# 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)

# Resource Depletion

Fossil Fuels (Stored Solar Energy)
will eventually run out

~ 500 years for coal 200?

Nuclear Power? Stopgap…

Ultimately Solar Power

Little Attempt to Plan Ahead

# World Energy Usage

World ~500 "Quads" Per year

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

Average power is 17 × $10^{6}$ MW

U.S. uses 26% of this

Energy per capita ~ 6 metric tonnes of oil equivalent

~ 2 × Europe

~ 5 × World avg.

# History of Energy Use in USA

## Consumption by Source

Figure 5. Energy Consumption by Source, 1635-2003

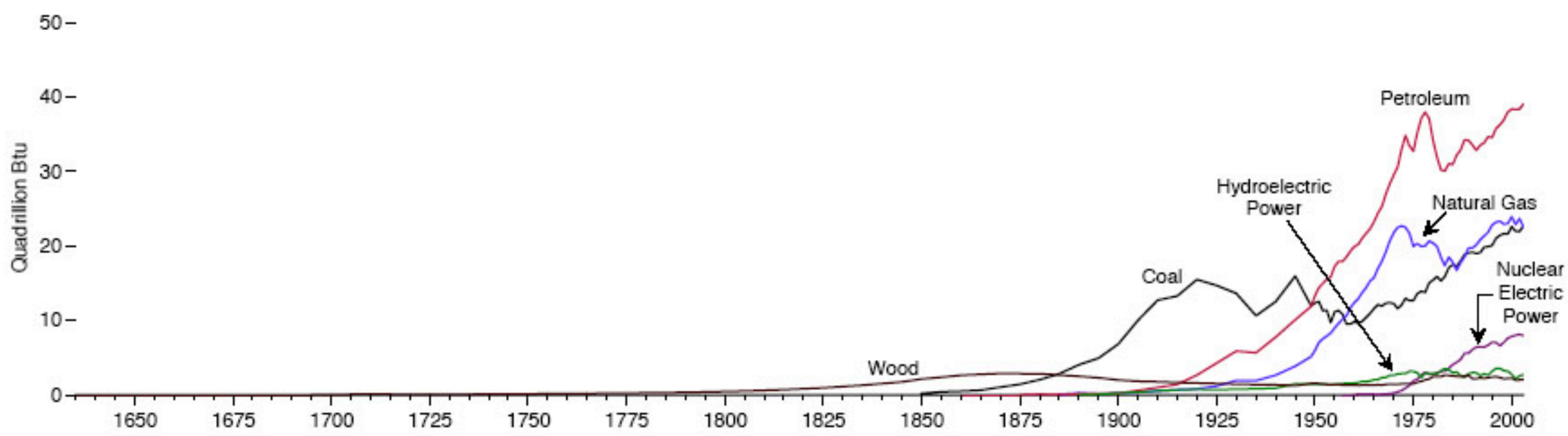
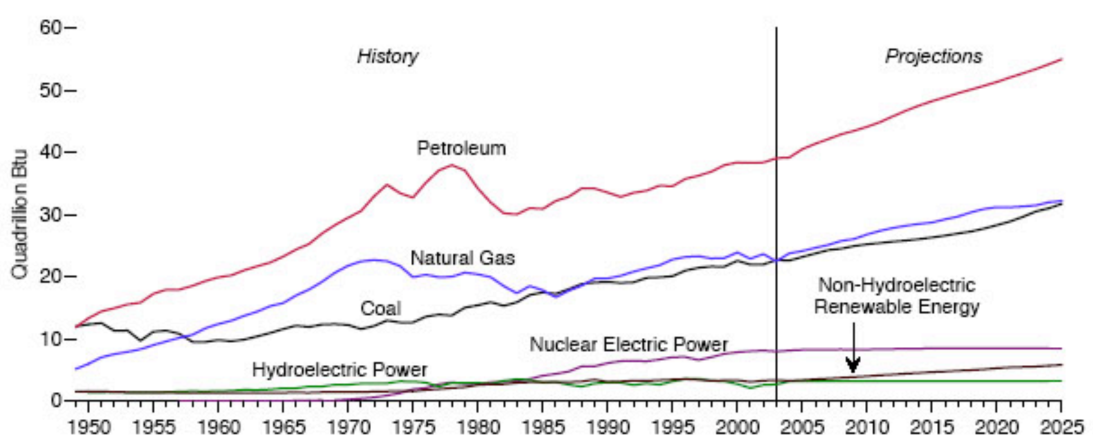


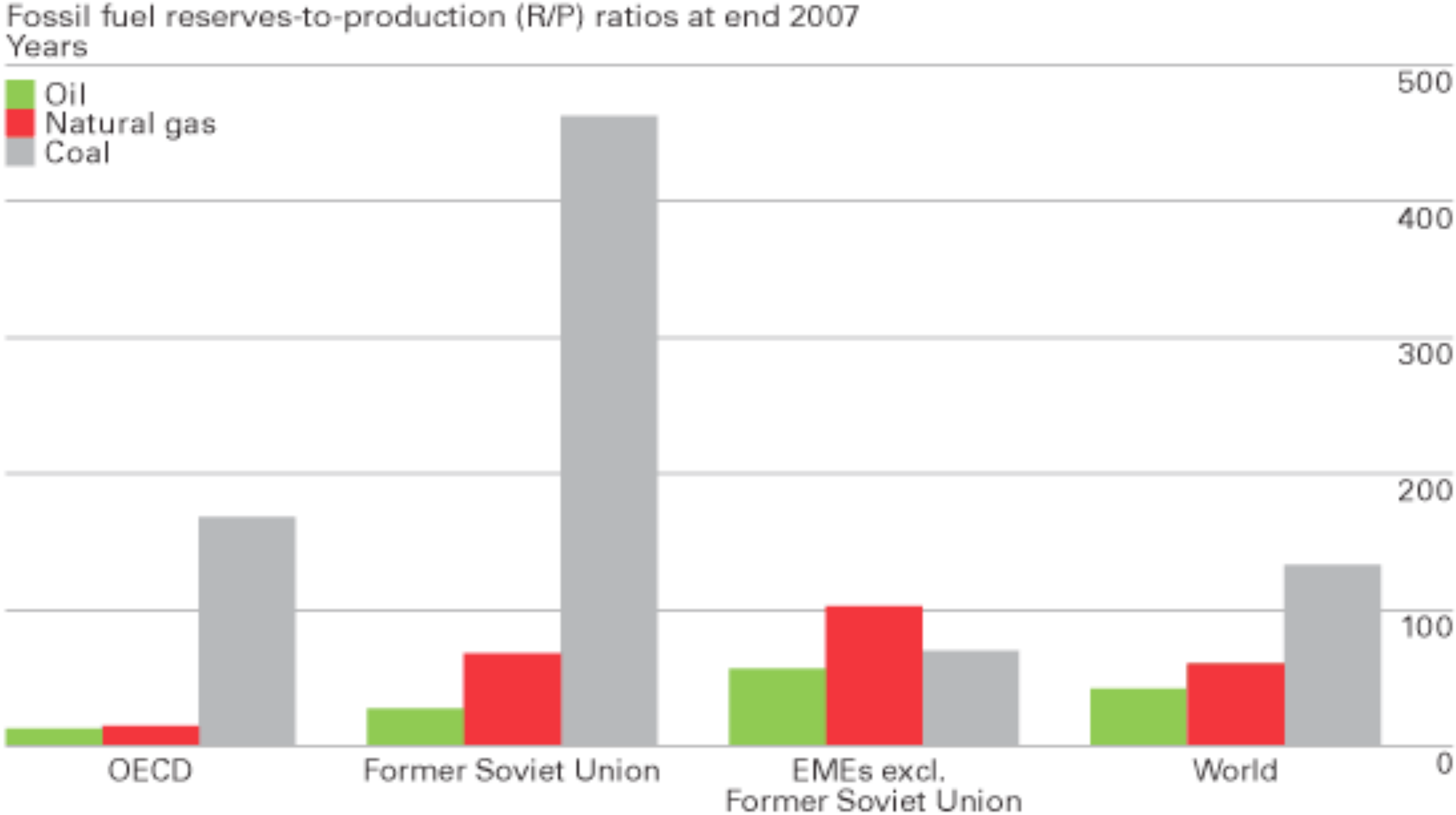

Figure 6. Energy Consumption History and Outlook, 1949-2025




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.

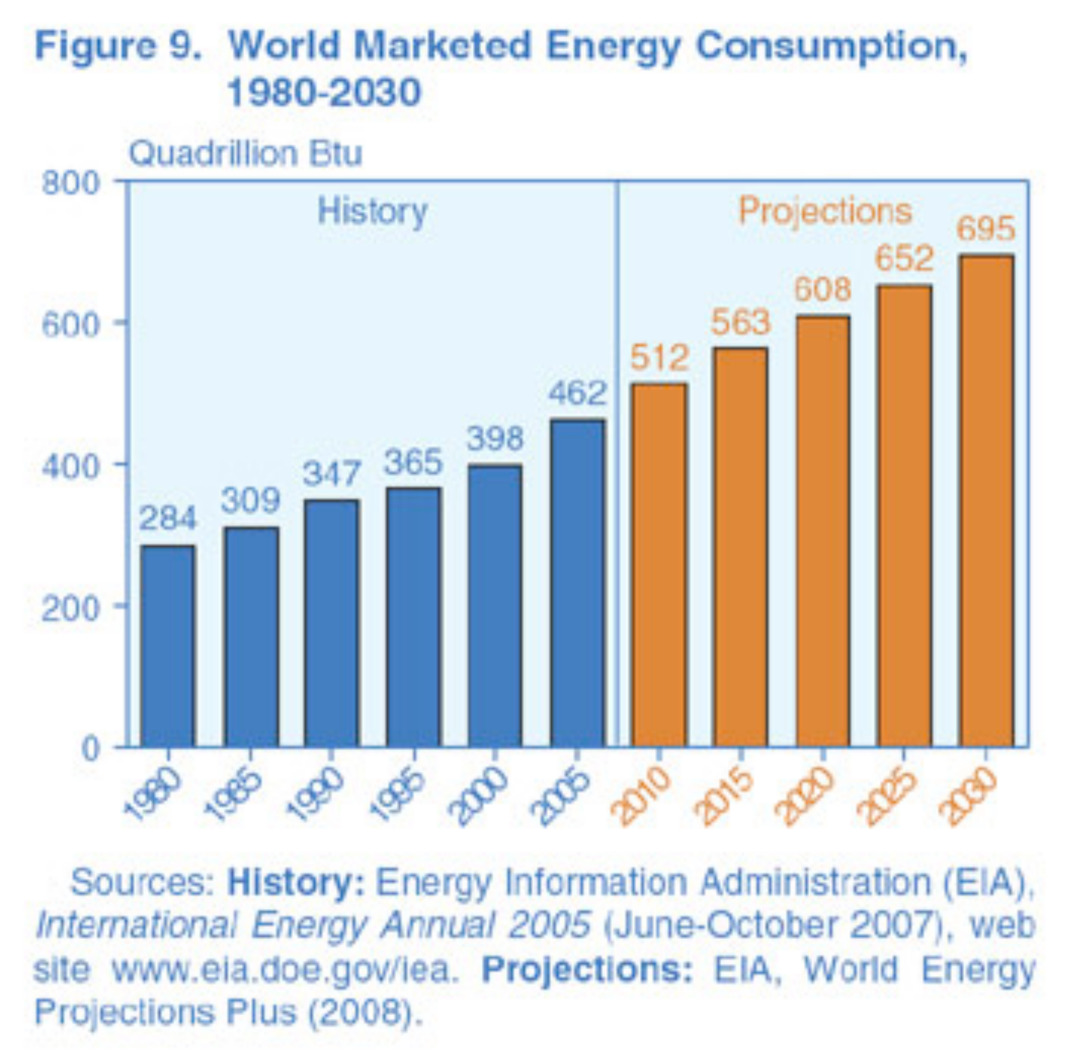
While the Nation's energy history is one of large-scale change as new forms of energy were developed, the outlook for the next couple of decades (assuming current laws, regulations, and policies) is for continued growth and reliance on the three major fossil fuels—petroleum, natural gas, and coal—modest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

