EXPLORING THE DATA FOR DELINEATING THE CAUSES OF GLOBAL SEA LEVEL RISE

Scott A. Sinex
Department of Natural Sciences
Prince George's Community College
Largo, MD 20774
sinexsa@pgcc.edu

Abstract

From tide gauges to satellite altimetry, global sea level is rising and the incidence of coastal flooding has increased. Here we will explore seven large NASA/NOAA data sets via mathematical modeling that yield the evidence to delineate the causes of sea level rise. To tackle this project, it is recommended as an online collaborative spreadsheet venture with a final presentation by student groups. Here, Google Sheets and Slides are used to demonstrate the task, which gets students using big data sets that contain scatter.

Introduction

The worldwide rise in sea level has been well documented by a variety of scientific approaches. Tide gauges, which measure relative sea level rise locally, show rising levels in general for the globe. See Sinex (2022a) for getting local tide gauge data and its analysis. For handling a large data set, consider using NASA's satellite altimetry data to analyze global sea level rise. Sinex (2022b) gets students to derive the sea level rise from regression analyses using 29 years of NASA data, and also ties it to the worldwide tide gauge data. The acceleration of sea level is also discussed. Coastal flooding incidents have also increased (EPA 2021).

Global sea level rise is difficult to deny. So why is sea level rising? In this article and accompanying Google Sheets spreadsheets, the causes of sea level rise are investigated by examining a variety of large data sets from NASA and NOAA. We try to get to the root cause of the problem, which is global warming caused by the addition of greenhouse gases. The increase in the volume of seawater occurs due to the melting of glacial ice (ice on land) and the thermal expansion of seawater from the addition of ocean heat. See Figure 1 for a concept map of what influences sea level rise.

Students will plot and examine large data with a large amount of scatter in the data. Mathematical models, typically linear and quadratic models, will be derived and

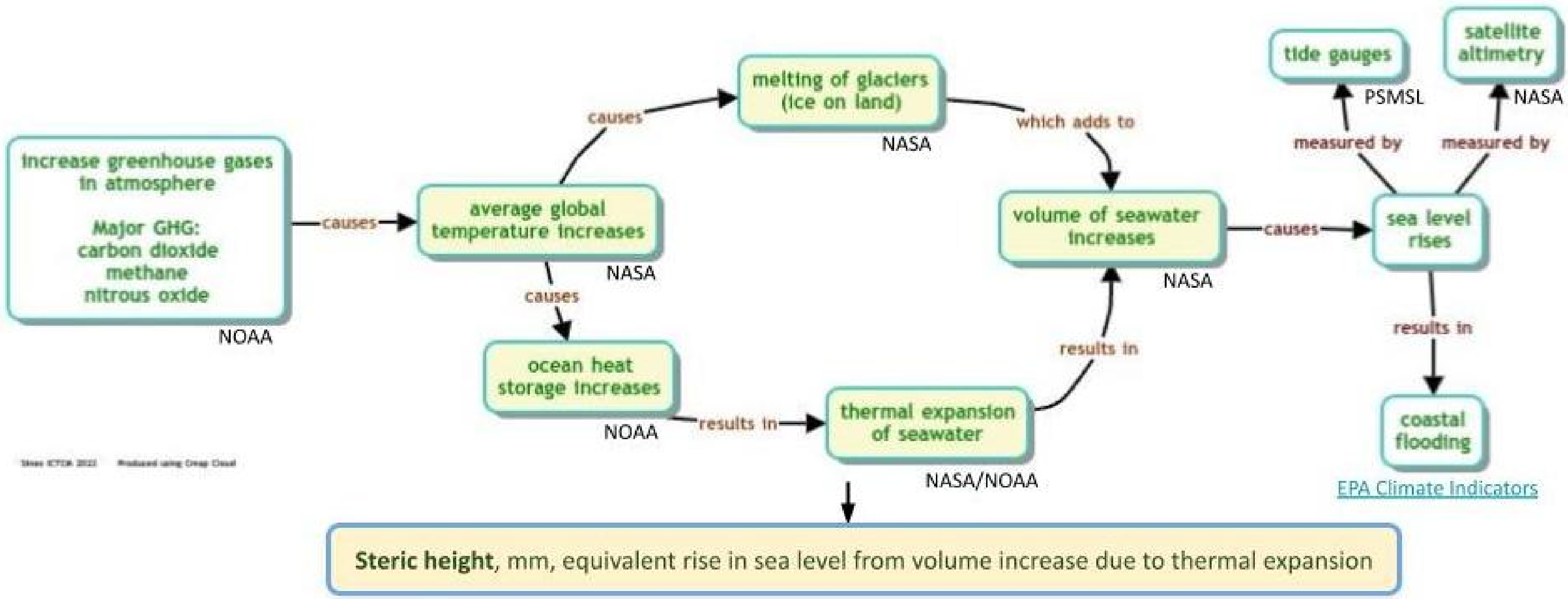


Figure 1 - The Causes of Sea Level Rise (data sources listed below boxes) Each data set is on a separate spreadsheet with links provided to all original data sources.

goodness-of-fit will be judged by r-square. It is assumed that students are familiar with graphing and modeling in Google Sheets. For a nice trio of simple manipulative-based experiments, which produce linear models and examine measurement errors, see Sinex (2013). For an introduction to examining random and systematic errors via a spreadsheet, see Sinex (2005).

The objectives of this activity are given below.
1. Explore the trends in authentic scattered data and develop mathematical models and judge goodness-of-fit for the following data sets:

- Have we ever solved a global environmental problem? Explore the Antarctic ozone hole, which is related to the cause of global warming by addition of greenhouse gases (CFC's, HCFC's) and contributes to sea level rises; however, does have a positive outcome (for instructor demo to students). A smaller ozone hole, traps more high-energy UV radiation.

- Develop mathematical models for the data sets, each provided on a separate GSheets spreadsheet (consider dividing class into 5-7 groups). The mathematics and modeling involved plus general comments are given in Table 1.
    - Greenhouse gases (major GHG) - carbon dioxide, methane, and nitrous oxide
    - Earth's average temperature
    - Glacial ice mass (ice cover on land) for Antarctica and Greenland
    - Ocean heat content to depths of 700m and 2000m
    - Steric height and ocean mass to validate seawater volume

2. Have groups summarize their results including their model via a Google Presentation slide, and, as a class, draw an overall conclusion and suggest possible solutions to prevent and/or reverse sea level rise. This is a nice collaborative group project summation, plus groups could peer review other groups! Concatenate slides, share with students, and have a class discussion. Can the students put the causes in order as shown on the concept map (Figure 1)?

3. Introduce students to big, authentic data (large number of data points) and especially data with a large amount of scatter.. Science educators are referring to this scattered data as "messy data" (Dorsey, 2021; Schultheis & Kjelvik, 2020).

The next sections of this article will examine the spreadsheet for each cause, but first the Antarctic ozone hole will be discussed to illustrate that environmental problems can have a positive outcome. Interactive features are on many of the spreadsheets including yellow cells (can type info in to change a variable) and check boxes that allow items to be turned on and off, such as comparison curves or translations of the data.

