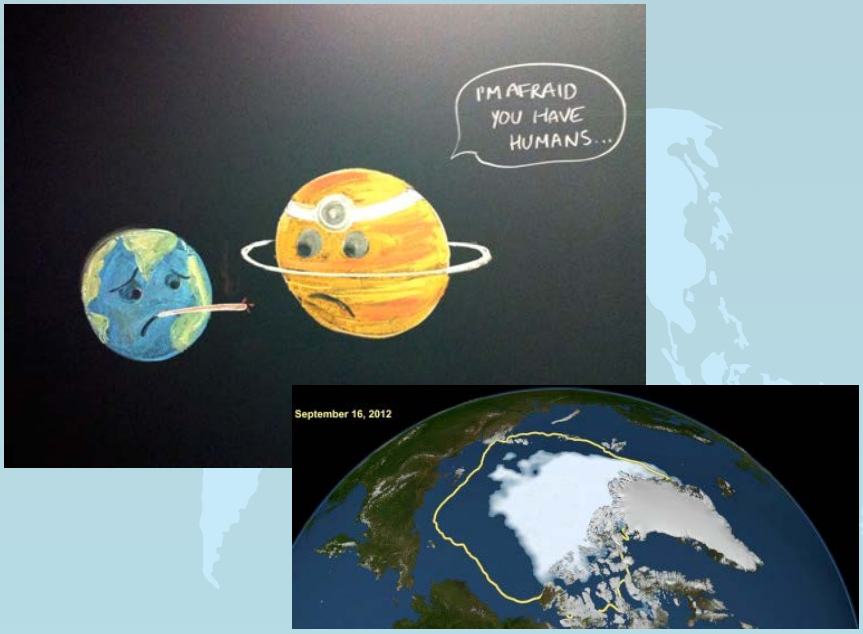


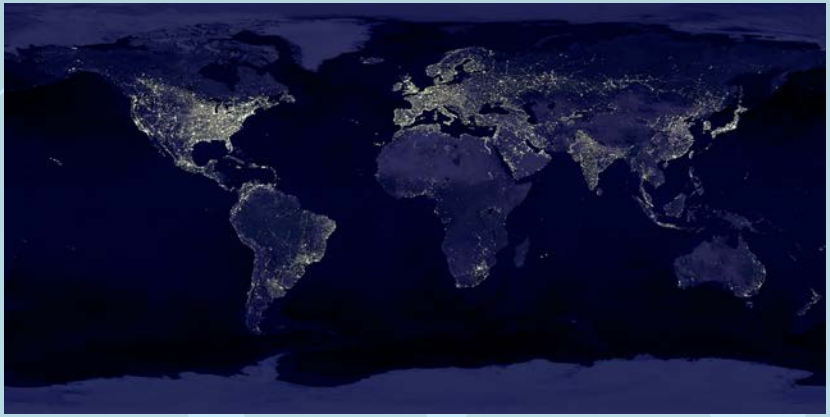
1

Lecture 28: Modeling Climate Change

Yellowstone supercomputer

2

Previous Lecture Global Warming



The strongest evidence for the sensitivity of the climate system is the empirical fact that the warmth of the current interglacial period, with Earth 5°C warmer than during the ice age 20,000 years ago, is maintained by a forcing between 6 and 9 Watts/m^2. This observation supports the National Academy of Sciences 1979 estimate of about 3°C warming for a doubling of CO_2, which causes a forcing of 4.3 Watts/m^2.

3

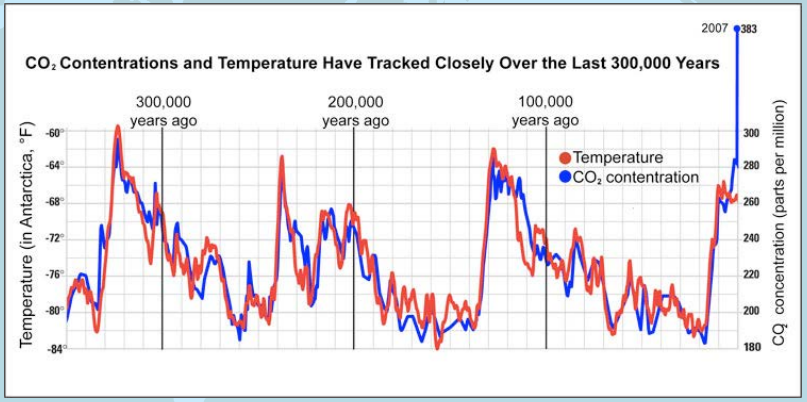
Twenty-four hours a day, the Tar Sands operation eats into the most carbon rich forest ecosystem on Earth. The vast mines, tailings ponds, fire- and pollution-belching refineries.

4

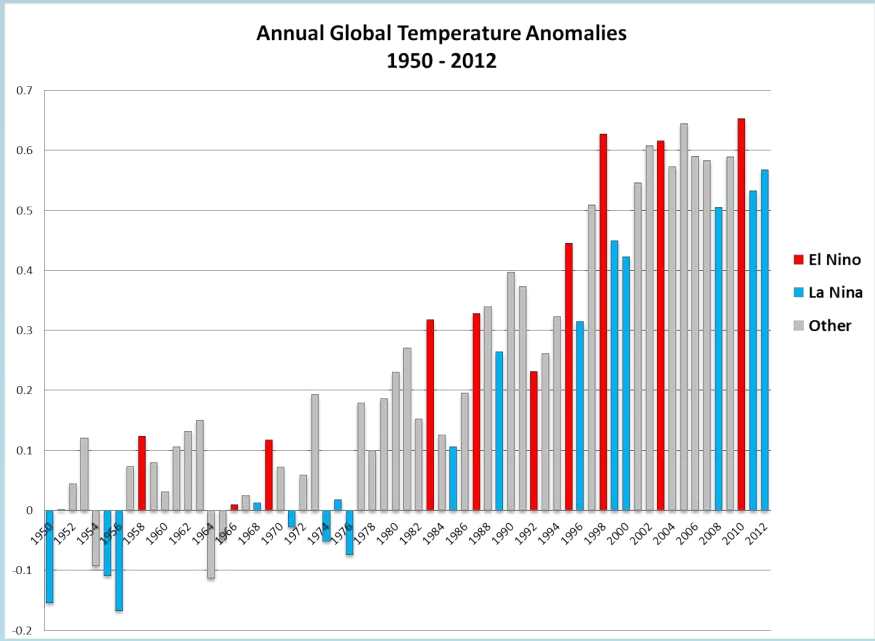
Summary: Evidence for Recent Warming

- The global average surface temperature increased by 0.6 ˚C since 1970.
  - the bulk of the warming has occurred at higher latitudes.
- Hydrological cycle is more intense
  - Heavy rain events increasing - more latent-heat energy for storms
  - Droughts and heat waves more common
  - Increased in number and size of wild fires
- Decrease in sea ice thickness and extent in last 40 years
- Widespread melting of permafrost.
- Widespread retreat of mountain glaciers seen in non-polar regions.
  - Snow cover extent decreased ~20% in last 40 years
- Sea surface temperature rise
  - increasing incidence of coral bleaching
- A gradual rise in sea level shows recent signs of acceleration.

Carbon Dioxide Record



Current CO_2 concentration in the atmosphere from Mauna Loa is around 390 ppm

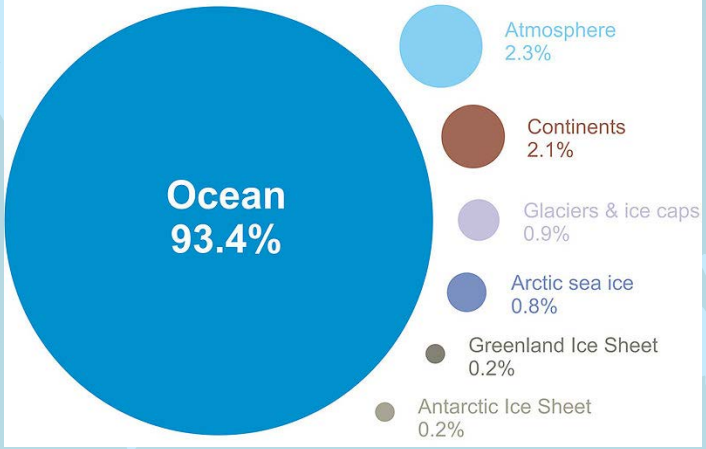


Anthropogenic Climate Change will Persist for a Long Time

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 long lived greenhouse gases.

