



OIL SPILL SCIENCE

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PREDICTING THE MOVEMENT OF OIL

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When oil spills occur, one of the first questions is “Where will the oil go?” Pollutants, such as oil, float on the surface and move through and along with the water. Computer models are tools that help predict the path of pollutants. They help minimize oil spill impacts by estimating the landfall and movement of oil. Plans for protecting the environment, society, and the economy require reliable forecasts that predict where oil will spread in the event of a spill.



Photos like this one, taken during a U.S. Coast Guard flyover in May of 2010, helped scientists and responders keep track of the Deepwater Horizon oil's location. (David Rencher)

The Deepwater Horizon (DWH) oil spill was the largest spill in U.S. history. About 172 million gallons of crude oil entered the Gulf of Mexico waters, causing an unprecedented threat to marine life and the environment. Determining the spill's potential impacts and planning response strategies required getting information unique to the situation because no two oil

spills are alike. Each spill occurs in a different location under different circumstances. The type and amount of oil, the proximity of oil to sensitive resources, the season, the weather, and the water currents all combine to make each spill a unique event.

Oil spill models predict the movement of oil and possible landfall locations. They

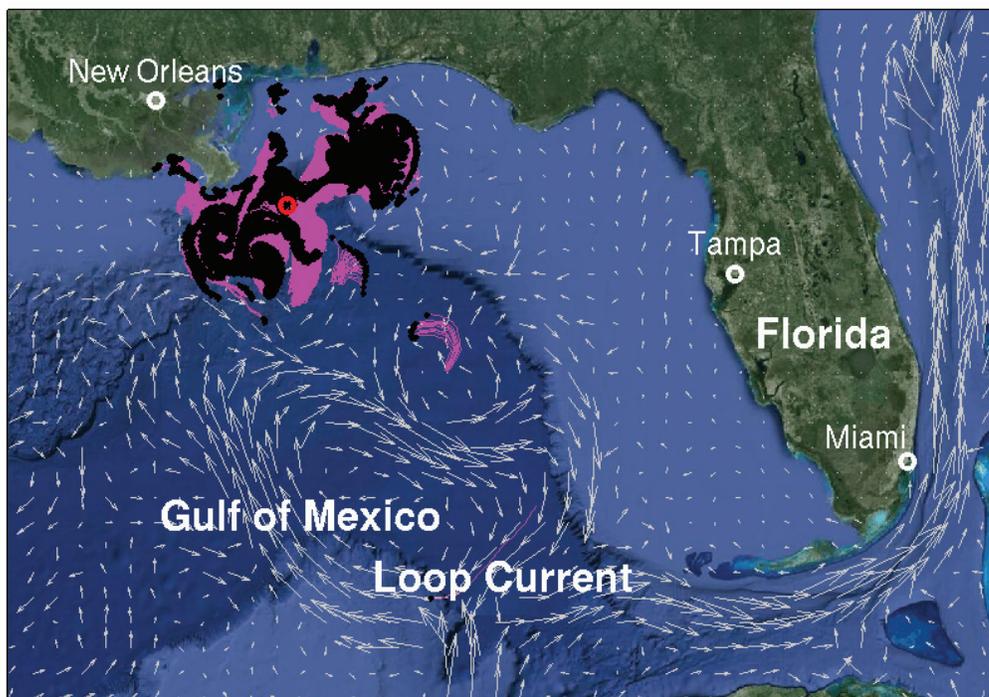


FIGURE 1. In this computer simulation of the Deepwater Horizon spill (red dot), pink colors depict the actual location of oil on June 12, 2010, day 53 of the spill, and black shows the predicted locations of oil after three and a half days. Gray arrows represent the movement of ocean currents. The length of the arrow indicates the currents' strength. (Adapted from Liu, Weisberg, Hu, & Zheng, 2011)

calculate how oil weathers as it spends more time in the water, how it spreads, and the rate at which it evaporates.¹ These forecasts help responders develop cleanup strategies based on more accurate estimates of how long spilled oil will remain in the environment, where it will go, and how it will change over time.²

Response efforts for oil or other chemical spills must be quick, effective, and relevant to the event. In the case of the DWH spill, oil was on the surface and at extreme depths. Models predicted the movement of oil both at and below the surface to guide response efforts and direct ships assessing the situation during the spill (Figure 1).³

WHAT ARE MODELS AND HOW DO THEY WORK?

