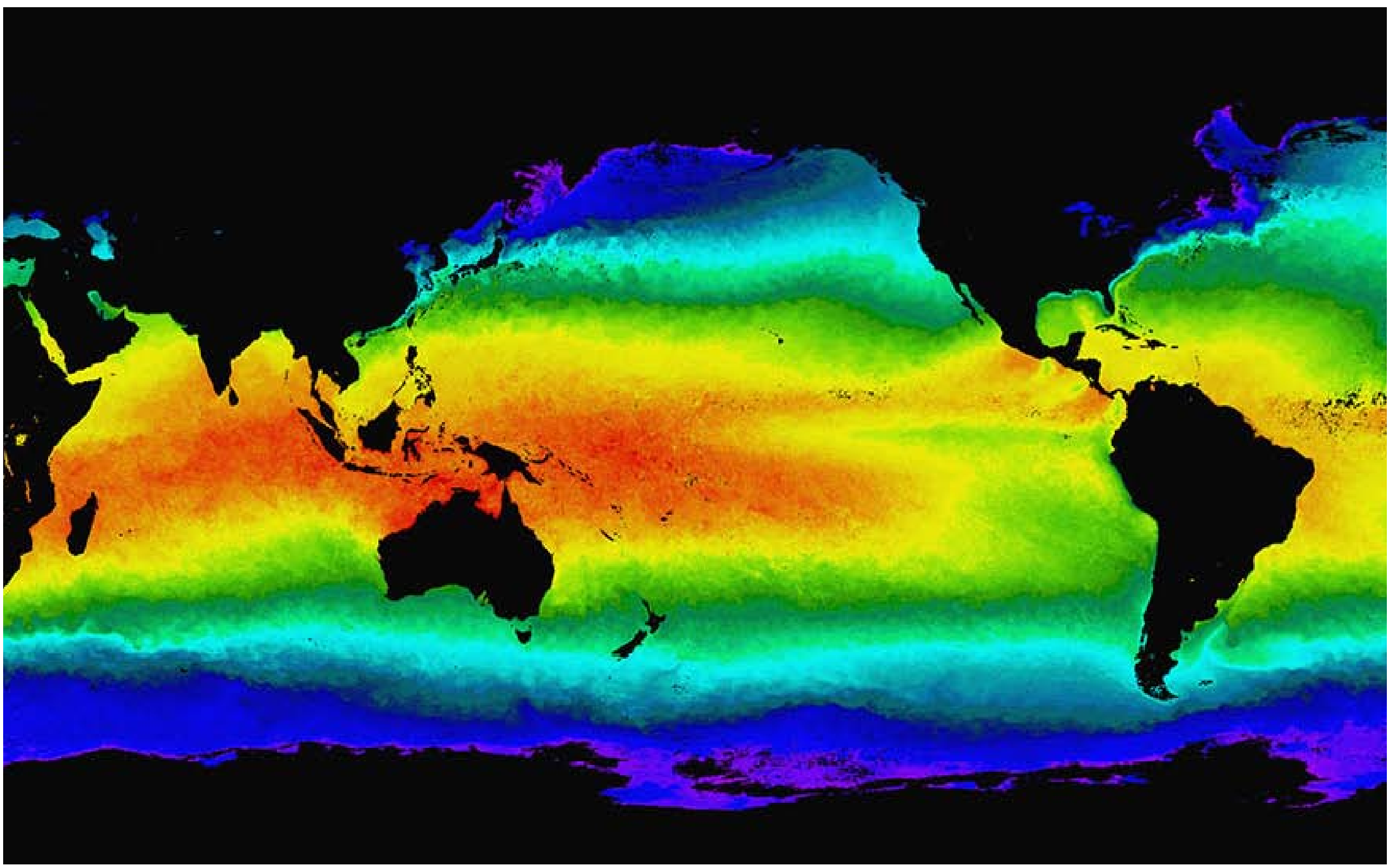
Global Ocean Warming

Table of Contents



Sea Surface Temperature, MODIS satellite data, NASA, GSFC

• To demonstrate an understanding of scientific models.