Where is global warming going?



9

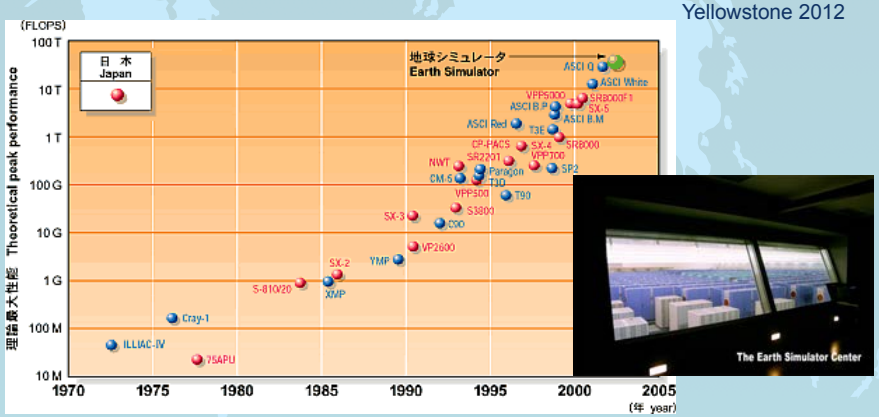
Lecture 28: Modeling Climate Change

Yellowstone is an IBM iDataPlex supercomputer system, consisting of 149.2 terabytes of memory, 74,592 processor cores, and a peak computational rate of 1.6 petaflops.

10

Modeling Climate Change requires the fastest super computers

Yellowstone 2012

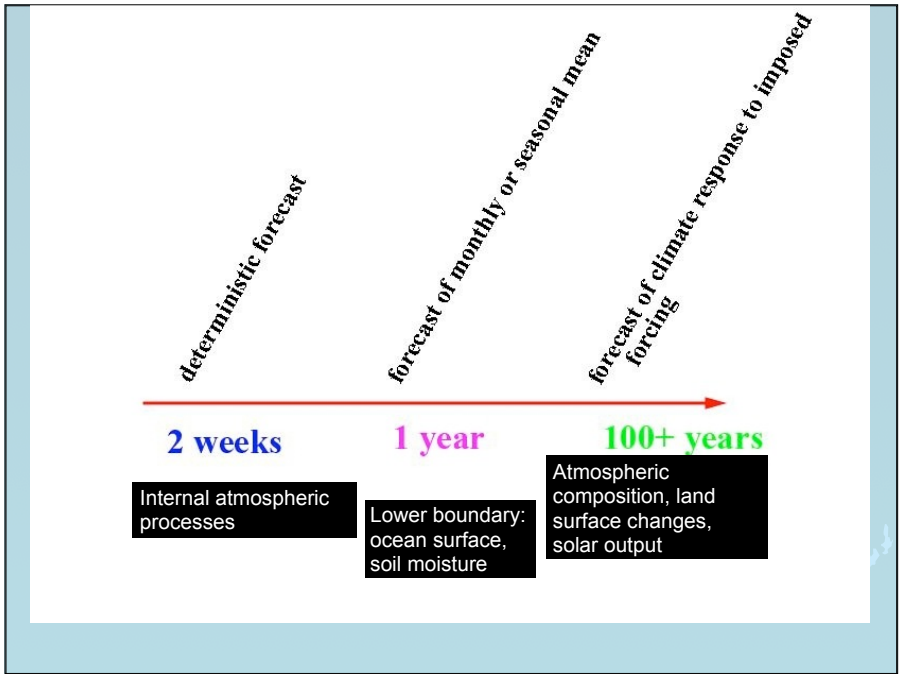


11

How Reliable are Climate Models?

- A common argument heard is "scientists can't even predict the weather next week - how can they predict the climate years from now". This betrays a misunderstanding of the difference between weather, which is chaotic and unpredictable, and climate which is weather averaged out over time.
- The major forcings that drive climate are well understood. In 1988, James Hansen projected future temperature trends (Hansen 1988). Those initial projections show good agreement with subsequent observations (Hansen 2006).

12

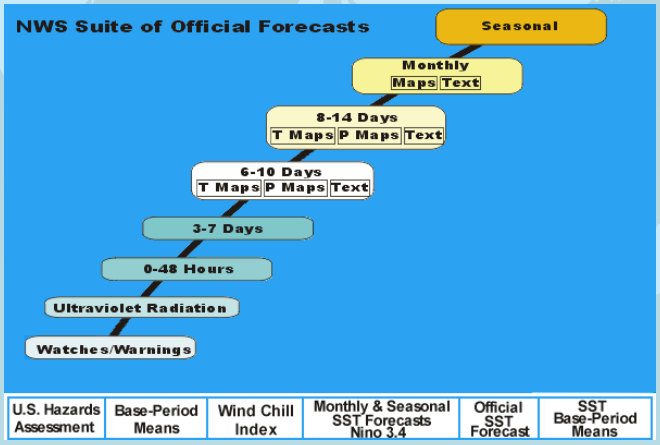


13

Extended-range Forecasting – weeks-months-seasons-years

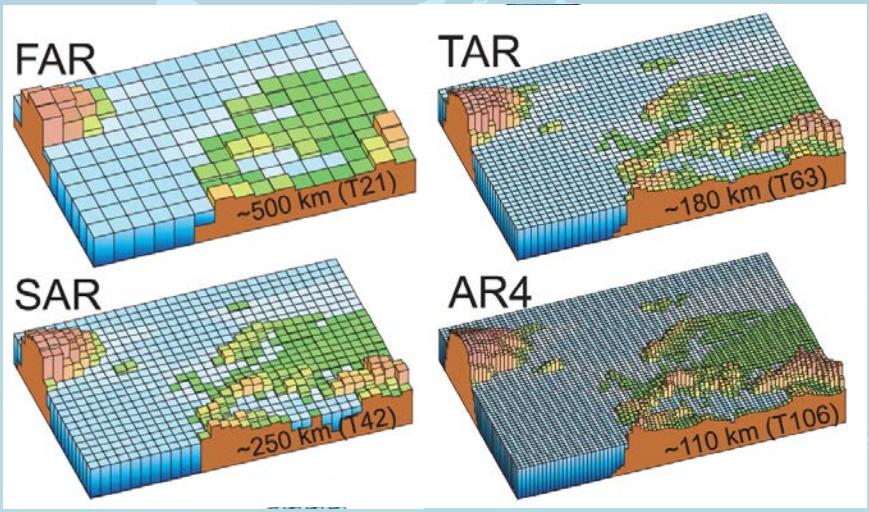
- National Weather Service Climate Prediction Center (CPC)

