



# 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)

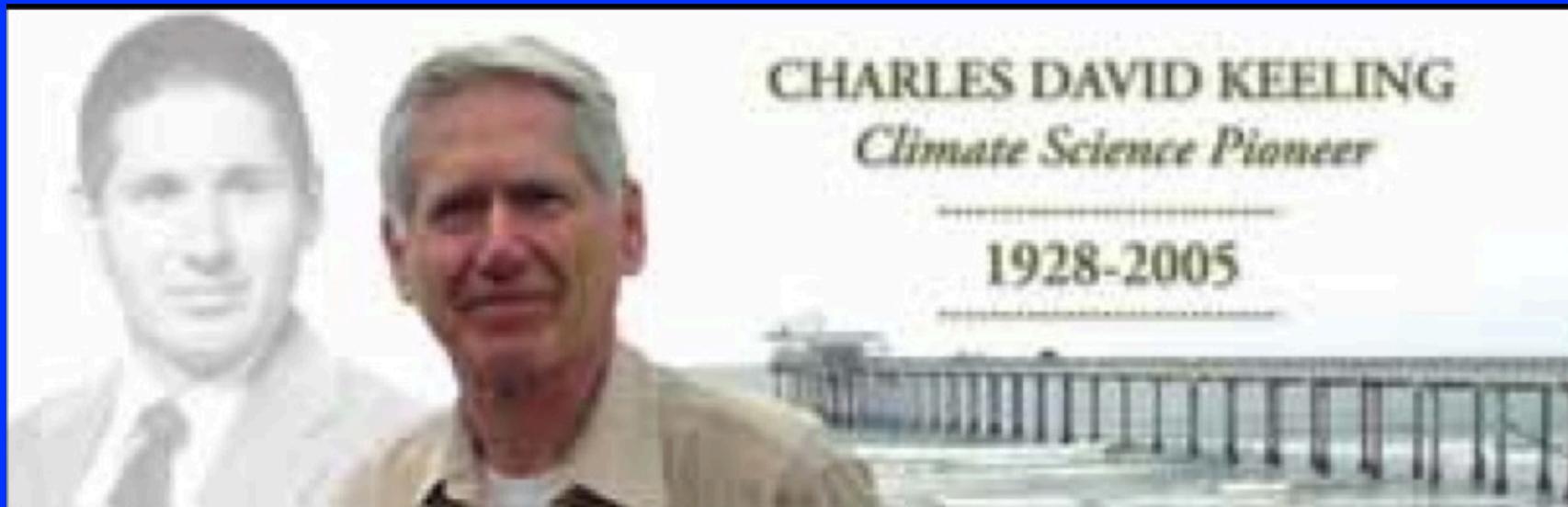
<http://www.youtube.com/user/wwiscombe>

begins with classic TV science show from 1956

interview with Plass

shows advanced understanding of CO<sub>2</sub> problem

clips from great movie "Earth: The Biography"



## Charles Keeling: Climate-Quality CO<sub>2</sub> measurements

Began measuring CO<sub>2</sub> in mid-1950s as student

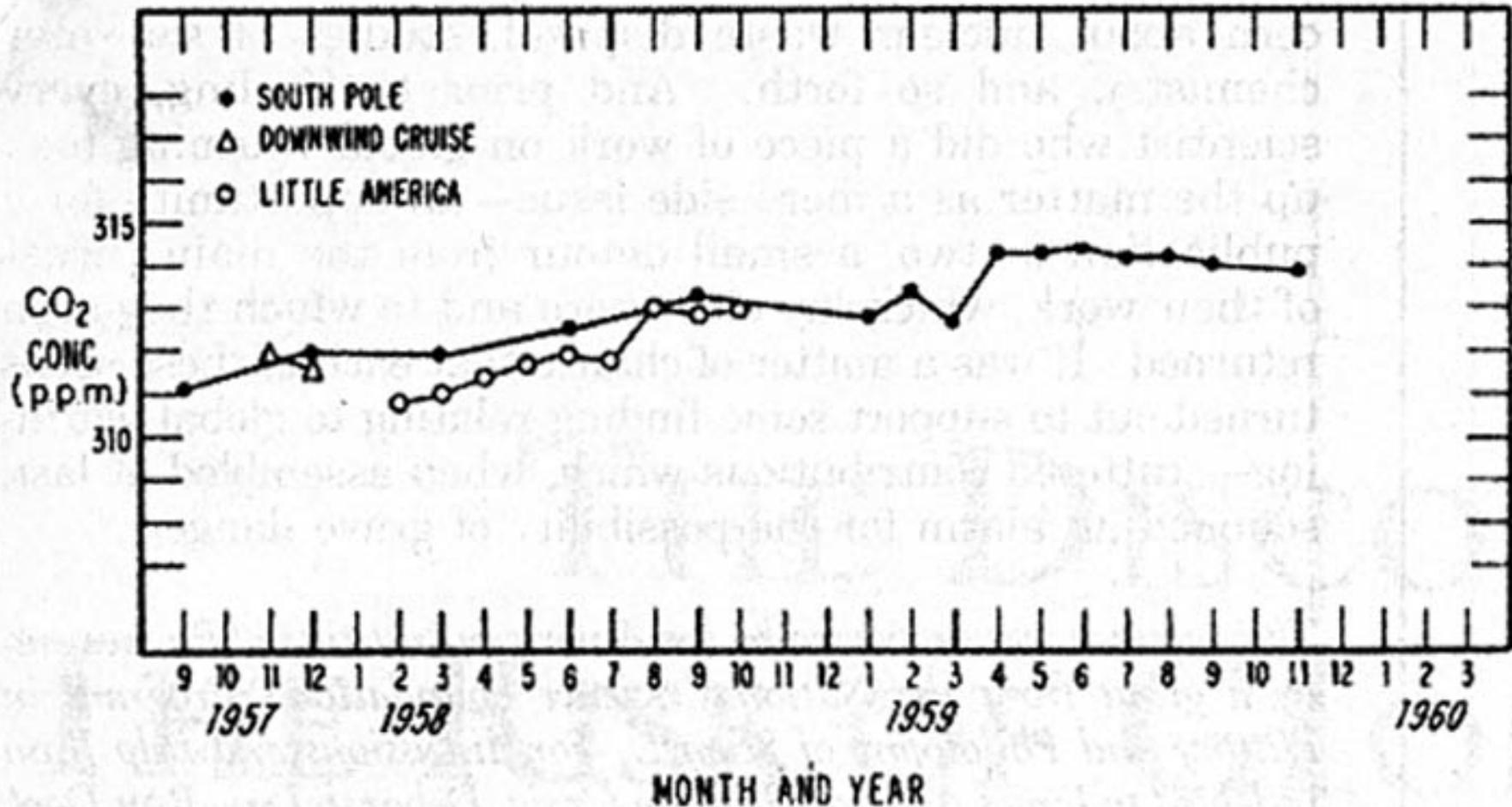
Kept finding a minimum value of 315 ppm no matter where he measured CO<sub>2</sub>.

(Callendar calculated 290 ppm for 1900)

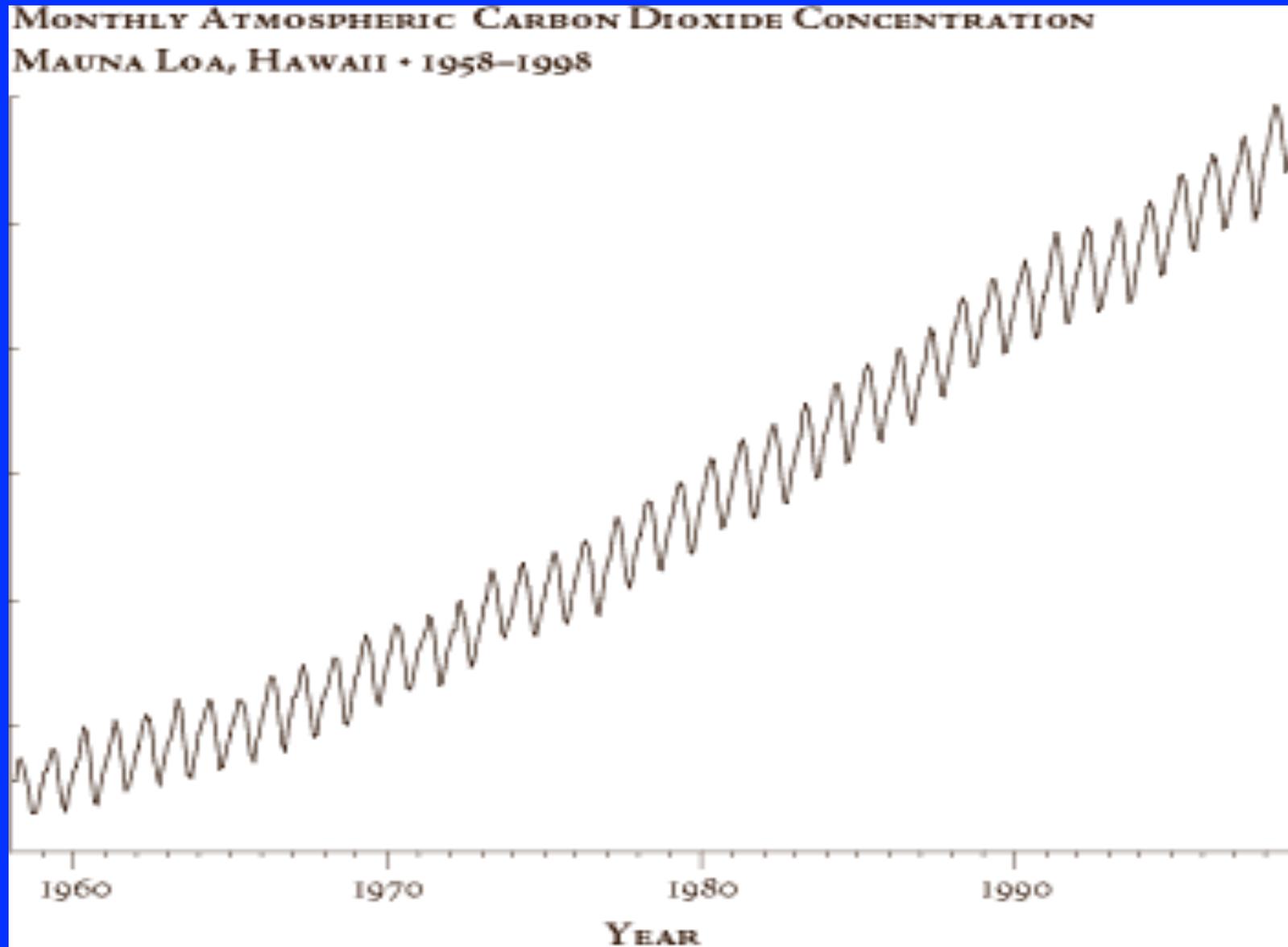
Joined 1957 International Geophysical Year

CO<sub>2</sub> 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  $^{14}\text{C}$  in atmos is smoking gun for human causation of  $\text{CO}_2$  rise

Revelle: oceans take < half of extra  $\text{CO}_2$

Much better  $\text{H}_2\text{O}$  absorption meas'ts

Plass: physicist, radiative transfer expert, crusader for  $\text{CO}_2$  theory of climate change

