

Games & Simulations for Climate Education

Randy Russell

UCAR Center for Science Education

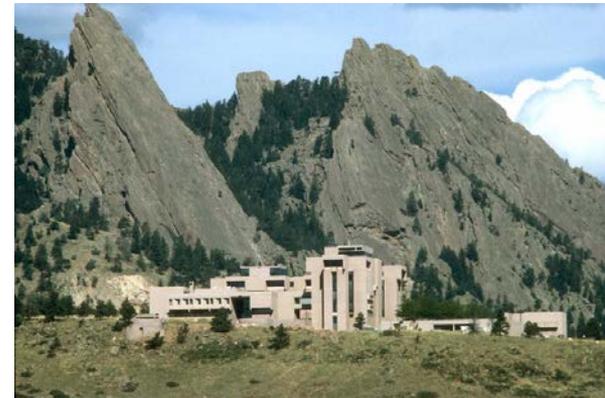
CLEAN Network Telecon

19 May 2015



National Center for Atmospheric Research

Boulder, CO



Some of our games originally developed for exhibit touchscreens



Exhibit Touchscreens



Similar to development
for mobile touch devices
(smartphones, tablets)

All models are wrong, but...

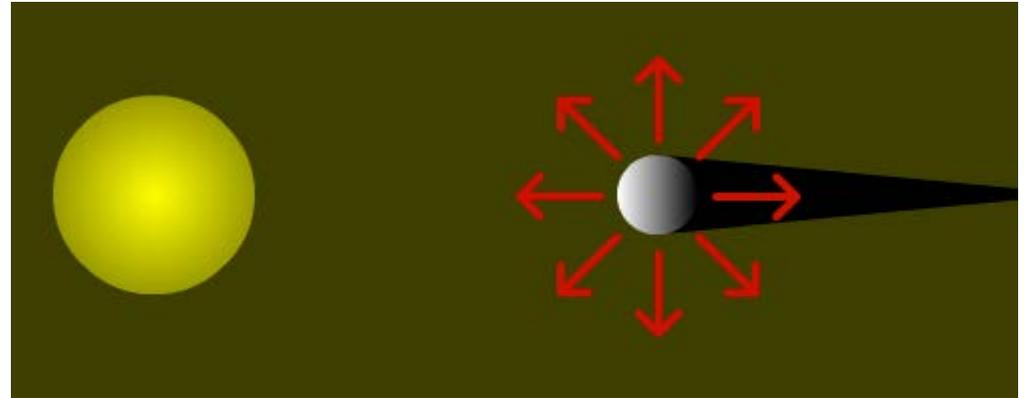
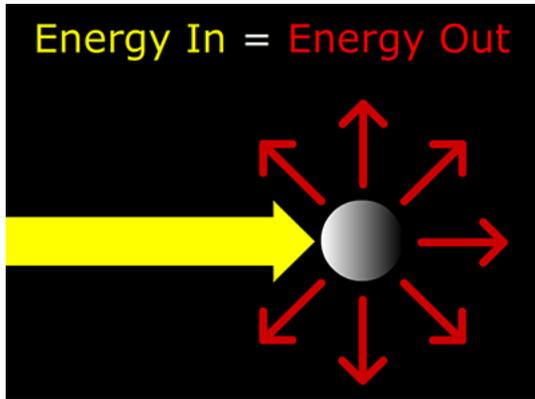


“Essentially, all models are wrong,
but some models are useful.”

- George E. P. Box (1951)

Modeling Planetary Energy Balance

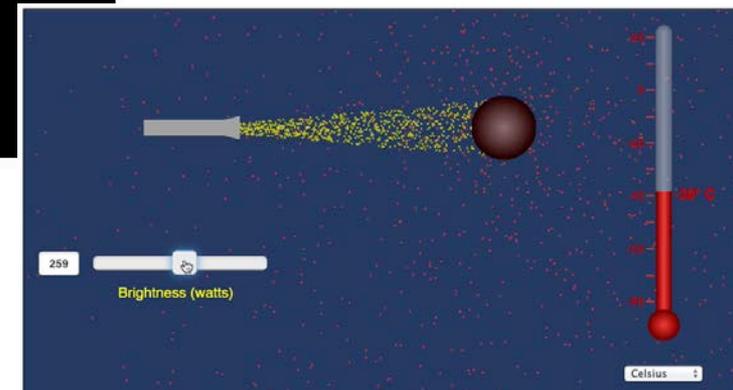
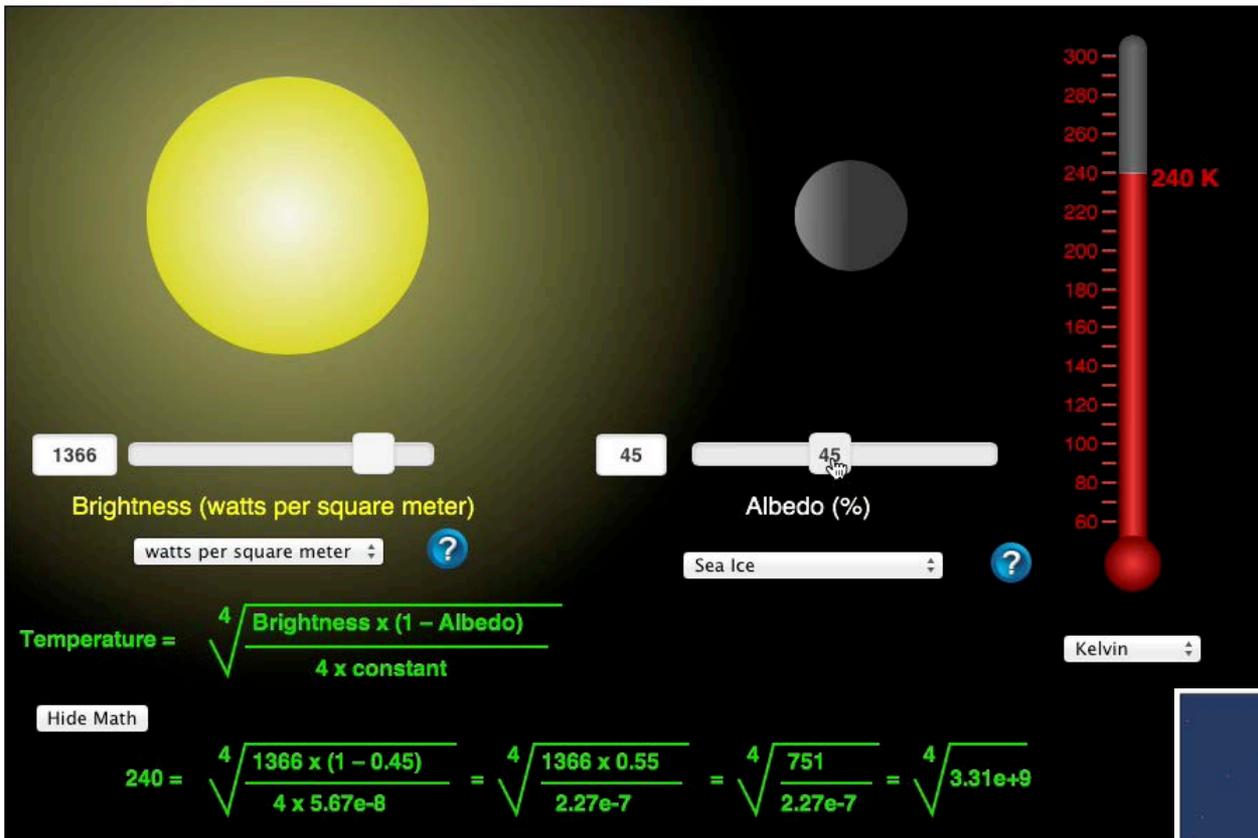
- Calculate theoretical temperature of a planet with some simple math
- Discover that Earth would be frozen without the greenhouse effect



Science Topics

- Blackbody Radiator and the Stefan-Boltzman Law
- Conservation of Energy (Energy In = Energy Out)
- Albedo

Earth's Energy Balance



URL: scied.ucar.edu/earths-energy-balance

LASP: Kelvin Climb

The screenshot shows the 'Planet Designer Kelvin Climb' interface. At the top, the title 'Planet Designer Kelvin Climb' is displayed next to a 'KC' logo. On the left, a vertical menu lists various simulation options: PROGRESS, DISTANCE, ALBEDO, ATMOSPHERE, SUMMARY, EM RADIATION, and DEBRIEFING. The 'ALBEDO' option is currently selected. The main workspace features a 3D planet model on a black and white checkerboard background. The planet is partially colored with a green landmass and a blue ocean, with a white polar ice cap. Above the planet is a row of color selection circles in red, orange, yellow, green, cyan, blue, magenta, and white. To the right of the planet, a control panel displays 'Albedo' as 0.1672 with a 'What's this?' help button, and 'Blackbody Temperature' as 179 K, accompanied by a thermometer graphic. Below the control panel are 'BACK' and 'NEXT' navigation buttons. At the bottom, a text box provides instructions: '*Sizes and distances not to scale. Paint the planet to see how coloring affects albedo, and note how the albedo affects the planet's blackbody temperature. Click 'Next' when finished.'

URL: lasp.colorado.edu/home/education/k-12/project-spectra/kelvin-climb-interactive

Add an Atmosphere with Greenhouse Gases

Planet Designer Kelvin Climb KC

PROGRESS

DISTANCE

ALBEDO

ATMOSPHERE

SUMMARY

EM RADIATION

DEBRIEFING

Atmosphere thickness: Moderate

Mars Earth

Greenhouse strength: Moderate

Mars Earth

Tip: increase atmosphere thickness to enable a stronger greenhouse.

0.50

Atm. pressure (bars)

276 K

Avg. Surface Temperature

800

600

400

200

0

This planet could have lakes of liquid water. Its atmosphere could contain nitrogen or oxygen, and may contain greenhouse gases such as carbon dioxide or methane.

ARTISTIC RENDERING

*Sizes and distances not to scale.

Change the atmosphere thickness and greenhouse strength and see what your planet might look like from the surface. What sort of atmosphere is required in order to have liquid water on your planet? Click 'next' when finished.

◀ BACK

NEXT ▶

Change distance from Sun

Planet Designer Kelvin Climb KC

PROGRESS

- DISTANCE
- ALBEDO
- ATMOSPHERE
- SUMMARY
- EM RADIATION
- DEBRIEFING

Mass

Avg. density

Planet mass (Earth masses) 1.00

Planet radius (Earth radii) 1.00

Avg. density (kg / m³) 5490

Avg. distance from Sun (AU) 3.00

161 K

Blackbody Temperature

800
600
400
200
0

← BACK NEXT →

*Sizes and distances not to scale.

