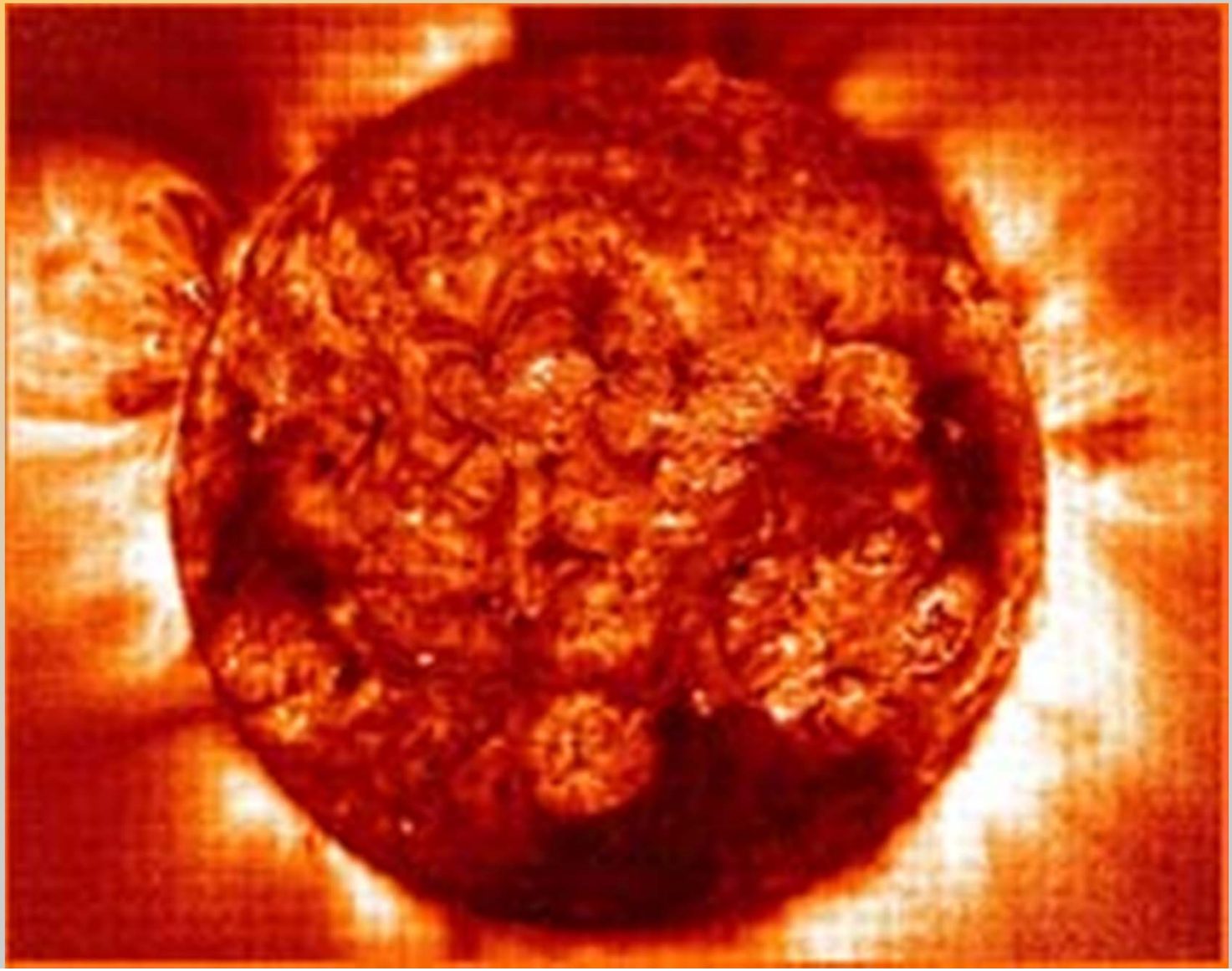
The Earth's Energy Balance
CCS 203

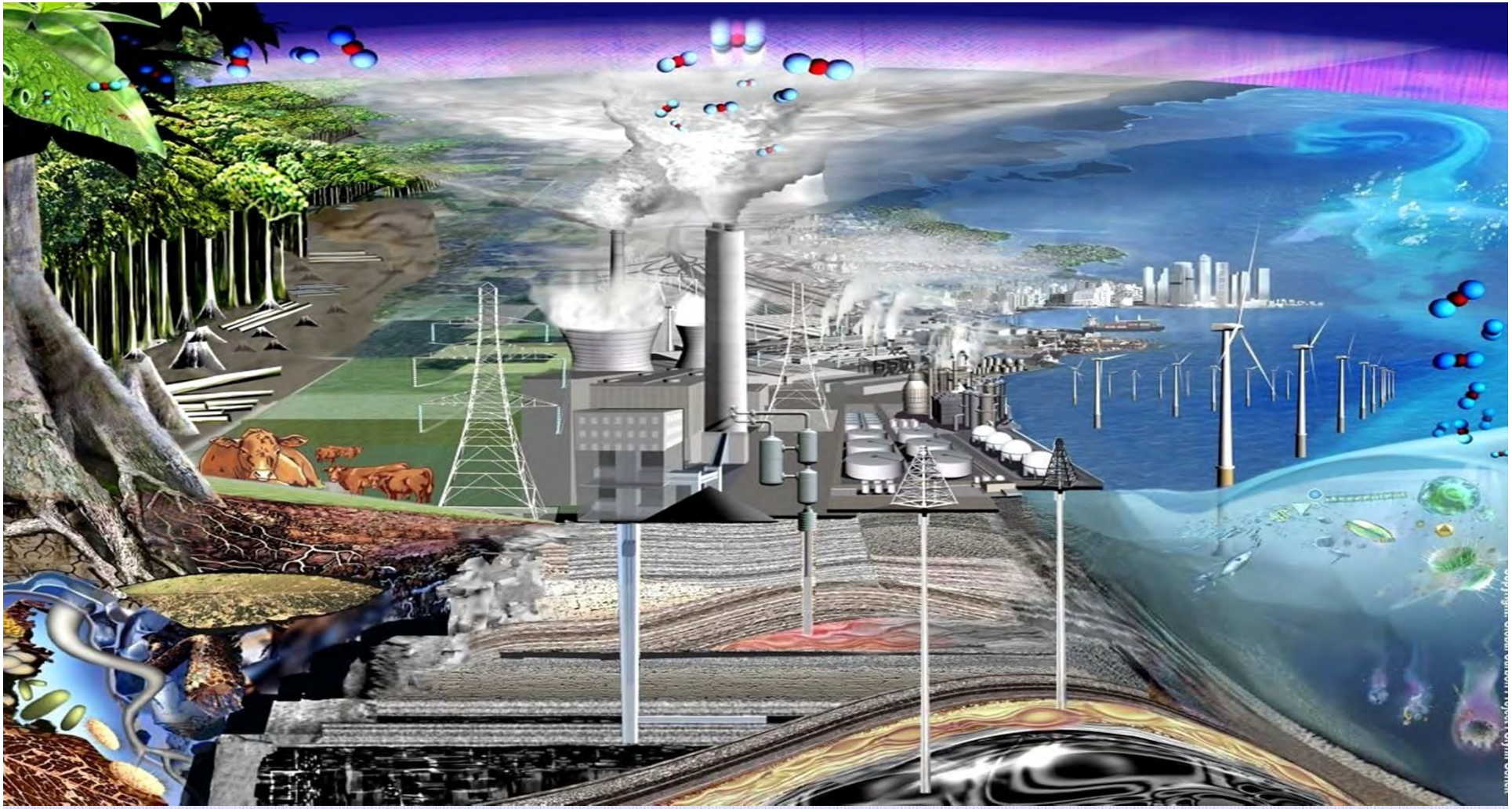


Carbon dioxide has risen by 36% since accurate measurements began in 1958

388 ppm (2008)

318 ppm (1958)

