

# Pale Blue Dot



Earth as seen from Voyager 1,  
when it was 6 billion km from  
home.

# The Earth



## General Features

Mass:  $M_{\text{Earth}} = 6 \times 10^{27} \text{ g}$

Radius:  $R_{\text{Earth}} = 6378 \text{ km}$

Density:  $\rho = 5.5 \text{ g/cm}^3$

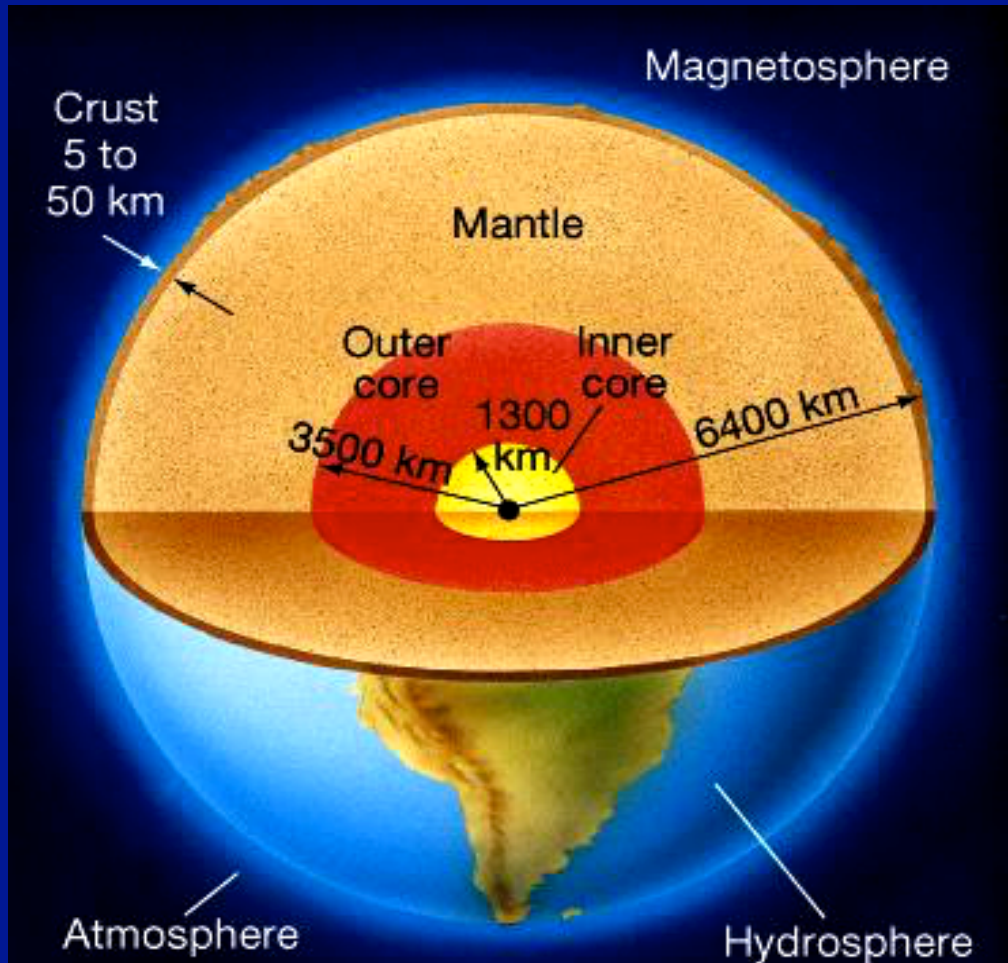
Age: 4.6 billion years





# Earth's Internal Structure

How do we know? Earthquakes. See later



Crust: thin. Much Si and Al (lots of granite). Two-thirds covered by oceans.

Mantle is mostly solid, mostly basalt (Fe, Mg, Si). Cracks in mantle allow molten material to rise => volcanoes.

Core temperature is 6000 K. Metallic - mostly nickel and iron. Outer core molten, inner core solid.

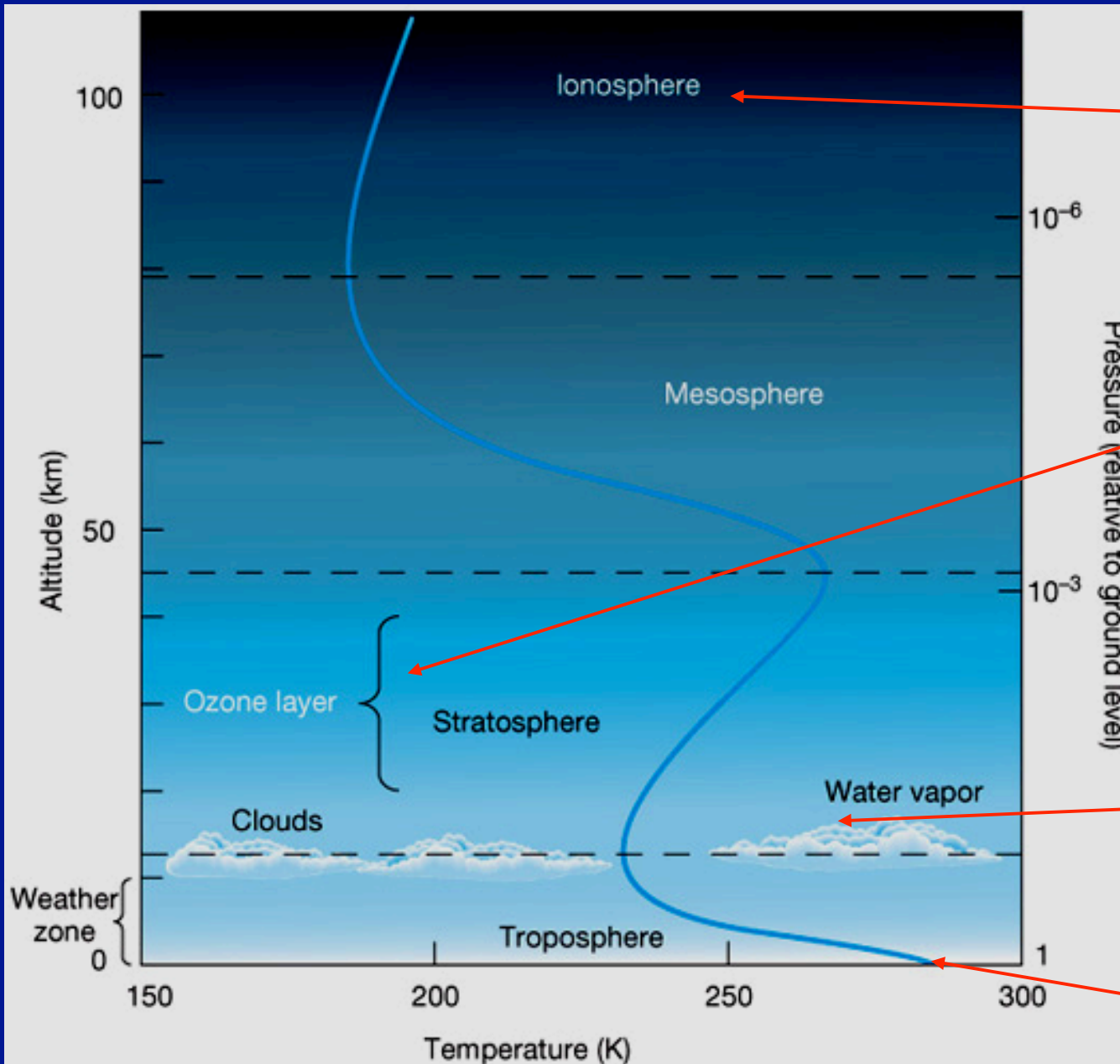
Atmosphere very thin



# Earth's Atmosphere

78% Nitrogen  
21% Oxygen

Original gases disappeared. Atmosphere is mostly due to volcanoes and plants!



gas is ionized by solar radiation

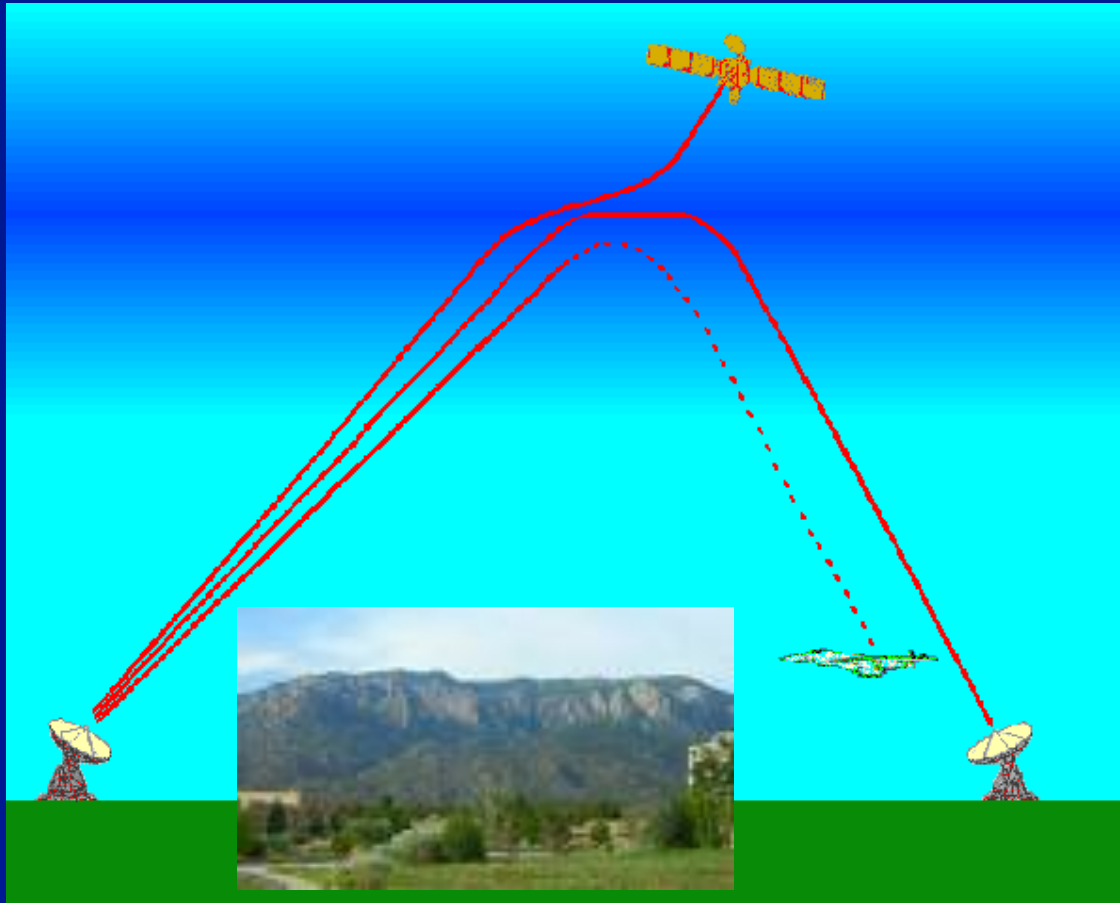
ozone is  $O_3$ , which absorbs solar UV efficiently, thus heating stratosphere

commercial jet altitudes

temperature on a cool day

# Ionosphere

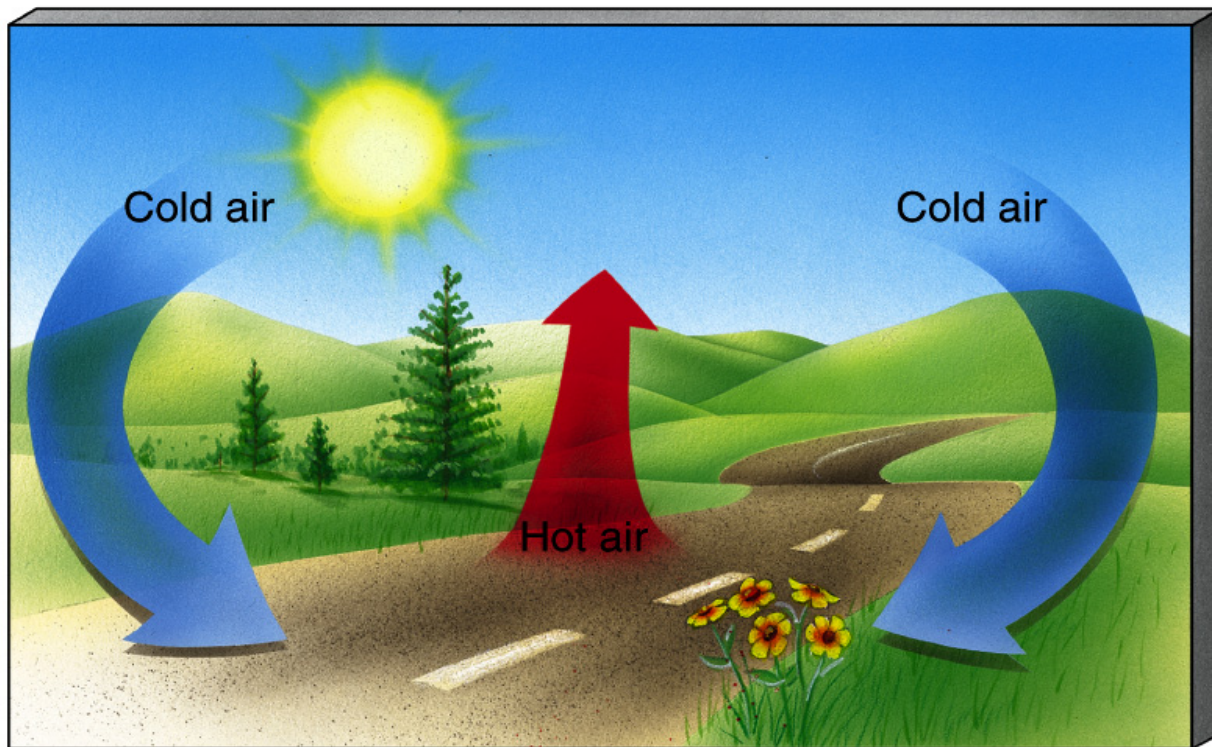
Particles in the upper reaches of the atmosphere are ionized by the sun.



