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Drifters, Drogues, and Circulation

BY THOMAS O. MANLEY

PURPOSE OF ACTIVITY

Circulation within a body of water controls not only fluid transport but also, just as importantly, chemical, biological, and sedimentological constituents. Transport and dispersal of these constituents is of major concern when it comes to the proper management of rivers, bays, lakes, and nearshore communities; however, most students fail to realize the complexities related to the forcing of this flow field or its variability over time. Through the use of very basic tools, students having access to a small research vessel would be able to map surface and deeper circulation of a small region within a given water body (for ease, "lake" will be used from here on even though it implies any region of interest). Meteorological data will be used to look at the effects of wind forcing, and bathymetric information can provide aspects of topographic control. The acquisition of these data during repeated cruises will lead to a better understanding of mean circulation and its variability.

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AUDIENCE

This activity would be directed to undergraduates, although first-year graduate students may also benefit from this exercise. Access to a suitable boat/research vessel for a minimum three- to four-hour cruise is essential for students to gain a real understanding of the survey equipment and the environment that they are attempting to study.

BACKGROUND

Presently, lakes are experiencing water-quality issues that can or have already affected the aquatic community and, hence, the political, social, environmental, and economic characteristics of the surrounding population. Nitrogen and phosphorus accelerate eutrophication, and, in specific cases, create byproduct anoxic zones. Wastewater treatment facilities pump varying degrees of processed water back into the lake while water intake facilities process lake water for public consumption at the same time. If a new wastewater treatment facility were needed, coastal management personnel would have to understand where and how fast the effluent would move as well as its effects on the local biological community. But, how do these chemical constituents move and disperse throughout this fluid environment? On a river, the answer would be obvious in that downstream flow would dominate movement and dispersal. In a lake, complexities of circulation dynamics rise exponentially due to the effects of bottom topography, wind forcing, precipitation, river and groundwater influx, shoreline configuration, internal pressure variations within the water column, turbulence (mixing), solar radiation, air temperature, and wind forcing, to name a few.

Although the general public grasps the detrimental aspects of pollutants within the environment, there is a surprising lack of understanding as to how these chemical constituents get from one place to another. To understand this movement, advection and diffusion need to be considered. Simply, advection can be viewed as an average or mean transport produced by a current while diffusion is a more complex topic that encompasses a broad mixing domain, from large-scale eddies, to small-scale turbulence, and finally, molecular transfer (i.e., created by deviations from mean flow and/or movement from higher to lower concentrations).

The purpose of this activity is to look at the advection component within a small region, and, if enough measurements are taken, the class will gain a sense of its variability. This activity will expose students to myriad static and dynamic factors that control currents. Static factors do not change over time and would represent the controlling nature of bottom bathymetry and shoreline configuration. Dynamic factors are time variants and represent the greatest challenge. Although there are a wide variety of dynamic factors to consider, the two most important ones are wind (i.e., direction and stress [a function of the square of wind speed; Open University Course Team, 1989]), and the internal layering (stratification) of the water column.

POSING THE RESEARCH QUESTION

Research questions can be posed depending on location (i.e., lake, river, or estuary), the class's educational level, and most assuredly, the instructor's specialty. Small lakes or small bays within larger lakes offer more to the student because tides (which can mask wind-driven currents) are removed. River environments, on the other hand, could be considered too simple. For an introductory class, however, a very basic research question would be: What is the mean circulation of the focus region? This deceivingly simple question is intertwined with the complexity of observations and correlations, and requires students to think about related questions such as: What is the difference between mean and observed currents? What is the relationship of wind stress to current speed? How long do the winds have to be maintained in order to set up a circulation pattern? Is there a relationship between wind direction and current direction (i.e., are there Ekman dynamics present or are there other dynamics that need to be considered)? If currents were observed at deeper levels with drogues (see modification section), what is their relationship to the internal density structure? Are there changing current speeds or directions (i.e., accelerations), and if so, why? If observations were taken over a longer time, could a better mean circulation pattern be discerned?

MATERIALS

The materials for this activity are readily available, but some fabrication will be required. The activity also requires the availability of a local meteorological site for obtaining wind speed and direction, and these data should be gathered for several days preceding the cruise as well as the entire day of each cruise. (Note that educational institutions can get free data from the NOAA National Climatic Data Center site, http://cdo.ncdc.noaa.gov/qclcd/QCLCD?prior=N, but for same-day observations, local stations may have their own Web sites, for example, http://www.erh.noaa.gov/er/btv/html/colreef.html).

