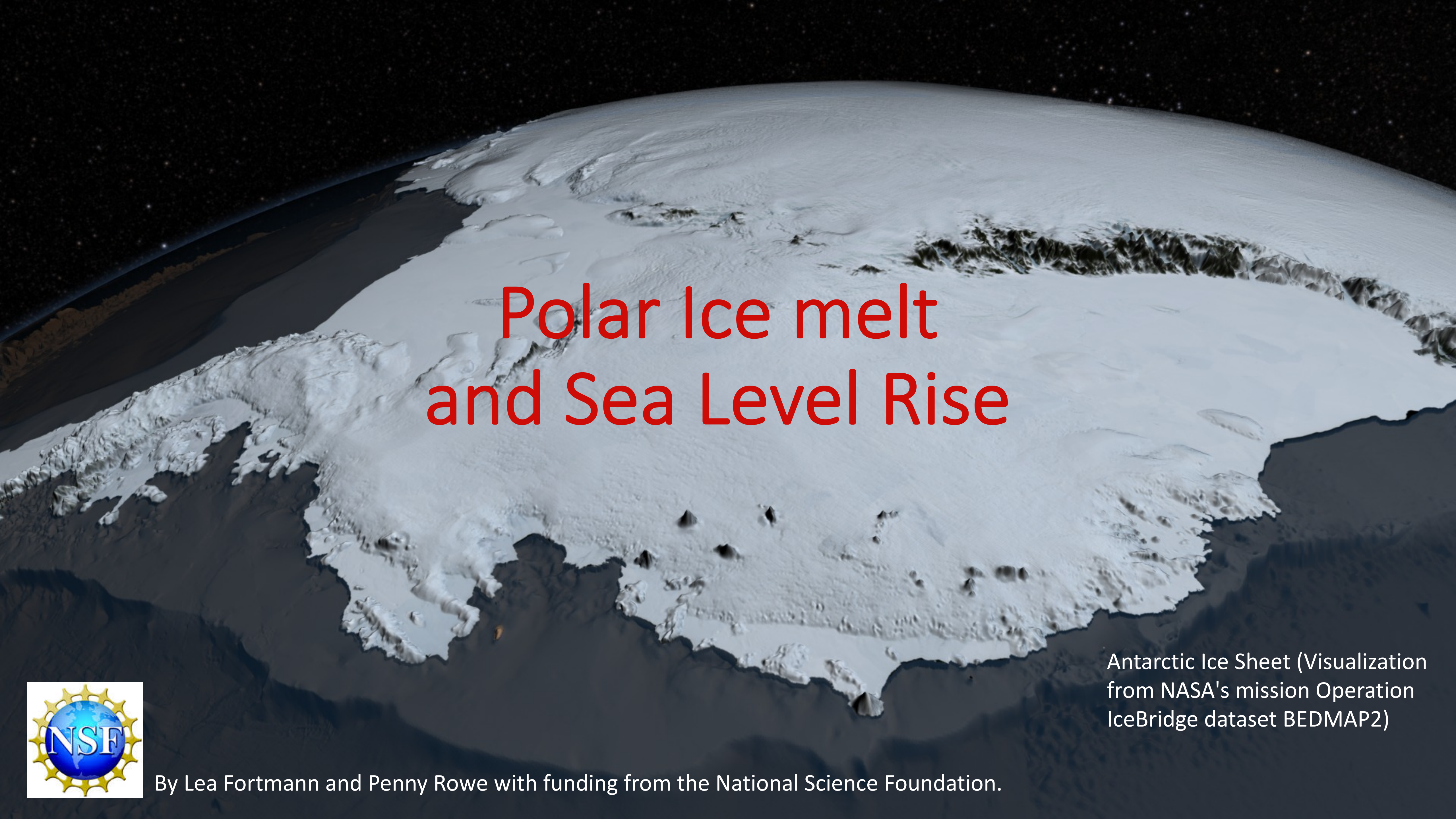


Polar Ice melt and Sea Level Rise

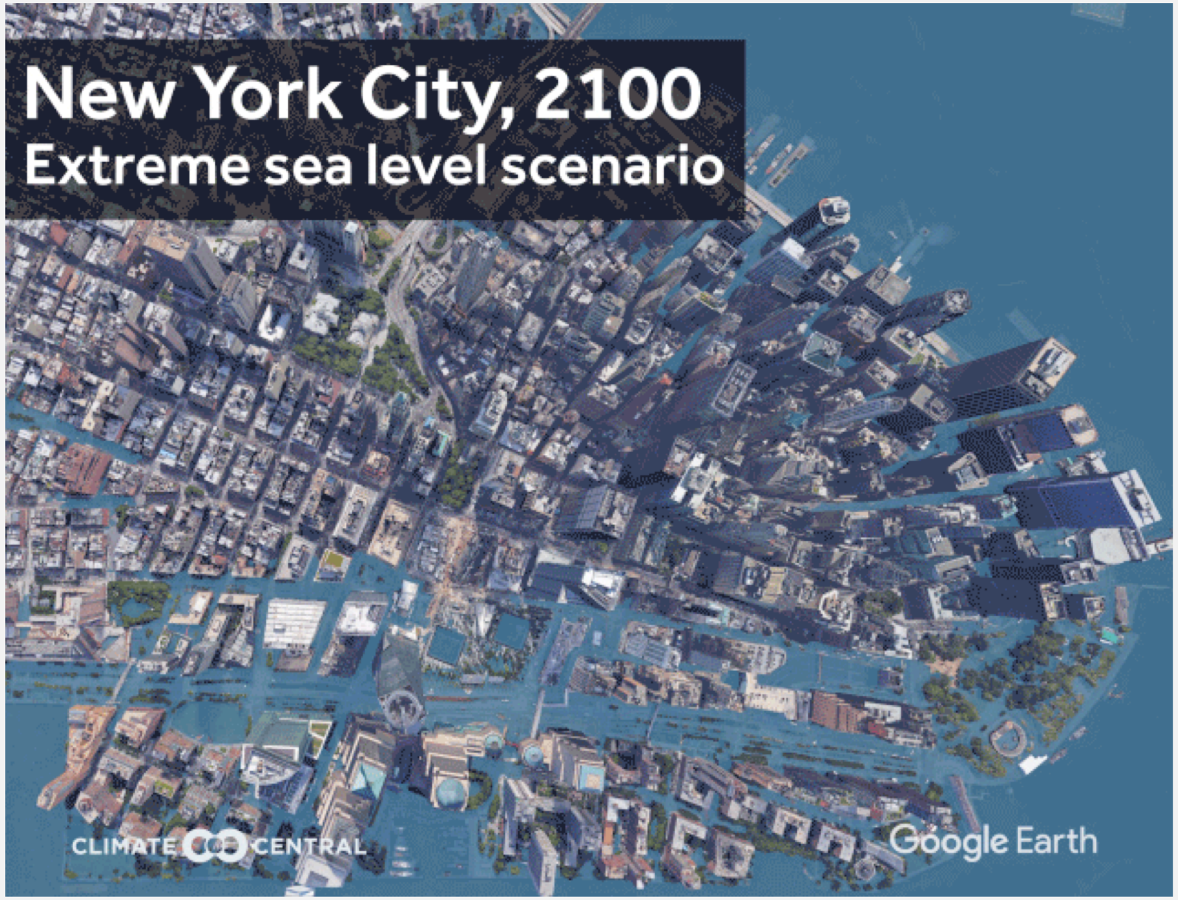
Antarctic Ice Sheet (Visualization from NASA's mission Operation IceBridge dataset BEDMAP2)

By Lea Fortmann and Penny Rowe with funding from the National Science Foundation.

Learning Objectives and Module Overview

In this module you will explore:

- Why is sea level rising and how are polar regions contributing?
- What is storm surge and how will it affect us?
- How should we prepare?