This is a completely black planet with no atmosphere. Drag the planet to change its distance from the Sun, and adjust its mass and density to see how temperature is affected. Click 'Next' when done.

NASA Spreadsheet: GEEBITT

The Planet With Surface Features and a Non-Absorbing Atmosphere

(1) Enter an appropriate *albedo* in the gray box below, then examine the resulting solar energy absorbed at the planet's surface and its surface temperature in the boxes to the right. (To change the luminosity or distance, return to the first page and make your changes there.)

Current Luminosity of the Sun (Watts): $3.85E+26$

Distance From Sun (Astronomical Units): 1.000

Average Reflectivity of the Planet (or albedo): 0.310

Solar Energy Reaching the Planet's Surface Each Second (Watts/meter²):
Average = 341.79 Maximum = 1367.17

Energy Absorbed At the Planet's Surface Each Second (Watts/meter²):
Average = 235.84 Maximum = 943.35

(Incoming Solar Radiation must be in watts/meter ²)	Resulting Surface Temperature		
	Kelvin	Centigrade	Fahrenheit
Black Body Planet	278.6	5.5	41.9
Planet With Albedo	254.0	-19.2	-2.6

Suggested Average Albedos For Modeling Planets In Our Solar System:	Known Average Albedo* (planetary albedo) (unitless)
Mercury	0.11
Venus	0.76
Earth	0.306
Mars	0.25
Jupiter	0.34
Saturn	0.34
Uranus	0.3
Neptune	0.29
Pluto	0.3

The albedo value must be between 0 and 1.0 . An albedo of 0 indicates the object absorbs all the light hitting it, while an albedo of 1.0 indicates the object reflects all of the light hitting it. The albedo is determined by the surface features and the atmosphere.

URL: icp.giss.nasa.gov/education/geebitt

Greenhouse Effect - PhET

Greenhouse Effect | Glass Layers | Photon Absorption

Legend

- Sunlight photon
- Infrared photon

Greenhouse Gas Concentration

None | | Lots

Atmosphere during...

- Today
- 1750
- Ice age
- Adjustable concentration

Greenhouse Gas Composition

H ₂ O	70% rel. humidity
CO ₂	388 ppm
CH ₄	1.843 ppm
N ₂ O	0.317 ppm

Options

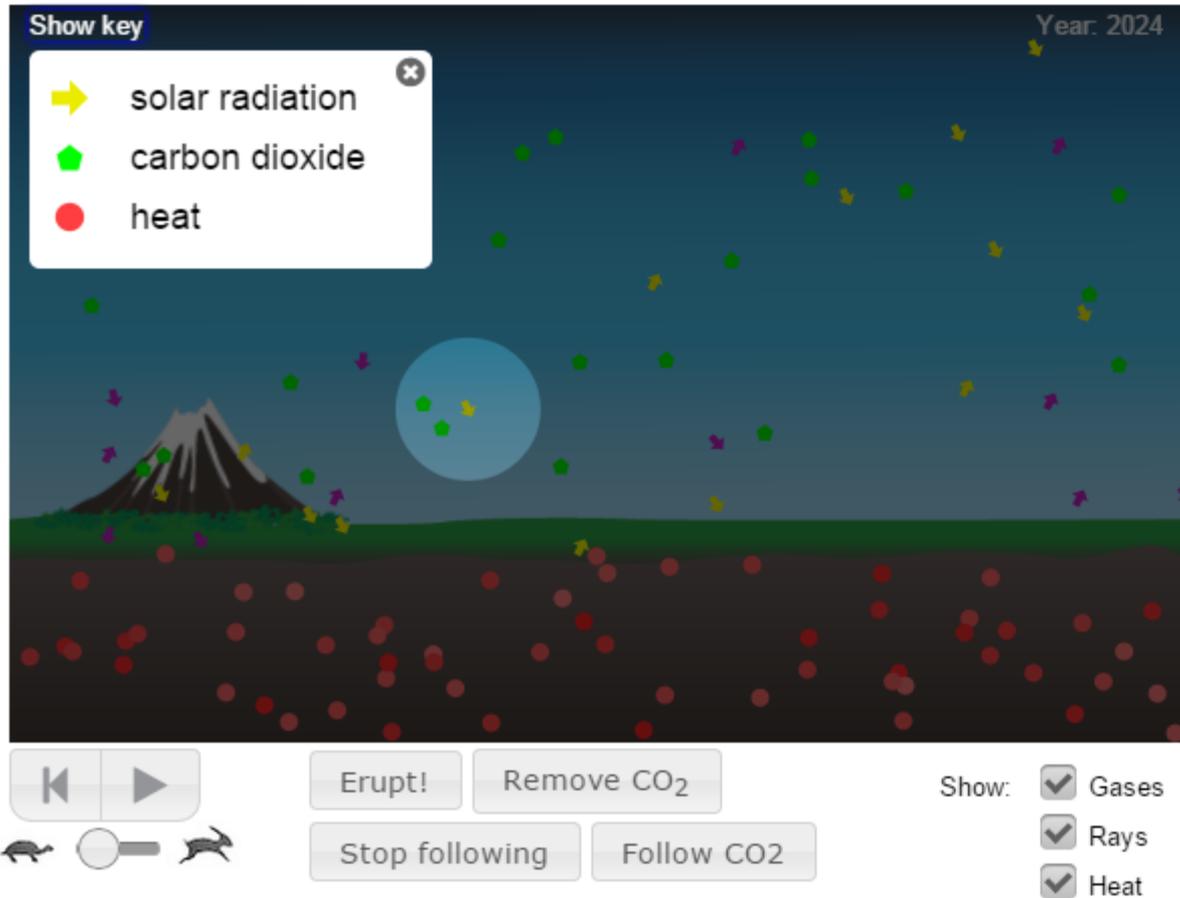
- 1 Number of Clouds
- Thermometer
- Fahrenheit Celsius
- View all photons

Reset All

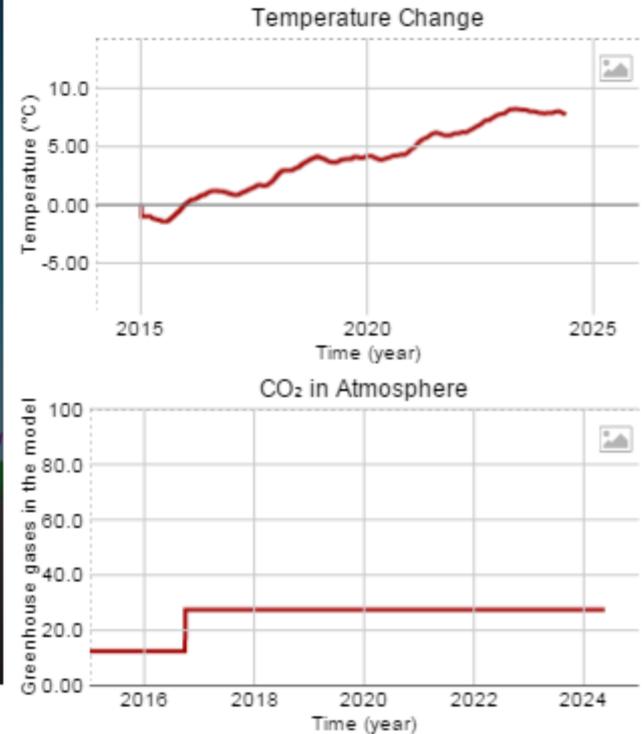
slow | fast

URL: phet.colorado.edu/en/simulation/greenhouse

Greenhouse Effect – Concord Consortium



[About these graphs](#)

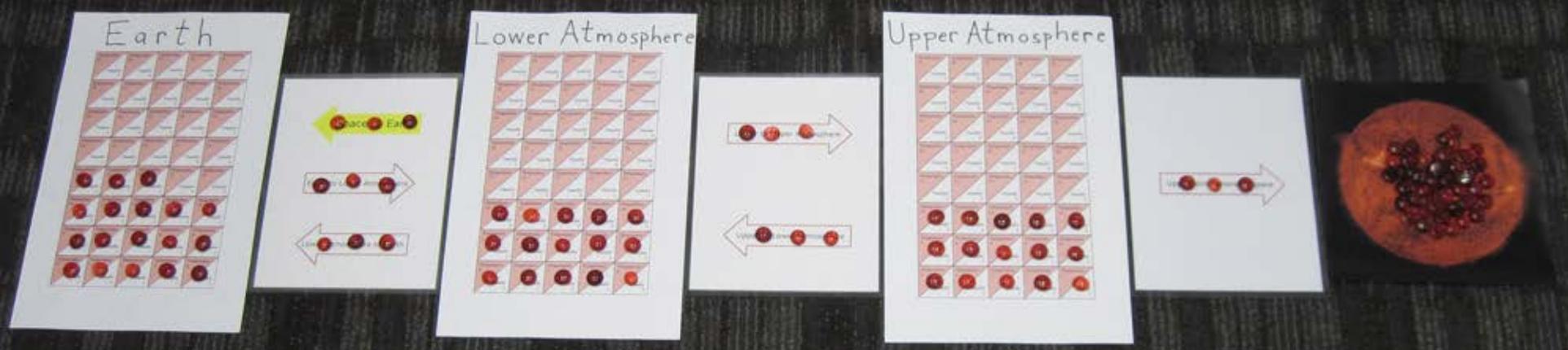
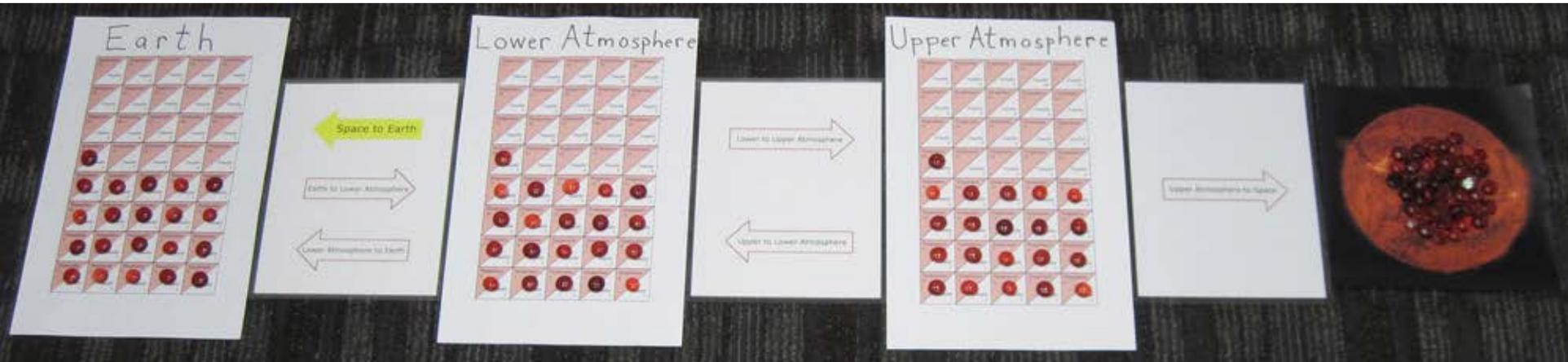