Computer models are tools used to simulate what might or what did happen in a given situation. A common example of a computer model is a weather forecasting model. It calculates what the weather might be in the next few days or over the week. Other models also simulate ocean currents, tides, waves, and mixing in the ocean, which all affect the movement and spread of pollutants through the sea.⁴ The predictions depend on the information that enters the model, or inputs. Some examples of inputs to ocean

models include bottom depth, wind measurements, and river inflow. The information that comes out can include water level, current speeds, water temperature, and **salinity**.⁵

To improve the quality of computer models, scientists compare model predictions to direct observations in the field (Figure 2).⁶ If the model predictions do not match what is actually occurring in the field, the model is re-examined and modified until it produces more reasonable results. Some models may be compared with data and corrected while an event is occurring. This process is called data assimilation.

Combining multiple models helps scientists understand how different environments interact. One example is when **meteorological models** are paired with **ocean circulation models** to understand events such

as approaching storms, hurricane paths, and El Niño. In the case of an oil spill model, which simulates the fate and transport of oil pollution, several model components are needed.

COMPONENTS OF AN OIL SPILL MODEL

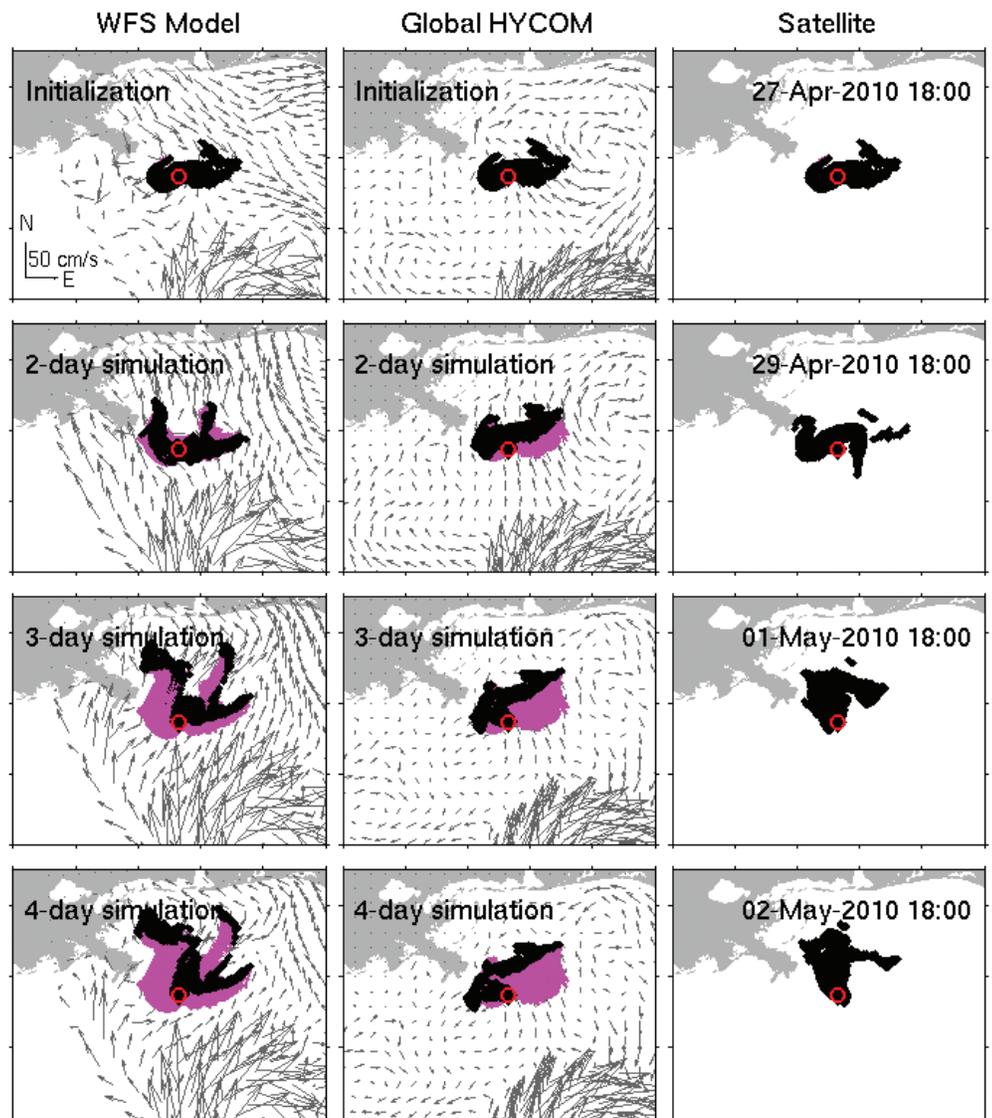
- Meteorological models simulate the present and predict future behavior of the atmosphere (wind, temperature, precipitation).
- Ocean circulation models simulate the motion of water, such as ocean currents.
- **Trajectory** models simulate how particles move up and down and horizontally in the water.
- Chemical models (or “Fate models”) estimate the changing state of pollutants as they move through the water.

