

# Technological Advances in Ocean Sciences Resulting from the Deepwater Horizon Oil Spill

BY LAURA BRACKEN, DAN DINICOLA, JESSIE KASTLER, AND SARA BERESFORD

- In response to the Deepwater Horizon disaster, many innovative researchers adapted instruments not previously used in oil spill research, or invented new instruments that would change the way ocean science is done moving forward.
- From using normal cameras in extraordinary ways to designing new platforms for data collection, scientists collaborated in order to develop new and improved scientific methods to investigate the environmental impacts of the spill on the Gulf's ecosystem.
- The marine science technology developed through the Gulf of Mexico Research Initiative (GoMRI) will be one of the lasting legacies of the program. These tools can be used in other bodies of water, for other spills, to improve the response, and mitigation of future disasters.
- Developing or modifying existing technologies in order to answer specific research questions is common throughout the scientific process. In order to exemplify this process in the classroom, an associated activity will guide students through developing their very own drifters, just like GoMRI scientists did to understand currents in the Gulf of Mexico and where oil will go after an oil spill.

## INTRODUCTION

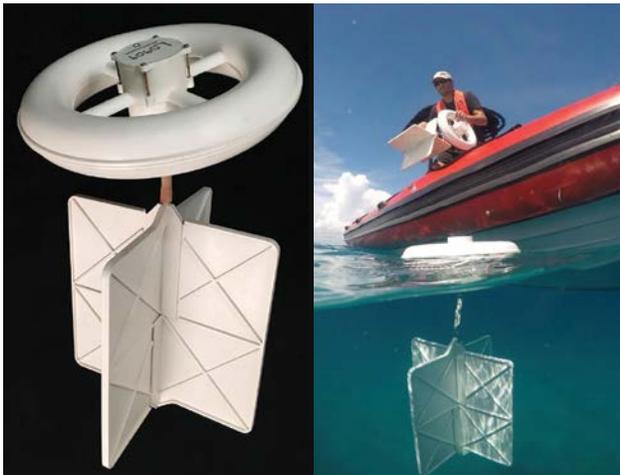
As scientists across the world dove into action following the Deepwater Horizon (DWH) oil spill, many innovative researchers adapted instruments not previously used in oil spill research or invented new instruments that would change the way ocean science is done moving forward. This unprecedented disaster pushed scientists to collaborate and innovate in order to find new and improved scientific methods to investigate the environmental impacts of the spill on the Gulf's ecosystem. Here we highlight a small sample of the many significant contributions made by Gulf of Mexico Research Initiative (GoMRI) researchers.

## DRIFTERS

During an oil spill, some of the first questions that arise are "where will the oil go?" and "how fast will it get there?" Answering these questions requires knowledge of the speed, location, and direction of ocean currents. Scientists have used satellite remote sensing (Goldstein et al. 1989) and a series of individual GPS receiver-equipped buoys known as drifters across the globe (Lumpkin and Johnson 2013) to study large currents. But those methods do not provide enough detail about the important small-scale currents needed to understand how oil moves once it reaches the surface.

Consortium for Advanced Research on the Transport of Hydrocarbon in the Environment (CARTHE, <http://carthe.org>) scientists are studying the small-scale surface currents that drive the initial transport of oil using large-scale experiments in which hundreds of drifters are released into a relatively small area of the Gulf of Mexico (Poje et al. 2014; D'Asaro et al. 2018). The onboard GPS transmits its location every five minutes for about three months, giving the team a detailed track of the drifter's (and therefore the current's) movements.

In order to collect data on the dynamic surface currents in the Gulf, researchers developed a plan to release 1,000 drifters. They spent two years designing and testing a custom-made, GPS-equipped, biodegradable drifter that could be assembled at sea (Novelli et al. 2017). The team began with a wood drifter and quickly realized that the untreated wood would become waterlogged too soon and not float for the two- to three-month timeframe that was needed, so instead they selected polyhydroxyalkanoate (PHA), a compostable bioplastic known to be biodegradable in water.

