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Teaching Climate With Models: Future Climate Projections

Presented by: Scott Denning and Randy Russell

February 28, 2013

6:30 p.m. – 8:00 p.m. Eastern time

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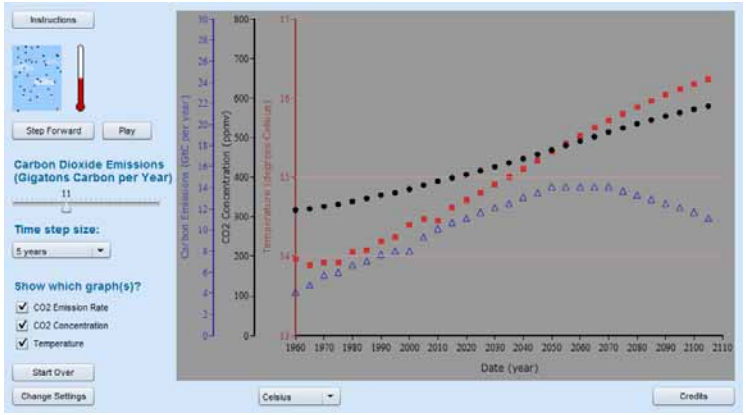
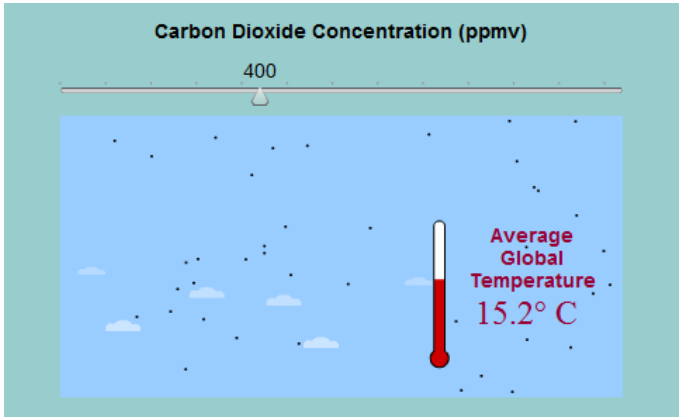
Introducing today's presenters…

Scott Denning
Colorado State University
Center for Multiscale Modeling of Atmospheric Processes (CMMAP)

Randy Russell
Spark
National Center for Atmospheric Research (NCAR)

Teaching Climate with Models: Future Climate Projections





Scott Denning

Randy Russell

Scott Denning

- Professor of Atmospheric Science at Colorado State University
- Director of Education, Center for Multiscale Modeling of Atmospheric Processes (CMMAP)
- BS in Geology, PhD in Atmospheric Science

Randy Russell

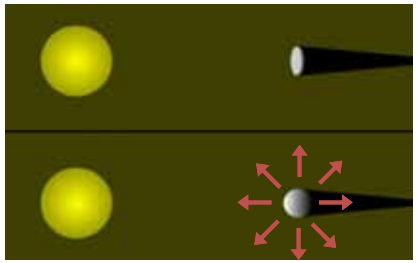
- Lead web & interactive multimedia developer at Spark in Boulder, Colorado

- Spark is the science education group at the National Center for Atmospheric Research (NCAR)
- BS astrophysics, MS aerospace engineering, PhD in education

Understanding and Prediction: Modeling the Earth System

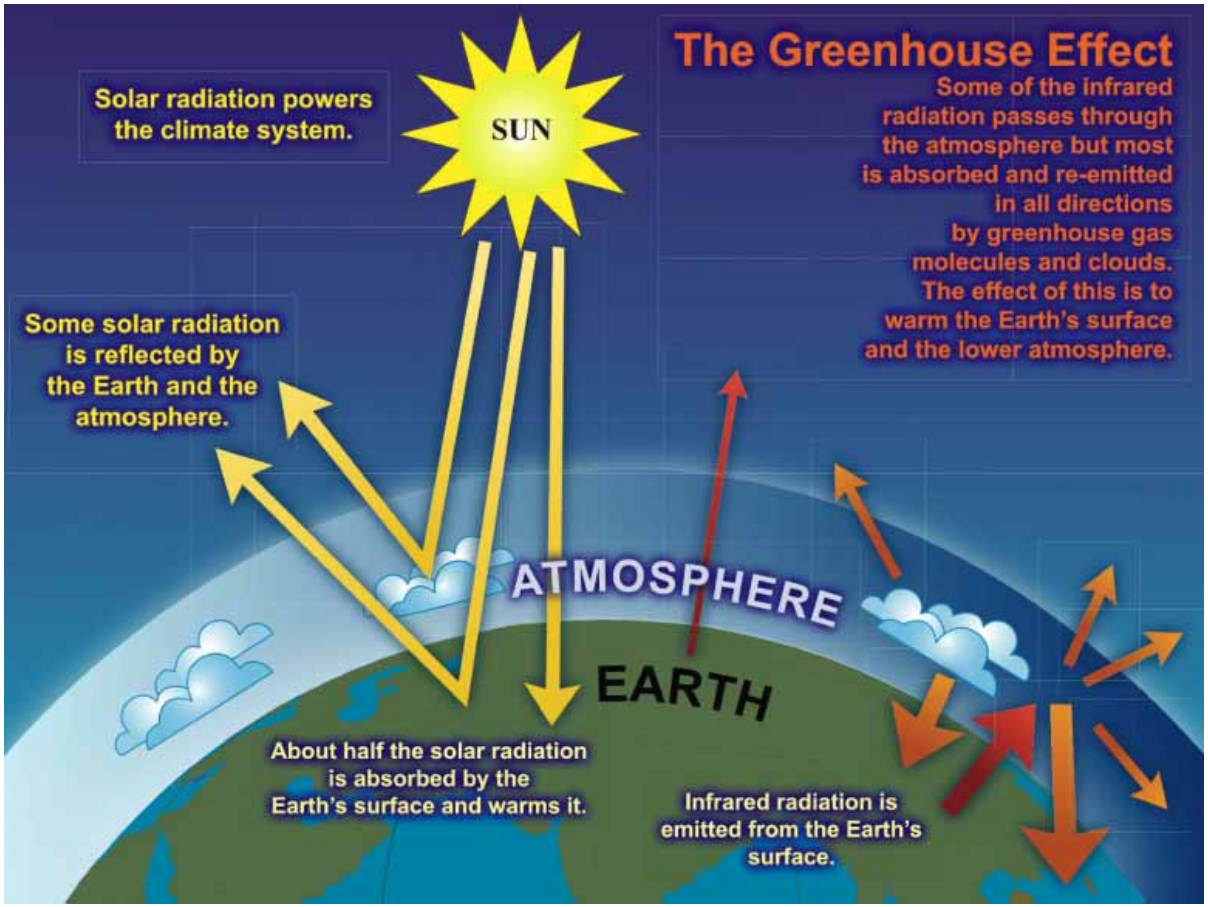
This is the third in a series of four webinars in which we will use very simple models to explore the way the Earth's climate works and how it's changing.

- Teaching Climate with Models: Breathing of the Earth (June 11, 2012 – archived)
- Heating and Warming: Sensitivity of Earth's Climate to Atmospheric CO_2 (September 24, 2012 – archived)
- Teaching Climate with Models: Future Climate Projections
- Opportunities for Abundance: Solving the problems of energy, carbon, and climate



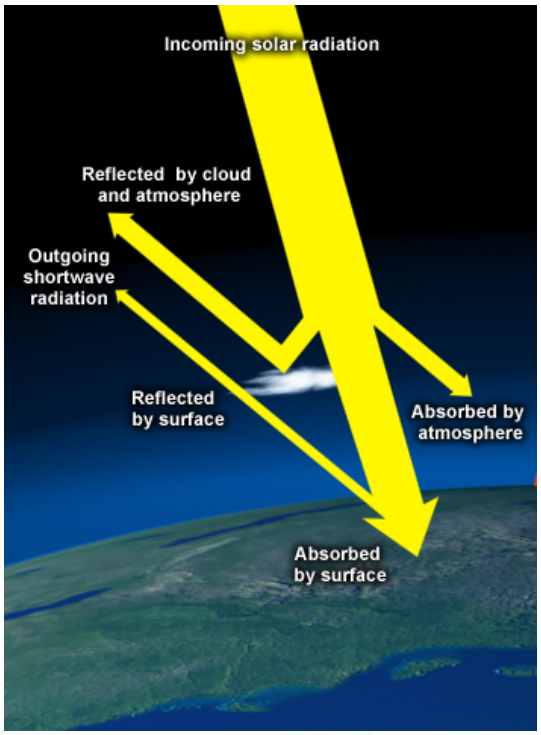
Greenhouse Effect Review

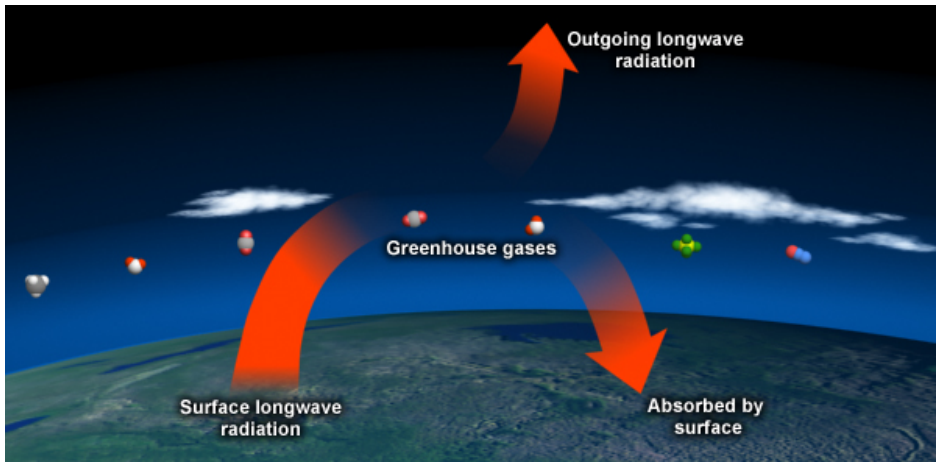
- CO_2 absorbs heat in the atmosphere
- When heat accumulates in the Earth system, the average global temperature rises

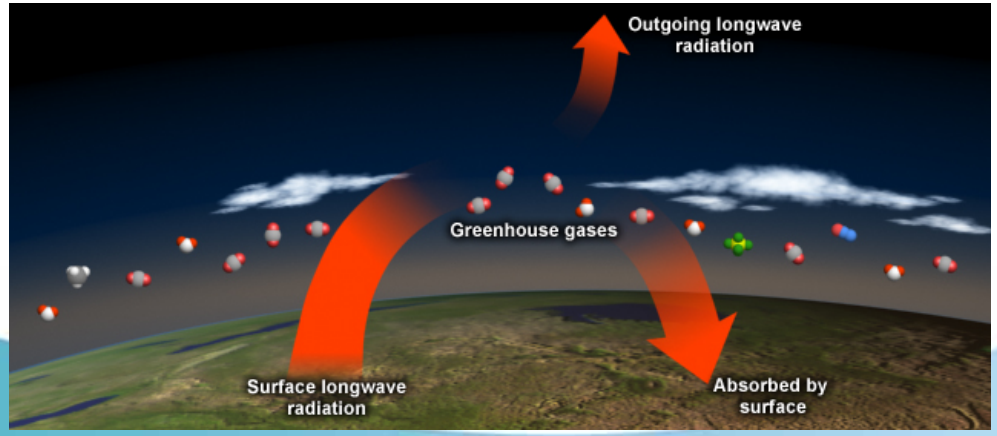


Increased CO_2 & the Greenhouse Effect

- When the amount of **carbon dioxide** in the atmosphere **increases**, average global **temperature rises**.
- Longwave radiation emitted by CO_2 is absorbed by the surface, so average global temperature rises.

