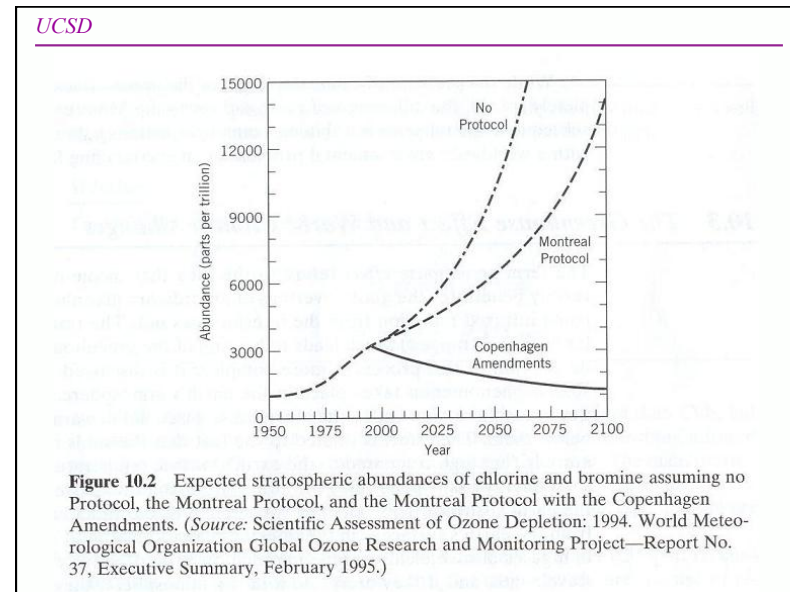
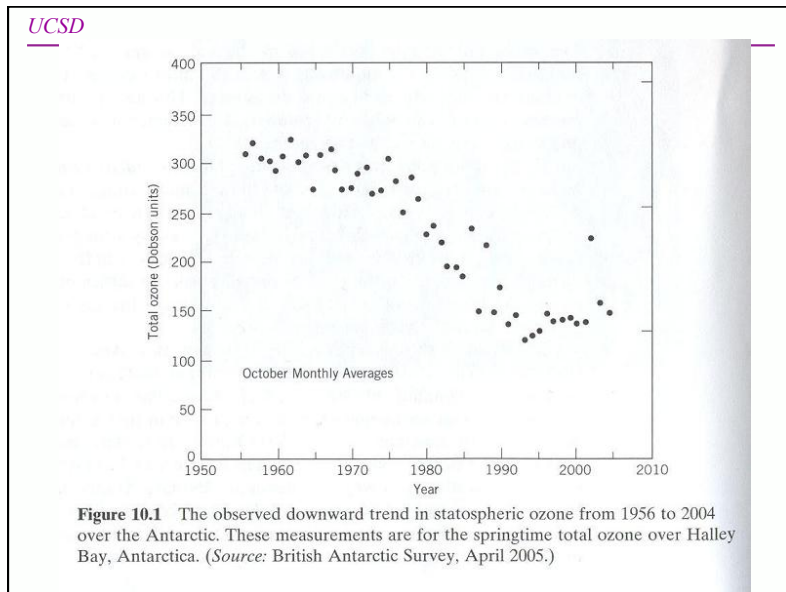
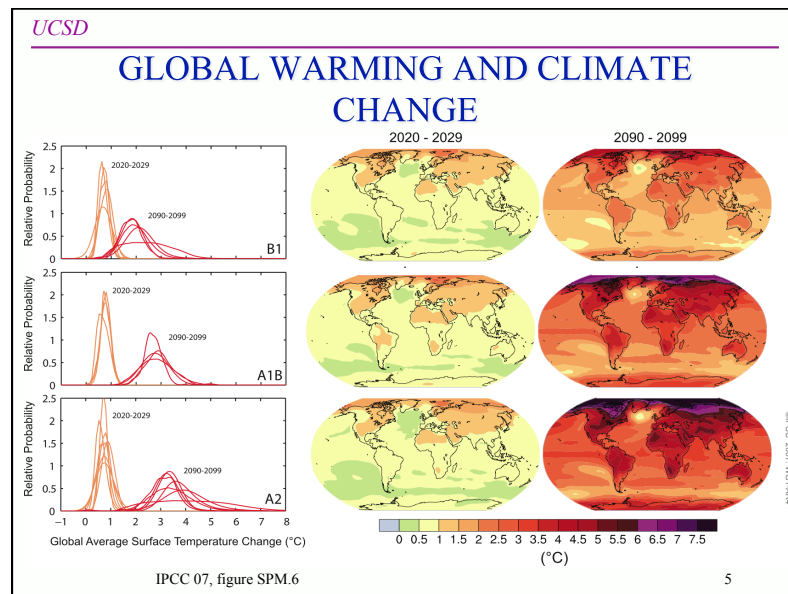


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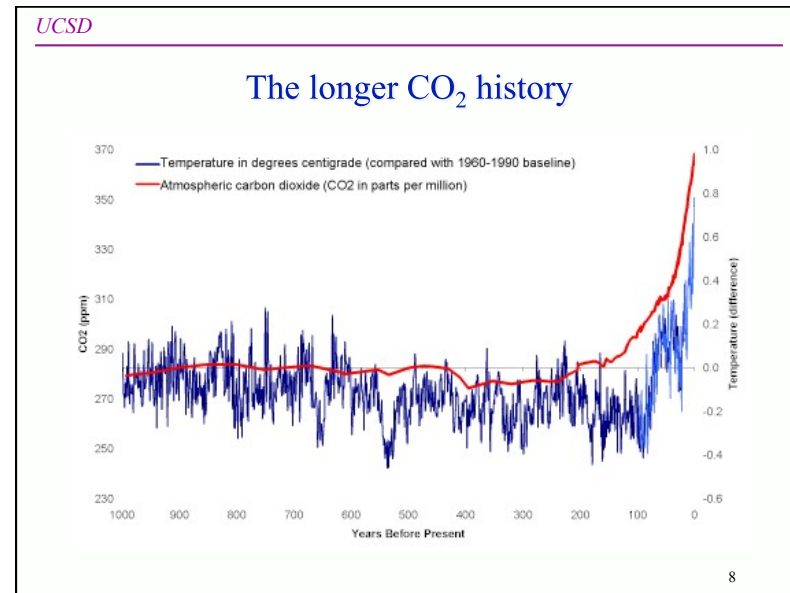
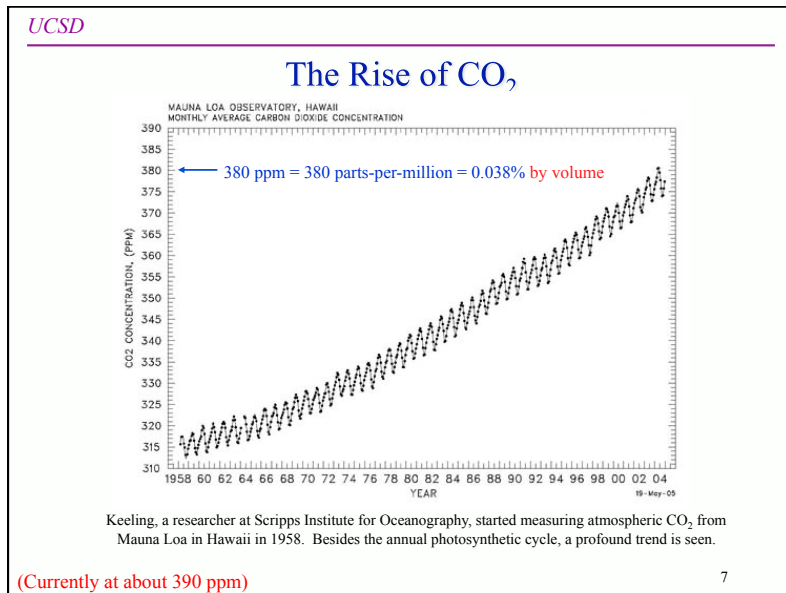
But first the hole in the ozone:

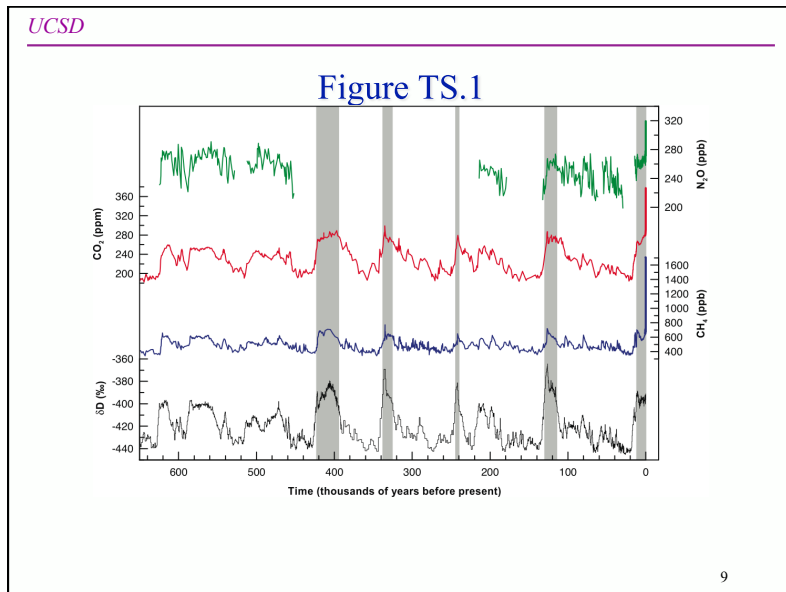
2





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- ## Science vs. Influence
- Scientists have seen direct signs of climate change for decades
 - confidence has grown based on loads of *data*, often collected by scientists who are themselves skeptical about climate change
 - Scientific consensus is not as easy as you may think
 - practiced by humans, each interested in making a mark
 - scientists are by nature skeptical, and eager to find errors in others ideas
 - but in the end, driven by *evidence*, not emotion or pet ideas
 - Long after scientific consensus, waters were still muddied
 - overt influences by financial powers emphasized controversy and “lack of consensus”
 - and had a bigger bullhorn: popular media ran the controversy over the consensus, which has had a damaging delay-effect
 - skeptics like to say “teach the controversy”, but the controversy doesn’t exist in the scientific community. Only in the “paid for by energy companies”, political and media communities.
- 6



