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# Aquaculture Drifter Programme: Progress Update 2010

# Programme d'étude avec bouées dérivantes pour l'aquaculture : Mise à jour 2010

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## ABSTRACT

The aquaculture industry in Newfoundland is currently expanding rapidly with an increasing number of finfish sites being developed. To conduct a preliminary investigation of the marine circulation along the south coast of Newfoundland, 14 deployments of a total of 68 CAST drifters were released and monitored at different locations in Bay d'Espoir and Fortune Bay in summer 2009 and 2010. The information was used to assess the circulation of the surface layer of the area. The influence of wind forcing, tidal exchange, and freshwater discharge on the surface water transport was estimated. Most of the drifters were at liberty for more than one semi-diurnal tidal cycle. The wind driven circulation may predominate over tidal mechanisms. During the experiments, the river discharge did not show any clear effect on the surface movement of the water. All together, the average velocity of the drifters was between 0.10 and 0.25 m/s and the typical zones of influence ranged between 5 and 18 km over a period of 24 h.

## RÉSUMÉ

L'industrie de l'aquaculture de Terre-Neuve-et-Labrador connaît actuellement une croissance rapide, avec le développement de sites de plus en plus consacrés aux poissons à nageoires. Afin de pouvoir procéder à une étude préliminaire de la circulation marine le long du littoral sud de Terre-Neuve-et-Labrador, on a procédé à 14 déploiements d'un total de 68 bouées dérivantes CAST (Convertible Accurate Surface Trackers) qui ont été observées dans différent endroits de la baie d'Espoir et la baie Fortune à l'été 2009 et 2010. L'information recueillie a été utilisée pour évaluer la circulation à la couche de surface de la zone. L'influence du forçage du vent, du mouvement des marées et du débit d'eau douce sur le transport de l'eau de surface a été estimée. La plupart des bouées dérivantes sont restées en liberté durant plus d'un cycle de marée semi-diurne. La circulation due aux vents peut avoir le dessus sur les mécanismes des marées. Durant les expériences, le débit fluvial n'a pas eu d'effet visible sur le mouvement de l'eau à la surface. Dans l'ensemble, la vitesse moyenne des bouées dérivantes s'élevait entre 0,10 et 0,25 m/s et les zones typiques d'influence se situaient entre 5 et 18 km sur une période de 24 heures.

# INTRODUCTION

The aquaculture industry in Newfoundland is currently expanding rapidly with an increasing number of finfish sites being developed. Historically, finfish aquaculture began in Newfoundland in the late 1970s. Based on preliminary oceanography investigations along the south coast of the island, the inner areas of the Bay d'Espoir fjord were identified as potential locations for rainbow trout (*Oncorhynchus mykiss*) culture, whereas culture of Atlantic salmon (*Salmo salar*) required more exposed sites during summer (MSRL 1980). With advances in rearing cage mooring systems, deeper water and more exposed sites were developed for finfish aquaculture. Recently exposed and deep water sites are being established outside of the traditional range of finfish culturing sites with areas along the coast and into Fortune Bay now being utilized, particularly for Atlantic salmon.

The expanding aquaculture industry has presented challenges to regulators and decision makers. Although there is a minimum of 1 km spacing between most sites, there is concern that pathogens or other water borne vectors may be transmitted between sites through natural oceanographic processes. Most vectors relevant to marine finfish aquaculture occur near the surface. For example, sea lice (*Lepeophtheirus salmonis* and *Calanus finmarchicus)* are phototactic (Aarseth and Schram 1999) and studies of surface water movement have investigated the potential large scale distribution of sea lice in areas with aquaculture activities (Brooks 2005; Brooks and Stucchi 2006). The large geographic area, complex topography and high variability in conditions on the south coast of Newfoundland where finfish aquaculture occurs, dictates that oceanographic modelling be employed to address the potential dispersal of vectors in near surface waters. Estimation of zones of influence around fish farms is essential to address fish health issues and manage the production in a way that help control spread of water-borne diseases such as ISA, sea lice, etc. among fish farms. Establishing BMA has become a priority in the province of NL to face this fast expansion.

Oceanographic numerical models of water distribution and circulation have been used to inform aquaculture policy decisions in many jurisdictions. These models have not been validated for this province due to the lack of sufficient oceanographic data. Southall et al. (2004) reviewed some of the early oceanographic models that simulated the drift of particles (e.g., waste) from aquaculture sites. More sophisticated models grew out of these, such as the widely-used DEPOMOD (Cromey et al. 2000). This model is used by the Scottish Environmental Protection Agency to predict the fate of wasted food and faecal matter from finfish cages using data on cage positions, bathymetry, fish biomass, food conversion ratios, and water currents. Other hydrodynamic models are useful in understanding the spread of pathogens such as infectious salmon anemia (ISA) (Murray et al. 2006). In Norway, environmental capacity modelling for aquaculture and all other coastal activities is applied to broad coastal regions under the LENKA programme (Bergheim et al. 1991; Ibrekk et al. 1993) and at the aquaculture site level the approach MOM (Modelling, fish Ongrowing, and Monitoring) is applied to estimate carrying capacity (Ervik et al. 1997).

Since good knowledge of the water circulation in the area of interest is essential for the development of circulation models to implement BMA, the Program for Aquaculture Regulatory Research (PARR) has supported an oceanography project to collect water current data in the areas of intereSt. Drifters have been used routinely to obtain data on water movement as they move following the current systems and broadcast their locations to satellite receivers. Extensive work with drifters in New Brunswick has been successful in showing the potential transport of particles from finfish sites and this information has informed management decisions in the Bay of Fundy (Chang et al. 2007). This Research Document describes the surface water

layer drift patterns, derived using data from multiple deployments of drifters near aquaculture sites on the south coast (Figs. 1 and 2). The influence of wind forcing, tidal exchange, and freshwater discharge on surface water transport was estimated using these surface drifters.

## MATERIALS AND METHODS

Surface drifts were studied using Convertible Accurate Surface Tracker (CAST) drifters which float near the water surface and record their position at preset time intervals. We conducted twelve releases comprised of clusters of four or five drifters and two releases of lines of four drifters. Drifter positions were monitored for approximately 48 h post release.

Each drifter consisted of a perforated plastic barrel and an electronic package housed within a central waterproof tube (Fig. 2). The electronics consisted of a global positioning system (GPS) unit. The combination extends from the sea surface to a depth of 1 m hence the drifters are carried by water movements occurring in the top 1 m of the water column.

The electronics were configured to record the drifter's position every 30 min, but occasionally obstructions by the topography of the area (e.g., cliffs) prevented a transmission being recorded. All times were recorded in UTC (GMT), which is 2.5 h ahead of Newfoundland time zone in the summer (NDT).

Data from the internal memory of the drifters was edited to remove low quality and outlier position fixes, plus position fixes that were recorded prior to deployment and following recovery. Tracks of the drifters were plotted on maps corresponding to the study area. Tracks were plotted as straight line segments connecting temporally-sequential positions. The speed of displacement of the drifters is estimated as distances divided by the time interval.

For the atmospheric conditions in the area, Environment Canada (EC) maintains only one weather station with wind speed and direction. The only available wind data is from a weather station on Sagona Island (WMO ID: 71408, 47°2204.000N, 55°47'41.000W. Elevation: 59.70 m), about 12 km south of Harbour Breton. Hourly wind speed and direction were downloaded from the EC database at http://www.climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html?

The complex topography of the area and the distance of the station with respect to the points of release of the drifters suggest that this wind measurement may not represent the real wind conditions at different locations of the bay. However, because of lack of complete wind data, this EC data set was used to determine the possible influence of wind forcing on drifter transport. Another set of atmospheric data were recorded every hour in 2010 by HOBO U30 weather stations attached to aquaculture cages near Harbour Breton; this was used to determine whether local wind patterns differed from those at Sagona Island. The wind direction was first converted to degree true north before any analysis.

Estimates of tidal height were calculated using a tidal model (Foreman 1978) for the nearest Canadian Hydrographic Service (CHS) tide gauge location with tidal constituents provided by CHS (http://www.tides.gc.ca/english/DataAvailable.shtml). Four locations are available for the area of study (Fig. 1), they are Pushthrough (station #690), St. Alban's (station #705), and Hermitage (station #710), Harbour Breton (station #720). For the tidal movement, a preliminary tidal analysis of currents and sea level height in the area, using bottom-mounted Acoustic Doppler Current Profilers, shows that the semi-diurnal M2 tides are the main tidal constituents.

The phase lag between the M2 tidal currents and M2 tidal heights ranges between 80-100º, meaning that the tides in the area are nearly standing waves. In this case, the maximum flood and ebb currents will occur mid-way between the high and low tides. Between each other, the phase lag of the M2 tides for the three CHS stations are around 8-16 min., less than 50 times the period of the M2 tidal constituent.

## RESULTS

In 2009-10 a total of 68 CAST drifters were released at different locations in Bay d'Espoir and in Northeast Arm west of Great Bay de l'Eau (Fig. 1). The period of drift of each experiment is given in Table 1 for 2009 and Table 2 for 2010.

*Table 1. Time period of each drifter release for 2009.*

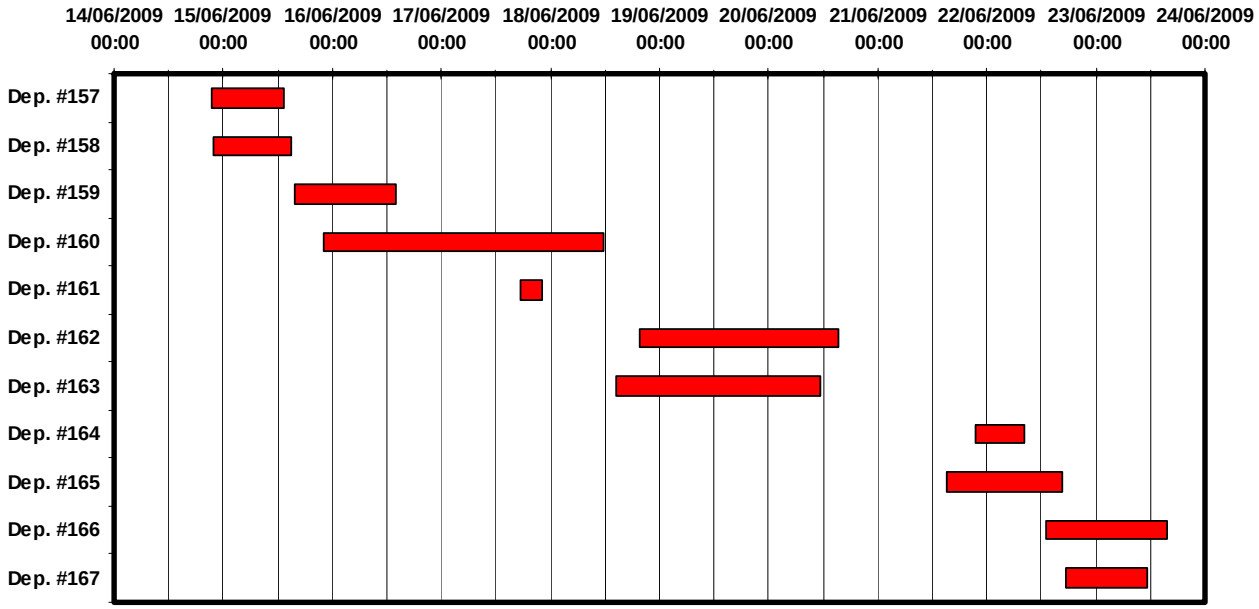
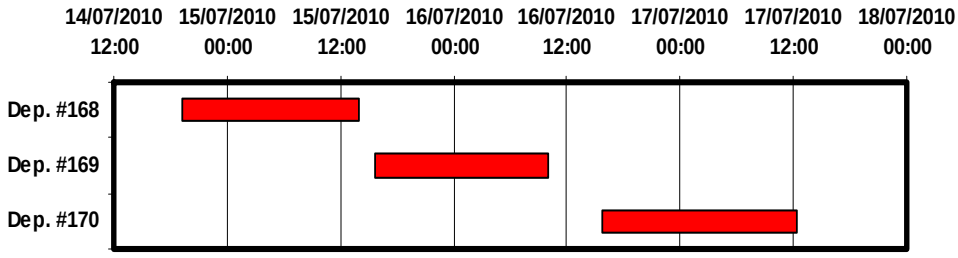



*Table 2. Time period of each drifter release for 2010.*



## EXPLANATION OF THE FIGURE LAYOUT AND TABLE

For each deployment, a map of the area with the track of each drifter is presented together with an inserted smaller map showing the geographical position of the area of study. In addition to the maps, there is a panel of three figures showing the series of speed of each drifter, the tidal height of the area for the same period as the drifter, and the corresponding wind conditions at Sagona Island, respectively. Each drifter is assigned a specific color for the track, the corresponding track numbers are specified in each figure caption, the same color in the time series of speed represents the same drifter in the map. The initial position, which really corresponds to the location where the drifter's GPS started to transmit its position to the satellite, is specified with a red triangle with the number 0 inserted (as for 0 h post release). The circles represent the position of the drifter approximately every 2 h with the hour inserted every other circle. The same colored marks (and inserted hour number, if applicable) are found on both the map of trajectories and the series of drifter velocities and they represent the same time. The black arrows on the map specify the approximate locations of aquaculture sites in the area.

The horizontal and vertical axes of the map are the extent distance in kilometers to easily evaluate the distance travelled by the drifters.

The horizontal axis of the time series represents the time. The numbers at the top of the figure is the number of hours from release. For the panel of wind conditions, a feather plot of the wind velocity is presented with the stick showing the magnitude and the direction toward which the wind blows.

For each deployment, a Table is also provided. It gives the average speed, minima and maxima for the whole drifting time, distance travelled, and drifting time for each drifter. The average velocity is computed using all the available data including the period when the drifter was on a motionless status, when the latter is not right at the beginning or right at the end of the drifter journey. The straight line distance is the distance between the release location and the last location where drifter data is present in the file. The last column of the Table is the total time of sail of the drifter.

In the description of wind direction, abbreviations will be used to specify the direction of the wind. Appendix 1 gives a list of possible wind direction with the corresponding angle from where the wind comes.

## DRIFTER DEPLOYMENTS

Following is the description of each deployment.

### Deployment 157 (Figure 3)

On 14 June 2009, four CAST drifters were released along a section just south of St. Alban's shortly before low tide (Fig. 3a). All drifters were released within minutes of each other and initially headed north, into the bay. One drifter (ID 2210) hit the western shore 2.6 h post release having travelled 2.14 km, the other three drifters continued into the bay and approached the western shore approximately 7 h later. Two drifters were recovered at the shore in this area between 7.2 and 7.6 h post release after travelling approximately 7.40 km. One drifter (ID 2079) remained almost motionless near the shore for about 3 h; it then headed out of the bay and hit the western shore, farther south, 15.6 h post release. The total distance travelled by this drifter was 8.38 km (5.70 km of which going north and the rest to the south).

For this deployment, the minimum and maximum average speeds of the drifters are 0.15 m/s and 0.23 m/s (0.54–0.83 km/h), respectively (Table 3).

The general pattern of the variation of the drifter speed of displacement with time (Fig. 3b) seems to show opposite variation with that of the tides during the period of sail. The speed of all four drifters decreased during the first flood tide. The only drifter (ID 2079) that continued its sail for longer time was monitored for almost two flood tides, its speed tended to increase during the last part of the ebb tide with the drifter moving south.

During the period of sail of the drifters, the wind at Sagona Island had started to blow SW and turned anticlockwise until it became SE at the recovery of the last drifter (15 h post release) (Fig. 3b). The wind speed decreased for the first hour, but then increased from 4 to 19 km/h in the following 3 h (up to hour 4 post release). During the rest of the time it decreased.

*Table 3. Speed, distance travelled, and drifting time data for the four CAST drifters deployed south of St. Alban's on 14 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.22 | 0.09-0.43 | 5.75 | 5.60 | 7.2 |
| 1830 | 0.20 | 0.02-0.37 | 5.36 | 5.15 | 7.6 |
| 2079 | 0.15 | 0.01-0.47 | 8.38 | 3.19 | 15.6 |
| 2210 | 0.23 | 0.04-0.52 | 2.14 | 2.09 | 2.6 |

**Deployment 158 (Figure 4)**

On 14 June 2009, five CAST drifters were released in a cluster shortly before low tide just northwest of Riches Island (Fig. 4a). All drifters were released within minutes of each other and initially headed north, into Bay d'Espoir. They all followed similar track for almost 10 h. One drifter (ID 2795) hit the western shore and was recovered at 10 h post release after travelling 7.71 km. The other four drifters continued into the bay and at approximately 11-12 h post release (and a travelled distance of nearly 10 km) their paths diverged, position fixes recorded by the respective GPS showed change of direction 12.5 h post release for drifter ID 2328, 11.0 h for drifter ID 2662, 11.2 h for drifter ID 2772, and 11.5 h for drifter ID 2995. One drifter (ID 2328) headed southeast and hit the eastern shore. Two drifters (ID 2774 and ID 2995) headed southwest and hit the western shore. Drifter ID 2662 also headed southeast, but changed direction again to move northwest and hit the shore off St. Alban's.

All drifters tended to have a consistent speed (Table 4) during their journey, approximately 0.20 m/s, or 0.72 m/h.

This deployment overlapped with deployment 157. After the first hour of sail, the wind blew from the south and its speed increased from 4 km/h to approximately 19 km/h in a matter of 3 h. Low tide occurred 1 h after release with the drifter speed showing some tendency to increase during the first part of the flood tide (Fig. 4b). The highest wind speed 19 km/h took place half way during flood tide. Later on, the wind speed as well as the drifters speed started to decrease, this was observed during the second part of the flood tide and the whole following ebb tide. At hour 13 after release, the tides reached its low level and the drifters had already changed direction. During this last period, the wind veered SSE to NE with speed decreasing from 10 to 6 km/h.

At the recovery of drifter ID 2662, the tide was close to high and the wind blew NE at 6 km/h (Fig. 4b).

