OERA Research Project
Project Completion Report

Drones and Drifters:
The Great Pumpkin Race

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Executive Summary

The Drones and Drifters project focused on proof-of-concept testing for measuring flow speeds using one of the oldest tools in oceanography, the drifter, combined with one of the newest, the drone. Specifically, Unmanned Aerial Vehicles (UAVs) were used to collect geo-referenced images of biodegradable drifters (pumpkins) in tidal flows. Motion tracking was applied to the the images to map flow features and calculate the speed and direction of the drifters. The primary objective was to develop a cost-effective and environmentally friendly method for mapping flow fields in tidal channels and rivers.

Media coverage for Drones and Drifters included CBC radio interviews with Greg Trowse and Dr. Thomas Roc (in French), a feature on the Grand Passage experiments on Discovery Channels Daily Planet, a French Canadian scientific magazine for teenagers called Curium, and the Exploramer ocean education center in Sainte Anne des Monts. The Daily Planet feature is available here.

Preliminary tests were conducted in Shad Bay on November 13 through 15, 2016 to evaluate data collection procedures including image capture settings, flight altitudes, and drifter types. It was determined that initial proof-of-concept testing could be conducted at relatively low altitudes (less than 100 m), thus avoiding the need for obtaining a Transport Canada (TC) Special Flights Operating Certificate (SFOC), and would focus on 4K video (3840 x 2160 pixels) from the DJI Phantom 4, with time-lapse from the 3D Robotics Iris+ and GoPro 3 to also be collected for future analysis.

The primary tests were conducted in Grand Passage on November 17, 2016, including data collection at 1) a small channel between Brier Island and Peters Island on the flood and ebb tides, and 2) over the full length of Grand Passage on the ebb tide for the Great Pumpkin Race. A sample video clip from 1) is available here. For the Great Pumpkin Race we carved numbers into 82 pumpkins and provided sign-up sheets at local stores (and in-person) for participants to pick a pumpkin at no charge, with donations to a local charitable cause.

Additional data collection was conducted in the Minas Passage due to an opportunity to align with GPS drifter data collection on August 18, 2017. The data set was used for direct comparisons between GPS measured flows speeds and the results from the Drones and Drifters method.

Alpha and beta versions of the software were developed between December 2016 and February 2017, and further refined through to winter of 2017. Flow velocities are output in MATLAB format. Post processing including data analysis and export to GIS are preformed in MATLAB. The beta version is available OpenSource on GitHub.

Flow velocities calculated by Drones and Drifters were compared to measurements by GPS drifters and predictions by a numerical model. There was good agreement for flow speeds, with room for improvements. There was less agreement for flow direction, where the differences could be related to the Drones and Drifters geo-referencing code, the UAV yaw measurement, and/or FVCOM may have inaccurate predictions of flow direction in certain areas of the Minas Passage and Grand Passage. Overall, the results support successful proof-of-concept testing.

The Drones and Drifters method has advanced to a stage where it is useful for initial site assessments. This allows tidal and river site investigators to purchase a bag of locally sourced produce (preferably spoiled), throw the contents into the water, and measure the flow field for the purpose of determining project feasibility and narrowing in on potential areas of interest. Results are also promising for applying Drones and Drifters to more advanced flow analysis, however additional work is required to refine for use in detailed site assessments, including providing data of sufficient quality to validate/calibrate numerical models and refine potential berth sites for in-stream tidal and river turbines.

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The Drones and Drifters project focused on proof-of-concept testing for measuring flow speeds using one of the oldest tools in oceanography, the drifter, combined with one of the newest, the drone. Specifically, Unmanned Aerial Vehicles (UAVs) were used to collect geo-referenced images of biodegradable drifters (pumpkins) in tidal flows. Motion tracking was applied to the the images to map flow features and calculate the speed and direction of the drifters.

The primary objective was to develop a cost-effective and environmentally friendly method for mapping flow fields in tidal channels and rivers.

The scope of work included:

1. Obtain data sets useful for initial and ongoing development of the Drones and Drifters software package.
2. Develop the beta version of the software, mapping flow features and performing hydrodynamic analysis from multiple drifters observed in temporally sequential aerial images using off-the-shelf UAVs and camera systems.

Media coverage for Drones and Drifters included CBC radio interviews with Greg Trowse and Dr. Thomas Roc (in French), a feature on the Grand Passage experiments on Discovery Channels Daily Planet, a French Canadian scientific magazine for teenagers called Curium, and the Exploramer ocean education center in Sainte Anne des Monts. The Daily Planet feature is available at:

https://vimeo.com/lunaocean/dronesanddrifters

Deployment of pumpkin drifters from a lobster fishing boat in Grand Passage, Nova Scotia is shown from the viewpoint of a UAV (DJI Phantom 4) in Figure 1

