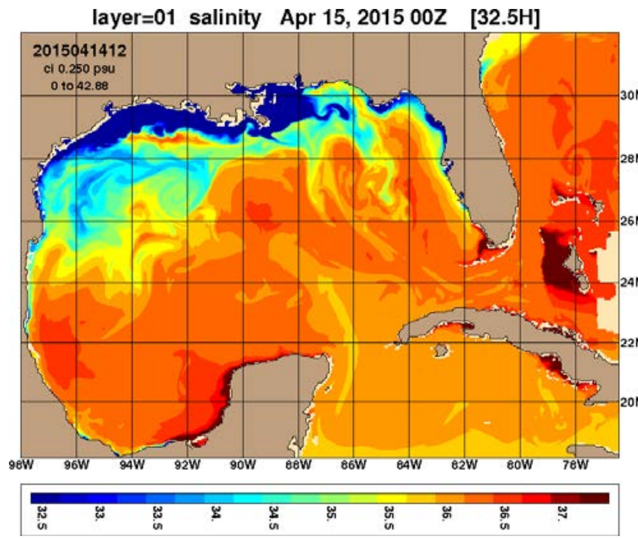
Computer Modeling

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.

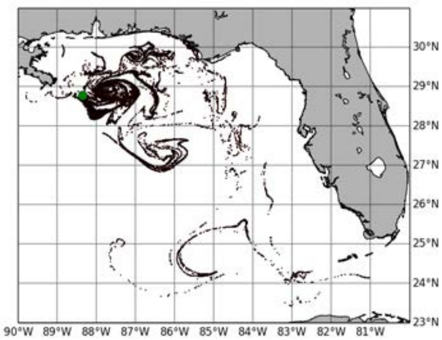
Deep-C modeling research

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.

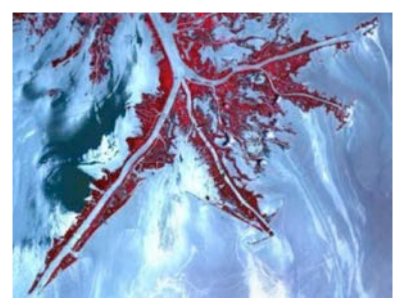


Deep-C Map Viewer

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.

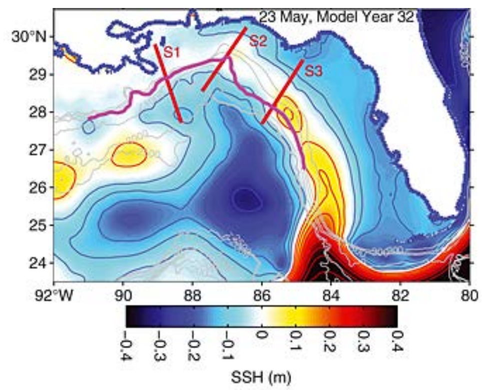
Wave data can improve forecasts that help search and rescue operations and oil spill response

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).*



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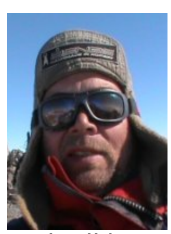

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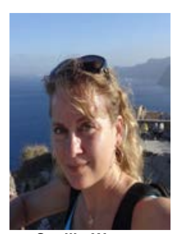

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What Did We Learn?

- 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

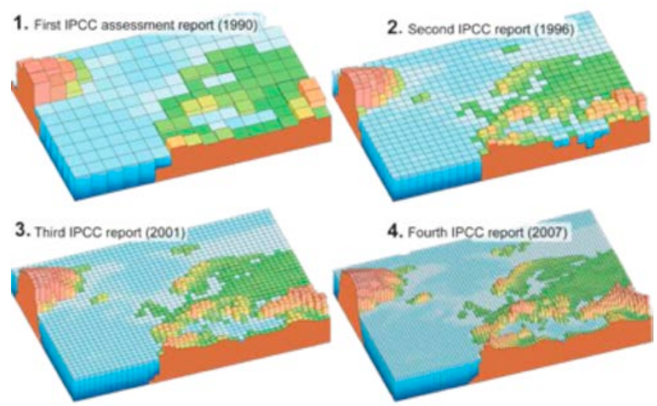
Time Required: One 50-minute class period

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.