# Fossil Fuel R/P ratios

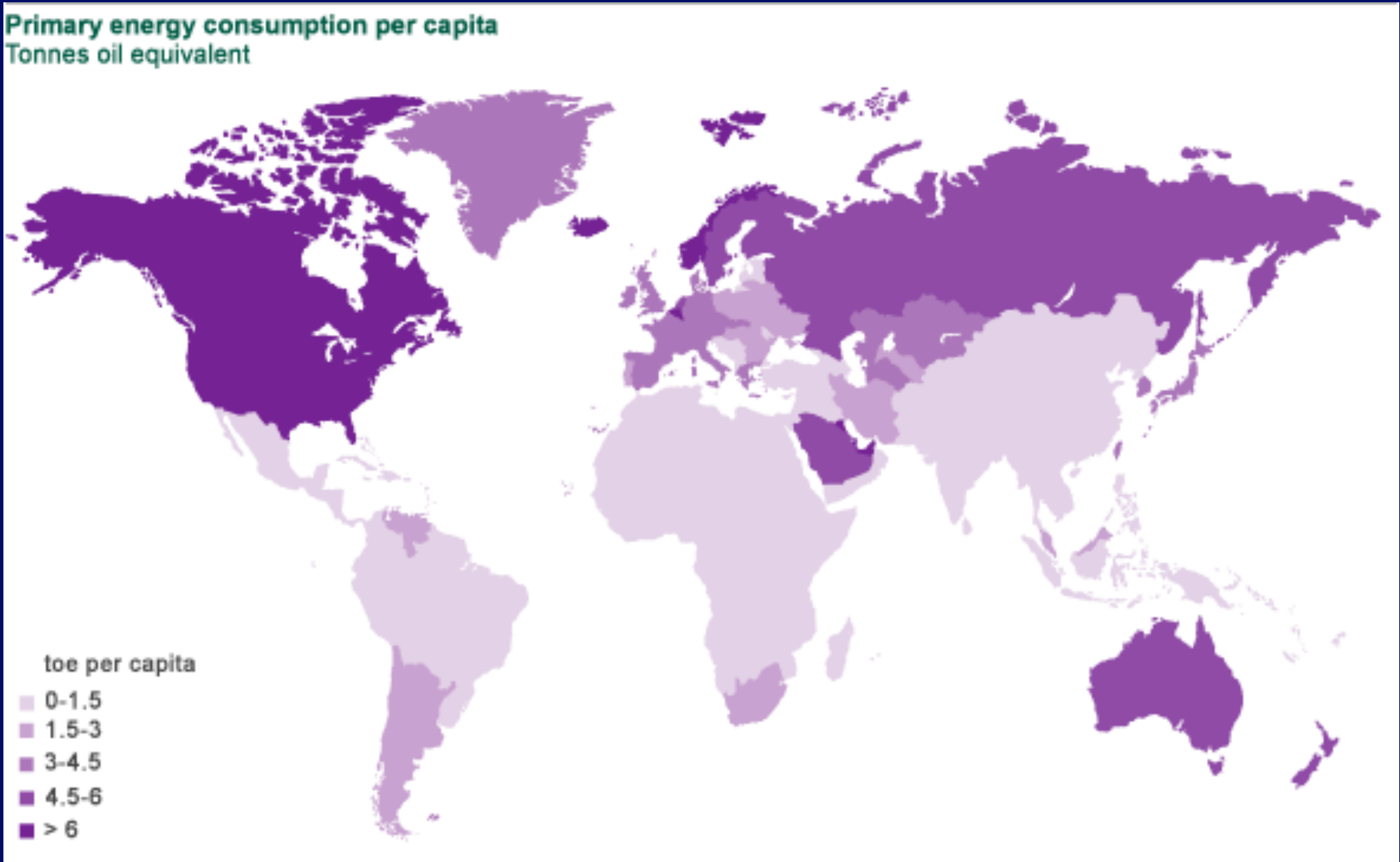



Coal remains the world's most abundant fossil fuel, with an R/P ratio of more than 130 years. In addition to being cost-competitive, coal has emerged as the world's fastest-growing fuel in part because reserves are located in key consuming countries.

# Total Energy Usage



# Energy Consumption per capita



# 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

  $\Longrightarrow$ UV reaches surface

  Skin Cancer, Cataracts, …

  Crop Damage

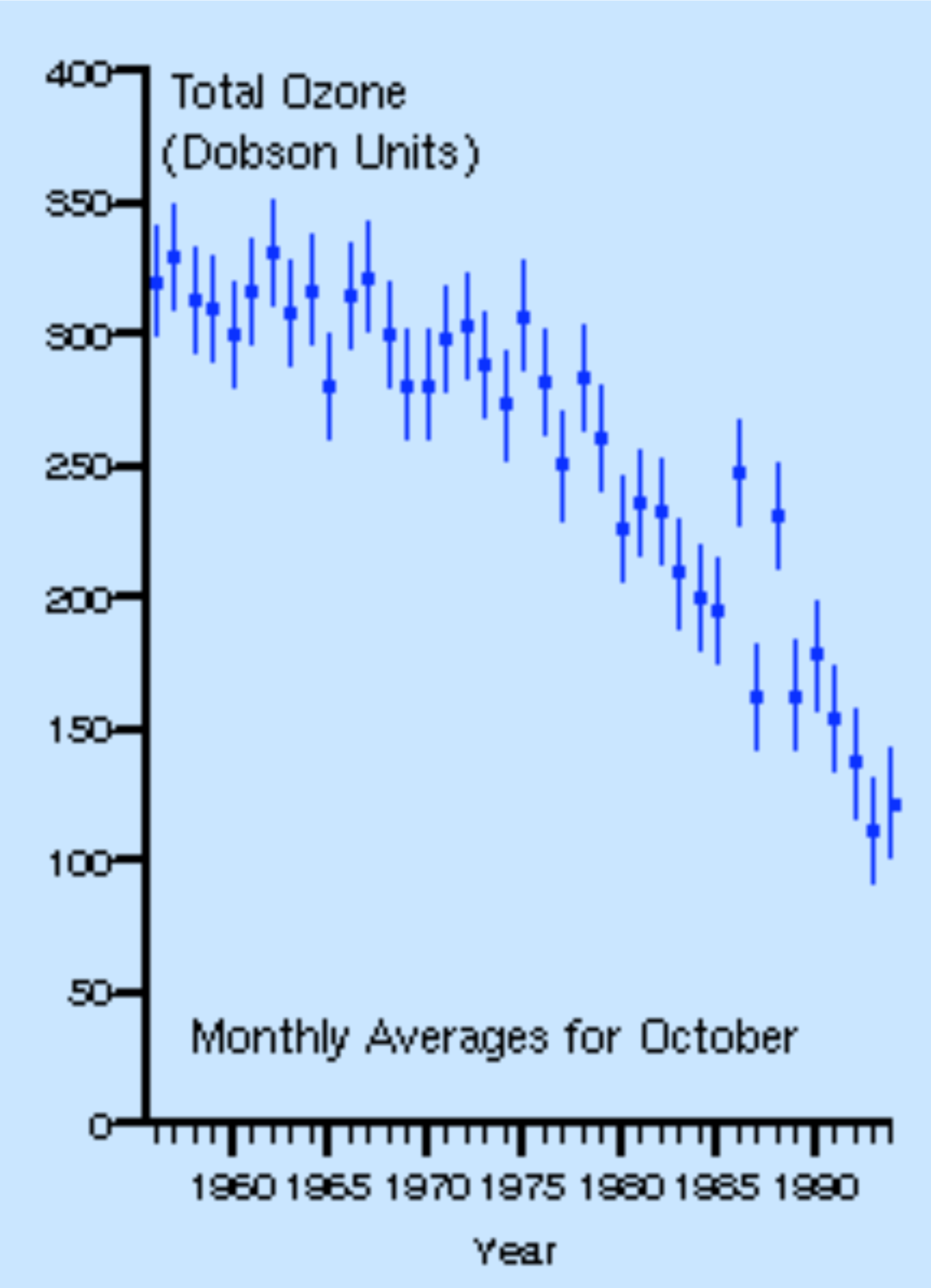
Caused by CFC's (refrigeration, styrofoam,…)
other chemicals

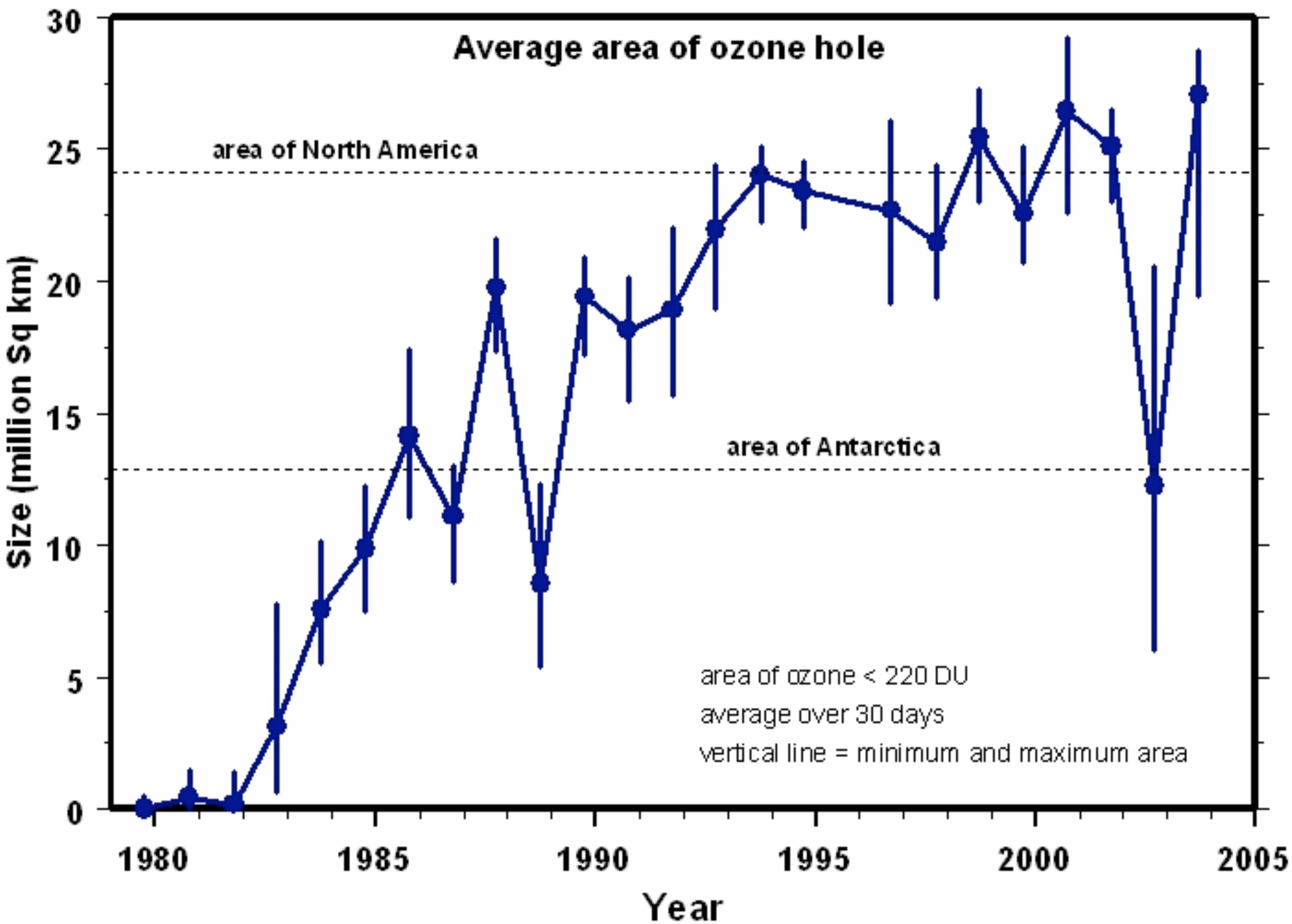
Stratosphere is very sensitive and poorly understood