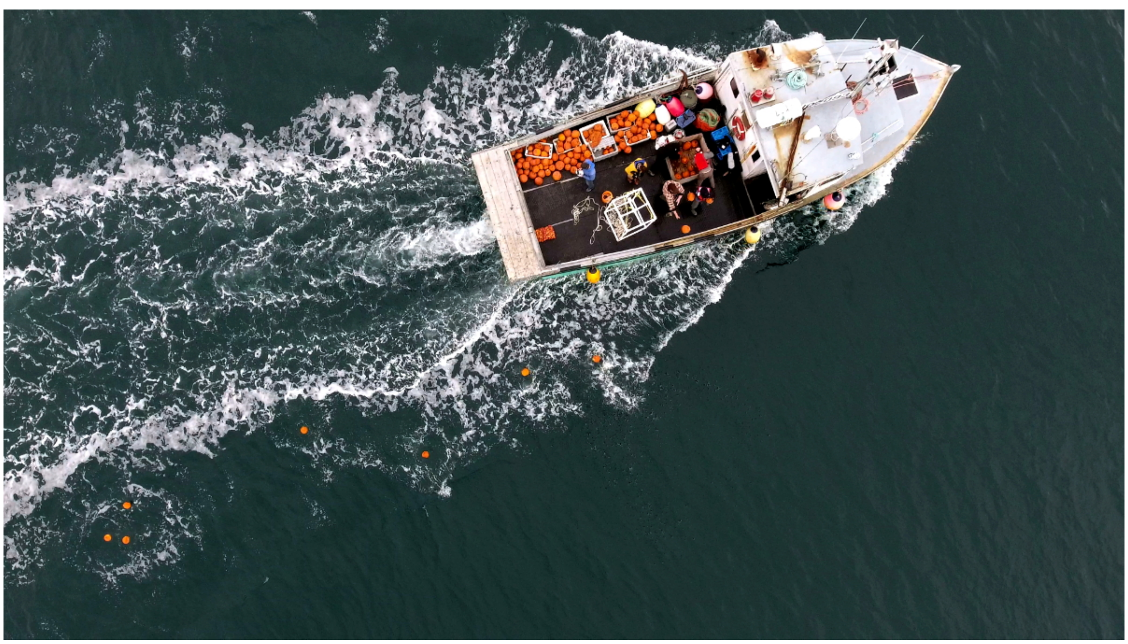

Figure 1: Pumpkin drifter deployment

2 Methodology

2.1 Data Collection

2.1.1 Preliminary Tests - Shad Bay

Preliminary tests were conducted in Shad Bay on November 13 through 15, 2016 to evaluate data collection procedures including image capture settings, flight altitudes, and drifter types. Tests were conducted using pumpkins, apples, and GPS drifters in Shad Bay (low flow) observed by two different UAV systems:

1. 3D Robotics Iris+ with a GoPro 3 camera on a 2-axis gimbal, and

2. DJI Phantom 4 with fully integrated camera on 2-axis gimbal.

Example images are shown on Figures 2 and 3, respectively.

Figure 2: Shad Bay tests - 3DR Iris+ with GoPro 3 (prior to correcting barrel distortion)

Images of pumpkins and apples in seawater were also collected with a near-infrared (NIR) camera from the dock at the Luna Ocean office in Shad Bay. The camera did not need to be risked at an elevated position above the target images to gain info on the usefulness of NIR for improving image recognition. An example image is shown on Figure 4. A laser range finder was use to measure the distances.

Figure 3: Shad Bay tests - DJI Phantom 4

Figure 4: Shad Bay tests - NIR image of pumpkins

It was determined that initial proof-of-concept testing could be conducted at relatively low altitudes (less than 100 m), thus avoiding the need for obtaining a Transport Canada (TC) Special Flights Operating Certificate (SFOC), and would focus on 4K video (3840 x 2160 pixels) from the DJI Phantom 4, with time-lapse from the 3D Robotics Iris+ and GoPro 3 to also be collected for future analysis.

2.1.2 Primary Tests - Grand Passage

The primary tests were conducted in Grand Passage on November 17, 2016, including data collection at 1) a small channel between Brier Island and Peters Island on the flood and ebb tides, and 2) over the full length of Grand Passage on the ebb tide for the Great Pumpkin Race.

The small channel was chosen for proof-of-concept testing to provide desired flow speeds (up to approximately 3 m/s) and an easily observable flow feature (large eddy, with turbulent zones), also allowing land to be seen while complying with flight altitudes acceptable without permit from Transport Canada. The presence of land in the area of interest helps with initial evaluation of georeferencing accuracy. The location of the small channel in Grand Passage is shown on Figure 5. The channel is shown looking roughly north or south on Figure 6 and south to north on Figure 7. Example images from data collection are show on Figures 8 and 9. A sample video clip from the tests is available at:

https://vimeo.com/lunaocean/dndgp

The sample video has been reduced from native 3840 x 2016 pixel resolution to 1920 x 1080 pixels. Only the portion of the video prior to the boat entering the frame of view was used due to complications associated with motion tracking of the boat, the pumpkins on the boat, and the boat wake. The additional footage including the boat was collected for use by Discovery Channel, without compromising the objectives of the test.

2.1.3 Great Pumpkin Race - Grand Passage

For the Great Pumpkin Race (November 2016) we carved numbers into 82 pumpkins and provided sign-up sheets at local stores (and in-person) for participants to pick a pumpkin at no charge, with donations accepted to a local charitable cause. The funds were taken by the local councillor directly to a family in need. Initially 80 pumpkins were prepared, but 2 additional ones were added at last minute due to local fisher interest on the dock as we were loading the boat.

The pumpkin start position was at the north end of Grand Passage (near Cow Ledge, as shown on Figure 10) and the finish was the southern end of Grand Passage (near Peters Island, as shown on Figure 11). The pumpkins were released from a fishing boat and followed as they made their way down the passage with the ebb tide. UAV images were collected with the DJI Phantom 4 while following the pumpkins, including stopping to hover at several positions. The winning pumpkins were determined by observers on the fishing boat, and gift certificates to a local restaurant were awarded to the first, second, and third place winners. The winning pumpkins are shown on Figure 13.

2.1.4 Opportunistic Data Collection - Minas Passage

Additional data collection was conducted in the Minas Passage due to an opportunity to align with GPS drifter data collection on August 18, 2017. The DJI Phantom 4 was launched, landed, and piloted from a Rosborough RF-18 (the Puffin) while drifting in the Minas Passage. An aerial view of the site is shown on Figure 14. Aerial images of GPS drifters were collected to provide a data set for direct comparisons between GPS measured flows speeds and the results from the Drones and Drifters method.