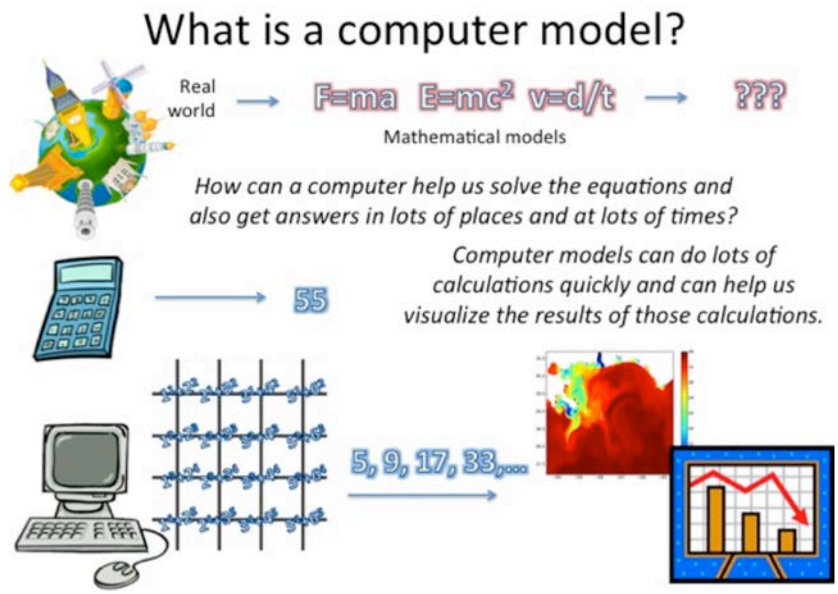
2. Algebra Race

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.

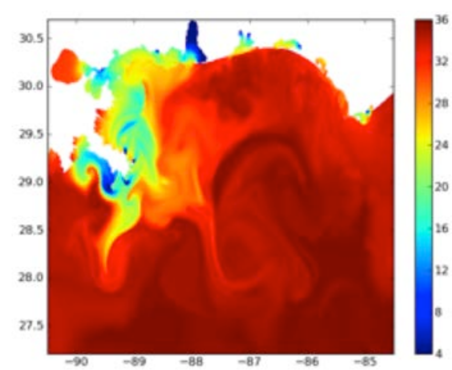
A computer is far faster than a calculator and can do lots of calculations very quickly.



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?"


Model output of the Mississippi River Plume

- 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.

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

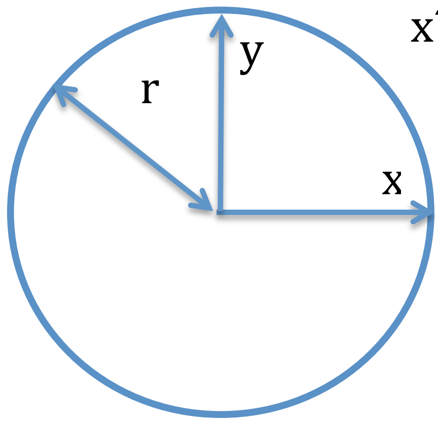
More lesson plans on computer modeling and stimulation
https://code.org/curriculum/science/files/CS_in_Science_Module_1.pdf

Contributing Expert

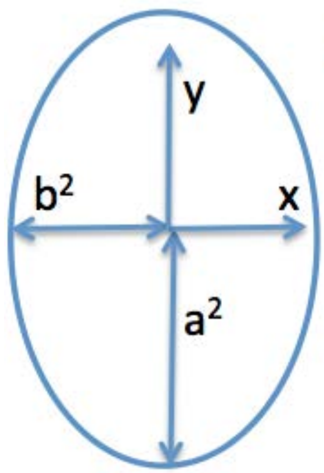
Dr. Hannah Hiester, Research Scientist at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

