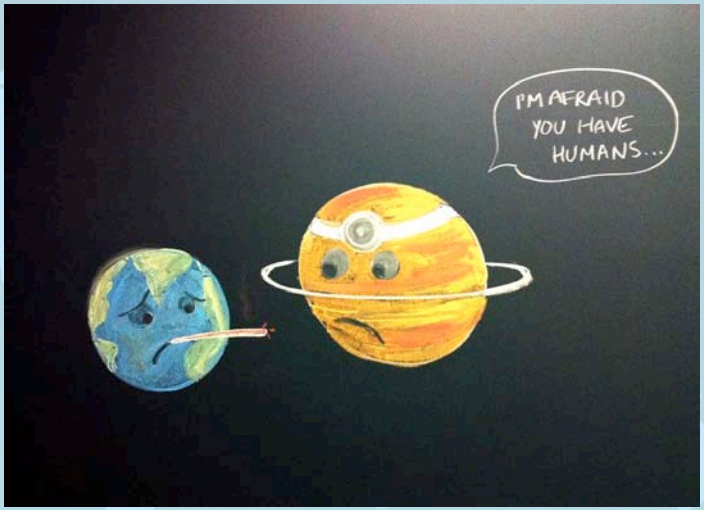
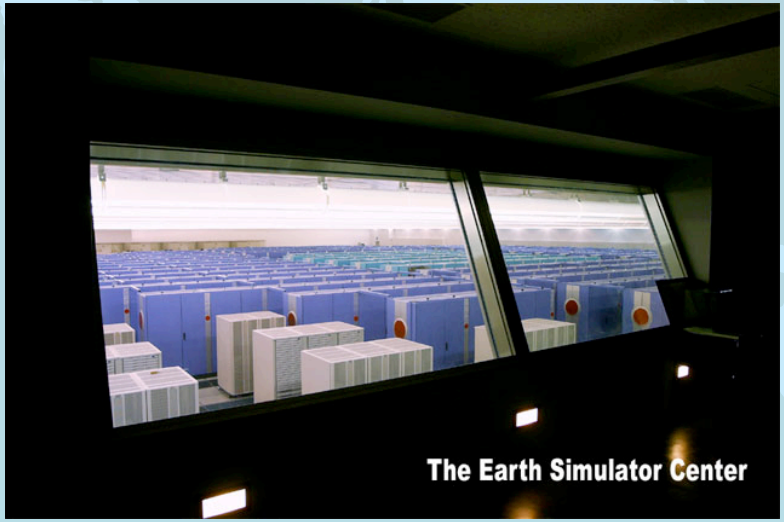


Is there a cure?

Lecture 28: Future Global Warming
Modeling Climate Change



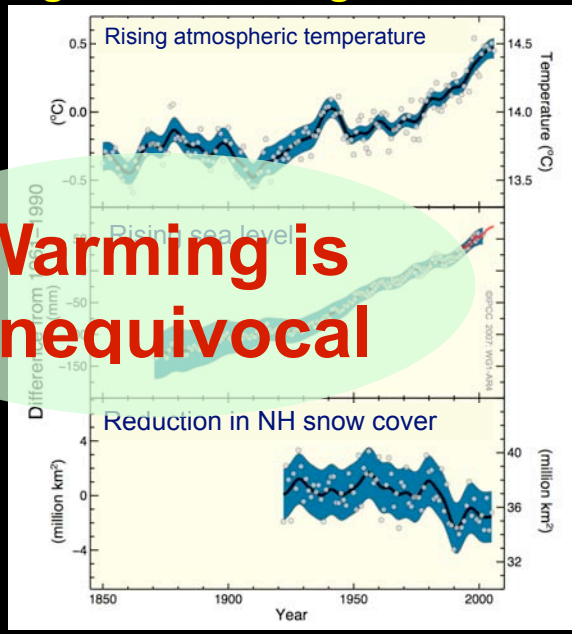
Previous Lecture Global Warming

"This past year 2010 tied for the warmest year on record" NASA.

Many Changes Signal A Warming World

And……

- Atmospheric water vapor increasing
- Glaciers retreating
- Arctic sea ice extent decreasing
- Extreme temperatures increasing
- ……



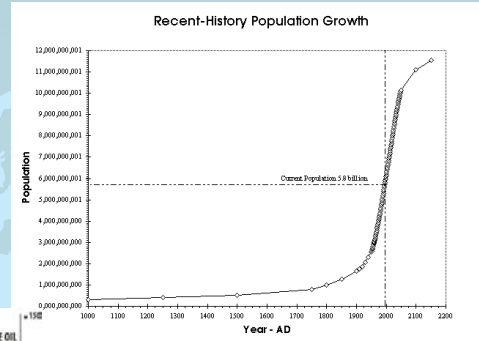
Warming is Unequivocal

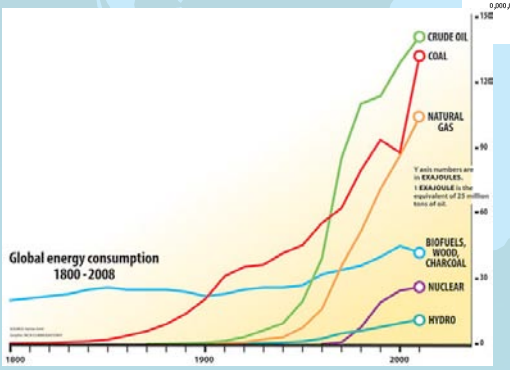
IPCC WG1 (2007)

The Human Factor

The Human Factor

Is Global Warming linked to population and industrialization?





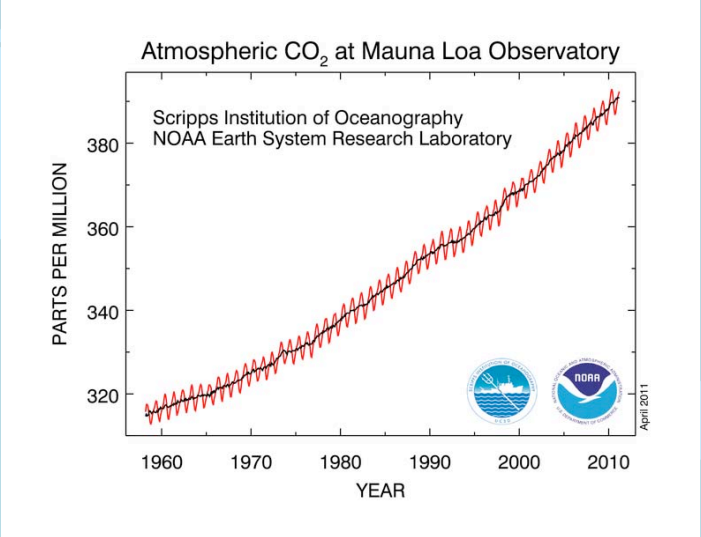
Global trend in energy consumption.

Anthropogenic Climate Change will Persist for a Long Time

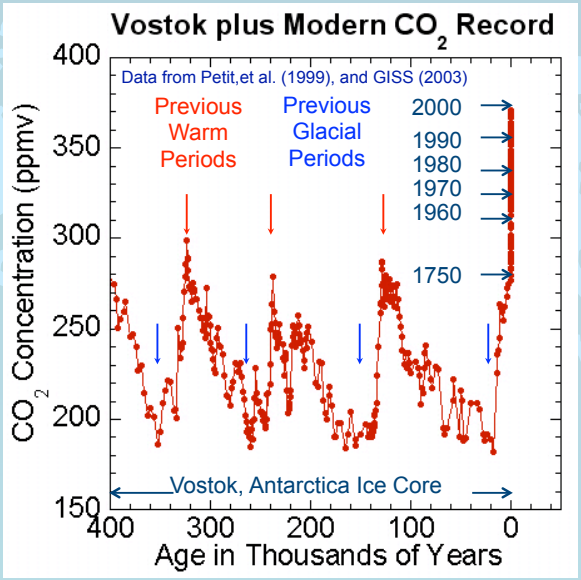
Gas	CO_2	CH_4	N_2O	CFC's
Atmospheric lifetime	50-200 yr	12	120	50-300

- Water vapor has a residence time in the atmosphere of only a few weeks. Therefore, it is a slave (positive feedback) to the other longer lived greenhouse gases.

