Lecture 2: Greenhouse Gases

- Basic Background on Atmosphere
- GHG Emission and Concentration Rise
- California Regulation (AB32)

METR 113/ENVS 113

Spring Semester 2011

February 15, 2011

Suggested Reading

(Appropriate Portions in Following Texts on Reserve)

- Turco “Earth Under Siege”, Chapters 11 through 13
- Jacobson “Atmospheric Pollution”, Chapters 1, 2, 3, 7, 11 and 12
- Ahrens “Essentials of Meteorology”, Chapters 1 – 3.
- Hensen “Rough Guide to Climate Change”, check chapters and index yourself for relevant sections
- Any other stuff referenced in slides to follow …

Background

- Composition of Atmosphere
- Vertical Structure of Atmosphere
- Atmospheric Radiation (Sun vs. Earth)

Composition of Atmosphere

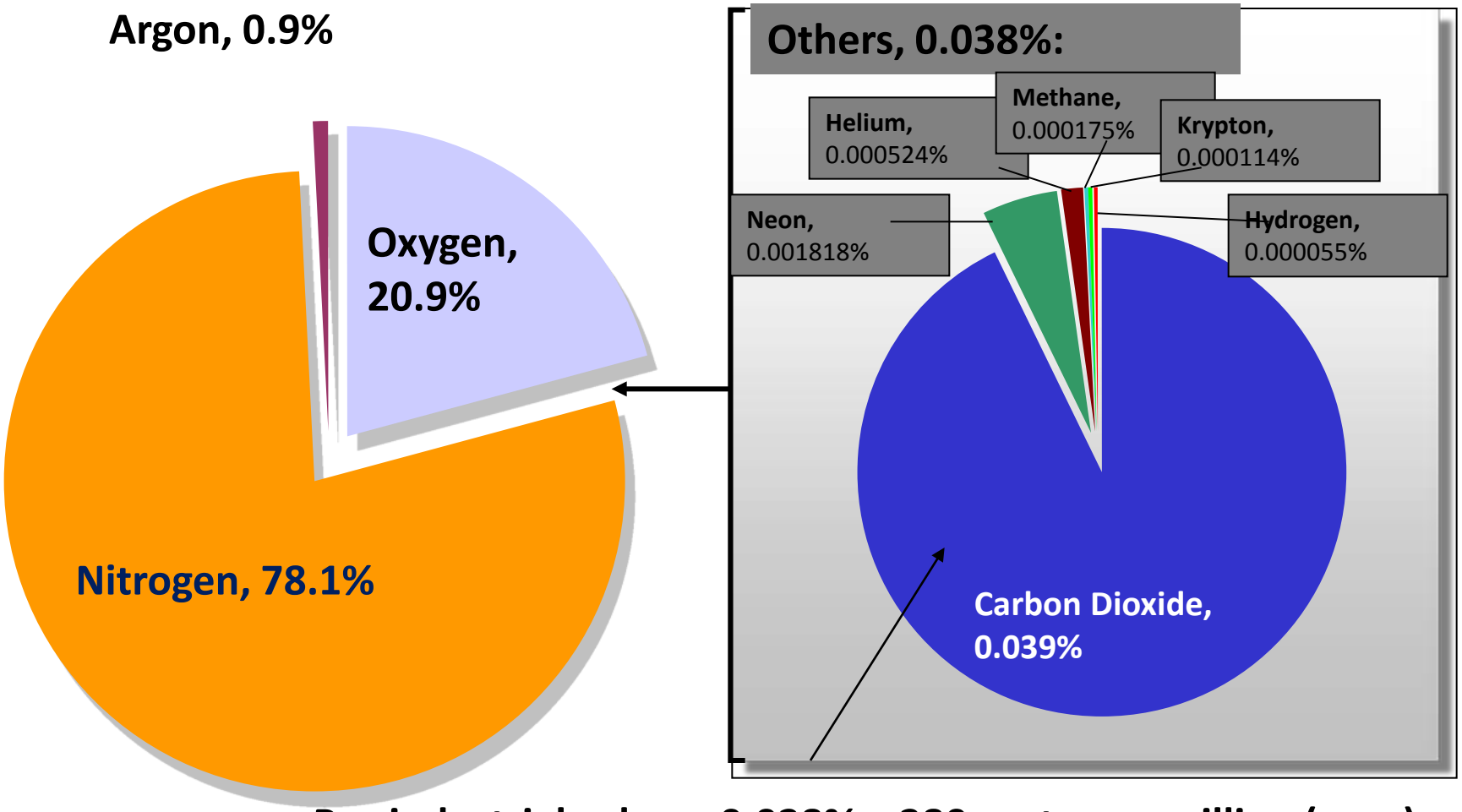
- **78% nitrogen (N_2)**
- **21% oxygen (O_2)**
- **These two comprise 99% of atmosphere (assuming no water vapor).**
- **1 to 4% water vapor (H_2O)**: Depending on time and location
- **Trace amounts (very low %) of other gases, for example …**

Argon (Ar)	Methane (CH_4)
Carbon dioxide (CO_2)	Krypton (Kr)
Neon (Ne)	Hydrogen (H_2)
Helium (He)	Ozone (O_3)

- **Various particles ("aerosols"):** dust, sand, pollen, soot, sulfate, nitrate, others
- **"Hydrometeors":** clouds, ice, snow, rain, hail, etc …

Composition of Atmosphere

(* assuming no water vapor)



Pre-industrial value = 0.028% = 280 parts-per-million (ppm)

Current value = 0.039% = 390 ppm

Typical Percentages of Some Air Pollutants (Urban/Industrial Environment)

0.003% (= 30 ppm)	Carbon Monoxide (CO)
0.000007% (0.07 ppm = 70 ppb)	Ozone (O_3)
0.000002% (0.02 ppm = 20 ppb)	Nitrogen Dioxide (NO_2)
0.00001% (0.1 ppm = 100 ppb)	Sulfur Dioxide (SO_2)

Others have comparable or even lower percentage …

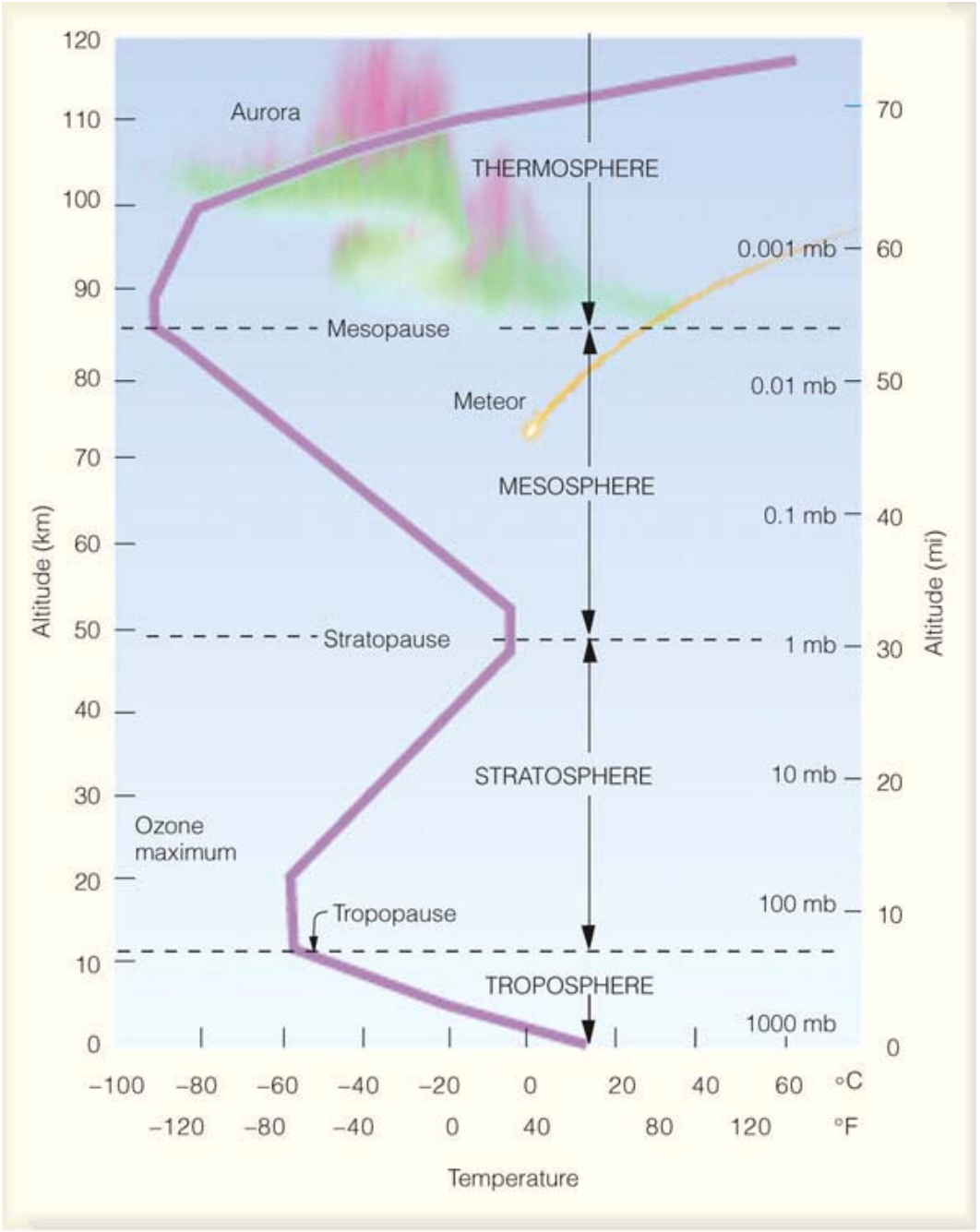
Air pollutants comprise a **very** small percentage of the atmosphere

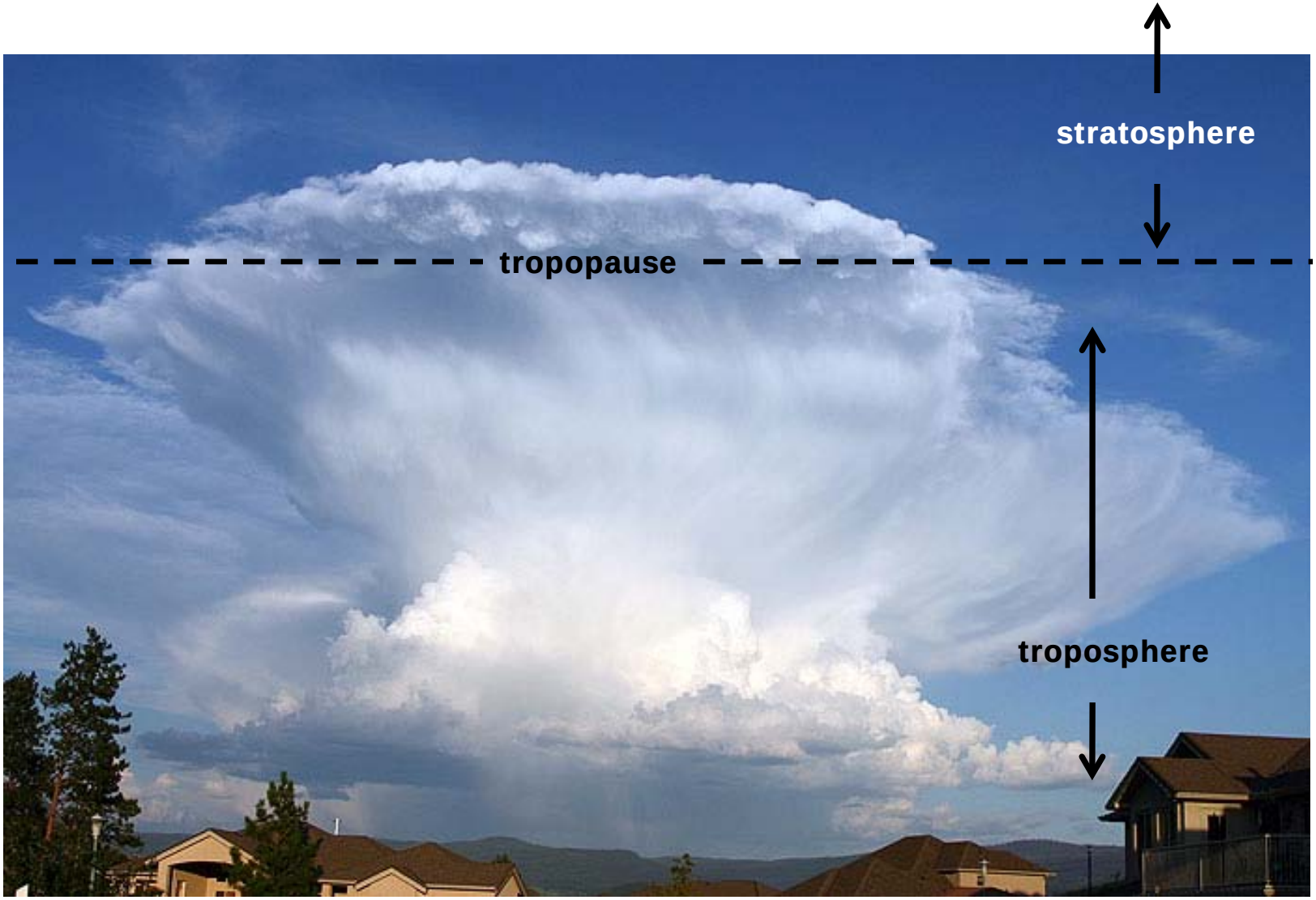
Vertical Variation of Temperature (as seen on average in atm.)

