AMERICAN METEOROLOGICAL SOCIETY

The Maury Project

Measuring Sea Level from Space

TEACHER'S GUIDE

The Maury Project

This guide is one of a series produced by The Maury Project, an initiative of the American Meteorological Society and the United States Naval Academy. The Maury Project has created and trained a network of selected master teachers who provide peer training sessions in precollege physical oceanographic education. To support these teachers in their teacher training, The Maury Project develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Forward

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

If we except the tides, and ... those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea water at one place and sea water at another; for wherever there is such a difference, whether it be owing to difference of temperature or to difference of saltiness, etc., it is a difference that disturbs equilibrium, and currents are the consequence.

Matthew Fontaine Maury
from The Physical Geography of the Sea. 1855.

Introduction: Measuring Sea Level from Space

Observations of sea level and sea level change over time provide unique information about the ocean and its dynamic interaction with the atmosphere. Before ocean sensing instruments were launched aboard satellites, ocean conditions were primarily observed by costly and time consuming ship-based surveys. To investigate ocean features, a few observations often had to be averaged over thousands of kilometers and several decades. Observations made by new instruments aboard Earth-orbiting satellites have dramatically improved scientists' ability to map ocean features, including sea level.

Positioned on a polar-orbiting satellite, a radar altimeter provides a measure of the apparent distance to the sea surface based on the return time of a microwave beam the instrument directs downward. The latest satellite altimeters make it possible for oceanographers to determine the height of the ocean surface to an accuracy of a few centimeters. Determination of the height of the sea surface takes into consideration different effects including those arising from the satellite's orbit, atmospheric effects on the radar signal, and tides. Variations in sea surface elevation are then compared to a mathematical model of the Earth's shape. This model, flattened at the poles and bulging at the equator due to Earth's rotation, is called the reference ellipsoid, and it is used as a benchmark to describe relative heights of the actual ocean surface.

Fluctuations of sea surface height are governed by numerous factors, with changes in local gravitational attraction being one of the most influential. Ocean water flows horizontally toward areas of greater gravitational attraction, piling up and increasing sea surface height, and away from areas of lesser gravitational attraction, decreasing sea surface height. The upper portion of the solid Earth is not uniformly dense or level. Density differences within Earth's interior can cause sea surface height differences as great as about 200 meters, the height of a 60-story building. Sea level lowers about 4 meters for every 1,000 meter increase in ocean depth, owing to local gravitational effects of the Earth's crust on the overlying ocean water. Ocean bottom features such as ridges and trenches can cause variations in sea height as great as tens of meters.

The satellite radar altimeter has proven to be a versatile and powerful tool for remote sensing of the ocean. Analysis of satellite altimeter derived sea-surface elevations provides the most complete data set on the topography of the ocean bottom. Physical oceanographers also use satellite altimetry to measure changes to the height of the ocean surface due to wind and density differences. This enables them to calculate the patterns of surface currents from observed sea surface slopes. Altimeter data are also being used to determine wave heights, estimate surface wind speed, and track surface water masses including the movement of warm surface water related to an El Niño event.

Basic Understandings

Remote Sensing

1. Observations made by instruments on Earth-orbiting satellites in conjunction with ship observations, have dramatically improved scientists' ability to map ocean features.

2. Positioned aboard a polar orbiting satellite, a radar altimeter provides a measure of the apparent distance to the sea surface based on the round trip travel time of a microwave beam it directs downward.

3. The latest satellite altimeters make it possible for oceanographers to determine the height of the ocean surface to an accuracy of a few centimeters.

Satellite Radar Altimeters

1. A radar altimeter transmits microwaves down through the atmosphere at the speed of light.

2. When the transmitted pulse strikes the sea surface, part of the signal is reflected back to the radar aboard the satellite.

3. The time between the transmission of the original pulse and the receipt of the reflected signal, and the known speed of the signal allows the determination of the distance between the satellite and the ocean surface.

4. The calculated distance is corrected for various effects including those arising from the satellite's orbit, atmospheric properties, and tides.