Mauna Loa Observatory on Hawai'i

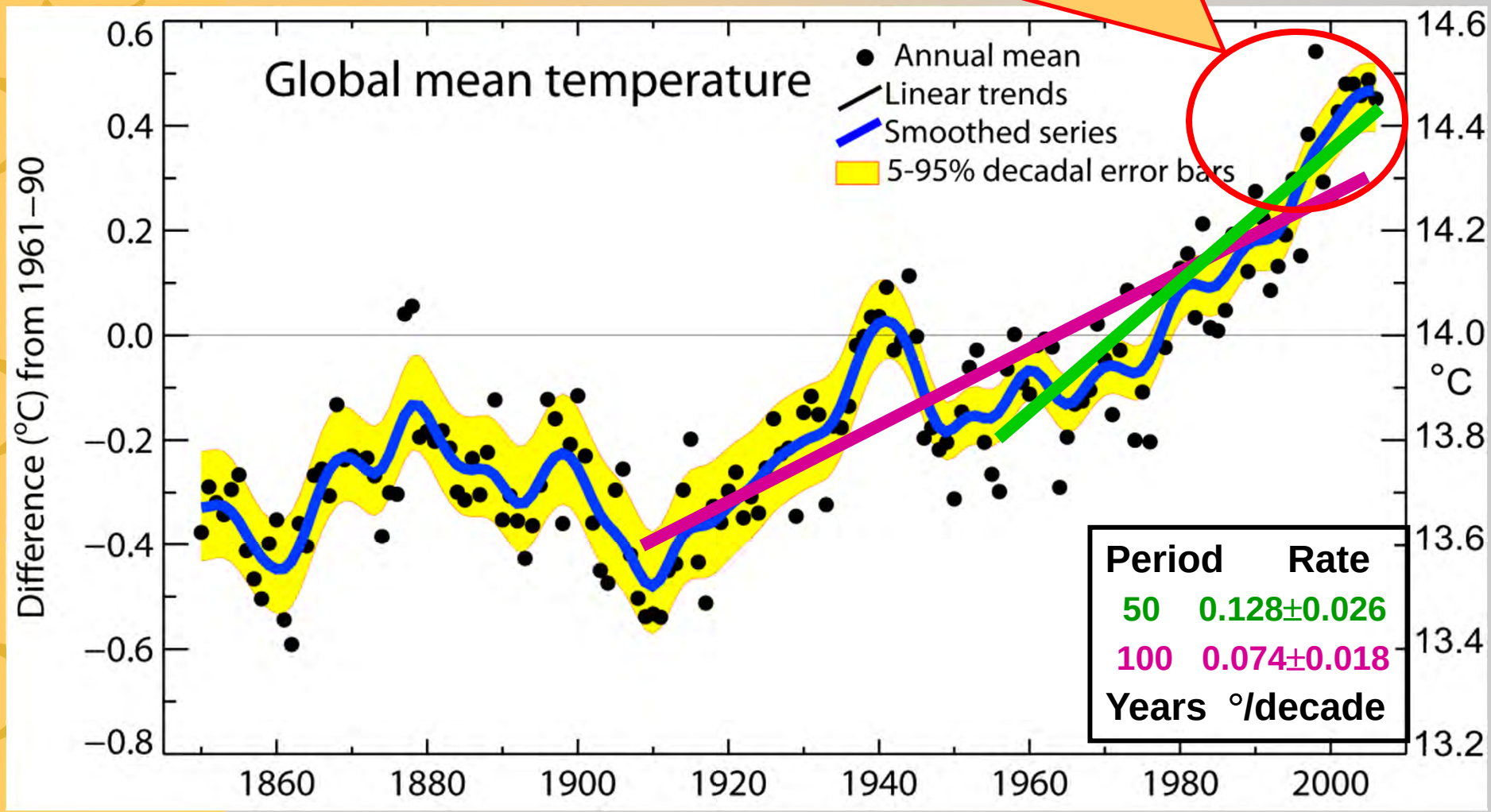


"The rise in CO_2 is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist"

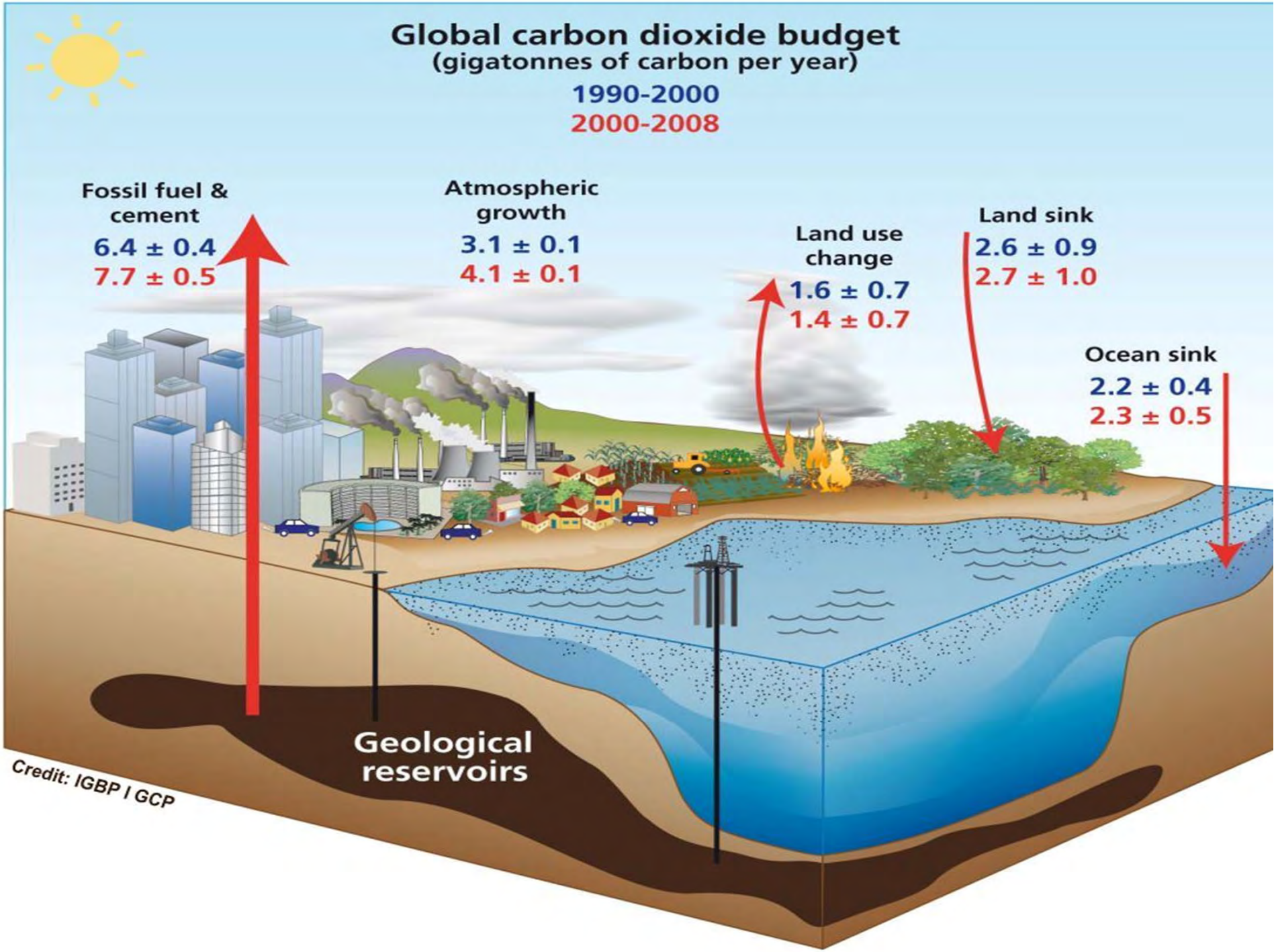
Keeling CD, Harris TB, Wilkins EM, 1968. Concentration of atmospheric carbon dioxide at 500 and 700 millibars. J. Geophys. Res. 73:4511-28

Global mean temper

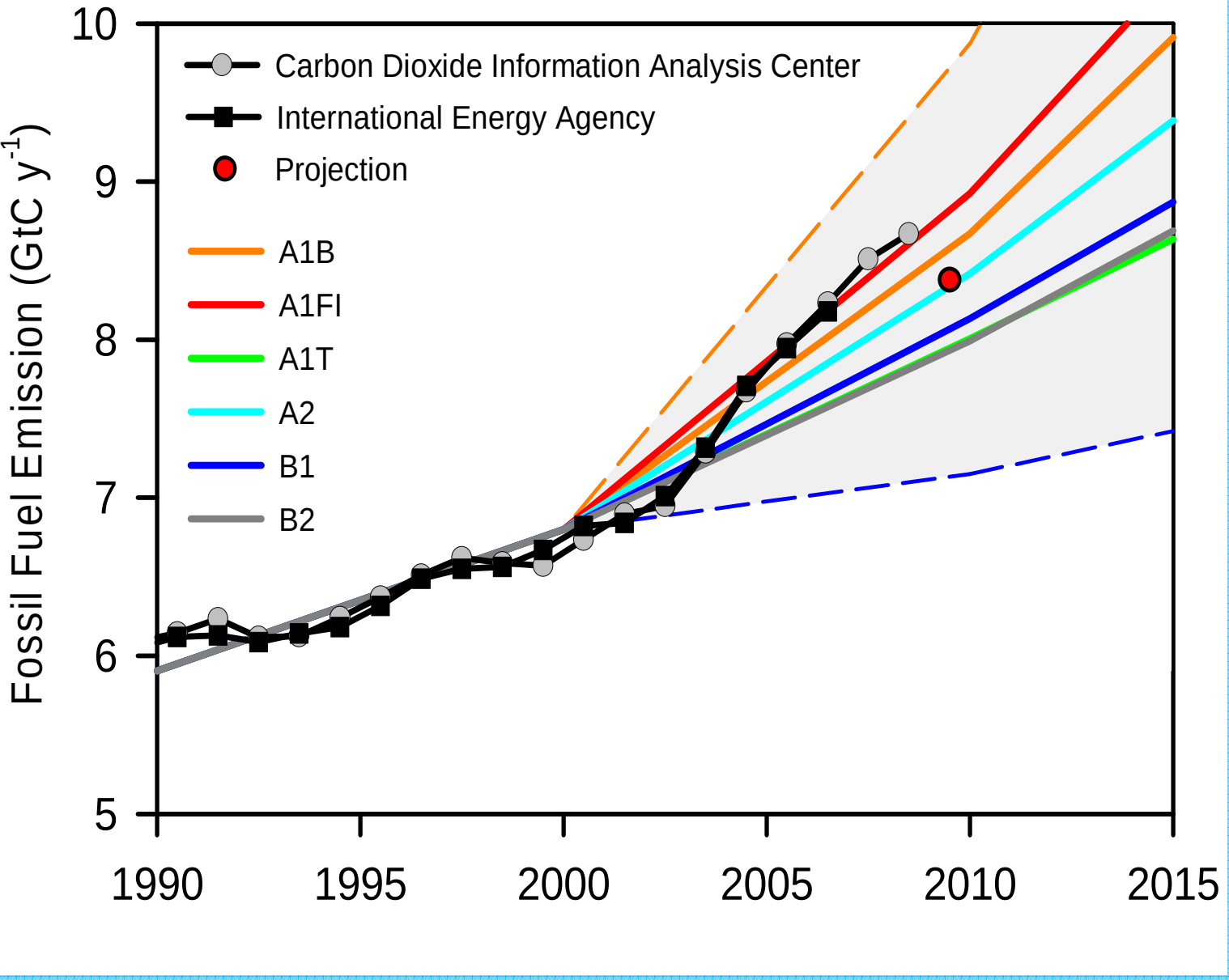
Warmest 12 years:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000




