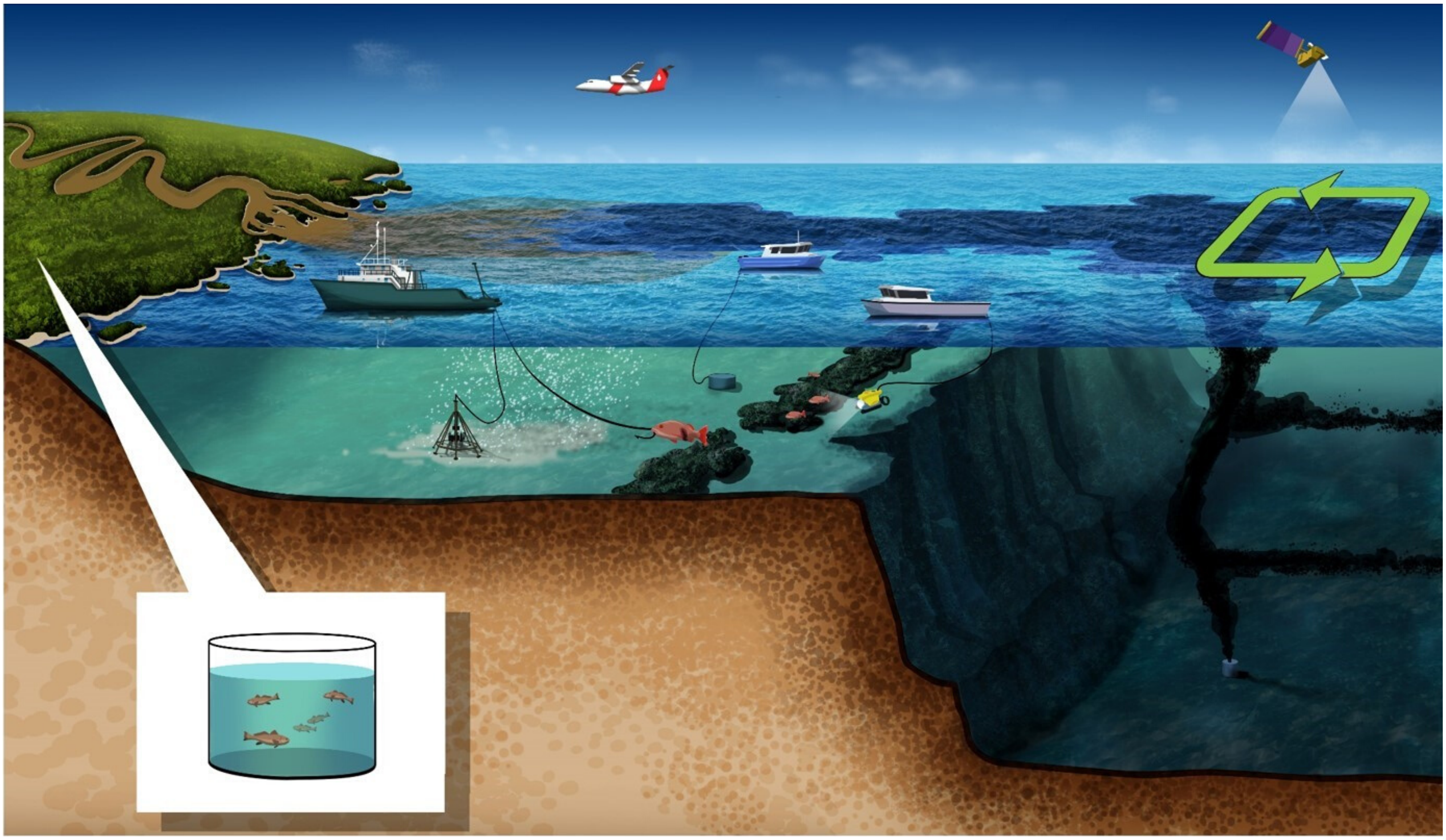
C-IMAGE

UNIVERSITY OF SOUTH FLORIDA
College of MARINE SCIENCE

The Center for the Integrated Modeling and Analysis of the Gulf Ecosystem



THE *DEEPWATER HORIZON* OIL SPILL

On April 20th 2010, one mile deep in the northern Gulf of Mexico, a surge of natural gas broke through the inadequate cement casing at the *Deepwater Horizon* site, breached the blowout preventer, and unexpectedly traveled to the rig's platform, resulting in a fiery explosion. Ultimately, 11 workers were killed, 17 were injured, and two days later, the rig capsized and sank to the bottom, rupturing the riser and allowing a free-flowing blowout of oil and gas into the deep Gulf of Mexico for 87 days.

One month after the explosion, BP (British Petroleum, one of the responsible parties) committed $500 million to create a 10 year independent research program to study the impact of the oil spill on the environment and public health in the Gulf of Mexico.

This research program, the Gulf of Mexico Research Initiative (GoMRI) was established to improve society's ability to understand, respond to and mitigate the impacts of petroleum pollution and related stressors of the marine and coastal ecosystems.

Images: Schematic showing the many tools used by C-IMAGE from Morzaria-Luna et. al. 2018 (above), Early response to the *Deepwater Horizon* oil rig explosion (right).

Funding and Collaboration

Since 2011, the University of South Florida's (USF) College of Marine Science has successfully competed for almost $37 million in research funding from the Gulf of Mexico Research Initiative (GoMRI) to examine the impacts of oil spills in the Gulf of Mexico ecosystem through its Center for the Integrated Modeling and Analysis of the Gulf Ecosystem (C-IMAGE). C-IMAGE is an international team of experts, led by Dr. Steven Murawski at USF's College of Marine Science, from six countries and 19 institutions working together to answer some of the more complex questions related to the spill. What have we learned over the past almost 10 years of research?