MODELING CHALLENGES

Several factors reduce the ability of models to predict oil movement:

- Errors in forcing — Oil spill models rely on forecast modeling to supply forces that make the ocean move.

FIGURE 2. Scientists compared model forecasts from the West Florida Shelf (WFS) model (left column) and the Global Hybrid Coordinate Ocean Model (HYCOM, middle column) to actual oil locations from satellite imagery (right column) on four different days of the DWH oil spill. The open red circle indicates the location of the spill, black shows the predicted or actual location of the oil on a particular day, and pink indicates where the oil was prior. These comparisons help scientist determine how the models differ from one another and how well they predict where oil will go. The model trajectories successfully mimicked the surface oil locations for the first two days, but became less accurate on days three and four.²⁵ (Reprinted from Liu, Weisberg, Hu, & Zheng, 2011)



These forces include winds, tides, temperature, and precipitation. Forecast models' errors increase with time. The longer the model predicts into the future, the larger the errors get and the less reliable the forecast becomes.

- Errors in estimating the amount of oil and its properties — During the DWH oil spill, the amount of oil released into the Gulf was not well known. Modelers had to make assumptions about how much oil entered the environment, which could impact the accuracy of the model.
- Response techniques — Application of **dispersants**, burning oil, and **skimming** oil added uncertainties to the fate and transport of the oil spill model.
- Lacking understanding of how and why oil changes over time — The fate of oil in the ocean depends on many factors:

- spreading caused by ocean currents, waves, and dispersants;
- chemical changes in oil that take place when oil is **weathered**; and
- **biodegradation** that occurs when bacteria break down the oil.^{3,7}

MODELS USED TO UNDERSTAND THE DEEPWATER HORIZON OIL SPILL

During the DWH oil spill, the National Oceanic and Atmospheric Administration (NOAA), university researchers, and other agencies used numerous models to predict where the oil was and where it was going.^{7,8}

Beginning in late April, 2010, NOAA's Office of Response and Restoration modeling team began generating daily forecasts for the DWH oil spill. NOAA produced forecast maps twice a day from April 23 to May 19. These maps

showed the surface location of oil and predicted where it would go next. Scientists produced forecasts for where surface oil would be at 12-, 24-, 36-, 48-, 60-, and 72-hour intervals to support daily response plans. All forecasts ended on August 23, 2010, when no more evidence of floating oil appeared and no recoverable oil could be seen in flights over the area for three weeks.^{7,12,13}

COASTAL PREDICTIONS

Models also predicted how oil would move in the nearshore environment. Early in the spill, emergency responders were most concerned that oil would reach coastlines from Loui-

siana to the Florida Panhandle. Other forces were at work, however. By May, the nearby Mississippi River was swollen with spring rains, playing an important role in influencing where the oil went. The model simulations, satellite data, and on-site observations helped scientists understand the relationship between the river's outflow and the movement of surface oil. They learned that when winds were weak, the increase in the river's outflow helped protect the coast by pushing the oil away from the shoreline.¹⁴

Some of the oil that was not collected or dispersed made its way to the northern Gulf of Mexico coastline. Oil mixed with suspended sediment and formed **sand and oil agglomer-**

