NSTA WEB SEMINARS

LIVE INTERACTIVE LEARNING @ YOUR DESKTOP

Heating and Warming: Sensitivity of Earth's Climate to Atmospheric CO_2

Presented by: Scott Denning and Randy Russell

September 24, 2012

6:30 p.m. – 8:00 p.m. Eastern time

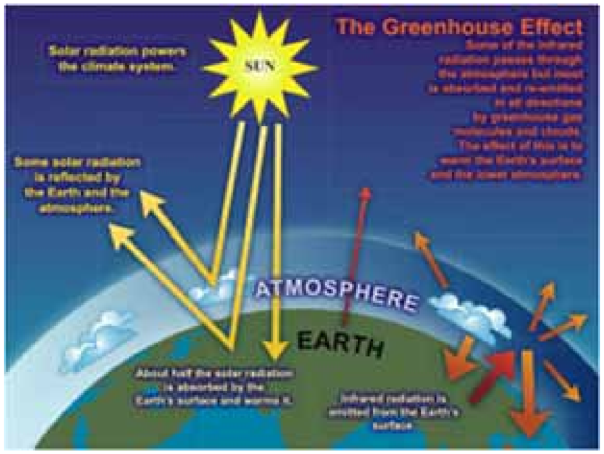
Introducing today's presenters…

Scott Denning

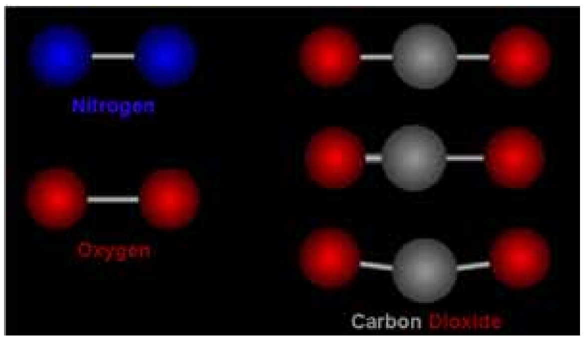
- Colorado State University
- Center for Multiscale Modeling of Atmospheric Processes

Randy Russell

- Spark, National Center for Atmospheric Research



Heating and Warming: Sensitivity of Earth's Climate to Atmospheric CO_2



Randy Russell

Scott Denning

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

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Understanding and Prediction: Modeling the Earth System

This is the second 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
- Challenges for Our Children: Projections of the future of Earth's climate and carbon cycle
- Opportunities for Abundance: Solving the problems of energy, carbon, and climate

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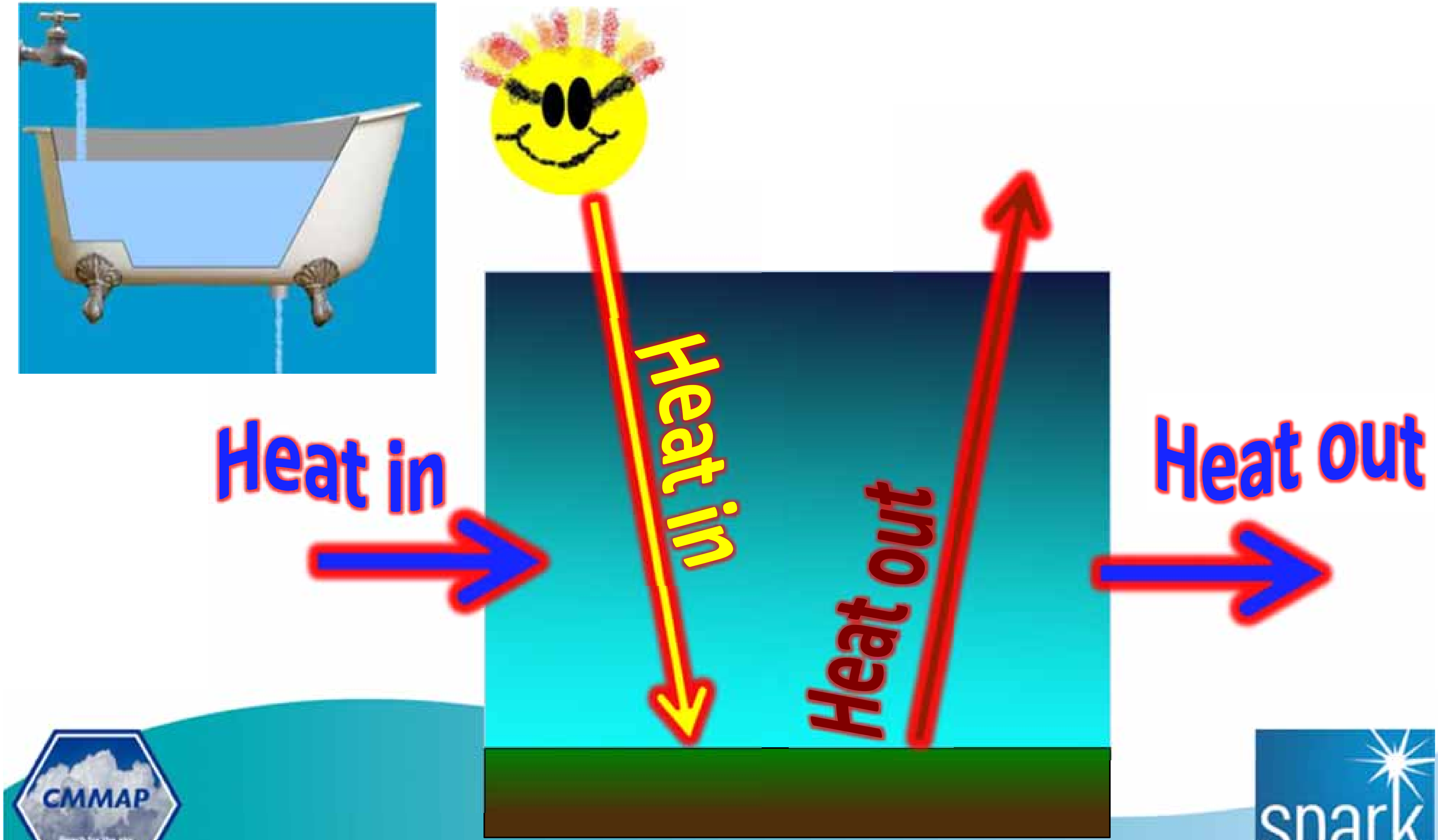
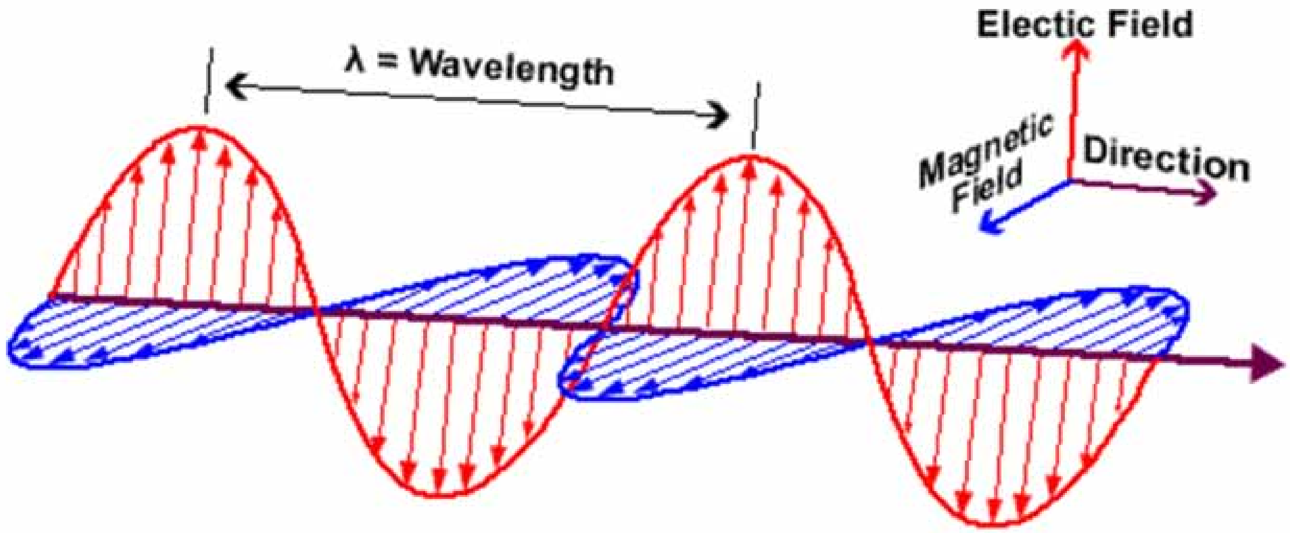
Ever Wonder Why?

- Day is warmer than night
- Summer is warmer than winter
- Miami is warmer than Minneapolis

Heat Budgets



Electromagnetic Radiation



Travels through space at 186,000 miles / sec!

Distance in one cycle is called the wavelength

- Changing electric fields create changing magnetic fields … and vice versa!
- This makes energy move across space
- We can see it & feel it … it warms and cools the Earth