What is the future of Earth's Climate? module

URL: concord.org/stem-resources/what-future-earths-climate

URL: authoring.concord.org/activities/279/pages/1736/c05ea8e7-f131-447d-8b68-ef31c4d2206b

Greenhouse Effect – Little Shop of Physics



What is a "model"? activity

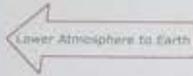
URL: littleshop.physics.colostate.edu/activities/atmos1/WhatIsAModel.pdf

Earth



Start

Space to Earth



Lower Atmosphere



Lower to Upper Atmosphere



Upper Atmosphere

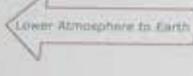
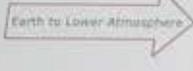


Earth

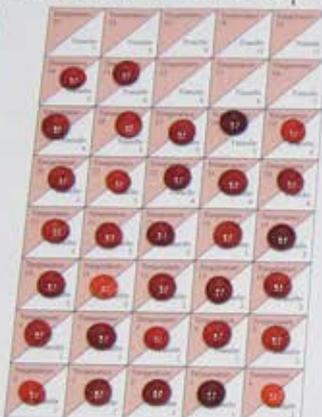


Equilibrium

Space to Earth



Lower Atmosphere

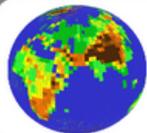


Lower to Upper Atmosphere



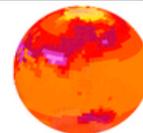
Upper Atmosphere





Monash simple climate model

Scenarios with external forcings



Language: [English](#)

Input

Scenario:

CO₂ Forcing

Output

Variable:

[compare two scenarios](#)

Map **Time Series**

Scenario: IPCC RCP 8.5 CO₂-forcing
annual mean year: 2010

atmospheric temperature change [K]

0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

Stop - + Continue

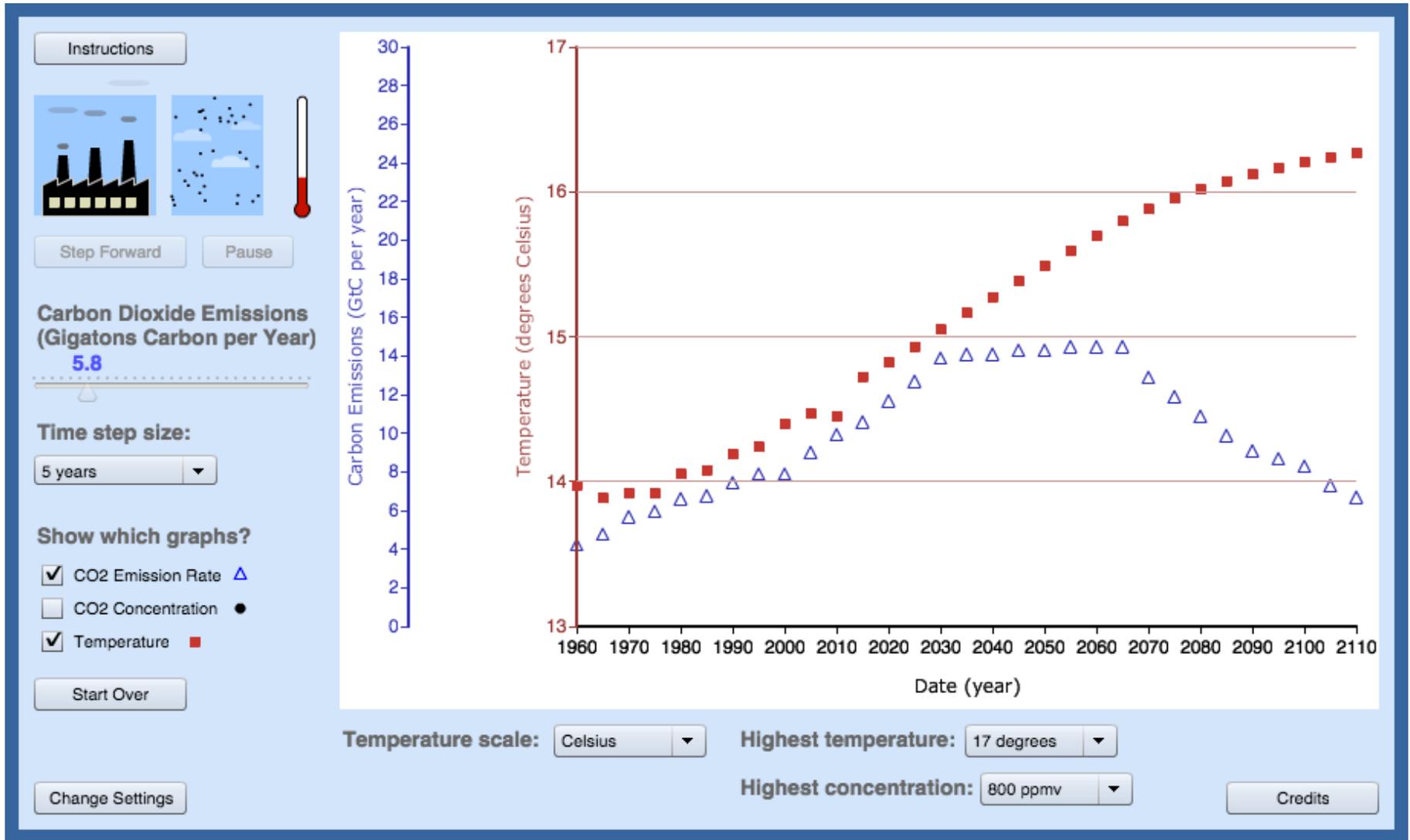
URL: monash.edu/research/simple-climate-model/mscm/index.html

Columbia University - EdGCM



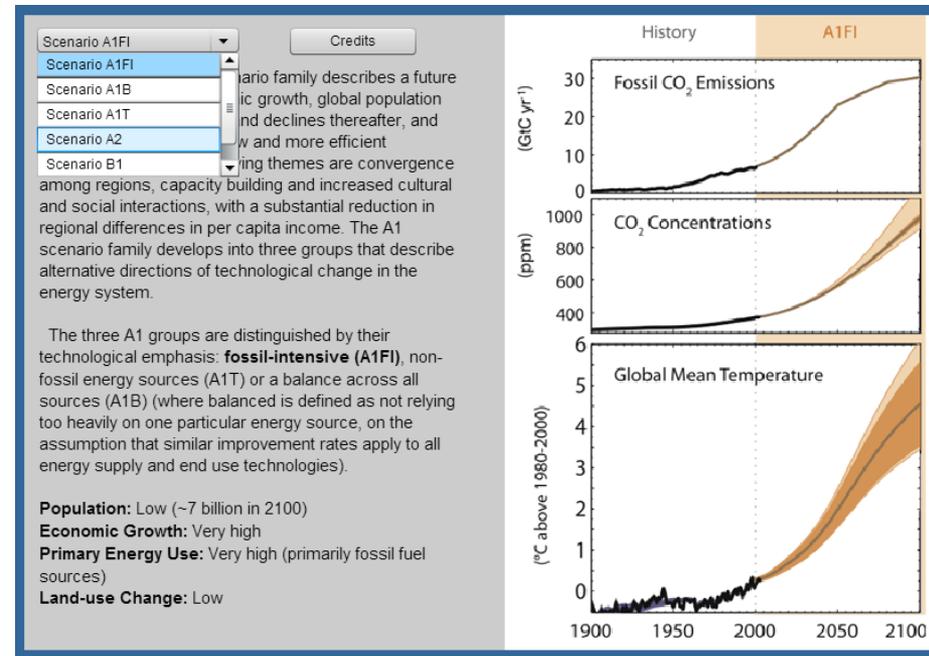
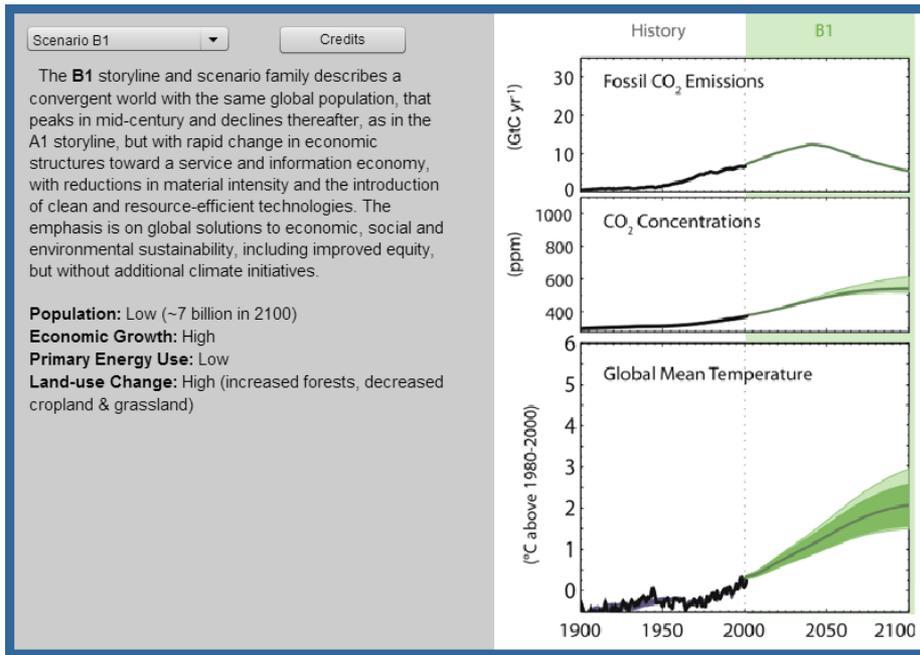
URL: edgcm.columbia.edu