In this course we are most interested in troposphere and stratosphere

<u>Troposphere</u> – Lowest ~ 10km, weather systems

<u>Stratosphere</u> – 10 – 50 km, ozone layer

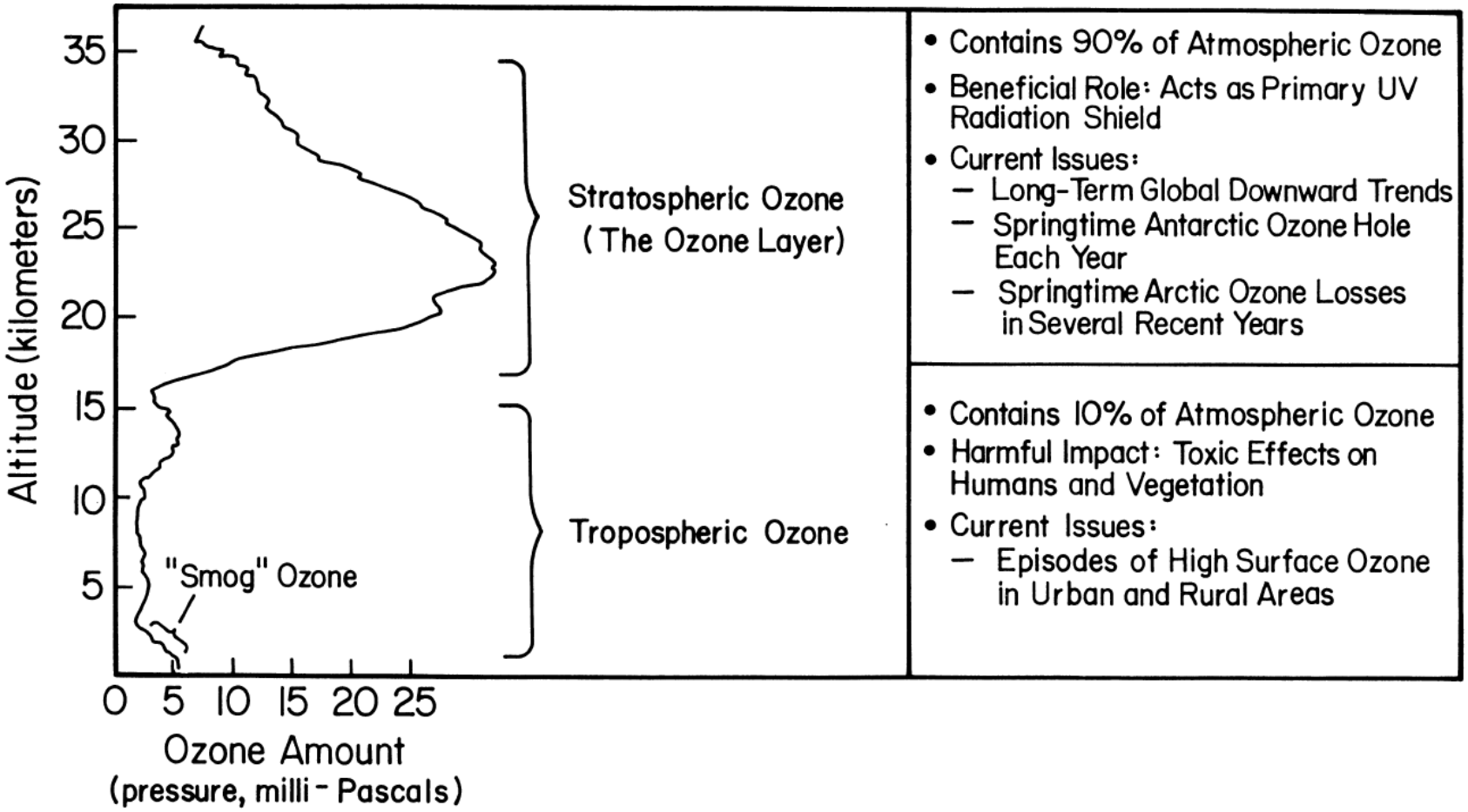




Weather systems form in the troposphere and do not rise far into the stratosphere.

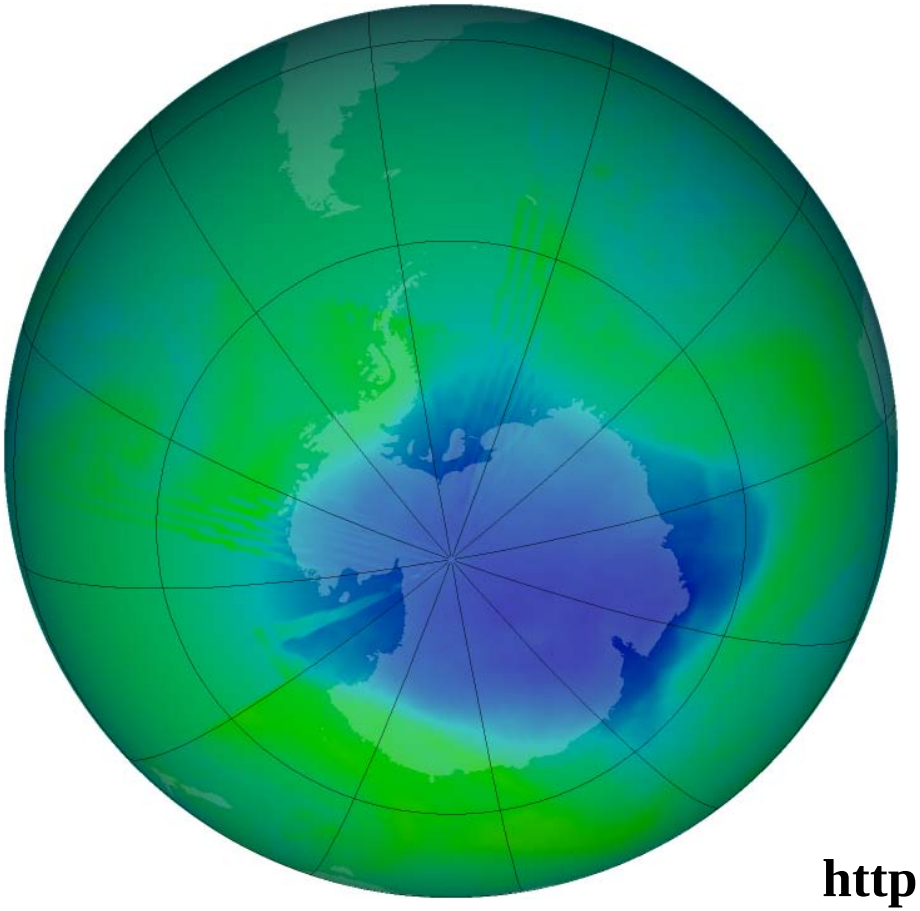
http://www.physicalgeography.net/fundamentals/7t.html

Ozone (O_3) Concentration vs. Height



- **Tropospheric ozone concentrations due to industrial air pollution (“smog”, “bad” ozone)**
- **Stratospheric ozone concentrations comprise the “ozone layer” (“good” ozone)**

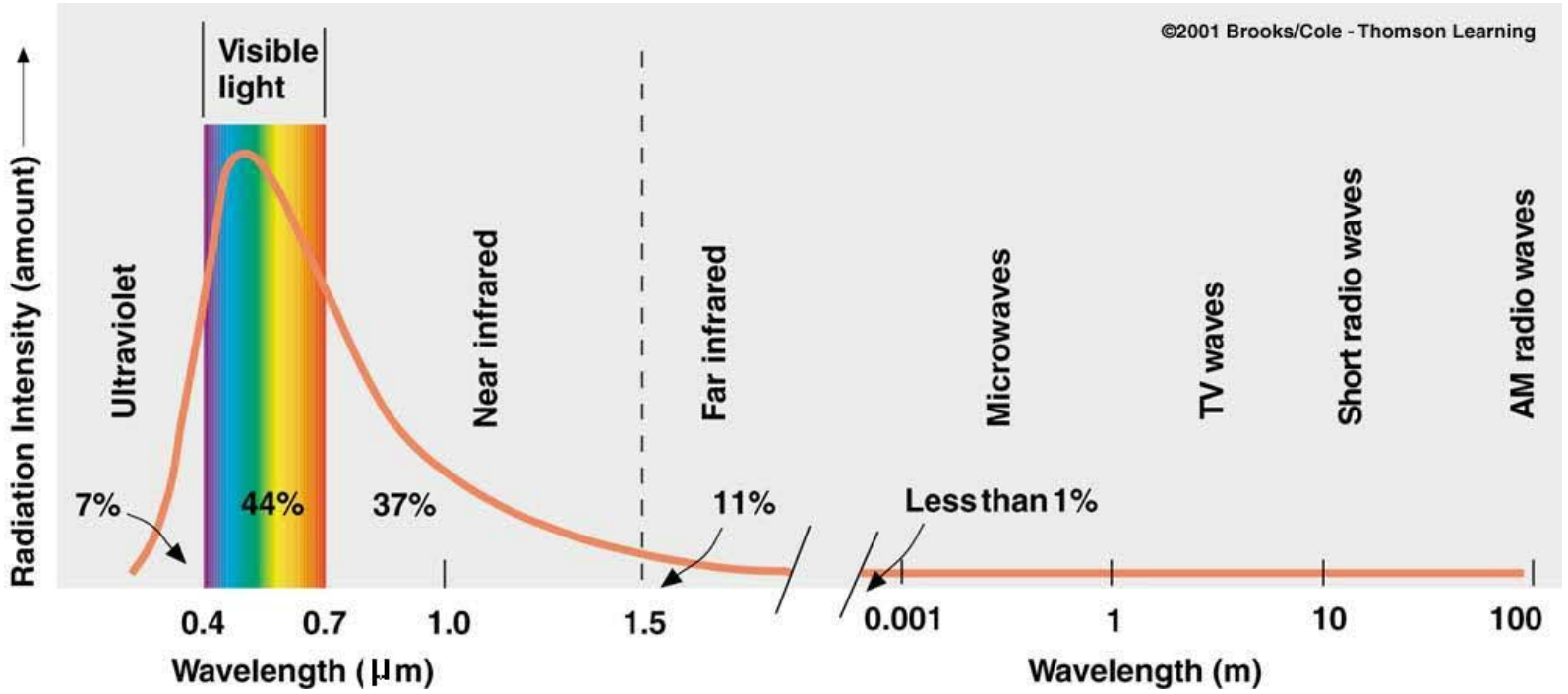
Ozone Hole (Antarctica)



December 4, 2007

http://ozonewatch.gsfc.nasa.gov/

Solar Radiation (Sunlight)

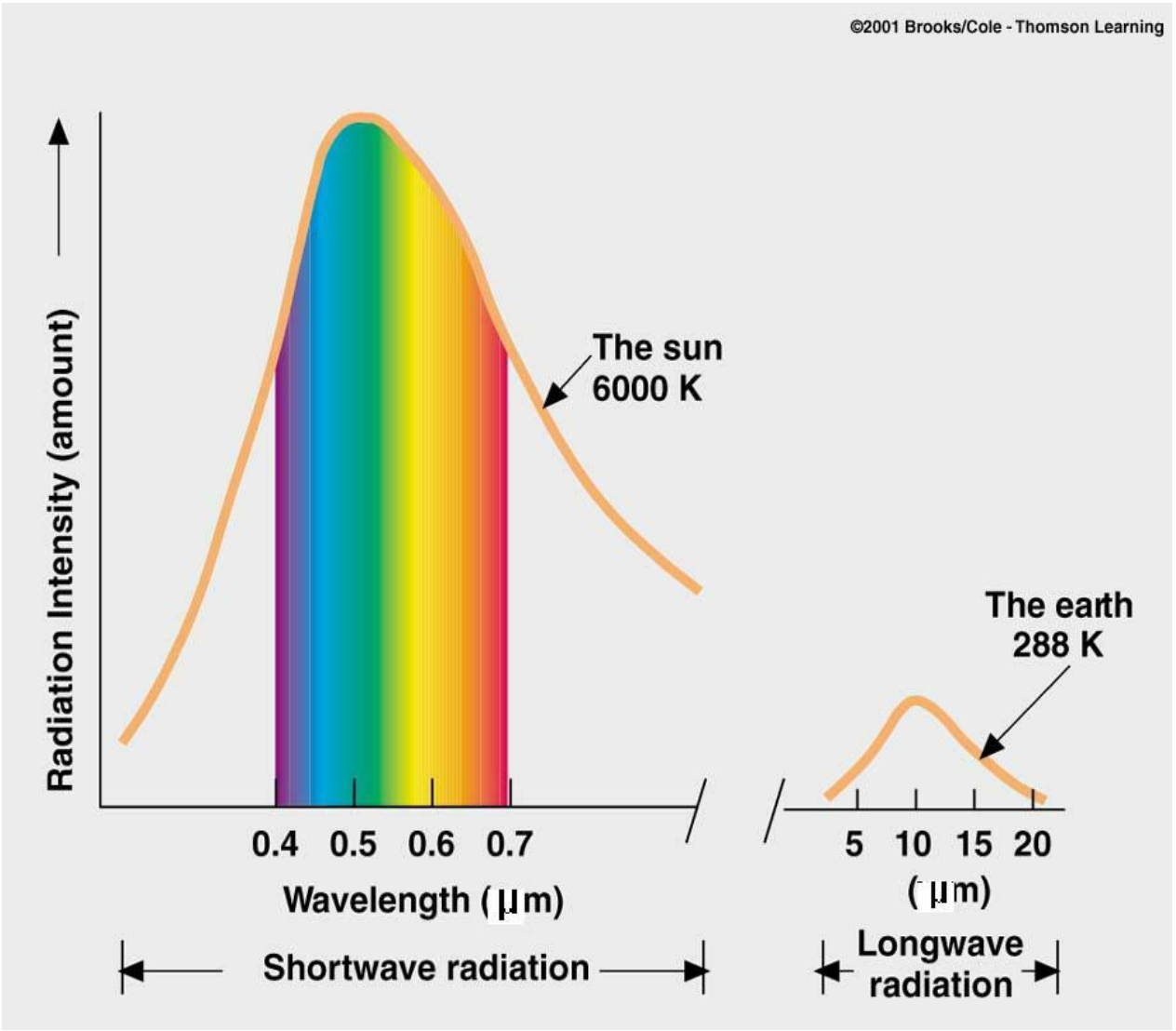


- **Sunlight is primarily made up of …**
  - Visible Light (44%)
  - Infrared Radiation (48%)
  - Ultraviolet Radiation (7%)