http://www.cpc.ncep.noaa.gov/



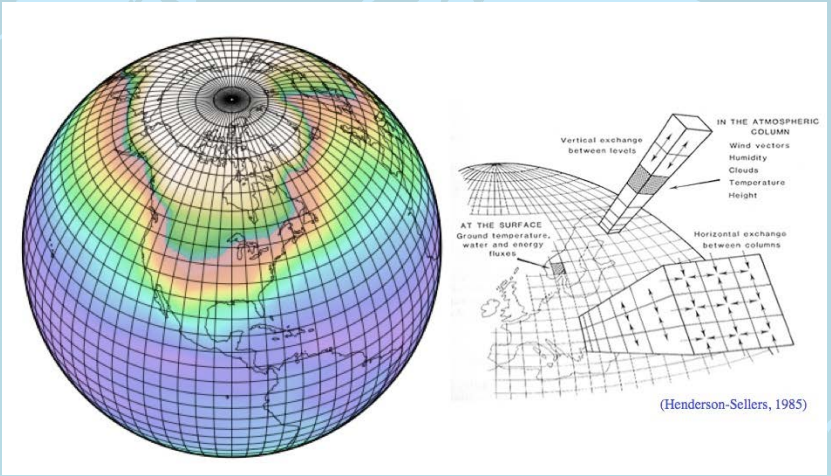
14

Improving Climate Change Model by Adding Resolution



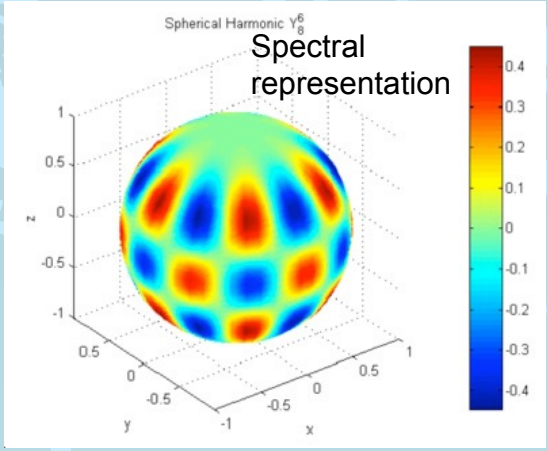
15

Global Model Grid has 4 Dimensions



16

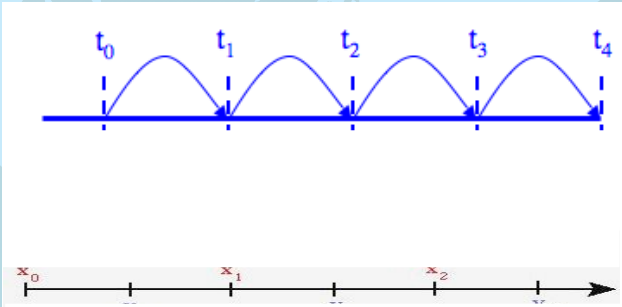
Atmosphere/Climate Simulation Models



A finite numerical discretization in space
(e.g. a spatial grid, spectral Fourier series)

17

Atmosphere/Climate Simulation Models

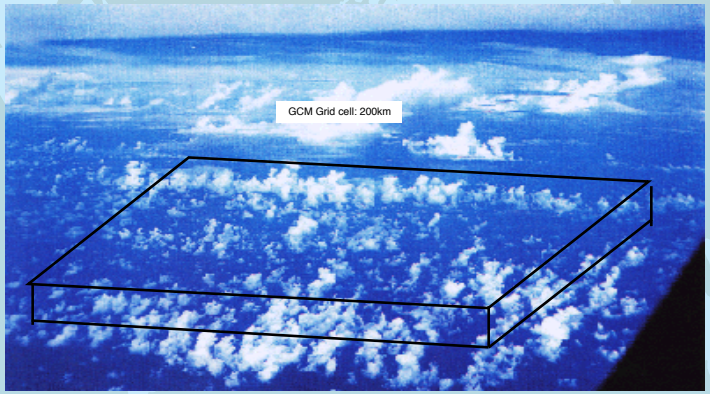


Timesteps for moderate resolution models may be ~15 minutes, for high resolution models they could be considerably shorter

Discretization in time ("timesteps")

18

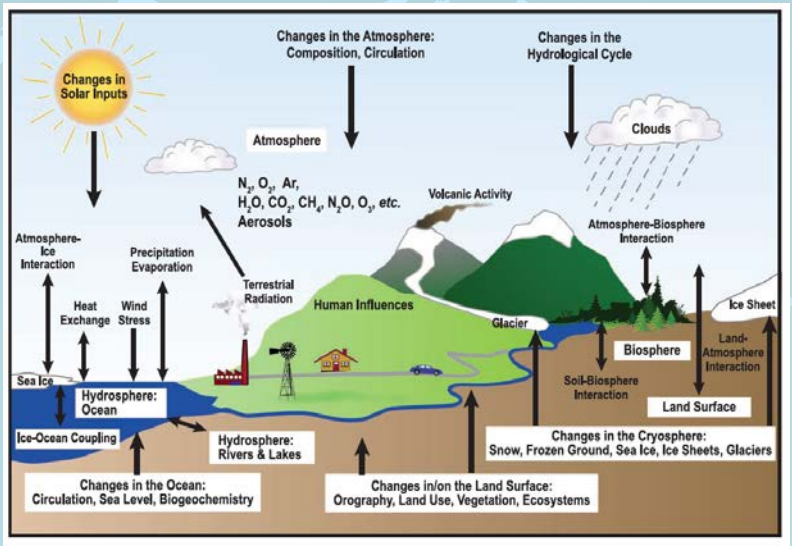
Challenge of Modeling Clouds



Typical grid box in a GCM with inhomogeneous distribution of clouds within it. Distribution of clouds must be parameterized in the model.

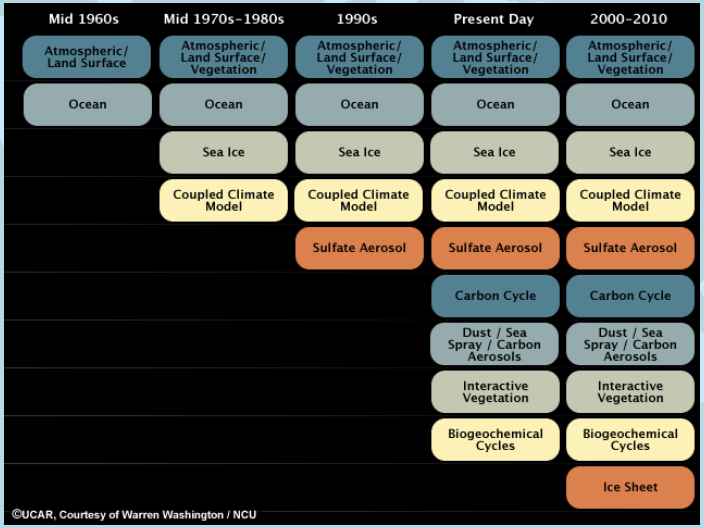
19

The Complexity of the Climate System

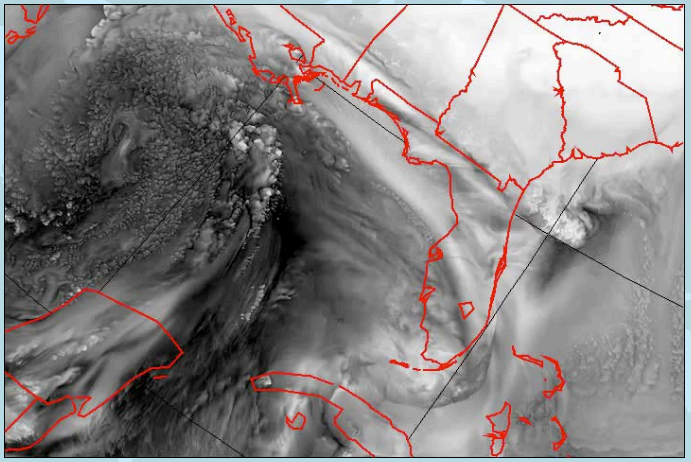


20

Adding Complexity



Modeling Climate Change

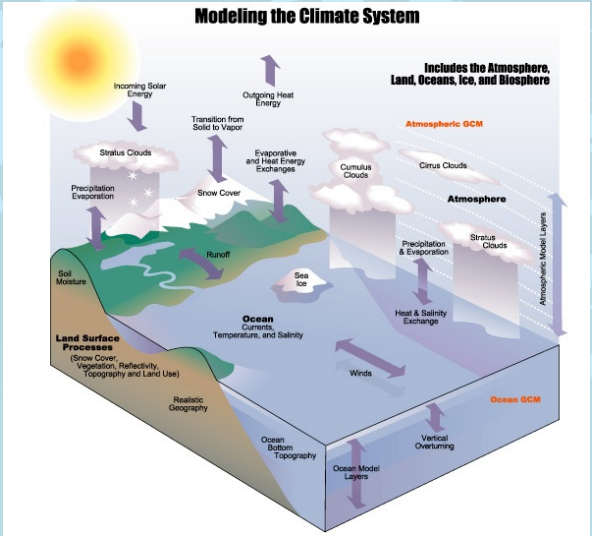


Resolution and sophistication of climate models is increasing.