Very, Very Simple Climate Model



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

Compare Graphs of IPCC Scenarios

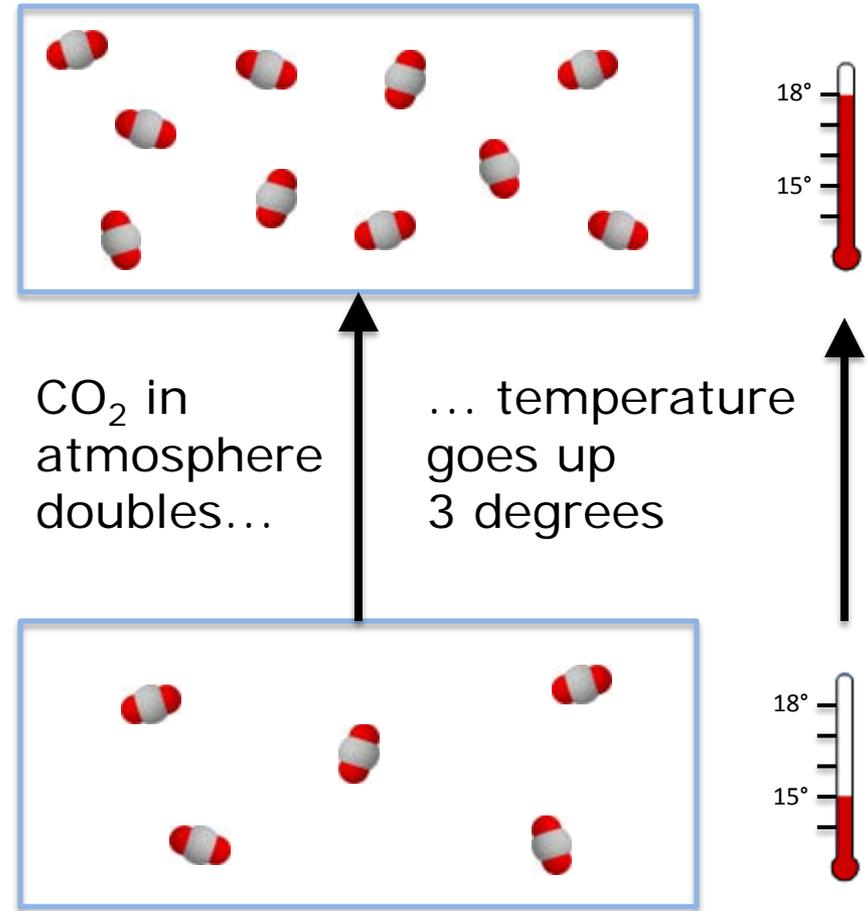


Version for 5th Assessment Report under development

URL: scied.ucar.edu/compare-ipcc-scenarios-interactive

Climate Sensitivity Calculator

The screenshot shows the Climate Sensitivity Calculator interface. At the top, a slider for Carbon Dioxide Concentration (ppmv) is set to 400. Below the slider is a blue sky background with clouds and a thermometer showing an Average Global Temperature of 15.2° C. At the bottom, there are two dropdown menus: 'Climate Sensitivity' set to '3 degrees Celsius' and 'Baseline CO2 Concentration & Temperature' set to 'Year: 1820, CO2 = 280 ppmv, Temperature = 13.7° C'. A 'Credits' button is located at the bottom right.



URL: scied.ucar.edu/climate-sensitivity-calculator

Climate Bathtub Animations

CO₂



Atmosphere

Photosynthesis

CO₂

Plant respiration

CO₂

Anthropogenic carbon

Plant biomass

CO₂

CO₂

CO₂

Soil carbon

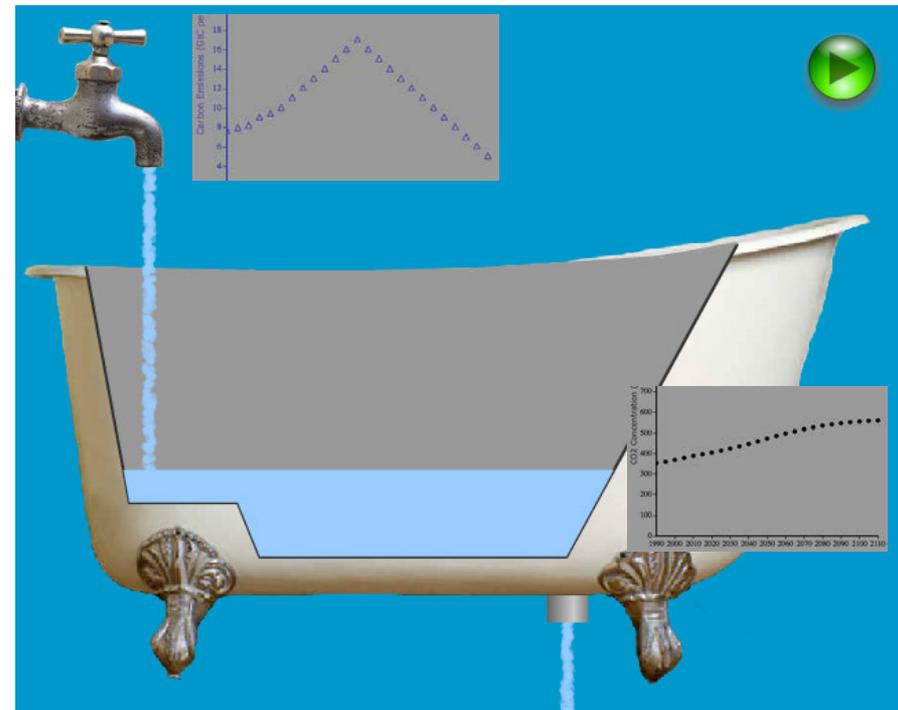
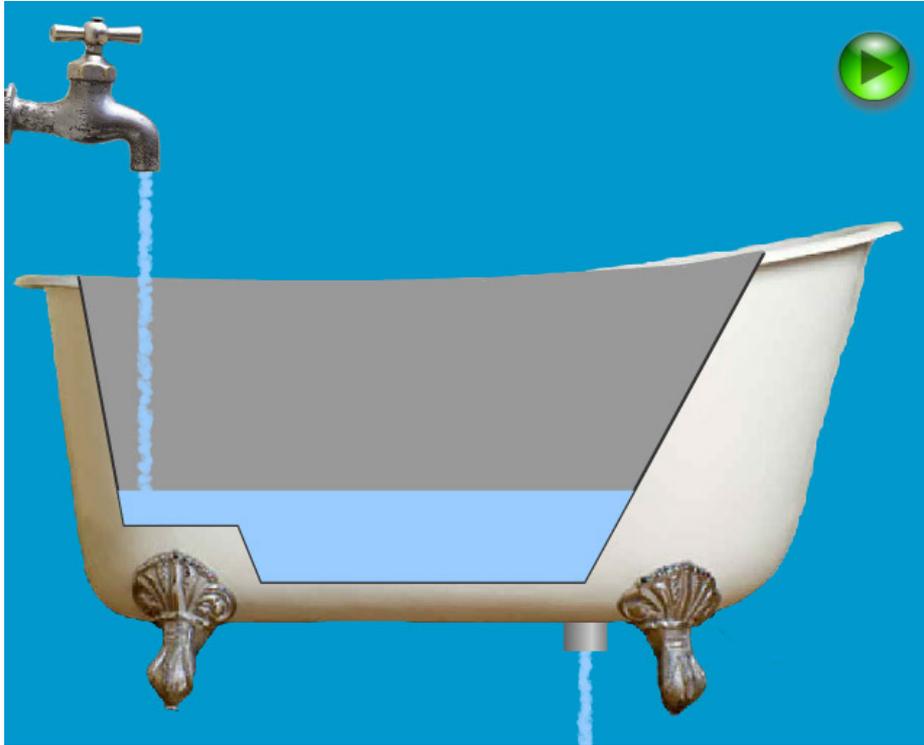
Decomposition