*Table 4. Speed, distance travelled, and drifting time data for the five CAST drifters deployed northwest of Riches Island on 14 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 2328 | 0.21 | 0.05-0.52 | 11.85 | 8.95 | 15.4 |
| 2662 | 0.20 | 0.02-0.37 | 12.62 | 9.16 | 17.4 |
| 2774 | 0.21 | 0.04-0.56 | 11.40 | 8.36 | 15.4 |
| 2795 | 0.21 | 0.04-0.36 | 7.71 | 7.30 | 10.0 |
| 2995 | 0.20 | 0.05-0.37 | 11.25 | 8.17 | 15.8 |

**Deployment 159 (Figure 5)**

On 15 June 2009, five CAST drifters were released from the middle of Lampidoes Passage, in a cluster shortly before high tide (Fig. 5a). All drifters were released within minutes of each other and initially headed east into the bay as the tide ebbed. One drifter (ID 2079) hit the southeast shore after 6.2 h for a total travelled distance of 4.16 km. Drifter ID 2820 followed a similar path, it reached the south shore after sailing 4.50 km (about 6 h post release), stayed close to the shore for the following 4.6 h before heading west until it went back west of the point of release. Another drifter (ID 1440) approached the northeast shore and sailed northeast close to the shore until approximately 13 h from release, it travelled about 3.10 km before changing direction and moved southwestward following the shore again. It did so for the following 3.5 h (up to hour 16.6 post release) for a distance of 1.80 km after which it looped in a cove, east of the point of release for the next 2 h and then was recovered. The remaining two drifters continued much further east and entered Bay d'Espoir (8.4 h post release for ID 2210 and 10 h for ID 1830). Both of these drifters reversed direction approximately 13 h post release and headed south. Of these two, drifter ID 2210 hit the eastern shore of Bay d'Espoir 16.7 h post release (after travelling a total distance of 15.99 km) and drifter ID 1830 continued further south and hit the shore 22.2 h post release, the total distance travelled by this drifter was 18.99 km.

For this deployment, the minimum and maximum average speeds of the drifters are 0.00 m/s and 0.82 m/s (0.00–3.00 km/h), respectively (Table 5).

One drifter (ID 2820) changed direction at mid-flood tide (10.6 h post release) while the other three drifters (ID 1830, 2210, and 1440) did so right before high tide (13.0-13.5 h post release) (Fig. 5b).

During the whole experiment the wind blew generally from the bottom left quadrant (between southerly and westerly wind), except for a few hours shortly after the second low tide (approximately 17.5-20.0 h post release, when it came from the north) (Fig. 5b). The wind speed decreased from hour 7 (19 km/h) to hour 18 (2 km/h) after release. The change of direction of the drifters corresponded to the wind veering from the south to the west with the speed decreasing.

*Table 5. Speed, distance travelled, and drifting time data for the five CAST drifters deployed in Lampidoes Passage on 15 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.08 | 0.00-0.24 | 5.42 | 1.32 | 19.0 |
| 1830 | 0.24 | 0.04-0.66 | 18.99 | 10.49 | 22.2 |
| 2079 | 0.19 | 0.00-0.82 | 4.15 | 4.09 | 6.2 |
| 2210 | 0.27 | 0.01-0.57 | 15.99 | 11.52 | 16.7 |
| 2820 | 0.14 | 0.00-0.68 | 10.18 | 1.02 | 20.5 |

**Deployment 160 (Figure 6)**

On 15 June 2009, five CAST drifters were released in a cluster in Little Passage shortly before low tide (Fig. 6a). All drifters were released within minutes of each other and initially headed southeast, out of the passage. Approximately 1.2 h post release, all five drifters started to meander in the area where Little Passage widens. The meandering lasted just under 5 h. Six hours after release, all five drifters continued out of the passage with one drifter continuing south following the western shore and the other four sailing closer to the eastern shore. Drifter ID 2774 headed southwest and further across the bay until 21.6 h post release when it changed direction and headed northeast into Hermitage Bay. At approximately 35 h post release, the drifter was off Furby's Cove and remained there until 38 h post release. It eventually continued northeast and at approximately 42 h post release this drifter approached the eastern coast, remained there for a little less than 10 h, crossed the bay for about 2 h and started to move back towards the outer bay approximately 54 h from release. It was recovered in this area 61.7 h post release with a total travel distance of approximately 30 km. The other four drifters exited Little Passage with a path closer to the eastern mouth of the passage and were entrained closer to the southern shore of Hermitage Bay while drifting toward its mouth. Two drifters, ID 2662 and ID 2782, hit the southern shore of the bay after approximately 12-13 h of sail (travel distance of 7 km and 8.60 km, respectively). Two other drifters continued out of the bay. One (ID 2795) was recovered heading out of the bay 15.1 h post release. The other one (ID 2328) suddenly headed south at approximately 15 h post release, and went into Hermitage Cove where it was recovered 18.9 h post release. Such sudden changes of direction appear anomalous; a possible explanation of it will be given later.

For this deployment, the minimum and maximum average velocities of the drifters are 0.00 m/s and 0.73 m/s (0.00-2.62 km/h), respectively (Table 6).

The speeds of the four drifters were higher when they sailed toward the outer bay, close to the southern side of the bay as compared to the only drifter that sailed close to the northern side (Fig. 6b). When moving into the bay, the velocity of Drifter ID 2774 was of similar magnitude in the same area, but it slowed when further in the bay.

For the first 1.2 h from release, the water level was falling and the wind was relatively strong (15-19 km/h) with direction from SSW (Fig. 6b). The drifters meandered within the wide part of the passage during flood tide until shortly before high tide. During ebb tide the wind speed decreased and its direction turned westerly to southerly. The wind reached its lowest speed (2 km/h) shortly before low tide (about 11 h post release). Although the wind speed subsequently increased, it remained low (~9 km/h) until the recovery of three of the drifters (before 15.1 h post release). By 21 h post release, the wind was high (18-19 km/h) again and

blew from the west. This corresponds to the time when drifter ID 2774 changed direction to sail into the bay and when water level started to fall. The period when this drifter remained off Furby's Cove corresponded to ebb tide and to a period of low wind speed (35-38 h post release) of less than 11 km/h. The second time when the same drifter remained almost motionless close to the shore corresponded to a period of the second half of a flood tide and an ebb tide, but with wind blowing strongly (>25 km/h) from WSW. It moved farther from shore and southwest toward the outer bay starting at the second half of a flood tide with high wind again (>20 km/h) from WSW. After it went toward the inner bay, the speed of this drifter showed some relationship with the tide, it increased during flood tide and decreased during ebb tide. Drifter ID 2772 changed its direction to move towards the inner bay at the beginning of an ebb tide and to move towards the outer bay during a flood tide.

*Table 6. Speed, distance travelled, and drifting time data for the five CAST drifters deployed in Gaultois (Lampidoes) Passage on 15 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 2328 | 0.22 | 0.00-0.73 | 14.63 | 8.92 | 18.9 |
| 2662 | 0.17 | 0.05-0.56 | 6.99 | 5.39 | 11.8 |
| 2774 | 0.14 | 0.00-0.71 | 29.97 | 7.03 | 61.7 |
| 2782 | 0.18 | 0.03-0.59 | 8.64 | 5.81 | 13.3 |
| 2795 | 0.24 | 0.02-0.57 | 12.86 | 7.81 | 15.1 |

**Deployment 161 (Figure 7)**

On 17 June 2009, five CAST drifters were released south of the North Bay Head in a cluster some time during flood tide (Fig. 7a). All drifters were released within minutes of each other and initially headed north into North Bay. Unlike most of the other deployments, this experiment was much shorter (maximum sailing time was 4.7 h before the drifters hit the shore and were recovered) and signal transmission was difficult. Position fixes were not transmitted during the first 3 h for two drifters (ID 1440 and 1830) and they were transmitted only intermittently for the other two drifters (ID 2210 and 2820). Only one drifter (ID 2079) had more regular position fixes recorded. The track of this drifter seems to represent the general track for all the drifters. It entered North Bay approximately half an hour after release, sailed north until it hit the western shore at 4.7 h post release, with a total travelled distance of 8.48 km. The average velocity of the drifters during their sail is about 0.50 m/s (1.80 km/h).

For this and 1.28 m/s (0.22-4.61 km/h), respectively (Table 7).

Interference with coastal features and a short period of drifting (less than half tidal cycle) prevented any good evaluation of a tidal influence on drifter velocities during this deployment (Fig. 7b); however, the drifter speed seemed to decrease during ebb tide.

During this experiment, the wind speed was high (over 20 km/h) and blew from W to WSW, corresponding with the direction of drifter movement (Fig. 7b).

*Table 7. Speed, distance travelled, and drifting time data for the five CAST drifters deployed south of* deployment, the minimum and maximum average speeds of the drifters are 0.06 m/s *North Bay Head on 17 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.63 | 0.63-0.63 | 6.38 | 6.37 | 2.8 |
| 1830 | 0.58 | 0.58-0.58 | 7.56 | 7.56 | 3.6 |
| 2079 | 0.50 | 0.06-1.28 | 8.48 | 7.96 | 4.7 |
| 2210 | 0.59 | 0.20-0.89 | 8.27 | 8.04 | 3.9 |
| 2820 | 0.51 | 0.09-0.61 | 8.51 | 8.12 | 4.7 |

**Deployment 162 (Figure 8)**

On 18 June 2009, five CAST drifters were released at the southern mouth of Lampidoes Passage, in a cluster shortly before high tide (Fig. 8a). All drifters were released within minutes of each other and initially headed northeast following the passage. They all followed similar tracks for the first 2 h, although drifter ID 2210 was closer to the southern shore of the passage. Approximately 4 h after release, this drifter changed direction and started to meander and loop around within the wider part of the passage. It did so for the following 17 h until it approached the southern shore of the passage. It stayed close to shore for almost 11 h before starting to drift southwestward to the mouth of the passage. It exited the passage and crossed Bay d'Espoir and was recovered approaching the north shore of Long Island. The total distance travelled by the drifter is 16.17 km. In relation to tides, this drifter started its meandering within the passage during the first flood tide and began its journey southwestward after the second high tide. Drifter ID 2820 was recovered near the southern shore of the passage 7.8 h post release with a small meandering in the last 3 h of its journey and a total travelled distance of 4 km. Drifter ID 2079 followed the same path as ID 2820 but continued northeastward close to the northern shore of Bois Island. After 10.5 h from release (and 6.20 km of distance), it changed direction and started to move southwestward. At 14 h post release, it again reversed direction (northeast), it was recovered at 17.6 h post release with a travelled distance of 8 km. The period when this drifter made a short southwest sail corresponded to the period of ebb tide. The path of drifter ID 1830 was farther to the west of that of the previous two drifters, it was entrained farther north before turning clockwise after 10 h from release. It continued its clockwise turn until it reached the northern part of Pomley Cove where it was recovered 19.5 h post release. In total, its journey consisted of almost 9 km. Drifter ID 1440 followed a similar path as ID 1830, it also veered clockwise after 10 h from release. However, when moving southwest, it approached the eastern shore of Bois Island and moved along the shore until it was recovered 14.9 h post release (total travelled distance of 8.16 km).

In this passage, the average velocity of the drifters was approximately 0.14 m/s (~0.5 km/h) as shown in Table 8.

Drifters ID 2079, 1830, and 1440 changed direction and started to move southwest towards outer bay during the first flood tide (10 h post release) (Fig. 8b). The second change of direction for drifter ID 2079 (to go northeast towards inner bay) and the time when drifter ID 1830 started to move back to the north again (14 h post release) corresponded to the beginning of the second ebb tide.

The wind generally blew from WSW to W during this experiment (Fig. 8b). Its speed was generally greater than 15 km/h except on one occasion when it drastically dropped (to 6 km/h) for short time. This drop in wind speed coincided with the change of direction of drifter ID 2079 and 1830.

*Table 8. Speed, distance travelled, and drifting time data for the five CAST drifters deployed at the southern mouth of Lampidoes Passage on 18 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.15 | 0.00-0.35 | 8.16 | 5.36 | 14.9 |
| 1830 | 0.13 | 0.00-0.43 | 8.96 | 6.48 | 19.5 |
| 2079 | 0.13 | 0.02-0.59 | 8.08 | 5.95 | 17.6 |
| 2210 | 0.10 | 0.00-0.51 | 16.17 | 3.65 | 43.7 |
| 2820 | 0.15 | 0.02-0.31 | 4.09 | 3.88 | 7.8 |

**Deployment 163 (Figure 9)**

On 18 June 2009, right after low tide, four CAST drifters were released along a transect line north of Green Point at the mouth of Bay d'Espoir (Fig. 9a). After release, all drifters initially headed northeast toward the northern side of the bay. Drifter ID 2795, which was released on the northern part of the section, was recovered near the coast, south of Lampidoes Passage at 5.2 h post release (with only 1.89 km of sail). The other three drifters continued further northeast and approached the shore south of Snooks Harbour at the first low tide (12.5 h post release with nearly 12 km of travelled distance). All drifters stayed in the same area until recovery, at 18.4 h post release, for drifter ID 2662 and until half way the second ebb tide at approximately 21 h post release for the remaining two drifters (ID 2995 and 2774). These two drifters subsequently continued northeast and crossed Snooks Harbour. Drifter ID 2995 followed the shore northeastward and was recovered at 28.2 h post release while drifter ID 2774 stayed east of the harbour from approximately hour 24 to 33 post release and changed direction to move southwest. This drifter was recovered outside of the entrance to Lampidoes Passage at 44.7 h post release with a total distance travelled of 21.69 km.

For this deployment, the minimum and maximum average speeds of the drifters are 0.00 m/s and 0.53 m/s (0.00–1.91 km/h), respectively (Table 9).

The period when the two drifters started to cross Snooks Harbour (~12.5 h post release) corresponded to the beginning of the second flood tide while the time when the last drifter started to move out of the bay (southwestward) corresponded to half-way the third ebb tide.

During this deployment, the wind at Sagona Island was from WSW to WNW (Fig. 9b). Drifter ID 2774 stayed off Snooks Harbour during period when the wind was variable but typically greater than 15 km/h. It moved back towards southwest when the wind decreased from approximately 35 km/h to 14 km/h. There was no obvious effect of wind on other drifters.

*Table 9. Speed, distance travelled, and drifting time data for the five CAST drifters deployed at the mouth of Bay d'Espoir on 18 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 2662 | 0.21 | 0.01-0.53 | 13.88 | 11.81 | 18.4 |
| 2774 | 0.14 | 0.00-0.42 | 21.69 | 6.54 | 44.7 |
| 2795 | 0.10 | 0.05-0.17 | 1.89 | 1.89 | 5.2 |
| 2995 | 0.16 | 0.00-0.77 | 16.29 | 15.39 | 28.2 |

**Deployment 164 (Figure 10)**

On 21 June 2009, five CAST drifters were released in Bay d'Espoir north of Muddy Hole, in a cluster shortly before high tide (Fig. 10a). All drifters were released within minutes of each other and initially headed north. Within 1.5 h of release, all five drifters reversed direction, headed south, out of the bay. They followed a similar path and were recovered relatively close together near the shore to the north of Roti Bay, at periods between 6.6 and 10.7 h post release.

For this deployment, the minimum and maximum average velocities of the drifters are 0.00 m/s and 0.54 m/s (0.00–1.94 km/h), respectively (Table 10).

In relation to the tide, the speed for all the drifters showed an inverse relation with the tidal height with a short time lag (Fig. 10b). During ebb tide, the drifter speed increased and it then decreased as the tide flooded.

The wind blew E to ENE during this deployment with higher speed (>28 km/h) in comparison to that during other deployments (Fig. 10b). Drifter velocity decreased during the second half of the deployment although wind speed had increased from 28 km/h to 39 km/h in approximately 1 h. At this stage, the drifters were also closer to the western shore.

*Table 10. Speed, distance travelled, and drifting time data for the five CAST drifters deployed in Bay d'Espoir north of Muddy Hole on 15 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.24 | 0.02-0.43 | 5.58 | 5.36 | 6.6 |
| 1830 | 0.19 | 0.01-0.37 | 5.79 | 5.54 | 8.4 |
| 2079 | 0.17 | 0.03-0.41 | 6.69 | 5.41 | 10.7 |
| 2210 | 0.18 | 0.00-0.39 | 5.65 | 5.17 | 8.8 |
| 2820 | 0.19 | 0.00-0.54 | 6.02 | 5.78 | 8.7 |

**Deployment 165 (Figure 11)**

On 21 June 2009, five CAST drifters were released in the middle of Little Passage in a cluster shortly before low tide (Fig. 11a). All drifters were released within minutes of each other. Initially, two drifters (ID 2782, 2795) headed north and other two (ID 2774, 2995) headed south. One drifter (ID 2662) did not have its position transmitted for the first 2.6 h. Drifter ID 2782 was recovered 4.7 h post release, 425 m northwest of the release location. Drifter ID 2795 reversed direction at 6.7 h post release and moved southeastward. It was recovered just about 270 m

northwest of the point of release after 11 h of sail. The two southward moving drifters did so for approximately 1 h post release, then reversed direction. One drifter (ID 2774) moved northwest towards the western shore; close to the shore, it again reversed direction at about 9.7 h post release and sailed southeastward following the shore until it was recovered at 22.7 h post release (with a total of 1.83 km of sailing distance, 1.20 km of which going southwestward in the last 13 h). After initially moving southward, the second drifter (ID 2995) moved northward and sailed nearly 2 km farther north. It reached the eastern shore and changed direction and started to move south at around 7.5 h post release. It meandered between 11.7 and 12.7 h around the point of release and continued southeastward towards the eastern shore where it was recovered 16.3 h post release. Drifter 2662 also sailed northwest following the passage and at approximately 7.8 h reversed direction and start to move south again. It continued farther south until 16.8 h post release where it started to loop around a couple of times before it headed west at about 21 h post release. It continued west and was recovered in a large cove on the southeast of Long Island 25.5 h after release.

The average speed computed for the drifters of this deployment were low (Table 11): three drifters had velocity less than 0.03 m/s (or ~0.11 km/h) and the other two between 0.08 and 0.12 m/s (0.28-0.43 km/h).