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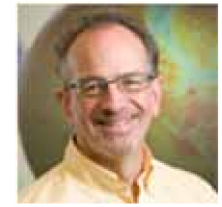
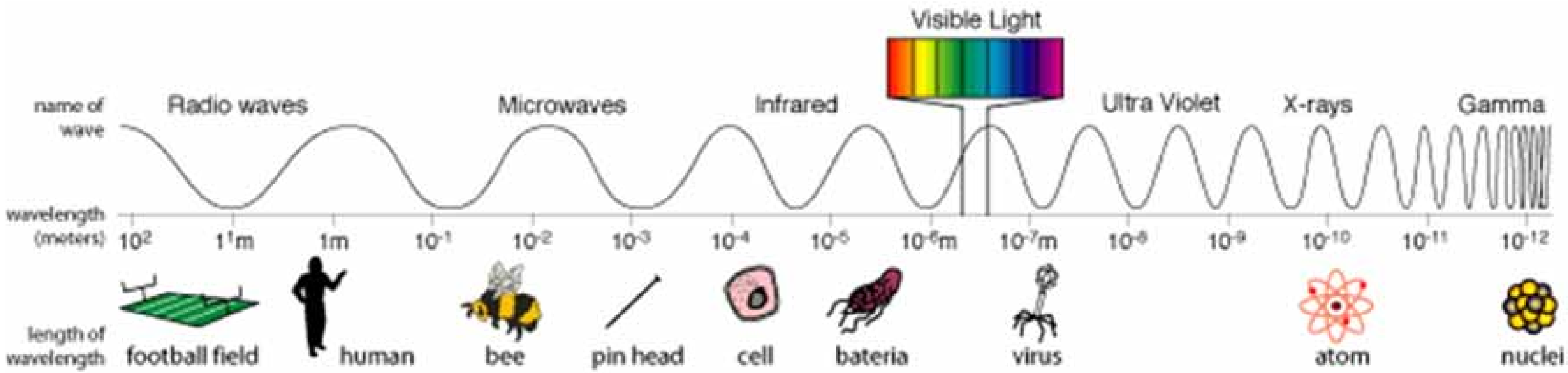
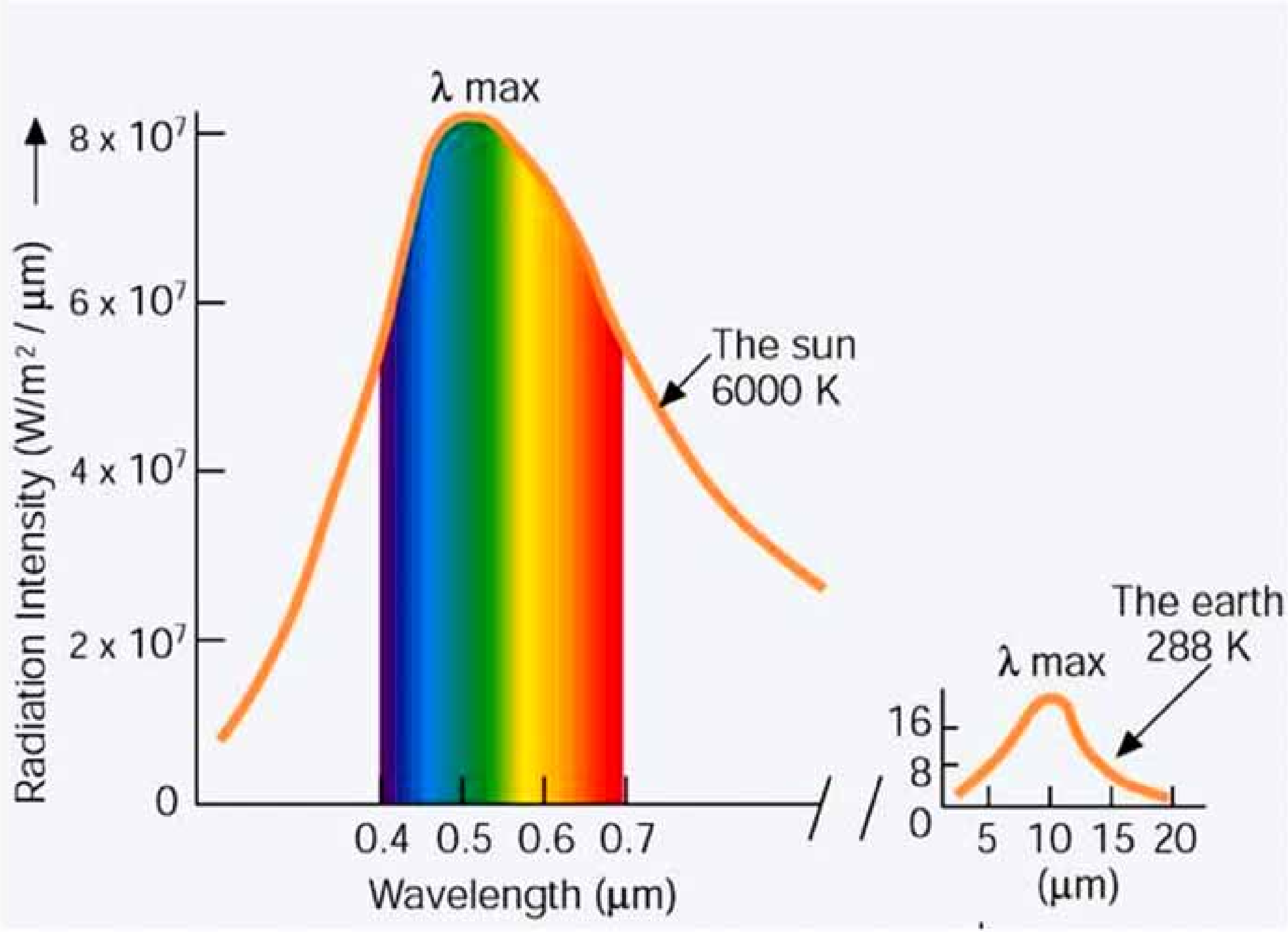
Electromagnetic Spectrum





- Shorter waves carry more energy than longer waves
- Radiation interacts with matter at similar scales (sizes) as the waves

Emission Spectra of the Sun & Earth

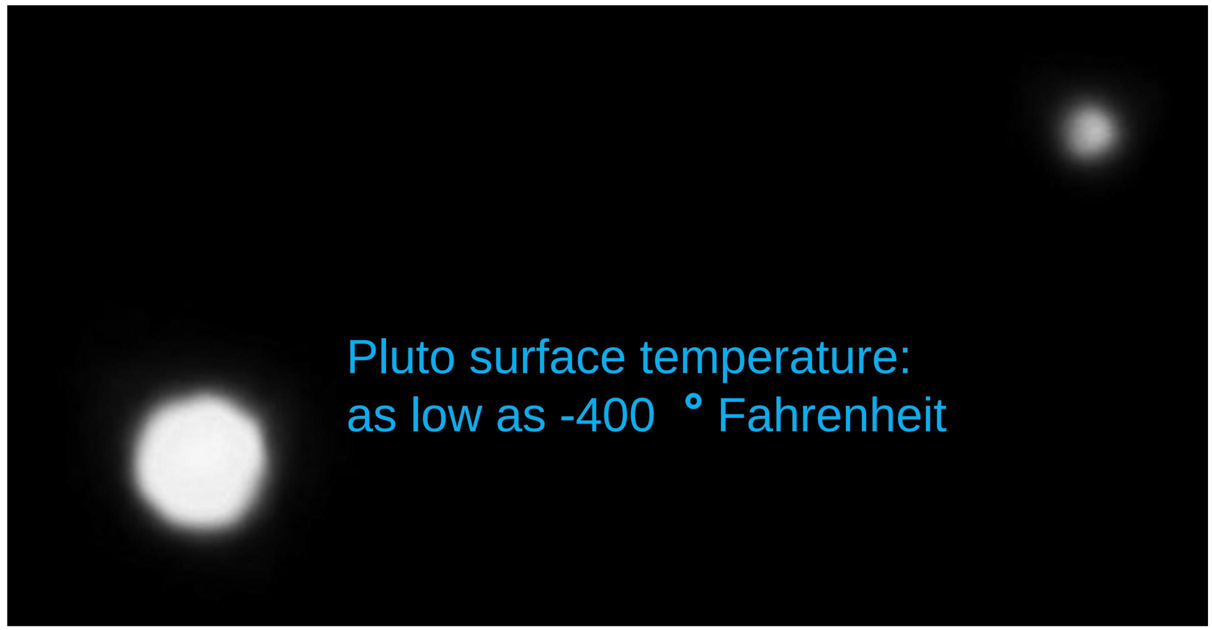


- The hot sun radiates at shorter (visible) wavelengths that carry more energy
- The cooler Earth radiates absorbed solar energy at longer (thermal) wavelengths

Poll: Which gives off longer wavelength infrared radiation:

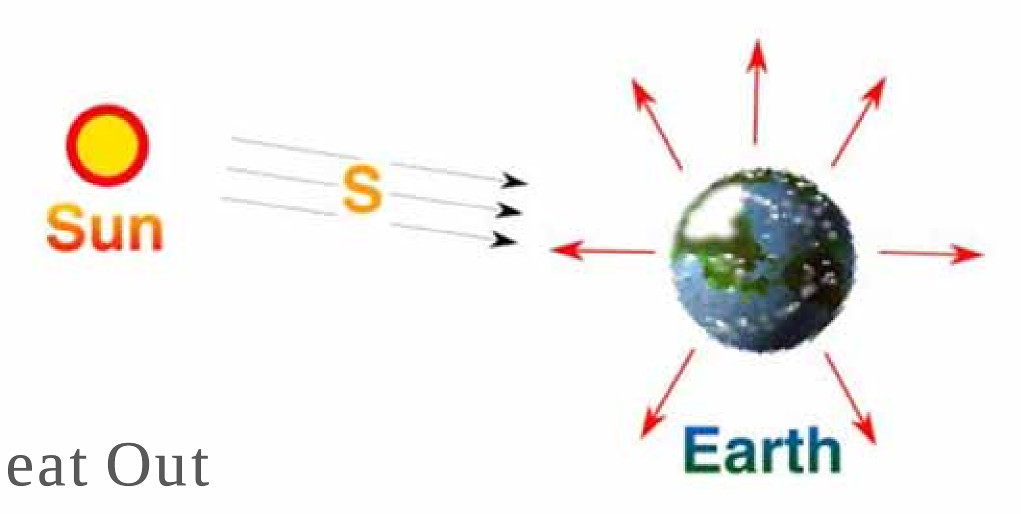
A) hot Mercury or

B) cold Pluto?



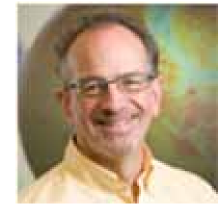
Mercury surface temperature:
up to 800 ° Fahrenheit