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

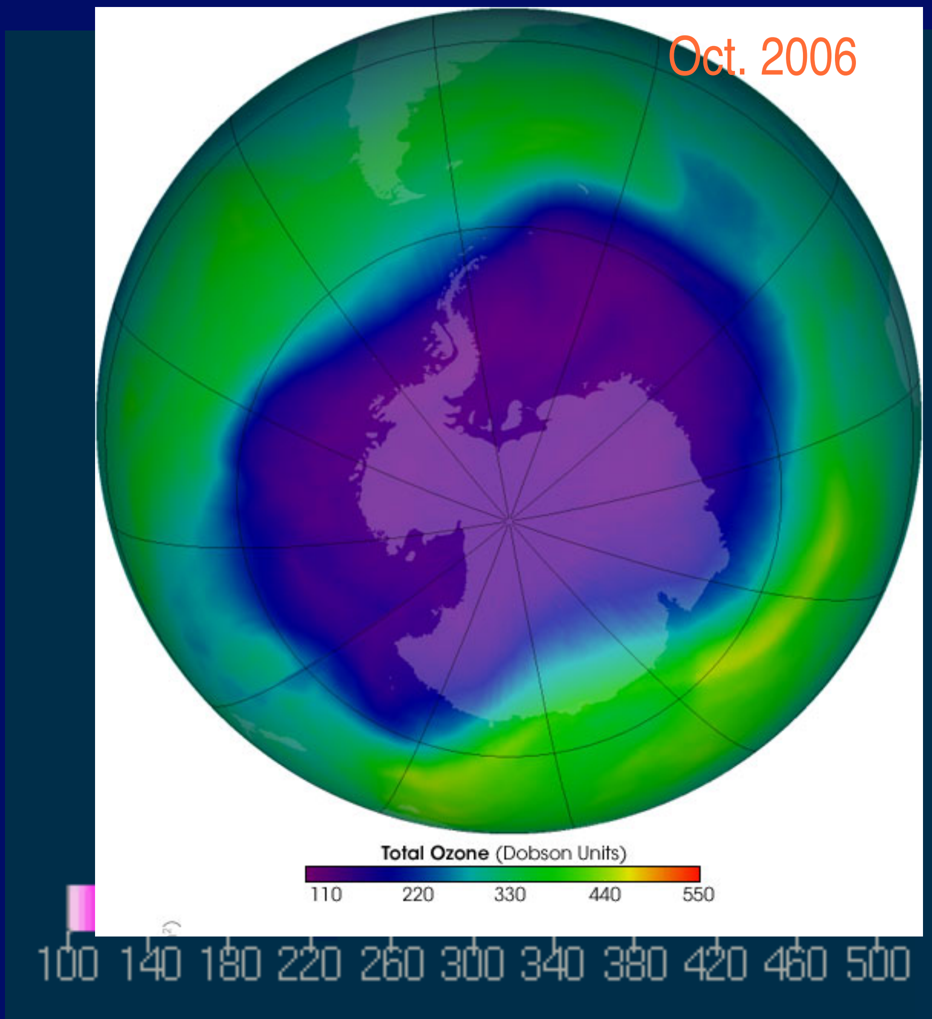
$O_3 \longrightarrow O_2$

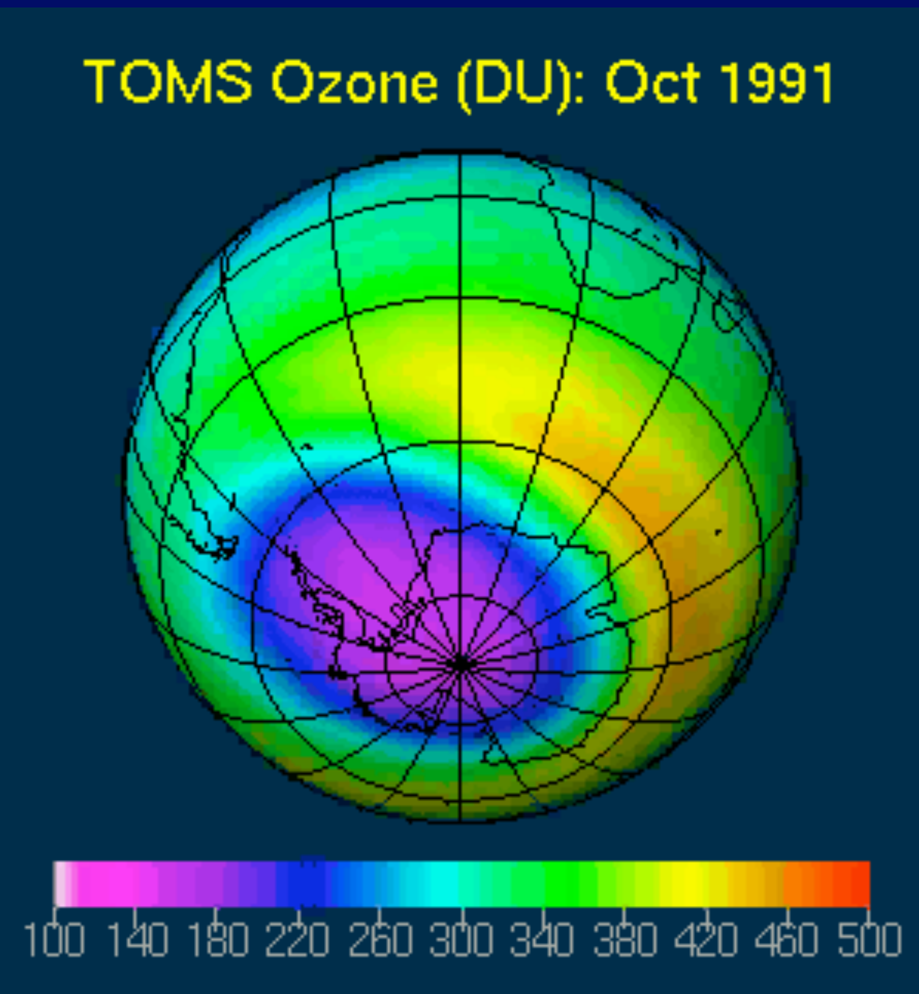
Ozone over South Pole




Average area of ozone hole
Size (million Sq km)
Year
area of North America
area of Antarctica
area of ozone < 220 DU
average over 30 days
vertical line = minimum and maximum area
0
5
10
15
20
25
30
1980
1985
1990
1995
2000
2005

# Growth of ozone hole



# Side Effects (cont.)

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

Global warming

and warmer water

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

Climate changes: (40 - 100 yrs)

Increased desertification

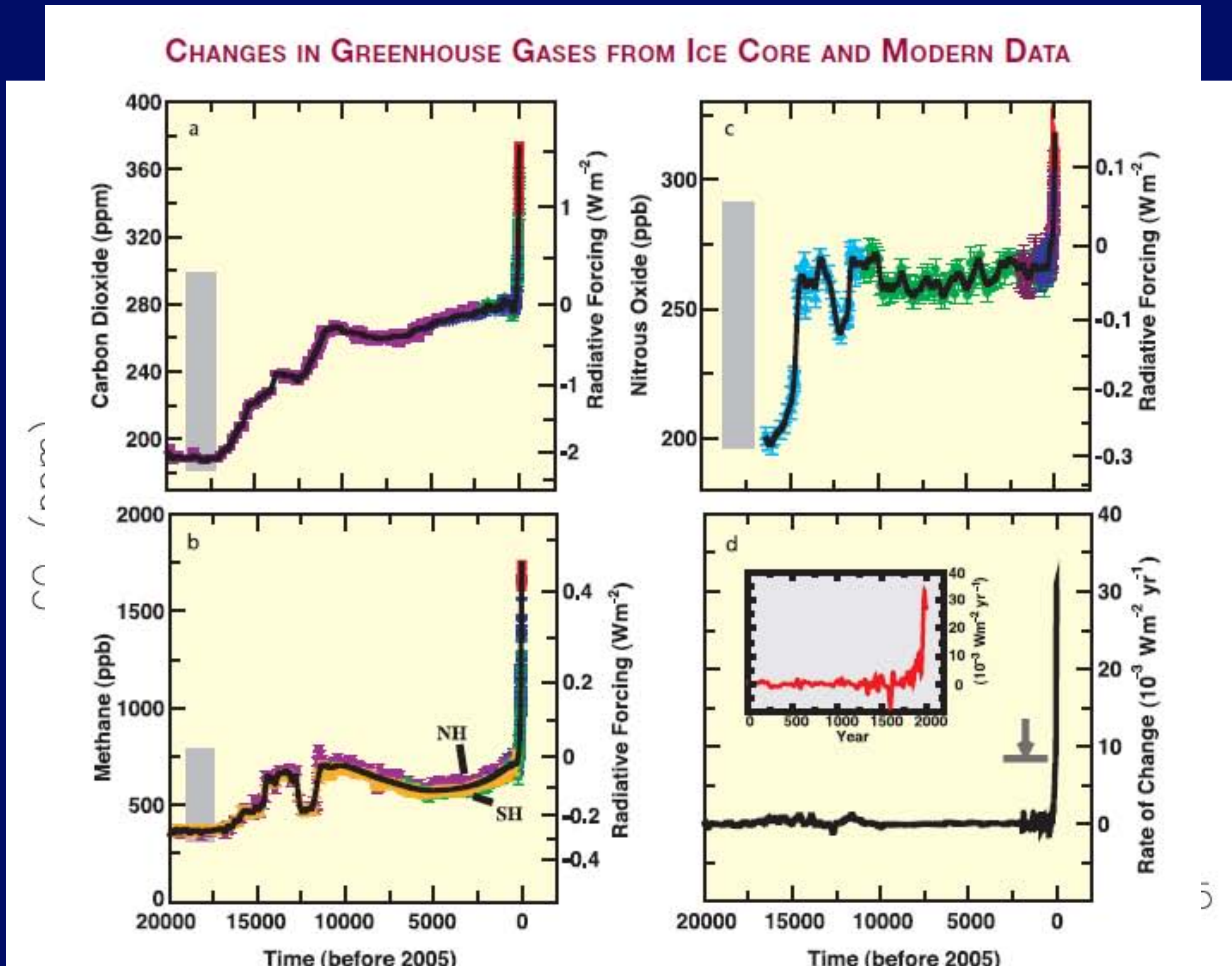
Crop yields?

Runaway greenhouse?

(Earth become like Venus?)