The Atmosphere is very
small


Global carbon dioxide budget
(gigatonnes of carbon per year)
1990-2000
2000-2008
Fossil fuel & cement
6.4 ± 0.4
7.7 ± 0.5
Atmospheric growth
3.1 ± 0.1
4.1 ± 0.1
Land use change
1.6 ± 0.7
1.4 ± 0.7
Land sink
2.6 ± 0.9
2.7 ± 1.0
Ocean sink
2.2 ± 0.4
2.3 ± 0.5
Geological reservoirs
Credit: IGBP I GCP

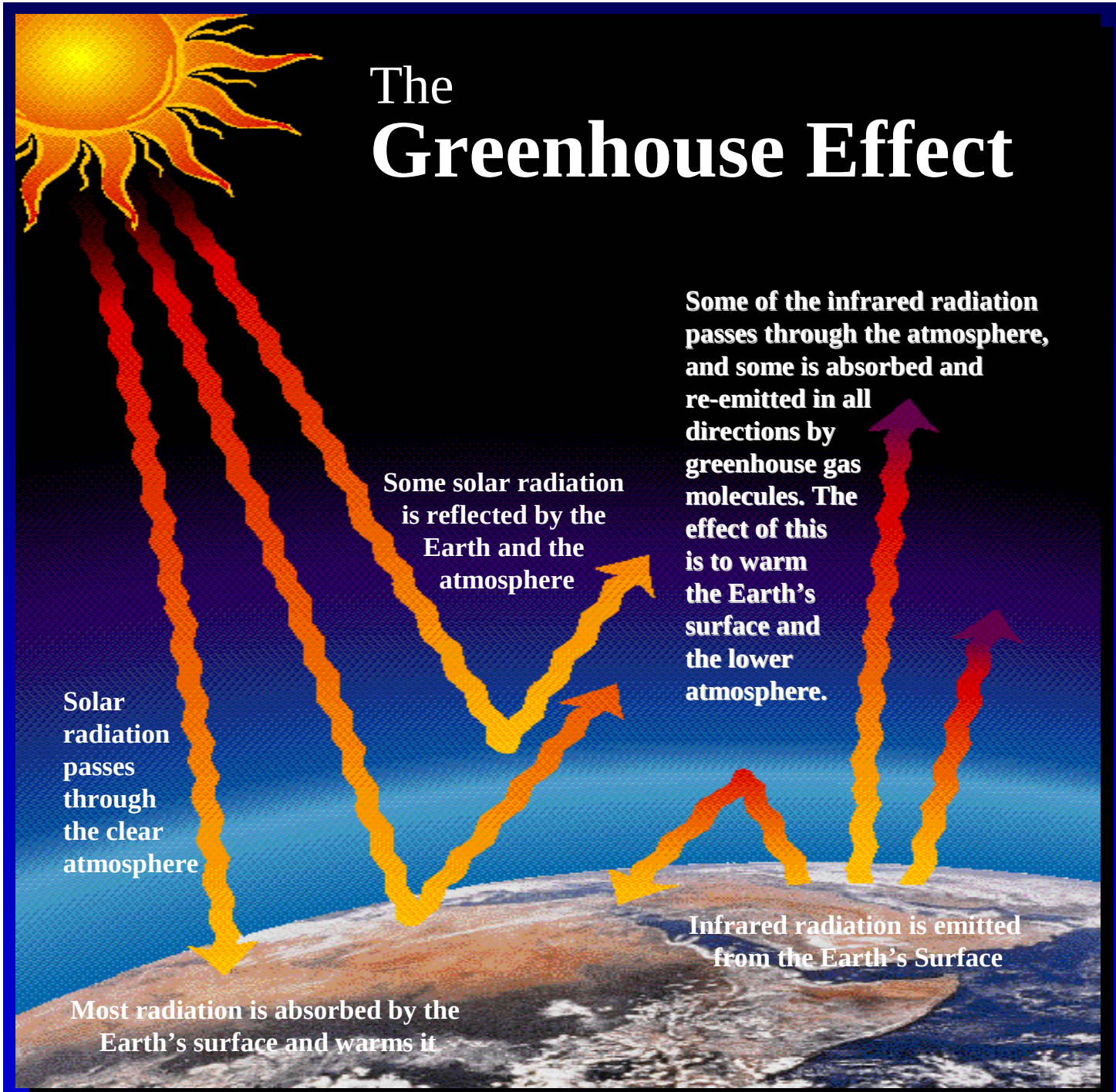
Fossil Fuel Emissions: Actual vs. IPCC Scenarios

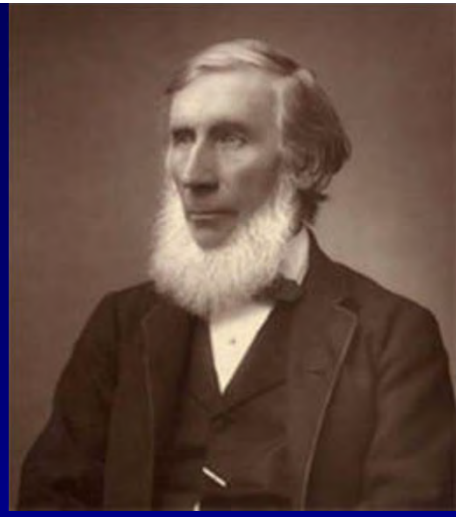


Projection 2009
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature-geoscience; International Monetary Fund 2009

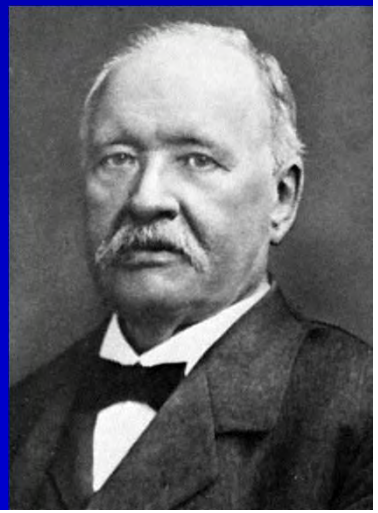
The Greenhouse Effect





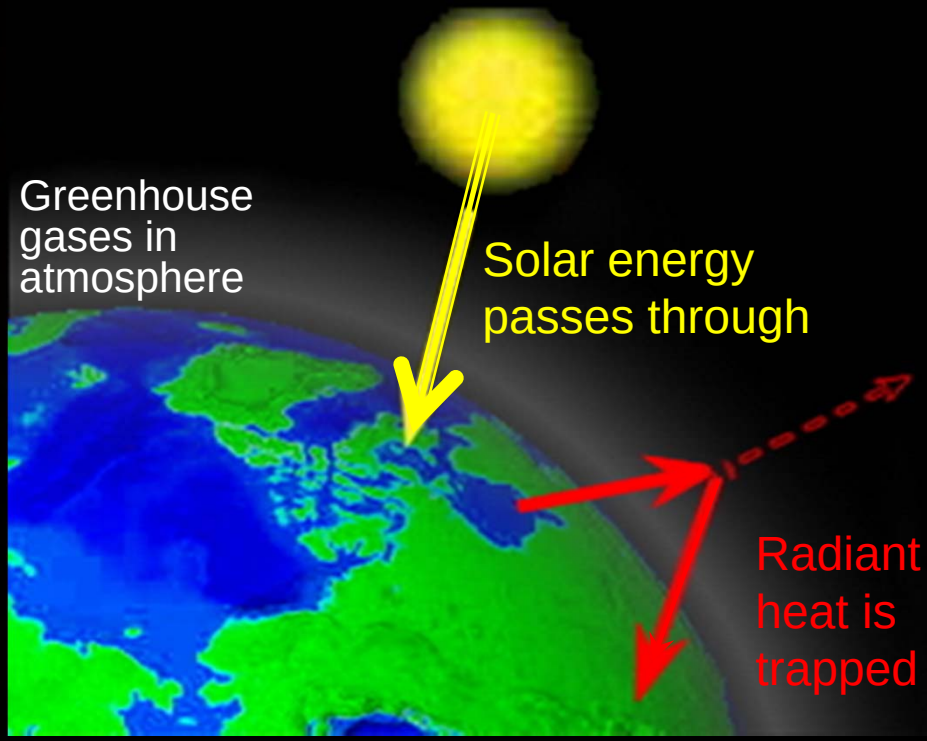
John Tyndall

Svante Arrhenius

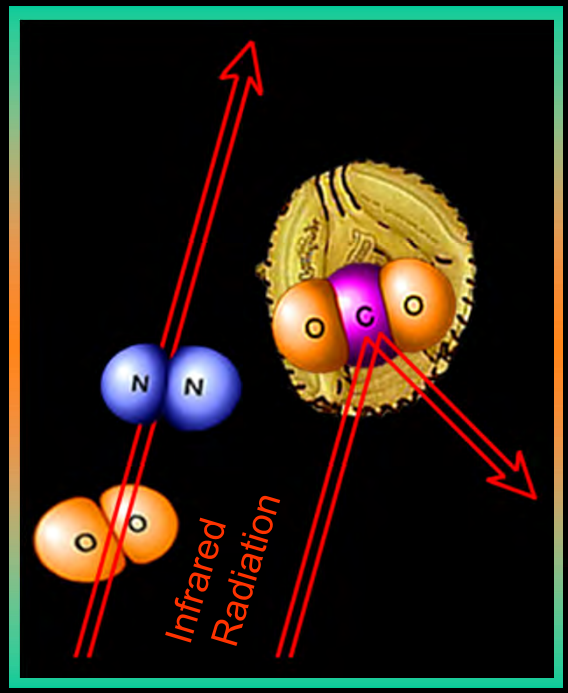


Pollution is the Primary Cause

The "Greenhouse gases" (e.g., carbon dioxide, methane, nitrous oxide, CFC's) trap heat in the earth's atmosphere.