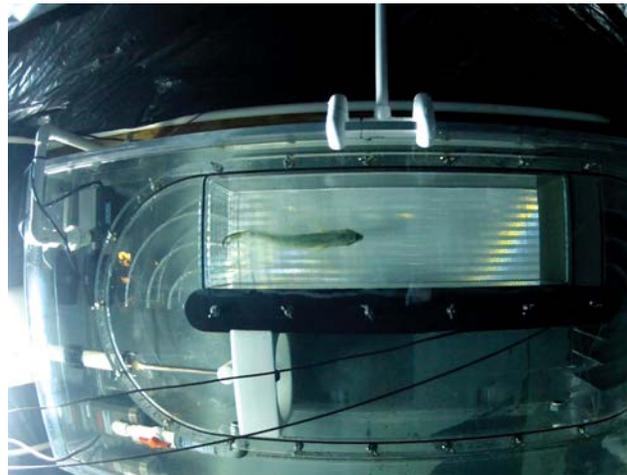


**FIGURE 1.** (left to right) CARTHE drifter. Courtesy of CARTHE/Cedric Guigand

The drifter has a donut-shaped device that floats at the surface and keeps the GPS above the water line (Figure 1). The majority of the drifter stays below the water to avoid being moved by the wind. Two flat, interlocking panels connect quickly to make the “drogue,” the underwater sails that catch the water and cause the drifter to move with the current. A flexible neck connects the float and the drogue. The flexible connection was an important addition to later designs because it allowed the float to move with the waves without causing the drifter to “ride the waves.”

The finished product is a valuable tool that can be used across the world to study ocean currents and related research questions. These drifters were developed for CARTHE studies in the Gulf, but have also been used in a variety of other bodies of water, including the Arctic Ocean (Mensa et al. 2018) and Biscayne Bay near urban Miami, Florida (Bracken 2016).

The drifter was also used by fellow GoMRI consortium Relationships of Effects of Cardiac Outcomes in Fish for Validation of Ecological Risk (RECOVER, <http://recoverconsortium.org/>), in work tracking fish movement off the south Florida coast. In 2016, RECOVER scientists released the drifters alongside mahi-mahi fish that had been tagged with pop-up satellite archival tags, which measure temperature, depth, light, and acceleration. Data from the tags revealed where the fish are and how they move in the water, offering insight into spawning and feeding behaviors of mahi that have not been exposed to oil. The drifters documented the extent to which mahi associate with currents.



**FIGURE 2.** Mahi-mahi in a swim chamber; see video <https://youtu.be/xz6mwID3aXA>. Courtesy of RECOVER

### FISH “TREADMILLS”

Mahi and red drum are also studied in controlled laboratory experiments to give scientists an idea of how oil exposure alters their physiology. RECOVER scientists use specialized swim chamber respirometers that monitor a fish’s oxygen consumption and swim performance. Fish swimming in the chamber is similar to humans running on a treadmill (Figure 2).

In the experiments, fish are exposed to oil dissolved in water at concentrations similar to what was observed during the DWH spill (Stieglitz et al. 2016), then placed in the swim chamber where they swim against a controlled, artificial current. During the experiment, a computer monitors how much oxygen is used by each fish swimming at a programmed water velocity. The water velocity is progressively increased until the fish is exhausted and unable to swim at such a speed. The data collected from this type of experiment provide scientists with information that can be used to determine the potential types of impacts oil exposure has on fish.

Scientists are learning that oil-exposed fish cannot swim as long or as fast as their non-exposed counterparts. As a result, fish are less able to avoid predators, feed, spawn, and migrate (Stieglitz et al. 2016).

### CAMERAS: In the Lab

RECOVER researchers also use video cameras during lab experiments to document fish behavior. Cameras positioned above the swim chambers allow scientists to monitor the performance of individual fish without impacting the

controlled setting. The recorded footage is entered into specialized software that can track specific behavior, such as how often a fish beats its tail. Scientists are using video footage collected with GoPro® cameras to study how oil exposure can impact social interactions as fish compete for limited resources, like shelter. Similarly, GoPros® are used in vision experiments where scientists monitor a fish's ability to track movement in a circular chamber (Figure 3).

### CAMERAS: In the Deep Sea

Investigating the impacts of the 2010 oil spill on deep-sea ecosystems has been challenging considering some areas of the Gulf can be as deep as 4,000 meters (m). Remotely operated vehicles (ROVs; operated from the ship to which the vehicle is tethered) and submersibles like the Deep Submergence Vehicle (DSV) *Alvin* (an untethered vehicle operated by a pilot from within) have been critical in studying the impacts on deep-sea ecosystems, such as deep-sea corals.

