UCAR CENTER FOR SCIENCE EDUCATION

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Simulations and Models for Teaching Earth System Science

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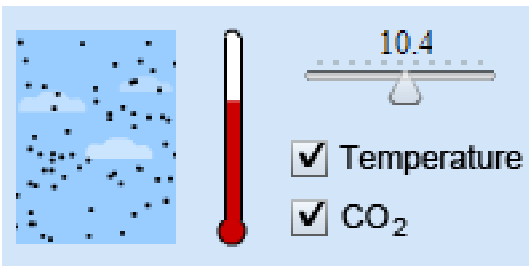
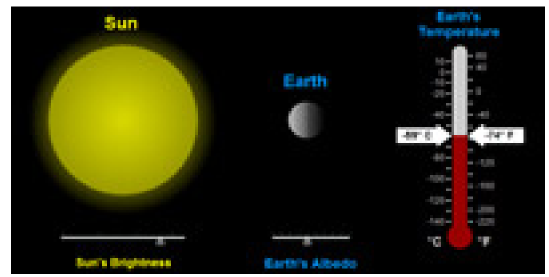
UCAR Center for Science Education

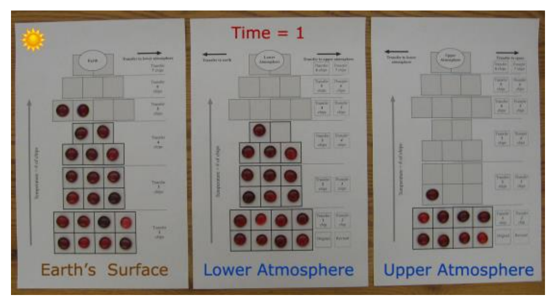
December 2018

Presentation Overview

- Mostly: demo simulations
- Quick introductions: myself, NCAR, UCAR Center for Science Education
- NGSS & Modeling
- A bunch of quick demonstrations







About Me

- started in science and engineering (BS astrophysics, MS aerospace engineering)
- switched to STEM education (PhD from Michigan State)
- at NCAR/UCAR in Boulder, Colorado for 15 years and counting
- develop simulations and games, online courses, web pages and activities, teacher PD (online and face-to-face)

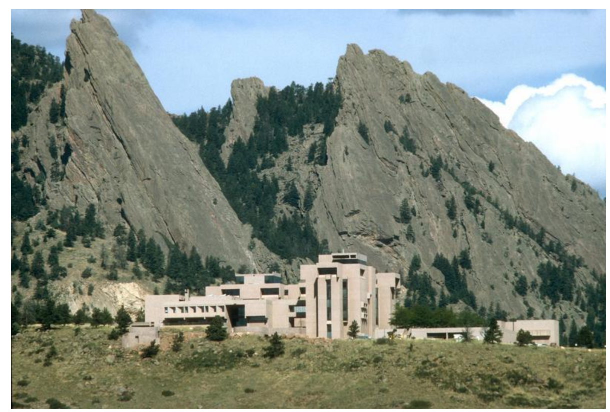
National Center for Atmospheric Research

Boulder, CO

NSF

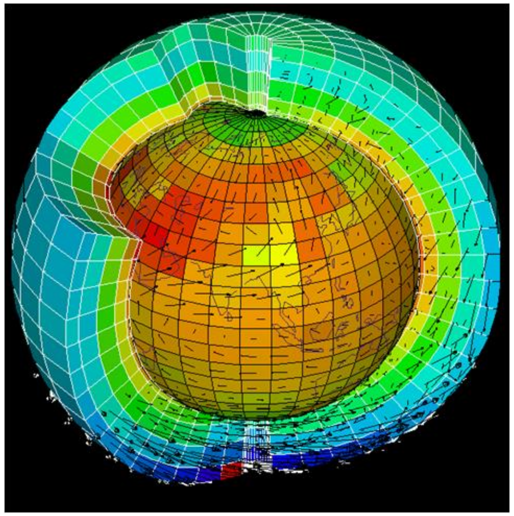
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

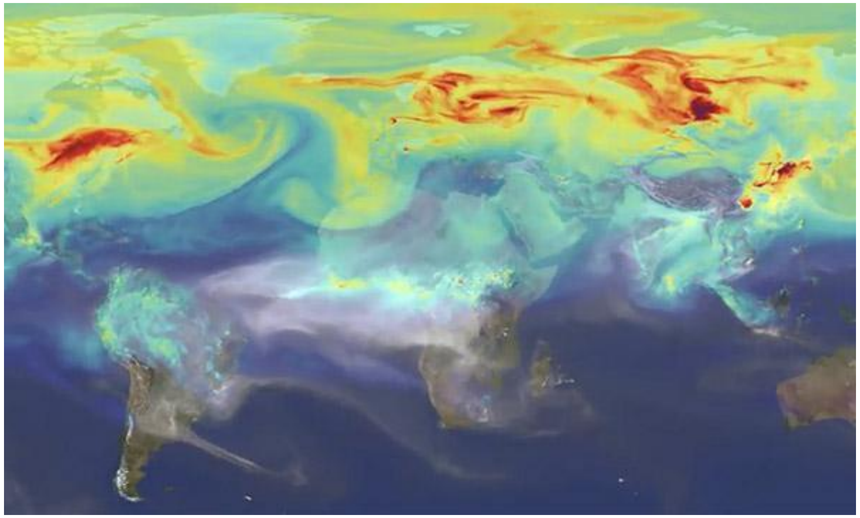
UCAR
UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

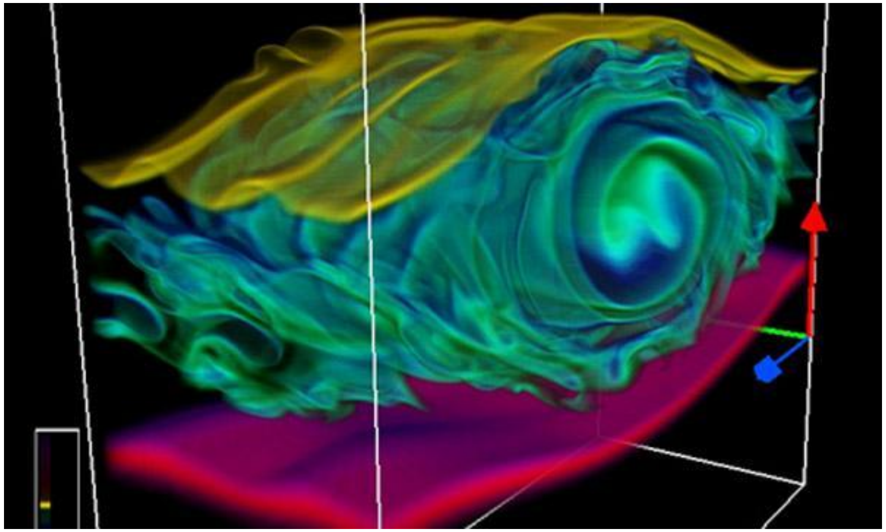


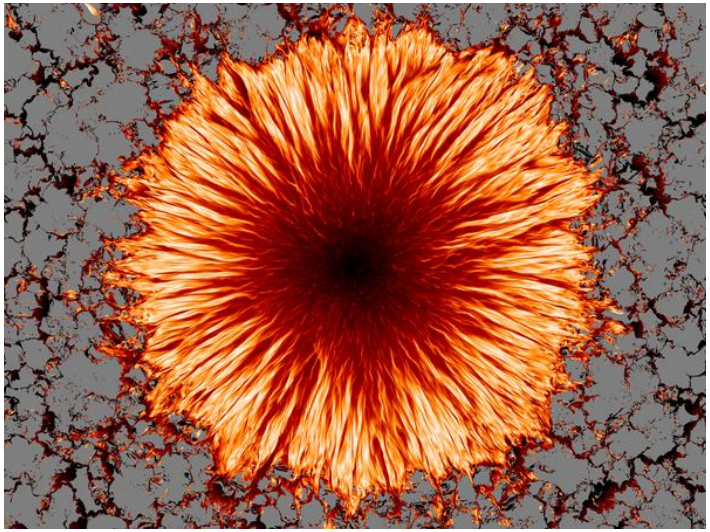
Computing & Modeling at NCAR

Modeling & Computing at NCAR



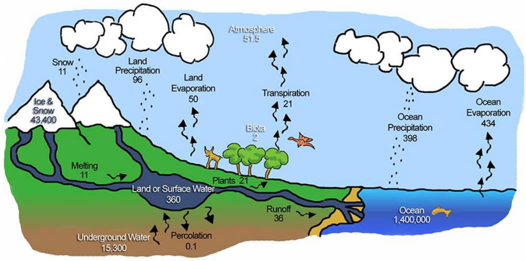




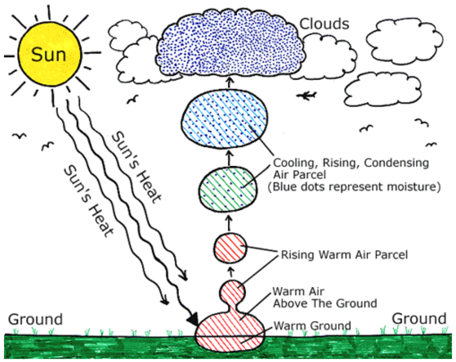


Types of "Models"

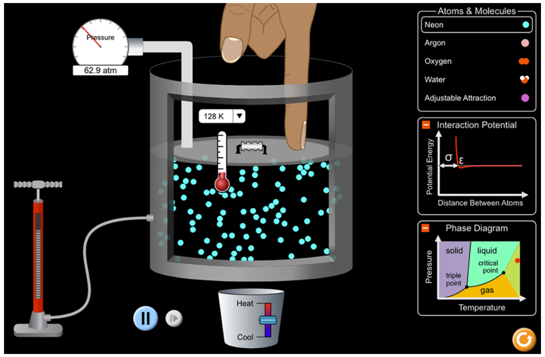
Mental Models



Conceptual Models



Diagrams



Computer Simulations

$$\frac{\Delta \text{Rabbits}}{\Delta \text{Time}}$$

Mathematical Representations

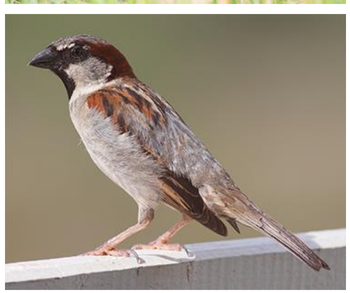
Physical Replicas

Mental Models vs. Conceptual Models

NGSS distinguishes between **mental** models and **conceptual** models

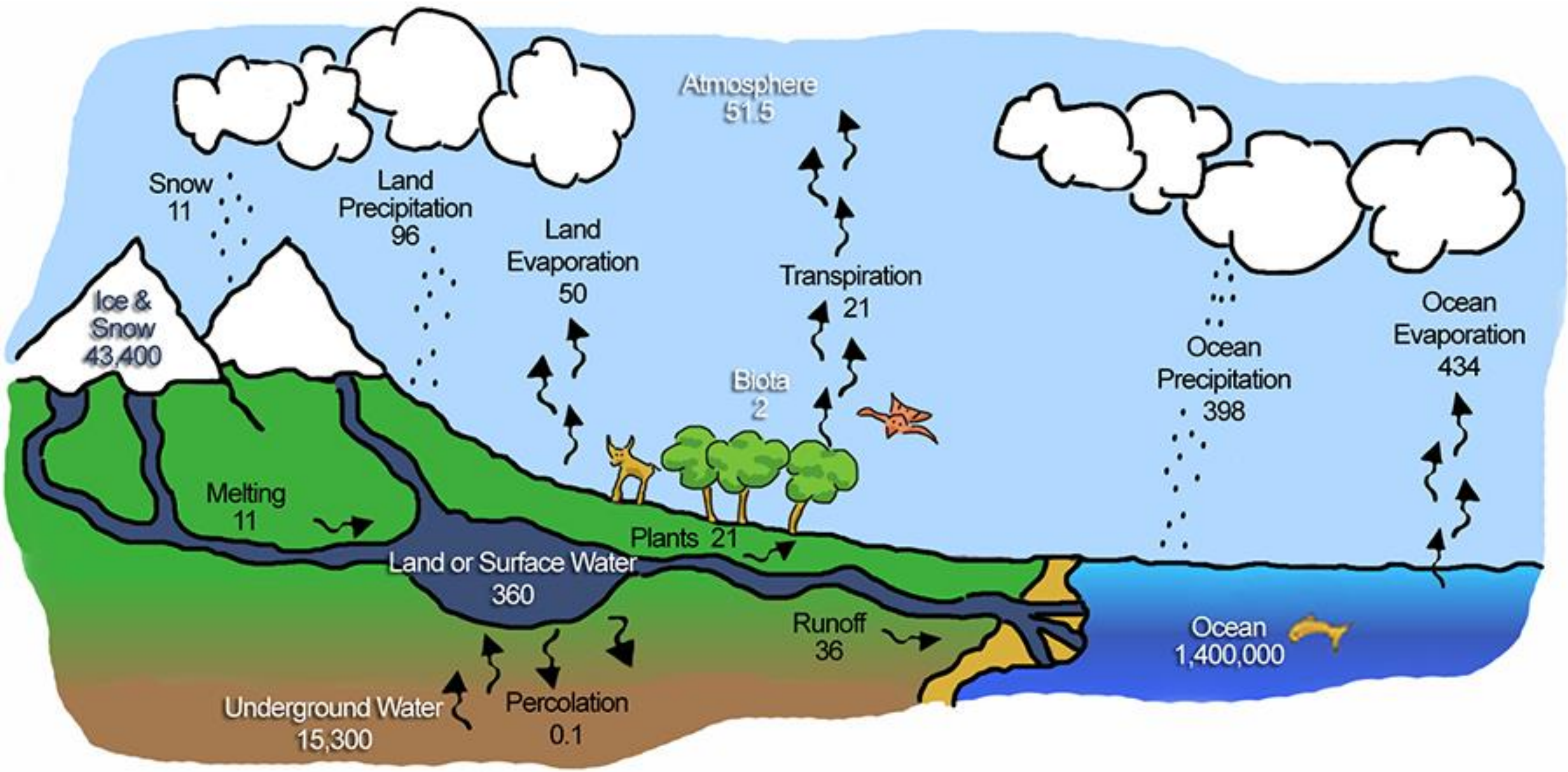
"Scientists construct mental and conceptual models of phenomena. Mental models are internal, personal, idiosyncratic, incomplete, unstable, and essentially functional. They serve the purpose of being a tool for thinking with, making predictions, and making sense of experience." (NGSS p. 56)

Mental Model: "Bird"



Conceptual Models

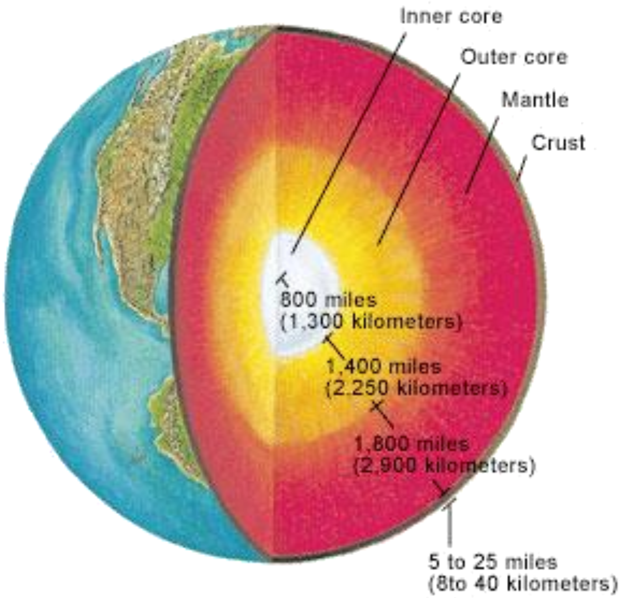
"Conceptual models, are, in contrast, explicit representations that are in some ways analogous to the phenomena they represent. Conceptual models allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem." (NGSS p. 56)

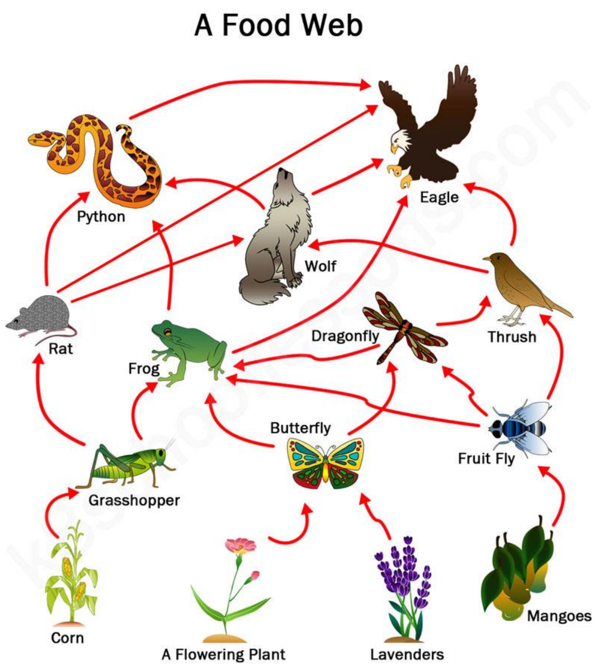


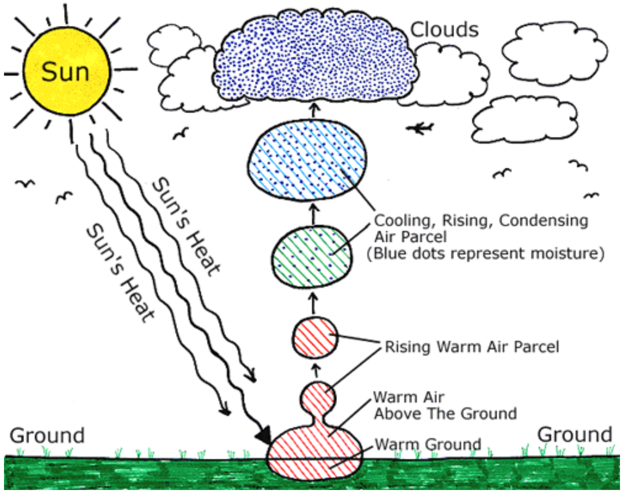
Conceptual Models

"… conceptual models include **diagrams**, **physical replicas**, **mathematical representations**, **analogies**, and **computer simulations**." (NGSS p. 56)

Diagrams







Conceptual Models

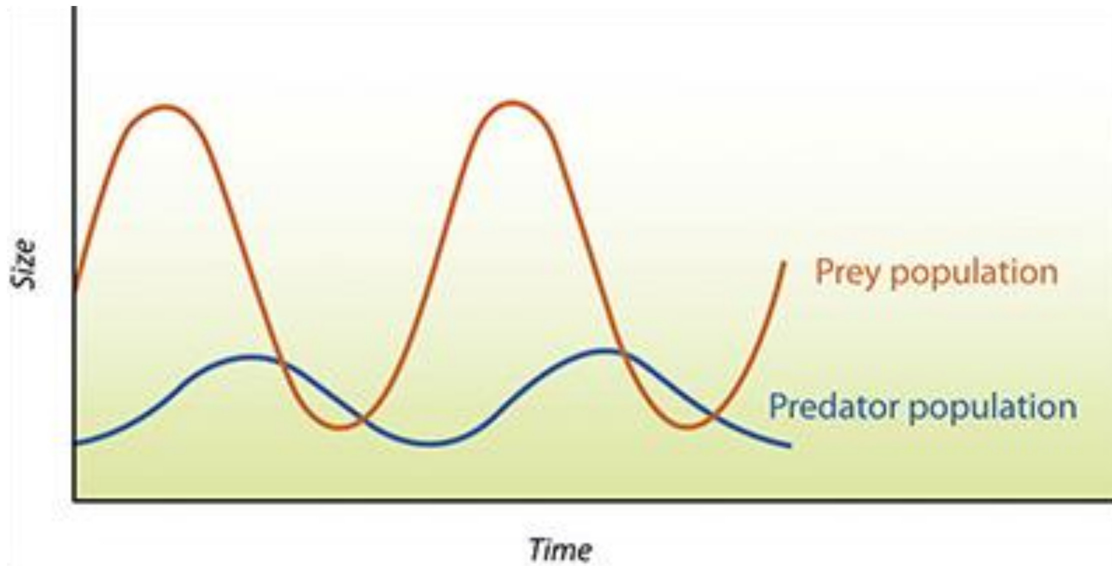
"… conceptual models include diagrams, **physical replicas**, mathematical representations, analogies, and computer simulations." (NGSS p. 56)

Physical Replicas & Scale Models

Conceptual Models

"… conceptual models include diagrams, physical replicas, **mathematical representations**, analogies, and computer simulations." (NGSS p. 56)

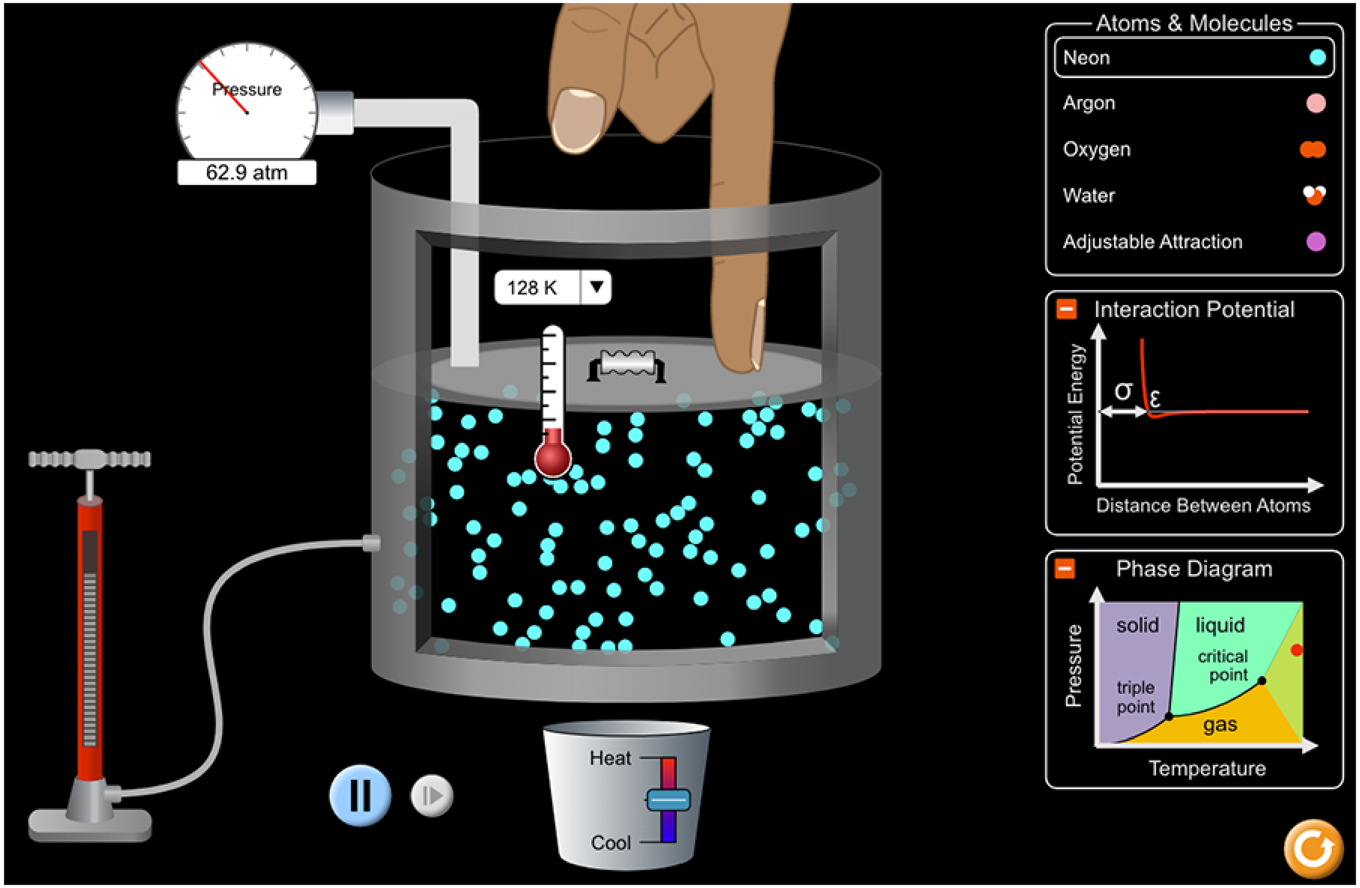
Mathematical Models



$$\frac{\Delta \text{ Rabbits}}{\Delta \text{ Time}} = (\text{birth rate}) \times (\#\text{ rabbits}) - (\text{eat rate}) \times (\#\text{ rabbits}) \times (\#\text{ wolves})$$

Conceptual Models

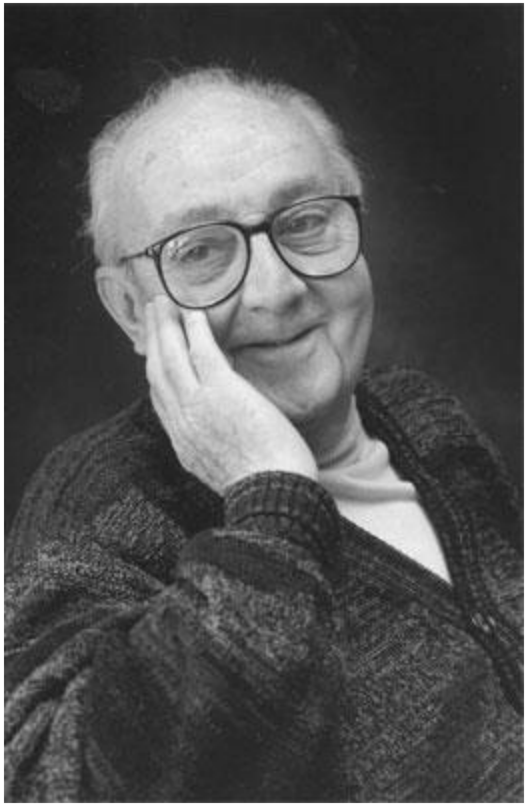
"... conceptual models include diagrams, physical replicas, mathematical representations, analogies, and **computer simulations**." (NGSS p. 56)



Most of Webinar on Computer Simulations

- importance of having students behave like scientists – running models – not just being told about them
- other topics important too – students **constructing** depictions of their own models – concept maps as example of this
- models that only show “connections” via arrows are OK as far as they go, but limited… what is the math/behavior behind the arrow (this is often crucial in determining the behavior of the system)… important to also have students run mathematical models expressed as computer simulations to see how systems behave (feedback loops, delays, exponential growth or oscillations)
- visual, interactive, game-like models can allow even very young students to experience “running” models; better prepares them to encounter more advanced simulations and models in MS/HS and beyond, (like math; teach them arithmetic now, knowing they’ll do algebra and trigonometry later)

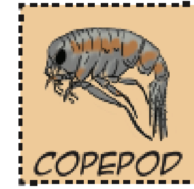
All models are wrong, but...