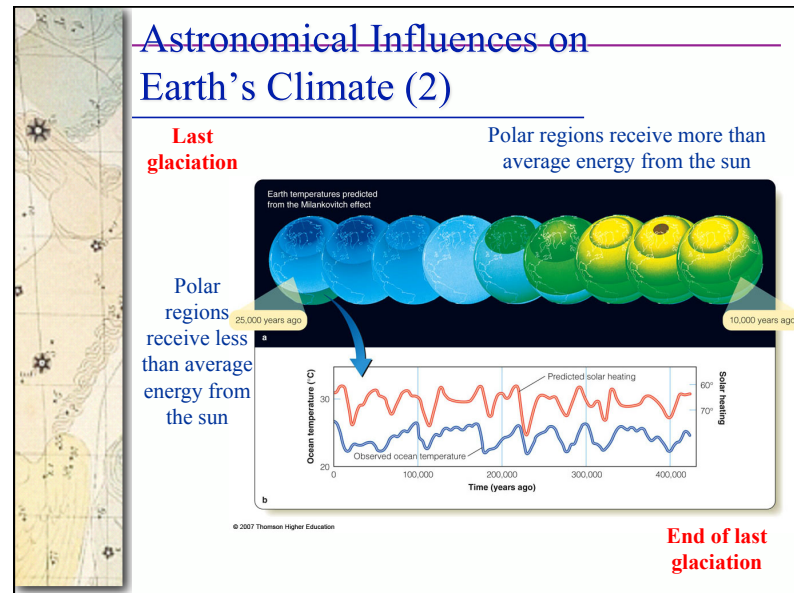
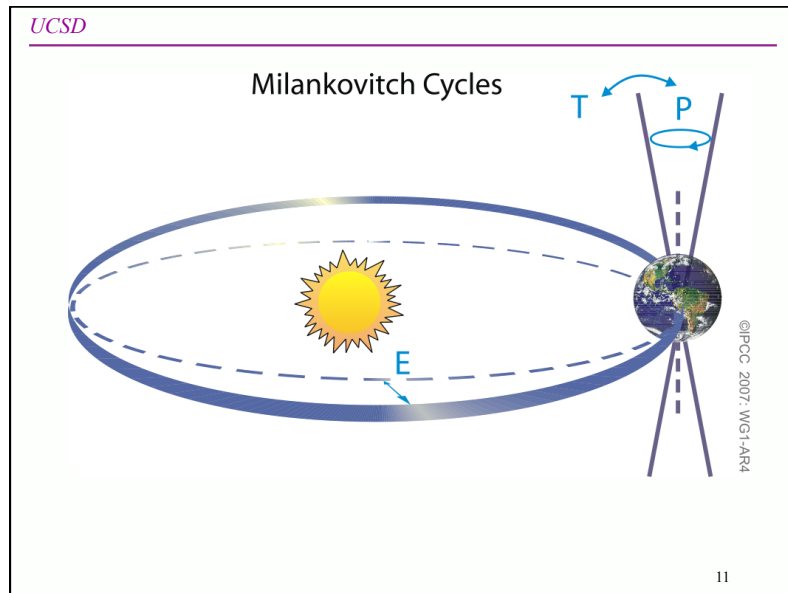


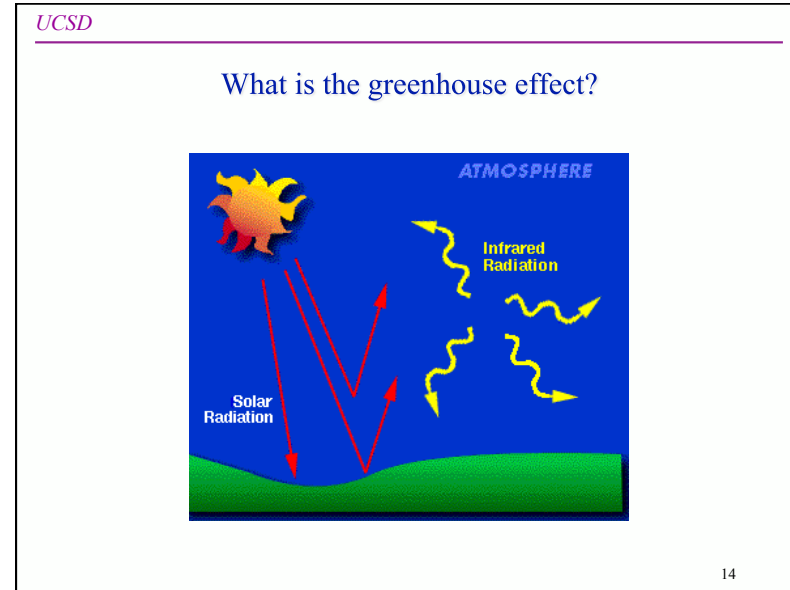
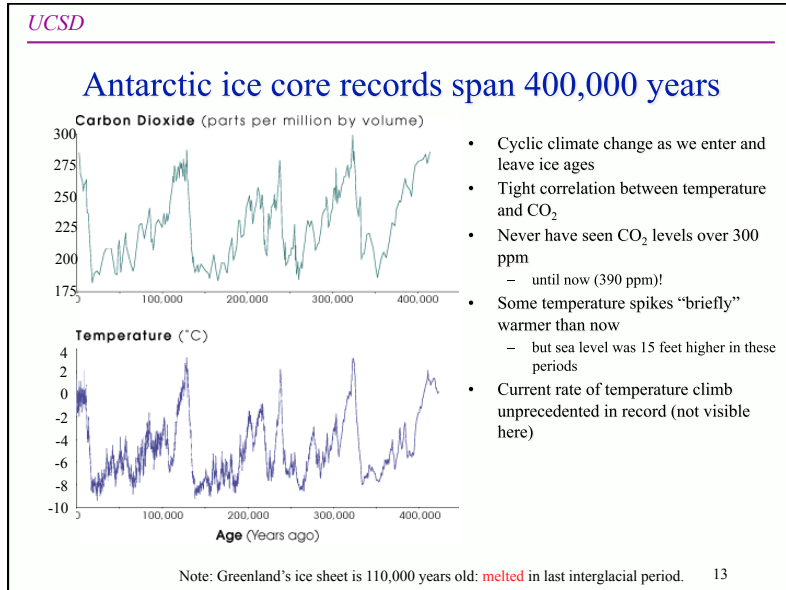
Astronomical Influences on Earth's Climate

Factors affecting Earth's climate:

- Eccentricity of Earth's orbit around the Sun (varies over period of ~ 100,000 years)
- Precession (Period of ~ 26,000 years)
- Inclination of Earth's axis versus orbital plane

Milankovitch Hypothesis: Changes in all three of these aspects are responsible for long-term global climate changes (ice ages).





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What happens with more CO₂?

- Adding CO₂ to the atmosphere changes the radiative balance on earth
 - CO₂ absorbs infrared light, so more of the thermal emission trying to escape from earth is absorbed in the atmosphere, causing earth to warm
 - it's like the glass sheet over the solar hot water collector: like a greenhouse
 - eventually, a hotter earth radiates more prodigiously (according to σT^4 law), and balance is re-established

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H₂O and CO₂: major greenhouse gases

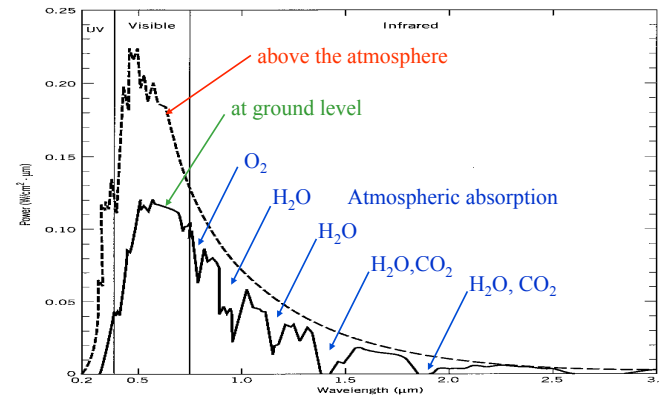
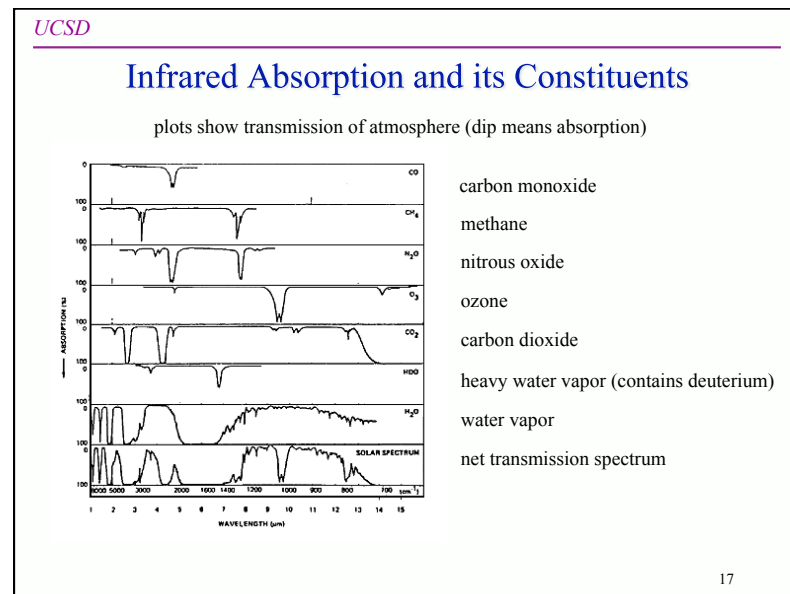


Figure 4.1 The wavelength distribution of solar radiation above the atmosphere (dashed line) and at the earth's surface (solid line). The Solar Constant is given by the area under the dashed curve. The sharp dips in the solid line are due to absorption of certain wavelengths by various atmospheric gases, including water vapor and carbon dioxide. (Adapted from *On the Nature and Distribution of Solar Radiation*, Watt Engineering, Washington, D.C.: U.S. Government Printing Office, Department of Energy HCPT12552-01, 1978).



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- ### Other Greenhouse Gases
- CO₂ is the main greenhouse contributor, at 57%, but not the whole story
 - CH₄ (methane) contributes 17%
 - N₂O (nitrous oxide) contributes another 5%
 - the rest from refrigerants (chloro-fluorocarbons; CFCs and the like) and ozone (the man-made tropospheric stuff)
 - Note H₂O is actually largest contributor, but it's concentration is not directly controlled by emissions; it is part of feedback effect
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Is rise in CO₂ caused by humans?

- Absolutely expected! Rough estimate: (could do better)
 - Recall every gallon of gas gives 20lb CO₂. Roughly estimate entire world's CO₂ as if all energy was from gasoline (coal gives more, nat gas less)
 - total energy = 400 QBtu/year (0.17 Gboe/1QBtu)(42 gal/bbl) = 3 trillion gal/year
 - times 20 or $\sim 6 \times 10^{13}$ pounds of CO₂/year. What fraction of the atmosphere is this?
 - Atm pressure = 14.7 lbs/in² is weight of air above each square inch of earth
 - Total weight is 14.7 x area = 14.7 x 4 pi R² = 184 (4000 mi)² = 1.2 x 10¹⁹ lb
 - So fraction is $6 \times 10^{13} / 1.2 \times 10^{19} = 5 \times 10^{-6}$ or 5 ppm/year BY MASS
 - This is 3.8 ppm by volume (CO₂ is 44 g/mol vs 29 for air)
 - if half goes into ocean, half into atmosphere (roughly true), atmospheric rise is 1.9 ppm/yr, by volume
 - this is dam close to what we see on the “Keeling curve” graph
- Anyone who claims CO₂ is not caused by humans needs to explain where all the CO₂ we are putting into the atmosphere is going. Who cares that there are also natural sources of CO₂. These are small potatoes.