From Climate Central (https://www.climatecentral.org/outreach/alert-archive/2017/2017SeaLevelCM-TVM.html)

Learning Objectives and Module Overview

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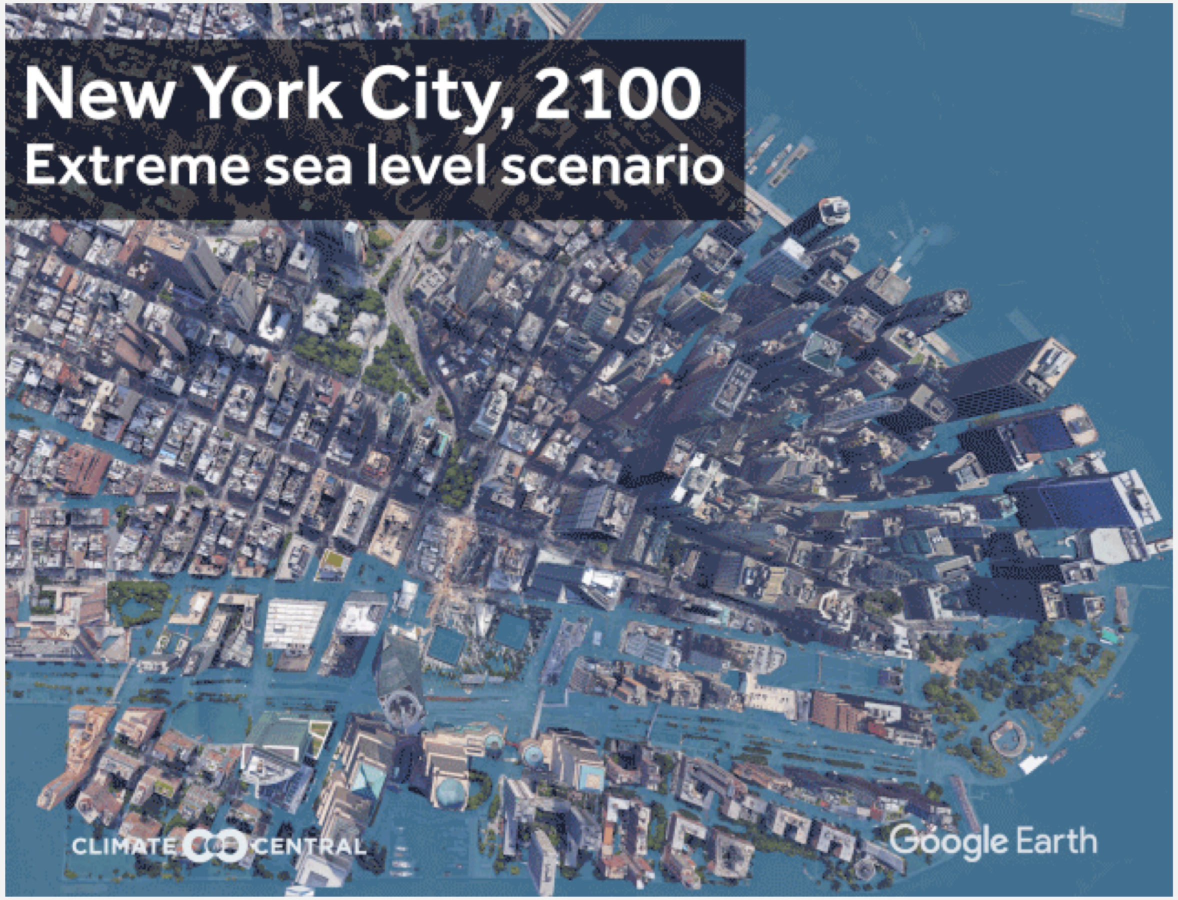


From Climate Central (https://www.climatecentral.org/outreach/alert-archive/2017/2017SeaLevelCM-TVM.html)

Making Decisions Under Uncertainty

How should we prepare for sea level rise?

We could build a wall to keep out the rising seas.

How high should it be?

- $ How much will it cost?
- $ How much will it save (in damages)?

By Oikos-team at English Wikipedia - Transferred from en.wikipedia to Commons., Public Domain, https://commons.wikimedia.org/w/index.php?curid=2746549

How much will the damages from sea level rise be?

Quick review of calculations of damages due to SLR so far:
We calculated expected damage values using the probability of a selected flood level for different sea level rise scenarios.

In your worksheet, click on the “Damage Graphs” tab in the bottom left.

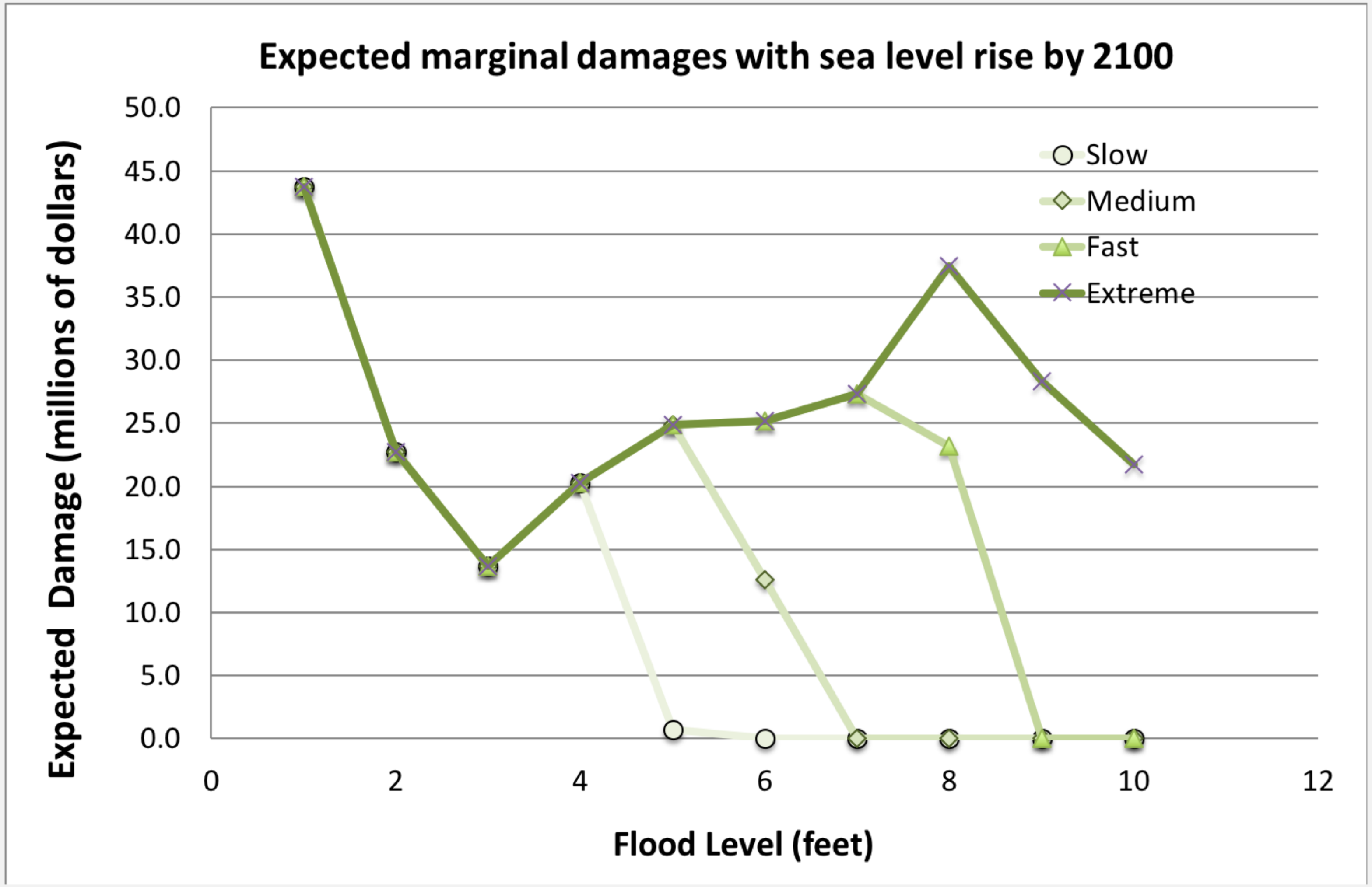
Note that Table 3 was auto filled with the expected marginal damages you calculated for the different sea level rise scenarios.