CO_2 Gas Concentrations



Famous carbon dioxide data from Mauna Loa, Hawaii.



What is causing the CO_2 to increase in the Atmosphere?

A: Fossil Fuel Burning: Coal, Oil and Natural Gas.

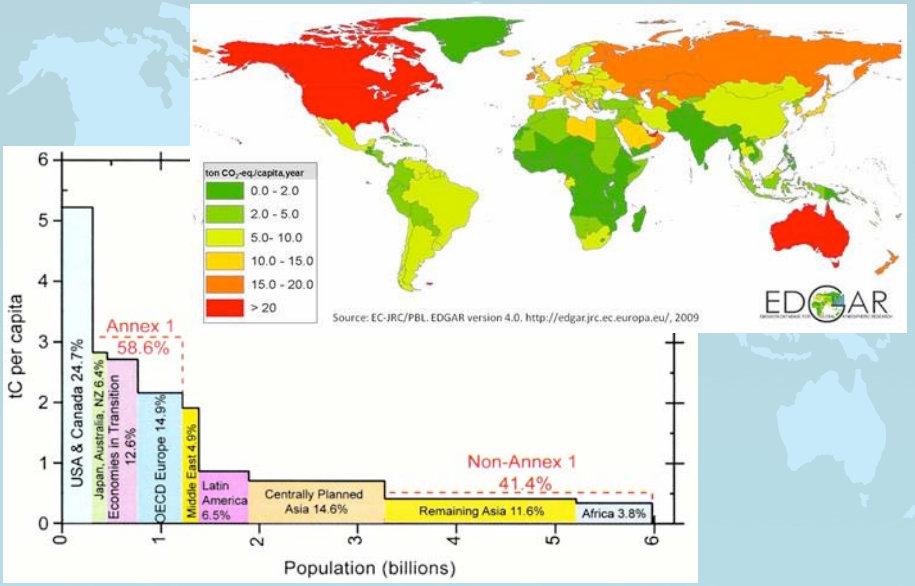
How do we know that?

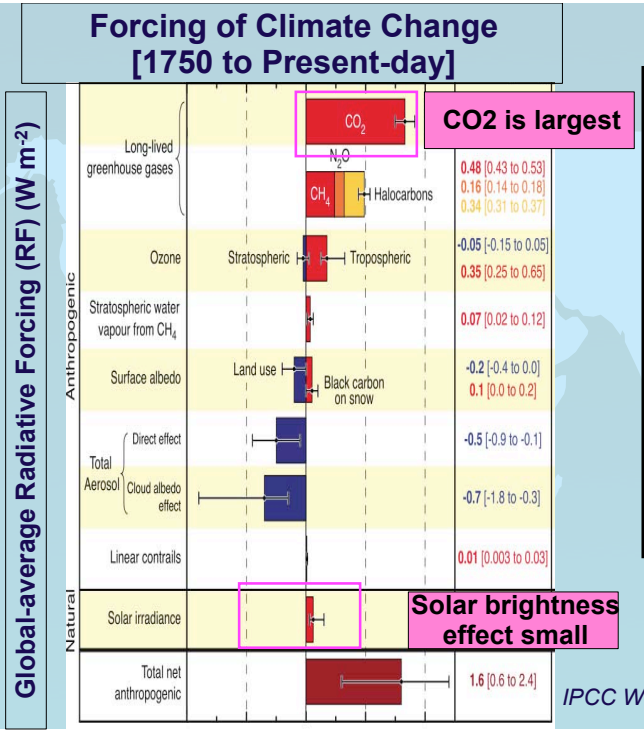
- Circumstantial Evidence of timing of increase with rise of fossil fuel use.
- Smoking gun evidence of isotopic studies.

The Carbon Isotope Evidence

- The Carbon 14 isotope is produced in the atmosphere by cosmic rays.
- C_{14} is incorporated into CO2 and taken up in plants during photosynthesis
- Dead plant matter is used to make Fossil Fuels
- C_{14} is radioactive and decays with a half life of ~5,700 years
- Since the plant matter in fossil carbon fuels is millions of years old, it contains no C_{14}.
- C_{14} is decreasing with time in the atmosphere at the right rate to be explained by fossil fuel burning.
- This is strong evidence that the new carbon in the atmosphere in the form of CO_2 is coming from fossil fuel burning.

Greenhouse Gas Emitters

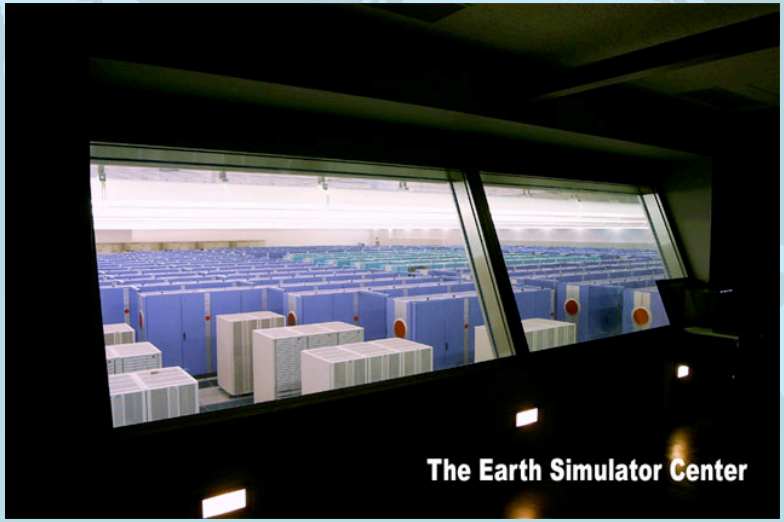




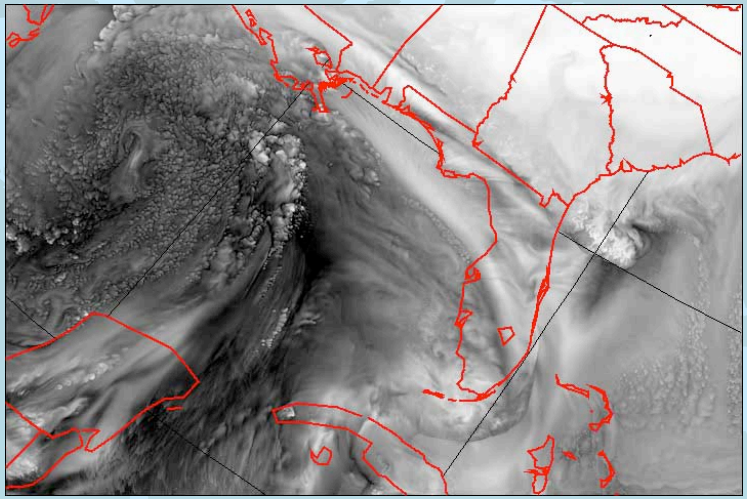
Carbon dioxide is causing the bulk of the forcing, and it lives a long time in our atmosphere (some of it lives for more than 1000 years). Every year of emission means a commitment to climate change for more than 30 generations.