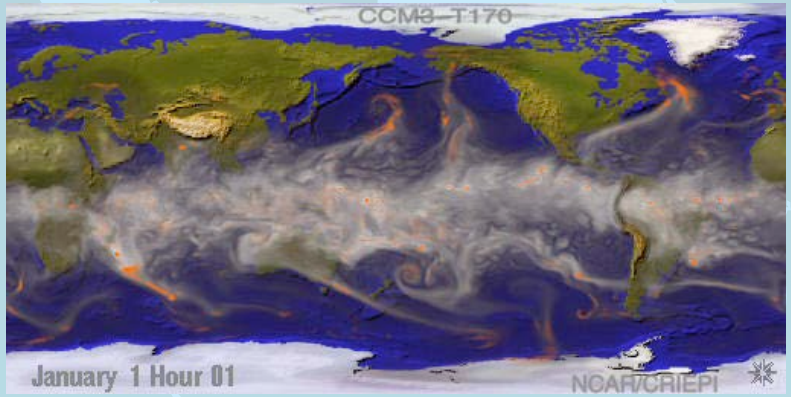
Even so Yellowstone is not fast enough to do the job.

Models Need to Resolve Convective Clouds

Modeling the Water Cycle

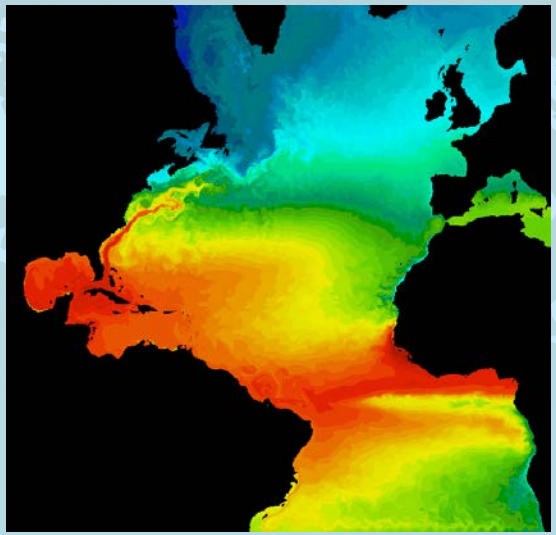


Global Simulation showing Tropical - Extratropical Interaction



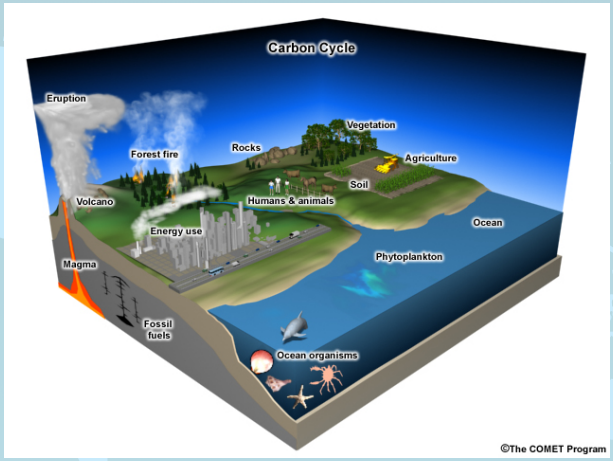
Water Vapor is shown in white and precipitation in orange.

Modeling Climate Change



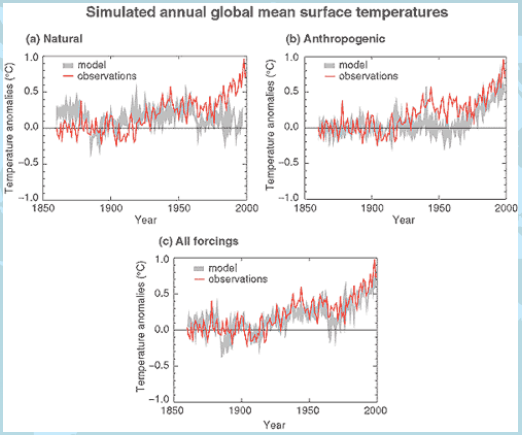
Modeling climate change means modeling the ocean circulation.

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.

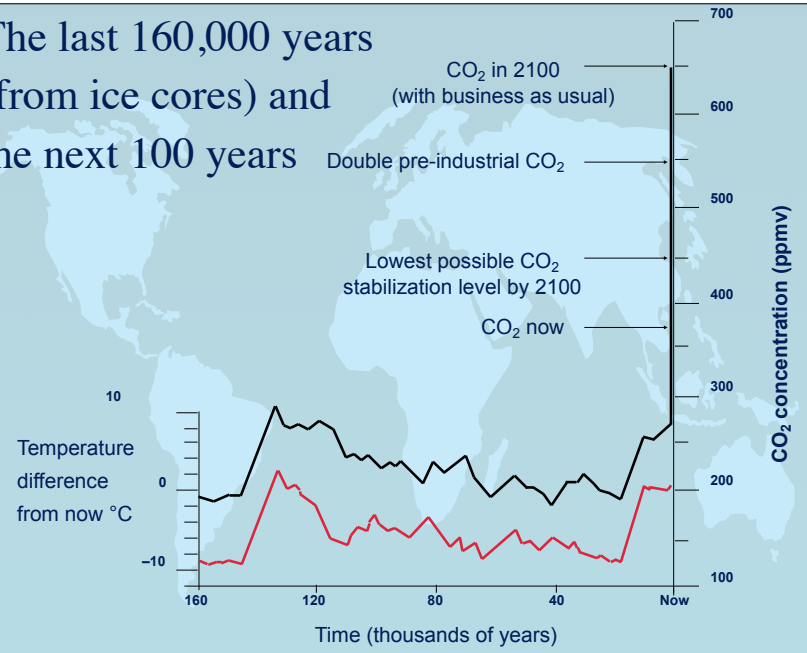
How Reliable are Climate Models?



Climate models are unable to duplicate the recent warming without taking GHG into account.

http://www.skepticalscience.com/climate-models-intermediate.htm

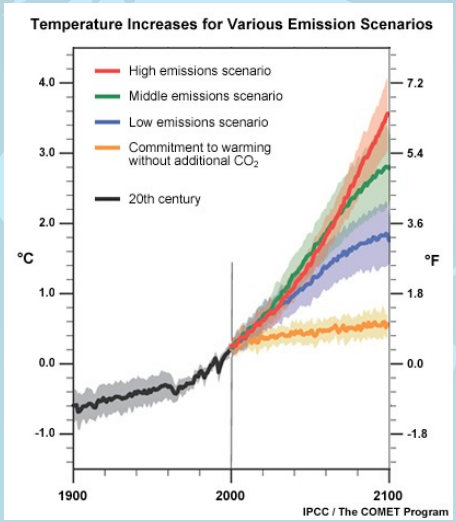
The last 160,000 years (from ice cores) and the next 100 years