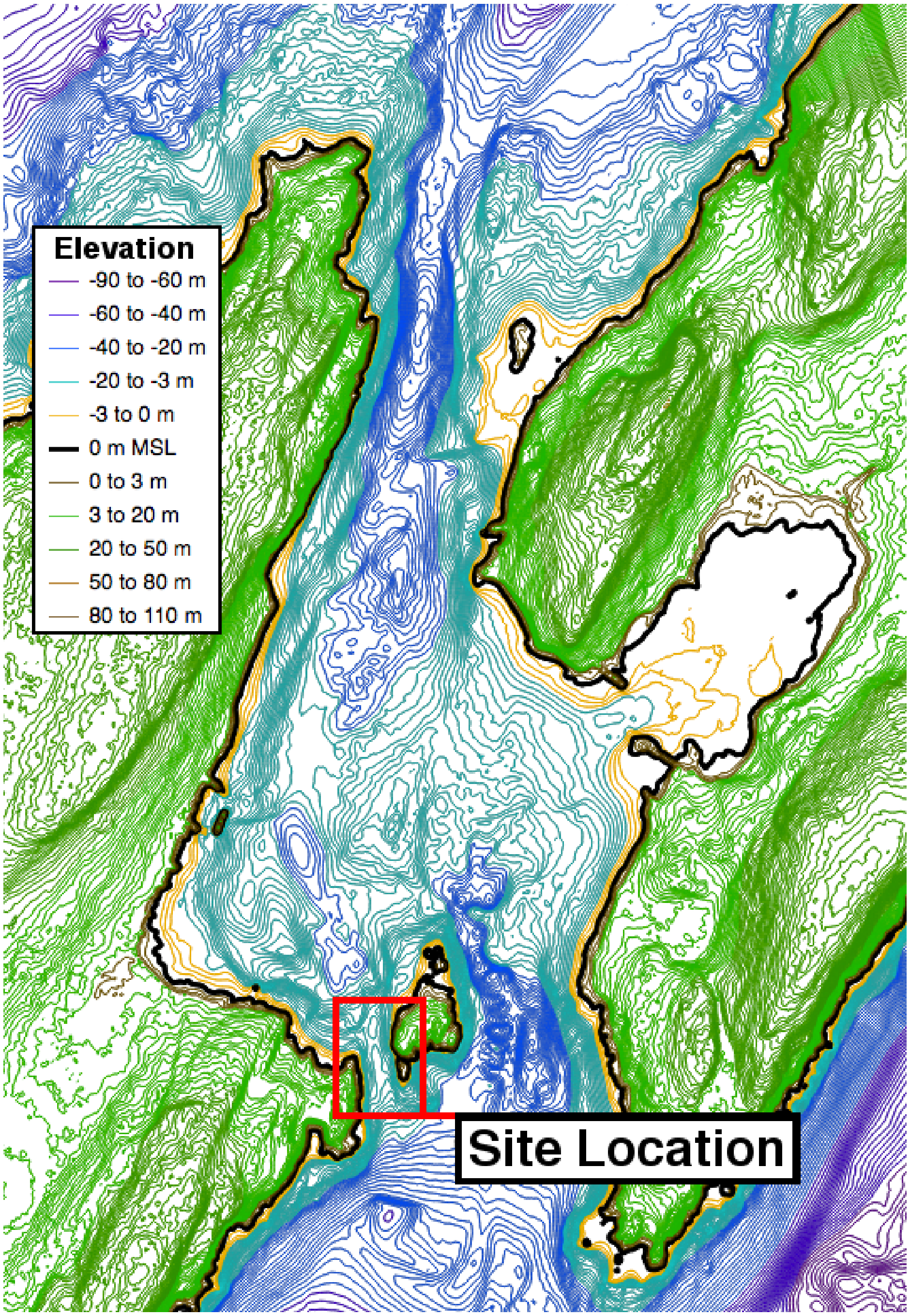

Figure 5: Grand Passage small channel - Location

Figure 6: Grand Passage small channel - North to south

Figure 7: Grand Passage small channel - South to north

Figure 8: Grand Passage small channel - Data collection example image 1

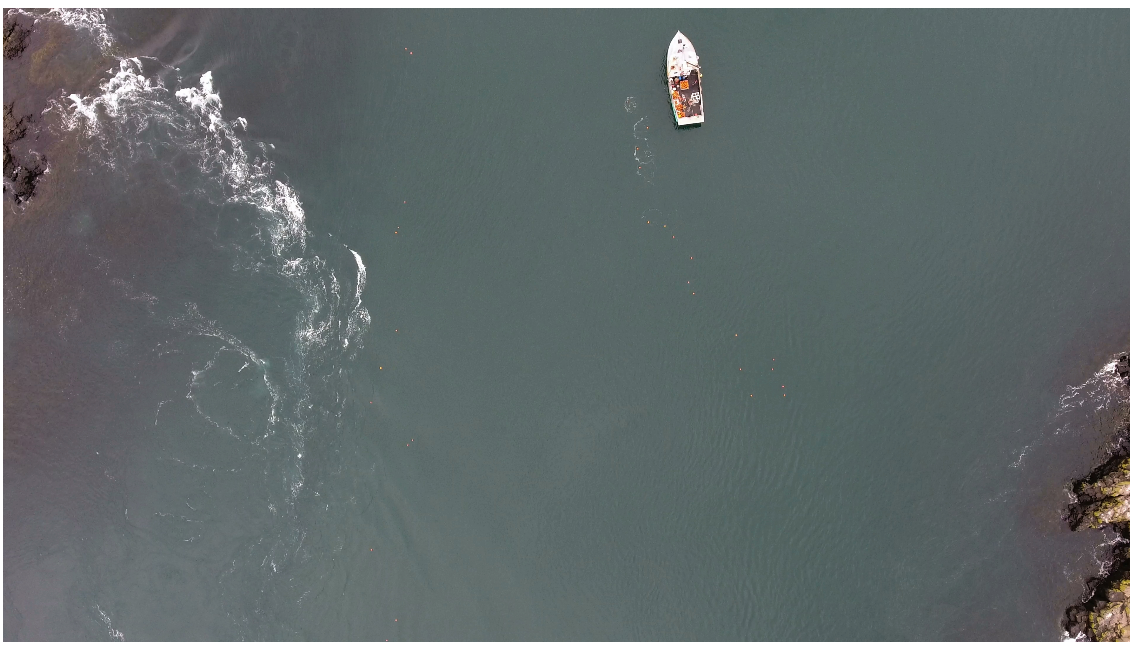

Figure 9: Grand Passage small channel - Data collection example image 2

Figure 10: Great Pumpkin Race - Start

Figure 11: Great Pumpkin Race - Finish

Figure 12: Great Pumpkin Race - Data collection example image

Figure 13: Great Pumpkin Race - Winning pumpkins (38, 18, and 67 in order of finishing)