Photosynthesis

Decomposition

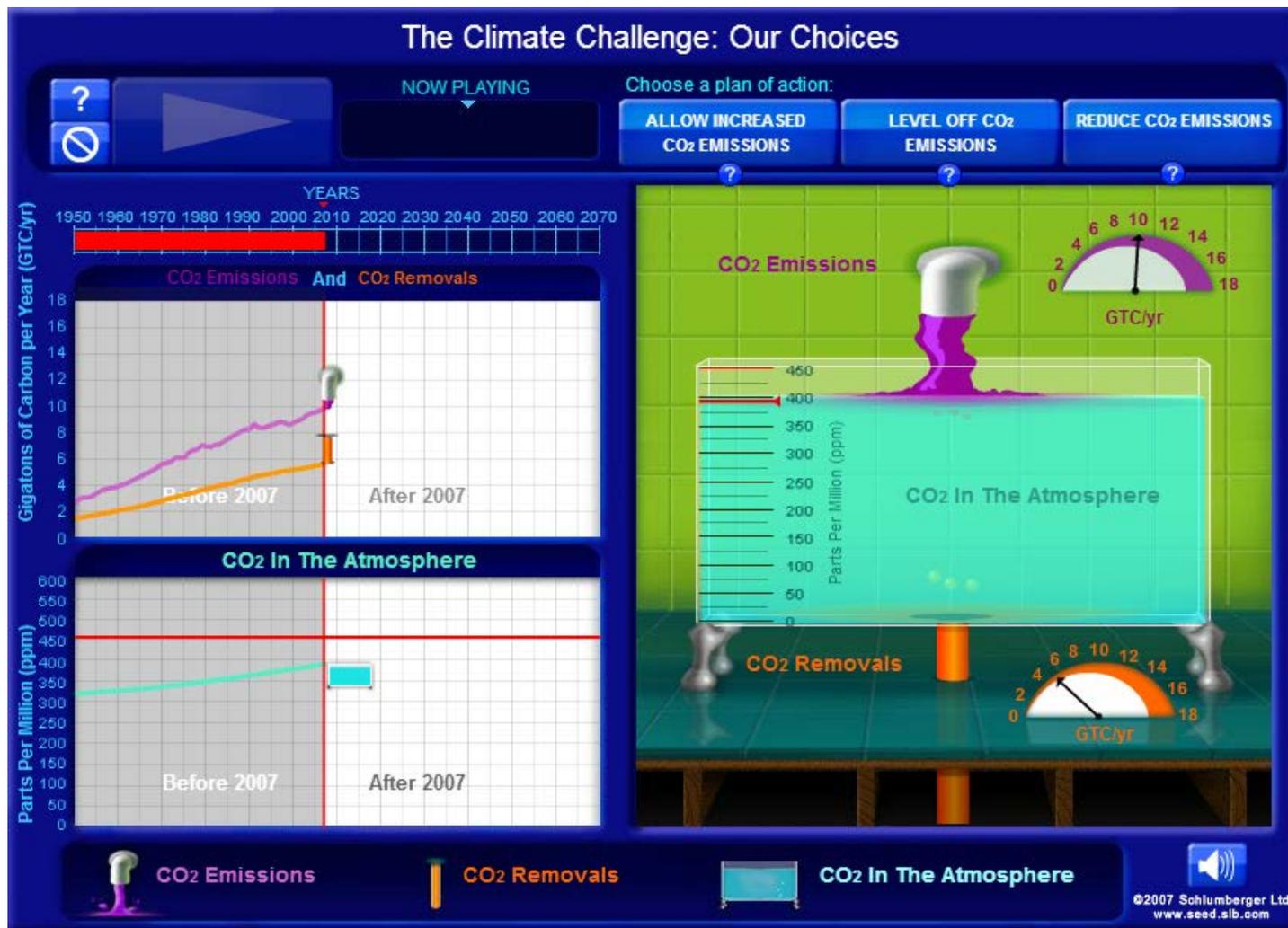
Ocean sediment carbon

Climate Bathtub Animations



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

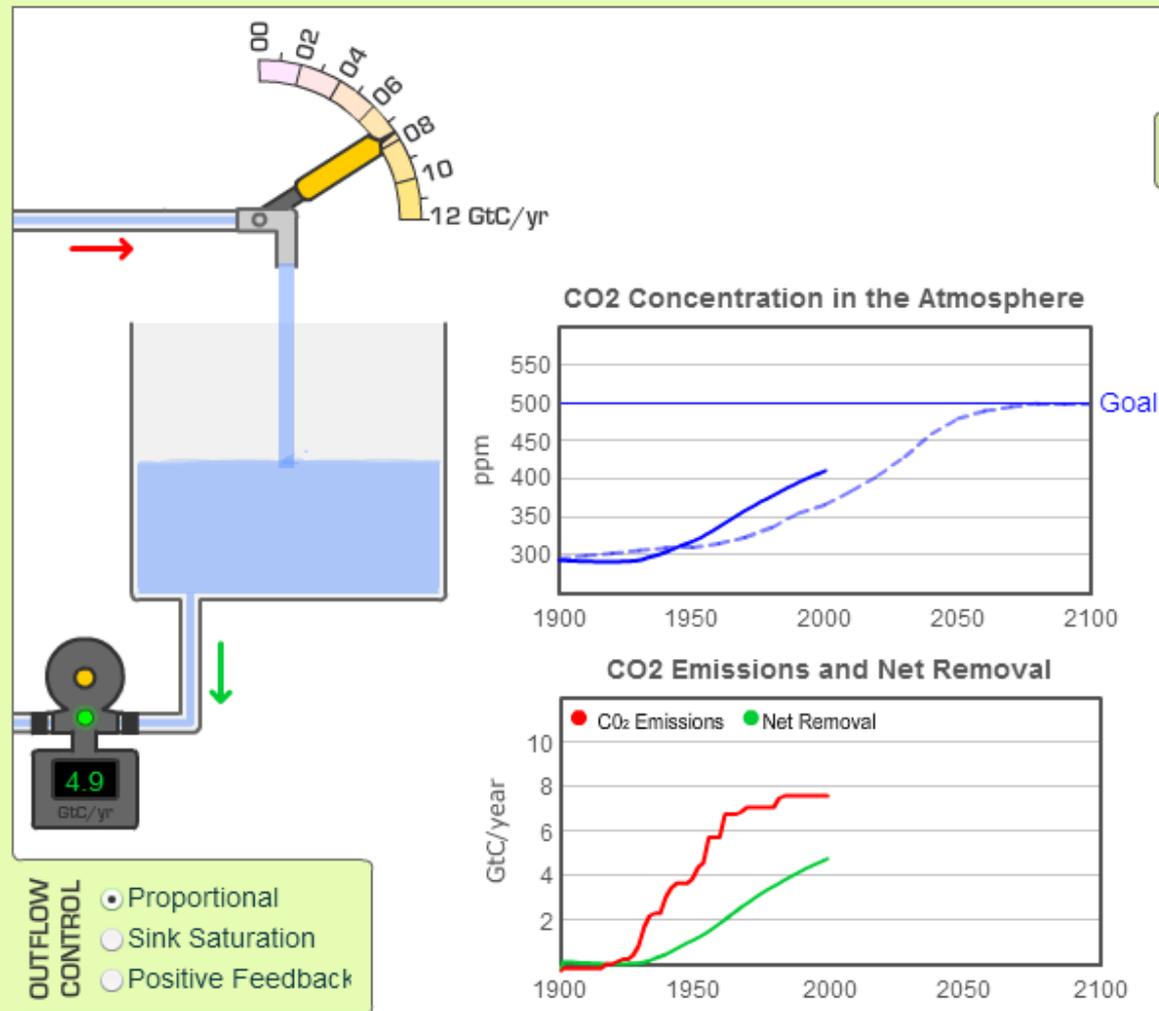
Climate Interactive – Climate Bathtub Simulation



URL: www.climateinteractive.org/tools/climate-bathtub-simulation

Climate Interactive – MIT Greenhouse Gas simulator

Bathtub Dynamics and Climate Change



Also:

- World Climate roleplaying activity
- World Energy
- En-ROADS, C-ROADS and C-Learn

URL: www.climateinteractive.org/tools/mits-greenhouse-gas-simulator/



Introduction Petroleum Coal **Natural Gas** Nuclear Hydro Biofuels Wind Solar Geothermal Help Results

 Natural gas is a non-renewable fossil fuel. People burn natural gas to heat buildings, cook food, generate electricity, and power vehicles. Natural gas supplies nearly one-quarter (22.9%) of the world's energy - about 31.7 pettawatt-hours per year.

Natural gas is relatively "clean" compared to other fossil fuels. Burning natural gas emits much less carbon dioxide per kilowatt-hour of energy produced than does burning petroleum or coal. Natural gas is more challenging to store and to transport than are other fossil fuels.

 Natural gas shall be used to produce pettawatt-hours of energy.

 It is reasonable to assume that natural gas emits kilograms of carbon dioxide for every megawatt-hour of energy produced.

 It is reasonable to assume that natural gas costs cents per kilowatt-hour of energy produced.

 The impact on the environment caused by the use of natural gas is .

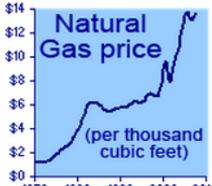
 The public, businesses, and/or government have use of natural gas.

Natural Gas Overview

Amount of Energy from Natural Gas

Carbon Dioxide Emissions

Cost of Natural Gas

 Natural gas costs about \$14 per thousand cubic feet sold to residential customers. That works out to about 4.7 cents per kilowatt-hour of energy produced. When used to generate electricity (instead of for heating), natural gas costs about 3.7 cents per kWh of electricity delivered to customers.

The price of natural gas had remained quite steady for many years. As shown in the graph, prices throughout most of the 1980s and 1990s hovered around \$6 per thousand cubic feet. However, the cost of natural gas rose sharply in the past decade as prices more than doubled during that time.

Environmental Impacts of Natural Gas

Support for or Resistance to Natural Gas?

