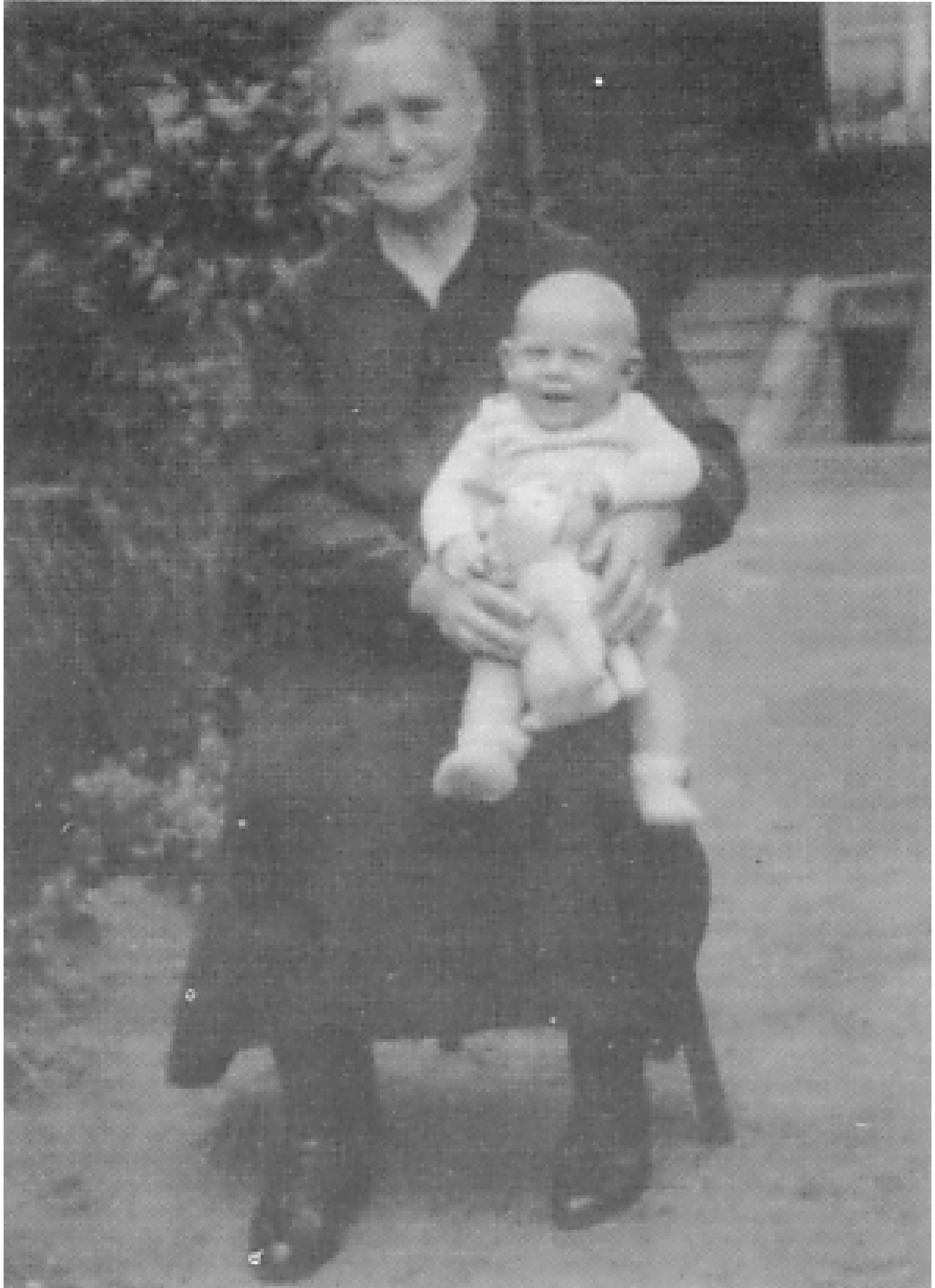


World Population (thousand million) and Annual growth (% per year)

1820	1	
		0.5
1850	1.2	
		0.6
1900	1.6	
		0.8
1950	2.5	
		1.8
1990	5.3	
		1.5
2000	6.0	

- During the past 3 centuries human population has increased tenfold to 6000 million and fourfold in the 20th century
- Cattle population increased to 1400 million (one cow/family); by a factor of 4 during the past century
- Urbanisation grew more than tenfold in the past century; almost half of the people live in cities and megacities
- Industrial output increased 40 times during the past century; energy use 16 times
- Almost 50 % of the land surface has been transformed by human action
- Water use increased 9 fold during the past century to 800 m^3 per capita; 65 % for irrigation, 25 % industry, ~10 % households

- Human appropriation of terrestrial net primary productivity ~ 30%, but with large uncertainties 3-39%, Vitousek et al., Science, 494, 1997; 10-55%, Rojstaczer et al., Science, 2549, 2001
- Fish catch increased 40 times
- The release of SO_2 (160 Tg/year) by coal and oil burning is at least twice the sum of all natural emissions; over land the increase has been 7 fold, causing acid rain, health effects, poor visibility, and climate changes due to sulfate aerosols
- Releases of NO to the atmosphere from fossil fuel and biomass burning is larger than its natural inputs, causing high surface ozone levels over extensive regions of the globe
- Several climatically important ”greenhouse gases” have substantially increased in the atmosphere, eg. CO_2 by 30 %, CH_4 by more than 100 %.

WEEKLY | NEWS IDEAS INNOVATION | THE BEST JOBS IN SCIENCE

NewScientist

25 February 2006

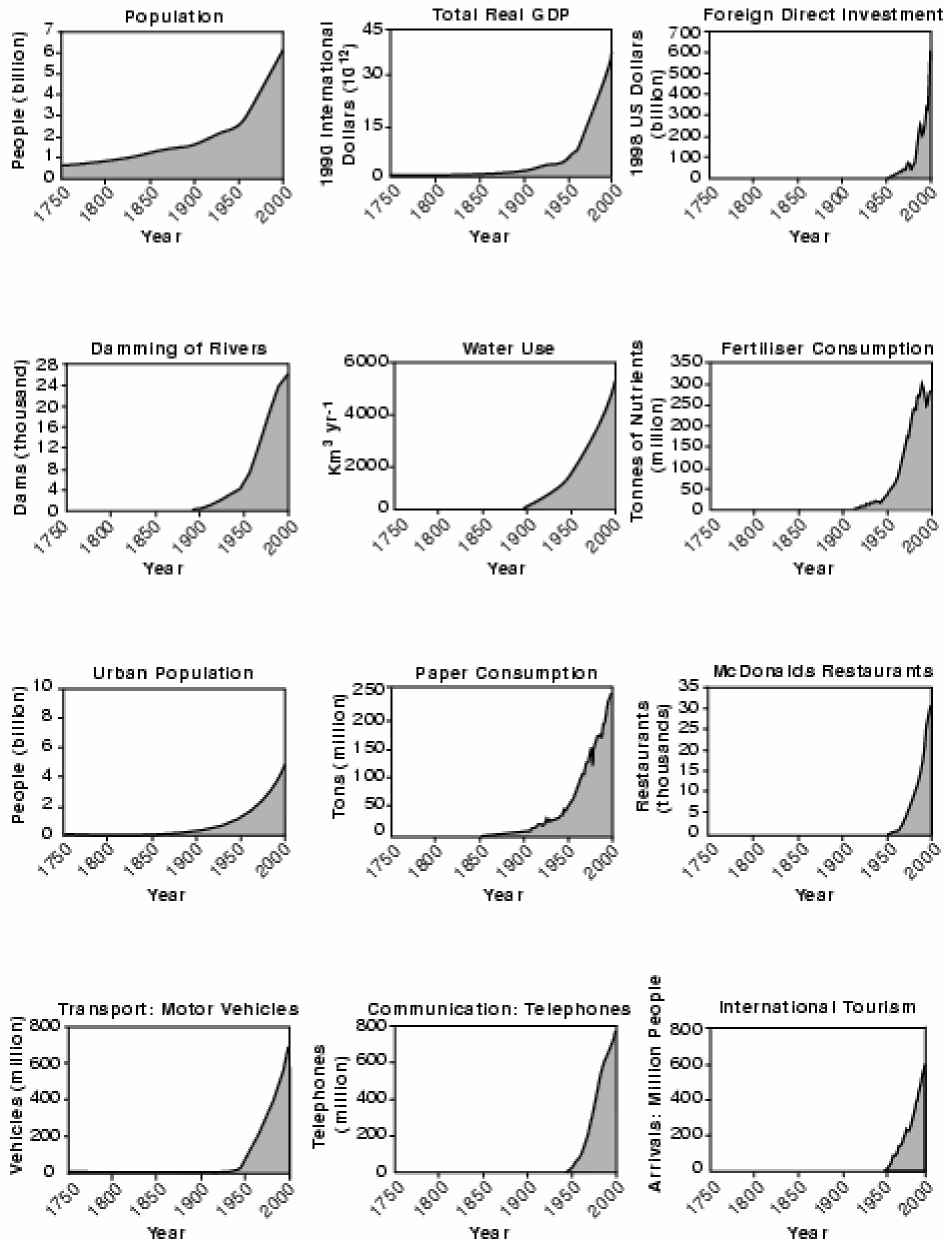
It takes **20,000 litres** of water to grow 1 kilo of coffee,

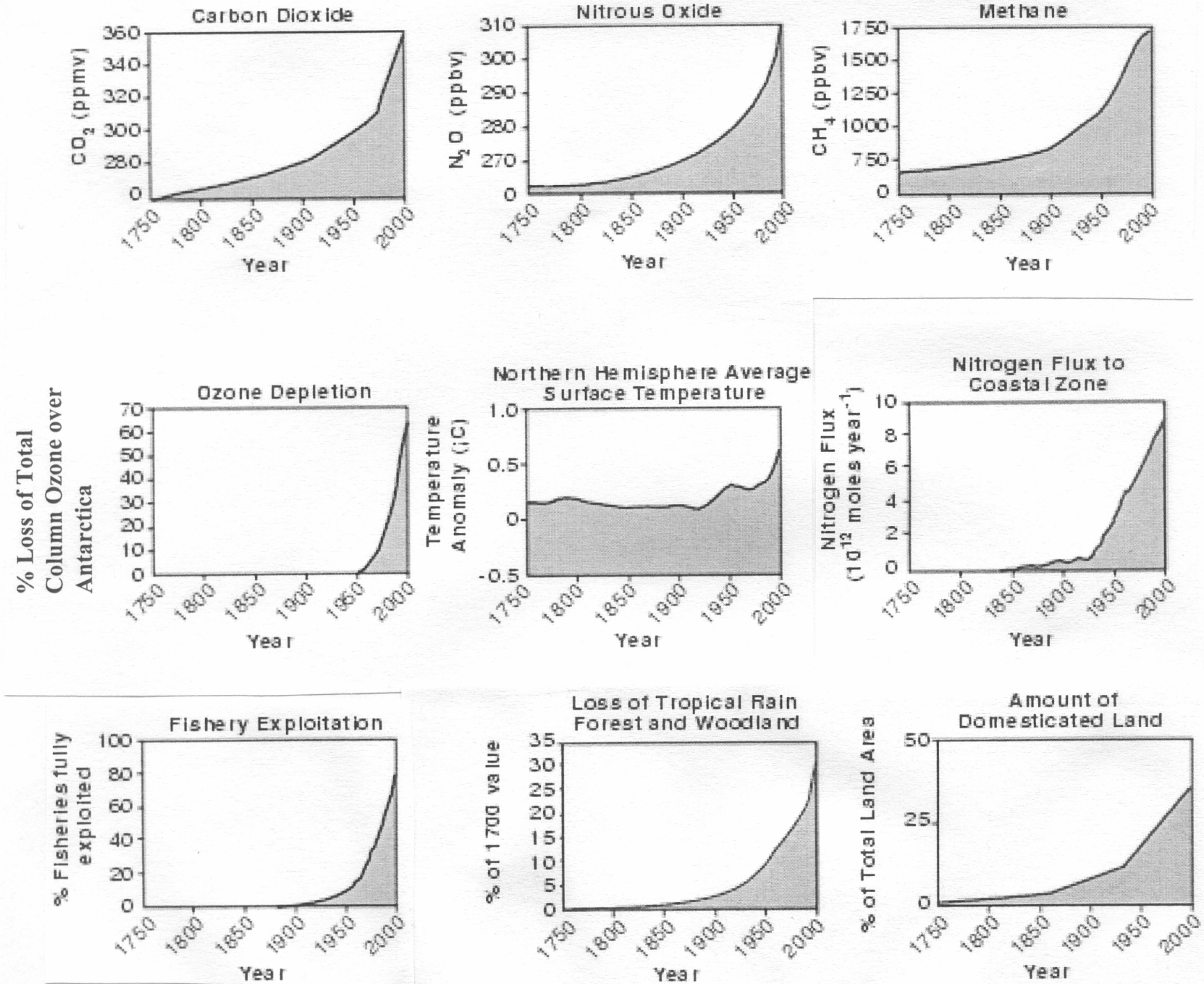
11,000 litres of water to

make a quarter pounder,

and **5000 litres** of water to make 1 kilo of cheese

No wonder the Earth is running dry...


Population
People (billion)
Total Real GDP
1990 International Dollars (10^{12})
Foreign Direct Investment
1998 US Dollars (billion)
Damming of Rivers
Dams (thousand)
Water Use
$Km^3\ yr^{-1}$
Fertiliser Consumption
Tonnes of Nutrients (million)
Urban Population
People (billion)
Paper Consumption
Tons (million)
McDonalds Restaurants
Restaurants (thousands)
Transport: Motor Vehicles
Vehicles (million)
Communication: Telephones
Telephones (million)
International Tourism
Arrivals: Million People
Year



Carbon Dioxide
CO_2 (ppmv)
360
340
320
300
280
0
1750
1800
1850
1900
1950
2000
Year
Nitrous Oxide
N_2O (ppbv)
310
300
290
280
270
0
Methane
CH_4 (ppbv)
1750
1500
1250
1000
750
0
Ozone Depletion
% Loss of Total Column Ozone over Antarctica
70
60
50
40
30
20
10
0
Northern Hemisphere Average Surface Temperature
Temperature Anomaly (¡C)
1.0
0.5
0
-0.5
Nitrogen Flux to Coastal Zone
Nitrogen Flux (10^{12} moles year^{-1})
10
8
6
4
2
0
Fishery Exploitation
% Fisheries fully exploited
100
80
60
40
20
0
Loss of Tropical Rain Forest and Woodland
% of 1700 value
35
30
25
20
15
10
5
0
Amount of Domesticated Land
% of Total Land Area
50
25
0

- Humanity is also responsible for the presence of many toxic substances in the environment and even some which are not toxic at all, but which have, nervetheless, led to the ozone hole.
- Among the „greenhouse gases“ are also the almost inert CFC (chlorofluorocarbon) gases. However, their photochemical breakdown in the stratosphere gives rise to highly reactive chlorine atoms, which destroy ozone by catalytic reactions. As a consequence UV-B radiation from the sun increases, leading for instance to enhanced risk of skin cancer.

Coral Reef Death During the 1997 Indian Ocean Dipole Linked to Indonesian Wildfires

Nerilie J. Abram,[1*] Michael K. Gagan,[1] Malcolm T. McCulloch,[1] John Chappell,[1] Wahyoe S. Hantoro[2]

Geochemical anomalies and growth discontinuities in *Porites* corals from western Sumatra, Indonesia, record unanticipated reef mortality during anomalous Indian Ocean Dipole upwelling and a giant red tide in 1997. Sea surface temperature reconstructions show that although some past upwelling events have been stronger, there were no analogous episodes of coral mortality during the past 7000 years, indicating that the 1997 red tide was highly unusual. We show that iron fertilization by the 1997 Indonesian wildfires was sufficient to produce the extraordinary red tide, leading to reef death by asphyxiation. These findings highlight tropical wildfires as an escalating threat to coastal marine ecosystems.

Long-Term Region-Wide Declines in Caribbean Corals

Toby A. Gardner,[1,3] Isabelle M. Côté,[1*] Jennifer A. Gill,[1,2,3] Alastair Grant,[2] Andrew R. Watkinson[1,2,3]

We report a massive region-wide decline of corals across the entire Caribbean basin, with the average hard coral cover on reefs being reduced by 80%, from about 50% to 10% cover, in three decades. Our meta-analysis shows that patterns of change in coral cover are variable across time periods but largely consistent across subregions, suggesting that local causes have operated with some degree of synchrony on a region-wide scale. Although the rate of coral loss has slowed in the past decade compared to the 1980s, significant declines are persisting. The ability of Caribbean coral reefs to cope with future local and global environmental change may be irretrievably compromised.

Global Trajectories of the Long-Term Decline of Coral Reef Ecosystems

John M. Pandolfi,[1*] Roger H. Bradbury,[2] Enric Sala,[3] Terence P. Hughes,[4] Karen A. Bjorndal,[5] Richard G. Cooke,[6] Deborah McArdle,[7] Loren McClenachan,[3] Marah J. H. Newman,[3] Gustavo Paredes,[3] Robert R. Warner,[8] Jeremy B. C. Jackson[3,6]

Degradation of coral reef ecosystems began centuries ago, but there is no global summary of the magnitude of change. We compiled records, extending back thousands of years, of the status and trends of seven major guilds of carnivores, herbivores, and architectural species from 14 regions. Large animals declined before small animals and architectural species, and Atlantic reefs declined before reefs in the Red Sea and Australia, but the trajectories of decline were markedly similar worldwide. All reefs were substantially degraded long before outbreaks of coral disease and bleaching. Regardless of these new threats, reefs will not survive without immediate protection from human exploitation over large spatial scales.

Coral reefs and associated tropical nearshore ecosystems have suffered massive, long-term decline in abundance, diversity, and habitat structure due to overfishing and pollution (*1–7*). These losses were more recently compounded by substantial mortality due to dis-

- E.O. Wilson “Before humans existed, the species extinction rate was (very roughly) one species per million species per year. Estimates for current species extinction rates range form 100 to 10,000 times that, but most hover close to 1,000 times prehuman levels (0.1% per year)
- In an article with title “Humans as the World‘s Greatest Evolutionary Force“, Palumbi (Science, 7 September 2001) mankind also effects evolutionary change in other species, especially in commercially important, pest, and disease organisms, through antibiotica and pesticides. This accelerated evolution costs at least $33 billion to $50 billion a year in the United States.

Man the Eroder

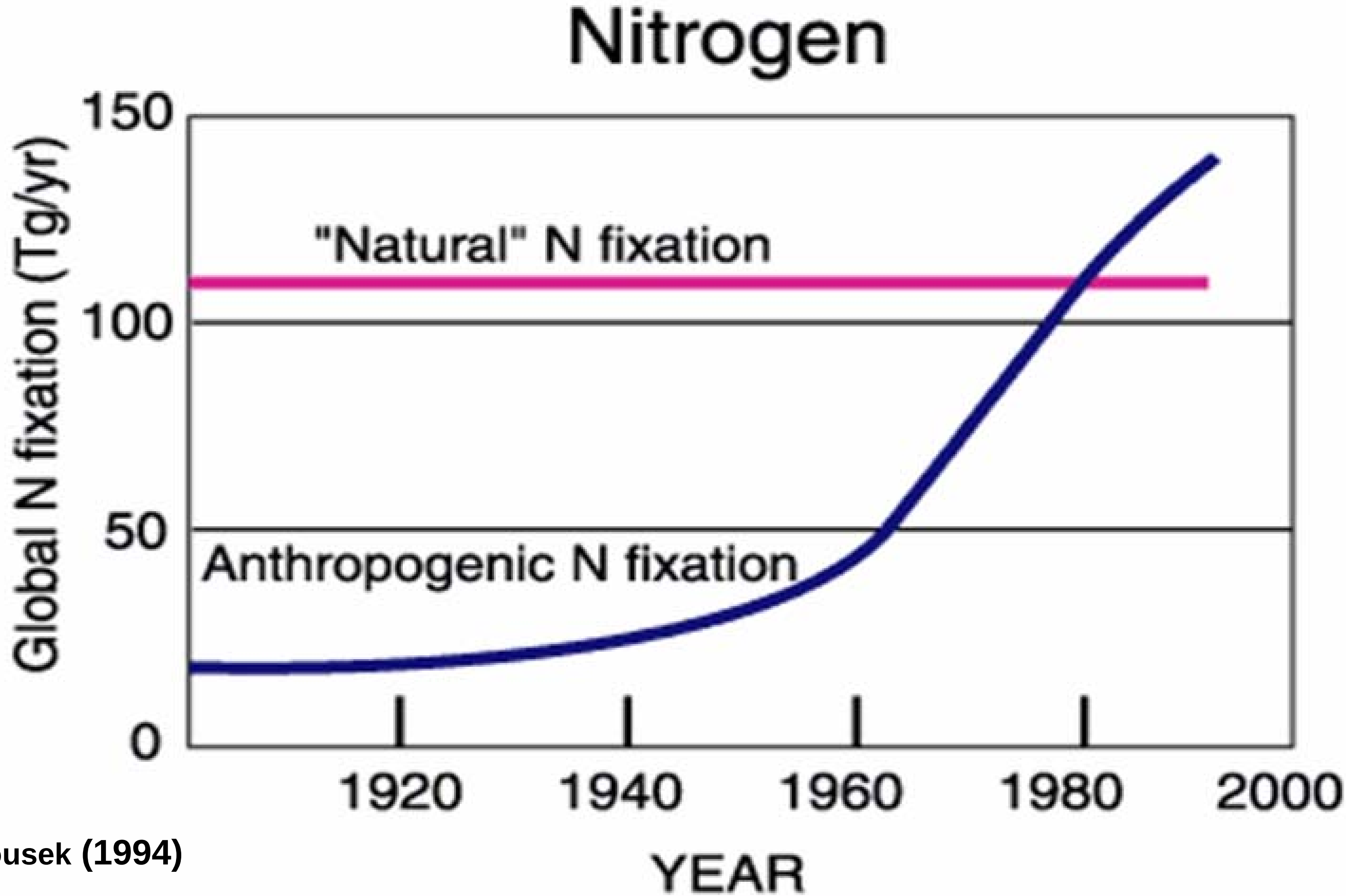
- Sedimentary rock formation over 500 million years corresponds to an erosion rate of 24 meters per million years.
- Man-caused erosion (crop tillage, land conversion for grazing and construction): 15 times natural erosion
- At current rate anthropogenic soil erosion would fill the Grand Canyon in 50 years.

According to Wilkinson (Geology) March 2005.

