Using A.I. to Investigate Coastal Instability

An educational module using linear regression and artificial intelligence to increase climate resiliency

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MODULE SUMMARY

This module is a mathematical and quantitative literacy activity on finding linear regressions, as well as a technological literacy activity on using artificial intelligence to research possible strategies for climate resiliency. The information being modeled comes from the National Oceanic and Atmospheric Administration's Tides and Currents tool, which shows the amount of mean sea level change at various geographic locations across time. Sea level rise and increased flooding in the coastal regions can threaten supply chains and endanger human lives. Conducting climate analyses is now a routine part of national

defense strategy, as being informed about the risks of the results of climate change and planning ahead accordingly can help us alter our actions to better prepare for disaster relief (Mehta, 2021; Coast Guard, 2023).

Note to teachers: Teacher sample solutions appear in red in the module, allowing faculty to pull these notes off the teacher version to create a student version of the module.

TARGET AUDIENCE

The intended audience includes undergraduate freshmen and sophomores enrolled in several different types of courses: foundational algebra-intensive mathematics classes, mathematics for liberal arts students, and for pre-service and in-service teachers enrolled in mathematics courses.

PREREQUISITES

Students are expected to know how to do the following mathematical procedures and understand their underlying linear function related concepts: distinguish between dependent and independent variable, interpreting slope and y-intercepts of linear equations. Given an input for a linear function, students should know how to find the output; and given the output for a linear function, students should know how to find the input.

Technological literacy prerequisites (Stolpe & Hallstrom, 2024) include the following:

- An ability to use technology (specifically being able to download data from websites, use formulas on spreadsheets of data)
- A beginning awareness of the relationships between technology, society and the environment

TOPICS

- Using a variety of technological tools to find data, analyze data, and use the data to describe a social and security issue.
- Understanding the climate change issues of global mean temperature rise and sea level rise across years.
- Using artificial intelligence to research possible ways to increase climate resilience for a coastal community.

ANTICIPATED NUMBER OF MEETINGS

Depending on student knowledge and course competencies, the module will require between two to four hours of activity time. We may encourage completing Sections 1&2 synchronously or in-person during one session of class time, and having students complete Sections 3&4 asynchronously.

ACKNOWLEDGEMENT AND DISCLAIMER

This module was developed as a part of the *Reconnect 2024 Workshop on Artificial Intelligence* held in Chadds Ford, Pennsylvania from June 16 – 19, 2024 organized and funded by the Department of Homeland Security (DHS), the Center of Discrete Mathematics and Theoretical Computer Science (DIMACS), and SENTRY (Soft-target Engineering to Neutralize the Threat RealitY). The authors would like to thank Dr. Midge Cozzens for her valuable suggestions and continued support.

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Introduction

Sea level rise can cause flooding, which in turn affects human safety and health. Additionally, sea level rise is a concern with national security implications, as it threatens transportation and energy supply infrastructure in coastal areas (White House, 2015). Describing sea level rise mathematically can help us better understand the scope of the climate change problem we are facing as a society and make plans to change our short-term actions which will have lasting impacts for future generations. This module uses publicly available resources from the National Oceanic and Atmospheric Administration's (2024) Tides and Currents tool to help students analyze the rate of change of the sea level in specific geographic locations. Students are introduced to artificial intelligence (AI) and asked to use AI tools to further research possible explanations for the sea level rise and potential ways to mitigate it. We hope that by using these resources as a basis for mathematical explorations, more citizens will become aware of the resources that are available publicly to help us better understand climate change solutions.

1. A Very Brief History of AI

Artificial Intelligence (AI) refers to machines or systems that can perform tasks that would typically require human intelligence. These tasks include problem-solving, understanding language, recognizing images, making decisions, and even learning from experience.
The roots of what we now call AI can be traced back to early 20th-century work in mathematics and logic. One key figure was Alan Turing, whose groundbreaking 1936 paper on computable numbers laid the foundation for modern computing. In 1950, Turing published his famous essay, "Computing Machinery and Intelligence," in which he proposed the Turing Test to assess a machine's ability to exhibit intelligent behavior equivalent to or indistinguishable from that of a human, i.e., to think and communicate like one of us.

The term "artificial intelligence" was first coined by John McCarthy at the now famous 1956 Dartmouth Conference, where leading scientists gathered to discuss the possibility of creating machines that could simulate human thinking. Early AI systems were based on symbolic reasoning, essentially using rules and logic to solve problems. For example, the Logic Theorist, developed by Allen Newell and Herbert Simon in the 1950s, was one of the first programs that could prove mathematical theorems by mimicking human problem-solving.