Diagrams: Jennifer Allen



Science understood since 1859 - John Tyndall

Greenhouse Gases

- Water vapor (H_2O)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Other - Direct
  - Nitrous oxide (N_2O)
  - Fluorocarbons
- Other - Indirect
  - Carbon monoxide (CO)
  - Nitrogen oxides (NO_x)

Greenhouse Gases – Water Vapor

- Most abundant and important GHG
- Keeps earth warm enough for liquid water to form
- Varies in concentration in the lower atmosphere from nearly 0% to 4%
- Not considered important in anthropogenic climate change
  - Naturally correcting

Energy Transfer Mechanisms

Radiation

Conduction

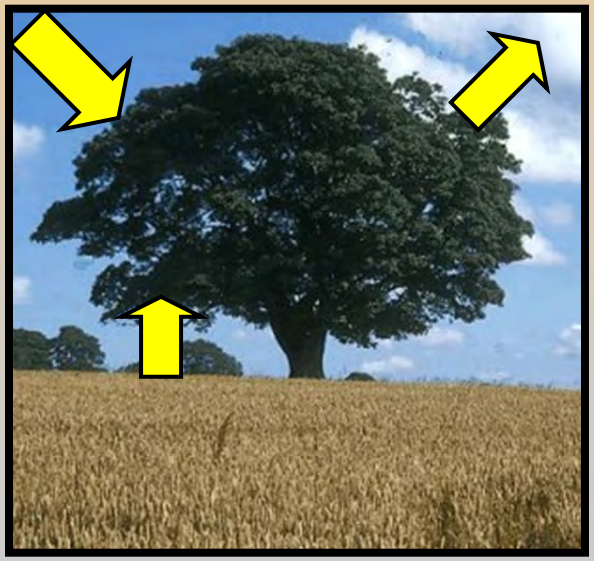
Convection

Important Radiation Laws & Concepts

Net radiation

$$Rn = \text{incoming} - \text{outgoing}$$

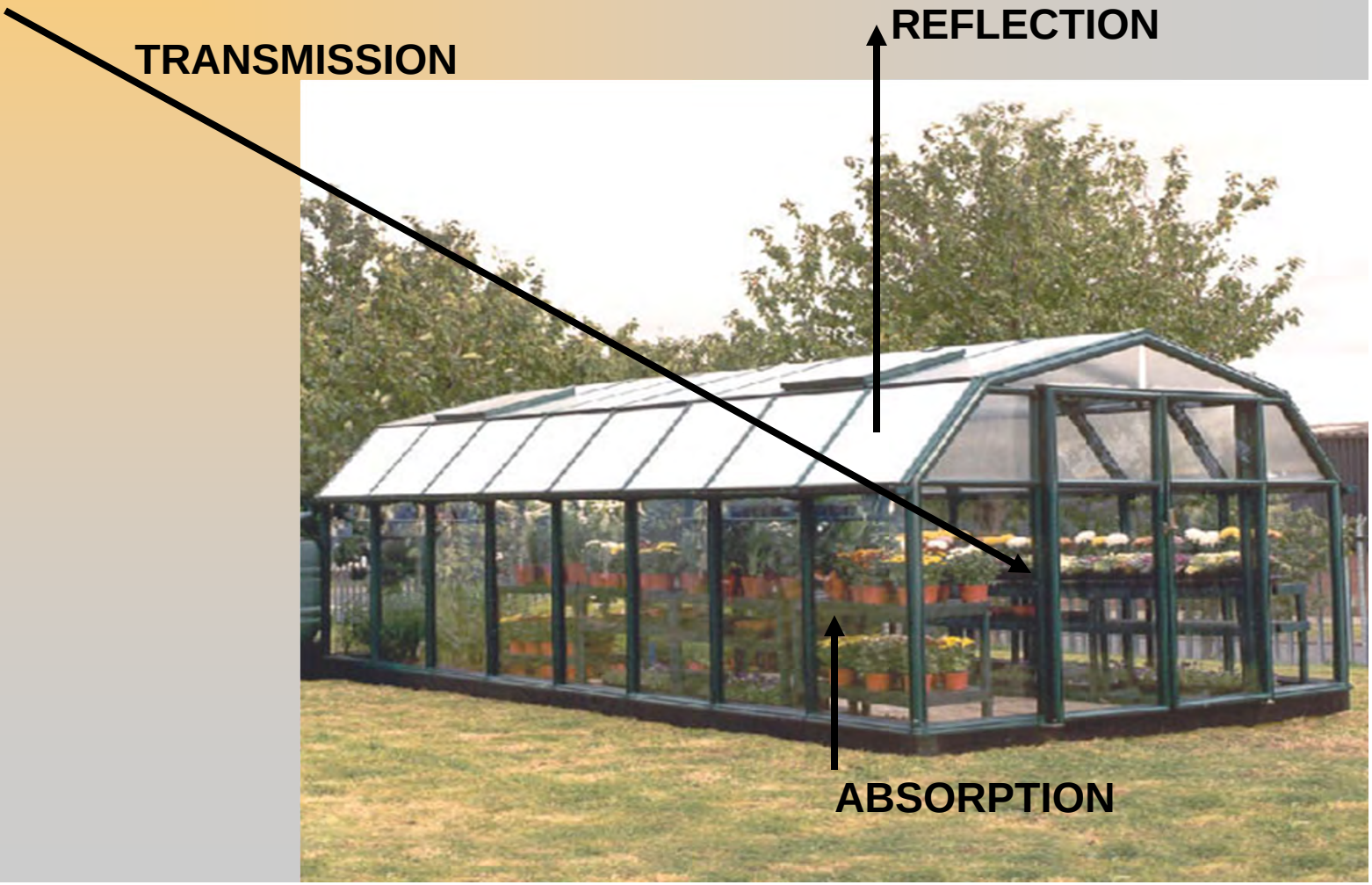
$$Rn = (1- \alpha)I_s + E_L \sigma T^4(\text{surface}) - \sigma T^4(\text{sky})$$



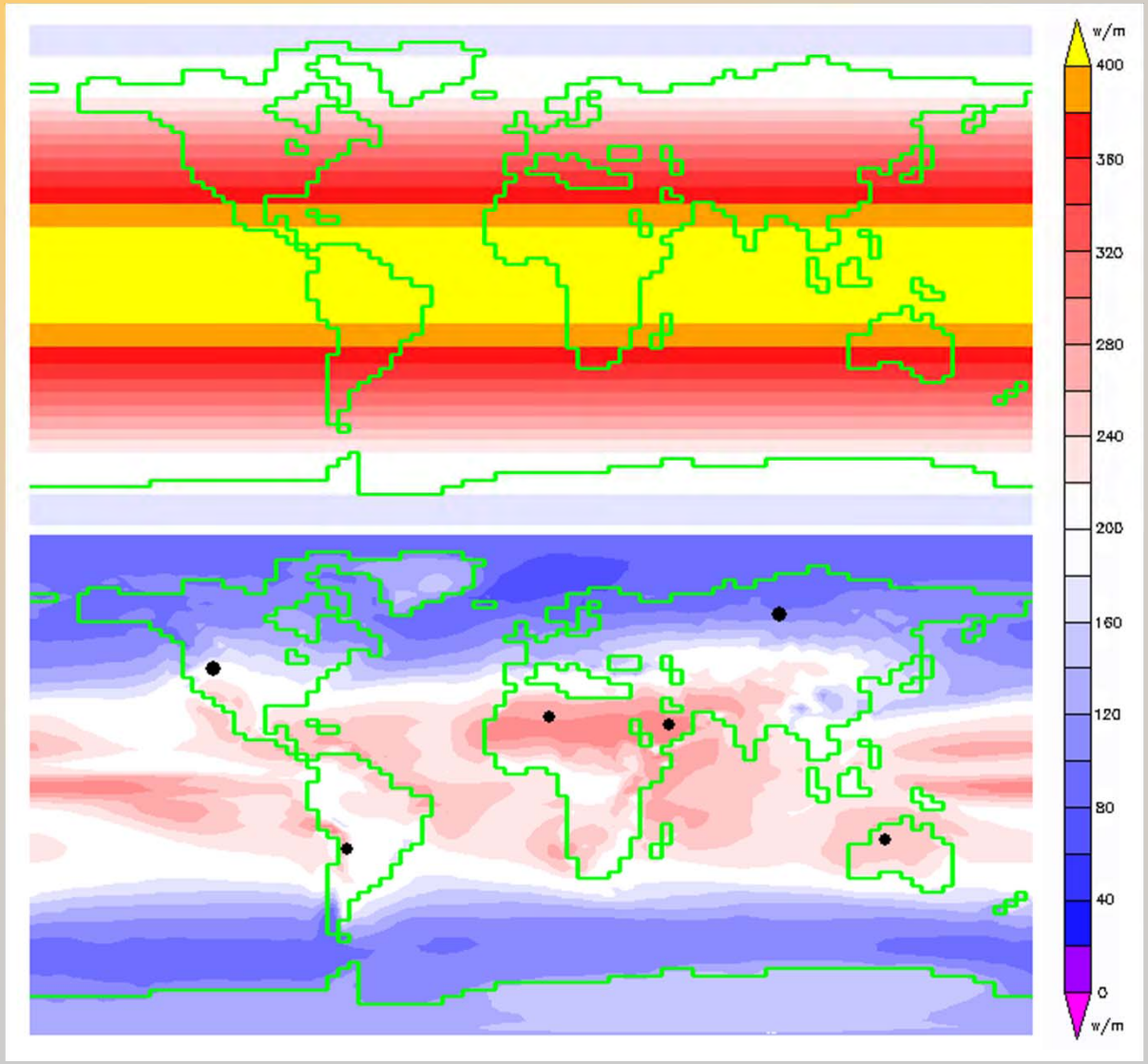
α is ***albedo***, which is the reflectivity of a surface

fresh snow has a high albedo (0.9)
dark forest has a low albedo (0.05 – 0.15)
light colored soils are in between (0.4 – 0.5)
mean albedo for earth ≈ 0.36