Table 1 - Summary of data sets for delineating the causes of global sea level rise

Date Sets*	Math and model(s)	Comments
The Antarctic Ozone Hole **Practice Example for Class Demo by Instructor**	Quadratic models examining ozone concentration & area of ozone hole over time, concentration over area (explains the concept of the ozone hole), plus predictions to recovery Introduces adding scatter to data or random error & reducing r-squared	Pre-project model for class discussion led by instructor Derivative by finding slope, $\Delta y/\Delta x$ between points Illustrates a positive environmental result
Carbon dioxide	Increasing levels with a periodic signal (Keeling curve), horizontal translation Quadratic model	Discussion of acceleration by greater addition of CO_2
Methane	Cubic model on periodic signal, examine behavior	Derivatives, estimated & exact
Nitrous oxide	Linear with weak periodic signal	Consider quadratic model
Average global temperature	Both quadratic model on whole data set & linear model on recent data & how a baseline of comparison is set	Discussion of acceleration of global temperature rise
Ocean heat content	Quadratic models on heat content data to two different depths, build a two-layered ocean model, examine ocean surface temperatures with 95% confidence limits, & linear models on recent data	Discussion of acceleration of ocean heat content Compare rates for heat content in 2 layer ocean
Glacial ice mass	Linear models illustrating mass loss plus predictions to total melting	Nice comparison between Antarctica & Greenland
Steric height & glacial melt mass	Summation of two measurements (converted to equivalent sea level rise, mm) to compare to sea level by satellite altimetry Introduces $y = x$ comparison line for judging errors, both random & systematic	Validation of sea level rise If students work in pairs, this is a good place to put the odd numbered student or just a larger group

*each data set is linked to a separate Google Sheets spreadsheet

Antarctic Ozone Hole

The Antarctic ozone hole was discovered by two British scientists in the early 1980s and verified by NASA TOMS data. Essentially, in the Antarctic winter (October), the polar vortex encircles Antarctica and polar stratospheric clouds form in the cold environment and the ice crystals allow ClOx and NOx to react with ozone, causing a decrease in ozone concentration, hence the hole. This decrease in ozone allows higher levels of ultraviolet-B and -C radiation to reach the ground.

Using NASA data from 1979 to the present, students can explore the relationship of ozone concentration and the area of the ozone hole of Antarctica as a function of time in years. The cause of the destruction of ozone was the chlorine from a class of compounds called chlorofluorocarbons, CFCs, which were thought to be inert. Later, other compounds were found (HCFCs, HFCs, halons, & others, see NOAA, nd) to be involved as well. In 1987, the Montreal Protocol was approved by all members of the United Nations. Ozone depleting compounds were to be phased out of use over time. Figure 2 shows the level of ozone still declining through 1994. Removal from the atmosphere of ozone depleting compounds was going to take time. Today, Solomon et al. (2020a) describe that more work is needed.

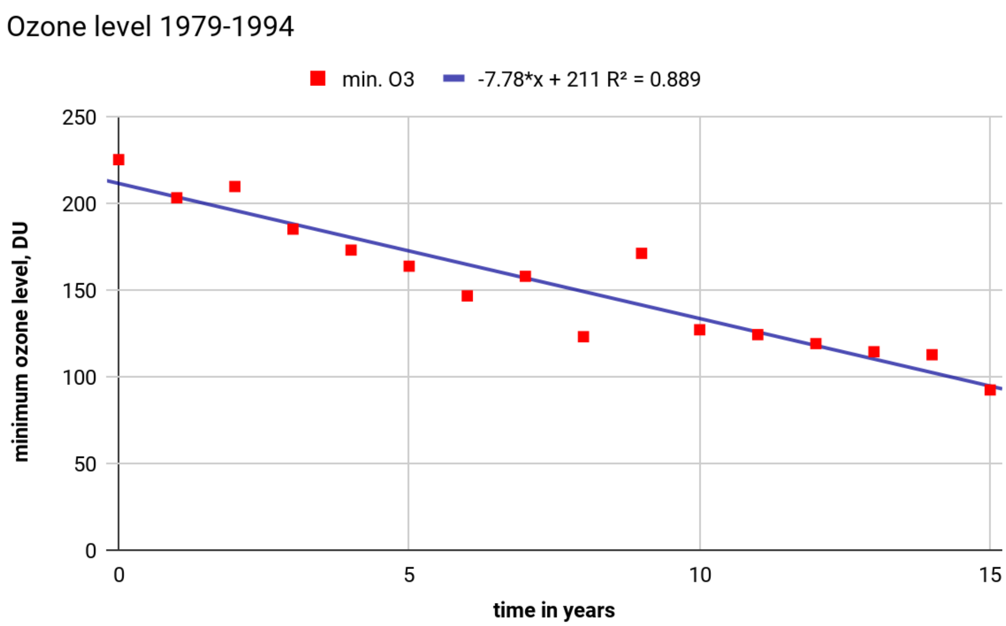
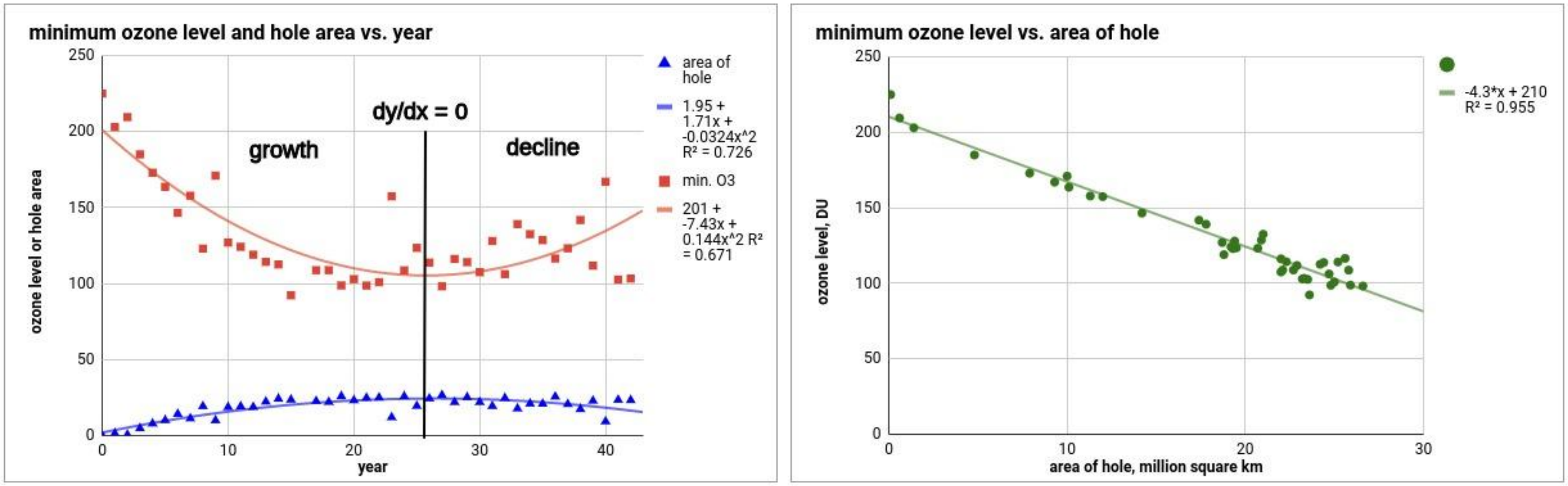


Figure 2 - Early levels of ozone decline

The NASA ozone levels in the Antarctic ozone hole are used in this project to examine data from 1979 to 2021 and is illustrated in Figure 3. What do you notice about the ozone levels?



The mean ozone hole size for 07 September–13 October and the minimum of Southern Hemisphere mean ozone for 21 September–16 October for each year.