• To develop an understanding of models and how they illustrate ocean surface energy transfer and storage processes.

• To explore how energy transfers and seasonal changes at the ocean surface affect temperatures in the mixed and upper ocean layers.

• To identify motion patterns of ocean surface currents in the tropical Pacific.

Glossary: eddy, hurricane, turbulence, climate, weather, model, advection, latitude, longitude, energy flux, isothermal layer

Introduction: Earth's Weather Machine

The ocean plays a major role in our planet's weather machine. Water covers 73% of the planet's surface and absorbs a high percentage of solar energy. Wind and currents mix solar energy into the ocean depths and circulate surface water between the Equator and the Poles. Powered by the Sun and influenced by Earth's rotation, the unceasing flow and turbulence of circulating fluids on the thin outer skin of our planet affects temperature, clouds, precipitation, humidity and wind speed, resulting in our weather.

Consider the 2005 hurricane season, which riveted the nation's attention as cities along the Gulf of Mexico were swept away and lives changed forever. Scientists monitoring ocean heat and circulation in the Gulf during Hurricanes Katrina and Rita used data gathered from satellites and buoys to learn how these tropical storms can suddenly intensify. A major contributor to the intensification of these hurricanes may have been the Gulf of Mexico's "Loop Current". The Loop Current is a clockwise flow that passes through the Yucatan Channel between the Yucatan Peninsula and Cuba. It follows a U-shaped path northward into the Gulf and then curves southeastward to join the Florida Current. It is likely that hurricanes intensify when passing over eddies of warm water that spins off the Loop Current.

Learn how scientists study and predict climate and weather patterns when you use the data visualizers in the following investigation.

Image: http://earthobservatory.nasa.gov/Newsroom/BlueMarble/BlueMarble_2002.html

What do you know?

Before beginning this lesson is it helpful to learn how much you already know about the patterns of energy flow in the ocean. A simple survey has been created for you to assess your prior knowledge.

1. Click on the blue **Quiz** button below.
2. Take the quiz
3. Submit your responses online and they will be automatically scored.
4. Return to this guide and begin your exploration of ocean warming.

Scientific/Mathematical Models In Your Backyard

What, When and Why?

Models impact our lives everyday. They are developed to represent important features of a target system. Engineers might develop a model airplane to test a new wing or tail design they plan to use for a full size airplane. By studying, manipulating or practicing with a model, investigators can gain expertise and experience that they can apply to the target system. Practicing on models instead of with the target system can offer important practical advantages. It may save time, effort, money, and resources and reduce environmental impact. Investigators can test a wider range of possibilities than they can by using the target system. Since the models are not the real thing, investigators must make sure they understand and compensate for their models' limitations. A model provides an idea or vision that helps investigators simplify and study reality. The following bullets describe models we might use to help organize our lives.

- If you want to build a boat or building, you may begin by constructing a small-scale model, or drawing a virtual object on a computer.
- If you want to look stylish and follow trendsetters, you might look at pictures of fashion models and movie stars to learn how to update your wardrobe, lifestyle and appearance.
- If you earn money on your first job, you may make a budget (a mathematics model) to help you decide how you might spend your money.
- If you play a computer game, you are using a computer model to simulate worlds in which you can play unusual, important roles.

Using the research tools available to you, respond to the three questions below so that you may better understand the implication of using models to explain ocean heating and cooling.

1. What is a scientific model?

2. When are models used in science?

3. What are some assumptions you might make when building a model airplane? What basic parts should it have?

A Model In A Cup

A cup of hot water is a model that illustrates some facts about ocean water.

To understand the complexities of the ocean and how it heats, cools and interacts with the atmosphere, compare and contrast heat and energy transfer using a simple model—a cup of hot water. How is a cup of hot water similar to the ocean? How is it different?

For each of the following questions about a cup of water heated in a microwave oven, write a corresponding statement, in the box under "Ocean," that compares and contrasts this model to the ocean.