The next required item is the surface drifter that houses the GPS receiver. It is useful for prospective users of this lab to understand the various designs of drifters and drogues created by others (e.g., Perry and Rudnick, 2003; Austin, 2004; Richardson, 2010; http://gisweb.wh.whoi.edu/ioos/drift/driftdesign.html), as well as some of the results obtained from the use of these devices (Stevenson et al., 1974; Davis, 1985; Fratantoni, 2001). Conceptually, a majority of the drifter's surface area has to be in the water so that wind effect is minimal, yet, at the same time, the GPS receiver needs to be placed above the water line such that it has a clear line-of-sight access to the ship. The 1.22-m-long watertight drifter used for our labs is made from heavy-duty, 8.9-cm (outer diameter) PVC pipe. The upper 20 cm has its own separate foam-lined compartment with a screw top for the GPS. The bottom is sealed with a watertight end cap that has a metal eyebolt to enable a small 4.5-kg anchor to be attached (Figure 1). The anchor is attached to the drifter with a 2.4-m cable to provide drifter stability as well as to stop the float if it moves into shallow water. A waterline-to-anchor base distance of ~ 3.7 m usually represents a safe depth for most research vessels to recover a stranded float. The top of the float is equipped with a small flag for visual location as well as a lanyard that can be used to pull the unit out of the water.

In order to track the float, it is essential to have a handheld GPS that can record positional data as well as transmit its location when commanded to do so. The Garmin Rino 130 has proven to be quite effective in that it can be set to record time-stamped positional information at user-selected intervals (we use 20 sec) and can communicate its location with other similar receivers via its two-way radio. Data from the Rino can be downloaded with Garmin's MapSource US Inland Lakes software ($85). Total cost of one of the surface floats with flag, anchor, and cables is ~ $50, while the Rino 130 can be purchased for less than $280. Once the design is complete and all the materials are available, a drifter can be made in under three hours.

ACTIVITY

Due to the size of our research vessel (10 m), we restrict the number of students within each lab (research team) to 10. For a three-hour lab, we leave the college at 12:30 (40 minutes ahead of a typical afternoon lab) in order to gain additional transit time to the lake (~ 30 minutes away). During that time, students eat their lunch on the bus and are ready to "hit the deck running." At the end of the lab, the vessel docks at 15:30 for offloading, cleanup, and transit back to the college by 16:15. It is important for the instructor to realize that the most important aspect of this activity is that it be entirely student driven. Students must plan ahead for the upcoming cruise by (1) gathering weather forecasts for the lake, (2) estimating the movement or trajectories of the floats so they will not ground out during the observational time frame, and (3) defining the deployment sites. Then they should be responsible for (4) deploying the drogue, (5) continuously monitoring float positions while in the water, and (6) recovering, (7) downloading, and (8) processing the data from each GPS unit. These steps are not as easy as they appear because the floats have to be prepared for launching; the GPS units must be checked for operation, battery life, and proper initialization; the exact GPS time (to the second) has to be recorded for each deployment and recovery; and the essential updating of float positions throughout the project requires teamwork. Typically, with a 10-student research team, four groups are set up: *Drifter*, *GPS*, *Monitoring,* and *Archiving*. If the research vessel has a conductivity-temperature-depth (CTD) sensor, an additional student team (*CTD*) becomes responsible for its use and the acquired data. All of the deployment and recovery steps require common sense and basic safety procedures. While safety is always an issue on a research vessel, it is worthwhile to note that safety is the realm of the captain. He/she will devise safe working parameters so that students and the instructor can focus entirely on the activities and science.

