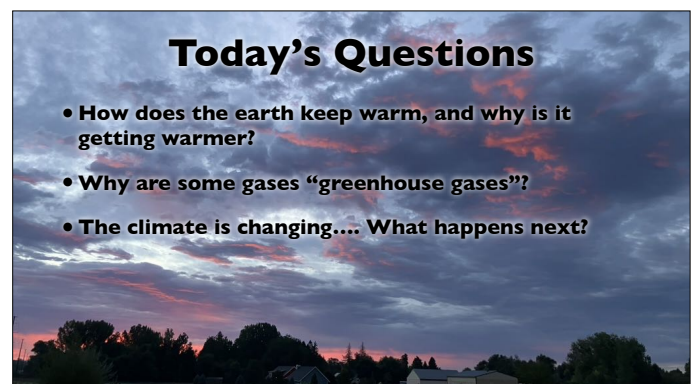
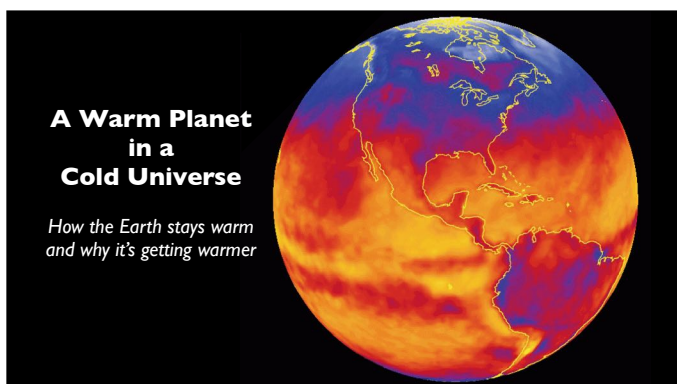
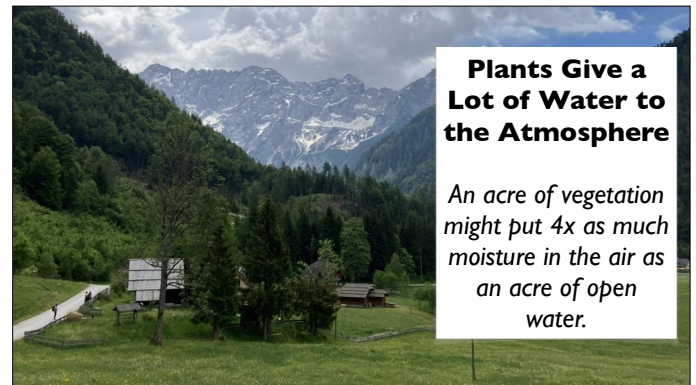
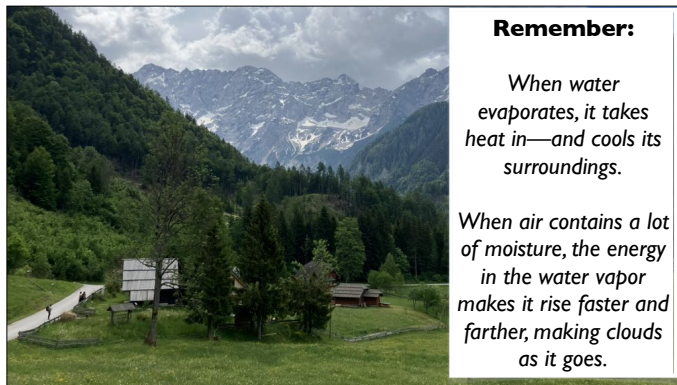
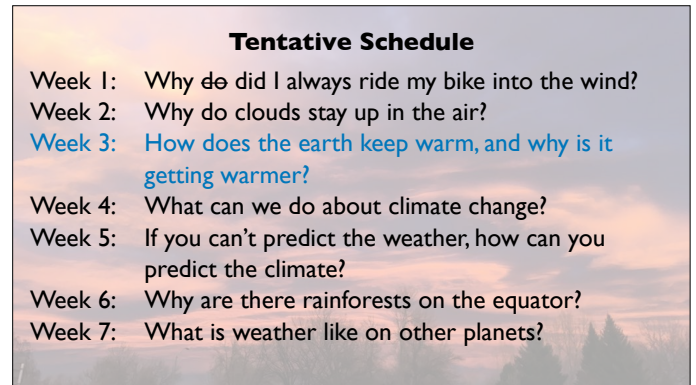