Since the beginning of the 19th Century, by its own growing activities, Mankind opened a new geological era: the Anthropocene

Increase in world food production and agricultural inputs from 1961 to 1996, based on FAO data

	Number-fold increase in 35 years (1961-1996)
World food production	1.97
Land under cultivation	1.098
Proportion of irrigated land	1.68
Nitrogen fertilization	6.87
Phosphorus fertilization	3.48

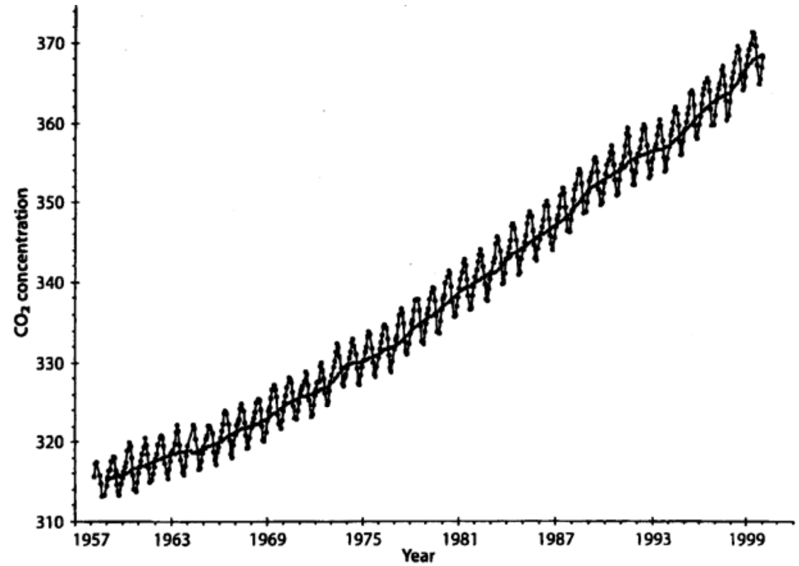


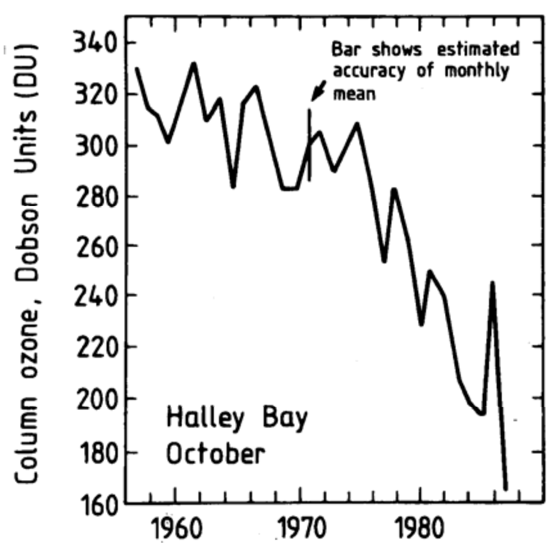
Vitousek (1994)

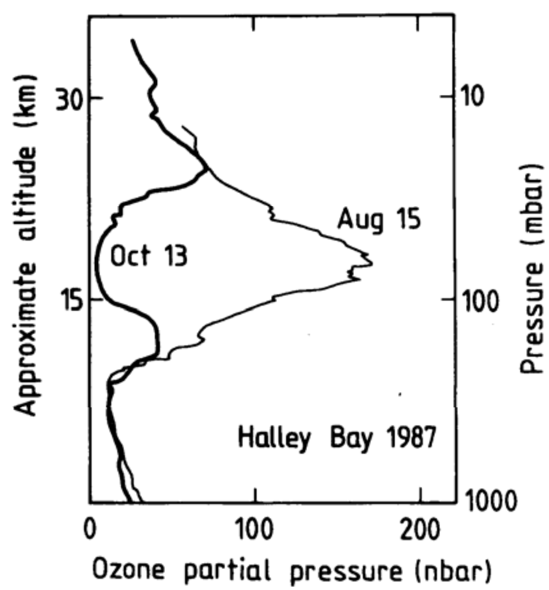
Composition of Dry Air at Ground Level in Remote Continental Areas

CONSTITUENT	FORMUAL	% CONCENTRATIONS	ANNUAL GROWTH (%/YEAR)
Nitrogen	$N2$	78.1	
Oxygen	$O2$	20.1	
Argon	Ar	0.93	
Carbon dioxide	$CO2$	0.037 (370 ppmv)	+ 0.4
Methane	$CH4$	0.00017 (1.7 ppmv)	~ 0
Ozone	$O3$	10^{-8} to 10^{-5}	height dependent
Nitrous oxide	$N2O$	0.000031 (0.31 ppmv)	+ 0.25
(CFC-11)	$CFCl_3$	0.00000027 (0.27×10^{-9})	< 0
(CFC-12)	CF_2Cl_2	0.00000053 (0.53×10^{-9})	< 0

The "Keeling curve", showing the steady increase in atmospheric CO_2 concentration recorded monthly at Mauna Loa in Hawaii, 1958–1999 (adapted from Keeling and Whorf 2000)







Ozone production in stratosphere:

$$O_2 + h\nu \rightarrow 2\,O\ (< 240\ nm)$$
$$O + O_2 + M \rightarrow O_3 + M\ (2\,x)$$

$$\Sigma \quad 3\,O_2 \rightarrow 2\,O_3$$

can not be influenced by human activity.

However, reconversion from $O_3 \rightarrow O_2$ can:

$$2\,O_3 \xrightarrow{X,\ XO\ \ldots} 3\,O_2$$

X = NO, Cl, Br , H, OH

NO↑ from aircraft and nuclear explosives

$$N_2O + O(^1D) \rightarrow 2\,NO$$

N_2O↑ 0.2 - 0.3%/yr (e.g. N-fertilizers)

Cl↑ and Br↑ via:

$$CF_xCl_y + h\nu \rightarrow y\ (Cl, ClO, HOCl, HCl, ClONO_2)\ (\text{and } x\ HF)$$
$$CF_xBr_y + h\nu \rightarrow y\ (Br, BrO, HOBr, HBr)\ (\text{and } x\ HF)$$

in the stratosphere

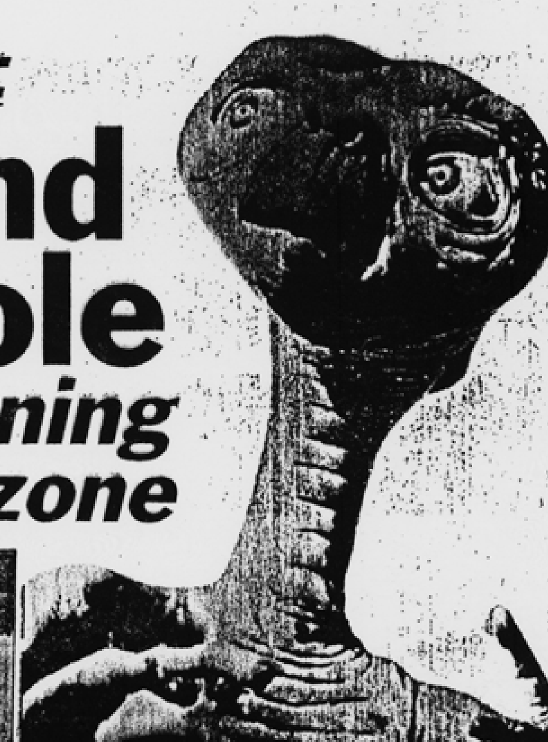
Vol. 4 — No. 50 December 16, 1986

Sun

Scientists reveal shocking discovery:

UFO aliens found at South Pole

ETs are burning up Earth's ozone



A GROUP of biologists stumbled on a UFO base at the South Pole and researchers believe trips by space aliens to and from the area are burning up Earth's ozone layer.

Scientists discovered the base through aerial photographs taken of a remote section in Antarctica.

"We believe it is a base for alien spaceships," says Olen Gunderson, who examined the pictures from his UFO research center in New Zealand.

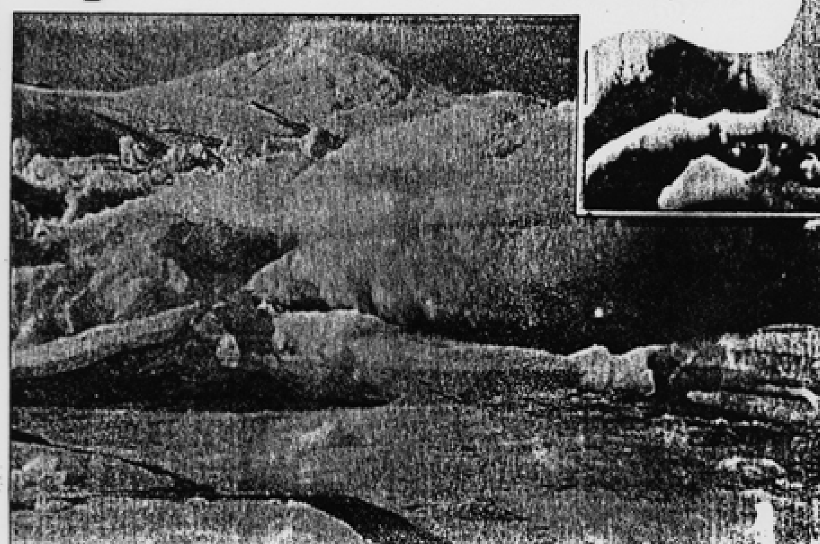
"There is clearly a base perhaps a mile long right near the center of the South Pole. This field was not there in the early 1970s when other pictures were taken of the area.

Markings

"There are also distinct markings along the field that show it is some type of UFO air base," he adds.

Olen points out that several photographs have not been available because they were confiscated by U.S. government officials when the biologists returned home.

"Those photographs showed actual vehicles flying into the area and leaving," says Olen.



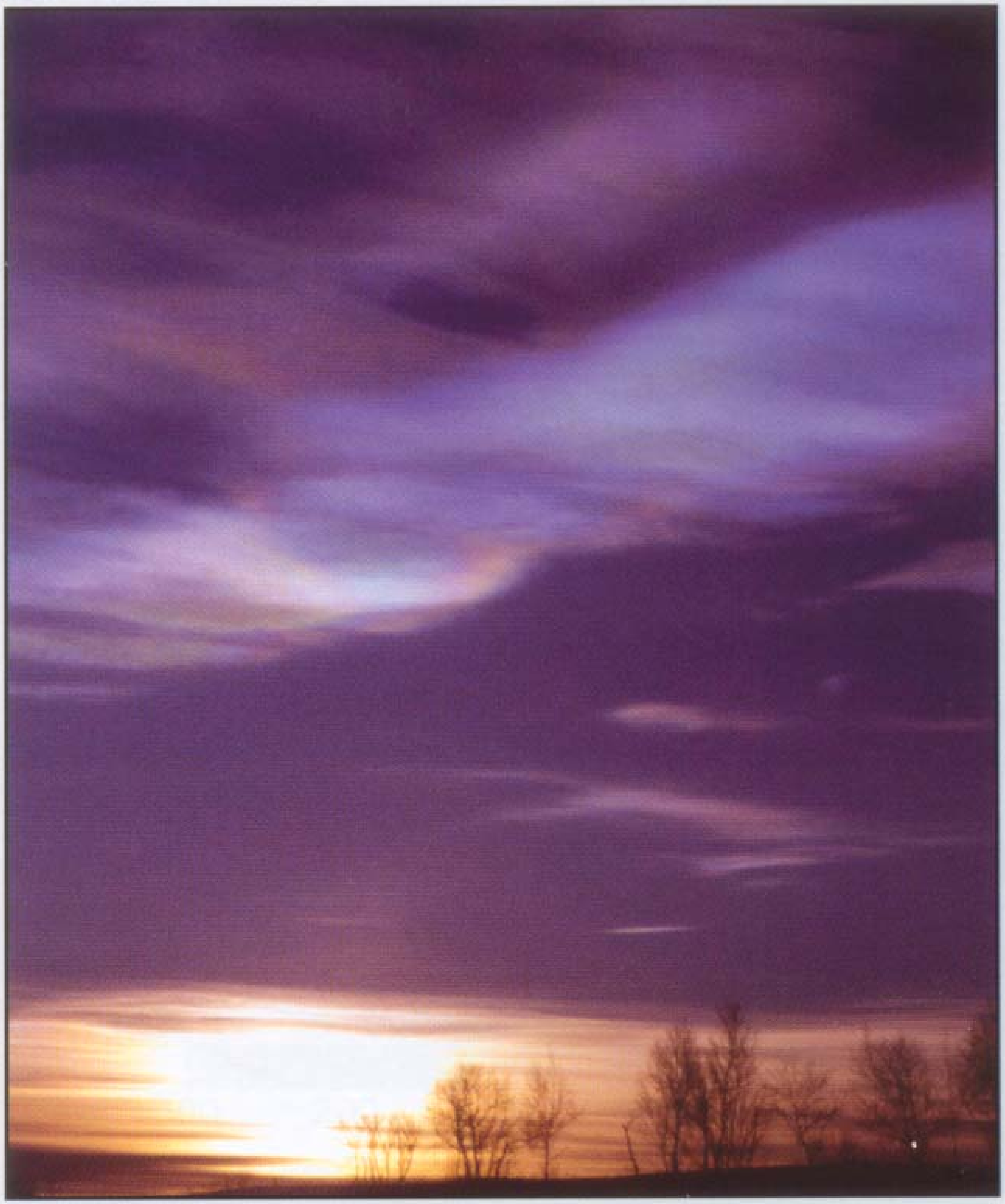
• SCIENTISTS say ETs are burning up our ozone with their spaceships, which landed at an icy base in Antarctica, right. Olen Gunderson, who took pictures, now confiscated, of the base, plans future polar expeditions.

Baby gets gift of arms for birthday

DELIGHTFUL TODDLER Vicky

HELD CAME FROM TOTALLY UNEXPECTED QUARTERS

Arctic Polar Stratospheric Clouds



Polar stratospheric clouds. This photograph on an Arctic polar stratospheric cloud (PSC) was taken from the ground at Kiruna, Sweden (67°N), on 27 January 2000. PSCs form during winters in the Arctic and Antarctic stratospheres. The particles grow from the condensation of water along with nitrogen and sulfur gases. Beceause the particles are large and numerous, the clouds often can be seen with the human eye when the Sun is near the horizon. Reactions on PSCs cause the highly reactive chlorine gas ClO to be formed, which is very effective in the chemical destruction of ozone.

First: Low temperatures, below about –80°C, are needed to produce ice particles consisting of nitric acid and water (nitric acid trihydrate or NAT) or water molecules.. In this process also the NOx catalysts are removed from the stratosphere through the reactions

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + NO_3 + M \rightarrow N_2O_5 + M$$
$$N_2O_5 + H_2O \rightarrow 2\ HNO_3$$

thereby producing HNO_3 which is incorporated in the particles.

Second: On the surface of the ice particles HCl and $ClONO_2$ react with each other to produce Cl_2 and HNO_3;

$$HCl + ClONO_2 \rightarrow Cl_2 + HNO_3$$

the latter is immediately incorporated in the particles.

Third: After the return of daylight after the polar night, Cl_2 is photolyzed to produce 2 Cl atoms.

$$Cl_2 + h\nu \rightarrow 2\ Cl$$

Fourth: The chlorine atoms start a catalytic chain of reactions, leading to the destruction of ozone:

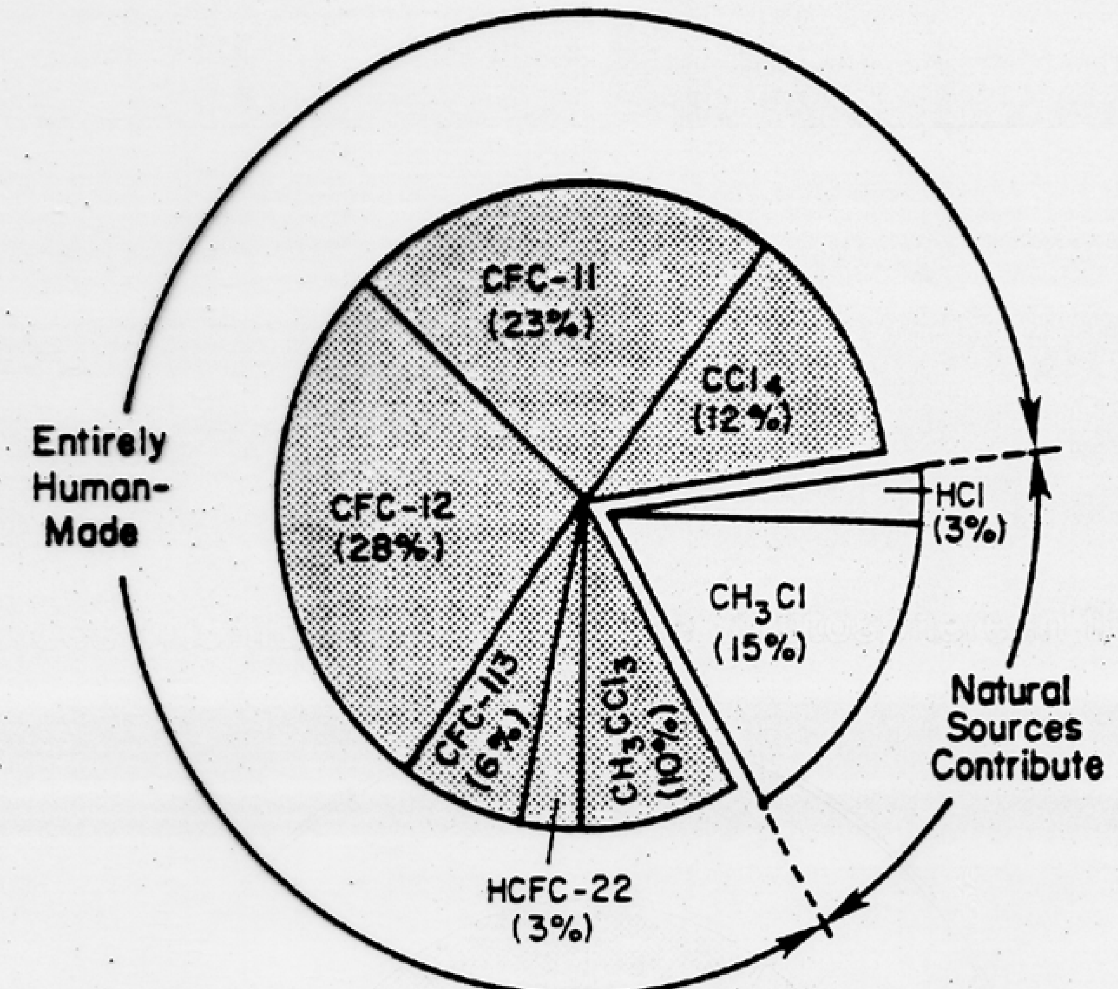
	$Cl + O_3$	$\rightarrow$	$ClO + O_2$
	$Cl + O_3$	$\rightarrow$	$ClO + O_2$
	$ClO + ClO + M$	$\rightarrow$	$Cl_2O_2 + M$
	$Cl_2O_2 + hv$	$\rightarrow$	$Cl + ClO_2 \rightarrow 2Cl + O_2$
Net:	$2\ O_3$	$\rightarrow$	$3\ O_2$.

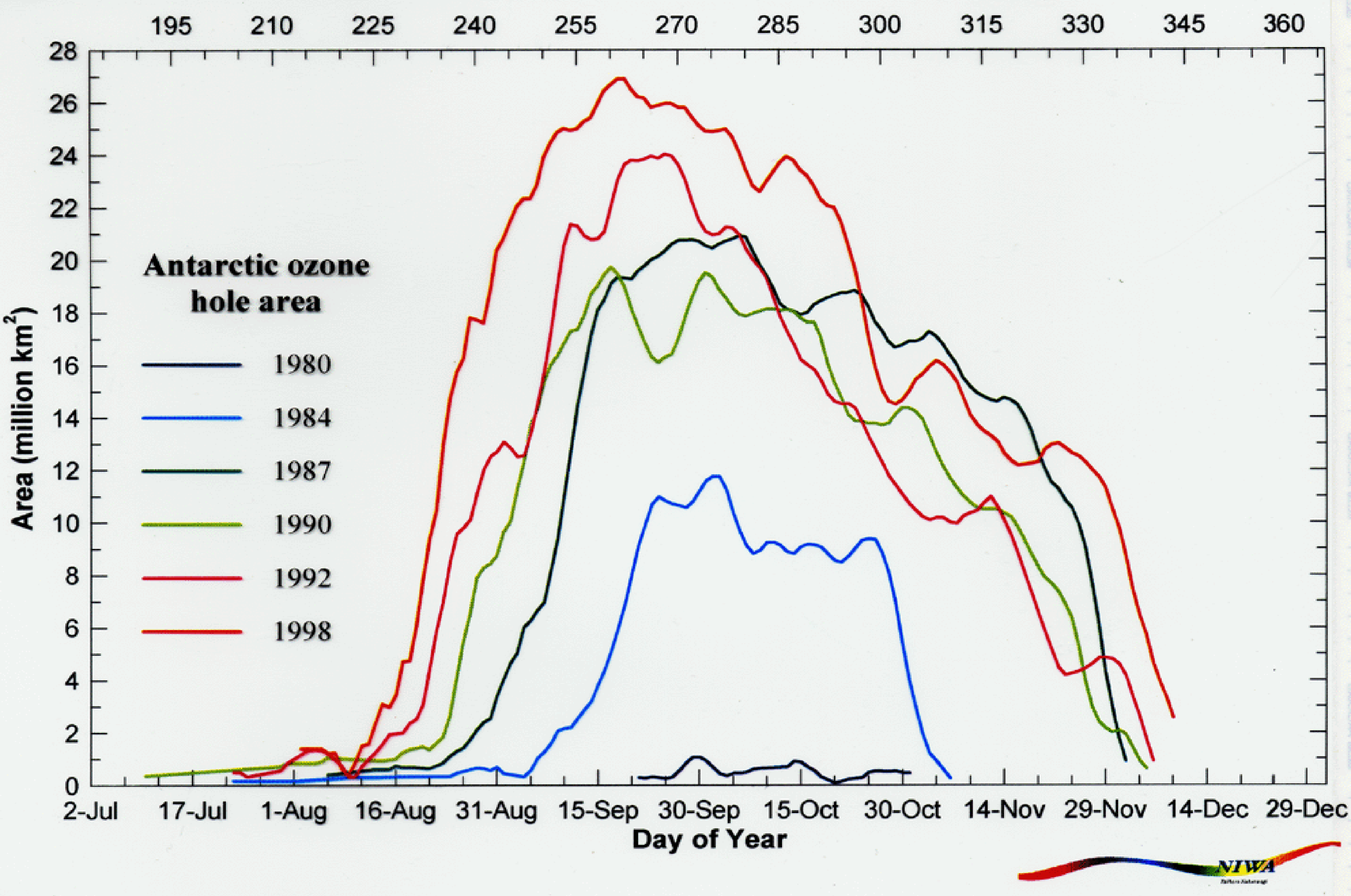
Note that the breakdown of ozone is proportional to the square of the ClO concentrations. As these grew for a long time by more than 4% per year, ozone loss increased by 8% from one year to the next. Also, because there is now about six times more chlorine, about 3 nmol/mol, in the stratosphere, compared to natural conditions when chlorine was solely provided by CH_3Cl, the ozone depletion is now 36 times more powerful than prior to the 1930s when CFC production started. Earlier, under natural conditions, chlorine-catalysed ozone destruction was unimportant and it will be so by the end of this century.

Fifth: Enhanced inorganic chlorine (Cl, ClO, HCl, ClONO2, Cl2O2) concentrations, produced by CFC photolysis above 25-30 km are brought down during winter into the lower stratosphere by downwind transport from the middle and upper stratosphere within a meteorologically stable vortex with the pole more or less at the center. This is important because at the higher altitudes more organic chlorine is converted to much more reactive inorganic chlorine gases, including the ozone-destroying catalysts Cl, ClO, and Cl2O2.

