Towards 'Smart' Waterborne Hazard Plume Mapping and Tracking in Coastal Systems

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Background and Objectives

In this study sponsored by the U.S. Defense Threat Reduction Agency (DTRA), a custom surface ocean drifter was designed and built to follow a simulated waterborne hazard agent plume in a coastal system to enable plume tracking and mapping using a custom-built Autonomous Surface Vessel (ASV). Results will be used to further efforts to develop a 'smart' waterborne hazard plume mapping and tracking capability (*Smith and Hickman, 2022*).

Methods and Approach

Custom Surface Ocean Drifter

The custom drifter was designed and fabricated in Hendrix Oceanography Laboratory. The drifter housing was made from a 12", 2-1/2" NPT Thick-Wall PVC Pipe threaded on one end. An end-cap was epoxied onto the unthreaded end. On the other end, a threaded end-cap was counterbored with a drill press to allow a pass through for an RF antenna connected to a transceiver on the inside of the cap. Silicone sealant was used to ensure a watertight seal. A Method X 3-D printer (https:// ultimaker.com/3d-printers/method-series/) was used to print brackets to hold 4, 6" x 6" impact-resistant polycarbonate panels near the top of the drifter (**Fig. 1**). The drifter electronics consisted of an Arduino MKR GPS Shield, Arduino MKR Zero w/HDR ATSAMD21, and DIGI XBEE-PRO S38. Arduino IDE software was used to code the GPS program for the Arduino hardware and transmitted data was linked to a custom MATLAB script that enabled a live feed GPS-tracking map. The system was powered by eight AA batteries and ballast was adjusted using small lead weights internal to the housing.

Figure 1. Midshipman 1/C Oldfield and Midshipman 1/C Guzman with the custom surface ocean drifter in Hendrix Oceanography Laboratory.

Field Test, 19 March 2026 – Simulated Waterborne Hazard Incident

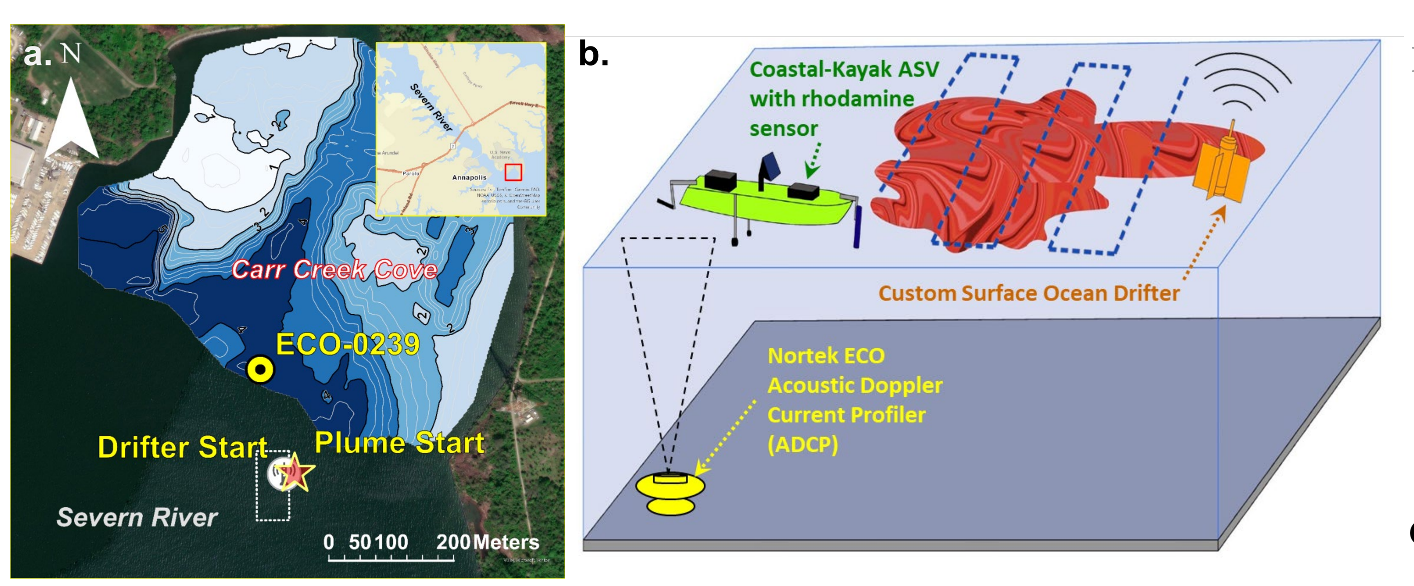


Figure 2. (**a**) Test area (white outline) in the vicinity of Carr Creek Cove with locations for rhodamine dye release (star), drifter start point and the deployment location for a Nortek ECO ADCP (ECO-239; yellow circle) and (**b**) Conceptual diagram of field test approach.

