CEDAR MEETING, 21–26 June 92, Boulder CO

EFFECTS OF SOLAR VARIABILITY ON GLOBAL CHANGE

Judith Lean
Naval Research Laboratory

- ***Global Change Research***
- ***Solar Forcing of Climate***
- ***Solar Variability and Ozone***
- ***Solar Effects on the Upper Atmosphere***

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List of Viewgraphs

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THE U.S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP) AT-A-GLANCE

(from Our Changing Planet: The FY 1990 Research Plan, The U.S. Global Change Research Program, A Report by the Committee on Earth Sciences, July 1989)

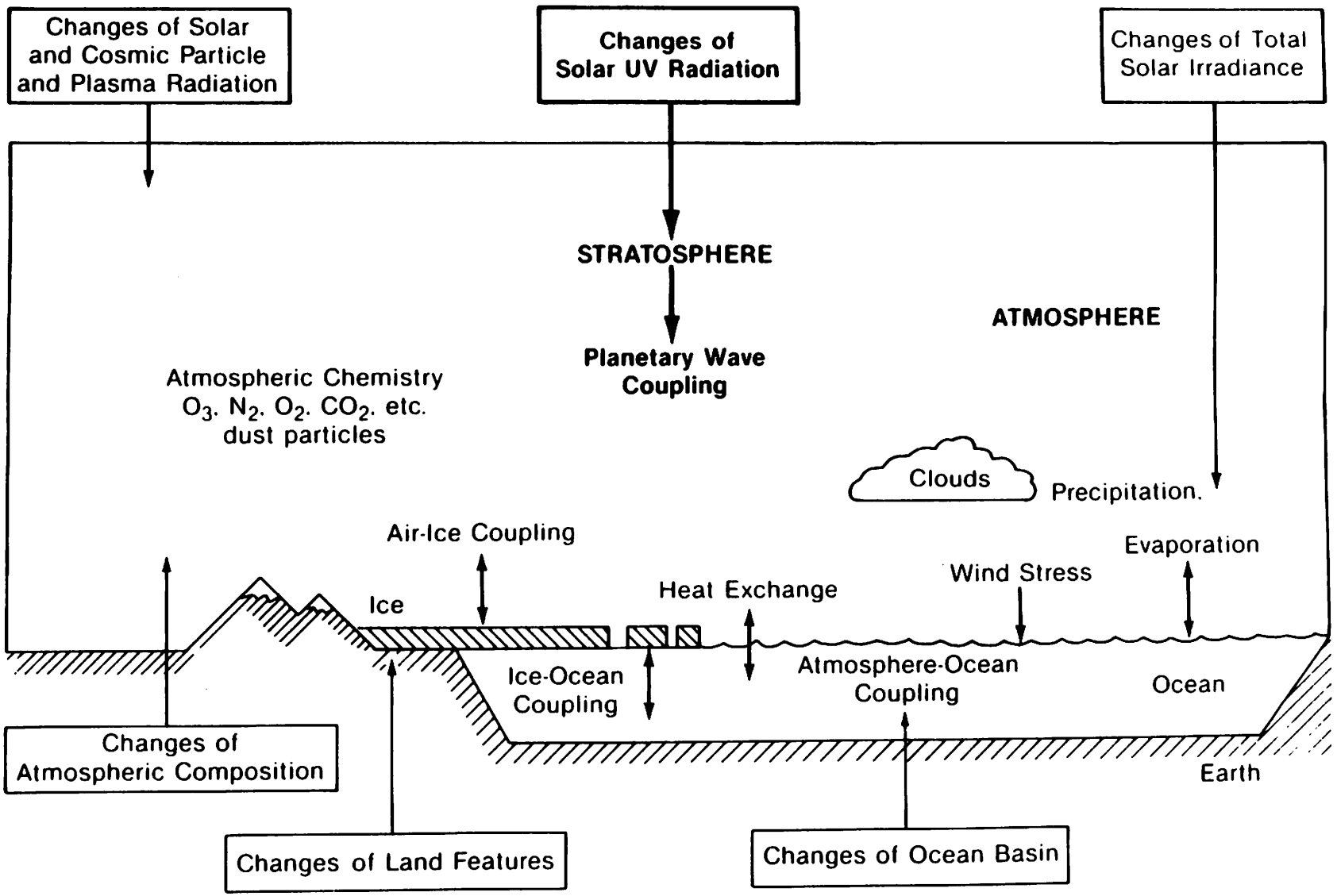
* ***Many global changes can have tremendous impact on the welfare of humans. These events may stem from natural processes that began millions of years ago or from human influence.***

* ***The goal of the USGCRP is to provide a sound scientific basis for national and international decision making on global change issues.***

* ***The scientific objectives of the USGCRP are to monitor, understand and ultimately predict global change.***

* ***The USGCRP is broad in scope, encompassing the full range of earth system changes, including physical, chemical, geological, social and biological changes. It addresses both natural phenomena, as well as the effects of human activity.***

* ***The particular research activities which comprise the USGCRP are grouped into seven interdisciplinary scientific elements:***
    1. ***Climate and Hydrologic Systems***
    2. ***Biogeochemical Dynamics***
    3. ***Ecological Systems and Dynamics***
    4. ***Earth System History***
    5. ***Human Interactions***
    6. ***Solid Earth Processes***
    7. ***Solar Influences***


Changes of Solar and Cosmic Particle and Plasma Radiation
Changes of Solar UV Radiation
Changes of Total Solar Irradiance
STRATOSPHERE
ATMOSPHERE
Planetary Wave Coupling
Atmospheric Chemistry
O_3. N_2. O_2. CO_2. etc.
dust particles
Clouds
Precipitation.
Air-Ice Coupling
Evaporation
Wind Stress
Heat Exchange
Ice
Ice-Ocean Coupling
Atmosphere-Ocean Coupling
Ocean
Changes of Atmospheric Composition
Earth
Changes of Land Features
Changes of Ocean Basin

GLOBAL CHANGE FORCING AGENTS

Hansen & Lacis, Nature, 1990

Anthropogenic

- CO_2 carbon dioxide
- CH_4 methane
- N_2O nitrous oxide
- CFCs chloroflurocarbons
- aerosols sulphates from SO_2
- albedo change desertification, deforestation

Natural

- solar variability
- volcanos sulphates from SO_2

National Academy of Sciences, 1982

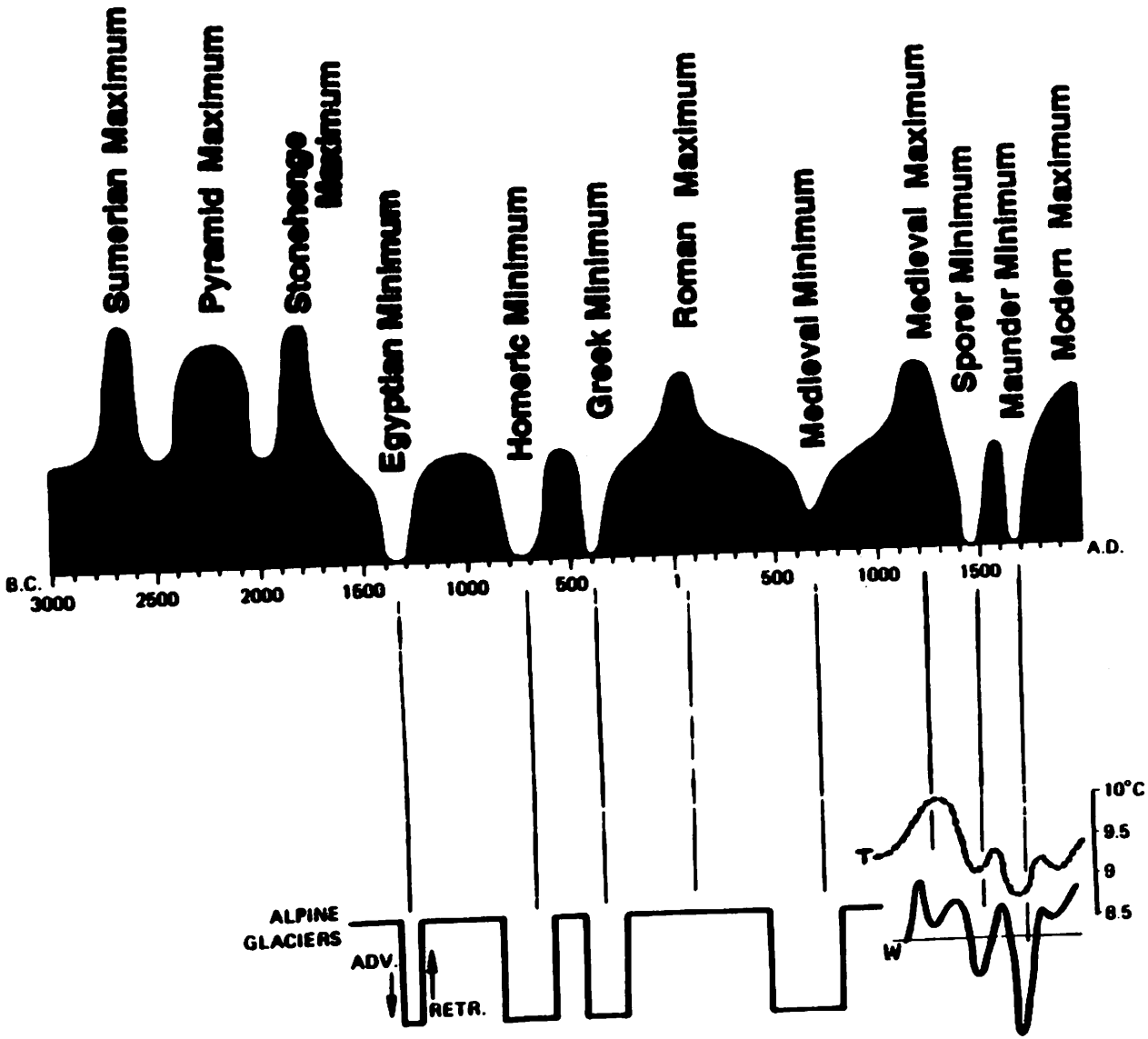
Panel on Solar Variability, Weather and Climate

J. Eddy (Chair)

...it is conceivable that solar variability plays a role in altering weather and climate at some yet unspecified level of significance ...

Historical Solar Activity

Eddy (1978)

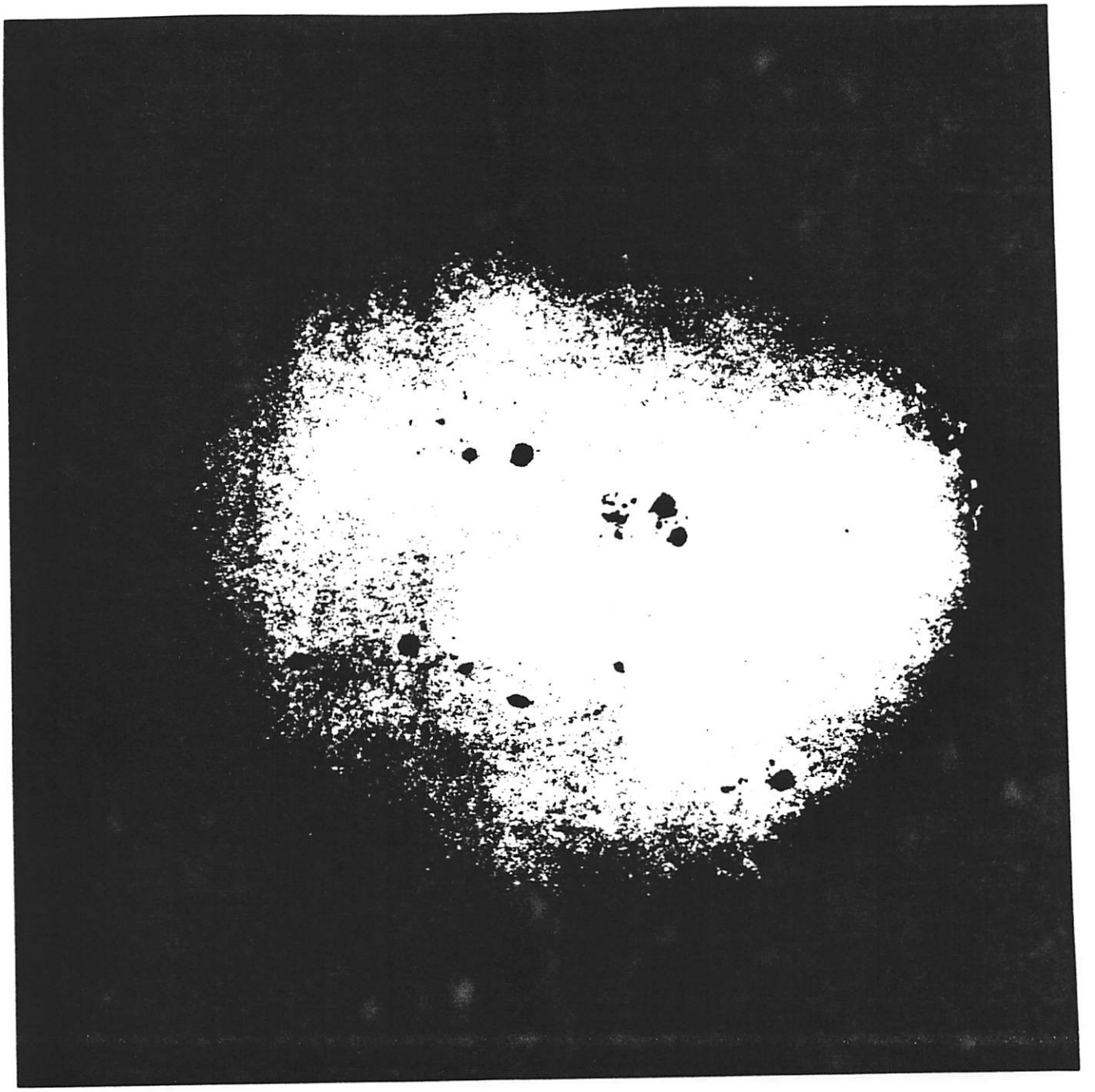


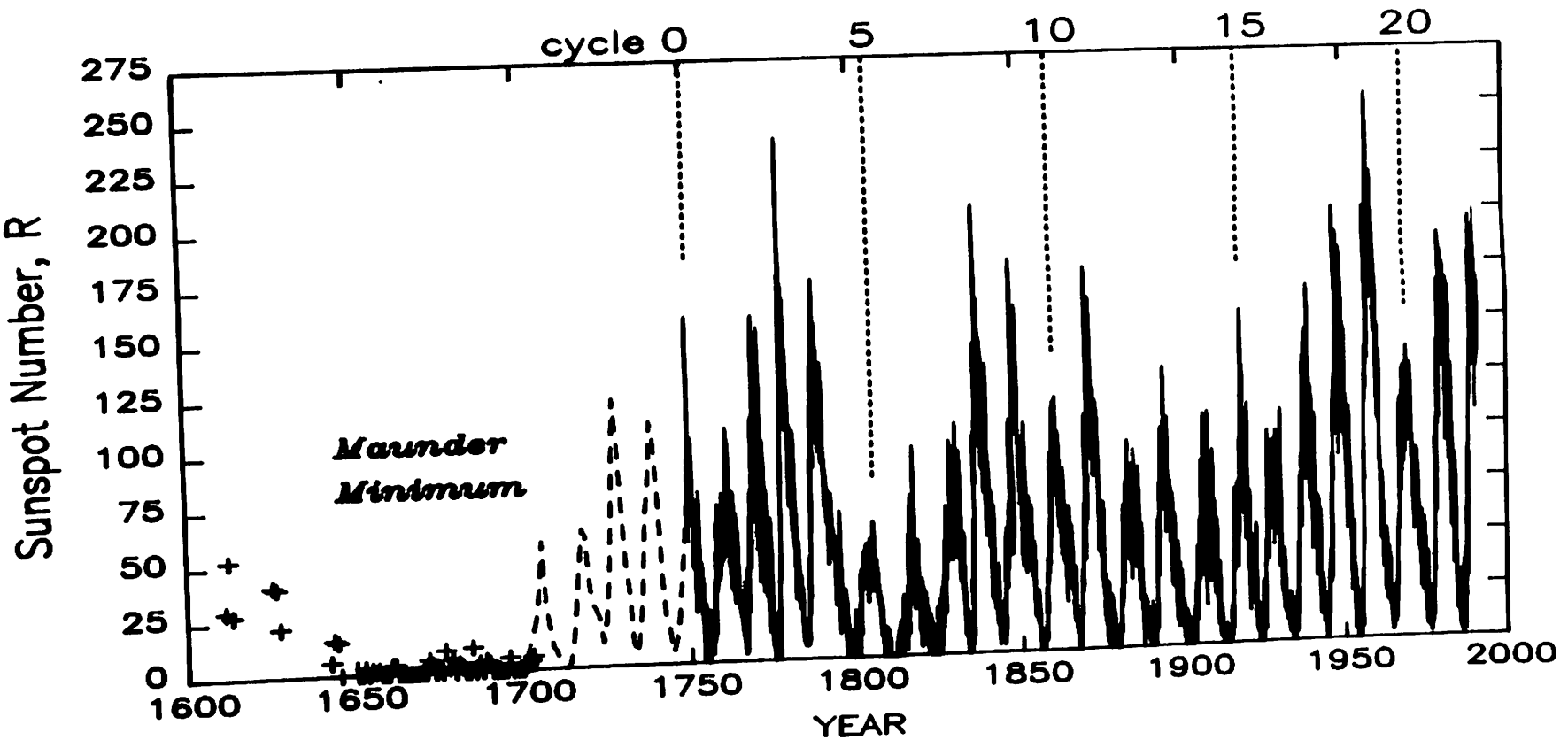
Solar Activity Envelope
from 50-yr smoothed ^{14}C record