Question	Hot Water in a Cup	Ocean
How is the water heated?	Microwave radiation penetrates the water surface and heats the water on top and through all sides of the cup.	
Does the water circulate?	The less dense hot water rises up to the top and the more dense colder water sinks to the bottom where it is heated. These rising and sinking flows set up a natural circulation of the water that will heat it throughout.	
What happens to the heat in the water?	If the surrounding environment (the room) is cooler than the water, heat will conduct through the sides and bottom of the cup and energy will radiate outwards. The hottest water (least dense) will remain at the top and the coldest (most dense) will stay at the bottom of the cup. At the top of the cup, evaporating steam rises, transferring heat to the air.	
How does the temperature of the surroundings affect the rate of heat loss?	If we put the cup in the freezer, it will lose heat more rapidly.	
How does the water interact with the air?	If we blow air over the top of the cup, the moving air will drive away the energetic, evaporating water molecules and prevent them from remixing in the liquid. This speeds cooling. Blowing air over the top of the cup, or stirring the water in the cup, causes waves and turbulence that mixes the water and distributes heat more uniformly. This slows cooling.	

Weather Models

Additional models to better understand weather elements

In this next activity, you will find five weather-related models that we'll call targets. These targets are matched with a concrete, everyday object. Choose at least three targets and describe how they are similar to, and different from, their corresponding concrete objects. Write your answers in the table below.

Target	Concrete Object	Similar	Different
Wind	Breeze from an electric fan		
Rain	Spray from a lawn sprinkler		
Ocean Current	Moving walkway or baggage conveyor belt		
Sunlight	A 120W light bulb		
Clouds	White mist of water droplets produced by condensing steam from boiling water		

Note: The point of doing the last two exercises, using everyday items to better understand more complex concepts/processes, is to stimulate your thinking. In science, when you learn something new it is good to ask, “How is this similar to, or different from, something else I know?” Too often facts are learned in isolation and are not integrated with or connected to the real world.

Advection In The Ocean

Looking for patterns in movement of ocean surface water

The cup of water that we used to model the ocean surface was static. One could make the model more interesting by using a bathtub and employing a fan to generate surface waves and currents. Increasing the size of the model 10-100 times still does not capture the complexity and dynamic of the ocean currents that act as efficient conveyors for our terrestrial solar-powered heat engine.

Advection

Earth's oceans contain currents that move water across the globe. *Advection is the transfer of mass, heat, or other properties by the movement of the ocean water.* The dominant movement of the ocean is horizontal. We refer to this lateral motion as currents. Vertical movement of water is typically much slower than the horizontal movement.

Click the picture of Dr. Kelly to play a movie in which she describes advection in the Gulf Stream.

Transcript – Text
QuickTime – High Resolution / Low Resolution
Windows Media – *High Resolution* / *Low Resolution*

To better understand the dynamic nature of advection in the ocean you will manipulate the online Ocean Surface Current Visualized, a computer model created from OSCAR data.

Click Ocean Surface Current Visualizer (OSCAR) to explore the computer model. See what it contains; take note of the calibrations; and determine how it can be manipulated. When you have a fair idea of how it works, go to the next step.

Set the following variables to the following parameters.

Year – **1992**
Month – **October**
Parameter – **Speed**
Tropical Pacific Region – **North West**

After the values are set, click on the **Pop-Up-Map** button and use it to answer the following questions.