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

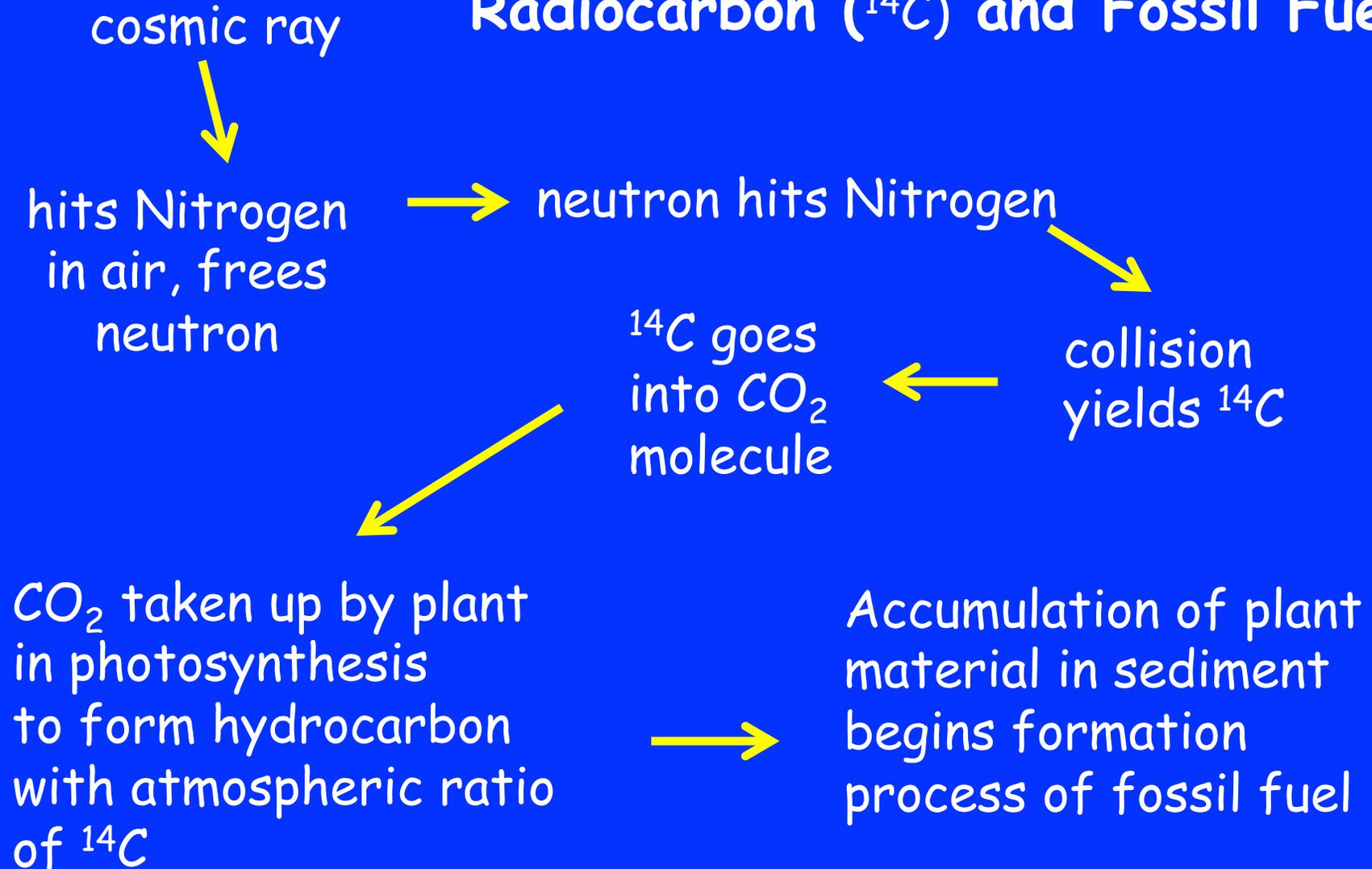


Measured carbon isotopes in  
tree rings

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 ( $^{14}\text{C}$ ) and Fossil Fuel



## The $^{14}\text{C}$ evidence ( $^{12}\text{C}$ is normal)

Dead plant matter becomes fossil fuels

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

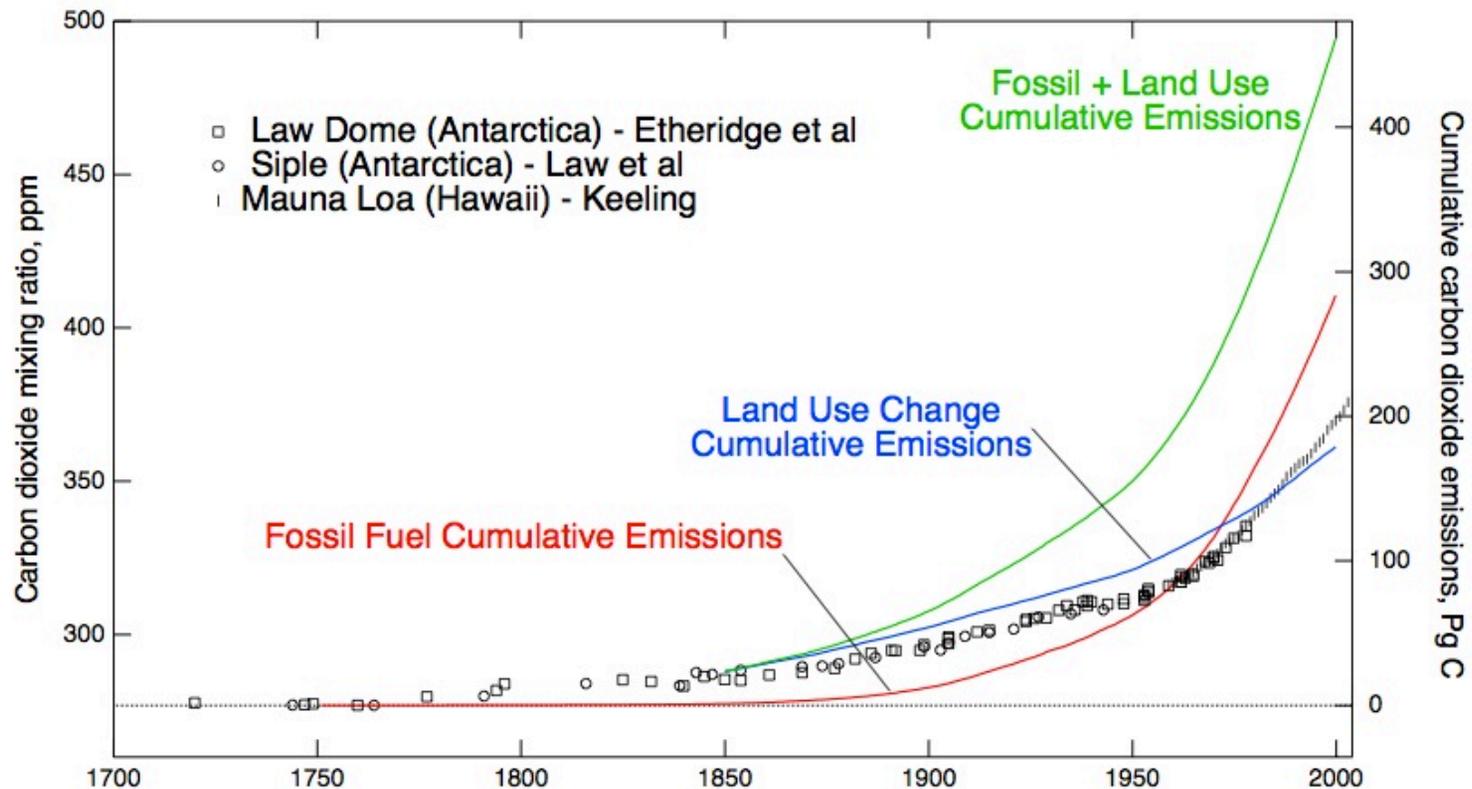
Plant matter in fossil fuels is millions of yr old, so contains no remaining  $^{14}\text{C}$ .

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

"Smoking gun" that new carbon in atmospheric  $\text{CO}_2$  is from fossil fuel burning.

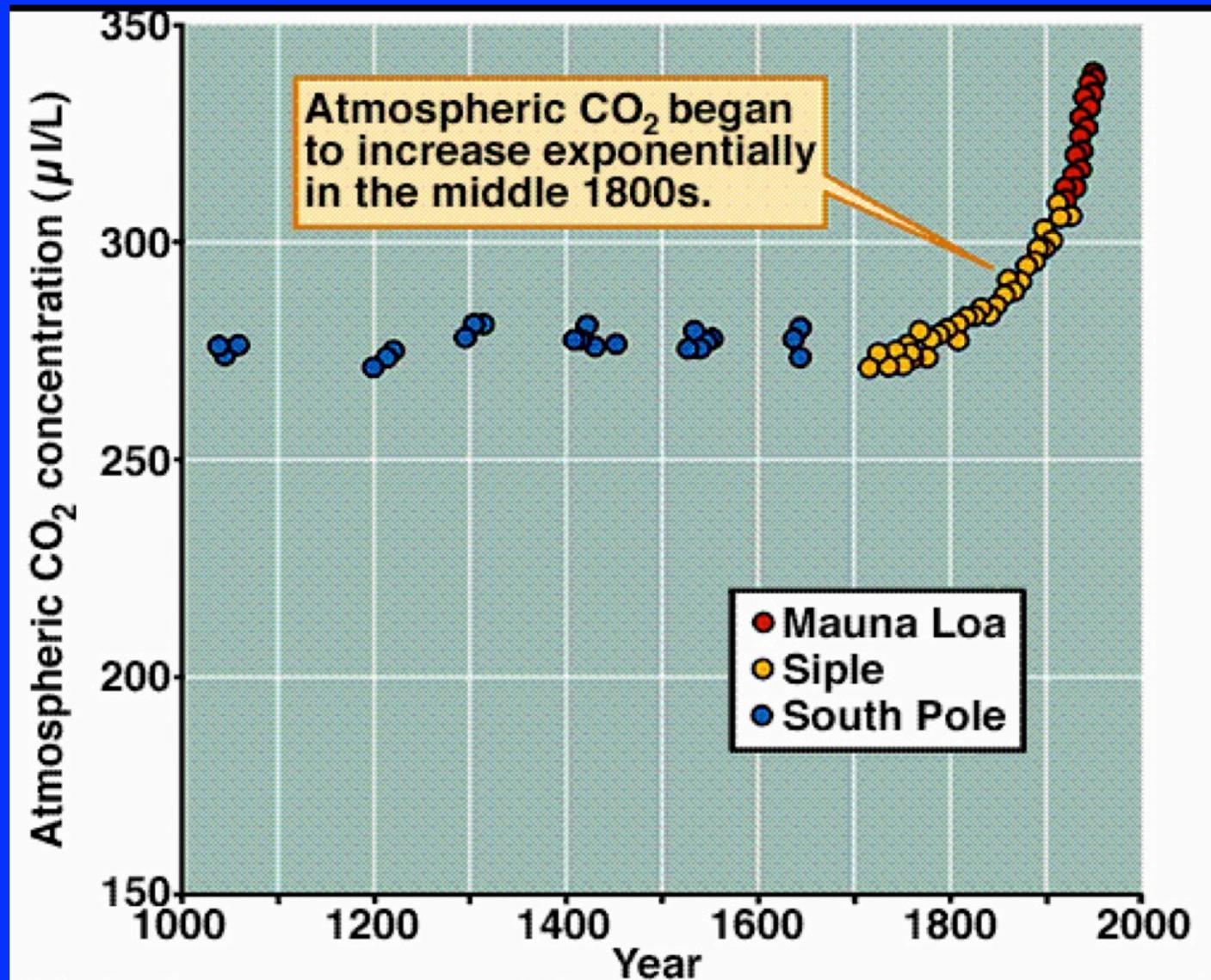
# ATTRIBUTION OF INCREASE IN ATMOSPHERIC CO<sub>2</sub>

Comparison of *cumulative* CO<sub>2</sub> emissions from fossil fuel combustion and land use changes with measured increases in atmospheric CO<sub>2</sub>.