When will level return to 225 DU?	y	ax^2+bx+c	x	actual year
	225	225.0	54.65	2034

using the derived regression

adjust formula if new data added

1st derivative, set equal to zero

$dy/dx = 2ax + b = 0$

Find the vertex	x = -b/2a	actual year	Why?
ozone vs. year	26	2005	ozone level stops dropping and rises again
area vs. year	25	2004	area of hole stops growing larger and decreases

variation/error causes a slight difference

Figure 3 - Ozone Hole: top left, ozone concentration and hole area over time; top right, ozone level vs. area of hole; bottom left, calculating minimum ozone and maximum area; bottom right, predicting year of recovery to 225 DU.

The ozone concentration vs. time and the area of the ozone hole vs. time are definitely not linear. Both of these can be fit with a quadratic regression. When the ozone concentration is plotted as a function of the area of the hole, a nice linear fit is obtained.

Since 2004/2005 the ozone hole has started to decline in area and the ozone concentration has started to increase. The inflection points are calculated from the derivative since dy/dx = 0 or locating the vertex, x = -b/2a. The slight difference in the two vertices is due to the noise or scatter in the data. The predicted year of the ozone level returning to the prehole value (225 DU) is also estimated. The "add random variation to data" tab will demonstrate how a slight change in random variation can influence the prediction. The Montreal Protocol has actually allowed the ozone hole to recover, and one has to hope, return to its 225 DU value with further elimination of ozone depleting chemicals. Today, a new concern is the increase in nitrous oxide, which can contribute to ozone depletion. Solomon et al (2016) predicted healing started in 2000. NOAA (nd) predicts the recovery to pre ozone hole levels between 2040-2080.

Carbon Dioxide

In 1958, a Scripps Institution of Oceanography at UC San Diego scientist by the name of Charles Keeling started measuring carbon dioxide (CO_2) at the Mauna Loa Observatory in Hawaii. The hourly measurements have occurred almost continuously through today. Here students will plot the Keeling Curve, shown in Figure 4, and analyze it. A great discussion point is to see if students can deduce the cause of the periodic signal in the data set.

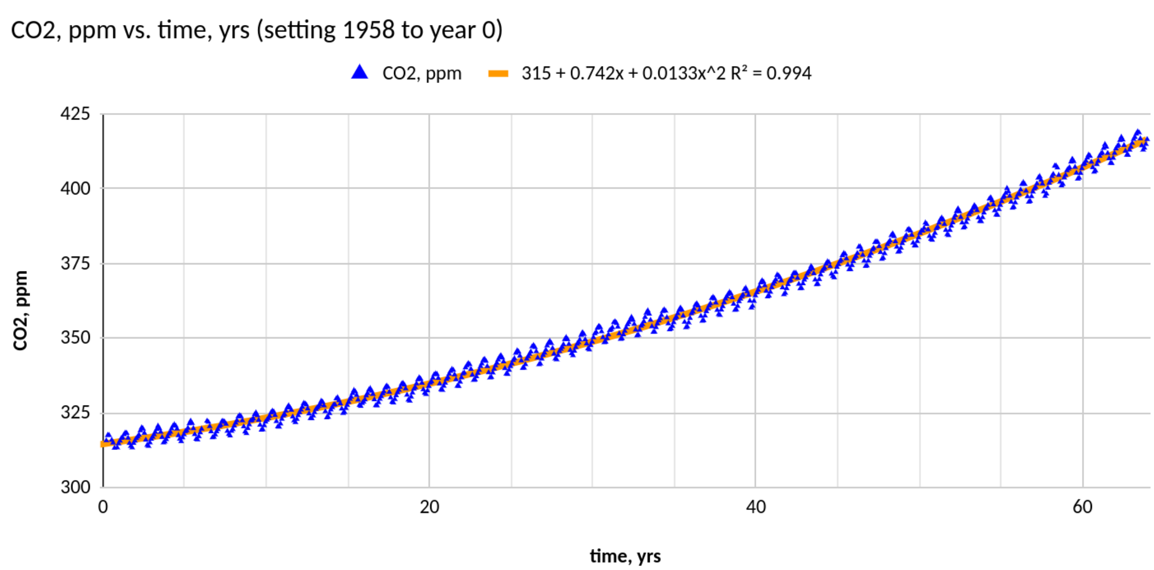


Figure 4 - The Keeling Curve (1958 - 2021) Data points (blue, n = 768) are the monthly means plotted at mid month, the curve was horizontally translated to set 1958 to year 0 and fitted with a quadratic regression (orange curve).

Let's examine the data over four different decades (Figure 5) to see how things have changed, but also to enhance the visualization of the periodic signal. Again the data is horizontally translated to start each decade at year zero. The timing of the peaks and valleys for the four decades are nicely aligned due to the seasonal cycle of photosynthesis. The four decades can each be fit by linear regressions that show the growth in the rate of carbon dioxide. The regression equations can be used to calculate the change/decade. Notice there is some missing data in year 4 of the 1960-1969 decade, which has no effect on the analysis. Missing data is just that, missing data!

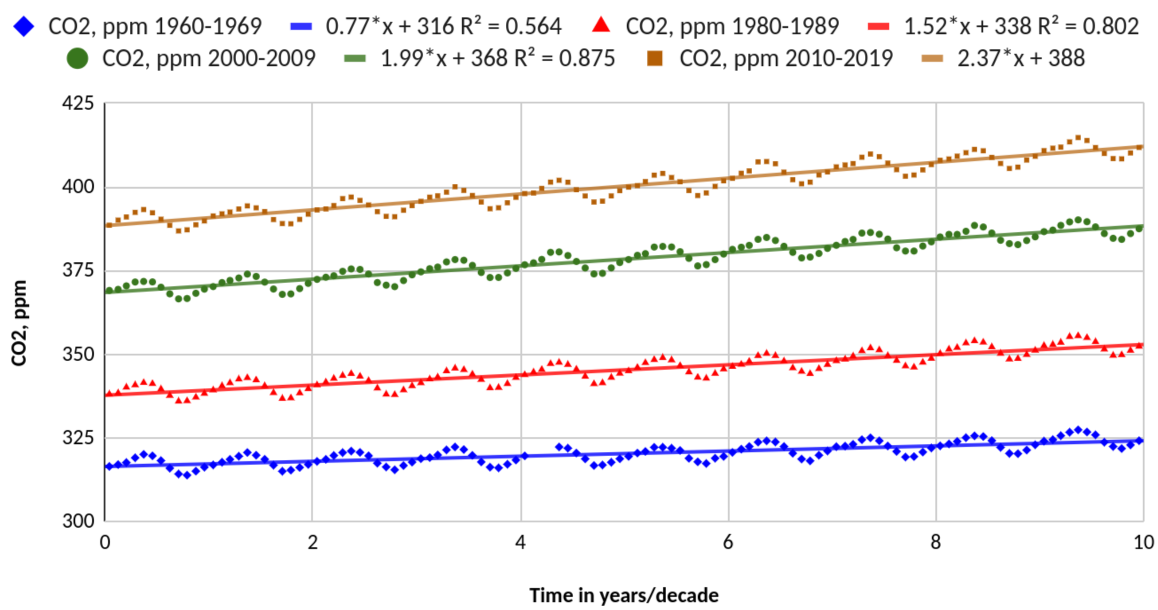


Figure 5 - Decadal comparisons of carbon dioxide

Methane

Methane (CH_4) is released into the atmosphere predominantly by wetlands and a variety of other sources. The level of methane in the atmosphere has had an interesting variation as shown in Figure 6. After an initial rise, it appears to have leveled off from 1999-2006, and then rises again. The rapid rise after 2007 is now thought to be from anthropogenic emissions (Zhang, 2022). This is a classic cubic function and the cubic regression has a high degree of goodness-of-fit as judged by the r-square of 0.996. The trend in the monthly data also shows a periodic signal which is due to the seasonal cycle of photosynthesis.