IPCC WG1 (2007)

Future Global Warming Modeling Climate Change

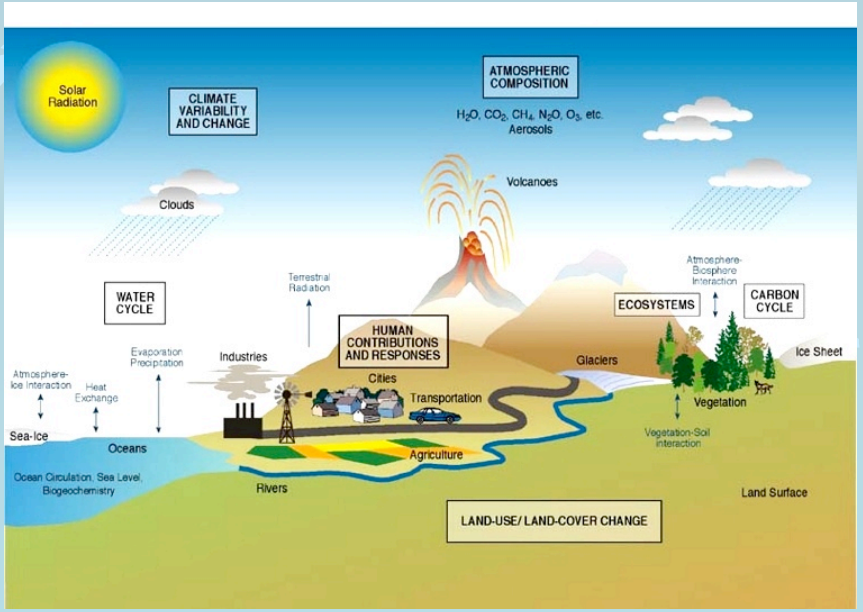


Modeling Global Warming

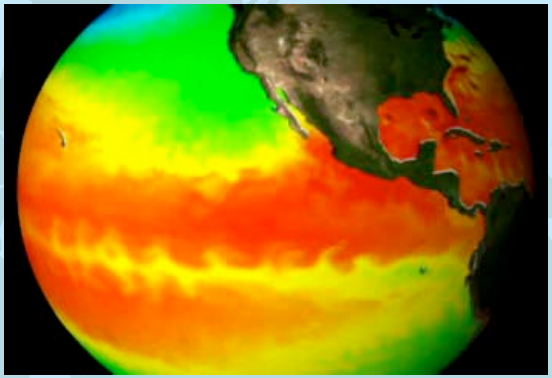


What the Bleep do we Know About Global Warming?

The Complexity of the Climate System

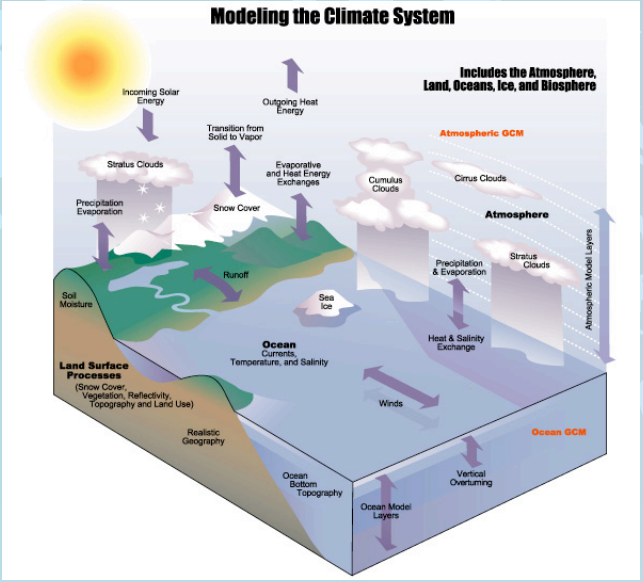


Modeling Climate Change requires Modeling the Oceans

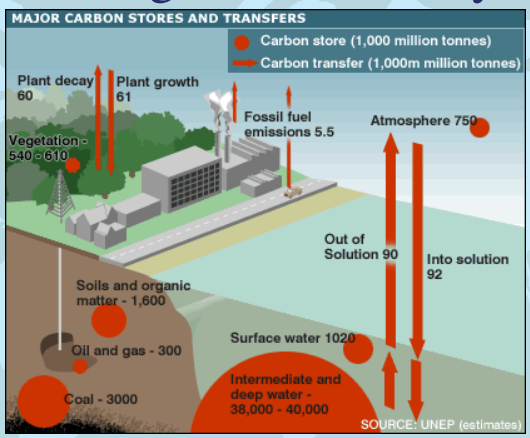


Modeling climate change means modeling the ocean circulation.

Modeling the Water Cycle

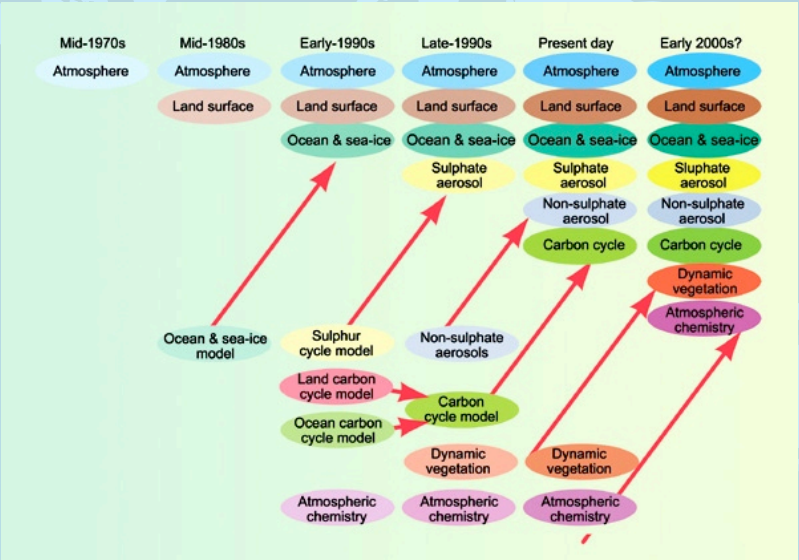


Modeling the Carbon Cycle

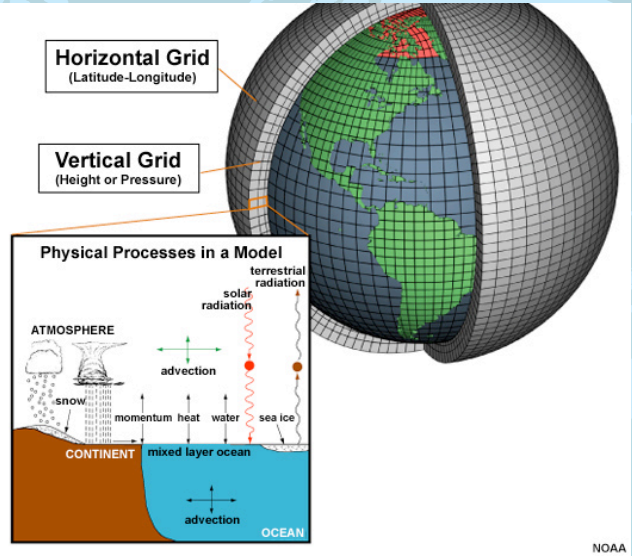


- Some man-made CO2 goes (in the short-term) from the atmosphere to vegetation, surface ocean.
- Long term sink is deep ocean. It's very slow.

