

# Virtual Oceanography

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## Studying river plumes using data visualization tools, ocean model data, and satellite imagery

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**C**ruise planning may seem like an ordinary task for oceanographers, but it actually involves logical and strategic thinking, collaboration, and multidisciplinary work. The *Challenger* expedition, led by Charles Wyville Thomson from 1872 to 1876, was the first to be fully dedicated to understanding our oceans (Rice et al. 1999) and was responsible for the discovery of over 4,000 new species.

In this activity, we encourage students to set their imaginations free by playing the role of the adventurous Thomson to prepare and virtually execute an oceanographic cruise plan and report their findings. We use the northeastern Gulf of Mexico (GoM), which includes the Mississippi River Bird-Foot Delta, as a sample location for preparing a cruise plan. We encourage teachers to explore other areas such as the Hudson, Congo, or Amazon rivers.

The Mississippi empties into the Gulf of Mexico, where it creates large river plumes that can be observed from satellites (Witman 2017). Plumes result from the interaction of water with different densities, in this case river (fresh) water and sea (salt) water from the Gulf. Fresh water is lower in density than salt water, so it settles above the sea water, forming a layer on the surface. In addition to density differences, river water often carries sediment, phytoplankton, and organic matter that can change the color of the water, creating dramatic color contrasts when it interacts with clearer ocean water.

For this activity, we provide satellite-derived chlorophyll-a imagery and model-derived salinity data. Phytoplankton use light-harvesting pigments such as chlorophyll-a to carry out photosynthesis and thrive. Chlorophyll-a alters the color of the ocean and allows scientists to observe these changes from space. The nutrients in river plumes promote phytoplankton growth; therefore, chlorophyll-a is usually higher within the river plume than in ocean waters. Additionally, river plumes bring fresh water, which has low salinity, from land to the ocean. The term *salinity* refers to the concentration of salts in the ocean. The salinity data from the model output will define the area of the river plume. Keep in mind that the model data is a prediction. Similar to a weather forecast, it contains a margin of error.

Therefore, it is possible to see a difference in the location of the plume as seen by the satellite-derived chlorophyll-a images (Figure 1a) and the salinity model output (Figure 1b).

Using the imagery and model data, students will work as a group or individually to:

1. Define the scientific objectives of a research cruise.
2. Learn about satellite and model ocean technology.
3. Create a virtual cruise track with measurement stations using ArcGIS Earth.
4. Answer scientific questions and create a cruise report.

The activity uses two main pedagogic techniques: active learning and technology integration. Bonwell and Eison (1991) suggest that students should engage in higher-order thinking tasks such as analysis, synthesis, and evaluation. Active learning, first introduced by Reginald Revans, encourages students to actively participate in the learning process instead of passively listening to the instructor (Pedler 2017). Active learning engages the student in self-directed learning through problem-based learning (Prince 2004) and allows the teacher to decide whether to have students complete the activity independently or divide the classroom into small groups. Active learning encourages successful integration of technology into the classroom (Ziegenfuss 2005). In this activity, we use technology to develop reasoning skills while preparing the cruise plan and report.

## The activity

The activity consists of preparing an oceanographic cruise plan to study the Mississippi River plume using ArcGIS Earth, a geographic information system (GIS) that can be used to discover and analyze mapped geographic information. ArcGIS Earth is a visualization software dedicated to educational use,

