The Quantum Mechanics of Global Warming

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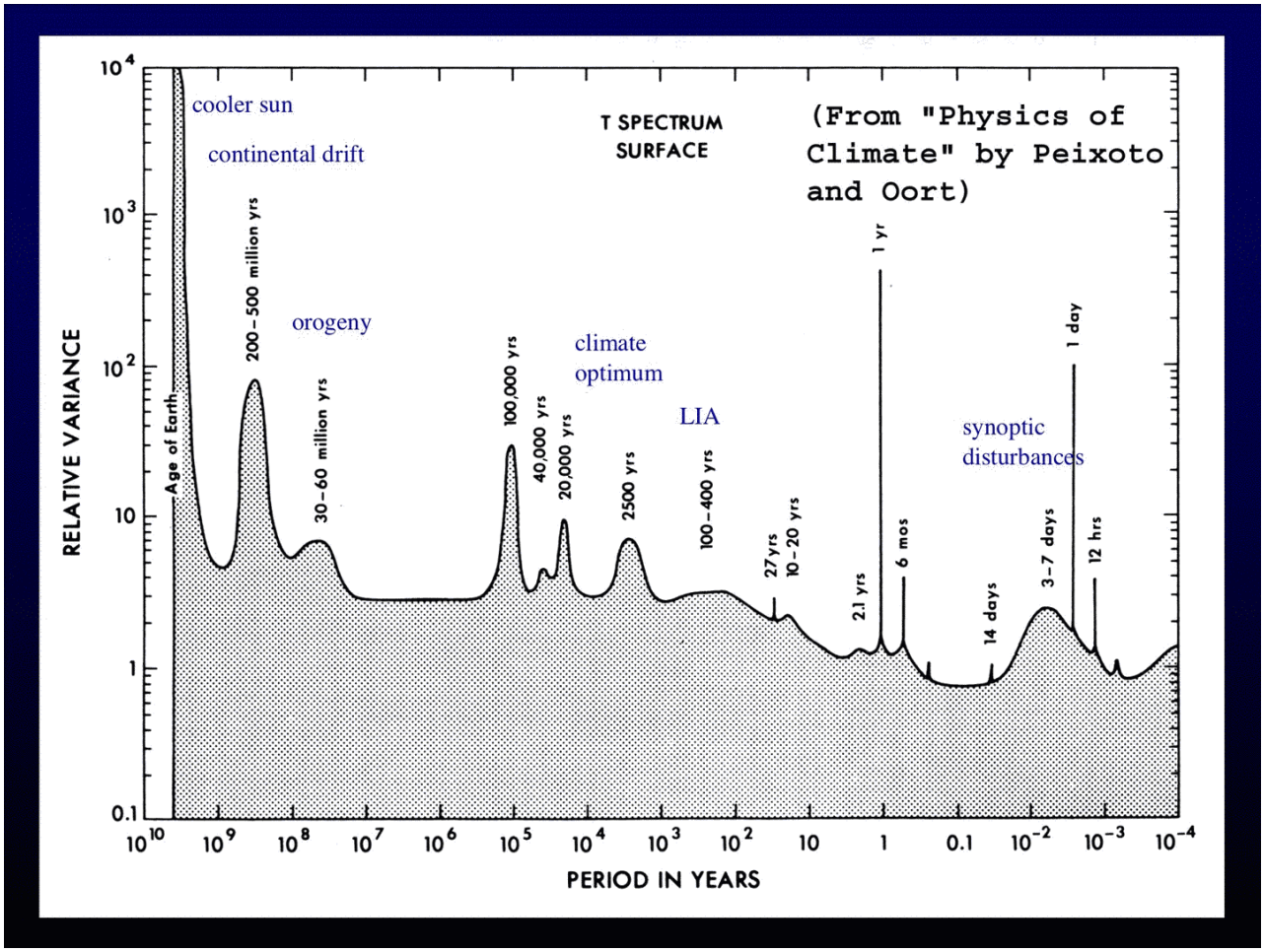
The Sciences of Climate Change

- Applied Math
- Astronomy
- Biology
- Chemistry
- Geology
- Meteorology
- Oceanography
- Physics:
  - Basic equations and simple estimates
  - Construction of complicated models.

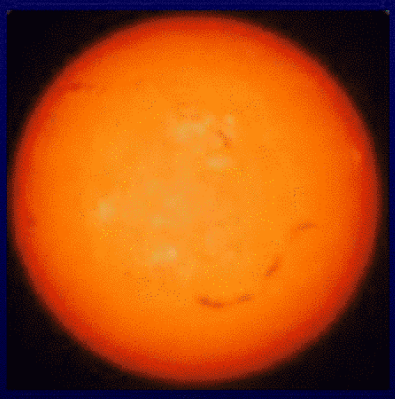
As multidisciplinary as it gets ….



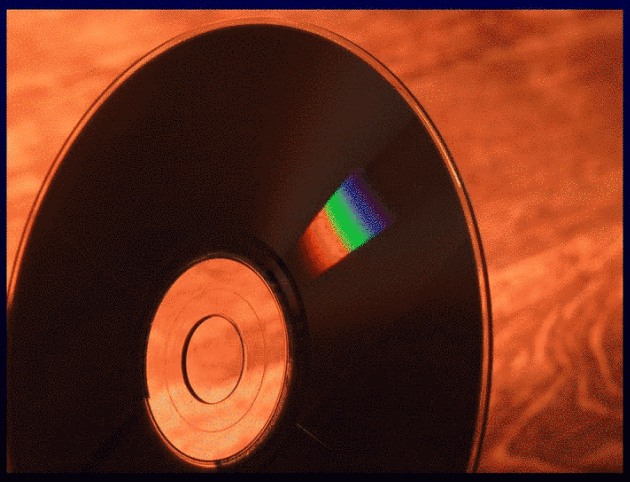
Outline

- Quantum mechanics #1: The ultraviolet catastrophe and Planck's blackbody radiation.
- QM #2: Why aren't we freezing?
- QM # 3: Deciphering ice and sediment records of the past several million years.
- The recent past.
- The 21st century.
- Quantum field theory of global warming?
- Politics of climate change.

Planck's Blackbody Radiation



Intensity is a function of both temperature and the frequency of light.



Sunlight is very nearly blackbody radiation.

(spectrum photo by Bodo Huckenstein)

Crisis in 19th Century Classical Physics

$$Intensity = function(Temperature, frequency)$$

$$[I] = \frac{Watts}{meter^2} = \frac{Joules}{m^2\ s} \qquad [k_B T] = J \qquad [\nu] = \frac{1}{s}$$

$$c = 3 \times 10^8 m/s \text{ speed of light}$$

$$k_B = 1.38 \times 10^{-23} J/K \text{ Boltzmann's constant}$$

$$\Delta I(T,\nu) \propto \frac{k_B T \nu^2}{c^2} \Delta\nu \longrightarrow I = \sum_{\nu=0}^{\infty} \Delta I(T,\nu) \rightarrow \infty$$

UV Catastrophe!

Max Planck's Solution: Quanta

Light is composed of particles -- quanta -- called photons.

$\epsilon = h\nu$ Photons carry energy.