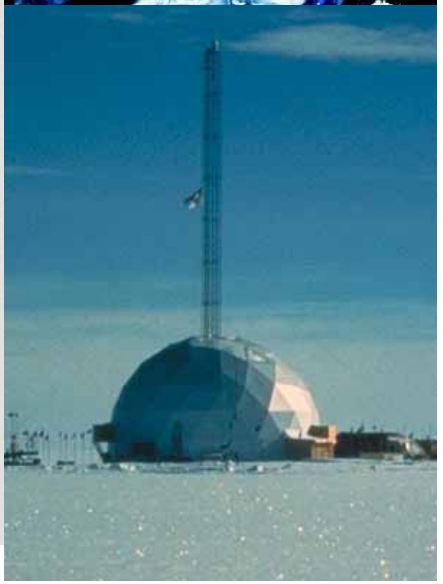


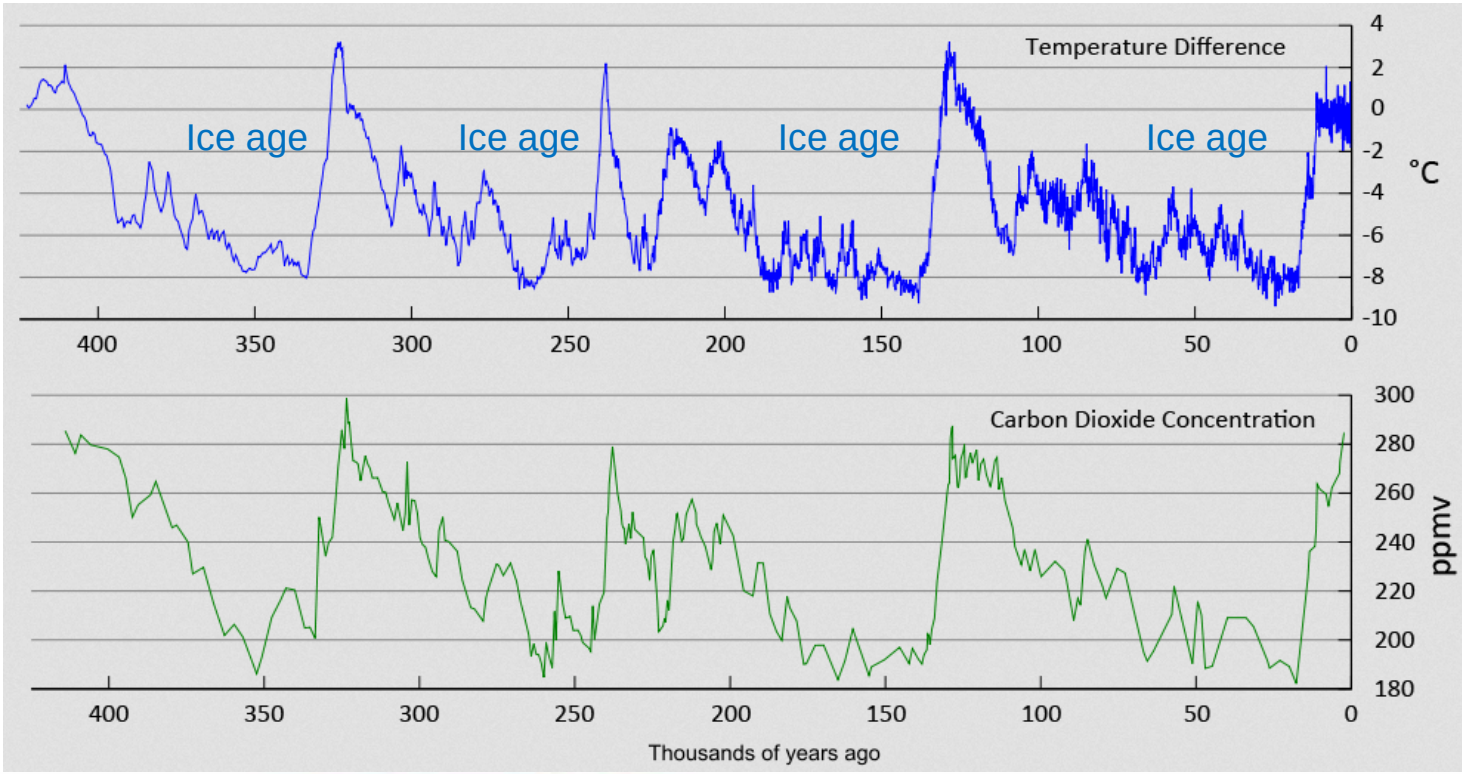




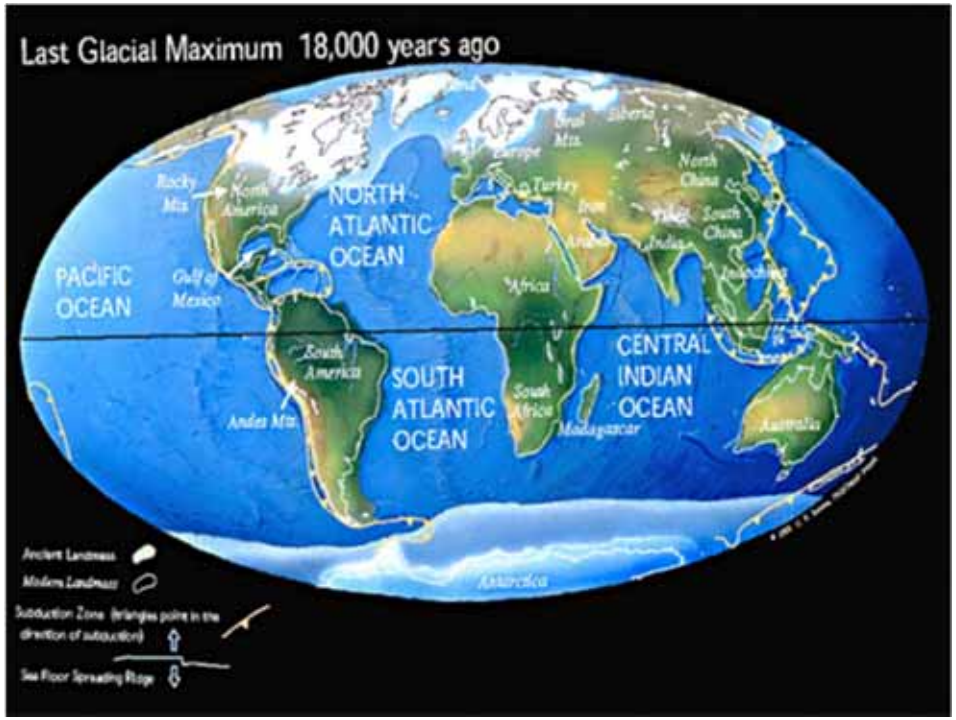
Learning from the Past

Lower Ice Age CO_2 allowed 3.7 W m^{-2} extra thermal emission to space





Learning from the Past



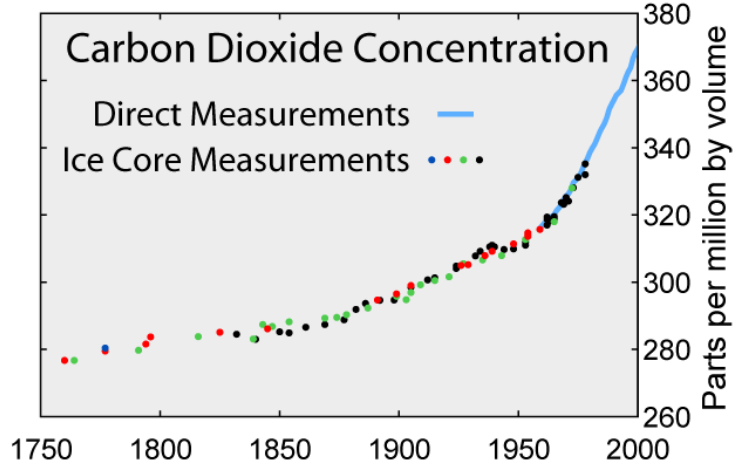
- Huge ice sheets made Earth brighter, reflected 3.4 W m^{-2}
- Ice Age surface heat balance was about (3.7 from CO_2 + 3.4 from albedo) = 7.1 W m^{-2} less
- **After Ice Age, extra 7.1 W m^{-2} heat warmed surface by 5 ° C**

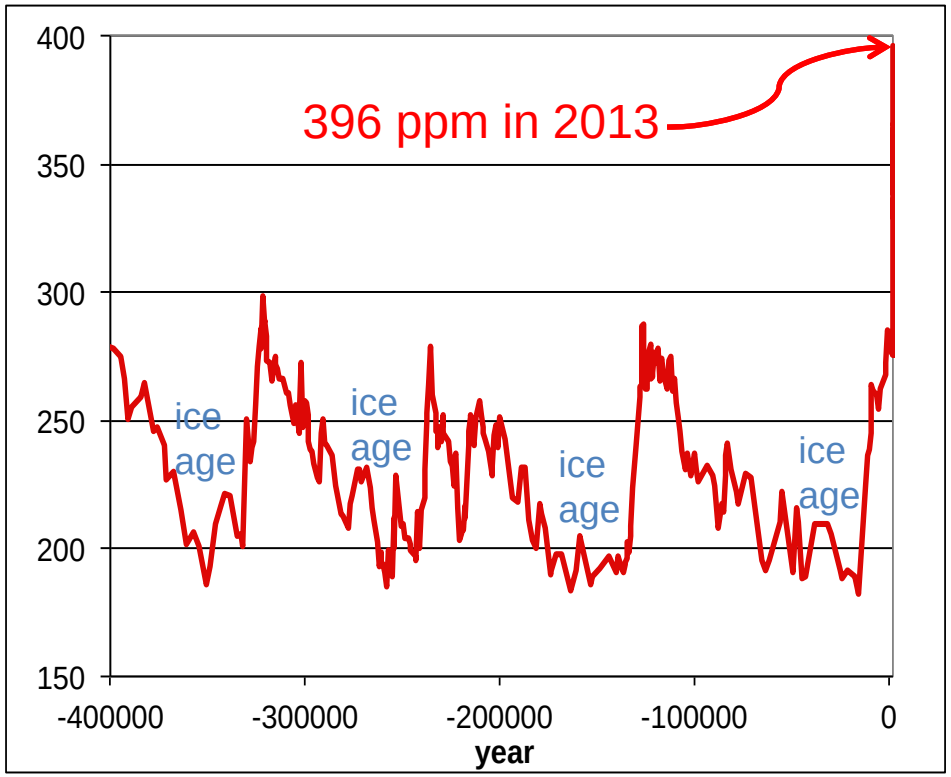
Total Climate Sensitivity = 5°C / 7.1 W m^{-2}
= 0.7 °C per W m^{-2}

CO_2 – Where are we now?

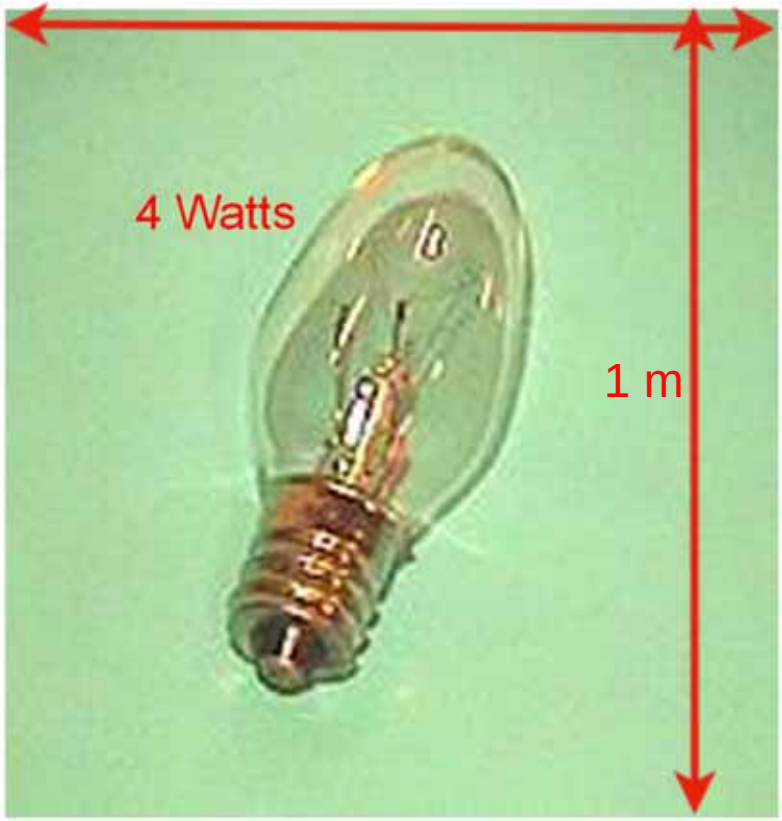
- For hundreds of thousands of years, CO_2 varied between 180 and 280 parts per million, beating in time with ice ages

- Since the Industrial Revolution, CO_2 has risen very rapidly to about 400 ppm today





Climate Sensitivity to CO_2



- Doubling CO_2 in the atmosphere would add 4 Watts of heat to every square meter of Earth
- Climate sensitivity is about 0.7 °C per W m^{-2}
- Climate sensitivity to doubling CO_2 is about
  (4 W m^{-2}) x (0.7 °C per W m^{-2})
  = 2.8 °C

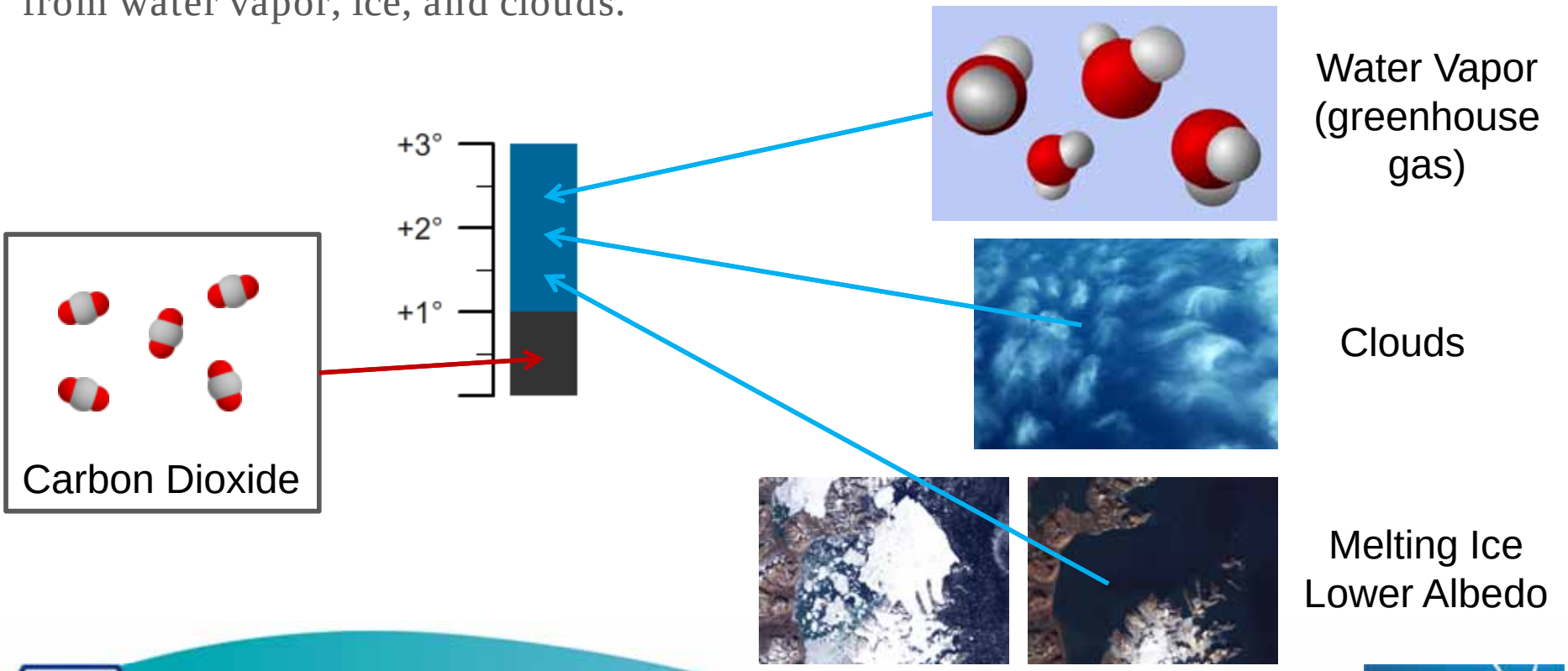
Climate Sensitivity is about 3 °C per doubling of CO_2



Questions?