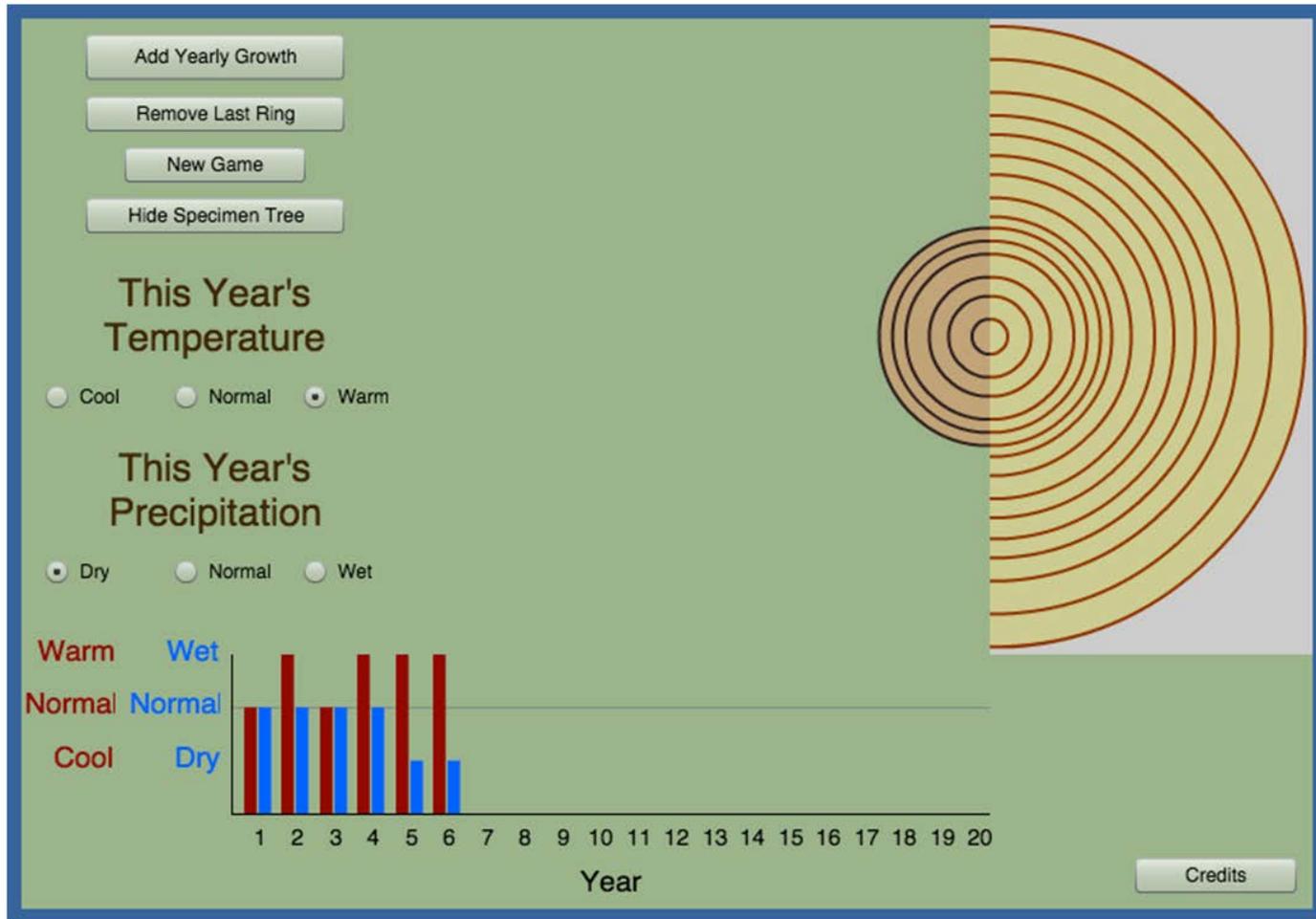
URL: scied.ucar.edu/ruler-world

BBC Climate Challenge

The screenshot displays the BBC Climate Challenge game interface. At the top left, there are two panels: 'RESOURCES' and 'ENVIRONMENT'. The 'RESOURCES' panel shows four categories: Euro (€), lightning bolt (⚡), gear (⚙️), and water drop (💧), each with a red bar indicating usage. The 'ENVIRONMENT' panel shows a cloud icon with a red bar indicating CO2 rise. Below these panels is a '1990' year indicator. The main game area features a 3D isometric view of various sectors: a government building (EU flag), a ship, an airplane, a factory (labeled 'INDUSTRY'), and houses. A grey road labeled 'AGRICULTURE & INDUSTRY' with a close button (X) runs through the scene. On the right, a group of people is shown. At the bottom, there are three policy cards: 'Promote industrial energy efficiency' (lightning bolt icon), 'Switch from coal to gas' (factory icon), and 'Subsidise aviation' (airplane icon). Each card has resource and environment bars. Below the cards are five 'Send foreign aid' buttons with downward arrows. In the bottom right corner, there are question mark and play buttons.

URL: www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge

Tree Rings - Dendrochronology



Hoping to make a suite of paleoclimate sims; ice cores, sea sediments, etc.

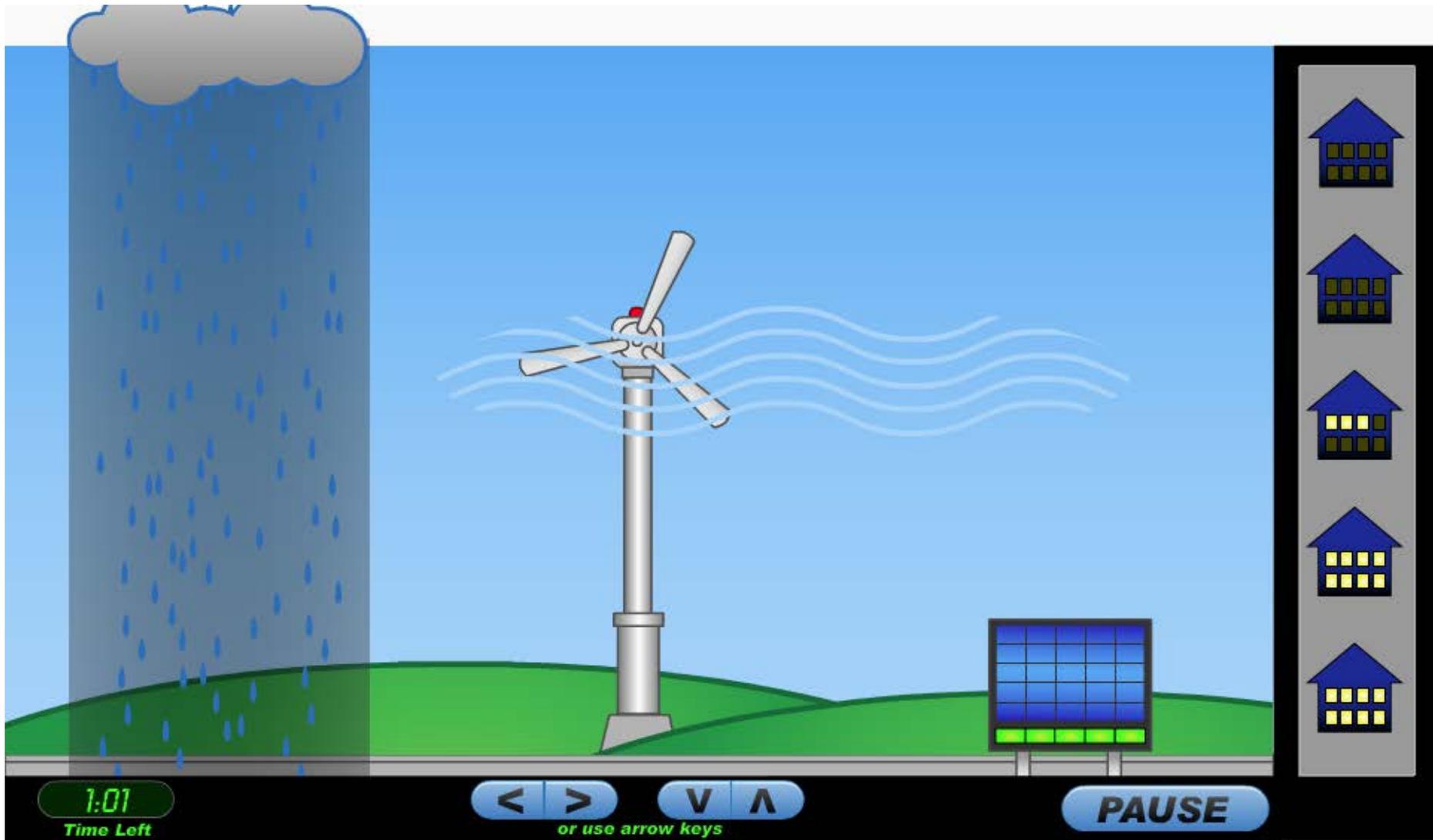
URL: scied.ucar.edu/tree-ring-interactive

Glacier Model - PhET

The screenshot shows the PhET Glacier Model simulation interface. At the top, there are tabs for "Introduction" and "Advanced", with "Advanced" selected. The main simulation area displays a cross-section of a glacier system. A red flag is placed on the glacier surface, and a blue and red drill is shown drilling into the ice. A data box on the right indicates a depth of 293.481 ft. A toolbox on the left contains various tools: a thermometer, a green dome, a red flag, a white box, a drill, and a yellow device. Below the simulation area, there are control panels. The "View" panel includes options for units (English selected, metric unselected), a checkbox for "equilibrium line" (unselected), and a checked checkbox for "snowfall" with a star icon. The "Climate" panel features two sliders: "Sea-level air temperature" ranging from 55.4 to 68.0 with a value of 66.2 °F, and "Average snowfall" ranging from 0.0 to 4.9 with a value of 3.1 ft. At the bottom, there is a time slider set to 75 years, with "slow" and "fast" labels, and play/pause buttons. On the right, there are buttons for "Show real glacier", "Set glacier to steady state", and "Reset All".

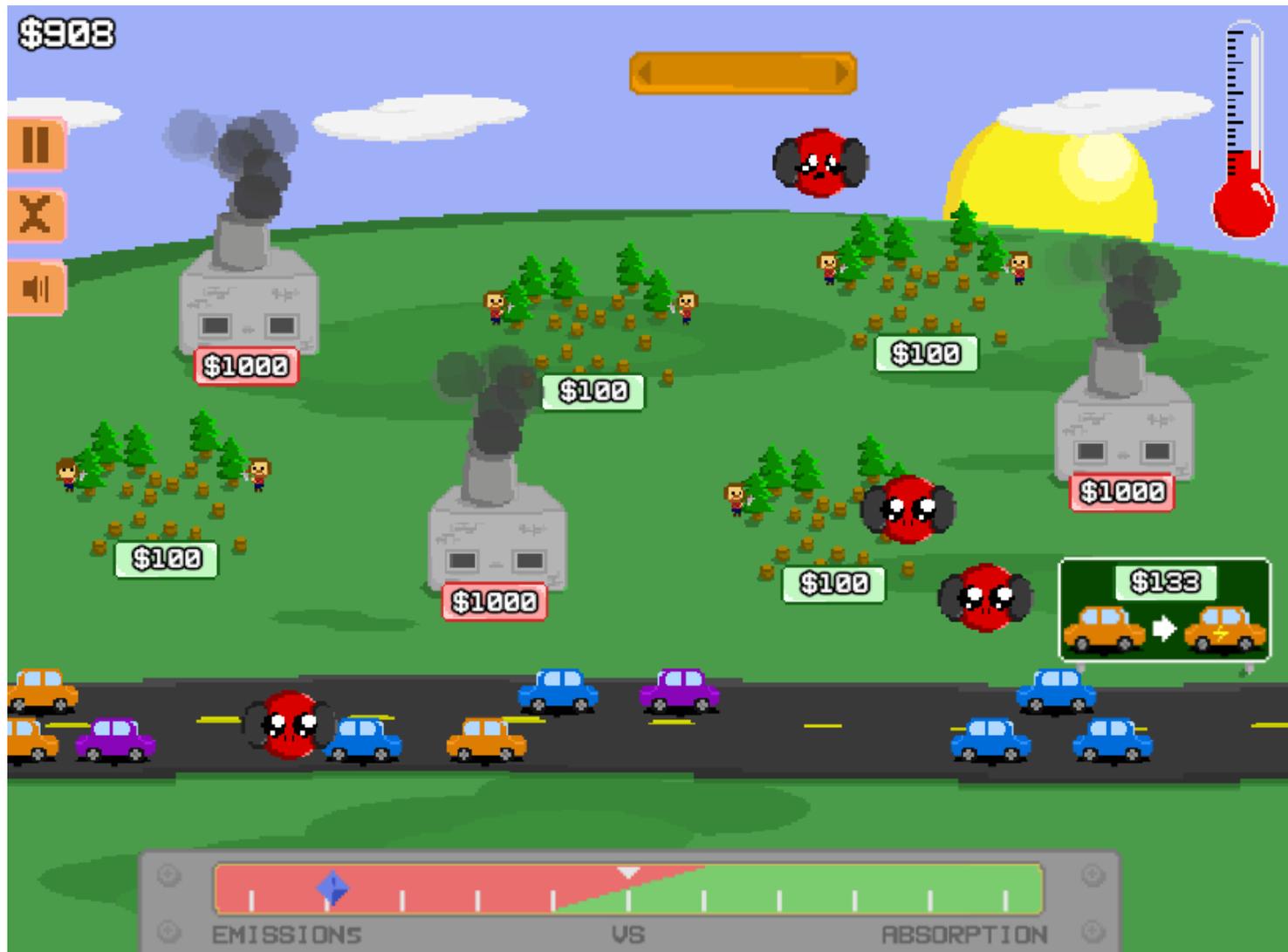
URL: phet.colorado.edu/en/simulation/glaciers

NASA's Climate Kids –Power Up!