Temperature (T)

Winter Severity Index (W)

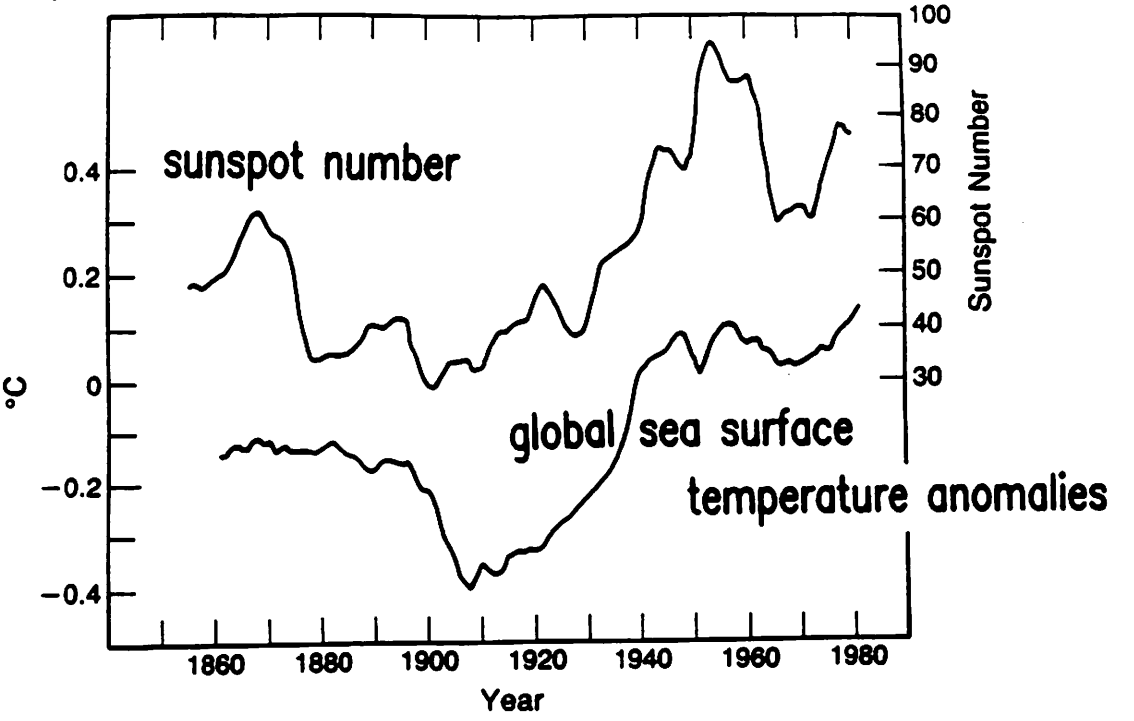
Mt. Wilson +
Palomar Obs.
near sunspot max.
July 13, 1937



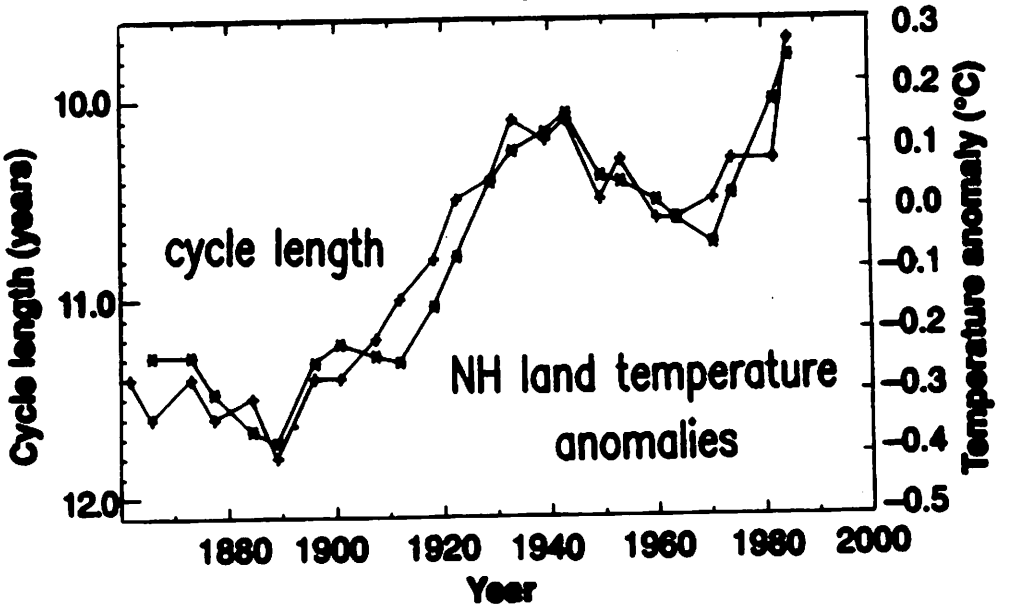

cycle 0
5
10
15
20
275
250
225
200
175
150
125
100
75
50
25
0
Sunspot Number, R
Maunder
Minimum
1600
1650
1700
1750
1800
1850
1900
1950
2000
YEAR

SOLAR VARIABILITY AND TEMPERATURE

Reid, JGR, 1991

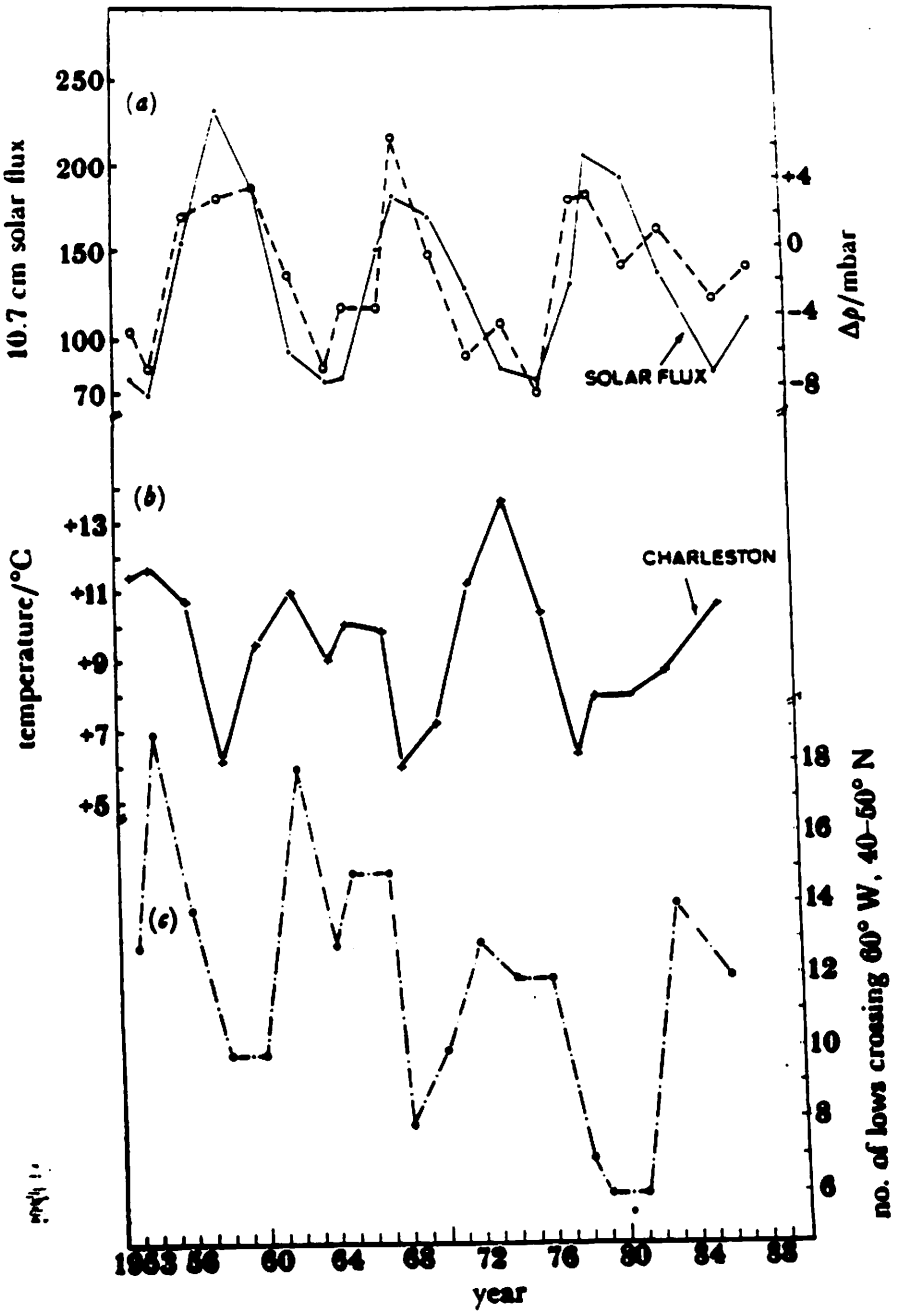


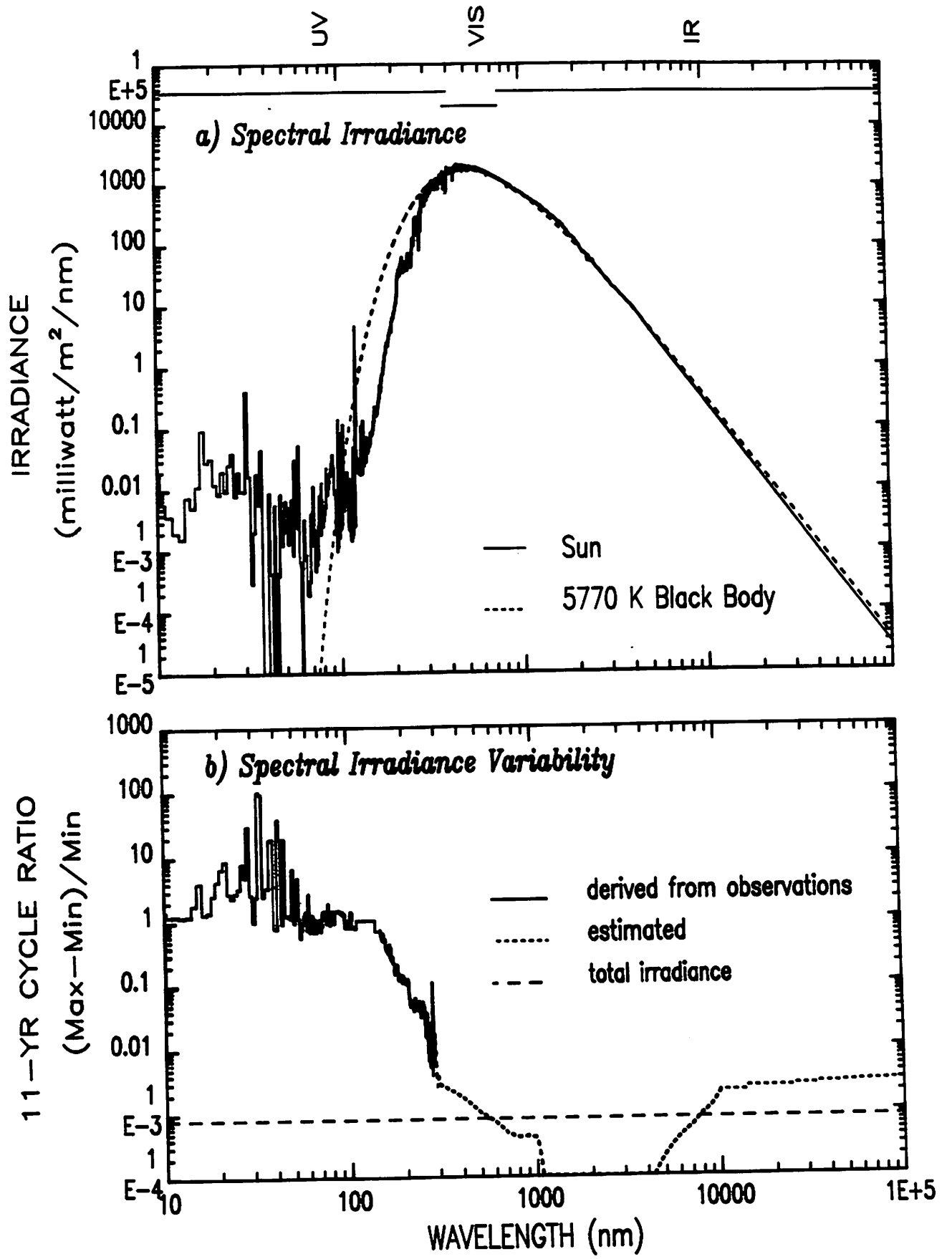
Friis-Christensen & Lassen, Science, 1991