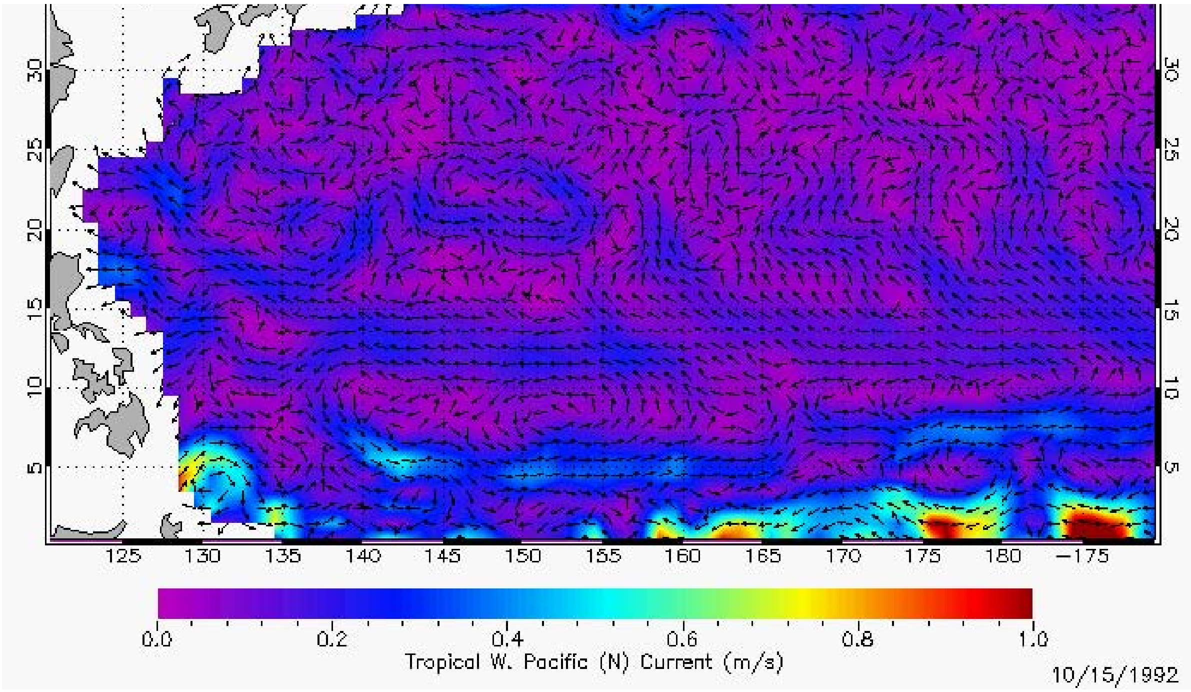
5. What latitude range does the map cover?

6. What longitude range does the map cover?

7. What do the colors on the map represent?

8. What do the arrows on the map represent?

9. How many degrees do the horizontal, dotted bands cover?



Beginning at the Equator, observe each 5^{o} latitude band across the entire map above. (It may help to take two pieces of paper and section off each individual band as you examine it.) You will determine the variables: dominant speed and dominant current direction for each band.

- To determine the dominant speed, observe the entire band and decide what color makes up the majority of the band. Then, using the color key below the map, determine the speed of the current and record the speed in the table below. Repeat this step for each of the latitude bands. Note: If there are many colors in the band, it is acceptable to conclude that the dominant speed varies.

- To determine the dominant direction of the current, observe each band again and examine the direction of the arrows. What direction are most arrows pointing—east or west?

Record your results in the data table below. Note: If you are unable to find that a majority of arrows point one direction or another, it is acceptable to conclude that the dominant current direction varies.

Data Collected from the Tropical Surface Current Computer Model		
Latitude Bands	**Dominant Speed (meter/sec)**	**Dominant Current Direction**
0–5 N		
5–10 N		
10–15 N		
15–20 N		
20–25 N		
25–30 N		
30–35 N		

10. Most people walk at a speed of about 1 meter/sec. Using the data you just collected, would you describe the ocean surface currents as slower or faster than a person walking?

currents, at what latitude would you start to go eastward (assuming currents do not change with time)?

12. At what latitude would you start to go westward?

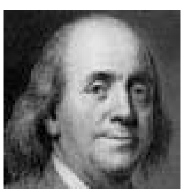
13. Estimate how many days it would take to cross the Pacific Ocean (about 13 million meters) floating along on the surface currents?

The ocean surface shows large-scale patterns of surface flow. The speed and direction of the flow is of interest to scientists. Currents at the Equator in the tropical Pacific (as well as in the Atlantic and Indian Oceans) show patterns in current speed and direction.

The ocean surface is in motion and the simple water-in-a-cup model is too limited to include larger scale ocean features like advection.

Energy Flow and Sea Surface Temperatures

Temperature is a measure of the energy content of the water.