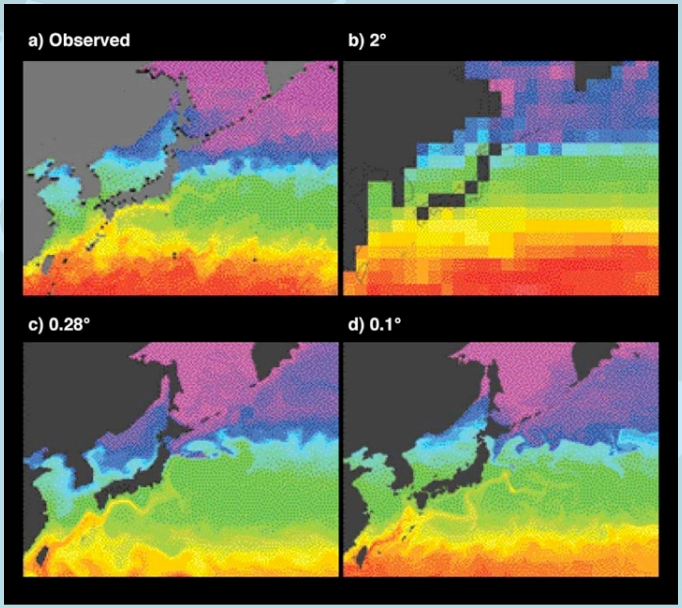
Adding Complexity



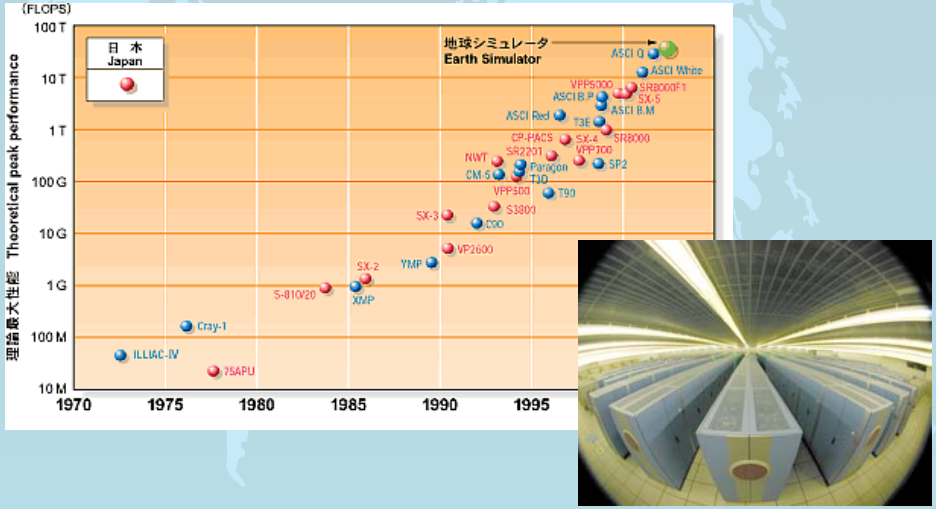
Global Model Grid has 4 Dimensions



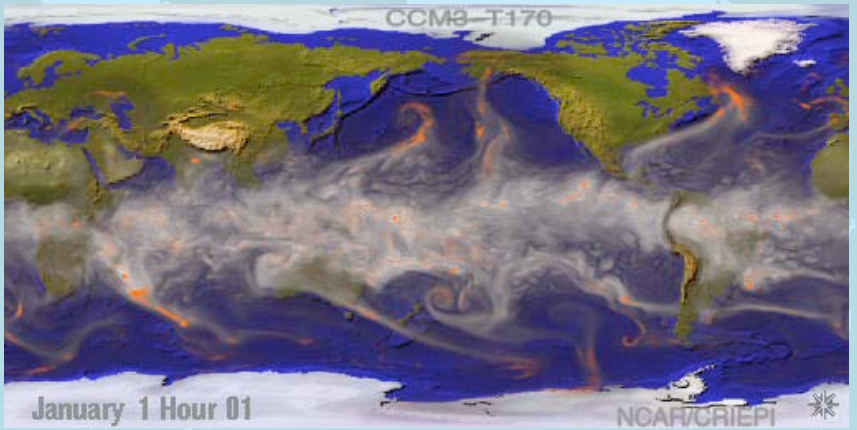
Improving Climate Change Model by Adding Resolution



Modeling Climate Change requires the fastest super computers

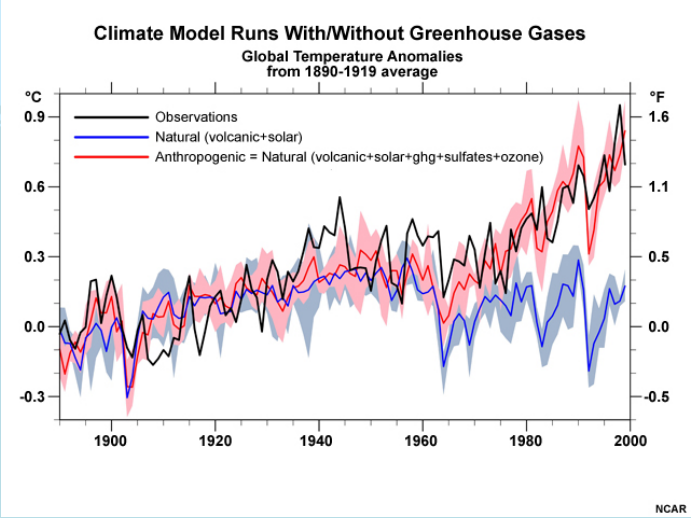


Global Simulation showing Tropical - Extratropical Interaction

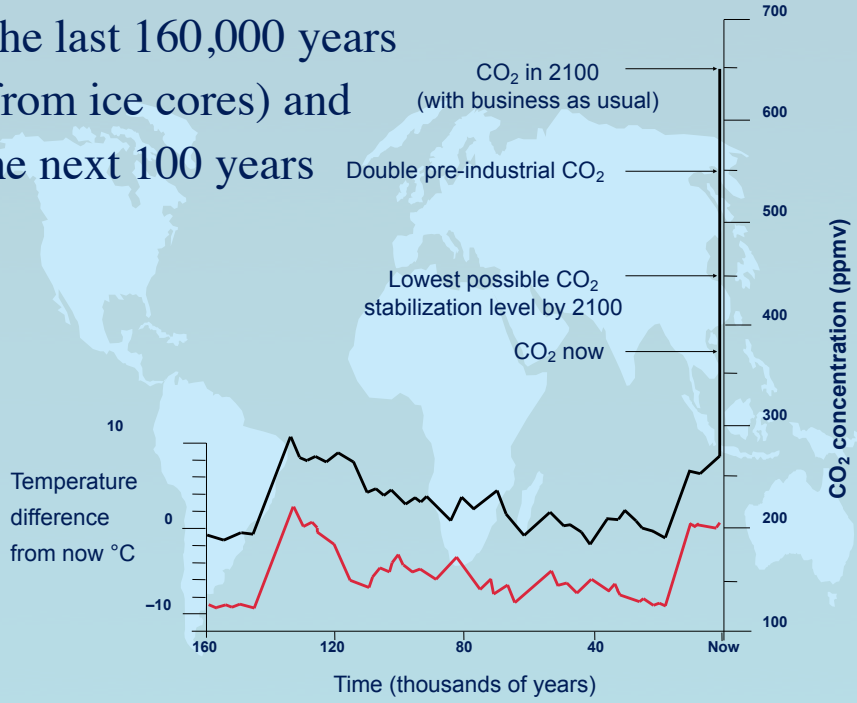


Water Vapor is shown in white and precipitation in orange.

Climate Change with and without Greenhouse Gases

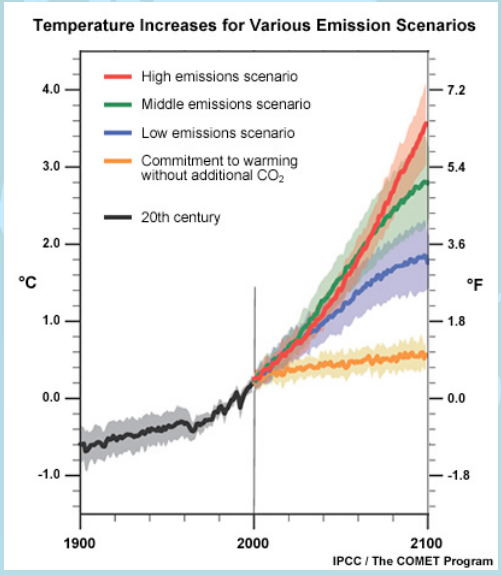


The last 160,000 years (from ice cores) and the next 100 years

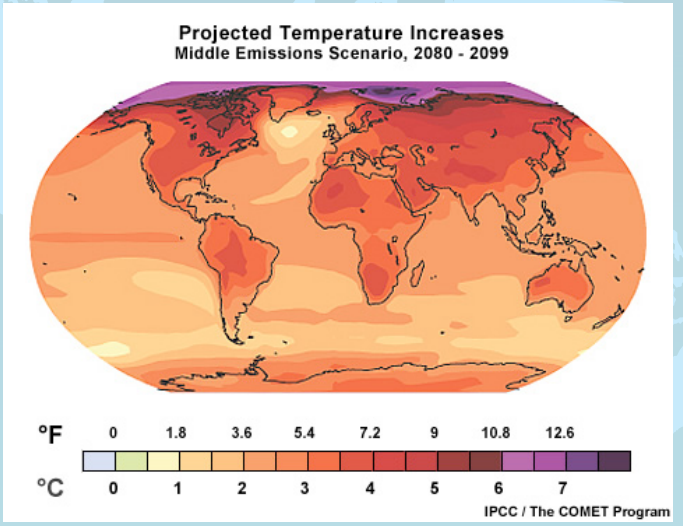


Future temperature trends for different responses to global warming

Variations of the Earth's surface temp., 1900 to 2100



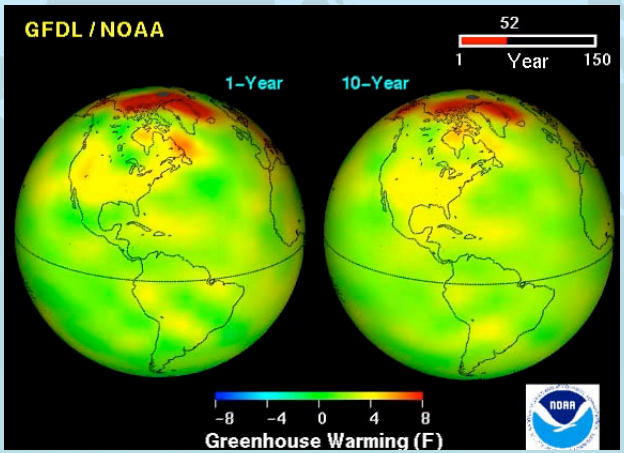
Future Temperature for Middle Emission Scenario