Radio signals below  $\sim 20$  MHz can “bounce” off the ionosphere allowing Communication “over the horizon” (or mountains)

## Convection

Earth's surface heated by Sun. What would happen if it couldn't get rid of the energy as fast as it gets in?

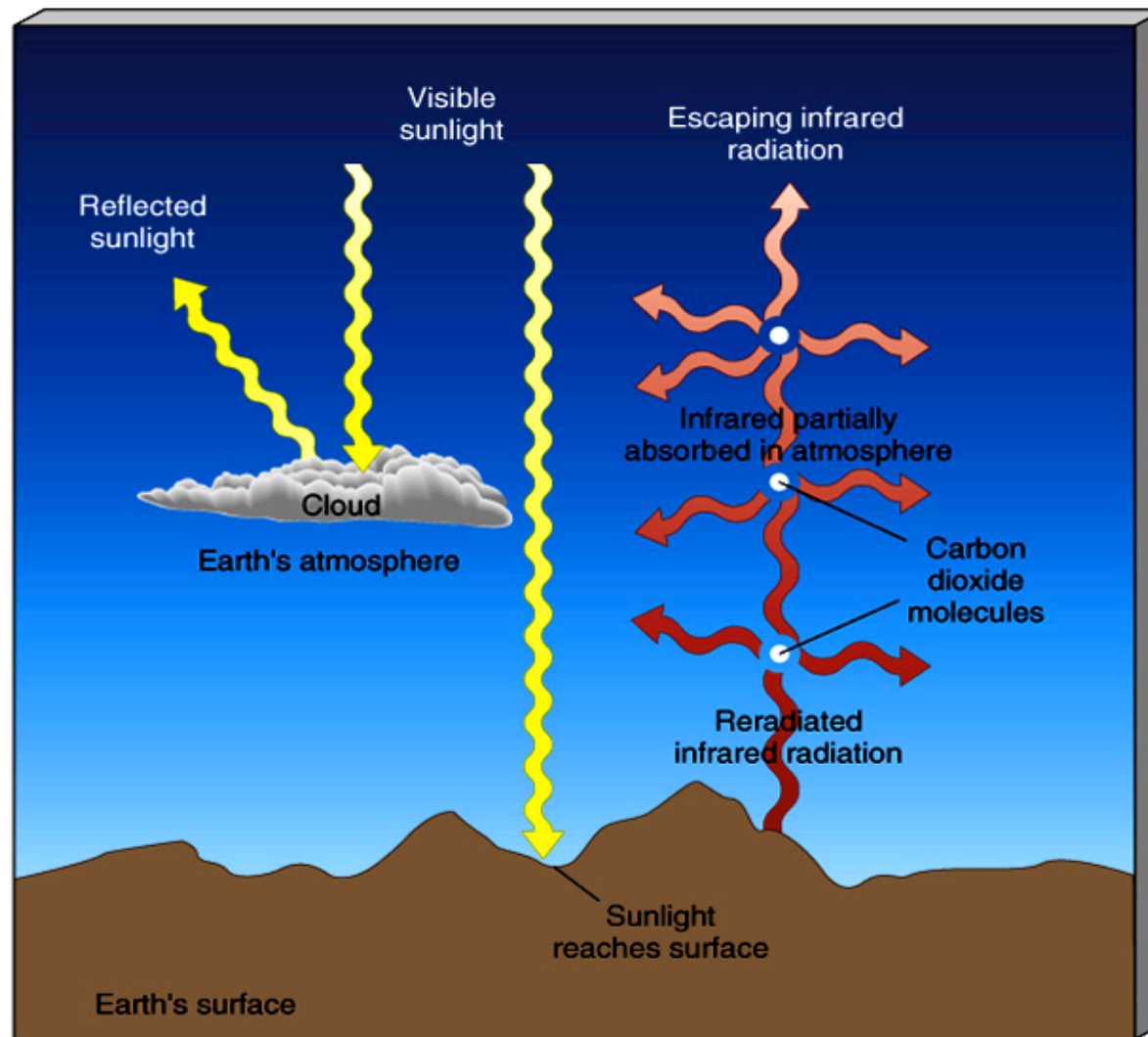


Convection also occurs when you boil water, or soup. Think of Earth's surface as a boiling pot!

Convection causes both small-scale turbulence and large scale circulation patterns. It also occurs within Earth, on other planets, and in stars.



# The Greenhouse Effect



Main greenhouse gases are  $\text{H}_2\text{O}$  and  $\text{CO}_2$ .

If no greenhouse effect, surface would be  $40^\circ\text{C}$  cooler!

DEMO

# Clicker Question:

**A leading cause of Global Warming is:**

- A: Increased soot (smog) in the atmosphere.
- B: Increased carbon dioxide in the atmosphere.
- C: The Earth is getting closer to the sun.
- D: The luminosity of the sun is steadily increasing.

# Clicker Question:

The Greenhouse effect would not occur if:

A: The Earth had no atmosphere.

B: The amount of carbon dioxide doubled.

C: We got rid of all the forests.

D: The Earth didn't have an ocean.



# Clicker Question:

**My feeling about global warming is:**

A: Not convinced that it is happening.

B: It's a natural phenomena, nothing to worry about.

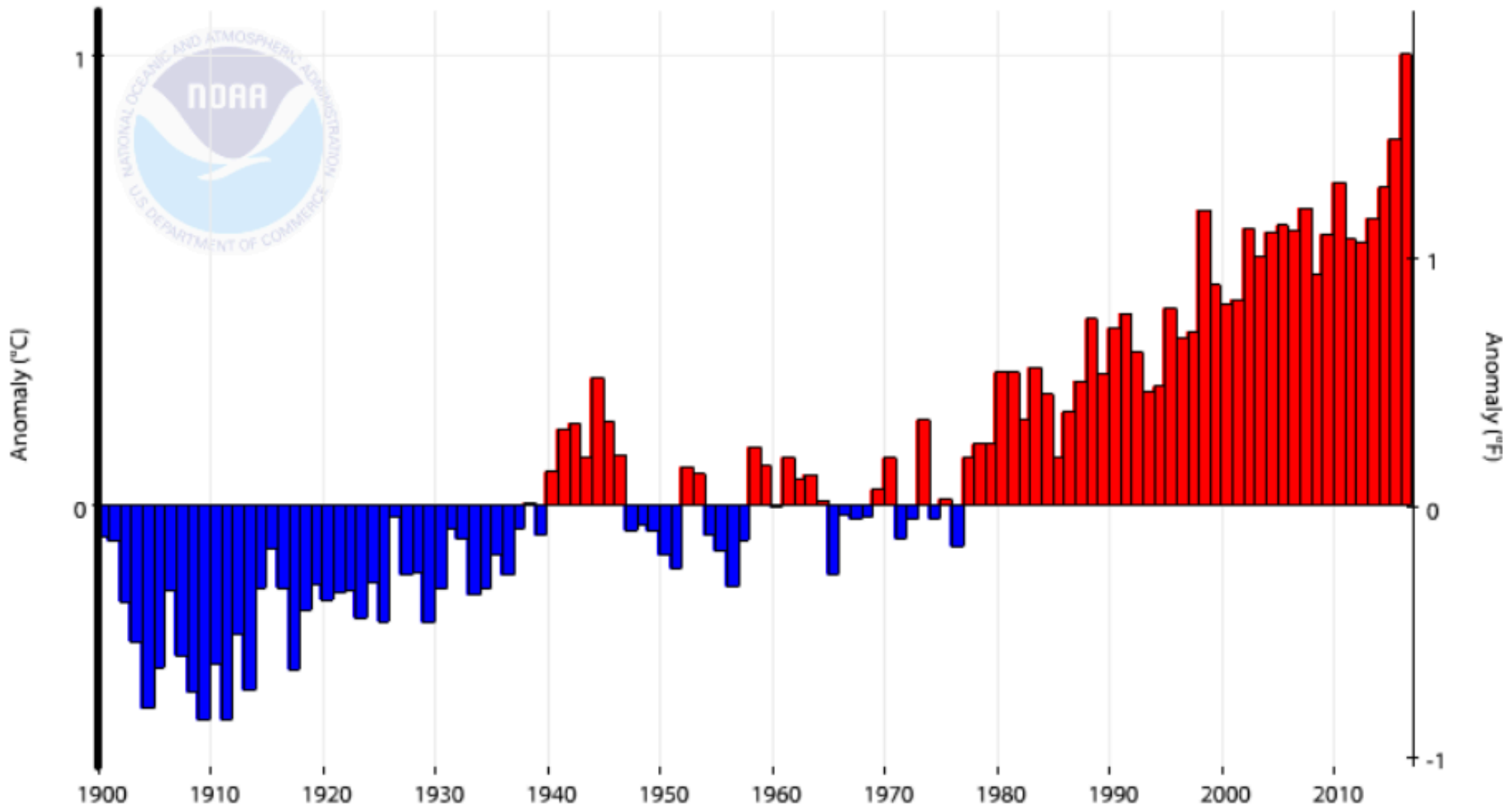
C: It's definitely caused by people's actions, but there's nothing much we can do about it.

D: It's definitely caused by people's actions, and I'm willing to do whatever I can to reduce my carbon footprint and help to solve the problem.

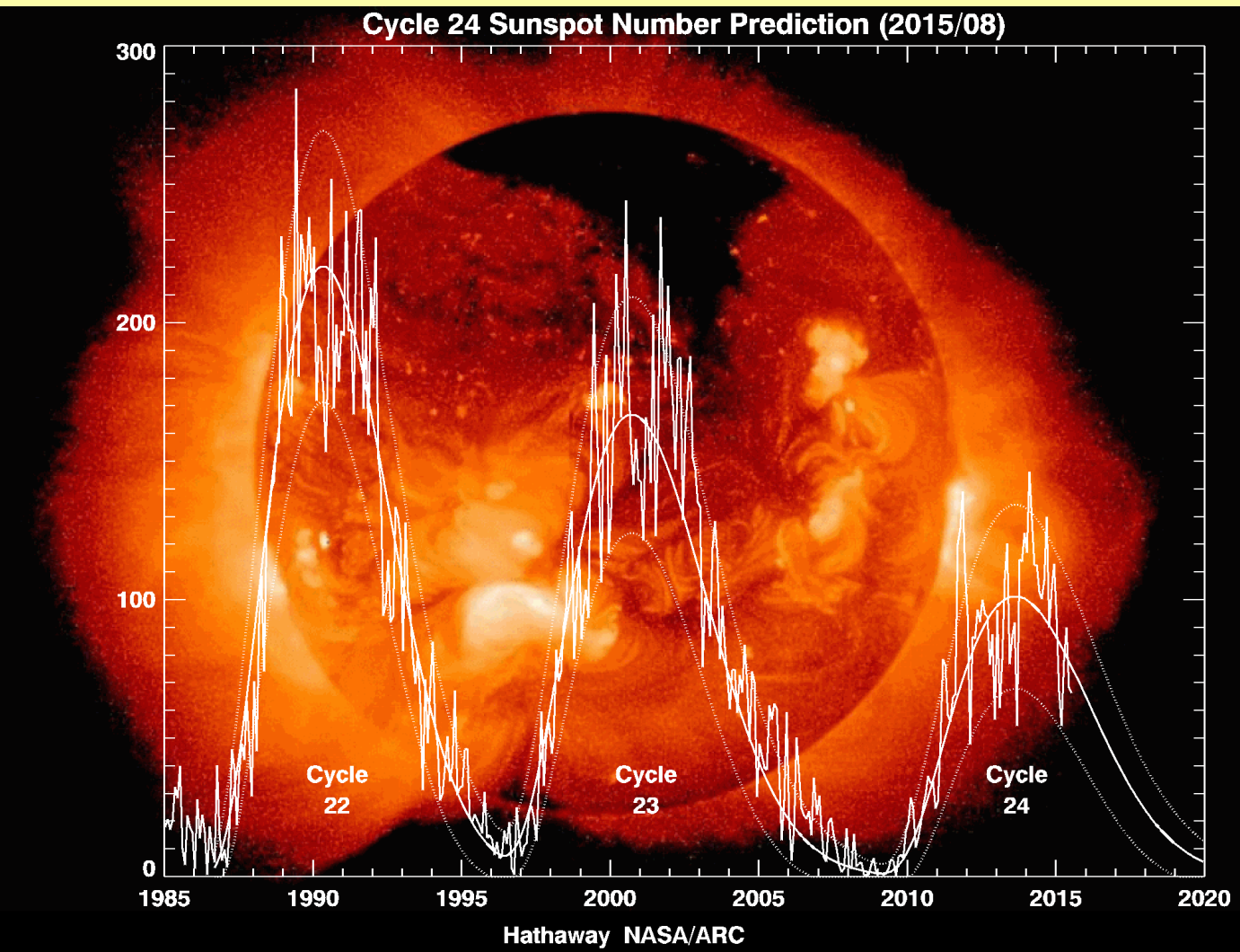
E: We should start making plans to colonize Mars.