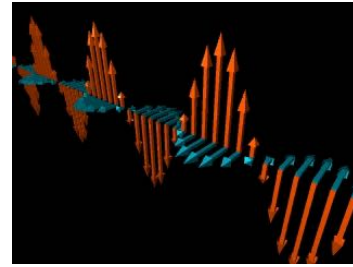


# Physics Principles

## Electromagnetic waves

### Interaction of electromagnetic waves with matter

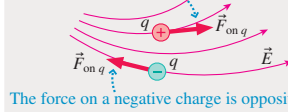
#### The electromagnetic wave.



An oscillating charge will emit an electromagnetic wave.  
It's a wave of electric and magnetic fields.

#### The Electric Fields Exert Forces on Electric Charges.

The force on a positive charge is in the direction of  $\vec{E}$ .



The force on a negative charge is opposite  $\vec{E}$ .

$$\vec{F}_{\text{on } q} = q\vec{E}$$

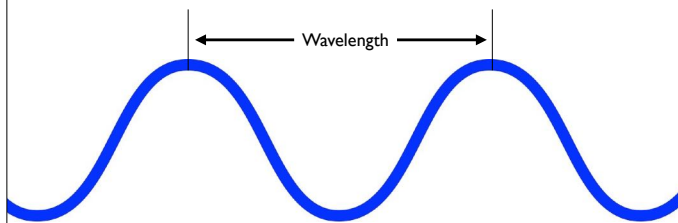
Charge (C)  
Force on charge  $q$  (N)  
Electric field (N/C)

#### The Radio Shack

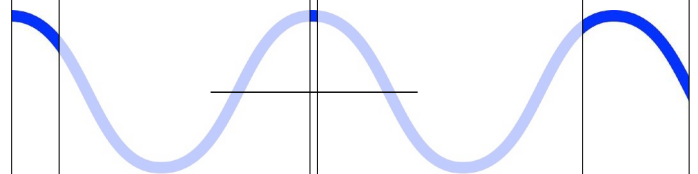


**Question:**  
Explain what is happening.

#### Frequency and Wavelength



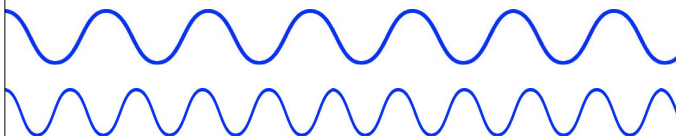
#### Frequency and Wavelength



Frequency is how many waves per second hit one point.

1 cycle per second = 1 hertz (1 Hz)

**Shorter wavelength means higher frequency.**



#### The rainbow of visible light

Long wavelength  
Low frequency

Short wavelength  
High frequency

### The Electromagnetic Spectrum

| Wave              | Wavelength (cm) | Frequency (GHz) |
|-------------------|-----------------|-----------------|
| FM Radio          | 300             | 0.1             |
| Microwave         | 12              | 2.45            |
| Thermal Radiation | 0.001           | 30,000          |
| Near Infrared     | 0.0001          | 300,000         |
| Red               | 0.00007         | 400,000         |
| Blue              | 0.00004         | 700,000         |
| Ultraviolet       | 0.00003         | 1,000,000       |

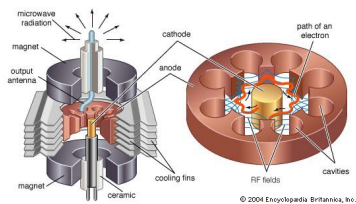
### Electromagnetic Waves Interact With Matter



#### Question:

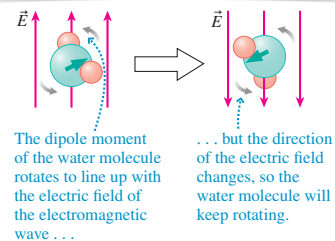
What are some ways in which this photo illustrates the interaction of electromagnetic waves with matter?

