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 380 "Quads"

Per year Quad = 10^{15} BTU $\simeq$ 3×10^{11} kw - H

$\longrightarrow$ 13×10^{6} MW Avg. power

U.S. uses 26% of this

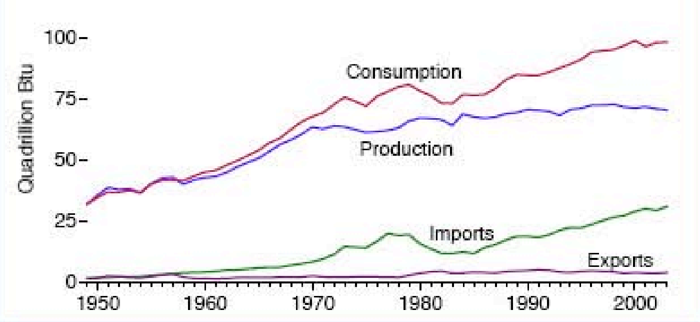
Energy per capita ~ 6 metric tonnes of oil equivalent

~ 2 × Europe

~ 5 × World avg.

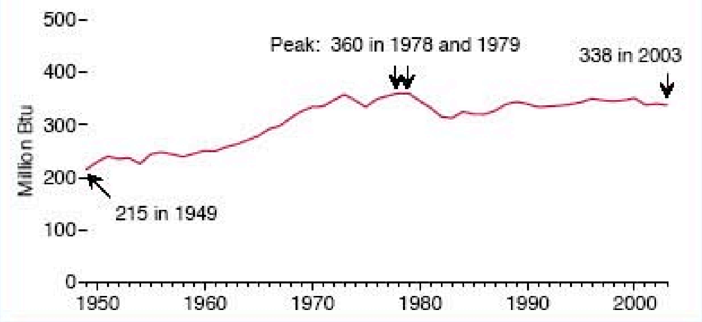
Overview

Figure 1. Energy Overview



The United States was self-sufficient in energy until the late 1950s when energy consumption began to outpace domestic production. At that point, the Nation began to import more energy to fill the gap. In 2003, net imported energy accounted for 27 percent of all energy consumed.

Figure 2. Energy Consumption per Person

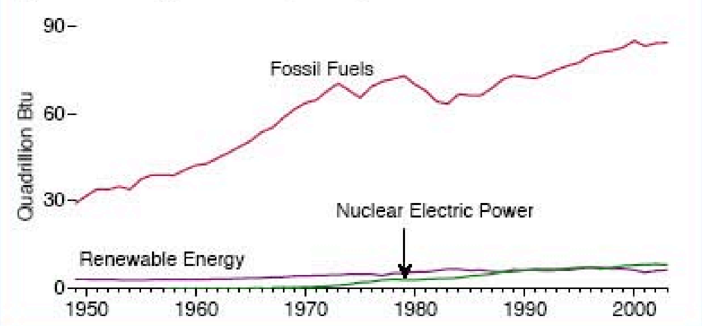


Energy use per person stood at 215 million Btu in 1949. The rate generally increased until the oil price shocks of the mid-1970s and early 1980s when the trend reversed for a few years. From 1988 on, the rate held fairly steady. In 2003, 338 million Btu of energy were consumed per person, 57 percent above the 1949 rate.

Figure 3. Energy Use per Dollar of Gross Domestic Product

After 1970, the amount of energy consumed to produce a dollar's worth of the Nation's output of goods and services trended down. The decline resulted from efficiency improvements and structural changes in the economy. The level in 2003 was 48 percent below that of 1970.

Figure 4. Energy Consumption by Source



Most energy consumed in the United States came from fossil fuels. Renewable energy resources supplied a relatively small but steady portion. In the late 1950s, nuclear fuel began to be used to generate electricity, and in most years since 1988, nuclear electric power surpassed renewable energy.

Consumption by Source

Figure 5. Energy Consumption by Source, 1635-2003

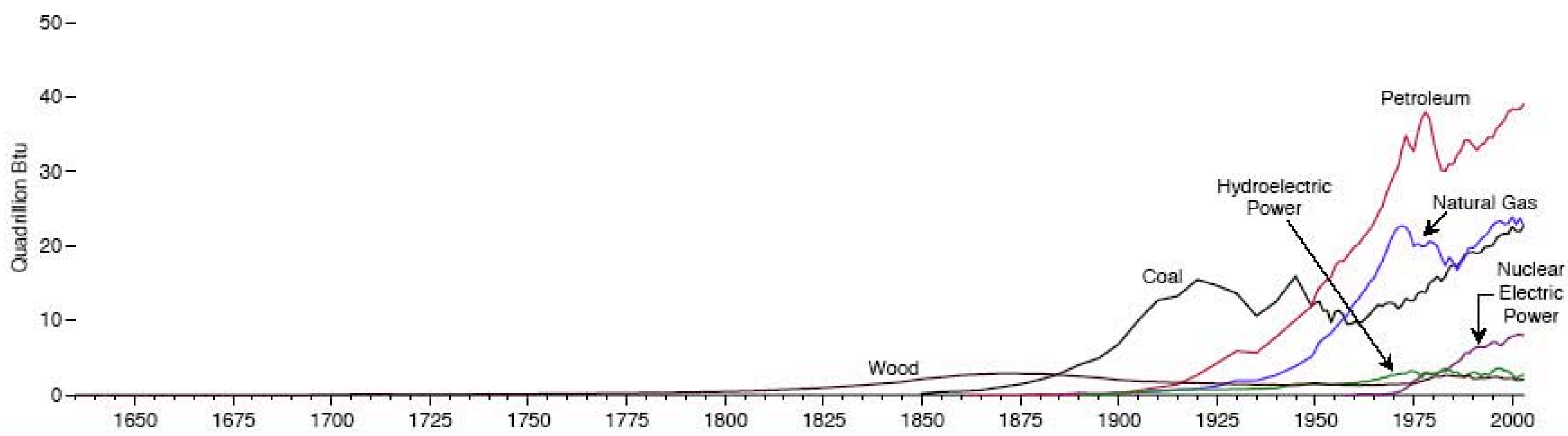
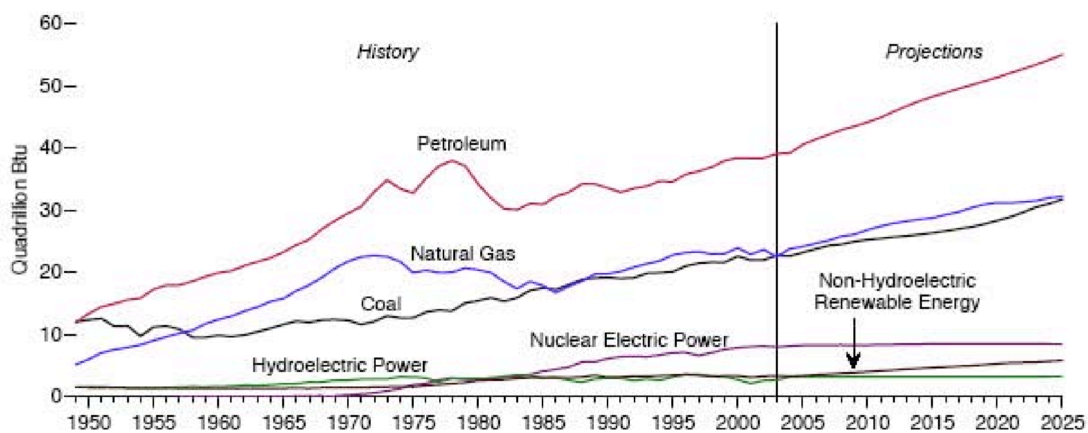


Figure 6. Energy Consumption History and Outlook, 1949-2025

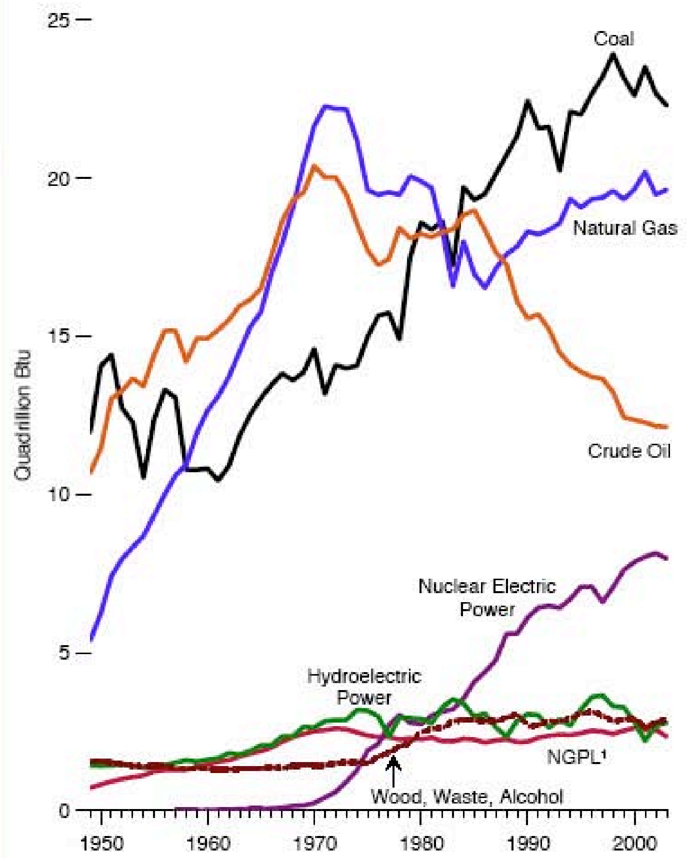


In the long view of American history, wood served as the preeminent form of energy for about half of the Nation's history. Around 1885, coal surpassed wood's usage. Despite its tremendous and rapid expansion, coal was, in turn, overtaken by petroleum in the middle of the 20th century. Natural gas, too, 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.

Production and Trade

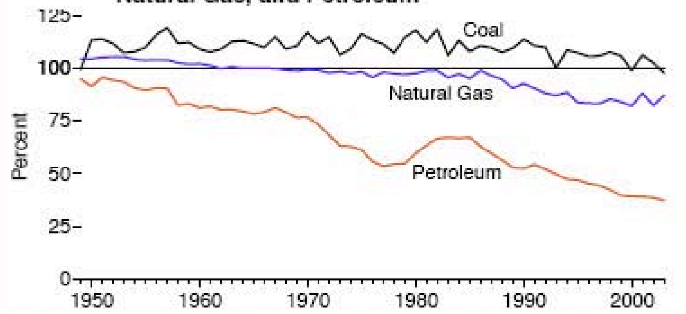
Figure 11. Energy Production by Major Source, 1949-2003



¹ Natural gas plant liquids.

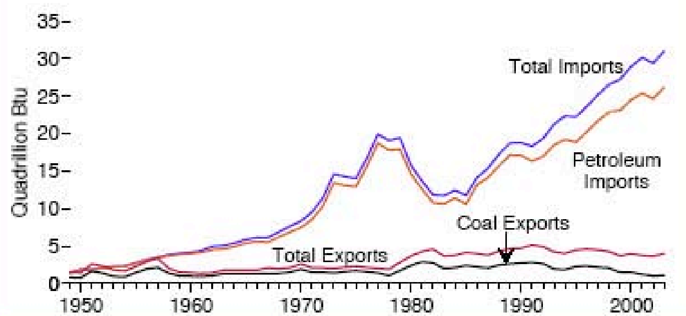
Most energy produced in the United States came from fossil fuels—coal, natural gas, and crude oil. Coal, the leading source at the middle of the 20th century, was surpassed by crude oil and natural gas for many years, but again became the leading source of energy in the mid-1980s, used primarily for electric generation. By the 1970s, electricity produced from nuclear fuel began to make a significant contribution.

Figure 12. Production as Share of Consumption for Coal, Natural Gas, and Petroleum



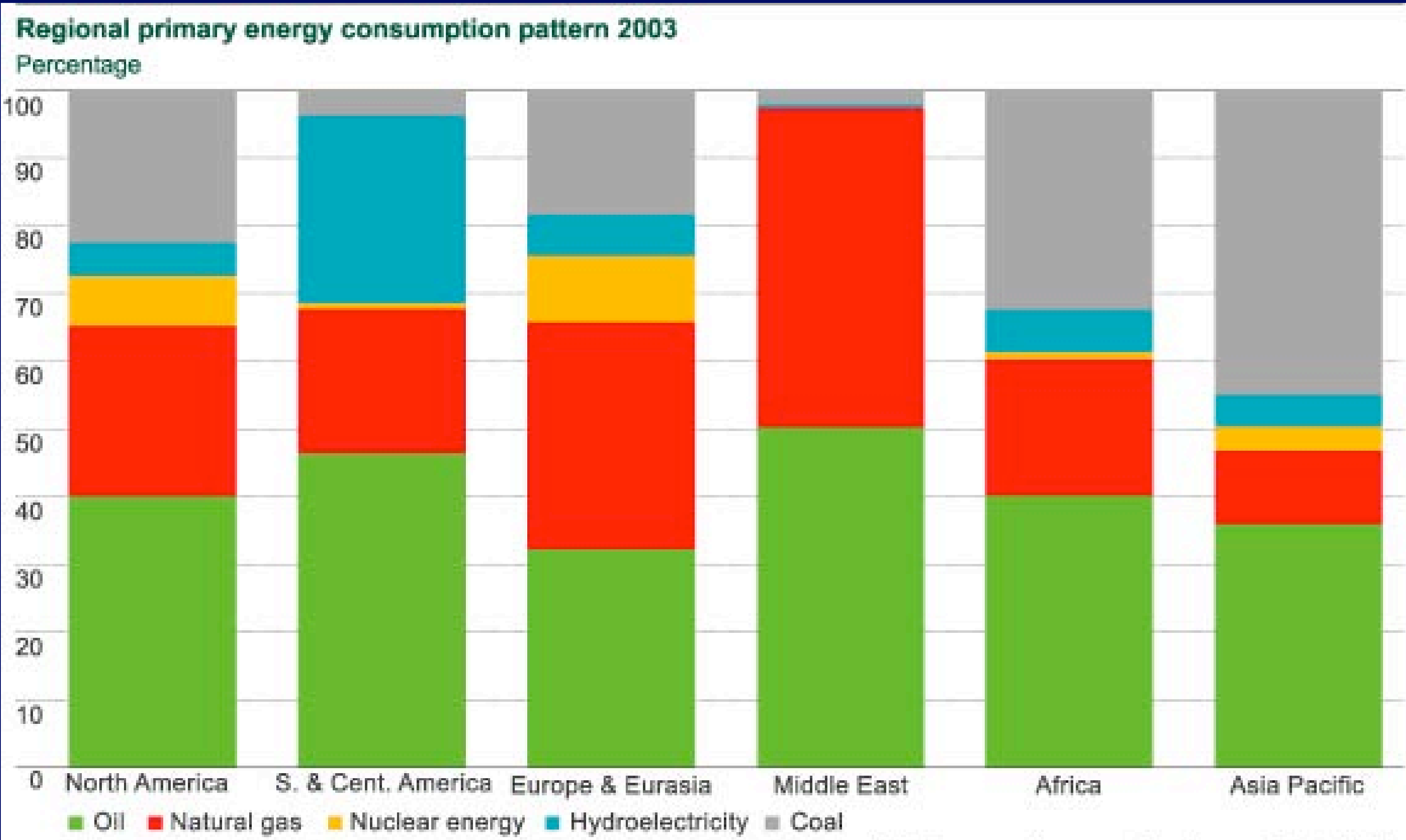
The Nation almost always produced more than enough coal for its own requirements. For many years, the United States was also self-sufficient in natural gas, but after 1967, it produced less than it consumed each year. Petroleum production fell far short of domestic demands, requiring the reliance on imported supplies.

Figure 13. Energy Imports and Exports



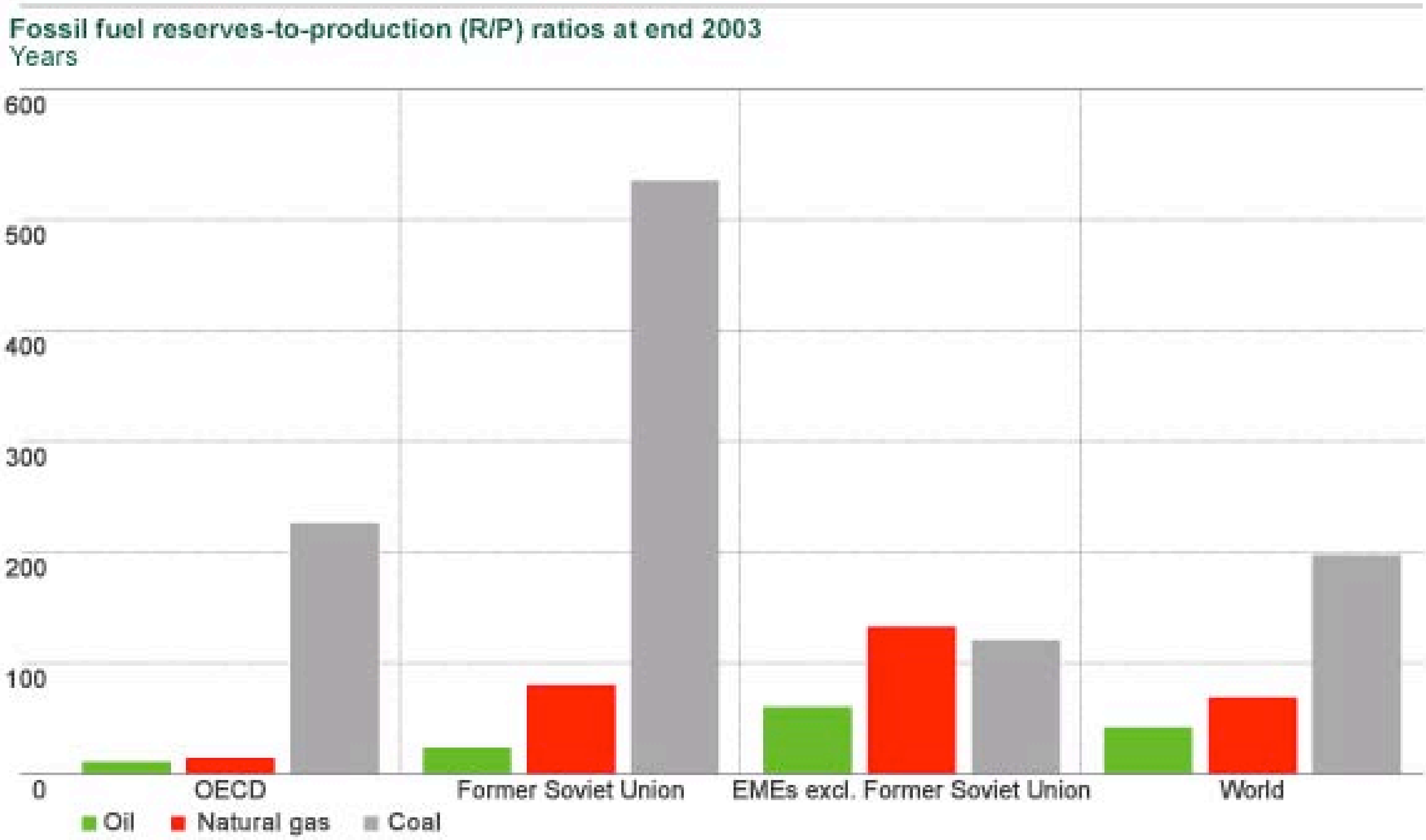
Since the mid-1950s, the Nation imported more energy than it exported. In 2003, the United States imported 31 quadrillion Btu of energy and exported 4 quadrillion Btu. Most imported energy was in the form of petroleum; since 1986, natural gas imports expanded rapidly as well. Through 1992, most exported energy was in the form of coal; after that, petroleum exports often exceeded coal exports.

Regional Primary Energy Consumption Pattern



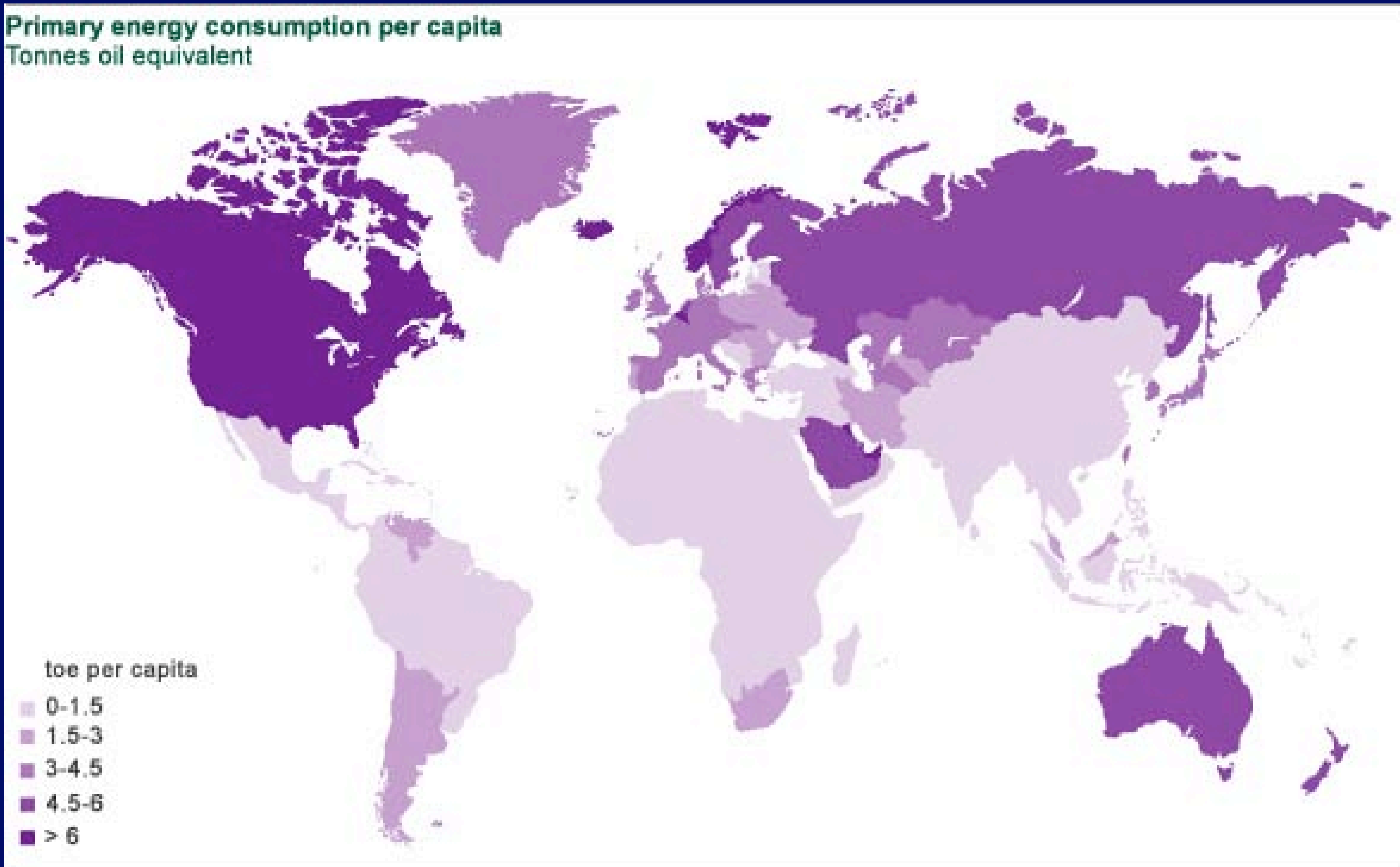
Oil remains the largest single source of energy in most parts of the world. The exceptions are the Former Soviet Union, where gas dominates and Asia Pacific where coal is the dominant fuel.

Fossil Fuel R/P ratios



The world's reserves-to-production ratio for coal is around five times that for oil and more than three times that for natural gas. Coal's dominance in reserves-to-production ratio terms is particularly pronounced in the OECD and the Former Soviet Union.

Energy Consumption per capita



Side Effects

- General Pollution of Air, Water, Land

  Makes resources less usable

  Unbreathable Air

  Undrinkable water

  Desertification of farm-lands

- Ozone Layer Destruction

  $\Longrightarrow$ UV reaches surface

  Skin Cancer, Cataracts, …

  Crop Damage

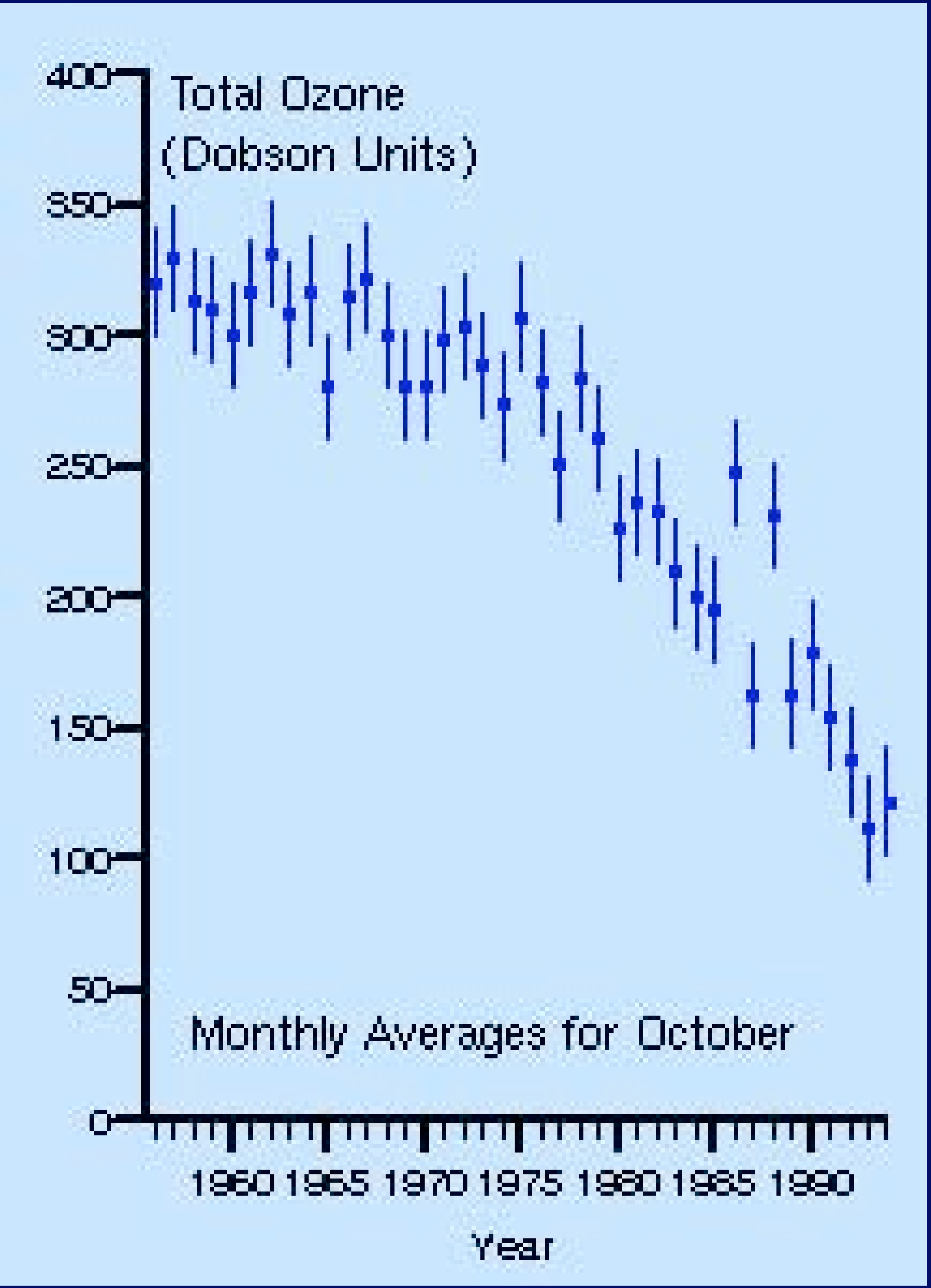
Caused by CFC's (refrigeration, styrofoam,…)
other chemicals

Stratosphere is very sensitive and
poorly understood

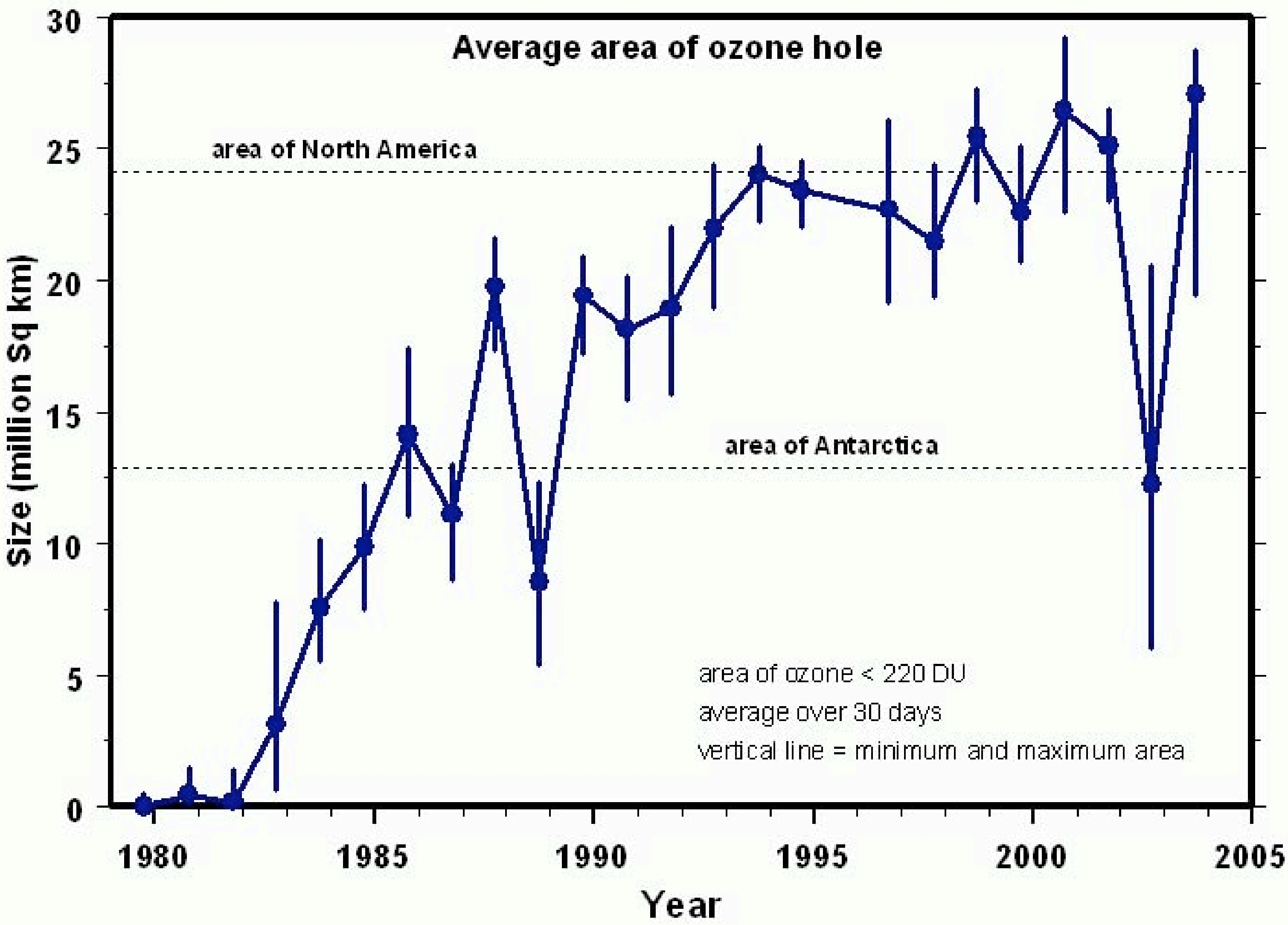
Catalytic reactions: One CFC molecule
leads to the destruction of many ozone
molecules

$O_3 \longrightarrow O_2$

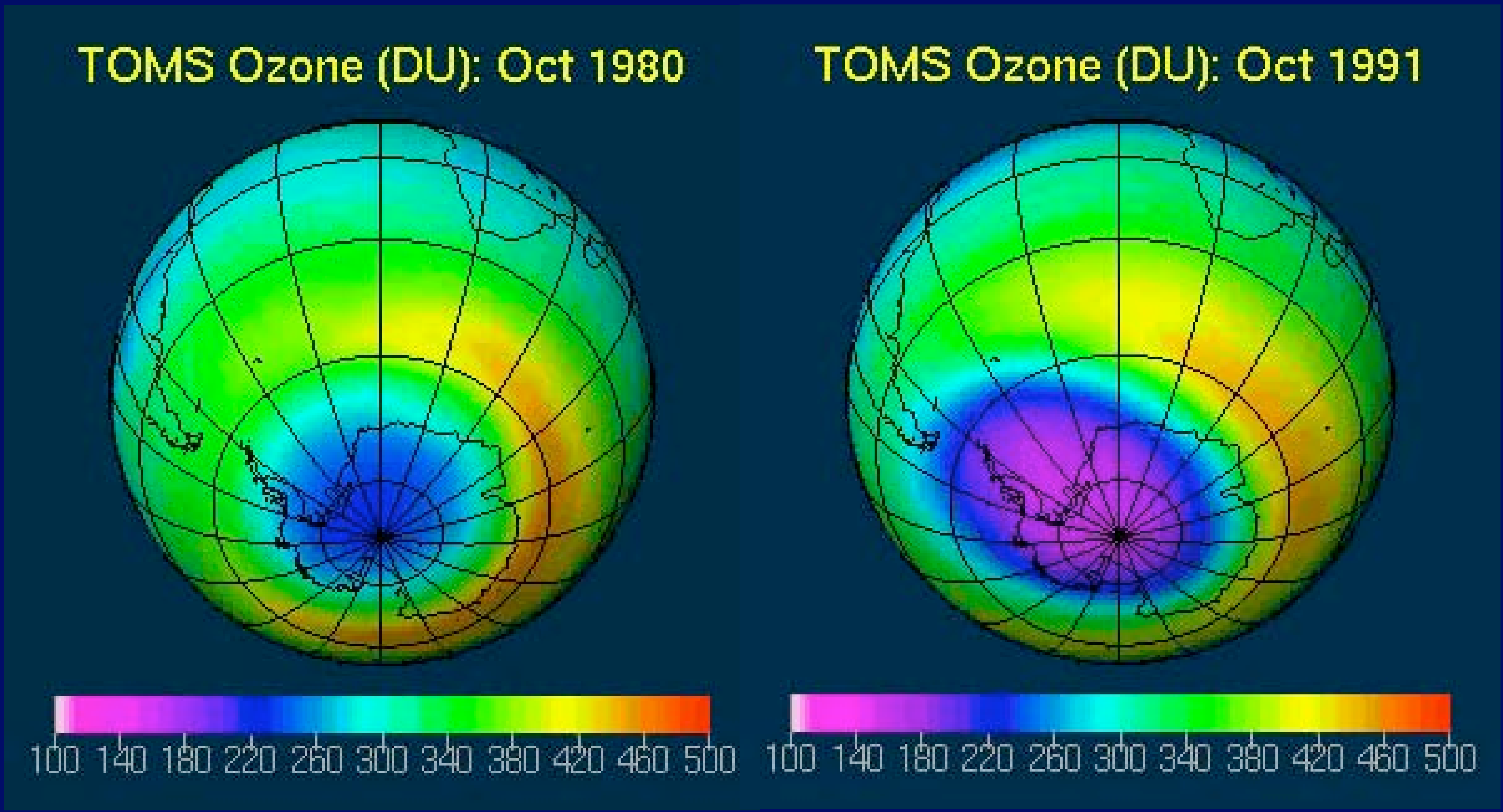
Ozone



Total Ozone
(Dobson Units)
400
350
300
250
200
150
100
50
0
Monthly Averages for October
1960 1965 1970 1975 1980 1985 1990
Year



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



TOMS Ozone (DU): Oct 1980
100 140 180 220 260 300 340 380 420 460 500
TOMS Ozone (DU): Oct 1991
100 140 180 220 260 300 340 380 420 460 500

Side Effects (cont.)

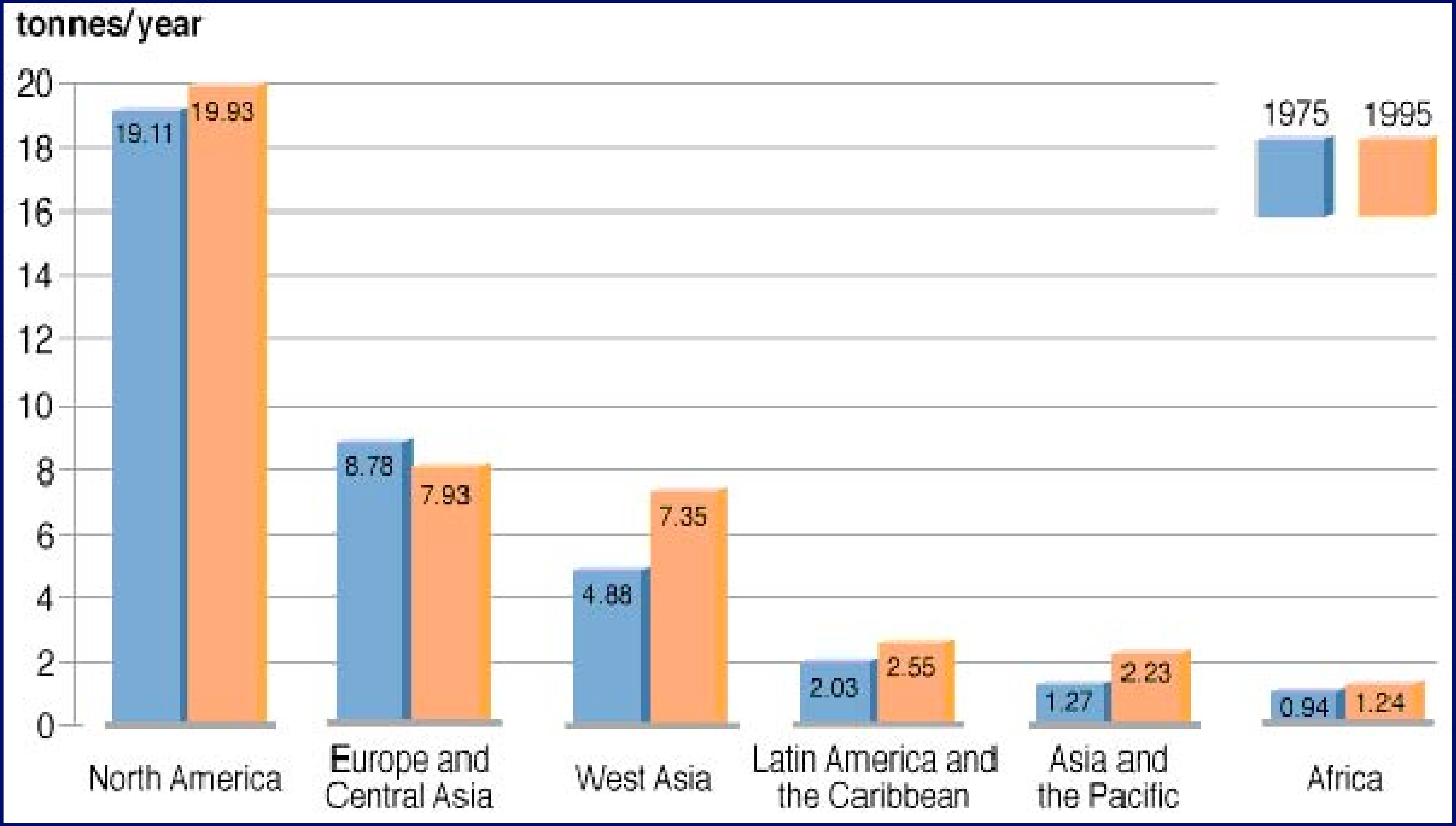
- Fossil fuels → CO_2 → Greenhouse
  (any chemical fuel)
  ↓
  Global warming

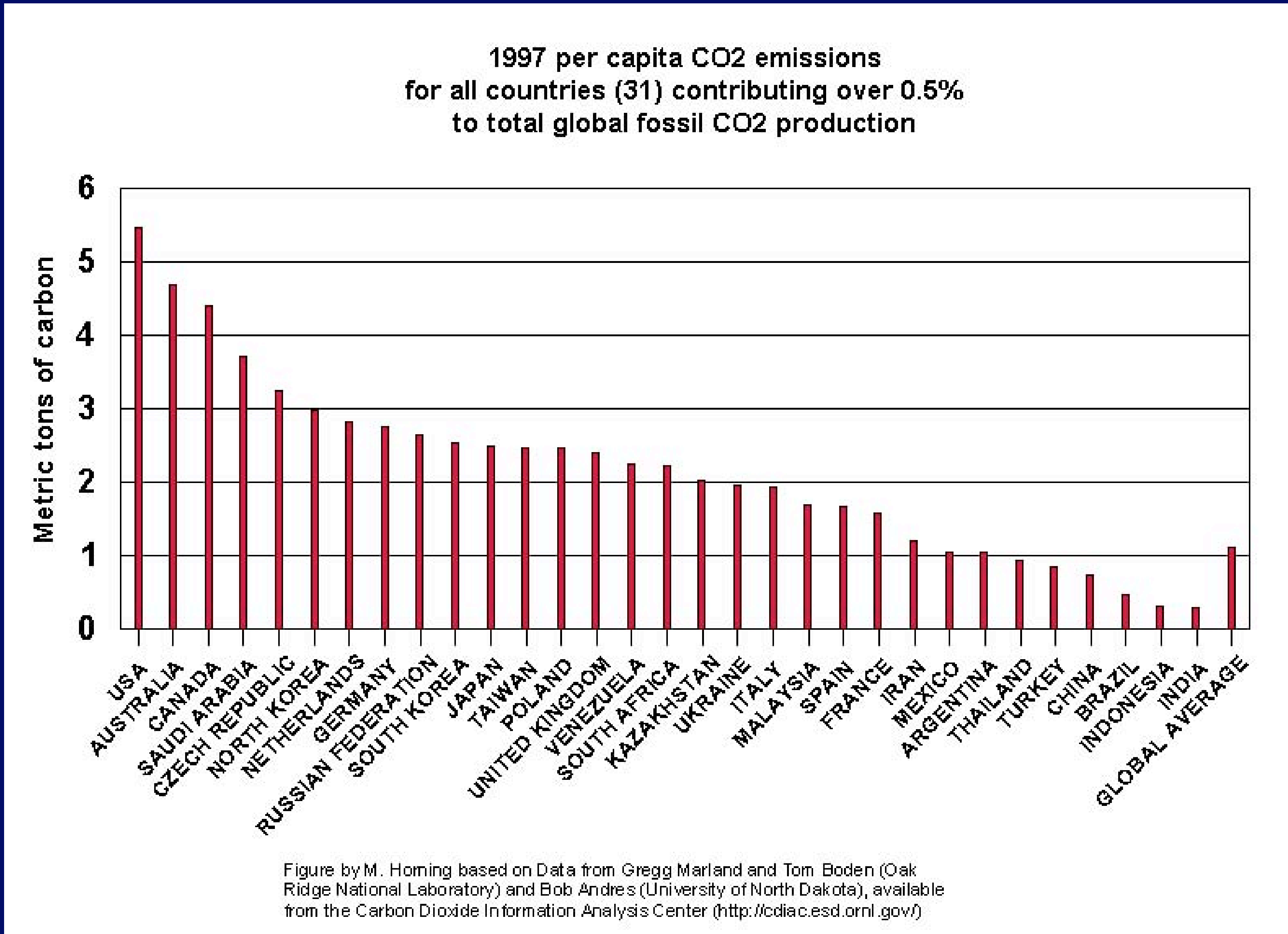
and warmer water ←

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

Climate changes: (40 - 100 yrs)
Increased desertification ←
Crop yields?
Runaway greenhouse? ←
(Earth become like Venus?)
Not likely to go this far

CO_2 Production

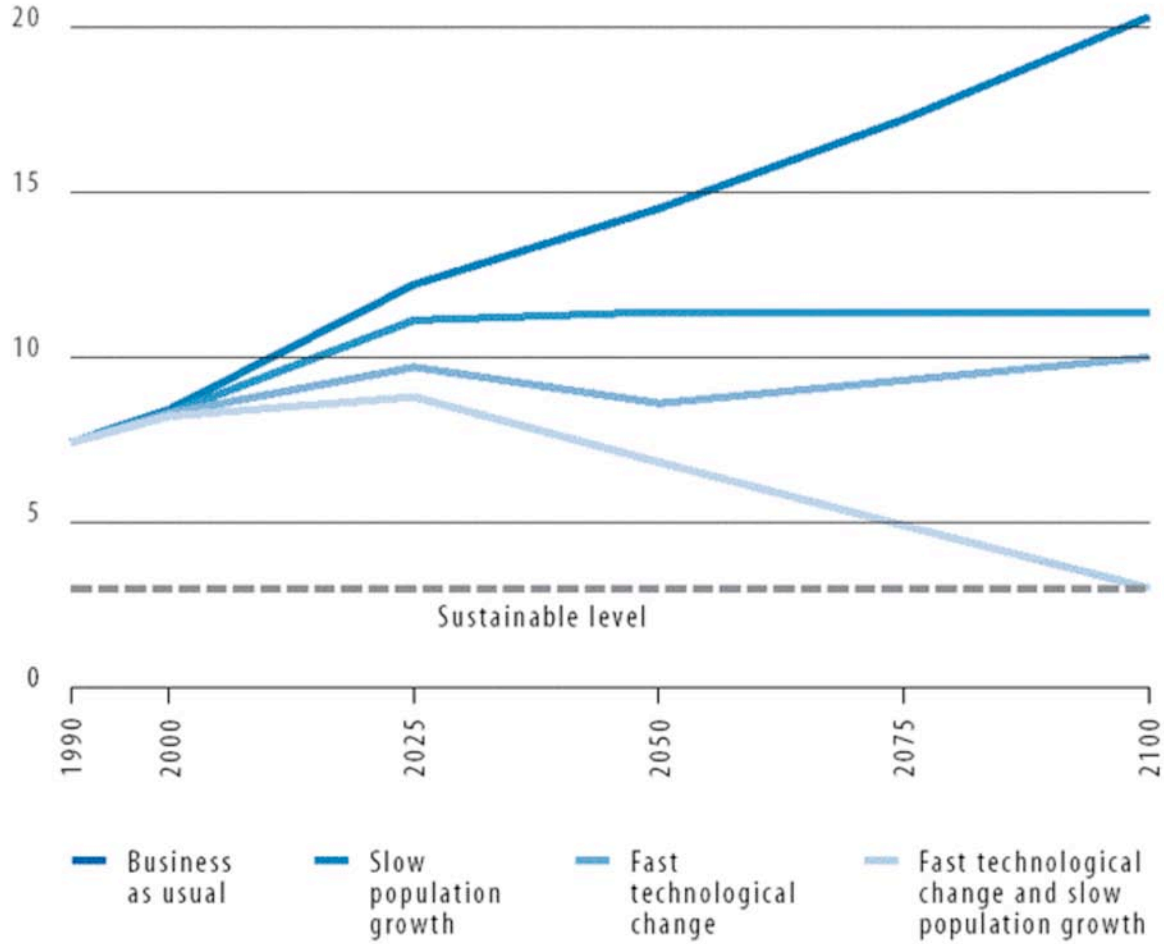




Carbon production (12/44 of CO_2)

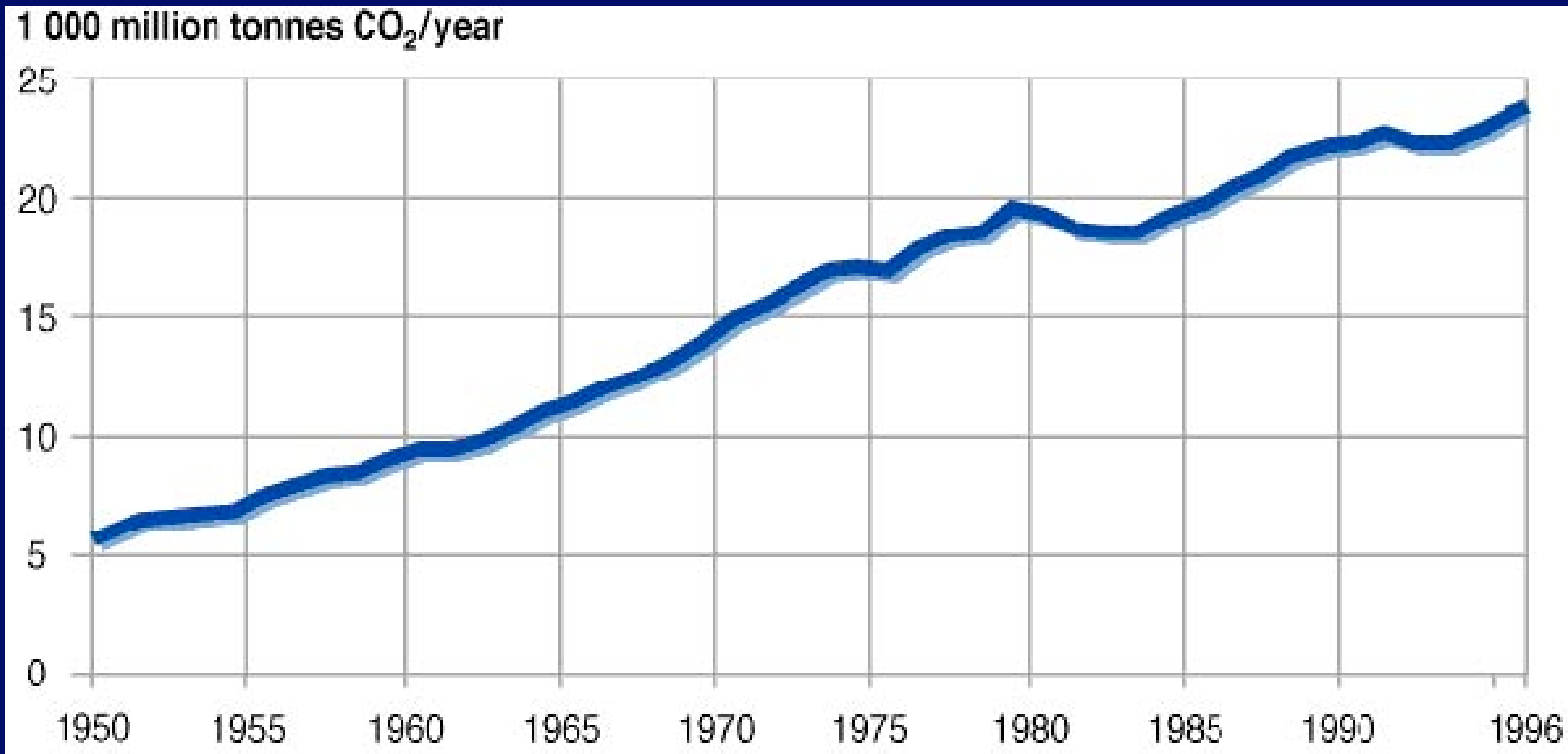
FIGURE 6: PROJECTED CO_2 EMISSIONS UNDER DIFFERENT POPULATION AND TECHNOLOGY ASSUMPTIONS, 1990-2100

(billions of metric tons of carbon)

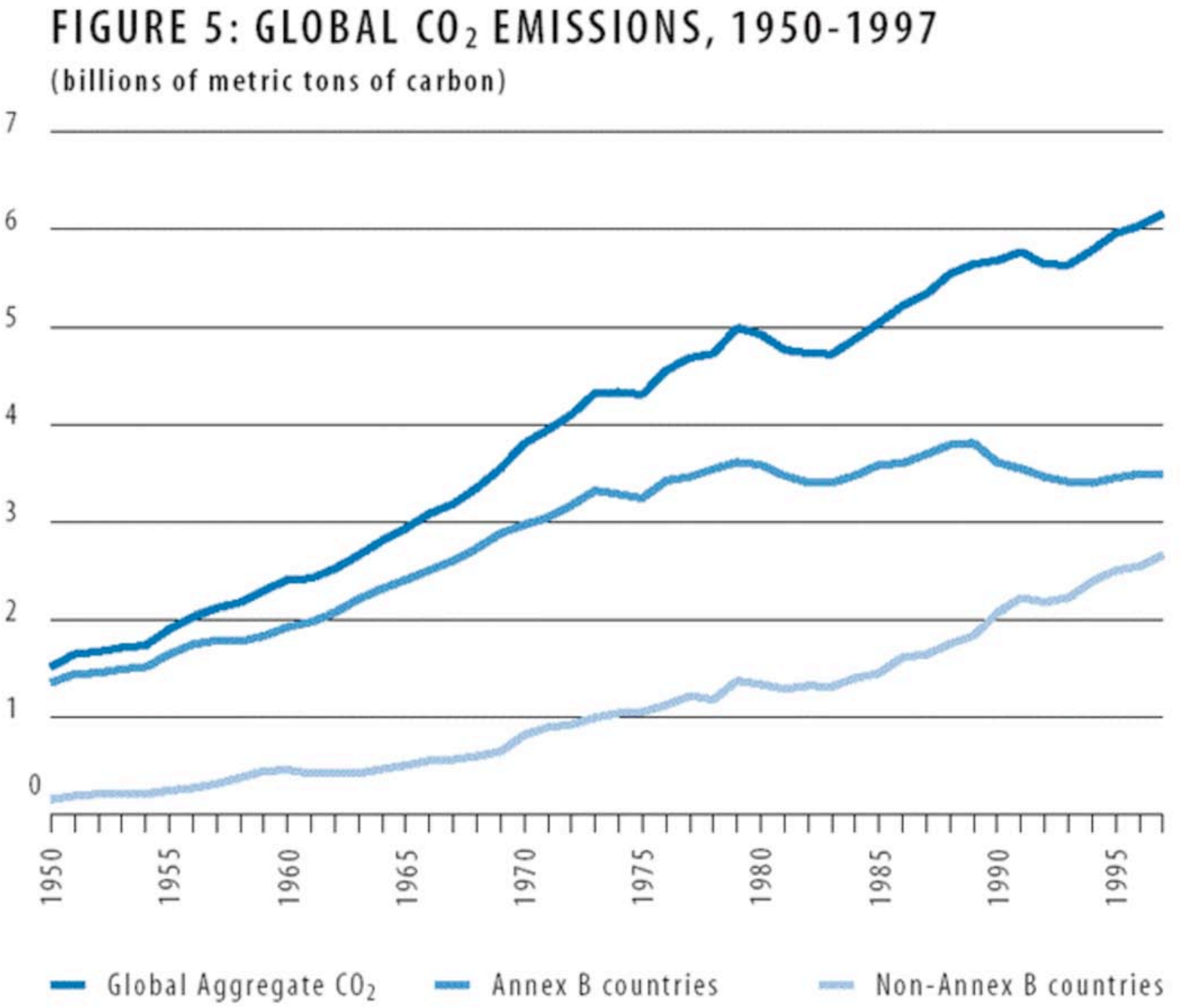


This figure expresses CO_2 emissions as elemental carbon.
1 ton elemental carbon = 33.664 tons CO_2 3.66 tons CO_2

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.*



1 000 million tonnes CO_2/year
25
20
15
10
5
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1996



Source: Meyerson, F. A. B. 2001. "Population and Climate Change Policy." *In:* Climate Change Policy: A Survey, *edited by S. Schneider, A. Rosencranz, and J. Niles. (Forthcoming.) Washington, D.C.: Island Press.*

Update on CO_2 leading to Global Warming

- 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 10° C)

Our current stable climate may not be typical of interglacials

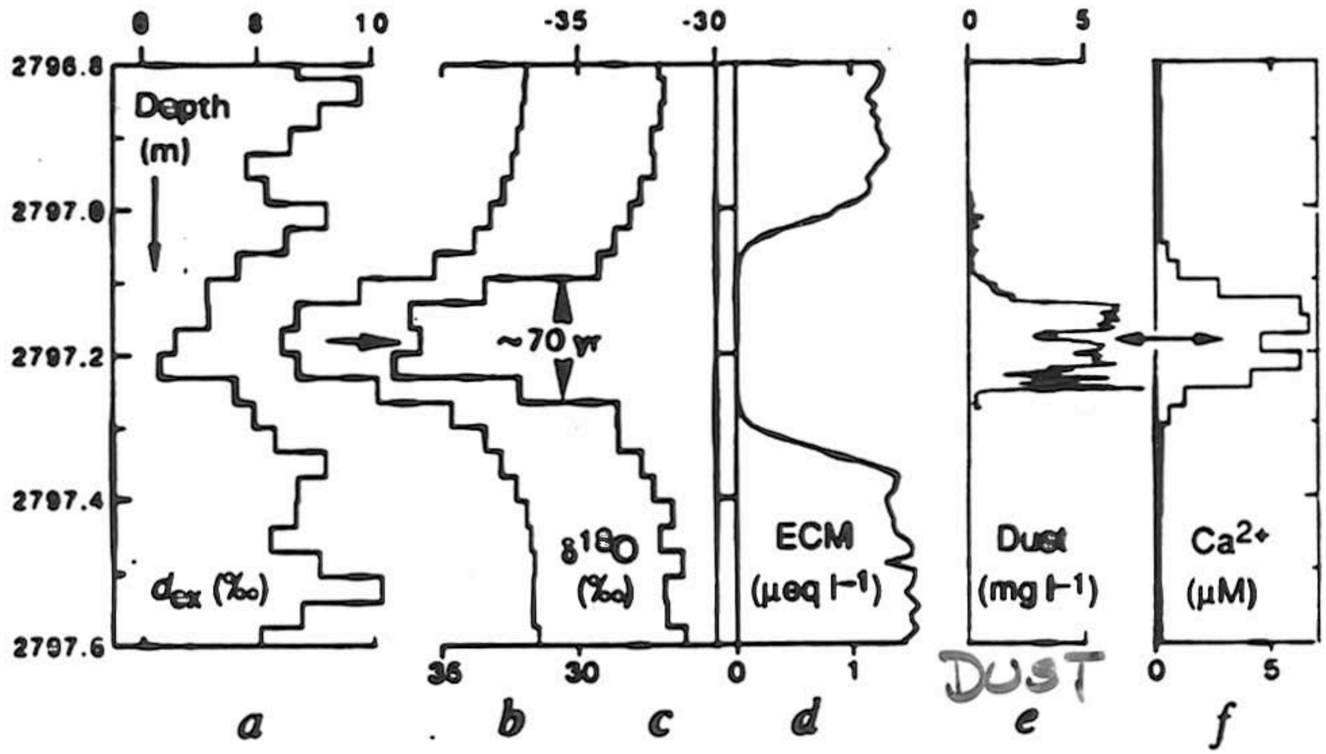
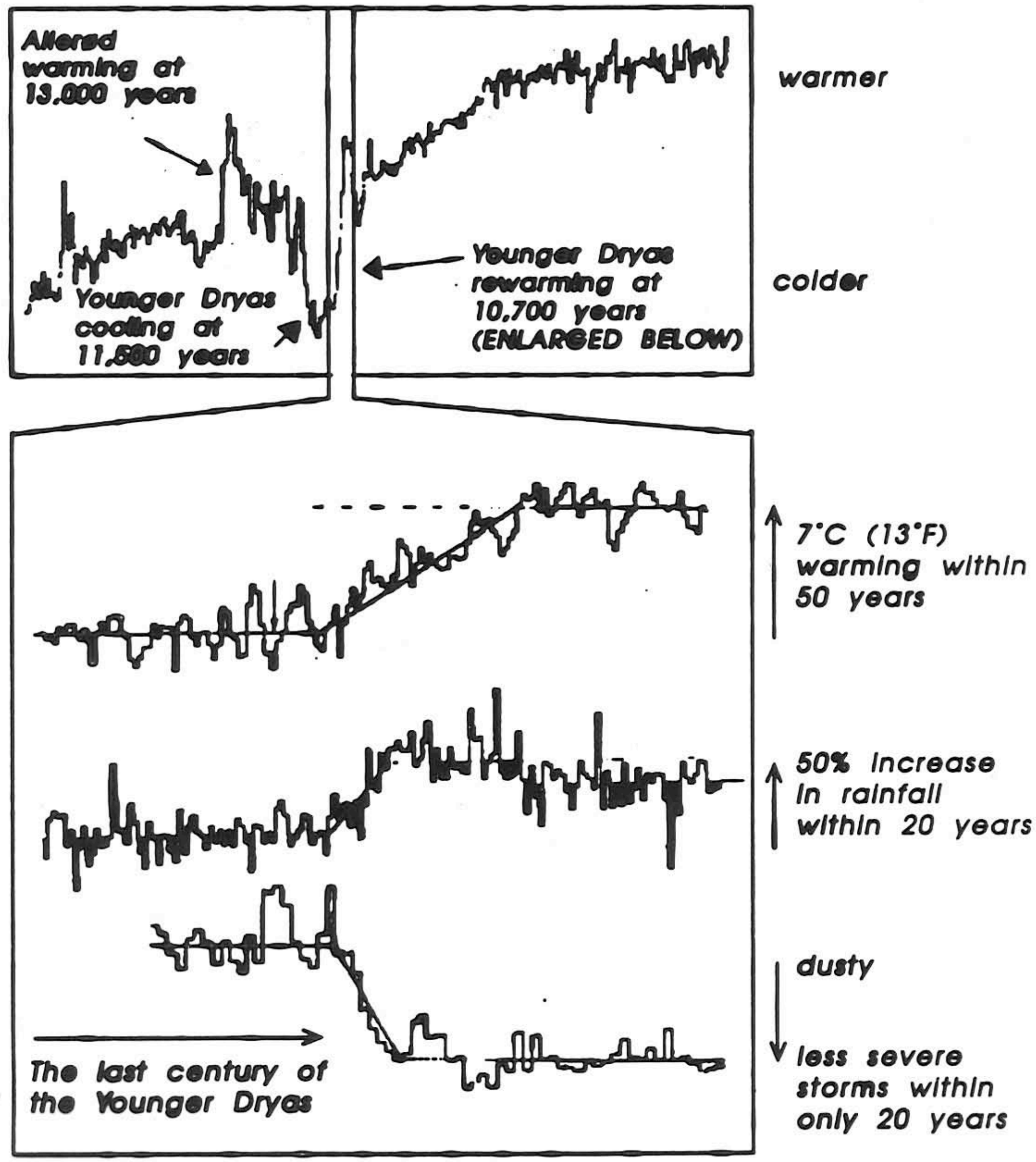