"Essentially, all models are wrong, but some models are useful."

- George E. P. Box (1951)

NGSS on the Limitations of Models

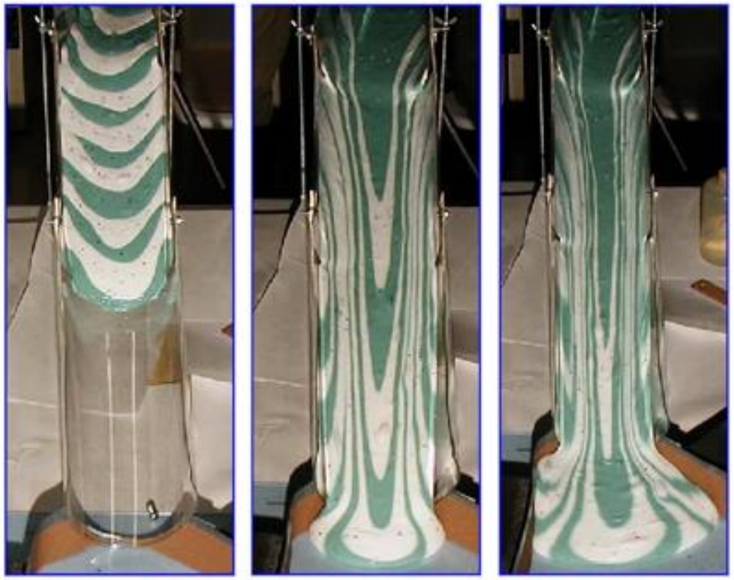


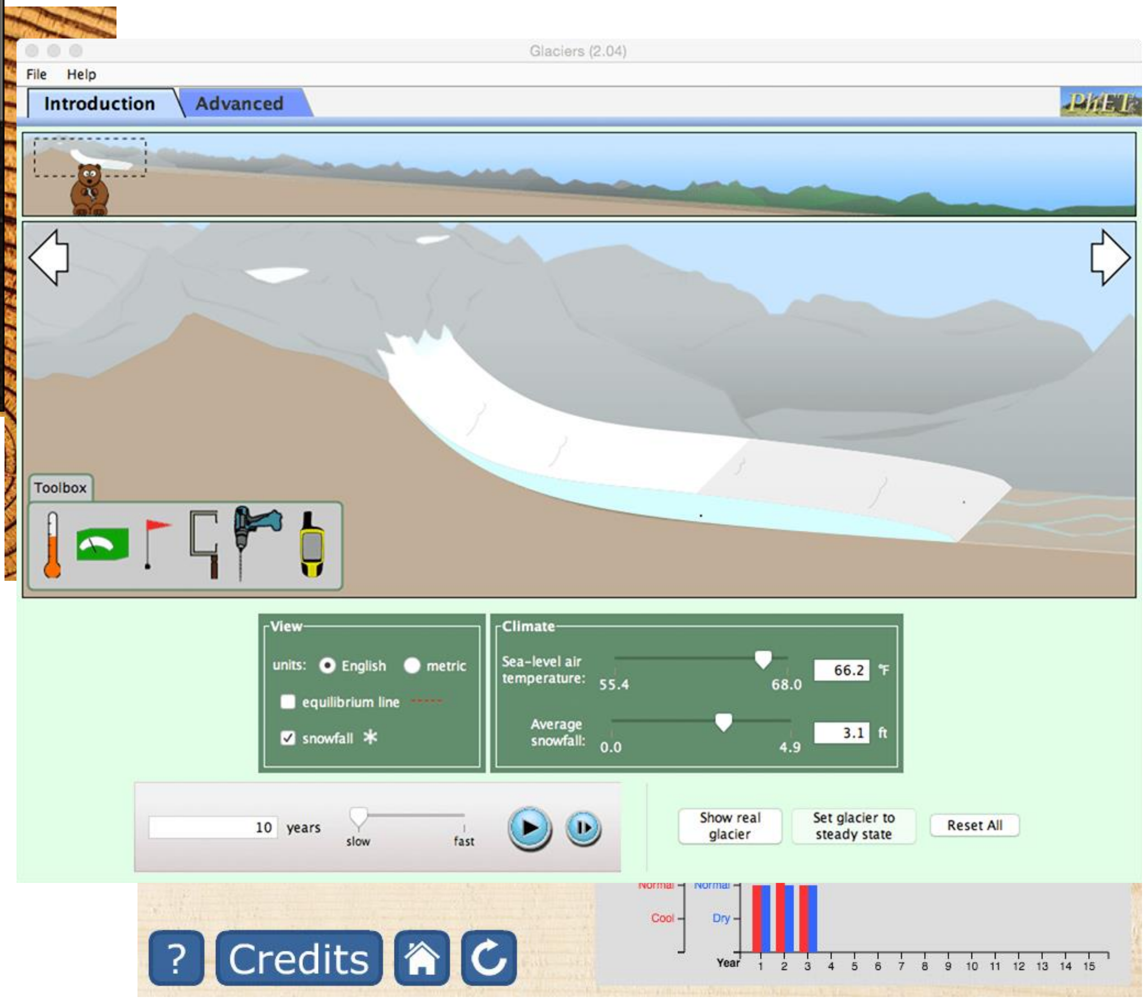
"Although they [conceptual models] **do not correspond exactly** to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, **it is important to recognize their limitations**." (NGSS p. 56)

"But as in science, engineers who use models must be aware of their **intrinsic limitations** and test them against known situations to ensure that they are reliable." (NGSS p. 57-58)

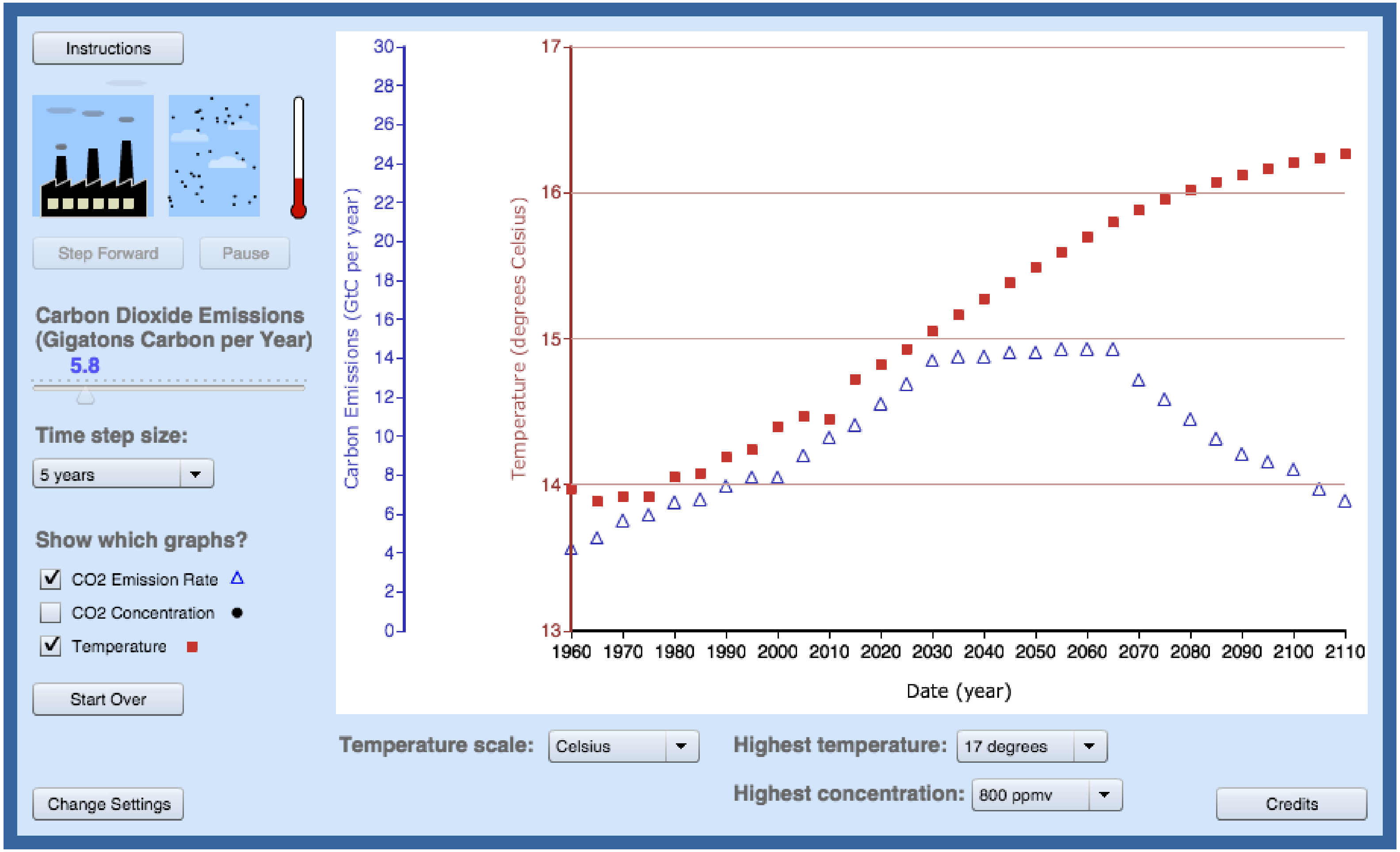
[By grade 12, students should be able to:] "Discuss the **limitations and precision of a model** as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality and explanatory power." (NGSS p. 58)

Possible Strategy: Pair Concrete Physical Demonstrations with Computer Simulations



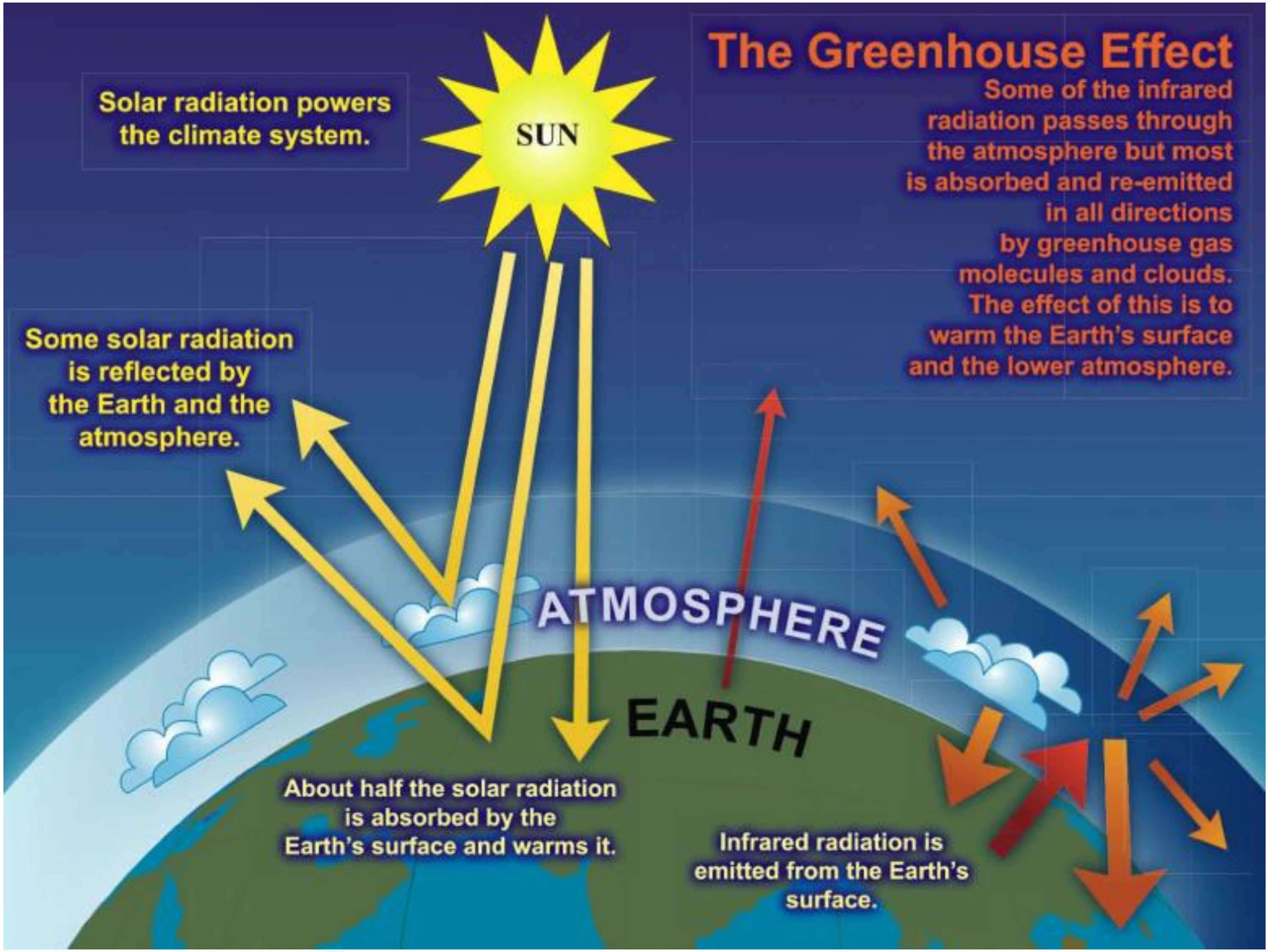


The Very, Very Simple Climate Model

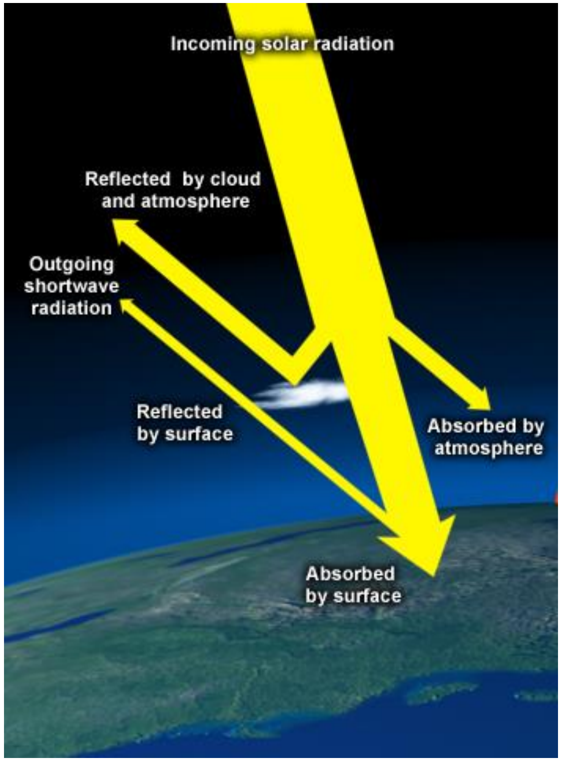


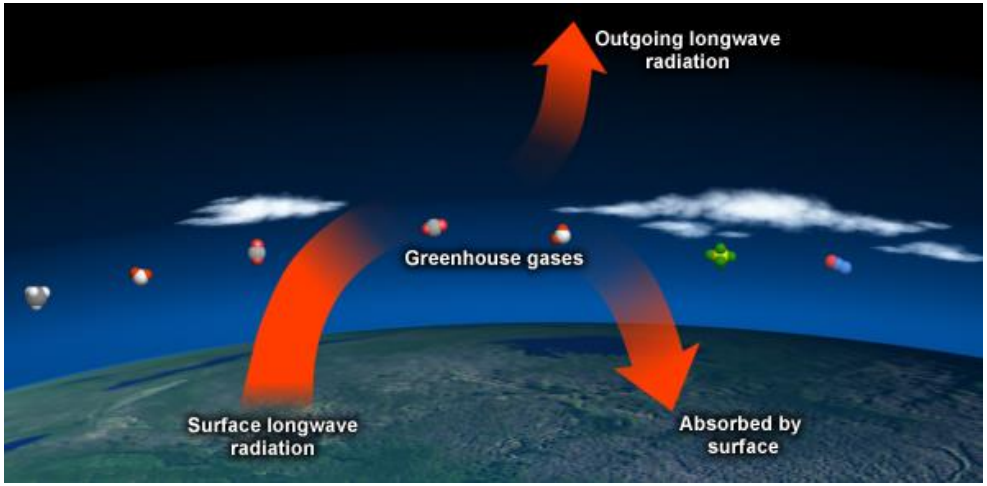
URL: SciEd.ucar.edu/simple-climate-model