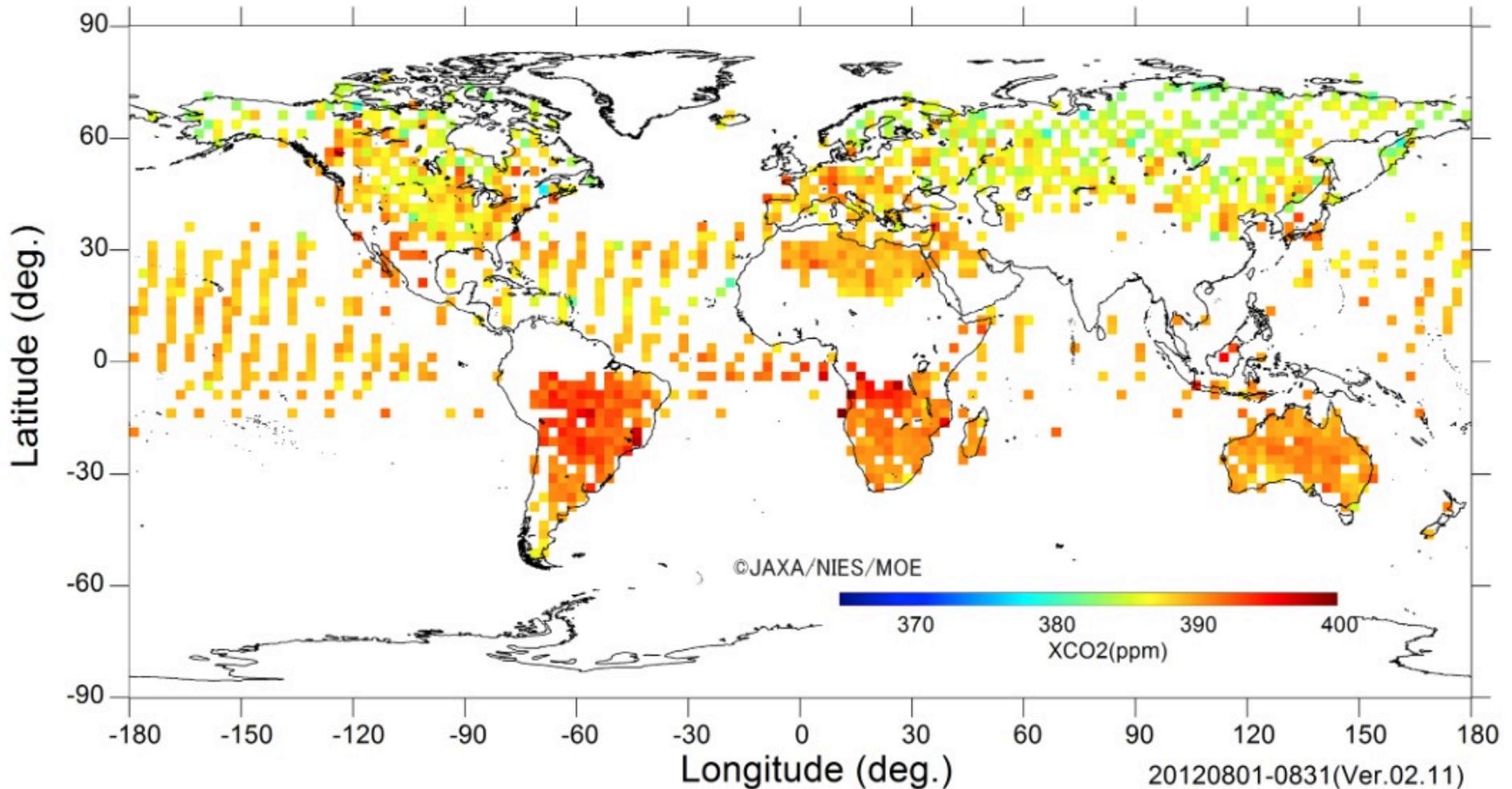


**Prior to 1970** the increase in atmospheric CO<sub>2</sub> was dominated by emissions from land use changes, not fossil fuel combustion.

# Ice cores began to give a clearer picture of the pre-industrial CO<sub>2</sub> record

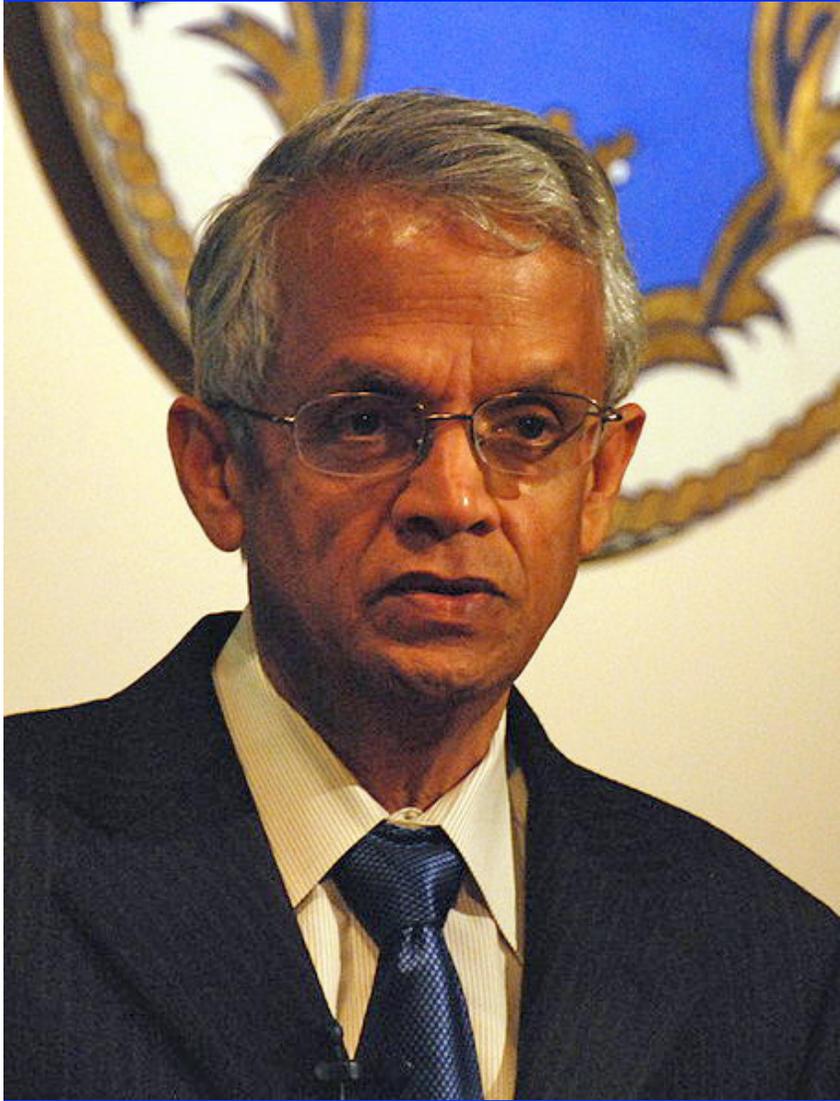


# GOSAT CO<sub>2</sub> column-avg mixing ratio, Aug 2012



Monthly Global Map of the CO<sub>2</sub> column-averaged volume mixing ratios in 2.5 deg by 2.5 deg mesh  
August 2012 Ver.02.11