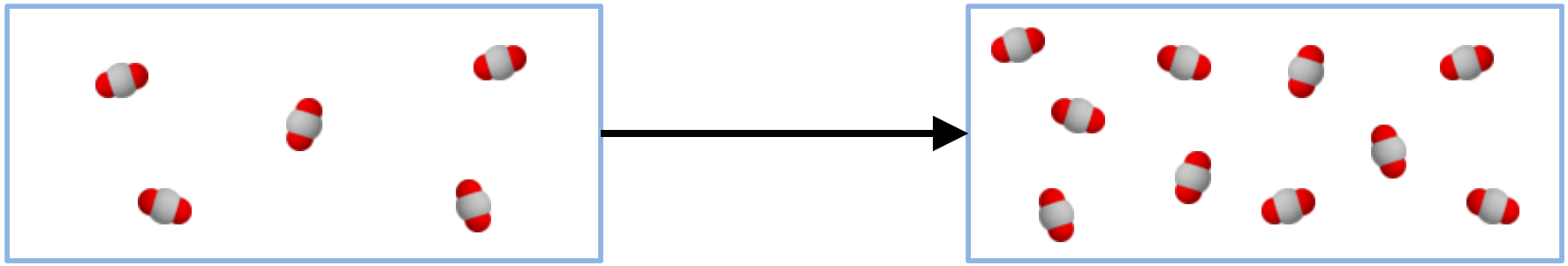
Water Vapor Amplifies Greenhouse Effect from Increased CO_2

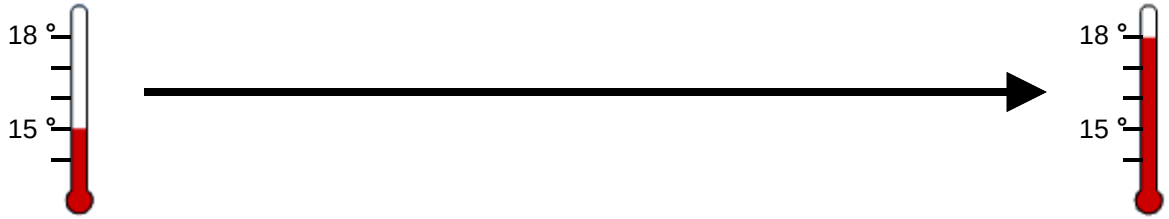
About 1/3rd of the 3 degree "climate sensitivity" temperature rise is caused directly by the greenhouse effect of CO_2. The other 2 degrees result from feedback effects from water vapor, ice, and clouds.



Climate Sensitivity - definition

Whenever the amount of **carbon dioxide** in the atmosphere **doubles**, average global **temperature rises by 3 degrees** Celsius.



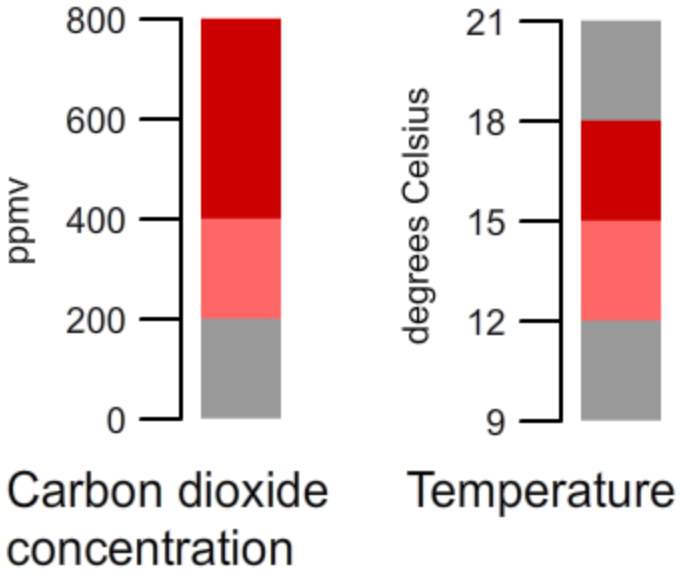


Math of Climate Sensitivity

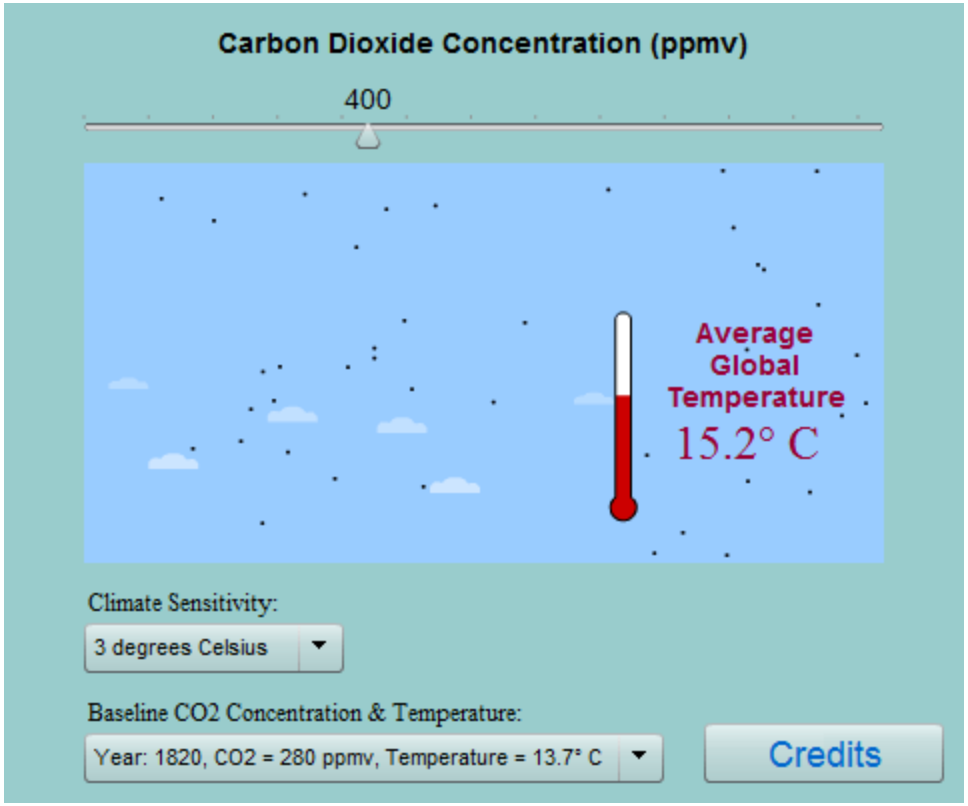
When the CO2 concentration in the atmosphere doubles, temperature rises by 3 ° Celsius (about 5.4 ° F)

Examples:

- If CO_2 rises from 200 ppmv to 400 ppmv, temperature rises 3 ° C
- If CO_2 rises from 400 ppmv to 800 ppmv, temperature rises 3 ° C
- Note: as CO_2 rises from 200 to 800 ppmv (800 = 4 x 200), temperature rises 6 ° C (= 2 x 3 degrees, **not** 4 x 3 degrees)

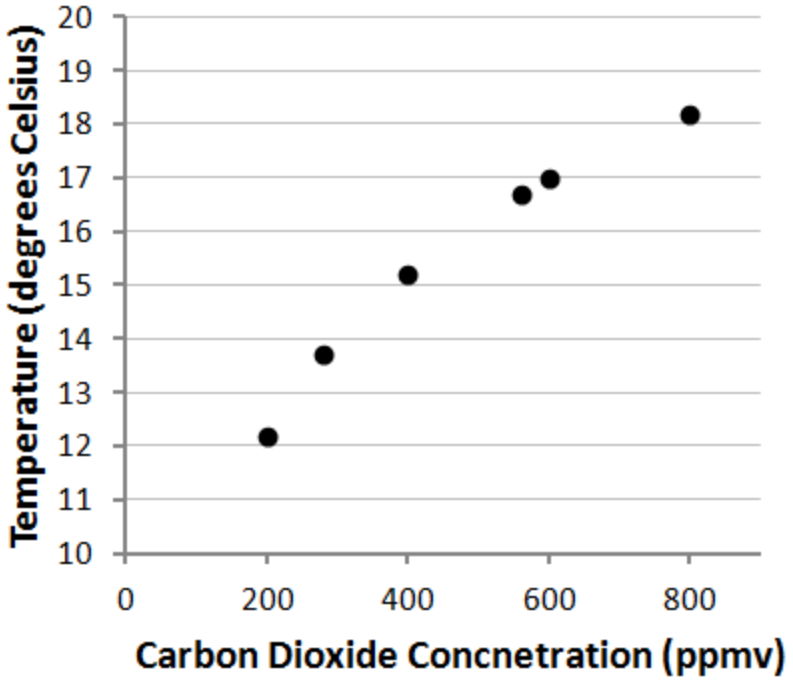


Climate Sensitivity Calculator demo



Climate Sensitivity Calculator Activity

CO_2 Concentration (ppmv)	Temperature (°C)
200	12.2
280	13.7
400	15.2
560	16.7
600	17.0
800	18.2



Advanced Climate Sensitivity Math

$$T = T_0 + S \log_2 (C / C_0)$$

T : new/current temperature
T_0 : reference temperature (e.g. 13.7 degrees C in 1820)
S : climate **S**ensitivity (3 degrees C)
C : new/current atmospheric CO_2 concentration
C_0 : reference atmospheric CO_2 concentration (e.g. 280 ppmv in 1820)

Example:

What is new **temperature** if CO2 rises to 400 ppmv (from 280 ppmv)?

$T = T_0 + S \log_2 (C / C_0) = 13.7 + 3 \log_2 (400/280) = 13.7 + 3 \log_2 1.43$
$= 13.7 + 1.54$
$= 15.2$ degrees C

Math of CO_2 Emissions and Atmospheric Concentration

Dry air mass of atmosphere = 5.135×10^{18} kg = 5,135,000 Gigatons
CO_2 currently about 599 ppm by mass (395 ppmv) = 0.0599%
CO_2 current mass = 0.0599% x 5,135,000 Gt = 3,076 Gt
CO_2 current emissions = 9.5 GtC/year
Atmospheric fraction = 45%

$M = M_0 + [0.45 \times (3.67 \times m)]$
$= 3{,}076\ GtCO_2 + [0.45 \times (3.67 \times 9.5\ GtC/yr)]$
$= 3{,}076 + 15.7\ GtCO_2 = 3{,}092\ GtCO_2$

(16 + 12 + 16) / 12

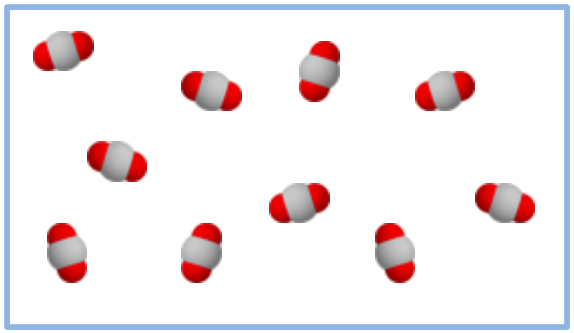
= 44/12 = 3.67

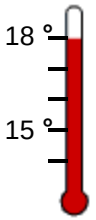
CO_2 concentration = 3,092/5,135,000 = 602 ppm by mass
CO_2 concentration = (602/599) x 395 ppmv = 397 ppmv



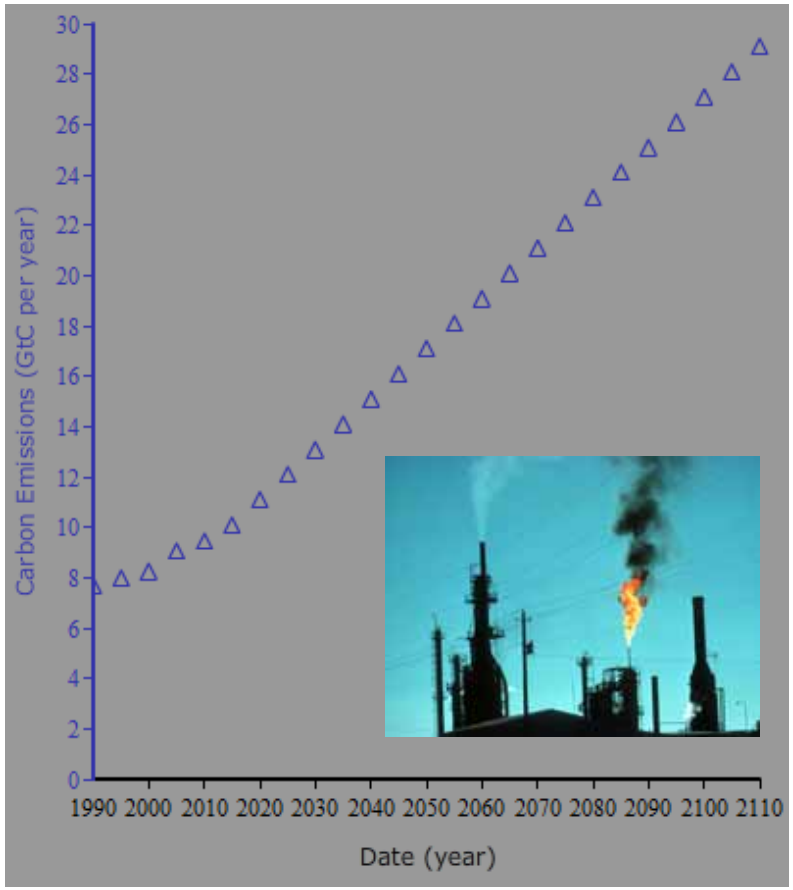
Questions?