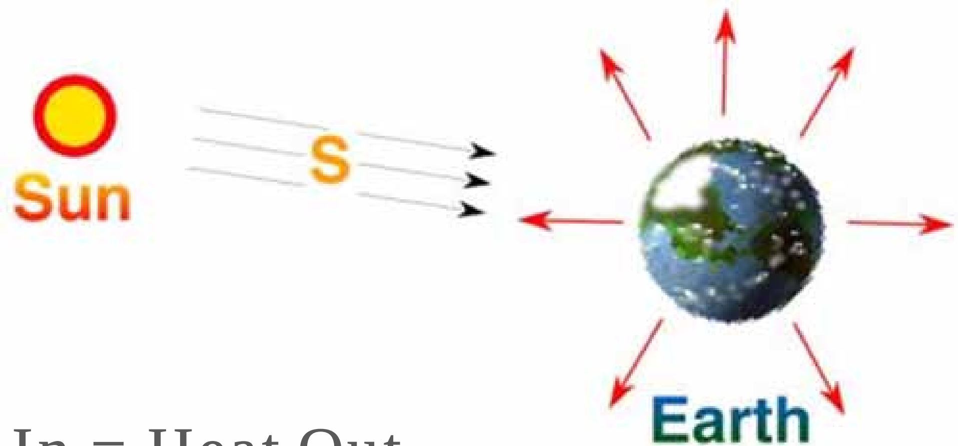
Planetary Heat Balance



- Heat In = Heat Out
- Absorbed solar energy in = emitted thermal energy out

Planetary Heat Balance

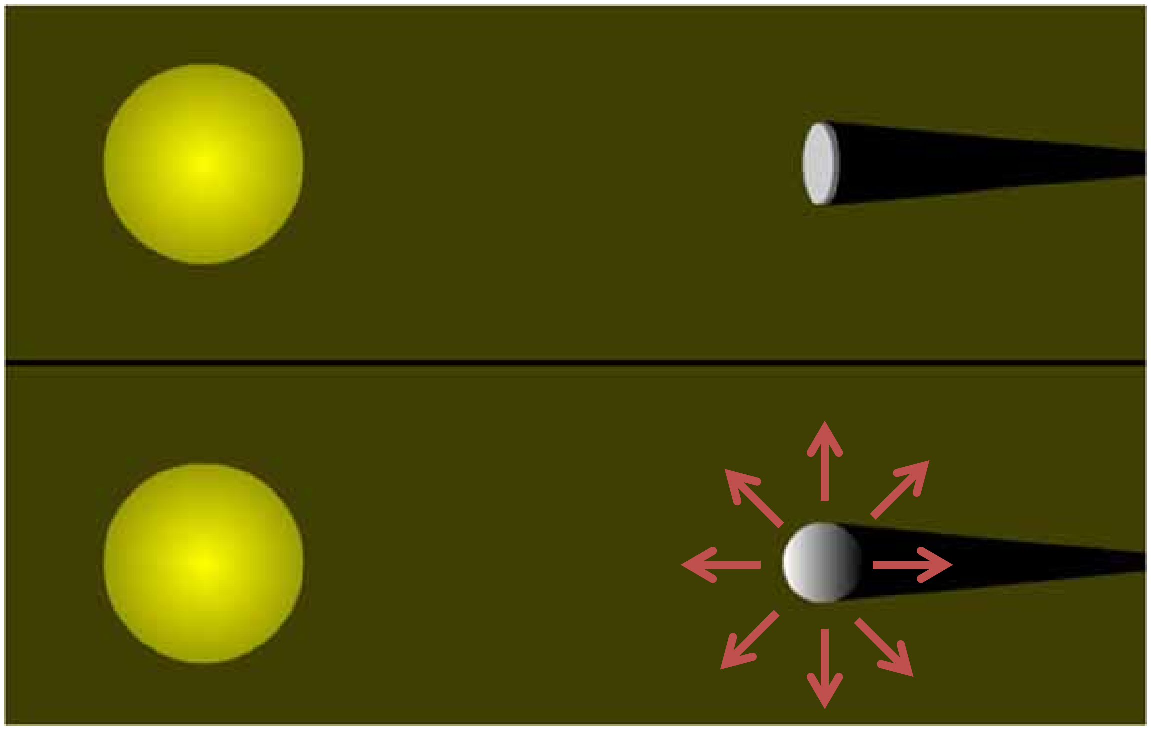




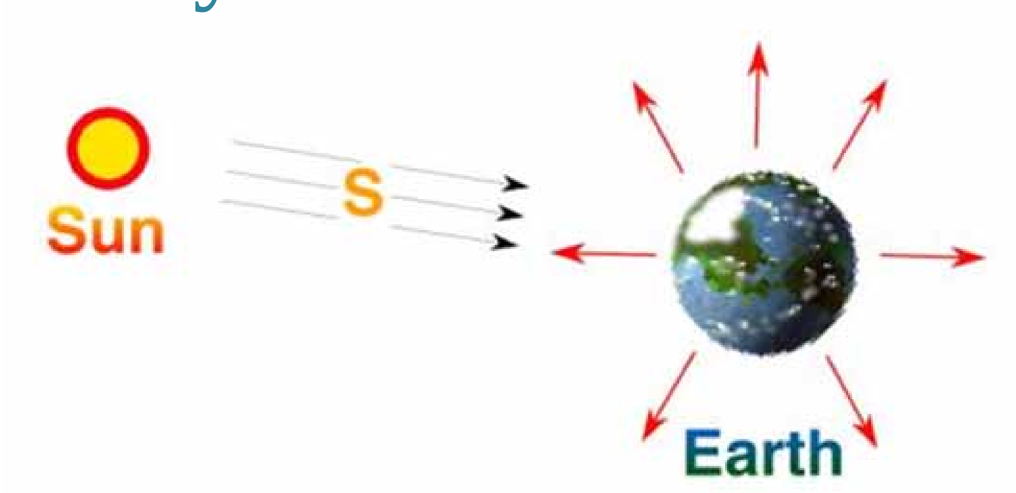
- Heat In = Heat Out
- Absorbed solar energy in = emitted thermal energy out
- HEAT IN: S * (1-albedo) * area of Earth's ***shadow***
  = HEAT OUT: Thermal emission * area of Earth's ***surface***
- area of Earth's ***surface*** = $4\pi R^2$

Energy In vs. Energy Out

- We can think of Earth as a circle when calculating sunlight absorbed
- We must treat Earth as a sphere when calculating energy emitted



Planetary Heat Balance



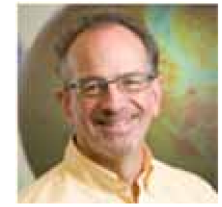
- HEAT IN: S * (1-albedo) * area of Earth's ***shadow***

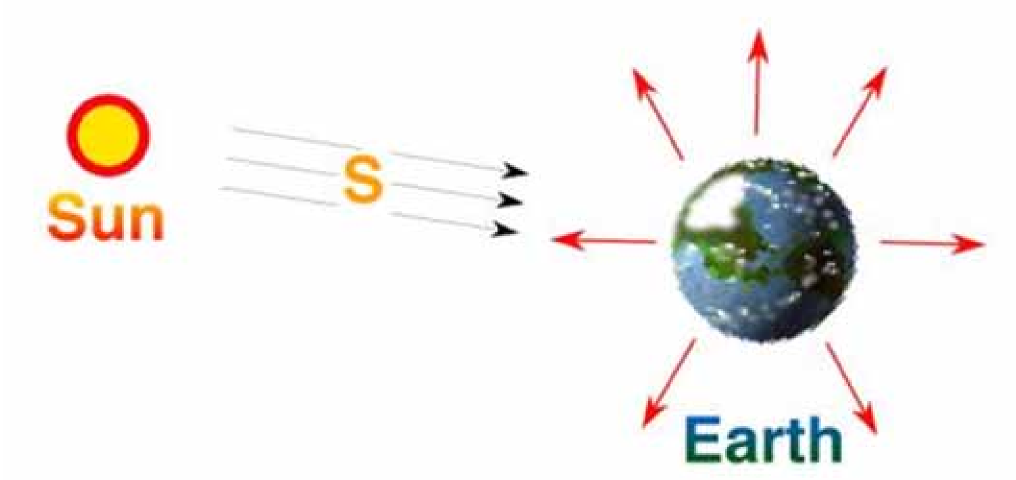
  Earth's albedo (reflected fraction) = 30%

  area of Earth's ***shadow*** **=** πR^2

- HEAT IN: $$S(1-\alpha)\pi R^2$$

Planetary Heat Balance





- HEAT OUT: Thermal emission * area of Earth's ***surface***

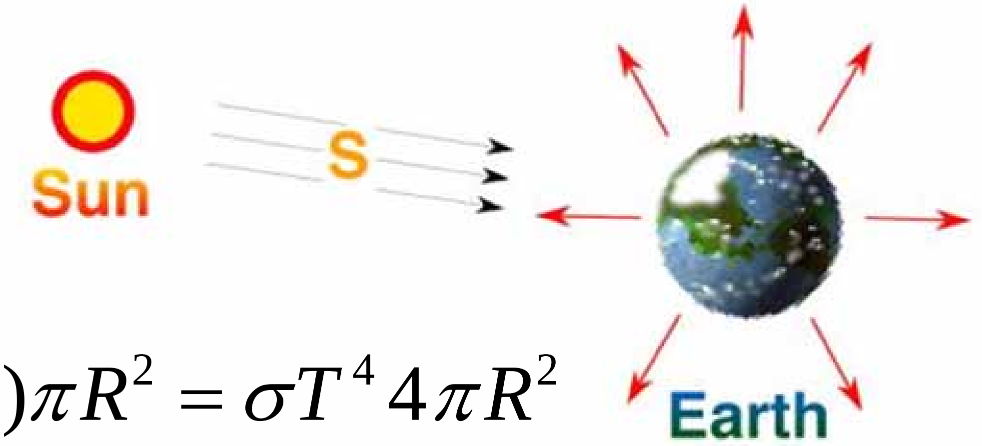
  Thermal emission is ***very sensitive to temperature***