# The saga of V. Ramanathan

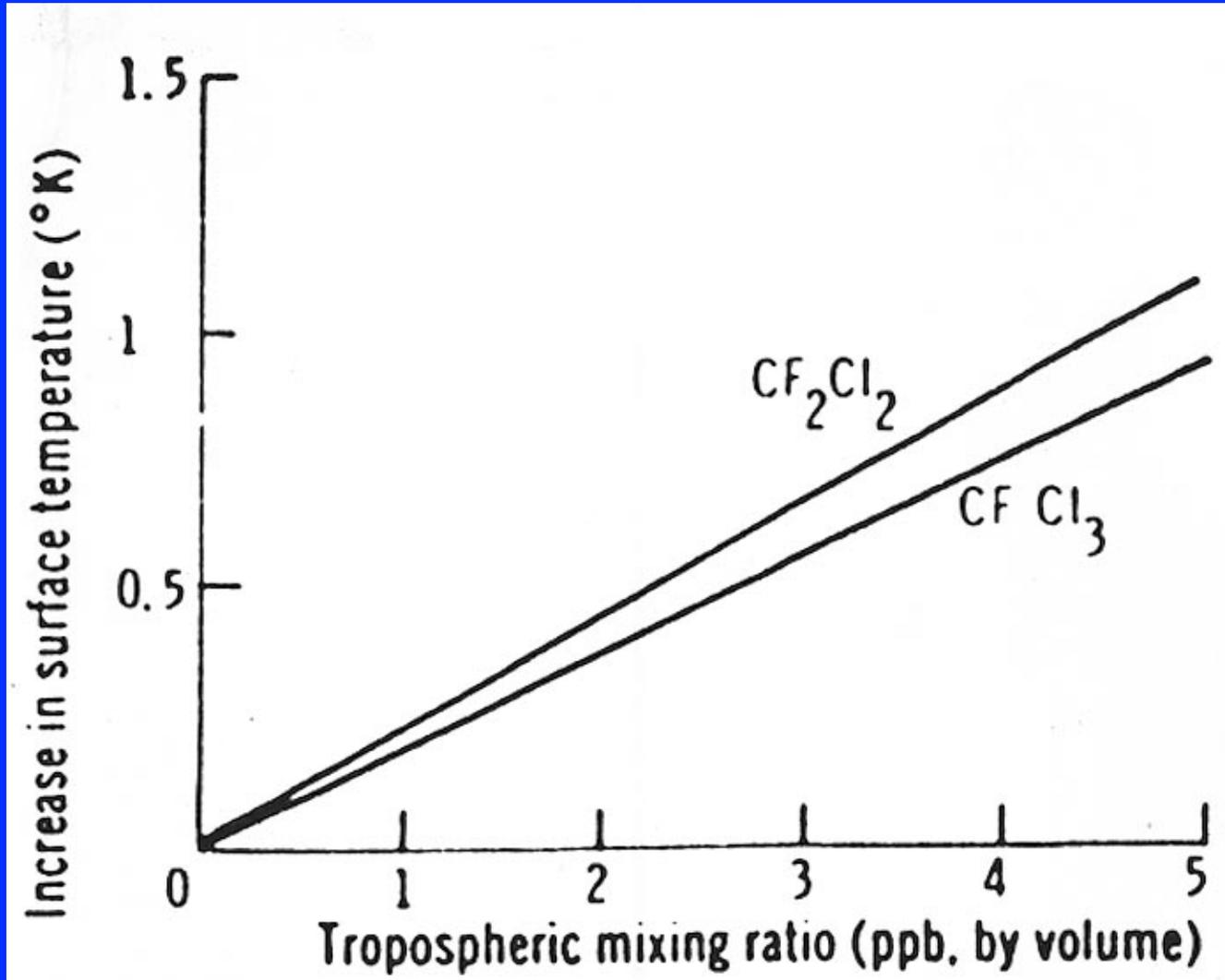


refrigeration engineer  
in India

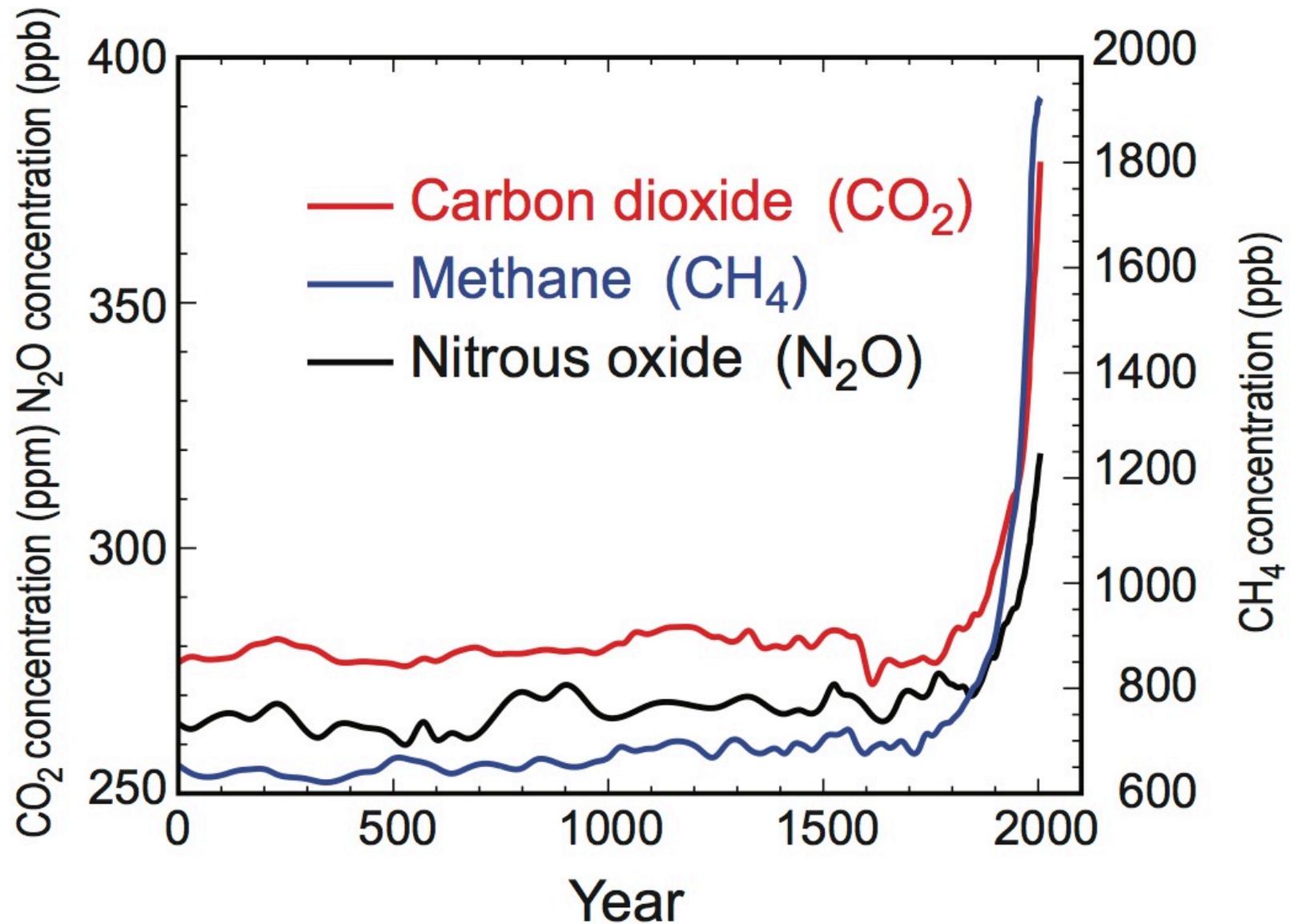
thesis on Venus  
dynamics

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

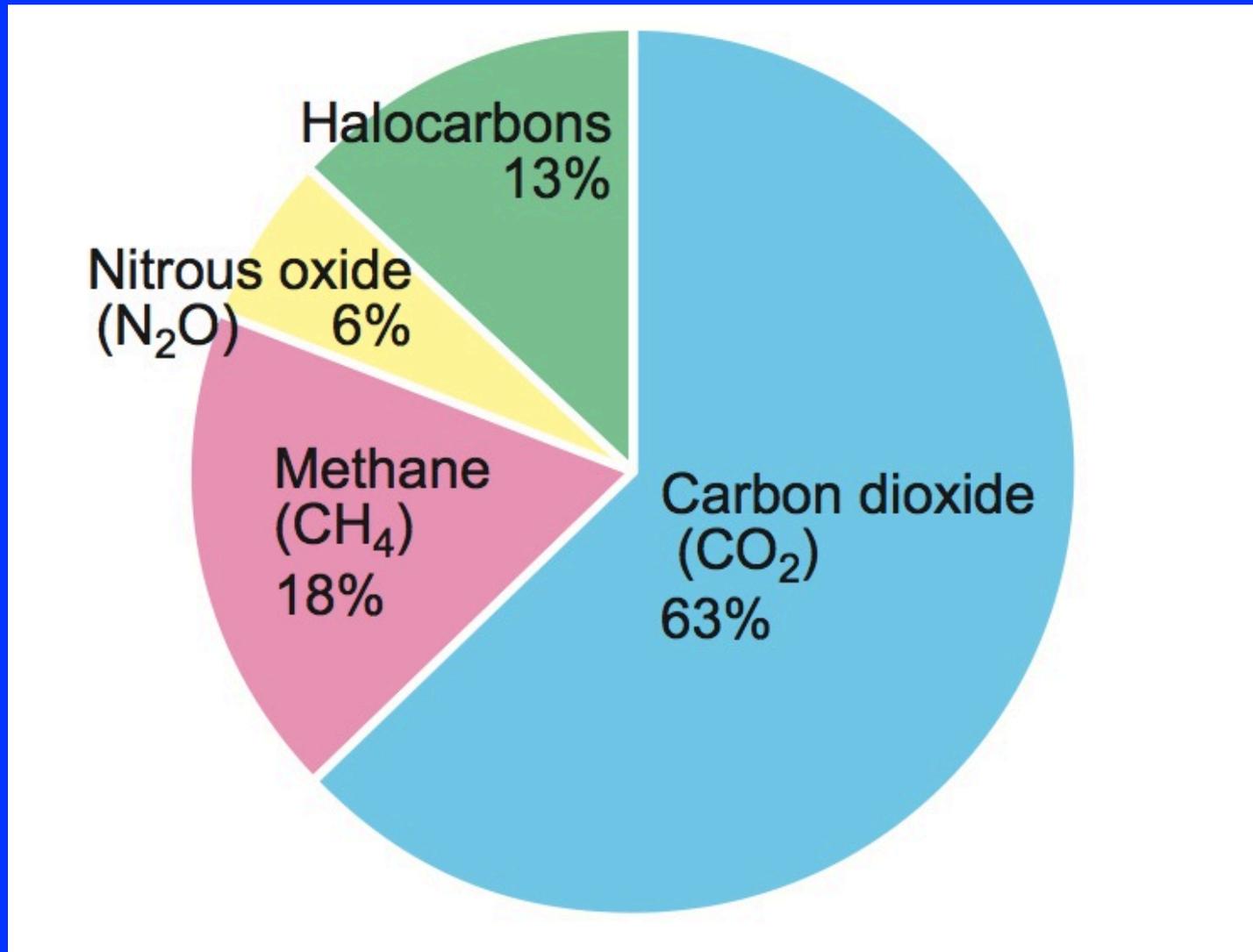
# Ramanathan's famous 1976 graph of global surface temperature vs. CFC concentration



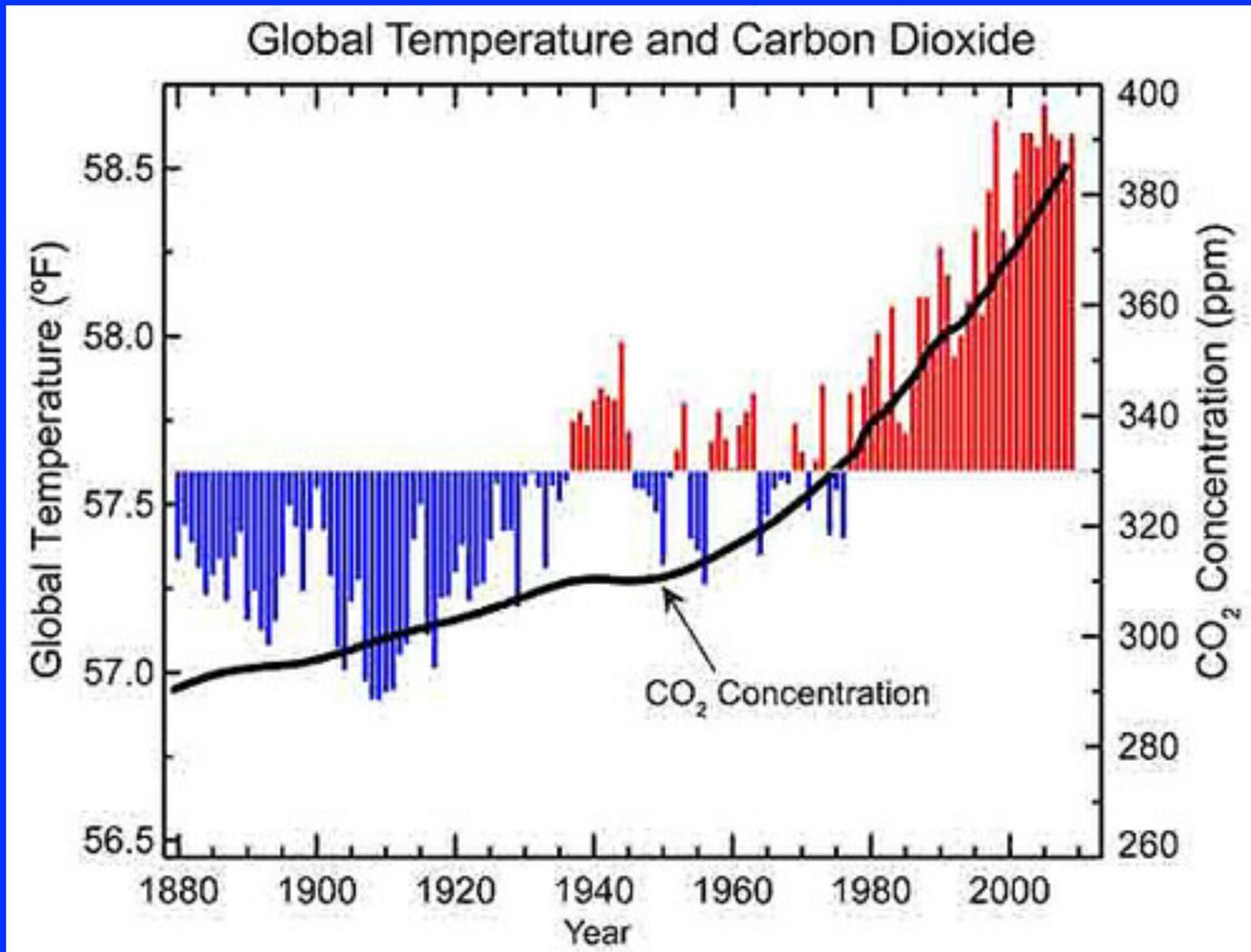
## Other greenhouse gases are rising too



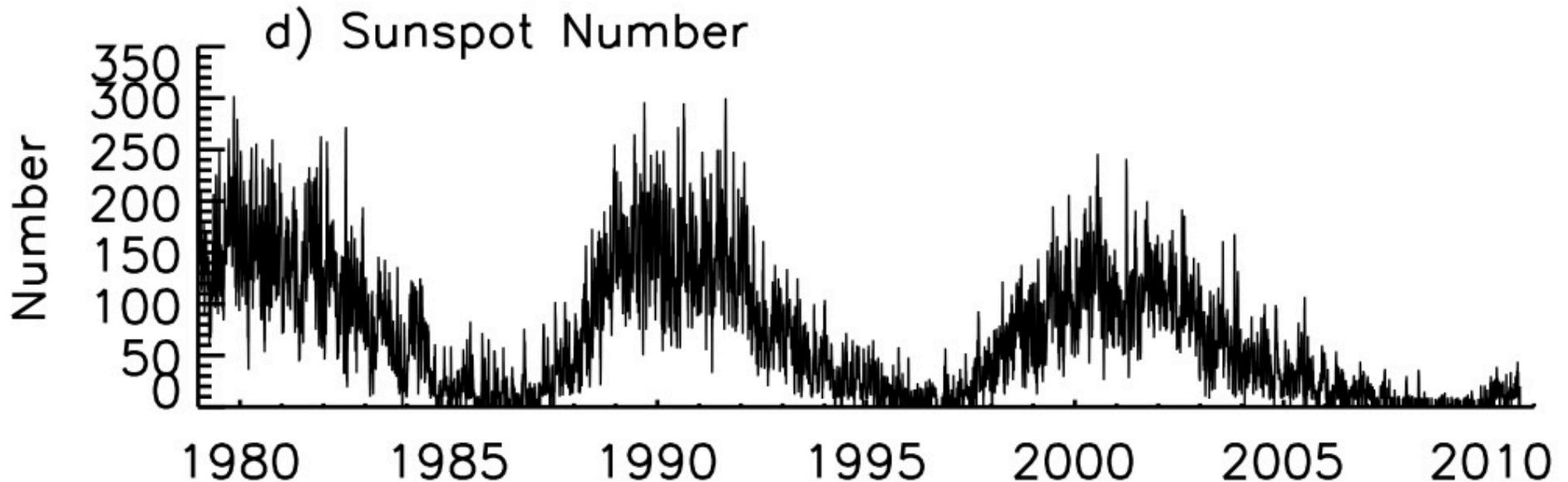
## Other greenhouse gases: contribution to warming (IPCC 4)



# Strong indication of causal relation



# The “global warming slowdown” of 2000-2010



Sunspots had a protracted minimum during 2000-2010.

Other contributors:

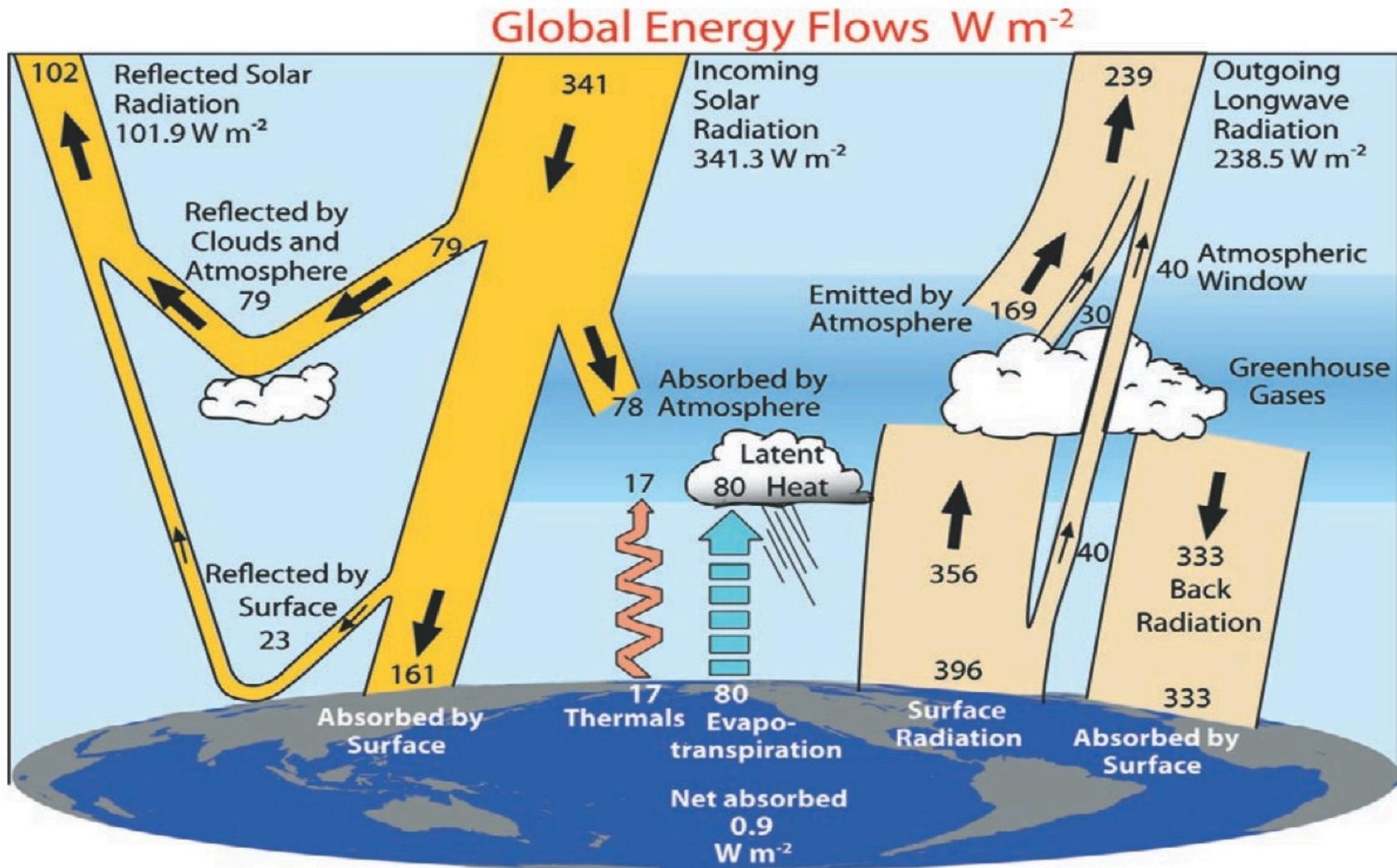
Chaos (who knew? Gerry Meehl)