Emissions ->
More CO2 in Air ->
Higher Temperature





Poll: Rising Emissions



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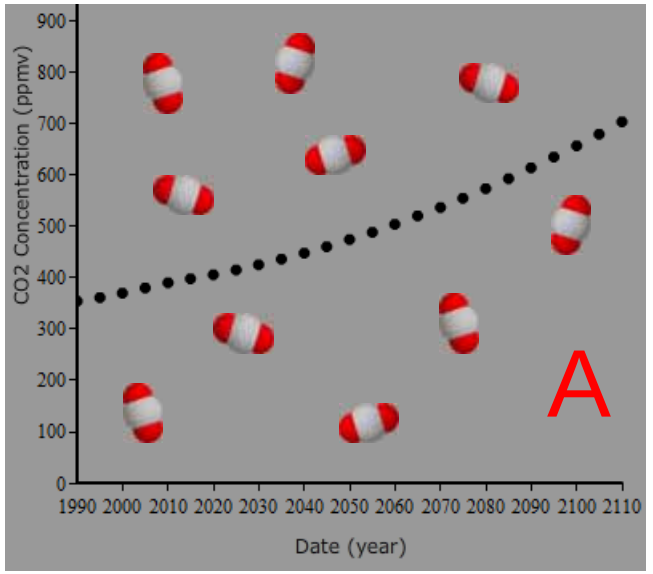

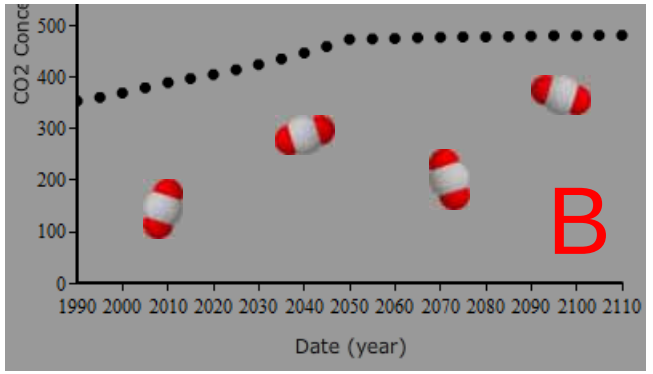

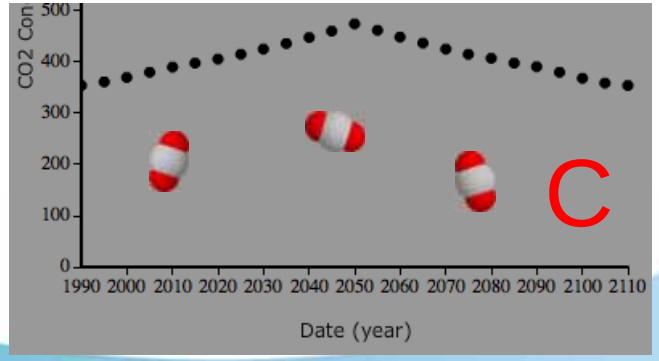

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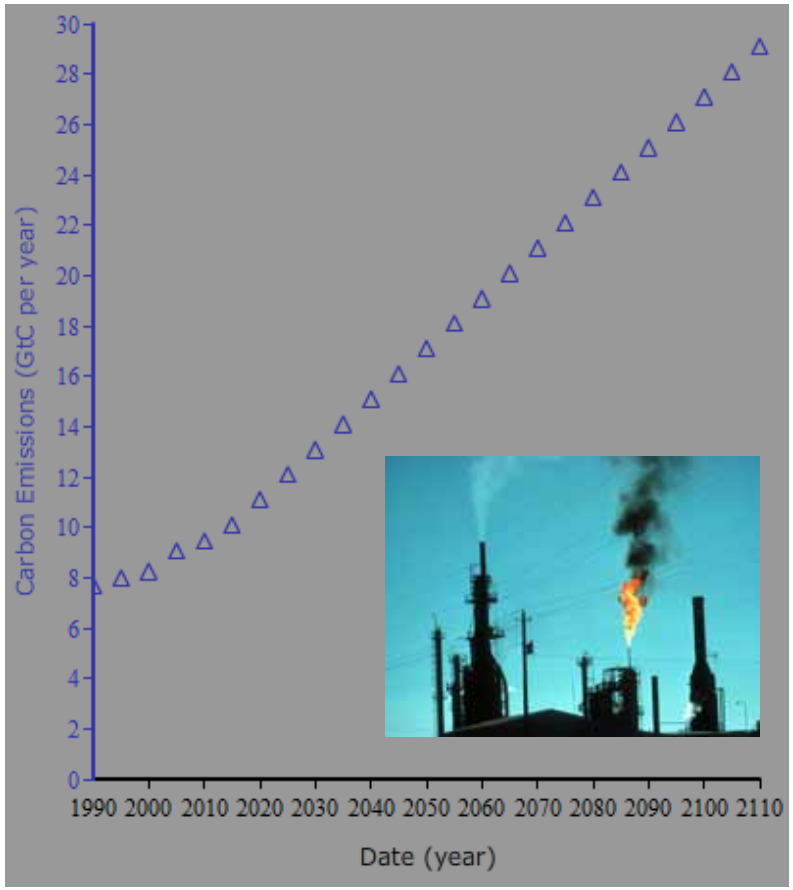

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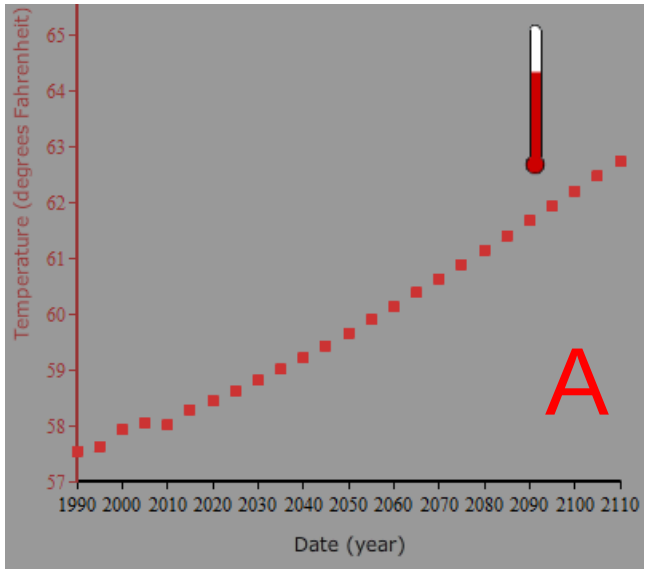
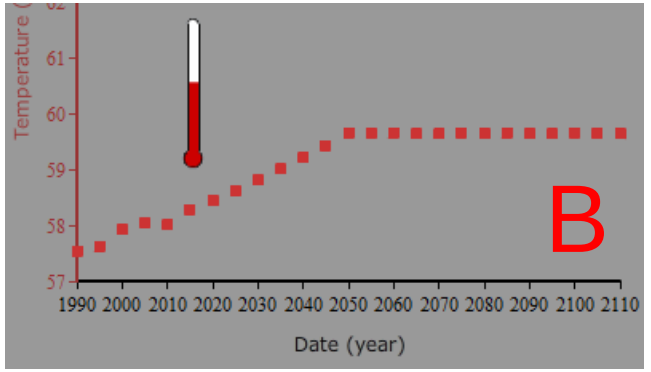
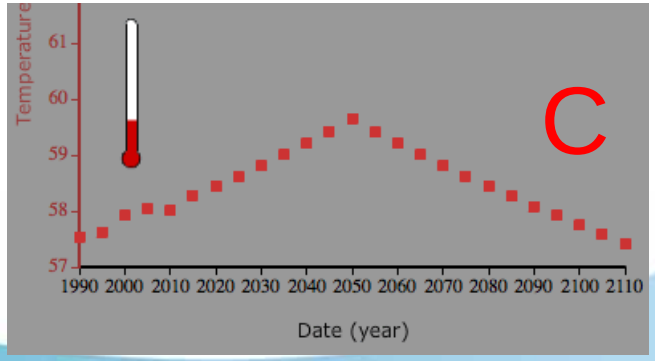
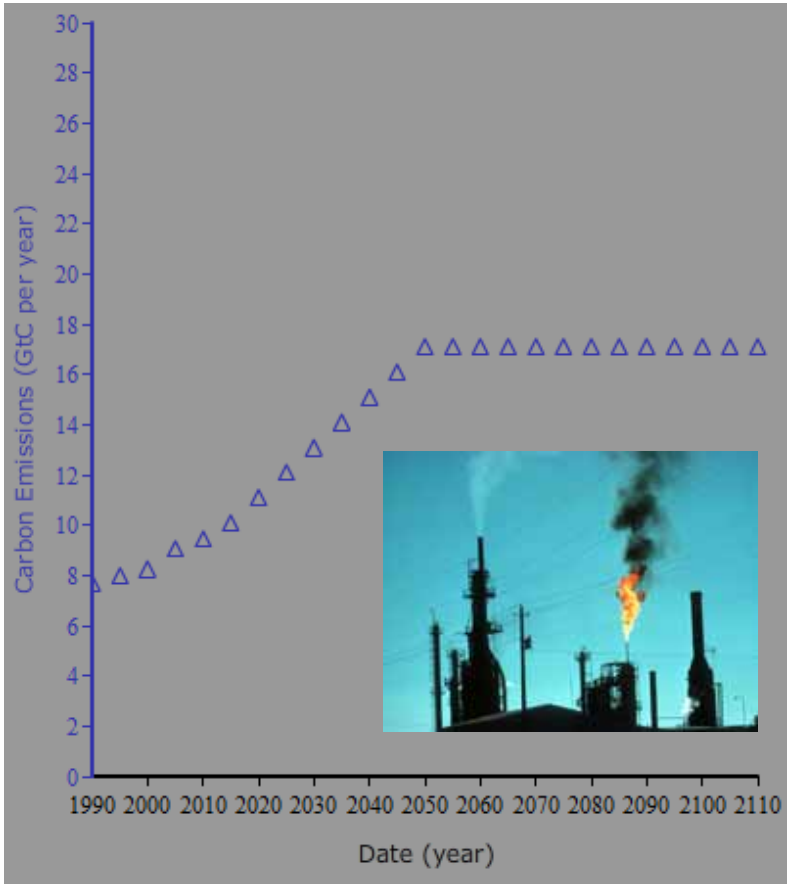






Poll: Emissions rise then steady



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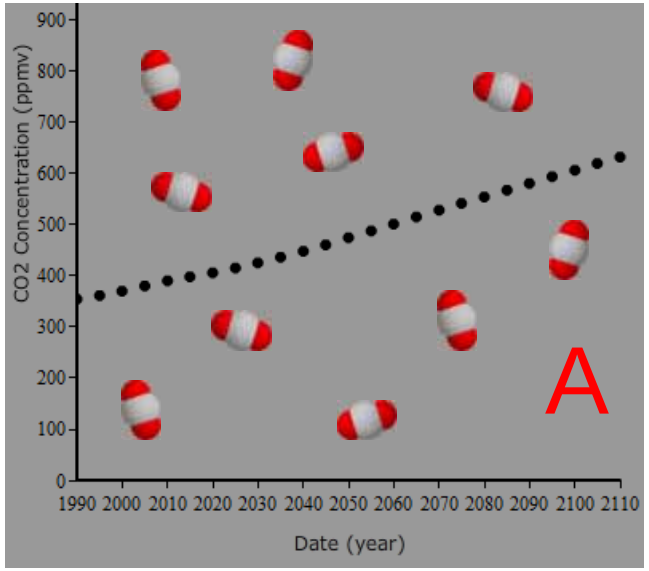