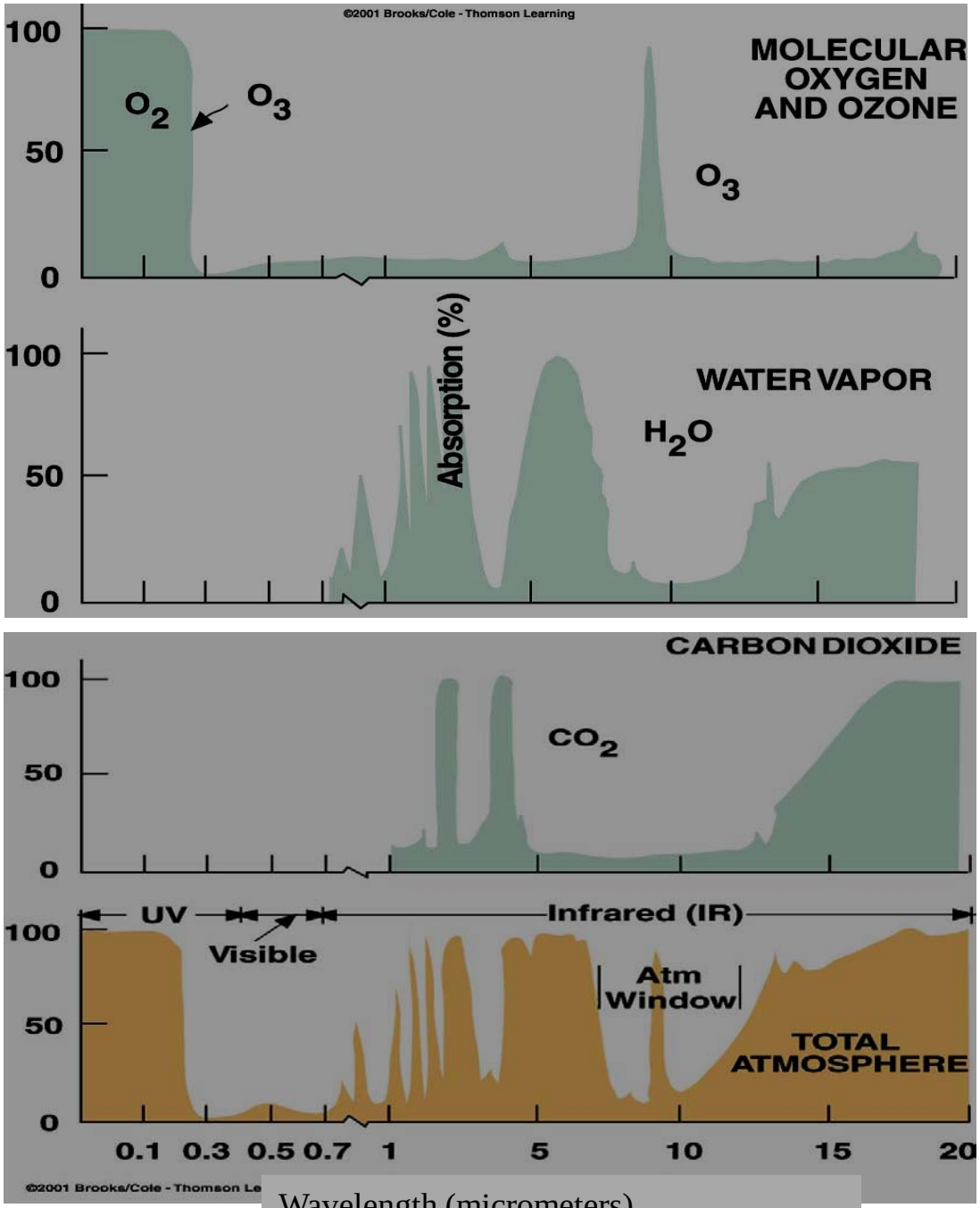
Unit: 1 μm = 0.000001 m

Solar vs. Terrestrial ("Earth") Radiation

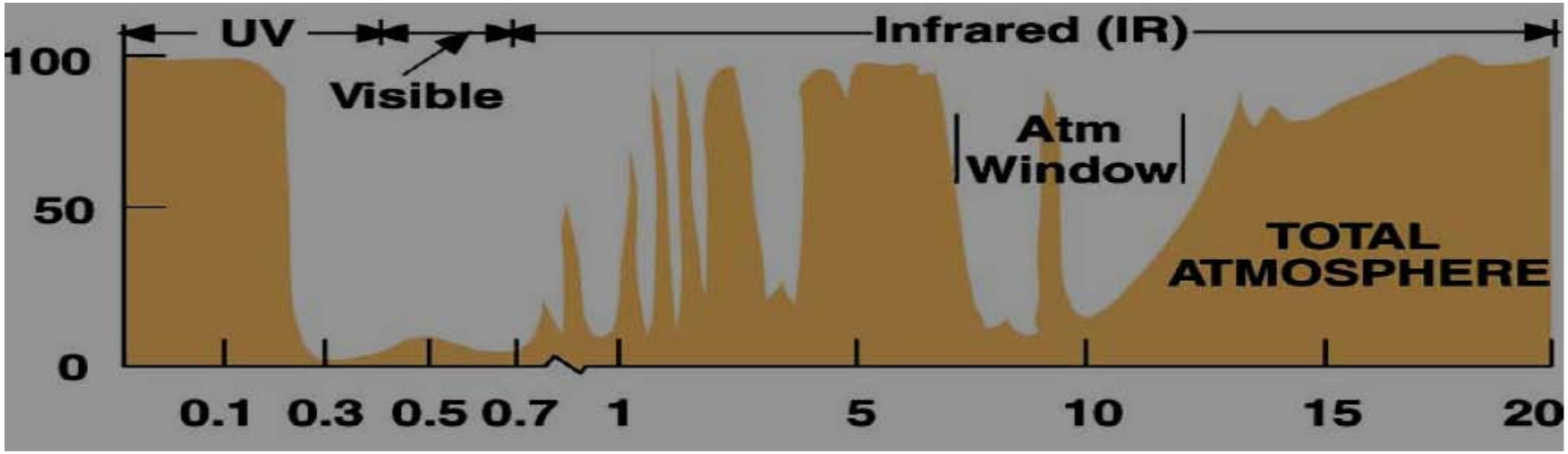
Sun is much hotter than the Earth, therefore sunlight is emitted more intensely at shorter wavelengths than Earth's radiation



Absorption of Radiation by Atmospheric Gases



Absorption of Radiation by Atmospheric Gases:
(Blowing up bottom-most plot on previous slide …)



wavelength (micrometers)

Summary

- % of radiation absorbed by atmospheric gases at different wavelengths is shown above.
- Greenhouse gases (GHGs) are atmospheric gases that absorb infrared (IR) radiation.
- GHGs shown on previous slide are CO_2, H_2O vapor and O_3.
- Others important GHGs: Methane (CH_4), CFCs, Nitrous Oxide (N_2O)
- Slide above is for "total atmosphere", and therefore the infrared portion of plot is for all GHGs combined.
- Note from previous slide, O_2 and O_3 absorb ultraviolet radiation. This leads to formation of stratospheric ozone layer and the shielding of earth's surface from ultraviolet radiation (see chalkboard exercise done in class for illustration).

The Earth's "Greenhouse Effect"

(See also chalkboard exercise done in class, any of the books on course reserve, as well as any of the lots of other books and sites on web that explain this.)

1. Solar radiation absorbed by earth's surface.
2. Earth emits infrared radiation.
3. Greenhouse gases **absorb** some of the Earth's infrared radiation.
4. Greenhouse gases (water, CO_2, others) then **re-emit** infrared radiation in all directions.
5. Earth **absorbs** the downward directed infrared radiation
6. Result: a warmer surface temperature and troposphere than would otherwise be.

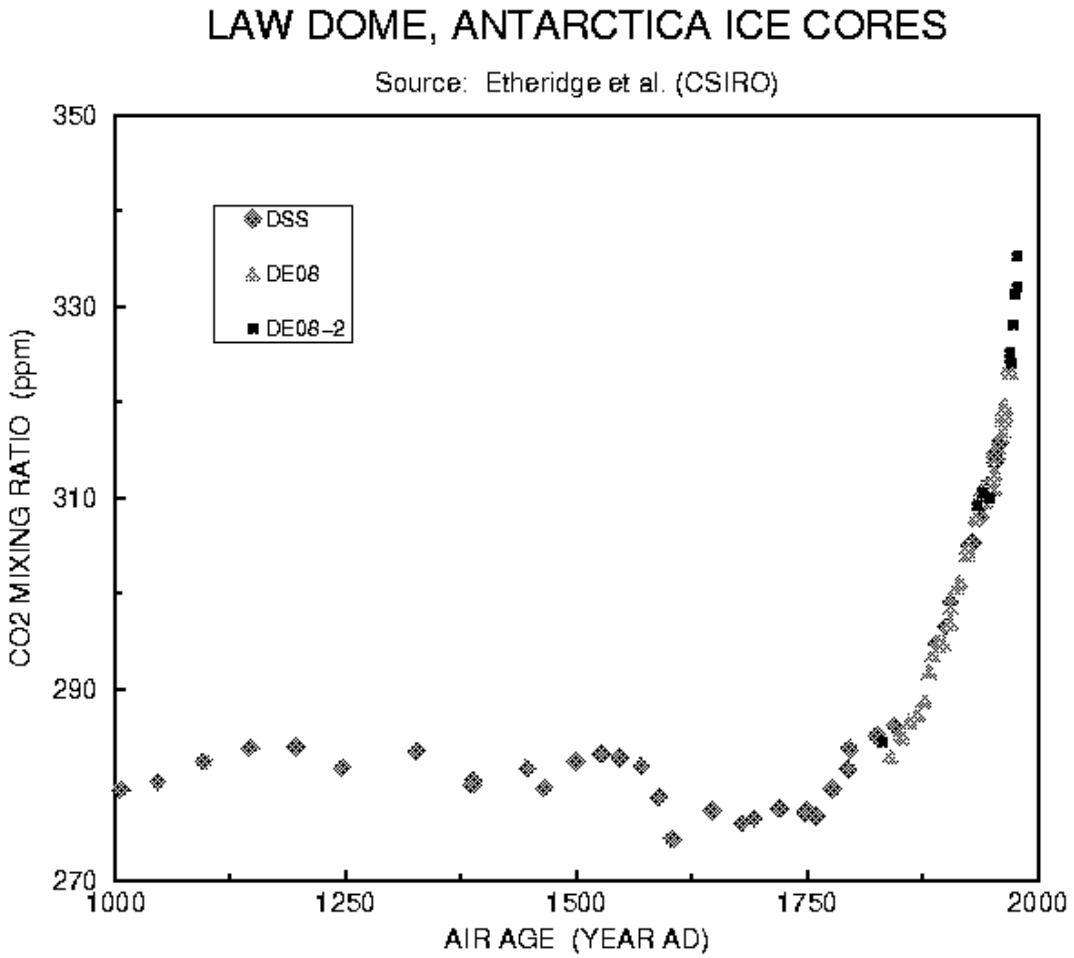
Note: Increased emissions of GHGs the last 100+ years have increased GHG concentrations in the atmosphere. This is believed by the consensus of climate scientists to have amplified the greenhouse effect, and therefore the main reason behind the global warming experienced the last 100+ years.