Templates

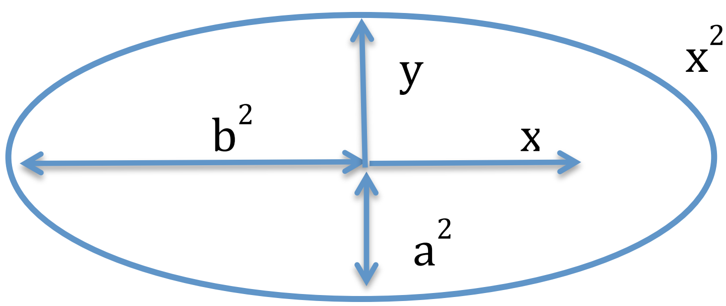
Draw a cloud in your box:



$$x^2+y^2=r^2$$



$$x^2/a^2 + y^2/b^2 = 1$$



$$x^2/a^2 + y^2/b^2 = 1$$

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

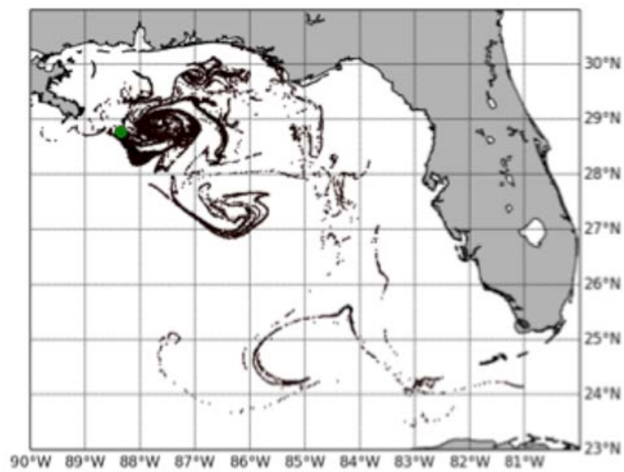
Time Required: One or two 50-minute class periods

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



A graphic of oil droplets at the surface on day 30 of a DwH blowout simulation.
http://stargazer.coaps.fsu.edu/dcom/index.html

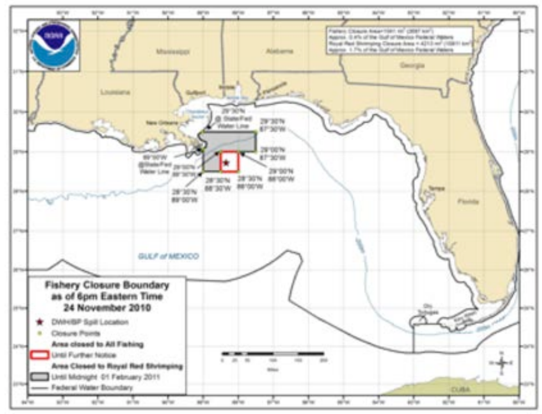
Models capture different physical phenomena that impact and change a system, and they respond dynamically to different inputs and physical characteristics. By calculating the effect of one component of the system on another, models allow us to understand how different parts of the system interact. This 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.**