Not likely to go this far

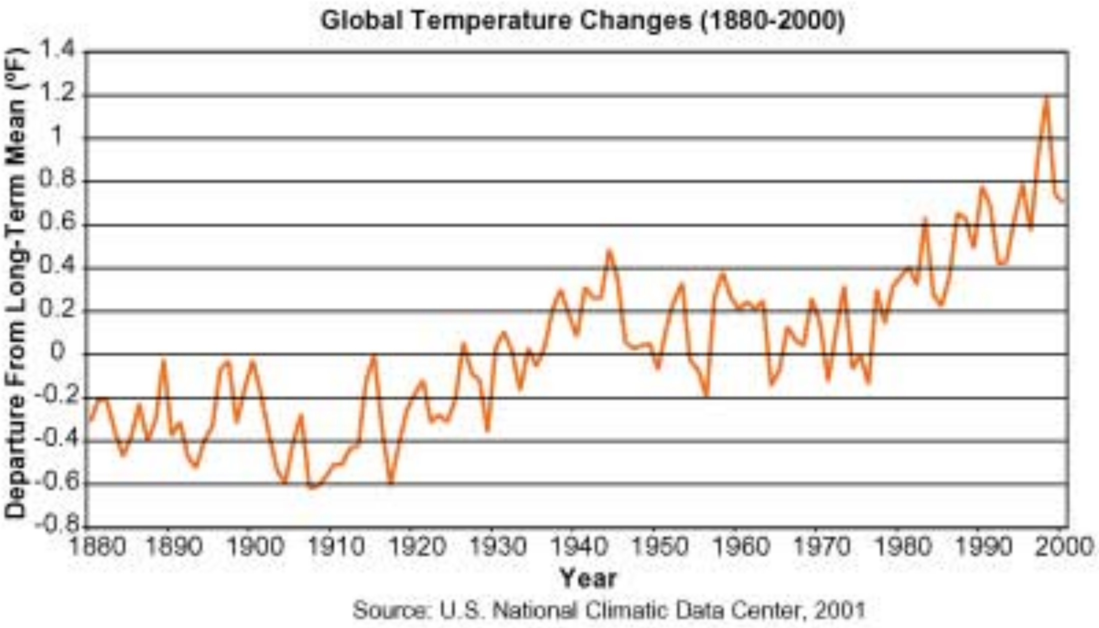
# Carbon Dioxide Increase



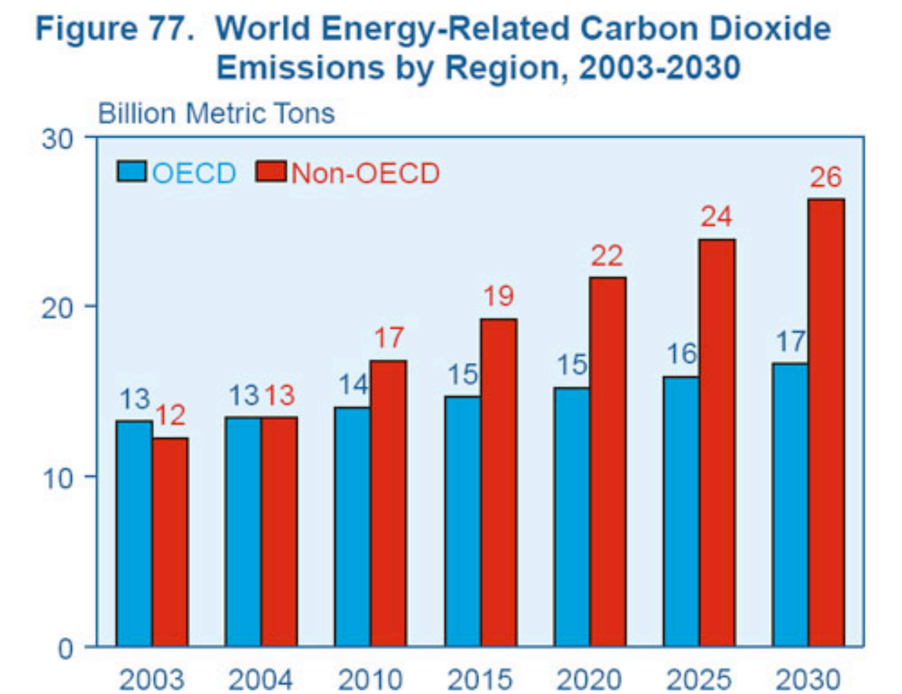
# The Temperature is Warming

## Changing Climate

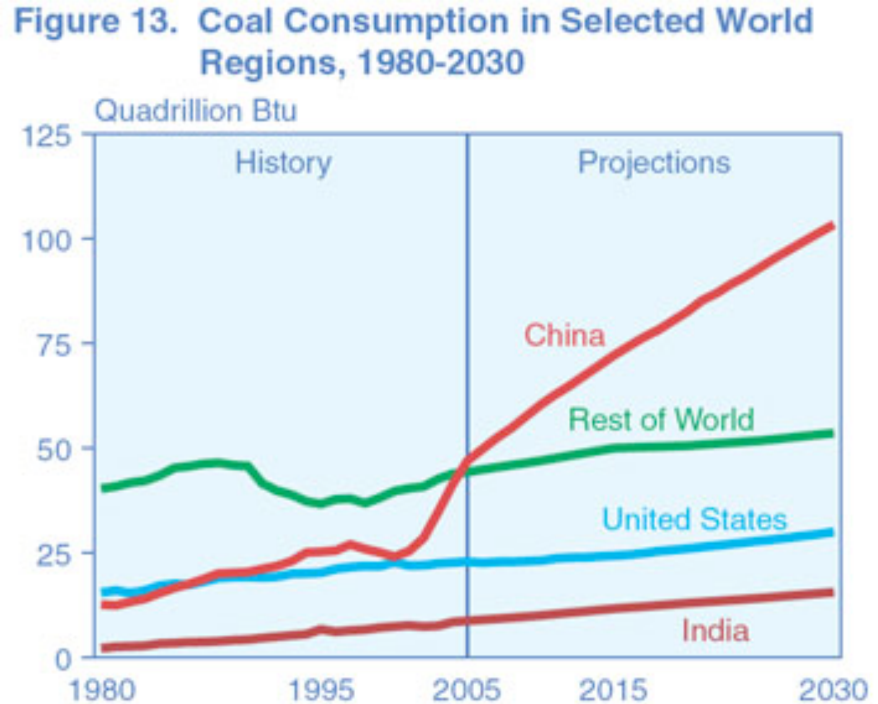
Global mean surface temperatures have increased 0.5-1.0°F since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century. Of these, 1998 was the warmest year on record. The snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean have decreased. Globally, sea level has risen 4-8 inches over the past century. Worldwide precipitation over land has increased by about one percent. The frequency of extreme rainfall events has increased throughout much of the United States.



# Update on production balance

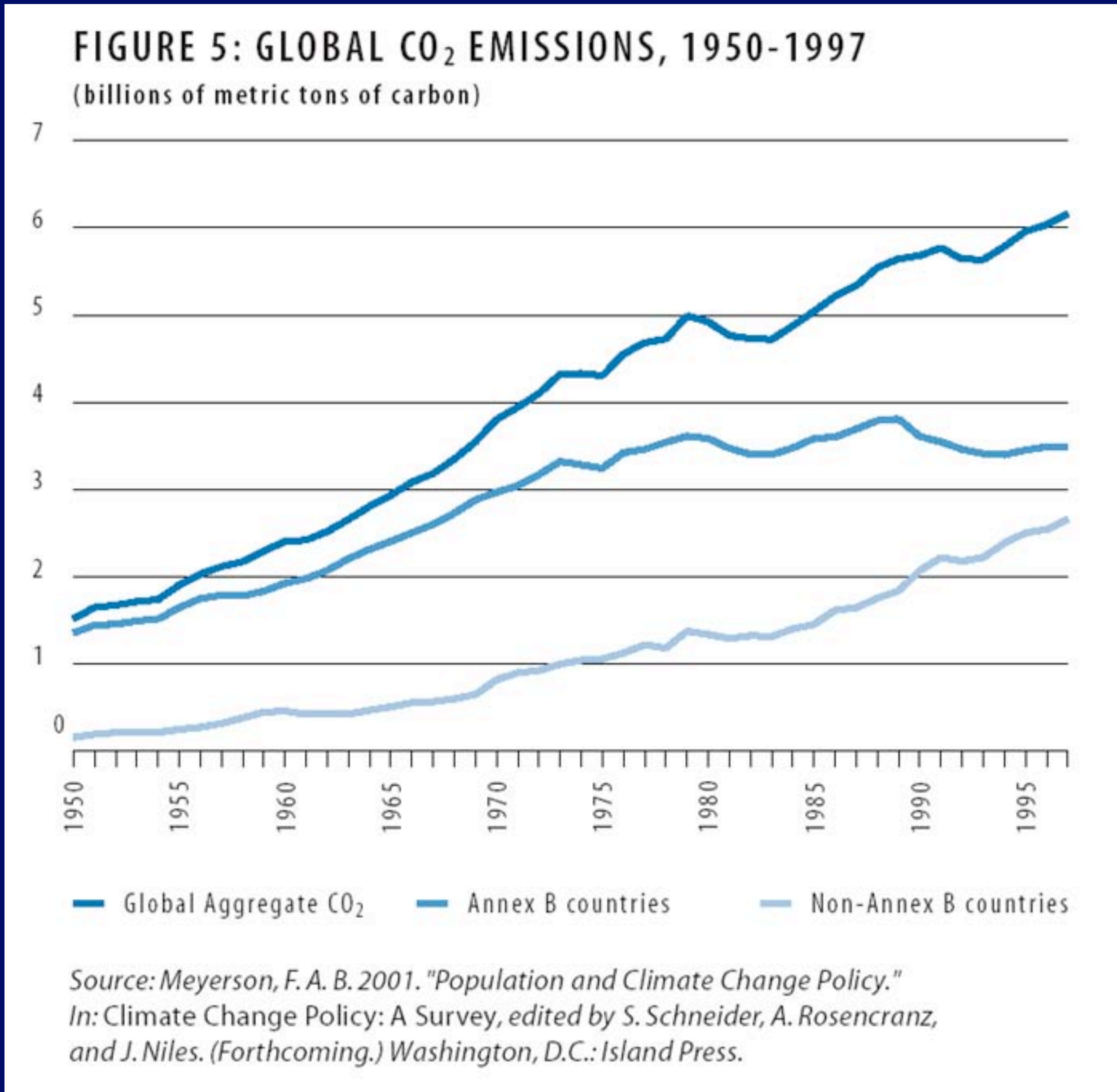



Sources: **2003 and 2004:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).



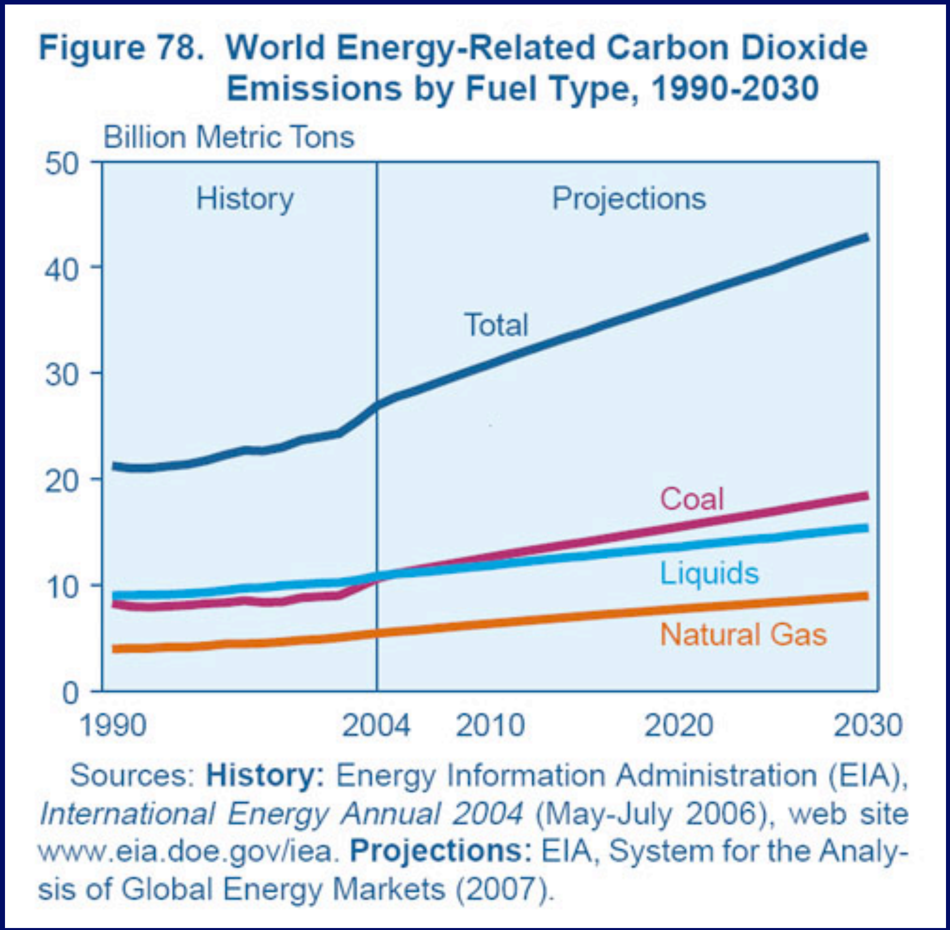

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2008).