2016 was the hottest year on record.

Global Land and Ocean Temperature Anomalies, August-July



# Recent solar variability



We have just passed through an extremely low **solar minimum**

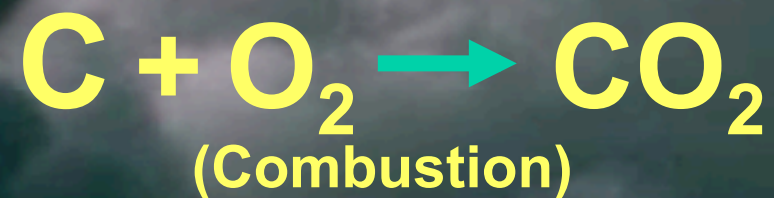
... contributing to recent relatively cool global temperatures

... and warmer temperatures over the next few years?

<http://www.swpc.noaa.gov/SolarCycle/>



# Burning Fossil Fuels is the Primary Cause



Burning carbon-containing fossil fuels produces carbon dioxide.

# Global Warming Basics

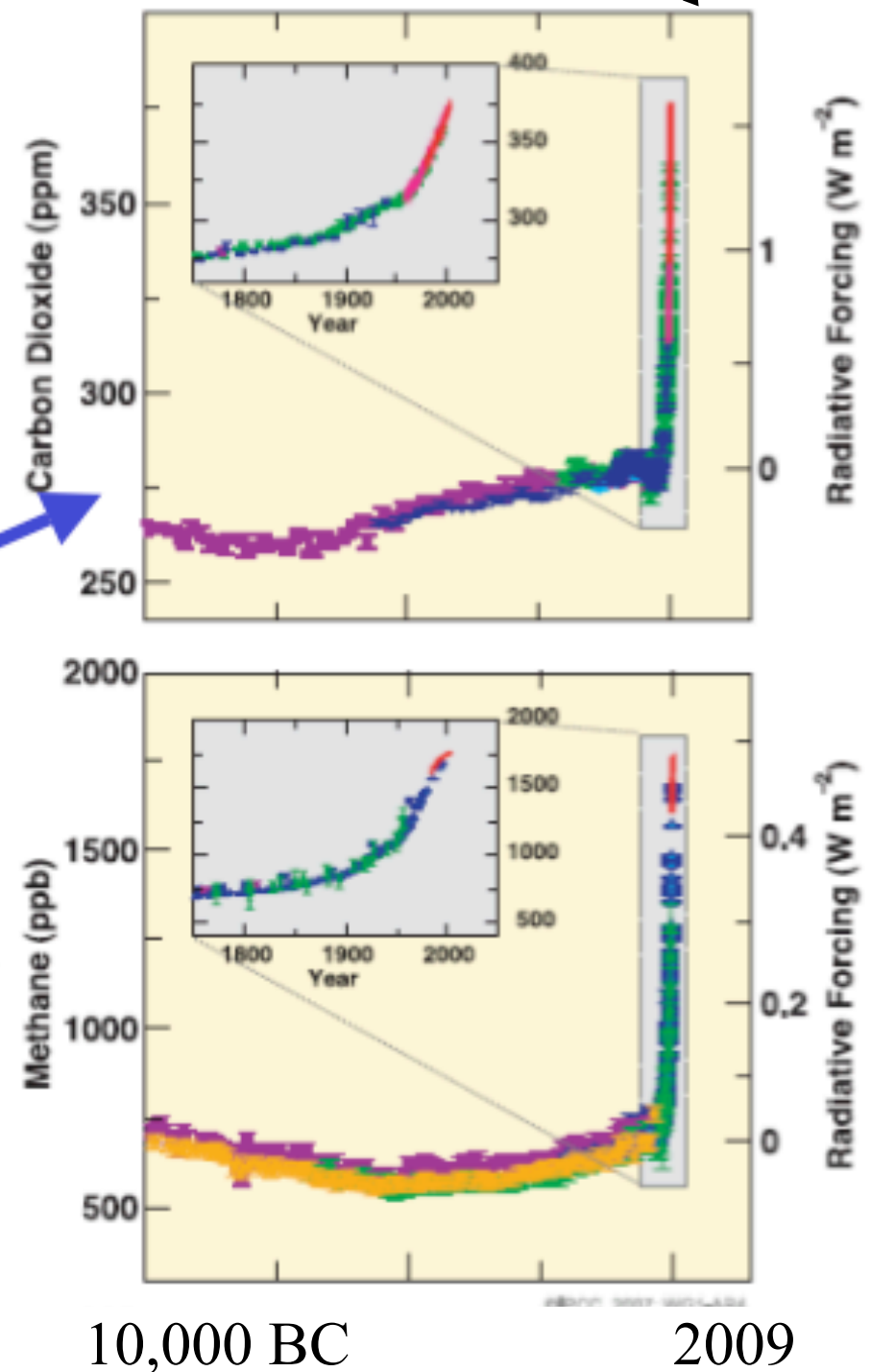
- Humans have increased carbon dioxide (CO<sub>2</sub>) in the atmosphere by more than **40%** since the Industrial Revolution.

(National Oceanic and Atmospheric Administration 2006)

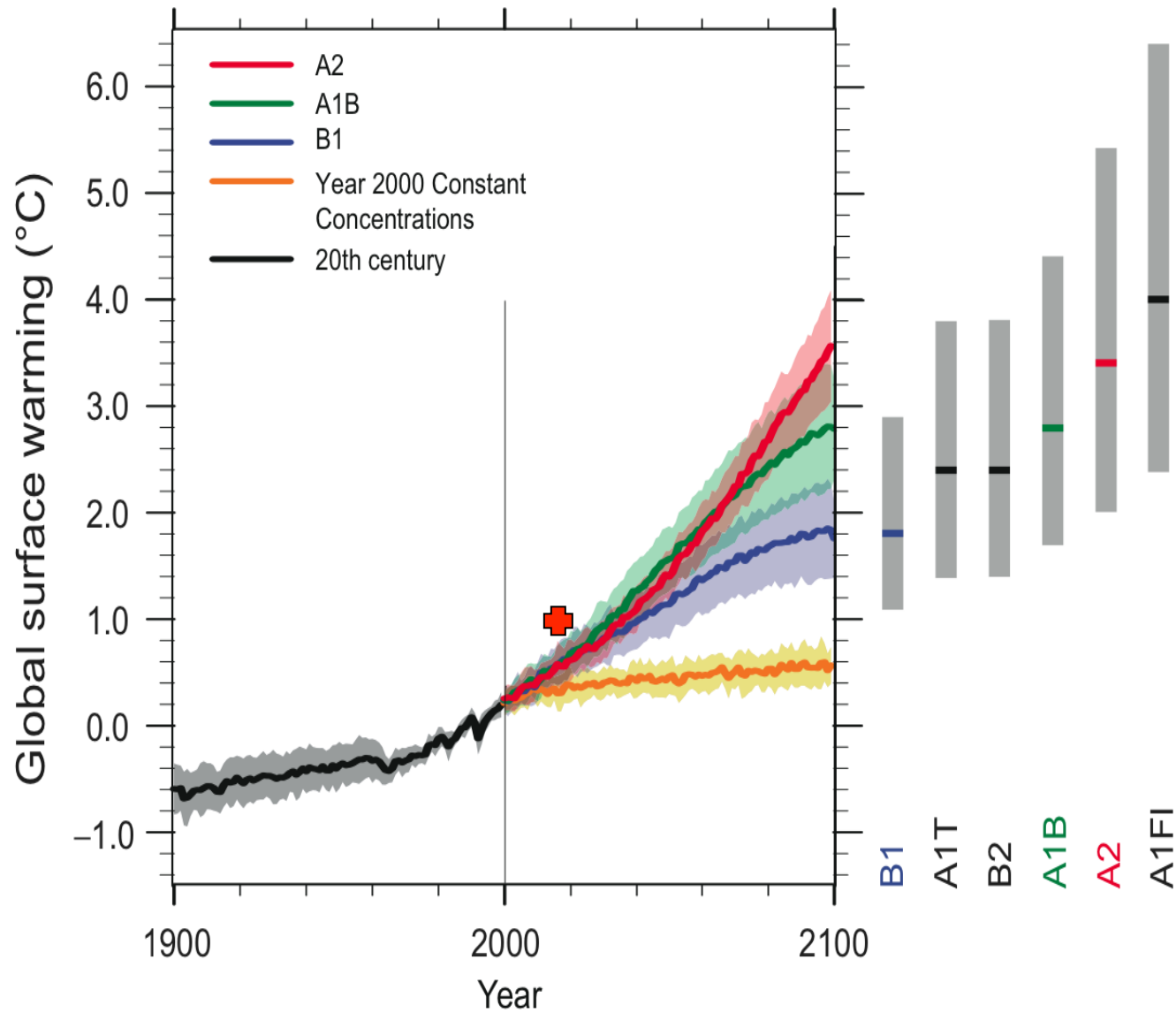
- The most carbon dioxide in **800,000 years**. (IPCC 2014)

(CO<sub>2</sub>)

## CHANGES IN GREENHOUSE GASES FROM ICE CORE AND MODERN DATA



# Temperature Predictions







Alaska is Ground  
Zero:

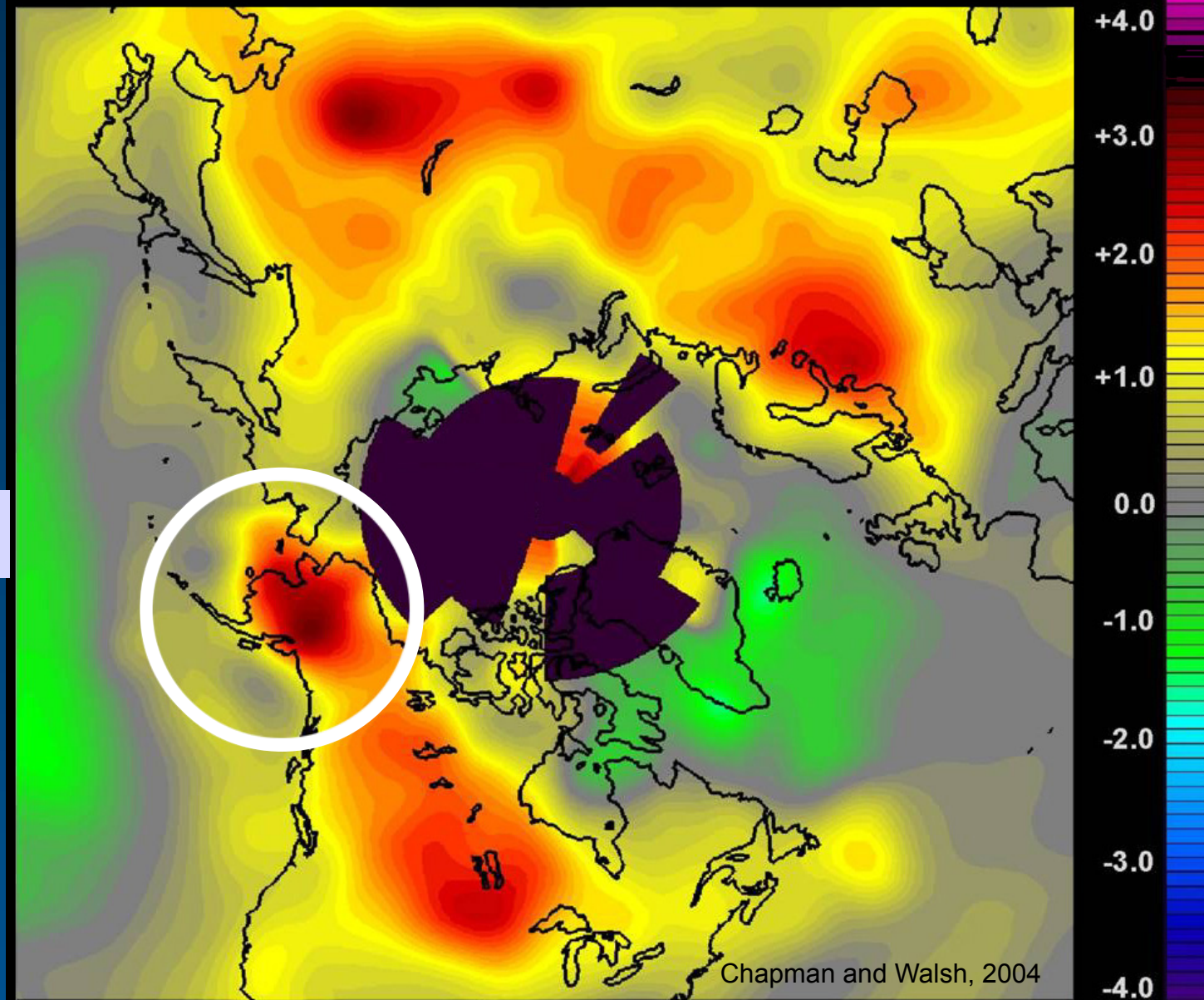
In past 50 years,  
temperatures have  
increased 4° F.