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

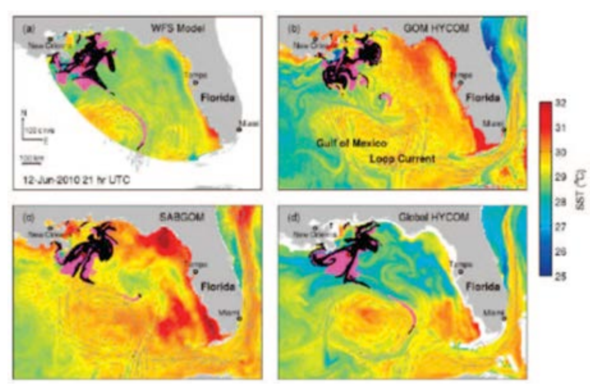
Materials: Lettered cards and paper

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

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

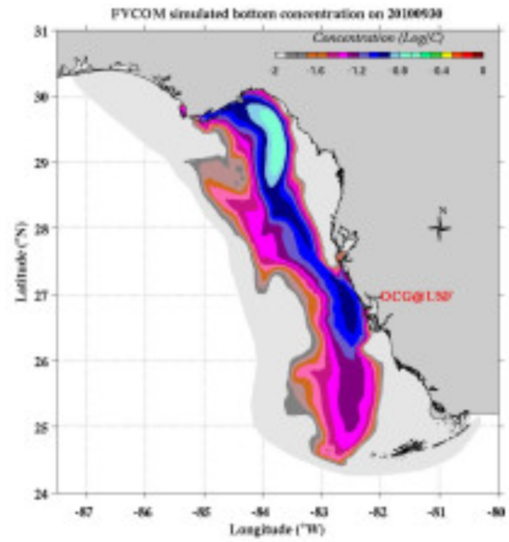
Dr. Hannah Hiester, Research Scientist at the Florida State University, Center for Ocean-Atmospheric Prediction Studies (COAPS)

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.

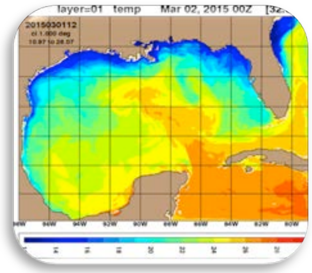
The team also noted that the design of sampling programs for future damage assessment would "benefit greatly from closer interactions between agency personnel charged with such activities and local scientists knowledgeable in the coastal ocean workings of the region."

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

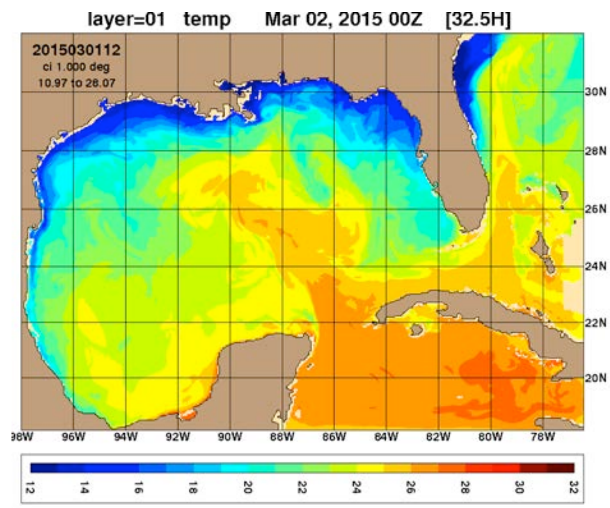
Background

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?

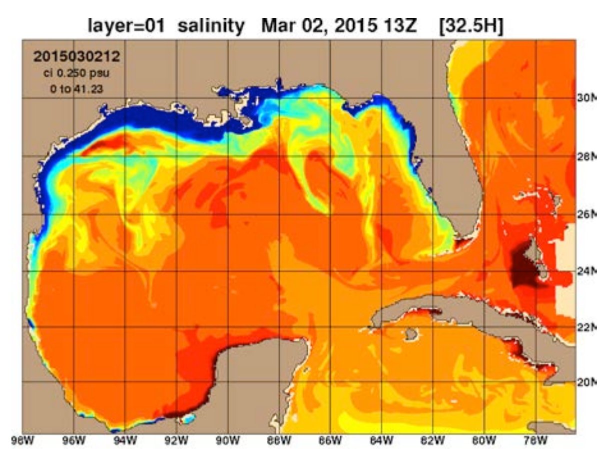
Some commonly used quantities are Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and Sea Surface Height (SSH). The values can come from computer models or satellites and the colors show a range of values from high to low. Different water masses can have different signatures, For example, 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