Over 350 coral colonies have been photographed by Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG, <http://ecogig.org>) scientists in the years since the spill using high-resolution camera equipment mounted on submersibles. Analysis of these time-series photographs has shed light on the spill's impact on the corals over time (documenting an increase in dead or dying corals and an increase in the number of hydroids on corals) as well as factors influencing their recovery (Fisher et al. 2014a). Cameras have also provided useful information about the movement of the oil and the footprint of the oil spill's impact by showing affected corals much farther than oil was previously believed to have spread (Fisher et al. 2014b). A digital live-feed from the ROV to the research team on the ship gives the scientists virtual "eyes on the bottom" during the dive, enabling them to employ their scientific intuition to make spontaneous decisions about the research (Figure 4).

ROVs with high-resolution cameras have also gathered precise measurements of the bubbles and oil droplets rising up out of natural seeps (Figure 5). Using high speed video, scientists from the Gulf of Mexico Integrated Spill Response consortium (GISR, <http://research.gulfresearchinitiative.org/research-awards/projects/?pid=137>) observed a significant difference in the behavior of the methane bubbles containing oil versus without oil. These data offer insights into how spilled oil rises from a deepwater well and assists with predicting where it might go.



FIGURE 3. GoPro® camera mounted on a fish vision chamber. Inset photo is of downward camera view. Courtesy of RECOVER

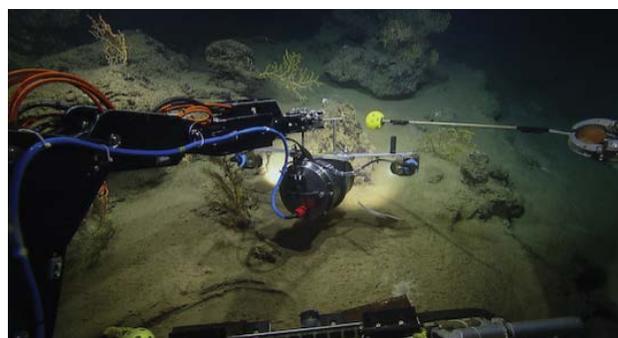


FIGURE 4. Scientists utilized high-definition camera systems mounted on ROVs to photograph deep-sea corals after the oil spill. The whiffle ball is used for scale. Courtesy of ECOGIG and Ocean Exploration Trust



FIGURE 5. Observing bubbles from underwater gas seeps (<https://www.youtube.com/watch?v=0sRbaEUKyE4>). Video highlighting Gulf of Mexico Integrated Spill Response (GISR) consortium produced by the American Geophysical Union (Wang 2016)

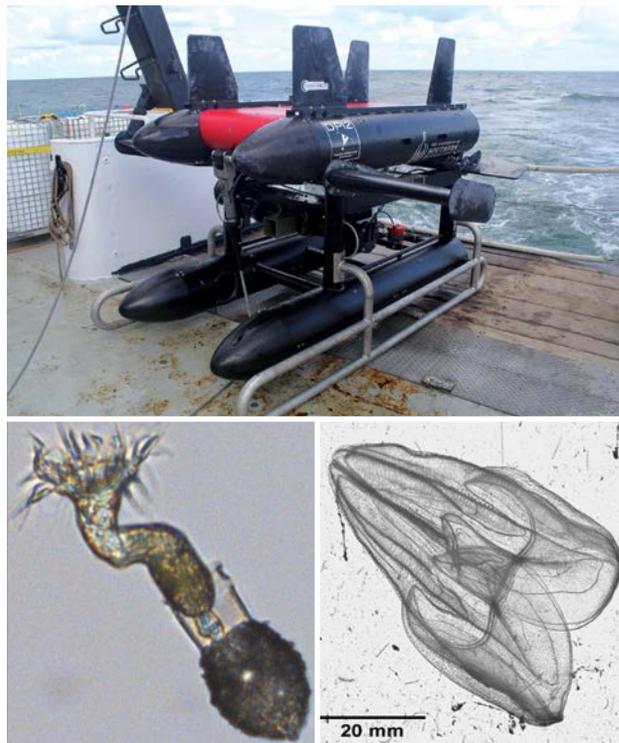
GoMRI scientists have used digital camera systems to document the movement of oil from the surface down as well, clarifying the role of marine oil snow formation (when oil is incorporated into falling debris) in transporting hydrocarbons to the seafloor after the accident. Digital camera systems were utilized to collect vertical profiles of marine snow abundance at multiple locations and depths between the sea surface and seafloor, and were paired with data from sediment traps and particle sinking speed measurements to develop an understanding of how oiled materials are transported from the sea surface to the seafloor.