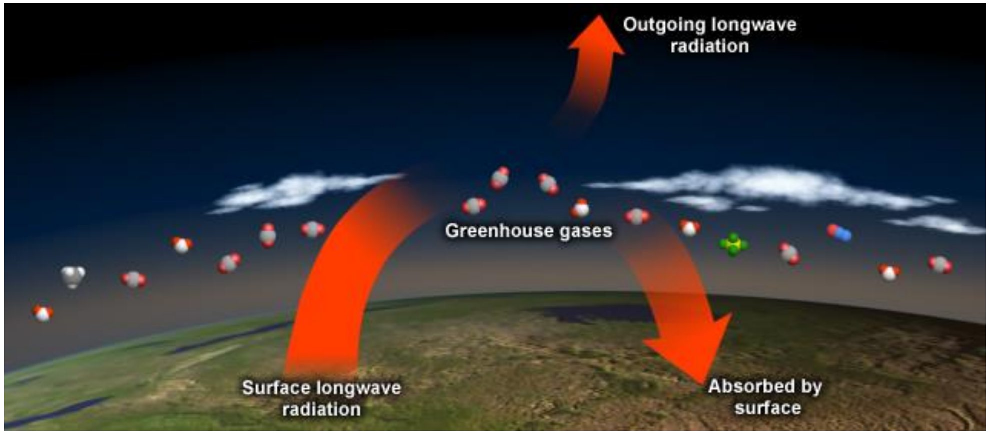
The Greenhouse Effect



The Greenhouse Effect





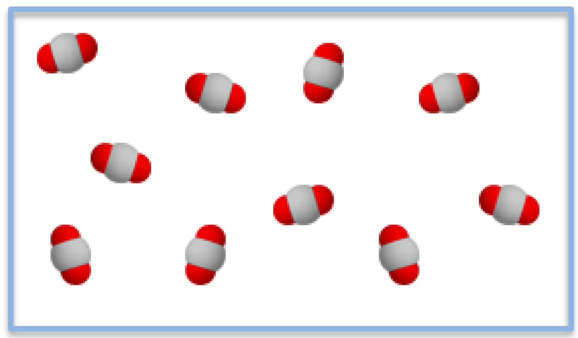


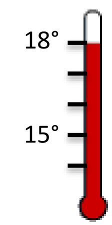
CO_2 Emissions and a Warming Climate

Carbon Dioxide Emissions

More Carbon Dioxide in the Atmosphere

Higher Temperatures



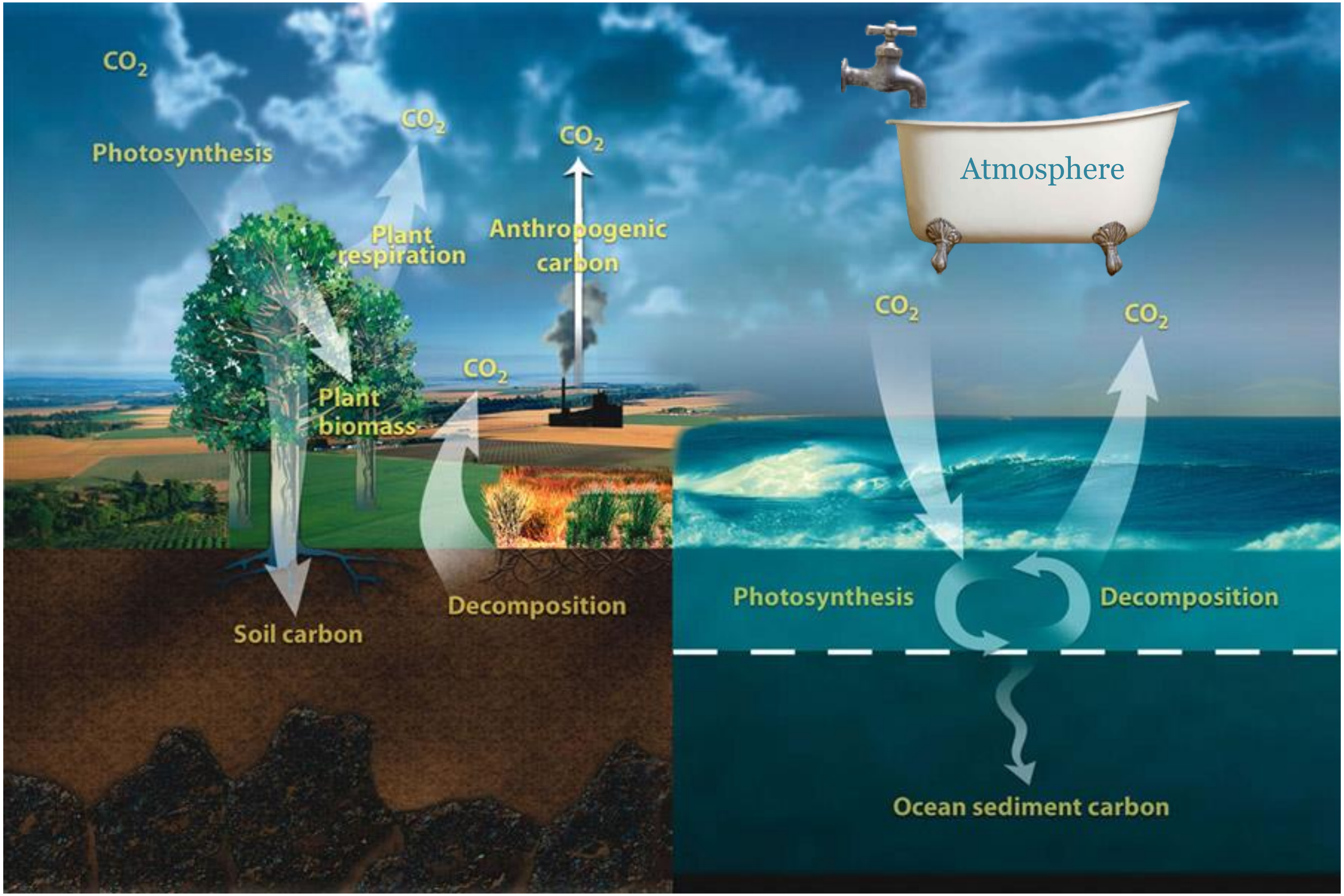


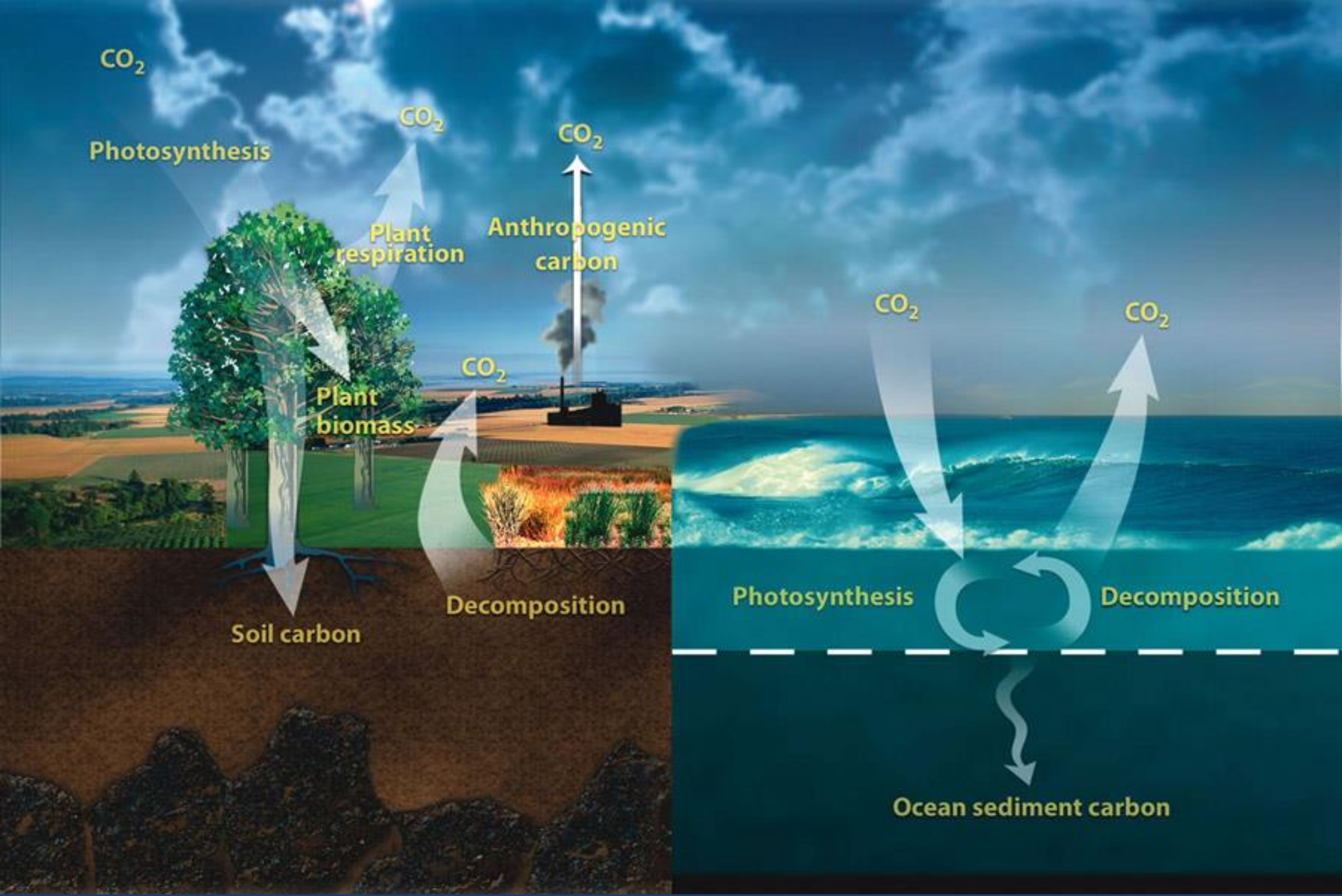
People Control This (input)

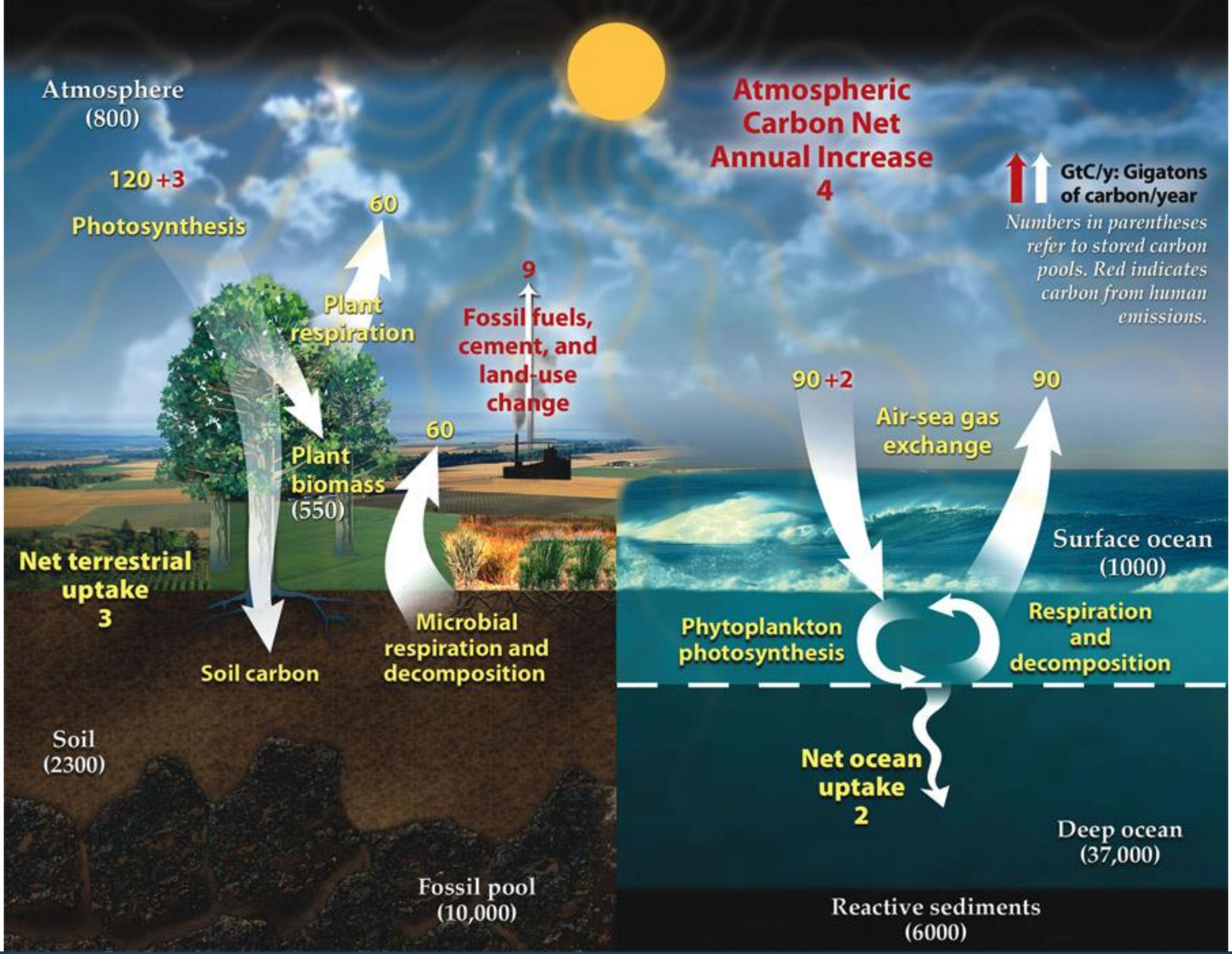
What Happens (output)

What Happens (output)

The Carbon Cycle

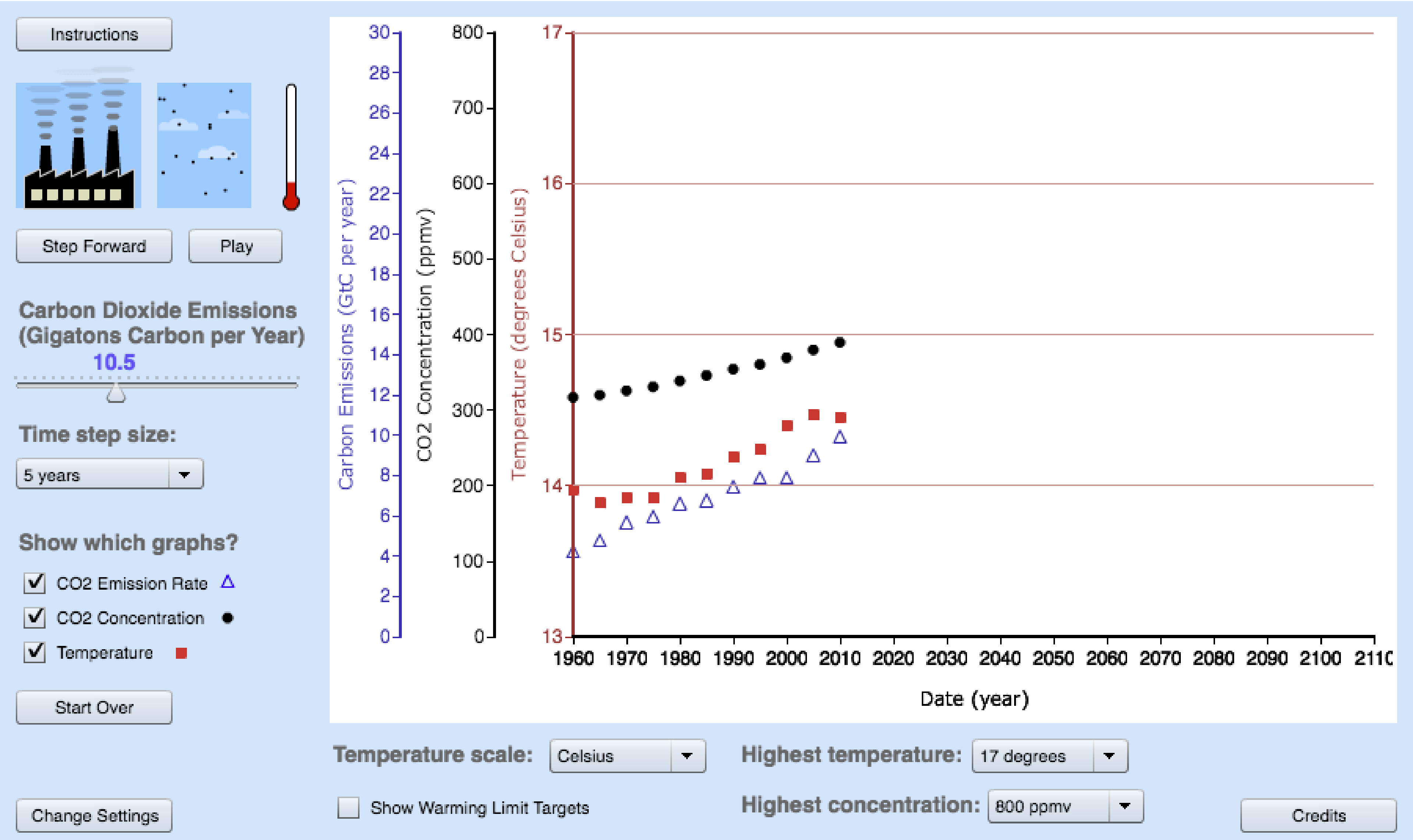



CO_2
Photosynthesis
CO_2
Plant respiration
CO_2
Anthropogenic carbon
CO_2
Plant biomass
Soil carbon
Decomposition
CO_2
CO_2
Photosynthesis
Decomposition
Ocean sediment carbon



Atmosphere
(800)
120 +3
Photosynthesis
60
Plant
respiration
9
Fossil fuels,
cement, and
land-use
change
Atmospheric
Carbon Net
Annual Increase
4
GtC/y: Gigatons
of carbon/year
Numbers in parentheses
refer to stored carbon
pools. Red indicates
carbon from human
emissions.
60
Plant
biomass
(550)
90 +2
Air-sea gas
exchange
90
Surface ocean
(1000)
Net terrestrial
uptake
3
Soil carbon
Microbial
respiration and
decomposition
Phytoplankton
photosynthesis
Respiration
and
decomposition
Net ocean
uptake
2
Soil
(2300)
Deep ocean
(37,000)
Fossil pool
(10,000)
Reactive sediments
(6000)

The Very, Very Simple Climate Model



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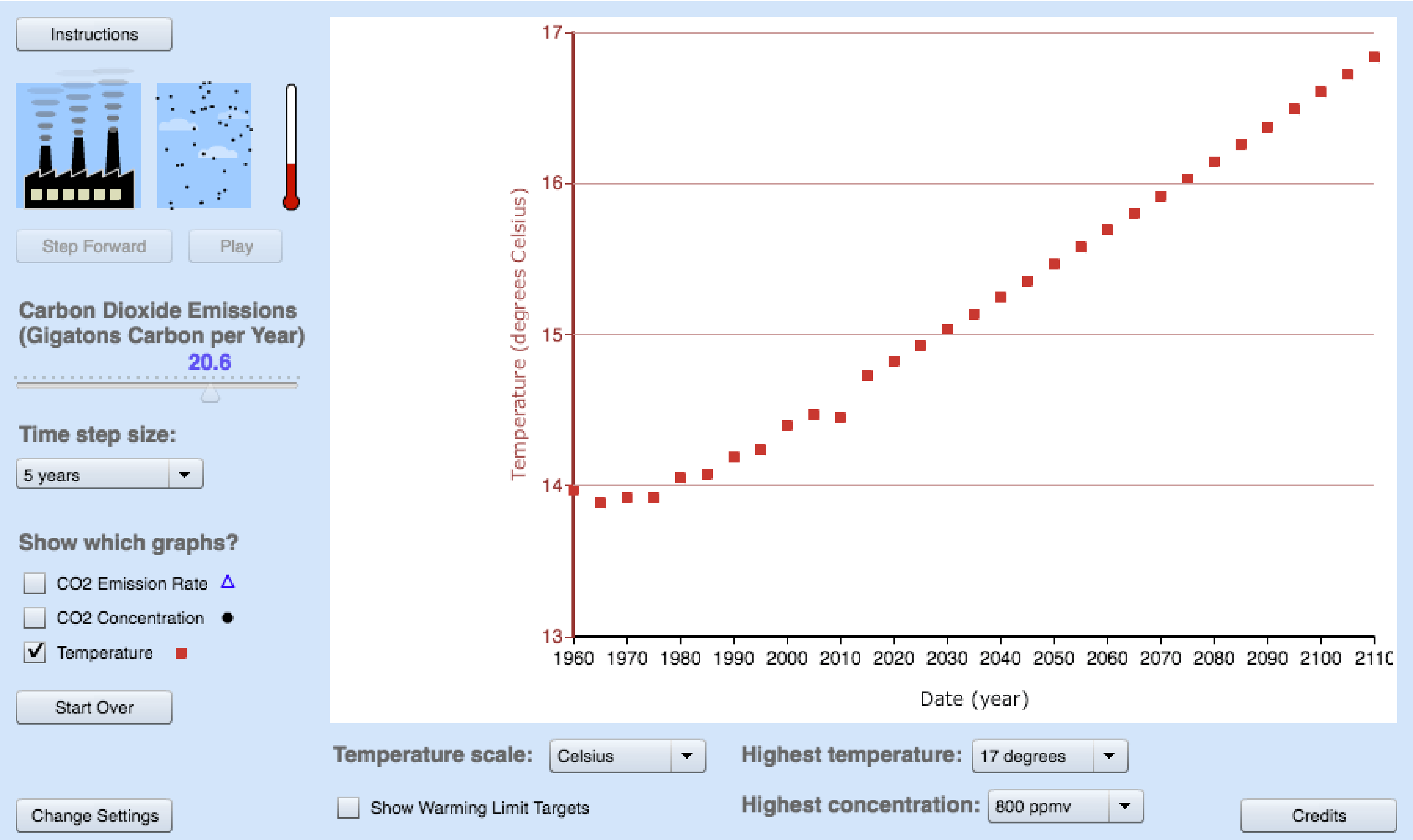

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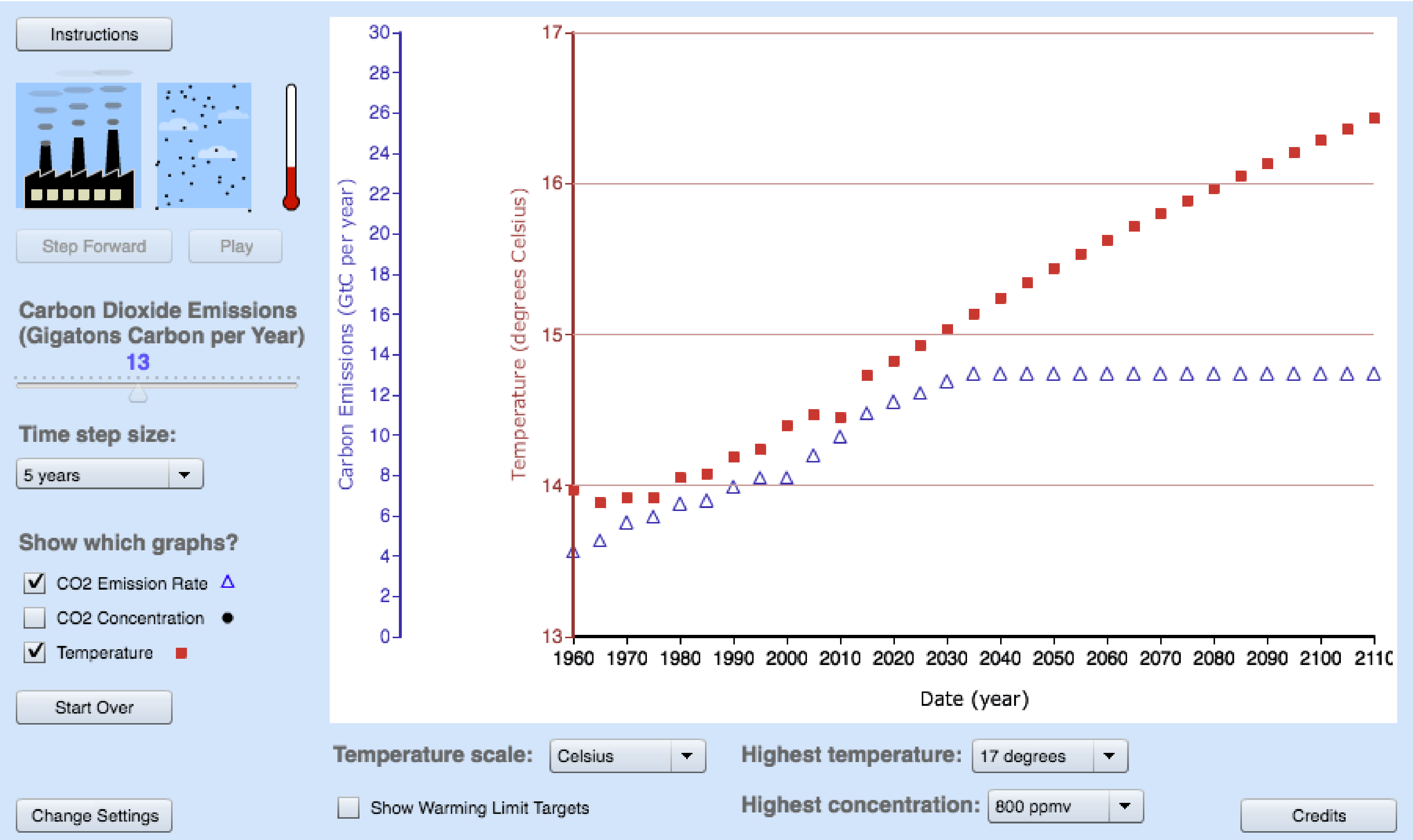
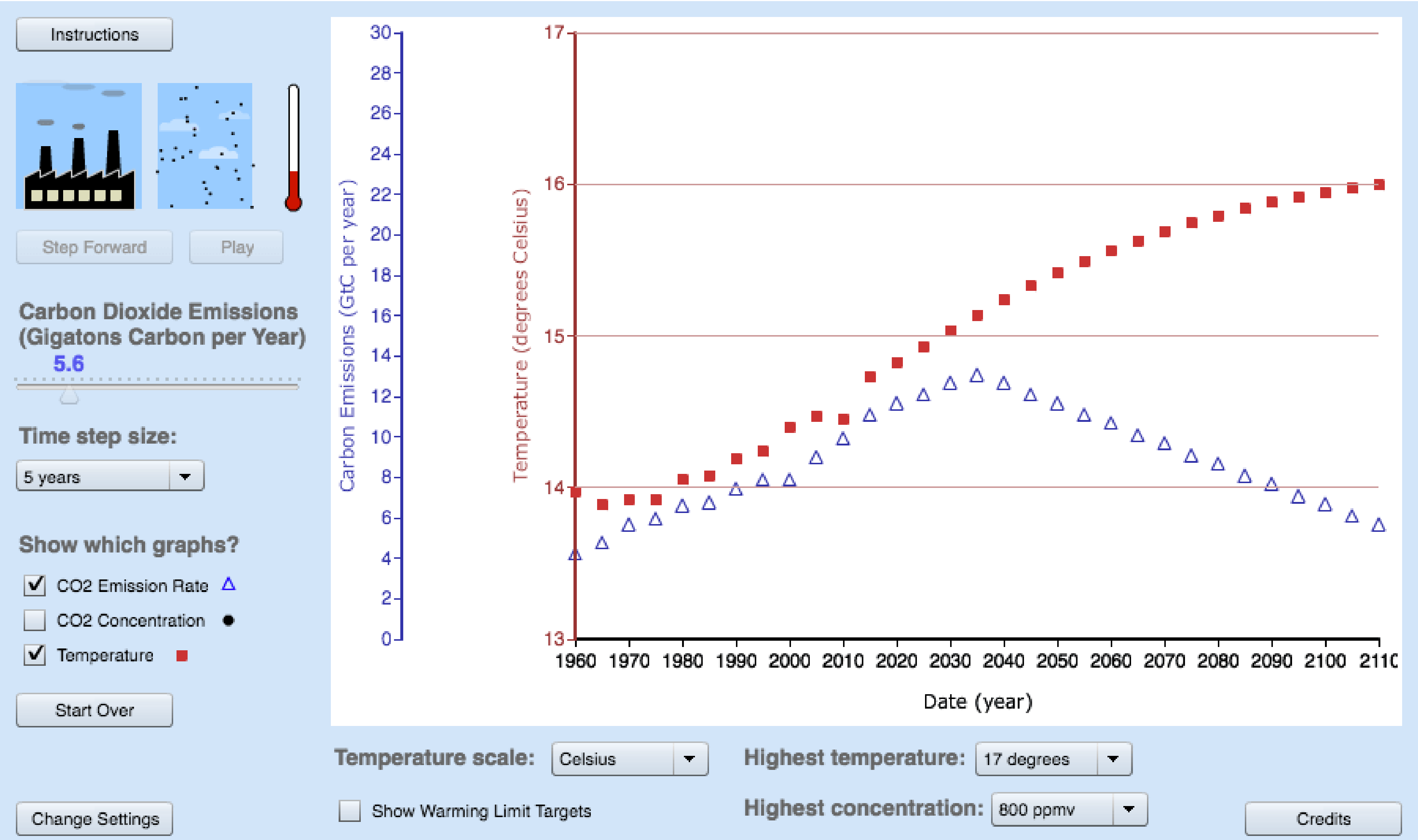


