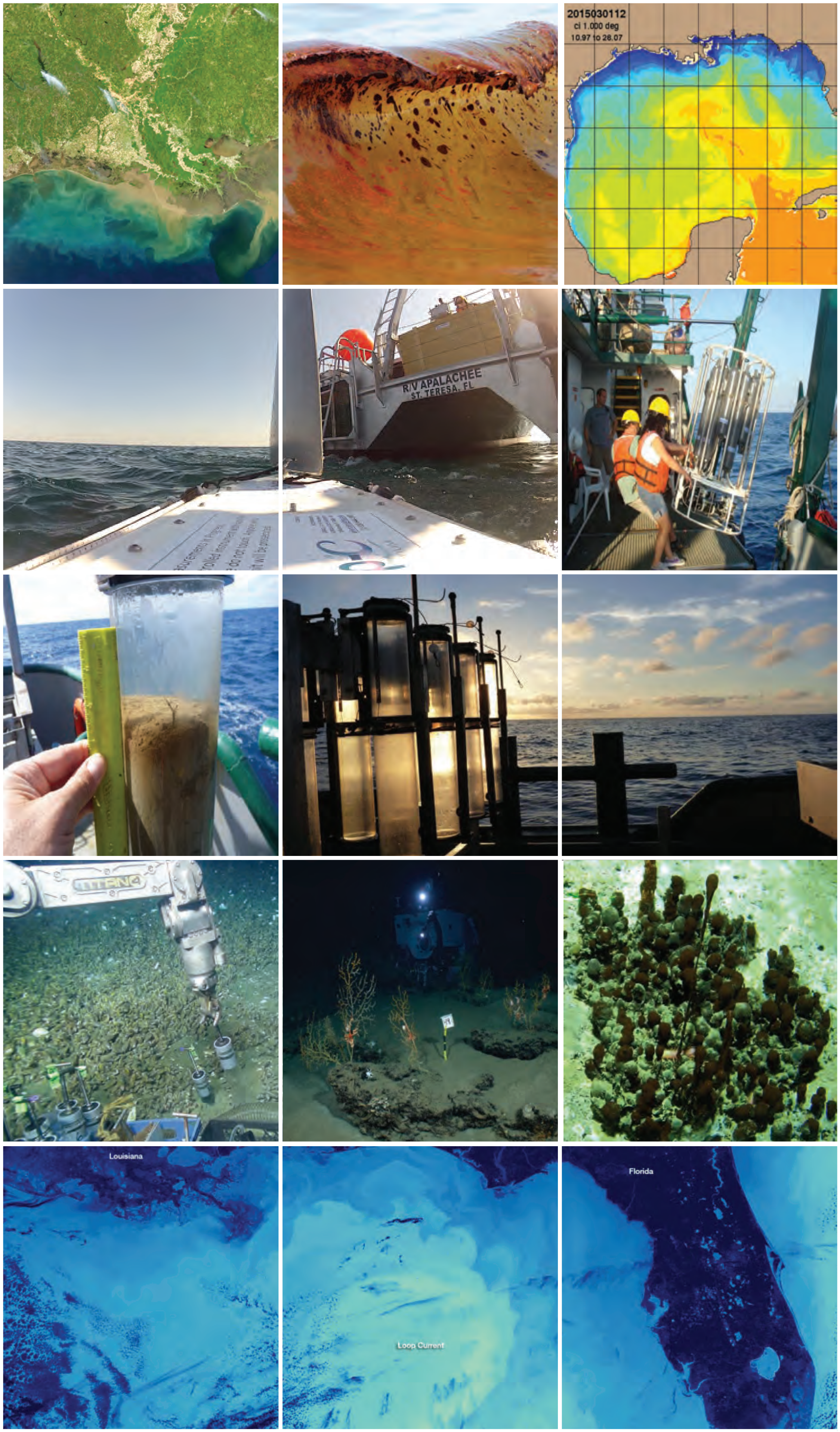

Gulf of Mexico

Deep Sea to Coast Connectivity

Utilizing scientific research to help students make connections between the theoretical nature of science and real world applications

A Multi-disciplinary Curriculum for High School Science

Developed by
Brittany Pace &
Amelia Vaughan

Deep-C
CONSORTIUM

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About This Curriculum

Developed by Deep-C Ocean Science Educators Brittany Pace and Amelia Vaughan. Edited by Deep-C Coordinator Tracy Ippolito.

Deep-C Ocean Science Educators Brittany Pace (left) and Amelia Vaughan (right).

Deep Sea to Coast Connectivity: Utilizing scientific research to help students make connections between the theoretical nature of science and real world applications

This Gulf of Mexico multidisciplinary curriculum was developed around the five main research areas of the Deep-C Consortium: geomorphology, geochemistry, ecology, physical oceanography, and modeling. Each module includes five cumulative lessons, background information on the topic, relevant supplementary reading materials, a glossary, and an assessment. The purpose of this curriculum is to:

1. Provide teachers with a user-friendly curriculum that will introduce students to real-world applications of science as well as specific examples of environmental disasters – their impacts on ocean ecosystems as well as nature's ability to and mechanisms for recovering from such events.
2. Synthesize some of the Deep-C Consortium's research efforts, to date.
3. Increase Gulf of Mexico literacy.

It is our hope that this curriculum can serve as a model for future curricula developed based off of scientific research endeavors.

Contributing experts are listed throughout curriculum. Many thanks to these Deep-C researchers and students who edited, authored content, or assisted with development of the lesson plans.

Aligned with Ocean Literacy Principles and the Next Generation Sunshine State Standards

Ocean Literacy: *The Essential Principles of Ocean Sciences for Learners of All Ages, Version 2* was published in March 2013. http://oceanliteracy.wp2.coexploration.org/

Next Generation Sunshine State Standards: CPALMS is the state of Florida's official source for standards information and course descriptions. http://www.cpalms.org/Public/

This curriculum is available online at https://deep-c.org/education-and-outreach/gom-curriculum

For questions or feedback, email contact@coaps.fsu.edu

The Deep-C Consortium conducted an interdisciplinary study of deep sea to coast connectivity in the northeastern Gulf of Mexico.

This research was made possible by a grant from BP/The Gulf of Mexico Research Initiative to the Deep-C Consortium.

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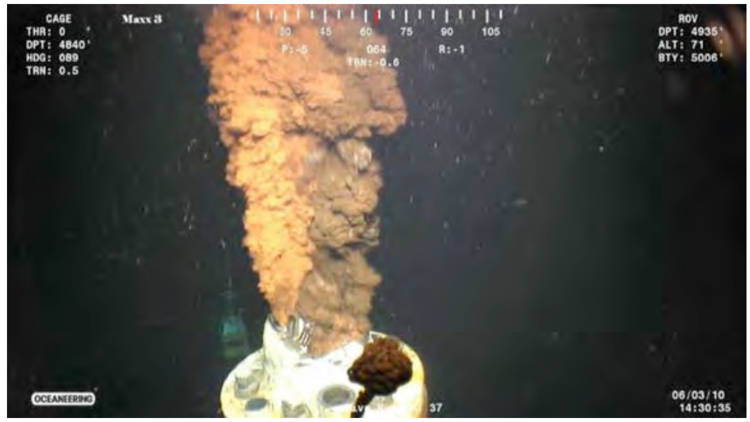


The Macondo well was two days from completion when high-pressure methane gas from the well expanded into the riser, and rose into the drilling rig, where it ignited into an explosion. Experts estimated that oil flowed from the well at a rate of 62,000 barrels per day.

On April 20, 2010, a devastating explosion on the Deepwater Horizon oil rig ~41 miles off the coast of southeastern Louisiana resulted in the deaths of 11 people and triggered a leak at the Macondo well that released close to five million barrels of crude oil into the Gulf of Mexico. Clean-up personnel, scientists, and researchers from all over the country were among the first responders to this environmental disaster. They were tasked with stopping the oil flow, limiting exposure, and cleaning up as quickly as possible using the tools available to them (i.e., dispersants, top kills, in situ burning, oil booms). In the days and months that followed the accident, many of these first responders continued to play an active role in not only helping to mitigate the effects on site but also to offer valuable insight into where the oil and gas would go and the possible effects to the unique and varied Gulf of Mexico ecosystems. When the well was finally capped nearly three months later, many were left wondering what would happen next and what the long-term repercussions might be, both on the Gulf itself as well as the communities that rely on it.

Funding Research in the Gulf of Mexico

In May 2010, BP (the company who owned the rights to the oil from the Macondo well) committed $500 million over a 10-year period to create a broad, independent research program to be conducted at research institutions primarily in the Gulf Coast states. This program, the Gulf of Mexico Research Initiative (GoMRI), has since awarded numerous grants to research consortia, one of which was the Deep-C Consortium. The subsequent research has produced an exhaustive amount of data and provided many new insights into this under-studied ocean environment.

Deep-C Consortium: Deep Sea to Coast Connectivity in the Eastern Gulf of Mexico

Consortium Director: Dr. Eric P. Chassignet

Member and Affiliated Institutions: Florida State University (lead), Dauphin Island Sea Lab, Eckerd College, Georgia Institute of Technology, Leidos, Naval Research Laboratory at Stennis Space Center, Norwegian Meteorological Institute, University of Miami – RSMAS, University of North Florida, University of South Florida, University of West Florida, Valdosta State University, Woods Hole Oceanographic Institution.

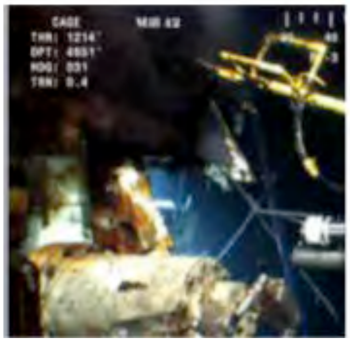
Research Goal: To examine geomorphologic, hydrologic, and biogeochemical settings that influence the distribution and fate of the oil and dispersants while also evaluating and predicting the environmental consequences through integrated earth system and food web models. Research conducted by the Deep-C Consortium, a group of research institutions primarily located in the southeast U.S., provided an opportunity to develop an ocean science curriculum that brings current scientific research into K-12 classrooms.

During and after the Deepwater Horizon oil spill, Deep-C scientists investigated the consequences of petroleum hydrocarbon release in the deep Gulf of Mexico on living marine resources and ecosystem health, as well as nature's response and surprising resiliency. The project sought to answer key questions, including:

1. What are the magnitudes, directions, and spatial and temporal scales of hydrodynamic processes that transport particles and dissolved substances (including oil, gas nutrients, solutes, and organisms) from the deep Gulf to the Florida panhandle shelf waters in the northeastern Gulf of Mexico? How are these influenced by canyon and shelf topography?
2. How does the transport of these particles and dissolved substances influence geochemical, biological, and demographic processes, including food web dynamics, across sea floor, pelagic, and near-shore ecosystems?

The Science of Oil in the Ocean: Origin and Chemical Composition
Exploring Oil Spills on a Molecular Basis

Adapted from National Ocean Science Bowl Professional Development Webinar Series 2015. This webinar, given by Dr. Chris Reddy, a marine geochemist at the Woods Hole Oceanographic Institution, explored how oil is formed, the composition and structure of oil and processes that affect oil. Listen to it at: **http://nosb.org/learn/professional-development/guest-expert-dr-christopher-reddy/**



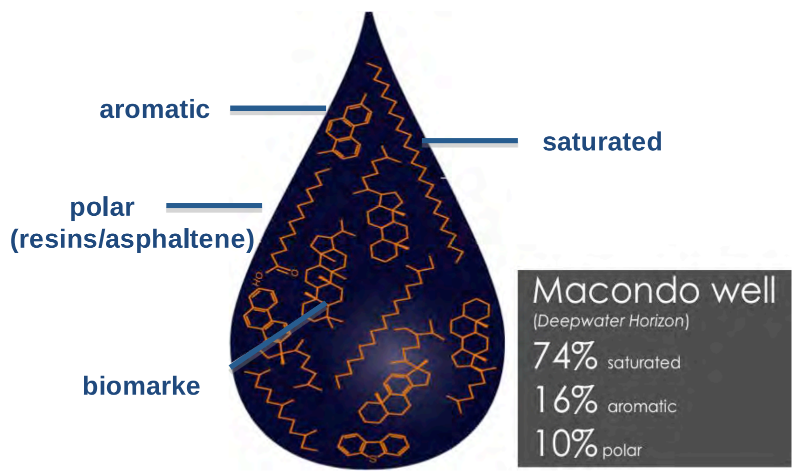

Key Points

- All oils and oil spills are not the same. Oil contains thousands of different compounds with different chemical and biological characteristics.
- What happens to oil released into the environment and the subsequent impacts are dictated by the type of molecules comprised in the spilled oil.
- Released oil's composition changes immediately due to weathering by different processes (e.g. evaporation and microbial degradation that occurs at different speeds and preference for different types of molecules in the oil).
- Where the oil is released is important.
- Investigation of oil spills reveal how nature responds to uninvited guests.

How is Oil Formed?

1. Algae and other organisms fall from the surface to the floor.
2. Debris is reworked by microbes and chemical reactions to form a geopolymer.
3. The geopolymer is "cooked and squeezed" into oil and gas.

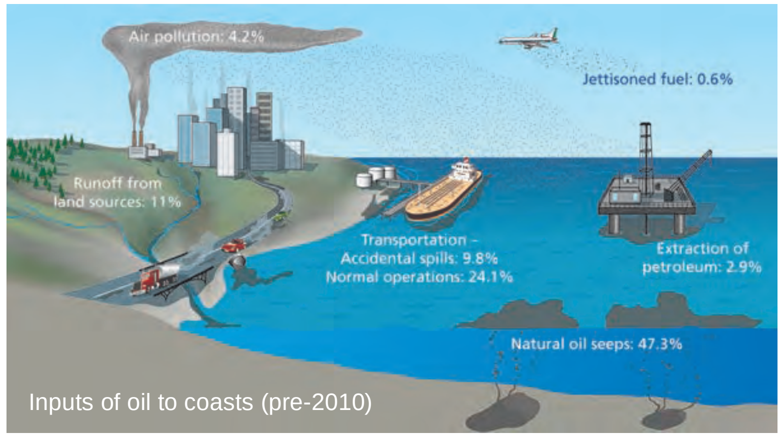
Composition of Oil



Oil is made up of aromatic hydrocarbons, saturated hydrocarbons, and polar compounds. The majority of hydrocarbons in the Macondo well oil were of the saturated variety. Various processes, such as the types of organic matter, depth, temperature, pressure, and time cause differences in the molecular composition of oil. All oil molecules have a different make-up due to the different "personalities" of the many compounds.

Asphaltenes and resins are examples of larger molecules that make up oil and their behavior in the environment is unknown. Petroleum biomarkers, such as hopane, are molecular fossils, invaluable for capturing the "genetic" code of oil. They are the biochemical equivalent of the skeletal remains found at an archeological dig. They do not degrade very fast and can be used for oil fingerprinting to find the source.

Once crude oil is moved from its reservoir, it is then taken to a refinery. The oil is refined through a process where the carbon atoms are broken apart, forming "fractions." For example: there are 5-10 carbons in gasoline, whereas diesel oils have 14 to 20 carbons. The spectrum of oil that can be released into the environment is vast.

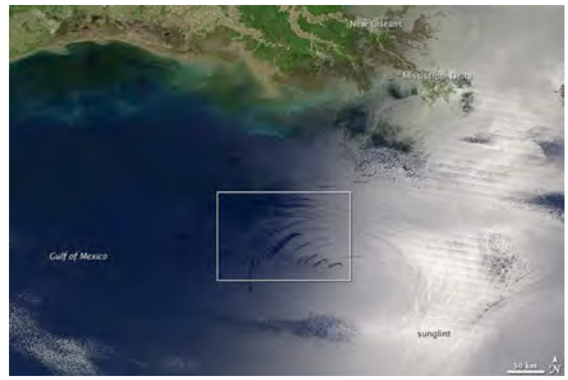


Inputs of oil to coasts (pre-2010)

Natural Oil Seeps versus the Deepwater Horizon Oil Spill

Hydrocarbons are a natural part of the Gulf ecosystem and are released into the ocean environment through a crack in the reservoir, called a natural seep – which creates an oil spill everyday (otherwise known as the "leaky faucet" effect). Specialized bacteria have evolved to eat oil near the seeps. Oil is a calorie rich material for microbes like butter is for us. When oil leaves the reservoir and enters the water column, it changes chemically and its fate is based on both its physical location as well as its molecular makeup.

Characteristic	Natural seeps in the Gulf of Mexico	Deepwater Horizon Disaster
Duration	Occurred everyday for 1000s of years	87 days in 2010
Source	1000s of seeps throughout the Gulf	The Macondo well, 50 miles offshore
Release of oil per/day (Total 2010)	200,000 gallons/day (~800,000,000 gallons in 2010)	55,000 gallons/day (~200,000,000 gallons in 2010)
Type of oil	Weathered crude	Fresh crude
Cause	Nature	Catastrophe
Ecosystem	Evolved to releases	Overwhelmed initially
Damages	Hard to quantify and confirm	Hard to quantify; but they did occur



Satellite imagery of oil slicks in the Gulf of Mexico. Source: NASA Earth Observatory

Processes that Affect Oil

Spreading, drift, evaporation, dissolution, dispersion, emulsification, sedimentation, biodegradation, and photo oxidation are examples of weathering processes that affect a marine oil slick over time. Photochemical degradation is a function of the compound's capacity to absorb sunlight. The rate of these processes varies. Deepwater Horizon oil traveled 5,000 feet to the surface and its chemical composition at the well when compared to the surface slick was very different. The most volatile compounds evaporated first. And microbes feasted on the released hydrocarbons (first the natural gas, and eventually the oil).

Resources & References

Mixing Oil and Water: Tracking the source and impact of oil pollution in the marine environment - http://www.whoi.edu/oceanus/feature/mixing-oil-and-water

Science in a Time of Crisis - http://www.whoi.edu/deepwaterhorizon

Oil in the Ocean: A Complex Mix - http://www.whoi.edu/oil/main

Contributing Expert

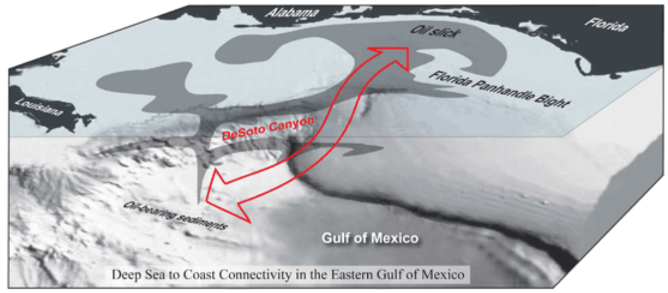
Dr. Christopher Reddy, Marine Chemist at the Woods Hole Oceanographic Institution

Geomorphology

In the Gulf of Mexico

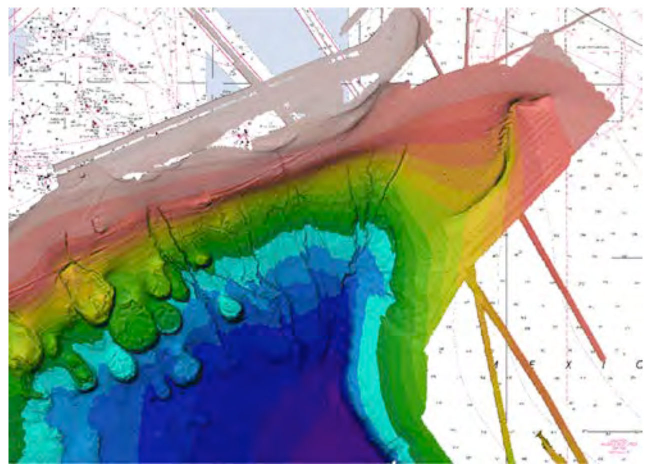
What is Geomorphology?

The scientific study of the origin and evolution of topographic and bathymetric features created by physical or chemical processes operating at or near Earth's surface.



A Quest to Map the Gulf's Seafloor

Mapping the seafloor and the use of digital imaging are two important methods for understanding how geological formations influence habitat and ecosystem development. After the 2010 Deepwater Horizon (DwH) oil spill occurred, two main questions emerged: *how were organisms and ecosystems impacted* and *what measures could be taken to protect them in the future?* The eastern Gulf of Mexico was largely unmapped at the time and many of its topographic features were unknown. So Deep-C researchers undertook basic mapping and descriptive studies of the seafloor in this region because: (1) oil from the DwH oil spill moved toward the Alabama and Florida coasts through a specific feature of the area, the De Soto Canyon, and there was a need to understand the mechanism by which this occurred; and (2) the region is considered a hotspot of biological diversity and has the highest biological productivity in the Gulf of Mexico thus it has tremendous economic value.



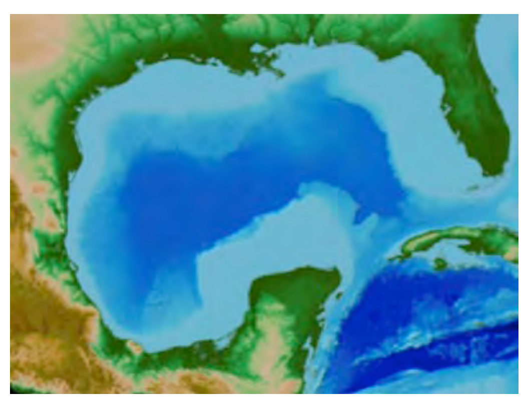
Multibeam image of numerous small downslope channels distributed within the broader De Soto Canyon indention.

How Were Benthic Habitats Impacted by the Oil Spill?

Deep-C's geomorphology team was tasked with characterizing the seafloor geomorphology, bathymetry, sediment, and primary benthic habitats specific to the De Soto Canyon, with an emphasis on topographical features that influence deep sea-to-shelf connectivity. These results are being used to hindcast estimates of damage resulting from past oil spills and forecast vulnerabilities of key communities to future spills.

The De Soto Canyon

The De Soto Canyon is a broad southwest to northeast feature formed at the intersection between the Florida Peninsula and the southeastern portion of the continental U.S. The two components contain distinct features, which often support different ecosystems. The west/north side is the North American margin where river flows have deposited sediment layers that are literally miles thick. In many places, these layers are characterized by salt domes, economic hydrocarbon reserves and natural seeps. The east/south side is the Florida Platform – a huge structure comprised of carbonate rock with much less sediment accumulation.

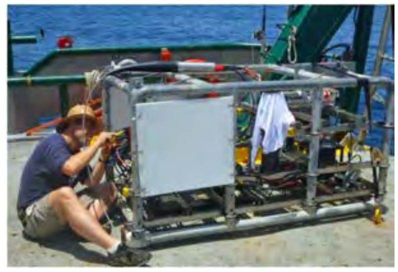


Source: www.ngdc.noaa.gov (public domain)

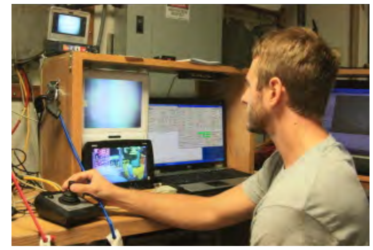
Deep-C Geomorphology and Habitat Classification Research

Innovative MILET system aids environmental monitoring in the Gulf

A team led by FSU's Dr. Ian MacDonald developed the Modular Instrument Lander and Equipment Toolshed (MILET) that allows scientists to map the seafloor and water column. This benthic imaging platform is a cost-effective alternative for deep-ocean surveys that can be deployed from the type of coastal ships most readily available for academic users. The MILET has been used by Deep-C scientists to investigate the downslope channel of the De Soto Canyon. Using this tool, continuous video and high-resolution digital images can be taken at altitudes of 2-5 m above bottom.



Ian MacDonald (FSU) working on the MILET benthic imaging platform during a summer 2013 research cruise.

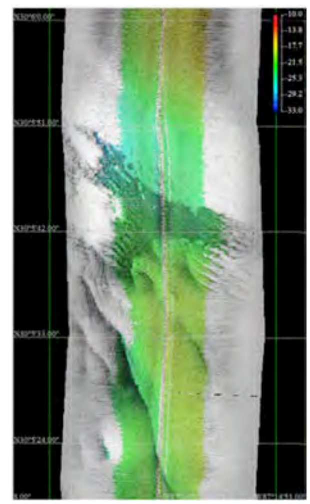


FSU PhD student Chris Malinowski flies the MILET 2-3 m above bottom by reeling cable in or out from the winch.

Mapping the seafloor with a C3D side scan sonar

A C3D side scan sonar maps the seafloor using sound to create maps of bottom type and bathymetry (elevation). These maps help us to understand how contaminants might move around in the marine environment and where monitoring for impacts might be warranted. The sonar is deployed on a cable in deeper water or mounted to the side of the research vessel. C3D side scan sonar is used to understand sediment transport patterns and to locate sensitive habitat hosting important benthic communities (i.e. coral) and essential fish habitat. High-resolution topographic imaging of the seafloor reveals new details about both high-relief and low-relief benthic habitats. Processed and interpreted geophysical data from side scan images collected on Deep-C research cruises has facilitated map development that includes new hard-bottom habitat and improved data on sedimentary transport and resuspension processes.

Chief scientist Stan Locker (USF) preparing his sonar system for deployment on a 2013 geomorphology research cruise.

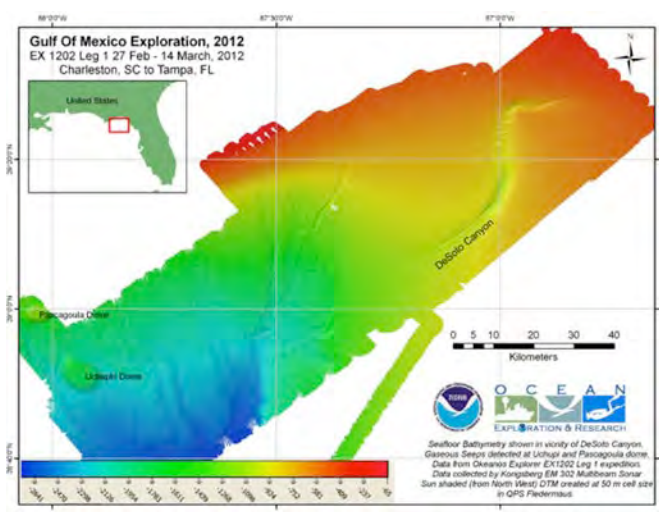


Side-scan imaging from the De Soto Canyon.

Bathymetry data from a 2012 NOAA expedition led to discovery of asphalt and oil seeps

The Deep-C geomorphology research team used bathymetry data collected during the 2012 NOAA R/V *Okeanos Explorer* cruise in the northern Gulf of Mexico to target a search for natural oil seeps in the De Soto Canyon region. Data indicated that natural hydrocarbon seeps could be found at salt domes on the western extent of De Soto Canyon. The use of bathymetry data from the 2012 NOAA expedition was vital to refining the Deep-C team's search strategy.

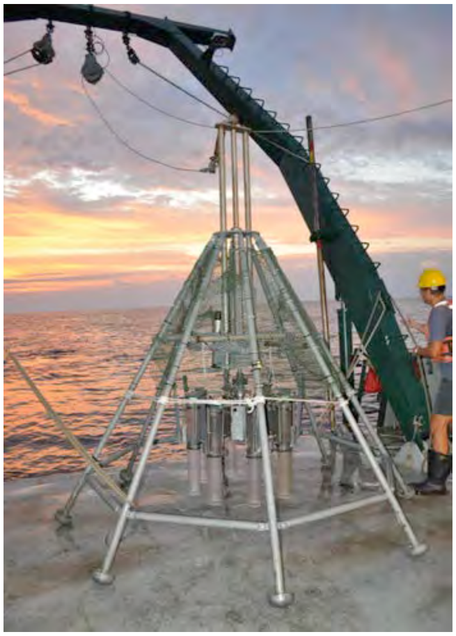
According to Dr. Ian MacDonald (FSU), "having the high-resolution bathymetry data that R/V *Okeanos Explorer* collected during its Gulf of Mexico surveys has lifted our ability to work smart in the De Soto Canyon by an order of magnitude or more. Because we had the bathymetric data set, we felt confident flying the MILET toolsled into the side of a seep mount which rose steeply about 400 meters above the surroundings. This effort resulted in remarkable imagery and the first-ever observation of asphalt volcanism in the eastern Gulf of Mexico." During a 2013 research cruise, MILET images confirmed benthic indicators of seeps at two potential sites.



Bathymetric data from NOAA R/V Okeanos Explorer, 2012 Northeastern Gulf of Mexico Expedition.

Multicore sampling of sediments helps with identification of benthic habitats

In addition to mapping the seafloor and utilizing digital imaging, geomorphologists are also incorporating sediment and water column data into their work on habitat classification in the De Soto Canyon region using tools such as a multi-corer, which is a simple, yet highly effective tool for collecting sediment cores that can be used to study benthic environments. This "spyder" device takes eight sediment cores from the ocean floor each time it is deployed.



Multi-corer on deck and an up close view of full cores. (Photo credit: Amy Baco-Taylor, FSU)

The instrument's pins and springs release through the motion of gravity and close as the tubes are lifted up. Each core tube is held in a separate detachable holder, enabling the sealed samples to be removed for analysis. It has no electronic connections or computer configuration, working off of gravity and precision-made moving parts. Deep-C scientists from multiple disciplines (i.e. biologists, chemists, and geologists) examine the sediments collected for the presence of oil, oxygen levels, benthic microorganisms, microbial communities, and degradation rate (rate a which materials breakdown).

Deep-C's Geomorphology Team

Dr. Ian MacDonald
Florida State University

Dr. Albert Hine
University of South Florida

Dr. Stan Locker
University of South Florida

What Did We Learn?

- New innovations in instrumentation, such as the MILET system, can aid researchers in mapping the seafloor and the water column.
- Maps have helped us understand how contaminants might move around in the marine environment and where monitoring for impacts might be warranted.
- Collaboration with NOAA resulted in the discovery of asphalt seeps in the northeastern Gulf of Mexico.
- Using a multi-corer, scientists learned more about the benthic habitats on the two sides of the De Soto Canyon.

LESSON PLAN:
Geologic Beginnings of the Gulf

Exploring the geologic history of the Gulf of Mexico

Objective: To describe the geologic development of the Gulf of Mexico's oceanic features, with emphasis on the De Soto Canyon. Students should know about plate tectonics prior to this lesson.

Standards: OLP 1-2; SC.912.E.6.3, SC.912.E.6.5

Time Required: One 50-minute class period

Keywords: plate tectonics, seafloor spreading, topography, geologic processes, De Soto Canyon

Materials:

- Whiteboard
- Projector
- Images of oceanic features
- Copies of the "Geologic Beginnings in the Gulf" article (see page 10)

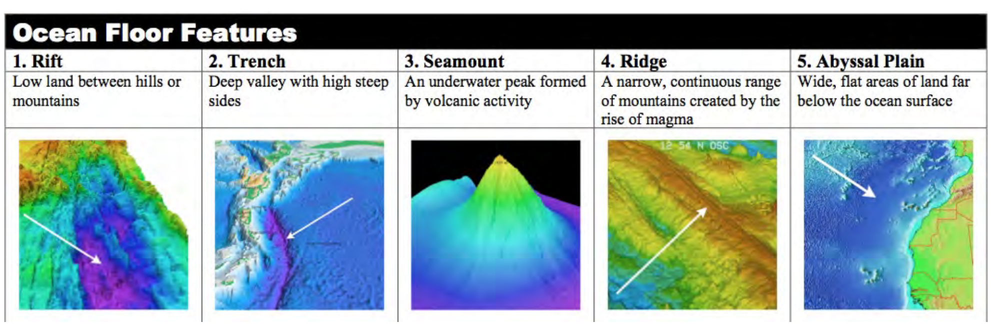
Background

The ocean floor is dynamic and has changed over the years due to tectonic activity. **Plate tectonics** is the theory in which the Earth's **lithosphere** (crust and upper mantle layer) is fragmented into pieces that are constantly moving and changing the geological features of the planet. There are **convergent boundaries** in which two plates come together (in the ocean, typically a trench is formed), and **divergent boundaries** where two plates move away from one another (in the ocean, typically a mid-ocean ridge is formed).

***Seafloor spreading** is a process of plate tectonics in which new oceanic crust is created and spreads outward. This process is how the Gulf of Mexico was formed.* The seafloor spreading motion moving continental blocks occurred from about 160 to 140 Ma (million years ago). This process moved the Yutacan Block to the south and the Florida Straits Block to the southeast, thus creating the ocean basin of the Gulf. The original basin was much larger than the basin today, extending north nearly to Oklahoma and west to West Texas. The margins filled in with sediment to form land. Multiple flooding events evaporated to form halite (salt) deposits and sediment eventually covered them. Today, the Gulf of Mexico is an ~3,400 m deep, semi-enclosed ocean basin whose entrance is dominated by two huge carbonate platforms—Yucatan Peninsula/Campeche Bank on the west and the Florida Platform on the east. Both support very wide shallow, submerged shelves. The northern Gulf of Mexico basin is also dominated by one of the largest river deltas in the world — the Mississippi Delta. It also has many salt-movement related structures forming the "dimple-like" bathymetric appearance in the deeper water areas. In the northeast section, the De Soto Canyon can be seen as an indentation.

Procedure

1. **Completing a lesson on formation of oceanic features prior is strongly encouraged, to give students a background in plate tectonics and oceanic features.**
   Possible Primer Lessons (see page 8 for links): "Formation of Oceanic Features" and "What's Really Under the Ocean?" contains Ocean Floor Feature Cards (shown at right) – sonar images, classification, vocabulary, and an assessment.



2. **Once the primer lesson is completed, review oceanic features by having small groups of students observe and explain features found in the images and then share ideas with the class.**

   Ask the following questions:

   - What geological features might one find on the ocean floor? (i.e. *seamounts, ridges, atolls, hills, continental shelf, continental slope, abyssal plain, abyssal hill, trench, and rifts*)
   - How could you tell one feature from the other? (i.e. *differences in color, shades, shape, or other markings*)
   - How do you think the feature formed? (i.e. *plate tectonic activities such as subduction, divergent boundaries, weathering erosion, current movement, or deposition of sediments*)

3. **Ask students how they think the Gulf of Mexico was formed?**

4. **Have students read the article, "*Geologic Beginnings of the Gulf of Mexico with Emphasis on the Formation of the De Soto Canyon" (see page 10)*.**

5. **Conduct an article discussion, make a list of key points on the whiteboard, and explain the seafloor spreading process.**

Article Assessment Questions

1. The Gulf of Mexico was formed by the process of ___________? *Seafloor spreading*.
2. Is it considered a true ocean basin? *Yes*.
3. What is the De Soto Canyon? *Not a true submarine canyon; it is an expansive, gently-sloped, geomorphic indentation in the modern shelf and shelf-slope system; contains a network of smaller canyons*.
4. What does the De Soto Canyon's geologic future hold? *Sediment infill*.
5. Was the original Gulf of Mexico basin larger or smaller than the basin today? *Larger, extending north nearly to Oklahoma and west to west Texas*.

Extension

Create a three-dimensional model of the Gulf of Mexico basin or specific features using modeling clay.

Resources & References

"Formation of Oceanic Features" Lesson Plan
http://www.cpalms.org/Public/PreviewResourceLesson/Preview/29756

"Geologic Beginnings of the Gulf of Mexico" Article
http://deep-c.org/news-and-multimedia/in-the-news/geologic-beginnings-of-the-gulf-of-mexico-with-emphasis-on-the-formation-of-the-de-soto-canyon

Ocean Features Handout
http://seagrant.uaf.edu/marine-ed/curriculum/images/stories/grade6/oceanfeatures.pdf

Seafloor Spreading Defined
http://education.nationalgeographic.com/education/encyclopedia/seafloor-spreading/

"What's Really Under the Ocean?" Lesson Plan
http://www.mbari.org/earth/mar_geo/bathy/under/under_ocean.html

ARTICLE REPRINT

Geologic Beginnings of the Gulf of Mexico with Emphasis on the Formation of the De Soto Canyon

By Albert C. Hine, Shane C. Dunn, and Stanley D. Locker, College of Marine Science, University of South Florida (Posted online August 14, 2013). Source: http://deep-c.org/news-and-multimedia/in-the-news/geologic-beginnings-of-the-gulf-of-mexico-with-emphasis-on-the-formation-of-the-de-soto-canyon

With the research now hitting full stride investigating the effects of the 86-day long BP oil spill triggered by the explosion and sinking of the Deepwater Horizon drilling platform (Macondo Site 252), it seems appropriate to review the geologic history of the Gulf of Mexico (Fig. 1). Here, we do that with a special emphasis on the De Soto Canyon, a feature in the northeastern Gulf of Mexico of particular interest to scientists.

Figure 1. The Gulf of Mexico is a ~3,400 m deep, semi-enclosed ocean basin whose entrance is dominated by two huge carbonate platforms—Yucatan Peninsula/Campeche Bank on the west and the Florida Platform on the east both supporting very wide shallow, submerged shelves. The northern Gulf of Mexico basin is also dominated by one of the largest river deltas in the world — the Mississippi. This small ocean basin also has many salt-movement related structures forming the "dimple-like "bathymetric appearance in the deeper water areas. Note the indentation in the northeast section, which is commonly named the De Soto Canyon on most maps and charts. (Illustration credit: Gulfbase.org)

One of the overlooked narratives of the disaster is why there is so much oil and gas in the Gulf of Mexico in the first place, since it is the center of huge investments in exploration and production. Indeed, today, the Gulf of Mexico provides 23% of the total US production of crude oil (according to US Energy Information Agency), 9% of the world's oil reserves, and 11% of the world's reserves (Nehring et al., 1991). Only the Arabian-Iranian Province supplies more. But, offshore drilling is a very fast-moving target worldwide, with reserve and production numbers changing monthly.

Contrary to political statements such as "drill baby drill", or "drill here, drill there, drill everywhere," which imply that drilling might occur *anywhere*, drilling can only be successful where oil and gas are found, and they are found in great abundance only where key geologic factors have allowed their development over geologic time. The key factors are:

- abundant and rich, organic source rocks,
- ideal pressure-temperature-time environments to convert organic matter in the source rock to kerogens and natural gas,
- abundant, highly porous and permeable reservoir rocks for hydrocarbon migration, and
- numerous suitable traps with seals to allow the upward migrating hydrocarbons to accumulate.

Oil and gas can form in trace amounts in many places, but economically-viable accumulations are realized only where these factors combine to form an ideal environment.

The Early Days— 200 to 160 million years ago (Ma)

The Gulf of Mexico, formed by the process of sea-floor spreading, and is considered a true ocean basin[1]. It formed as part of the complex breakup of the mega-continent Pangea starting about 180 million years ago (Ma), when a 6,000-km long ragged crack split Pangea into two supercontinents, Laurentia (consisting mostly of what is now North America) and Gondwana (consisting of what is now South America and Africa) (Fig. 2).

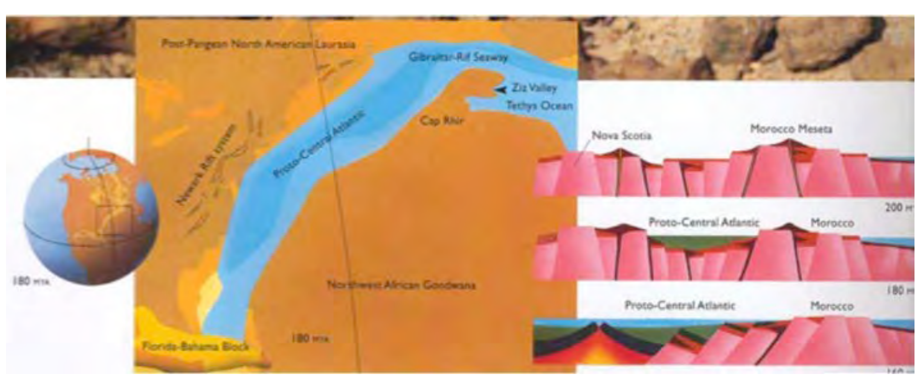


Figure 2. Simplified cartoon illustrating early ocean basin separating North America (Laurentia) from Africa (Gondwana). This water body was initially called the Tethys Sea and with further widening became the North Atlantic Ocean (modified from Redfern, 2001; Hine, 2013).

Prior to actual breakup, numerous long, narrow-rift basins formed due to extension and stretching of continental crust creating topographically low valleys surrounded by uplands, sometimes mountains, and bounded by large normal faults that were active during the Triassic and Early Jurassic periods, but are no longer active today (Fig. 3). Along the eastern continental margin of North America, they became filled with alluvial fans, deltas, rivers, and lakes, and shallow mud flats famous for their three-toed dinosaur footprints, but not filled with seawater. Some of these basins today control modern topography and drainage such as those in the lower Connecticut and Hudson River valleys. Other basins have been completely filled with non-marine sediments or buried and have little to no modern topographic expression.

Figure 3. Distribution of early rift basins along the eastern margin of North America formed when Pangea began to split apart. Note the position of the South Georgia Rift Basin (modified from

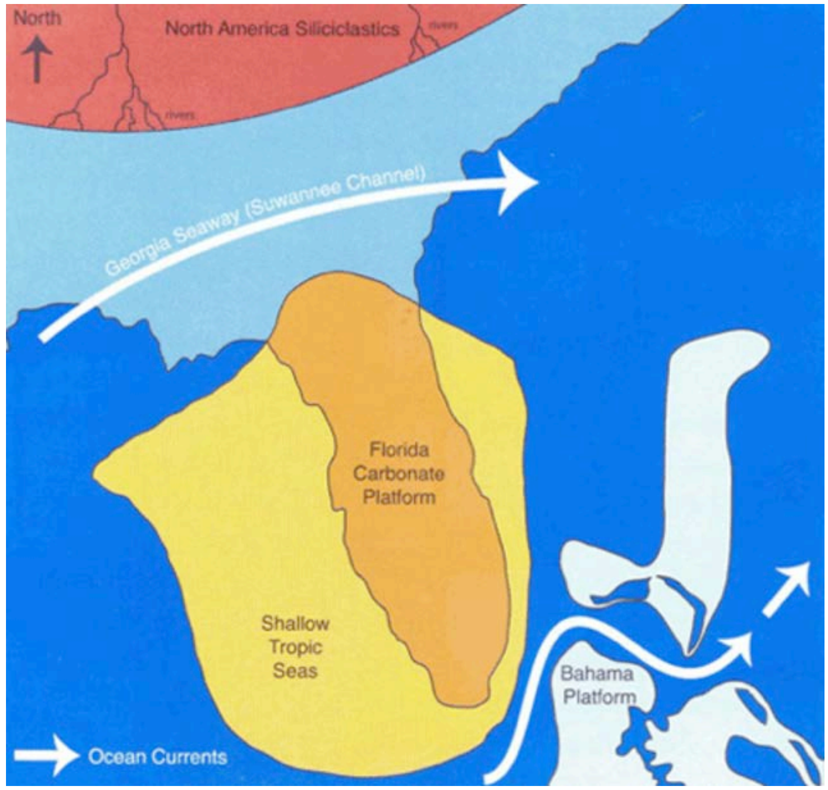


Figure 4. Illustration of seawater filling in the South Georgia Rift Basin forming the Georgia Seaway (modified from Redfern, 2001; Hine, 2013).

During this early extension and before the Tethys Sea (the proto-Atlantic Ocean) formed between Laurentia and Gondwana, a significant rift basin formed across South Georgia. This NE-SW trending structure, commonly called the South Georgia Rift Basin[2], was probably >500-km long, >100-km wide, and had about 1-km relief. Rifting ceased in this area but seafloor spreading continued to propagate around the peninsula Florida, splitting Laurentia from Gondwana and forming the Tethys Sea, where the southern and western parts became the Caribbean Sea and North Atlantic Ocean. Eventually, the South Georgia Rift Basin flooded with seawater, thus forming a seaway that has been referred to by a number of names—the Georgia Channel System, the Georgia Seaway the Suwannee Channel, and the Gulf Trough (Fig. 4). This seaway separated the Florida Platform from southeast North America, allowing carbonate sediments to accumulate in great abundance in Florida without being negatively influenced or even buried by continental sediments being shed off the rapidly eroding southern Appalachian Mountains.

Figure 5. Map illustrating opening on the Gulf of Mexico by movement of the Yucatan Block and Florida-Bahama blocks of continental/transitional crust (modified from Redfern, 2001; Hine, 2013).

The Early Gulf of Mexico—The Emplacement of Salt—160-140 Ma

The seafloor spreading motion moving continental blocks occurred from about 160 to 140 Ma. This process moved the Yucatan Block to the south and the Florida Straits Block (also known as the Florida Bahamas Block) to the southeast, thus creating the Gulf of Mexico basin (Fig. 5). The movement of these blocks of highly-stretched and extended transitional crust (continental crust intruded by oceanic crust-like rocks) eventually created a broad, deep basin still not yet permanently connected to the open ocean or filled with seawater. The primary early connections were to the Pacific Ocean to the west and the proto-Caribbean and Atlantic Ocean to the south and east respectively. Outline of original Gulf of Mexico basin (Fig. 6) extending beneath modern land areas. Salt beneath land areas in Texas, Louisiana, Alabama, and Florida were deposited in the earlier, much larger Gulf of Mexico Basin (Salvador, 1991).

The original Gulf of Mexico basin was much larger than the basin of today, extending north nearly to Oklahoma and west to West Texas (Fig. 6). Most of the original geologic basin filled along the margins with sediments to form land, leaving only a smaller portion of the original basin. As mentioned, the Gulf of Mexico basin also includes the Florida and Yucatan Platforms and their huge, now submerged, shelves.

Figure 6. Outline of original Gulf of Mexico basin extending beneath modern land areas. Salt beneath land areas in Texas, Louisiana, Alabama, and Florida were deposited in the earlier, much larger Gulf of Mexico Basin (Salvador, 1991).

Seawater poured into the developing Gulf of Mexico basin from the Pacific Ocean through small gaps in the Mexican terrain that would open and close with changes in local tectonics and global sea level. Due to the arid environment of this region, the seawater introduced during these multiple flooding events evaporated to form halite (NaCl) deposits up to 4-km thick. Eventually, the ocean crust formed by continued seafloor spreading, split the salt deposits into two provinces and the entire basin became permanently filled with open-marine, normal salinity seawater (Fig. 7). Sediments from the surrounding land mass began to accumulate on top of the salt (called the Louann Formation) and a huge physically-connected carbonate complex continued to grow (Yucatan-Florida-Bahama Platform). Continued infilling of the Gulf of Mexico basin from the North American continent explains why oil traps associated with salt structures are found well inland today—these traps originally evolved underwater within the earlier Gulf of Mexico basin (Figs. 6 & 7) but now lie beneath dry land.

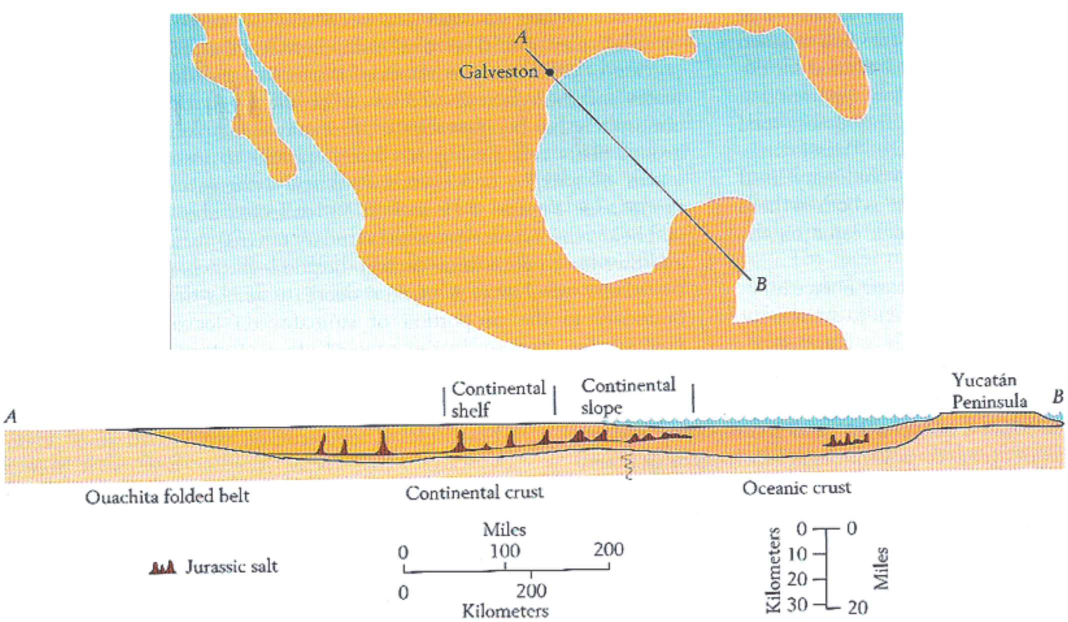


Figure 7. Cross section of the Louann Formation showing Jurassic salt deposits, which rose into domes in some places because of their low density. (Wilhelm and Dwing 1972).

The South Georgia Rift Basin also was partially filled with salt—particularly the western end that was connected to the larger Gulf of Mexico developing basin. It was this salt deposit that formed the highly visible diapirs that form topographic highs in the deeper portion of the modern De Soto Canyon.

What is the De Soto Canyon?

Based upon the presence of salt structures in the Apalachicola Embayment, most geoscientists think that the De Soto Canyon is fundamentally an indention in the trend of the West Florida and North Florida shelf. As a result, the De Soto Canyon represents a modern, but incompletely filled in western portion of the Jurassic South Georgia Rift Basin (Fig. 8). Most of the South Georgia Rift Basin and the flooded Georgia Seaway were completely filled by continental sediment eroding from the Appalachian Mountains by the Oligocene (~28 Ma). The Appalachian Mountains are thought to have been as high as the Himalayas when they were first formed. Given that the Himalayas are over 8,000-m high and the present day Appalachians are barely 2,000-m high, this suggests that approximately 6,000-m of rock were eroded, transported, and re-deposited over the past 300 Ma. These sediments formed the Mesozoic-Cenozoic continental margins of the southern United States, including much of peninsular Florida. This filling during sea-level lows allowed existing river deltas to migrate from South Georgia to North Florida. Today, one can drive from Florida up through Georgia on roads built on a flat coastal plain that covers the once 100-km wide x 500-km long x 1-km deep basin.

