Average Lifetime of Technological Civilization

Average Lifetime of Technological Civilization

L = ?

- End of Communication Efforts
  (Civilization Survives)
  (Decades?)

- Civilization **Evolves** away from interest or capability (Post-technological Civilization)
  (Centuries - Millenia)

- Civilization **Collapses**
  (Reversion to Pre-technological Culture)

  Exhaustion of resources

  Population explosion

  (~ 100 yrs - 1000 yrs)

- Sudden, Catastrophic End of Civilization or Extinction of our Species

  Nuclear War leads to Nuclear Winter

  (10's - 100's of years)

  Natural Catastrophes (> 10^5 yr for most)

Resource Depletion

Metals, Drinkable Water, Arable Land, …

Energy is most fundamental

Energy is conserved

"Depletion" = conversion to less usable forms
(entropy increases)

World Energy Usage

World ~400 “Quads” Per year

1 Quad = 10^{15} BTU $\simeq$ 3×10^{11} kW- H $\simeq$ 10^{18} Joules (one exajoule)

Average power is 13×10^{6} MW

U.S. uses ~20% of this

Energy per capita ~ 7.5 metric tonnes of oil equivalent (Mtoe)

~ 2 × Europe

~ 4 × World avg.

Energy Perspectives

History of Energy Use in USA

Consumption by Source

Figure 5. Energy Consumption by Source, 1635-2003

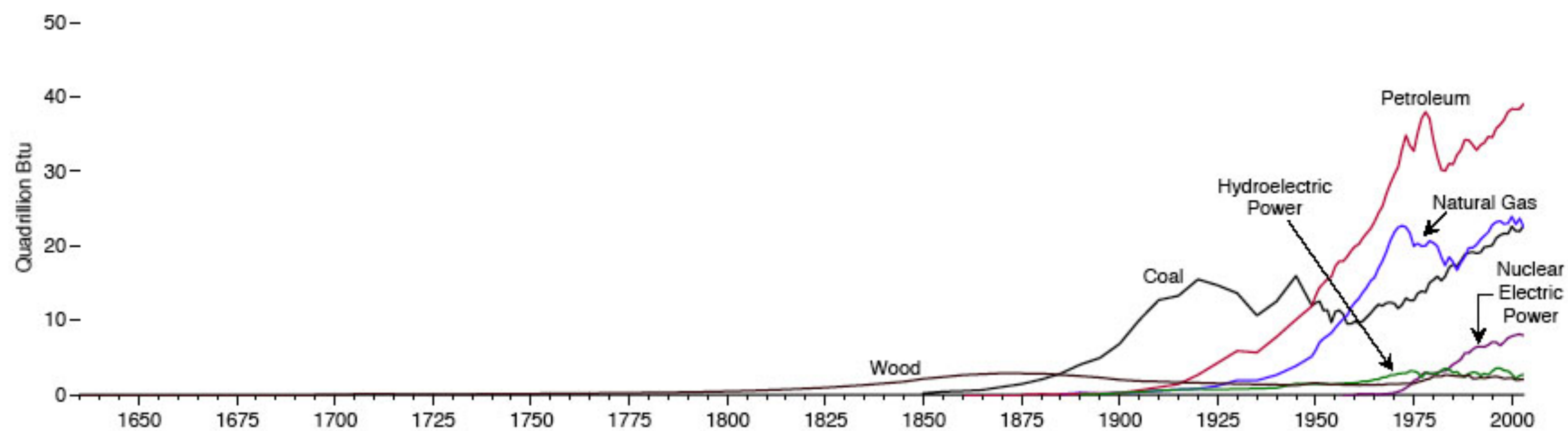
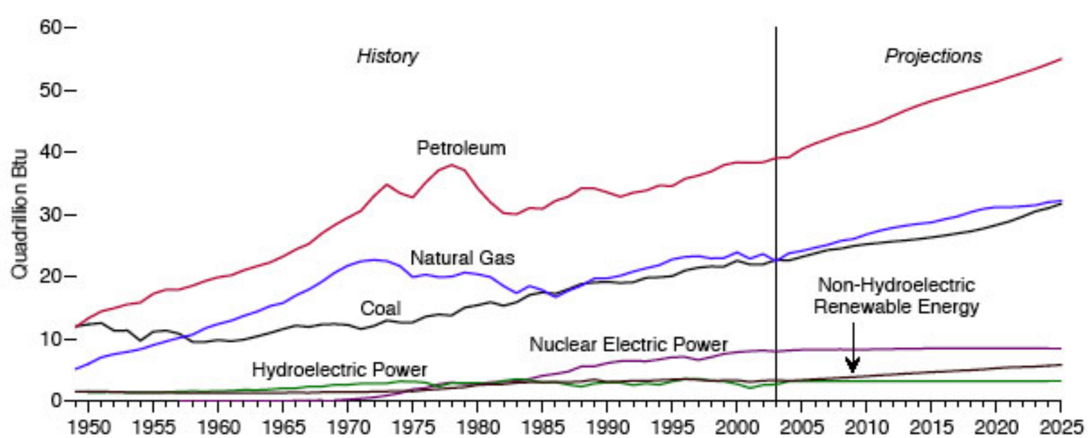


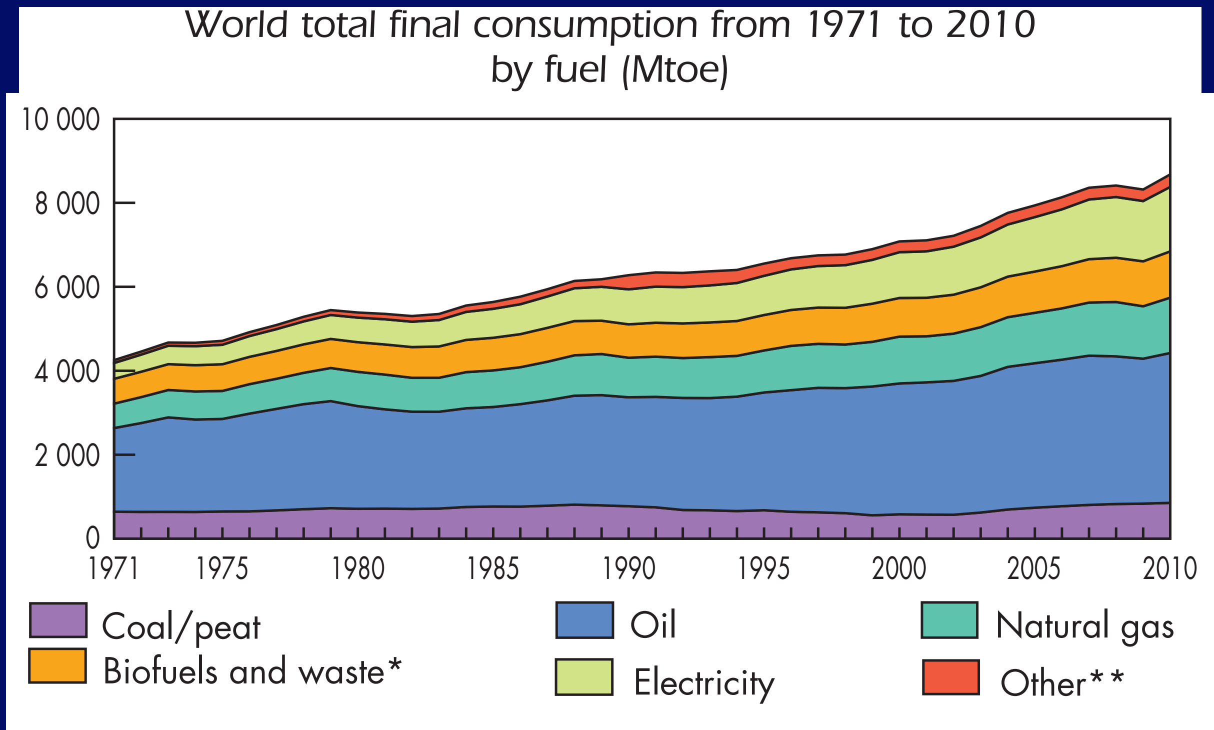
Figure 6. Energy Consumption History and Outlook, 1949-2025



In the long view of American history, wood served as the preeminent form of energy for about half of the Nation's history. Around 1885, coal surpassed wood's usage. Despite its tremendous and rapid expansion, coal was, in turn, overtaken by petroleum in the middle of the 20th century. Natural gas, too, experienced rapid development into the second half of the 20th century, and coal began to expand again. Late in the 20th century still another form of energy, nuclear electric power, was developed and made significant contributions.

While the Nation's energy history is one of large-scale change as new forms of energy were developed, the outlook for the next couple of decades (assuming current laws, regulations, and policies) is for continued growth and reliance on the three major fossil fuels—petroleum, natural gas, and coal—modest expansion in renewable resources, and relatively flat generation from nuclear electric power.