The Very, Very Simple Climate Model



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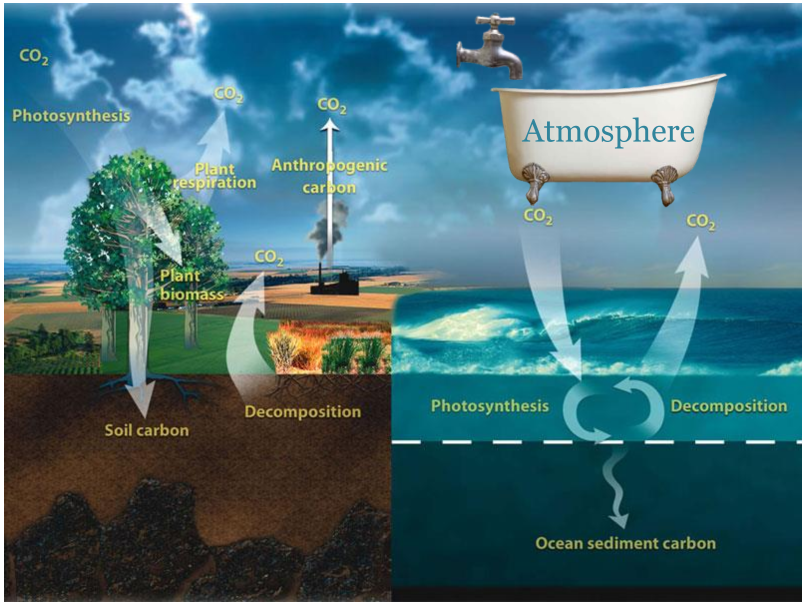
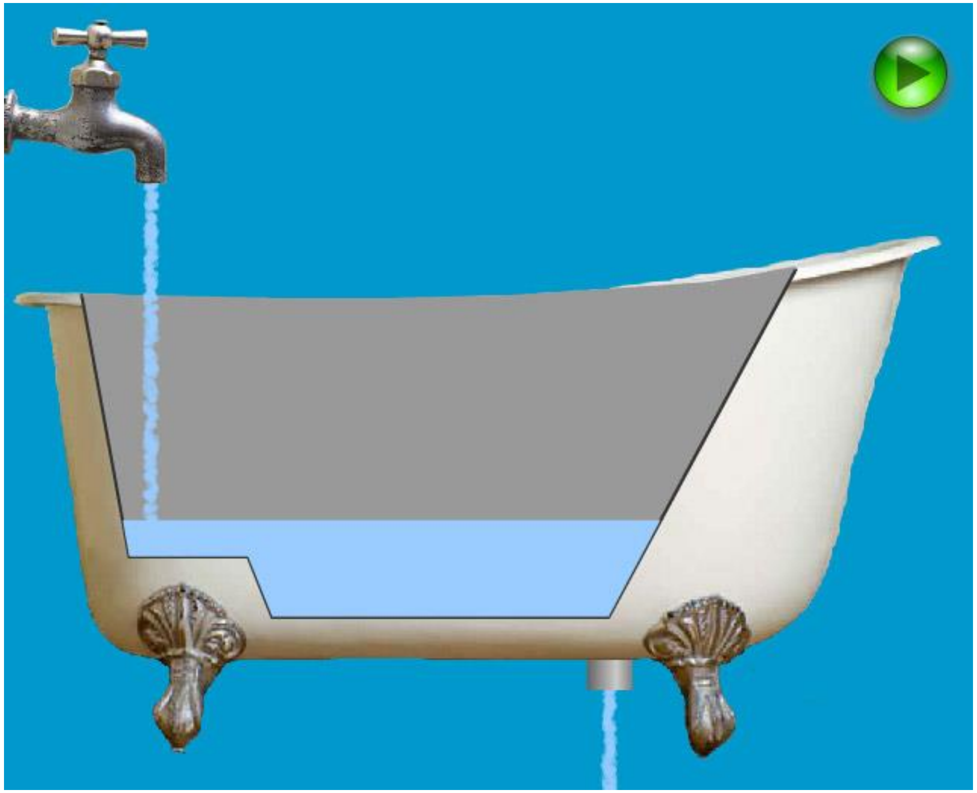
Simulations in Earth Science Education

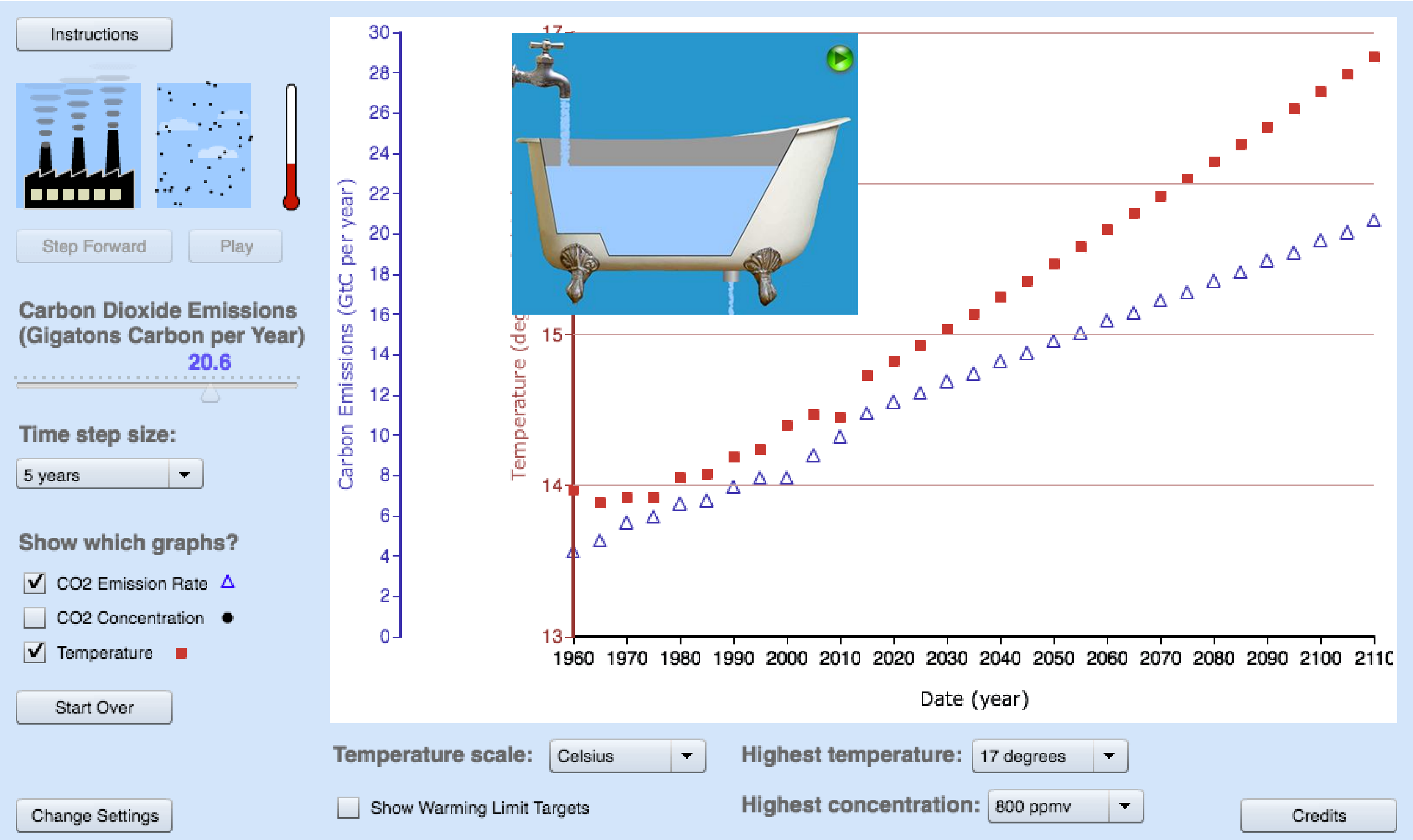
Carbon Bathtub Animations



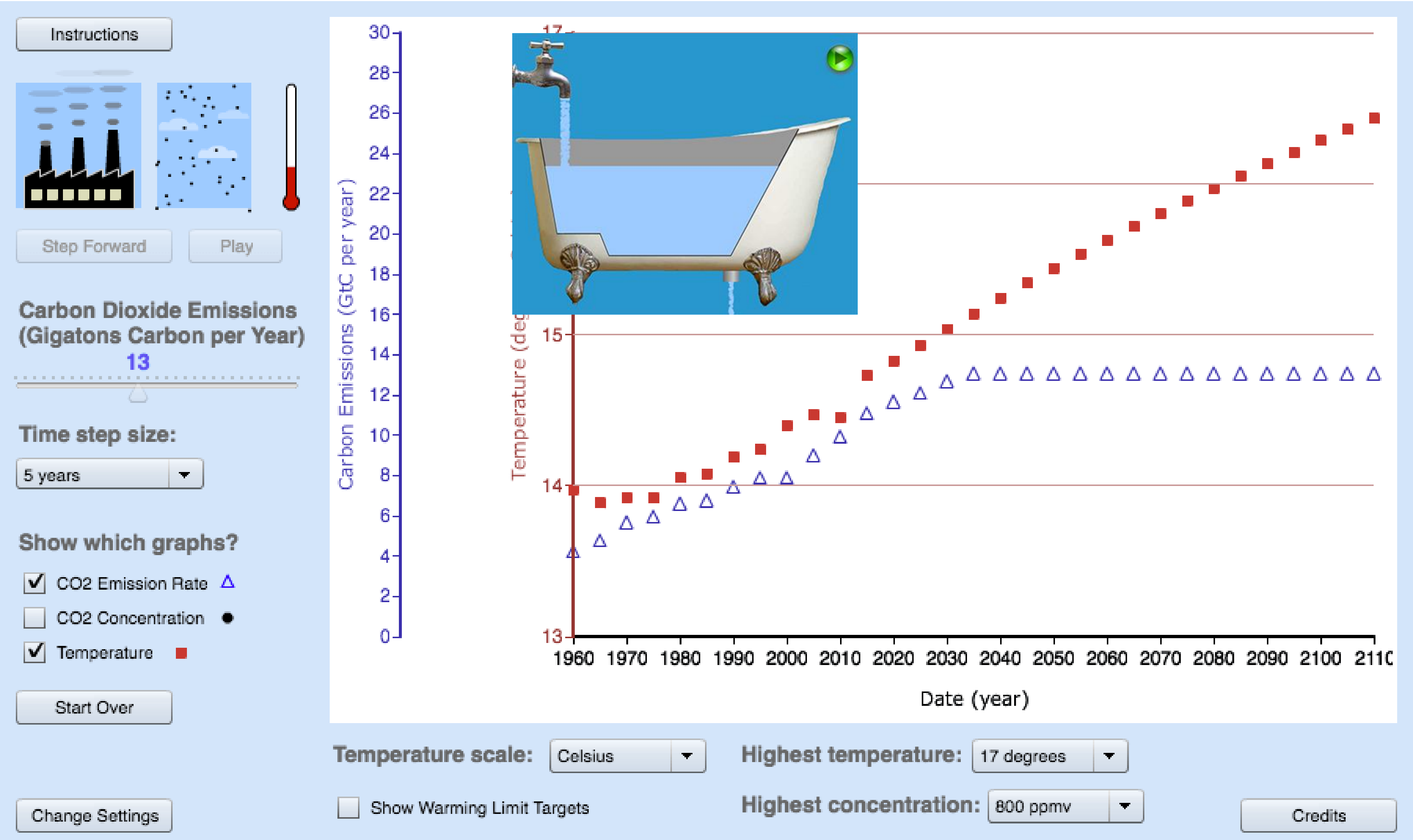


URL: SciEd.ucar.edu/climate-bathtub-model-animations

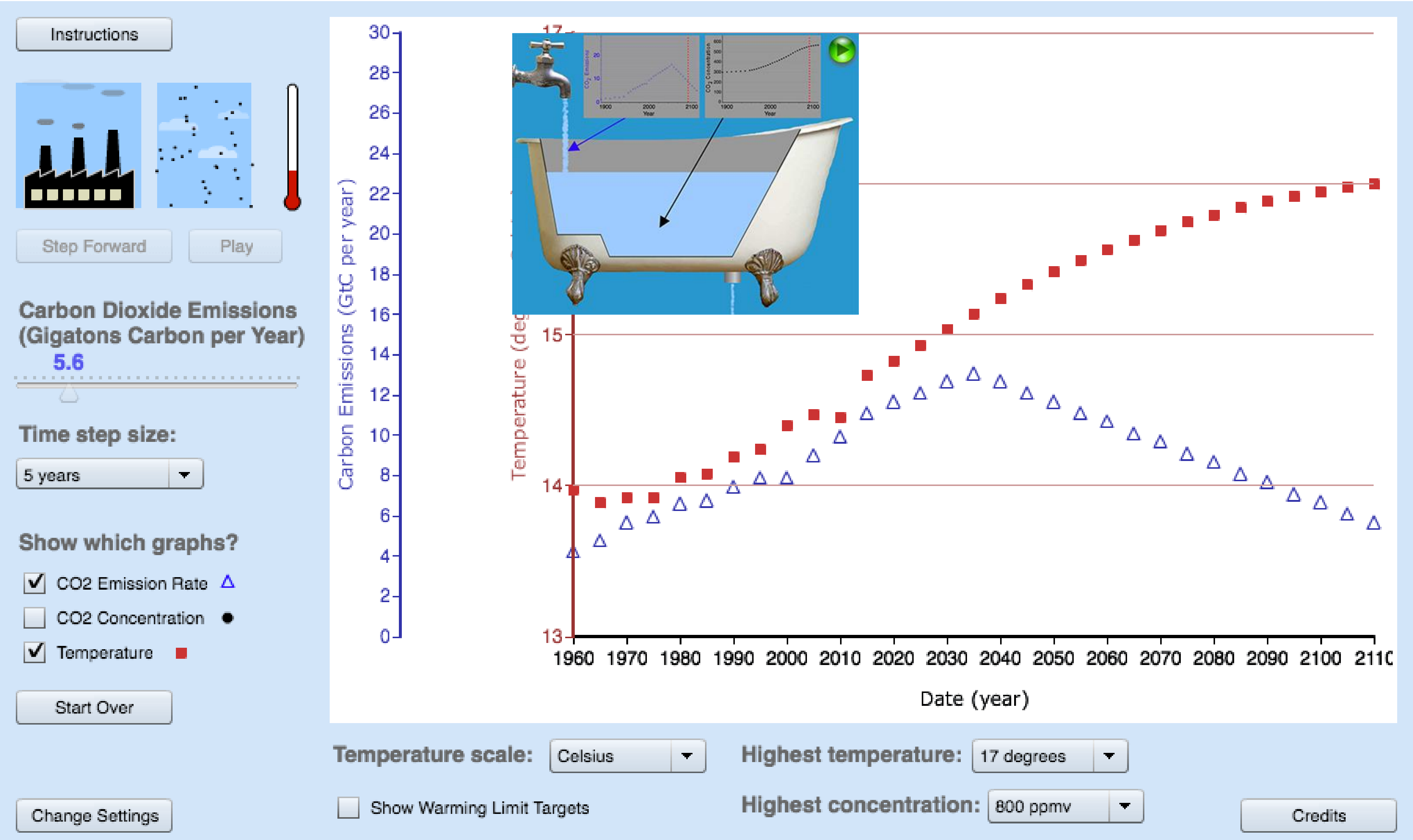
Constantly Rising Emissions



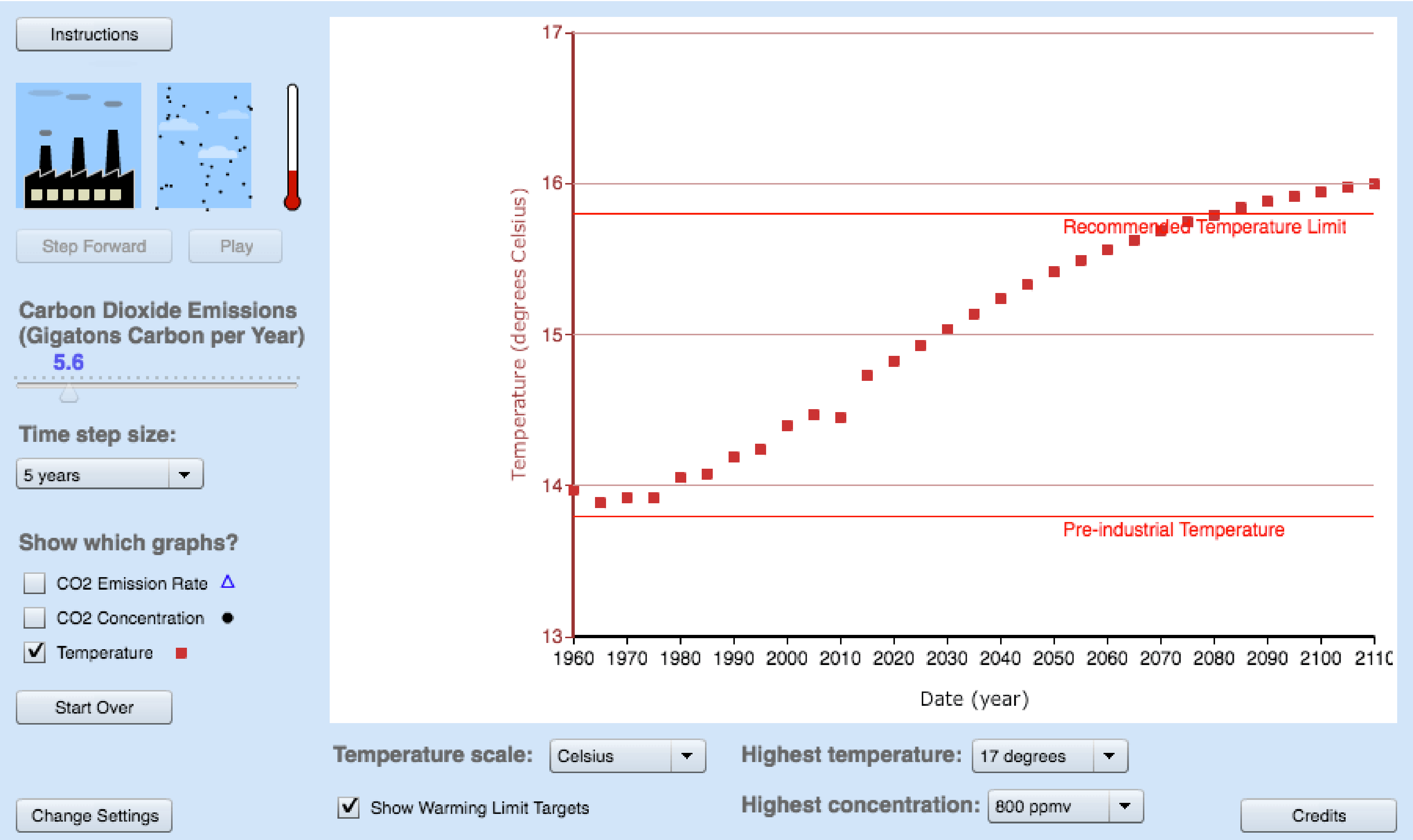
Emissions Rise, Then Level Off



Emissions Rise, Then Fall (to 1970s level)

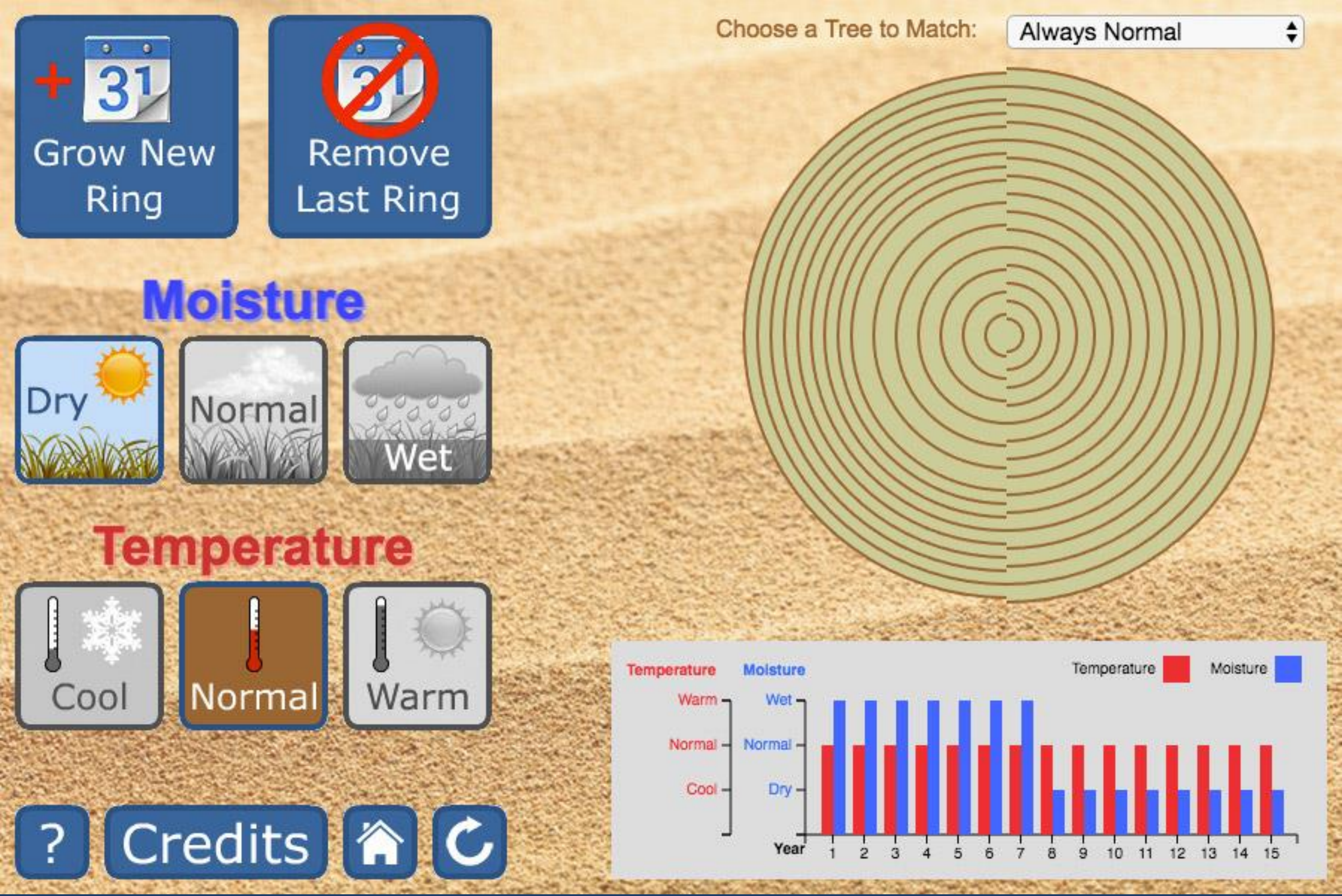


2 degree temperature rise

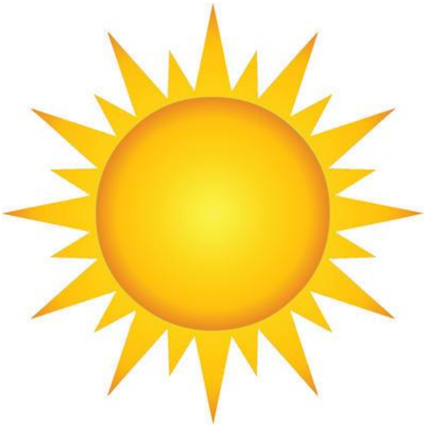


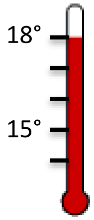
Tree Rings – Dendrochronology - Paleoclimate

• Have students work with actual tree cookies (counting annual growth rings) BEFORE using the tree ring simulation
• Help students make connections between concrete, physical object and the abstract computer simulation


Grow New Ring
Remove Last Ring
Choose a Tree to Match:
Always Normal
Moisture
Dry
Normal
Wet
Temperature
Cool
Normal
Warm
?
Credits
Temperature
Moisture
Temperature
Moisture
Warm
Normal
Cool
Wet
Normal
Dry
Year
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

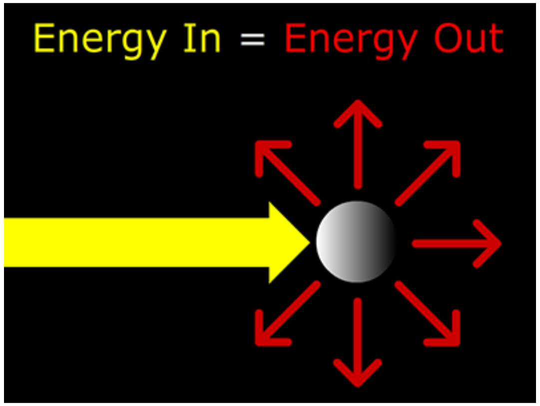
Which is hotter on a sunny day?