Deep ocean

Small volcanoes

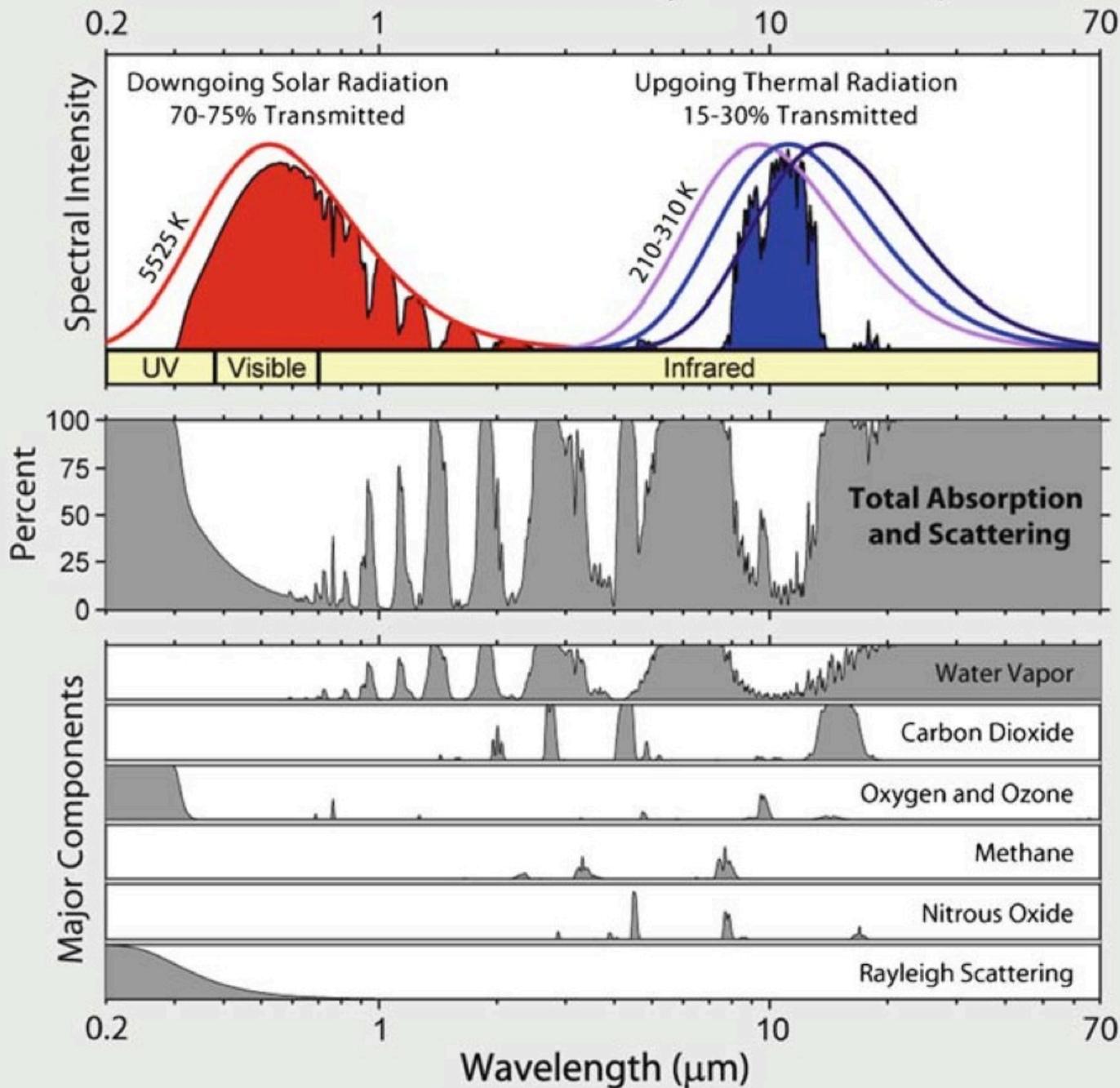
Stratospheric H<sub>2</sub>O increase

# Trenberth/Kiehl 2009



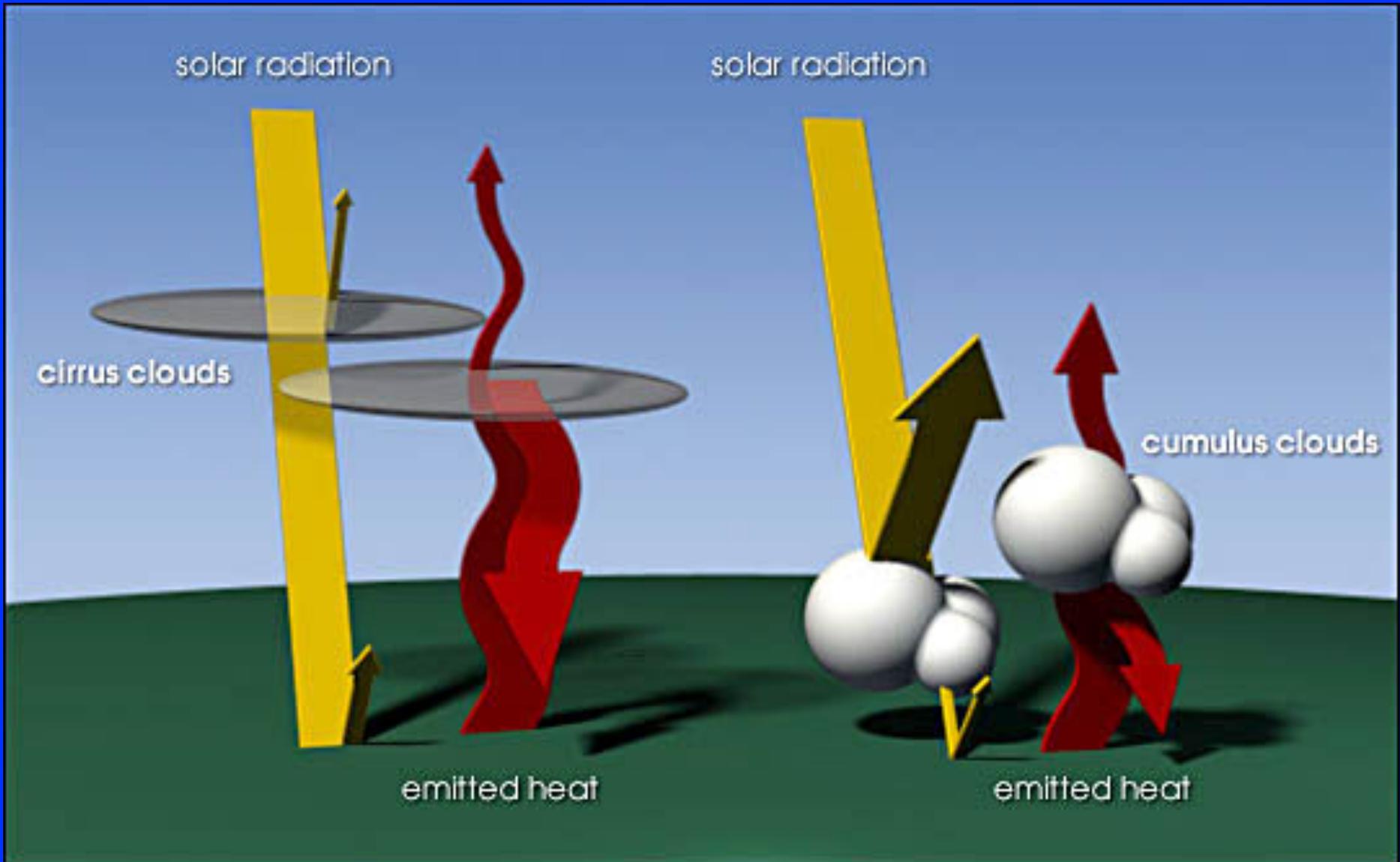
**FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period ( $W m^{-2}$ ). The broad arrows indicate the schematic flow of energy in proportion to their importance.**

