Lesson 2: Climate Models

Phenomena:
Scientists must use models to understand highly complex systems and make predictions about future outcomes. Climate scientists use many sources of data to come up with comprehensive climate models, which can be used to predict weather and long-term climate trends.

Introduction:
A scientific model is representation of cause and effect relationships between components of a system that attempts to replicate the system in such a way as to be predictive. Models are necessary when the system being studied is too large or complex to be able to isolate each component and test variables within those components and the impact of these variables on the whole system. Climate is a highly complex system, but modelling allows climate scientists to identify the variables within the system and study each of them independently and then as an integrated working system.

This lesson will help students understand how models are constructed, how models work to make predictions, and the value of models to our understanding of changing climate. This lesson will also address the misconception that models cannot be trusted because they have been wrong in the past. Climate models have in fact been extremely helpful in our understanding of climate in general, and in our ability to predict the impacts of human activity on future expected changes in climate.

There are actually two ways to teach this lesson. The approach described in this main lesson challenges students to make predictions about the future which leads them to the realization that they need a model to help them. In this approach, students realize that a model grows from real data and is used to make sense of how that data is produced by complex systems.

Another approach is to ask the students to identify components of the climate system and then put them into a 2 D model. This approach works by turning the model into a diagram, similar to those of the water cycle, which identifies components and shows relationships. What students realize by turning a diagram into a model is that systems are dynamic and not static. They must think about how the relationships between components are themselves impacted by many factors. See this approach in Lesson 2 Lower Grade Levels.

Lesson Outline:

Age Level	Grade 5-12 (three options will be developed for 5th, middle, and high school applications. High school accommodations will also be developed for 9th grade bio, AP Bio, and Envi Sci applications)
Time Needed	2-3 60 minute periods

Vocabulary	● **Weather**: Short term (minutes to months) changes in the atmosphere that we can feel and see. ● **Climate**: Long term averages (usually 30 years) of daily weather. ● **Climate change**: Change in Earth's climate. ● **Climate change prediction**: Prediction of the average weather over a long timescale into the future. ● **Climate models**: Models are a set of mathematical equations representing the earth system and constructed using the known physical laws. ● **AGCM**: Atmospheric general circulation model ● **CGCM**: Coupled general circulation model ● **Predictability**: Limit of prediction. ● **Skill**: Ability to faithfully forecast. ● **Uncertainty**: Error in forecast.
Student Learning Outcomes	● Student will learn how a climate model is developed and why it's necessary. ● Students will learn how climate models perform from past to present. ● Students will learn why is it necessary to keep improving the climate models. ● Students will learn the chaotic nature of the atmosphere. ● Students will learn why the failure of a climate model in the past does not invalidate its value.
Disciplinary Core Ideas	● HS-ESS2.D3: Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. ● HS-ESS2.D4: Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. ● HS-ESS3.D1: Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. ● HS-ESS3.D2: Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.
Performance Expectations	● HS-ESS2-4: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

	• HS-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
Educator Prep	• FLICC: Five characteristics of science denial • Video: Expert interviews on climate models • Video: Comparing climate model predictions to subsequent observations • Scientific poster: examples of 2D models by students • TMEO Lesson 2 Temp Graphs to Print • TMEO Lesson 2 Climate Model Data - Students • TMEO Lesson 2 Climate Model Data and Graphs - Teacher Key • TMEO Lesson 2 Climate Model Graphs (slides)
Fact	Climate models have made many successful predictions of long-term warming and specific climate patterns. While there are parts of climate that are challenging to simulate, such as short-term predictions, models are continually being improved to introduce more detailed physical processes.
Myth	Model predictions have failed in the past, therefore models can't be trusted.
Fallacy	**Impossible Expectations:** No model is perfect but they are useful tools that can reproduce the past and provide insights into the future.

Engage

In this lesson, students will be challenged to make predictions based on trends in evidence, and to justify their predictions.

Explore

This lesson is broken into 5 parts. It will take 2-3 days to complete.

PART 1: What do you know?

Form your students into learning groups. Have them write down ALL of the things they can think of that might influence climate.

Have each group create a poster showing how all of the these items interact.

PART 2: Background

Guide the students though the following websites. Using a worksheet like the box below, have them write down some pieces of information they think they will need to add to their posters.

https://www.climate.gov/maps-data/primer/ocean-oceanic-climate-variables	
https://www.climate.gov/maps-data/primer/land-terrestrial-climate-variables	
https://www.climate.gov/maps-data/primer/air-atmospheric-climate-variables	
https://www.climate.gov/maps-data/primer/climate-forcing	

Have the students add these pieces of information to their posters.

PART 3: Making Predictions from Real Data

Goal: Accurately predict the global anomaly for the last 20 years.