$h = 6.63 \times 10^{-34} Js$ Planck's constant

New constant of nature makes it possible to write the correct intensity.

$$\Delta I(T,\nu) = \frac{2\pi h\nu^3}{c^2} \frac{1}{e^{h\nu/k_B T} - 1} \Delta\nu$$

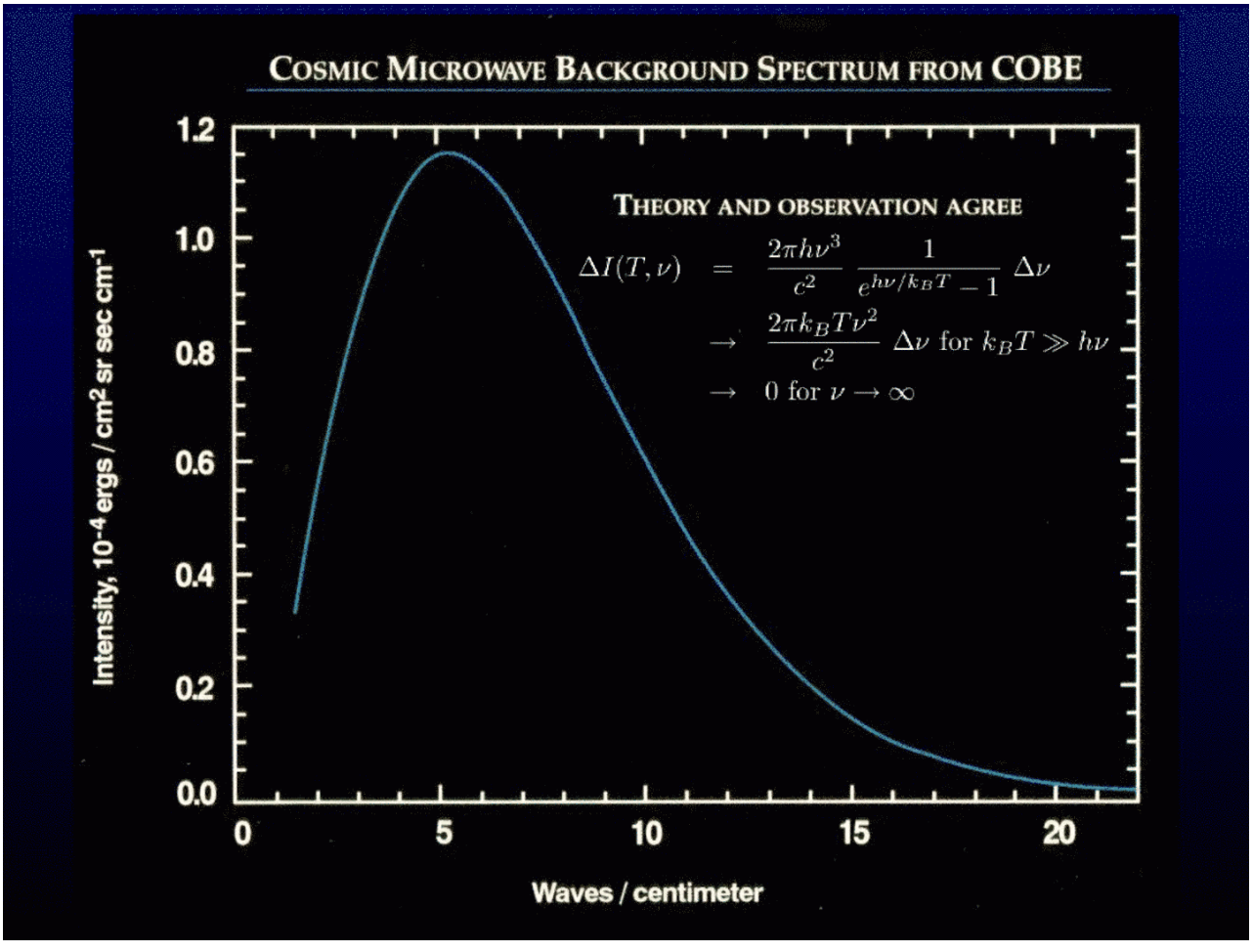
$$\rightarrow \frac{2\pi k_B T \nu^2}{c^2} \Delta\nu \text{ for } k_B T \gg h\nu$$

$$\rightarrow 0 \text{ for } \nu \rightarrow \infty$$

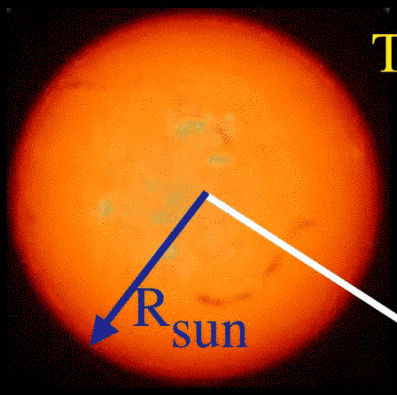
Now we can do that sum over frequency!

$$I = \sigma T^4$$

$$\sigma \equiv \frac{2\pi^5 k_B^4}{15 h^3 c^2} = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$



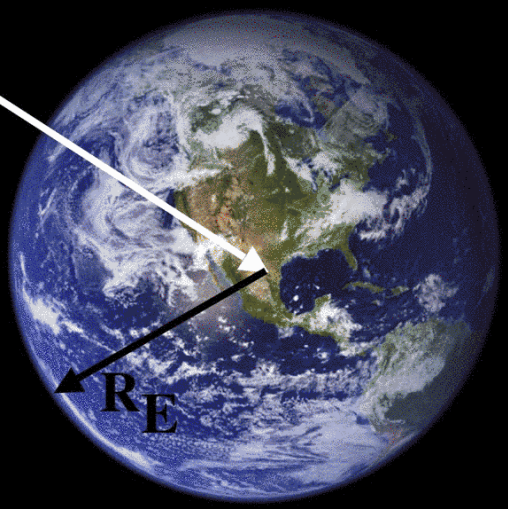
Temperature of the Earth



R_{sun}

The earth is (almost) in a thermal steady state: it emits as much radiation as it receives from the sun.

r_E



R_E

Albedo = a = 30 to 35% visible light reflected directly back to space ("earthshine" on the new moon).

$$fraction = \frac{\pi R_E^2}{4\pi r_E^2} \times (1-a)$$

Energy Balance

$$Luminosity = Area \times Intensity$$
$$= 4\pi R_{sun}^2 \times \sigma T_{sun}^4$$

Space

incoming energy flux

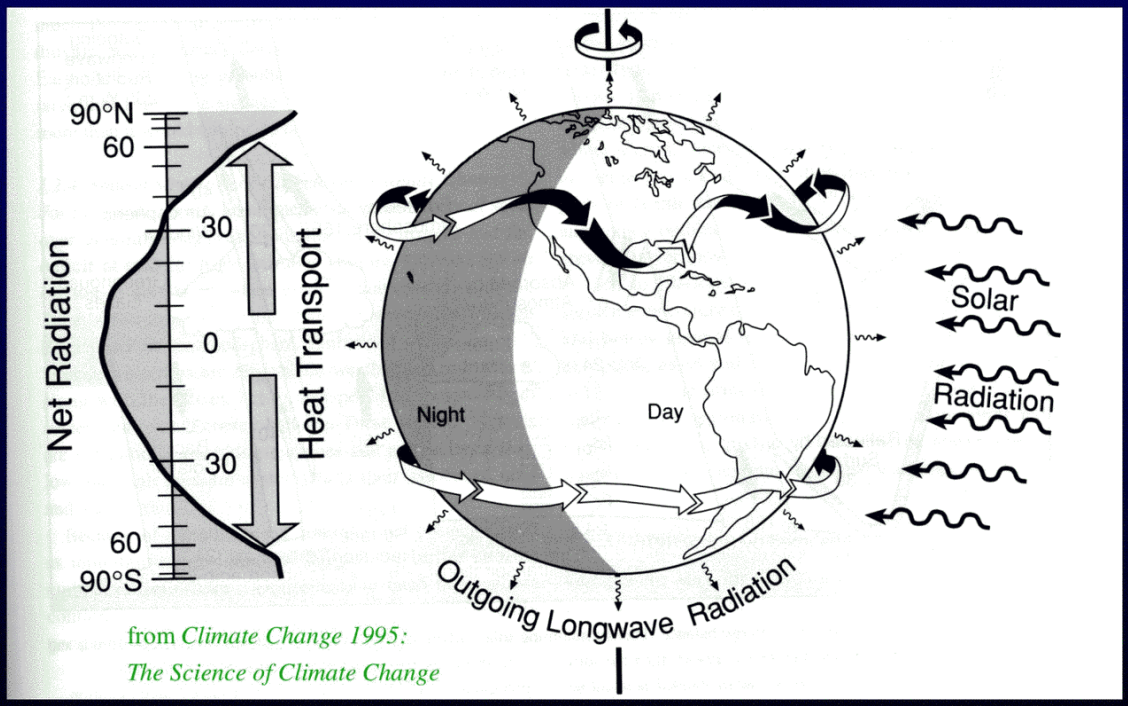
outgoing energy flux (IR)

$$\frac{\pi R_E^2}{4\pi r_E^2}(1-a)\,4\pi R_{sun}^2\,\sigma T_{sun}^4 = 4\pi R_E^2\,\sigma T_E^4$$

$$r_E = 150 \times 10^9 m$$
$$R_{sun} = 6.96 \times 10^8 m$$
$$T_{sun} = 5,800K$$

$$T_E = (1-a)^{1/4}\sqrt{\frac{R_{sun}}{2r_E}}\,T_{sun}$$
$$\approx 251K = -22C$$