  Thermal emission is ***proportional to*** $\boldsymbol{T^4}$ = T x T x T x T

  area of Earth's ***surface*** = $4\pi R^2$

- HEAT OUT: $\sigma T^4 4\pi R^2$

Planetary Heat Balance



$$S(1-\alpha)\pi R^2 = \sigma T^4 4\pi R^2$$

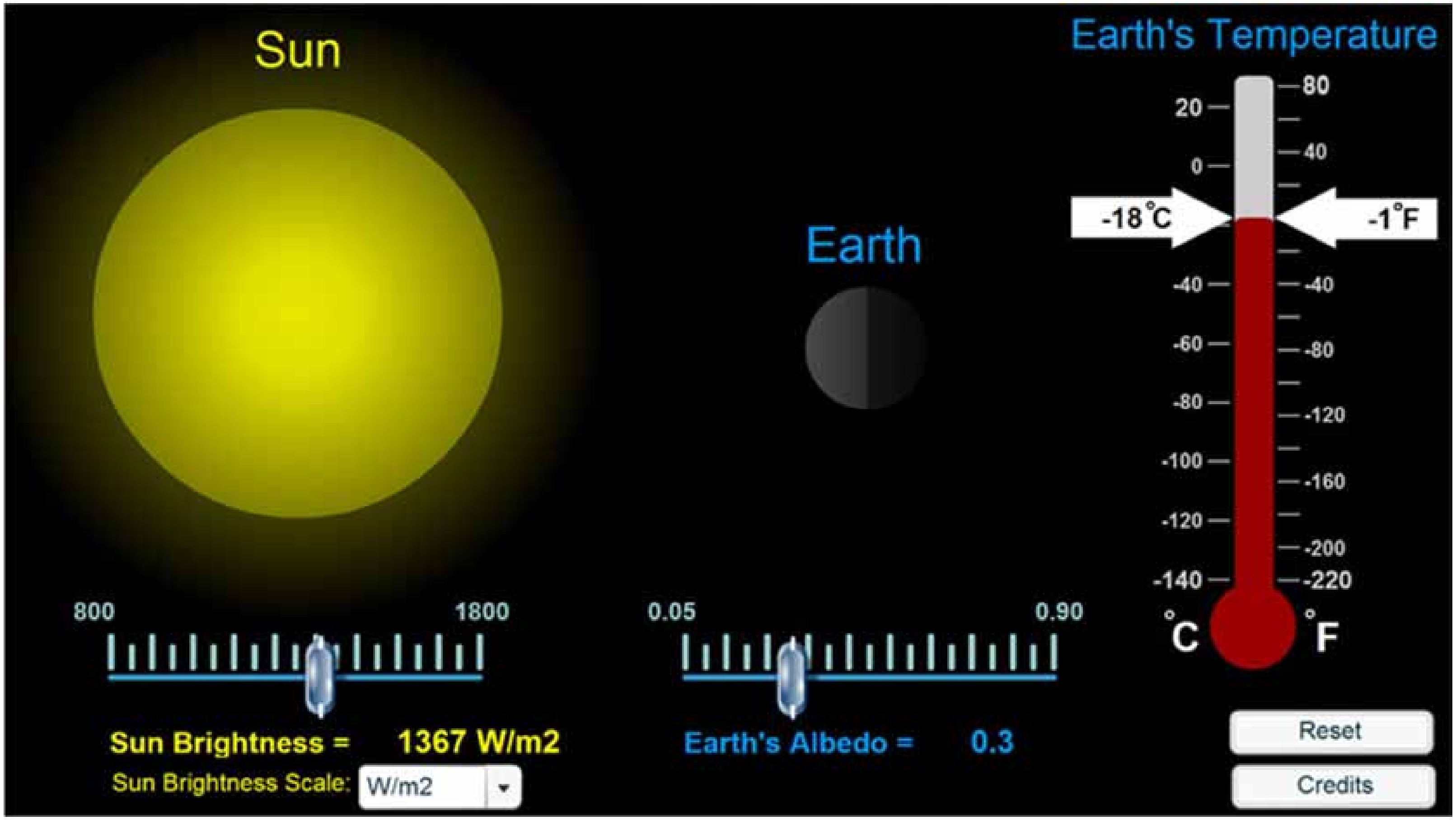
$$S(1-\alpha) = \sigma T^4 4$$

$$T = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{1/4}$$

T	=	255	° Kelvin
	=	-18	° Celsius
	=	0	° Fahrenheit

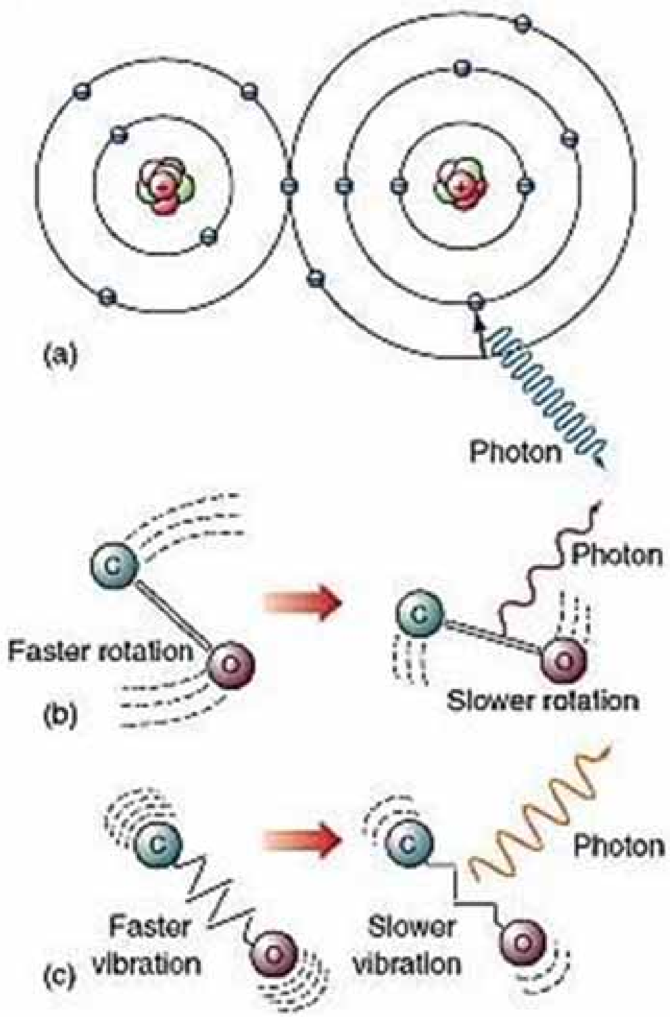
Brrrrrr!

Interactive: Earth's Energy Balance



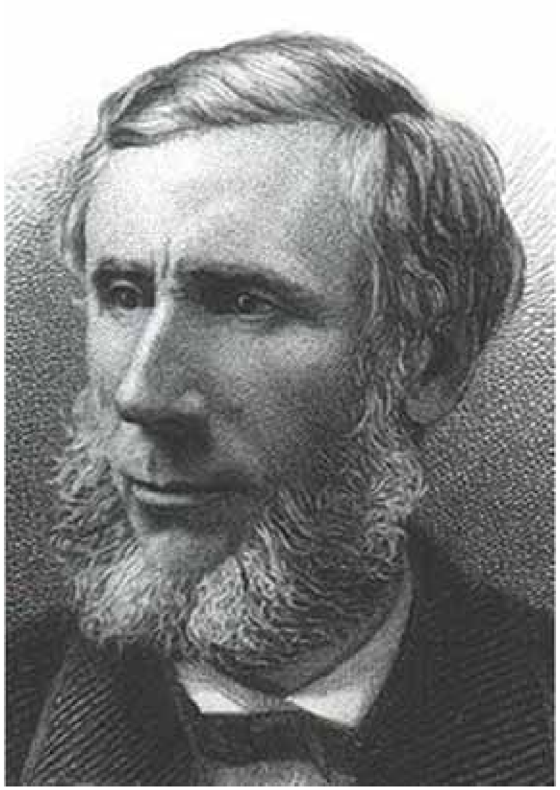
Questions?

Atoms, Molecules, and Photons



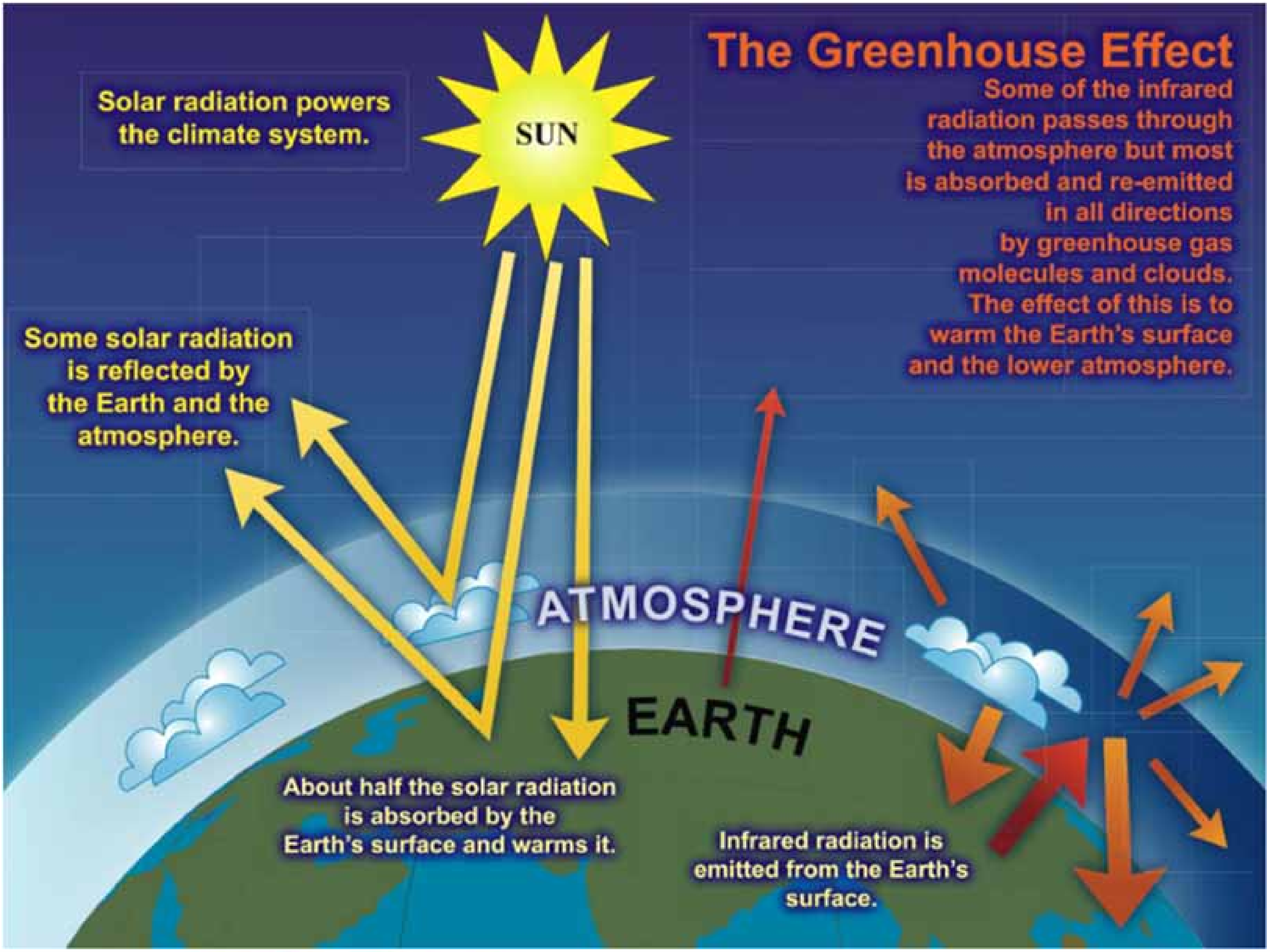
- Atmospheric gases are made of molecules
- Molecules are groups of atoms that share electrons (bonds)
- Photons can interact with molecules
- Transitions between one state and another involve specific amounts of energy

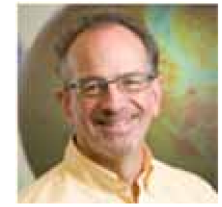
Absorption and Emission of Heat by CO_2 Gas in the Laboratory



John Tyndall, January 1863

- Absorption and emission of thermal radiation by CO_2 gas was first measured in 1863
- Since that time, the measurements have been made thousands of times, with better and better instruments
- Results show that **doubling CO_2 in the atmosphere would add 4 Watts of heat to every square meter of Earth**


The Greenhouse Effect
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation powers the climate system.
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
ATMOSPHERE
EARTH
About half the solar radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.



Transparency and Opacity: Infrared vs. Visible Light

Transparency and Opacity: Infrared vs. Visible Light

Transparency and Opacity: Infrared vs. Visible Light

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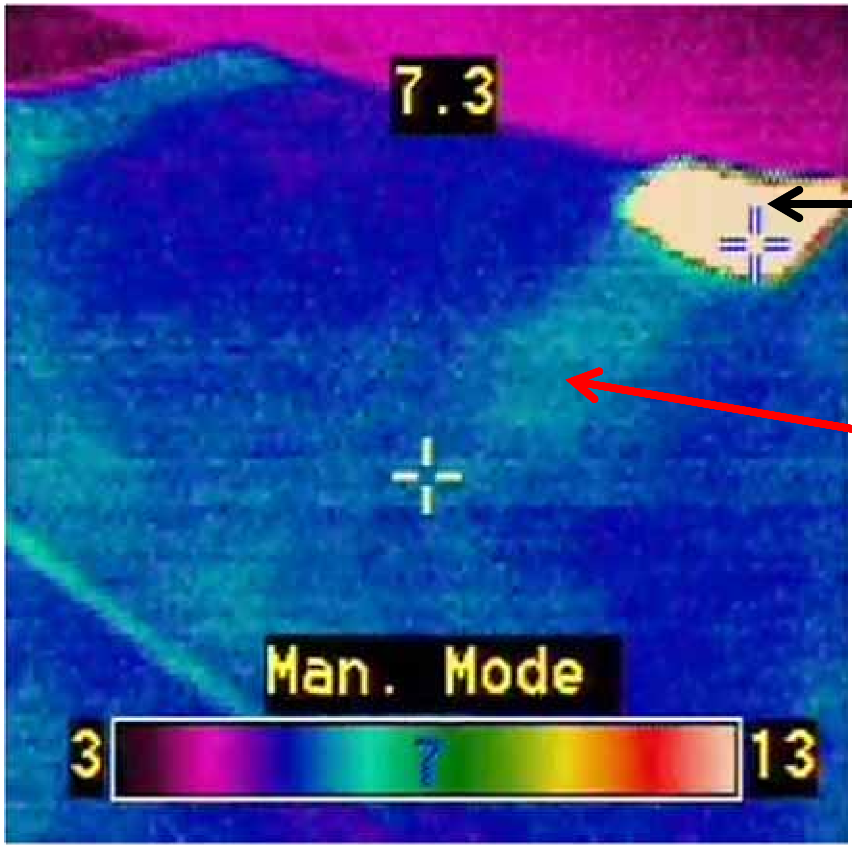
Hot (Dry) Air is
NOT Visible in the Infrared