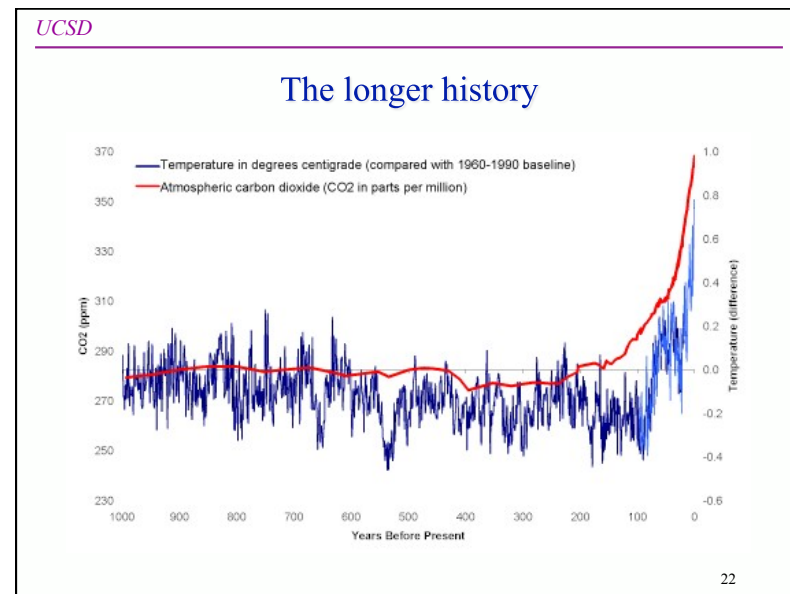
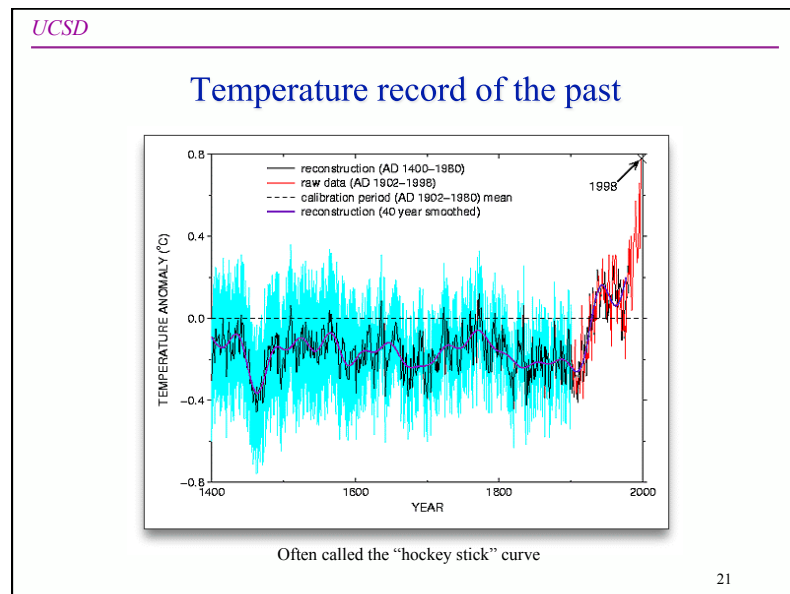
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Total CO₂ rise

- We can do the same thing for the entire fossil fuel history
 - have gone through 1 trillion barrels of oil → 140 Gtoe
 - Gtoe is gigaton (10⁹ ton) oil equivalent (by energy)
 - used about 160 Gtoe coal worldwide
 - using 40 Gtoe U.S. times four, since U.S. uses 25% of world energy
 - used 1037 tcf natural gas in U.S. → 27 Gtoe, so guess 100 Gtoe worldwide
 - 400 Gtoe of fossil fuels → 1.2×10¹⁵ kg of CO₂ (3× FF mass)
 - 228 ppm of atmosphere by mass; 150 ppm by volume
 - half into atmosphere → 75 ppm increase
 - see 100 ppm increase (280 ppm pre-industrial to 380 ppm)
- So the CO₂ increase is absolutely expected! Human fossil fuel use is only sensible explanation.

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A little more detail: IPCC Assessments

- The Intergovernmental Panel on Climate Change (IPCC) is a body of scientists tasked with providing the most robust analysis on climate change available
 - about 1000 scientists
 - emphasis is on consensus view of the most solid facts/data
 - governments are allowed to request changes
 - as a result, the conclusions are very conservative
- Have worked on four major assessments
 - third assessment in 2001; latest is fourth in 2007
 - can see products at: <http://www.ipcc.ch/>
- Explore a variety of scenarios as modifications to our current “business as usual” trend

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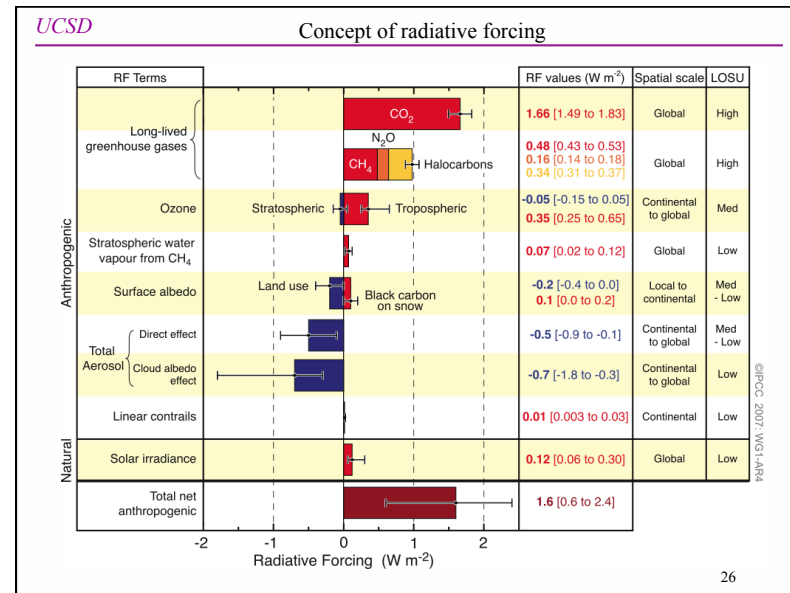
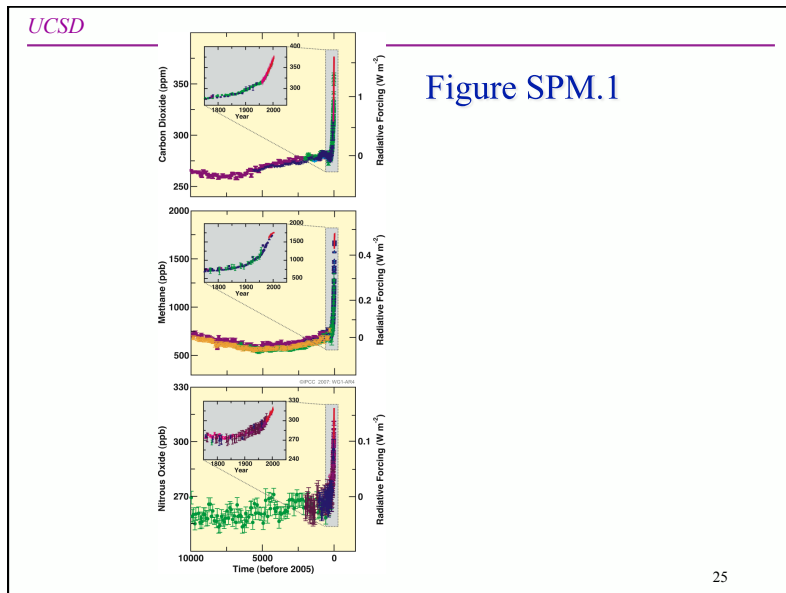
IPCC Working Group I Summary for Policymakers

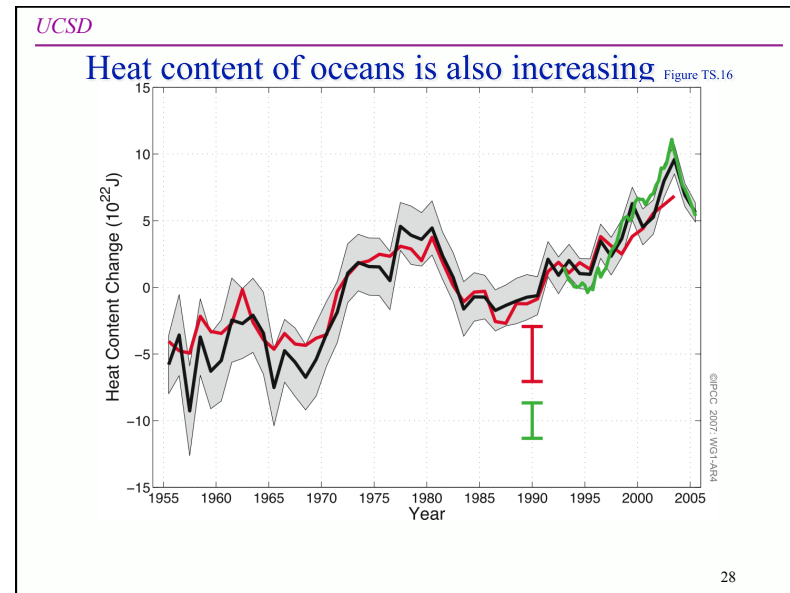
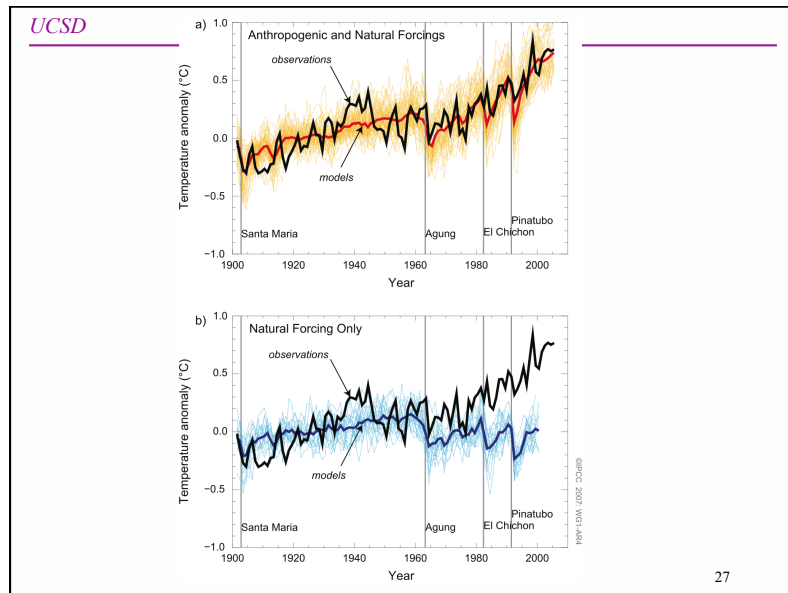
FINAL FIGURES

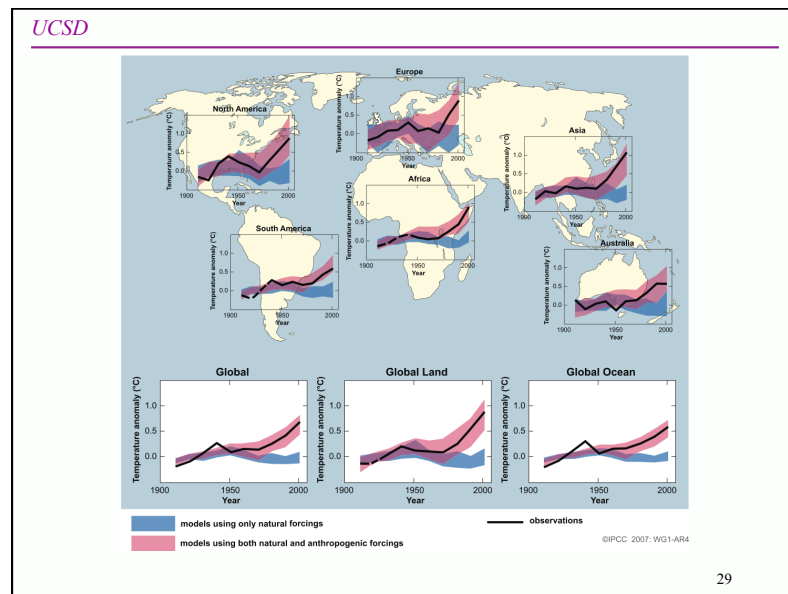
Please note...

A copyright release from the IPCC Secretariat is required if you plan to use any of these figures in a publication. Please contact IPCC-Sec@wmo.int for further information.

The caption text for each figure can be found in the “notes” pane/page for each slide. To view the caption, select “Notes Page” from the “View” Menu.