Since 2010, USF's College of Marine Science was awarded almost $37 million to **advance understanding of the processes and mechanisms involved in marine blowouts and their environmental consequences** through the development of the Center of the Integrated Modeling and Analysis of the Gulf Ecosystem (C-IMAGE).

THE GOALS OF THIS RESEARCH WERE TO...

1. To inform the public and regulators of the short-, medium-, and long term consequences of the disaster to the environment and people.
2. To better understand the consequences of response measures undertaken by the responsible parties and government responders to mitigate spill effects.
3. To evaluate the connectivity of the Gulf of Mexico and assess ecosystem resiliency.

C-IMAGE's approach was to, early on, gather expertise from across the globe to tackle the complex issues associated with this unprecedented deep blowout. C-IMAGE organized an "all-hands-on-deck" approach to assess the impacts of the disaster.

Above: C-IMAGE is a research consortium of 19 institutions from 6 countries studying the impacts of oil spills on the Gulf of Mexico.

HOW DID THE OIL SPILL IMPACT FISHES IN THE GULF OF MEXICO?

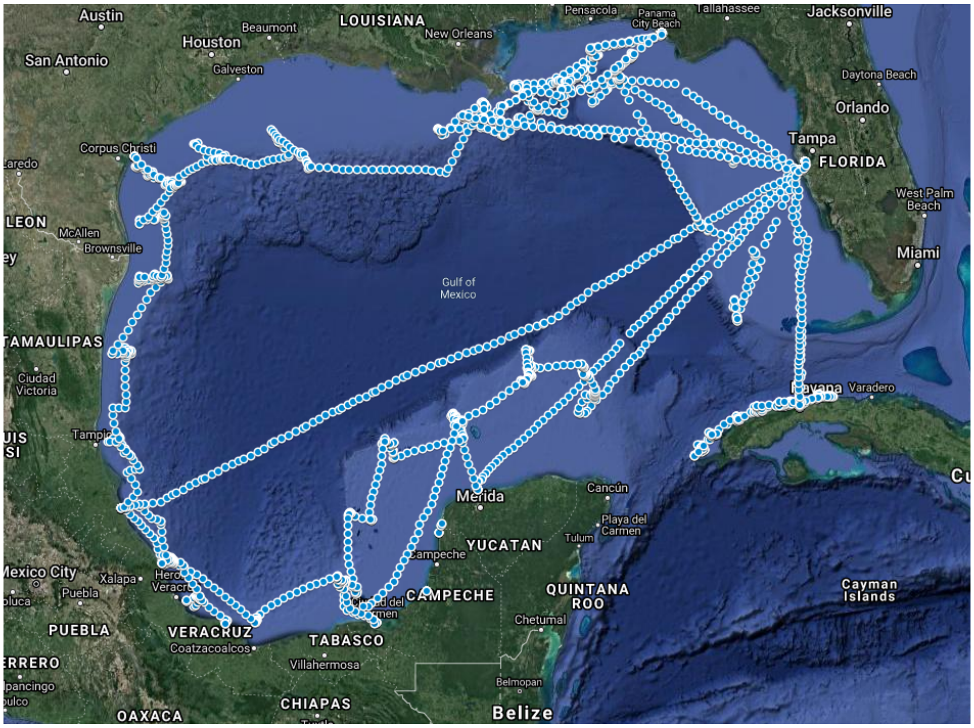
C-IMAGE researchers developed the first comprehensive baseline of oil contamination in fishes and sediments of the Gulf of Mexico, including all the waters off the United States, Mexico and Cuba. Researchers spent almost 250 days at sea circumnavigating the Gulf and sampled over 15,000 fishes and took over 2,500 companion sediment cores to develop these baselines. Baseline data, which were not available for fish and sediment contamination pre-*Deepwater Horizon*, are critical for assessing impacts from a specific spill and for calculating how quickly the ecosystem can return to its pre-spill state.

Above: The *R/V Weatherbird II*

Below: The *R/ V Justo Sierra*

Repeated sampling of the region during 2011-2018 around the spill site has led to estimates of how quickly various species are able to detoxify oil pollution, impacts on the health of various species (e.g. “microbes to mammals”) and how fast oil stranded on the bottom is becoming “landfilled” there due to subsequent sediment accumulation. Importantly, no fish from yet sampled has been free of hydrocarbons, emphasizing the chronic and ongoing pollution of the Gulf.

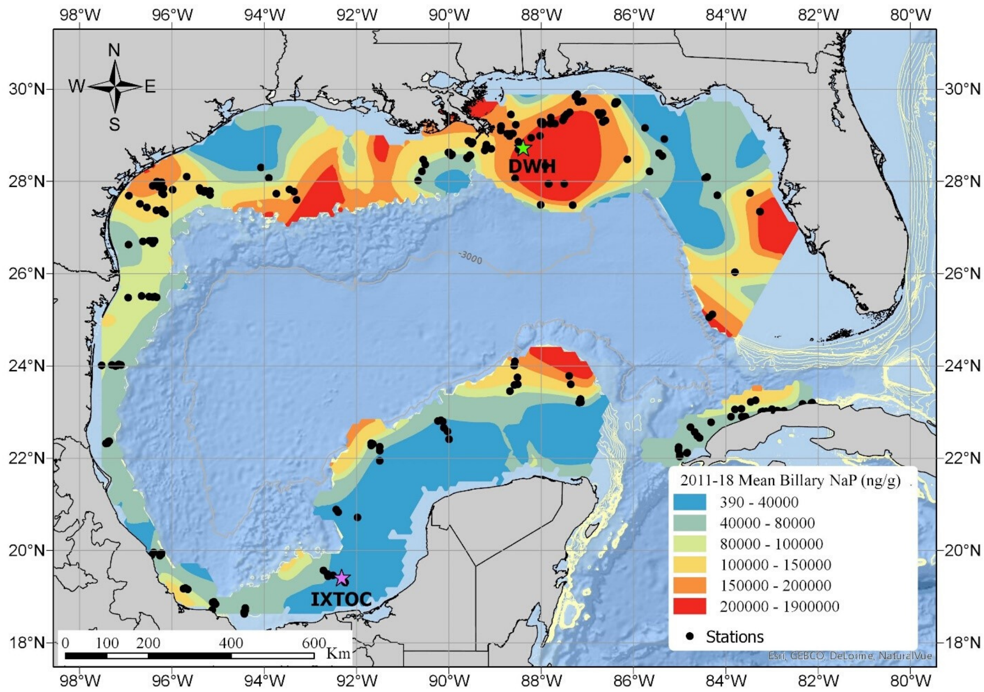
AN OIL SPILL TRIGGERS A “NATURAL RESOURCE DAMAGE ASSESSMENT” OR NRDA, TO ASSESS THE INJURY TO A RESOURCE AND INCLUDES THE RESTORATION PLAN TO MAKE “THE ENVIRONMENT AND PUBLIC WHOLE”. IT’S DIFFICULT TO ASSESS HOW MUCH SOMETHING IS INJURED WITHOUT KNOWING THE PRE-SPILL CONDITION. THIS CONDITION IS KNOWN AS THE **BASELINE**.