One of the measurements made by early sea travelers, including Benjamin Franklin, is the surface temperature of the ocean water. Significant changes in surface water temperature could indicate warm western boundary currents that could speed up a journey or cold, nutrient-rich waters upwelling from the depths that could support varieties of marine life. Today, patterns of sea surface temperatures help scientists identify ocean surface currents and track energy fluxes (rate of energy exchange.) These fluxes may relate to regional weather or short-term climate change.

The surface of the ocean is dynamic and continuously exchanges energy with the environment through the following processes:

• Absorption of Electromagnetic Radiation from the Sun: This energy varies with the season and depends on cloud cover and the albedo (reflectivity) of the ocean's surface. The ocean's albedo depends on various factors including wind speed and chlorophyll concentration of the seawater.

• Emission of Infrared Radiation: Water emits electromagnetic radiation that depends strongly on its Kelvin temperature. This is affected by the emissivity of seawater and by the cloud cover.

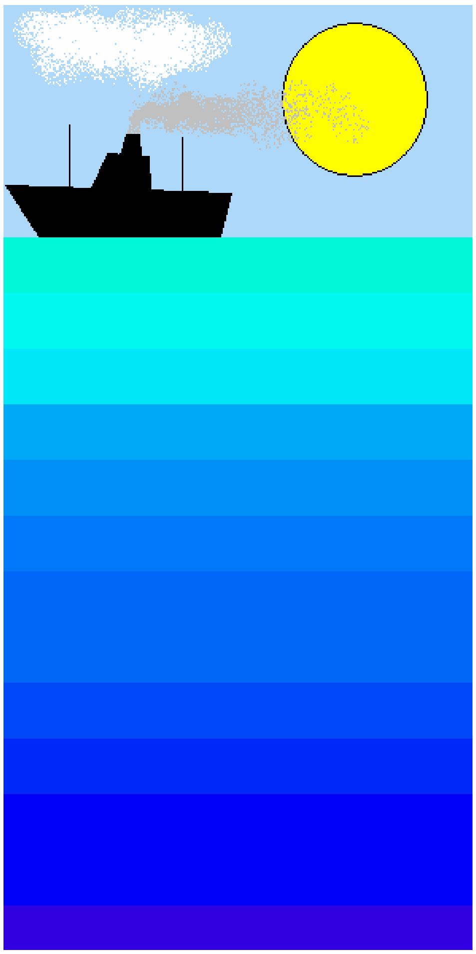
• Sensible Heat Transfer: This is the energy that air and the water exchange through their contact at the air-ocean boundary. This depends on wind speed as well as the air-sea temperature difference.

• Latent Heat Transfer: The ocean loses energy when some of its water evaporates and becomes water vapor in the atmosphere. The amount of energy lost depends on wind speed, and the humidity of the air.

The Energy Flow Model
How does the ocean store energy over time?

In this investigation, you will explore the energy flow at the ocean's surface using a simple computer model, The Energy Flow model, to track energy exchanges. Using this model will help you develop a better understanding of how the ocean's surface responds to solar heating and how the ocean stores energy over time.

You will need to know the following parameters to understand energy flow at the ocean's surface.



Parameter	Relevance
Solar Energy (SE)	Energy emitted from the Sun
Heat Transfer (HT)	Energy transfers happen between the sea and the air by evaporation, sensible heat and long-wave radiation. A cool atmosphere absorbs heat from a warm ocean and vice-versa. Heat transfer determines how fast the ocean surface loses or gains heat energy through the surface.
Water Transparency (WT)	Indicates the depth that sunlight energy penetrates below the surface of the water.
Wind Speed (WS)	Wind causes turbulence that mixes water in the surface layers.
Water Diffusion (WD)	Water undergoes diffusion (spread of water molecules) and conduction (energy transfer between water molecules) that tend to equalize temperatures in the layers.
Air Temperature (AT)	Air temperature above the ocean's surface determines the temperature threshold that affects whether heat transfers from ocean to atmosphere or vice-versa.