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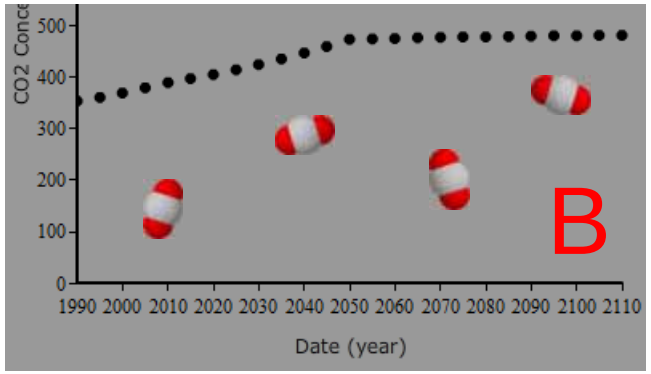

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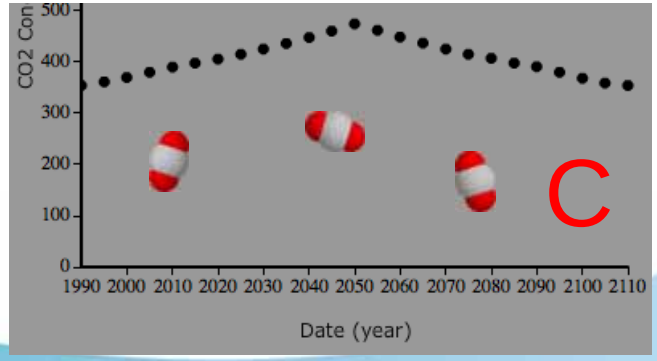

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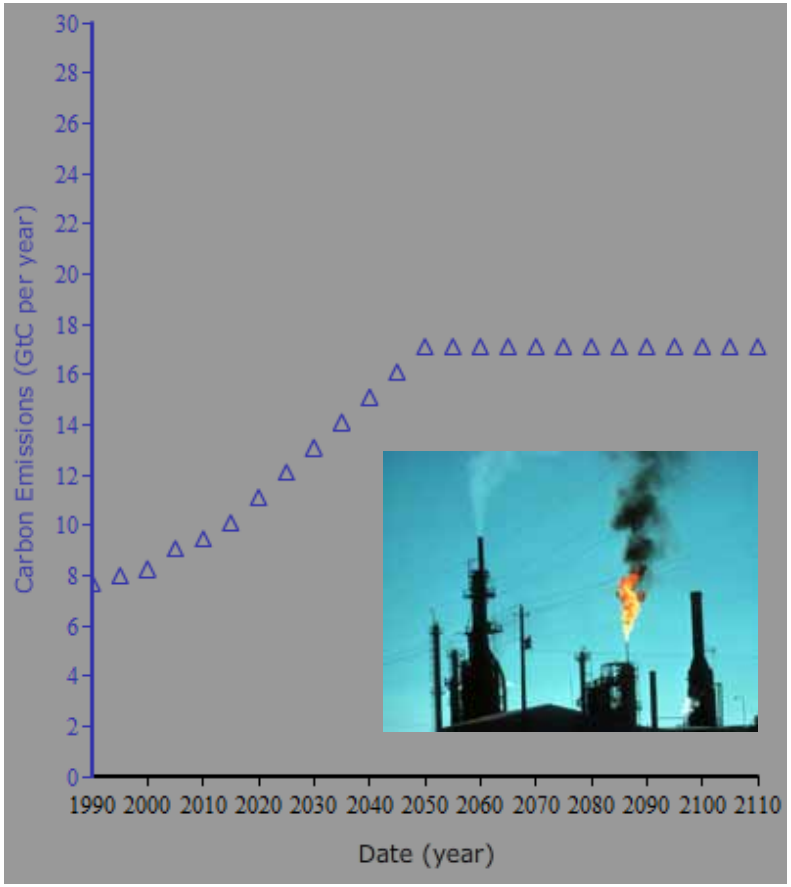

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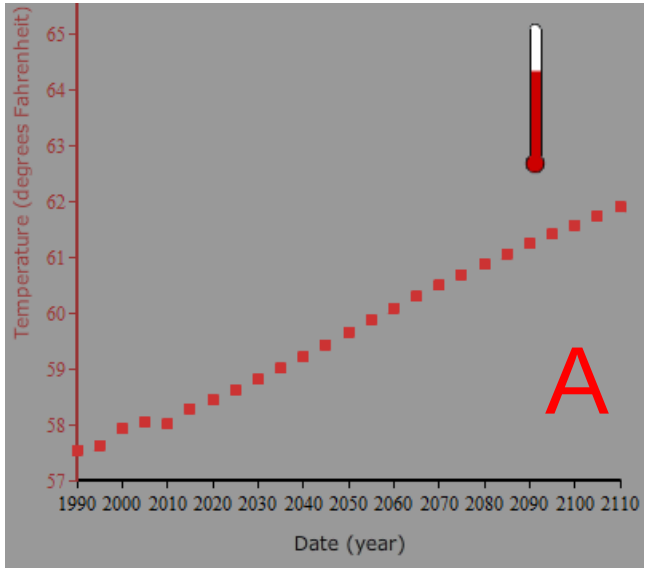
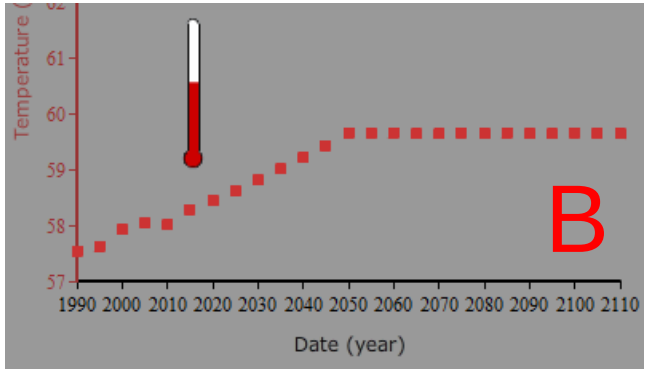
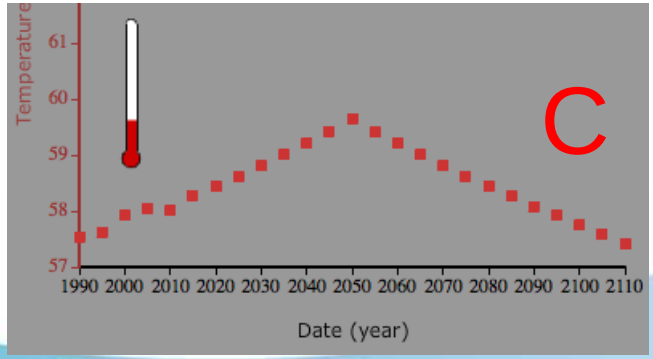
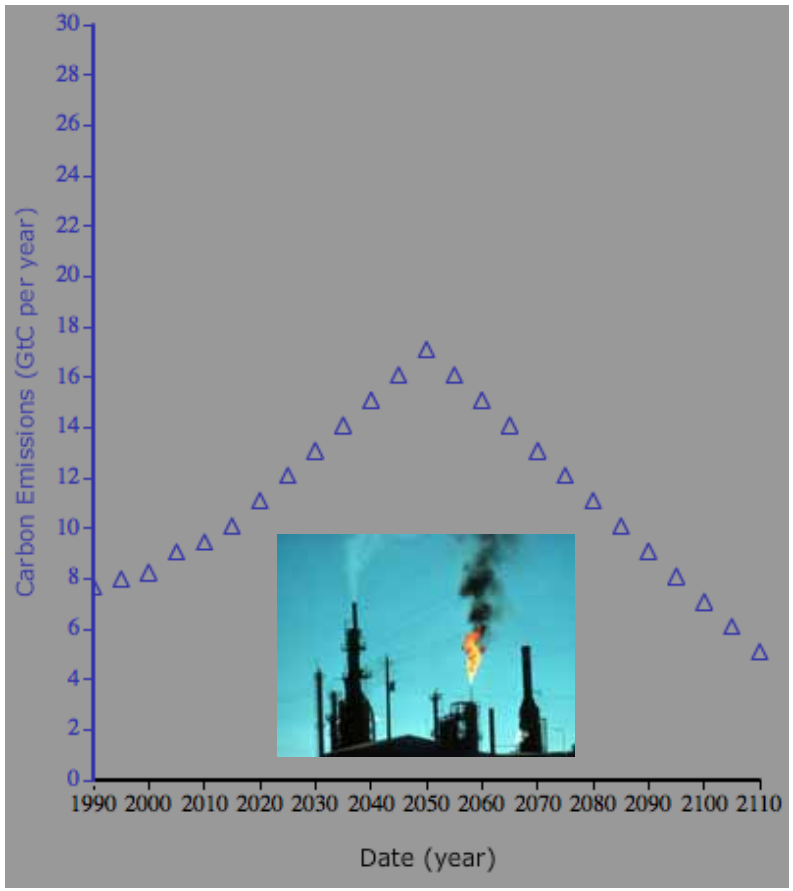






Poll: Emissions rise then fall



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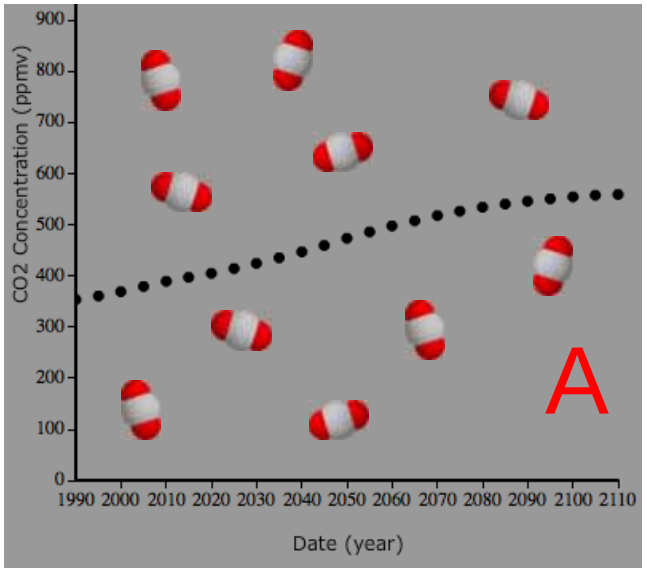

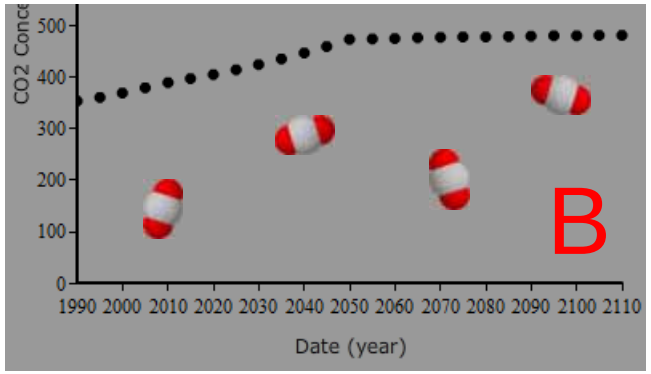

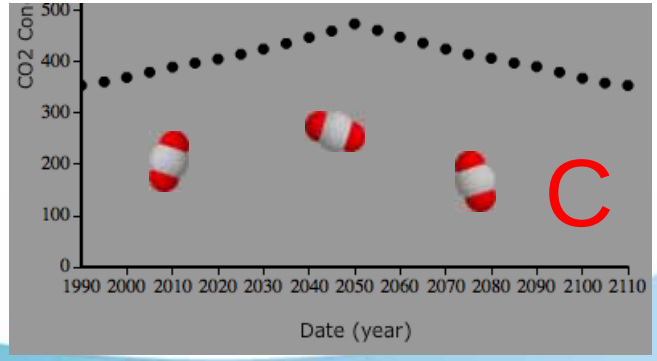

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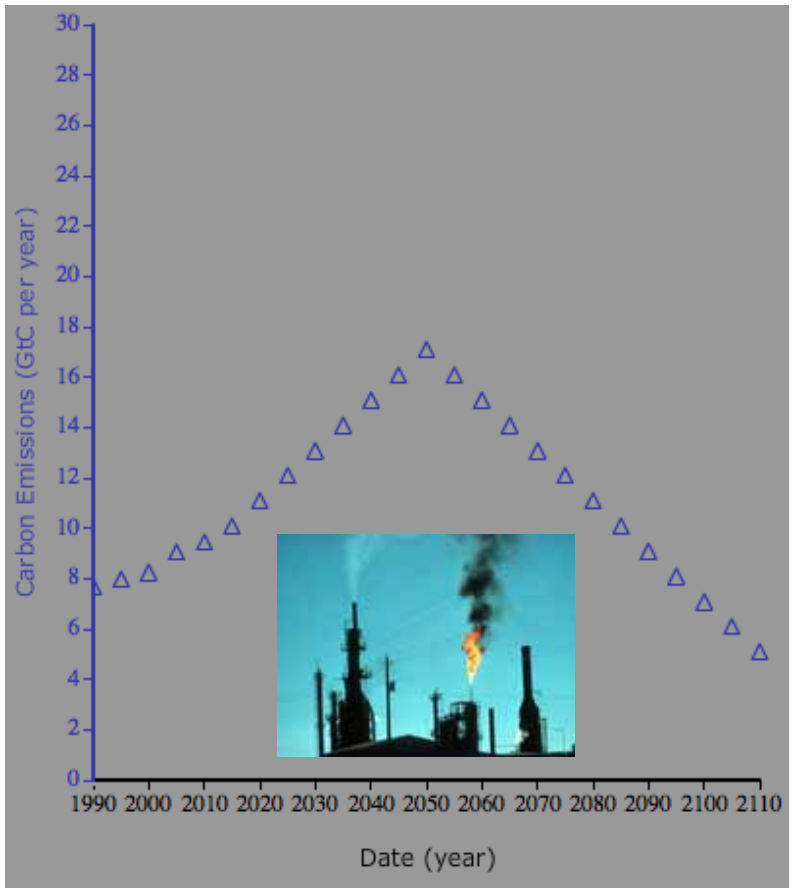