RADIATION TRANSFER

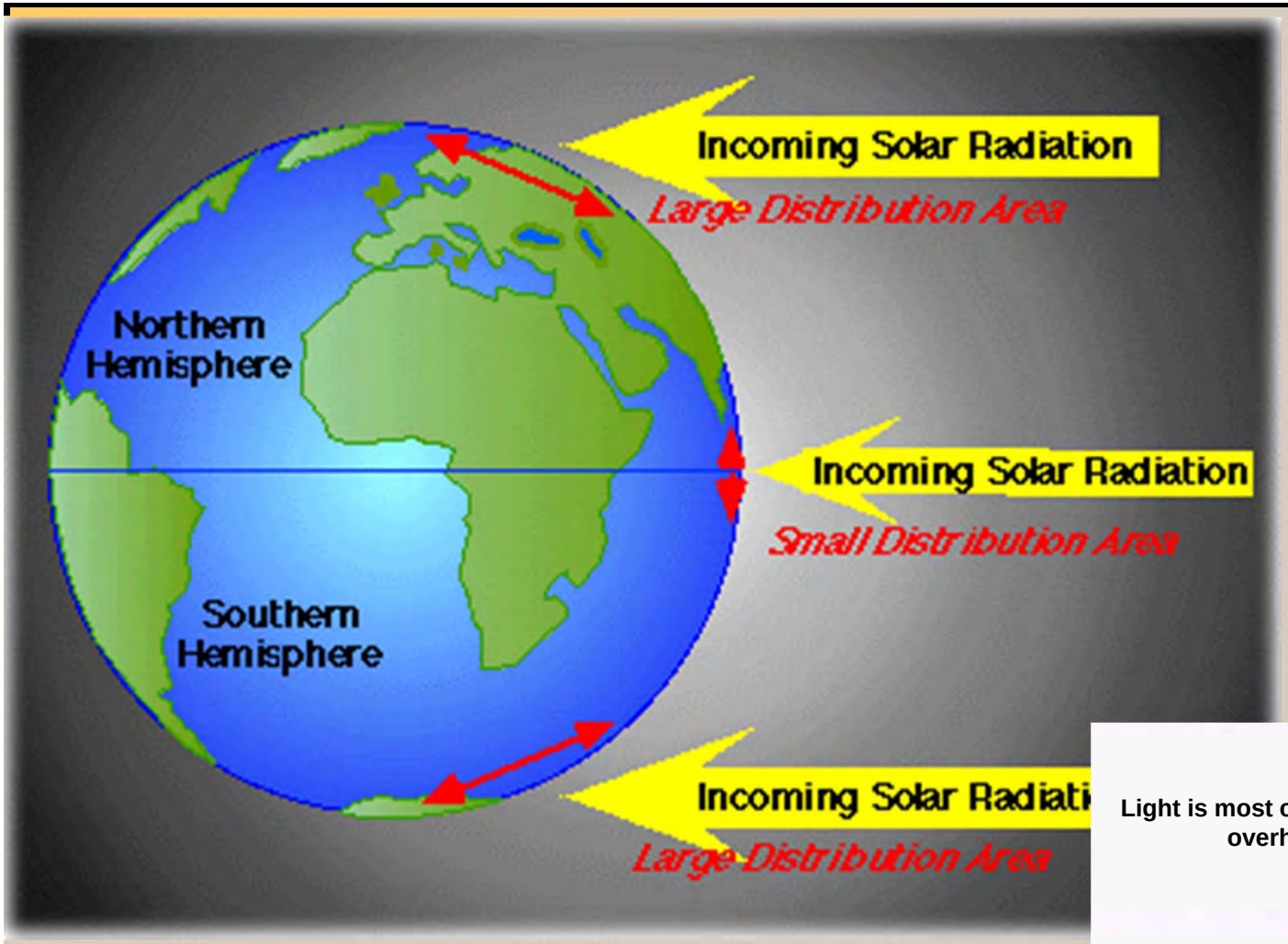


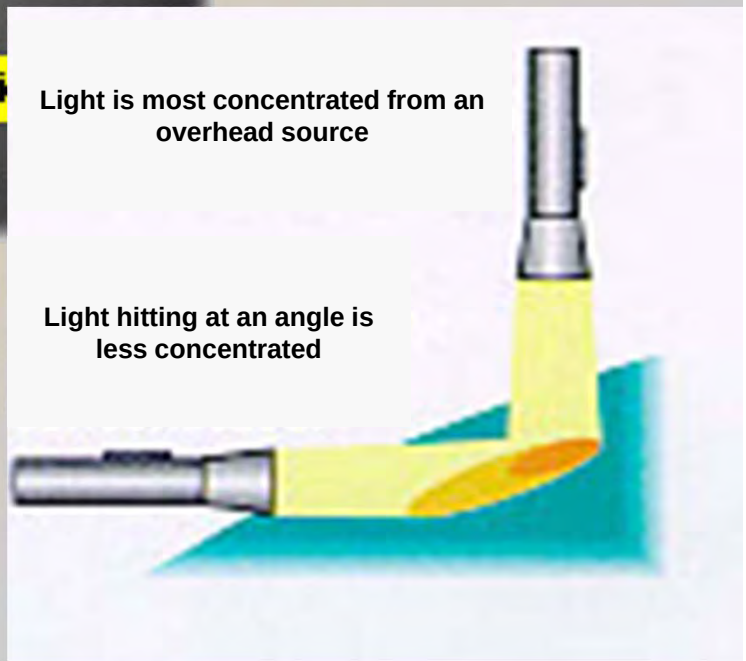
Annual Average Insolation

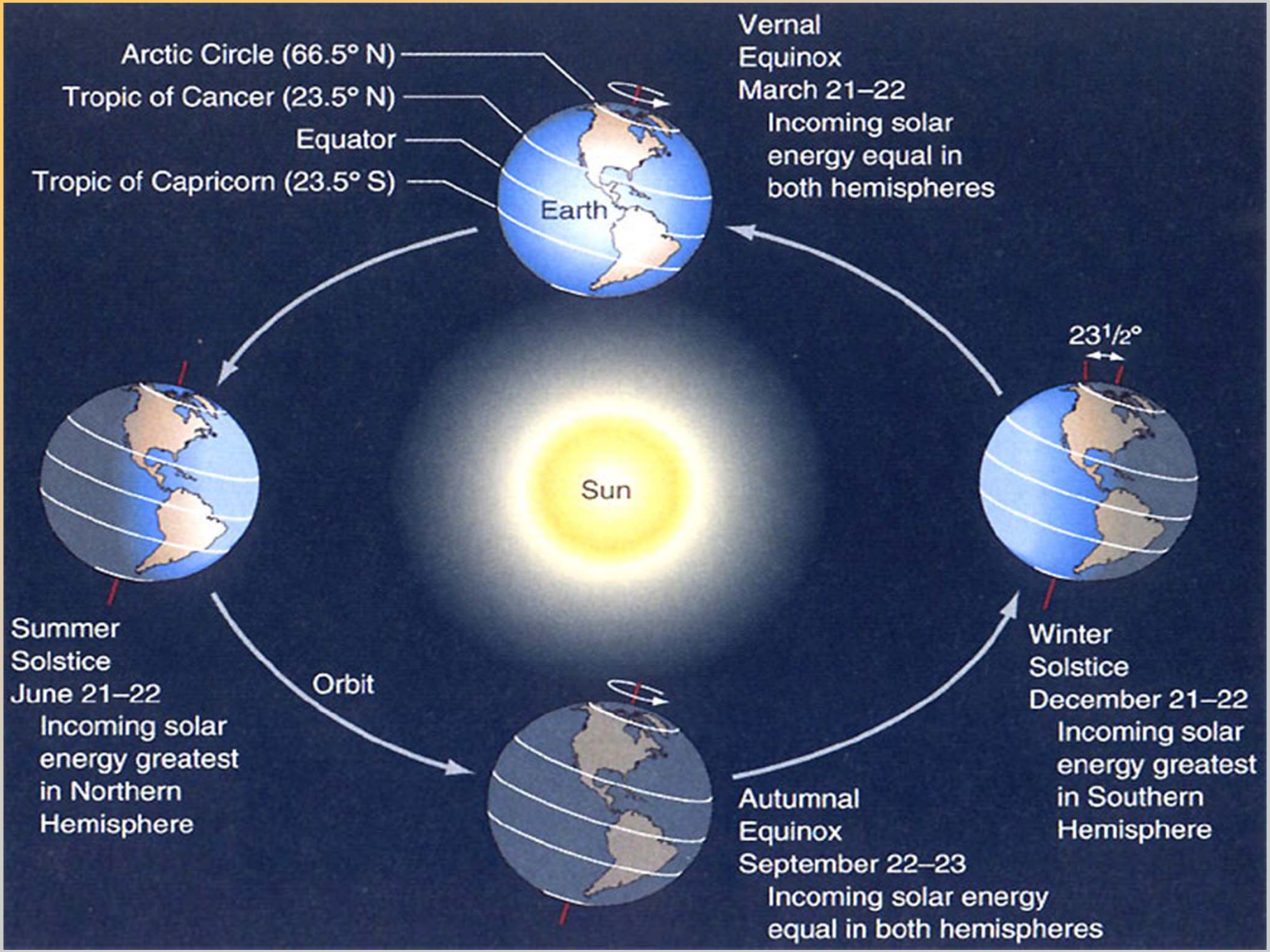


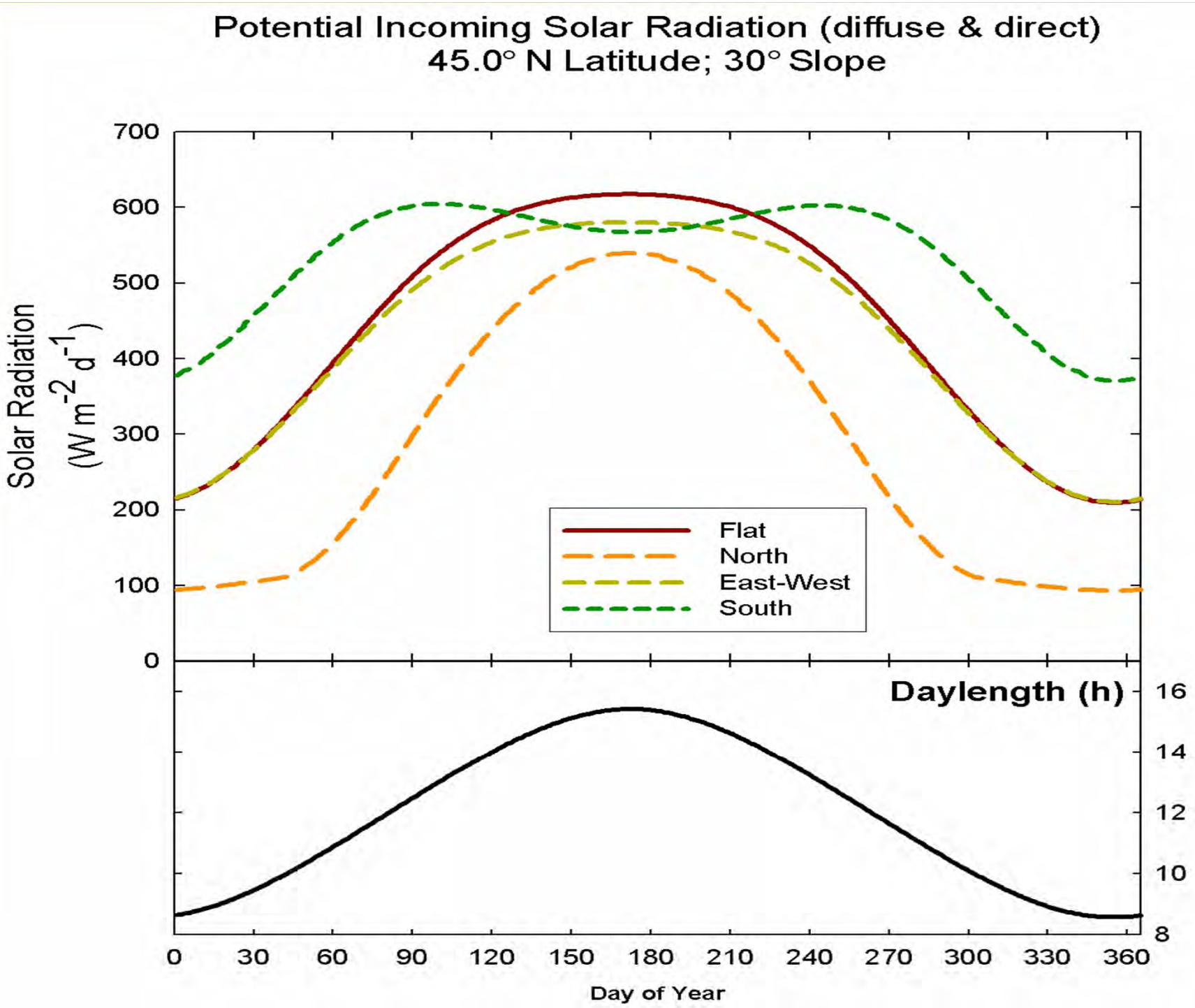
Top Of Atmosphere

Earth's Surface


Incoming Solar Radiation
Large Distribution Area
Northern Hemisphere
Incoming Solar Radiation
Small Distribution Area
Southern Hemisphere
Incoming Solar Radiati
Large Distribution Area


Light is most concentrated from an overhead source
Light hitting at an angle is less concentrated

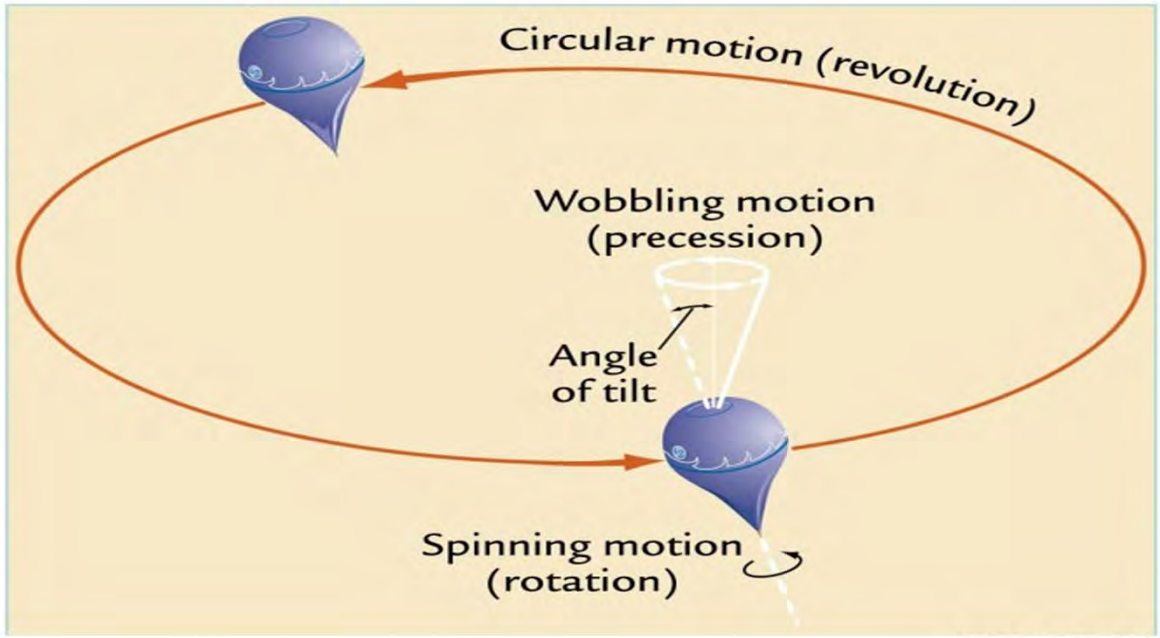

Arctic Circle (66.5° N)
Tropic of Cancer (23.5° N)
Equator
Tropic of Capricorn (23.5° S)