To explore the energy flow at the ocean's surface and track changes, you will complete four trials. In each trial, you will alter four parameters in the Energy Flow model and determine their impacts on temperatures and the isothermal layer (i.e., a vertical column of water that has a constant temperature with depth).

The **Energy Flow model** represents water at the surface of the ocean as columns of color-coded layers that are each 10 meters thick. The colors represent the water temperature (red = warm, blue = cold). The model assumes that the ocean water is chemically homogeneous (i.e., has the same salinity throughout). In this case, temperature will determine the ordering of layers–warm water (low density) at the top, cold (high density) at the bottom. You will use this to study the effect of solar energy (SE), heat transfer (HT), water transparency (WT), and seasons of the year on temperatures in the water column. As you manipulate the values of the four parameters, you will observe the surface temperature, the average water temperature and the depth of the constant temperature (isothermal or mixed) layer.

Note: The temperature values marked with an asterisk (*) are within 0.5°C of the top layer temperature and are considered to be within the isothermal layer.

Before you begin Trials 1 - 4, make a prediction about how each parameter affects temperatures and the isothermal layer. Enter your predictions in the chart below then go to the exercise in which you will manipulate the parameters of the model. After you complete each trial, you will be prompted to return to this chart and determine if your predictions were correct.

Exploring Parameters That Affect Energy Flow At the Ocean Surface			
Trial	**Parameter**	**Prediction**	**Conclusion**
1	Solar Energy (SE)		
2	Heat Transfer (HT)		
3	Water Transparency (WT)		
4	Season of the Year (Cycle)		

Trial 1: Solar Energy (SE)

In the first trial, you will explore the impact of changes in ocean energy as the **Solar Energy** parameter is manipulated.

Step 1: Note the values for parameters other than solar energy listed below. You will manipulate the model to show the following settings. *Important: Once set, the values for these parameters will remain constant during trial 1.*

Trial 1 - Constant Settings					
HT	**WT**	**WN**	**ND**	**AT**	**IST**
MEDIUM	MEDIUM	OFF	OFF	OFF	14

Step 2: Connect to the Energy Flow Model and set the variables as indicated above.

Step 3: Use the model to manipulate the **Solar Energy** parameter to **Low** then click the START button and read the *Top Layer Temperature* and the *Average Temperature*. Record these temperatures in the table below. Repeat this step two more times changing the SE value to **Medium** then, **High**.

Step 4: Click the Run Model button (This button runs the model for a fixed time interval.) until the Average Temperature does not change much. Note the values for *Top Layer Temperature, Average Temperature, and Isothermal Layer Depth* and record them below.

Trial 1 - Solar Energy (SE)					
	Initial (Start Button)		**Final (Step Button)**		
Solar Energy Values	Top Layer Temp	Average Temp	Top Layer Temp	Average Temp	Isothermal Layer Depth (m)
LOW					
MEDIUM					
HIGH					

Step 5: Analyze the data you collected in Trial 1 and determine if your prediction for solar energy was accurate. Record your conclusion(s) in the **Exploring Parameters That Affect Energy Flow At the Ocean Surface** then, proceed to Trial 2.

Trial 2: Heat Transfer (HT)

In this trial, you will manipulate the **Heat Transfer** parameter.

Step 1: Note the values for parameters other than Heat Transfer listed below. You will manipulate the model to show the following settings. *Important: Once set, the values for these parameters will remain constant during Trial 2.*

Trial 2 - Constant Settings					
SE	**WT**	**WN**	**ND**	**AT**	**IST**
MEDIUM	MEDIUM	OFF	OFF	OFF	14

Step 2: Connect to the Energy Flow model and set the parameters as indicated above.

Step 3: Use the model to manipulate the **Heat Transfer** parameter to **Low**. Then click the Start button and read the *Top Layer Temperature and the Average Temperature*. Record these temperatures in the table below. Repeat the step two more times setting the HT to **Medium**, then **High**.

Step 4: Click the Run Model button (This button runs the model for a fixed time interval.) until the Average Temperature does not change much. Note the values for *Top Layer Temperature, Average Temperature, and Isothermal Layer Depth* and record them below.