Table 3. Expected marginal damages per foot of additional flooding by 2100 by SLR scenario (millions of $)

Flood (ft)	Slow	Medium	Fast	Extreme
1	39.6	39.6	39.6	39.6
2	20.7	20.7	20.7	20.7
3	8.1	8.1	8.1	8.1
4	13.0	13.0	13.0	13.0
5	0.5	15.4	15.4	15.4
6	0.0	9.8	19.6	19.6
7	0.0	0.0	24.9	24.9
8	0.0	0.0	21.5	34.7
9	0.0	0.0	0.0	23.8
10	0.0	0.0	0.0	19.6

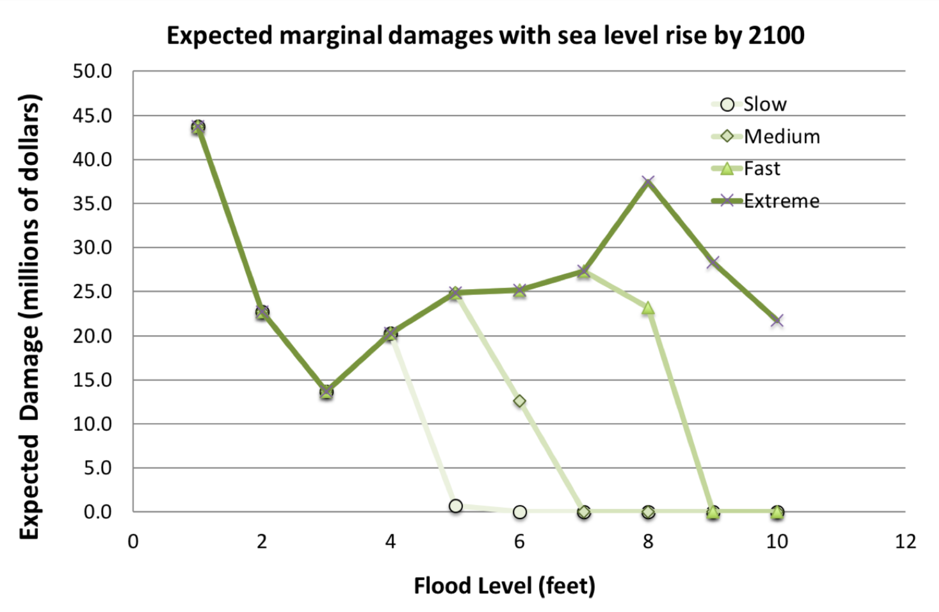
How much will the damages from sea level rise be?

Pause for Analysis 7: Discuss as a class or think about the marginal damage graph, and answer the questions to the right. (The example shown here may differ from your graph).



- What does this graph show?
- Why is the marginal damage sometimes lower for higher flood levels?
- For what flood levels are the damages the same for all scenarios and why?
- Why do the damages drop off to 0?

How much will the damages from sea level rise be?



- This graph shows the marginal damages, or the *additional damages, for each additional foot of sea level rise*.

In the example to the left:

- There is more damage for the first foot of SLR than for the second foot. This may be because the second foot of flooding impacts fewer additional homes or because it is less probable.
- For flood levels below 5 feet, the marginal damages are the same for all scenarios because they all have the same likelihood of flooding to these levels.
- The damages drop off to zero when the additional homes affected drops to 0 or the probability of a flood at that level drops to zero.

How much will the damages from sea level rise be?

Q: Which expected marginal damage value should we use?

Table 3. Expected marginal damages per foot of additional flooding by 2100 by SLR scenario (millions of $)				
Flood (ft)	Slow	Medium	Fast	Extreme
1	39.6	39.6	39.6	39.6
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4	13.0	13.0	13.0	13.0
5	0.5	15.4	15.4	15.4
6	0.0	9.8	19.6	19.6
7	0.0	0.0	24.9	24.9
8	0.0	0.0	21.5	34.7
9	0.0	0.0	0.0	23.8
10	0.0	0.0	0.0	19.6

A: It depends on how much sea level rises, which depends on **how much fossil fuel we burn**.

What greenhouse gas emissions path will we take?

Will we follow the slow, medium, fast, or extreme sea level rise?

- It depends on the path we take: how much greenhouse gases we emit.
- What are the possible greenhouse gas emission paths?
- Which will we follow?
- How much polar ice will melt and how fast?
- Lots of uncertainty!

What greenhouse gas emissions path will we take?

The Intergovernmental Panel on Climate Change (IPCC) has defined paths we may take

- Depend on our greenhouse gas emissions.
- Plenty of uncertainty!

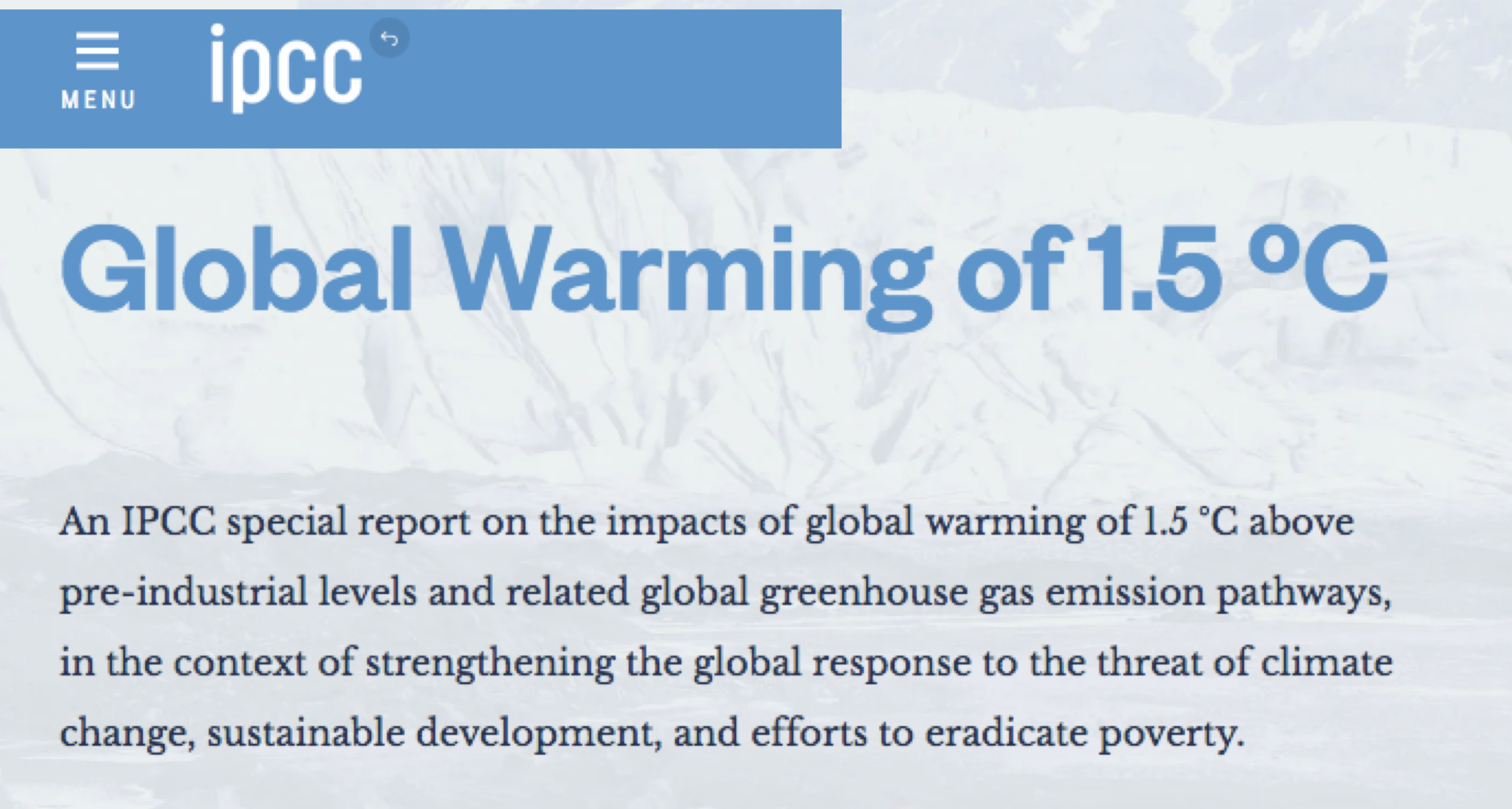
What is the IPCC?