### Microwave Oven



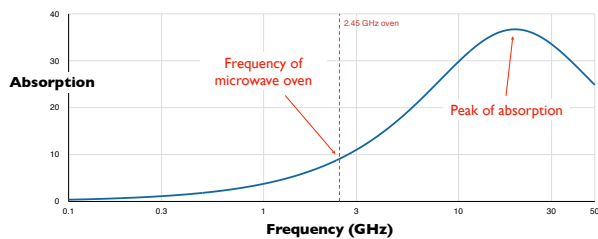
High intensity electromagnetic waves, with large electric fields

### Microwave Oven



Rotates water molecules, heating up the water.

### The strength of the interaction depends on frequency.



#### Question

Why would you choose this particular frequency for a microwave oven?

### Incandescent lamps glow because the filament in them is warm.

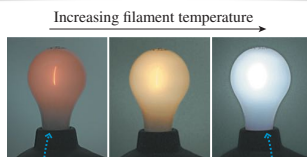


#### Observation:

As the filament gets warmer, how does the emitted light change?

### Warm objects emit electromagnetic waves.

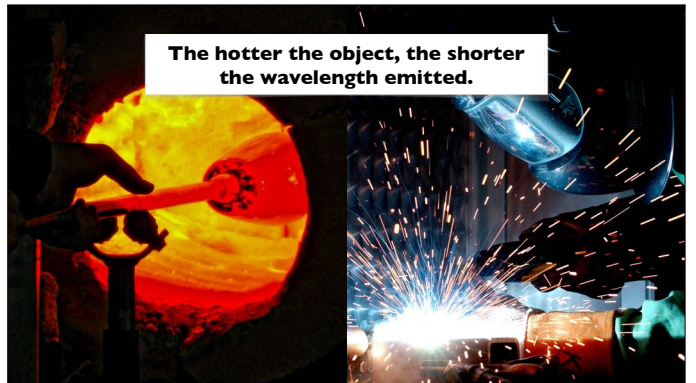
As things get warmer, the wavelength of emitted radiation gets shorter.



At lower filament temperatures, the bulb is dim and the light is noticeably reddish.

When the filament is hotter, the bulb is brighter and the light is whiter.

### The hotter the object, the shorter the wavelength emitted.



### The Electromagnetic Spectrum

| Wave              | Wavelength (cm) | Frequency (GHz) | Temp (°F) |
|-------------------|-----------------|-----------------|-----------|
| FM Radio          | 300             | 0.1             | -         |
| Microwave         | 12              | 2.45            | -         |
| Thermal Radiation | 0.001           | 30,000          | 60        |
| Near Infrared     | 0.0001          | 300,000         | 4,800     |
| Red               | 0.00007         | 400,000         | 6,500     |
| Blue              | 0.00004         | 700,000         | 12,000    |
| Ultraviolet       | 0.00003         | 1,000,000       | 17,000    |

### 100 Watt Bulb?

A 100 W incandescent light bulb emits 100 W of electromagnetic waves. But most of the electromagnetic waves emitted *isn't* visible light.



### 100 Watt Bulb?

At the filament temperature of a typical incandescent bulb, most of the light emitted is in the infrared region of the spectrum. Only 4% of the light from a 100 W bulb is visible to the eye—the bulb is only 4% efficient.



### 4 W light, 96 W heater

96% of the electromagnetic waves emitted by the bulb can't be seen. They simply warm the room up—they don't illuminate it.



