



Hot Topics in Climate 1: Global Warming

Warren Wiscombe

NASA Goddard

Note: there is some supplementary material at the end

TV segment about global warming from 1958 (1 min)

Recommended movie: Climate Science 1956 (10 min)

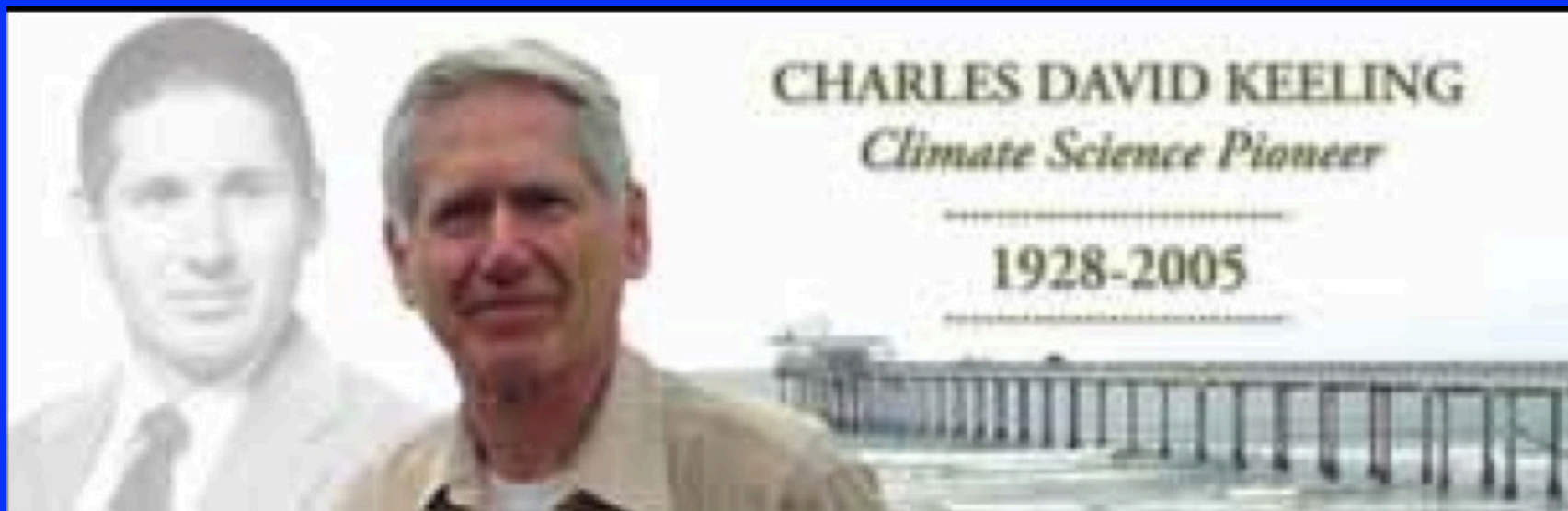
<http://www.youtube.com/user/wwiscombe>

begins with classic TV science show from 1956

interview with Plass

shows advanced understanding of CO₂ problem

clips from great movie "Earth: The Biography"



Charles Keeling: Climate-Quality CO₂ measurements

Began measuring CO₂ in mid-1950s as student

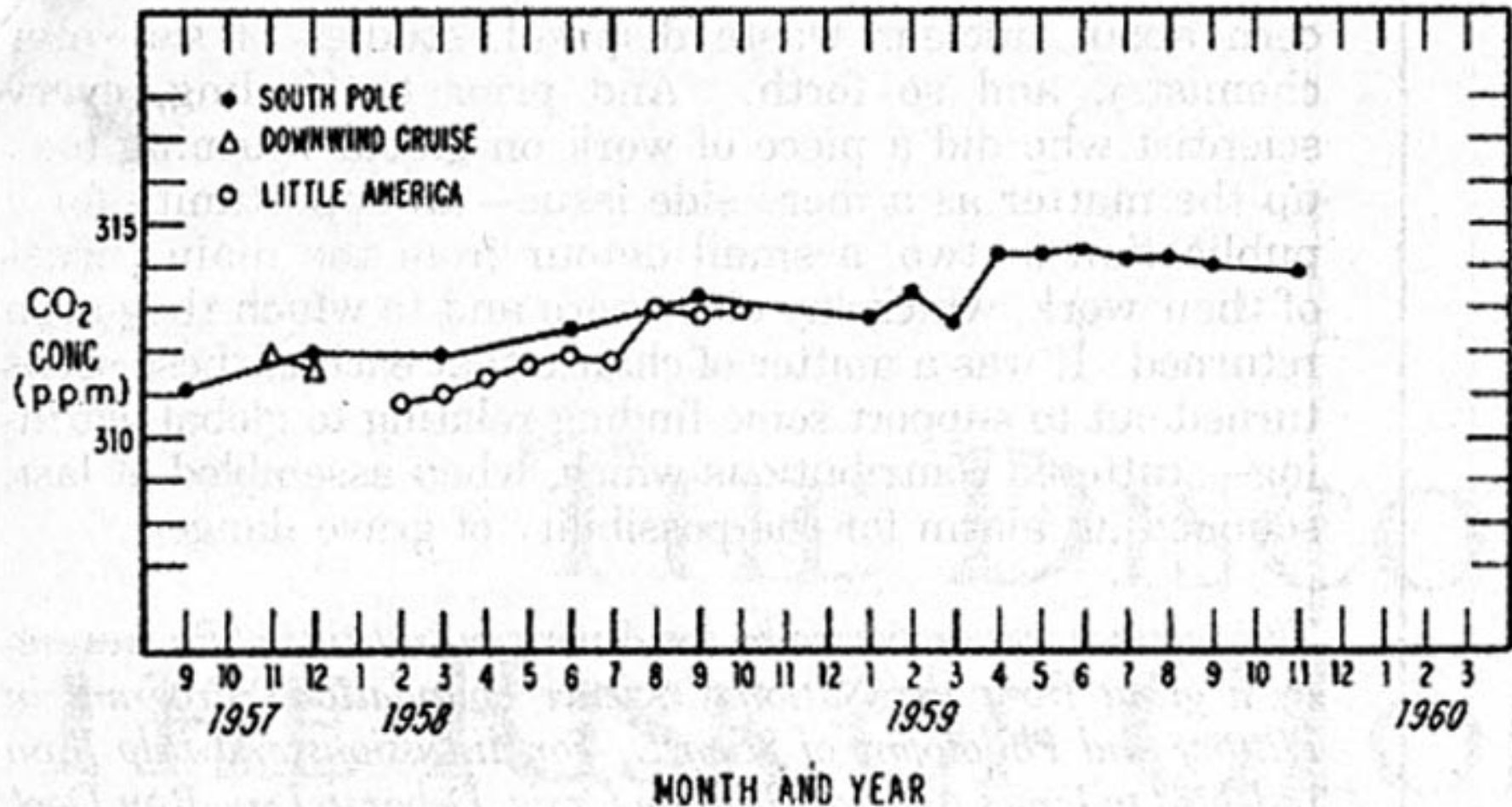
Kept finding a minimum value of 315 ppm no matter where he measured CO₂.

(Callendar calculated 290 ppm for 1900)

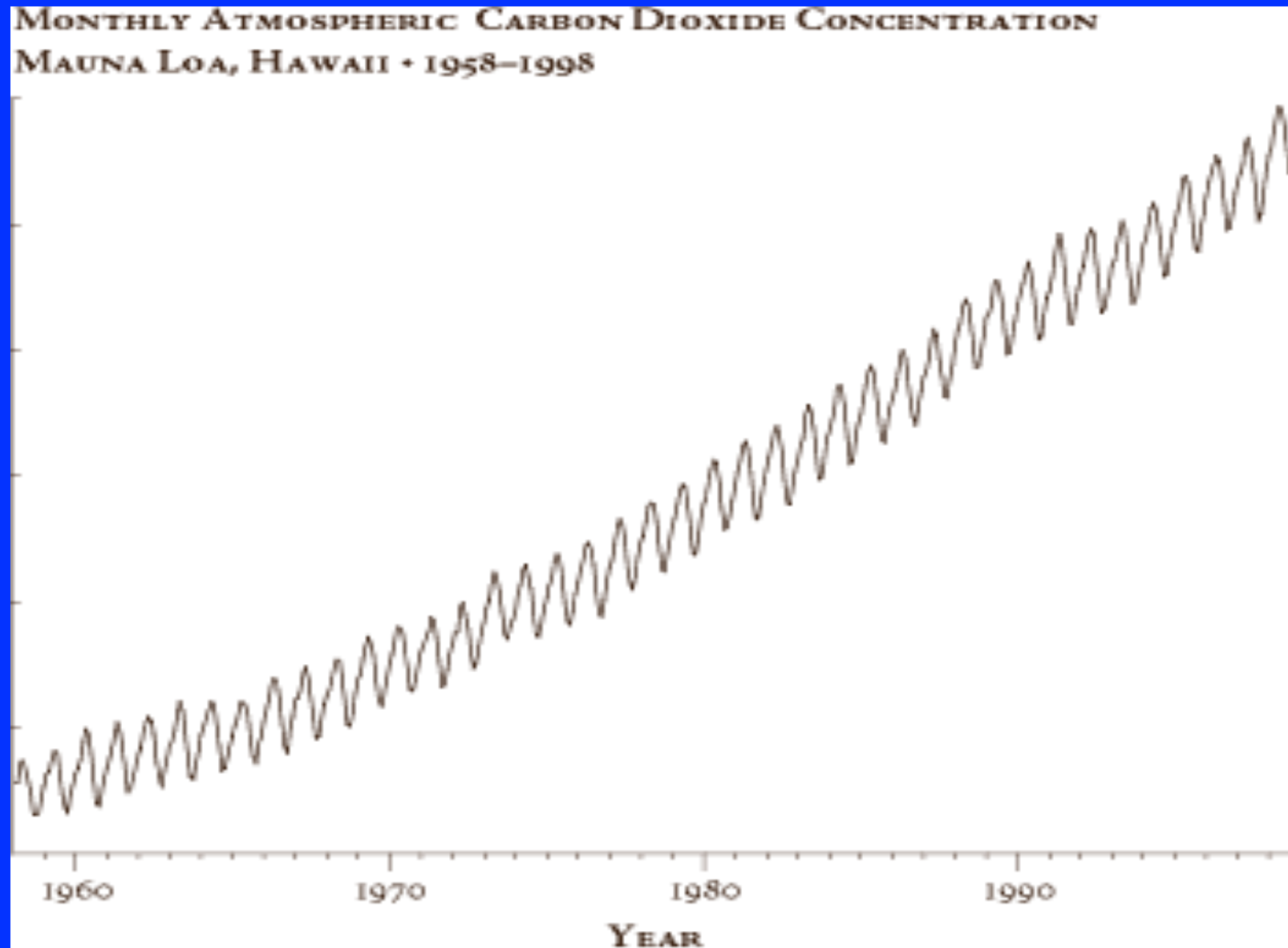
Joined 1957 International Geophysical Year

CO₂ increase obvious at South Pole after only two years

First published graph by Keeling, Tellus, 1960



Keeling's graph: the first icon of climate change



Timeline - 1950s

Suess (1953): declining ^{14}C in atmos is smoking gun for human causation of CO_2 rise

Revelle: oceans take < half of extra CO_2

Much better H_2O absorption meas'ts

Plass: physicist, radiative transfer expert, crusader for CO_2 theory of climate change

Hans Suess: belonged to Willard Libby's group
that developed ^{14}C dating

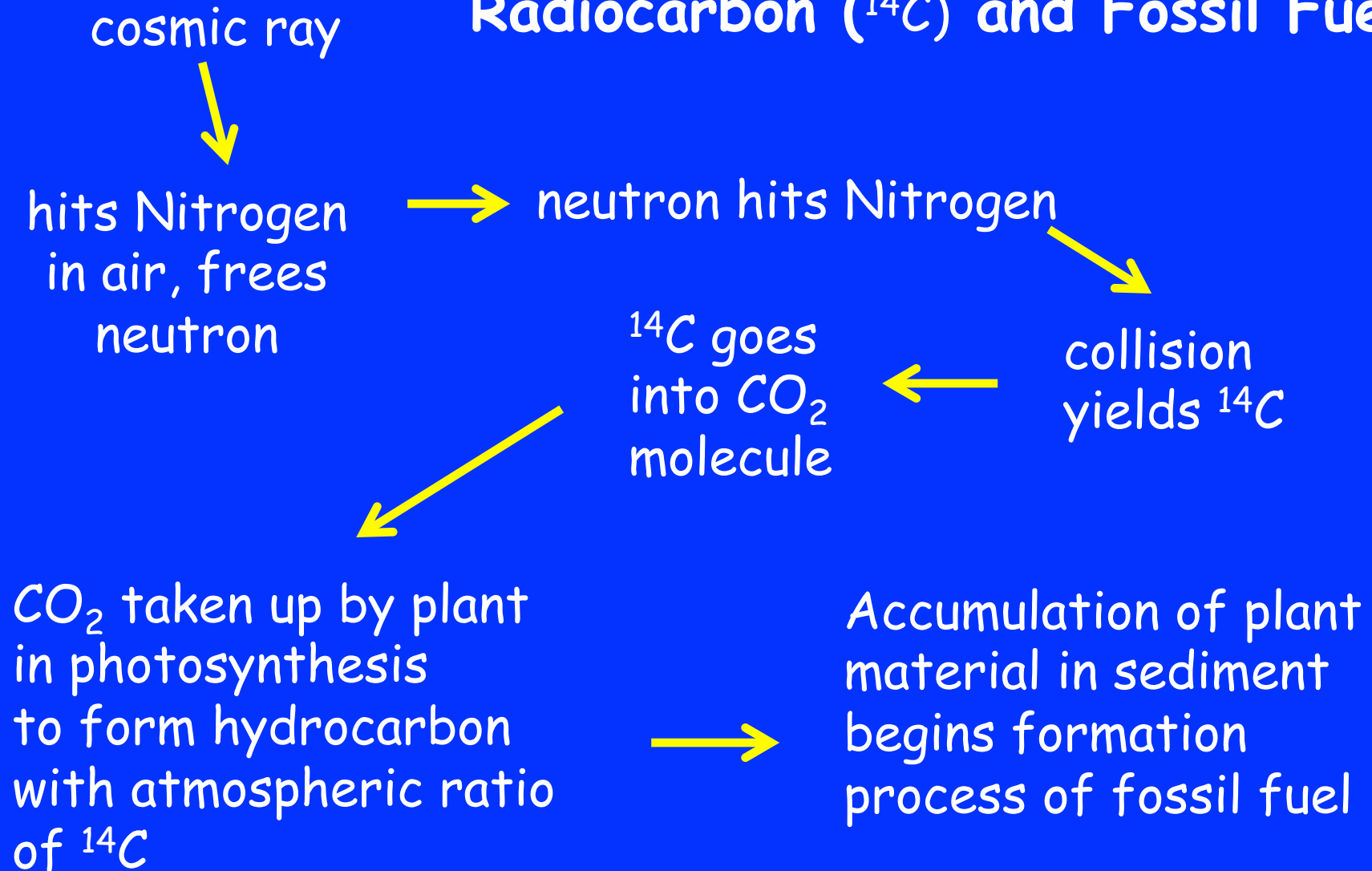


Measured carbon isotopes in
tree rings

1955: pre-bomb increase in ratio
 $^{12}\text{C}/^{14}\text{C}$ in post-1900 tree rings
proved that *ancient carbon was
being added to modern
atmosphere by human burning.*