“THE STRENGTH OF OUR RESEARCH IS OUR PARTNERS AND COLLABORATORS. LOOKING AT A PROBLEM THROUGH MULTIPLE PERSPECTIVES (BIOLOGISTS, CHEMISTS, GEOLOGISTS, ENGINEERS).”

-Dr. Steven Murawski

C-IMAGE's ship-based field sampling efforts across the Gulf of Mexico over the past 10 years (left) has demonstrated the importance of international collaborations. Each blue symbol represents a sampling location. The home bases for these expeditions is St.Petersburg, Florida and Tuxpan, Mexico.

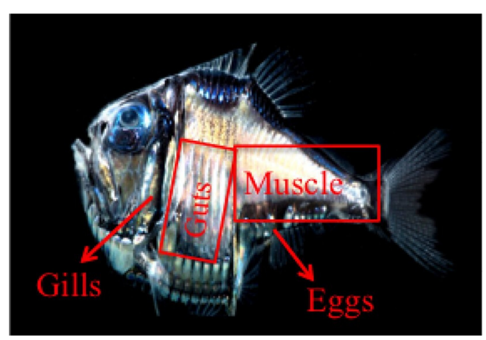


This contour map (left) shows the relative concentration of oil related contamination. The north central region of the Gulf of Mexico is shown as the hot spot of PAH concentrations (specifically a chemical component of oil called naphthalene), as confirmed in the study of bile from 92 fish species sampled in the Gulf of Mexico from 2011-2018. This is the largest study of its kind. Additional hotspots are located off major population centers, such as Tampa Bay (Pulster et al. 2020).

Left: Heatmap taken from Pulster et al. 2020.

- Researchers documented a steep decline in skin lesion frequency in Red Snapper and other species after the spill, coinciding with declines in oil contaminants, indicating that lesions were a major symptom of fish health effects.
- There are documented reports of increasing exposures to hydrocarbons over time in economically and environmentally important Gulf species, like Golden Tilefish, Red Snapper, groupers and hakes. This increased exposure occuring after initial declines in oil pollutants in fish, for some species oil contamination increased probably due to re-suspension of oil in sediments.
- Yellowfin tuna and Golden Tilefish have the highest observed exposure levels to hydrocarbons.
- Increasing concentrations of hydrocarbons in liver tissues of some species (e.g, groupers) suggest these species have experienced long-term, chronic exposure to oil.
- Chronic exposures have been associated with the decline of health indices in tilefish and groupers.
- Comprehensive fish surveys in the Gulf of Mexico since 2011 have provided the basis for evaluating the resilience of species across the Gulf of Mexico. These data will identify species and/or subregions that are most vulnerable to the cumulative effects of fishing, climate change, habitat loss, invasive species and anthropogenic pollution, including oil spills.
- An oil exposure test facility at the Mote Aquaculture Park was established to understand how contamination pathways (water, sediment, food) impact adult fishes. Southern flounder were exposed to oiled sediments for 35 days and showed evidence of oxidative stress, which can cause decreased fertility, increased cellular aging, and decreased survival.

Fish populations living in the mesopelagic zone (1,200 to 6,000 feet deep) were also was impacted by the oil spill. These fish are especially important because they are a food source for larger pelagic, commercially relevant fish, as well as for marine mammals and birds. USF researchers with another GoMRI-funded center, DEEPEND, found an increase in PAH concentrations in mesopelagic fish tissue after the *Deepwater Horizon* oil spill, and PAH levels years later (in 2015-2016) still are elevated from pre-*Deepwater Horizon* levels. The distribution of concentrations in the different tissues indicate that the main sources of this contamination are through their diet and maternal transfers.