Total Energy Usage

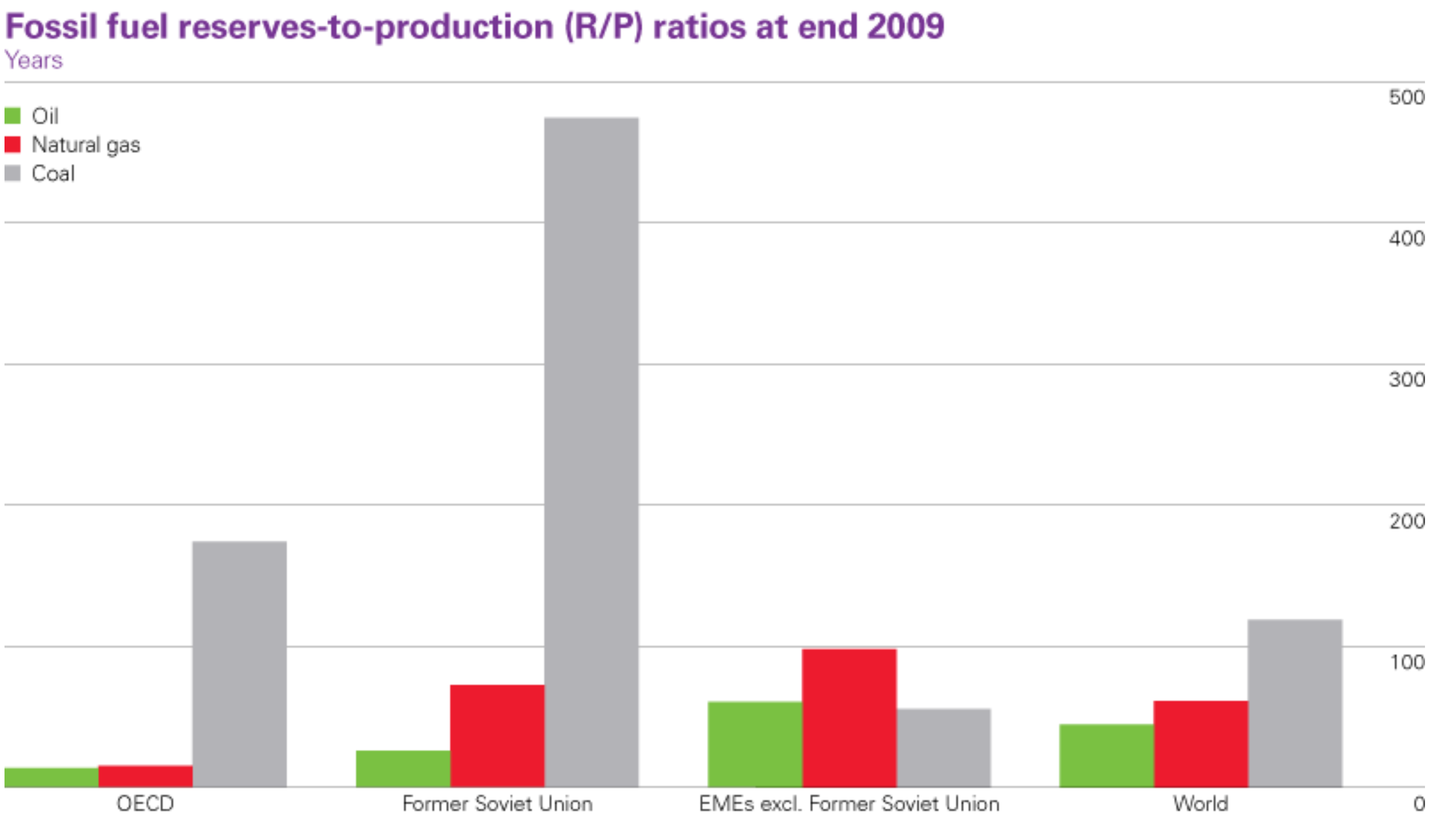


International Energy Agency

1 Mtoe = energy from burning 1 Million metric tonnes of oil

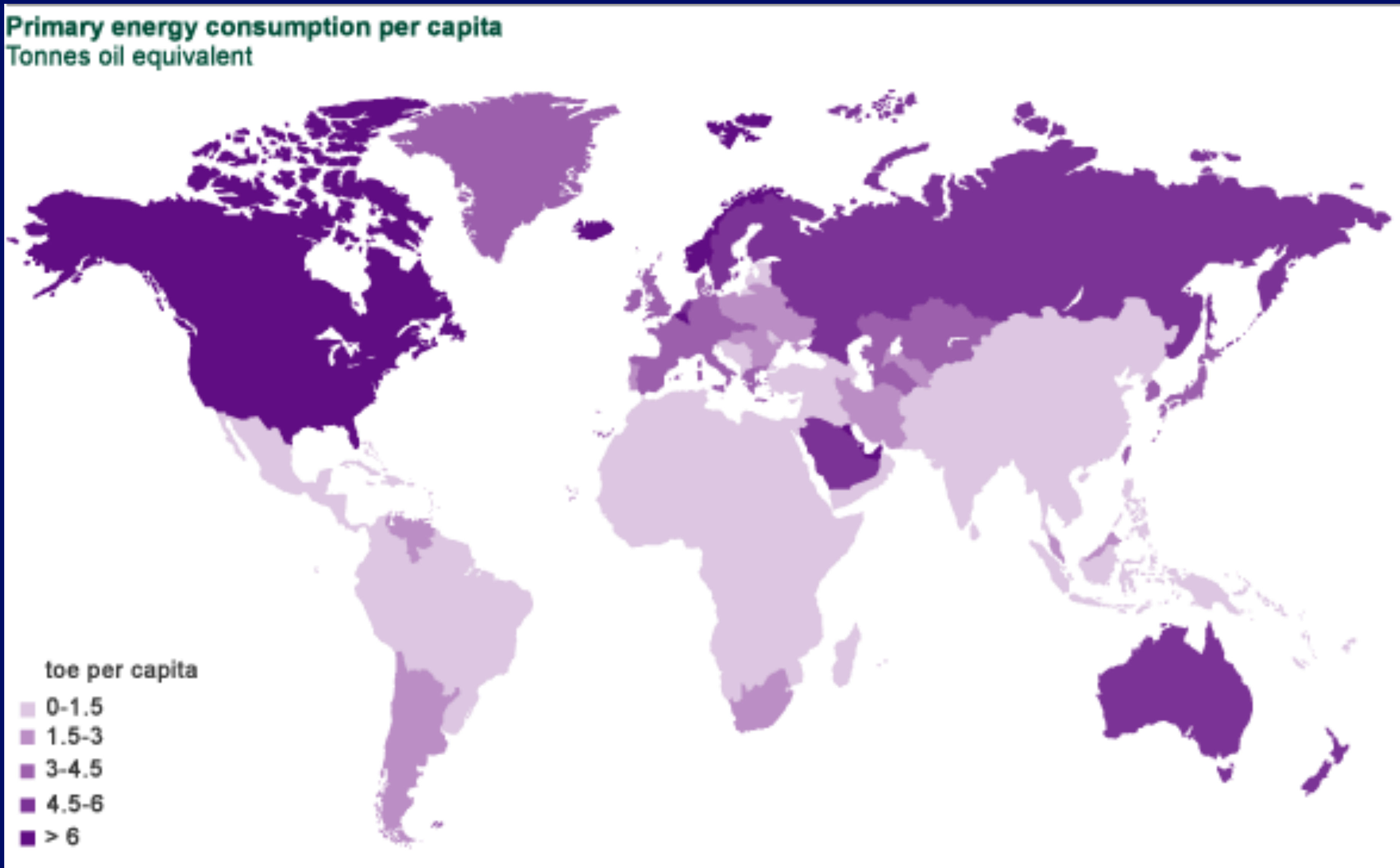
1 toe = 42×10^9 Joules

Fossil fuel reserves-to-production (R/P) ratios



While coal remains the world's most abundant fossil fuel, with an R/P ratio of 119 years, proved reserves of oil and natural gas increased in 2009 and have tended to rise over time. OECD countries account for less than 10% of global proved reserves for oil and natural gas, but 42.6% of proved coal reserves.

Energy Consumption per capita



International Energy Agency

Side Effects

- General Pollution of Air, Water, Land

  Makes resources less usable

  Air pollution, respiratory problems

  Undrinkable water

  Desertification of farm-lands

- Ozone Layer Destruction

  $\Rightarrow$ UV reaches surface

  Skin Cancer, Cataracts, …

  Crop Damage

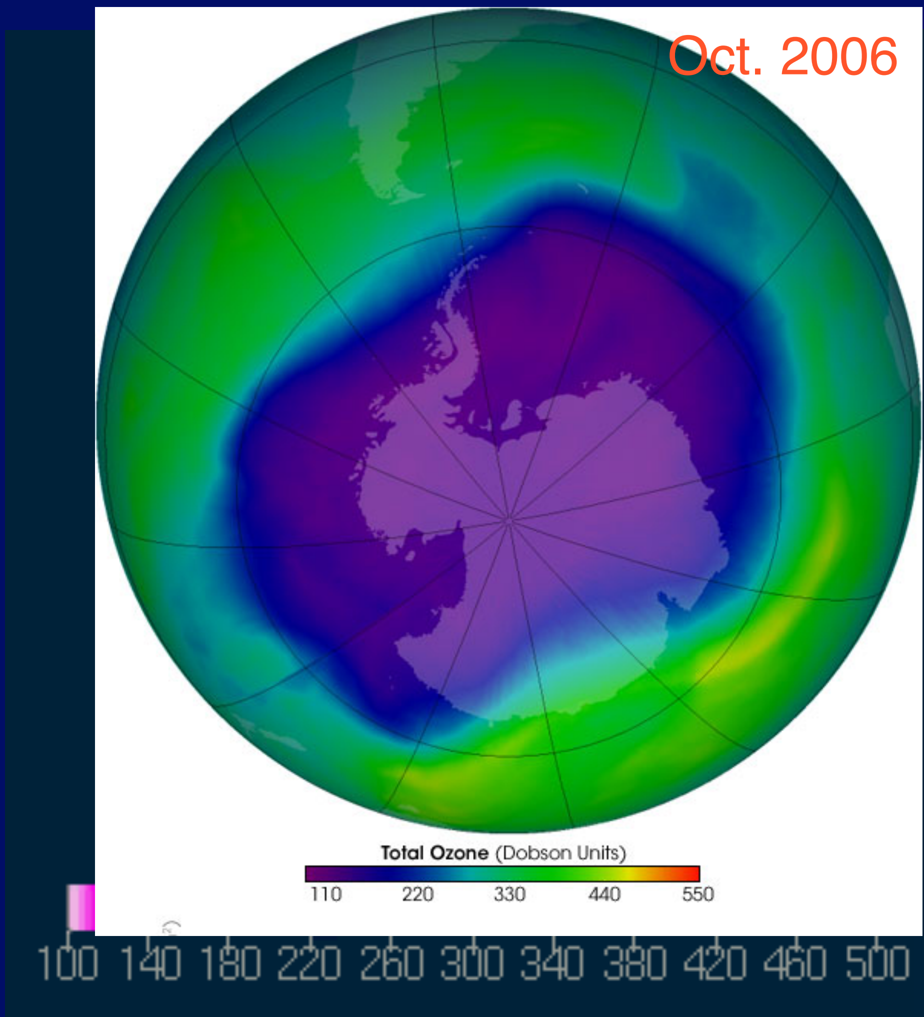
Caused by CFC’s (refrigeration, styrofoam,…)
other chemicals