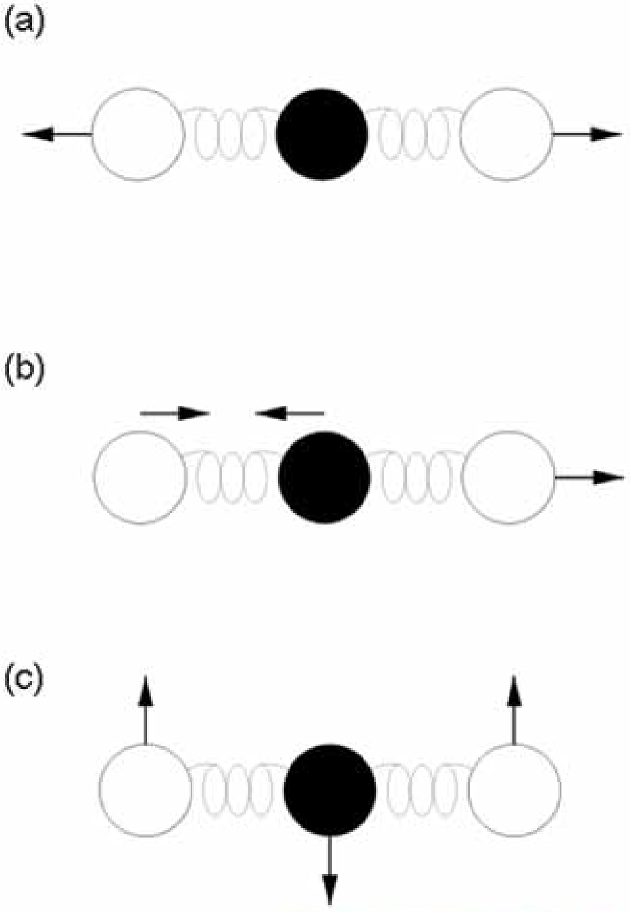
Hot Car Exhaust (with lots of CO_2) IS Visible in the Infrared

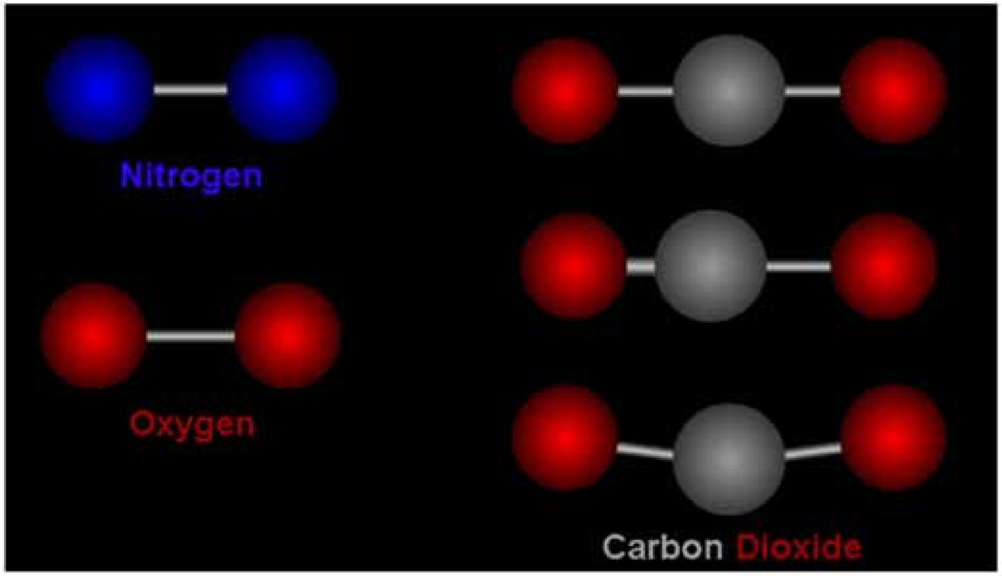


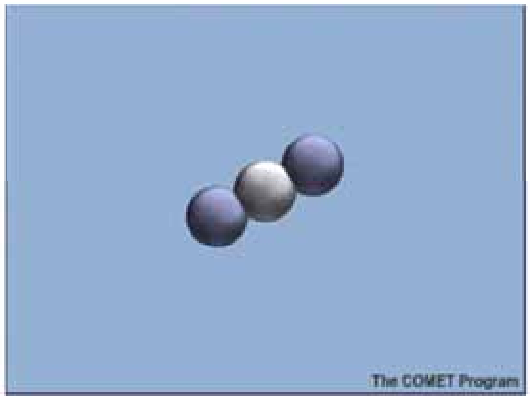
VERY hot tailpipe

Hot exhaust with lots of CO_2

Molecular Vibration Modes and the Greenhouse Effect

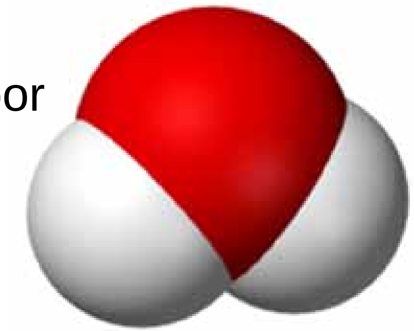


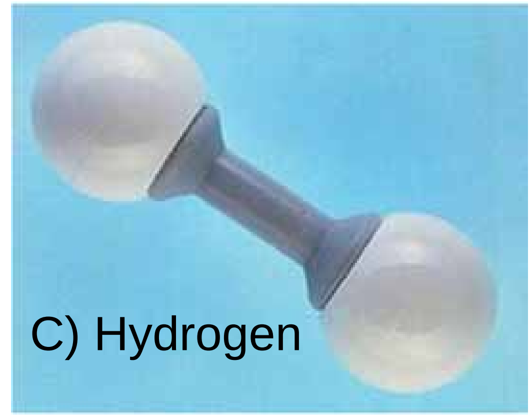




Poll: Which is NOT a GHG molecule?

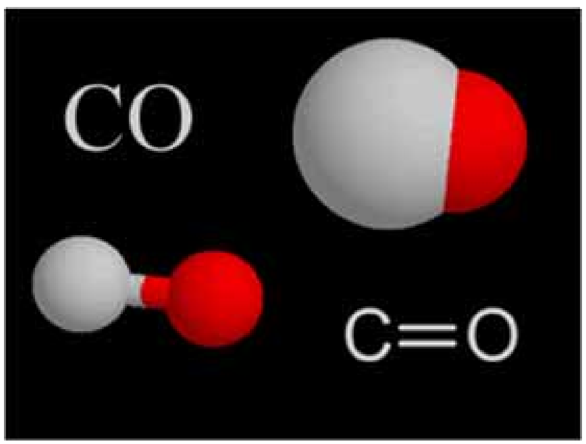
A) Water vapor

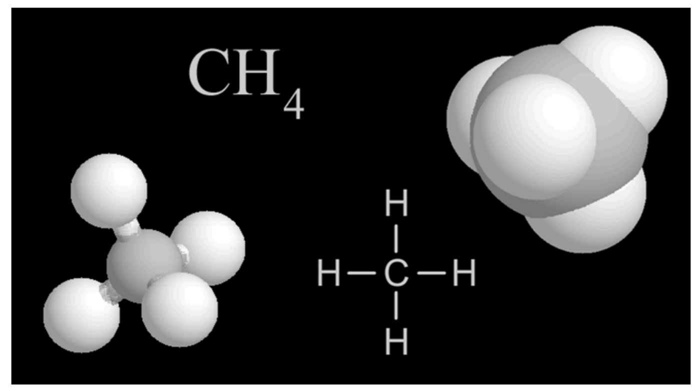




C) Hydrogen

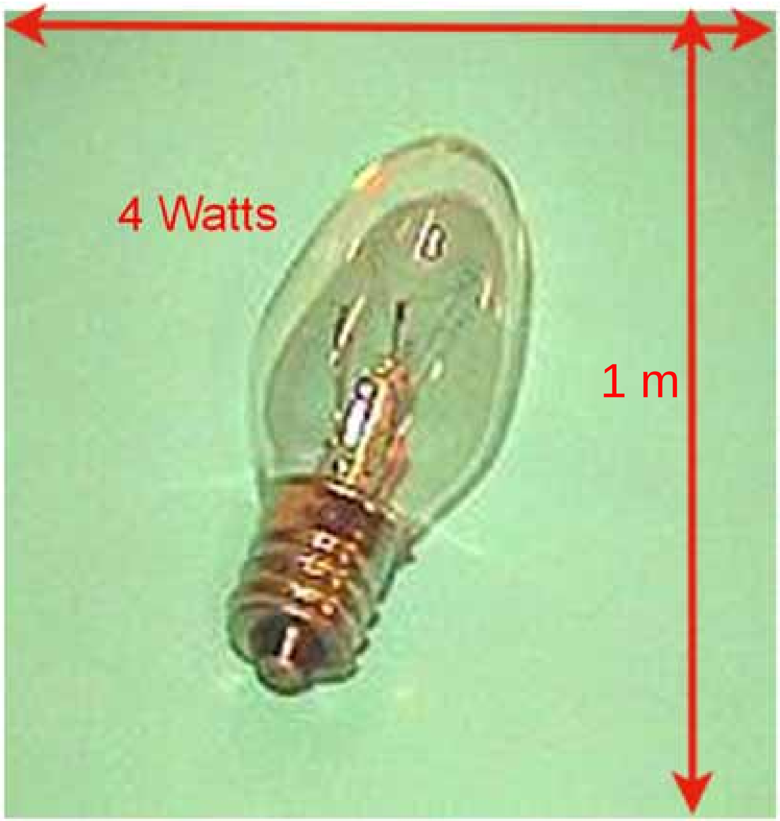
B) Carbon monoxide





D) Methane

Heat and CO_2 in Earth's Climate



- Doubling CO_2 in the atmosphere would add 4 Watts of heat to every square meter of Earth
- The extra heat would be applied 24 hours a day, 365 days a year
- That would make the Earth's surface warmer
- This has been known since 1863

Climate Forcing, Response, and Sensitivity

Forcing
(change in sunshine)

Response:
(Change in Surface Temperature)

"Let 's do the math …"

$$S_0(1-\alpha)\pi r^2 = 4\pi r^2 \sigma T^4$$

$$T = \left[\frac{S_0(1-\alpha)}{4\sigma}\right]^{1/4}$$

Climate Forcing, Response, and Sensitivity

Forcing
(change in sunshine)

Response:
(Change in Surface Temperature)

- Doubling CO_2 adds 4 W m^{-2} to the Earth's surface
- If everything else stayed the same, adding 4 W m^{-2} would warm the surface by about 1 °C (1.8 °F)

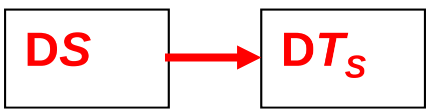
Climate Forcing, Response, and Sensitivity

Forcing (change in sunshine)

Response: (Change in Surface Temperature)

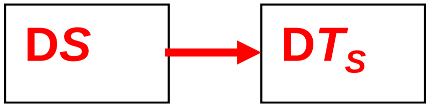
- Doubling CO_2 adds 4 W m^{-2} to the Earth's surface
- If everything else stayed the same, adding 4 W m^{-2} would warm the surface by about 1 °C (1.8 °F)
- **BUT everything else wouldn't stay the same!**

Climate Feedback Processes

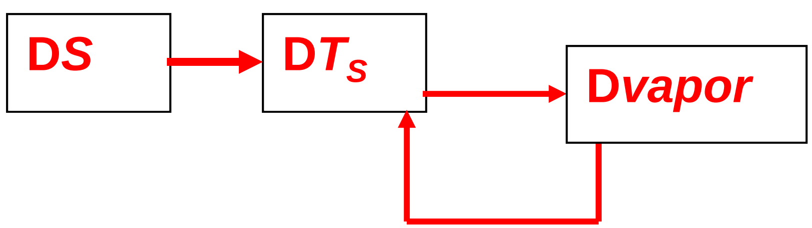


Climate Feedback Processes

- **Positive feedbacks amplify the changes**
- We know there are positive feedbacks because tiny changes in heat in and out have produced Ice Ages and other climate changes in the past!
- How do they work?