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The consensus view

- From 2007 IPCC report (a rather conservative body):
 “Most of the observed increase in global average temperature since the mid-20th century is VERY LIKELY due to the observed increase in anthropogenic GHG concentrations.”
 (But Ralph Keeling says that many of the authors in the IPCC report say that this conclusion was deliberately made less conclusive; “very likely” means 90%-95% confidence. He says science actually says ~99% confidence (report should have said “extremely likely”).

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Predicted Temperature Changes

- The IPCC predicts an increase of 1.4°C to 5.8°C from 1990 to 2100 depending on scenario
- Earth can be slow to respond, due to thermal sink of oceans, and this lag means the temperature will continue to rise *even if we ceased burning fossil fuels today!*
- CO₂ hangs around long enough that we would likely not see the end of changes until ~2300
 - this is under scenario that we **STOP** fossil fuels tomorrow (not going to happen!)
 - also sea-level rise is a gift that keeps on giving

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Impacts

- Heat stress on ecosystems/people
- Diseases/plants will change
- Impacts of more intense rainfall on storm drains/sewers/levees
- Changes in circulation and the implications for air pollution
- Coastal cities and tidal surge
- Implications of increased wind storms
- Sea level rise will swamp low elevation islands and coastal cities

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Sea-level rise

- Thermal expansion of water plus glacial and polar ice-cap melting raise the sea level
- The oceans are predicted to rise something like around 1 meter by 2100, maybe more
 - goodbye to much of Bangladesh, much of the Nile valley, Louisiana, much of Florida
- Doesn't stop there: it won't stabilize until maybe 2300, by which time the rise could be several meters
 - this is even if we stop the CO₂ production *today*

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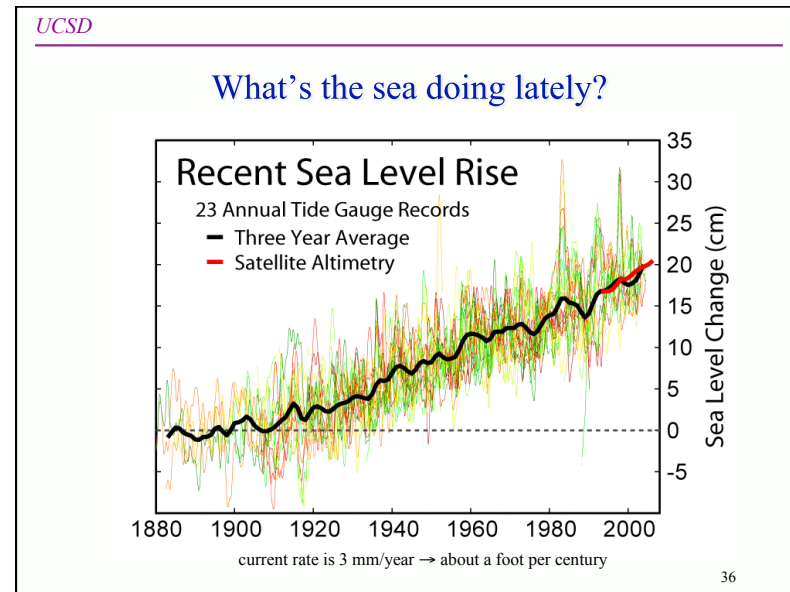
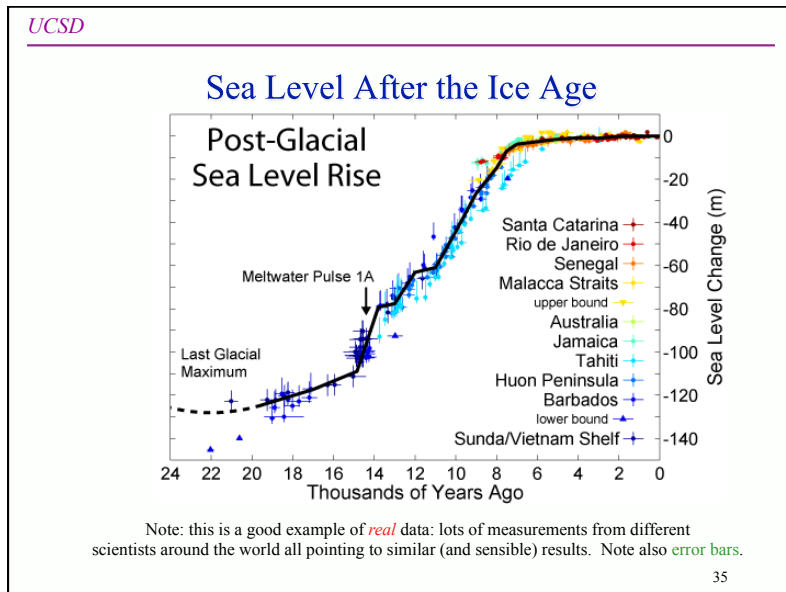
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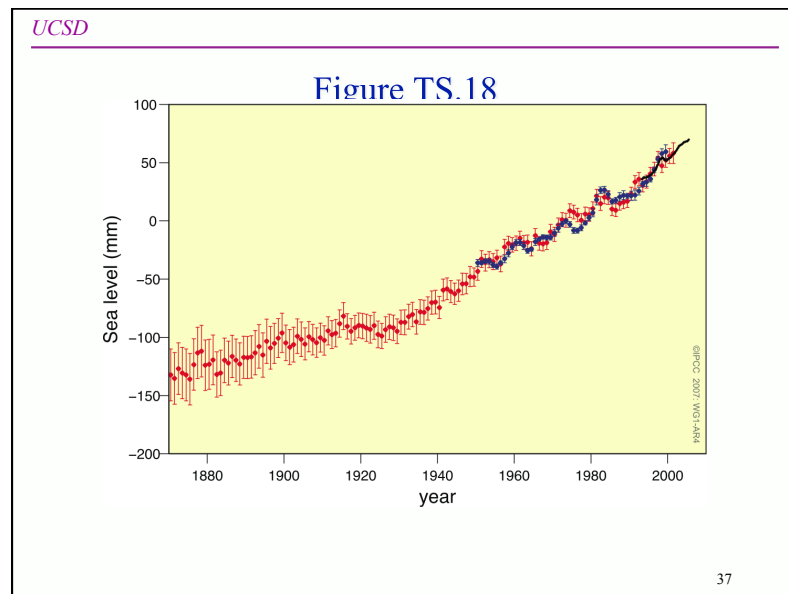
History of Sea Level

- Over the past four cycles, each lasting about 100,000 years, sea level **rose and fell by about 400 feet**, with ice ages having lower sea level and warm interglacial periods having higher sea level.
- During the warmest part of the last interglacial period (about 130,000 years ago), global average temperature was **2–3 °F** warmer than today and global **sea level was 13–20 feet higher**.
- During the Middle Pliocene (3 million years ago), global temperature was **3.5–5.5 °F** warmer than today and **sea level was 80–115 feet higher**.
- If emissions of man-made greenhouse gases continue without abatement, the earth could warm by **5.5 °F (3 °C)** within the next century.

from <http://www.pewclimate.org/global-warming-basics/slr.cfm>

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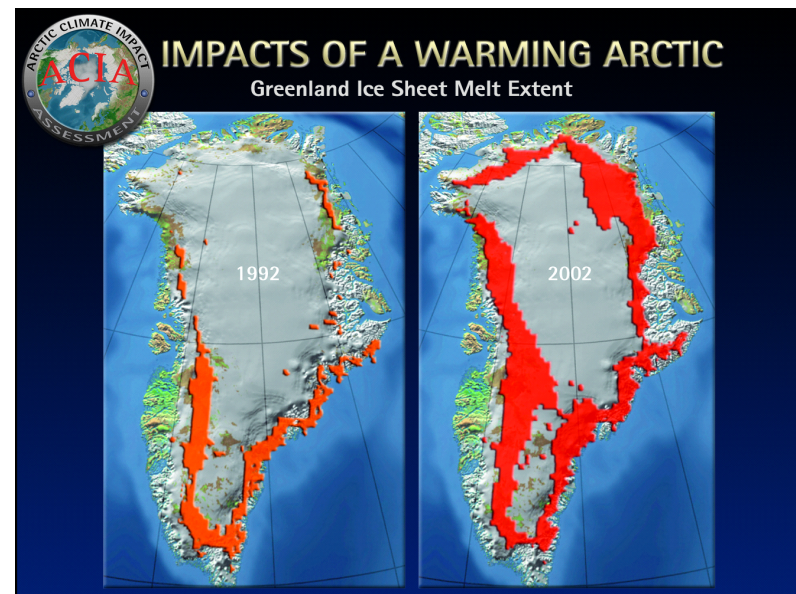
- UCSD
- ### Global Consequences
- The earth's ocean/atmosphere/ice system is *very* complex
 - it's difficult to make predictions due to the **interconnectedness**
 - Naïve extrapolations say that by the end of this century, the global temperature will be **1.4 to 5.8 °C warmer** than today
 - Same predictions have oceans rising roughly one meter by 2100, and **several meters** by 2300
 - These predictions don't account for all possible feedback scenarios; if all ice in Greenland and Antarctica melts sea will rise about 65 meters (215 ft); Greenland alone would cause 7 meters
- 38

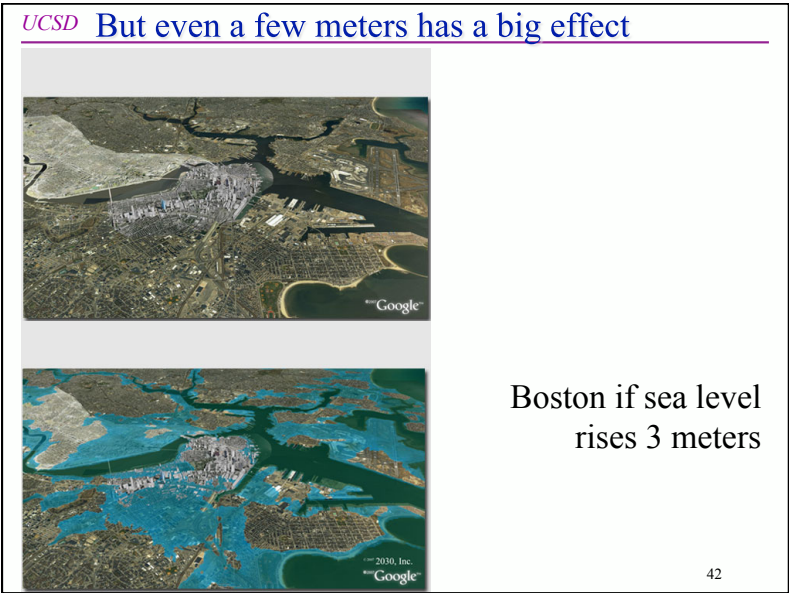
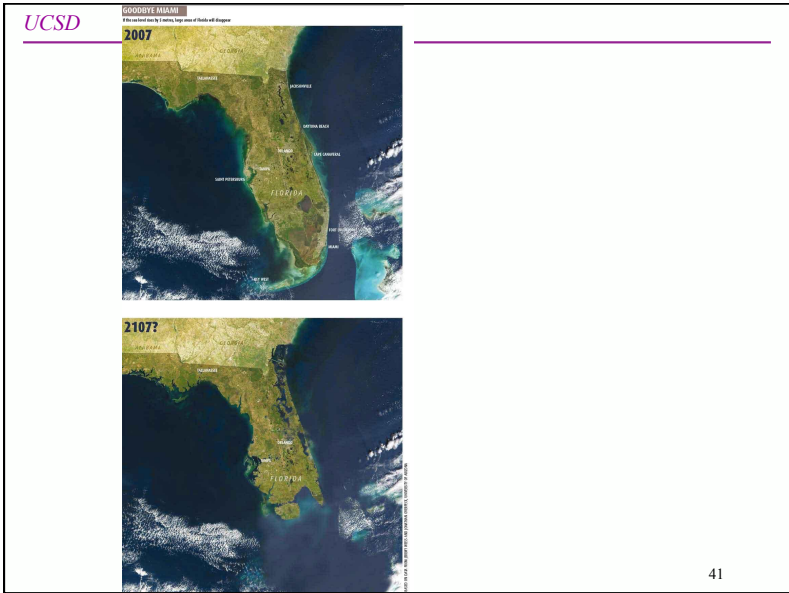
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What about surprises/abrupt climate change?