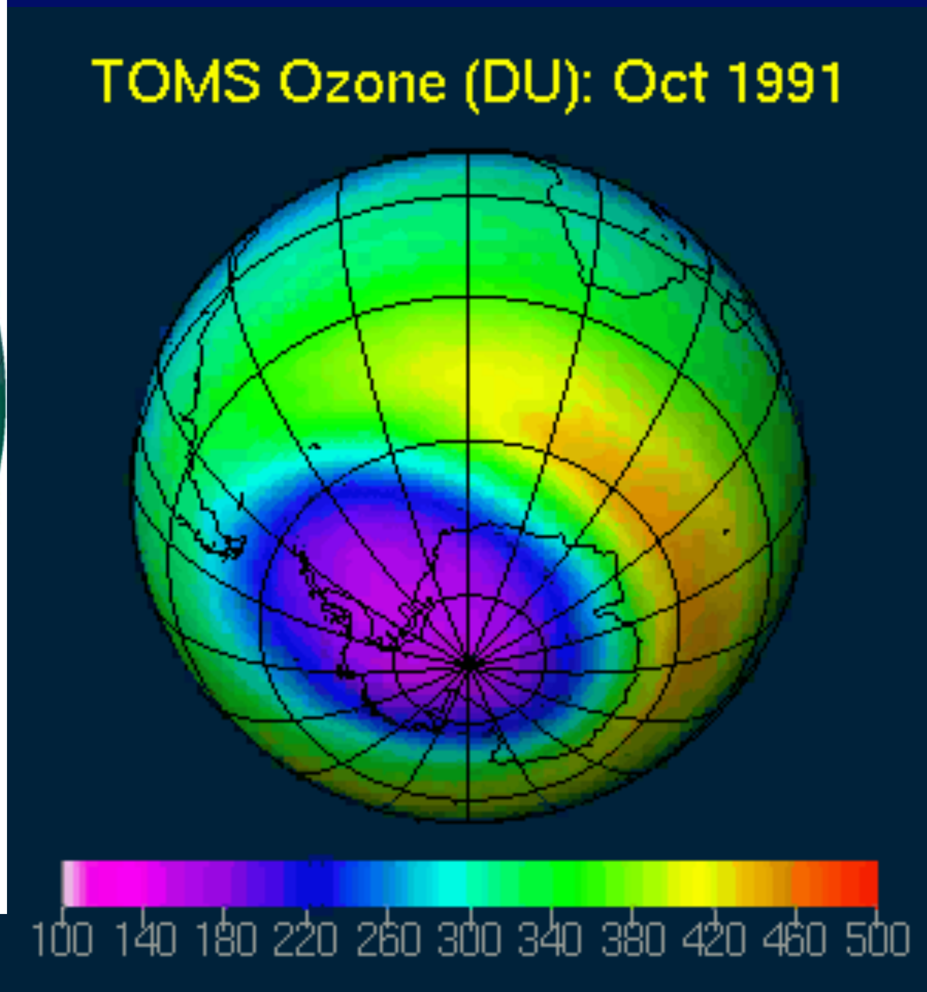
Stratosphere is very sensitive and poorly understood

Catalytic reactions: One CFC molecule leads to the destruction of **many** ozone molecules

$O_3 \longrightarrow O_2$

Growth of ozone hole





Side Effects (cont.)

- Fossil fuels → CO_2 → Greenhouse
  (any chemical fuel)

↓

Global warming

warmer water

Rise in Sea level ← Melting land ice (50 - 100 yrs)

Climate changes: (40 - 100 yrs)

Increased desertification

Crop yields?

Runaway greenhouse?

(Could Earth become like Venus?)