National Assessment  
Synthesis Team

Worldwide,  
temperatures have  
increased slightly  
more than 1.5° F

(IPCC) 2014

## Surface Air Temperature Trends 1942-2003

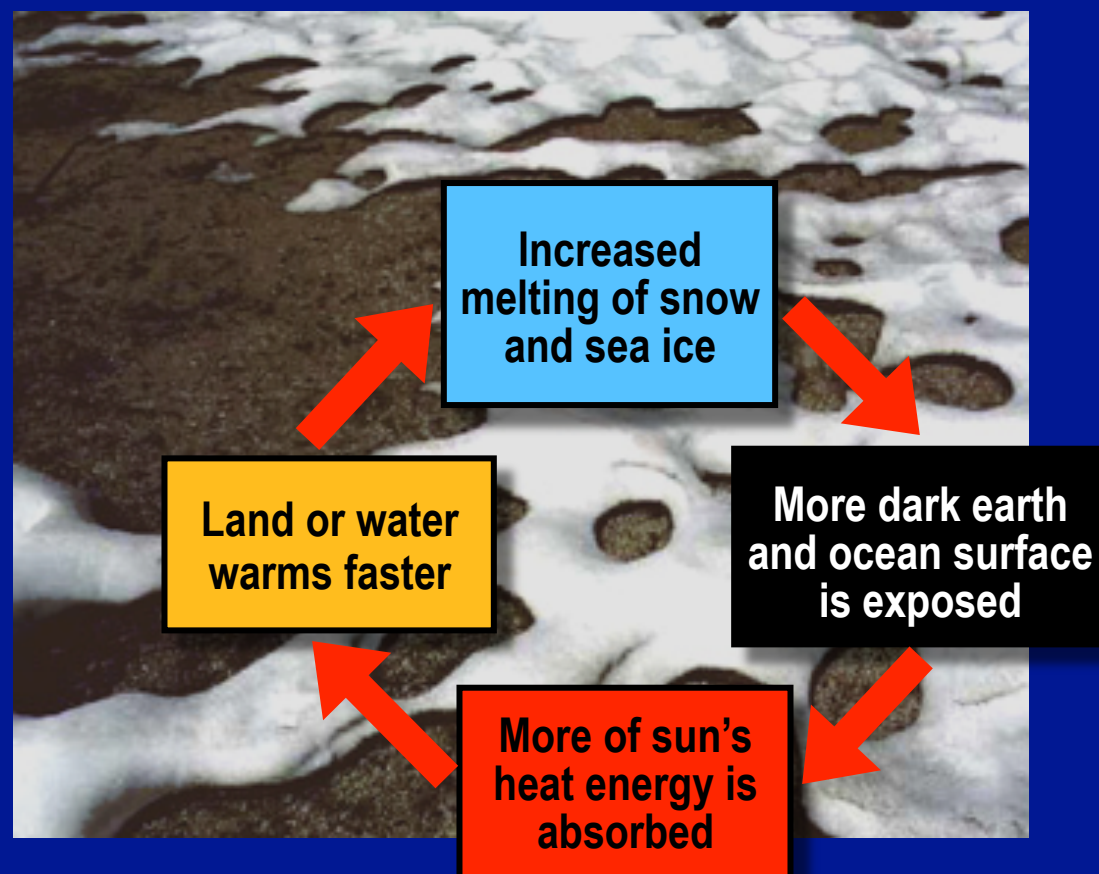


# Why has Alaska warmed the most?

## The Albedo Effect

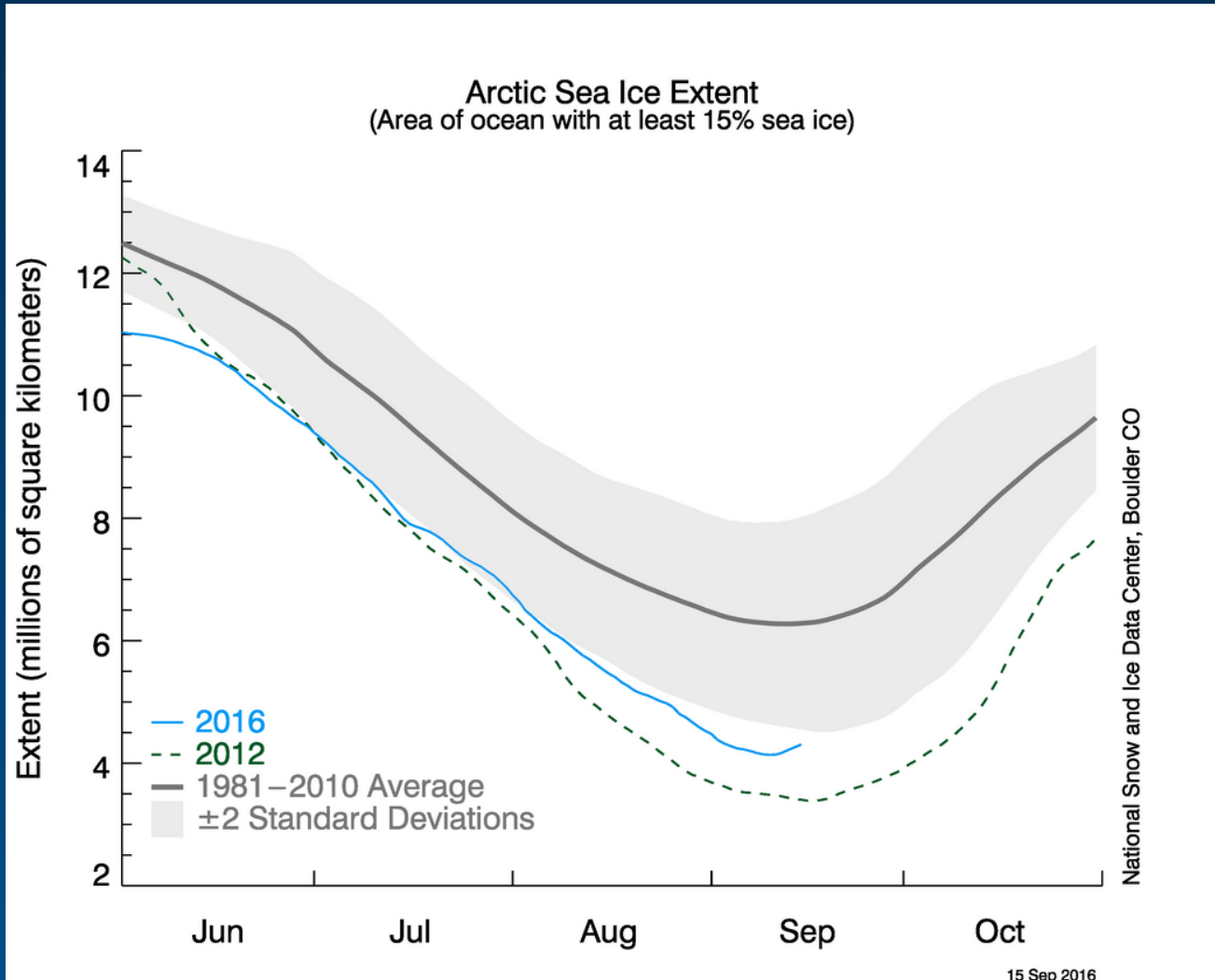
- Snow and sea ice reflect 85-90% of sun's energy.
- Ocean surface and dark soil reflect only 10-20%.

(ACIA 2004)



“White shirt versus Black shirt”

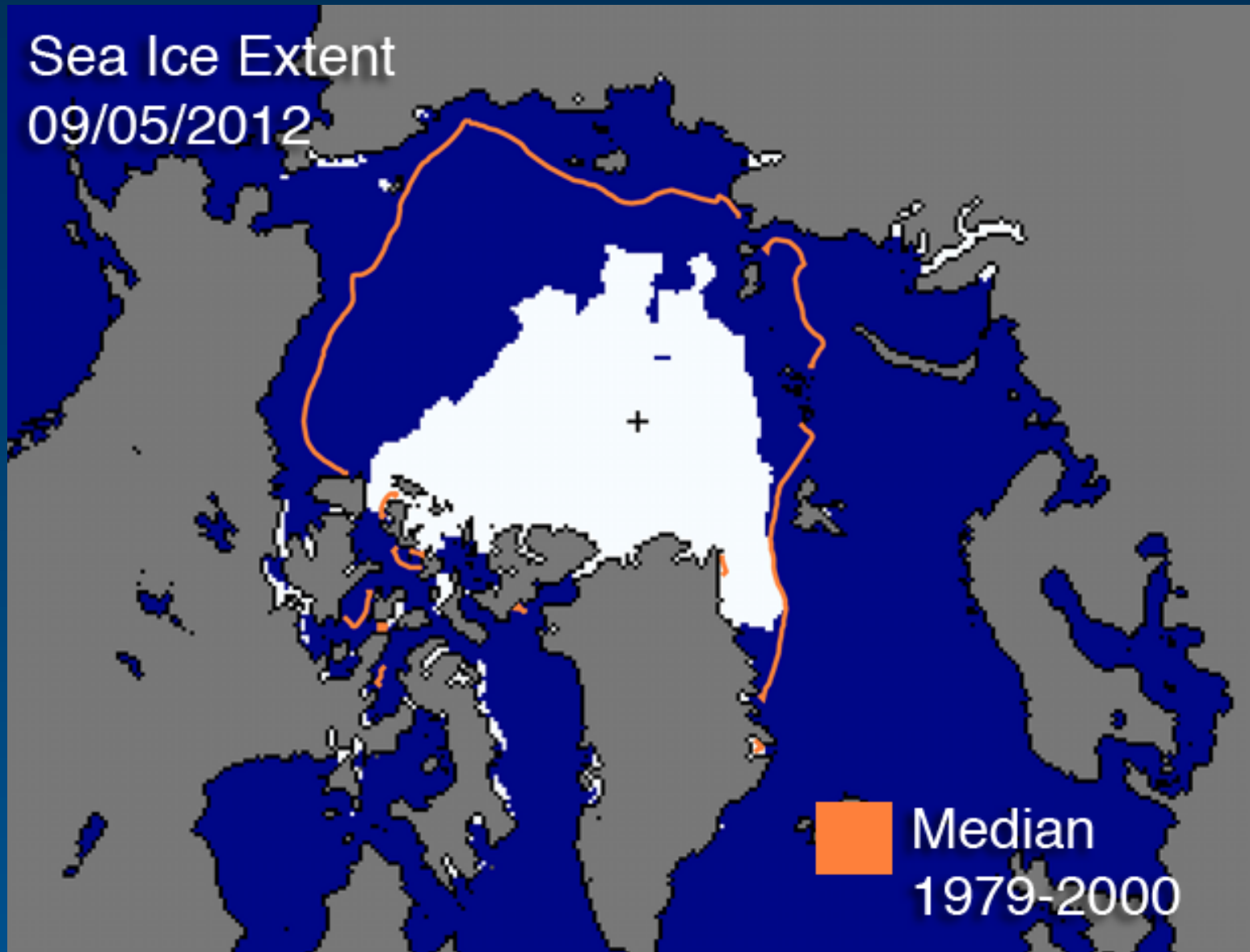
# Melting Sea Ice



- An area twice the size of Texas has melted away since 1979 (over 50% decrease).
- Ice 40% thinner.  
(Rothrock, D.A., et al. 1999)
- Ice free summer in 20 years?
- Bering Sea Ice Sheet also retreating (Science 3/10/06).