FIG. 4 Profiles of five parameters through 'event 1', a rapid climatic oscillation (~70 yr duration) at the culmination of the Eemian interglacial, ~115 kyr BP. *a*, Deuterium excess[15]; *b*, oxygen isotope ratio[7]; c, same as *b*, but deconvoluted to account for diffusion (estimated diffusion length 3 cm); *d*, acidity measured by ECM in microequivalents per litre[31]; e, dust concentration measured from scattered laser light and calibrated by Coulter Counter by integrating size distribution[33]; *f*, calcium ion concentration[38].

The abrupt termination of the Younger Dryas



A = Collapse of Pre-Pottery Neolithic Period B.

B = Late Ubaid collapse of village settlements in Mesopotamia.

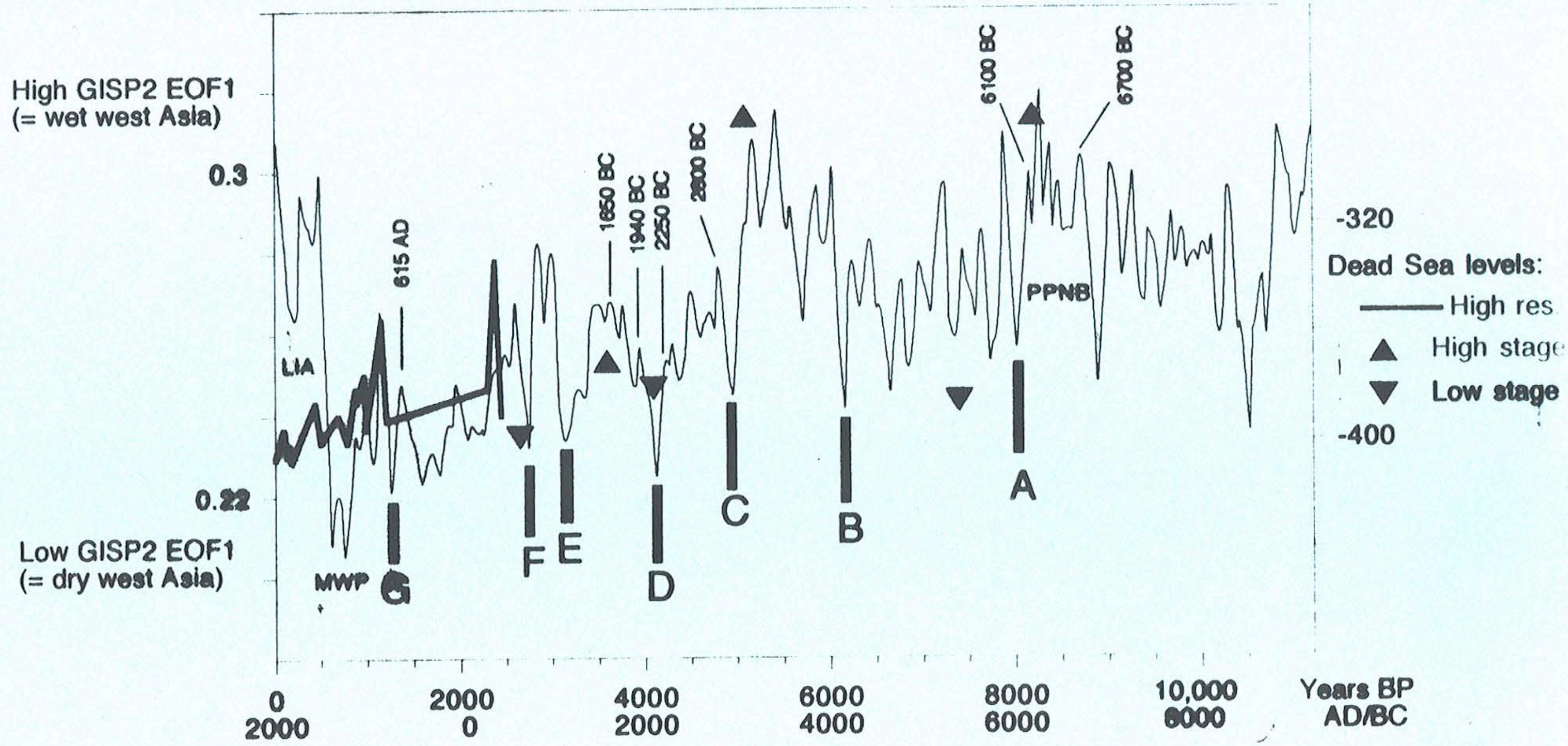
C = Late Uruk period collapse of early city states and colonies in Mesopotamia.

D = "2200 BC" collapse across Europe, Egypt, West Asia and East Asia.

E = Collapse across Europe, Egypt, West Asia and Indus Valley.

F = Assyrinan imperial expansion across Mesopotamia.

G = Collapse of Byzantine Empire and Arab expansion.



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	~ 8×10^6 (??)	0.015
~ 8000 B.C. - 1 A.D.	~ 3×10^8	0.36
1 AD - 1750 A.D.	~ 8×10^8	0.56
1750-1800	~ 1×10^9	4.4
⋮		
1950 - 1975	4×10^9	17.1
2000	6×10^9	~ 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 $\simeq$ 55 years

So doubles in 55 yrs

Quadruples (2^2) in 110 yrs, …

990 yr ($18\ t_d$) Pop = 1.3×10^{15}

~ fills land area

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

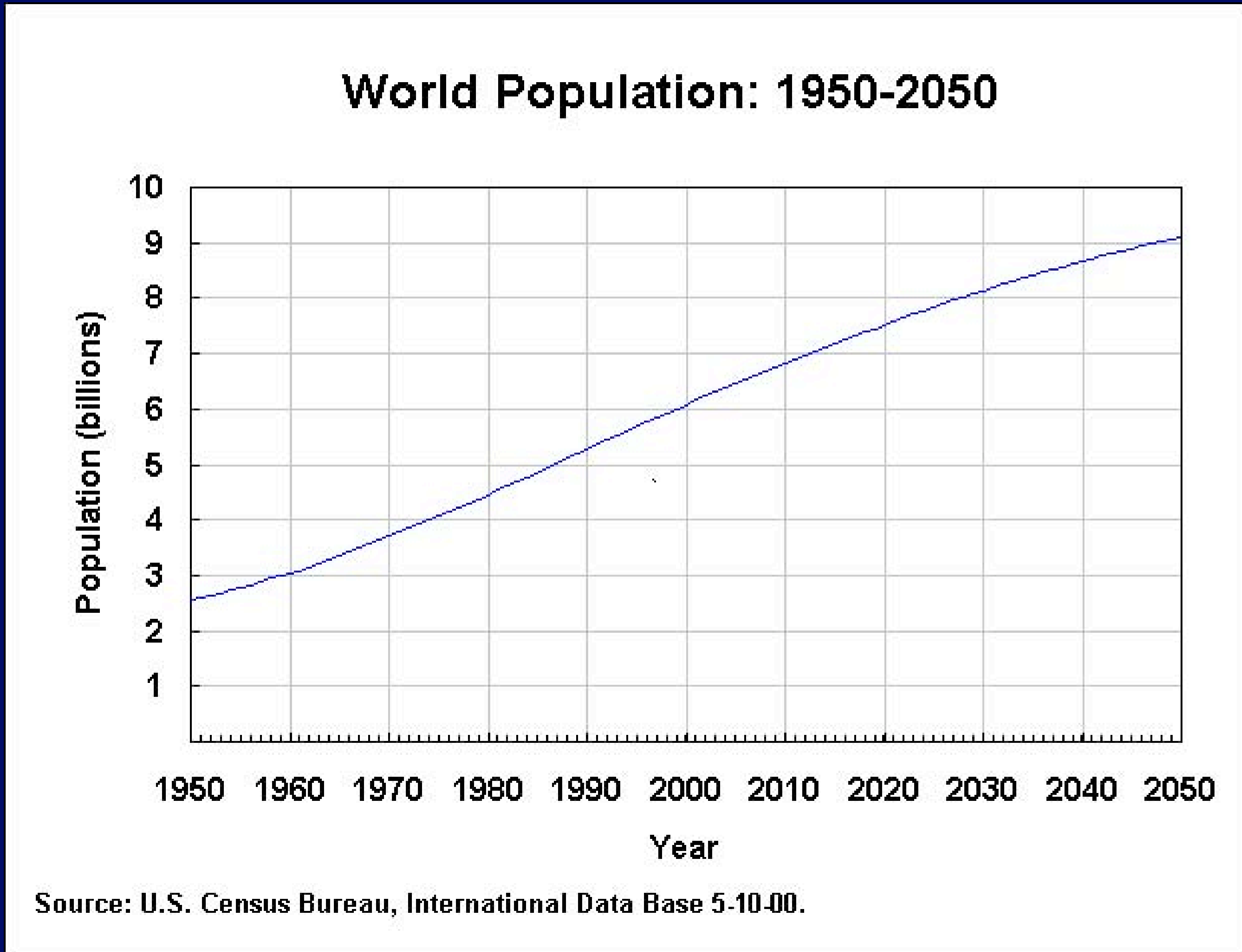
12, 375 yr ($225\ t_d$) Mass expands at c !!

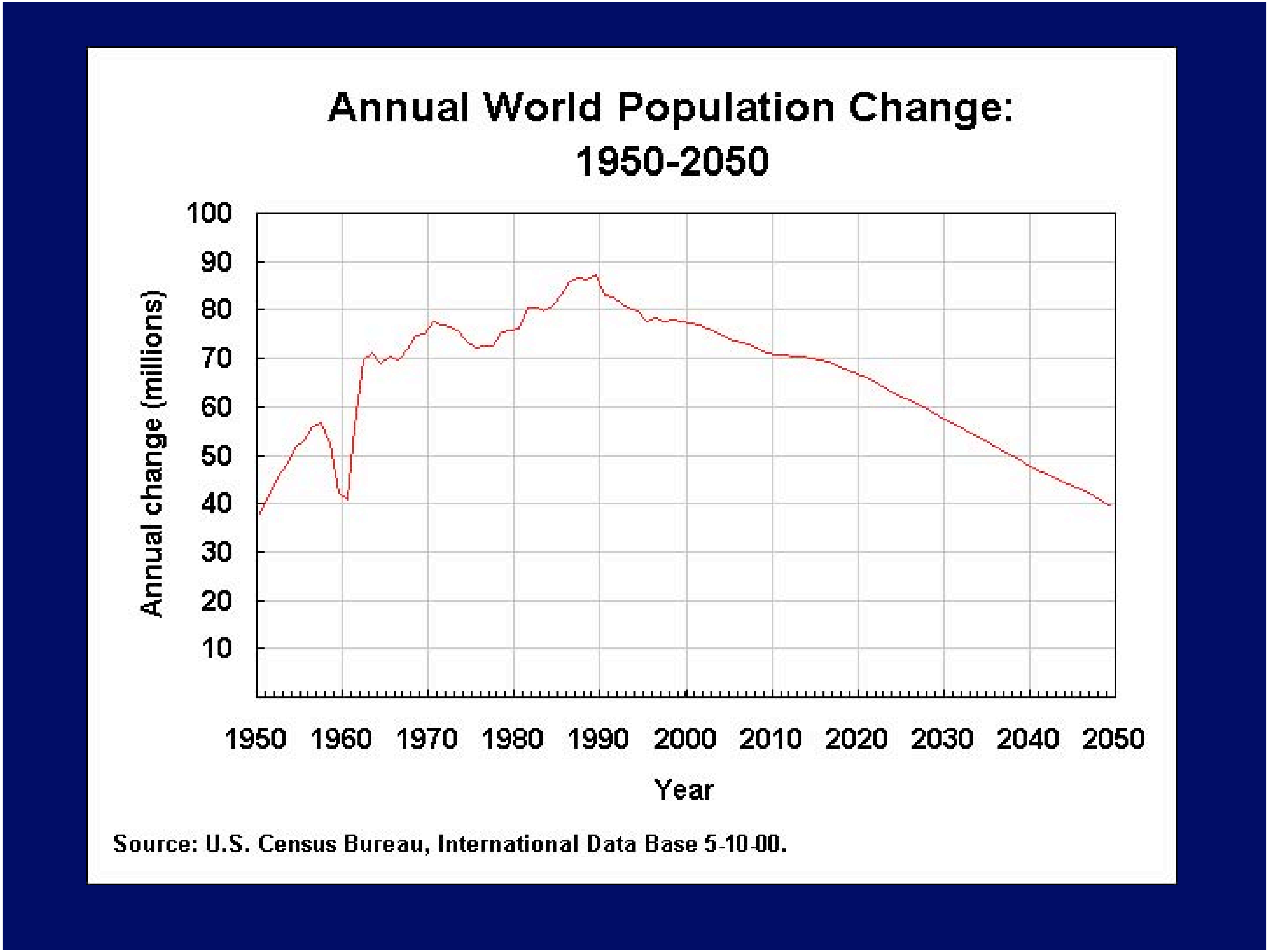
Current population growth is NOT sustainable

World Vital Events Per Time Unit: 2005

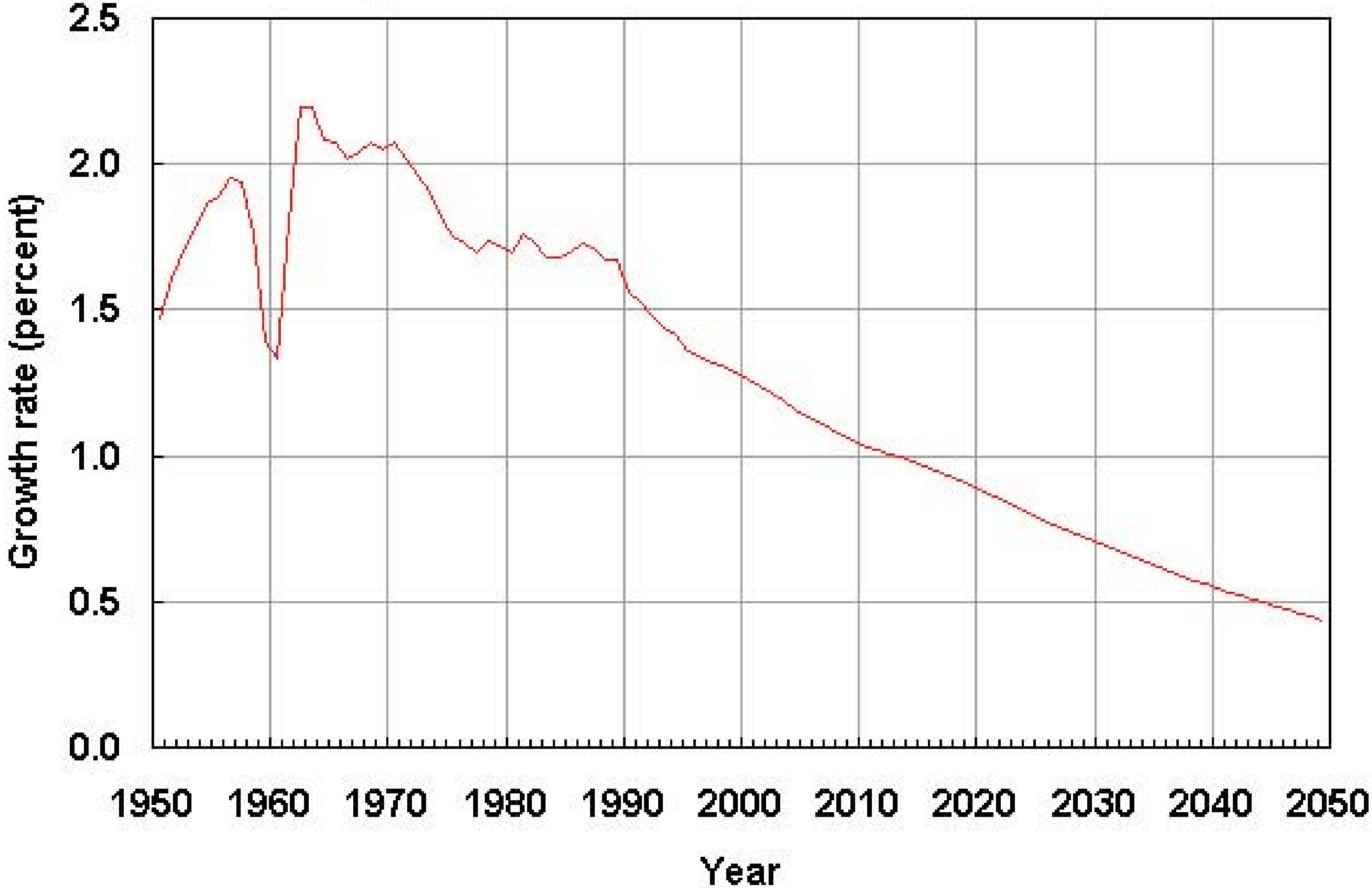
(Figures may not add to totals due to rounding)

Time unit	Births	Deaths	Natural increase
Year	129,908,352	56,622,744	73,285,608
Month	10,825,696	4,718,562	6,107,134
Day	355,913	155,131	200,782
Hour	14,830	6,464	8,366
Minute	247	108	139
Second	4.1	1.8	2.3


World Population: 1950-2050
Population (billions)
10
9
8
7
6
5
4
3
2
1
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Source: U.S. Census Bureau, International Data Base 5-10-00.

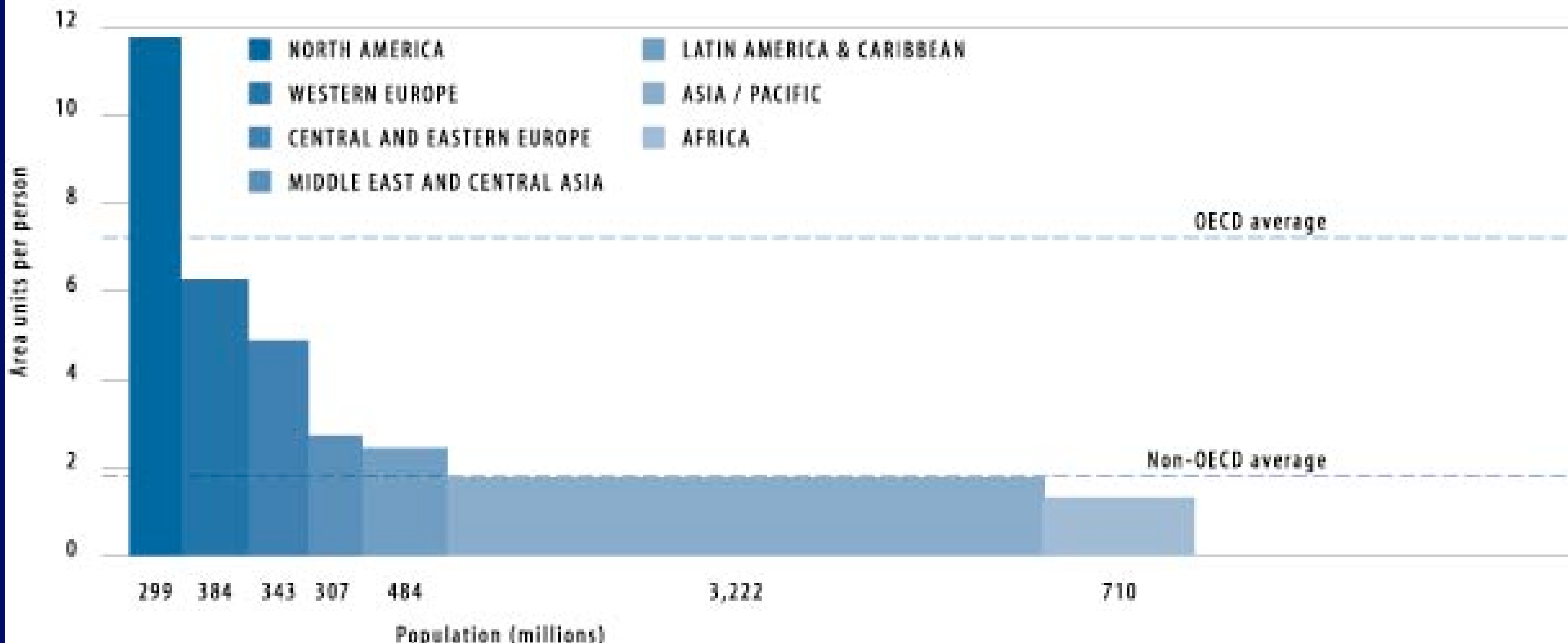

Annual World Population Change:
1950-2050
Annual change (millions)
100
90
80
70
60
50
40
30
20
10
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Source: U.S. Census Bureau, International Data Base 5-10-00.

World Population Growth Rate: 1950-2050



Source: U.S. Census Bureau, International Data Base 5-10-00.