A field test was conducted in the vicinity of Carr Creek Cove on Thursday, 19 March 2026 (**Fig. 2a**). The test occurred after high tide approaching ebb with winds from the southeast at 3-5 m/s. A Nortek ECO Acoustic Doppler Current Profiler (ADCP; https://www.nortekgroup.com/info/eco) was deployed to measured bulk surface current speed and direction during the test (**Fig. 2b**). At the test start, ~300-500 ml of 2.5 % rhodamine dye was released into surface waters from a small boat to simulate a waterborne hazard incident and the drifter was released into the center of the plume (**Fig. 3a**). A custom-built Coastal Kayak autonomous surface vessel (ASV; *Lamendola, 2022*) equipped with a YSI EXO1 Multiparameter Sonde with a rhodamine sensor was piloted via remote control through the rhodamine plume in a ladder pattern during three separate plume surveys (**Fig. 3b&c**). The drifter and ASV transmitted position and sensor data via RF to a laptop on the boat at 1 second and 2 second time intervals, respectively, for live drifter and plume mapping.

Figure 3. Midshipman 1/C Oldfield and Midshipman 1/C Guzman (**a**) releasing the drifter and (**b**) mapping the rhodamine dye plume by remote control with (**c**) the Coastal Kayak ASV.

Results and Discussion

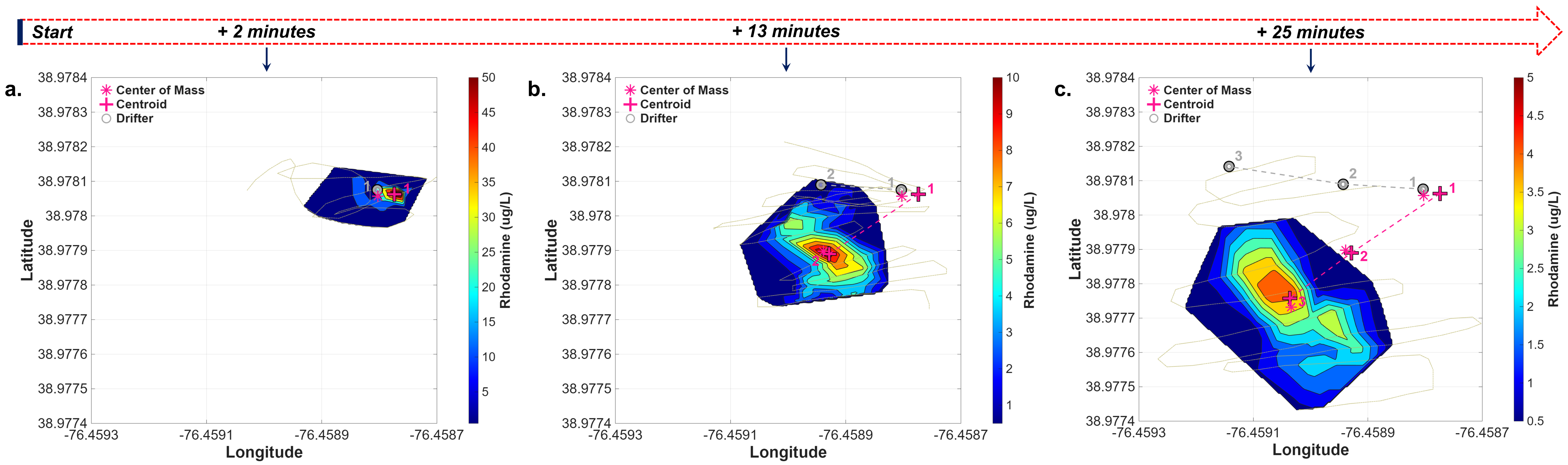


Figure 4. Contoured rhodamine concentration with plume center of mass and geometric centroid position and track along with mean drifter position and track for: (**a**) plume survey 1 (mean time +2 minutes from incident start); (**b**) plume survey 2 (mean time +13 minutes from incident start) and; (**c**) plume survey 3 (mean time +25 minutes from incident start). Colorbar on the right shows rhodamine concentration (μg/L). A background threshold of 0.5 μg/L was used to determine plume extent. The Coastal Kayak ASV path is overlaid as a light green dashed line. Each grid of longitude is ~ 17 m and each grid of latitude is ~ 11 m.