Set up:

- Each partner pair or small group will be assigned a specific data set.
- All Data Sets will include Temp Anomalies 1880-1995 and CO2 Concentrations 1880-2017
- Some will be assigned other data including: Volcanic Activity, ENSO, or Solar Irradiance. (See this spreadsheet for data.)

Student Instructions:

1. Using a spreadsheet, (Excel, Google Sheets, etc) create separate line graphs for the data sets provided.
2. Once all data has been plotted, get a printed version of the Temp Anomaly graph.
3. Based on the information your group was able to plot, predict what the Temp Anomaly graph would look like if it were plotted all the way to 2017. Draw a line to represent your prediction. Try to be as ACCURATE as possible.
4. Present your prediction to the class. Compare your line to the lines other groups drew.
5. Next, receive a printed copy of the ACTUAL Temperature Anomaly graph 1880-2017. Draw your predicted line right on the chart and compare your graph to the actual data.

Guiding Questions:

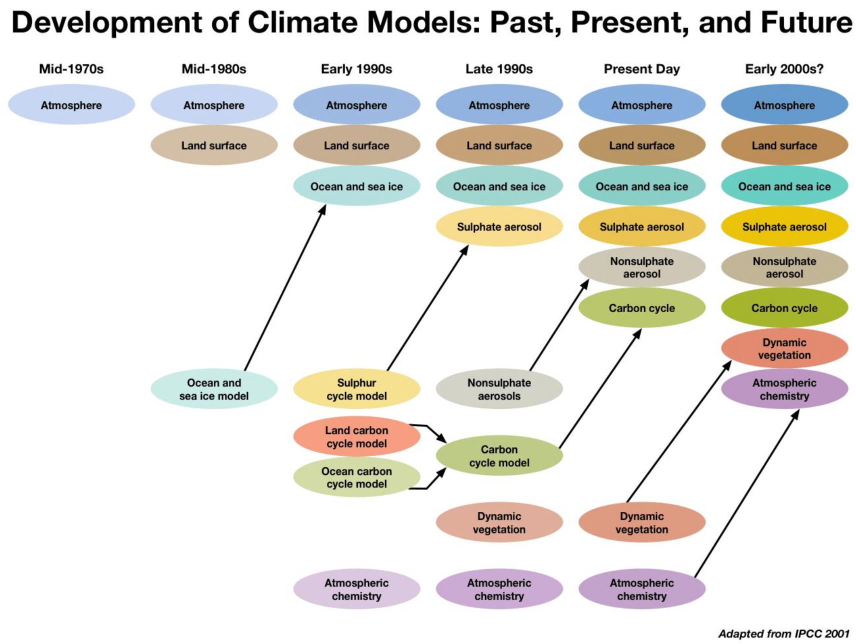
- How did your graph compare to the actual data?
- Were you accurate?
- Explain why you think this happened.

- How did your results compare to the other groups in the class.
- Did you all have the same predictions?
- Why do you think this happened?

- Were any graphs more accurate than your group's? Why do you think this happened?

Further Explanation:

Scientists model the actual climate based on a number of parameters. The chart below shows how new data sets have been added over time.



https://www.giss.nasa.gov/research/briefs/puma_02/

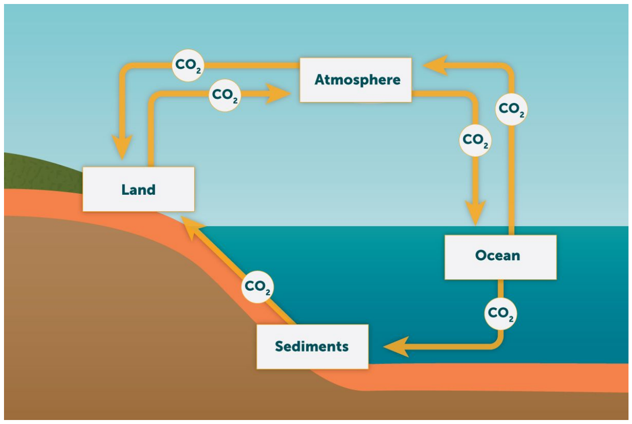
- Why do you think new data has been added?
- How was this represented in the previous graphing activity?

PART 4: Using models to make predictions

High-Adventure Science Interactive

Visit the High-Adventure Science site, "Using Models to Make Predictions".

Work through the **"Using Models to Make Predictions"** activities.



Page 1 “Complex climate models” shows the chart we saw on the previous page. Do you think that scientists have included everything that impacts climate in their models? Why or why not?

Page 2 “Time lags in temperature changes“ shows the chart on the right. Why does a lag occur in regards to CO_2 and Temperature change?

Page 3 “Meet a climate scientist: Mark Chandler” explains what climate models are and how people can determine if a model works or not. What did you learn from the video in regards to climate models?