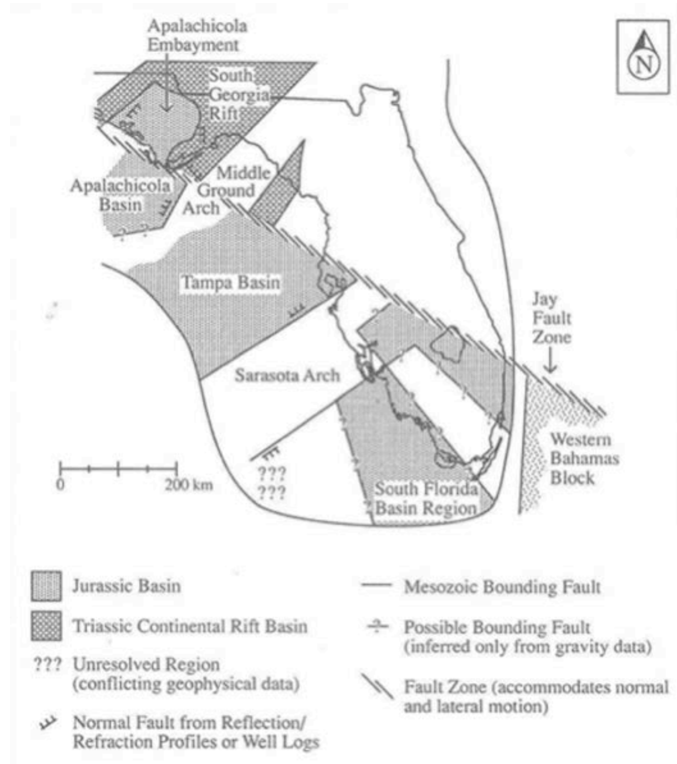


Figure 8. Illustration showing that the Apalachicola Embayment is actually part of the western end of the South Georgia Rift Basin. The De Soto Canyon occupies the western portion of the Apalachicola Embayment. (Smith and Lord, 1997).

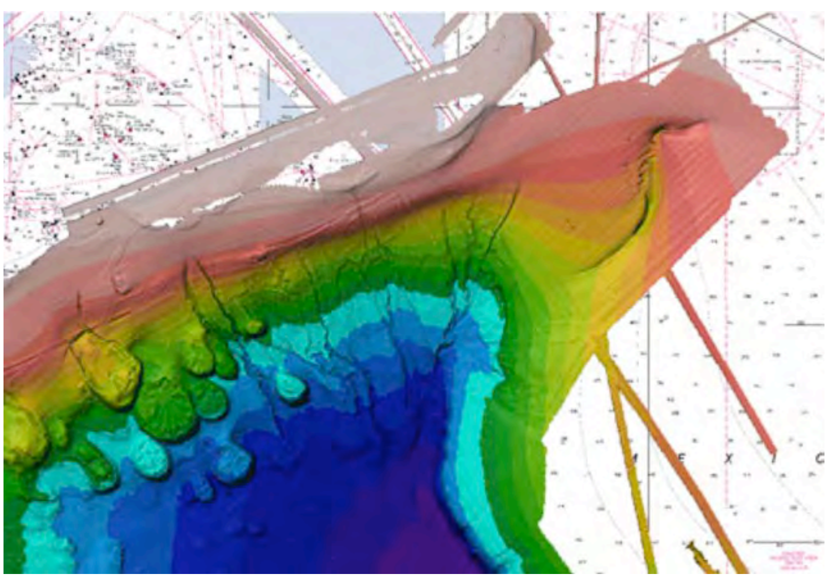


Figure 9. Multibeam image of numerous small downslope channels distributed within the broader De Soto Canyon indention (Source: Source map data from NGDC - National Geophysical Data Center, includes RV Okeanos Explorer and other multibeam data - Dr. Stanley D. Locker).

The De Soto Canyon area clearly is part of the Gulf of Mexico megaprovince (Fig. 9). But is it really a canyon? A submarine canyon, traditionally defined in geological oceanography, is a steep-sided (sometimes near vertical walled), narrow feature incised into a submarine slope. It can extend landward onto the continental shelf and seaward to depths of several (2-3) kilometers.

By this definition, the De Soto Canyon, in its broadest sense, is not a submarine canyon similar to the narrow, highly-incised, precipitous, steep-walled features such as the Hudson or Monterey Canyons or the hundreds of other well-known features around the world's continental slopes considered to be true submarine canyons (Fig. 10). It is, rather, an expansive, gently-sloped, geomorphic indentation in the modern shelf and shelf-slope system that is structurally controlled from below and represents the last unfilled segment of a huge Jurassic rift.

The details of this interpretation are the subject of the Ph. D. dissertation research of graduate student Shane Dunn at the University of South Florida, College of Marine Science.

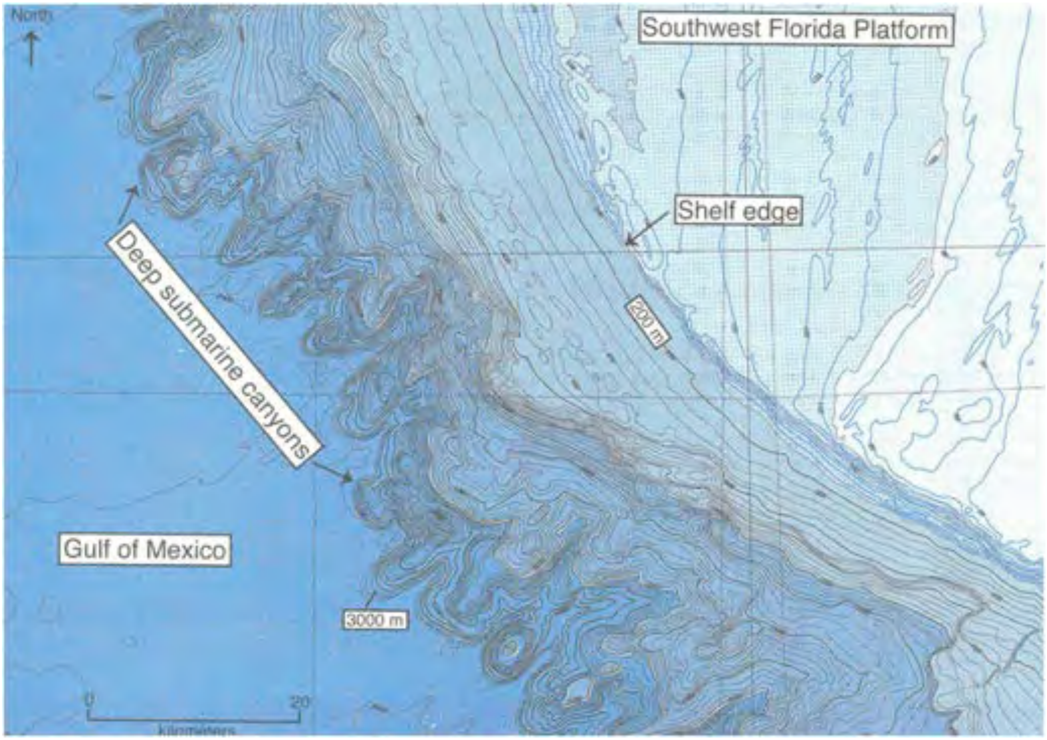


Figure 10. Submarine canyon complex along the base of the southwest Florida Platform. Some canyons have ~2 km of relief. These are headward-eroding, high-relief, steep-sided features that fit the classic definition of submarine canyon (NOAA National Ocean Survey map; Hine, 2013).

The modern De Soto Canyon contains a network of smaller canyons (many are more channel-like than canyon-like, given that the maximum relief of its canyons is ~100 m and most are much smaller) that will contribute sediment to its ultimate infill sometime in the geologic future. The De Soto Canyon also marks the long-term physical transition from the continental, siliciclastic sedimentary regime dominated by rivers along the north to the carbonate sedimentary regime dominated by shallow (pre mid-Cretaceous) and deeper water benthic and planktonic input (post mid-Cretaceous) to the south. Perhaps a more accurate term for this geologic feature is the De Soto embayment.

The De Soto Canyon in the Icehouse World—2.5 Ma to present

From the mid-Late Cretaceous (70 Ma) to the late Pliocene-early Pleistocene (~2.5 Ma), the Earth transitioned from a Greenhouse Earth—driven by very high CO_2 concentrations in the atmosphere that resulted in a very warm Earth with persistently high sea level—to an Earth that first accumulated a permanent ice sheet on Antarctica (beginning ~45 Ma). By ~2.5 to present, the Earth experienced high-frequency (23, 41, and 100 kya cycles; the well-known Milankovitch Cycles) glacial/interglacial events marked by the waxing and waning of the great northern hemisphere Laurentide and Fenno-Scandanavian ice sheets. Global sea levels fluctuated many dozens of times from ~50 to ~150 m amplitude during this latter period. We are still experiencing an Icehouse Earth, although at an interglacial stage having just come out of a the Last Glacial Maximum ending about 18 ka (18 thousand years ago) when sea level was about 120-125 m lower than present-day sea level.

The long-term transition from Greenhouse to Icehouse Earth, particularly in the past ~2.5 Ma, must have fundamentally changed the style of sedimentary infilling in the De Soto Canyon embayment. This transition and the nature of infilling resulting from many high frequency, high amplitude sea-level fluctuations that rarely occurred on the Greenhouse Earth is largely unknown. However, the imagery shown in Figure 9 clearly reveals erosive events creating a complex series of channels (small canyons) that accommodated transfer of sedimentary material from the upper slope or even the outer shelf to the base of the De Soto Canyon embayment. When and under what conditions this sedimentary transfer occurred creating this incised channel network is not known. Possibly, during sea-level highstands, infilling was not channelized and finer-grained sediments accumulated whereas during sea-level lowstands and stillstands, infill was coarser-grained and more channelized. But, existing published deeper penetrating seismic data and unpublished industry-based data do not indicate that the De Soto Canyon is a long-term erosional feature that is incising landward. Rather, it is a broad sedimentary basin that has undergone long-term infilling prograding seaward only interrupted by short-term, relatively small-scale erosional events.

Endnotes

[1]Other large bodies of water such as Hudson Bay, while geographically large, are not considered ocean basins because they did not form by seafloor-spreading tectonics. These are considered shallow, epicontinental (defined as “up on the continent”) seas that filled with seawater flooding large areas on top of continental rocks generally sea-level highstands.

[2]We maintain that the western end of this structural feature underlies and controls the location of the modern De Soto Canyon.

Acknowledgments

We thank Dr. Felicia Coleman for the wonderful review, which greatly helped to change the geologic prose to one more understandable for the general reading public. We thank Tracy Ippolito for additional editing, her patience, and her help while we generated this document.

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LESSON PLAN:
Mapping the De Soto Canyon

Underwater exploration using marine technology

Objective: To become aware and understand bathymetry and ways in which scientists can explore and map the seafloor using marine technology.

Standards: OLP 1, 2, 5, 7; SC.912.E.6.4, SC.912.E.6.5, SC.912.E.6.6

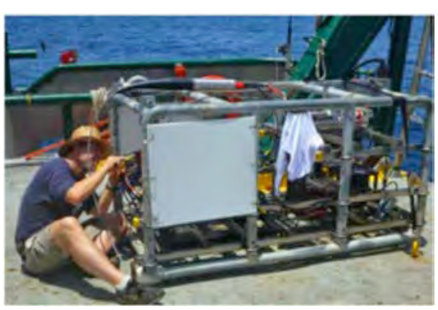
Time Required: One 50-minute class period

Keywords: bathymetry, side-scan sonar, ROV, AUV, MILET

Materials: Computer, projector, copies of the student worksheet (see page 16)

Background

The characteristics of the ocean floor in the Gulf of Mexico change greatly with depth and distance from shore. In many areas there are geological features such has rocky areas, canyons, steep slopes, and even natural oil and gas seeps. Together, these features influence the development of the many different and unique ecosystems. Mapping the floor of the Gulf is an important first step as scientists try to understand the diversity and abundance of marine life. On land, elevation is referred to as topography. In the ocean, the seafloor elevation is referred to as **bathymetry**. Bathymetry is the measurement of the depth of water bodies, including the ocean, rivers, streams, and lakes. Using sonar, scientists are able to map ocean trenches, ridges, plains, and submerged islands, creating maps that help them predict where different marine ecosystems—such as coral reefs and fishing grounds—may be found. Today, scientists make use of many different types of sonar systems for bathymetric mapping that range from single-beam depth measurements directly below a boat, to multi-beam and interferometric sidescan systems that record a broad swath of depth measurements extending to both sides of the boat. The swath mapping sonars can be attached to the boat or towed closer to the seafloor behind the boat in a towfish. The mapping sonars are also routinely operated on **Remotely Operated Vehicles** (ROVs – tethered to the boat) and **Autonomously Operated Vehicles** (AUVs – unattached and freely maneuvering small vehicles).



An area of particular interest to researchers is the De Soto Canyon. It is a broad southwest to northeast feature formed at the intersection between the Florida Peninsula and the southeastern portion of the continental U.S. The two components contain distinct features, which often support different ecosystems. The west/north side is the North American margin, where river flows have deposited sediment layers that are literally miles thick. In many places, these sediment layers are characterized by salt domes, economic hydrocarbon reserves and natural seeps. The east/south side is the Florida Platform – a huge structure comprised of carbonate rock with much less sediment accumulation.

Deep-C scientists Drs. Ian MacDonald (FSU) and Stan Locker (USF) are investigating the role that the De Soto Canyon plays in the transport of material and energy between the coast and the deep sea. Detailed bathymetric data collected by the NOAA *R/V Okeanus Explorer* on its 2011 expedition to the Gulf of Mexico was used to establish ten sampling sites for repeated measurement for sediment geochemistry, microbiology, macrofauna, and geomorphology of the benthic habitat. The sites are distributed at depths from 500 to 2500 m in two transects, one along the main axis of De Soto Canyon, southwest to northeast (along-canyon) and one northward across the steepest slope of the canyon (cross-canyon).

Using equipment such as **side-scan sonar** and the Modular Instrument Lander and Equipment Toolsled (**MILET**) system, quantitative imaging has been conducted to investigate the fine-scale geomorphology of the benthic transect. The Okeanus Explorer surveys and existing data had indicated that natural hydrocarbon seeps could be found at salt domes on the western extent of De Soto Canyon. MILET images confirmed benthic indicators of seeps at two potential sites. A brief survey of a location known as Peanut Hill revealed bacterial mats and asphalt extrusions. This is the first report of surface asphalts from the eastern Gulf of Mexico.

An unexpected patch of asphalt on Peanut Hill indicates natural hydrocarbon seepages.

Procedure

1. Ask students how scientists map the seafloor. How do they explore underwater topography, what tools do they use, why would we want to know what lies beneath the water?
2. Watch *Mapping the Seafloor* by NOAA at http://oceanservice.noaa.gov/caribbean-mapping/mapping-video.html (2:01min)
3. Visit the *Gallery: Sonar Operations* at http://oceanservice.noaa.gov/caribbean-mapping/gallery-sonar.html to learn about how sonar is used to map the seafloor and how scientists can determine whether the ocean bottom is smooth (mud or sand) or rough (coral or rocks).
4. Look at NOAA's infographic: *Tools of the Trade* http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html
5. Ask students if they have heard of the De Soto Canyon and if so what do they know about it?
6. Pass out student worksheets. Discuss the background information and describe how and why Deep-C scientists wanted to map the De Soto Canyon region.
7. Have students ID features on the map.
8. Collect student worksheets.

Source:http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html

Extensions

Have students read *Working Smart: Deep-C and NOAA Collaboration Improves Gulf Oil Research* http://gulfresearchinitiative.org/working-smart-deep-c-and-noaa-collaboration-improves-gulf-oil-research/

Read and Watch the ROV *Deep Discover*. *Okeanos Explorer* EX1402L3: Gulf of Mexico 2014 Expedition Dive 12: April 24, 2014: Tar Lilies http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/apr24/apr24.html

Resources & References

Learning Ocean Science through Ocean Exploration, Section 2: Mapping the Ocean Floor: Bathymetry http://oceanexplorer.noaa.gov/edu/curriculum/section2.pdf

Leg 1 Mission Summary: DeSoto Canyon Mapping Mission http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/leg1-summary/welcome.html

Gallery: Sonar Operations http://oceanservice.noaa.gov/caribbean-mapping/gallery-sonar.html

Mapping the Seafloor by NOAA http://oceanservice.noaa.gov/caribbean-mapping/mapping-video.html

Tools of the Trade Infographic http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html

USGS - National Seafloor Mapping and Benthic Habitat Studies: Head of De Soto Canyon, Northeastern Gulf of Mexico https://walrus.wr.usgs.gov/pacmaps/ds-index.html

Contributing Experts

Dr. Stan Locker at the University of South Florida, College of Marine Science
Dr. Al Hine at the University of South Florida, College of Marine Science
Dr. Ian MacDonald at the Florida State University, Department of Earth, Ocean, and Atmospheric Science

STUDENT WORKSHEET – Mapping the Seafloor in the Gulf of Mexico

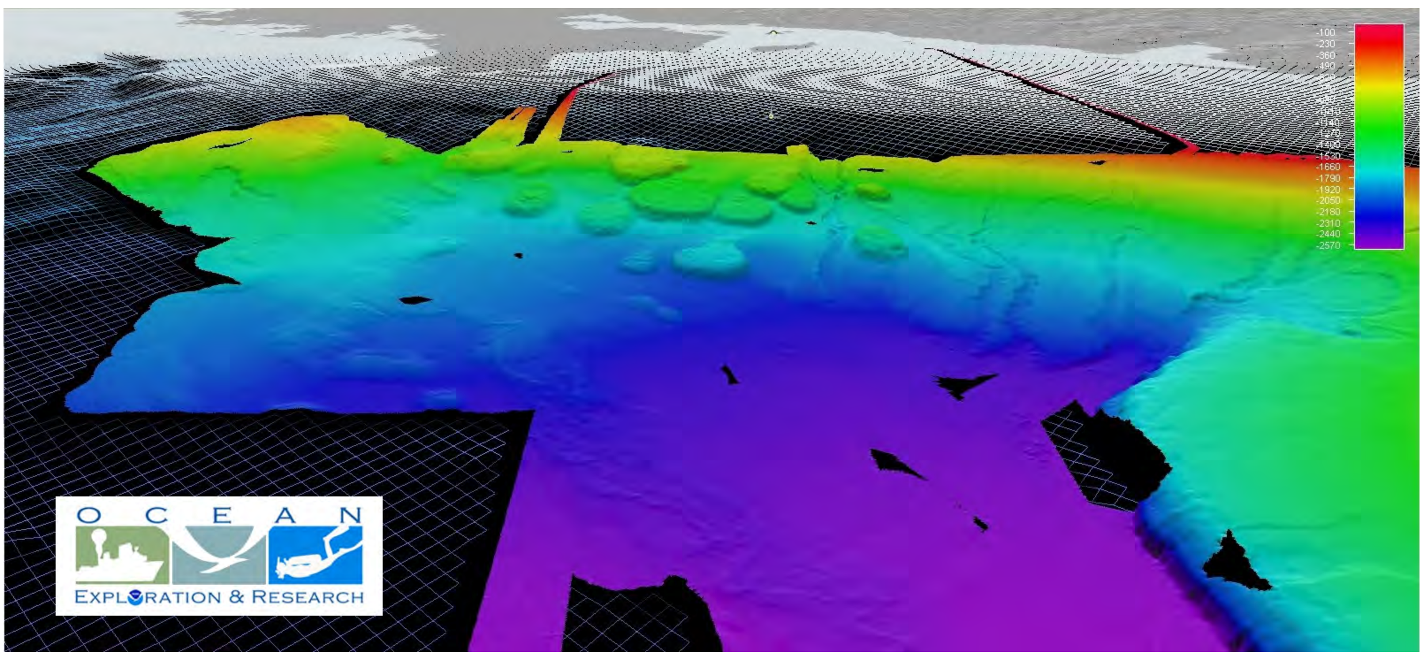
Bathymetric maps show the depth to, or elevation of, water bodies—including the ocean, rivers, streams, and lakes. These maps allow new information to be discovered and revealed about ocean geology and benthic habitats.

About the De Soto Canyon

- The De Soto Canyon lies approximately 100 kilometers south-southwest of Pensacola, Florida.
- The canyon's gradual gradients and unusual S-shape makes it distinct.
- It cuts through the continental shelf in the northern part of the Gulf, hosting an upwelling of deep nutrient-rich water and resulting in relatively high primary productivity in this area.
- The origin and distinct shape of the canyon has been debated to be a result of the presence of salt domes, erosion, and deposition due to bottom currents, and subsurface structure of possibly a salt ridge (Harbison, 1968).
- The canyon's bottom depths range from ~ 400-1,000 meters.

Source: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/leg1-summary/welcome.html

The De Soto Canyon is a key geologic boundary between two different sedimentary depositional regimes. The canyon is a geologic enigma in that the north side is dominated by complex topography associated with downslope movement, whereas the south side looks much more "pelagic" in nature—soft sediment cover, morphologically featureless. ~ Al Hine, USF Professor



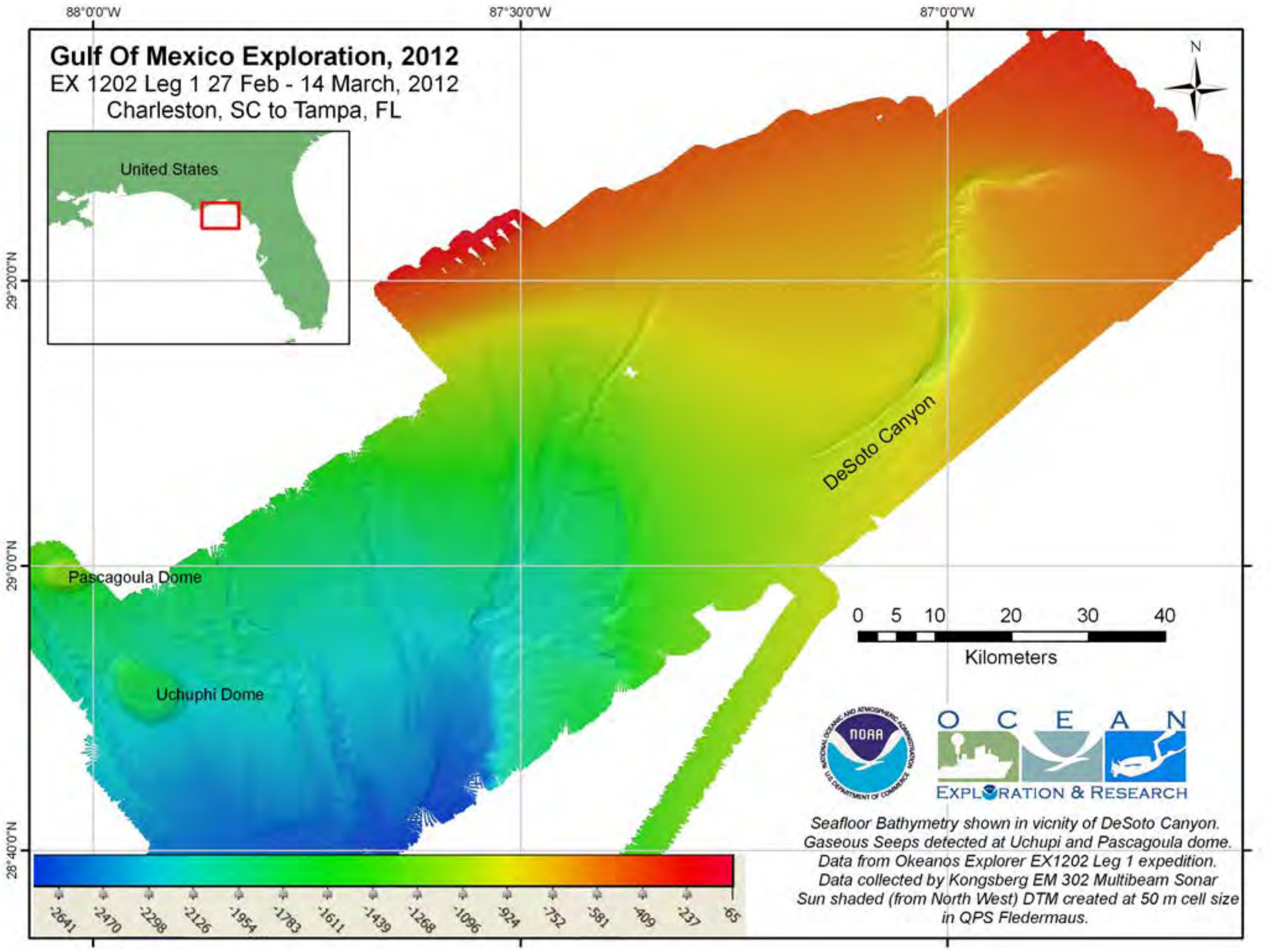
Multibeam bathymetry data showing the DeSoto Canyon (right) and Salt Domes (middle) in the northern Gulf of Mexico. EM302 bathymetry data acquired by NOAA vessel Okeanos Explorer during five cruises in 2011 and 2012. Image courtesy of NOAA Okeanos Explorer Program. Source: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/dailyupdates/media/apr15_update.html

About the Channel Systems

The channel systems seen in the R/V *Okeanos Explorer* map formed off the front of these deltas. One phase was 20,000 years ago during the last sea level lowstand. The shallow shelf was exposed, rivers deposited deltas at what is now the outer shelf break. Sediment from the deltas was channeled downslope (turbidities and debris flows) through the De Soto Canyon area into the deep Gulf of Mexico. Those channels may be mostly inactive now—but we do not know how much present-day ocean currents may cause sediment to move in the channels. This would be important for understanding if the 2010 Deepwater Horizon oil spill contaminants are being reworked and redistributed, further impacting bottom communities. Further research is needed—a project waiting for future students-turned-scientists to tackle.

Mapping Activity

On this map, identify the following features: salt domes, slope channel systems, the De Soto Canyon, and the continental shelf margin.

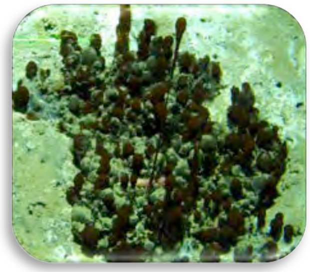


Bathymetric map of the De Soto Canyon generated at 50 meter grid cell size resolution based on preliminary data processing onboard during the expedition. Source: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/leg1-summary/media/desoto.html

Questions

1. What is the general shape of the De Soto Canyon?
2. Are there other canyons or features? Are these features easy to distinguish?
3. Are there any abrupt transitions?
4. What do the colors represent?
5. What is the depth on the deepest part shown on the map?
6. Why is it important to know the bathymetry of the De Soto Canyon?
7. How might the physical features of this region affect ocean currents and circulation in the area?

LESSON PLAN:
Seeping through the Seafloor



Natural Oil Seeps - Part 1

Objectives: To learn about natural hydrocarbon (oil) seeps in the Gulf of Mexico and their associated animal communities. To understand the presence and movement of oil and gas are essential for specific deep-sea organisms to flourish.

Standards: OLP 1, 5; SC.912.E.6.5, SC.912.E.6.6

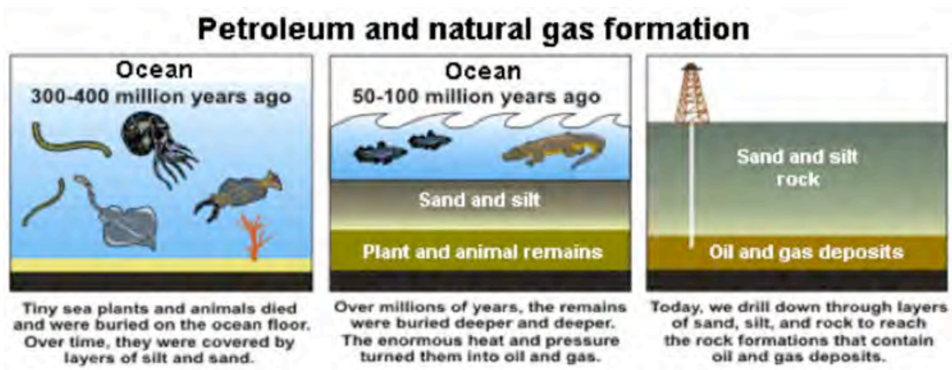
Time Required: One 50-minute class period

Keywords: natural seep, reservoir**,** gas hydrate, oil slick, deep-sea communities

Materials: Computer, projector, photos

Background

According to Woods Hole Oceanographic Institution, as much as one half of the oil that enters the coastal environment comes from **natural seeps** of oil and natural gas. The oil was formed from plants and animals (organic matter) that died and were buried over millions of years on the seafloor. With time, heat, and pressure, oil and natural gas were created.



Source: U.S. Energy Information Administration (public domain)

Geologic exploration is continually under way in search of new oil and gas deposits, which are often found together. These mixtures are less dense than rock and migrate upward through porous rock layers accumulating in pools beneath nonporous or impermeable rock layers. This process created expansive **reservoirs** that lie deep beneath the seafloor. Petroleum companies tap into these reservoirs to pull oil to the surface, to be refined and sold. But at natural seeps, oil leaks out of these reservoirs little by little, slowly making its way through sediments to the seafloor.

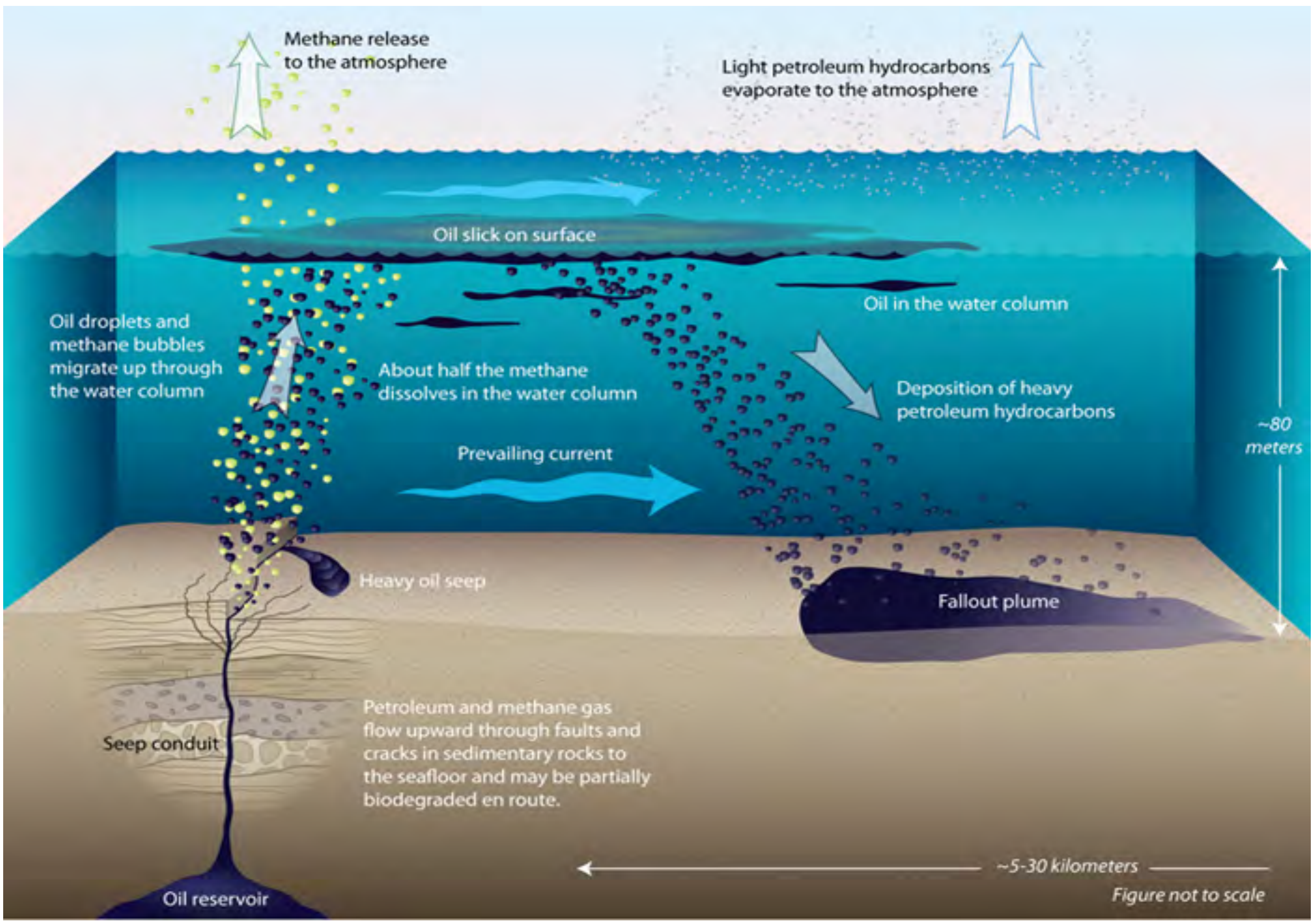
Natural seeps are geologic features known to occur in clusters around the world, such as off the southern coast of California and in the Gulf of Mexico. They are still relatively unstudied. In the Gulf, they can be found from depths of about 300ft to 12,000ft and concentrated in the central and western Gulf, from the U.S. south to Mexico. In locations where seeps are found, oil flows slowly up through networks of cracks forming springs of hydrocarbons. Lighter compounds rise buoyantly to the surface and evaporate or become entrained in the ocean currents; others fall to the seafloor and collect over hundreds or thousands of years. Seeps are often found in places where oil and gas extraction activities are also located.

Natural Seep Formations in the Gulf of Mexico

Image Credit: Dr. Ian MacDonald, FSU (2012)

As a result, many **surface oil slicks** and **tar balls** caused by seeps are often attributed to releases from oil and gas platforms. NASA uses satellite images of the sea surface to locate and track the oil slicks (see image to the right), which then can be used to locate the oil seeps at the seafloor. The question arises, then: If oil occurs naturally in the ocean and if seeps are the biggest single source, why is there concern about the occasional accidental spill? The answer lies in the nature and rates of oil inputs by these different sources. Seeps are generally very old and flow at a very slow rate. Flow rates will be discussed in Part 2 of this lesson.

Satellite imagery of oil slicks in the Gulf of Mexico. Source: NASA Earth Observatory



This illustration shows the route traveled by oil leaving the subseafloor reservoir as it travels through the water column to the surface and ultimately sinks and falls out in a plume shape onto the seafloor where it remains in the sediment. (Illustration by Jack Cook, Woods Hole Oceanographic Institution)

Surviving Near the Seeps: How Oil Feeds the Deep Sea

Excerpts from Caroline Johansen's Smithsonian Blog

Posted online November 18, 2014
Source: http://ocean.si.edu/blog/how-oil-feeds-deep-sea

When a large amount of oil is spilled into the ocean, there can be catastrophic results. But did you know that a little bit of oil in the ocean is actually necessary for many organisms to survive?

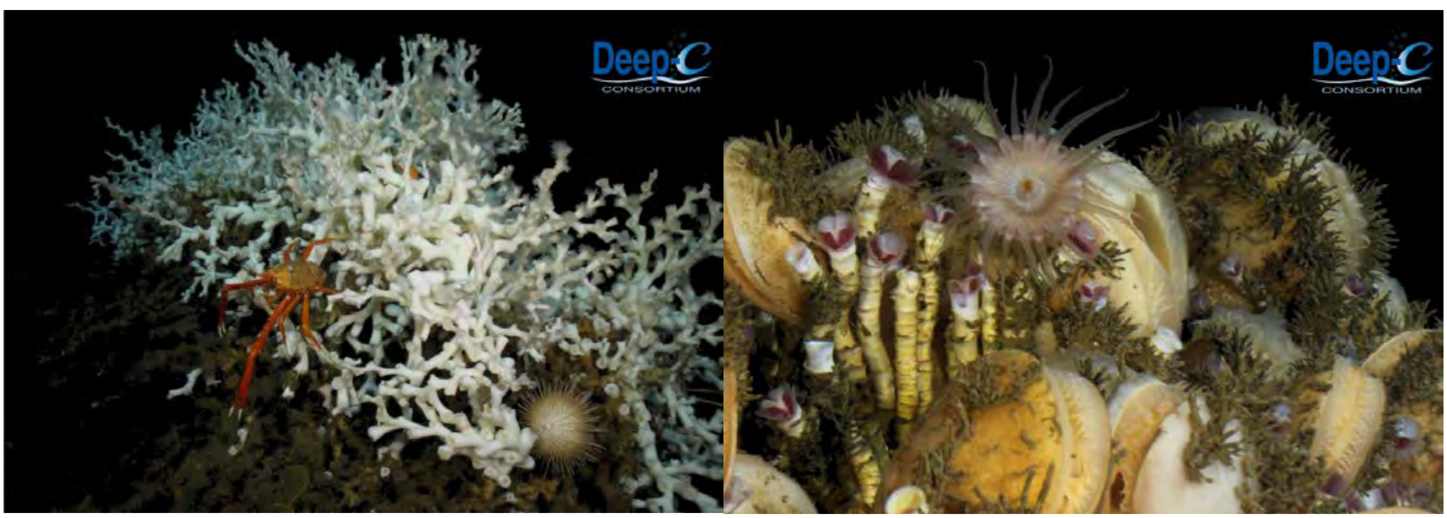
In the Gulf of Mexico, oil seeps are often associated with solid ice-like structures called gas hydrates (also called methane hydrates), which accumulate on the bottom around the seep. Gas hydrate is made up of a gas molecule (often methane, CH_4) trapped in a cage of water molecules. These gas-trapping cages are rigid in structure but very sensitive to temperature and pressure and will break apart if there is a drastic change. When they do break apart, the gas is released into the water. We see an abundance of wildlife including bacterial mats, ice worms (which burrow through the gas hydrates and graze on the bacteria), mussels, clams, crabs, eels, and fish living around these seep sites. These organisms are adapted to these toxic conditions. A few unique species of animals are actually able to use the hydrocarbons and other chemicals as a source of metabolic energy. Microbial (bacteria) degradation is active in these locations. The migration of natural oil and gas is extremely important for deep-sea communities.

Ice worms on a methane hydrate. Methane is the simplest hydrocarbon, and is the primary component of the natural gas that we burn for energy. Image courtesy of NOAA Okeanos Explorer Program.

Fun Fact from Ocean Explorer: If you hold a hydrate nodule in your hand and light it with a match, it will burn like a lantern wick. There is fire in this ice!

The deep sea is often thought to be a barren, unfavorable place for life; however, we see a diverse congregation of organisms flourish around these natural seeps.

Communities Near Natural Oil Seeps



Unique deep sea communities near natural oil seeps in the Gulf of Mexico. These ecosystems are an oasis of life where deepwater corals, crabs, mussels, tubeworms, and bacteria thrive.

Procedure

1. Begin a class discussion on natural oil seeps by asking the students where they think oil in the Gulf of Mexico comes from. Brief students on how oil is formed.

2. Guess how many known natural oil seeps are in the Gulf? (*Approximately 900-1,000*)

3. Project map images of the natural seeps in the Gulf of Mexico http://sarsea.org/natural_seapage.html

4. Watch "Geology in the Gulf" video https://www.youtube.com/watch?v=bcv8yUK_iWU and discuss the key points:
   - In the northern Gulf of Mexico, there is oil and gas-baring shale with a salt sheet underneath and a layer of sediment on top.
   - As these different geological forces interact, cracks in the oil baring shale form and natural seepage comes out of the seafloor.
   - Thousands of places on the Gulf's seafloor, oil is naturally seeping.
   - Special communities of animals such as mussels, tubeworms, and bacteria thrive in those environments.
   - Bacteria eat oil and as a byproduct they create a chemical environment, which rocks form. In places where oil seeps are located, carbonates form and where there is rock, deep-water corals grow.
   - The type of species that are seen near these natural seeps change with depth.

5. Discuss communities that thrive in these environments.

Questions

1. What is a natural seep and where are they located? *A place where oil naturally seeps from the seafloor; they are located in clusters off the southern coast of California and in the Gulf of Mexico*

2. Where does the oil go that is leaked out of the seep? *Travels through the water column to the surface*

3. How does NASA track the oil slicks? *Using satellite imagery*

4. Is oil always bad for the environment? *No, some communities thrive on these natural seeps*

5. What animals thrive in natural seep environments? *Bacteria, ice worms, mussels, clams, crabs, eels, and fish*

Resources & References

Gas Hydrates http://oceanexplorer.noaa.gov/facts/hydrates.html

"Geology in the Gulf" Video by coexploration https://www.youtube.com/watch?v=bcv8yUK_iWU

Natural Gas http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_home

Natural Seepage of Hydrocarbons in the Gulf of Mexico http://sarsea.org/natural_seapage.html

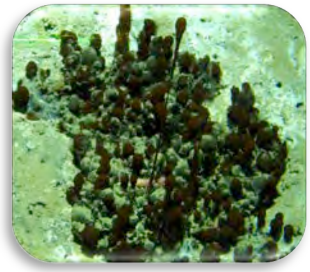
NOAA Ocean Explorer: The Ecology of Gulf of Mexico Deep-sea Hardground Communities
http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html

Oil in the Ocean: Natural Oil Seeps http://www.whoi.edu/oil/natural-oil-seeps

Ocean Portal Blog "How Oil Feeds the Deep Sea" http://ocean.si.edu/blog/how-oil-feeds-deep-sea

Perspectives Video – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1
http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GGMD13_CJ_1.aspx

LESSON PLAN:
Calculating Flow Rate



Natural Oil Seeps - Part 2

Objectives: To define flow rate, conduct experiment, calculate flow rate, and convert units. To understand how rates are calculated from natural oil seeps.

Standards: OLP 1, 5, 6; SC.912.E.6.5, SC.912.E.6.6, SC.912.N.1.7

Time Required: One or two 50-minute class period(s)

Keywords: flow rate, natural seep, experiment

Materials:

- Calculator

For Faucet Flow Rate Lab each group needs:

- Faucet Flow Rate Worksheet
- Water faucet
- Gallon jug (i.e. empty milk jug)
- Stopwatch

For Demonstrations:

- Water Bottles or Small Aquariums (2)
- Straws or Air Stone/Bubblers (2)
- Water
- Vegetable Oil

Background

Seeps release toxic chemicals, but they generally flow at a very low rate. The organisms that live near the seeps are adapted to these conditions. Some unique species of animals are able to use the hydrocarbons and other chemicals as a source of metabolic energy. The material flowing from seeps is often heavily biodegraded by microbial action deep below the ocean floor.

"*Seeps are often looked upon as a living laboratory for scientists to study how natural processes affect the fate of released oil or how individual species or communities of plants and animals are capable of dealing with the burden of otherwise toxic chemicals. From this may one day come a better understanding of how to help places affected by oil spills recover and regain much of their pre-spill health and function*" (WHOI-Oil in the Ocean: Natural Oil Seeps, 2014).

Calculating the Number and Size of Bubbles

Excerpts from *"How Oil Feeds the Deep Sea" by Caroline Johansen, FSU PhD student*

"One of my research goals is to determine how much oil and gas is released by these natural seeps. We use video cameras to film the exit points of oil bubbles at the sea floor. A video time-lapse camera is placed close to the seep site and is left to take video footage for extended periods of time. We deploy the cameras at depths of around 4,000 feet (1,200 meters), which is deeper than any diver can go. Instead, we use remotely operated vehicles (ROVs) controlled by pilots on a research vessel to place the camera in the right spot at the bottom of the ocean…When we bring the camera back up, I use automated image processing techniques that I developed to count the bubbles filmed. Calculating the number and size of bubbles can give us an idea of how much oil and gas is released from natural seeps.

Some areas have rapid bubble release, and some areas extremely slow. The amount of oil and gas in the bubbles also differs. Some natural seep areas release very oily bubbles, which we can identify by their dark brown color. Others have much higher gas content, where you see shiny clear spheres bubbling out of the gas hydrate. We are still in the process of investigating exactly why we see such differences between the bubble releases at separate natural seep areas, but this bubble counting technique I have developed allows us to get a range of bubble release rates. By knowing where this oil and gas comes from, how it travels through the sediments to the sea floor, and how much oil and gas is being released, we can begin to understand the complex dynamics of these deep-sea seep systems.

We know that the migration of this oil and gas is extremely important for deep-sea communities. The deep sea is often thought to be a barren, unfavorable place for life; however, we see a diverse congregation of organisms around these natural seeps. The presence and movement of oil and gas is essential for these organisms to flourish and could possibly give us insight to how the first life forms evolved on Earth."

Comparing Natural Oil Seeps with the BP Discharge

Source: Testimony of Ian R. MacDonald, Professor of Oceanography, FSU. (2010). *Determining the Rate of the BP Oil Discharge and Comparison with Natural Oil Seeps.* National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

"An active natural seep discharges about 10 barrels of oil per day (BOPD) with variable magnitudes of gas. The BP discharge was as much as 62,000 barrels of oil and over 31,000 barrels of oil equivalent gas during the initial phases of the emergency, decreasing to an estimated 53,000 BOPD at the end."

"Oil from natural seeps, like the oil that rose to the surface from the BP well, leaves traces that can be detected by satellite remote sensing. Natural seeps create floating layers (slicks) that are <1% of the thickness of human hair (<1µm) and cover surface areas of 0.5 to 1 km^2. The oil from BP's discharge created large slicks with similar thicknesses and included substantial areas around the well where the oil was at least 100 fold thicker. In all, the surface oil from the discharge covered an area over 20,000 km^2 during much of the discharge episode."

"The BP oil discharge was at least 10,000 times more concentrated in space and time and about 12 times greater in magnitude than the total annual release from natural seeps of the Gulf of Mexico."

Flow rate is the volume of water passing a point in a fixed period of time. Flow rate is usually measured in cubic feet per second (cfs or ft^3/sec) but it can also be measured in gallons or liters per minute or second.

For example, if a running faucet took one minute to fill a gallon container, its flow rate would be one gallon per minute.

Water flow in a stream, river or pipe also has a flow rate. The flow rate in a river, stream or pipe can be determined by multiplying water velocity by the cross-sectional area. For example, if water was flowing through a 1 foot diameter pipe (area = 0.8 ft^2) at 5 feet per second, the flow rate would be 0.8 ft^2 x 5 ft/sec = 4 ft^3/sec.

Procedure

1. **Review Background Information and Read aloud** "Calculating the Number and Size of Bubbles (Excerpts from *How Oil Feeds the Deep Sea by Caroline Johansen*)" to the class.

2. **Watch the CPALMS Perspectives Video** – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1 http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GGMD13_CJ_1.aspx (5:42min)

3. **Faucet Flow Rate Activity** *Adapted from Teaching Engineering*
   Summary: Students conduct experiments to determine the flow rate of faucets by timing how long it takes to fill gallon jugs. They do this for three different faucet flow levels (quarter blast, half blast, full blast), averaging three trials for each level. They convert their results from gallons per second (gps) to cubic feet per second (cfs).

   One important aspect of good experiments is repeating the experiment and averaging the data from numerous trials. Averaging the data from repeated trials reduces data error.

   1. Divide the class into three groups and hand out the Flow Rate Experiment worksheet.
   2. Explain the experiment and read the procedure.
   3. Instruct Group 1 to complete Table 1 gathering the Full-Blast Data; Group 2 to complete Table 2 and gather the Half-Blast Data; and Group 3 to complete Table 3 and gather the Quarter-Blast Data.

4. Have groups begin the experiment and make sure that they record the data in the correct locations (tables) on the worksheet.
5. When students are finished with the faucet, timing and jug filling, instruct them to dry their lab area and share data across the different groups.
6. Then groups can begin graphing and calculating. The calculation of flow rates in gallons per second takes place in Tables 1, 2 and 3. The calculation of flow rates in cubic feet per second takes place in Table 4. (If necessary, assign calculations as homework.)

4. **Discuss and Demonstrate**. How it would be different with oil. (Density difference between water and oil and how this affects fluid flow)…Stokes Law of Fluid Flow
   Demonstration that represents two different substances that flow in the ocean with differing densities: Place a straw to the bottom of a water-filled (¾ full) bottle, blow air through the straw, and watch the flow rate of "gas" rise up. Repeat using a bottle ¾ filled with vegetable oil and compare. Discuss what factors would change the rate.

   *This could also be demonstrated using small aquariums and bubblers (air stones). Fill one aquarium with water and the other with oil. Place a bubbler or air stone in the bottom on the tank. Compare and contrast the flow rate in the different substances.

   Food for Thought: Introduce the three-dimensional aspects of the ocean…meaning the flow rate of less dense substances will want to flow upwards (vertically), but there are also horizontal factors in the ocean such as currents which would deflect the path of the flow.

5. **Discuss** "**Comparing Natural Oil Seeps with the BP Discharge"** Talk with the students about how they think the amount of 2010 BP oil spilled compared to the natural oil seeps.

Questions

1. What is flow rate? Why is it important? *The volume of water passing a point in a fixed period of time; gives us an idea of how much oil and gas is released from natural seeps*
2. How is flow rate calculated? *Cubic feet per second (cfs or ft³/sec)*
3. What is the difference between the flow rate of oil and water? *Oil should have a slower flow rate*
4. How is flow rate calculated for natural oil seeps? *Using automated image processing techniques to count the bubbles filmed by the ROV; then calculating the number and size of bubbles*
5. How do you think the amount of oil that flows out of natural oil seeps compares to the amount of oil discharged by the 2010 Deepwater Horizon Spill? *Answers will vary*

Resources & References

Ocean Portal Blog "How Oil Feeds the Deep Sea" http://ocean.si.edu/blog/how-oil-feeds-deep-sea

Oil in the Ocean: Natural Oil Seeps http://www.whoi.edu/oil/natural-oil-seeps

Perspectives Video – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1
http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GGMD13_CJ_1.aspx

Teaching Engineering Lesson: Flow Rates of Faucets and Rivers
Contributed by: Civil and Environmental Engineering Department, Colorado School of Mines
https://www.teachengineering.org/view_lesson.php?url=collection/csm_/lessons/csm_engineering_our_water/csm_lesson1_flow_rate_experiment.xml

Testimony of Ian R. MacDonald, Professor of Oceanography, Florida State University. (2010). ***Determining the Rate of the BP Oil Discharge and Comparison with Natural Oil Seeps.*** National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling
http://www.motherjones.com/files/092710macdonaldtestimonyrevised.pdf

Contributing Expert: Caroline Johansen, PhD student at Florida State University

Group Members:____

Flow Rate Experiment Worksheet

Adapted from Teaching Engineering

Brainstorm with your group and then summarize your answers in the spaces provided.

What is flow rate? How does it relate to your life?

____

____

____

____

You will conduct experiments to determine the flow rate of faucets by timing how long it takes to fill gallon jugs. The class will do this for three different faucet flow levels (quarter blast, half blast, full blast), averaging three trials for each level. Your group will convert the results from gallons per second (gps) to cubic feet per second (cfs).