Revelle hired Suess at Scripps

Radiocarbon (^{14}C) and Fossil Fuel



The ^{14}C evidence (^{12}C is normal)

Dead plant matter becomes fossil fuels

^{14}C decays with a half life of $\sim 5,700$ years

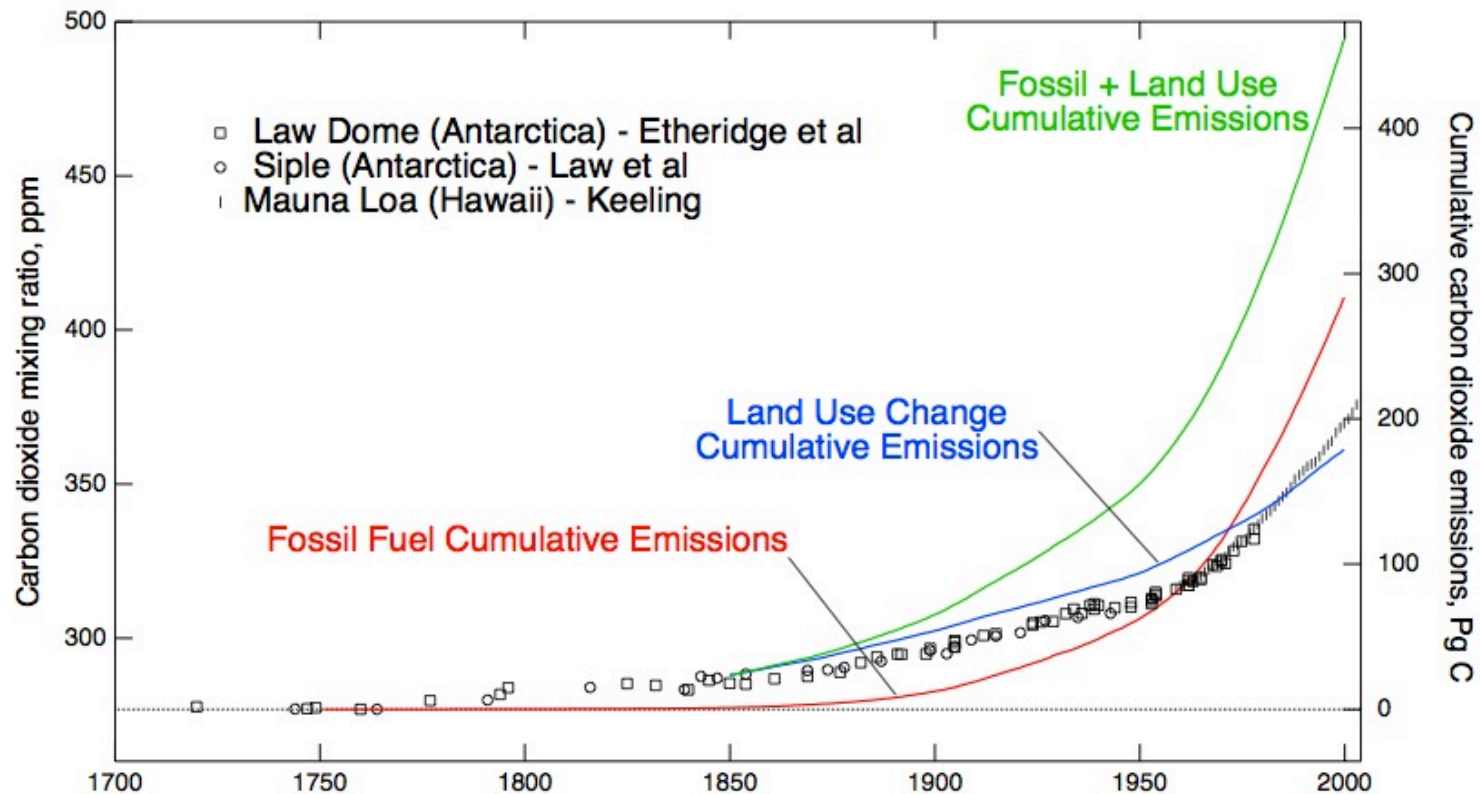
Plant matter in fossil fuels is millions of yr old, so contains no remaining ^{14}C .

Atmos'c ^{14}C is decreasing with time at right rate to be explained by fossil fuel burning.

"Smoking gun" that new carbon in atmospheric CO_2 is from fossil fuel burning.

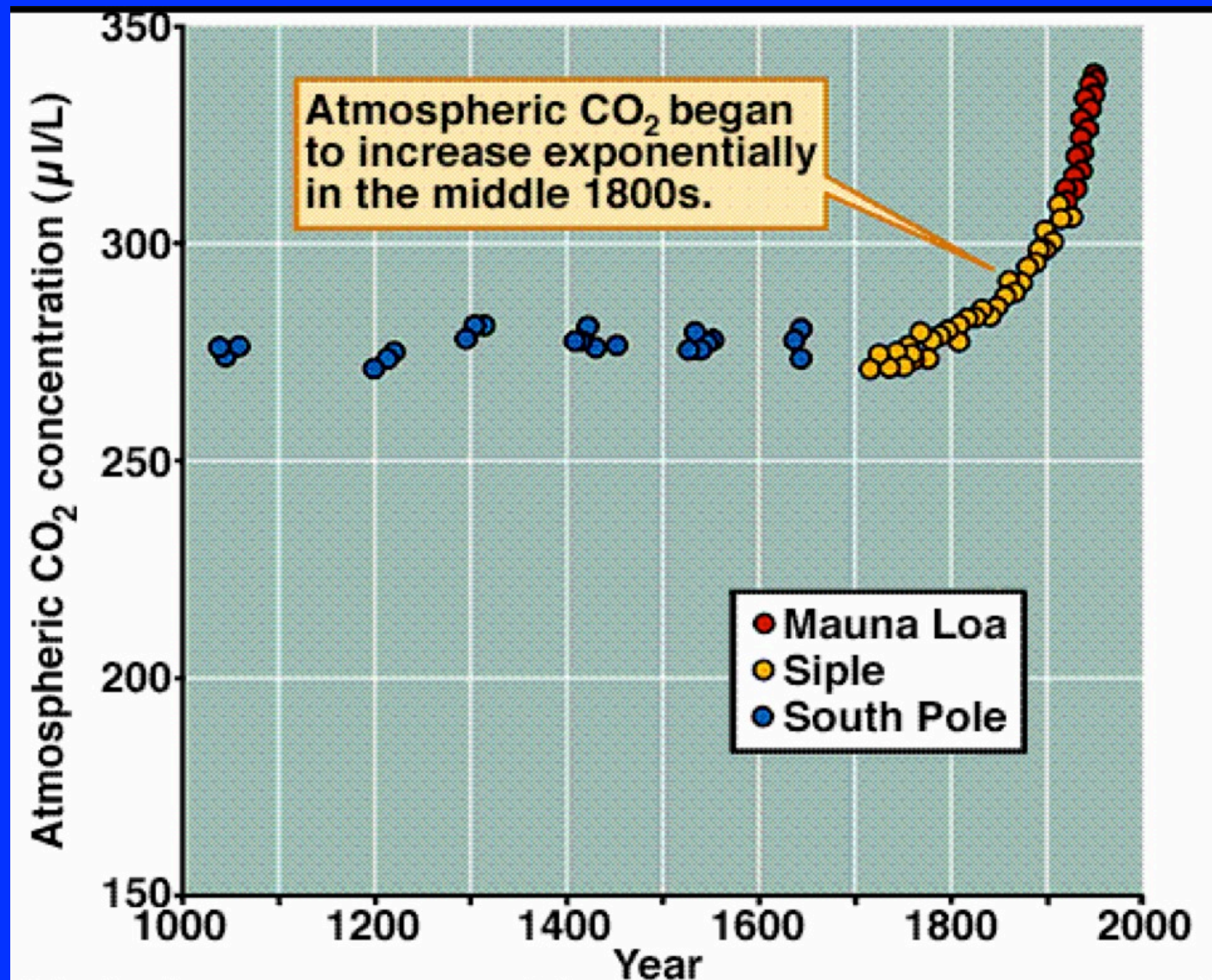
ATTRIBUTION OF INCREASE IN ATMOSPHERIC CO₂

Comparison of *cumulative* CO₂ emissions from fossil fuel combustion and land use changes with measured increases in atmospheric CO₂.

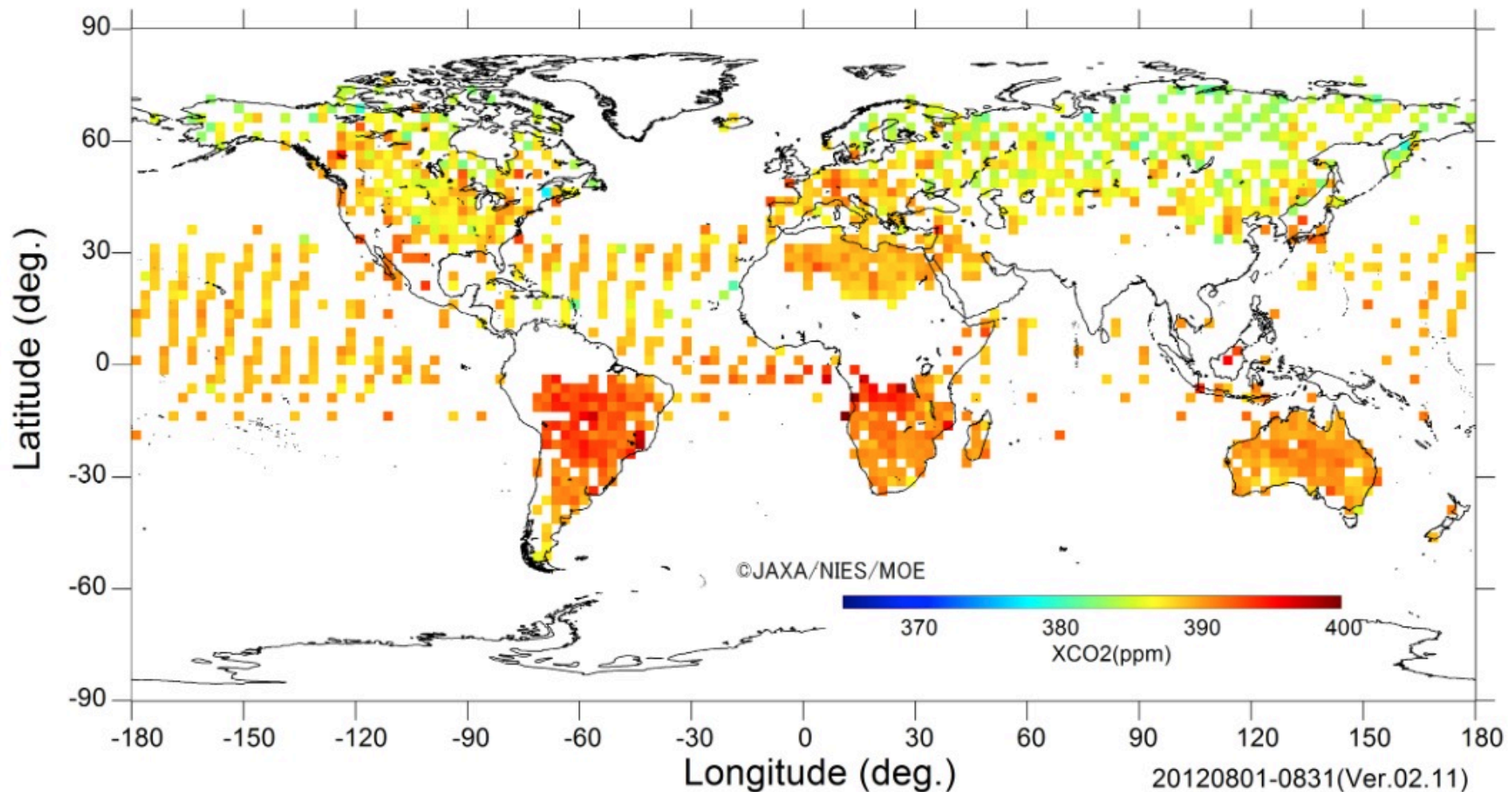


Prior to 1970 the increase in atmospheric CO₂ was dominated by emissions from land use changes, not fossil fuel combustion.