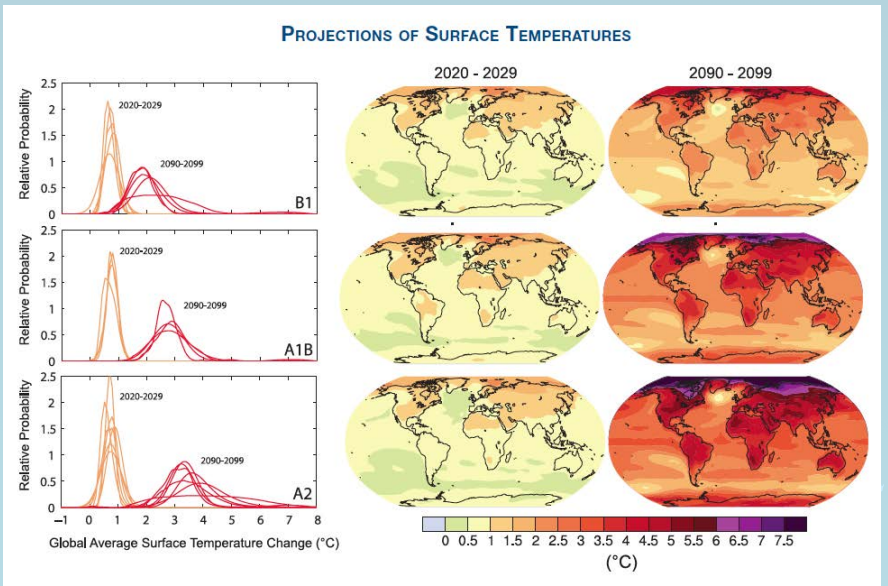
29

Future temperature trends for different responses to global warming

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

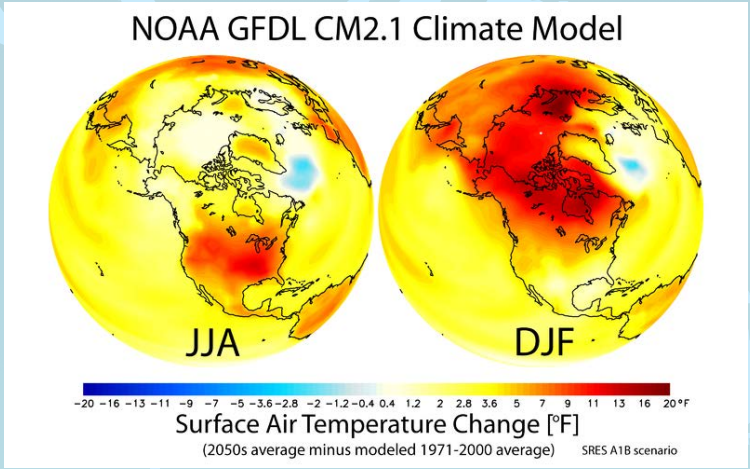


30



31

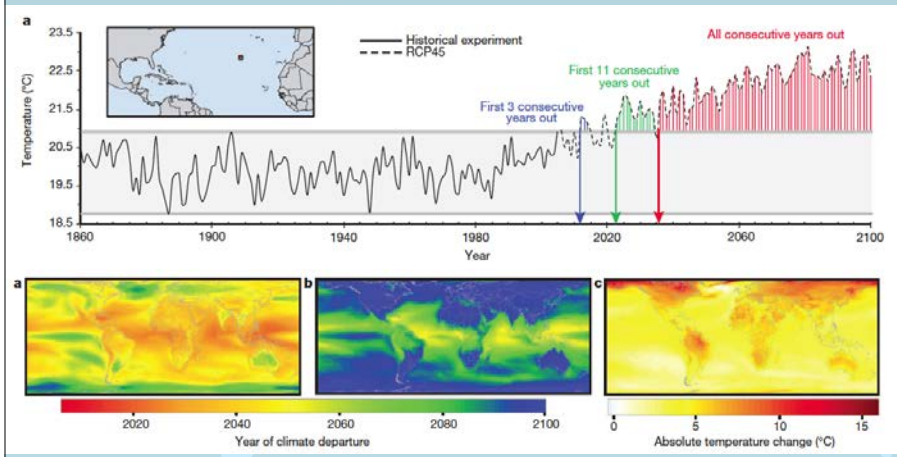
Global Warming is Non-Uniform



Warming pattern changes with season.

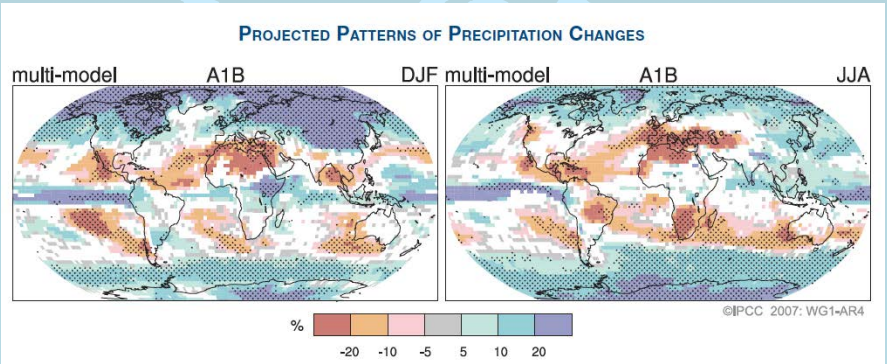
32

Kiss Your Climate Goodbye



Year when the climate model projection exceeds historical maximum mean annual temperature. Mora et al. 2013.

More Rain for Some, Less for Others



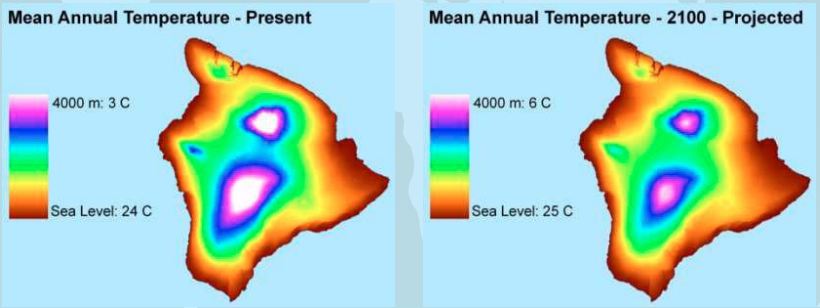
(2090s: medium emissions scenario; highest confidence in stippled areas)

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

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

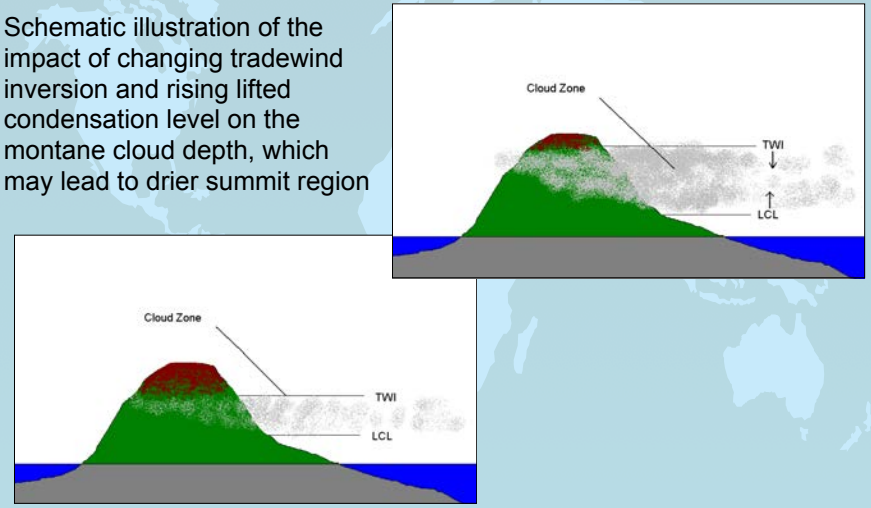
Anticipating Climate Change

Guidance (e.g., maps below) can be developed to illustrate how the climatic zones and their attendant ecologies on Mauna Kea and Mauna Loa will be impacted by large-scale climate change.