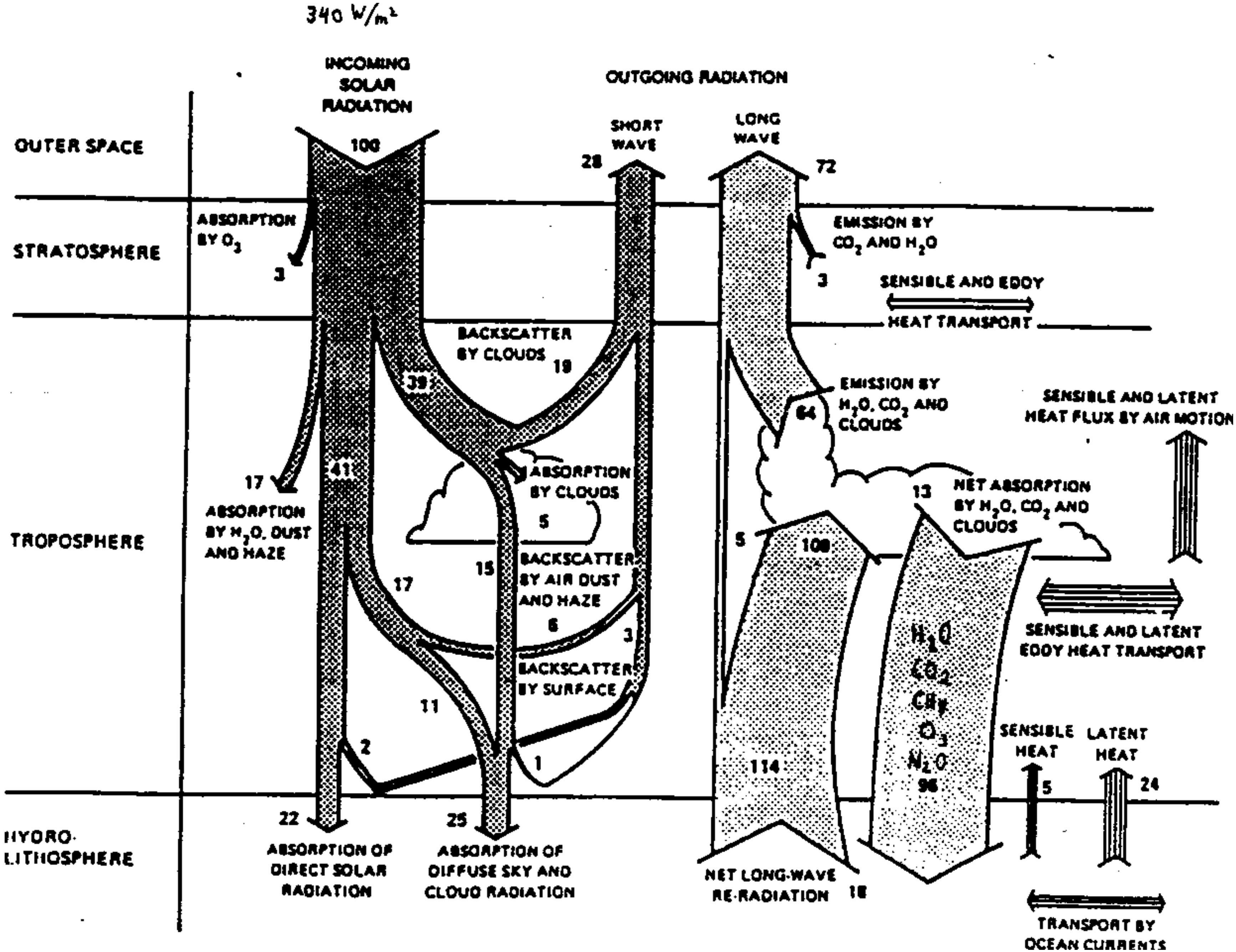
All five factors have to come together to cause the ozone hole (Figure 2). It is thus not surprising that the ozone hole was not predicted. This experience shows the critical importance of measurements. What other surprises may lie ahead involving instabilities in other parts of the complex Earth system?

Primary Sources of Chlorine Entering the Stratosphere in the Early 1990s

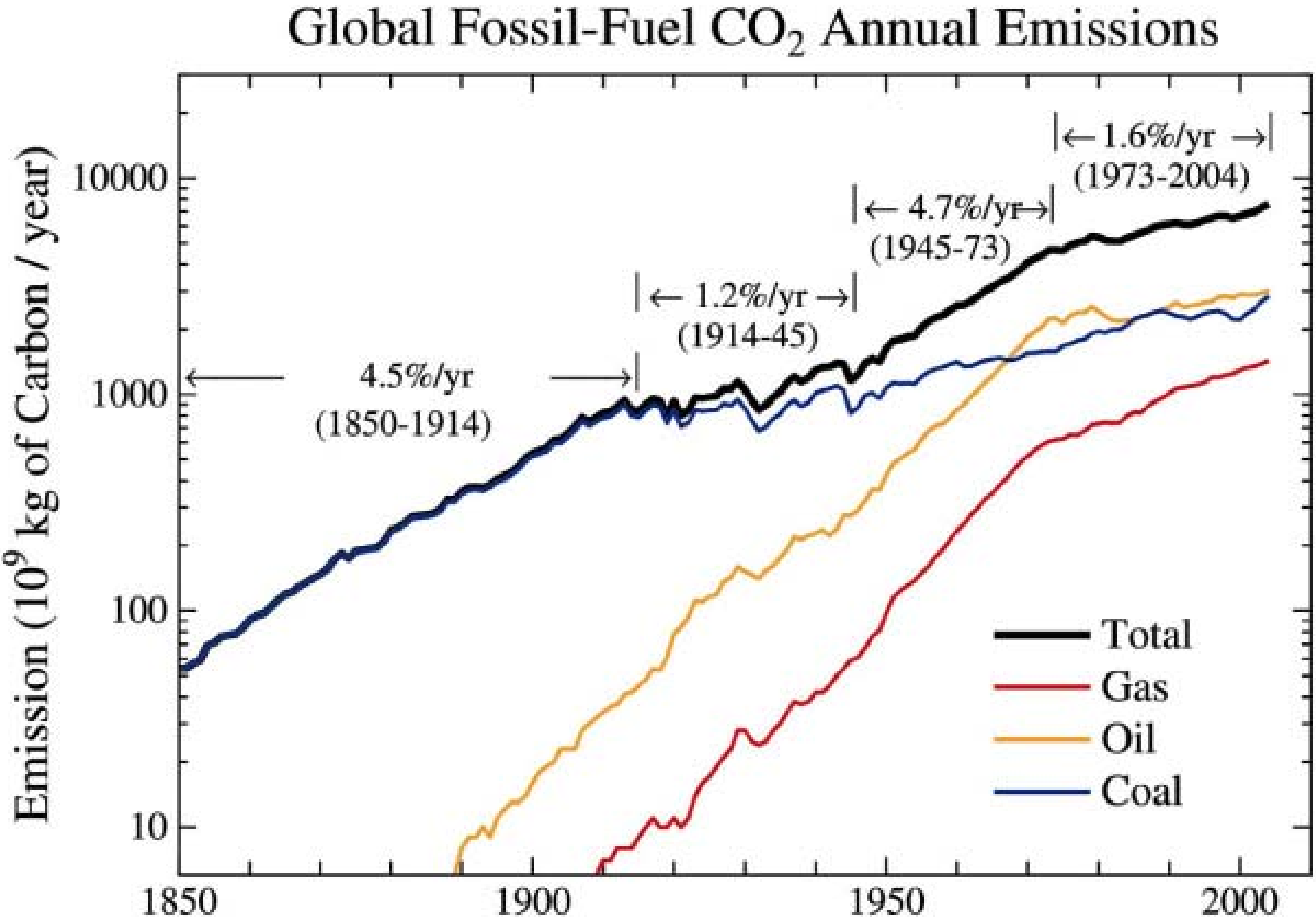




195
210
225
240
255
270
285
300
315
330
345
360
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Area (million km²)
Antarctic ozone hole area
1980
1984
1987
1990
1992
1998
2-Jul
17-Jul
1-Aug
16-Aug
31-Aug
15-Sep
30-Sep
15-Oct
30-Oct
14-Nov
29-Nov
14-Dec
29-Dec
Day of Year
NIWA



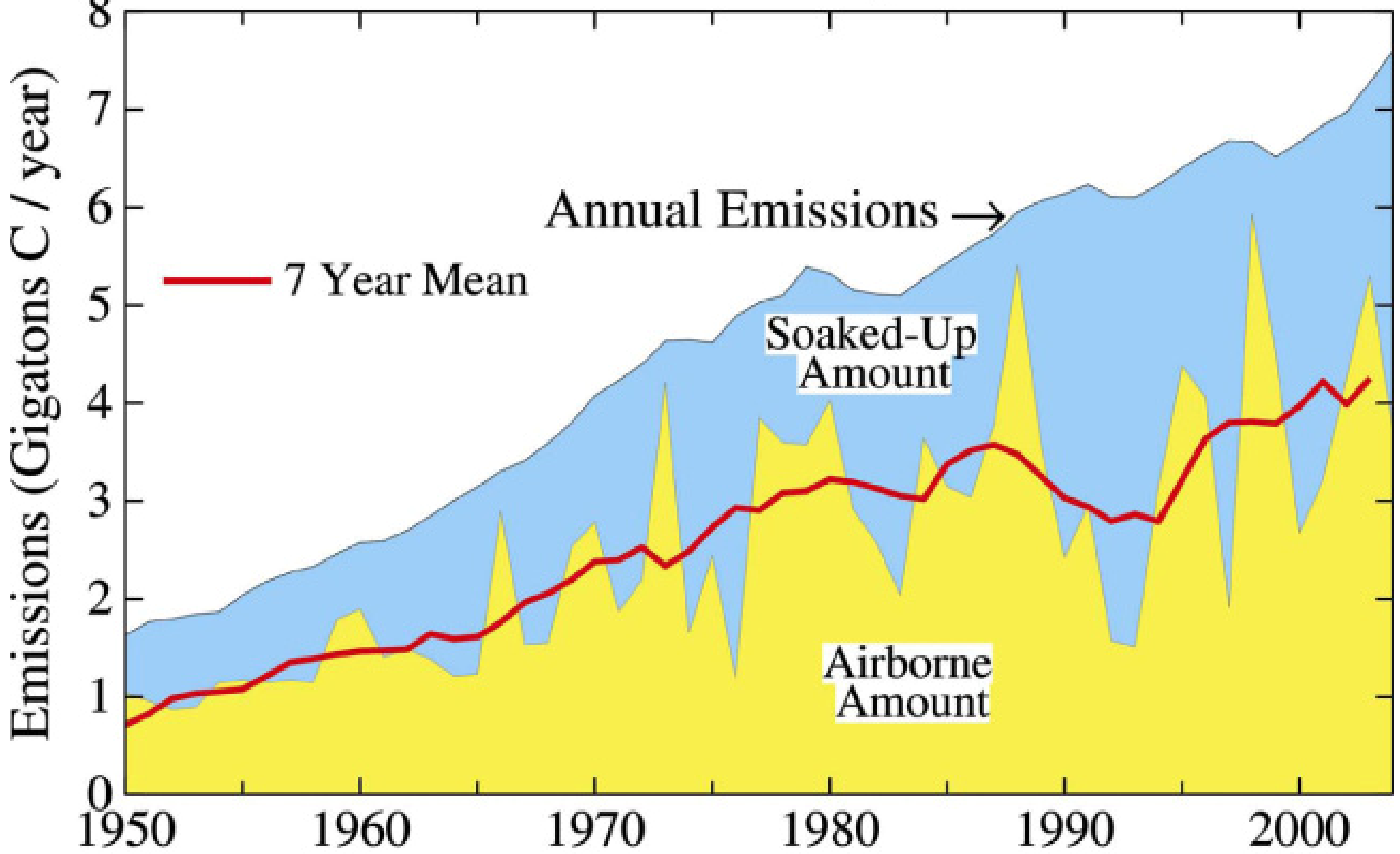
340 W/m²
INCOMING SOLAR RADIATION
100
OUTGOING RADIATION
SHORT WAVE
28
LONG WAVE
72
OUTER SPACE
STRATOSPHERE
ABSORPTION BY O3
3
EMISSION BY CO2 AND H2O
3
SENSIBLE AND EDDY HEAT TRANSPORT
BACKSCATTER BY CLOUDS
19
39
EMISSION BY H2O, CO2 AND CLOUDS
64
SENSIBLE AND LATENT HEAT FLUX BY AIR MOTION
41
17
ABSORPTION BY H2O, DUST AND HAZE
ABSORPTION BY CLOUDS
5
NET ABSORPTION BY H2O, CO2 AND CLOUDS
13
TROPOSPHERE
15
BACKSCATTER BY AIR DUST AND HAZE
17
6
3
5
108
SENSIBLE AND LATENT EDDY HEAT TRANSPORT
BACKSCATTER BY SURFACE
11
2
1
H2O
CO2
CH4
O3
N2O
96
114
SENSIBLE HEAT
5
LATENT HEAT
24
HYDRO-LITHOSPHERE
22
ABSORPTION OF DIRECT SOLAR RADIATION
25
ABSORPTION OF DIFFUSE SKY AND CLOUD RADIATION
NET LONG-WAVE RE-RADIATION
18
TRANSPORT BY OCEAN CURRENTS



Fossil fuel CO_2 emissions based on data of Marland and Boden (DOE, Oak Ridge) and British Petroleum.

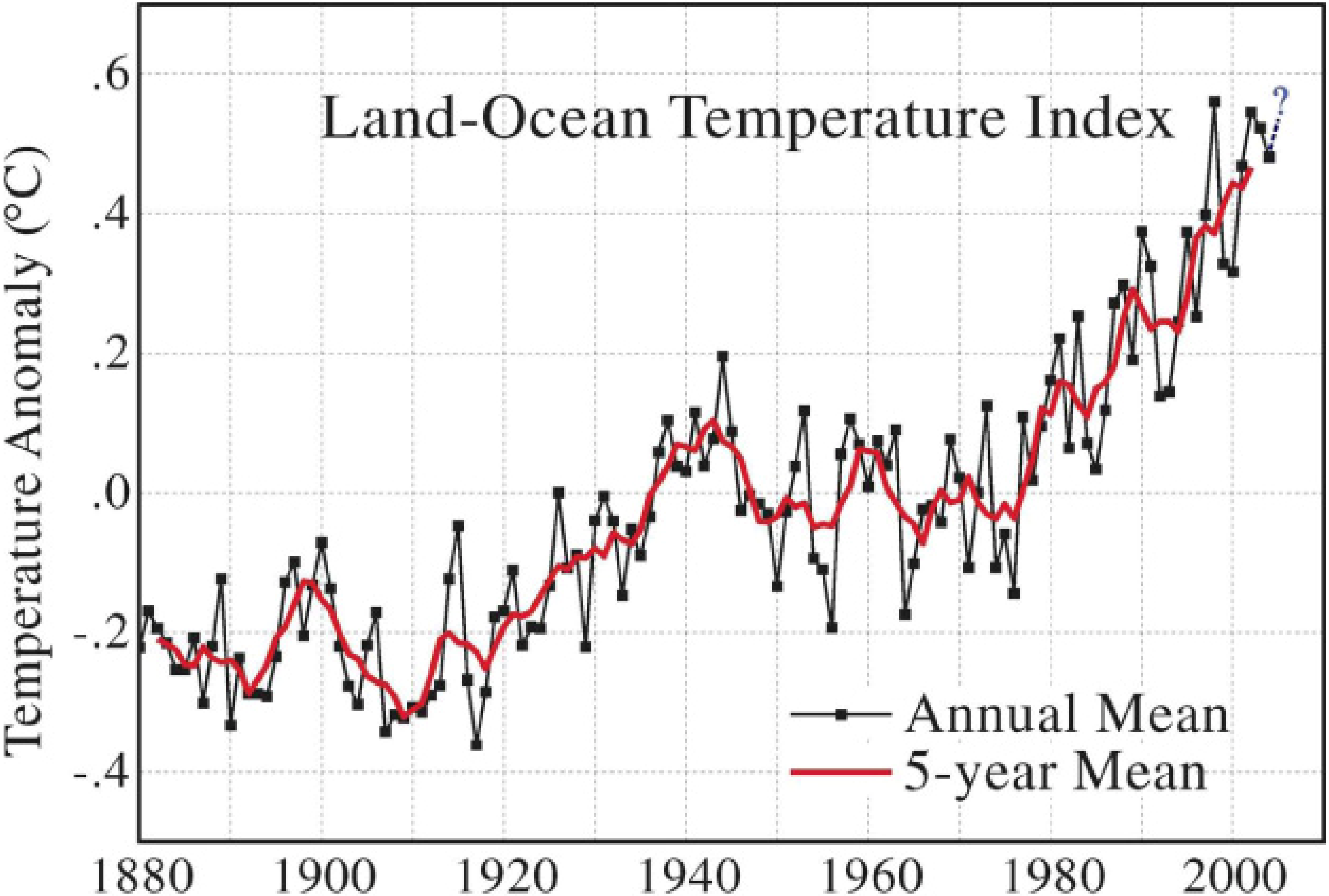
Source: Hansen and Sato, *PNAS*, **98**, 14778, 2001.

Global Fossil Fuel CO_2 Emissions



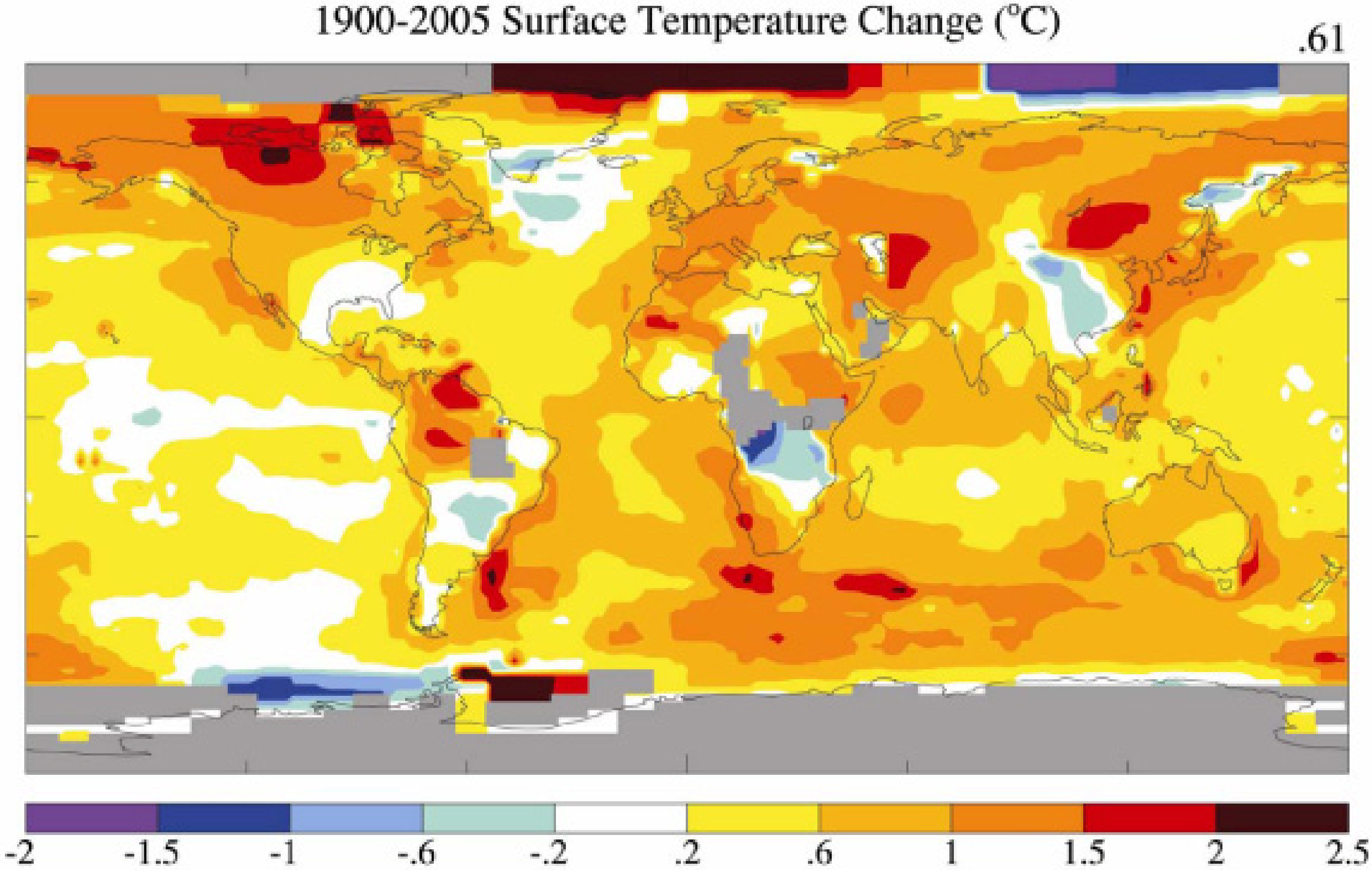
Global fossil fuel CO_2 emissions with division into portions that remain airborne or are soaked up by the ocean and land.

Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.



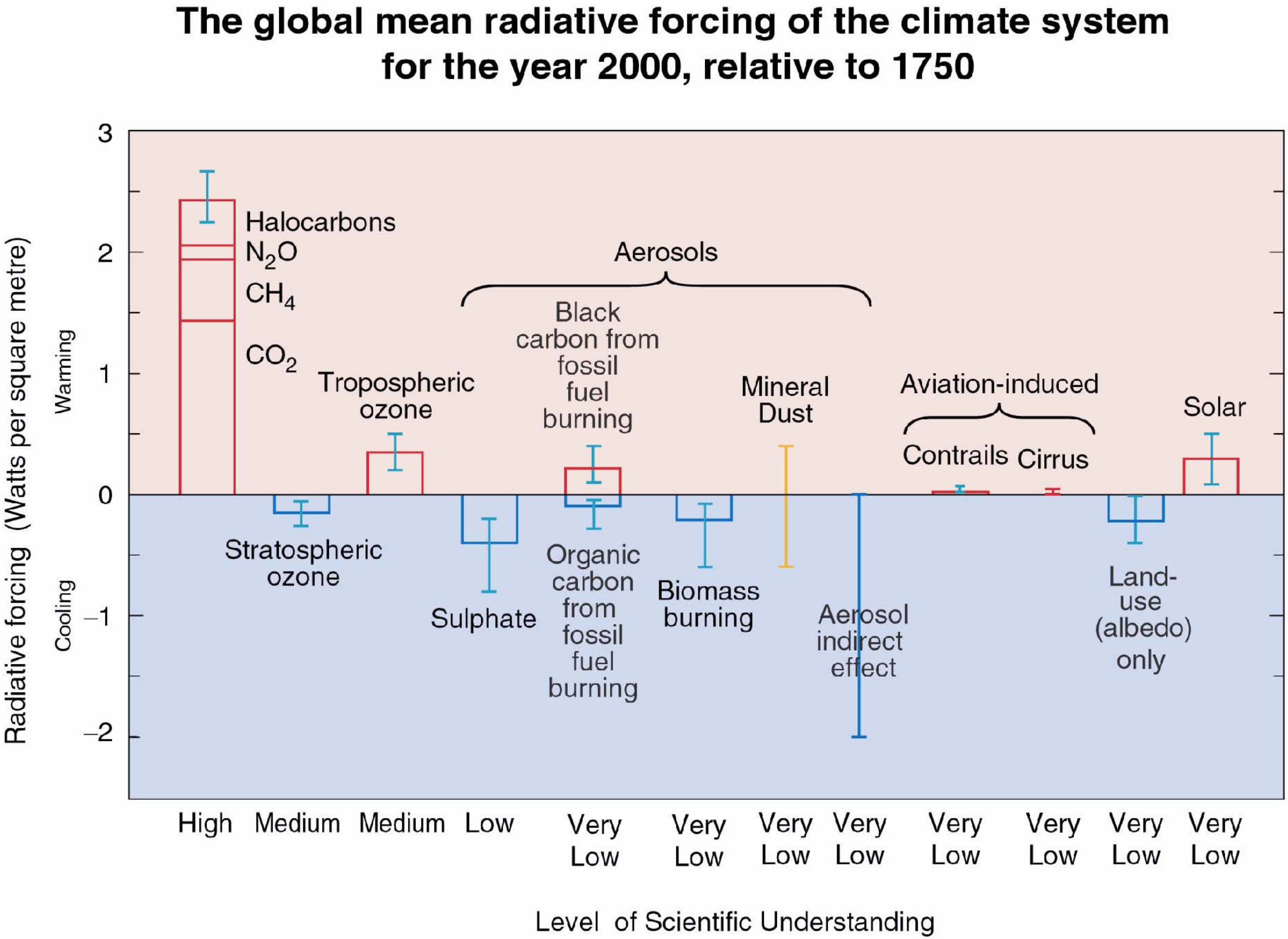
Global mean surface temperature change based on surface air measurements over land and SSTs over ocean

Source: Update of Hansen et al., *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.



