Hot Topics in Climate 1: Global Warming

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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”
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 CO2 rise

Revelle: oceans take < half of extra CO2

Much better H2O absorption meas’ts

Plass: physicist, radiative transfer expert, crusader for CO2 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 $^{12}$C/$^{14}$C in post-1900 tree rings proved that ancient carbon was being added to modern atmosphere by human burning.

Revelle hired Suess at Scripps
Cosmic ray hits Nitrogen in air, frees neutron. Neutron hits Nitrogen. Collision yields $^{14}\text{C}$ goes into $\text{CO}_2$ molecule. $\text{CO}_2$ taken up by plant in photosynthesis to form hydrocarbon with atmospheric ratio of $^{14}\text{C}$. Accumulation of plant material in sediment begins formation process of fossil fuel.
The $^{14}$C evidence ($^{12}$C is normal)

Dead plant matter becomes fossil fuels

$^{14}$C decays with a half life of ~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 CO2 is from fossil fuel burning.
ATRIBUTION 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

- Carbon dioxide (CO₂)
- Methane (CH₄)
- Nitrous oxide (N₂O)
Other greenhouse gases: contribution to warming (IPCC 4)

- Carbon dioxide (CO₂): 63%
- Methane (CH₄): 18%
- Nitrous oxide (N₂O): 6%
- Halocarbons: 13%
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
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.
Planck functions of Sun and Earth almost non-intersecting
Energy balance: cloud effect
HISTORICAL ESTIMATES OF EARTH GLOBAL ALBEDO

- Meteorological method
- London's determination
- Earthshine method
- Satellite - isotropic reflection (Lambertian)
- Satellite - anisotropic reflection

GLOBAL ALBEDO

YEAR

**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 cal cm$^{-1}$ 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
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.

from Rodhe, Charlson, eds.: The Legacy of Svante Arrhenius, 1998

http://www.aip.org/history/climate/index.htm
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?

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
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


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.
In 1936 Revelle began studying the chemical interaction of $CO_2$ with seawater.

He left the subject, returning in 1956 to discover that the absorption of $CO_2$ 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 CO2 -- 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” CO2 -- 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 CO2 had remained in the air,

and that 2/3 of anthropogenic CO2 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
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 2°C)
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\textsuperscript{st} global map of direct forcing by sulfate aerosol; -0.3 to -1.0 W/m\textsuperscript{2} compared to 2.4 W/m\textsuperscript{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 (≈1360 W/m²)

Earth’s surface area = 4πR²

Earth intercepts sunlight over area = πR²

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

Sun can vary by 1-2 W/m² in solar cycle, but the climate sees only 0.25-0.5

2xCO2 forcing is ≈3.7 W/m²
**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?”
“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)
Plass 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.
Plass also notes that CO2 greenhouse action is relatively unimpeded above 2–3 km.

H2O scale height $\sim 2$ km $\left[\exp(-z/2)\right]$

CO2 scale height $\sim 8$ km

so... radiative effect of H2O 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.”
Motivation: Ice Ages

Method: surface energy balance

Result: $\Delta T_s = 3.5C$ for $2 \times CO2$

(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:

\[ \Delta T_s = 10 \, ^\circ C \text{ for } 2 \times CO2 \]

Said small changes in humidity profile or cloud can completely compensate CO2 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