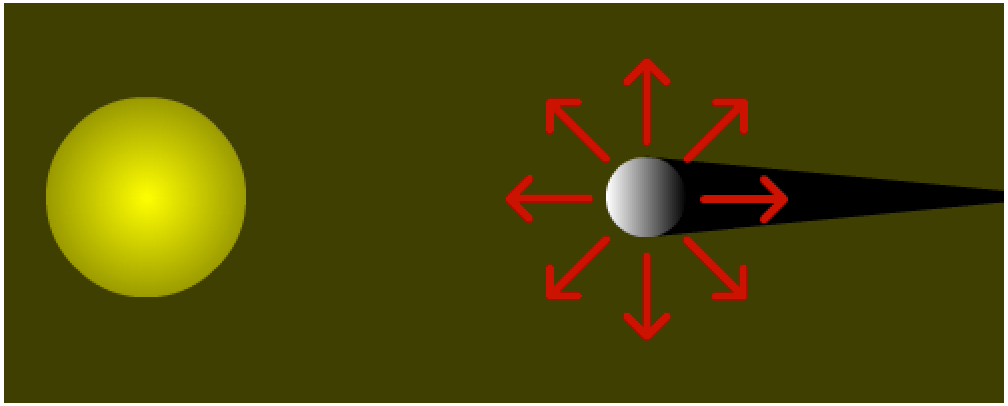




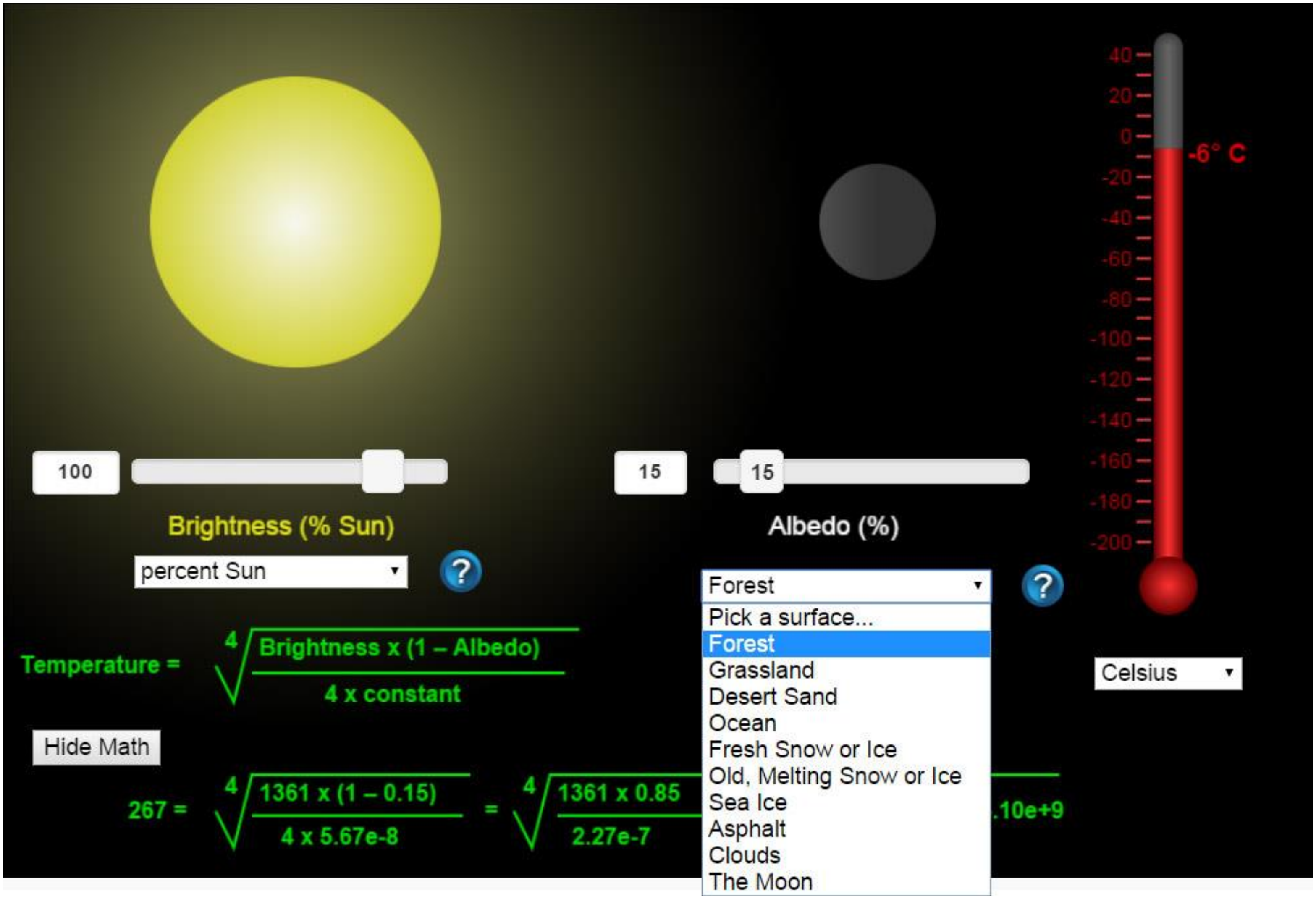
Draws on personal experience – concrete experience paired with abstract simulation

Earth's Energy Balance





Earth's Energy Balance

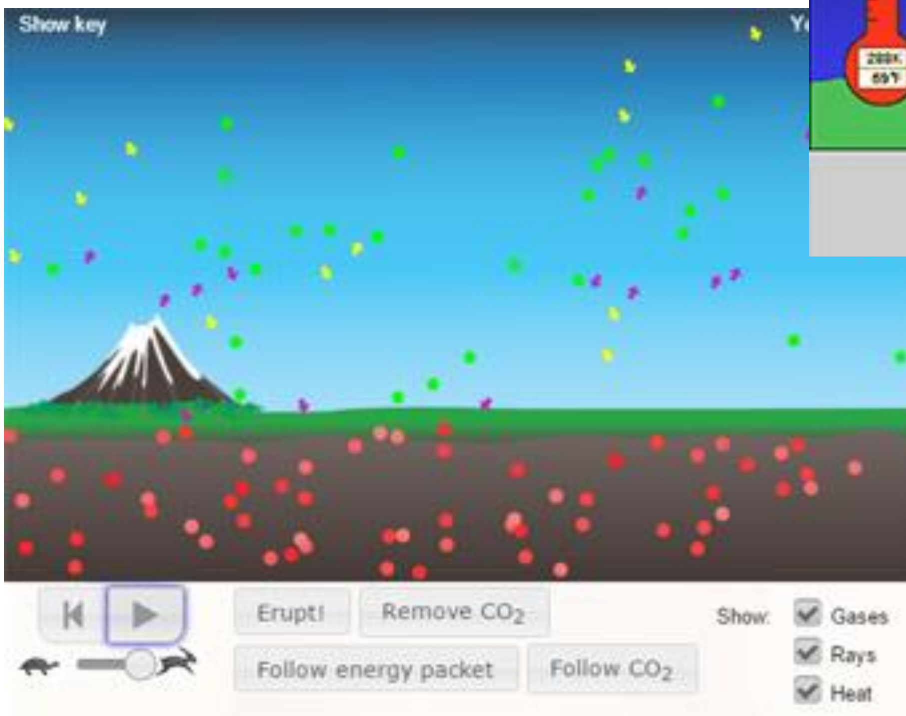


LASP Kelvin Climb

Add an Atmosphere with Greenhouse Gases

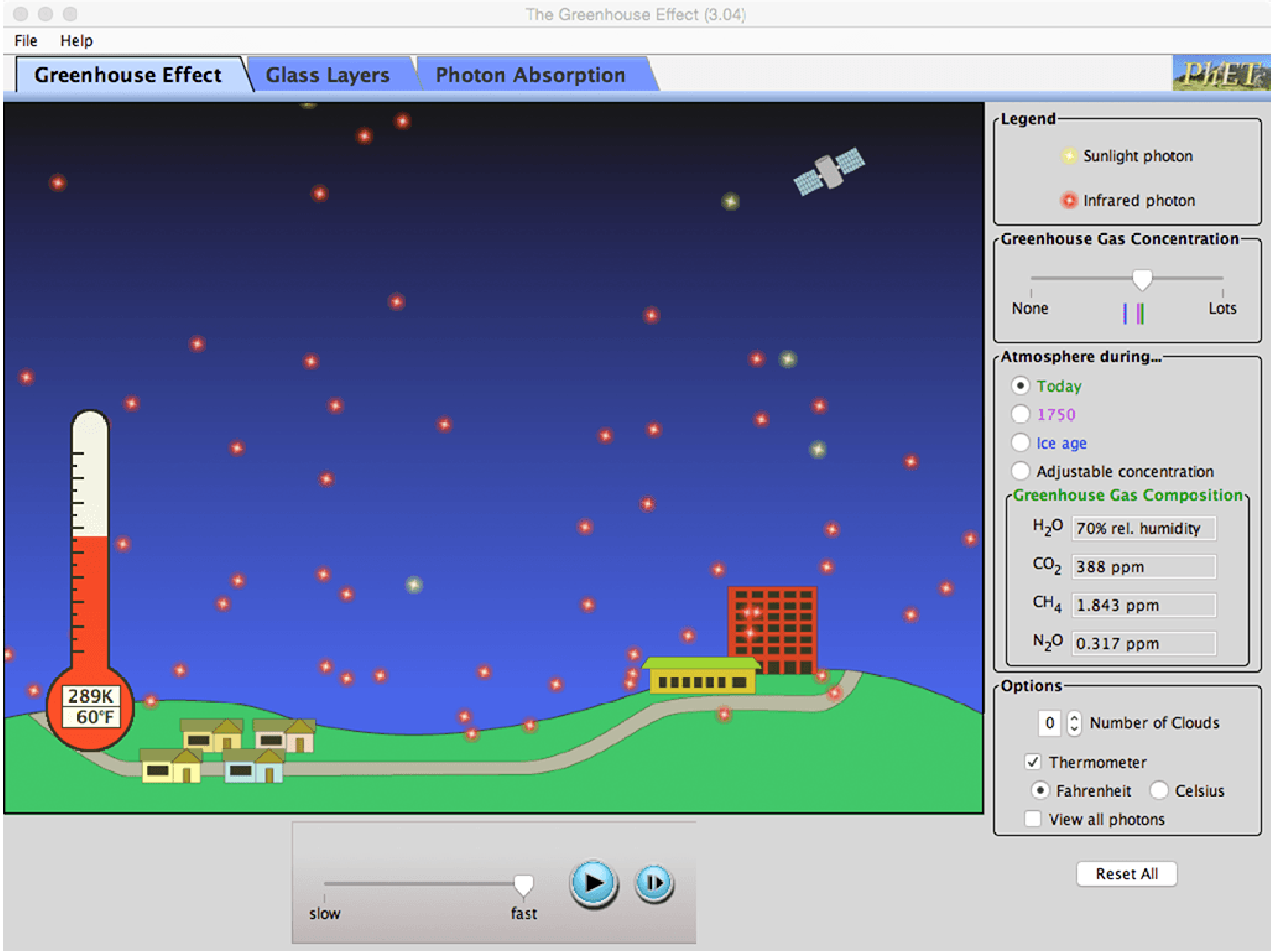
Change distance from Sun

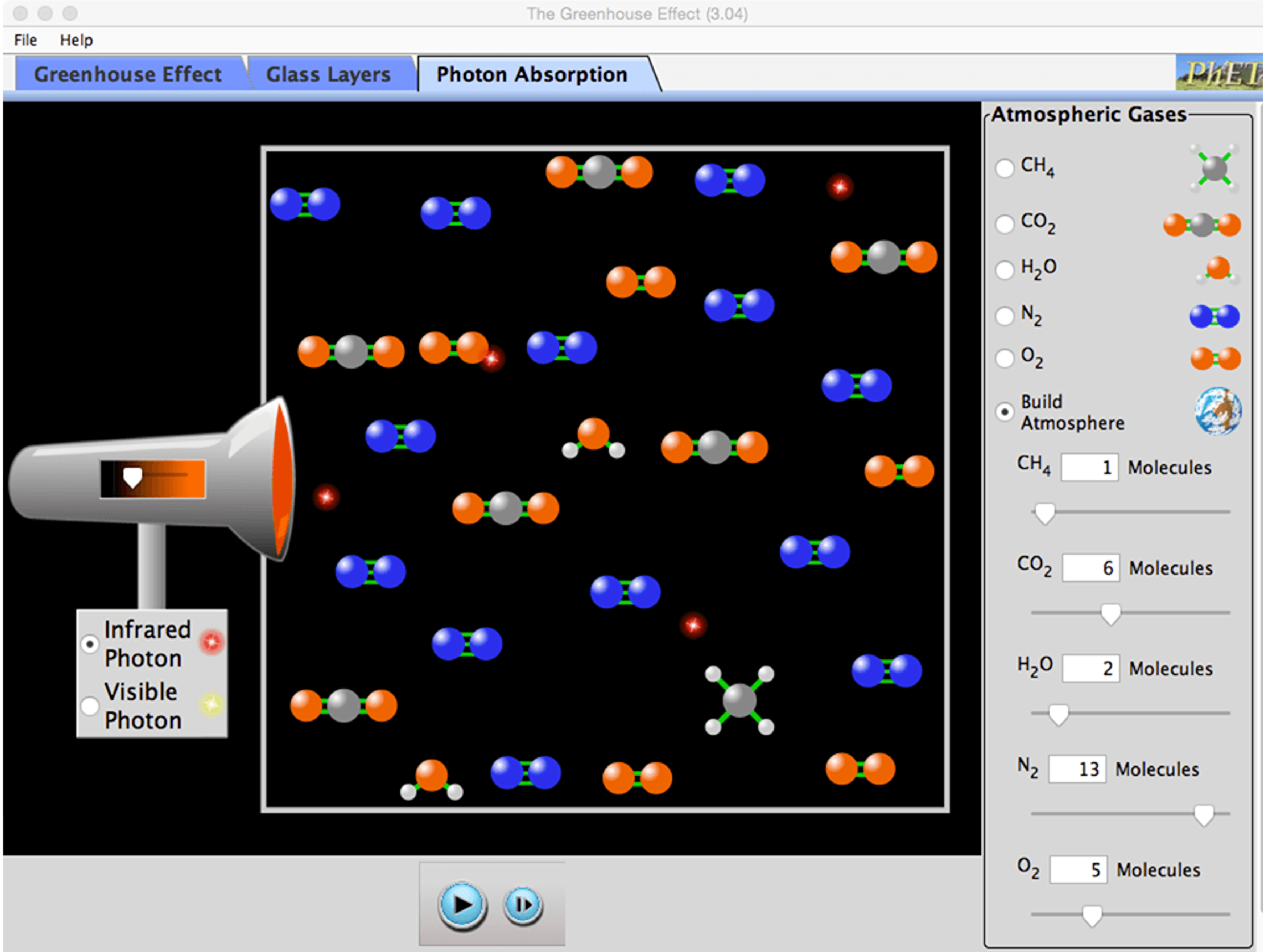
Greenhouse Effect Teaching Box



URL: SciEd.ucar.edu/teaching-box/greenhouse-effect

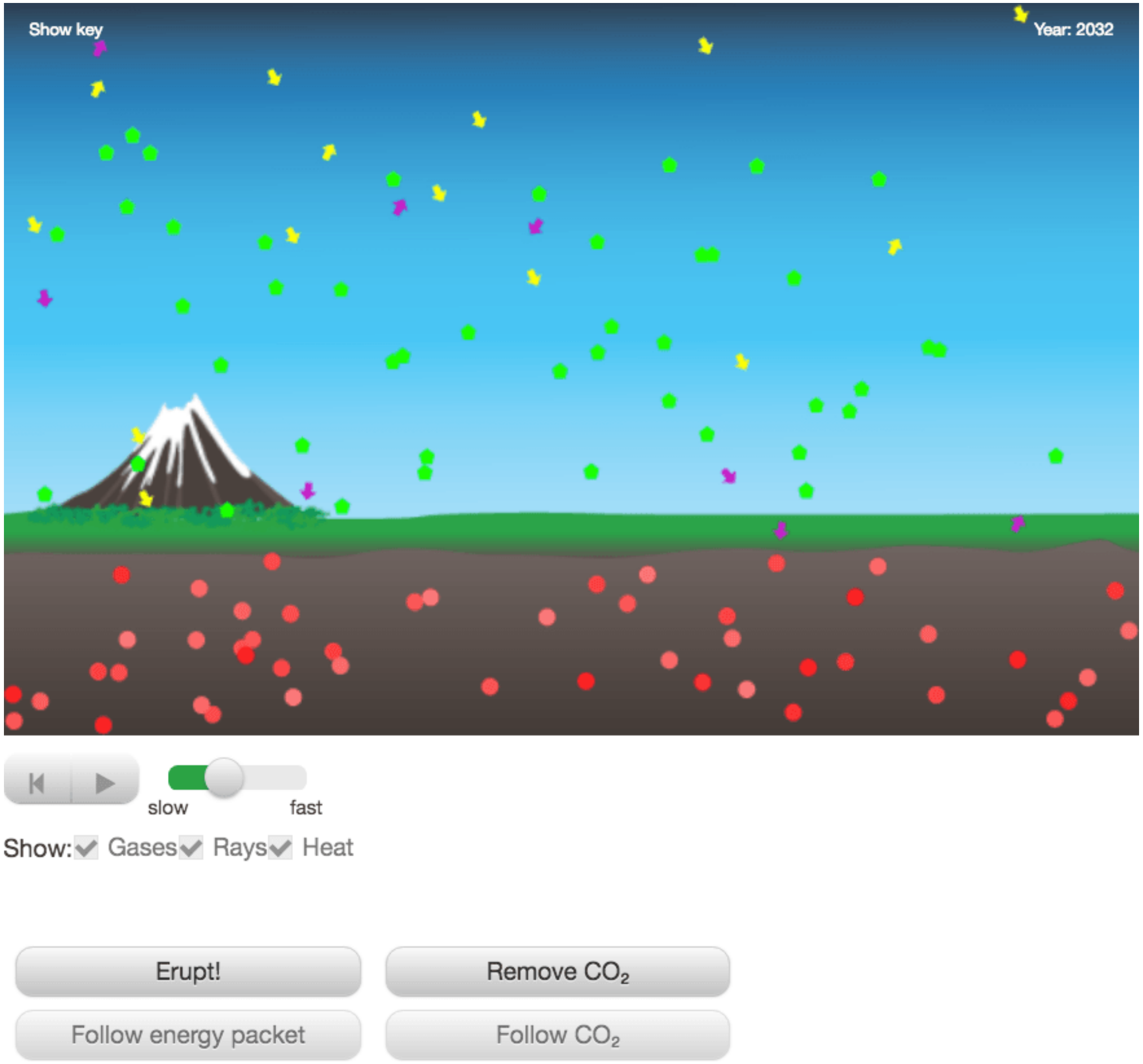
PhET (U. Colorado) – Greenhouse Effect

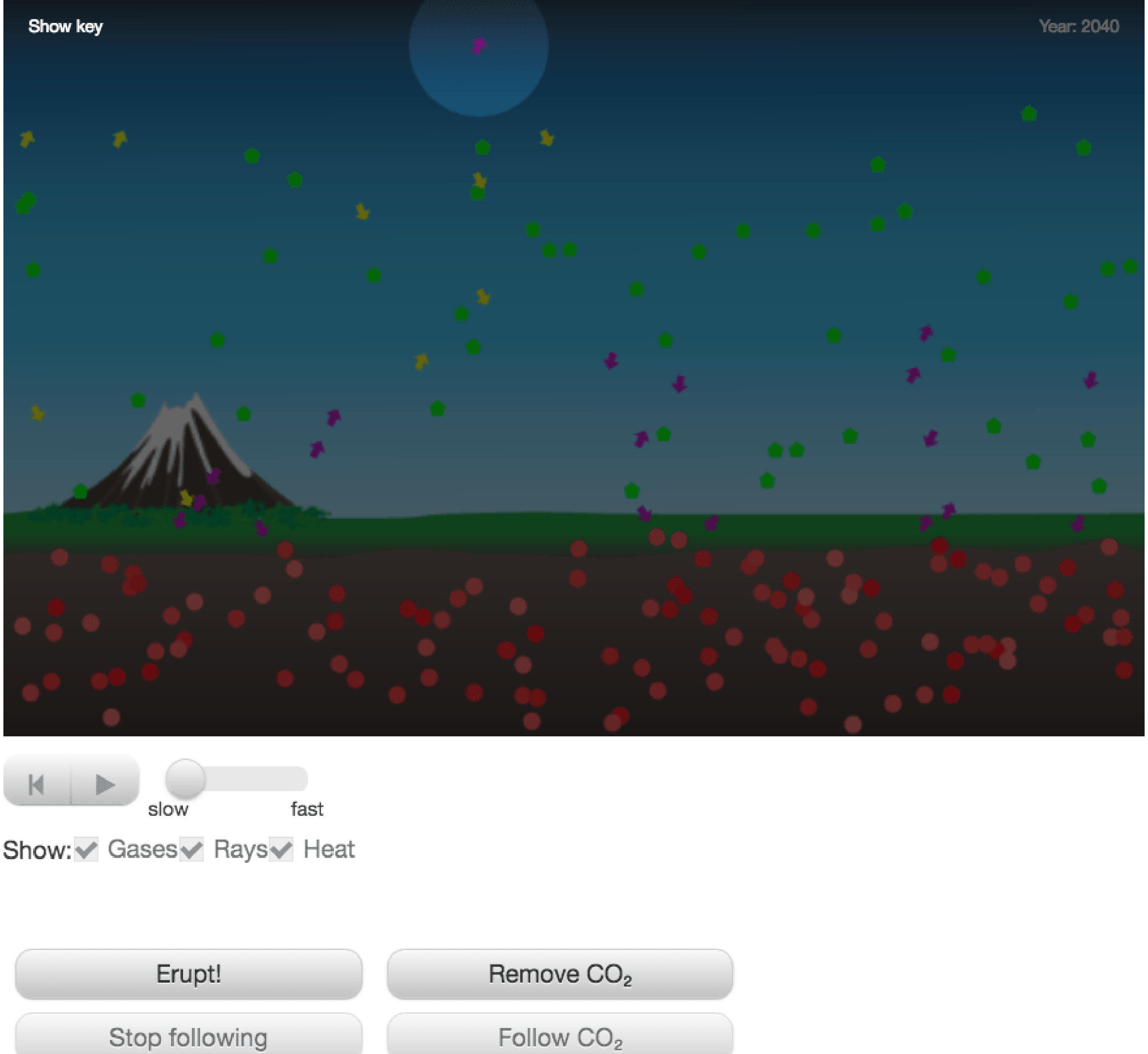


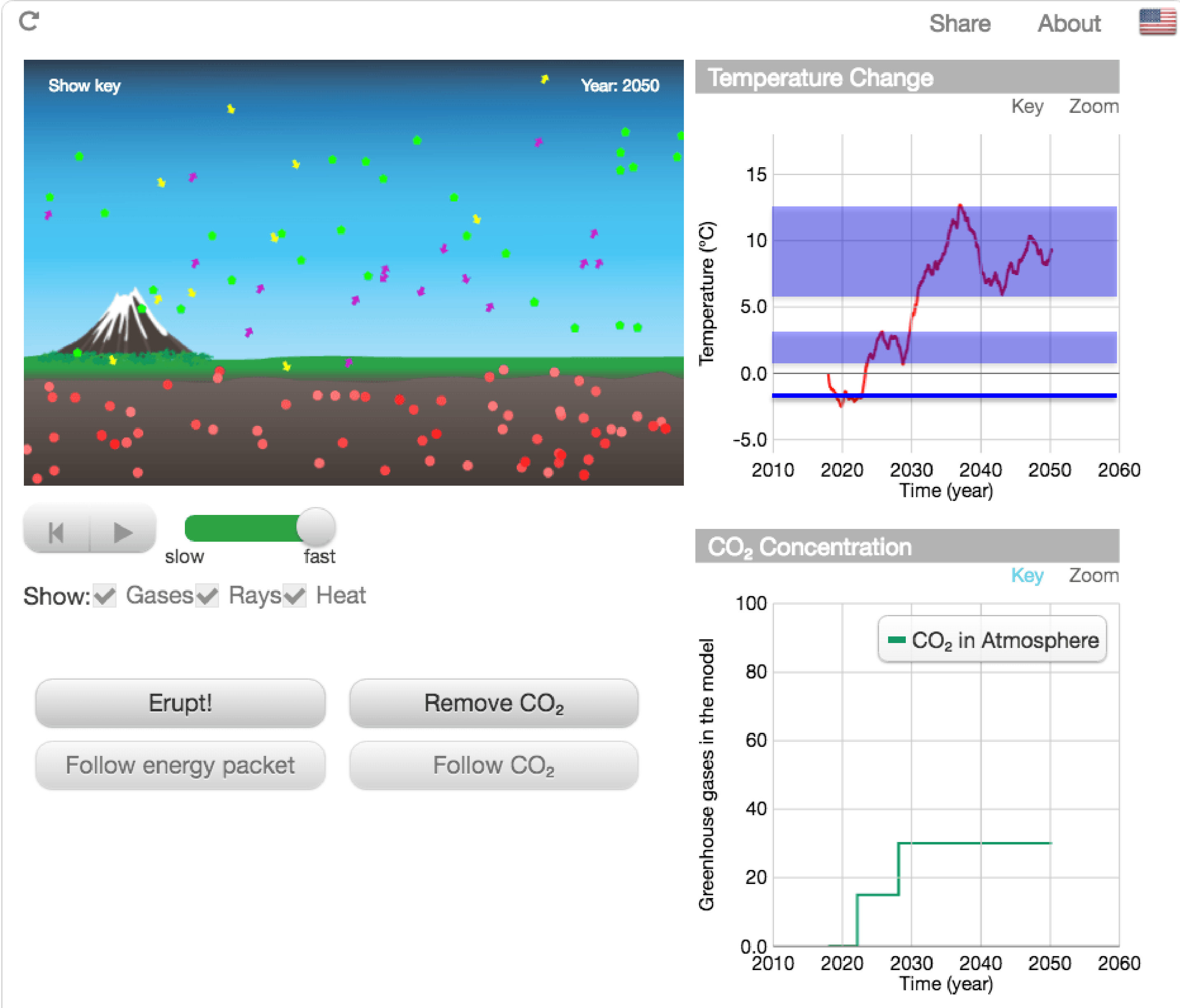


The Greenhouse Effect (3.04)
File
Help
Greenhouse Effect
Glass Layers
Photon Absorption
PhET
Atmospheric Gases
CH4
CO2
H2O
N2
O2
Build Atmosphere
CH4 1 Molecules
CO2 6 Molecules
H2O 2 Molecules
N2 13 Molecules
O2 5 Molecules
Infrared Photon
Visible Photon