### Incandescent bulbs are only 4% efficient.

LED bulbs are much better (up to 40% efficient), especially if you get daylight bulbs.



### Go ahead and leave the light on.

If I turn on the primary lights in our dining room at the usual brightness, the total power used is only about 12 W.

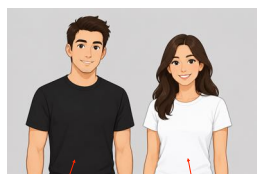


### Absorption vs. Transmission / Reflection

The interaction of waves with matter depends on frequency.

If there is a strong interaction, the wave is strongly absorbed—it heats up the matter.

If there is a weak interaction, the wave is weakly absorbed—it is transmitted, reflected, or scattered. Not much heating happens.



Visible light absorbed

Visible light scattered

### Observation:

What things look bright in the near infrared?  
What things look dark?



### WARNING:

30% of radiation from the sun is near infrared.  
**DO NOT LOOK AT THE SUN!**

### Emissivity

Some things emit  
really well.  
Some things  
don't.



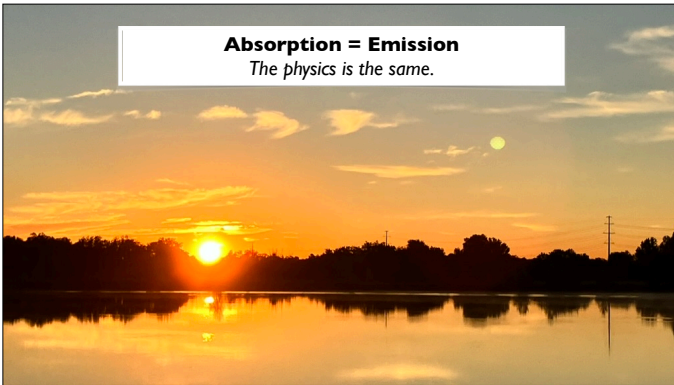
### Observation

Which emits  
more, the water  
or the metal can?



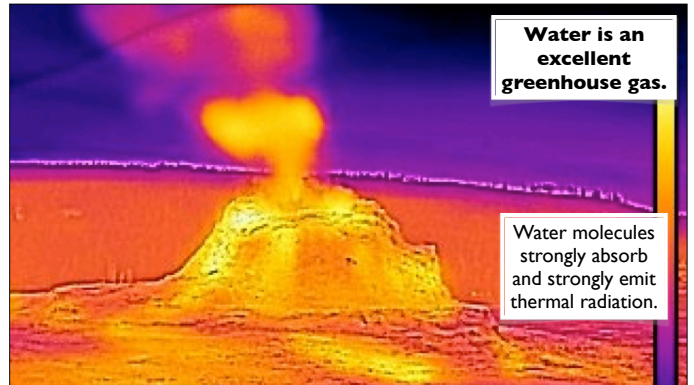
### Absorption = Emission

*The physics is the same.*



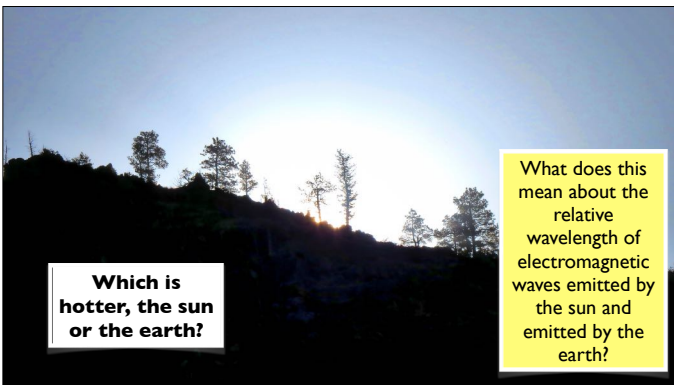
Water is an  
excellent  
greenhouse gas.