<u>Materials</u>

- A water faucet
- An empty gallon jug
- A stopwatch

<u>Procedure</u>

1. Select one person to be the timer and one to hold the gallon jug.
2. Turn the faucet on full blast. Estimate the time you think it will take to fill up the gallon jug. Record your answer in Table 1.
3. Start the timer at the same time as the jug is placed under the faucet.
4. Determine how much time (in seconds) it takes to fill the jug all the way to the top. Record the time in Table 1 on Data Sheet 1 in the line called Full-Blast Trial #1.
5. Empty out the jug.
6. Repeat steps 3-6 two more times, and fill in the lines called Full-Blast Trial #2 and Full-Blast Trial #3 in Table 1.
7. Now turn the faucet on half-blast. Repeat steps 2-6 and record your data in Table 2. ***Make sure to open the faucet to the same place for each trial!***
8. After you have done three tests at half-blast, turn the faucet to quarter- blast, and repeat steps 2-6. ***Make sure to open the faucet to the same place for each trial!*** Record your data in Table 3**.**
9. Use your data to determine the flow rate for each of your trials; record the answers in each table.

HINT: You know how many seconds it took to fill up one gallon, so IF it took 17 seconds to fill up the gallon jug your calculation might look like this:

$$\frac{1gal}{17\sec} = 0.059 gallons / second$$

Table 1 – FULL-BLAST DATA

Faucet Level: **Full Blast**	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

Table 2 – HALF-BLAST DATA

Faucet Level: **Half-Blast**	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

Table 3 – QUARTER-BLAST DATA

Faucet Level: **Quarter-Blast**	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

10. Create a graph of your average flow rate (on y-axis) versus average time to fill the jug (on x-axis). Your graph should have three data points. Include a title and labels on each axis.

11. Draw a “best fit” straight line through the data points.

12. What percent does the flow rate increase as you go from half blast to full blast?

13. Using the graph, what would the flow rate be at ¾ blast?

14. Now that you have your flow rates in gallons per second, you need to convert them to cubic feet per second. Cubic feet per second are very common units for flow rate.
Fill in Table 4 using the following conversion:

$$1\,gallon = 0.134\ ft^3 \text{ or } 0.134 \text{ cubic feet}$$

<u>HINT</u>: IF your flow rate was 0.059 gal/sec you would divide by 0.134 ft^3/gal (given above), and your calculation would look like this:

$$\frac{0.059}{0.134} = 0.44\ ft^3\ /\ sec \text{, or } 0.44 \text{ cfs}$$

Table 4: Converting Gallons/Second to Cubic Feet/Second

Faucet Level	Flow rate (gal/sec) ***FROM DATA SHEET 1***	Flow rate (cubic feet per second)
Quarter-blast		
Half-blast		
Full-blast		

Flow rate is the volume of water passing a point in a fixed period of time. Flow rate is usually measured in cubic feet per second (cfs or ft^3/sec) but could also be measured in gallons or liters per minute or second. For example, if a running faucet took one minute to fill a gallon container, its flow rate would be one gallon per minute. Water flow in a stream, river or pipe also has a flow rate. The flow rate in a river, stream or pipe can be determined by multiplying water velocity by the cross-sectional area. For example, if water was flowing through a 1 foot diameter pipe (area = 0.8 ft^2) at 5 feet per second, the flow rate would be 0.8 ft^2 x 5 ft/sec = 4 ft^3/sec.

LESSON PLAN:
Sifting through Sediments

Investigating sediment cores from the NE Gulf of Mexico

Objectives: To understand the role that sediment investigations play in understanding ecosystem development. To investigate seafloor composition, discuss the potential effects of Deepwater Horizon oil settling on the seafloor, and analyze a sediment core. Students should know about geology of the Gulf of Mexico.

Standards: OLP 1, 6; SC.912.E.6.4

Time Required: One 50-minute class period

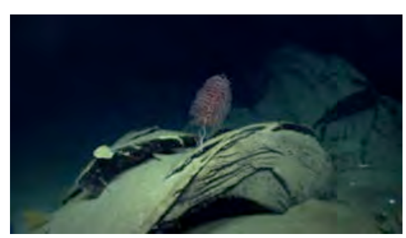
Keywords: sediment, multi-corer, benthic, smear slide analysis

Materials:
- Whiteboard
- Modeling clay
- An 8-inch cylindrical vessel filled ¾ full with corn syrup; mark off the top of the liquid with tape/marker and then mark off a line 20cm below that
- Stopwatch
- Rocks in various sizes
- Copies of the article "*"Scientists Find Thick Layer Of Oil On Seafloor" (on page 33)*
- Sediment cores (see lesson for more information)
- Microscope
- Slides
- Toothpicks

Background

The ocean floor is made almost entirely of different types of **sediment** such as mud, sand, and gravel. This sediment comes from a variety of places including materials washed into the ocean from rivers, the decomposition of plankton and sea animals, chemical reactions (i.e. volcanoes and vents), and dust carried by the wind that settles in the ocean. Surprisingly, material from land makes up 75% of seafloor sediment. The Mississippi River deposits 145 million metric tons of sediment per year into the Gulf of Mexico and much of this settles on the continental shelf. In the deep ocean however, most of the seafloor is composed of organic matter that has fallen to the seafloor from the surface. This happens continuously. Finally, sediment can form around deep sea volcanoes and vents and from other chemical process in the ocean. These sediments are rare comparatively, but they often serve as a home for unique habitats and niche ecosystems. An example of this in the Gulf of Mexico is the asphalt seeps discovered near the De Soto Canyon. Ocean currents and tides also play a part in distributing and filtering sediments. A strong storm can change the composition of the seafloor overnight. Protected areas, such as harbors, estuaries and fiords encourage silt and clay to settle. Deep-C scientists went on several research cruises in the northeastern Gulf of Mexico to collect data on seafloor sediments, particularly in the De Soto Canyon region. Using a tool called a **multi-corer**, they are able to extract sediment cores from the seafloor. These cores are analyzed to determine their composition as well as to make predictions regarding the amount of Deepwater Horizon oil that settled to the seafloor. Soft sediments characterize the De Soto Canyon, and the two sides of the canyon have different sediment compositions because of the influence of the Mississippi River on the western edge. An easy methodology for determining sediment

Sediment core with a layer of oil on top.



Asphalt extrusion with coral attached. Image courtesy of NOAA Okeanos Explorer Program, Gulf of Mexico 2014 Expedition.

composition is to perform a **smear slide analysis**. A small amount of sediment is observed under a microscope and grain types are put into three different categories: minerals, microfossils, and volcanic glass. In this lesson, students will investigate seafloor composition, discuss the potential effects of Deepwater Horizon oil settling on the seafloor, and analyze a sediment core.

A device called a multi-corer is used to take sediment core samples from the seafloor.

Procedure

1. **Sediment Particle Speed Demonstration:** Use modeling clay to create sediments of various sizes (at least six). Measure the diameter of each sediment sample and write it on the whiteboard (see table below for an example). Ask students to hypothesize which sediment will settle the fastest when dropped into the cylinder of corn syrup. Drop the clay pieces into the tube one at a time, recording the time it takes to reach the bottom and writing it in the table on the board. Have students calculate the average settling rate by dividing the diameter of the clay pieces by the time it took them to settle on the bottom (cm/sec) and discuss. Repeat the experiment using the rocks.

Particle Size	Trial	Time (seconds)	Settling Rate (cm/sec)
.5 cm			
1 cm			
3 cm			

2. **Sediment Settling:** Have students read the article, *"Scientists Find Thick Layer Of Oil On Seafloor"* and answer the following questions.
   - If oil is less dense than water, how could it settle on the seafloor? Describe the process that makes this happen.
   - What are the potential impacts of a layer of oil covering the seafloor?
   - How might this influx of oil change the composition of seafloor sediment?

3. **Sediment Core Analysis:** For this portion of the lesson you can chose from a variety of options:
   - Make a core for students to analyze out of various sediments of different sizes, such as gravel, sand, clay, etc. Use one-liter soda bottles with the ends cut off for an inexpensive tube.
   - Buy pre-made cores from ENSCO (https://www.enasco.com/product/SB27465M)
   - Have students take sample cores from an area water source such as a lake, river, pond, or the ocean using a soil sampler. You can purchase soil samplers from Carolina Biological Supply, among other places.

Nick Myers (FSU) and Kala Marks (Georgia Tech) sectioning a sediment core from a sampling site near the De Soto Canyon.

Using their sediment cores, have students conduct a smear slide analysis by swiping a toothpick across the cross section of the core and examine it under a microscope. They should record their observations and make note of grain size, color, texture, and composition.

Have students research sediment composition and create a dichotomous key using their notes from the smear slide analysis.

Questions

1. What kinds of materials do you expect to find on the seafloor? *Mud, sand, gravel, microfossils, volcanic glass, etc.*
2. Where does the majority of sediment on the seafloor come from? *Land.*
3. What factors can affect sediment settling rates? *Currents, wind, waves, topographic features.*
4. How could this influence how oil from the Deepwater Horizon oil spill reached the seafloor? *Open-ended.*
5. Think of a water source near where you live. What might the sediment in that place be composed of? *Open-ended.*

Extension

Combine this lesson with the "*What can we learn from Sediment Profiling?*" in the Geochemistry module (see page 52) to investigate other information that scientists can glean from sediment cores.

Resources & References

John, Kristen. Reconstructing Earth's Climate History: Inquiry-based Exercises for Lab and Class. Hoboken, N.J.: Wiley, 2012. Print.

Lewis, Keith. Sea Floor Geology – How sediment forms. Te Ara – The Encyclopedia of New Zealand, updated 13-Jul-12. http://www.TeAra.govt.nz/en/sea-floor-geology/page-6

ARTICLE REPRINT

Scientists Find Thick Layer Of Oil On Seafloor

By Richard Harris (Posted online September 10, 2010)
Source: NPR http://www.npr.org/templates/story/story.php?storyId=129782098

To obtain a copy of the article, go to: *http://www.npr.org/templates/story/story.php?storyId=129782098*

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LESSON PLAN:
Remotely Operated Vehicles (ROVs)

An Essential Tool for Underwater Exploration

Objective: To provide students with an opportunity to build and test a working ROV and to gain knowledge related to the way in which ROVs are used in scientific research.

Standards: OLP 6-7; SC.912.N.1, SC.912.P.12.3

Time Required: Several class periods or afterschool sessions

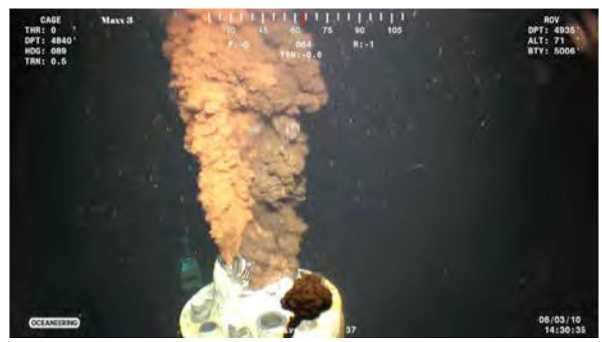
Keywords: marine technology, ROVs, tether, propulsion, buoyancy, pressure

Materials:

- 16 oz. plastic soda bottle
- Marshmallows
- Vacuum pump (needs to fit bottle)
- Index card
- Eye-droppers
- Pre-made ROV kits or Parts to construct ROVs (see lesson for more information)
- Pool

Background

Underwater **Remotely Operated Vehicles (ROVs)** are exploration robots that are operated by a person on a boat. They are safer than manned submarines and relatively easy to maneuver. ROVs are linked at all times to the boat by a **tether**, which consists of cables that carry electrical signals back and forth between the operator and the vehicle. ROVs come in many shapes and sizes, ranging from the size of a small computer to a small truck. The larger ones are very heavy and require additional equipment just to put them over the side of a ship. Most ROVs include a camera and lights, but other gear, such as sonar, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature can be installed and enhance their capabilities.



ROVs were used to monitor and attempt to cap the well during the Deepwater Horizon oil spill.

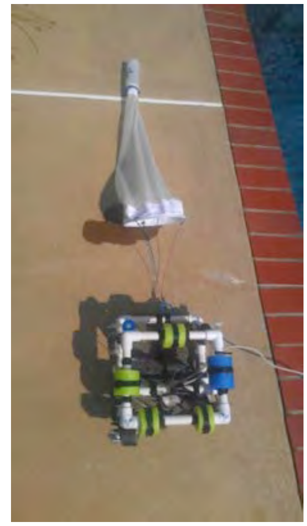



The ROV operator (or pilot) controls the device from the ship, similar to how you would play a videogame. Using a joystick, camera control, and video monitor, the pilot flies the ROV to desired locations. The pilot can see what the ROV is seeing, steer the ROV, take photos and video, and capture samples using robotic arms. ROVs, and other innovations in **marine technology**, are enabling scientists to more fully explore underneath the surface of the ocean. In the Gulf of Mexico, researchers are investigating deep sea corals, natural oil seeps, and much more with the help of ROVs. In this lesson, students will discover the science behind ROVs, practical applications, and build their own ROV.

Procedure

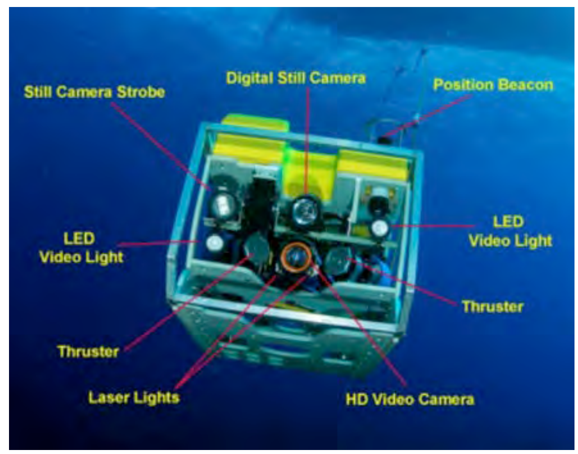
1. **How ROVs work**: Understanding how pressure and buoyancy work in the ocean is essential to building an ROV. Review with the students by conducting the following demonstrations.
   Pressure: Fill the plastic bottle halfway with marshmallows. Use the vacuum pump to create a vacuum in the bottle that will cause the marshmallows to expand in order to fill the bottle. As you release the vacuum the marshmallows will decrease in size!
   Pushy Air: Place water in a clear plastic cup. Place a piece of cardstock (index card) over the cup and make sure that it has a good seal. Turn the cup upside down and remove your hand from the cardstock. The cardstock continues to stay in place because air is exerting pressure upward on the cardstock.

Buoyancy: Fill a plastic bottle with water and fill an eyedropper two-thirds full of water. Place dropper in the bottle. The eyedropper should float about 1-2 inches from the top of the bottle. If not, repeat changing the amount of water in the dropper until you obtain neutral buoyancy. Place the cap on the bottle and tighten. Try to make the dropper become negatively buoyant so that it sinks to the bottom of the bottle without turning the bottle upside down. Once the dropper sinks, then make the dropper become positively buoyant and return to its neutral buoyant position.



ROV with a plankton tow made by Deep-C intern Rachel Holliday.

2. **Have students explore the NOAA Ocean Explorer 2014 Pulley Ridge Mission site**, http://oceanexplorer.noaa.gov/explorations/14pulleyridge/welcome.html and answer the following questions:
   - What are the main research goals of this mission?
   - How are ROVs being used to collect data?
   - Who are ROV pilots and what are their main duties?
   - What are some other examples of marine technology that are being used to complete this mission?
   - Where is Pulley Ridge and why is it important to study?
3. **Ask students to find a video of ROVs being used for scientific research and write a review**. Review must include source of the video as well as information about the types of observations being made and the scientists involved. Here is an example of a seafloor mapping expedition aided by the use of ROVs: http://oceanservice.noaa.gov/caribbean-mapping/
4. **Have students build their own ROVs and stage a class competition in a pool or off of a dock.** MATE (Marine Advanced Technology Education) will lend ROV kits to teachers for a fee. See http://www.marinetech.org/mate-loaner-rov-kit-request-form-/ for more information and watch the video tutorial. Alternately, you can buy ROV kits from MATE or SeaPerch (http://www.seaperch.org/order_kit), or you can purchase parts individually to permit students the maximum flexibility in ROV design. See the NOAA resource “ROV in a Bucket” for a detailed list of items needed to construct an ROV.

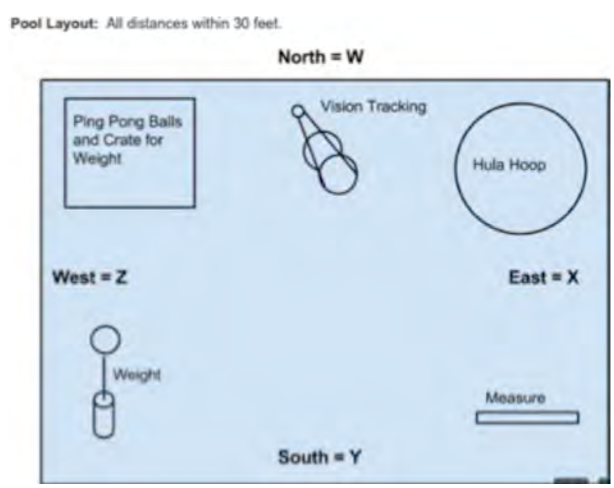


Source: http://flowergarden.noaa.gov/science/mohawkrov.html

Assign students into teams of at least 2-3 to build an ROV for a class competition. Building can take place during class or as part of an after-school program. Give the teams the following mission:

“Your team has been sent to the northeastern Gulf of Mexico to help Deep-C scientists assess the impact of the Deepwater Horizon oil spill on Gulf ecosystems. You must design an ROV that can take measurements, maintain neutral buoyancy, and be able to manipulate objects underwater.”

Arrange for the use of the pool and set up a course that the students have to complete (see diagram). Ask parents, other teachers, or professionals in the field to come to judge the teams (see sample score sheet) on their ability to complete the challenges, as well as on the design of their ROV and a short presentation on their building process (using the judging rubric on the following page). Have each team run through the course twice, tally up the scores, and declare a winner.



Pool diagram developed by JaSun Burdick of SAIL High School in Tallahassee, FL

	Specification	Tasks	Scoring (Max 25pts/Task)	Round 1	Round 2
1	Neutral Buoyancy	# of consecutive seconds able to keep a visual target aligned on the side of the pool, lined up between two 4" rings 1 meter apart	2 pt / sec		
2	Navigate	Retrieve to tether person as many 4" rings as possible. 2 hanging from the surface 2 suspended, and 1 on the bottom.	5pt each		
3	Navigate	Flip a milk crate to release 5 ping pong balls at the bottom of the pool. Collect and deliver to tether person.	5pt each		
4	Navigate small spaces	Pass in and out of a 38" Hulla hoop	25 pts		
5	Motor Power	Lift a 1lb weight into a milk crate. Weight will be tied to a floating 4" ring to help lifting.	25 pts		
6	Vision, Data Collection	Measure the size of a unknown object (Possible range 5-30cm)	25pt right (-1pt for every cm off)		
7	Vision, Data Collection	Read 4 signs on each side of pool (N,S,E,W). Solve simple order of operations math problem	5pts / sign (math +5)		
		Deductions			
		Pulling on tether to assist robot motion	5pts / infraction		
		Communicating with the driver	5pts / infraction		
		Driving ROV before round start	5pts		
			Best Round used for Final Scoring		
	Design Presentation	**Sections**	**Scoring**		
		Presentation illustrating the strategy, difficulty, design iterations	10		
		Creativity, inventiveness, originality	10		
		Engineering Design concepts (thrust, buoyancy,...)	10		
		Open Questions by the judges	10		
			Presentation Score		

Score sheet and Pool Diagram developed by JaSun Burdick of SAIL High School in Tallahassee, FL

Resources & References

Marine Advanced Technology Education (MATE) - MATE is a national partnership of educational institutions and organizations working to improve marine technical education in the U.S. The MATE Center and its partners have developed several curriculum modules and programs including: an introduction to Aquaculture, career scenarios (problems) for the classroom, technology rich lab exercises, a new A.S. degree program, high school pathways, and a careers course. Some of these materials are available online. http://www.marinetech.org/home.php

NOAA Ocean Explorer - Discover how NOAA uses ROVs and learn more about the various NOAA ROVs currently in use. Read how ROV Hercules was built just for scientific research and can travel to depths of 4,000 meters. http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html

Office of National Marine Sanctuaries – National Oceanic and Atmospheric Administration - http://monitor.noaa.gov/education/pdfs/rov_lesson.pdf

Remotely Operated Vehicles Curriculum Guide - This curriculum introduces middle and high school students to ROVs and careers in marine science and underwater archaeology. Students use problem based learning and hands-on STEM activities to solve real world problems, while learning about the engineering design process. Curriculum can be used in its entirety or activities can be used independently.

Teacher One-Pager (http://monitor.noaa.gov/education/pdfs/rov_teacher.pdf)

Student One-Pager (http://monitor.noaa.gov/education/pdfs/rov_student.pdf)

ROV Curriculum Guide (http://monitor.noaa.gov/education/pdfs/rov_lesson.pdf)

Remotely Operated Vehicle (ROV) In a Bucket - This is an excellent manual to get you started building your own underwater robot. The manual includes a detailed list of ROV parts and pieces and where to find them. (Doug Levin, NOAA Chesapeake Bay Office). http://monitor.noaa.gov/publications/education/rov_manual.pdf

Woods Hole Oceanographic Institution - Though ROVs have been used extensively by the oil and gas industry for several decades, *Jason/Medea* was the first ROV system to be adopted and extensively used by ocean researchers. Visit this site to learn how scientists and researchers use *Jason/Medea* to conduct underwater expeditions. http://www.whoi.edu/page.do?pid=8423

Geomorphology Quiz

1. How was the Gulf of Mexico formed?

2. What is the De Soto Canyon?

3. How is bathymetric data of the seafloor collected?

4. Why is it important to know the bathymetry of the De Soto Canyon?

5. How is a natural oil seep formed?

6. What are some factors that could influence the flow rate of an oil seep?

7. What kind of information can scientists gather from taking sediment core samples?

8. Where does the sediment on the Gulf of Mexico seafloor come from?

9. What do ROVs do?

10. Provide three specific examples of ways in which ROVs can be used in research.

Geomorphology Glossary

AUV: Autonomously Operated Vehicle, unattached and freely maneuvering small underwater vehicles

Bathymetry: the measurement of the depth of water bodies, including the ocean, rivers, streams, and lakes

Benthic: refers to the ecological region at the lowest level of a body of water

Buoyancy: the upward force, caused by fluid pressure, that keeps things afloat

Continental Shelf: an extension of the continent that is under shallow water; varies from place to place, potentially not existing in some places; sediment from the continents can accumulate on the shelf

Convergent boundaries: two plates coming together (in the ocean, typically a trench is formed)

Divergent boundaries: two plates moving away from one another (in the ocean, typically a mid-ocean ridge is formed)

Flow Rate: the volume of water passing a point in a fixed period of time

Hydrocarbon: organic compounds that contain hydrogen and carbon

Lithosphere: crust and upper mantle layer for which the tectonic plates are made of

Mantle: liquid layer containing magma. Layer between the crust and outer core

Marine technology: tools that are developed to aid in ocean exploration

Methane hydrates: aka gas hydrates are reserves of natural gas located in porous rock in the deep ocean sediments

Mid-Ocean Ridge: similar to a mountain chain underwater; two oceanic plates are diverging and magma rises from the mantle to add new crust to the ridge

MILET: Modular Instrument Lander and Equipment Toolsled, marine technology that maps the seafloor

Multi-Corer: a device used to take core samples from the seafloor

Natural gas: a mixture of gaseous hydrocarbons (primarily methane) that occurs, often with oil deposits, in the Earth's crust

Oil: a thick, yellow to black, flammable liquid hydrocarbon mixture found in the Earth's crust

Oil Seep: oil that escapes from its reservoir through a naturally occurring crack in the bedrock

Oil Slick: oil at the surface of the water

Plate Tectonics: theory in which the Earth's lithosphere is fragmented into pieces that are constantly moving and changing the geological features of the planet

Propulsion: a means of creating force that leads to movement

ROV: Remotely Operated Vehicle, which is a tethered robot that operates underwater and is controlled from a boat or ship by an operator

Sediment: solid material that is moved and deposited in a new location and can consist of rocks and minerals, as well as the remains of plants and animals

Side-scan sonar: a tool used to detect objects and geological features on the seafloor

Smear slide analysis: a laboratory technique used to analyze sediment core samples

Tar Balls: oil that has been weathered after floating in the ocean and washed ashore

Tether: a cord or flexible attachment that anchors something movable to a reference point, which may be fixed or moving

Geochemistry

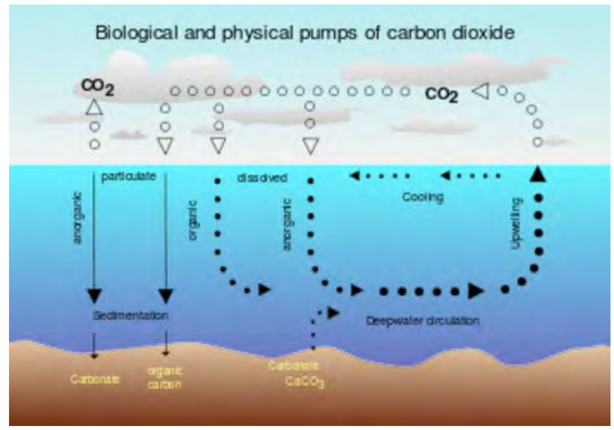
In the Gulf of Mexico

What is Geochemistry?

The study of the geological processes that affect the chemistry of the ocean.

Geochemistry in the Gulf

The Gulf of Mexico has many features that make it unique – from its natural oil seep ecosystems to asphalt extrusions. It is also considered a marginal sea because of borders that extend from the Yucatan Peninsula to encompass much of the southeastern United States. In addition, the Mississippi River, which drains approximately one-third of the contiguous U.S., transports about one million cubic yards of sediment, water, and nutrients per day to the Gulf. All of this contributes to the chemical composition of the Gulf of Mexico.



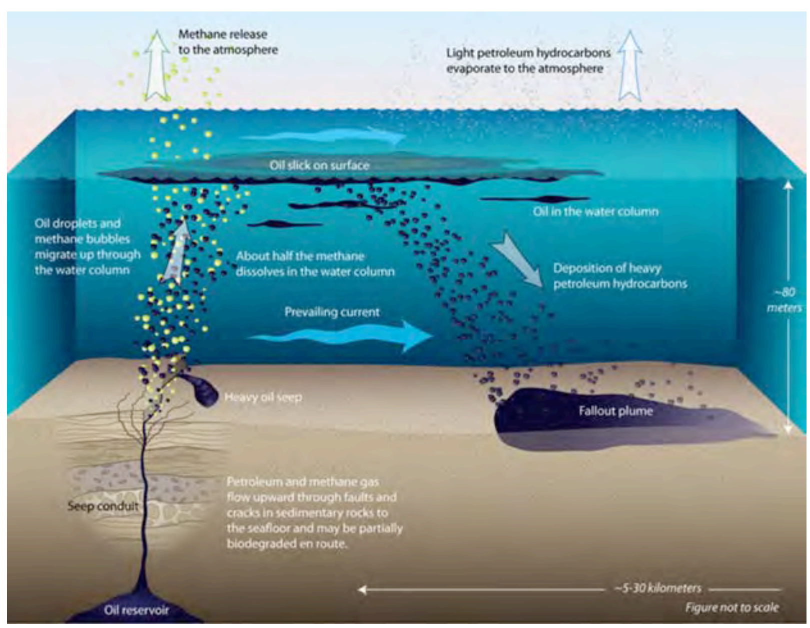
The biological pump acts as a filtering system for the ocean waters. Source: wikimedia

A process called the biological pump helps to regulate the movement of minerals and chemical elements as well as sediments and nutrients from the atmosphere and the surface of the ocean to the deep sea. The introduction of 4.9 million barrels of oil into the Gulf of Mexico during the 2010 Deepwater Horizon oil spill caused chemical oceanographers to wonder how the chemicals present in oil would be incorporated into the ecosystem and how would they degrade and weather over time.

Tracing the journey of hydrocarbons from the seafloor to the sandy beaches

Deep-C's geochemistry team was tasked with assessing the influence of oil and gas on water column and sediment biogeochemical processes and determing how this would affect biological productivity in the northeastern Gulf of Mexico. Researchers also investigated how hydrocarbons evolve under a variety of environmental conditions.

Evidence suggests that the fate of volatile compounds that either occur naturally in the sea (such as methane) or reach the sea through anthropogenic-induced pathways (such as mercury) was dramatically affected by the Deepwater Horizon oil spill. Understanding the impact of oil on the distribution and abundance of methane and mercury in the water column and in sediments, as well as its impact on primary production in the northeastern Gulf of Mexico, will help to answer the question *"what are the consequences for living organisms in the sea and on land?"*



This illustration shows the route traveled by oil leaving the sub seafloor reservoir as it travels through the water column to the surface and ultimately sinks and falls out in a plume shape onto the seafloor where it remains in the sediment. (Illustration by Jack Cook, WHOI) http://www.whoi.edu/oil/natural-oil-seeps

Deep-C Consortium Geochemical Research

Oil mixed with sediments to form marine oil snow

As plants and animals near the surface of the ocean die and start to decay, they slowly sink to the bottom of the seafloor. The transport of these types of particulates through the water column is called “marine snow” because the organic matter resembles flakes of snow as it falls. Researchers theorize that oil from the Deepwater Horizon spill mixed with marine snow and sunk at an accelerated rate due to flocculation, the process by which particles clump together and increase in mass. This may have led to dramatic increases in sediment accumulation rates on the deep sea floor. Deep-C researchers collaborated with scientists from all over the world to study the pathway that oil took from the surface to the seafloor. And why is this important? Dr. Uta Passow from the University of California-Santa Barbara summarized the need for this research. “The impact of the oil on the open ocean ecosystem when it is disbursed and diluted at the top of the water column is very different from the impacts it has when it sinks and accumulates on the seafloor. We need to know where the oil is to learn how to keep the damage to a minimum for the whole ecosystem, and for that we need to understand all of the pathways involved.”

New technology used to study oil weathering and degradation

A process called “gas chromatography” is typically used to separate oil into the individual elements that make up hydrocarbons. Next generation chromatography (performed at Woods Hole Oceanographic Institution) combined with ultrahigh resolution Fourier transform ion cyclotron resonance (FT-ICR) mass spectrometry (a process used at the National High Magnetic Field Laboratory at FSU), can identify the tens of thousands of components in oil samples from the damaged well, tar balls collected along from along the Gulf Coast beaches, and contaminated beach sediments. This research is helping scientists improve our understanding of the degradation pathways for oil/hydrocarbons.

Gas chromatography: A carrier gas, such as helium or nitrogen is used to help separate chemical compounds.

An example of an oiled sand patty collected at Fort Pickens near Pensacola, Florida.

By tracing how oil weathers in the environment and breaks down over time, researchers gained invaluable insight into the physical and chemical processes that occurred between release and deposition. Between 2010 and 2014, researchers collected and analyzed more than 700 oiled sand patties along beaches from Louisiana to Pensacola, Florida. These samples were added to an online repository that will be used by scientists for years to come.

Methane in the water column

FSU PhD student Nick Myers collects water samples from the CTD (connectivity, temperature, depth) during a research cruise to analyze for the presence of methane (CH_4).

It is estimated that approximately a third of the hydrocarbon compounds released during the Deepwater Horizon oil spill was methane (CH_4). Methane occurs naturally in the deep sea and there is a robust ecosystem of methanotrophs that consume methane. During the oil spill, large plumes of methane were observed. After a few months, the plumes disappeared leading to a debate about their fate. This identified a need to study the rate of consumption and transport of methane when it enters the water column. Deep-C researcher Dr. Jeff Chanton (FSU) and colleagues used a process called “atomic forensics” to trace the origins of the methane in the water column. When plants turn sunlight into energy, the new carbon atoms carry a chemical signal – sometimes called "new carbon" – that fades away over thousands of years, after which it becomes "old carbon." Oil and gases like methane are millions of years old and thus made of purely old carbon. If plankton ate methanotrophs from the plume during the oil spill, those plankton should have more old carbon than run-of-the-mill Gulf of Mexico plankton, which typically eat food loaded with new carbon. In light of this research, it is believed that methane-derived carbon from the oil spill entered the food web via methanotrophy.

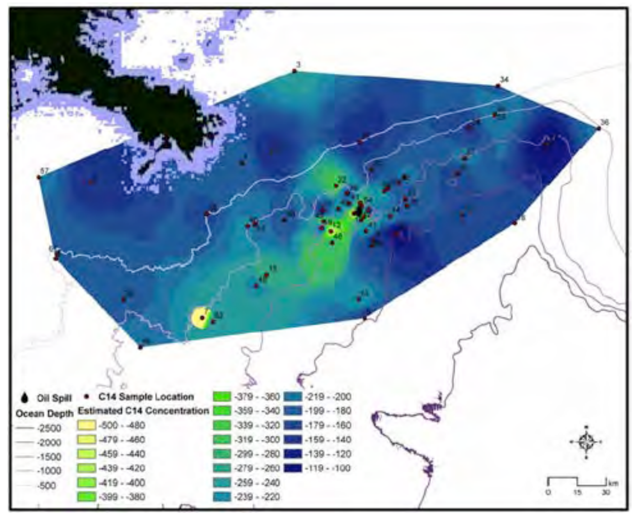
Bioaccumulation: Oil spill led to increased levels of MeHG concentration

Methylmercury (MeHg), the more toxic form of mercury, bioaccumulates through the food chain from the microscopic phytoplankton to the top predators such as sharks. Because it is an element, mercury does not break down into less toxic substances. In other words, as long as fish continue to be exposed to mercury, mercury continually builds up in their bodies and fish that eat other fish become even more highly contaminated. Thus, the largest tend to be the most contaminated. How does this relate to the Deepwater Horizon oil spill? Sulfate reducing bacteria are the primary producers of methylmercury, and the pulse of organic material from the oil spill resulted in a more oxygen-depleted environment where sulfate reducers can thrive. An analysis of several species in the northeastern Gulf of Mexico food chain conducted by FSU PhD student Alex Harper showed an increase in MeHg concentration following the spill which provides some evidence of the oil spill's marked effect on MeHg bioaccumulation in the food chain.

Sediment profiling for carbon 14

A cross section of a sediment core from the seafloor.

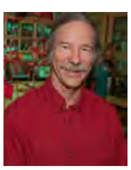
Researchers are using carbon 14, a radioactive isotope as an inverse tracer, to determine where oil might have settled on the seafloor. Unlike other sediments on the seafloor, oil does not contain carbon 14 so sediment that contained oil would immediately stand out in comparison. This process has allowed scientist to make predictions and draw conclusions about the amount of oil that is currently buried in the sediment of the seafloor. In collaboration with the Department of Geography at FSU, GIS mapping was used to create a map of the oiled sediment distribution on the sea floor (see image at right). Since less oxygen exists on the sea floor relative to the water column, the oiled particles are more likely to become hypoxic, meaning they experience less oxygen. When that happens, it becomes much more difficult for bacteria to attack the oil and cause it to decompose, leaving the oil in sediment to degrade very slowly.



Distribution of oil in the sediment near the site of the Deepwater Horizon oil spill.

Deep-C's Geochemistry Team

Gregg Brooks
Eckerd College



Jeff Chanton
Florida State University

David Hastings
Eckerd College

David Hollander
Univ. of South Florida

William Landing
Florida State University

Amy McKenna
Florida State University

Alan D. Marshall
Florida State University

Chris Reddy
WHOI

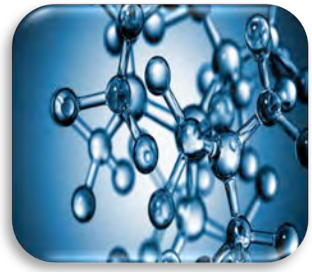
Ryan Rodgers
Florida State University

Vincent Salters
Florida State University

What Did We Learn?

- Following the Deepwater Horizon accident, released oil mixed with suspended particulate matter to form marine snow, which may have been deposited on the seafloor at an accelerated rate due to a process called "flocculation."
- Using a radioactive isotope called carbon 14, scientists were able to determine where oil was located in the seafloor sediment and a GIS map helped track its distribution.
- The oil spill increased the rate of bioaccumulation of methylmercury in some northeastern Gulf fish species.
- Methanotrophs consumed a large portion of the methane released by the Deepwater Horizon spill and this allowed methane from the oil spill to enter the food web.
- Innovations in next generation gas chromatography and FT-ICR Mass Spectrometry led to increased ability to fingerprint oil from its source and provided insight into the degradation of the biomarkers present in oil over time.
- Data collected led to an improved understanding of how oil breaks down in the environment and its effect on the biological pump that helps regulate the ocean's chemistry.

LESSON PLAN:
Chemical Components of the Gulf



Investigating the chemical processes of the ocean

Objective: To understand the composition of seawater, chemical processes which regulate the ocean and investigate factors that impact ocean salinity and chemical processes that regulate the ocean.

Standards: OLP 1, 4, 6; SC.912.E.7.1, SC.912.L.17.10

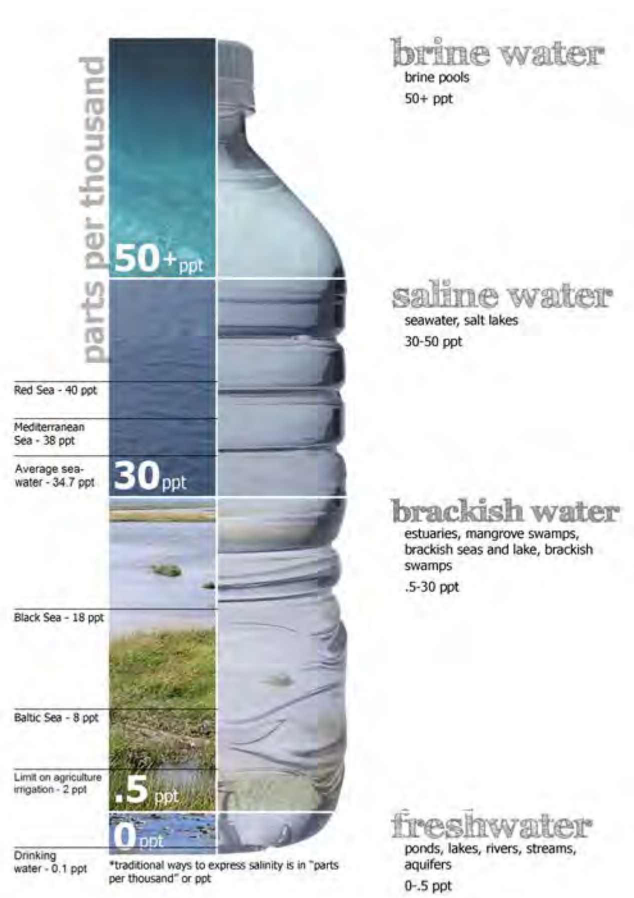
Time Required: One 50-minute class period

Keywords: biogeochemical cycles, chemical processes, salinity, upwelling, ppt (parts per thousand)

Materials:
- Graph paper
- Colored pencils
- Computer
- Hydrometer
- 500ml beaker of saltwater
- 500ml beaker of freshwater

Background

Did you know that almost all of the elements represented in the Periodic Table are present in the ocean? Chemicals in the ocean are part of an Earth system that recycles materials infinitely and the ocean is in delicate balance because of this. The Earth's systems contain fixed amounts of each stable chemical element and each element moves among reservoirs in the solid earth, oceans, atmosphere, and living organisms as part of **biogeochemical cycles** (i.e. nitrogen, water, carbon, oxygen, and phosphorus). An influx of chemicals from extreme weather events, increased industrialization, and environmental disasters such as the 2010 Deepwater Horizon oil spill can have a profound affect on the **chemical processes** in the ocean.



Source: http://commons.wikimedia.org/wiki/File:Water_salinity_diagram.png

Chemical oceanographers and marine chemists study the composition of seawater, as well as the interactions between the sun's energy, atmospheric compounds, dissolved and suspended oceanic organic and inorganic material, sea life, and the seafloor. Seawater is a mixture of water, salts, smaller amounts of other substances and atmospheric gases such as nitrogen, oxygen, and carbon dioxide. The six most abundant ions of seawater are chloride (Cl^-), sodium (Na^+), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+). By weight, these ions make up approximately 99% of all sea salts. The amount of these salts in seawater varies around the world, due to precipitation and evaporation. Salt content is indicated by **salinity**, the amount of salt in grams dissolved in one kilogram of seawater and expressed in **parts per thousand** (ppt or ‰). That is, a salinity of 35‰ means 35 grams of salt per liter of seawater. The Northern Gulf has an average salinity of 36.2‰.

The salinity of the ocean can be affected by a variety of factors from the inflow of river water to **upwelling** that causes mixing of seawater. The introduction of nearly 5 million barrels of oil into the Gulf of Mexico's chemical cycle is bound to have an effect on the composition of seawater. Scientists studying the effects of the 2010 Deepwater Horizon oil spill on **chemical processes** of the ocean are investigating how oil breaks down over time, how it reacted with other chemicals, and pathways into the food chain. In this lesson, students will investigate the factors that impact ocean salinity, how components present in oil interact with other ocean chemicals, and gain an understanding of chemical processes that regulate the ocean.

Procedure

1. **Watch:** Have students watch the following Ted Ed video on Biogeochemical Cycles and answer the corresponding multiple-choice questions. http://ed.ted.com/on/mireRMZO.

2. **Measuring salinity**: (Prior to class prepare a beaker with saltwater and a beaker with freshwater. Set aside with hydrometer.) In this activity students will look at a specific ocean chemical – salt – and how its presence is influenced by environmental factors.

Major dissolved constituents in seawater with a chlorinity of 19 ‰ and a salinity of 34.32 ‰.			
Dissolved substance	Ion or compound	Concentration (grams per kilogram)	Percent by weight
Chloride	Cl^-	18.980	55.04
Sodium	Na^+	[illegible]	30.61
Sulfate	SO_4^{2-}	[illegible]	7.68
Magnesium	[illegible]	1.272	3.69
Calcium	[illegible]	0.400	1.16
Potassium	[illegible]	0.380	1.10
Bicarbonate	HCO_3^-	0.14	0.41
Bromide	Br^-	0.065	0.19
Boric Acid	H_3BO_3	0.026	0.07
Strontium	Sr^{2+}	0.013	0.04
Fluoride	F^-	0.001	0.0
Totals		34.482	99.99

SAMPLE

Discuss with students the chemical definition of salt and its presence in the ocean. Have students answer the following questions:

- Where do the salts come from?
- How do they get to the ocean?
- What processes increase salinity?
- What processes decrease salinity?
- How would the weather conditions this past spring affect salinity?
- Seawater has a fairly constant salinity; why might this be?

Explain to students that salinity is measured in ppt (parts per thousand). Demonstrate this by using the hydrometer to test the salinity of the prepared seawater and freshwater. How might the influx of fresh water affect the salinity of the salt water? Combine the freshwater with the salt water and test the salinity. Show students the table above that breaks down the major dissolved constituents in seawater.

3. **Factors that impact the salinity of the ocean:** Explain to the class that they will be comparing the salinity of two different locations. Pass out the graph paper and colored pencils. Using the table below, have the class plot salinity vs depth using the salinity values in column two using the red pencil. Put the salinity units on the x-axis across the top and depth on the y-axis, increasing from top to bottom. Using the blue pencil repeat this step using the data from column 3.

Have students answer the following questions:

- Describe the distribution of salinity with increasing depth.
- What might be causing the variations at the surface?
- Why is the salinity constant at depth?
- What is the difference between the two plots?
- What process is responsible for the salinity values in the surface water?

Depth (meters)	Salinity - #1 (parts per thousand)	Salinity - #2 (parts per thousand)
0	37.2	10.5
20	36.8	20.5
50	35.9	32.5
100	34.9	33.8
200	34.8	34.9
500	34.5	35.2
1000	34.9	34.9

4. **Literature Review:** Divide students into groups of 3-4 and assign them an element that is abundant in the ocean to research (i.e. methane, mercury, dissolved oxygen, carbon, sodium, etc.) and ask them to create a power point presentation to share with the class. Presentations should be 10 minutes long, consist of at least 10 slides, one video, and include the following information:
   - The source and structure of the element.
   - How the element reacts with other chemicals present in the ocean.
   - Toxicity of the element.
   - Human impact on the elements abundance and distribution.

Questions

1. Describe how biogeochemical cycles affect ocean processes.
2. What is seawater made up of? *Sodium, chlorine, other chemicals, metals, and minerals.*
3. What is salinity and how is it measured? *The amount of salt in grams dissolved in one kilogram of seawater*
4. What processes would increase or decrease salinity of the ocean? *Evaporation, influx of fresh water, temperature.*
5. How do humans impact the abundance and distribution of elements in the ocean? *Answers will vary.*
6. How do you think the oil spill influenced the chemical components in the Gulf of Mexico? *Answers will vary.*

Extensions

Pair this lesson with “Oceanography Demos” in the Physical Oceanography module (see page 91) to discuss how salinity affects density.

Conduct a desalinization lab.

Resources & References

Chemistry of the Gulf of Mexico
http://www.sarasota.wateratlas.usf.edu/upload/documents/Chemistry-in-GOM.pdf

More Salinity Activities
http://www.usc.edu/org/cosee-west/oceanglobe/pdf/densitysalinity/densityentire.pdf

National Ocean Service: Salty Questions
http://oceanservice.noaa.gov/facts/whysalty.html and http://oceanservice.noaa.gov/facts/riversnotsalty.html

“Parts Per Thousand” Lab from COSEE
http://www.ucar.edu/learn/1_4_2_14s.htm

Uncovering the Ocean’s biological pump
http://www.whoi.edu/oceanus/viewArticle.do?id=192409

“Why is the Ocean Salty?” By the U.S. Geological Survey
http://www.palomar.edu/oceanography/salty_ocean.htm

LESSON PLAN:
Methane Mania

Investigating the influx of methane into the Gulf of Mexico food web

Note: This lesson plan works best in conjunction with the *Chemical Components of the Gulf* lesson.

Objective: To introduce students to the carbon cycle and its influence on the marine food web.

Standards: OLP 2, 5; SC.912.L.17.9, SC.912.L.17.10, SC.912.E.7.1

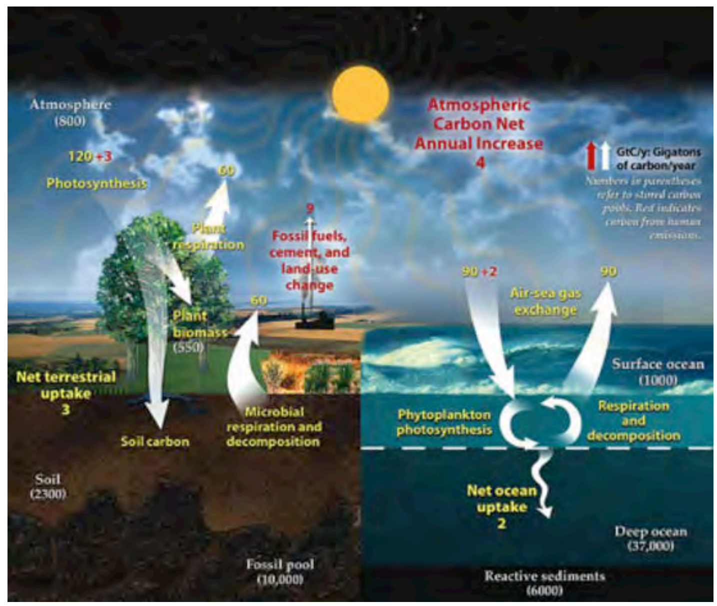
Time Required: At least two 50-minute class periods

Keywords: carbon cycle, methane, methanotrophy, marine food web

Materials: Computer and copies of the article, "*Study Confirms Methane-Eating Bacteria Contributed to Carbon Entering Food Web*" (see page 47)

Background

The **carbon cycle** is a biogeochemical process that is one of the keys to life on Earth. Carbon is one of the main components of all biological entities and as such is constantly being recycled and is in a delicate balance. There are many activities that can cause a disruption in the carbon cycle including geothermal events such as volcanoes and seeps as well as those caused by the action of humans such as the 2010 Deepwater Horizon oil spill in the northern Gulf of Mexico. Scientists and concerned citizen scientists are wondering what the effect of the oil spill has been on the carbon cycle and therefore the **food web** that is intricately connected with the flow of carbon in the ocean.



The Carbon Cycle in action
http://en.wikipedia.org/wiki/Carbon_cycle#/media/File:Carbon_cycle.jpg

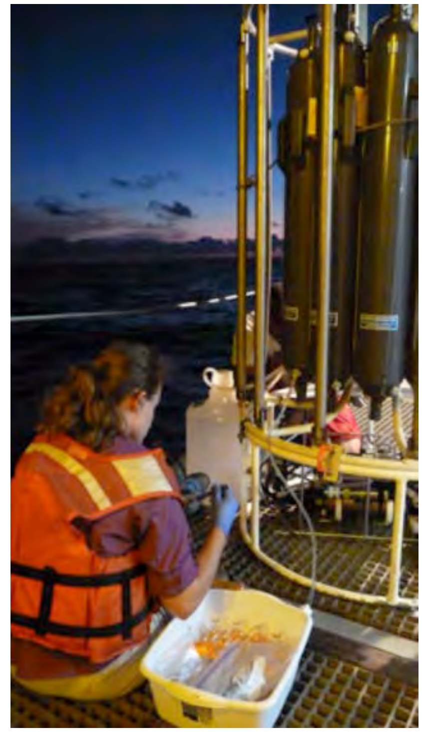
Researchers from FSU and their collaborators throughout the southeast have discovered a pathway for **methane** (CH_4), a colorless, odorless and combustible gas that was released along with the crude oil from the spill. Specialized bacteria called **methanotrophs**, consumed the methane that was released and transferred it up the food chain through the zooplankton that ate the bacteria. The abundance of methane caused a bloom of microbes to feast on the released gas. These methanotrophs helped to mitigate the effects of the spill and demonstrate the resiliency of the ocean's cycles. Understanding the carbon cycle and its influence on marine food webs is essential to determining the potential affects of an influx of methane into the Gulf of Mexico ecosystems. In this lesson students will gain an understanding of the carbon cycle, its influence on the food web, and the potential pathways for methane to have entered the marine food web in the Gulf of Mexico.

Procedure

1. **Demonstration:** Discuss the carbon cycle with students. Conduct a "Methane Mamba" experiment like the one here: http://chemmovies.unl.edu/chemistry/beckerdemos/BD015.html or watch a video like the one here: http://www.stevespanglerscience.com/lab/experiments/methane-mamba-tower-of-bubbles to show students how methane, a key component of the carbon cycle and a byproduct of the oil spill, behaves.

