Sea Level

To solve problems, scientists ask scientific questions. They determine the best methods to answer the question, collect the data, and analyze it to draw evidence-based conclusions that answer the question. You will be practicing these steps in the process of science in this lab.

Learning objectives:

- Students will be able to use data to describe and explain how tides, hurricanes, tsunami, and sea level rise affect sea level.
- Students will be able to apply and analyze steps in the **process of science** (scientific literacy).
- Students will be able to **read graphs** (quantitative literacy).
- Students will be able to identify and analyze **causal relationships** (scientific literacy).

Materials needed:

- Access NOAA Tides and Currents (http://tidesandcurrents.noaa.gov)
- Access to Sea Level Rise and Coastal Flooding Impacts (https://coast.noaa.gov/slr/#/layer/slr)

Part 1: Navigating NOAA Tides and Currents

The height of the sea level is constantly changing. It moves up and down in a daily pattern because of tides. It can also change from what is expected because of storms or tsunami caused by earthquakes. In addition, the sea level is slowly rising as Earth's temperature increases. In this lab, you will collect and analyze data related to these changes in the sea level.

Examine the NOAA Tides and Currents website by the National Oceanic and Atmospheric Administration (NOAA). If you click on a state and zoom in, you can see "pins" for different stations. Choose a state and click on a pin on the coast that is red or half red (you may need to zoom in). For the pop up box, click on "Station Home" at the top, then choose the "Tides/Water Levels" tab, then "Water Levels". For help, watch the Tides & Currents Map Tutorial Video.

Scientists use graphs to interpret data because they turn numbers into visual patterns that are easier to understand. They help communicate data by showing trends and patterns and making comparison easier. To **read a graph**, start by examining the labels to understand what the axes represent. Then look at the data points to identify trends, patterns, or comparisons.

1. When you **read the graph**, how many days are shown along the bottom for the station you chose? Note that you can change this setting using the "From" and "To" boxes at the bottom.

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7

2. When you **read the graph**, what does the blue line indicate and what are the units?

- ○ Predicted water level height in meters
- ○ Predicted water level height in feet
- ○ Verified water level height in meters
- ○ Verified water level height in inches
- ○ Preliminary water level height in inches
- ○ Preliminary water level height in feet

There are three different types of tides:

- Diurnal tides have one high tide - low tide cycle each day.
- Semidiurnal tides have two high tide - low tide cycles each day.
- Mixed tides have two high tide - low tide cycles each day, but one cycle is significantly larger than the other.

These three tides can be found on the West Coast, the East Coast, and the Gulf Coast of the US.

Navigate to the following three stations and look at the Water Levels for each.

- East Coast: Station 8534720 in Atlantic City, NJ
- West Coast: Station 9415020 in Point Reyes, CA
- Gulf Coast: Station 8761724 in Grand Isle, LA

3. Match the station with the type of tides as described above.

East Coast •	• Diurnal tides
West Coast •	• Semidiurnal tides
Gulf Coast •	• Mixed tides

Part 2: Collecting data about storm surge

Hurricane hitting Florida (source: pixabay.com)

The storm surge of a hurricane is the rise of the water level above the predicted level due to low pressure and wind.

A **causal relationship** is a cause-and-effect connection, where changing one thing (the cause) directly produces a change in the other (the effect).