Global Trends in CO_2

Emissions & Concentration

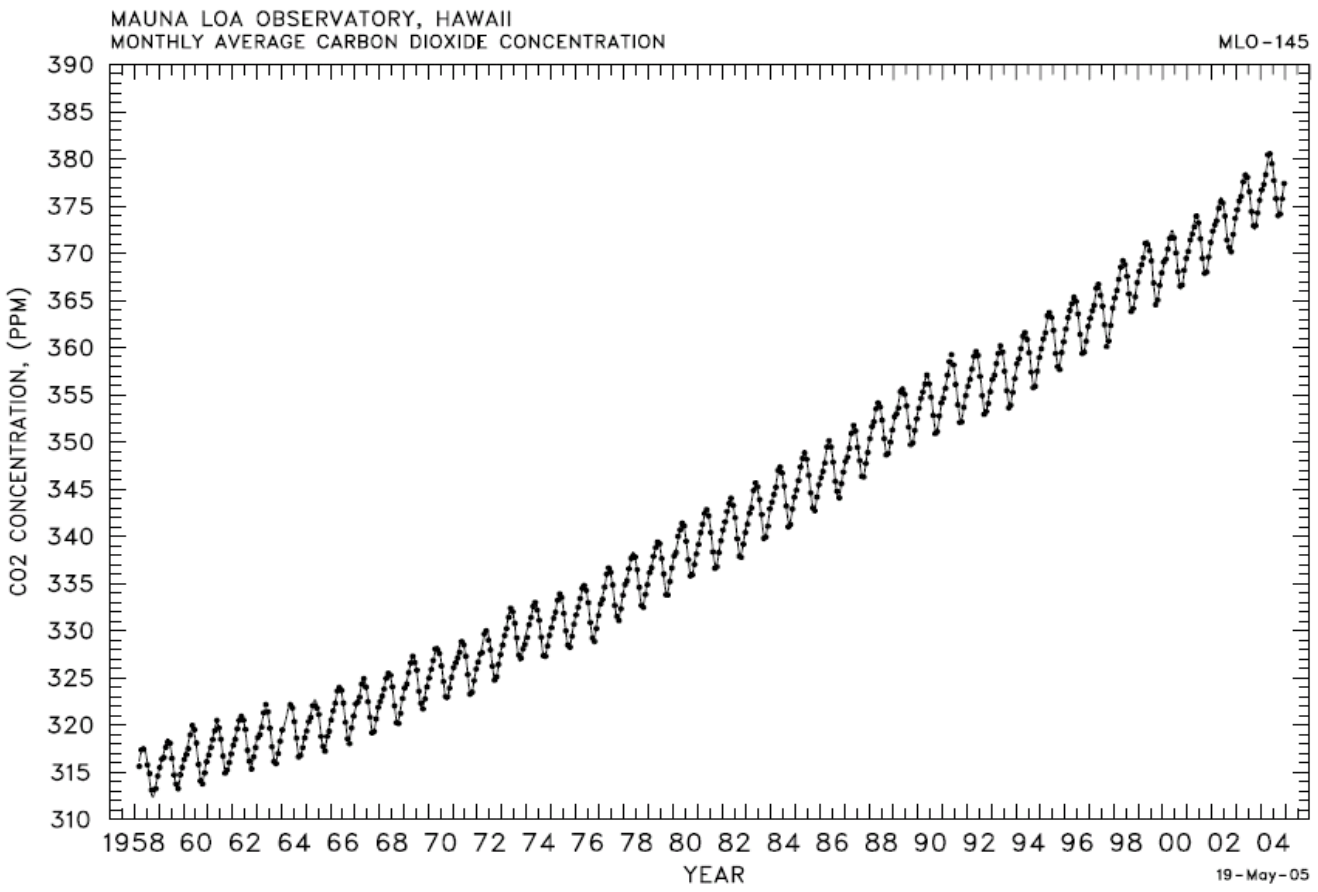
Industrial Era (circa 1750) and before

CO_2 Concentrations in Atmosphere (Last 1000 years) ...



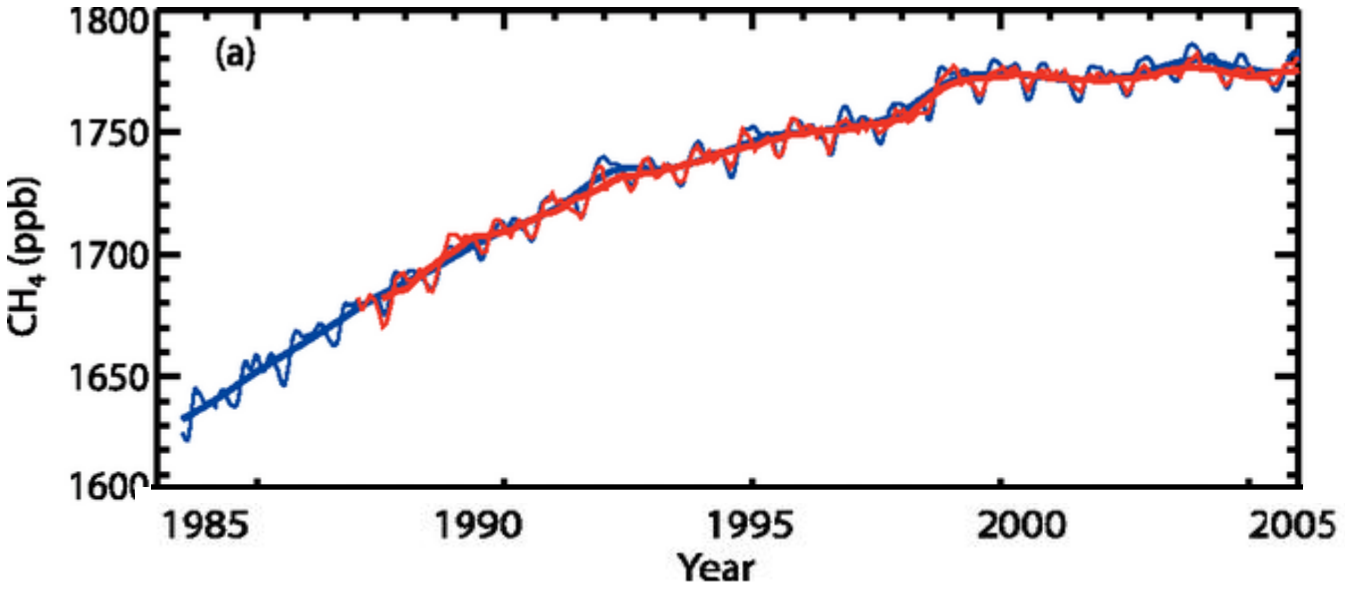
Measurements from Ice Cores (Antarctica)

CO_2 Concentrations in Atmosphere (Last 50+ years) …



Observations from
Mauna Loa Observatory (Hawaii)

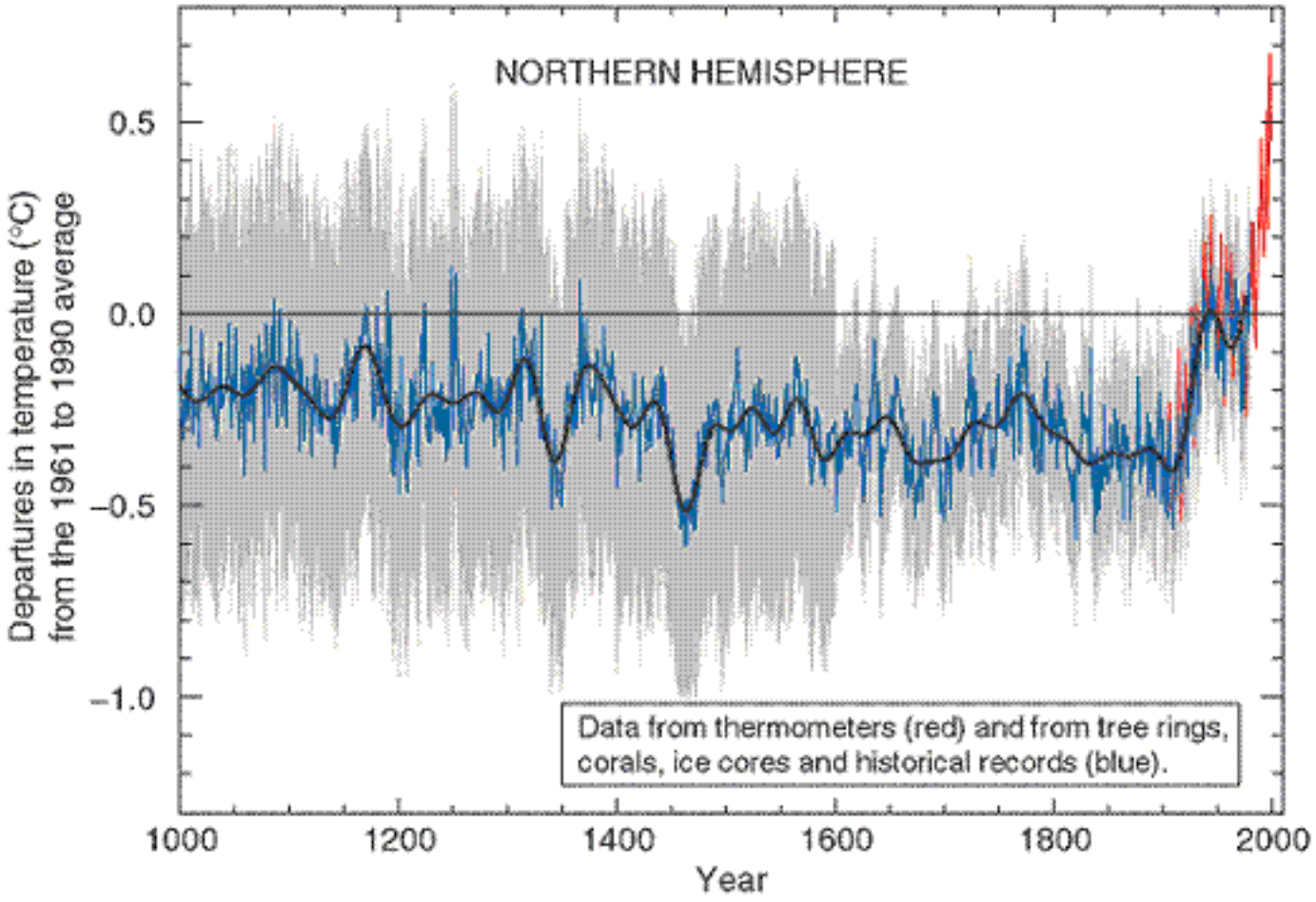
Methane (CH_4) Measurements



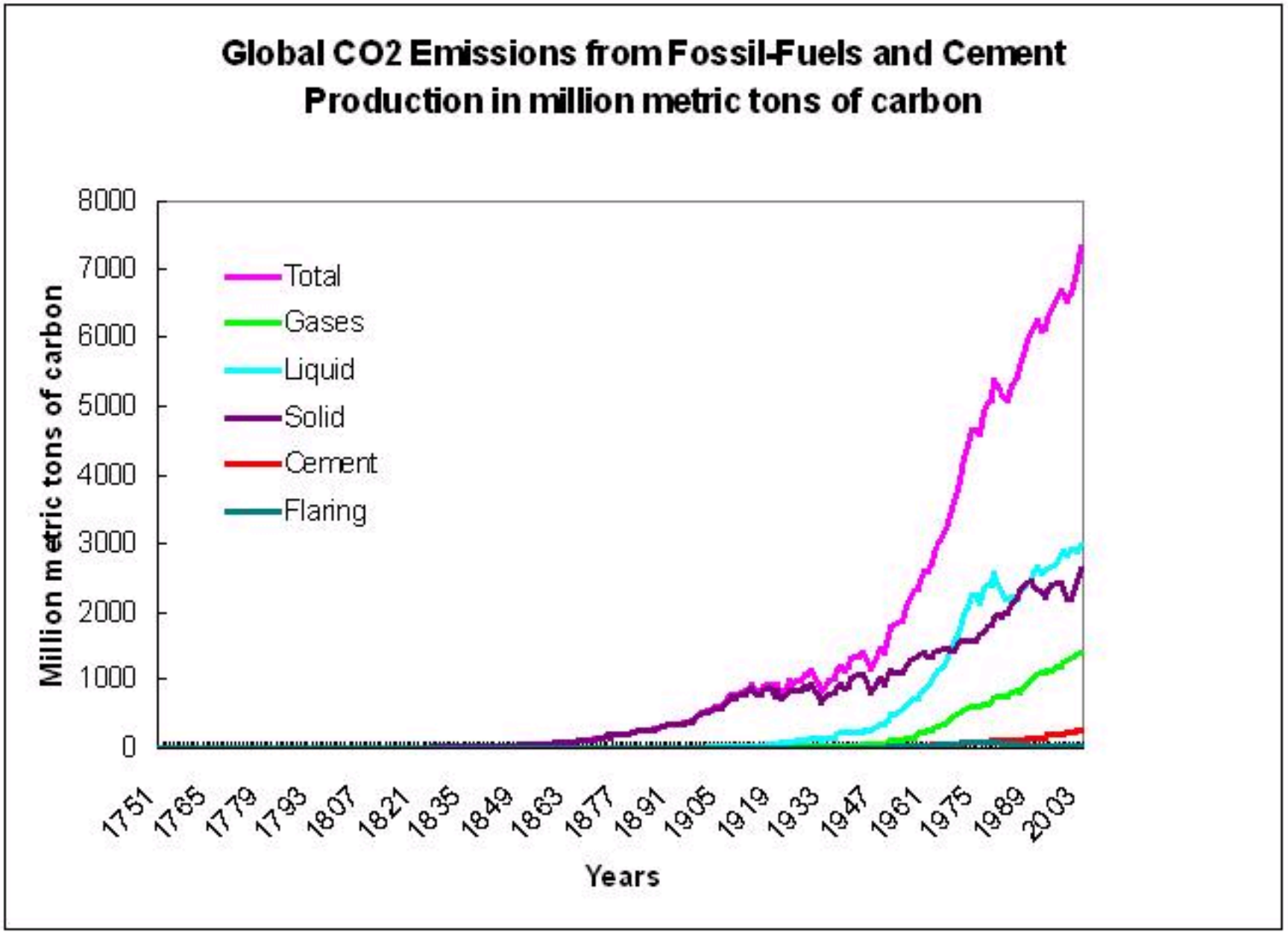
- Recent day direct measurements: Mauna Loa (Hawaii)
- Pre-Industrial concentrations approximately 700 ppb!