- Collapse of the West Antarctic Ice Sheet
- Melting of the Greenland ice cap
- Collapse of the North Atlantic thermohaline circulation
- Of course, the real surprises are the ones we haven't thought of

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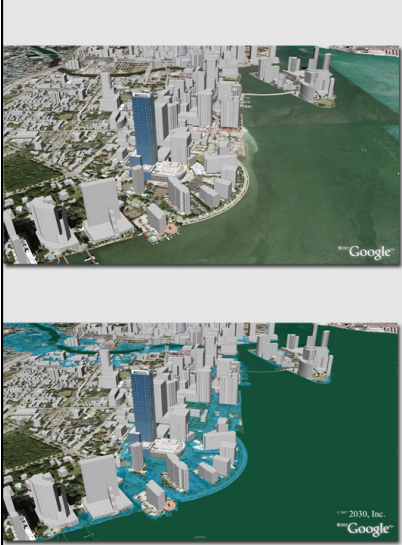
UCSD San Diego with a 3 meter rise in sea level



A 3D architectural rendering of San Diego, California, showing the city's buildings and infrastructure. The sea level is depicted as a light blue area that has risen significantly, inundating large portions of the coastal and low-lying areas. The water is shown in a darker blue, and the submerged areas are highlighted in a lighter blue. The rendering includes a large stadium-like structure and various commercial buildings. In the bottom right corner, there is a copyright notice: "©2007 2030, Inc. Google".

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Two 3D architectural renderings of Miami, Florida, showing the city's buildings and infrastructure. The top image shows the city with a 1-meter sea level rise, with water (light blue) inundating the coastal areas. The bottom image shows the city with a 1-meter sea level rise, with water (light blue) inundating the coastal areas. Both images include a copyright notice: "©2007 2030, Inc. Google".

Miami if sea level rises 1 meter

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Ice-age scenario

- The interconnectedness could drive us in the opposite direction
- As Greenland ice cap melts, North Atlantic becomes less salty, and the “Great Conveyor Belt” that is responsible for bringing warmth to northern latitudes (especially Europe and eastern North America) could shut off
 - **already faltering**, possibly foreshadowing collapse
 - could shut off this year, or in next several decades
 - climate shift would be *abrupt and dramatic*

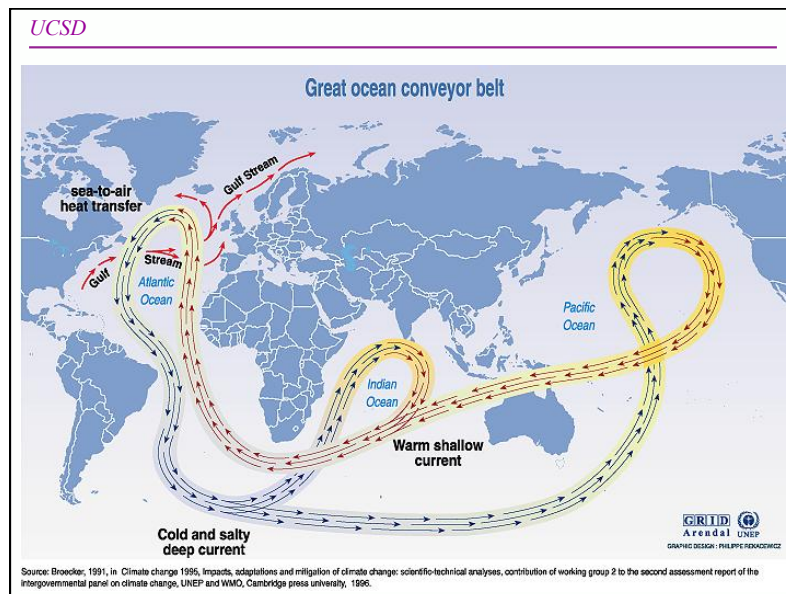
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The Great Conveyor Belt

- ...of which the Gulf Stream is a part, it goes like this:
 - warm water from the tropics flows on the surface to the North Atlantic
 - as it goes, much evaporates, leaving saltier water
 - as water becomes colder and saltier, it becomes denser
 - dense water sinks to ocean floor (near Greenland)
 - cold, salty flow empties into Pacific
 - warm surface water from Pacific replaces lost water, flowing north and closing the cycle
 - called *thermohaline* cycle

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If the circulation stops...

- If the conveyor belt shut off, Europe, Canada, northeastern U.S. would be **plunged into Siberian winter**
- Transition would take *only 2–3 years*, based on historical onset of ice ages
- Much greater reflectivity of snow would result in much less absorbed solar energy → global *cooling*
 - oh—the irony
- Condition would be sustained for 700–100,000 years, judging by durations of previous ice ages
- Lower latitudes are not spared: droughts, firestorms
 - less evaporation off of warm surface currents in ocean

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The Venus Scenario

- Increasing temperatures could unleash a *runaway* process:
positive feedback
- Example of **negative feedback** (tendency toward stability)
 - warmer→more clouds→more reflection→cooler
- Examples of **positive feedback**:
 - warmer→less CO₂ absorption by water→more greenhouse gases→gets warmer
 - warmer → air holds more water vapor → more greenhouse effect → warmer
 - colder→more ice on planet→more reflection→colder
- The open question is which type of feedback will dominate: positive feedback means runaway

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Positive feedback contributors

- Warm water has diminished ability to absorb CO₂
 - already “sharp drop” observed in Pacific CO₂
- Hotter soil means CO₂ is given off
- More stable ocean (hot on top) starves plankton
 - they rely on nutrients swept up from bottom
 - net result: reduced activity means less CO₂ absorbed
- Thawing tundra→wetlands→more methane
 - a powerful greenhouse gas
- Submarine methane-hydrates frozen in place are warmed out

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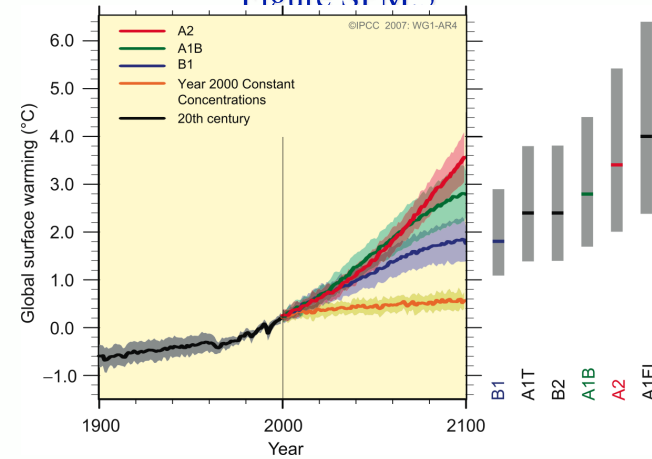
The consensus view?

- The majority view among climate researchers globally is that positive feedback is likely to dominate over negative feedback
 - but this isn't being explicitly stated (published), as the uncertainties are still too high
 - good lesson of less-than-alarmist science community

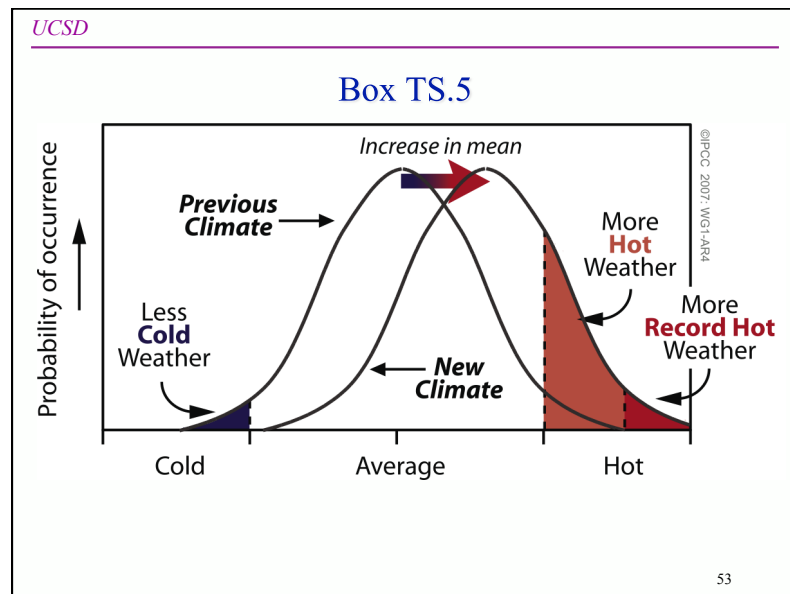
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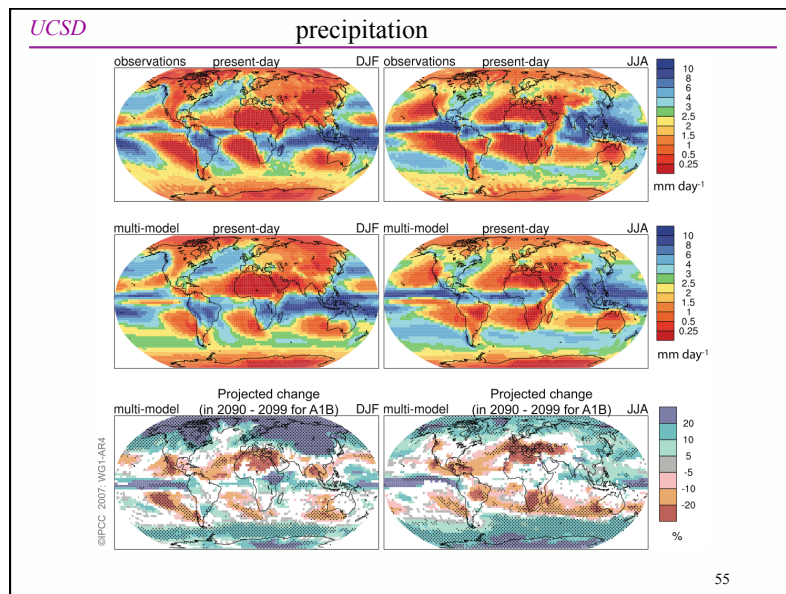
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Figure SPM 5



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- ### Other effects from climate change
- The earth is slowing down as polar ice melts and redistributes into the oceans
 - like an ice-skater slowing down by holding arms out
 - Glaciers retreating
 - More erratic weather (hard to quantify, though)
 - Species extinctions at an unprecedented rate
 - Plant growing season and insect cycles are longer
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How are we responding?

- Globally, the response is positive and encouraging
- The U.S., however, has been egregiously reluctant to accept the consequences
 - doing so would impact “our way of life”
 - not surprising that the worst offenders/contributors are behaving the least responsibly (e.g. U.S., China)
 - Very recently both U.S. and China are saying they will reduce emissions. So far no actual actions by either.
- A tragic human epitaph:
 - We wanted to save the world, but our leaders told us it would be too expensive
- Result so far: Business as Usual

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A detailed look at the U.S. response

- I highly recommend reading the document put out by the Union of Concerned Scientists in March 2004
 - titled: Scientific Integrity in Policymaking
 - http://www.ucsusa.org/scientific_integrity/
 - under “Read the UCS reports” link
- Conclusion:
 - The Bush administration suppressed and distorted the truth at an unprecedented level; this is according scientists who are both Republican and Democrat. Obama has been slow to correct things. Will he ever?