5. Variations in sea surface elevation are then compared to a mathematical model of Earth's shape, called the reference ellipsoid, to describe relative heights of the ocean surface.

Variations in Sea Surface Height

1. Variations in sea surface height are governed by numerous factors, with changes in local gravitational attraction being one of the most influential.

2. The local gravitational attraction between the solid Earth and its overlying water is determined by both distance and the mass of crustal rock. The greater the mass, the greater is the attraction, while the greater the distance, the smaller is the attraction.

3. Seawater moves horizontally toward areas of stronger gravitational attraction, piling up and increasing sea height. Seawater moves away from areas of weaker gravitational attraction, decreasing sea height.

4. The upper portion of the solid Earth is not composed of materials with the same density. Density variations within Earth's interior can result in sea surface height changes from place to place as great as about 200 meters.

5. The height of the sea surface rises about 4 meters for every decrease in ocean depth of 1,000 meters, owing to local gravitational effects on the ocean surface. Conversely, the sea surface drops about 4 meters with each 1,000 meter increase in ocean depth.

6. Ocean bottom features such as ridges and trenches cause variations in sea level as great as tens of meters.

Applications

1. Precise measurement of sea level from space by satellite altimetry serves as a benchmark for monitoring sea level changes over time and distance.

2. Altimeter data may help determine if sea level changes in response to changes in global temperatures. If global warming is taking place, is sea level rising?

3. Analysis of satellite altimeter-derived sea surface elevations provides the most complete, although indirect, data on the topography of the ocean bottom.

4. Physical oceanographers use satellite altimetry to measure changes in the height of the ocean surface produced by wind and water density differences. This enables them to calculate the patterns of surface currents from the sloping of observed sea surfaces.

5. Altimeter data are also being used to determine wave heights, estimate surface wind speed, and track surface water masses including the movement of warm surface water in the tropical Pacific related to an El Niño event.

Activity: On the Sea Level

Introduction

Measuring differences in elevation of the ocean surface is a challenging task, but sensing instruments aboard satellites have made it easier and more accurate. Positioned aboard a polar orbiting satellite, a radar altimeter provides a measure of the apparent distance to the sea surface with an accuracy of a few centimeters, based on the reflections of a microwave beam the instrument directs downward. Determination of the height of the sea surface takes into account the satellite's orbit, atmospheric effects on the radar signal, and tides. Variations in the sea surface elevation are then compared to a reference "ellipsoid," a mathematical model of the Earth's shape, to describe relative heights of the ocean surface.

The following activity uses data acquired by the TOPEX/Poseidon altimeter to investigate the relationship between the topography of the sea surface and the topography of the sea floor. Variations in sea level due to known density differences within Earth's interior have been accounted for and the data adjusted to eliminate these effects.

Materials

Diagrams, pencil, scissors, 3 inch by 3 inch plain stick-on note paper.

Objectives

After completing this activity, you should be able to:

- Describe the use of a radar altimeter to measure sea surface height.
- Describe the relationship between a sea floor ridge and the height of the overlying sea surface.
- Describe the relationship between a sea floor trench and the height of the overlying sea surface.

Investigations

1. Examine the accompanying map of the North Atlantic Ocean which shows segments of the ground tracks of two orbits of the satellite carrying the TOPEX/Poseidon altimeter. The segments of interest for these activities are about 1,800 km in length between 24 and 40 degrees North latitude. Mark with an "X" each end of these ground track segments directly on the map.