Above: A mesopelagic fish, *Argyropelecus aculeatus.*

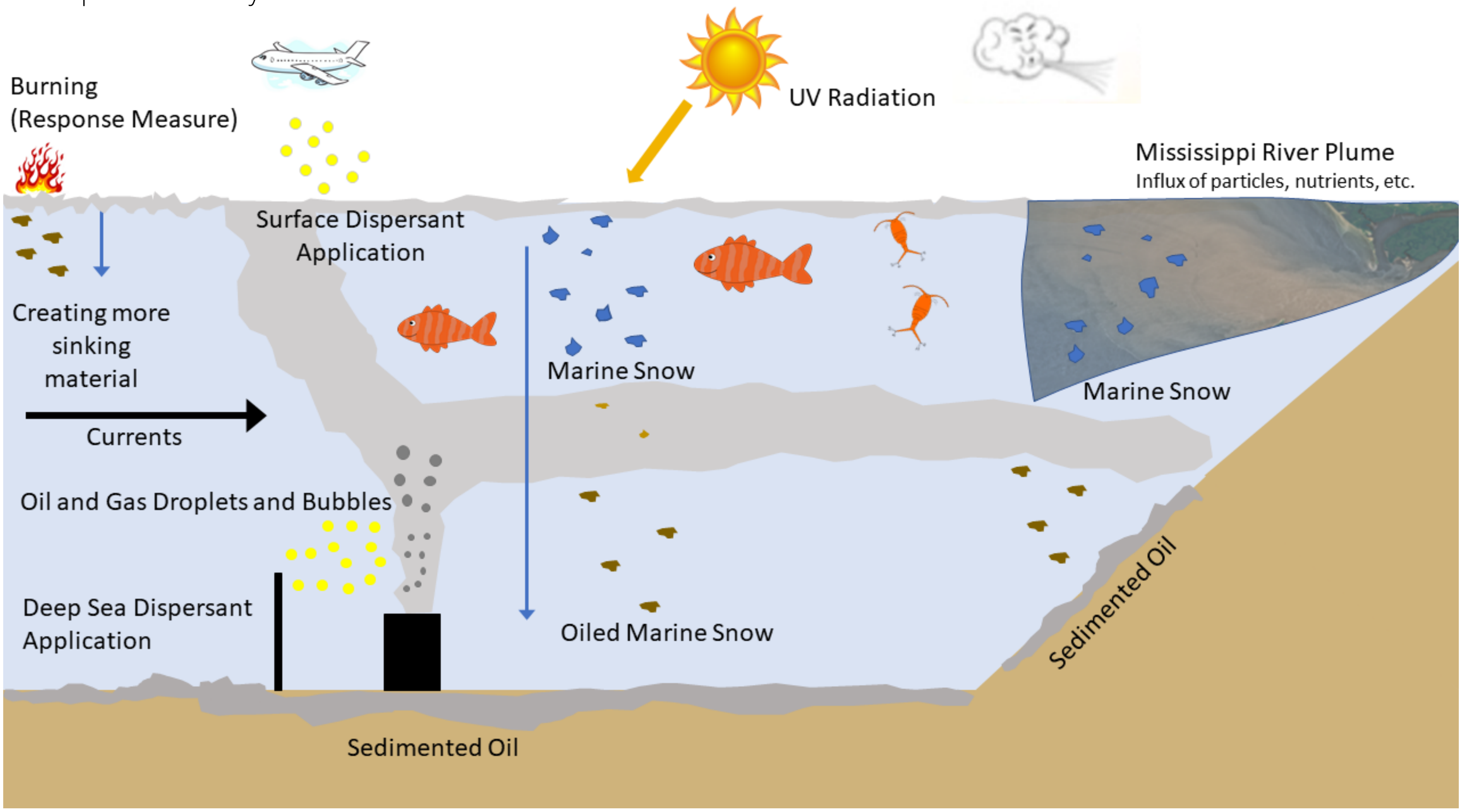
WHAT DO YOU MEAN "OIL SINKS"?

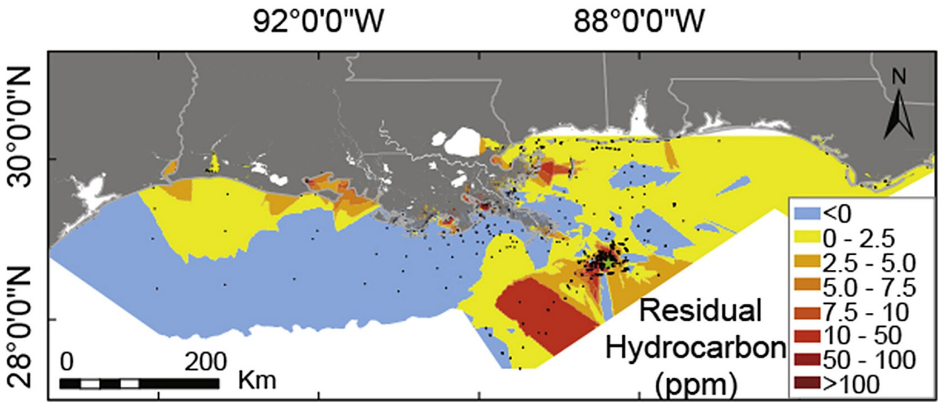
Through water column and sediment sampling, researchers from University of South Florida, Florida State University, Eckerd College, and the National Autonomous University of Mexico in Mexico City discovered that oil contamination not only occurred widely in surface waters, but that significant quantities of crude oil were deposited at the bottom of the deep sea. Marine snow occurs in all of the world's oceans and is made up of aggregations of organic and inorganic particles, like plankton, fecal pellets, biominerals, and land-derived erosion products. These aggregates settle through the water column, attaching to oil droplets as they descend. Researchers coined the term MOSSFA (Marine Oil Snow Sedimentation & Flocculent Accumulation) to describe this mechanism for the deposition of significant oil on the seabed. Researchers speculate that the marine snow process has greatest impact when oil spills during spring and summer when there are plankton blooms and during years of high river flow.

Adding to the complexity of these marine snow events is the increased toxicity of burned oil compounds. Crude oil is made of thousands of different arrangements of carbon that become more toxic after they are burned. These toxic compounds can be trapped in the marine snow where they can cover the seabed and harm the organisms living on the sea floor. These findings have led to the incorporation of MOSSFA in oil spill response models and USF researchers have also developed methods to predict the intensity of MOSSFA should a similar-sized oil spill occur anywhere in the Gulf of Mexico.

RESEARCHERS COINED THE TERM **MOSSFA (MARINE OIL SNOW SEDIMENTATION & FLOCCULENT ACCUMULATION)** TO DESCRIBE THIS MECHANISM FOR THE DEPOSITION OF SIGNIFICANT OIL ON THE SEABED.