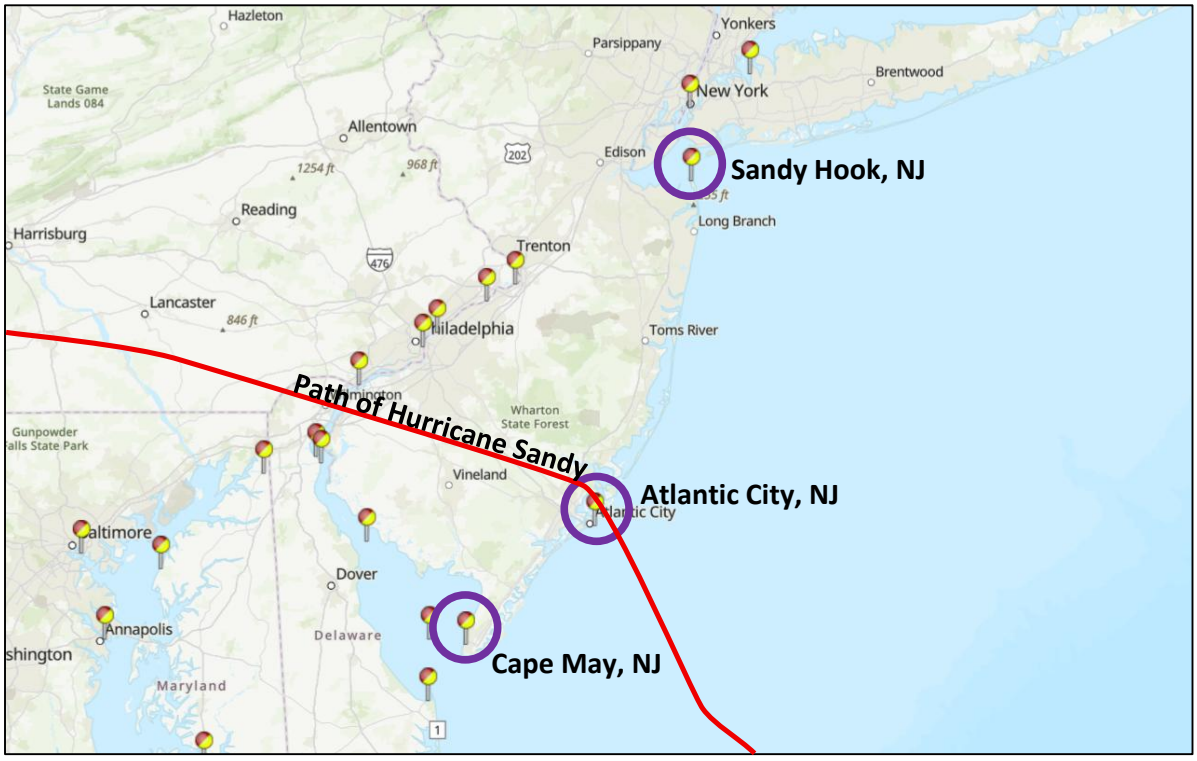
4. Which of the following is a correct **causal relationship** regarding storm surges?

- ○ Hurricanes cause storm surges.
- ○ Storm surges cause hurricanes.
- ○ Tides cause storm surges.
- ○ Storm surges cause tides.

When a hurricane moves from over the ocean to over land, where is the highest storm surge?

Consider the scientific question above about storm surge. Using NOAA Tides and Currents and Time and Date website, you will collect data to answer this question about these effects.

The first step in the methods is to identify a hurricane, in this case Hurricane Sandy, as the hurricane we would study, and to identify 3 stations along the coast near the path of the hurricane. This allows us to compare the center of the hurricane (Atlantic City, NJ) with the part of the hurricane where wind is blowing towards the shore (Sandy Hook, NJ) and the part of the hurricane where wind is blowing away from the shore (Cape May, NJ).



Go to the Tides and Currents homepage with the map of the United States. In the Search box on the left, Search: Station ID/City/State/Territory/Zip type "8534720" for the Atlantic City, NJ station. Navigate to the Water Levels page as previously directed and change the dates to Oct 26, 2012 to Oct 31, 2012. Click Update Plot. Plot

To determine the storm surge at any given time, identify where the verified water level is higher than the expected water level. The storm surge is the difference between measured water level and expected water level, so the maximum storm surge can be during high or low tide. Record the highest storm surge for high tide and for low tide in the table below for Cape May and Sandy Hook in New Jersey.

Data Table 1

	Verified High Tide (ft)	**Expected High Tide (ft)**	**High Tide Storm Surge (ft)**	**Verified Low Tide (ft)**	**Expected Low Tide (ft)**	**Low Tide Storm Surge (ft)**
Atlantic City, NJ 8534720 (eye of the hurricane)	8.8	4.1	4.7	4.8	0.4	4.5
Cape May, NJ 8636110 (wind blowing toward ocean)						
Sandy Hook, NJ 8531680 (wind blowing toward land)						

5. For the Cape May station, when was the maximum storm surge you recorded?

- ○ High tide, when the verified tide was 13.2 ft
- ○ High tide, when the verified tide was 8.9 ft
- ○ Low tide, when the verified tide was 6.0 ft
- ○ Low tide, when the verified tide was 5.3 ft

6. What part of the **graph** did you pay particular attention to as you identified the maximum storm surge for Cape May?

- ○ I looked at the peak of the green line to figure out the maximum storm surge.
- ○ I looked at the peak of the blue line to figure out the maximum storm surge.
- ○ I looked at the vertical distance between the green and blue line to figure out the maximum storm surge.
- ○ I looked at the horizontal distance between the peaks of the green line to figure out the maximum storm surge.