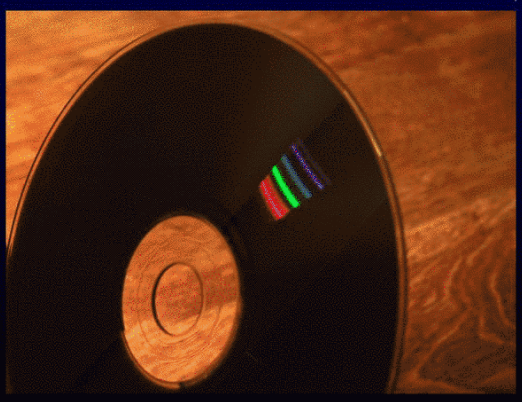
FREEZING



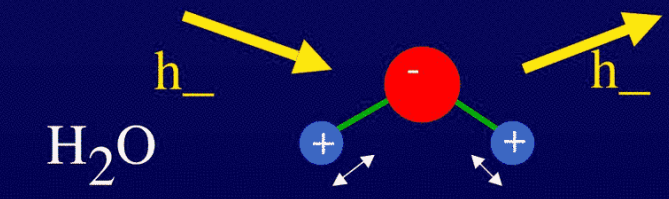
from *Climate Change 1995: The Science of Climate Change*

Terrestrial Planets

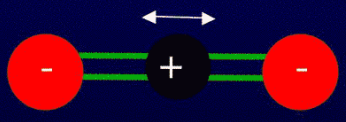
Planet	Venus	Earth	Mars
distance from sun (x 10^9 m)	108	150	228
albedo (a)	75%	30%	15%
cloud cover	100%	50%	small
radiative temperature	-39 C	-18 C	-56 C
mean surface temperature	427 C	15 C	-53 C
greenhouse warming	466 C	33 C	3 C

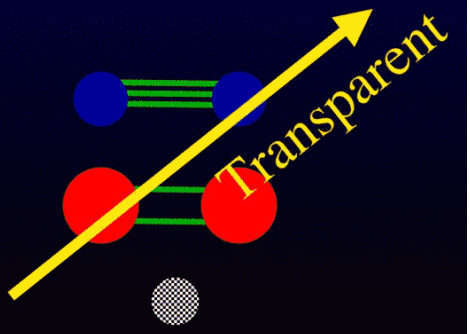


(photos by Bodo Huckenstein)