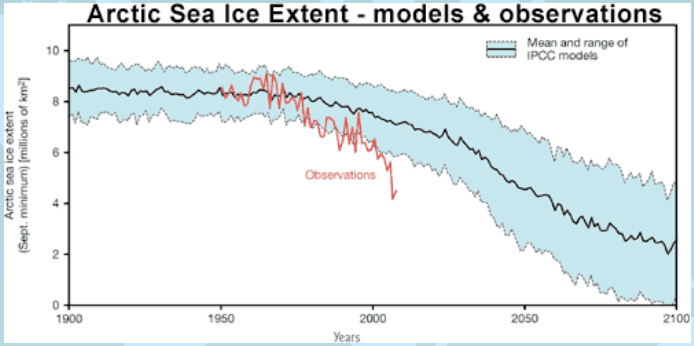


Climate Change in Hawaii

Schematic illustration of the impact of changing tradewind inversion and rising lifted condensation level on the montane cloud depth, which may lead to drier summit region



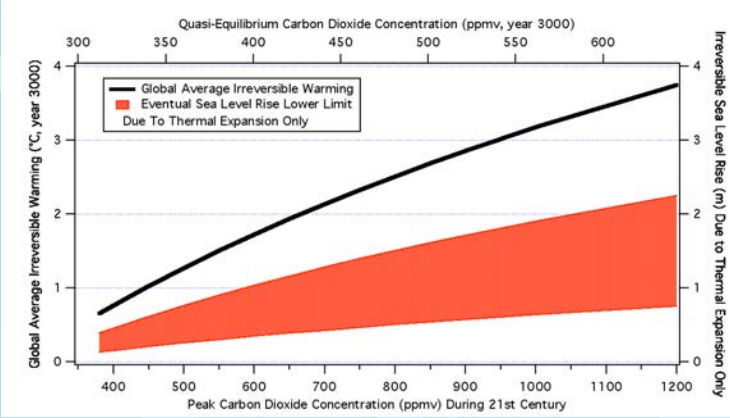
Sea-Ice Modeling



Most land areas and high latitudes will warm faster than the global average, resulting in melting and thinning of arctic ice sheets. Models have underestimated the pace of sea-ice loss.

37

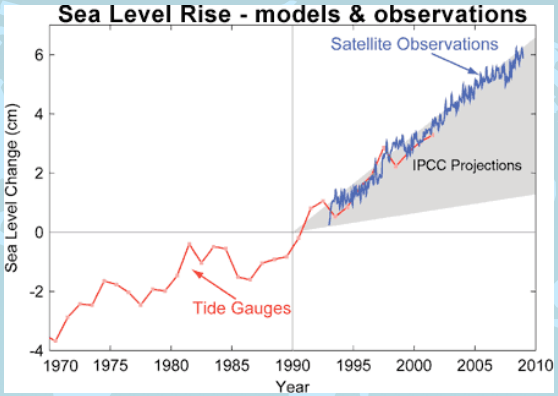
Sea Level Rise: How High Will it Go?



add glaciers
(0.3 - 1 m)
add ice sheets?

38

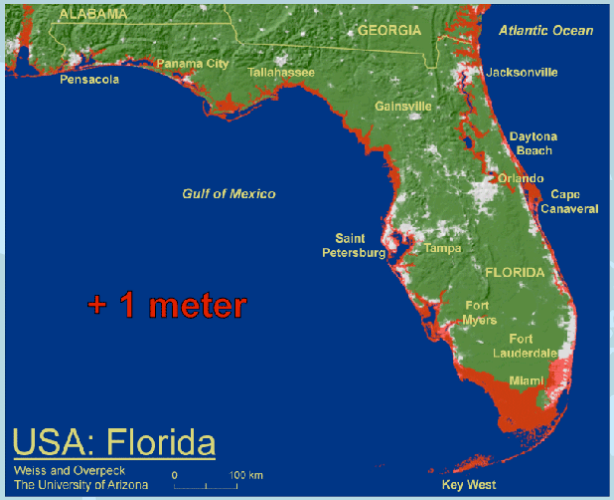
Modeling Sea Level Rise



Thermal expansion of seas and melting of land ice expected to cause sea level rise of 0.3 to 1 m by 2100 depending on societies response to global warming. Current sea-level rise is at the upper range of earlier IPCC projections.

39

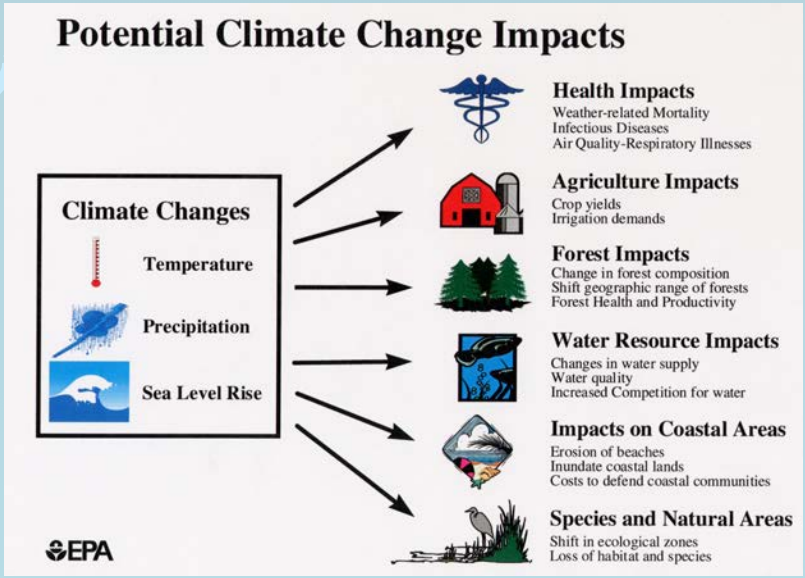
Sea-Level Rise



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

40

Global Warming – Some Implications



What is causing the CO_2 to increase in the Atmosphere?

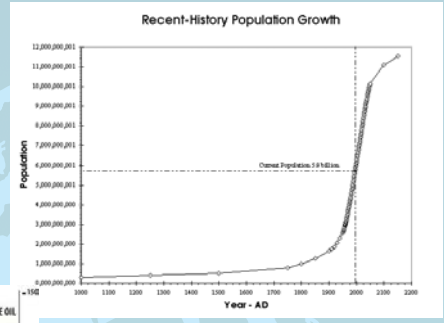
A: Fossil Fuel Burning: Coal, Oil and Natural Gas.

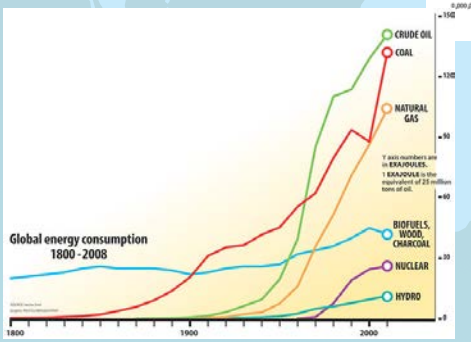
How do we know that?

- Circumstantial Evidence of timing of increase with rise of fossil fuel use.
- Smoking gun evidence of isotopic studies: ratio of C_{14} to C_{12}.

The Human Factor

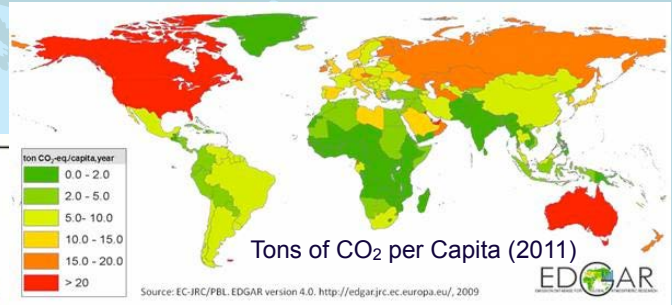
Global Warming is linked to population and industrialization.



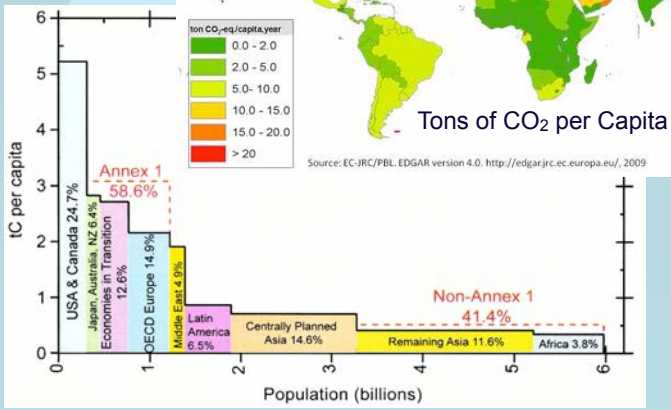


Global trend in energy consumption.