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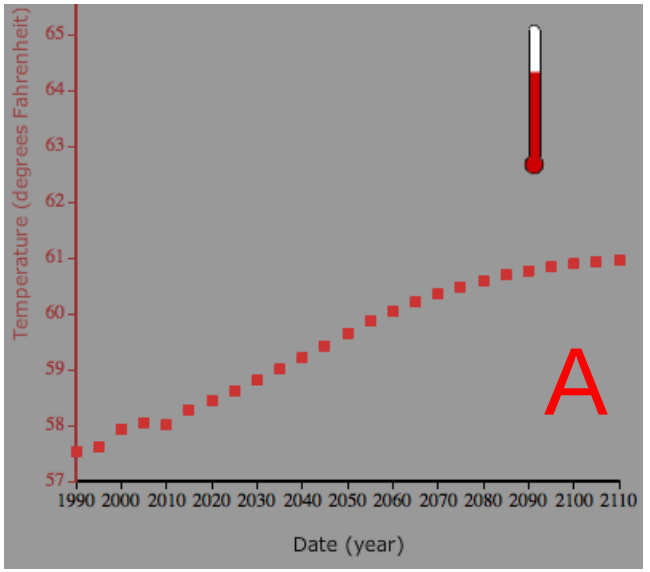

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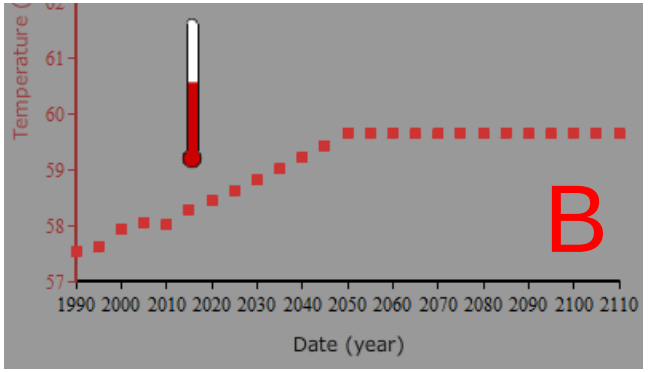

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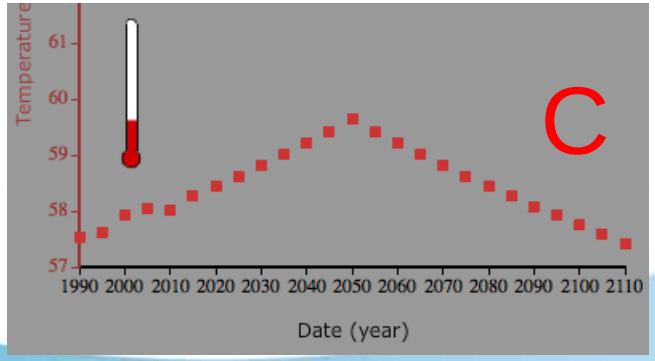


Very Simple Climate Model demo

Instructions

Step Forward | Play

Carbon Dioxide Emissions (Gigatons Carbon per Year)

12.4

Time step size:

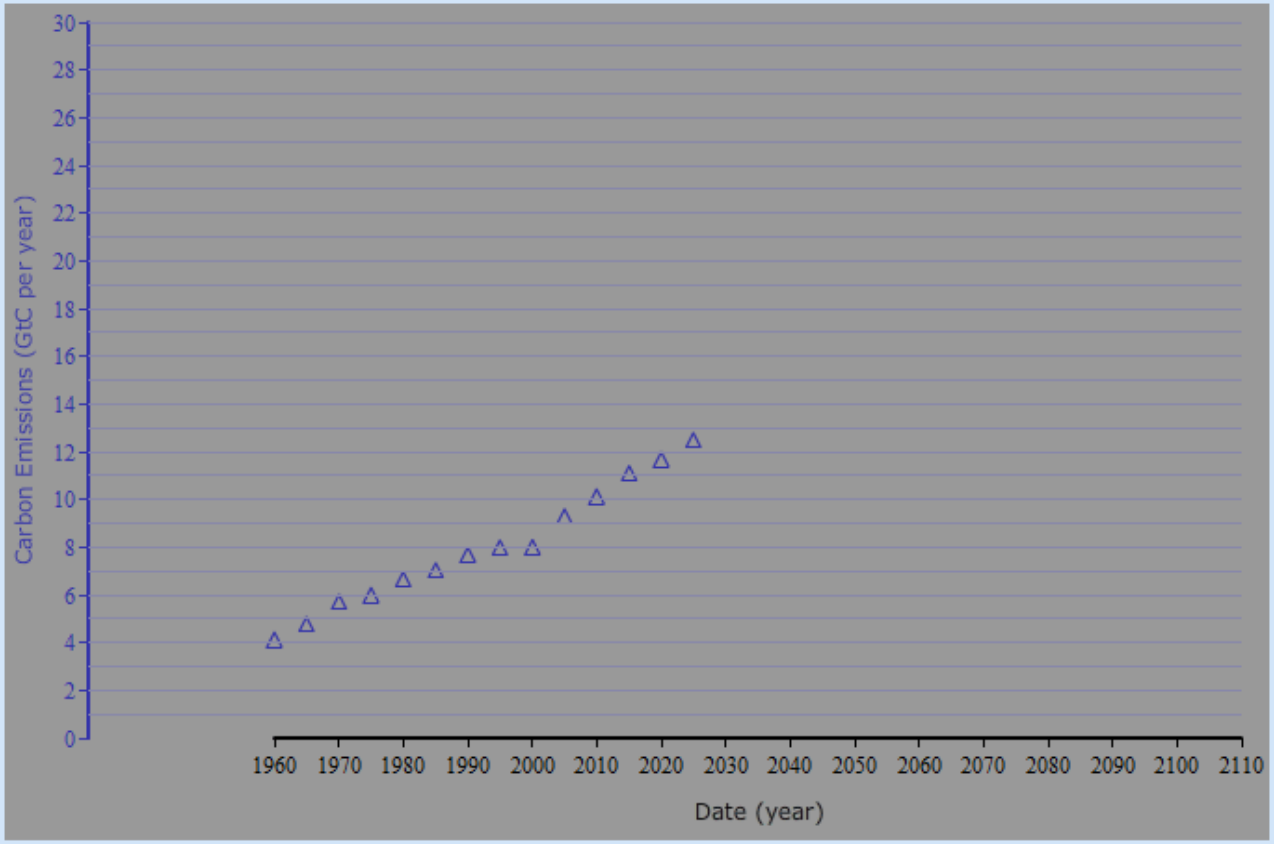
5 years

Show which graph(s)?

- [x] CO2 Emission Rate
- [ ] CO2 Concentration
- [ ] Temperature

Start Over

Change Settings

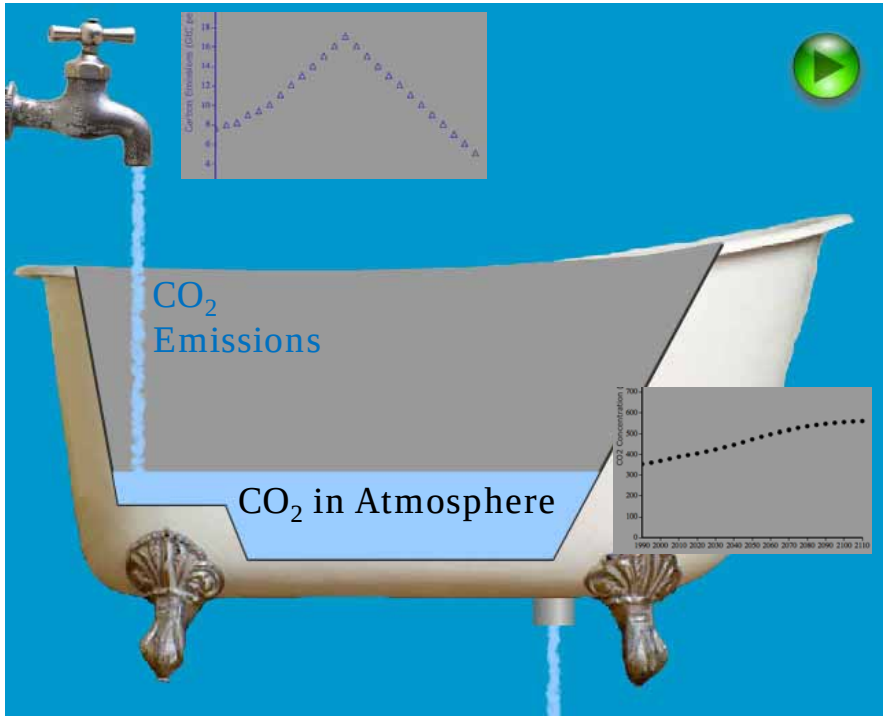


Celsius | 17 degrees

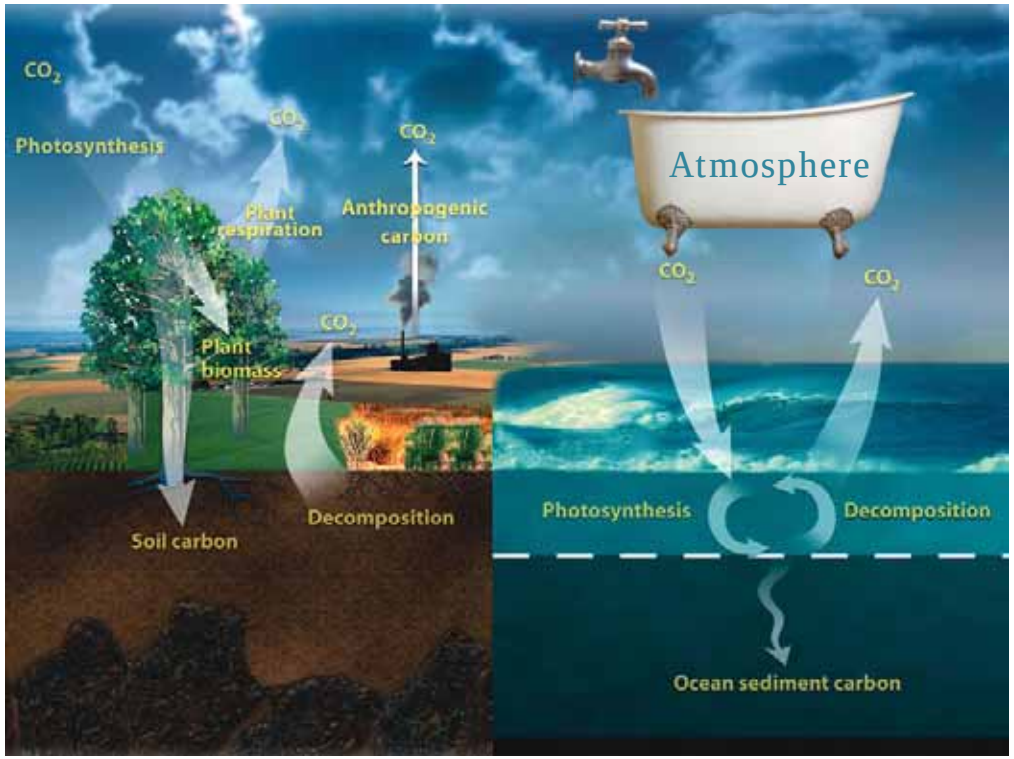
800 ppmv

Credits

Why does temperature continue to rise as emission rate declines?

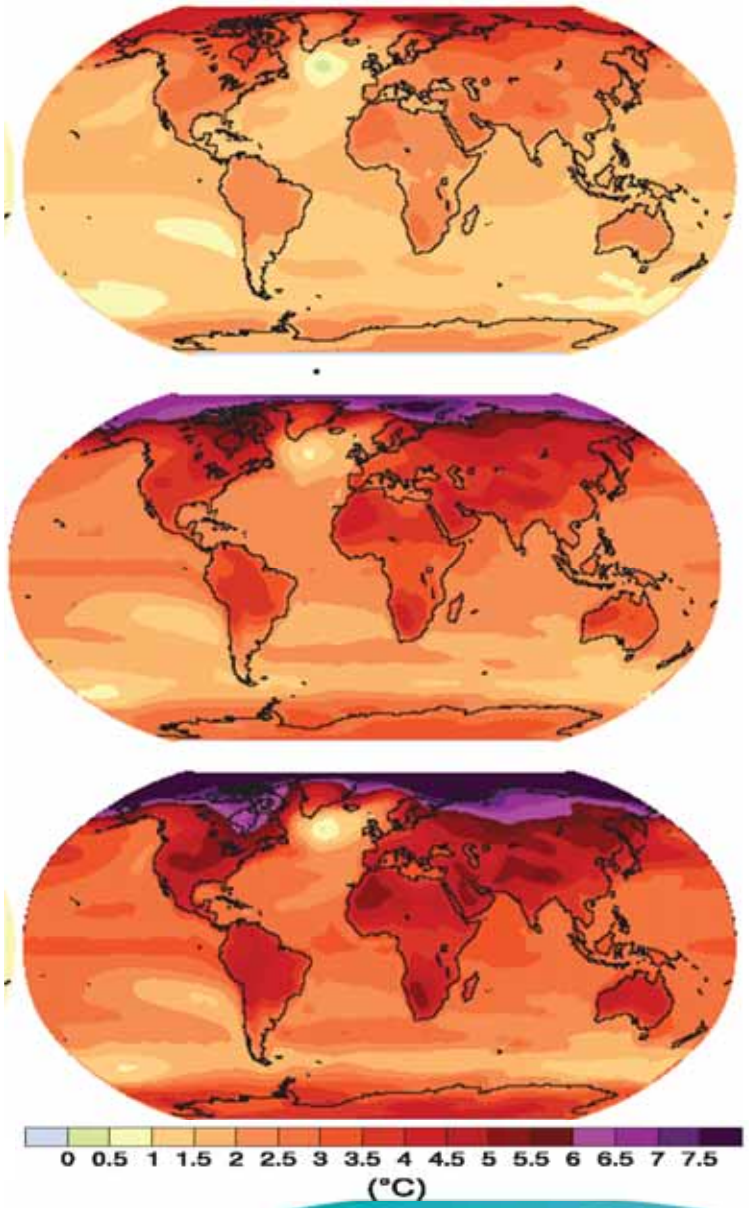


CO_2 Removal by Oceans & Plants





Questions?



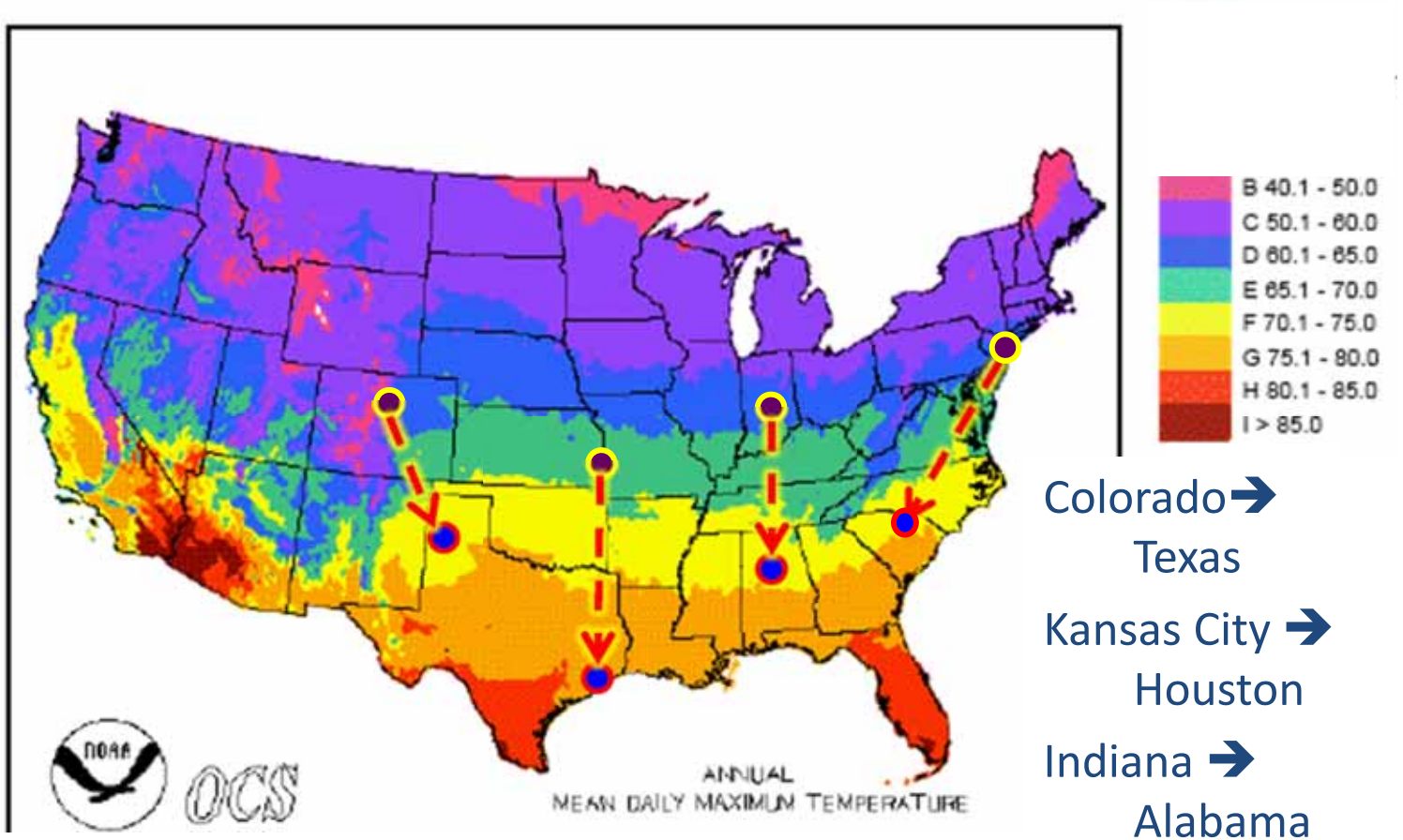
How Much Warmer by 2100?

- Land vs Ocean
- North vs South
- Arctic "amplification"

- North American warming of 3° to 6° C

= 5° to 11° F

Climate is Place: Where is it 10 ° F Warmer (on the average)?



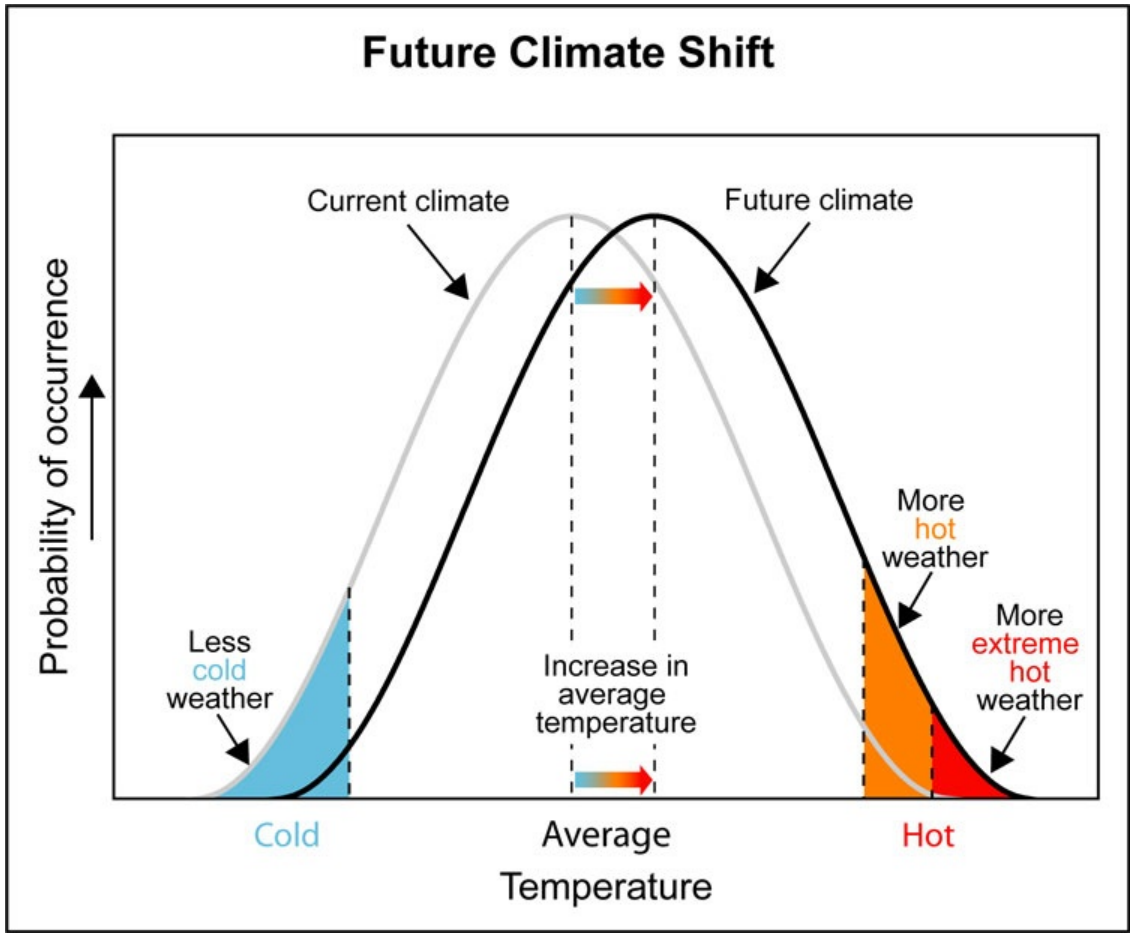
Colorado➔
Texas

Kansas City ➔
Houston

Indiana ➔
Alabama

New York ➔
South Carolina

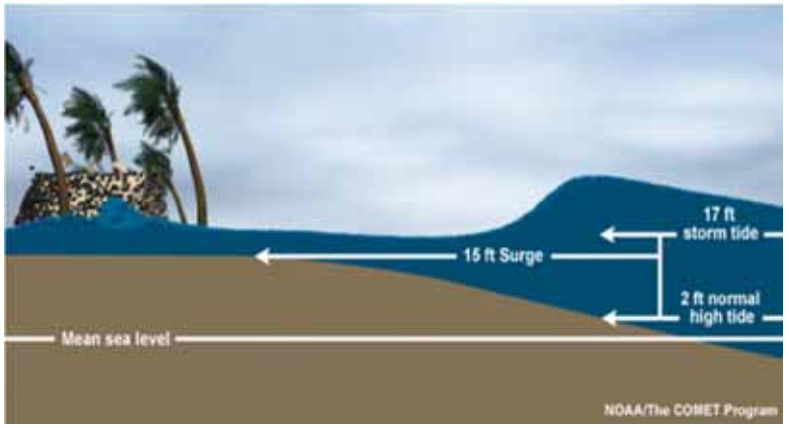
Changes in Means *vs* Extremes

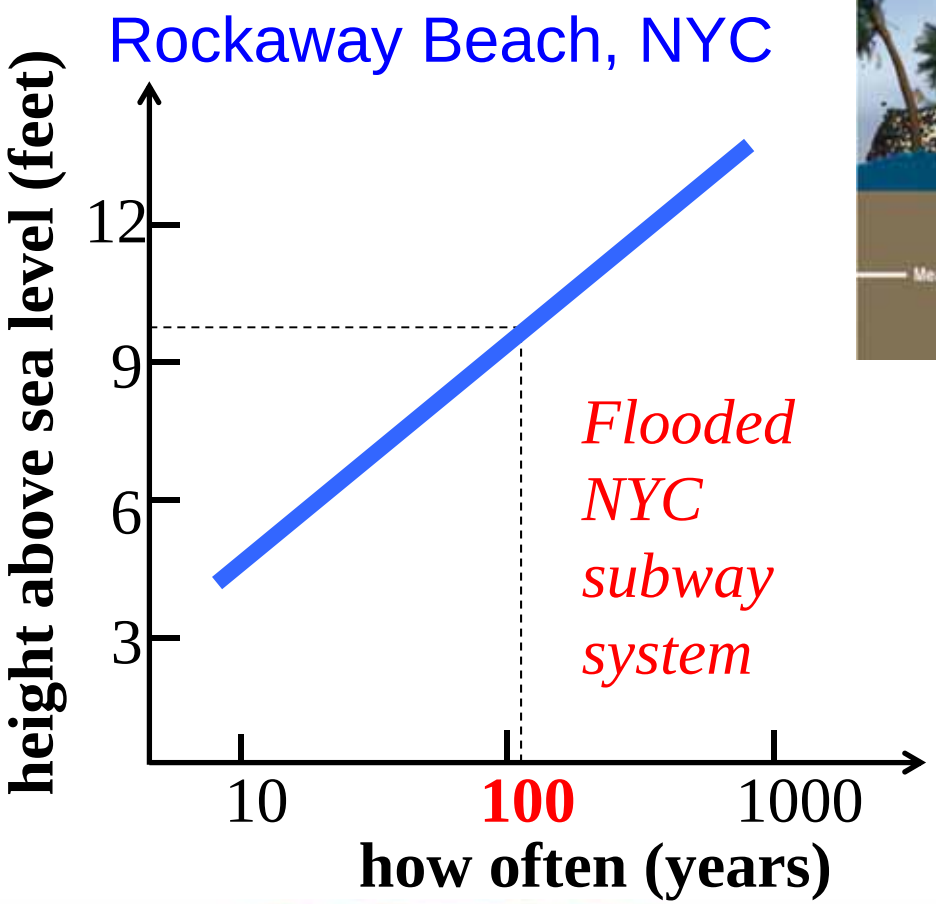


- Economic and social impacts typically result from extremes not average conditions

- Even a small shift in the average conditions can result in a huge increase in the frequency of extremes

Coastal Flooding is not Gradual!

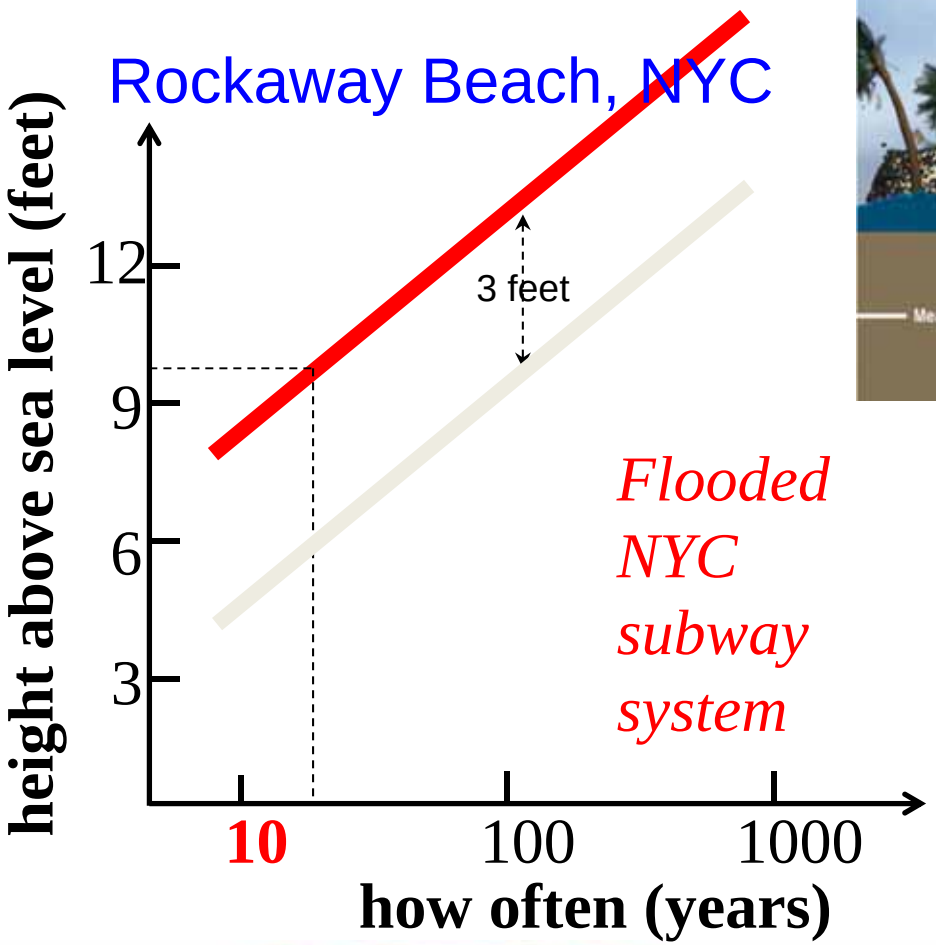


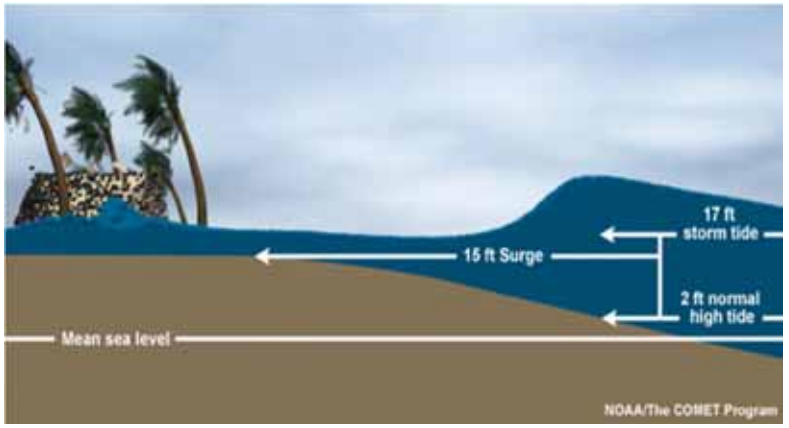


- Small floods are much more frequent (10 year) than big floods (100 year)

- Thresholds for severe damage are rarely exceeded

Coastal Flooding is not Gradual!

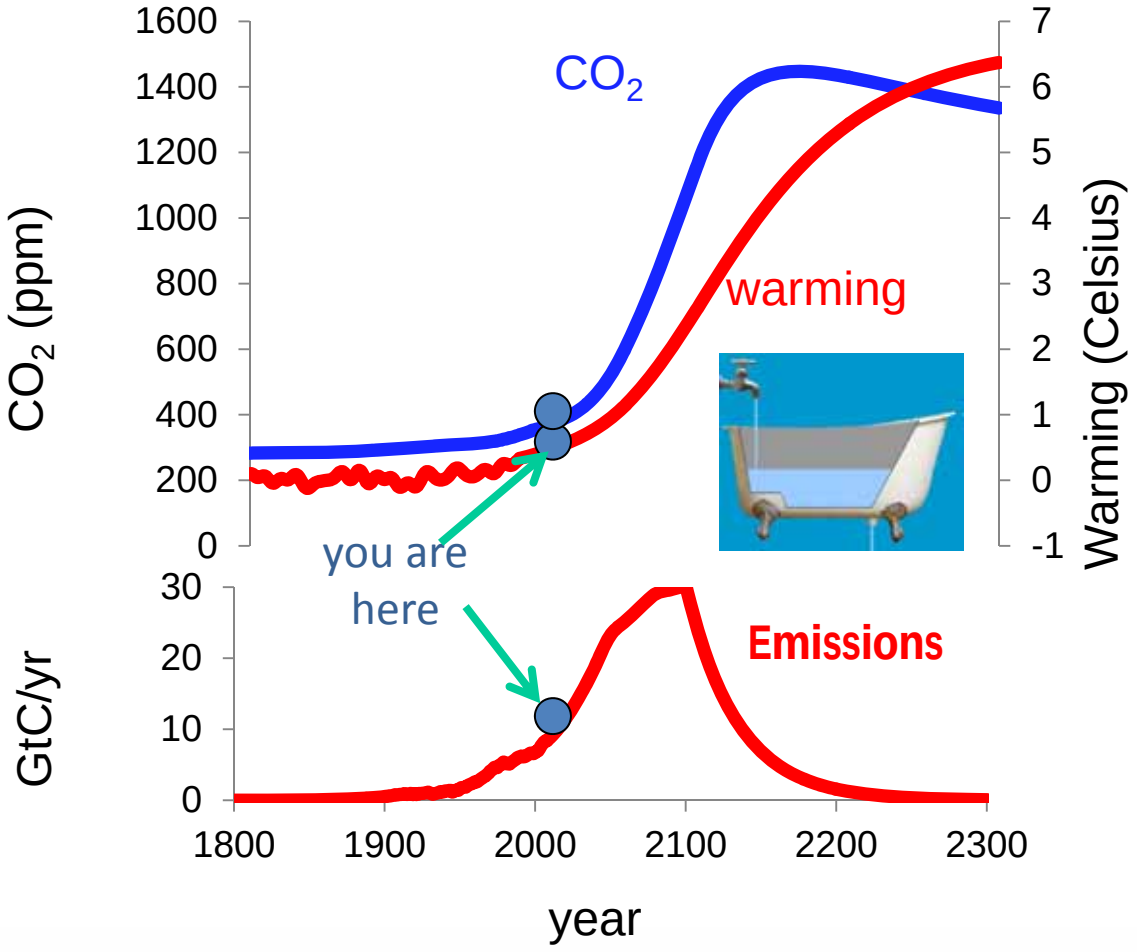




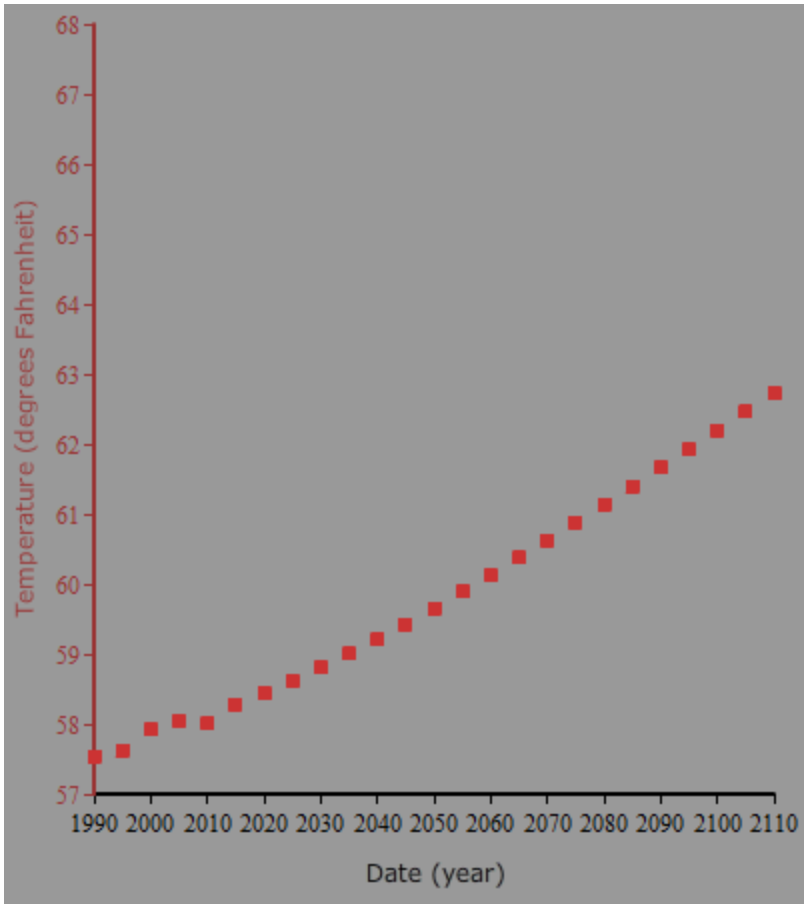
- Sea levels expected to rise 2 to 6 feet by 2100
- What was a rare event (110 years) becomes much more frequent (20 years)

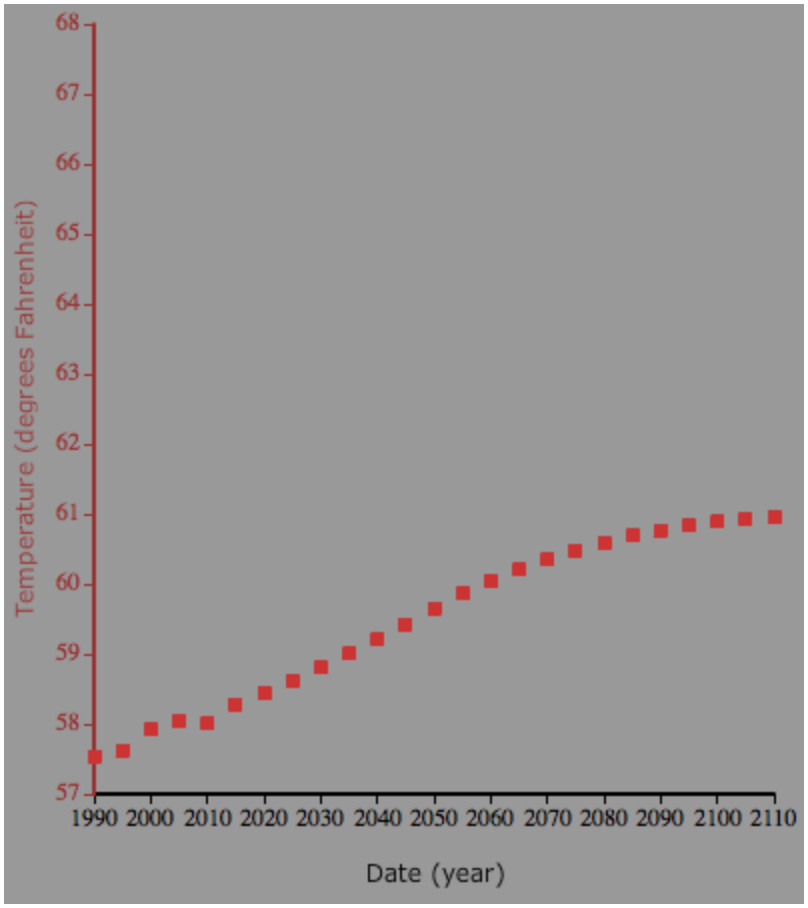
How Warm for How Long?

- If developing countries industrialize with fossil fuel, CO_2 will rise to 4x preindustrial
- Even after emissions go to zero, extra CO_2 will last for centuries
- Warming could last long enough to melt ice sheets



If we are already committed to rising temperatures, why bother doing anything?





We may avoid some "tipping points"

…and more floods, ocean acidification, melting sea ice, …

Is there any reason for hope? Yes!

Join us for our next webinar on April 25th:

"Opportunities for Abundance:
Solving the problems of energy, carbon, and climate"

1. What needs to be done? (generate huge amounts of energy without putting CO_2 in the air)
2. How it can be done (it's certainly technically feasible)
3. How it's not so hard when we see this job in the historical context of the last 200 years



Questions?

Thanks to today's presenters!

Scott Denning
Colorado State University
Center for Multiscale Modeling of Atmospheric Processes (CMMAP)

Randy Russell
Spark
National Center for Atmospheric Research (NCAR)

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