Earth
Vernal
Equinox
March 21–22
Incoming solar
energy equal in
both hemispheres
23½°
Sun
Summer
Solstice
June 21–22
Incoming solar
energy greatest
in Northern
Hemisphere
Orbit
Winter
Solstice
December 21–22
Incoming solar
energy greatest
in Southern
Hemisphere
Autumnal
Equinox
September 22–23
Incoming solar energy
equal in both hemispheres

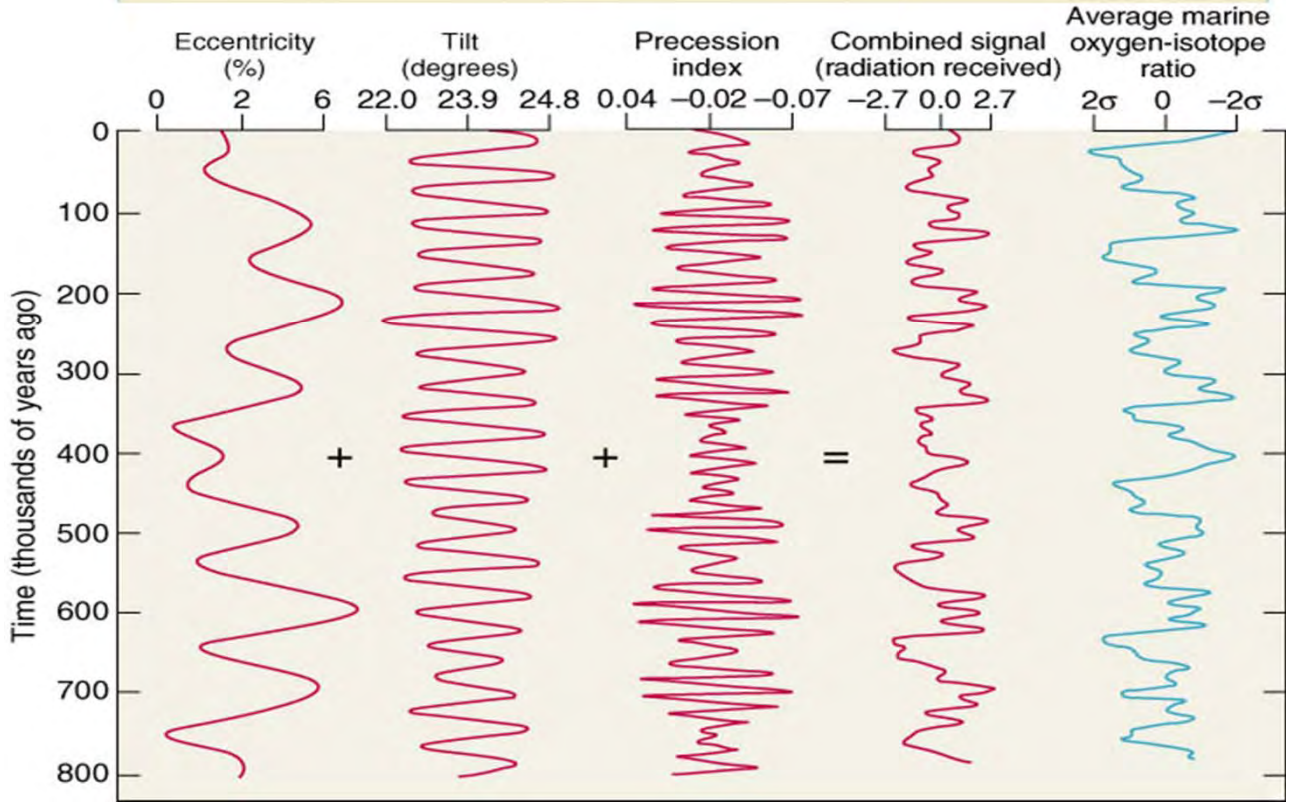

Potential Incoming Solar Radiation (diffuse & direct)
45.0° N Latitude; 30° Slope
Solar Radiation
(W m-2 d-1)
700
600
500
400
300
200
100
0
Flat
North
East-West
South
Daylength (h)
16
14
12
10
8
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year