For decades, AI research followed a "rule-based" approach, where experts programmed machines with explicit deterministic knowledge and decision-making rules. However, these systems struggled when faced with more complex, real-world problems. In the 1980s, researchers began to explore neural networks, inspired by the human brain's ability to learn from experience. This approach gained momentum in the 2000s, thanks to advances in computer processing power and access to vast datasets, giving rise to modern techniques like deep learning.

Today, AI is a rapidly advancing field, its methods being used to power technologies as diverse as self-driving cars, speech recognition systems, and recommendation algorithms used by companies like Tesla, Amazon and Netflix. However, as AI's uses expand so to do the ethical and societal questions about AI, questions about biases in algorithms, the future of work, and how to ensure that AI systems act responsibly and fairly.

One example of AI you may encounter daily is voice assistance, like Apple's Siri or Amazon's Alexa. Such systems use AI to understand your spoken language and respond appropriately. When you ask, "What's the weather like today?" AI processes your words, understands the question, and retrieves relevant information, all within a few seconds. While these systems seem intelligent, they are examples of narrow AI, which excels at specific tasks but lacks general reasoning abilities.

2. Types of AI

AI is broadly classified into three types based on its level of intelligence and capabilities: Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI), and Artificial Superintelligence (ASI).

Artificial Narrow Intelligence (ANI), also known as Weak AI or Narrow AI, refers to AI systems designed to perform a specific task. These systems are very good at what they do but can only operate within the narrow confines of that task. For example, image recognition software like Google's image search can quickly identify and categorize images, but it cannot understand or interpret the broader context of the image. Self-driving cars can navigate streets and obey traffic laws, but they cannot perform unrelated tasks like cooking dinner or composing music. The majority of AI systems in use today fall under the category of Narrow AI. They are highly specialized and, although powerful, are not capable of performing tasks outside their designated function.

A specific example of ANI: Large Language Models (LLMs)
One of the most exciting advancements in modern AI is the development of Large Language Models (LLMs), such as GPT-3 and BERT. These models are capable of processing and generating human-like text by analyzing patterns in vast amounts of text data. Later on in this module we will discuss how best to use them.

Artificial General Intelligence (AGI), also known as Strong AI, is the concept of a machine that possesses the ability to understand, learn, and apply intelligence across a broad range of tasks—much like a human being. An AGI system would be able to solve problems, understand language, recognize patterns, and exhibit creativity across diverse domains without needing explicit programming for each task. While AGI remains a theoretical goal, they are still far from achieving it. Currently AI systems lack the ability to reason about the world in the flexible, adaptable way humans do. For example, imagine an AI that could not only recognize a picture of a dog but could also understand what it means to pet a dog, train a dog, or identify what might be harmful to a dog—all with no additional training. This kind of broad, adaptable intelligence is the goal of AGI.

Artificial Superintelligence (ASI) refers to a machine that can surpasses human intelligence in all areas—creativity, problem-solving, emotional intelligence, and even social skills. ASI would potentially be able to solve problems that humans are incapable of understanding and could have vast implications for fields like science, economics, and ethics. However, ASI is a speculative concept, and its development raises many concerns about safety, control, and ethics. At present, ASI is a distant goal/fear existing more in the realm of science fiction than in reality. Nonetheless, researchers are actively discussing what safeguards should be in place to ensure that superintelligent machines do not pose a threat to humanity.

3: AI Some Limitations and Misconceptions

While AI can be incredibly useful, it is important for us to recognize its limitations:

- AI lacks general intelligence. Current AI systems, including LLMs and other advanced models, possess narrow intelligence; they excel at specific tasks but lack the general cognitive abilities of humans. For example, an AI that excels at playing chess cannot transfer its skills to tasks like driving a car or cooking a meal.

- AI is data dependent. AI systems rely heavily on large amounts of data for training. The quality and bias of this data can significantly impact the performance and fairness of AI models. For instance, facial recognition systems trained on unbalanced datasets may perform poorly on underrepresented groups.

- AI's interpretability and transparency can be concerning. Many AI models, especially deep learning models, are often seen as "black boxes" due to their complexity. That is, even the people who have engineered an AI model are not exactly sure how their model work. This lack of interpretability can pose challenges in understanding and trusting AI decisions. For example, it can be difficult to explain why a deep learning model made a specific medical diagnosis.

- AI's use gives rise to ethical concerns. AI systems can inherit and amplify biases present in training data, leading to unfair or discriminatory outcomes. Ensuring ethical AI development and deployment remains a critical concern. An example is hiring algorithms that may favor candidates based on biased historical data, perpetuating historical injustices.

- AI's use gives rise to new security and privacy risk. The use of AI in various applications raises concerns about data security and privacy. AI systems can be vulnerable to attacks and misuse, necessitating robust security measures.