- United Nations panel
- Assesses climate change: implications, risks, adaptation, mitigation
- Produces Assessment Reports
- Uses existing research

What greenhouse gas emissions path will we take?

Optional: check out the IPCC

https://www.ipcc.ch/



What greenhouse gas emissions path will we take?

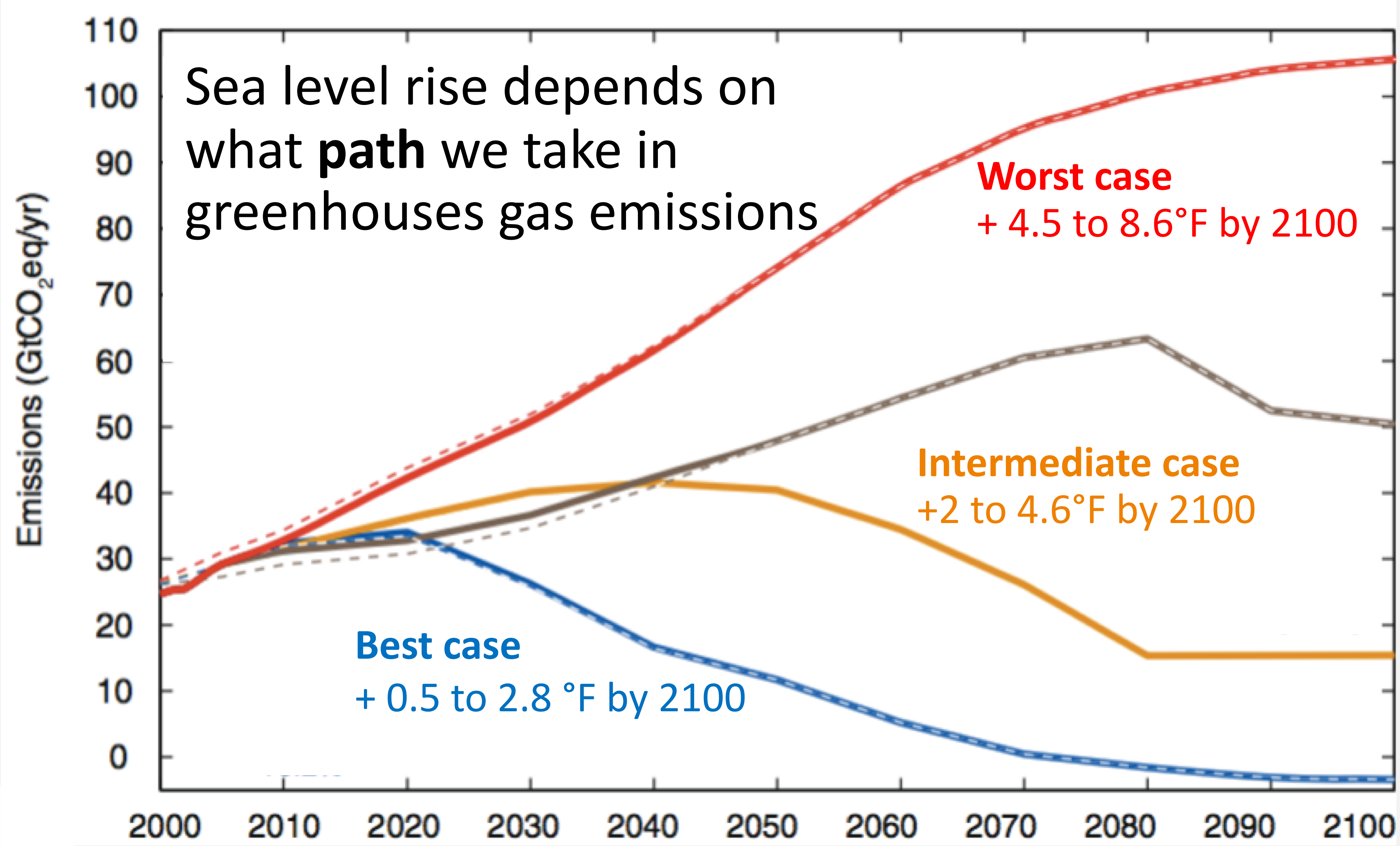


Figure adapted from Meinshausen et al (2011).

What greenhouse gas emissions path will we take?

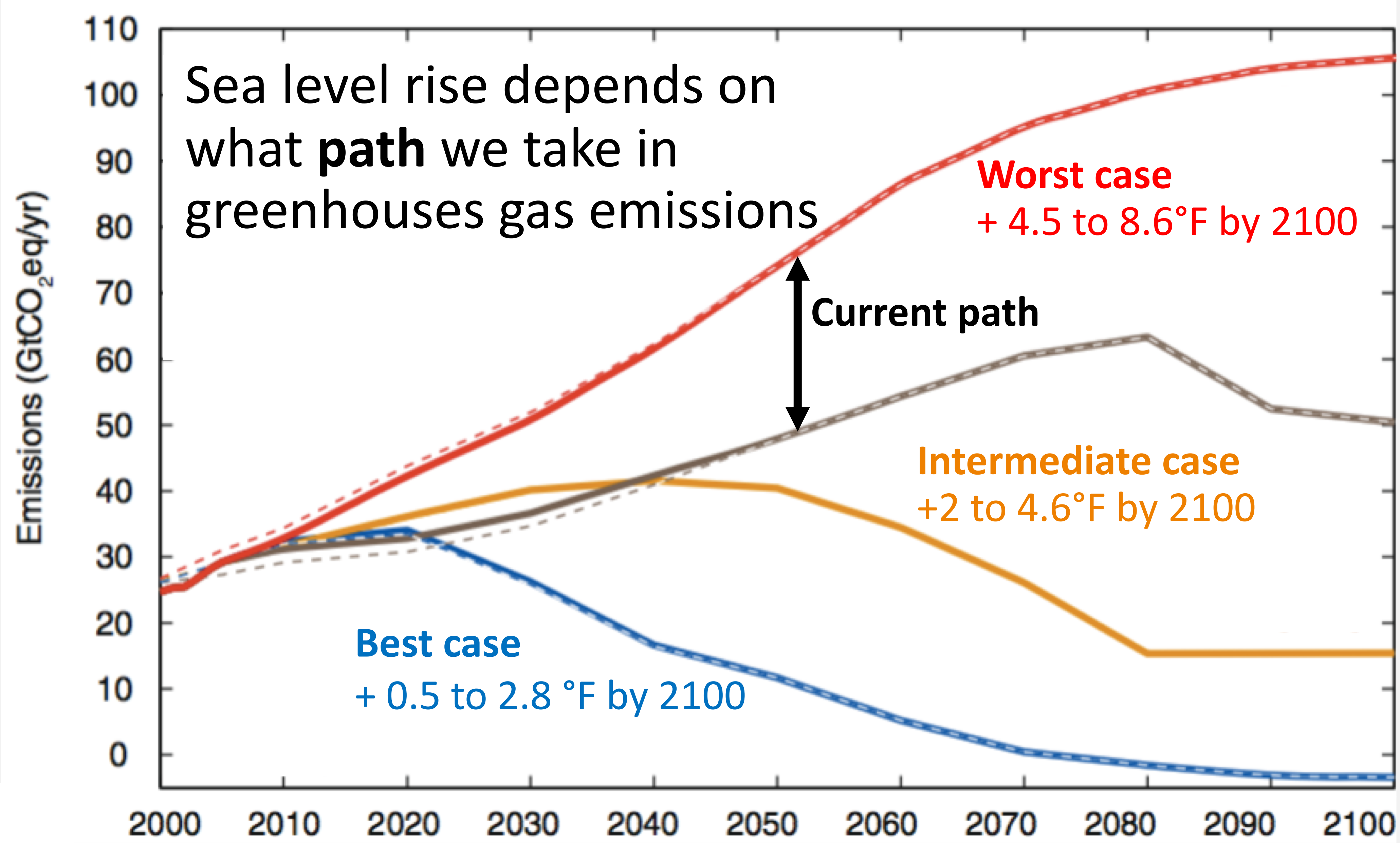


Figure adapted from Meinshausen et al (2011).