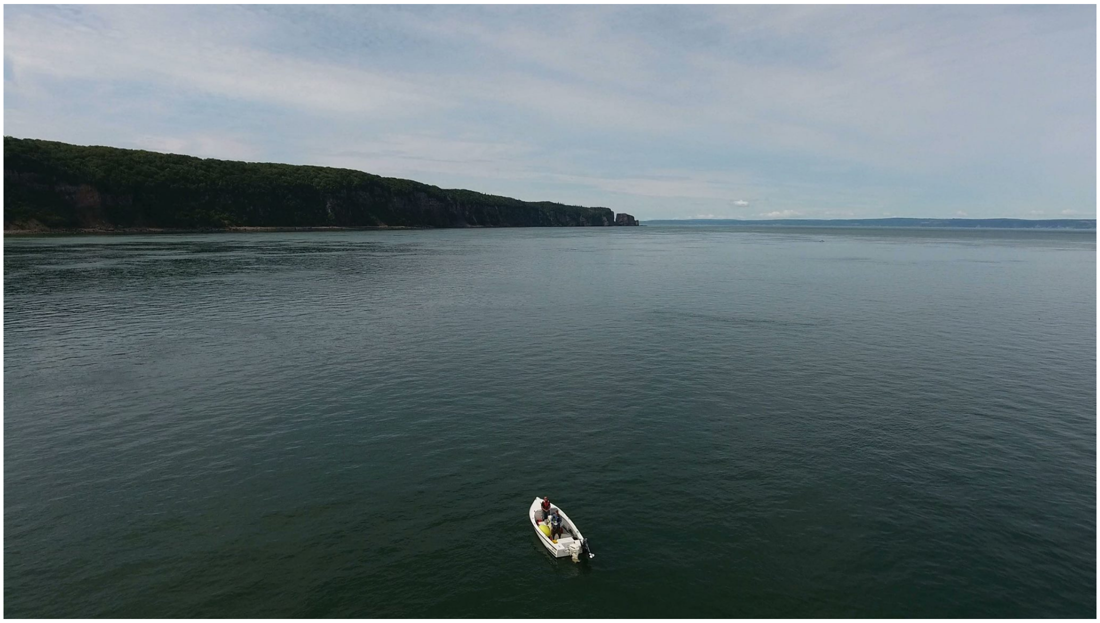

Figure 14: Minas Passage - Aerial view of vessel and site location

2.2 Software Development

Alpha and beta versions of the software were developed between December 2016 and February 2017, and further refined through to winter of 2017. The beta version is available Open Source at:

https://github.com/theelectricbrain/Drones-Drifters

The software was developed with a modular structure including georeferencing, motion (drifter) tracking, and flow characterization (data processing). The outputs include drifter flow velocities (u, v, speed, and direction) and mapping of turbulent areas.

Prior to loading video into the Drones and Drifters software, the UAV flight log is evaluated to extract video sections where the UAV is hovering, based on minimum acceptable differences in latitude, longitude, yaw, and velocity.

Georeferencing is conducted using the latitude, longitude, yaw, and altitude of the UAV while hovering. The Field of View (FOV) of the image (number of meters in x and y directions) is calculated based on the camera specifications and altitude of the UAV. The image is then rotated as per the UAV yaw, center point determined based on UAV latitude and longitude, and corners positions calculated in latitude and longitude based on the FOV (including transformation onto earth spherical coordinates).

Drones and Drifters uses the Lucas-Kanade method to track pixel motion (See OpenCV documentation for details). The code will track all motion in the video, or focus on a target colour and/or shape. Flow velocities are output in MATLAB format. Post processing including data analysis and export to GIS are preformed in MATLAB.

3 Results

3.1 Processed Data in GIS

Processed data from a segment of UAV video from the small channel in Grand Passage (Figure 5) are shown on Figure 15. The georeferencing agrees well with the Lidar base map, and an aerial image brought into GIS. The automatic detection of surface turbulence successfully picks up a strong shear line as well as less significant turbulence along the shore of Peters Island (eastern extent of field of view). Colour and shape screening was not applied in this example, as such, motion from bubbles near the surface turbulent areas are also tracked, and their speeds included in the plot.

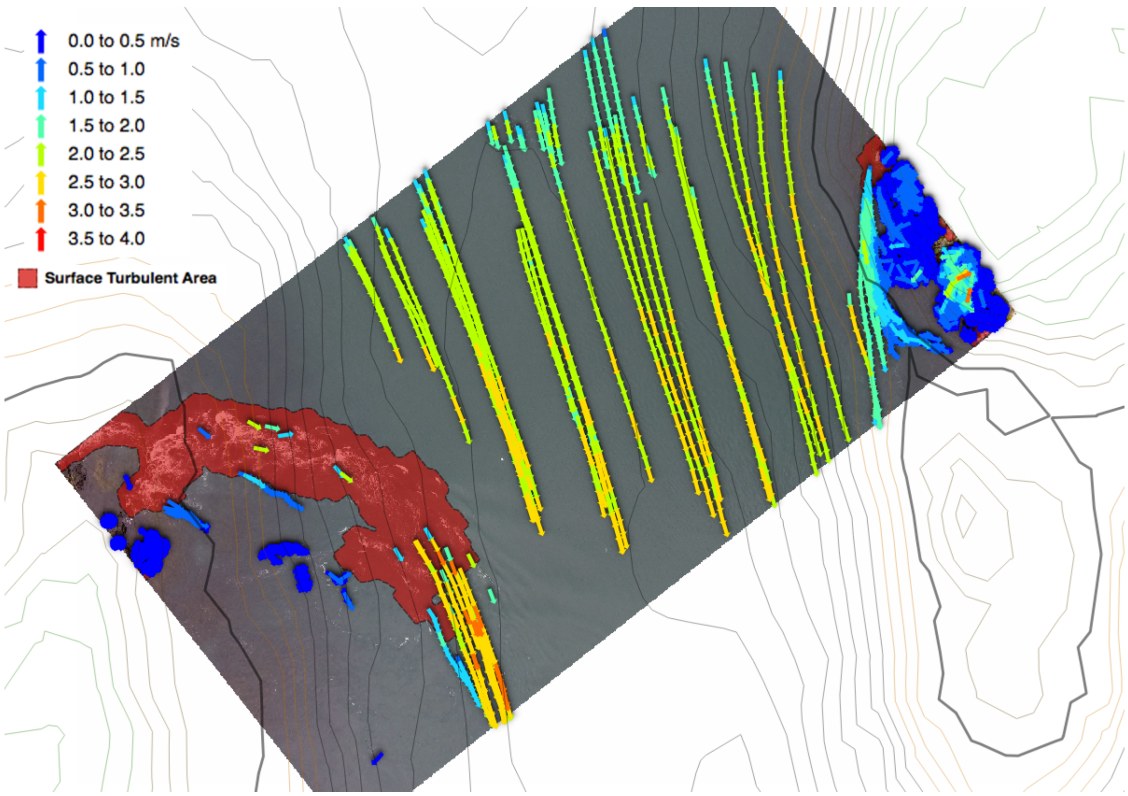

Figure 15: Grand Passage small channel - Surface turbulent areas and flow speeds calculated by Drones and Drifters using aerial observations of drifting pumpkins (north up). Long tracks down the main channel are from pumpkins. Flow speeds calculated near the eastern and western boundaries are from bubbles generated in turbulent areas. The experiment was conducted near the start of ebb tide with the water level above mean sea level (solid black bathymetry line).