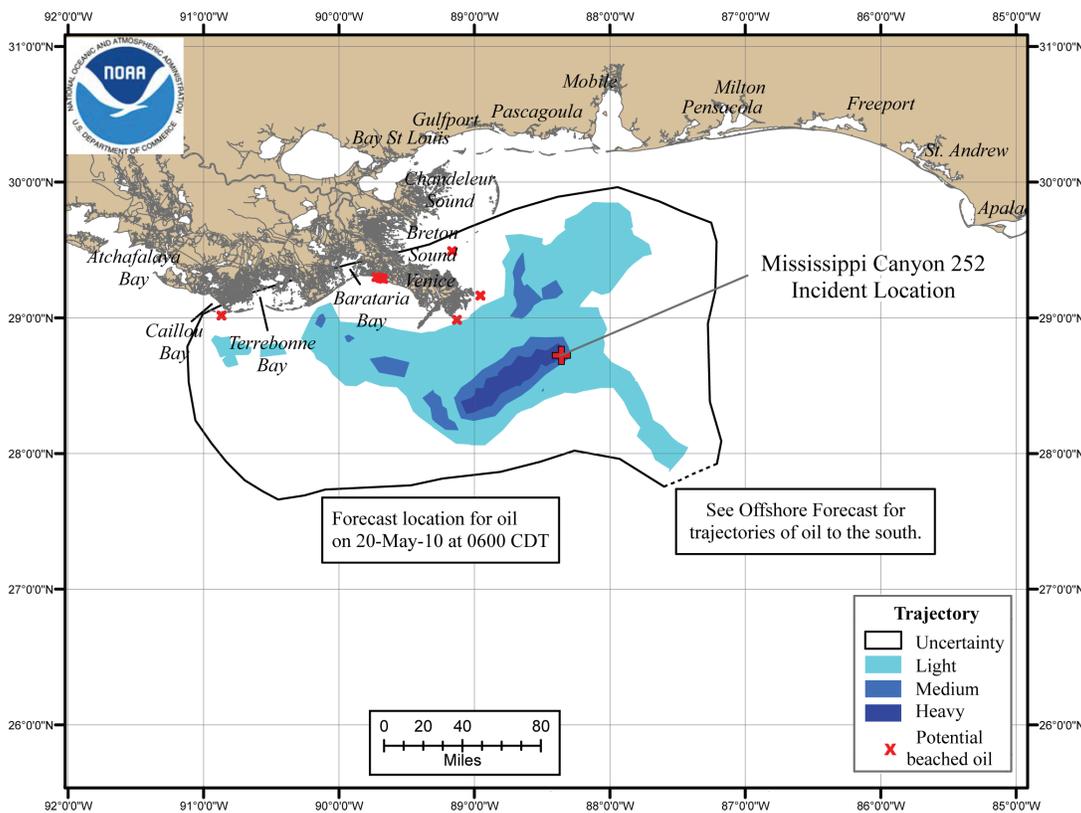


FIGURE 3. The General NOAA Operational Modeling Environment, or GNOME model, for May 20, 2010, predicted the possible trajectory of oil spilled by the DWH accident.²⁶ (adapted from NOAA, 2016)

NOAA'S OFFICE OF RESPONSE AND RESTORATION USES TWO PREDICTIVE MODELS:

General NOAA Operational Modeling Environment (GNOME)

- Predicts possible route oil may follow in or on a body of water.⁹
- Produces **spill trajectories** that support response operations.
- Uses satellite images and flight observations to set starting values for predictions (Figure 3).¹⁰

Automated Data Inquiry for Oil Spills (ADIOS)

- Predicts how different types of oil break down and change over time in the marine environment.
- Incorporates a database of more than one thousand types of crude oils and **refined products** so that it can quickly estimate the pollutant's expected behavior.
- Includes the changes of oil over time due to weathering.¹¹