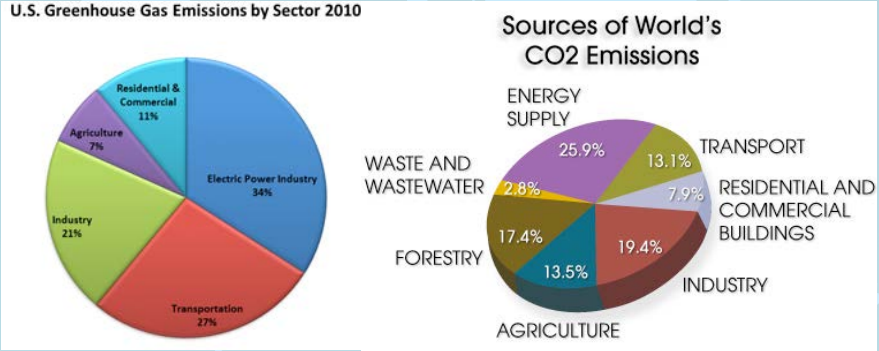
Greenhouse Gas Emitters



Tons of CO_2 per Capita (2011)

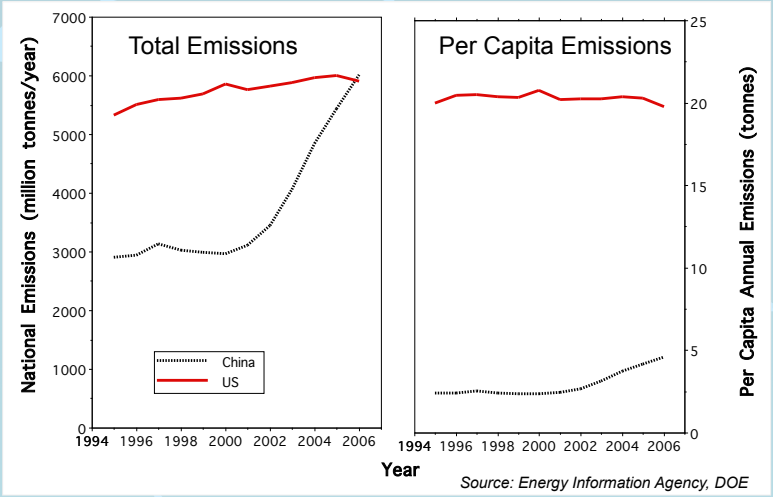


Why: Going, Doing, Making, Growing Food, Being Comfortable….. In short, just about everything.



45

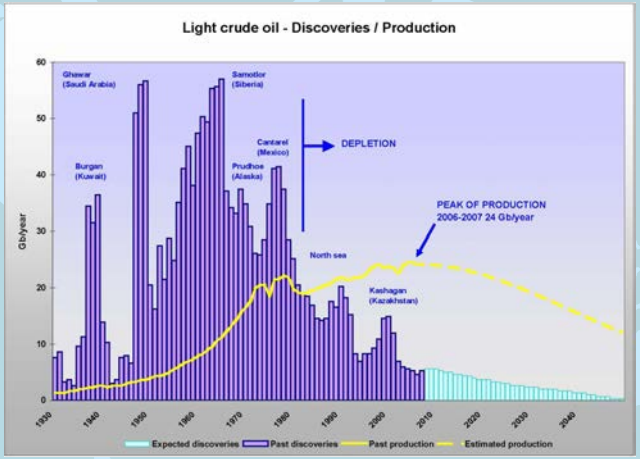
Changes in Total and Per Capita Emissions of Carbon Dioxide From Fossil Fuel Burning in China and the USA



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

46

Oil Discovery v Production



We now are discovering fewer than 8 billion barrels annually compared with the 28 billion barrels we consume.

47

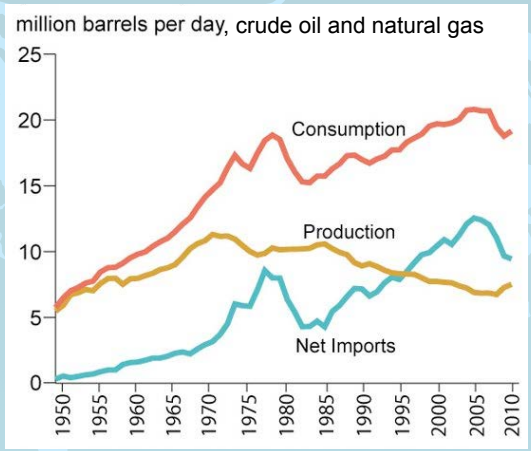
Oil Producers

Saudi Arabia	10,584
Russia	9,285
United States	7,241
Iran	4,081
Mexico	3,824
China	3,490
Norway	3,188
Canada	3,085
Venezuela	2,980
United Arab Emirates	2,667
Nigeria	2,508
Kuwait	2,424
United Kingdom	2,029
Iraq	2,027
Algeria	1,933
Libya	1,607
Brazil	1,542
Kazakhstan	1,295
Indonesia	1,126
Angola	991

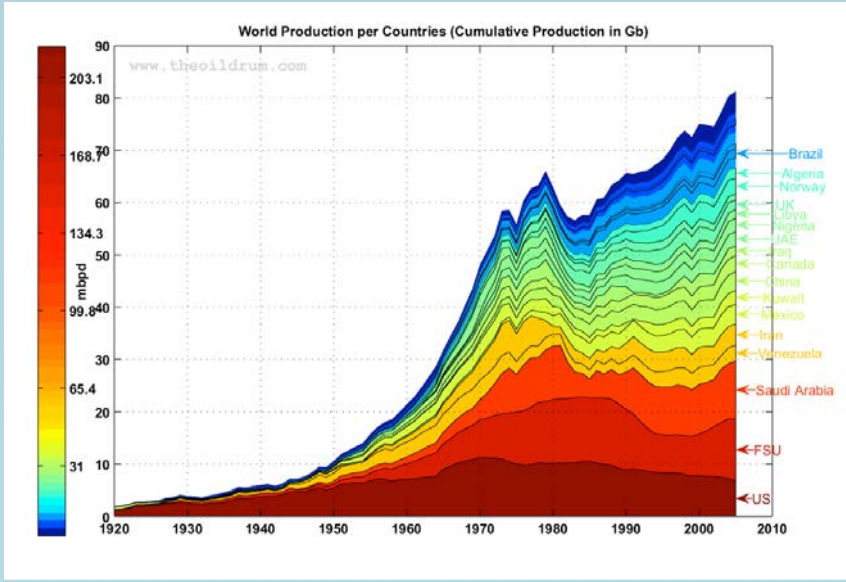
Oil producers in 1000 barrels per day

48

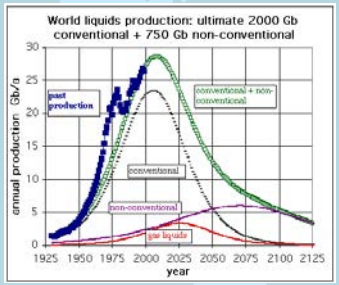
US Oil Production and Consumption

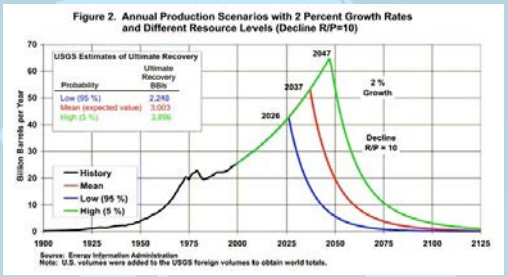


US consumption exceeds production. An increasingly hostile group of Middle Eastern nations are in control.



Global Oil Past and Projected Production



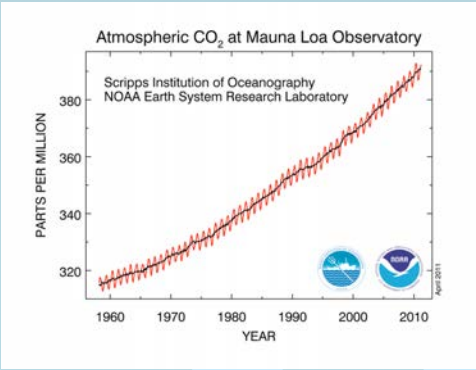


Pessimistic view vs the optimistic view.