In addition to using high-resolution cameras in deep-sea vehicles, GoMRI scientists have towed them behind ships, hung them from balloons, and mounted them in marshes. Cameras can document phenomena that cannot be easily seen otherwise and eliminate the risk of damaging the environment being studied.

### CAMERAS: On the Sea Surface

Plankton nets towed behind vessels are standard equipment for studying organisms drifting in the ocean that are not big enough to catch on hook and line. However, filtering the water destroys delicate organisms. The Consortium for Oil Spill Exposure Pathways in Coastal River-Dominated Ecosystems (CONCORDE, <http://www.con-corde.org>) is collecting comprehensive information about plankton populations using cameras instead of nets. The FlowCAM is an onboard instrument that counts and identifies single-celled organisms up to 0.5 millimeters (mm) in length (Figure 6; Sieracki et al. 1998). It collects images and compares them to a database as a water sample flows through, providing quick assessments of populations in the field.

The In-Situ Ichthyoplankton Imaging System (ISIS) is a camera system that is towed behind a ship (Cowen and Guigand 2008). As the ISIS moves through the water column, it collects images of everything within a continuously moving box. Scientists can see their study subjects as they appear in the water column and as they compare to other organisms. This device is ideal for viewing mid-sized zooplankton (0.4 mm to 13 centimeters (cm) in length). By observing these particles undisturbed in the water, the ISIS can show how they are distributed and link them specifically to water quality and flow conditions. This can connect specific types of plankton to conditions like a gradient in salinity, such as that seen where terrestrial freshwater meets ocean saltwater in an estuary. It can also show delicate structures like particles of marine snow, which would be destroyed during collection.



**FIGURE 6.** (top) ISIS on ship prepared for deployment; (bottom left) tintinnid, recorded by FlowCAM; (bottom right) ctenophore, recorded by ISIS. Courtesy of CONCORDE

### CAMERAS: In the Air

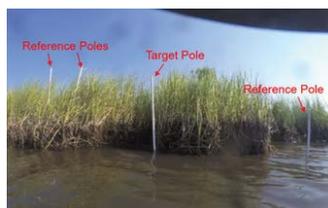
CARTHE relies on high-resolution cameras mounted to drones (Brouwer et al. 2015; Laxague et al. 2018) and a large balloon called an aerostat (Carlson et al. 2018) to track the initial transport of drift cards (biodegradable bamboo plates) during experiments to measure surface currents (Figure 7). Drones have the advantage of being highly maneuverable; a skilled pilot can easily move one with a patch of drift cards. However, the battery life is still the limiting factor, requiring multiple drones to alternate between flying and charging. The aerostat on the other hand can fly for many hours and is extremely stable, but it is towed behind a ship so maneuvering is more challenging. With either platform, extremely high-resolution cameras are the key to these experiments. The acquired images are used to determine how small-scale mixing driven by waves, winds, and short-lived currents affects how oil spreads and moves over time. While the GPS-equipped drifters discussed earlier measure currents at scales of 200 m to many kilometers (km) over a period of two to four months, the drone and aerostat camera systems allow scientists to see what happens at a scale of 1 to 1200 m while flying over a patch of drift cards for several hours.



**FIGURE 7.** (left) Drone monitoring a patch of drift cards during an experiment examining the near-surface layer of the ocean; (right top) high-resolution camera system hanging from the aerostat; (right bottom) image from the aerostat camera of thousands of drift cards gathering into lines during a dispersion experiment. Courtesy of CARTHE

### CAMERAS: On Land

Other camera systems are designed to collect data for much longer periods of time. Coastal Waters Consortium (CWC, <http://cwc.lumcon.edu/>) used time-lapse cameras (GoPros®) to document the daily marsh loss over a year in heavily oiled shorelines in southern Louisiana (Figure 8). Some of these areas were significantly affected by the DWH spill, resulting in loss of root mass (McClenachan et al. 2013). The cameras were placed at two locations on poles facing the marsh edge, initially 1.5 m from marsh vegetation. They were programmed to take photos at two-hour intervals over consecutive four- to six-week periods for more than a year.