We should also be aware of some of the most common misconceptions about AI:

- People are often afraid that AI will replace all of our jobs. While AI may transform the job market, it is unlikely to replace all jobs. Instead, AI is expected to augment human capabilities and create new opportunities. For example, AI can handle repetitive tasks, allowing humans to focus on more creative and strategic activities. The industrial revolution in general has done so too, though perhaps at a slower pace, over the last 300 years.

- People often think that AI is sentient, but, despite advancements, AI systems do not possess consciousness or self-awareness. They operate based on algorithms and data without understanding or experiencing emotions. For example, a chatbot can simulate empathy but does not *feel* emotions. It has no limbic system.

- There are those who may think that AI systems are perfect and can't make mistakes, but especially when faced with unfamiliar or ambiguous situations, this is not true. Continuous monitoring and improvement are essential for AI systems. They always need more real-world data! For instance, an autonomous vehicle that has been programmed to drive in sunny southern California may struggle to navigate in snowy Alaska.

- There are those who may think that AI Can Do Anything, but AI has limitations and is not a universal solution. It excels in specific tasks but struggles with tasks requiring general knowledge, creativity, and common sense. For example, AI can generate text but may struggle with tasks requiring deep understanding and context of that text. Wise human supervision, editing and intervention is and, we believe, will always be the key to its effective and safe use!

4. AI: A Guide to Prompt Engineering.

Now that we've discussed a bit about what AI is and what it can do, let's get into how to go about using it to do something. Specifically, how best to interact with large language models. Here is some useful tips.

A. Define your Objective Clearly

What is it you want the AI to do for you? Start with a clear goal in mind. Are you seeking information or do you want more? Do you want the AI to do creative writing or generate code? Is there something else you need? Before you start, answer these questions for yourself and then be explicit about what you want the AI to do including the output format desired. Should it be a paragraph, a list, bullet points, C++ code or something entirely different?

> Example of ineffective query: Tell me about AI.
> Example of more effective query: Provide a detailed explanation of AI, focusing on its applications in healthcare and list three examples.

B. Provide Context

Add background details to help the model understand the subject or purpose. If you are depending on a specific perspective or tone, mention it.

> Example of ineffective query: Write a story.
> Example of a more effective query: Write a story about a detective, from the perspective of his assistant. The tone should be in the style of an American film noir from the late 1940s.

C. Be Specific and Avoid Ambiguity

Avoid vague or overly broad prompts. Provide specific details such as tone, style, length, or complexity.

> Example of ineffective query: Summarize this text.
> Example of more effective query: Summarize this text in three sentences, focusing on the main argument and excluding examples.

D. Use Examples or Templates

Provide examples of the output you're looking for to set clear expectations.

> Example:
> Prompt: Create a three sentence poem about nature in the style of Haiku.
> Prompt example: Morning dew sparkles,
> Sunlight filters through the leaves,
> Whispers of the breeze.

E. Require Step-by-Step Instructions

Break down complex requests into smaller tasks. Ask for step by step reasoning if relevant.

> Example of ineffective inquiry: Add 5Ω resistance to 5Ω inductance.

Example of more effective inquiry: Show the method of adding 5Ω resistance to 5Ω inductance step by step.

F. Experiment and Refine

Start with a basic prompt and iteratively refine it based on the output. Test multiple versions of the prompt to determine which works best.

Initial Example: Write a marketing slogan for a coffee shop.
Refined Example: Write a catchy and upbeat marketing slogan for a cozy coffee shop that emphasizes organic, locally sourced ingredients.

G. Leverage "Few-Shot" Examples

If the task requires learning from examples, include a few labeled examples in the prompt. For simpler tasks, specify the rules clearly without examples.

Few-Shot Example: Convert the following sentences into passive voice: "The cat chased the mouse" -> "The mouse was chased by the cat." Now convert: "The chef cooked a meal."

H. Use "Zero-Shot" Examples

If a task requires recognizing an object, provide means of recognizing them, without providing an example of the actual object.

Example:
If you want an AI which is already able to recognize cars to be able to recognize sports cars, provide it with images of spoilers, air dams, etc, that make the category "sports car" stand out from the category car.

I. Use Constraints and Limits

Impose constraints like word counts, character limits, or stylistic guidelines.

Ineffective Example: Write about Shakespeare.
Effective: Write a 100 word persuasive paragraph on why Shakespeare's tragedies have influenced modern literature.

J. Ask for Iterations or Refinements

If you're not satisfied with the first output, specify changes for improvement.

Example Prompt: Revise this answer to make it more concise while keeping the formal tone.

K. Consider the Audience

Tailor the language and style to suit the intended audience (e.g. technical professionals, children, casual readers).