Not likely to go this far

Global Mean Sea Level

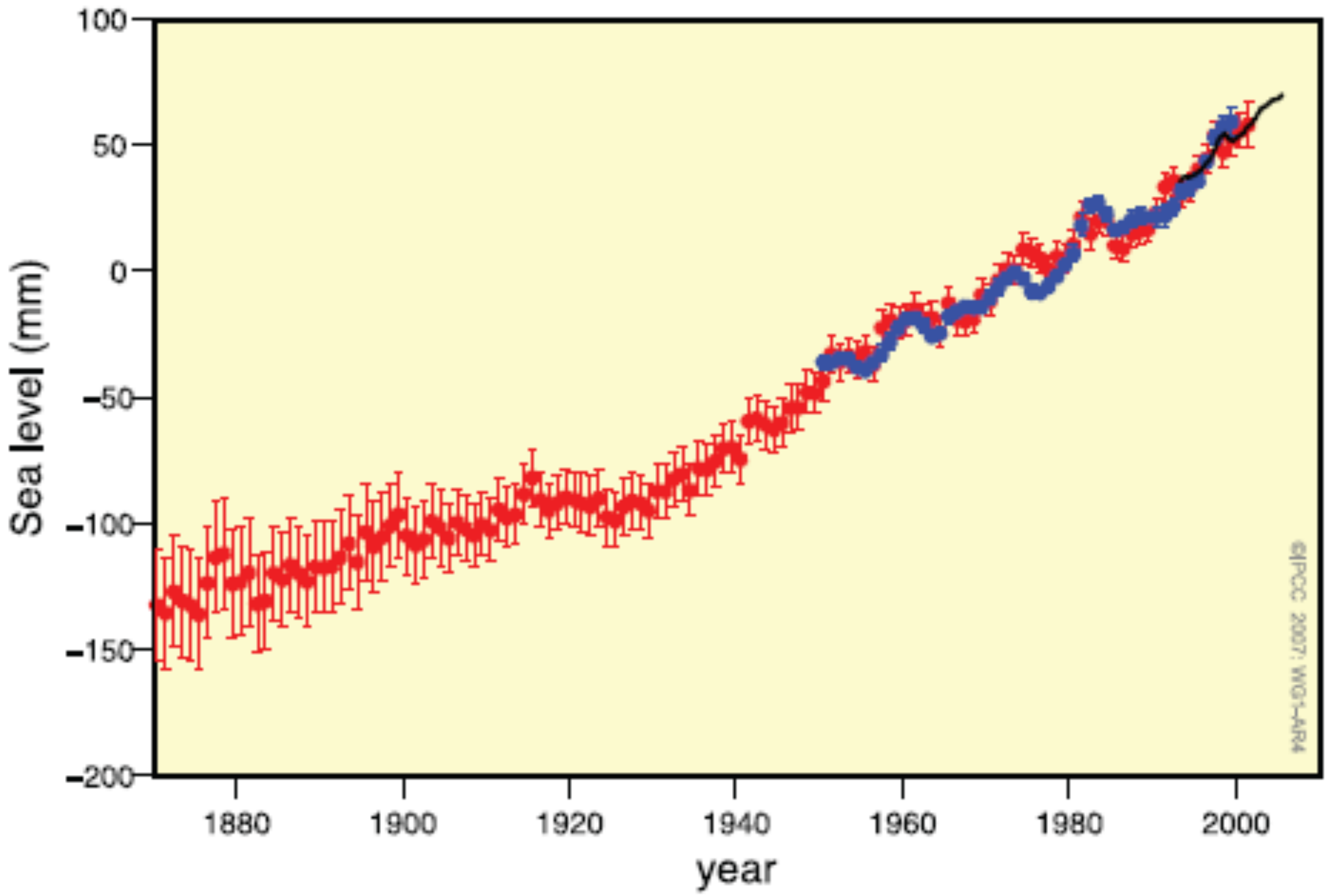
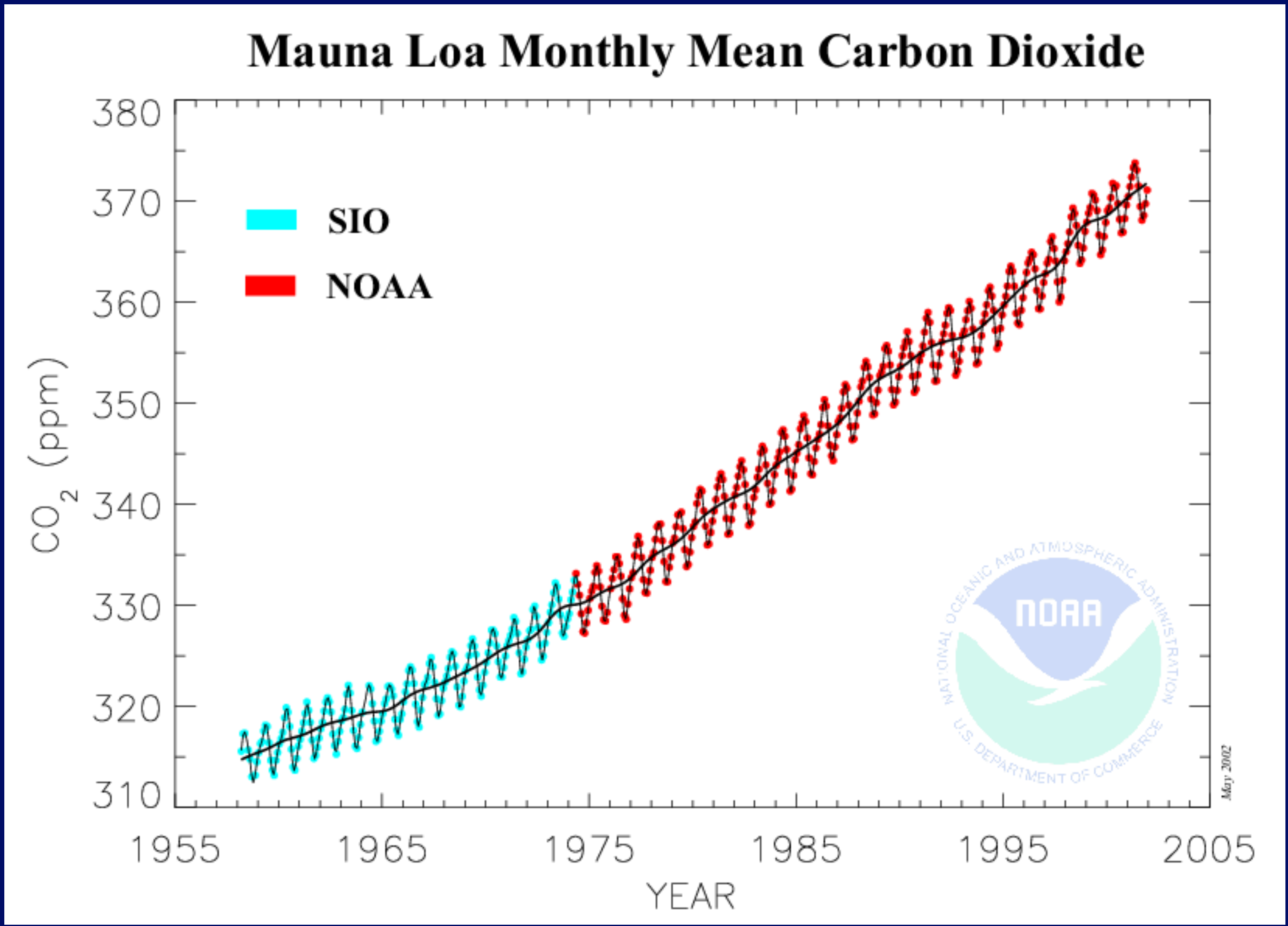
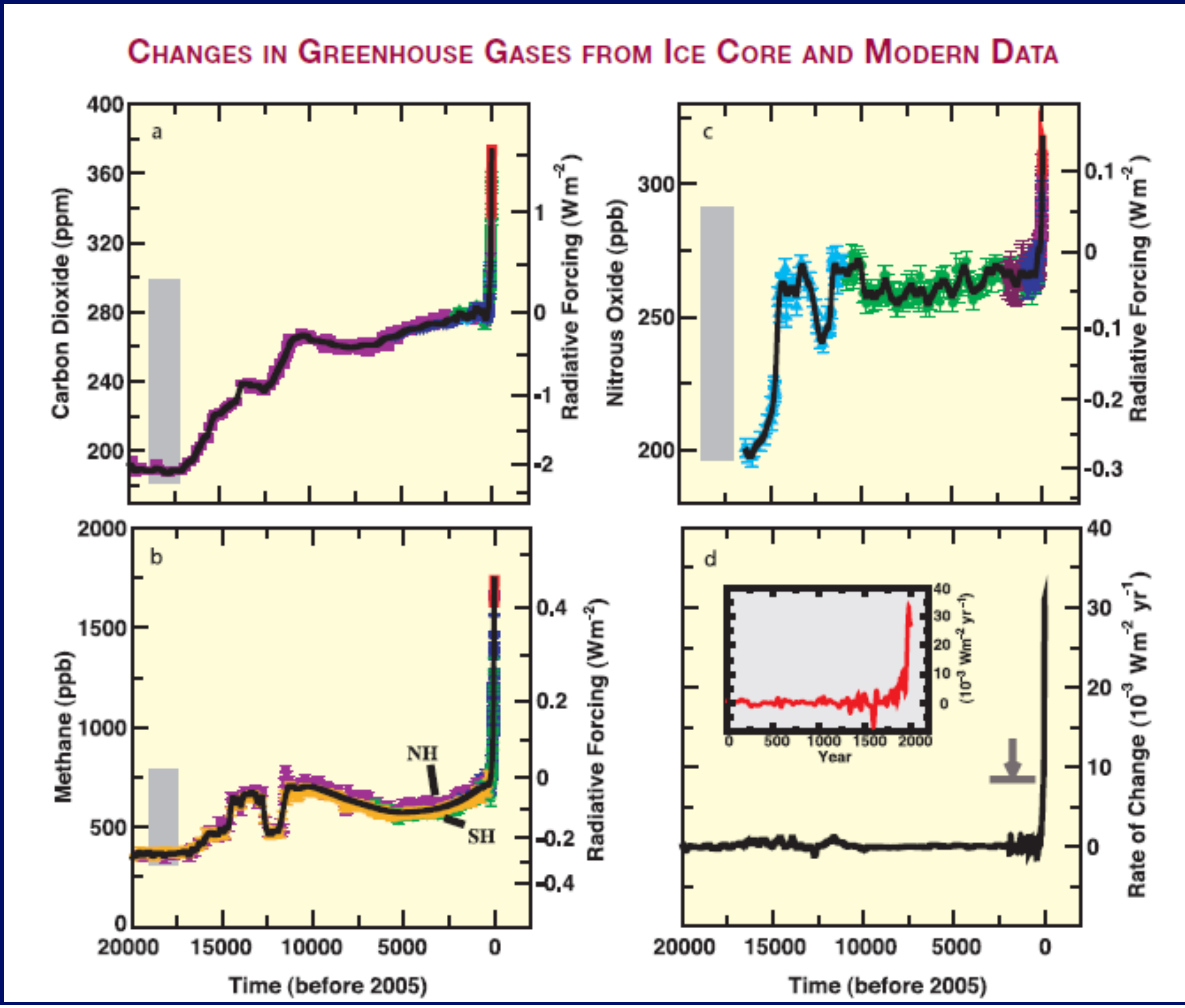


Figure TS.18. *Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals. {Figure 5.13}*