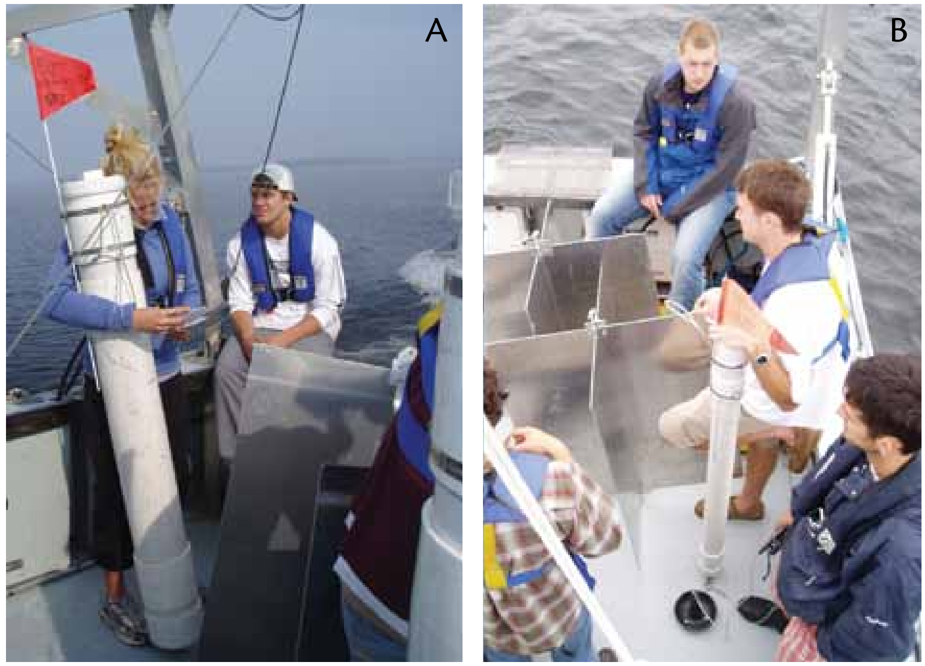

Figure 1. The float required for drogue operations (pictured at left) is larger than the surface float (pictured at right with its small, 4.5-kg anchor attached to its base) because it has to carry the additional load of the 1 m x 1 m aluminum drogue vanes shown assembled in both images.

For every research cruise, two students are responsible for all planning aspects and scientific decisions while underway. These individuals are classified as the principal investigator (PI) and the co-PI. The co-PI will gain on-the-job experience/training and will become PI on the next cruise when a new co-PI is brought in from the group. It is their job to interface with the captain and the various teams on the back deck to ensure that the research program is completed, while at the same time modifying plans and maintaining time schedules in order to be back at the dock on time. The PIs have to gather wind information prior to the cruise, plan the deployment location for all the drifters, and once on board, discuss their plans with the captain. The remaining students break up into their teams and start preparing for deployment. The *GPS* team immediately checks all of the units for battery life and operation, clears the memory, and initializes the units for deployment. The *Drifter* team is responsible for assembling, deploying, recovering, breaking down, and storing all drifters and drogues. The *Monitoring* team sets up the drifter log sheets and continually follows the instruments' movements until they are brought back onboard.

Once underway, the objective is to deploy all of the drifters as rapidly as possible to maximize observational time.