# Radiation Transmitted by the Atmosphere

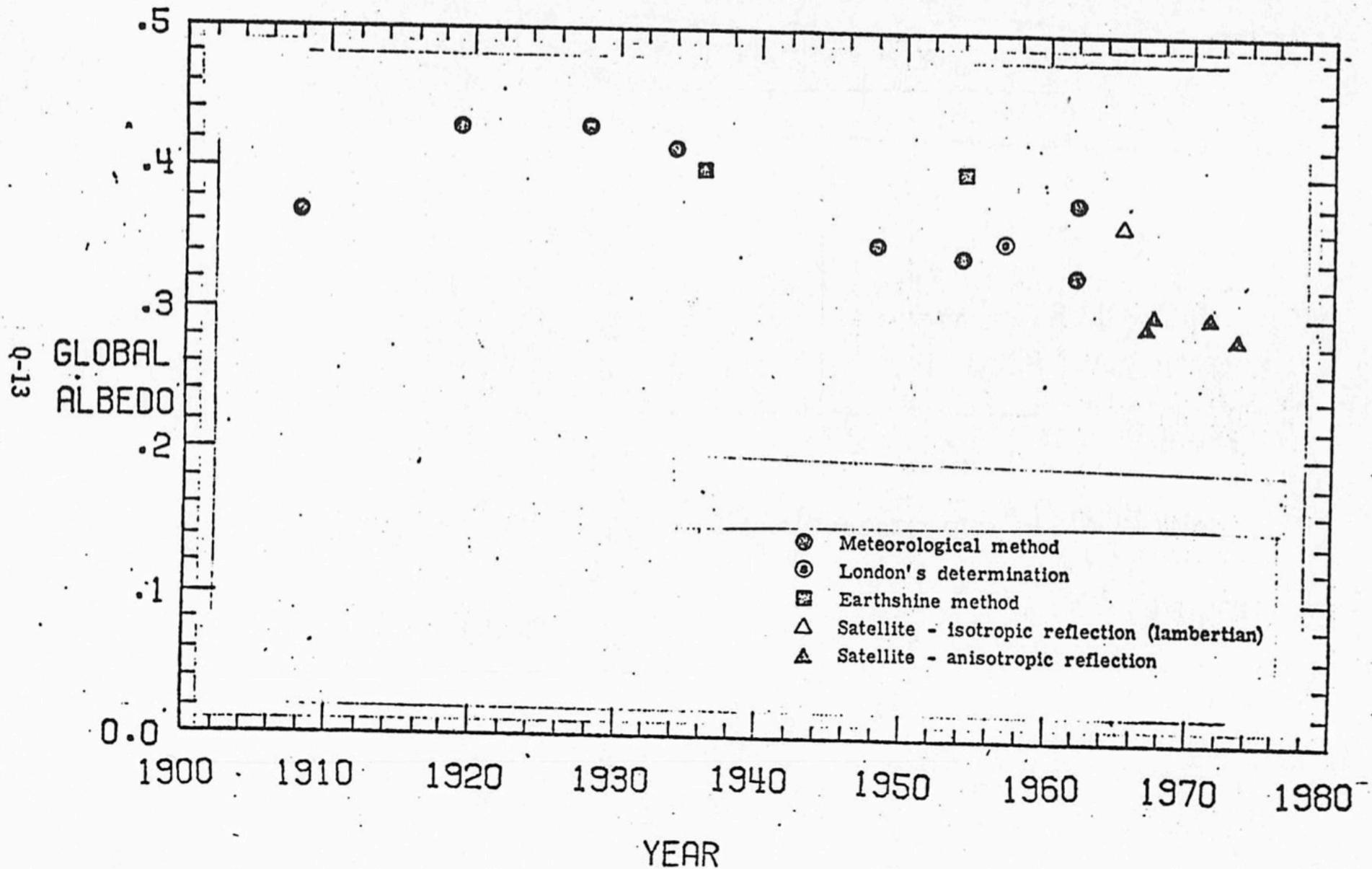


Planck functions of Sun and Earth almost non-intersecting

# Energy balance: cloud effect



# HISTORICAL ESTIMATES OF EARTH GLOBAL ALBEDO.



# 1962-65 Earth radiation balance: Suomi/Vonder Haar

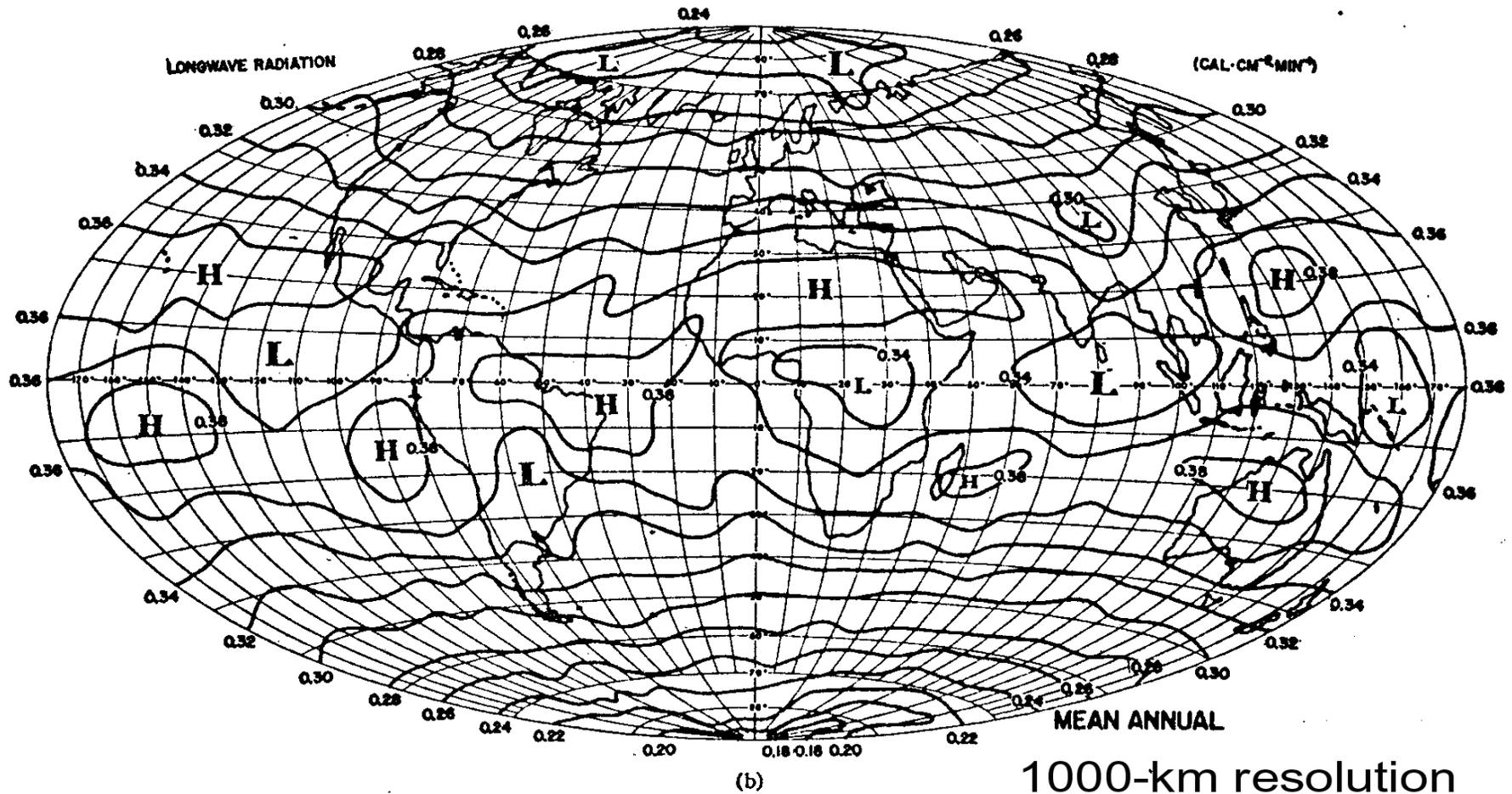
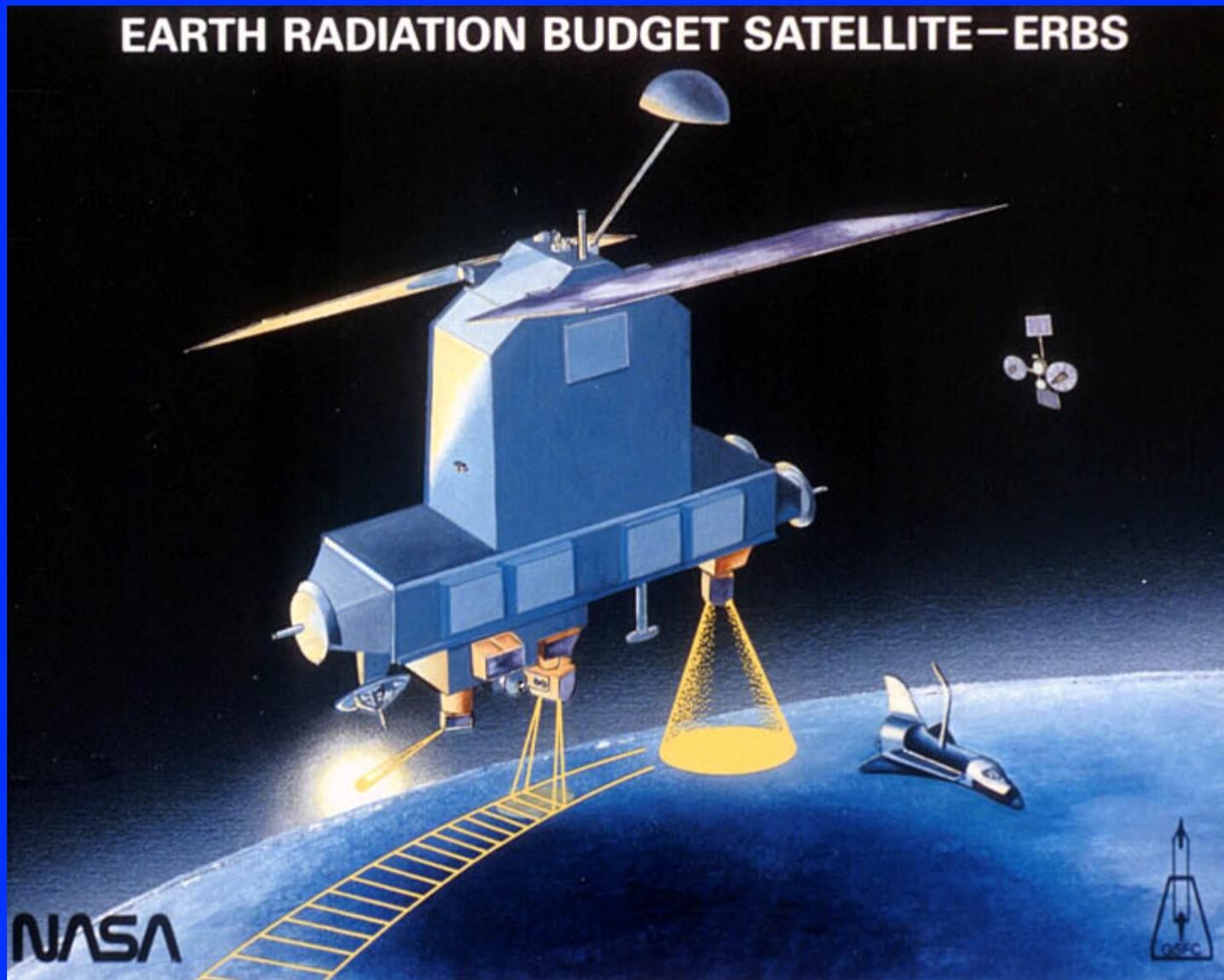


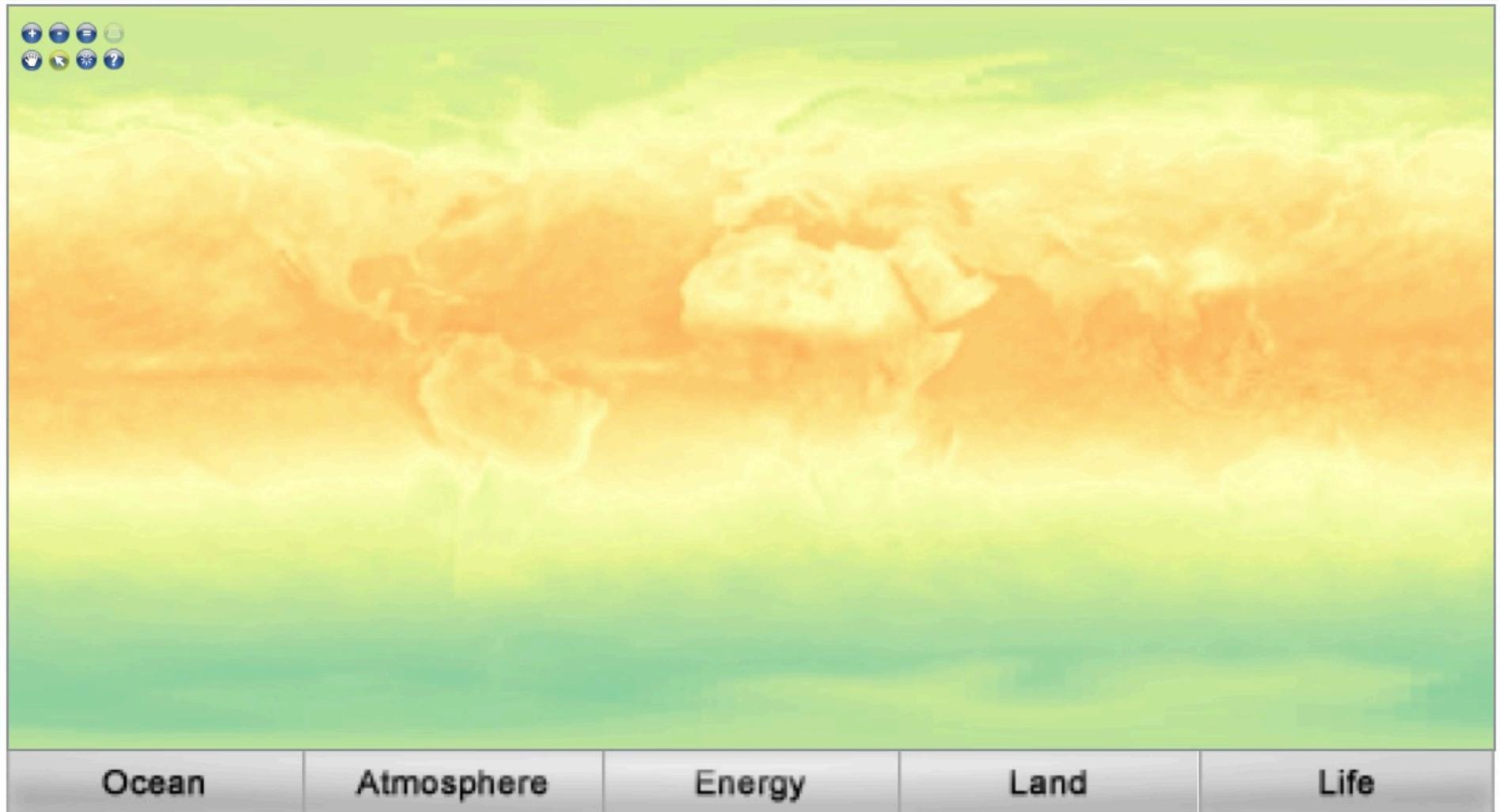
FIG. 4. Mean annual geographical distributions of radiation budget parameters. Planetary albedo and longwave radiation were measured from satellites during 1962-1965. Net radiation values were derived using a solar constant of  $2.00 \text{ cal cm}^{-1} \text{ min}^{-2}$ .