If students are familiar with derivatives by either differences or determining an exact expression, f'(x) they can find the inflection point by finding the minimum. The difference method is messy due to the scatter in the actual data. Since the inflection point occurs when the second derivative is zero, $f''(x) = 6ax + 2b = 0$, so that $x_{\text{inflection point}} = -b/3a$.

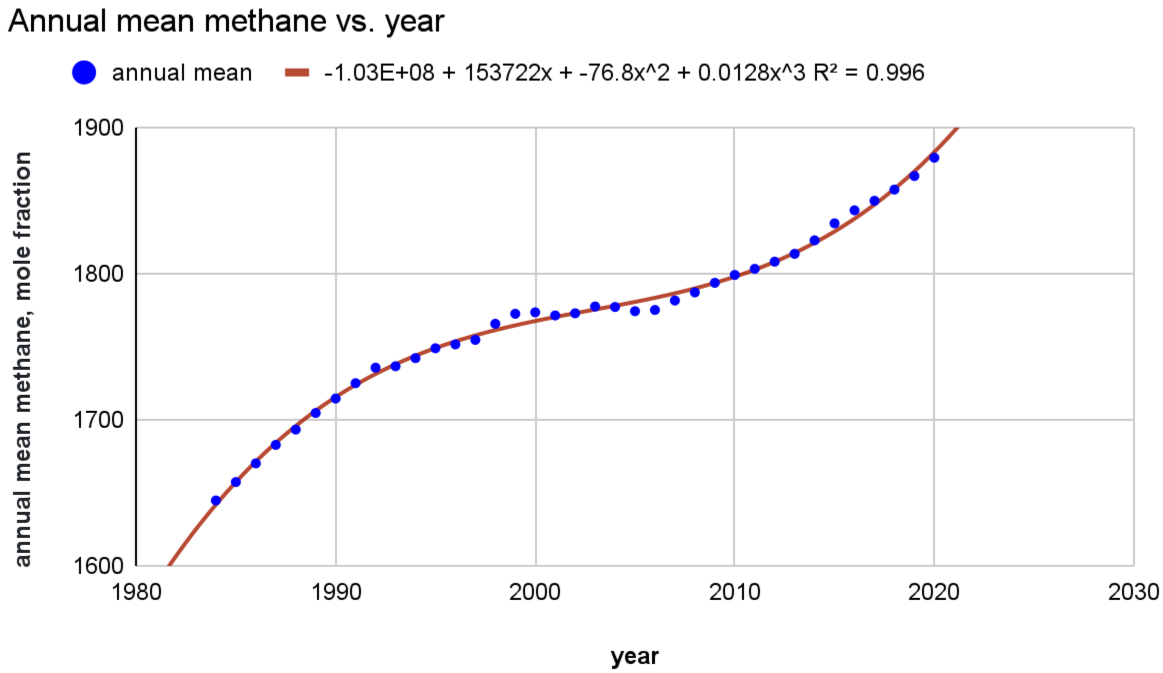


Figure 6 - Annual mean levels of methane in atmosphere

Nitrous Oxide

In the nitrogen cycle, nitrous oxide (N_2O) can be produced during both nitrification and denitrification, which are driven by different bacteria. The growth of nitrous oxide in the atmosphere is shown in Figure 7, showing somewhat of a periodic signal. The linear regression plotted in Figure 7 is a really good fit; however, the data shows a good sign of curvature. Calculating and plotting the residuals would show a pattern. Hence, an improved fit would be to do a quadratic regression, as it shows slightly better fit and accelerated growth.

Nitrous oxide is a potent greenhouse gas with a global warming potential 265 times the equivalent amount of carbon dioxide. The major source of nitrous oxide is agricultural land management, which offers a challenge to control (Reay, 2015). There is recent concern over the growth of nitrous oxide, as it is a risk to the stratospheric ozone shield (Solomon, 2020b).

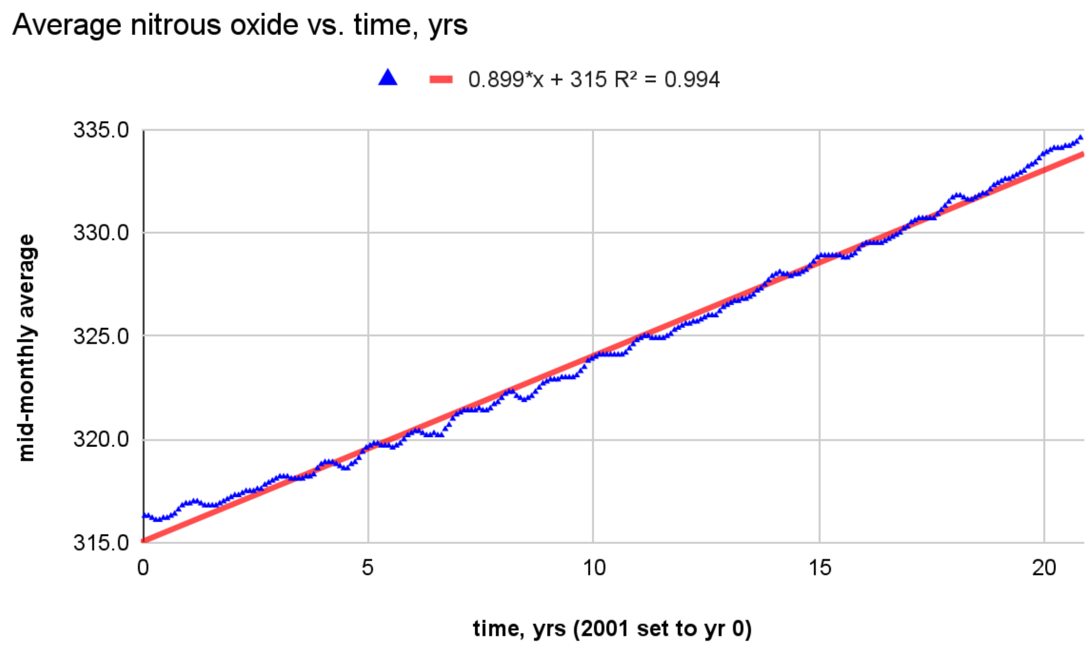


Figure 7- Monthly Means for Nitrous Oxide

Global Temperature

Mean global temperature, which has been recorded back to 1880, is reported as the relative change in temperature. The baseline used to set the zero is the record from 1951-1980. This is illustrated in Figure 8, which shows that the surface temperature has warmed 1ºC in the last fifty years. This is the basis of the term *global warming*, which is caused by the increased amounts of greenhouse gases as discussed above.

Students will examine a quadratic fit of the temperature data, generate a 10-yr moving average that mimics the Lowess curve, and examine a linear regression for the 1970-2021 data. The slope of the linear regression yields a temperature rise of 0.018ºC/yr.

For more on global temperature changes, see Jim Hansen's monthly summaries at https://csas.earth.columbia.edu/blog/temperature-update or NASA GISS Surface Temperature Analysis.