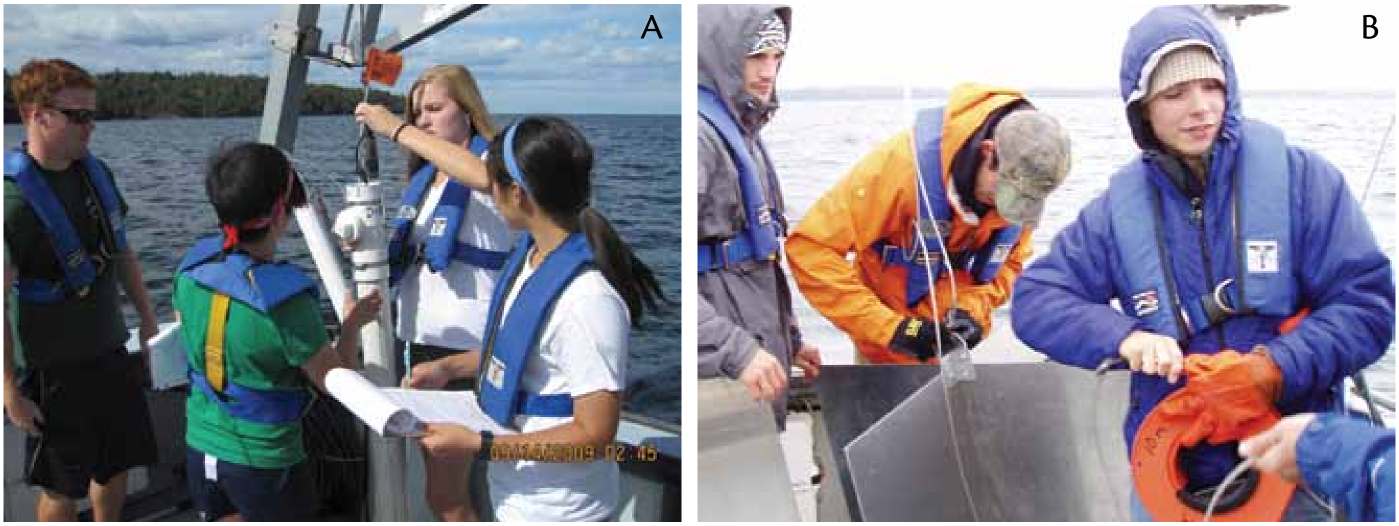

Figure 2. (A) Deployment of a surface float. The two students at center are part of the *GPS* team and are responsible for the initialization and setup of these units. The student to the right is part of the *Monitoring* team and is logging information pertaining to this drifter. The student to the left is part of the *Drifter* team. (B) Drogue deployment requires additional support. In this photo, the drop cable is being attached to the top of the drogue. Note the orange payout spool that holds multiple 10-m cables. Five payout spools with different line lengths are available to properly set drogue depth.

The *Monitoring* team turns on the GPS, records its identification number, the exact time (to the second) when it was released, and ship's position for every float placed in the water (Figure 2). The onboard Rino GPS unit that is referred to as the "Master" is used exclusively for communicating with the deployed drifters. Through a simple menu on the Master GPS unit, the operator can poll (i.e., obtain latitude and longitude) any of the deployed units within line of sight (< 2 km). After the first float release, the *Monitoring* team begins the continual tracking of the various floats every 5–15 minutes, depending on the speed of the drifters. Updated poll locations are logged and immediately transferred to the PIs so that updated positions can be entered onto the ship's navigational computer. This exercise provides the captain and PIs an easy way to see the dispersal pattern of the drifters as well as to determine the most efficient method for recovery. Once all of the floats have been deployed (Figure 3A), operations move into a CTD acquisition phase to provide further information throughout the region. A typical CTD survey takes approximately one to two hours and provides the time for the floats to acquire sufficient drift information.

The recovery process simply reverses the deployment process; however, once the GPS units have been recovered and acquisition has been halted, the *Archiving* team downloads the data from each unit (Figure 3B). Concurrently, the *CTD* team members process their data using a second shipboard computer. At the end of the cruise, all of the digital data, handwritten logs, and any generated plots are taken back to the college for later analysis. Once our student-driven research teams become proficient with all of these activities, deployment and recovery of eight drifters along with the acquisition of six CTD stations is considered typical.

Once back on campus, analysis of the collected data can range from rudimentary to complex, but no matter how detailed the instructor wants to be, he/she always has to start with the basics—and this level will be where the students start. Between the end of the cruise and the next class meeting, wind data from the local met station(s) must be obtained and the latitude/longitude-based drifter information must be converted to some type of Cartesian coordinate system (e.g., UTM, state plane). GIS labs can easily accomplish this task, and there are many sources on the Web for this type of conversion (e.g., http://www.uwgb.edu/dutchs/usefuldata/UTMFormulas.htm).

Meteorological and drifter data sets (and any CTD data) should be in a format that can be easily incorporated into a spreadsheet. In-class activities would include organizing students into meteorology, drifter, drogue (if used), and CTD teams with the following goals:

- Meteorology. Using a spreadsheet, plot wind speed and direction over time and determine basic information, such as: (1) consistency of wind speed and direction prior to the cruise, (2) wind conditions during the cruise, (3) conversion of wind speed into wind stress, (4) wind speeds and, therefore, wind stress variability during the cruise, (5) average wind speed and direction during the cruise (Note: this task requires the use of orthogonal components), and (6) the expected speed of the surface drifters using the standard wind drift rule of surface currents being 2–3% of wind speed (Open University Course Team, 1989).

- CTD. Using a spreadsheet, (1) plot all CTD stations superimposed on one another where the vertical axis is depth and the horizontal axis is density; (2) as per Step 1, but make the horizontal axis temperature; (3) determine whether there is any similarity among the CTD stations; (4) draw horizontal lines to divide the water column into mixed, transitional (pycnocline), and deep layers; (5) if drogues were deployed, place arrows at the depths where they were located; (6) if more than one CTD station was taken, determine whether there was any significant change in the density structure within the region; and (7) if so, where did this change occur and think about a possible explanation for the change.
- Drifters. On a per-drifter basis and using a spreadsheet, (1) plot the drift track, (2) modify/remove outliers so the track is relatively smooth and continuous, (3) add an additional column that converts time into decimal days, (4) calculate speed and direction between every two (or more) observational points, (5) remove all data that are prior to the entry of the *last* drifter into the water as well as all data after the *first* drifter was picked up (this task is called "syncing" the data sets and will permit direct comparison among drifters). Next, using the synced data set, (6) define significant changes in speed and direction, (7) calculate the average speed and direction of each drifter, and (8) combine all of the processed drifters into a single spreadsheet and plot their trajectories. Ask the students whether they see a pattern in the data. Have them hand sketch the trajectories of all drifters onto a bottom bathymetry map of the research area. Ask them to think about whether bottom bathymetry or the shoreline can be affecting these trajectories.