Vonder Haar/Suomi, 1971

# 1980s (2 more; first true constellation)



# Apr 2012: CERES net radiation

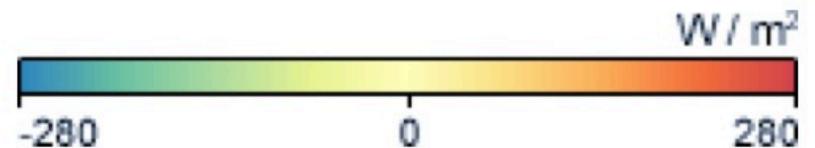


## Net Radiation (1 month)

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

[About this dataset](#)

Summer 2013



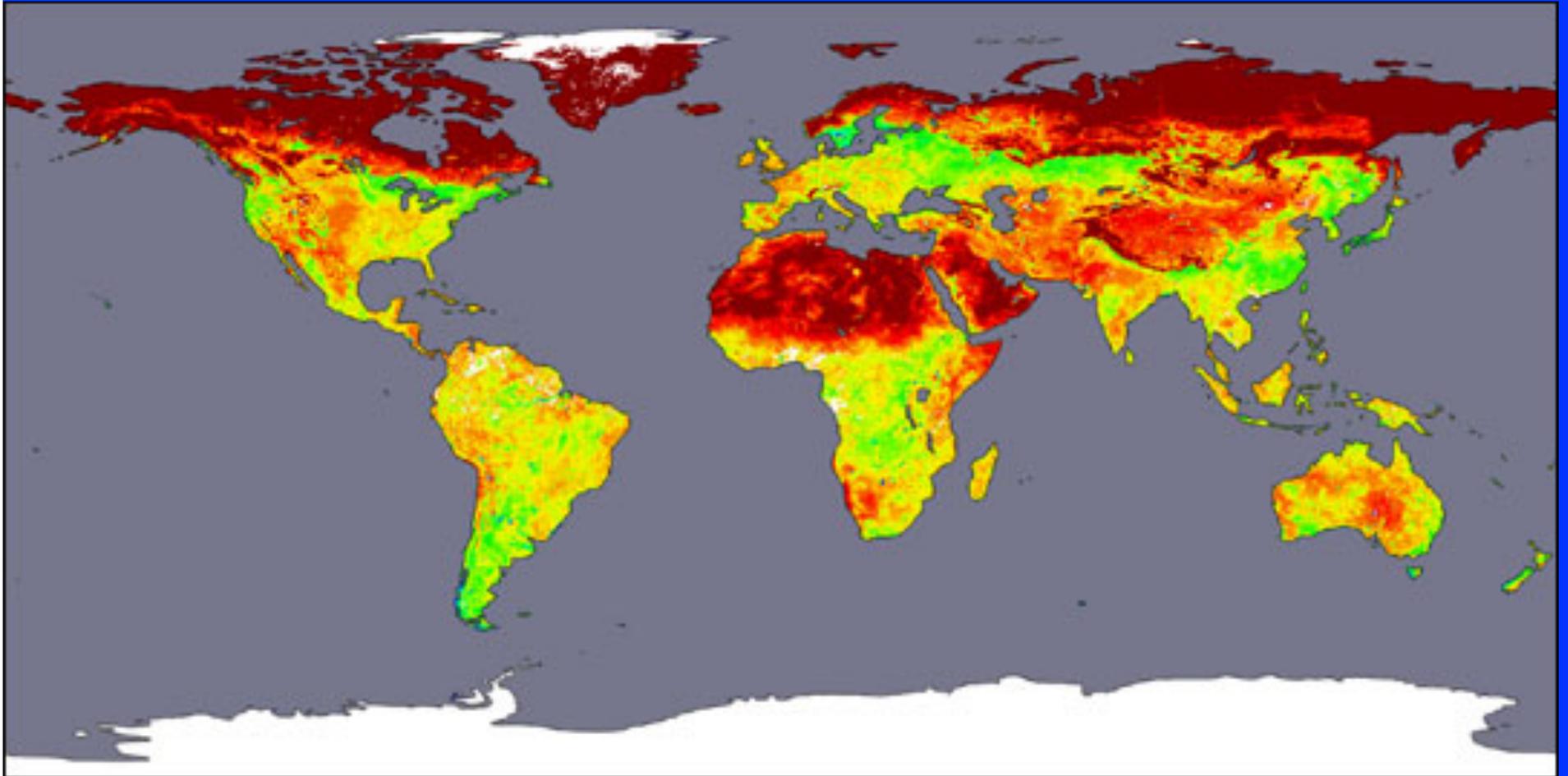
European: 2000s

# Geostationary Earth Radiation Budget *Experiment*

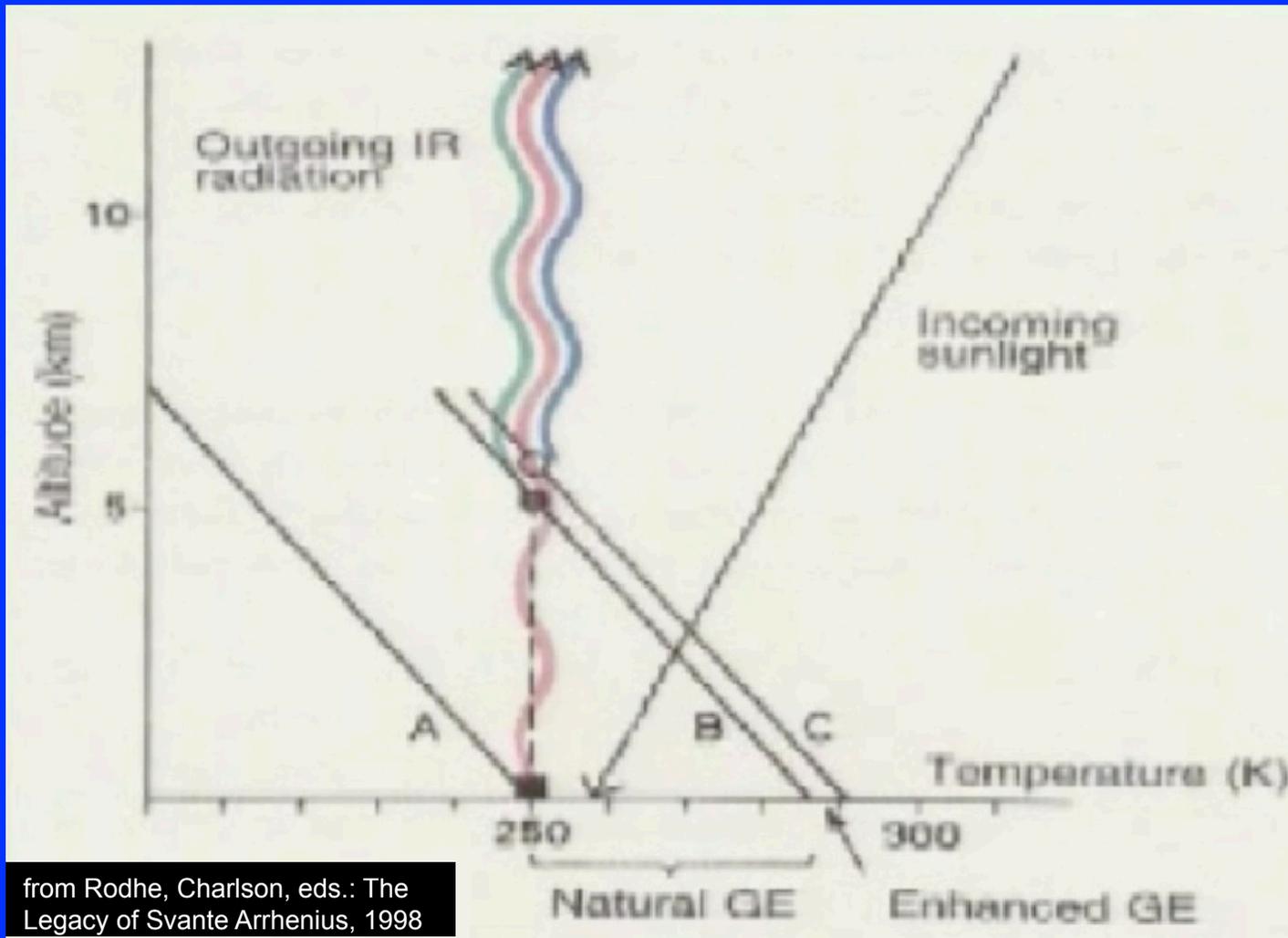
**GERB is an Announcement of Opportunity Instrument for Meteosat Second Generation (MSG) intended to make accurate measurements of the Earth Radiation Budget from geostationary orbit. It is being produced by a European Consortium led by the UK. The development, integration and flight of GERB on MSG is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

The screenshot shows the homepage of skepticalscience.com. At the top, there is a navigation bar with links for Home, Arguments, Software, Resources, Comments, The Consensus Project, Translations, About, and Donate. Below the navigation bar is a search bar and social media icons for Twitter, Facebook, YouTube, and Pinterest. The main content area features a large article titled "Explaining climate change science & rebutting global warming misinformation" by John Hartz, dated June 29, 2013. The article discusses the importance of scientific skepticism and provides a list of 10 "Most Used Climate Myths" with a thermometer graphic indicating their frequency. To the right of the main article is a sidebar with a "The Consensus Project Website" section, which includes a "Winner of the 2011 Eureka Prize" badge and a "Climate Change" textbook cover by G. Thomas Farmer and John Cook. The website also features a "Newcomers, start here" section and a "History of Climate Science" timeline from 1930 to 1960.

**Skeptical Science**  
*Getting skeptical about global warming skepticism*

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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...](#)

**the consensus project**

## 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 CO<sub>2</sub>
- 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 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

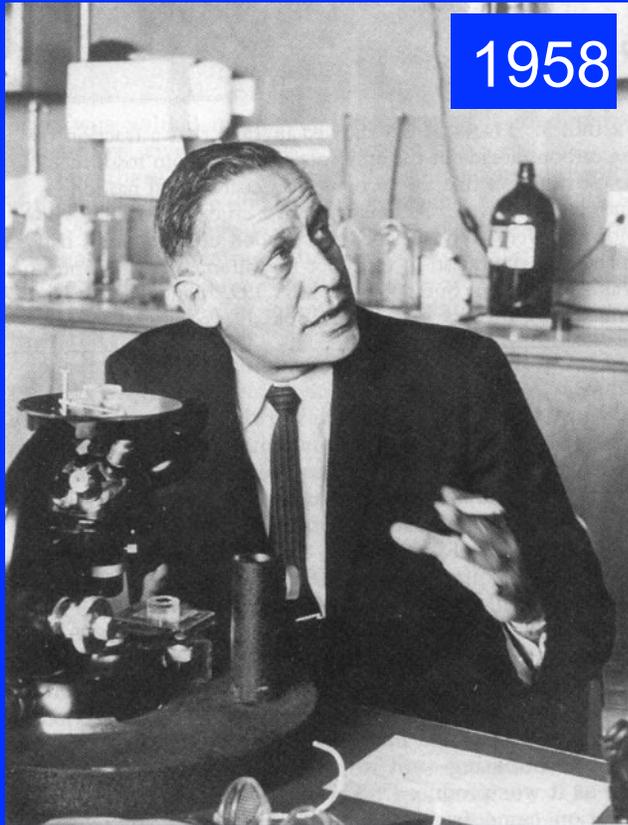
## Oreskes lectures outing global warming "skeptics"

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): $\text{CO}_2$ in oceans



In 1936 Revelle began studying the chemical interaction of  $\text{CO}_2$  with seawater.