Trial 2 - Heat Transfer (HT)					
	Initial (Start Button)		**Final (Step Button)**		
Heat Transfer Values	Top Layer Temp	Average Temp	Top Layer Temp	Average Temp	Isothermal Layer Depth (m)
LOW					
MEDIUM					
HIGH					

Step 5: Analyze the data you collected in Trial 2 and determine if your prediction for Heat Transfer was accurate. Record your conclusion(s) in the **Exploring Parameters That Affect Energy Flow At the Ocean Surface** then, proceed to Trial 3.

Trial 3: Water Transparency (WT)

In this trial, you will manipulate the **Water Transparency** parameter.

Step 1: Note the values for parameters other than Water Transparency listed below. You will manipulate the model to show the following settings. *Important: Once set, the values for these parameters will remain constant during Trial 3.*

Trial 3 - Constant Settings					
SE	**HT**	**WN**	**ND**	**AT**	**IST**
MEDIUM	MEDIUM	OFF	OFF	OFF	14

Step 2: Connect to the Energy Flow model and set the parameters indicated above.

Step 3: Use the model to manipulate the **Water Transparency** parameter to **Low**. Then click the Start button and read the *Top Layer Temperature and the Average Temperature.* Record these temperatures in the table below. Repeat the step two more times to **Medium**, then **High**.

Step 4: Click the Run Model button (This button runs the model for a fixed time interval.) until the Average Temperature does not change much. Note the values for *Top Layer Temperature, Average Temperature, and Isothermal Layer Depth* and record them below.

Trial 3 - Water Transparency (WT)					
	Initial (Start Button)		**Final (Step Button)**		
Water Transparency Values	**Top Layer Temp**	**Average Temp**	**Top Layer Temp**	**Average Temp**	**Isothermal Layer Depth (m)**
LOW					
MEDIUM					
HIGH					

Step 5: Analyze the data you collected in Trial 3 and determine if your prediction for Water Transparency was accurate. Record your conclusion(s) in **Exploring Parameters That Affect Energy Flow At the Ocean Surface** then, proceed to Trial 4.

Trial 4: Season of The Year (Cycle)

In this trial, you will manipulate the **Season of the Year** parameter.

Step 1: Note the values for parameters other than **Season of the Year** listed below. You will manipulate the model to show the following settings.

Trial 4 - Constant Settings					
HT	**WT**	**WN**	**ND**	**AT**	**IST**
MEDIUM	MEDIUM	OFF	OFF	OFF	14

Step 2: Next, connect to the Energy Flow model and set the parameters as indicated above.

Step 3: Next, click the **Cycle** button then observe the data printed out in the Data Logger box under the model. Record the data in the table below.

Trial 4 - Season of the Year (Cycle)				
Season of the Year	**Average Temperature in Data Logger**		**Isothermal Layer Depth in Data Logger**	
	Minimum Average Temperature	Maximum Average Temperature	Minimum Isothermal Layer Depth	Maximum Isothermal Layer Depth
Winter				
Spring				
Summer				
Fall				

Step 5: Analyze the data you collected in Trial 4 and determine if your prediction for Season of the Year was accurate. Record your conclusion(s) in the Exploring Parameters That Affect Energy Flow At the Ocean Surface.

Energy Exchange

The pattern of temperatures near the ocean surface determines the energy that the ocean has available to exchange with the atmosphere. You have used a computer model to test your hypotheses about how some simple processes can affect surface layer water temperatures.

Create additional trials by manipulating the three parameters in the model not used in the four trials above, including:

- Wind Speed (WS),
- Water Diffusion (WD), and
- Air Temperature (AT).

Follow the same steps described in each trial of this lesson.

Matrix for Grading Lesson 4

Performance List	**Points**	**Student Evaluation**	**Teacher Evaluation**
Shows evidence of understanding models and their uses to explain scientific concepts and processes.			
Proficiently manipulates a computer model to explore near real-time data collected from satellites.			
Form predictions and follows through to determine accuracy of prediction.			
Collects data from computer models accurately.			
Analyses of data are accurate.			
Total Points			