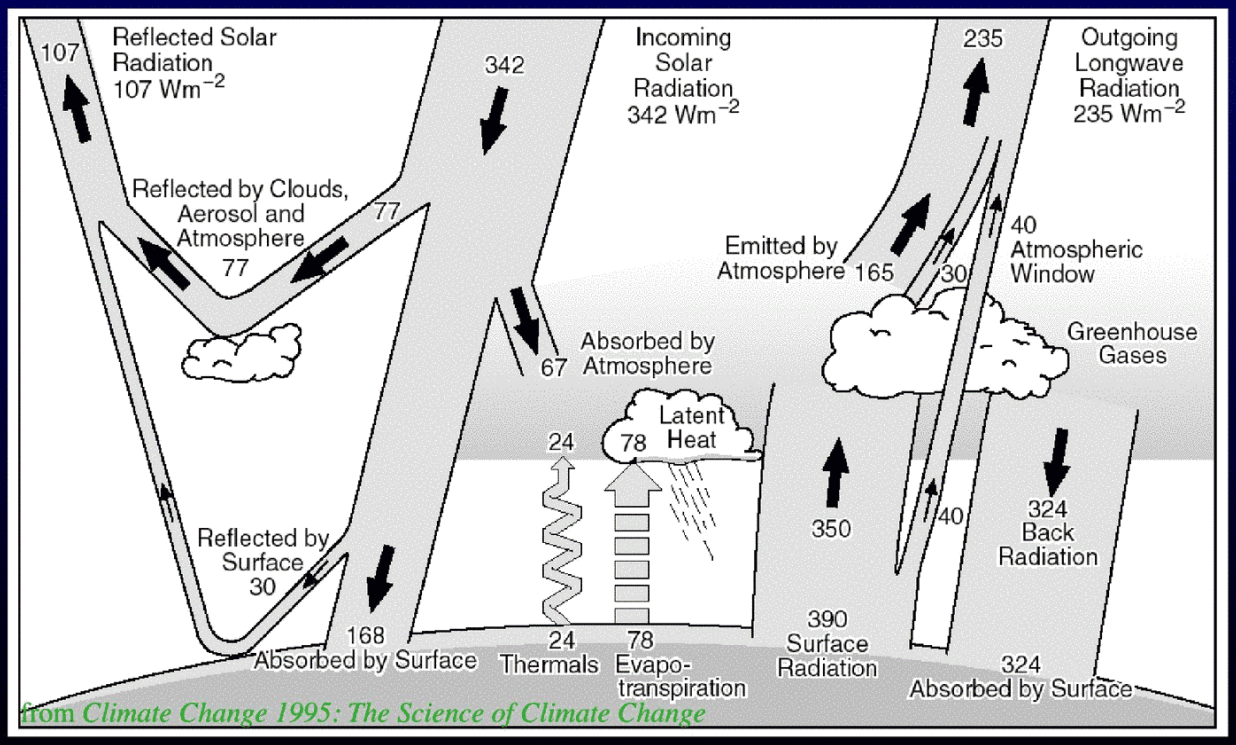


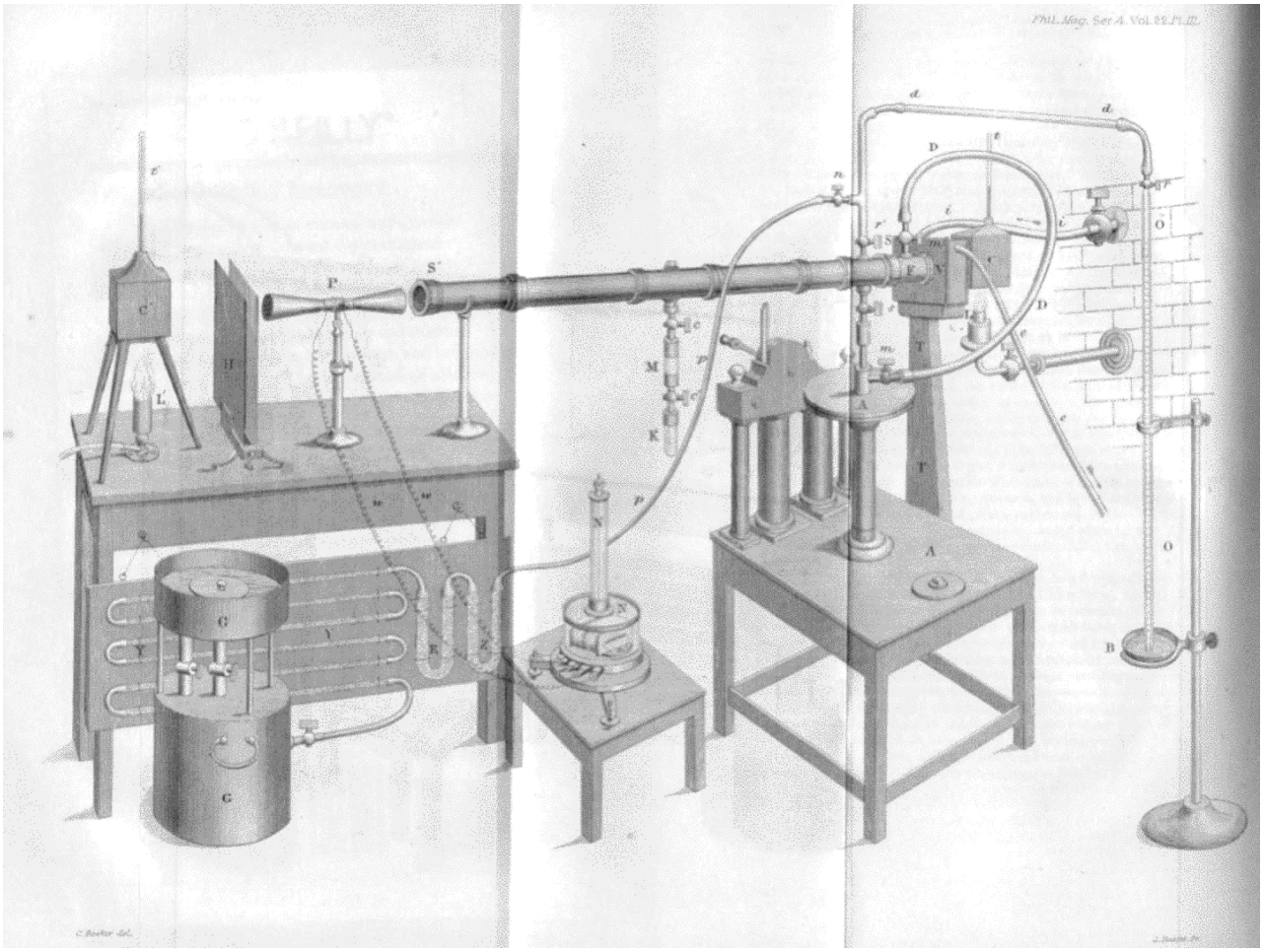
$h\nu = E_f - E_i$

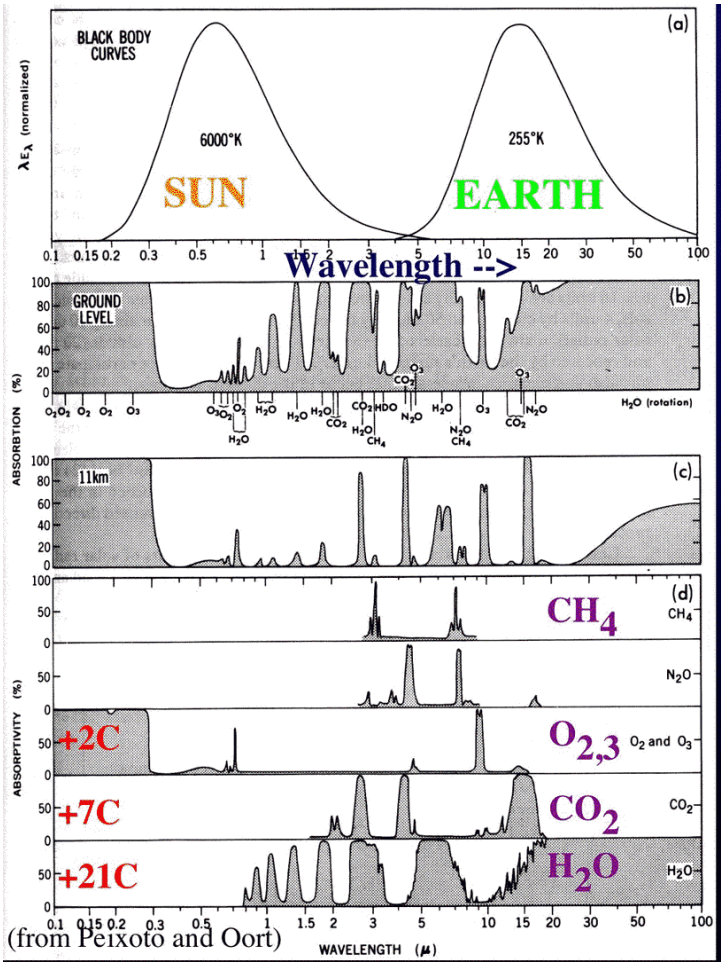




Svante Arrhenius, "On the influence of carbonic acid in the air upon temperature on the ground," Philos. Mag. **41**, 237 (1896)







(from Peixoto and Oort)