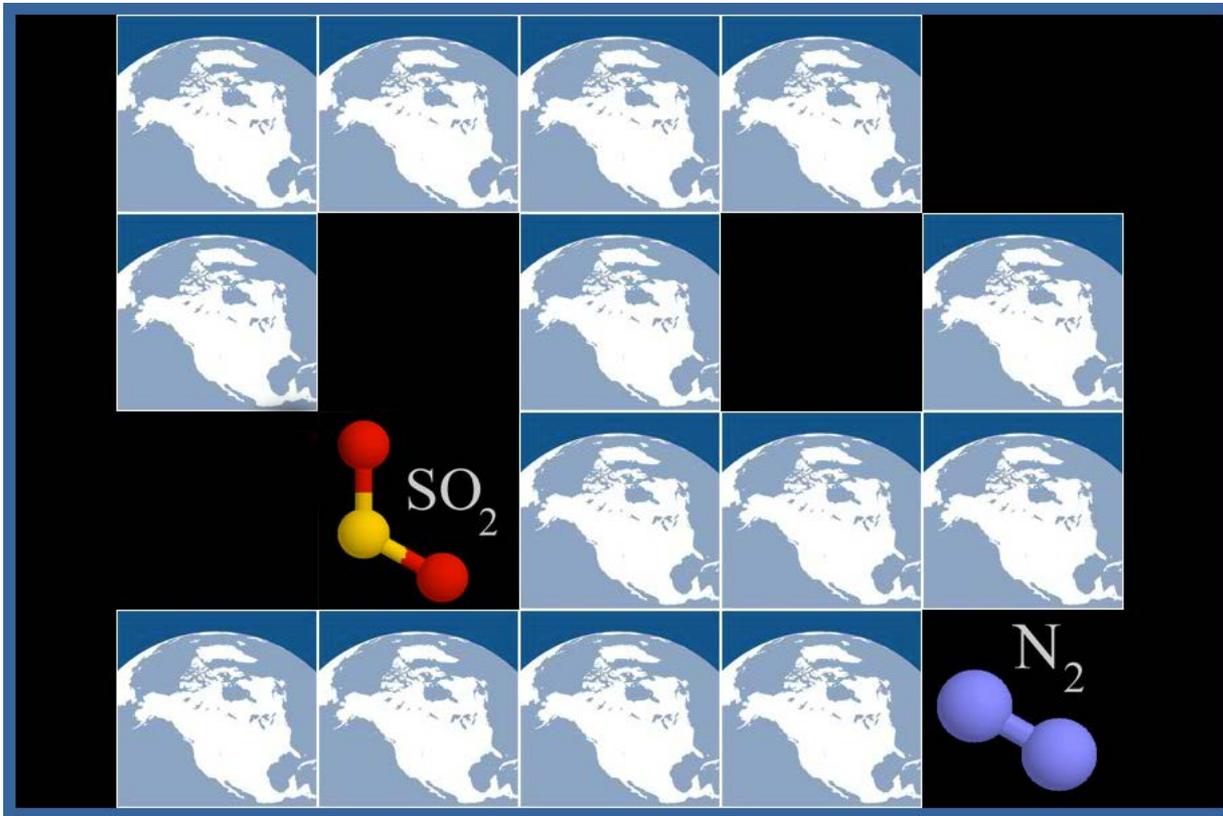
URL: climatekids.nasa.gov/power-up

NASA's Climate Kids – OFFSET!

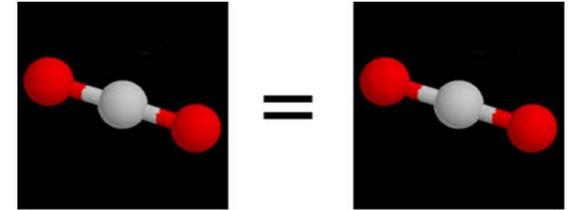


URL: climatekids.nasa.gov/offset

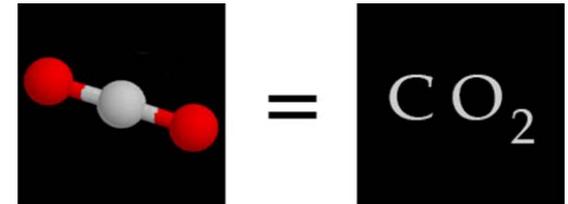
Atmospheric Chemistry Memory Game



Easy Level



Advanced Level



Includes the GHGs carbon dioxide and methane

Advanced level: compare equivalent, not identical, representations

URL: scied.ucar.edu/molecules-memory-game

Cloud Sorting Game

Sort Clouds by Altitude

Cirrus	Contrails	Cirrostratus	Stratocumulus
			
Stratus	Altostratus		
			

High Clouds 16,000 - 43,000 feet (5,000 - 13,000 meters)
Cirrocumulus 

Middle Clouds 7,000 - 23,000 feet (2,000 - 7,000 meters)
Altostratus 

Low Clouds surface - 7,000 feet (surface - 2,000 meters)
Cumulus 

Your Score is 75 points.

[Instructions](#) [Choose Level](#)
[Credits](#) [Start Over](#)

Sort Clouds by Composition

Cirrostratus	Altostratus	Cirrocumulus
		

Ice
Cirrus 

Mix of Ice & Water
Cumulonimbus 

Water
Stratus 

Your Score is 100 points.

[Instructions](#) [Choose Level](#)
[Credits](#) [Start Over](#)

URL: scied.ucar.edu/cloud-sorting-game

El Niño Sorting Game

Sort It Out: El Niño or La Niña

Jan 2013	Jun 2001	Dec 2010
Oct 2007	Dec 2002	May 1997

Your Score is 75 points.

Can you tell El Niño from La Niña?

