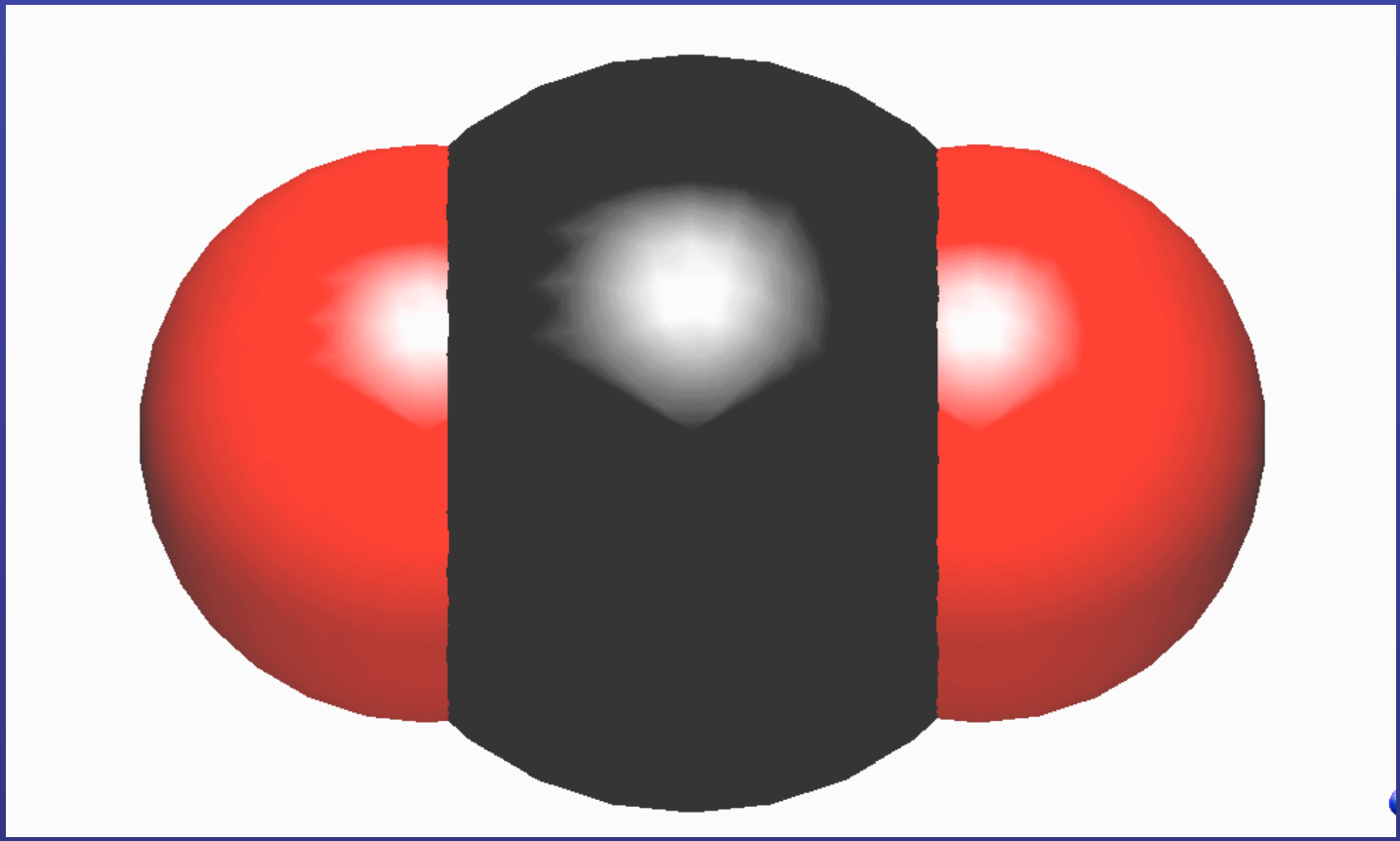
The Carbon Conundrum



The Carbon Economy and Sustainability

Ankur Desai, Atmospheric & Oceanic Sci., UW-Madison

CEE 698: Sustainability Principles, Practices, and Paradoxes

Feb 9, 2010

DISCUSS:

Sustainable development requires that we move away from a carbon-energy economy immediately.

Questions

- What are atmospheric greenhouse gases?
- Why are they changing and how do we know they are?
- How do ecosystems react to changing atmospheric composition?
- Why does that matter for climate policy and sustainable development?

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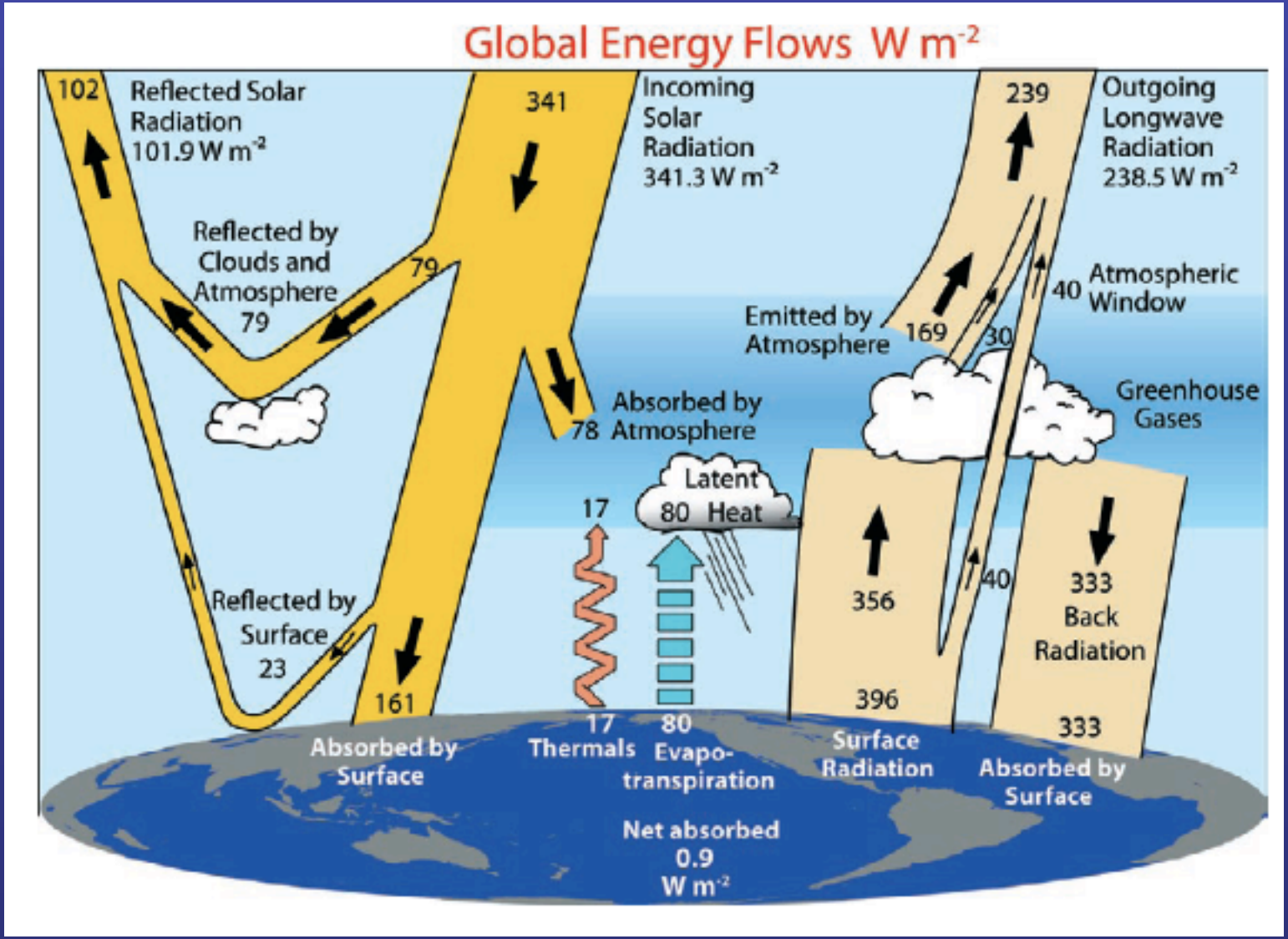
Living in a Greenhouse

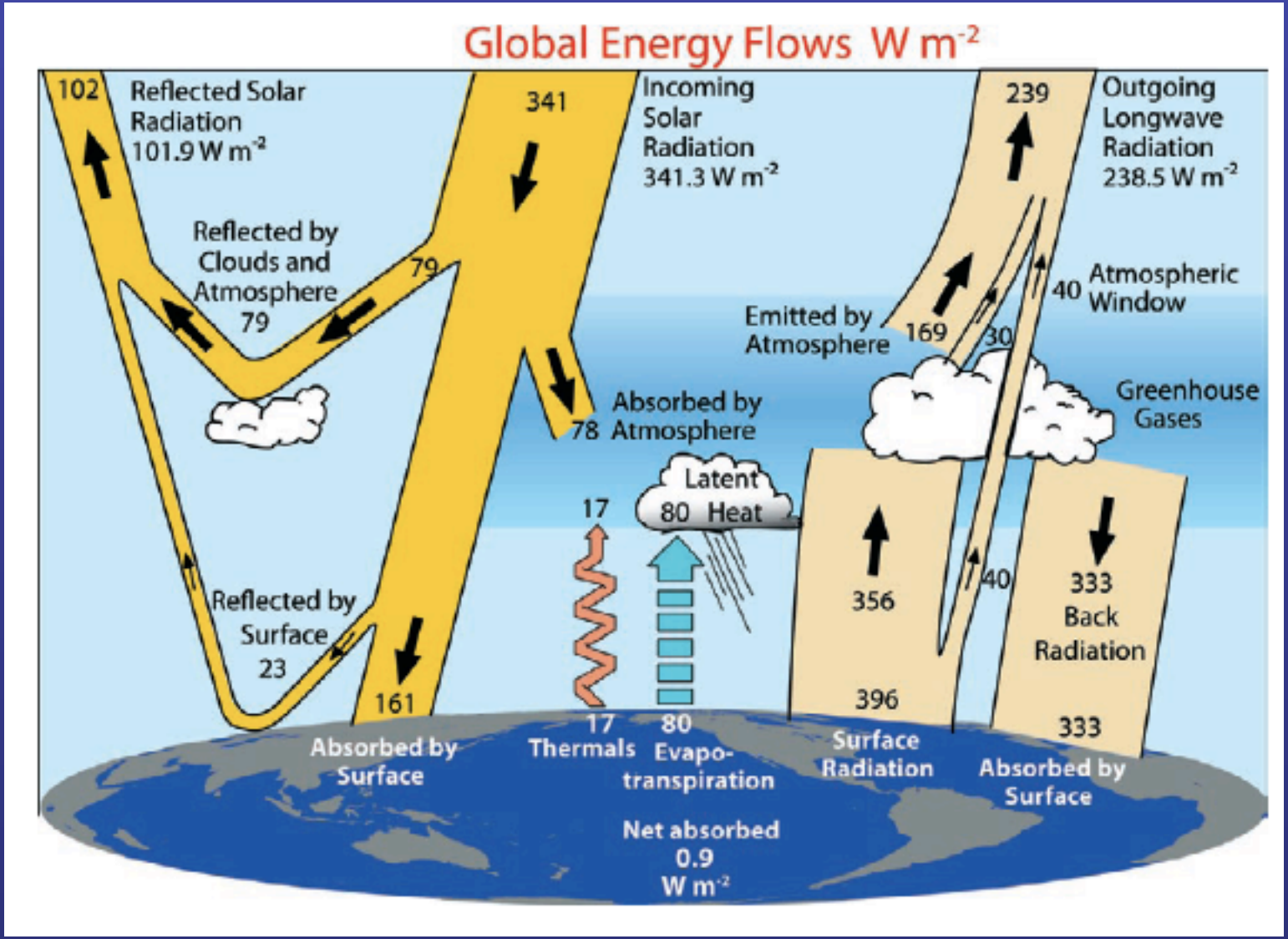


- Trenberth et al., 2009

Climate 101

- Earth's climate is regulated by:
  - Solar "shortwave" input
    - Sun bathes earth primarily with visible light, which varies very little year to year on short timescales
  - Surface energy budget
    - Solar energy is reflected or converted into other forms of energy (photosynthate, longwave IR, heat, evaporation)
  - Atmospheric absorption and emission of surface and solar energy
    - Atmosphere is mostly transparent to solar energy but opaque to infrared and longer waves
  - Fluids that move energy around
    - Weather and ocean currents
    - Mainly affects spatio-temporal distribution