Ice cores began to give a clearer picture of the pre-industrial CO₂ record



GOSAT CO₂ column-avg mixing ratio, Aug 2012



Monthly Global Map of the CO₂ column-averaged volume mixing ratios in 2.5 deg by 2.5 deg mesh
August 2012 Ver.02.11

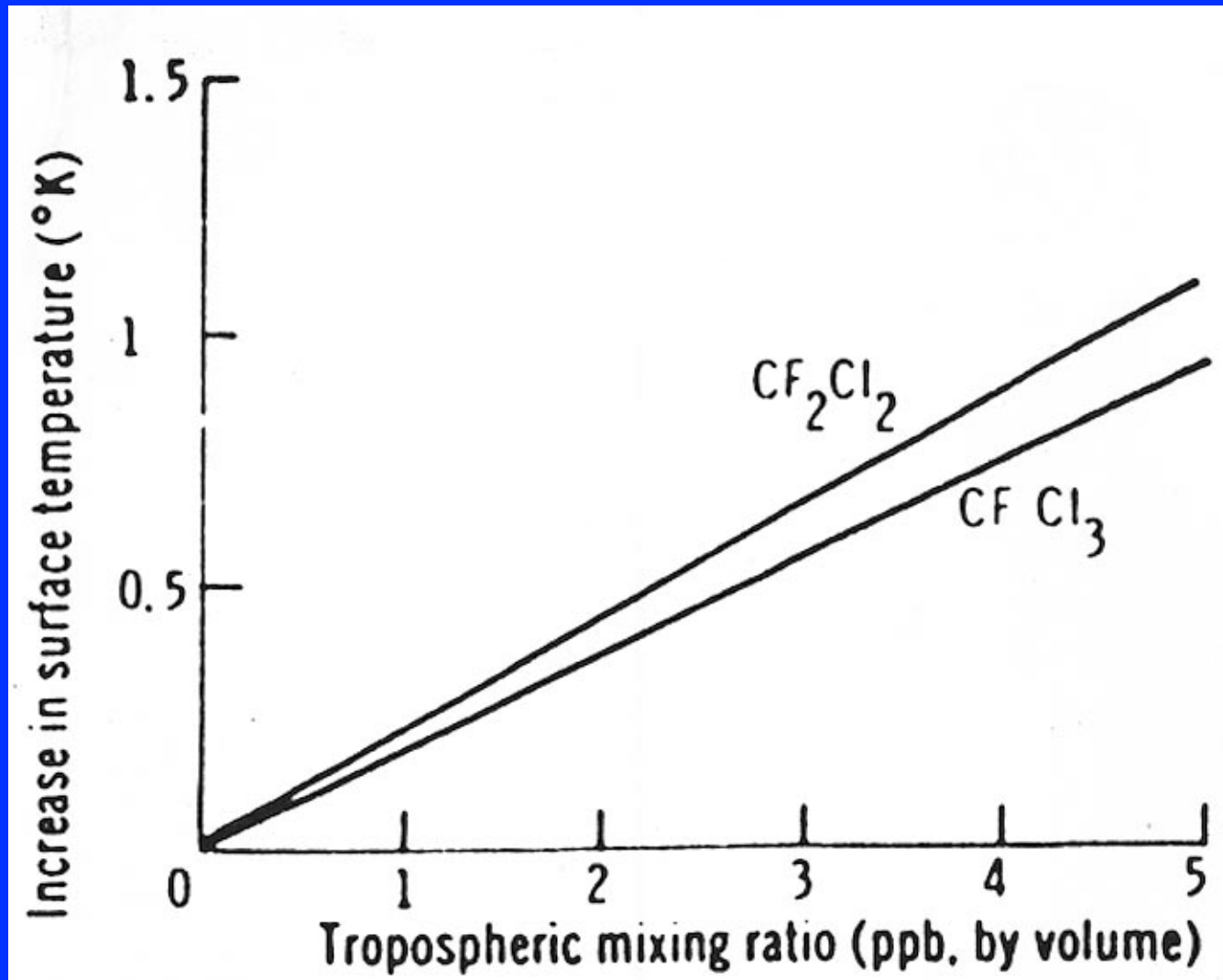
The saga of V. Ramanathan

refrigeration engineer
in India

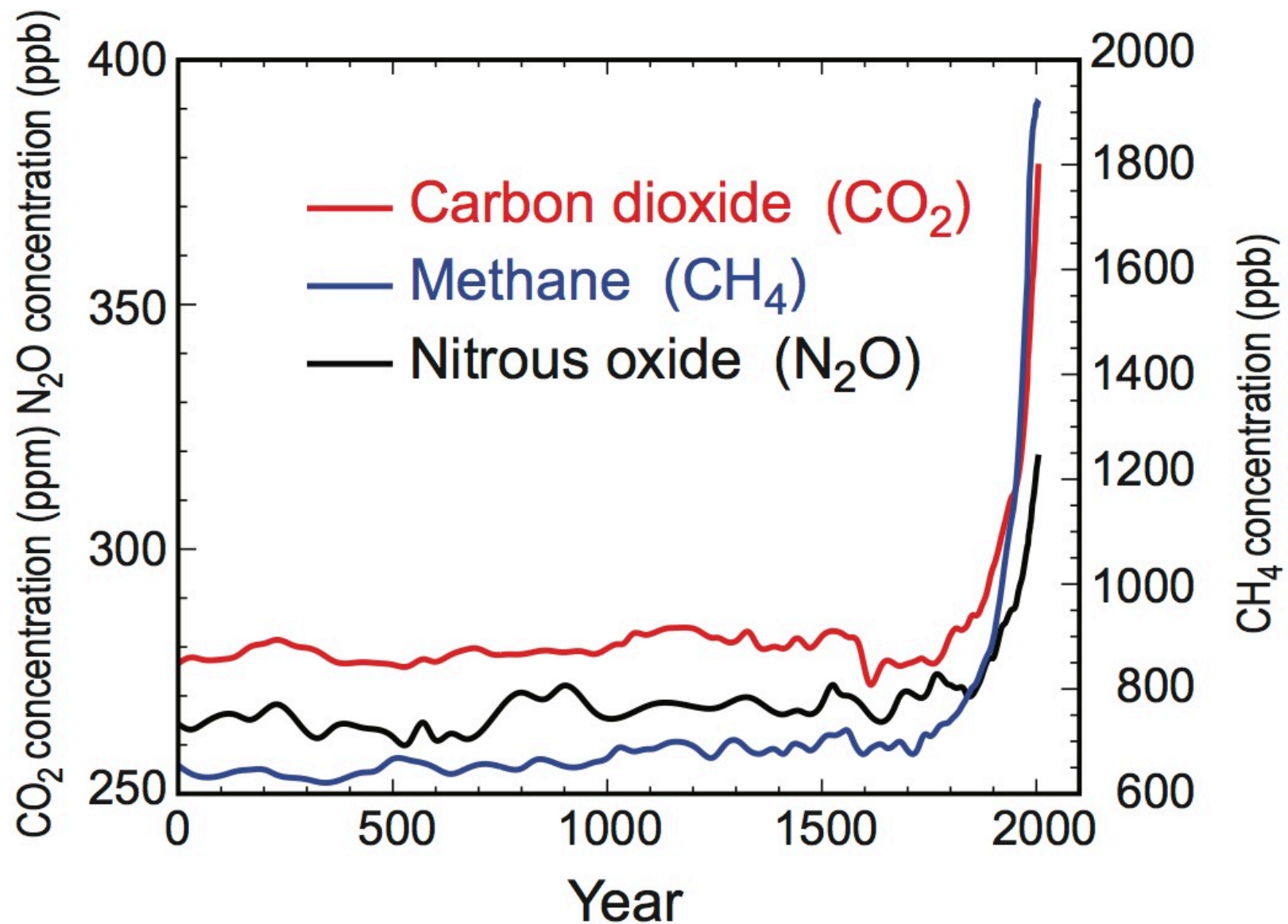
thesis on Venus
dynamics

got into climate
because thesis adviser
Bob Cess abandoned
his previous career as
a mechanical engineer
and went into climate

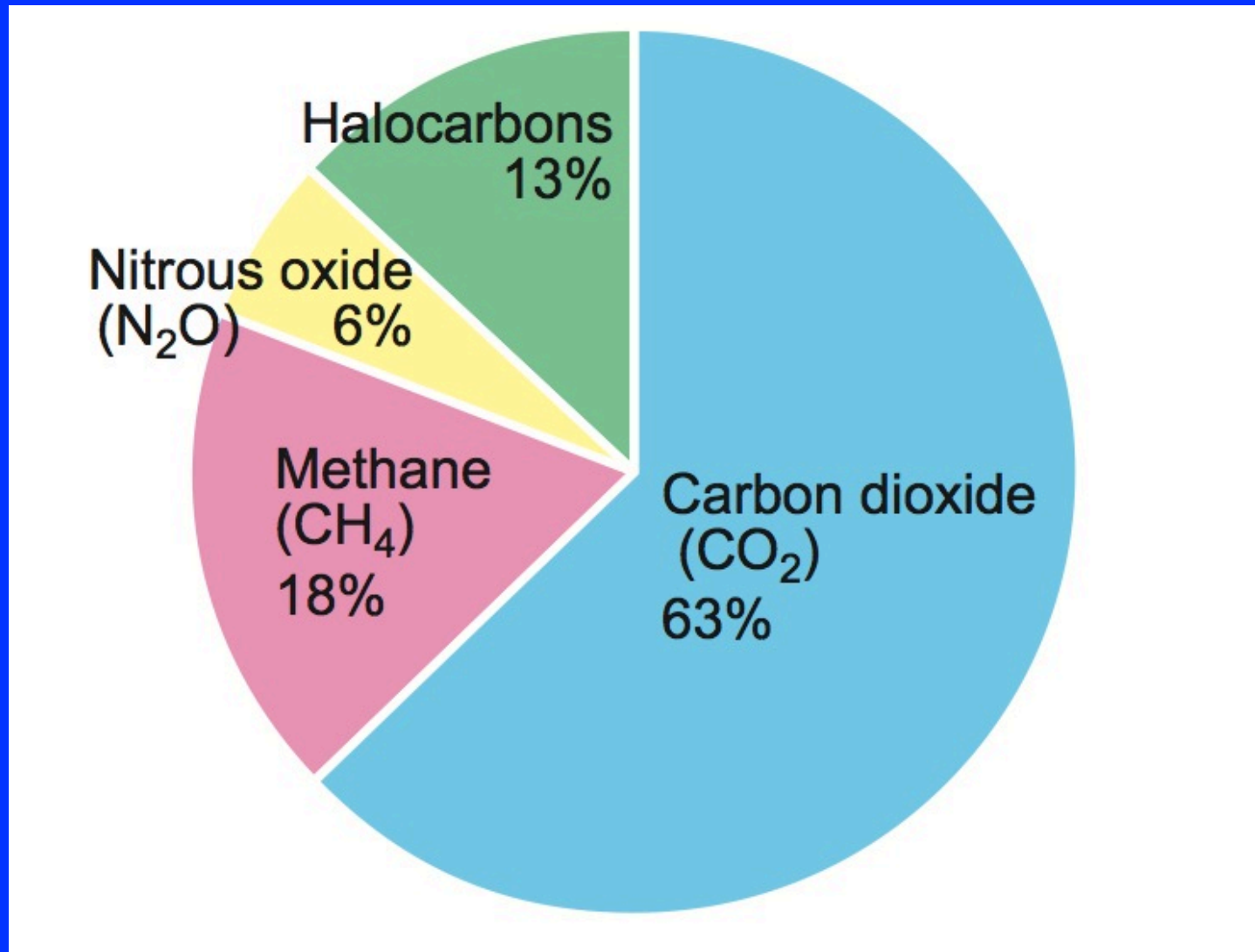
Ramanathan's famous 1976 graph of global surface temperature vs. CFC concentration