What greenhouse gas emissions path will we take?

Pause for Analysis 8: Consider the emissions scenarios.

- Think about or discuss with peers what factors (economic, social, political, technological, etc.) would increase the probability of following the best case path?
- What factors would increase the probability of following the worst case path?
- What path do you think we will follow? Why?
- Do you think Coronavirus will have any effect on the path we follow?

Connecting our greenhouse gas emission path to sea level rise

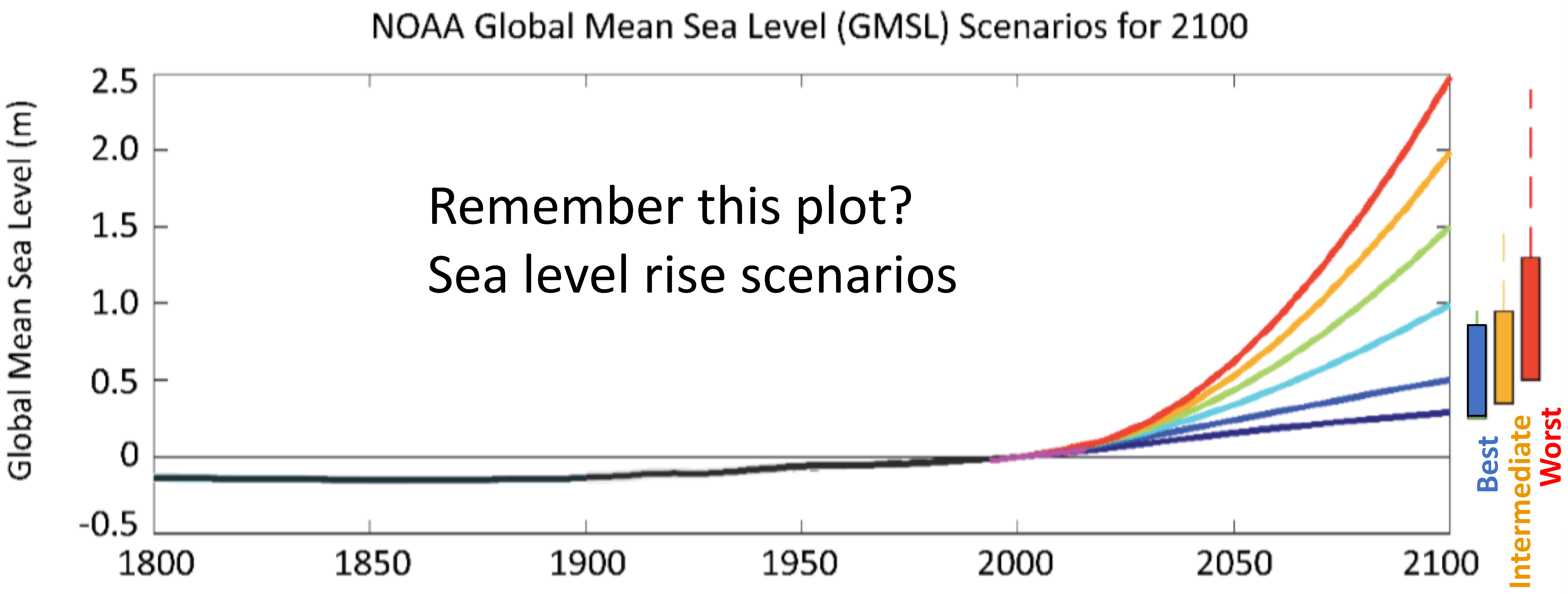
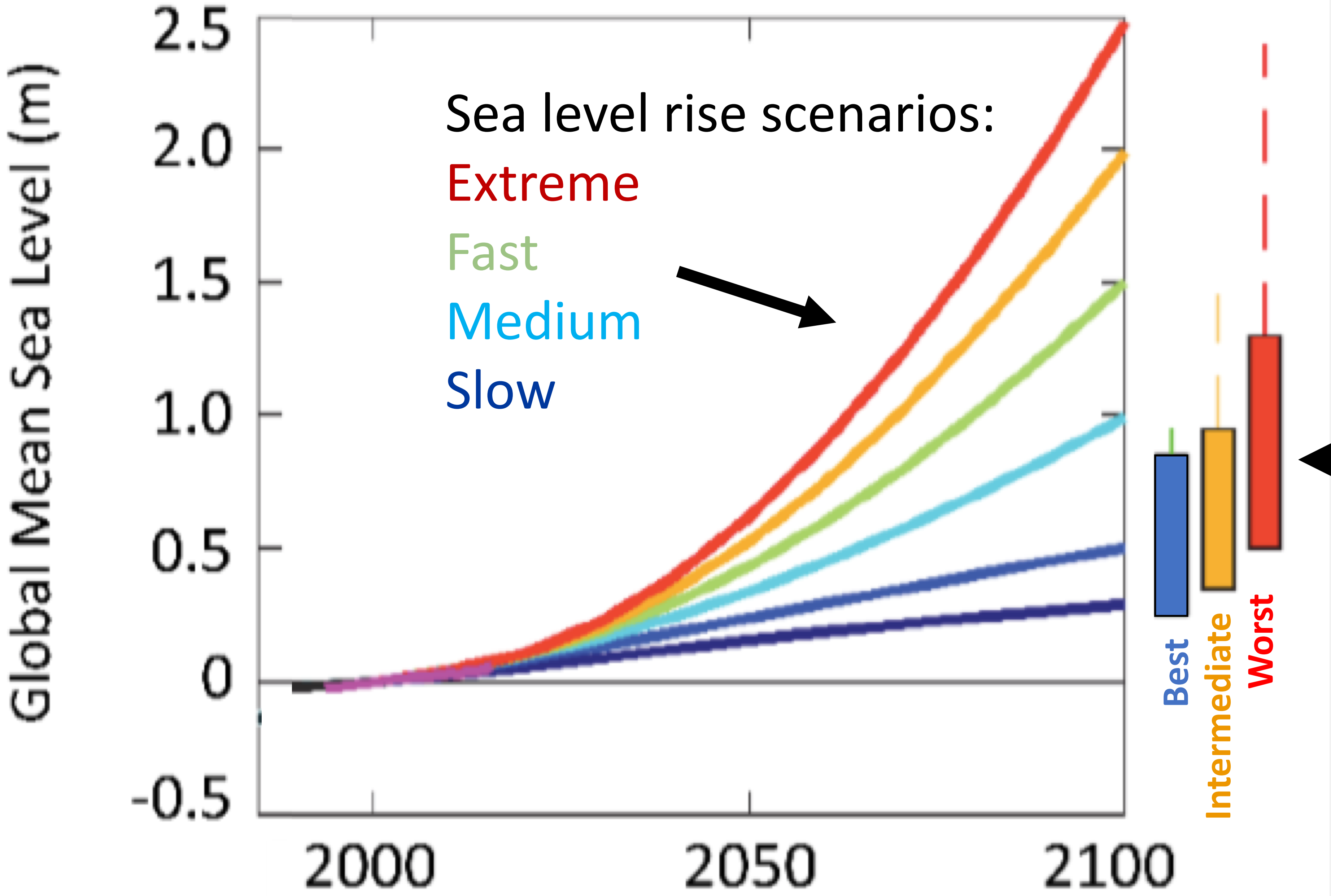


Figure 8. This study's six representative GMSL rise scenarios for 2100 (6 colored lines) relative to historical geological, tide gauge and satellite altimeter GMSL reconstructions from 1800–2015 (black and magenta lines; as in Figure 3a) and central 90% conditional probability ranges (colored boxes) of RCP-based GMSL projections of recent studies (Church et al., 2013a; Kopp et al., 2014; 2016a; Slangen et al., 2014; Grinsted et al., 2015; Mengel et al., 2016). These central 90% probability ranges are augmented (dashed lines) by the difference between the median Antarctic contribution of Kopp et al. (2014) probabilistic GMSL/RSL study and the median Antarctic projections of DeConto and Pollard (2016), which have not yet been incorporated into a probabilistic assessment of future GMSL. (A labeling error in the x-axis was corrected on January 30, 2017).