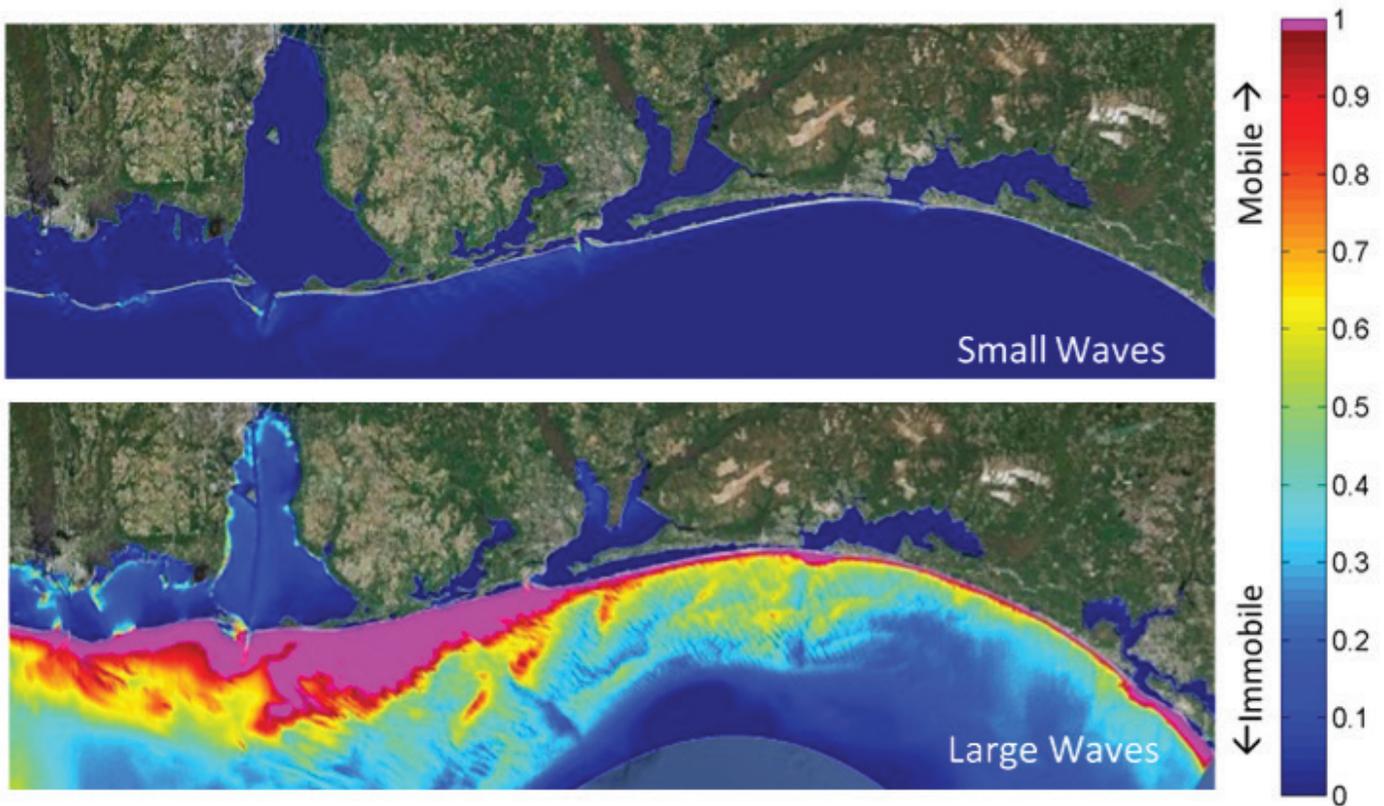
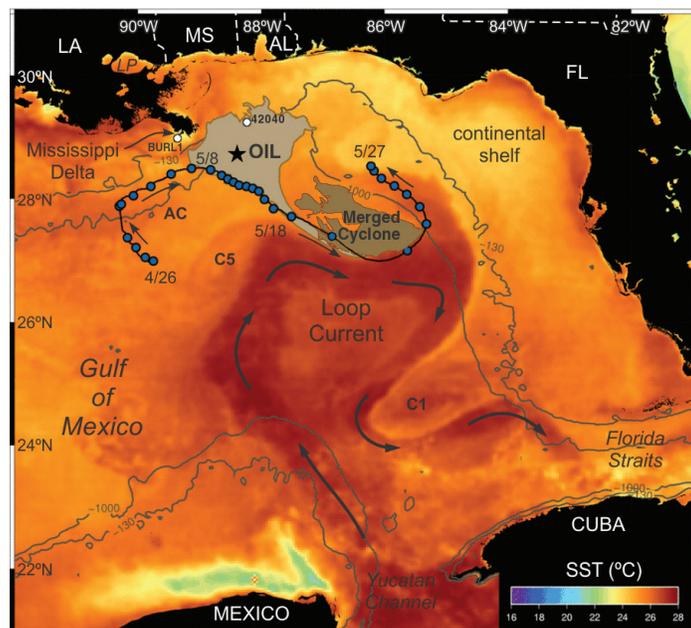


FIGURE 4. A computer model predicted the movement of surface residual balls (SRBs) during calm conditions (top) and storm conditions (bottom). Pink indicates SRBs are mobile; blue means they are immobile.²⁷ (Adapted from Plant, Long, Dalyander, Thompson, & Raabe, 2012)

ates that sank to the seafloor. Wave action caused these agglomerates to break up into smaller, more mobile pieces known as **surface residual balls (SRBs)**.¹⁵ Scientists use models to predict how SRBs move along the Alabama and western Florida coast (Figure 4). SRBs continue to show up on beaches years after the spill.¹⁶