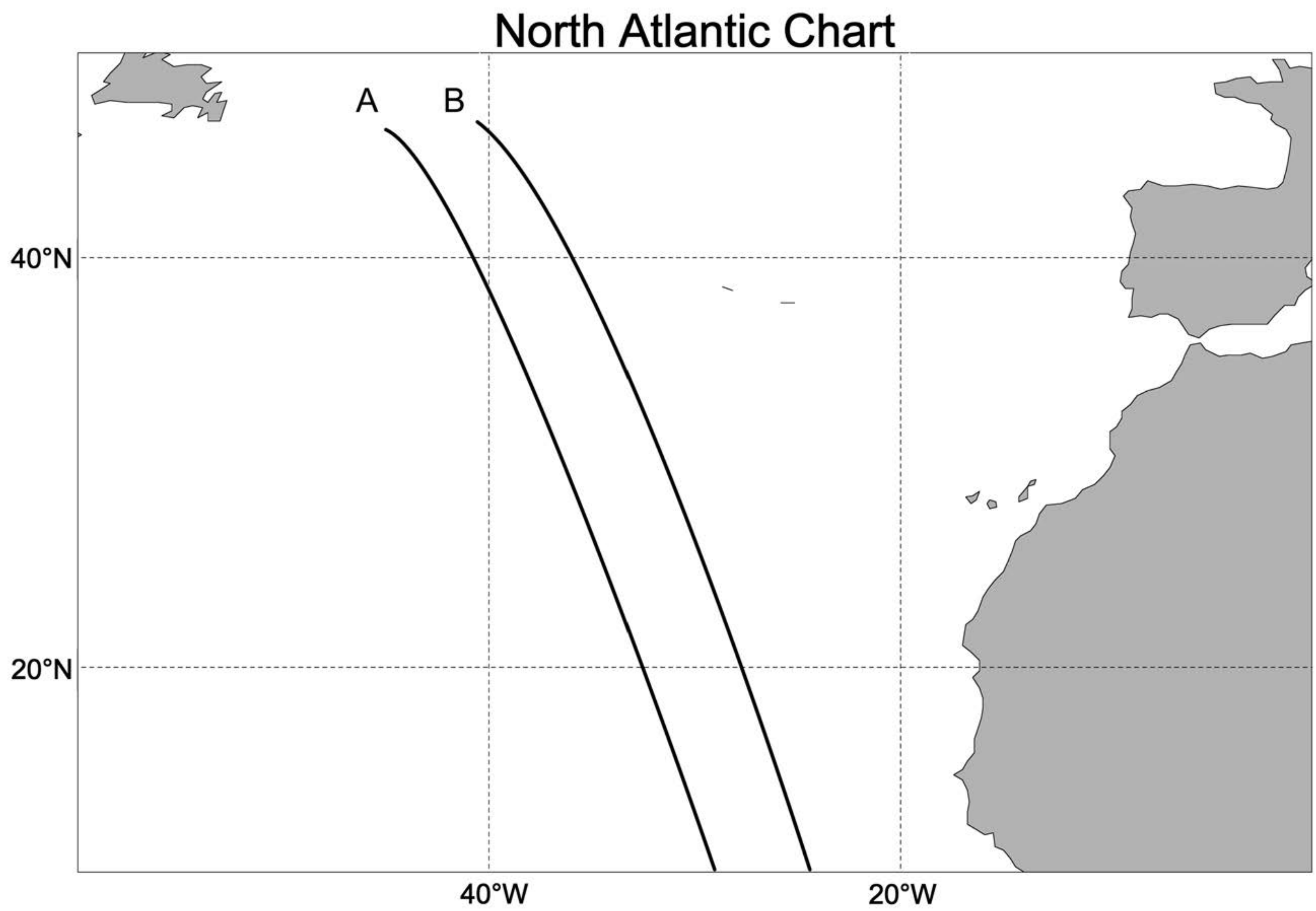
2. Turn to the Sea Surface Height Tables for tracks A and B. The sea surface heights appearing in each table are in meters above (positive numbers) or below (negative numbers) the reference ellipsoidal shape of the Earth's sea surface. The heights are listed at regular intervals measured along the two ground tracks of the altimeter. In the two tables, the total difference in height between the highest and lowest sea surface heights is about (***1***) (***10***) (***100***) meters.

3. Place a sheet of the stick-on note paper on the Sea Surface Height Template as indicated with the sticky side down at the bottom and the sides aligned with the graph. On the note paper, plot the sea surface heights as reported in the table for the first satellite track. Connect adjacent plotted points with solid straight lines. Use the scissors to cut along the lines you drew. You now have a side view of the sea surface along satellite track A. Label the bottom of the note with the track letter and latitude end points and fold where indicated so that it can stand straight up.