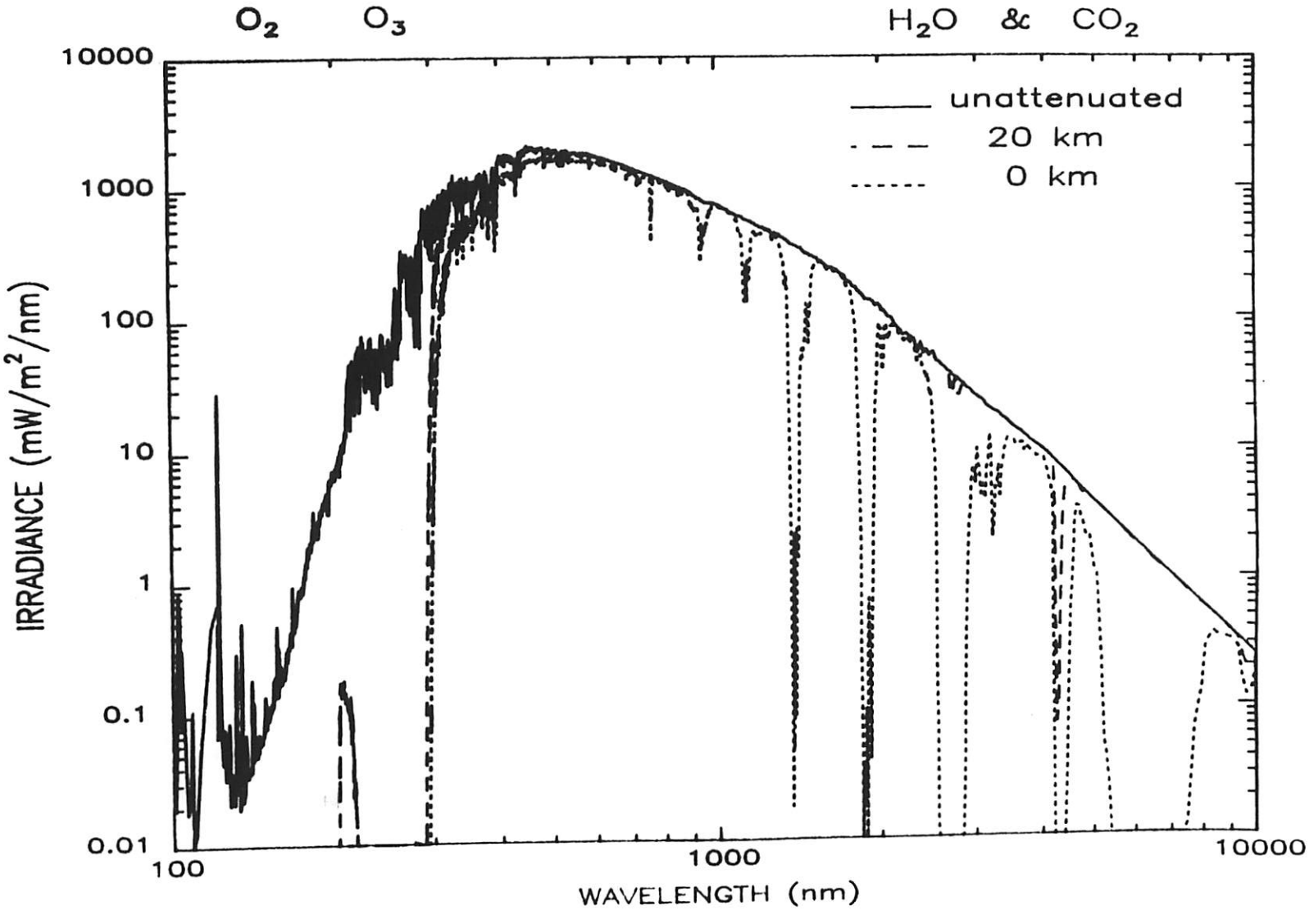


Solar Variability, the Quasi Biennial Oscillation and the Weather

Labitzke and van Loon, 1990

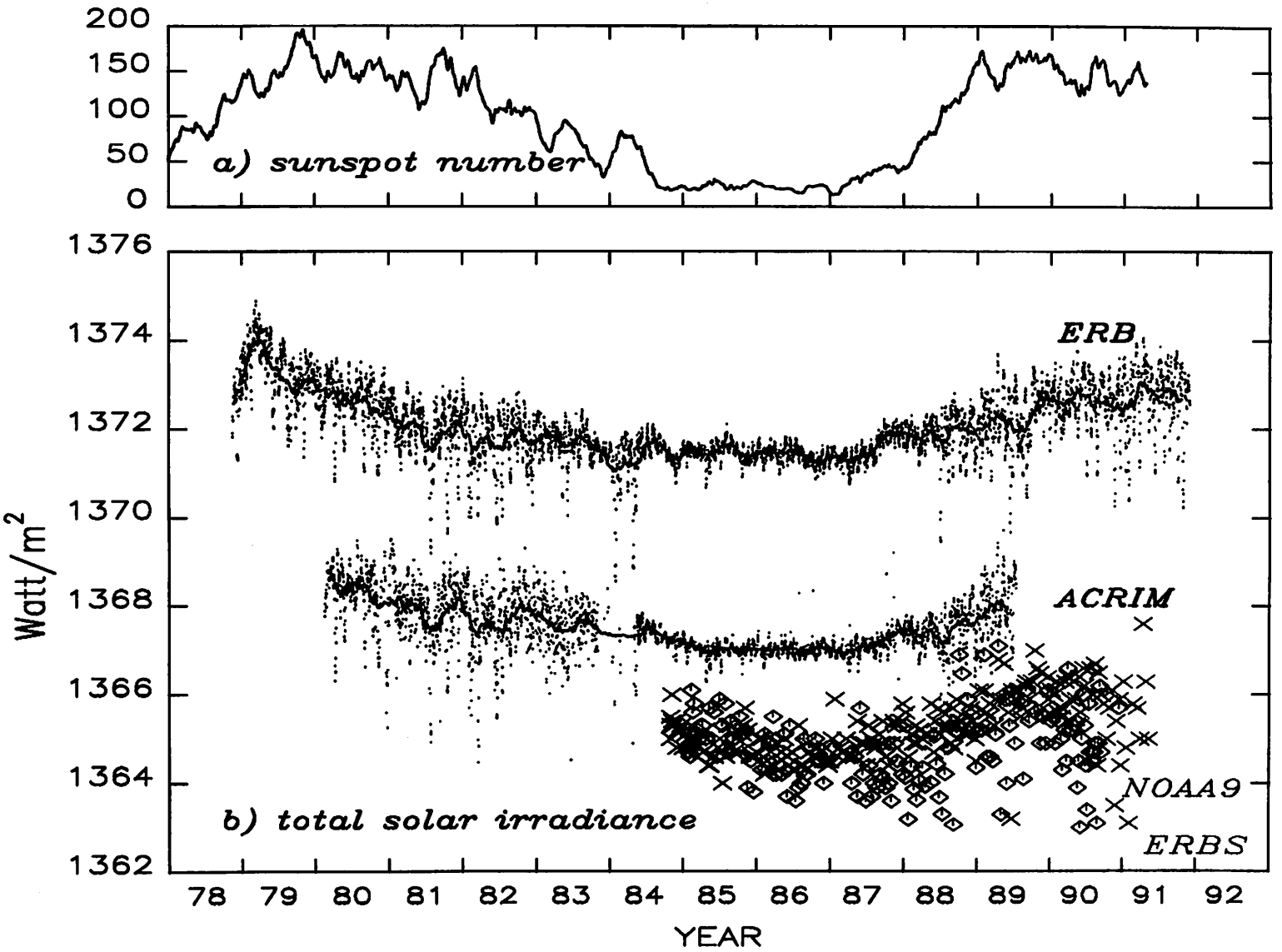



UV
VIS
IR
a) Spectral Irradiance
IRRADIANCE
(milliwatt/m²/nm)
1
E+5
10000
1000
100
10
1
0.1
0.01
1
E-3
1
E-4
1
E-5
Sun
5770 K Black Body
b) Spectral Irradiance Variability
11-YR CYCLE RATIO
(Max-Min)/Min
1000
100
10
1
0.1
0.01
1
E-3
1
E-4
derived from observations
estimated
total irradiance
10
100
1000
10000
1E+5
WAVELENGTH (nm)


O_2
O_3
H_2O & CO_2
unattenuated
20 km
0 km
IRRADIANCE (mW/m^2/nm)
10000
1000
100
10
1
0.1
0.01
100
1000
10000
WAVELENGTH (nm)

SOLAR–TERRESTRIAL ENERGY SOURCES

Source	Energy (Watt/m^2)	Solar Cycle Change (Watt/m^2)	Depostion Altitude
Solar Radiation			
total solar irradiance	1370	1.2	surface
UV 200–300 nm	16	0.14	0–50 km
VUV 0–200 nm	0.15	0.15	50–500 km
Particles			
Solar protons	0.002		30–90 km
Proton aurora, disturbed	0.036		30–90 km
Galactic cosmic rays	0.0000007		0–90 km
Joule Heating of Thermosphere			
E=100 mV/m	0.14		100–500 km
Solar Wind	0.0003		above 500 km


200
150
100
50
0
a) sunspot number
1376
1374
1372
1370
1368
1366
1364
1362
Watt/m2
ERB
ACRIM
NOAA9
ERBS
b) total solar irradiance
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
YEAR

SOLAR FORCING OF GLOBAL SURFACE TEMPERATURE

Change in equilibrium global temperature ΔT ***for change in input solar energy*** ΔS ***is***

$$\Delta T = \lambda^{-1} \, 0.7\Delta S/4$$

where

$$\lambda^{-1} \sim 0.3 \text{ to } 1.0 ^\circ C/Wm^{-2}$$

is the climate sensitivity

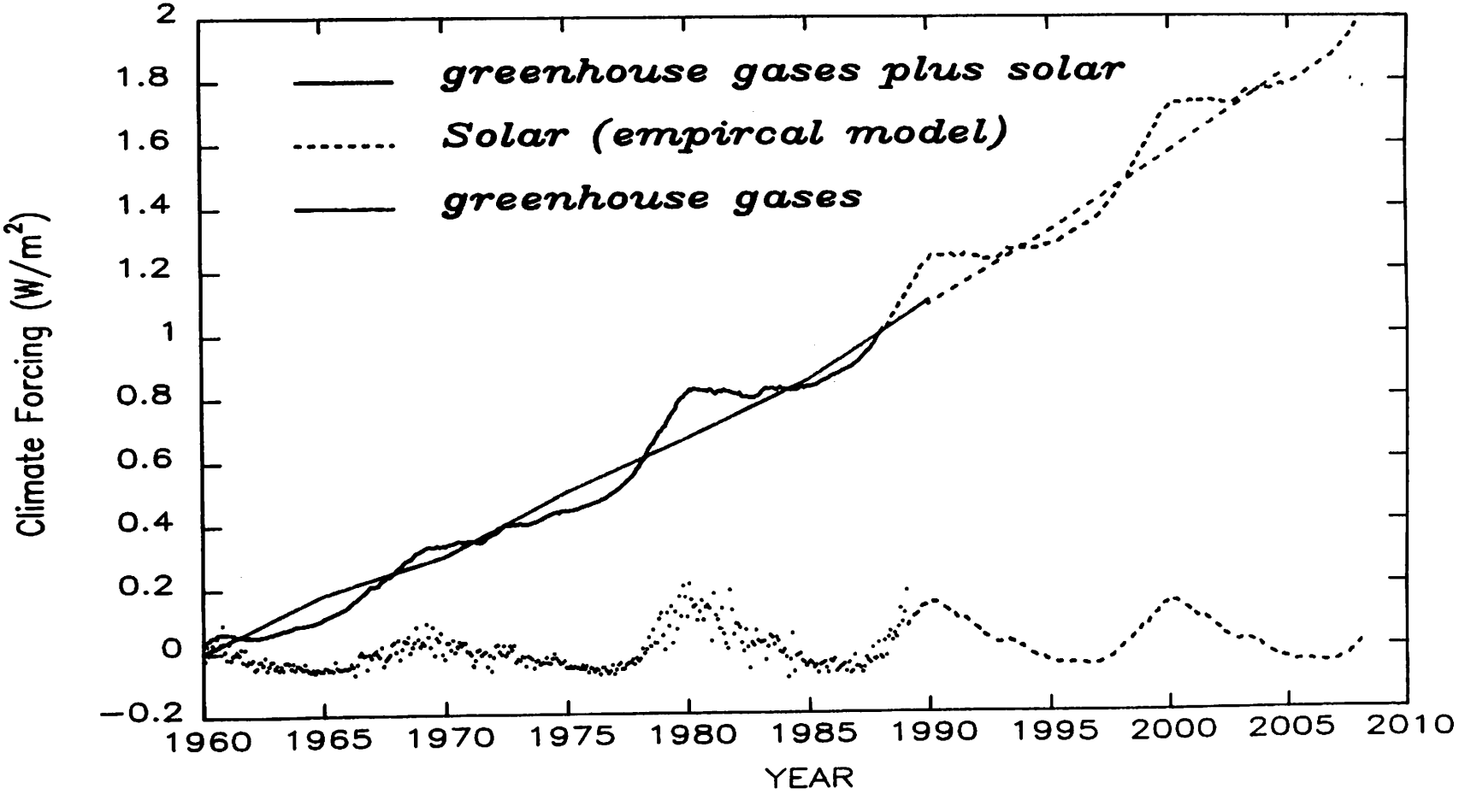
(Wigley & Raper, GRL, 1990).

Cycle 21 solar max to solar min

$$\Delta S = 1.2 \ Wm^{-2} \qquad \Delta T = 0.06 - 0.21 ^\circ C$$

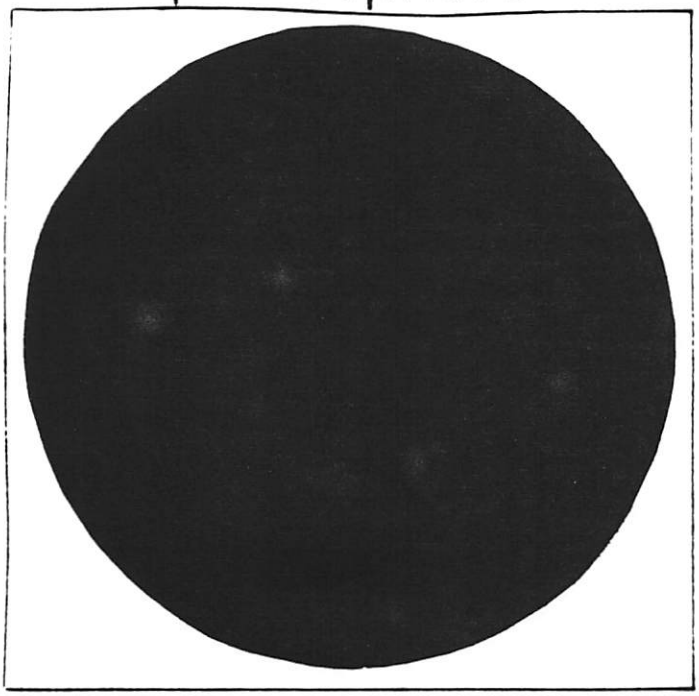
SOLAR vs. GREENHOUSE CLIMATE FORCING

adapted from Hansen & Lacis (1990) and Foukal & Lean (1990)

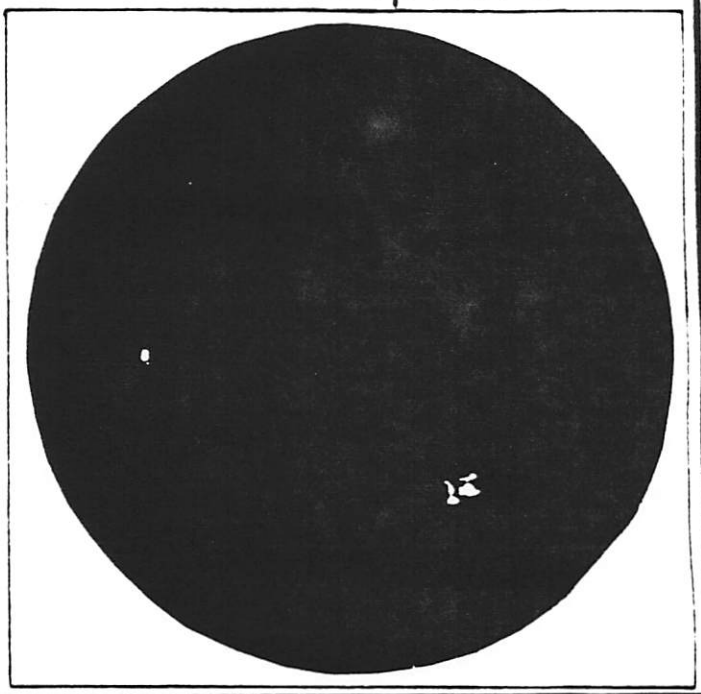


10 MAY 75

photosphere

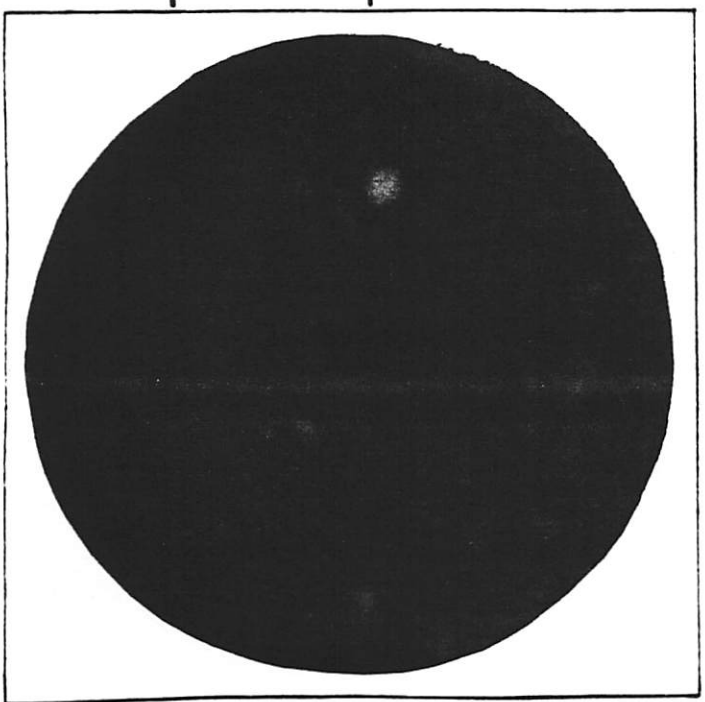


chromosphere

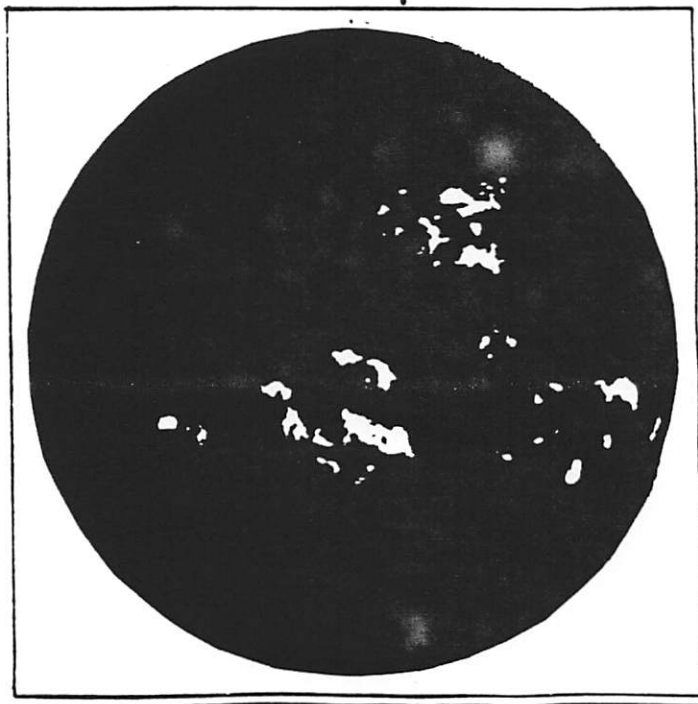


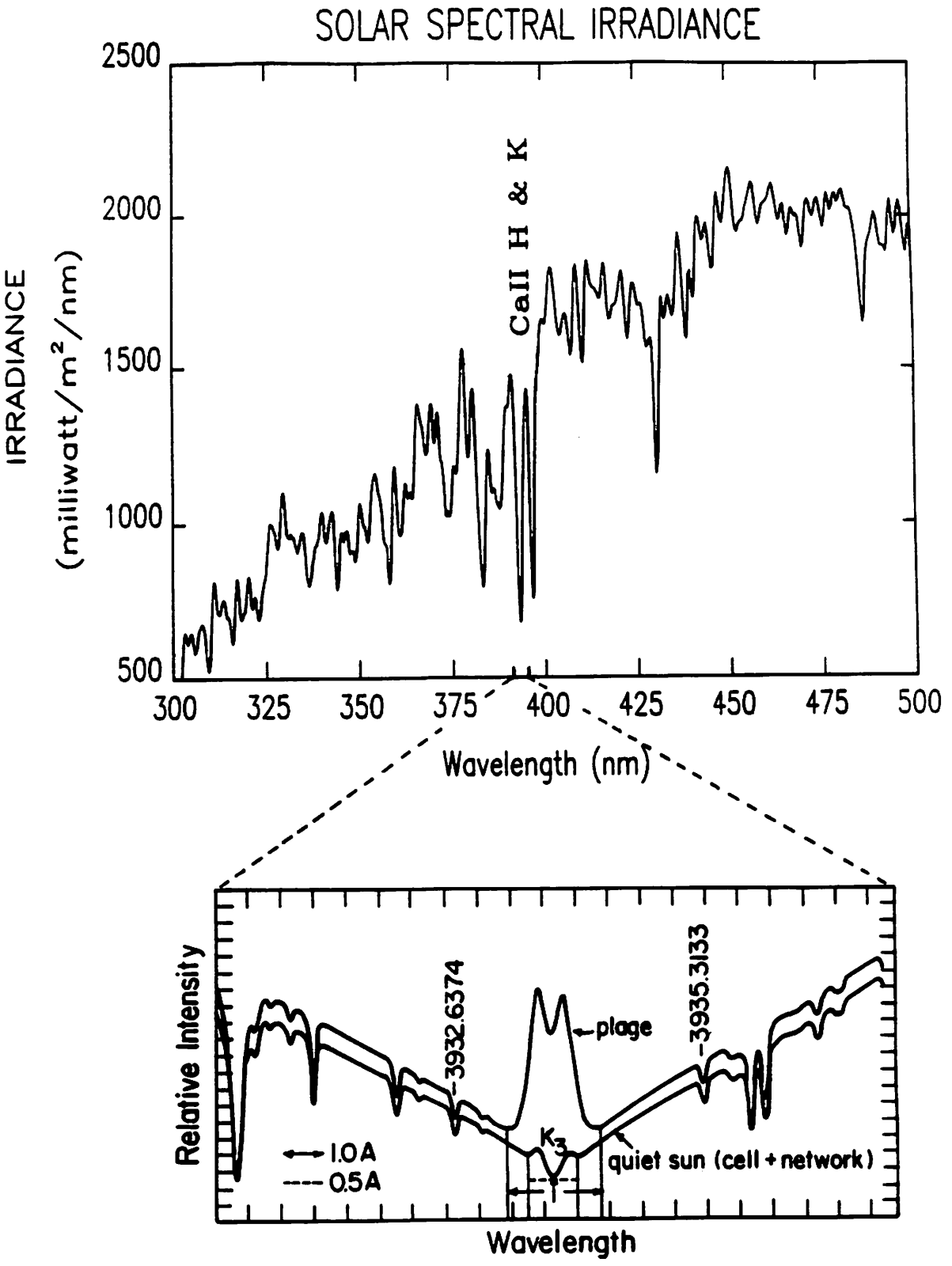
7 MARCH 79

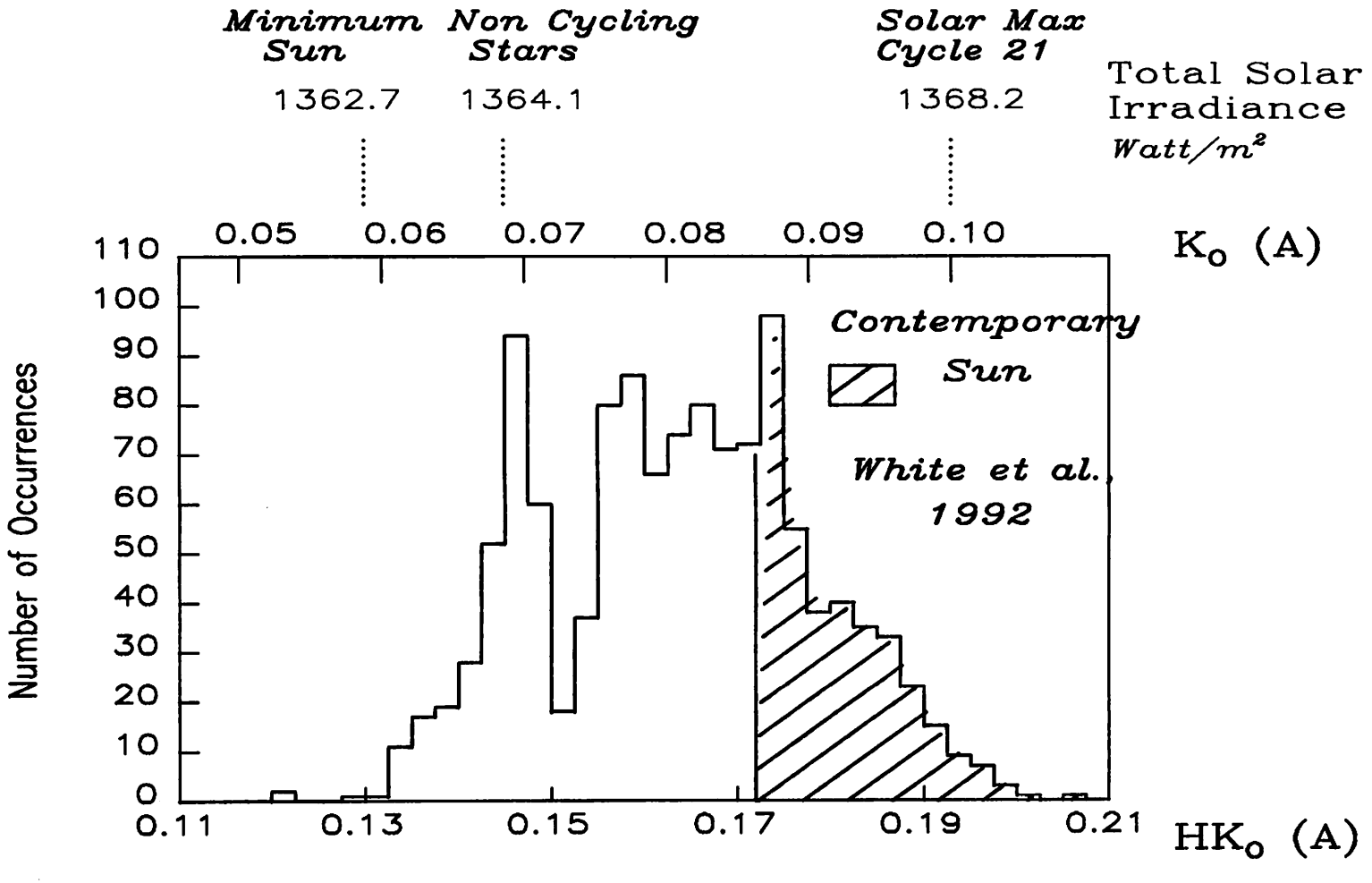
photosphere



chromosphere




SOLAR SPECTRAL IRRADIANCE
IRRADIANCE
(milliwatt/m²/nm)
2500
2000
1500
1000
500
CaII H & K
300
325
350
375
400
425
450
475
500
Wavelength (nm)
Relative Intensity
3932.6374
plage
3935.3133
1.0A
0.5A
K3
quiet sun (cell + network)
Wavelength


Minimum Sun
Non Cycling Stars
Solar Max Cycle 21
1362.7
1364.1
1368.2
Total Solar Irradiance
Watt/m²
0.05
0.06
0.07
0.08
0.09
0.10
K₀ (A)
110
100
90
80
70
60
50
40
30
20
10
0
Number of Occurrences
Contemporary Sun
White et al., 1992
0.11
0.13
0.15
0.17
0.19
0.21
HK₀ (A)

SOLAR FORCING OF GLOBAL SURFACE TEMPERATURE

Change in equilibrium global temperature ΔT ***for change in input solar energy*** ΔS ***is***

$$\Delta T = \lambda^{-1} \, 0.7\Delta S/4$$

where

$$\lambda^{-1} \sim 0.3 \text{ to } 1.0^{\circ}C/Watt m^{-2}$$

is the climate sensitivity

(Wigley & Raper, GRL, 1990)

Cycle 21 solar max to solar min

$\Delta S = 1.2$ Watt/m^2 $\quad \Delta T = 0.06 - 0.21^{\circ}C$

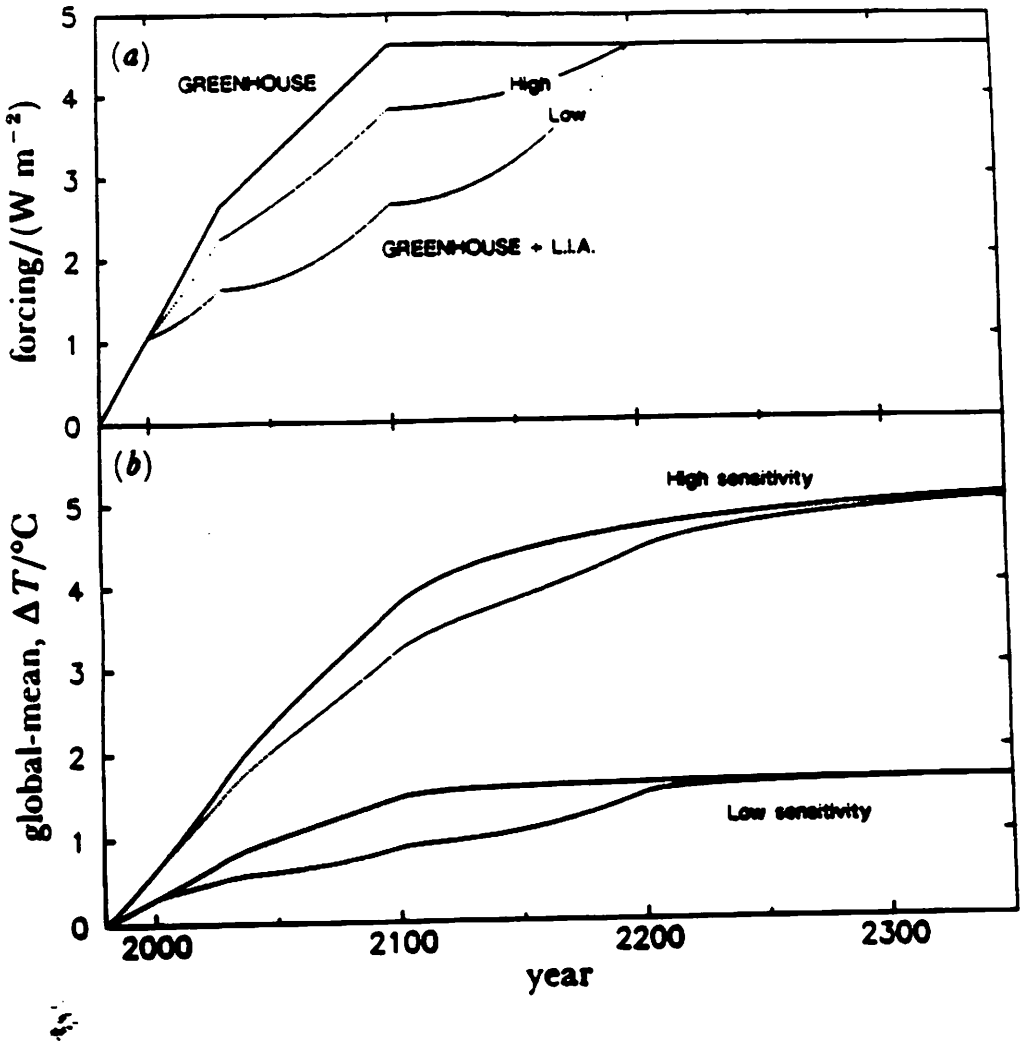
Cycle 21 solar max to Maunder Minimum

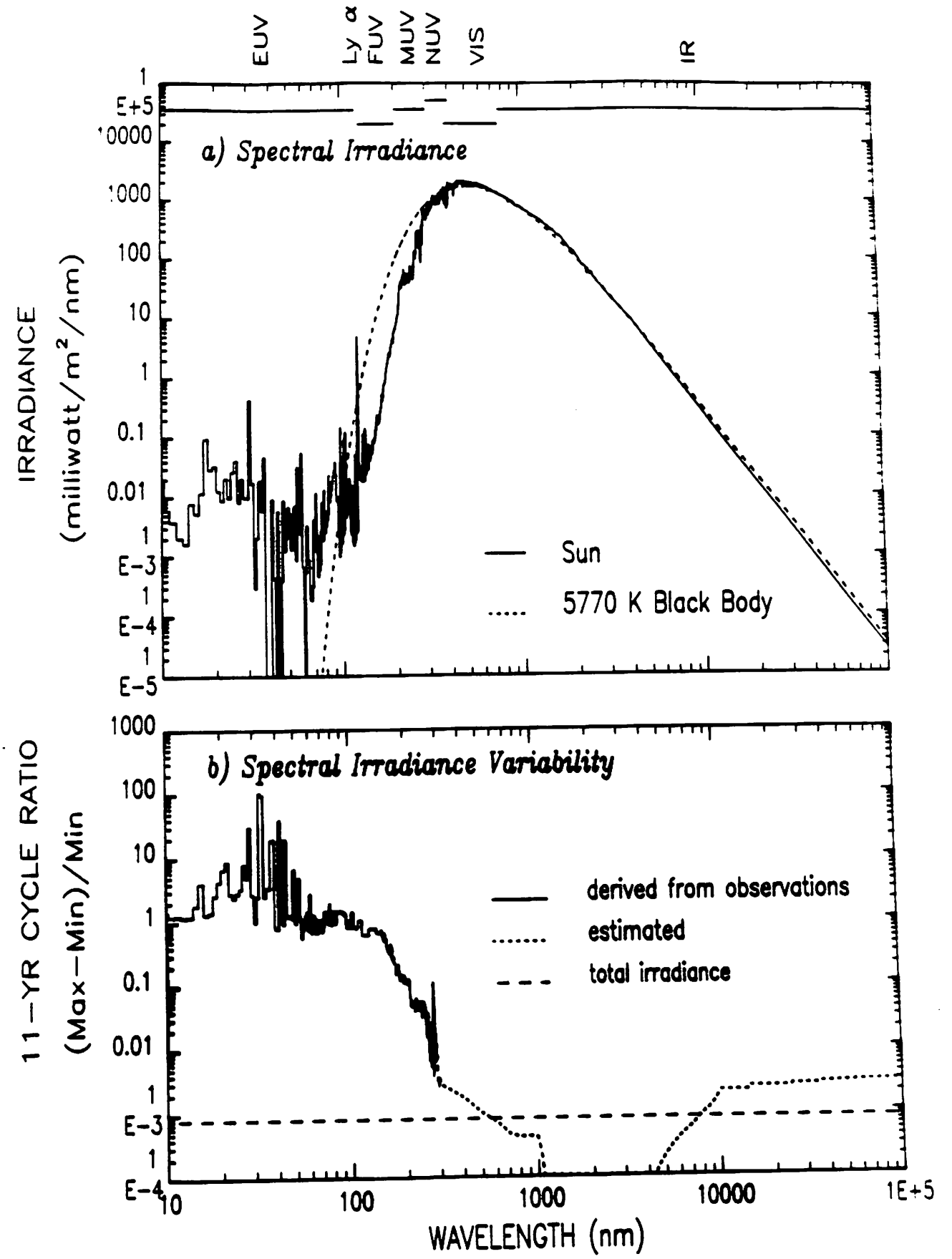
$\Delta S = 3.9$ Watt/m^2 $\quad \Delta T = 0.2 - 0.68^{\circ}C$

ΔSURF AIR TEMP (°C) ANNUAL -.25% S.C.-CONTROL

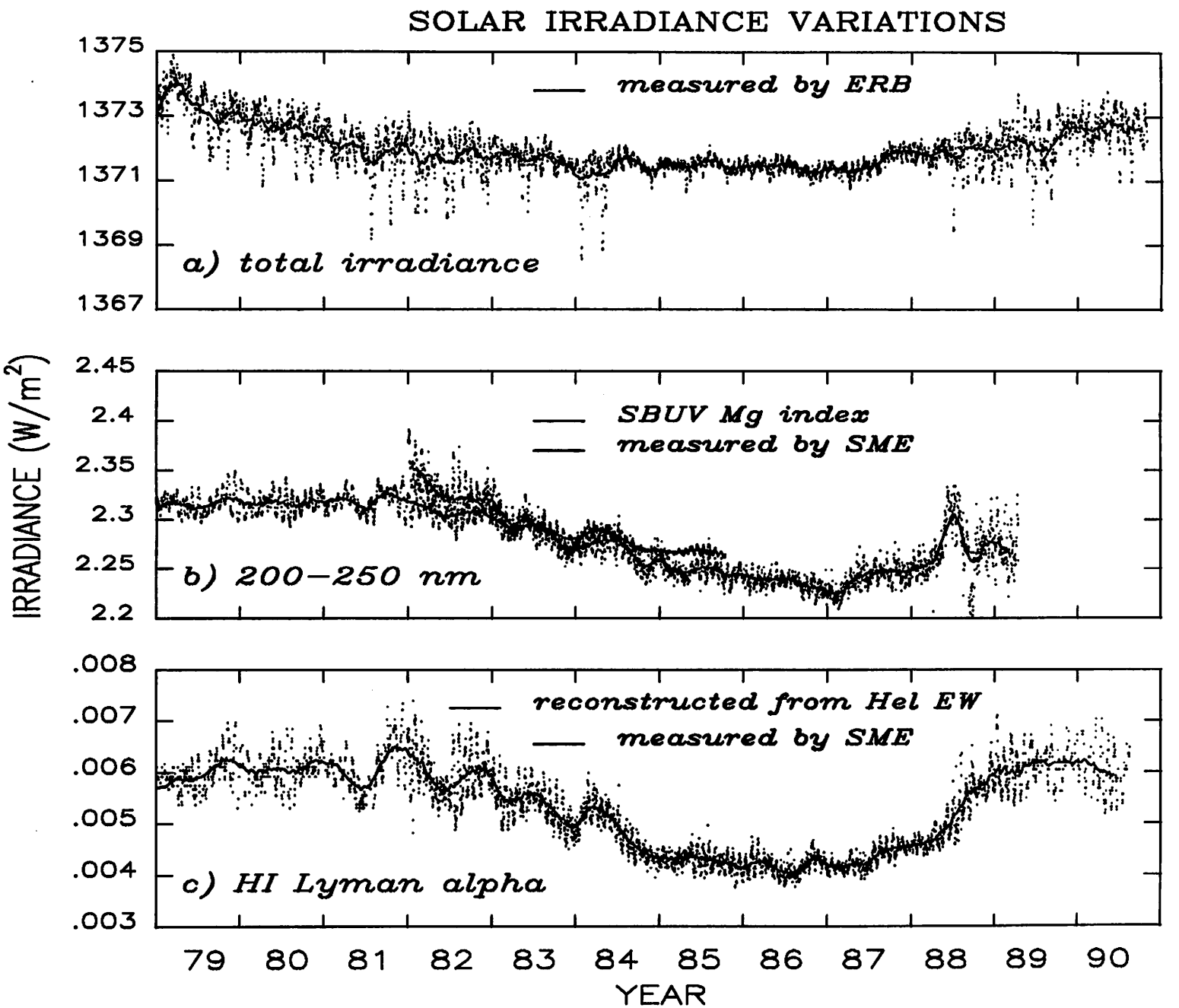
Scenarios for Future Climate Change: Greenhouse Gases vs. Solar "Little Ice Age"

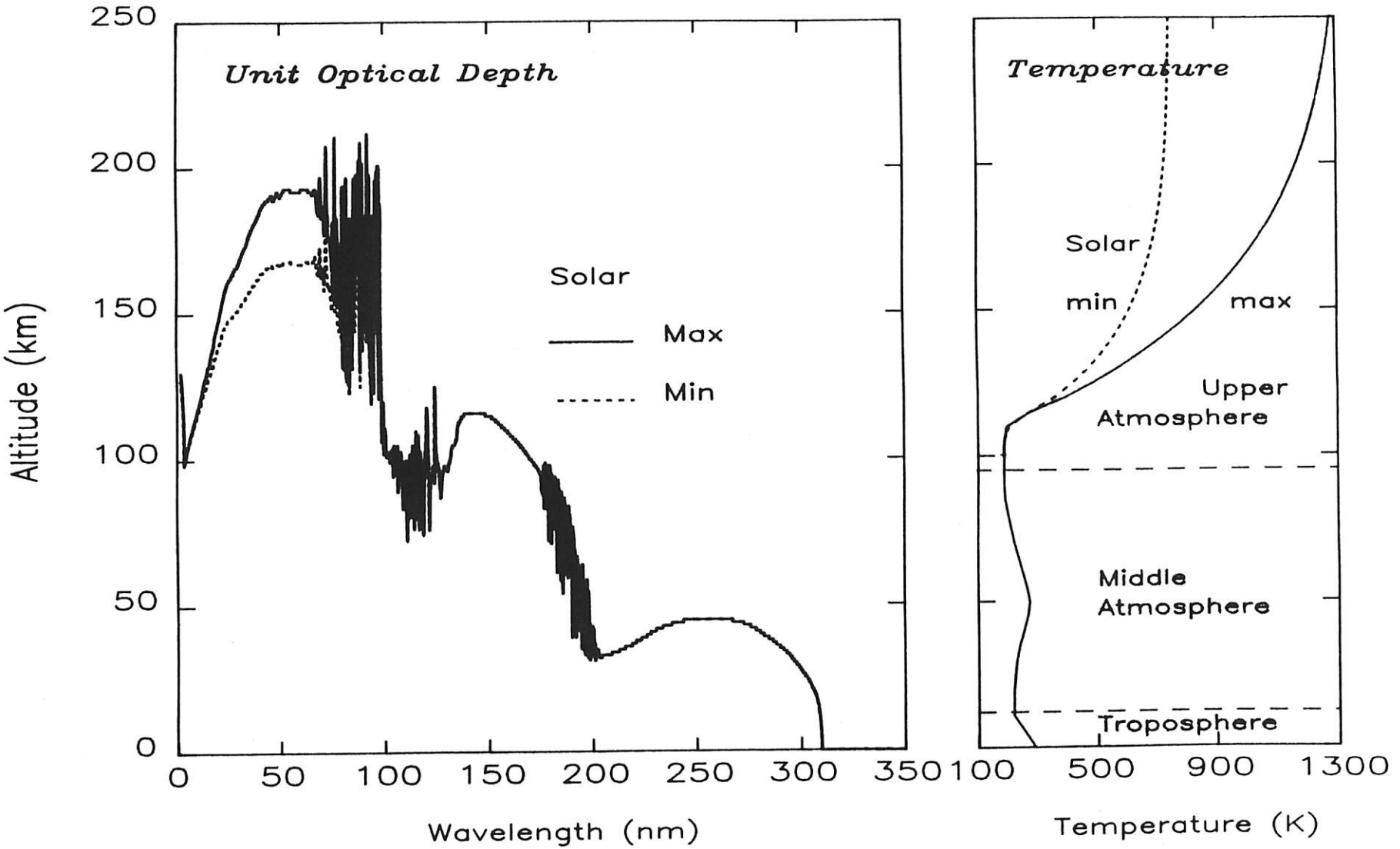
Wigley and Kelly. 1990



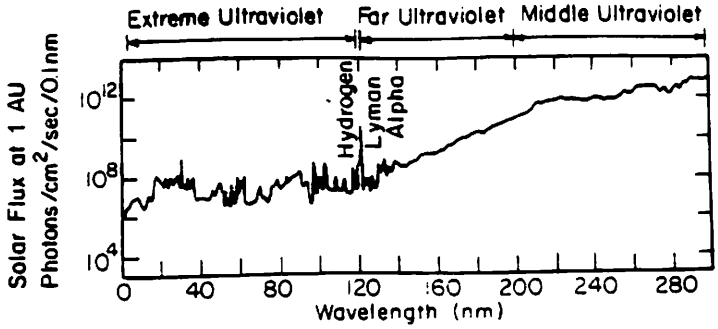


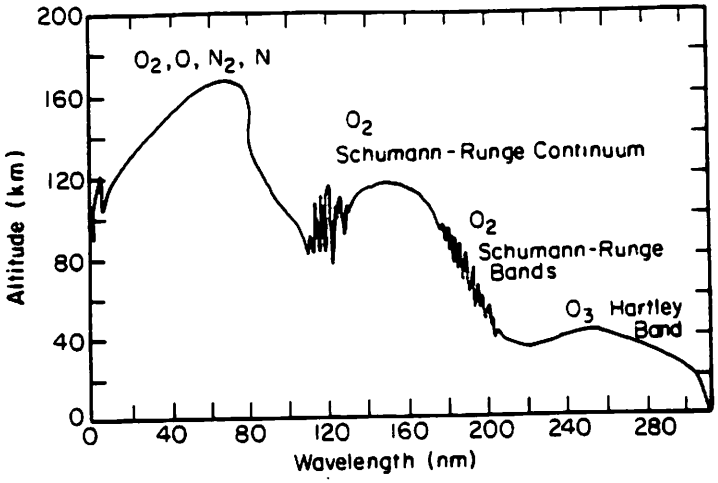
Lean, Rev. Geophys, 199

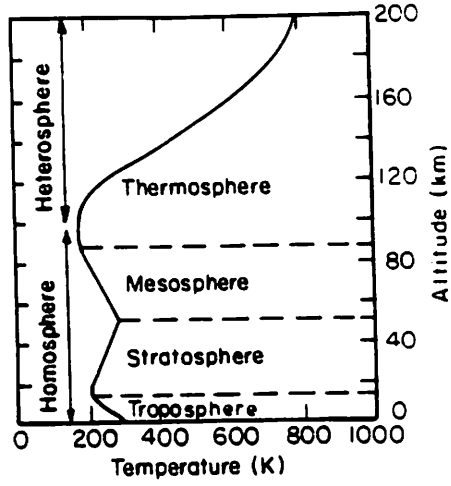

SOLAR IRRADIANCE VARIATIONS
1375
1373
1371
1369
1367
measured by ERB
a) total irradiance
IRRADIANCE (W/m²)
2.45
2.4
2.35
2.3
2.25
2.2
SBUV Mg index
measured by SME
b) 200–250 nm
.008
.007
.006
.005
.004
.003
reconstructed from Hel EW
measured by SME
c) HI Lyman alpha
79
80
81
82
83
84
85
86
87
88
89
90
YEAR


Unit Optical Depth
Solar
Max
Min
Altitude (km)
250
200
150
100
50
0
0
50
100
150
200
250
300
350
Wavelength (nm)
Temperature
Solar
min
max
Upper
Atmosphere
Middle
Atmosphere
Troposphere
100
500
900
1300
Temperature (K)