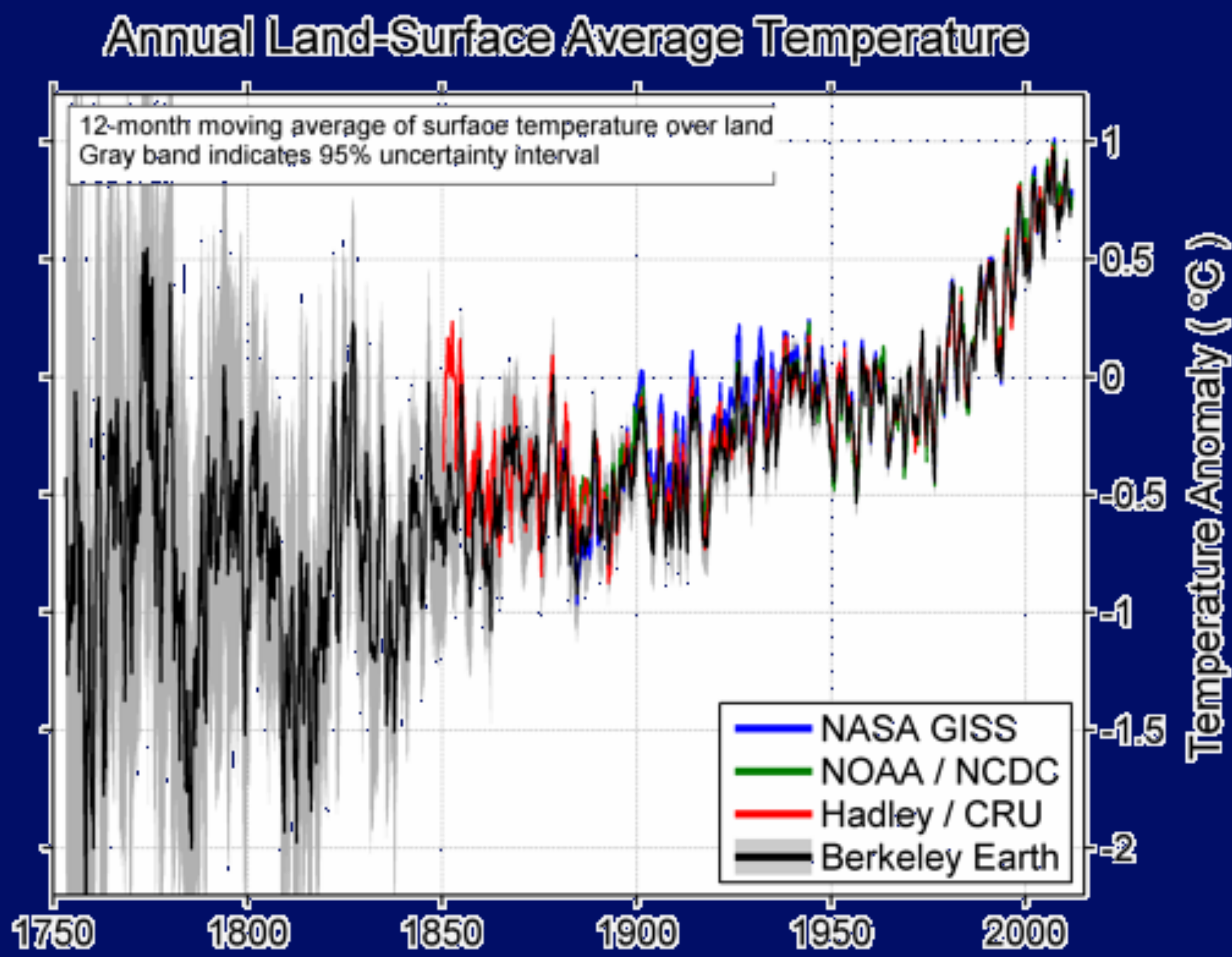
Carbon Dioxide Increase



Over a Longer Period



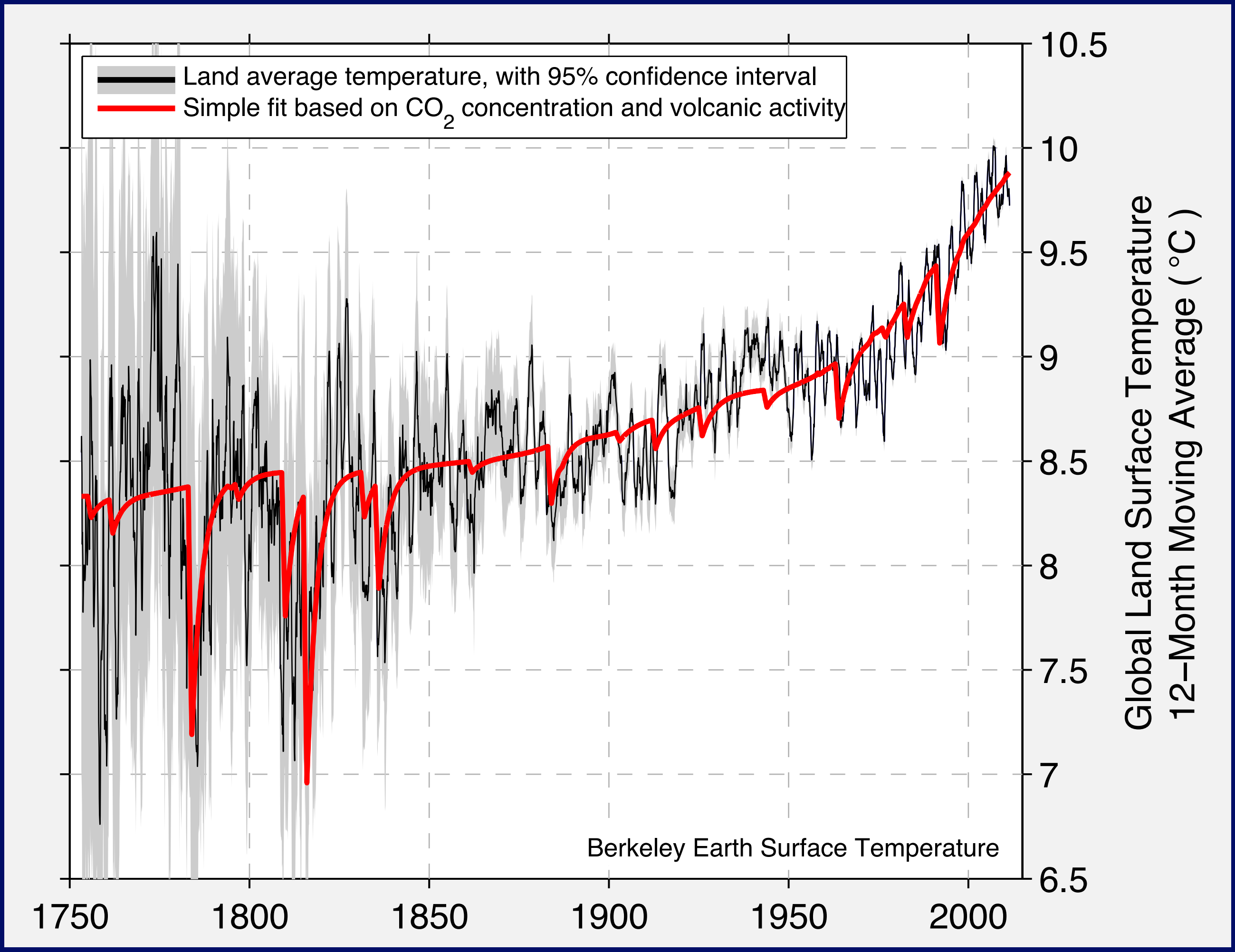
The Temperature is Warming



berkeleyearth.org

From R. Muller, a climate change skeptic until 2012

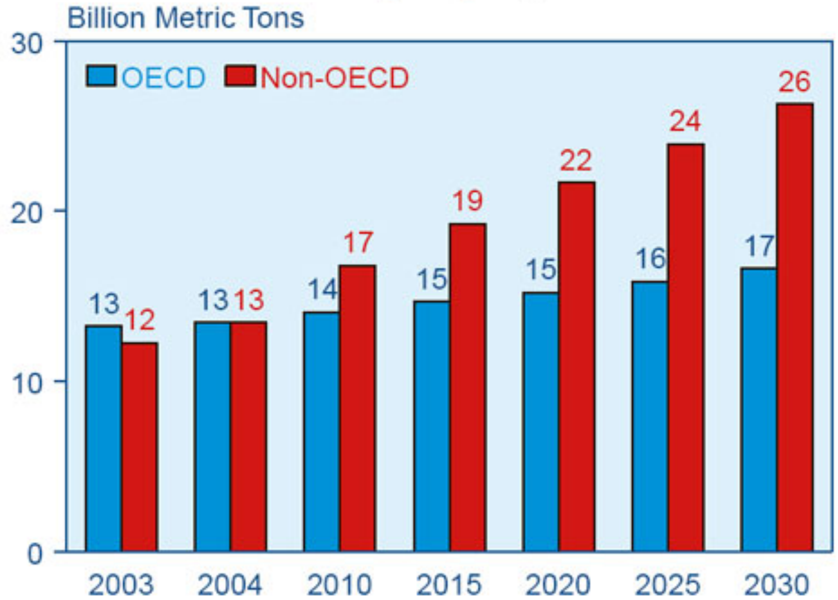
Increased CO_2 and Volcanoes Explain the Data



Muller found no effects from changing solar output.

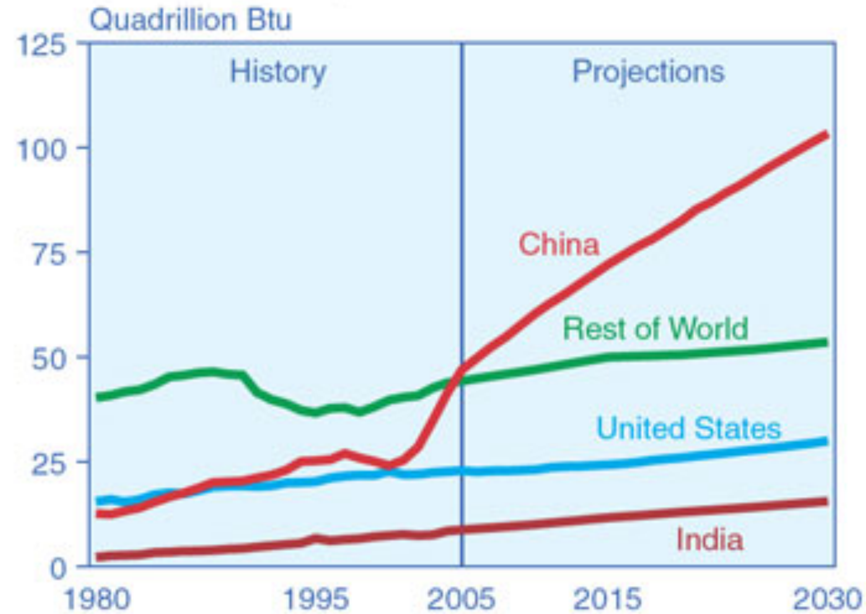
Production of CO_2

Figure 77. World Energy-Related Carbon Dioxide Emissions by Region, 2003-2030



Sources: **2003 and 2004:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Figure 13. Coal Consumption in Selected World Regions, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2008).

OECD: Europe, US, Canada, Australia, Japan, Mexico

Not Russia, India, China

Population Explosion

(The revenge of Malthus?)

Agriculture - Population Growth - Disease

Population Growth leads to more rapid depletion of resources

More pollution

More conflict?