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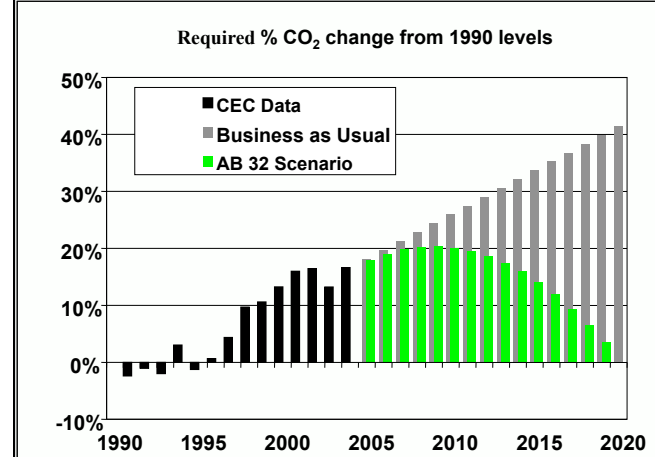
Good references on the subject

- http://www.ucsusa.org/global_warming/
– Union of Concerned Scientists
- lwf.ncdc.noaa.gov/oa/climate/globalwarming.html
– NOAA: the National Oceanic and Atmospheric Admin.
- <http://epa.gov/climatechange/index.html>
– Environmental Protection Agency site
- Ten myths about global warming
– <http://www.sierraclub.ca/national/programs/atmosphere-energy/climate-change/ten-myths.html>
- *Field Notes from a Catastrophe*, by Elizabeth Kolbert
– well-written overview book on climate change

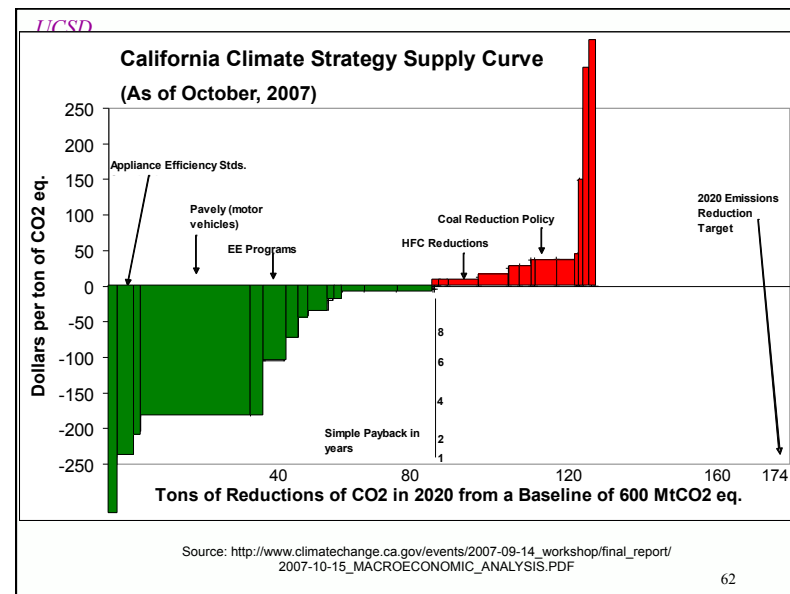
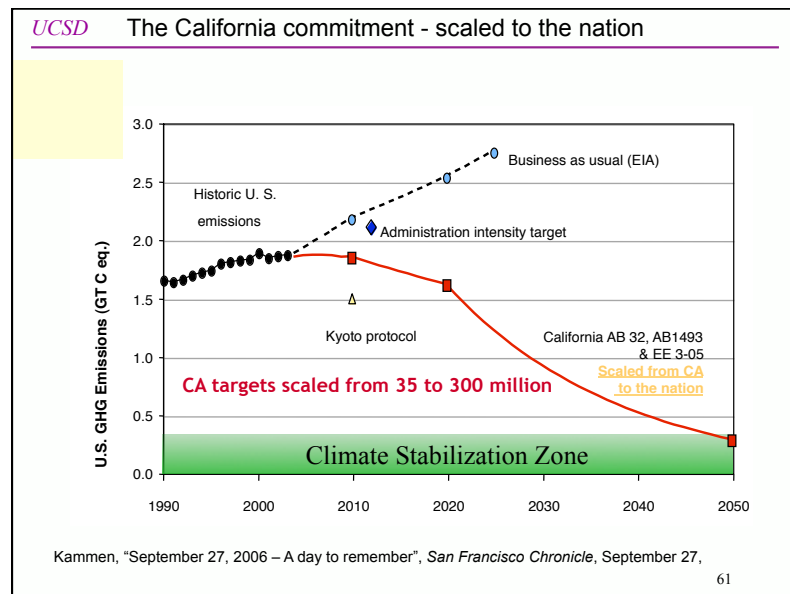
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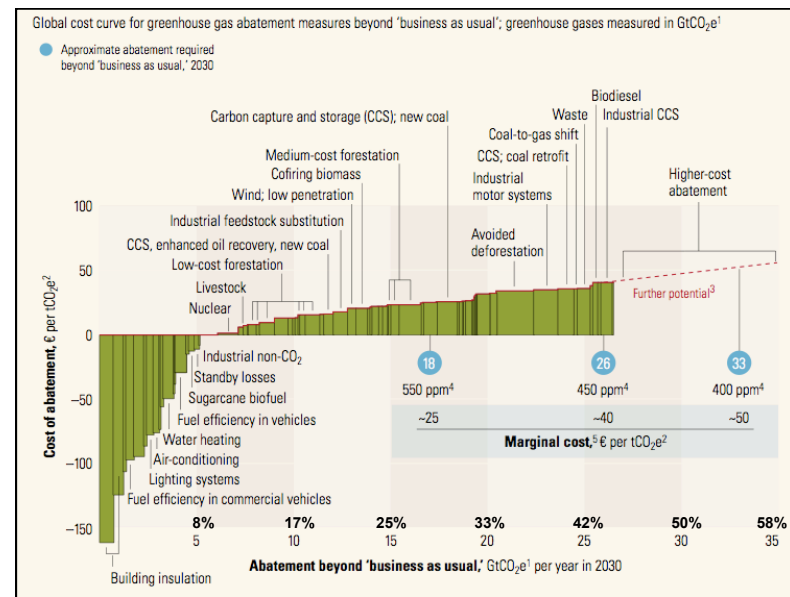
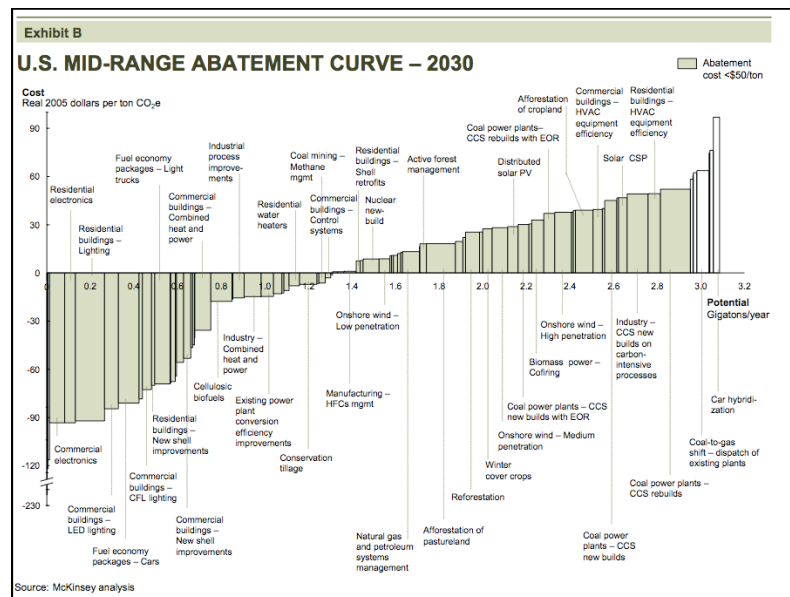
UCSD What can we do about Climate change?

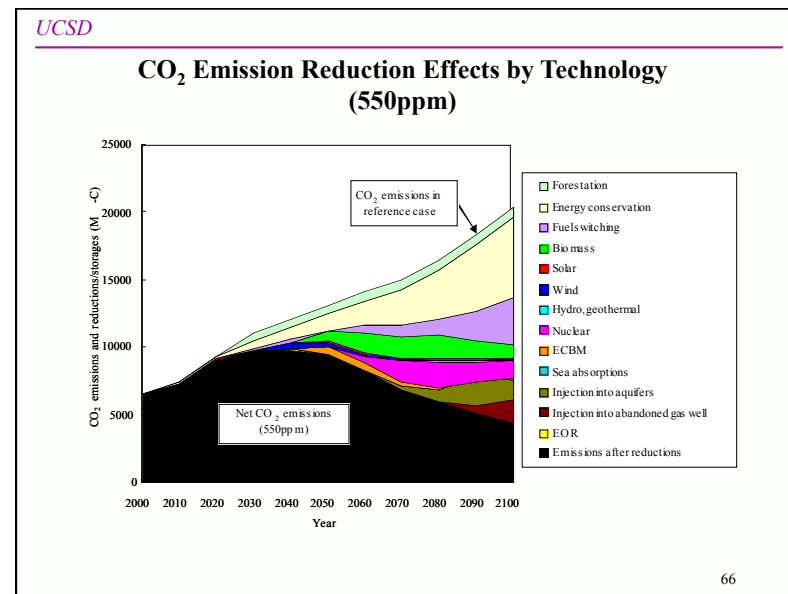
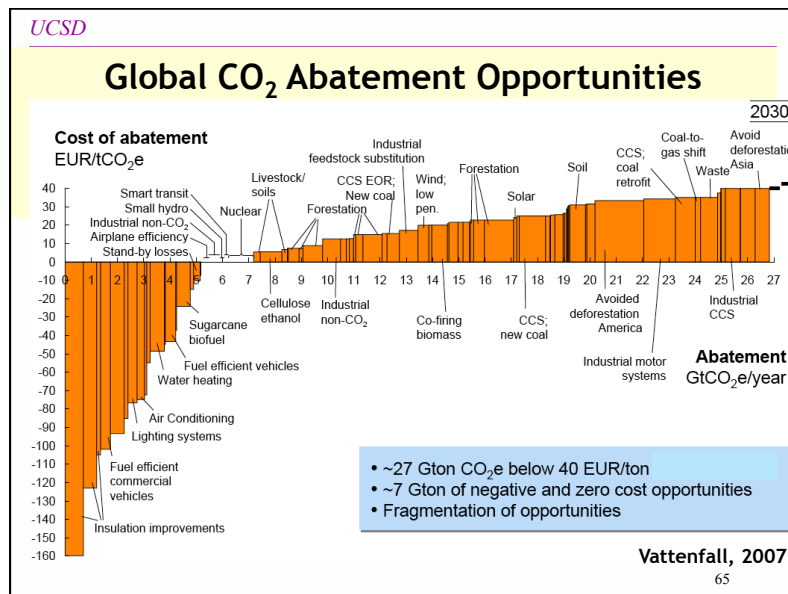
Calif. law: AB 32 Emissions Reductions