Principal greenhouse gas: water vapor

Secondary: carbon dioxide, methane, CFC's, …

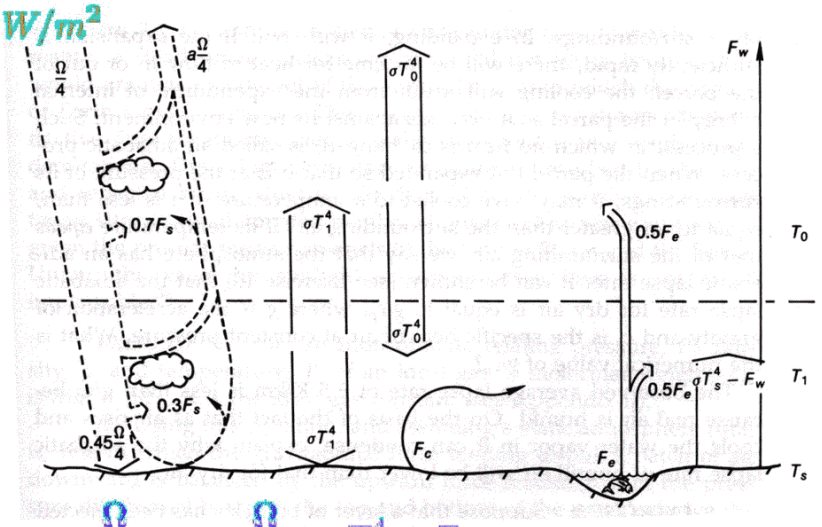
Absorption lines are pressure-broadened

radiative blackbody

greenhouse effect

$T_{earth} = 254K + 33K = 14\ C$

$\Omega = 1372\ W/m^2$



John Harte, *Consider a Spherical Cow*

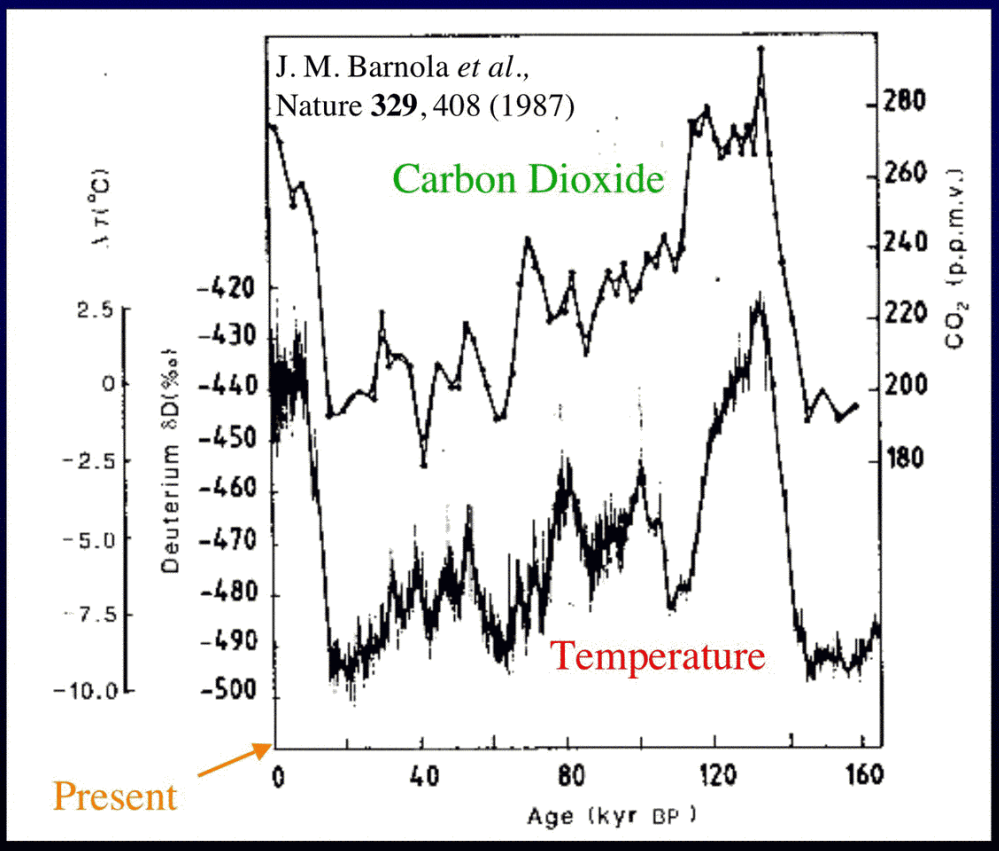
$$\frac{\Omega}{4} = a\frac{\Omega}{4} + \sigma T_0^4 + F_w$$
$$2\sigma T_0^4 = \sigma T_1^4 + 0.5F_e + 0.7F_s$$
$$2\sigma T_1^4 = \sigma T_0^4 + \sigma T_s^4 - F_w + F_c + 0.5F_e + 0.3F_s$$

F_s	$\approx$	86 W/m^2	Solar flux absorbed by atmosphere
F_e	$\approx$	80 W/m^2	Latent heat from evaporating water
F_w	$\approx$	20 W/m^2	IR flux directly to space
F_c	$\approx$	17 W/m^2	Convective heat transfer

$T_0 = 250K$
$T_1 = 278K$
$T_s = 289K = 16C$

Excellent agreement for such a simple model

The Past 160,000 Years



articles

Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica

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The recent completion of drilling at Vostok station in East Antarctica has allowed the extension of the ice record of atmospheric composition and climate to the past four glacial–interglacial cycles. The succession of changes through each climate cycle and termination was similar, and atmospheric and climate properties oscillated between stable bounds. Interglacial periods differed in temporal evolution and duration. Atmospheric concentrations of carbon dioxide and methane correlate well with Antarctic air-temperature throughout the record. Present-day atmospheric burdens of these two important greenhouse gases seem to have been unprecedented during the past 420,000 years.

The late Quaternary period (the past one million years) is punctuated by a series of large glacial–interglacial changes with cycles that last about 100,000 years (ref. 1). Glacial–interglacial climate changes are documented by complementary climate records[1,2] largely derived from deep sea sediments, continental deposits of flora, fauna and loess, and ice cores. These studies have documented the wide range of climate variability on Earth. They have shown that much of the variability occurs with periodicities corresponding to that of the precession, obliquity and eccentricity of the Earth's orbit[1,3]. But understanding how the climate system responds to this initial orbital forcing is still an important issue in palaeoclimatology, in particular for the generally strong ~100,000-year (100-kyr) cycle.

Ice cores give access to palaeoclimate series that includes local temperature and precipitation rate, moisture source conditions, wind strength and aerosol fluxes of marine, volcanic, terrestrial, cosmogenic and anthropogenic origin. They are also unique with their entrapped air inclusions in providing direct records of past changes in atmospheric trace-gas composition. The ice-drilling project undertaken in the framework of a long-term collaboration between Russia, the United States and France at the Russian Vostok station in East Antarctica (78° S, 106° E, elevation 3,488 m, mean temperature −55 °C) has already provided a wealth of such information for the past two glacial–interglacial cycles[4–13]. Glacial periods in Antarctica are characterized by much colder temperatures, reduced precipitation and more vigorous large-scale atmospheric circulation. There is a close correlation between Antarctic temperature and atmospheric concentrations of CO_2 and CH_4 (refs 5, 9). This discovery suggests that greenhouse gases are important as amplifiers of the initial orbital forcing and may have significantly contributed to the glacial–interglacial changes[14–16]. The Vostok ice cores were also used to infer an empirical estimate of the sensitivity of global climate to future anthropogenic increases of greenhouse-gas concentrations[17].

The recent completion of the ice-core drilling at Vostok allows us to considerably extend the ice-core record of climate properties at this site. In January 1998, the Vostok project yielded the deepest ice core ever recovered, reaching a depth of 3,623 m (ref. 17). Drilling then stopped ~120 m above the surface of the Vostok lake, a deep subglacial lake which extends below the ice sheet over a large area[18], in order to avoid any risk that drilling fluid would contaminate the lake water. Preliminary data[17] indicated that the Vostok ice-core record extended through four climate cycles, with ice slightly older than 400 kyr at a depth of 3,310 m, thus spanning a period comparable to that covered by numerous oceanic[1] and continental[2] records.

Here we present a series of detailed Vostok records covering this ~400-kyr period. We show that the main features of the more recent Vostok climate cycle resemble those observed in earlier cycles. In particular, we confirm the strong correlation between atmospheric greenhouse-gas concentrations and Antarctic temperature, as well as the strong imprint of obliquity and precession in most of the climate time series. Our records reveal both similarities and differences between the successive interglacial periods. They suggest the lead of Antarctic air temperature, and of atmospheric greenhouse-gas concentrations, with respect to global ice volume and Greenland air-temperature changes during glacial terminations.

The ice record

The data are shown in Figs 1, 2 and 3 (see Supplementary Information for the numerical data). They include the deuterium content of the ice (δD_{ice}, a proxy of local temperature change), the dust content (desert aerosols), the concentration of sodium (marine aerosol), and from the entrapped air the greenhouse gases CO_2 and CH_4, and the $\delta^{18}O$ of O_2 (hereafter $\delta^{18}O_{atm}$) which reflects changes in global ice volume and in the hydrological cycle[19]. (δD and $\delta^{18}O$ are defined in the legends to Figs 1 and 2, respectively.) All these measurements have been performed using methods previously described except for slight modifications (see figure legends).

The detailed record of δD_{ice} (Fig. 1) confirms the main features of the third and fourth climate cycles previously illustrated by the coarse-resolution record[17]. However, a sudden decrease from interglacial-like to glacial-like values, rapidly followed by an abrupt return to interglacial-like values, occurs between 3,320 and 3,330 m.