2. Research: Have students research the carbon cycle and write a two-page report on the different stages and the role of methane in the carbon cycle. Require two graphics and cited sources from either academic or government sources.

3. Group Project: Divide students into groups of two or three. Have students' research and create a multimedia presentation that accurately depicts the marine food web in the Gulf of Mexico and explains a potential pathway of the methane from the oil spill into the food web. This should be done as a multi-day assignment.



FSU graduate student Kelsey Rogers takes water samples that will later be analyzed from the presence of methane and other chemical components.

4. Evaluation: To test their theories on pathways for methane to enter the marine food web, have students watch the video "Food Web" from FSU researchers Ian MacDonald and Jeff Chanton. https://ecogig.org/content/ecogig-food-web and read the article, "Study Confirms Methane-Eating Bacteria Contributed to Carbon Entering Food Web" and answer the following questions:

- Approximately what percentage of the carbon-composing plankton collected in 2010 and 2011 could be attributed to carbon released by the oil spill?
- How were researchers able to match the carbon found in plankton samples with the methane that was released during the oil spill?
- Describe the pathways that scientists believe led to methane from the spill entering the food web.
- Why is it difficult to say with certainty that the carbon found in planktonic organisms originated from the Macondo well?

Questions

1. What is the carbon cycle and how does it affect ocean processes. *Answers will vary.*
2. What is methane? Is it a liquid, gas, or solid? *A colorless, odorless, combustible gas.*
3. What is a marine food web? How is it affected by the carbon cycle? *Answers will vary.*
4. Where did the methane released from the spill come from? *A byproduct of the formation of crude oil.*
5. Describe the pathway that methane used to enter the food web. *Methanotrophy.*

Extension

Divide the class into study groups. Assign each group an ecosystem (estuary, coastal shelf, deep sea). Each group should then create a food web for their study site. Include as many components as they can identify. The students should then share their findings with the class.

Resources & References

Background Information on the Carbon Cycle from NASA
http://earthobservatory.nasa.gov/Features/CarbonCycle/

ECOGIG Research: Plankton and Water Column Dynamics
https://ecogig.org/plankton-water-column-dynamics

ARTICLE REPRINT

Study Confirms Methane-Eating Bacteria Contributed to Carbon Entering Food Web

Posted online January 14, 2014

Source: GoMRI http://gulfresearchinitiative.org/study-confirms-methane-eating-bacteria-contributed-carbon-entering-food-web/

Scientists confirmed that methane-derived carbon, likely from the Deepwater Horizon oil spill entered the food web via small particles through a pathway known as methanotrophy.

Bubbles of methane gas rise through a mussel bed at the Pascaguola Dome. (Image courtesy of the NOAA Okeanos Explorer Program)

They published their findings in the December 2013 issue of Environmental Science and Technology Letters: **Fossil carbon in particulate organic matter in the Gulf of Mexico following the Deepwater Horizon event**.

The 2010 Gulf oil spill released large volumes of both oil and methane. Above water measurements at the time indicated that little of this methane went into the atmosphere, suggesting that the majority of it remained in the water column. Summarizing findings from his **2012 study**, Chanton said they found "approximately 5-15% of the carbon-composing plankton collected in 2010 and 2011 could be attributed to carbon released by the oil spill" with "smaller size plankton appearing to have more petro-carbon in it" and that "methane (rather than oil) seemed a more likely avenue for the intrusion of petro-carbon into the food web."

In this 2013 study, scientists report that tiny particles floating in the deep Gulf water column have organic carbon in them that matches the carbon released as methane from the Deepwater Horizon spill. Chanton estimates that "28 to 43% of the carbon in these particles is from fossil methane from the spill." The team used carbon isotopes (^{13}C and ^{14}C) to match carbon from methane with carbon in plankton and floating particles. Both studies show that the amount of oil spill carbon increases as the size of things gets smaller because floating particles are smaller than plankton.

These methane-eating bacteria (methanotrophs) are very efficient in converting the gas into biomass. Chanton explained that "methanotrophic transfer to biomass can be as great at 40-50%" as compared to "more traditional food webs where trophic transfers that are generally about 10% – meaning that 90% of the food consumed is lost to produce energy and carbon dioxide." He also said that this high transfer rate of methane into biomass is "significant and allows the highly successful symbiotic relationship of methanotrophic bacteria with seep fauna, particularly mussels." The researchers believe that this appears to be true for the wider Gulf, too. Chanton said, "As much as 40% of the methane released from the spill went into bacteria, which then became small particles ingested by plankton."

The team described their model for this process as methane → bacteria → particles → plankton.

In their discussions, the researchers stated that the carbon which entered the food web is "likely associated with the Macondo oil spill" but they also note that lack of prior "background" data regarding the ^{13}C and ^{14}C levels of particulate organic carbon in the area makes it difficult to determine the relative importance of natural seepage effects. Nonetheless, this study's results are consistent with the earlier hypothesis (Chanton et al.) "that a small size fraction of ^{13}C- and ^{14}C-depleted carbon affected the planktonic food web and this fraction was likely affected by methanotrophy."

The study's authors are J. Cherrier, J. Sarkodee-Adoo, T. P. Guilderson, and J. P. Chanton (Environmental Science and Technology Letters, 2013).

LESSON PLAN:
Oiled Marine Snow

How oil travelled from the surface to the seafloor

Note: See *Resources* (page 50) for where to order the chemicals needed for this lab.

Objective: To increase students understanding of the chemical process that influenced the settling of oiled marine snow on the seafloor.

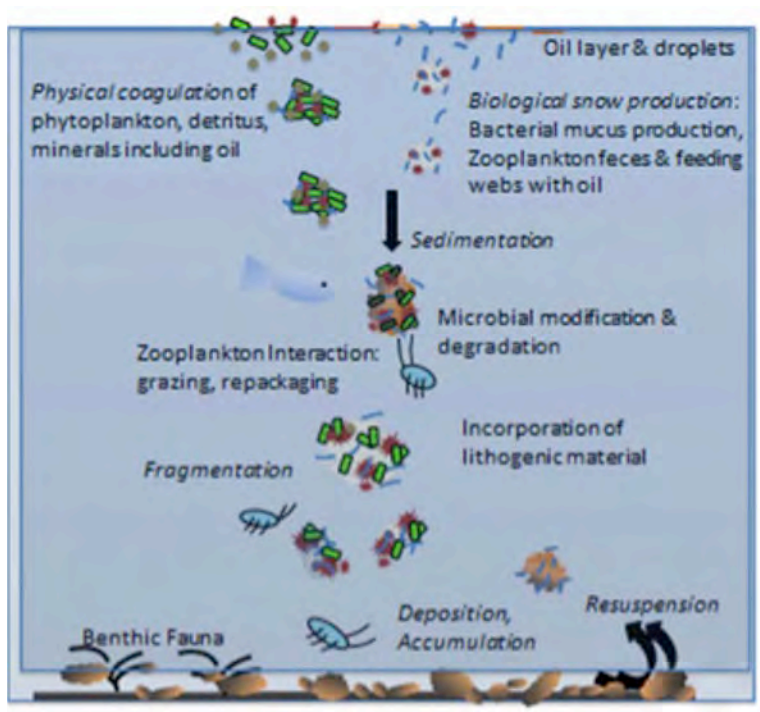
Standards: OLP 5, 6; SC.912.E.7.1

Time Required: One 50-minute class period

Keywords: marine snow, flocculation, upwelling

Materials:
- Copies of the article, **"***Study Explains Pathways for Oiled Marine Snow Formation"* (see page 50)
- "Muddy water" (add one cup of dirt to 1 liter of water) or pond water with suspended particulate matter (500mL per demonstration)
- Alum solution (1 tsp potassium aluminum sulfate or ammonium aluminum sulfate to 1 liter of water)
- Stirring rod
- Jars or beakers (one for each group)
- Limewater (3 tsp calcium hydroxide in 1 liter of water)
- Two jumbo (15 ml) transfer pipettes (one set for each group)
- Litmus paper, pH indicator paper (one for each group)

Background



Source: Dr. Jeff Chanton, Florida State University

Marine snow is organic material including dead animals and plants as well as sediment and fecal matter that is produced in the photic zone of the ocean, where sunlight penetrates and allows phytoplankton, the primary producers in the ocean, to thrive. Marine snow travels from the highly productive photic layer down to the seafloor where sunlight cannot penetrate, and is the major food source for many of the deep ocean inhabitants. The amount of marine snow changes with surface productivity. Marine snow is decomposed into nutrients by bacteria as it sinks to the ocean floor. **Upwelling** brings the nutrients as food up to the phytoplankton thus completing the cycle of matter and flow of energy in the open ocean food chain. **Flocculation** is the process by which particles mix with other particles that cause them to coagulate (thicken and become solid). Often flocculation is accompanied by an accelerated rate of settling on the seafloor. Oil from the 2010 Deepwater Horizon oil spill is thought to have mixed with plankton and sediment to form oiled marine snow. In order to gain an understanding of the mechanisms that contribute to oiled marine snow, students will read an article on its formation and conduct a lab demonstrating the process of flocculation.

Procedure

1. **Read Article:** Have students read the article, *"Study Explains Pathways for Oiled Marine Snow Formation"* and answer the following questions:
   - What is marine snow? And is the formation of marine snow a common ocean process?
   - What contributes inorganic particle inputs to the northern Gulf of Mexico?
   - The experiments demonstrated the potential of __________-mediated or __________-aggregate snow to transport oil to the seafloor.

2. **Watch ECOGIG's video on Marine Snow** https://www.youtube.com/watch?v=EfeNlavFmIk (4:30min)

3. **Flocculation Lab:** (Adapted from *"Things that Matter to Flocculants"* from USF)
   Prior to class prepare an alum solution (1 tsp potassium aluminum sulfate or ammonium aluminum sulfate to 1 liter of water) and a limewater solution (3 tsp calcium hydroxide in 1 liter of water). Lay out materials for each group.

   Break students up into groups of 3-4 and explain that they will be conducting a lab to determine how oil mixed with other particles to form marine snow. Have students complete the following:
   - Prepare a jar with muddy water (add one cup of dirt to 1 liter of water)
   - Add a transfer pipette full of the lime solution to the muddy water
   - Dip a piece of pH indicator paper into the beaker and observe the color. If the litmus paper turns blue, the solution is basic. If it stays red, add more lime solution.
   - Add a pipette full of alum solution to the muddy water mixture. Observe for a moment. If nothing happens, add another pipette full of alum.
   - A thick precipitate will form and begin to settle out.

   Have students answer the following questions:
   - Describe the process that caused the particles in the water to coagulate after the alum solution was added.
   - What implications does this have for the flocculation that occurred after the Deepwater Horizon oil spill?

Questions

1. How is marine snow formed? *Organic material that is produced at the surface and than falls to the seafloor.*
2. Explain the role of flocculation and sedimentation in the ocean ecosystem. *Helps with transport of materials.*
3. How might oil from the Deepwater Horizon spill reach the bottom of the seafloor? *Flocculation and sedimentation.*

Extensions

Repeat the flocculation experiment using a mixture of oil and sediment instead of muddy water to demonstrate how oil and sediment mixed in the ocean environment.

Combine this lesson with a filtration lab.

Resources & References

Carolina Biological Supply (A source for the chemicals needed to complete this lab) http://www.carolina.com

ECOGIG Marine Snow Video https://www.youtube.com/watch?v=EfeNlavFmIk

Things that Matter to Flocculants
https://www.teachengineering.org/view_activity.php?url=collection/usf_/activities/usf_flocculant/usf_flocculant_activity01.xml

ARTICLE REPRINT

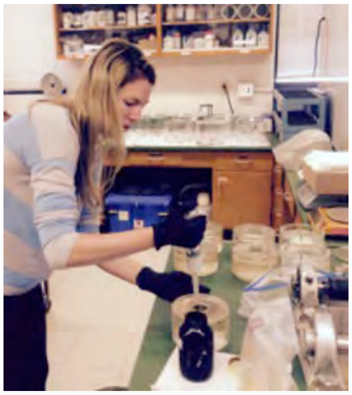
Study Explains Pathways for Oiled Marine Snow Formation

Posted online March 24, 2015

Source: GoMRI, http://gulfresearchinitiative.org/study-explains-pathways-for-oiled-marine-snow-formation/

University of California Marine Science Institute researcher Uta Passow investigated the formation of aggregated oil and organic material, commonly called marine snow, after the Deepwater Horizon spill.

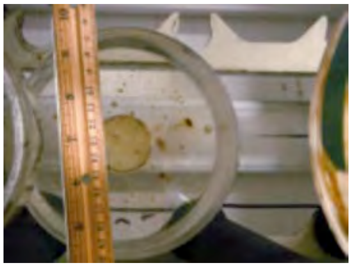
She found that microbes and plankton had distinct interactions with oil, subsequently providing alternate marine snow development pathways, and that the presence of Corexit likely inhibited the formation of microbial-generated marine snow. Passow published her findings in the October 2014 issue of Deep Sea Research II – Topical Studies in Oceanography: **Formation of rapidly-sinking, oil-associated marine snow**.



Lab manager Julia Sweet prepares treatments for the rolling tanks experiments (Photo provided by: Uta Passow)

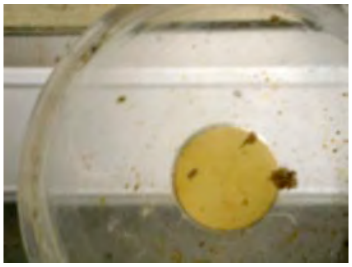
The formation of marine snow, which are sinking composite particles greater than 0.5 millimeters, is a common ocean process that rapidly transports particles from surface waters to the sea floor. The continental shelf topography of the northern Gulf of Mexico facilitates a suspended sediment zone. Additionally, the northern Gulf receives inorganic particle inputs from rivers, run-off, and coastal erosion. These subsurface conditions along with natural hydrocarbon seafloor seeps provide an environment favorable for the formation and sinking of oiled mineral aggregates.

Macondo oil accumulated at the sea surface and in subsurface plumes. Prior research has documented observations of large (millimeter to centimeter sized) sinking marine snow near surface slicks from the spill (**Passow, et al., 2012**) and flocculent oily material that coated coral reefs near the spill site (**Fisher, et al., 2014**). In this study, Passow used roller table experiments to investigate the conditions that induce marine snow and the effects of oil type (Louisiana light crude, Macondo oil, and bucket-collected spill oil), photochemical weathering, and phytoplankton and dispersant presence on its development.



Diatom oil aggregate. (Image credit: Julia Sweet)

Seawater treatments, with no particles greater than one millimeter present, incubated with collected spill oil formed centimeter-sized marine snow rich with microbial-generated mucus. Smaller, yet similar, marine snow formed in incubations with weathered crude oil. Marine snow formed even when spill oil was added to artificial seawater, suggesting that the oil included the microbial community responsible for snow formation.

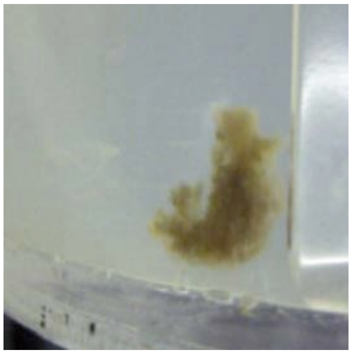


Microbial oil aggregate. (Image credit: Julia Sweet)

Phytoplankton presence in seawater treatments resulted in appreciable carbon amounts (16%-65%) incorporated in diatom aggregates, independent of oil type. However, the oil type did affect aggregates' appearance, size, and dynamics and likely increased the stability, cohesion, and sinking speed of these plankton aggregates.

Low concentrations of Corexit 9500A in treatments slowed, reduced, or completely inhibited microbial-mediated snow production. Conversely, higher dispersant concentrations produced buoyant oil aggregates that did not sink, suggesting that the oil contributed to the cohesion and stability of Corexit-mediated aggregates.

Passow explained that "this study contributed a central piece towards the understanding of the mechanisms that lead to oil-sinking products." In her discussions, she said that microbial-mediated marine snow may provide a potentially effective mechanism for surface oil removal. While acknowledging the difficulty in currently assessing Corexit's overall effects on oily marine snow, she suggested that Corexit likely reduced post-spill snow perhaps by impacting bacterial exudates or promoting a shift in less mucus-generating strains.



Microbial oil snow. (Image credit: Julia Sweet)

These experiments demonstrated the potential of microbial-mediated or plankton-aggregate snow to transport oil carbon to the seafloor. Passow recommends that future modeling efforts and oil spill budget calculations should include marine snow as an oil distribution mechanism and include inputs on microbial and phytoplankton populations and oil weathering rates. Additionally, scientists should re-evaluate dispersants as a mediating measure.

Oil-associated marine snow formation and its subsequent transport is the focus of a larger dedicated effort. Passow explained, "MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) is a working group that facilitates investigations of processes leading to the observed seafloor oil accumulation. Founded in May, 2013, the MOSSFA working group organized a **workshop**, **town hall meeting**, and continues to hold smaller topic-specific meetings. Recently-funded consortia and the MOSSFA group are working together towards a new marine snow research phase."

LESSON PLAN:
What can we learn from sediment profiling?

Determining the fate of oil in the sediment

Note: This lesson plan works best in conjunction with, "*Sifting through the Sediment*" lesson in the Geomorphology module (page 30).

Objective: To introduce students to sediment cores, sediment profiling, and the sediment research that is being conducted in the Gulf of Mexico.

Standards: OLP 2, 5; SC.912.E.6.4, SC.912.E.6.5, SC.912.E.6.6, SC.912.N.1.1

Time Required: One or two 50-minute class periods

Keywords: sediment, sediment profiling, sediment core, multi-corer

Materials:

Note: You will need enough materials for groups of 3-4 to do the lab twice.

- 3 wide-mouth containers
- 2 measuring cups (or small paper cups)
- Coarse-grained sand or gravel
- Medium- to fine-grained sand
- Clay or mud
- Glass, jar, or paper cup to use as a stamp
- Molasses
- Mineral oil
- Copies of the article, *"Study Reveals Oil Spill Changed Oxygen Conditions in Gulf Sediment"* (page 55)

Background

The **sediment** at the bottom of the seafloor can hold clues to the chemical processes that occur in the ocean. Scientists take core samples of the sediment using a device called a **multi-corer** to determine the chemicals present, how they are degrading over time, and the effect of these chemicals on the ocean food chain. After the 2010 Deepwater Horizon oil spill, researchers hypothesized that a large percentage of the spilled oil may have accumulated in the sediments and were potentially being recycled and incorporated into the ecosystems that inhabit the seafloor from microbes to predators. Scientists are looking at the impact on sediment composition as well as the organisms that live in the sediment.

Still shot of the multi-corer as it retrieves sediment cores on the seafloor. Taken during a Deep-C research cruise. Photo credit: Ian MacDonald (FSU).

By analyzing existing baseline data from previous core sampling expeditions and comparing the results with **sediment cores** collected since the spill, researchers at FSU and USF have been able to identify potential changes in sediment characteristics related to the Deepwater Horizon oil spill. It is hypothesized that these changes were due to the influx of hydrocarbons that fueled a major biogenic bloom in northeastern Gulf of Mexico surface waters and ultimately led to high sediment accumulation rates.

Sediment retrieved from the seafloor during a Deep-C research cruise. The note next to the sample denotes the date and location that the sediment was retrieved from.

Sediment cores retrieved during several Deep-C research cruises provide unique natural archives with the potential to accurately record the biological and chemical processes and the environmental conditions that existed prior to oil drilling, through the Deepwater Horizon oil spill, and including the eventual environmental and ecosystem recovery. These archives will provide vast amount of baseline data to analyze the state of the Gulf of Mexico for years to come. Deep-C's analytical work includes core photography, grain size analysis, bulk density determinations, stable isotope analysis, and radiocarbon analysis of bulk sediments among other things. Researchers at several institutions are using experimental approaches to evaluate the fate of buried Deepwater Horizon oil including tracking the degradation of oil in near shore and off shore environments and using the radioactive isotope, carbon 14, to detect the presence of oil on the seafloor. In this lesson, students will read an article on information gained from sediment profiling of the northern Gulf of Mexico seafloor, see the tools of the trade in action, and conduct a sediment penetration activity to determine oils ability to penetrate the seafloor.

Procedure

1. Research: In small groups or individually, have students research the sources of sediment in the Gulf of Mexico and write a 500-word report on their findings. Report must include at least three different sources of sediment in the Gulf and an explanation of the pathways. Students should cite their sources.

2. Article: Have students read the article, “Study Reveals Oil Spill Changed Oxygen Conditions in Gulf Sediment” and answer the following questions:

- What was the purpose of this study?
- How did researchers track changes to the natural cycle?
- When were the sediment cores used in this study collected?
- Describe the differences between the pre- and post-spill metal concentrations in sediment cores.

3. Videos: Show students the following two videos to illustrate some of the methods researhers use to collect sediment samples for analysis:

- Multi-corer Test Video: https://youtu.be/gRt2icfYYZ0
- ECOGIG Sediment Traps Video: https://ecogig.org/content/sediment-traps-2

4. Lab: Divide students into groups of 3-4 and pass out lab materials. Explain that you will be performing an experiment to see how oil penetrates a variety of sediments. Run the experiment twice, once using dry sediment and once with wet sediment, and then compare results. This can also be done as a demonstration.

1. Each group should have three wide-mouthed containers, one each of dry coarse sand, fine sand, and clay/mud, which are about two-thirds full.
2. Instruct students to press the bottom of a small glass, jar, or paper cup into two places on the surface of the sediment to make two treatment areas in each container.
3. Next, measure out equal volumes of molasses and mineral oil into the two cups
4. Choose one of the containers. Pour the molasses into one of the treatment areas, and mineral oil into the other.
    - Observe the immediate behavior of the liquids. Do they penetrate the sediment? How fast does this happen? What differences between the two liquids do you see?
5. Repeat these steps for the other two containers then compare.
6. Repeat steps 1-5 using wet sediment.
7. Answer the following questions: Which penetrated faster? Is the Deepwater Horizon oil more like the molasses or the mineral oil? What can we infer about this in terms of the rate of crude oil sediment penetration? Which sediment allowed the liquid to penetrate the quickest? Slowest? Why?

Questions

1. What is a sediment core? *A section of sediment extracted from the ground as a tube.*
2. What is sediment profiling? *A methodology used to analyze sediment cores.*
3. How is it useful in conducting scientific research? *Answers will vary.*
4. Describe two methods that scientists use to collect sediment samples. *Multi-corer, sediment trap, etc.*
5. What have scientists studying the Deepwater Horizon oil spill learned from sediment profiling? *Hydrocarbons caused a bloom.*

Extensions

Combine with the "*Sifting through the Sediment*" lesson in the Geomorphology module (page 30).

Conduct a porosity lab.

Investigate sediment core repostiories and see if they will send you a sample to analyze as a class.

Resources & References

Columbia University Sediment Core Repository
https://www.ldeo.columbia.edu/core-repository

Coleman, F., Chanton, J., & Chassignet, E. (n.d.). Ecological Connectivity in the Northeastern Gulf of Mexico. *International Oil Spill Conference Proceedings*, 2014(1), 1972-1984. doi:10.7901/2169-3358-2014.1.1972

ARTICLE REPRINT

Study Reveals Oil Spill Changed Oxygen Conditions in Gulf Sediment

Posted online May 26, 2015

Source: GoMRI, http://gulfresearchinitiative.org/study-reveals-oil-spill-changed-oxygen-conditions-in-gulf-sediment

A team of scientists from Eckerd College and University of South Florida conducted a time-series sediment study to better understand impacts from the Deepwater Horizon oil spill.

Three years post-spill, they found a continued state of altered geochemical conditions in sediment near the spill site. Concentrations of manganese, rhenium, and cadmium in sediment indicated a large organic carbon influx and subsequent decreases in oxygen concentrations. Decreases in the density of benthic foraminifera coincided with these altered conditions, suggesting potential impacts on benthic ecosystems. The researchers published their findings in Deep Sea Research Part II: Topical Studies in Oceanography: **Changes in sediment redox conditions following the BP DWH blowout event**.

Using a multi-core sediment sampler, David Hastings recovers sediment cores from the Northern Gulf of Mexico. (Photo credit: David Hastings, Eckerd College)

During and after the oil spill, scientists observed increased microbial activity and the forming, sinking, and settling of hydrocarbon enriched marine snow on the sea floor. The purpose of this study was to improve understanding about the association of these biological responses to the large hydrocarbon influx from the oil spill and identify potential impacts on the deep ocean environment.

Researchers analyzed concentrations of metals that indicate low oxygen and anoxic conditions as a means to track changes to the natural cycle that takes place when carbon gradually settles on the ocean's floor and slowly becomes incorporated into sediment. Peaks in manganese indicate the upper boundary of a geochemical cycle in sediment known as redoxcline. Enrichments of rhenium and cadmium indicate low oxygen or reducing conditions beneath that upper boundary of manganese.

After recovering sediment cores from the Gulf, Hastings removes the sediment core from the sampler. Frequently, the cores are extruded on board the ship. (Photo credit: David Hastings, Eckerd College)

The team established pre-spill baseline profiles of manganese, rhenium, and cadmium using sediment cores collected in 2007 and 2009 and two weeks after the oil spill, prior to the substantial organic carbon sedimentation that scientists observed in the months following the spill. They determined post-spill profiles of these metals using sediment cores collected between August 2010 and August 2013.

Pre-spill concentrations of these metals were typical of continental slope sediments. Post-spill metal concentrations showed noticeable differences in the top 5-30 millimeters of sediment, with rhenium concentrations three to four times higher than background levels. These metal enrichments demonstrated a change in post-spill sediment conditions, likely as a result of organic carbon remineralization.

The team analyzed benthic foraminifera that live in the upper sediment layers as potential indicators of impacts from shifting redoxcline conditions. Decreases in the density of benthic foraminifera were coincident with the changes in metal concentrations at the same depth range. In December 2010 there was a 40-60% reduction in the two most abundant genera of benthic foraminifers, and in February 2011 there remained a reduction in the genera.

In their discussion, the researchers noted that the more subtle changes in manganese, rhenium, and cadmium concentrations deeper in sediment suggest that a **marine snow event** associated with the oil spill likely contributed to the changed conditions closer to the seafloor. Diminishing rhenium and cadmium concentrations in sediment cores collected in the third year may signal a return to pre-spill conditions. Continued assessment of metal concentrations can help describe the temporal evolution of sediment conditions and document potential long-term effects as well as a possible return to background conditions.

This study's authors are D.W. Hastings, P.T. Schwing, G.R. Brooks, R.A. Larson, J.L. Morford, T. Roeder, K.A. Quinn, T. Bartlett, I.C. Romero, and D.J. Hollander.

LESSON PLAN: Oil Weathering and Fingerprinting

Investigating how oil breaks down over time

Objectives: Students will learn about oil spill forensics and develop an understanding of how oil breaks down over time. They will also learn how scientists use gas chromatography to separate oil molecules.

Standards: OLP 1,6; SC.912.L.17.2, SC.912.L.17.16, SC.912.N.1.6

Time Required: One or two 50-minute class periods

Keywords: chromatography, solvent, analyte, retention factor, oil fingerprinting, chromatogram, oil weathering

Materials:

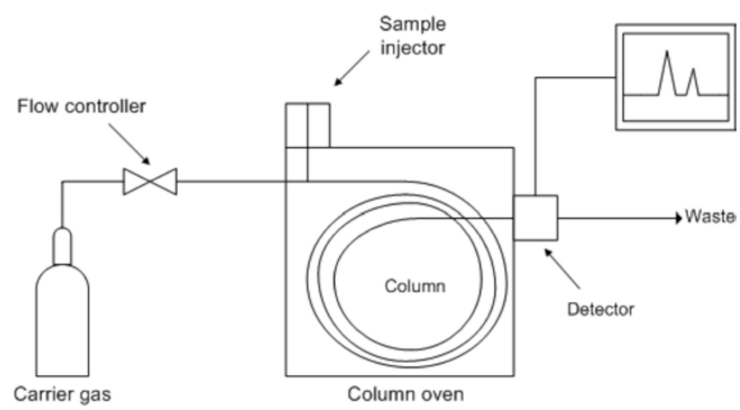
- Chromatography paper or coffee filters
- Three different black pens (analyte) (e.g. Crayola marker; Sharpie; Vis-a Vis)
- Rubbing alcohol (solvent)
- Flat toothpicks
- Small plastic or glass cups
- Ruler
- Calculator

Background

Oil is the result of plant debris and prehistoric organisms that have been heated and compressed ("cooked and squeezed") over millions of years – a process that changed their chemical composition, eventually transforming them into oil. Oil from around the world has different properties. Yet, even oils made in the same general area will have unique characteristics and can be definitively matched. So similar to the way that a crime scene investigator can look at fingerprints to identify a suspect…scientists can look at the distinct **"fingerprints"** or "genetic markers" of oil and determine its origin, much like a forensic investigator analyzes DNA.

One of the ways we can determine the fate of oil released into the environment is to study an effect called **"weathering"** — that is, how oil changes over time due to natural processes such as sunlight or microbial degradation. Oil is made up of many different compounds and weathering affects each of its properties in different ways.

Chromatography is a precise laboratory technique that allows scientists to analyze oil by separating the molecules contained in a sample. Analytical chemistry uses chromatography to conduct qualitative analysis (identify the components) and quantitative analysis (determine the concentration) of unknown substances. By separating a molecule from the oil mixture, it can be isolated and quantified. The different peaks on a **chromatogram** (the visualization of the data collected) correspond to different components in the sample and allow for tracking the fate or extent of weathering of many compounds. In the following lesson students will read a paper on oil spill forensics, locate data on analyzed oil samples from Woods Hole Oceanographic Institution (WHOI), and conduct a paper chromatography lab.



Gas Chromatography

Source: http://commons.wikimedia.org/wiki/File:Gas_chromatograph-vector.svg

Procedure

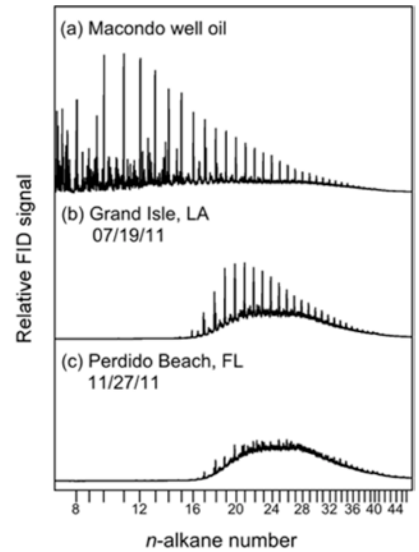
1. Have students read the article "Study Describes Use of Oil Fingerprinting to Identify Source of 2012 Gulf Sheen" and answer the following questions:

- *Where did the oil that the scientists from WHOI are studying originate?*
- *What is the name of the analytical instrument scientists developed to more effectively separate oil molecules?*
- *Describe the mechanism that scientists believe caused the oil sheen.*
- *What is a biomarker and why is it significant?*

2. Comparing Chromatograms Lab. Direct students to the WHOI Gulf Coast Sample Repository (https://www.whoi.edu/page/live.do?pid=73756) and have them select samples from three different states to compare (see example at right). Make sure that the samples selected have a linked chromatogram. Ask students to compare and contrast the three samples and answer the following questions:

- *What is the same?*
- *What is different?*
- *What could account for the differences?*
- *Why is this sort of precise information about oil weathering useful for scientists?*

Repeat activity using three different time frames (i.e. 2012, 2013, 2014).



Gas chromatographic traces from the Deepwater Horizon as well as samples from Louisiana and Florida. The samples found clearly show that nature has changed the composition relative to the original oil but also that weathering is different in the Grand Isle sample vs. Perdido Beach, even though both were collected at nearly the same time. Source: Chris Reddy, WHOI

3. Paper Chromatography Lab

(Adapted from: "Ink Chromatography", Museum of Science & Industry Chicago, IL)

In this lab, students will be separating the pigments that make up the color of three black pens. The ink acts as the **analyte** (the substance to be analyzed) and alcohol is the **solvent**. As the alcohol moves up the paper, the dye molecules from the ink mixture will move with it. If they are more strongly attracted to the alcohol molecules than to the paper molecules, the dyes will continue to move up the paper. If the dye molecules are more strongly attracted to the paper than the alcohol, they will move more slowly than the alcohol or not at all. Each paper chromatogram displays a unique pattern formed by the separation of the visible bands of dyes. After running the chromatogram, each separated band can be assigned a **Retention factor (Rf)** which is characteristic of each specific dye(s). The Rf is a ratio of the distance the band of color travels to the distance the solvent (alcohol) travels. The Rf is calculated by dividing the band distance by the solvent distance.

Results from an ink chromatography experiment using three different black markers.

1. Pour 10ml of rubbing alcohol into a small cup.
2. Cut a strip of filter paper to form a point at one end.
3. Choose a marker and make a dot above the pointed end. Record the brand of marker by initialing the top of the filter paper.
4. Lower the pointed end of the paper into the solvent. Make sure the dot stays above the solvent level.
5. Wait for the solvent to rise toward the top of the paper.
6. Once solvent has finished moving up the strip, (usually takes 3-5 minutes) remove the paper from the cup and mark with a pencil the highest point the solvent traveled.
7. Let the strip dry and tape it to the chart on the following page.
8. Fill in the sections on the Lab Sheet. To calculate the retention factor divided the distance the pigment travelled by the distance the solvent travelled.

Ink Chromatography Lab Sheet

Tape Strip Here	Tape Strip Here	Tape Strip Here
Total # of colored pigments	Total # of colored pigments	Total # of colored pigments
Solvent distance measured	Solvent distance measured	Solvent distance measured
Colored Pigment #4 ________ Color Distance Measured ________ Rf ________	Colored Pigment #3 ________ Color Distance Measured ________ Rf ________	Colored Pigment #4 ________ Color Distance Measured ________ Rf ________
Colored Pigment #3 ________ Color Distance Measured ________ Rf ________	Colored Pigment #4 ________ Color Distance Measured ________ Rf ________	Colored Pigment #4 ________ Color Distance Measured ________ Rf ________
Colored Pigment #2 ________ Color Distance Measured ________ Rf ________	Colored Pigment #2 ________ Color Distance Measured ________ Rf ________	Colored Pigment #2 ________ Color Distance Measured ________ Rf ________
Colored Pigment #1 ________ Color Distance Measured ________ Rf ________	Colored Pigment #1 ________ Color Distance Measured ________ Rf ________	Colored Pigment #1 ________ Color Distance Measured ________ Rf ________

Questions

1. What is oil spill forensics and what are some of the tools that scientists use to fingerprint oil?

2. How does ink chromatography relate to oil fingerprinting?

3. What are other mixtures that could potentially be separated by gas chromatography?

4. What are biomarkers? How could they potentially degrade over time?

Extensions

Contact a nearby university to see if anyone working with gas chromatography and could show your class.

Conduct a leaf chromatography experiment (See: http://www.msichicago.org/online-science/activities/activity-detail/activities/see-the-colors-in-leaves/)

Resources & References

Ink Chromatography Lab - http://www.msichicago.org/fileadmin/Education/learninglabs/lab_downloads/EL_ink_chromatography.pdf

NOAA Tar Ball Fact Sheet - http://www.noaa.gov/factsheets/new%20version/tar_balls.pdf

ARTICLE REPRINT

Study Describes Use of Oil Fingerprinting to Identify Source of 2012 Gulf Sheen

Posted online August 12, 2013
Source: GoMRI, http://gulfresearchinitiative.org/study-describes-use-of-oil-fingerprinting-to-identify-source-of-2012-gulf-sheen/

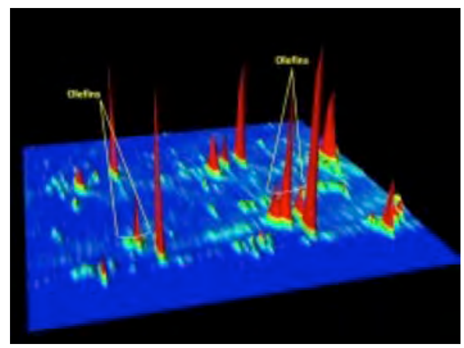
Scientists from Woods Hole Oceanographic Institution and University of California, Santa Barbara used a novel fingerprinting technique to identify the source of oil sheens that appeared in late 2012 near the site of the *Deepwater Horizon* disaster.

The sheens contained a mixture of Macondo well oil and alkenes (commonly called olefins) that are used in drilling operations. Researchers found that the sheens most likely came from pockets of Macondo well oil that were on the rig before it exploded and are now in the debris field on the ocean floor. They also showed conclusively that the oil was not leaking from the Macondo well which was “shut-in” in the summer of 2010. They published their findings in the June 2013 issue of *Environmental Science & Technology*: **Recurrent oil sheens at the Deepwater Horizon disaster site fingerprinted with synthetic hydrocarbon drilling fluids**.

After researchers retrieved oil-coated screens used to collect samples from surface sheens, each screen was sectioned into several pieces for analyses. Some were reserved for DNA extraction; others analyzed for drilling fluids and shared with the National Oceanic Atmospheric Administration for standard petrochemical analyses. (Photo by Christoph Aeppli, WHOI)

In mid-September 2012, the US Coast Guard received reports from BP of oil sheens near the site of the *Deepwater Horizon* incident. There was concern that the Macondo Well, capped in July 2010, might be leaking. Identifying the source of the oil was important because of environmental and legal issues and also to estimate the magnitude of the problem and inform the response process.

This study’s research team has been analyzing the chemical makeup of *Deepwater Horizon* oil since the incident began. Several years before the incident, they patented a highly-sensitive and accurate method to detect and identify alkenes found in drilling fluids (lubricants that aid the process of drilling for oil) using “comprehensive two-dimensional gas chromatography.” They developed this patent for the petroleum industry, but this was the first time they used this technique to address an environmental issue. Since drilling-fluid alkenes are not present in crude oil or natural seeps, and thus not in the oil that was released from the broken blowout preventer (drilling operations were over at that time), being able to identify these alkenes provided the team with a means to use them as a fingerprint to determine the sheens’ source.



Chemical compounds present in an oil sheen sample, highlighting the alkene or olefin fingerprint. (Credit: Robert Nelson, Woods Hole Oceanographic Institution)

The team collected 14 samples (taken in October and December, 2012) from the new sheens. They compared these samples to oil and chemicals from the Macondo well, the cofferdam (the device used in an attempt to cover the Macondo well in May 2010), drilling fluids, oil slick and oiled field samples, and floating rig debris (a broken piece of the riser assembly collected in May 2010 which had drilling fluids). Analysis of chemical biomarkers (measurable characteristics that indicate the presence of a chemical compound) showed the presence of Macondo well oil and drilling-fluid alkenes in all sheen samples and in the floating rig debris. There were no alkenes in oil from the cofferdam or in beach samples that the team have been collecting and analyzing since the disaster. These findings pointed to the source of the sheens as most likely “an oil/drilling mud mixture [that] originated from the DWH wreckage site” and that the source was a “finite volume of oil, rather than a leaking well.” The researchers also analyzed the spatial pattern of how the sheens evaporated, looking for areas with the least amount of evaporation. They determined that the sheens “surfaced closer to the DWH wreckage than the cofferdam site.”

In their discussions, researchers suggest that “drilling mud olefins are a powerful forensic tool” and “provide a framework for assessing the fate of drilling fluids released during hydrocarbon exploration and other activities around the globe.”

Additionally, researchers described this work as having another “victory.” They, as members of academia, were able to play a key role with multiple stakeholders, working closely with industry (BP) and federal agencies (U.S. Coast Guard, NOAA). The science team operated with transparency, alerting the government and BP about their research plans. All stakeholders sought to determine the source of the oil, though each required a different level of certainty about the results, and each had different questions to answer.

Dr. Christopher Reddy said, “The long lasting impacts of this effort were highlighting that academia can play a useful role during a crisis. We can be unbiased and collaborative without losing our integrity. What is lost on many of our colleagues is that interacting with representatives of the government and BP provided advice and input that improved our research. This is a win-win.”

The study authors are Drs. Christoph Aeppli, Christopher M. Reddy, Robert K. Nelson, Matthias Y. Kellermann, and David L. Valentine (*Environmental Science & Technology,* 2013, 47 (15), 8211–8219).

The research team’s second sampling expedition in December 2012, was more challenging due to the close proximity of a BP survey vessel, Olympic Triton, which was operating two ROVs, and a mobile offshore deep drilling unit. The rig and vessel each require a reasonable stand-off distance for safety precautions. WHOI’s Chris Reddy is shown here, with the drilling rig behind him. (Photo by Christoph Aeppli, Woods Hole Oceanographic Institution.)

Geochemistry Quiz

1. What is salinity and how is it measured?

2. Describe how biogeochemical cycles affect ocean processes.

3. What is the carbon cycle and how does it affect ocean processes?

4. Describe the pathway that methane used to enter the food web.

5. How is marine snow formed?

6. Explain the role of flocculation and sedimentation in the ocean ecosystem.

7. What is sediment profiling?

8. Describe two methods that scientists use to collect sediment samples.

9. What is oil spill forensics and what are some of the tools that scientists use to fingerprint oil?

10. What are biomarkers? How could they potentially degrade over time?

Geochemistry Glossary

Analyte: a substance whose chemical constituents are being identified and measured

Biogeochemical cycles: the process by which chemicals move through the other earth cycles

Carbon cycle: the movement of carbon through the different spheres of the Earth

Chemical processes: the processes that cause chemical to combine and break apart

Chromatogram: the visual result of conducting chromatography

Chromatography: laboratory techniques used to separate mixtures

Flocculation: the process by which individual particles clump together

Marine food web: a system of interlocking and interdependent food chains in the marine environment

Marine snow: decomposed or waste materials that slowly sink to the bottom and serve as a food source for deeper water animals

Methane: an odorless, colorless, combustible gas (CH_4)

Methanotrophy: the use by bacteria of methane as a food source

Multi-Corer: a tool used to extract sediment cores from the seafloor

Oil fingerprinting: a methodology used to pinpoint where an oil spill came from

Oil weathering: the process by which oil is weathered over time by the earths systems

PPT (parts per thousand): the common measurement for salinity

Retention factor: the amount of the analyte that is retained in during chromatography

Salinity: the dissolved salt content of a body of water

Sediment: a naturally occurring material that is broken down by processes of weathering and erosion

Sediment core: a section of the ground that is extracted as a tube for analysis

Sediment profiling: a method of analyzing sediment for information

Solvent: a substance that dissolves a solute (a chemically different liquid, solid, or gas), resulting in a solution

Upwelling: a process in which deep, cold water rises toward the surface

Ecology

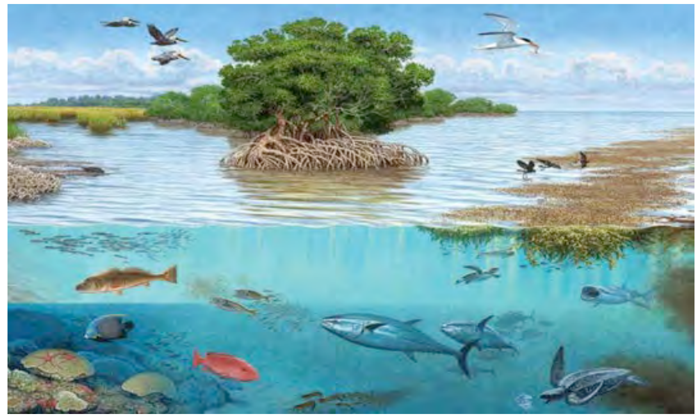
In the Gulf of Mexico

What is Ecology?

The study of the relationships between living organisms and their environment.

Ecological Connectivity in the Gulf of Mexico

The Gulf of Mexico is a productive, warm-water marine ecosystem. It is the ninth largest body of water in the world and supports high levels of biodiversity. The Gulf ecosystem has been altered by human activities such as nutrient loading, hypoxia, overfishing, and oil and gas drilling.



"Layers of Life" from National Geographic (used with permission).

Understanding the relationships between the marine organisms and their environment is essential to their protection. The ecology of the slope and shelf edge in the eastern Gulf of Mexico is poorly known and woefully understudied compared to the central and western Gulf where oil and gas extraction predominates. When the Deepwater Horizon oil spill occurred in 2010, ecologists were concerned about the profound effects it might have on marine life from the coast to the deep sea and how those effects would ripple throughout the trophic system, from primary producers to apex predators. The magnitude of these effects and potential consequences for ecological processes needed to be studied.

Deep-C Ecologist Tasks

The ecological component of Deep-C research focused on time series that define changes in community structure and function associated with the Deepwater Horizon blowout and its aftermath, while developing post-spill baselines of unstudied environments. Concentrating their efforts in the northeastern Gulf of Mexico, Deep-C scientists focused on biodiversity, species distribution, and the effect of exposure to oil. The ecology team was tasked with defining and quantifying the diversity of biological responses to the dynamic physical and chemical properties of the environment in order to understand the severity and longevity of the oil spill and demonstrate the cumulative effect on mid- to upper-trophic level responses and resiliency of the system. From the deep sea to the coast, studies were conducted across trophic levels to assess the sensitivity of marine organisms to specific compounds released during the oil spill.

Deep-C Ecological Research

Microbial responses to the Deepwater Horizon oil spill

Sediment core from October 2012 ecology cruise

Microbes serve as a vehicle for transferring hydrocarbons (oil) into the food web. Within weeks of the Deepwater Horizon oil reaching, and subsequently penetrating beach sands, the proportion of hydrocarbon-degrading species increased by orders of magnitude reducing both the relative abundance of other microbial groups and their biological diversity. In response to this microbial bloom, rates of oil degradation increased. In deep sea sediments, the presence of protist grazers, other organisms that consume the oil-eating microbes, slowed the rate of degradation. As the oil degraded, the diversity and species composition of these sediments began to re-approach baseline conditions. This indicates that oil-degrading microbes are ever-present in the sediments, they bloomed in response to the presence of hydrocarbons, and that the overall community is resilient.

Warm temperatures accelerated the degradation of buried oil on the beach

Deep-C researchers spent two years studying oil that had been buried in the sand in the days following the Deepwater Horizon spill. This research, conducted in Pensacola Beach, Florida, was conducted by digging trenches in the sand and analyzing the buried oil for evidence of microbial degradation. After one year, most of the buried oil had disappeared and it was determined that temperature was a pivotal factor: during warm summer temperatures oil degraded three times faster than during colder winter months. Buried oil layers consumed four to five times more oxygen and produced up to six times more carbon dioxide than the unpolluted beach sand, revealing strong aerobic microbial decomposition activities. Modeling of this data over time allows for the calculation of decomposition rates for specific oil components under in-situ conditions and predictions of the beach recovery period. The results of this research can be used for designing responses in future beach oil contamination events.

Dispersants mobilized Polycyclic Aromatic Hydrocarbons (PAHs) faster

Studies have shown that crude oil attaches readily to sand grains and because of this typically oil cannot penetrate the surface of the seafloor by more than a few centimeters. Corexit (a dispersant used after the Deepwater Horizon oil spill) detaches the oil that is coating the sand grains and reduces adhesion of oil to sands, thereby enhancing mobility of oil components in submerged coastal sands. Through this mechanism, potentially harmful PAHs can penetrate tens of decimeters into the sediment, extending persistence, and may reach groundwater level in shore environments.

Benthic macrofauna

Benthic macrofauna provide critical links between the microbial and planktonic communities on which they depend. In addition, they also facilitate the transfer of hydrocarbons throughout the trophic web via their role as prey in deep sea environments. Preliminary results from comparisons of recent (2012-2013) collections from sediments in the De Soto Canyon with existing pre-spill (2000-2002) data suggest that while the overall biodiversity changed little, macrofaunal density increased and community structure changed significantly perhaps as a result of organic enrichment provided by the increase in oil and subsequently microbes. If this turns out to be the case, then an important source of food for bottom dwelling species could have increased at least in the short term.

New plankton records set in the Gulf

Researchers documented the abundance and variety of phytoplankton in the Gulf during several research cruises from 2011-2014. Species identified include 90+ species of coccolithophores, 123+ species of diatoms, and 29+ species of dinoflagellates. In addition, a new species, and several new subspecies were identified. Using Niskin bottles and .2 micron filters, the Deep-C team was able to analyze samples collected along West Florida Shelf transects that revealed dominance shifts from the diatom *Nanoneis cf. longta* in September to the coccolithophorid *Emiliania huxleyi* in December 2013.

Navilithus altivelum, rare phytoplankton discovered in the Gulf of Mexico.

Sampling fishes by region and depth

Biological diversity declines with depth, as does basic knowledge of ecology and life histories, which makes characterizing the fishes in the northeastern Gulf a challenging task. Prey, predators, and scavengers all have their ecological niches within distinct depth ranges. To determine if and how the oil from Deepwater Horizon impacted these populations, intensive long-term surveys were initiated across geographic regions and depth strata. Surveys were undertaken at various depths along the continental shelf-edge (68 to 200m), upper slope (200-400m), mid-slope (400-900m), and deep slope (>900 m to 2,645m) of the De

Soto Canyon region Deep-C researchers conducted 10 research cruises (between 2011-2014), which resulted in sampling more than 4,000 fishes from 101 species (including 34 species of sharks and rays) making this the largest survey of deep-sea elasmobranch (sharks and relatives) fishes ever conducted in the Gulf of Mexico. More than 10,000 biological samples, from whole fish to whole organs and varied tissue samples, were distributed globally for analysis across 18 research institutions. These samples provided critical life history information and data on heavy metal contamination for a wide range of significantly understudied species.

Elevated exposure to PAHs close to spill site

To test whether Polycyclic Aromatic Hydrocarbons (PAHs), the most toxic substances in crude oil, are affecting deepwater Gulf fish, Deep-C scientists measured levels of commonly used fingerprints or "biomarkers" of PAH exposure in more than 1,000 deep sea fish, focusing on abundant sharks (gulper sharks, shortspine dogfish) and bony fish (tilefish, hakes) that were collected 12 to 42 months following the Deepwater Horizon blowout. The PAH biomarker used in this research included liver enzymes, which break down PAHs for excretion and tend to increase when animals are exposed to these pollutants, and the bile that collects in the gallbladder. Although findings vary by species, the results of this research suggest that fish collected closer to the oil spill are more likely to exhibit higher levels of PAH biomarkers, suggesting that they may be biologically affected by oil exposure. However, since the actual biomarker levels observed in deep sea fish were low in comparison with earlier studies on coastal fish (perhaps due to lower metabolism in deep sea fish), it is unclear whether these species will experience the types of health effects that can occur as a result of chronic PAH exposure, such as cancer or reproductive complications.