Surface Temperature – 2080 to 2099

Future Global Warming is Non- Uniform

- Change in surface temperatures due to a doubling of CO_2 concentrations and anthropogenic sulfur emissions
- Most land areas will warm faster than the global average

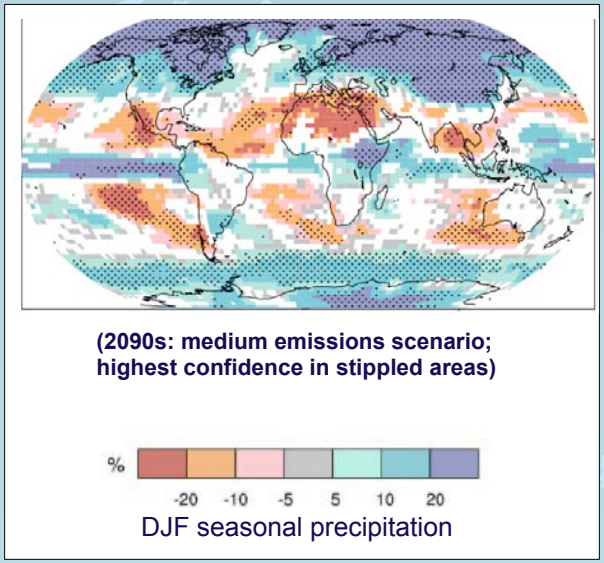


A World of Change: More Rain for Some, Less for Others

Regional changes (+/-) of up to 20% in average rainfall.

At mid to low latitudes, dry get drier, wet get wetter.

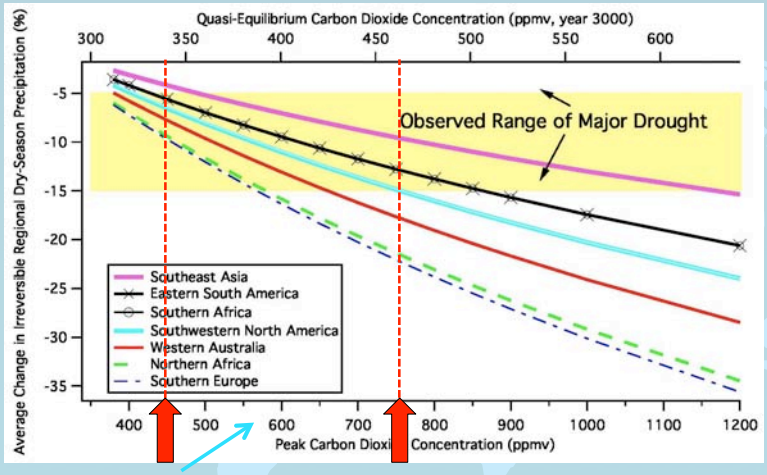
Dust bowl and other major droughts of the past: 5-15% less rain over 10-20 yrs.

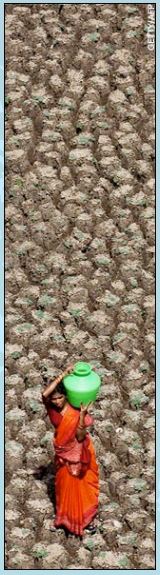


(2090s: medium emissions scenario; highest confidence in stippled areas)

IPCC WG1 (2007) SPM

Precipitation Change: How Far Will We Go?



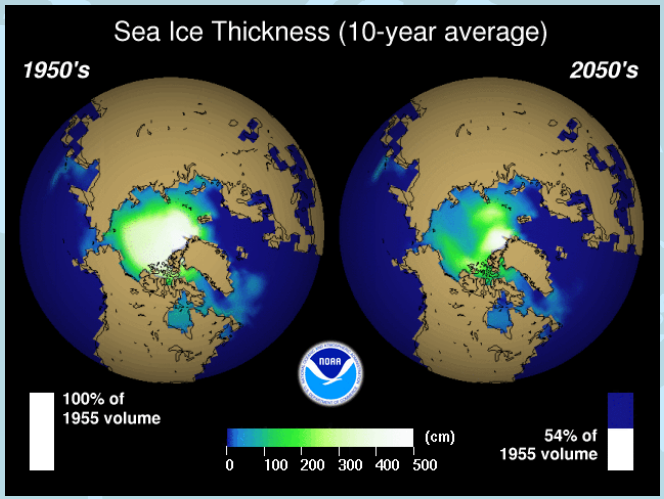


Best estimate of 21st century choices.

The longer we wait to act, the more rainfall change we will be locked into.

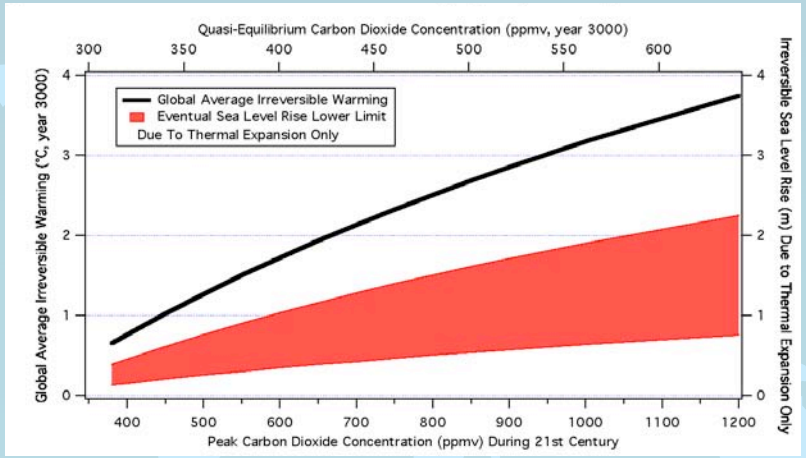
Solomon et al, PNAS, 2009

Future Global Warming Non- Uniform



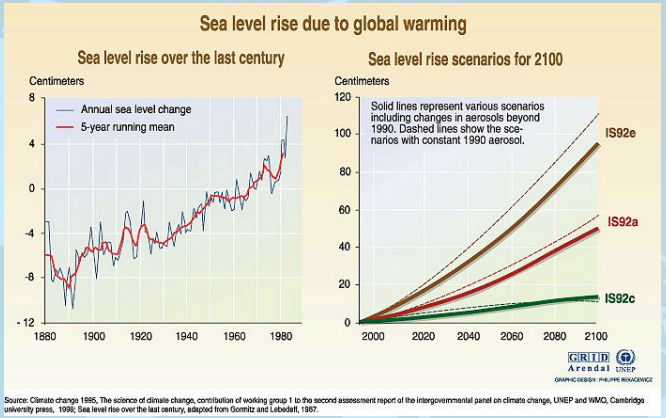
Most land areas and high latitudes will warm faster than the global average, resulting in melting and thinning of arctic ice sheets.

Irreversible Sea Level Rise: How Far Will We Go?



add glaciers
(0.2-0.7m)
add ice sheets?