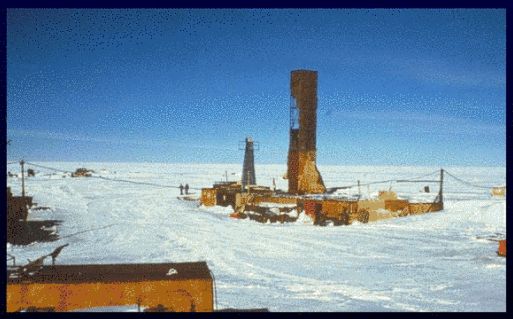
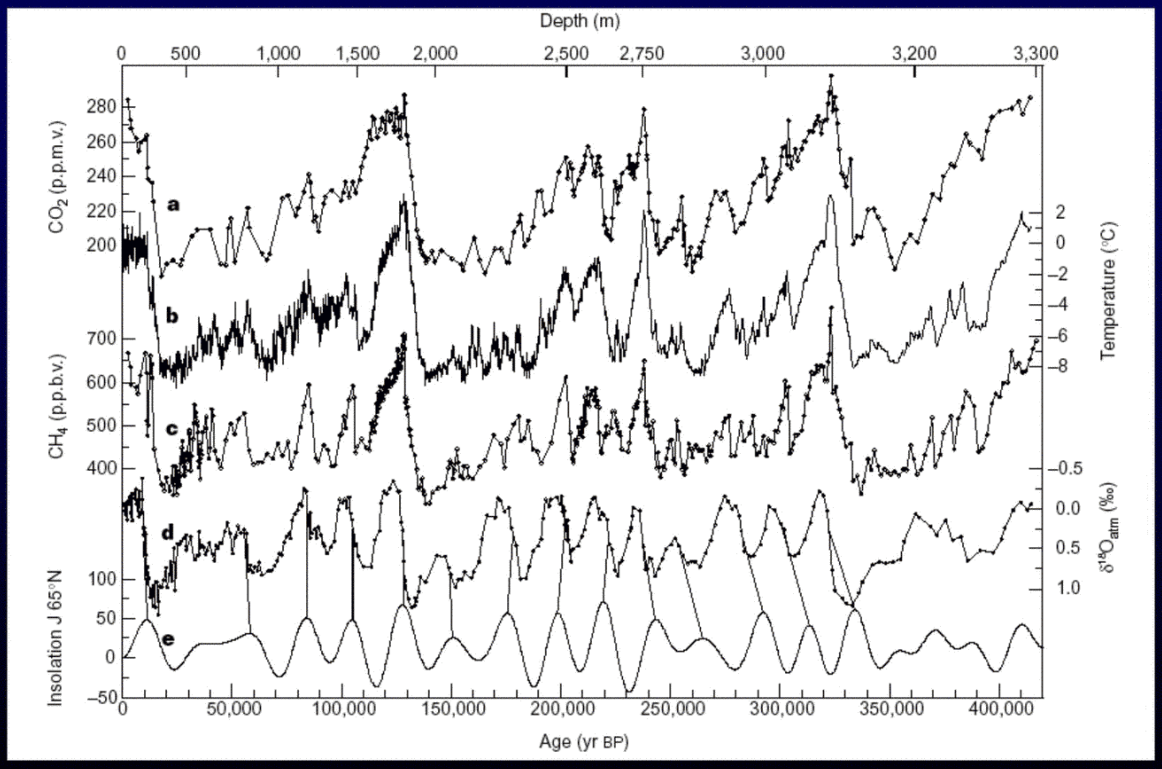


photo: Todd Sowers LDEO, Columbia University, Palisades, New York.

420,000 Year Record From Vostok



Quantum Zero-Point Motion

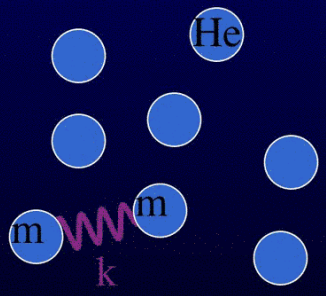
Classically: All motion ceases at absolute zero temperature.
Everything freezes into a solid.

Quantum physics: There is still some motion even at T = 0.
This is why liquid helium never freezes!

Small mass --> large quantum zero-point motion and energy.

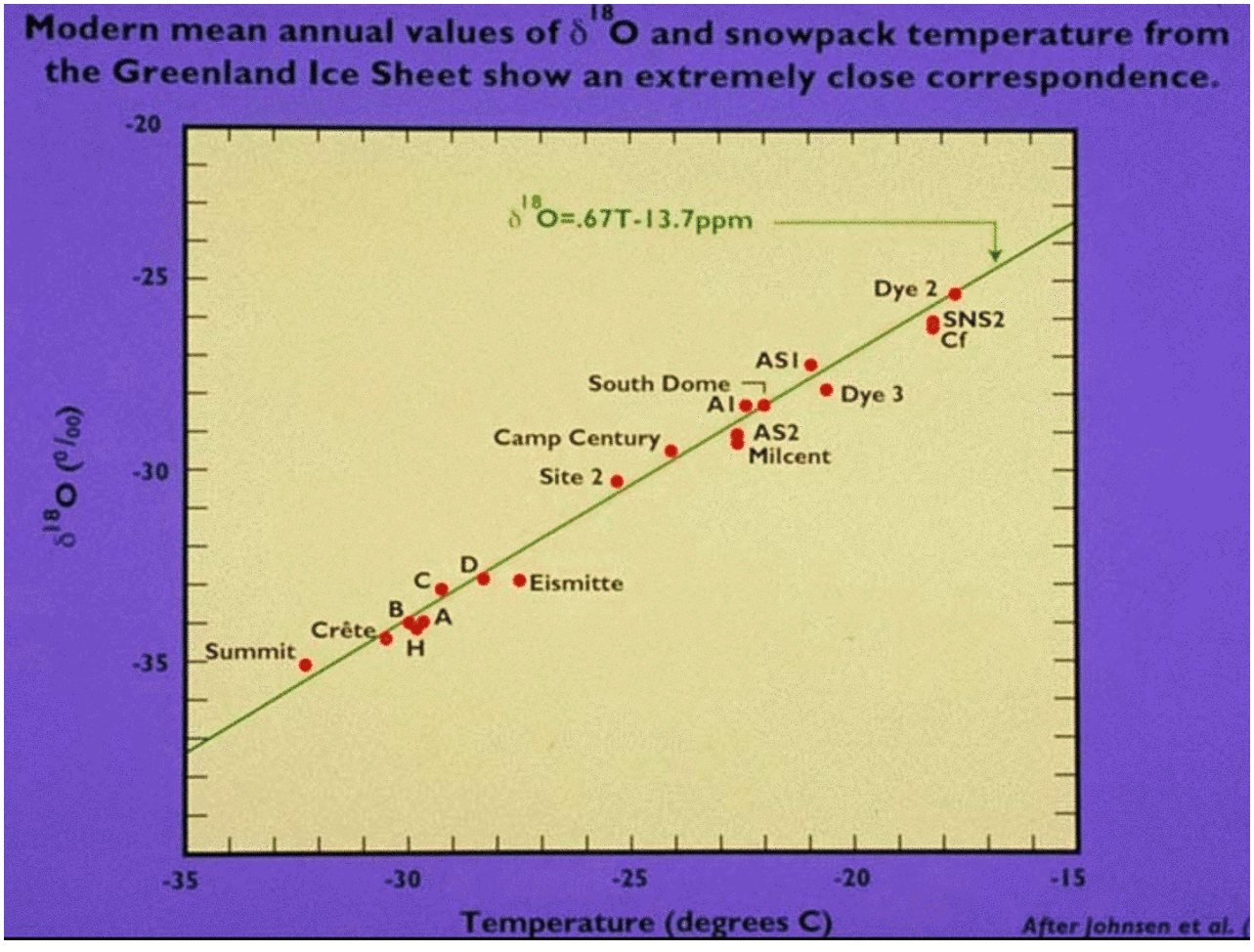
$$\nu = \frac{1}{2\pi}\sqrt{\frac{2k}{m}}$$

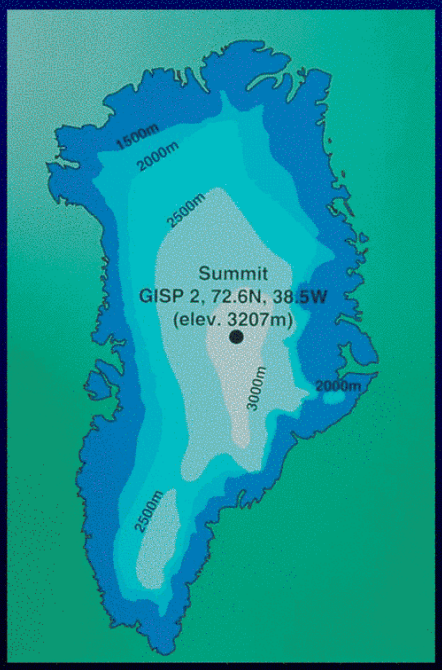
$$E_0 = \frac{1}{2}h\nu$$



^{18}O versus ^{16}O in H_2O: Classically both molecules have same energy.
Quantum zero-point energy means that ^{18}O water is slightly less likely to evaporate during cold spells.