OECD: Europe, US, Canada, Australia, Japan, Mexico Not Russia, India, China




In Billion Metric tonnes of CARBON (12/44 of $CO_2$)

# $CO_2$ Production Continues to Increase

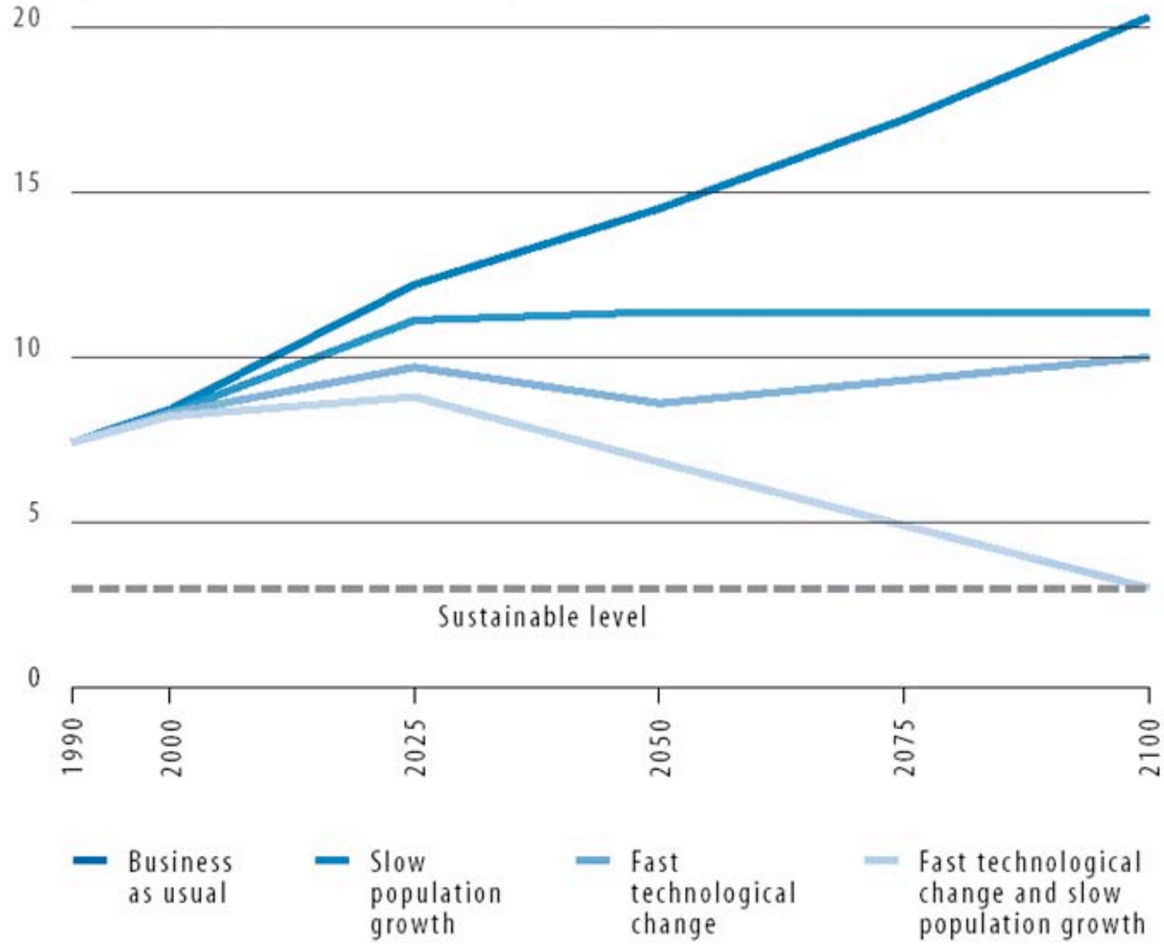



Note: this is for $CO_2$ rather than C.
So 44/12 times next plot

From Energy Information Administration 2008

## FIGURE 6: PROJECTED $CO_2$ EMISSIONS UNDER DIFFERENT POPULATION AND TECHNOLOGY ASSUMPTIONS, 1990-2100

(billions of metric tons of carbon)




This figure expresses $CO_2$ emissions as elemental carbon.

1 ton elemental carbon = 33.664 tons $CO_2$ 3.66 tons $CO_2$

*Source: Harrison, Paul, and Fred Pearce, 2001.* AAAS Atlas of Population and Environment *(Victoria Dompka Markham, editor). American Association for the Advancement of Science and the University of California Press.*

# Other factors

- New models include Sulfate

  emission leads to haze which leads to increase in albedo

- Cooling tends to balance warming from

  Greenhouse $CO_2$

  Less temperature rise in short term

Ice core analysis shows strong correlation
of temperature and astronomical cycles -
rotation axis, orbital variations, solar cycle

Also - we are still in last stages of “little ice age”
In climate behavior, but not temperature

# Greenland ice cores *Nature*, 15 July 1993

Study temperature, climate… over 150,000 yr

Last interglacial (Eemian)

115,000 - 130,000 yr ago

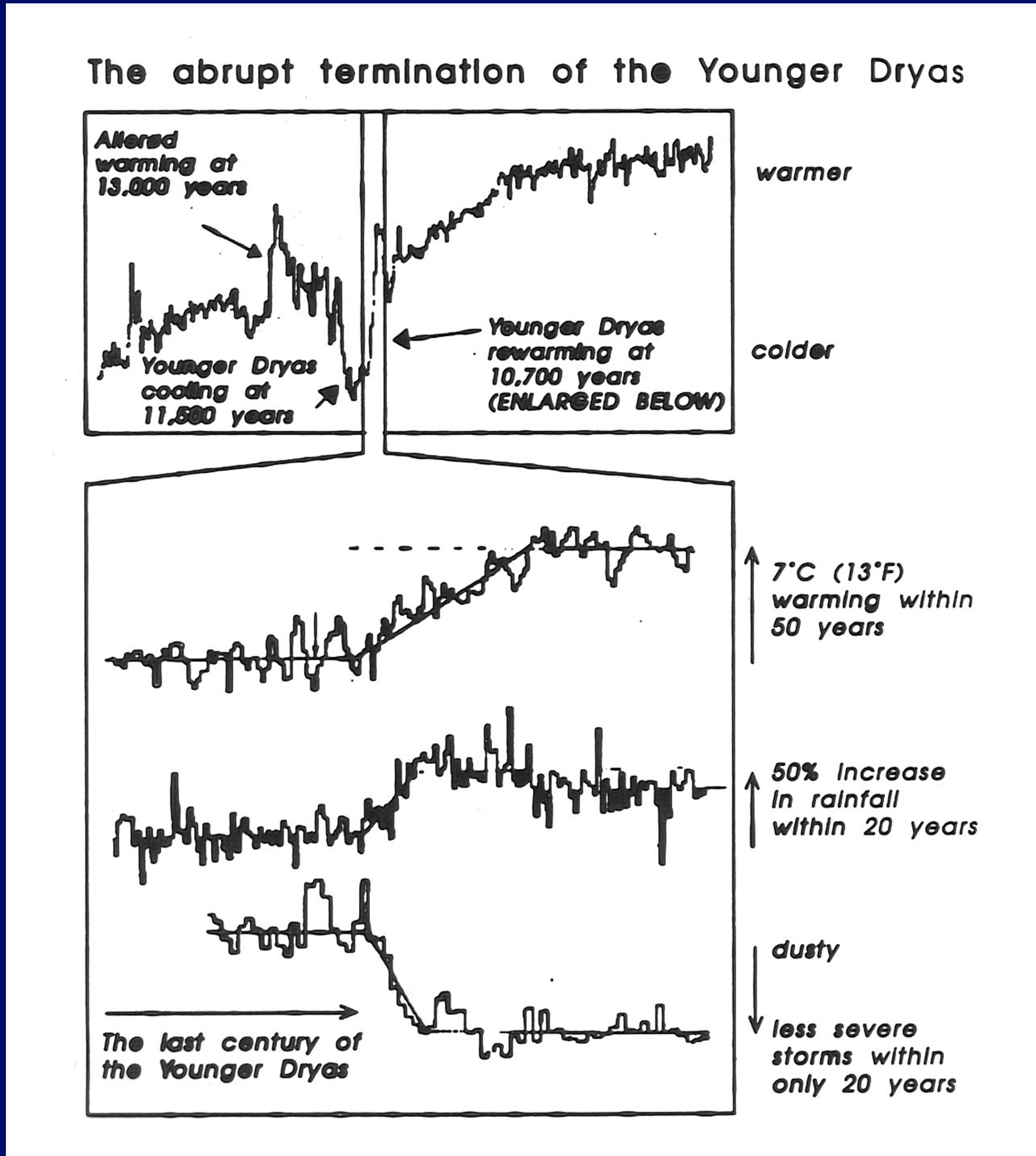
warmer

3 temp. states: like present

colder

Very rapid switches (up to 10º C)

Our current stable climate may not be typical of interglacials



The abrupt termination of the Younger Dryas
Allerød warming at 13,000 years
Younger Dryas cooling at 11,500 years
Younger Dryas rewarming at 10,700 years (ENLARGED BELOW)
warmer
colder
7°C (13°F) warming within 50 years
50% increase in rainfall within 20 years
dusty
less severe storms within only 20 years
The last century of the Younger Dryas

# 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 | $4 \times 10^9$ | 17.1 |
| 2000 | $6 \times 10^9$ | ~ 18 |

Population Doubling in 55 years

# Population Mathematics

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

leads to exponential growth if (Birth - Death) constant

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

$t_d$ = doubling time $\underset{\sim}{\ }$ 55 years

So doubles in 55 yrs

Quadruples ($2^2$) in 110 yrs, …

990 yr (18 $t_d$) Pop = $1.3 \times 10^{15}$

~ fills land area

2530 yr (46 $t_d$) Mass > $M_{(earth)}$ !

12, 375 yr (225 $t_d$) Mass expands at c !!