# September 2012



# Glacial Retreat

- The rapid retreat of Alaska's glaciers represents about 50% of the estimated mass loss by glaciers through 2004 worldwide. (ACIA 2004)
- Loss of over 588 billion cubic yards between '61 and '98. (Climate Change 11/05)
- Alaska's glaciers are responsible for at least 9% of the global sea level rise in the past century. (ACIA 2004)

McCall Glacier  
Glacier Bay (Peters Glacier)





# Animals at Risk

- Polar bears
- Walruses
- Ice seals
- Black guillemots
- Kittiwakes
- Salmon
- Caribou
- Arctic grayling

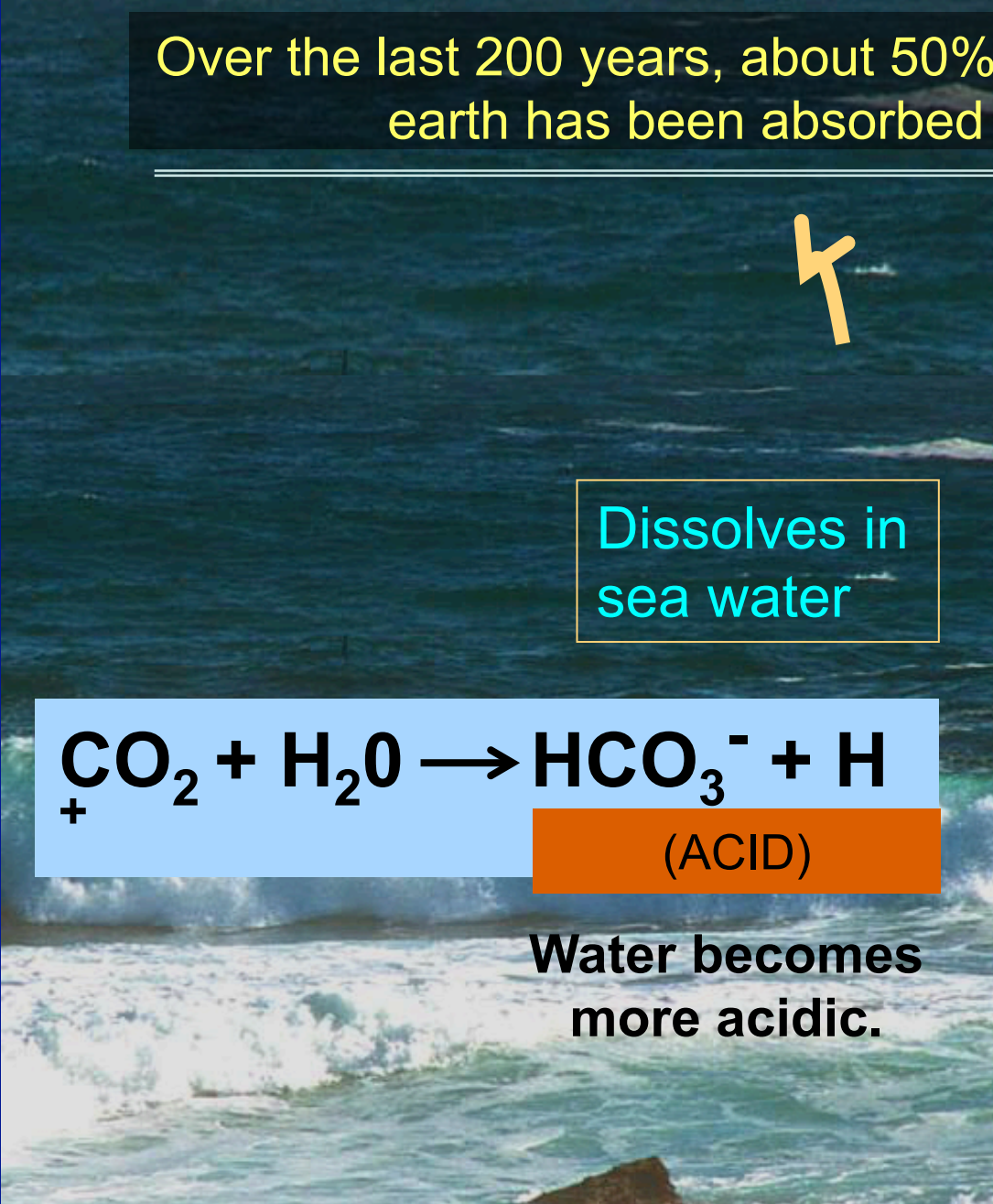
- Arctic grayling

- Rising temperatures
- Shrinking habitat
- Food harder to get
- Expanding diseases
- Competition

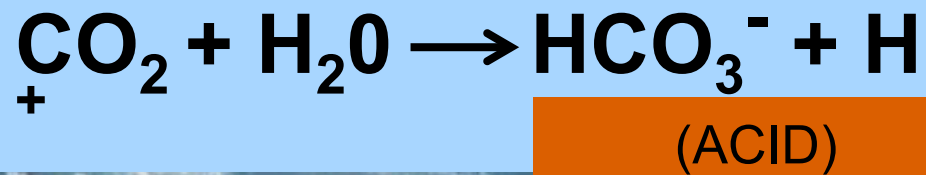


# Ocean Acidification

Over the last 200 years, about 50% of all CO<sub>2</sub> produced on earth has been absorbed by the ocean. (Royal Society 6/05)

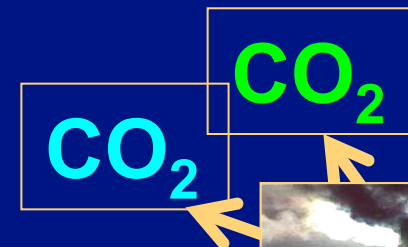



Dissolves in  
sea water



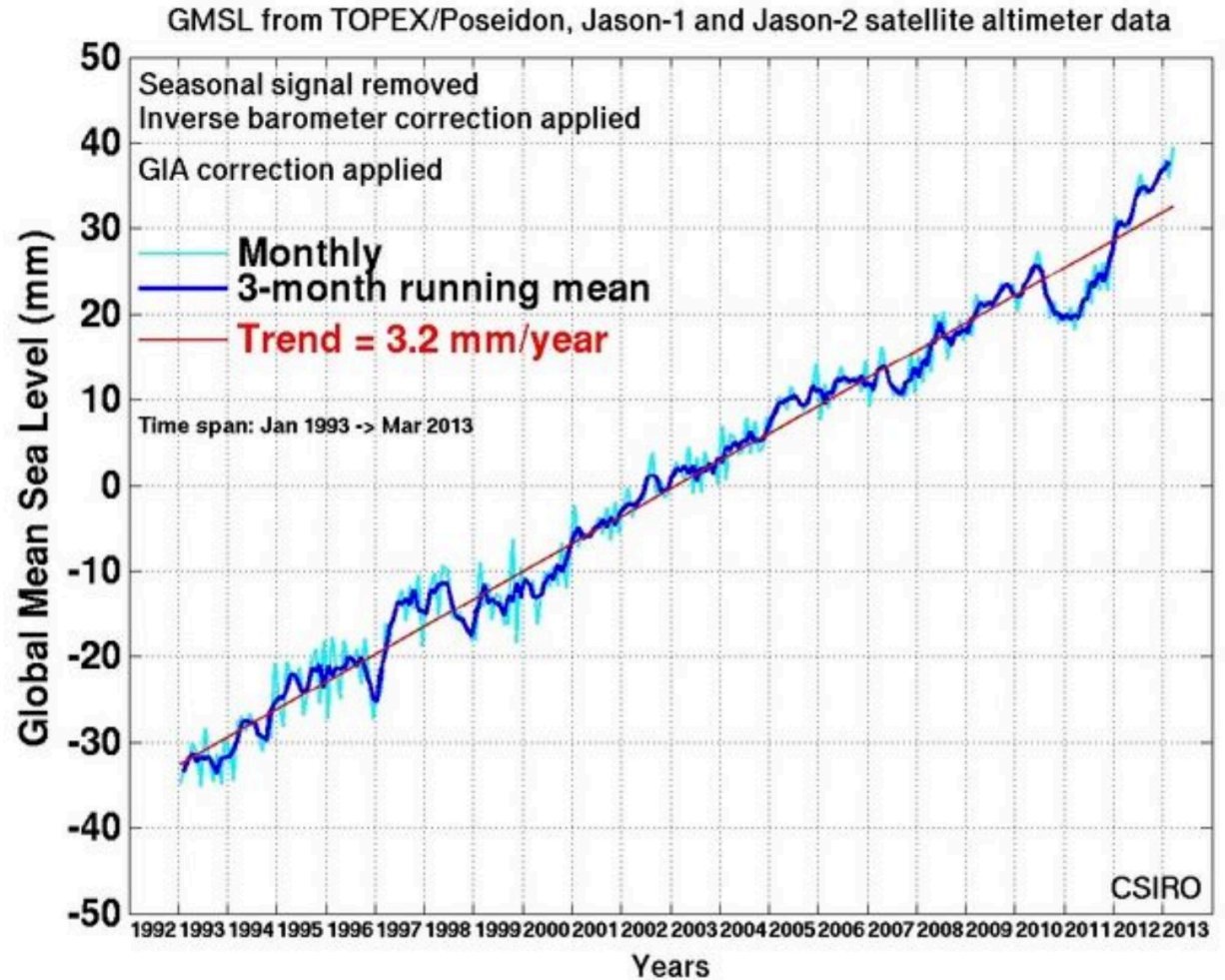
Water becomes  
more acidic.

Remains in the  
atmosphere  
(greenhouse gas)



# Inundation

- Sea level has increased 3.2 mm/year between 1993 and 2003 (IPCC 2007).
- 2 meters of sea level rise by 2100 (DeConto & Pollard 2016)
- This is 10-20 times faster than during the last 3,000 years (ACIA 2004).



1993

2013



# Ocean Nations Threatened

Maldives nation held cabinet meeting 20 feet under water.

Tuvalu nation considering exodus (highest elevation is 15 feet)

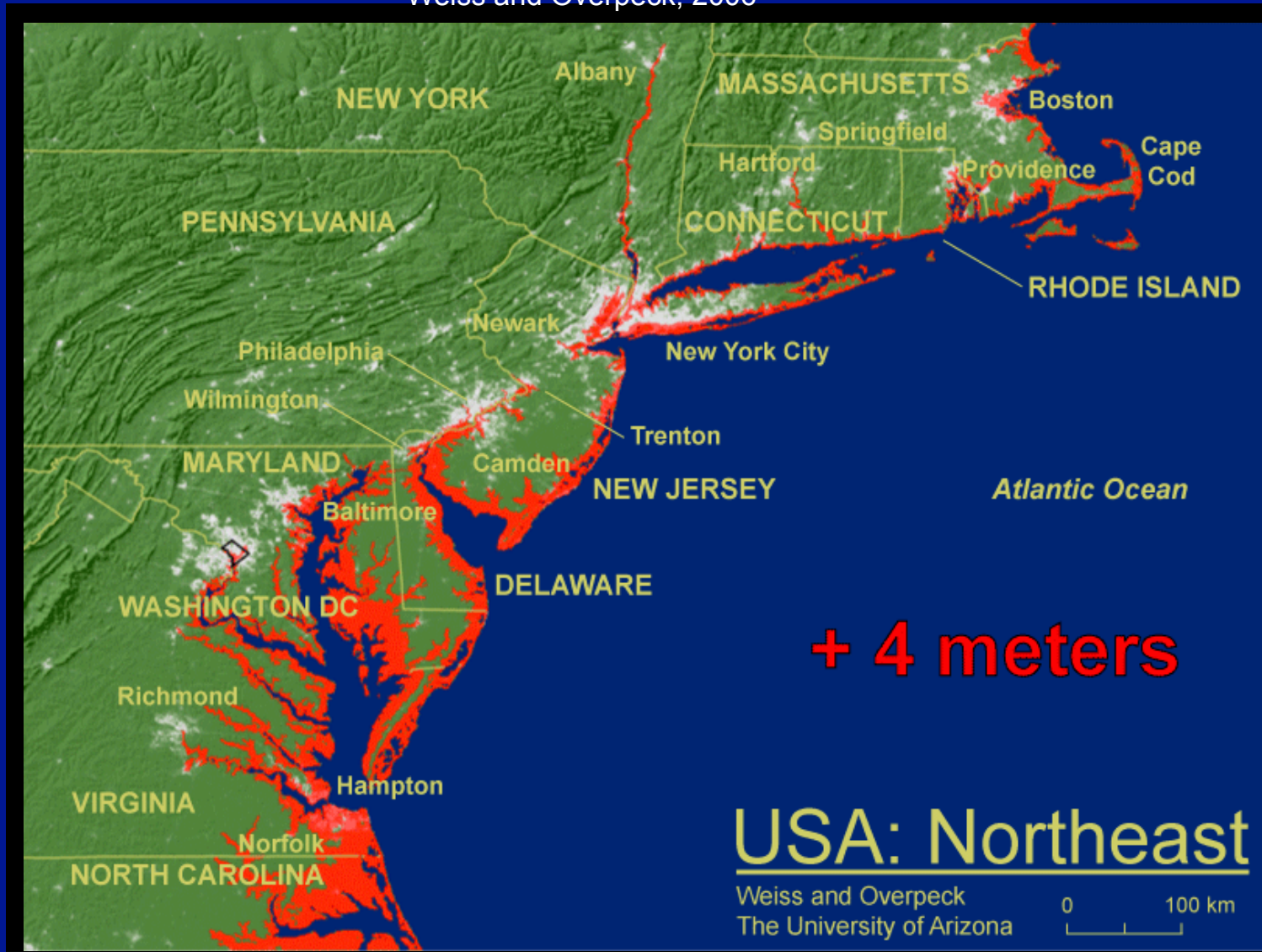
New Moore Island goes under in March 2010