4. On the Ocean Depth Diagrams, the depth of the water to the ocean bottom measured by sounding from ships is plotted in meters. The rise and fall of the ocean bottom along the satellite ground track A reveals a mid-ocean (***ridge***) (***trench***).

5. Remove the stick-on note from the template and lay its folded edge along the base of Ocean Depth Diagram for track A to compare the two curves. Repeat step three for ground track B. Although very different in vertical scales, the shapes of the ocean height and the ocean bottom curves indicate that generally, the sea surface elevation is highest in the region where the elevation of the ocean bottom is (***highest***) (***lowest***).

6. Now place the two stick-on notes on the North Atlantic Map so that their folded edges fall along the appropriate ground track lines. With the notes standing straight up, a 3-D model of the topography of the ocean surface attributed to sea floor effects is obtained. The rise and fall of the ocean surface along the satellite ground track mimic the mid-ocean (***ridge***) (***trench***) below.


North Atlantic Chart
A
B
40°N
20°N
40°W
20°W

Sea Surface Height Tables

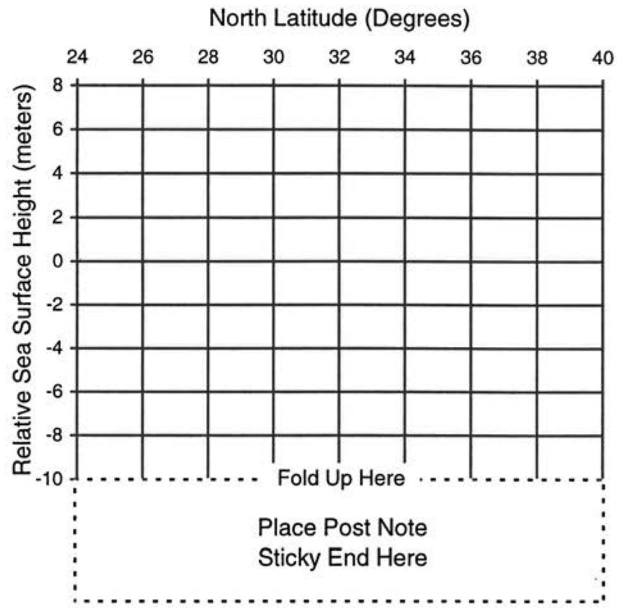
A

Latitude (°N)	24	26	28	30	32	34	36	38	40
Height (m)	-4.1	-3.7	-0.7	+1.5	+3.9	+6.1	+3.3	+1.3	-0.4