3.2 Comparison to GPS Drifters

During the Grand Passage small channel test, GPS drifters were deployed from the fishing boat after the pumpkins with the intention of observing them with aerial images from the UAVs. However, an equipment failure resulted in the DJI Phantom 4 stopping video recording prior to the GPS drifters passing through view. As a result, a direct comparison of GPS measurements to Drones and Drifters using aerial images of the GPS drifters in Grand Passage is not possible. Comparisons were made spatially, assuming that temporal variation is not significant over the 5 to 10 minute time period between the measurements of drifting pumpkins by UAV and the GPS drifters by satellite.

An along channel comparison is provided on Figure 16, showing good agreement where the pumpkins and GPS drifters both speed up as they moved south through the channel. This plot does not account for cross-channel variation, and some, but not all, of the speeds from motion detection of bubbles have been removed from the plot. Figure 17 provides a comparison of the Drones and Drifters measured flow speeds to the closest GPS drifter measured speeds, with a threshold of 10 m maximum distance. The comparison also shows good agreement, with room for improvements.

The Minas Passage test was conducted due to an opportunity to align with GPS drifter data collection on August 18, 2017. No bio-degradable drifters were used; however, a UAV flight was conducted to collect data useful for direct comparisons between GPS measured flows speeds and the results from the Drones and Drifters method.

A comparison of the GPS measured positions to the georeferencing using Drones and Drifters is shown on Figure 18. The tracks line up well, with average offsets in the range of 3 to 10 m. A speed comparison is shown on Figure 19, including a histogram on Figure 20. The mean residual is -0.066 m/s and the standard deviation is 0.114 m/s.

Overall, these results support successful proof-of-concept testing.

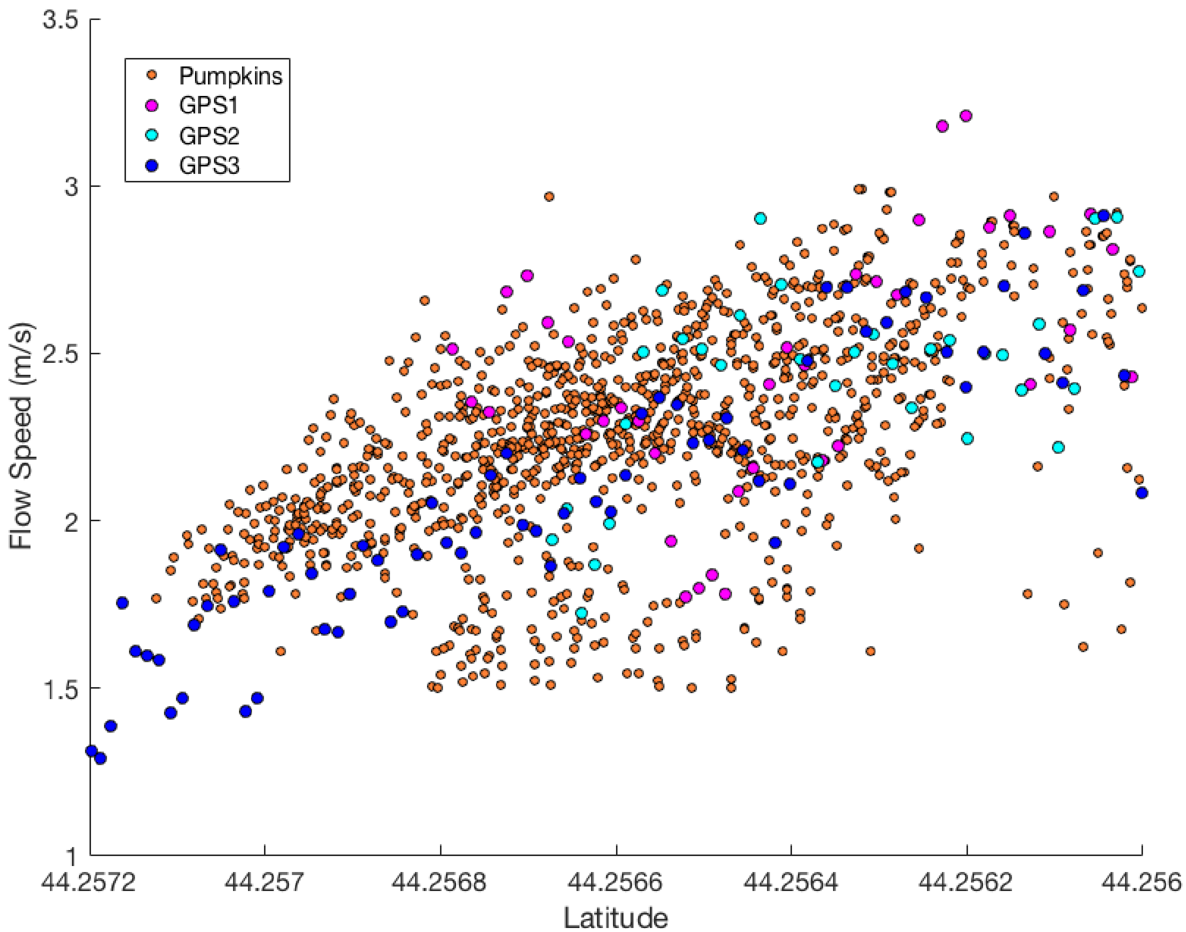

Figure 16: Grand Passage small channel - Along channel flow speed comparison showing values measured by GPS drifters and calculated by Drones and Drifters using aerial observations of drifting pumpkins. Shows good agreement on flow speeds including down channel acceleration, where drifters move from north to south. Does not account for cross channel (east to west) variation.