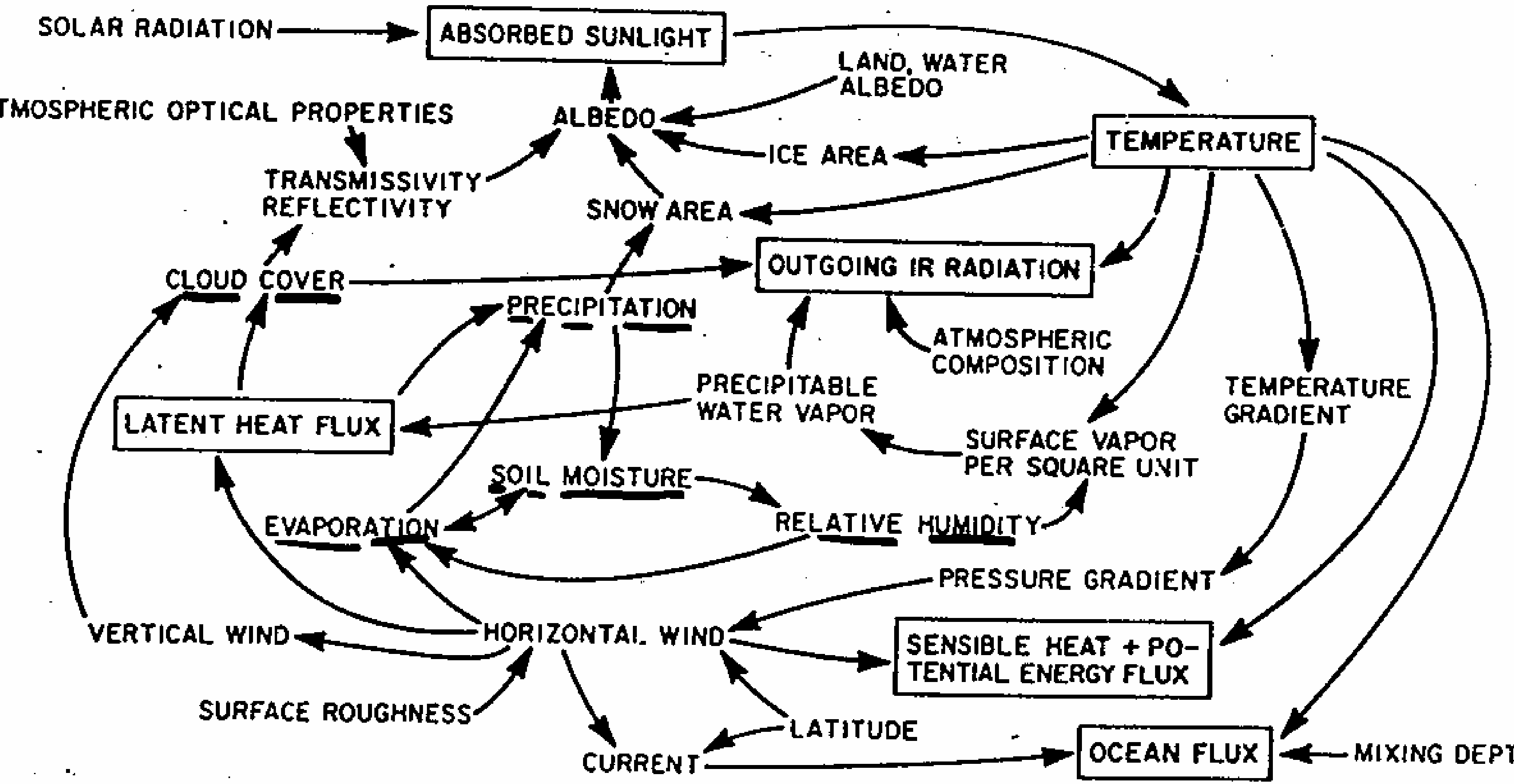
Change of surface temperature index based on local linear trends using surface air temperature over land and SST over ocean.

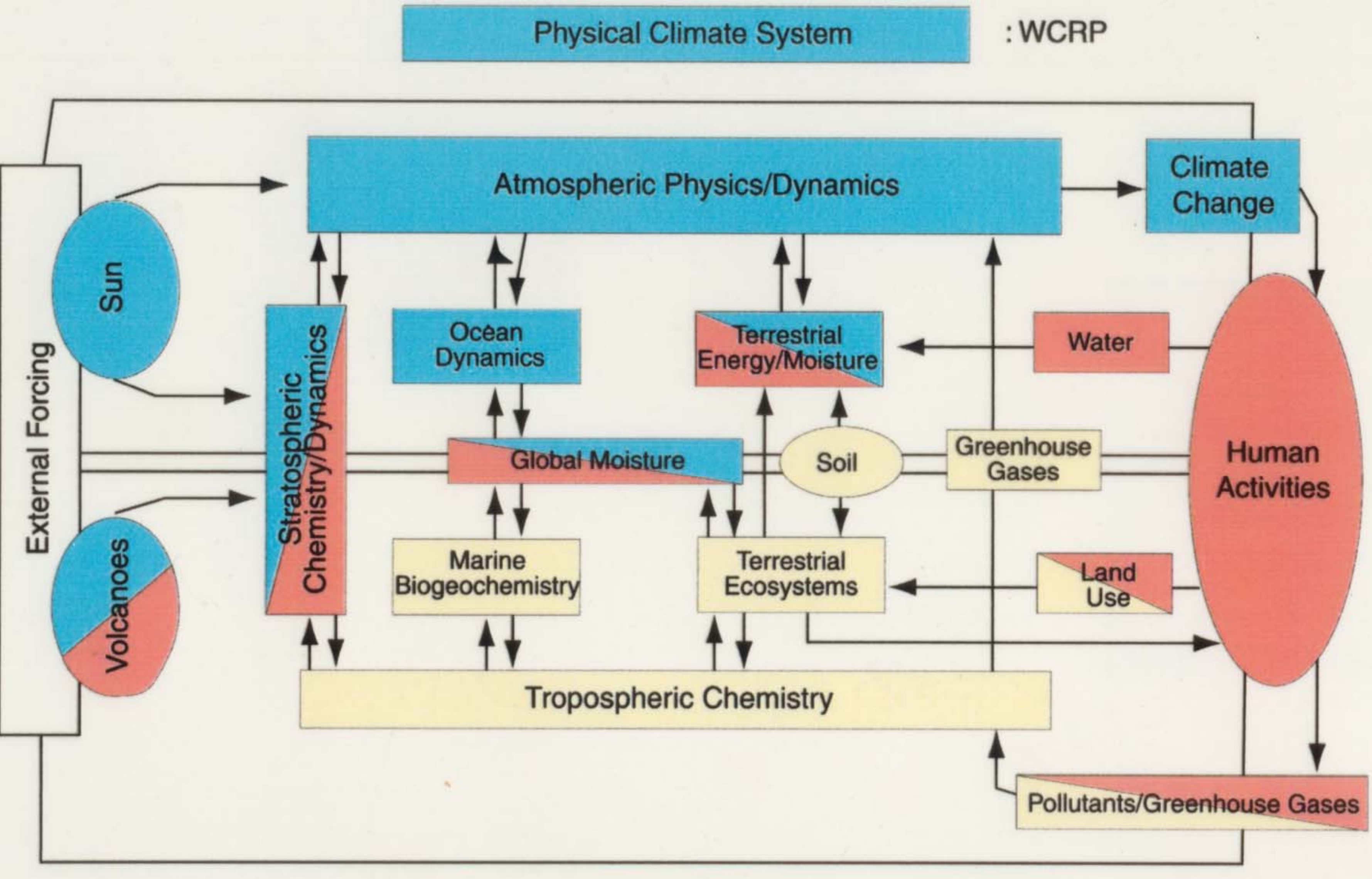
Sources: Hansen et al., *JGR*, **106**, 23947, 2001; Reynolds and Smith, *J. Climate*, **7**, 1994; Rayner et al., *JGR*, **108**, 2003.



The global mean radiative forcing of the climate system
for the year 2000, relative to 1750
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
–1
–2
Halocarbons
N2O
CH4
CO2
Tropospheric ozone
Stratospheric ozone
Aerosols
Black carbon from fossil fuel burning
Sulphate
Organic carbon from fossil fuel burning
Biomass burning
Mineral Dust
Aerosol indirect effect
Aviation-induced
Contrails
Cirrus
Land-use (albedo) only
Solar
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

CLIMATIC CAUSE-AND-EFFECT (FEEDBACK) LINKAGES





Physical Climate System
: WCRP
Atmospheric Physics/Dynamics
Climate Change
Sun
External Forcing
Volcanoes
Stratospheric Chemistry/Dynamics
Ocean Dynamics
Terrestrial Energy/Moisture
Water
Global Moisture
Soil
Greenhouse Gases
Human Activities
Marine Biogeochemistry
Terrestrial Ecosystems
Land Use
Tropospheric Chemistry
Pollutants/Greenhouse Gases

“The balance of evidence suggests a discernable human influence on global climate“ (IPCC, 1995)

„There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities“ (IPCC, 2001)

Average Global Temperature Rise: 1.4 – 5.8 °C from 1999 to 2100 (includes cooling effects by sulfate aerosol)

Sea level rise: + 9 – 88 cm until 2100.
+ 0.5 – 10 m until ~ 3000.

Redistribution of precipitation

Enhanced risk for extreme weather (flooding, desertification)?

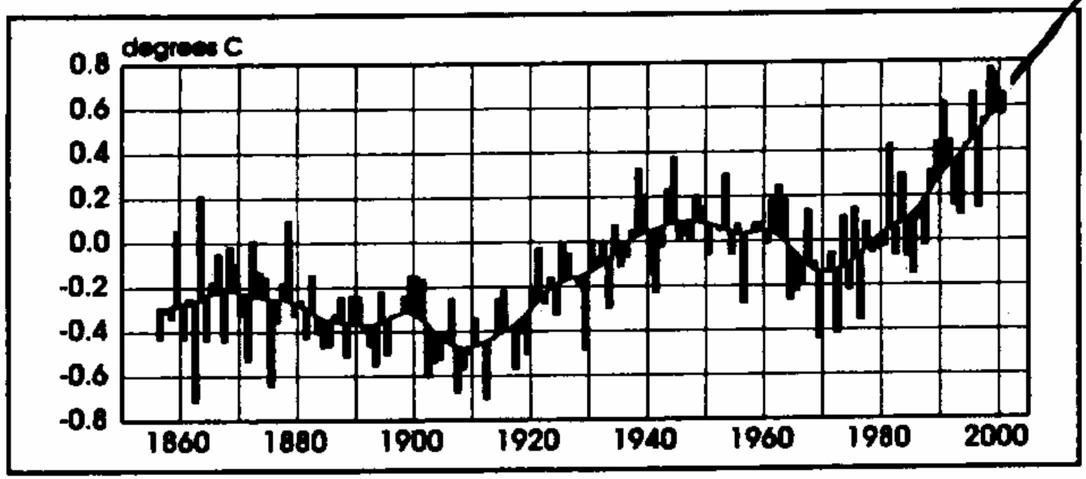
Increase in heat waves in Europe, as in the summer of 2003?

Too rapid climate changes, so that ecosystems cannot adapt.

Global climate 2000

1.4–5.8°C by 2100

The year 2000 was the 22nd consecutive year with a global surface air temperature higher than the 1961-1990 normal, according to the latest World Meteorological Organization summary of world climate.



Mean surface air temperature north of 30°N as annual departures from the 1961-90 mean.

Despite regional cooling due to the continuing La Niña event in the tropical Pacific, the year was the seventh warmest since 1961. The warmth was most marked over extra-tropical northern latitudes. A severe heat wave over southern Europe claimed many lives as temperatures rose above 43°C mid-year.

Tropical storms caused widespread damage in Central America, record rainfall in Japan and serious flooding over the Korean Peninsula and Vietnam. Storms also brought flooding and much suffering to Madagascar, Mozambique and southern Africa early in the year.

Heavy rainfall caused severe flooding during the summer monsoon season over much of south and southeast Asia, with over ten million people affected in India. Coupled with mudslides, heavy rainfall caused widespread devastation in Central and South America during May and June. Much of the disruption in tropical rainfall was associated with the La Niña event.

***Further information:** The "Statement on the Status of the Global Climate in 2000" can be obtained from the WMO address on page 37.*

Tiempo

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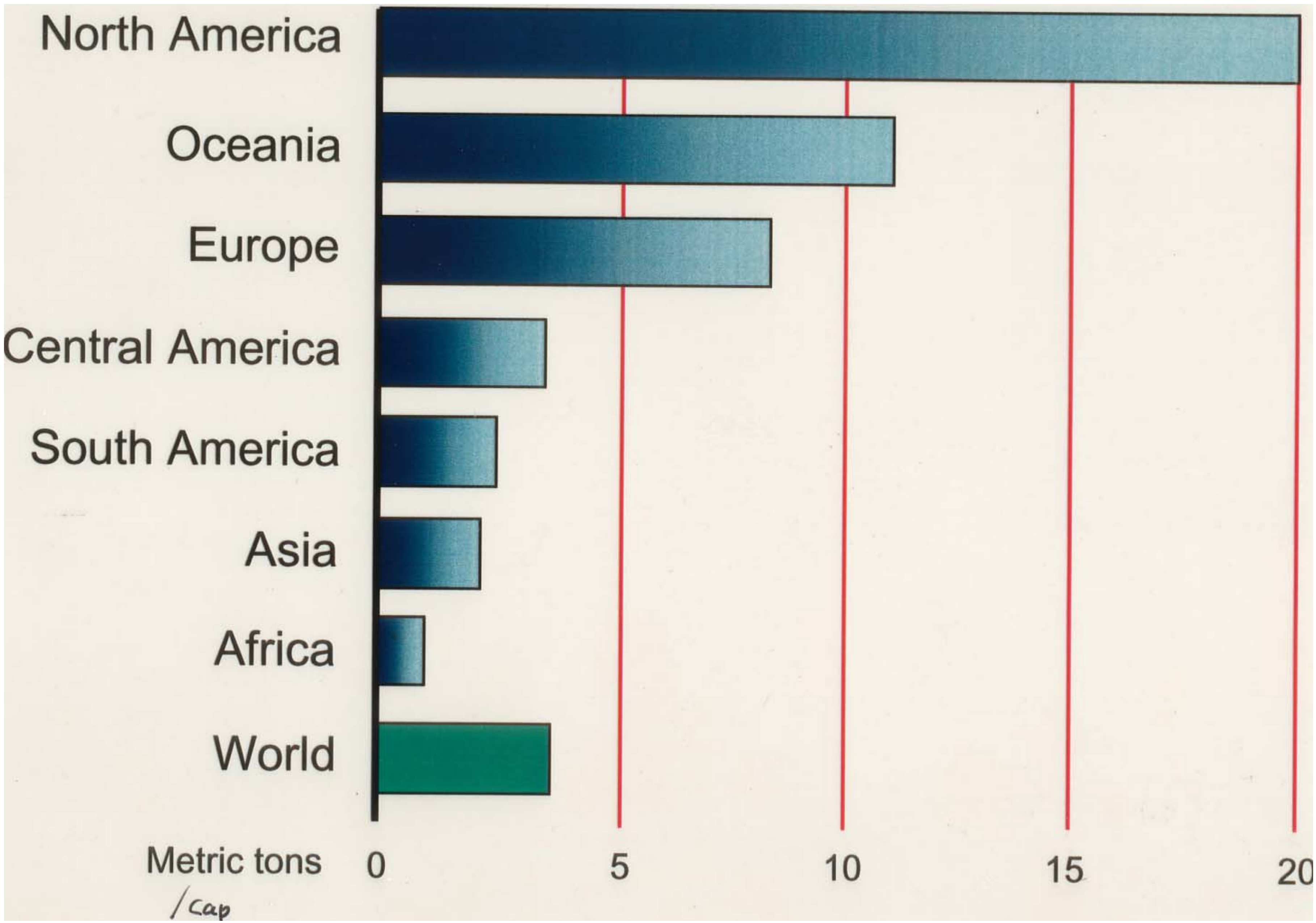
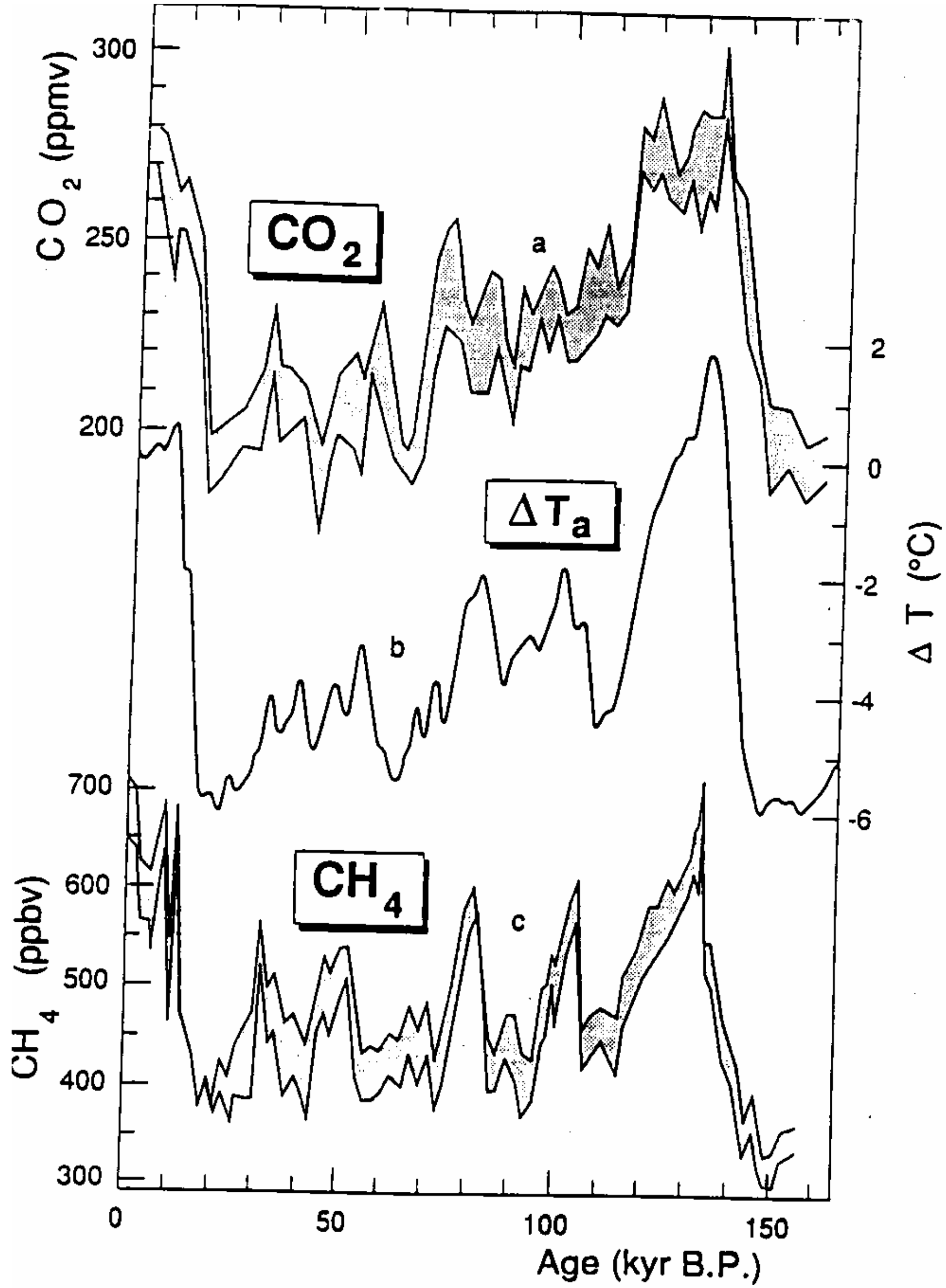
Stabilisation of Atmospheric Concentrations. Reductions in the human-made emission required to stabilise concentrations at current levels

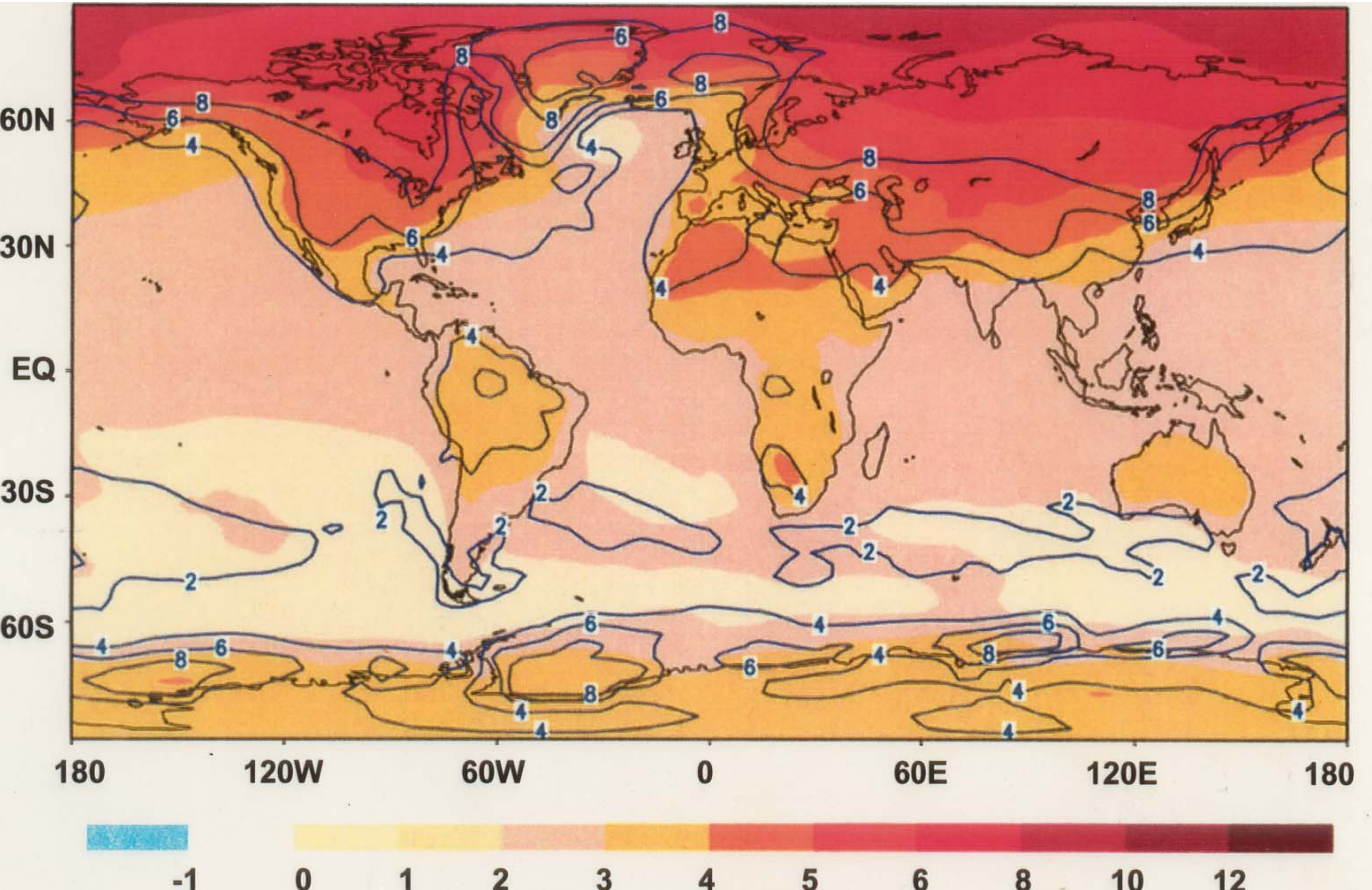
Greenhouse Gas	Reduction Required
Carbon Dioxide	> 60%
Methane	(achieved, but long term stabilisation is uncertain for instance by thawing of permafrost)
Nitrous Oxide	70-80%
CFC-11	Achieved
CFC-12	achieved