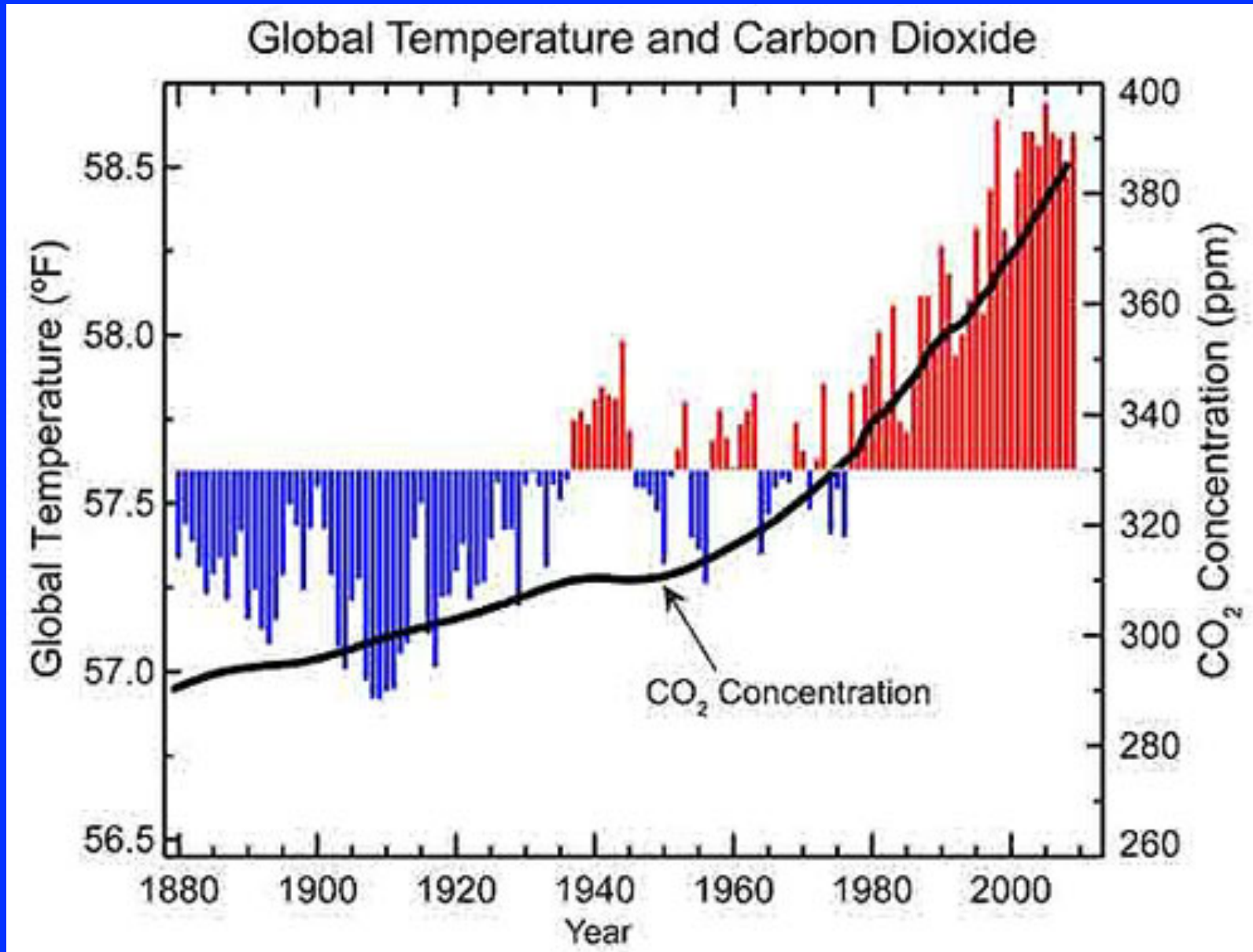
Other greenhouse gases are rising too



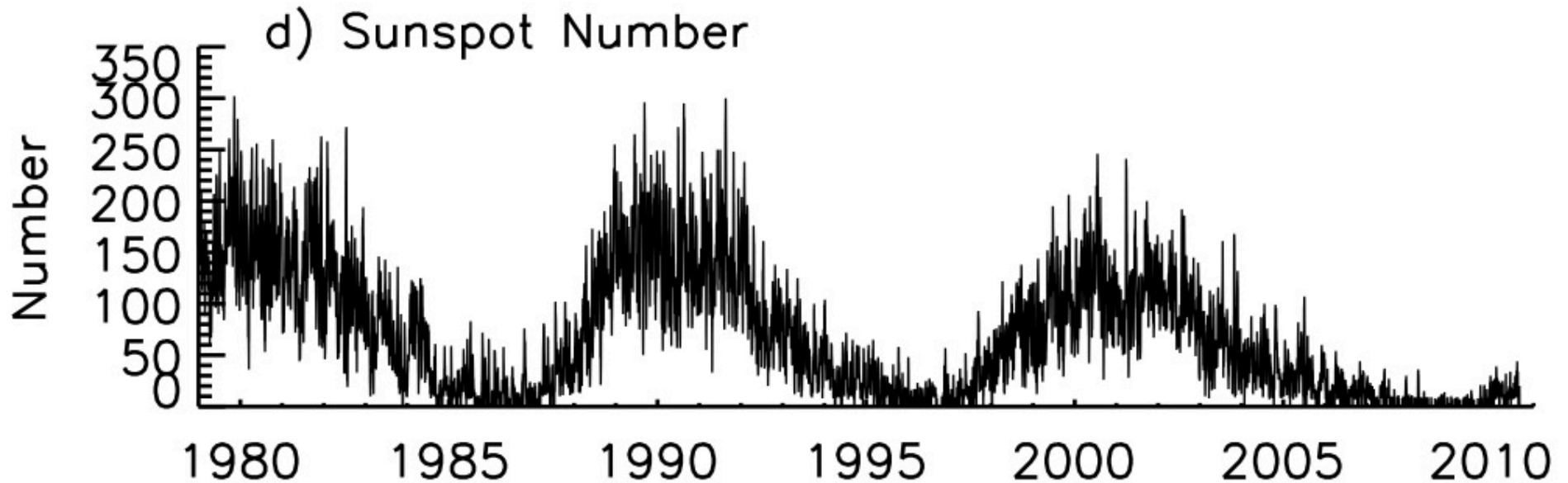
Other greenhouse gases: contribution to warming (IPCC 4)



Strong indication of causal relation



The “global warming slowdown” of 2000-2010



Sunspots had a protracted minimum during 2000-2010.

Other contributors:

- Chaos (who knew? *Gerry Meehl*)

- Deep ocean

- Small volcanoes

- Stratospheric H₂O increase

Trenberth/Kiehl 2009

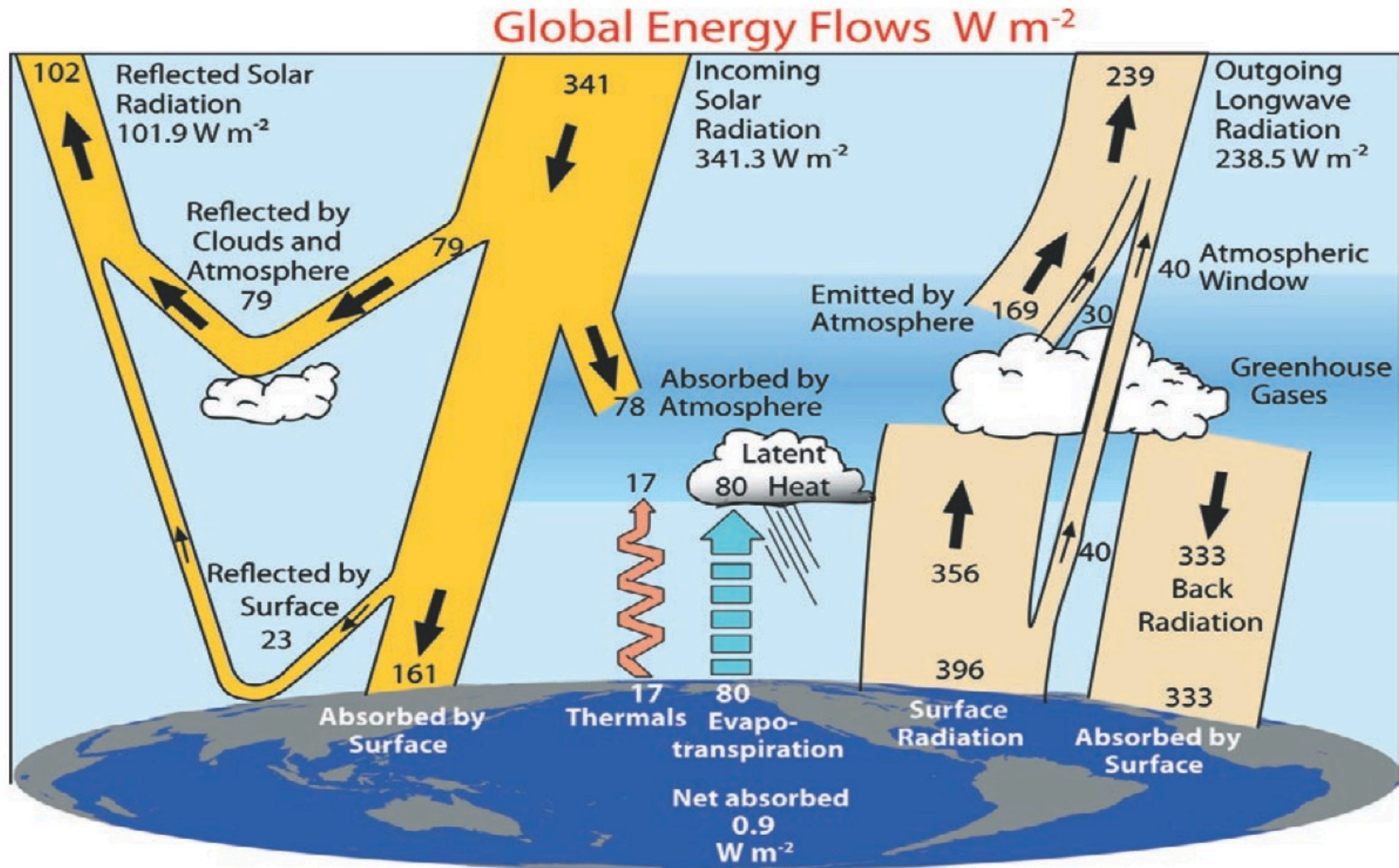
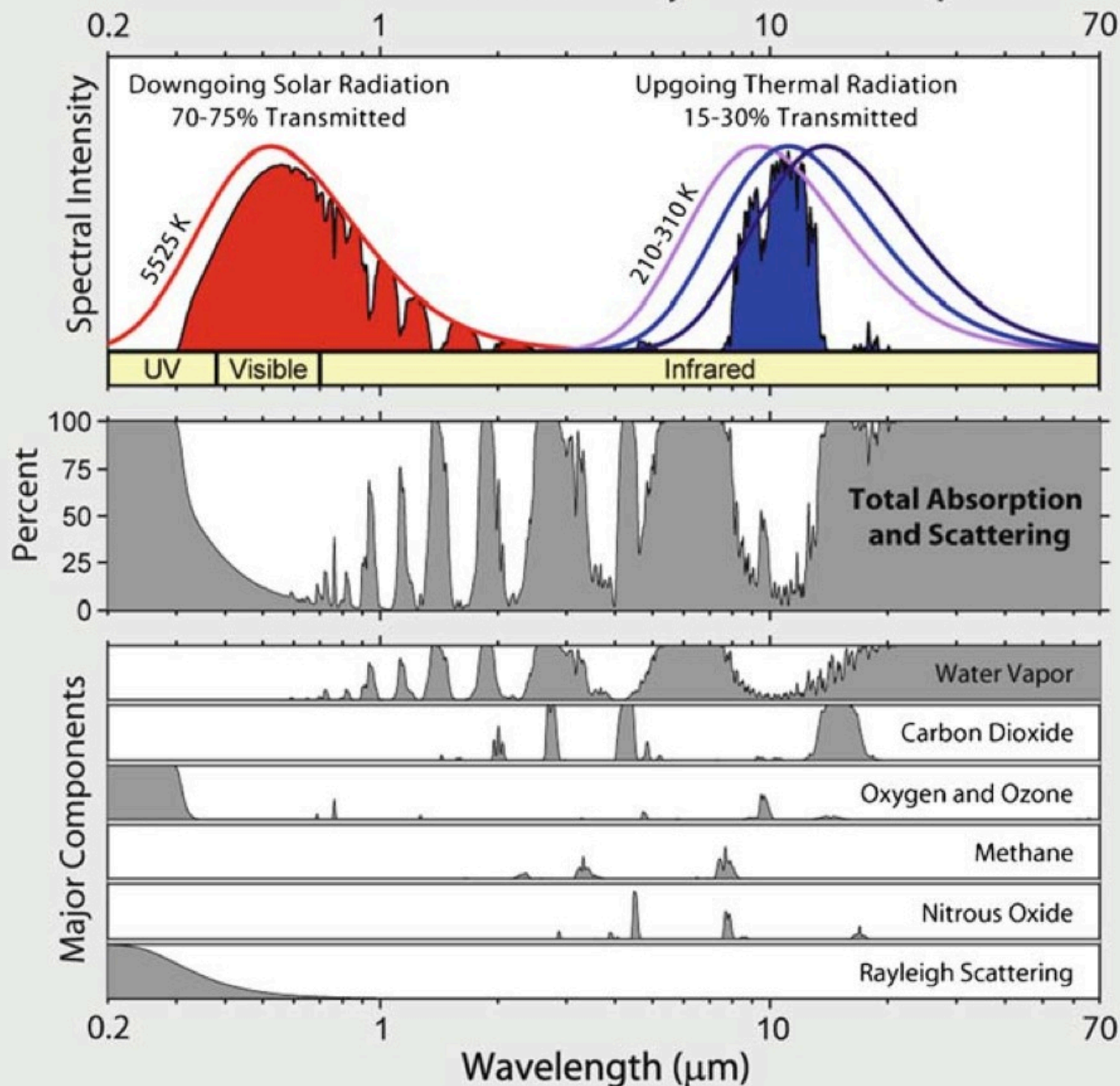