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

# World Vital Events Per Time Unit: 2008

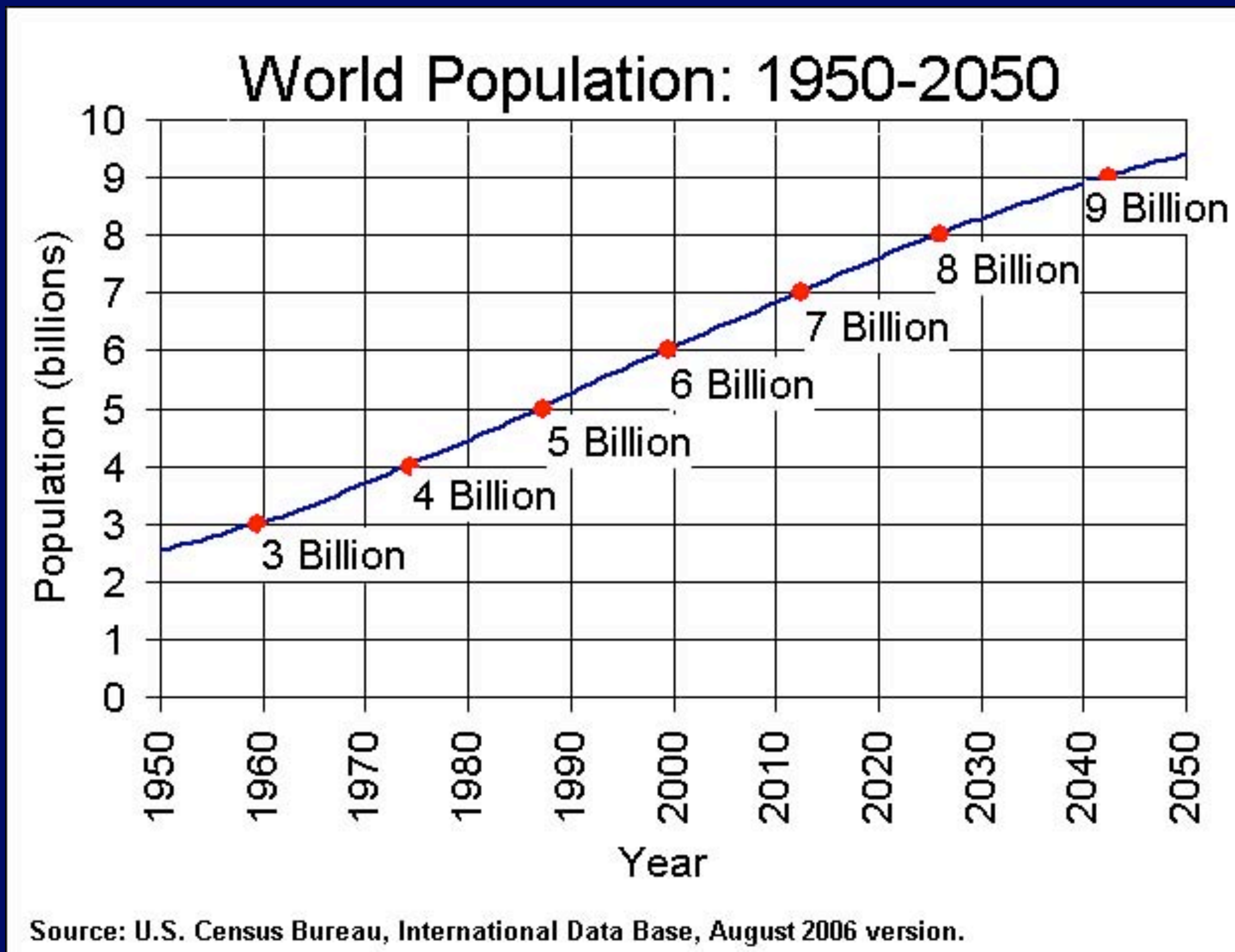
World Vital Events Per Time Unit: 2009

- (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



# Changes in Population

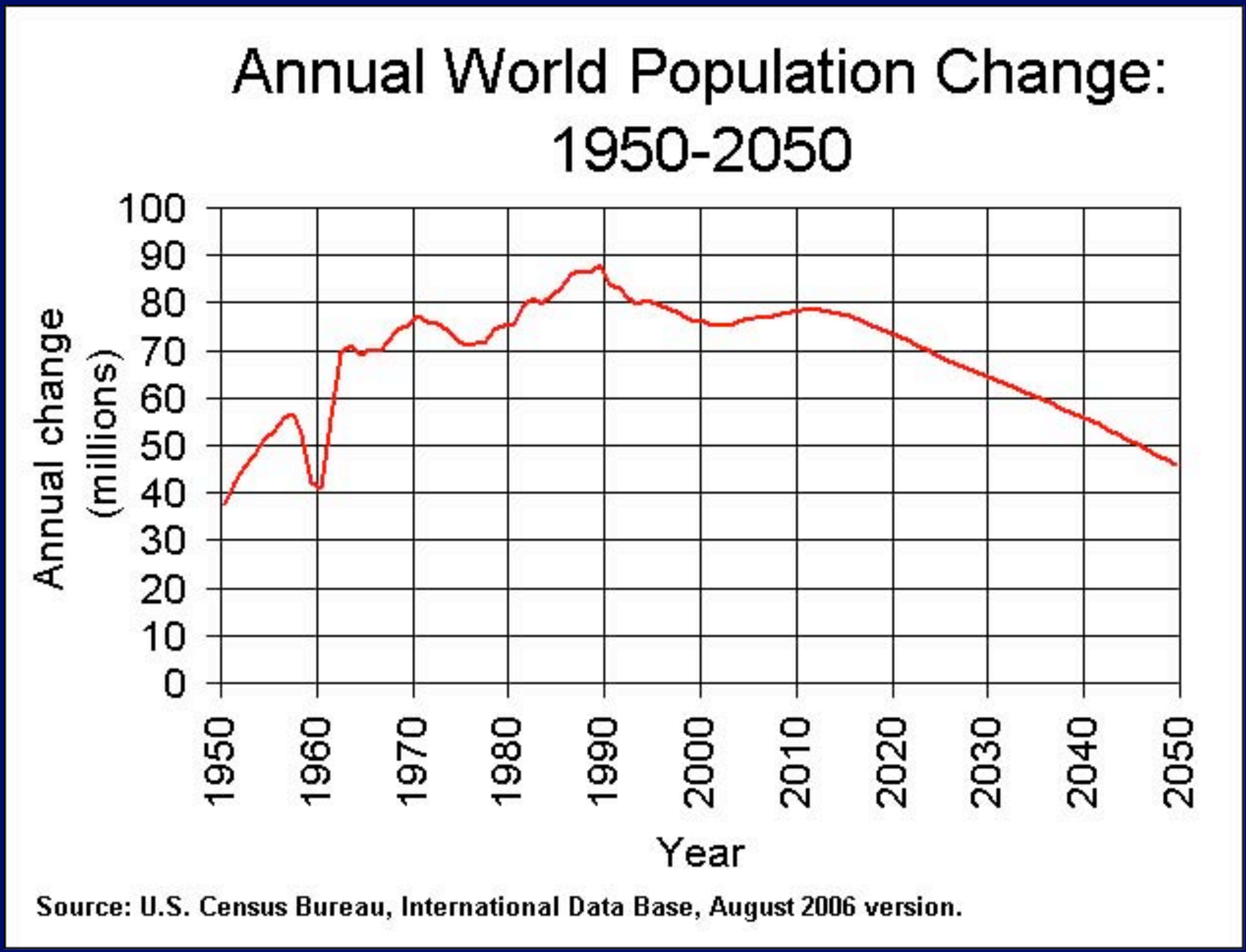
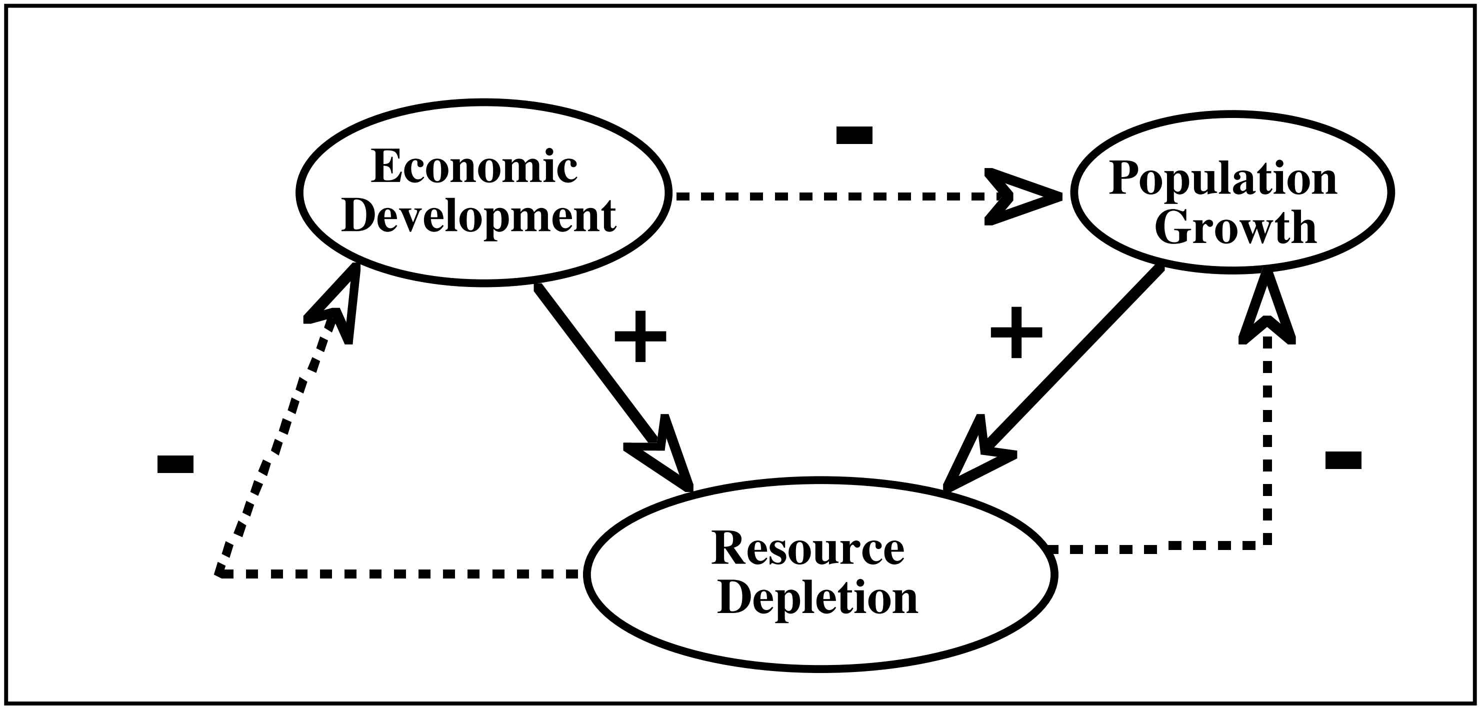


FIGURE 3: PERCENTAGE OF POPULATION UNDERNOURISHED, BY SUBREGION, 1996-1998


*Source: United Nations Population Division*

*Caribbean average is skewed by high malnourishment in Haiti.




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

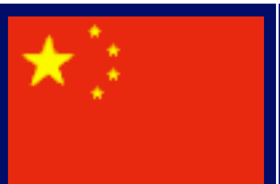
# Nuclear War

Total arsenal world-wide ~ 10,000 megatons

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)

| | Country | Suspected Strategic Nuclear Weapons | Suspected Non-Strategic Nuclear Weapons | Suspected Total Nuclear Weapons |
|---|---|---|---|---|
|  | Russia | ~ 6,000 | ~ 4,000 | ~ 10,000 |
|  | United Kingdom | 180 | 5 | 185 |
|  | United States | 8,646 | 2,010 | 10,656 |

http://www.cdi.org/issues/nukef&f/database/nukearsenals.cfm

# Nuclear Warheads being Deactivated

- US-Russia Agreement to deactivate warheads (START Agreement 1994)
  - Agreed to reduce to 6000 warheads each
  - Expires Dec 2009
- Moscow Agreement (2002)
  - Decrease to 1700 to 2200 by 2012
  - Down to about 4000 on each side.
  - Others are dismantled, but not destroyed
- Mar. 31, 2009 Idea floated of decrease to 1500
  - But issues of how to count…

# Natural Catastrophes

Collisions

Stars? Negligible

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 Asteroid Impact:

e.g. 1/4 km radius

$V = 30$ km $s^{-1}$ (65,000 miles/hour)

$E_k = 1/2\, Mv^2 \simeq$ 7200 megatons of TNT

$\simeq$ all-out nuclear war

Crater ~ 10 km across, few km deep

$10^{12}$ tons of debris released into atmosphere

If covers globe, leads to temperature drop and "asteroid winter"

## How Often do Large Asteroids Strike the Earth?

| | | |
|---|---|---|
| 1937 | Hermes | ~ 500,000 miles |
| 1989FC | | Similar |
| 1993BA | | 170,000 km (5 - 10 m diameter) |

How often might we expect global catastrophe?

"Substantial" Impacts

(1 km or larger) $t \sim 10^5$ yr - $10^6$ yr

Major Extinctions $t \sim 30 \times 10^6$ yr

Mass Extinctionst $\sim 100 \times 10^6$ yr ?

More massive asteroids more destructive,
but also more rare, so collisions are less likely

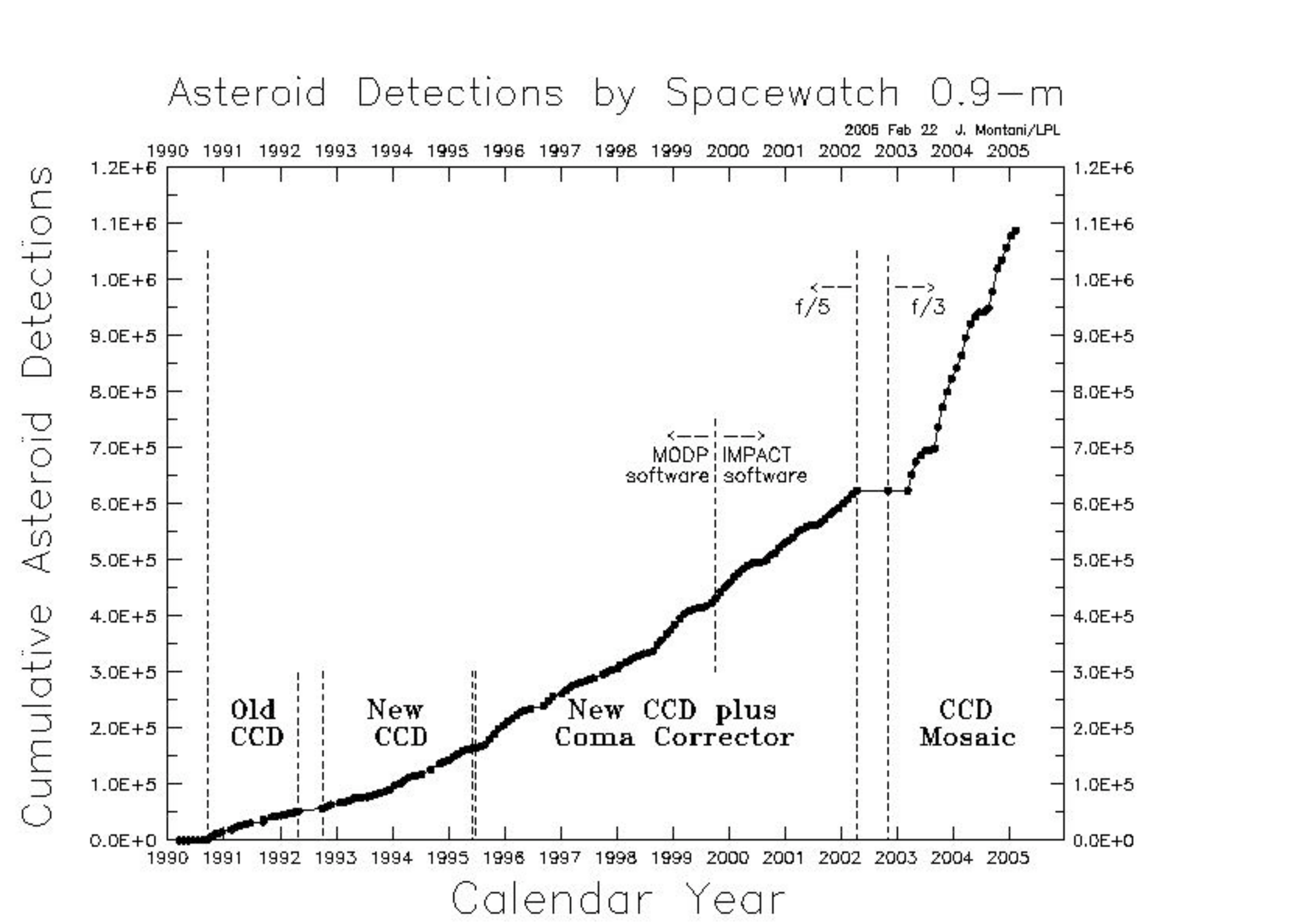
Preventable by advanced civilization?