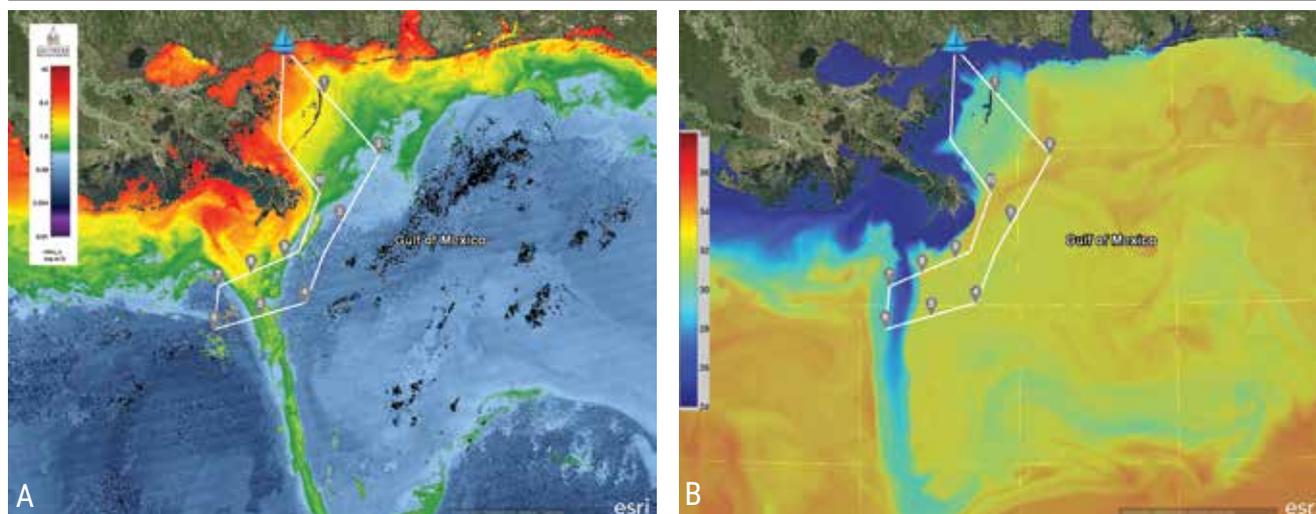
commonly used in college and high school classes. Students will need a computer with ArcGIS and a text editor. We have included an instructional video of the activity and an instruction sheet with step-by-step instructions on how to use ArcGIS Earth (see “On the web”). We also provide three chlorophyll-a images from the Visible Infrared Radiometer Suite (VIIRS) instrument onboard the Suomi satellite operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) and three corresponding salinity forecasts from the Navy Coastal Ocean Model (NCOM) from the U.S. Naval Research Laboratory (NRL) (see “On the web”). Each image or forecast has been converted to a geographic information system format (.kmz), which is readable by visualization tools. Students use these source files to prepare the cruise plan and answer scientific questions.

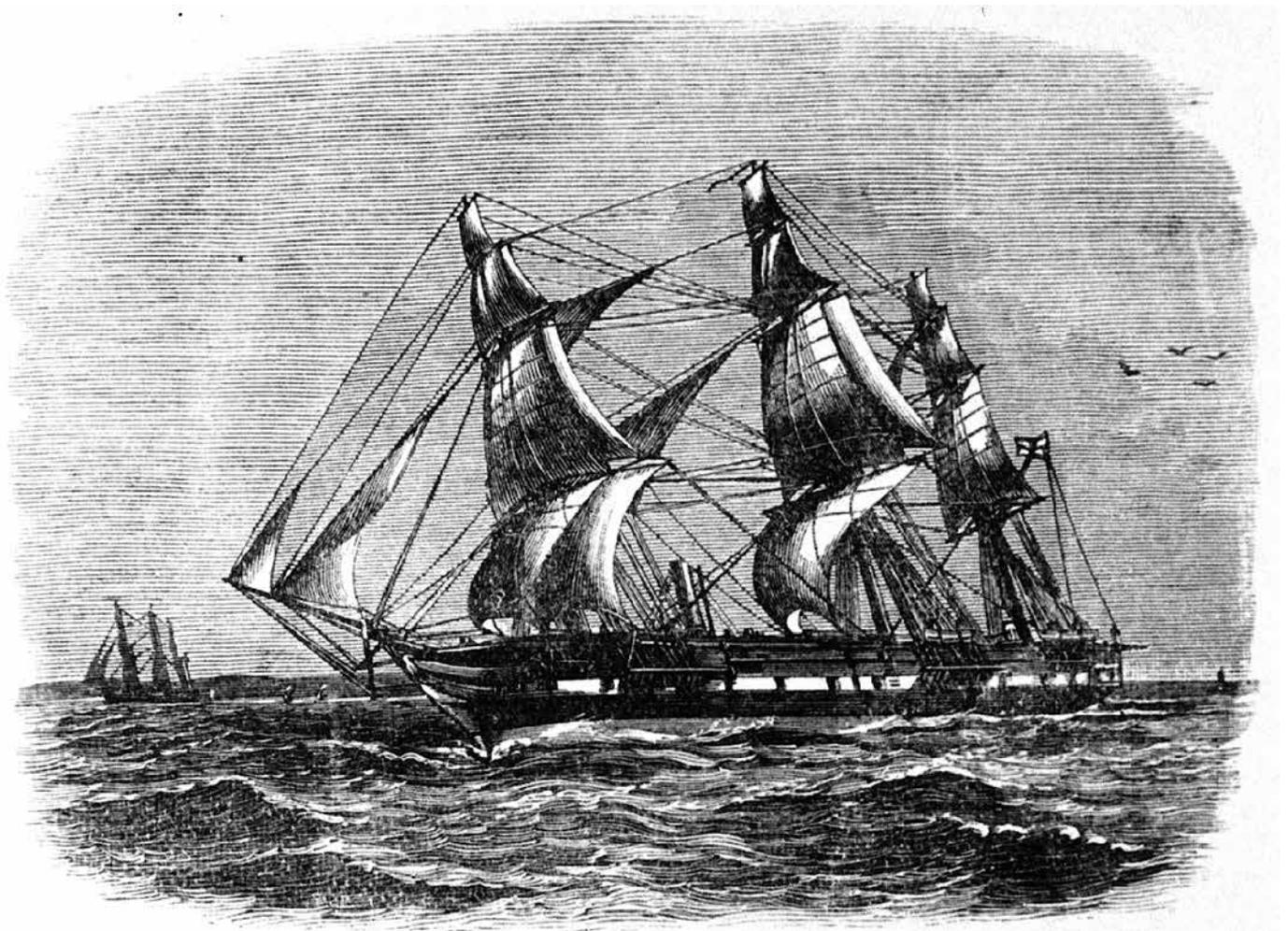
## Background information

This activity may be modified and transferred to other rivers around the world. However, focusing the activity on the GoM allows teachers to talk about important topics such as GoM hypoxia (“The dead zone”) or the *Deepwater Horizon* oil spill. McDonnell et al. (2010) provide an educational module that explains river plumes, focused especially on the Hudson River plume. It can be combined with our activity to better understand river plumes and their ecosystem relevance, providing background information for this activity. The ocean model NCOM is a numerical modeling system that simulates the physical dynamics of the GoM and produces forecast outputs of physical variables such as salinity and temperature (Martin et al. 2009). Ocean color images from VIIRS estimate chlorophyll-a concentration, an indicator of phytoplankton production.

FIGURE 1

**Difference in the location of the plume as seen by (a) satellite-derived chlorophyll-a images and (b) salinity model output.**





*HMS Challenger, 1874.*

### **Part 1: Define objectives and hypothesis of the oceanographic cruise**

The objective of the cruise is to study the Mississippi River plume, comparing the salinity and chlorophyll-a patterns inside and outside the plume. The amount of Chlorophyll-a is higher and salinity is lower inside the Mississippi River plume compared to the open ocean. The high level of chlorophyll-a inside the plume results from high levels of nutrients, not low salinity. This relationship between salinity and chlorophyll-a does not necessarily apply to the open ocean.

### **Part 2: Navigate in ArcGIS Earth and explore ocean circulation models**

Open ArcGIS Earth and show students the basic functions explained in the instructional video or instruction document. Open the NCOM salinity .kmz files. (See video for assistance.) There are files for three consecutive days, which can be animated (see Figure 2a–2c). Make sure you open the color bar. Mod-

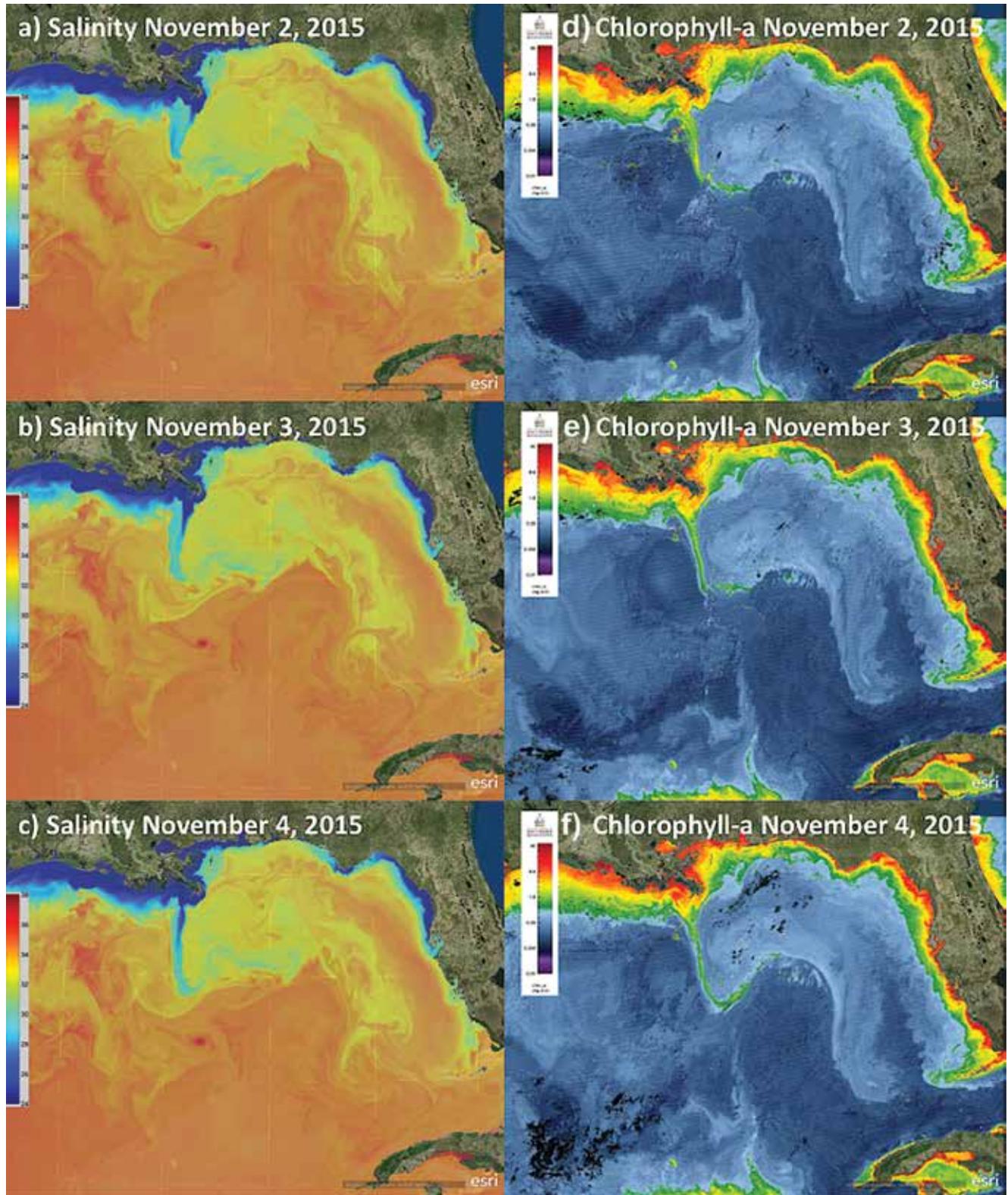
eled salinity may be considered a forecast used to plan the cruise three days ahead of time and satellite chlorophyll-a images may be used during the cruise as the most recent snapshot of reality.

### **Part 3: Create a cruise track**

Now that students have seen model salinity fields and identified the Mississippi River plume, allow them to create a cruise track starting at one of the main ports like Gulfport, the home of research vessel *Point Sur*, a major oceanographic research vessel conducting scientific studies in the GoM. Ship speed and travel distance are important considerations when creating the cruise track. The average transit speed of a research vessel is 9 knots (nautical miles/hour) between stations; however, the speed would be lower, ~5 knots, if they were towing a measurement instrument. Cruise time can be costly, so give the students a budget that allows them to have the vessel for only three days. That means they will have to measure their track carefully for an on-time return to port. They can also include sampling sta-

FIGURE 2

**Salinity and chlorophyll-a fields of the Mississippi River plume over three consecutive days.**





INIA SOTO

The research vessel *Point Sur*.

tions to collect chlorophyll-a and salinity. It takes approximately one hour to collect these data, so add an hour to ship travel time for each sampling station.

Ask the students to save an image of the ArcGIS Earth screen with the cruise track (Figure 1) and create a table with the coordinates of their stations. These coordinates will be used to create the cruise plan and report.

#### **Part 4: Address the hypothesis and create a cruise report**

Students use the chlorophyll-a images (Figures 2d–2f) to estimate chlorophyll-a at each station and evaluate the hypothesis. Chlorophyll-a .kmz files were provided for the same three consecutive days (see “On the web”). They estimate the salinity using the NCOM salinity model and compare salinity versus chlorophyll-a, create a plot, and calculate basic statistics (e.g., mean, minimum, and maximum) from all the stations. The step-by-step instructions document includes a link to a cruise report example (see “On the web”). Note that salinity here is a proxy for nutrient concentration so that students study the relationship between predicted salinity concentration from the model and measured chlorophyll-a from satellite imagery.

#### **Assessment**

At the end of the activity, students should be able to prepare a cruise plan that includes objectives and a formal scientific hypothesis. We provide a cruise report template in the instruction sheet. The use of satellite images allows students to execute the cruise virtually and write a full report that includes results, analysis, and conclusion. The activity reinforces understanding of scientific practices and allows teachers to include different oceanographic topics such as interaction between river plumes and the ocean, salinity gradients, phytoplankton abundance, and distribution.

At the beginning of the activity, a short questionnaire could be used as a baseline assessment. Some possible questions are:

- How do you think oceanographic cruises are planned?
- What technology do scientists use while planning their cruises?
- What factors must be considered when planning a scientific cruise?

This activity is flexible regarding formative or summative assessment. As a formative assessment, the students could

present a brief oral report of their findings and compare their results with other students, or they could write a blog to share their experiences during their virtual cruise. As a summative assessment, we suggest the creation of a cruise report that includes their analysis of the results and hypothesis. This allows assessing the student's skills in analysis and synthesis as well as critical thinking.

## Teacher feedback

Eighty-two environmental science students at Saint Thomas More Catholic High School in Lafayette, Louisiana, completed this lesson, and it was well-received by both the teacher and students. The teacher agreed that the activity improved students' understanding of marine science, created awareness of how scientists collect scientific data, and made them feel like scientists. The teacher mentioned that the activity "benefits students of math and science by providing real-world data obtained by technologies, which can be interpreted as to its meaning and impact on the environment. Simple, but useful math was used to determine the cruise path for students to plan a research cruise, which sampled the area of interest at enough relevant points, and be able to return to port in a set time frame in order to come in 'at budget' for the amount of ship time allotted." The teacher noted: "I found, for my needs, that customizing the lesson by adding to the product(s) the students created ensured that students did their own work." The teacher also suggested allowing additional time for students to become familiar with ArcGIS Earth and the study region. As students put it: "I liked seeing the salinity near shore in the water and how it compares to the salinity further out," "I liked using ArcGIS, creating my own path, and having the freedom to choose my own path," and "It was fun to find out how far you could go in two days."

## Conclusion

Active learning and technology integration engage students in real-life tasks performed by oceanographers and marine scientists. In this activity students independently plan an oceanographic cruise and virtually execute it. This encourages students to think strategically in preparing a cruise plan. Integrating ArcGIS with model products and satellite imagery invites students to use their imagination to prepare an oceanographic cruise. At the end of the activity, students will be familiar with scientific practices, oceanographic technology, and river plumes. The activity is appropriate for three different types of assessment: baseline, formative, and summative.

Teachers can use questionnaires at the beginning of the activity, oral presentation, and formal cruise reports for the different types of assessments. ■

## ON THE WEB

Chlorophyll-a images and salinity forecasts: [www.nsta.org/highschool/connections.aspx](http://www.nsta.org/highschool/connections.aspx)

Step-by-step Instruction Sheet and cruise plan template: [www.nsta.org/highschool/connections.aspx](http://www.nsta.org/highschool/connections.aspx)

Cruise report example: [www.nsta.org/highschool/connections.aspx](http://www.nsta.org/highschool/connections.aspx)

ArcGIS Earth: [www.esri.com/software/arcgis-earth](http://www.esri.com/software/arcgis-earth)

ArcGIS instructional video: <https://youtu.be/Gp34pjBbnlY>

KMZ files and instructional video can also be found at GRIIDC DOI: 10.7266/N75719N0

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## Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

### Standard

HS-ESS2 Earth's Systems

HS-ESS3 Earth and Human Activity

### Performance Expectations

- The chart below makes one set of connections between the instruction outlined in this article and the NGSS. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

**HS-ESS2-2.** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

**HS-ESS3-6.** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

### DIMENSIONS

### CLASSROOM CONNECTIONS

#### Science and Engineering Practices

##### Analyzing and Interpreting Data

Analyze data using tools, technologies, and/or models in order to make valid and reliable scientific claims or determine optimal design solutions.

Students use satellite imagery and models, linking them with a visualization mapping tool to design a research cruise and address scientific questions.

##### Using Mathematics and Computational Thinking

Simple computational simulations are created and used based on mathematical models of basic assumptions.

Students use real data to create empirical relationships and understand the dynamics in coastal waters.

#### Disciplinary Core Ideas

##### ESS2.A: Earth Materials and Systems

Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

Students consider the role of river plumes in the ocean and how the nutrients they add can alter the ecosystem and in extreme cases lead to low dissolved oxygen and harmful algal blooms.

##### ESS3.D: Global Climate Change

Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities

Students use satellite imagery and models to understand land-ocean interactions and how anthropogenic fertilizer use on land impacts the ocean by way of the river.

#### Crosscutting Concept

##### Stability and Change

Much of science deals with constructing explanations of how things change and how they remain stable.

Students develop hypotheses and draw conclusions using satellite data and models. They explore relationships between different ecosystems and independent variables.

## Connecting to the *Common Core State Standards* (NGAC and CCSSO 2010)

### ELA/Literacy

**SL.11-12.5** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.

**MP.2** Reason abstractly and quantitatively.