Two “events” (transitions)

10,000 yrs ago	Agriculture
250 yrs ago	Disease lessened (demographic transition)

Time	Total Pop.	Growth Rate (per thousand per year)
Before Agriculture	$\sim 8 \times 10^6$ (??)	0.015
~ 8000 BCE - 1 CE	$\sim 3 \times 10^8$	0.36
1 CE - 1750 CE	$\sim 8 \times 10^8$	0.56
1750-1800	$\sim 1 \times 10^9$	4.4
⋮		
1950 - 1975	4×10^9	17.1
2000	6×10^9	~ 18
2012	7×10^9	

Population Mathematics

Rate of increase $\propto$ Number $\times$ (Birth - Death)

leads to exponential growth if (Birth - Death) constant

$\text{Pop}(t) = \text{Pop}(\text{Now})\ 2^{(t/t_d)}$

t_d = doubling time $\underline{\sim}$ 65 years currently

So doubles in 65 yrs

Quadruples (2^2) in 130 yrs, …

1170 yr (18 t_d) Pop = 1.8×10^{15}

~ fills land area

2990 yr (46 t_d) Mass > $M_{(earth)}$!

14,625 yr (225 t_d) Mass expands at c !!

Current population growth is <u>NOT</u> sustainable

World Vital Events Per Time Unit: 2009

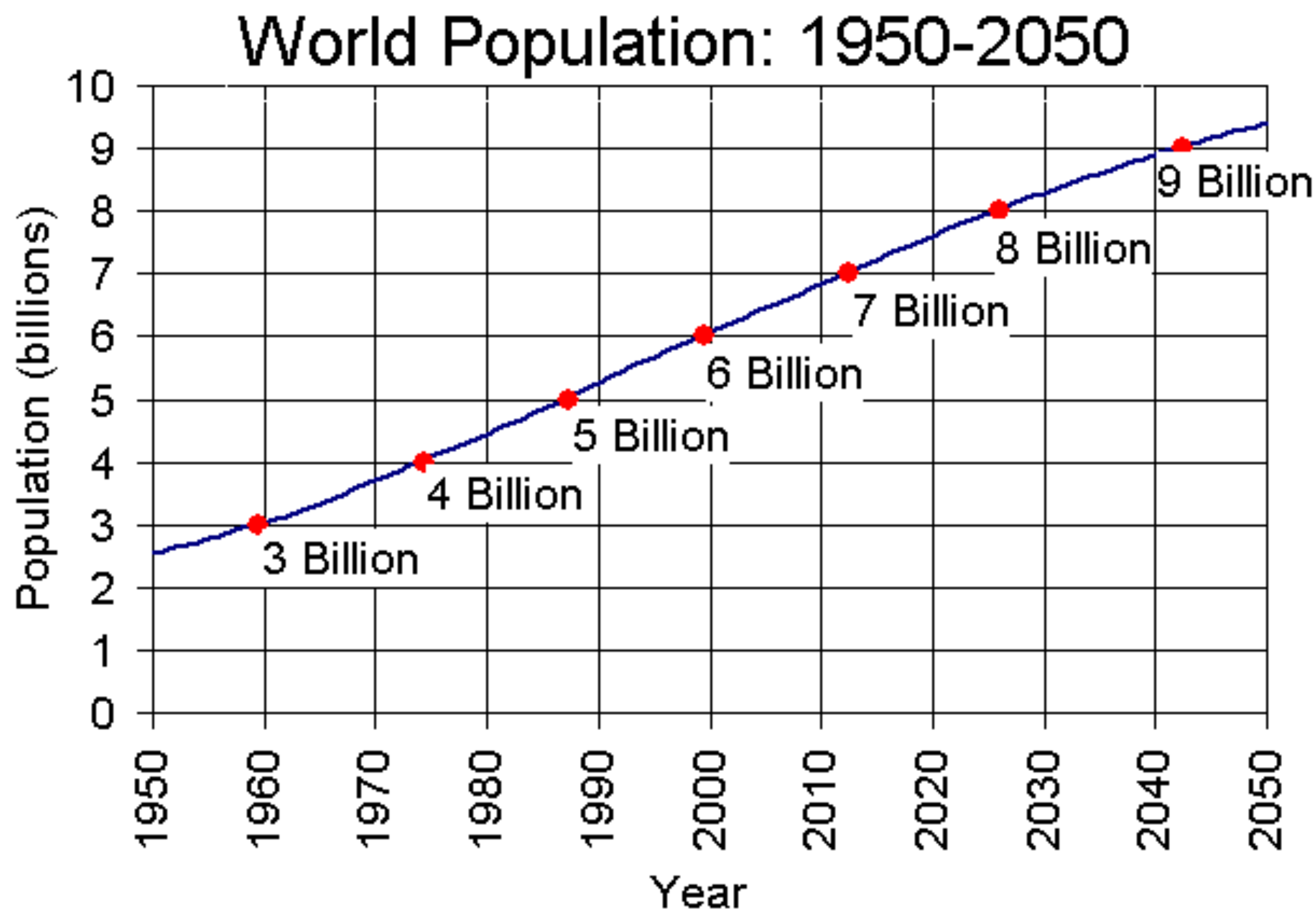
World Vital Events Per Time Unit: 2009

- (Figures may not add to totals due to rounding)
- --

Time unit	Births	Deaths	Natural increase
Year	135,474,672	55,664,164	79,810,508
Month	11,289,556	4,638,680	6,650,876
Day	371,163	152,505	218,659
Hour	15,465	6,354	9,111
Minute	258	106	152
Second	4.3	1.8	2.5

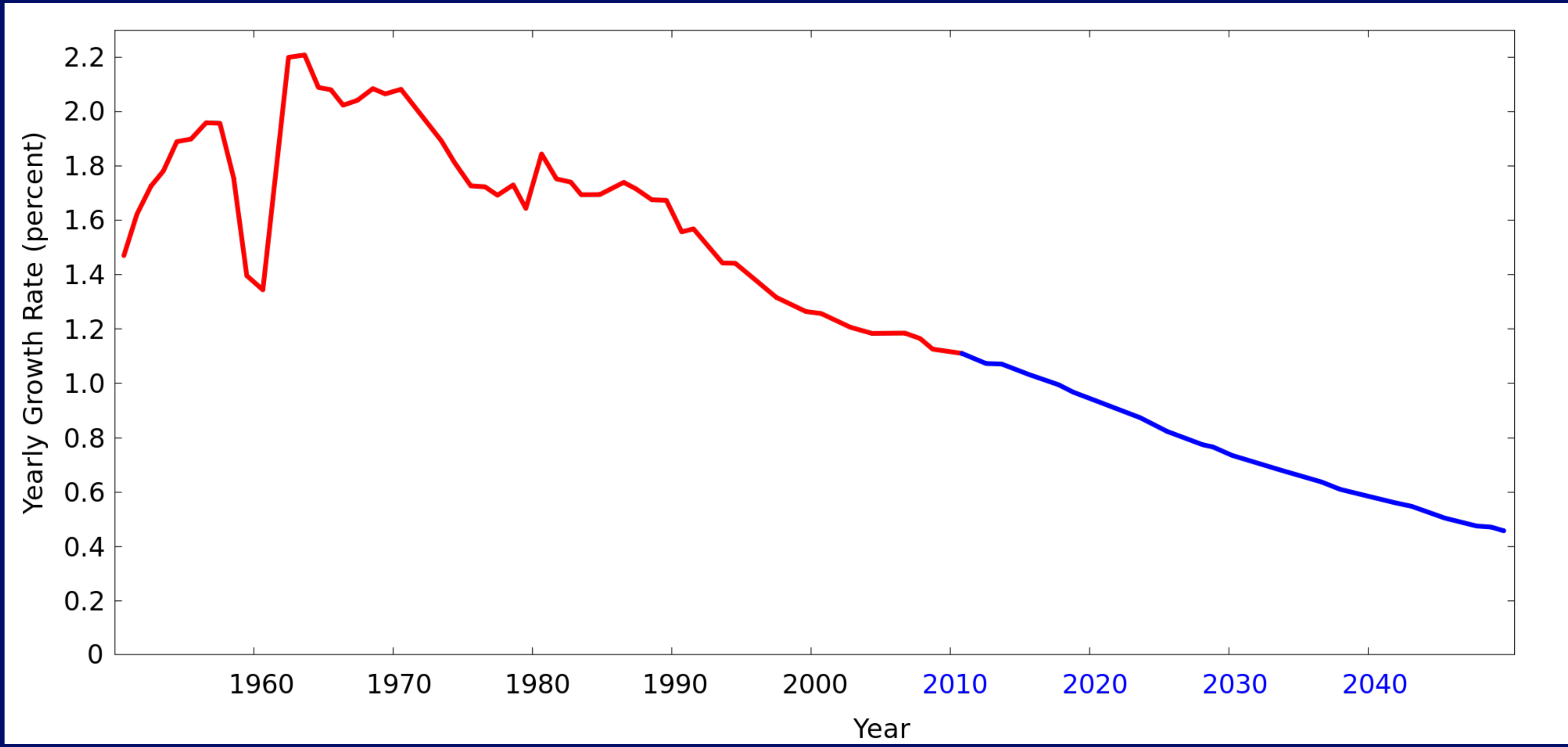
http://www.census.gov/main/www/popclock.html