1911: Milutin Milankovitch proposes:

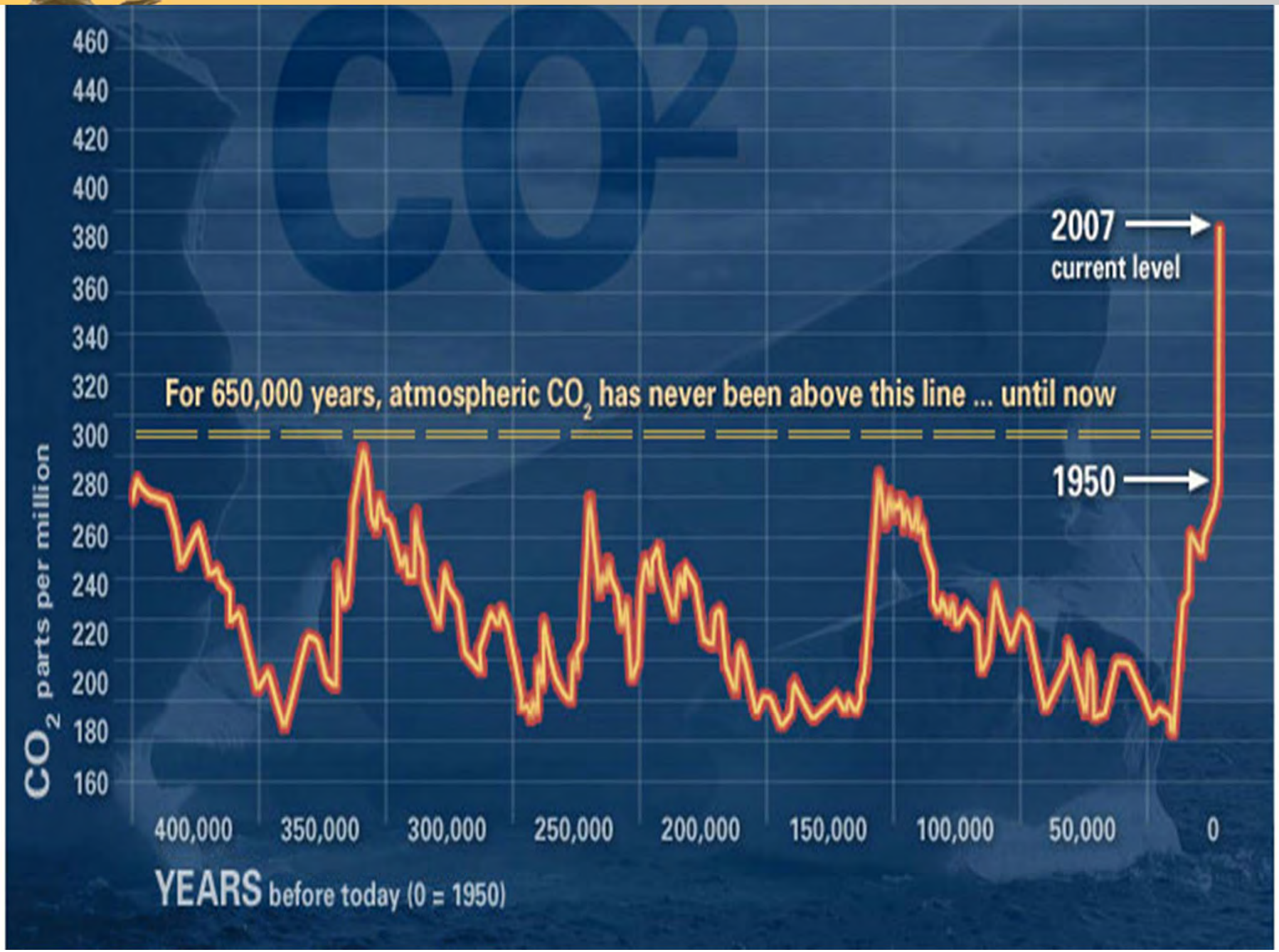
All 3 cycles (23, 41, & 100 KYA) together contro ice age

Summer insolation is driver

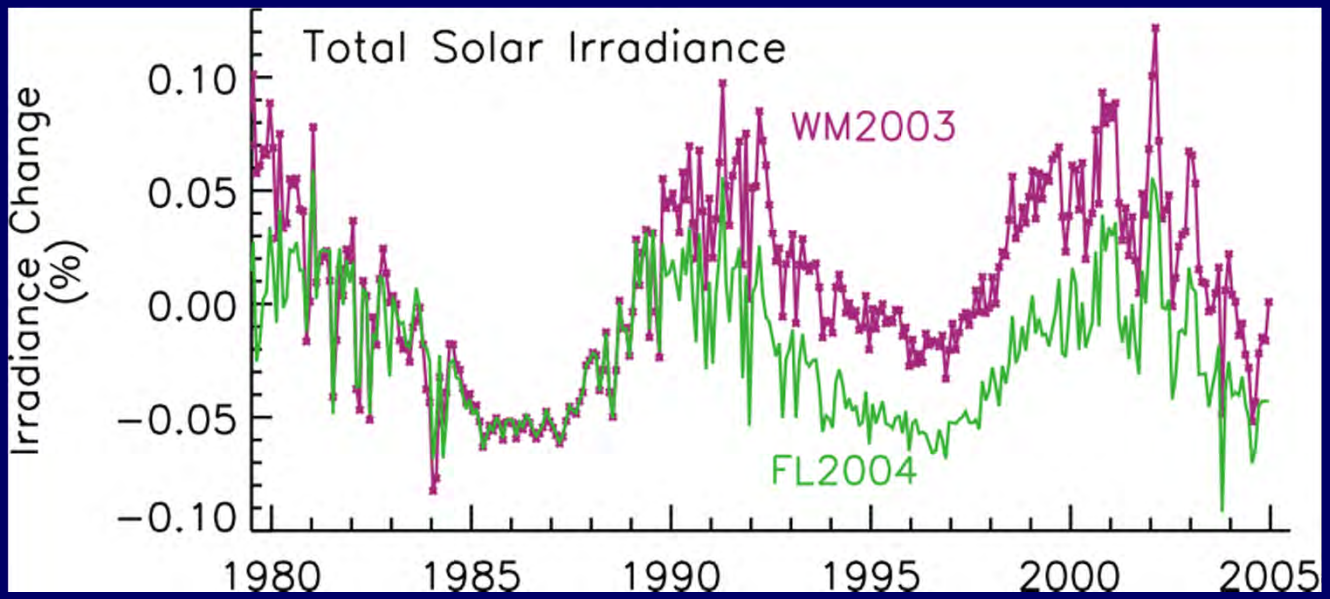


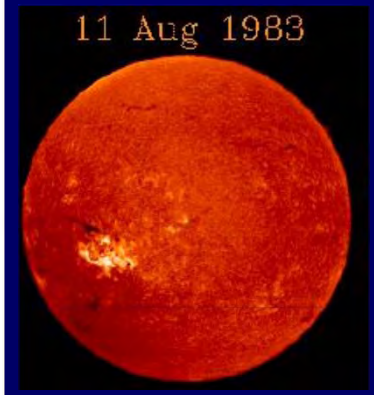


Credit: Anna Klene


460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
CO2 parts per million
2007
current level
For 650,000 years, atmospheric CO2 has never been above this line ... until now
1950
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
YEARS before today (0 = 1950)