**FIGURE 8.** Researchers documented daily marsh loss using PVC poles and time lapse photography. Video (<https://www.youtube.com/watch?v=bEumDAFWnqw>) shows a time lapse of land loss in coastal Louisiana. Courtesy of CWC/ Giovanna McClenachan

By photographically documenting significant land loss to erosion in areas with lower root mass, CWC scientists were able to confirm the importance of living roots, which were negatively impacted by the oil, for the maintenance of marsh vegetation and healthy shorelines (McClenachan et al. 2013).

### HYDROPHONES

Littoral Acoustic Demonstration Center - Gulf Ecological Monitoring and Modeling (LADC-GEMM, <http://www.ladcgemm.org/>) scientists are studying marine mammals—specifically whales and dolphins—using techniques inspired by their study subjects. Light doesn't travel far underwater, so marine mammals have evolved to use sound to find food, communicate, and gather information about their environment. Researchers use sound to study the location and movement of marine mammals. Sound is recorded using hydrophones and researchers attach them to (1) ocean gliders: small (~2 m), sleek, buoyancy-driven, deep-diving, autonomous robots; (2) autonomous surface vehicles (ASVs): self-propelled robotic vessels; and (3) moorings placed on the seafloor (Figure 9). These technologies cover varying scales of time and space: ASVs cover distances fairly quickly for days to weeks, while gliders travel more slowly but for many weeks to a few months. Autonomous hydrophones do not move at all, but can remain in place and observe marine mammals for years with routine maintenance. These instruments provide researchers information on the impact of the oil spill on the deep-diving, marine mammal populations in the Gulf.

### TECHNOLOGY GUIDES ADAPTIVE SAMPLING

Technology can inform adaptive sampling and allow scientists aboard a ship to process data immediately and change course (figuratively or literally), if needed. Although researchers utilize information from previous studies and their knowledge of a study area to plan a sampling effort prior to going into the field, conditions can change and GoMRI scientists have come up with ways to adapt to the changing conditions that are inevitable during a research cruise or experiment.

One example of adaptive sampling took place during a CONCORDE research cruise. One of the goals of the research was to observe plankton distributions in areas where fresh and salt water mix. Four (7-10 days) research campaigns used massive deployments of instrumentation for comprehensive collections of data. A fleet including two, 35 m research vessels, small boats, an autonomous underwater vehicle (AUV), and drifters were deployed simultaneously.



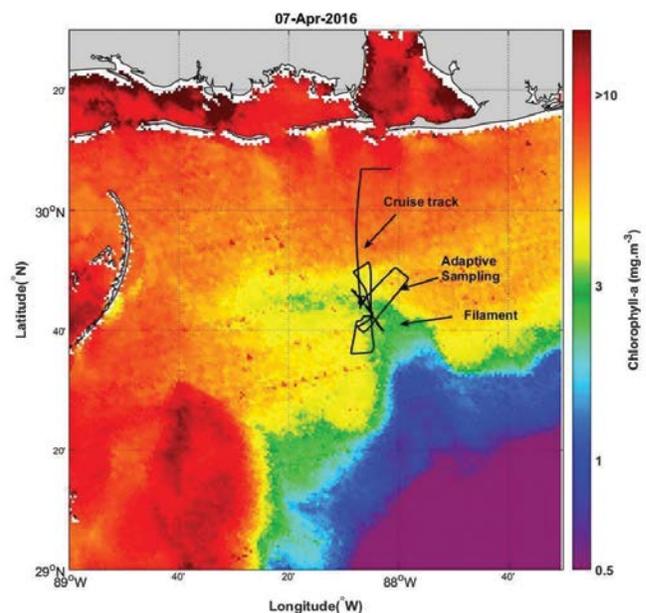
**FIGURE 9.** (left) Ocean glider. Courtesy of LADC-GEMM. (center) Autonomous surface vehicle. Courtesy of ASV Global. (right) Moored hydrophone (black cylinder) with line of buoys. Courtesy of LADC-GEMM

To ensure the success of the highly choreographed data collection effort, the fleet was supported by the land-based Ocean Weather Laboratory (OWX) that used model interpretations of satellite images to illustrate conditions like phytoplankton pigment (chlorophyll) concentrations and the direction and velocity of water flow.