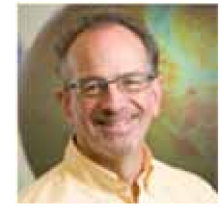


Climate Feedback Processes

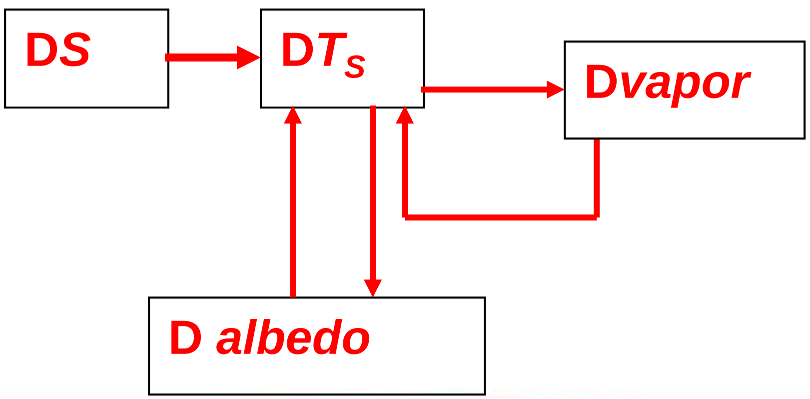


- **Positive feedbacks amplify the changes**
- More water evaporates from a warmer surface
- Water vapor is a strong greenhouse gas
- **Extra water vapor warms the surface even more**

Climate Feedback Processes



- **Positive feedbacks amplify the changes**
- Warmer surface has less ice and snow (darker)
- A darker surface absorbs more incoming sunshine
- **Darker surface warms**

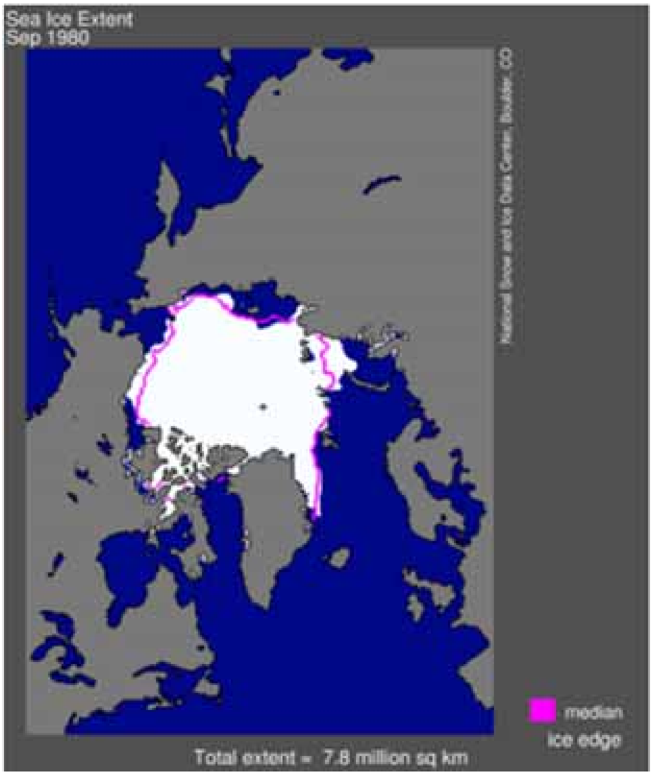


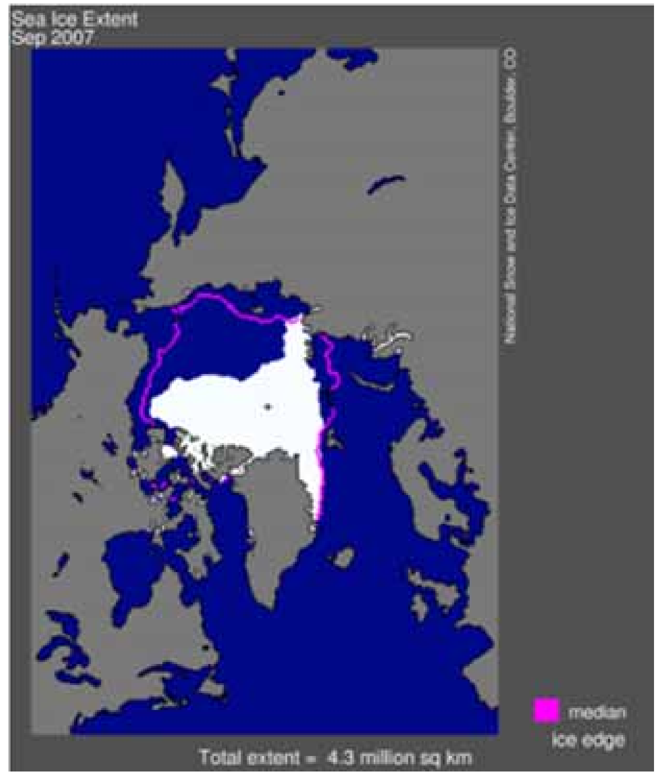
Ice Albedo Feedback

Satellite (LANDSAT) images of the coast of Greenland in August 1985 (left) and September 2002 (right) show how ice reflects much more sunlight than water. Melting ice causes more absorption of energy from sunlight, leading to further warming.

Sea Ice Decline in the Arctic

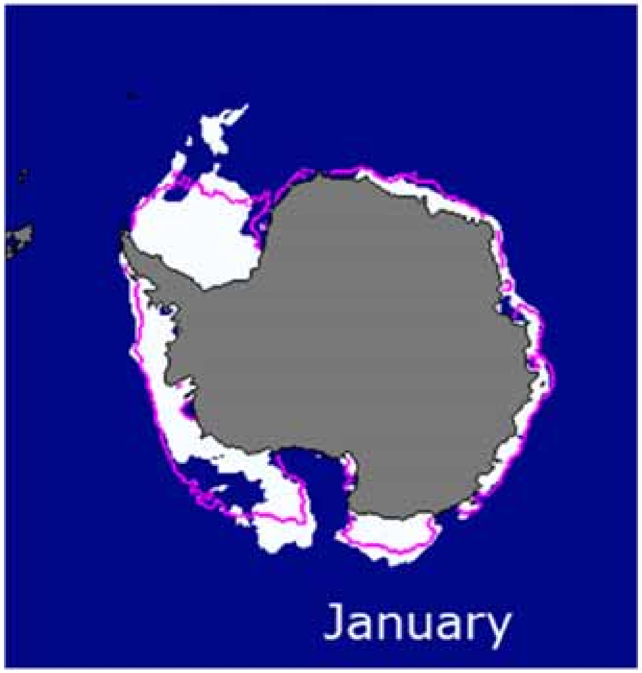
The amount of sea ice in the Arctic has been declining dramatically in recent decades, as seen here in 1980 (left) and 2007 (right).



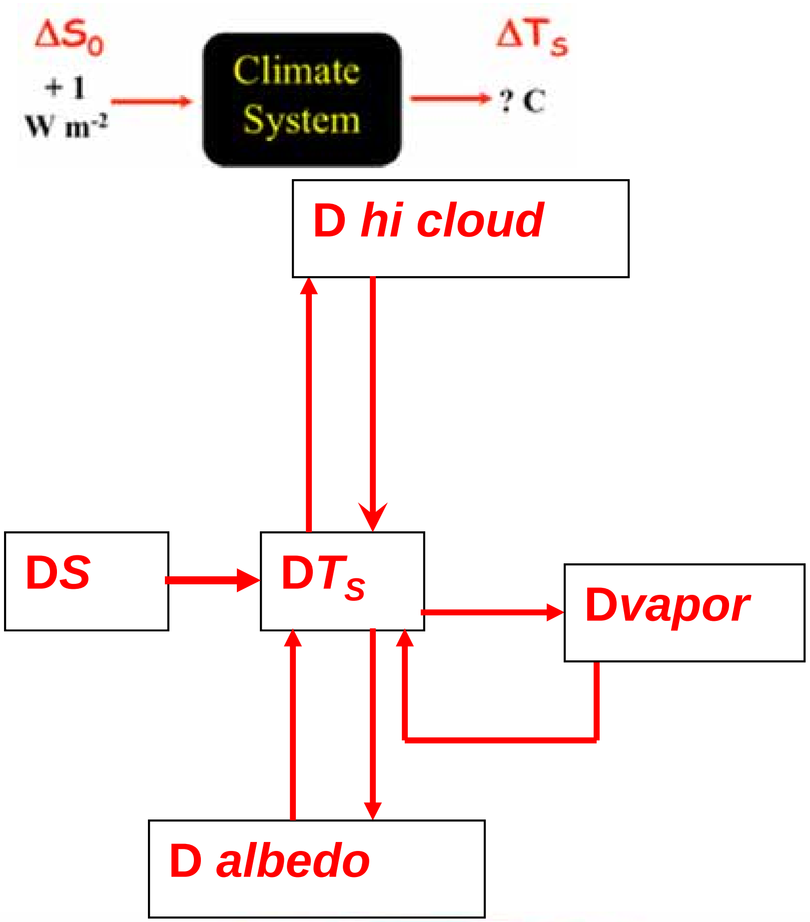


Graphing Sea Ice Extent Activity

… and animations and interactive viewer.