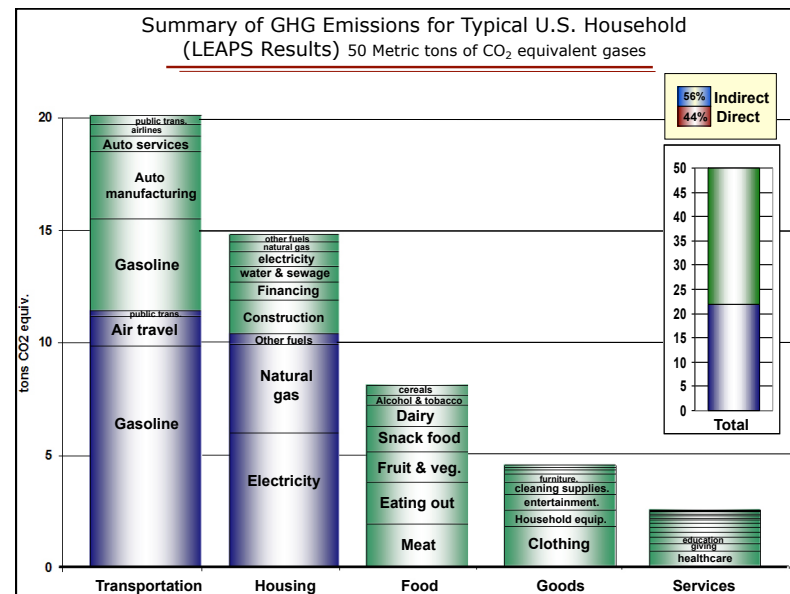
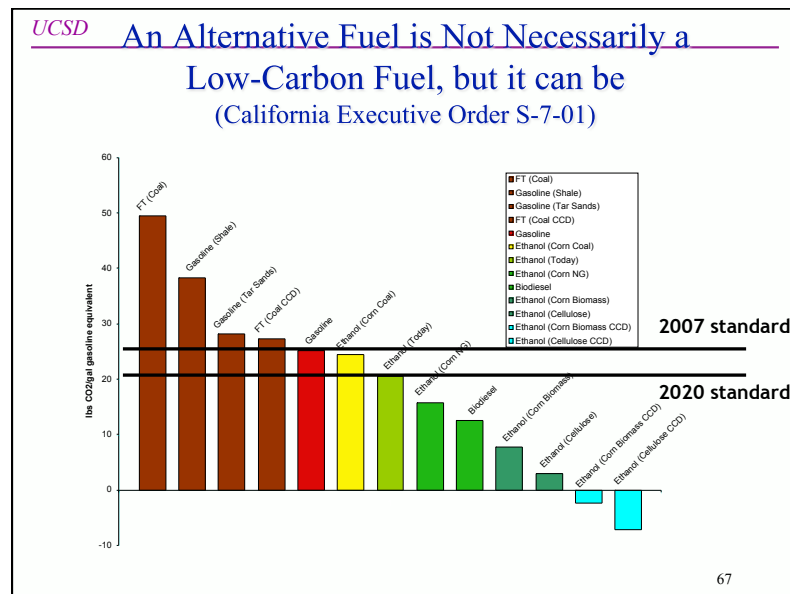


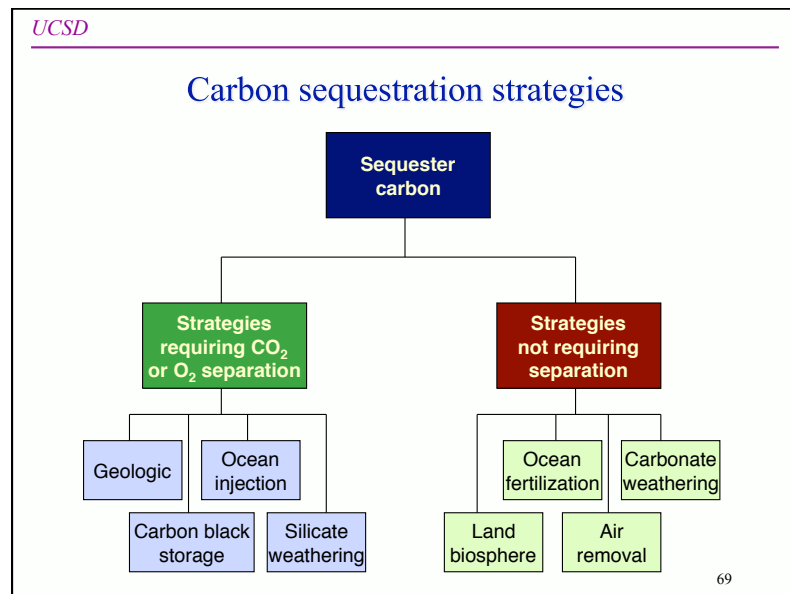
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UCSD **Carbon sequestration:**
A carbon-emission-free fossil-fuel economy

fossil fuel	Resource energy [TW-yr]	Carbon content [GtC]	$(E/C)_{fuel}$ [TW-yr/GtC]	(E/C) [TW-yr/GtC]	Burial/mining rate [GtC/yr]
Gas	1200	570	2.1	1.6 - 0.7	6 - 14
Oil	1200	750	1.6	1.2 - 0.5	8 - 19
Coal	4800	3690	1.3	1.0 - 0.4	10 - 23

Carbon sequestration rates to produce 10 TW CO₂-emission-free from fossil fuels

DOE goals:
1 GtC/yr by 2025
4 GtC/yr by 2050

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CO₂ Burial: Saline Reservoirs

130 Gt total U.S. sequestration potential
Global emissions 6 Gt/yr in 2002 Test sequestration projects 2002-2004

Study Areas

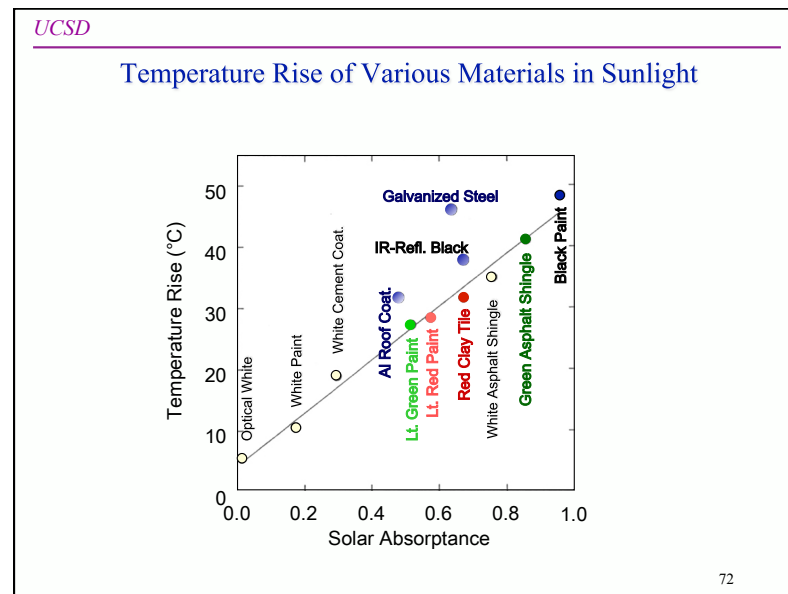
- Near sources (power plants, refineries, coal fields)
- Distribute only H₂ or electricity
- Must not leak

One Formation Studied

Two Formations Studied

Power Plants (dot size proportional to 1998 carbon emissions)

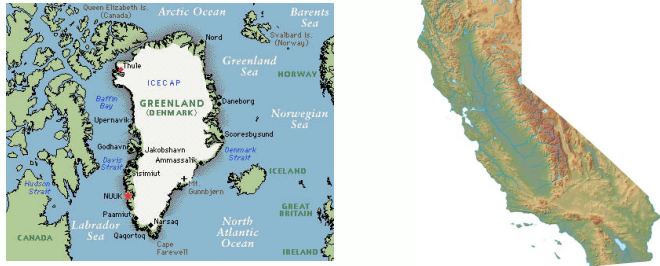
DOE Vision & Goal:
1 Gt storage by 2025, 4 Gt by 2050



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Cooler cities as a mirror


- Mirror Area = $1.5 \times 10^{12} \text{ m}^2$ [5] $\times (0.1/0.7) [\delta \text{ albedo of cities} / \delta \text{ albedo of mirror}]$
 = $0.2 \times 10^{12} \text{ m}^2 = 200,000 \text{ km}^2$ {This is equivalent to an square of 460 km on the side}
 = 10% of Greenland = 50% of California



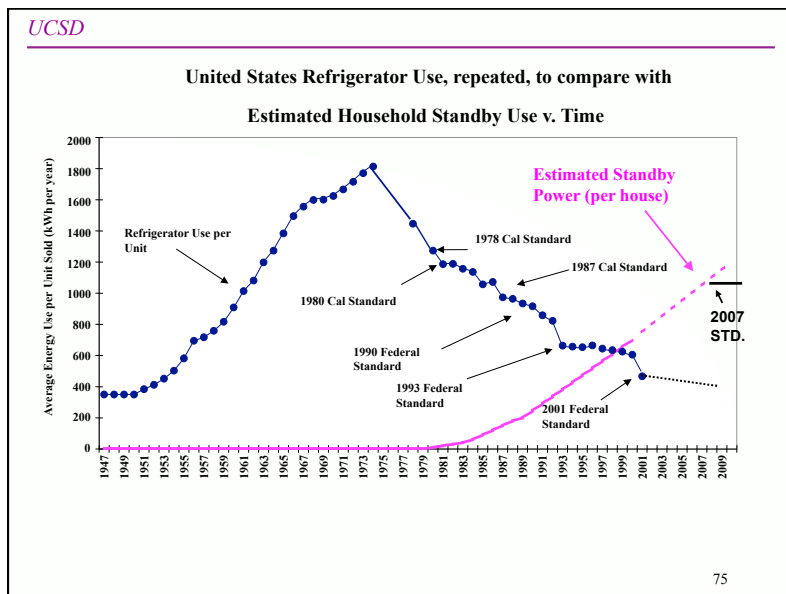
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and in Santorini, Greece



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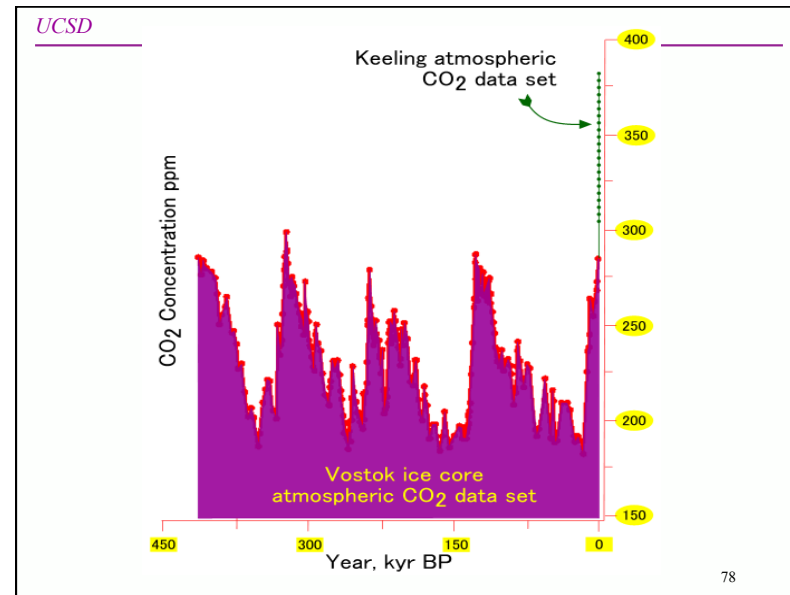
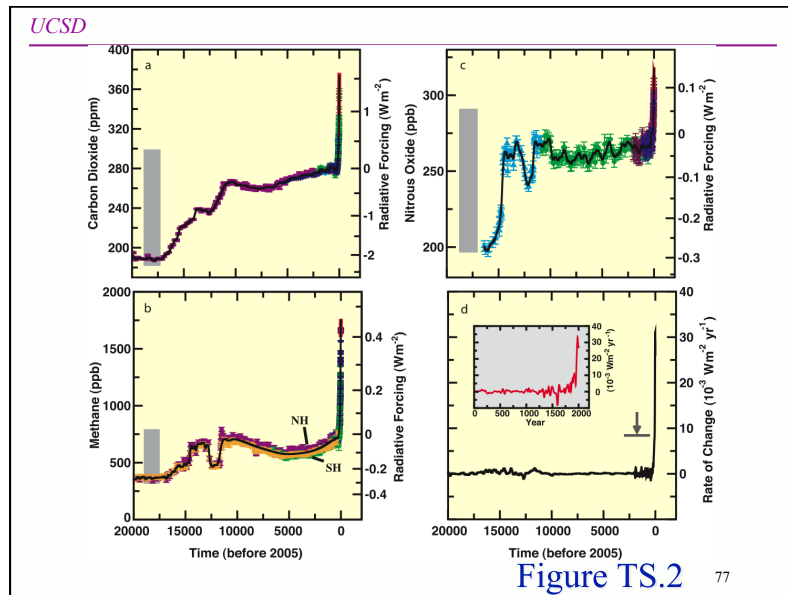
Switching from Kerosene Lanterns to Rechargeable LEDs