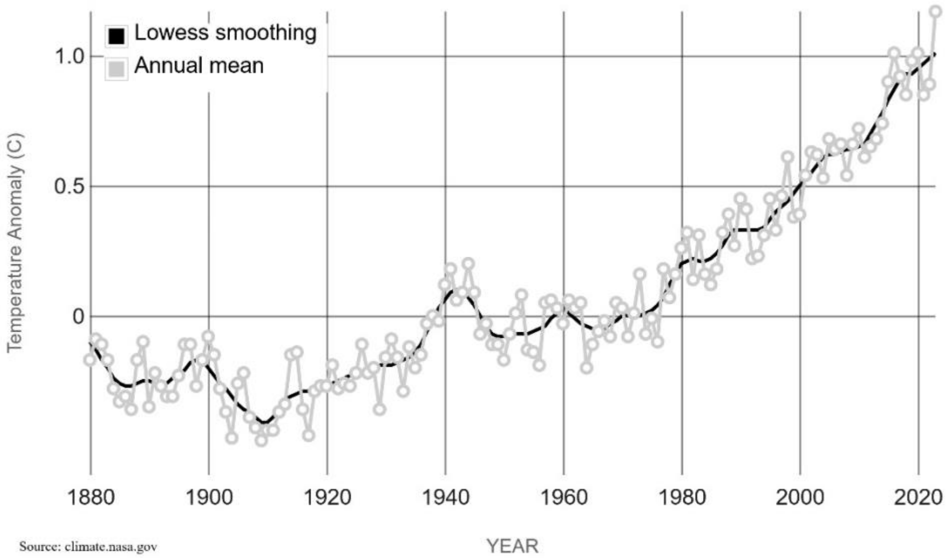
Example:
For children: Explain photosynthesis in simple terms for a 10-year old.

For experts: Provide a technical overview of photosynthesis, including its biochemical stages.

When it comes down to good prompt engineering, practice helps. Experiment with different wording and build upon what works for your specific needs.

5. LAUNCH: DISCUSSION OF MEAN GLOBAL TEMPERATURE

One of the causes of sea level change is an increase in the mean global temperature. In order to help students visualize the changes in temperature, NASA (2024) generated an image that shows temperature, included below. We hope that students will recognize that although there are natural fluctuations, the overall trend shows that the mean global temperature is rising at a more rapid rate in more recent years.



As an alternate representation, a video showing a map of the world and the mean global temperature as a time series also conveys the same information as the graph, and is available on the same NASA (2024) website.

Instructor questions:

- What are your observations about this graph. List five observations. (Alternate wording: What do you notice and wonder about this graph?)

Possible sample responses from students: The global mean temperature is rising. The slope of the increase from 1980 to 2020 is higher than the slope from 1880 to 1980. Scientists have been able to measure global sea level since 1880. From 1960 to 2000, the temperature increased by approximately 0.5 degrees Celsius. From 1960 to 2020, the temperature increased by approximately 1 degree Celsius.

- Select one of the things you noticed/wondered about the graph and, with the assistance of artificial intelligence tools, research some possible causes or explanations for what you noticed/wondered.

Possible additional research from Microsoft's CoPilot: "The rise in global sea levels is primarily due to **two factors** related to **global warming**:

1. **Melting Ice Sheets and Glaciers**: As the planet warms, glaciers and ice sheets around the world are melting. This added meltwater contributes to rising sea levels.
2. **Thermal Expansion of Seawater**: As ocean temperatures increase, seawater expands. This expansion results in higher sea levels.

These processes are driven by increasing human greenhouse gas emissions, which lead to a warmer Earth. The combination of melting ice and thermal expansion has caused global mean sea levels to rise, with recent rates being unprecedented over the past 2,500-plus years"