Modeling Sea Level Rise

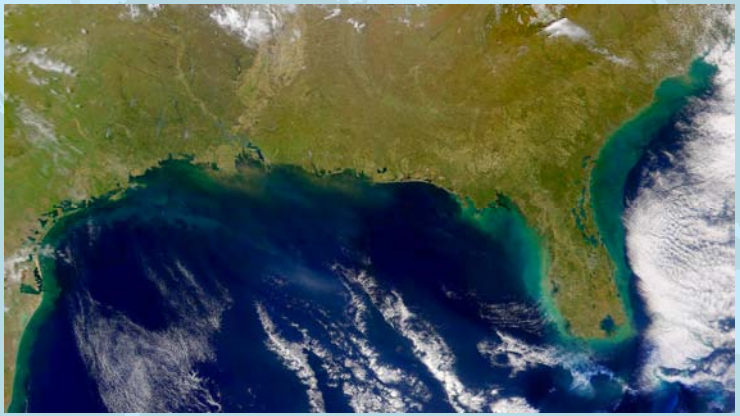


Thermal expansion of seas and melting of land ice expected to cause sea level rise of 0.1-0.9 m rise expected by 2100 depending on societies response to global warming.

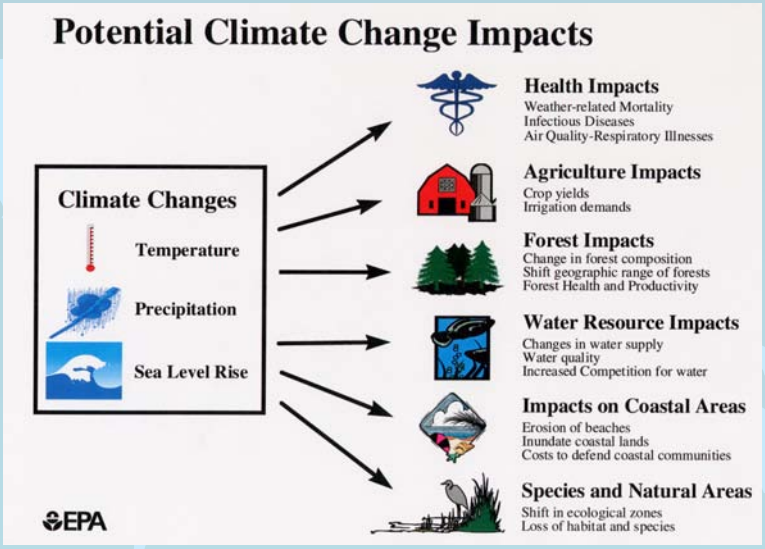
Sea-Level Rise

Should Greenland's Glaciers melt, it would result in a 20-meter rise in sea level.

Questions?

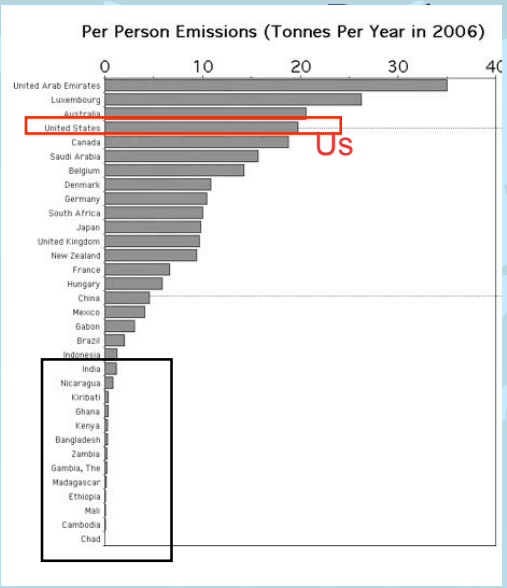


Global Warming – Some Implications



Under conditions of global warming, the troposphere will warm, the stratosphere will cool, rainfall patterns will change, and ocean surface temperatures and sea level will rise.

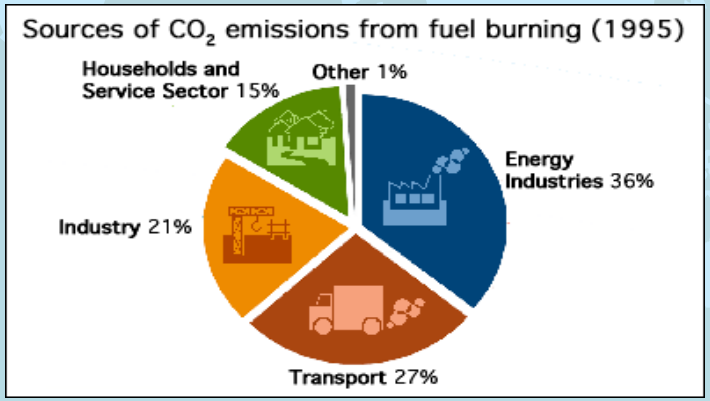
Carbon Dioxide Emission From Fossil Fuel



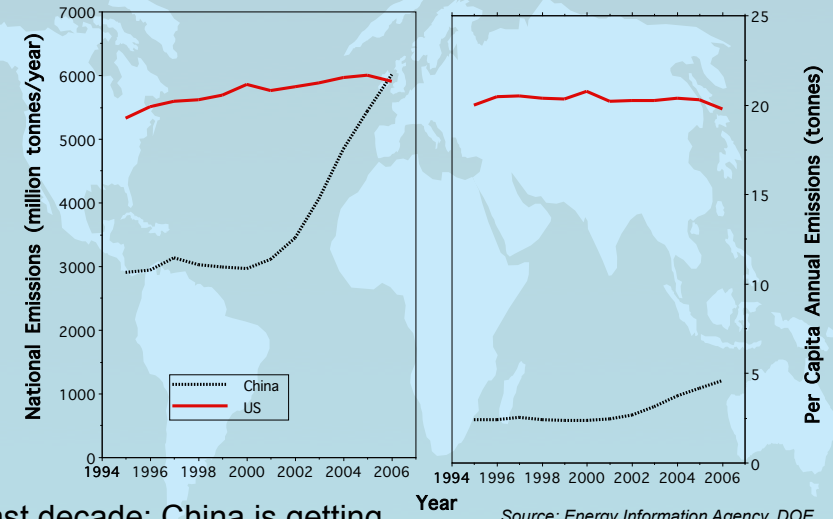
Who?

Source: Energy Information Agency, DOE

Why: Going, Doing, Making, Being Comfortable…..
In short, just about everything.



Changes in Total and Per Capita Emissions of Carbon Dioxide From Fossil Fuel Burning in China and the USA

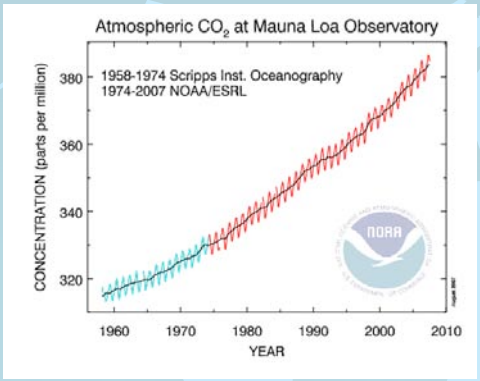


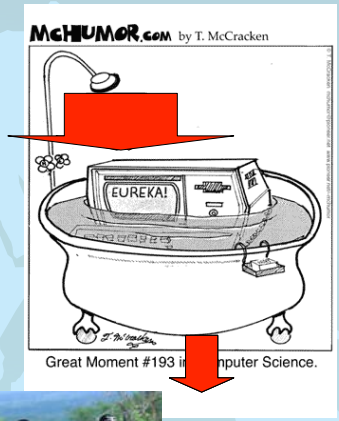
Source: Energy Information Agency, DOE

Last decade: China is getting richer, and emitting more CO_2

Kyoto Protocol?

