

# Climate Change

How does it work?

Why is Colorado Vulnerable?

What can be done about it?



Scott Denning

Director of Education, CMMAP

Atmospheric Science, CSU



"Scientists are  
necessary,  
but not  
sufficient to  
solve the  
climate  
problem"

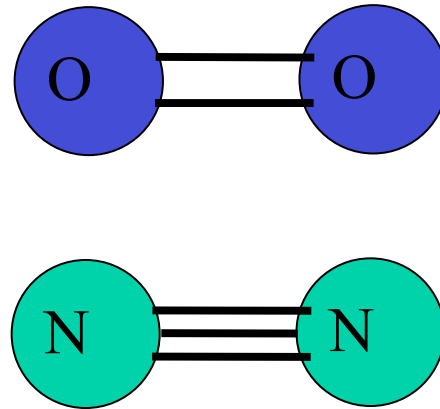
**Dr. Ralph Cicerone,  
President of the National Academy of Science, November 2007**

# Global Warming is Based on Common Sense

not computer models ...  
not recent temperatures ...  
not complicated!

# Dancing Molecules and Heat Rays!

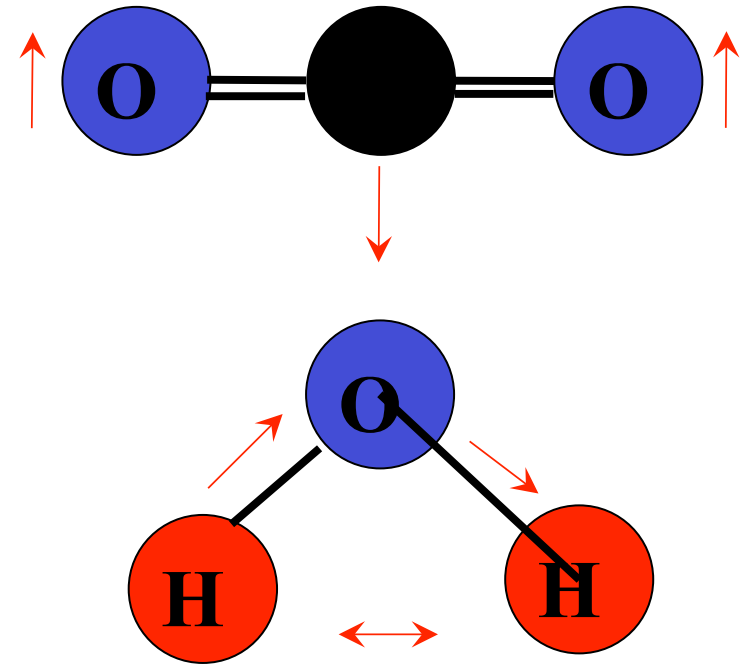
- Nearly all of the air is made of oxygen ( $O_2$ ) and nitrogen ( $N_2$ ) in which **two atoms of the same element** share electrons
- Infrared (heat) **energy radiated up from the surface can be absorbed** by these molecules, but not very well



*Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical*

# Dancing Molecules and Heat Rays!

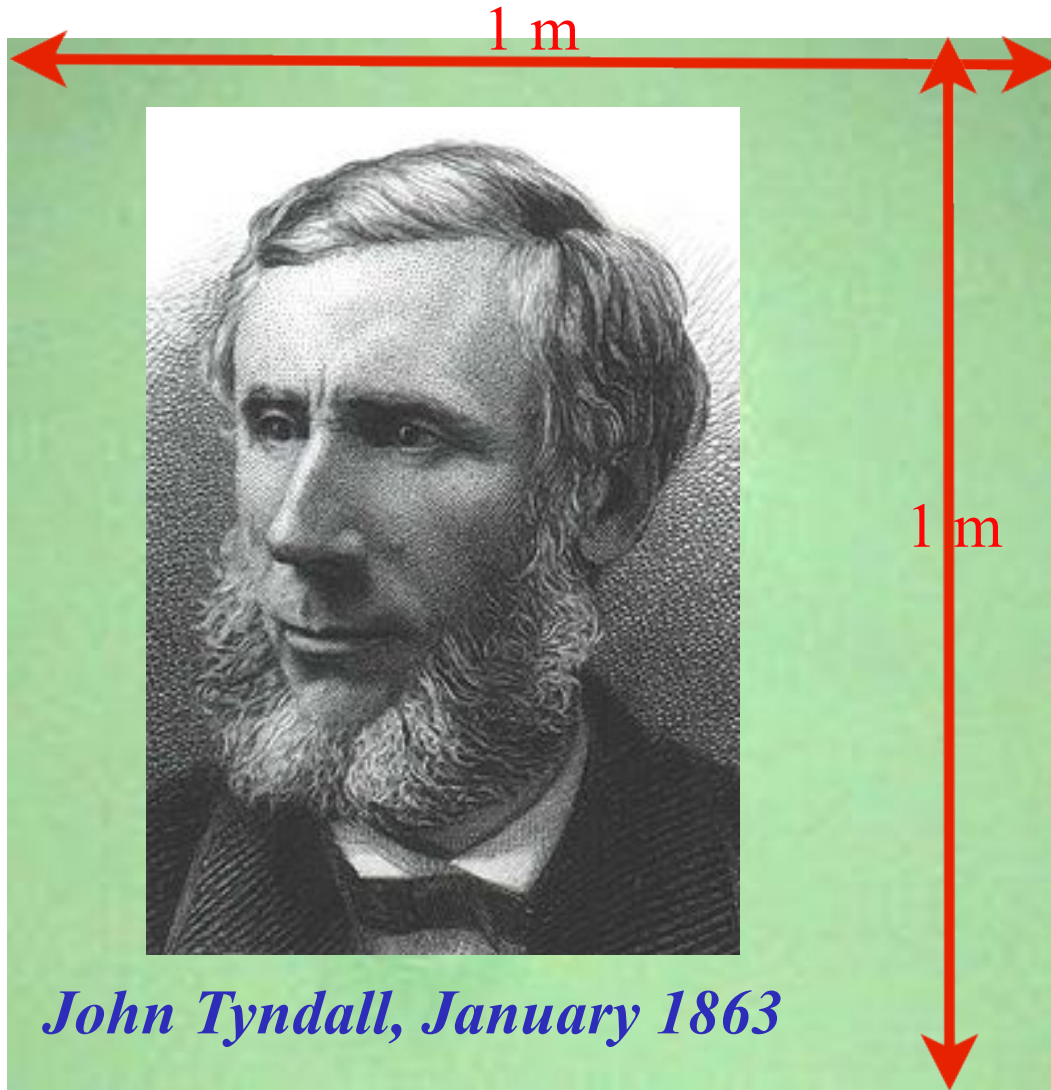
- Carbon dioxide ( $\text{CO}_2$ ) and water vapor ( $\text{H}_2\text{O}$ ) are different!
- They have **many more ways to vibrate** and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



*Molecules that have many ways to wiggle are called “Greenhouse” molecules*

*Absorption spectrum of CO<sub>2</sub> was measured by John Tyndall in 1863*

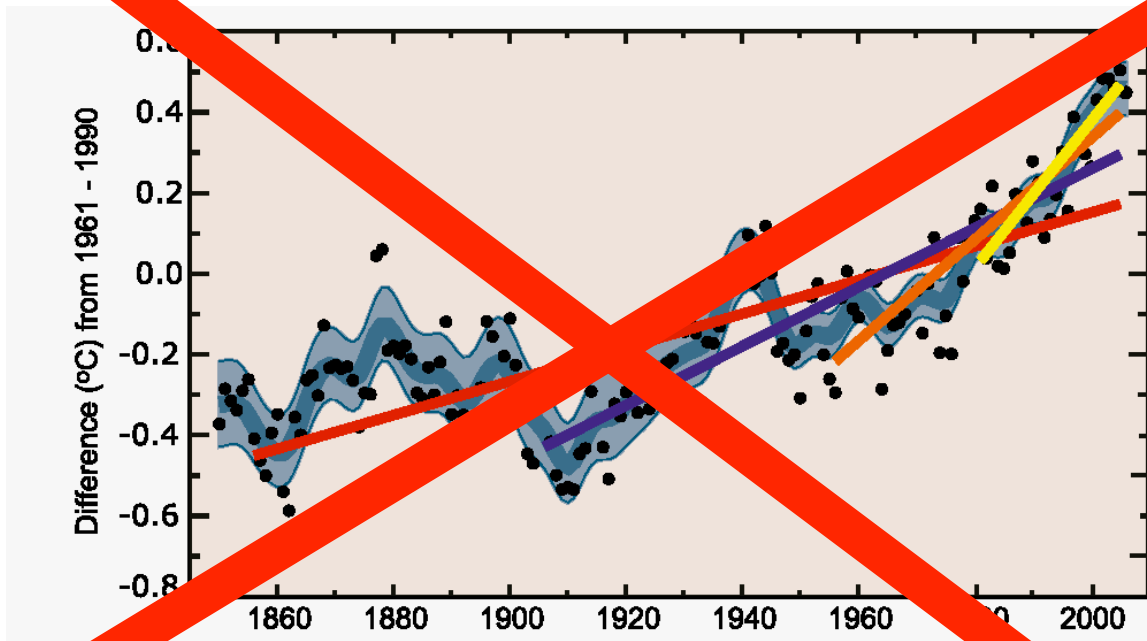
# Common Sense



- Doubling  $\text{CO}_2$  would add **4 watts** to **every square meter** of the surface of the Earth, **24/7**
- Doing that would make the surface **warmer**
- This was known before light bulbs were invented!

# Common Misconception #1

"People are worried about climate change because it's been warming up recently"



**WRONG!** We're worried because we know that when we add heat to things, they warm up

# Be a Climate Skeptic

- Maybe something will happen in the Earth system that "cancels out" an extra 4 watts of heat in every square meter of the planet
  - The sun could dim by  $4 \text{ W m}^{-2}$
  - Giant clouds of interplanetary dust might block the sunshine
  - Fog could suddenly shroud the Earth's surface
- Some media celebrities are certain something like this will happen
- **Call me a skeptic!**



# Warming in 2090's

- Land vs ocean!
- North vs South
- Global mean warming of 2° to 5° C
- North American warming of 3° to 6° C  
= 5° to 11° F
- Arctic warming of 8° to 14° F

*Rainfall?*

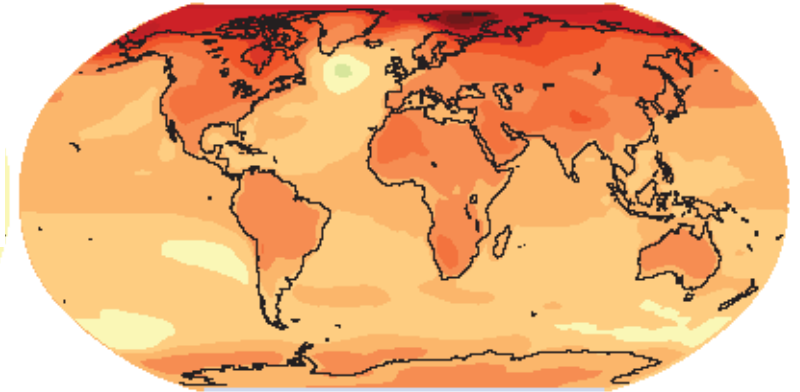
*Water supply?*

*Mass immigration?*

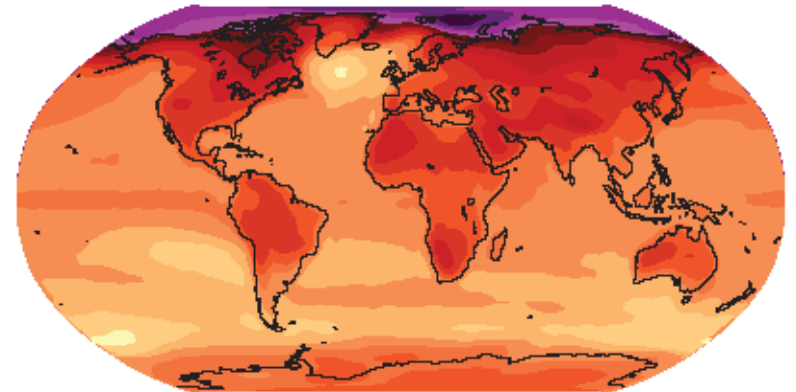
*Agriculture?*

*Ski industry?*

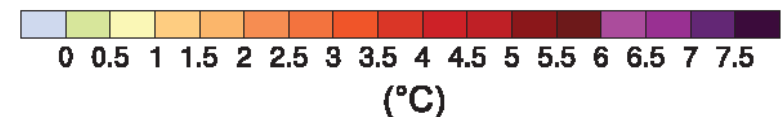
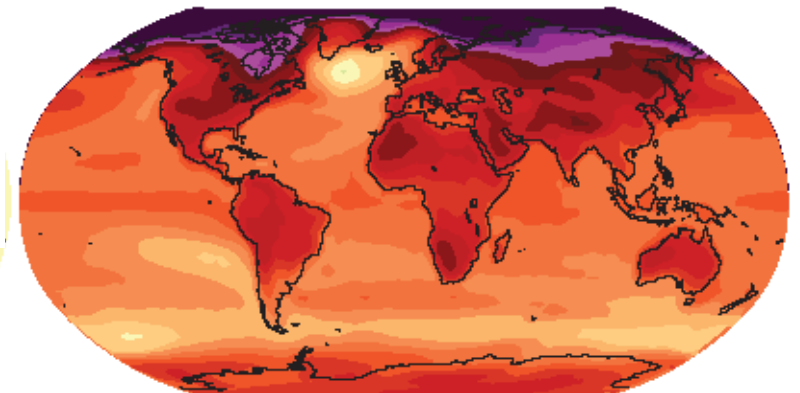
Low  
Emissions



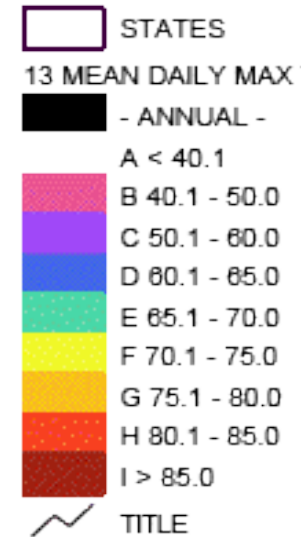
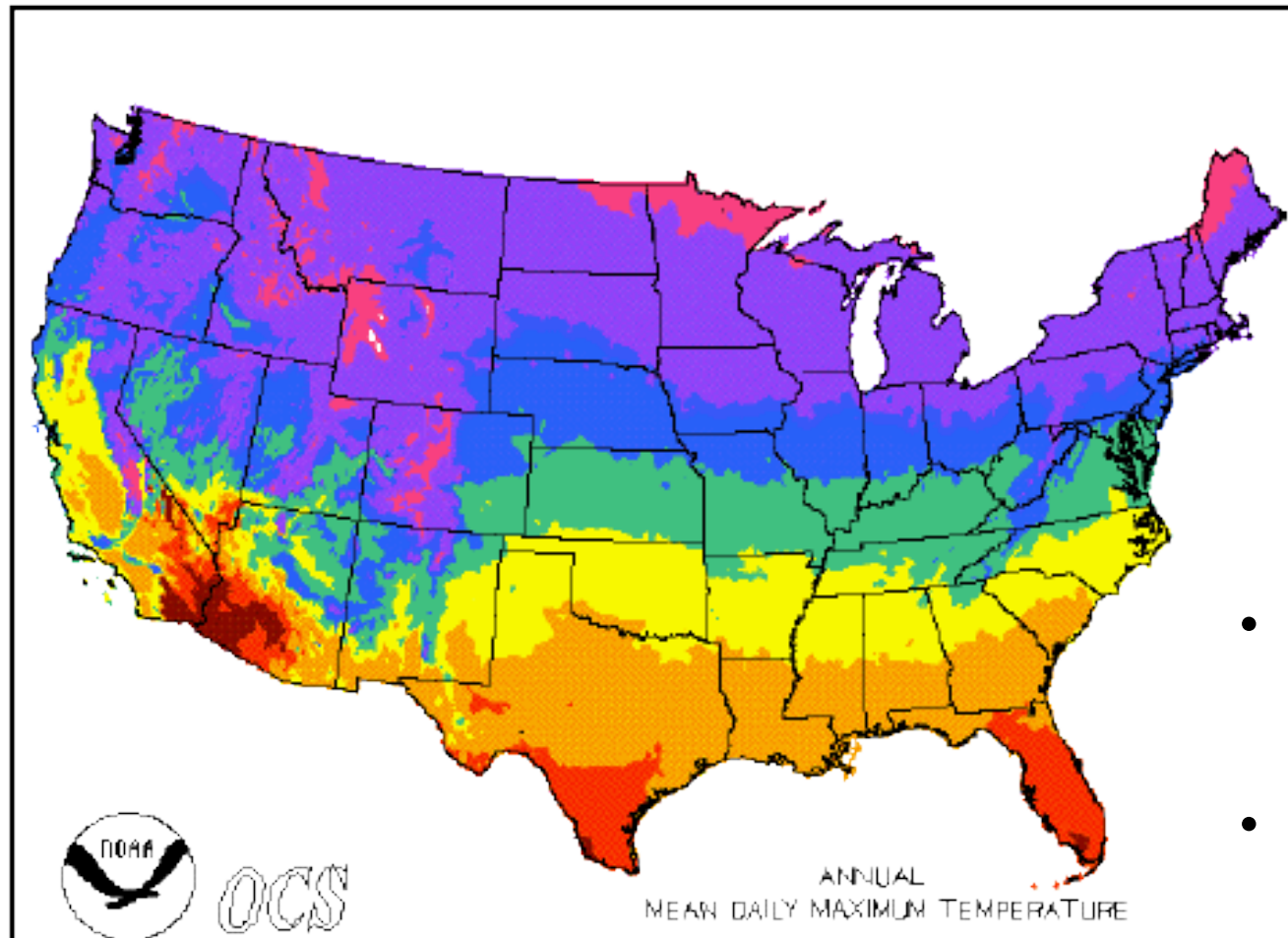
Moderate  
Emissions



High  
Emissions



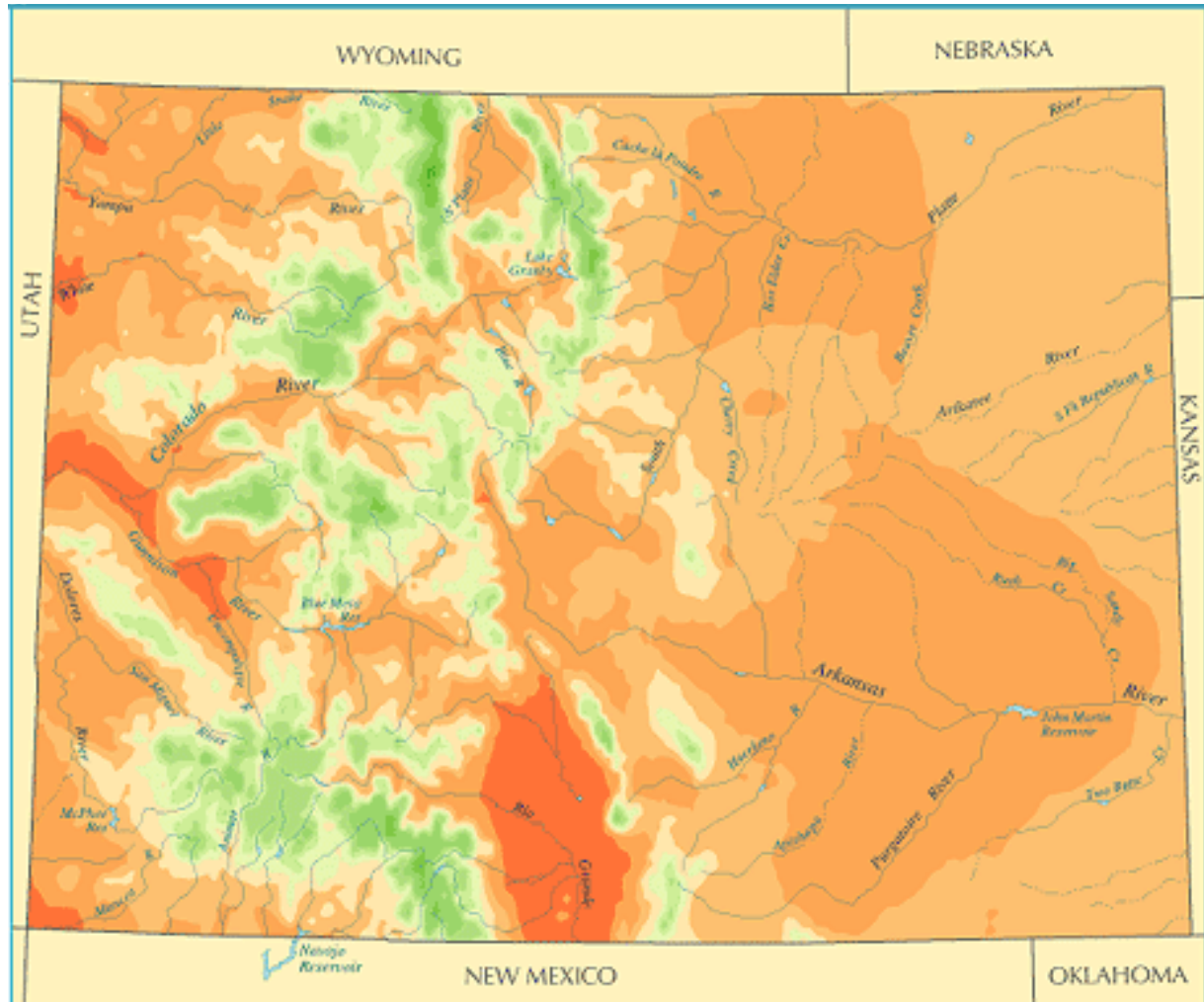
# Where is it 10°F warmer "on average?"



- Breckenridge  
→ Denver
- Denver →  
Roswell, Fresno
- Washington DC  
→ Atlanta

# A Region On the Edge

## *Colorado Precipitation Map*



Much of the region already receives only marginal precipitation

Just enough snow to support forests and reservoirs

Just enough irrigation water to support farming

# A Region on the Edge



# Ski Industry



# Real Estate Development



# Irrigated Agriculture



corbis.

**Drought**





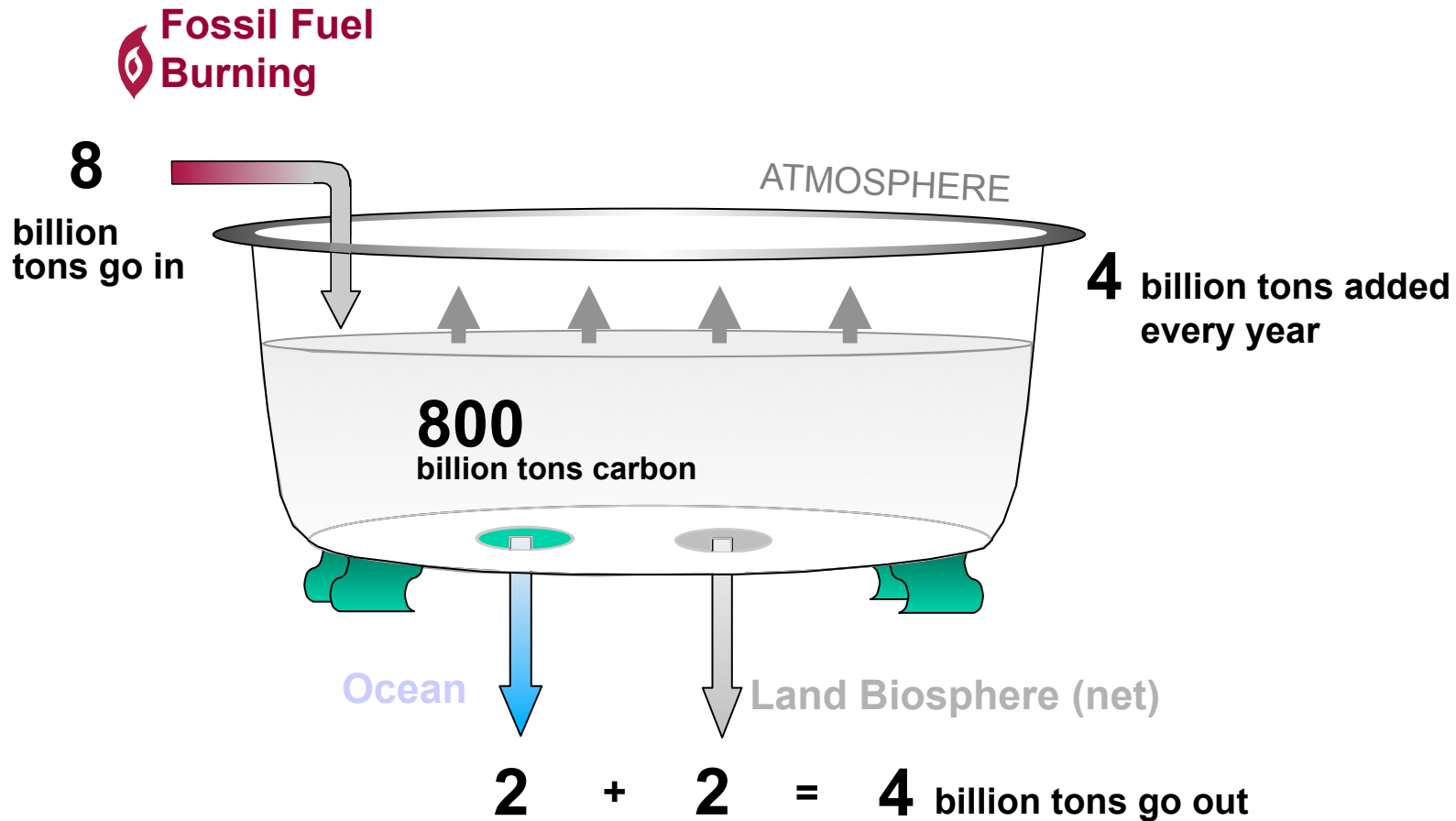


# Insect Pests



**Wildfire**

# CO<sub>2</sub> "Budget" of the Atmosphere



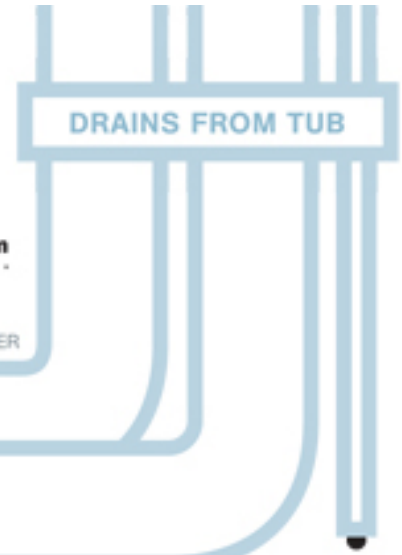
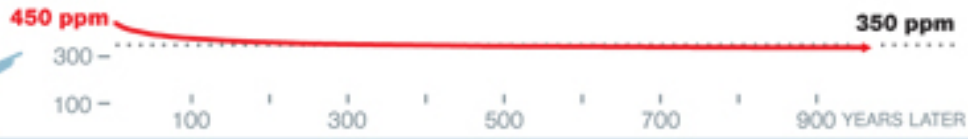
*Rob Socolow and Steve Pacala <http://www.princeton.edu/wedges/>  
Climate Mitigation Initiative, Princeton University*



# Bathtub Drainage

What if we stop emissions completely?

It will take centuries for plants and the ocean to soak up most of the human-made CO<sub>2</sub>. It will take hundreds of millennia for the rest to be removed by rock weathering, which converts CO<sub>2</sub> to carbonate sediments and rocks.

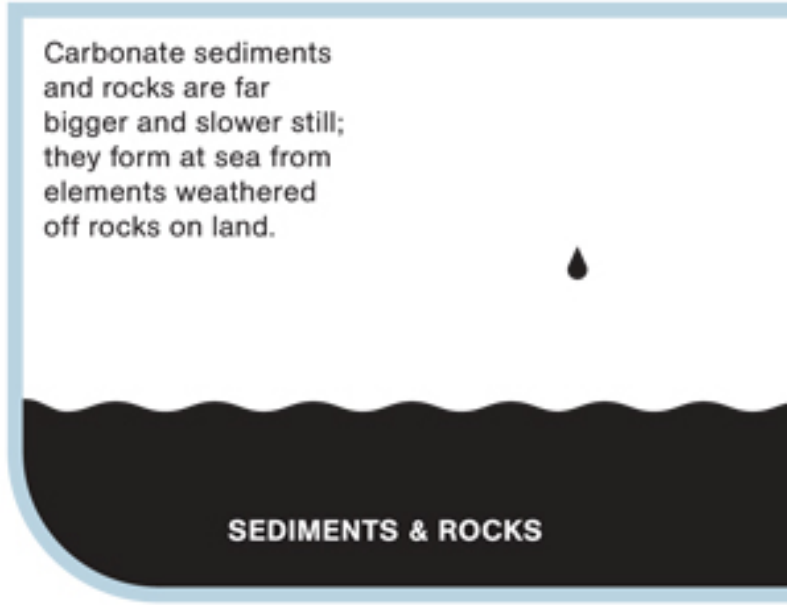


Why would the level stay high for so long?

Plants and soil absorb CO<sub>2</sub> quickly, but that reservoir fills up fast.

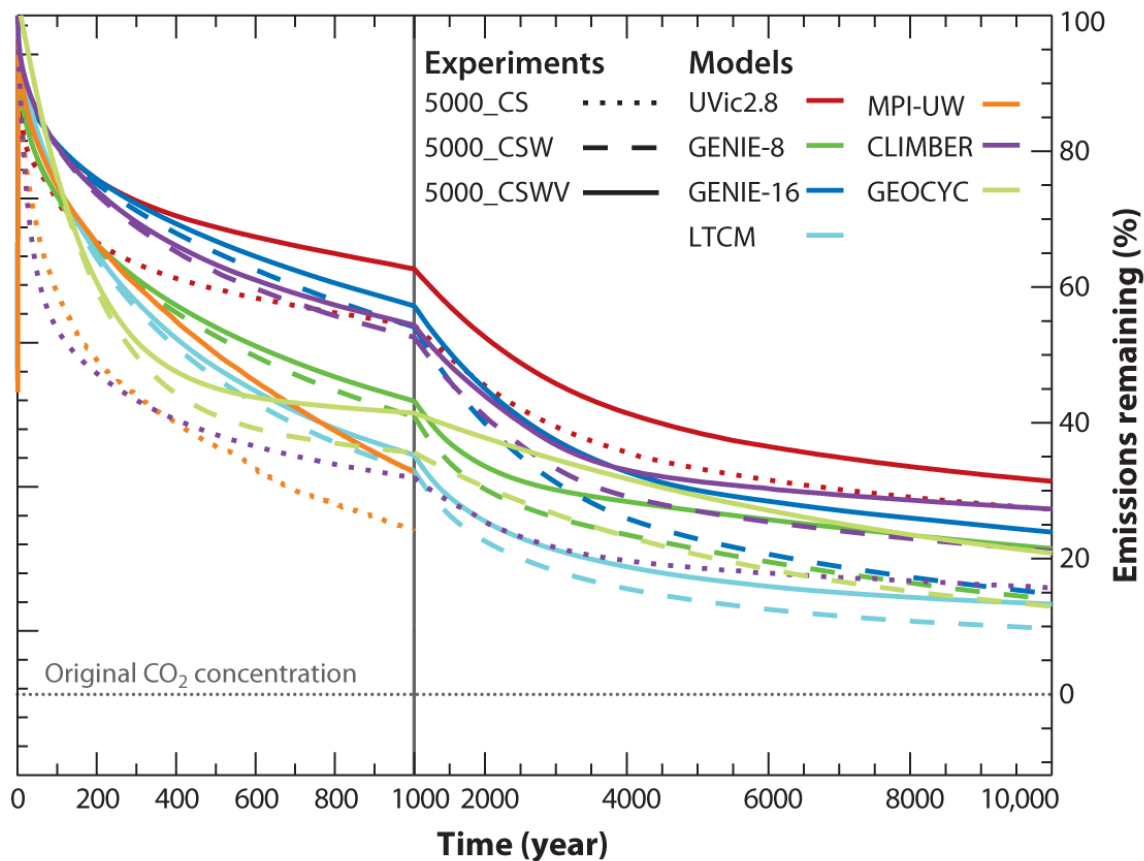
The deep ocean is bigger, but access is slow; CO<sub>2</sub>-laden surface water sinks at only two places near the Poles.

Carbonate sediments and rocks are far bigger and slower still; they form at sea from elements weathered off rocks on land.



# Common Misconception #2

- “When we reduce or stop the burning of fossil fuel, the  $CO_2$  will go away and things will go back to normal”



$CO_2$  from fossil fuel will react with oceans, but only as fast as they “mix”

Eventually, fossil  $CO_2$  will react with rocks

**About 1/3 of today's emissions will stay in the air permanently!**

*Archer et al, Ann. Rev. Earth Plan. Sci. (2009)*

# What Science Knows for Sure

- $\text{CO}_2$  molecules absorb & re-emit thermal radiation (Tyndall, 1863)
- Doubling the number of  $\text{CO}_2$  molecules would add  $4 \text{ W m}^{-2}$  to the surface 24/7 (Arrhenius, 1896)
- If China and India industrialize with coal,  $\text{CO}_2$  will approach 400% preindustrial by 2100
- Additional  $\text{CO}_2$  will continue adding heat to Earth's surface for thousands of years

# What Science Can't Really Know

- When and in precisely what ways the climate will change, especially locally
- The economic, political, and social consequences of these changes
- What to do about all of this!

# The Worst Media Myth of All

- Without the subsidy of cheap fossil energy, civilization will crumble!
- People will freeze in the dark!
- They'll starve!

**"The sky is falling!"**

*Be skeptical ... be very skeptical !*



# Choose Your Future

- Alarmist politicians and celebrities say:
  - "Modern wealth is due to the subsidy of cheap fossil fuel. If we stop burning coal we'll freeze in the dark!"
- I prefer:
  - "Modern wealth results from ingenuity and hard work. Before we run out of oil, we'll invent energy technologies for the 21<sup>st</sup> Century.
  - **Our future is bright."**