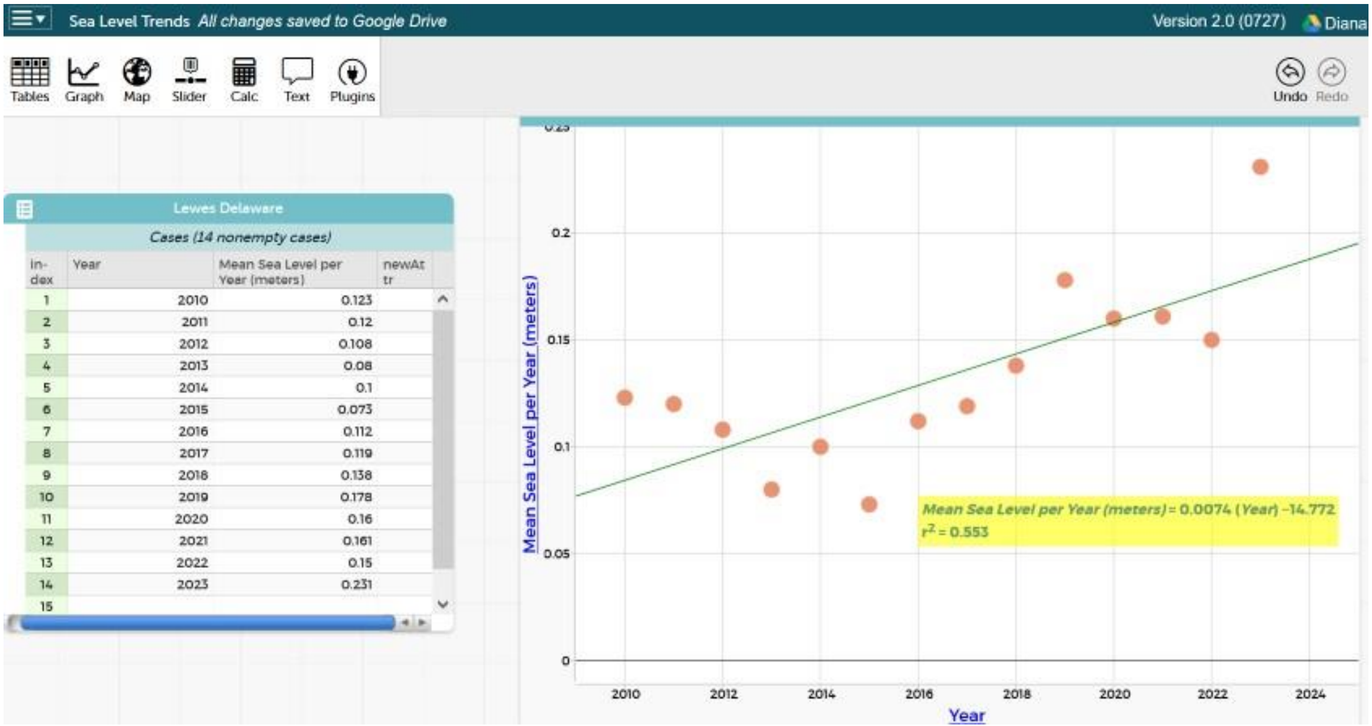
6. GUIDED INTERPRETATION OF MEAN SEA LEVEL IN LEWES, DELAWARE

The local mean sea level (MSL) is defined as the height of the sea with respect to a selected benchmark on the land. To help students understand the concept of the local sea level and how this data is gathered, we would explain that if we chose a post on the land, each day we would measure the level of the sea based on how much the sea level is above or below a horizontal line on the post. An analogy is measuring your height against a ruler on the wall.

The data used for this illustration was taken from the NOAA's (2024) Tides and Currents resource and is related to Lewes, Delaware. Our intention is to show how this can be done for one specific station in Part 2, and have the students conduct their own analyses using a similar data set for a different geographic location in Part 3.

After downloading the data related to Lewes, Delaware, (see Appendix A for instructions), students will see that the data is provided by year and month beginning in the year 1919. For the purposes of this analysis, we will conduct a guided exploration of the yearly mean sea level by graphing a scatterplot of the mean sea level (in meters) for each year. Since the data from the NOAA (2024) website provides the mean sea level by month and year, it is necessary for us to determine the mean sea level per year, which can involve using a pivot table to compute the average of the 12 months' mean sea levels (see Appendix B for instructions). Students can use the .csv with the columns Year and Mean Sea Level obtained by following the instructions in Appendix B and find the linear regression equation using any technological tool. While this can be done in Microsoft Excel, another possible technological tool is the website CODAP (2024), with a screen shot below.

Any number of years' data can be used for the linear regression, and the correlation coefficient is likely to be stronger with more years' worth of data included. In this illustration, we only used the data from the year 2010 on and onwards. This is because in Part 1, the graph of global mean temperature seems to show different increases across time periods, with the most recent years' mean temperature increasing more rapidly than from 1880 through 2010. Since global mean temperature is related to sea level rise, we decided to use just a subset of the data for this mean sea level investigation. https://codap.concord.org/app/static/dg/en/cert/index.html#shared=https%3A%2F%2Fcfmshared.concord.org%2FTqftqNaJWvFLwmL10tyP%2Ffile.json



6.1 Spreadsheet data literacy questions

A. What is the independent quantity? (time in years)

B. What is the slope? Interpret the slope. (0.0074 meters, or 7.4 mm; this means that on average, for each year that passes, the mean sea level is increasing by 7.4 mm)

C. What is the y-intercept? Interpret the y-intercept (what does it mean for the y-intercept to be negative?). (0.0074 meters, or 7.4 mm; this means that on average, for each year that passes, the mean sea level is increasing by 7.4 mm)

D. What is the linear regression equation? (MSL = 0.0074 (Year) – 14.772)

E. Based on the linear regression equation found in question D, what would the mean sea level in Lewes Delaware be in 2018? How closely does the mean sea level from the equation match the data provided from the NOAA website? (From the NOAA website, the 2018 mean sea level is 0.138 m. From the equation, the predicted 2018 average mean sea level is 0.0074*(2018)-14.772 m = 0.161 m. The predicted mean sea level is 0.023 m higher than the observed.)