1991 BA ~ 40 kilotons TNT (3 × Hiroshima)

50 meter objects - once per century

April 1992 - proposal for project to search and identify - space watch underway

# Spacewatch Detections

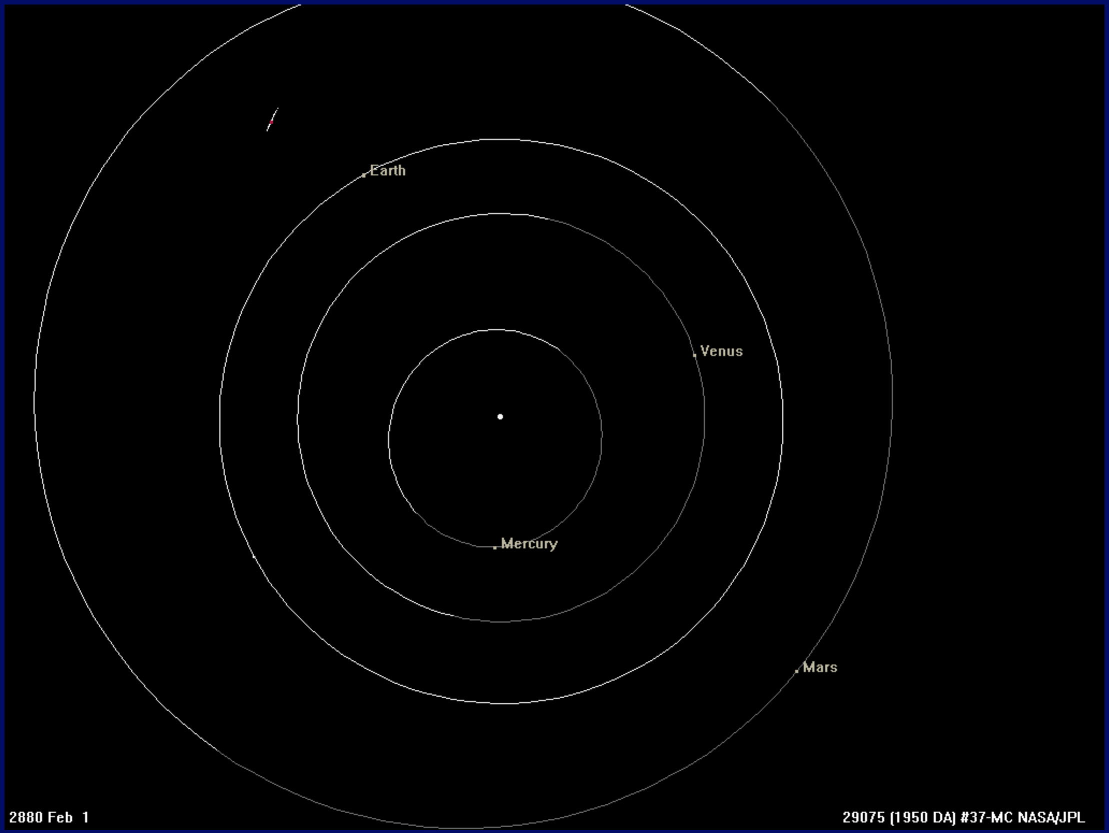


# Most Dangerous Known Asteroid

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 $7.6 \times 10^9$ 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 $\ell$y, 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

~ $10^{12}$ 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]

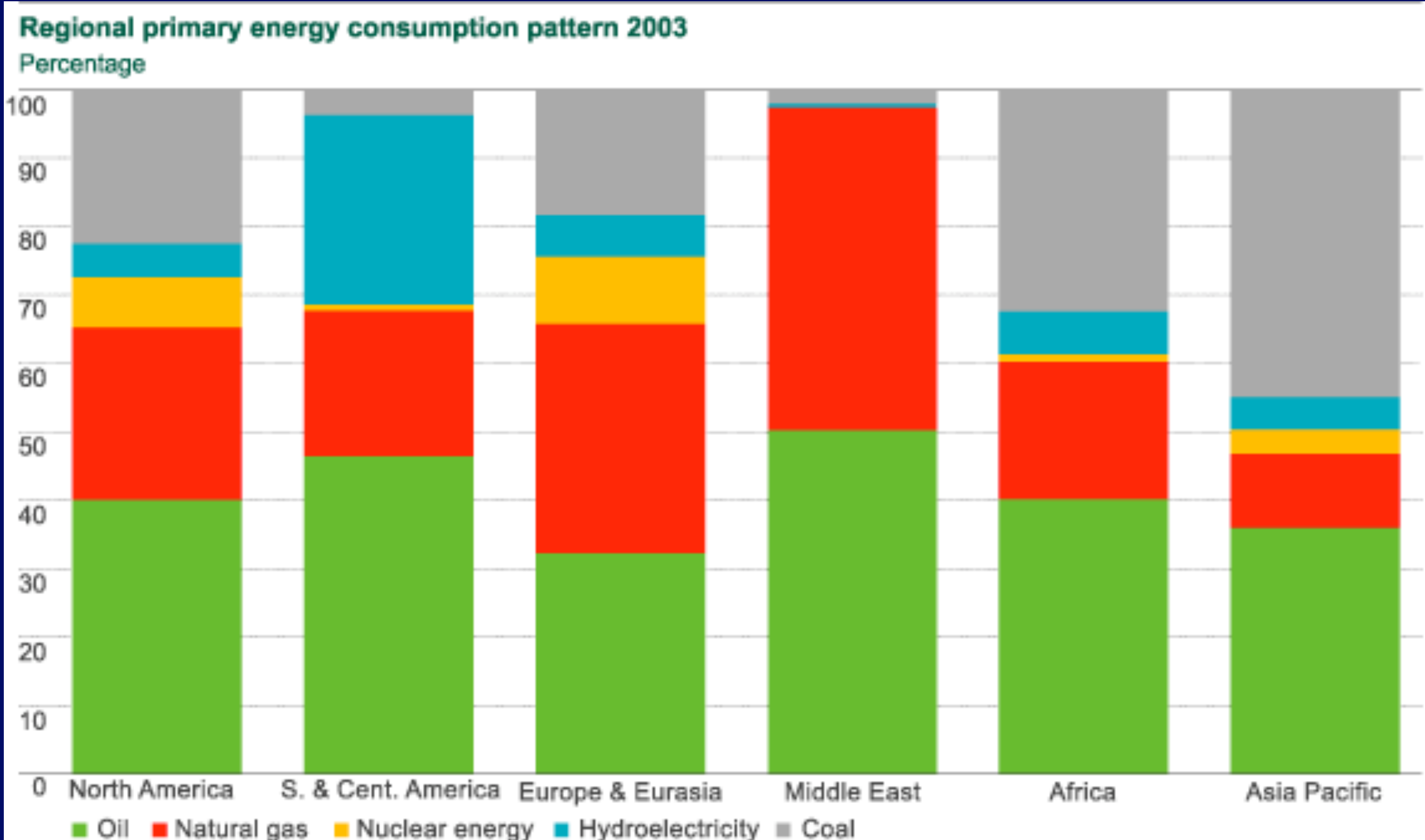
Important to choose L consistent with what you think is the most likely way civilizations end.