Figure 3. (A) Drogues and drifters are often deployed in pairs to show their net divergence over time as well as to provide optimal post processing for the drogue data. (B) Downloading data from the 10 GPS units can take up to half an hour, so this process must start immediately upon recovery.

By combining the analysis products from the various groups, a single unified picture of forcing (wind) and control (bathymetry and shoreline structure) of circulation within the region can be obtained and discussed in more detail. As an example, Figure 4 shows surface and deep (obtained from drogues) circulation trajectories on two successive days, and provides an indication of how fast circulation patterns can shift within the lake, particularly with significant changes in wind direction. On October 19, southward flow that had already moved through the narrow passage between Thompsons Point, VT, on the east, and Split Rock, NY, on the west, flared out in a clockwise fashion while conforming to the general shape of the southern embayment, but it did not follow the bottom contours. The single deep observation at 35 m was opposed to the surface flow and was in general agreement with internal

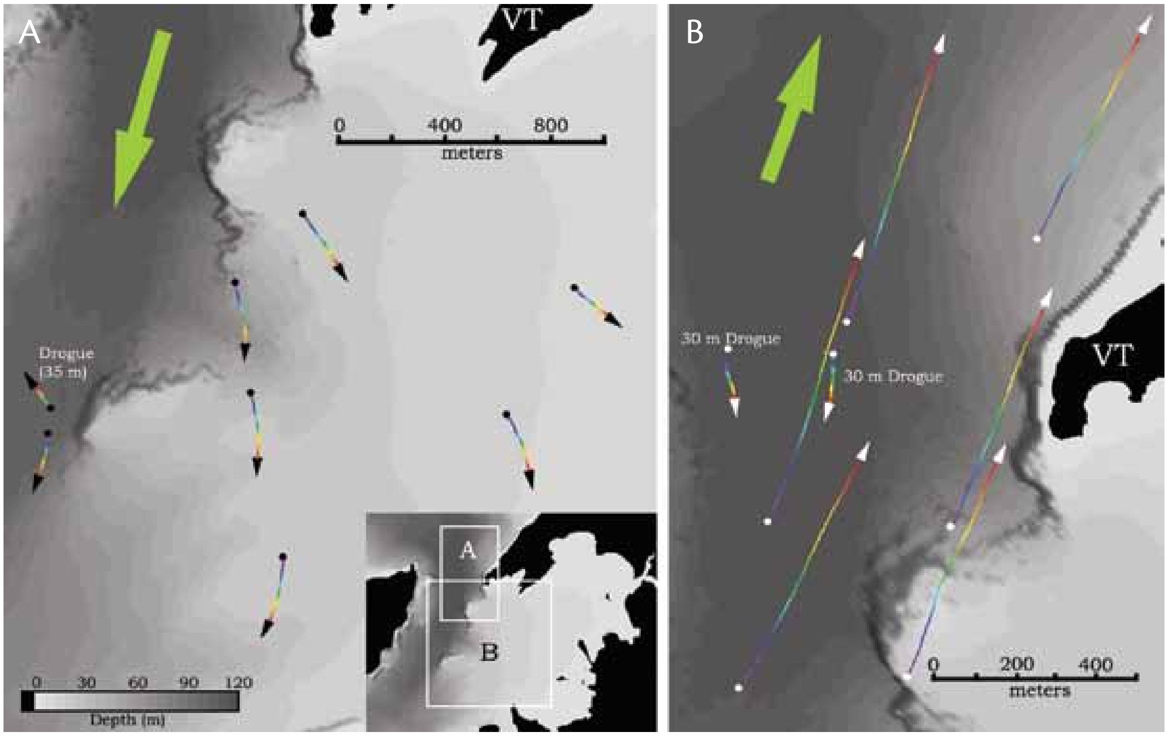

Figure 4. Drogue and float trajectories obtained from (A) October 19, 2009, and (B) October 20, 2009. Inset shows relationship of panels A and B. The broad green arrow shows wind direction. For any given day, all data have been synced, which means that dots and arrows define the same starting and ending times, respectively. Both panels show drift accumulated during 40 and 47 minutes, respectively. Drogues are shown with their associated depths. Remaining trajectories were obtained via surface drifters. On October 19 (A), winds were 4–6 m s^{-1} for the previous 28 hours, while on October 20 (B), winds were fairly consistent at 3.1 m s^{-1} for the previous 21 hours. Dynamic Graphics Inc. earthVision software was used for the imagery.