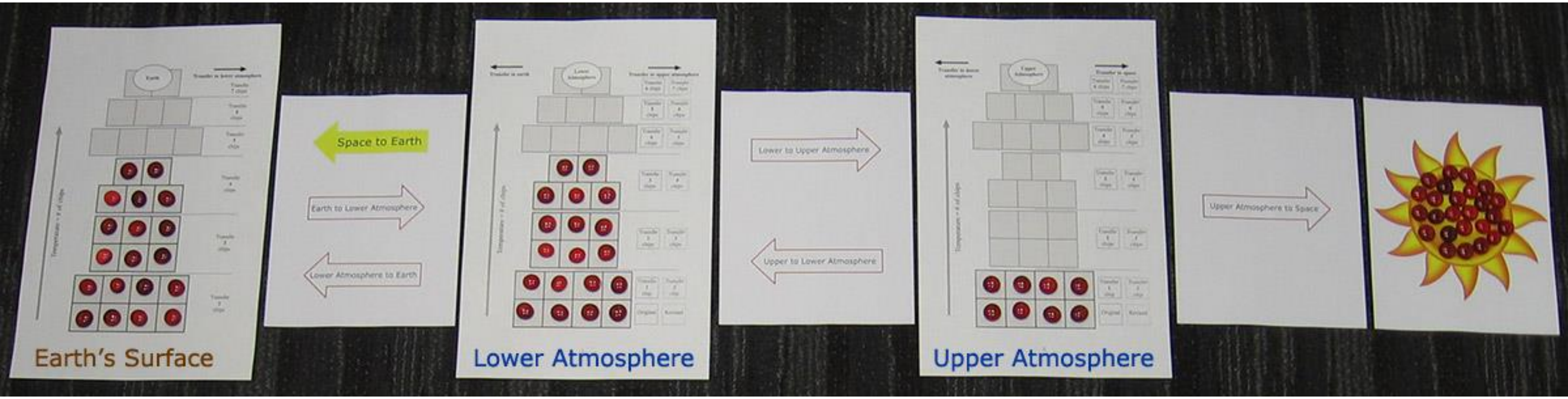
Concord Consortium – Greenhouse Effect

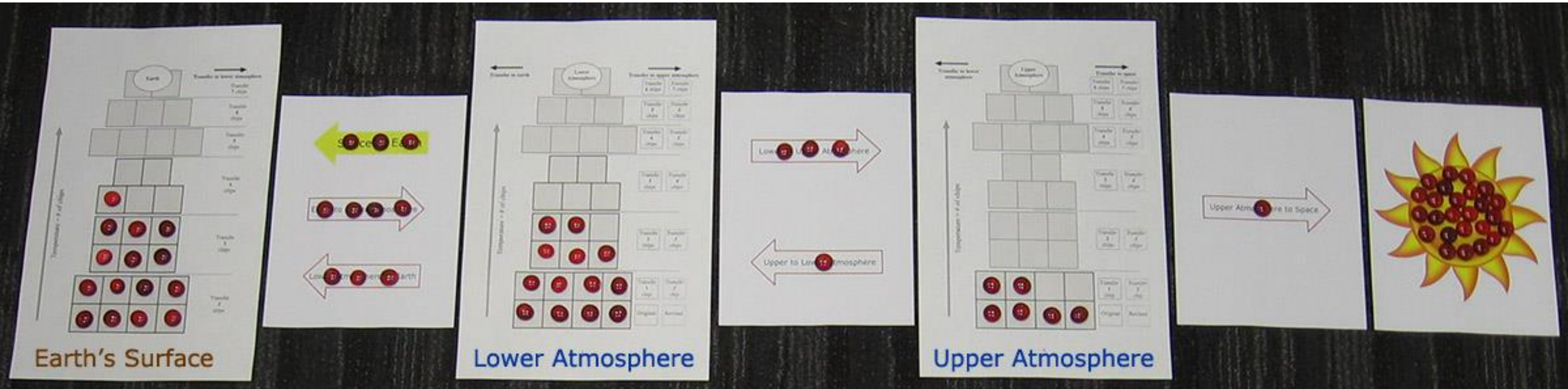


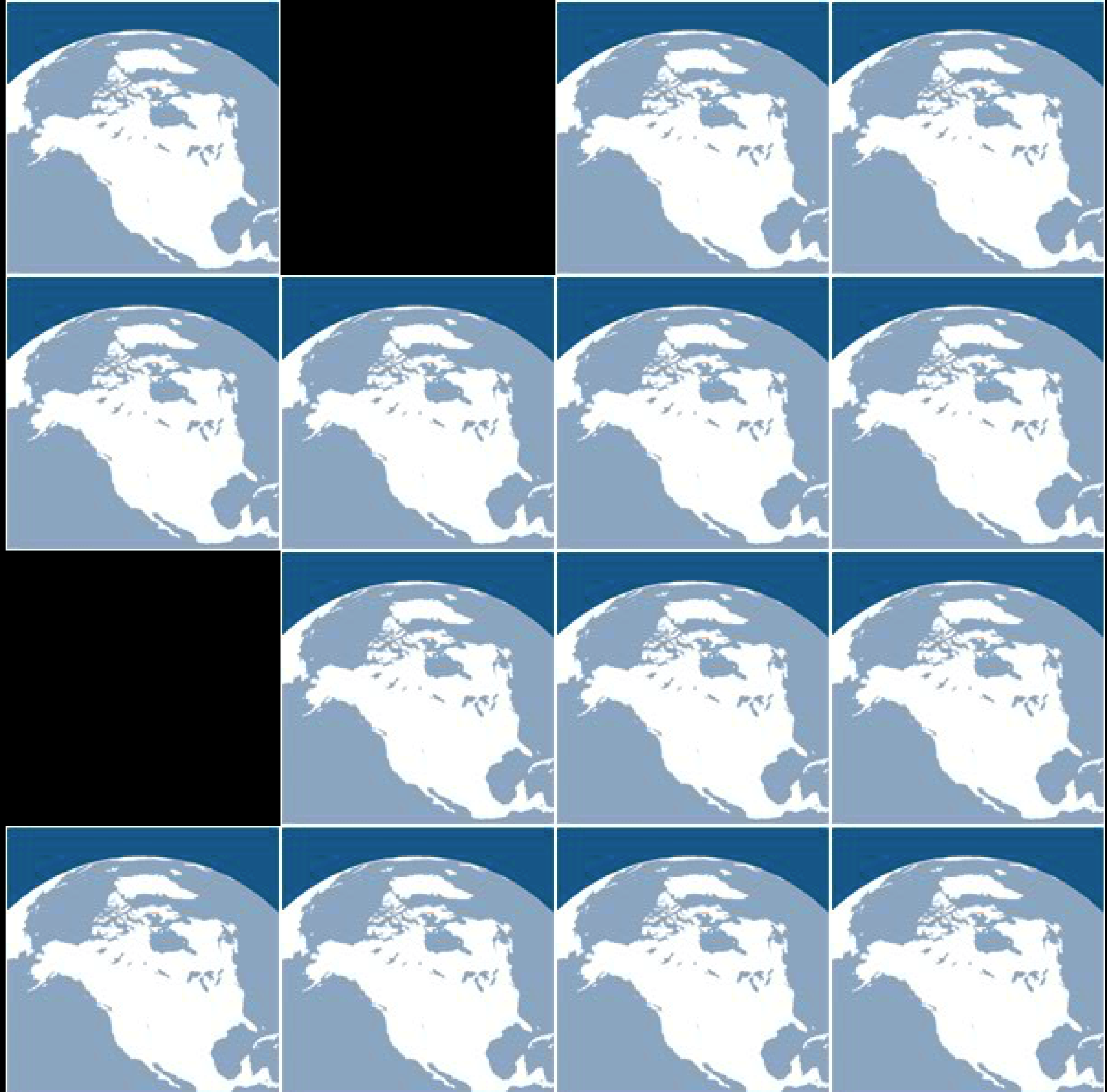

Show key
Year: 2040
slow
fast
Show: Gases Rays Heat
Erupt!
Remove CO_2
Stop following
Follow CO_2

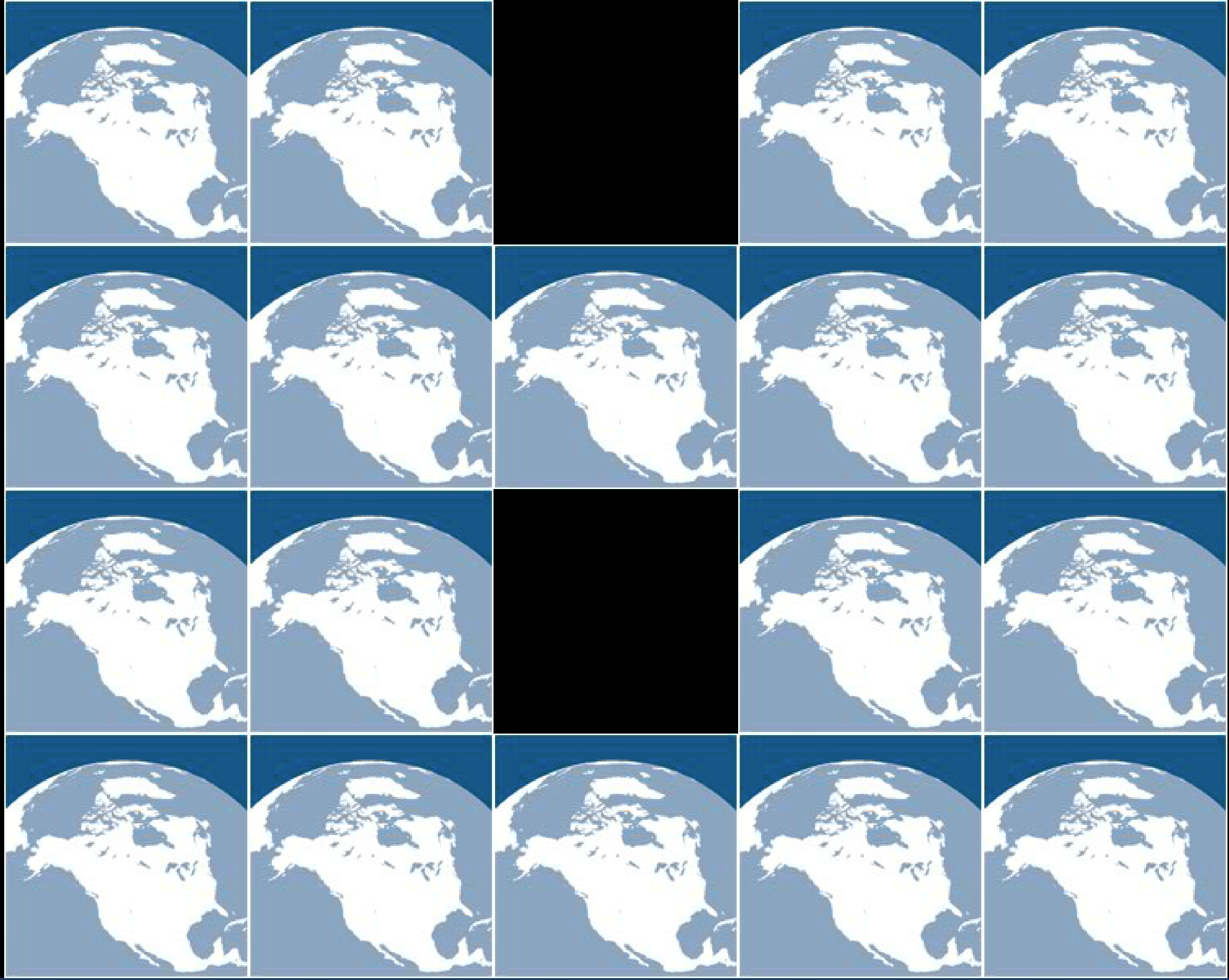

Share
About
Show key
Year: 2050
slow
fast
Show: Gases Rays Heat
Erupt!
Remove CO_2
Follow energy packet
Follow CO_2
Temperature Change
Key
Zoom
Temperature (°C)
15
10
5.0
0.0
-5.0
2010
2020
2030
2040
2050
2060
Time (year)
CO_2 Concentration
Key
Zoom
CO_2 in Atmosphere
Greenhouse gases in the model
100
80
60
40
20
0.0
2010
2020
2030
2040
2050
2060
Time (year)