Water molecules  
strongly absorb  
and strongly emit  
thermal radiation.



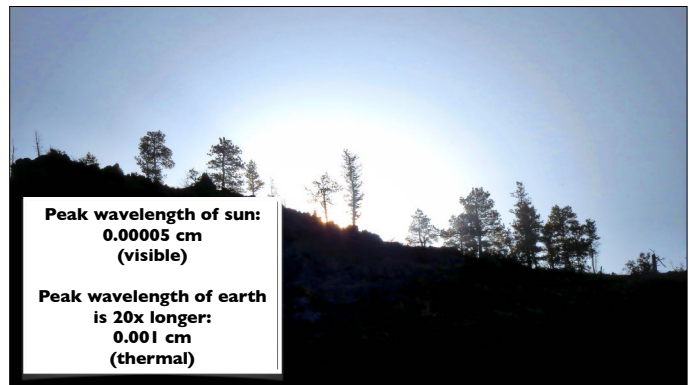
Which is  
hotter, the sun  
or the earth?

What does this  
mean about the  
relative  
wavelength of  
electromagnetic  
waves emitted by  
the sun and  
emitted by the  
earth?



Peak wavelength of sun:  
0.00005 cm  
(visible)

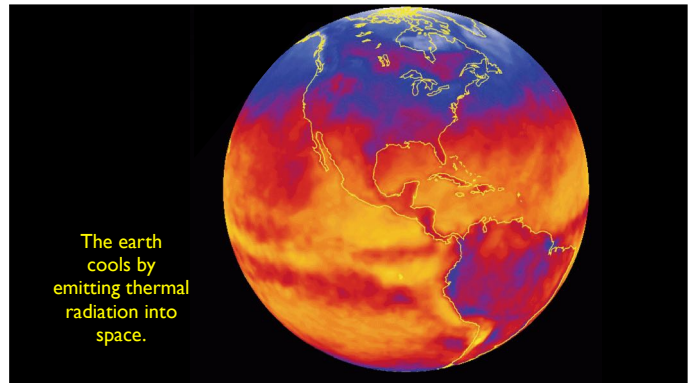
Peak wavelength of earth  
is 20x longer:  
0.001 cm  
(thermal)