http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-3-2.html

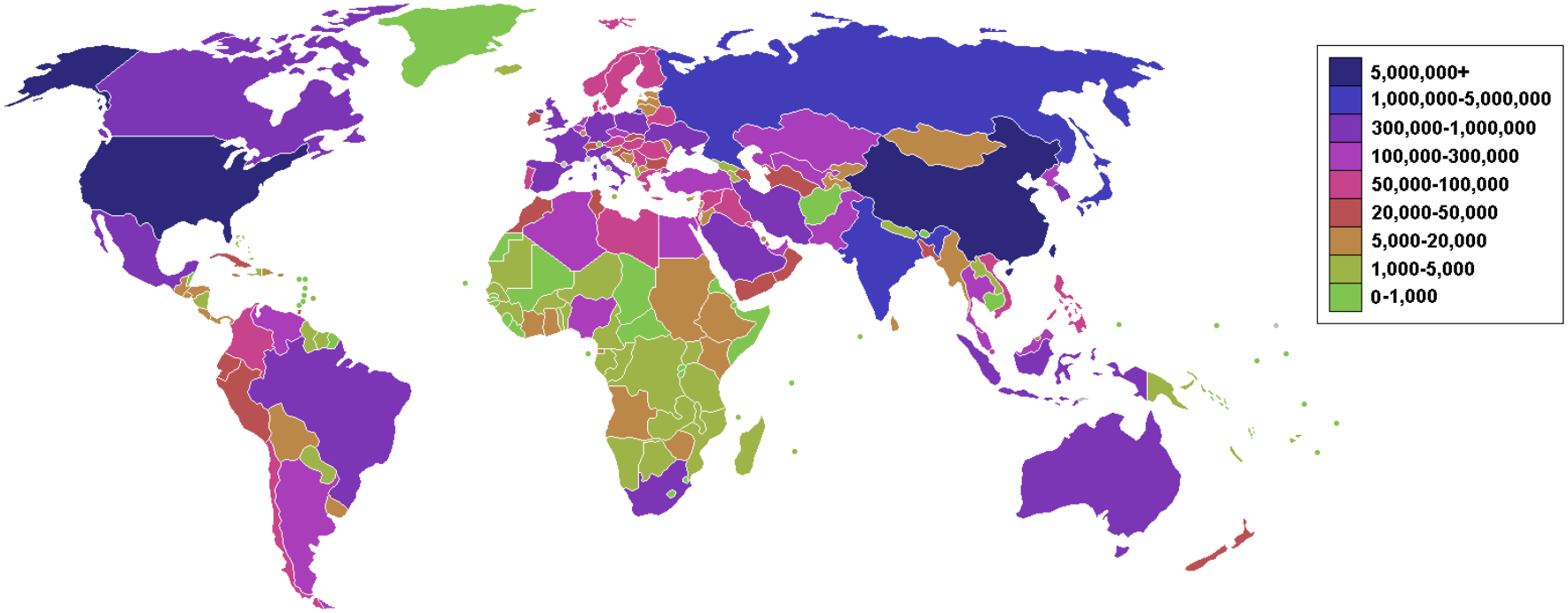
Temperatures of Past Millennium



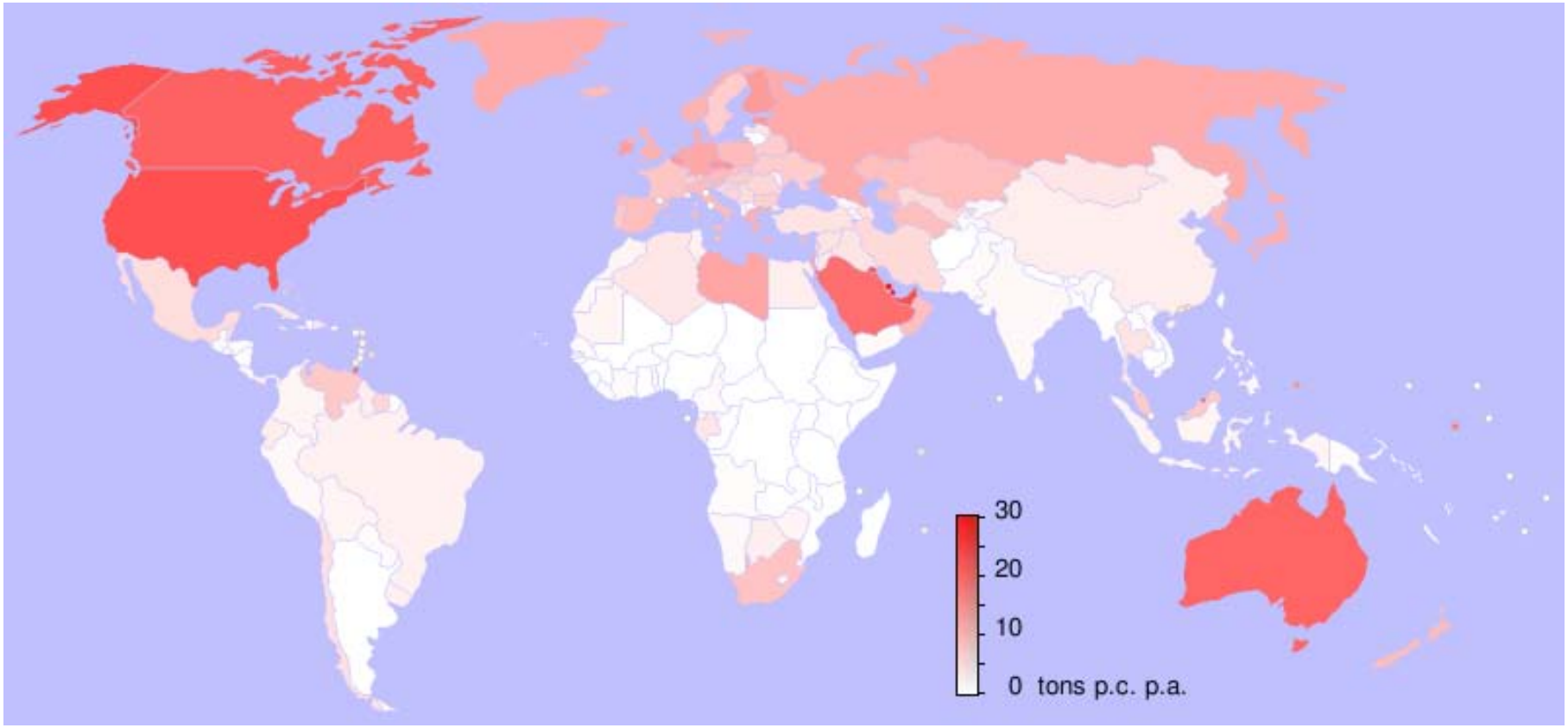
Temperatures in graph represent near-surface air temperature in northern hemisphere, averaged across many sources of data. Temperatures are in terms of differences relative to 1961 – 1990 average.


Global CO2 Emissions from Fossil-Fuels and Cement Production in million metric tons of carbon
Million metric tons of carbon
8000
7000
6000
5000
4000
3000
2000
1000
0
Total
Gases
Liquid
Solid
Cement
Flaring
1751
1765
1779
1793
1807
1821
1835
1849
1863
1877
1891
1905
1919
1933
1947
1961
1975
1989
2003
Years

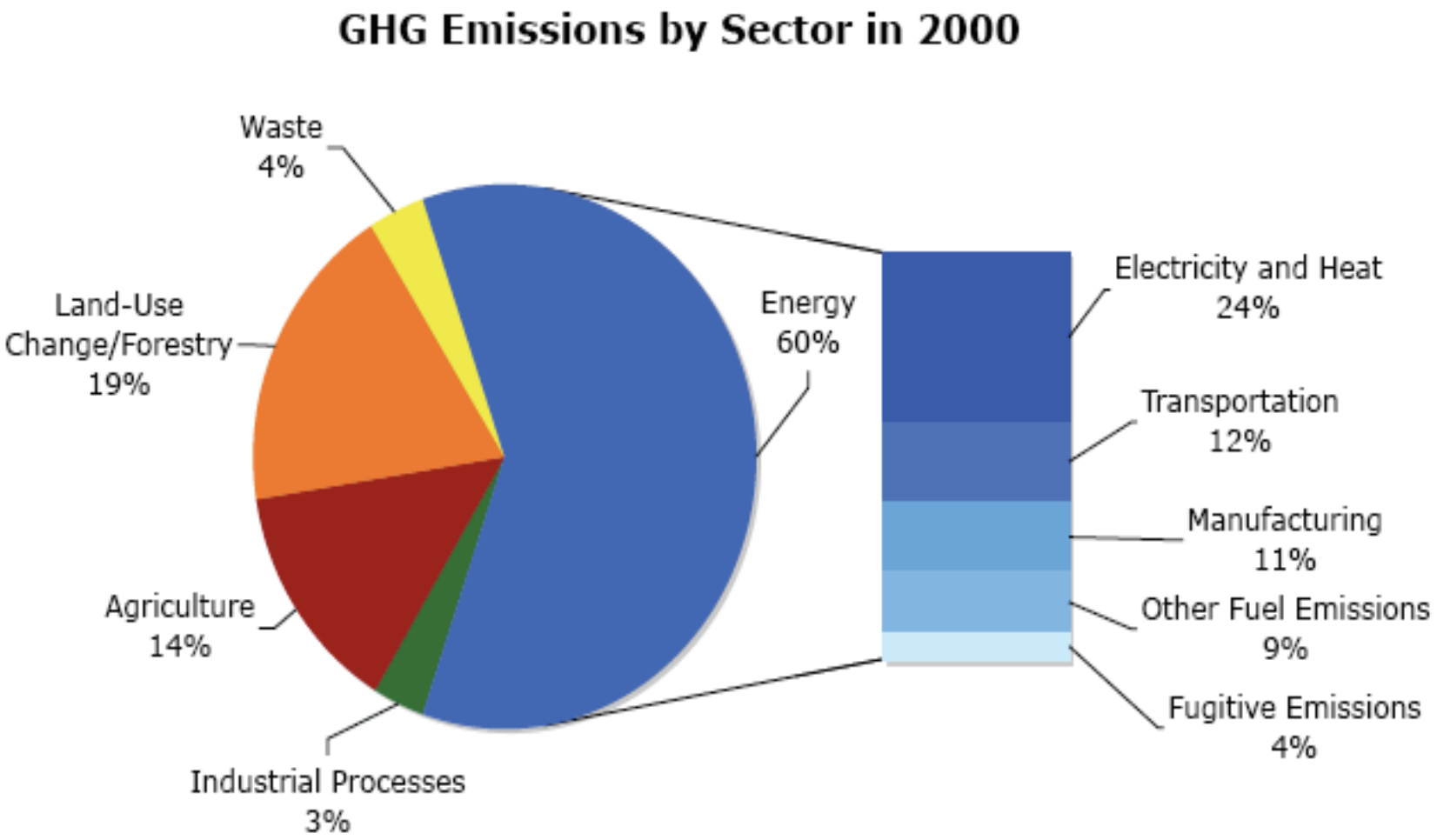
Carbon Dioxide Emissions by Country



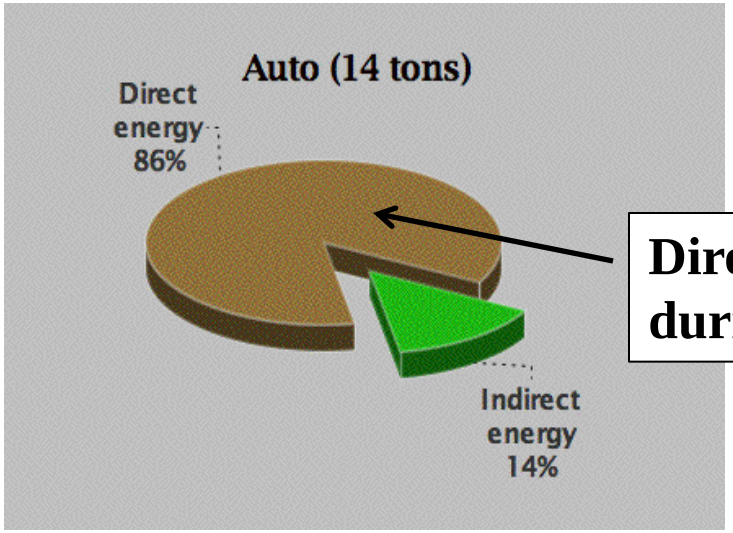
Tons of CO_2 emitted per capita



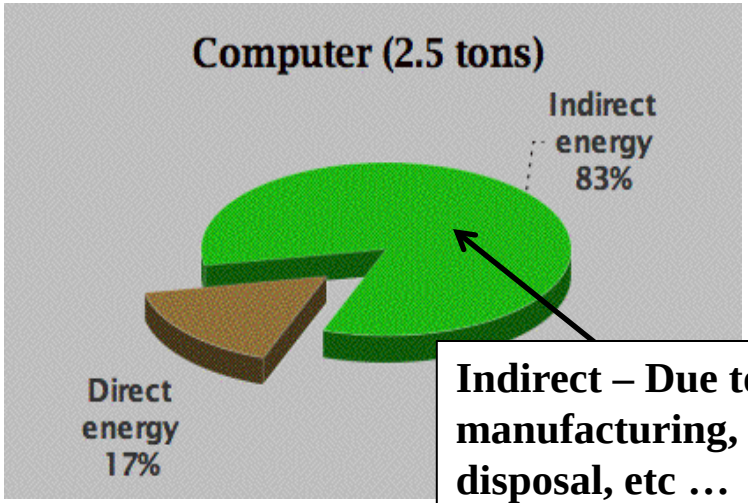
Global Greenhouse Gas Emissions



Direct and Indirect Energy



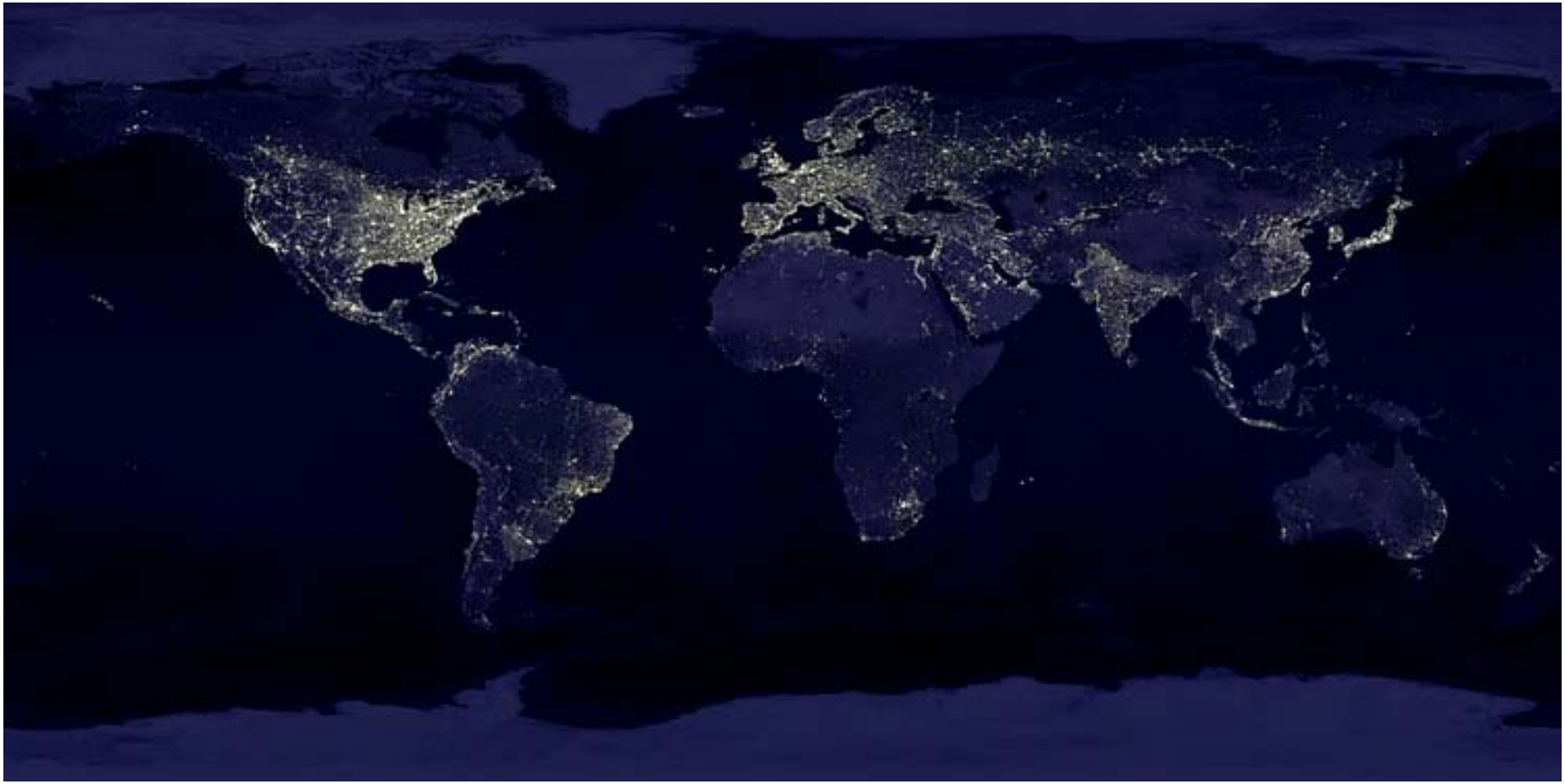
Direct – Used only during operation



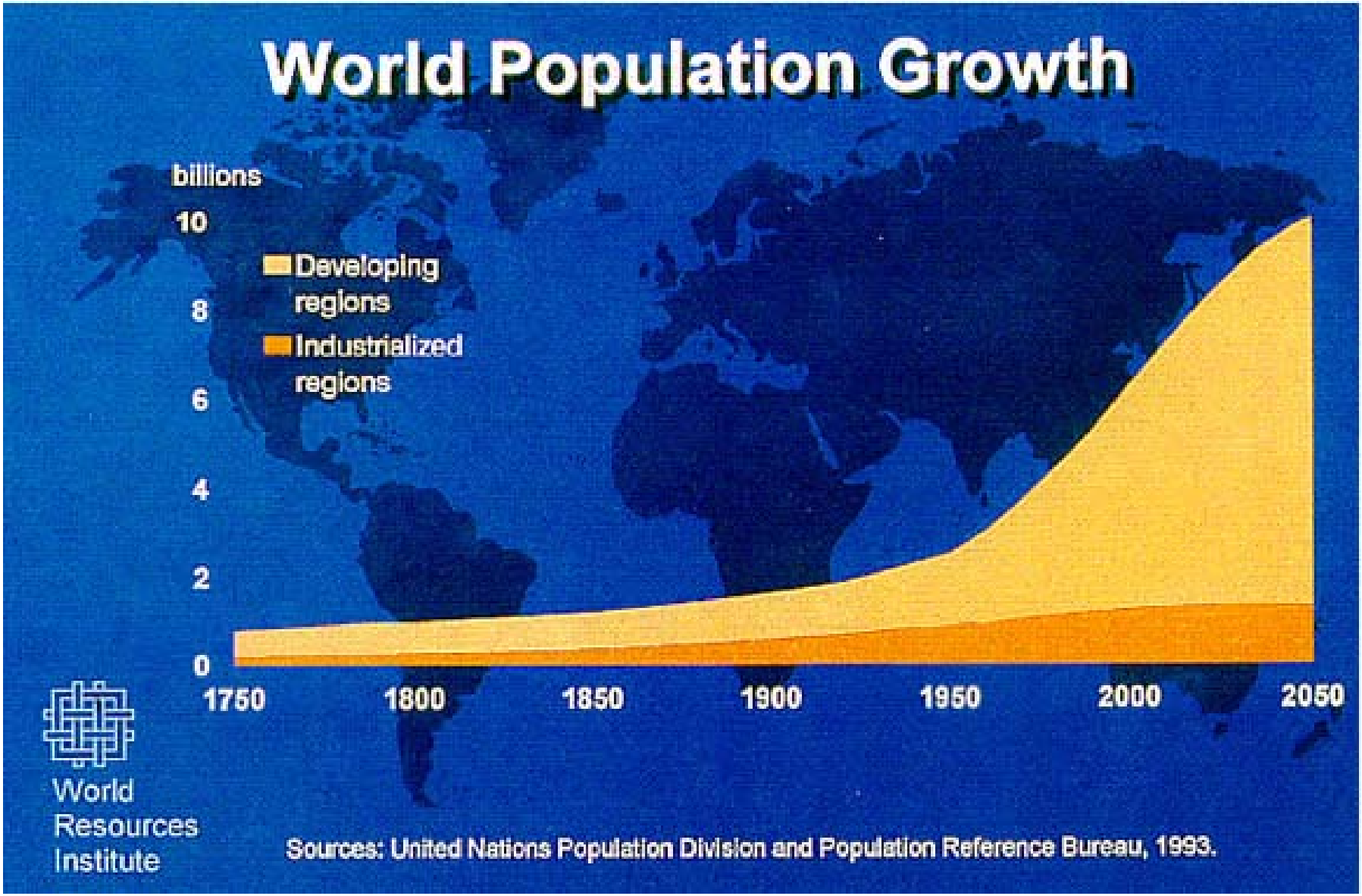
Indirect – Due to manufacturing, transportation, disposal, etc …