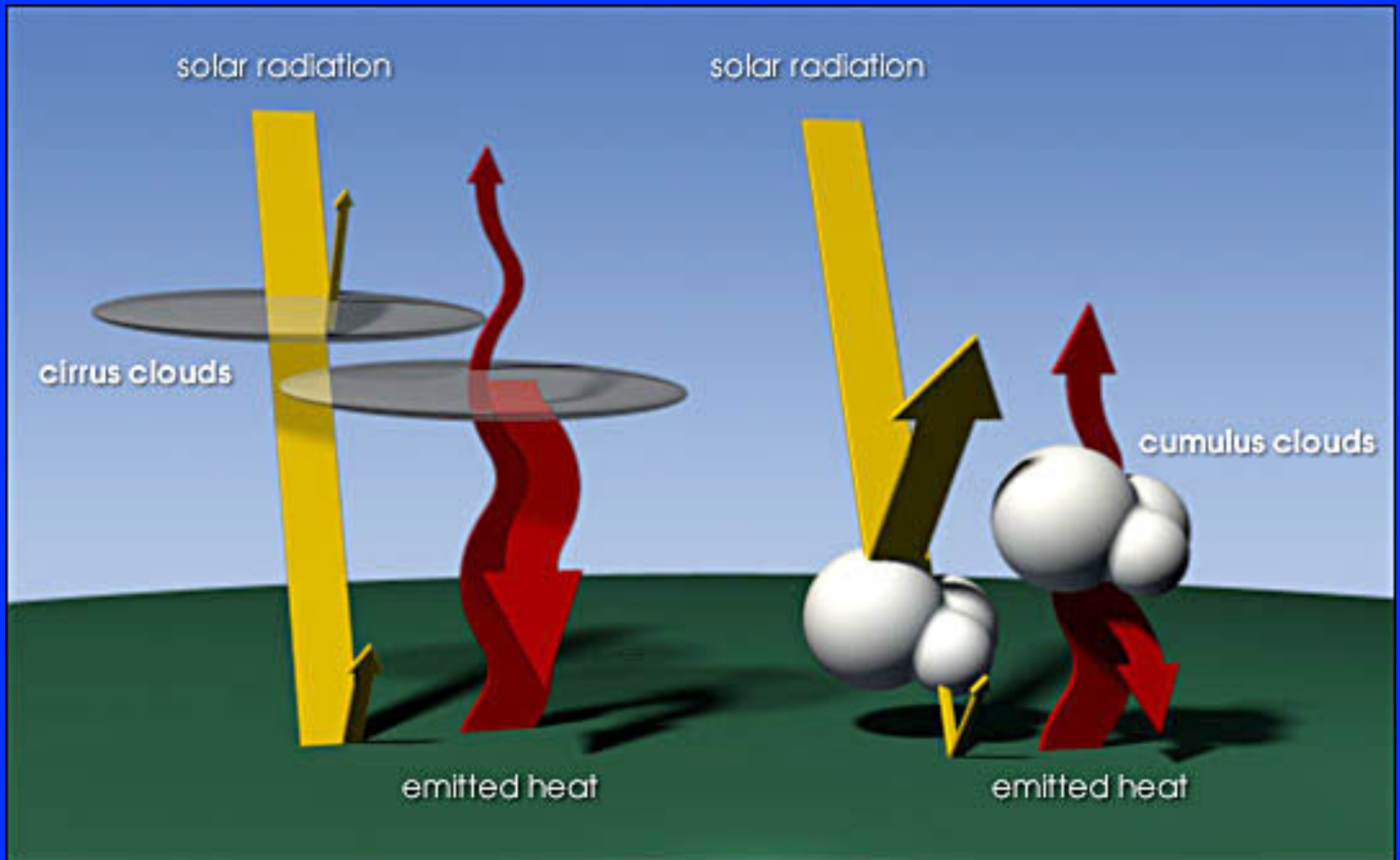
FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Radiation Transmitted by the Atmosphere

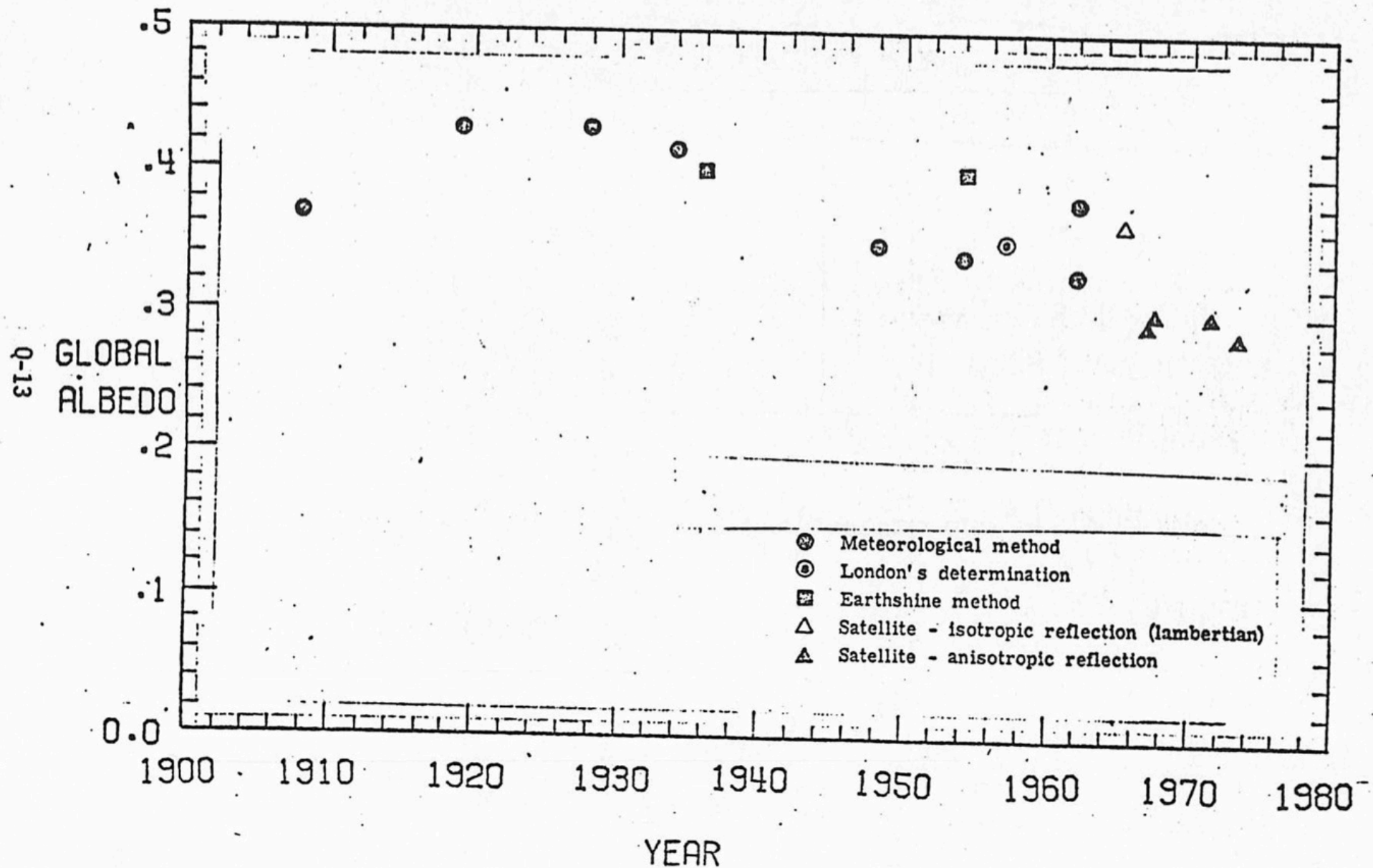


Planck
functions
of Sun and
Earth
almost non-
intersecting

Energy balance: cloud effect



HISTORICAL ESTIMATES OF EARTH GLOBAL ALBEDO



1962-65 Earth radiation balance: Suomi/Vonder Haar

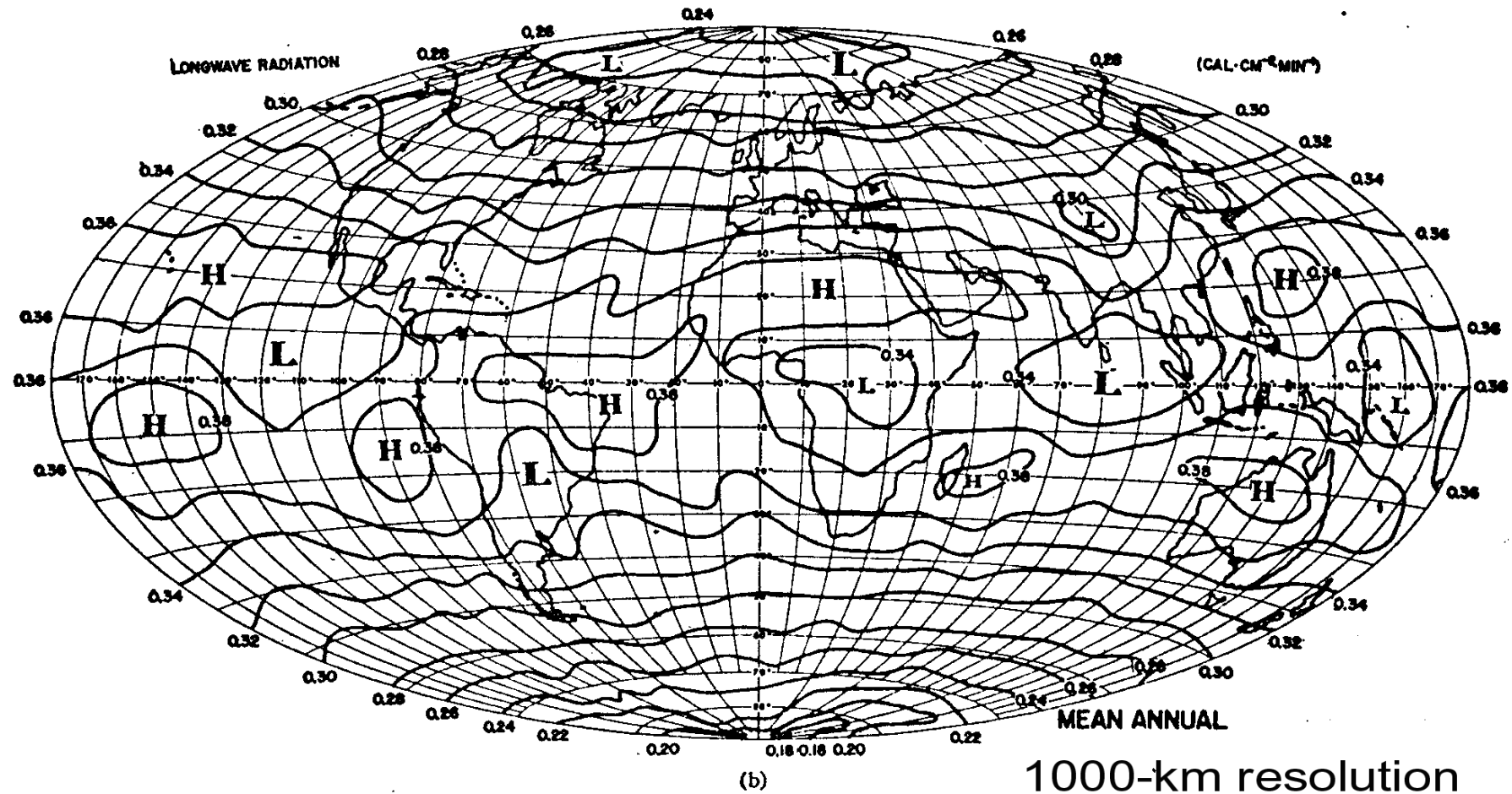
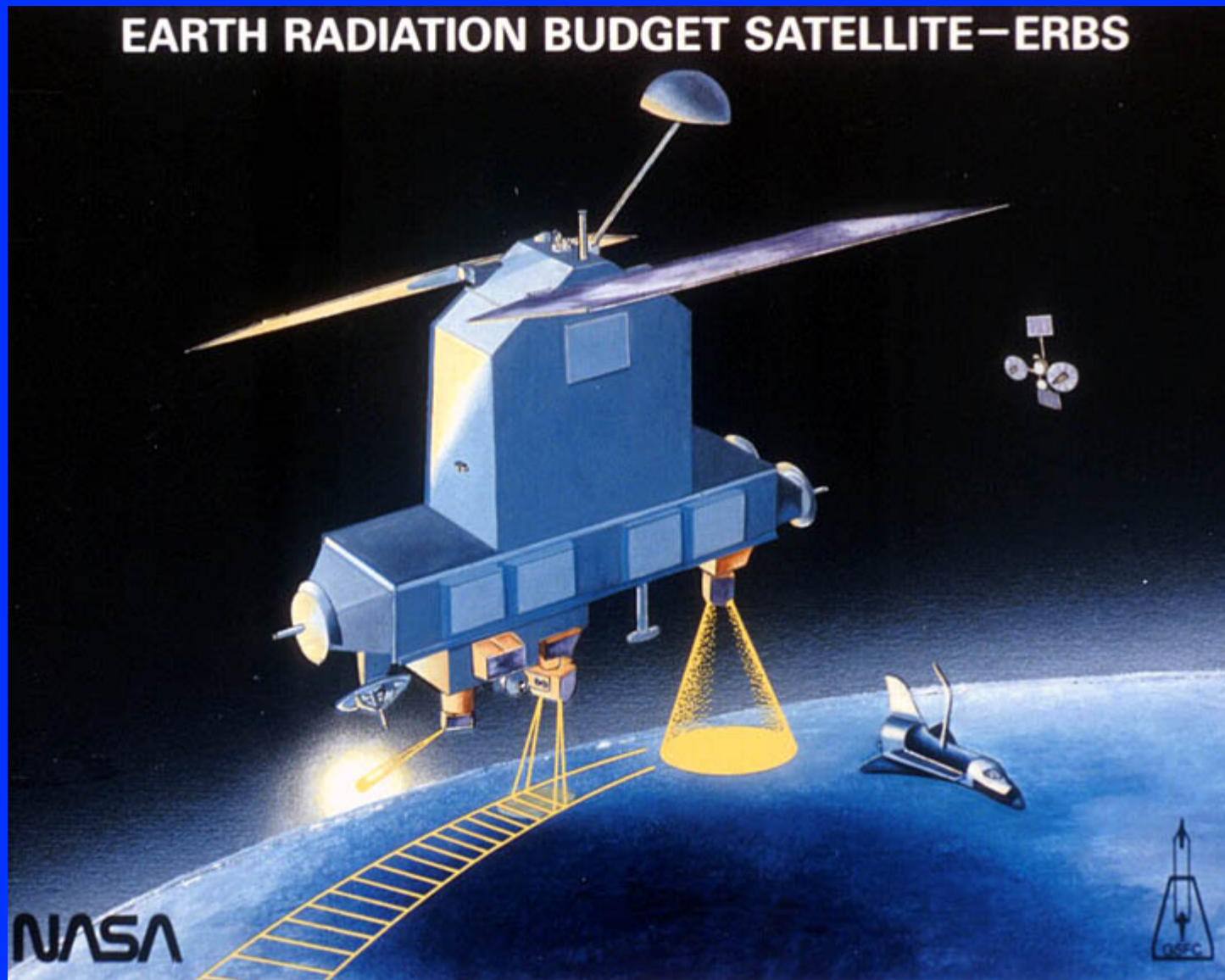


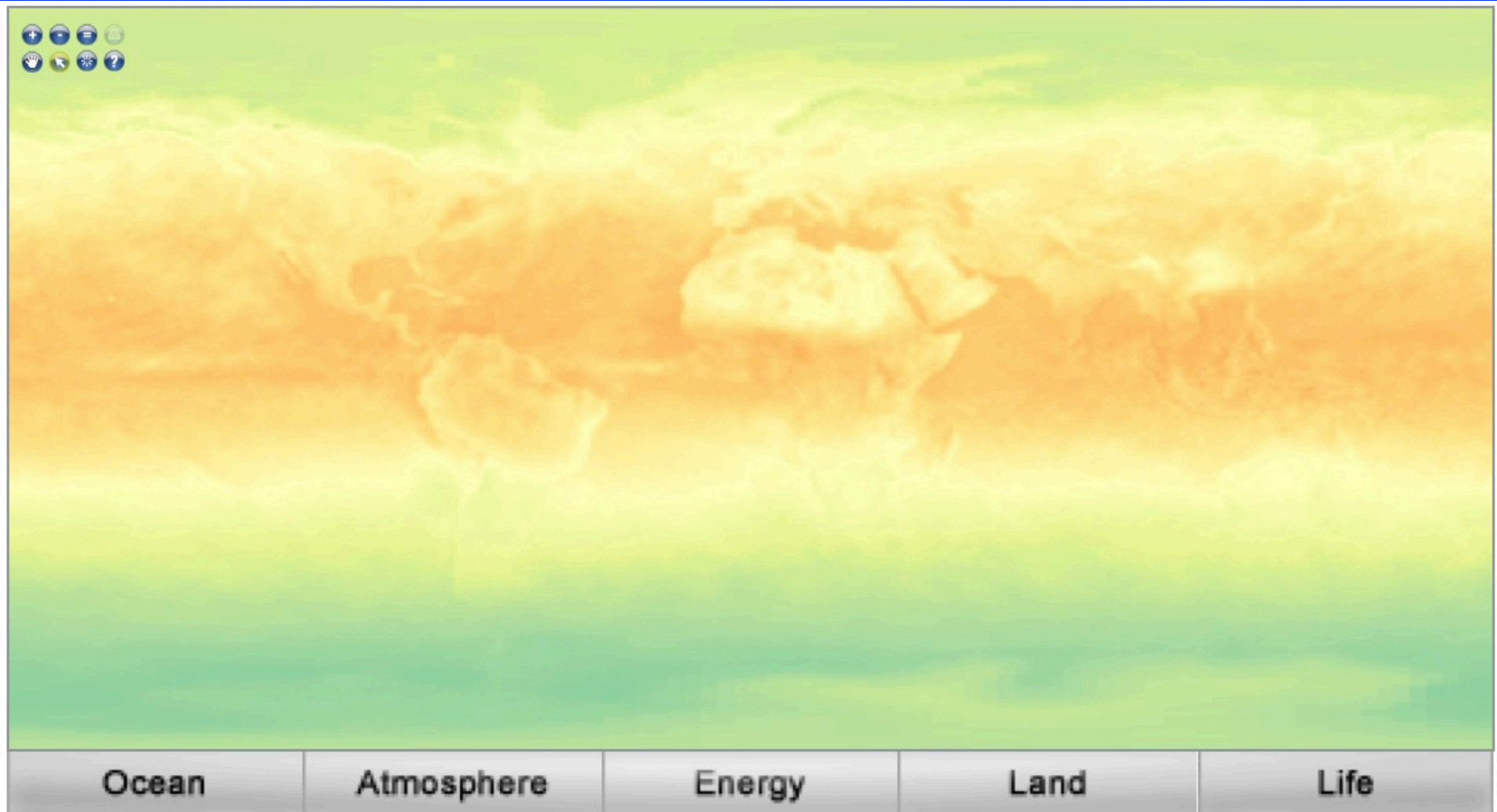
FIG. 4. Mean annual geographical distributions of radiation budget parameters. Planetary albedo and longwave radiation were measured from satellites during 1962-1965. Net radiation values were derived using a solar constant of $2.00 \text{ cal cm}^{-1} \text{ min}^{-2}$.

Vonder Haar/Suomi, 1971

1980s (2 more; first true constellation)



Apr 2012: CERES net radiation



Net Radiation (1 month)

April 1, 2012 00:00-April 30, 2012 23:59

About this dataset

Summer 2013



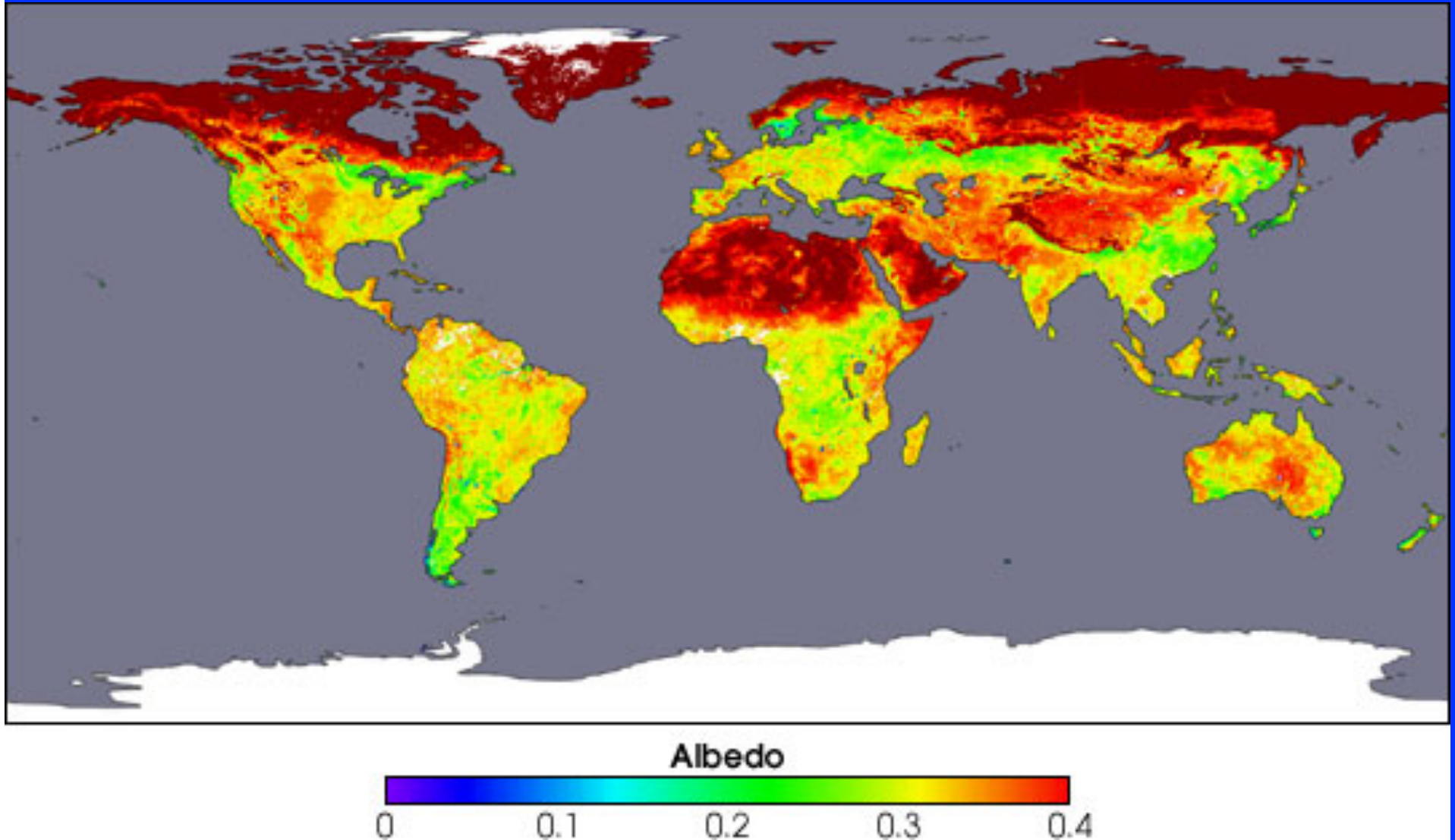
European: 2000s

Geostationary Earth Radiation Budget *Experiment*

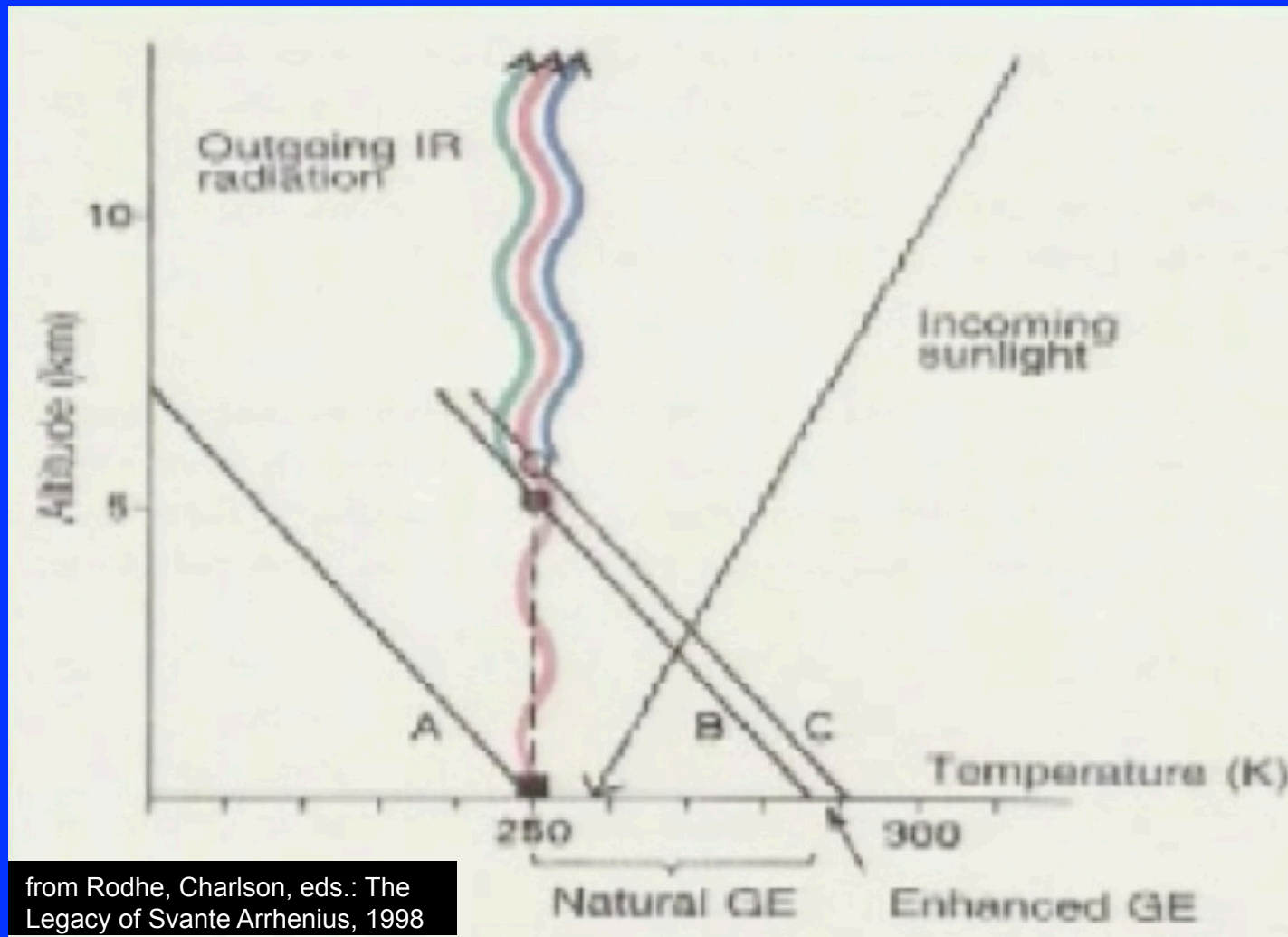
GERB is an Announcement of Opportunity Instrument for Meteosat Second Generation (MSG) intended to make accurate measurements of the Earth Radiation Budget from geostationary orbit. It is being produced by a European Consortium led by the UK. The development, integration and flight of GERB on MSG is being supported by EUMETSAT and the European Space Agency (ESA).



Surface albedo from MODIS (7-22 Apr 2002)



Temperature profiles for no (A), natural (B), and enhanced (C) greenhouse effects



Symbols mark the effective altitudes for IR emission to space.

Book: Spencer Weart, "The Discovery of Global Warming", 2nd ed. 2009

<http://www.aip.org/history/climate/index.htm>



skepticalscience.com (John Cook, Australia)

Skeptical Science
Getting skeptical about global warming skepticism

Home Arguments Software Resources Comments The Consensus Project Translations About Donate

Search... GO

Twitter Facebook YouTube Pinterest

Posts Comments Email

MOST USED Climate Myths
and what the science really says...

- 1 Climate's changed before
- 2 It's the sun
- 3 It's not bad
- 4 There is no consensus
- 5 It's cooling
- 6 Models are unreliable
- 7 Temp record is unreliable
- 8 Animals and plants can adapt
- 9 It hasn't warmed since 1998
- 10 Antarctica is gaining ice

[View All Arguments...](#)

Explaining climate change science & rebutting global warming misinformation

Scientific skepticism is healthy. Scientists should always challenge themselves to improve their understanding. Yet this isn't what happens with climate change denial. Skeptics vigorously criticise any evidence that supports man-made global warming and yet embrace any argument, op-ed, blog or study that purports to refute global warming. This website gets skeptical about global warming skepticism. Do their arguments have any scientific basis? What does the peer reviewed scientific literature say?

Newcomers, start here **History of Climate Science** **The Big Picture**

2013 SkS Weekly News Roundup #26B
Posted on 29 June 2013 by John Hartz

- 21 percent of homes emit 50 percent of CO₂
- Alberta floods a wake up call to dangers of extreme weather
- Big Oil's big lies about alternative energy
- Coal industry fuels opposition to emissions regulations
- Global warming worsened Australia's record hot summer
- Heat wave may threaten world's hottest temp. record
- Obama asks American voters to declare on climate change
- Obama is right on climate change
- The myriad benefits of a carbon tax
- While Congress sleeps

The Consensus Project Website
Winner of the 2011 Eureka Prize
Australian museum
Advancement of climate change knowledge
TEXTBOOK
G. Thomas Farmer
John Cook
Climate Change

John Cook's "Most Used Climate Myths"

It's the Sun

No warming since 1998

Models unreliable

Temp record unreliable

No consensus (Naomi Oreskes YouTube vids)

It's cooling

Climate has changed before

Flora, fauna can adapt (only to slow change)

Antarctica is gaining ice

It's not bad

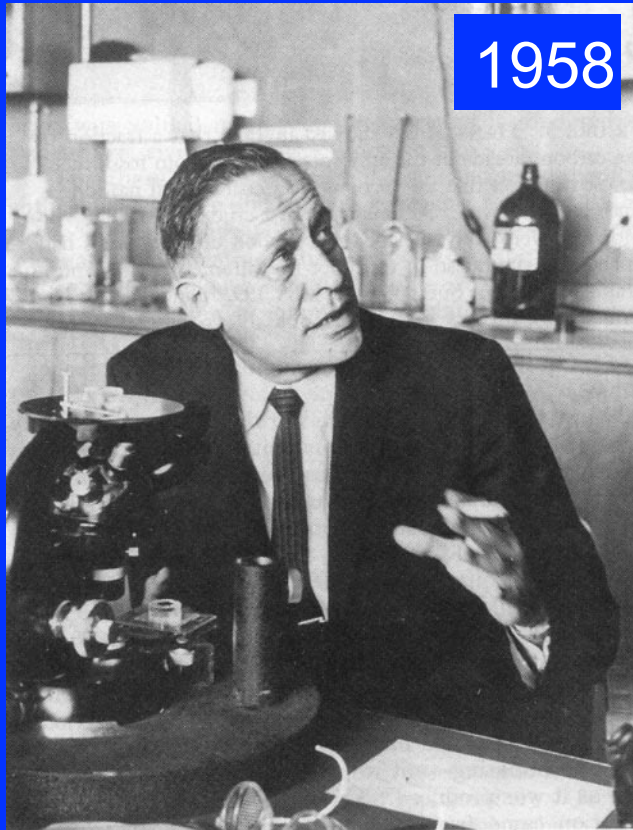
Oreskes lectures outing global warming “skeptics”

Search for her name on YouTube, or

<https://dl.dropboxusercontent.com/u/32694790/Oreskes-MerchantsOfDoubt-lecture-YouTube.zip>

See how these criminals used disinformation tactics to undercut research on acid rain, Ozone Hole, smoking-lung cancer connection, etc., and form “foundations” specifically designed to attack research that threatens corporations.

Roger Revelle (1909-1991): CO₂ in oceans



In 1936 Revelle began studying the chemical interaction of CO₂ with seawater.

He left the subject, returning in 1956 to discover that the absorption of CO₂ was taking place at a much lower rate than anyone had thought.

Revelle and Suess paper (Tellus, 1957) was confusing and even contradictory

They wrote that oceans would take up most of the new CO_2 -- then, at last minute, Revelle added a few sentences saying that this would not happen!

- (taped to manuscript just before publication)

Revelle's breakthrough was to realize that 1930s equilibrium models could not account for how ocean would react to "new" CO_2 -- thru buffering.

**But then Revelle makes the bold statement
which is engraved in the lobby of B33**

"Thus human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future.

Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years."

20 years later... in 1977

Revelle chaired National Academy of Sciences Energy and Climate Panel, which found that ~40% of the anthropogenic CO_2 had remained in the air,

and that $2/3$ of anthropogenic CO_2 was from fossil fuel, $1/3$ from forest clearing ("land use change" now)

Followed in 1979 by Charney committee report that raised the alarm another level.

Manabe & Wetherald invented “radiative-convective modeling” (1964, 1967)

Like Arrhenius, consider whole atmosphere, not just surface - use computer iteration to get $T(z)$

Lapse rate dT/dz continually adjusted to 6 K/km

Two positive feedbacks which radiate more IR to surface:

- more H₂O vapor in air (~ constant rel humidity)
- troposphere warms

Net result: 4x amplification of bare CO₂ effect

Many climate change mechanisms were studied with their approach — CO₂ but one in a crowd

to mid 1970s: CO₂ somewhat eclipsed by...

Aerosol cooling effect:

- the "Human Volcano" (Bryson)
- Rasool/Schneider (1971): could "be sufficient to trigger ice age"
- Twomey (1971): aerosol increase cloud albedo

Ozone layer in danger: CFCs

Surface albedo changes (desertification)

Glaciers Are Coming! (cooling trend continues...)

Highlights of the modern period - 1

1975 Global cooling stops; warming begins

1978 Growing awareness of huge potential radiative impact of clouds; aerosols eclipsed

mid-80s onward: Radiative forcing slowly replaces temp increase as most fundamental measure of climate chg



United States Department of Energy

Office of Energy Research
Office of Basic Energy Sciences
Washington, D.C. 20545

May 1982
DOE/CONF-8106214
UC-11

018

Carbon Dioxide Effects Research and Assessment Program

Proceedings of the Workshop on First Detection of Carbon Dioxide Effects

Harpers Ferry, West Virginia
June 8-10, 1981

Harry Moses & Michael C. MacCracken, Coordinators

Prepared by
The Institute for Energy Analysis
Oak Ridge Associated Universities

Noelle B. Beatty, Editor

Work Supported by
U.S. Department of Energy
Office of Energy Research
Washington, D.C. 20545

Contract No. DE-ACO5-76ORO0033

First detection of global warming: How?

I attended this
workshop (1981).

No one had found any
unambiguous sign of
warming at that time.

Manabe strongly
advocated using global
average surface
temperature.

Highlights of the modern period - 2

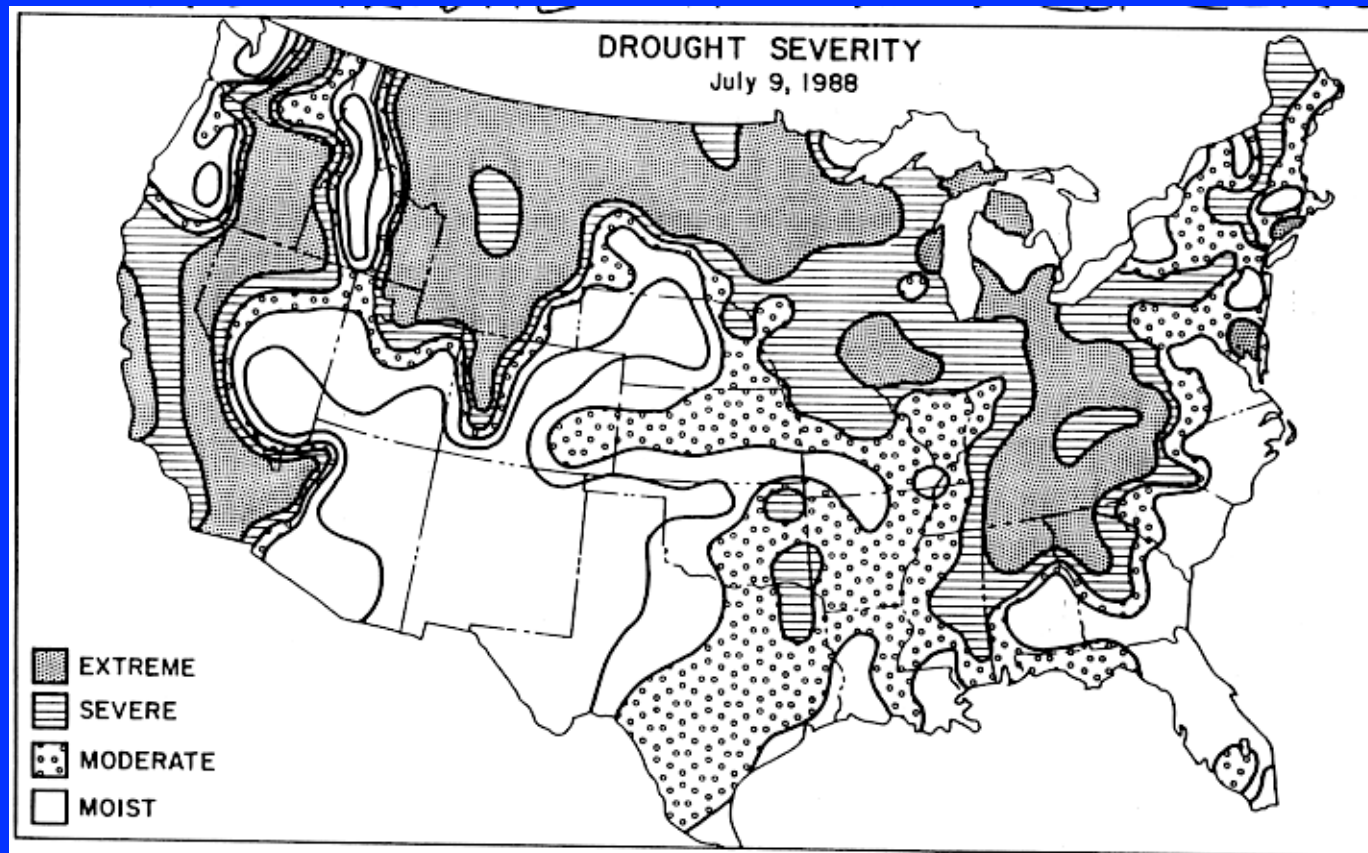
mid-80s onward: ice core bubbles begin to reveal CO₂ history: 270 ppm pre-industrial, 180 in ice ages

1988 Hansen says greenhouse warming already here (testimony to Congress)

1990 IPCC Reports begin (Intergov'l Panel on Climate Change)

1991 *Cess*: put GCM intercomparison on logical basis (raise, lower SST by 2C)

Drought that brought the global warming concern to center stage in the US...



and led to Jim Hansen's brave testimony to Congress that he was "99% sure" of an anthropogenic global warming signal both in his model and in temp. data

Highlights of the modern period - 3

- 1991 *Charlson*: 1st global map of direct forcing by sulfate aerosol; -0.3 to -1.0 W/m^2 compared to 2.4 W/m^2 by anthropogenic GGs
- 1992+ aerosols slowly regain prominence, partly due to their indirect effect on clouds (and again in 2000-2010 due to global warming hiatus)

Supplementary Material

Humphreys, Physics of the Air, 1921: CO2 skeptic

Classic atmospheric science textbook, USED UP TO 1950

“7. The Carbon Dioxide Theory

Now, the amount of CO₂ in the atmosphere is equivalent to a column of the pure gas, at ordinary room temperature and atmospheric pressure, of roughly 250 cm in length. Hence, as a little calculation proves, using the coefficients of absorption at different pressures given by the experiments of Angstrom and Bahr, just described, the CO₂ now in the atmosphere must, under its present vertical distribution, absorb radiation very approximately as would a column 475 cm long of the pure gas at the barometric pressure of 400 mm. But Schaefer's experiments, above referred to, show that such a column would be just as effective an absorber as a cylinder two or three times this length, and, on the other hand, no more effective than a column one-half or one-fourth as long. In each case, the absorption would be complete in the selective regions of the gas in question.

Hence, finally, doubling or halving the amount of CO₂ now in the atmosphere, since this would make but little difference in the pressure, would not appreciably affect the total amount of radiation actually absorbed by it, whether of terrestrial or of solar origin, though it would affect the vertical distribution or location of the absorption.