seiche dynamics specific to this region (Manley et al., 1999). Conversely, with a change in wind direction during the evening of October 19, surface flow had reversed by the time of the October 20 lab. After accelerating northward through the passage, surface flow slowed and later fanned out to conform to the shoreline. Not only had deep flow at 30 m reversed (in keeping with internal seiche dynamics) but trajectories were also conforming to bottom bathymetry. Mass conservation through this passage (i.e., shallower high-velocity flow to the north compensating the thicker low-velocity layer moving to the south) is generally preserved in that the deeper layer is about seven times thicker than the surface layer.

POSSIBLE MODIFICATIONS TO ACTIVITY

Separate labs could be devoted to: (1) design and fabrication of the surface drifters by using the mathematical concepts of buoyancy, (2) learning about geographic coordinate systems and the various transforms used to move into Cartesian coordinate systems, (3) incorporating Ekman dynamics, (4) statistics related to dispersion (see http://iridl.ldeo.columbia.edu/dochelp/StatTutorial/Dispersion; Murthy, 1975), (5) kinetics (Richardson, 1983), or (6) more advanced concepts of Lagrangian integral length and time scales (McCormick et al., 2006, 2008), provided enough data have been collected.

In order to investigate currents at deeper levels, drogues that employ high-drag devices at depth could also be used in this research activity. In essence, the drogue (due to its high resistance) will move with the deep current and drag the low-resistance surface drifter with it (Stevenson et al., 1969; Richardson, 2010). To be effective, the drogue assembly must be large enough to create the drag necessary to overpower the resistance of the surface float (and connecting cable) as well as be heavy enough to stay at the desired depth. We have developed rugged 1 m x 1 m x .32 cm aluminum cross-vane drogues that can easily be disassembled into two flat plates with small right angle attachment mechanisms at the top and bottom. Due to the additional weight of the drogue vane, the surface float must be larger (i.e., 16.5 cm outer diameter, Figure 1). The additional length of cable to suspend the drogue to a desired depth from the base of the drifter is known as the drop cable. To simplify deployments, five cable spools are available; each spool is wound with multiple cables of 5-, 10-, 20-, 30-, and 50-m lengths. Choosing a single length or combining multiple lengths allows the research team to position the drogue at a wide variety of depths (Figure 2). The anchor and its cable must then be attached to the bottom of the drogue for stability and to prevent kiting. Drogue data are processed in the same way as drifter data, with only one variation related to the initial assumptions. Earlier, it was stated that the drogue overpowers all other components in the system and that the resulting observations represent only the currents at the level of the drogue. In reality, our students have conducted tests of drogues moving past bottom-mounted acoustic Doppler current profilers (ADCPs) and found that the surface drifter does play a significant role in modifying drogue observations. To obtain true velocity at drogue depth for our system only, the following equation needs to be applied:

$$\textit{velocity at depth} = \textit{observed drogue velocity} - 0.35 \times \textit{surface velocity},$$

where surface velocity is obtained from the closest surface drifter. Because the drift track is time dependent, this equation can be easily applied to every time step within a spreadsheet. Once calculated, the resultant velocities can be turned into distance traveled per unit time step and then combined to form a final trajectory. If drogues are to be used during the cruise, an initial CTD station should be obtained in order to define the density structure of the water column. Knowing the density structure, the PI and co-PI can then set the observational depths for the drogues, depending on their research objectives.

When it comes to deployment and recovery of drogues, a whole new layer of safety regulations is required. Our student teams do not work with drogues until they have demonstrated proper procedures with surface floats, which is usually by the end of their second cruise, and even then, the presence of an aft-deck winch operator (doubling as a safety officer) is required for the recovery of these heavier devices. While the use of drogues is challenging, it is quite clear that research teams have been, over the past 12 years with over 1500 deployments and recoveries, enthusiastic about their use and ability to uncover the more complex dynamics of lake circulation.

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