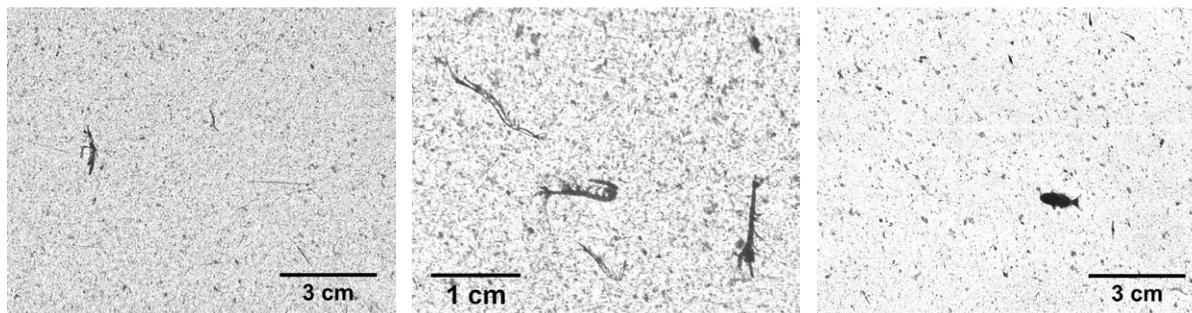
During this research campaign, OWX detected a sharp transition of chlorophyll concentration from the high values observed in productive waters close to land (red to yellow) to lower concentrations typical of the continental shelf (green to blue). Immediately all of the vessels at sea mobilized, traveling approximately 75 km to sample a filament of shelf water surrounded by highly productive coast water (Figure 10).

A series of ISIS images were collected in less than two minutes over an approximately 275 m distance and across a gradient from 31 to 35 parts per thousand (ppt) salinity. The images documented increase in the concentration of plankton and the size of marine snow particles (Figure 11). Understanding what happens to plankton and other particles at the boundary between different water masses is important to predicting the movement and impacts of oil in the event of a future spill.

CARTHE uses adaptive sampling to select the location for drifter deployments. With limited resources and the need to collect as much high-quality data as possible in a short time period, CARTHE scientists collect data from satellites, aircraft, and the ship to find fronts, eddies, and other features in the



**FIGURE 10.** Satellite image of enhanced ocean color shows concentrations of the pigment chlorophyll. The black line shows how the cruise track of the R/V *Point Sur* changed to allow researchers to sample the front between the continental shelf filament and surrounding coastal water. Courtesy of CONCORDE/Inia Soto Ramos



**FIGURE 11.** ISIS images collected (from left to right) before reaching the front; within the front showing high concentration of shrimp—note change in scale; and just beyond the front showing increased size of marine snow aggregates. Please note, this sample was collected in 2016, and these are unoiled marine snow particles. Courtesy of CONCORDE/Adam Greer

water. An aerial survey over the northern edge of the Loop Current during a CARTHE experiment spotted an interesting feature (a set of fronts coming from a cyclonic vortex) and alerted the ship team, who dropped 326 drifters in that area (Figure 12). Rather than dispersing, many of these drifters converged into clusters along those fronts (D'Asaro et al. 2018). During an oil spill, the ability to predict such convergence would greatly assist in mitigation efforts.

## CONCLUSION

The marine science technology developed through GoMRI since the DWH spill will leave a lasting impact on our understanding of oceanographic, biological, and chemical processes in the ocean. It is also one of the lasting legacies of the program itself. Because of these technological advancements, the scientific community will be better prepared to respond in the event of a future spill.

## CLASSROOM ACTIVITY RESOURCES

### Design-a-Drifter

Meet Consortium for Advanced Research on the Transport of Hydrocarbon in the Environment (CARTHE) scientists and experience the drifter design process in this fun and informative video: [vimeo.com/carthe/drift](http://vimeo.com/carthe/drift). Then try your hand at designing and building your own surface drifter. Students are given background information on ocean current research and the guidelines for making drifters, and then invited to brainstorm, plan, build, and test their very own drifters using inexpensive (often free) materials. Drifters can be deployed in a nearby pool, lake, or the ocean to learn about the movement of water in your local area. This challenge blends science, technology, engineering, art, and math (STEAM) and allows students to be creative while working on a very complex physical oceanography research question.

Background information and lesson plan can be found at [CARTHE.org/drifter\\_lesson.pdf](http://CARTHE.org/drifter_lesson.pdf).