Atmosphere Model – Hands-on Activity

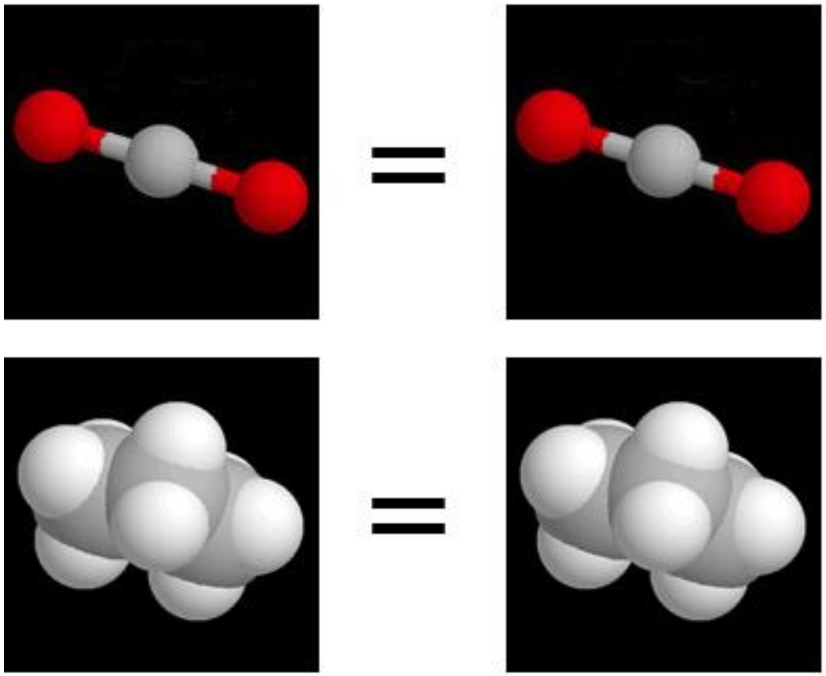




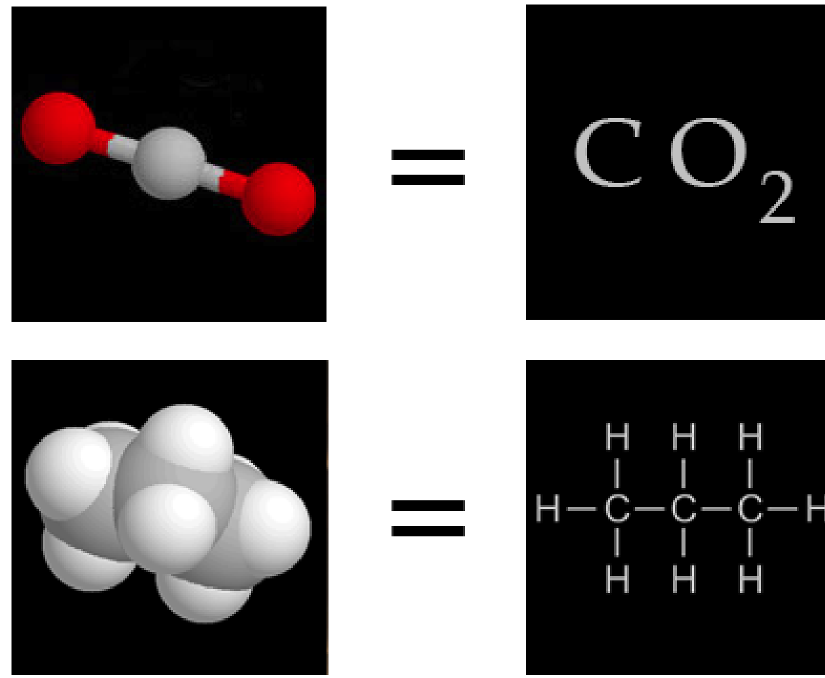




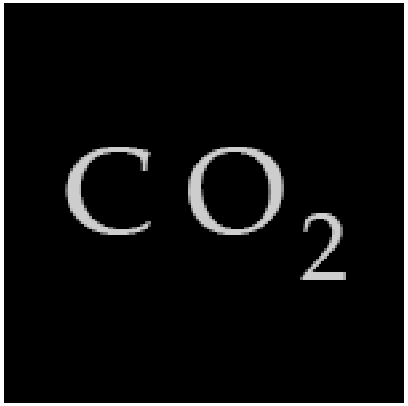
Identical Models

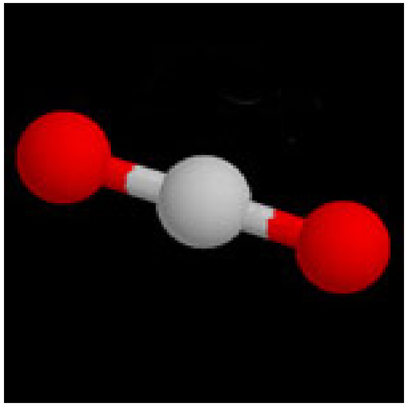


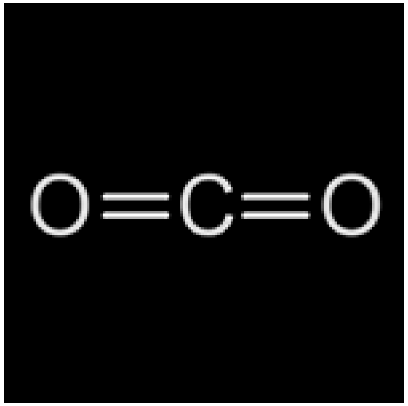
Equivalent Models

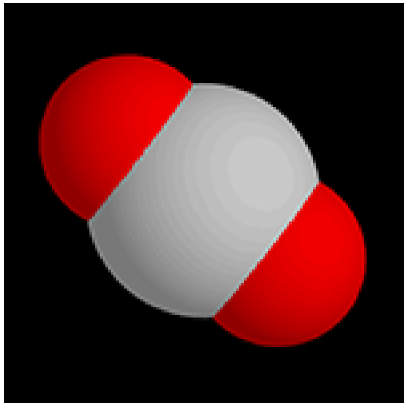


Carbon Dioxide – Various Models of Molecules



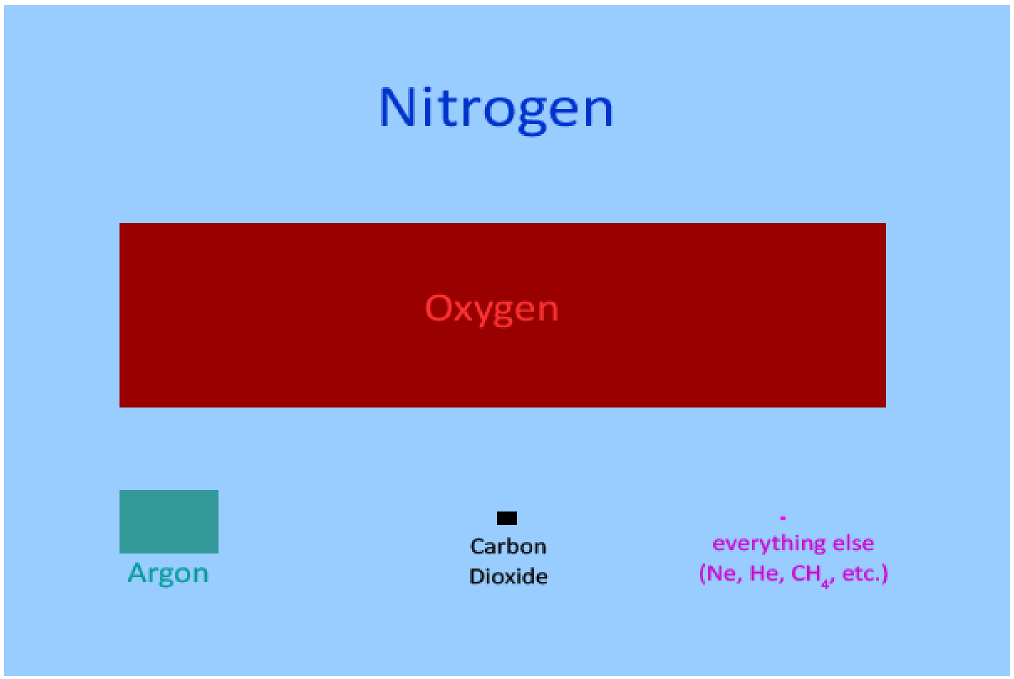


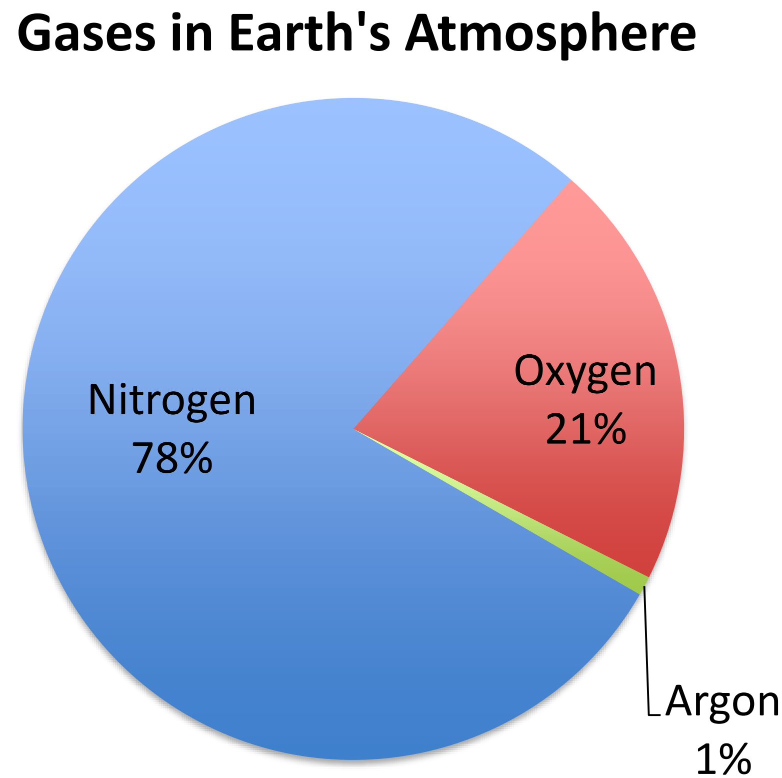




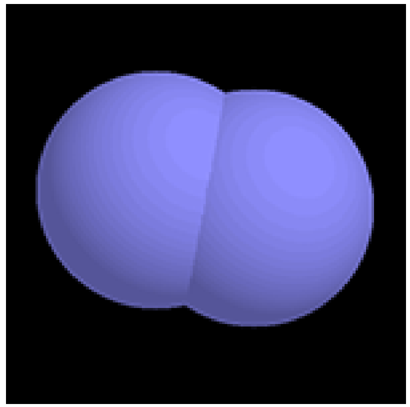
Marshmallow Models of Molecules

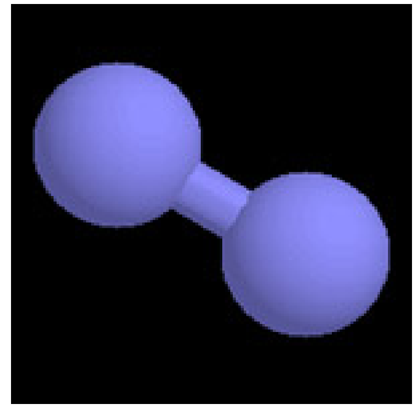
Molecules in Earth Science

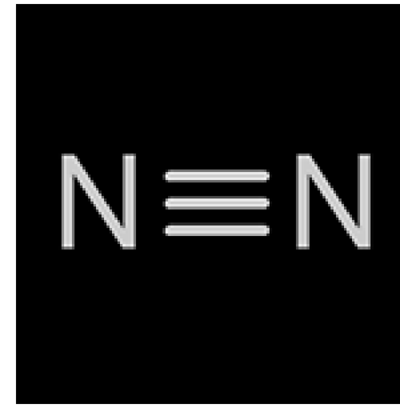




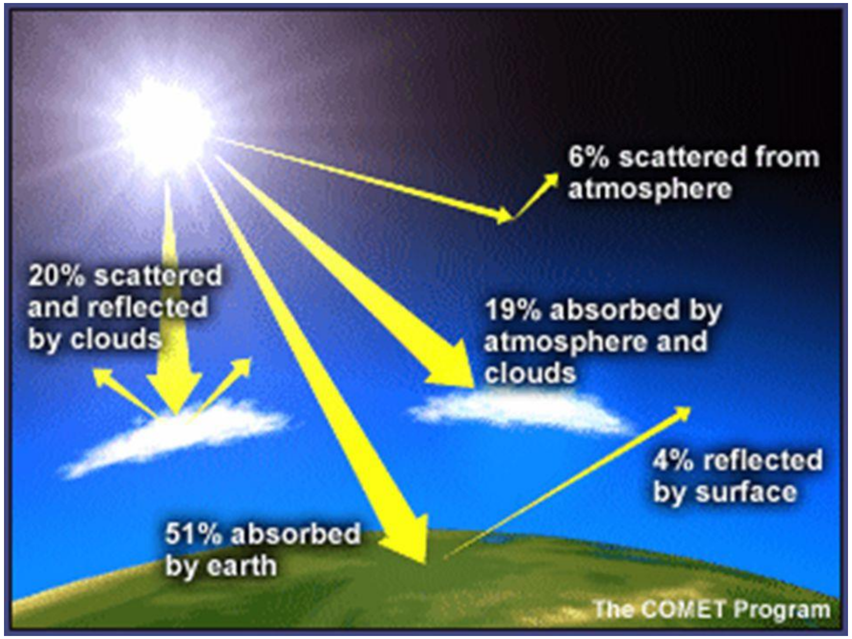
Why so much nitrogen? Triple bond!

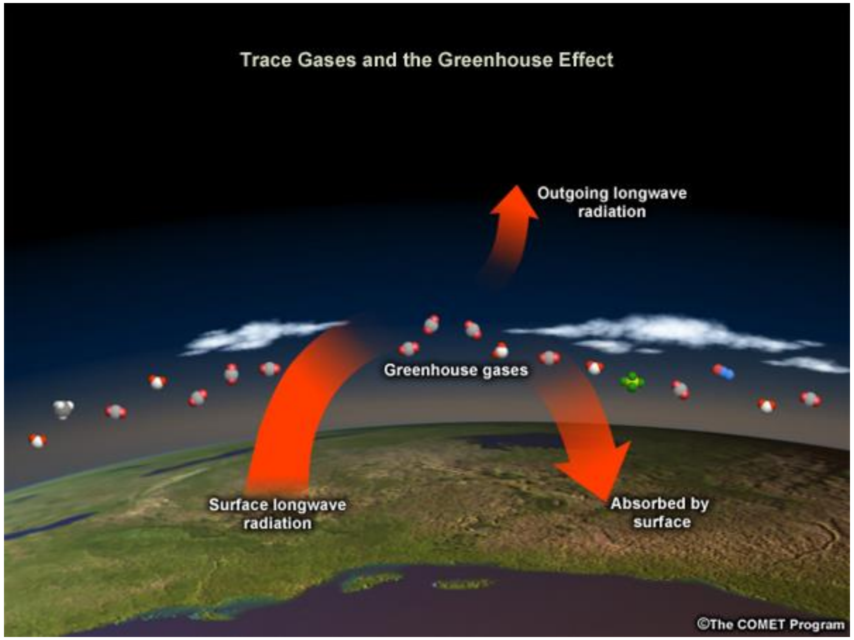






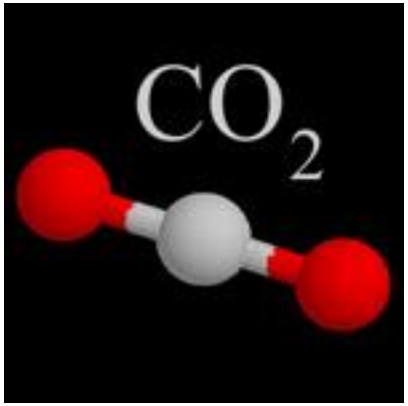
Molecules in Earth Science – Greenhouse Gases

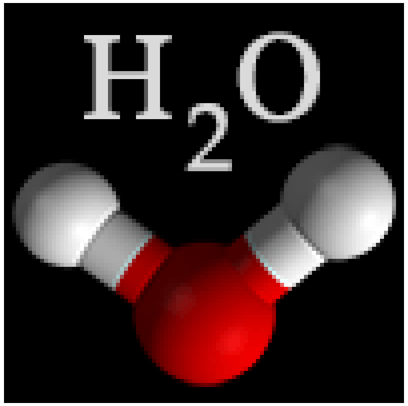


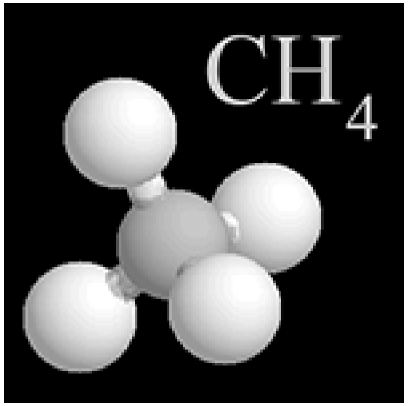


- most sunlight passes right through the atmosphere
- some infrared "light"

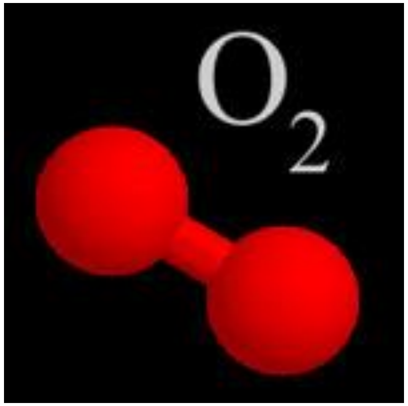
Greenhouse Gas Molecules



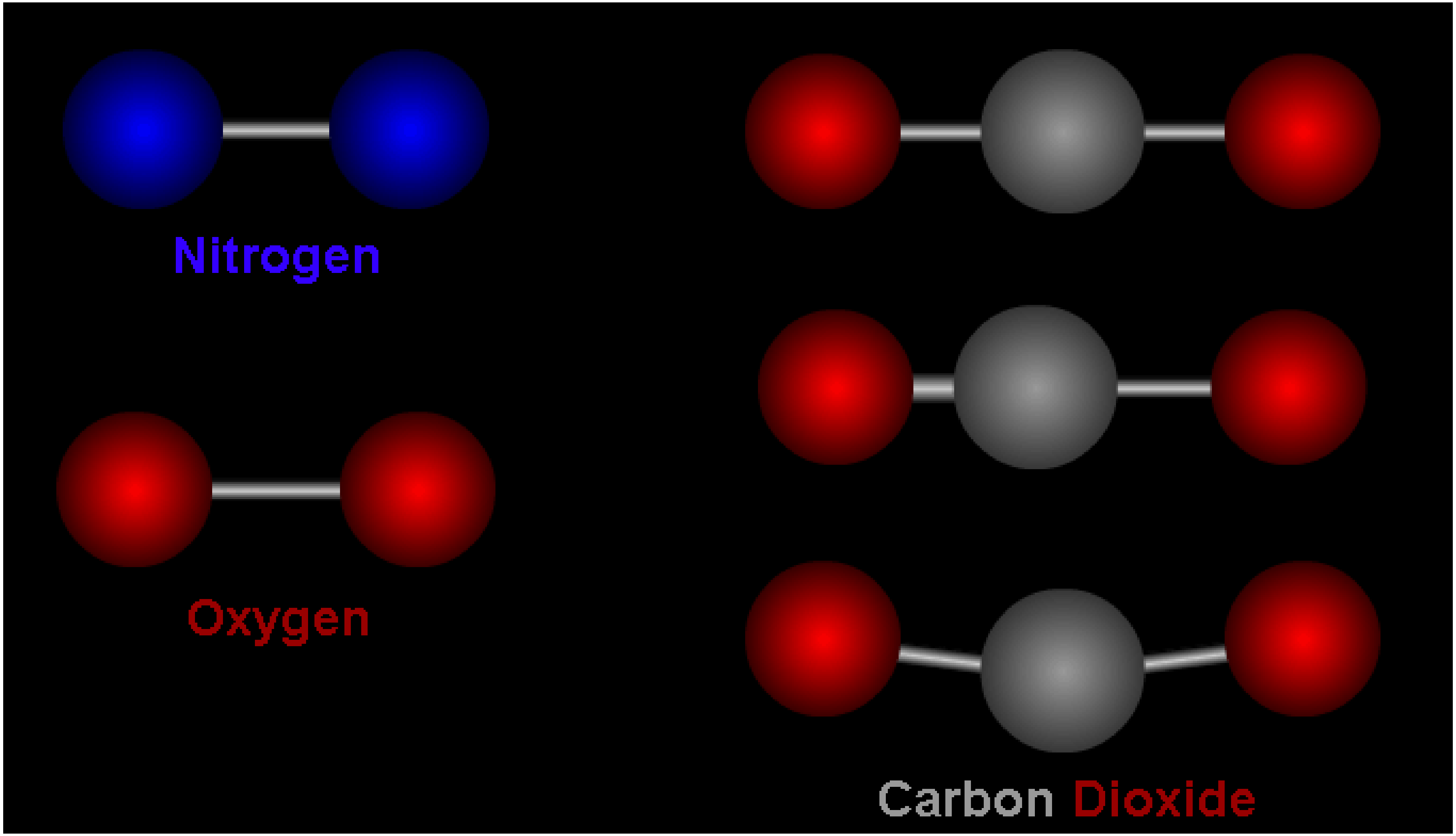




Not Greenhouse Gases

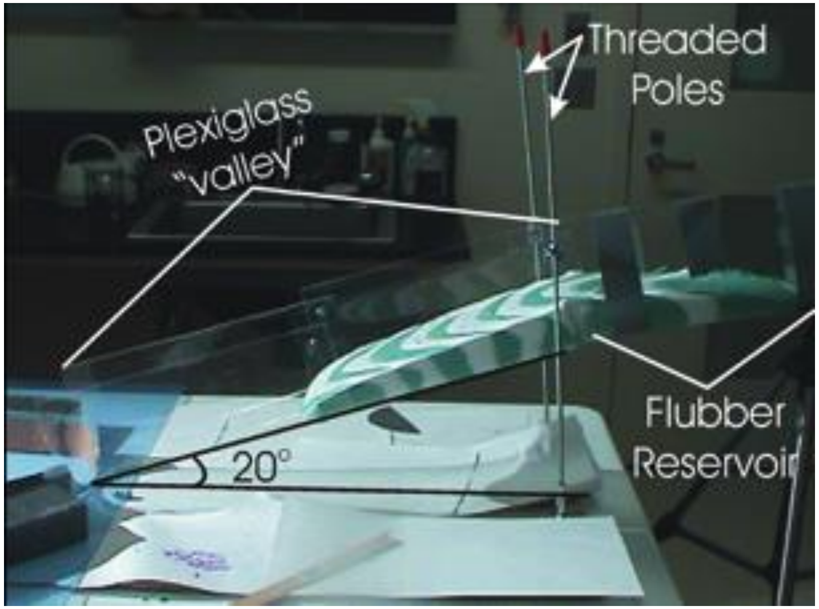


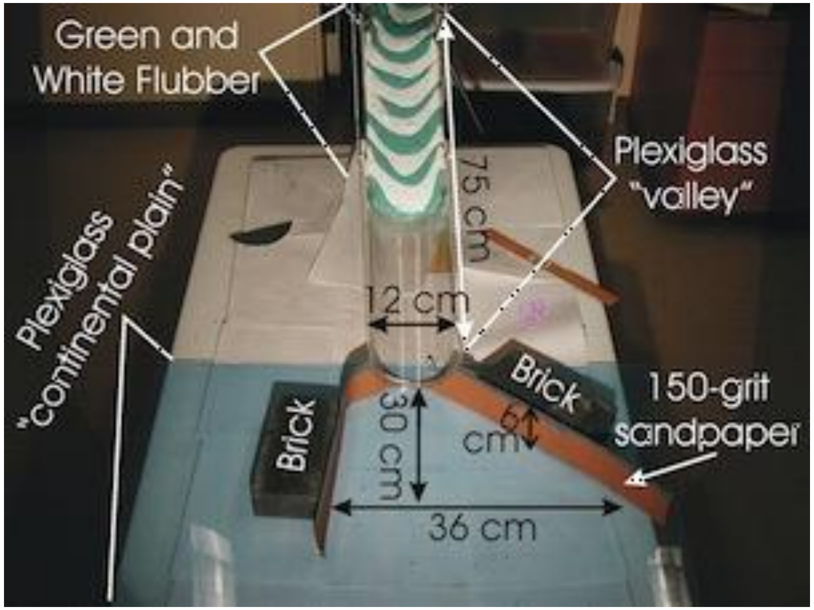
Shape -> Vibration Energy -> GHG (or not!)



Glaciers Then and Now Activity

Model a Moving Glacier Activity ("Glacier Goo")





PhET (U. Colorado) – Glaciers

Levels of Interaction with Simulations/Models

- Run the Model, observe the results

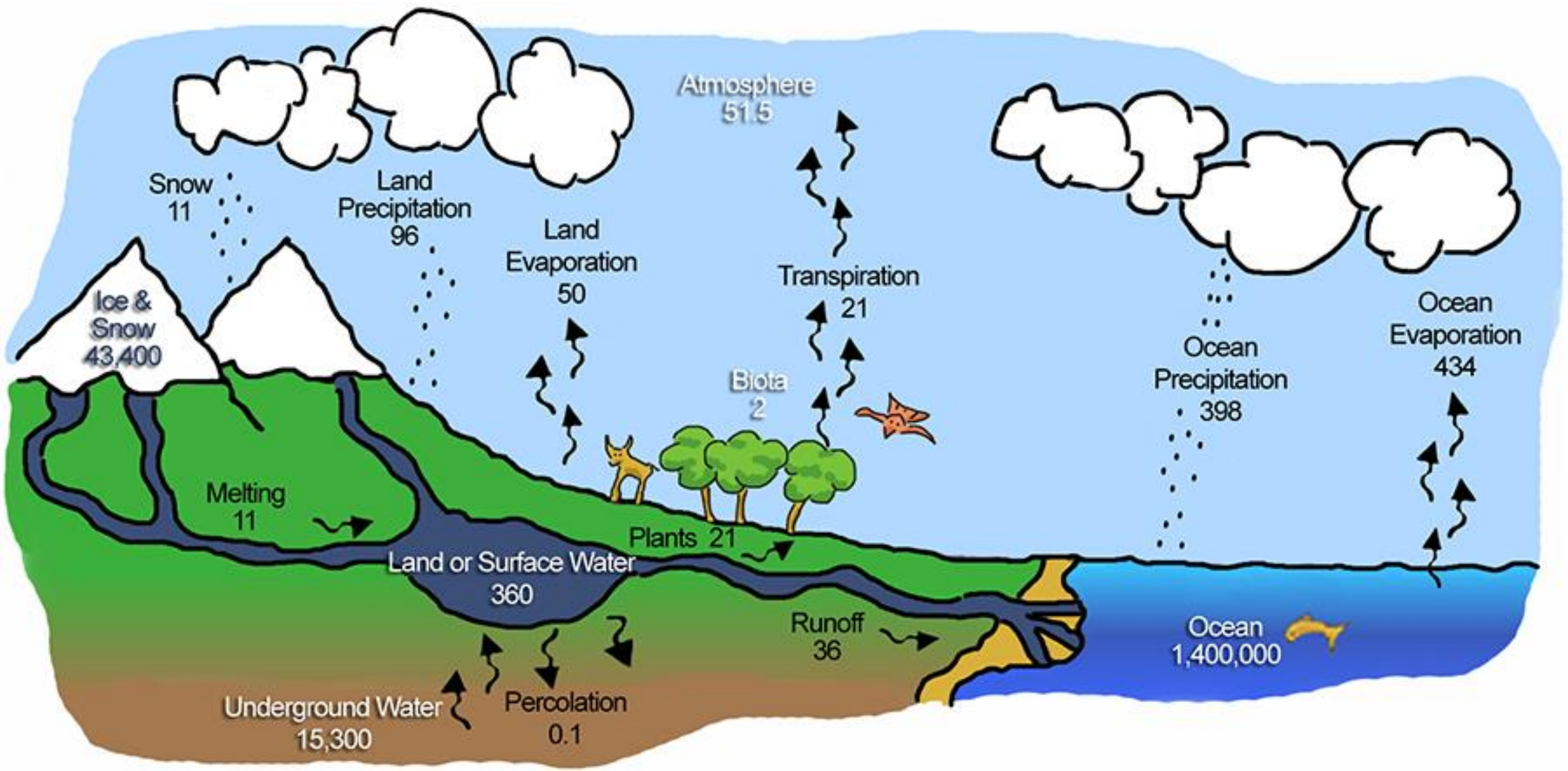
- Adjust inputs/parameters, run the model more than once, see what is different

- Modify the model – can be as simple as changing some constants or the relationships between variables (exponential growth versus linear trend), or may involve adding whole new sections to the existing model

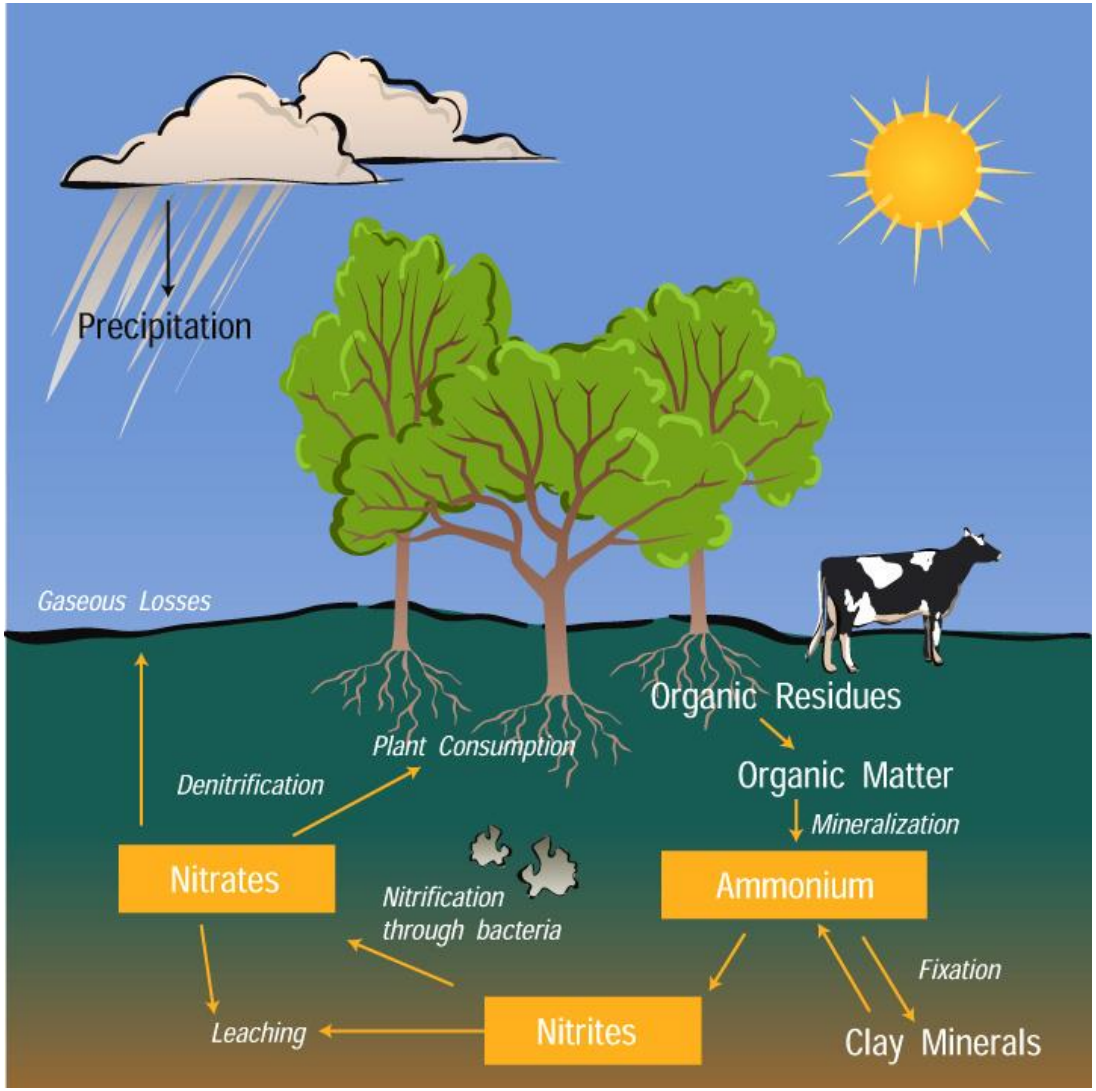
- Construct a model from scratch – Spreadsheets an easy way, but also block programming languages like Scratch