Adapted from Sweet, William V., et al, Global and regional sea level rise scenarios for the United States (2017).

Connecting our greenhouse gas emission path to sea level rise

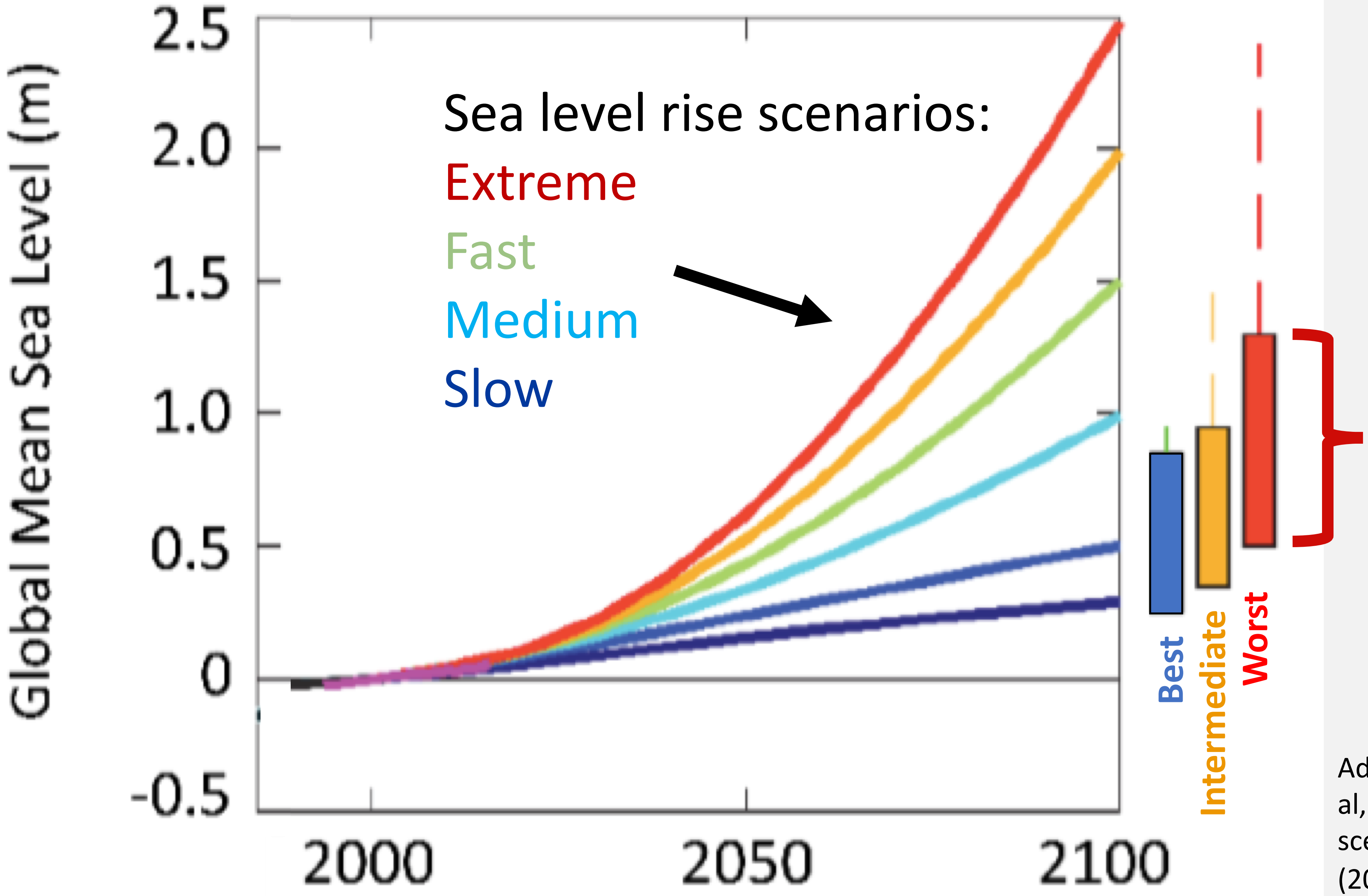


SLR scenarios depend on

Greenhouse gas emission pathways

Adapted from Sweet, William V., et al, Global and regional sea level rise scenarios for the United States (2017).

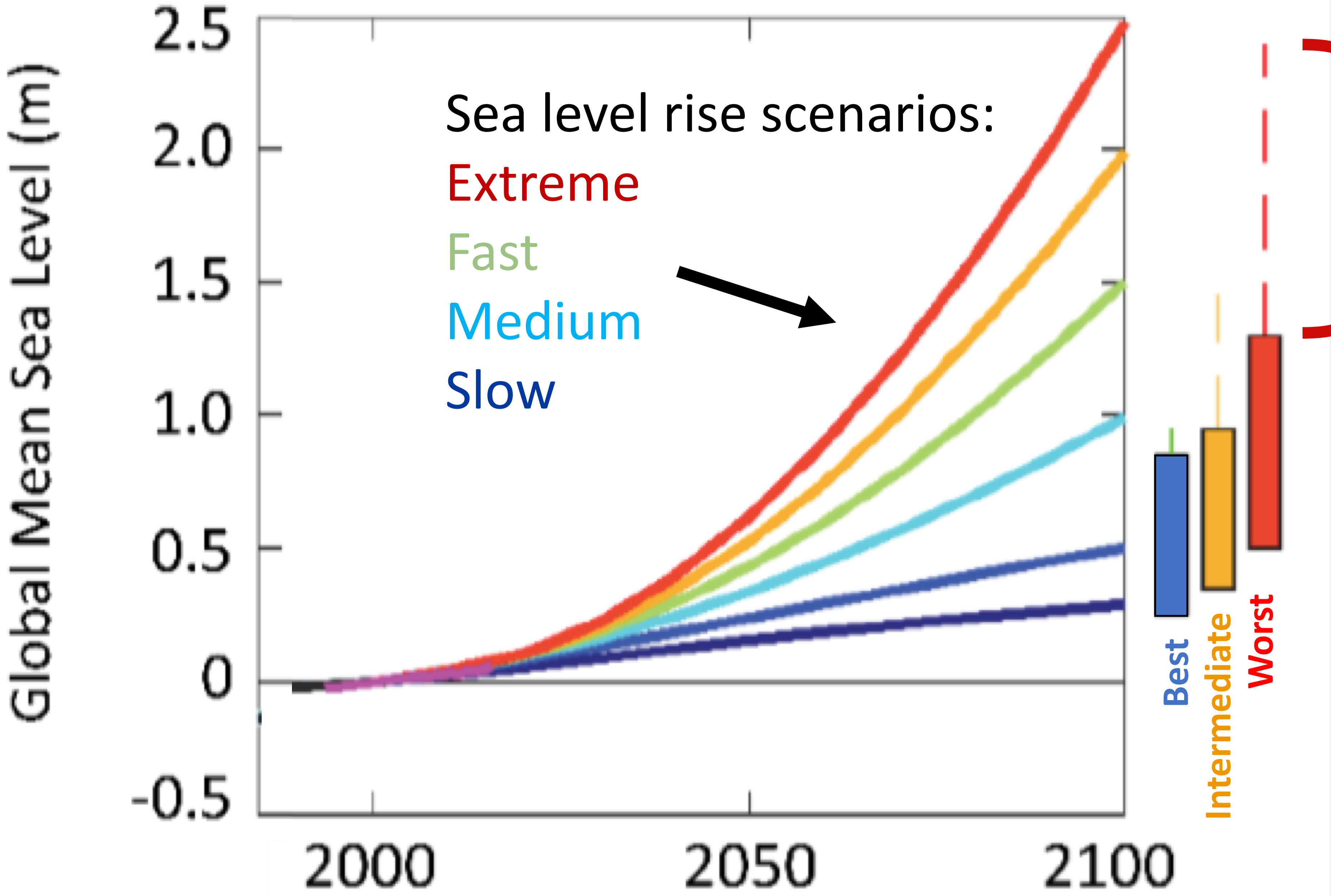
Connecting our greenhouse gas emission path to sea level rise



There's a lot of uncertainty

Adapted from Sweet, William V., et al, Global and regional sea level rise scenarios for the United States (2017).