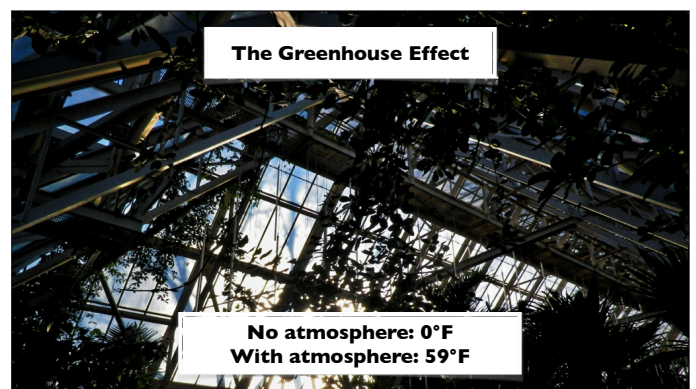
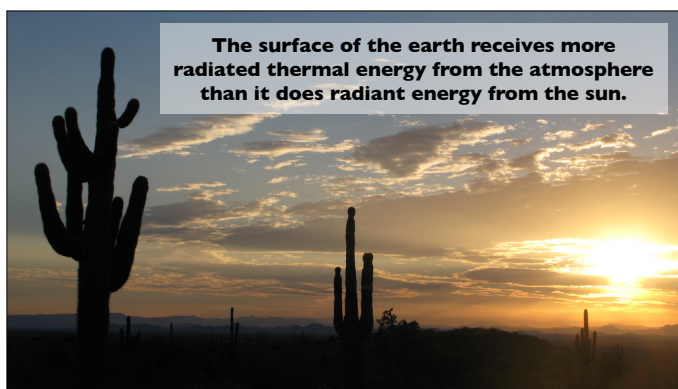
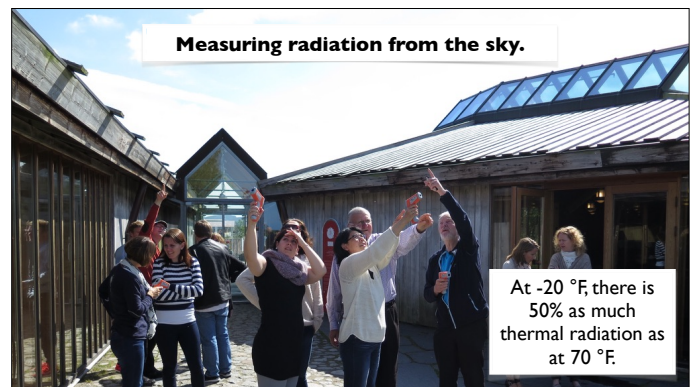
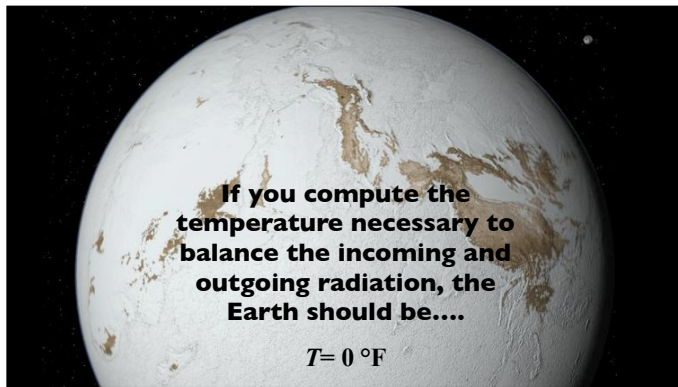
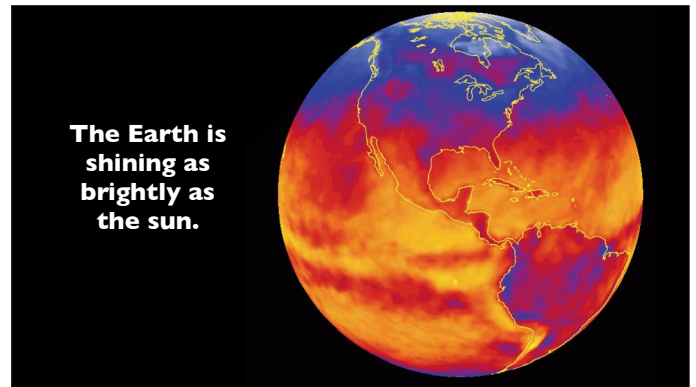


The earth  
warms by  
absorbing  
visible light  
from the sun.



The earth  
cools by  
emitting thermal  
radiation into  
space.





Not all gases emit (and absorb) thermal radiation.

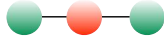
Look at charge sharing.  
Red=positive  
Green=negative  
Blue=neutral

Unequal sharing of charges means oscillation leads to emission of EM waves.

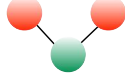
Nitrogen/Oxygen:  
**Nope.**



Carbon Dioxide:  
**Yes.**



Water Vapor:  
**Oh Yeah.**



## Radiation

Check out the plume from the candle.



Resonant frequencies of greenhouse gases mean they absorb (and emit!) thermal radiation, but not visible light.