Credits **Start Over**

El Niño warmer than normal water

Jan 1998

El Niño

La Nada neutral water temperature

Nov 2003

La Nada

La Niña cooler than normal water

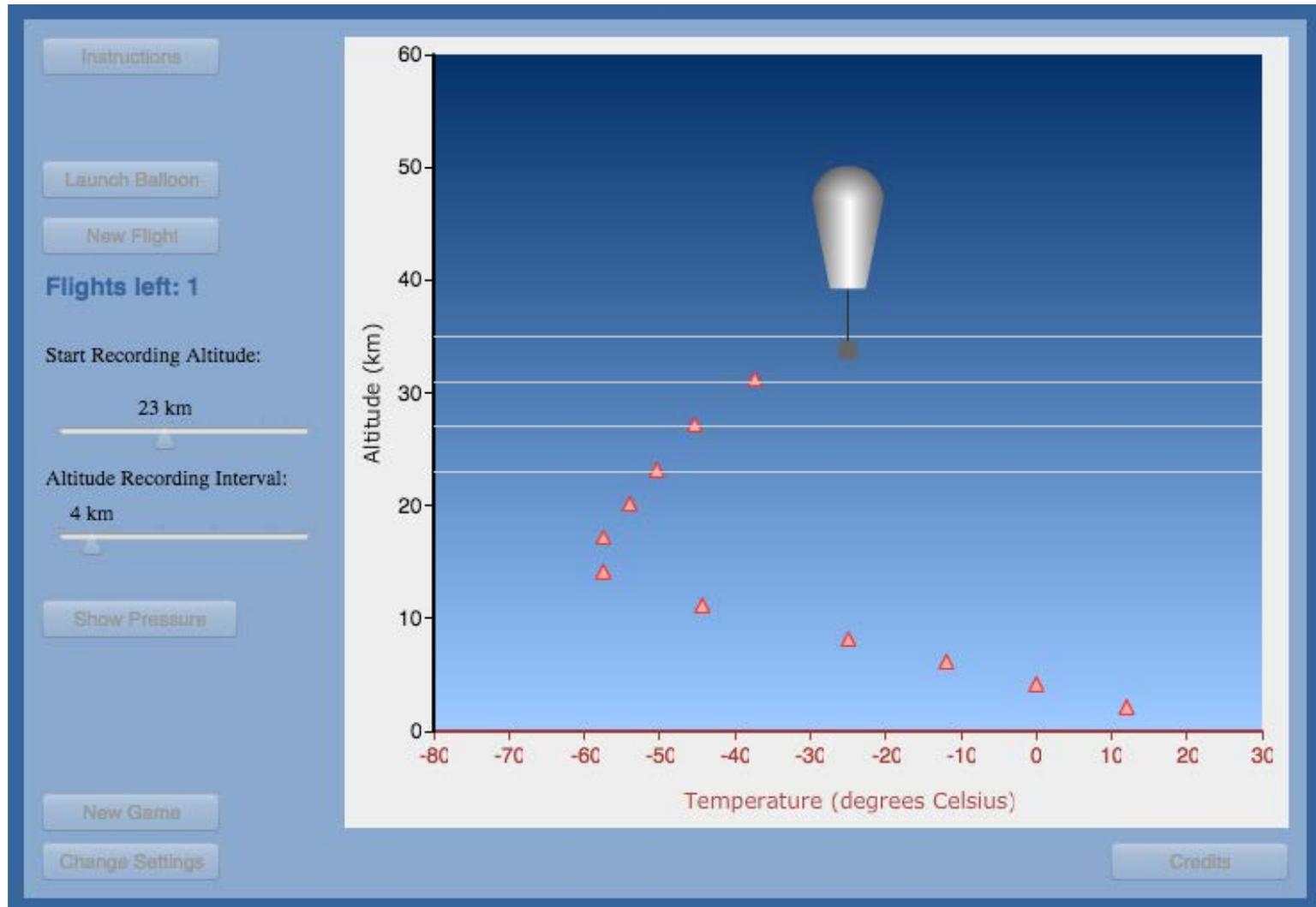
Feb 1999

La Niña

Plans for a "Sort Molecules: Greenhouse Gas or non-GHG" version

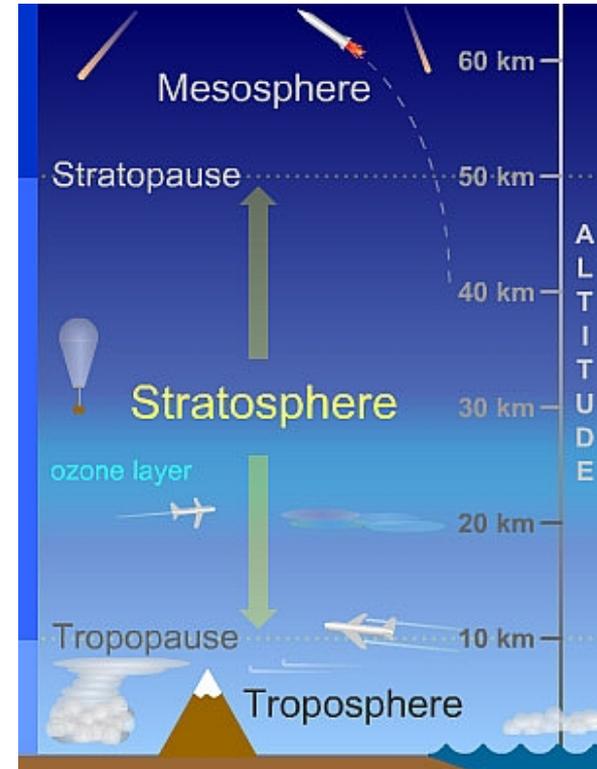
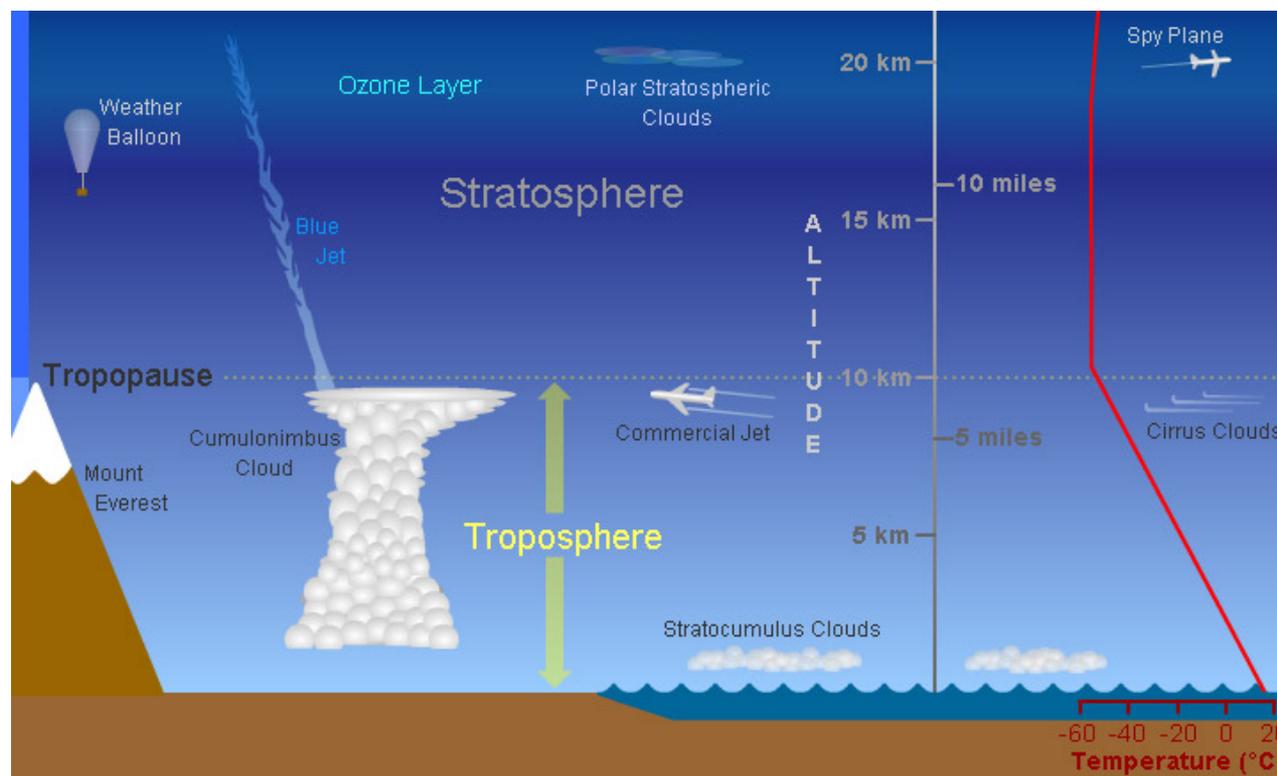
URL: scied.ucar.edu/enso-sorting-game

Virtual Ballooning – Atmosphere Layers



URL: scied.ucar.edu/virtual-ballooning

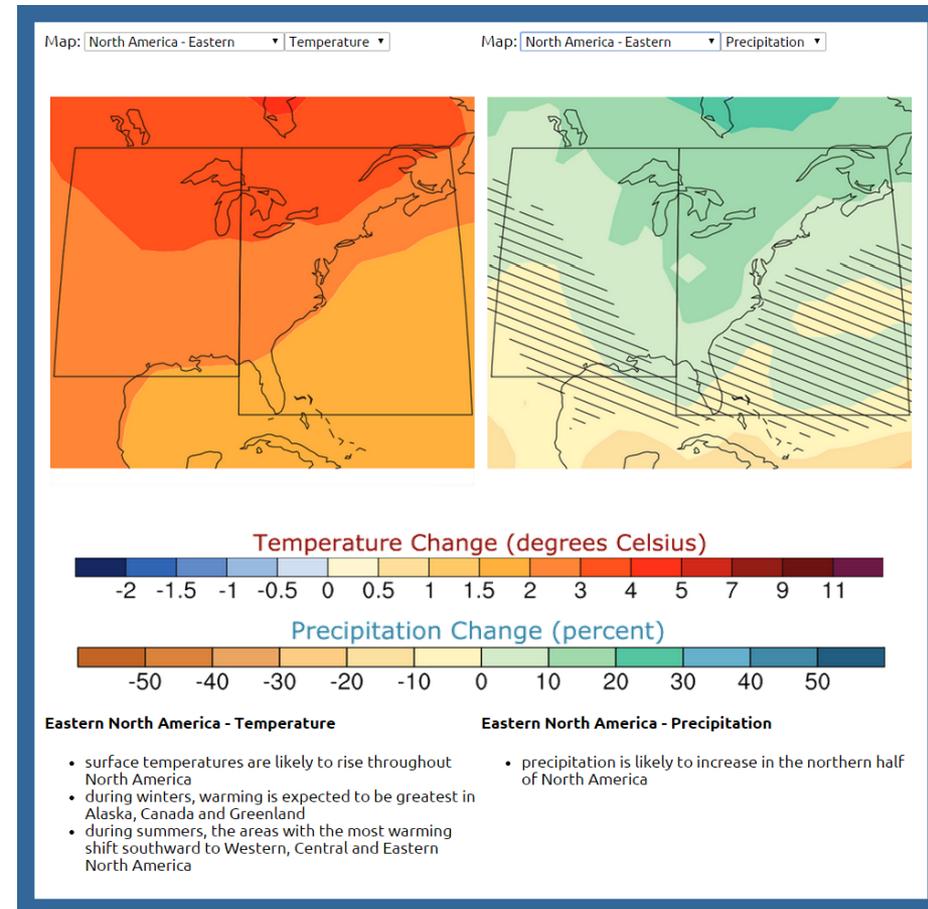
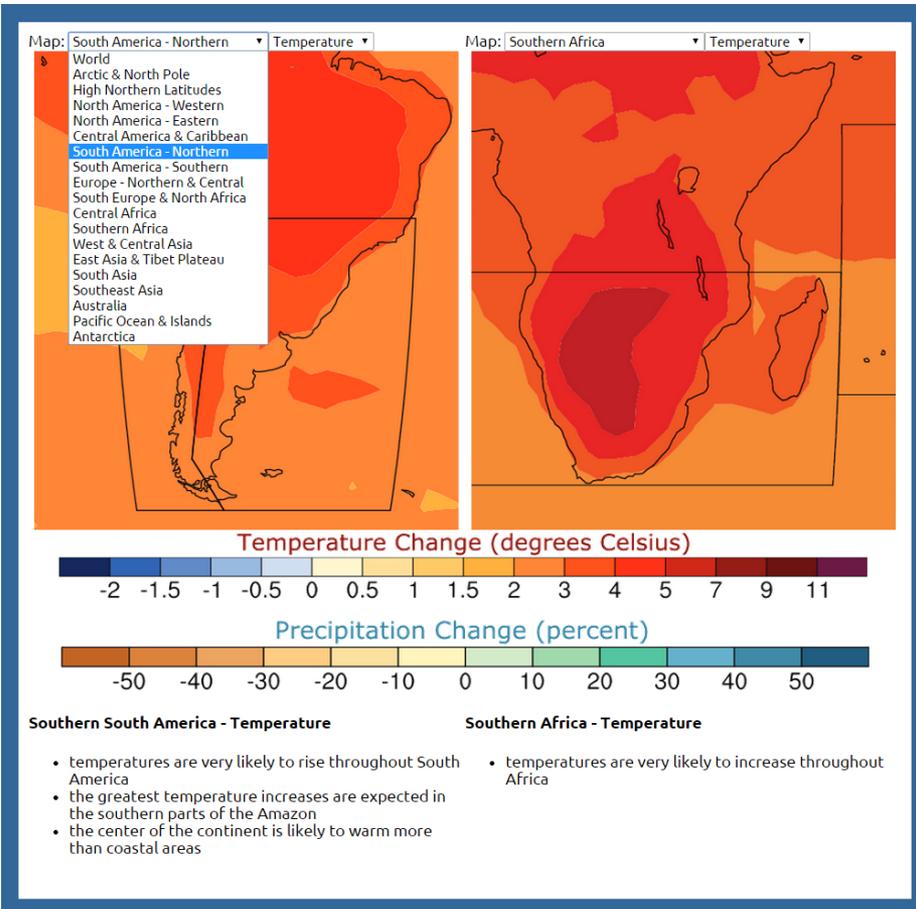
Atmosphere Layers



URL: scied.ucar.edu/shortcontent/troposphere-overview

URL: scied.ucar.edu/shortcontent/stratosphere-overview

Compare Maps of Future Climate Projections



- Compare two different places, or
- Compare temperature vs. precipitation for same place

URL: scied.ucar.edu/compare-climates-regional-future-selector