Climate And Bathtubs: A Poorly-Understood Principle



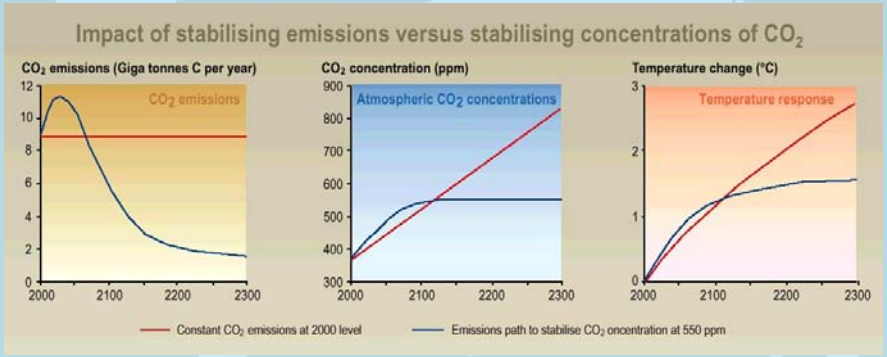


Stabilization of CO_2 would require 50% emissions reductions (for a few decades) and then 80%

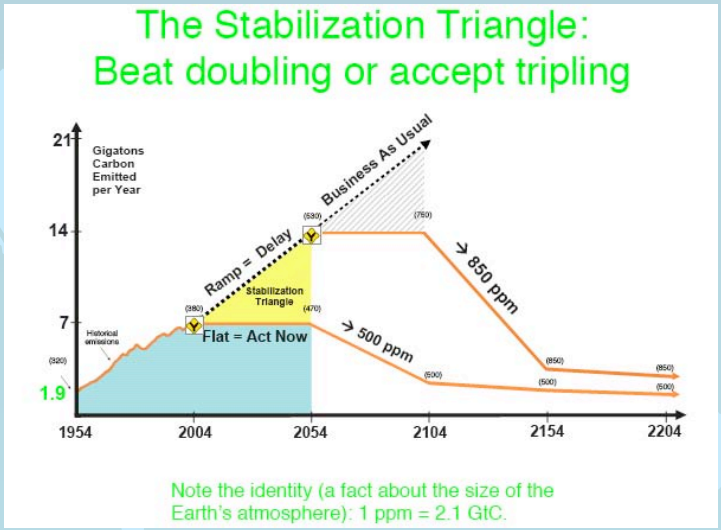
Geoengineering? Cool the planet? Real and 'artificial' trees?

5/6 of the people now emit 5x less per person than 1/6

Impact of Stabilizing CO_2



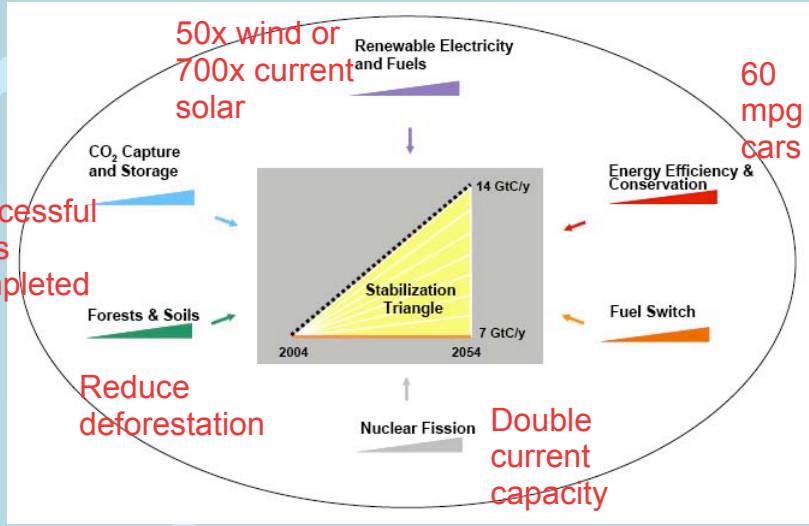
How Far Will We Go?



The longer we wait to act, the more climate change we will be locked into.

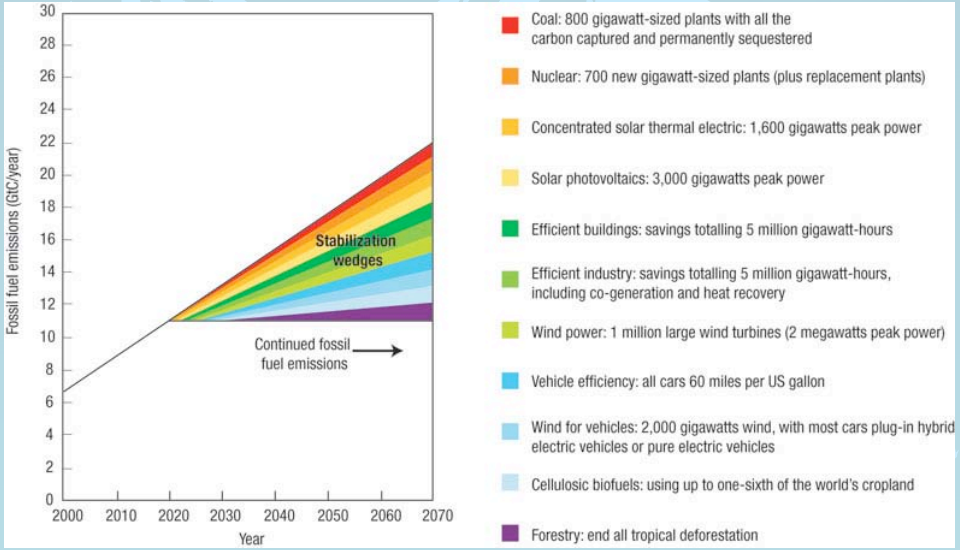
Image: Socolow and Pacala

Some Possible Future Choices: Just Illustrations



There are no silver bullets but there is much silver buckshot. Technology matters.

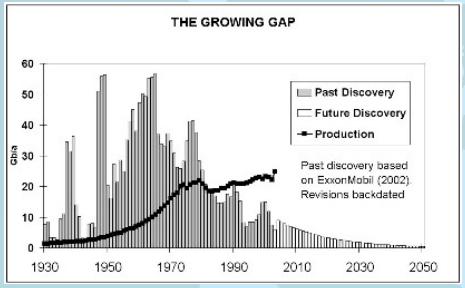
Stabilization Strategy



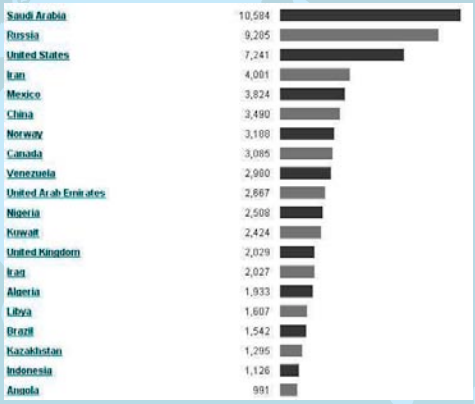
Climate and Energy Policy

- The International Energy Agency issued a warning stating that; "Current global trends in energy supply and consumption are patently unsustainable — environmentally, economically, and socially.
- One of the most fundamentally unsustainable facts of our economy is that each year, almost two trillion dollars are spent overseas, $324 billion more than other countries spend in the US. Oil imports, primarily from Saudi Arabia and Venezuela, make up approximately half of the import trade imbalance.
- Renowned investor Warren Buffett has observed "The U.S trade deficit is a bigger threat to the domestic economy than either the federal budget deficit or consumer debt..."

Oil Discovery vs Production

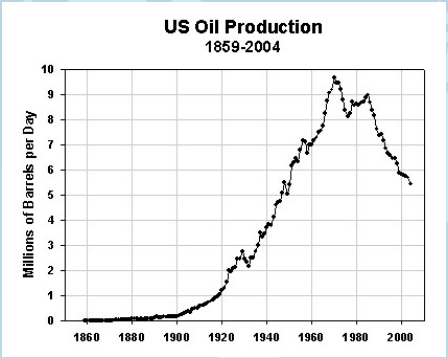


We now are discovering fewer than 8 billion barrels annually compared with the 28 billion barrels we consume. Suppose that a 200 billion-barrel bonanza is found, an amount of oil equal to all that the United States will ever produce. At our projected rate of consumption, the 200 billion barrels would be burned in seven years!