OFFSHORE PREDICTIONS

The **Loop Current** is a warm current that flows northward between Cuba and the Yucatan Peninsula, moves into the Gulf of Mexico, and then exits through the Florida Straits. The Loop Current sheds rings of warm water, known as **eddies**, that separate from the main current.¹⁷ Keeping track of the Loop Current and its eddies became important during the DWH oil spill. If oil entered the Loop Current, it could have been transported as far away as the Florida Keys, Cuba, or the Bahamas.

In May 2010, a portion of oil entered a large eddy on the northern part of the Loop Current (Figure 5). NOAA began producing maps to provide daily updates of the location of the Loop Current and its major eddies. These maps also provided the location of floating oil relative to the Loop Current. The forecasts predicted the likelihood of oil being

FIGURE 5. One computer model produced this map showing the path of the Loop Current and associated eddy. Colors indicate sea surface temperature (SST). The oil slick is shown in gray. The black star represents the location of the oil well. White dots represent wind stations. Blue dots represent drifter positions from April 26 to May 27.¹⁸ (Reprinted from Walker et al., 2011)

sent to the Florida Straits and other parts of the Gulf.^{12,18} Oil never reached the Florida Keys because the eddy remained stationary for several months.^{12,13,18}

HOW GOOD WERE THE OIL SPILL MODELS?

It is important to keep in mind that no two models are alike. Each model has its own unique features, inputs, and properties that can make their predictions vary from one another. During DWH, a number of computer models existed for the Gulf of Mexico. Scientists tested some of these models to see how well they represented the path of the oil. Researchers from NOAA's Emergency Response Division used satellite images as guides to help them run four different models. Essentially, they made an outline of the oil slick from the images, filled it with particles that represented the oil, and then let the model predict the path of the oil (Figure 6). No one model consistently gave the best estimate. Because a spill impacts many different marine environments such as bays, estuaries, shallow, and deep areas, it is difficult to represent the water circulation in all regions. Multiple model trajectories are needed to get an understanding of the movement of the oil.⁷

OTHER BENEFICIAL USES FOR MODELS

These are examples of other ocean-related models in use today.

Search and Rescue

The U.S. Coast Guard uses the Search and Rescue Optimal Planning System (SAROPS) for search planning. It helps predict the location of persons or objects lost at sea.¹⁹

Sea-Level Rise, Hurricanes, and Storm Surge

Models have become increasingly important to help predict hazards to coastal communities. As the world's population continues to grow and move toward the coast, modeling the impacts of sea-level rise and **storm surge** are important for storm preparation and recovery.²⁰ Models have also been applied for hurricane forecasts as well. Additionally, scientists use **hindcasts** for the development of coastal risk assessments and the design of levee protection systems.²¹