# Inundation

Inundation from Four Meter Sea Level Rise (or, 1m rise + 3m storm surge)

Weiss and Overpeck, 2006





# Hurricane Sandy

12' surge  
tides+storm

72 people  
killed

\$50 billion  
in damages



# Impact on Ski Industry

- In the US skiing is a \$20B industry
- Ski Seasons have shortened by 1 day/year for the last 30 years
- 2 close each year on average since 2000 (30% are at risk to close)
- Some resort to snowmaking
  - Expensive
  - Requires lots of water
  - Requires lots of energy
- In New Mexico, many ski areas can't open until after Xmas
- In recent years, some resorts never opened



# What We Can Do

## REDUCE CO<sub>2</sub> EMISSIONS

1. Is it Achievable?
2. Action Is Essential at Every Level
  - Individual
  - Corporate
  - Local
  - State
  - Federal
  - International
3. Critical Steps

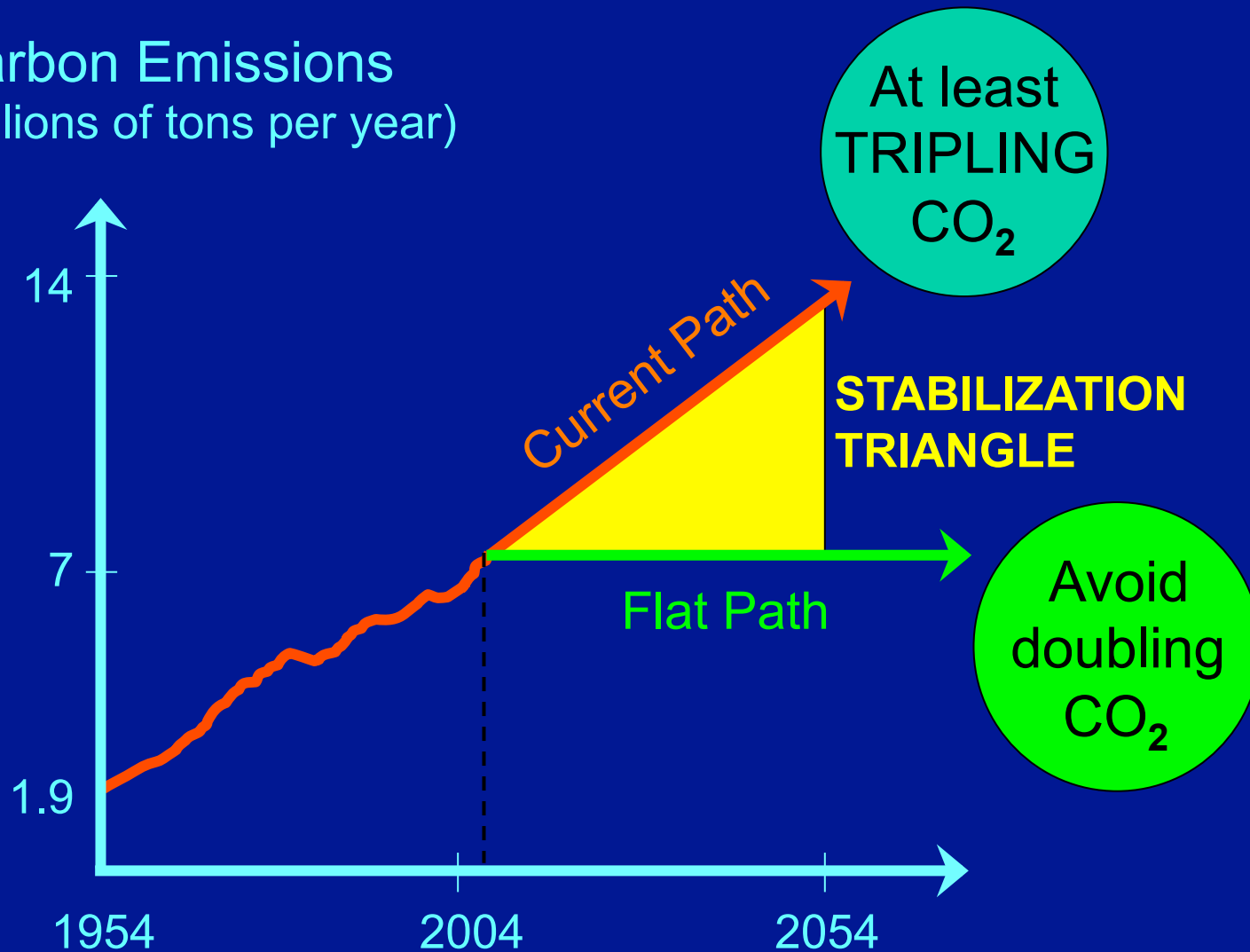


Go Electric!

# Is it Achievable?

What We Can Do

Carbon Emissions  
(Billions of tons per year)



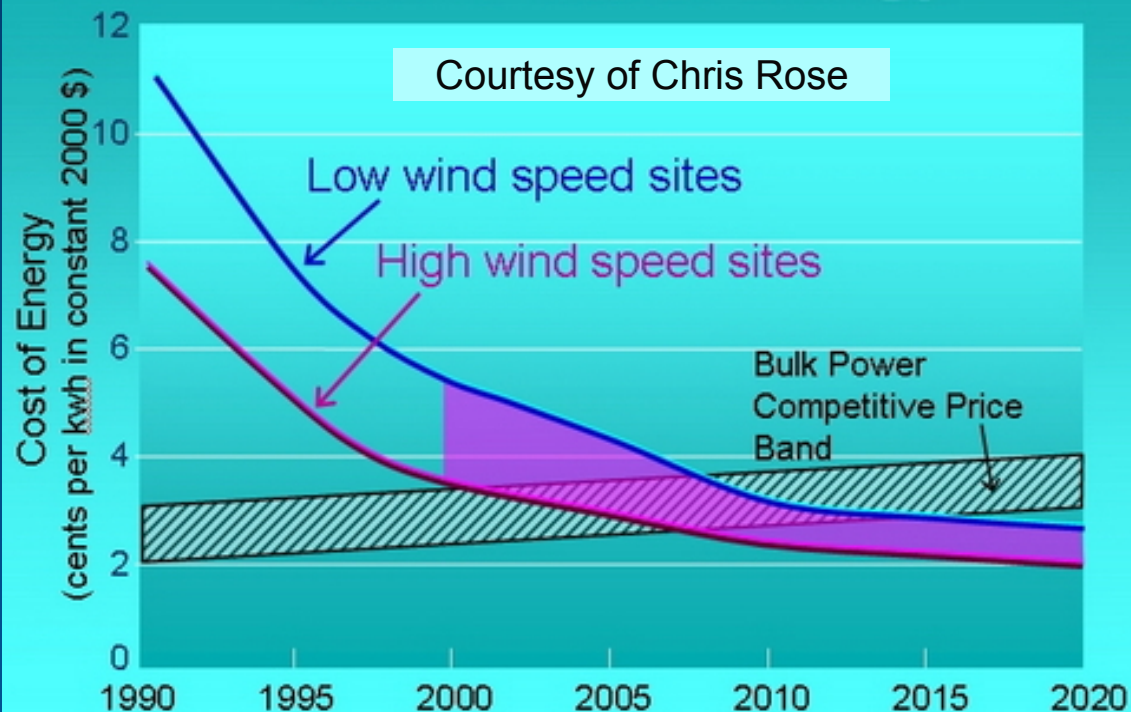


# Wind Power



NM wind:  
780 MWatt  
as of 2014

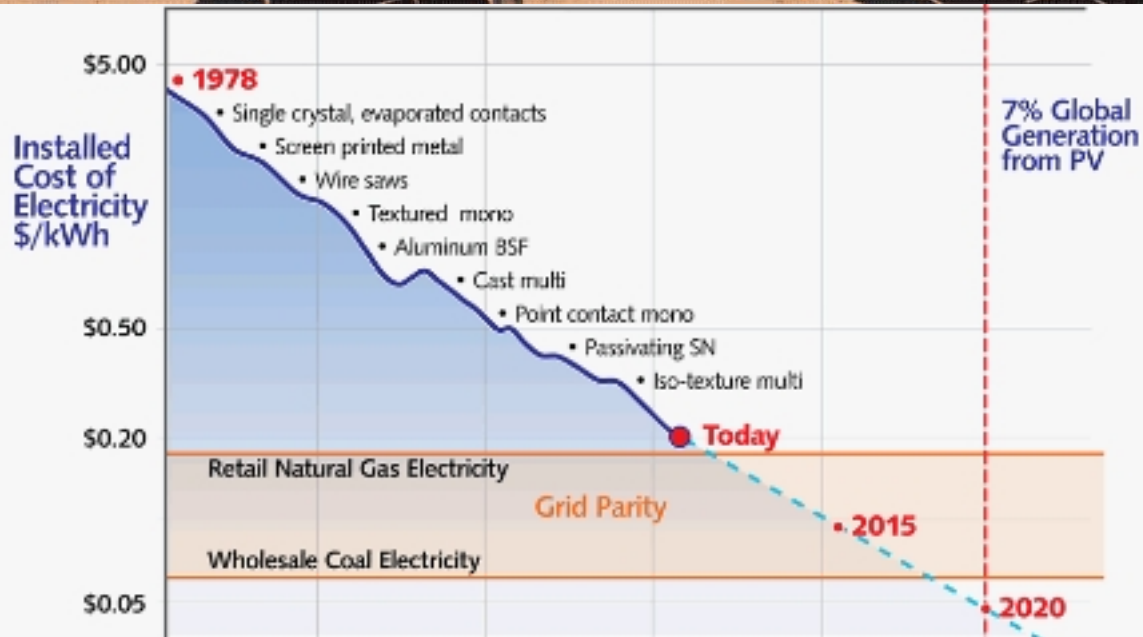
## Wind Cost of Energy





# Solar Power

What We Can Do



Source: Professor Emanuel Sachs, Massachusetts Institute of Technology.  
\* Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 10% capacity factor and 7% discount rate.

NM solar:  
365 MWatt in 2015

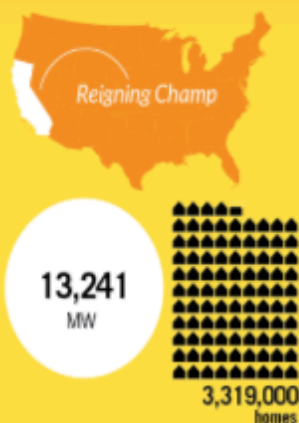


# TOP 10 SOLAR STATES

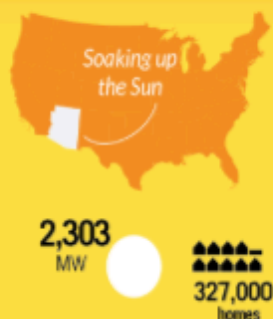
State ranking based on the amount of cumulative solar electric capacity installed (as of December 2015)



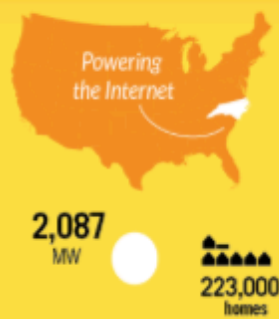
## 1 California



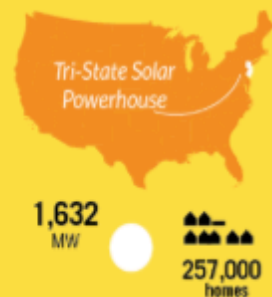
## 2 Arizona



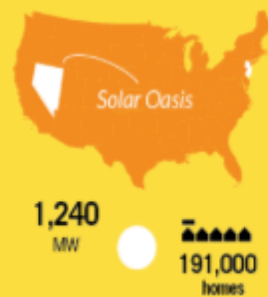
## 3 North Carolina



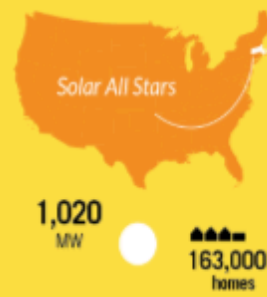
## 4 New Jersey



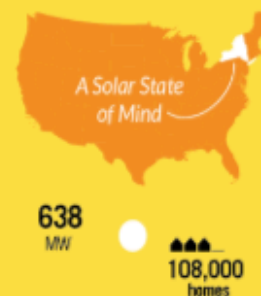
## 5 Nevada



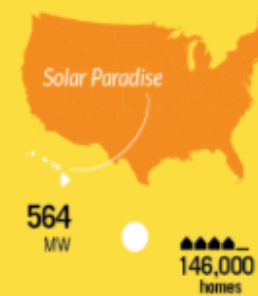
## 6 Massachusetts



## 7 New York



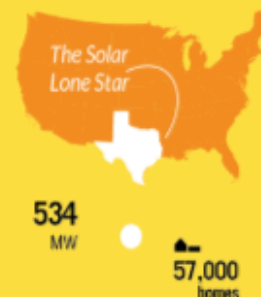
## 8 Hawaii



## 9 Colorado



## 10 Texas



● Cumulative Installed Solar Capacity (MW)<sup>1</sup>  
 ▲ Homes powered by solar<sup>2</sup> (35,000 homes)  
 (an estimate of the number of homes powered per megawatt of solar capacity installed, including both photovoltaic and concentrating solar power)



# TOP 10 SOLAR STATES REMIXED



Number of Solar Jobs<sup>3</sup>

1	75,598	California
2	15,095	Massachusetts
3	8,764	Nevada
4	8,250	New York
5	7,071	New Jersey
6	7,030	Texas
7	6,922	Arizona
8	6,560	Florida
9	5,950	North Carolina
10	4,998	Colorado



Solar Capacity Per Capita (watts/person)<sup>4</sup>

1	429	Nevada
2	394	Hawaii
3	338	California
4	337	Arizona
5	206	North Carolina
6	182	New Jersey
7	175	New Mexico
8	171	Vermont
9	150	Massachusetts
10	99	Colorado

# Measuring Your Carbon Footprint

Major Carbon Contributors:

- Electric Consumption
- Gas/Heating Oil Consumption
- Car and Miles Driven
- Miles Flown
- Recreational Vehicle Use

Average Footprint is 30,000 pounds



# Making a Difference as an Individual

## Conservation Measures:

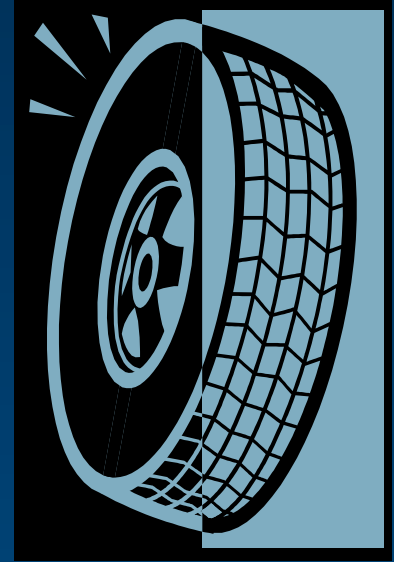
- Walk, bike, ride public transit, or carpool
- Make sure your tires are fully inflated and your car tuned up
- Lower your water heater and home thermostats
- Run your dishwasher only with full loads
- Reduce your shower length and temperature
- Buy locally produced food
- Unplug appliances not in use
- Turn off lights when leaving a room
- Use recycled paper
- Reuse or recycle as much as you can
- Cut down on consumerism
- **Encourage elected officials to address global warming on state/national level.**





# Conservation: Three Examples

- Unplug Appliances: Vampires!
  - 43 billion kWh lost/year in US
  - Est: 1,000 lbs/year/person
- Pump Up Tires:
  - 4 million gallon of gas wasted daily in US
  - Extends life of tires by 25%
  - Est: 1,000 lbs/year/person
- Bike to work
  - 3/week
  - Est: 5,000 lbs/year/person





# Clicker Question:

Sunlight absorbed by the Earth's surface is reemitted in the form of?

A: radio waves

B: infrared radiation

C: visible radiation

D: ultraviolet radiation

E: X-ray radiation

# Clicker Question:

What steps are you willing to take to reduce your carbon dioxide footprint?

A: Walk/bike/bus to work

B: Unplug appliances when not in use

C: Replace light bulbs with compact fluorescents

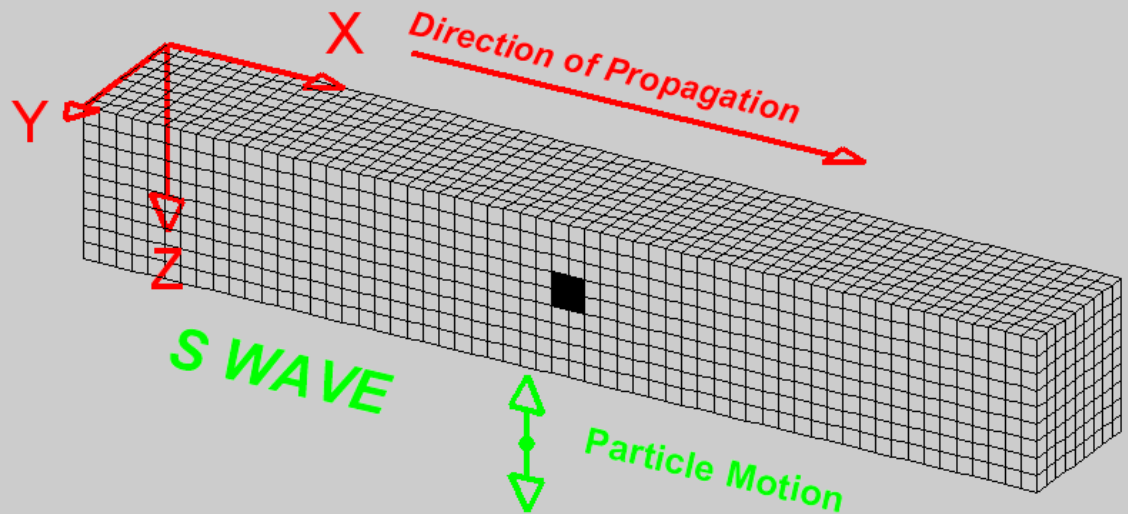
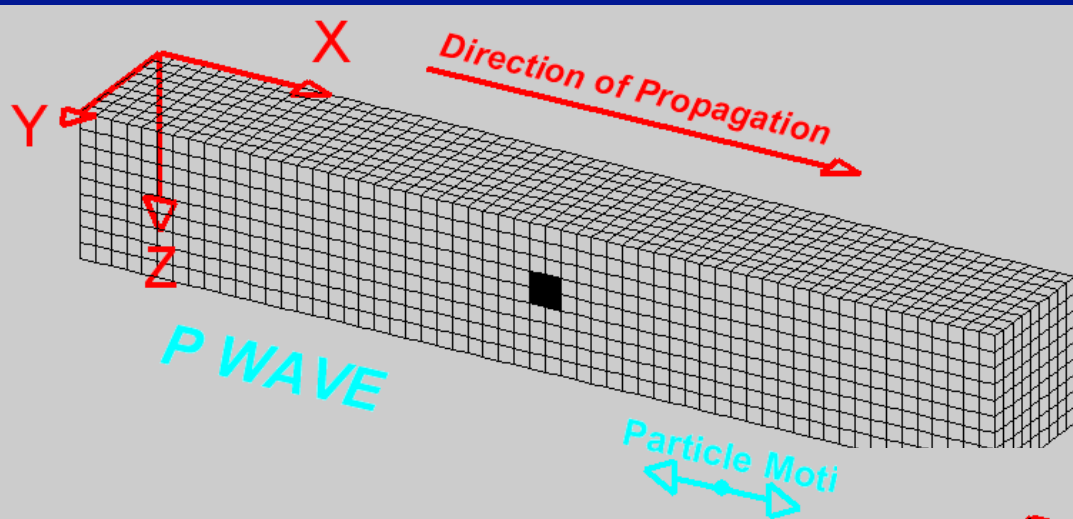
D: Wash clothes in cold or warm water

E: Buy a hybrid or electric vehicle

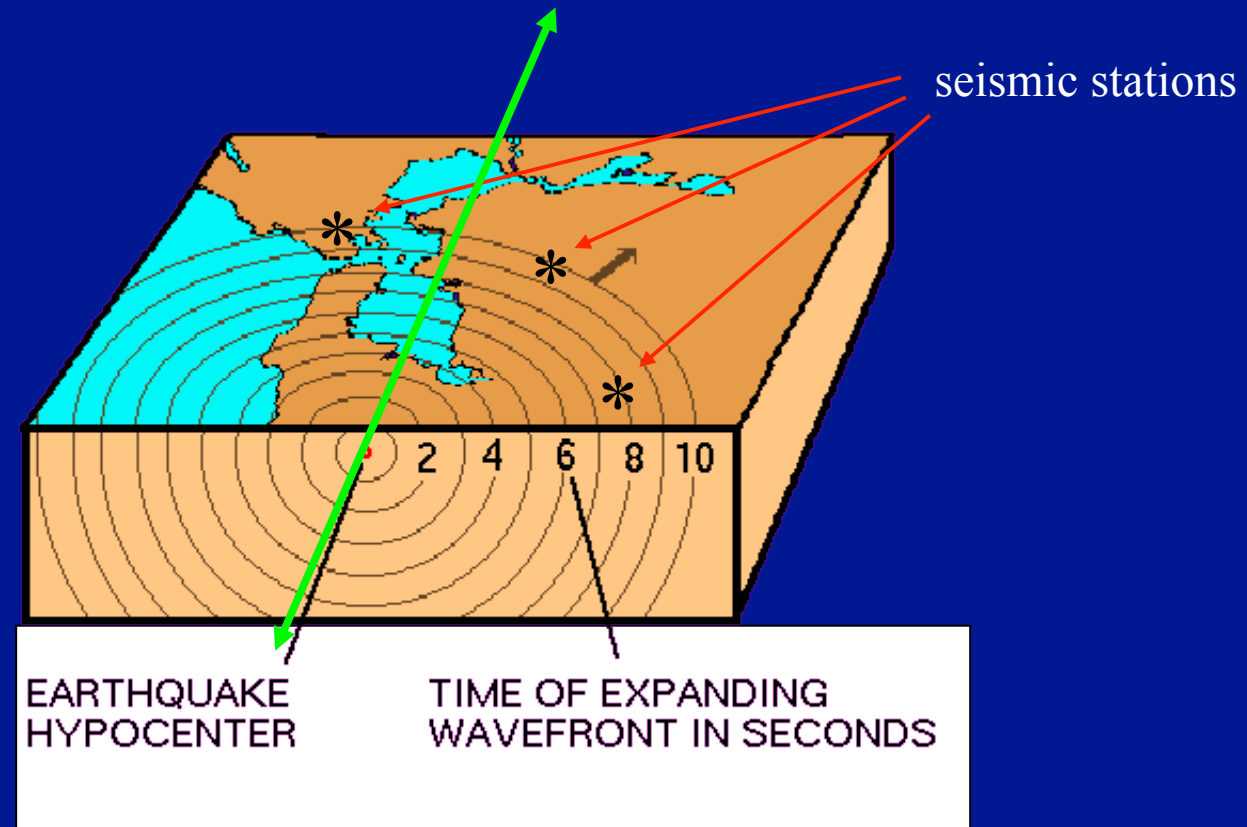
# Earthquakes

They are vibrations in the solid Earth, or seismic waves.

Two kinds go through Earth, P-waves ("primary") and S-waves ("secondary"):



How do they measure where Earthquakes are centered?





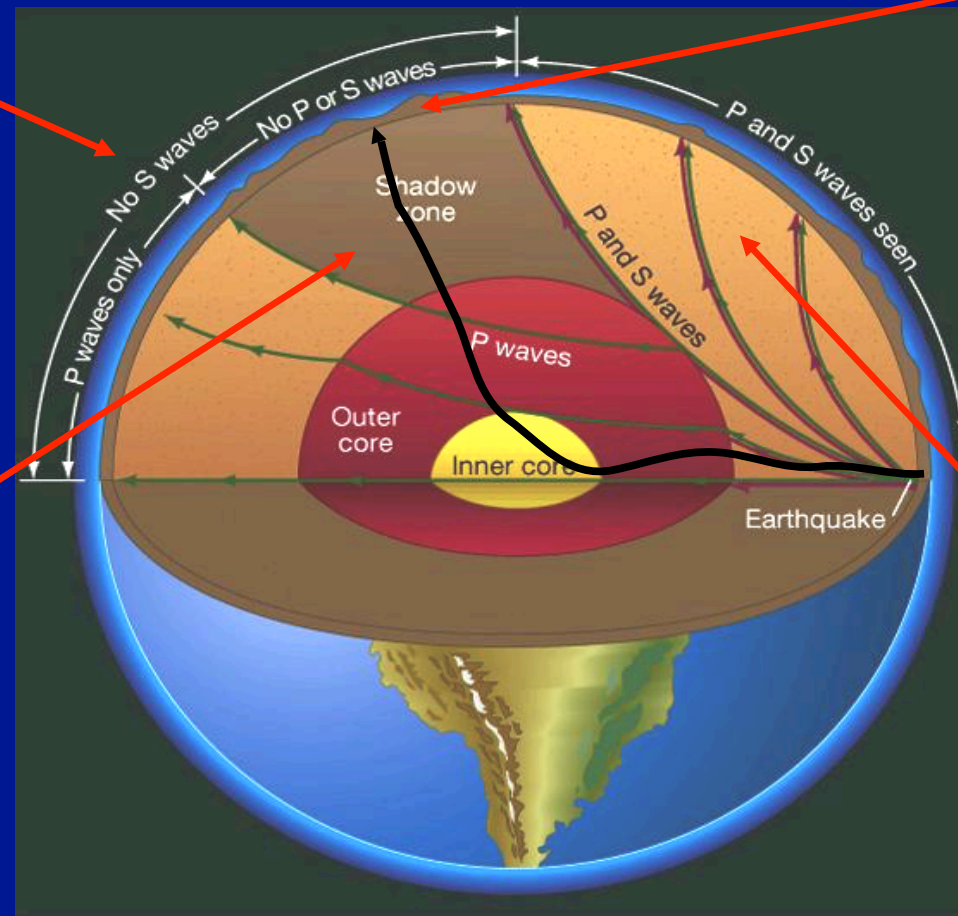
Like all waves, seismic waves bend when they encounter changes in density. If density change is gradual, wave path is curved.

S-waves are unable to travel in liquid.

Thus, measurement of seismic wave gives info on density of Earth's interior and which layers are solid/molten.

Zone with no S waves:  
must be a liquid core  
that stops them

But faint P waves  
seen in shadow zone,  
refracting off dense  
inner core



No P waves too:  
they must bend sharply  
at core boundary

Curved paths of  
P and S waves:  
density must slowly  
increase with depth

## Earth's Interior Structure

Average density	5.5 g/cm <sup>3</sup>
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Crust	3 g/cm <sup>3</sup>
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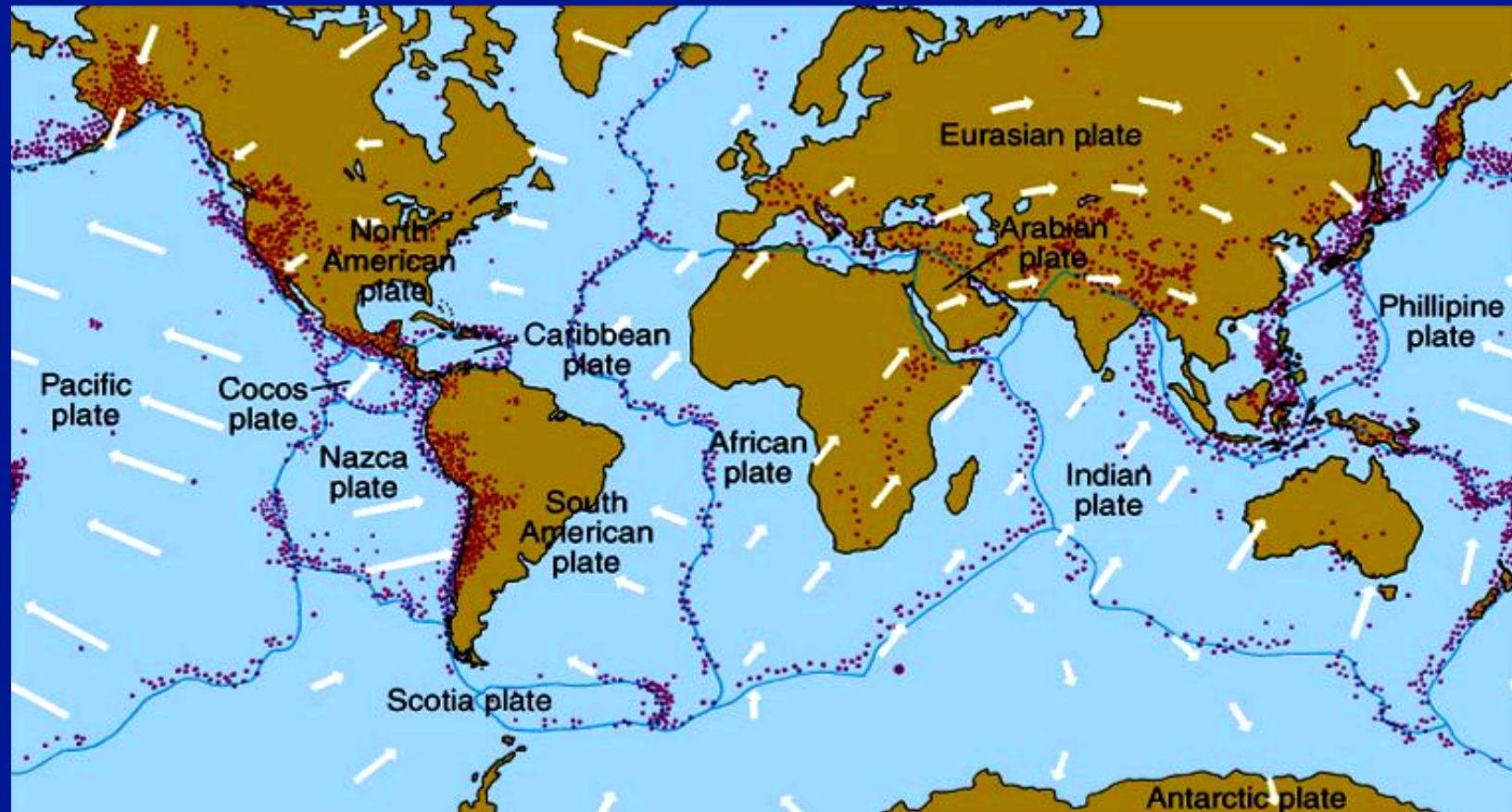
Mantle	5 g/cm <sup>3</sup>
--------	---------------------

Core	11 g/cm <sup>3</sup>
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Density increases with depth => "differentiation"

Earth must have been molten once, allowing denser material to sink, as it started to cool and solidify.

Earthquakes and volcanoes are related, and also don't occur at random places. They outline plates.



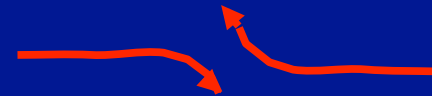
Plates moving at a few cm/year. "Continental drift" or "plate tectonics"

## When plates meet...

- 1) Head-on collision  
(Himalayas)



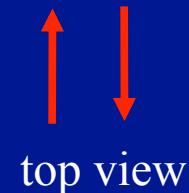
- 2) "Subduction zone"  
(one slides under the other)  
(Andes)



- 3) "Rift zone"  
(two plates moving apart)  
(Mid-Atlantic Ridge)



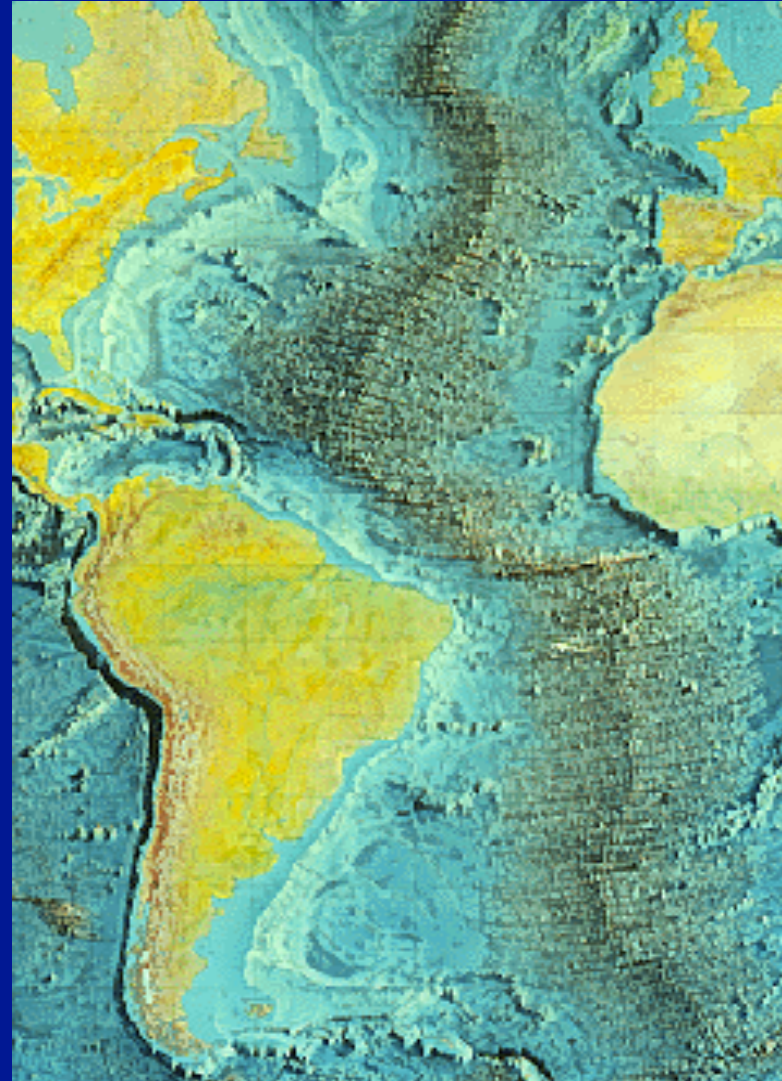
- 4) They may just slide past each other  
(San Andreas Fault)



=> mountain ranges, trenches, earthquakes, volcanoes

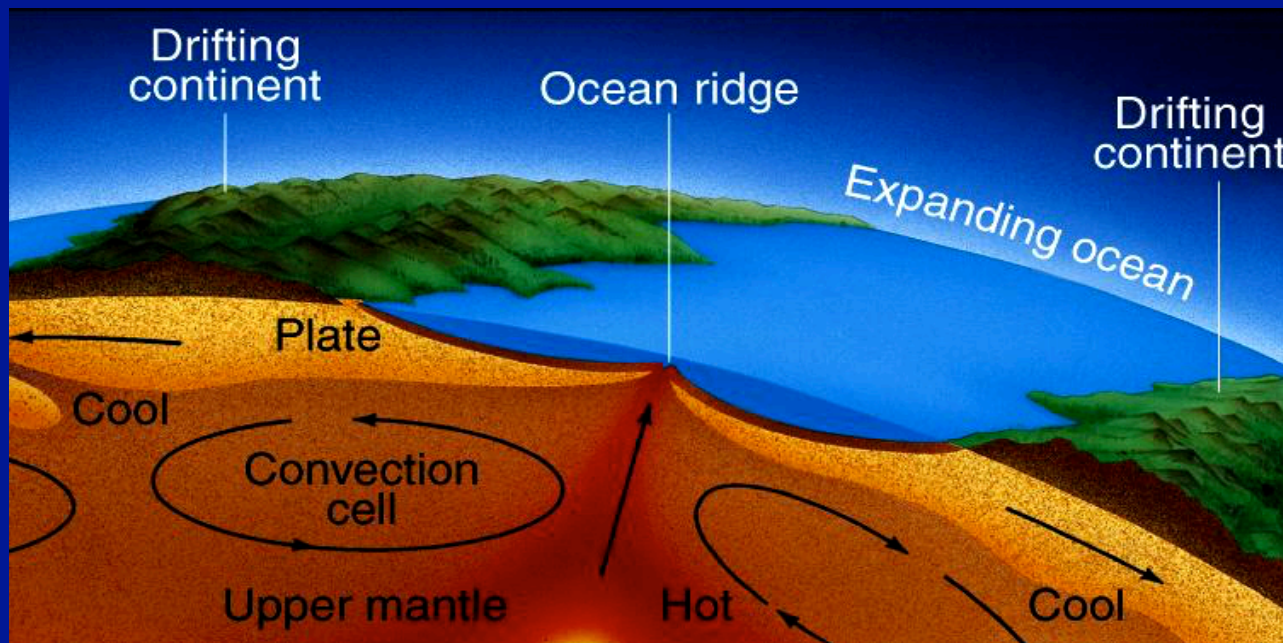


The Mid-Atlantic Ridge is a  
rift zone.



## What causes the drift?

Convection! Mantle slightly fluid and can support convection. Plates ride on top of convective cells. Lava flows through cell boundaries. Earth loses internal heat this way.



Cycles take  $\sim 10^8$  years.

Plates form lithosphere (crust and solid upper mantle).  
Partially melted, circulating part of mantle is asthenosphere.

Pangaea Theory: 200 million years ago, all the continents were together!