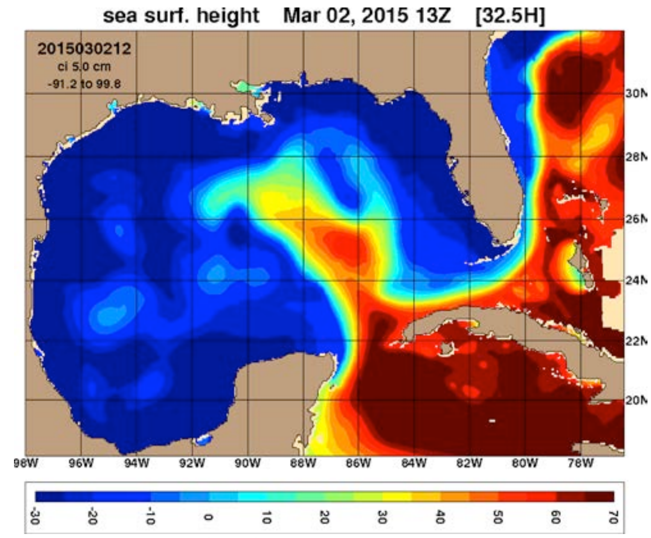
Sea Surface Temperature (SST) from HYCOM Model 1/25° Gulf of Mexico. Color Coding: Blue – cold; Red – warm. The scale in the image above is 12 to 32 degrees Celsius, which is 53.6 to 89.6 degrees Fahrenheit respectively.



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: 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.



Sea Surface Height (SSH) from HYCOM Model 1/25° Gulf of Mexico

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

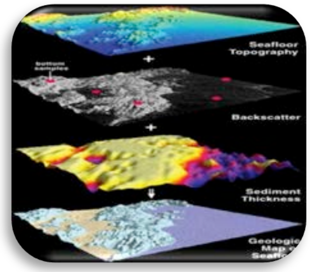
HYCOM Model 1/25° Gulf of Mexico http://www7320.nrlssc.navy.mil/hycomGOM2/glfmex.html

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.

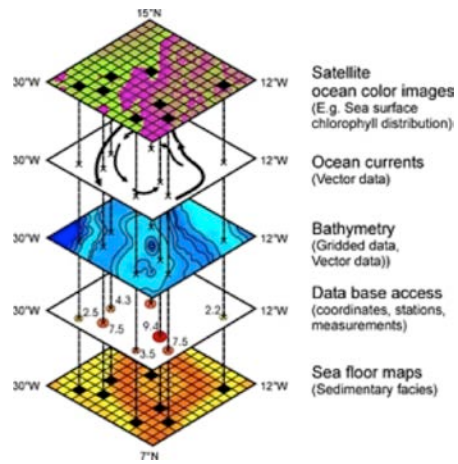
Standards: OLP 1, 6, 7: SC.912.L.17.16, SC.912.L.17.17, SC.912.N.3.5, SC.912.N.4.1

Time Required: One 50-minute class period

Keywords: GIS, mapping, data visualization

Materials: Computers, projector

Background



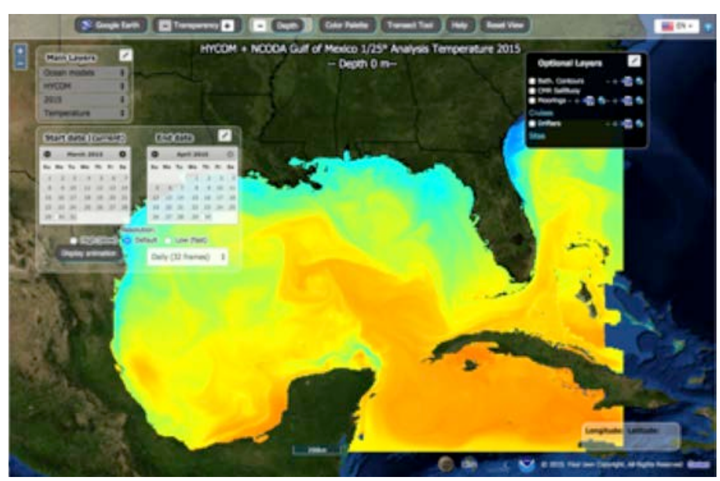
Information Layers by Alfred Wegener Institute

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