Page 6 “How much reduction?” offers you a chance to run a simplified climate model. Press “Play” and examine how the chart moves. Describe what happens:

Run the simulation briefly again and watch the temperature graph closely. Did it follow the same path as before?

Repeat the process and run it again. Did it follow the same path this time? Why do you think this is happening?

PART 5: Uncertainty

Do you follow the weather habitually? Find someone in the class who knows what the predicted high temperature for the day is supposed to be.

Write it here: _____________ then visit https://www.weather.gov/forecastmaps .

Enter your zip code and write down the current temperature ______________

How close are the two values? Why might they not match?

Click “Get Detailed Info” and analyze the forecast.
How far does the forecast extend? Do you trust the accuracy of the prediction this many days away? Why or why not?

Now, examine the predicted future of your area’s climate. Visit https://crt-climate-explorer.nemac.org/, click “Select your location”, then enter your zip code again.

This chart shows you the predicted temperature increase expected in the city due to climate change. The shaded areas represent a range of temperatures. Why are the predictions represented by these shaded areas and not just the solid lines?

- What does “Higher Emissions” and “Lower Emissions” mean?

- Why is there so much uncertainty with these predictions?

Examine the various temperature graphs, including days 95+ degrees or <32 degrees. Does this concern you? Why or why not?

Explain

This lesson does a good job of building explanation into the activities, but you could also have your class watch a short video introduction to climate models. Main points communicated from this video are what climate models are, how models have grown in complexity, and why we can trust climate models:

https://www.youtube.com/watch?v=bPtR8YrT-fg&feature=youtu.be

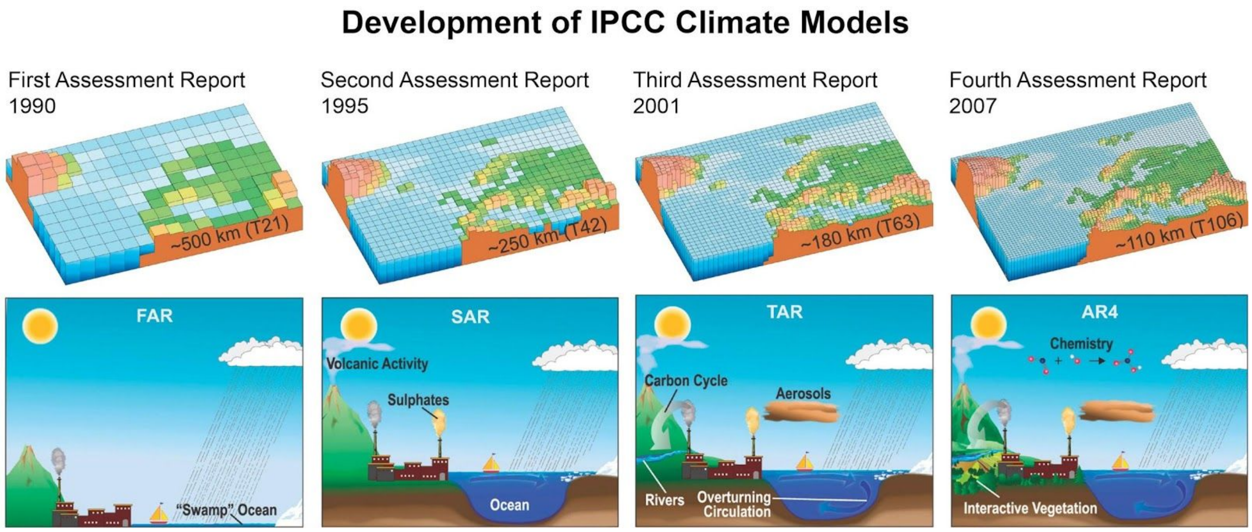


Illustration of increasing complexity and diversity of elements incorporated into common models used in the Intergovernmental Panel on Climate Change (IPCC) process over the decades. Evolution of the resolution (top) and physical complexity (bottom) of climate models used to inform IPCC reports. The illustrations (top) are representative of the most detailed horizontal resolution used for short-term climate simulations. Adapted from Figure 3.1 in A National Strategy for Developing Climate Models by NAS.