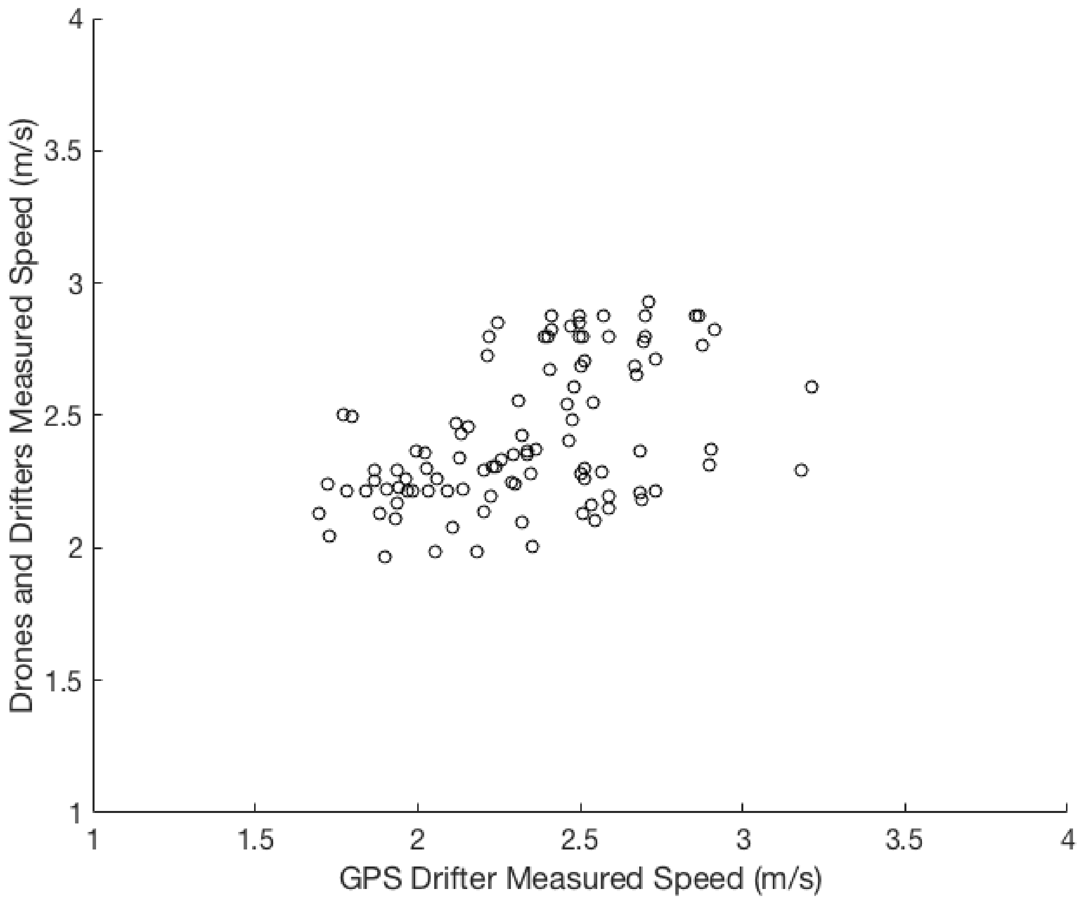

Figure 17: Grand Passage small channel - Point to point flow speed comparison showing values measured by GPS drifters and calculated by Drones and Drifters using aerial observations of drifting pumpkins, focusing on closest data points with a threshold of 10 m maximum distance. Shows good agreement, with room for improvements.

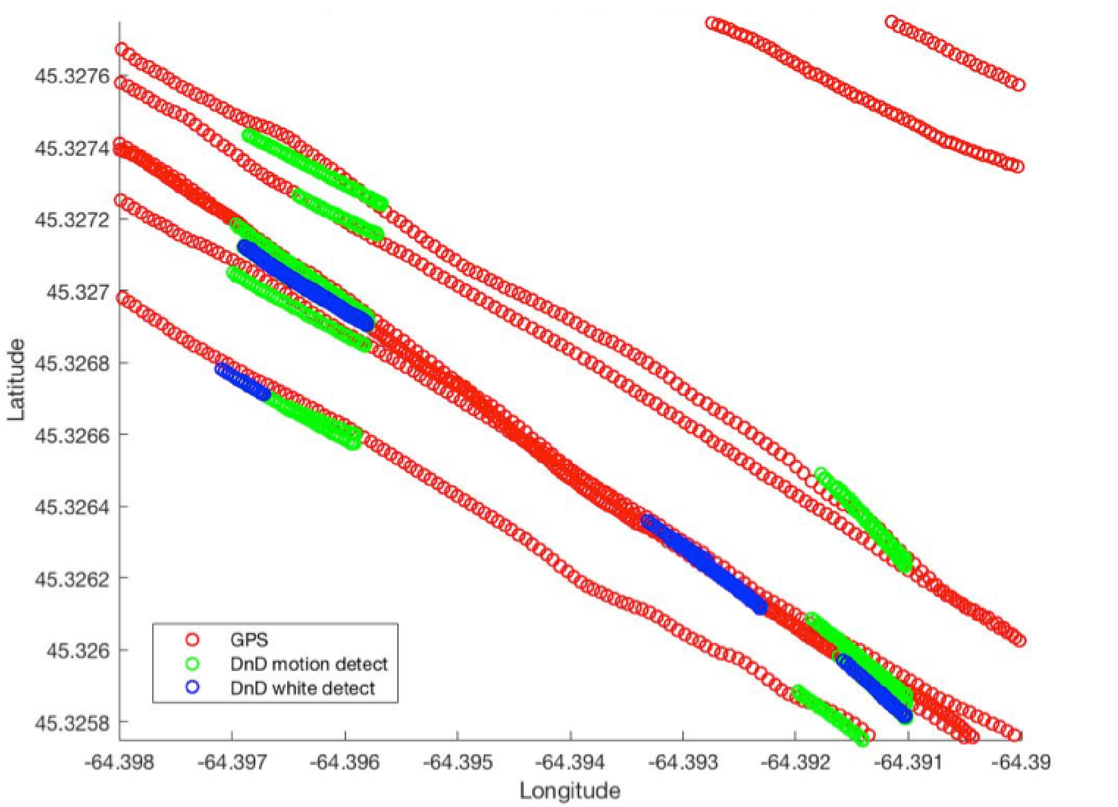

Figure 18: Minas Passage - Location comparison for GPS drifters to Drones and Drifters using aerial observations of GPS drifters. Shows good agreement with and without focusing on the white colour of the drifters.