(Harold Urey, "The thermodynamic properties of isotopic substances," 1946)





Thomas Andrews from a map drawn by Sherry Palmer

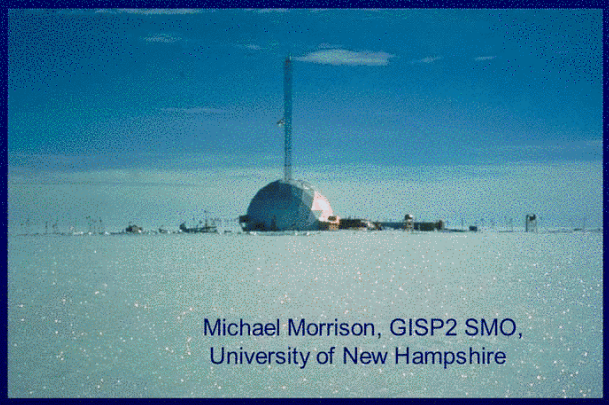
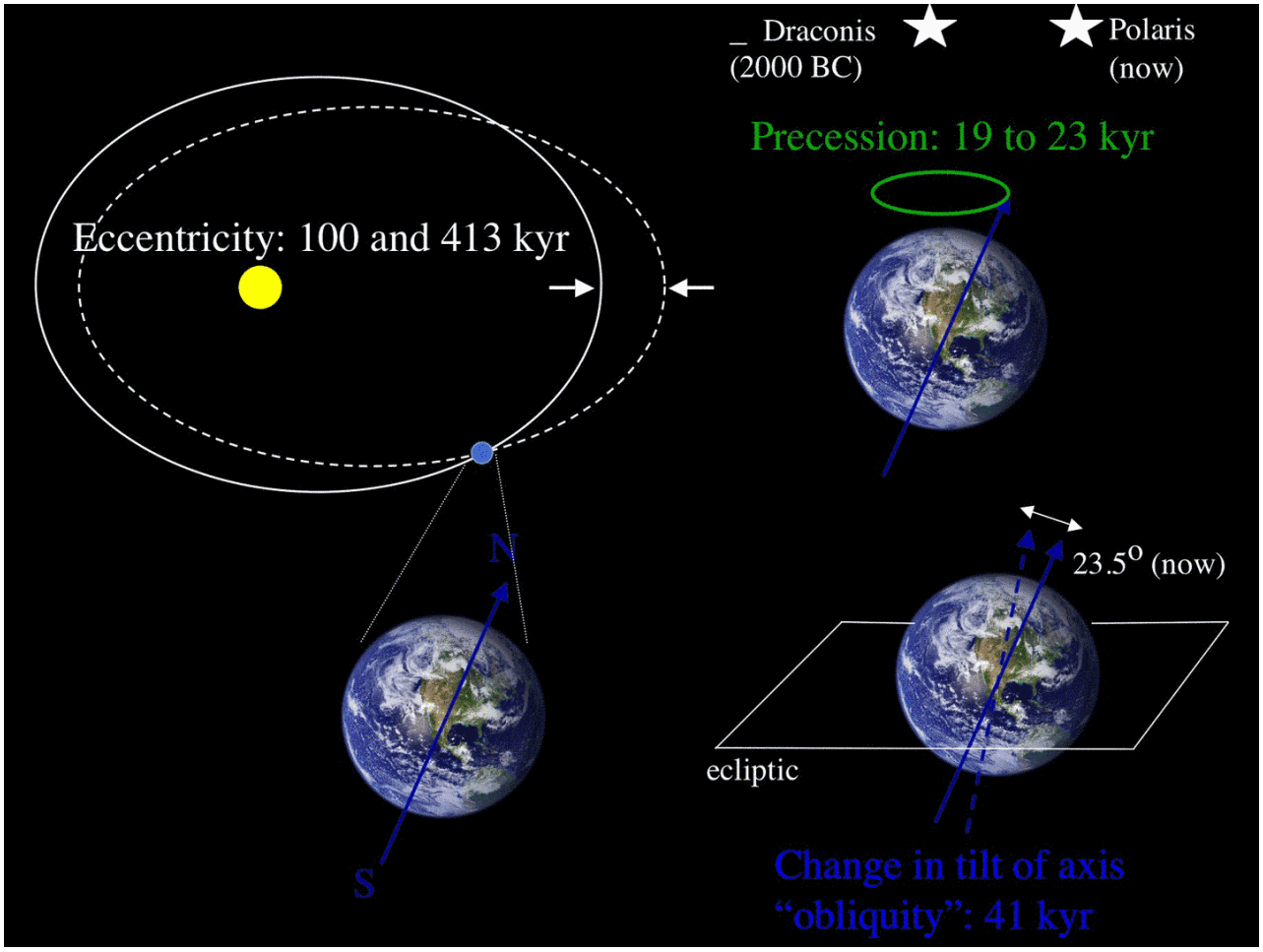


Photo by Kendrick Taylor, Desert Research Institute,
University and Community College System of Nevada.

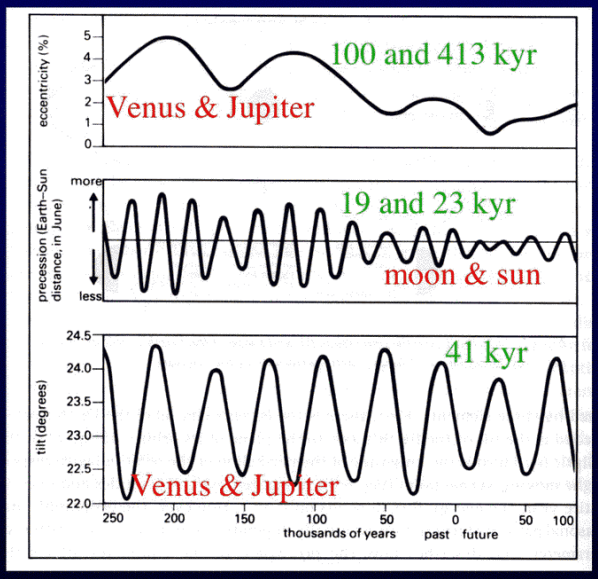


Astronomical Theory of the Ice Ages

- 1864: James Croll accounts for the ice ages in terms of precession of equinoxes and changes in eccentricity.

- 1920 - 38: Milutin Milankovitch identifies summer radiation at high latitudes as primary cause -- forcing -- of ice ages.

- 1976: Spectral analysis of ocean sediment cores by John Imbrie at Brown and others supports this.



(graph from Burroughs, "Weather Cycles: Real or Imaginary?")

Spectral Analysis of Isotope Records

Figures from *Ice Ages and Astronomical Causes: Data, Spectral Analysis, and Mechanisms* by R. Muller and G. MacDonald

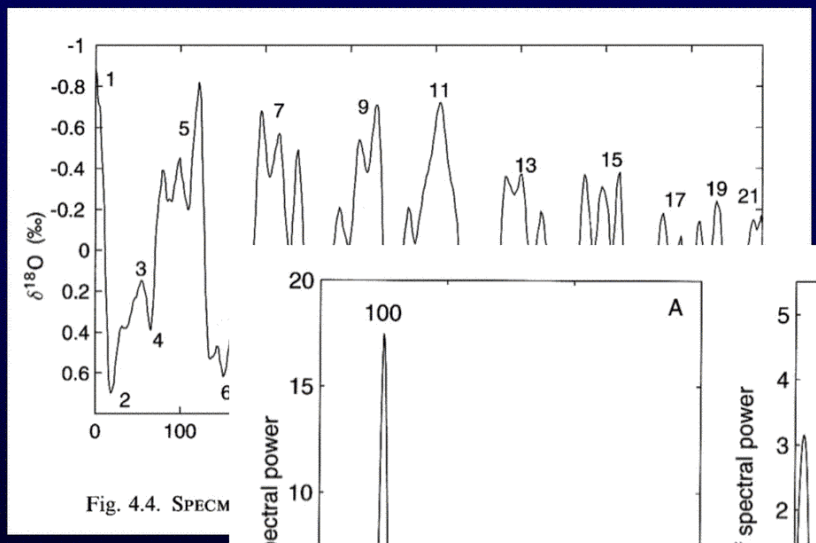


Fig. 4.4. SPECM

Fig. 4.5. Spectrum of original SPECMAP stack.