# 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;

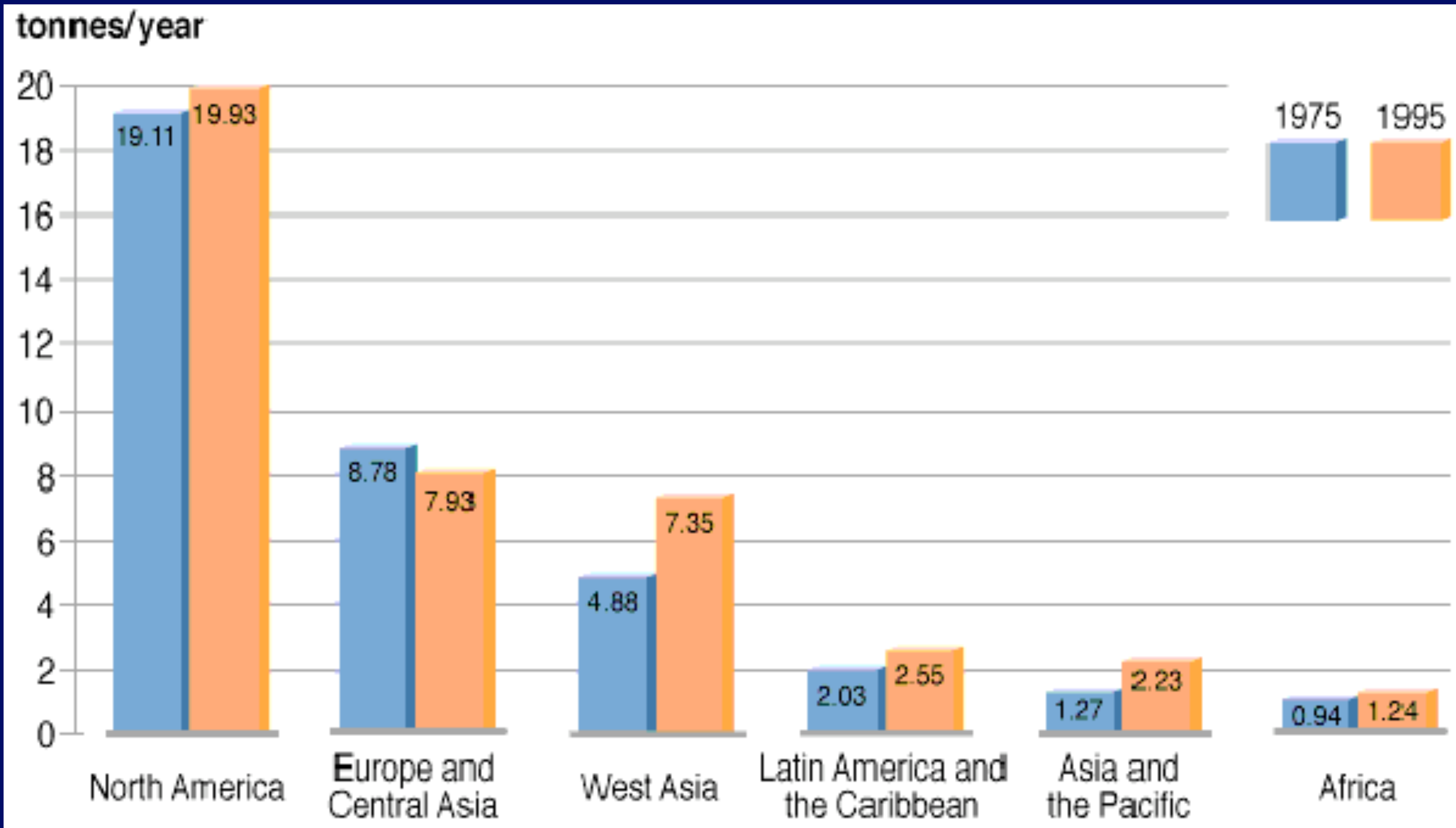
- Lord Byron, 1816

# Regional Primary Energy Consumption Pattern

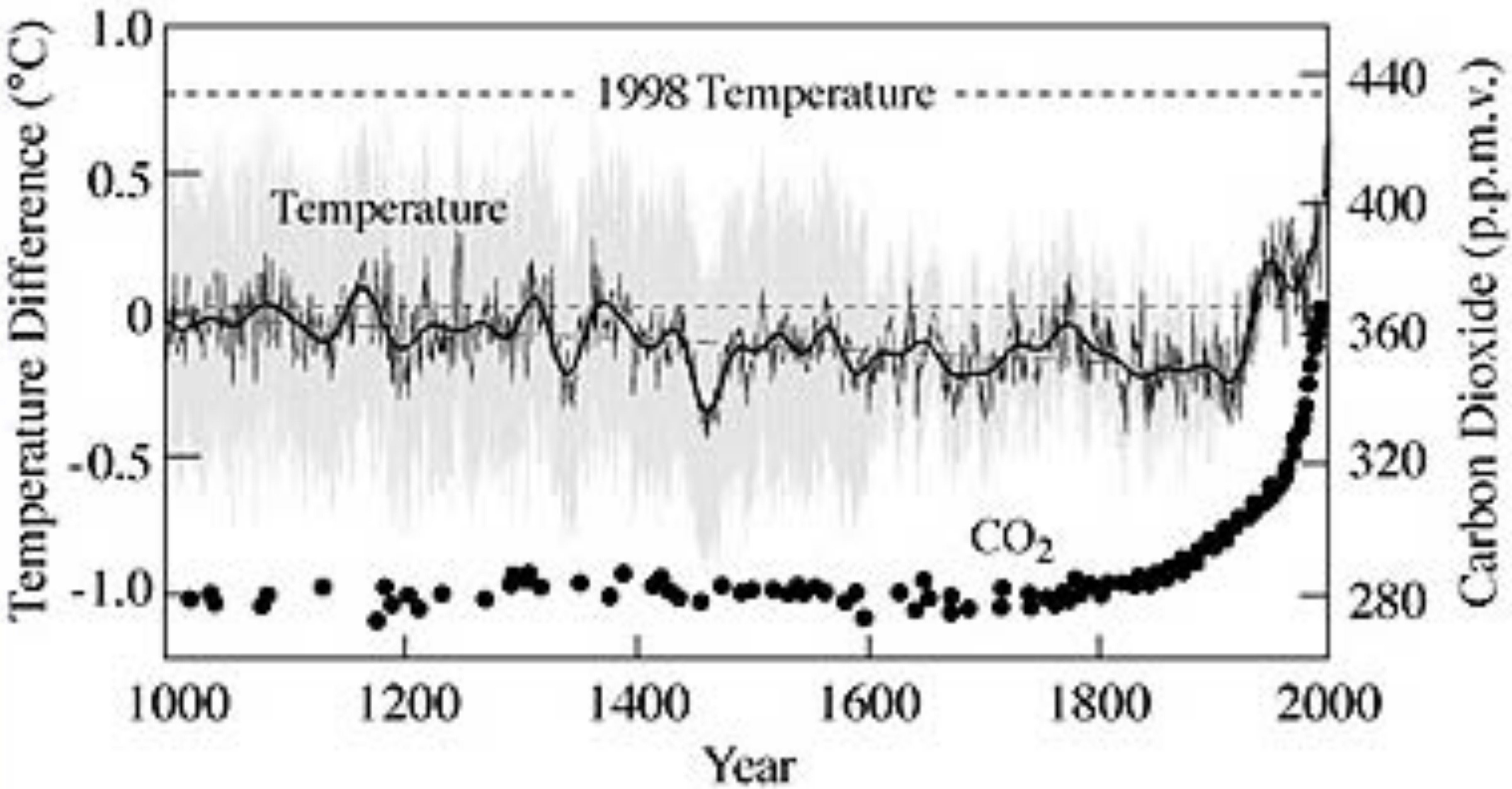



Oil remains the largest single source of energy in most parts of the world. The exceptions are the Former Soviet Union, where gas dominates and Asia Pacific where coal is the dominant fuel.

# $CO_2$ Production



## Temperature is rising with the greenhouse gasses



# Global Mean Sea Level

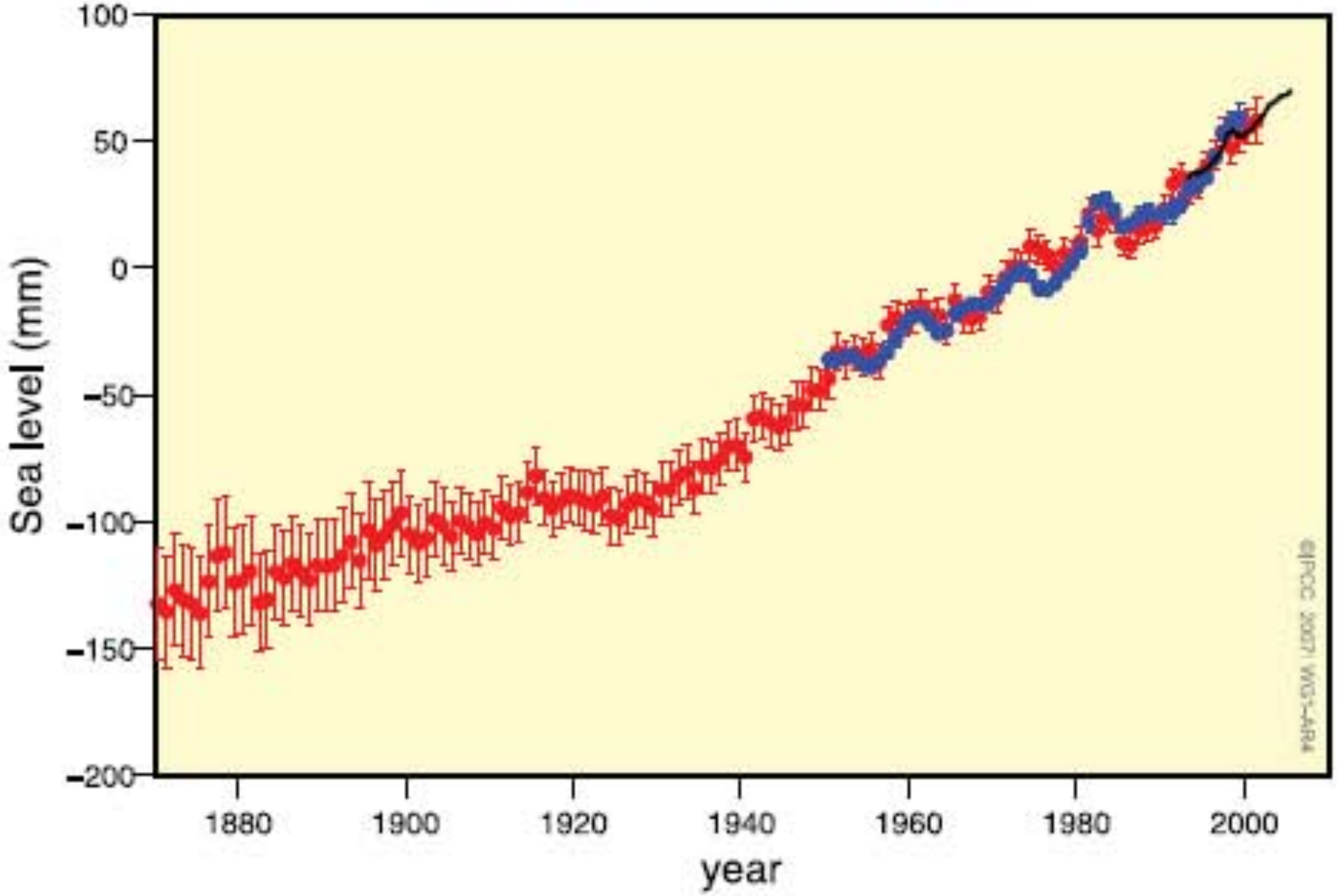
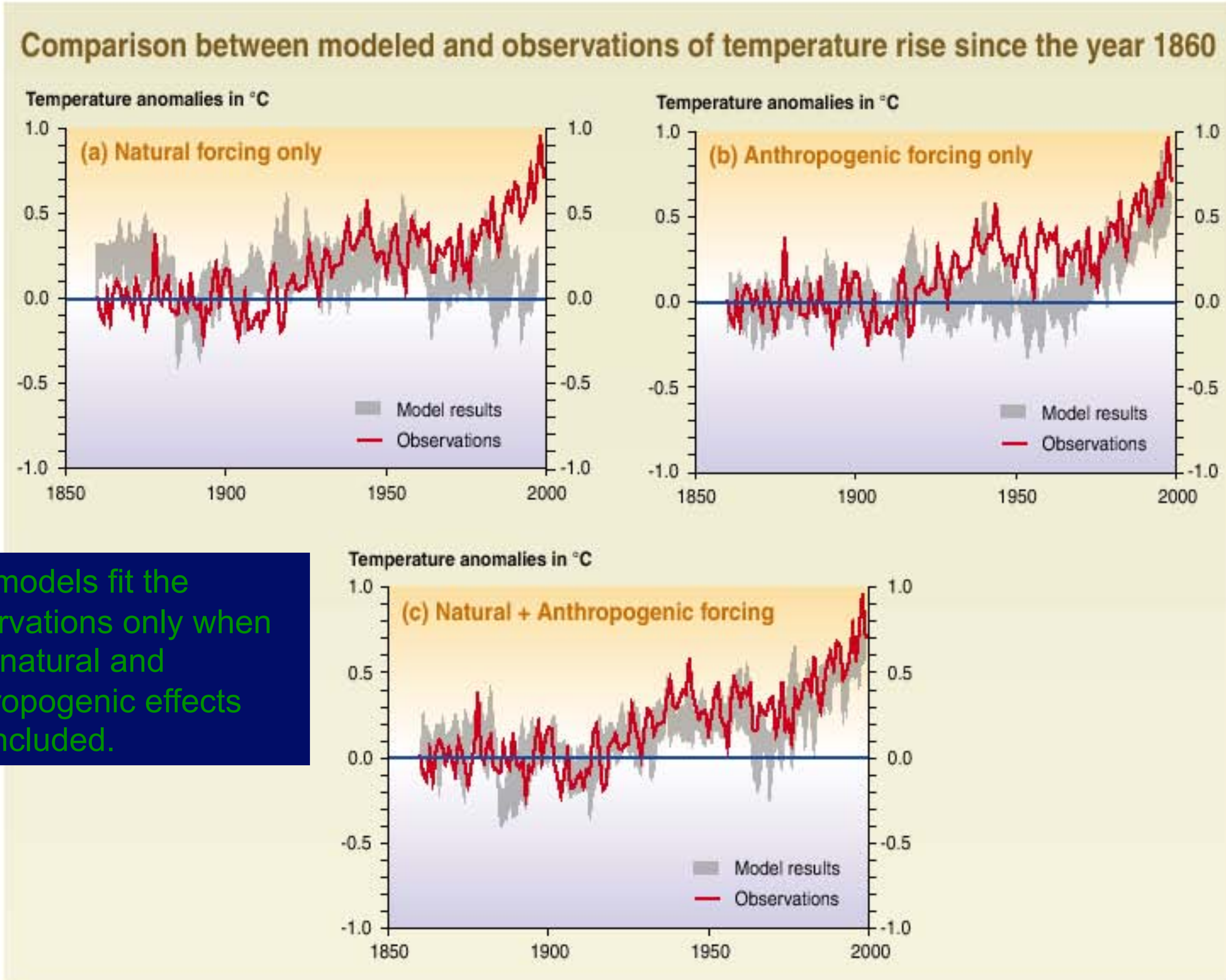



**Figure TS.18.** *Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals.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




The models fit the observations only when both natural and anthropogenic effects are included.