Below: Conceptual diagram of various processes contributing to the formation and transport of MOSSFA adapted from Daly et. al 2016.





Above: Distribution of residual hydrocarbon concentrations (from Romero at al. 2017).

- There was a 2 to 3 fold increase in oil compounds from background levels accumulated on the seafloor (Figure above).
- Declines in benthic foraminifera (a very small shelled invertebrate at the base of the food chain) density (80-90%) and species diversity (30-40%) were documented in sediment cores around the *Deepwater Horizon* well-head.
- In the three years following the spill, there was a decrease in the oxygen levels of the surface sediment.
- Researchers are projecting that it will take 50-100 years for the deep ocean ecosystem to recover from the *Deepwater Horizon* spill.

DISPATCHES FROM THE GULF

The *Dispatches from the Gulf* collection is part of the documentary television series "Journey to Planet Earth" narrated by Matt Damon that highlights the GoMRI-funded research being done through the dozens of research centers across the Gulf.

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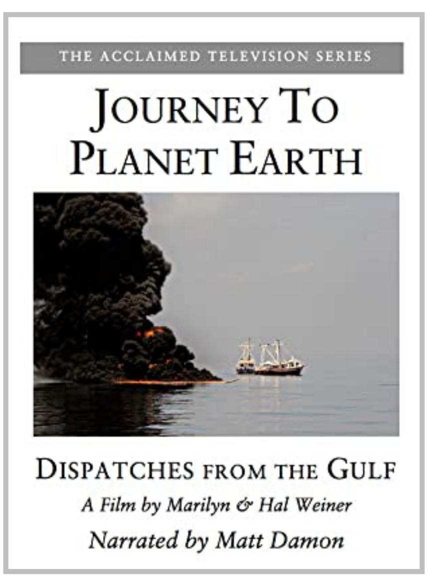

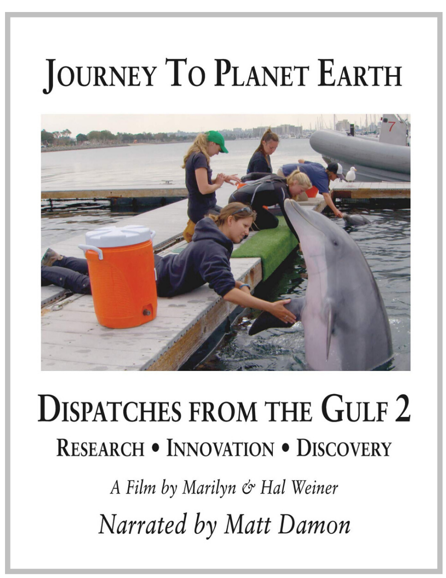

For a full picture of the breadth of what we've learned over the past ten years, we refer interested readers to our two-volume series from Springer Publishing;

Deep Oil Spills
and
Scenarios and Responses to Future Deep Oil Spills.

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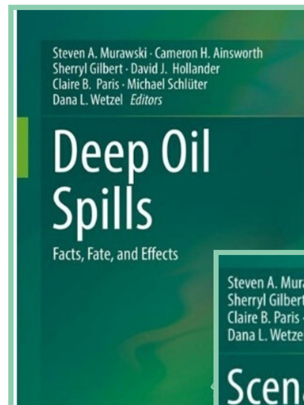

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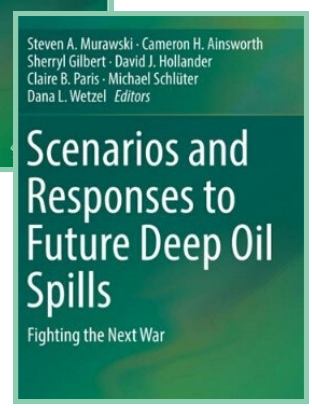