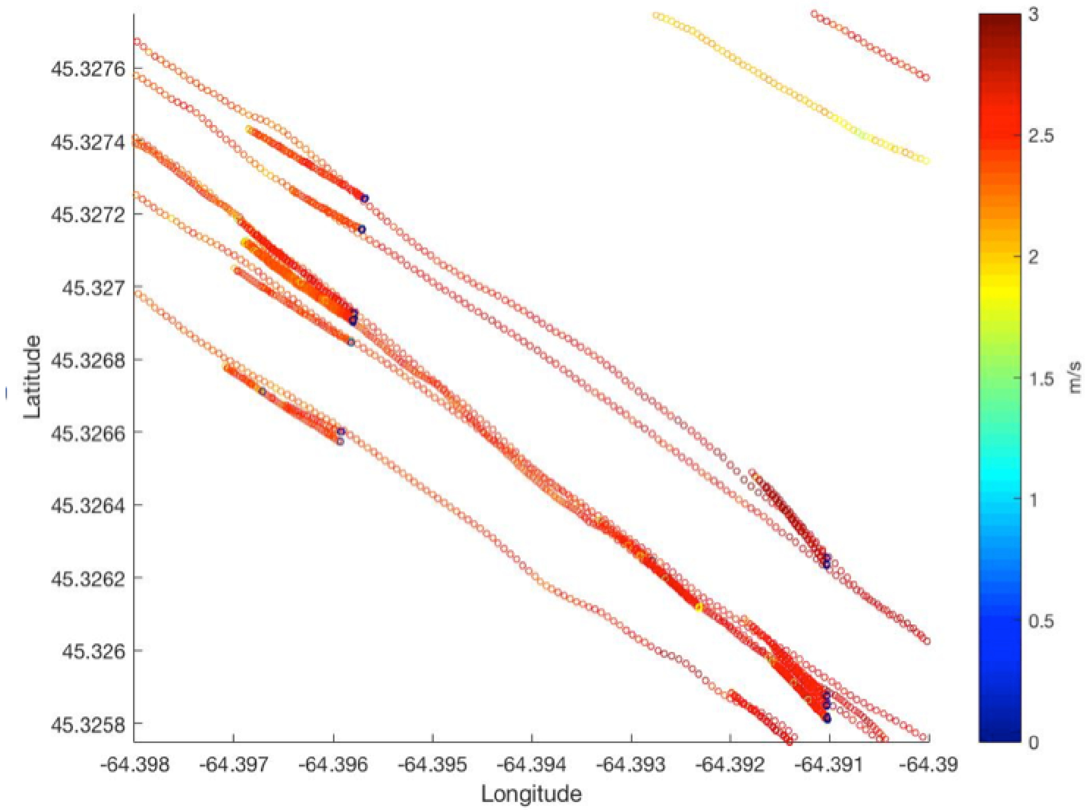

Figure 19: Minas Passage - Speed comparison for GPS drifters to Drones and Drifters using aerial observations of GPS drifters. Shows good agreement, with some outliers at the drift endpoints.

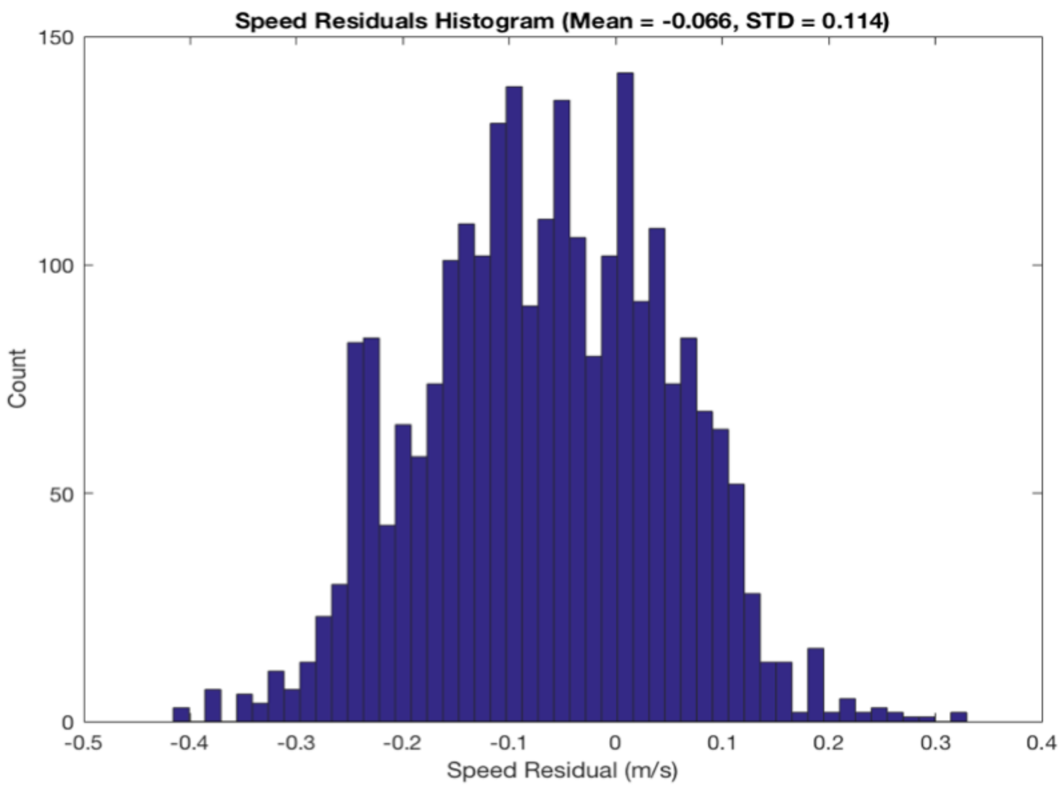

Figure 20: Minas Passage - Histogram of speed comparison for GPS drifters to Drones and Drifters using aerial observations of GPS drifters.