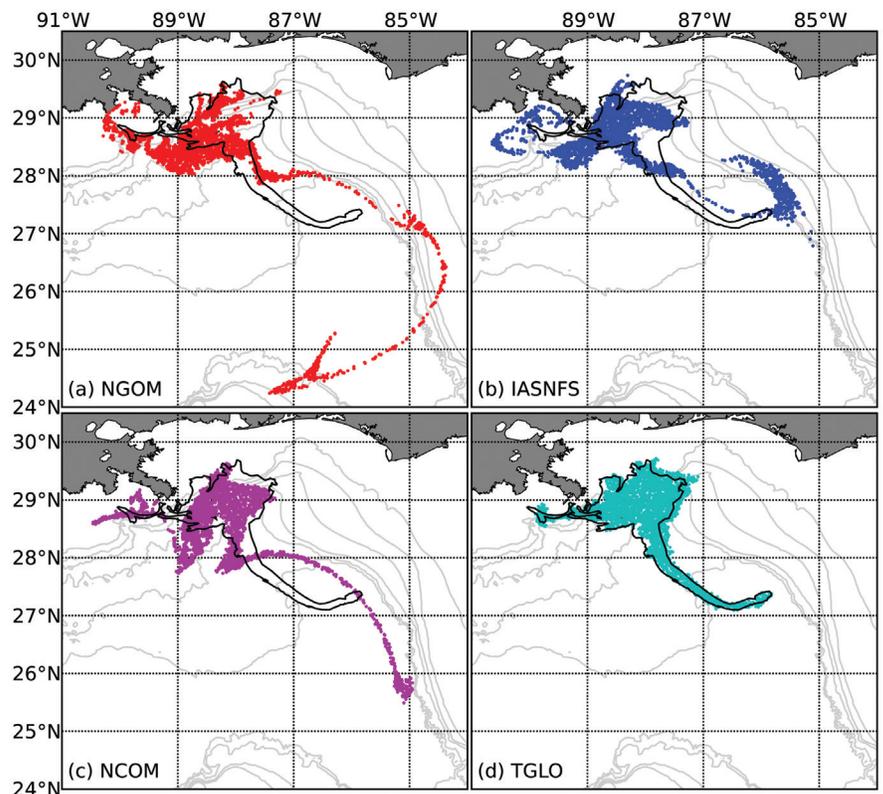


FIGURE 6. In these model comparisons, the black line is the outline of where oil was on May 17, obtained from satellite images. Using four different models, (a) National Ocean Survey Gulf of Mexico Model (NGOM), (b) Intra-Americas Sea Nowcast/Forecast System model (IASNFS), (c) Navy Coastal Ocean Model (NCOM), and (d) Texas General Land Office model (TGLO), researchers filled the outline with colored particles representing the oil, and then let each model predict where the oil would move next. Because models include different forces in their calculations, they predicted different paths for the oil. Responders used multiple predictions to track the active spill, because no one model consistently gave the best estimate.⁷ (Reprinted from Macfadyen, Watabayashi, Barker, & Bee-ge-Krause, 2011)

Navigation

NOAA's Operational Forecast System (OFS) shares existing conditions and makes short-term forecasts of water levels, salinity, temperature, and waves. The information is used by the maritime community for planning safe navigation through estuaries and bays.²²

Flushing of Coastal Waters

Circulation models estimate flushing and **residence time** within an **estuarine system**. They can calculate how long water particles and pollutants will remain in an area. They also predict the effects of channel deepening and widening on the movement of water in an estuary.²³ The models can describe how water moves between an estuary and the ocean through tidal inlets. This can help predict the water quality in an estuary.²⁴

The use of computer models can simulate real-world events, providing powerful predictive tools that can be applied to serve specific needs. Oceanographic models calculate the effects that winds and waves have on water circulation, increasing the understanding of how water and pollutants move within an area. The Gulf of Mexico Research Initiative continues to fund modeling studies as

well as observational studies that improve the accuracy of existing models. Emerging information can be found on GoMRI's website at <http://gulfresearchinitiative.org>. To access other oil-spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website: www.gulfseagrant.org/oilspill-outreach.

GLOSSARY

Biodegradation — The natural breakdown of a substance, especially by bacteria.

Dispersants — Chemicals that are used during oil spill response efforts to break up oil slicks and limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Eddies — Currents having a rotary or circular motion.

Estuarine system — A partially enclosed body of water where freshwater from rivers and streams mixes with salt water from the ocean; the areas of transition between the land and sea.

Hindcast — A model that is run for a time period in the past to understand what has previously occurred.

Loop Current — A warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf of Mexico, loops east and south before exiting to the east through the Florida Straits and joining the Gulf Stream to flow between Florida and the Bahamas.

Meteorological models — Models that describe the current and future behavior of the atmosphere (wind, temperature, precipitation) over large geographic areas.

Ocean circulation models — Models that describe the physical processes in the ocean.

Refined products — Products that have had unwanted chemicals (impurities) removed.

Residence time — Average amount of time a water parcel spends in an area.

Salinity — The average concentration of dissolved salts in a body of water.

Sand and oil agglomerates — A term that refers to oil mats, surface residual balls, and surface residual patties and does not distinguish them by size.

Skimming — Using special tools to remove oil from the sea's surface before it reaches the coastline.

Spill trajectories — Show how and where a spill will move in or on the water.

Storm surge — Rising water levels caused by high wind events such as hurricanes or winter storms.

Surface residual balls (SRBs) — Pieces of oil that washed up after the Deepwater Horizon oil spill and were mostly made up of pieces of sand, shell, and other materials loosely bound by oil.

Trajectory — The path followed by a parcel of water or pollutant, such as oil, in the water column or water surface.

Weather (-ed, -ing, -s) — A collection of physical, chemical, and microbial processes that can alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

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