Again, as explained by Abbot and Fowle, the water vapor always present in the atmosphere, because of its high coefficients of absorption in substantially the same regions where CO₂ is effective, leaves but little radiation for the latter to take up. Hence, for this reason, as well as for the one given above, either doubling or halving the present amount of CO₂ could alter but little the total amount of radiation actually absorbed by the atmosphere, and, therefore, seemingly, could not appreciably change the average temperature of the earth, or be at all effective in the production of marked climatic changes.

Nevertheless, in spite of the above objections, there appears to be at least one way (variation in absorption at levels above the water vapor) by which a change, especially if a decrease, in the amount of CO₂ in the atmosphere might affect temperatures at the surface of the Earth. Hence, the above arguments do not, perhaps, fully warrant the idea that no such change was ever an appreciable factor in the production of an ice age.”

Arrhenius' Swedish colleague Angstrom was the first "climate skeptic"

In 1900, Angstrom measured the transmission of IR radiation thru a tube filled with CO₂ (amount ~ that in air)

Then he reduced the amount of CO₂ by 1/3

The transmission changed by only 0.4%

Thus, Angstrom concluded, the greenhouse effect of CO₂ was already saturated, so adding more wouldn't make any difference.

Arrhenius (1901) rebutted Angstrom

The upper layers of the atmosphere, which are much thinner, matter MOST for the greenhouse effect...

and water vapor would play no role in those very dry upper layers...

and spectral bands where water vapor absorbs do not entirely overlap the CO₂ absorption bands.

Further arguments against Angstrom

Angstrom's spectral measurements made at sea level, where absorption lines are "fat" . . .

But absorption lines thin with altitude.

It was not until the 1950s, and the work of Plass, that all this was finally cleared up, and these objections overcome.

Handwaving doesn't work. Real radiative transfer calcul'ns are needed.

"Factor of 4" important when deconstructing "It's the Sun" skeptic arguments

TSI = Total Solar Irradiance ($\sim 1360 \text{ W/m}^2$)

Earth's surface area = $4\pi R^2$

Earth intercepts sunlight over area = πR^2

... so incident TSI is diluted by Factor of 4

Sun can vary by $1\text{-}2 \text{ W/m}^2$ in solar cycle, but
the climate sees only $0.25\text{-}0.5$

$2\times\text{CO}_2$ forcing is $\sim 3.7 \text{ W/m}^2$

Callendar: Temperature change vs. CO2 concentration

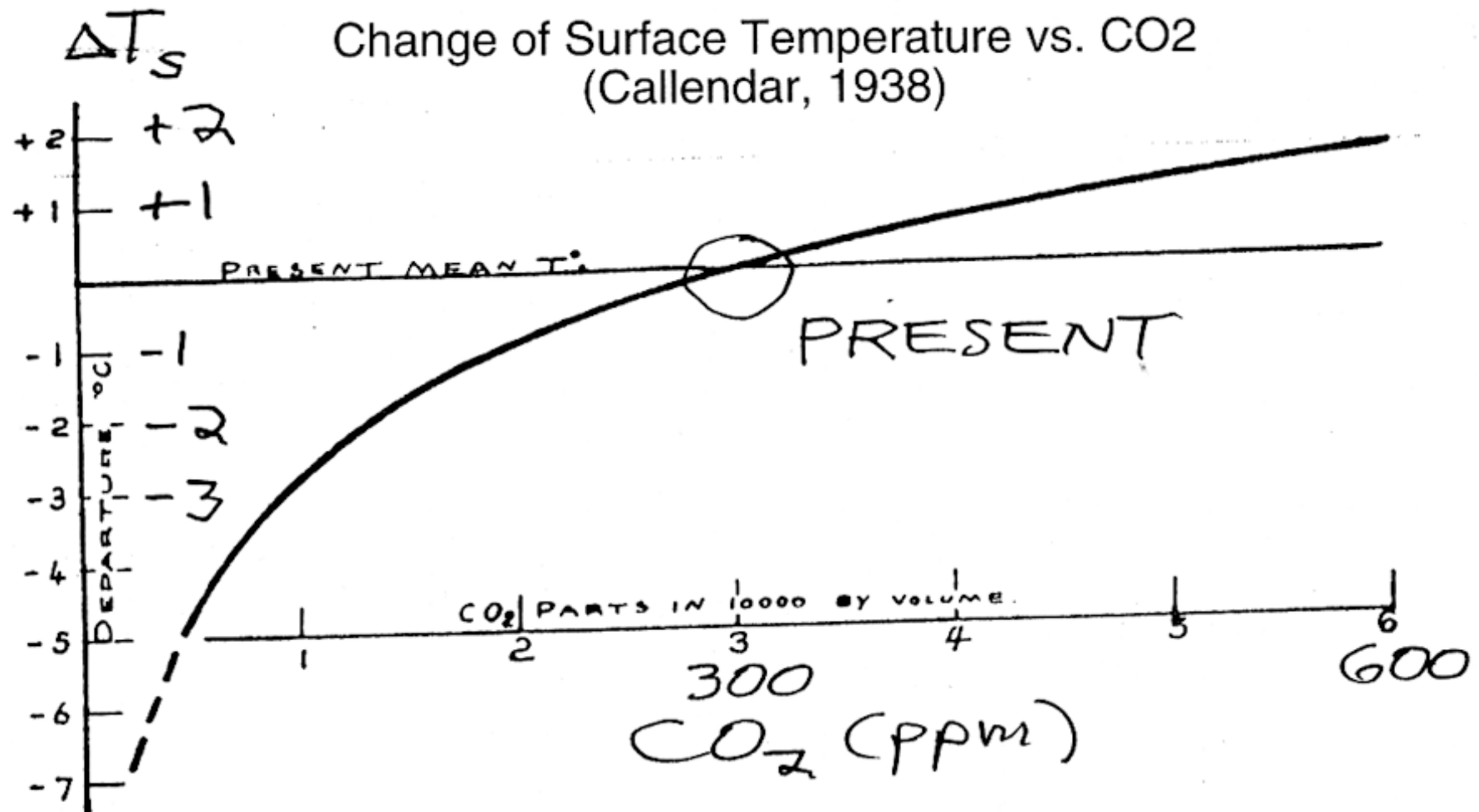


FIG. 2.—Change of surface temperature with atmospheric carbon dioxide
(H₂O vapour pressure, 7.5 mm. Hg.)

The Callendar Roast at Ye Olde Royal Meteorological Society

As an "outsider" (a steam technologist), he was politely but firmly snubbed...

Sir George Simpson:

"It is not sufficiently realized by non-meteorologists ... that it is impossible to solve the problem of the temperature distribution in the atmosphere by working out the radiation. The atmosphere is not in a state of radiative equilibrium."

The Callendar Roast: Prof. David Brunt

"...the effect of an increase in the absorbing power of the atmosphere would not be a simple change of temperature, but would modify the general circulation, and so yield a very complicated series of changes in conditions."

The Callendar Roast: Mr. L. Dines

"Was Mr. Callendar satisfied the change in the temperature of the air which he had found [in the historical record] was significant, and not merely a casual variation?"

Callendar Replies

"If any substance is added to the atmosphere which delays the transfer of low temperature radiation, without interfering with the arrival or distribution of the heat supply, some rise of temperature appears to be inevitable in those parts which are furthest from outer space."

Callendar was wrong in ascribing the warming to CO₂

The warming up to the mid-1930s was mainly due to CO₂ from land use change.

- continued to 1960s.

From 1860 to 1900 there was a "pioneer agriculture explosion", mainly in the US & Canada but also in other parts of the world

Land clearance = release of stored carbon from trees and newly-plowed soil.

Disbelief Period #2

Rising temperature trend since 1880 reversed around 1940.

A cooling trend, lasting until ~1974, began.

Also, the oceans and biosphere would take up any extra CO₂...

- (a kind of Gaian faith in the Earth which we find in current skeptics not paid by fossil fuel companies)

Platt attacks Rejection Reason #1

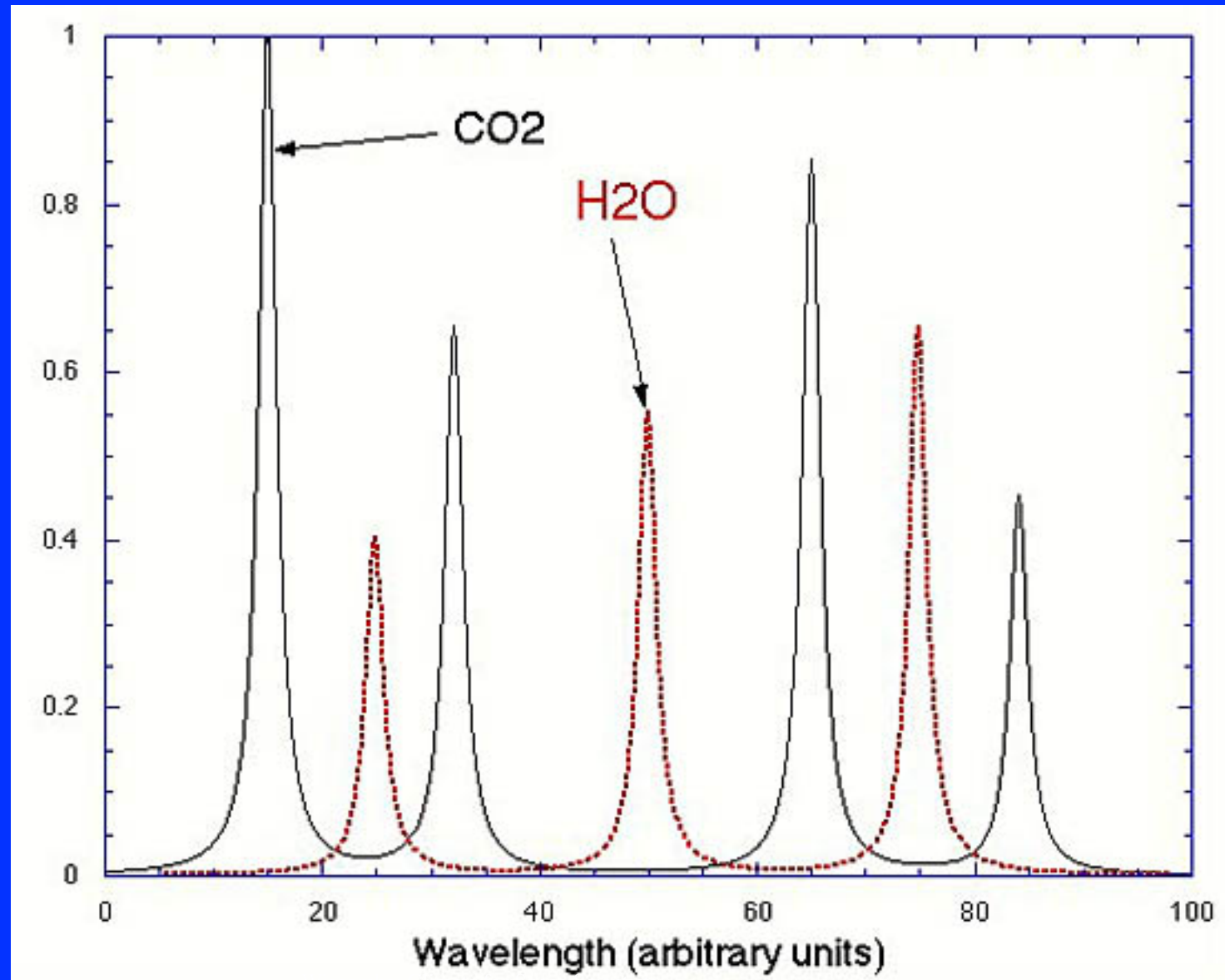
"... that H₂O vapor absorbs in the same spectral region as CO₂."

BUT...

"The individual spectral lines of those gases occur at random with respect to each other; they only slightly interfere."

Overlapping gas absorption bands are just collections of narrow lines which don't overlap

Gas
absorption
(normalized)



Platt also notes that CO_2 greenhouse action is relatively unimpeded above 2-3 km

H_2O scale height ~ 2 km $[\exp(-z/2)]$

CO_2 scale height ~ 8 km

so... radiative effect of H_2O is weak above 2-3 km.

Plass attacks Rejection Reason #2

that CO₂ absorption is saturated.

BUT...

"This completely neglects the many hundreds of spectral lines in the band wings."

Plass' results

Motivation: Ice Ages

Method: surface energy balance

Result: $\Delta T_s = 3.5C$ for $2 \times CO_2$

(Callendar: $1.4C$; Arrhenius, $5C$)

Ignored clouds ($\Delta T_s = 2C$ when included)

Plass' recognized that "CO₂-Climate Theory" still needed two things to be settled:

(1) "the temperature trend during the remainder of this century should provide a definitive test"

(done by Hansen etc., early 1980s)

(2) "Unfortunately, we cannot even say with certainty whether or not the CO₂ content of the air has increased since 1900."

(done by Keeling, late 1950s, + ice cores)

Moller (1963)

Still surface energy balance, but...

Held relative humidity fixed (instead of absolute humidity like previous investigators).

Got ~ runaway greenhouse effect:

$$\Delta T_s = 10\text{ C for } 2 \times \text{CO}_2 \text{ !!}$$

Said small changes in humidity profile or cloud can completely compensate CO_2 radiative effect.

Timeline - 1960's

Manabe-Wetherald: a watershed

Manabe: Ocean-atmosphere GCM's

AFCRL: Absorption line parameter table
(HITRAN)

CO₂ a lesser concern (glaciers returning...)

Paleo takes off - isotopes, ocean drilling, etc

Disbelief Period #4
Doubters: SMIC Report;
Rasool/Schneider 1971

SMIC = Study of Man's Impact on Climate, 1971