3.3 Comparison to Numerical Model Predictions

The Drones and Drifters measured flow speeds from the Grand Passage (November 17, 2016) and Minas Passage (August 18, 2017) tests were compared to predictions using the Finite-Volume Community Ocean Model (FVCOM). Five video clips for each day were identified that met the camera stability (hover) criteria, and were used for the comparison.

The FVCOM data used for the comparison has a time-step of 1 minute with 20 to 50 m spatial resolution. Spatial interpolation was applied to extrapolate the FVCOM data to each drift point. A statistical comparison was then conducted comparing the Drones and Drifters measured flow velocities to the predictions from FVCOM.

The FVCOM predicted flow speeds compare well with the Drones and Drifters measurements, with an overall residual bias of 0.042 m/s and normalized root mean squared error of 0.116 m/s including all 10 video clips. The residuals for the small channel experiment conducted in Grand Passage are shown on Figure 21. There was less agreement when comparing the east and north components of the flow velocities, where the combined magnitude of residual bias is 0.305 m/s. This suggests good agreement for flow speed, but less for direction. The differences in direction could be related to the Drones and Drifters geo-referencing code, the UAV yaw measurement, and/or FVCOM may have inaccurate predictions of flow direction in certain areas of the Minas Passage and Grand Passage. To investigate FVCOM accuracy, a comparison was conducted using all GPS drifter data from August 18, 2017. This included approximately 200 drifts with over 75,000 data points. The comparison shows a mean direction difference of 5.2 degrees, but a standard deviation of 27.6 degrees. As such, there are areas in the Minas Passage (outside of the FORCE region) where there is significant difference in direction between GPS drifter measurements and FVCOM predictions.

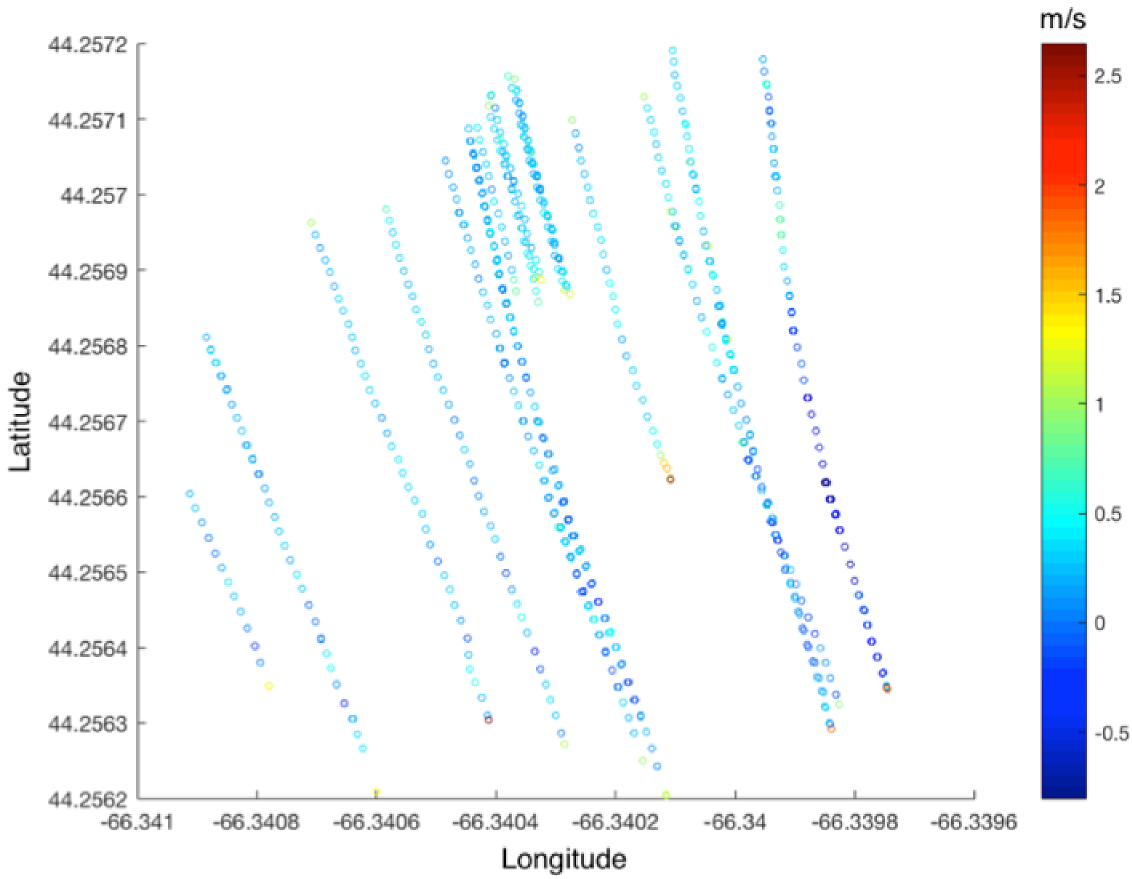

Figure 21: Grand Passage small channel - Flow speed residuals for values predicted by FVCOM minus those calculated by Drones and Drifters using aerial images of drifting pumpkins. Shows good agreement, with some outliers at the drift endpoints.

4 Conclusions and Recommendations

The Drones and Drifters method has advanced to a stage where it is useful for initial site assessments. This allows tidal and river site investigators to purchase a bag of locally sourced produce (preferably spoiled), throw the contents into the water, and measure the flow field for the purpose of determining project feasibility and narrowing in on potential areas of interest.

Results are also promising for applying Drones and Drifters to more advanced flow analysis, however additional work is required to refine for use in detailed site assessments, including providing data of sufficient quality to validate/calibrate numerical models and refine potential berth sites for in-stream tidal and river turbines.

Moving forward, successful proof of concept testing justifies further time directed to:

1. Refining the Drones and Drifters code, including to resolving the outliers located at drift endpoints
2. Advanced analysis of existing data sets to better understand the differences between Drones and Drifters, GPS drifters, and FVCOM
3. Conducting tests to further investigate and improve georeferencing accuracy
4. Investigating improvements in accuracy and survey areas using different UAV platforms and payloads
5. Development of data collection methods
6. Data analysis (methods and outputs)
7. Obtaining TC SFOC for higher altitude flights

Acknowledgements

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- The captain and crew of School of Fish for pumpkin deployments in Grand Passage
- All participants in the Great Pumpkin Race
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- OERA, Innovacorp, and Mitacs for funding support