Living in a Greenhouse



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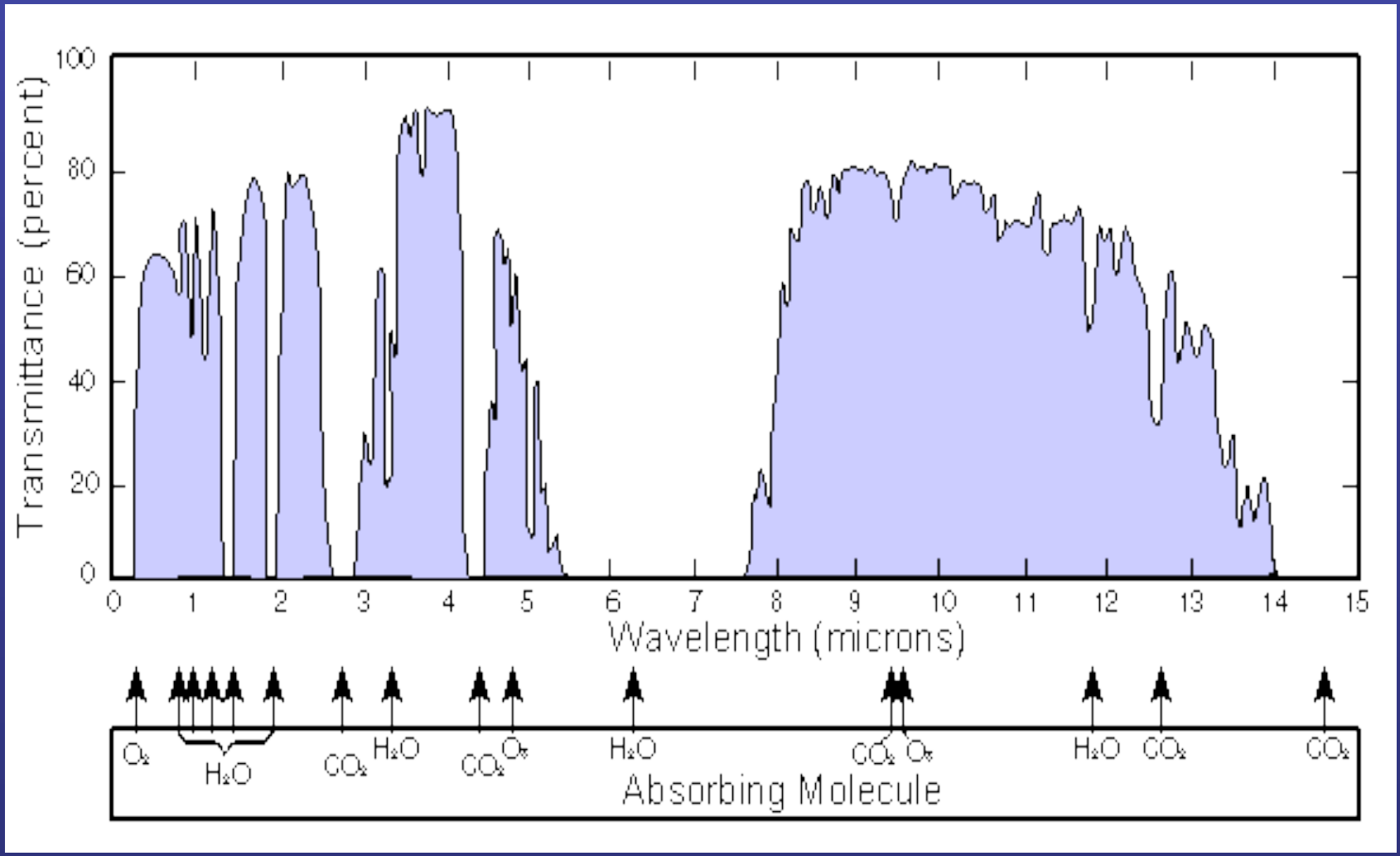
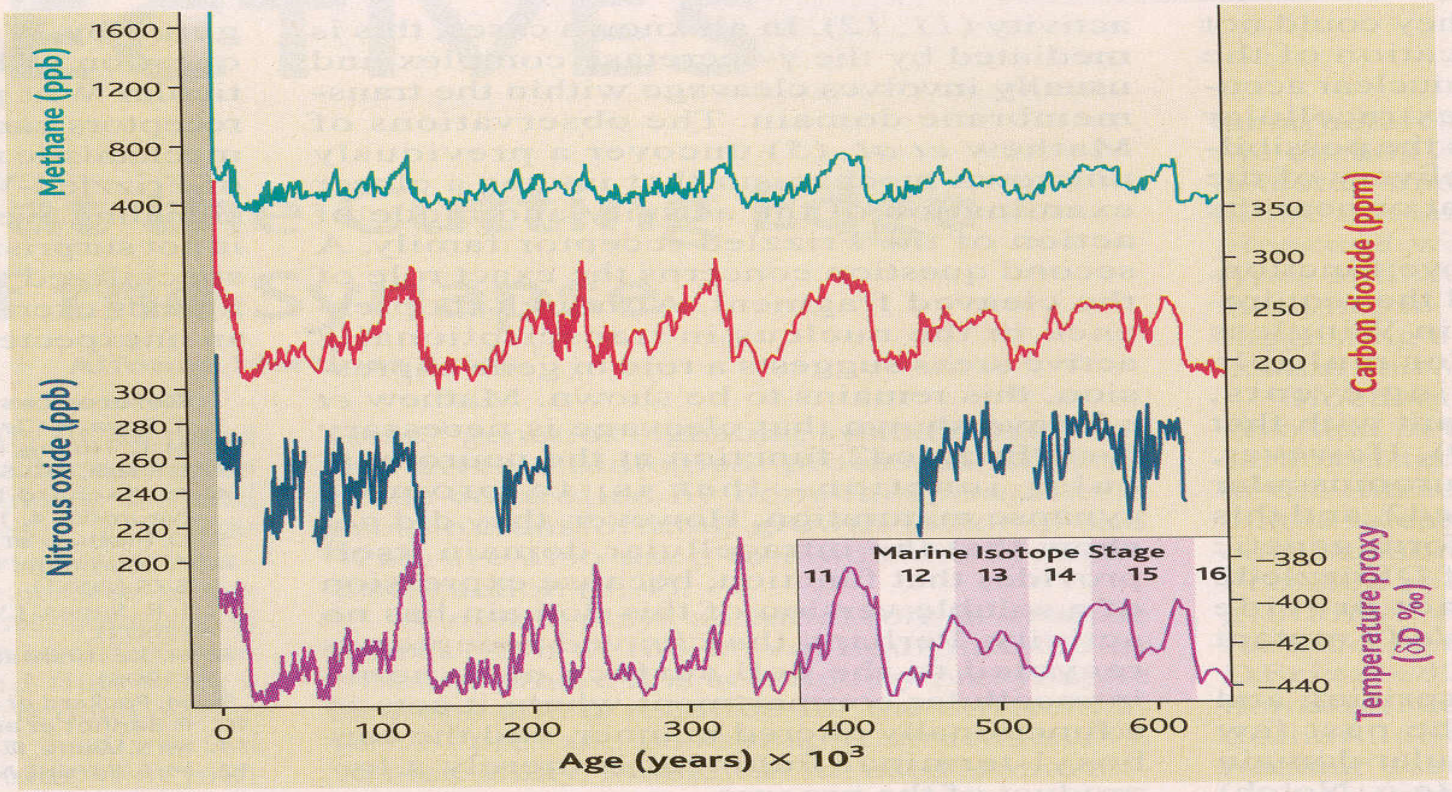
Living in a Greenhouse



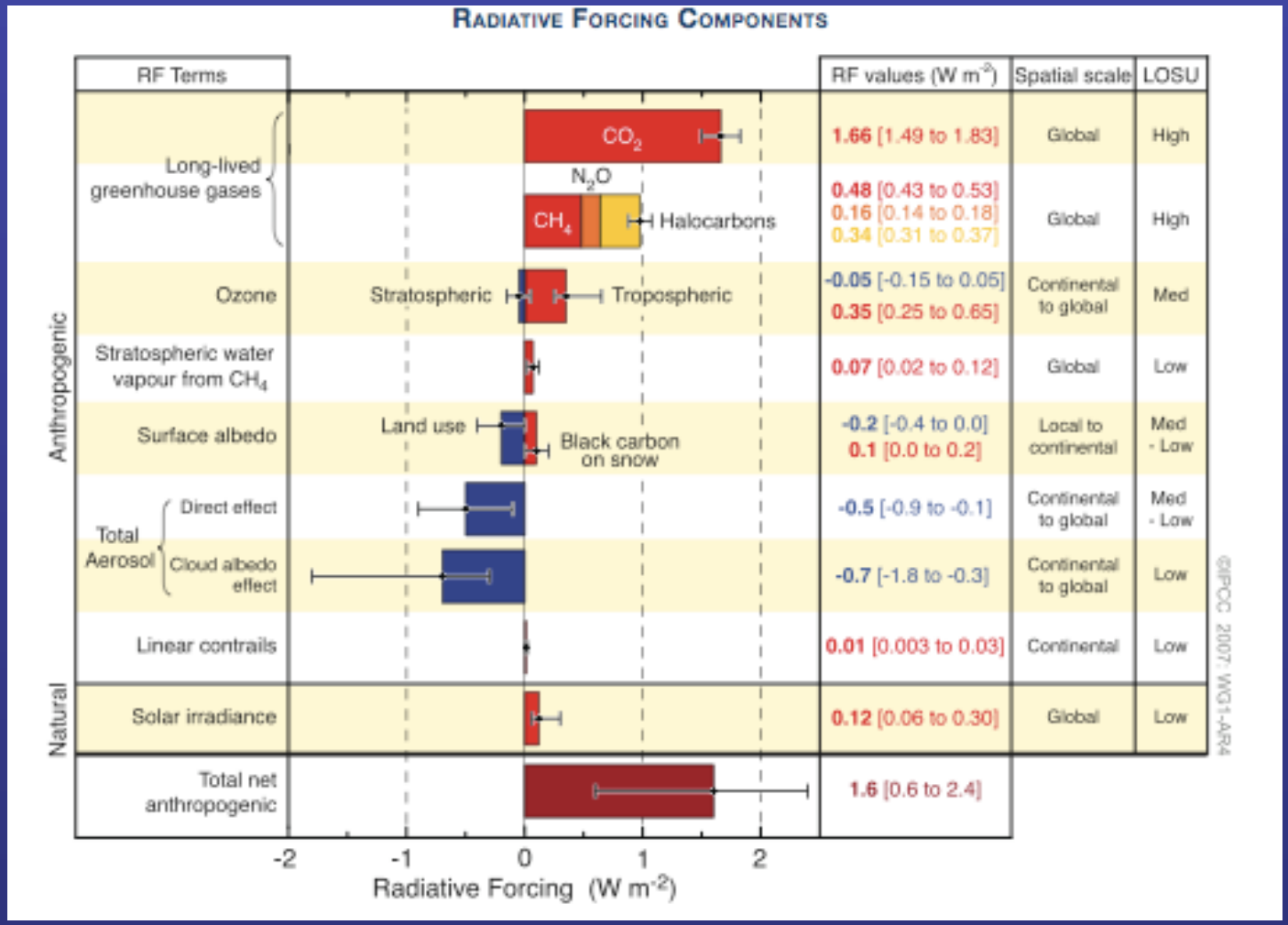
The Long View



The long view. The greenhouse gas (CO_2, CH_4, and NO_2) and deuterium (δD) records for the past 650,000 years from EPICA Dome C and other ice cores, with marine isotope stage correlations (labeled at lower right) for stages 11 to 16 (*2*, *3*). δD, a proxy for air temperature, is the deuterium/hydrogen ratio of the ice, expressed as a per mil deviation from the value of an isotope standard (*4*). More positive values indicate warmer conditions. Data for the past 200 years from other ice core records (*20*–*22*) and direct atmospheric measurements at the South Pole (*23*, *24*) are also included.

- CO_2 and climate are closely linked
- Siegenthaler et al., 2005; Petit et al., 1999

It's Not Just CO_2



- IPCC, 4th AR, 2007

Questions

- What are atmospheric greenhouse gases?
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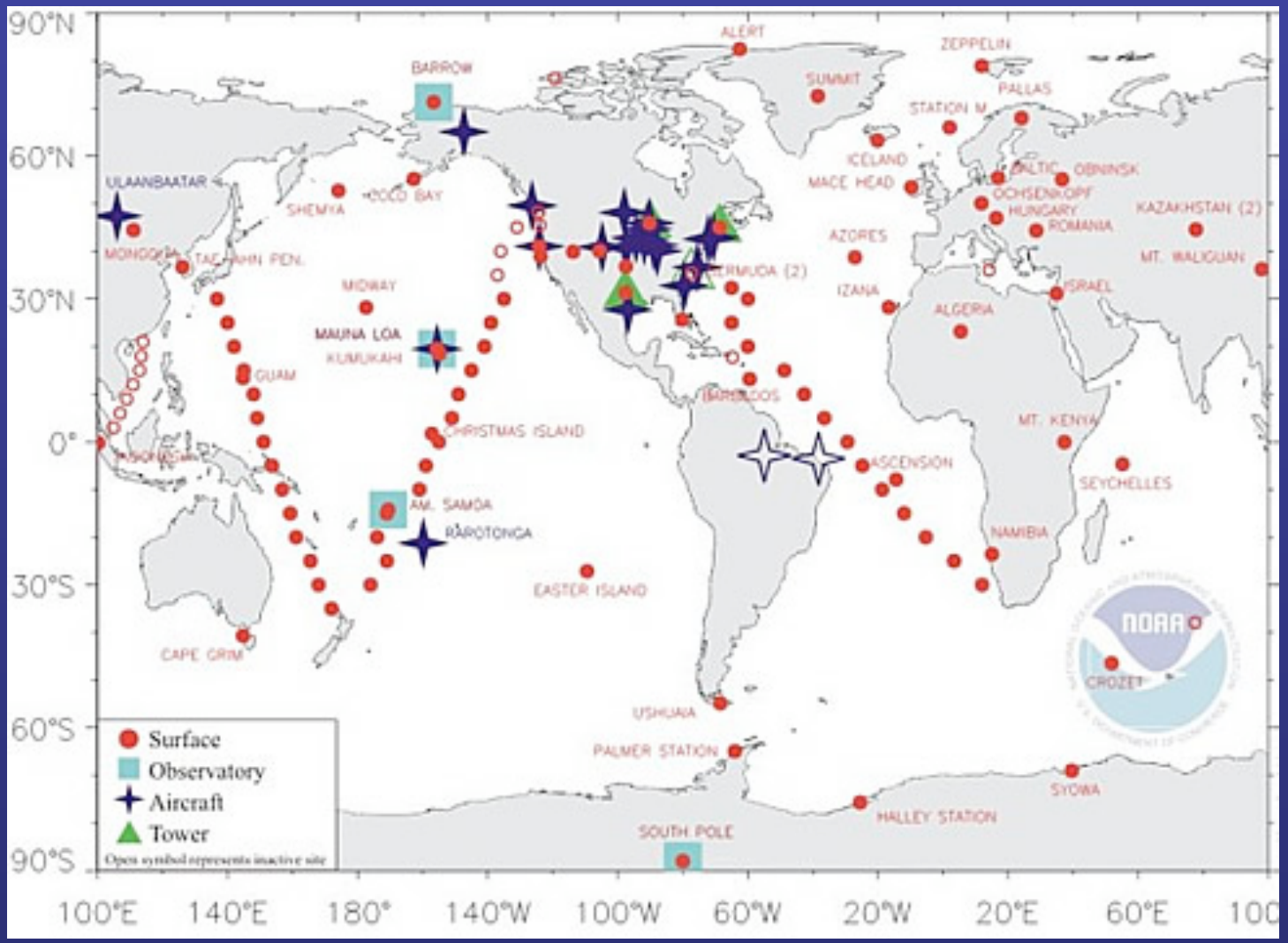
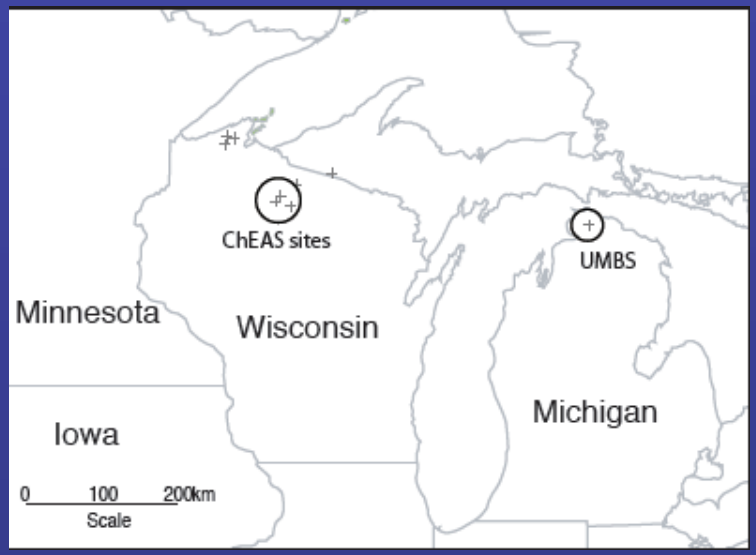
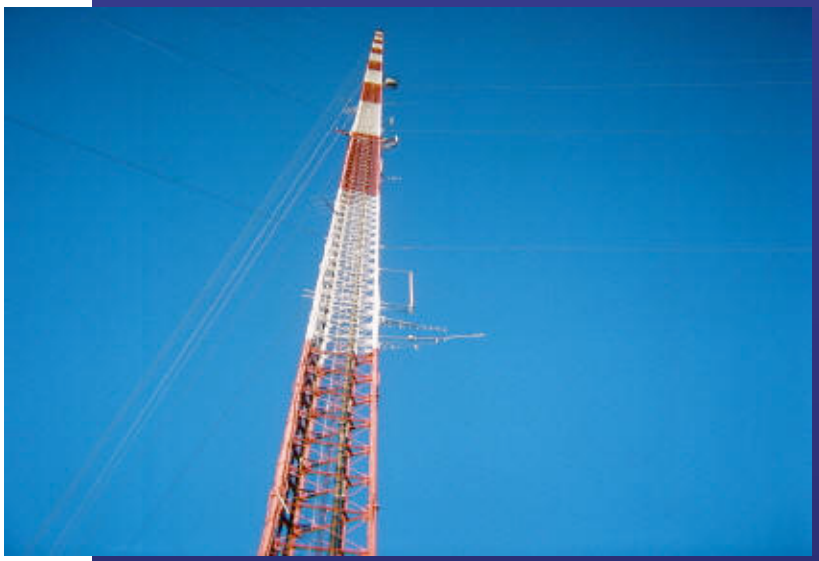
Greenhouse Gas Observation