1. Radiation







2. Chemistry

O_x Photochemistry

$O_2 + h\nu \longrightarrow O + O \quad (h\nu < 242\ nm)$

$O + O_2 + m \longrightarrow O_3 + m$

$O_3 + h\nu \longrightarrow O + O_2 \quad (h\nu < 1.08\ \mu m)$

$O + O + m \longrightarrow O_2 + m$

$O + O_3 \longrightarrow 2O_2$

Catalytic Ozone Destruction

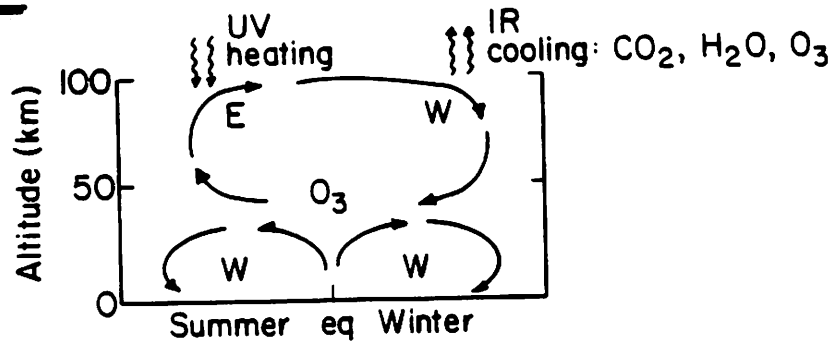
$X + O_3 \longrightarrow XO + O_2$

$XO + O \longrightarrow X + O_2$

$O + O_3 \longrightarrow 2O_2$

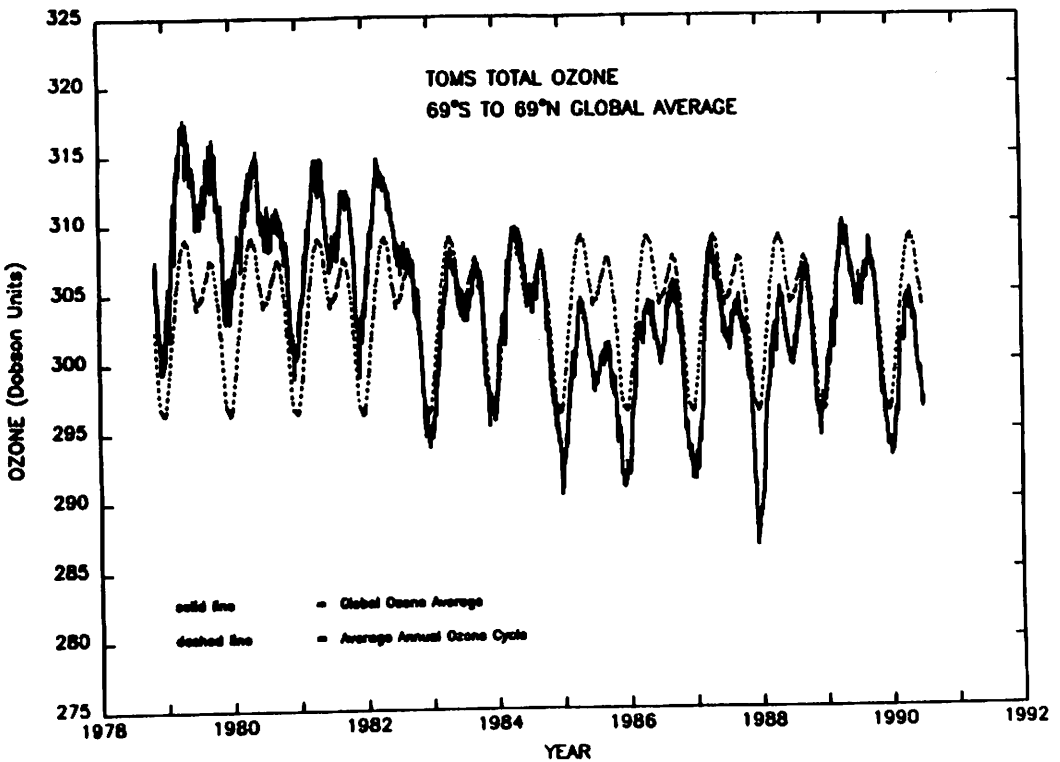
X: HO_x, NO_x, Cl_x

3. Dynamics

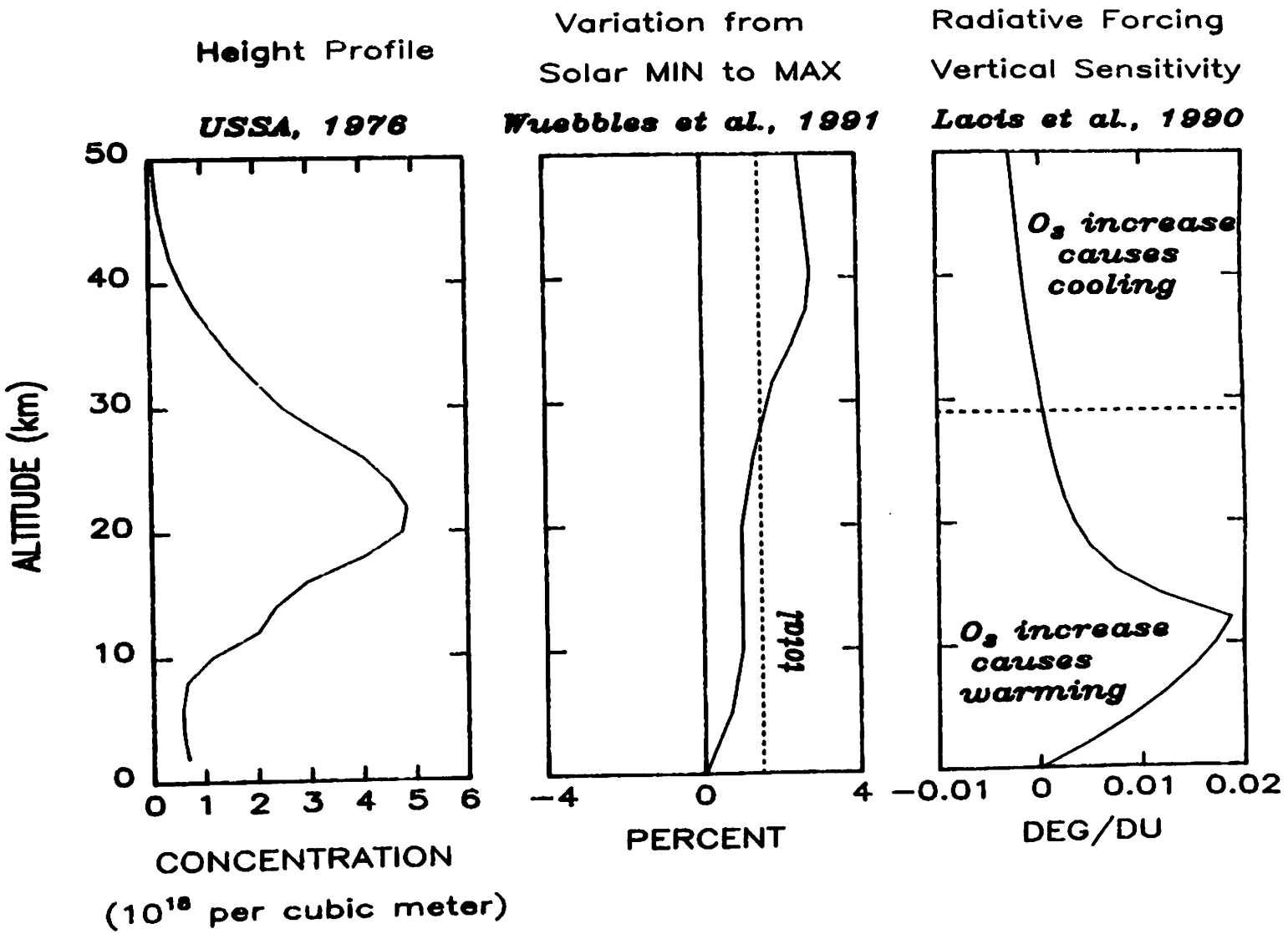


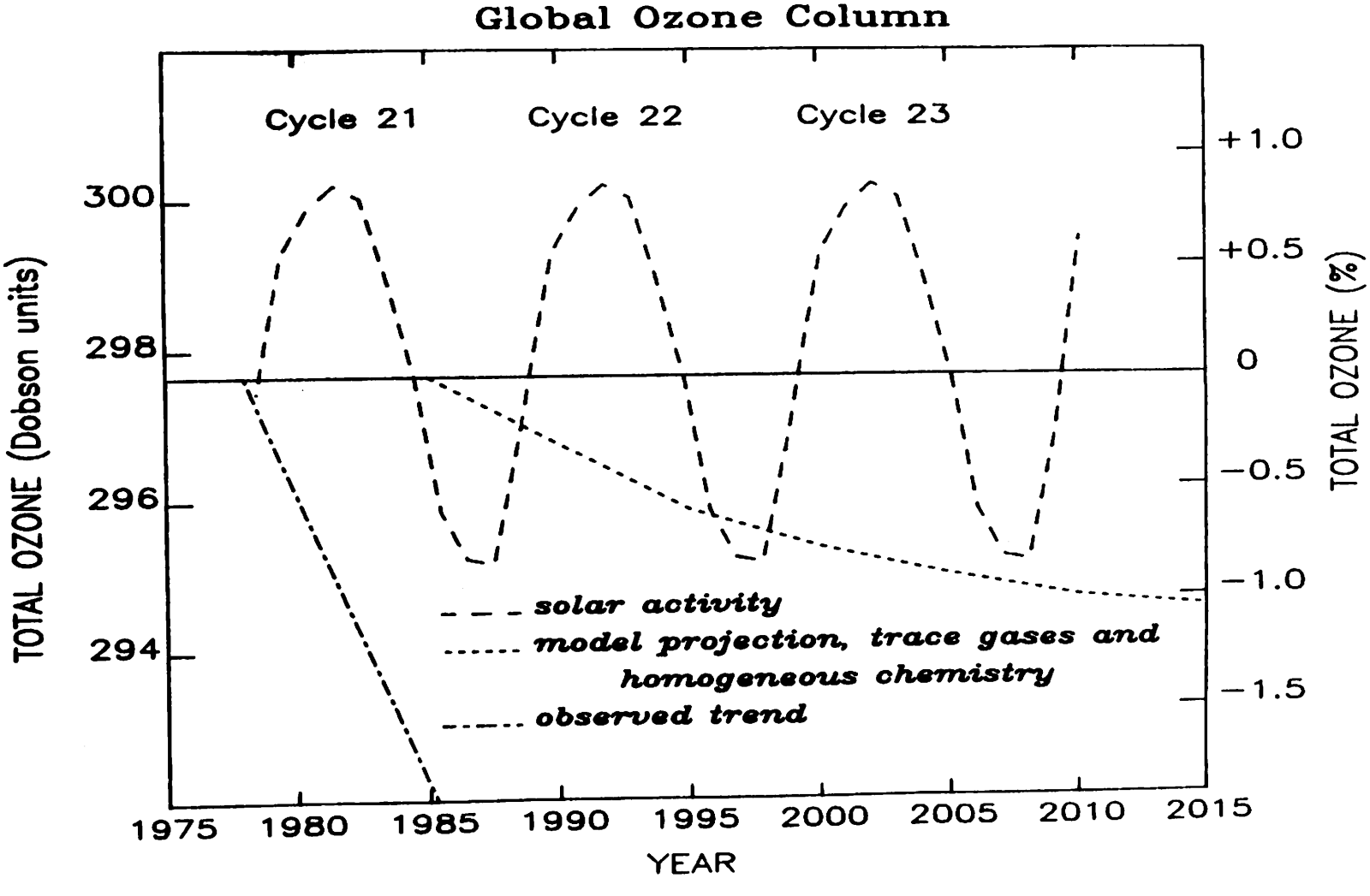
LONG TERM VARIATIONS IN TOTAL OZONE

Herman et al., J. Geophys. Res., 1991

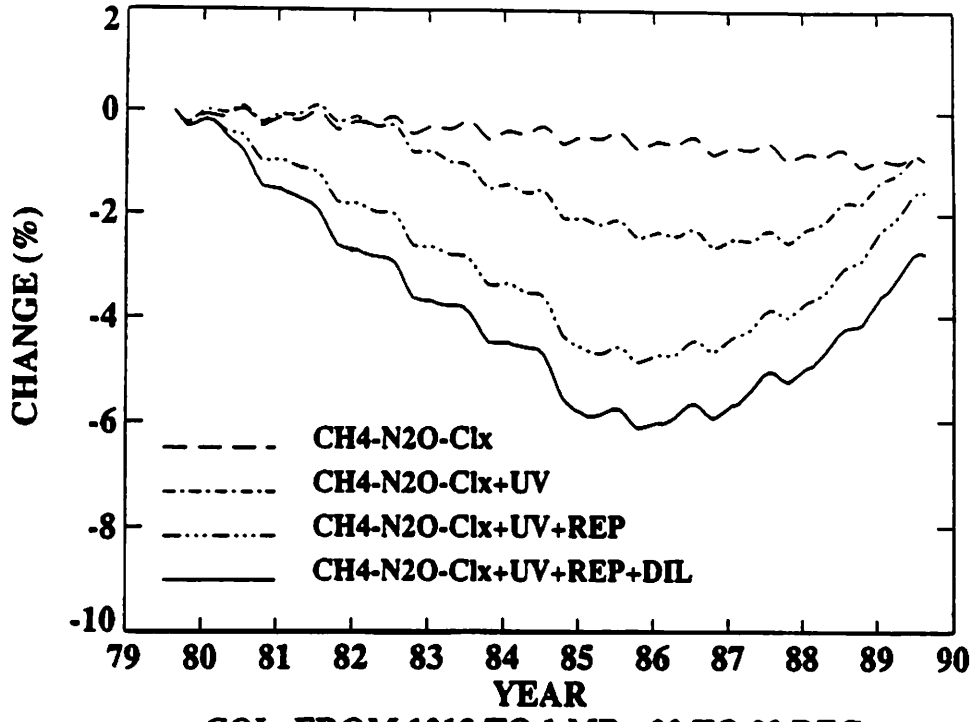


ATMOSPHERIC OZONE



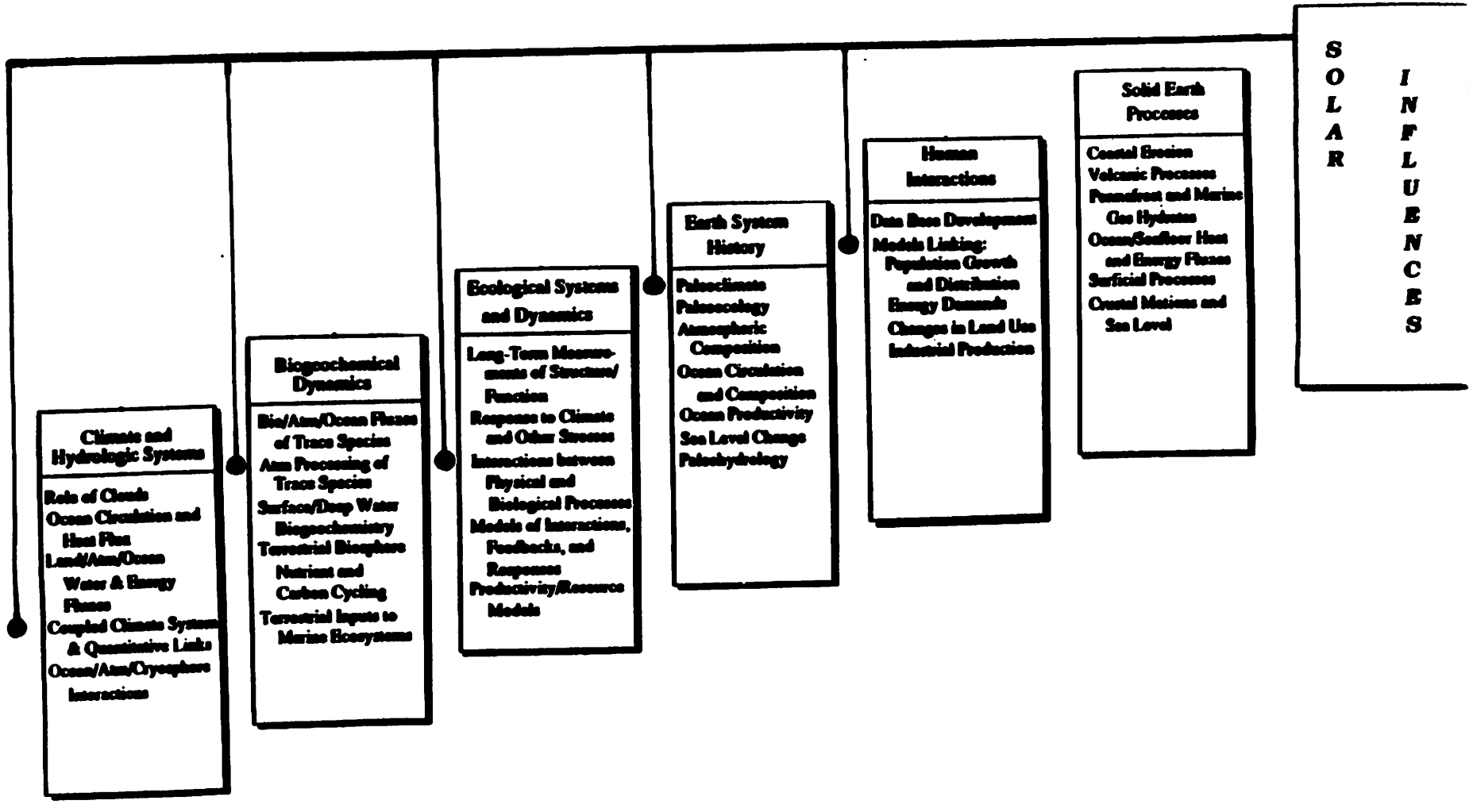

Global Ozone Column
Cycle 21
Cycle 22
Cycle 23
300
298
296
294
+1.0
+0.5
0
−0.5
−1.0
−1.5
TOTAL OZONE (Dobson units)
TOTAL OZONE (%)
solar activity
model projection, trace gases and homogeneous chemistry
observed trend
1975
1980
1985
1990
1995
2000
2005
2010
2015
YEAR