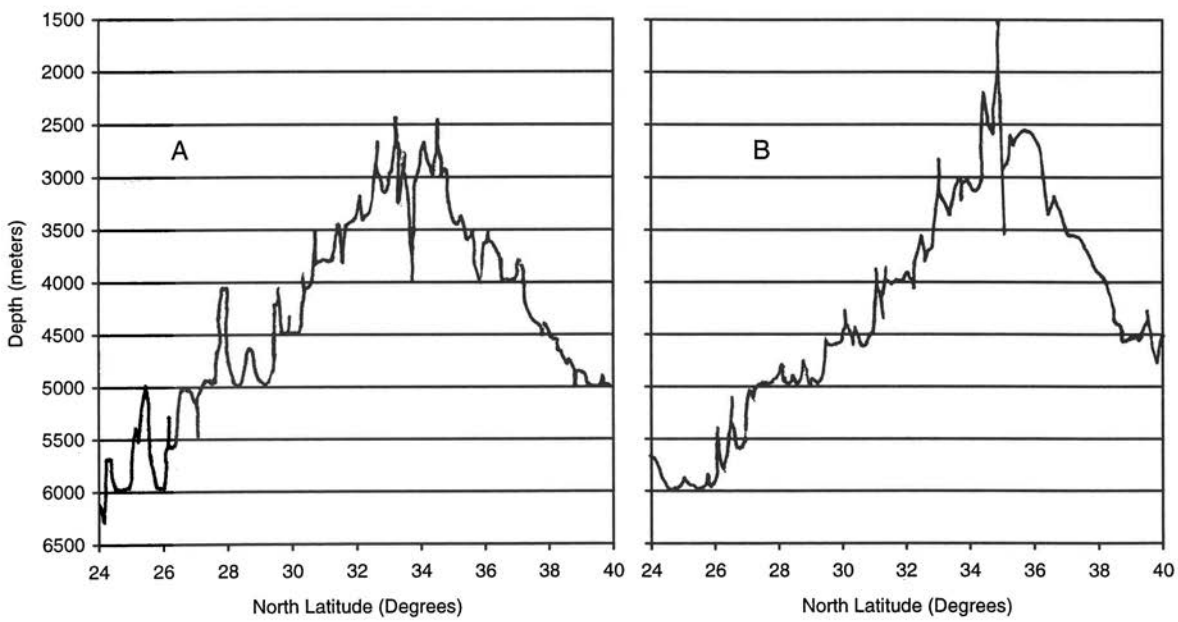
B

Latitude (°N)	24	26	28	30	32	34	36	38	40
Height (m)	-6.0	-4.4	-1.2	-1.4	+3.5	+6.2	+6.4	+3.0	+0.4

Sea Surface Height Template



Ocean Depth Diagrams



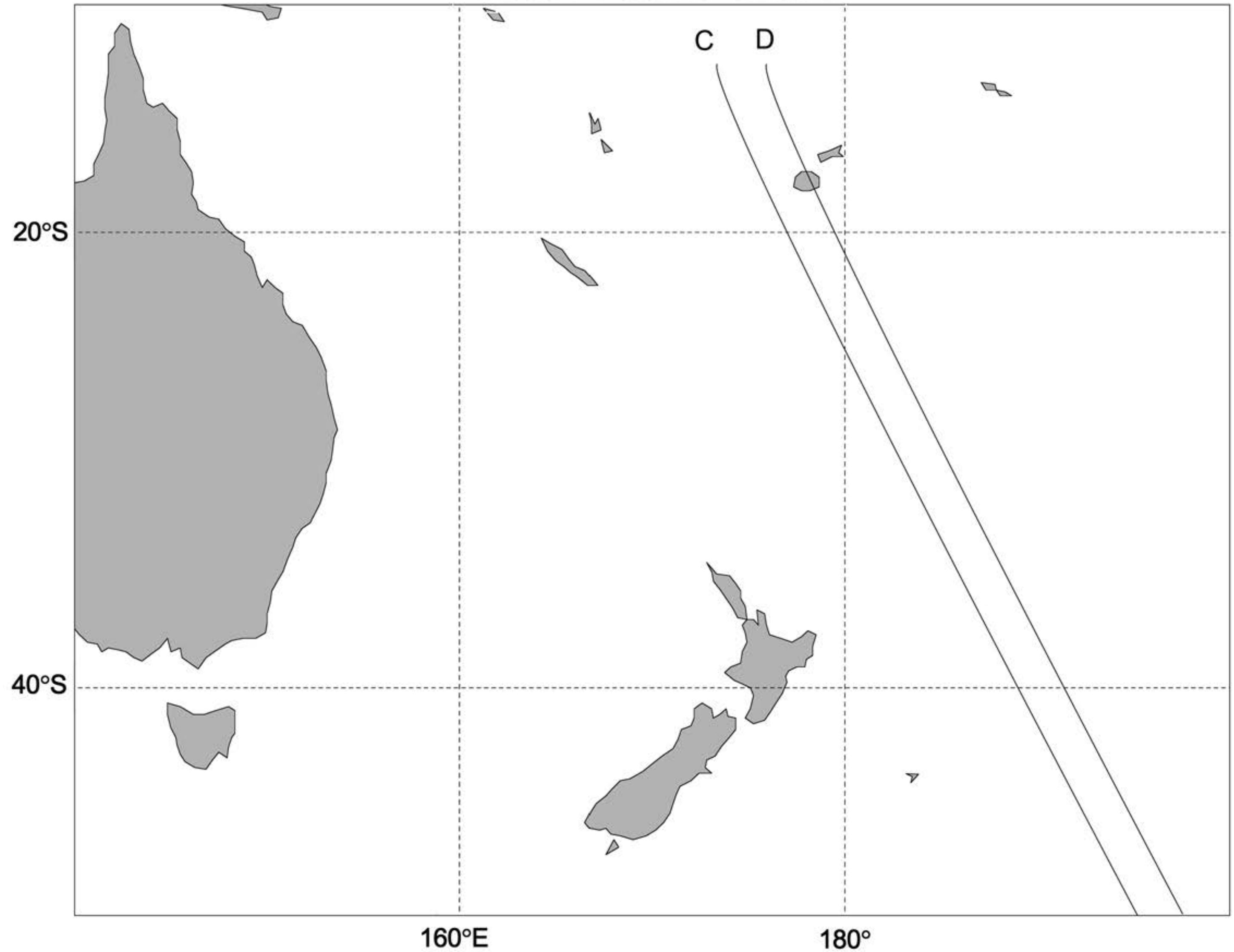
7. Repeat all the above steps with the accompanying data and map of the South Pacific Ocean by first marking satellite ground track segments from 24° S to 40° S. Note the differences in vertical scales. The rise and fall of the ocean bottom along the satellite ground tracks C and D reveal an ocean (***ridge***) (***trench***).