- Established in Mauna Loa 1958



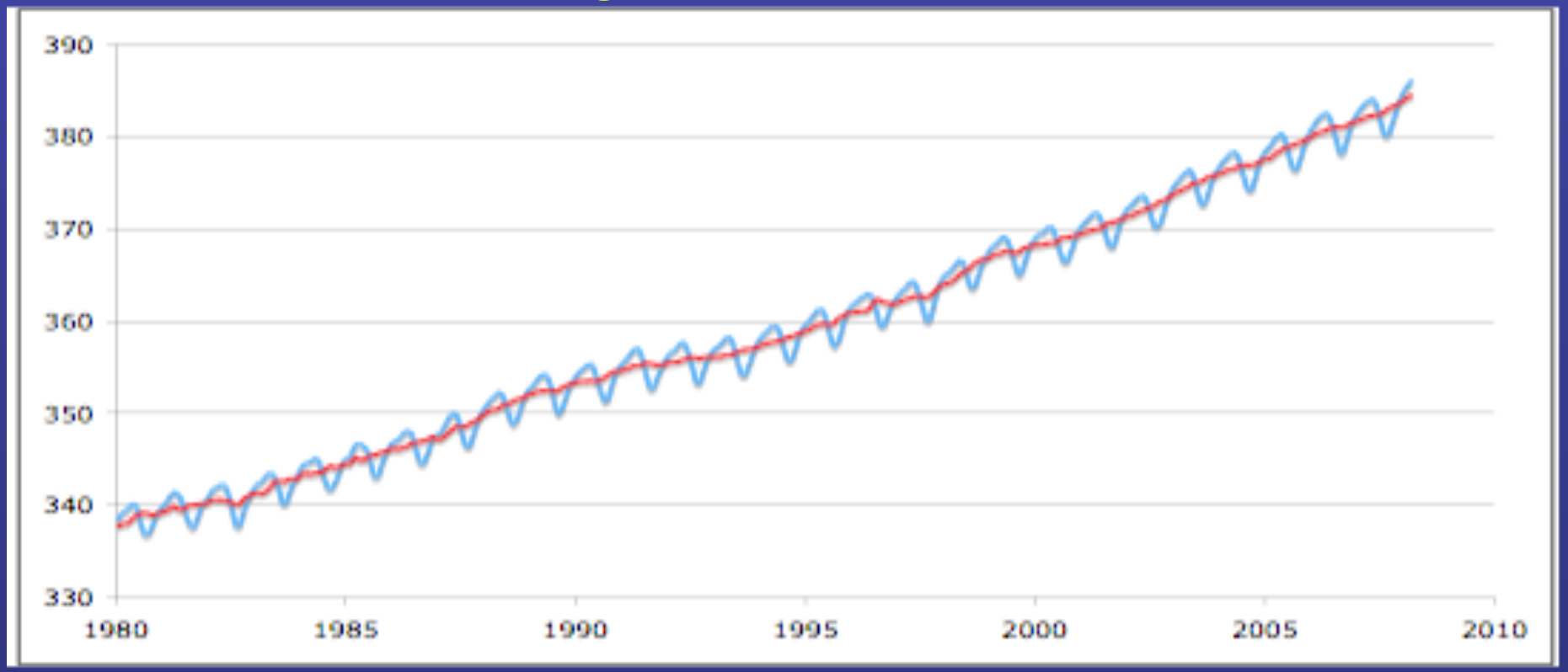
Measuring Greenhouse Gases



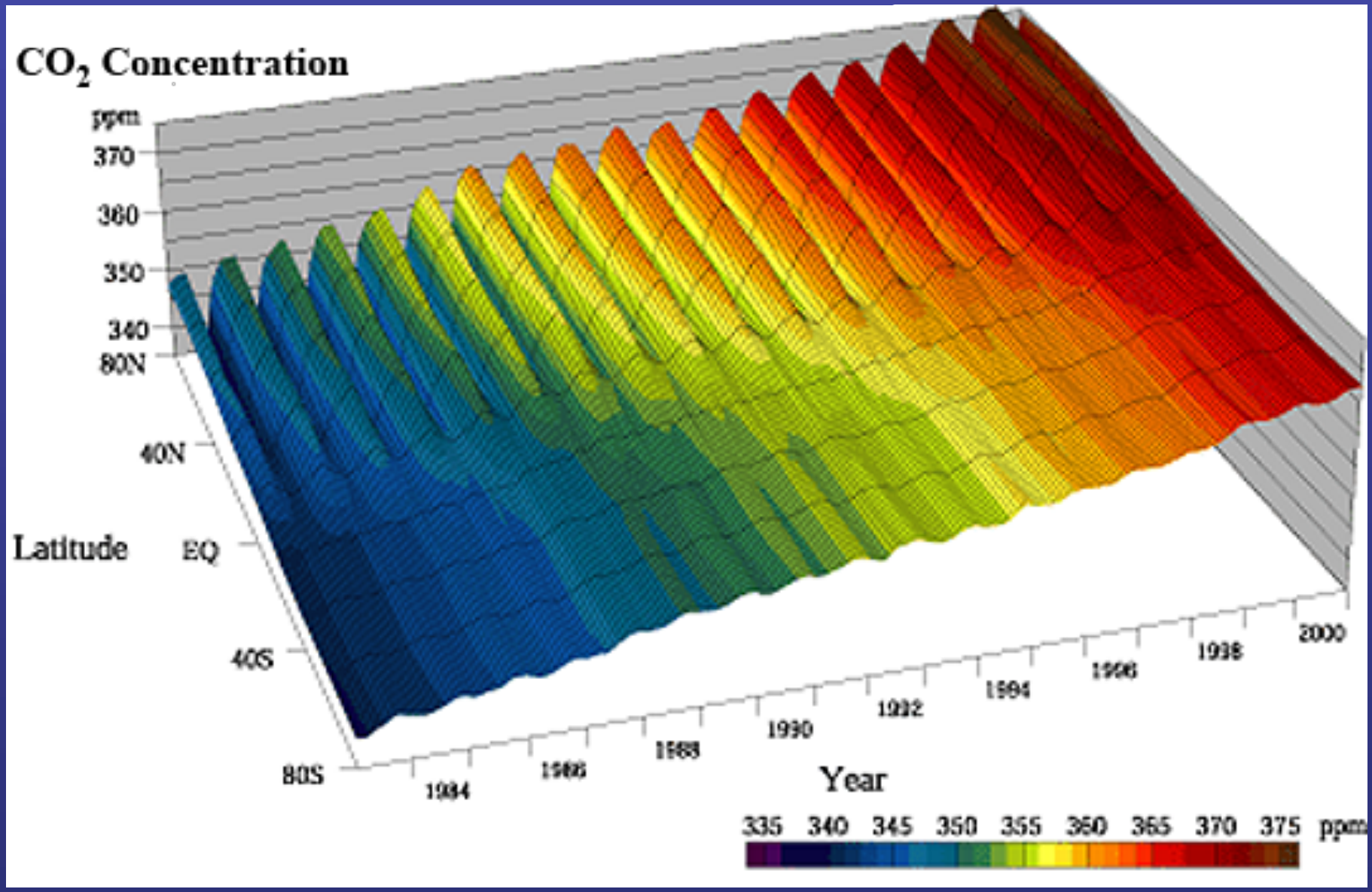


Greenhouse Gas Observation

- Global average

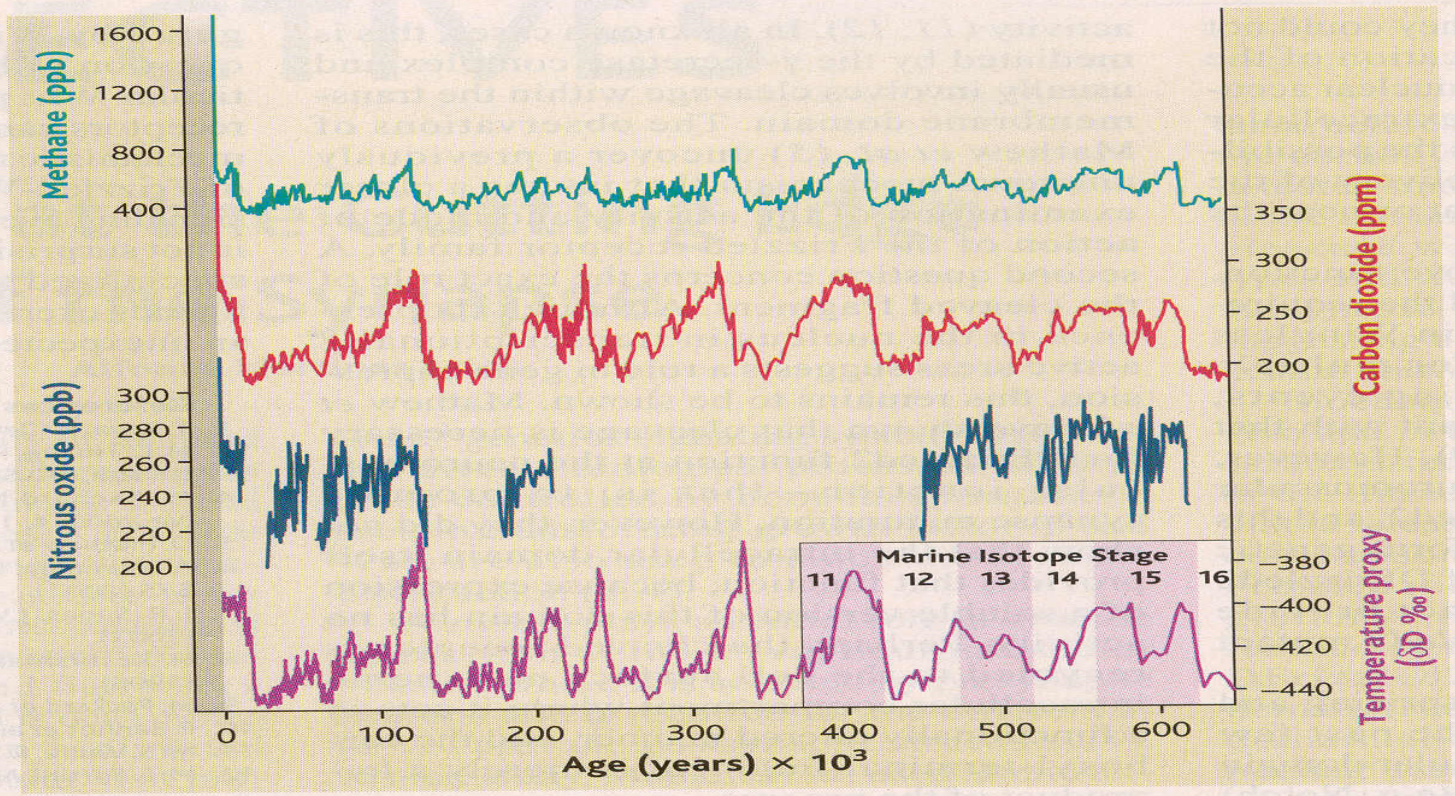


Gradients


CO2 Concentration
ppm
370
360
350
340
80N
40N
EQ
40S
80S
Latitude
1984
1988
1990
1992
1994
1996
1998
2000
Year
335 340 345 350 355 360 365 370 375 ppm

The Long View

- Recall:



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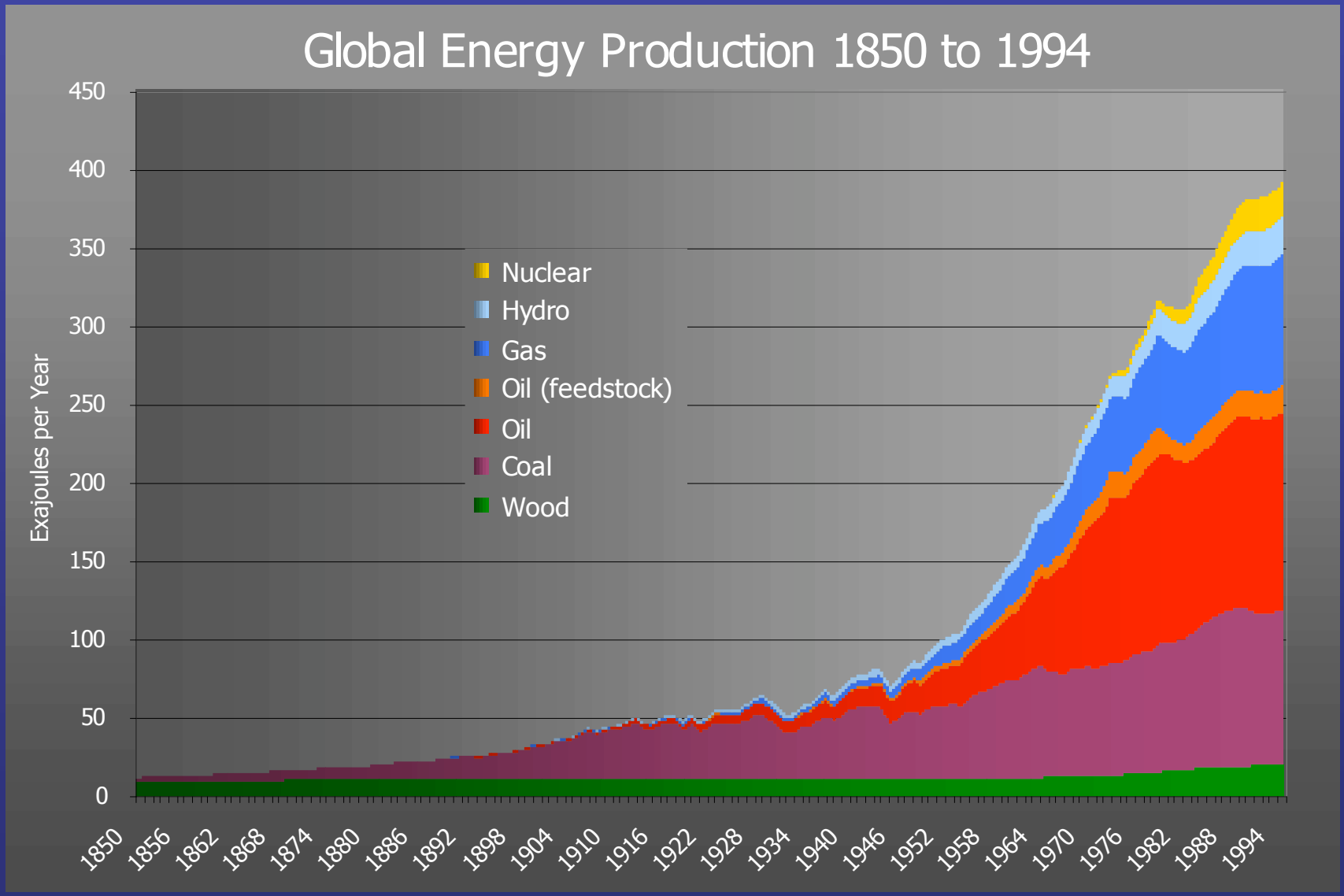
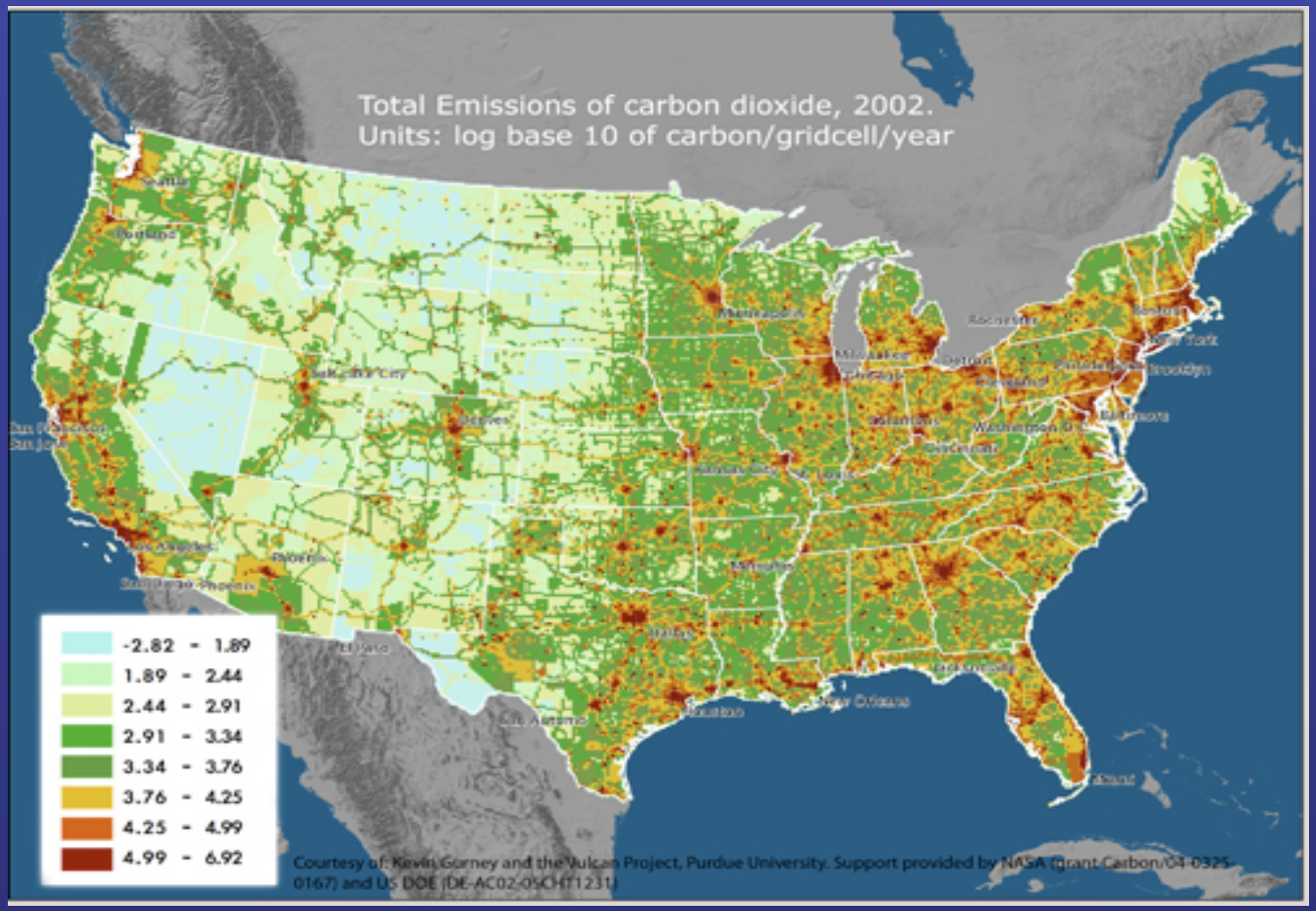
Our Carbon Economy

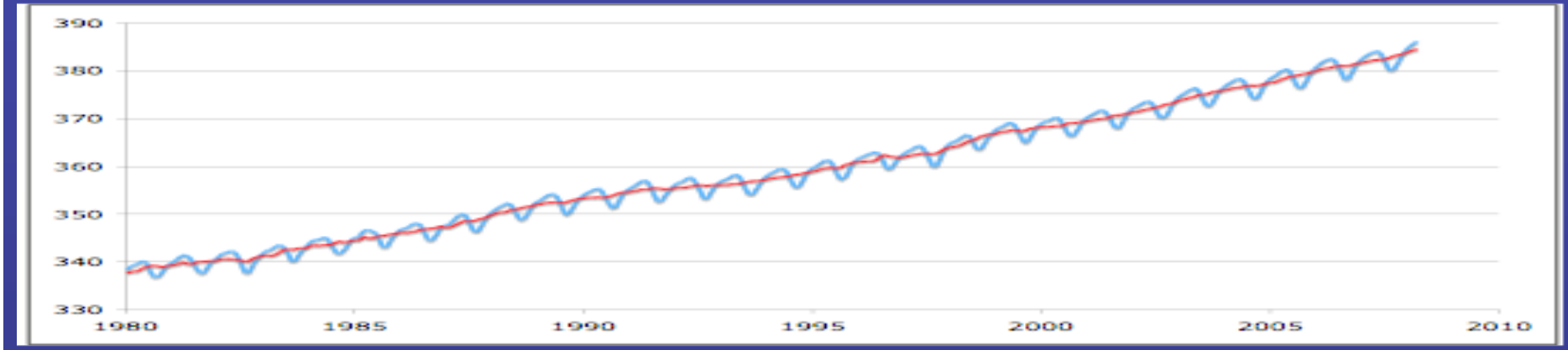


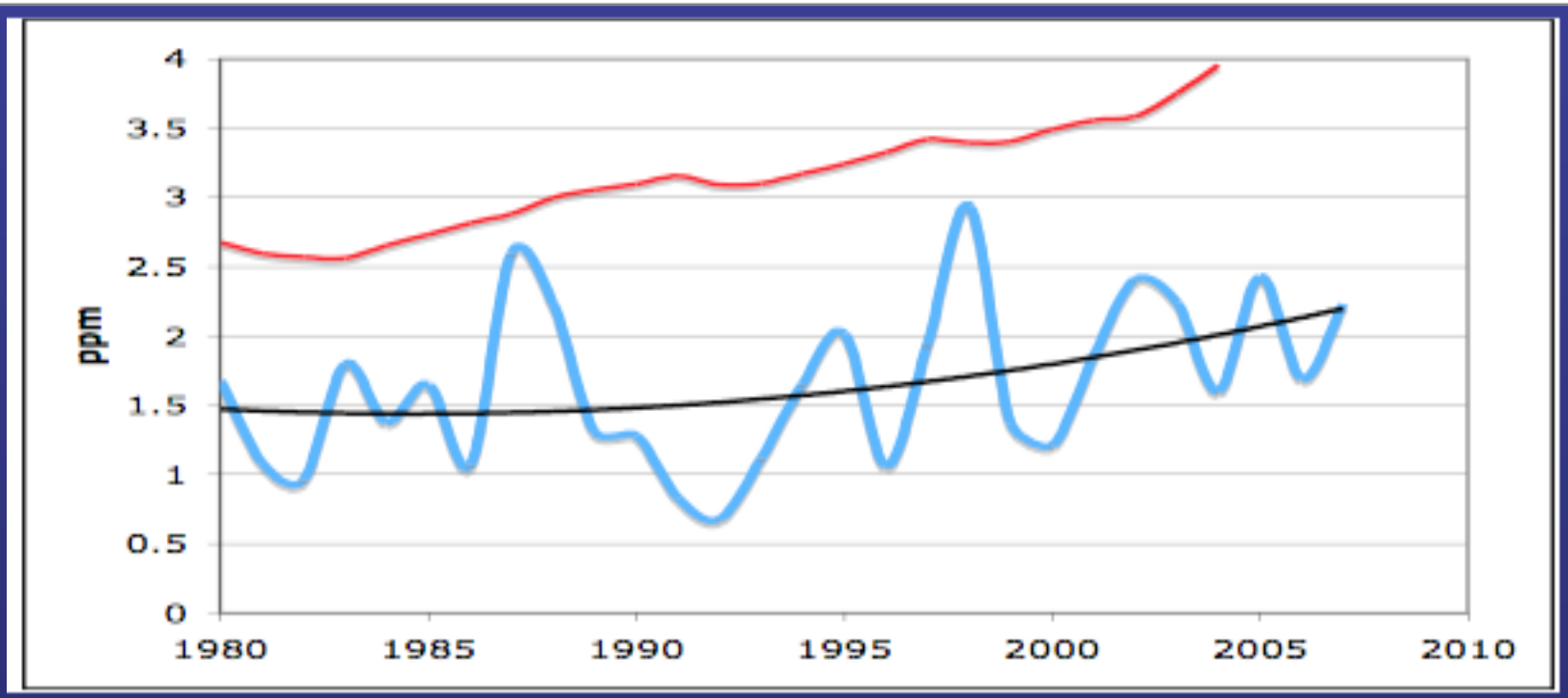
Fossil Fuel Emissions



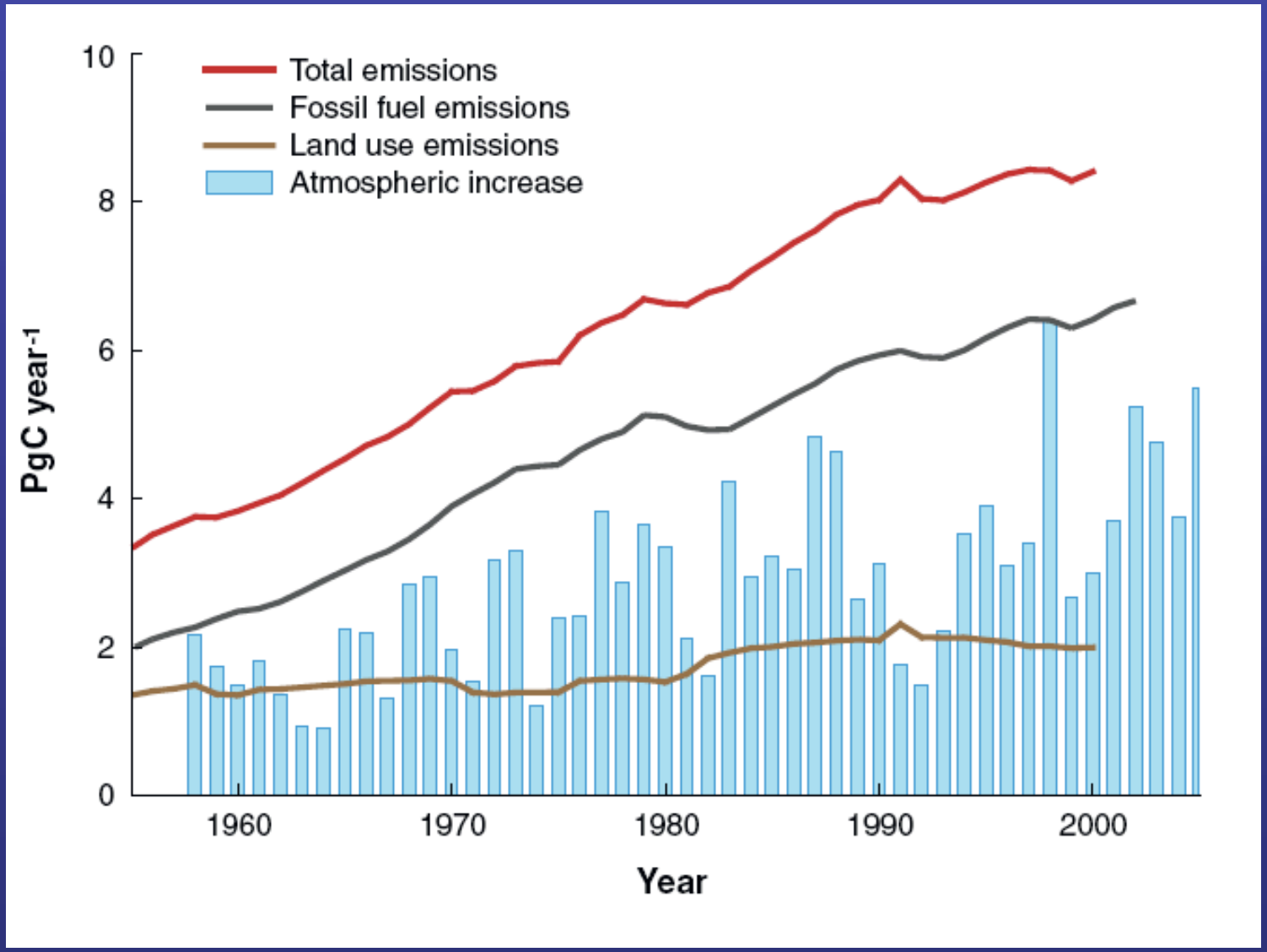
- Courtesy K. Gurney, Purdue U.

Variability



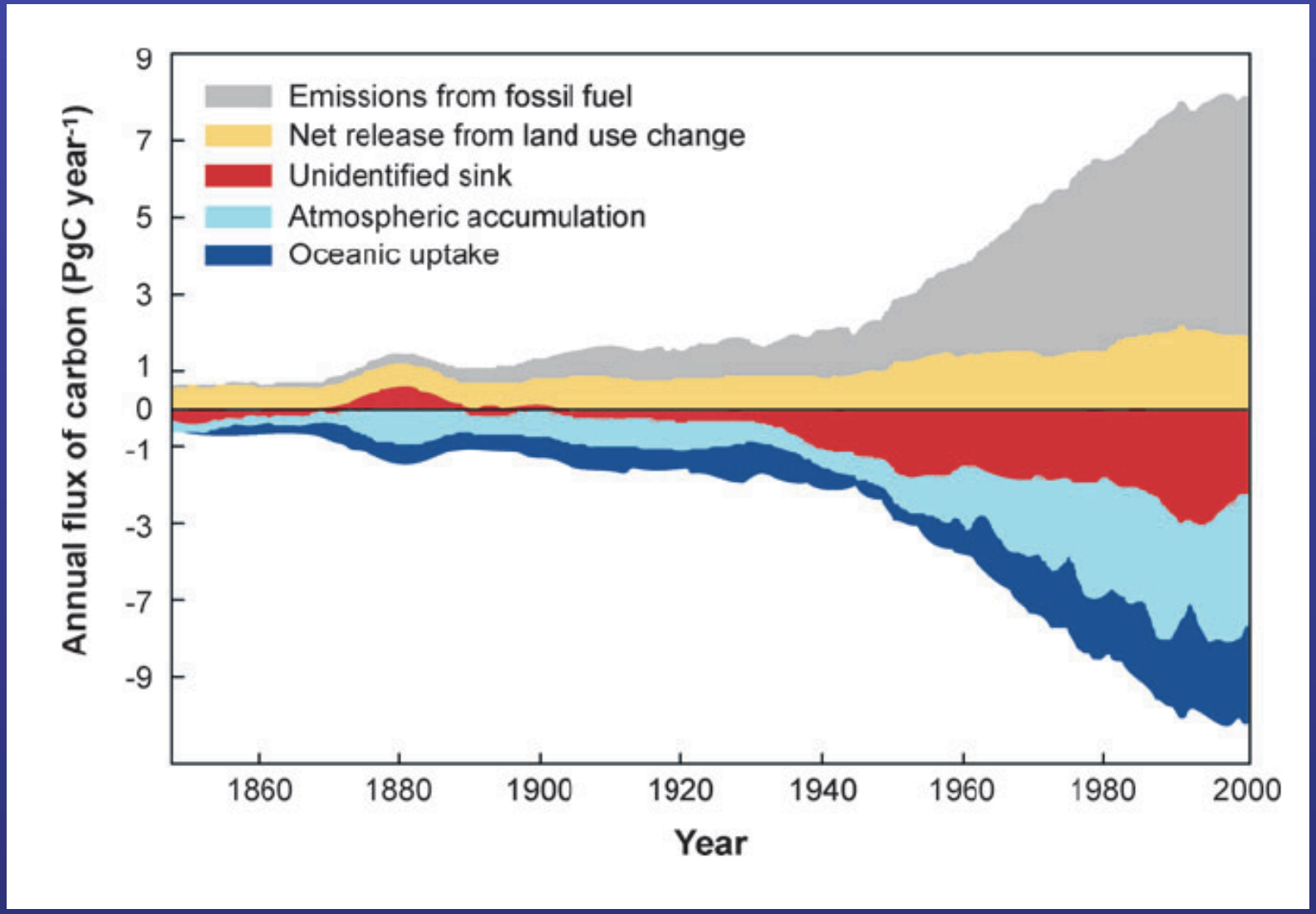


Where Is The Carbon Going?