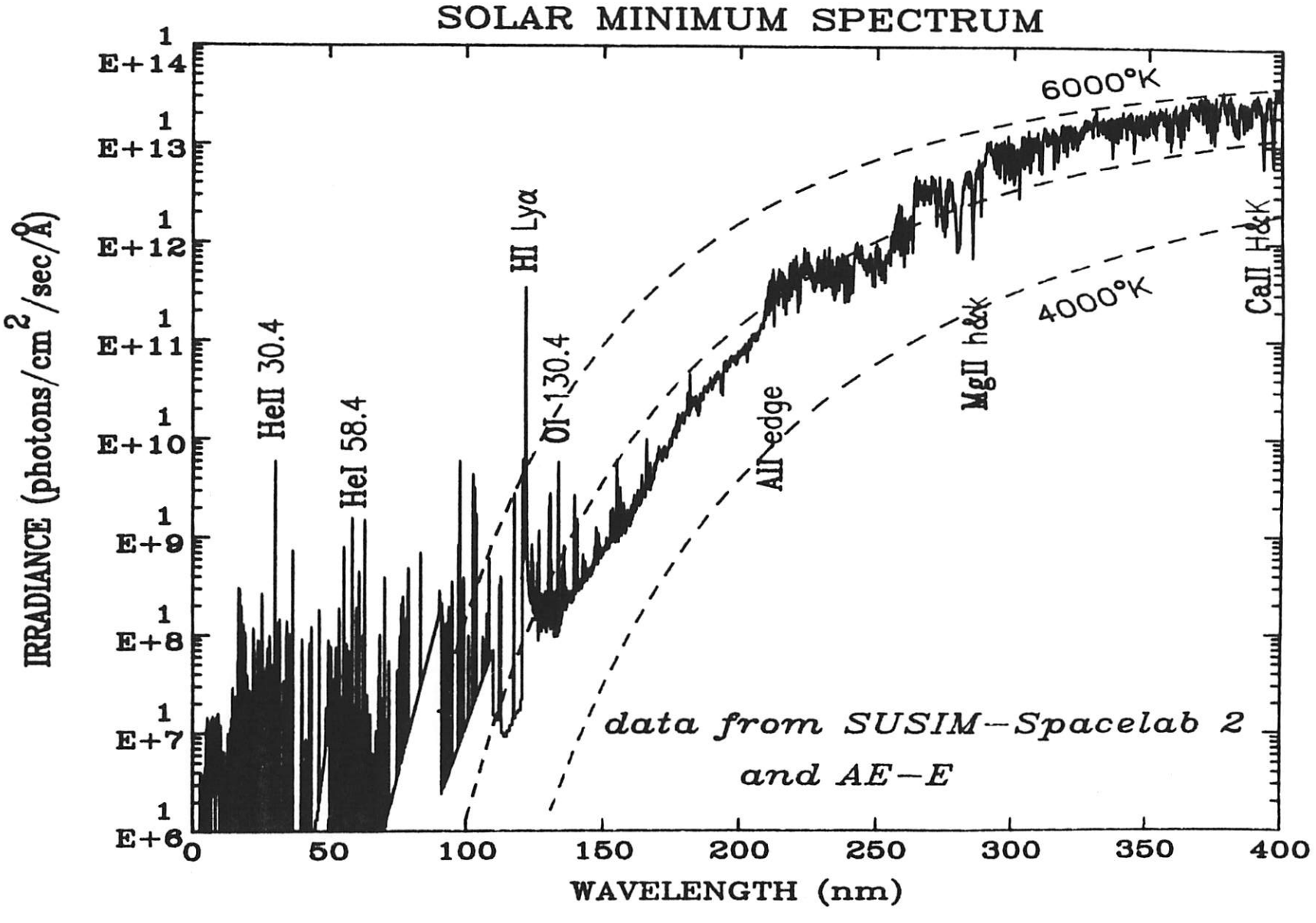
Callis et al., J. Geophys. Res., 1991

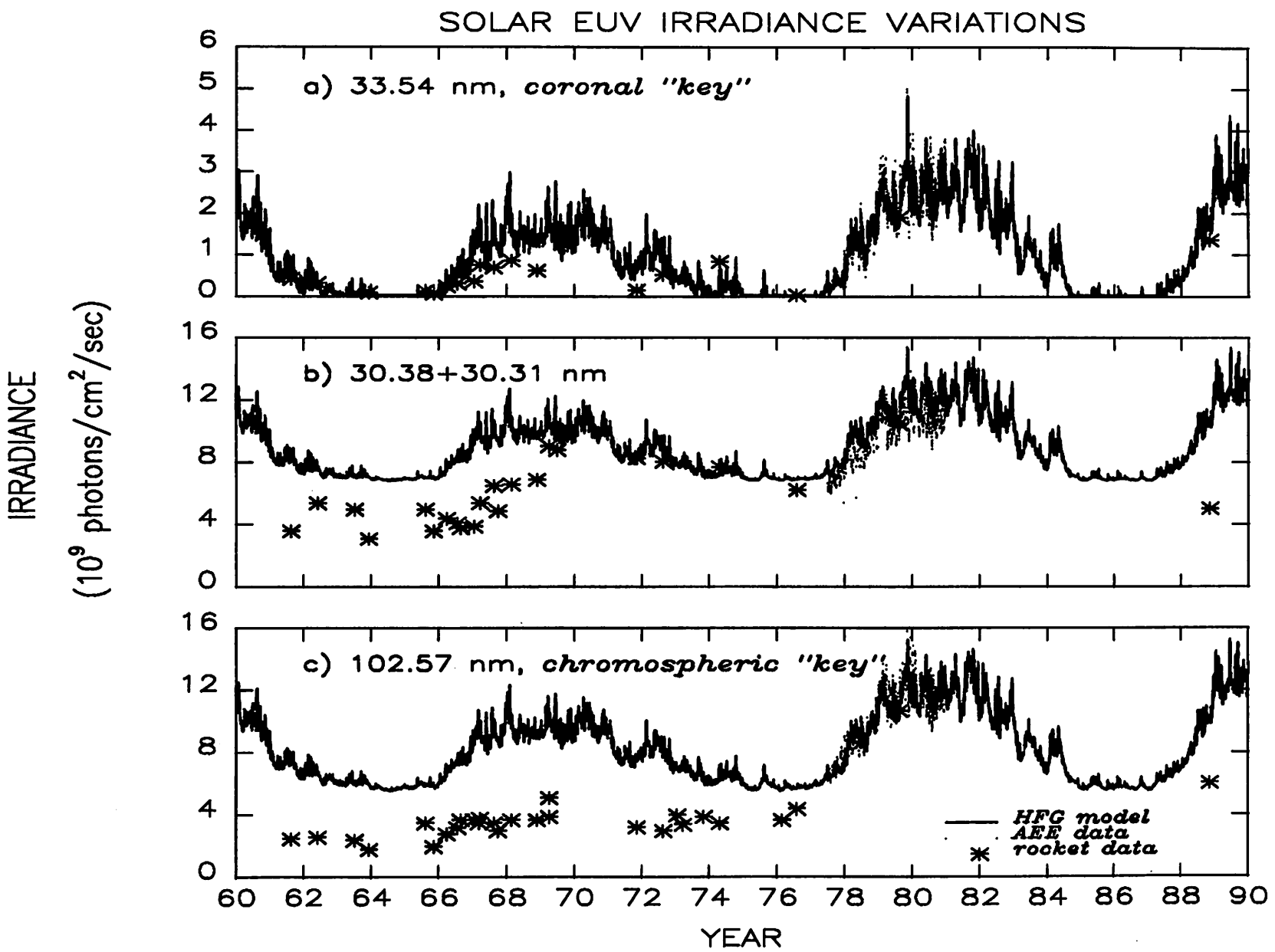


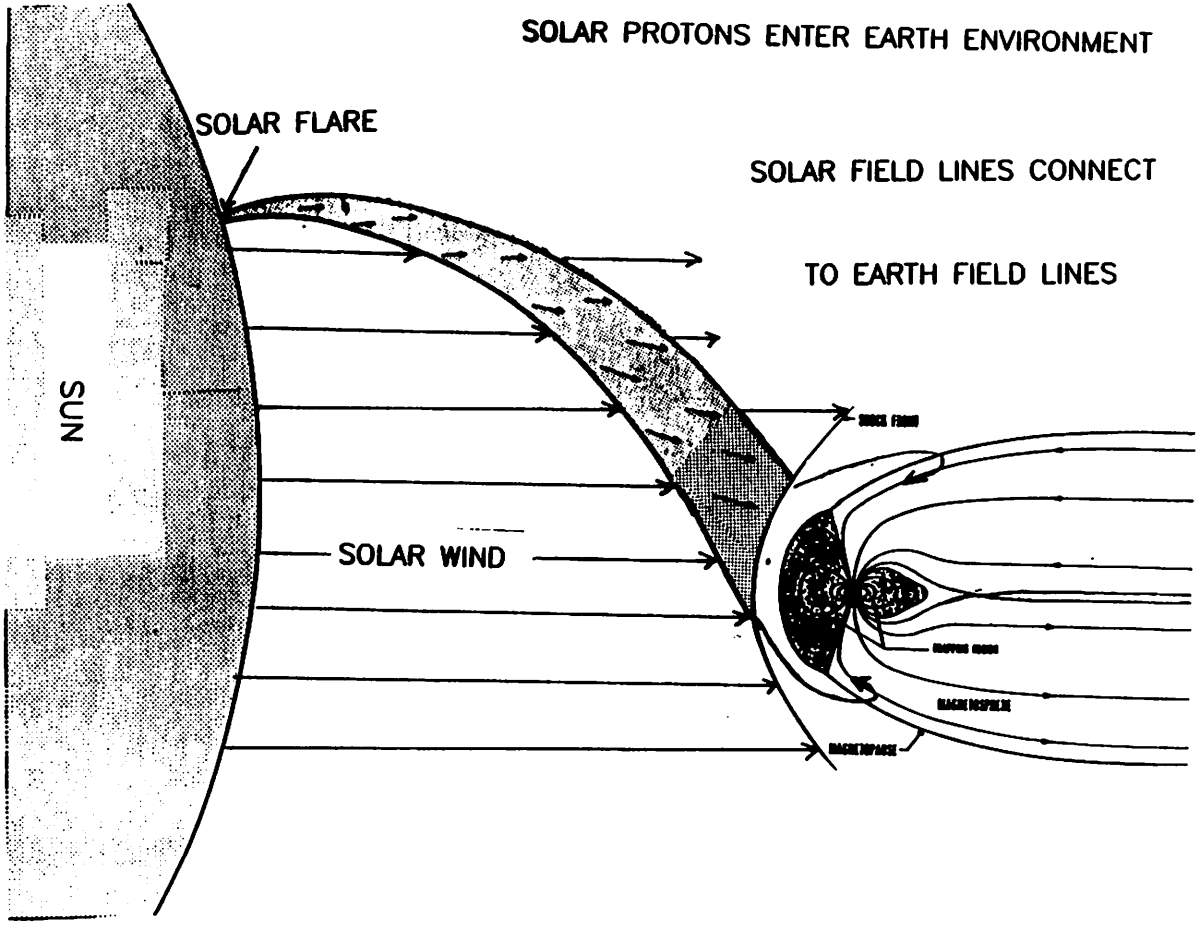
Percentage changes in global (90 S to 90 N) total column ozone as calculated for four scenarios.

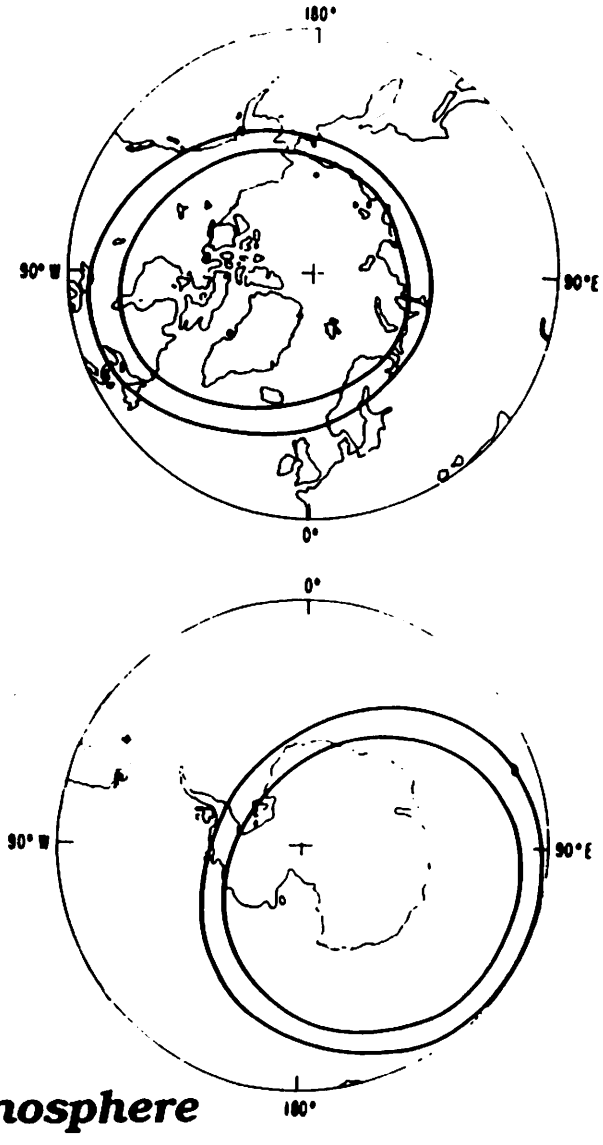
Connections between Solar Influences on Global Change and other elements of the US Global Change Research Program




SOLAR MINIMUM SPECTRUM
IRRADIANCE (photons/cm^2/sec/Å)
1 E+14
1 E+13
1 E+12
1 E+11
1 E+10
1 E+9
1 E+8
1 E+7
1 E+6
0
50
100
150
200
250
300
350
400
WAVELENGTH (nm)
HeII 30.4
HeI 58.4
HI Lyα
OI~130.4
AlI edge
MgII h&k
CaII H&K
6000°K
4000°K
data from SUSIM–Spacelab 2
and AE–E