He left the subject, returning in 1956 to discover that the absorption of  $\text{CO}_2$  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 H<sub>2</sub>O vapor in air (~ constant rel humidity)
- troposphere warms

Net result: 4x amplification of bare CO<sub>2</sub> effect

Many climate change mechanisms were studied with their approach — CO<sub>2</sub> but one in a crowd

to mid 1970s: CO<sub>2</sub> 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

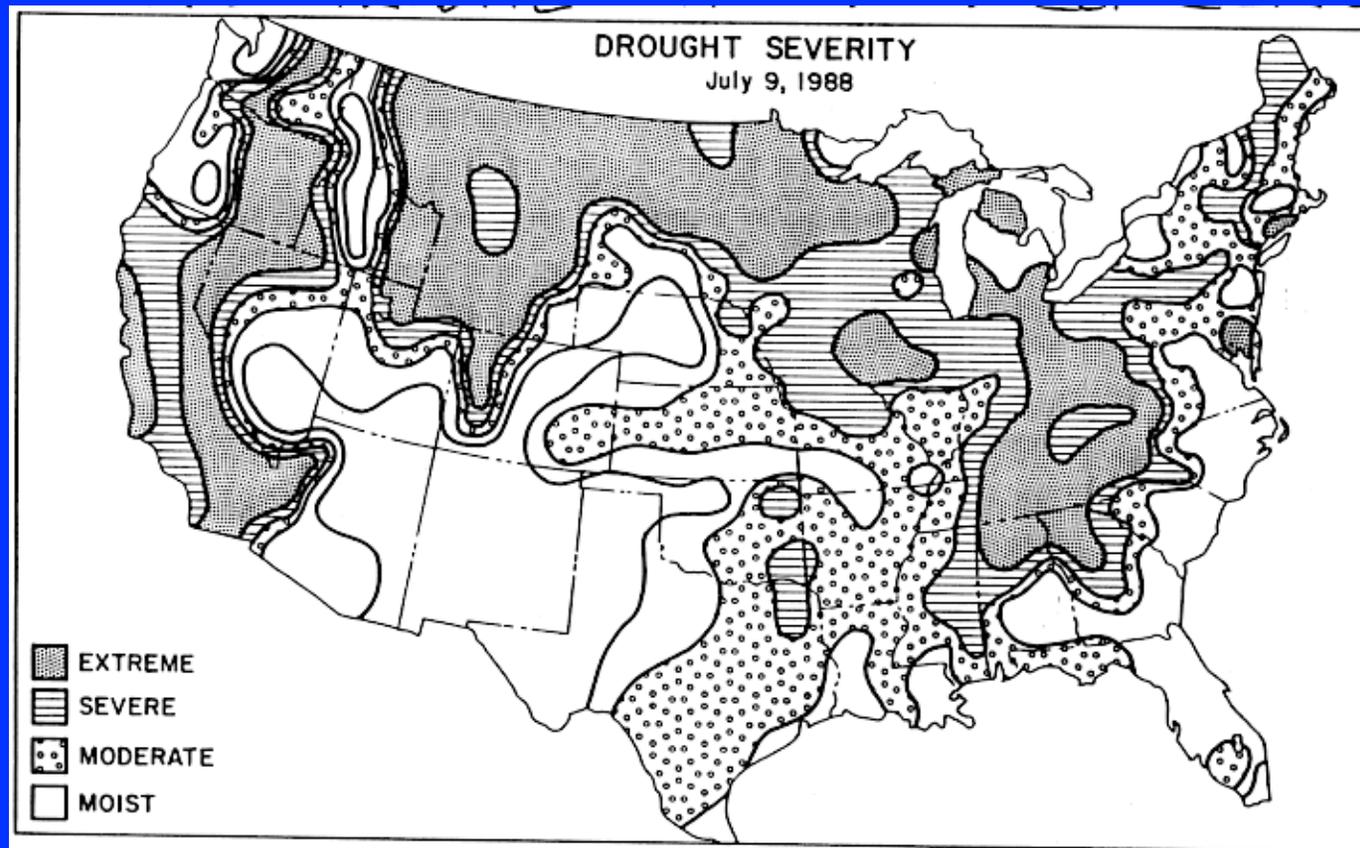
mid-80s onward: ice core bubbles begin to reveal CO<sub>2</sub> history: 270 ppm pre-industrial, 180 in ice ages

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*: 1<sup>st</sup> global map of direct forcing by sulfate aerosol;  $-0.3$  to  $-1.0$   $\text{W}/\text{m}^2$  compared to  $2.4$   $\text{W}/\text{m}^2$  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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> (amount ~ that in air)

Then he reduced the amount of CO<sub>2</sub> by 1/3

The transmission changed by only 0.4%

Thus, Angstrom concluded, the greenhouse effect of CO<sub>2</sub> 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 CO<sub>2</sub> 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 =  $\pi R^2$

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

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

2xCO<sub>2</sub> forcing is  $\sim 3.7 \text{ W/m}^2$

# Callendar: Temperature change vs. CO2 concentration

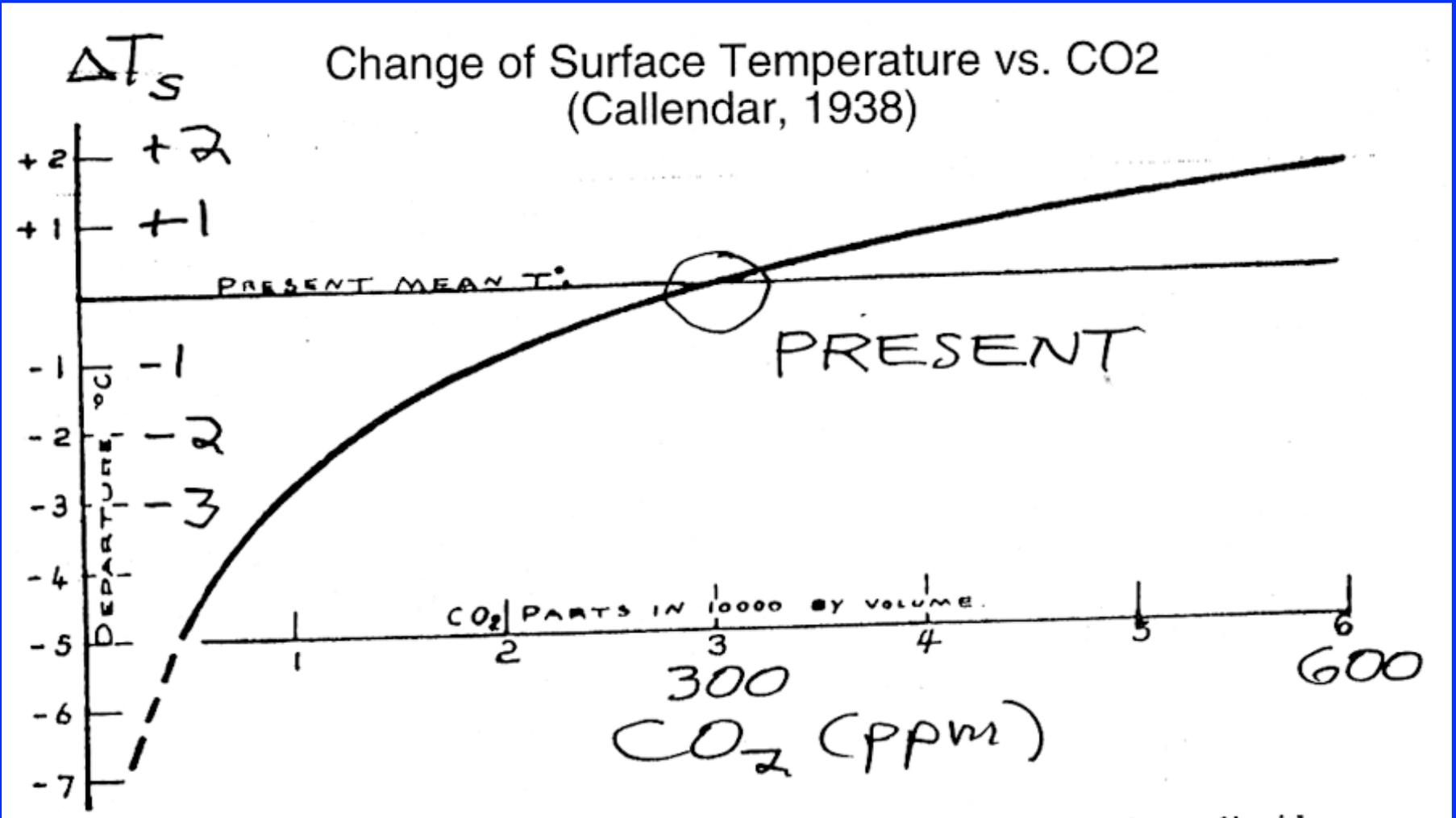


FIG. 2.—Change of surface temperature with atmospheric carbon dioxide (H<sub>2</sub>O vapour pressure, 7.5 mm. Hg.)

## 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 CO<sub>2</sub>

The warming up to the mid-1930s was mainly due to CO<sub>2</sub> 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 CO<sub>2</sub>...

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

## Plass attacks Rejection Reason #1

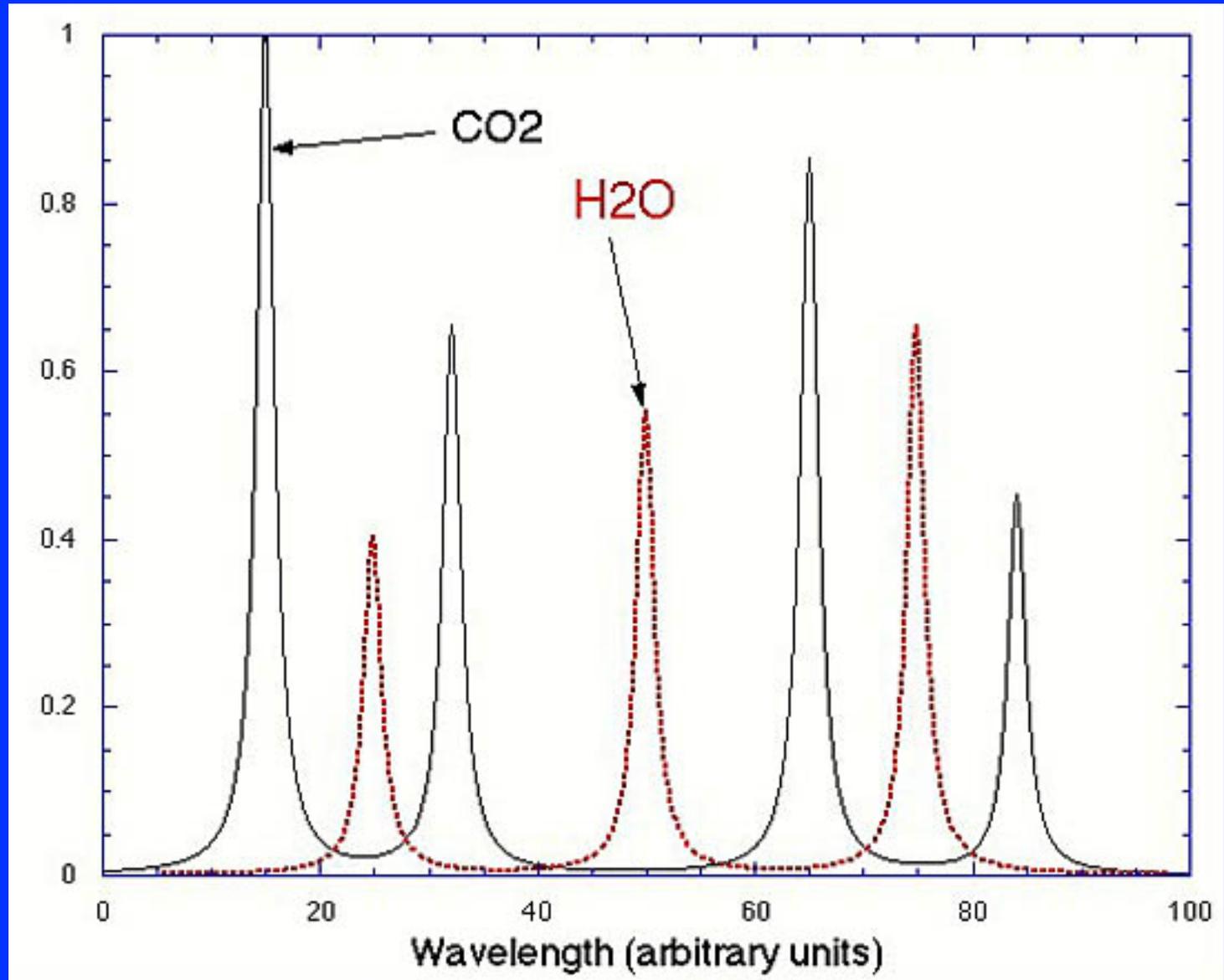
"... that H<sub>2</sub>O vapor absorbs in the same spectral region as CO<sub>2</sub>."

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)



Plass also notes that  $\text{CO}_2$  greenhouse action is relatively unimpeded above 2-3 km

$\text{H}_2\text{O}$  scale height  $\sim 2$  km [ $\exp(-z/2)$ ]

$\text{CO}_2$  scale height  $\sim 8$  km

so... radiative effect of  $\text{H}_2\text{O}$  is weak above 2-3 km.

## Plass attacks Rejection Reason #2

that CO<sub>2</sub> absorption is saturated.

BUT...

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

## Platt's 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)

**Platt** recognized that “CO<sub>2</sub>-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 CO<sub>2</sub> 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<sub>2</sub> radiative effect.

## Timeline - 1960's

*Manabe-Wetherald*: a watershed

*Manabe*: Ocean-atmosphere GCM's

AFCRL: Absorption line parameter table  
(HITRAN)

CO<sub>2</sub> 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