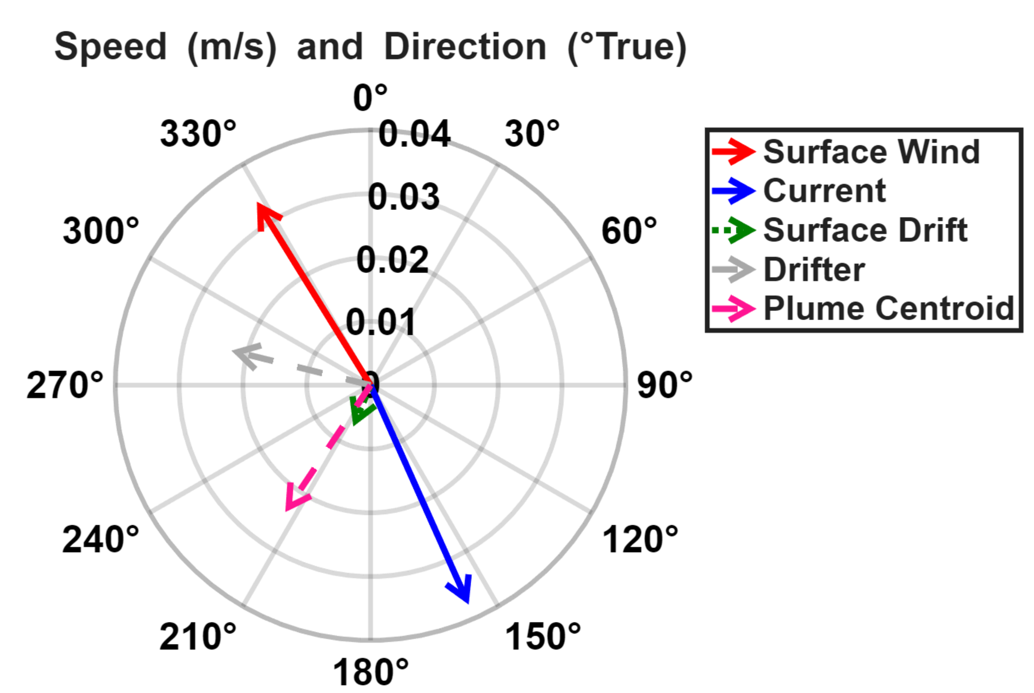
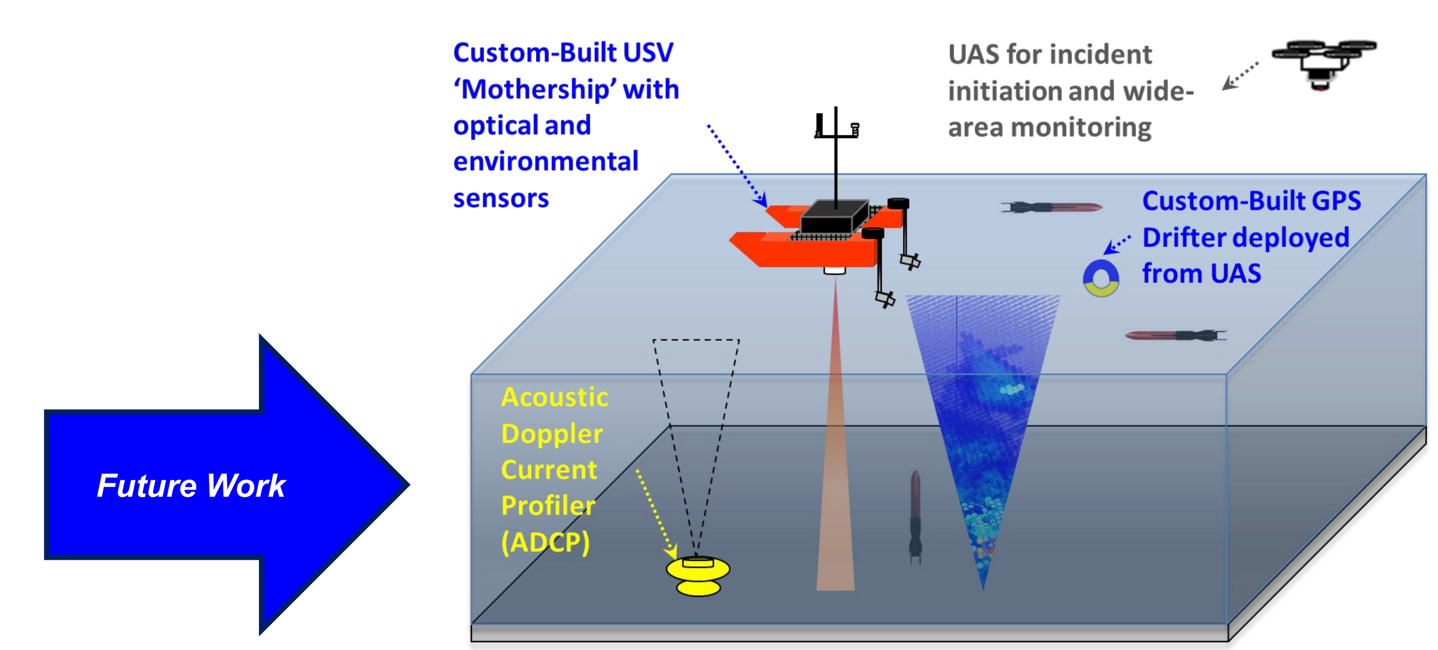


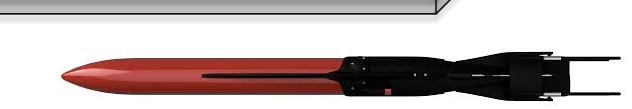
Figure 5. Polar plot of mean surface wind (red arrow), mean bulk surface current (upper 2.52 m); blue arrow), resultant surface drift (green dashed arrow) shown with mean drifter track (gray dashed arrow) and plume centroid track (pink dashed arrow). The surface wind vector estimated as 1.5% of the mean surface wind speed and direction at 2.2 m/s from 148.2º true (*Wu, 1975*). Speed is in m/s.

Results of plume survey 1 (+2 minutes after dye release) showed the drifter located near the center of mass and centroid of the plume. Peak rhodamine concentrations at the center of the plume were > 50 μg/L. Assuming the dye was vertically dispersed in the upper 0.5 m of the water column, the estimated total mass of rhodamine surveyed was 0.022 g or ~1.8-3.1 % of the total mass released (**Fig. 4a**). Results from plume survey 2 (+13 minutes), showed that the plume center of mass and centroid converged, the plume dispersed outward, and moved towards the southwest. Peak plume rhodamine concentration was ~10 μg/L. The estimated total mass of rhodamine surveyed in plume survey 2 was 0.014 g or ~1.2-1.9 % of the total mass. The drifter tracked almost due west (**Fig. 4b**). Plume survey 3 (+25 minutes) showed additional plume dispersion as the centroid continued to move towards southwest with peak rhodamine concentrations of only 4-5 μg/L. The estimated total mass of rhodamine surveyed in plume survey 3 was 0.016 g or ~1.3-2.2 % of the total mass. The drifter continued to track to the west-northwest (**Fig. 4c**). The similarity in the total mass of rhodamine captured by each survey shows that the plume was adequately tracked and mapped. The track of the drifter was significantly different than the track of the centroid of the rhodamine plume. **Figure 5** shows the mean track of the drifter and the centroid of the rhodamine plume relative to the bulk current and surface wind speed and direction. The resultant surface drift vector was towards the general direction of the plume track, albeit at a smaller magnitude. The Nortek ECO ADCP measured bulk current velocity in the upper 2.52 m rather that at the surface where the plume was located so this could explain the difference. The drifter track, however, was clearly more influenced by the wind than the current. Ocean surface drifters are known to experience a degree of "slip" or "leeway" and are therefore more sensitive to wind at the ocean surface (*Niiler et al., 1995*). The design of the drifter used in this study could potentially be improved by adding a drogue to the drifter to account for upper bulk layer dynamics and/or by modifying the antenna sticking out of the water. Another recommendation would be to employ a fleet of smaller drifters to create a higher density of data to more accurately track the plume by averaging out random errors and reducing the impact of outliers.

Conclusions and Future Work

- ***Results showed that the single, ocean surface drifter designed and built for this study worked well in field testing but failed to track with the centroid of a plume of rhodamine dye meant to simulate a waterborne hazard agent as it dispersed and moved with the local coastal physics***
- ***Results showed that a custom ASV operated remotely was able to track and map a visible waterborne hazard plume as it dispersed and moved with local coastal physics***
- ***Results suggest design improvements could be made to the drifter used in this study to improve plume tracking performance and that multiple smaller, cheaper, and expendable drifter devices could be designed to better contribute to the development of a 'smart' waterborne hazard plume mapping and tracking capability***
- ***Future work will continue in the form of collaborative research sponsored by DTRA involving USNA and the U.S. Naval Research Laboratory that will build upon the results of this study and will involve multiple uncrewed platforms with specialized sensors designed to autonomously track and map a host of waterborne threat agents in coastal systems.***





JaiaBOT Micro-UUV 'Swarm' with electrochemical sensor chips (https://www.jaia.tech/solutions/)

Acknowledgements: This work was funded by the U.S. Defense Threat Reduction Agency (DTRA). Special thanks to Richard Fry (DTRA) and collaborators from the U.S. Naval Research Laboratory (NRL). ***References**: Smith and Hickman (2022). DTRA CBD Science &Technology Conference; LaMendola (2022). USNA Independent Research; Wu (1975). Journal of Fluid Mechanics 68(1); Niiler et al. (1995). Deep Sea Research Part I, 42(11-12).*

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