Note: Embedded energy in food production is also an example of indirect energy

Why the increase in carbon emissions? Industrialization …

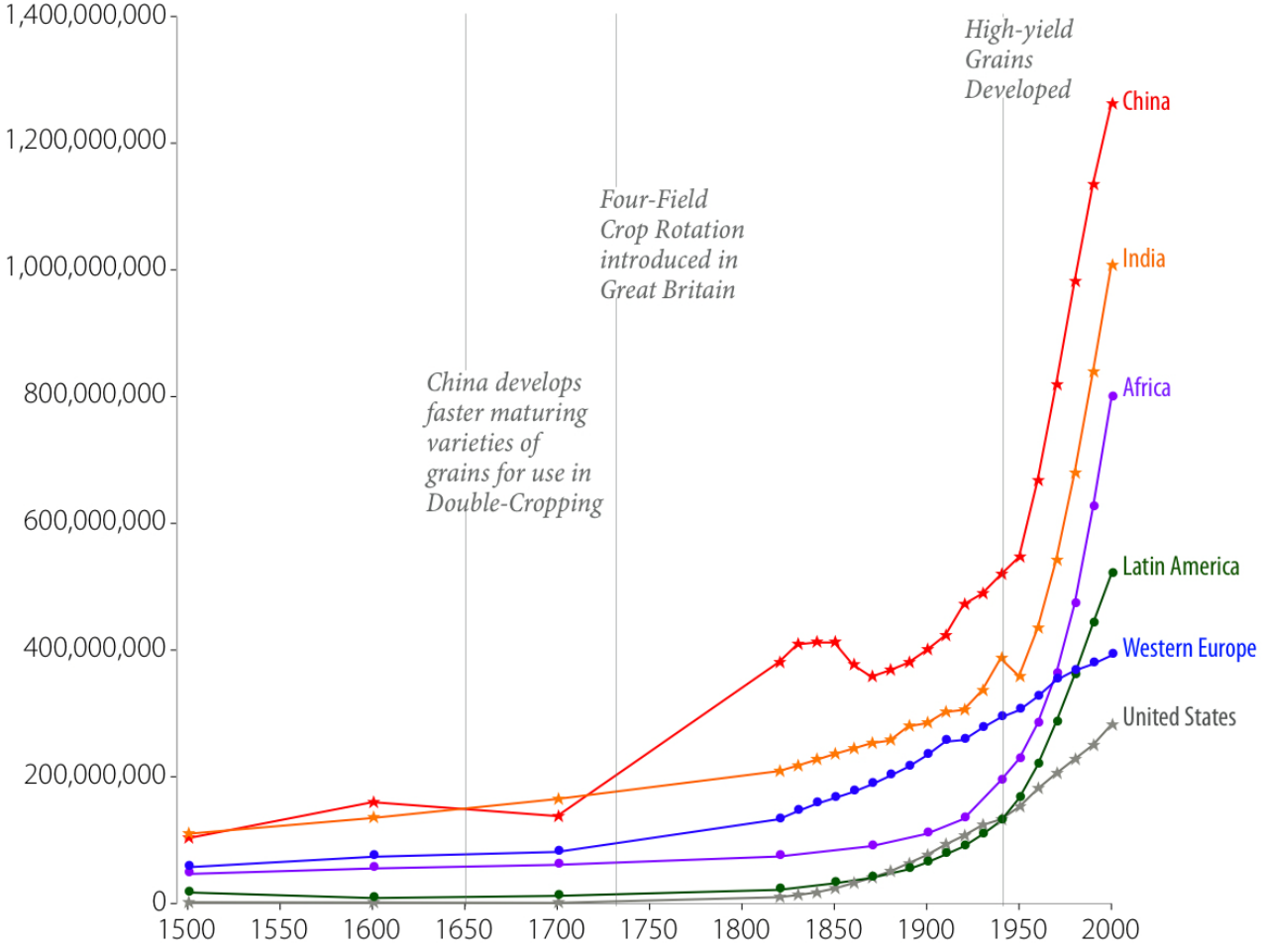


Why the increase in carbon emissions? Population Growth …



Population Growth over the Last 500 Years

China, India, Africa, Latin America, Western Europe, and United States



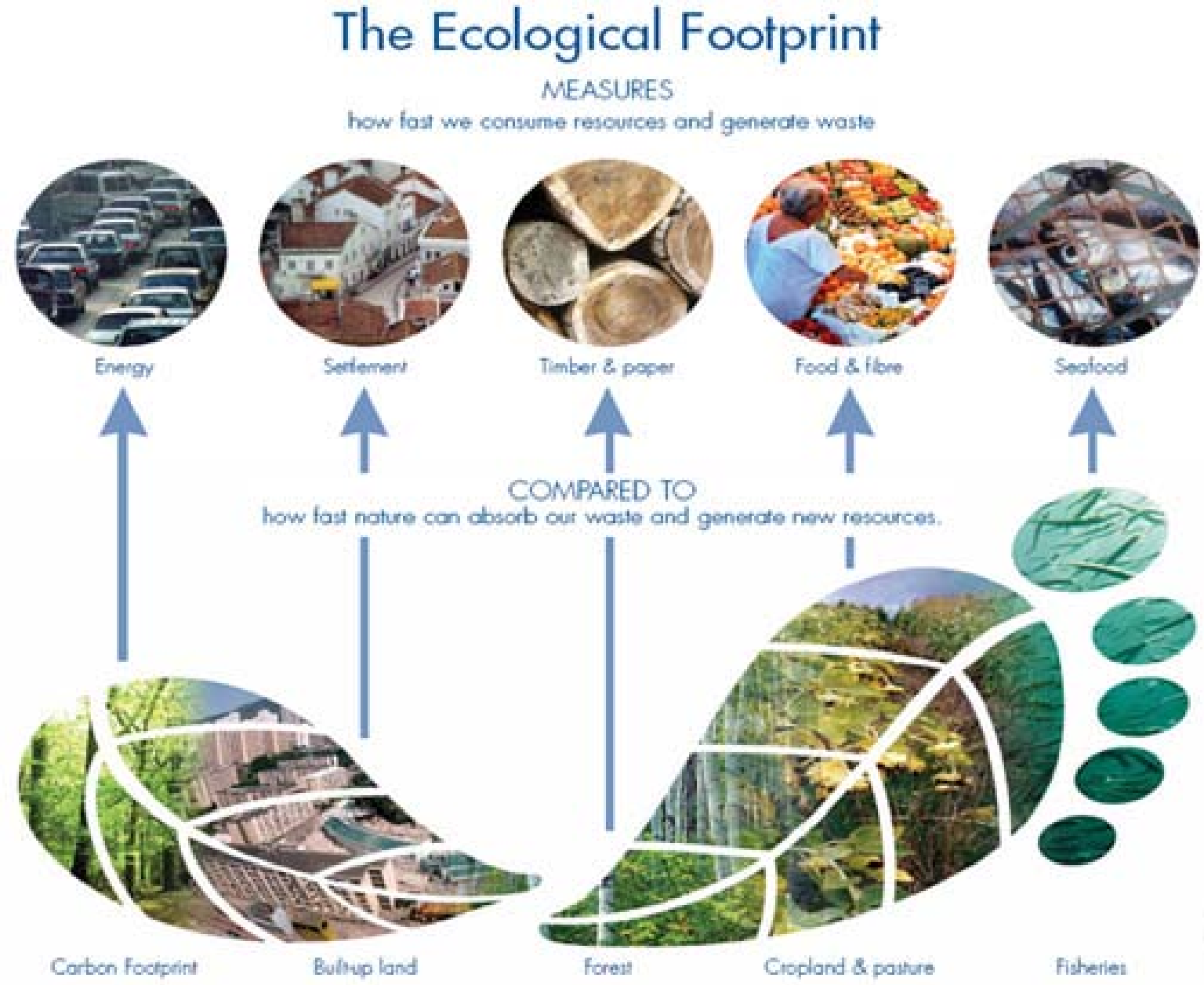
Source: Angus Maddison, University of Groningen

Thinking of these things in terms of “Ecological Footprint” …

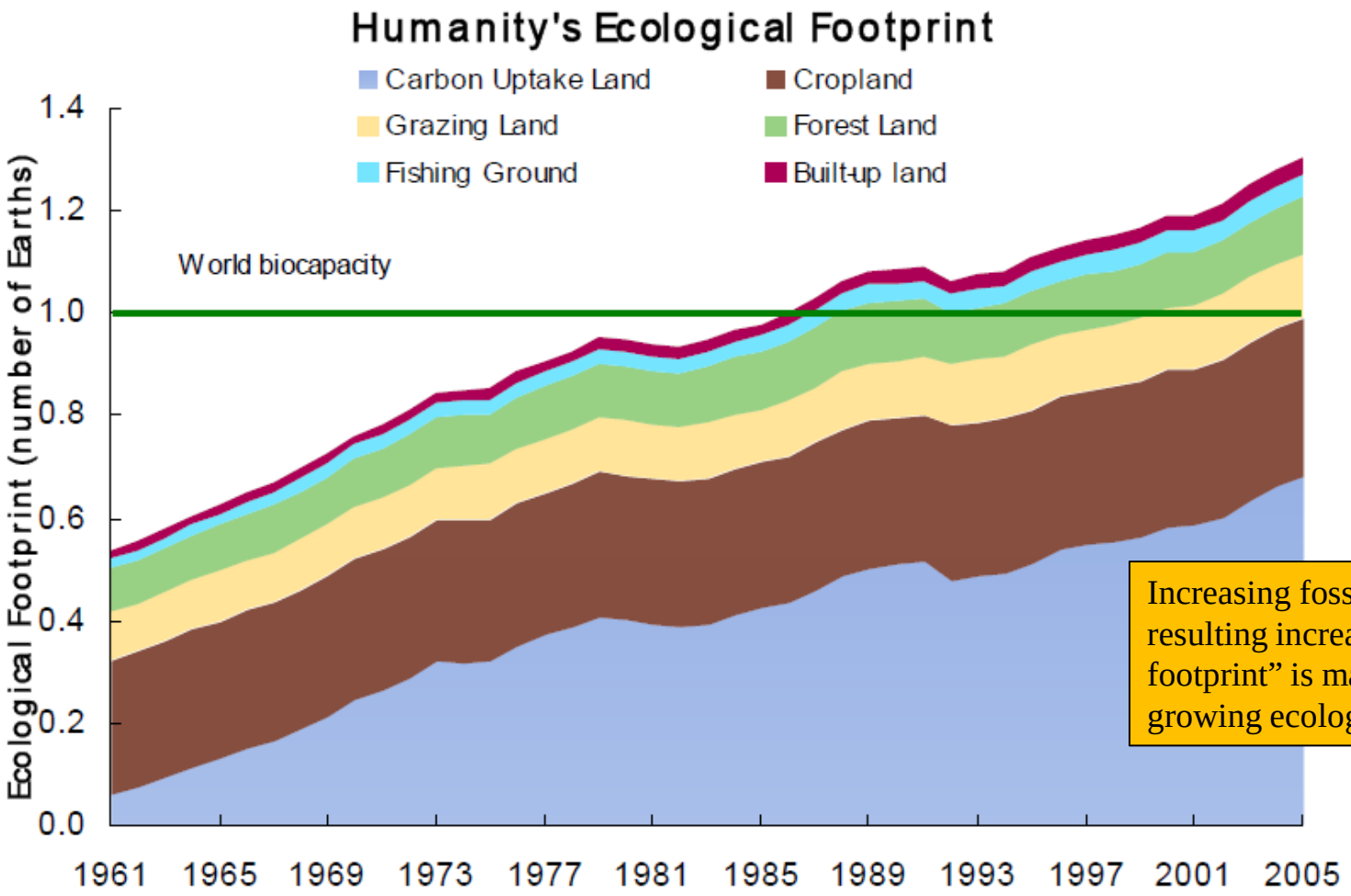
Background:

- http://www.footprintnetwork.org/en/index.php/GFN/
- Watch video “The Ecological Footprint: Accounting for a Small Planet”, which can be downloaded and viewed from …

  http://www.footprintnetwork.org/en/index.php/GFN/page/interviews_films/



Taken from http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/



Increasing fossil energy use and resulting increase in "carbon footprint" is main reason for growing ecological footprint.

Figure 4: World overshoot according to the 2008 edition of the National Footprint Accounts. Humanity's Ecological Footprint, expressed in number of planets demanded, has increased significantly over the past 45 years.

From "Calculation Methodology Paper", hyperlinked on http://www.footprintnetwork.org/en/index.php/GFN/page/methodology/

Thinking of carbon emissions in terms of a "footprint" …

- Term "footprint" implies an area
- Carbon footprint is a way of expressing annual emissions of carbon in terms of how much area would be required to place these emission back to the earth annually (source of carbon = sink of carbon)
- Carbon footprint is one part of the "ecological footprint" (see previous slides)
- Sink processes involved in removal of carbon to earth (mostly in form of CO_2)
  - Photosynthesis (earth sink)
  - Oceanic uptake by phytoplankton and other ocean life (ocean sink)
  - Absorption of CO_2 into the oceans (ocean sink)
- See http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle.php

Homework

Personal Ecological Footprint Calculation

- Calculate your personal ecological footprint according to the utility on http://www.footprintnetwork.org/en/index.php/GFN/ (pull down “Footprint Basics”, then “Personal Footprint”)
  - How many earth’s would it take to support your lifestyle if everyone on planet lived as you do?
  - By how much can you reduce your footprint value by making different choices in **a)** diet and **b)** energy use? Explain why the footprint reduced in these cases (i.e. what sectors of the footprint reduced and why?)
  - Can you bring your footprint to less than one earth? If not, why not?
  - Can you bring your footprint down to one earth if you exclude “services”?
  - What does the “services” sector represent? Do you have control of this? Why or why not?
- Hand in printouts of two or three outputs from the utility that address these questions. Hand these with your completed Exam #2 on March 11.
- Be prepared to answer a “short answer” question on this topic on Exam #2 (March 11).

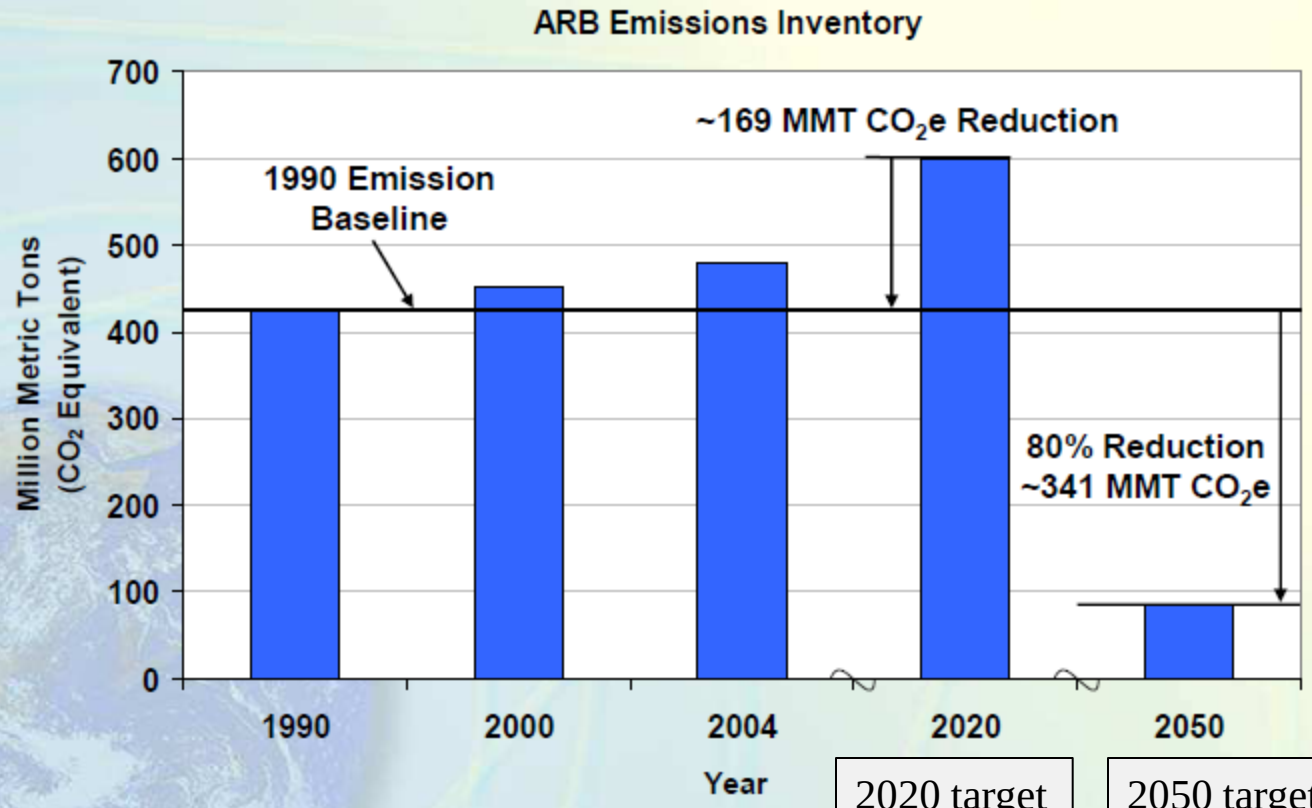
Greenhouse Gases Regulation in California (AB32)

http://www.arb.ca.gov/cc/ab32/ab32
http://www.arb.ca.gov/cc/inventory/1990level/1990level.htm
http://www.arb.ca.gov/cc/inventory/pubs/reports/staff_report_1990_level.pdf

California Global Warming Emission Reduction Targets

- ~~By 2010, reduced to 2000 levels, or by 11%~~
- By 2020, reduced to 1990 levels, or by 25%
- By 2050, reduced to 80% below 1990 levels