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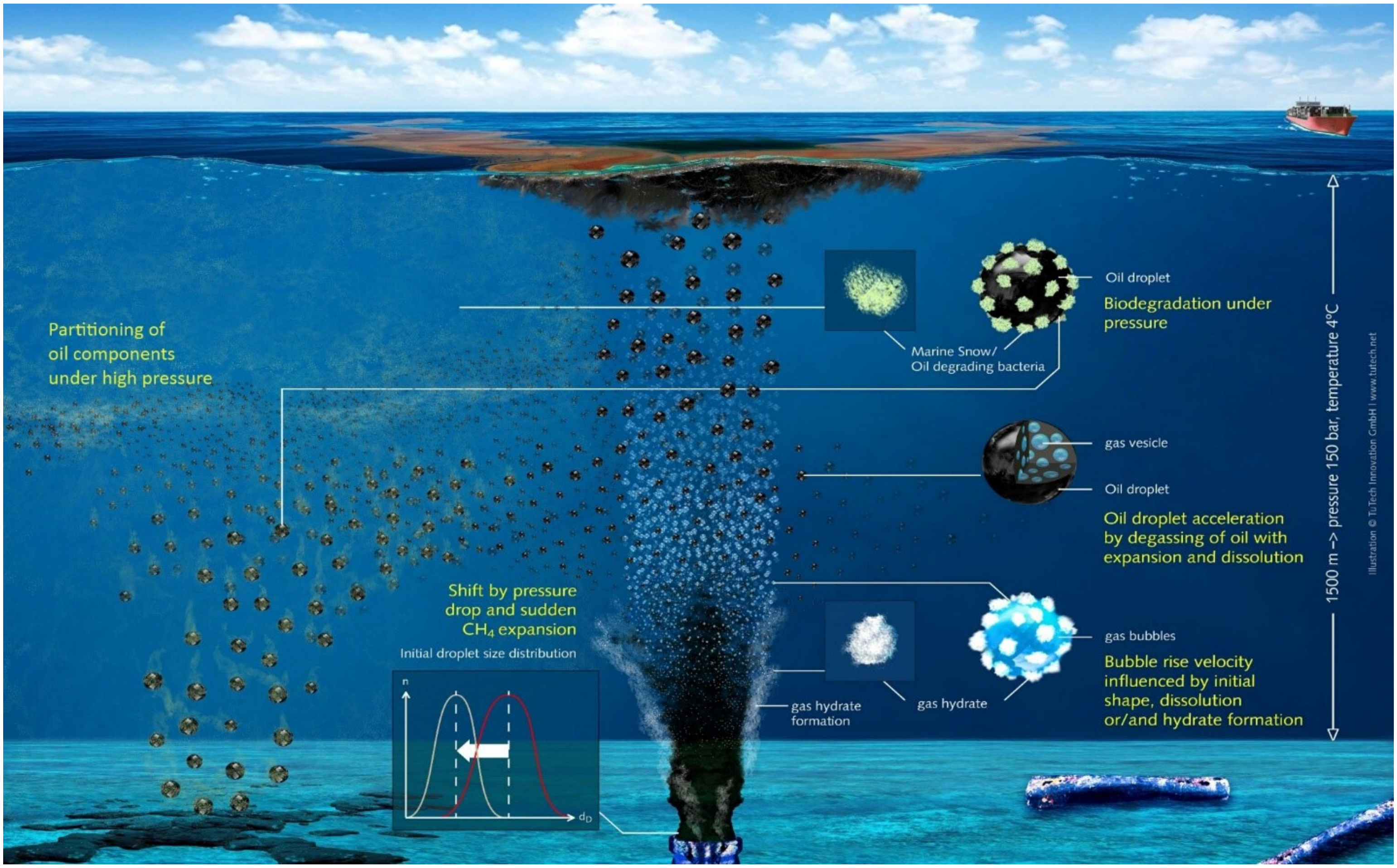
These books synthesize information developed with the aid of the tens of millions of research dollars committed to answering key questions about the *Deepwater Horizon* event, and more broadly, how this information can predict how future oil spills with different characteristics or locations can impact the environment. These books include authors from C-IMAGE, other GoMRI funded centers, the federal government, and private industry.

WHAT HAPPENS TO OIL AND GAS WHEN IT'S MIXED WITH DISPERSANT ONE MILE DEEP IN THE OCEAN?

During the *Deepwater Horizon* event, chemical dispersing agents were applied directly into the stream of oil and natural gas coming out of the broken pipe 1500 meters below the water's surface. Typically, dispersants are applied after a spill on the surface slick to break up the oil droplets and to enhance biodegradation. The *Deepwater Horizon* event was notably the first time dispersants were applied at such extreme depths directly at the blowout site. C-IMAGE researchers from the Hamburg University of Technology, the University of Calgary and the University of Western Australia developed the first and most realistic high-pressure testing facilities to better understand processes associated oil well blowouts in water depths of one mile and deeper.

Oil, gas and water escaping from the broken well was under extreme pressure (over 200 times sea level atmospheric pressure) and the pressure drop at the well head was sudden and substantial. Tests conducted at the Hamburg facility conclusively demonstrated that oil was "atomized" into very small droplet particles that remained in deep water forming submerged plumes in the absence of chemical dispersants. Petroleum chemists at the University of Calgary discovered that high pressures resulted in the differential rates of partitioning of toxic substances contained in oil into seawater, increasing their toxicity to deep sea life. Today over half of the oil from the Gulf of Mexico comes from wells over one mile deep, and the deepest are nearly two miles. Thus, understanding the high-pressure world is key to more effective oil spill response.

Below: Process diagram from the Hamburg University of Technology showing how oil and gas behave in the water column.

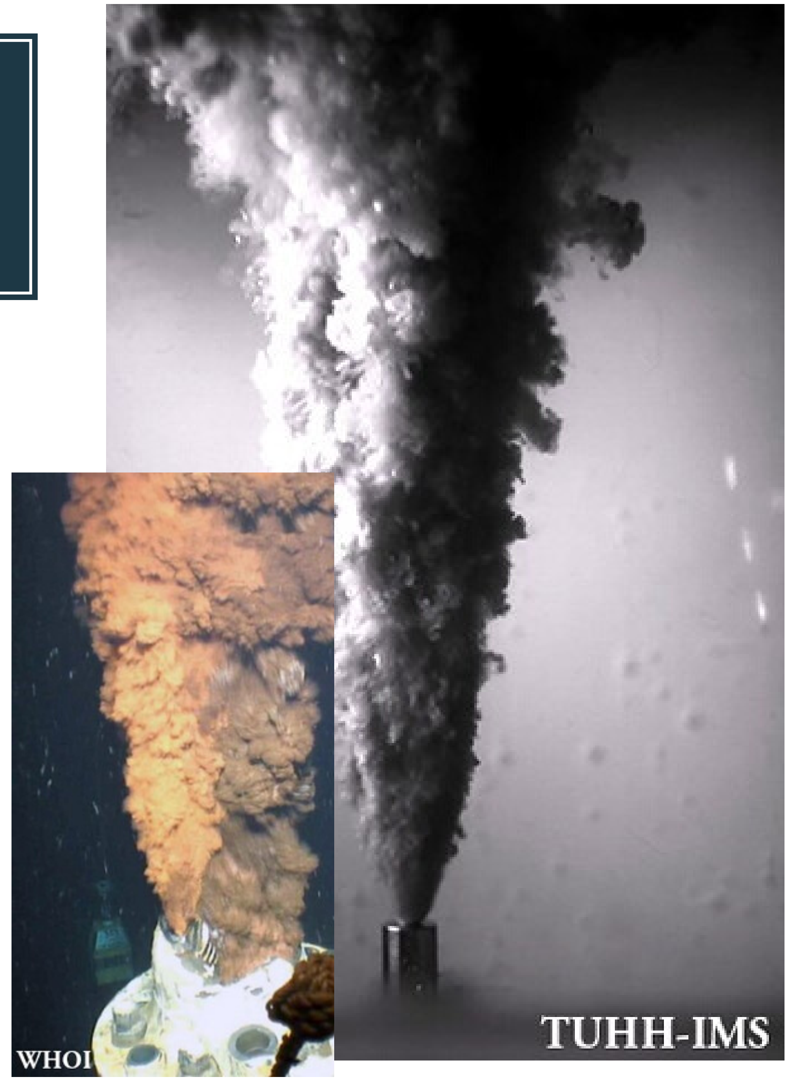


TODAY, OVER HALF OF THE OIL FROM THE GULF OF MEXICO COMES FROM WELLS OVER ONE MILE DEEP, AND THE DEEPEST ARE NEARLY TWO MILES.