8. Comparison of the sea surface profiles with the ocean bottom topography reveals that the sea surface elevation is lowest in the region where the elevation of the ocean bottom is (***highest***) (***lowest***) .

9. From what you have learned so far in this activity, in the absence of other effects, the topography of the sea surface generally (mimics) (is the opposite of) the topography of the underlying ocean bottom, although their vertical dimensions are much different.

10. Variations in sea surface height are governed by numerous factors. Ocean currents and seasonal changes can result in variations of the sea surface of a meter or so. Density differences within the Earth's interior can result in sea surface height changes as great as 200 meters. From what you have learned in this activity, ocean bottom features such as ridges and trenches can result in variations of sea surface height on the order of (a single meter) (tens of meters) (hundreds of meters) .

South Pacific Chart



Sea Surface Height Tables

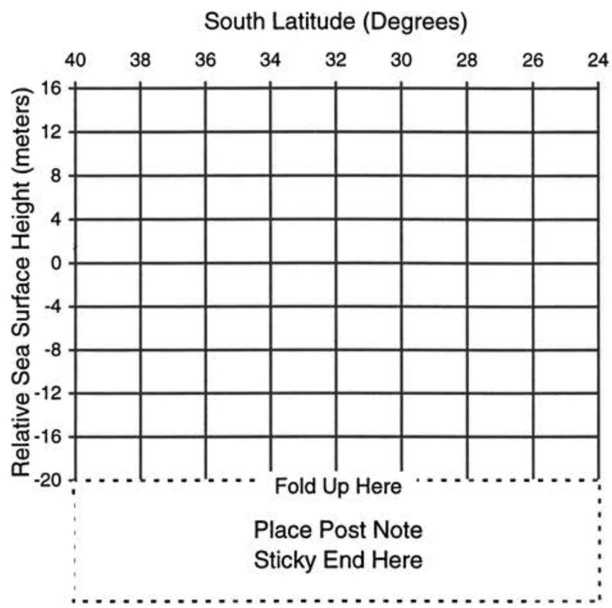
C

Latitude (°S)	40	38	36	34	32	30	28	26	24
Height (m)	-0.2	+0.7	+1.6	-0.2	-16.8	-0.3	+4.3	+2.0	-