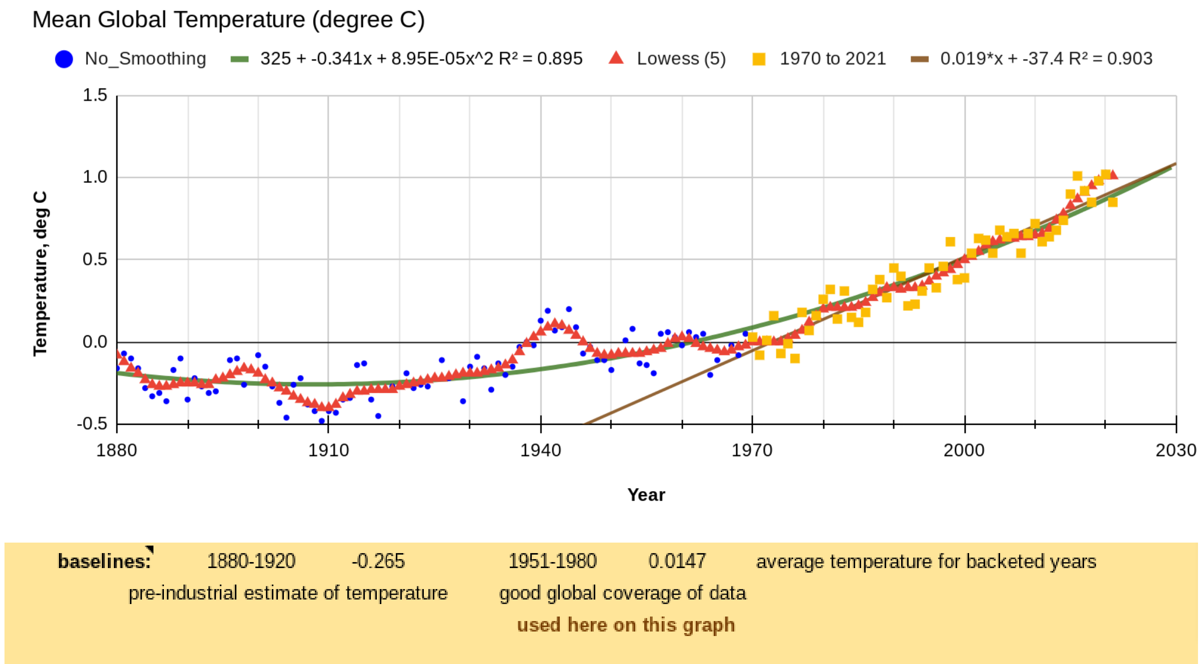


Figure 8 - Global Temperature

Ocean Heat

According to von Schuckmann et al. (2020), the oceans absorb 90% of incoming radiation from the Sun. So let's examine the distribution of ocean heat, which is measured in energy units of joules, J. The baseline for ocean heat is the average for 1971-2000 data.

Students will examine ocean heat in the 0-700m and 0-2000m layers of the ocean. The nonlinear nature of the data can be fit with quadratic regressions with fairly high r-square values. Students then build a two-layer ocean model by subtracting the 0-700m layer from the 0-2000m layer. This is illustrated in Figure 9, which after 1990 shows the 0-700m layer warming much faster than the 700-2000m layer.

Students can compare the rates of heat absorbed by linear regressions that can be added for the data from 2000 to 2020, as given in Table 2.

Table 2 - Heat Absorbed in Two Layer Ocean

Layer	Linear Regression	Rate of heat absorbed
0 - 700 m	$H = 0.630t - 1255$ $r^2 = 0.962$	$0.630 \bullet 10^{22}$ J/yr
>700 - 2000 m	$H = 0.374t - 745$ $r^2 = 0.961$	$0.374 \bullet 10^{22}$ J/yr

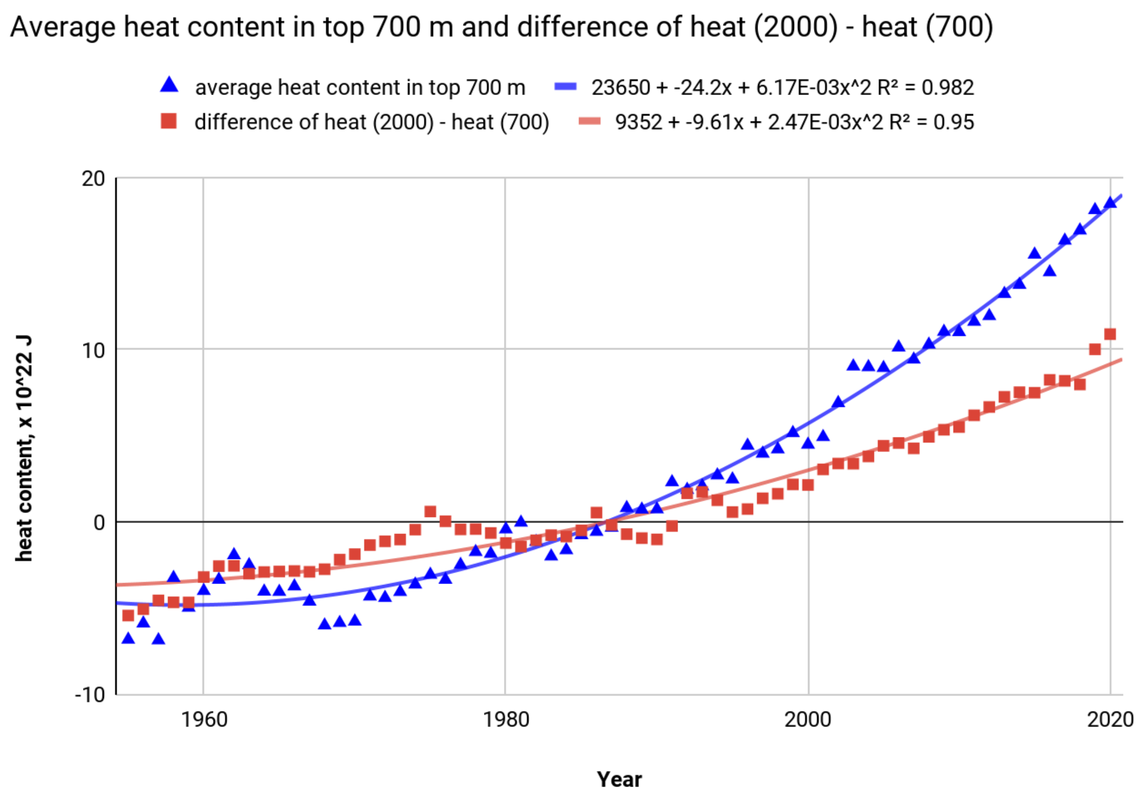


Figure 9 - Two Layer Ocean - Heat Content: top 700 m (blue triangles) and layer from below 700 m to 2000 m (red squares)

Glacial Ice Mass

Glacial ice is ice covering land, and the two most prominent glaciers are Antarctica and Greenland. NASA has measured mass loss by gravity recovery via the GRACE and GRACE-FO satellites (NASA JPL 2022). The measurements for Antarctica and Greenland are plotted in Figure 10. Students plot the data and determine the rate of mass loss from the slope of the linear regressions. Students investigate why Greenland is melting faster and determine the year of complete melting for both glaciers, assuming the rate remains constant.