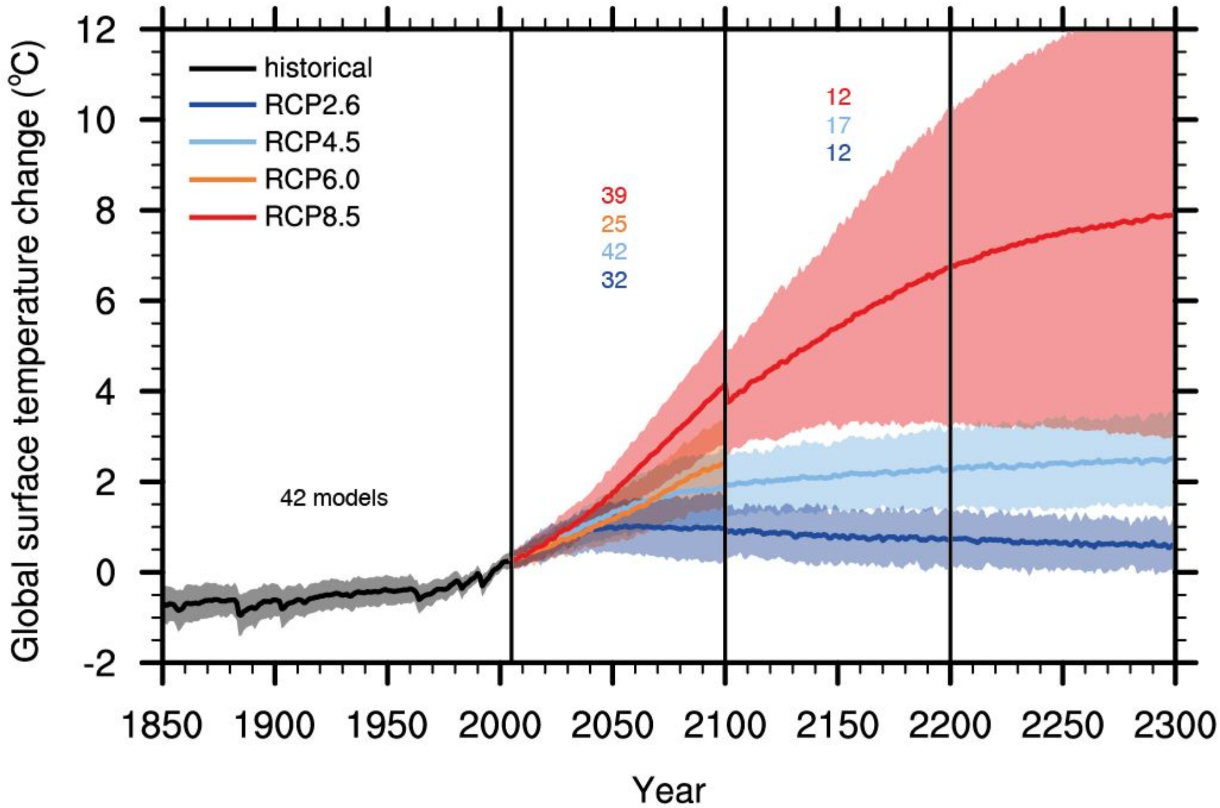
Another example of development of climate models:
https://sealevel.nasa.gov/understanding-sea-level/projections/overview

Reflection questions:

1. How do the climate models change through time?
2. What variables are present in all of the models? What variables are introduced later?

Evaluate – FLICC

The diagram below represents the latest chart illustrating the predictions of various Climate Models released in 2017 in the IPCC Fifth Assessment Report (https://www.ipcc.ch/report/ar5/).



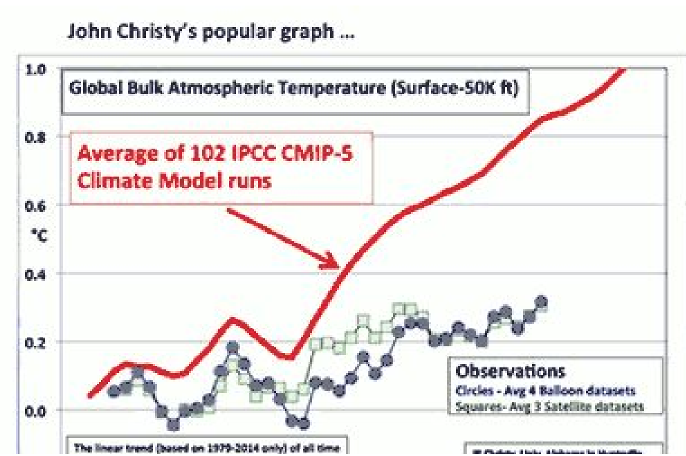
What does this represent?

Why is is so spread out? Why is there so much uncertainty?

However, some people point to the work of certain scientists who have questioned the validity of the Climate Models.

An example is shown here:
In this graph, the model clearly does not line up with the observations.

How can that be?



Go to https://skepticalscience.com/graphics.php?g=243
and examine the analysis of this graph.

What was done to make the data appear so far off from the predicted levels?

Based on the activities we have investigated, are the models perfect? Are they supposed to be? Explain your reasoning.

This is the line of thinking employed by the Climate Deniers:

Model predictions have failed in the past, therefore models can't be trusted.

This represent the characteristics called **Impossible Expectations.**
Explain how this can be used against scientists.

The animation shows a number of graphs that are accurate and show that Climate Change is happening. In the boxes below, sketch them quickly- including titles.