7. One of the tide stations stopped working at some point during the hurricane. What was the measured water level when it stopped working?

- ○ Around 4 ft
- ○ Around 7 ft
- ○ Around 10 ft
- ○ Around 13 ft

Since one of the tide stations stopped working during the time period we are looking at, the methods used to answer the scientific question do not work.

8. What part of the **process of science** comes next?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

In case the broken tide station was malfunctioning, it is important to verify its measurements by checking a nearby station. Go to the Tides and Currents website and look at the map to find a tide station near the one that broke. Fill in the last row of Data Table 1 with the storm surge data for that station.

9. Compare your storm surge calculation for the new tide station with the one that broke. How similar are the storm surges that you calculated?

- ○ Identical
- ○ Around 1 foot different
- ○ Around 3 feet different
- ○ Around 5 feet different
- ○ Over 7 feet different

10. Which of the following is the likely **causal relationship** regarding the broken tide station?

- ○ High tide likely caused the tide station to break.
- ○ Storm surge likely caused the tide station to break.
- ○ Storm surge during high tide likely caused the tide station to break.
- ○ Hurricane winds likely caused the tide station to break.

11. Now that you are done collecting data, what part of the **process of science** are you ready to do next?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

12. Look at the table in Data Table 1. Where is the highest storm surge when a hurricane moves over land?

- ○ At the eye of the hurricane
- ○ Where the wind is blowing toward the ocean
- ○ Where the wind is blowing toward land

Part 3: Collecting data about the timing of tsunami

Do some brief independent research to learn about the main way tsunami form and how they are different from tides. A side-view video or diagram is helpful to see the causal relationship.

13. Which of the following is a correct **causal relationship** regarding tsunami and tides?

- ○ Earthquakes cause tsunami, and the Moon's gravity causes tides.
- ○ Tsunami cause earthquakes, and tides cause the Moon's gravity.
- ○ The Moon's gravity causes tsunami and tides.
- ○ Tsunami cause tides, and the Moon's gravity causes earthquakes.
- ○ Tides cause tsunami, and tsunami cause an increase in the Moon's gravity.

How much time would I have between the first tsunami wave and the second?

A student examines the scientific question above about the timing between tsunami waves. The student decides the best method to answer this question is to identify four tsunami in the Pacific Ocean recorded by the NOAA tide station on Sand Island, Midway Islands (station 1619910). Use the NOAA Tides and Currents website to collect the data to fill in Data Table 2.

Data Table 2

Tsunami	Year	Date	Time peak wave 1	Time peak wave 2	Time between waves
Chile 8.8 earthquake	2010	February 27-28			
Japan 9.0 earthquake	2011	March 11-12	10:36	11:00	24 minutes
Chile 8.3 earthquake	2015	September 16-17			
Kamchatka 8.8 earthquake	2025	July 29-30			

14. When you **read the graphs**, what did you consider when you recorded the measurements?

- ○ I wrote down the heights of the peak for the first and second wave.
- ○ I wrote down the times of the first and the second wave.
- ○ I wrote down the times for the two highest water levels for the day.
- ○ I wrote down the times the two highest predicted water levels because the green verified line was so inconsistent.

15. What is the average time it takes for the second wave to peak after the first? To calculate the average, add up your measurements, then divide by the total number of measurements.

_____minutes

The student noticed that for the Kamchatka earthquake, the second wave reached a higher water level than the first wave. Look at the data for the Japan 2011 earthquake, and note the tallest wave.

16. Which wave was the tallest in the Midway Islands for the Japan 2011 earthquake?

○ First wave ○ Second wave ○ Third wave ○ Fourth wave

After the student analyzed these data, they were surprised. As a result, they decided to find out if most tsunami had later waves larger than the first.

17. Usually, after analyzing data, the next step of the process of science is to develop conclusions. In this case, analyzing the data also lead to a different step in the process of science. What additional part of the **process of science** did the student do after analyzing data?

○ Ask a scientific question
○ Determine the methods to use
○ Make observations and collect data
○ Analyze data and develop conclusions
○ Share results and conclusions

Part 4: Collecting and analyzing data about tsunami heights

Is the first wave of a tsunami usually the largest?

A student examines the scientific question above about the differing sizes of tsunami waves. The student decides the best method to answer this question is to use data from the Japan, 2011 tsunami because it was the largest recent tsunami, and it reached a variety of NOAA tide stations.