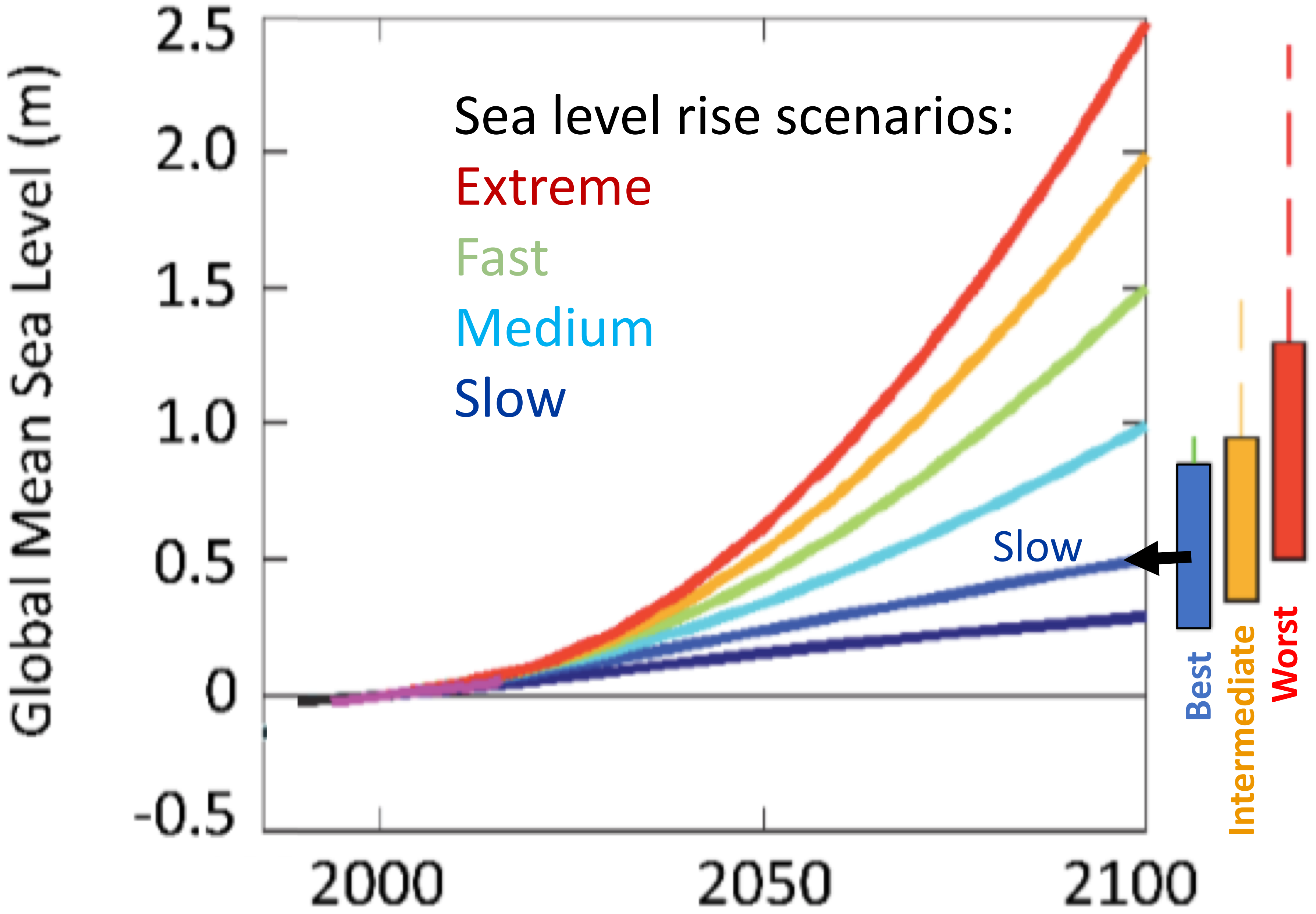
Connecting our greenhouse gas emission path to sea level rise



Dashed regions include polar ice melt

Adapted from Sweet, William V., et al, Global and regional sea level rise scenarios for the United States (2017).

Connecting our greenhouse gas emission path to sea level rise



Next we will match up the greenhouse gas paths with the closest sea level rise scenario.

1. The Best case path seems to correspond to the slow SLR scenario.

2. In your worksheet, in the Cost-Benefit tab, look at Table 4.

Adapted from Sweet, William V., et al, Global and regional sea level rise scenarios for the United States (2017).

Connecting our greenhouse gas emission path to sea level rise

Table 4. Sea Level Rise (SLR) Scenarios and greenhouse gas emission pathways

	Greenhouse gas emission path			
SLR Scenario	**Best Case**	**Intermediate**	**Worst Case, some polar melt**	**Worst Case, extreme polar melt**
Slow	0	0	0	0
Medium	0	0	0	0
Fast	0	0	0	0
Extreme	0	0	0	0
Total Sum	0.00	0.00	0.00	0.00

3. For the Best Case scenario, on the previous slide we equated it with the slow sea level rise scenario. Replace the 0 in that cell with a 1.

4. Find the closest corresponding SLR scenario for the Intermediate path and put a 1 in the corresponding cell.

5. Repeat for the Worst case path with some polar melt and with extreme polar melt.

Advanced: If you want to you can “split the difference” by putting numbers in more than one row of a column. BUT the column must sum to 1.

Connecting our greenhouse gas emission path to sea level rise

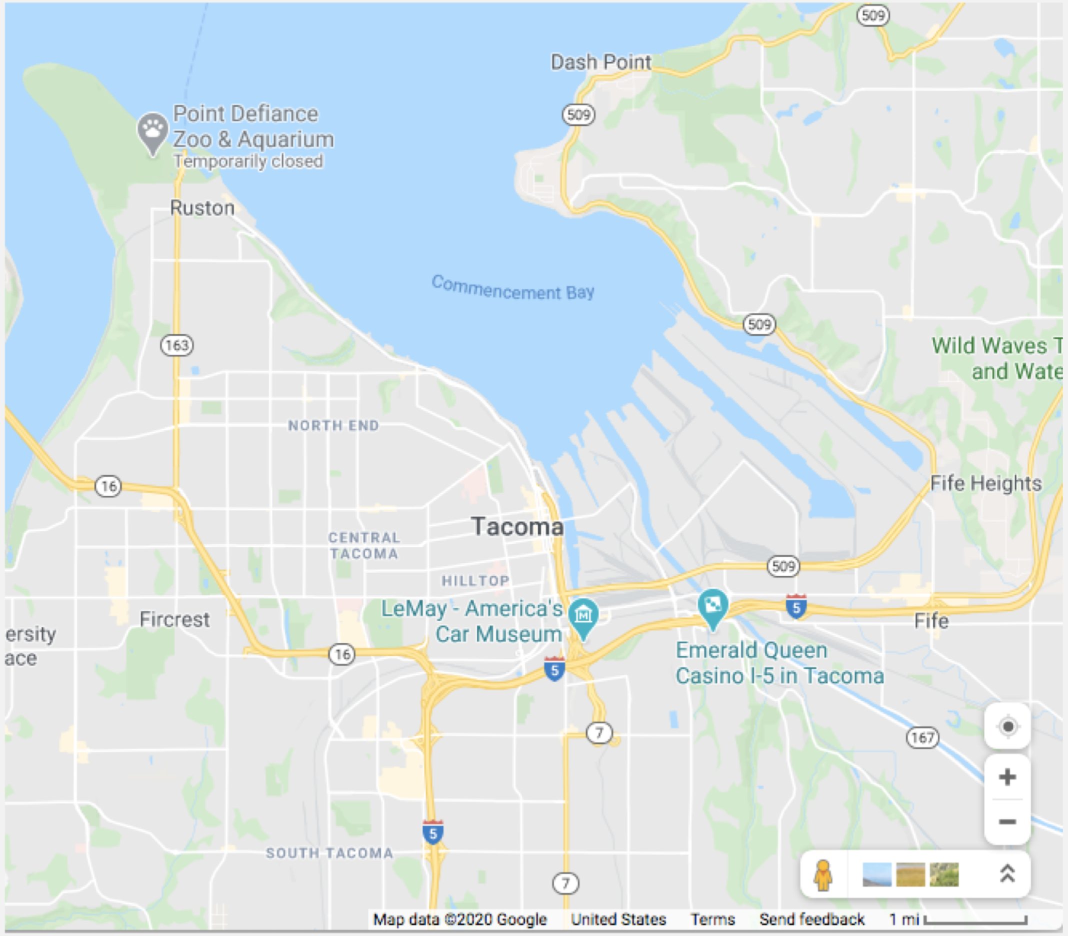
Pause for Analysis 9:

Look at the graph in the Cost-benefit for Damages tab of your worksheet.

- What influence does extreme polar ice melt have on the damages?
- How might you account for intermediate scenarios, such as different speeds of polar ice melt?
- What do you think happens after 2100?

Estimating the Cost of Building a Seawall

The final part of the analysis is to consider how much it would cost to prevent these damages. One option to consider is building a sea wall along the shoreline that would prevent the water from reaching the homes given a flooding event.

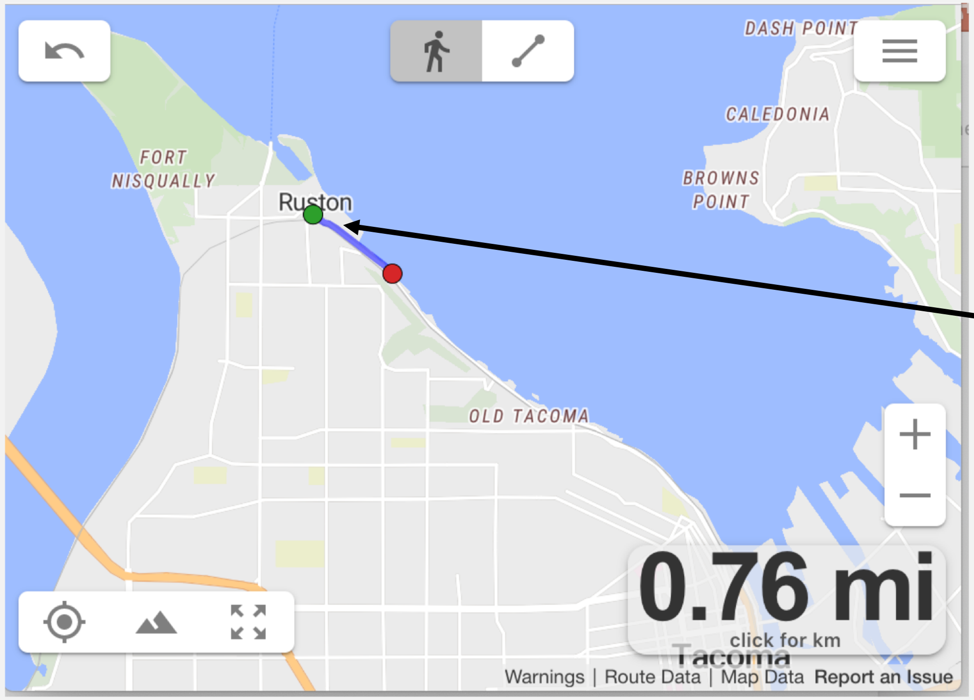


1. Go back to the riskfinder website.
2. Where would you build a seawall? What areas would you most want to protect and why?
3. Where would it be easier/harder to build a seawall?
4. What about other infrastructure might you want to protect?

We'll make our seawall 3 miles long and assume it could protect all the houses. Based on the scale in the lower right of the map, would this be a reasonable assumption for Tacoma, WA?

Estimating the Cost of Building a Seawall

Optional: choose your own seawall location and length.



1. Go to the website [onthegomap](onthegomap.com) (onthegomap.com).
2. Consider the highest priority shoreline in your region to be protected.
3. Click the plus arrow at the right to zoom in as desired.
4. Click on the map at the starting point of the wall.
5. To estimate the distance, continue clicking new points along the seawall path using the nearest road or path to the shoreline. It's ok if it's approximate.
6. To undo a point, click the reverse arrow in the upper left corner.
7. Determine how many miles long the wall would be.

In a report on cost estimates of coastal protection, researchers estimated that the cost of building a sea wall is $762 per square foot (Hudson et al. 2015). That's $762 per foot of length, per foot of height. Assume that the additional cost of building the sea wall 1 foot taller is <u>constant</u> at $762 per square foot for every foot taller the wall is built, i.e. marginal costs are constant. We'll do the calculations in the next slide.

Estimating the Cost of Building a Seawall

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Estimating the Cost of Building a Seawall

Pause for Analysis 10:

- How much would it cost to build a 1 foot tall sea wall along the length of the shoreline you just measured?
- After you've built the seawall 1 foot tall, how much would it cost to build it another foot taller?
- Hint: Do the calculations in your Spreadsheet.

Calculations

$$\#\ \mathbf{ft} = \#\ \mathbf{miles} \times \frac{\mathbf{5280\ ft}}{\mathbf{1\ mile}}$$

$$\frac{\mathbf{cost}}{\mathbf{ft}} = \frac{\mathbf{\$762}}{\mathbf{ft^2}} \times (\#\ \mathbf{ft})$$

Cost per additional foot of sea wall height

Price per foot length and per foot height

Length of wall

Estimating the Cost of Building a Seawall

Pause for Analysis 11: Figure 3 now also shows the estimated cost of building the seawall. The final step is to compare the cost of the sea wall to the damages it would prevent. Imagine you're a city planner. Discuss with a partner or in a small group what recommendations you would make based on your analysis of the graph in Figure 3 (which now also shows the seawall cost).

- Do you recommend building a sea wall?
- If so, how tall should it be?
- What factors went into your decision (sea level rise scenario you think we'll follow, level of polar ice melt you want to include, etc)?

Discussion Questions

With a partner or in a small group, discuss the following:

1. What are the assumptions you have made? What are the uncertainties?
2. Given the assumptions and uncertainties, how would you improve this analysis to make it more realistic?
3. With climate change, it's important to consider who is vulnerable and who receives the benefits of protections like seawalls. For sea level rise in your coastal city, who is vulnerable? (In the Riskfinder website, you can find information about such factors as income levels and race/ethnicity.)
4. The extreme sea level rise scenario has a very low probability of occurring. In fact one model reports that even in the event of the worst case scenario, the likelihood of 2.5+ meters of sea level rise by the end of the century is only 0.1% (Kopp et al. 2014; NOAA, 2017). Given this small probability, why do you think it is still important to take these extreme scenarios into consideration?

Post-Module Memo Assignment

Suppose that you were hired by the City to conduct an analysis on the impacts and potential damages of impending sea level rise in the region. For this assignment you will need to synthesize the information and data you have analyzed while working through the module into a 2- 3 page memo (including key figures) to the director of the City's Office of Environmental Policy and Sustainability.

The memo should:

- briefly outline the problem,
- describe how you conducted the analysis,
- summarize your results, including a recommendation for action, and
- discuss the limitations of your results.

Keep the writing clear and concise. Your recommendations should be based on data and evidence supported by your analysis.

For guidance on writing a memo, you can refer to this website from Purdue University's Online Writing Lab.

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Acknowledgements

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