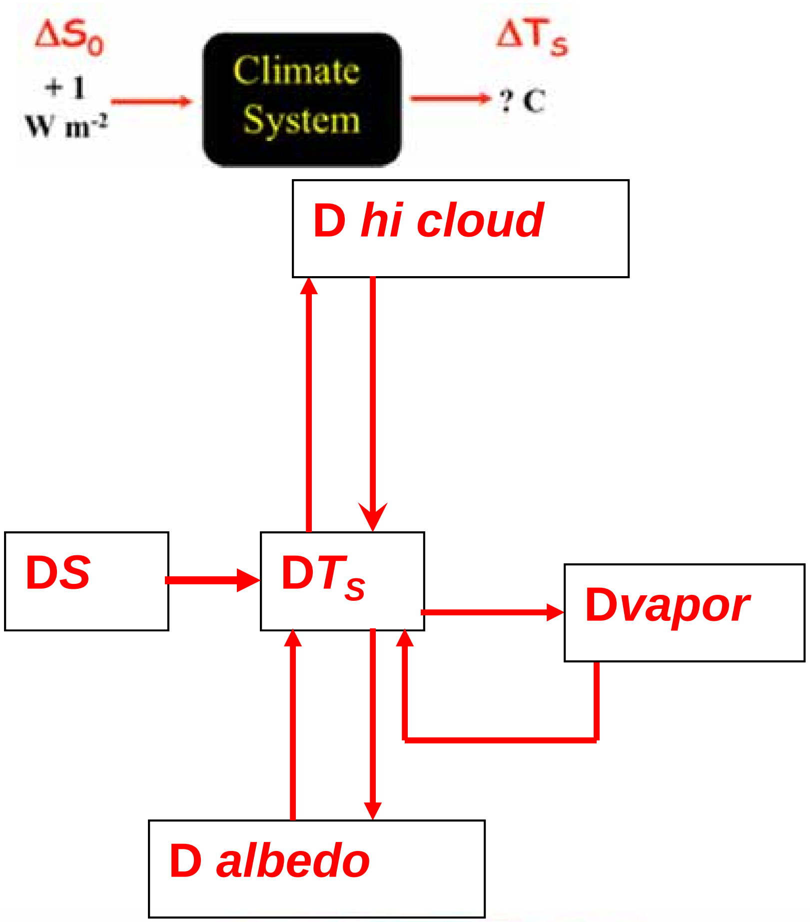


Climate Feedback Processes



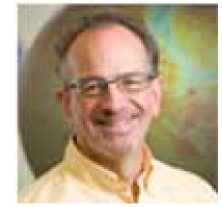
- **Positive feedbacks amplify the changes**
- Some of the extra water vapor turns into high clouds
- High clouds block some outgoing thermal radiation
- **High clouds warm the surface even more**

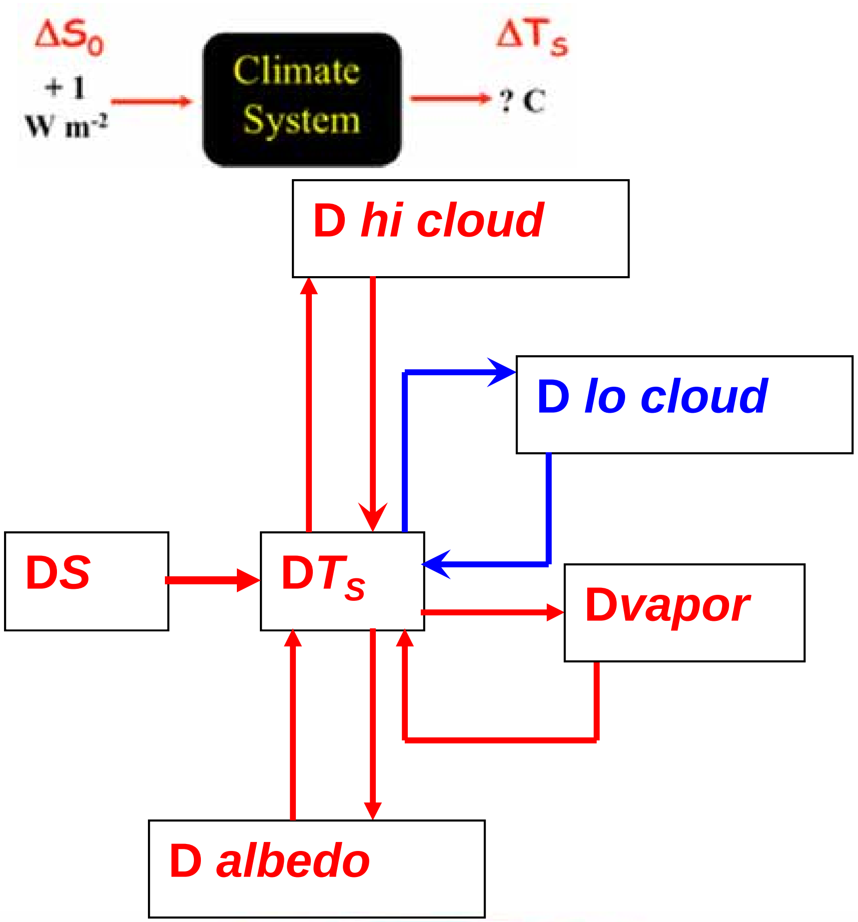
Climate Feedback Processes



- **Negative feedbacks reduce the changes**
- We know there are negative feedbacks because the climate has not "run away"
- Liquid water has always existed throughout geologic time
- How do they work?

Climate Feedback Processes



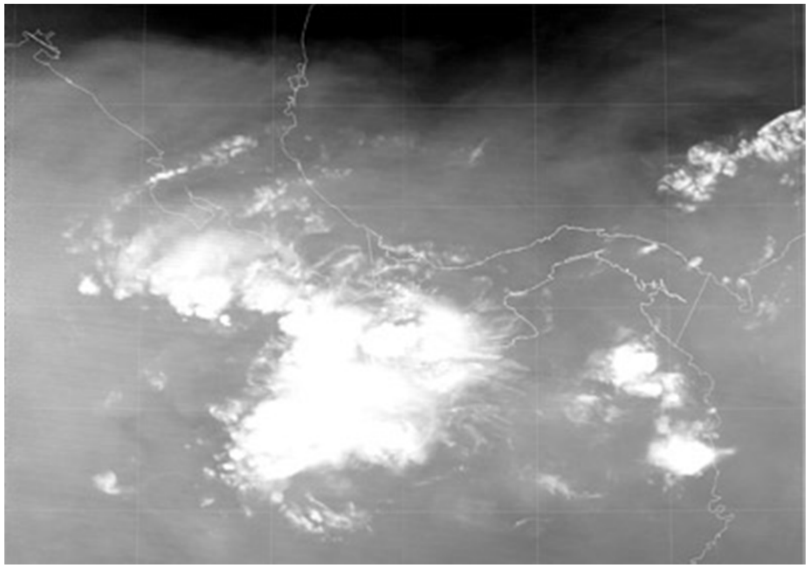


- **Negative feedbacks reduce the changes**
- Some extra water vapor turns into extra low clouds
- Low clouds block sunlight, but don't block as much outgoing thermal energy
- **Extra low clouds cool the surface**

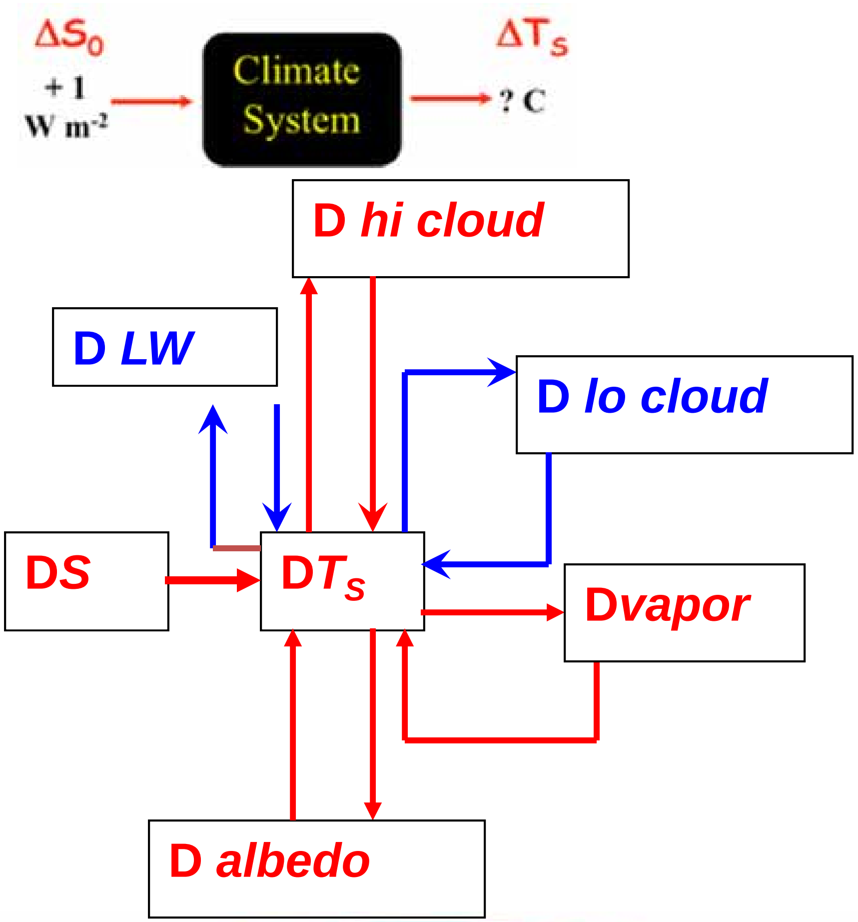
High vs. Low Clouds
Different Effect on Climate

Satellite Views of Clouds in Visible Light and Infrared

Satellite views of clouds over Panama in April 2000 show how low and high clouds have different impacts on climate. Image on left is visible light; only shows low clouds. Infrared image on right also shows high cirrus clouds.

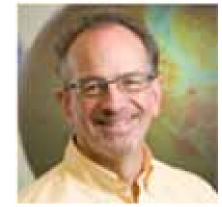


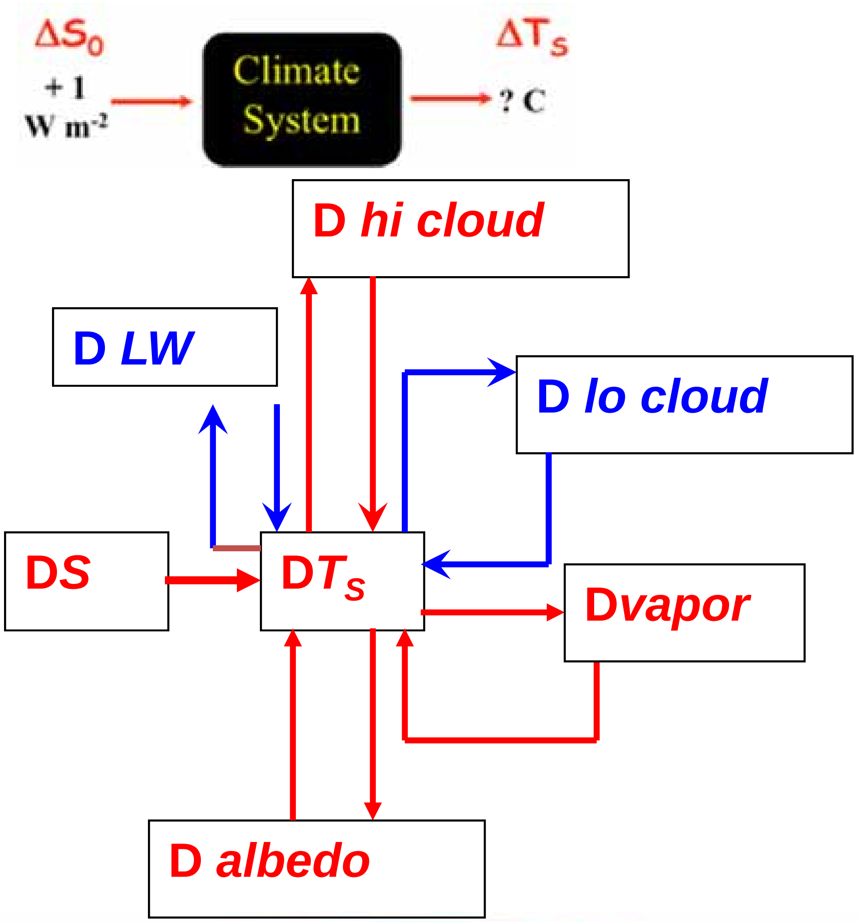
Climate Feedback Processes



- **Negative feedbacks reduce the changes**
- Warmer surface emits more thermal radiation
- **Extra thermal emission cools the surface**