Deep-C's Ecology Team

Amy Baco-Taylor
Florida State University

Sandra Brooke
Florida State University

Felicia Coleman
Florida State University

Charles Cotton
Florida State University

Dean Grubbs
Florida State University

Markus Huettel
Florida State University

James Gelsleichter
University of North Florida

Mark Hay
Georgia Tech University

Wade Jeffrey
University of West Florida

Christopher Koenig
Florida State University

Joel Kostka
Georgia Tech University

James Nienow
Valdosta State University

Richard Snyder
University of West Florida

Sherwood Wise
Florida State University

What Did We Learn?

- New fish and plankton species were discovered during the research cruise surveys.
- When researching fish species' ability to metabolize the oil, it was found that near the site of the spill that chemicals in species were continuing to increase after the well was capped. However, now that is starting to decline.
- When the dispersants were sprayed at the well, it may have contributed to the production of big plumes in the deep sea leading to a scientific theory that oil settled down there instead of coming up to the surface.
- Overall, the majority of species sampled were able to recuperate from the toxicity exposure that followed the Deepwater Horizon oil spill. However, researchers are still seeing elevated levels of PAHs in deepwater sharks, which suggests that time is still needed for a complete recovery.
- Microbes bloomed in response to the oil spill and are now returning to baseline conditions.
- Studies showed that warm temperatures accelerated the degradation of buried oil on Florida beaches.

LESSON PLAN:
Setting the Baseline

It is difficult to assess the health of the Gulf of Mexico after the 2010 Deepwater Horizon oil spill due to lack of critical baseline data.

Importance of collecting baseline data

Objective: To understand what baseline data is and its importance.

Standards: OLP 6-7; SC.912.L.17.13, SC.912.L.17.16

Time Required: One 50-minute class period

Keywords: baseline data, monitoring

Materials: Copies of the *"Dealing with Disasters"* article (on page 68)

Background

Baseline data is the initial data collection, which serves as a basis for comparison with the subsequently acquired data. In other words, baseline is information that is used as a starting point by which to compare other information. Establishing baseline ecological conditions allows scientists to understand existing environmental conditions and track changes over time, aka **monitoring**. Why collect baseline information?

- To provide a description of the status and trends of environmental factors against which predicted changes can be compared and evaluated.
- To provide a means of detecting change by monitoring.

"*Ask virtually any scientist working to understand the spill's ecological effects and they're likely to name one major obstacle: baseline data. Whether the focus is birds, whales, or other animals, scientists have only partial knowledge of what the Gulf was like before the spill. Like pencil marks on a door frame recording children's height as they grow, baseline data tell us where we were, so that we can understand what has happened since. They're a crucial piece of the scientific method, and they can only be collected ahead of time, through monitoring programs. Unfortunately, monitoring work is easy to undervalue, right up to the point where a major change such as an oil spill happens. Then the data become priceless—but only if we've collected them*" (Cornell University, 2015).

Procedure

1. **Read the *"Dealing with Disasters"* article** and have a discussion in class.
2. **For Homework:** Write a 1-2 page paper focusing on how the article relates/parallels to the Deepwater Horizon oil spill disaster and what baseline data you think was needed to accurately assess the damages.

Questions

1. What is baseline data? *The initial collection of data, which serves as a basis for comparison with the subsequently acquired data.*
2. Why is it important to collect? *Allows scientists to understand existing environmental conditions and track changes over time.*
3. How can baseline data be collected? *Answers will vary; it depends on what is being studied.*
4. How do scientists assess impacts? *Based on the comparison of pre-and post-data.*
5. If you were a scientist, what kind of data would you collect in order to monitor marine organisms? *Answers will vary.*

Resources & References

Dealing with Disasters http://blog.disasterexpert.org/2011/08/importance-of-having-good-baseline-data.html

Environmental Impact Assessment, Chapter 5: Baseline Information
http://www.ku.edu.np/aec/envs402/eia%20chapter%205%20%20baseline%20information.pdf

Oil Spill Recovery http://www.birds.cornell.edu/page.aspx?pid=1855

ARTICLE REPRINT

Dealing with Disasters

Posted online Wednesday, August 31, 2011 (Reprinted with approval.)
By Gisli Olafsson, Emergency Response Director for NetHope a consortium of 33 of the leading international NGOs in the world
Source: http://blog.disasterexpert.org/2011/08/importance-of-having-good-baseline-data.html

The importance of having good baseline data

Information and communication is the lifeline of any disaster response. It is critical for people on the ground to convey the situation, as well as the urgent need for supplies and relief in specific locations. It helps organizations collaborate to avoid duplicative effort and gaps in assistance.

The crisis response community has long known that the use of information and communications technology (ICT) can quickly coordinate efforts, thereby making their work more targeted and effective. Recent improvements in ICT, such as availability of BGANs, WiMax and WiFi mesh networks, provide an opportunity to improve information sharing, not only within organizations but also between them.

This blog post illustrates the need for a coordinated collection of baseline data in disaster prone countries through a cross-organizational, multi-phased approach.

The humanitarian sector has the opportunity to harness technological advancements to improve information-sharing during a crisis. Technology is not the solution. But it is a significant tool that can enhance intelligent and immediate decision-making.

The State of Crisis Information Management

Numerous challenges in information management arise when responding to a major disaster or conflict, such as:

- recording the damage to housing, infrastructure, and services
- tracking displaced populations
- distributing the massive influx of humanitarian supplies
- coordinating the work in and between clusters, as well as the work of dozens of agencies outside the cluster approach

A recent survey of organizations that responded to the devastating earthquake in Haiti pointed out that one of the key issues they faced was an overall lack of baseline information about the situation in the country. For many of the UN clusters operating, it took months to get a comprehensive overview of what the situation was like before the earthquake struck, and then to start understanding what effects it had.

In Haiti the situation was particularly devastating because almost all government offices and ministries had been destroyed in the earthquake, and most of their data systems were lost. This is a common issue faced by response organizations around the world.

Baseline and post-disaster information is collected and controlled by many autonomous parties, including national authorities, many of whom may be working together for the first time. Due to the lack of a common repository of baseline data, organizations spend considerable amount of time either recreating the data or searching for it. Therefore, it is important to improve access to, and interoperability of, data collected before, during, and after an emergency. This is essential to building better response capacity.

Humanitarian response to sudden onset disasters requires:

- rapid assessment of the spatial distribution of affected people and existing resources
- good geographical information to plan initial response actions
- shared knowledge of which organizations are working where (who-what-where or “3W data”) so that response can be coordinated to avoid gaps and overlaps in aid

This applies to any humanitarian response. But in a sudden onset disaster, the timeframes of information supply and demand are severely compressed. Pre-assembled information resources for the affected area may not exist. Even in areas where development projects have been present before the crisis occurred, data is often dispersed and unknown by the wider humanitarian community, or cannot be accessed and assimilated quickly enough.

Recurring data problems include:

- Discoverable data. Data is either not made available to, or is not discoverable by, relevant organizations.
- Available data. Data may not be immediately accessible, archived, or stored/backed up in a location outside of the devastated area.
- Released data. Data sets may be subject to legal restrictions. Even if these restrictions are waived for humanitarian use, there may be problems with immediate authorization and redistribution.
- Formatted data. Data may be unsuitable for direct import into a database or GIS system, and may require substantial processing.
- Conflicting data.

Emergencies create an ever increasing number of information web portals, which is in itself a good thing. However, it can be problematic when the data is rapidly evolving. The enthusiasm to (re)publish as much information as possible can lead to confusion and inefficiencies, as users search through multiple copies of similar looking data to extract what is new or different.

The above issues are widely recognized by practitioners in humanitarian information management. Still, these problems recur in almost every sudden onset disaster emergency, in both developed and developing countries.

Each emergency brings together a unique collection of local, national and international humanitarian players. Some are experienced emergency responders, and some are not. Some are government-endorsed, whilst others are simply concerned citizens. While there will be some common elements across every emergency (government, UN agencies, major INGOs), the varying roles played by each makes it impossible to predict a 'humanitarian blueprint' for each new emergency. This vast range of experience, resources, and mandates, can make sharing response best practices extremely difficult.

Common problems with baseline data can - and must - be resolved for each emergency. For example:

- During the initial days of an emergency, the main coordinating agencies agree at a national or local level which administration boundaries and P-code datasets should be used for coordination. It is critical that this decision is communicated to everyone involved in the disaster response.
- Humanitarian assessment templates and base map data should be standardized and made compatible.
- The supply of baseline data should be driven by the information needs of the humanitarian response. Priorities differ from emergency to emergency, and this presents a constant challenge in using limited resources to meet urgent information needs at each stage of the response.
- The information needed by the affected community is not necessarily the same as the information demanded by large humanitarian agencies.

A well-coordinated humanitarian response will use multiple datasets, created by different personnel in different agencies, describing a highly dynamic and multi-faceted situation. To make these datasets interoperable and manageable imposes a higher overhead cost. But to create a data model that is planned strategically versus reactively will minimize that cost.

Moving forward

A multi-agency effort is essential to improve the availability and accessibility to baseline and crisis information. This needs to be a collaborative effort of the entire humanitarian response community with support and involvement of the private and academic sectors. The now no longer existing IASC Task Force on Information Management did a good job by defining what the Core and Fundamental Operational Datasets (COD/FOD) are that we need to collect for each country, but the difficult part is to actually ensure they are available for each country and that those that have been collected are actually kept up to date.

LESSON PLAN:
Breaking it down

An experiment on how microbes affect oil degradation

Adapted from: Slick Oil Lab, Science in the Real World: Microbes in Action

Objectives: To demonstrate methods of scientific inquiry and laboratory skills. To understand ecology concepts by identifying carbon compounds as a food source, discussing microbial degradation, and identifying a color change as indicative of a chemical reaction.

Standards: OLP 5-6; SC.912.L.17.16, SC.912.L.18.8, SC.912.P.8.12, SC.912.N.1.1

Time Required: Two 50-minute class periods, plus quick daily observations for a week

Keywords: microbes, oil degradation, bioremediation, tetrazolium indicator

Materials:

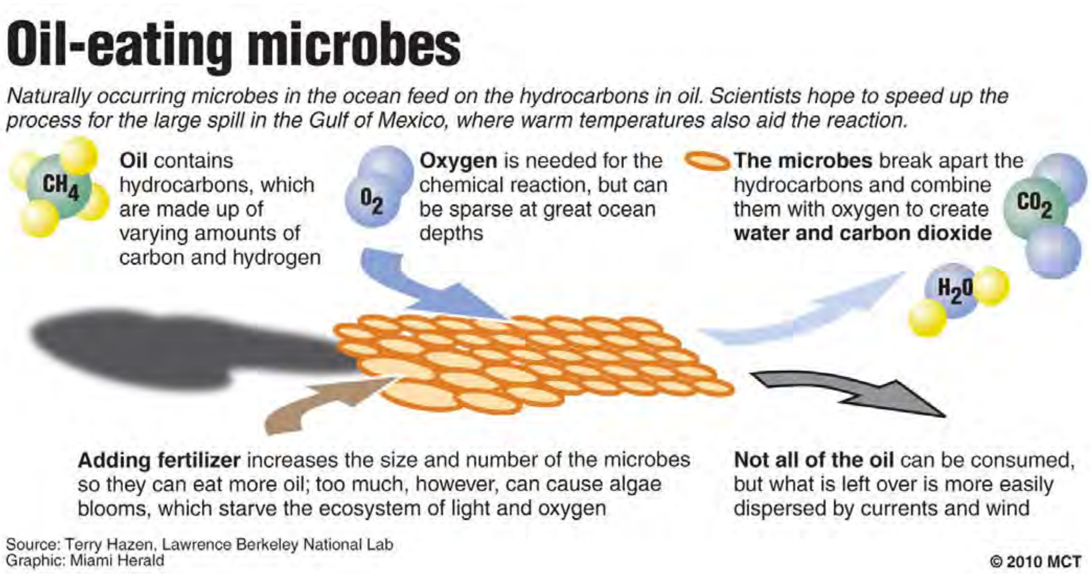
- Four culture tubes
- Four caps
- One test tube rack
- Marking pen
- Label tape
- 1ml plastic pipettes
- 3ml 0.02% tetrazolium indicator*
- 1ml of each drain cleaner (Rid-X Septic System Treatment, BioKleen Bac-Out Drain Care Gel, and Drain Care Build-Up Remover (powdered; mix 1tbsp w/ 500mL of water))
- 2-3ml of cooking oil (each group will test one kind – canola, peanut, vegetable, olive oil)
- Copies of the student worksheets (1 worksheet, print double-sided for each group)

**Note: Requires preparation of solutions before the lab; Takes 1-5 days for results*

Background

What are microbes?

Microbes are tiny, single-cell organisms too small to be seen with the naked eye. Since oil is a great food source for microbes, many different types (primarily bacteria and fungi) have evolved to break down oil into carbon dioxide and water. Oil seeps occur naturally at the seafloor, and thus hydrocarbon-degrading microbes are present everywhere in the marine environment, especially in the oil-rich Gulf of Mexico. The majority of microbial degradation occurs by aerobic respiration, which means the oil-degrading microbes “breathe” oxygen and burn or decompose oil hydrocarbons just as humans breathe oxygen and break down food for energy.



Used with permission

Why are microbes so important?

Biodegradation mediated by native microbial communities is the ultimate fate of the majority of oil hydrocarbons that enter the marine environment. The Deepwater Horizon oil spill released light crude oil composed of a variety of compounds with varying degrees of biodegradability. Research has shown that microbes can biodegrade up to 90% of some light crude oils. Therefore during the oil spill, the microbe population bloomed and was instrumental in helping clean up the oil-contaminated environment in the Gulf.

Oil Degradation Lab

Microorganisms can degrade toxic compounds in petroleum products. Scientists often select microbial strains for their unique ability to degrade various compounds. At sea and on shore, oil spills can be “seeded” with these oil-degrading organisms along with inorganic nutrients that enhance their growth on the oil. This technique is a type of **bioremediation**.

Think of a clogged drain…waste that contains oil is difficult to dissolve and causes other compounds to become stuck in the waste. Mixtures of bacteria can digest the oil and nutrients in the waste, allowing the remainder of the waste to dissolve. In this lab, you will visibly determine whether microorganisms in some brands of drain cleaners can metabolize cooking oil. The following ingredients will be mixed in test tubes and observed for one week: commercial drain cleaners that list bacteria as an ingredient, **tetrazolium indicator** solution that turns pink when oil-degrading bacteria are present, and cooking oil. Tetrazolium is an indicator dye that is colorless in its oxidized form, but pink when reduced. When microorganisms metabolize carbon compounds they make waste products that serve as reducing agents (aka reductants or electron donors) that will reduce tetrazolium, turning it pink. Therefore, when bacteria metabolize a particular carbon source, they make reducing agents and the tetrazolium turns pink. This is how you will measure microbial metabolism.

Procedure

1. **Prepare tetrazolium stock solution (0.2%)**

   The day before the lab…2,3,5 triphenyl tetrazolium chloride: Make a stock solution of 0.2% tetrazolium by adding 0.05 g tetrazolium powder to 25 ml distilled water. Mix thoroughly and store in refrigerator.

   The day of the lab…Dilute the tetrazolium - Make a fresh 0.02% solution the day of the lab by mixing 1 part 0.2% tetrazolium with 9 parts distilled water. Put solution in a flask or bottle with a 1 ml dropping pipette. Caution: do NOT to use the pipette for any other solution.

2. **Set up group lab materials.** Each group should have:
   - One test tube rack
   - Four test tubes with caps
   - 1ml pipettes
   - Masking tape and a permanent marker
   - 3ml 0.02% tetrazolium indicator
   - 1ml of each drain cleaner (Rid-X Septic System Treatment, BioKleen Bac-Out Drain Care Gel, and Drain Care Build-Up Remover (powdered; mix 1tbsp w/ 500mL of water)
   - Five drops oil for each test tube (cooking oils: canola, peanut, vegetable, or olive oil. Assign one oil per group)

3. **Discuss the microbe background information with your students and then review the "Oil Degradation Lab" information.**

4. **Hand out the student worksheets (pages 74-75) for each group.** Have the students read over the procedures once, and then review the procedure step-by-step with the class.

   Tips and Tricks
   - Provide examples of controls in experiments and sample data tables for students to assist them with the process.
   - Caution students that if a reagent has a pipette—do not use that pipette in any other solution.
   - Results should take 1-5 days; if there is no change after five days, keep tubes a few days longer. If you have an incubator, set the temperature to 30-32°C.

   Lab Procedure

   i. Write down the names of the drain cleaners and cooking oil on the worksheet. Mark test tubes 1, 2, and 3.
   ii. Add 1 ml tetrazolium indicator to each test tube, followed by five drops of cooking oil. IMPORTANT: Use the same type of cooking oil for each test tube!
   iii. To test tube 1, add 1ml of drain cleaner 1.
   To test tube 2, add 1ml of drain cleaner 2.
   To test tube 3, add 1ml of drain cleaner 3.
   iv. Cap the tubes. Gently tap the tube with your index finger while holding it with your other hand to create a whirlpool to mix.
   v. Set up a control tube for this experiment.
   vi. Design a data table to record your observations for a week starting with today. Oil degradation will cause the tetrazolium indicator to turn pink.
   vii. Label your test tube rack and store in a safe place in order to make observations for the next week. Record any physical changes on your data table.

5. **Have students make observations and record them for a week starting today.**

CLASS #2

6. **Once all the observations have been recorded for a week, have students work on analysis questions in their groups and review them as a class.**

Questions

1. Did all drain cleaners react the same? Which ones showed the most evidence of microbial metabolism? *Answers will vary.*
2. Compare your results with classmates who used a different type of oil. Did all oils show evidence of microbial metabolism? Explain your answer. *Answers will vary.*
3. Why do you think some bacteria might grow better with certain oils as a food source compared to other oils? *Presence of different enzymes or metabolic pathways allow some bacteria to use one oil but not another.*
4. Do you think bacteria could degrade petroleum oil products? Would all bacteria be effective for treating oil spills? *Yes. Some bacteria would have metabolic pathways to degrade oil, but not all bacteria.*

Resources & References

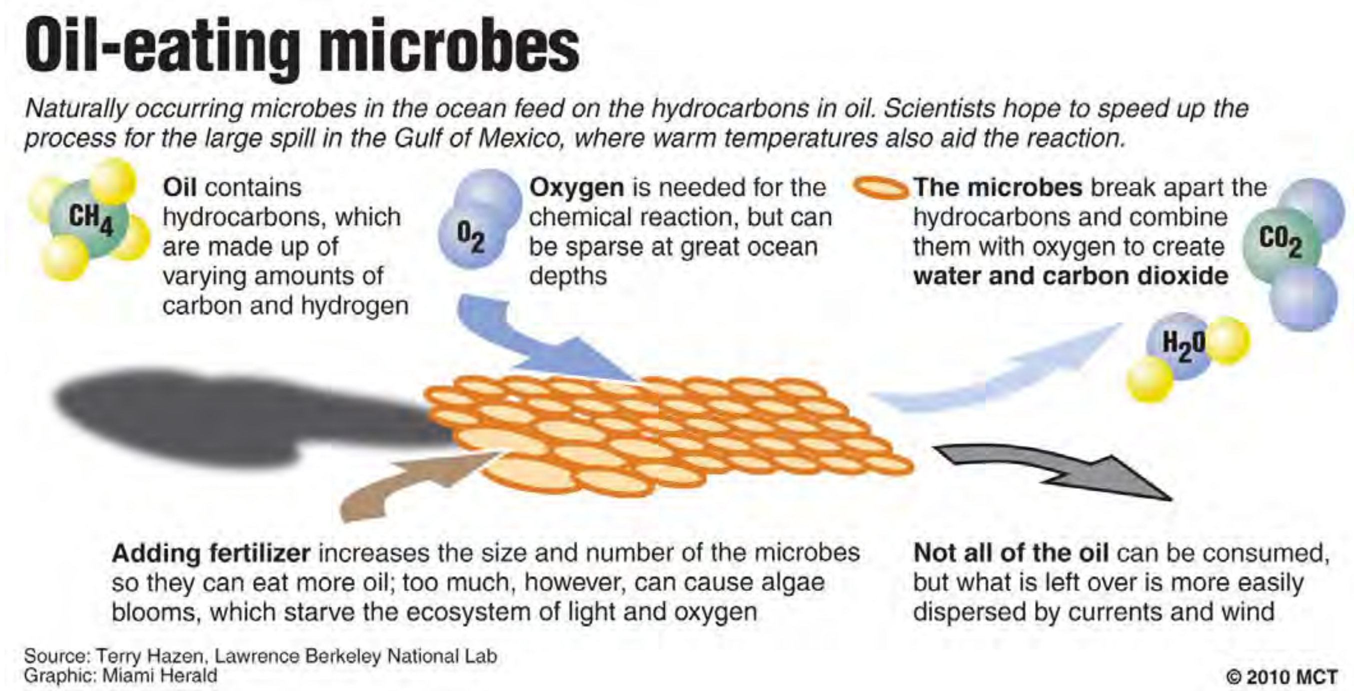
Oil-eating Microbes Fact Sheet: http://deep-c.org/images/documents/fact-sheets/Microbes_FactSheet-web.pdf

Science in the Real World: Microbes in Action, Slick Oil Lab:
http://www.umsl.edu/~microbes/pdf/A%20Slick%20Oil%20Lab.pdf

STUDENT WORKSHEET

Names of Group Members: ____

Over the last 3 ½ billion years, microorganisms have evolved that can use almost every carbon compound as a food and energy source. Oils are long chain hydrocarbon molecules with a variety of side branches. Specialized bacteria can break down all types of oils including those that are derived from mineral and petroleum products. In this experiment, you will determine whether microorganisms in some brands of drain cleaners can metabolize (break down) cooking oil.



Used with permission

Materials

- One test tube rack
- Four test tubes with caps
- 1ml pipettes
- Masking tape
- Permanent marker
- 3 ml 0.02% tetrazolium indicator
- 1 ml of each drain cleaner
- Five drops oil for each test tube

Procedure

1. Write down the names of the drain cleaners and cooking oil. Mark 3 test tubes 1, 2, 3.
2. To each test tube add 1 ml tetrazolium indicator, followed by 5 drops of cooking oil. IMPORTANT: Use the same type of cooking oil for each test tube!
3. To test tube 1, add 1ml of drain cleaner 1. To test tube 2, add 1ml of drain cleaner 2. To test tube 3, add 1ml of drain cleaner 3.
4. Cap the tubes. Gently tap the tube with your index finger while holding it with your other hand to create a whirlpool to mix.
5. Set up a control tube for this experiment.
6. Design a data table in which to record your observations for a week starting with today. Oil degradation will cause the tetrazolium indicator to turn pink.
7. Label your test tube rack and store in a safe place in order to make observations for the next week. Record any physical changes on your data table.

STUDENT WORKSHEET

Name of Drain Cleaners:

1.________________________ 2. ________________________ 3. ________________________

Name of Cooking Oil: ________________________

Data Table

Analysis

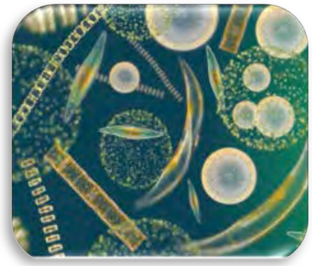
1. Did all drain cleaners react the same? Which ones showed the most evidence of microbial metabolism?

2. Compare your results with classmates who used a different type of oil. Did all oils show evidence of microbial metabolism? Explain your answer.

3. Why do you think some bacteria might grow better with certain oils as a food source compared to other oils?

4. Do you think bacteria could degrade petroleum oil products? Would all bacteria be effective for treating oil spills?

LESSON PLAN:
Go with the flow: the life of plankton



Use microscopes and illustrations to dive into the world of plankton

Objectives: To understand the types of plankton and their importance. To use a microscope to identify and illustrate plankton.

Standards: OLP 5,6; SC. 912.L.17.2, SC.912.L.17.8, SC.912.L.17.9

Time Required: One 50-minute class period

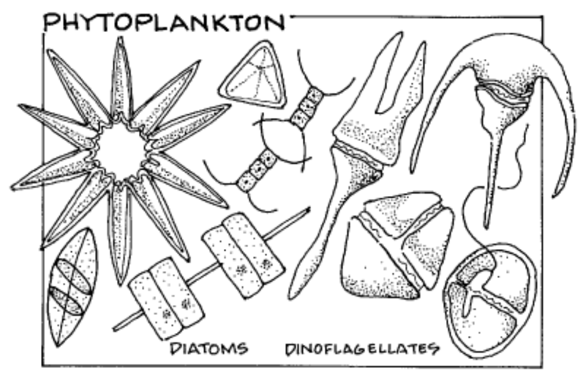
Keywords: phytoplankton, zooplankton, neutral buoyancy

Materials:

- Microscopes
- Live plankton or prepared slides
- For live plankton: dish with plankton sample and pipettes
- Drawing paper
- Plankton ID guides
- Copies of the *Images of Tiny Drifters*

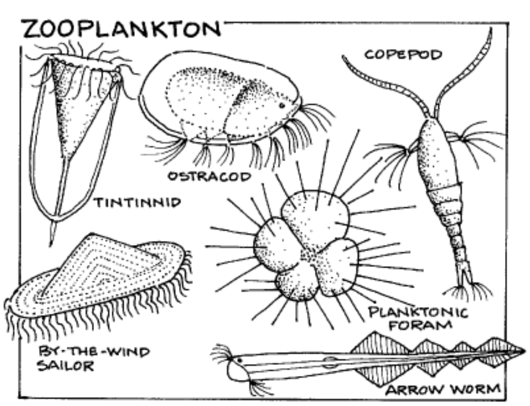
Background

What are plankton?
Plankton are primarily microscopic plants and animals that live in the water and cannot swim against major currents. These drifting creatures *go with the flow*. Most plankton can only control their movements vertically in the water column through the use of **neutral buoyancy**. That means it will neither float on the surface or sink to the bottom. This is done by controlling surface area and density. There are two major types of plankton: zooplankton and phytoplankton.



Phytoplankton: primary producers
Phytoplankton, or plant plankton, live near the surface of the ocean because they need sunlight to make food. As a plant, phytoplankton contains chlorophyll and thus makes its food through the process of photosynthesis. This process not only adds oxygen back into the water, but is also responsible for a high percentage (about 50 to 70%) of the atmospheric oxygen on Earth.

The two most common types of phytoplankton are **diatoms** and **dinoflagellates**. Diatoms are surrounded by a cell wall made of silica; these organisms actually live in a glass house. They can be found in diatomaceous earth, which is the source of abrasives in certain brands of toothpaste. Dinoflagellates have some characteristics of both plants and animals. They have a tail-like flagellum to move around. They are most commonly known as the source of a dangerous toxin, which is the cause of “red tide.” This, however, is only when certain species form an algal bloom. Red tides often result in fish kills, and have the capability of producing toxins that can accumulate in fish and shellfish.



Zooplankton or animal plankton are consumers that feed on phytoplankton or other zooplankton. They both are, however a food source for many other aquatic animals. Zooplankton can be separated into two categories. **Meroplankton** spend part of their lives as plankton (typically during its larval stage, such as crabs and fish). **Holoplankton** spends their whole lives as plankton (jellyfish, copepods, and amphipods).

Why is plankton so important?

Plankton is the base of the food chain. They are primary producers and important in nutrient cycling, which can tell us a lot about changes in our ocean. These organisms serve as indicator species and can demonstrate how marine environmental changes might affect larger organisms such as birds, fish, and sharks.

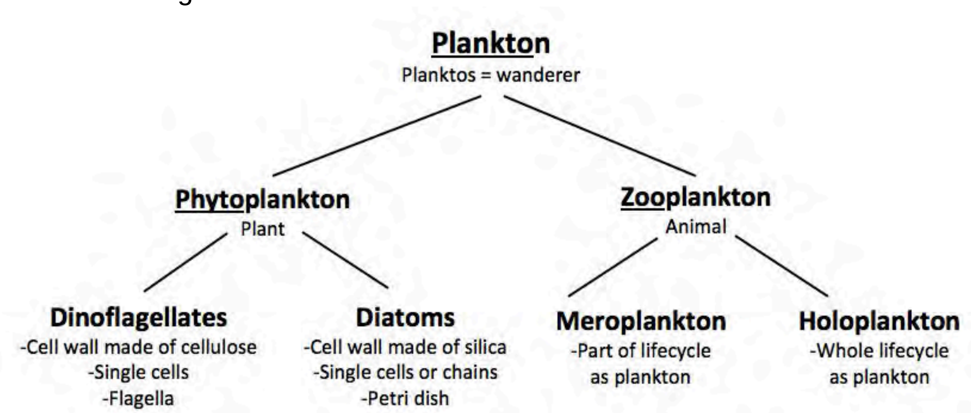
Oil spill affect on plankton:

The 2010 Deepwater Horizon oil spill exposed plants and animals to harmful crude oil. Though less visible, plankton were impacted as well. Oil and dispersants can dramatically shift the balance of energy flow in the microbial loop and fundamentally change basic trophic interactions among lower trophic levels, meaning a disruption such as the spill could have caused a major disruption in the pelagic food web. The extent of the disruption is not clear. However, dramatic fluctuations in the structure of the plankton association in northwestern Florida were observed as late as May 2011, eight months after the closure of the well. Additional analyses of the data are currently being conducted to determine whether the spill or other environmental factors were responsible for these fluctuations.

Sedimentation of oil and detritus from the water columns provides an archival record of chemical constituency, environmental conditions, and biological effects of pre-spill, spill, and post-spill conditions (including evidence of recovery), which appear in progressively shallower core-depth intervals. Important primary producers in the Gulf of Mexico are photosynthesizing protists, including pelagic diatoms and nanoplankton. Their presence in sediments are particularly useful because they leave sedimentary records that extend from the present to far back in geologic time, enabling us to identify abrupt, large-scale changes in living populations and extreme environmental events.

Procedure

1. Introduction to plankton: Define and discuss types and importance.
The following diagram can be drawn on the board to allow students to follow along.



Fun Facts:
Plankton produce about 50% of all the oxygen we breathe!

Did you know... that every time you swallow seawater, you could be consuming plankton?

There could be over a million phytoplankton in one teaspoon of seawater!

Plankton are most visible when certain conditions lead to a population explosion known as a bloom.

2. Use a microscope to view plankton

- Plankton can be collected using a plankton tow. If you have live plankton, the wet-mount slides will need to be prepared OR prepared slides can be used (see Carolina Biological).
- Explain how to identify phytoplankton and zooplankton using the ID Guides (see resources).
- Demonstrate how to operate the microscopes properly.
- Have students illustrate the plankton being observed and use ID guides to label the type.

If using live plankton: Each workstation should have a microscope, a dish with a plankton sample, pipettes, slides, the drawing paper, and writing supplies. Using the pipette demonstrate how much water they should put on their slides. Show them how to use the slide covers (optional). Help them to properly focus their microscopes, as needed.

After observation questions: What kind of plankton did you find? How did they look different? Did they move different? Did you see holo- or meroplankton? Which was the most abundant? and Did you see any adaptations or special features on the plankton that help it to meet a survival need?

3. Look at the attached images of phytoplankton and write a descriptive paragraph about their characteristics.

- Phytoplankton shapes: spines, chains, hard shells, flagella (long tails) serve as adaptations.
- Move up and down in the water using neutral buoyancy and controlling their surface area and density.
- The formation of chains helps gain surface area to stay afloat. Others have vacuoles within their bodies to provide buoyancy.

Questions

1. What is the definition of plankton? *Primarily microscopic plants and animals that live in the water and cannot swim against major currents.*
2. When looking under the microscope, how do phytoplankton and zooplankton differ? *Phytoplankton are typically smaller than zooplankton; zooplankton typically move around in your slide.*
3. What physical characteristics assist with neutral buoyancy? *Formation of chains and vacuoles.*
4. How do you think the Deepwater Horizon oil spill may have affected the plankton? *Answers will vary.*
5. How do you think plankton respond to varying environmental conditions? *Answers will vary.*

Extensions

Have students classify plankton (kingdom, phylum, class, scientific name, and common name).

Activity to recognize larval and adult forms. Meroplankton Match-Up
www.nps.gov/cuis/learn/education/.../Meroplankton%20Match-up.doc

Resources & References

Carolina Biological (prepared slides can be purchased here)
http://www.carolina.com/life-science/microscope-slides/10449.ct?mCat=10337&intid=srchredir_microscopeslide&_requestid=49937

Lab#1: Microscopy & Plankton (for directions on how to use a compound microscope, prepare a wet-mount slide, and how to find plankton in a slide)
http://www.biosbcc.net/fukui/labs/01.pdf

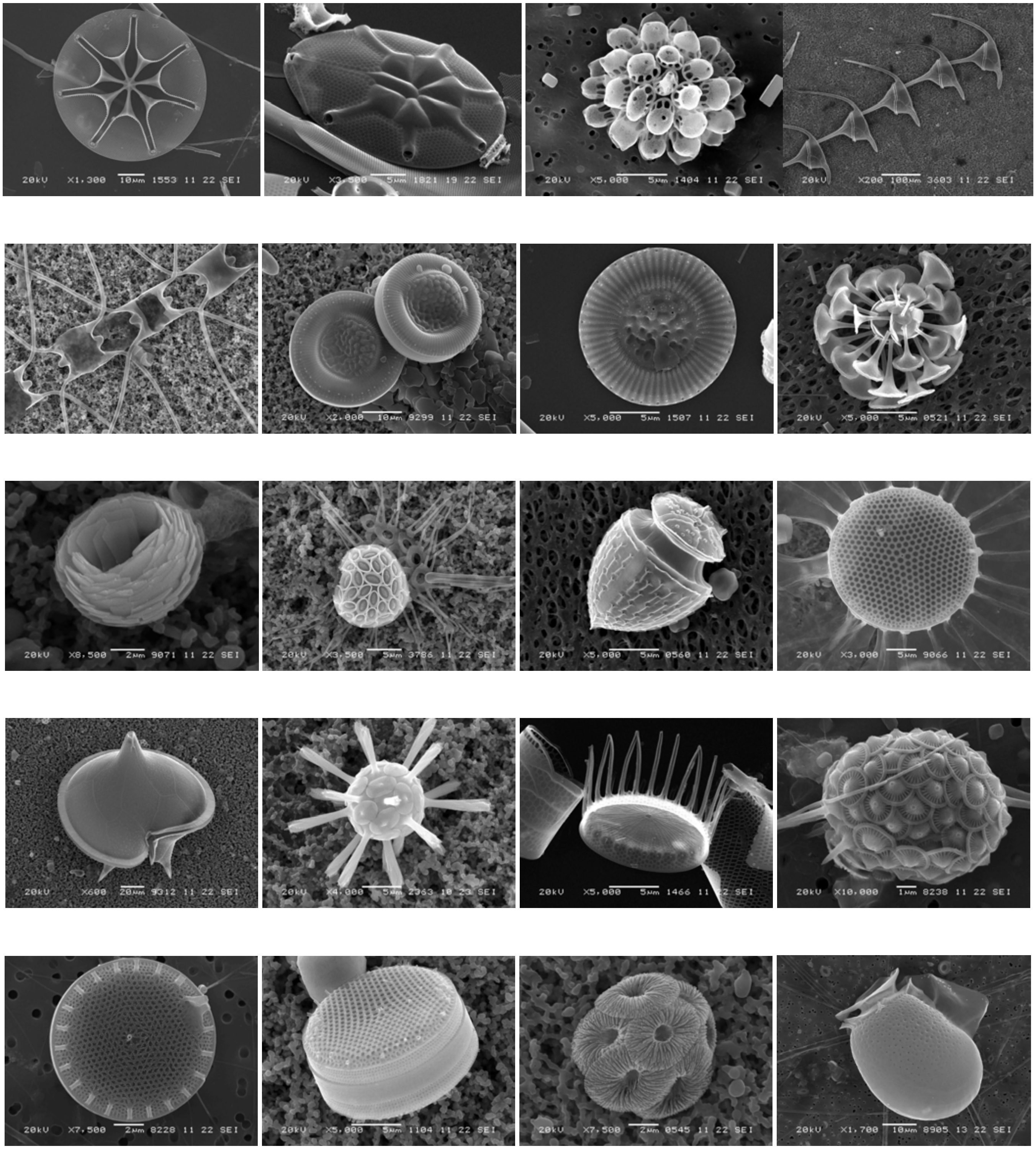
Phytoplankton and the Oil Spill – NGI Discovery Porthole
http://www.northerngulfinstitute.org/impact/resources/gulfResearchInitiative/phytoplanktonOilSpill.pdf

Plankton Fact Sheet from Deep-C
http://deep-c.org/images/documents/fact-sheets/Plankton_FactSheet-web.pdf

Plankton ID Guides:

- Plankton Identification (page 4 and 5) http://er.jsc.nasa.gov/seh/Ocean_Planet/activities/ts3ssac3.pdf
- Common Phytoplankton Key
  http://estuaries.noaa.gov/teachers/pdf/plankton/common_phytoplankton_key.pdf

Images of Tiny Drifters: Phytoplankton, Plant Plankton



Images provided by Dr. James Nienow, Professor of Biology at Valdosta State University

"Suppose you fill up a one-liter water bottle with seawater from just about anywhere along the coast. If you look at it, the water appears clear. However, when you look at it more closely, you find that it contains thousands of diatoms and other types of microalgae. These microorganisms, virtually invisible to the naked eye, in aggregate are responsible for about half of the world's oxygen production, roughly equivalent to all of the terrestrial forests and grasslands we are so familiar with." – Dr. James Nienow

LESSON PLAN: Research Cruises in the Gulf

Catching and sampling deep-sea fishes and sharks

Note: This lesson plan works well in conjunction with the following lesson on *"Toxicity: Exposure to PAHs*" on page 83

Objective: To learn about what it is like to go on a scientific research cruise, and to develop a research question and sampling scheme.

Standards: OLP 5 & 7; SC.912.N.1.1, SC.912.N.4.1

Time Required: One 50-minute class period (can be expanded over two class periods, to allow additional discussion time)

Keywords: research cruise, sampling

Materials: Computer, projector, and student worksheets

Background

Studying the ecological impacts of the 2010 Deepwater Horizon oil spill from the deep sea to coastal communities is a challenging undertaking. It involves a team of scientists working on various research projects taking multiple samples from a several locations to put the pieces of the puzzle together. **Sampling** many times is necessary in order to be able to draw well-supported conclusions. One sample can only tell you what was happening at that single place at that specific time. Therefore, a variety of techniques are used to conduct the research. In particular, the fieldwork under Deep-C Consortium projects required intensive use of the Research Vessels Apalachee and Weatherbird II.

Deep-C ecologists Dr. Dean Grubbs and Dr. Chip Cotton from the Florida State University Coastal & Marine Laboratory researched the bony fishes and sharks in the northeastern Gulf of Mexico. The research focused on learning what animals can be found in the region of the Deepwater Horizon oil spill in the deep sea; particularly the ones closest to the bottom that potentially could have been directly impacted by the spill. The ecology team concentrated their efforts in three regions: the Louisiana slope to the west side of De Soto Canyon (–direct exposure), the east side of De Soto Canyon and north Florida Slope (–less affected), and southwest of Tampa on west Florida Slope (–unaffected/lightly affected). Working with Dr. Jim Gelsleichter from the University of North Florida, they compared community abundances and used a toxicological approach, looking at their exposure to toxins that are associated with oil across those three regions. Most people think the deep sea is relatively homogeneous, but in fact it is not in terms of species found there. The community of animals on the west side of the canyon is completely different than that found on the west Florida Slope. Small regional differences translate to big differences in the community.

As part of the Deep-C Consortium, the ecology team went on 10 **research cruises** resulting in the sampling of more than 4,000 fishes from 101 species (including 34 species of sharks and rays), making this the largest survey of deep-sea elasmobranch fishes ever conducted in the Gulf of Mexico. Deep sea is considered deeper than 200m (600-700ft). Using sampling methods Dr. Grubbs developed, they caught a wide variety of sharks, from the lantern shark that is about 10 inches long (a bioluminescent shark that migrates vertically) to the six-gill shark that is 16-17ft long (likely the largest fish predator in the Gulf). Every cruise they caught some species that hadn't been caught previously. From their research they found a difference in exposure and metabolism of PAHs (polycyclic aromatic hydrocarbons) among regions and the time frames of exposure varied based on species. For some deep sea bony fishes, the peak exposure was one and a half years after the Deepwater Horizon oil spill and may be recovering. Deepwater sharks grow very slowly and for some species, their peak signals of oil exposure were two and a half years after the spill. The researchers are seeing signs of recovery in some species, while signals of oil exposure are persistent in others.

This research requires lethal sampling. To make the most out of sacrificing an animal, many tissue samples are collected for a variety of studies:

- Muscle (stable isotopes, mercury)
- Fin clips (genetics)
- Liver (toxicants, mercury, PCBs, condition)
- Bile (toxicants)
- Blood (toxicants, reproduction, stress physiology)
- Gills (stable isotopes)
- Reproductive tracts (life history)
- Aging structures (spines, vertebrae for life history)
- Stomachs (diet studies)
- Heads (biomechanics, brain studies)
- Jaws (tooth studies)
- Eyes (visual physiology)
- Hearts (cardiac function)
- Rectal glands (osmoregulation)
- Vouchers (taxonomic studies)

Procedure

1. Ask students what they think it is like to go out on a scientific research cruise? (5 min)
2. Pass out Student Worksheets #1 and #2.
3. Separate them into small groups and have them discuss the following: If they were ecologists studying the impacts of the oil spill, how would they set up an experiment to figure out how the oil was affecting the fishes and sharks? (15 min)
4. Have student read *"A day out on the research vessel - Account from Dr. Dean Grubbs"* on page 82 (5 min)
5. Watch a portion of "Creatures of the Deep" (end at 11:45 min; 19:50-21min talks about teams and hauling gear) – the Toxicity lesson will pick up from there and run to the end of the video at 26:42 min. Answer the questions on Student Worksheet #2.
   https://www.youtube.com/watch?v=WEIqgFUxV2g&list=UU2L3PrUh7nWFA_Fva8RoGcA
   In the cold, deep waters of the Gulf of Mexico, little-known animals spend their entire lives far removed from our human world. Until now, little research has been conducted on these creatures of the deep, keeping much of their lives a mystery.
6. Discuss the video and ask the students what they thought…have their ideas of what it is like to go out on a research cruise changed? (10min)
7. Collect the Student Worksheets.

Answers to Research Cruise Questions from Creatures of the Deep - Changing Seas TV

1. In the deep sea; of the 500 shark species, 55-60% of them live their whole lives deeper than 700ft
2. 10
3. Northern Gulf of Mexico
4. Expensive, far away in depth/ hard to access
5. To catch fishes in different habitats and depths
6. To look at different things to find information on age, genetics, diet, exposure to toxic chemicals
7. Isopods
8. True

Resources & References

Background Information on Sharks http://ocean.si.edu/sharks

Creatures of the Deep Video – Changing Seas TV http://www.changingseas.tv/episode503.html
https://www.youtube.com/watch?v=WEIqgFUxV2g&list=UU2L3PrUh7nWFA_Fva8RoGcA

Deep-C's *Voices from the Field* Blog: Fisheries/Ecology Cruise
http://deepcconsortium.blogspot.com/search/label/Ecology%2FFisheries%20Cruise%20-%20October%202012

Deep-C's Deepwater Sharks Fact Sheet
http://deep-c.org/images/documents/fact-sheets/DeepwaterSharks_FactSheet-web.pdf

Sampling the Ocean – Cal Echoes Lesson Plan (extension questions utilized for student worksheet)
https://calechoes.wordpress.com/lesson-plans/

Contributing Expert

Dr. Dean Grubbs, Marine Ecologist at the Florida State University Coastal and Marine Laboratory

Student Worksheet #1

Group Work: You are an ecologist studying the impacts of the 2010 Deepwater Horizon oil spill. How would you set up an experiment to figure out how the oil was affecting the fishes and sharks in the northeastern Gulf of Mexico? With your team of researchers, come up with a sampling scheme.

1. What is your testable research question?

2. What is the time scale of your question (does it happen quickly or slowly)?

3. What is the spatial scale of your question (does it occur over a large area or a small area)?

4. What kind of equipment would you use? What are the advantages of using this equipment? What are the limitations?

5. Would it be useful to combine data from more than one type of equipment in order to address your question?

6. How often will you take samples? Why?

7. Where will you take samples? Why?

8. How many samples will you take? Why?

9. What is the time period over which sampling will occur (one day, ten years, etc.)?

10. What are the aspects of your sampling environment that you cannot control? Is it possible to account for those factors when analyzing your data?

Student Worksheet #2

Working around the clock: A day out on the research vessel - Account from Dr. Dean Grubbs

"A day out on the research vessel – we don't ever stop, we work 24-hours-a-day. We carry a science crew that we can divide in half for setting our gear, then everyone is involved in hauling the gear.

So when we get on our first site for example, half of the team would set three of our deep-water sets that include a 'short' long-line (500m of line on the bottom, five different hook sizes, several different trap styles, temperature depth recorder, oxygen probe on the line). We will target very specific depths in specific habitats.

The team may set at 300, 500, and 700m deep. Only takes about 20 minutes to set the gear. Wake up the other half of the science crew and will haul all of those lines. When each line comes on board, each fish that comes up, it is quite a process to keep everything on track when sampling fishes.

The fish immediately gets a photograph and a specimen ID, so we can go back in the future because a lot of these are species that are poorly known to science and some are new species. We need photographic record so we can link the samples back to that original timestamp of when we collected the animal.

It then goes through a process of getting measured and weighed. There are about 20 different samples taken from each animal. Things for genetics, life history studies (such as reproduction and telling how old the animal is), muscles are taken for stable isotopes to look at the food web, muscles are taken for mercury bioaccumulation, blood is taken for stress physiology and reproductive parameters, and then we take liver, bile, and blood that's also used for the toxicity study, biomarker studies where the look for exposure to and metabolism of any toxins that might be associated with the oil spill.

It is a long process to take the animals from capture to all the samples. Takes several hours. As soon as they are done processing all the animals from those three stations, then finally that first team gets to go to sleep for three hours while the other team sets the next set of gear. It is typically three or four hours of sleep for every 30 hours on the boat."

"Creatures of the Deep" Video from Changing Seas TV – Answer the following questions:

1. Where do most shark species live?

2. How many days was this particular research cruise?

3. Where are the scientists headed?

4. Why is it difficult to study the deep sea?

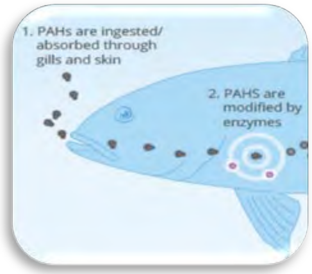
5. What is the reason for different traps and hooks?

6. Why do they need to take multiple samples from one specimen?

7. What is the name of the scavenger that eats the fish on the line?

8. True or false. The type of species found changes, as you get deeper in the ocean.

LESSON PLAN:
Toxicity: Exposure to PAHs



How do scientists sample marine organisms for PAHs

Note: This lesson plan works well in conjunction with the *Research Cruise* lesson.

Objective: To become aware of how exposure to a pollutant such as Polycyclic Aromatic Hydrocarbons (PAHs) can be toxic to organisms and how marine scientists sample for PAHs.

Standards: OLP 5-7; SC.912.L.14.46, SC.912.L.17.16, SC.912.L.17.9, SC.912.N.1.7

Time Required: One 50-minute class period

Keywords: PAHs, toxicity, liver, gallbladder, food chain/web, biomarkers, enzymes

Materials: Computer, projector, copies of Student Worksheet

Background

What are PAHs?

Polycyclic Aromatic Hydrocarbons (PAHs) are organic compounds containing only carbon and hydrogen which are composed of multiple aromatic rings. They are a group of more than 100 chemicals that are formed by the partial burning of coal, oil and gas, garbage, or other organic substances (such as tobacco or charbroiled meat). Some PAHs are manufactured and may be found in coal tar, crude oil, creosote, and roofing tar. A few are used to manufacture medicines, dyes, plastics, and pesticides. Some PAHs have been shown to interfere with reproductive and immune systems in laboratory animals and may be carcinogenic to humans.

According to NOAA's *How Oil Affects Habitats and Species*, PAHs can:

- cause direct toxicity (mortality) to marine mammals, fish, and aquatic invertebrates through smothering and other physical and chemical mechanisms.
- also cause sublethal effects such as: DNA damage, liver disease, cancer, and reproductive, developmental, and immune system impairment in fish and other organisms.
- accumulate in invertebrates, which may be unable to efficiently metabolize the compounds.
- then be passed to higher trophic levels, such as fish and marine mammals, when they consume prey.

How did the Deep-C Consortium study PAHs in fish?

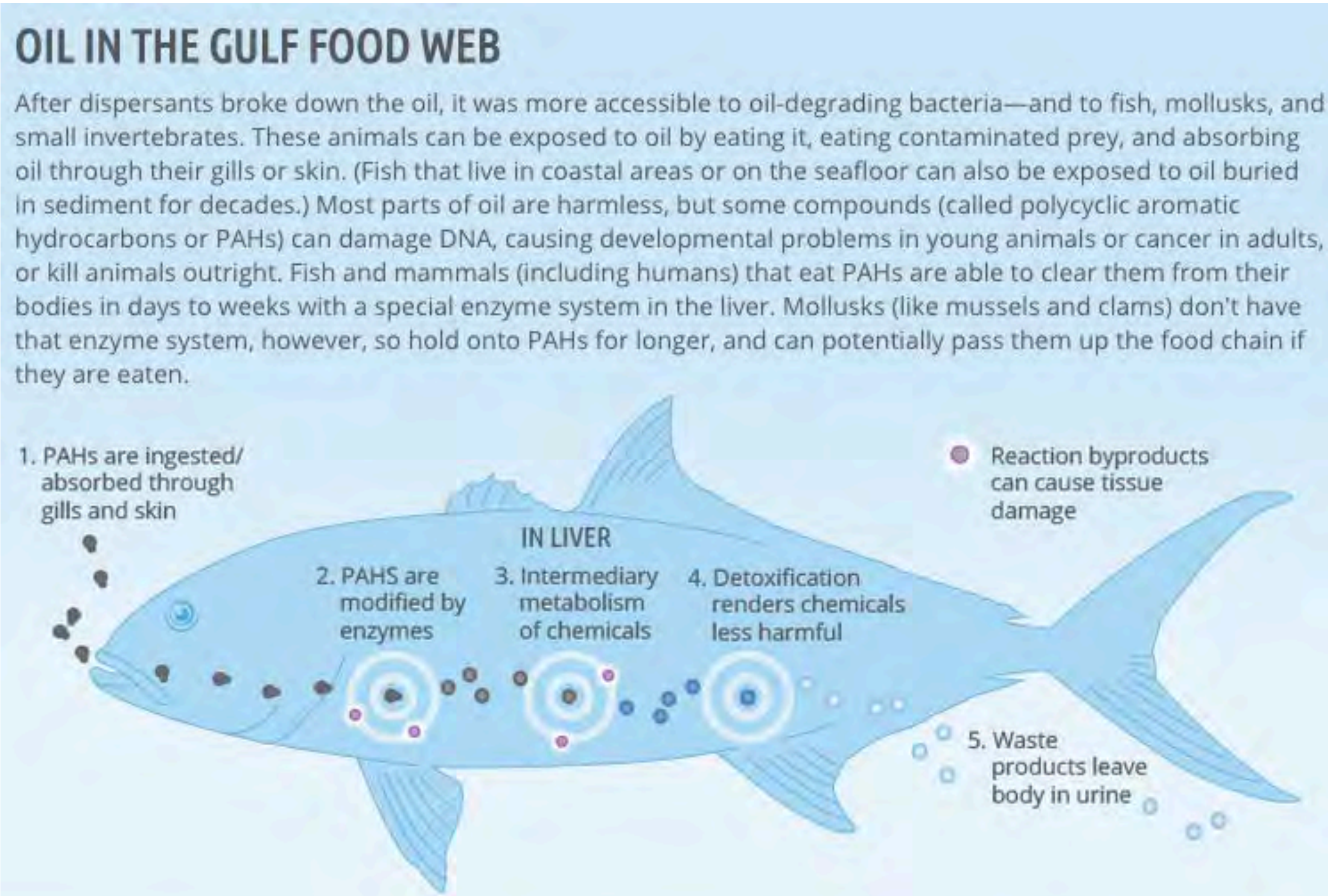
Deep-C studies of the trophic interactions of fish species in the northeastern Gulf of Mexico are motivated by evidence that Deepwater Horizon oil reached the continental shelf from the deep sea via the De Soto Canyon, and by anecdotal evidence from fishermen and scientists that this event had a significant effect on fish health and community composition. Given the strong linkages between large-scale oceanographic features such as the Loop Current, geomorphology (i.e. the De Soto Canyon and the Apalachicola River Delta), and fisheries productivity, Deep-C researchers evaluated post-spill impacts on the Gulf ecosystem that link results from the ecological research with those of the other Deep-C research areas. The goal was to survey fish assemblages to determine the level and effect of exposure to PAHs, the most toxic substances in crude oil, on fish health and characterize areas most likely affected by the spill.

To test whether PAHs are affecting deep water Gulf fish, Deep-C scientists measured levels of commonly used fingerprints or **"biomarkers"** of PAH exposure in more than 1,000 deep sea fish, focusing on abundant sharks (gulper sharks, shortspine dogfish) and bony fish (tilefish, hakes) that were collected 12 to 42 months following the Deepwater Horizon blowout. The PAH biomarker used in this research included **liver enzymes**, which break down PAHs for excretion and tend to increase when animals are exposed to these pollutants, and the bile that collects in the **gallbladder**. Although findings vary by species, the results of this research suggest that fish collected closer to the oil spill are more likely to exhibit higher levels of PAH biomarkers, suggesting that they may be biologically affected by oil exposure. However, since the actual biomarker levels observed in deep sea fish were low in comparison with earlier studies on coastal fish (perhaps due to lower metabolism in deep sea fish), it is unclear whether these species will experience the types of health effects that can occur as a result of chronic PAH exposure, such as cancer or reproductive complications. Further research is needed.

Procedure

1. **Ask students what type of pollutants/chemicals they think went into the Gulf of Mexico when the oil spill occurred in 2010 and how do they think animals responded to those pollutants?** (Write answers on worksheet on page 86.)

2. **Project the "Oil in the Gulf Food Web" image below from** *[http://ocean.si.edu/gulf-oil-spill-interactive.](http://ocean.si.edu/gulf-oil-spill-interactive)*
   - Read the description aloud and discuss the process step-by-step from ingestion/absorption to waste.
   - Have students write and/or draw this process.



Designed by: Lucy Reading-Ikkandal, Development by: Edward Wisniewski
Source: Gulf of Mexico Oil Spill Interactive, http://ocean.si.edu/gulf-oil-spill-interactive

3. **Watch eight minutes of "Creatures of the Deep" (start at 11:45min and stop at 19:45min) and have student answer eight questions on their worksheet.**
   https://www.youtube.com/watch?v=WEIqgFUxV2g&list=UU2L3PrUh7nWFA_Fva8RoGcA
   Notes from the video:
   - PAHs take a long time to break down.
   - Blood, liver, and bile samples were collected to assess exposure to and metabolism of PAHs.
   - Blood – looking at effects of oil spill or toxicity in general.
   - Liver (large pink), associated with the gallbladder, which contains bile (green/brown tint). It is time and light sensitive so they try to get the samples as quickly as possible. It goes into a light sensitive container and then immediately ice. The toxicity samples are worked up in the lab at UNF.

- Is there evidence that the PAHs have been taken up in the food chain? Are they getting sequestered in the liver and then disappearing or metabolizing? Chromosome damage?
- Closer to the oil site – higher rate of occurrence of PAHs.
- Deep sea fishes metabolism is slow.

4. Wrap up with a summary of the video and have students turn in their worksheets.

Answers to Research Cruise Questions from Creatures of the Deep - Changing Seas TV

1. Polycyclic Aromatic Hydrocarbon
2. Looking for metabolites of toxins
3. Gallbladder
4. Yes
5. Slow
6. Mercury
7. Yes
8. True

Resources & References

Creatures of the Deep Video – Changing Seas TV
https://www.youtube.com/watch?v=WEIqgFUxV2g&list=UU2L3PrUh7nWFA_Fva8RoGcA OR
http://www.changingseas.tv/episode503.html

Gulf of Mexico Oil Spill Interactive
http://ocean.si.edu/gulf-oil-spill-interactive

How oil affects habitats and species – from NOAA shorelines coastal habitats fact sheet
http://www.noaa.gov/factsheets/new%20version/shorelines_coastalhabitat.pdf

Contributing Expert

Dr. James “Jim” Gelsleichter, Associate Professor of Biology at the University of North Florida

Student Worksheet for Lesson on Toxicity: Exposure to PAHs

Name: ___________________________________

What type of pollutants or chemicals do you think went into the Gulf of Mexico when the oil spill occurred in 2010?

____

____

How do you think the animals responded to those pollutants?

____

____

"Oil in the Gulf Food Web" (see image)
Draw the exposure process and how PAHs enter and exit the fish:

Class discussion notes about this image:

____

____

____

____

____

____

"Creatures of the Deep" Video from Changing Seas TV – Answer the following questions:

1. What does PAH stand for?
2. Why do the scientists sample the liver?
3. What organ is associated with the liver?
4. Is there a higher rate of occurrence of PAHs closer to the spill site?
5. Do deep sea animals have slow or high metabolism?
6. Muscle is taken for ___________ analysis.
7. Does mercury bioaccumulate through the food web?
8. True or False. Body size increases with depth.

Ecology Quiz

1. What is baseline data?

2. Why is it important to collect baseline data?

3. From the oil degradation experiment, what indicated evidence of microbial metabolism?

4. Are microbes found naturally in the Gulf of Mexico ecosystem?

5. Why are phytoplankton known as primary producers?

6. What physical characteristics of plankton assist with neutral buoyancy?

7. From "Creatures of the Deep" video, name three samples that were collected from fish during the research cruise in the Gulf of Mexico.

8. When scientists are out at sea, what is the reason for different traps and hooks on the line?

9. What are PAHs?

10. What organs do scientists sample to measure exposure and metabolism of PAHs?

Ecology Glossary

Baseline Data: is the initial collection of data, which serves as a basis for comparison with the subsequently acquired data

Biomarkers: biological marker, generally refers to a measurable indicator of some biological state or condition; occasionally used to refer to a substance the presence of which indicates the existence of a living organism; like fingerprints, used to measure PAHs (in the lesson's case)

Bioremediation: the use of either naturally occurring or deliberately introduced microorganisms or other forms of life to consume and break down environmental pollutants, in order to clean up a polluted site

Consumer: an organism that gets its energy from eating other organisms

Food Web: a system of interlocking and interdependent food chains

Gallbladder: an organ associated with the liver that collects bile

Holoplankton: organisms that are planktonic for their entire life cycle (i.e. jellyfish, copepods, and amphipods)

Liver: a large lobed glandular organ in the abdomen of vertebrates, involved in many metabolic processes

Liver enzymes: biological molecules (proteins) that act as catalysts and help complex reactions occur everywhere in life

Meroplankton: organisms that are only planktonic for part of their life cycle (i.e. larval stage, crabs, fish)

Microbes: tiny, single-cell organisms too small to be seen with the naked eye

Monitoring: tracking changes over time

Neutral buoyancy: neither floats or sinks

Oil Degradation: the break down or weathering of oil

Photosynthesis: the process of converting sunlight into food/energy

Phytoplankton: plant-like plankton, primary producers

Plankton: free-floating, microscopic organisms that move through the water column and with the currents

Polycyclic Aromatic Hydrocarbons (PAHs): organic compounds containing only carbon and hydrogen—that are composed of multiple aromatic rings; the most toxic substances in crude oil

Producer: an organism that produces its own energy, either from the sun or from chemicals

Tetrazolium: an indicator dye that is colorless in its oxidized form, but turns pink when it is reduced

Toxicity: the degree to which a substance can damage an organism; can refer to the effect on a whole organism, such as an animal, bacterium, or plant, as well as the effect on a substructure of the organism, such as a cell or an organ such as the liver

Zooplankton: animal-like plankton such as newly hatched crabs and other invertebrates

Physical Oceanography
In the Gulf of Mexico

What is Physical Oceanography?

The study of waves, tides, and currents; the ocean-atmosphere relationship that influences weather and climate; and the transmission of light and sound in the oceans.

Circulation in the Gulf

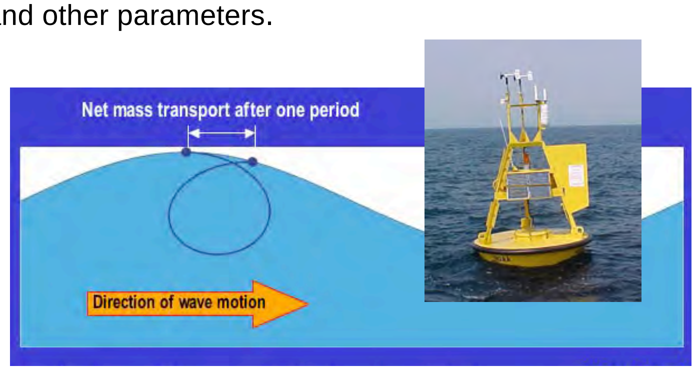
Circulation in the Gulf of Mexico is dominated by the highly variable Loop Current, which is a warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf, and then loops east and south before exiting through the Florida Straits where it joins the Gulf Stream. The Loop Current takes various tracks, sometimes moving fairly directly from the Yucatan Peninsula to the Florida Straits and sometimes forming a large loop that extends into the northern Gulf. Soon after the 2010 Deepwater Horizon oil spill, there was concern that the Loop Current would carry oil up the East Coast. Fortunately, the top part of the current pinched off, forming an eddy (vortex), and stayed on a persistent southerly track, which prevented the transport of oil into the Atlantic Ocean.

Tracking the currents to discover where the Deepwater Horizon oil went

Deep-C's physical oceanographers were tasked with researching where the oil went. To do this, they focused on factors that control the movement of oil and other contaminants in the Gulf of Mexico. They looked at both surface currents and deep ocean currents, using a variety of instruments including moorings and subsurface floats deployed near the head and within the De Soto Canyon. They also conducted a two-month experiment using self-powered and wind-propelled SailBuoy. In conjunction with NOAA flight missions, ocean profilers were dropped into the Gulf waters. Also, a new float technology is being developed to measure currents near the seafloor with "bottom drifters," profiling the water column regularly for temperature, salinity, oxygen, and other parameters.

Deep-C Physical Transport Research

Stokes Drift



Stokes drift is the lateral motion of a particle via wave action. The inter-annual variability of the Stokes drift in the Gulf of Mexico was quantified using NOAA's National Oceanographic Data Center (NODC) buoy data with wave measurements, such as the ones found at The National Data Buoy Center http://www.ndbc.noaa.gov/.

Moorings: Anchored buoys with observational sensors

Moorings are anchored buoys with a number of observational sensors collecting data at different ocean depths. In 2012, six moorings were deployed by a Deep-C research team near the head and within the De Soto Canyon, and then retrieved in 2013. The data collected by these moorings can be used to draw conclusions about the physical transport of materials (such as oil and sediments) from the deep ocean to the coast.

A team prepares to deploy a series of anchored moorings. The connecting lines secure the instruments that record data such as temperature, pressure, and velocity.

Subsurface floats: Drift with the currents and gyres to track the motion of the water

RAFOS is SOFAR (SOund Fixing and Ranging) spelled backwards, which refers to the way these floats track the motion of the water. A drifting RAFOS float listens and records sound signals from stationary acoustic beacons. At the end of their pre-programmed mission, the floats drop their ballast weights, rise to the surface, and beam their data to orbiting satellites. Deep-C scientists analyzed data from the floats' one-year mission and found that they moved laterally along the slope, reversing direction from time-to-time, suggesting a mixing effect. Eventually many escaped the slope region and entered the interior in a couple of key locations. The most prominent of these locations is the along the Sigsbee Escarpment, which guided the drifters southward into the interior of the Gulf of Mexico.

The green dot is the location of the Deepwater Horizon oil rig. The white lines represent subsurface (RAFOS) tracks near 400m depth as observed using floats deployed in the De Soto Canyon (red dots).

Deep-C bottom drifter for shelf and canyon research

Scientists at FSU's Geophysical Fluid Dynamics Institute designed a new multi-sensor, subsurface coastal drifter that provides effective ways to acquire oceanographic data at depths that remote sensing cannot penetrate. It is equipped with a Seabird sensor which can record conductivity, temperature, and pressure at a given sampling rate. The drifter is also outfitted with a Doppler Velocity Log that provides high quality positioning data with bottom tracking, acoustic doppler current profiling, float positioning, and earth/ship referenced velocity information. *The prototype of a new coastal drifter is currently being tested by FSU in a pool environment.*

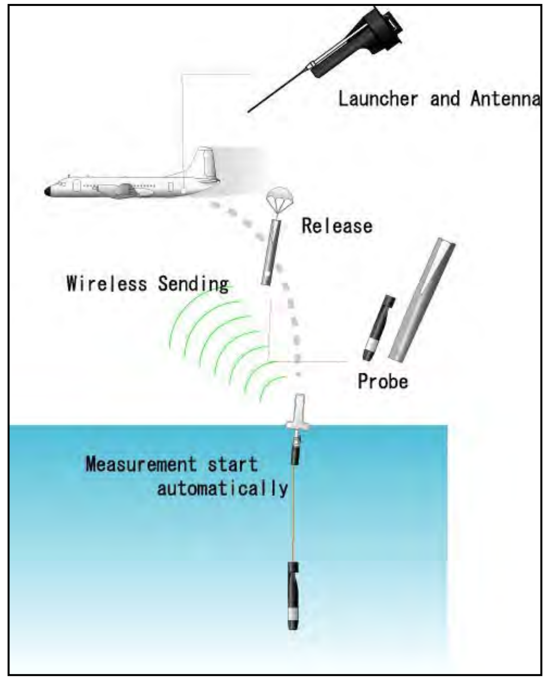
An unmanned, wind-propelled SailBuoy

In March of 2013, the self-powered, wind-propelled Christian Michelsen Research (CMR) SailBuoy was deployed by Deep-C scientists in the northeastern Gulf of Mexico. During its two-month mission, it sailed approximately 840nm on a cruise track across the Gulf coast, from the Florida Panhandle to West Louisiana. Sensors were mounted on the SailBuoy that allowed scientists to monitor seawater parameters, such as temperature, salinity and dissolved oxygen. Equipped with two-way satellite communication for real-time data streaming and GPS updates, it transmitted data to the Operations Center (located at the Norwegian Meteorological Institute) at regular intervals along a planned course.

Flight missions with ocean profilers

During Hurricane Isaac (2012), scientists at the University of Miami Rosentiel School of Marine and Atmospheric Science were aboard a NOAA aircraft that flew into the storm to drop Aircraft Expendable Current Probes (AXCPs) at optimum locations around the De Soto Canyon. These AXCPs collect measurements of ocean heat content, salinity, and currents during the hurricane.

The data, when coupled with numerical models, demonstrated that it is plausible for upwelling events associated with hurricanes to lead to the re-suspension of weathered oil in the water column and onto the shelf. Several follow-up flight missions over the Gulf of Mexico were also conducted to test new and improved AXCPs.



Deep-C's Physical Oceanography Team

Allan Clarke
Florida State University

Kevin Speer
Florida State University

Lynn "Nick" Shay
University of Miami-RSMAS

Nico Wienders
Florida State University

Peter Hamilton
Leidos (prev. SAIC)

Bob Weisberg
University of South Florida

What Did We Learn?

- The magnitude of the Macondo well leak became increasingly apparent as the surface area covered with oil expanded.
- The spread of the oil towards the Loop Current raised concern that it may become entrained and affect more coastal areas.
- Environmental conditions that affected where the oil went: regional open sea dynamics, the Loop Current and associated eddies, shelf processes, Mississippi-induced buoyancy-driven and wind-driven flows.
- Current velocity, temperature, and salinity fields are critical to the fluid particle evolution.
- The velocity of an oil droplet depends on density and size.
- Oil particles at the surface and at depth are subject to biodegradation.
- The wind and waves strongly influenced the displacement of oil.

LESSON PLAN:
Oceanography Demonstrations

Exploring Density, Temperature, Salinity, Pressure & Currents

Objective: To demonstrate density in a variety of ways, understanding how layers of water with different properties interact. Use as a physical oceanography lesson primer.

Standards: OLP 1; SC.8.P.8.4, SC.912.E.7.2

Time Required: 30 minutes for each demonstration

Keywords: density, mass, volume, temperature, salinity, pressure, currents, wind, waves

Materials: Refer to individual demonstrations for specific lesson materials

Background

Density is a physical property of matter, as each element and compound has a unique density associated with it. Density is defined as the measure of the relative "heaviness" of objects with a constant volume or how closely "packed" or "crowded" the material appears to be. For example: a Styrofoam cup is less dense than a ceramic coffee mug.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

This equation defines density as the **mass** of water per unit **volume**. The units are grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3). The density of freshwater at 4°C is 1.0000 g/cm^3 or 1000 kg/m^3. In the oceans, the density ranges from 1.020 to 1.070 g/cm^3.

Three seawater properties control density:

Temperature: As water cools, its density increases. The water molecules pack more closely together and take up less volume, resulting in a higher density. Globally, there is an average of approximately 20°C temperature decrease from the surface to the bottom of the ocean. Deeper water is more dense than surface water. The majority of the ocean is warm at the surface and colder at increasing depths. The region where temperature decrease is greatest with depth is called the **thermocline**.

Salinity: The salt in seawater makes it denser than freshwater. Typically, seawater contains between 33 to 37 grams of salt per liter of seawater (g/L) or parts per thousand (ppt). In general, the salinity decreases from the surface ocean to the deep water is very small, from about 36 ppt at the surface to 35 ppt in the deep water.

Pressure: As pressure increase, density increases. The water molecules pack tighter together as pressure increases. The pressure increases with depth in the ocean due to the weight of the water above. This is where the greatest density changes are seen in seawater with depth.

Decreasing temperature, increasing salinity, and increasing pressure causes the water to become more dense. Understanding density is important in understanding how layers of water with different properties interact, such as when freshwater flows from the Mississippi River and meets the salty water of the Gulf of Mexico. Density also plays a role in how organisms move in the water column, how different chemicals (such as the crude oil) behave, and how sediment is transported.

Slight density differences can be seen in the Gulf of Mexico. The Gulf's surface water has a density of approximately 1022 kg/m^3, whereas the water 4000m below at the bottom has a density of approximately 1028 kg/m^3—an increase of less than 0.5%. Even though the density difference may seem small, it is important to the mixing, circulation, biological productivity.

Demonstration #1: Calculating the Densities of Freshwater and Saltwater

Students will measure salinity, temperature, mass, and volume of the water in order to calculate the density.

Materials for Demonstration #1:

- 2.5 mL glass vials
- Laminated index cards
- Triple beam or electronic scale
- Graduated cylinder
- Food coloring
- Seawater or salt mixed with tap water
- Refractometer
- Thermometer
- 1-gallon milk jugs (2)
- Beakers
- Pipettes
- Calculator

Procedure

1. **Prepare the gallon jugs of saltwater and freshwater. If seawater is unavailable, then mix salt into tap water.**
2. **Add yellow food coloring to the saltwater and blue food coloring to the freshwater.**

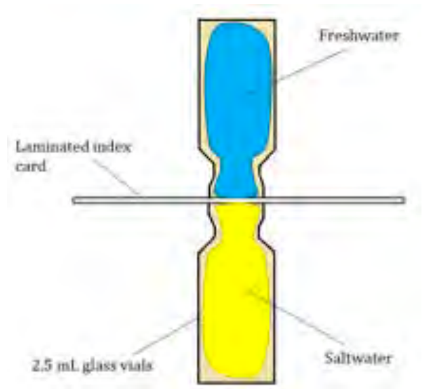
Taking Measurements

3. **Pour 200 mL into the beaker.**
4. **Measure salinity with a refractometer, temperature with a thermometer, and mass with the scale.**
5. **Calculate the density of the two water samples. Record all observations.**

Parameters	Yellow Solution (Saltwater)	Blue Solution (Freshwater)
Temperature (°C)		
Salinity (psu)		
Volume (mL)		
Mass (g)		

Density Observations

5. **Pipette saltwater and freshwater into two 2.5 mL glass vials, filling each vial completely.**
6. **Place a laminated index card on top of the saltwater vial, then invert the freshwater sample and place upon the same card in the same position as the saltwater vial. Slowly remove the card and record observations.**
7. **Grasp both vials and turn them upside down, so that the freshwater vial is on the bottom; record the observations.**



Questions

1. Is saltwater or freshwater more dense? Explain why.
2. Which is denser, cold or warm water? Explain why.
3. Draw a diagram of how water might layer when a river enters the ocean.
4. How might oil from the earth's crust move into the ocean? Explain.
5. If a large amount of oil is spilled into the ocean, will the oil float or sink?

Demonstrations #2 and #3: Surface Current and Deep Current

Adapted from COSEE - "Loop Current in the Gulf of Mexico"
Source: http://ocean.si.edu/for-educators/lessons/loop-current-gulf-mexico

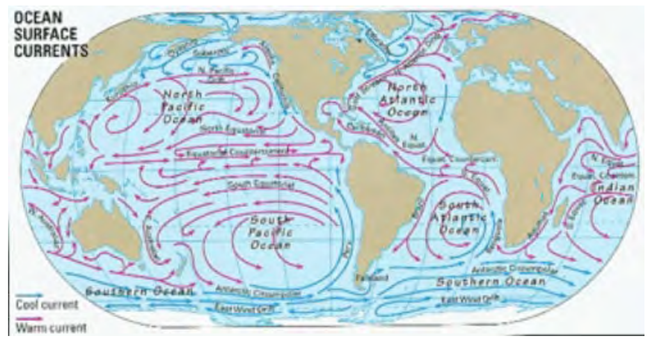
Students will create demonstrations of a surface current and a deep ocean current.

Materials for Demonstrations #2 and #3:

- Aluminum foil
- Plastic shoebox
- Food coloring
- Masking tape
- Sharpened pencil
- Pepper
- Aluminum pie plates
- Salt
- Water (warm and cold)
- 600 ml beakers
- Soda straws

Demonstration #2: Surface Current

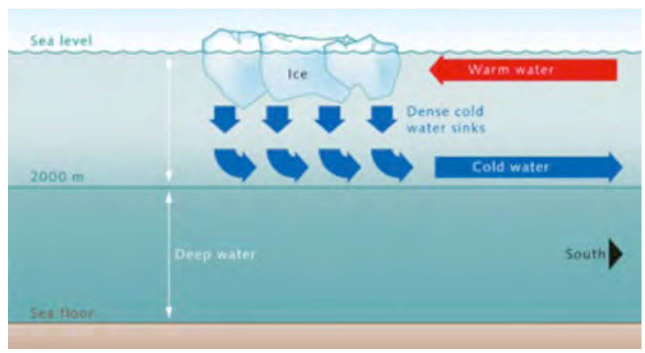
1. Fill a pie plate with cold water to the inner rim.
2. Sprinkle pepper on the surface of water. What happens to the pepper? What kind of current is being shown here?
3. Using the straw, gently blow across the top of the water from one edge.
4. Discuss what happened to the pepper. What caused the movement of the pepper?



Source: http://oceanexplorer.noaa.gov/

Demonstration #3: Deep Ocean Current

1. Create a wall separating the two ends of the plastic shoebox using aluminum foil and masking tape. Use tape along all three edges of the aluminum foil wall to prevent any leakage.
2. Once the walls have been created, add 6 drops of red food coloring and warm water to one beaker. Stir. Add and stir in 6 drops of blue food coloring, 10 grams of salt, and cold water to the other beaker.
3. Carefully, pour the beaker of each color water on opposite sides of the plastic shoebox (pour equal amounts at the same rate or the aluminum foil wall will fall).
4. Use the sharp pencil to make a hole in the aluminum foil wall 5 mm above the bottom of the shoebox.
5. Then make a second hole in the aluminum foil wall 5 mm below the water surface.
6. Observe from the side of the plastic shoebox. Discuss student observations.



Source: http://worldoceanreview.com/en/wor-1/climate-system/great-ocean-currents/

Questions

1. What type of ocean currents do these demonstrations simulate?
2. What happens when cold water enters warm water?
3. What happens when salt water meets fresh water?
4. Discuss deep ocean currents and their cause. *Density-driven currents caused by changes in temperature and salinity.*

Demonstration #4: Wind Waves

Adapted from SECOORA, Source: http://secoora.org/classroom/virtual_wave/wind_waves

Students will investigate the factors affecting wind waves.

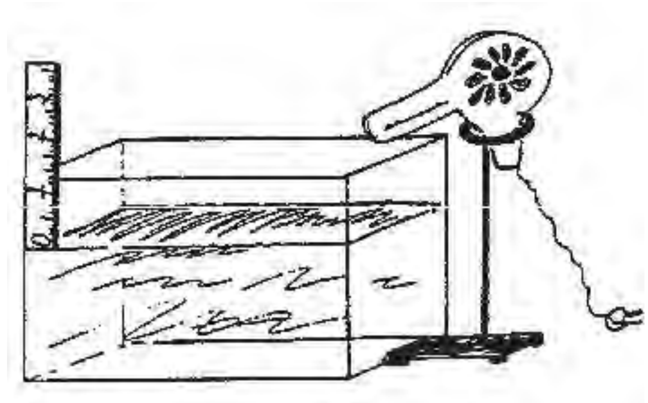
Materials for Demonstration #4:

- Hair dryer
- A small glass or plastic rectangular container (such as an aquarium)
- Ring stand (to hold and position hair dryer)
- Erasable markers
- Ruler
- Water
- Tape
- Clock or watch

Background

See the SECOORA Waves Fact Sheet http://secoora.org/classroom/virtual_wave/waves_fact_sheet

Procedure



1. Fill the container until it is approximately three-fourths full with water.
2. Tape a ruler on the outside of the container such that the zero mark is at the level of the water's surface.
3. Place the ring stand opposite the side of the container with the ruler. Set up the hair dryer on the stand such that it is a few inches above the water.
4. *Comparing waves.* Mark the position of the still water's surface using erasable marker along the side of the container and label it accordingly.
5. For each of the different speed settings of the hair dryer:
    - Start the hair dryer. Record observations about the initial set of waves.
    - After 3 minutes, mark and label the maximum height of the waves using erasable marker on the side of the container. Calculate the difference between this maximum height and the still water's height. Describe the shape of these waves.
    - Repeat Step 2 after two more minutes (after dryer has run for a total of five minutes).
    - Describe what happens to the waves as the hit the sides of the container.

Questions

1. What is the relationship between the height of a wave (distance from crest to trough) and the position of the crest above the still water level?
2. How is the wave height affected by the length of time the wind blows?
3. Describe how the force or strength of the wind affects the height of the waves.
4. What happens to the waves when they hit the end and sides of the container?
5. Does the strength of the wave have any effect on this movement of the waves?

Demonstration #5: Wave Size and Depth

Adapted from Margaret Olsen, SouthEast COSEE Education Specialist. Source: http://secoora.org/webfm_send/313

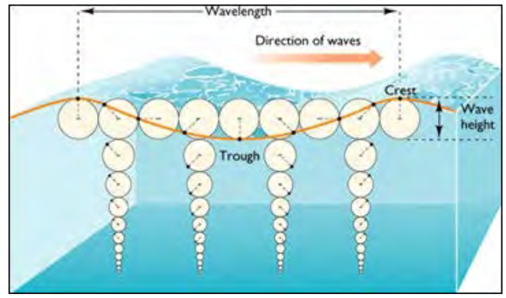
Students will investigate *how deep the energy of a wave goes and investigate the relationship between the size of a wave and depth of wave energy.*

Materials (per group) for Demonstration #5:

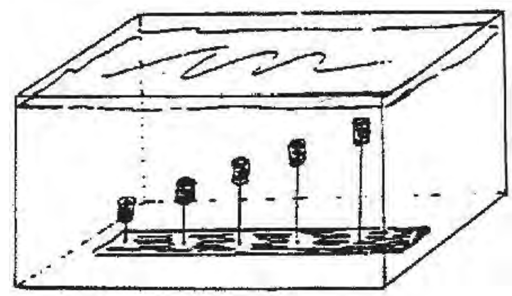
- Aquarium
- String
- Five corks (of equal size and weight)
- Water
- Permanent and erasable markers
- Two rulers (one must fit inside the aquarium)
- Modeling clay (to secure the ruler to the bottom of the aquarium)
- Straight pins

Background

Most waves are generated by wind. Such a wave's size depends on how long the wind blows, the strength of the wind, and the fetch (the distance over which the wind blows). The water in a wave moves in a circular orbital pattern downward to a depth of one-half the wavelength.



Source:http://secoora.org/classroom/flowing_ocean/skidaway_river



Procedure

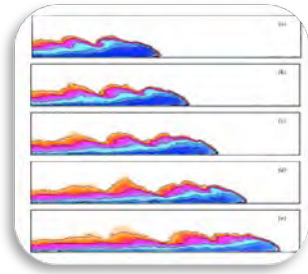
1. Label each cork using the permanent marker.
2. Cut five lengths of string (at least seven inches in length).
3. Tie one end of each string to one of the rulers. Secure this ruler to the bottom of the aquarium using the modeling clay.
4. Attach corks to the strings with straight pins. The first should one inch from the bottom, the second two inches from the bottom, and so on.
5. Add water to aquarium until it is about one inch above the cork with the longest string.
6. Record the depth of each cork *as measured from the surface*.
7. Make small waves by moving your hand or a block of wood back and forth in the water. Record your observations of the motion of each cork.
8. Increase the size of the waves by moving your hand or block of wood faster. Observe and record how the increased wave size affects the motion of each cork.
9. Let the water settle. With an erasable marker, mark the water level on the outside of the aquarium. This line represents "sea level."
10. Hold a ruler vertically beside the aquarium and make small waves with your hand again. Measure the heights of the crests and troughs of these small waves and determine the wave height.

	Cork 1	Cork 2	Cork 3	Cork 4	Cork 5
Depth (inches)					
Effect of smaller waves					
Effect of larger waves					

Questions

1. When waves were small, which corks moved?
2. When waves were larger, which corks moved?
3. How deep did the effect of the small waves go? The larger waves?
4. Is there a relationship between wave height and the depth to which the effects of the waves' energy can be observed? Explain.

LESSON PLAN:
Gravity Currents in the Gulf of Mexico



How the mighty Mississippi River influences density and ocean circulation

Objective: To demonstrate how the relationship between the density of a fluid, weight of an object, and buoyancy is critical in understanding the ocean.

Standards: OLP 1; SC.912.L.17.3, SC.8.P.8.4

Time Required: One or two 50-minute class periods

Keywords: buoyancy, density, mass, salinity, practical salinity unit (PSU), volume

Materials:

For Gravity Currents

- Stack of books/block
- 3 500ml beakers
- Stir stick
- Turkey baster
- Cold, hot, and room temperature water
- Red and blue food coloring
- Tank

For Potato Float Demonstration

- Beaker labeled “A” that contains saturated salt water
- Beaker labeled “B” that contains fresh water
- Cubed potato
- Beaker labeled “C” that contains saturated salt water on the bottom and layered fresh water on top. *To minimize mixing, pour the water down the side of the glass or use a spoon to direct the stream against the side of the glass*

Background

Gravity currents are everywhere, from the kitchen, to the air, and to the ocean. Currents can be either finite in volume, such as the release from a dam break, or continuously supplied from a source, such as in doorway or lava flows. They are fluid flows driven by density differences between fluids, hence gravity currents also sometimes are referred to as "density currents". These currents are characterized by a sharp front often followed by a bulbous head and longer thinner tail. Dust storms, oil spills, and river outflows are all gravity currents.

For example, when the Mississippi River enters the Gulf of Mexico, the lighter, fresher river water spreads out over the denser, saline Gulf water as a gravity current. As the current spreads, the river water mixes with the ambient Gulf water, changing the properties of the river water including its density and salinity. In this lesson, we will be investigating how density influences the currents and the effect that the Mississippi River has on the circulation of the Gulf of Mexico.

These photos illustrate different types of gravity currents. (l-r) the ocean floor, a simulation in the lab, avalanches, and a dust storm.

Activity #1 - Potato Float Demonstration

To show students the relationship between density of different fluids, the weight of an object, and buoyancy.

Procedure

Source: https://makeanimpression.wordpress.com

1. Carefully place a cube of potato in Beaker A and discuss the results. What type of liquid is in the beaker?
2. Carefully place a cube of potato in Beaker B and discuss the results. Why is there a difference in the location of the potato in the water?
3. Carefully place a cube of potato in Beaker C and discuss the results. Why did the potato only sink half way?
4. Ask students to hypothesize about what made the density (or mass) of each solution different.
5. Based on their experiences with placing potatoes in water before boiling, can they guess which of the two liquids is water?

Assessment

Ask students to write a brief paragraph describing their observations and results during the experiment.

Activity #2 - Sea Water Mixing and Sinking

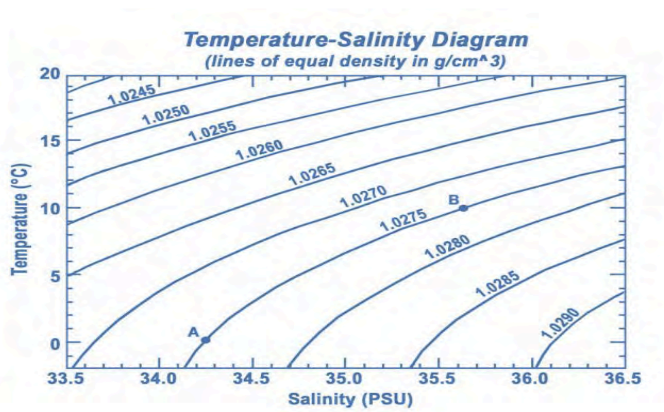
To see how temperature affects salinity.

Background and Procedure

Salinity and temperature help determine the density of seawater, which is a major factor in controlling the ocean's vertical movements and layered circulation. In the oceans, the salinity varies over time and from place to place. Typical open ocean salinities vary between 33 and 36 **PSU (Practical Salinity Unit)**, equivalent to 33-36 parts per thousand. A Temperature-Salinity (T-S) Diagram is a simple, but powerful tool that is used to study seawater density, mixing, and circulation. Temperature is plotted along the vertical axis in degrees Celsius and salinity is measured along the horizontal axis in PSU. Seawater density is illustrated in the diagram by curved lines of constant density (see diagram below). Using the T-S diagram, have your students plot various seawater samples using temperature and salinity data from a Deep-C cruise in the table below and compare and contrast the salinity of different times of year at the same location.

Date	Location	Depth (m)	Temperature [ITS-90, deg C]	Salinity (PSU)
December 2013	29.9161 -87.25154	30	22.3717	36.0973
September 2013	29.9161 -87.25154	30	25.0213	36.0953
June 2013	29.9161 -87.25154	30	21.7588	36.1483
April 2013	29.9161 -87.25154	30	19.624	35.9092

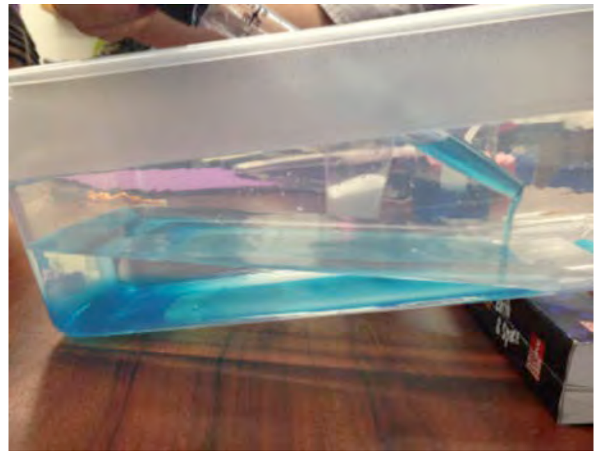
This data was taken from several different data sets. To find more examples go to: https://data.gulfresearchinitiative.org/data-discovery



Activity #3 - Making Gravity Currents

To demonstrate how the influx of water and sediment from the Mississippi River into the Gulf of Mexico influences currents and how oil from the 2010 spill could have affected the ocean's circulation.

Procedure



Students making a gravity current during a Deep-C "Scientists in the Schools" presentation.

1. Prepare the tank:
   - Fill the tank with room temperature water and place on a stack of books or blocks so that the bottom of the tank is at an angle.
2. Make a cold gravity current:
   - Fill the beaker halfway with cold water (use ice if available).
   - Add two drops of the blue dye.
   - Using the turkey baster, release the cold water mixture SLOWLY into the top of the tank.
3. Make a warm gravity current:
   - Fill the beaker halfway with hot water.
   - Add two drops of the red dye.
   - Using the turkey baster, release the hot water mixture SLOWLY into the top of the tank.

Questions

1. How can you make the gravity current travel faster? *Increase the slope.*
2. How can you make the current sit at a different level? *Change the temperature or salinity of the water.*
3. What happens when you add salt to the water? *The density of the water changes.*
4. Does an oil gravity current look like one made from water? *No, because oil is less dense than water.*
5. Does wind cause oil and water to mix? What happens to the current? *Answers will vary.*
6. What happens when a river plume meets an oil spill? *Answers will vary.*

Assessment

Have students read the GoMRI article, **"***Study Demonstrates Substantial Role of Mississippi River in Oil Transport" (page 100).* Using their knowledge of density and gravity currents, have them make a case for why and how the Mississippi River influenced the transport of oil, in 2-3 paragraphs. For an additional challenge, ask students to provide scholarly sources to support their claims.

Reference & Resources

Deep Circulation in the Ocean. Texas A&M University
http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/chapter13_03.htm

GRIIDC: Data Discovery
https://data.gulfresearchinitiative.org/data-discovery

What makes gravity currents flow downhill? Woods Hole Oceanographic Institution
https://www.whoi.edu/fileserver.do?id=21473&pt=10&p=17352

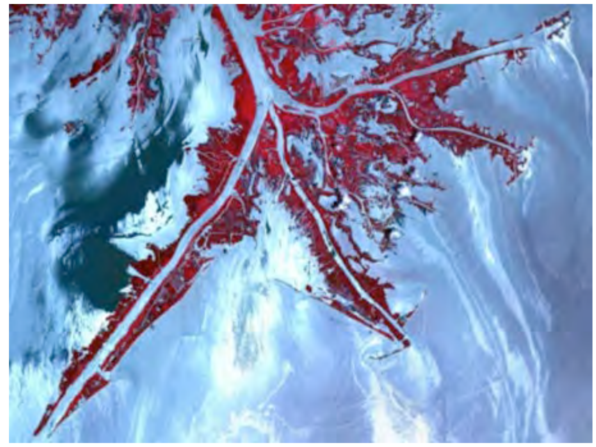
ARTICLE REPRINT

Study Demonstrates Substantial Role of Mississippi River in Oil Transport

Posted online November 11, 2013
Source: GoMRI http://gulfresearchinitiative.org/study-demonstrates-substantial-role-mississippi-river-oil-transport/

Scientists from the University of Miami used a high-resolution prediction model to study the relationship between the Mississippi River and the *Deepwater Horizon* oil spill.

Simulations showed that the Mississippi River plume created rapidly changing circulation patterns and fronts that influenced the direction of surface oil, guiding some towards the Louisiana-Texas shelf and shielding some from the Mississippi-Alabama-Florida shelf.



Oil from the Deepwater Horizon spill laps around the mouth of the Mississippi River delta in this May 24, 2010, image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on NASA's Terra spacecraft. The oil appears silver, while vegetation is red. (Image credit: Jesse Allen/NASA/GSFC/METI/ERSDAC/JAROS, and

The researchers published their findings in the October 2013 *Journal of Geophysical Research: Oceans*: **Influence of Mississippi River induced circulation on the Deepwater Horizon oil spill transport.** The study marks the first time scientists tracked a large river plume in relation to the surface spreading of a deep water oil spill and provides new information on contaminant behavior in the Gulf.

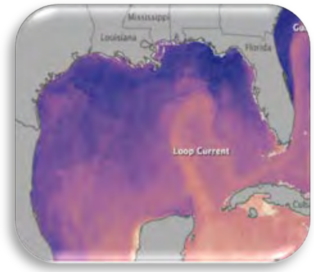
The location of the incident site led disaster responders to consider the possibility that flooding the Mississippi River might help initially divert the oil from coastal marshes. However, no operational computer models with detailed river plume dynamics existed to predict the environment's reaction to flooding.

To understand the influence of Mississippi River waters and quantify connecting patterns of river and oiled waters, researchers developed a high-resolution northern Gulf of Mexico model with daily freshwater inputs from all major rivers and detailed representation of the river plume development under the influence of winds, the complicated northern Gulf topography, and also the Loop Current system. Dr. Kourafalou, lead author of this study, explained, "Since the Gulf of Mexico is a complex ocean system and the oil spill was near the Mississippi Delta, we had to carefully account for both the offshore and coastal currents, which are largely dominated by the Mississippi River plume." For this study, they added observational data on marine and atmospheric conditions from that region and daily satellite images of the surface slick.

The model showed that periods of increased Mississippi output during May and June of 2010 resulted in "enhanced buoyancy-driven currents and created frontal zones that contributed to the overall evolution of the near-surface oil patch." Oil movement "showed a remarkable relationship with the Mississippi River discharge which was maintained throughout the entire oil spill period" (well leakage to capping). Patterns of the river plume and surface oil had a "close synergy that followed the variability in Mississippi River discharge and wind patterns," indicating a "strong relation" between the outflow rates and oil transport.

Researchers noted that while wind was a "main forcing agent" of the drifting oil, their study "established characteristic pathways that governed the parallel evolution between the Mississippi River plume and oil laden waters," identifying "different aspects east and west of the Mississippi Delta." The researchers' data-validated model is now part of an Earth System modeling framework to help inform future response decisions. The study authors are Vassiliki H. Kourafalou and Yannis S. Androulidakis (*Journal of Geophysical Research: Oceans* 2013, *118*, 3823–3842).

LESSON PLAN:
Tracking the Loop Current



Make observations and predictions about the Loop Currents' movement

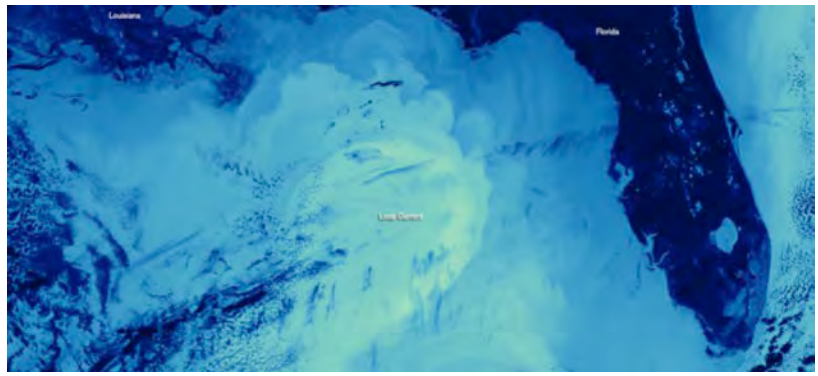
Objectives: To become aware of the Loop Current in the Gulf of Mexico and to make observations and predictions about the movement of the LC using satellite imagery. Students should already be familiar with the causes of ocean currents prior to this lesson.

Standards: OLP 1; SC.912.E.7.2, SC.912.L.17.3, SC.912.N.1.6

Time Required: 50+ minutes

Keywords: Loop Current, eddies, ocean altimetry, satellite, remote sensing, SSH, SST

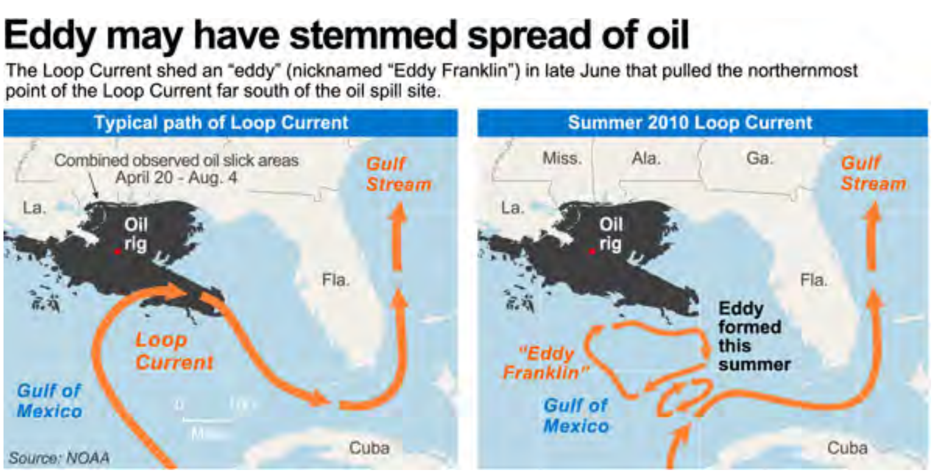
Materials:
- Computer
- Projector
- Gulf of Mexico map
- Satellite images



In this image from the NOAA Environmental Visualization Lab, the Loop Current in the center of the Gulf of Mexico is large and warm, while winter-chilled water draining the Mississippi River watershed envelop the bayous and bays of Louisiana.

Background

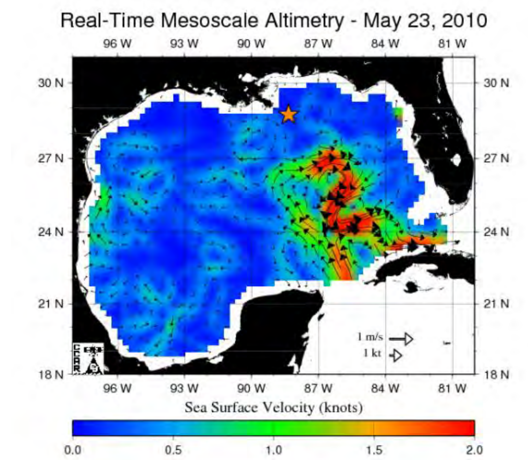
The Gulf of Mexico is dominated by the highly variable **Loop Current** (LC), which is a warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf, and then loops east and south before exiting through the Florida Straits where it joins the Gulf Stream. The Loop Current takes various tracks, sometimes moving fairly directly from the Yucatan Peninsula to the Florida Straits and sometimes forming a large loop that extends into the northern Gulf. Often, portions of the Loop Current will shed or breakaway forming **eddies** which affect regional current patterns. Soon after the 2010 Deepwater Horizon oil spill, there was concern that the Loop Current would carry the oil up the East Coast. Fortunately, the top part of the current pinched off, forming an eddy, and stayed on a persistent southerly track, which prevented the transport of oil into the Atlantic Ocean.



Source: http://usatoday30.usatoday.com/news/nation/2010-09-28-loopcurrent28_ST_N.htm

With the high variability of the Loop Current, there is a need for high frequency sampling of the current over a broad scale. The best way to map ocean currents is from space with **ocean altimetry**, which is the measurement of sea surface topography. **Satellite** measurements of **Sea Surface Height (SSH)** are used to create maps showing the location, direction, and speed of currents. Satellites also measure the **Sea Surface Temperature (SST)**.

Maps aid scientists, decision makers, and emergency response personnel in identifying and tracking ocean circulation features.



Source:http://photojournal.jpl.nasa.gov/jpegMod/PIA13155_modest.jpg

SSH gives a measurement of the deviation of the sea surface from a reference height. A high SSH means the sea surface is relatively raised and a low SSH means the sea surface is relatively depressed. The Loop Current and clockwise rotating eddies in the Gulf of Mexico have a high SSH signature; while counter-clockwise rotating eddies have a low SSH signature. The differences in SSH can be caused by the wind, differences in density, or changes in the water slope due to tides and waves. Changes in SSH tell us about slope of the ocean surface and ultimately the pressure gradient. By assuming relations with density structure and momentum, this information can be used to determine how water is redistributed in the ocean by both vertical and horizontal currents. SSH data can also provide clues to studying the ocean's temperature. Warm water expands raising the sea surface height, whereas cold water contracts lowering the height of the sea surface. Measurements of SSH can provide information about the heat content of the ocean. The height can tell us how much heat is stored in the ocean water column below its surface.

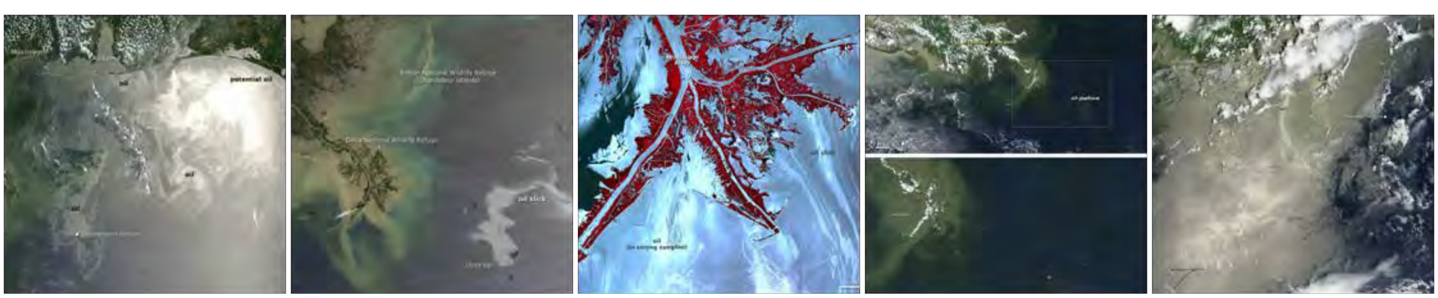
SST is the temperature of the water at or near the surface (aka the skin temperature of the ocean surface water). Since the surface of the ocean is where the ocean and atmosphere interact, the SST can affect the weather and vice versa. SSTs influence sea breezes, and warm SSTs are known to play a part in the generation of tropical cyclones.

Procedure

1. **Introduce the Loop Current:** Watch the *Gulf of Mexico - Relative Vorticity - Global 1/25° HYCOM* – Video https://www.youtube.com/watch?v=SeLbswc2OjA (1:12min)
   In this video, students can see the variability of the LC and the shedding of eddies over a year.

2. **Discuss Ocean Currents and Why Scientists Track Them:** Watch and discuss the National Ocean Service video, "Oil Spill 101: The Loop Current"
   http://oceanservice.noaa.gov/video/oilspill101/loop-current.html (1:35min)
   - Why do scientists track ocean currents?
   - Is the Loop Current at surface current or a deep ocean current?
   - Why is it difficult to predict the LC's movement?
   - When the oil spill occurred, why was the LC's path a concern?

3. **Show students satellite images:** from "Oil Slick in the Gulf of Mexico: Natural Hazards"
   http://earthobservatory.nasa.gov/NaturalHazards/event.php?id=43733 and discuss what information we can gain from these satellite images.



Ask students: From these images, can you tell what is happening? Was the oil entrained in the LC? Discuss SSH and SST.

4. **Visit the Colorado Center for Astrodynamics Research (CCAR) website:** Gulf of Mexico Historical Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/hist_gom_grid_viewer to see what occurred with SSH and SST on one particular day.

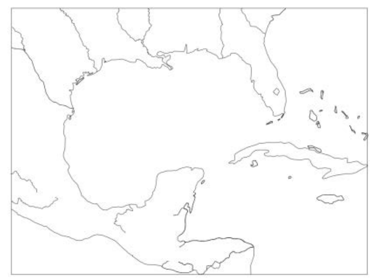
   There are many options to produce an image using this source, however it is only necessary to…
   - Select the date you are interested in (the oil spill occurred on April 20, 2010, flowed for 87 days, and was capped on July 15, 2010)
   - Overlay SSH on Other Data: Select GOES SST or GHR SST
   - Select "Submit"

   Once an image has been produced, observe closely to
   - Locate the circular features (where are the eddies)
   - Determine temperature differences (where is the water warmer or colder?)

   * You can also visit CCAR Near-Realtime Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/nrt_gom_grid_viewer to see what is happening currently in the Gulf.

5. **Explore animations from the "HYCOM Model 1/25° Gulf of Mexico" site** http://www7320.nrlssc.navy.mil/hycomGOM2/glfmex.html
   This site contains real-time nowcast/forecast results from the 1/25° Gulf of Mexico HYbrid Coordinate Ocean Model (HYCOM), including snapshots, animations and forecast verification statistics for many zoom regions, mainly SSH, SST, surface currents, and subsurface temperature and salinity.

6. **Drawing the Loop Current on the "Gulf of Mexico Map" (pg 144) could be used as an assessment** - Gulf of Mexico Map http://fcit.usf.edu/florida/maps/stateout/photos/64200.pdf
   Source: Florida Center for Instructional Technology) **OR Have students produce an image using one of the websites and write a paragraph describing it.**



Resources & References

Bird's Eye View of The Spill https://ocean.si.edu/gulf-oil-spill-interactive

Chemistry in the Gulf of Mexico
http://www.gomr.mms.gov/PDFs/2006/2006-018.pdf

Colorado Center for Astrodynamics Research (CCAR) - Gulf of Mexico
Historical Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/hist_gom_grid_viewer
Near-Realtime Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/nrt_gom_grid_viewer

NASA Satellite Images of the Loop Current in the Gulf
http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=44036

NOAA AOML: Monitoring the Gulf of Mexico Conditions
http://www.aoml.noaa.gov/phod/dhos/index.php

NOAA National Ocean Service: Education on Currents
http://oceanservice.noaa.gov/education/kits/currents/lessons/currents_tutorial.pdf

The Loop Current
http://oceanservice.noaa.gov/facts/loopcurrent.html
http://oceancurrents.rsmas.miami.edu/atlantic/loop-current.html

Tracking the Oil Spill in the Gulf
http://www.nytimes.com/interactive/2010/05/01/us/20100501-oil-spill-tracker.html?_r=0

LESSON PLAN:
Go with the Flow

Designing Ocean Drifters
in collaboration with the CARTHE Consortium

Objective: To introduce students to concepts in ocean engineering and design, as well as to gain knowledge related to the way in which data is collected for research.

Standards: OLP 1,7; SC.912.N.1.7, SC.912.N.1.6

Time Required: Five class periods (Three for building, one for presentation, and one for testing)

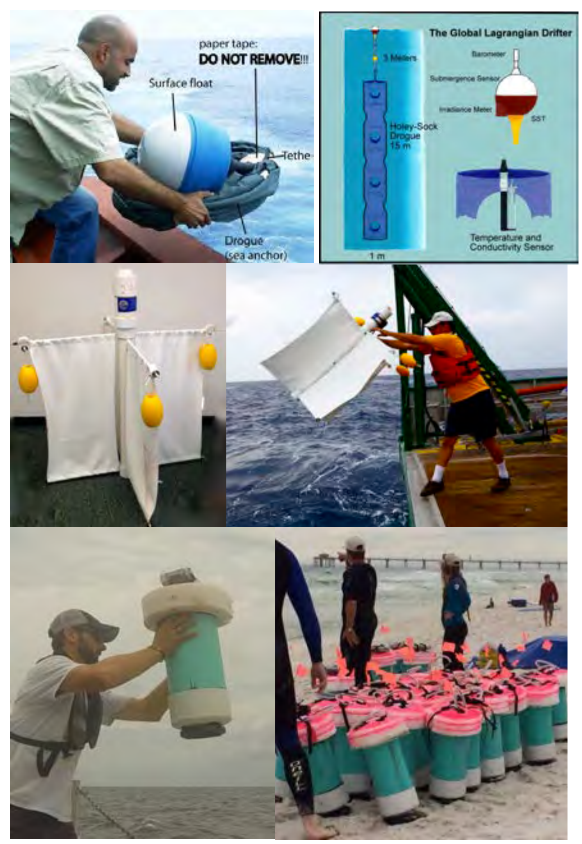
Keywords: drifter, GPS, currents, CARTHE, buoyancy

Materials:
A wide variety of materials can be used. Some examples include:

- Cloth
- Wooden dowels
- Styrofoam and other types of foam
- String
- Duct tape
- PVC piping
- Various household materials
- Spray paint
- Zip ties
- Washers
- Measuring tape
- Scissors
- Copies of the article, *"Tracking the Last Mile before the Oil Meets the Beach"* (page 108)

Background

A **drifter** is an object that drifts with the ocean **currents** and collects data along the way about its location and speed. Surface drifters consist of a marine anchor/sail and a float. The anchor/sail catches the water and moves through the ocean with that piece of water. The float is used to keep the drifter at the surface, visually see the drifter and hold the **GPS** transmitter, which is used to send data to orbiting satellites. Scientists use drifters to track the movement of ocean currents in the Gulf of Mexico. The more that is known about the currents, the better prepared we will be to predict how oil or other toxins will move throughout the Gulf in the event of a future oil spill.



Photos from NOAA's Global Drifter Program, the CODE experiment, and the SCOPE experiment respectively.

Physical oceanographers use a variety of drifters to study different currents throughout the ocean:

- The [NOAA Global Drifter Program] studies the mixed layer currents in the upper ocean so their drifters consist of a round buoy at the surface and a 6m long drogue (sea anchor).
- The "**CODE**" surface drifters consist of "X" shaped sails and only 1m deep, so they are specialized to measure the surface currents only.
- The "**SCOPE**" drifters are also designed to measure the surface currents, but they are only 50cm deep and are more durable so they can withstand pounding coastal waves.

CARTHE (Consortium for Advanced Research on the Transport of Hydrocarbon in the Environment) based at the University of Miami has conducted several large-scale experiments to study the currents in the Gulf of Mexico. For each one, they have designed and built new drifters that will measure the currents in the study area. These drifters are used to determine how oil in the water gets from the site of a spill, through the surf zone, and onto the beaches. This data is then used to make more accurate computer models that can predict the fate of spilled oil, or even be used to predict where larval fish or people lost at sea may end up.

Two MAST Academy students make minor adjustments to their ocean drifter before deploying it in the waters of Biscayne Bay.

In 2013, students in Miami, Hollywood, and Tallahassee, FL designed drifters to be deployed in conjunction with one of these large-scale experiments called SCOPE (Surfzone Coastal Oil Pathways Experiment). In 2015, students are once again creating the next generation of surface drifters— this time for the January 2016 LAgragian Submesoscale ExpeRiment (LASER). We invite you and your students to try your hand at developing equipment for measuring the movement of surface currents.

Rickards High School students' drifters ready to be tested.

In this lesson, students will have the opportunity to design and build their own easy-to-use, low-cost drifter that can move with surface currents. Each drifter will be evaluated on buoyancy, durability, and portability. Students should consider possible new eco-friendly materials that might be best for future scientific research as well as how wind, currents, storms, and boats will affect their drifter.

There are widespread applications for drifters in optimizing shipping routes, recreation, search and recovery, and oil spill mitigation.

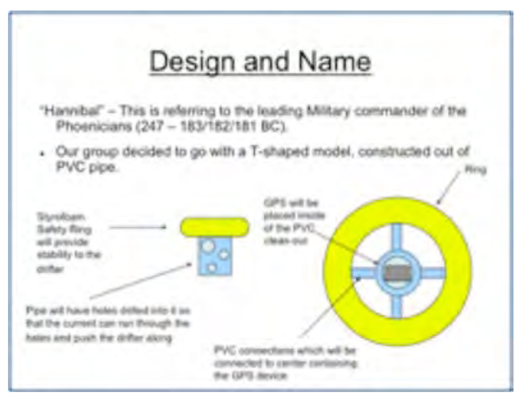
Procedure

1. **Introduction:** Have students read the article, *"Tracking the Last Mile before the Oil Meets the Beach"*, and explain to them that they will be designing a drifter to take part in this experiment, based on the following criteria:

Criteria for Drifters:

- Buoyancy - Must be able to float!
- Durability - Must be durable and sturdy enough to withstand, wind, waves and strong currents
- Portability - Should be easy to hold on to (i.e. have a handle to assist with deployment and retrieval)
- Must be small and light enough to be carried on a jet ski (between 3-5 kilos)
- Visibility - Must be visible from the surface of the water so it can be retrieved
- Create a designated space for data collection mechanisms (i.e. GPS and sensors)
- Must include the following labels: your Institution, Transmitter ID, email address, and "Drifter Study"

2. **Design Plan & Presentation:** Have students form groups of two or three and come up with a design for their drifter. Groups will then prepare a presentation that includes the following components:
    1. Picture of drifter design
    2. List of materials
    3. Description of construction
    4. Justification: Why do you think this will work? How will you make this visible? How will it right itself if it gets tumbled in the surf?



Example of drifter design from Rickards High School in Tallahassee, FL.

3. **Feedback:** After each presentation, provide feedback to each group on their drifter design. As a class, discuss any improvements that need to be made before testing.

4. **Construct Drifter:** Pending teacher approval, students will build drifters to be tested in a pool, at the beach, or in a lake (wherever is most convenient).

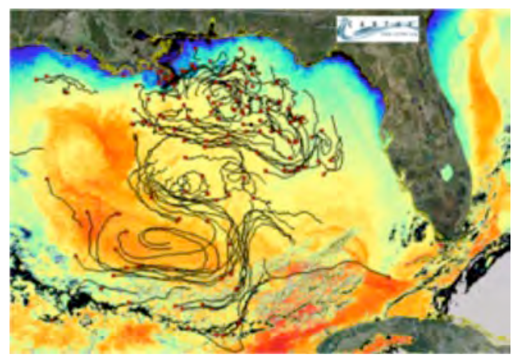
5. **How to Test Your Drifter:**
1. Have each group place their drifter in the body of water.
2. Using the judging rubric, evaluate the drifters on how well they meet each of the criteria.
3. If using a pool or lake, create a disturbance in the water to make sure that the drifter is self-righting and can withstand wind and waves.

Extensions

Build mini-drifters and test in a small tank.
Could be used as an afterschool science club project.
Plot the drifter's trajectories.

Single SCOPE drifter track

SCOPE drifter tracks (including students')



GLAD drifter tracks

Resources & References

Global Drifter Program
http://www.aoml.noaa.gov/phod/dac/gdp_drifter.php - design

Monitoring the Gulf of Mexico Conditions, Surface Drifter Observations http://www.aoml.noaa.gov/phod/dhos/drifters.php

Student Drifters http://studentdrifters.org/

Surfzone Coastal Oil Pathways Experiment (SCOPE) http://carthe.org/scope/

Contributing Expert

Laura Bracken, Outreach Manager for the CARTHE Consortium led by the University of Miami

Drifter Judging Rubric

Name of Drifter: Group Members:	Superior	Above Average	Average	Below Average
Design Originality and Creativity:				
Efficient Use of Low-Cost Materials:				
Timely Construction:				
Presentation:				
Meets specific requirements: -Buoyancy -Durability -Portability -Visibility				
Other Comments:				

Assessment Questions:

1. What was your team's inspiration for the design?
2. What are specific challenges your team faced while building the drifter?
3. What information can be gained by using this drifter in surface currents?
4. After testing the drifter, how would you change the design to make it better?

ARTICLE REPRINT

Tracking the Last Mile Before Oil Meets the Beach

Posted online January 17, 2014
Source: GoMRI http://gulfresearchinitiative.org/tracking-last-mile-oil-meets-beach/

Rolling waves, swirling currents, converging fronts, shifting sediments – all are connected as anyone who has chased a ball in beach waters knows. But how?

To understand the mechanisms that move water-borne objects or contaminants onshore, over 30 researchers from 16 universities gathered in Ft. Walton Beach, Florida in December 2013 – armed with drifters, dye, and drones – and conducted a three-week Surfzone Coastal Oil Pathways Experiment (SCOPE).

Kate Woodall, Naval Postgraduate School, injects EPA-approved in the surf zone in Ft. Walton Beach, FL. (Photo provided by CARTHE)

"We're studying the region most hit by the Deepwater Horizon oil spill, which includes the coasts surrounding the Gulf," explained Tamay Özgökmen, the team's principal investigator, "to learn more about how things in the water get outside of the surf zone and onto the beaches."

Scientists are tracking elusive ocean processes to visualize the movement of Gulf waters in 3D. For this experiment, they deployed 250 GPS-equipped drifters (30 were biodegradable) to track surface waters, using a "release and catch" method for repeated use of these specially-outfitted devices. Researchers injected an EPA-approved dye both along and outside the surf zone to trace its movement through the water column. Various in-situ instruments recorded water and atmospheric conditions.

"This study will collect important data necessary to understand the currents in the near-shore marine environment," said Ad Reniers, co-lead scientist for SCOPE. "The information collected will be used to develop computer models of the coastal zone, to improve our scientific understanding of this region in the event of future oil spills, and to better understand how larvae or pollutants travel close to shore."

Kimberly Arnott (Texas A&M University, Corpus Christi) prepares microstructure instruments for deployment to record measurements of water turbulence such as dissipation and diffusivity. (Photo provided by CARTHE)

These researchers are members of the Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE), a science team funded by the Gulf of Mexico Research Initiative (GoMRI). The University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM-RSMAS) administers CARTHE under Özgökmen's direction. Joining Reiners as co-lead scientist for SCOPE is Jamie MacMahan with the Naval Postgraduate School.

"Computer models will be able to give us better estimates of where the oil spill will go and how fast and in which patterns it will spread," said Özgökmen. "This can help emergency responders to better direct their limited resources and help us understand ecological damage that may have occurred." He is confident that "a lot of beneficial information will come out of this study, not just about the oil spill."

For example, the spreading pattern of dye revealed dangerous rip currents. "That's the best visual image of a rip tide I've ever seen," said Chuck Wilson, GoMRI Chief Scientist. "If people could see that, they might understand a little better how they work."

To construct data on the multiple factors that influence the behavior of ocean currents, the scientists have to collect data at one time. "We combine a lot of different instruments at once to capture the complete picture of all the drivers of surface currents," explained SCOPE team member Guillaume Novelli, a UM-RSMAS postdoctoral fellow. "It took a village to pull off SCOPE successfully," said Özgökmen referring to the many dedicated staff who coordinated logistics, people, equipment, and, of course, the science.
Prior to the SCOPE execution in Ft. Walton Beach, about 15 modelers from three distinct groups – University

of Miami Coupled Model (UMCM), Naval Research Laboratory (NRL), and ADvanced CIRCulation model (ADCIRC) – began running real-time, predictive simulations. Together these models provided SCOPE scientists with important, high-resolution transport information.

The first week of SCOPE was a flurry of preparations: teams finalized local permits, assembled drifters and identified specific locations for launching (freshwater inlets, surf zones, and along the inner shelf and fronts) and then staged them for deployment; others prepared dye injection equipment and assembled camera-equipped drones and kites; and divers positioned observing instruments in the water at various distances from the beach and depths in the water column. The Florida International University team erected a meteorological data-gather tower on site.

CARTHE scientists releasing SCOPE drifters just outside the surfzone. (Photo provided by CARTHE)

The next week, the team ran test trials of the experiments to make final adjustments for local conditions, aerial observations and imagery, and to inform their remote modeling teams. Scientists also hosted on-site interactive demonstrations with local middle and high school students.

In the final week, everyone, in a synchronized manner, executed their tasks of well-informed, targeted releases of dye and deployment of drifters with the coordinated use of Synthetic-aperture radar (SAR) images, microstructure and air-sea interaction measurements, observations of frontal features, and detailed modeling adjusted to observations.

Once models are supplemented by real-time data from experiments, climate scientists can combine these data with wind and tides and use them to predict oil transport in scenarios under a variety of conditions. In the long-term, improved transport predictions can inform environmental policy and support the development of crisis response plans. The U.S. Coast Guard can use improved transport predictions to pinpoint vessels in distress and with search and rescue operations, and fisheries can better understand larval movement of important commercial species.

SCOPE is the second large CARTHE experiment that brings together a wide range of scientific experts to experiment with measurement methods and study oil transport. CARTHE conducted their first experiment, GLAD (Grand LAgrangian Deployment), near the Deepwater Horizon site in the summer of 2012. Scientists will use data from both experiments to more accurately model the transport and fate of oil in the Gulf.

Novelli eloquently explained the importance of understanding ocean processes in both deep and near-shore waters: “What happens in the last 100 meters of coastal transport is determined by what happened in the first 100 meters of the spill.”

The CARTHE I program (2012-2014) includes 26 principal investigators from 12 research institutions in eight states. The CARTHE II program (2015-2017) includes 40 principal investigators from 27 research institutions. Together these scientists are engaged in novel research through the development of a suite of integrated models and state-of-the-art computations that bridge the scale gap between existing models and natural processes.

For more information about CARTHE, please visit **www.carthe.org**.

This aerial photo, taken from the camera-equipped drone, shows a mile-long dye strip injected outside the surf zone.

LESSON PLAN:
The SailBuoy's Journey in the Gulf of Mexico

Analyzing data from the CMR SailBuoy

Objectives: To introduce students to marine observations and data collection with new technologies (CMR SailBuoy and Deep-C Map Viewer). To use Deep-C's Map Viewer, create graphs using the SailBuoy data, analyze the data, and draw conclusions.

Standards: OLP 7; SC.912.N.1.7

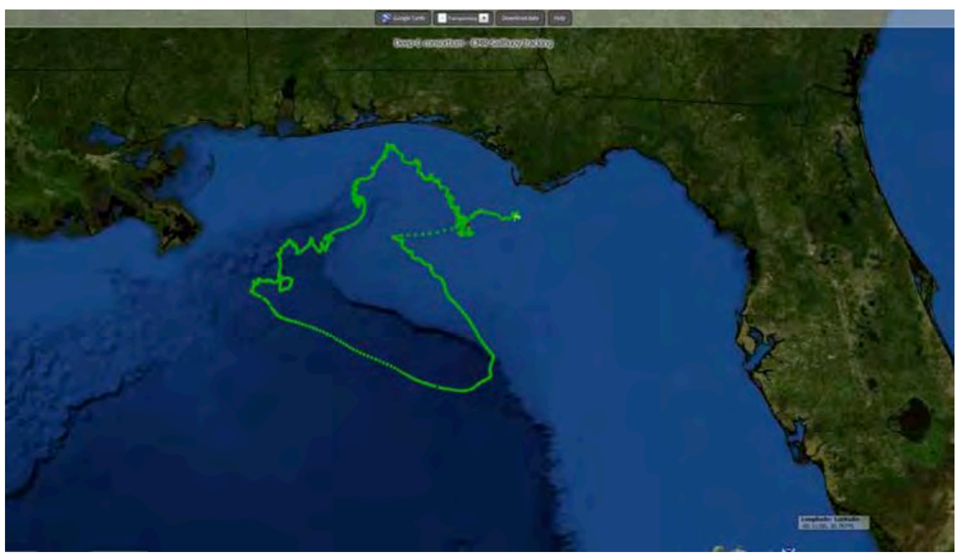
Time Required: One or two 50-minute periods

Key Words: marine observations, CMR SailBuoy, satellite, seawater parameters

Materials: A computer and copies of the article "Deep-C Launches the Gulf's First SailBuoy for Scientific Observations" (see page 113)

Background

The SailBuoy, developed by a Norwegian company - Christian Michelsen Research (CMR) Instrumentation, is an unmanned ocean vessel capable of traveling the oceans for extended periods of time. The CMR SailBuoy is part of a new generation of vehicles designed for marine observations that are enabling scientists to expand and intensify the study of our seas and oceans. It is self-powered, wind-propelled, and it navigates the oceans autonomously. The SailBuoy is similar to a surfboard in shape and size — two meters in length and has an average speed of 1-2 knots.



Deep-C Consortium – CMR SailBuoy Tracking, Map Viewer
http://viewer.coaps.fsu.edu/DeepCProject/mapviewer

During the spring of 2013, Deep-C scientists utilized the CMR SailBuoy, dubbed the Argonaut, to gather data in the northeastern Gulf of Mexico. It was launched approximately 11 nautical miles (nm) south of Cape San Blas. It was at sea for approximately two months, and during its mission sailed approximately 840nm on a cruise track across the Gulf coast, from the Florida Panhandle to West Louisiana. For the Deep-C mission, it was equipped with two-way satellite communication for real-time data streaming and GPS waypoint updates. While at sea, it transmitted data to the Deep-C Operations Center at regular intervals along a planned course.

Sensors were mounted on the SailBuoy that allowed scientists to monitor seawater parameters, such as temperature, salinity and dissolved oxygen. Collection and analysis of this data helped Deep-C researchers better understand how particles and dissolved substances (such as oil) are transported from the deep Gulf to the shelf waters in the northeastern Gulf across the continental shelf and the De Soto Canyon – an erosional valley that cuts through the continental shelf in the northern part of the Gulf. The researchers also investigated parameters of the "Mississippi River plume" — a plume caused by fresh sediment-rich rainwater runoff entering the Gulf of Mexico via the Mississippi River. This plume is visible, nutrient rich sediment that spreads out from the coastline, forming a kind of cloud in the water.

The SailBuoy Sensors

- Conductivity-Temperature (CT) sensor - low-drag, fast-response CT sensor manufactured by Neil Brown Ocean Sensors, Inc. (NBOSI); The CT sensor is a fast response unit composed of a 4-electrode conductivity cell and a stable thermistor.
- Oxygen optode - AS4835, manufactured by Aanderaa Data Instruments (AADI); the optode samples the dissolved O_2 concentration and air saturation at a resolution of 1microM and 0.4%, respectively.

Procedure

1. Have the students read the GoMRI Article, “Deep-C Launches the Gulf’s First SailBuoy for Scientific Observations”: http://gulfresearchinitiative.org/deep-c-launches-the-gulfs-first-sailbuoy-for-scientific-observations/

2. Access the Deep-C Map Viewer at: http://viewer.coaps.fsu.edu/DeepCProject/mapviewer

- To the left, under “Main Layers”: Click on the first tab and change to CMR SailBuoy
- Click “+” to Zoom in to the area of interest
- To introduce the data of the Map Viewer, have students select a data point on the SailBuoy path and record latitude and longitude (bottom of the screen), time, temperature, conductivity, oxygen concentration, and salinity.

Questions

1. The SailBuoy was deployed at a latitude and longitude of?
2. When first deployed, the water temperature was ____ degrees C.
3. Which area had warmer surface water temperatures?
4. Which area had higher salinity levels?
5. What would you predict the dissolved oxygen to be like for this area?
6. Was your prediction correct?

3. Download and graph the 2013 SailBuoy dataset (excel file) which includes seawater parameters, such as temperature, salinity and dissolved oxygen collected using a wind-powered sailing buoy in the northeastern Gulf of Mexico.https://data.gulfresearchinitiative.org/data/R1.x138.077:0008/

4. Have students open the Excel file, “SB02 - ArgoKnot_MissionData”. Since the SailBuoy was deployed on March 15, 2013 – go to line 49 where it says “3/15/13 18:30”. Students can create their own graphs using temperature, conductivity, oxygen etc.

The following are the labels on the table:

Time	Lat	Long	TxTries	U	Electronics Temp
GMT (Greenwich Mean Time)	º N (North)	º E (East)	Counts	Volts	º C

TxTries = number of times the SailBuoy tries to communicate a data field to the satellite (every hour). (unnecessary to plot)

U = Battery levels (of the SailBuoy). They start at 12 V. This is helpful to decide when to stop a mission (before the instrument stops responding).

Electronics Temp = temperature near the circuit board.

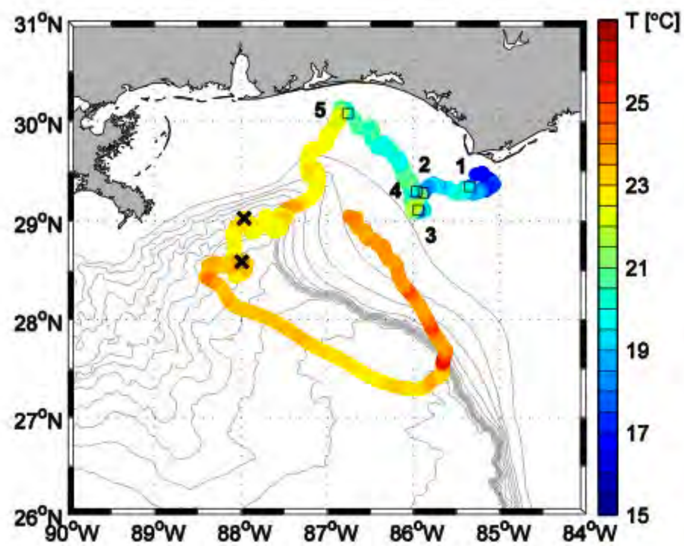
Conductivity-temperature (CT) sensor	
CTTemperature	CTConductivity
º C (degrees Celsius)	mmhos/cm (millimhos per centimeter)

The conductivity-temperature sensor is measuring salinity (via conductivity) and temperature. This is a very accurate and expensive, although very reduced in size instrument. Description: http://www.neilbrownoceansensors.com/prod01_gctd.htm

Oxygen optode sensor		
Oxy_Oxygen	Oxy_Saturation (Oxygen Air Saturation)	Oxy_Temperature
µM (micrometer; 10^{-6} meters)	% (percentage)	º C (degrees Celsius)

Oxy_Temperature = This is the temperature from a different sensor (not from the CTD) near the oxygen optode. (Not necessary to plot)

5. **Have students analyze the data and draw conclusions in a written paragraph.**
6. **Discuss as a class and compare student results with the report summary below.**



SailBuoy Report Summary:

"Results are reported from a two-month long deployment of the SailBuoy SB02 between 15 March and 15 May 2013 in the Gulf of Mexico. The instrument sampled across fronts between the shelf and basin waters in the Gulf of Mexico in the early part of the record, and then drifted with a large cyclonic gyre in the basin. The shelf is characterized by cold, low salinity and oxygen rich waters. Off shelf surface waters with relatively higher temperature and salinity, but lower oxygen concentration show variability of typically 0.2 in salinity and less than 1°C in temperature." *(Ref. no.: CMR-13-A10265-RA-1 Date:14.10.2013 Page 12)*

Resources & References

More information about this project can be found at www.deepc.org/sailbuoy and www.sailbuoy.no.

Deep-C's Voices from the Field blog for an account of its journey from the Deep-C scientists: http://deepcconsortium.blogspot.com/search?q=sailbuoy

Datasheet from Offshore Sensing AS: http://sailbuoy.no/files/Sailbuoy_datasheet.pdf

Gulf of Mexico Report: http://www.sailbuoy.no/files/CMR-13-A10265-RA-1%20GulfOfMexicoReport.pdf

Contributing Experts

Dr. Nico Wienders, Physical Oceanographer at the Florida State University, Department of Earth, Ocean, and Atmospheric Science (EOAS)
Dr. Lars Hole, Senior Research Scientist at the Norwegian Meteorological Institute

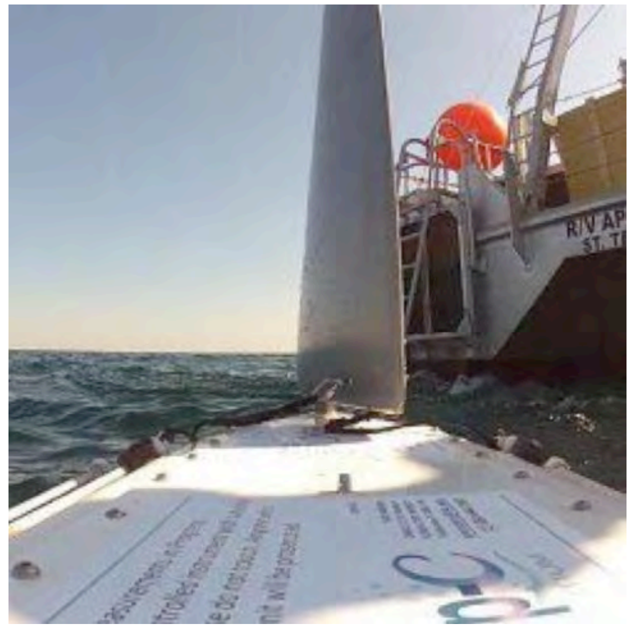
ARTICLE REPRINT

Deep-C Launches the Gulf's First SailBuoy for Scientific Observations

Posted online April 3, 2013
Source: GoMRI http://gulfresearchinitiative.org/deep-c-launches-the-gulfs-first-sailbuoy-for-scientific-observations/

Think of a surfboard-sized water version of an Unmanned Aerial Vehicle and you have the SailBuoy.

The self-powered, wind-propelled, autonomously-controlled vessel advances the way that scientists gather and transmit oceanic and atmospheric data. With its two-way communications and ability to make observations over extended periods of time in all types of weather and at low cost, researchers can use the data it collects in a wide variety of ocean applications – from taking measurements to tracking oil spills to acting as a communication relay station for underwater instruments.



The Deep-C SailBuoy sets sail after researchers launched it from the Florida State University Coastal and Marine Laboratory's RV Apalachee. Photo taken by camera on the SailBuoy.

"A typical drifter buoy deployed around the De Soto Canyon would move out of the area within a few days. What makes the SailBuoy extremely valuable to our research is that we can sustain observations for days, weeks, months or even longer from the same location. We can navigate and change its location remotely from our Operations Center." – Dr. Lars Hole, Norwegian Meteorological Institute

Dr. Lars Hole with the Norwegian Meteorological Institute and Dr. Nico Wienders with Florida State University lead the SailBuoy Project for the **Deep Sea to Coast Connectivity in the Eastern Gulf of (Deep-C) consortium**. In mid-March, Dr. Wienders and his team launched the SailBuoy from the RV Apalachee. In this first-time use of the SailBuoy in the Gulf, it will crisscross the northeastern Gulf of Mexico over the next two months gathering and transmitting data on salinity, temperature, and oxygen in the DeSoto canyon region. Researchers specifically selected this time period, known as "spring bloom", in order to capture conditions when hypoxia is typically at its worst. This information will help scientists better understand the interactions between the Mississippi River plume and currents in the De Soto Canyon, both of which affected how oil moved from the Deepwater Horizon oil spill site to coastal shorelines.

Mr. David Peddie and his research team with CMR Instrumentation in Bergen, Norway designed the SailBuoy. CMR's technology environment traces its roots back to 1930, as part of the Chr. Michelsen Institute (CMI). CMI was established to provide free and independent research, as a result of a bequest from former prime minister and ship-owner Christian Michelsen.

Physical Oceanography Quiz

1. Name the three physical properties that control density in the ocean.

2. The ocean is composed of several layers of water with different densities. How does this layering occur and what are some things that could disrupt ocean layers?

3. What is the Loop Current? What role does it play in the circulation of the Gulf of Mexico?

4. How is satellite imagery used to track ocean currents in the Gulf of Mexico?

5. How does the Mississippi River influence density and ocean circulation?

6. What is a drifter and how does it collect data about the ocean? What kind properties can be measured using drifters?

7. How does data collected by drifters help scientists to predict the fate of spilled oil?

8. Name three tools that scientists can use to make marine observations. Describe the types of data that can be collected and provide specific examples.

9. What is a gravity current? What are some examples of gravity currents on land? In the ocean?

10. The 2010 Deepwater Horizon oil spill released nearly 5 million barrels of oil into the Gulf of Mexico over a three-month period. How might the release of oil change the density of the ocean? Do you think the change of density could greatly impact circulation in the Gulf of Mexico? Why or why not?

Physical Oceanography Glossary

Buoyancy: the ability or tendency to float in water or air or other fluids

CMR SailBuoy: an unmanned wind-propelled ocean vessel capable of traveling the oceans for extended periods of time, designed for marine observations. Developed by a Norwegian company, CMR Instrumentation

Corriolis effect: the apparent (when viewed from Earth) deflection of objects (including air) above the surface of the Earth as a result of the Earth's rotation; objects in the Northern Hemisphere appear to curve to the right whereas objects in the Southern Hemisphere appear to curve to the left

Current: the steady flow of water in a prevailing direction

Deep Ocean Current: water movement patterns more than 300 feet below the surface of the ocean

Density: the mass per unit of volume of a substance

Drifter: an object that drifts with the ocean currents and collects data about its location and speed

Eddy: a circular current of water; vortex

Global Conveyor Belt: a large-scale ocean circulation pattern driven by wind and density differences in the ocean. Cool, high salinity water sinks in the North Atlantic, travels in deep ocean currents south to Antarctica, east across the globe, and north to the North Pacific, where it rises to the surface due to upwelling. Water then moves in surface ocean currents south and west toward the tip of Africa and north via the Gulf Stream, returning finally to the North Atlantic

GPS: Global Positioning System, a satellite-based navigation system

Gravity Current: driven by density differences between fluids, hence also referred to as "density currents"; characterized by a sharp front often followed by a bulbous head and longer thinner tail

Gulf Stream: a warm ocean current that flows from the Gulf of Mexico northward through the Atlantic Ocean

Longshore Current: a current created by the energy released when waves break on the beach; these currents travel parallel to the beach

Loop Current: a warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf, and then loops east and south before exiting through the Florida Straits where it joins the Gulf Stream

Mass: a unit of measurement, a measure of how many atoms are in an object

Ocean Altimetry: satellite measurement of sea surface topography

Pressure: the continuous physical force exerted on or against an object by something in contact with it

RAFOS Floats: floats that track the motion of the water; the float listens and records sound signals from stationary acoustic beacons; at the end of their pre-programmed mission, the floats drop their ballast weights, rise to the surface, and beam their data to orbiting satellites

Remote Sensing: the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites

Rip Current: a current that is the result of water funneling out of a narrow opening; water flows away from land

Salinity: the saltiness or dissolved salt content of a body of water

SSH: Sea Surface Height, a measurement of the deviation of the sea surface from a reference height

SST: Sea Surface Temperature, the temperature of the water at or near the surface, aka the skin temperature of the ocean surface water

Stokes Drift: the lateral motion of a particle via wave action

Surface Current: ocean currents that occur at less than 300 feet below the surface of the ocean; most ocean currents are usually wind-driven

Thermocline: a steep temperature gradient in a body of water such as a lake, marked by a layer above and below which the water is at different temperatures

Tidal Current: currents generated by tides

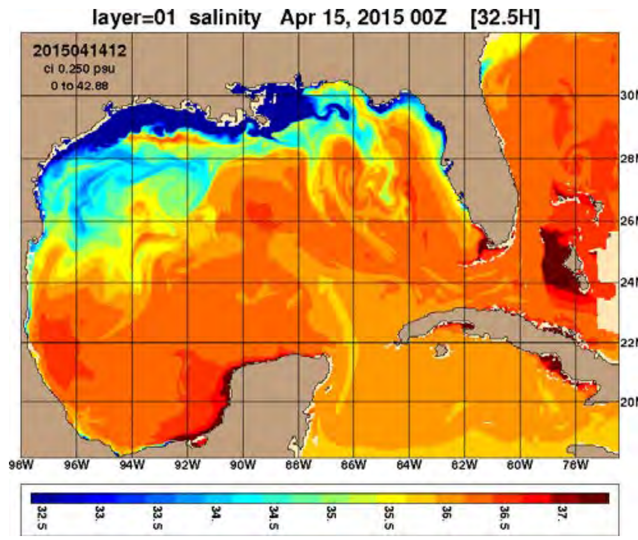
Tide: the rise and fall in sea level caused by the gravitational forces of the moon and sun in combination with the rotation of the Earth

Volume: the amount of space that a substance or object occupies, or that is enclosed within a container

Computer Modeling

In the Gulf of Mexico

What is Computer Modeling?



Sea Surface Salinity from HYCOM Model 1/25° Gulf of Mexico

Computer models are computer programs based on mathematical models of the real world. They offer powerful electronic laboratories, which can be used to investigate phenomena and explore scenarios. Computers are also excellent tools for analyzing and visualizing data.

Models of the Real World

Since the Gulf of Mexico is such a complex ocean system, many geophysical processes must be accounted for when modeling it. Wind, waves, and currents are some examples of such processes that move floating objects and material – from large items to tiny droplets – in the ocean. Models need to account for all of these processes in order to produce accurate forecasts of where things will move. Researchers use models to simulate the atmosphere, waves, and the ocean. These models can be used alone or coupled together into more complex systems, which is technically very challenging. In all cases, researchers have to choose which inputs to use to drive the model, which model configuration best suits their problem, and then how to interpret the data produced by the model. This means models are supported by data from many different research areas (ecology, physical oceanography, geochemistry, and geomorphology), which improve the input and model configuration, and support other research areas by providing data about the processes and phenomena studied with the model. As the models simulate the state-of-the-ocean, atmosphere, and processes therein, they can help predict movement of oil after environmental disasters aiding cleanup efforts. Furthermore, improving our predictions of the fate of oils and their impact on the environment requires deepening our knowledge of the geophysical processes in the Gulf of Mexico, and models provide useful tools for researching these topics.

Modeler's Tasks: Applications

The Deep-C modeling team uses computer models to investigate circulation patterns, surface winds, waves, sediments, and biogeochemistry in order to research the coastal to deep sea connections in the Gulf of Mexico. They are working to understand the processes that govern the interaction between the deep ocean flow and the bathymetry (underwater topography), specifically in the De Soto Canyon region, and how the deep ocean responds to events that affect the upper ocean such as hurricanes and winter storms or Loop Current and eddy intrusions. In addition to the deep ocean processes, the modeling team has been investigating flows at the surface such as waves and river spreading. They have also been developing ways to analyze the shape of the river plume based on techniques that are usually applied in facial recognition software. The results of this work shed light on how oil, biota, or sediment may move in the De Soto Canyon region, and this complements the investigations of other Deep-C researchers.

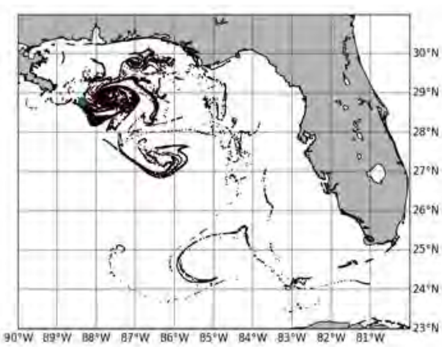
Deep-C modeling research

Earth System Model

The ocean, atmosphere, land, and biosphere are interconnected in fundamental ways that ensure changes in one realm will echo throughout all others. Deep-C researchers developed and work with models of the ocean, atmosphere, and biosphere for the Gulf of Mexico. They also worked to develop a comprehensive coupled Earth System Model that incorporates all of these components and has the capability to both forecast the system state and predict the level of risk associated with specific outcomes. These predictions allow for planning and response as well as simulation and analysis of scenarios and experiments that cannot otherwise be performed due to restrictions such as space, time, resources, or risk. For more information, look at the Gulf of Mexico Earth Forecasting System website https://coaps.fsu.edu/gom-efs.

Oil Fate Model

Deep-C researchers have developed a new oil fate model that can simulate the *transport* of oil in the ocean. The model represents the oil spill as a cloud of droplets. The motion pathways and chemical composition of the droplets are calculated using a combination of environmental conditions taken from the Earth System Model and statistical techniques. The model allows rapid evaluation of plausible scenarios and enhances the potential for informed decisions in case of accidental spills. Our understanding of oil fate modeling also enhances our understanding of how uncertainties in the environmental model inputs and uncertainties in the physical, chemical, and biological characteristics of oil affect the fate of the oil discharged. *Depicted to the left is a graphic of oil droplets at the surface on day 30 of a Deepwater Horizon blowout simulation.* To see this model in action, go to http://stargazer.coaps.fsu.edu/dcom/index.html.

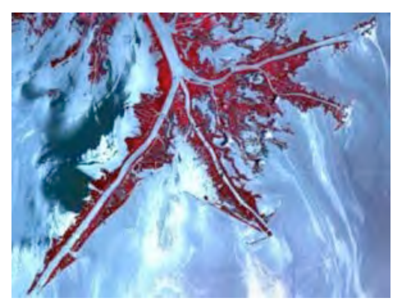


Deep-C Map Viewer

The Deep-C Map Viewer is a graphical user interface that overlays the location of Deep-C field samples over user-selectable oceanographic maps (*http://viewer.coaps.fsu.edu/DeepCProject/mapviewer*). The Map Viewer displays temperature, salinity, sea surface elevation, and ocean currents for the Gulf of Mexico. The oceanographic variables are generated daily, using outputs from the HYbrid Coordinate Ocean Model (HYCOM) ocean prediction system (Chassignet et al., 2009). This Gulf of Mexico Atlas utilizes Geographic Information Systems (GIS).

Illustrating the Mississippi River's role in the transport and fate of the oil

In 2013, a study led by Dr. Villy Kourafalou (UM-RSMAS) used a high-resolution model in conjunction with observations to examine the movement of the surface oil patch resulting from the Deepwater Horizon release under the influence of daily variability of the Mississippi River. The study concluded that fronts created by the Mississippi plume helped to keep oil released during the incident away from the coasts east of the Mississippi Delta. This study marks the first time a connection was established between the near surface signatures of a large river plume and the hydrocarbons released from a deep oil plume.



Satellite image of the oil at Mississippi Delta's Mouth during the DwH accident. (Photo by: JPL/NASA)

Modeling surface waves

Deep-C researchers, Johannes Rohrs and Kai Christensen (Norwegian Meteorological Institute), used a numerical modeling experiment to study how surface waves contribute to the fate of Northeast Arctic cod eggs and larvae. While some results were species specific, the main results apply to all buoyant particles in the upper ocean (e.g. plankton and oil droplets) and to all regions where surface waves are present. By considering wave effects for particle transport and vertical mixing, the researchers found that waves modified the fate of cod eggs by moving the buoyant particles closer to shore over the long term. Breaking waves are also responsible for mixing particles downwards. Understanding these processes for transport of plankton and oil serves our efforts to model oil spill accidents and impacts on the ecosystem.

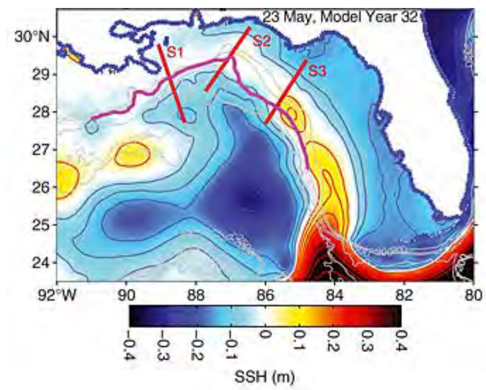
Wave data can improve forecasts that help search and rescue operations and oil spill response

Deep-C scientists with the Norwegian Meteorological Institute are also quantifying wave effects using observations, which in turn are used in ocean models that predict the direction of surface water movement. They found that predictability of the drift of an object (e.g. oil) can be improved by adding wave effects and therefore provide better information in time-critical situations such as accidents and disasters.

Johannes Rohrs and Kai Christensen prepare to deploy two types of surface drifters. The drifter in the cardboard box unfolds once in contact with water. (Photo by: Göran Broström)

Characterizing upwelling and downwelling

Researchers at FSU used an ocean model to characterize upwelling and downwelling in the De Soto Canyon near the Deepwater Horizon spill. These are important mechanisms for exchange between the deep ocean and shelf. Downwelling was found to occur more frequently when the Loop Current impinged on the West Florida Shelf, hundreds of kilometers to the southeast of the De Soto Canyon region. A high-pressure anomaly that extends along the coast served to connect the remote Loop Current forcing to the De Soto Canyon. These findings help researchers better understand the potential impacts of pollutants released in the deep ocean in this region. *At right: Fields of sea surface height that show the Loop Current impinging on the West Florida Shelf and the pressure anomaly traveling north to the De Soto Canyon region (Nguyen et al., 2015).*



Deep-C's Modeling Team

Eric Chassignet
Florida State University

Mark Bourassa
Florida State University

Dmitry Dukhovskoy
Florida State University

Hannah Hiester
Florida State University

Steve Morey
Florida State University

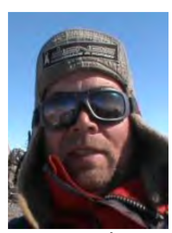
Wilton Sturges
Florida State University

Panagiotis Velissario
Florida State University

Robert Weisberg
University of South Florida

Mohamed Iskandarani
University of Miami-RSMAS

Villy Kourafalou
University of Miami-RSMAS



Lars Hole
Norwegian Meteorological Institute

Cecilie Wettre
Norwegian Meteorological Institute

Ashwanth Srinivasan
Tendral, LLC

NOT PICTURED

Sergio deRada and Pat Hogan
Naval Research Laboratory at Stennis Space Center

What Did We Learn?

- Coupled ocean-atmosphere Earth System Models can be used to make forecasts in the Gulf of Mexico.
- Environmental data and statistical techniques can be combined to advance oil spill modeling capabilities.
- Capturing waves in a model is important for predicting surface water movement and therefore spreading of oil at the surface.
- Waves can modify the fate of fish eggs by moving the particles close to shore and it is possible this process can affect oil particles as well.
- Oil transport is affected by the complex flow patterns of the Gulf of Mexico which, in the northeastern Gulf of Mexico, are influenced by the Mississippi River, the De Soto Canyon, and the Loop Current and associated eddies.

LESSON PLAN:
Modeling 101

Using mathematical equations to create computer models and simulations

Objectives: Explore how computer models work. Engage in building and using a mathematical model. Determine and discuss strengths and limitations of a computer model.

Standards: OLP 1, 3, 6; SC.912.N.3.5

Time Required: One 50-minute class period

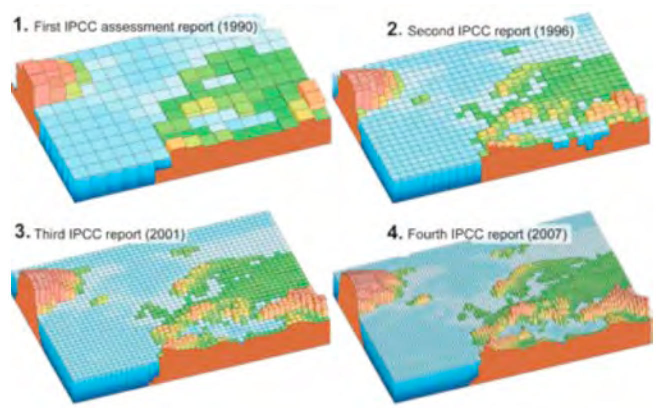
Keywords: modeling, computer model, mathematical model, resolution

Materials:

- Paper with an illustration of a box
- Transparency with cloud models (circle, ellipses), one for each group of four (see template)
- Gridded paper, coarse and high resolution, if desired with coastline or location already drawn on
- Projector

Background

Models are everywhere and used constantly in science. **Computer models** are a particular type of model that allow researchers to simulate phenomena over a wide range of spatial and temporal scales. They provide an electronic laboratory where researchers can experiment and investigate scientific problems that might otherwise be restricted by time, resources, or basic practicalities. Scientists cannot make a hurricane and send it across America to see what will happen, but they can simulate it on the computer and then analyze the output to learn more about the hurricane itself and also make better storm preparations and disaster plans.



Models displayed at various spatial resolutions.
http://nas-sites.org/climatemodeling/page_3_2.php

While people often see the output of computer models, for example in the form of a weather forecasts or stock market predictions or even graphics in movies, they do not often think about what a computer model really is. In fact, computer models are built on theoretical and **mathematical models** that are then written into code the computer can understand. Computer models can do lots of calculations quickly and can help us visualize the results of those calculations. This lesson reveals key steps in computer modeling and in doing so causes us to think about the strengths and limitations of computer models and how this influences the output. For example, if the spatial **resolution** of a computer model is higher more details are captured (see figure above), but this also means the computer has to do more calculations and therefore the model takes longer to run.

Procedure

1. Warm up: What is a model? Why do we use models?

Show students some models (i.e. toy car, map, doll, and equation) and discuss with them what these are models of and the strengths and limitations of the models.

- What do you think are some of the similarities and differences between the toy car and a real car?
- Is the toy car a good model? There is no right answer to this question. Furthermore, whether a model is good or not depends on the question being

asked. For the toy car example, the toy car is a reasonable model if you want to answer the question “What does a car look like?” However, it is not such a good model if you want to answer the question “How does a car run?”

Ask students what they think computer models might be used for and why they might be useful.

Explain to students that we can use computers to make models and describe the computer model diagram below.

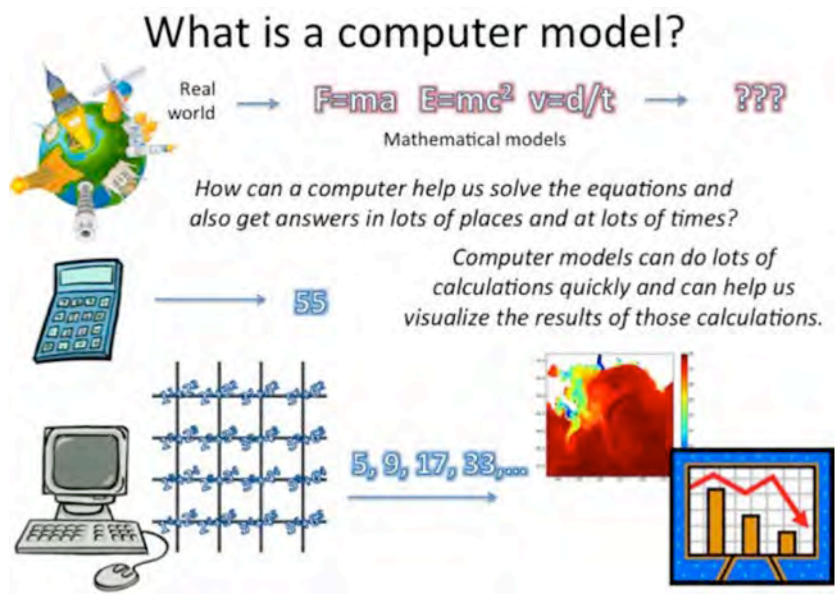
2. Algebra Race

Computers are very fast at solving simple equations:

Ask students to see how quickly they can complete the sum 1+2+3+4+5+6+7+8+9+10

Then see how quickly they can do it on a calculator.

A computer is far faster than a calculator and can do lots of calculations very quickly.

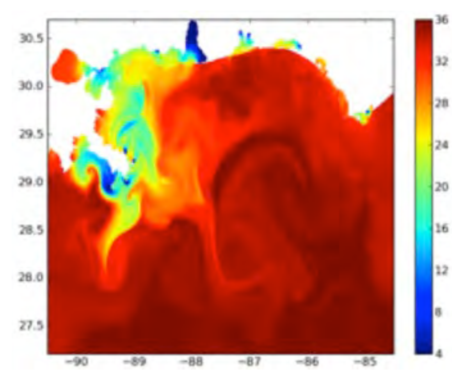


Source: Hannah Hiester, Florida State University.

3. Cloud Modeling Activity

The students will work through a series of steps to create a cloud model. At each stage, the question “Is this a good model?” can be posed as well as comparing the different models. As the answer depends on what question you are asking, it may be helpful to ask “Is this a good model for understanding what a cloud looks like?” and “Is this a good model for telling you if you will get rained on?”

- Ask students to draw a beach scene or crowd of people on gridded paper. Put the gridded paper to one side.
- Have students draw a cloud in box. This is a **2D model** of a cloud.
- Have students select the best model for a cloud from the transparencies. This is the **mathematical model** of the cloud.
- Explain to the students that they will now be the computer and fill in the cloud on the grid. It is generally a good idea to demonstrate the steps to the students. Students place the transparency over the top of the gridded paper. They then mark on the gridded paper, which points are in the cloud (if a point is on the line, the students have to decide if it is in or out – essentially you make up a rule and stick to it). This step is where the **numerical modeling** takes place. Here the students are “being the computer” by asking for each grid point “Is this grid point in or out of the cloud” and then taking an action based on whether it is or is not. In reality the computer would evaluate the x^2+y^2 at every point and then assess if it is greater than or less than r^2 and hence whether it is outside or inside the cloud.
- Have the students connect the points on the grid using straight lines and then fill in the square within that shape. This is what the **computer model** of the cloud looks like.
- If time permits, repeat steps 3-6 with the high-resolution grid paper. Before doing so, ask the students if they think there would be a way to improve their models.



Model output of the Mississippi River Plume

Points of Discussion:

- What mathematical models did people use?
- How do your computer models of the clouds compare with each other?
- How did you feel about being a computer?
- Did the resolution of the grid make a difference?
- How might you improve the model? One possibility is to stick everyone's grids up at the front and to discuss how long it took them to do these, how long they think it would take to do lots of clouds by hand and then explain that the computer can actually do this very quickly.
- What might be some strengths and weaknesses of computer models?
- Did the mathematical model or the numerical model make more of a difference? In reality both make a big difference.

Questions

1. What do you think models are? *Answers will vary.*
2. Why might we use models? *Example: to gain an understanding of things that are difficult to study.*
3. What do you think a computer model is? *A visualization of mathematical equations.*
4. What might be some strengths and limitations of computer models? *Examples of strengths: fast, can simulate things we cannot create in real life, can make predictions. Examples of weaknesses: they are still a model and not real life, generally need more than one model to make a prediction to account for model biases.*

Extensions

Have students try a second cloud that is a different shape to the first.

For advanced math classes: calculate the value of the mathematical model for each/several points on the grid (easiest for the circle). Elicit that the condition to be in or out of the mathematical model of the cloud requires a greater than or less than condition in the equation. This is a numerical model that can be coded (it would go something like calculate $x^2 + y^2$, check if it is greater than or less than r^2. If greater than, no cloud; if less than, cloud.

Resources & References

Climate Modeling 101 http://nas-sites.org/climatemodeling/index.php

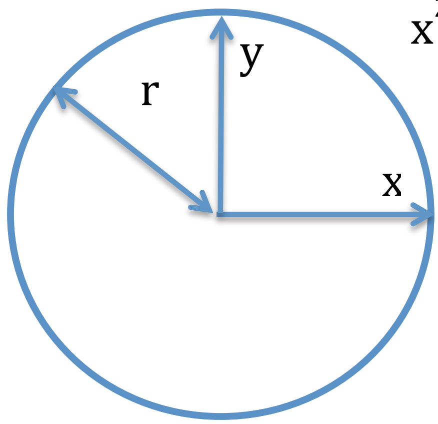
More lesson plans on computer modeling and stimulation
https://code.org/curriculum/science/files/CS_in_Science_Module_1.pdf

Contributing Expert

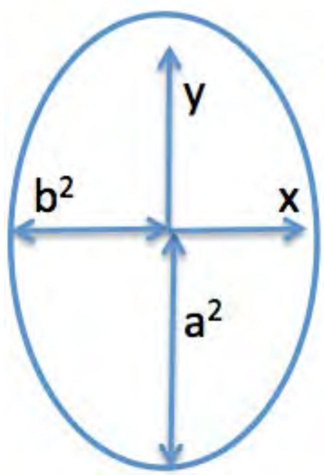
Dr. Hannah Hiester, Research Scientist at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

Templates

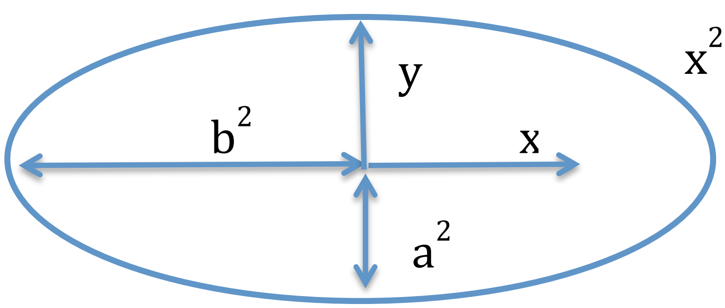
Draw a cloud in your box:



$$x^2+y^2=r^2$$



$$x^2/a^2 + y^2/b^2 = 1$$



$$x^2/a^2 + y^2/b^2 = 1$$

LESSON PLAN:
Oil Spill Models

Using statistical probability to forecast oil spills

Objective: To provide students with an understanding of how computer models and statistics are used to forecast the trajectory of an oil spill.

Standards: OLP 1, 3, 6; SC.912.N.1.7, SC.912.N.3.5

Time Required: One or two 50-minute class periods

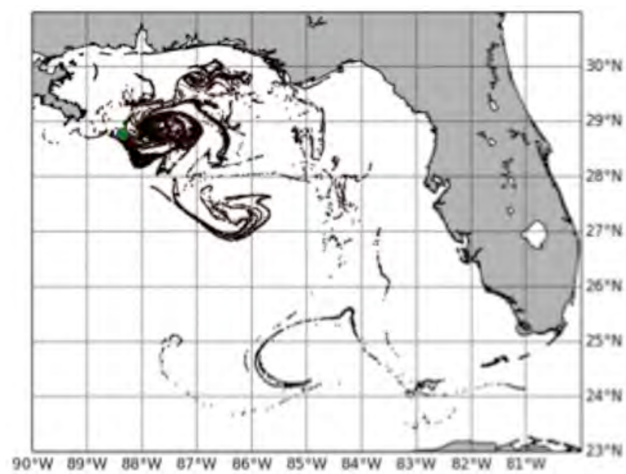
Keywords: computer model, oil spill model, environmental impact factors, forecast, trajectory

Materials:

- Graph paper
- Dice
- Computer
- Beans
- Impact Factor Cards (copy and cut individual cards)

Background

Models capture different physical phenomena that impact and change a system, and they respond dynamically to different inputs and physical characteristics. By calculating the effect of one component of the system on another, models allow us to understand how different parts of the system interact. This can help us learn about how the ocean and atmosphere work and help us make better models and **predictions** in the future. Deep-C scientists have been working on developing new Earth System Models and **oil spill models** to help with such research, and also using observations to improve the way in which processes are represented in models as discussed in the article by Rohrs et al. (2012). They have also considered the interaction of different system components, for example the researchers at Norwegian Meteorological Institute are studying the effect of waves on buoyant particles and computer modelers at the University of Miami are investigating the interaction between Mississippi River outflow and the 2010 Deepwater Horizon oil spill. Oil spill models assisted researchers in **forecasting** the **trajectory** of the oil spill as well as utilizing current data to discover new insights into the path that the Deepwater Horizon oil took after the spill. The following lesson looks at the various environmental **factors** that impacted the trajectory of the spill as well as how data collected about those factors can be incorporated into **computer models.**



A graphic of oil droplets at the surface on day 30 of a DwH blowout simulation.
http://stargazer.coaps.fsu.edu/dcom/index.html

Procedure

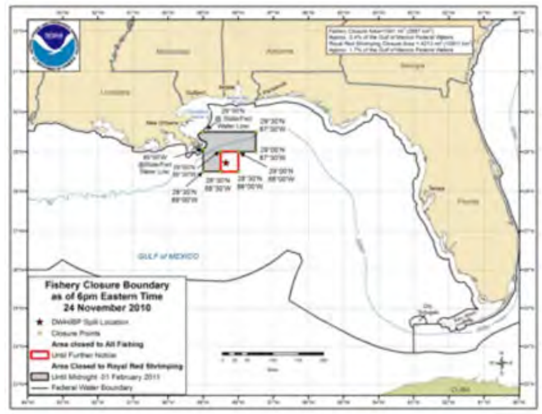
1. **Read and Answer:** Have students read the article, “Study: wave data can improve forecasts that help search and rescue operations and oil spill response”, and answer the following questions:
   - How can the predictability of current trajectories be improved?
   - How did the researchers from the Norwegian Meteorological Institute collect the data that was used in this study?
   - What role might waves play in the transport of oil?

2. **Impact Factors Research:** Assign groups of 3-4 students different environmental impact factors to research on the distribution of oil in the Gulf of Mexico after the 2010 spill (i.e. Loop Current, Mississippi River plume, wind, degradation, evaporation) and report their findings to the class.

3. **Forecasting Trajectory of An Oil Spill:** Pass out grid paper, beans, dice, and Impact Factor Cards to each group. Explain that they are going to run a model that takes into account different impact factors in order to forecast the trajectory of the oil spill. Have students draw an outline of the Gulf of Mexico on their graph paper and pinpoint the location of the Deepwater Horizon spill (See image to the right for reference). Each group will start with 15 beans piled on the spill source and will draw cards to determine the movement of oil along the grid. At the start of each turn:

    - Add five beans (to simulate oil gushing from the source).
    - Spread beans out by one square (to simulate oil movement by itself).
    - Pull a Degradation Card and follow instructions (weather, microbes, wave).
    - Pull a Transport (wind or wave) Card and follow instructions (explain wind direction).
    - Roll die. If you roll a 6, draw an Extreme Factor Card (hurricane, algal bloom, loop current, tropical storm).

    Have each group take 5-6 turns, and then draw an outline of their oil spill. Compare spill shapes as a class.



Maps like this one from NOAA can be used to help student gain an understanding of the geography of the area.

Questions

1. What are the main factors that impact the movement of an oil spill? *Wind, ocean currents and degradation.*

2. How do the impact factors influence the movement of the spill? *Wind and ocean currents transport the oil and degradation causes oil to be broken down either meaning less oil is available to transport (as in the activity) or smaller particles are transported that may be affected by the environment differently (as can happen in reality, for example they may be carried further as they are lighter or mixed more easily through the water column).*

3. Were the results what you expected? Why or Why not? *Answers will vary.*

4. Which factor seemed to have the most influence on the movement of oil? *Answers will vary.*

Extensions

For more advanced students, have groups write their own rules (parameters) to determine how oil moves into each grid point (i.e. flip a coin and heads means two beans added). Encourage to start simple and then make more complex. Have groups trade cards and create an oil spill using the new parameters.

Make clean-up cards (dispersant, in situ burning, boom, etc.) to add to the rotation.

Investigate impact factors that would influence an oil spill in other locations (e.g. Alaska, SE Gulf of Mexico, etc.) through research and by using the oil spill model found at http://www.livingoceans.org/maps/oil-spill-model

Resources & References

Surface Oil Trajectories during a Katrina-like Storm
http://deepwaterhorizon.fsu.edu/projections/hurricanes.php

Contributing Expert

Dr. Hannah Hiester, Research Scientist at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

ARTICLE REPRINT

Study: Wave Data Can Improve Forecasts that Help Search and Rescue Operations and Oil Spill Response

Posted online August 26, 2013 (Reprinted with permission)
Source: GoMRI, http://gulfresearchinitiative.org/study-wave-data-can-improve-forecasts-help-search-rescue-operations-oil-spill-response/

Scientists with the Norwegian Meteorological Institute are quantifying wave effects for use in ocean models that predict the direction of surface water movement. Calculations that go into these models have important implications and relevant applications: improving them can provide better information in time-critical situations such as accidents and disasters.

Breaking surface waves, generating whitecaps and ocean turbulence as seen from a ship's bull's eye. (Photo by: Kai Christensen)

Kai H. Christensen (R) and Johannes Rohrs (L) prepare to deploy two types of surface drifters. The drifter in the cardboard box unfolds once in contact with water. (Photo by: Göran Broström)

Researchers found that "the predictability of drift trajectories can be improved by adding wave information from a numerical wave model" with each "wave feature" helping to reduce uncertainties. They published their findings in the December 2012 edition of *Ocean Dynamics*: **Observation-based evaluation of surface wave effects on currents and trajectory forecasts**.

This Norway-based research team is part of a larger research group led by Florida State University, the Deepsea to Coast Connectivity in the Eastern Gulf of Mexico (Deep-C) Consortium. Deep-C is conducting research related to the *Deepwater Horizon* oil spill. The science team in Norway used sampling opportunities in the North Atlantic to conduct research and apply findings to improve Gulf of Mexico models of oil movement at the ocean surface. Wind, waves, and currents are the geophysical forces that move floating objects and material – from large items to tiny droplets – in the ocean. Models need all of these parameters to produce accurate forecasts of where things will move. Currently, there are separate numerical models for atmosphere, waves, and circulation, with some coupling between them. However, uniting these three forces remains a challenge for today's forecast models. While there are several approaches to account for wave effects, the assumption is that "waves always correlate with the local wind, something which is often not the case."

In April 2011, scientists collected data during a research cruise in the Vestfjorden area, northern Norway. They used a wave rider buoy for wave spectra and acoustic Doppler current profilers and two types of tracking buoys (sampling at different depths) for currents. The team formulated drift models with and without wind drag and with and without wave information.

They accounted for both pure wind and for wind drag that includes Stokes drift, which is the forward motion by waves. The team reconstructed observed drift trajectories and found that when they included wave information "the trajectories of the surface drifters were well reconstructed (by the Lagrangian mean currents)" and that "the relative importance of the Stokes drift was twice as large as the direct wind drag." Stating the importance of upper ocean currents for trajectory forecasts, they concluded that, "waves…have a significant contribution to the trajectories."

In their discussions, researchers noted that currently no consensus exists on how ocean models should incorporate processes for wave-induced turbulence and that progress "has to some extent been hampered by the lack of reliable turbulence measurements in the upper layer of the ocean." They suggest that adding a numerical wave model to existing ocean models "can provide the necessary directional wave spectra and algorithms for calculating the Stokes drift and the forcing fields."

The researchers are optimistic that forecasts will improve because "recent theoretical developments provide a framework for including these wave effects in ocean model systems.

The study authors are Johannes Rohrs, Kai Hakon Christensen, Lars Robert Hole, Goran Brostrom, Magnus Drivdal, and Svein Sundby (*Ocean Dynamics,* 2012, *62*, 1519-1533).

Impact Factor Cards

Extreme Hurricane comes through and increases degradation and transport. Spread beans out 6 squares in all directions. For every square that has more than 1 bean, remove 1 bean.	**Extreme** Oil gets caught in the Loop Current. Spread your spill out into a line from wherever it is to the SE corner of your grid, towards the Atlantic.	**Extreme** Algal bloom results in accelerated degradation. Remove half of the beans.
Transport Winds are blowing to the West, move beans 1 square to the west.	**Transport** Strong winds and waves… move beans 3 squares to the northeast.	**Transport** Wind and waves are moving the oil droplets East. Move beans 2 squares.
Degradation Evaporation occurs at the surface. Remove ANY 3 beans.	**Degradation** Microbes get hungry. Remove ANY 5 beans.	**Degradation** Waves break up oil into smaller particles, remove one bean.
Transport Winds are blowing to the North, move 3 beans 3 squares to the north.	**Transport** Strong winds and waves… move beans 3 squares to the northeast.	**Transport** Wind and waves are moving the oil droplets East. Move beans 2 squares.
Degradation Evaporation occurs at the surface. Remove ANY 3 beans.	**Degradation** Microbes get hungry. Remove ANY 7 beans.	**Degradation** Waves break up oil into smaller particles, remove 3 beans from the southeast corner.
Extreme Hurricane comes through and increases degradation and transport. Spread beans out 6 squares in all directions. For every square that has more than 1 bean, remove 1 bean.	**Extreme** Oil gets caught in the Loop Current. Spread your spill out into a line from wherever it is to the SE corner of your grid, towards the Atlantic.	**Extreme** Algal bloom results in accelerated degradation. Remove half of the beans.

LESSON PLAN:
Making Predictions

How scientists use models to predict earth system interactions

Note: This lesson works well in conjunction with the *Oil Spill Models* lesson.

Objective: To understand how models are used to make predictions about future events.

Standards: OLP 1, 3, 6; SC.912.N.3.5

Time Required: One or two 50–minute class periods

Keywords: probability, predictions, model ensemble, forecast

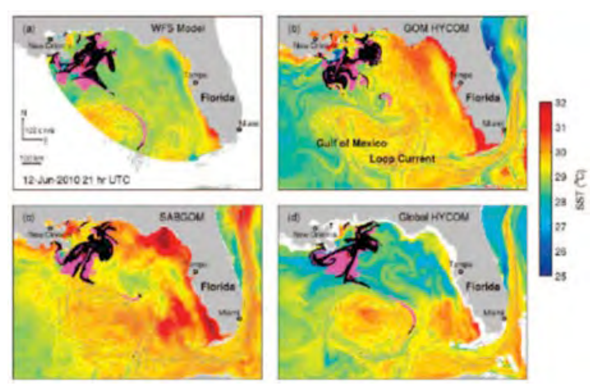
Materials: Lettered cards and paper

Background

Making **predictions** is challenging, as the ocean and atmosphere are inherently unpredictable and complex. Researchers use all available knowledge about these systems to design the best computer models to make as accurate predictions as possible. **Computer models** solve equations that are based on **mathematical models**, which in turn are derived from observations, experiments, and theory. All computer models differ in their set up in some way, for example through the equations used or the input data. For a given scenario, therefore, the predictions made by different models will vary. Often these predictions are similar or share some characteristics, but they can vary widely. A common approach for predictions is to use a **model ensemble,** which is simply a collection of models that all simulate a given scenario and each produces a prediction of the outcome. The similarities and differences from the models within the ensemble are then leveraged to make a best guess at the future system state. During the 2010 Deepwater Horizon oil spill, model ensembles were used to help make predictions about where the oil would go and to help aid clean up efforts. Deep-C researchers worked to improve models and our understanding of both models and the region so that we can continue to improve our modeling and prediction capabilities. This lesson has students investigating **oil spill models**, how they are run, and making predictions about the trajectory of the oil spill.

Procedure

1. **Read and Answer:** Have students read the article, "*Modeling Study Adds Evidence that Oil Compounds Traveled to West Florida Shelf*" and answer the following questions:
   - How can the predictability of current trajectories be improved?
   - How did the researchers from the University of South Florida collect the data that was used in this study?
   - What role might waves play in the transport of oil?
2. **Look at examples of oil spill model output:** In groups of 3-4, have students do a database or web search for "oil spill models" and see what they can find. Based on their research and their knowledge from reading the preceding article, ask them to draw 3 different oil spill shapes and assign a number to each shape (A, B, C). These shapes will represent model predictions of the oil spill.



Example of Model Outputs: Three- day oil trajectory forecast for June 12, 2010 based on (a) West Florida Shelf (WFS) model, (b) Gulf of Mexico Hybrid Coordinate Ocean Model (GOM HYCOM), (c) South Atlantic Bight–Gulf of Mexico model (SABGOM), and (d) Global HYCOM. Black denotes virtual drifters inferred from satellite imagery; purple denotes areas swept out by virtual drifters. Background fields are sea surface temperatures (SST) and currents. [*http://onlinelibrary.wiley.com/doi/10.1029/2011EO060001/full*](http://onlinelibrary.wiley.com/doi/10.1029/2011EO060001/full)

3. **Give students the following scenario:** It's May 10, 2010. The Deepwater Horizon spill has been ongoing for 20 days and your models are going to run and make a prediction about what the oil spill looks like on the current date + n (i.e. May 11, May 12, etc.). This information will help researchers to **forecast** the trajectory of the oil spill.

4. **Lettered Cards**: Give each group a set of shuffled cards labeled with the letters A, B and C (see following pages) and explain to them that they will be pulling four cards to stimulate running four different models in a model ensemble. Pulling one card represents running one model. The letter on the card pulled represents the oil spill shape that the model predicts. After pulling four cards, the students will have a set of four predictions, for example 2 models predict shape A, 1 model predicts shape B and 1 model predicts shape C. Based off the collected information, what would they say the oil spill looks like i.e. what does the model ensemble predict? Compare results between groups. The labeled cards on the following pages have a varying amount of each letter (18 x A, 12 x B, 6 x C). This biases the results of the card draw towards one shape and mimics the reality that usually most of the models in a model ensemble tend towards a similar prediction.

Questions

1. Why do scientists use models to make predictions about future events? *To help study phenomena that are difficult to physically analyze and to help scientists prepare for them.*
2. Based off of the results from running the three models, what would you advise the authorities? *Answers will vary.*
3. What are the strengths and limitations of using a model ensemble/several models to make predictions? *Strengths can include using several different models allows an average and uncertainty in a prediction to be determined, compensation for imperfections in different models and to balance the strengths and weaknesses of different models. Weaknesses can include several different models have to be run which increases computational cost and even if all models agree closely, they are still models and therefore have inherent imperfections which may lead to an incorrect prediction.*

Extension

Have students investigate hurricane forecasting and/or climate predictions.

Resources & References

Models: How Computers Make Predictions
https://student.societyforscience.org/article/models-how-computers-make-predictions

NOAA Geophysical Fluid Dynamics Laboratory, Ocean Models
http://www.gfdl.noaa.gov/ocean-model

Contributing Expert

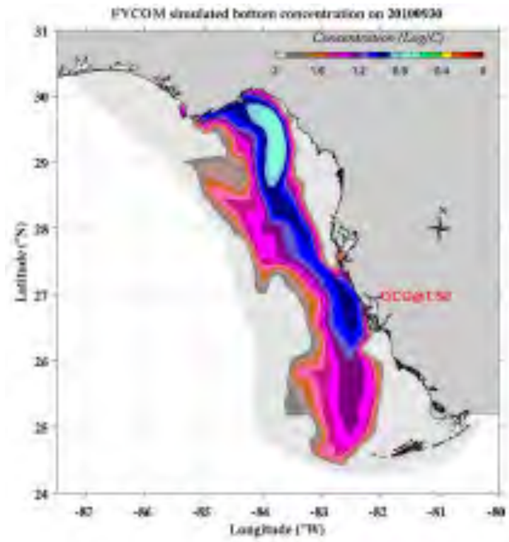
Dr. Hannah Hiester, Research Scientist at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

ARTICLE REPRINT

Modeling Study Adds Evidence that Oil Compounds Traveled to West Florida Shelf

Posted online March 17, 2014
Source: GoMRI, http://gulfresearchinitiative.org/modeling-study-adds-evidence-oil-compounds-traveled-west-florida-shelf/

Scientists from the University of South Florida used circulation models to conduct a tracer simulation and compared output patterns with ecological analyses to determine the possibility that hydrocarbons from the *Deepwater Horizon* oil spill could have moved onto the West Florida Shelf (WFS).



They found "plausible and consistent" evidence that currents caused by "an anomalously strong and persistent upwelling circulation" drove oil compounds through subsurface waters to the WFS. The researchers published their findings in the February 2014 edition of *Deep-Sea Research II Topical Studies in Oceanography*: **Did Deepwater Horizon hydrocarbons transit to the West Florida Continental Shelf**?

The coastal ocean region known as the WFS includes waters east of the De Soto Canyon and south to the Florida Straits. Oil from the *Deepwater Horizon* wellhead landed on northwestern Florida panhandle beaches in June of 2010. For three weeks, satellite and aerial images with accompanying model simulations showed oil moving on surface waters further east, close to Cape San Blas, then it receded and was no longer visible in that area. However, public and scientist findings were emerging that indicated compounds from this oil – though no longer visible – continued to impact the WFS marine environment.

Fisherman reported anecdotally that reef fish caught in the WFS region had lesions and deformities. Then scientists conducted systematic sampling of reef fish in the area and as far south as the Dry Tortugas, and their catches had lesions and other indicators of fish disease. Researchers then examined fish livers. Their results found signatures of oil compounds, similar in composition to that from oil samples taken from the *Deepwater Horizon* wellhead, in some reef fishes. Scientists for this study sought to demonstrate if conditions could have been such that subsurface currents transported oil through the WFS that would be consistent with these findings.

Over the years researchers have developed and combined several numerical circulation models to understand the complex current systems that work throughout the Gulf of Mexico. Already established was that the "WFS experienced a strong and persistent period of upwelling that began within one month of the *Deepwater Horizon* explosion and then lasted through the end of the year." The strong current data motived this research team to use the West Florida Coastal Ocean Model (WFCOM), which consists of the Finite Volume Coastal Ocean Model (FVCOM) nested in the Hybrid Coordinate Ocean Model (HYCOM), and add a passive tracer (a proxy for oil) to track where this current could have transported hydrocarbons.

The researchers crudely estimated upper and lower concentration levels of the tracer based on implied surface oil thickness from northern Gulf of Mexico observations: "3 ppb to 300 ppb based on a 10% incorporation [in the water column] and 6 ppb to 600 ppb based on a 20% incorporation." The water column incorporation tracer distribution was argued based on downward mixing by Langmuir circulation and the associated waves. When they ran the tracer simulation and considered the high end of the concentration levels, it implied the possibility of "6 ppb at the leading edge of the plume and 60 ppb over a large region past Cape San Blas on June 30." At the end of the simulation (September 30), it implied the possibility of "6 ppb would cover the entire domain, with values of 24 ppb at the Dry Tortugas and 60 ppb offshore of Sarasota." The highest values, 150 ppb, were in the Florida Big Bend.

The team compared the tracer patterns with "observations from a purposeful sampling program of fish lesions and fish liver chemistry" to demonstrate fidelity between tracer location and where lesions and contaminants in fish also occurred. The pattern comparisons were also in line with areas that showed "hydrocarbon contamination on the WFS presented on the basis of microbiological toxicity and mutagenicity analyses."

In their discussions, the researchers concluded that the consistency of the tracer modeling with the observations and analyses of other scientists working in the region "leaves open the possibility that hydrocarbons may have permeated much of the WFS" and may possibly have entered Tampa Bay.

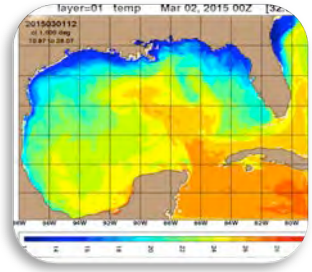
The team also noted that the design of sampling programs for future damage assessment would "benefit greatly from closer interactions between agency personnel charged with such activities and local scientists knowledgeable in the coastal ocean workings of the region."

The study's authors are Robert H. Weisberg, Lianyuan Zheng, Yonggang Liu, Steven Murawski, Chuanmin Hu, and John Paul (*Deep-Sea Research II*, February 2014).

Lettered Cards for Making Predictions

A	A	A	A	A	A
A	A	A	A	A	A
A	A	A	A	A	A
B	B	B	B	B	B
B	B	B	B	B	B
C	C	C	C	C	C

LESSON PLAN:
Interpreting the Ocean through Color



Harness the power of computer software to make useful visualization tools for all types of data, from observations to models

Objectives: To paint an image from a model output, discuss the meaning of the illustrated colors, and write a short narrative explaining the science. To increase awareness and understanding of ocean systems through coupled art and science education.

Standards: OLP 1, 3, 4, 6; SC.912.N.3.5; VA.912.S.1, VA.912.F.1

Time Required: One 50-minute art class; one 50-minute science class

Keywords: STEAM, SST, SSS, SSH, modeling

Materials:

- Computer
- Projector
- Images (download required before class)
- Canvas or thick paper
- Paint
- Paint brushes
- Cups of water

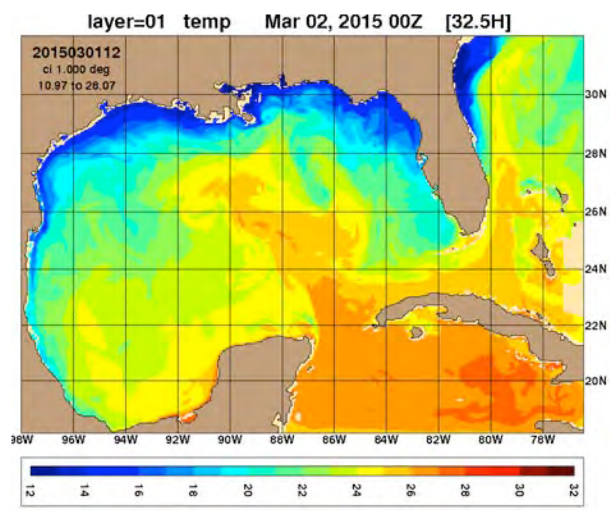
Background

Animated maps aid scientists, decision makers, and emergency response personnel in identifying and tracking ocean circulation features. However, have you ever wondered what the colors really mean and how they are interpreted?

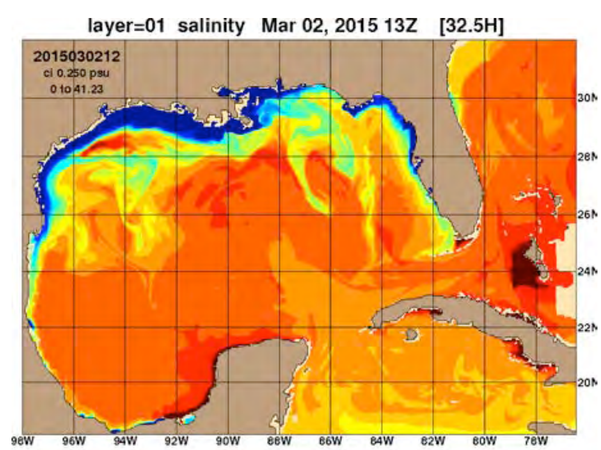
Some commonly used quantities are Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and Sea Surface Height (SSH). The values can come from computer models or satellites and the colors show a range of values from high to low. Different water masses can have different signatures, For example, river water is fresh and has a low SSS. The paths, evolution, and interaction of water masses can be analyzed by tracking the signatures in the color maps. Images used throughout this lesson are model outputs from the Gulf of Mexico HYbrid Coordinate Ocean Model (HYCOM).

Sea Surface Temperature: The SST is the temperature of the water at or near the surface (aka the skin temperature of the ocean surface water). Since the surface of the ocean is where the ocean and atmosphere interact, the SST can affect the weather and vice versa. SSTs influence sea breezes, and warm SSTs are known to play a part in the generation of tropical cyclones.

Sea Surface Salinity: The SSS is the salinity of the water at or near the surface. River water, glacier run-off, and ice melt are all freshwater sources, the signature of which can

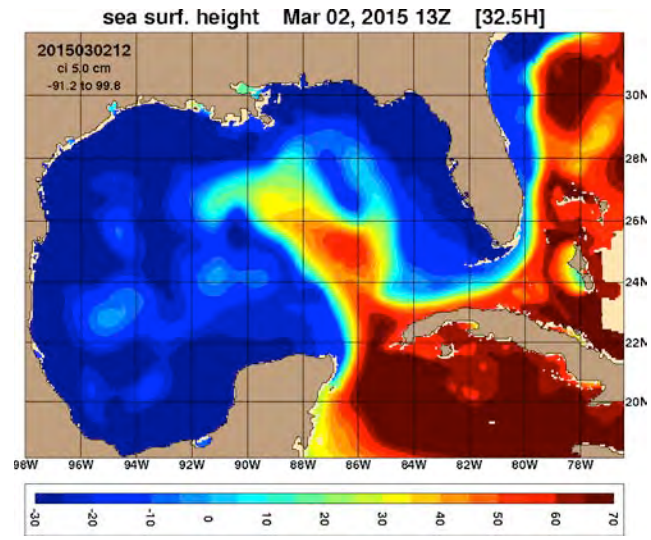


Sea Surface Temperature (SST) from HYCOM Model 1/25° Gulf of Mexico. Color Coding: Blue – cold; Red – warm. The scale in the image above is 12 to 32 degrees Celsius, which is 53.6 to 89.6 degrees Fahrenheit respectively.



Sea Surface Salinity (SSS) from HYCOM Model 1/25° Gulf of Mexico. Color Coding: Blue – less salt; Red – more salt. The scale in the image above is 32.5 to 37 psu (practical salinity units; equivalent to per thousand 0/00 or g/kg). This unit is based on the properties of sea water conductivity. The average salinity of the global ocean is 35.5 psu.

be seen in maps of SSS. The fresh water can also mix with the more saline ambient water leading to intermediate SSS values. These signatures and mixing patterns can be used to track the water and determine water pathways in the ocean.



Sea Surface Height (SSH) from HYCOM Model 1/25° Gulf of Mexico

Sea Surface Height: The SSH gives a measurement of the deviation of the sea surface from a reference height. A high SSH means the sea surface is relatively raised and a low SSH means the sea surface is relatively depressed. The Loop Current and clockwise rotating eddies in the Gulf of Mexico have a high SSH signature; while counter-clockwise rotating eddies have a low SSH signature. The differences in SSH can be caused by the wind, differences in density, or changes in the water slope due to tides and waves. Changes in SSH tell us about slope of the ocean surface and ultimately the pressure gradient. By assuming relations with density structure and momentum, this information can be used to determine how water is redistributed in the ocean by both vertical and horizontal currents. SSH data can also provide clues to studying the ocean's temperature. Warm water expands raising the sea surface height, whereas cold water contracts lowering the height of the sea surface. Measurements of SSH can provide information about the heat content of the ocean. The height can tell us how much heat is stored in the ocean water column below its surface.

Procedure

STEAM (Science, Technology, Engineering, Arts, and Math) Initiative - Art brings in the creativity, which is an essential component to innovation. This lesson has three basic components: PAINT. LEARN. WRITE.

1. **Obtain and print images for your class.** To save time, you can do this before class and save all the images in one folder or you can assign a certain day of the month to each student and they have to obtain that image for homework the day before. For example: If there are approximately 30 students in the class, the entire month can be shown. Each student can paint an image for a certain day of the month. Therefore, all the students have different days, and then you can line up the paintings on the wall by date and see how the ocean parameters changed within that month.

   For modeling outputs go to: "HYCOM Model 1/25° Gulf of Mexico" website at http://www7320.nrlssc.navy.mil/hycomGOM2/glfmex.html. This site contains real-time nowcast/forecast results from the 1/25° Gulf of Mexico HYbrid Coordinate Ocean Model (HYCOM), including snapshots, animations and forecast verification statistics for many zoom regions, mainly sea surface height (SSH), sea surface temperature (SST), surface currents and subsurface temperature and salinity.
   - Choose either SSH, SST, or SSS.
   - Select snapshot archive – The first date indicates when the model ran (2007070118 means the model ran on 1 July 2007 at 18Z). The second date indicates when the field is valid (2007062700 means the field is valid 27 June 2007 at 00Z). Blue links = the hindcast, red link = nowcast, black link = forecast.
   - "Save Image As"

Art Class Activity

2. **Instruct each student to bring his or her printed image to class.** Each student should be assigned a different day of the month. If there are ~30 students in a class, an entire month can be shown. Or select specific days to show more drastic changes.
3. **Instruct students to paint the image they brought to class**.
4. **Once the paintings are completed, line up them up on the wall by date** and see how the ocean parameters changed within that month OR create a flipbook with all the paintings to see the same concept.

5. **Open the following website:** http://www7320.nrlssc.navy.mil/hycomGOM2/glfmex.html
    - Choose either SSH, SST, or SSS to view.
    - Run an animation of the last 30 days or the last 12 months by clicking on "Last 30 days (gif)" or "Last 12 months (gif)".
6. **Discuss the background information: what the parameters are and what the colors mean.** The images are gridded, so latitude and longitude can also be discussed. Satellite data outputs can also be viewed at the "Colorado Center for Astrodynamics Research (CCAR)" website at the Gulf of Mexico Historical Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/hist_gom_grid_viewer to see what occurred with SSH and SST on one particular day OR CCAR Near-Realtime Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/nrt_gom_grid_viewer to see what is happening in the Gulf of Mexico.

    There are many options to produce an image using this source, however it is only necessary to:
    - Select the date you are interested in (the oil spill occurred on April 20, 2010, flowed for 87 days, and was capped on July 15, 2010).
    - Overlay SSH on Other Data: Select GOES SST or GHR SST.
    - Select "Submit"

    Once an image has been produced, observe closely to:
    - Locate the circular features (where are the eddies).
    - Determine temperature differences (where is the water warmer or colder?).
    - Have the students write a short narrative explaining their art piece and the science behind it.

Questions

1. What does SST, SSS, and SSH stand for? *Sea Surface Temperature, Sea Surface Salinity, Sea Surface Height.*
2. What do the colors mean? *SST: Blue – cold, Red – warm; SSS: Blue – less salt, (fresher) Red – more salt; SSH: Blue – lower SSH, surface depressed; Red – higher SSH, surface raised.*
3. Why is it important for scientists to utilize these models? *To track ocean circulation features. As the models simulate the state of the ocean, atmosphere and processes therein, they can help predict movement of oil after environmental disasters and could aid cleanup efforts.*
4. Are offshore or coastal inshore waters more influenced by seasonal changes? *Coastal waters.*
5. From observing the animations or paintings, how did the ocean parameters change within a month? *Answers will vary.*

Extension

Partner with a local art museum or gallery to display the students' work along with a summary of the project to further educate others in the community.

Resources & References

Colorado Center for Astrodynamics Research (CCAR) http://eddy.colorado.edu/ccar/ssh/hist_gom_grid_viewer

CCAR Near-Realtime Gridded SSH Data Viewer http://eddy.colorado.edu/ccar/ssh/nrt_gom_grid_viewer

HYCOM: Ocean Prediction http://hycom.org/ocean-prediction

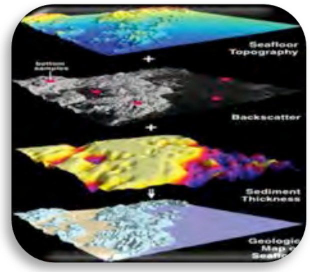
HYCOM Model 1/25° Gulf of Mexico http://www7320.nrlssc.navy.mil/hycomGOM2/glfmex.html

WOCE Global Hydographic Climatology (GHC) http://woceatlas.ucsd.edu/

Contributing Experts

Drs. Xiaobiao Xu and Hannah Hiester, Research Scientists at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

LESSON PLAN:
Deep-C Map Viewer



Visualizing Scientific Environmental Data

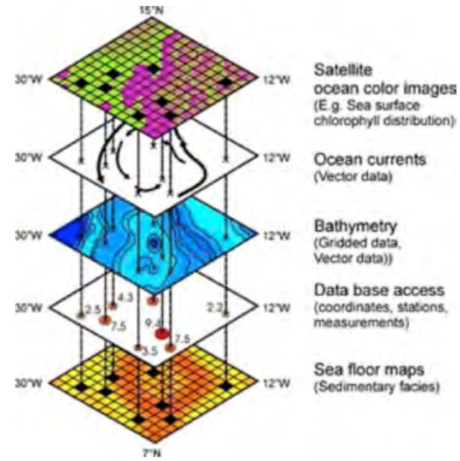
Objective: To introduce GIS and provide an example of how a graphical interface can be used to visualize scientific data.

Standards: OLP 1, 6, 7: SC.912.L.17.16, SC.912.L.17.17, SC.912.N.3.5, SC.912.N.4.1

Time Required: One 50-minute class period

Keywords: GIS, mapping, data visualization

Materials: Computers, projector



Information Layers by Alfred Wegener Institute

Background

What is GIS? GIS stands for Geographic Information System. It is a computer software system designed to capture, store, analyze, manage, and present all types of spatial or geographical data. GIS is a powerful tool that allows us to question and visualize multiple kinds of data on one map. This helps us to understand relationships, patterns, and trends, which leads to better decision-making.

GIS technology has an array of uses:

- Government: Federal – local, land administration, public works, architecture and engineering, urban and regional planning
- Business: insurance, manufacturing, real estate, marketing, media and entertainment
- Utilities and Communication: electric, gas, pipeline, telecommunications, water and wastewater
- Natural Resources: agriculture, climate change, conservation, environmental management, forestry, mining, oceans, petroleum, and water resources
- Others: aid and development, defense and intelligence, education, health and human services, transportation, and public safety

GIS uses location information, such as latitude and longitude, address, or zip code. Maps, digital data, satellite imagery, and tabular data can all be used and overlaid on top of one another on a single map. These GIS data layers can be added or removed on the map. When information is put into GIS, it is called data capture. Digital maps and images can simply be uploaded into GIS. Information from various sources must then be aligned so they fit together. Maps have different scales, which is the relationship between distance on a map and the actual distance on Earth. When GIS combines the information, it has the same scale. Several GIS and Web GIS sites have been developed and share common functionalities.

A screenshot of the Deep-C Map Viewer.

How did the Deep-C Consortium utilize GIS?

Based on OWGIS (Open WebGIS), an Open Source Java Servlets web application that creates WebGIS sites by automatically writing HTML and JavaScript code, Deep-C modelers created a web GIS site that display geographic data acquired by the scientist. This site, called the **Deep-C Map Viewer,** displays temperature, salinity, sea surface elevation, and ocean currents for the Gulf of Mexico. The oceanographic variables are generated daily, using outputs from the

HYbrid Coordinate Ocean Model (HYCOM) ocean prediction system. It can show variables from 2010 to time of access and forecasts for the next 15 days. This viewer also displays geographic information about moorings, drifters, and research cruises.

Some of the features of the Deep-C Map Viewer are: animations of the different ocean variables displayed for the Gulf of Mexico; vertical profiles and vertical transects obtained in real time at any location of the Gulf of Mexico; dynamic palette and color selection to visualize the ocean variables; different depths available to display the ocean variables; visualization in Google Earth by downloading the data in KML format; and a multilingual interface. Deep-C Map Viewer main users are scientists who want to analyze, visualize, share and compare the information displayed on the website.

OWGIS was developed at Florida State University's Center for Ocean-Atmospheric Prediction Studies (COAPS) in collaboration with the Universidad Nacional Autónoma de México (UNAM). OWGIS is used as the interactive visualization map of the Digital Climatic Atlas of Mexico, which provides access to more than 2000 layers of oceanic climate, climate change scenarios, bioclimatic parameters, and socioeconomic indicators. It is also used to display oceanographic data from the Gulf of Mexico.

Procedure

1. Watch "What is GIS?" http://video.esri.com/watch/3623/what-is-gis_question_ (1:10min)
   Watch "The Power of Maps" http://video.esri.com/ (43sec)
2. Discuss what GIS is and its uses. Can view ESRI http://www.esri.com/ and Story Maps http://storymaps.arcgis.com/en/
3. Introduce the Deep-C Map Viewer http://viewer.coaps.fsu.edu/DeepCProject/mapviewer based on background information. Show students the layers: Ocean models, CMR SailBuoy, moorings, cruises, drifters, shore missions, sites, bathymetry contours, temperature, salinity, elevation, and velocity.
4. Have students explore the Deep-C Map Viewer on individual computers, and then have them write a one-page paper on what they learned from using the interface and how GIS systems can serve as a beneficial tool for society.

Questions

1. What does GIS stand for? *Geographic Information System.*
2. How is GIS used? *Answers will vary i.e. government, business, utility, communication, natural resources.*
3. How is GIS important to society? *Allows us to question and visualize multiple kinds of data on one map; helps us to understand relationships, patterns, and trends, which leads to better decision-making.*
4. What is the Deep-C Map Viewer and what information can be obtained from using this interface? *A web GIS site that displays temperature, salinity, sea surface elevation, and ocean currents for the Gulf.*
5. When environmental disasters occur, how can GIS serve as an informational tool? *Answers will vary.*

Extension

Have students complete the SailBuoy lesson plan in the Physical Oceanography module (page 110).

Resources & References

Deep-C Map Viewer http://viewer.coaps.fsu.edu/DeepCProject/mapviewer; OWGIS http://owgis.org/

ESRI http://www.esri.com/; http://www.esri.com/what-is-gis

GIS from National Geographic http://education.nationalgeographic.com/education/encyclopedia/geographic-information-system-gis/?ar_a=1

Story Maps http://storymaps.arcgis.com/en/; Ocean Related Story Maps http://storymaps.arcgis.com/en/gallery/#s=0&md=storymaps-community:oceans

Web Mapping Portal http://www.nowcoast.noaa.gov

Contributing Expert

Olmo Zavala Romero, PhD student at the Florida State University

Computer Modeling Quiz

1. What is a computer model?

2. What might be some strengths and limitations of computer models?

3. What are the main factors that impact the movement of an oil spill?

4. Which factor seemed to have the most influence on the movement of oil?

5. Why do scientists use models to make predictions about future events?

6. What are the strengths and limitations of using a model ensemble/several models to make predictions?

7. What do SST, SSS, and SSH stand for and what do the different colors mean?

8. Why is it important for scientists to utilize models such as the HYCOM model?

9. What does GIS stand for and how is it used?

10. When environmental disasters occur, how can GIS serve as an informational tool?

Computer Modeling Glossary

Computer Modeling: a way to visualize and analyze data, computer programs based on mathematical models of the real world; they offer powerful electronic laboratories, which can be used to investigate phenomena and explore scenarios.

Data Visualization: the presentation of data in a pictorial or graphical format

Environmental Impact Factors: factors that have an effect on what is being studied (i.e. Loop Current, Mississippi River plume, wind, degradation, evaporation)

Forecast: a prediction or estimate of future events, especially coming weather

GIS: Geographic Information System, designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data

Mapping: an operation that associates each element of a given set (the domain) with one or more elements of a second set (the range); a representation, usually on a flat surface, of the features of an area of the earth, showing them in their respective forms, sizes, and relationships

Mathematical Modeling: a representation in mathematical terms of the behavior of real devices and objects

Model Ensemble: a collection of models that all simulate a given scenario and each produces a prediction of the outcome

Oil Spill Model: a model or representation of the location of oil after a spill

Prediction: a forecast, to predict an event or happening in the future

Probability: the extent to which something is probable; the likelihood of something happening or being the case

Resolution: the sharpness or detail of an image; the number of points in space or time.

SSH: Sea Surface Height

SSS: Sea Surface Salinity

SST: Sea Surface Temperature

STEAM: Science, Technology, Engineering, Arts, and Math

Trajectory: the path followed by a projectile flying or an object moving under the action of given forces

Deep-C Scientific Publications by Module Topic

Geomorphology

Garcia Pineda, O.M., Macdonald, I.R., Silva, M., Shedd, W., Daneshgar Asl, S., Schumaker, B., 2015. Transience and Persistence of Natural Hydrocarbon Seepage in Mississippi Canyon, Gulf of Mexico. Deep Sea Research Part II: Topical Studies in Oceanography accepted.

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MacDonald, I., 2013. Tracking Recovery From Deepwater Horizon MILET System Aids Environmental Monitoring in Gulf of Mexico. Sea Tech 54 (5).

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Geochemistry

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Camilli, R., Bowen, A., Reddy, C.M., Seewald, J.S., Yoerger, D.R., 2012. When Scientific Research and Legal Practice Collide. Science 337 (6102), 1608–1609.

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Gulf of Mexico Map http://fcit.usf.edu/florida/maps/stateout/photos/64200.pdf Source: Florida Center for Instructional Technology)

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Deep-C
CONSORTIUM

The Deep-C Consortium conducted a three-year, interdisciplinary study of deep sea to coast connectivity in the northeastern Gulf of Mexico. The study investigated the environmental consequences of the 2010 Deepwater Horizon oil spill on living marine resources and ecosystem health.

Florida State University
Center for
Ocean-Atmospheric
Prediction Studies
2000 Levy Avenue
Building A, Suite 292
Tallahassee, FL 32310

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