Magnitude of the Challenge



2020 target reduce to 1990 levels

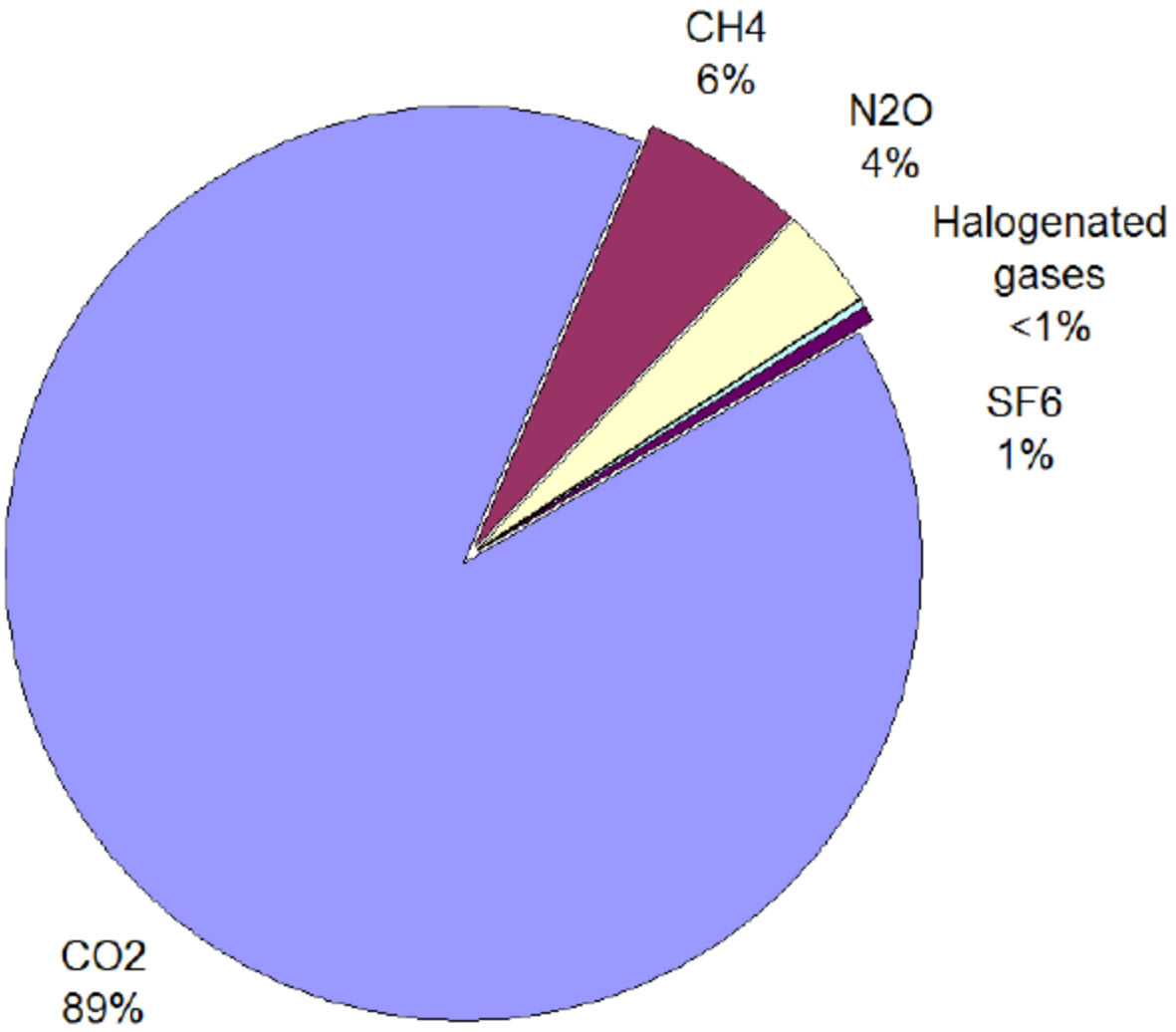
2050 target reduce to 80% below 1990 levels

Regulated Greenhouse Gases in AB32

- Regulations in CA targeted towards the following six gases (or classes of gases) through AB32 "Global Warming Solutions Act"
  1. **Carbon Dioxide (CO_2)**
  2. **Methane (CH_4)**
  3. **Nitrous Oxide (N_2O)**
  4. **Sulfur Hexafluoride (SF_6)**
  5. **Hydrofluorocarbons (HFCs)**
  6. **Perfluorocarbons (PFCs)**

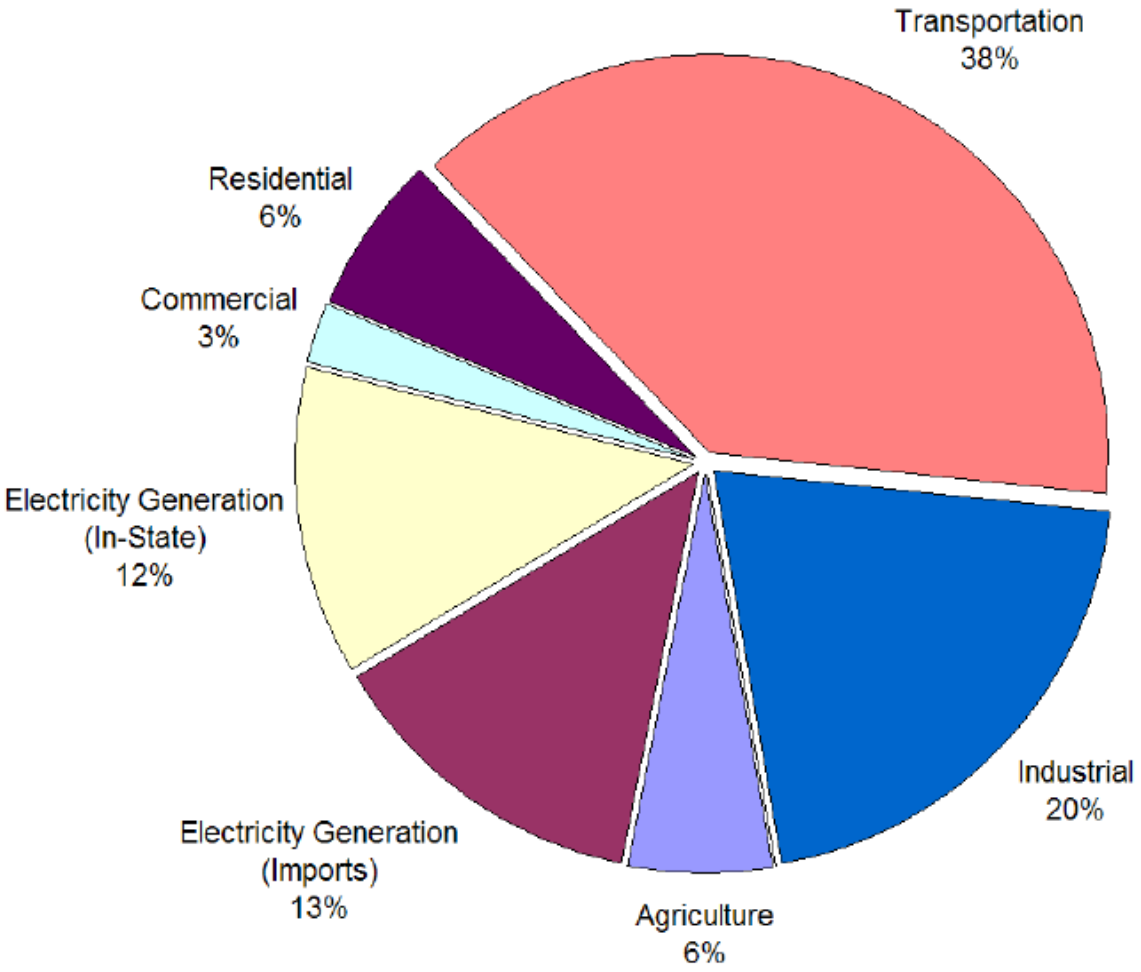
- First three (CO_2, CH_4 and N_2O) also occur naturally in atmosphere, i.e. they do not require "anthropogenic" emissions to exist in atmosphere.
- Last three (SF_6, HFCs and PFCs) only occur due to anthropogenic emissions.
- Last two (HFCs and PFCs) together are called "chlorofluorocarbons" (CFCs). Independent from this, CFCs are also known to be depleting ozone in stratosphere ("ozone depleting substances", ODS, in EPA lingo).

Figure 1. 1990 Gross Emissions by Greenhouse Gas



Percentages are similar today (year 2011) …

Figure 3. 2004 Greenhouse Gas Emissions by Sector[5]
(480 MMTCO2e Net Emissions)



MMTCO2e = Million Metric Tonnes CO_2-equivalent

B. Which global warming potentials are used?

Each greenhouse gas has a different capacity to trap heat in the atmosphere, with some more effective at trapping heat than others. To account for this difference, IPCC developed the metric of a global warming potential (GWP) for each gas. The GWP allows comparison of the global warming influence of different greenhouse gases relative to CO2. Total greenhouse gases can then be expressed as CO2 equivalents or CO2e.

Greenhouse Gas	SAR GWP (100 years)
CO2	1
CH4	21
N2O	310
HFC-23	11,700
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-32	650
CF4	6,500
C2F6	9,200
SF6	23,900

Source: IPCC Second Assessment Report

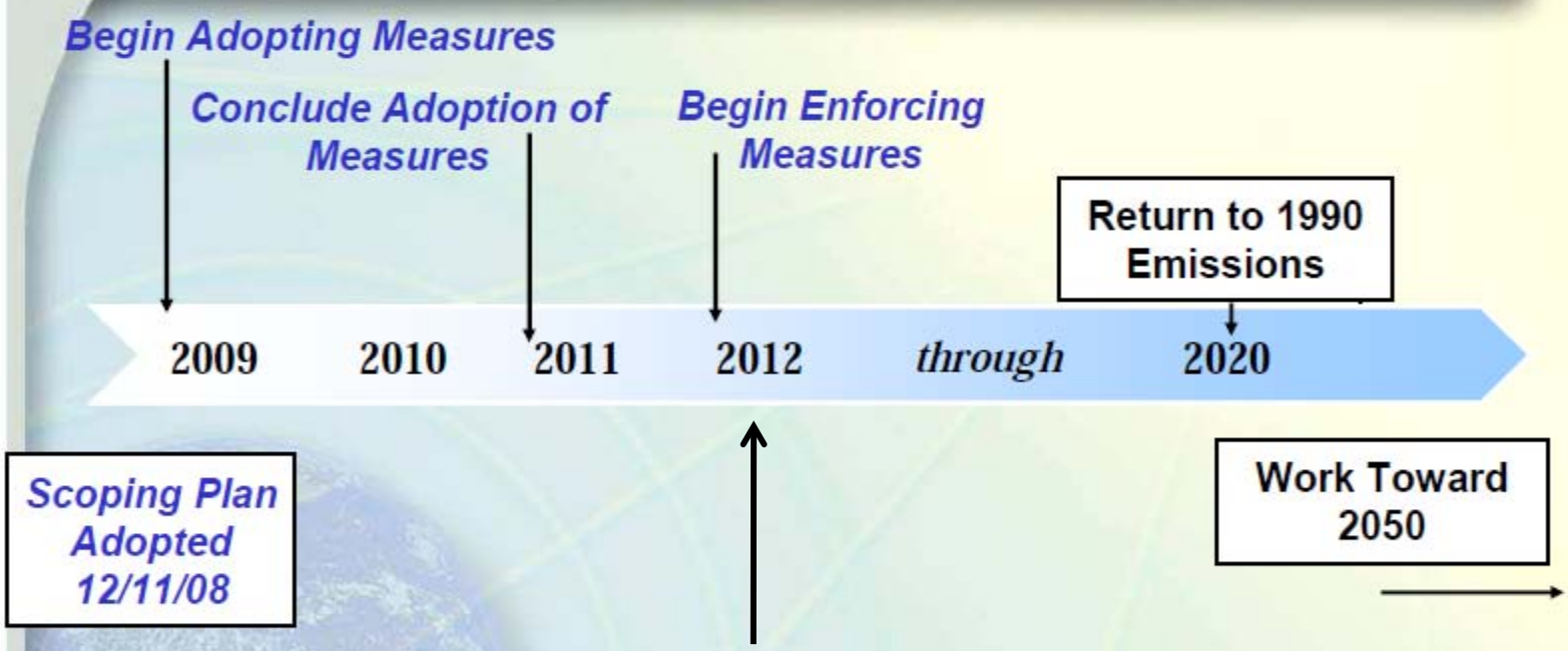
AB32 Regulations ("Measures")

- Many, many different regulations under the "umbrella" of AB32. Some take effect earlier than others. Details of many still being worked out.

- See http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm for details. The link "Measure Timeline" is especially good to help understand what is in AB32.

- May come back to this later in semester to get more familiarity with specific measures in AB32.

The Next Chapters



Formal enforcement of AB32 Jan 1 2012.

An Aside:
City of San Jose “Green Vision”

San Jose “Green Vision”

Adopted Municipal Greenhouse Gas Goals

While developing an inventory of municipal and community GHG emissions, staff found that accurate 1990 emissions data was not available for either the community or municipal operations. Verifiable community emissions data was, however, available for 2005. Since the data from 2005 is also more reflective of current emissions, and 2005 is the baseline year used by many of the other cities throughout the State of California as well as the baseline chosen for the California SB 375 regional GHG reduction methodology (currently under development), staff recommended revised goals consistent with Council's 2007 direction to set aggressive goals while changing the baseline year to 2005. On January 12, 2010, Council adopted the following revised greenhouse gas reduction goals.

2015:	*GHG emissions 15% below 2005 levels;*
2020:	*GHG emissions 20% below 2005 levels;*
2030:	*GHG emissions 35% below 2005 levels;*
2040:	*GHG emissions 65% below 2005 levels;*
2050:	*GHG emissions 80% below 2005 levels.*

The revised reduction goals are aggressive, long-term goals that continue San José's environmental leadership role and will be additional indicators of investments San José is making today through the Green Vision and Envision San José 2040 General Plan update.

- Taken from “Green Vision 2009 Annual Report”, City of San Jose
- http://greenvision.sanjoseca.gov/

Green Vision Goals (2007-2022)

1. Create 25,000 Clean Tech jobs
2. Reduce per capita energy use by 50%
3. Receive 100% of our electrical power from clean, renewable sources
4. Build or retrofit 50 million square feet of green buildings
5. Divert 100% of the waste from our landfill and convert waste to energy
6. Recycle or beneficially reuse 100% of our wastewater
7. Adopt a General Plan with measurable standards for sustainable development
8. Ensure that 100% of public fleet vehicles run on alternative fuels
9. Plant 100,000 new trees and replace 100% of our streetlights with smart, zero-emission lighting
10. Create 100 miles of interconnected trails