Projected World Population Growth

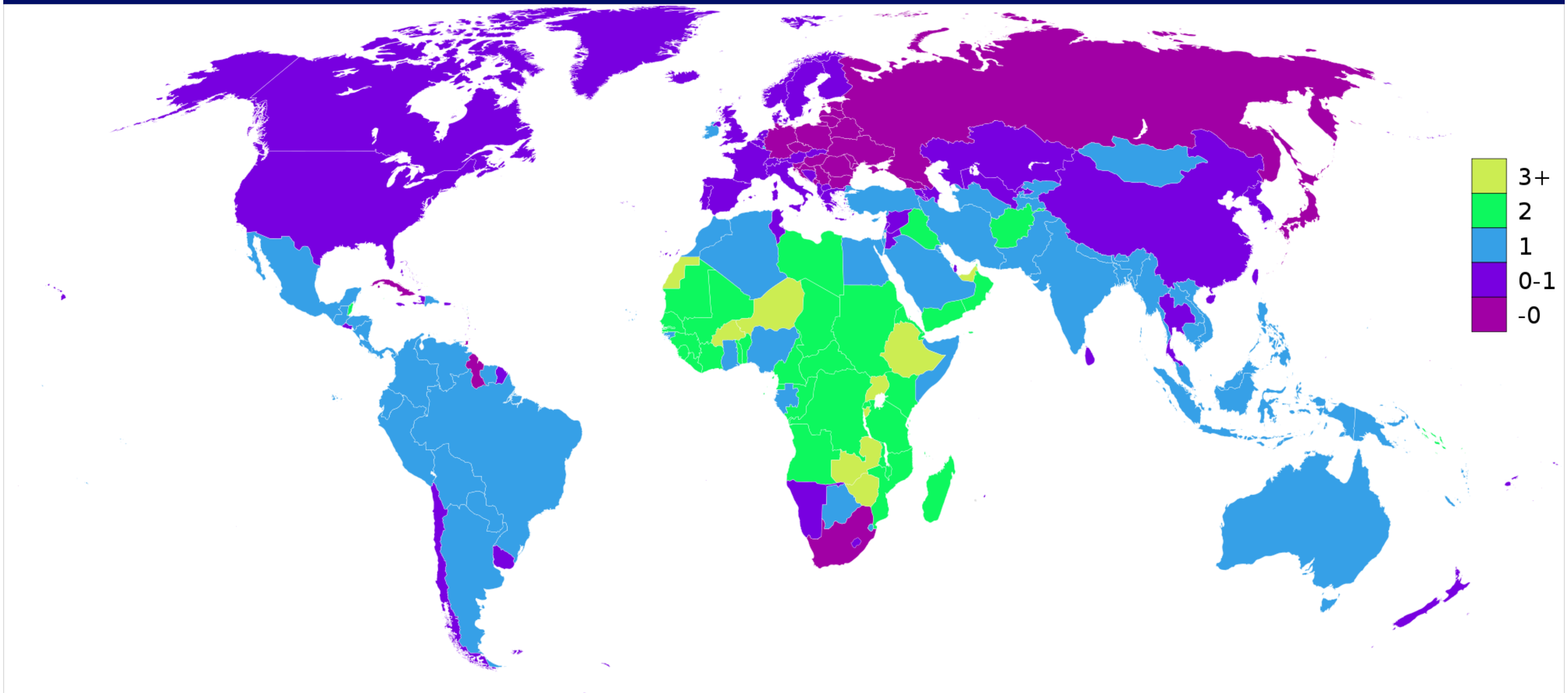


Source: U.S. Census Bureau, International Data Base, August 2006 version.

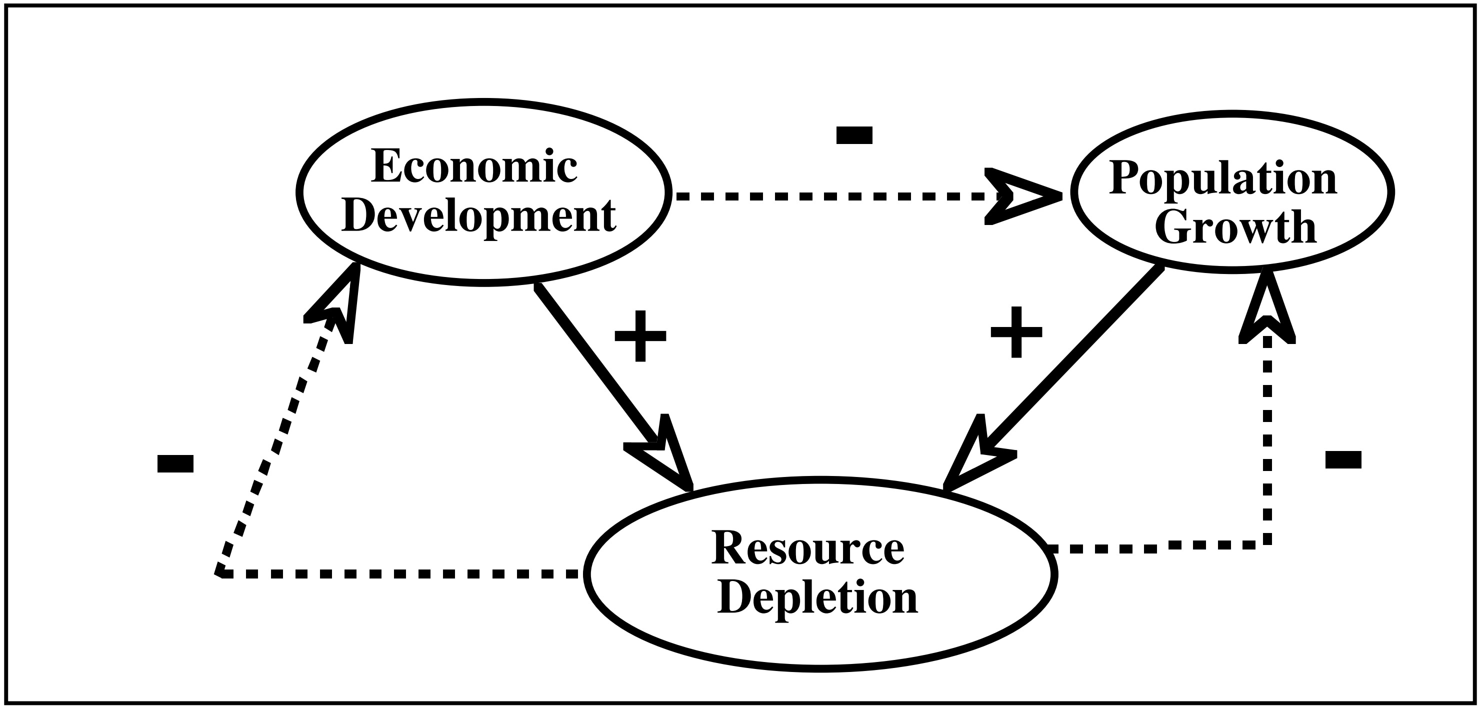
Changes in Population



Distribution of Growth Rate (in %)



CIA World Factbook



Does negative effect on population growth
Beat positive effect on resource depletion?

Can we get to sustainable economy before
We exhaust resources?

The Example of China

- From 1990 to 2004, 400 million Chinese citizens escaped poverty (~1/3 of population)
- Population grew by about 120 million
- Growth rate about 1% per year
- Rate projected to decrease to 0.2% by 2025
- Population will be about 1.5 billion

Nuclear War

Total arsenal world-wide

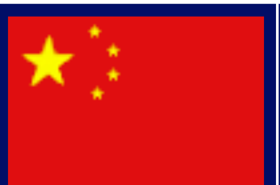
Peaked at ~ 10,000 megatons

One ton is energy equivalent to “ton of TNT”

Global effects of all-out war

- Depletion of ozone
- Radioactive fallout
- Dust and smoke in atmosphere would block sunlight and lead to cooling of the Earth “Nuclear Winter”

The World's Nuclear Arsenals

	Country	Suspected Strategic Nuclear Weapons	Suspected Non-Strategic Nuclear Weapons	Suspected Total Nuclear Weapons
	China	250	120	400
	France	350	0	350
	India	60	?	60+
	Israel	100-200	?	200+
	Pakistan	24-48	?	24-48

The World's Nuclear Arsenals (~2002)

(2013 update)

	Country	Suspected Strategic Nuclear Weapons	Suspected Non-Strategic Nuclear Weapons	Suspected Total Nuclear Weapons
	Russia	~ 1499	~ 3022	~ 4500
	United Kingdom	160	65	225
	United States	1722	3391	5113

Nuclear Warheads being Deactivated

- US-Russia Agreement to deactivate warheads (START Agreement 1994)
  - Agreed to reduce to 6000 warheads each
  - Expired Dec 2009
- Moscow Agreement (2002)
  - Decrease to 1700 – 2200 by 2012
- New Start
  - signed April 2010, into effect Feb. 2011
  - Reduces deployed nuclear weapons to 1550 per side

Natural Catastrophes

Collisions

Stars? Negligible Chance

Molecular Clouds? $t \sim 10^8$ yr

Likely, but the effects are unclear

Less dense clouds? More common but effects are probably less

Asteroids and other debris

(comets, meteoroids, …)

Effect of Meteorite/Asteroid Impact

- $E_{kin} = ½ M v^2$
- Two examples: 2013 Meteorite and larger one

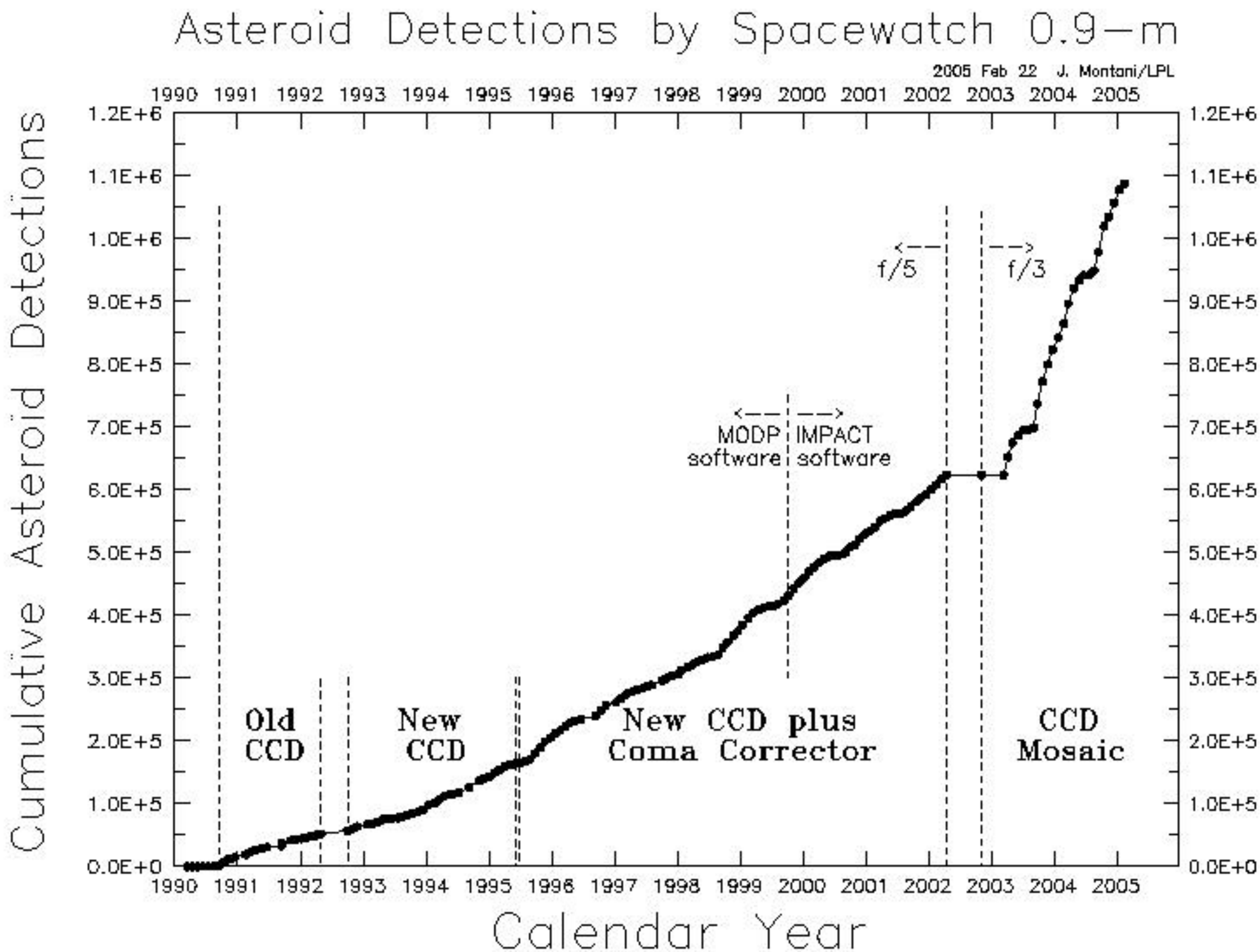
	2013 Siberian	Larger one
Size	~20 m	¼ km
Speed	18 km/s	30 km/s
E_{kin} (TNT equiv)	400 kilotons	7200 Megatons

- Hiroshima bomb was 13-18 kilotons
- 7200 Megatons would be like all-out nuclear war at height of cold war

How Often?

- Depends on size (many small, few large)
  - 2013 Siberian t ~ 100 yr
  - 1908 Siberian t ~ 1000 yr
  - (1 km or larger) t ~ 10^5 yr - 10^6 yr
  - Major Extinctions t ~ 30 × 10^6 yr
  - Mass Extinctions t ~ 100 × 10^6 yr ?
- These are statistical: no guarantees…

Spacewatch Detections

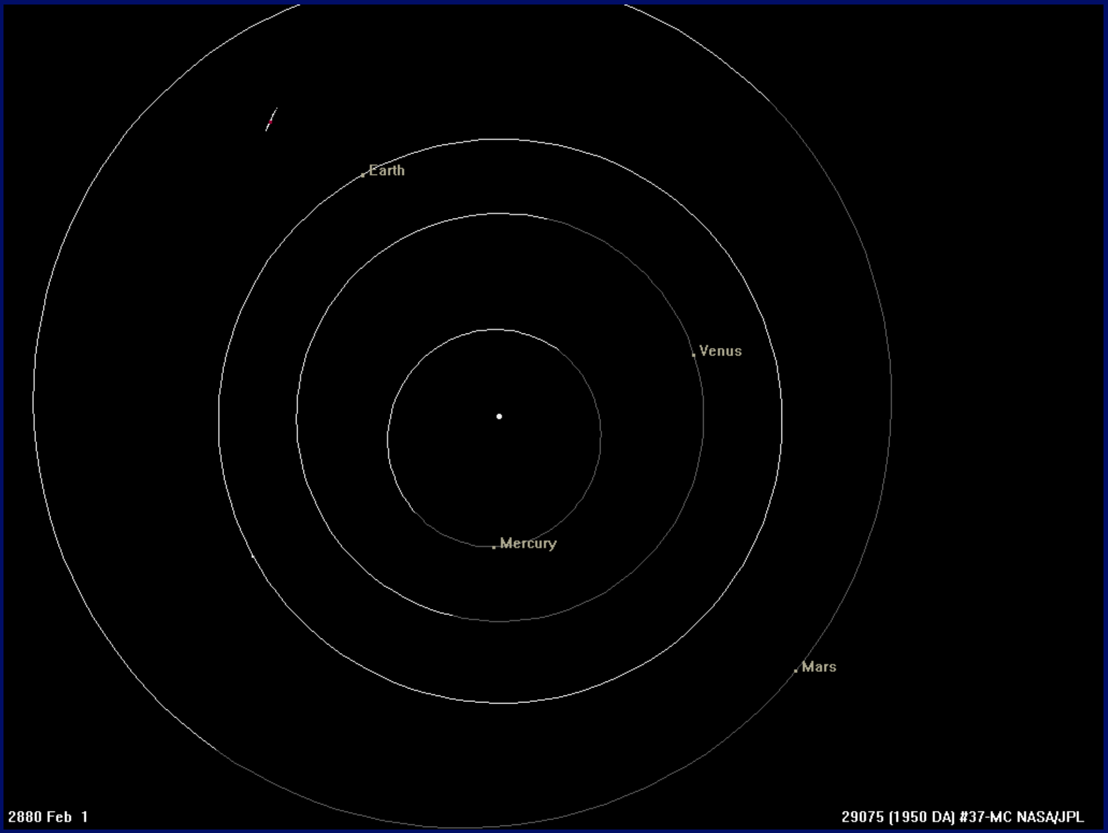


Most Dangerous Known Asteroid

1950 DA

Radar used to map orbit
~ 1 km in diameter

Close approach in Yr 2880



Probability of collision ~ 0.33%

V ~ 14 km s^{-1} E ~ 10^5 Megatons

Exact orbit depends on small effects - tugs from Earth, Mars, light absorption + radiation, …

Another "Interesting" Asteroid

- Apophis (2004 MN4)
- d = 0.25 km, would release 400 Megatons
- 1/45000 chance of collision in 2036
- http://neo.jpl.nasa.gov/risk/
- Has data base of Near Earth Objects

Solar variations

~ 10^5 yr

1. Short term - cyclic variations in L, orbit
   of Earth --------> ice ages, climate change

~ 1-2 $\times 10^9$ yr

2. Sun increases in L
   on main sequence --------> loss of oceans

$UV + H_2O = 2H + O$ H lost to space

~ 5 $\times 10^9$ yr

3. Off main sequence leads to Red Giant
   atmosphere evaporates

Could advanced civilization delay loss of oceans?

(Decrease greenhouse, add dust)

Move to Mars? Mars will be in HZ by end of Sun's main sequence lifetime.

Red giants lose mass in winds: Earth's orbit moves out to 1.15 AU by 7.6 x 10^9 yr; but HZ is now 50-80 AU!

Sun's atmosphere engulfs Earth and it spirals in.

Other stars?

Nearby star leads to Supernova

If within 30 ℓy, ozone is destroyed $\sim 2 \times 10^9$ yr

Extreme supernova, gamma ray burst

If within ~6000 ly, would affect ozone,

Atmospheric chemistry

Ultimate Limits

If Universe Closed, recollapses

$\sim 10^{12}$ Big Crunch (unlikely)

Very unlikely because evidence now indicates that expansion is accelerating (dark energy)

But, since we don't understand dark energy, it could reverse.

If open, expands forever

About 5 x 10^9 years, Andromeda collides with MW

10^{11} local galaxies collapse into a supergalaxy, if acceleration continues, all other galaxies have disappeared

10^{12} - 10^{14} all stars die

10^{17} planetary systems disrupted

10^{18} - 10^{20} galaxies “evaporate”

10^{32} - 10^{34} protons decay?

10^{100} Black holes evaporate

What to choose for L?

- For number of civilizations now,

  $L \leq 5 \times 10^9$ yrs -

  [age of galaxy – time to evolve]

Important to choose L consistent with what you think is the most likely way civilizations end.

Darkness

I had a dream, which was not all a dream.
The bright sun was extinguish’d, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;

- Lord Byron, 1816