FIGURE 7: ECOLOGICAL FOOTPRINT BY REGION, 1996

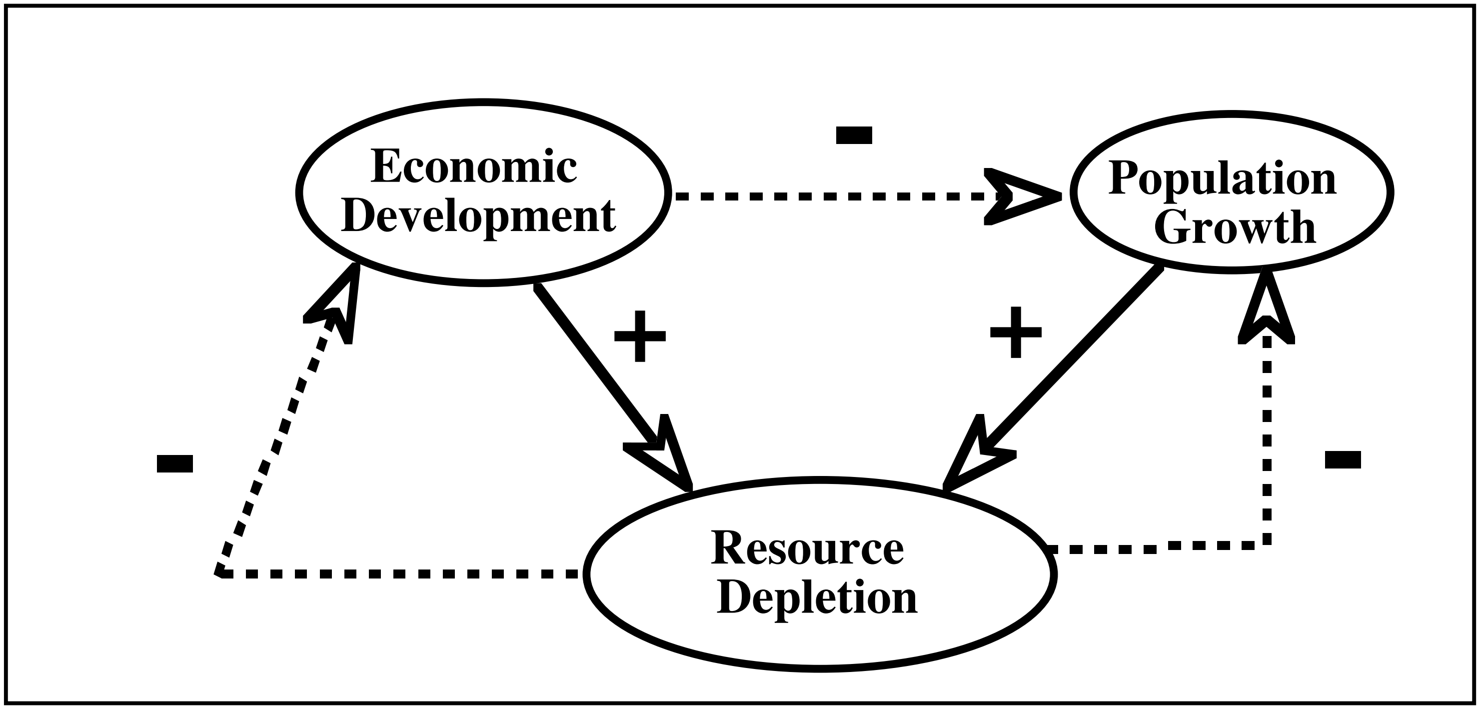


Source: World Wide Fund for Nature (WWF), United Nations Environment Programme World Conservation Monitoring Centre, Redefining Progress, Center for Sustainability Studies, and Norwegian School of Management. 2000. Living Planet Report 2000. *Gland, Switzerland: World Wide Fund for Nature*

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?

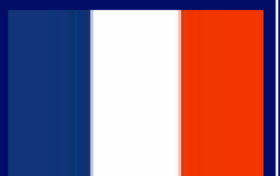
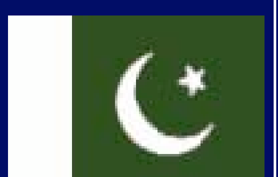
Nuclear War

Total arsenal world-wide   ~ 10,000 megatons

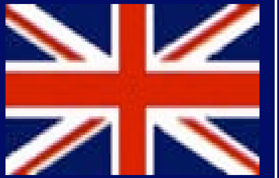
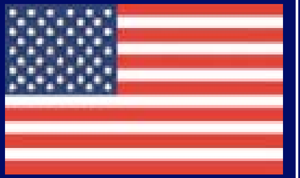
Global effects of all-out war

- 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

	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

Natural Catastrophes

Collisions

Stars? Negligible

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

Likely, but the effects are unclear

Asteroids and other debris

(comets, meteoroids, …)

Effect of Asteroid Impact:

e.g. 1/4 km radius

$V = 30 \text{ km s}^{-1}$ (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
1991BA		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 Extinctions $t \sim 100 \times 10^6$ yr ?

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

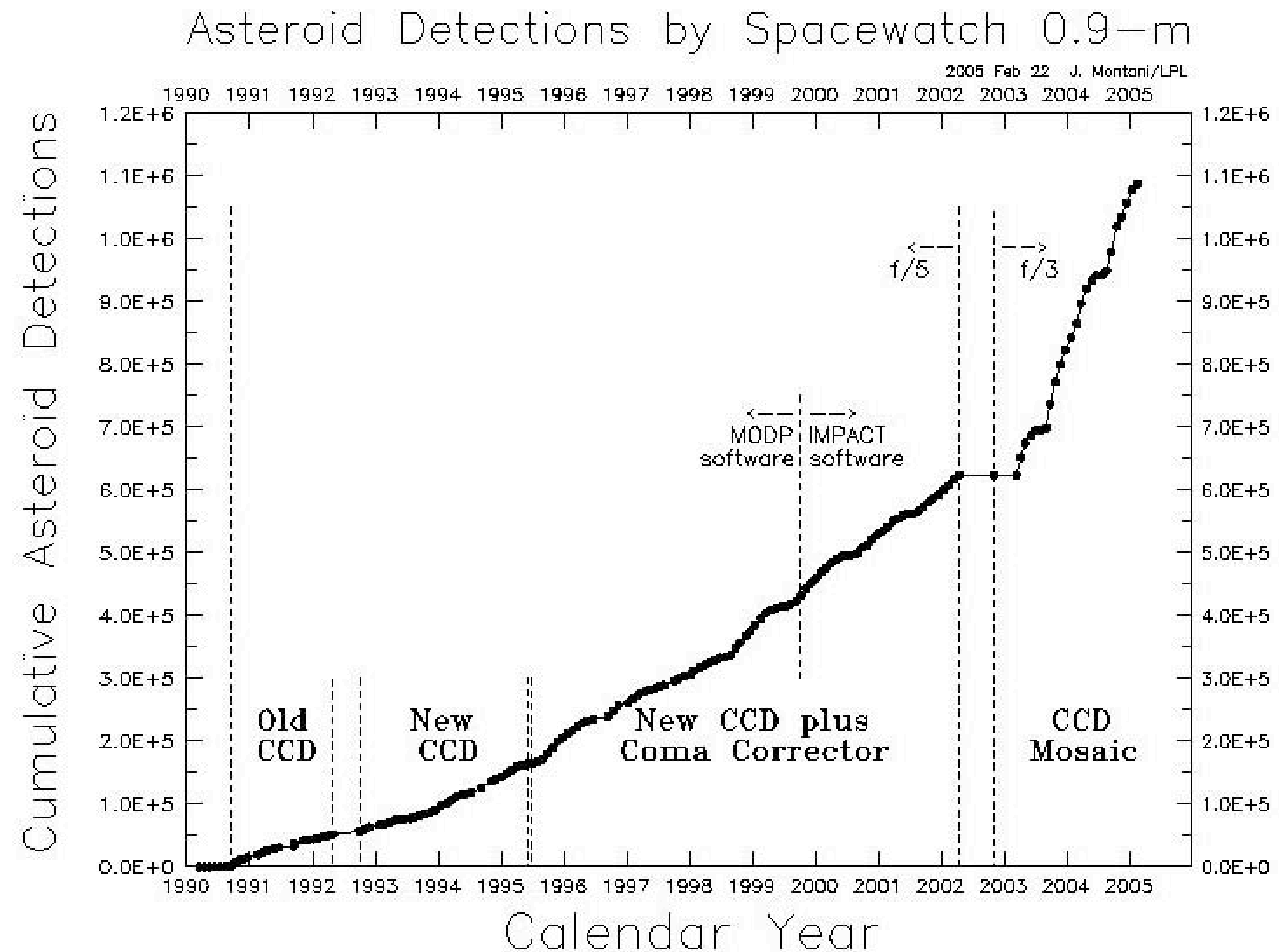
Preventable by advanced civilization?

1991 BA $\sim$ 40 kilotons TNT (3 $\times$ Hiroshima)

50 meter objects - once per century

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

Spacewatch Detections

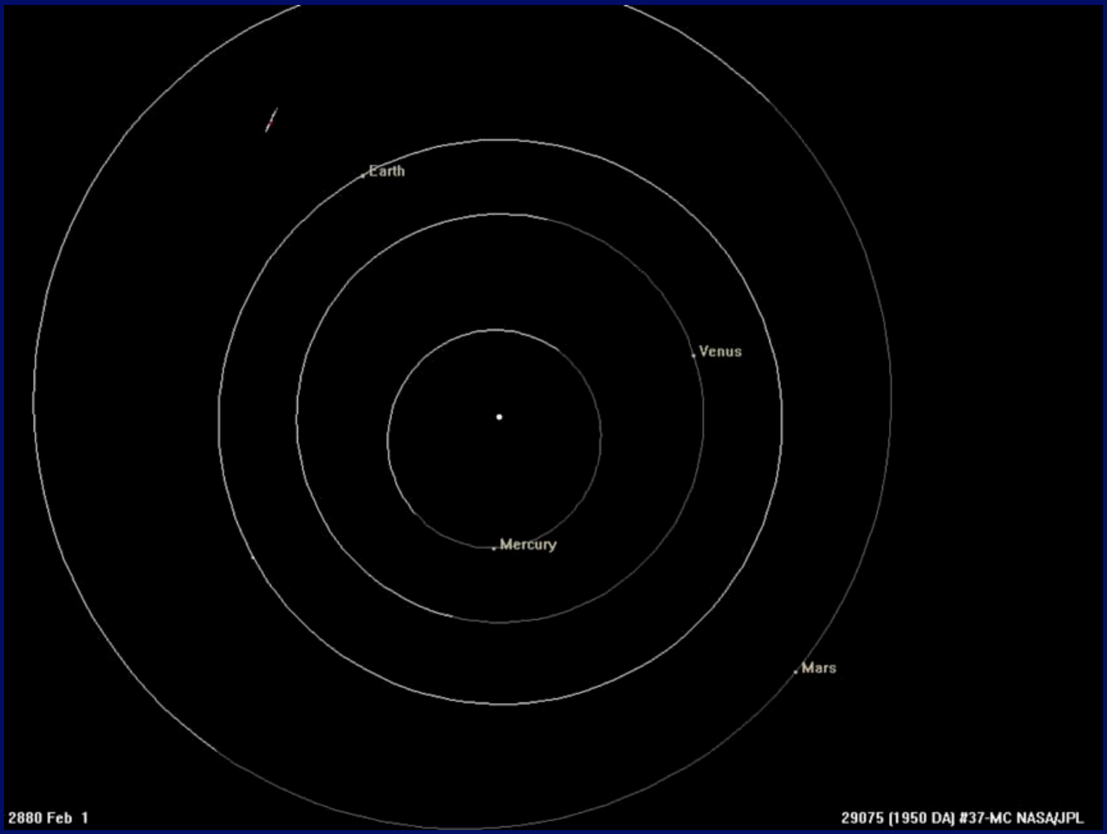


Most Dangerous Known Asteroid

1950 DA

Radar used to map orbit
~ 1 km in diameter

Close approach in Yr 2880



Probability of collision ~ 0.33%

$V \sim 14$ km s^{-1} $E \sim 10^5$ Megatons

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

Stellar Evolution

4-5 billion yrs - Sun will become a Red Giant

Before that, gradual increase in L_{sun}

and possible cyclic variations

Repeated ice ages $\sim 10^5$ yrs - 10^6 yrs

changes in L_{sun} or Earth orbit may be responsible

Gradual increase could lead to evaporation of oceans

UV + $H_2O \longrightarrow$ 2H + O   H $\longrightarrow$ space

Loss of water in $\sim 1 - 2 \times 10^9$ yr

Could advanced civilization delay this?
(Decrease greenhouse, add dust)

Move to Mars?

Nearby star $\longrightarrow$ supernovae within 30 ly,
could destroy ozone
Expect $\sim 2 \times 10^9$ yr

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

~ 5 $\times 10^9$ yr

3. Off main sequence leads to Red Giant -----------> atmosphere evaporates

Other stars

$\sim 2 \times 10^9$ yr

Nearby star leads to Supernova

within 30 ℓy ozone is destroyed

Ultimate Limits

1-2 $\times 10^9$	Loss of H2O Move within Solar System
4-5 $\times 10^9$ yr	Sun becomes a Red Giant loss of atmosphere move to a different star

If Universe Closed, recollapses

~ 10^{12}	Big Crunch (unlikely)

If open, expands forever

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

- For number of civilizations now,
  $L \leq 5 \times 10^9$ yrs -
  [age of galaxy – time to evolve]

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