North America
Oceania
Europe
Central America
South America
Asia
Africa
World
Metric tons
/cap
0
5
10
15
20



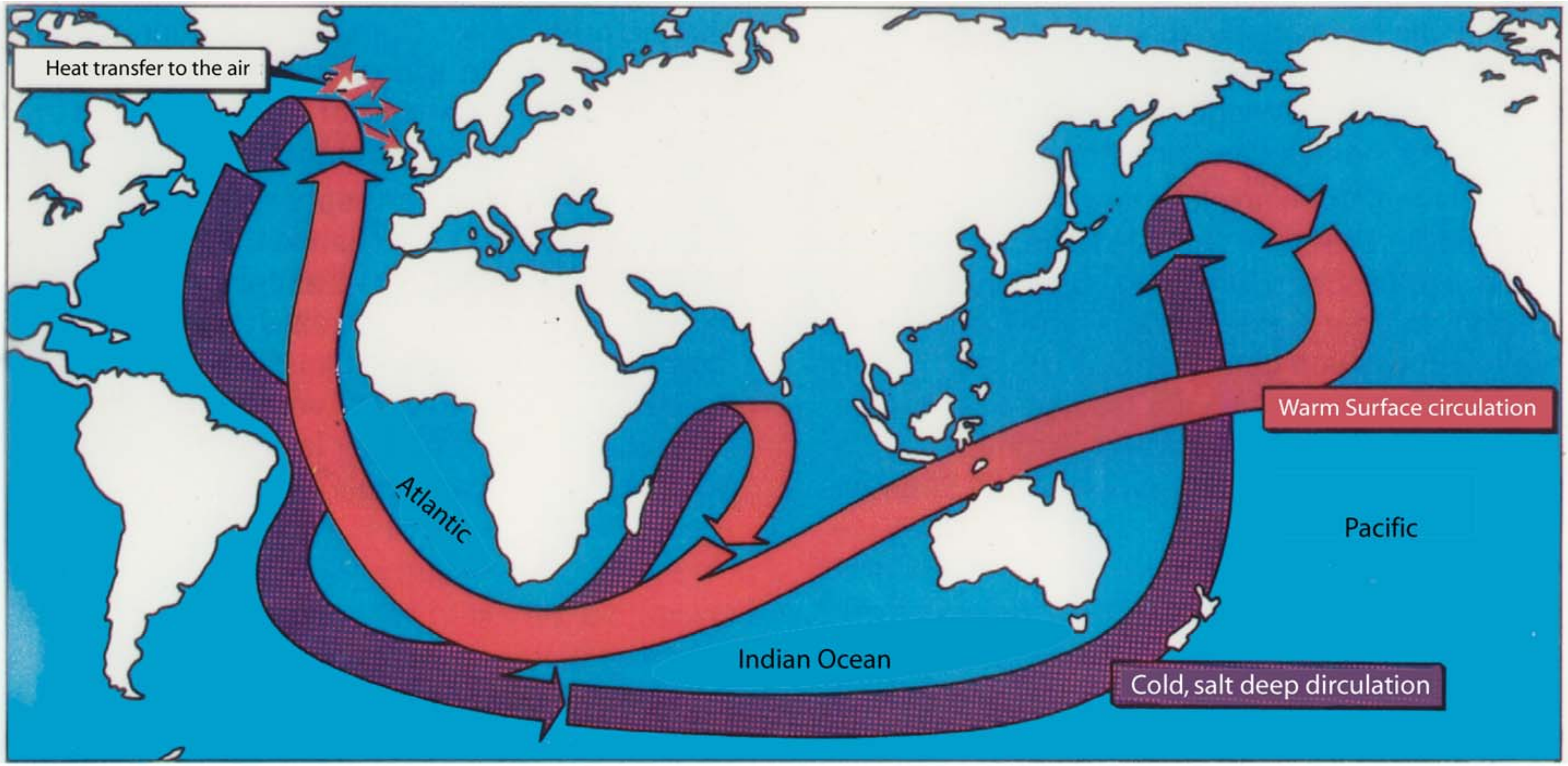
CO2 (ppmv)
300
250
200
CO2
a
ΔTa
b
ΔT (°C)
2
0
-2
-4
-6
CH4
c
CH4 (ppbv)
700
600
500
400
300
0
50
100
150
Age (kyr B.P.)

Climate of the polar regions is most sensitive
Model calculated temperature charges for a doubling of atmospheric CO_2 content



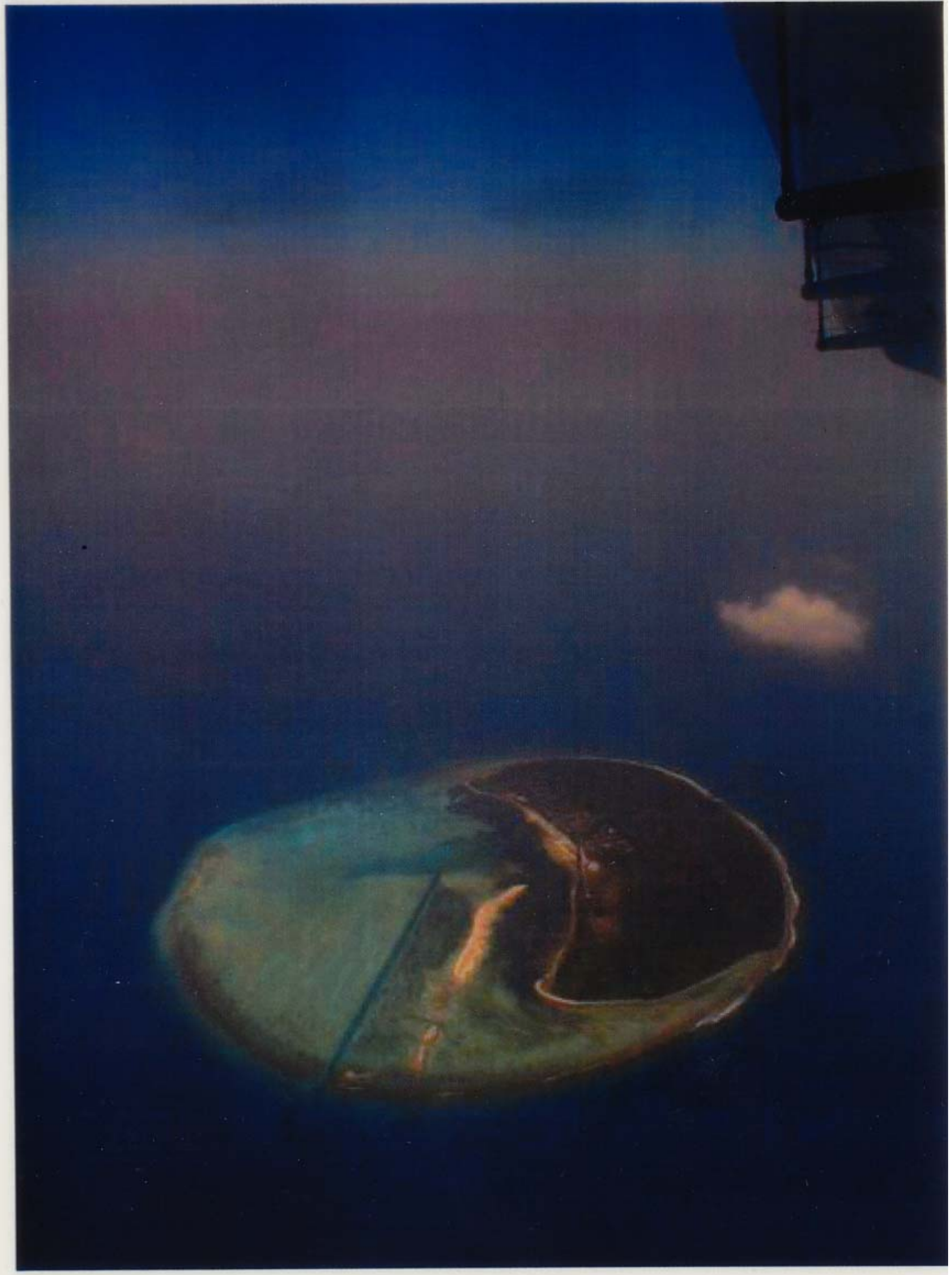
•„New studies indicate that the Arctic oceans ice cover is about 40% thinner than 20-40 years ago“. Levy, Physics Today, January 2000.

•There is dramatic climate change happening in the Arctic, about 2-3 times the pace for the whole globe: Robert Corell, Chairman of the Arctic Climate Impact Assessment, November 2004.


Heat transfer to the air
Warm Surface circulation
Atlantic
Pacific
Indian Ocean
Cold, salt deep dirculation

Patrick Zimmerman of the U.S. National Center for Atmospheric Research escapes to safety with a flask containing a sample of air from burning grass and brush in Brazil's Amazon region. Biomass burning is commonly practiced by farmers in tropical countries for land clearing and pesticide control; its effects on the atmosphere can be detected half a world away.

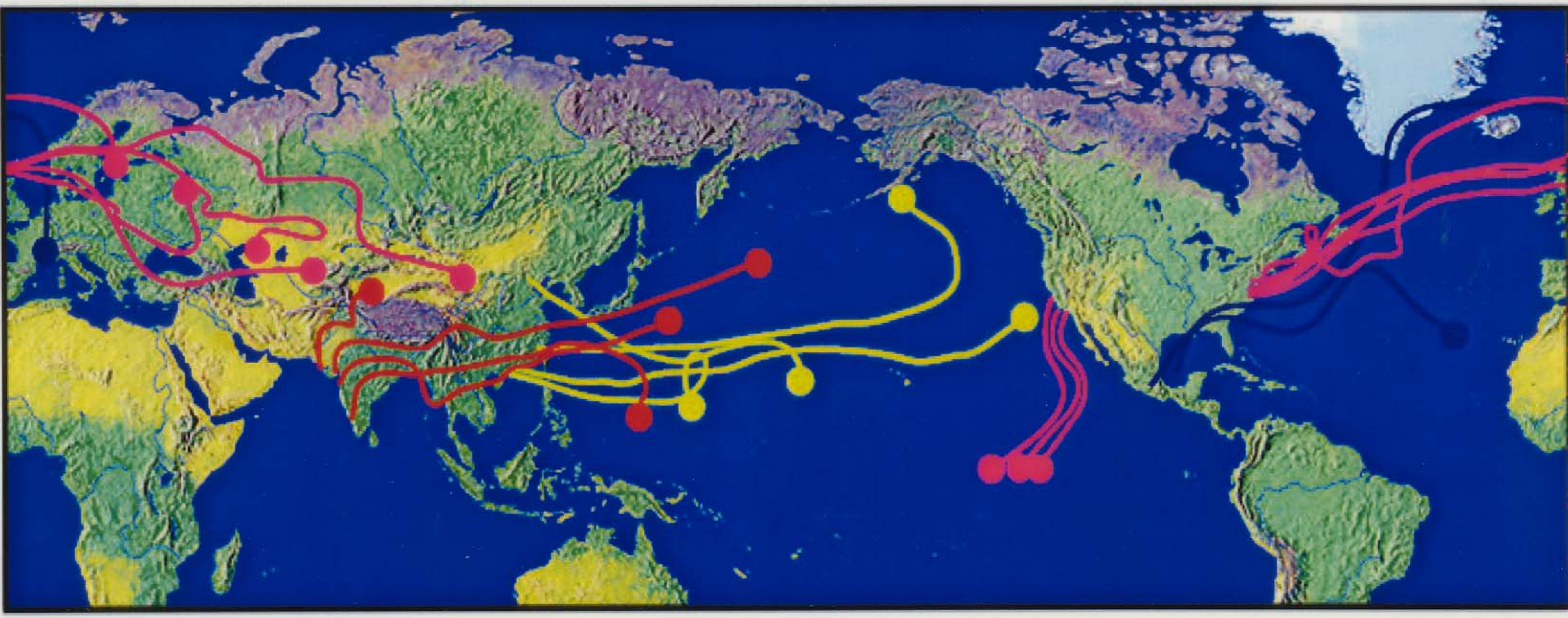
Phaplu, Nepal; March 29, 2001



Kaashidhoo under Haze Layer

Transcontinental Nature of the “Haze“

Forward Trajectories from 700 mb, March 14-21, 1999



Trajectories are from India, China, Mexico, US east and west coasts, London, Paris and Berlin (*courtesy of T.N. Krishmamurti*).

The author with his grandson Jan Oliver, 1999.

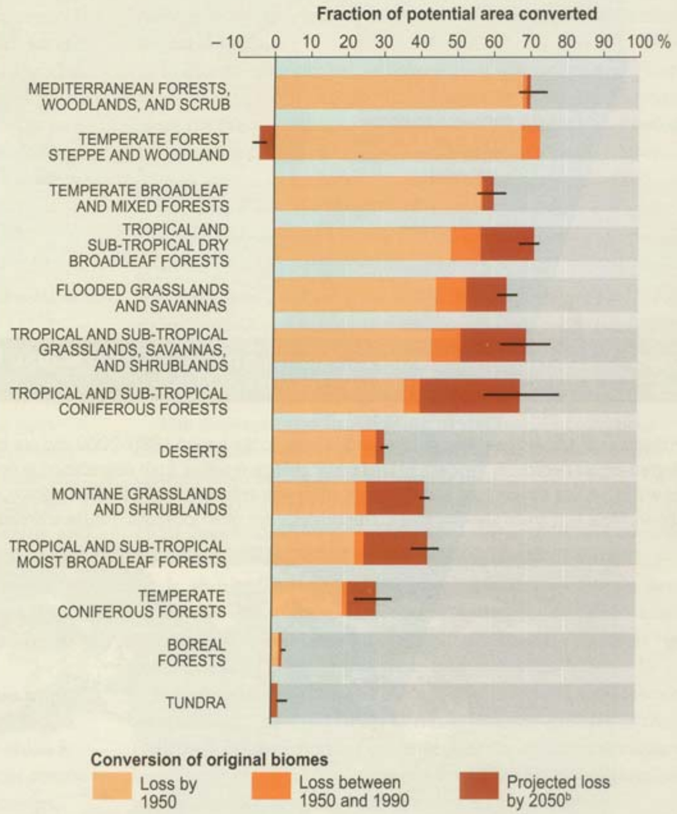
What world will he be living in?

He will certainly know whether climate is stable or instable.

There are good reasons to start to protect earth‘s climate from too large warming. Kyoto (2005) is by far not enough.

Figure 3. Conversion of Terrestrial Biomes[a] (Adapted from C4, S10)

It is not possible to estimate accurately the extent of different biomes prior to significant human impact, but it is possible to determine the "potential" area of biomes based on soil and climatic conditions. This Figure shows how much of that potential area is estimated to have been converted by 1950 (*medium certainty*), how much was converted between 1950 and 1990 (*medium certainty*), and how much would be converted under the four MA scenarios (*low certainty*) between 1990 and 2050. Mangroves are not included here because the area was too small to be accurately assessed. Most of the conversion of these biomes is to cultivated systems.



[a] A biome is the largest unit of ecological classification that is convenient to recognize below the entire globe, such as temperate broadleaf forests or montane grasslands. A biome is a widely used ecological categorization, and because considerable ecological data have been reported and modeling undertaken using this categorization, some information in this assessment can only be reported based on biomes. Whenever possible, however, the MA reports information using 10 socioecological systems, such as forest, cultivated, coastal, and marine, because these correspond to the regions of responsibility of different government ministries and because they are the categories used within the Convention on Biological Diversity.

[b] According to the four MA scenarios. For 2050 projections, the average value of the projections under the four scenarios is plotted and the error bars (black lines) represent the range of values from the different scenarios.

Source: Millennium Ecosystem Assessment

Figure 4. SPECIES EXTINCTION RATES (Adapted from C4 Fig 4.22)

"Distant past" refers to average extinction rates as estimated from the fossil record. "Recent past" refers to extinction rates calculated from known extinctions of species (lower estimate) or known extinctions plus "possibly extinct" species (upper bound). A species is considered to be "possibly extinct" if it is believed by experts to be extinct but extensive surveys have not yet been undertaken to confirm its disappearance. "Future" extinctions are model-derived estimates using a variety of techniques, including species-area models, rates at which species are shifting to increasingly more threatened categories, extinction probabilities associated with the IUCN categories of threat, impacts of projected habitat loss on species currently threatened with habitat loss, and correlation of species loss with energy consumption. The time frame and species groups involved differ among the "future" estimates, but in general refer to either future loss of species based on the level of threat that exists today or current and future loss of species as a result of habitat changes taking place over the period of roughly 1970 to 2050. Estimates based on the fossil record are *low certainty*; lower-bound estimates for known extinctions are *high certainty* and upper-bound estimates are *medium certainty*; lower-bound estimates for modeled extinctions are *low certainty* and upper-bound estimates are *speculative*. The rate of known extinctions of species in the past century is roughly 50–500 times greater than the extinction rate calculated from the fossil record of 0.1–1 extinctions per 1,000 species per 1,000 years. The rate is up to 1,000 times higher than the background extinction rates if possibly extinct species are included.

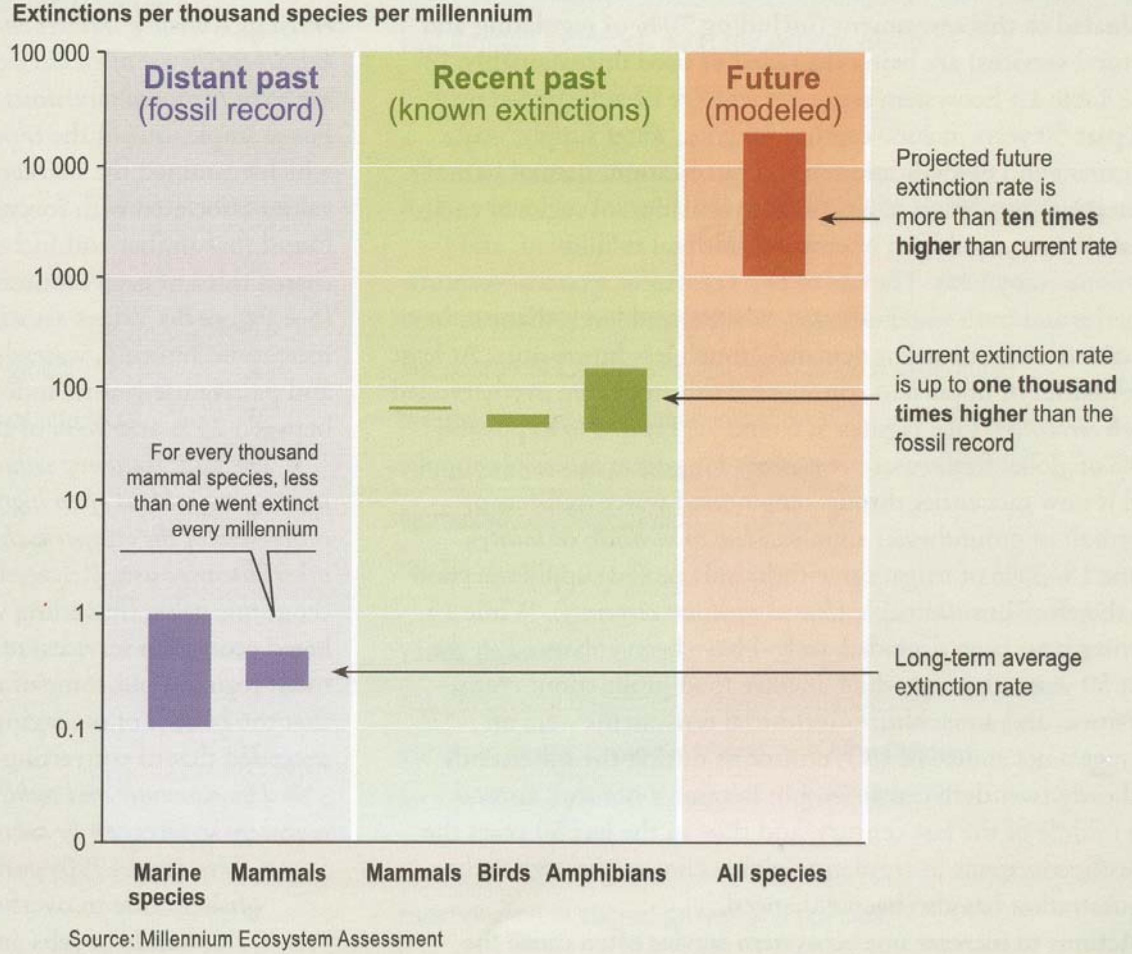
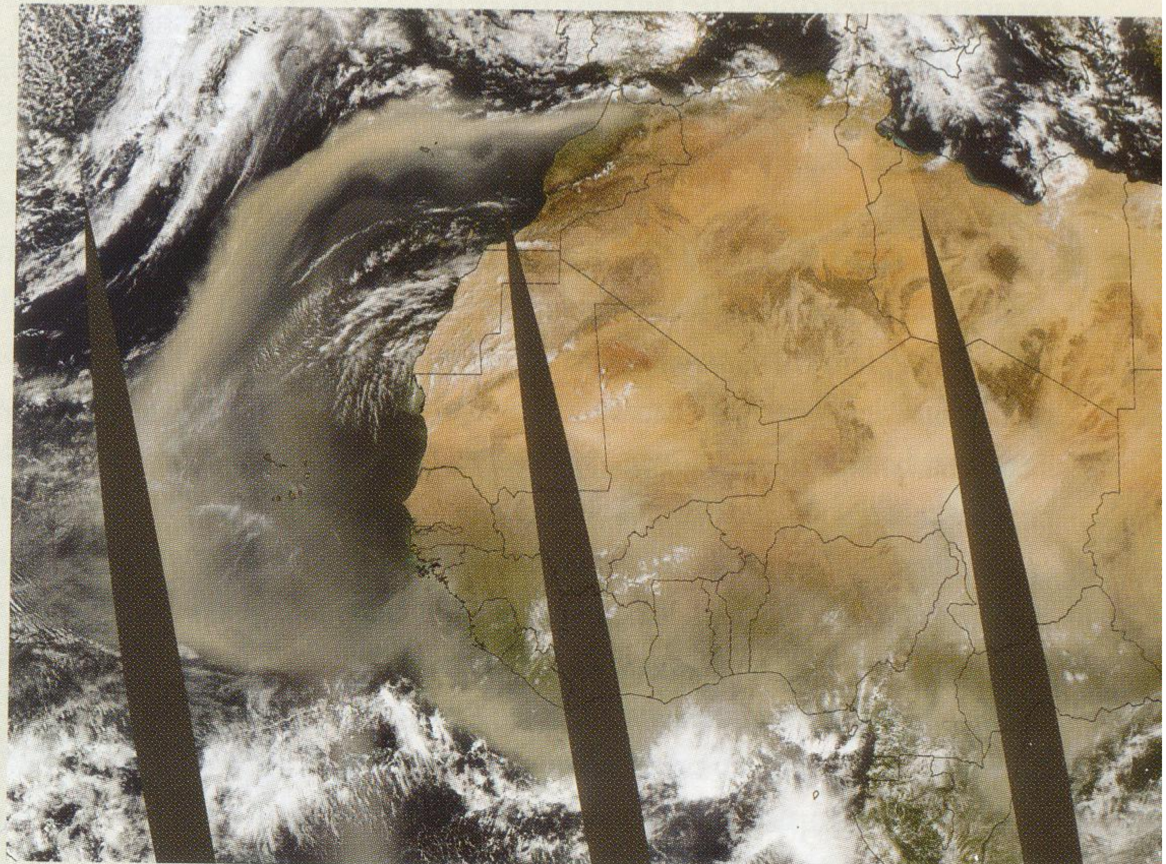