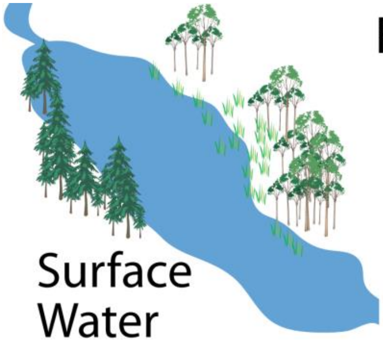

Glaciers (2.04)
File
Help
Introduction
Advanced
PhET
Toolbox
View
units:
English
metric
equilibrium line
snowfall
Climate
Sea-level air temperature:
55.4
68.0
66.2
°F
Average snowfall:
0.0
4.9
3.2
ft
204
years
slow
fast
Show real glacier
Set glacier to steady state
Reset All

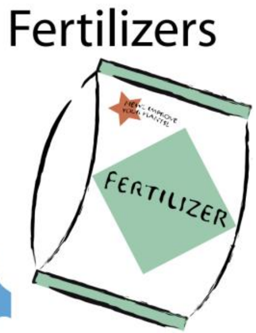
Cycles in the Earth Sciences

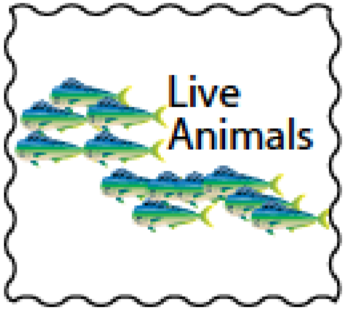


Nitrogen Cycle Game

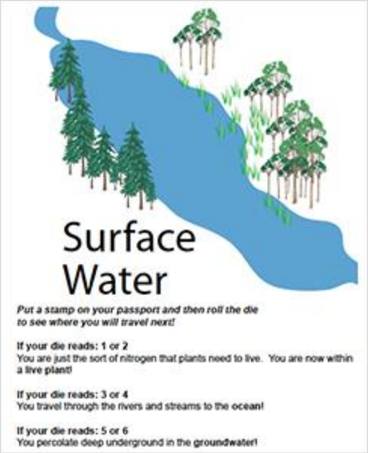


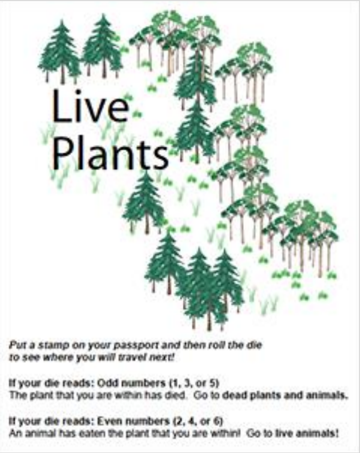


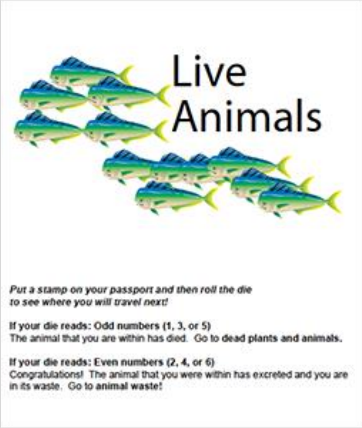


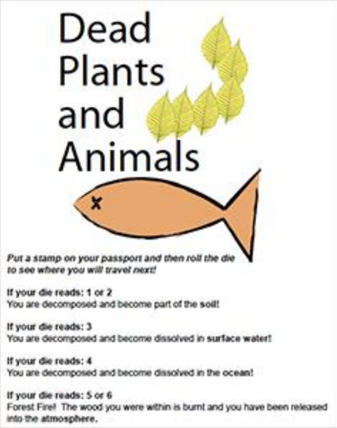


Nitrogen Cycle Game

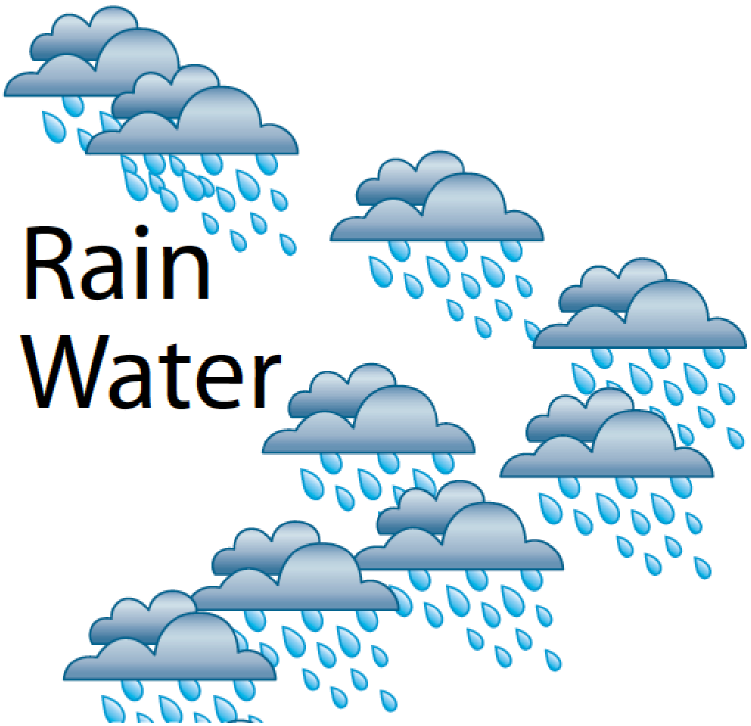








Nitrogen Cycle Game - Stations



Put a stamp on your passport and then roll the die to see where you will travel next!

If your die reads: 1
You fall into a lake or stream so now you are part of **surface water.**

If your die reads: 2 or 3
You fall on the land and become part of the **soil**!

If your die reads: 4
You percolate deep underground in the **groundwater**!

If your die reads: 5 or 6
You rain into the **ocean**!

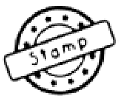
The Nitrogen Cycle Game
Passport Worksheet

Name: ______________________

Guess what! In this game you are a nitrogen atom. You are going to travel the nitrogen cycle stopping in many exciting locations - some of which you probably never have been to before.

For each stop along your journey, remember to record where you went and how you got there.

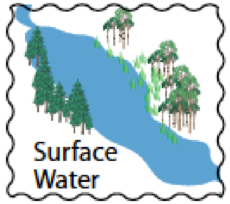
Here's an example of how to fill out each stop along the way:

Trip#1:How I traveled:	Where I went:
Fertilizer washed into stream	

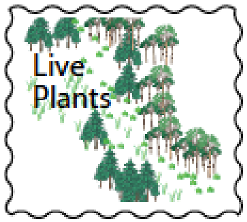
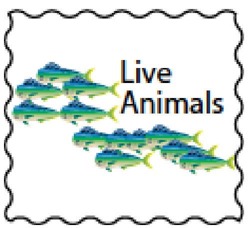
Directions:

1. Stamp your start location in the space below.

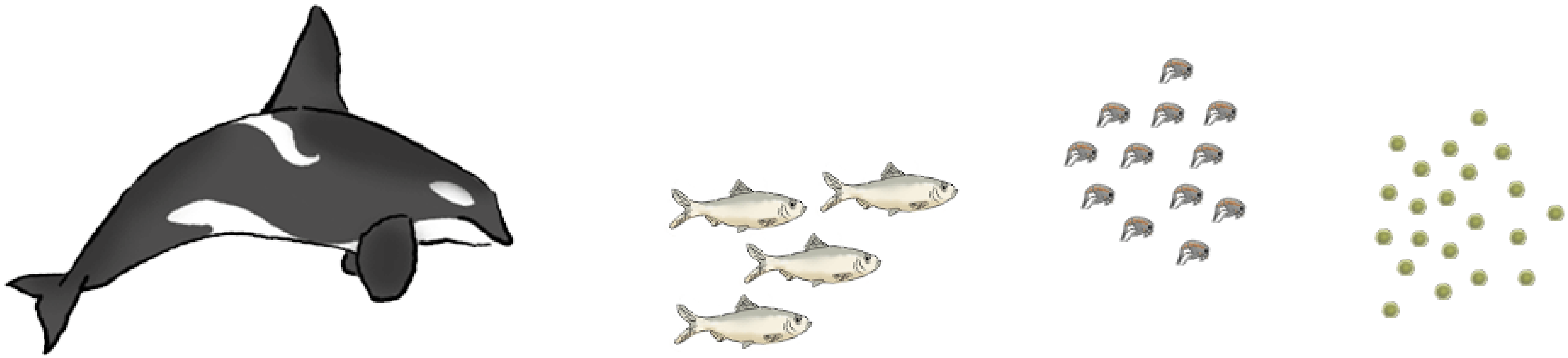
Start location

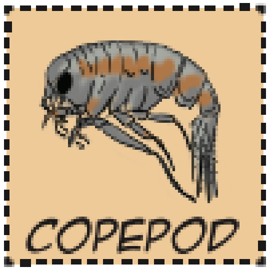


2. Roll the die to find out where to go next.
3. Write ***How I traveled*** in the Trip #1 (see example at right).
4. Go to that station and stamp the Trip#1 ***Where I went*** box.
5. Then, roll the die to find out where to go for Trip #2.

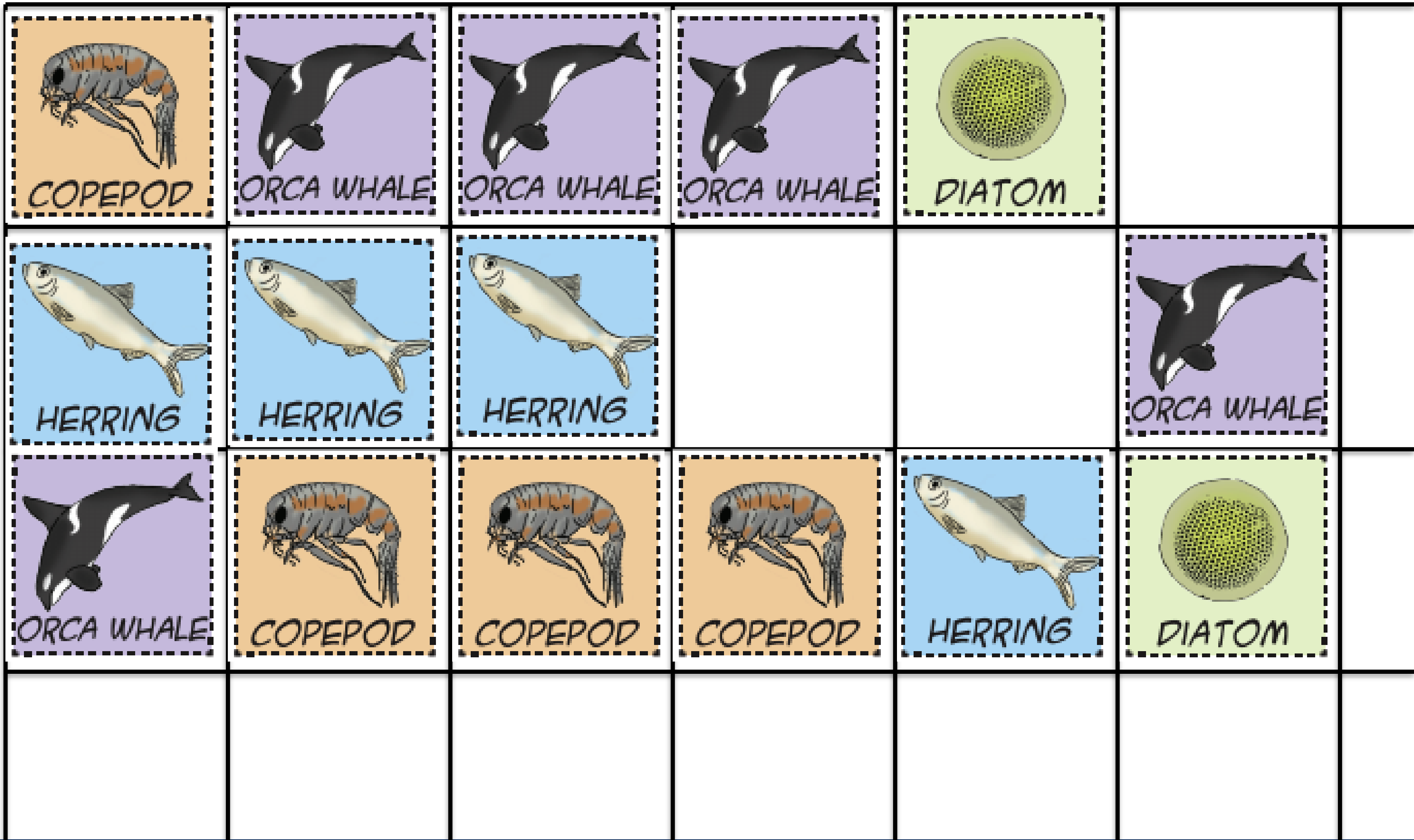
Trip	How I traveled:	Where I went:
Trip #1:		
Trip #2:		
Trip #3:		
Trip #5:		*Stamp above*
Trip #6:		*Stamp above*
Trip #7:		

Food Chain Checkers

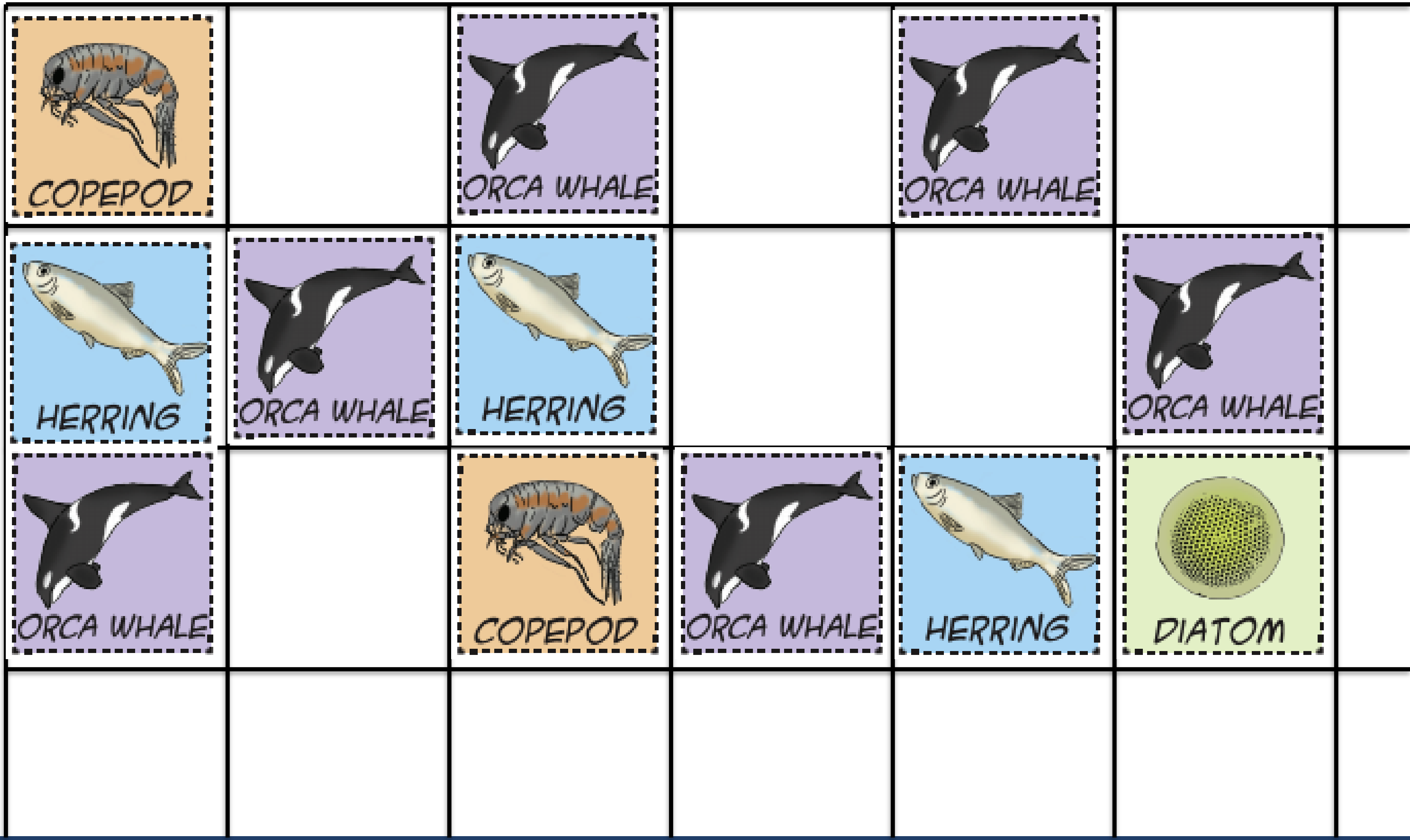




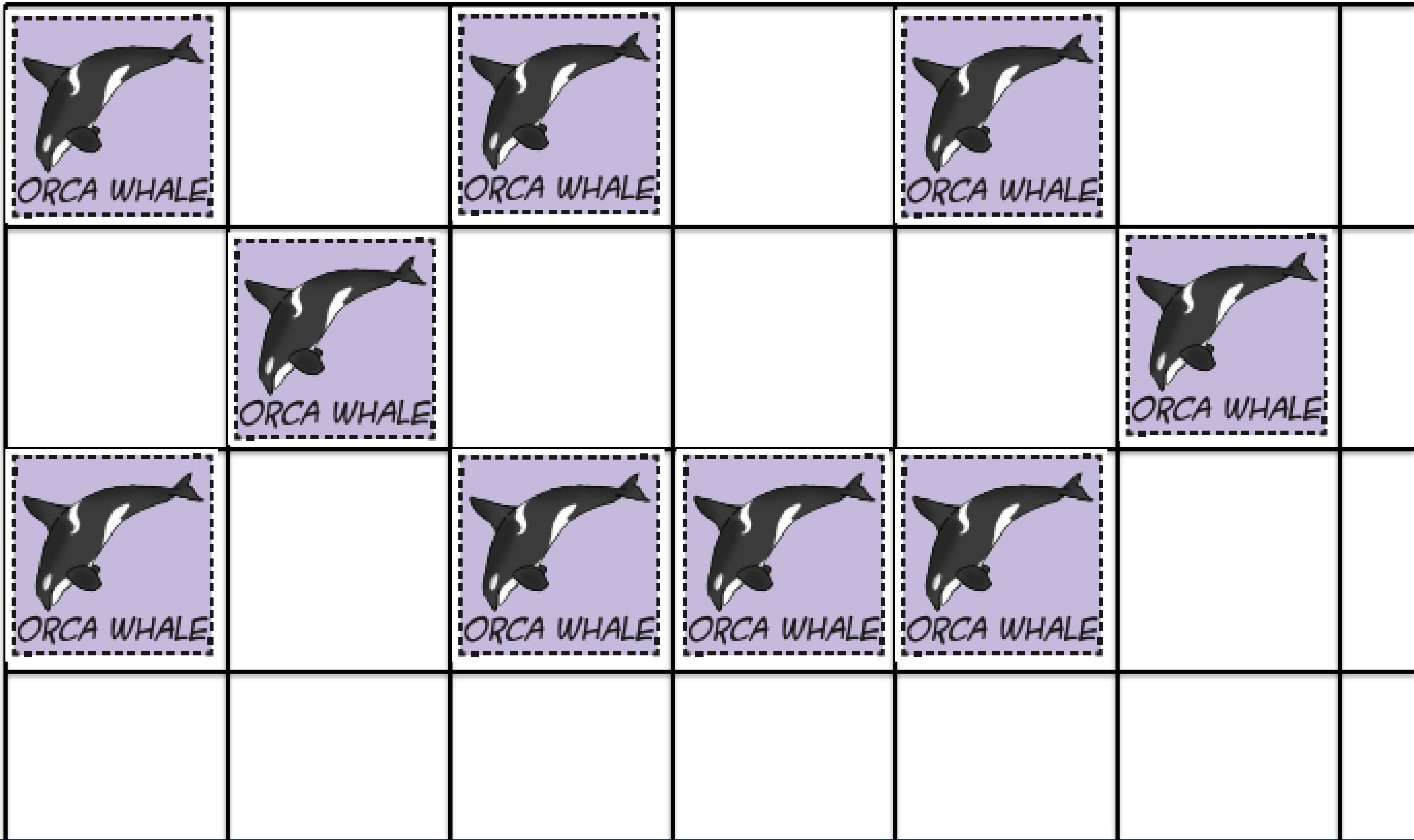
Food Chain Checkers

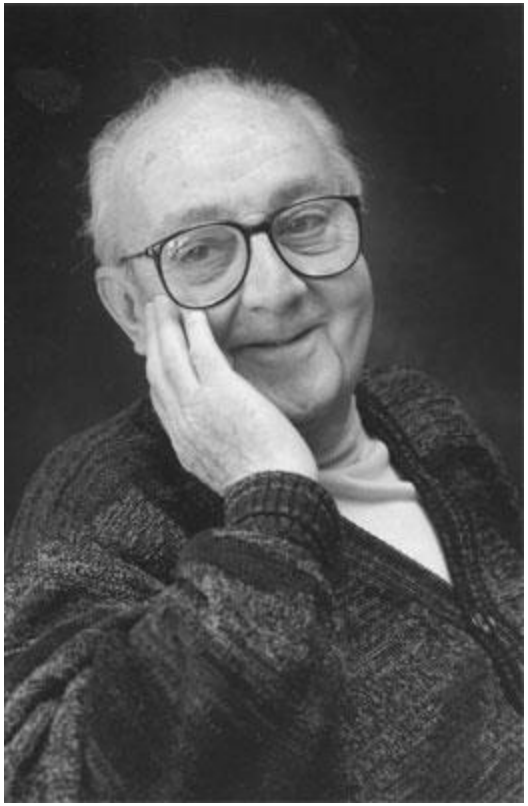


Food Chain Checkers



Food Chain Checkers





"Essentially, all models are wrong, but some models are useful."

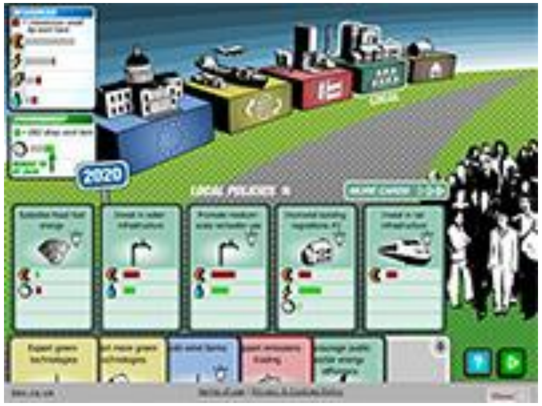
- George E. P. Box (1951)

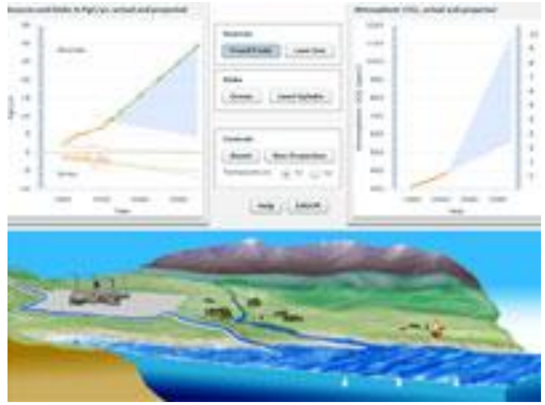
NGSS:

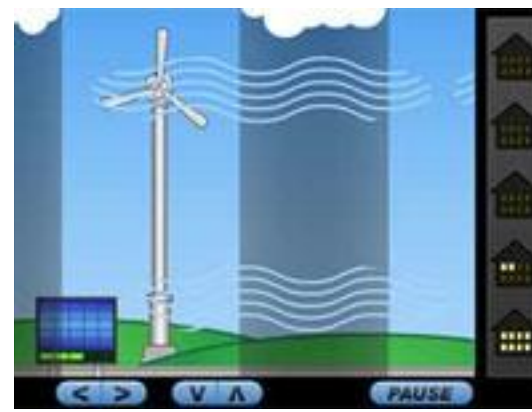
"Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, **it is important to recognize their limitations**."

"… and suggest ways in which the model might be **improved** to better fit available evidence…"

Collection of Sims/Games on Climate







URL: SciEd.ucar.edu/games-sims-weather-climate-atmosphere