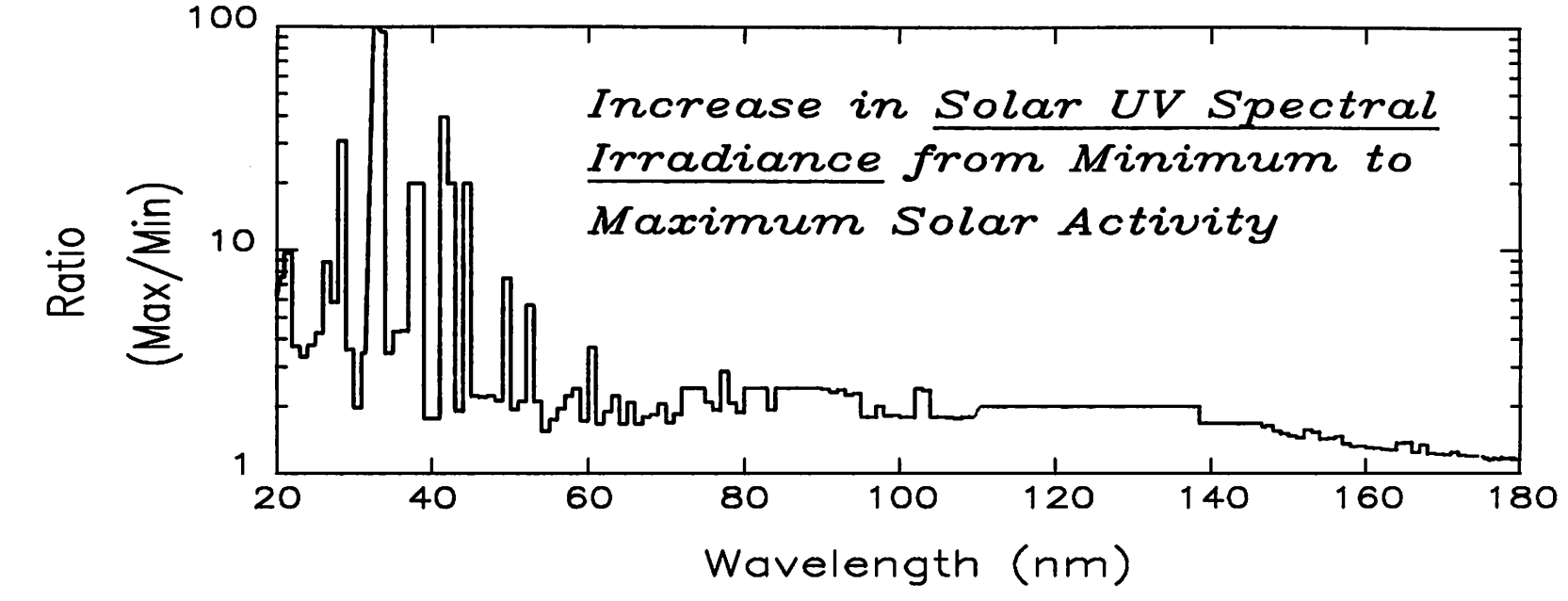

SOLAR EUV IRRADIANCE VARIATIONS
a) 33.54 nm, coronal "key"
b) 30.38+30.31 nm
c) 102.57 nm, chromospheric "key"
HFG model
AEE data
rocket data
IRRADIANCE
(10^9 photons/cm^2/sec)
YEAR
0
1
2
3
4
5
6
8
12
16
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90

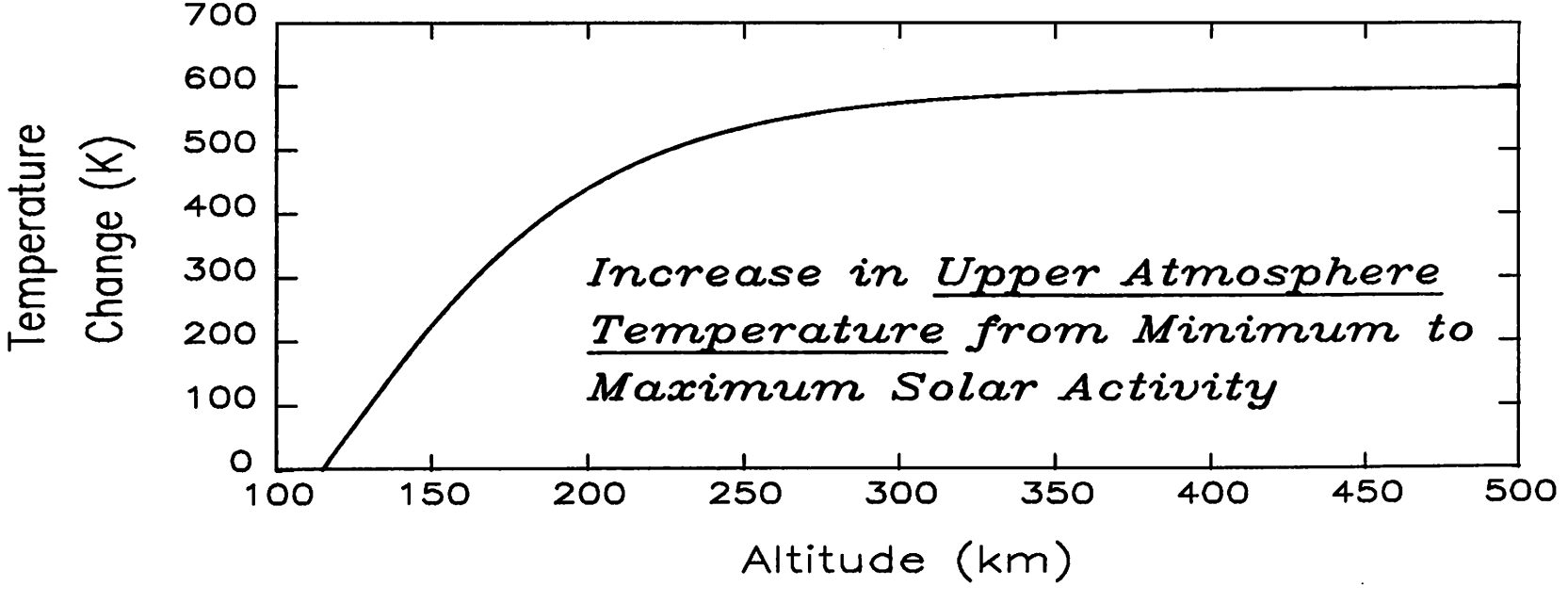




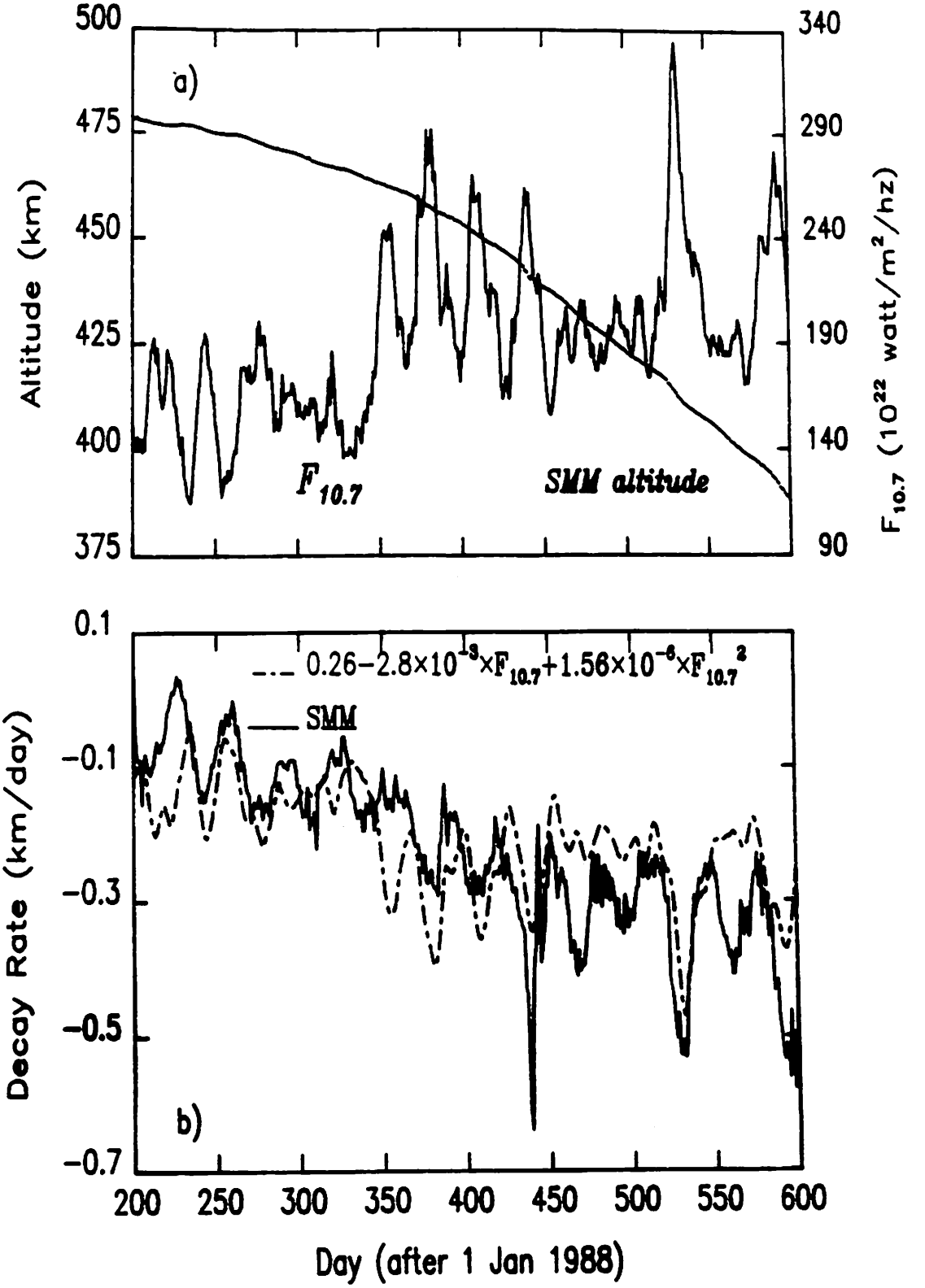
Penetration of energetic particles into the Earth's atmosphere

Adapted from C. Jackman and G. Reid


100
10
1
Ratio
(Max/Min)
Increase in Solar UV Spectral Irradiance from Minimum to Maximum Solar Activity
20
40
60
80
100
120
140
160
180
Wavelength (nm)


700
600
500
400
300
200
100
0
Temperature
Change (K)
Increase in Upper Atmosphere Temperature from Minimum to Maximum Solar Activity
100
150
200
250
300
350
400
450
500
Altitude (km)

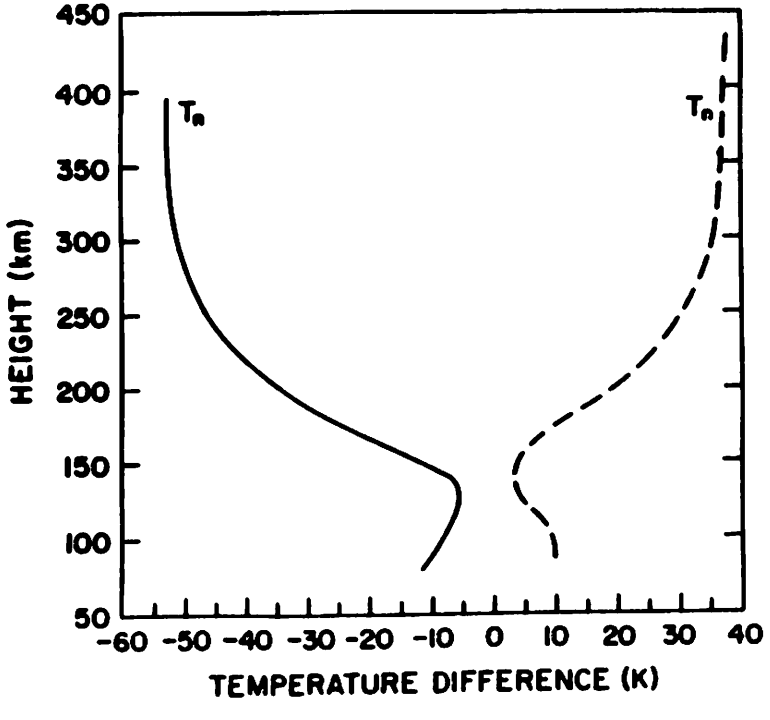
Lean, Rev. Geophys, 1991

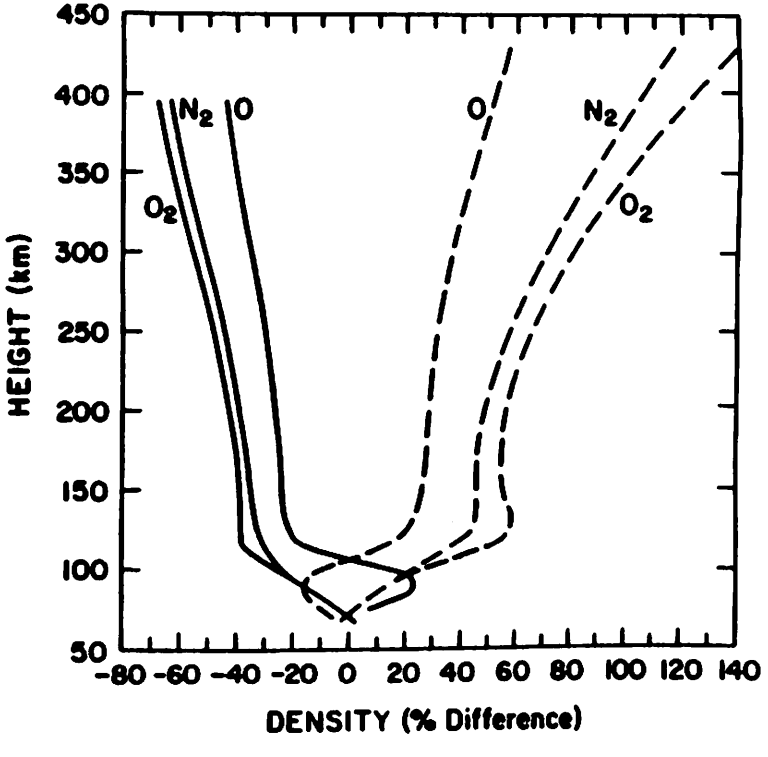


UPPER ATMOSPHERE SENSITIVIY TO CO_2 & CH_4

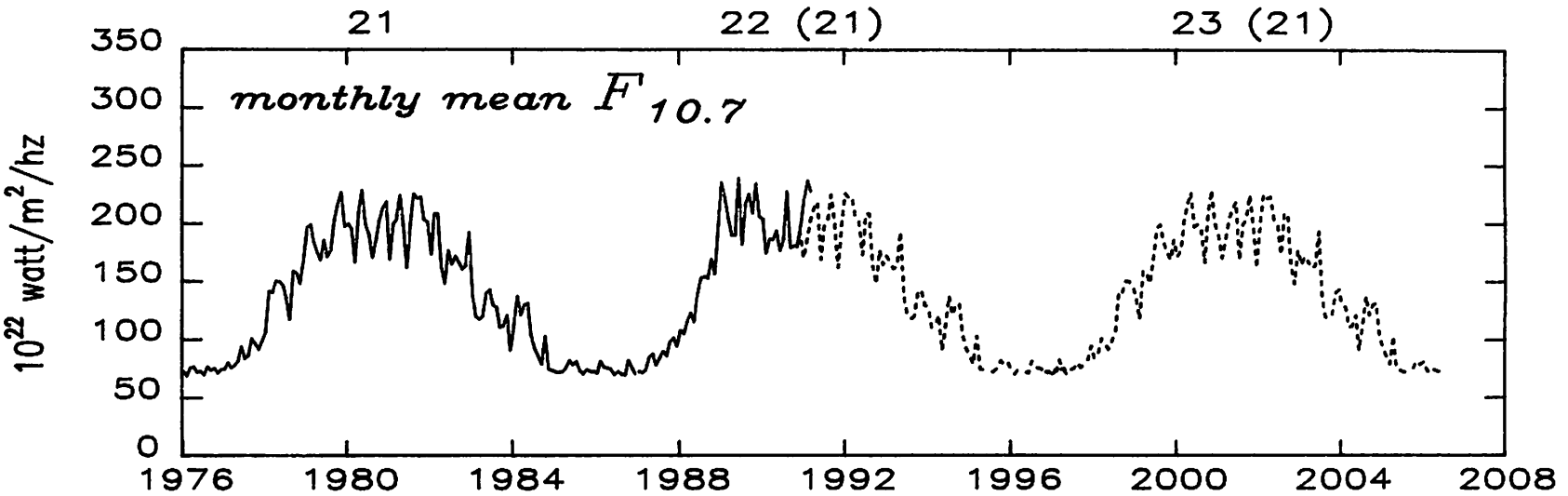
Roble & Dickinson, Geophys. Res. Lett., 1989

solid=double dashed=half





Satellite & Shuttle Measurements of Solar UV Irradiance



AEE: *EUV spectrometers*

NIMBUS–7: ***SBUV***

SME: *UV spectrometer*

* *
SHUTTLE:
SOLSPEC
SUSIM

* * *
SSBUV

NOAA–9/11: ***SBUV/2***

SAN MARCOS: *ASSI*

UARS: *SUSIM SOLSTICE*

* * * * * * * *
ATLAS: *SUSIM* ***SSBUV*** *SOLSPEC*

EOS: *SOLSTICE*

?? SOURCE:
EUV Spectrometers