Figure 10. Dust Cloud off the Northwest Coast of Africa, March 6, 2004

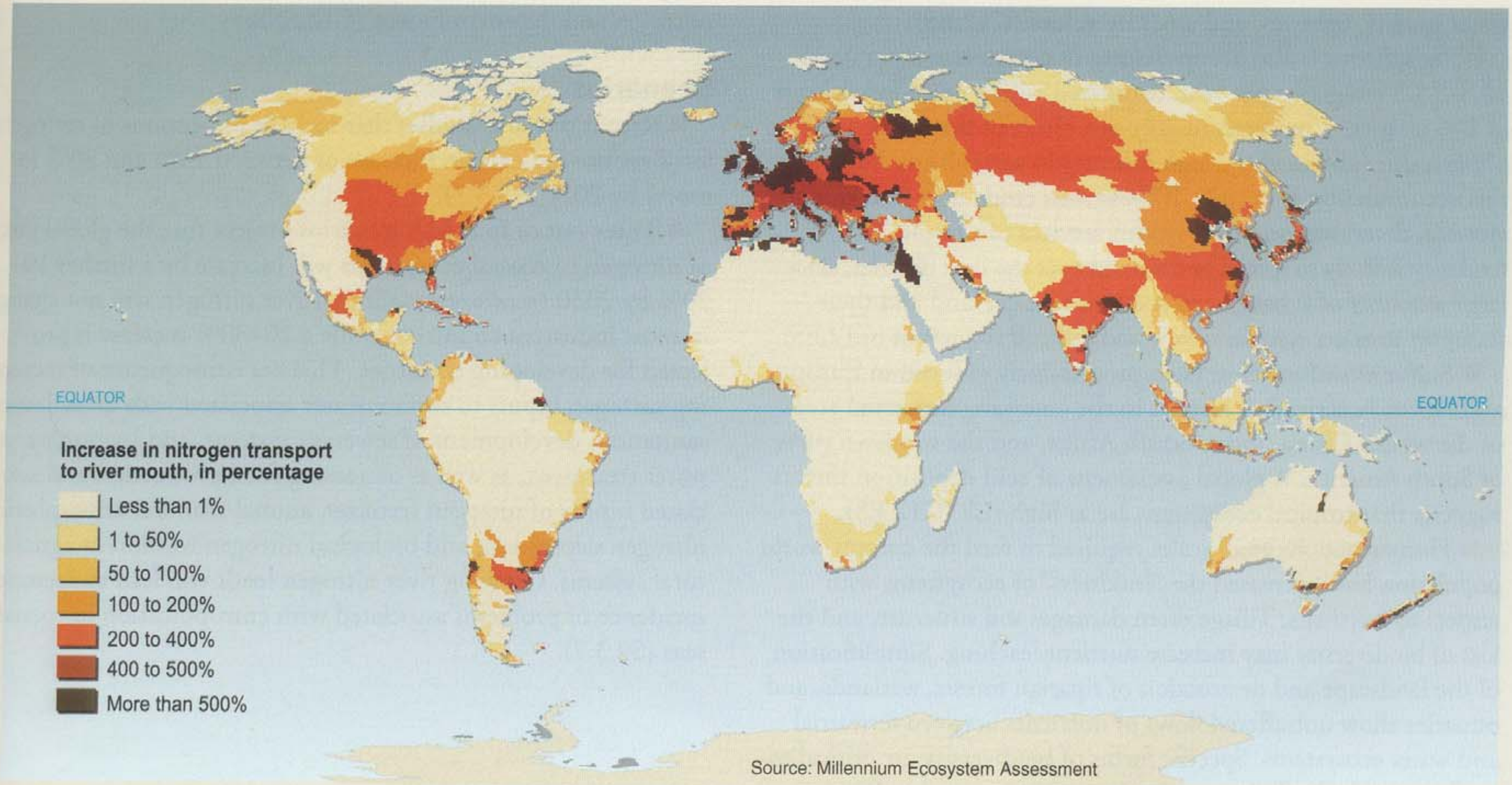
In this image, the storm covers about one fifth of Earth's circumference. The dust clouds travel thousands of kilometers and fertilize the water off the west coast of Florida with iron. This has been linked to blooms of toxic algae in the region and respiratory problems in North America and has affected coral reefs in the Caribbean. Degradation of drylands exacerbates problems associated with dust storms.



Source: National Aeronautics and Space Administration, Earth Observatory

Appendix Figure A.9. Contrast between Contemporary and Pre-disturbance Transports of Total Nitrogen through Inland Aquatic Systems Resulting from Anthropogenic Acceleration of This Nutrient Cycle (C7 Fig 7.5)

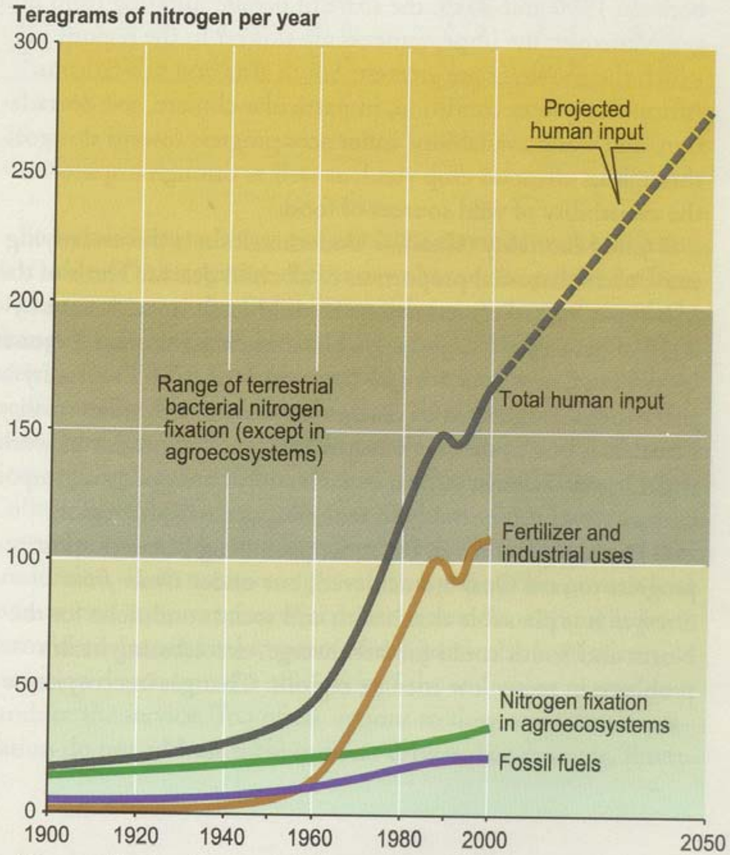
While the peculiarities of individual pollutants, rivers, and governance define the specific character of water pollution, the general patterns observed for nitrogen are representative of anthropogenic changes to the transport of waterborne constituents. Elevated contemporary loadings to one part of the system (such as croplands) often reverberate to other parts of the system (to coastal zones, for example), exceeding the capacity of natural systems to assimilate additional constituents.



Source: Millennium Ecosystem Assessment

Figure 14. Global Trends in the Creation of Reactive Nitrogen on Earth by Human Activity, with Projection to 2050 (R9 Fig 9.1)

Most of the reactive nitrogen produced by humans comes from manufacturing nitrogen for synthetic fertilizer and industrial use. Reactive nitrogen is also created as a by-product of fossil fuel combustion and by some (nitrogen-fixing) crops and trees in agroecosystems. The range of the natural rate of bacterial nitrogen fixation in natural terrestrial ecosystems (excluding fixation in agroecosystems) is shown for comparison. Human activity now produces approximately as much reactive nitrogen as natural processes do on the continents. (Note: The 2050 projection is included in the original study and is not based on MA Scenarios.)



Source: Millennium Ecosystem Assessment

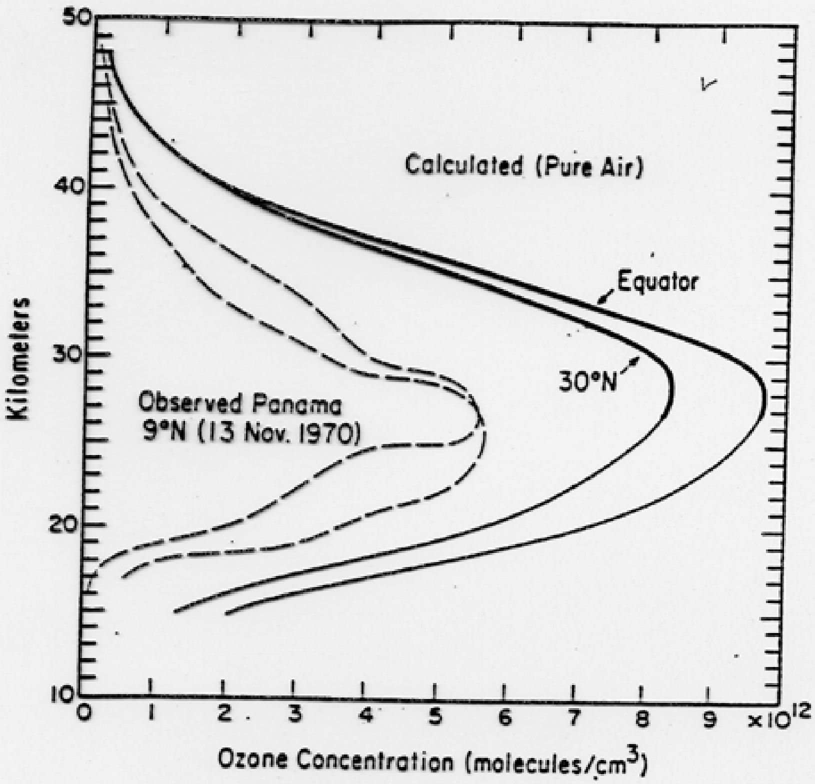


Figure 8. Ozone profiles, observed at Panama (9°N) and calculated from a model of pure dry air. The difference between these curves is referred to as the "ozone deficit".

Chapman (1930)

$O_2 + h\nu$ (< 240 nm)	→	2 O
$O + O_2 + M$	→	$O_3 + M$
net: 3 O_2	→	2 O_3
$O_3 + h\nu$ (< 1140 nm)	→	$O + O_2$
$O + O_3$	→	2 O_2
net: 2 O_3	→	3 O_2

Benson and Axworthy (1965) revision of $O + O_3$ and $O + O_2 + M$ reactions.

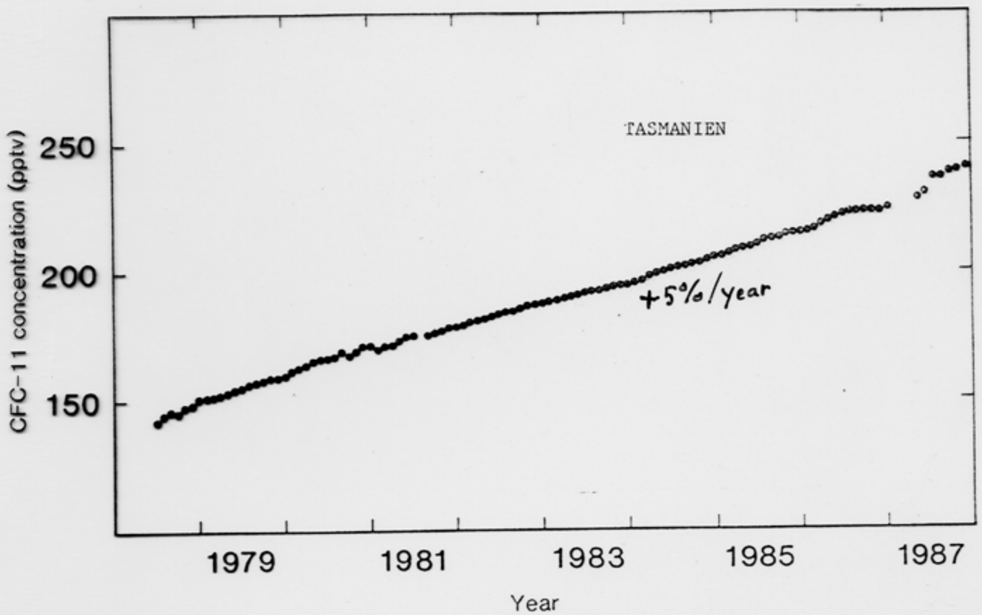
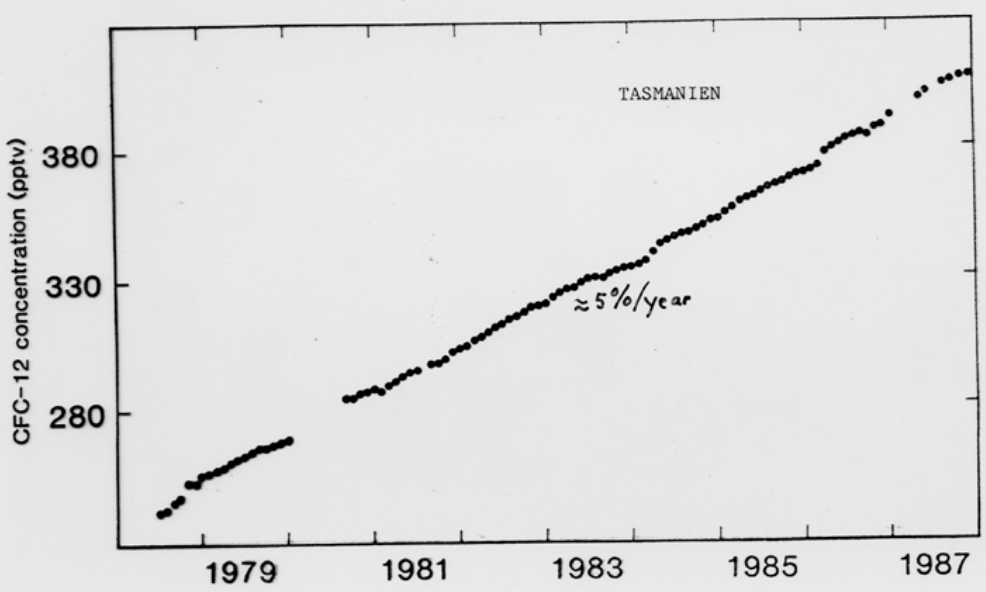
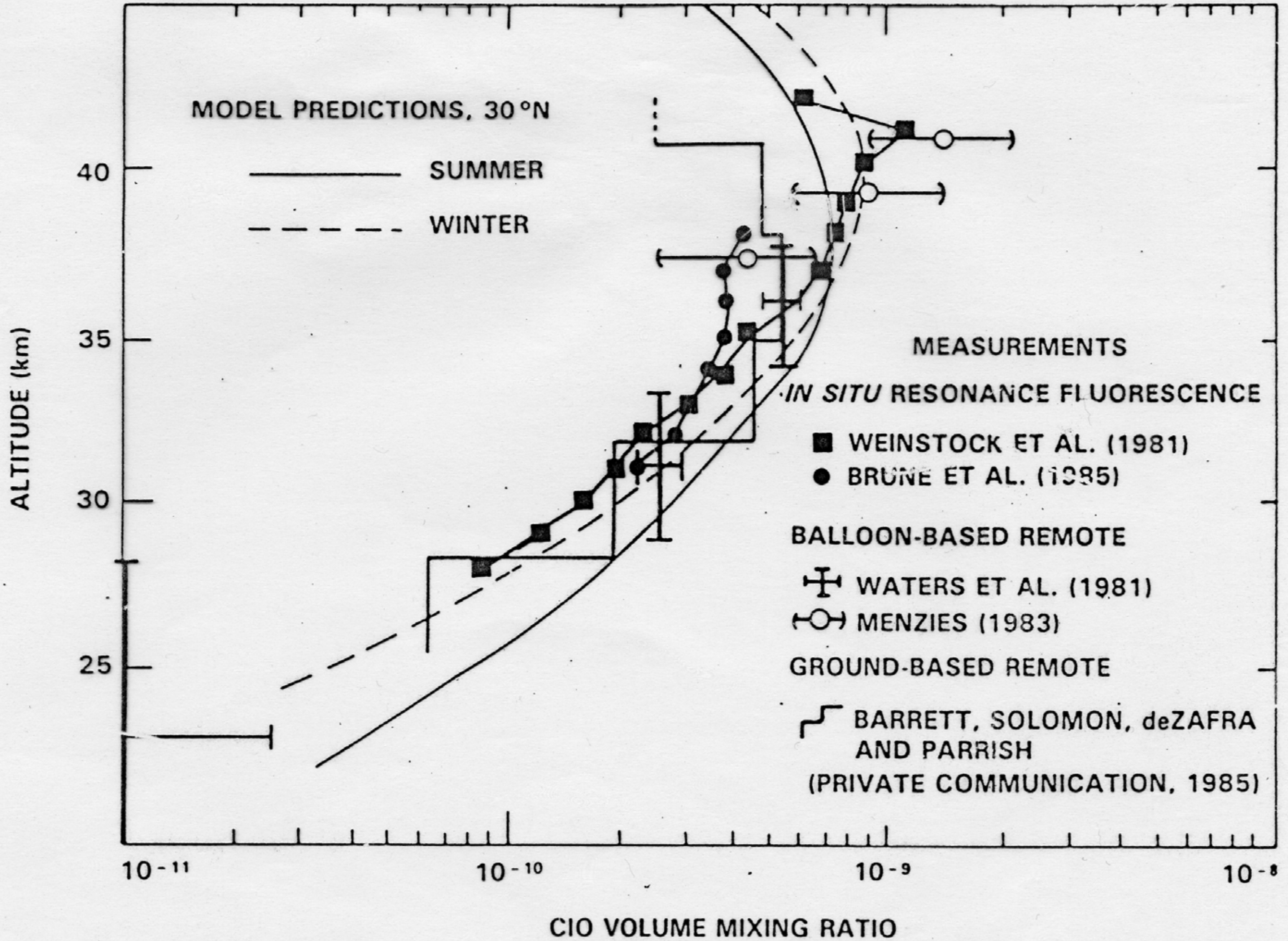


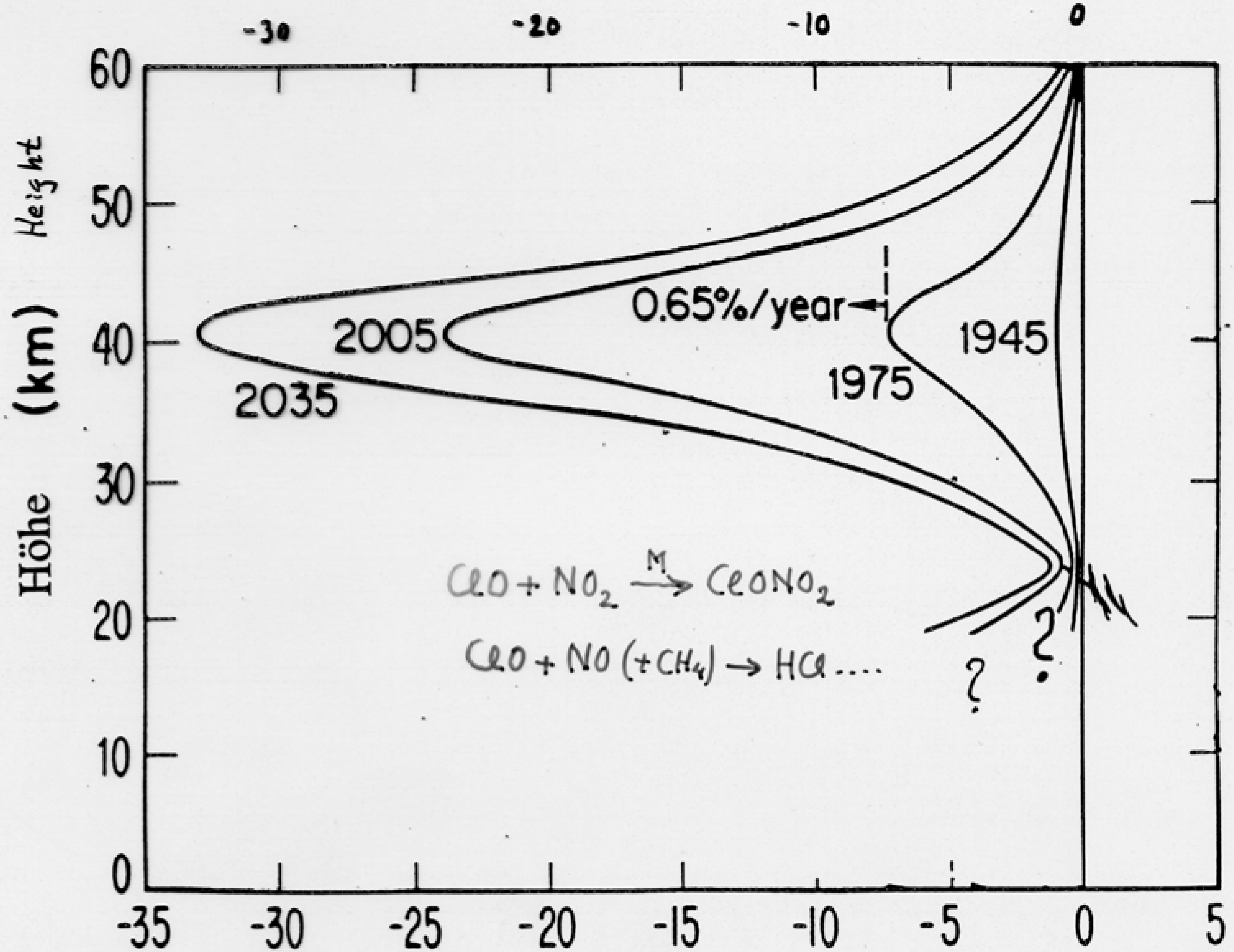
Figure 8. Trichlorofluoromethane (CFC-11) concentrations as observed at the Cape Grim Observatory (data from Fraser and Derek, 1987; updated by P J Fraser, pers.comm.).





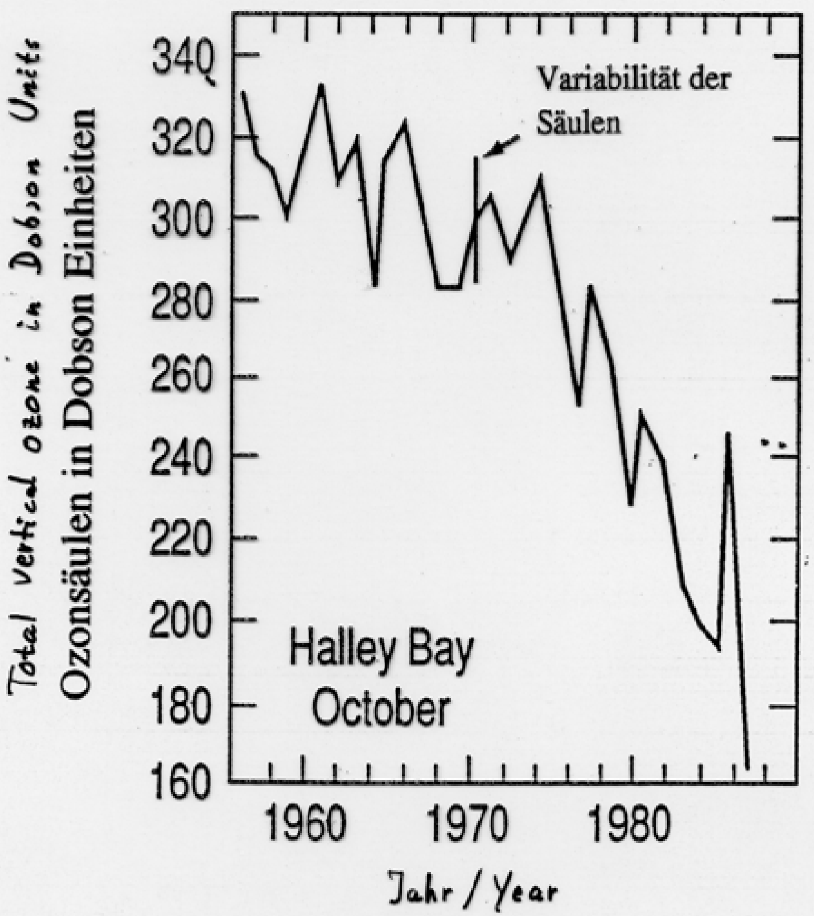
MODEL PREDICTIONS, 30°N
SUMMER
WINTER
MEASUREMENTS
IN SITU RESONANCE FLUORESCENCE
WEINSTOCK ET AL. (1981)
BRUNE ET AL. (1985)
BALLOON-BASED REMOTE
WATERS ET AL. (1981)
MENZIES (1983)
GROUND-BASED REMOTE
BARRETT, SOLOMON, deZAFRA AND PARRISH (PRIVATE COMMUNICATION, 1985)
ALTITUDE (km)
40
35
30
25
10⁻¹¹
10⁻¹⁰
10⁻⁹
10⁻⁸
ClO VOLUME MIXING RATIO

Percent ozone depletion at constant CFC-emissions after 1974

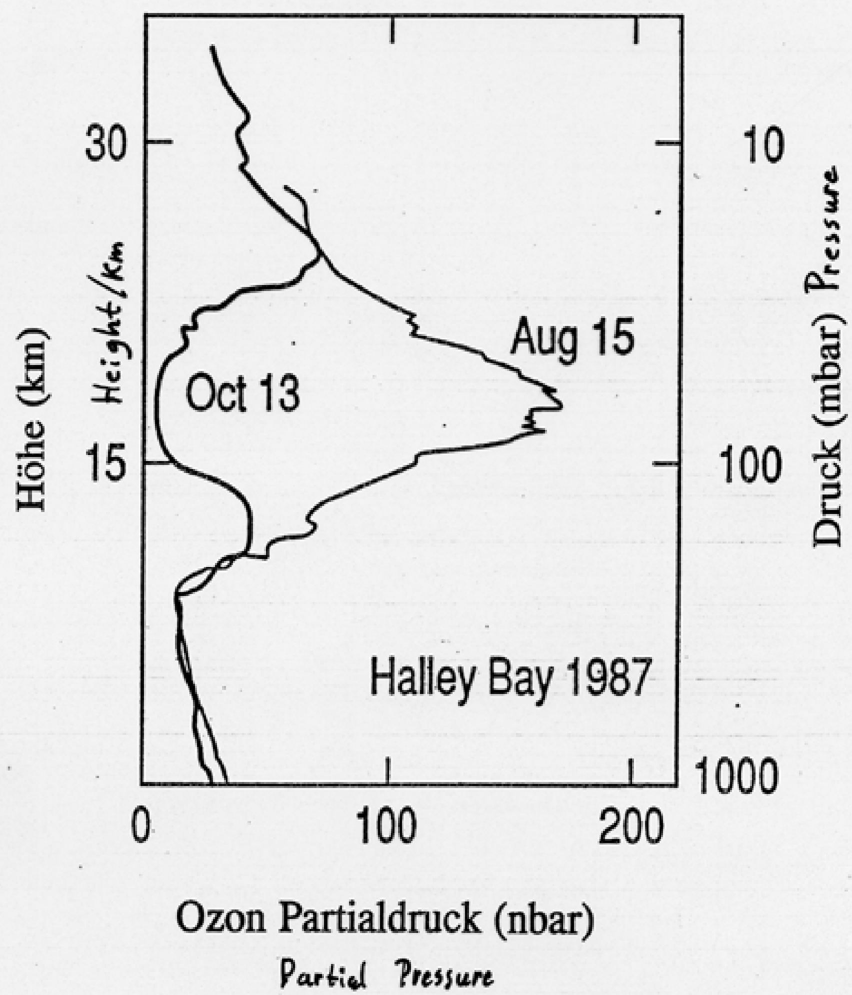


$ClONO_2$ und HCl reagieren nicht mit Ozon.

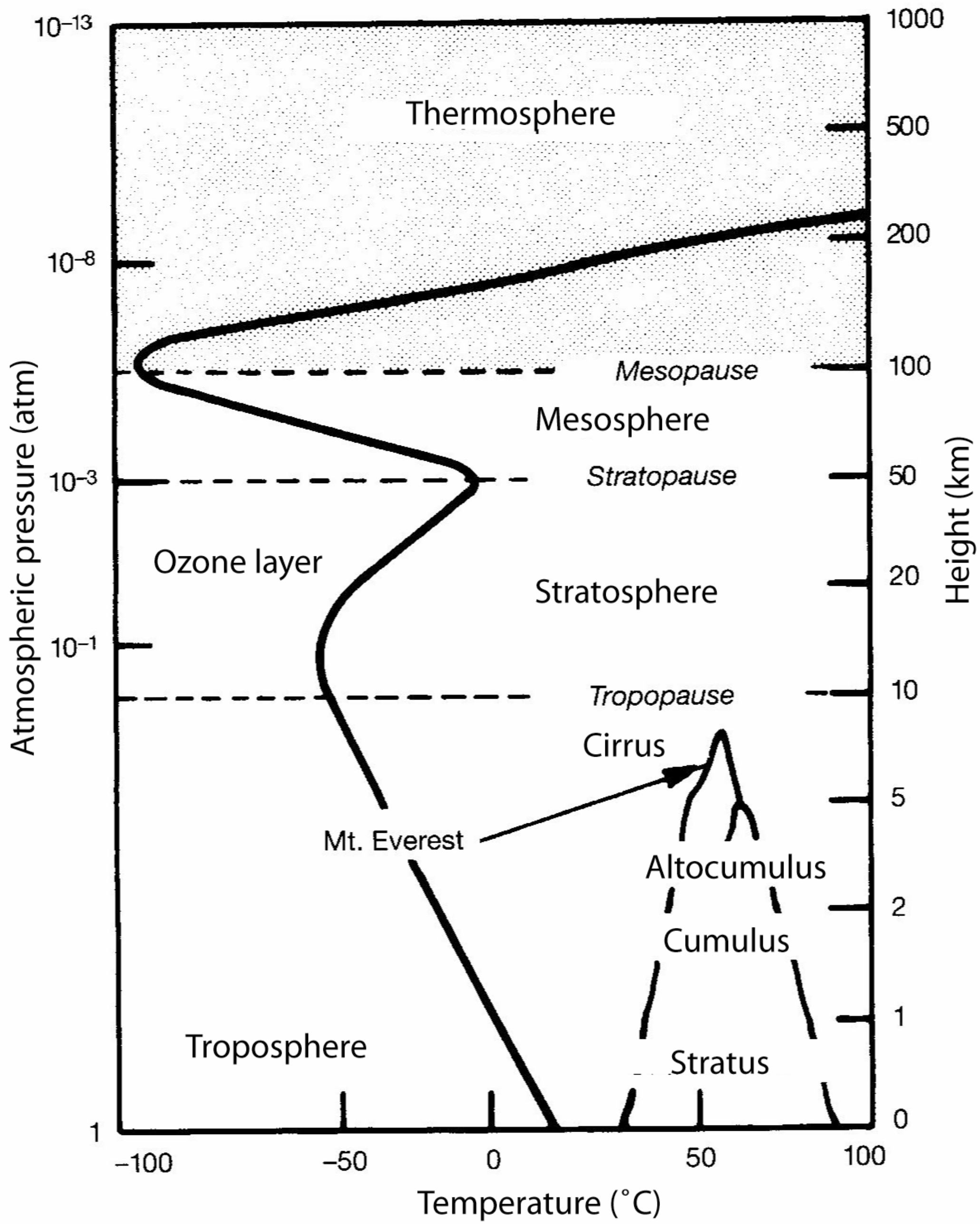
PROZENTUELLE ÄNDERUNGEN BEI KONSTANTER PRODUKTION DER FCKW- GASE



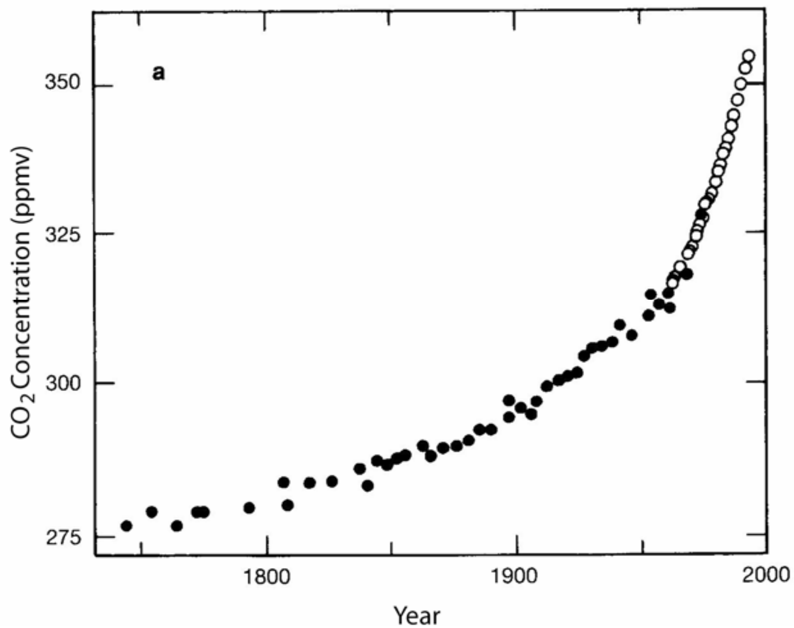
Total vertical ozone in Dobson Units
Ozonsäulen in Dobson Einheiten
340
320
300
280
260
240
220
200
180
160
Variabilität der Säulen
Halley Bay
October
1960
1970
1980
Jahr / Year



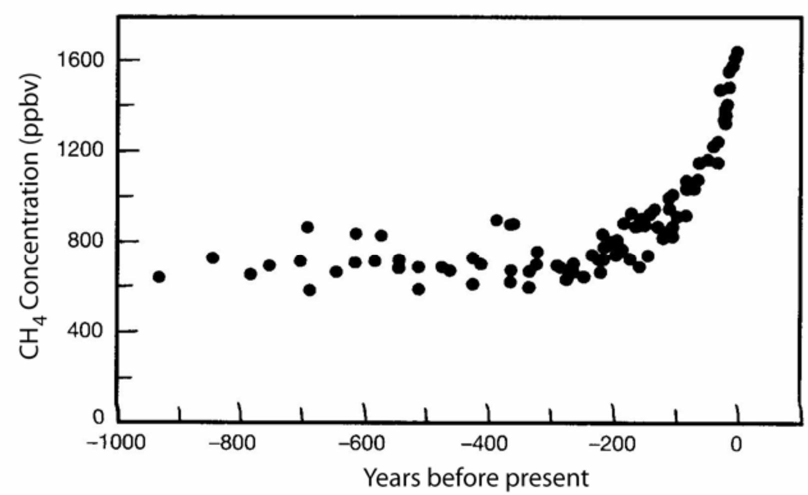
Höhe (km)
Height/Km
30
15
Druck (mbar) Pressure
10
100
1000
Aug 15
Oct 13
Halley Bay 1987
0
100
200
Ozon Partialdruck (nbar)
Partial Pressure



Thermosphere
Mesopause
Mesosphere
Stratopause
Ozone layer
Stratosphere
Tropopause
Cirrus
Mt. Everest
Altocumulus
Cumulus
Troposphere
Stratus
Atmospheric pressure (atm)
10^{-13}
10^{-8}
10^{-3}
10^{-1}
1
Height (km)
1000
500
200
100
50
20
10
5
2
1
0
−100
−50
0
50
100
Temperature (°C)



a
350
325
300
275
CO2 Concentration (ppmv)
1800
1900
2000
Year



1600
1200
800
400
0
CH4 Concentration (ppbv)
−1000
−800
−600
−400
−200
0
Years before present

Carbon Dioxide

Good News:

1. ~42% of annual fossil fuel emissions continues to be "soaked up" by ocean, soil, vegetation
2. Uptake % could increase if emissions decreased, or via improved forestation/agricultural practices

Bad News:

1. Stabilization of atmospheric CO_2 may require eventual reduction of emissions by 60-80%
2. Fossil fuel emission are increasing ~2% per year

Δ Greenhouse gas forcing (since pre-industrial times) $\approx 2.7\ W/m^2$

Heating of the ocean $\approx 0.3\ W/m^2$

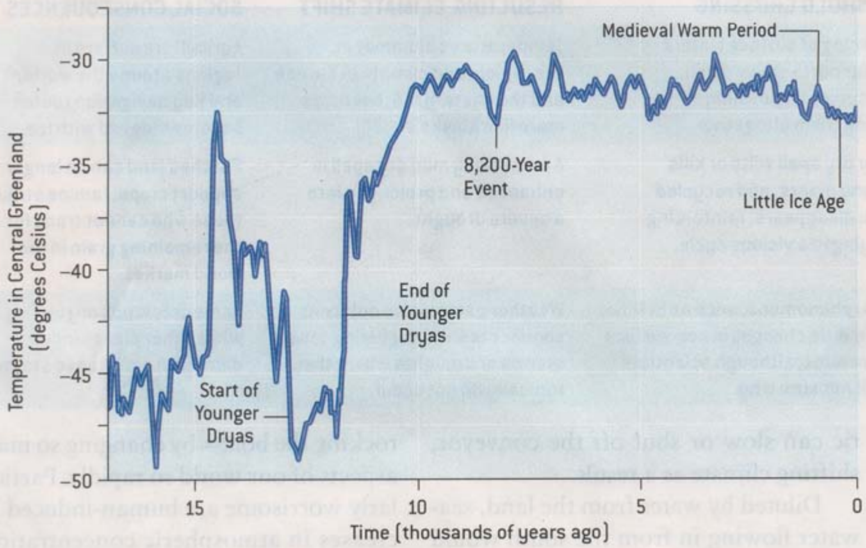
Increased upward IR (from hotter surface of earth) $\approx 1\ W/m^2$

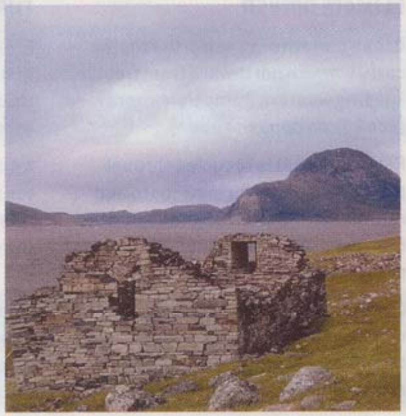
$\therefore$ Increased albedo effect $\approx 1.4\ W/m^2$ ($\approx$ 50% of GHF)

Heat release to atmosphere from fossil fuel burning (1995) $0.025\ W/m^2$

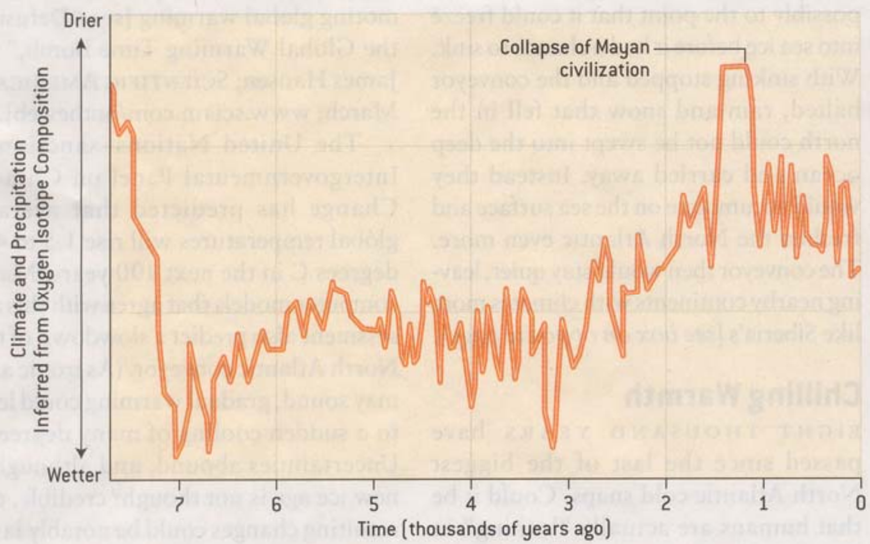
PAST AS PROLOGUE?

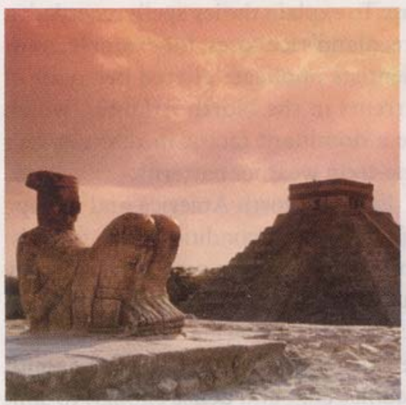
Abrupt climate change has marked the earth's history for eons. Ice cores from Greenland, for instance, reveal that wild temperature swings (*top left*) punctuated the gradual warming that brought the planet out of the last ice age starting about 18,000 years ago. Fossil shells in lake sediments from Mexico's Yucatán Peninsula record sudden and severe droughts (*bottom left*) because a diagnostic ratio of oxygen isotopes in the shells shoots up when more water evaporates from the lake than falls as rain. Societies have often suffered as a result of these rapid shifts (*photographs*).



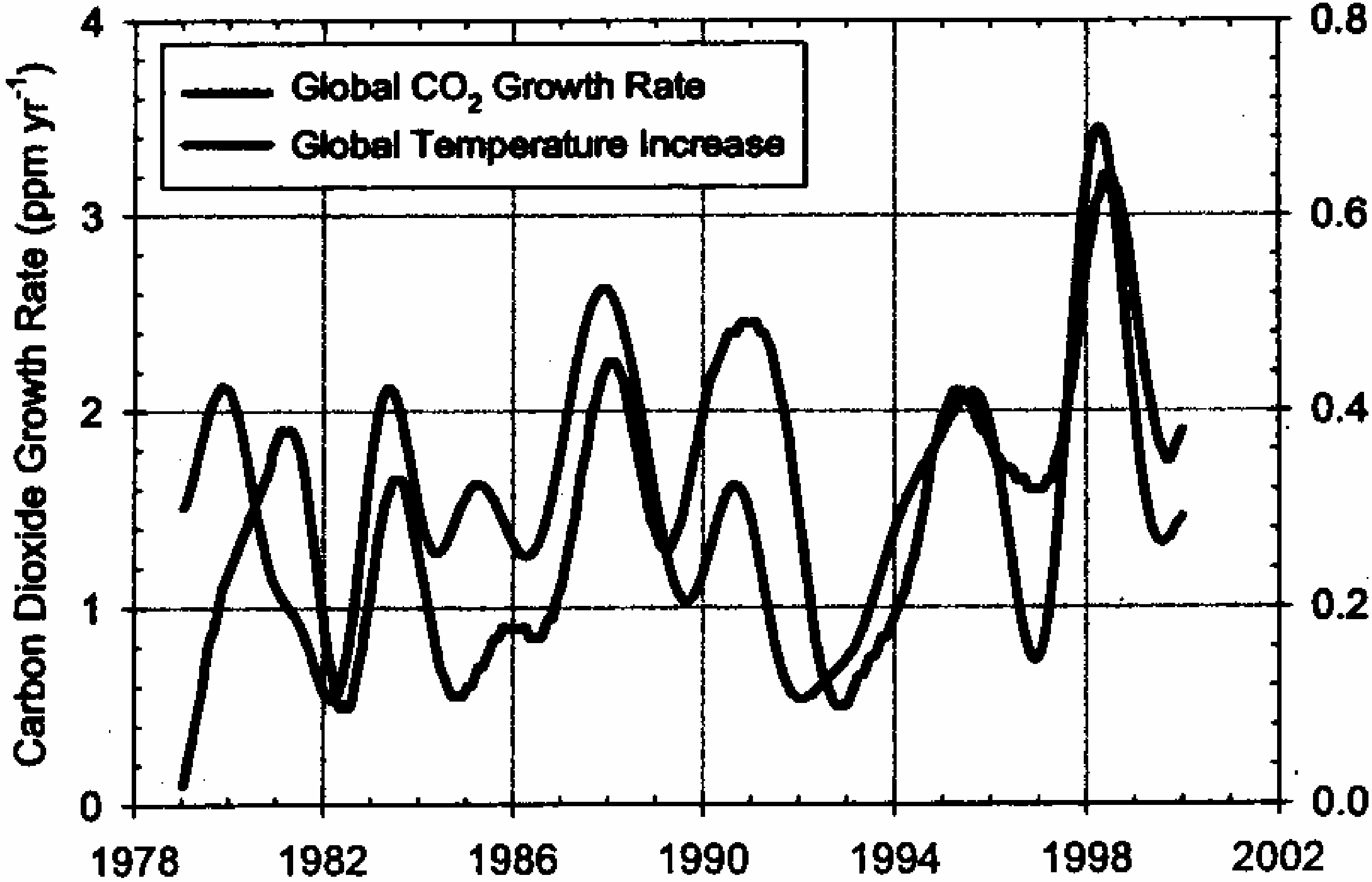


Viking settlement, now in ruins, was among those in Greenland abandoned during an abrupt cold spell called the Little Ice Age.

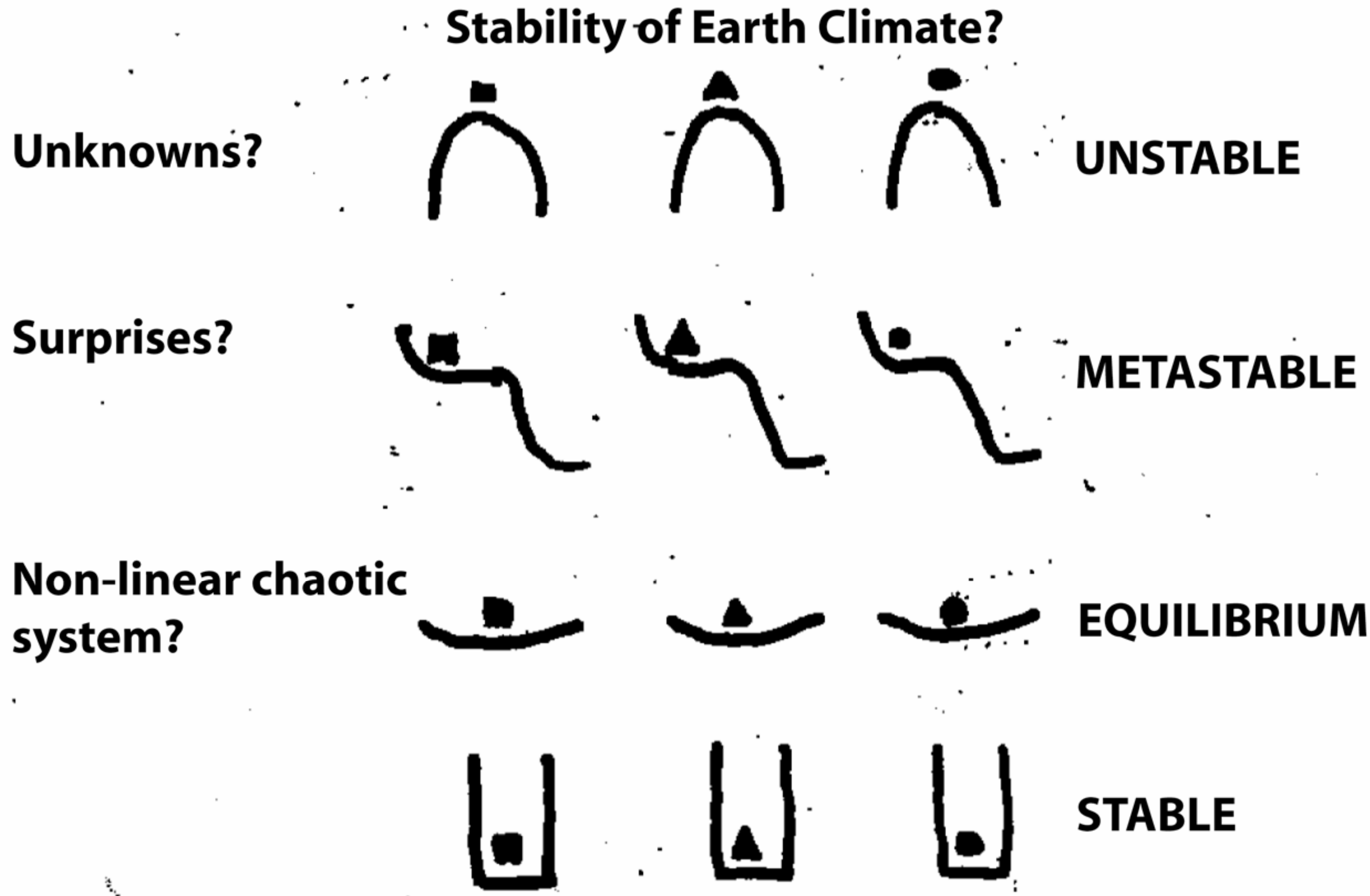




Mayan rain god (*statue in foreground*) was apparently no match for the drought now widely blamed for the collapse of Mayan civilization about 1,100 years ago.