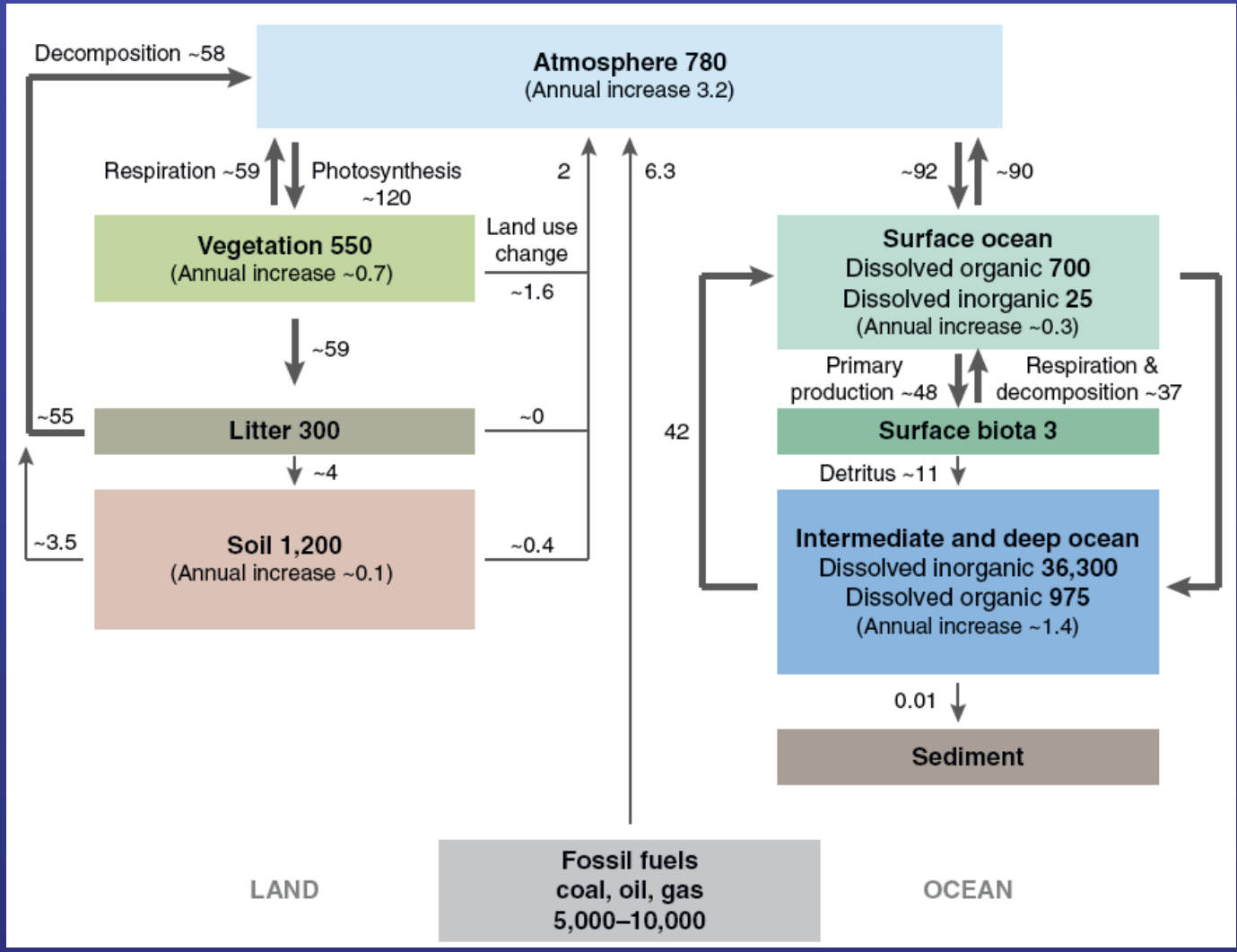
- Houghton et al., 2007

Carbon Sinks Matter



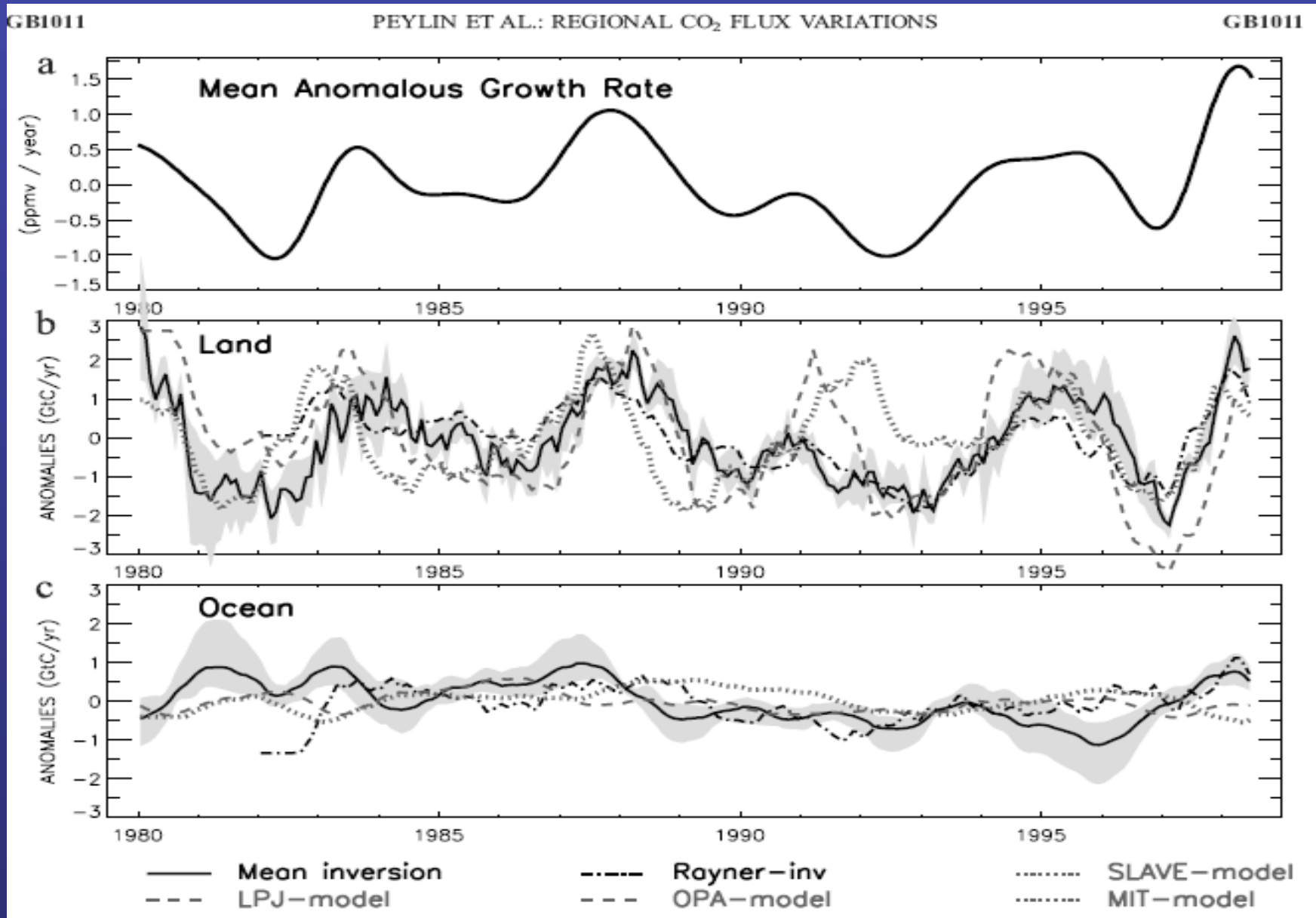
- Houghton et al., 2007

Carbon Cycle



- Houghton et al., 2007

Land Sink is Highly Variable



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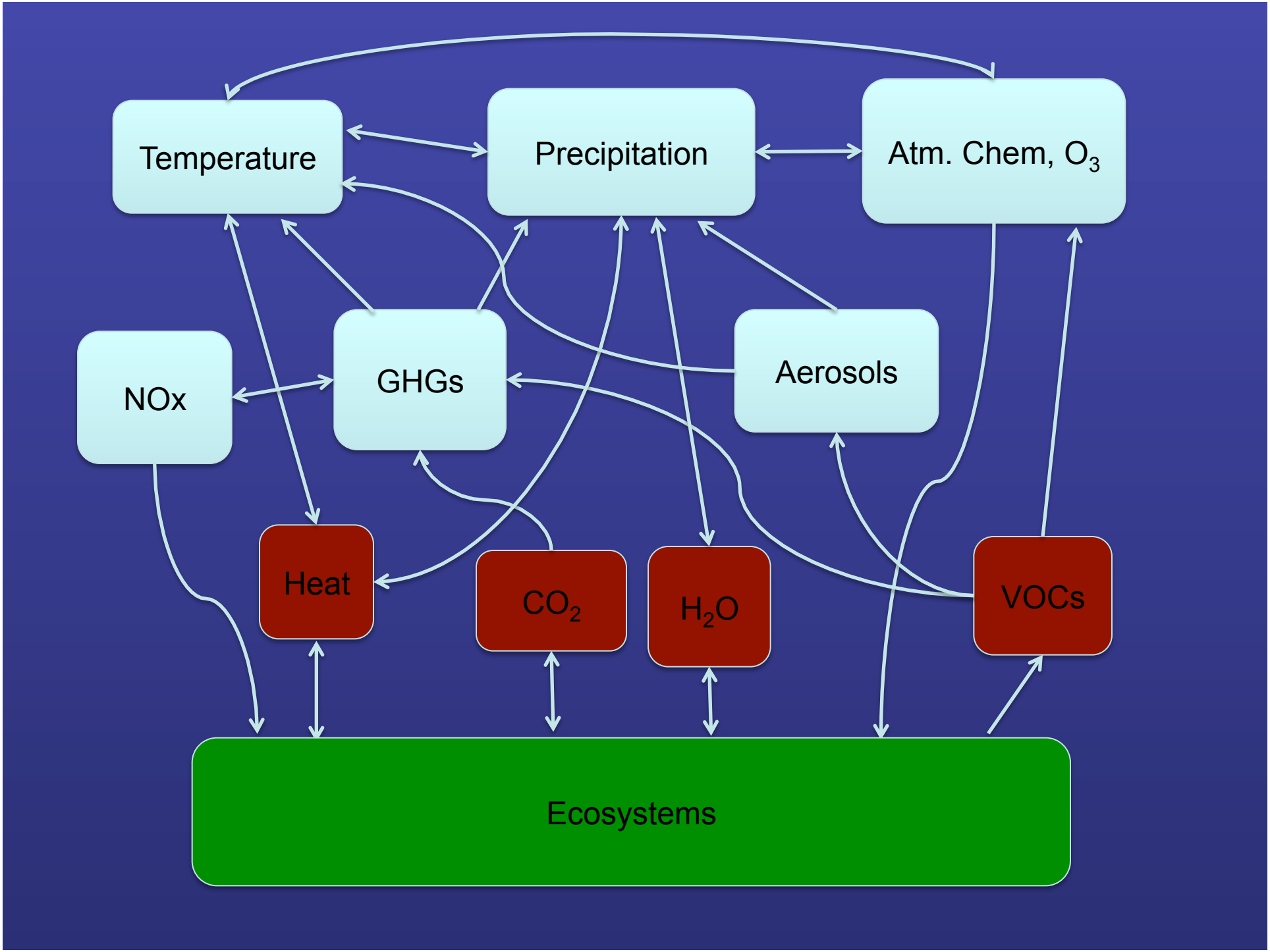
Ecosystem Ecology 101

- Land and ocean ecosystems have biophysical and biogeochemical dependence on the atmosphere
  - Biophysical – Feedbacks in moisture, heat, radiation
  - Biogeochemical – Cycling of nutrients, especially carbon and nitrogen
- Both of these are changing!


Temperature
Precipitation
Atm. Chem, O_3
NOx
GHGs
Aerosols
Heat
CO_2
H_2O
VOCs
Ecosystems

Land Use Change Feedbacks

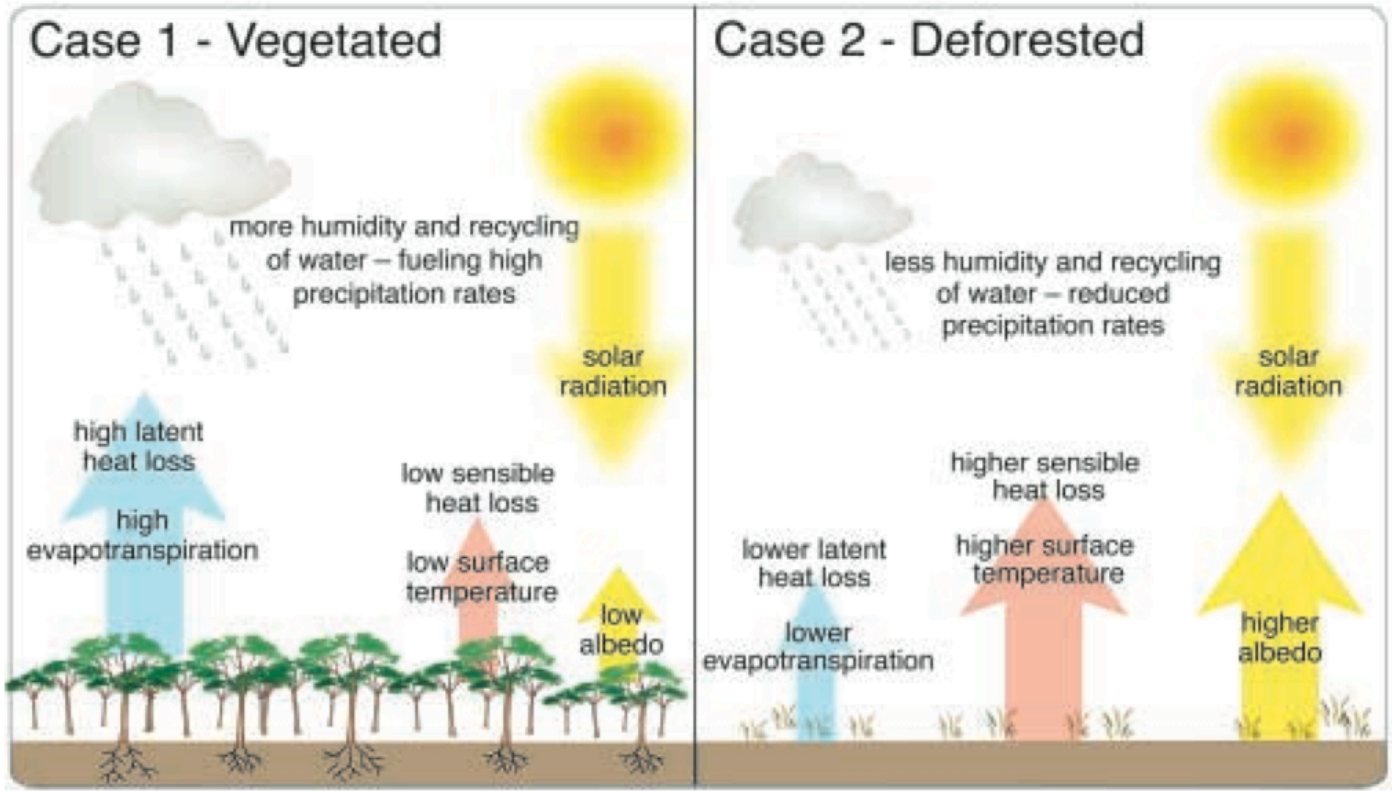
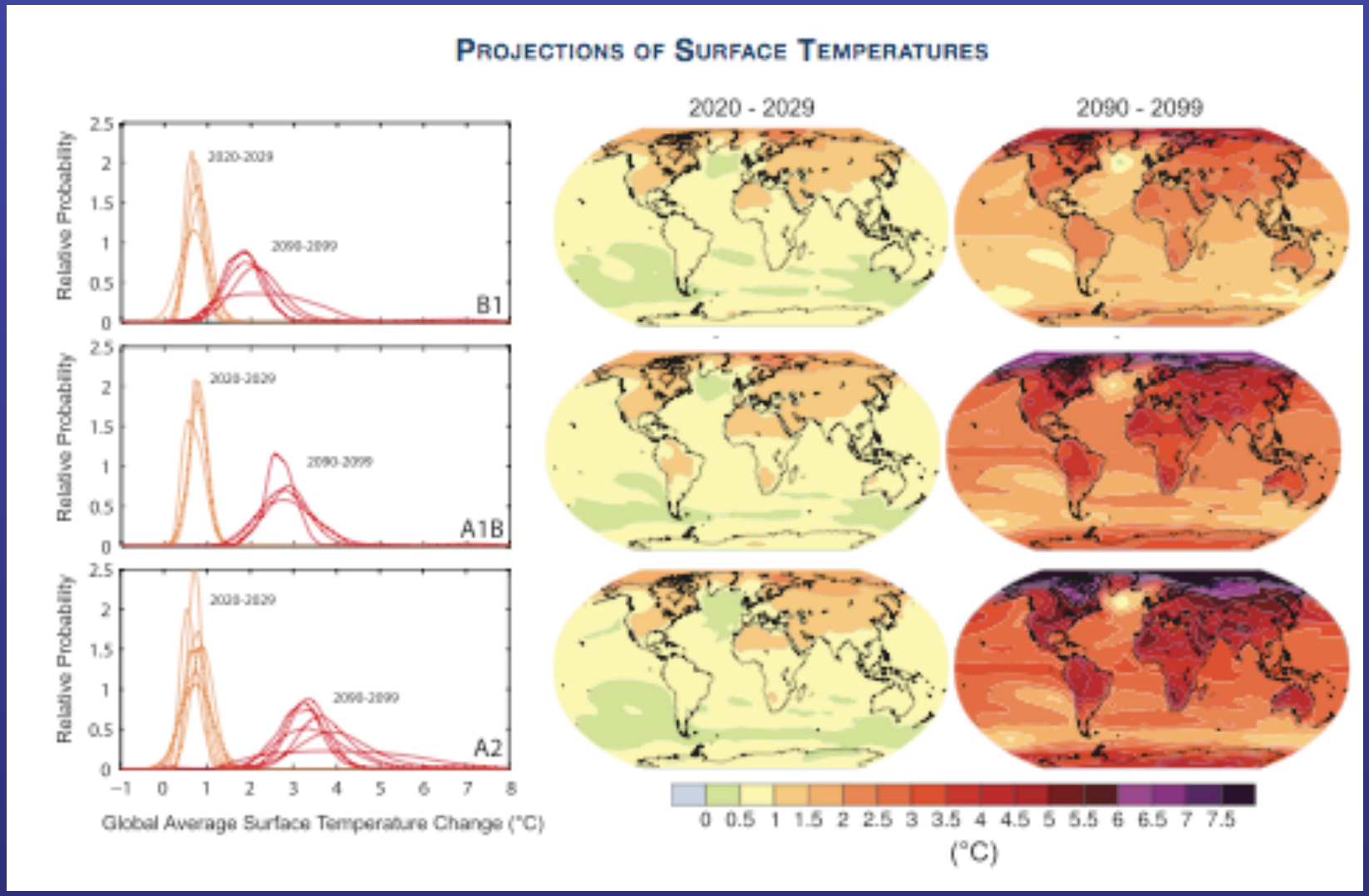


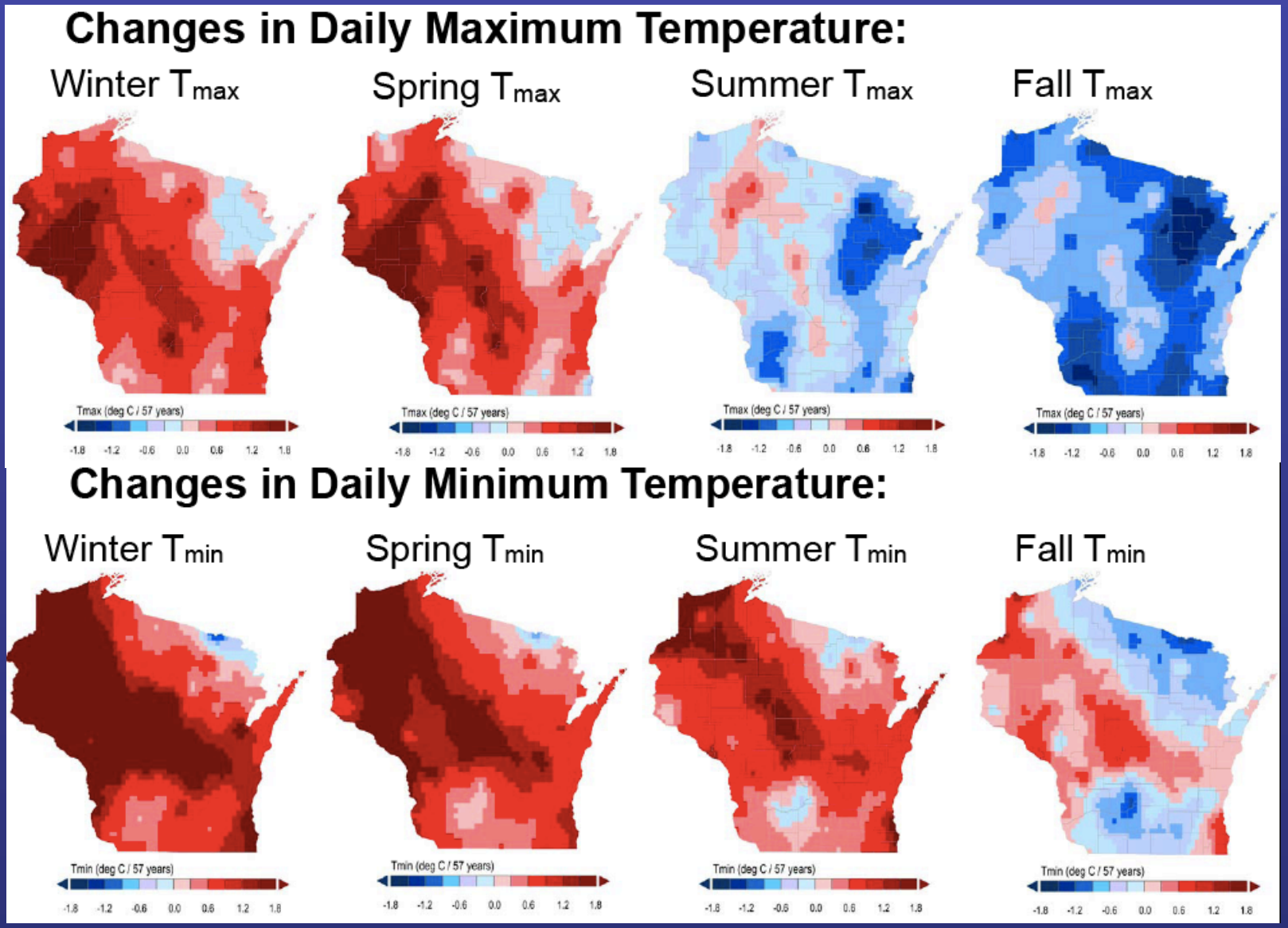
Figure 2. *Climatic effects of tropical deforestation on water balance, boundary layer fluxes, and climate. In vegetation-covered areas (left), the low albedo of the forest canopy provides ample energy for the plants to photosynthesize and transpire, leading to a high latent heat loss that cools the surface. In deforested areas (right), bare soil's higher albedo reduces the amount of energy absorbed at the surface. Latent heat loss is severely reduced and the surface warms, as it has no means of removing the excess energy through transpiration.*

- Foley et al., 2004

Temperatures Will Likely Rise

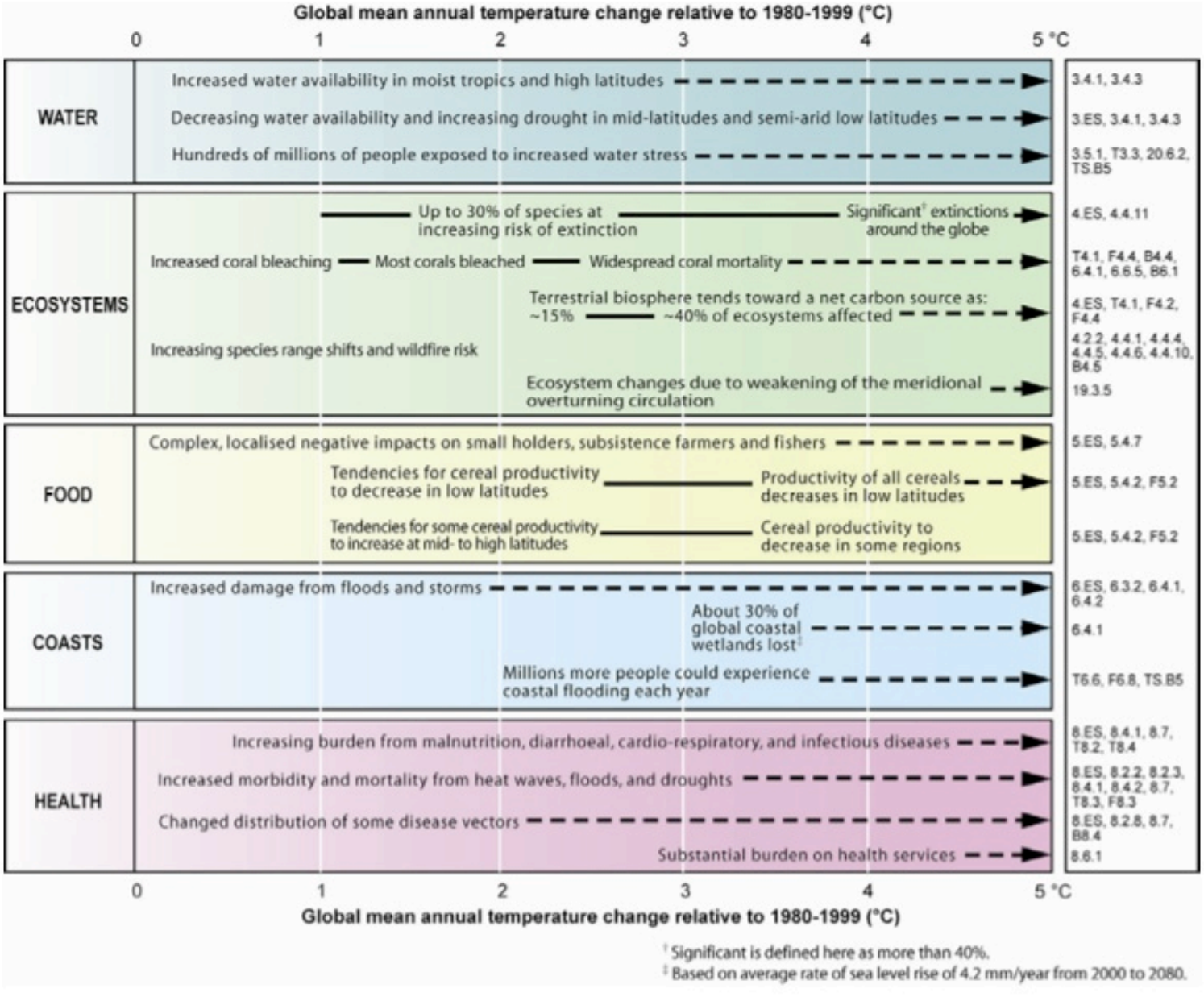


They Already Have

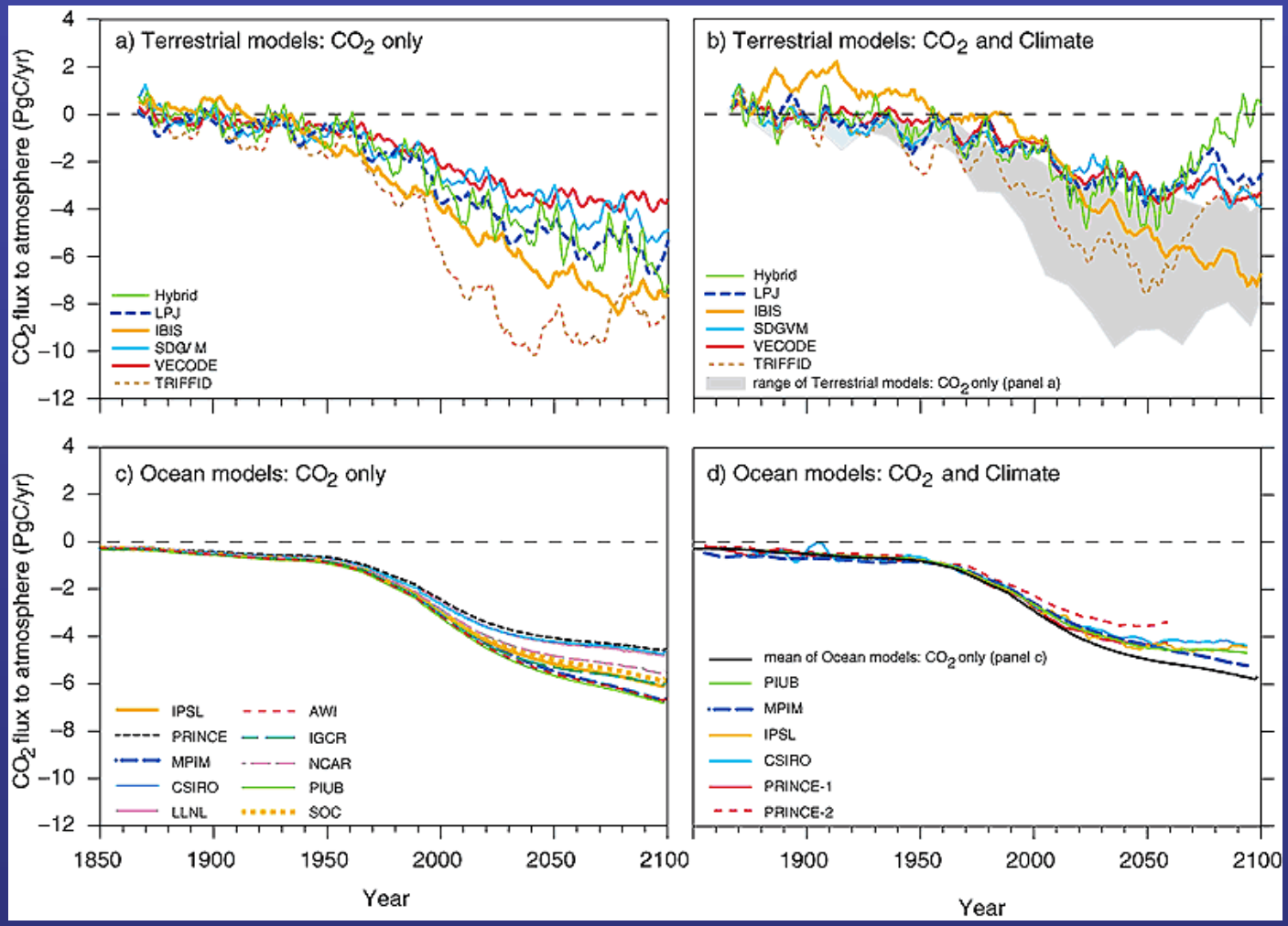


- Kucharik and Serbin (2009)

Ecosystems Will Respond



But How They Will Is Quite Uncertain



- Friedlingstein et al., 2006

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Is This Sustainable?

- Since 1990:
  - World Population increased 22% to 6.7 billion
    - U.S. Population grew 18% to 305 million
  - GWP grew 40%
    - U.S. GDP grew 30%
  - Global oil consumption grew 25% to 85,000,000 barrels per day
    - U.S. Oil consumption grew 20% to 21,000,000 bpd
  - Global CO_2 emissions grew 25% to 27,000,000,000 tons of CO_2 per year
    - U.S. CO_2 emissions grew 20% to 6,000,000,000 tons/yr
  - CO_2 in the air grew 10% to 385 parts per million
  - Earth has warmed 0.3 C (0.5 F) to the warmest in 100,000 years
  - Threatened species have increased by 40%
- Doubling Times have increased
  - 1850-1930, 80 years, 1-2 billion
  - 1930-1975, 45 years, 2-4 billion
  - 1975-2015, 40 years, 4-8 billion

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

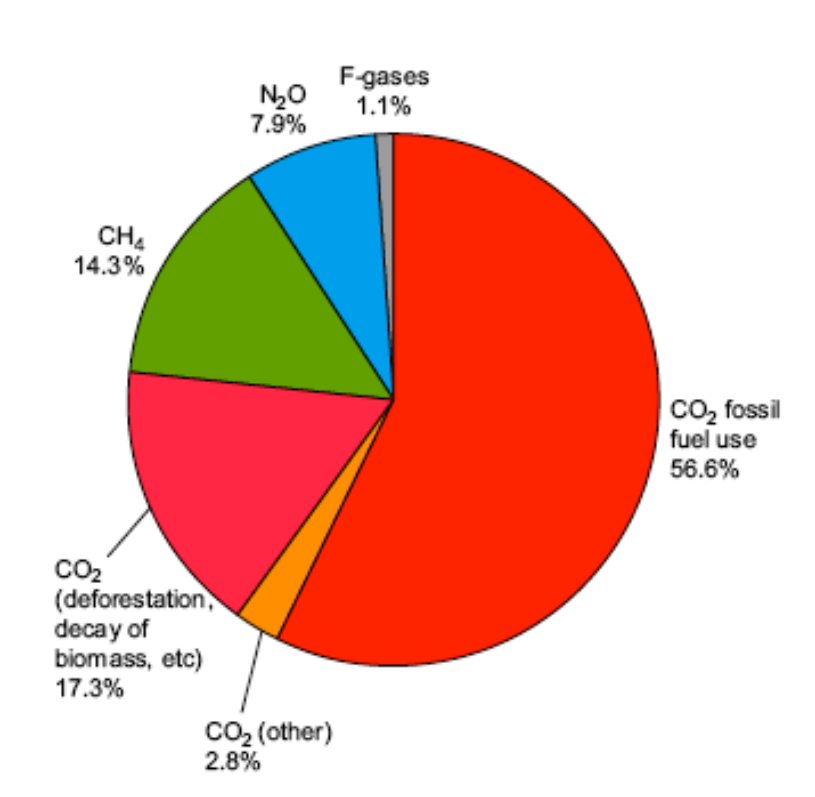
Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

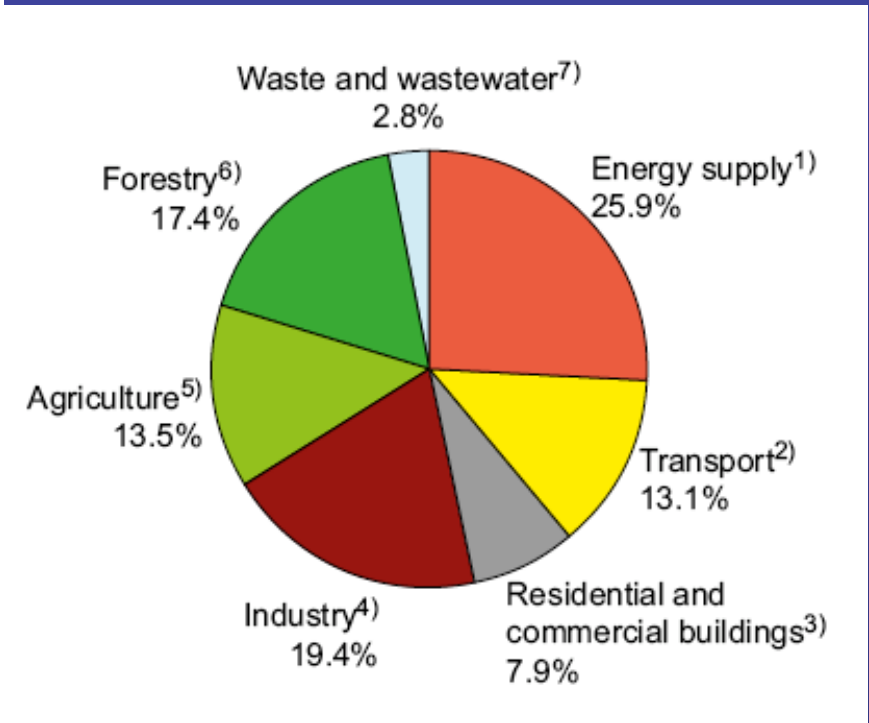
- Source: Nature Publishing Group

Options

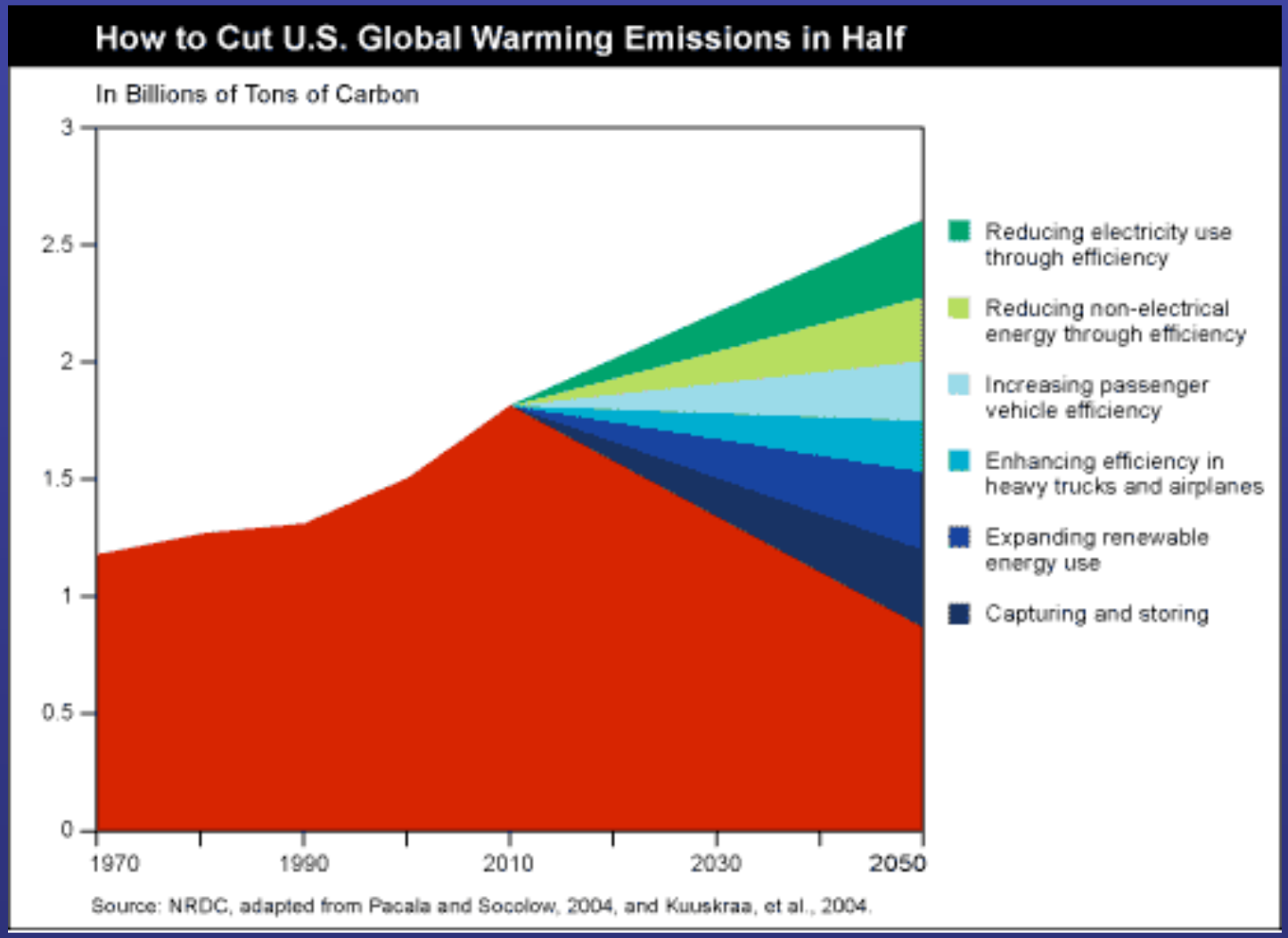
- Adaptation
  - Economic/political (relocation, tech transfer, payments for damages, reduce poverty, educate)
  - Technological (resilient tech, seawalls, genetic hybrids, cure malaria, colonize new planet)
- Mitigation
  - Economic (taxes, cap and trade, R&D)
  - Political (treaties, bans, compacts, fuel/energy standards, public transit, voluntary agreements)
  - Societal (sustainable development)
  - Technological (CO_2 capture, geoengineering, green tech, alternative energy, energy efficiency)

Multi-Faceted Problem



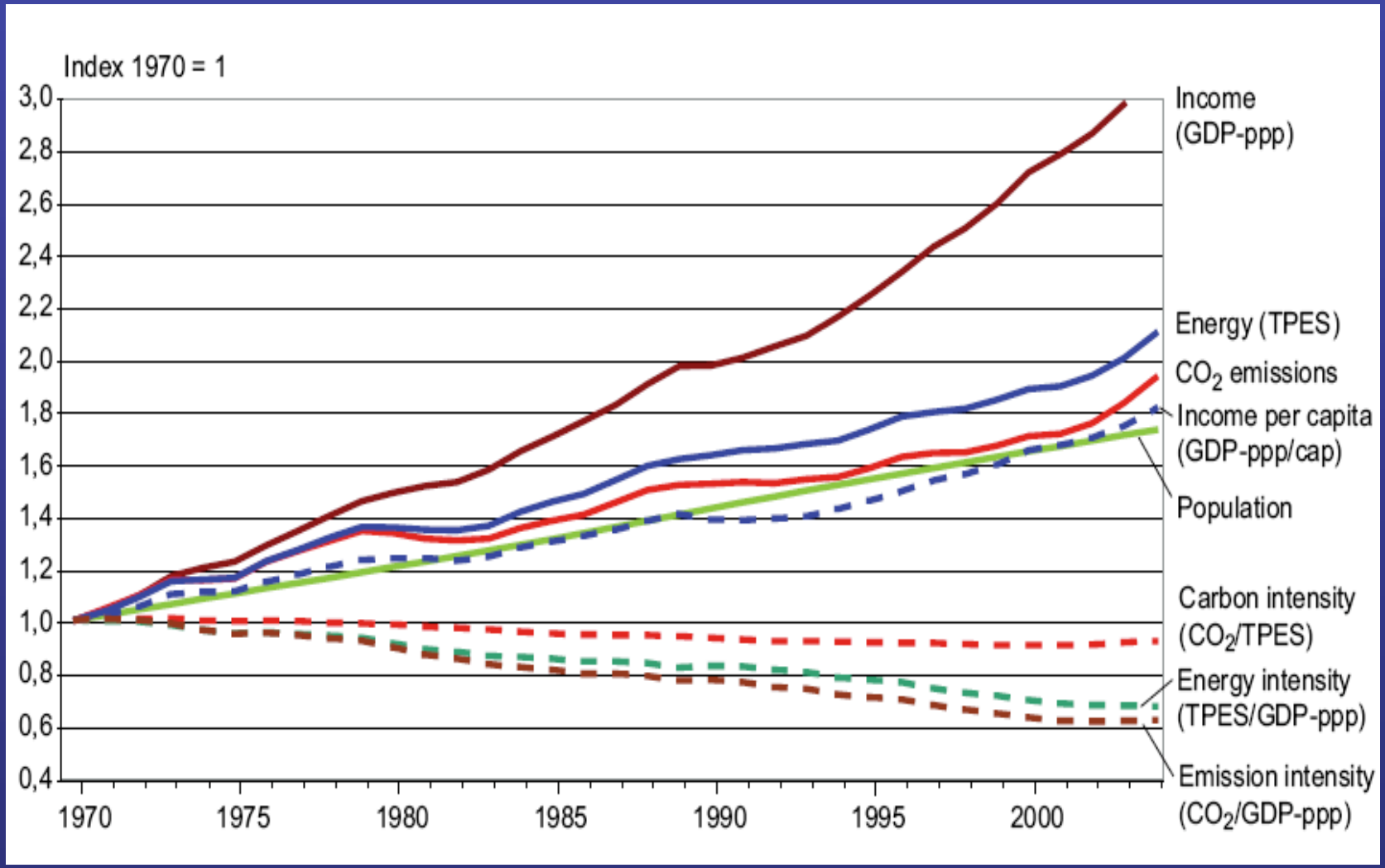


It's Not Impossible



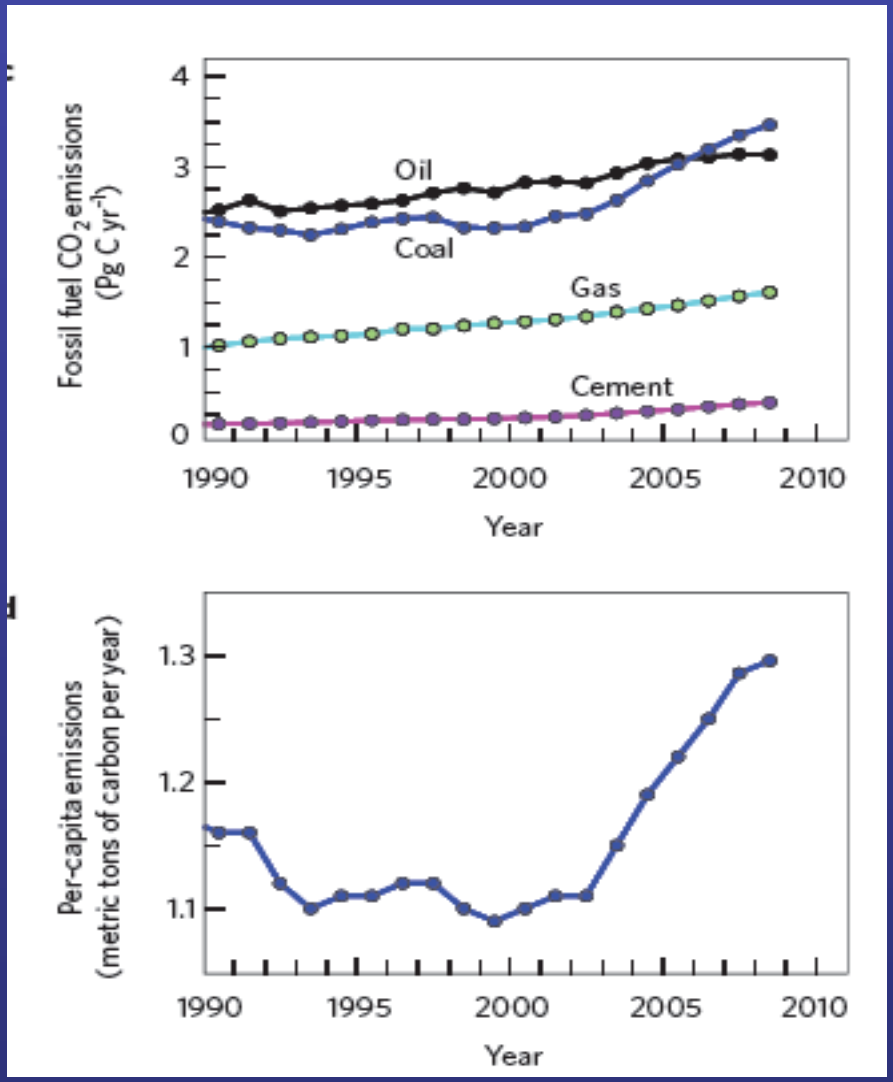
- Pacala and Socolow, 2004

Does a Richer World Pollute Less?



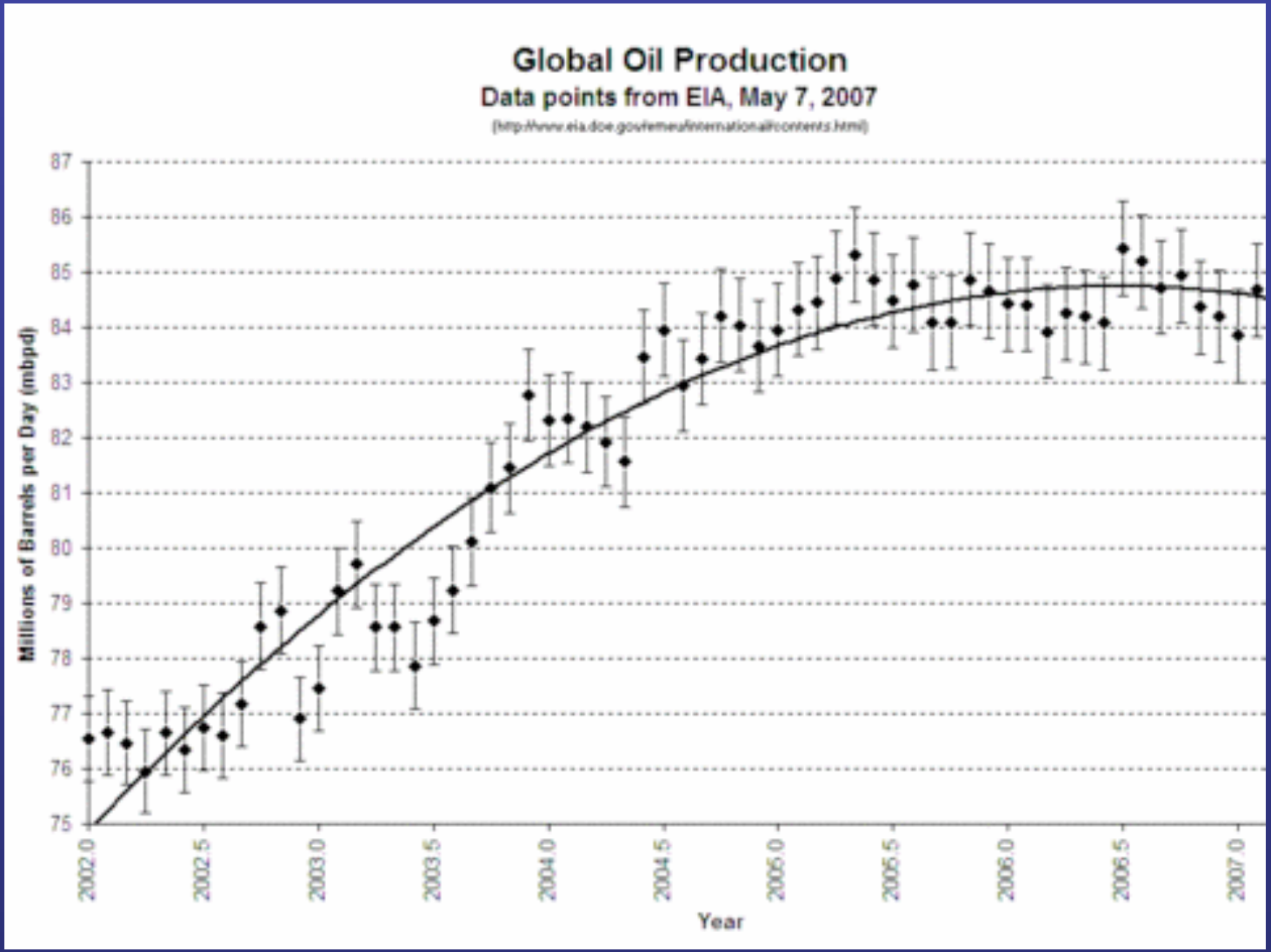
- Source: Nature

Since 1990



- La Quere et al., 2009

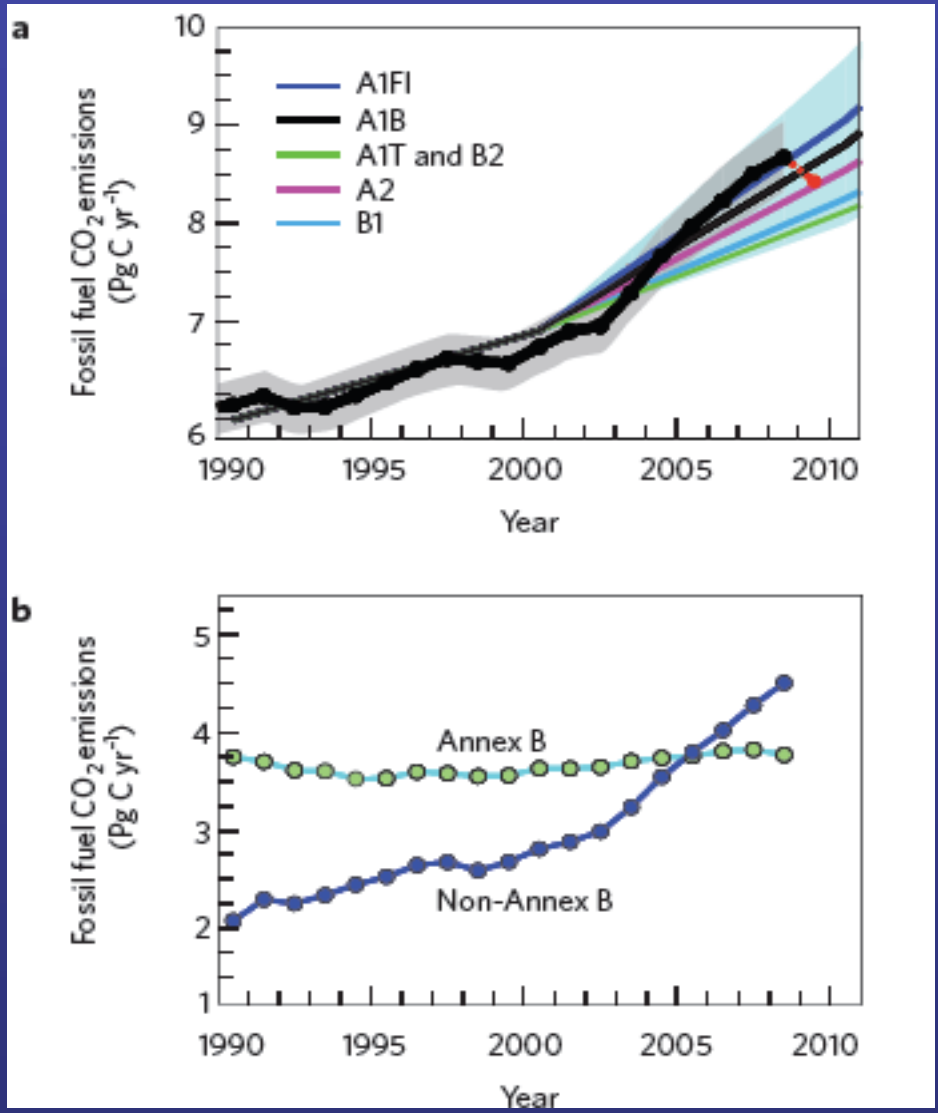
Will The Carbon Economy Meet Its Own Demise?



DISCUSS:

Sustainable development requires that we move away from a carbon-energy economy immediately.

Expectations



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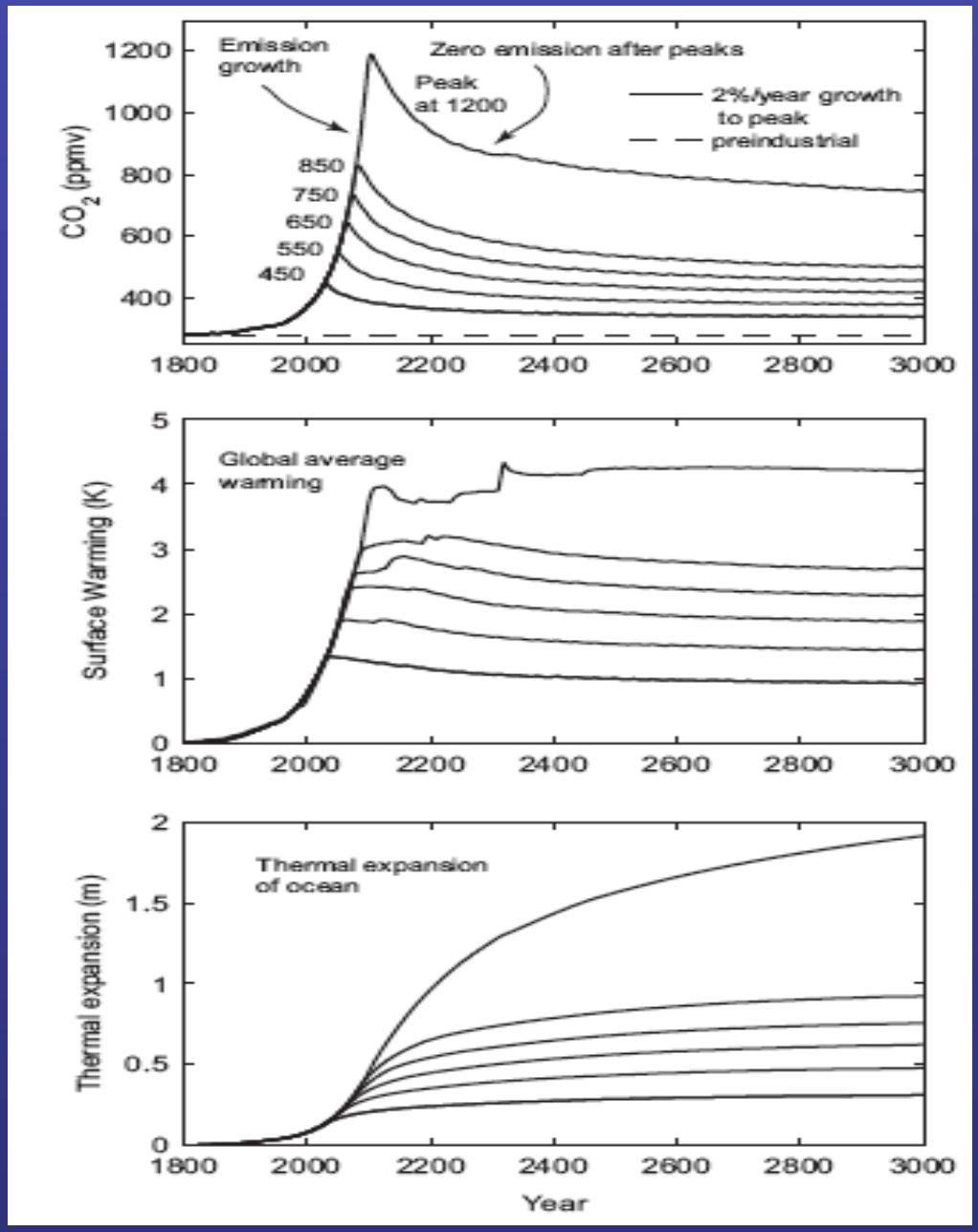

- Solomon et al., 2009

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  - Principle: Anthropogenic climate destabilization is a significant threat to ecosystems and human civilizations. Sustainable development must aim to minimize climate damage.

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- Sustainable development requires that we move away from a carbon-energy economy immediately
  - Principle: Anthropogenic climate destabilization is a significant threat to ecosystems and human civilizations. Sustainable development must aim to minimize climate damage.
  - Practice: Adopt climate mitigation and adaptation strategies in each sector of the economy that emits greenhouse gases.
  - Paradoxes and questions:
    - Every sector of the economy depends on a fossil fuel economy, where do we start?
    - Significant uncertainty in climate impacts requires us a adopt a probabilistic risk-based approach, but what is the right model?
    - Local, small changes don't make a big difference; global action is mired in politics and bureaucracy
    - It's hard to measure change. What if nothing happens?
    - Greenhouse gas mitigation and adaptation is likely to hamper the right of all people to lift the burden of poverty by economic development. Others argue that richer people are more likely to improve the environment. What to do?