Drifters ID 2995 and 2662, which went farther north, reversed direction at high tide while drifter ID 2774 did so during ebb tide (Fig. 11b). During the period of ebb tide, drifter ID 2995 meandered around the point of release. The double loops performed by drifter ID 2662 off a cove on Long Island started half-way during flood tide and ended at high tide (16.8 to 21.0 h post release).

During this experiment, the wind started from E and veered to NE with the speed generally increasing from approximately 22 km/h to 46 km/h (Fig. 11b). The wind speed was higher than that experienced during other experiments. One hour prior to the southeastward sail of drifter ID 2795 there was a sudden increase of wind from 22 km/h to 31 km/h. Drifter ID 2662 presented a higher southeastward velocity during the second flood tide completed by a strong easterly wind (28-40 km/h). During its first loop performed by this drifter, the wind speed increased from approximately 35-46 km/h while it momentarily decreased to 28 km/h by the end of the second loop.

*Table 11. Speed, distance travelled, and drifting time data for the five CAST drifters deployed in Little Passage on 21 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 2662 | 0.12 | 0.02-0.36 | 10.90 | 4.36 | 25.5 |
| 2774 | 0.02 | 0.00-0.14 | 1.83 | 1.08 | 22.7 |
| 2782 | 0.03 | 0.00-0.12 | 0.42 | 0.38 | 4.7 |
| 2795 | 0.03 | 0.00-0.10 | 1.11 | 0.27 | 10.9 |
| 2995 | 0.09 | 0.02-0.29 | 5.05 | 0.79 | 16.4 |

**Deployment 166 (Figure 12)**

On 22 June 2009, five CAST drifters were released east of May Head in Bay d'Espoir, in a cluster shortly after high tide (Fig. 12a). All drifters were released within minutes of each other and headed out of the bay. One drifter (ID 2820) was recovered at the western tip of Long

Island 14 h post release and after sailing 22.28 km. The other four drifters continued out of the bay and were transported westward along the south coast. Three of the drifters (ID 2079, 2210, and 1830) were recovered at sea after 23.5 to 26.2 h post release and travelled distances of 35.88 to 56.24 km and the remaining one (ID 1440) was recovered just inside the entrance to Hare Bay. Drifter ID 2820 was recovered half-way of the second ebb tide, at that time, the other three drifters were already in the open ocean.

For this deployment, the minimum and maximum average velocities of the drifters are 0.03 m/s and 1.07 m/s (0.11-3.85 km/h), respectively (Table 12).

In general, the velocity of the drifters was lower around period of high tide than around period of low tide with direction going west for both cases (Fig. 12b).

The wind during this experiment blew from ENE to E (Fig. 12b). The wind speed was relatively high but showed a rapid decrease (from 48 to 23 km/h in 3 h) at about hour 9 post release, shortly after the first high tide. No obvious effect of the wind on the drifter movement was observed.

*Table 12. Speed, distance travelled, and drifting time data for the five CAST drifters deployed east of May Head in Bay d'Espoir on 22 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1440 | 0.59 | 0.21-1.07 | 56.51 | 50.04 | 26.8 |
| 1830 | 0.60 | 0.23-0.97 | 56.24 | 52.00 | 26.2 |
| 2079 | 0.43 | 0.03-0.76 | 35.88 | 30.89 | 23.5 |
| 2210 | 0.52 | 0.24-0.92 | 48.79 | 45.11 | 25.9 |
| 2820 | 0.44 | 0.03-0.88 | 22.28 | 20.33 | 14.0 |

**Deployment 167 (Figure 13)**

On 22 June 2009, five CAST drifters were released east of Riches Island in Bay d'Espoir, in a cluster at low tide (Fig. 13a). All drifters were released within minutes of each other and headed out of the bay. The drifters were entrained toward Raymond Point, in the northeast of Long Island. Three drifters reached the coast just south of the point at periods between 8.7 and 13.0 h post release (with travelled distance of approximately 10.56 km) and the other two drifters continued out of the bay, drifter ID 2995 passed Isle Galet to the south and ID 2782 to its north. At nearly 12.5 h after release, these two drifters were located south of the entrance of Lampidoes Passage where they started to veer south and they approached the shore where they were both recovered at approximately 17.8 h post release. Their total distances travelled were over 18 km.

For this deployment, the minimum and maximum average speeds of the drifters are 0.00 m/s and 0.64 m/s (0.00-2.30 km/h), respectively (Table 13).

With respect to drifter speed and tidal height, the computed speeds seem to increase during flood tide and decrease during ebb tide (Fig. 13b).

During this experiment, the wind came from ENE to E and was relatively high, ranging from approximately 20 km/h to 48 km/h (Fig. 13b). There was no obvious effect of wind speed on direction of drifter movement during the deployment.

*Table 13. Speed, distance travelled, and drifting time data for the five CAST drifters deployed east of Riches Island in Bay d'Espoir on 22 June 2009.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 2662 | 0.37 | 0.19-0.64 | 11.58 | 10.45 | 8.7 |
| 2774 | 0.26 | 0.00-0.60 | 12.13 | 10.56 | 13.0 |
| 2782 | 0.33 | 0.00-0.63 | 21.15 | 18.39 | 17.8 |
| 2795 | 0.33 | 0.11-0.57 | 12.00 | 10.43 | 10.1 |
| 2995 | 0.34 | 0.07-0.58 | 21.46 | 18.75 | 17.8 |

**DEPLOYMENT 173 (FIG. 14)**

On 14 July 2010, five CAST drifters were released north of Harbour Breton in the Northeast Arm, in a cluster shortly before low tide (Fig. 14a). All drifters were released within minutes of each other and initially headed into the bay and toward the western shore. Drifter ID 1830 started to sail southward at about 4 h post release and moved along the shore until hour 10 when it was recovered. It travelled nearly 2.60 km before moving south and it travelled another 1.50 km before being recovered. The other drifters remained near the western shore until approximately 5.5 h post release then they headed south. One drifter (ID 2662) remained near the western shore as it headed south and was recovered at the western shore just over 17 h post release. The distance travelled toward the north was nearly 2.70 km and that toward the south was 2.40 km. A third drifter (ID 2079) continued south along the western shore until approximately 12 h post release (with a distance of nearly 2 km). Then, it generally headed out and across the bay and hit the eastern shore at 18.6 h post release. The fourth drifter (ID 2210) continued south until some time between 8.8 and 10.6 h post release when it headed into the bay briefly. It changed direction again and continued south, out of the bay, and was recovered at the eastern side of the bay 18.8 h post release. The distance travelled by this drifter during the last 8 h of drift was about 5.70 km. The final drifter (ID 2328) headed south until approximately 8.5 h post release when it headed across the bay, to the east. At approximately 11 h post release, this drifter headed south, out of the bay, but began to turn toward the northeast at approximately 15.7 h post release. It was recovered near the eastern shore 18.8 h post release.

For this deployment, the minimum and maximum average speeds of the drifters are 0.00 m/s and 0.66 m/s (0.00-2.38 km/h), respectively (Table 14).

The time when drifter ID 1830 started to move southward and the other drifters started to remain almost motionless near the western shore corresponded to mid-flood tide (around 4 h from release) (Fig. 14b). Drifters ID 2210 and ID 2328 changed direction to move east towards the middle of the bay at around 8.5-8.8 h post release, about 1 h after high tide. They started to move south again at mid-ebb tide.

During the deployment, the wind at Sagona Island changed from S to WSW and back to S again (Fig. 14b). At 7 h from release, it reversed direction and blew from the NE to turn anticlockwise. By the end of the experiment, the wind was blowing W. The wind speed was low (less than

10 km/h) during the first 6 h of experiment; it then started to increase up to 37 km/h by the end of the experiment. The rapid change of the wind speed was observed between hour 5 to hour 9 post release.

*Table 14. Speed, distance travelled, and drifting time data for the five CAST drifters deployed north of Harbour Breton in Northeast Arm on 14 July 2010.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1830 | 0.12 | 0.00-0.43 | 4.14 | 1.25 | 9.9 |
| 2079 | 0.14 | 0.01-0.49 | 9.03 | 3.37 | 18.6 |
| 2210 | 0.15 | 0.00-0.60 | 10.15 | 3.94 | 18.8 |
| 2328 | 0.16 | 0.00-0.66 | 11.00 | 2.29 | 18.8 |
| 2662 | 0.08 | 0.00-0.38 | 5.11 | 0.70 | 17.1 |

**Deployment 174 (Figure 15)**

On 15 July 2010, five CAST drifters were released, east of Harvey Hill in the Northeast Arm, in a cluster shortly after high tide (Fig. 15a). All drifters were released within minutes of each other and initially headed south, out of the bay. All five drifters approached Rocky Point, on the western shore, approximately 4.5 h post release (around 7 km of travelled distance from release). One drifter (ID 2662) remained in this area until approximately 10.5 h post release then, it started a counterclockwise loop, first heading southeast, across the bay. At about 16.2 h post release, it moved north, quickly changed direction to go east toward the eastern shore. It reached the shore south of Jersey Harbour where it was recovered 18.4 h post release. The other four drifters continued south just east of Rocky Point and when out of the bay started to move clockwise. One of the drifters (ID 1830) remained closer to shore than the others. In its clockwise sail, it started to move west at about 11 h post release and headed northwest and then north to end west of Woody Head about 14.8 h post release. The remaining three drifters (ID 2328, 2210, 2079) moved in a larger clockwise loop while remaining relatively close together and after approximately 12 h post release, they headed northeast and hit the shore west of Western Cove between 13.3 and 13.9 h post release.

For this deployment, the minimum and maximum average velocities of the drifters are 0.00 m/s and 0.92 m/s (0.00-3.31 km/h), respectively (Table 15).

All five drifters approached Rocky Point at around low tide (Fig. 15b). Drifter ID 2662 started to move southeast (along its counterclockwise sail) around 12 h post release at high tide, it switched to a short northward direction during ebb tide at about 1.5 h before low tide (hour 16 post release). When comparing the velocity of the drifters with the tidal height, the velocity of the drifters tended to be higher during the first ebb tide and gradually decreased during the following flood tide and ebb tide.

During the first period of this experiment, the wind was mainly blowing from the north, then between approximately 7-11 h post release it switched to westerly (Fig. 15b). The wind speed increased for the first 3 h (from 35 to 50 km/h) and decreased as low as 9 km/h during the following 5 h. This low wind speed took place at high tide (approximately 8 h post release). It then increased slowly until the end of the experiment. Drifter ID 2662 seemed to get entrained by the westerly wind at around 12 h post release, but no effect of wind could be detected in drifter movement.

*Table 15. Speed, distance travelled, and drifting time data for the five CAST drifters deployed east of Harvey Hill in Northeast Arm on 15 July 2010.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1830 | 0.24 | 0.00-0.92 | 12.93 | 10.16 | 14.8 |
| 2079 | 0.37 | 0.02-0.86 | 18.00 | 11.68 | 13.6 |
| 2210 | 0.36 | 0.03-0.80 | 18.21 | 11.63 | 13.9 |
| 2328 | 0.38 | 0.02-0.78 | 18.04 | 11.70 | 13.3 |
| 2662 | 0.17 | 0.00-0.87 | 11.17 | 7.87 | 18.4 |

**Deployment 175 (Figure 16)**

On 16 July 2010, five CAST drifters were released in a cluster at high tide (Fig. 16a). All five drifters were released within minutes of each other and initially moved northeast across and into Harbour Breton Bay. One drifter (ID 2662) reached the shore on the eastern coast 3.1 h post release. A second drifter (ID 2079) approached the eastern coast, remained just north of the first drifter that reached the shore until shortly before high tide, then headed south near the coast. This drifter hit the eastern shore 15.7 h post release. The other three drifters continued north, crossing the bay again and reached the western shore at periods between 11.2 and 20.6 h post release.

Overall, the velocity of drifters during 30 min sample intervals ranged from 0.00 to 0.84 m $s^{-1}$ (0.00-3.02 km/h) as depicted in Table 16.

These drifter tracks demonstrated consistent movement into the bay through periods of both ebb and flood tides (Fig. 16b). Only one drifter (ID 2079) headed south after initially heading north and this drifter remained near the shore during this period. It should be noted that winds were mostly from SSW to S (direction approx. 200 to 180 degrees) with speed relatively high (>19 km/h) during the study period and the direction of drifter tracks generally matched that of the wind (Fig. 16b).

*Table 16. Speed, distance travelled, and drifting time data for the five CAST drifters deployed at Harbour Breton on 16 July 2010.*

| Drifter ID | Average speed (m $s^{-1}$) | Min–Max speed (m $s^{-1}$) | Total distance (km) | Straight line distance (km) | Time (hours) |
|---|---|---|---|---|---|
| 1830 | 0.14 | 0.00-0.79 | 7.78 | 6.94 | 20.6 |
| 2079 | 0.12 | 0.00-0.64 | 5.23 | 2.80 | 15.7 |
| 2210 | 0.24 | 0.00-0.50 | 10.10 | 9.33 | 14.0 |
| 2328 | 0.20 | 0.00-0.84 | 8.10 | 7.53 | 11.2 |
| 2662 | 0.16 | 0.09-0.22 | 1.80 | 1.63 | 3.1 |

Except during four deployments, most of the average speeds of the drifters were between 0.08 and 0.26 m/s (0.28-0.96 km/h) as shown in Fig. 17. Higher speeds (>0.36 m/s) were observed during three deployments when drifters travelled near the open ocean.

Wind speed at Sagona Island ranged from 0 to 113 km/h. At Harvey Hill East, wind speed ranged from 0 to 54.7 km/h. The wind speed at Sagona Island tended to be higher when wind

speed was also high at Harvey Hill East during summer 2010 (Fig. 18); although, the correlation between the two data series is relatively weak ($R^2$= 0.24). The two panels of wind rose on Figure 19 show the distribution of wind direction (in this case, direction where the wind come from) and wind speed (km/h) at the two locations: Fig. 19a for Harvey Hill East and Fig. 19b for Sagona Island. In order to construct these figures, the whole 360 degrees were divided into 12 sectors of 30 degrees each and the concentric circles specify the different percentage of time the wind blows from a particular direction. In addition, the different colors show the frequency of wind from a particular direction with a certain speed range. Just looking at the wind direction, the wind at Harvey Hill East tended to be either SW, almost 45% of the time, or NE, almost 20% of the time (Fig. 19a). At Sagona Island the wind rose (Fig. 19b) shows that the main direction of the wind was from W to SSE, in total almost 66% of the time with ~34% from the SW.

Data from river discharge measured at the Newfoundland Labrador Hydro generating station were relatively constant, between 100-160 $m^3$/s, during the study periods of Summer 2009 (7 to 22 June 2009) and Summer 2010 (7-17 July 2010) (Fig. 20). At Conne River Pond, the overall discharge rates were two orders of magnitude lower than those reported at the hydro generating station. During both years, a small spike in discharge was observed at Conne River Pond two days before drifter deployments began.

Overall, the time of sail ranged from 4-5 h up to 61-62 h before the drifters were recovered (Fig. 21). In North Bay, the drifters grounded after 4-5 h and the maximum distance between two points on the drifter tracks was 8.50 km. In inner Bay d'Espoir and in Northeast Arm, the maximum sailing time, before grounding or retrieval, ranged from 10 to 23 h. The longest distances of displacement observed was approximately 13 km in inner Bay d'Espoir and roughly 11 km in Northeast Arm. The drifters that were at liberty for longer durations (i.e., 24-62 h) occurred in outer Bay d'Espoir and Hermitage Bay, largely in the vicinity of Long Island.

## DISCUSSION

The drifter experiments on the south coast were very successful in demonstrating the speed and pattern of surface water circulation in this complex topographic and bathymetric environment.

This study is the first to report drift trajectories within more than one tidal cycle and at numerous sites in the bays along the south coast of Newfoundland between Hermitage Bay and Harbour Breton. Also it is the first to accurately record the distance travelled with time. Within periods of less than 24 h, surface waters may move up to 52 km with the appropriate atmospheric conditions. If we consider the maximum distance between two points on the drifter tracks to represent a zone of influence (as depicted in Fig. 21), typical zones of influence in the study area would be in the range of 5 to 18 km over a period of 24 h. For water- borne disease (ISA, sea lice, etc.), the zone of influence will also depend on the life expectancy of the particular infectious agents. As for particulate matter or effluents, it will depend on how long they are diluted before getting washed out, sunk, or assimilated by other organisms. Both time scales can also depend on other environmental conditions such as temperature, salinity, UV radiation conditions.

During many of our deployments, drifter velocities were approximately 0.10-0.25 m/s (0.36-0.90 km/h). Velocities tended to be higher during three of the 14 drifter deployments (monitored longer than 6 h) and only during these deployments were drifters travelling near the mouth of Bays (south or southwest movement). This suggests that the complex local

bathymetry and topography reduces the surface water movement within bays relative to open ocean areas. Due to the narrow and convoluted fjords and numerous islands present in the study area, most of our drifters grounded within less than 24 h Therefore, longer term monitoring of surface water movements was not performed.

In Hermitage Bay and surrounding areas, the present data show that surface water movements may be influenced more by wind forcing than by tidal mechanisms, except in localized areas. The influence of wind on drifter movement was most apparent during summer of 2010 in Harbour Breton where most drifters moved in the direction of the prevailing winds both before and after changes of wind direction and despite changes in tidal stage. In 2009, wind effects were also observed in three deployments (Deployment 161, 163, and 166) where drifters generally moved in the direction of the predominant wind. This behavior has been observed in inlets in British Columbia (Pickard and Rodgers 1959; Farmer 1976; Farmer and Osborn 1976) and in Norway (Svendsen and Thompson 1978; Svendsen 1980). In larger bays, the effect of the rotation of the earth (Coriolis effect) will move water to a direction to the right of that of the wind. However, for our study area, the effect of rotation on the surface circulation should be negligible because the bay widths are much less than the external Rossby radius of deformation (~400 km). The wind stress at the interface between the ocean and the atmosphere would be expected to push the water in the same direction as the stress.

In addition to wind effects, surface tidal mechanisms may also influence surface water movement in the study area. During seven of our deployments, both tide and wind affected drifter movements. Also drifter movements may have been influenced by one forcing mechanism, e.g., wind, and then later influenced by another mechanism, e.g. tide during the same deployment. Also, both forcing mechanisms may be additive or one forcing may impede the other, for example during deployment 167 on 22 June 2009 drifters moved slowly out of the bay in the direction of the prevailing wind as the tide flooded, but their velocity increased during ebb tide. These patterns of drifter movement are consistent with the expected surface circulation in bays where both barotropic tidal mechanisms and wind forcing are important. In a bay or fjord, flood tide should occur as a mass of water flows towards the inner bay. Following high tide, water will be transported out of the bay as the surface level falls. Conceptually, a barotropic tide will move the whole water column in the same direction. Thus, during flood tide surface waters will move towards the inner bay and during ebb tide water movement will be out of the bay. While an effect of wind was evident independent of tidal stage for some deployments, tidal effects were not observed independent of wind effects.

During portions of some deployments, neither wind nor tidal forcing can explain the observed pattern of drifter movement. For example during deployment 157, drifter movement was opposite to that expected if wind or tide was affecting surface currents. It is possible that small scale oceanographic features such as eddies or coastal jets determine local surface water movements. Resolving such features requires more spatially intensive data.

There is no evidence that river discharge influenced the surface water circulation during our study. Drifters released in the inner Bay d'Espoir (Deployments 157, 158, 159) on 15 and 16 June 2009 all moved northward contrary to an expected southward moving freshwater layer at the surface. However, a distinct freshwater layer is known to occur in the inner Bay d'Espoir that can also respond to wind forcing (MSRL 1980). Movement of this water layer was not monitored during this study and its effect on surface currents could not be determined.

During the analysis, the wind data at Sagona Island were assumed to represent local wind conditions although the region of study represents an area of 100 by 50 km with complex

topography. At one local site, the wind speed was weakly associated with that at Sagona Island but wind direction was not consistent between the areas possibly due to wind steering by local topography. Interference from coastal features that may increase drag in localized areas was also assumed to be negligible. The tidal stage estimates used in the study were derived from a model that was not developed specifically for bays or fjords and its applicability to all sites within our study area, with its complex topography has not been validated. A tidal driven circulation that is not barotropic can not be determined using our data and is beyond the scope of this study.

Surface currents are expected to be highly variable among seasons, determining the seasonal variability in surface currents was beyond the scope of this study. Our observations are applicable to early Summer season but less is known about the variability of the oceanographic conditions in other seasons.

With respect to exchange of particles between farms, our study has shown that for the period of drifting, particles will likely be moved from the area of one farm to at least that of another one (as shown by the approximate location of farms on the different maps). Note that the drifters did not specifically go towards the farms but passed by the surrounding area. The potential to have particles from one specific farm to infect another is still subject to the rate at which the particles can move along or separately from the currents. Such study can only be done by either releasing a great number of drifters or by using the output of a high resolution circulation model to drive a particle tracking model with again analysing great numbers of particles.

## CONCLUSION AND FUTURE WORK

This report addresses the influences of environmental factors such as wind and tidal mechanisms on surface water circulation in the Bay d'Espoir area where finfish aquaculture is located in Newfoundland. The results were based on 14 surface drifter deployments conducted during the summers of 2009 and 2010. This was the first study that reported drifter movement for more than one tidal cycle in the Hermitage Bay/Fortune Bay area. Average speeds of surface drifters were between 0.10 and 0.25 m/s (0.36-0.90 km/h). Both winds and surface tidal mechanisms may influence surface drift in the area, but strong winds may predominate over tidal effects during some events. There was evidence of the effect of local topography on wind speed and direction enhancing local circulation patterns. Taken together, the findings suggest that typical zones of influence are between 5 and 18 km over a period of 24 h.

The present study has given a preliminary overview of the surface water circulation in the Hermitage Bay/Bay d'Espoir/Northeast Arm areas. However, the findings are site and time specific and additional studies need to be carried out in order understand the whole forcing fields that drive the circulation in the area thus the exchange of water and particles between sites. Further work will need to be carried out to i) develop a baroclinic circulation model that, will have sufficiently high resolution for aquaculture application, ii) deploy sets of Acoustic Doppler Current Profilers or other current meters simultaneously and for long period of time in order to assess the geographical and temporal variability of the currents in the area and to validate future circulation model experiments, iii) measure water properties that could be used to establish temperature and salinity initial conditions for the numerical model and to better understand the roles of freshwater discharge and heat flux forcing in the circulation patterns, iv) deploy set of simple weather stations that would provide model forcing and allow a more thorough evaluation of the applicability of using Sagona winds in the whole domain of interest.

## ACKNOWLEDGMENTS

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## REFERENCES

Aarseth, K.A., and Scharm, T.A. 1999, Wavelength-specific behaviour in *Lepeophtheirus salmonis* and *Calanus finmarchicus* to ultraviolet and visible light in laboratory experiments (Crustacea: Copepoda). Mar. Ecol. Prog. Ser. **186**: 211-217.

Bergheim, A., Aabel, J.P., and Seymour, E.A. 1991. Past and present approaches to aquaculture waste management in Norwegian net pen culture operations. *In* Nutritional Strategies and Aquaculture Waste. *Edited by* C.B. Cowey and C.Y. Cho. Fish Nutrition Research Laboratory, University of Guelph, Guelph. pp. 117-136.

Brooks, K.M. 2005. The effects of water temperature , salinity, and currents on the survival and distribution of the infective copepodid stage of sea lice (*Lepeophtheirus salmonis*) originating on Atlantic salmon farms in the Broughton Archipelago of British Columbia, Canada. Rev. Fish. Sci. **13**: 177-204.

Brooks, K.M., and Stucchi, D.J. 2006. The effects of water temperature , salinity, and currents on the survival and distribution of the infective copepodid stage of sea lice (*Lepeophtheirus salmonis*) originating on Atlantic salmon farms in the Broughton Archipelago of British Columbia, Canada (Brooks, 2005). A response to the rebuttal of Krkošek *et al*. Rev. Fish. Sci. **14**: 13-23.

Chang. B.D., Page, F.F., Losier, R.J., P Lawton, Singh, R. and Greenberg, D.A. 2007. Evaluation of bay management scenarios for the southwestern New Brunswick salmon aquaculture industry. Can. Tech, Rep. Fish. Quat. Sci. 2722. 69 p.

Cromey, C.J., Nickell, T.D., and Black, K.D. 2000. DEPOMOD: A model for predicting the effects of solids deposition from mariculture to the benthos. Scott. Assoc. Mar. Sci. 120 p.

Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johannessen, P., and Jahnsen, T. 1997. Regulating the local environmental impact of intensive marine fish farming; the concept of the MOM system (modelling on-growing fish farms-monitoring). Aquaculture **158**: 85-94.

Farmer, D.M. 1976. The influence of wind on the surface layer of a stratified inlet: Part II. Analysis. J. Phys. Oceanogr. **6**: 941–952.

Farmer, D.M., and Osborn, T.R. 1976. The influence of wind on the surface layer of a stratified inlet: Part I. Observations. J. Phys. Oceanogr. **6**: 931–940.

Foreman, M.G.G. 1978. Manual for tidal currents analysis and prediction. *In* Pacific Marine Science Report 78-6 (2nd ed.). Institute of Ocean Sciences, Patricia Bay, Sidney, B.C.

Ibrekk, H.O., Kryvi, H., and Elvestad, S. 1993. Nationwide assessment of the suitability of the Norwegian coastal coastal zone and rivers for aquaculture (LENKA). Coast Manage. **21**: 53-73.

MSRL (Marine Sciences Research Laboratory). 1980. Bay D'Espoir Aquaculture Feasibility Study Volume II. MSRL Contribution No. 409. Prepared for Bay D'Espoir Development Association and Newfoundland Department Fisheries by the Marine Sciences Research Laboratory with support from Canada Manpower (LEAP), Conne River Indian Band Council, National Research Council of Canada (STEP), Newfoundland and Labrador Hydro, and Newfoundland Department of Fisheries.

Murray, A.G., Amundrud, T.L., and Gillibrand, P.A. 2006. Models of hydrodynamic pathogen dispersal affecting Scottish salmon production: modeling shows how Scotland eradicated ISA, but not IPN. Bull. Aquacult. Assoc. Can. **105**: 79-86.

Pickard, G., and Rodgers, K. 1959. Current measurements in Knight Inlet, British Columbia. J. Fish. Res. Board Can. **16**: 635–678.

Southall, T., Telfer, T., and Hambrey, J. 2004. Environmental capacity modelling in aquaculture development. Tropeca Working Paper No. 1. 113 p.

Svendsen, H. 1980. Exchange processes above sill level between fjords and coastal water. *In* Fjord oceanography. *Edited by* H.J. Freeland, D.M. Farmer, and C.D. Levings. NATO Conference Series 4: Marine Science. Plenum Press, New York: pp. 355–361.

Svendsen, H., and Thompson, R. 1978. Wind driven circulation in a fjord. J. Phys. Oceanogr. **8**: 703–712.

## FIGURES

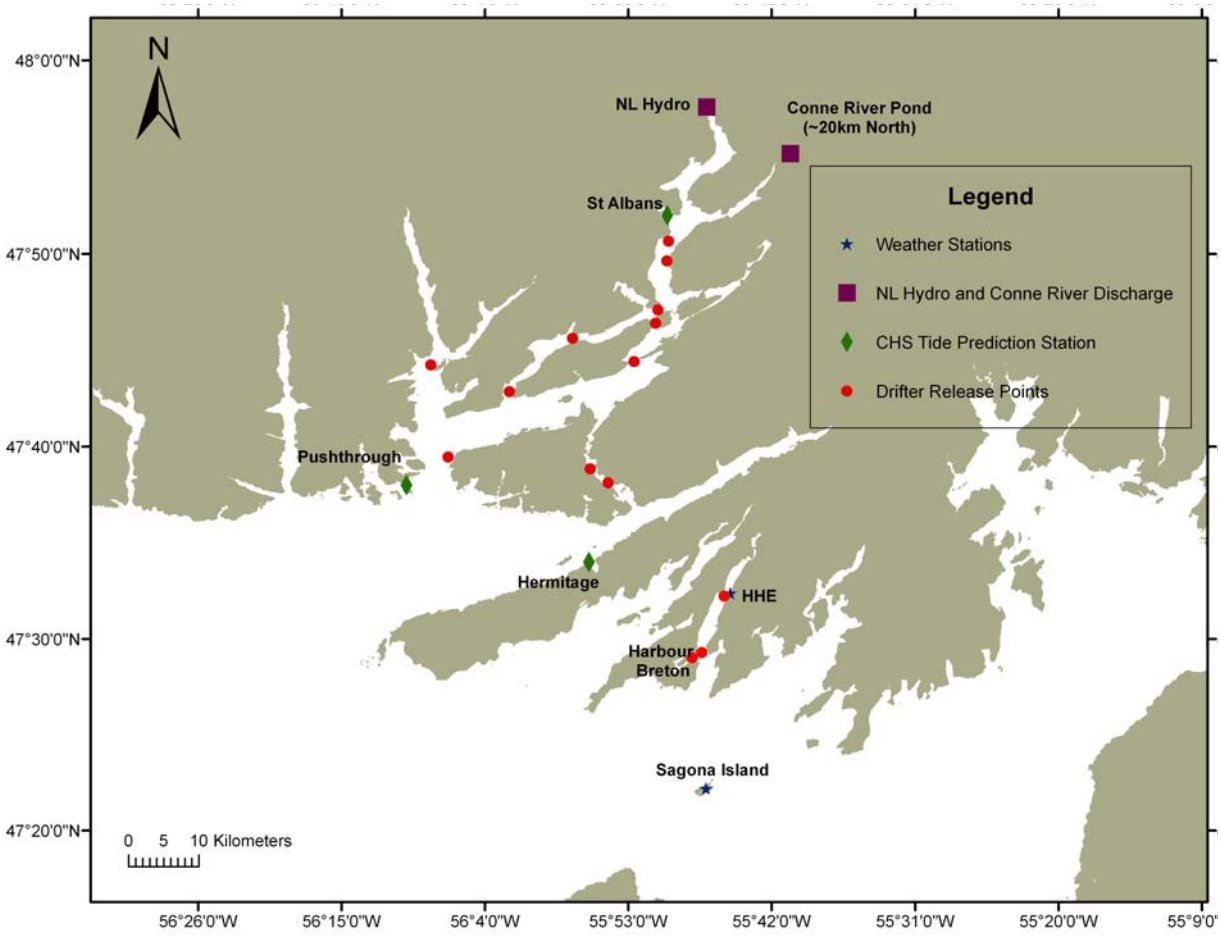



*Figure 1. Map of the south coast of Newfoundland showing the areas where drifters were released during 2009 and 2010.*


*Figure 2. Convertible Accurate Surface Tracker (CAST) drifter out of the water. The central orange cylinder contains the electronics package including the GPS receiver and transmitter.*

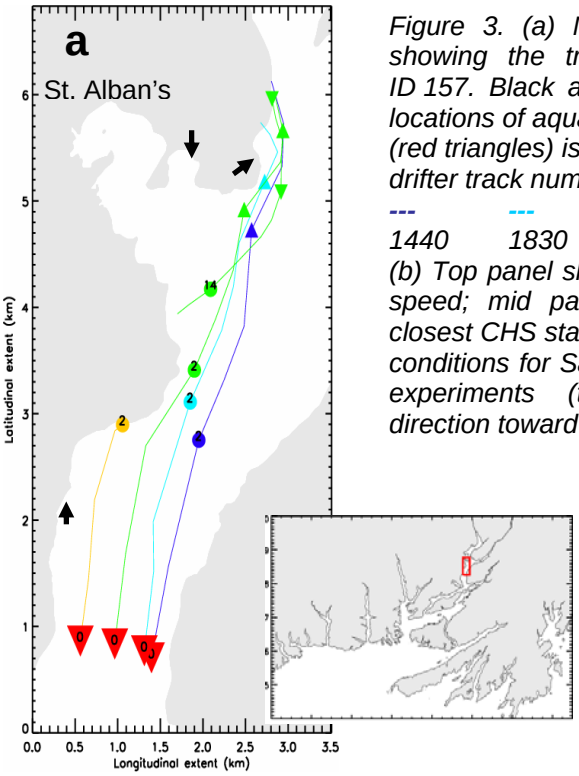
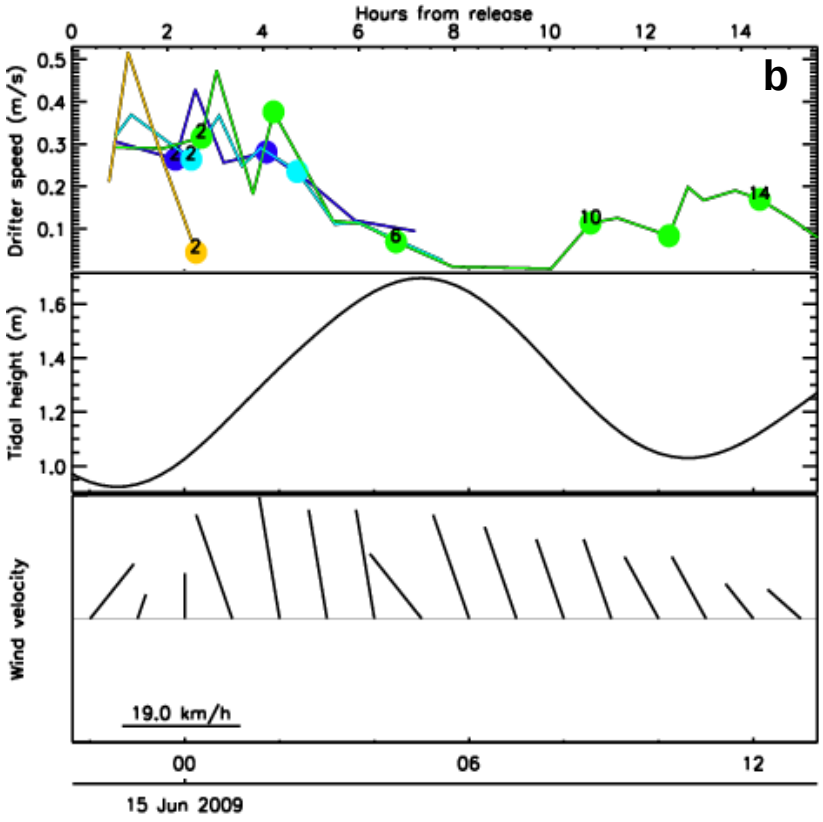



*Figure 3. (a) Map of the St. Alban's area showing the tracks of Drifter Deployment ID 157. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is just south of St. Alban's. The drifter track numbers are:*

*--- --- --- --- 2210*

*1440 1830 2079*

*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



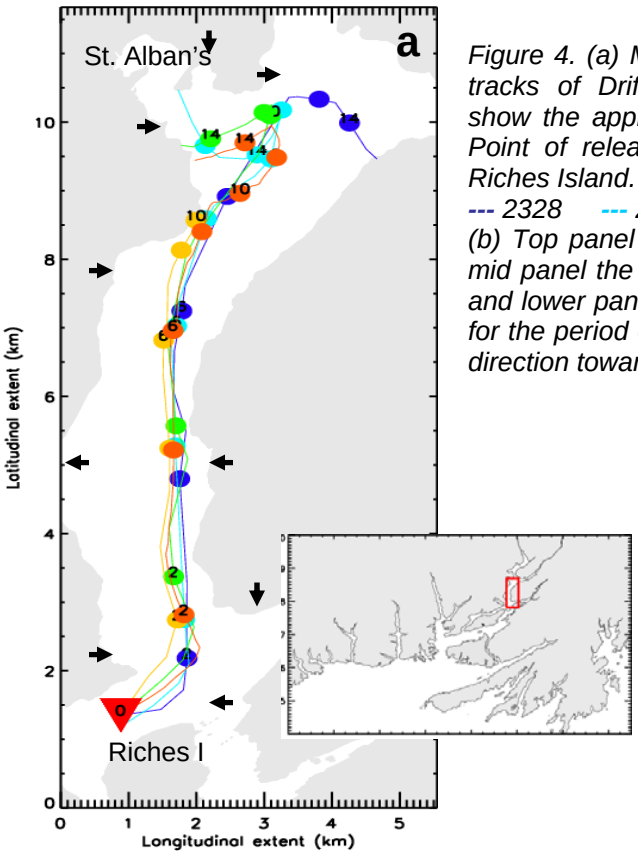
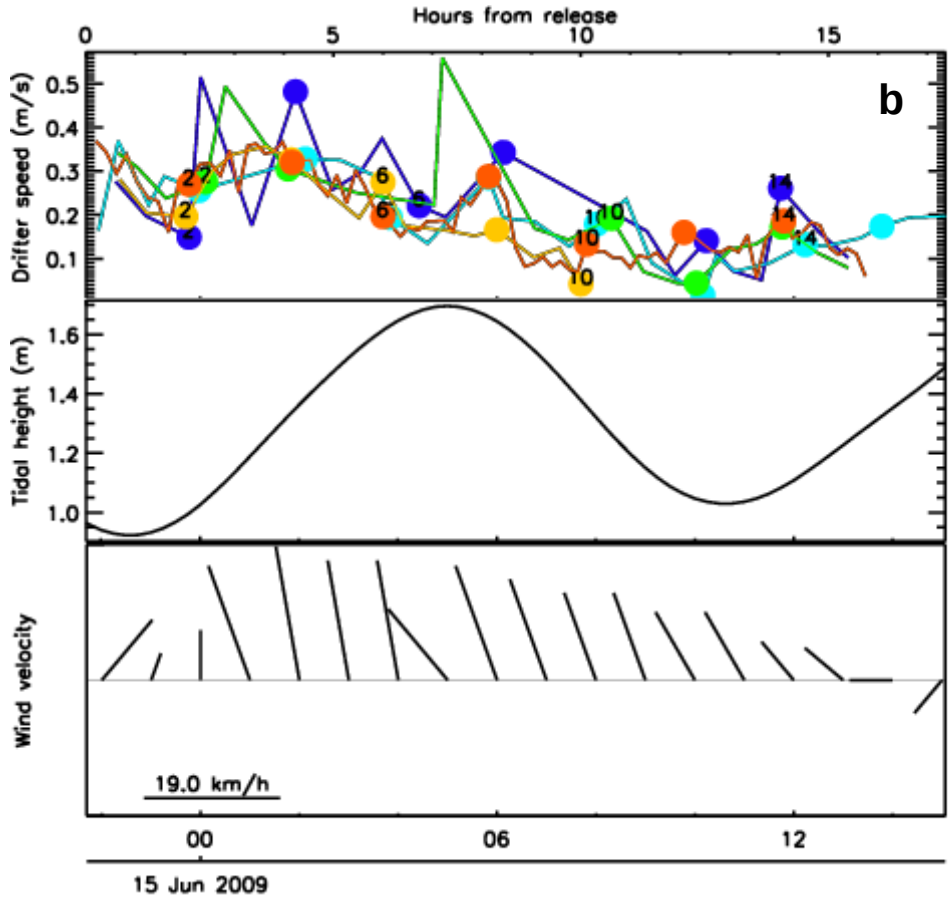



*Figure 4. (a) Map of the St. Alban's area showing the tracks of Drifter Deployment ID 158. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is just northwest of Riches Island. The drifter track numbers are:* *--- 2328* *--- 2662* *--- 2774* *--- 2795* *--- 2995* *(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



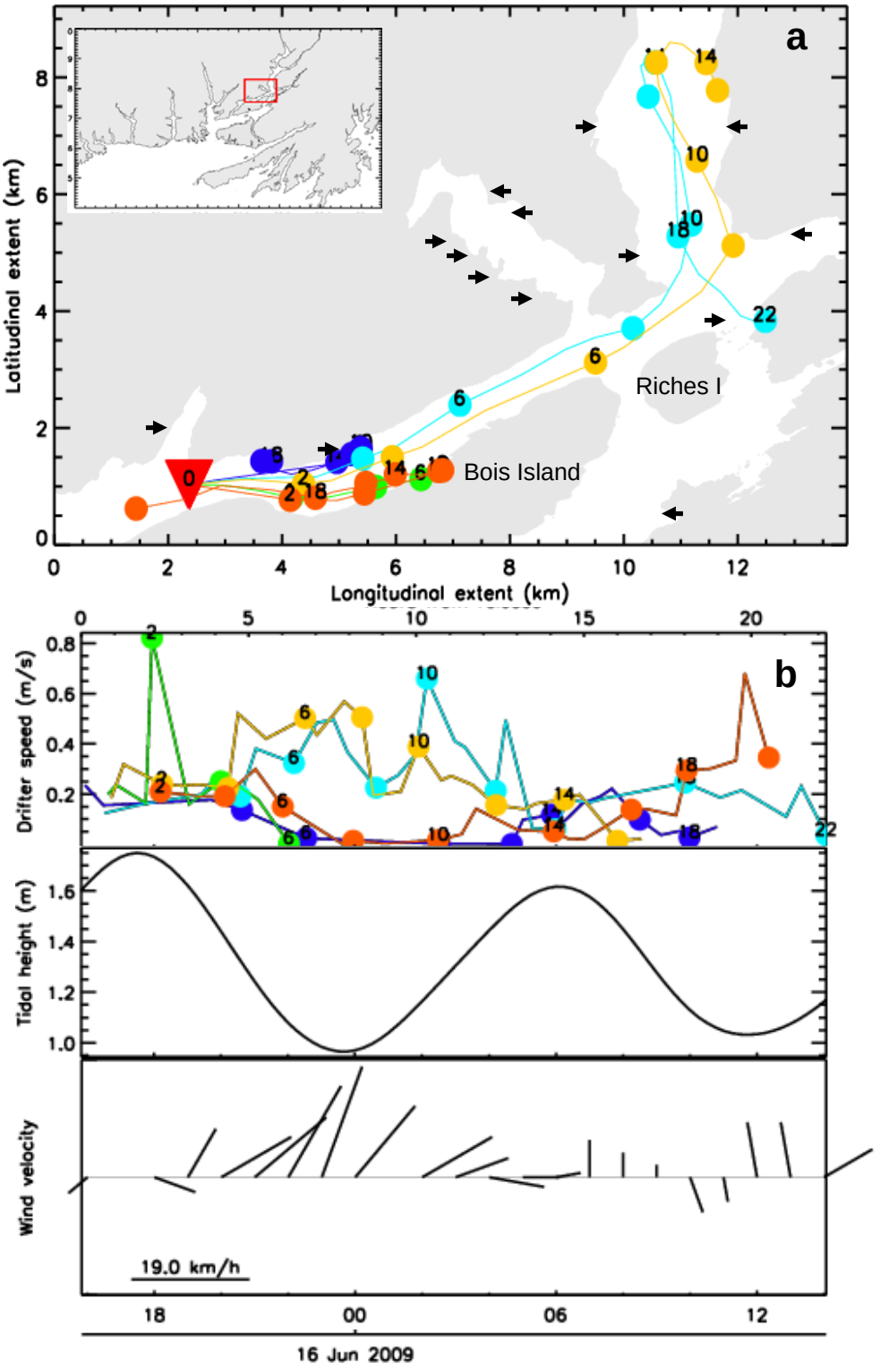



*Figure 5. (a) Map of the St. Alban's area showing the tracks of Drifter Deployment ID 159. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is within Lampidoes Passage, located north of Bois Island. The drifter track numbers are:*
*--- 1440 --- 1830 --- 2079 --- 2210 --- 2820*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

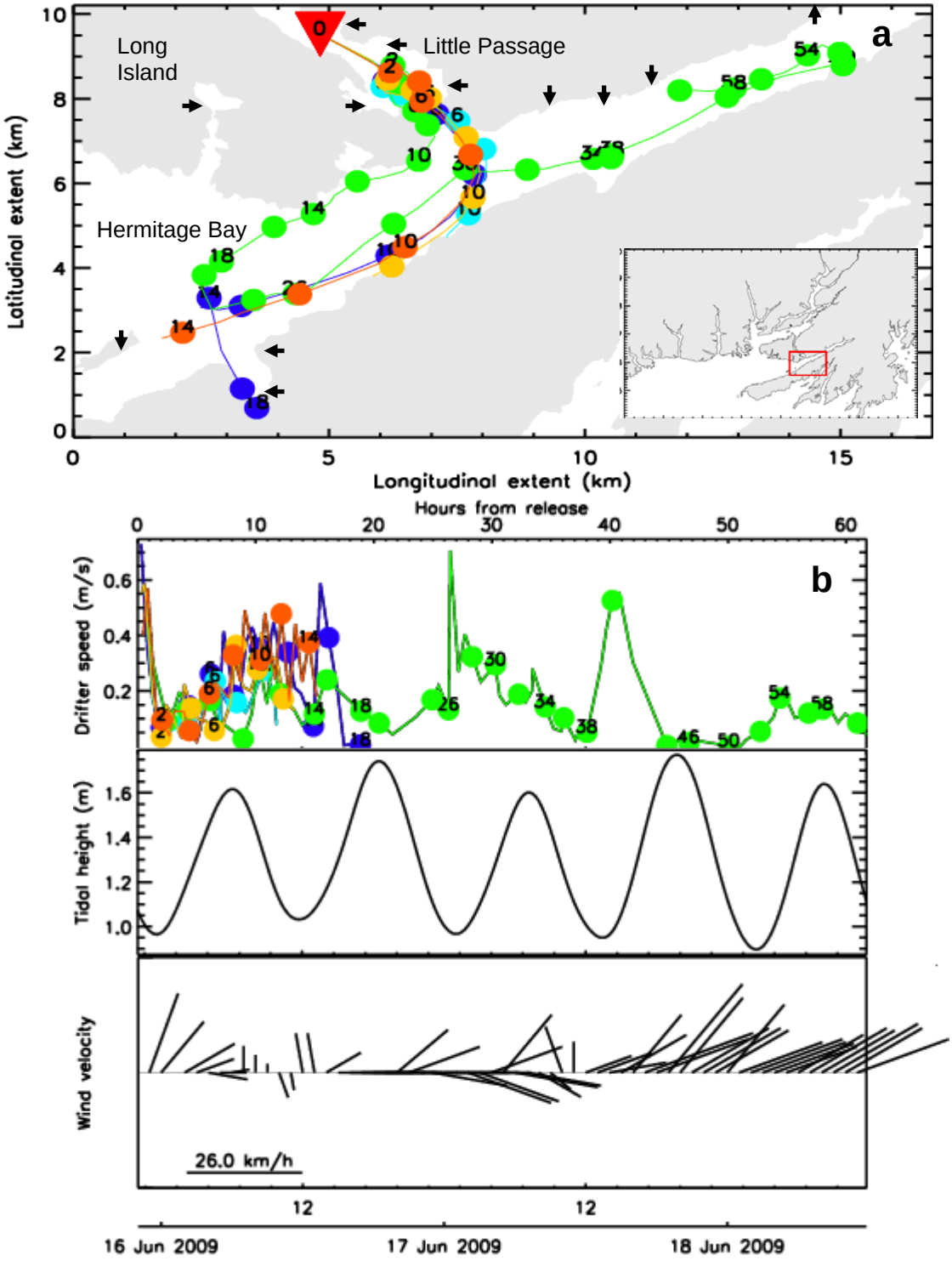



*Figure 6. (a) Map of the Hermitage Bay area showing the tracks of Drifter Deployment ID 160. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is within Little Passage, located northeast of Long Island. The drifter track numbers are:*

*--- 2328 --- 2662 --- 2774 --- 2782 --- 2795*

*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

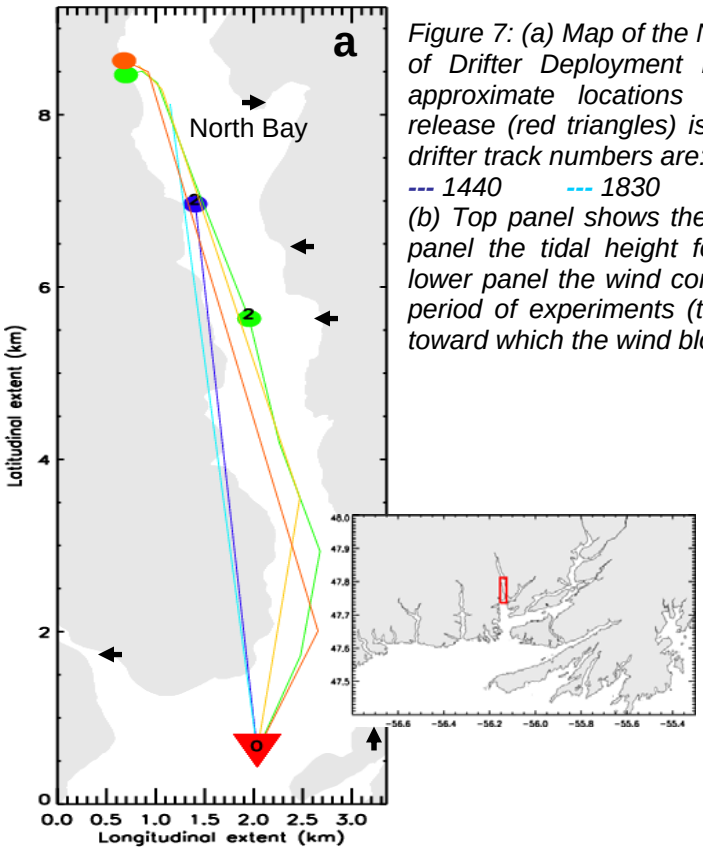
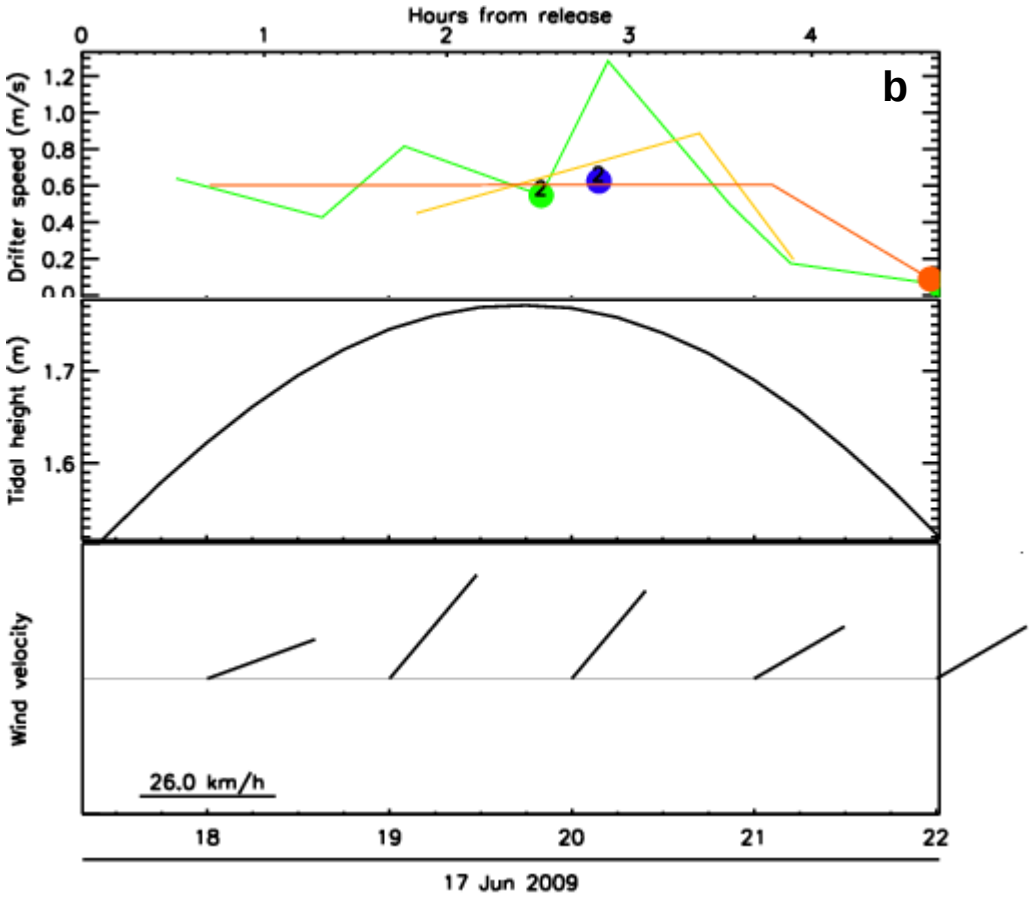
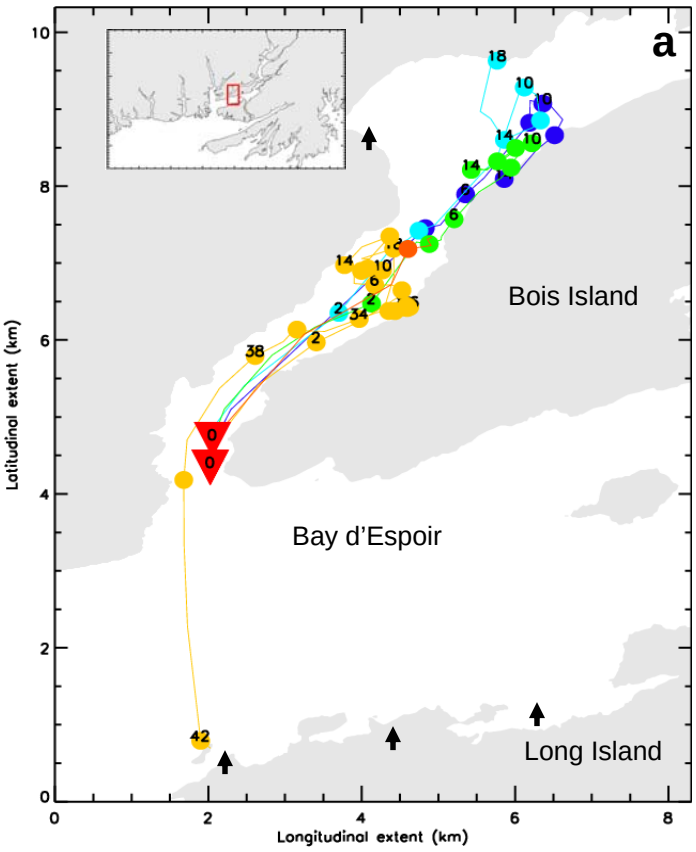



*Figure 7: (a) Map of the North Bay area showing the tracks of Drifter Deployment ID 161. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is south of North Bay Head. The drifter track numbers are:*
*--- 1440 --- 1830 --- 2079 --- 2210 --- 2820*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*





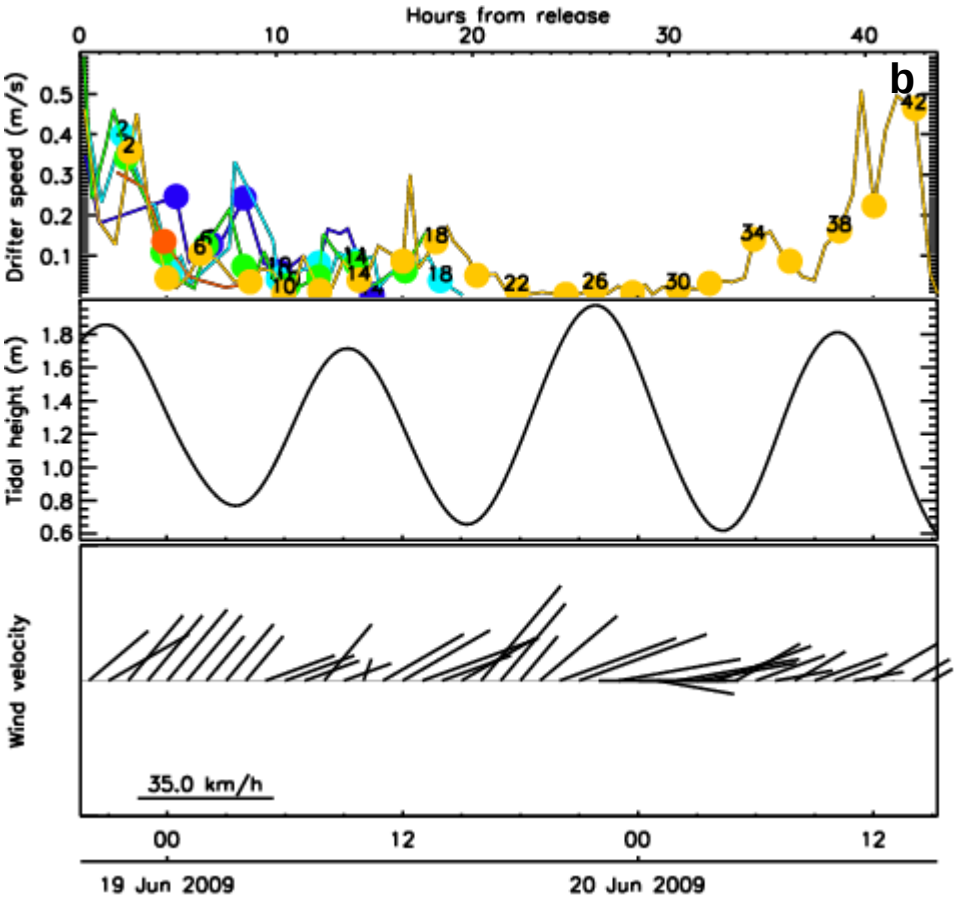




*Figure 8. (a) Map of the Bay d'Espoir area showing the tracks of Drifter Deployment ID 162. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is at the southern mouth of Lampidoes Passage. The drifter track numbers are:*

*--- 1440 --- 1830 --- 2079*
*--- 2210 --- 2820*

*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

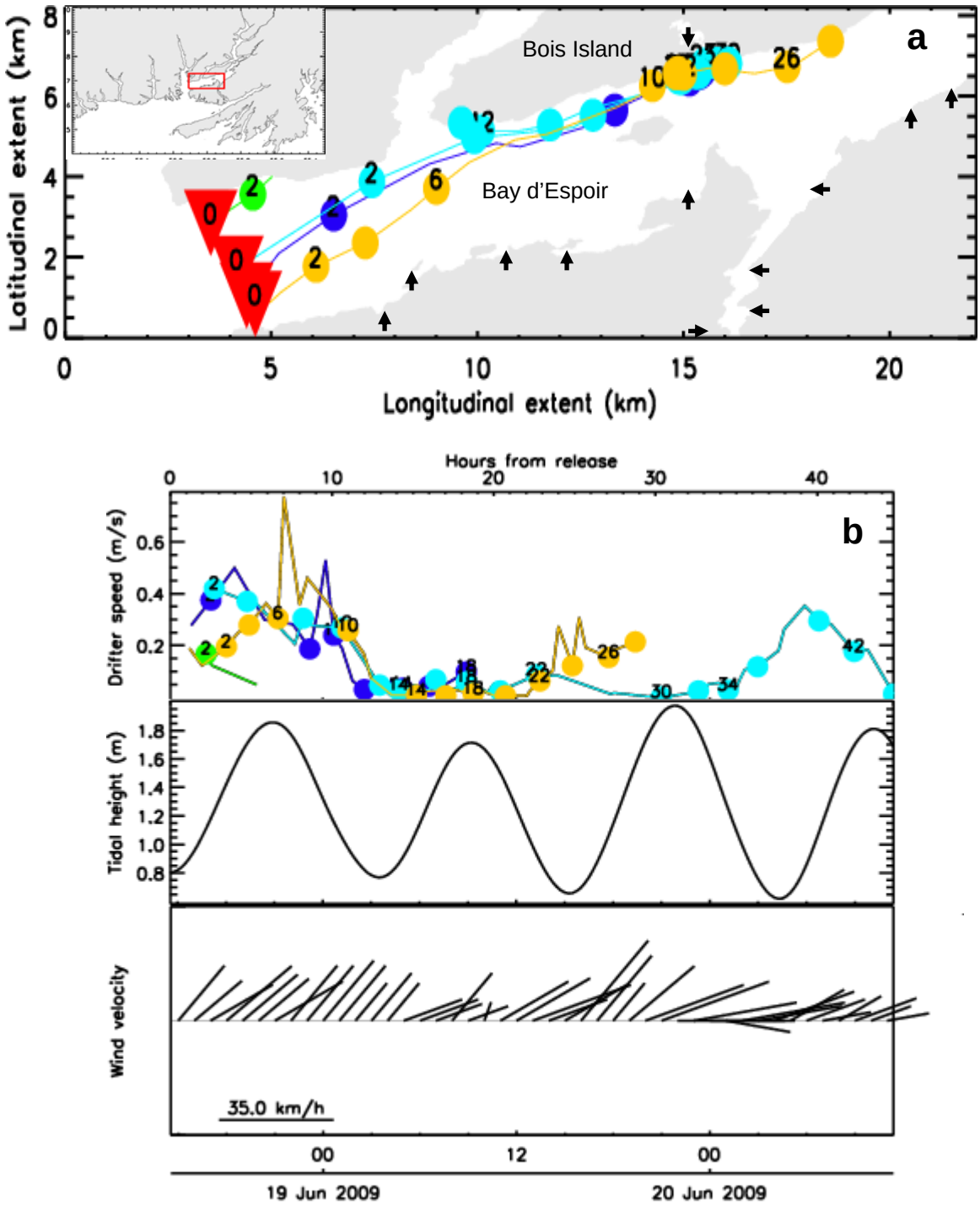



*Figure 9.: (a) Map of the Bay d'Espoir area showing the tracks of Drifter Deployment ID 163. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is north of Green Point at the mouth of Bay d'Espoir. The drifter track numbers are:*
*--- 2662 --- 2774 --- 2795 --- 2995*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

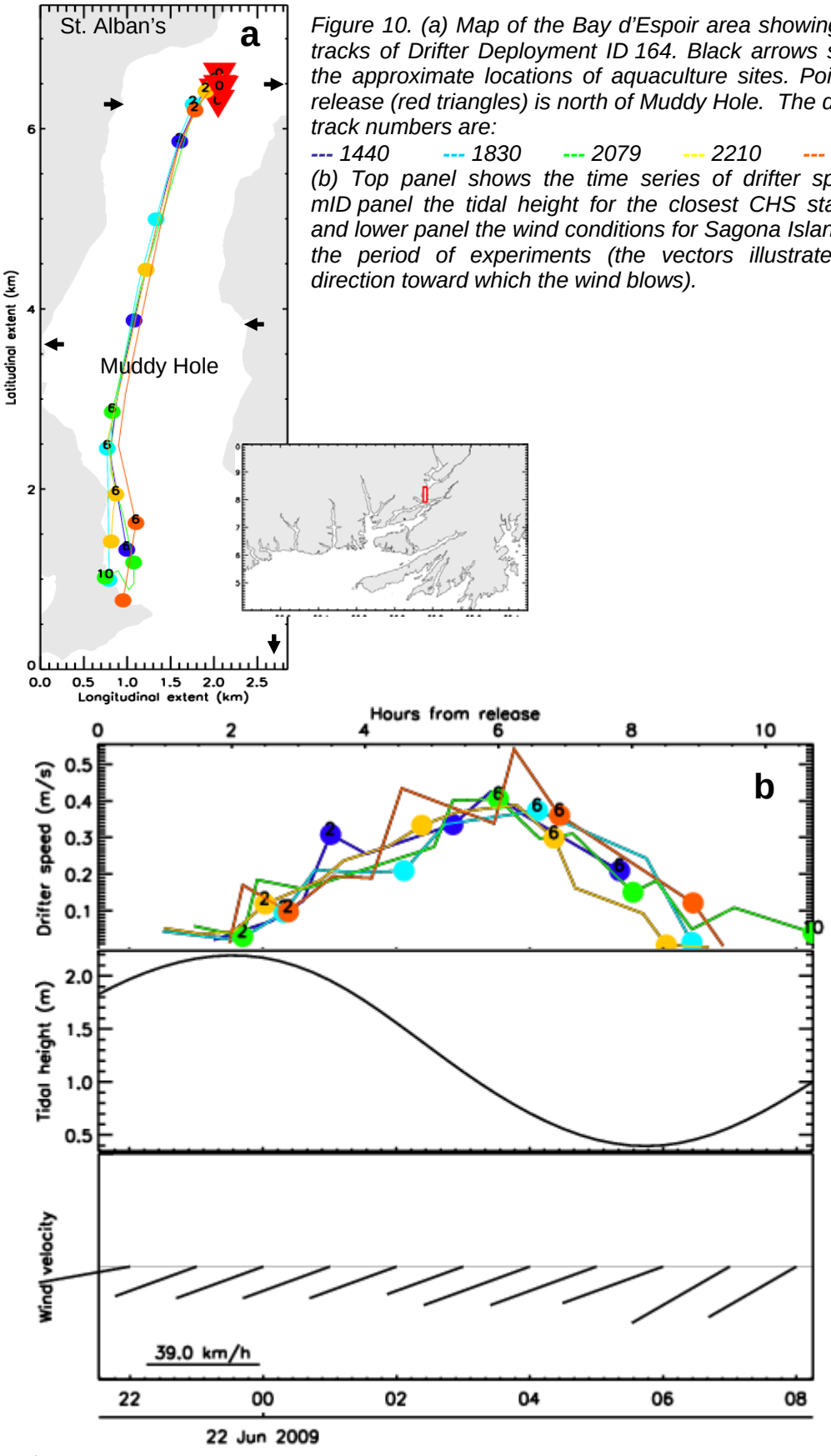
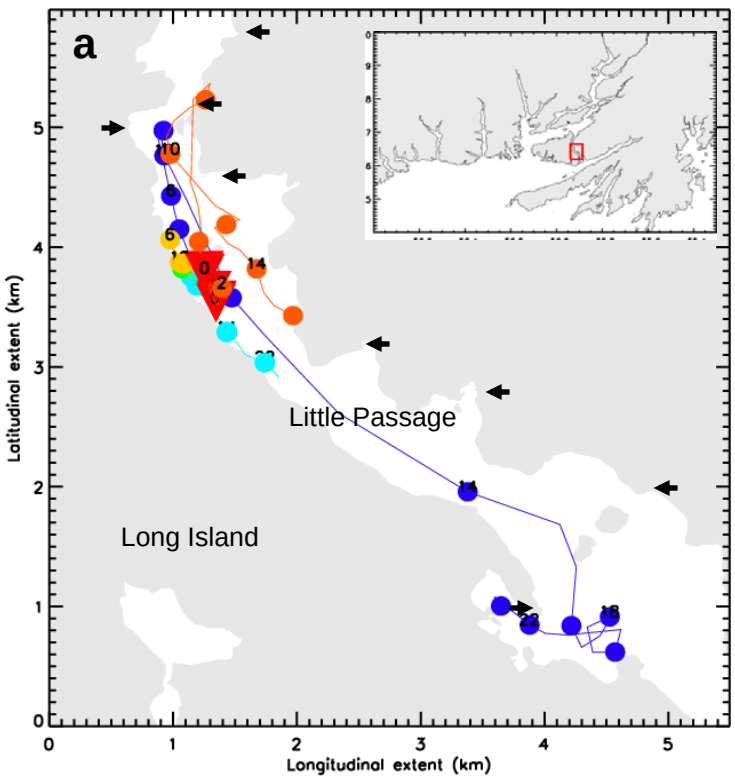



*Figure 10. (a) Map of the Bay d'Espoir area showing the tracks of Drifter Deployment ID 164. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is north of Muddy Hole. The drifter track numbers are:*
*--- 1440 --- 1830 --- 2079 --- 2210 --- 2820*
*(b) Top panel shows the time series of drifter speed; mID panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



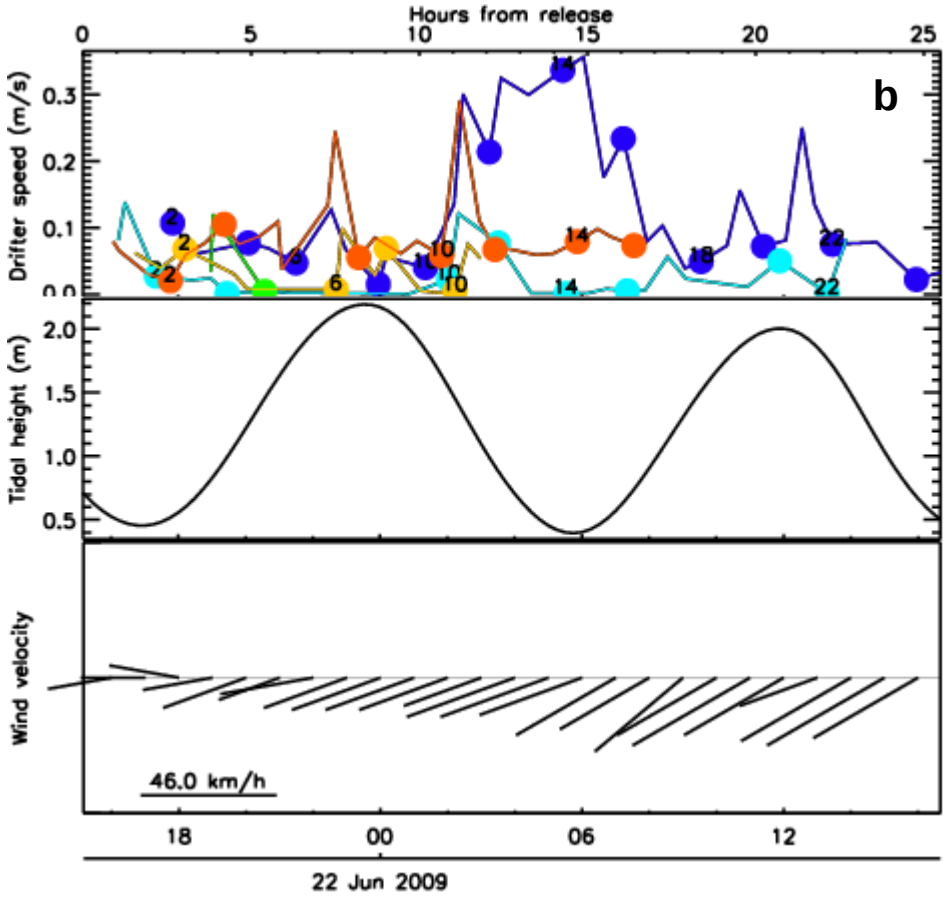
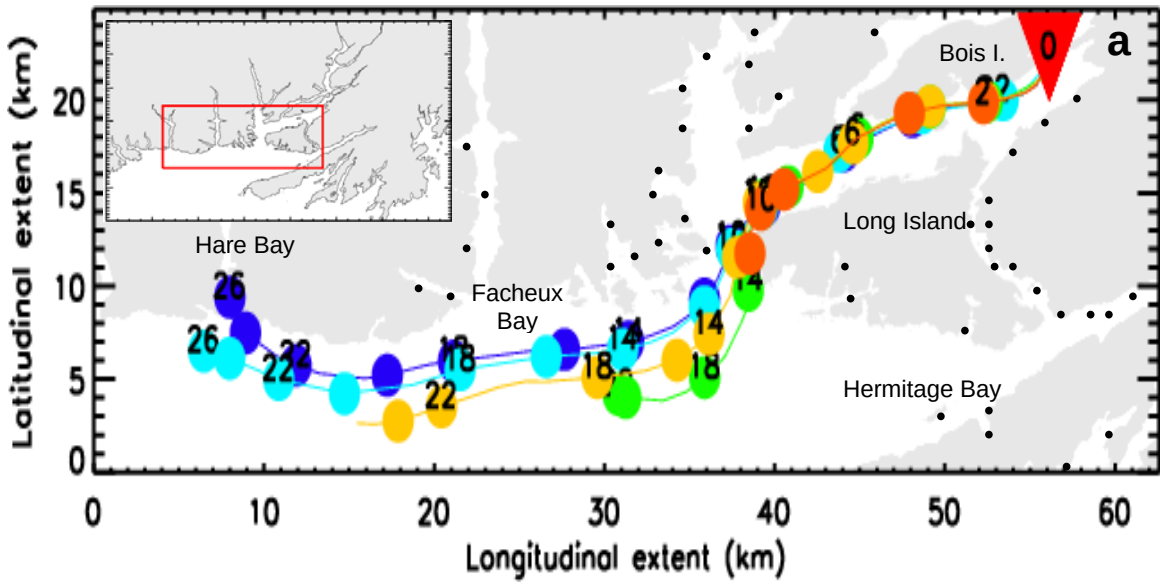




*Figure 11. (a) Map of the Little Passage area showing the tracks of Drifter Deployment ID 165. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is in the middle of Little Passage. The drifter track numbers are:*
*--- 2662 --- 2774 --- 2782*
*--- 2795 --- 2995*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



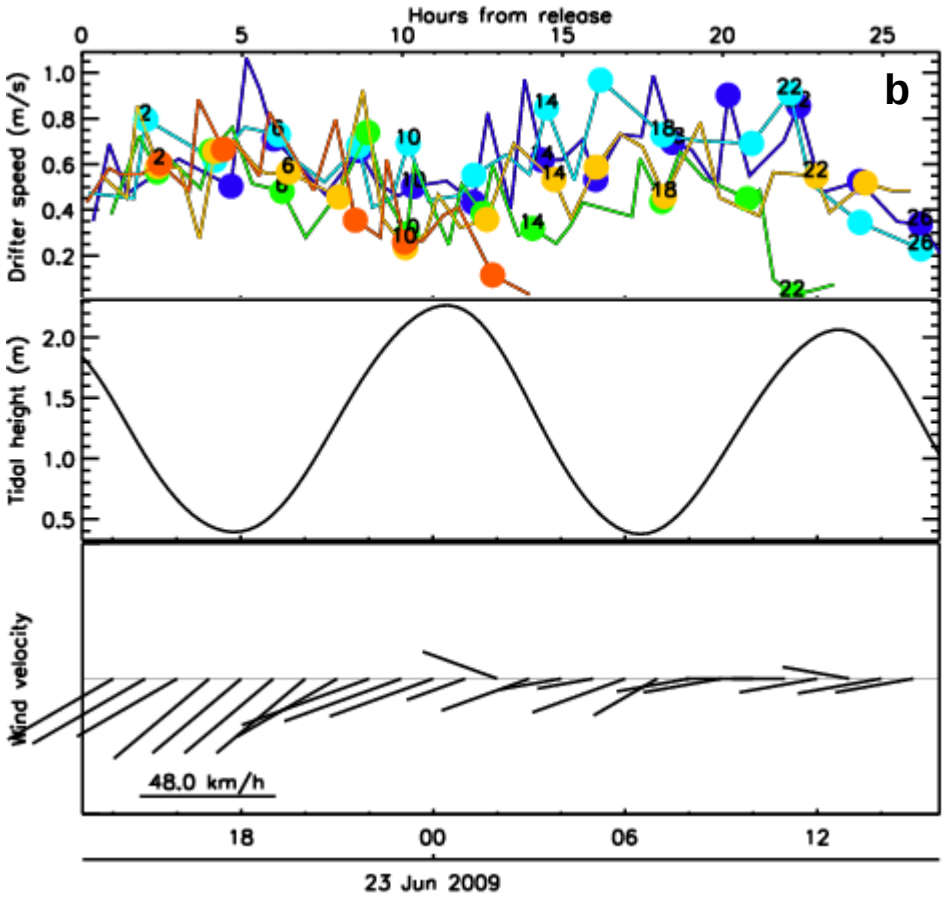




*Figure 12. (a) Map of the Bay d'Espoir area showing the tracks of Drifter Deployment ID 166. Black circles show the approximate locations of aquaculture sites. Point of release (red triangles) is east of May Head in Bay d'Espoir. The drifter track numbers are:*
*--- 1440 --- 1830 --- 2079 --- 2210 --- 2820*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

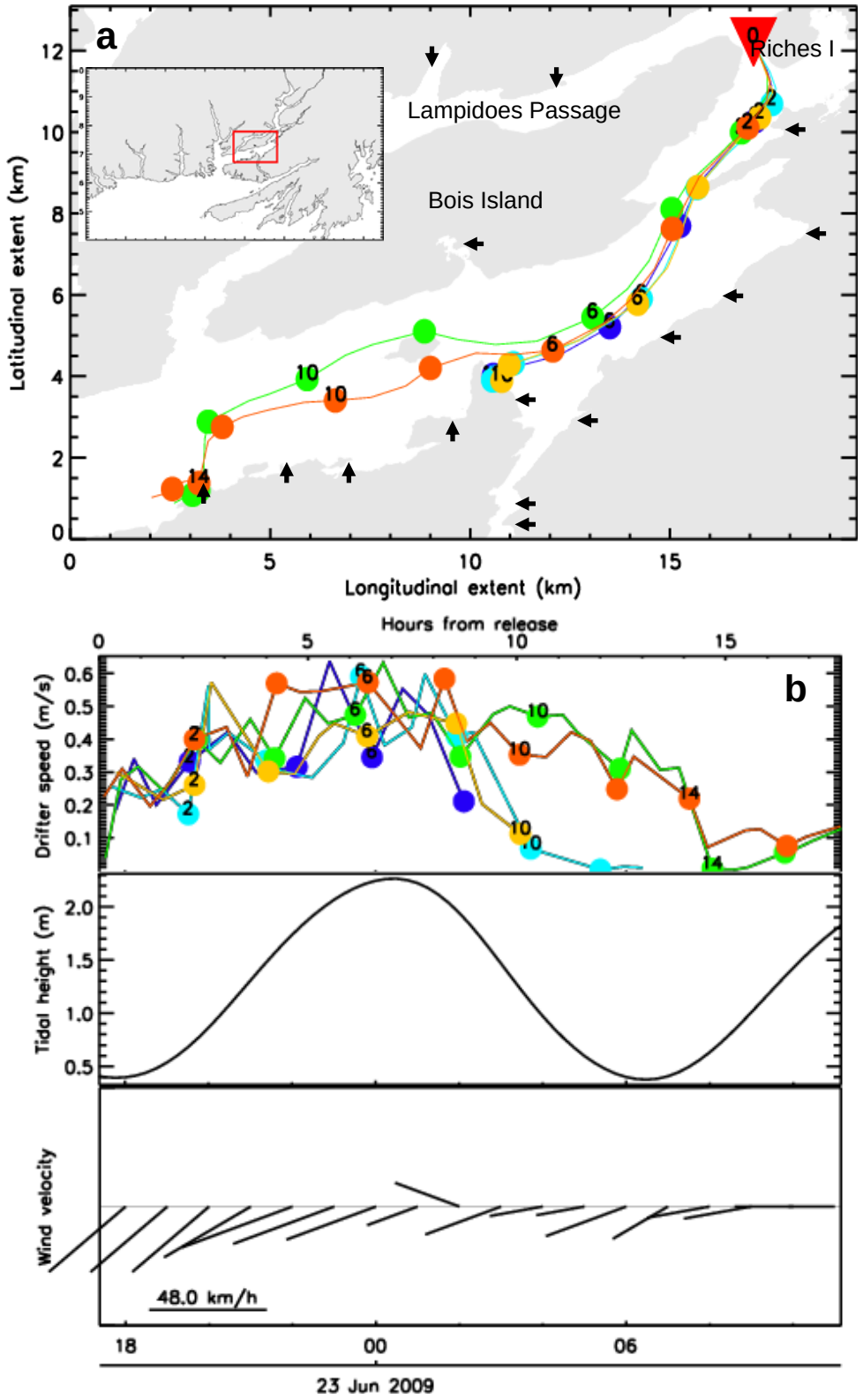



*Figure 13. (a) Map of the Bay d'Espoir area showing the tracks of Drifter Deployment ID 167. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is east of Riches Island in Bay d'Espoir. The drifter track numbers are:*
*--- 2662 --- 2774 --- 2782 --- 2795 --- 2995*
*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

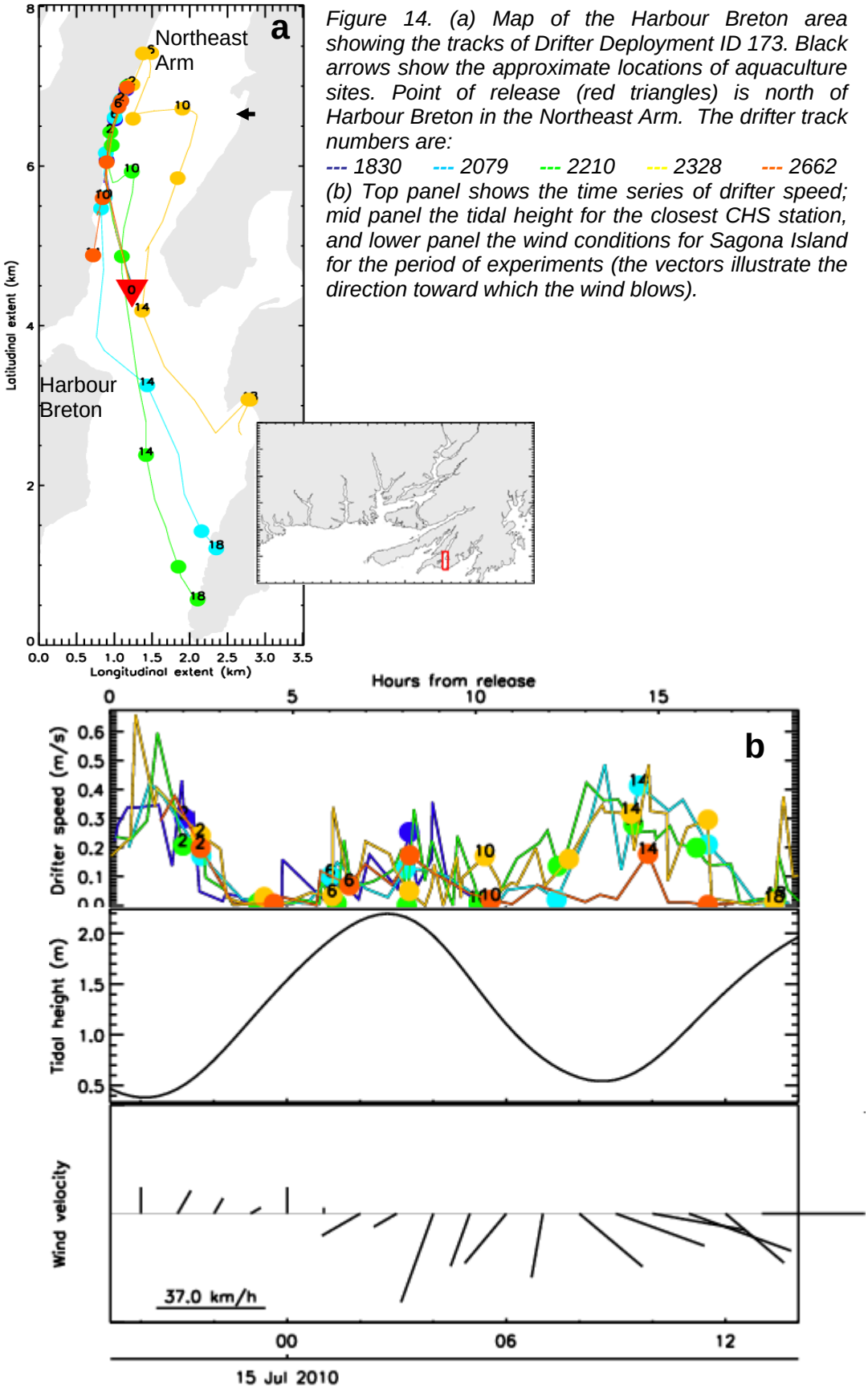



*Figure 14. (a) Map of the Harbour Breton area showing the tracks of Drifter Deployment ID 173. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is north of Harbour Breton in the Northeast Arm. The drifter track numbers are:*

*--- 1830 --- 2079 --- 2210 --- 2328 --- 2662*

*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*

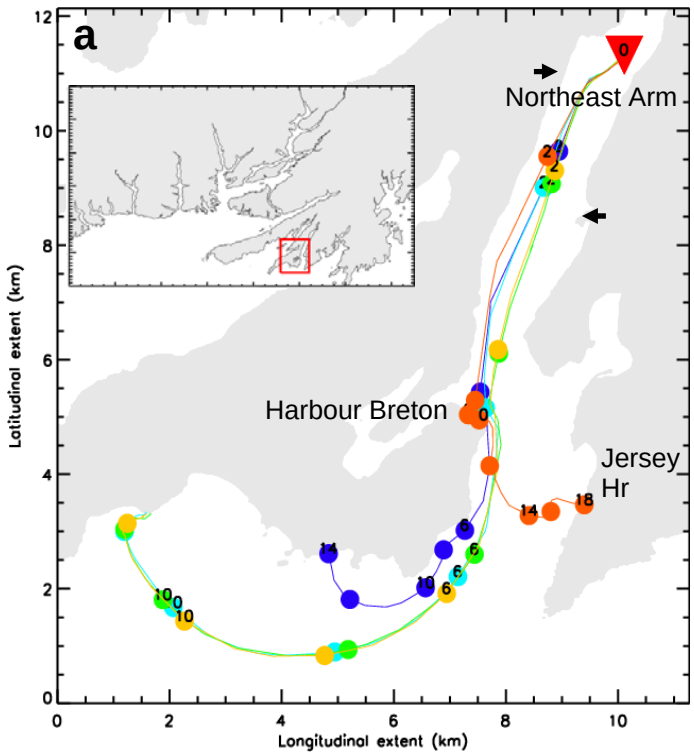
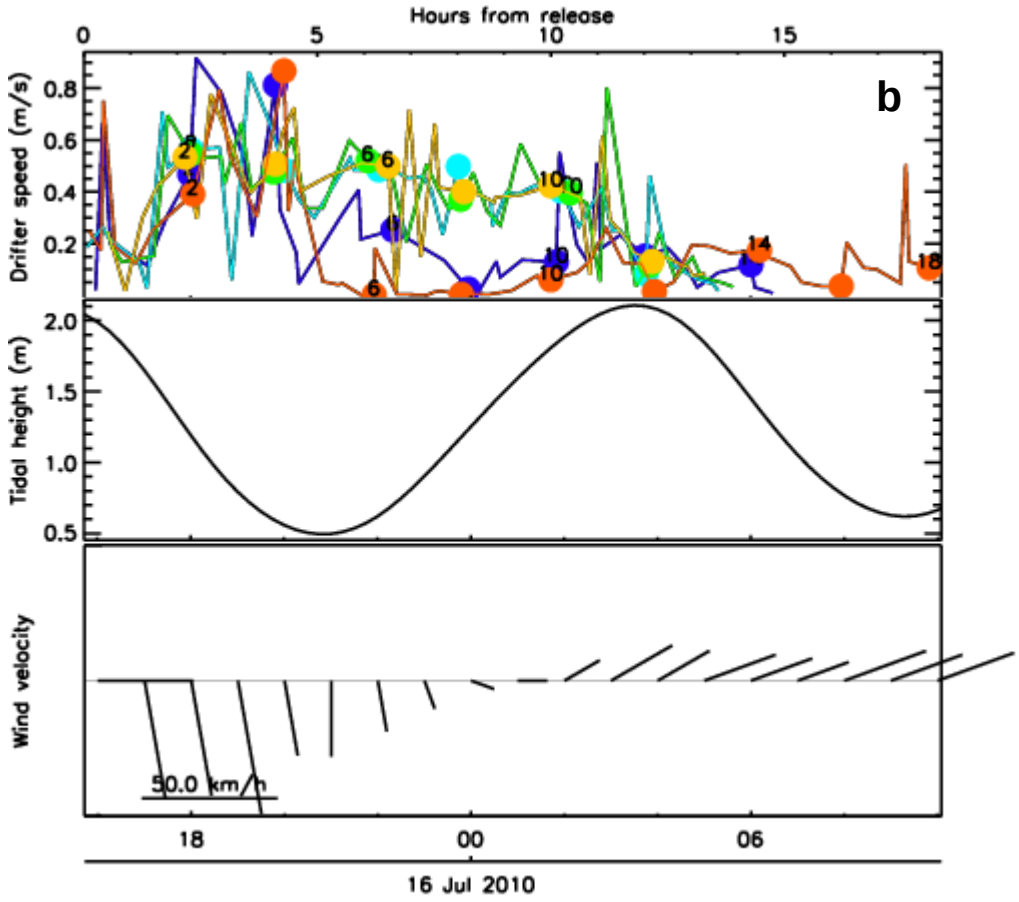



*Figure 15. (a) Map of the Harbour Breton area showing the tracks of Drifter Deployment ID 174. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is east of Harvey Hill in the Northeast Arm. The drifter track numbers are:*

*--- 1830 --- 2079 --- 2210*
*--- 2328 --- 2662*

*(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



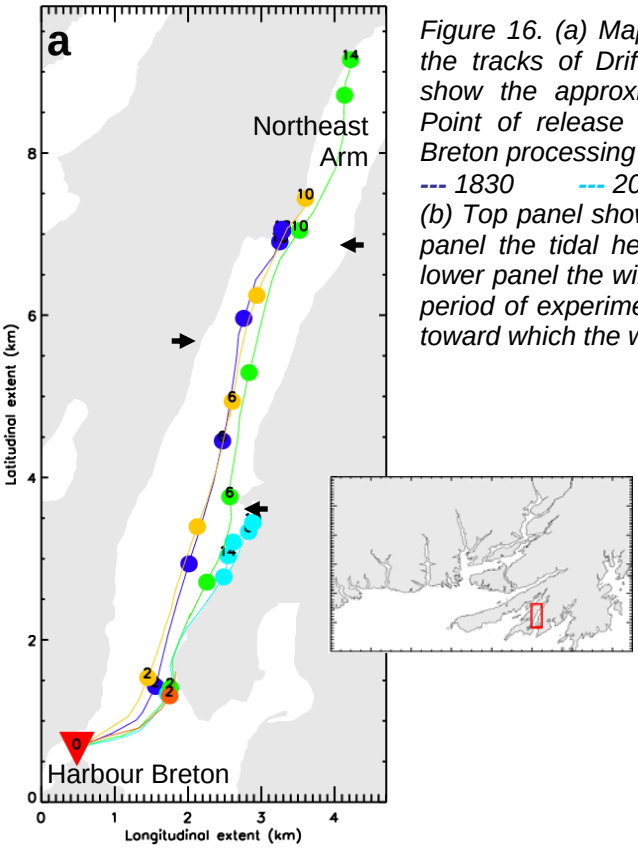
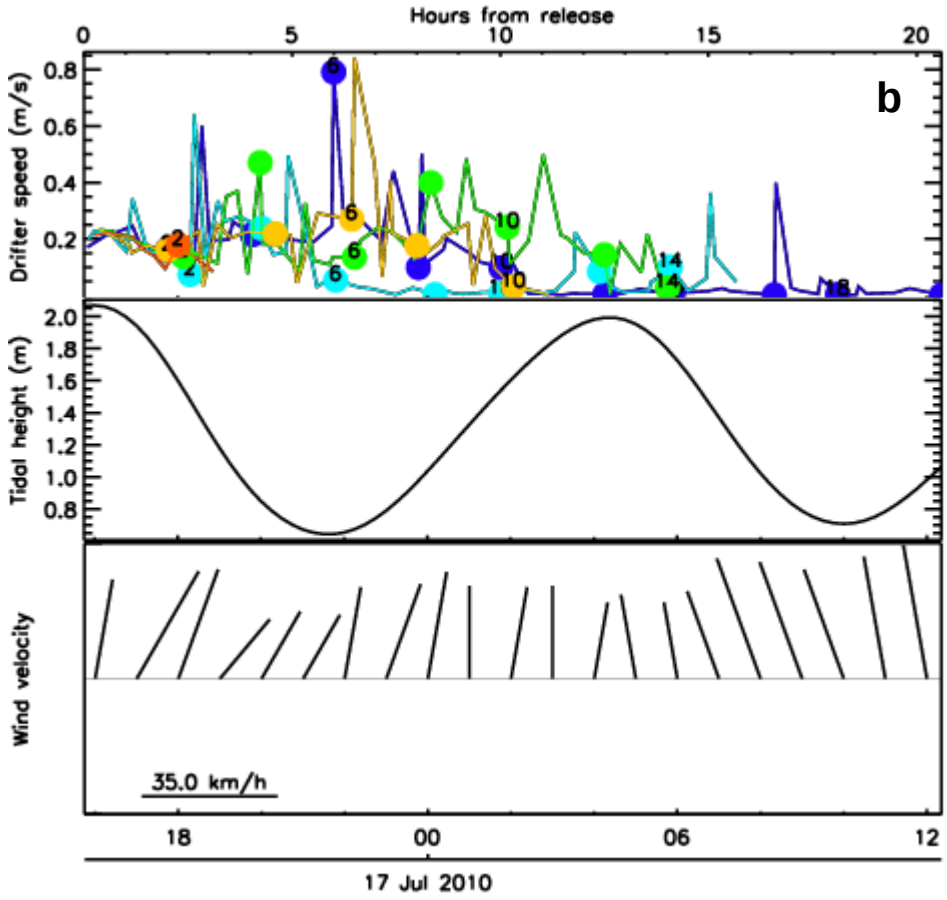



*Figure 16. (a) Map of the Harbour Breton area showing the tracks of Drifter Deployment ID 175. Black arrows show the approximate locations of aquaculture sites. Point of release (red triangles) is off of the Harbour Breton processing plant. The drifter track numbers are:* *--- 1830* *--- 2079* *--- 2210* *--- 2328* *--- 2662* *(b) Top panel shows the time series of drifter speed; mid panel the tidal height for the closest CHS station, and lower panel the wind conditions for Sagona Island for the period of experiments (the vectors illustrate the direction toward which the wind blows).*



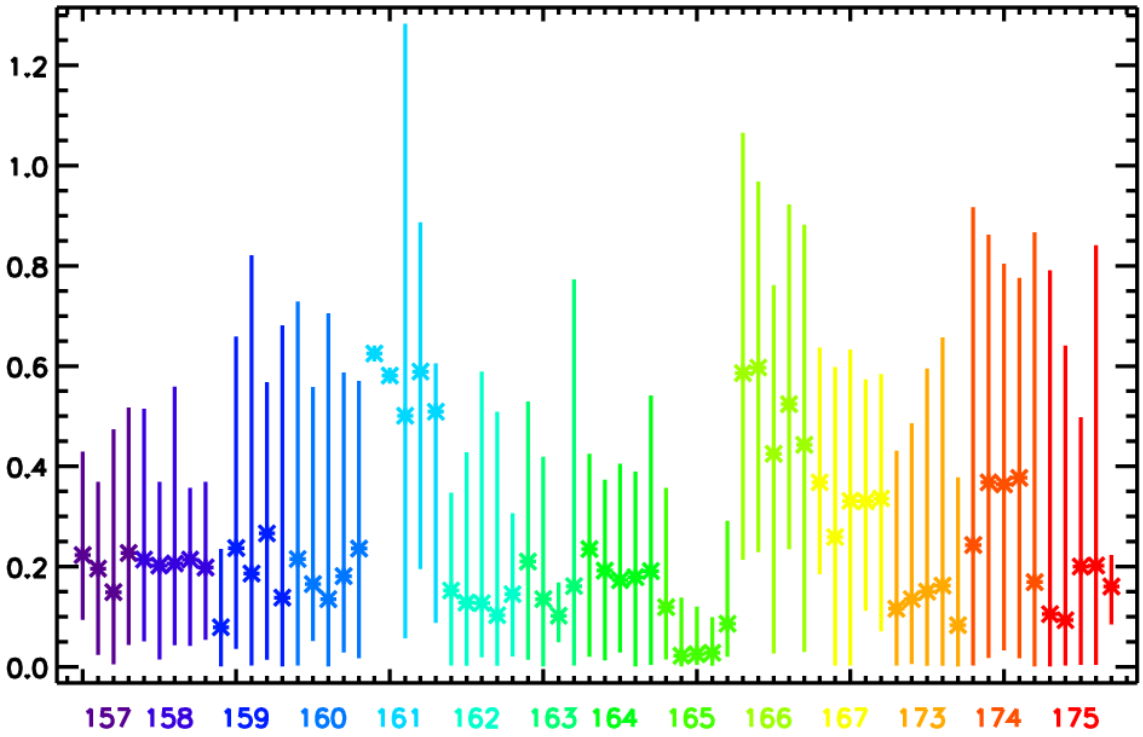



*Figure 17. Range and average velocity of each drifter for each deployment. The asterisk indicates the average velocity and the lower (upper) end of the vertical bar the minimum (maximum).*

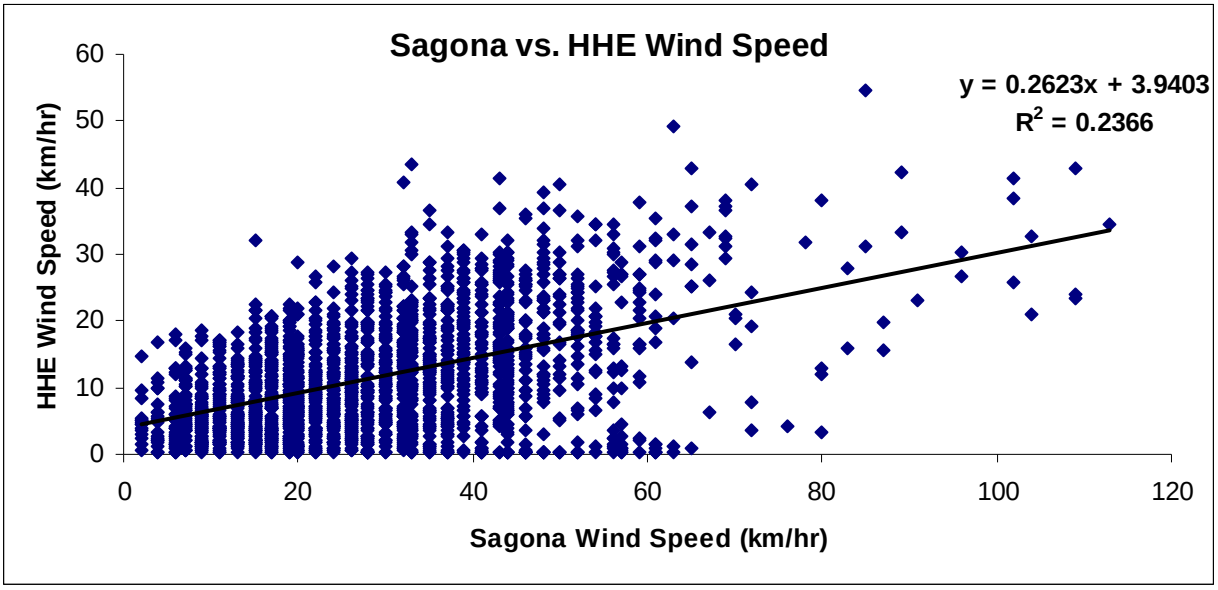



*Figure 18. Comparison of wind speed at Sagona Island and Harvey Hill East (A) and wind direction at Sagona Island and Harvey Hill East (B) during the period of 17 July to 19 October 2010.*

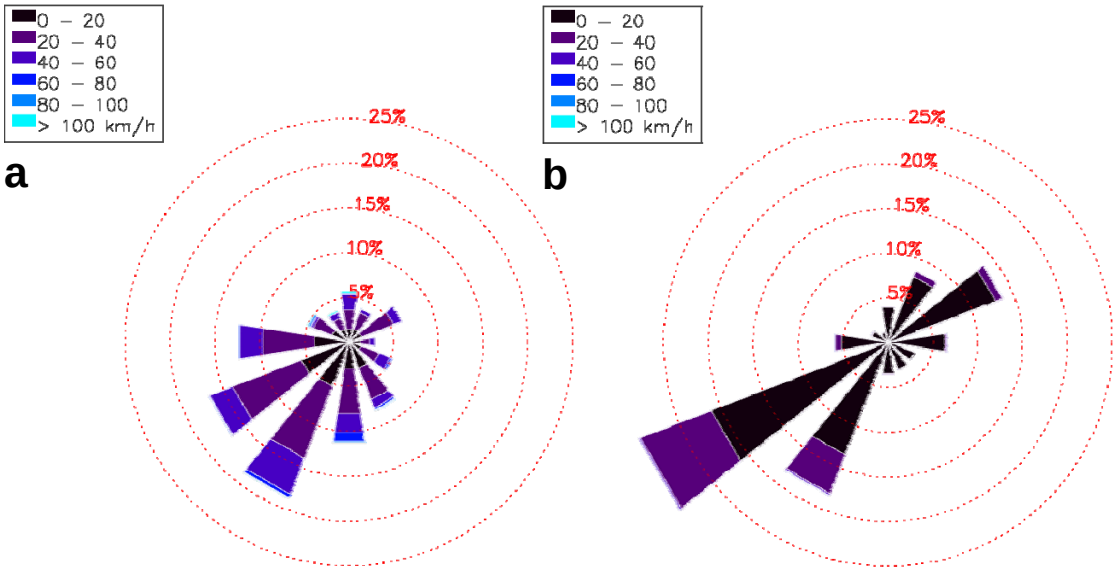



*Figure 19. Wind rose at Sagona Island (a) and at Harvey Hill East (b) during the period of 17 July to 19 October 2010.*

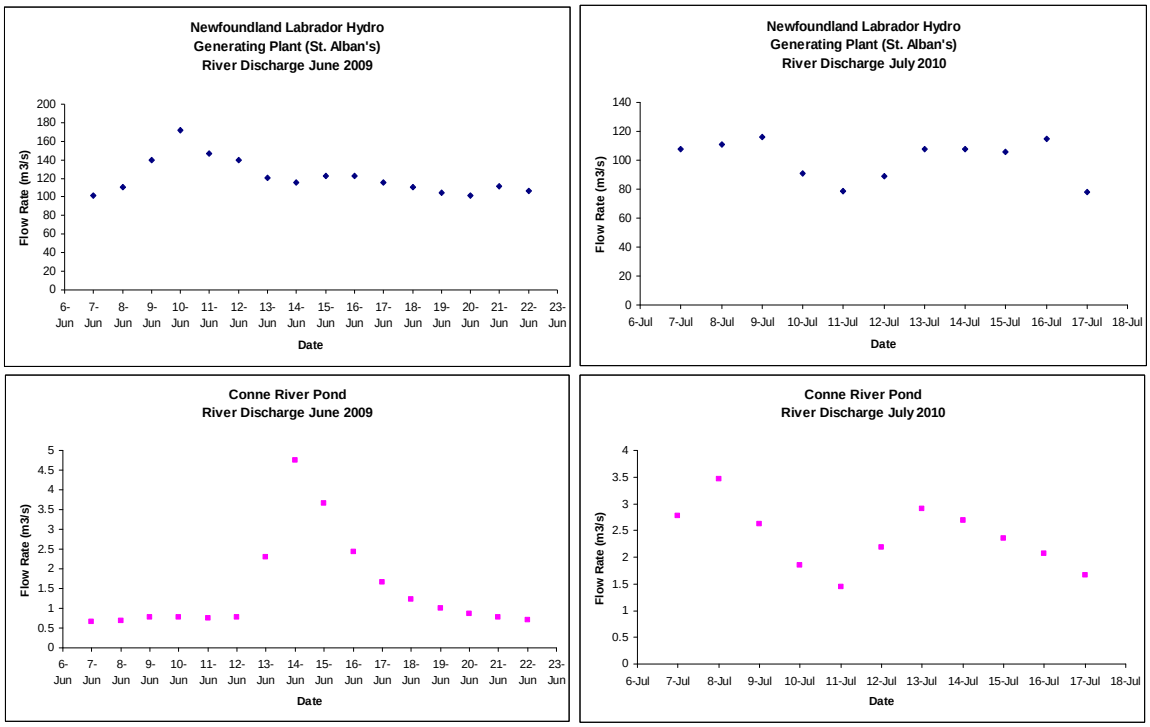



*Figure 20. River discharge data ($m^3/s$) for Newfoundland Labrador Hydro Generating Station, St. Alban's (upper panels) and Conne River Pond (lower panels) during June 2009 (left panels) and July 2010 (right panels).*

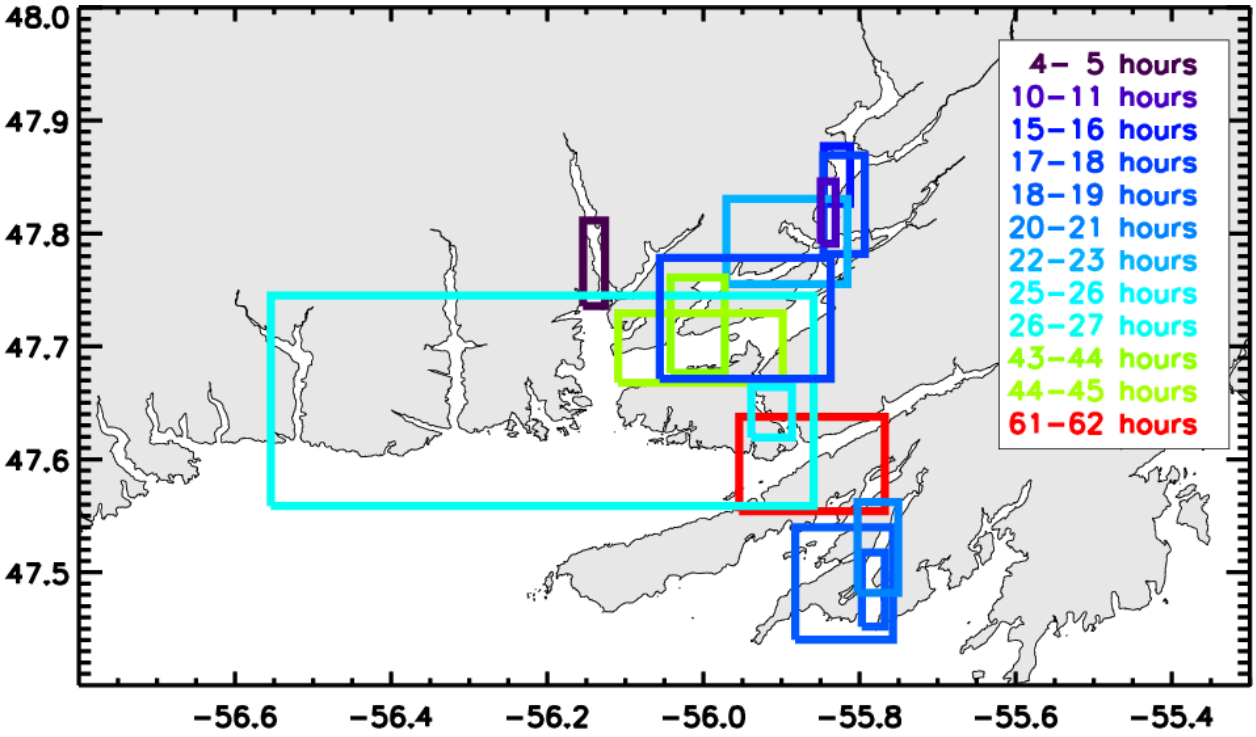



*Figure 21. Map representing the zones of influence and the maximum time of sail of the drifters for each deployment.*

## APPENDIX 1

Relation between wind directions (degree true north) and corresponding name conventions used in the present document.

| Abbreviation | Wind Direction | Degrees |
|---|---|---|
| **N** | North | 0° |
| **NNE** | NorthNorthEast | 22.5° |
| **NE** | NorthEast | 45° |
| **ENE** | EastNorthEast | 67.5° |
| **E** | East | 90° |
| **ESE** | EastSouthEast | 112.5° |
| **SE** | SouthEast | 135° |
| **SSE** | SouthSouthEast | 157.5° |
| **S** | South | 180° |
| **SSW** | SouthSouthWest | 202.5° |
| **SW** | Southwest | 225° |
| **WSW** | WestSouthWest | 247.5° |
| **W** | West | 270° |
| **WNW** | WestNorthWest | 292.5° |
| **NW** | Northwest | 315° |
| **NNW** | NorthNorthWest | 337.5° |

### Wind rose