Global CO_2 growth rate from the CMDL Cooperative Air Sampling Network and the global temperature anomaly from NASA GISS (Hansen, et al.). The cross correlation coefficient is 0.6, with warm temperatures associated with high CO_2 growth rate.

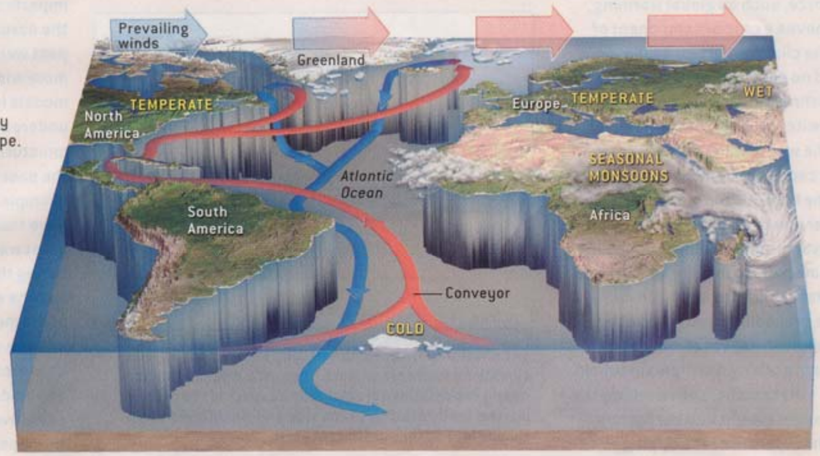

Stability of Earth Climate?
Unknowns?
UNSTABLE
Surprises?
METASTABLE
Non-linear chaotic system?
EQUILIBRIUM
STABLE

MELTING TOWARD A COLD SNAP?

As global warming continues to heat up the planet, many scientists fear that large pulses of freshwater melting off the Greenland ice sheet and other frozen northern landmasses could obstruct the so-called North Atlantic conveyor, the system of ocean currents that brings warmth to Europe and strongly influences climate elsewhere in the world. A conveyor shutdown—or even a significant slowdown—could cool the North Atlantic region even as global temperatures continue to rise. Other challenging and abrupt climate changes would almost certainly result.

CONVEYOR ON

Salty ocean currents (*red*) flowing northward from the tropics warm prevailing winds (*large arrows*) as they blow eastward toward Europe. The heat-bearing currents, which are dense, become even denser as they lose heat to the atmosphere. Eventually the cold, salty water becomes dense enough to sink near Greenland. It then migrates southward along the seafloor (*blue*), leaving a void that draws more warm water from the south to take its place.

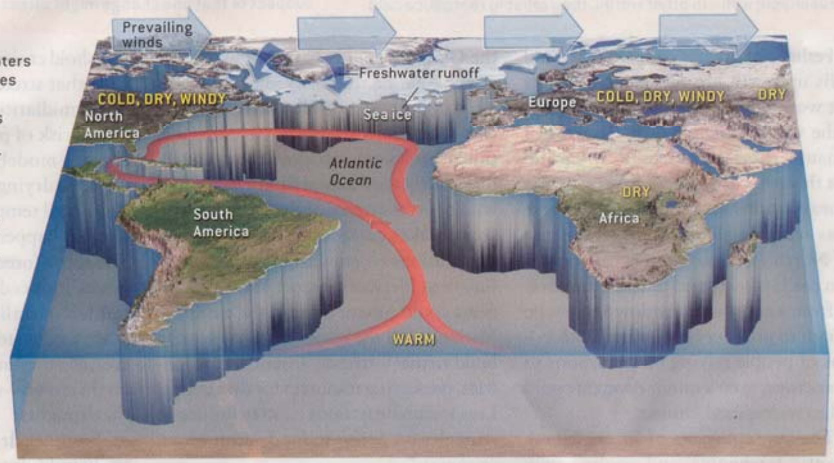


RESULTING CLIMATE

When the North Atlantic conveyor is active, temperate conditions with relatively warm winters enable rich agricultural production in much of Europe and North America. Seasonal monsoons fuel growing seasons in broad swaths of Africa and the Far East. Central Asia is wet, and Antarctica and the South Atlantic are typically cold.

CONVEYOR OFF

If too much freshwater enters the North Atlantic, it dilutes the salty currents from the south. Surface waters no longer become dense enough to sink, no matter how cold the water gets, and the conveyor shuts down or slows. Prevailing winds now carry frigid air eastward (*large arrows*). This cold trend could endure for decades or more—until southern waters become salty enough to overwhelm the fresher water up north, restarting the conveyor in an enormous rush.



RESULTING CLIMATE

As the conveyor grows quiet, winters become harsher in much of Europe and North America, and agriculture suffers. These regions, along with those that usually rely on seasonal monsoons, suffer from droughts sometimes enhanced by stronger winds. Central Asia gets drier, and many regions in the Southern Hemisphere become warmer than usual.

Richard B. Alley: Abrupt climate change
Scientific American, November 2004

The author (left) with Professor V. Ramanathan on an INDOEX research flight

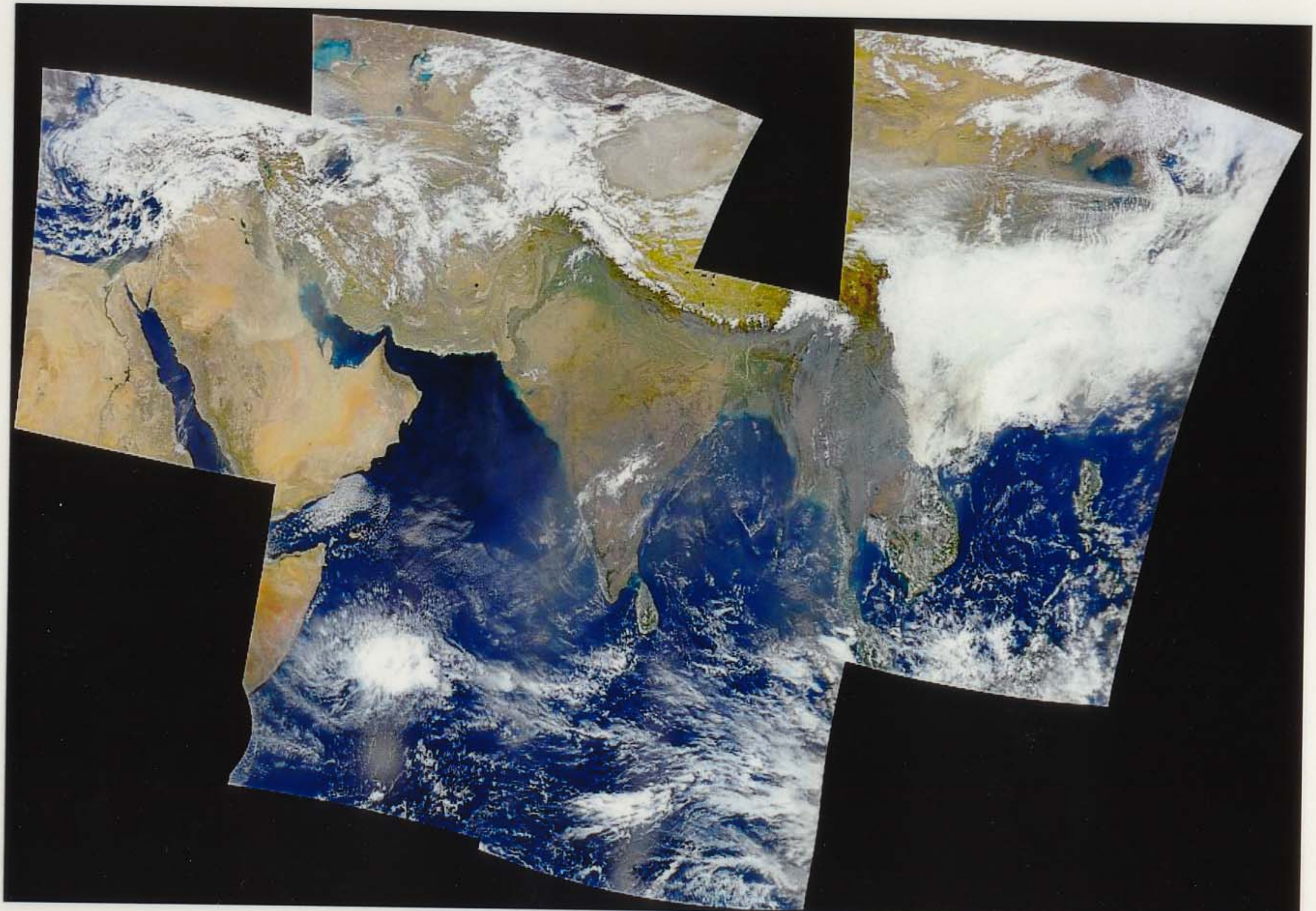
Table 1. Black carbon (BC) emissions from biofuel combustion in India, Asia, and the world. Estimates of BC emissions from biofuel combustion made use of emission factors (g kg⁻¹) from table S1. In the rightmost column, the total includes BC emissions from forest, savanna, and crop waste open burning as well as fossil fuel combustion.

Region	Base year	Biofuel consumption (Tg year^{-1})			Black carbon emissions (Gg year^{-1})				BC source ratio (biofuel/total) (%)
		Fuelwood	Dried cattle manure	Crop waste	Fuelwood	Dried cattle manure	Crop waste	Total biofuel	
India	1995	281* (192–409)‡ (*13*)	62* (35–108)‡ (*13*)	36* (20–67)‡ (*13*)	143* (75–272)‡	8* (3–17)‡	21* (9–51)‡	172* (87–340)‡	44†
Asia		800–930§ (*8, 25*)	130–200§ (*8, 25*)	430–545§ (*8, 25*)	400–470	15–25	220–280	635–775	30‡
Global		1324–1615§ (*8, 25*)	150–410§ (*8, 25*)	442–707§ (*8, 25*)	670–820	20–50	230–360	920–1230	15‡
India	1985	220 (*25*)	93 (*25*)	86 (*25*)	110	10	40	160	54
Asia		753 (*25*)	133 (*25*)	545 (*25*)	385	15	280	680	23
Global		1324 (*25*)	136 (*25*)	597 (*25*)	675	15	300	990	7

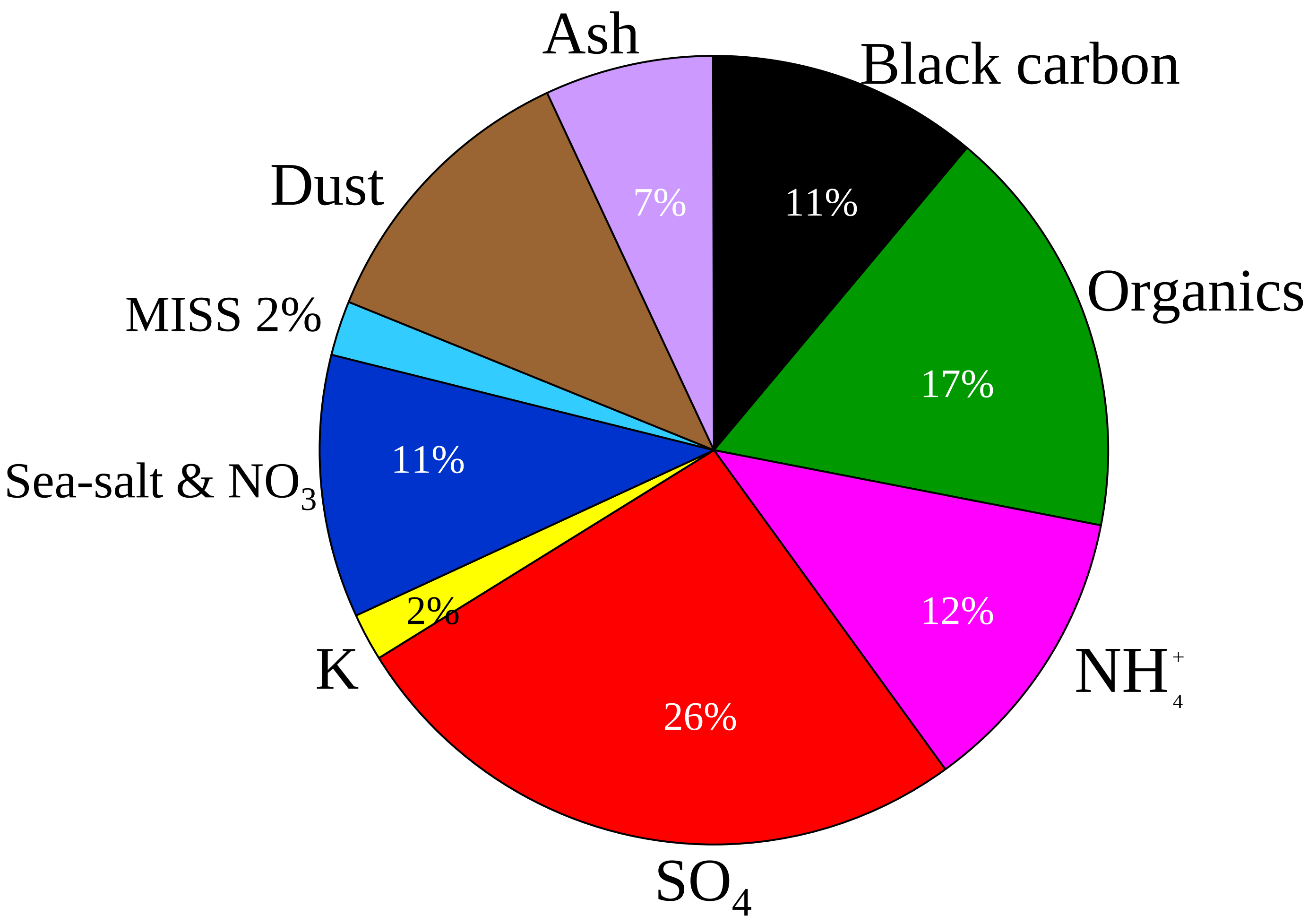
*Central value of biofuel consumption for cooking and BC emissions. †Central value of percent contribution of BC from biofuel combustion. ‡Lower and upper bound estimates of biofuel consumption for cooking and BC emissions at 95% confidence interval. §Asia and global numbers include biofuel consumption for cooking and space heating, excluding the amount used in industry. The ranges are from two different studies (*8, 25*).

Venkataraman, C., et al, Science, Vol. 307, March 2005

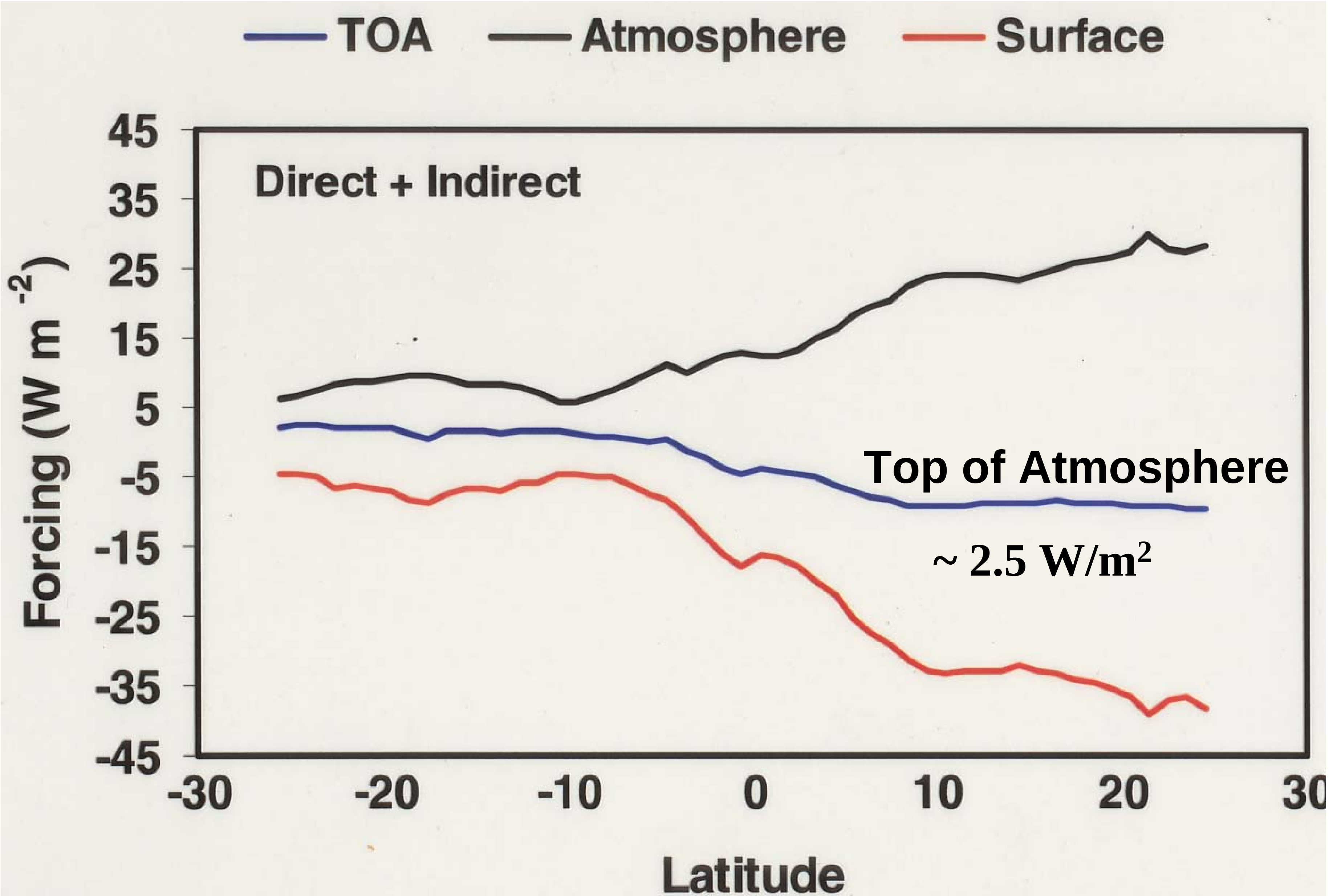
South Asian Haze: Seawifs Image; MARCH 21, 1999
Source: ORBIMAGE



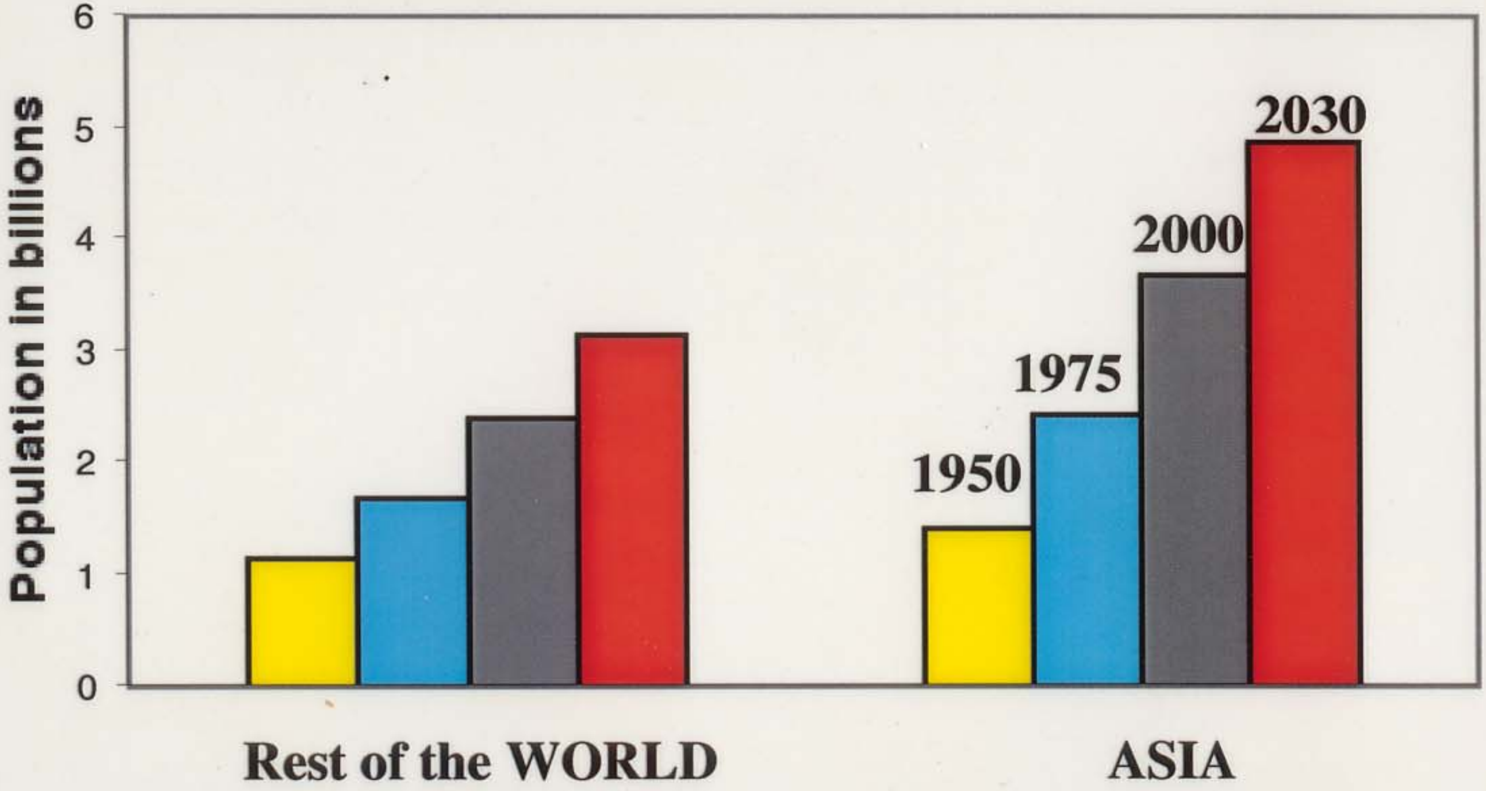
The Composition of Aerosol



Shows the relative contribution of the various chemical species to the aerosol optical properties at visible wavelengths (Satheesh et al., 2000; Lelieveld et al., 2000)


TOA
Atmosphere
Surface
Direct + Indirect
Top of Atmosphere
~ 2.5 W/m2
Forcing (W m -2)
45
35
25
15
5
-5
-15
-25
-35
-45
-30
-20
-10
0
10
20
30
Latitude

Population Growth



Source: World Population Prospects: The 2000 Revision; United Nations New York