Better and longer satellite data about the Sun



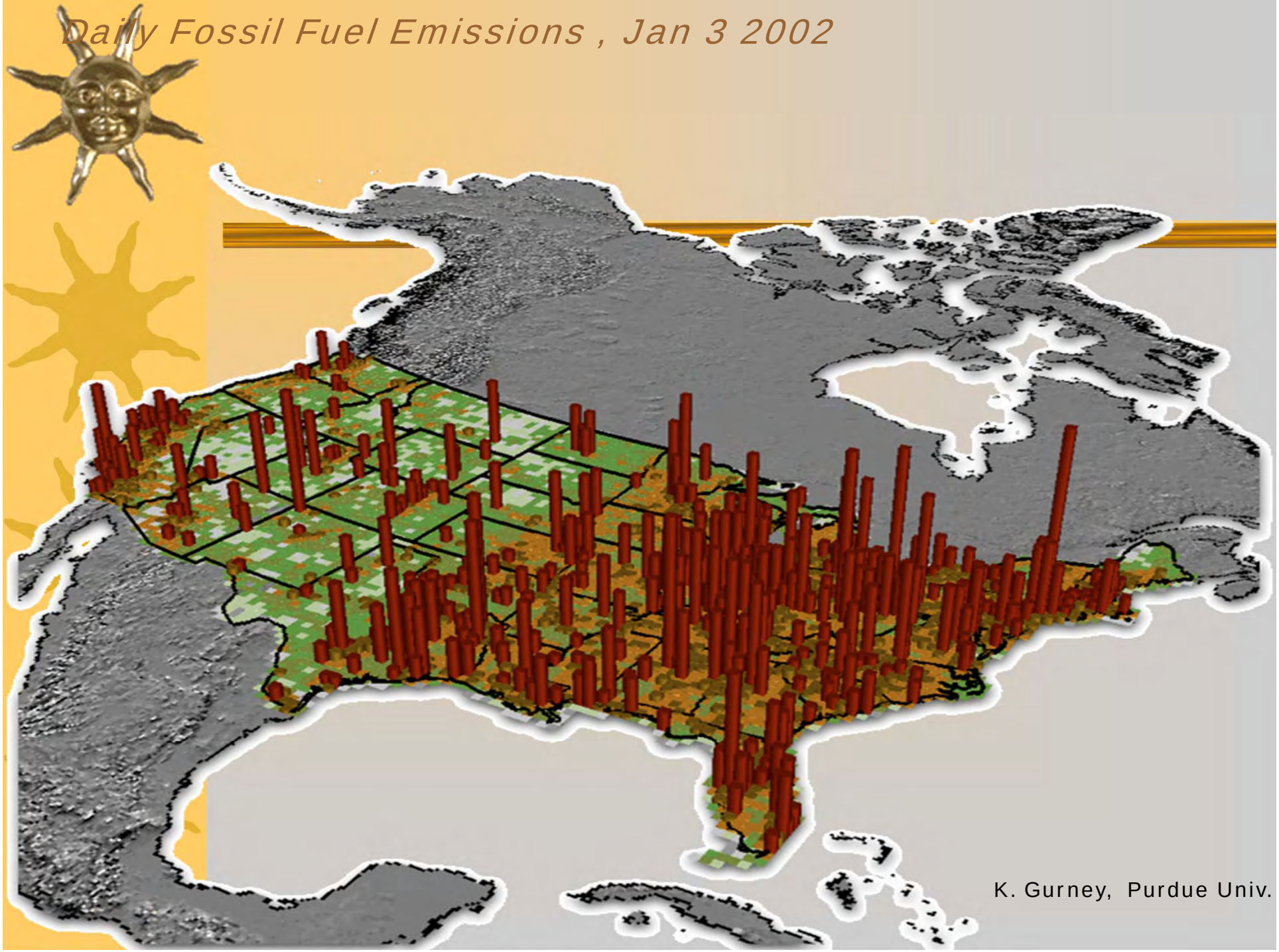


Improved assessment:

a) no observed trend in solar irradiance since 1978 using high quality inter-calibrated data; b) spectral information c) solar magnetic flux model rather than proxy data; d) re-evaluation of variations in Sun-like stars.

Solar irradiance forcing much smaller than GHG.

Daily Fossil Fuel Emissions , Jan 3 2002



K. Gurney, Purdue Univ.

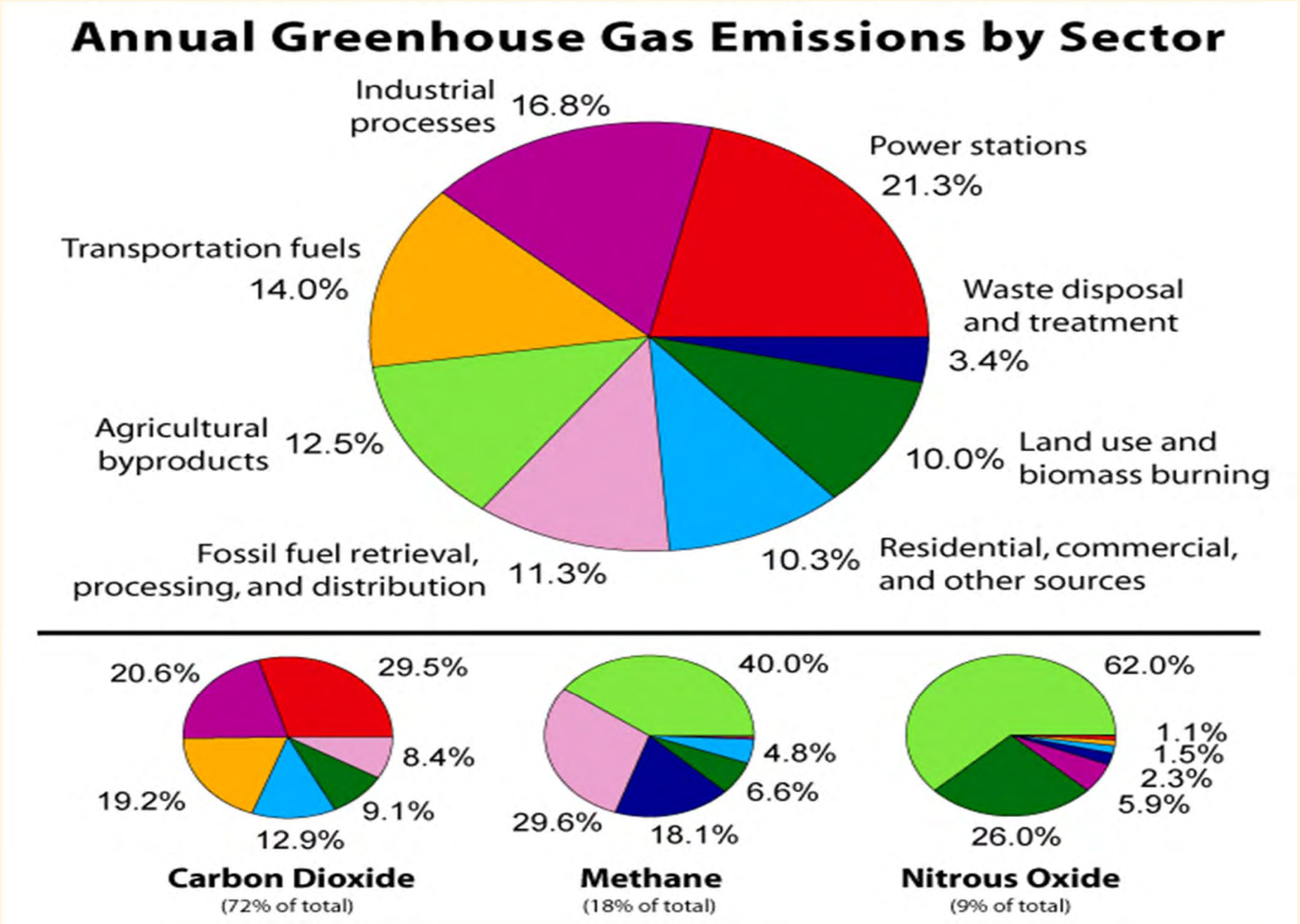
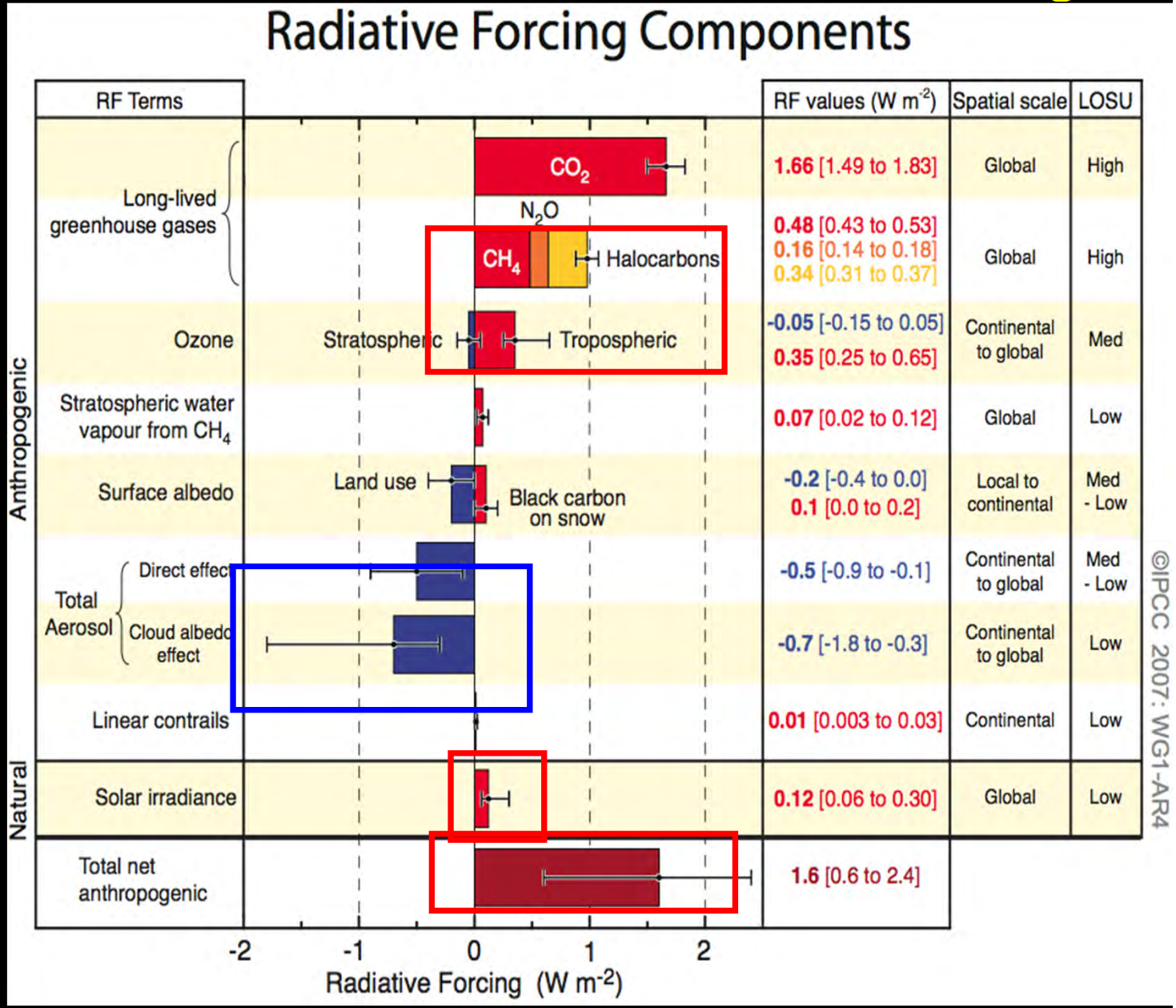


Image Credit: Robert A. Rohde, Global Warming Art

Human and Natural Drivers of Climate Change

1.6 W m^{-2} warms like 1.6 Xmas tree lights over every m^2 on Earth.

Carbon dioxide is causing the bulk of the forcing, and it lives a long time in our atmosphere so every year of emission means commitments to climate change for future generations.



Variations of the Earth's surface temperature; 1000 to 2100

1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections