1998 CEDAR Workshop
Boulder, Colorado
June 7-12, 1998

Tutorial Lecture

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Long-Term Variability and Global Change in the Middle and Lower Atmosphere

ATMOSPHERIC CHANGES

1. **Natural Variability**
   - **Solar forcing**
   - **Volcanic forcing**
   - **Internal fluctuations (noise)**

2. **Anthropogenic Effects**
   - **Fossil fuel burning**
   - **Biomass burning**
   - **Land-use change (deforestation, use of fertilizers)**
   - **Industrial production of chemicals (CFC's)**

EXAMPLES OF GLOBAL ENVIRONMENTAL CHANGES

- Degradation of air quality. Global pollution resulting from industrial combustion and biomass burning

- Increase of tropospheric oxidant and aerosol levels (human health and crop productivity)

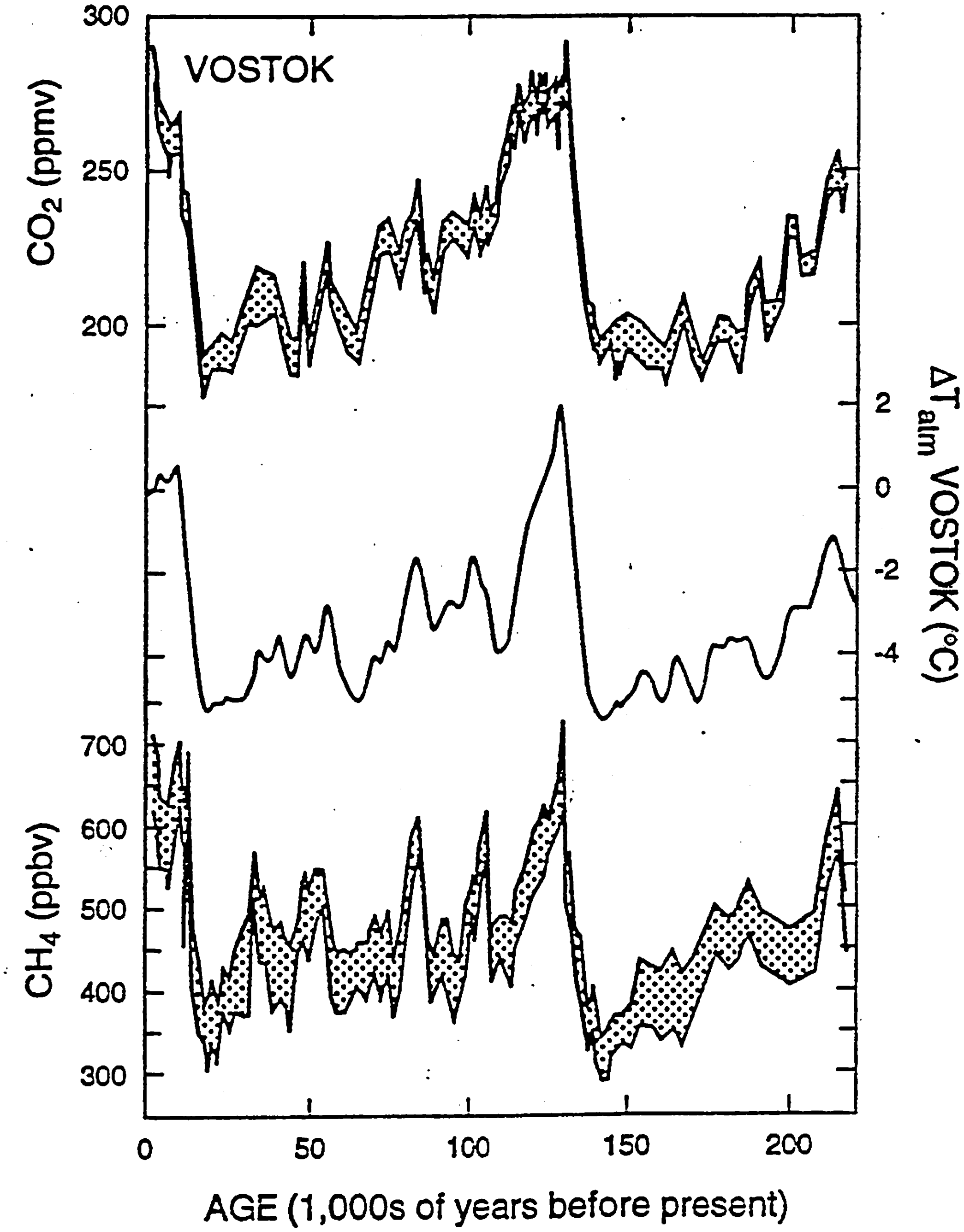
- Climatic and environmental impacts of land use changes (tropical deforestation, wetland destruction, etc.)

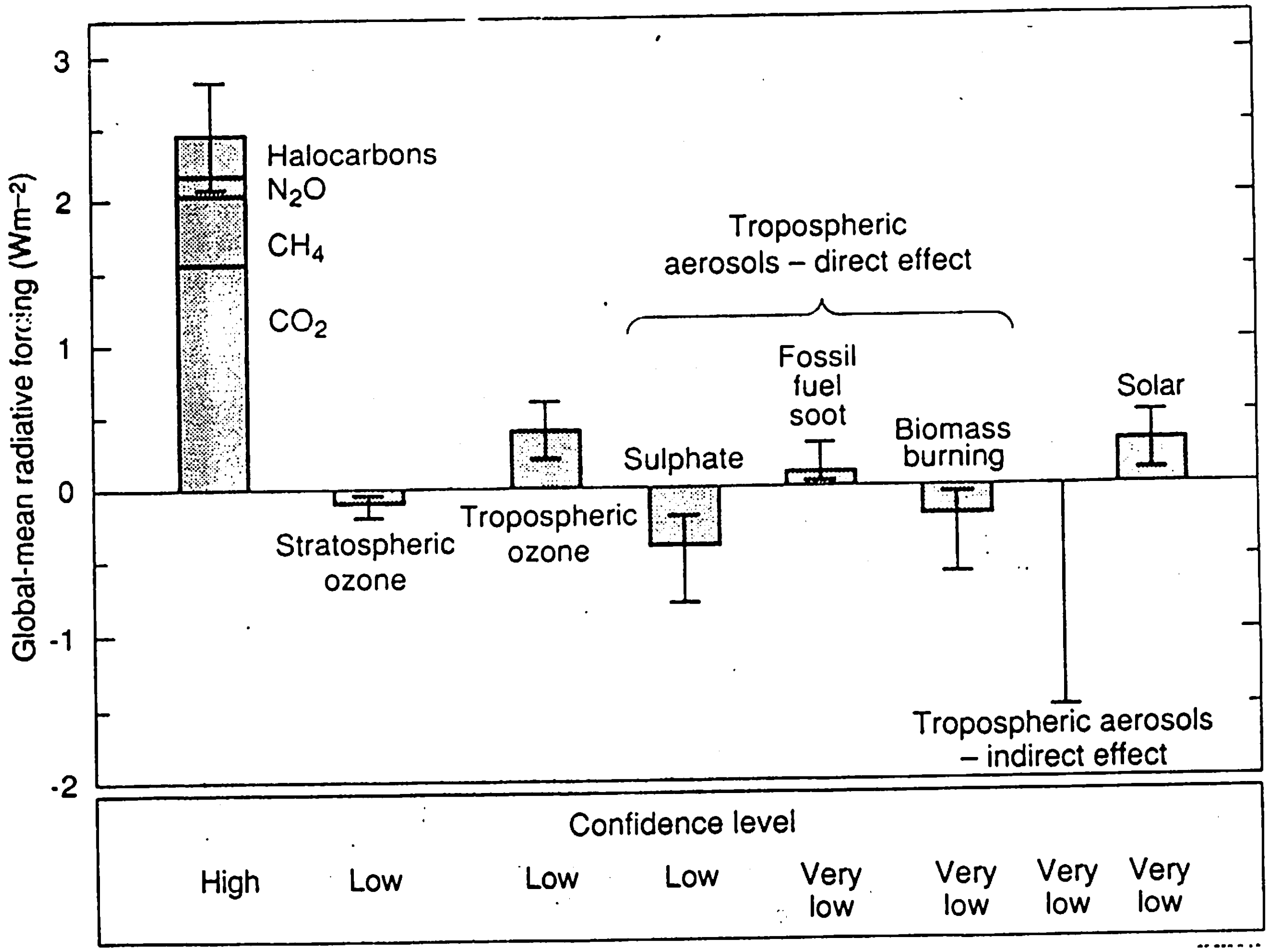
- Perturbations in global biogeochemical cycles (carbon, nitrogen, phosphorus, sulfur)

- Acidic precipitation

- Climatic impact of greenhouse gases and of anthropogenic sulfate

- Stratospheric ozone depletion


VOSTOK
CO_2 (ppmv)
300
250
200
ΔT_{atm} VOSTOK (°C)
2
0
-2
-4
CH_4 (ppbv)
700
600
500
400
300
0
50
100
150
200
AGE (1,000s of years before present)


Global-mean radiative forcing (Wm^{-2})
3
2
1
0
-1
-2
Halocarbons
N_2O
CH_4
CO_2
Stratospheric ozone
Tropospheric ozone
Tropospheric aerosols – direct effect
Sulphate
Fossil fuel soot
Biomass burning
Solar
Tropospheric aerosols – indirect effect
Confidence level
High
Low
Low
Low
Very low
Very low
Very low
Very low

IMPORTANT FACTORS IN RECENT ATMOSPHERIC EVOLUTION

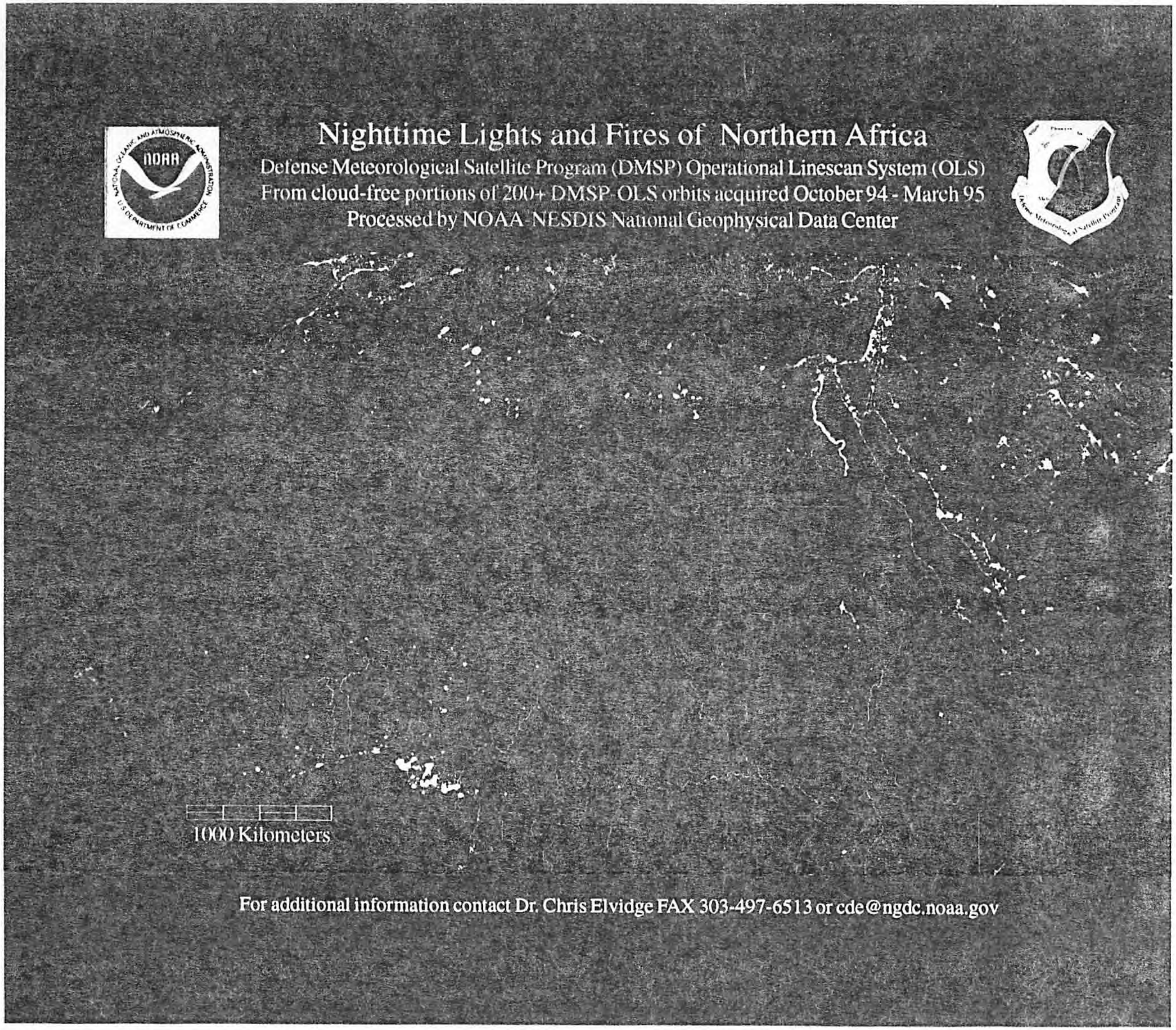
- **Over the last 100 years, the world's industrial production has increased by a factor of 100.**

- **Since 1850, the energy consumption has increased by a factor of 80.**

- **Over the last 200 years, the global population has increased by a factor of 8.**

- **Absolute population growth has been as large between 1950 and 1990 as during the entire previous historical period.**

- **Eighty percent of the world's primary energy is supplied by fossil fuel (largest contribution is oil; before 1975, it was coal).**


Nighttime Lights and Fires of Northern Africa
Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS)
From cloud-free portions of 200+ DMSP-OLS orbits acquired October 94 - March 95
Processed by NOAA-NESDIS National Geophysical Data Center
1000 Kilometers
For additional information contact Dr. Chris Elvidge FAX 303-497-6513 or cde@ngdc.noaa.gov

Changes in Land Use and Land Cover

Table 2: Estimated changes in the areas of the major land-cover types between preagricultural times and the present ($\times 10^6$ km^2)

Land-Cover Type	Preagricultural Area	Present Area	% Change
Total forest	46.8	39.3	–16.0
Tropical forest	12.8	12.3	–3.9
Other forest	34.0	27.0	–20.6
Woodland	9.7	7.9	–18.6
Shrubland	16.2	14.8	–8.6
Grassland	34.0	27.4	–19.4
Tundra	7.4	7.4	0.0
Desert	15.9	15.6	–1.9
Cultivation	0.0	17.6	+1760.0

From J.T. Matthews (personal communication).

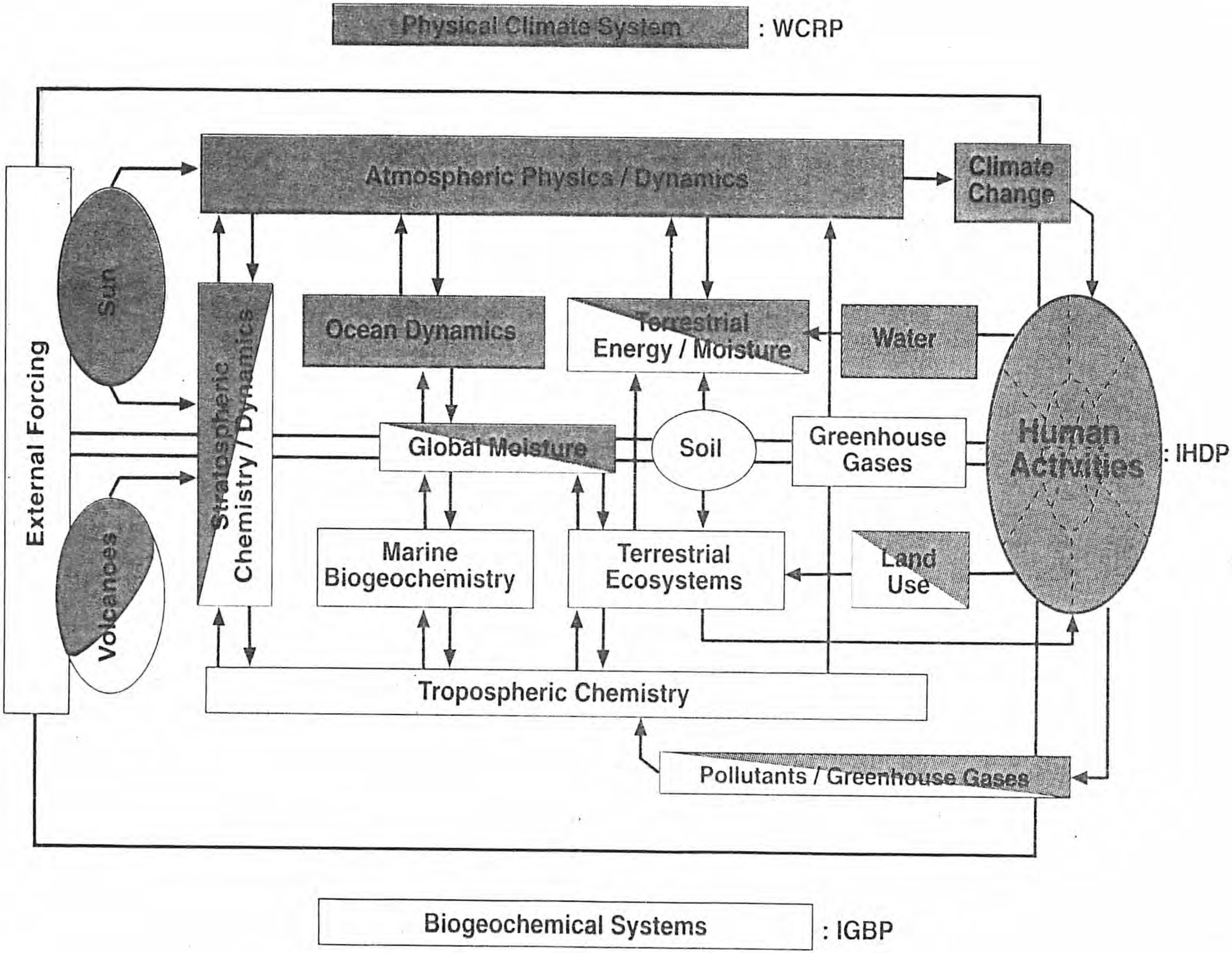
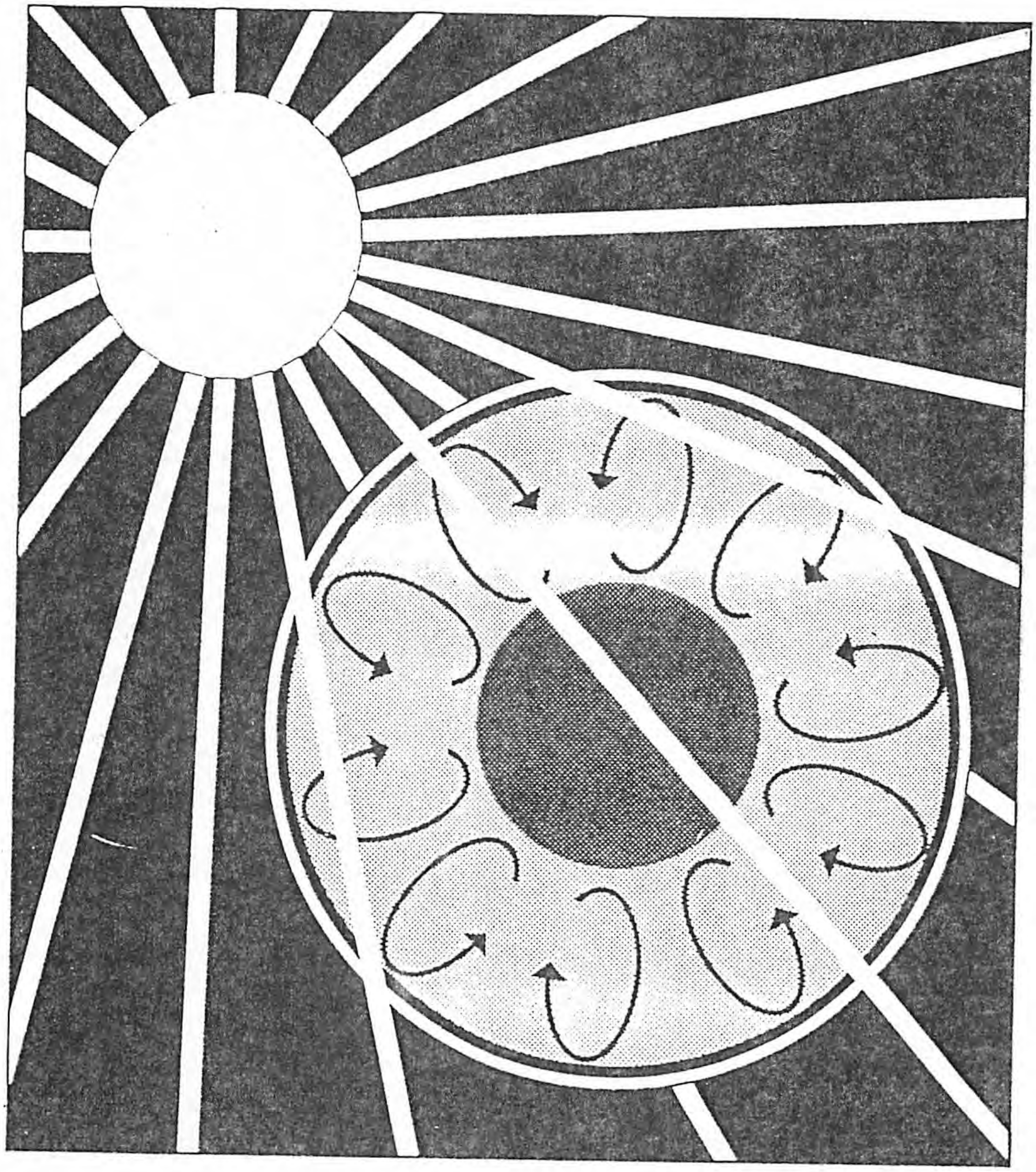
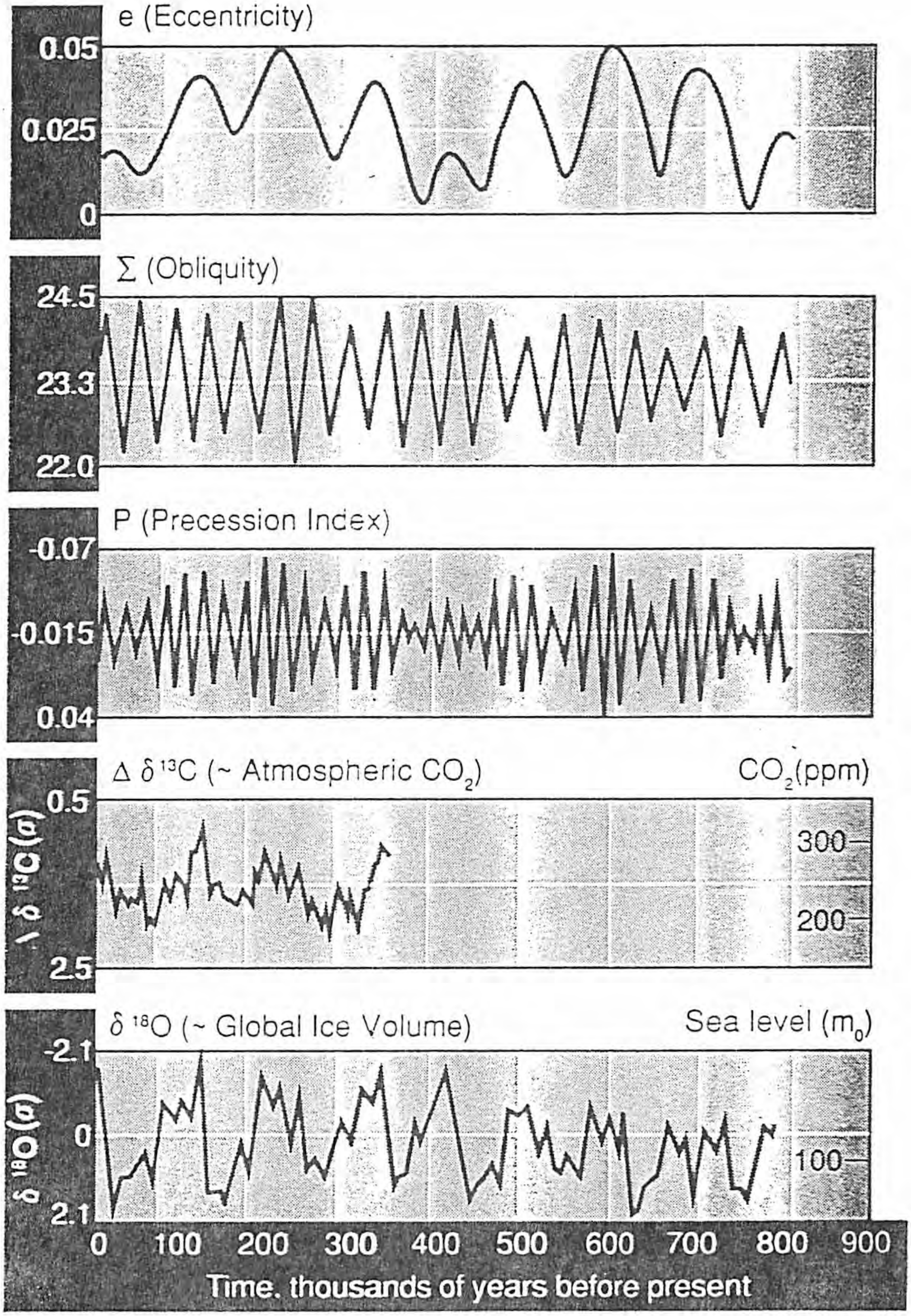
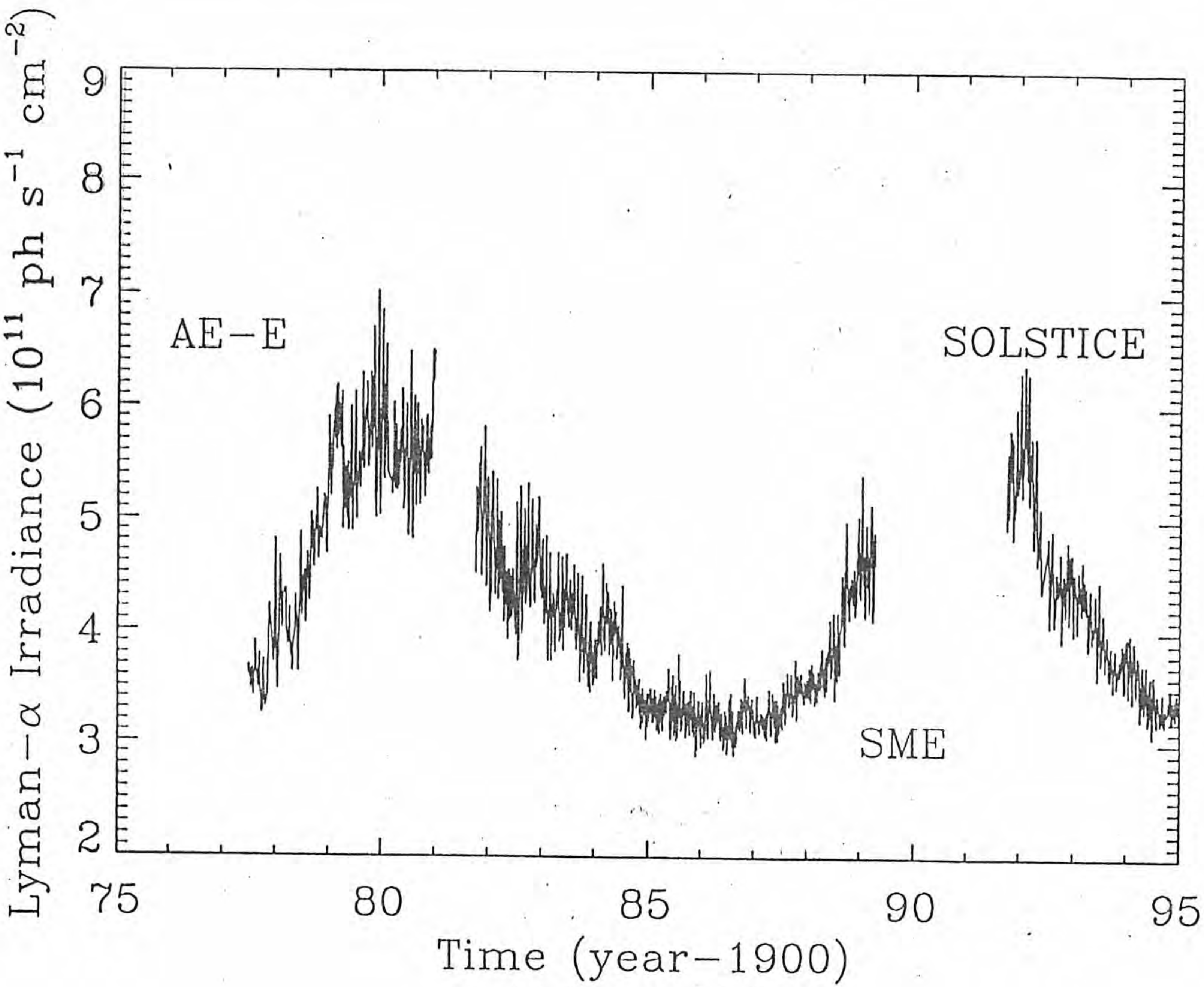

Physical Climate System
: WCRP
Atmospheric Physics / Dynamics
Climate Change
Sun
External Forcing
Stratospheric Chemistry / Dynamics
Ocean Dynamics
Terrestrial Energy / Moisture
Water
Human Activities
: IHDP
Global Moisture
Soil
Greenhouse Gases
Volcanoes
Marine Biogeochemistry
Terrestrial Ecosystems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

Figure 1.3 THE EARTH ENGINES: Earth system processes are driven by both internal and external (solar) energy.

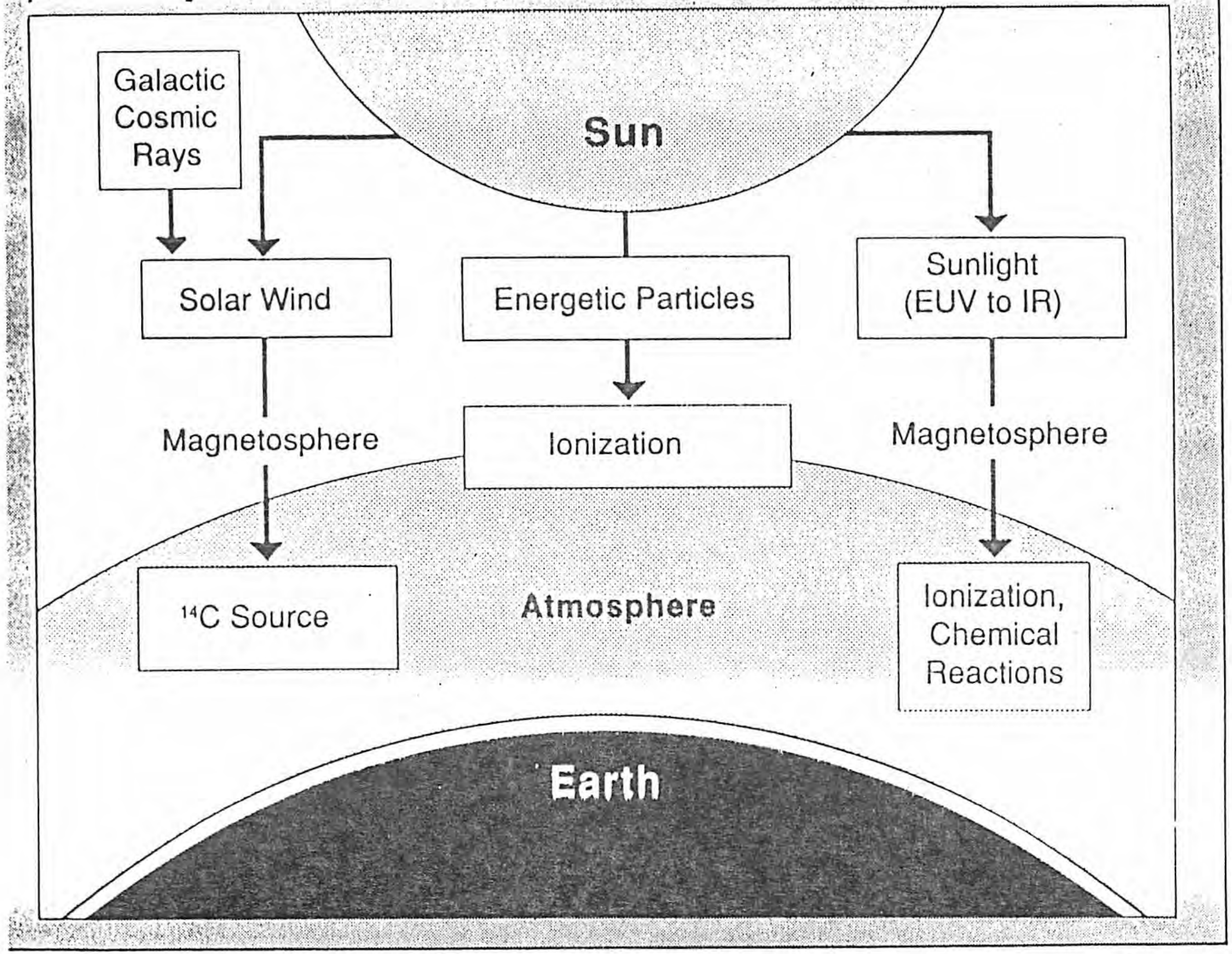


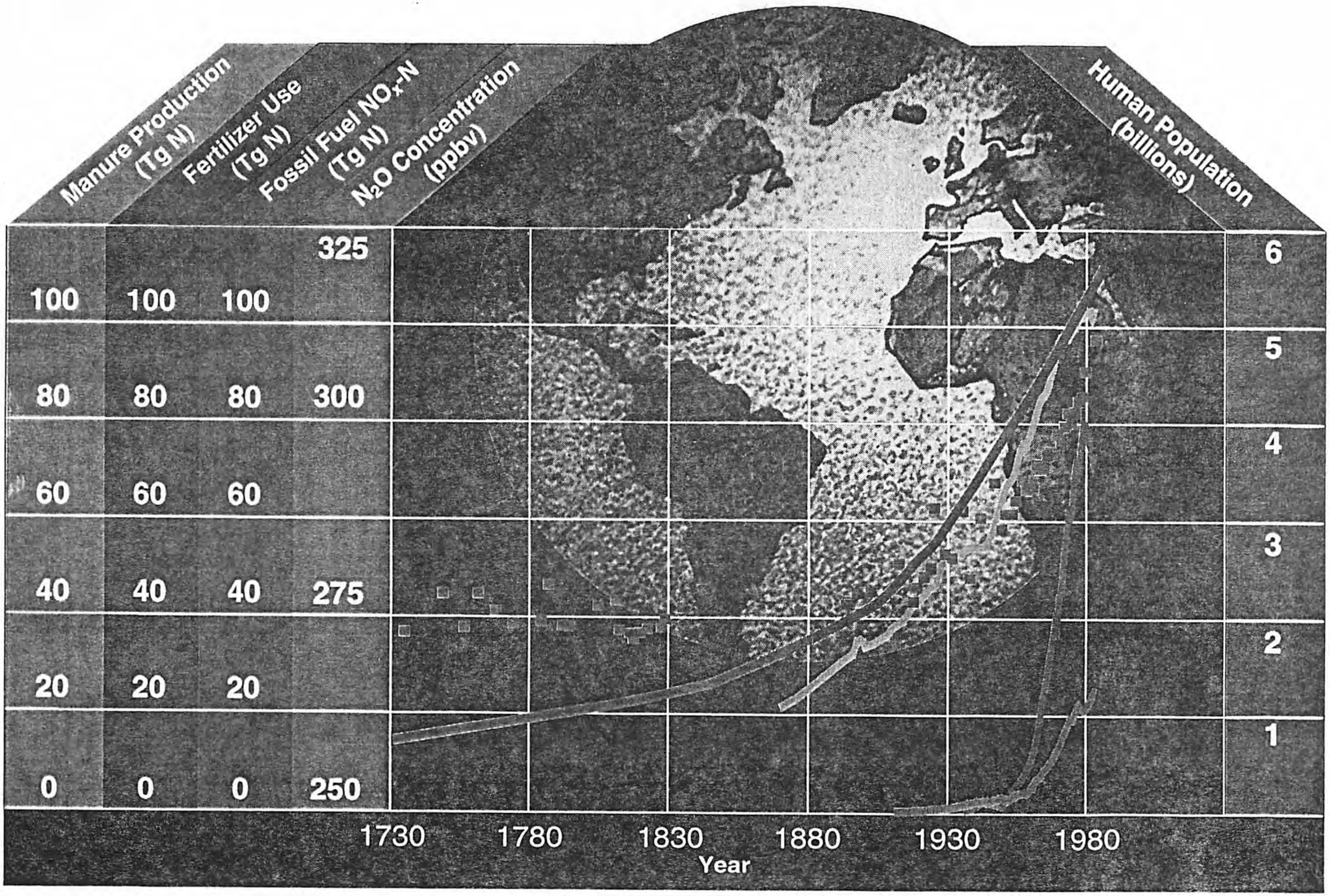

e (Eccentricity)
0.05
0.025
0
Σ (Obliquity)
24.5
23.3
22.0
P (Precession Index)
-0.07
-0.015
0.04
Δ δ 13C (~ Atmospheric CO2)
CO2(ppm)
Δ δ 13C (σ)
0.5
2.5
300
200
δ 18O (~ Global Ice Volume)
Sea level (m0)
δ 18O (σ)
-2.1
0
2.1
100
0
100
200
300
400
500
600
700
800
900
Time, thousands of years before present



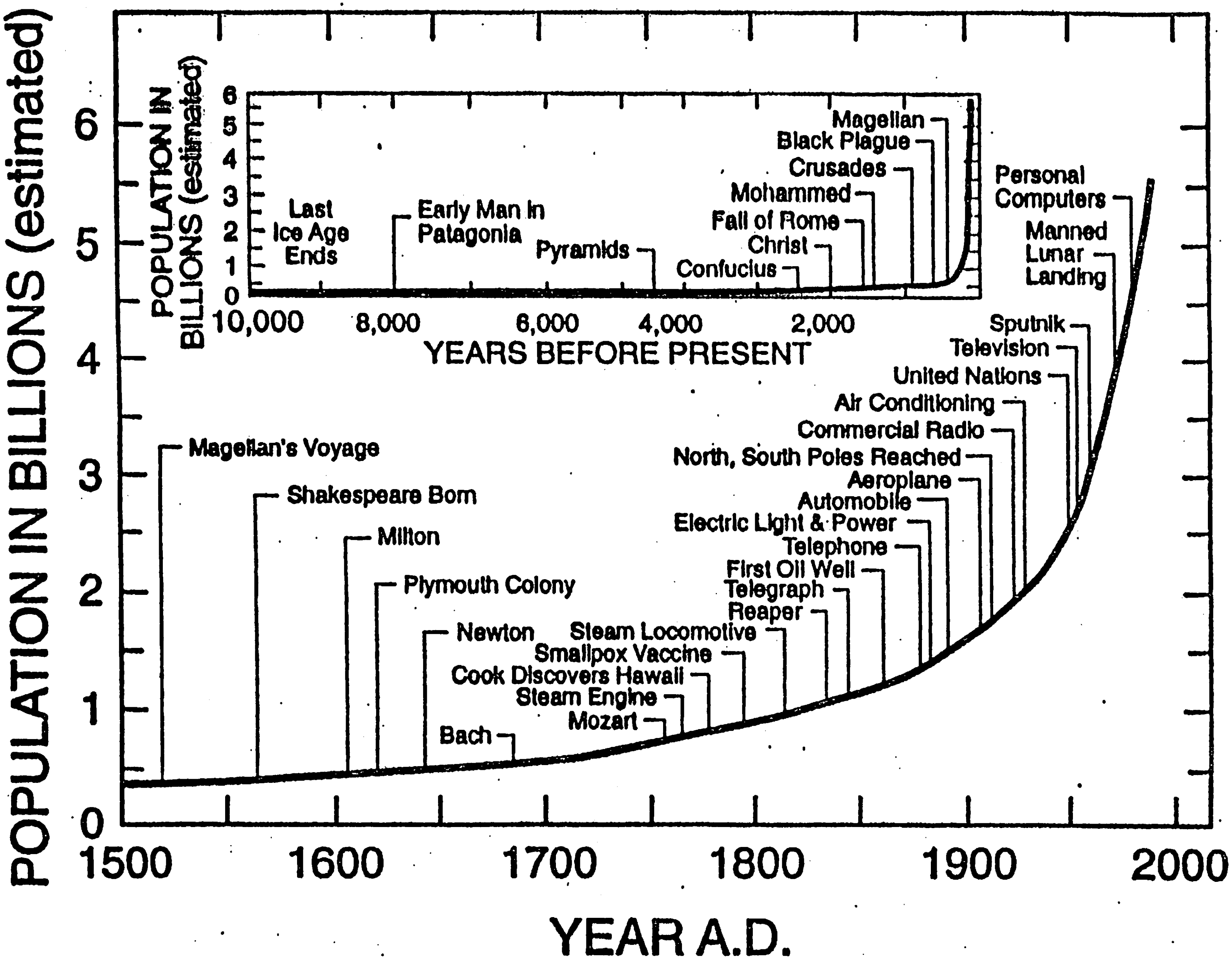
Lyman-α Irradiance (10^{11} ph s^{-1} cm^{-2})
9
8
7
6
5
4
3
2
AE-E
SOLSTICE
SME
75
80
85
90
95
Time (year-1900)

Figure 5.5 COMPLEX EARTH-SUN INTERACTION will be probed by the International Solar-Terrestrial Program.

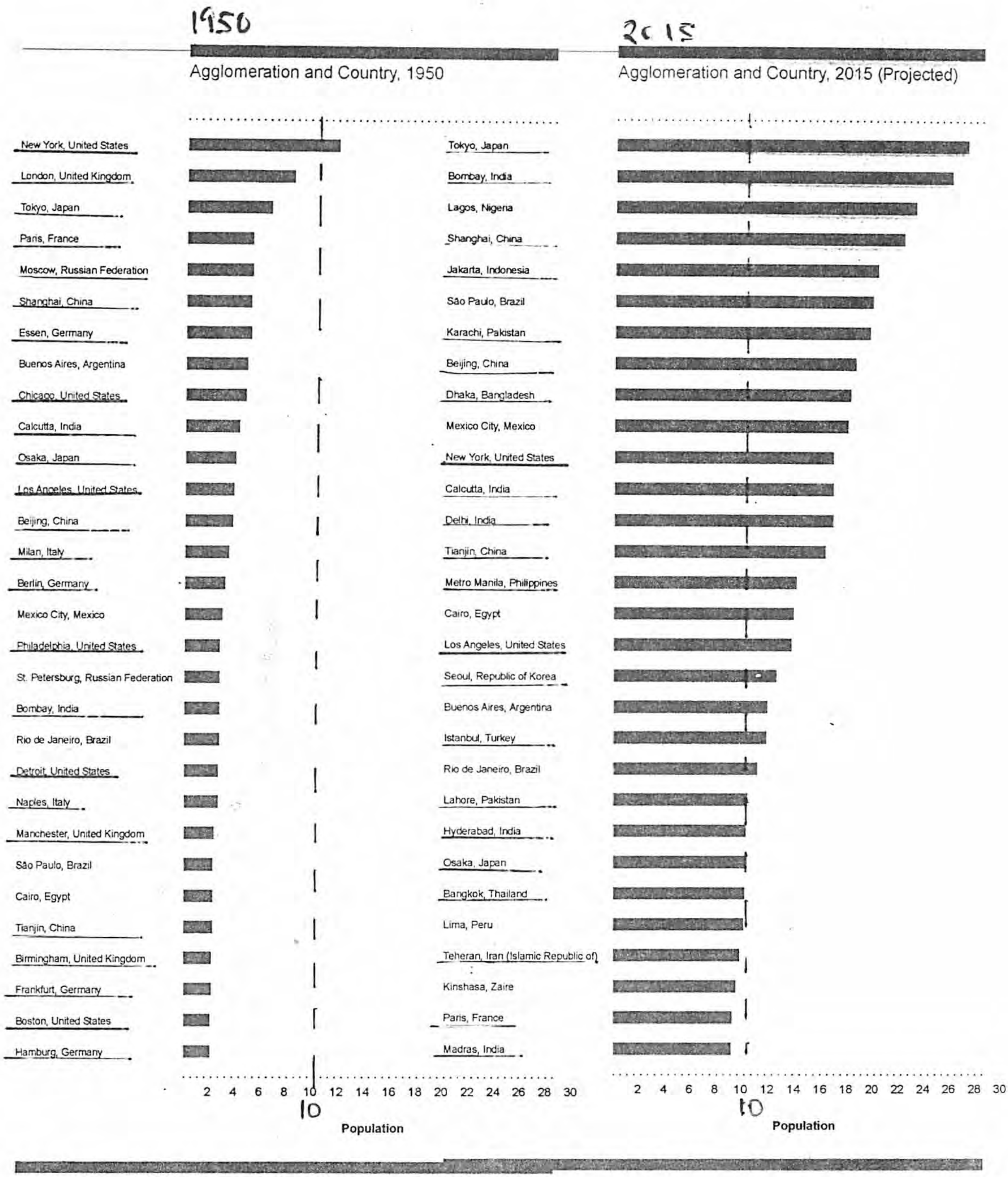




Manure Production (Tg N)
Fertilizer Use (Tg N)
Fossil Fuel NO_x-N (Tg N)
N_2O Concentration (ppbv)
Human Population (billions)
100 100 100
80 80 80
60 60 60
40 40 40
20 20 20
0 0 0
325
300
275
250
6
5
4
3
2
1
1730
1780
1830
1880
1930
1980
Year



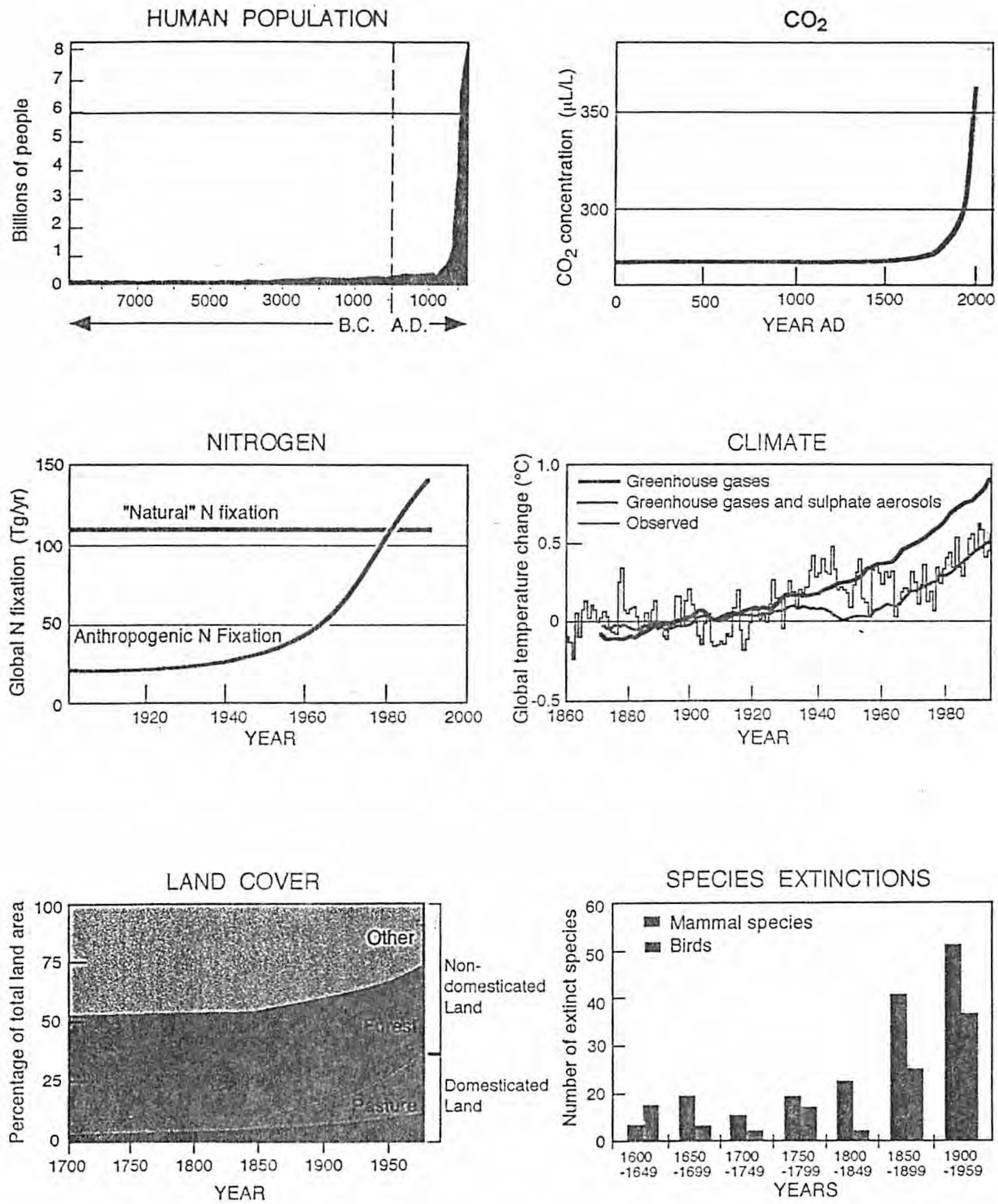
POPULATION IN BILLIONS (estimated)
0
1
2
3
4
5
6
1500
1600
1700
1800
1900
2000
YEAR A.D.
Magellan's Voyage
Shakespeare Born
Milton
Plymouth Colony
Newton
Bach
Mozart
Steam Engine
Cook Discovers Hawaii
Smallpox Vaccine
Steam Locomotive
Reaper
Telegraph
First Oil Well
Telephone
Electric Light & Power
Automobile
Aeroplane
North, South Poles Reached
Commercial Radio
Air Conditioning
United Nations
Television
Sputnik
Manned Lunar Landing
Personal Computers
POPULATION IN BILLIONS (estimated)
10,000
8,000
6,000
4,000
2,000
YEARS BEFORE PRESENT
Last Ice Age Ends
Early Man in Patagonia
Pyramids
Confucius
Christ
Fall of Rome
Mohammed
Crusades
Black Plague
Magellan



from: The State of World Population 1996 UNFPA

Figure 1

Some components of global change: (a) increase in human population; (b) increase in atmospheric CO_2 concentration; (c) anthropogenic alteration of the nitrogen cycle; (d) modelled and observed change in global mean temperature; (e) change in global land cover; and (f) increase in extinction of birds and mammals. From: Vitousek (1994); Houghton et al. (1995); Klein Goldewijk and Battjes (1995); and Reid and Miller (1989).



OUTLINE

1. **Surface Emissions of Trace Gases**
   - ❖ **Anthropogenic CO_2**
   - ❖ **Other greenhouse gases**
   - ❖ **Ozone precursors (CO, NO_x)**
   - ❖ **Sulfur dioxide**

2. **Changes in Tropospheric Composition**
   - ❖ **Ozone**
   - ❖ **Sulfates**

3. **Changes in stratospheric and mesospheric composition**
   - ❖ **Ozone (solar variability, CFC's, volcanic eruptions)**

4. **Changes in stratospheric and mesospheric temperature**

1. Changes in Trace Gases

CO_2

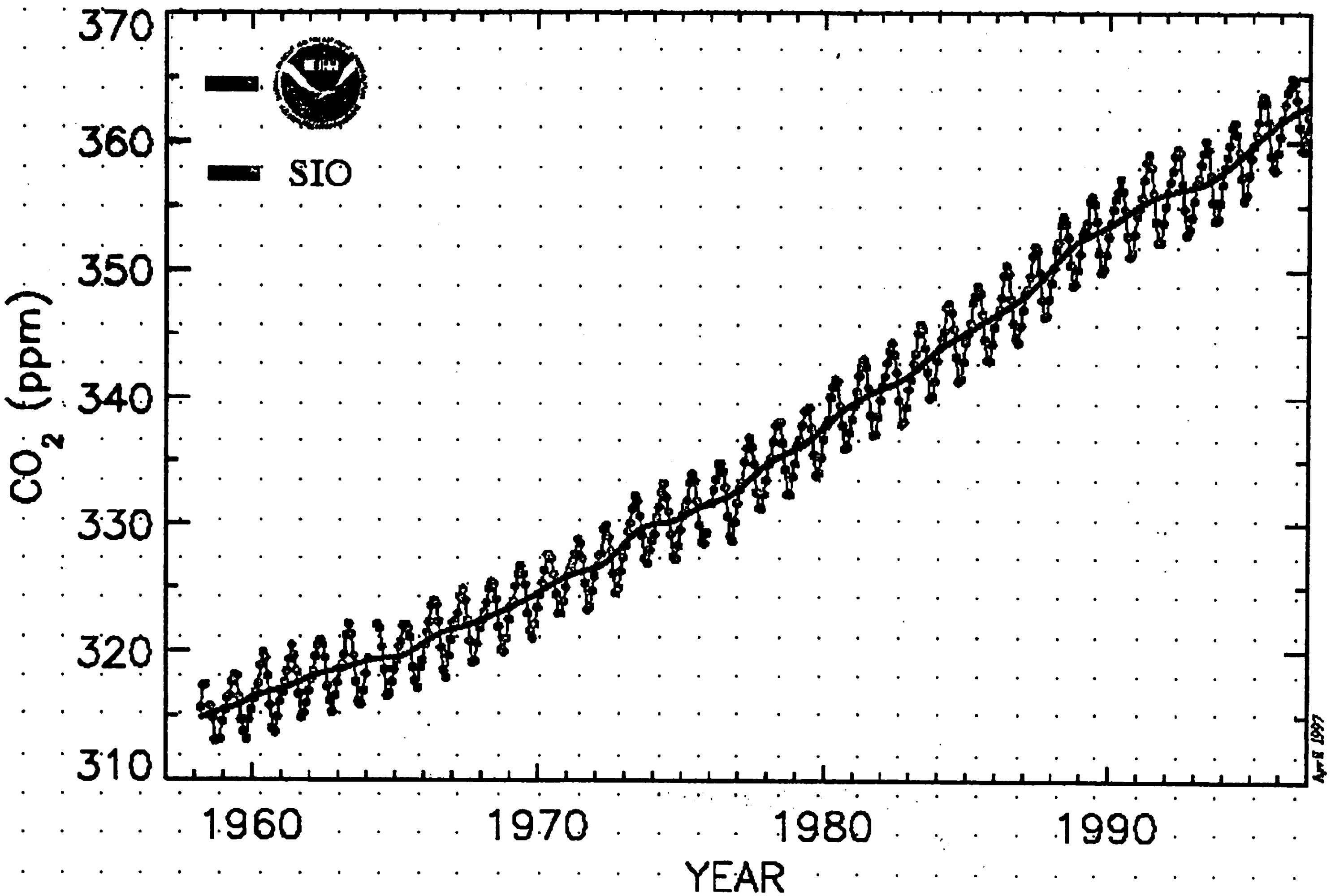
CH_4

N_2O

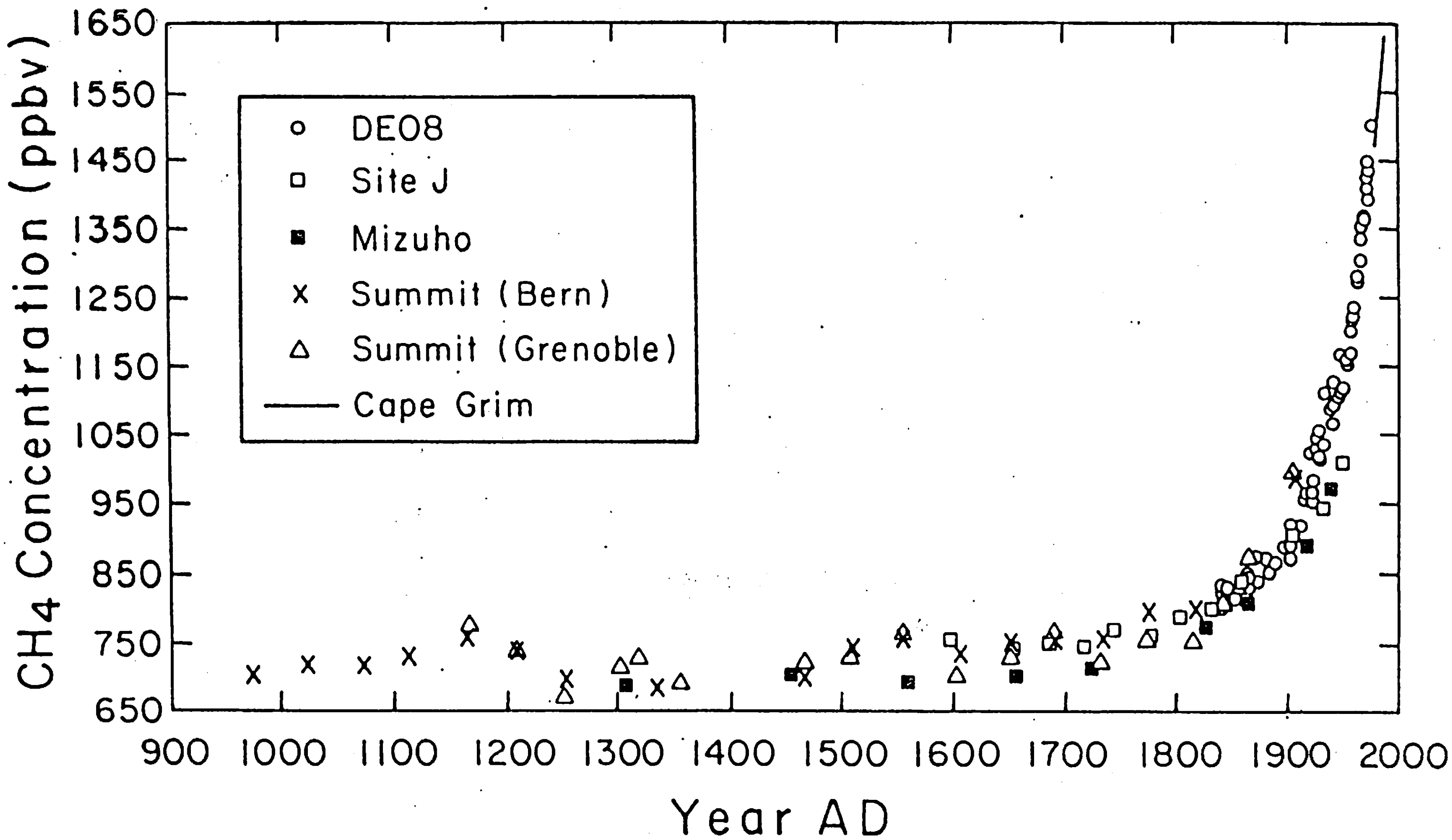
H_2O

Halocarbons

Mauna Loa Monthly Mean Carbon Dioxide

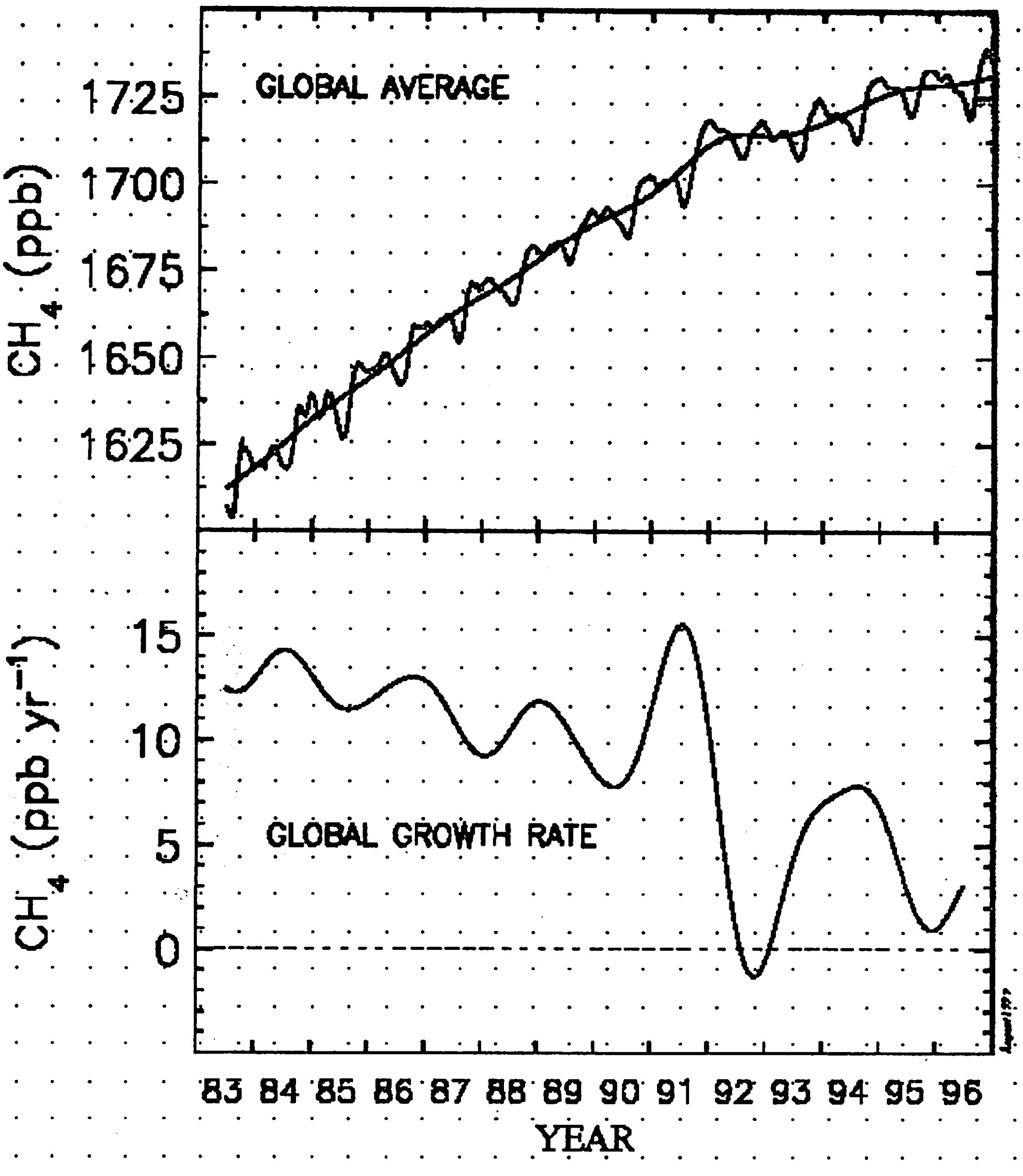


Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (•), data since May 1974 are from the National Oceanic and Atmospheric Administration (•). A long-term trend curve (—) is fitted to the monthly mean values. Principal investigators: Pieter Tans, NOAA/CMDL Carbon Cycle Group, Boulder, Colorado, (303) 497-6678, ptans@cmdl.noaa.gov, and Charles D. Keeling, SIO, La Jolla, California, (619) 534-6001.

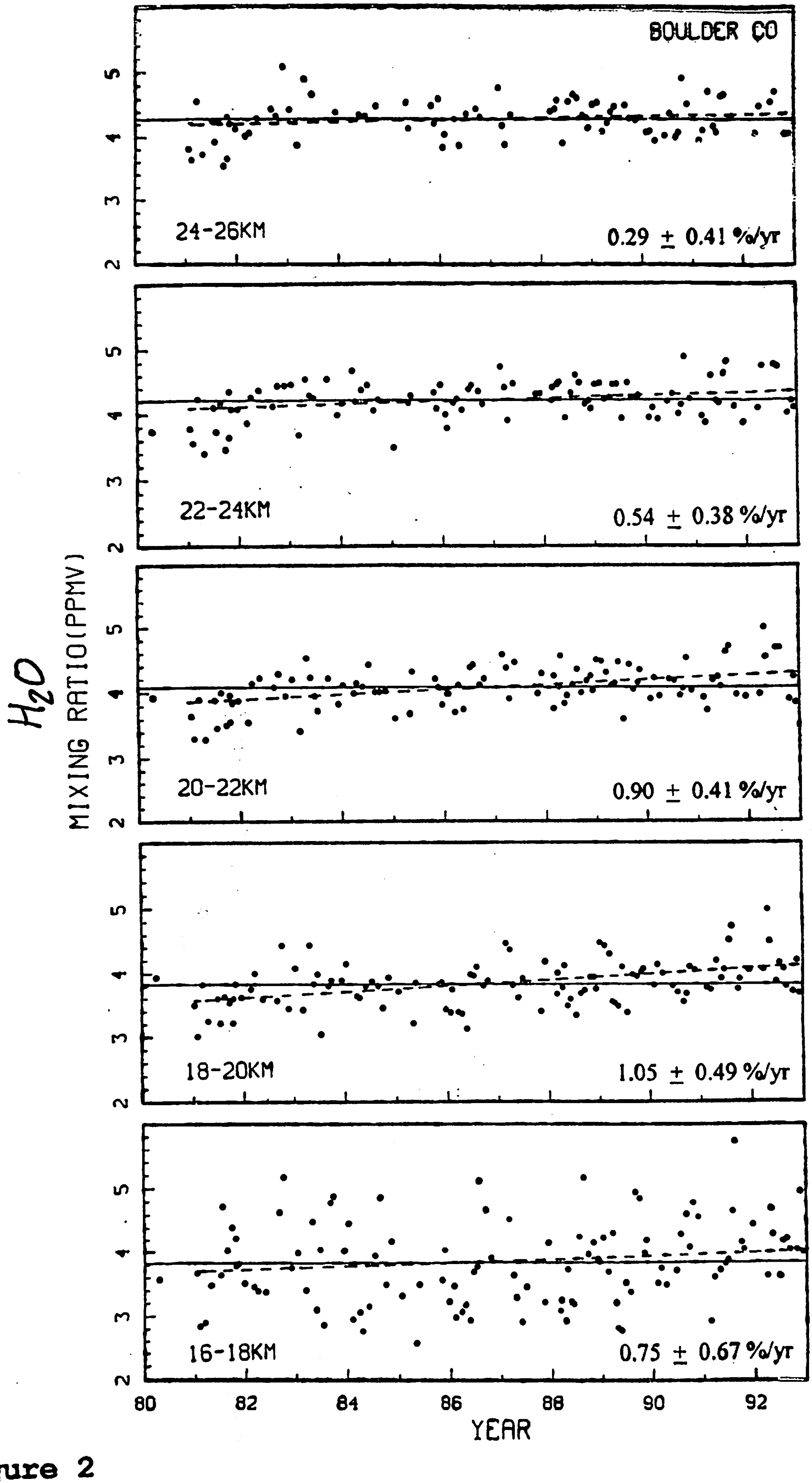


CH4 Concentration (ppbv)
1650
1550
1450
1350
1250
1150
1050
950
850
750
650
DE08
Site J
Mizuho
Summit (Bern)
Summit (Grenoble)
Cape Grim
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year AD

NOAA/CMDL Methane Measurements

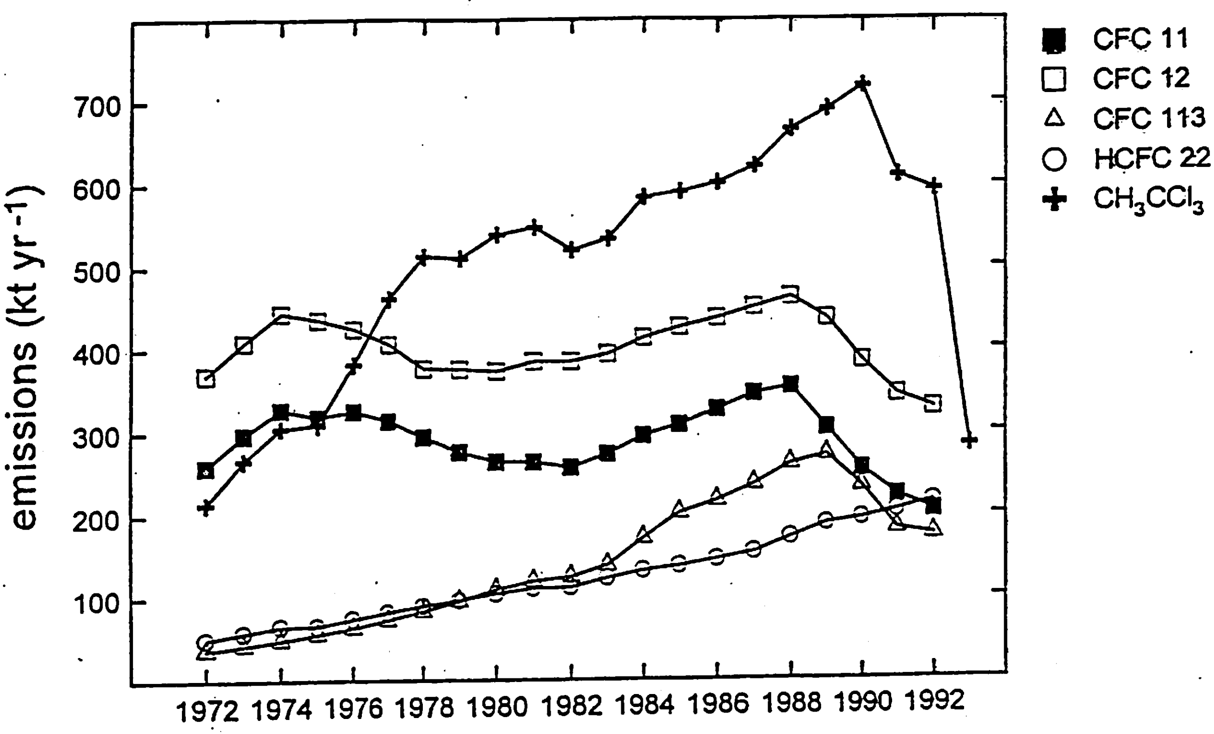


Top: Global average atmospheric methane mixing ratios determined using measurements from the NOAA CMDL cooperative air sampling network (blue). The red line represents the long-term trend. Bottom: Global average growth rate for methane. Principal investigator: Ed Dlugokencky, NOAA CMDL Carbon Cycle Group, Boulder, Colorado, (303) 497-6228. edlugokencky@cmdl.noaa.gov.

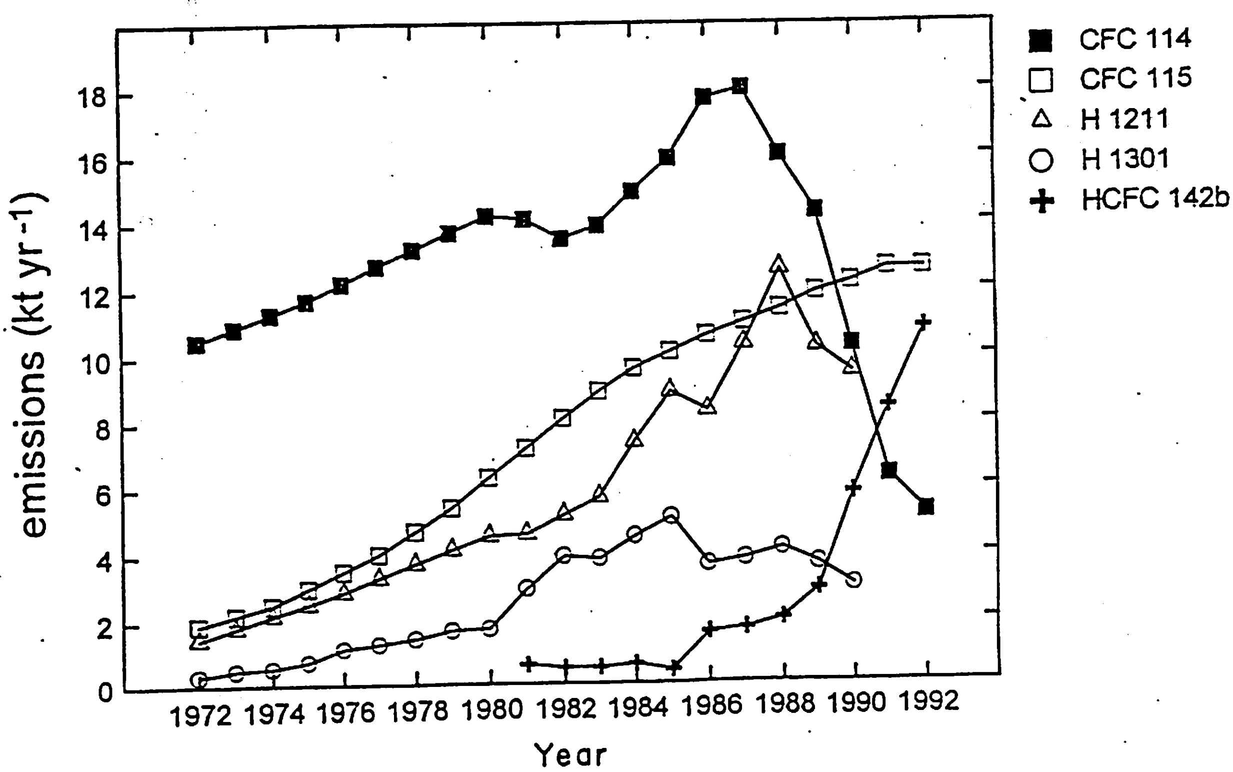


Oltmans
NOAA/CMDL

.gure 2

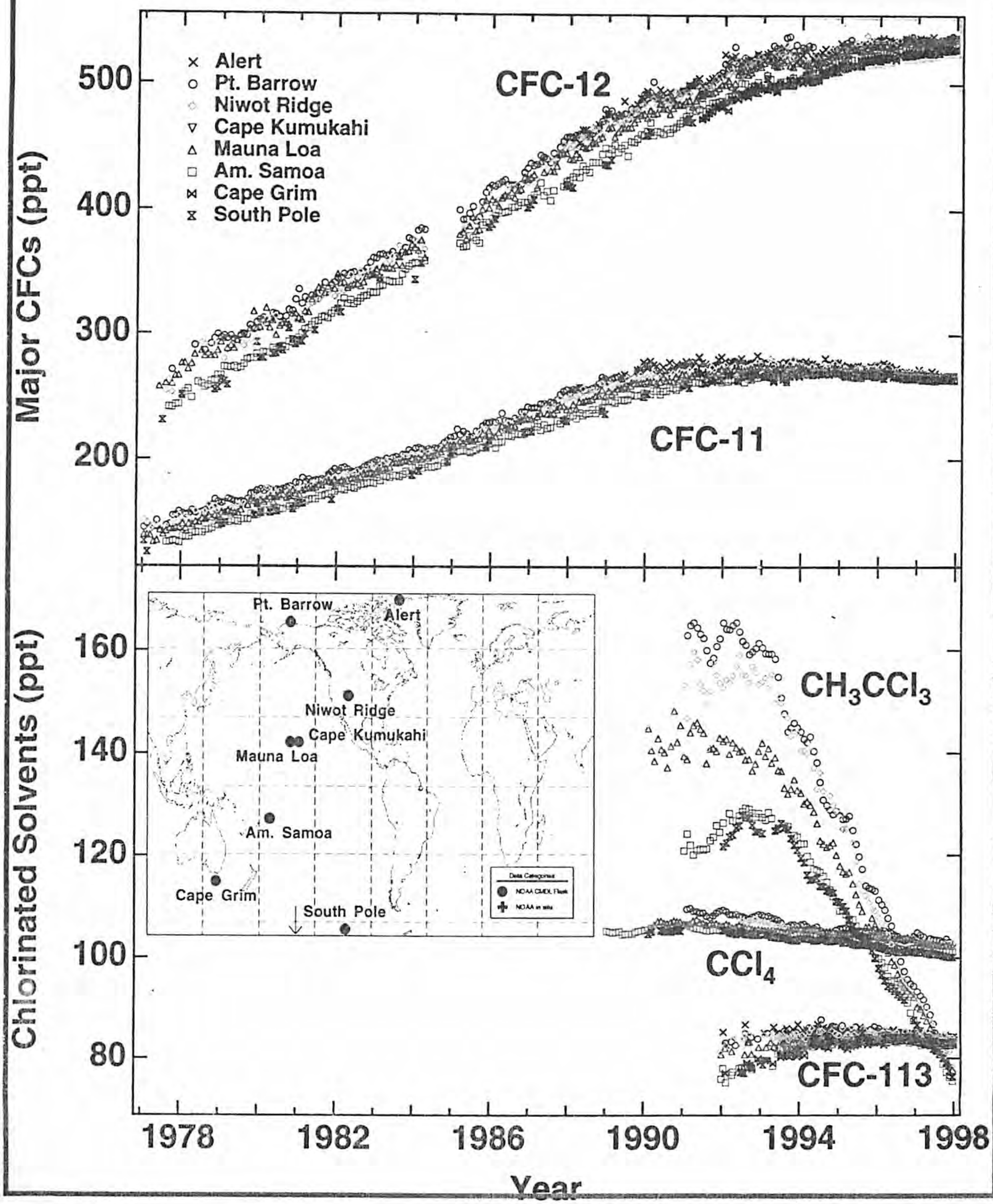


CFC 11
CFC 12
CFC 113
HCFC 22
CH3CCl3
emissions (kt yr -1)
700
600
500
400
300
200
100
1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992



CFC 114
CFC 115
H 1211
H 1301
HCFC 142b
emissions (kt yr -1)
18
16
14
12
10
8
6
4
2
0
1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992
Year

Trends of Controlled Ozone-Depleting Substances



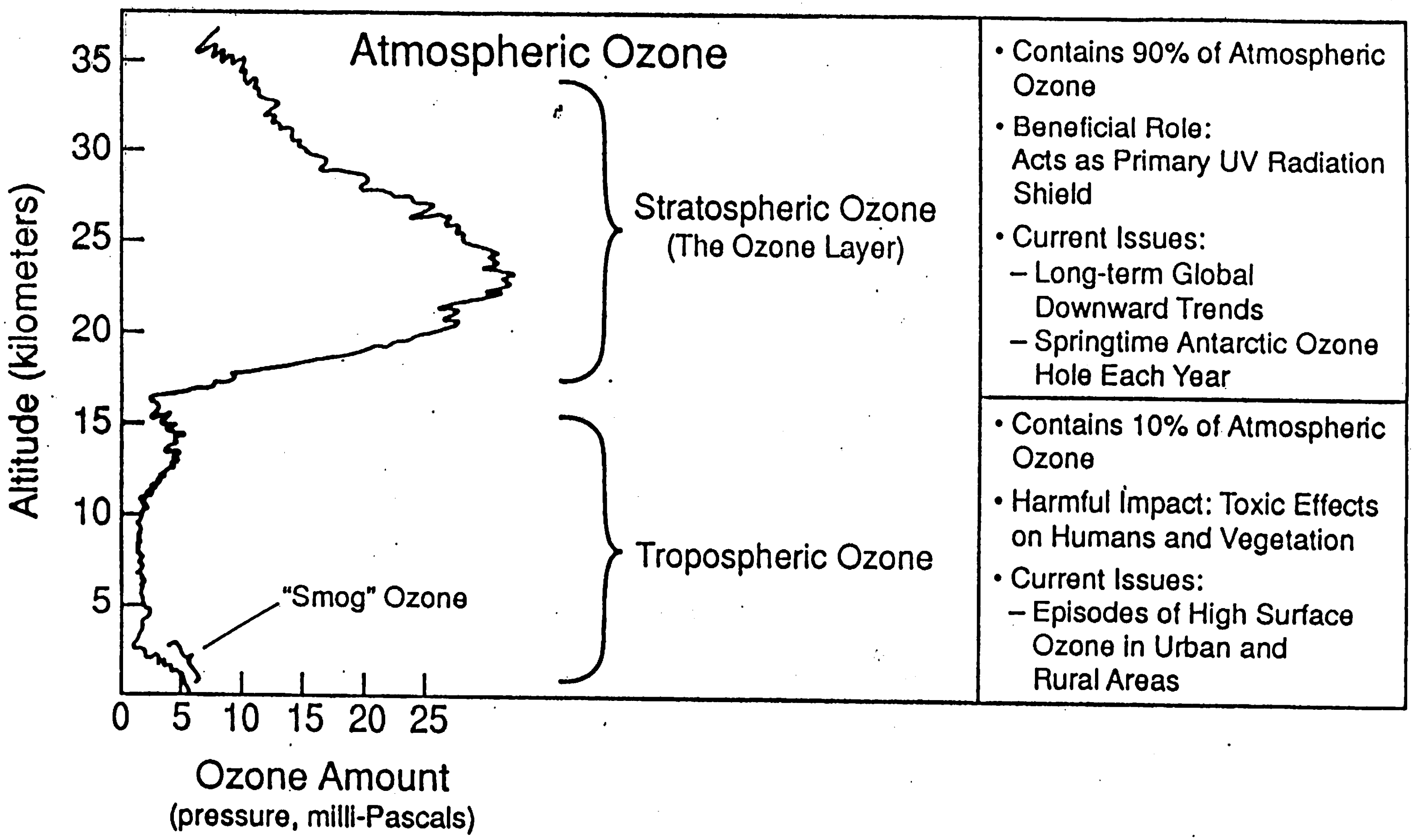
Mixing Ratios and Growth Rates of Several Greenhouse Gases

	CO_2 ppmv	CH_4 ppmv	N_2O ppbv	CFC-11 pptv
Pre-industrial	280	0.70	280	0
Year 1990	354	1.72	310	280
Rate of Increase (%) (1989-1990)	0.5	0.8	0.25	4

2. Changes in Tropospheric Oxidants

Ozone (O_3)

Hydroxyl Radical (OH)


Atmospheric Ozone
Altitude (kilometers)
35
30
25
20
15
10
5
0
5
10
15
20
25
Ozone Amount
(pressure, milli-Pascals)
"Smog" Ozone
Stratospheric Ozone
(The Ozone Layer)
Tropospheric Ozone
• Contains 90% of Atmospheric Ozone
• Beneficial Role: Acts as Primary UV Radiation Shield
• Current Issues:
– Long-term Global Downward Trends
– Springtime Antarctic Ozone Hole Each Year
• Contains 10% of Atmospheric Ozone
• Harmful Impact: Toxic Effects on Humans and Vegetation
• Current Issues:
– Episodes of High Surface Ozone in Urban and Rural Areas

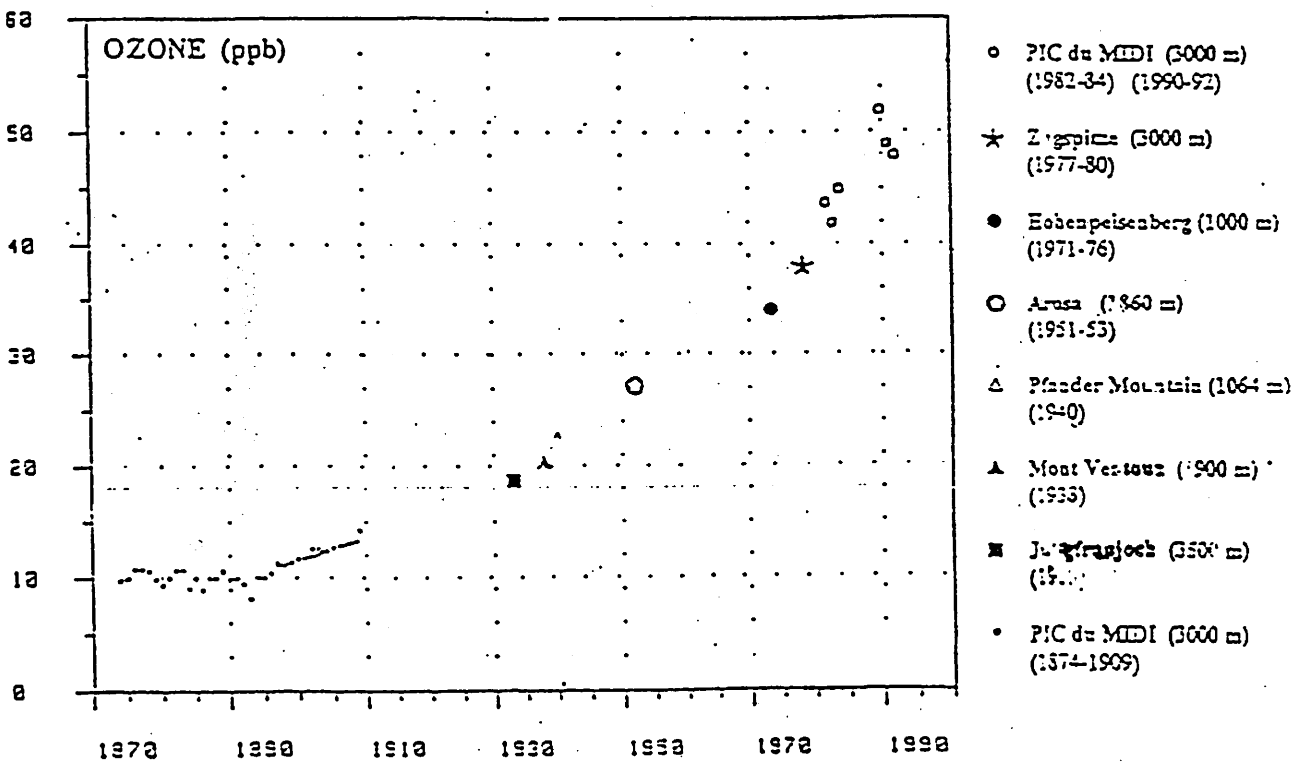


Figure 11 : Trends in ozone concentration measured at ground level in Europe during the 20th century (from Marenco et al., 1992).

x

Tropospheric Ozone Photochemistry

A. *Production*

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$

Null cycle

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$

Formation of ozone

In most cases, the ozone production is controlled by the NO_x abundance.

Ozone Production from CO oxidation

$$OH + CO \xrightarrow{+ O_2} HO_2 + CO_2$$

$$HO_2 + NO \text{ ---> } OH + NO_2$$

$$NO_2 + h\nu \text{ ---> } NO + O$$

$$O + O_2 + M \text{ ---> } O_3 + M$$

$$\text{Net : } CO + 2\,O_2 + h\nu \text{ ---> } CO_2 + O_3$$

x

Ozone Production from CH_4 oxidation

$$CH_4 + OH \xrightarrow{+ O_2} CH_3O_2 + H_2O$$

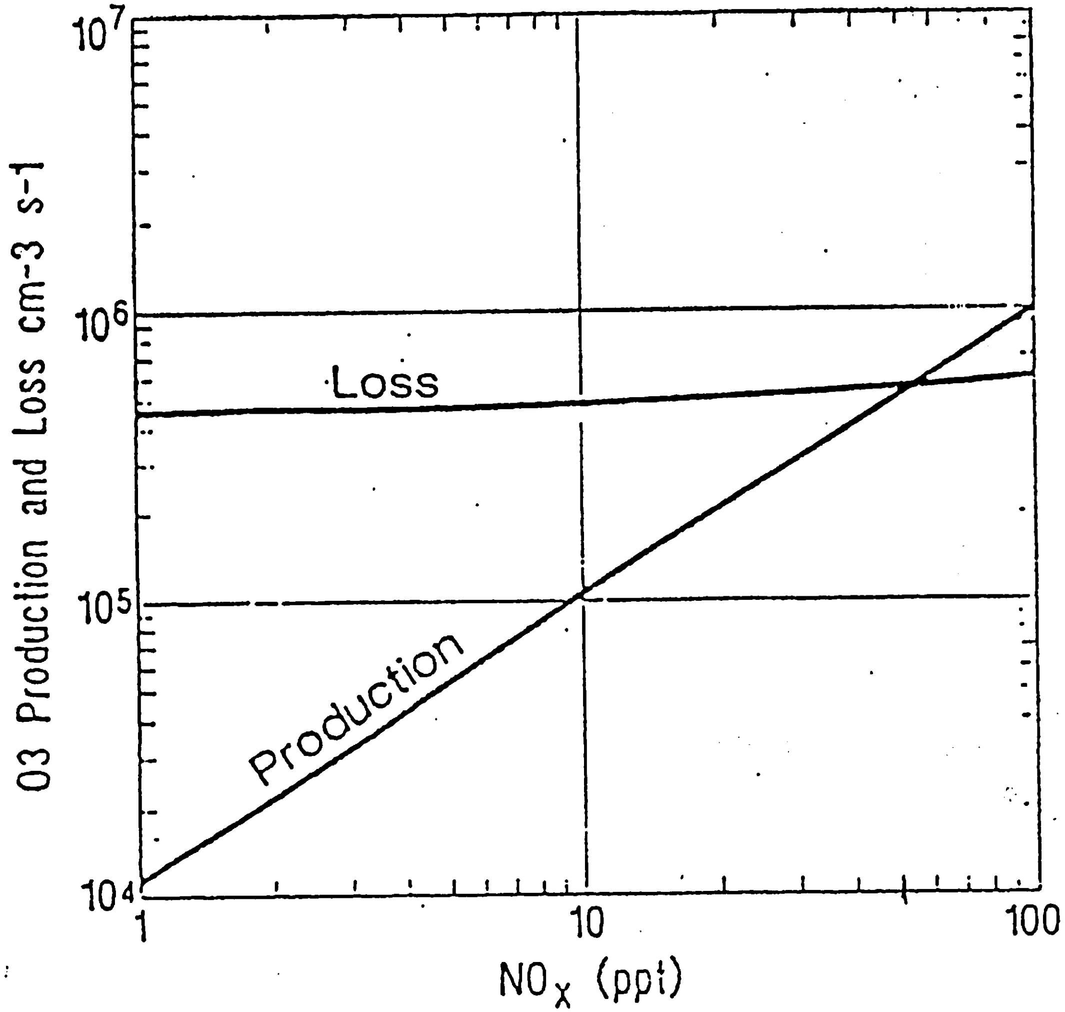
$$CH_3O_2 + NO \xrightarrow{+ O_2} HO_2 + NO_2 + H_2CO$$

$$HO_2 + NO \text{ ---> } OH + NO_2$$

$$2\ (NO_2 + h\nu \text{ ---> } NO + O)$$

$$2\ (O + O_2 + M \text{ ---> } O_3 + M)$$

$$\text{Net}: CH_4 + 4\ O_2 + h\nu \text{ ---> } H_2CO + H_2O + 2\ O_3$$



10^7
10^6
10^5
10^4
Loss
Production
03 Production and Loss cm-3 s-1
1
10
100
NOx (ppt)

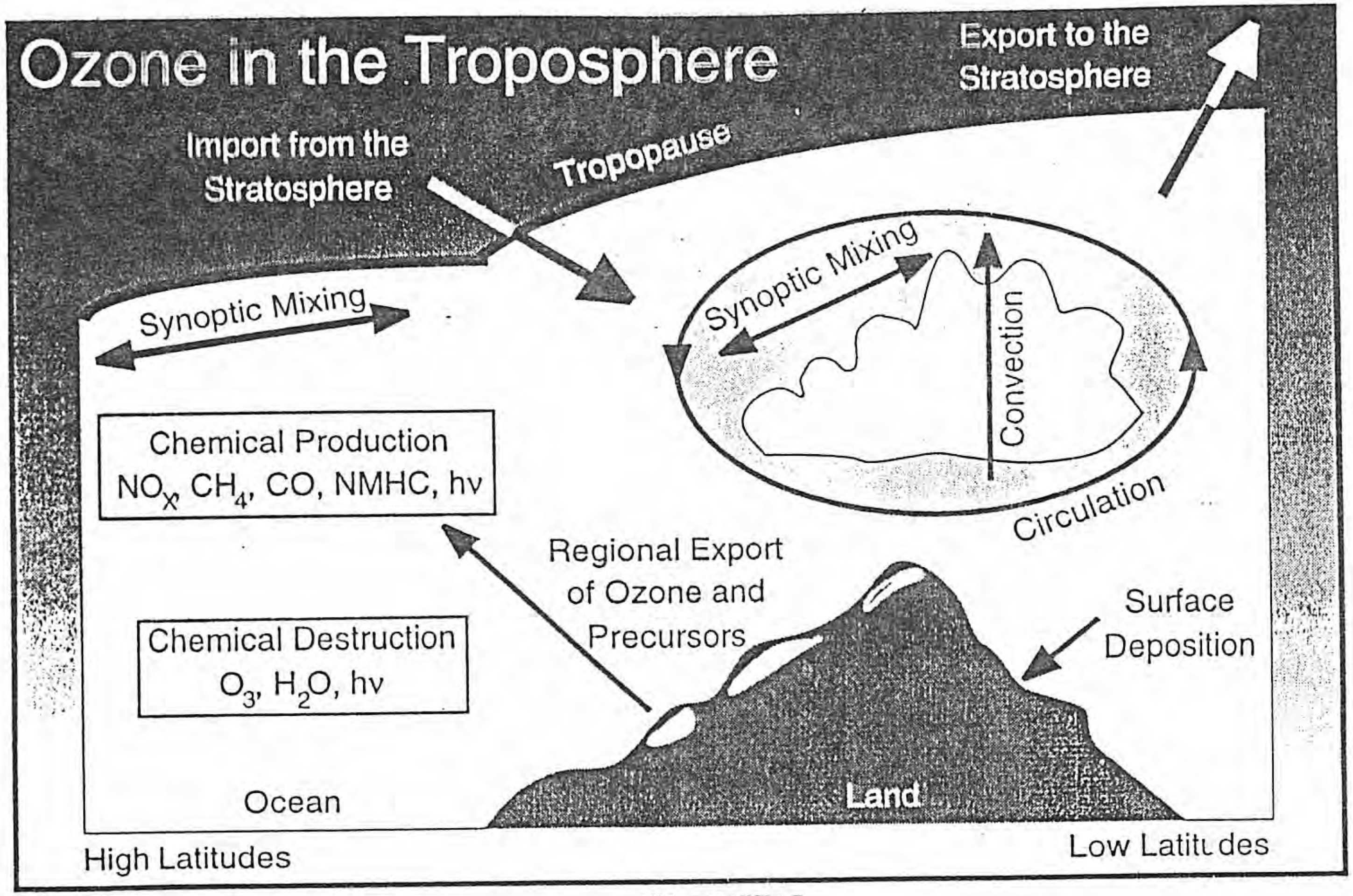
Estimated Sources and Sinks of CO (Tg/yr)

	Range	Likely
Sources		
Technological	300-900	500
Biomass Burning	400-700	600
Biogenics	60-160	100
Oceans	20-190	?
Methane Oxidation	400-1000	600
NMHC Oxidation	300-1300	600
Sinks		
OH Reaction	1400-2600	2100
Soil Uptake	250-640	250
To Stratosphere	~100	100

WMO (1985)

[illegible]

	[illegible] and Drummond ([illegible]1982)	Logan (1983)	[illegible]
Sources/Production			
Fossil fuel combustion	13.5 (8.2-18.5)	21.0 (14-28)	21
Biomass burning	11.5 (5.6-16.4)	12.0 (4-24)	2.5-8.5
Soil emission	5.5 (1-10)	8.0 (4-16)	10-20
Lightning	5.0 (2-8)	8 (2-20)	2-8
NH3 oxidation	3.1 (1.2-4.9)	? (0-10)	-
Ocean emission	-	1	-
Aircraft	0.3 (0.2-0.4)	-	0.6
Stratospheric input	0.6 (0.3-0.9)	0.5	1
Total	39 (19-59)	50.5 (25-99)	37-59
Sinks			
[illegible]ositio[illegible]	24 (15-3[illegible])	27 (12-42)	
D[illegible]ositi[illegible]		16 (1[illegible]-2[illegible])	
Total	24 (15-33)	43 (23-64)	


Ozone in the Troposphere
Export to the Stratosphere
Import from the Stratosphere
Tropopause
Synoptic Mixing
Synoptic Mixing
Convection
Circulation
Chemical Production
NO$_x$, CH$_4$, CO, NMHC, hν
Regional Export of Ozone and Precursors
Surface Deposition
Chemical Destruction
O$_3$, H$_2$O, hν
Ocean
Land
High Latitudes
Low Latitudes

Perturbations of Tropospheric Ozone

(Release of ozone precursors)

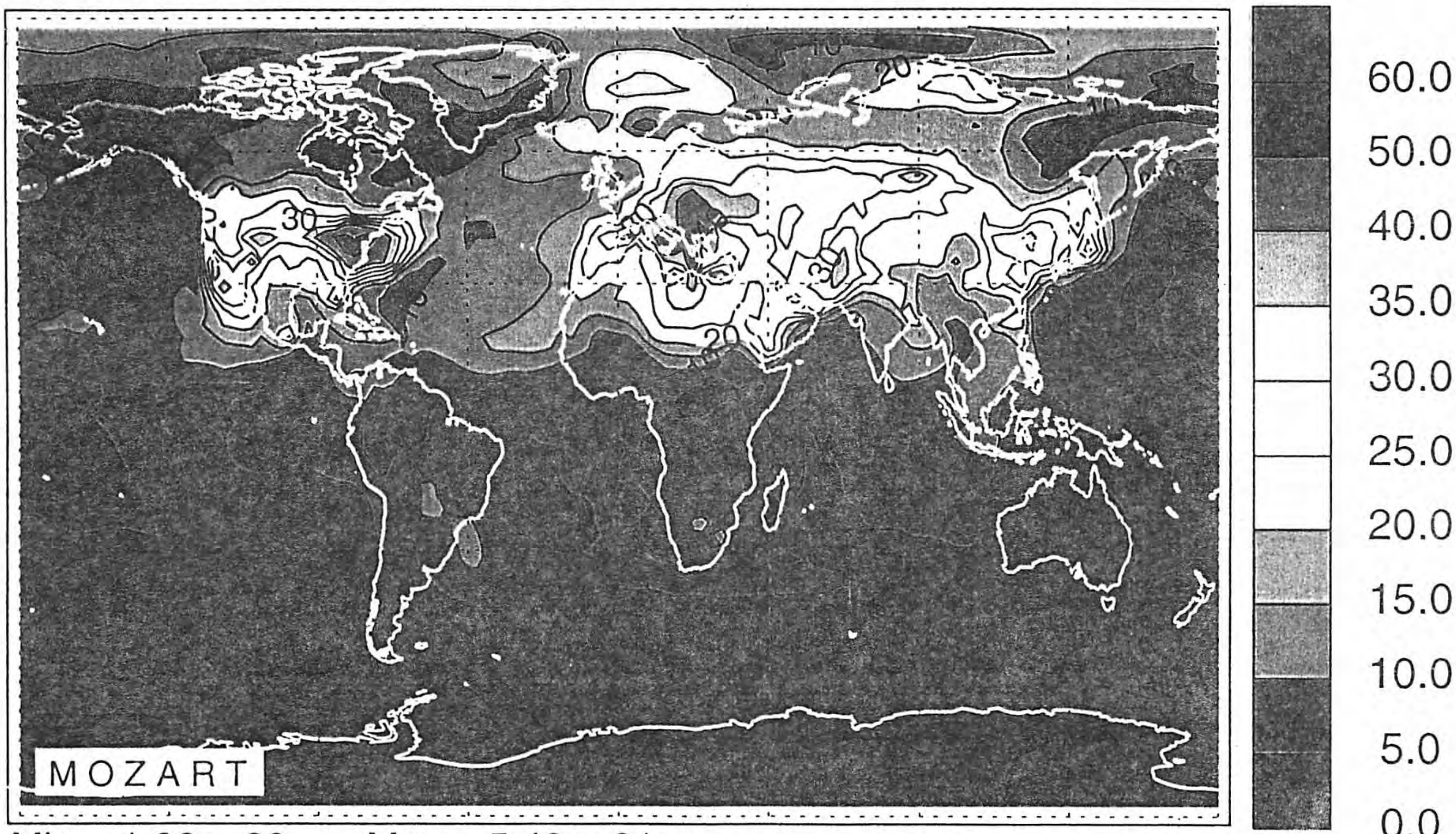
1. Industrial combustion (mostly in the Northern Hemisphere)

2. Biomass burning (mostly in the tropics)

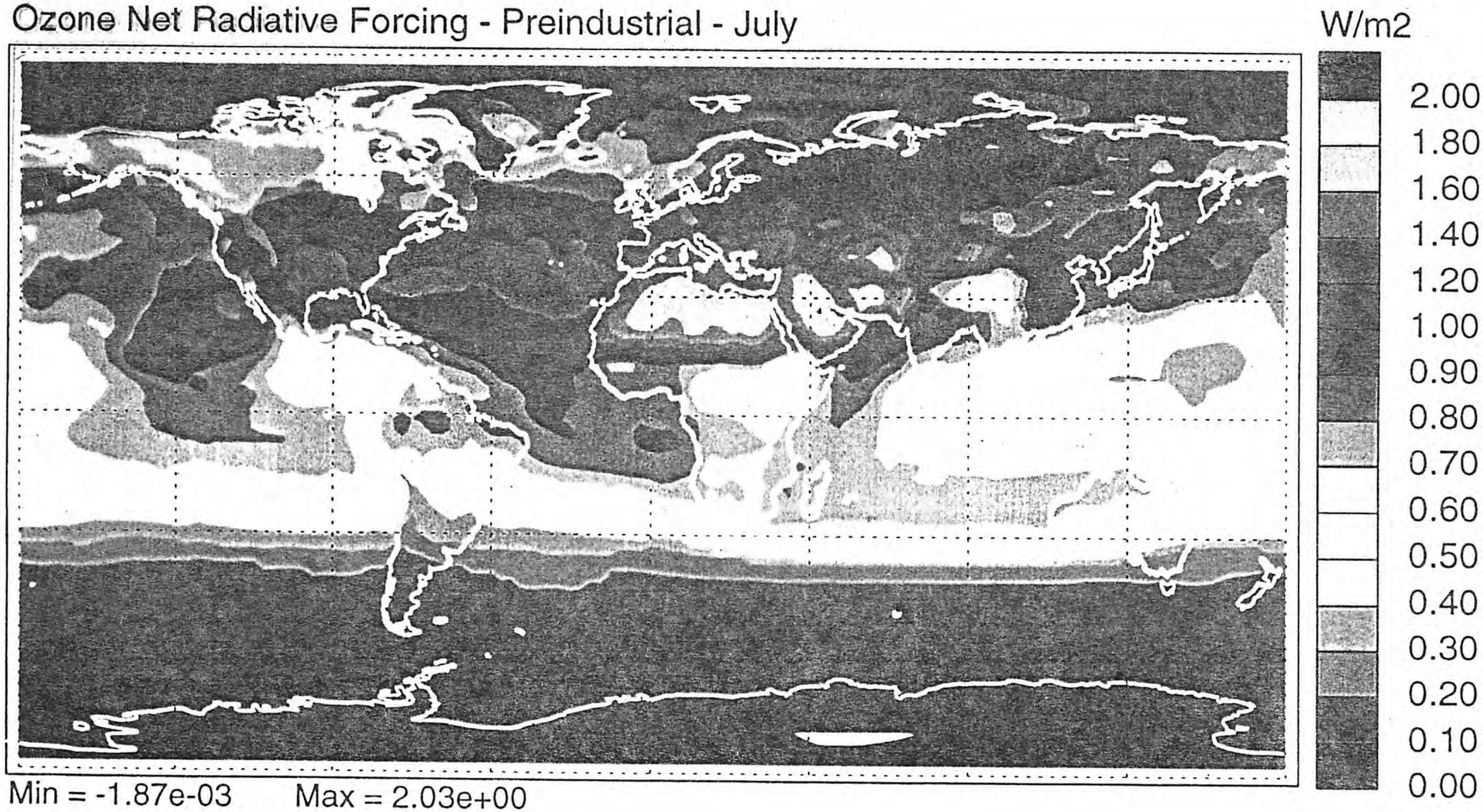
3. Emissions by aircraft engines (mostly at high altitude)

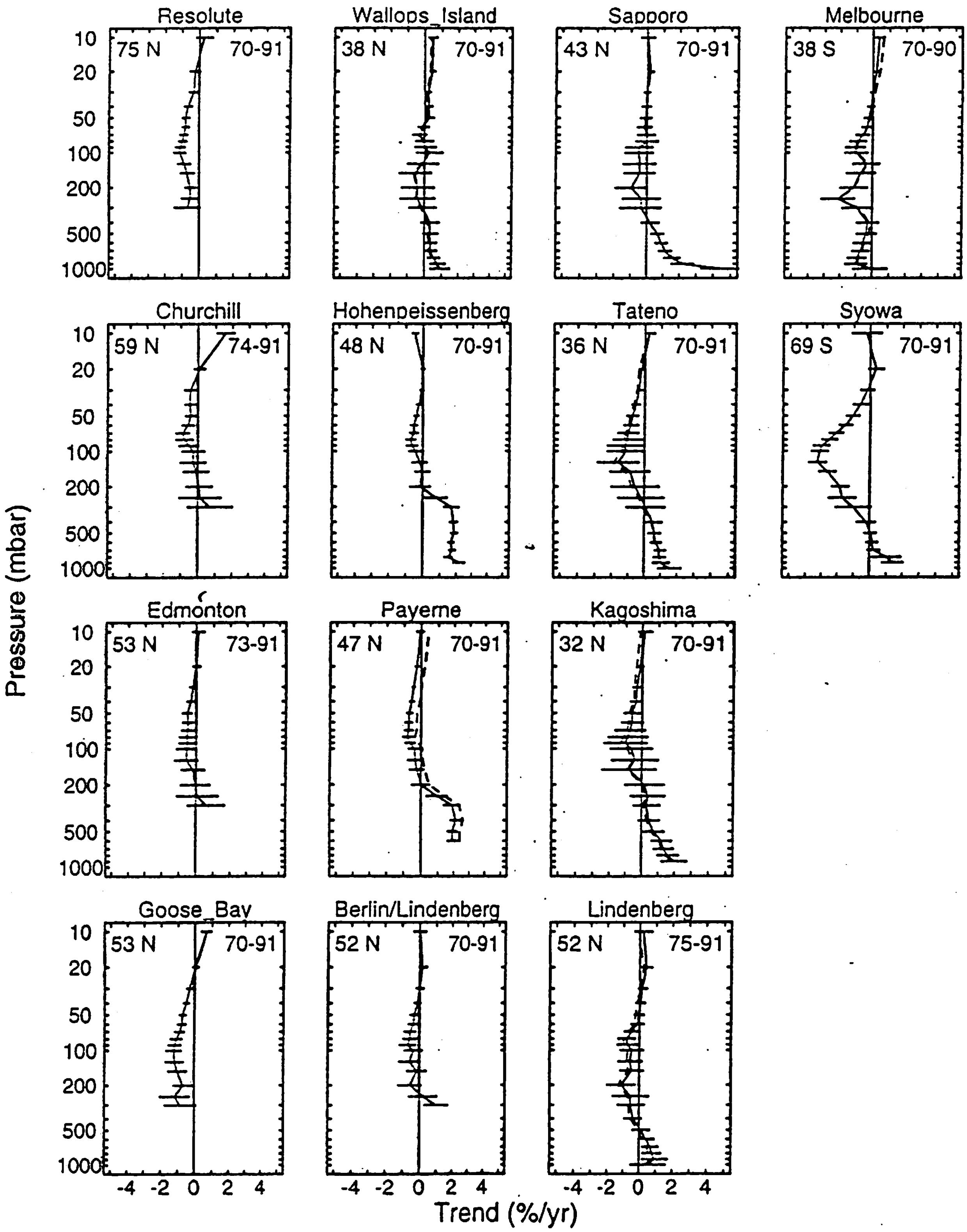
4. Ozone depletion in the stratosphere

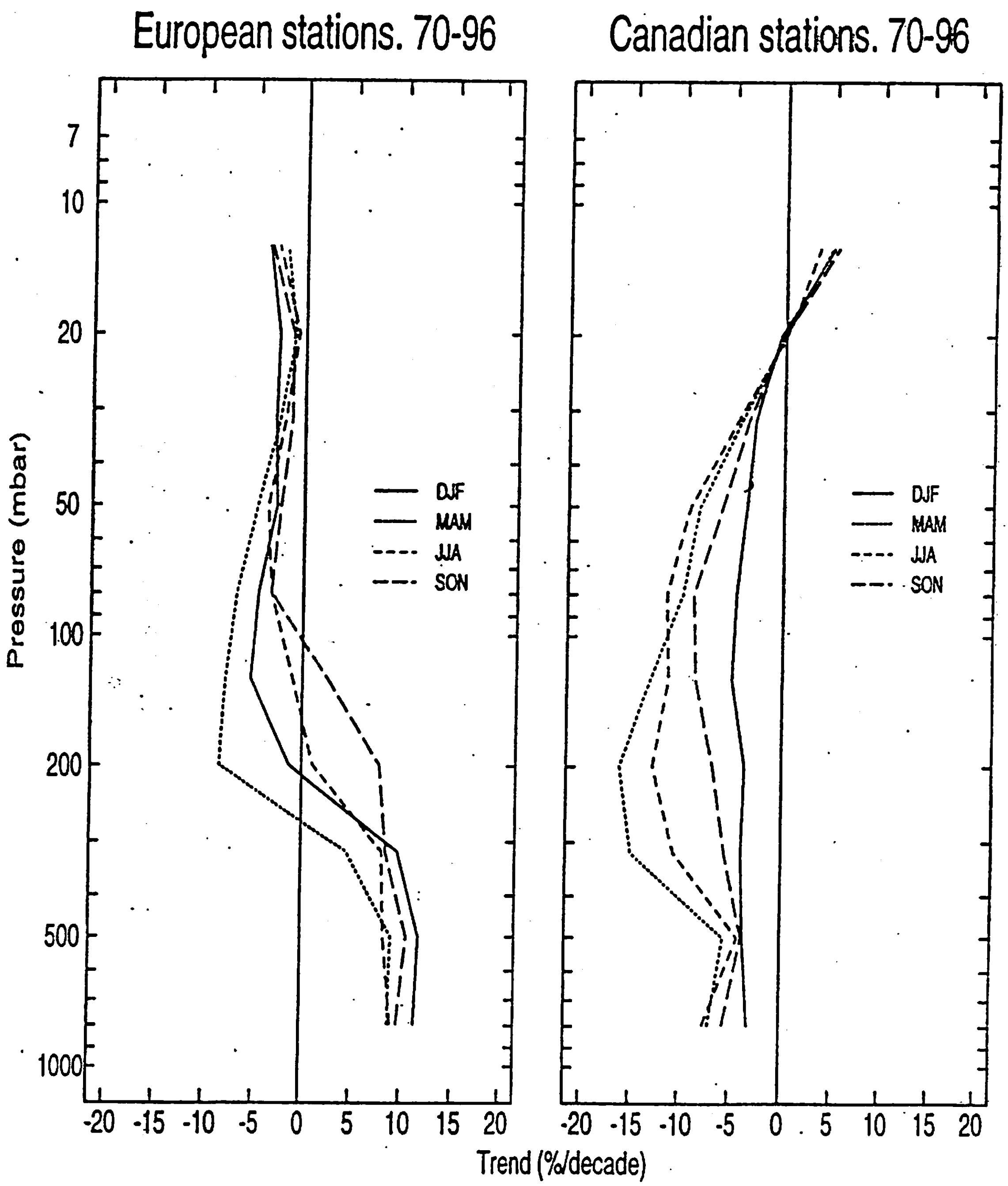
Surface Ozone Change - Preindustrial - July



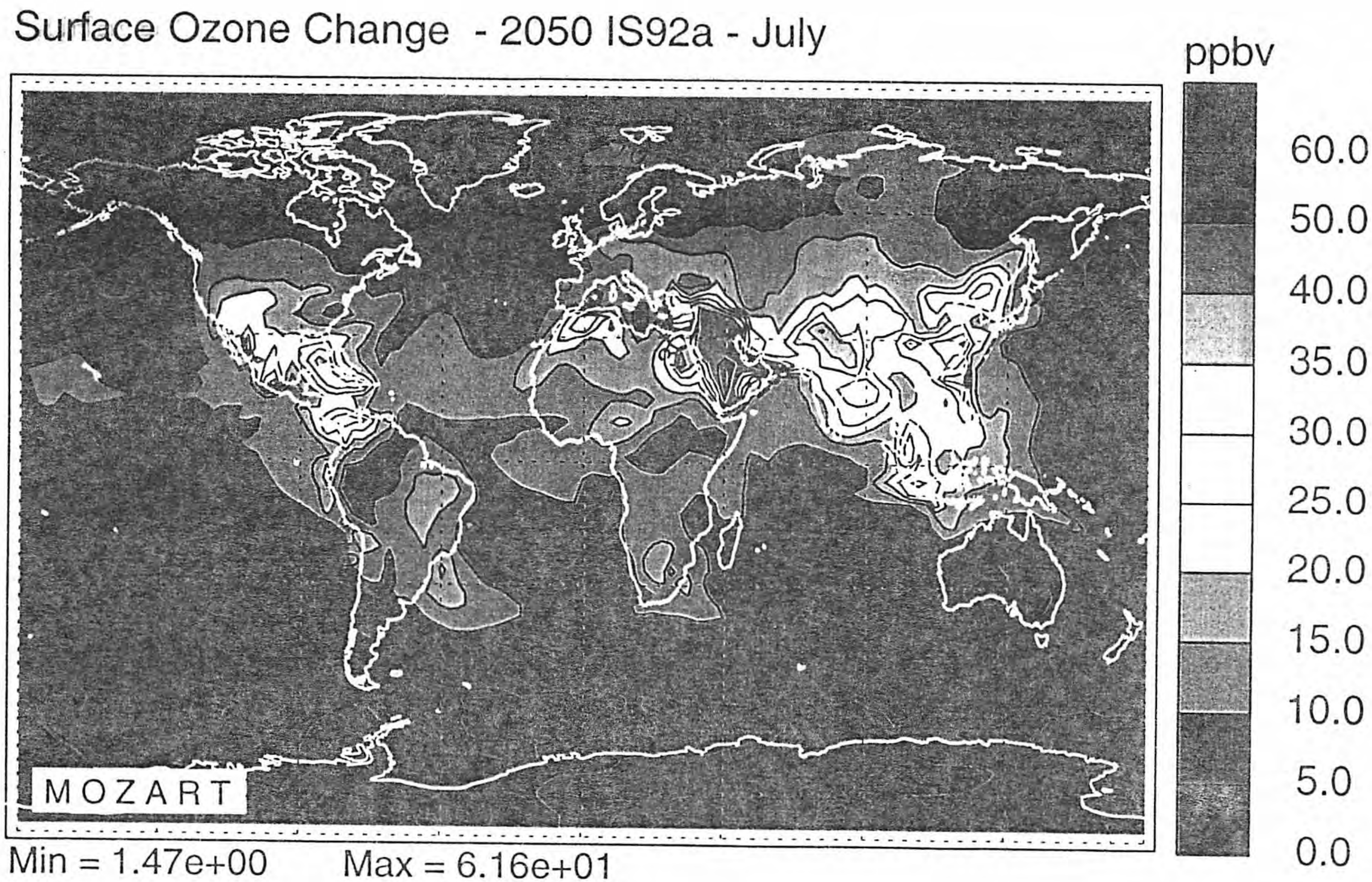
Min = 1.90e+00 Max = 5.40e+01


Ozone Net Radiative Forcing - Preindustrial - July
W/m2
2.00
1.80
1.60
1.40
1.20
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Min = -1.87e-03
Max = 2.03e+00


Resolute 75 N 70-91
Wallops_Island 38 N 70-91
Sapporo 43 N 70-91
Melbourne 38 S 70-90
Churchill 59 N 74-91
Hohenpeissenberg 48 N 70-91
Tateno 36 N 70-91
Syowa 69 S 70-91
Edmonton 53 N 73-91
Payerne 47 N 70-91
Kagoshima 32 N 70-91
Goose_Bay 53 N 70-91
Berlin/Lindenberg 52 N 70-91
Lindenberg 52 N 75-91
Pressure (mbar)
10 20 50 100 200 500 1000
-4 -2 0 2 4
Trend (%/yr)



European stations. 70-96
Canadian stations. 70-96
Pressure (mbar)
7
10
20
50
100
200
500
1000
DJF
MAM
JJA
SON
-20 -15 -10 -5 0 5 10 15 20
Trend (%/decade)


Surface Ozone Change - 2050 IS92a - July
ppbv
60.0
50.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
MOZART
Min = 1.47e+00
Max = 6.16e+01

x

The Hydroxyl Radical

Production of HO_x

$$H_2O + O(^1D) \longrightarrow 2OH$$

With the electronically excited $O(^1D)$ atom produced by photolysis of ozone:

$$O_3 + H\nu\ (\lambda < 310\ \text{nm}) \longrightarrow O(^1D) + O_2$$

x

The Hydroxyl Radical

Conversion of OH to HO_2

$$OH + CO \xrightarrow{O_2} H_2O + CO_2$$

$$OH + O_3 \longrightarrow HO_2 + O_2$$

$$OH + CH_4 \longrightarrow HO_2 + \ldots$$

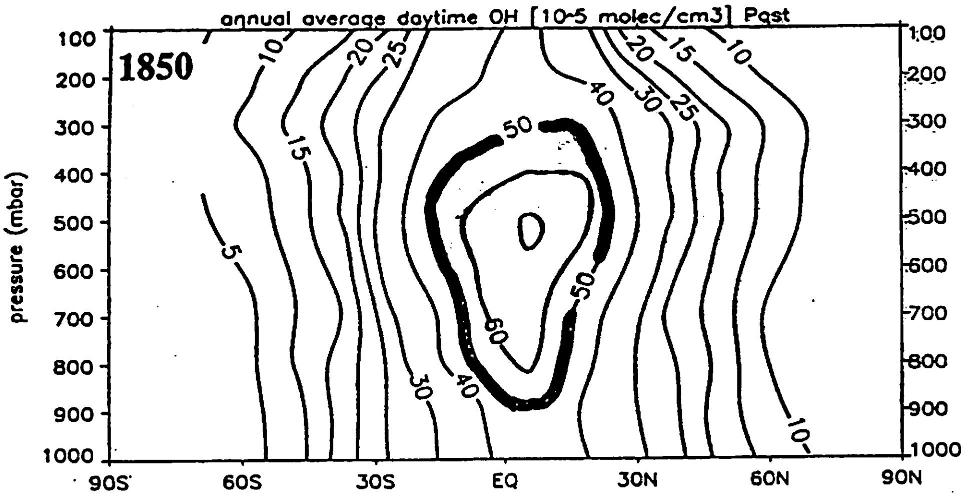
Conversion of HO_2 to OH

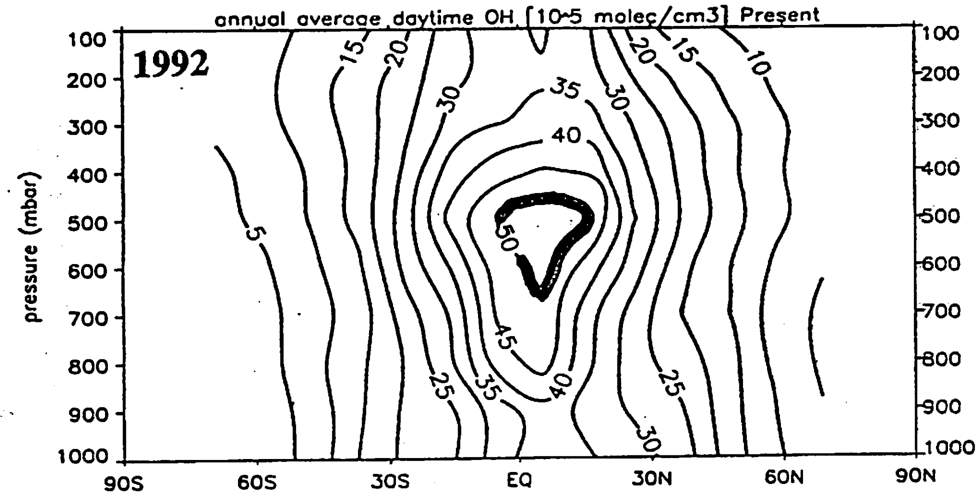
$$HO_2 + NO \longrightarrow OH + NO_2$$

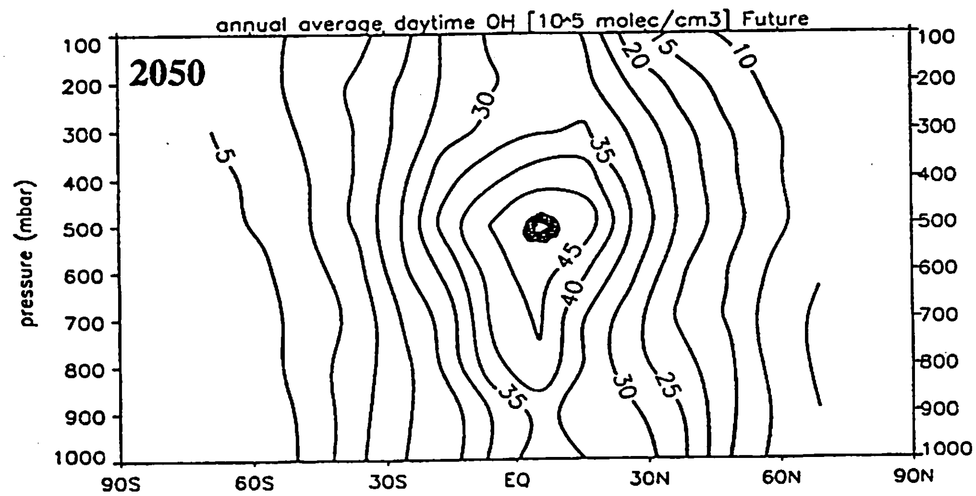
$$HO_2 + O_3 \longrightarrow OH + 2O_2$$

Abundances of OH and HO_2 affected by concentration of CO and NO_x (e.g., pollution)

Annual average daytime OH (10^{-5}/cm^3)



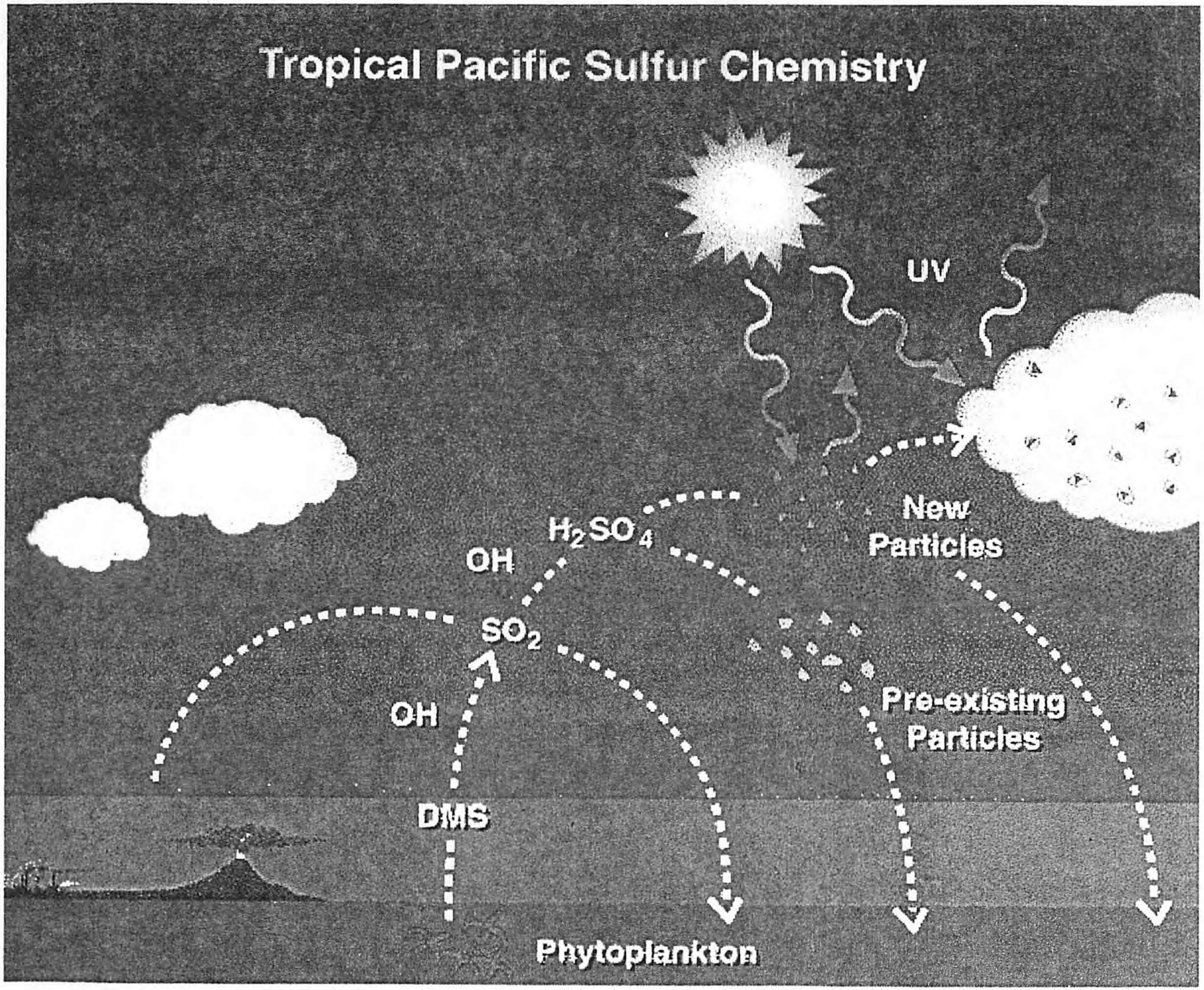




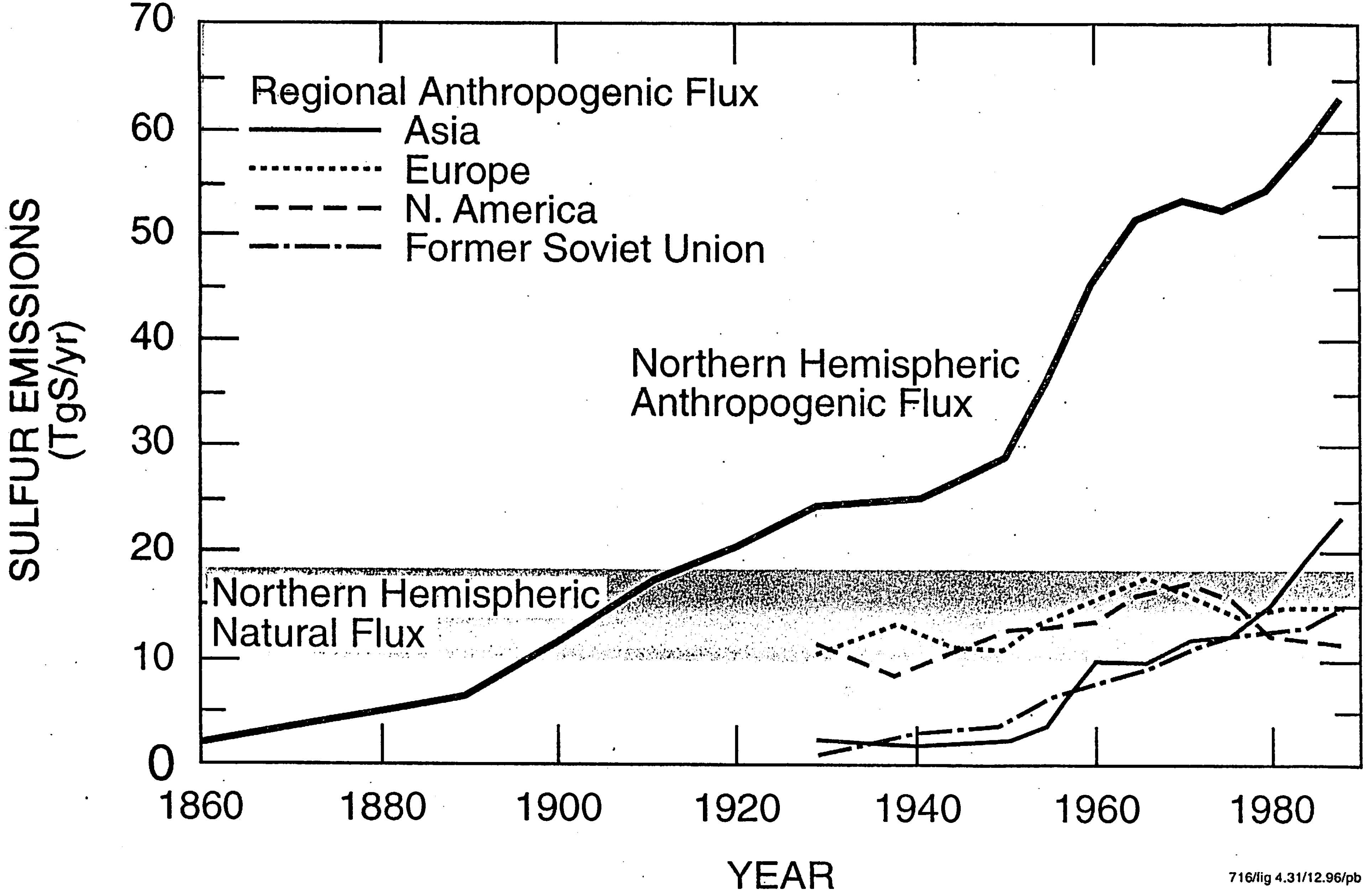
3. Changes in Sulfate Loading

SO_2

SO_4


Tropical Pacific Sulfur Chemistry
UV
New Particles
H_2SO_4
OH
SO_2
OH
Pre-existing Particles
DMS
Phytoplankton

NORTHERN HEMISPHERE SO_2 FOSSIL FUEL COMBUSTION AND NATURAL SOURCES



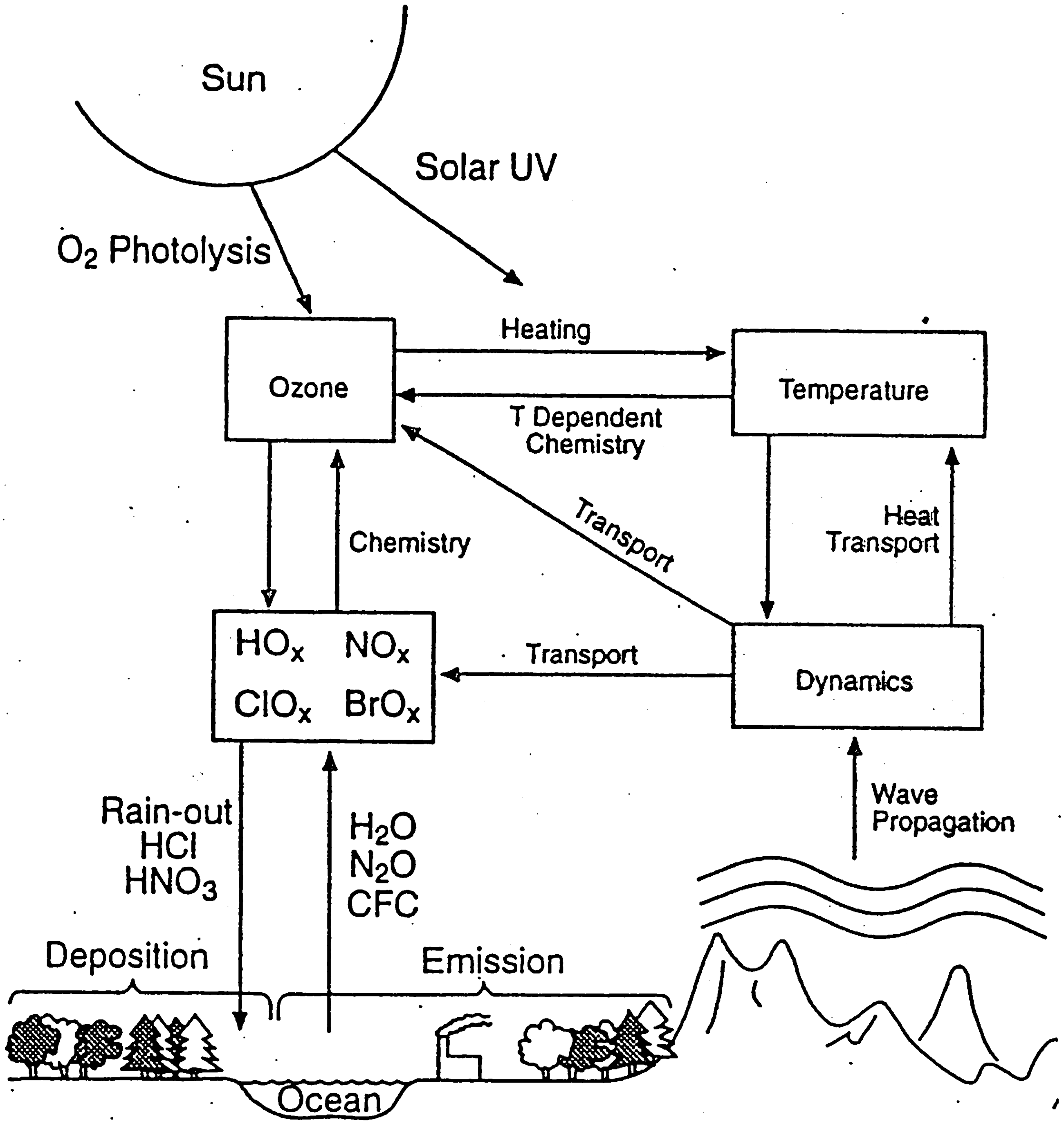
716/fig 4.31/12.96/pb

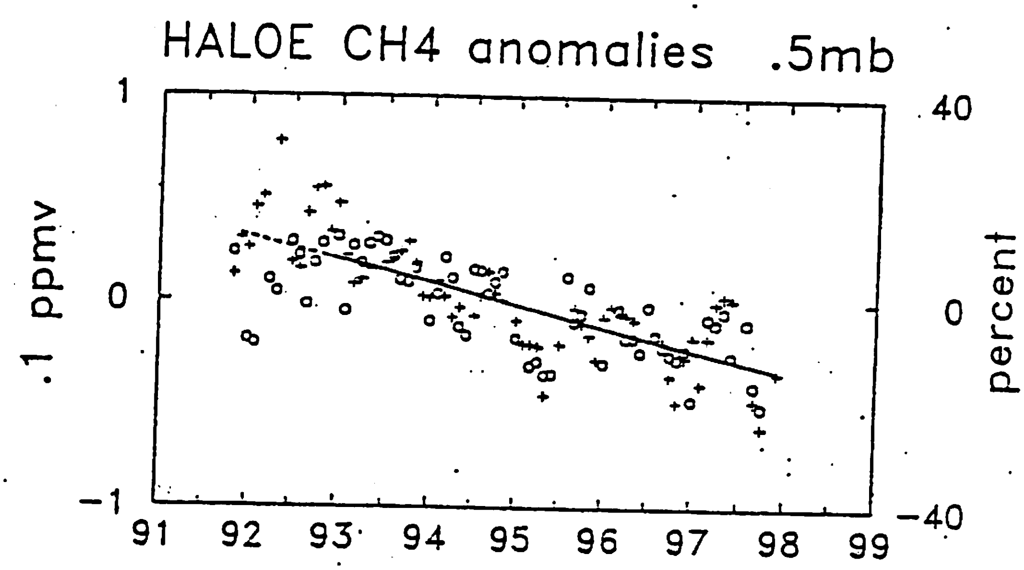
4. Changes in Stratospheric Ozone

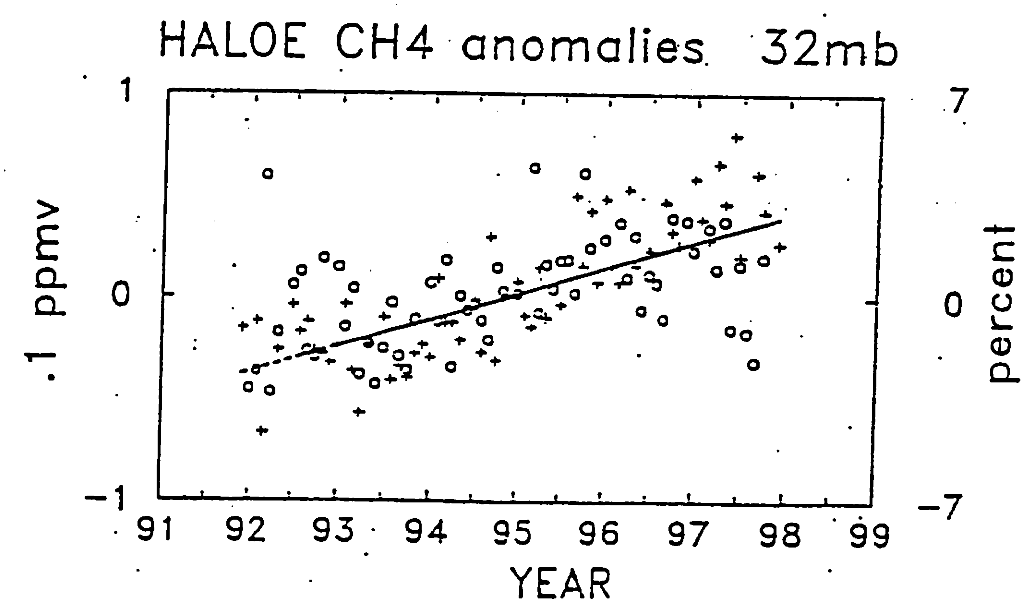
Caused by:

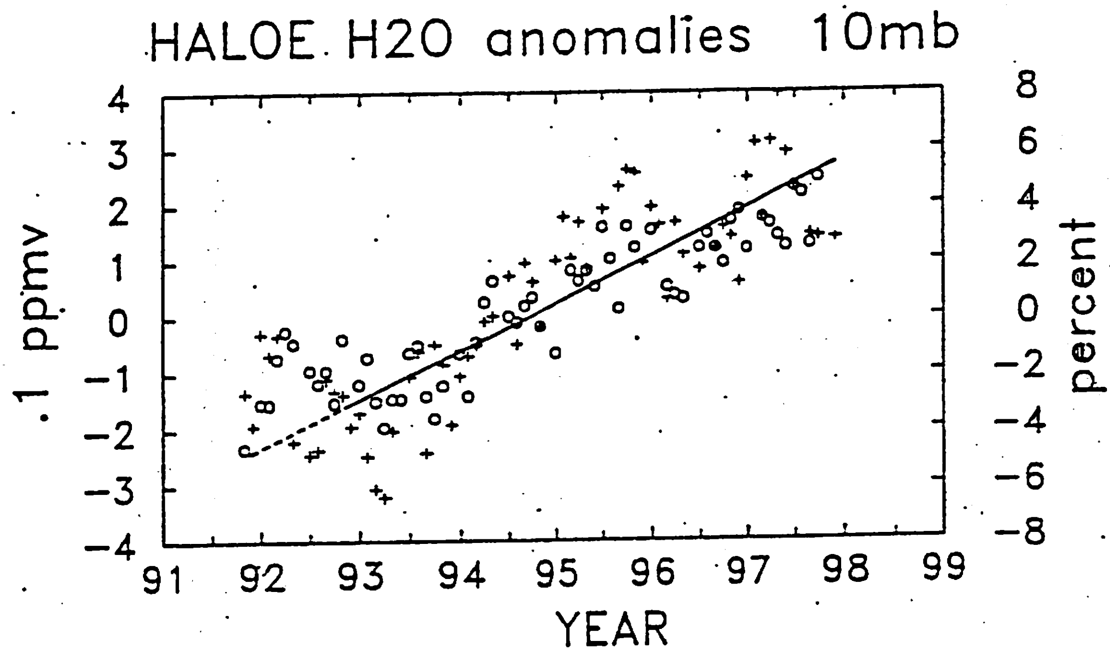
- ❖ **Chlorofluorocarbons**
- ❖ **Solar variability**
- ❖ **Volcanic eruptions**

STRATOSPHERIC SYSTEM

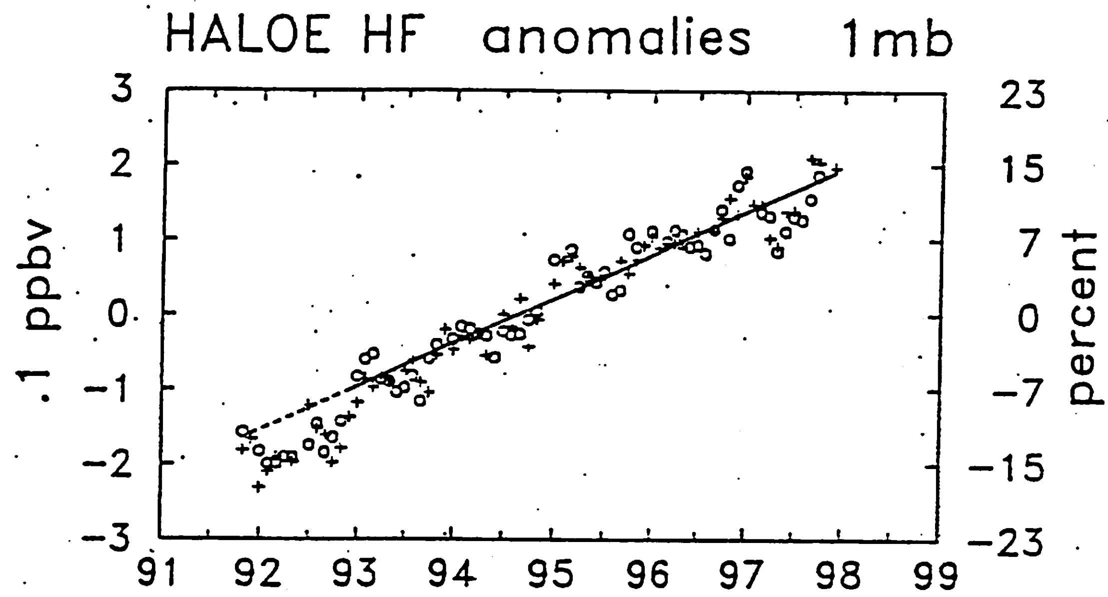


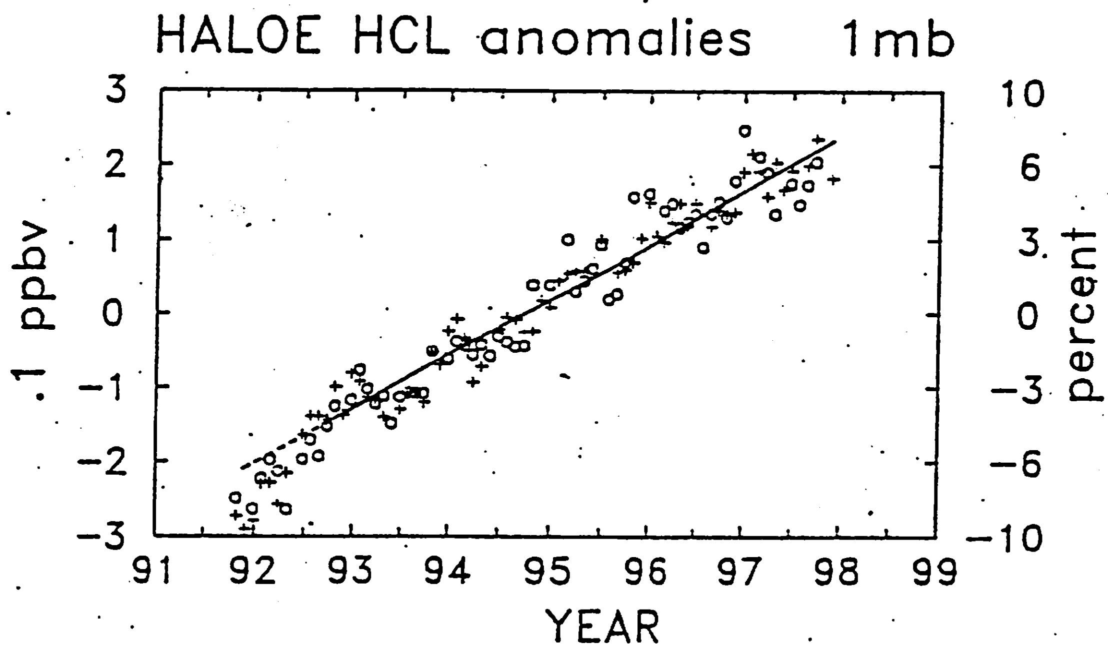

HALOE CH4 anomalies .5mb
.1 ppmv
percent
1
0
-1
40
0
-40
91 92 93 94 95 96 97 98 99

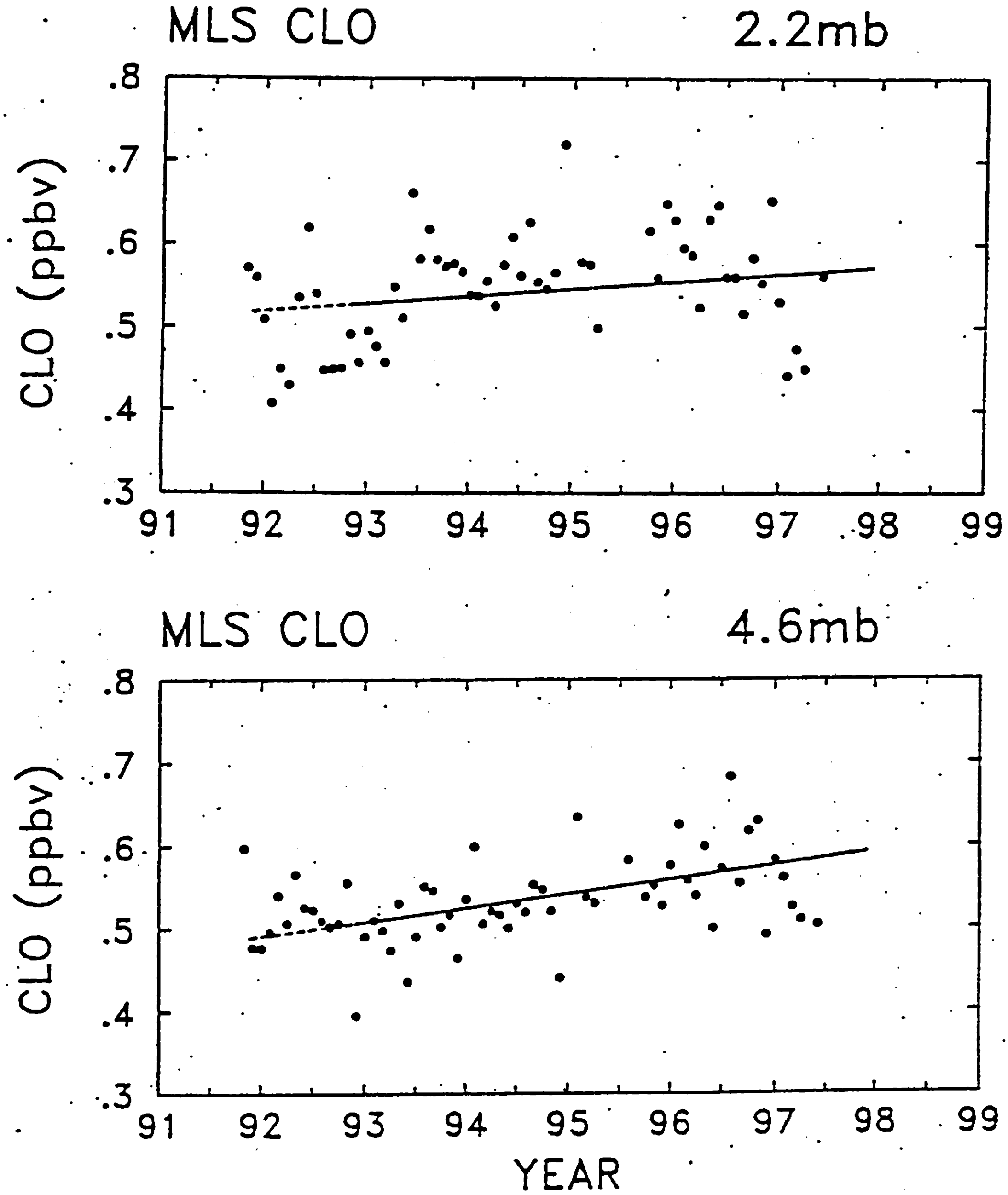

HALOE CH4 anomalies 32mb
.1 ppmv
percent
1
0
-1
7
0
-7
91 92 93 94 95 96 97 98 99
YEAR



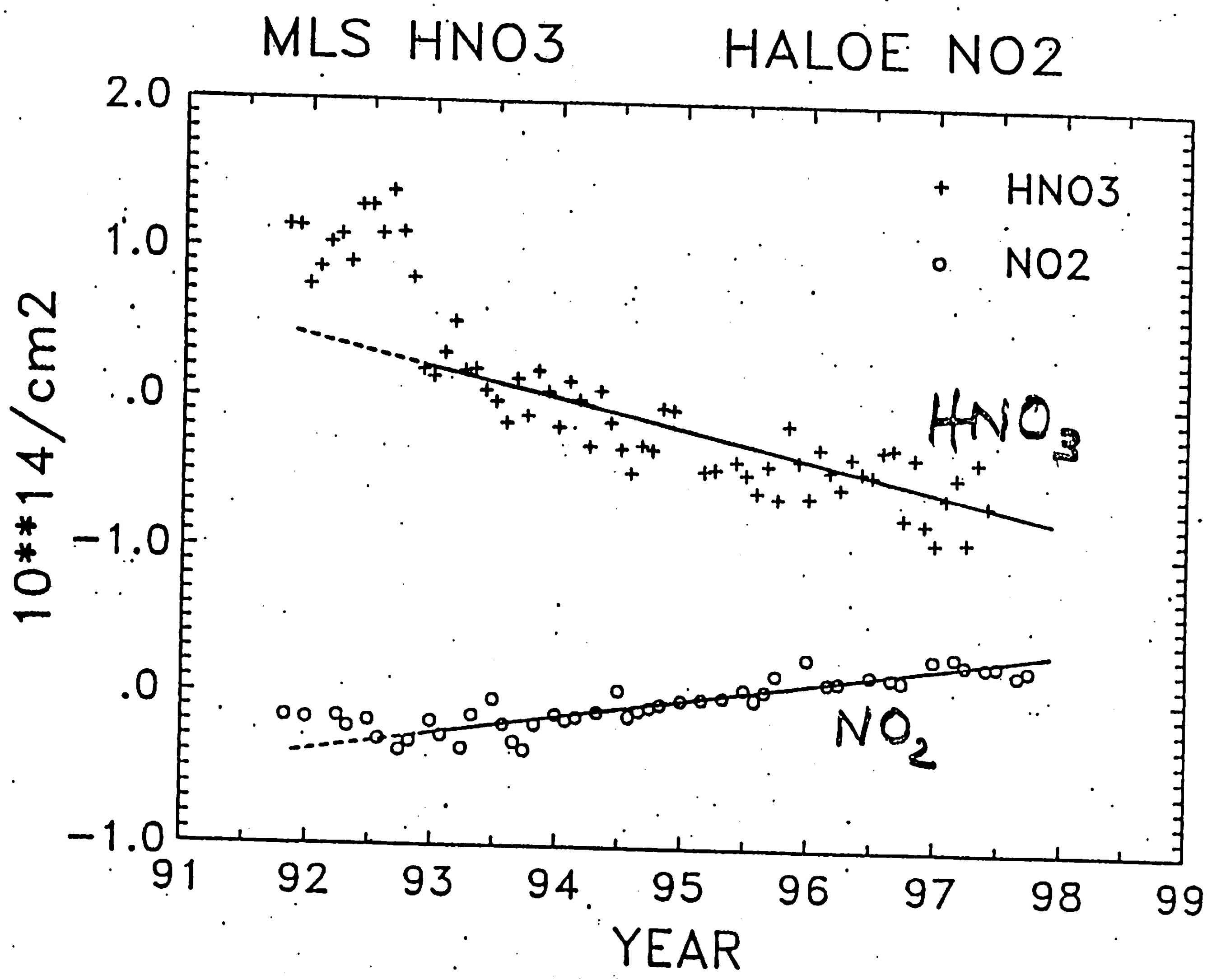
HALOE H2O anomalies 10mb
.1 ppmv
4
3
2
1
0
−1
−2
−3
−4
percent
8
6
4
2
0
−2
−4
−6
−8
91 92 93 94 95 96 97 98 99
YEAR


HALOE HF anomalies 1mb
.1 ppbv
percent
3
2
1
0.
−1
−2
−3
23
15
7
0
−7
−15
−23
91
92
93
94
95
96
97
98
99

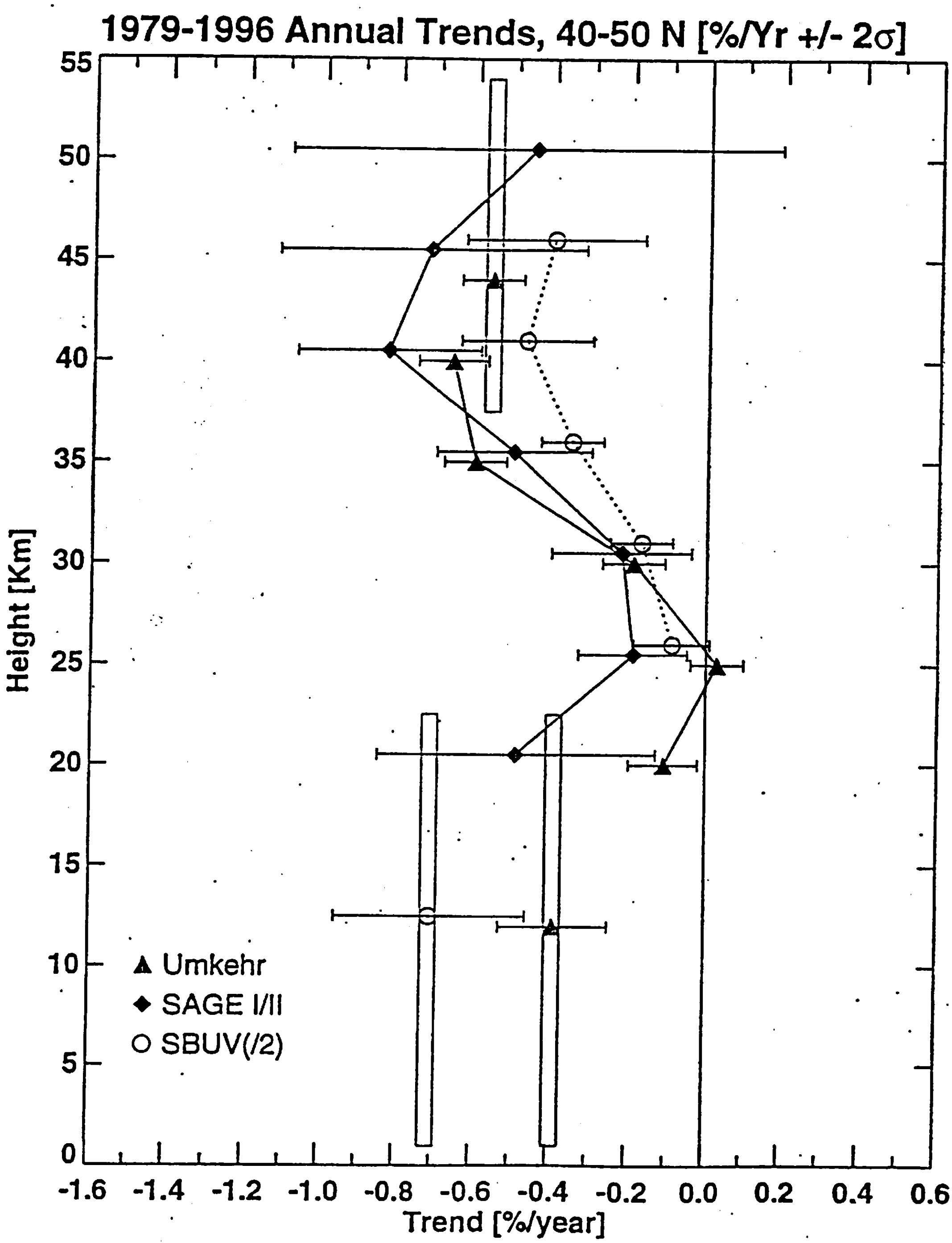

HALOE HCL anomalies 1mb
.1 ppbv
percent
YEAR
3
2
1
0
−1
−2
−3
10
6
3.
0
−3
−6
−10
91
92
93
94
95
96
97
98
99

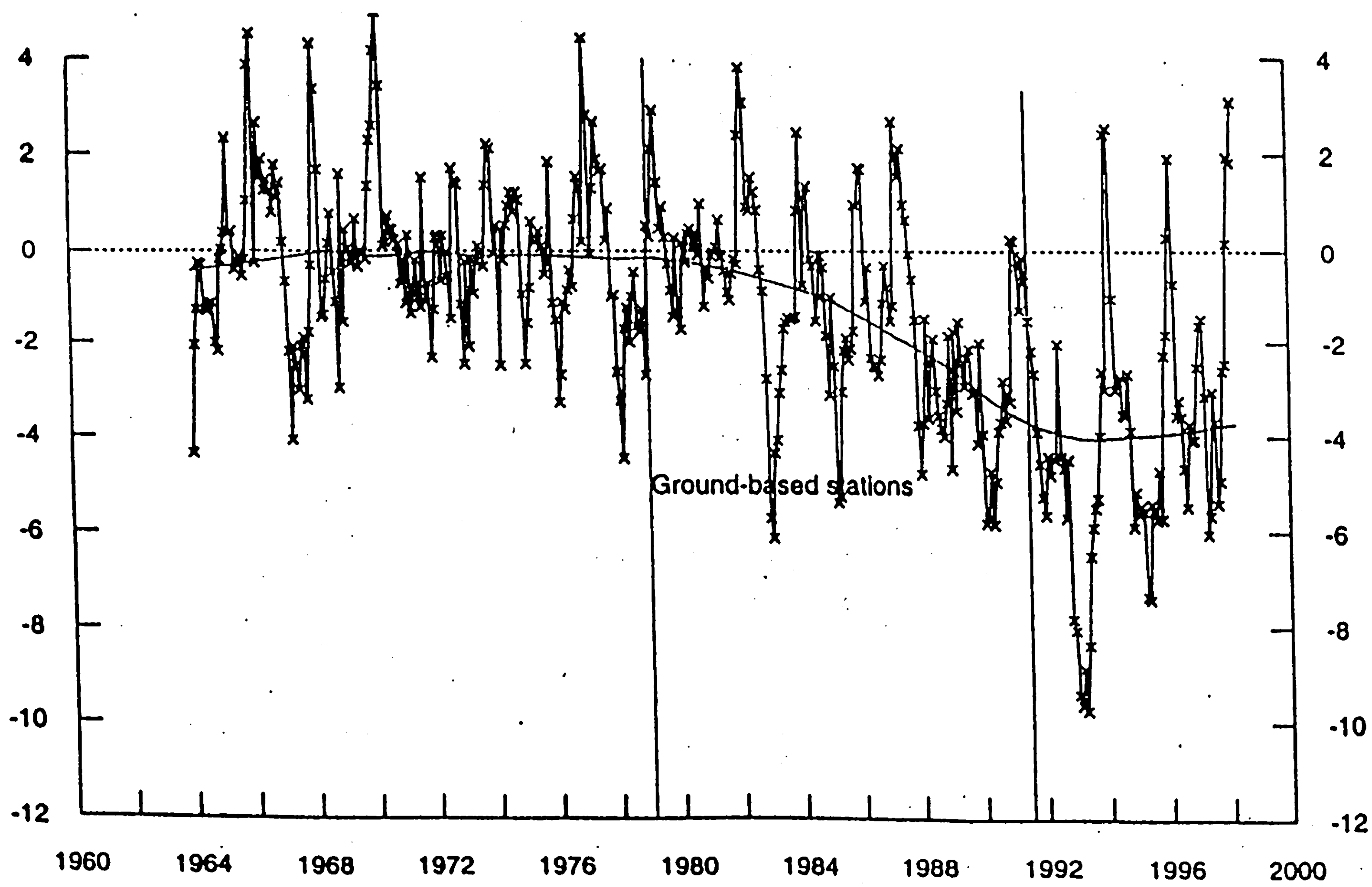


MLS CLO
2.2mb
CLO (ppbv)
.8
.7
.6
.5
.4
.3
91
92
93
94
95
96
97
98
99
MLS CLO
4.6mb
CLO (ppbv)
.8
.7
.6
.5
.4
.3
91
92
93
94
95
96
97
98
99
YEAR

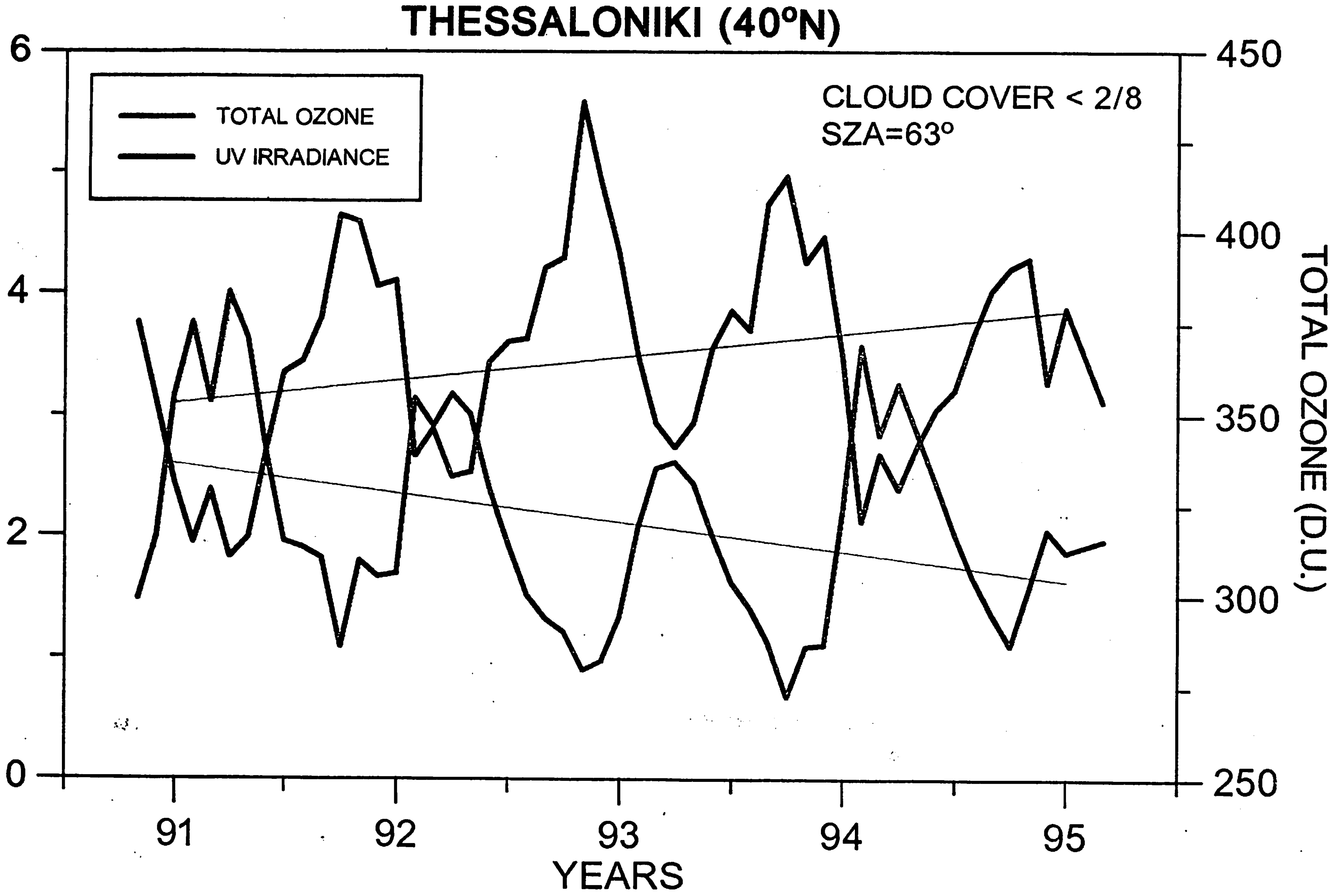


MLS HNO3
HALOE NO2
2.0
1.0
.0
−1.0
.0
−1.0
10**14/cm2
+ HNO3
o NO2
HNO_3
NO_2
91
92
93
94
95
96
97
98
99
YEAR

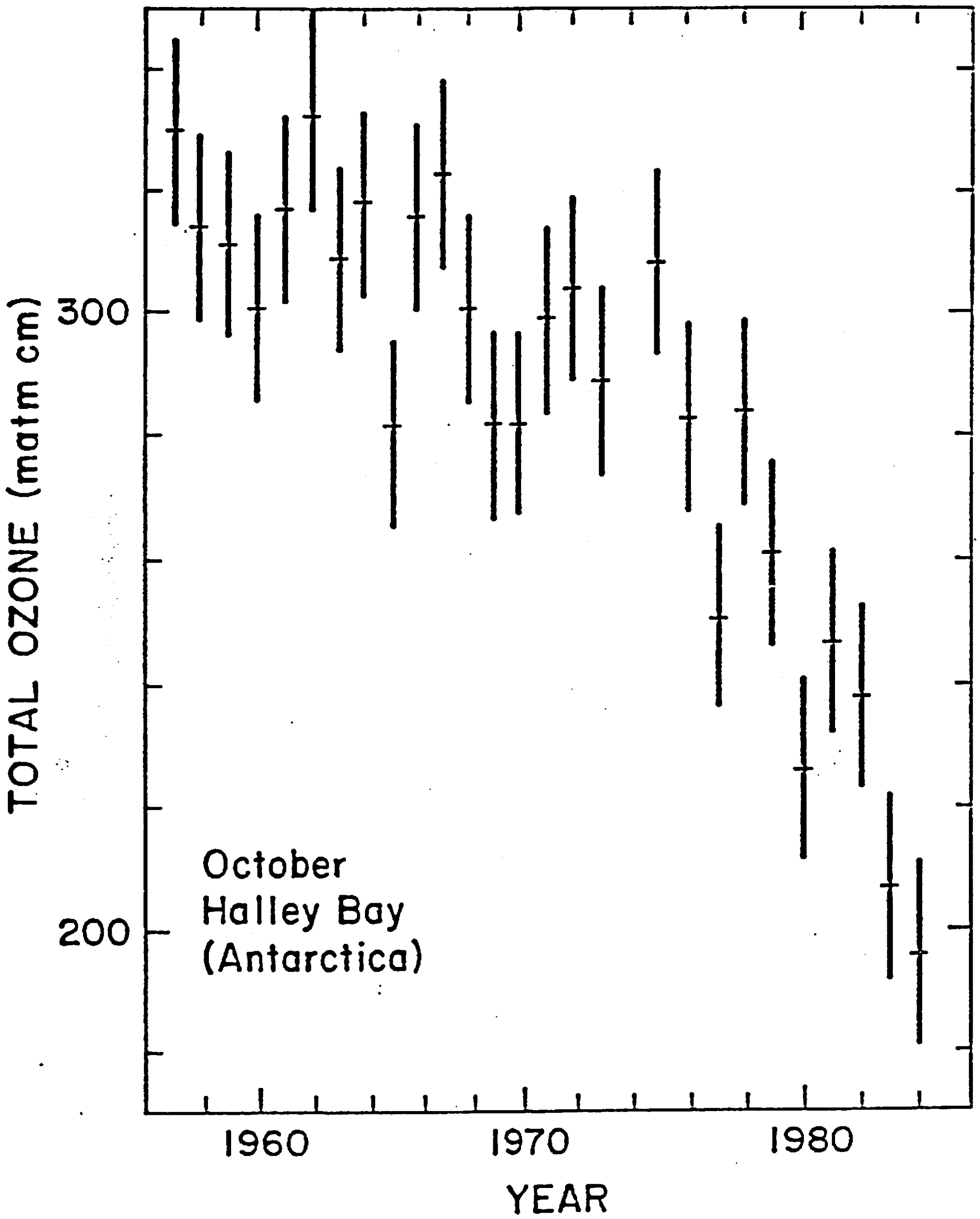

1979-1996 Annual Trends, 40-50 N [%/Yr +/- 2σ]
Height [Km]
Trend [%/year]
0
5
10
15
20
25
30
35
40
45
50
55
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
Umkehr
SAGE I/II
SBUV(/2)

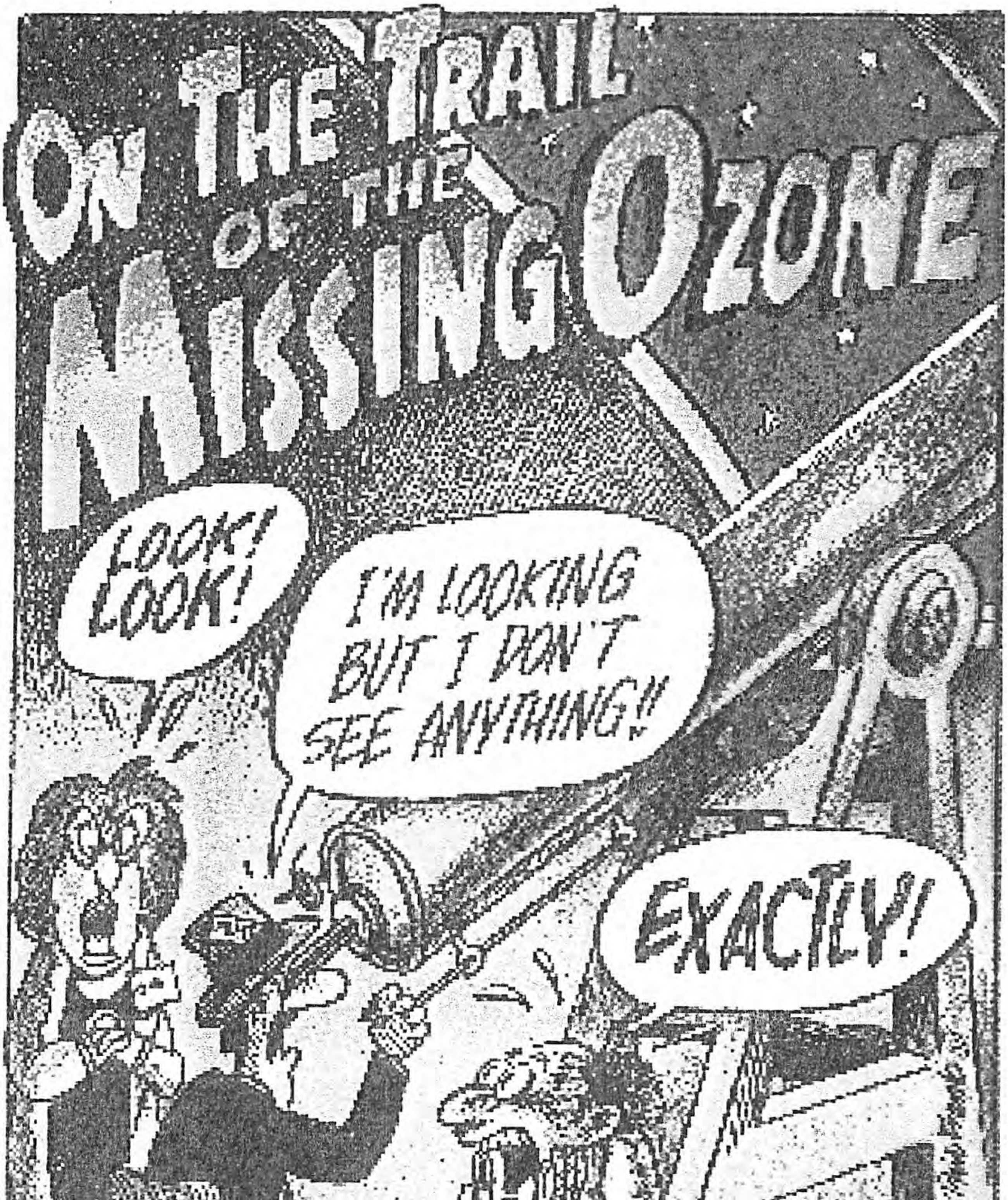


4
2
0
-2
-4
-6
-8
-10
-12
Ground-based stations
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000

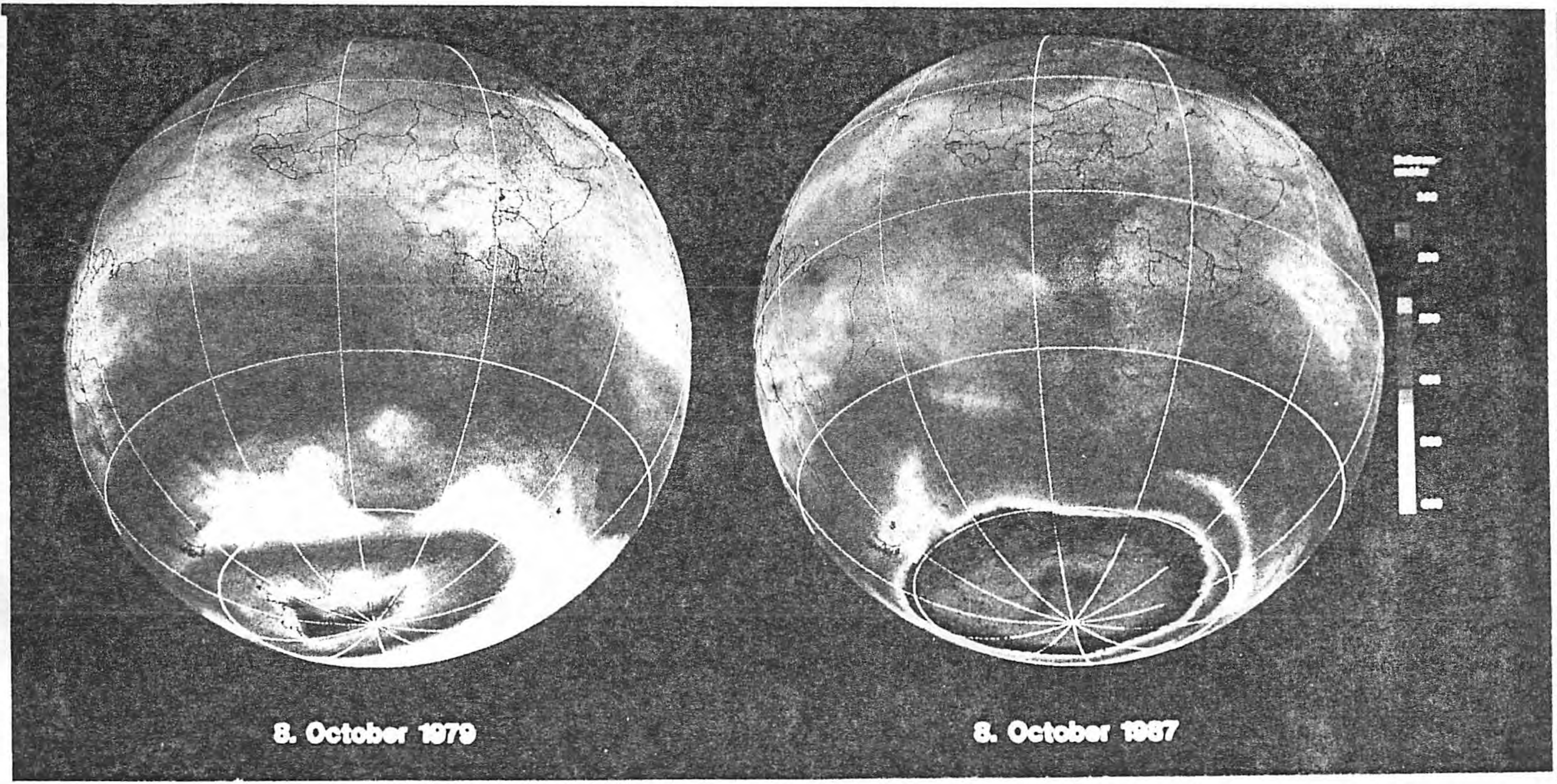


LAP, Univ. of Thessaloniki, Greece (1995)


TOTAL OZONE (matm cm)
300
200
October
Halley Bay
(Antarctica)
1960
1970
1980
YEAR

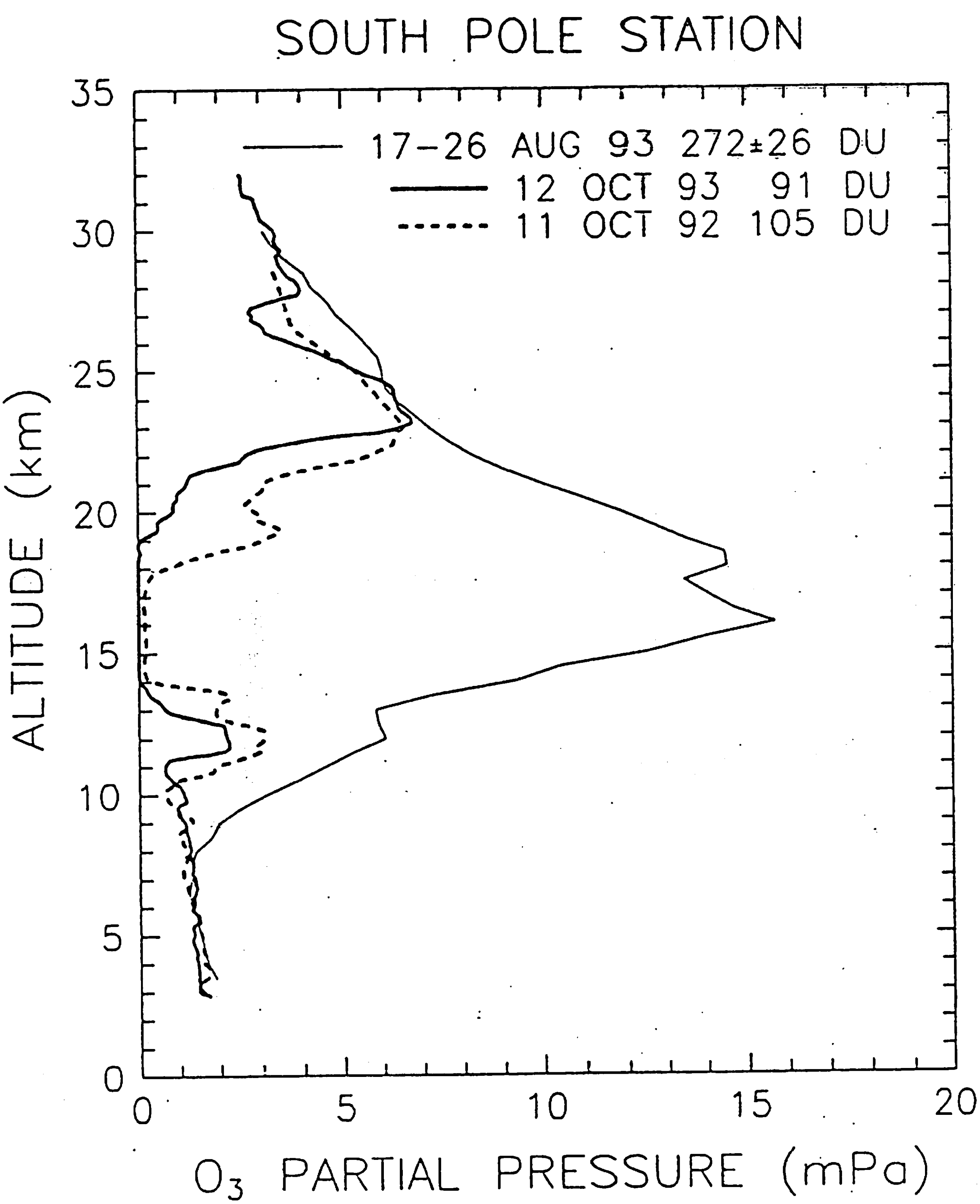

ON THE TRAIL OF THE MISSING OZONE
LOOK! LOOK!
I'M LOOKING BUT I DON'T SEE ANYTHING!!
EXACTLY!

SOURCE: EPA



Satellite data give information on changes in the ozone concentration which has seriously decreased in the polar [illegible]
regions. This picture is based on data measured by the TOMS-sensor on the American weather satellite NIMBUS-7. [illegible]
Dobson-units. The mainly stratospheric ozone protects the Earth from dangerous UV radiation of the sun.
(From: TOMS V6.0 processed by DLR Deutsches Fernerkundungsdatenzentrum)

x


SOUTH POLE STATION
17–26 AUG 93 272±26 DU
12 OCT 93 91 DU
11 OCT 92 105 DU
ALTITUDE (km)
0
5
10
15
20
25
30
35
0
5
10
15
20
O3 PARTIAL PRESSURE (mPa)

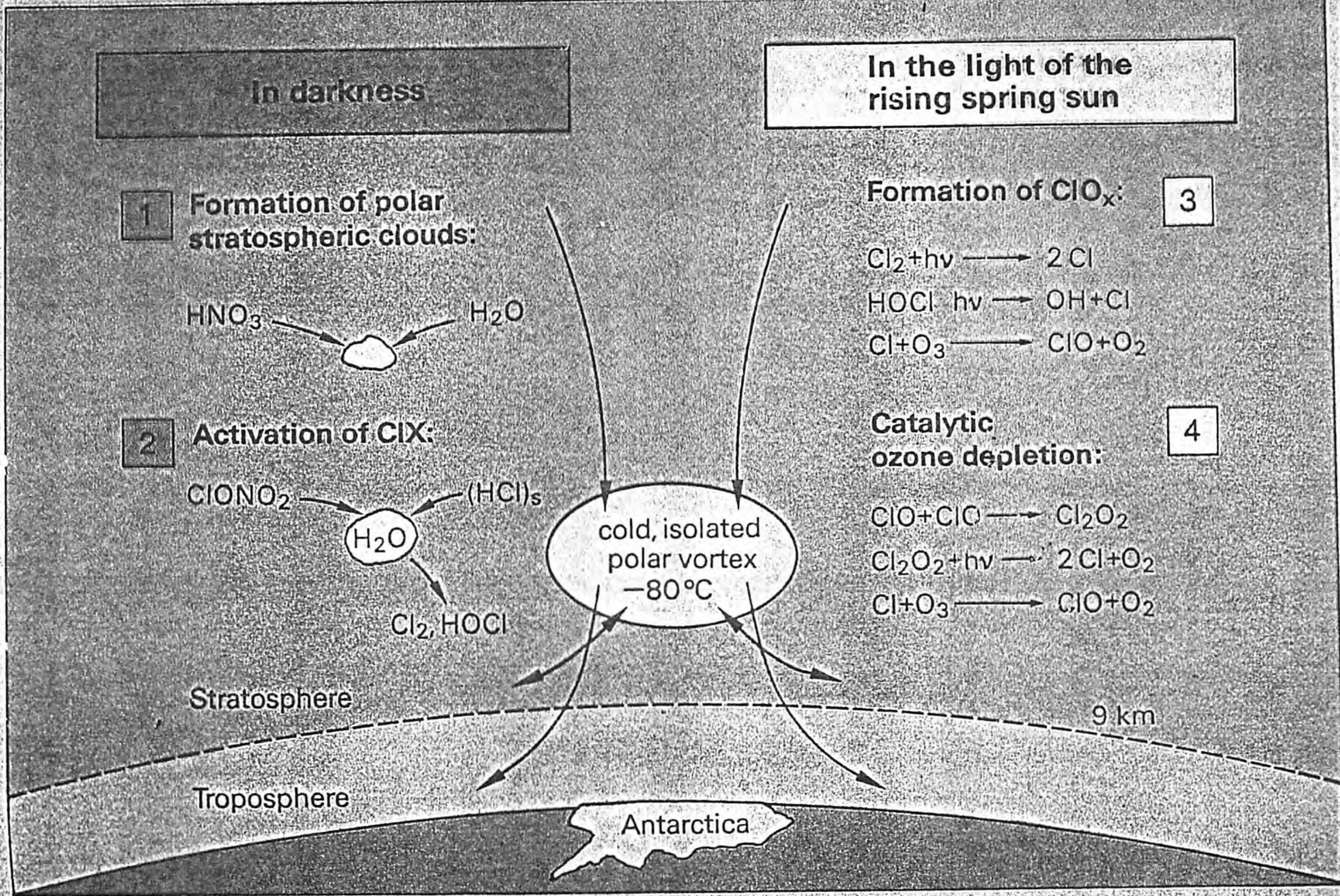
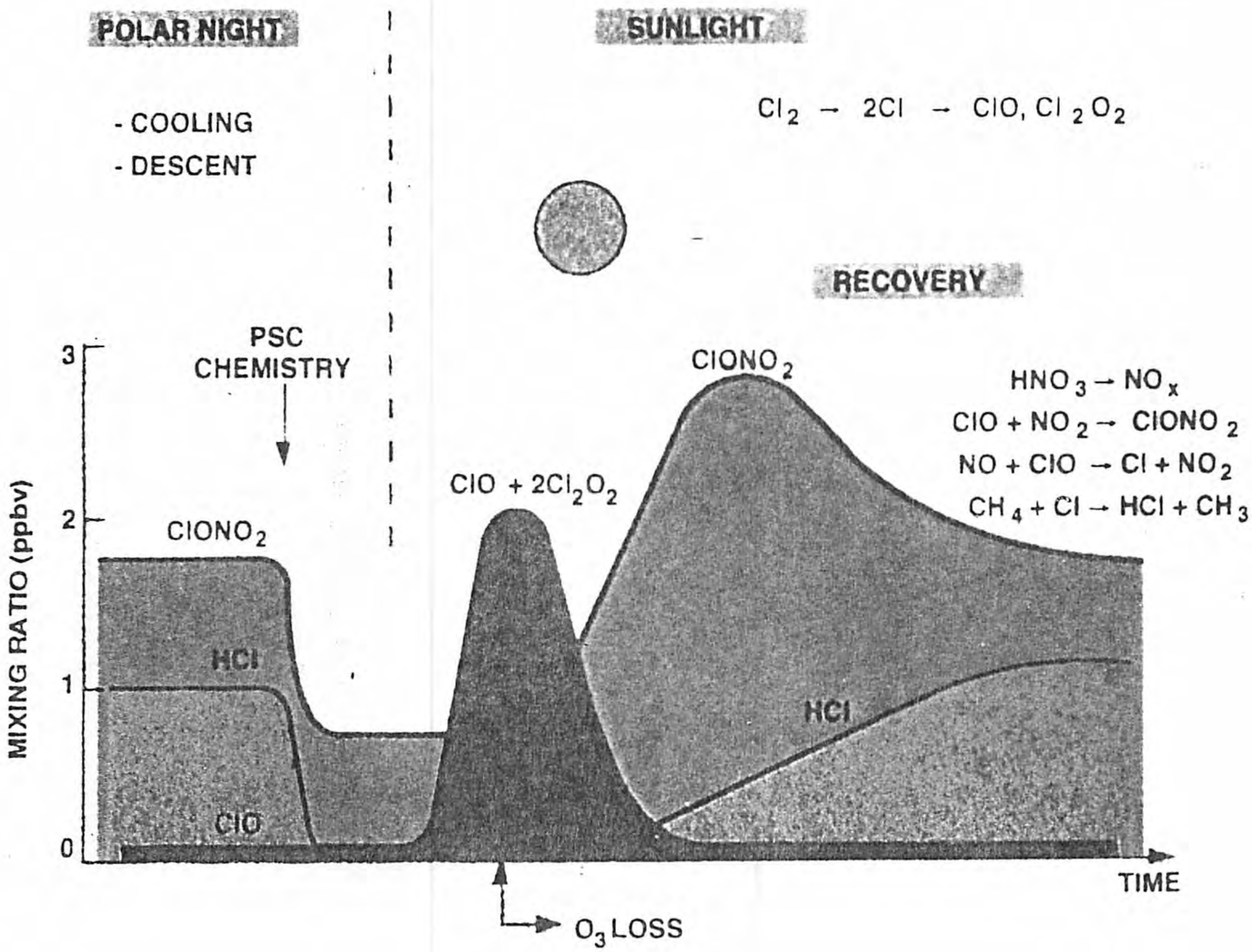
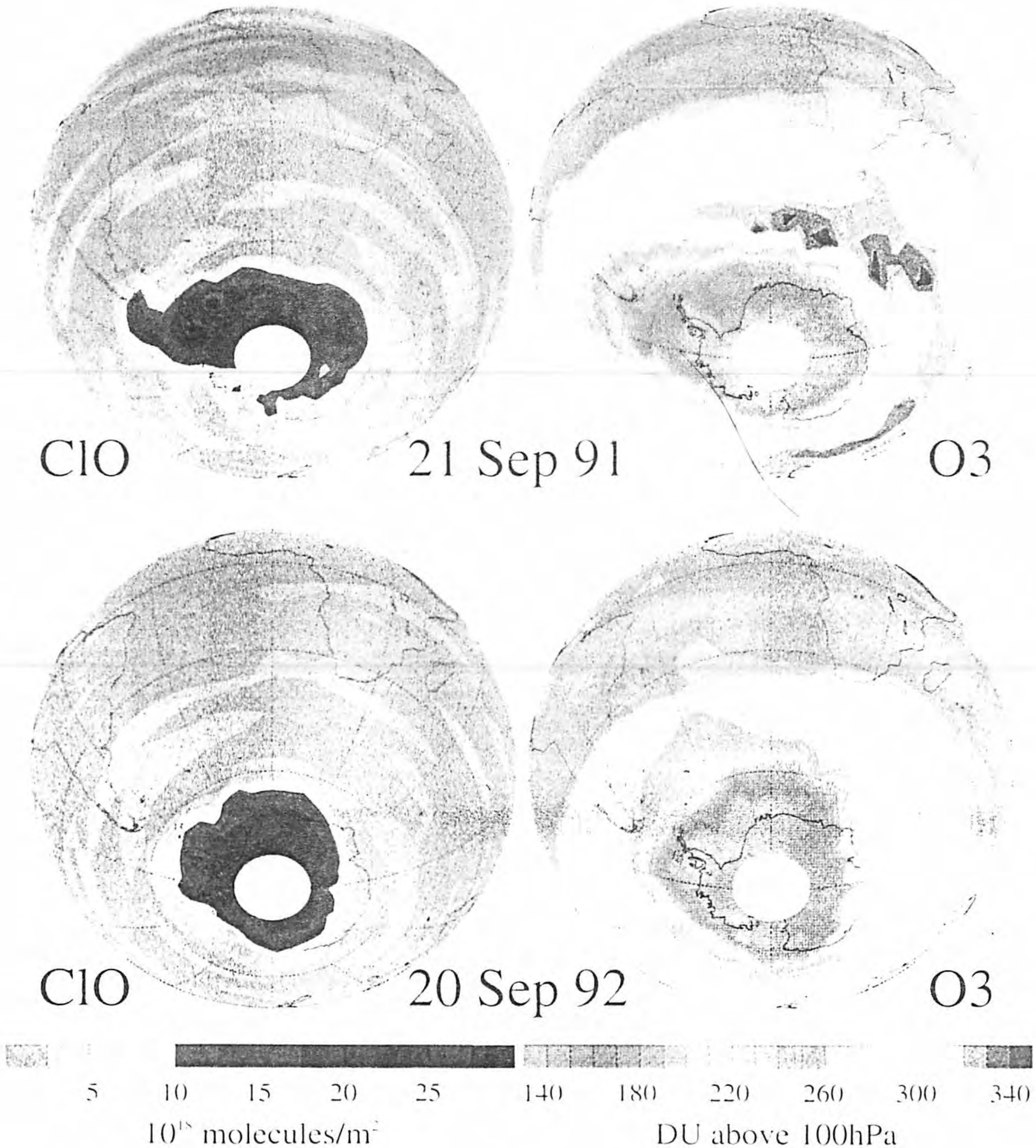
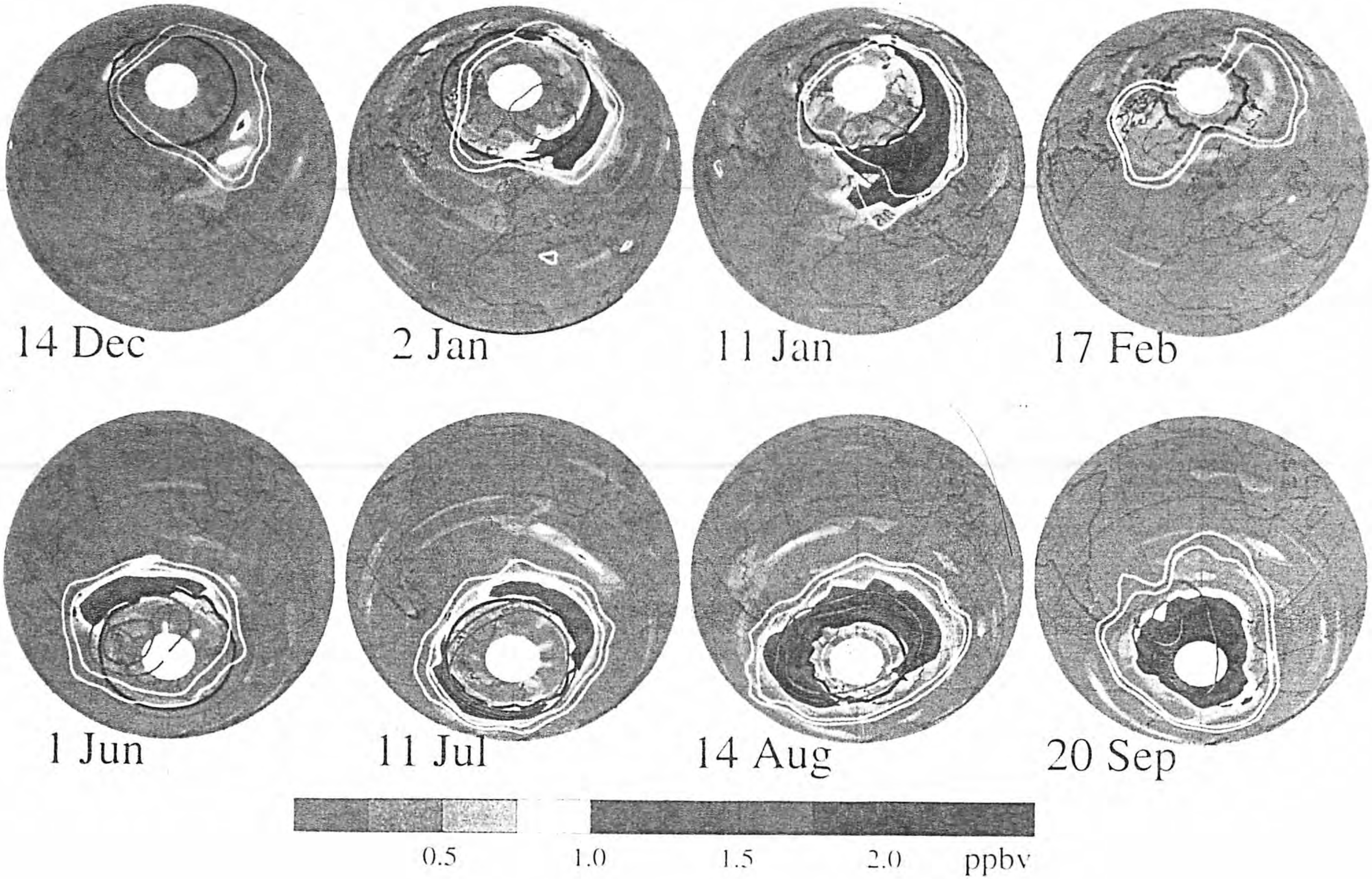


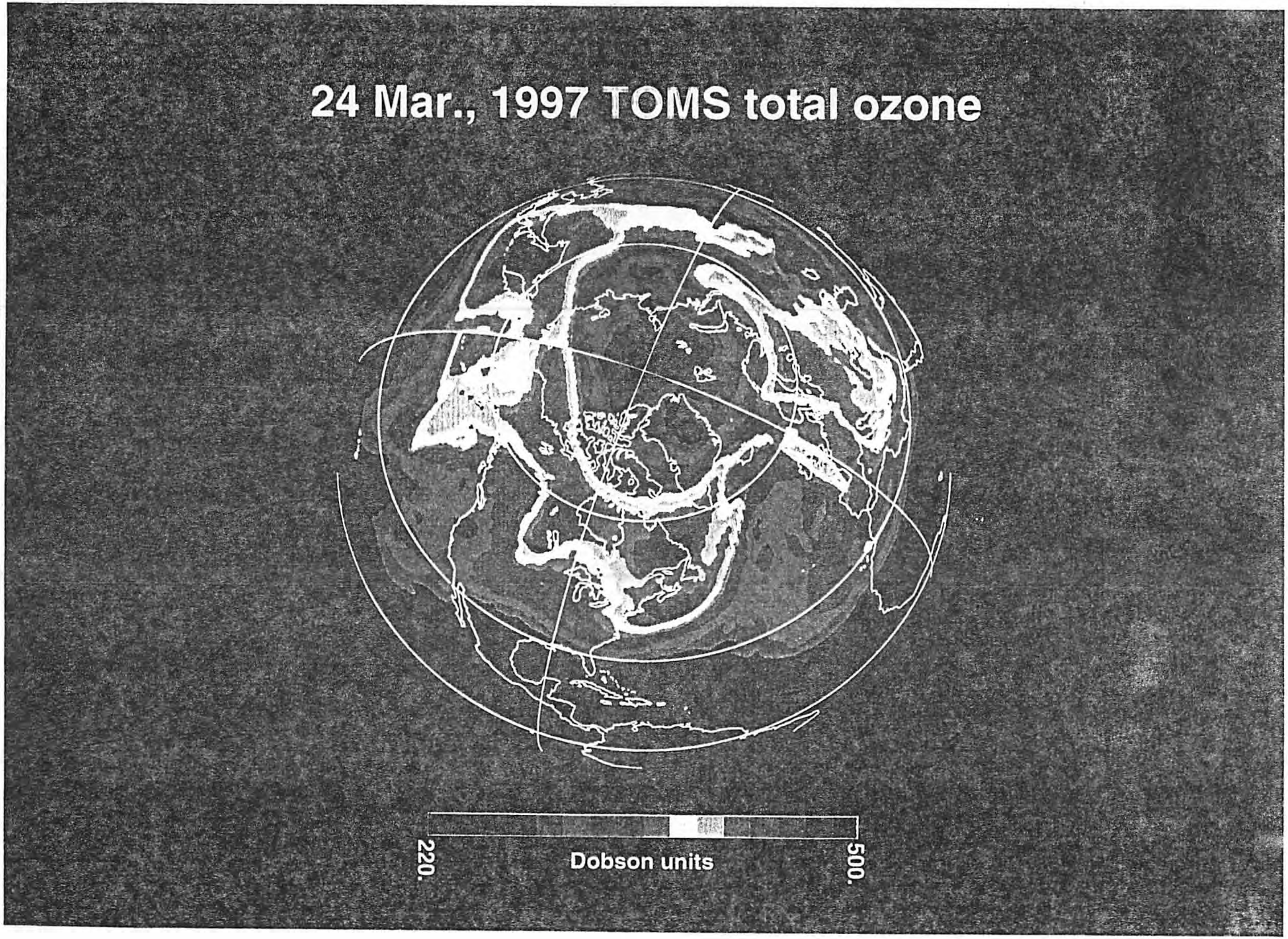
Fig. 19: Meteorology and chemistry of the Antarctic ozone hole.

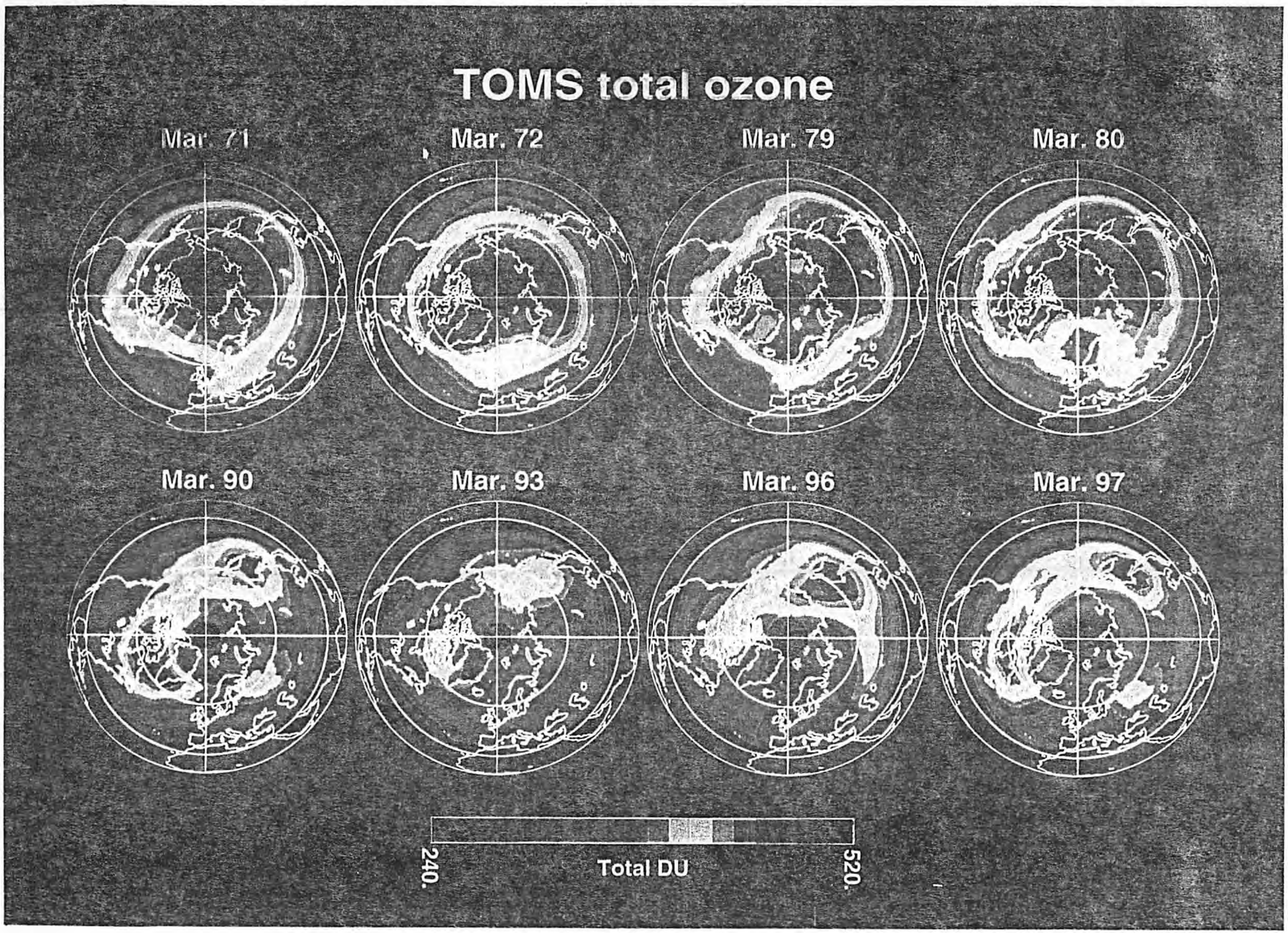

POLAR NIGHT
- COOLING
- DESCENT
SUNLIGHT
Cl2 → 2Cl → ClO, Cl2O2
RECOVERY
PSC CHEMISTRY
ClONO2
HNO3 → NOx
ClO + NO2 → ClONO2
NO + ClO → Cl + NO2
CH4 + Cl → HCl + CH3
ClO + 2Cl2O2
ClONO2
HCl
ClO
HCl
MIXING RATIO (ppbv)
3
2
1
0
TIME
O3 LOSS


ClO
21 Sep 91
O3
ClO
20 Sep 92
O3
5
10
15
20
25
140
180
220
260
300
340
10^18 molecules/m^2
DU above 100hPa

Lower Stratospheric ClO in the 1991-92 Polar Vortices




24 Mar., 1997 TOMS total ozone
220.
Dobson units
500.


TOMS total ozone
Mar. 71
Mar. 72
Mar. 79
Mar. 80
Mar. 90
Mar. 93
Mar. 96
Mar. 97
240.
Total DU
520.

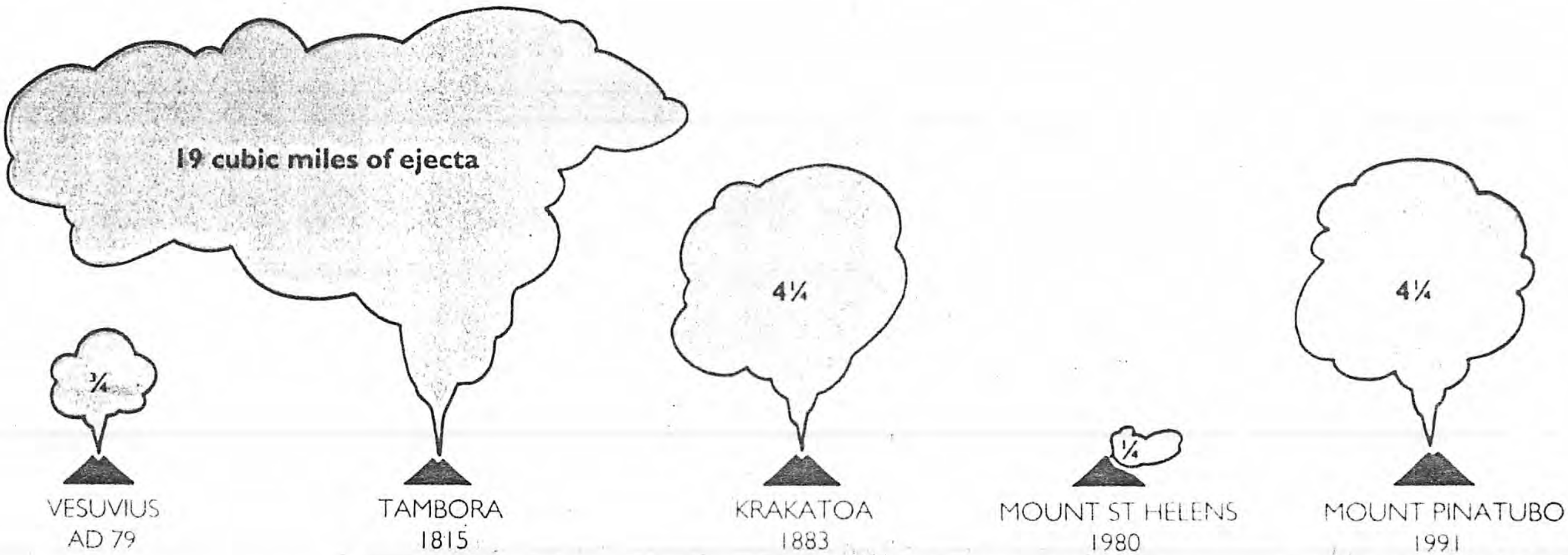
OZONE AND LARGE VOLCANIC ERUPTIONS

1. **Stratospheric sulfate particles resulting from large volcanic eruptions**

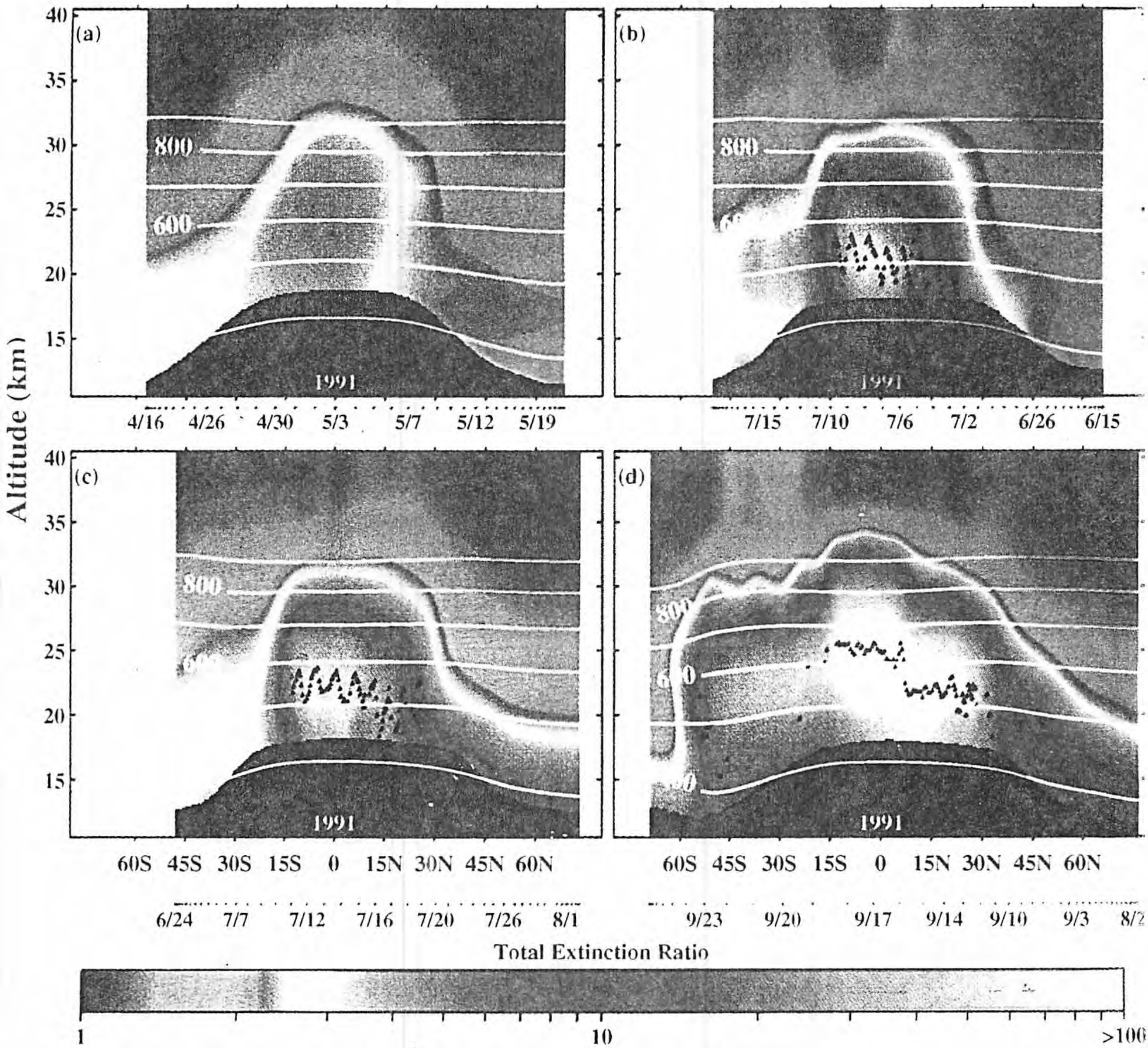
   - **Convert NO_x into HNO_3**
   - **Convert HCl and $CLONO_2$ into reactive chlorine**
   - **Produce local warming**

<u>Consequence</u>

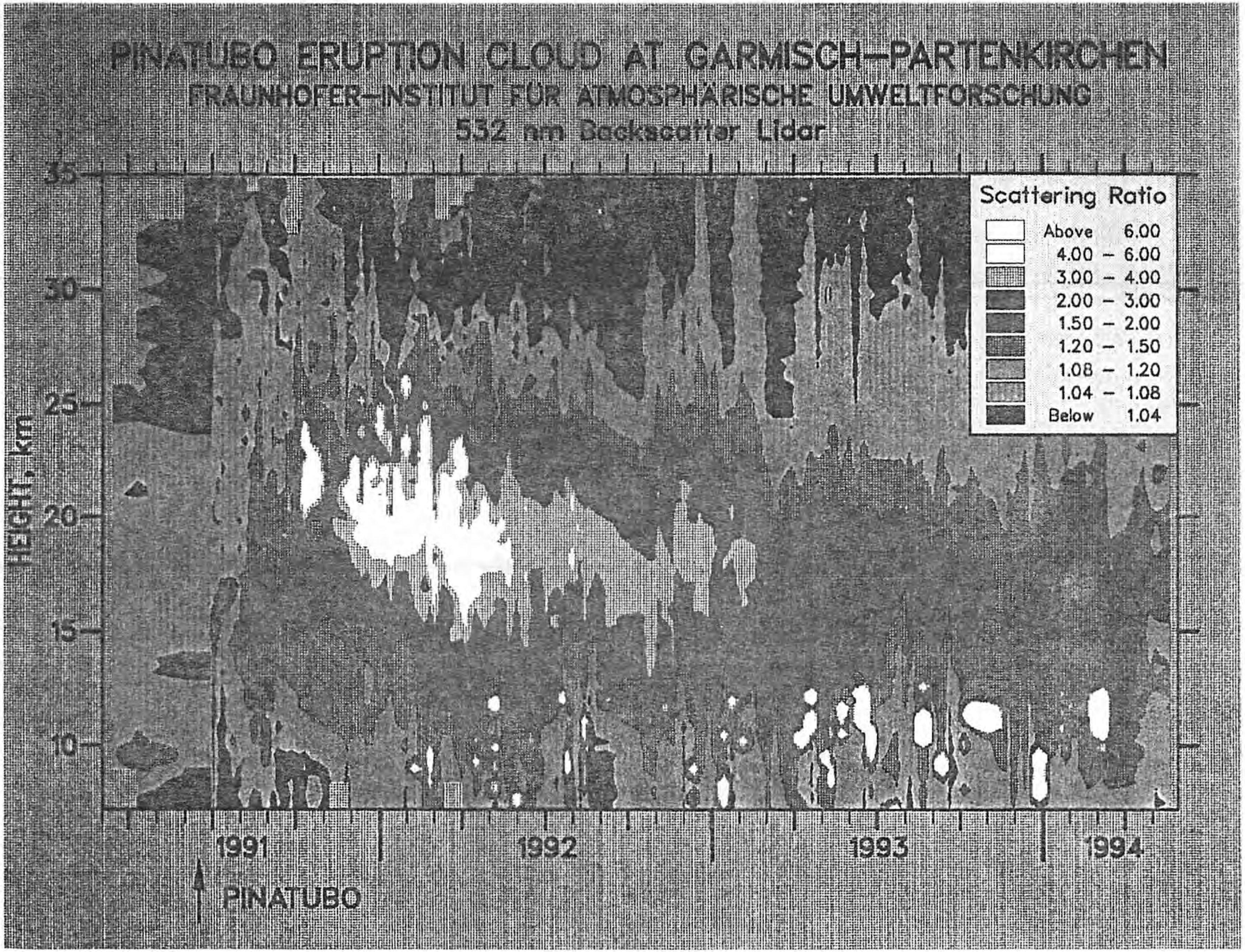
Under high chlorine load, significant ozone depletion is expected, and local temperature is enhanced – surface cooling is expected.



The eruption clouds of five famous volcanic eruptions.



(a)
(b)
(c)
(d)
Altitude (km)
40
35
30
25
20
15
800
600
1991
4/16 4/26 4/30 5/3 5/7 5/12 5/19
7/15 7/10 7/6 7/2 6/26 6/15
60S 45S 30S 15S 0 15N 30N 45N 60N
6/24 7/7 7/12 7/16 7/20 7/26 8/1
9/23 9/20 9/17 9/14 9/10 9/3
Total Extinction Ratio
1
10



PINATUBO ERUPTION CLOUD AT GARMISCH-PARTENKIRCHEN
FRAUNHOFER-INSTITUT FÜR ATMOSPHÄRISCHE UMWELTFORSCHUNG
532 nm Backscatter Lidar
Scattering Ratio
Above 6.00
4.00 - 6.00
3.00 - 4.00
2.00 - 3.00
1.50 - 2.00
1.20 - 1.50
1.08 - 1.20
1.04 - 1.08
Below 1.04
HEIGHT, km
35
30
25
20
15
10
1991
1992
1993
1994
PINATUBO

Heterogeneous Reactions on Sulfuric Acid Aerosols

(γ1) $N_2O_5(g) + H_20(aerosol) \rightarrow 2\ HNO_3$

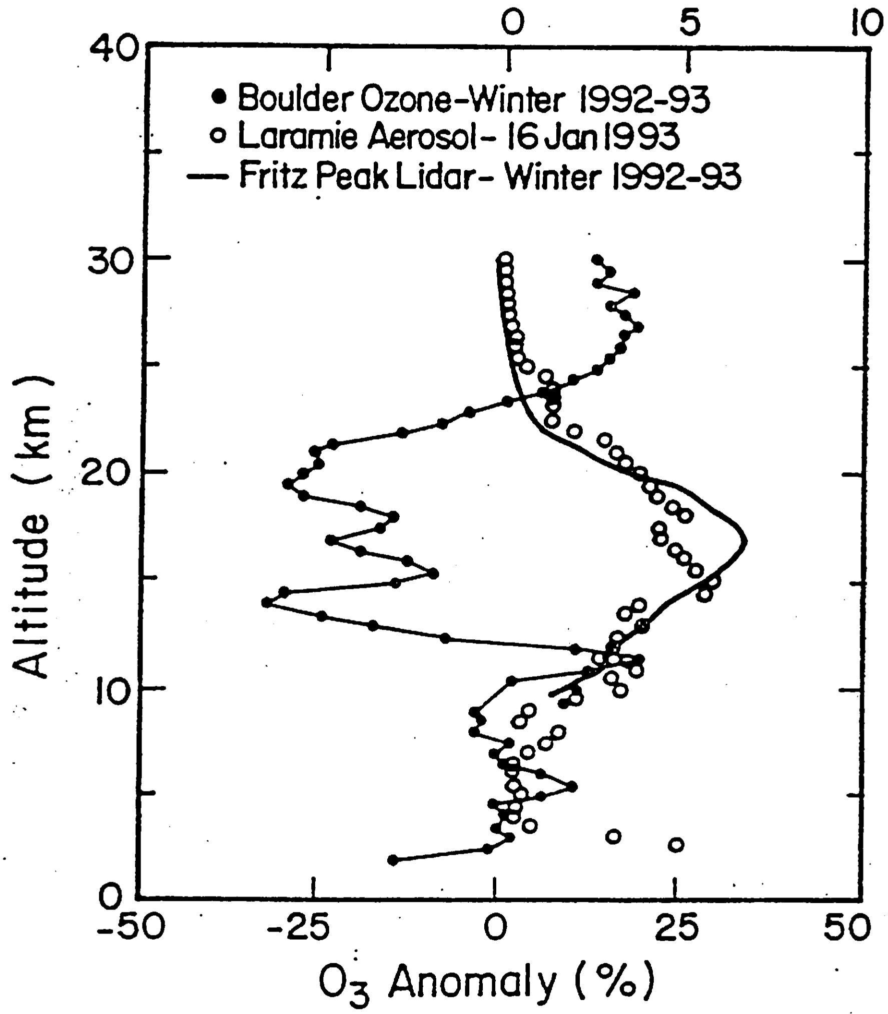
(γ2) $ClONO_2(g) + H_2O(aerosol) \rightarrow HNO_3 + HOCl$

Reaction rate (s^{-1})

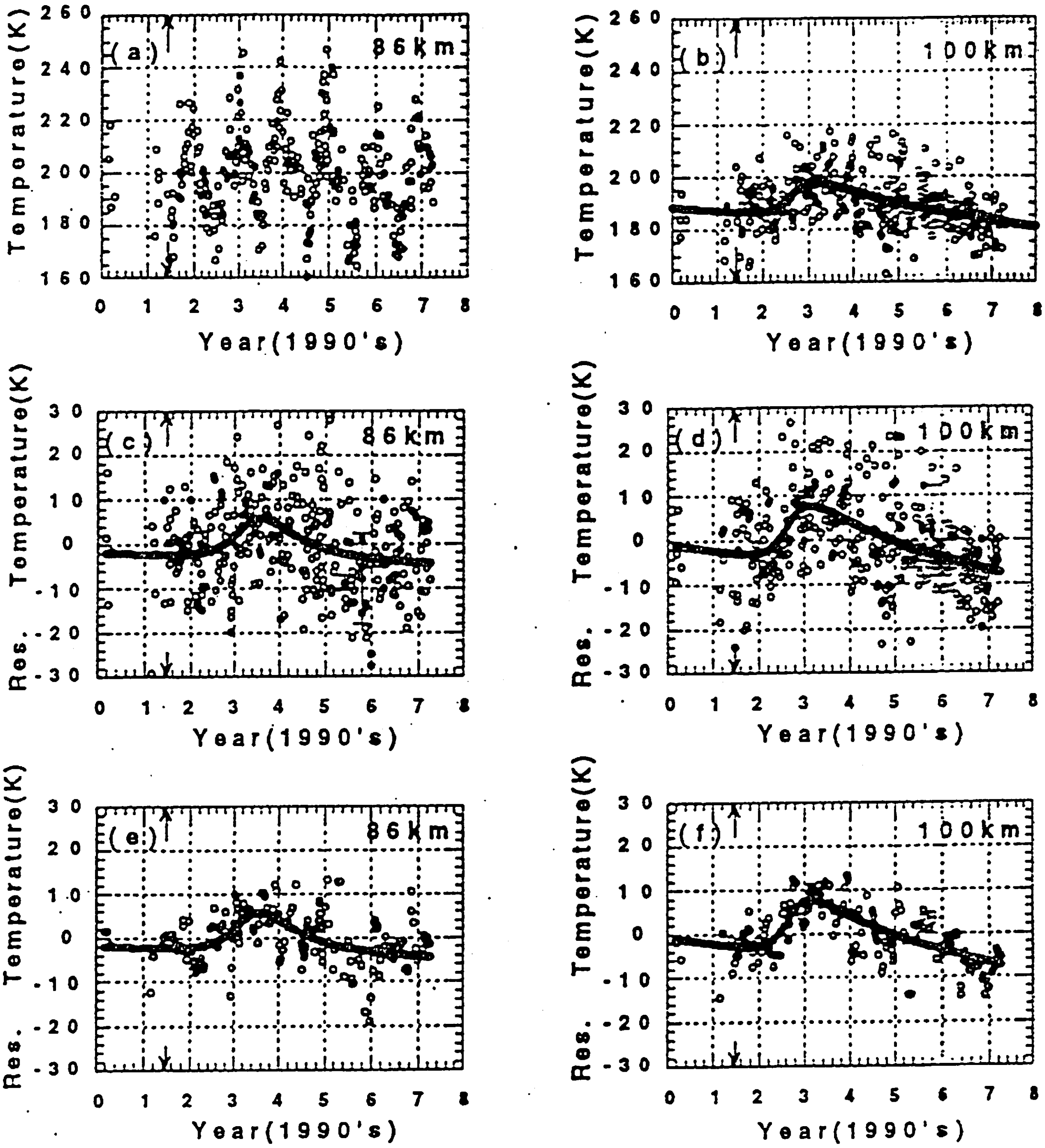
$$k = \gamma \frac{\mathbf{vA}}{4}$$

with

$$\mathbf{v} = \left[\frac{8kT}{\Pi m}\right]^{1/2}$$



0
5
10
40
30
20
10
0
Boulder Ozone-Winter 1992-93
Laramie Aerosol- 16 Jan 1993
Fritz Peak Lidar- Winter 1992-93
Altitude (km)
-50
-25
0
25
50
O_3 Anomaly (%)


(a)
86km
Temperature(K)
Year(1990's)
(b)
100km
Temperature(K)
Year(1990's)
(c)
86km
Res. Temperature(K)
Year(1990's)
(d)
100km
Res. Temperature(K)
Year(1990's)
(e)
86km
Res. Temperature(K)
Year(1990's)
(f)
100km
Res. Temperature(K)
Year(1990's)

OZONE AND SOLAR VARIABILITY

Ozone Production

$$O_2 + h\upsilon \rightarrow O + O \; (\lambda \simeq 200 \text{ nm})$$

$$O + O_2 + M \rightarrow O_3 + M$$

Ozone Destruction

$$O_3 + h\upsilon \rightarrow O + O_2 \; (\lambda \simeq 300 \text{ nm})$$

$$O + O_3 \rightarrow 2\, O_2$$

Or

$$O + OH \rightarrow O_2 + H$$

$$O + HO_2 \rightarrow O_2 + OH$$

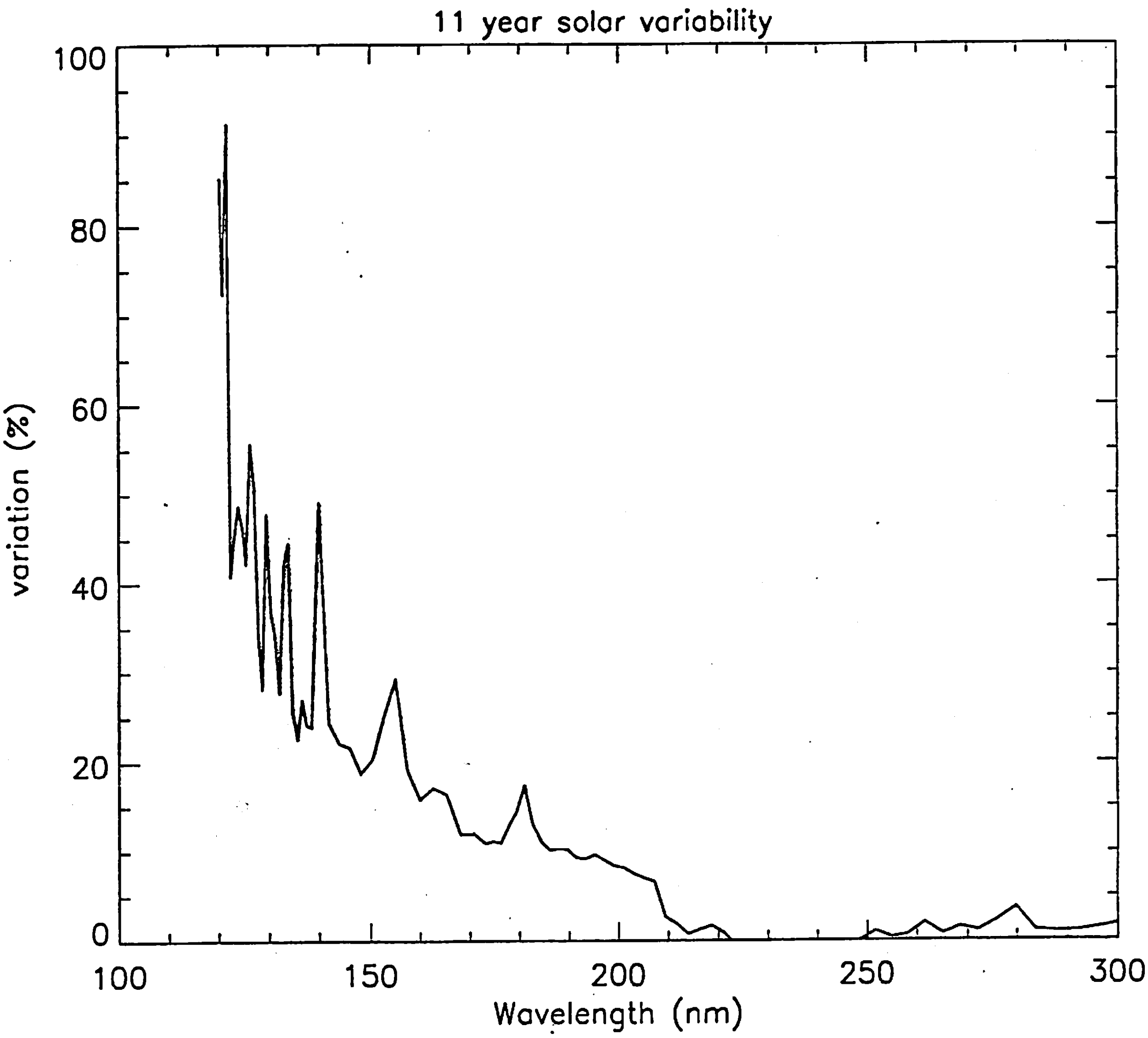
<u>Below 80 km</u>

Dominant effect is on O_3 <u>production</u> by O_2 photolysis. Positive response of ozone to increased solar UV flux.

<u>Above 80 km</u>

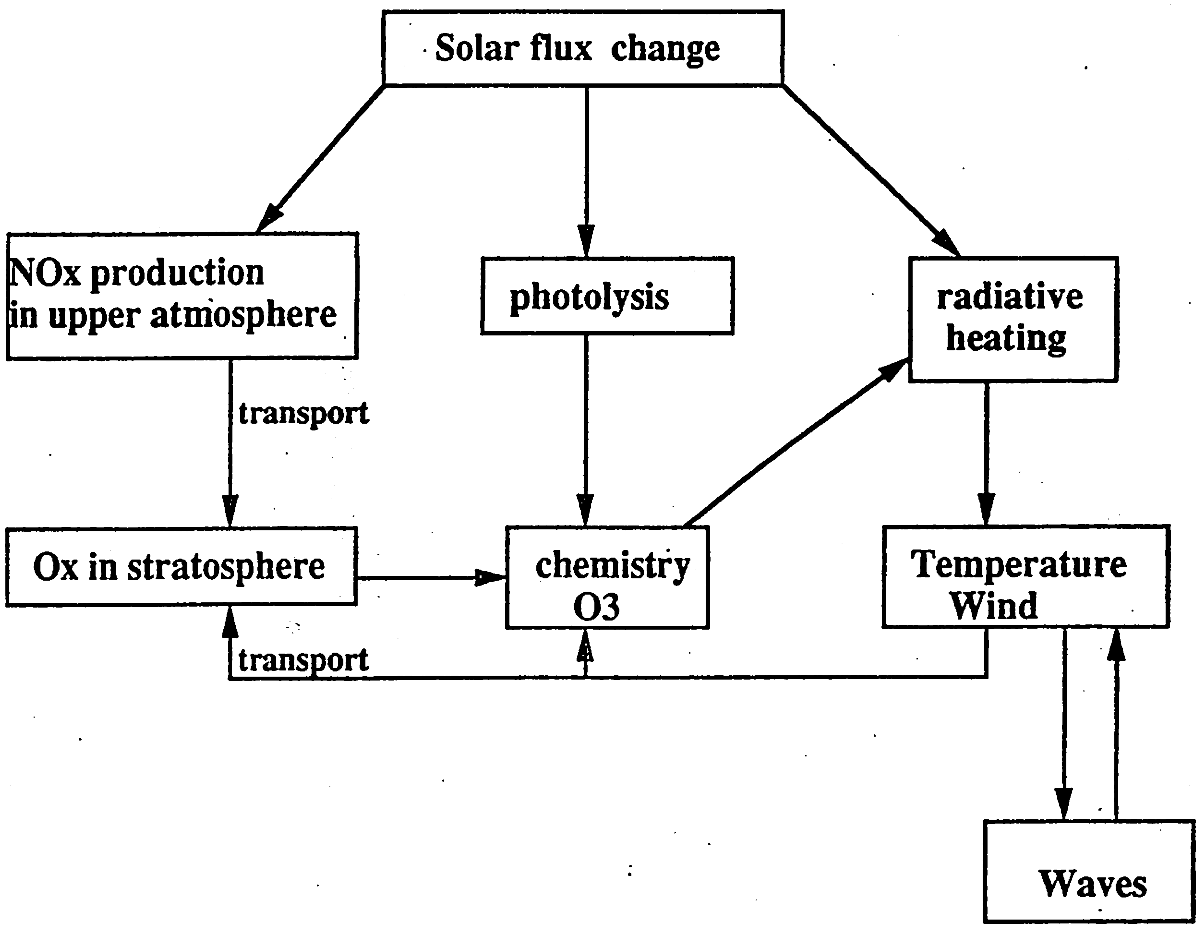
Dominant effect is on O_3 <u>destruction</u> associated with HO_x production by H_2O photolysis at Lyman-α. <u>Negative</u> response of ozone to increased solar UV flux.

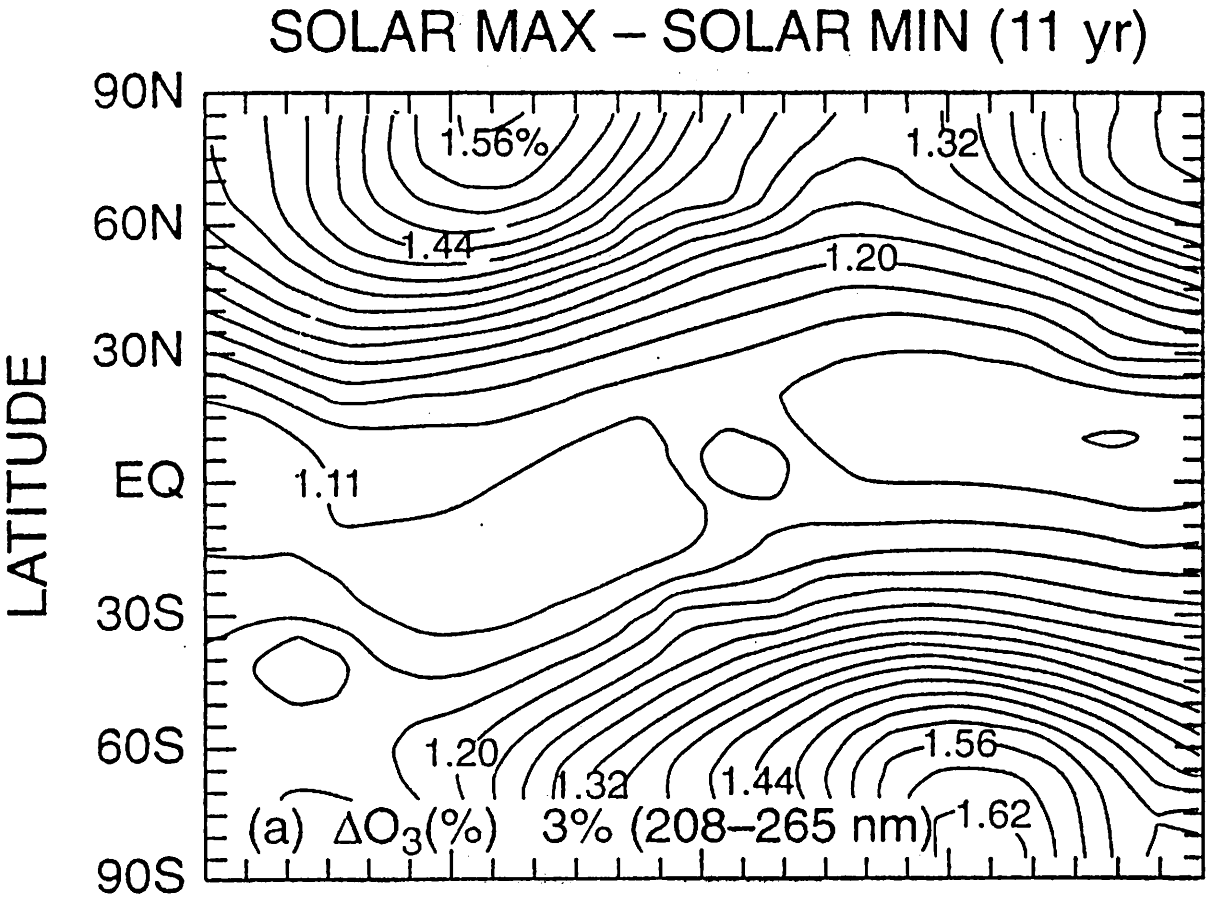
x



11 year solar variability
100
80
60
40
20
0
variation (%)
100
150
200
250
300
Wavelength (nm)

Effect of solar flux variation on the middle atmosphere




SOLAR MAX – SOLAR MIN (11 yr)
90N
60N
30N
EQ
30S
60S
90S
LATITUDE
1.56%
1.44
1.32
1.20
1.11
1.20
1.32
1.44
1.56
1.62
(a) ΔO3(%) 3% (208–265 nm)

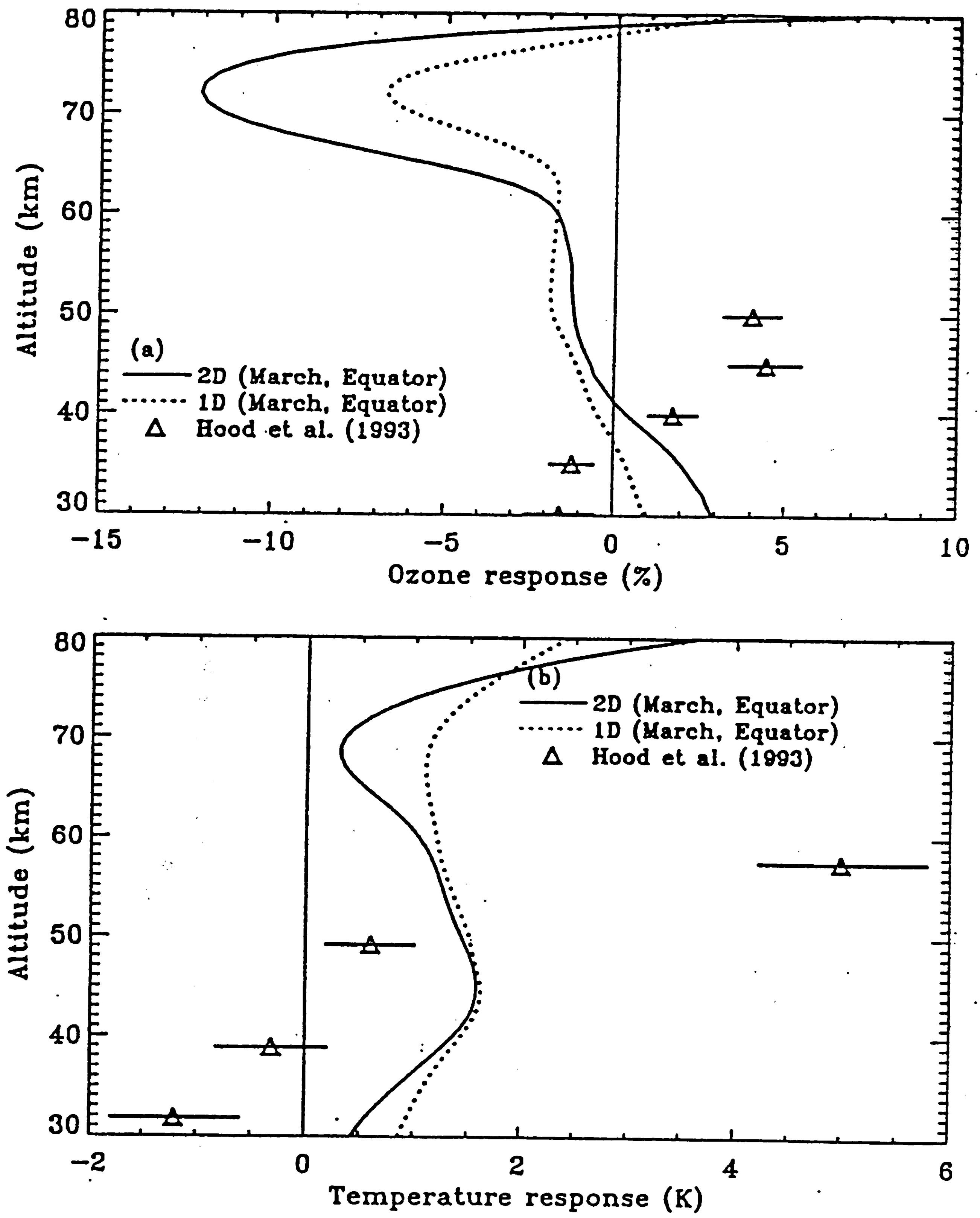
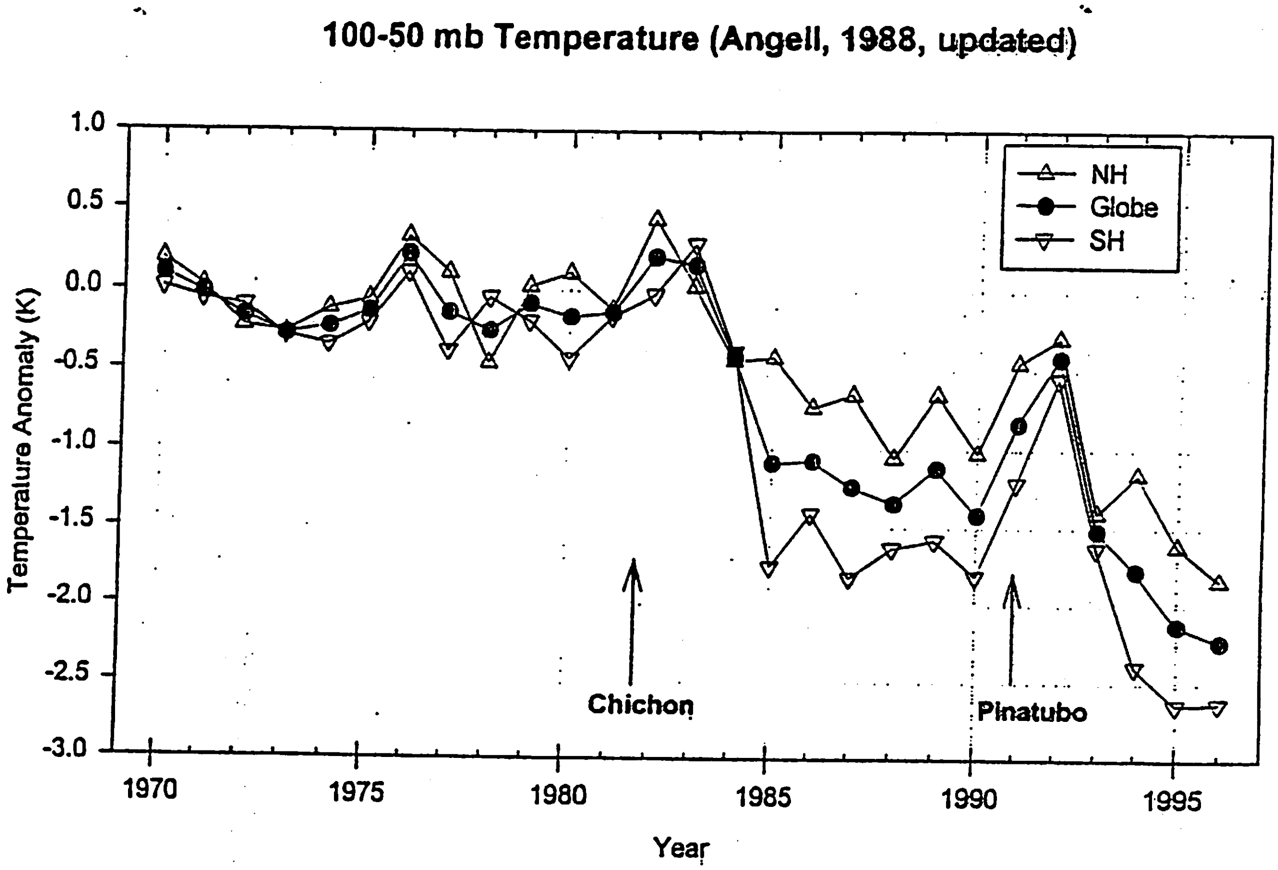


Figure 4-6 (a) Comparison of the ozone response calculated at the equator by the 2D model in March (solid) and by the 1D model (dotted) with the observed results (Δ) analyzed by Hood et al. (1993) from the Nimbus 7 SBUV observations. (b) The same as (a) except the comparison of the temperature response and the observed results are from NMC temperature data.

5. Changes in Middle Atmosphere Temperature

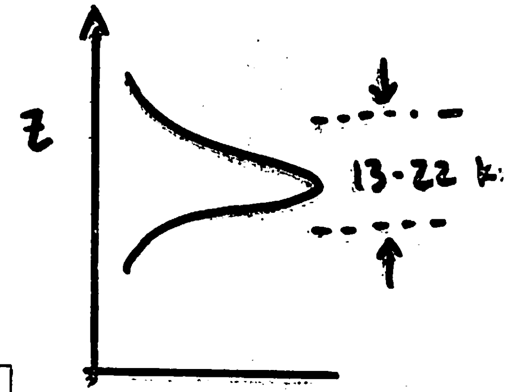
Enhanced levels of CO_2 and other greenhouse gases lead to increased infra-red emissions to space and hence to stratospheric and mesospheric cooling.

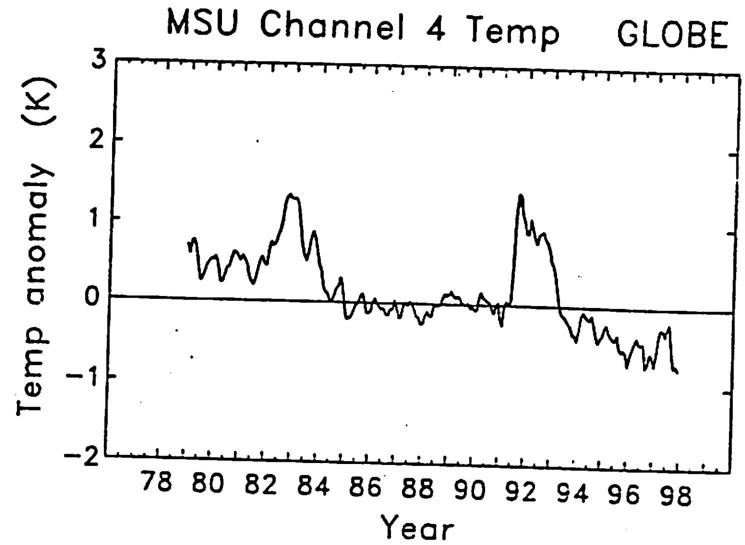
lower stratospheric temperature

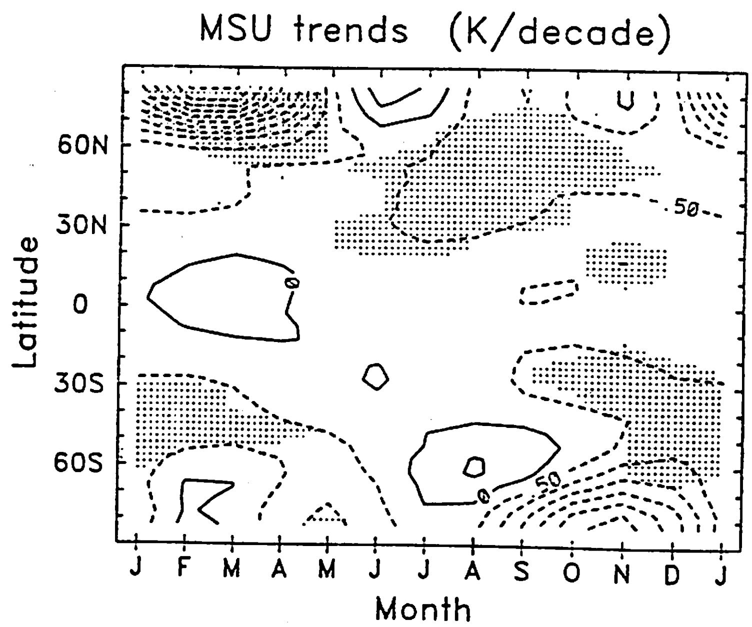


* radiosonde (balloon) measurements

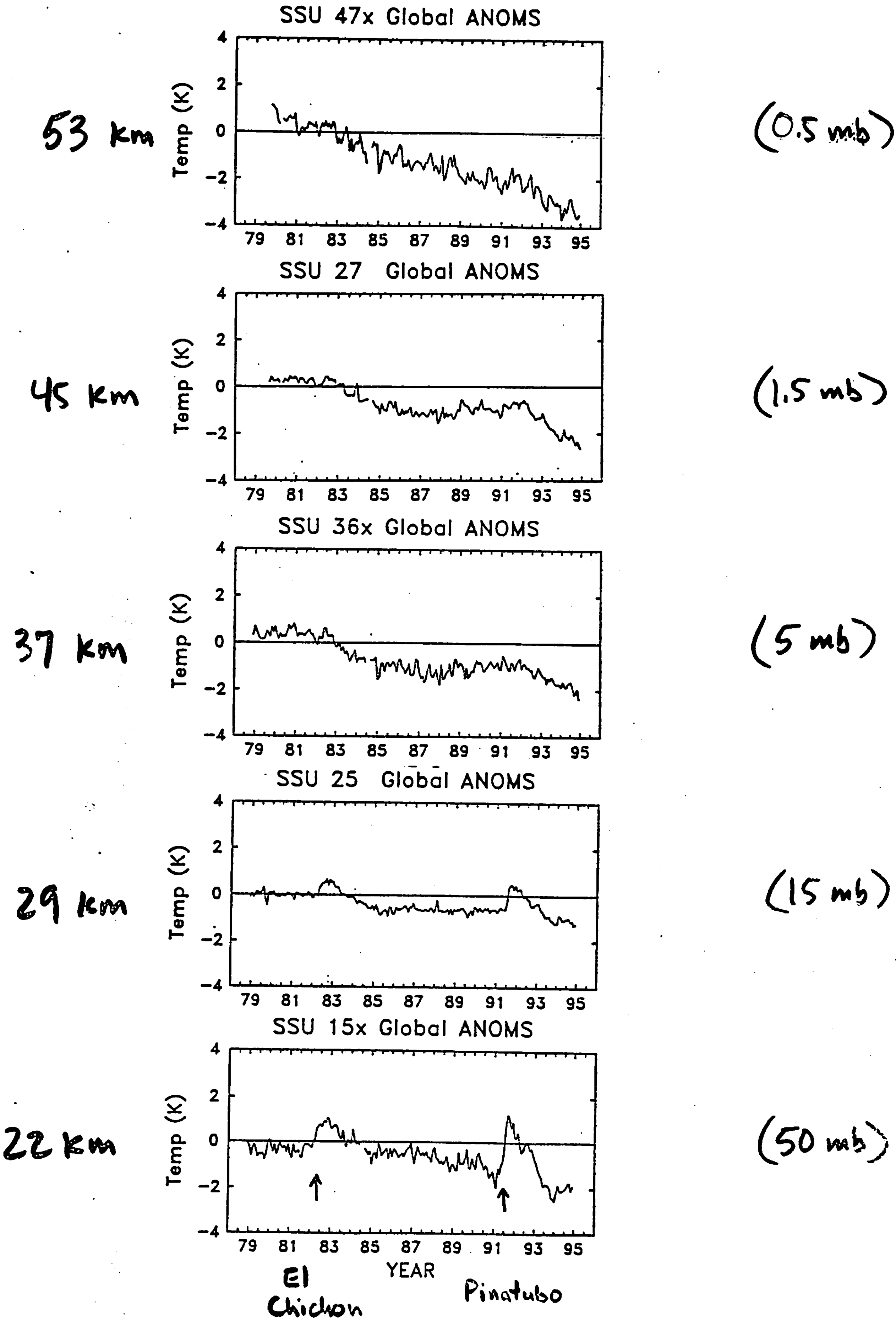
lower stratospheric satellite data

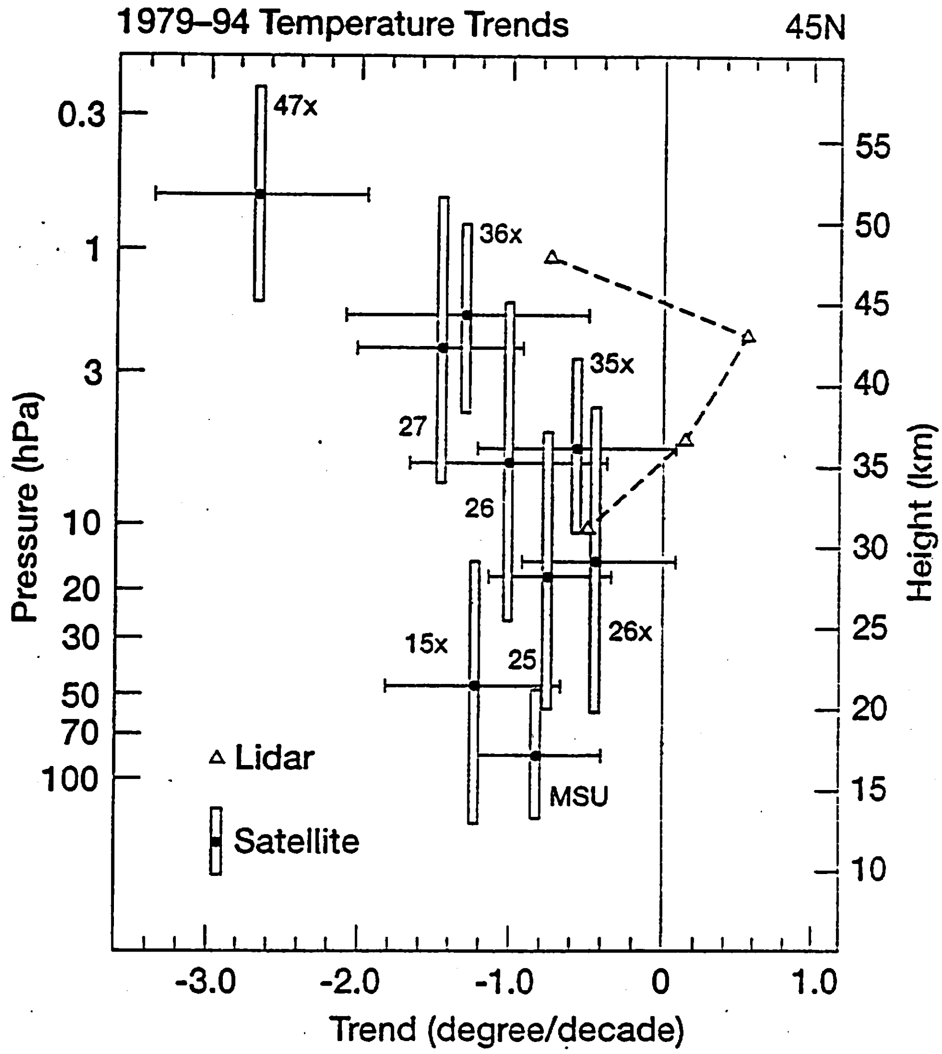


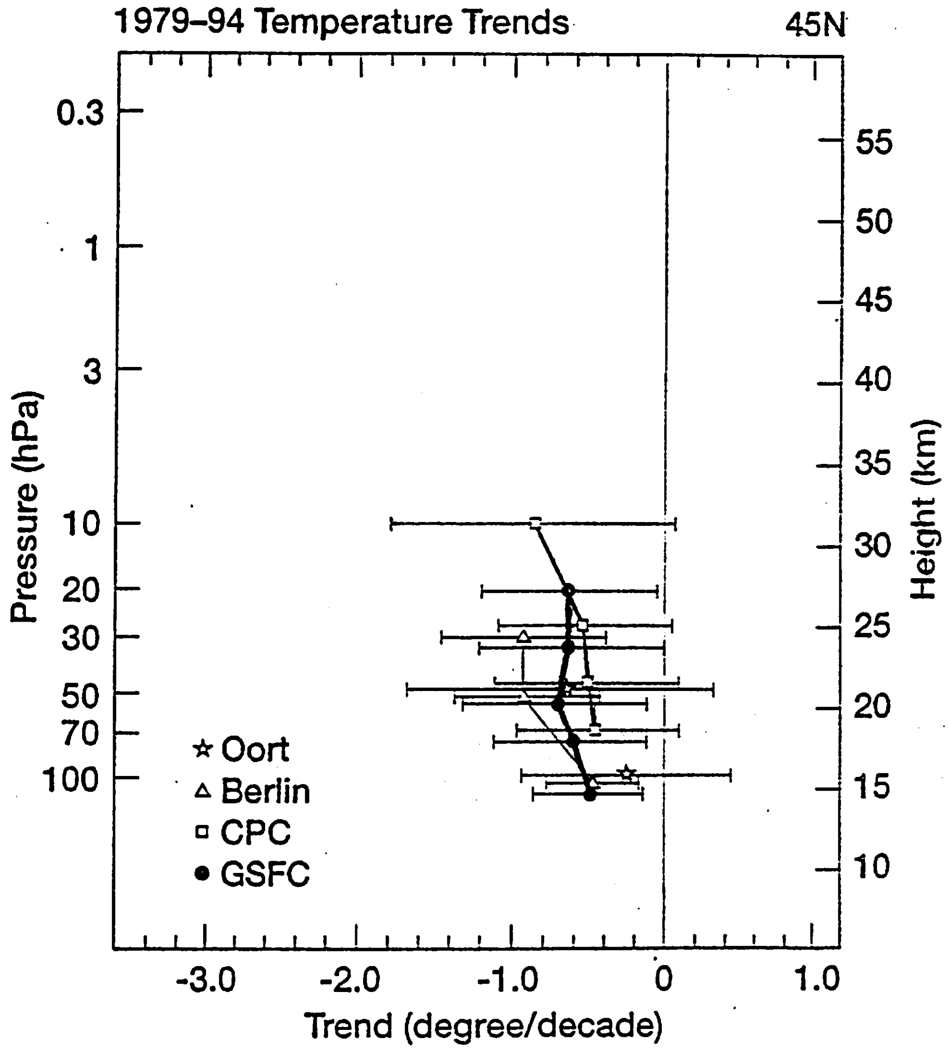




satellite temperature anomalies:

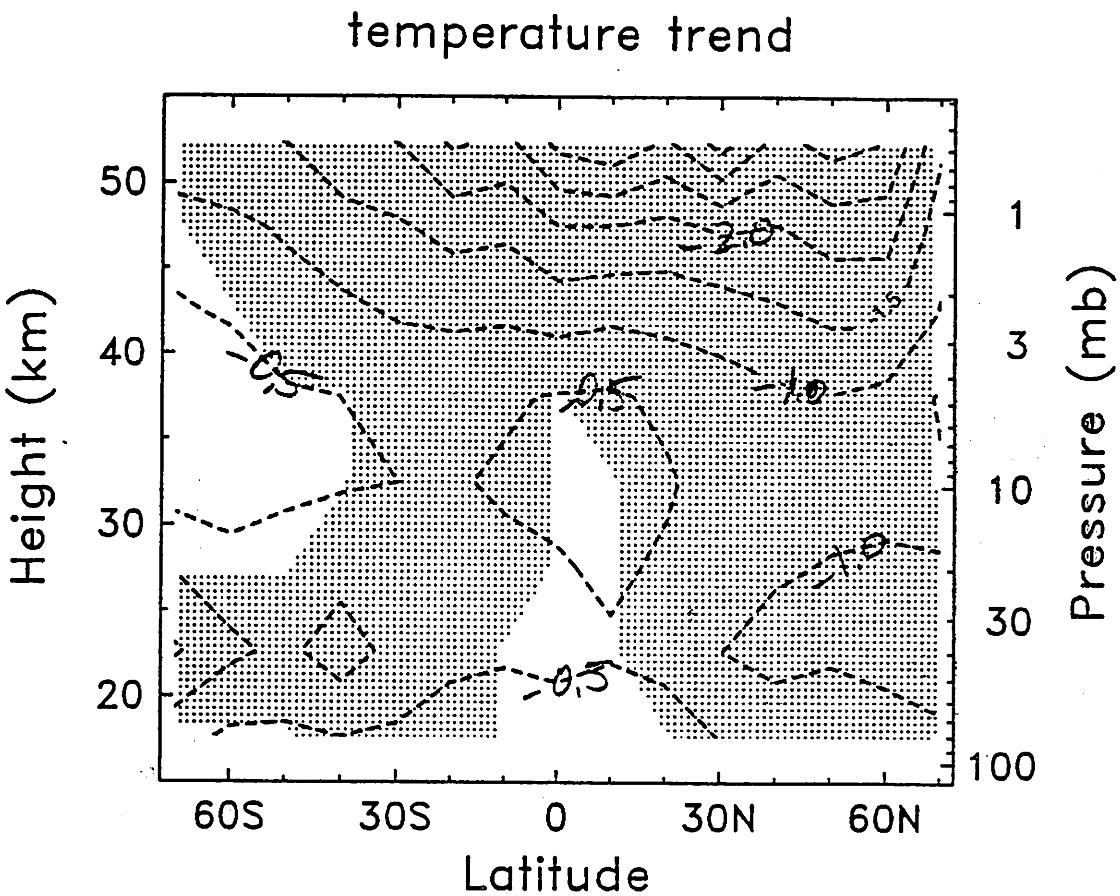


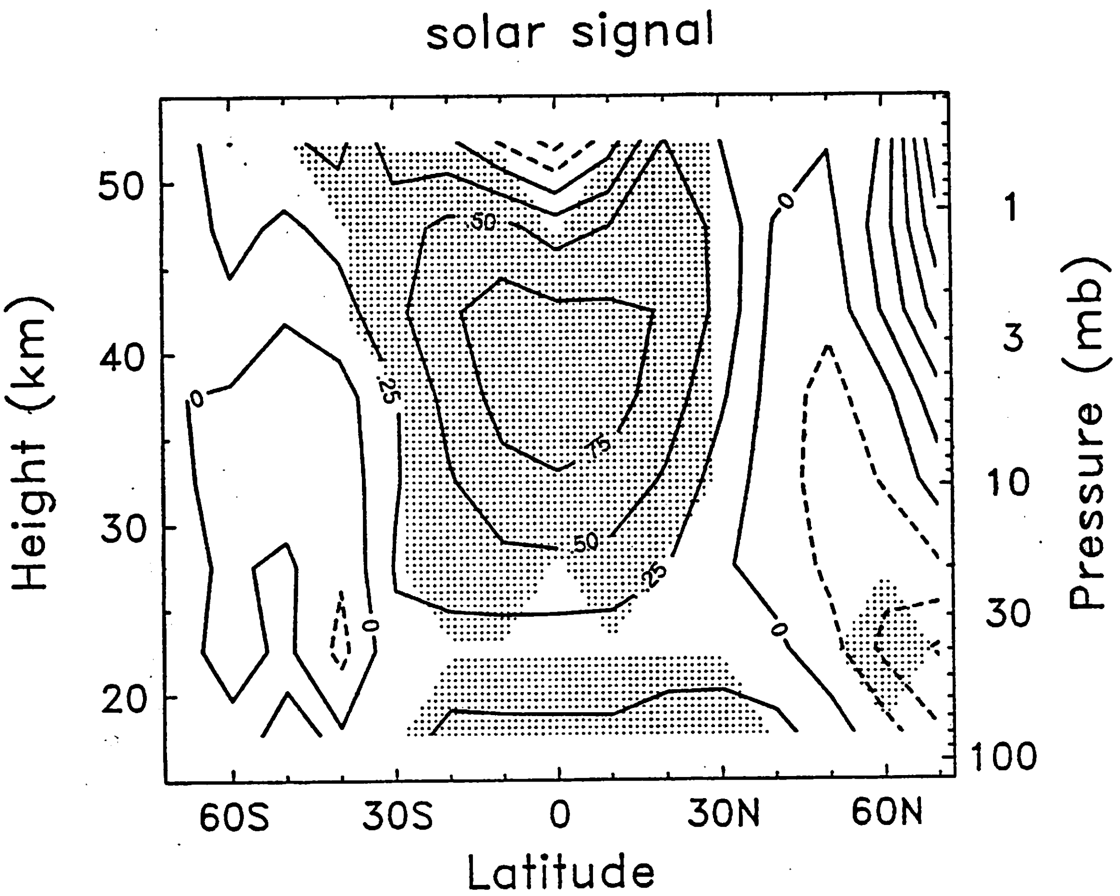

1979–94 Temperature Trends
45N
47x
36x
35x
27
26
26x
15x
25
MSU
Lidar
Satellite
Pressure (hPa)
0.3
1
3
10
20
30
50
70
100
Height (km)
55
50
45
40
35
30
25
20
15
10
-3.0
-2.0
-1.0
0
1.0
Trend (degree/decade)

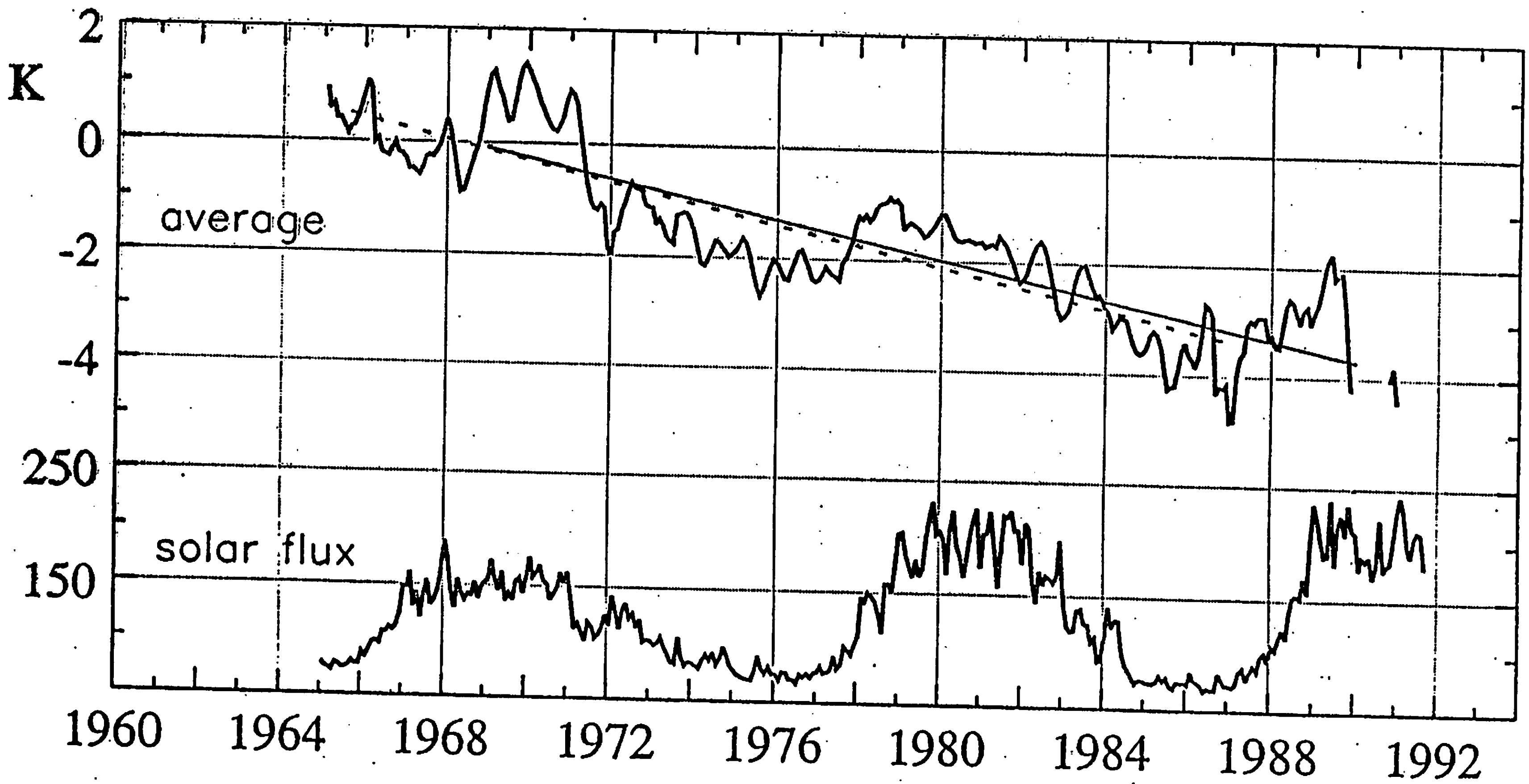


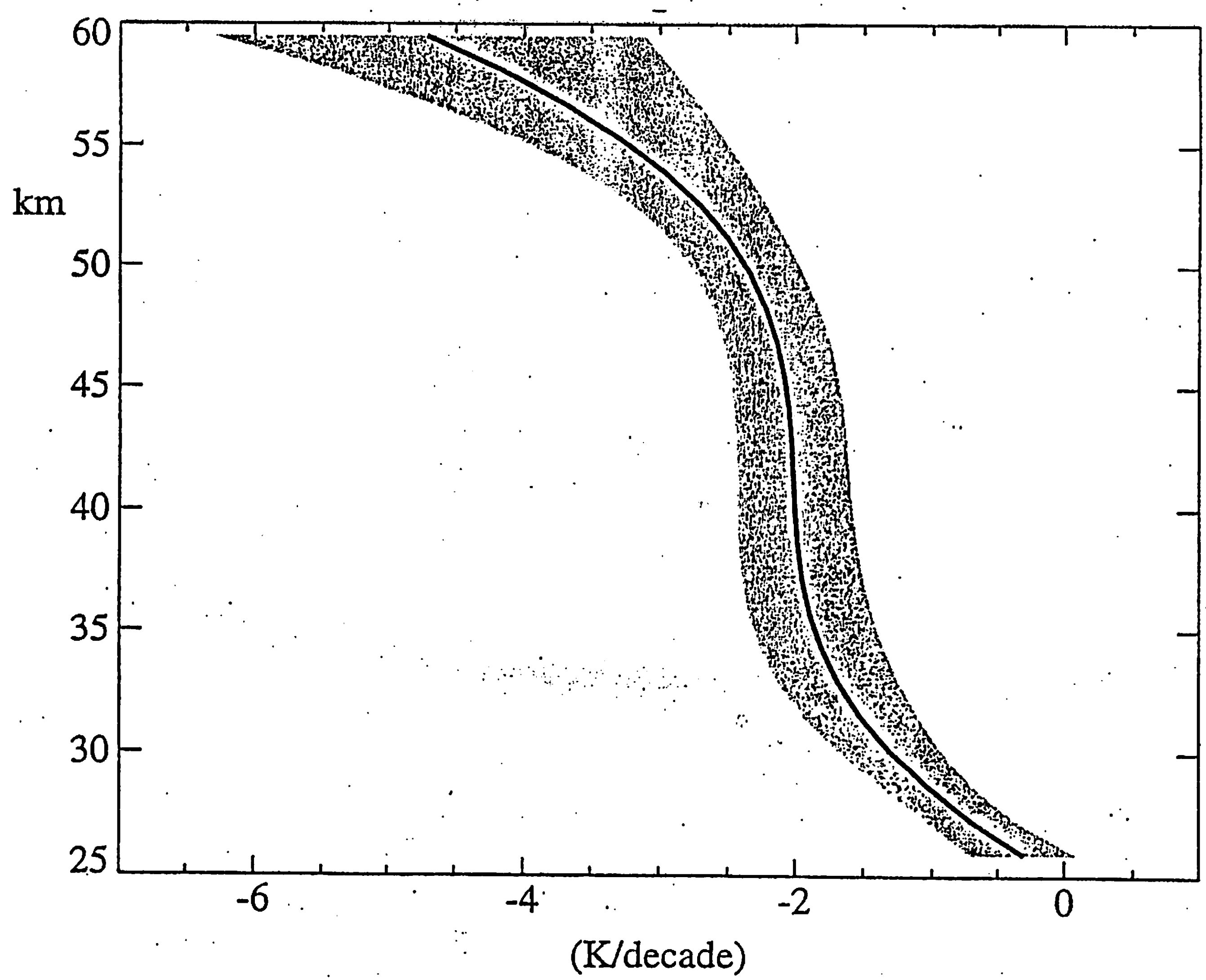
1979–94 Temperature Trends
45N
0.3
1
3
10
20
30
50
70
100
Pressure (hPa)
55
50
45
40
35
30
25
20
15
10
Height (km)
☆ Oort
△ Berlin
□ CPC
● GSFC
-3.0
-2.0
-1.0
0
1.0
Trend (degree/decade)

x

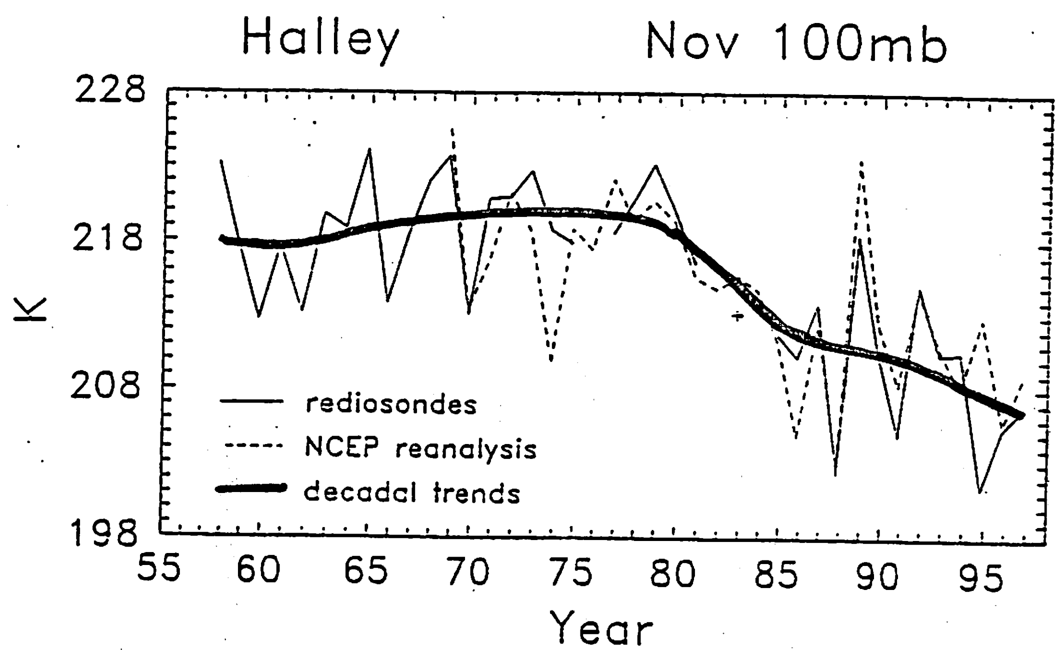

temperature trend
Height (km)
Pressure (mb)
Latitude
60S
30S
0
30N
60N
20
30
40
50
1
3
10
30
100
-2.0
-1.0
-0.5
-0.5
-1.0
-0.5


solar signal
Height (km)
50
40
30
20
Pressure (mb)
1
3
10
30
100
60S
30S
0
30N
60N
Latitude
0
25
50
75

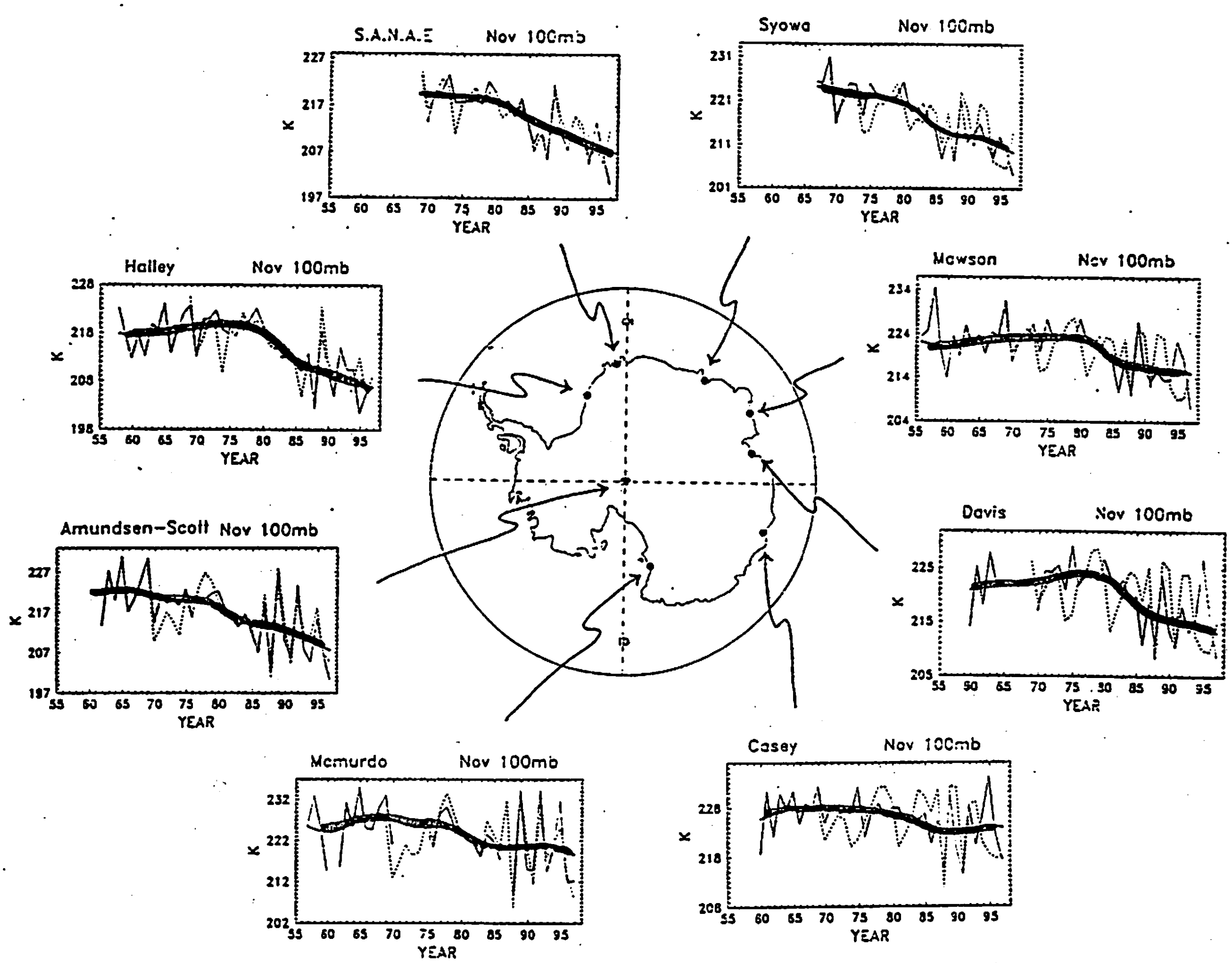

2
K
0
average
-2
-4
250
solar flux
150
1960
1964
1968
1972
1976
1980
1984
1988
1992

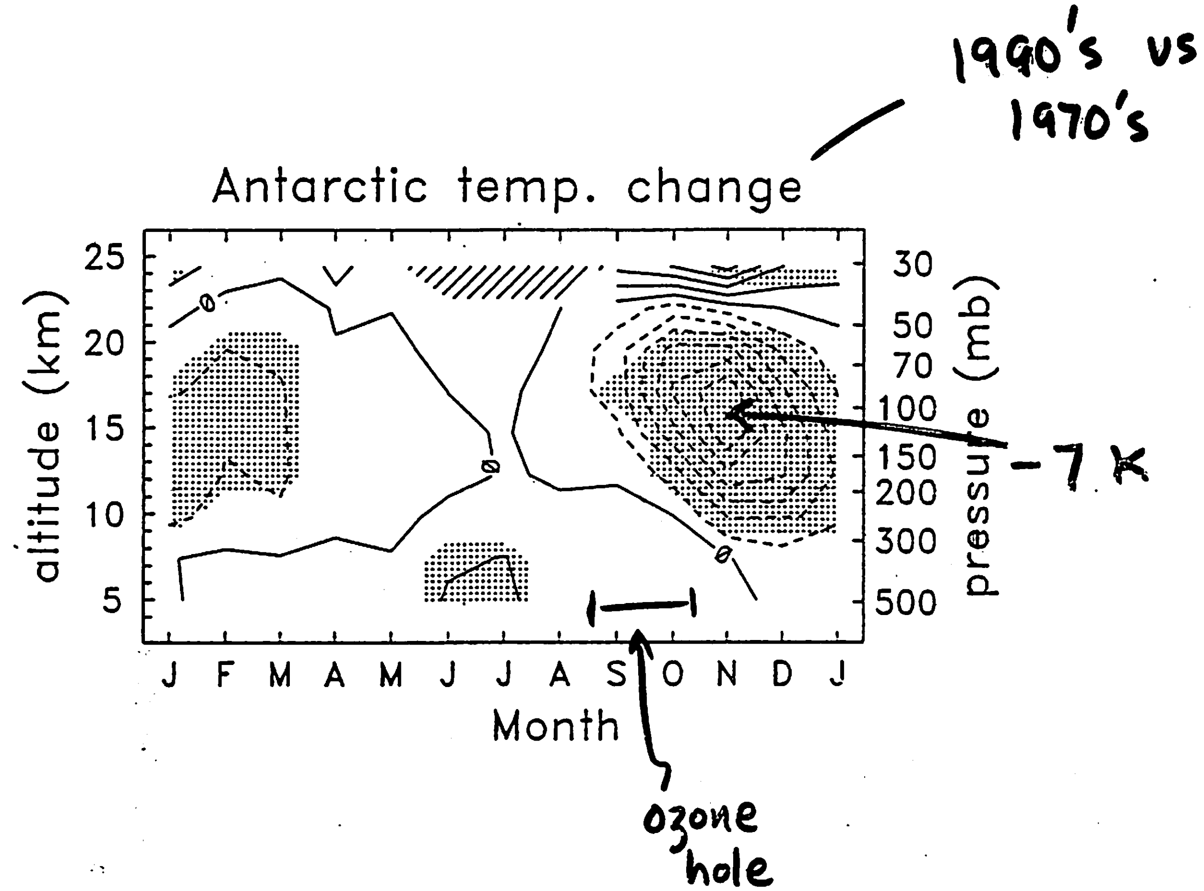

60
55
km
50
45
40
35
30
25
-6
-4
-2
0
(K/decade)

Antarctic temp. trends



Antarctic November temps. at 100 mb (~15 km)





1990's vs. 1970's
Antarctic temp. change
altitude (km)
25
20
15
10
5
pressure (mb)
30
50
70
100
150
200
300
500
-7 K
J F M A M J J A S O N D J
Month
ozone hole

NH polar stratosphere cooling

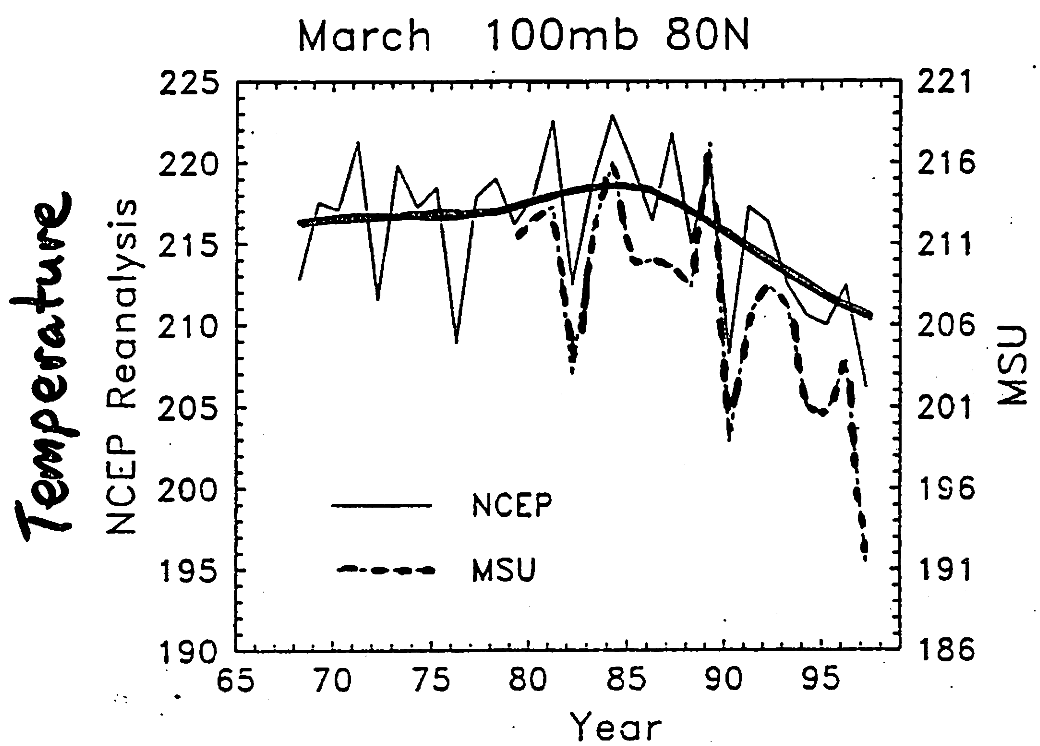


Figure 12. Time series of March 100 mb zonal mean temperatures at 80°N from NCEP reanalysis (1968-97) and MSU data (1979-97).

CONCLUSIONS

1. Human activities (fossil fuel consumption, biomass burning, land-use changes) have produced very substantial changes in the chemical composition of the troposphere, stratosphere, and mesosphere on the global scale.

2. These anthropogenic changes need to be compared with natural variations such as those produced by the 11-year solar cycle.

3. Several observed trends in trace gas concentrations are not yet well explained.

4. The mesosphere is probably most affected by global change forcing.

5. The analysis of atmospheric changes requires a global approach: Vertical propagation of atmospheric responses to natural and anthropogenic forcing (e.g., solar effects and human activities) is not well understood.