Use the NOAA Tides and Currents website to find the March 11, 2011 graph for each location. **Read the graph** to identify the highest wave. Find the wave height for the highest wave by calculating the difference between the verified height of the water level and the predicted water level, and record the wave height in Data Table 3. The highest wave height for Pago Pago, American Samoa has been filled in for you.

Data Table 3

Station	Station number	1st wave	2nd wave	3rd wave	4th wave	5th wave	6th wave	7th wave
Pago Pago, American Samoa	1770000	--	--	--	--	--	--	2.22-0.56 = 1.66 ft
Sand Island, Midway Islands	1619910							
Crescent City, California	9419750							
Hilo, Hawaii	1617760							

18. Based on your data, you decide to post about safety during a tsunami. Which of these would be the best evidence-based conclusion statement related to the scientific question?

- ○ The tallest wave I recorded was 7.26 feet tall, so I recommend avoiding elevations lower than 7.26 feet when there is a tsunami alert.
- ○ Pago Pago had the smallest tsunami at only 1.66 feet, so if you are vacationing in Pago Pago, do not worry about tsunami ruining your vacation.
- ○ In 1 out of 4 cases, the first tsunami wave was not the highest, so I recommend avoiding the area around the beach even after the first wave is over.
- ○ It was not always clear which wave was the tallest just by looking at the graph, so I recommend calculating every wave height to better answer the scientific question.

19. Based on the data you **read from the graphs**, which of these four locations in the US and its territories experienced the highest tsunami wave?

- ○ Pago Pago, American Samoa
- ○ San Island, Midway Islands
- ○ Crescent City, California
- ○ Hilo, Hawaii

20. **Read the graph** for the tide station you identified as having the highest tsunami wave. Did the highest wave happen during high tide or low tide?

- ○ High tide
- ○ Low tide

21. If the earthquake and tsunami happened 6 hours earlier, what would the water level have been at that station?

- ○ Around 1 foot
- ○ Around 5 feet
- ○ Around 10 feet
- ○ Over 12 feet

22. If the tsunami had arrived 6 hours earlier, how would that have affected the amount of damage in that location?

- ○ There would have been less damage, and probably no fatalities.
- ○ It would have been about the same amount of damage, and likely only the one fatality.
- ○ There would have been worse damage, and potentially more fatalities.

23. What part of the **process of science** did you do when you read the graph that was created using data from a NOAA tide station?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

24. Let's say you collected data for every wave instead of just the highest wave. What is a scientific question that could be answered by analyzing a single column in Data Table 3?

- ○ How do the average wave heights for a single tsunami compare between California and Hawaii?
- ○ What is the average first wave height at different locations for a single tsunami?
- ○ Do the wave heights tend to get higher or lower over the first seven waves?
- ○ What is the difference in wave height between the highest and lowest wave in a single tsunami?
- ○ Do wave heights decrease the further you are from the source of the tsunami?

Part 5: Planning methods to answer a scientific question

When glaciers on land melt faster than they are formed, the addition of that water to the ocean causes extra water in the ocean and the sea level to go up. Also, warmer water expands, which would cause the ocean water to take up more volume and the sea level to go up.

25. Select **two** of the following that have a correct **causal relationship** regarding sea level rise?

- ☐ Mud carried into the ocean causes Earth's surface to weigh down.
- ☐ A warmer climate causes glaciers on land to melt.
- ☐ Humans move more sand to beaches causing the water level to go up.
- ☐ Water from farms enters rivers and causes more plants to grow in the ocean.
- ☐ A warmer climate causes water to expand.

How is sea level changing on the West Coast, East Coast, and Gulf Coast?

The methods section of a scientific study gives the specific step-by-step strategy used to collect data to answer a scientific question. A student was asked the above scientific question about changes in sea level and came up with the following methods:

- Choose three stations to collect data: Point Reyes in California (9415020) to represent the West Coast, Charleston in South Carolina (8665530) to represent the East Coast, and Grand Isle in Louisiana (8761724) to represent the Gulf Coast.
- Create a table with one column labeled "Location" and one column labeled "Rate of Sea Level change."
- Go to the NOAA Tides and Currents website, navigate to each location, and click on the "Sea Level/Coastal Flooding" tab then "Sea Level Trends" to collect the data and record it in the table.

Go to the NOAA Tides and Currents website and choose one of the three stations to see the Sea Level Trends graph.

