ is available at https://vimeo.com/lunaocean/driftmp. The video includes comparison to flow speed predictions from the FVCOM model. FORCE has agreed to supply GPS data from their drifting hydrophone studies. The Minas Passage video is planned to be updated following additional data collection and contributions by FORCE.

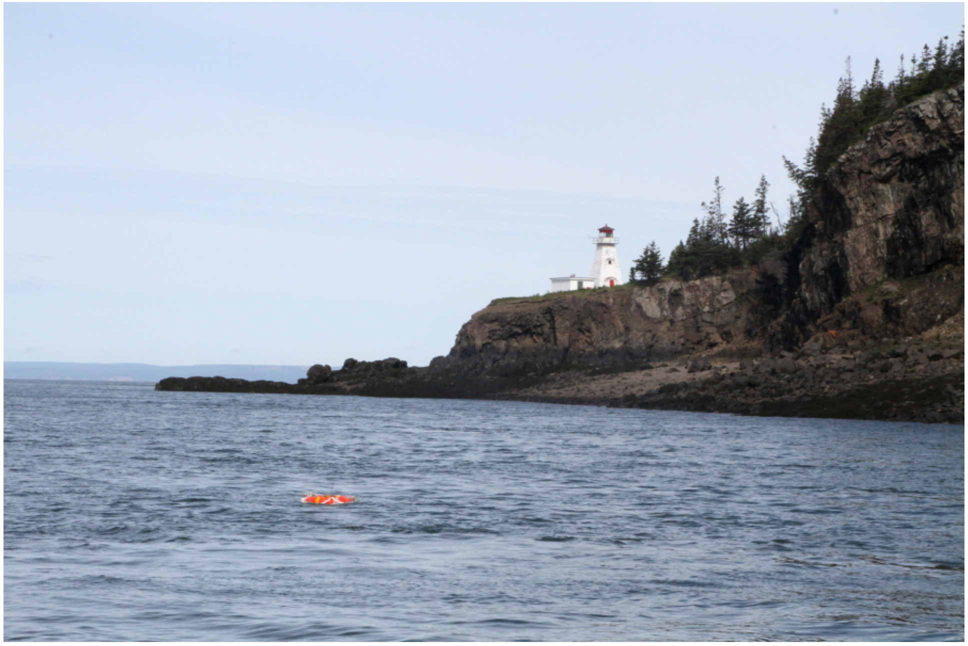

Figure 28: Minas Passage drifter data collection - Photo 1

Figure 29: Minas Passage drifter data collection - Photo 2

Figure 30: Minas Passage drifter data collection - Photo 3

Figure 31: Minas Passage drifter data collection - Photo 4

Figure 32: Minas Passage drifter data collection - Photo 5

Figure 33: Minas Passage drifter data collection - Photo 6

Figure 34: Minas Passage drifter data collection - Photo 7

Figure 35: Minas Passage drifter data collection - Photo 8

Figure 36: Minas Passage drifter data collection - Photo 9

Figure 37: Minas Passage drifter data collection - Photo 10

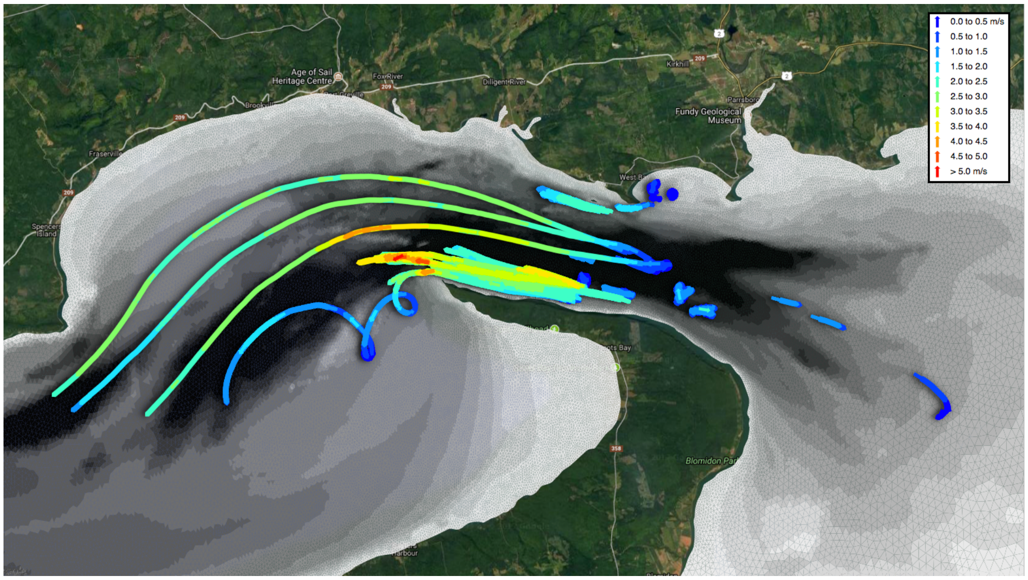

Figure 38: Minas Passage ebb tide surface flow drifter measurements ($\hat{T} \geq 0.5$, north up). The three most northerly long drift tracks are provided by the Acadia Centre for Estuarine Research.