F. In what year does the linear regression equation predict that the mean sea level will be 0.35 m? (0.0074*(Year)-14.772=0.35 m; Year = 2043.5, we would round to 2044)

G. What would the linear regression equation predict the mean sea level will be in the year 2050? (0.0074*(2050)-14.772=MSL; MSL=0.176)

H. The NOAA website indicates that the sea level has been on average rising 3.71 mm (or 0.00371

m) per year from 1880 to 2023. Compare this with the slope we found from the linear regression equation from 2010 to 2023. What does this tell you about the rate of change in the mean sea levels? (the slope in our linear regression equation is about 7 mm or 0.007 m, so the rate of change has increased substantially in more recent years).

6.2 Question to be answered with the assistance of artificial intelligence

I. Using artificial intelligence, ask for an image that shows what Lewes Delaware looks like currently, as well as what it might look like with the sea level at 0.35 m and 0.5 m. What are the differences that you notice? (in the future, the houses are built on stilts and the waves are bigger)

Appendix A: Gathering Sea Level Data from NOAA

<table>
<tr><th>Steps</th><th>Screen Shots</th></tr>
<tr><td>Step 1: From this NOAA (2024) “Water Levels – Station Selection” website, https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels click on a station at a location of interest. (here, we have selected Lewes, Delaware)</td><td>
</td></tr>
<tr><td>Step 2: The result of Step 1 brought us to another website with URL https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8557380.

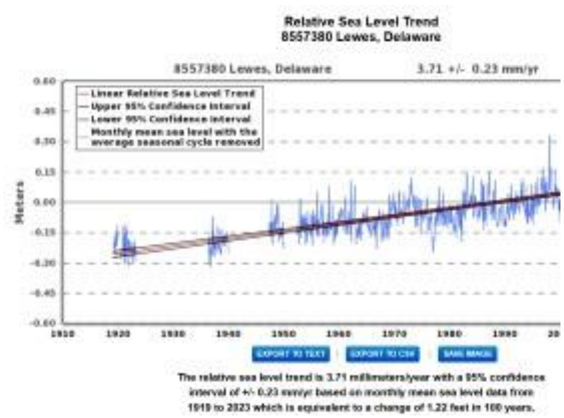
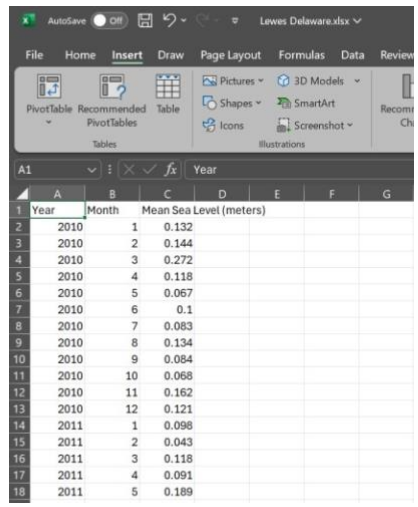
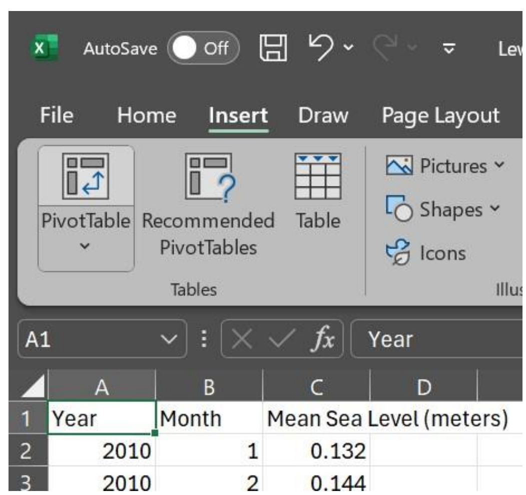
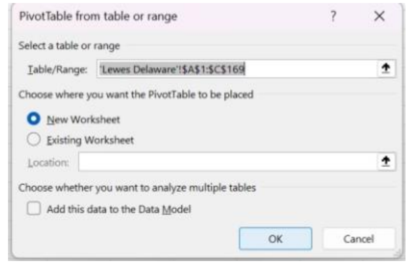
On the center bottom of the meters vs years graph, there is an option to “Export to CSV.” Download the data as a Comma Separated Value file (.csv).</td><td>
</td></tr>
<tr><td>Step 3: You will need to access your computer’s Downloads folder to find and open up the .csv file that was downloaded.</td><td>
</td></tr>
</table>

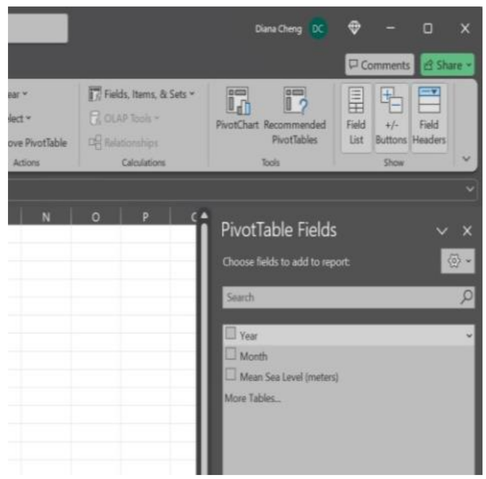
Table 1: Steps to download NOAA Currents and Trends data.

Appendix B: Instructions for Computing Yearly Mean Sea Level

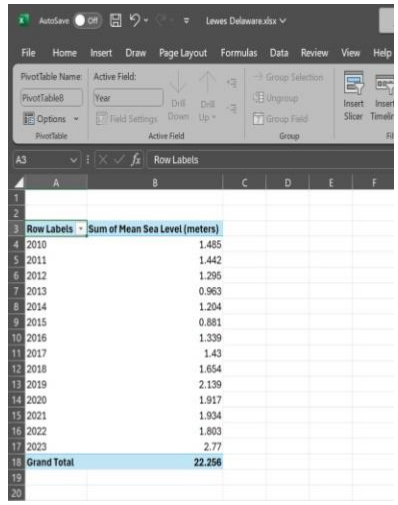
To create an Excel Pivot Table showing Yearly Averages of Mean Sea Levels from Lewes Delaware data, you will need to follow the below steps:

<table>
<tr><th>Steps</th><th>Screen Shots</th></tr>
<tr><td>Step 1: Open the Lewes Delaware data in Excel, select the Insert Tab, and place the cursor onto cell A1 (Year).</td><td>
</td></tr>
<tr><td>Step 2: Select the PivotTable icon. Note: Do not click near the downward arrow below the word PivotTable, click the square icon above.</td><td>
</td></tr>
</table>

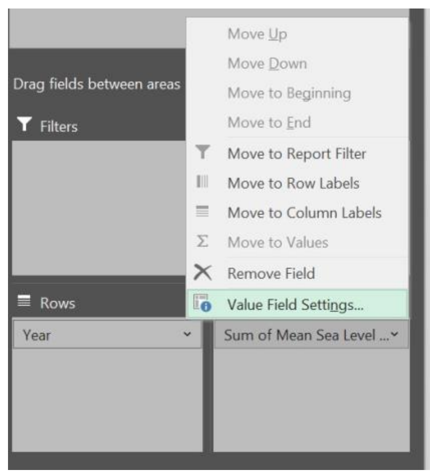
Step 3: From the pop-up window, select ‘OK” using default options, which should appear as in the picture. The result should automatically open a new tab within your Excel file showing a blank pivot table.	

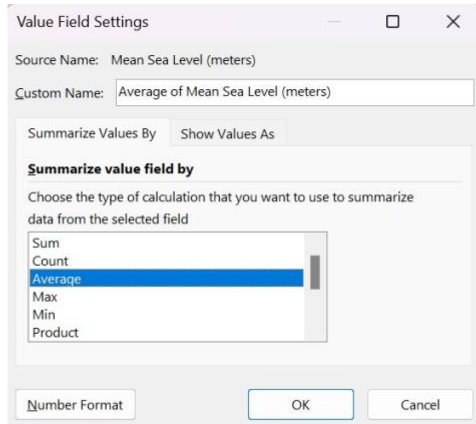
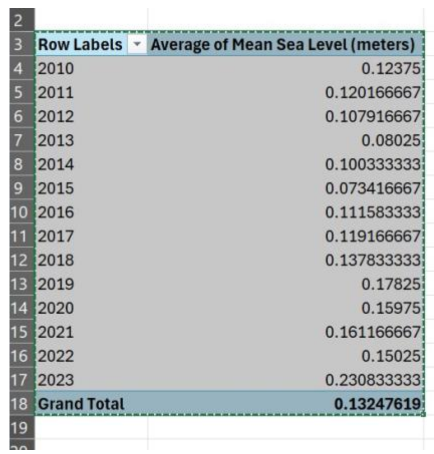
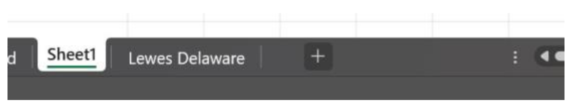
Step 4: View the blank pivot table and place mouse over the ‘Year’ field under the “PivotTable Fields” tab.	
Step 5: Click and hold the ‘Year’ field, dragging it down into the ’Rows’ box.	

Step 6: Click and hold the ‘Mean Sea Level (meters) field, dragging it down into the ‘Values’ box.

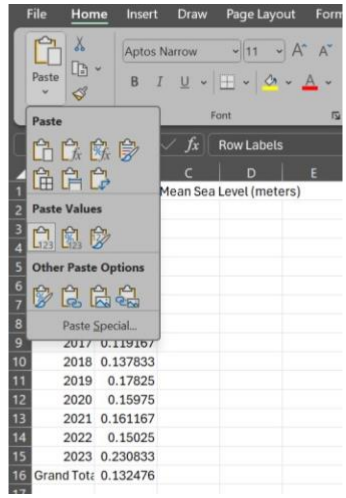


Step 7: Within the ‘Values’ Box, click the ‘Sum of Mean Sea Level’ down arrow, then select ‘Value Field Settings’.

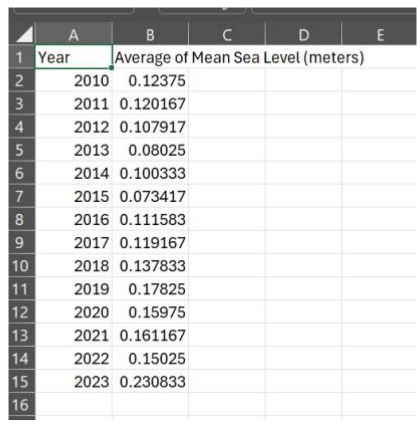


Step 8: From the 'Value Field Settings' window, click on 'Average', then 'OK'.	
Step 9: From the new table, place cursor on the 'Row Labels' cell, hit Ctrl-A, then Ctrl-C. This should select all cells within the table and create a moving dotted line around them.	 Row Labels / Average of Mean Sea Level (meters) 2010 0.12375 2011 0.120166667 2012 0.107916667 2013 0.08025 2014 0.100333333 2015 0.073416667 2016 0.111583333 2017 0.119166667 2018 0.137833333 2019 0.17825 2020 0.15975 2021 0.161166667 2022 0.15025 2023 0.230833333 **Grand Total 0.13247619**
Step 10: Click the '+' button to add a new Excel tab.	

Step 11: From the new sheet, in the Home Menu, click the down-arrow under Paste to bring up the Paste menu. From that menu, select the left-most icon under 'Paste Values'.



Step 12: Rename the 'Row Label' to 'Year' and clear contents of the bottom two cells showing Grand Total and its adjacent value.



Step 13: Save the tab as a CSV file by clicking File Save As. Change the file type to CSV. This creates a new file called Lewes Delaware.csv, which can then be used in other applications. Note: Excel may give you a warning about CSV files. You can ignore that but just know that the file Excel is showing you is NOT the new CSV file, it's still the original one you were using. We recommend closing that file now and reopening it to see the CSV file, which should only have one tab.

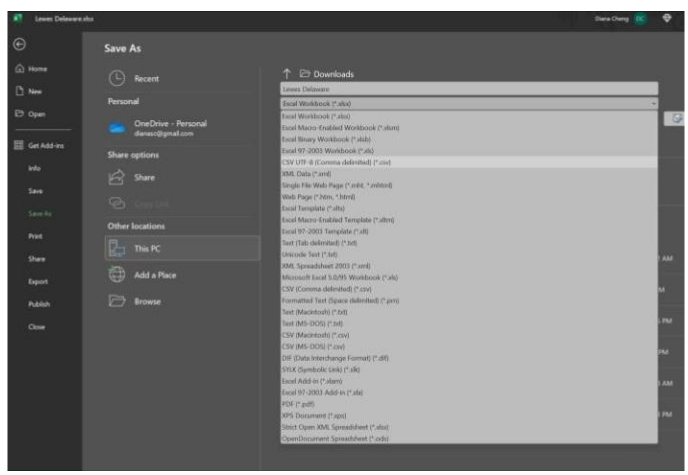


Table 2: Steps create a .CSV file with Yearly Averages of Mean Sea Levels.