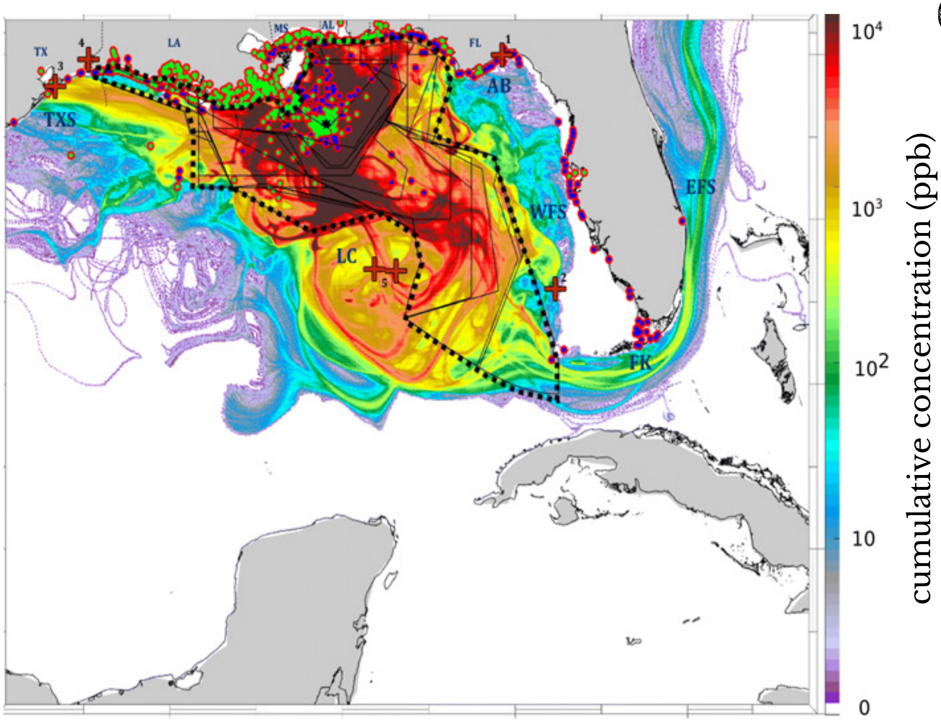
- C-IMAGE's partner at the Hamburg University of Technology developed high pressure experiments to mimic environmental conditions and used oil saturated with methane gas. Until C-IMAGE, laboratory experiments did not consider "live" oil.

- C-IMAGE researchers at the University of Miami, through their use of numerical models, show that small micro-droplets were created from the large pressure difference from the blowout preventor to the deep sea and not the direct application of dispersant, which was one of its purposes.

- Evidence shows that toxic and invisible oil extended beyond the current satellite footprint at potentially lethal and sub-lethal concentrations to a wide range of wildlife in the Gulf of Mexico (below).



Above: Still shot of the DWH blowout (left) and the high pressure facility at the Hamburg University of Technology (right).



Above: Berenshtein et al. 2020

- Pressure and dispersant application play important roles in how bacteria that live in the deep sea and the water column degrade the oil. Studies at Pennsylvania State University, Hamburg University of Technology and Georgia Tech show the complicated picture. The application of dispersant was shown to either enhance or inhibit biodegradation depending on the bacteria strain. It was also shown that elevated pressures can decrease biodegradation of oil. This area of research is still developing and not all questions have been answered.

Building Partnerships

"The Gulf of Mexico is comprised of three countries and we need a much better plan to coordinate among these three countries. The oil policies are different. There is some coordination on the response side, but we should have a better understanding of the Gulf as a complete ecosystem. Oil spills do not respect territorial boundaries. And so we need a more integrated multinational approach to this. That's certainly important."

-Dr. Steven Murawski

Collaborative Research

"The interdisciplinary research conducted in C-IMAGE has led to a better understanding of the physical, chemical, biological and geological functioning of the Gulf of Mexico. C-IMAGE researchers pioneered the development of high-pressure testing facilities, discovered the phenomena known as MOSSFA (Marine Oil Snow Sedimentation and Flocculant Accumulation) and quantitatively assessed many unforeseen ecologic impacts and long-term ecosystem consequences."

-Dr. David Hollander

The Next Generation of Scientists

"Over the past ten years, our team has pushed the boundaries of how academic research is executed. We've been able to provide continuous funding, training and professional development opportunities to students and early career researchers, and have connected them to a large interdisciplinary network of colleagues to support them deep into their careers. The future holds complex problems, and we've trained a team of scientists to tackle them with versatility and a broader view of their capabilities."

-Sherryl Gilbert

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3. THE PRESSURE IS ON!
6. OIL: IT'S WHAT'S FOR DINNER
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16. PANEL DISCUSSION

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REFERENCES AND SELECTED PUBLICATIONS

Berenshtein, I., Paris, C. B., Perlin, N., Alloy, M. M., Joye, S. B., Murawski, S. (2020) Invisible oil beyond the Deepwater Horizon satellite footprint, Science Advances, 6, 7.

Daly, K. L., Passow, U., Chanton, J., Hollander, D. (2016) Assessing the impacts of oil-associated marine snow formation and sedimentation during and after the Deepwater Horizon oil spill, Anthropocene, 13, 18-33.

Hastings, D., Schwing, P., Brooks, G., Larson, R., Morford, J., Roeder, T., Quinn, K., Bartlett, T., Romero, I., Hollander, D.(2016) Changes in sediment redox conditions following the BP DWH Blowout event, Deep Sea Research II, 129, 167-178.

Montagna, P. A. and Girard, F. (2020) Deep-sea benthic faunal impacts and community evolution before, during and after the Deepwater Horizon event. In S. A. Murawski, C. H. Ainsworth, S. A. Gilbert, D. J. Hollander, C. B. Paris, M. Schlüter, D. Wetzel (Eds.), Deep Oil Spills - Facts, Fate, and Effects (pp. 355-373). Springer International.

Morzaria-Lunaab, H. N., Ainsworth, C. H., Tarnecki, J. H., Grüsse, A. (2018) Diet composition uncertainty determines impacts on fisheries following an oil spill, Ecosystem Services, 33, 187-198.

Murawski, S. A., Schlüter, M., Paris, C. B., Aman, Z. M. (2019) Resolving the dilemma of dispersant use for deep oil spill response. Environmental Research Letters, 14(9), 091002.

Murawski, S. A., Hollander, D. J., Gilbert, S., Gracia, A. (2020) Deepwater Oil and Gas Production in the Gulf ofMexico and Related Global Trends. In S. A. Murawski, C. H. Ainsworth, S. A. Gilbert, D. J. Hollander, C. B. Paris, M.Schlüter, D. Wetzel (Eds.), Scenarios and Responses to Future Deep Oil Spills: Fighting the Next War (pp. 16-32).Springer International.

Paris, C. B., Berenshtein, I., Trillo, M. L., Faillettaz, R., Olascoaga, M. J., Aman, Z. M., Schlüter, M., Joye, S. B. (2018) BP Gulf Science Data Reveals Ineffectual Subsea Dispersant Injection for the Macondo Blowout. Frontiers in Marine Science, 5.

Pesch, S., Schlüter, M., Aman, Z. M., Malone, K., Krause, D., Paris, C. B. (2020) Behavior of rising droplets and bubbles - impact on the physics of deep-sea blowouts and oil fate. In S. A. Murawski, C. H. Ainsworth, S. A. Gilbert, D. J. Hollander, C. B. Paris, M. Schlüter, D. Wetzel (Eds.), Deep Oil Spills - Facts, Fate, and Effects (pp 65-85). Springer International.

Pulster, E. L., Gracia, A., Armenteros, M., Carr, B. E., Mrowicki, J., Murawski S. A. (2020) Chronic PAH exposures andassociated declines in fish health indices observed for ten grouper species in the Gulf of Mexico. Science of the TotalEnvironment, 703, 135551.

Pulster, E. L., Gracia, A., Armenteros, M., Toro-Farmer, G., Snyder, S. M., Carr, B. E., Schwaab, M. R., Nicholson, T. J., Mrowicki, J., Murwaski, S. A. (2020) A First Comprehensive Baseline of Hydrocarbon Pollution in Gulf of Mexico Fishes, Scientific Reports, 10, 6437. https://www.nature.com/articles/s41598-020-62944-6

Romero, I. C., Toro-Farmer, G., Diercks, A. R., Schwing, P. T., Muller-Karger, F., Murawski, S. A., Hollander, D. J. (2017) Large-scale deposition of weathered oil in the Gulf of Mexico following a deep-water oil spill, Environmental Pollution, 228, 179-189.

Romero, I. C., Schwing, P. T., Brooks, G. R., Larson, R. A., Hastings, D. W., Flower, B. P., Goddard, E. A., Hollander, D. J. (2015) Hydrocarbons in deep-sea sediments following the 2010 Deepwater Horizon Blowout in the Northeast Gulf of Mexico. PLoS ONE, 10(5).

Schwing, P. T., Montagna, P. A., Machain-Castillo, M. L., Escobar-Briones, E., Rohal, M. (2020) Benthic faunal baselines in the Gulf of Mexico: A precursor to evaluate future impacts. In S. A. Murawski, C. H. Ainsworth, S. A. Gilbert, D. J. Hollander, C. B. Paris, M. Schlüter, D. Wetzel (Eds.), Scenarios and Responses to Future Deep Oil Spills: Fighting the Next War (pp 96-108). Springer International.

Schwing, P. T., Romero, I. C., Brooks, G. R., Hastings, D. W., Larson, R. A., Hollander, D. J. (2015) A decline in deep-sea benthic foraminifera following the Deepwater Horizon event in the Northeastern Gulf of Mexico, PLoS ONE, 10(5).

Snyder, S. M., Pulster, E. L., Murawski, S. A. (2019) Associations between chronic exposure to polycyclic aromatic hydrocarbons and health indices in Gulf of Mexico Tilefish (Lopholatilus chamaeleonticeps) post-Deepwater Horizon. Environmental Toxicology and Chemistry, 38, 12, 2659-2671.

Snyder, S. M., Olin J., Pulster E. L., Murawski S. A. (2020) Spatial contrasts in hepatic and biliary PAHs in Tilefish (Lopholatilus chamaeleonticeps) throughout the Gulf of Mexico, with comparison to the Northwest Atlantic. Environmental Pollution, 258.

Struch, R. E., Pulster, E. L., Schreier, A. M., Murawski, S. A. (2019) Hepatobiliary Analyses Suggest Chronic PAH Exposure in Hakes (Urophycisspp.) Following the Deepwater Horizon Oil Spill. Environmental Toxicology and Chemistry, 38, 12, 2740-2749.

Booklet designed by Rachel Crabtree