Climate Feedback Processes



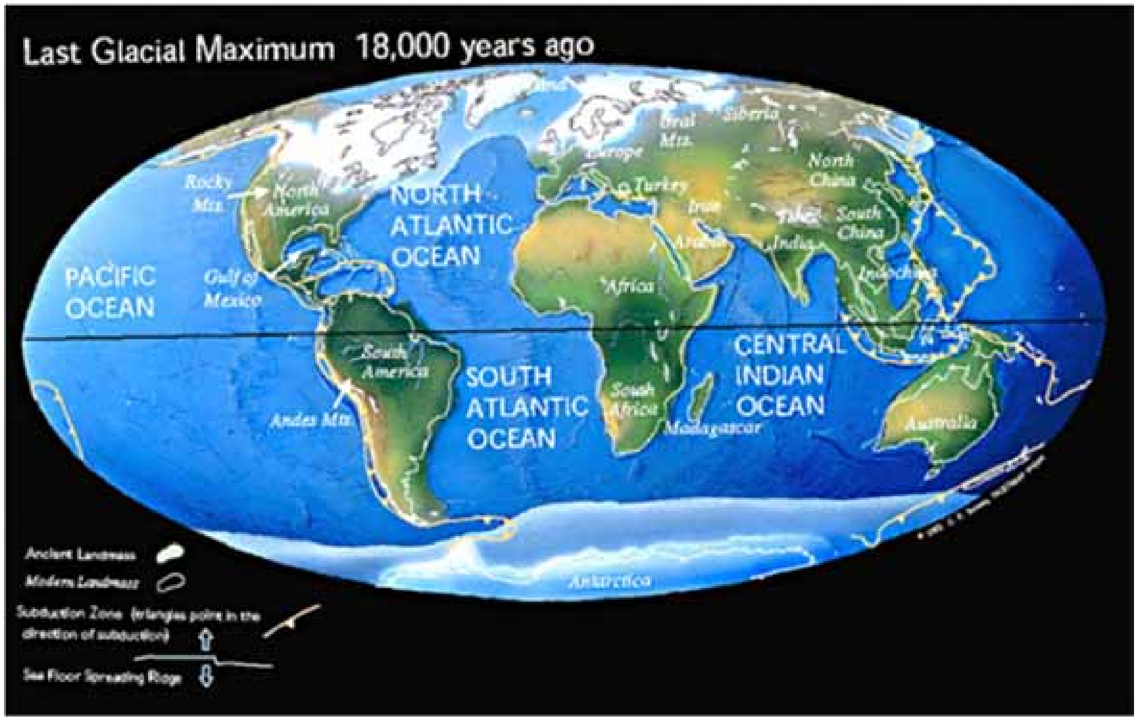


- Positive Feedbacks (amplify changes)
  - Water vapor
  - Ice-albedo
  - High clouds
- Negative Feedbacks (reduce changes)
  - Low clouds
  - Extra emission



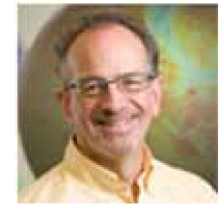
Questions?

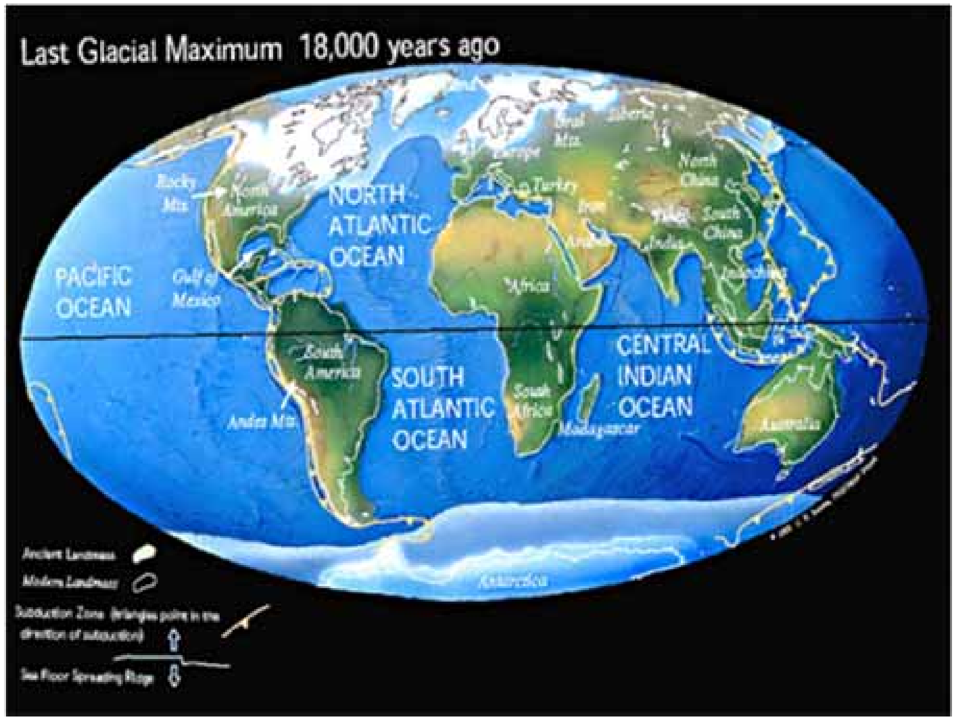
Learning from the Past



- **Bright surface reflected 3.4 W m^{-2} extra sunlight**
- **Lower Ice Age CO_2 allowed 3.7 W m^{-2} extra thermal emission to space**

Learning from the Past





- Ice Age surface heat balance was about (3.4 + 3.7) = 7.1 W m^{-2} less
- Ice Age surface temperature was about 5 °C colder (about 9 °F)
- **After Ice Age, extra 7.1 W m^{-2} heat warmed surface by 5 °C**

Total Climate Sensitivity about 0.7 °C per W m^{-2}

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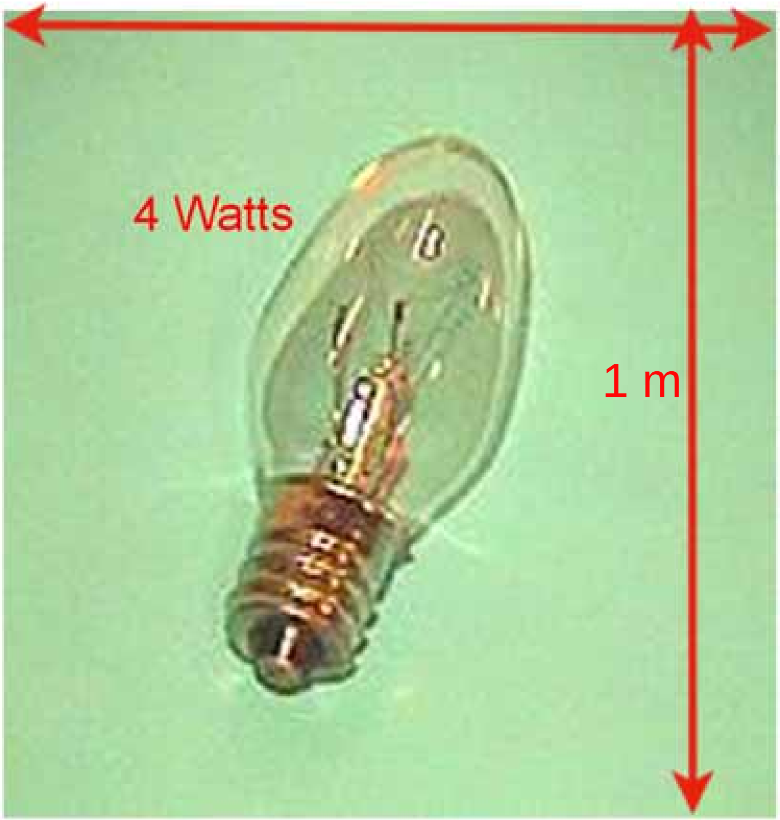
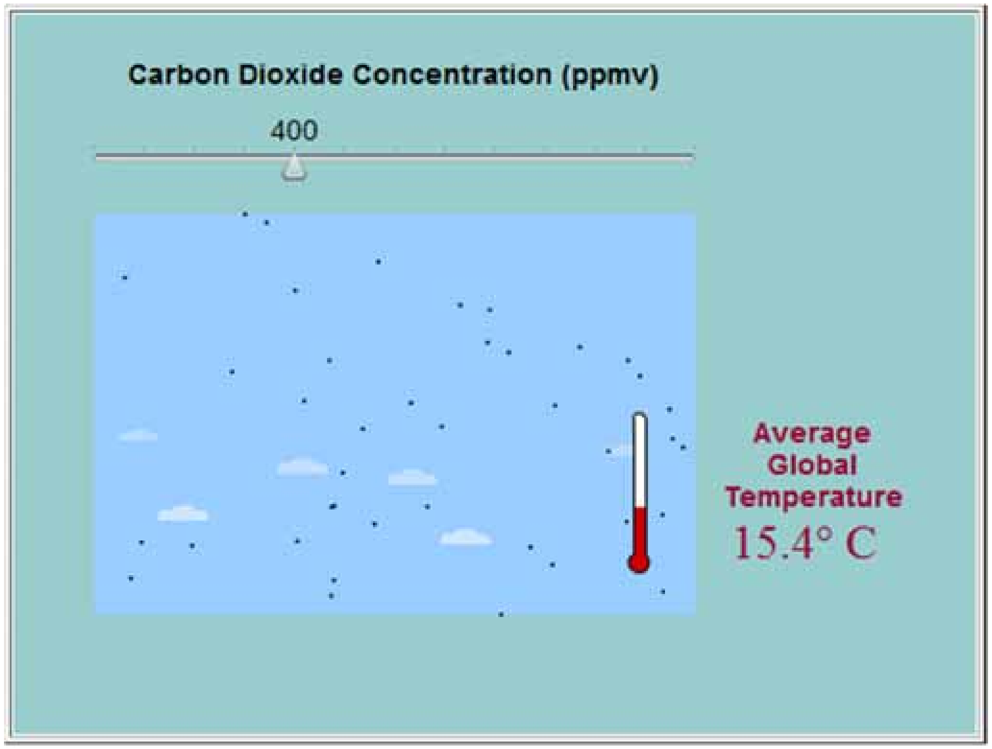
Climate Sensitivity to CO_2



- Doubling CO_2 in the atmosphere would add 4 Watts of heat to every square meter of Earth
- Climate sensitivity with all positive and negative feedbacks = 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})

Climate Sensitivity about 3 °C per doubling of CO_2

Climate Sensitivity Calculator



Questions?

Thanks to today's presenters!

Scott Denning

Randy Russell

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