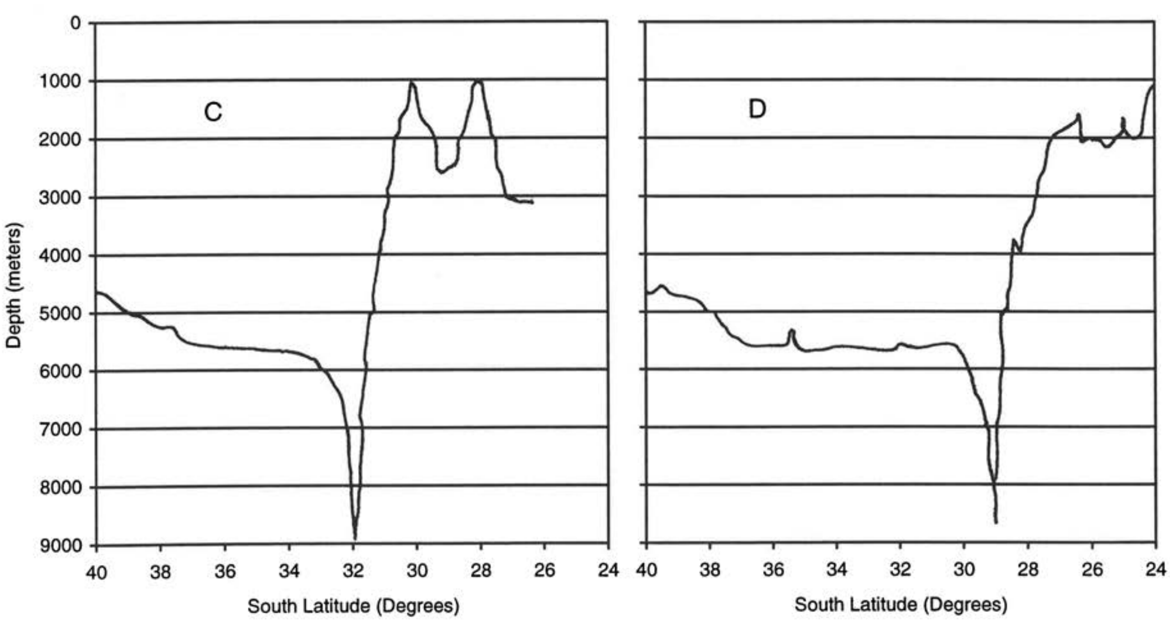
D

Latitude (°S)	40	38	36	34	32	30	28	26	24
Height (m)	+1.2	+3.1	+3.0	+3.2	+2.4	-9.1	-8.2	+9.1	+8.2

Sea Surface Height Template



Ocean Depth Diagrams



Information Sources

Ahrens, C.D., 1994. Meteorology Today, *An Introduction to Weather, Climate, and the Environment*, 5th. ed. West Publishing Co., St Paul, MN.

Cullen, V. (ed.), 1993, Coastal Science & Policy I, *Oceanus* Vol. 36(1), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1993, Coastal Science & Policy II, *Oceanus* Vol. 36(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1991, Naval Oceanography, *Oceanus* Vol. 33(4), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1992, Physical Oceanography, *Oceanus* Vol. 35(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Duxbury, A.C. and Duxbury, A.B., 1994. *An Introduction to the World's Oceans*, 4th. ed. Wm. C. Brown Publishers, Dubuque, IA.

Golden, F. (ed.), 1989, The Oceans and Global Warming, *Oceanus* Vol. 32(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Gross, M. Grant, 1992. *Oceanography, A View of the Earth*, 6th. ed. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Open University, 1991, *Case Studies in Oceanography and Marine Affairs*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Ocean Circulation*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Seawater: Its Composition, Properties and Behavior*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Waves, Tides and Shallow-Water Processes,* Pergamon Press, Tarrytown, NY.

Ryan, P.R. (ed.), 1990, Marine Education, *Oceanus* Vol. 33(3), Woods Hole Oceanographic Institute, Woods Hole, MA

Thurman, H.V., 1992, *Essentials of Oceanography*, 4th. ed. Merrill Publishing Co., Columbus, OH