26. **Read the graph**. What is the pattern of the monthly sea level (blue line)?

- ○ It slowly and consistently rises each month, with an overall rising trend over the decades.
- ○ It rises in the summer and lowers in the winter, with an overall rising trend over the decades.
- ○ It varies from month to month, with an overall rising trend over the decades.
- ○ It rises and falls every 10 years, with an overall rising trend over the decades.
- ○ It does not change before 2000, but there is an overall rising trend since then.

Data Table 4

Location	Rate of Sea Level change
West Coast	2.13
East Coast	3.51
Gulf Coast	9.17

27. What are **two** concerns with the student's methods and data table?

- ☐ The rates change so much decade by decade that it is impossible to get a rate of sea level change.
- ☐ There are not enough stations on each coast to get a reasonable rate.
- ☐ The rates change significantly around 2000, so it is difficult to determine one number.
- ☐ There are no units included for the measurements.

28. What **two** adjustments could be made to the student's methods to improve the results?

- ☐ The student should identify at least two more stations on each coast and collect data from them.
- ☐ The student should calculate the rate before 2000 and the rate after 2000 and average them together.
- ☐ The student should include the plus/minus uncertainty for each rate because this uncertainty is the focus of the scientific question.
- ☐ The student should calculate the rate for each decade and include them separately in the table.
- ☐ The student should examine the graph to determine the units for each measurement and include them in the table.

29. How would you adjust Data Table 4 to make it possible to collect all of the data needed to improve the student's results?

- ○ I would move the West Coast row to the bottom row.
- ○ I would add columns for multiple stations for each "Location."
- ○ I would add rows for each decade for each station.
- ○ I would add one more row labeled "Average."
- ○ I would add columns labeled "Before 2000" and "After 2000."

Part 6: Synthesizing the process of science

How long will it take for rising sea level to flood 30% of houses on Key Biscayne, Florida during an average high tide?

A student collects data to answer the question about rising seas and flooding land and then writes a research report. The student asks you to read the report as a peer reviewer to check for errors, an important step in science. Analyze the report and determine if there is anything wrong with it that you recommend be fixed.

Student's Research Report:

To answer the question about how long before Key Biscayne floods, I began by using the Sea Level Rise Viewer website. In the "Enter an address or city" prompt at the top, I typed "Key Biscayne, FL" and zoomed in to the populated part of Key Biscayne. On the Sea Level Rise Viewer on the left, the lowest setting of 0 feet MHHW (Mean High High Water) is the average high tide. To collect data, I increased the Water Level tool by 1 foot and estimated the percentage of buildings covered by water. See the recorded data in Data Table 5, below. I conclude from these data that a sea level increase of 4 feet will cause 30% of buildings to be flooded. Next, I used NOAA Tides and Currents to find that the sea level trend at the nearby station 8723214 at Virginia Key, Florida is 3.19 mm/yr. I converted mm to feet and found that it equals 1 foot every 100 years. I conclude that it will take 400 years for sea level to increase to the point that 30% of buildings will flood during an average high tide.

Data Table 5

Water Level above MHHW	Percent of buildings flooded
1 foot	0%
2 feet	0%
3 feet	5%
4 feet	30%
5 feet	80%

30. Follow the students' methods using the Sea Level Rise Viewer website and determine if the data they collected in Data Table 5 is correct.

- ○ No, 1 foot should be 30%, and 2 feet should be 80%.
- ○ No, 1 foot should be 5%, 2 feet should be 30%, and 3 feet should be 80%.
- ○ No, 4 feet should be 5%, 5 feet should be 30%, and 6 feet should be 80%.
- ○ Yes, it's correct.

31. What did the student do well in the report?

- ○ The student collected relevant data for the effect of sea level rise at Key Biscayne.
- ○ The student collected relevant data for the rate of sea level rise.
- ○ The student created a table with appropriate headers to record the data.
- ○ The student combined the two sources of data appropriately.
- ○ The student did all of this well.

32. As a peer reviewer, do you have major concerns that would prevent this report from being published?

- ○ I am concerned that the data in Data Table 5 are not accurate. I recommend that the data are fixed and new conclusions are made before the report can be published.
- ○ I am concerned that the rise in sea level is inappropriately thought to be caused by climate change. I recommend that the report is not published.
- ○ I am concerned that the data collected do not answer the scientific question. I recommend that the report is not published.
- ○ I do not have major concerns. I recommend that the report can be published.

33. What part of the **process of science** is the student trying do, when they asked you to peer review the report so they could publish it?

- ○ Ask a scientific question
- ○ Determine the methods to use
- ○ Make observations and collect data
- ○ Analyze data and develop conclusions
- ○ Share results and conclusions

34. Imagine a hurricane with a storm surge of 4 feet hits Key Biscayne in the next few years. How many houses would be flooded by the rising sea level of the storm surge, not including waves from the hurricane winds?

- ○ 0%
- ○ 5%
- ○ 30%
- ○ 80%
- ○ There is not enough information to answer this question.

Complete the same steps for the lab to determine when the area around Quincy Market near Faneuil Hall in Boston will flood. To do this, begin with using the Sea Level Rise Viewer, search "Quincy Market," and click on the Quincy Market, Boston, MA, USA option. Use the Water Level tool on the left to raise sea level until it begins to flood the area around Quincy Market.

35. What is the water level when it floods Quincy Market?

- ○ 1 foot
- ○ 3 feet
- ○ 5 feet
- ○ 7 feet

The next step is to determine how fast the sea level is rising by using NOAA Tides and Currents. The sea level rise at station 8443970 in Boston, MA is 1 foot per century (1 ft / 100 yrs).

36. How many years will it be until the area around Quincy Market in Boston floods during high tide?

- ○ Water is currently flooding Quincy Market at high tide.
- ○ 100 years
- ○ 300 years
- ○ 500 years
- ○ At the current rate, the water will never flood Quincy Market.

The student brainstormed different ways they could communicate the key findings from their study about Key Biscayne:

- Option 1: Write a paragraph detailing the methods used to determine whether each building will flood each century.
- Option 2: Create a graph with a line that compares the rise in sea level over each century for Key Biscayne compared to Quincy Market.
- Option 3: Create a graph with bars or dots that show the percentage of buildings that flood each century.
- Option 4: Create a journal of pictures of buildings, labeled with how many centuries are needed before each floods.
- Option 5: Create a series of maps circling the buildings that will flood each century.

37. How would you communicate the key findings from the study? Option #_____ (Include only one option, although there is more than one option that could be a good communication strategy)

Part 7: Determining how to answer scientific questions

Below are scientific questions (Questions A-E) that you will use to answer questions in Part 7.

- **Question A. "Where in the United States is the sea level rising the fastest?"**
- **Question B. "Which storms in the last 50 years had the largest storm surge?"**
- **Question C. "How long after the first wave of the 2011 tsunami were there detectible variations in the sea level?"**
- **Question D. "Which places along the coast would be underwater if sea level rose by 5 feet?**
- **Question E. "How often does the peak of a tsunami wave hit before the lowest point?"**

38. Which of the scientific questions (Questions A-E above) would need Sea Level Rise Viewer to answer the question?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read the following Methods Section that describes the plan to answer a scientific question:

1) Identify tide stations located every 50 miles along the US coastline.
2) Create a table. The header of the first column is location and the second column header is rate of sea level rise.
3) Collect data on NOAA Tides and Currents by filling out the table with the rate of sea level rise for each location.

39. Which of the scientific questions (A-E, above) is answerable using these methods?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read Data Table 6:

Data Table 6

Location	Date begin	Date end	Number of days
Pago Pago, American Samoa	3/11	3/14	3
Sand Island, Midway Islands	3/11	3/14	3
Crescent City, California	3/11	3/15	4
Hilo, Hawaii	3/11	3/16	5

40. Which of the scientific questions (A-E, above) needs a table like Data Table 6?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

Read this evidence-based conclusion statement:

"**For the 8 tsunami I measured, in 1 case the water level dropped before it began to flood the land, and in 7 cases, the water flooded the land before it dropped."**

41. Which of the scientific questions (A-E, above) is related to this conclusion?

○ Question A ○ Question B ○ Question C ○ Question D ○ Question E

42. Match the cause of sea level change with its description.

Storm surge •	• Sea level generally increasing over decades
Tsunami •	• Daily pattern of high and low sea level
Rising temperatures •	• Higher sea level for 2 or 3 days
Moon's gravity •	• High and low water level at an interval of tens of minutes

Reflection

43. Which question in this lab connects to your personal experience? Consider the lab topic, math skills, and the process of science. You may also consider your lived experience or stories you've encountered. To earn credit, list the question number and explain how it relates in 2-3 sentences.