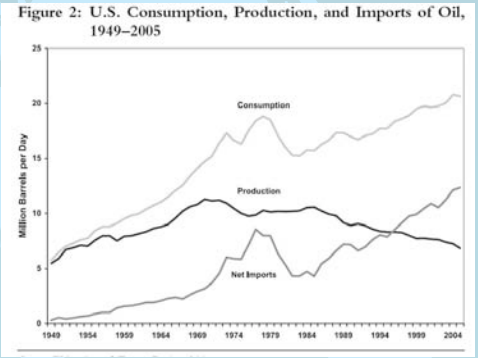


Oil producers in 1000 barrels per day

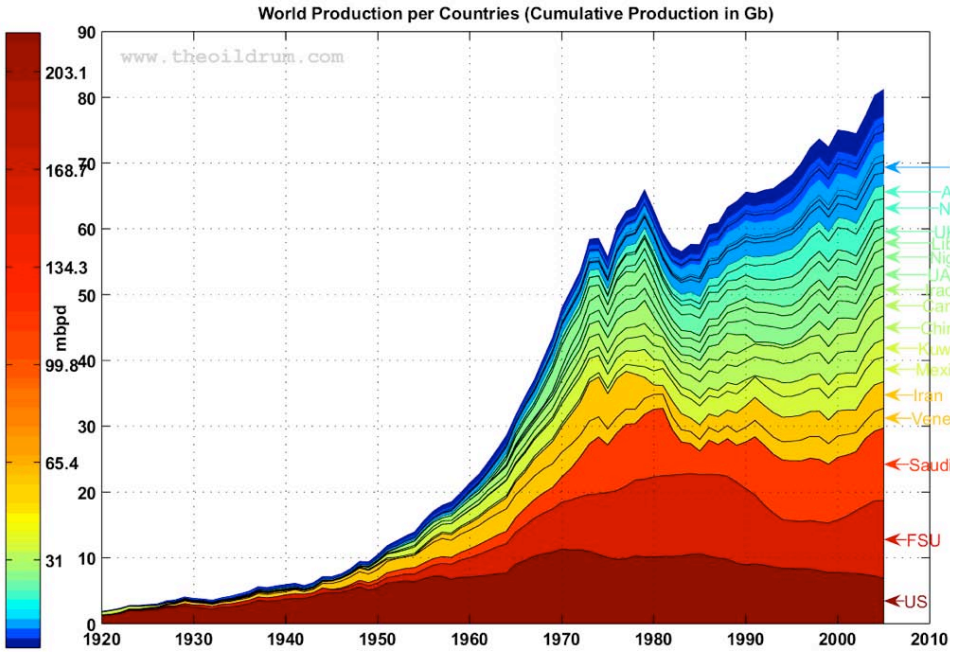
Oil Production vs Consumption



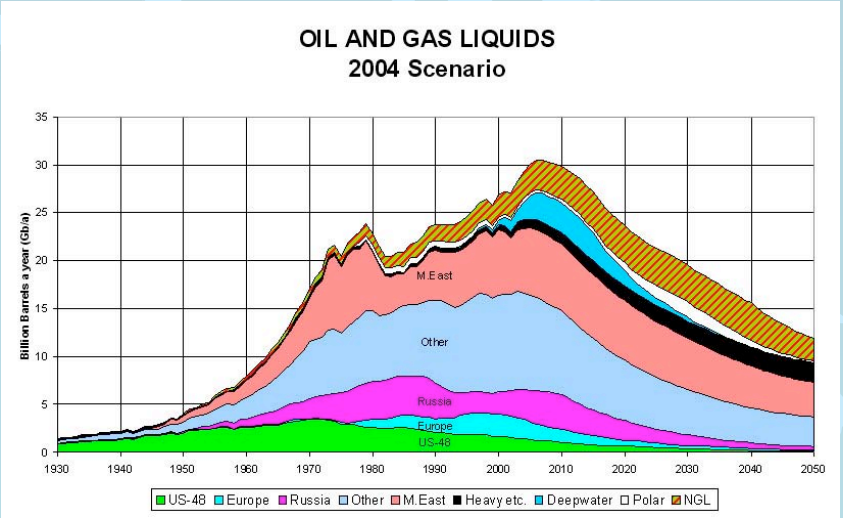
History of US Oil Production



US consumption exceeds production. An increasingly hostile group of Middle Eastern nations are in control.



Global Oil Past and Projected Production



Experts agree, oil prices will rise significantly in the future as production begins to drop.

Strategies to Control Warming

- Stabilize world population
- Initiate a no-coal world energy strategy
- Vastly enhance renewable energy dependence
- Institute strong energy conservation
- Develop treaties strongly controlling greenhouse gases
- Initiate CO_2 sequestration
- Discover counter-greenhouse technologies

Energy Conservation

- Promote mass transit where appropriate.
- Promote electric car technology.
- Expand use of natural gas (cleaner fuel).
- Improve quality of gas lines, especially in Eastern Europe.
- Recover methane from landfills.
- Promote co-generation technologies - e.g., recovery of waste heat; produce electricity as a by-product of production.
- Improve manufacturing techniques - e.g., electronic inventories; automated manufacturing where inventories are eliminated.
- Promote alternative energy-wind and solar power - local energy sources eliminate transmission loss.
- Strengthen efficiency standards throughout the economy. Improve building codes: insulation, improve lighting and appliance efficiencies, promote use of passive solar.

Strategies to Live With Warming

- Improve irrigation efficiency
- Develop new sources of irrigation water
- Stop deforestation – increase forestry – plant trees
- Conserve soil – prevent erosion
- Grow salt tolerant food plants and expand aqua culture
- Plan for increased ocean height

In Hawaii

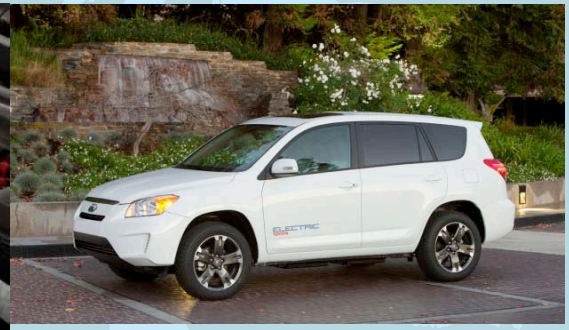
- Gasoline in Hawaii is not only expensive, the oil consumed represents an export of cash from our economy that literally just goes up in smoke.
- Ethanol from sugar cane: Cultivation requires significant fossil fuels, reduction in soil fertility, water consumption high, competition with food production.
- Hawaii's pre-1985 sugar production on 180,000 acres could have produced enough ethanol to cut gasoline consumption currently by 15% percent.
- Wind energy. The trade winds provide reliable source of energy. Wind farms must located in areas of enhanced winds, but with a minimum of terrain-induced turbulence, which causes wind turbines to wear out faster.
- Solar energy sources. Photovoltaic cells are becoming more efficient and economical.
- Geothermal energy sources
- Wave and tidal energy sources

Residential Solar Power

Plug-in Electric

family car plugs into the solar panel roof.

Electric Toyota Rav/Tesla



- Powerful electric motor with Lithium-ion (Li-ion) battery pack
- Zero emission vehicle (ZEV)
- Class-leading driving range, acceleration, and top speed
- Real world driving range of ~ 100 miles

Chevy Volt, Nissan Leaf, Mitsubishi MiEV, Tesla Model S

These models are currently in production.

Some Things I Hope You'll Remember About Climate Change

- Caused mainly by different long-lived gases produced by people via a well understood physical mechanism. CO_2 from fossil fuel burning is (by far) the main climate change agent.
- Abundant data for at least a century, carefully calibrated, show the changes in the industrial era.
- Temperatures are rising globally. There is local variability.
- Young people today will live in a world some 5-10°F warmer by the time they are old men and women, if emissions continue ramping.
- Rainfall changes with climate change would affect many people and ecosystems. Droughts like the dust bowl would be widespread.
- Climate changes from CO2 emissions should be expected to last more than 1000 years (unless we find a 'miracle cure' to remove CO2)
- Climate change challenges us to think beyond our own backyards.

Questions?