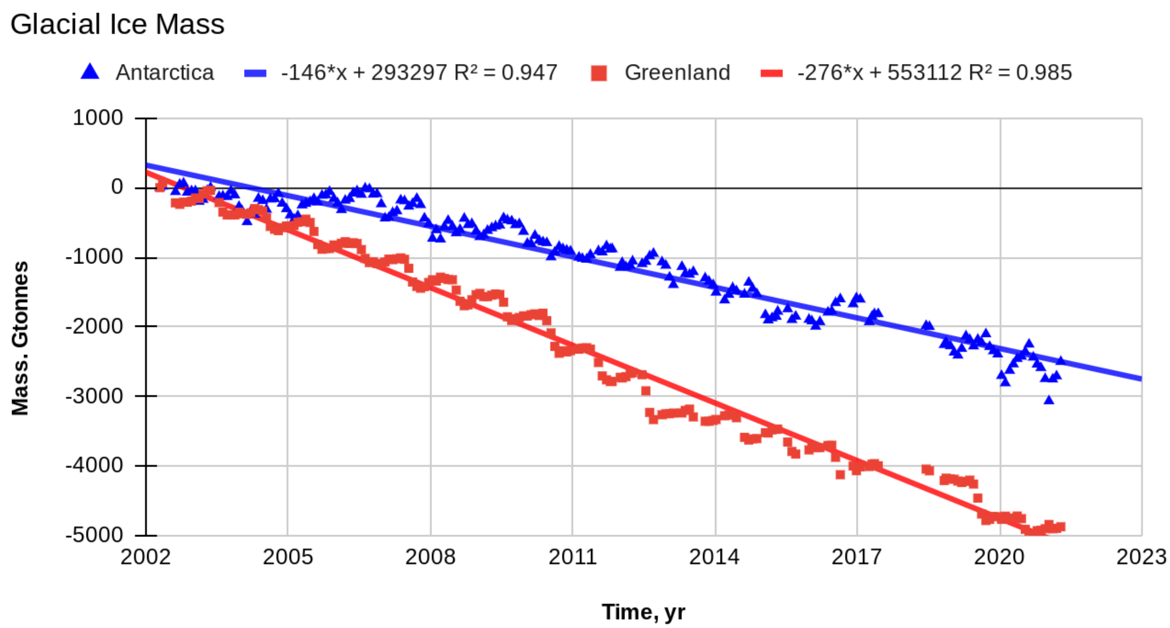


Figure 10 - Glacial Ice Mass Loss for Antarctica and Greenland

Increasing Volume of Seawater

What contributes to increasing the volume of seawater? Now melting glacial ice is a no brainer! Since the melt water contributes to a direct increase in the volume of seawater, the ocean mass can be converted to an equivalent rise in sea level in millimeters, mm. These are the blue squares plotted in Figure 11.

The other contributor to increasing the volume of seawater is the thermal expansion of seawater due to an increase in temperature. The increasing ocean heat content was shown in Figure 9. Hence, as temperature rises, the volume of seawater increases. The volume increase is converted to an equivalent rise in sea level referred to as the steric height (or sometimes referred to as the thermosteric height). The steric height (mm) is plotted as the green diamonds in Figure 11.

Now we can combine these two factors discussed above and calculate the rise in sea level as given by the simple equation:

Sea level rise (mm) = Ocean mass (mm) + Steric height (mm)

This is illustrated in Figure 11 as the red triangles and, with a linear regression, allows an estimation of sea level rise. The contribution of each factor can also be determined from the slopes of the appropriate linear regressions.

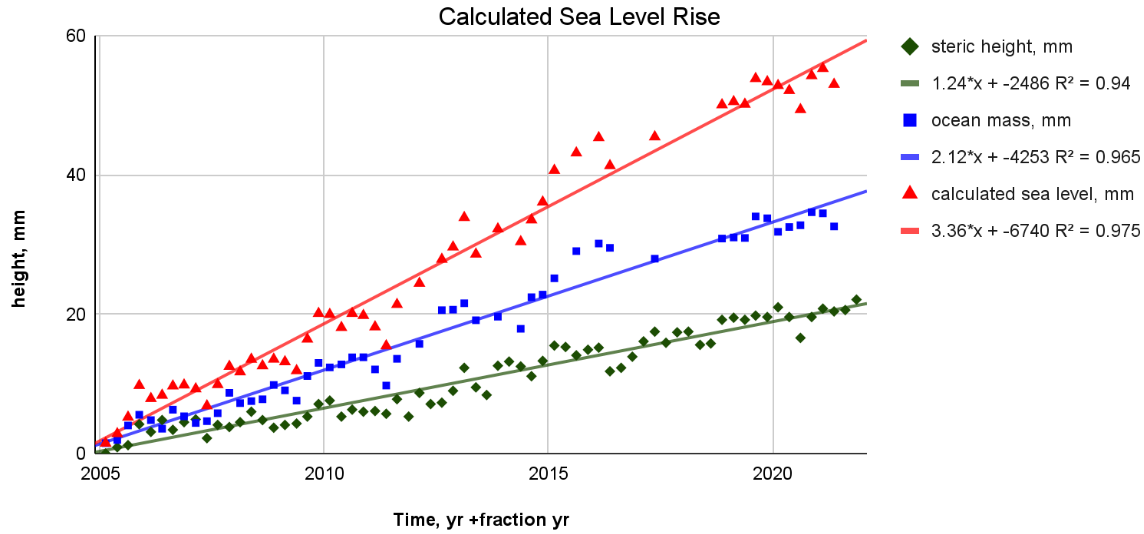


Figure 11 - Calculated Sea Level from Steric Height and Ocean Mass from Glacial Ice Melt (mass loss converted to volume of added water, then to sea level height in mm)

This calculated sea level discussed above allows for a comparison to the sea level determined by satellite altimetry (Sinex 2022b).

<u>Validation of Sea Level Rise Model</u>

Validation is an important part of the mathematical modeling process and it is not always readily possible in many situations. A really good manipulative activity to introduce validation can be found in Sinex (2017). Let's examine two different ways of comparing the two data sets.

The first method is to do a y = x comparison plot where, if the data sets are in perfect agreement with each other, the data points will all fall on the y = x line (slope = 1.00, y-intercept = 0, and r-square = 1.00). This implies both sets of data are errorless! This plot is illustrated in Figure 12 and clearly shows that there is variation in the data.

Since both data sets have a large variation or scatter in the data, perfect agreement is a pipe dream. What is the cause of the disagreement? Measurement error(s), random scatter, or more likely both, are all possible. …and consider the calculated sea level is a combination of two scattered measurements! All-in-all, the agreement between methods is not bad.

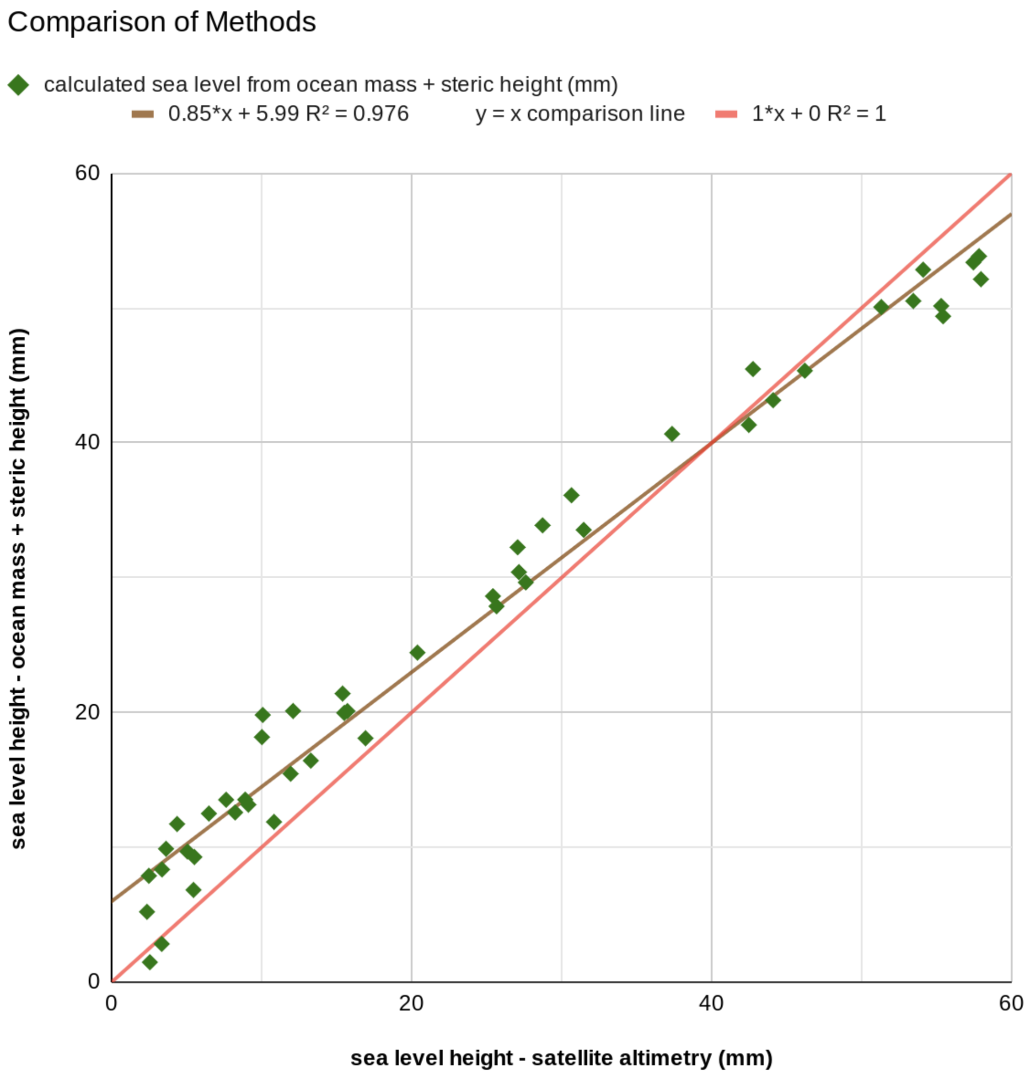


Figure 12 - Comparison of Methods of Sea Level Height: Calculated vs. Satellite Altimetry using a y = x line plot (for perfect match: slope = 1, y-intercept = 0, r^2 = 1.00)

The second method is to plot the two methods against the time in years. These results in Figure 13 are not in total agreement with NASA due to a slight difference in the time span used here. Here the altimetry data calculates a slope of 3.98 mm/yr for 2005-2021, while NASA uses the data range 1993-2020, where the slope is 3.34 mm/yr. Even using the 2005-2021 limited range data, the agreement is not bad.

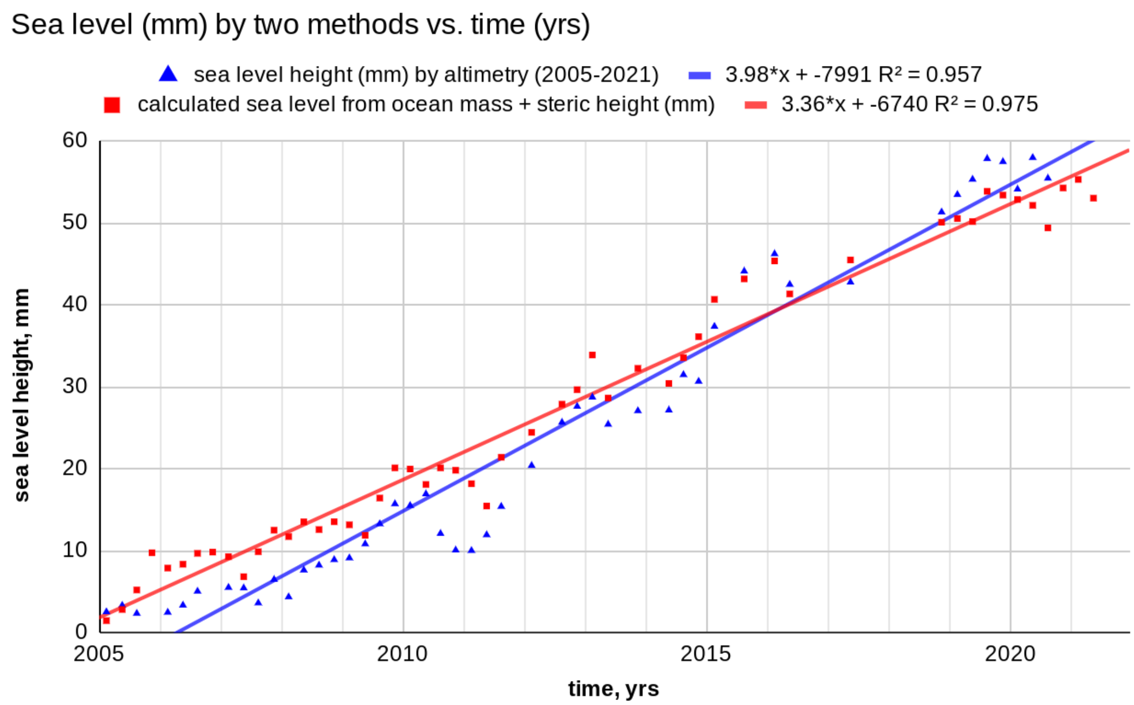


Figure 13 - Sea Level by Calculated (red squares) and Satellite Altimetry for 2005-2021 (blue triangles) vs. Time in years

Collaborative Project Presentation

This project lends itself to being a collaborative spreadsheet project and presentation of each group's results as summarized in Figure 14. Instructors would need to form small groups that would accomplish the following three tasks after assignment of the data set:

1. Spreadsheet development based on the task assigned. The instructor should have an active role in providing feedback and comments so students develop spreadsheets correctly.
2. Instructor scrambles groups for peer review and feedback for revision.
3. Groups design presentation slides (limit of 2) to deliver graphs and their models and analysis. Students should attempt to order the group presentation by cause (see Figure 1).

A whole class discussion, either face-to-face or online using the comment and chat feature in Google Slides should ensue. For instructors seeking more information, see Data Pool in the Cloud and Sinex et al. (2016a, 2016b).

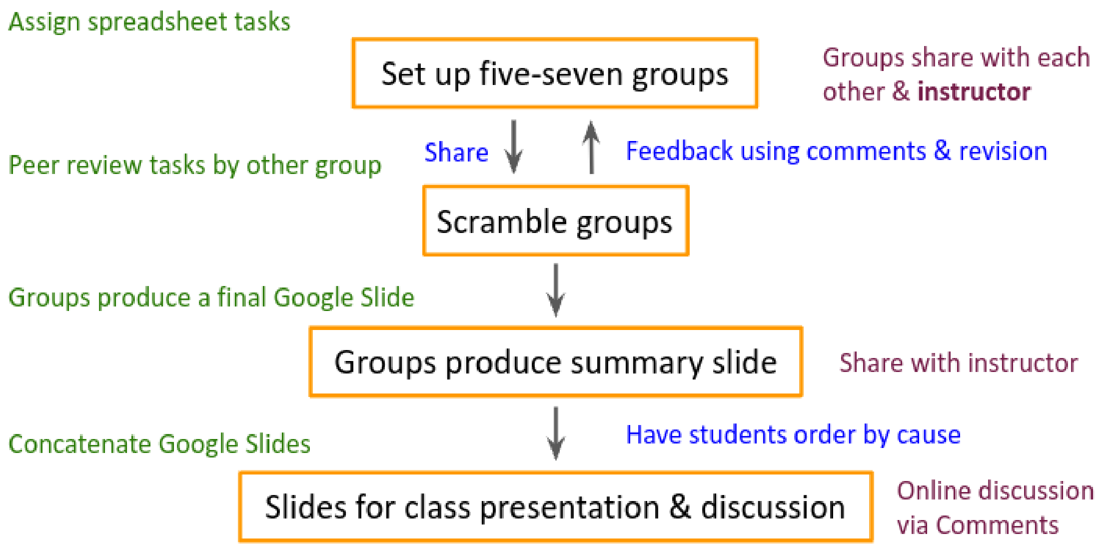


Figure 14 - Online collaborative project - class presentation of final results

Some Final Thoughts

So, what was accomplished? Using a wealth of publicly available large data sets, students investigated a variety of environmental issues using some basic mathematical modeling skills. The large data sets get students working with authentic and scattered data, which have led some to suggest the term messy data. Honestly, the messy data people have rediscovered error analysis! …and they added some things like missing data as an error! Missing data is just missing data, NOT an error. Missing data was very common in the data sets used here. One thing that is handled correctly is that variation in nature can be much greater than in the laboratory. So dealing with data that contains scatter is important and it should get more time in math and science classes. Teaching about variability is a good start (Hunter-Thomson 2022). Students also get to see a variety of measurements that really should convince them that the Earth is warming!