### Want More Building Projects?

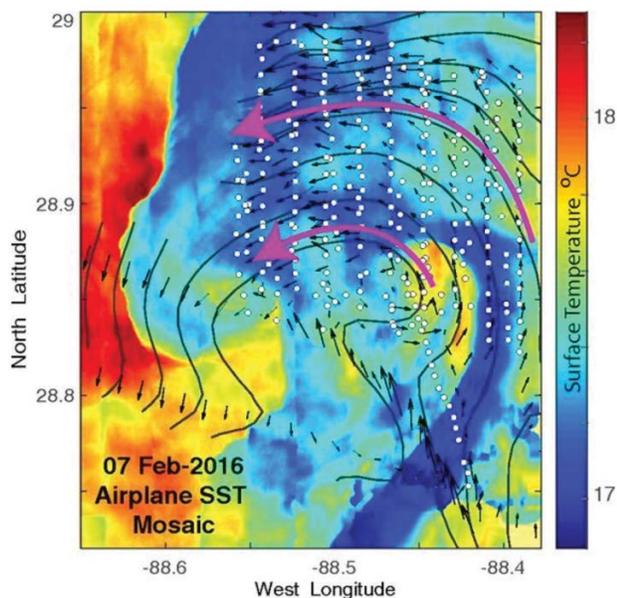
- LADC-GEMM + SeaGlide model gliders: Your students can build their own fully-functional ocean gliders to learn about buoyancy and engineering at <http://www.ladcgemm.org/model-gliders/>.
- ACER remotely operated vehicles (ROVs): Do your students want to build ROVs and compete against other budding oceanographers and engineers? Get started at <https://www.disl.org/dhp/rov-programs>.

## ACKNOWLEDGMENTS

In addition to the acknowledgments for the full issue, the authors of this article would like to thank Nancy Rabalais and Dave Mellinger for their contribution to the manuscript; Tamay Özgökmen, Martin Grosell, and Lela Schlenker for review of the article; and Cedric Guigand for his image contributions and review of the article. This article was made possible by funding from GoMRI to CARTHE, CONCORDE, ECOGIG, and RECOVER.

## REFERENCES

- Bracken, L. (2016.) "Bay Drift Study Hits Biscayne Bay." *CARTHE Blog*. 12 September 2016, [carthe.org/blog/bay-drift/](http://carthe.org/blog/bay-drift/).
- Brouwer, R.L., M.A. de Schipper, P.F. Rynne, F.J. Graham, A.J.H.M. Reniers, and J.H. MacMahan. (2015.) Surf zone monitoring using rotary wing Unmanned Aerial Vehicles. *Journal of Geophysical Research: Oceans*, 32(4): 855-863. doi.org/10.1175/JTECH-D-14-00122.1.



**FIGURE 12.** (left) Aircraft survey of sea surface temperature; white dots represent initial drifter position. Courtesy of CARTE/D'Asaro et al. 2018. (top) R/V F.G. Walton Smith seen from the plane as it moves toward the drifter release location. Courtesy of CARTE/Tamay Özgökmen

Carlson, D. F., T. M. Özgökmen, G. Novelli, C. Guigand, H. Chang, B. Fox-Kemper, J. A. Mensa, S. Mehta, E. Fredj, H. Huntley, D. Kirwan, M. Berta, M. Rebozo, M. Curcic, E. Ryan, B. Lund, B. Haus, J. Molemaker, C. Hunt, L. Bracken, and J. Horstmann. (2018.) Surface ocean dispersion observations from the ship-tethered aerostat remote sensing system. *Frontiers in Marine Science*, 5:479. doi:10.3389/fmars.2018.00479.

Cowen, R.K., and C.M. Guigand. (2008.) In situ Ichthyoplankton Imaging System (ISIS): system design and preliminary results. *Limnology and Oceanography: Methods*, 6: 126-132. doi.org/10.4319/lom.2008.6.126.

D'Asaro, E.A., A.Y. Shcherbina, J.M. Klymak, J. Molemaker, G. Novelli, C.M. Guigand, A.C. Haza, B.K. Haus, E.H. Ryan, G.A. Jacobs, H.S. Huntley, N.J.M. Laxague, S. Chen, F. Judt, J.C. McWilliams, R. Barkan, A.D. Kirwan Jr, A.C. Poje, and T.M. Özgökmen. (2018.) Ocean convergence and the dispersion of flotsam. *Proceedings of the National Academy of Sciences*, 115(6): 1162-1167. doi.org/10.1073/pnas.1718453115.