Mackay River, Boreal Forest and Tar Sands Mine

Boreal Forests and wetlands surrounding the Tar Sands are among the most carbon rich terrestrial ecosystem on Earth, with about as much carbon as tropical rainforests. Referred to by the Tar Sands industry as "overburden," these forests are scraped off and the wetlands dredged, to be replaced by tar mines like the one above.
From: Canada's Tar Sands and the True Cost of Oil. Photography by Garth Lenz.

Climate And Bathtubs: A Poorly-Understood Principle

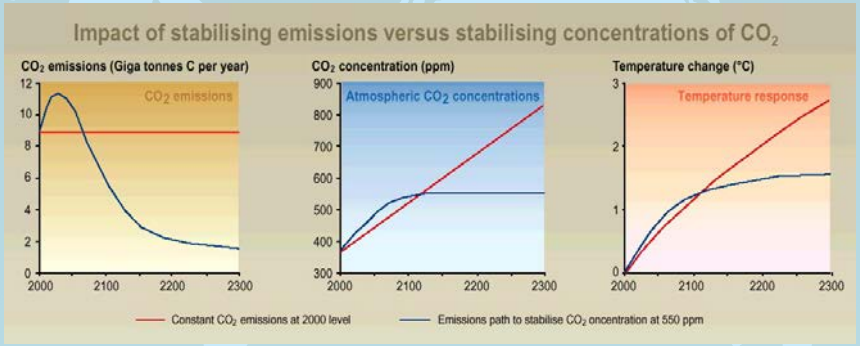


Stabilization of CO_2 would require 50% emissions reductions (for a few decades) and then 80%

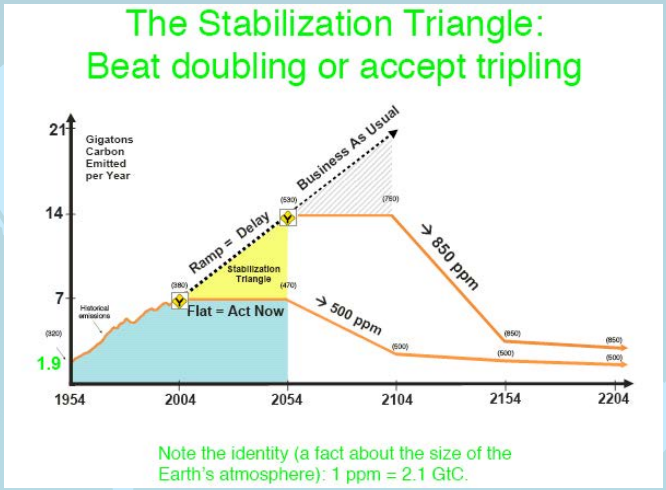
Geoengineering? Cool the planet? Real and 'artificial' trees?

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

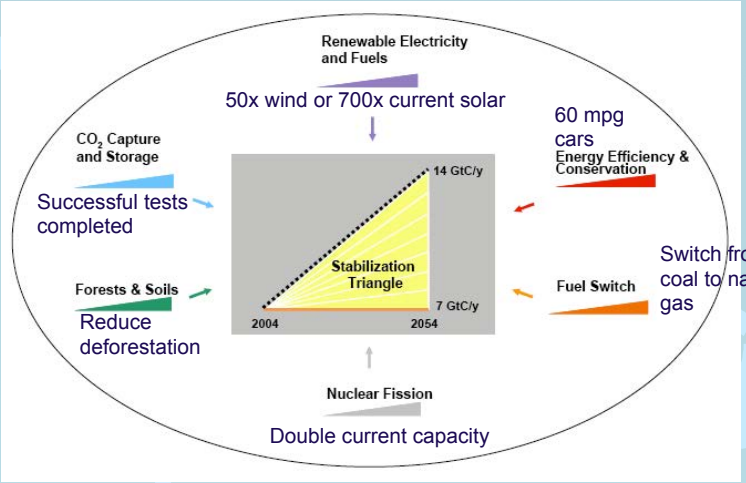
CO_2 Stabilization is Possible, But…

Essential Requirements

1. Quick Coal Phase-Out Necessary
   - All coal emissions halted in 20 years
2. No Unconventional Fossil Fuels
   - Tar sands, Oil shale, Methane hydrates
3. Don't Pursue Last Drops of Oil
   - Polar regions, Deep ocean, Pristine land

The Tar Sands were the inspiration for Avatar's Edmonton-born art director's vision of the mining operation on Pandora.

Some Possible Future Choices: Just Illustrations



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

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 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

What's Really Happening

1. Tar Sands Agreement with Canada
   Pipeline planned to transport oil
2. New Coal-fired Power Plants
   Rationalized by 'Clean Coal' mirage
3. Mountaintop Removal Continues
   Diminishes wind potential of mountains
4. Oil & Gas Extraction Expands
   Arctic, offshore, public lands

Crossroads in Alberta Tar Sands

Problem & Solution

1. Fossil Fuels are Cheapest Energy
   - Subsidized & Do Not Pay Costs
   - Solution: Rising Price on Carbon
2. Regulations also Required
   - Efficiency of Vehicles, Buildings,e.g.
   - Carbon Price Provides Enforcement
3. Technology Development Needed
   - Driven by Certainty of Carbon Price
   - Government Role Limited

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Fee & Dividend

1. Fee Applied at First Sale/Port of Entry
   Covers all Oil, Gas, Coal – No Leakage
2. Fee Specified: No Speculation, No Volatility
   No Wall Street Millionaires at Public Expense
3. Other Merits
   Only Potentially Global Approach
   Simple, Honest, Can be Implemented Quickly
   Market Chooses Technology Winners
   Most Efficient & Largest Carbon Reductions

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Fee & Dividend Addresses

1. Stimulates Economy
   Puts Money in Public's Hands– A Lot!
2. Energy: Stimulates Innovation
   Fastest Route to Clean Energy Future
3. Climate
   Only Internationally Viable Approach
   Zero Chance of China/India Accepting a Cap
   Would Result in Most Coal & Unconventional Fossil Fuels, and some Oil, left in the Ground

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Tar Sands Oil not Needed

If carbon price rises $10 per ton CO_2 after 10 years U.S. carbon emissions will have decreased approximately 30 percent. That is equivalent to 13 Keystone pipelines.

With a proposed 5-fold expansion of the Tar Sands, an area the size of Florida might be industrialized within as little as two decades.

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Adaptation: 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

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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

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Residential Solar Power

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Plug-in Electric

family car plugs into the solar panel roof.

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Solar Panels in Germany

Chevy Volt has ~45 mi range, after which a gas generator recharges the battery. If you drive short distances you never have to buy gas! But, if you want to go on a road trip, you can because it has a 300 mi range on the gas generator.

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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

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

These models are currently in production.

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Better Yet

Where the #$%^& did I leave my bike?

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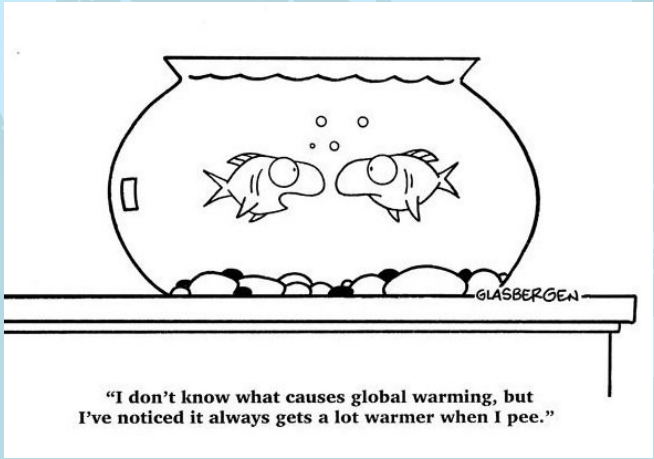
Some Things I Hope You'll Remember About Climate Change

- 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?



"I don't know what causes global warming, but I've noticed it always gets a lot warmer when I pee."