The results for the various data sets are summarized in Table 3. All but the glacial ice mass loss show acceleration in the measured parameters and when more recent data is examined show an increase in the rate compared to the total data set. The rise in sea level caused by the variety of factors discussed here will bring an interesting future to coastal and island areas and the environmental refugees that will migrate to higher ground.

How do you get students into error analysis? Start simple and have them make errors! Measuring objects (stacked cookies, Nerf balls) with rulers is a good start. If the rulers do not have the zero mark at the end of the ruler, did students notice and correct for it? Want to go nuts with ruler errors, see Rulers and Measurement Errors, a simple measuring device students think they understand how to use. This interactive Excel spreadsheet demonstrates how students can mess up a graphical data set, plus it illustrates absolute and relative error. Fun for all and it includes assessment questions.

Getting students to detect curvature in data sets requires some practice. Residuals could be done to help detect curvature in a data set. See Is it really linear?, an interactive Google Sheets spreadsheet that introduces residuals and the residual plot, plus has assessment questions.

Table 3 - Linear vs. quadratic models and more recent piecewise linear models

Measured parameter	Quadratic regression and acceleration, a*	Piecewise linear regressions	Comments
Satellite altimetry - global mean sea level (see Sinex 2022b)	Yes, a = 0.083	(2010-2020) Rate = 4.8	Acceleration model discussed in Sinex (2022b)
Carbon dioxide GHG GWP** = 1	Yes, a = 0.027	(2010-2019) Rate = 2.37	--
Methane GHG GWP = 28x	Cubic with rapid rise in 2007	NA	Rise from anthropogenic sources
Nitrous oxide GHG GWP = 265x	Yes, a = 0.022	NA	Ozone-depleting substance as well
Global mean temperature	Yes, a = 8.95×10^{-5}	(1970-2021) Rate = 0.019	--
Ocean heat 0-700m	Yes, a = 1.2×10^{-2}	(2000-2020) Rate = 0.63	Warming faster than deep water
Ocean heat >700-2000m	Yes, a = 5.0×10^{-3}	(2020-2020) Rate = 0.37	--
Ocean surface temperature	Yes, a = 2.6×10^{-4}	(1970-2021) Rate = 0.022	--
Glacial ice mass loss	No, still linear decline	NA	--

*acceleration, a = 2ɑ where ɑ = the coefficient of the x^2 term in standard form of the quadratic equation

**greenhouse gas global warming potential, relative to CO_2 for 100-yr time horizon from:
https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

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References

Dorsey, C (2021) Teaching in a World of Messy Data, **The Science Teacher 88** (5): 8.

EPA Climate Change Indicators (2021) at https://www.epa.gov/climate-indicators (accessed May 2022).

Hunter-Thomson, K (2022) Why is Variability Worth the Teaching Challenge? **Science Scope 45** (3), 8-13.

Keeling Curve (nd) at https://keelingcurve.ucsd.edu/ (accessed May 2022).

NOAA (nd) CFCs and their substitutes in stratospheric ozone depletion at https://gml.noaa.gov/hats/about/cfc.html (accessed May 2022).

NASA JPL (2022) Ice Sheets and Glaciers at https://gracefo.jpl.nasa.gov/science/ice-sheets-and-glaciers/ (accessed May 2022).

Reay, D (2015) **Nitrogen and Climate Change: An Explosive Story**, Palgrave Macmillan, New York, NY, 220pp.

Schultheis, EH & Kjelvik, MK (2020) Using Messy, Authentic Data to Promote Data Literacy and Reveal The Nature Of Science, **The American Biology Teacher 82** (7), 439–446.

Sinex, SA (2005) Investigating Types of Errors, **Spreadsheets in Education 2** (1) 115-124.

Sinex, SA (2013) Investigating and Visualizing Measurement Error for Novice "STEM" Learners in *Proceedings of the Spring 2013 Mid-Atlantic Section Conference of the American Society of Engineering Education*, pp. 222-234.

Sinex, SA, Chambers, TL, and Halpern, JB (2016a) Oh Sheets!: A Tool for Online Collaboration in the Cloud, **Spreadsheets in Education 9** (2), Article 2.

Sinex, SA, Chambers, TL, and Halpern, JB (2016b) Inspiring Online Collaborative STEM Learning, **MRS Advances 1** (56), 3727–3733.

Sinex, SA (2017) Multivariable Spreadsheet Modeling and Scientific Thinking via Stacking Bricks in *Electronic Proceedings of the ICTCM Conference*, Vol. **28**, pp. 381-390.

Sinex, SA (2022a) Relative Sea Level Change: A Global Problem in Your Backyard in *Electronic Proceedings of the ICTCM Conference*, Vol. **33**, 8pp.

Sinex, SA (2022b) Global Determination of Sea Level Height via Satellite Altimetry in *Electronic Proceedings of the ICTCM Conference*, Vol. **33**, 11pp.

Solomon, S, Ivy, DJ, Kinnison, D, Mills, MJ, Neely III, RR, & Schmidt, A (2016) Emergence of healing in the Antarctic ozone layer, **Science 353** (6296), 269-274.

Solomon, S, Alcamo, J, & Ravishankara, AR (2020a) Unfinished business after five decades of ozone-layer science and policy, **Nature Comm. 11**, Article number: 4272, 4pp.

Solomon, S (2020b) Risks to the Stratospheric Ozone Shield in the Anthropocene, **Ambio 50**, 44-48.

UN Environment Programme (nd), The Montreal Protocol at https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol (accessed May 2022).

von Schuckmann, K (2020) Heat stored in the Earth system: where does the energy go?, **Earth Syst. Sci. Data, 12**, 2013–2041.

Zhang, Z et al. (2022) Anthropogenic emission is the main contributor to the rise of atmospheric methane during 1993–2017, **National Science Review 9**: nwab200.

Classroom Resources

Is it really linear? (2019) at https://docs.google.com/spreadsheets/d/17k5NSx8iRuN2shtk-GzgDEctRvKDIbeOVuDn9CoThjc/edit?usp=sharing (accessed May 2022).

NASA Sea Level Change: Observations from Space at https://sealevel.nasa.gov/ (accessed May 2022).

Rulers and Measurement Errors (2012) at http://academic.pgcc.edu/~ssinex/excelets/Ruler_error.xls (accessed May 2022).

Sea Level Change at https://sites.google.com/view/ssinex/home/sea-level-change (accessed May 2022). This includes the tide gauge and satellite altimetry project GSheets.

For information on online collaboration in Google Drive, see Data Pool in the Cloud (accessed May 2022).