Fisher, C.R., A.W.J. Demopoulos, E.E. Cordes, I.B. Baums, H.K. White, and J.R. Bourque. (2014.) Coral communities as indicators of ecosystem-level impacts of the Deepwater Horizon spill. *BioScience*, 64(9): 796-807. doi.org/10.1093/biosci/biu129.

Fisher, C.R., P. Hsing, C.L. Kaiser, D.R. Yoerger, H.H. Roberts, W.W. Shedd, E.E. Cordes, T.M. Shank, S.P. Berlet, M.G. Saunders, E.A. Larcom, and J.M. Brooks. (2014.) Footprint of Deepwater Horizon blowout impact to deep-water coral communities. *Proceedings of the National Academy of Sciences*, 111(32): 11744-11749. doi.org/10.1073/pnas.1403492111.

Goldstein, R.M., T.P. Barnett, and H.A. Zebker. (1989.) Remote sensing of ocean currents. *Science*, 246(4935): 1282-1285. doi.org/10.1126/science.246.4935.1282.

Laxague, N.J.M., T.M. Özgökmen, B.K. Haus, G. Novelli, A. Shcherbina, P. Sutherland, C. Guigand, B. Lund, S. Mehta, M. Alday, and J. Molemaker. (2018.) Observations of near-surface current shear help describe oceanic oil and plastic transport. *Geophysical Research Letters*, 4: 245-249. doi.org/10.1002/2017GL075891.

Lumpkin, R., and G.C. Johnson. (2013.) Global ocean surface velocities from drifters: Mean, variance, El Nino–Southern Oscillation response, and seasonal cycle. *Journal of Geophysical Research: Oceans*, 118: 2992-3006. doi.org/10.1002/jgrc.20210.

McClenahan, G., R.E. Turner, and A.W. Tweel. (2013.) Effects of oil on the rate and trajectory of Louisiana marsh shoreline erosion. *Environmental Research Letters*, 8(4): 044030. doi.org/10.1088/1748-9326/8/4/044030.

- Mensa, J.A., M.L. Timmermans, I.E. Kozlov, W.J. Williams, and T.M. Özgökmen. (2018.) Surface drifter observations from the Arctic Ocean's Beaufort Sea: Evidence for submeso-scale dynamics. *Journal of Geophysical Research: Oceans*, 123: 2635-2645. doi.org/10.1002/2017JC013728.
- Novelli, G., C.M. Guigand, C. Cousin, E. Ryan, N.J.M. Laxague, H. Dai, B. Haus, and T.M. Özgökmen. (2017.) A biodegradable surface drifter for ocean sampling on a massive scale. *Journal of Atmospheric and Oceanic Technology*, 34(11): 2509-2532. doi.org/10.1175/JTECH-D-17-0055.1.
- Poje, A.C., T.M. Özgökmen, B.L. Lipphardt, Jr., B.K. Haus, E.H. Ryan, A.C. Haza, G.A. Jacobs, A.J.H.M. Reniers, M.J. Olascoaga, G. Novelli, A. Griffa, F.J. Beron-Vera, S.S. Chen, E. Coelho, P.J. Hogan, A.D. Kirwan, Jr., H.S. Huntley, and A.J. Mariano. (2014.) Submesoscale dispersion in the vicinity of the Deepwater Horizon spill. *Proceedings of the National Academy of Sciences*, 111(35): 12693-12698. doi.org/10.1073/pnas.1402452111.
- Sieracki, C.K., M.E. Sieracki, and C.S. Yentsch. (1998.) An imaging-in-flow system for automated analysis of marine microplankton. *Marine Ecology Progress Series*, 168: 285-296. jstor.org/stable/24828385.
- Stieglitz, J.D., E.M. Mager, R.H. Hoenig, D.D. Benetti, and M. Grosell. (2016.) Impacts of Deepwater Horizon crude oil exposure on adult mahi-mahi (*Coryphaena hippurus*) swim performance. *Environmental Toxicology and Chemistry*, 35: 2613-2622. doi.org/10.1002/etc.3436.
- Wang, B., S.A. Socolofsky, J.A. Breier, and J.S. Seewald. (2016.) Observations of bubbles in natural seep flares at MC 118 and GC 600 using in situ quantitative imaging. *Journal of Geophysical Research: Oceans*, 121: 2203-2230. doi.org/10.1002/2015JC011452.
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