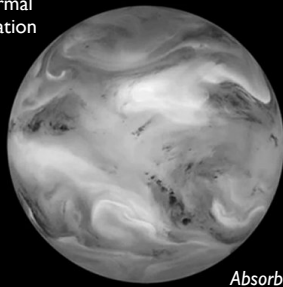
If you sit next to my fire pit, most of the warmth you feel comes from the rising gases, not the sides of the stove.  
**Explain.**



Visible Light



Thermal Radiation



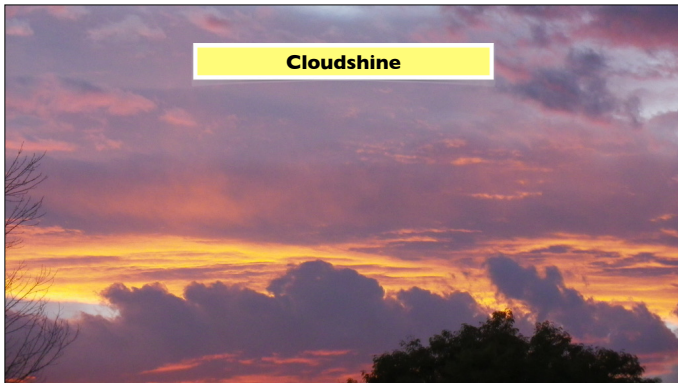
Transmitted.

Absorbed and emitted.

Why does it get colder on clear nights than on cloudy nights?



Cloudshine



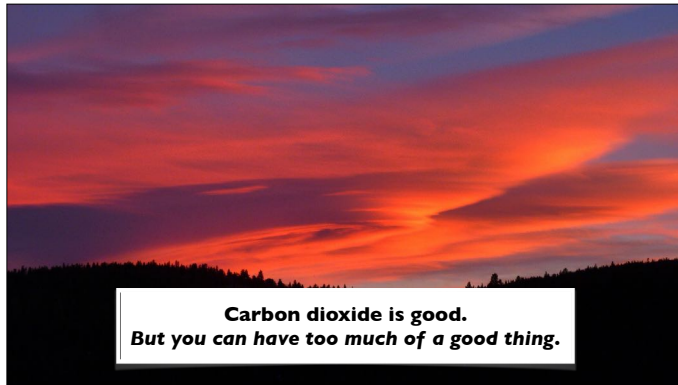
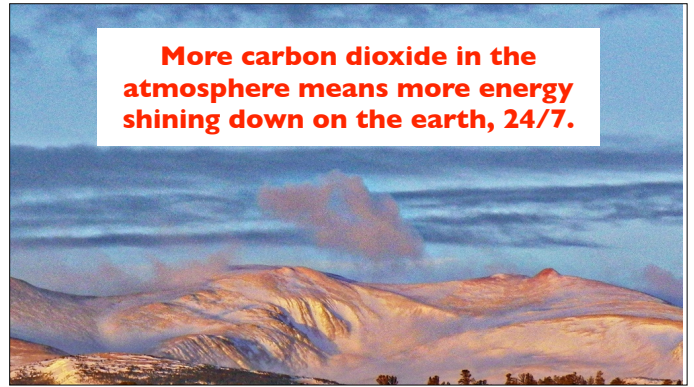
It doesn't snow because it's cold.  
It's cold because it snowed.  
**Question:**  
Explain this observation.





**More greenhouse gases = more radiation**

**More carbon dioxide in the atmosphere means more energy shining down on the earth, 24/7.**



**Carbon dioxide is good.  
But you can have too much of a good thing.**

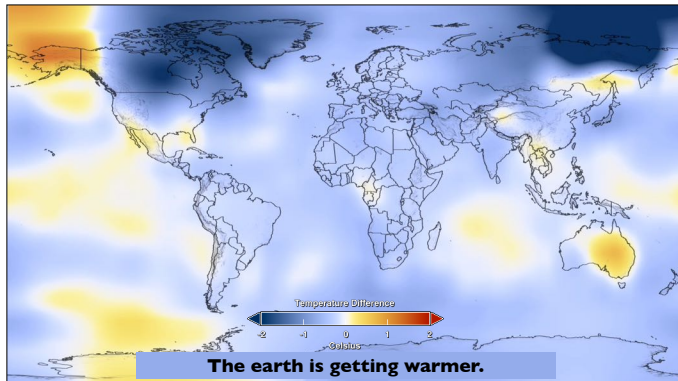
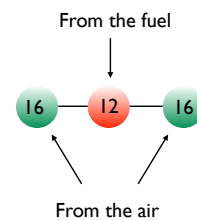


**Carbon dioxide in the atmosphere is increasing.**



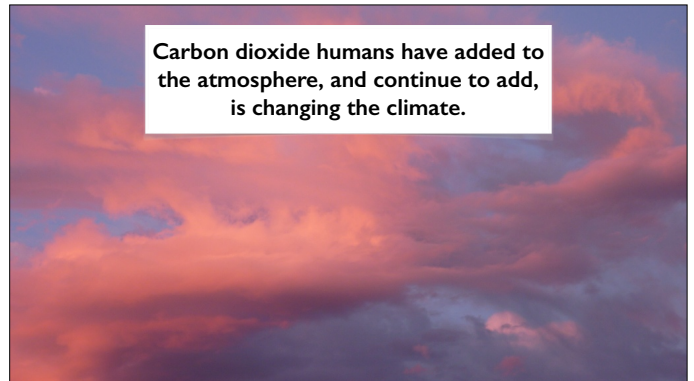
**The increase in carbon dioxide is due to human activities.**

**Burning 1 gallon of gas (6 pounds) produces 20 pounds of carbon dioxide.**

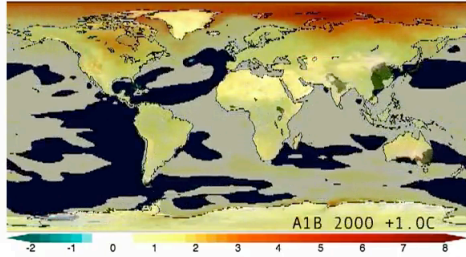


**The earth is getting warmer.**

**Carbon dioxide humans have added to the atmosphere, and continue to add, is changing the climate.**

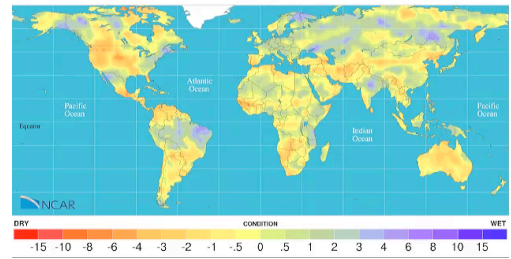


Surface temperature change relative to 1870-1899 baseline CCSM3 IPCC AR4



Model results, 2000 - 2098

Drought potential: 2000



Model results, 2000 - 2098



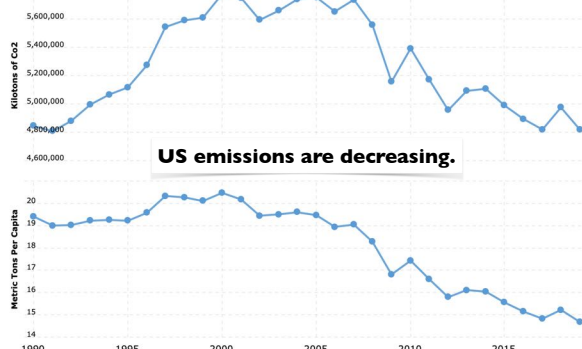
Global Weirding.

This is a pretty big deal.



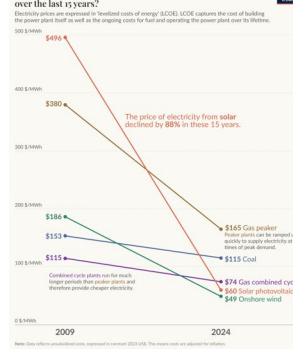
Next Week:  
What can be done?

Reasons for Hope



US emissions are decreasing.

How did the price of electricity from new power plants change over the last 15 years?



Carbon-free energy is cheaper.