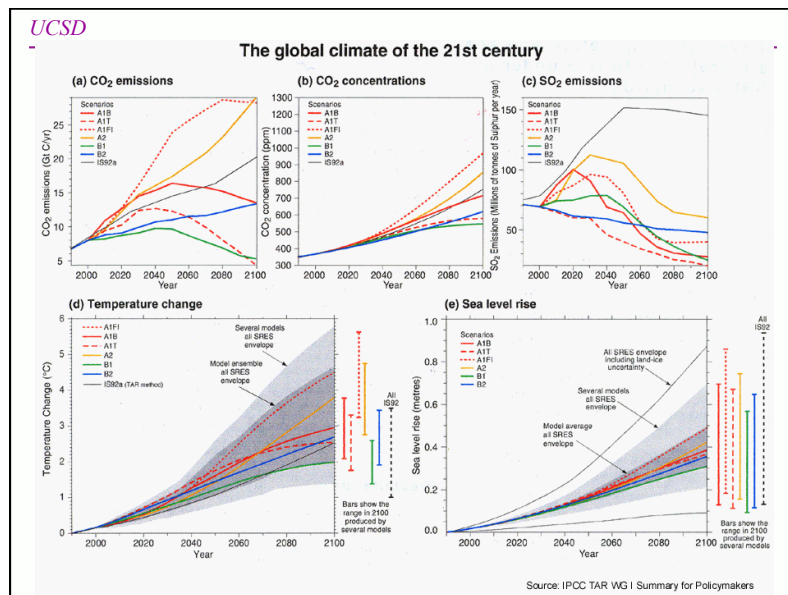
Commercially available LEDs

- 0.1 to 1 watt
- Lumens/watts > 100 better than kerosene lanterns
- Much better directionality adds to this advantage

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<http://www.ifc.org/led>

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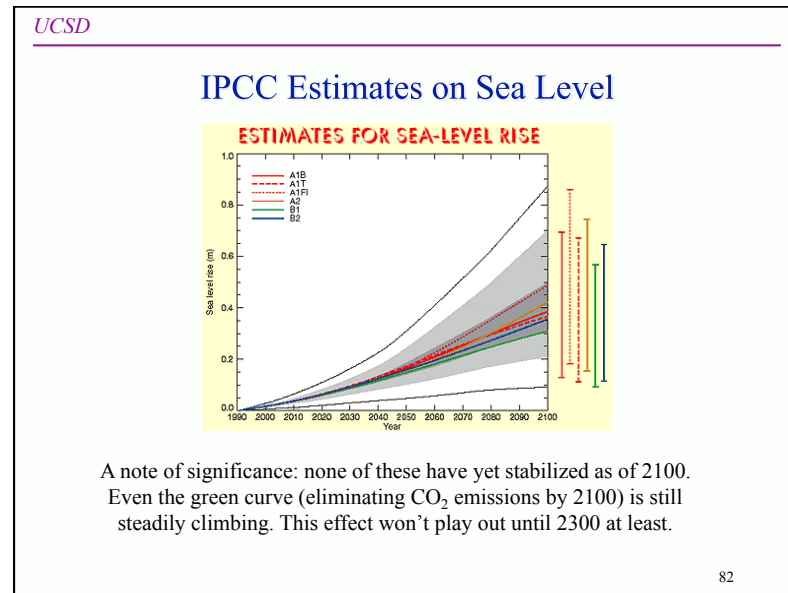
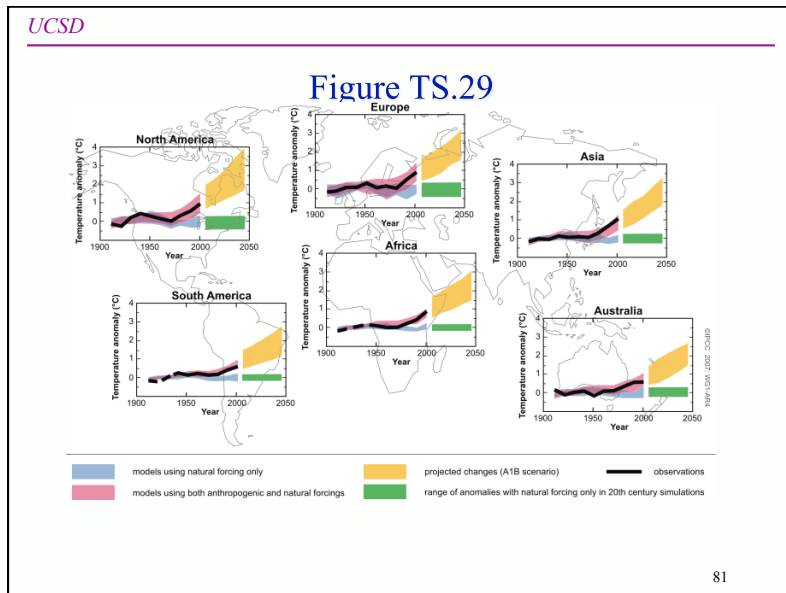


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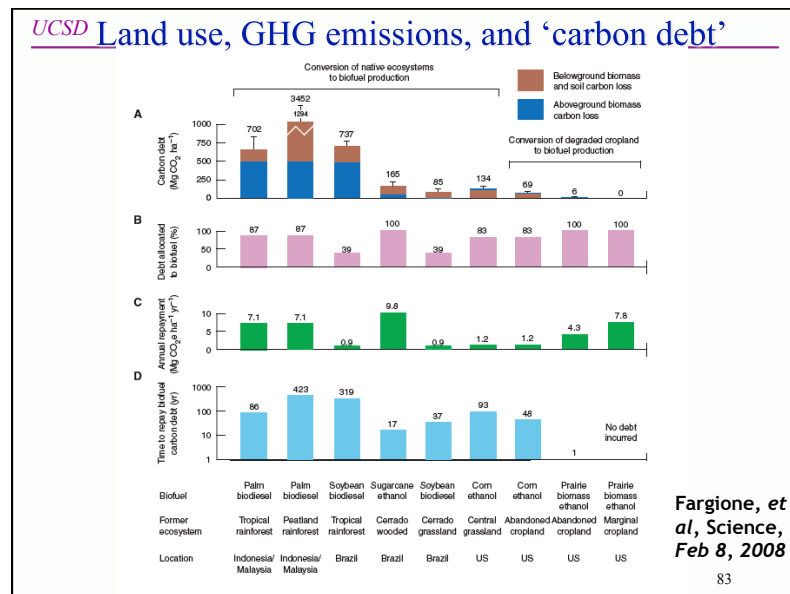
Hoffert et al.'s Conclusions

- “These results underscore the pitfalls of “wait and see”.”
- Without policy incentives to overcome socioeconomic inertia, development of needed technologies will likely not occur soon enough to allow capitalization on a 10-30 TW scale by 2050
- “Researching, developing, and commercializing carbon-free primary power technologies capable of 10-30 TW by the mid-21st century could require efforts, perhaps international, pursued with the urgency of the Manhattan Project or the Apollo Space Program.”

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A note of significance: none of these have yet stabilized as of 2100. Even the green curve (eliminating CO₂ emissions by 2100) is still steadily climbing. This effect won't play out until 2300 at least.



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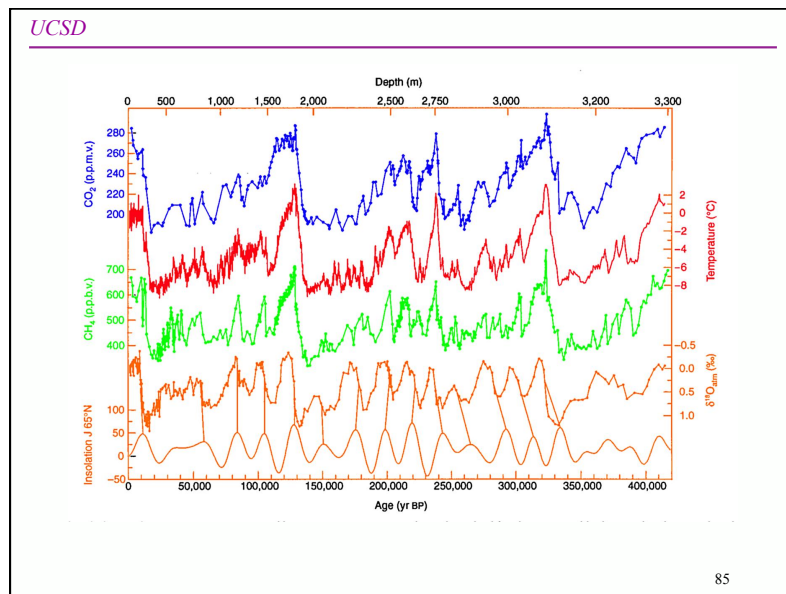
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How to Save 40 MtCO₂ eq. per year

- UV Water Purification– An alternative to boiling
 - Worldwide 3 Billion people have access only to polluted water
 - 1.2 Billion boil this; the remainder must use polluted water
 - Many get sick and children die
 - Boiling water emits an avoidable **20 MtCO₂ eq.** per year
 - Primarily fire wood is used for this
 - With heat content = 2 million barrels of petroleum per day
- Switching from Kerosene Lighting to LED rechargeable Flashlights
 - 2 Billion people off of electricity grid use kerosene lanterns
 - Rechargeable LED flashlights now cost less than \$20
 - Worldwide this will avoid another **20 MtCO₂ eq.** per year

The total of **40 MtCO₂ eq. per year** = **1%** of reduction target in the building sector, as estimated earlier in talk by “Design To Win”

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Is rise in CO₂ surprising?

- Every gram of fossil fuel used produces 3 grams of CO₂
 - it's straight chemistry: to get the energy out via combustion, the carbon from the hydrocarbon gets attached to oxygen and off it goes
- How much should we expect?
 - global energy budget is 4×10^{20} J; pretend all from fossil fuels
 - average 10 Cal/gram \rightarrow $\sim 40,000$ J/gram $\rightarrow 10^{16}$ g/yr F.F.
 - so 3×10^{16} g/yr CO₂ $\rightarrow 3 \times 10^{13}$ kg/yr CO₂
 - atmosphere has mass = 5.3×10^{18} kg \rightarrow CO₂ adds 5.7 ppm/yr by mass
 - about 3.7 ppm/yr by volume (CO₂ is 44 g/mol vs. 29 for air)
 - if half goes into ocean, half into atmosphere (what I'm told), atmospheric rise is **1.85 ppm/yr**, by volume
 - this is darn close to what we see on the “Keeling curve” graph

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