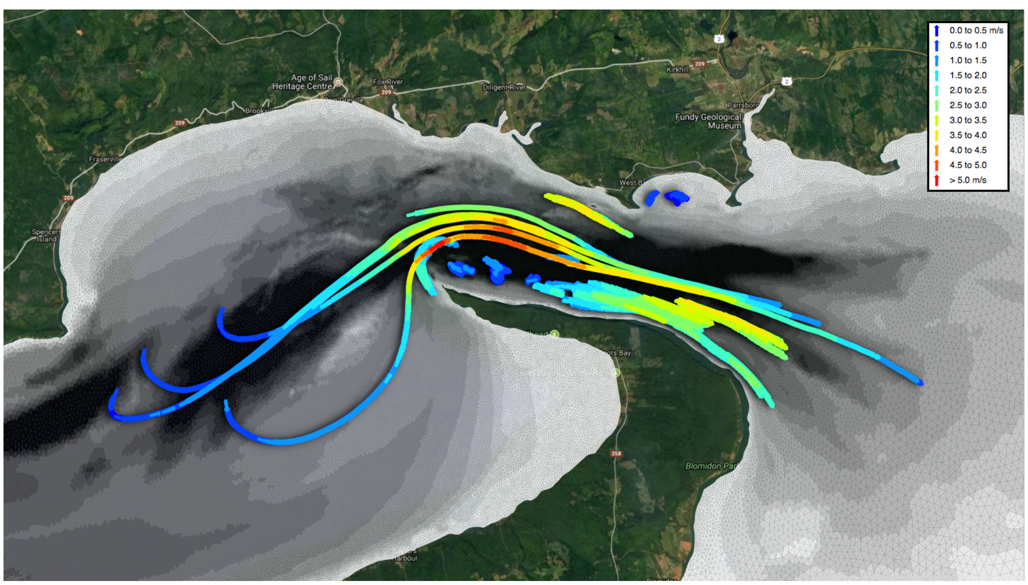

Figure 39: Minas Passage flood tide surface flow drifter measurements ($\hat{T} \leq 0.5$, north up). The four most northerly long drift tracks are provided by the Acadia Centre for Estuarine Research.

3 Conclusions and Recommendations

Going with the flow, through use of drifters, is a cost-effective approach for obtaining valuable information on the flow field and sound scape in high-energy tidal environments.

The GWTF project built upon previous success by the Project Team, and addressed limitations in drifter design by increasing functionality and making them useful at large scale sites such as the Minas Passage, including the FORCE site. Drifter development included adapting the platform to increase payload capacity enabling the drifters to carry a tracking device and an ADCP. Proof of concept testing was carried out in the Digby Region, followed demonstration and commercial application in the Minas Passage.

In addition to sensor development, research was conducted to advance data processing and assessment techniques. The calculation of surface flow speeds from GPS drifter data is relatively straight forward. However, the amount of measurements collected in surface flow field mapping requires smart and robust methods for data collection, processing, and analysis. To help streamline data processing, Luna Ocean developed a drifter data processing module as part of the Luna Ocean Data Analysis Software (LODAS). The code identifies individual drifts, allows for ”auto trimming” of known out of water GPS data points, manual review of individual drift tracks, smoothing of ”jumpy” GPS data, provides visualization of processed data, and exports data in CSV format for easy import to GIS software. This software has greatly reduced the time required to process large volumes of drifter data, while maintaining user review and visual data checks.

The tide time ($\hat{T}$) and relative tidal range ($\hat{R}$) parameters are useful for data analysis. The surface flow speed data are organized by $\hat{T}$ and indexed by $\hat{R}$, then used to generate flow field maps that highlight areas of potential development for tidal energy projects, provide information for designing tidal power systems, and a means for testing (and improving) the spatial and temporal accuracy of numerical models. The surface flow measurements are also useful for combining with concurrent bottom mounted ADCP data collection to fill near surface gaps in ADCP data sets.

The ADCP drifter has undergone successful proof-of-concept level development, including deign, build, deploy (43 times in the Minas Passage), and data processing. Luna Ocean is continuing to work with the Dalhousie Ocean Acoustics Laboratory on ADCP drifter design and data processing and analysis software. With funding support from the GWTF project the Nortek Signature 500 kHz ADCP has received an upgrade to the heading, pitch, and roll sensors that will allow us to conduct research focused on evaluating the spatial variability in turbulence, including the vertical structure of turbulent dissipation rate, and vorticity at the surface.

Comparison of SF drifter measurements to Model simulations for Grand Passage show: a) the majority of Model predictions to be within 0.5 m/s of the SF drifter measurements, with several locations within 0.1 m/s, and b) spatial and temporal variation in the performance of the Model with a tendency for the model to be a bit faster in most locations in Grand Passage, a known model issue. Luna Ocean is continuing to conduct research with Acadia University on calibration of the Model using surface flow measurements.

WP2 ”Preliminary proof-of-concept level data analysis of the drifter IMU data for waves measurements, including comparison to ADCP waves measurements” was not advanced. Due to timelines for Dalhousie student research work, the Grand Passage ADCP waves data is not yet available. WP2 requires these data for validation of the IMU based waves measurements. Research activities focused on WP1, WP3, and WP4 plus a demonstration in the Minas Passage with the SF drifters and ADCP drifter. WP2 is stand alone, and as such this did not significantly effect the overall project outcomes. A demonstration of SF drifters and the ADCP drifter in the Minas Passage was added to the project.

Recommendations for further GWTF research and development focus on use of the SF drifters and upgraded ADCP drifter 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, including:

- The ADCP drifter to evaluate the along track: a) vertical structure of the velocity, b) vertical structure of turbulent dissipation rate, and c) vorticity (at the surface).
- Several SF drifters to evaluate spatial variation in flow speeds throughout the flood-ebb tidal cycle, with a focus on filling spatial and temporal data gaps in the existing data sets including areas that are challenging for accurate modelling (such as eddies).
- Further investigation on the use of tide time ($\hat{T}$) and relative tidal range ($\hat{R}$) to predict flow speeds.

References

Lombardi, A., A. Hay, and D. Barclay, Soundscape characterization in a dynamic acoustic environment, Grand Passage, Nova Scotia, *Proc. of Mtgs on Acoustics (POMA)*, 2016.

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