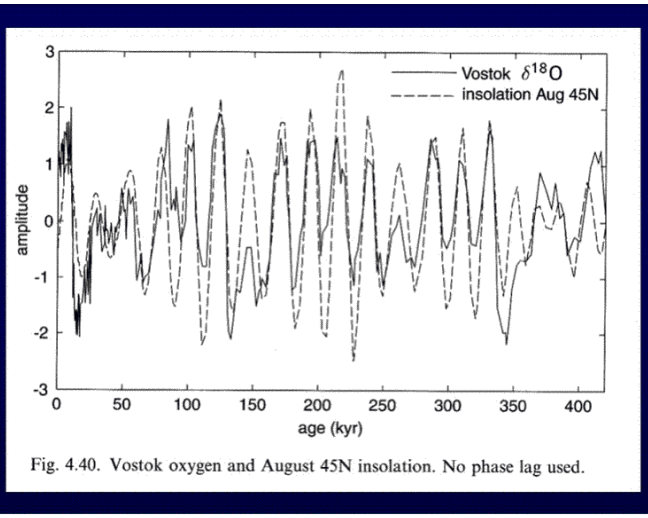
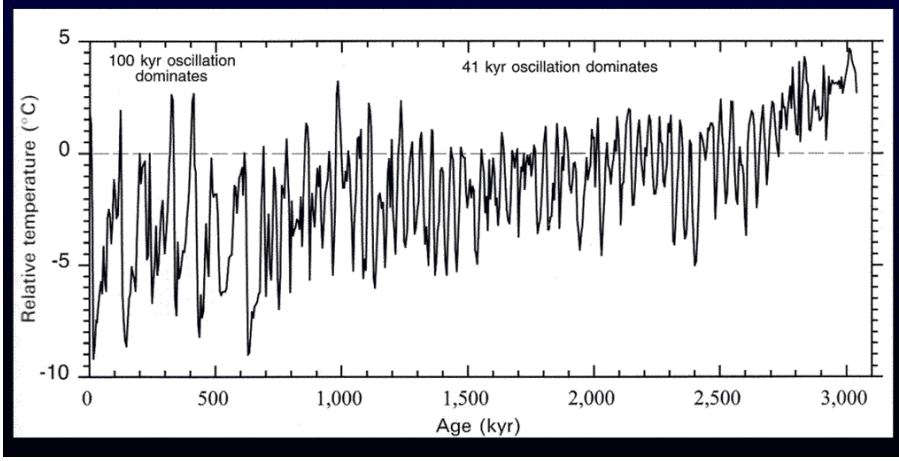


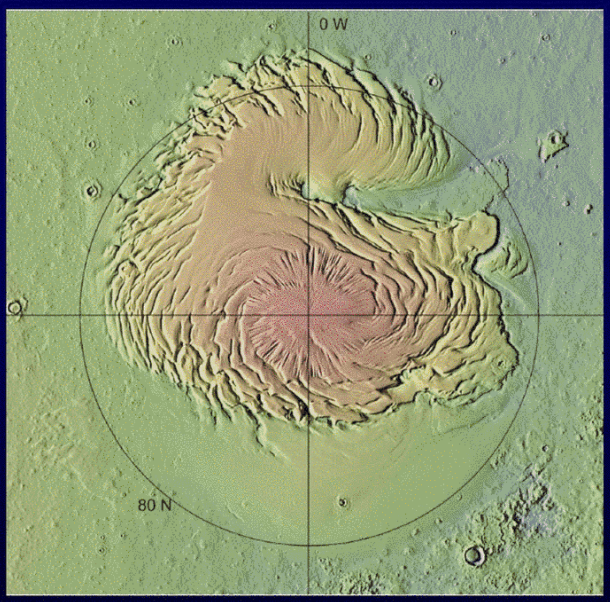
Fig. 4.40. Vostok oxygen and August 45N insolation. No phase lag used.

What amplifies orbital forcing to produce ice ages?

Why does 100 kyr eccentricity period dominate climate signal?

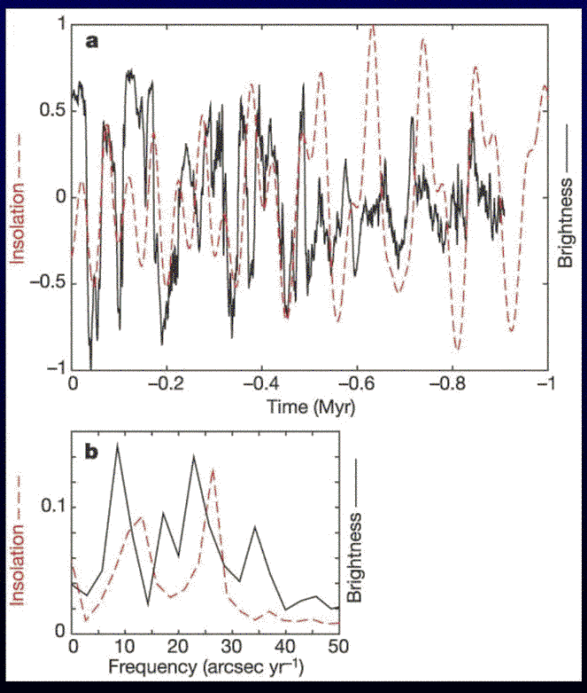


Why did the 41 kyr period dominate 1.5 million years ago?



North Polar Cap of Mars

Martian Climate May Also Show Orbital Forcing



Laskar, Levrard, and Mustard, Nature **419**, 375 (2002); Head *et al*. Nature **426**, 797 (2003).

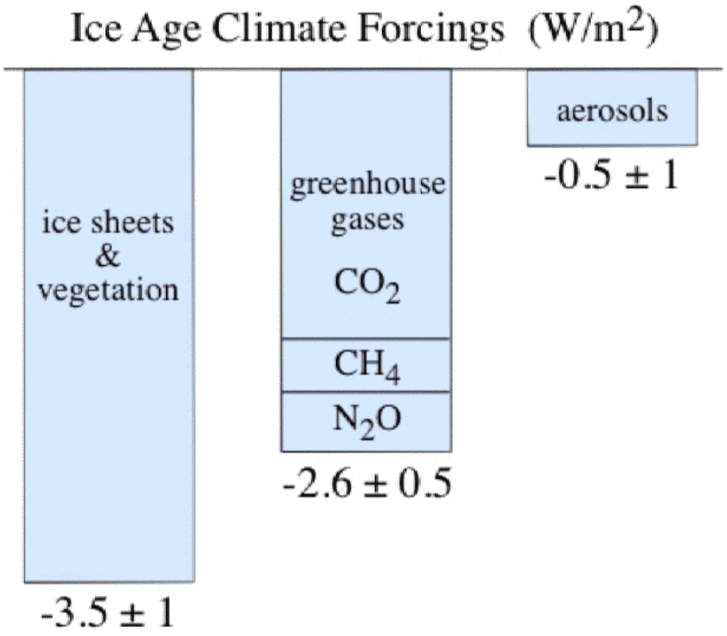
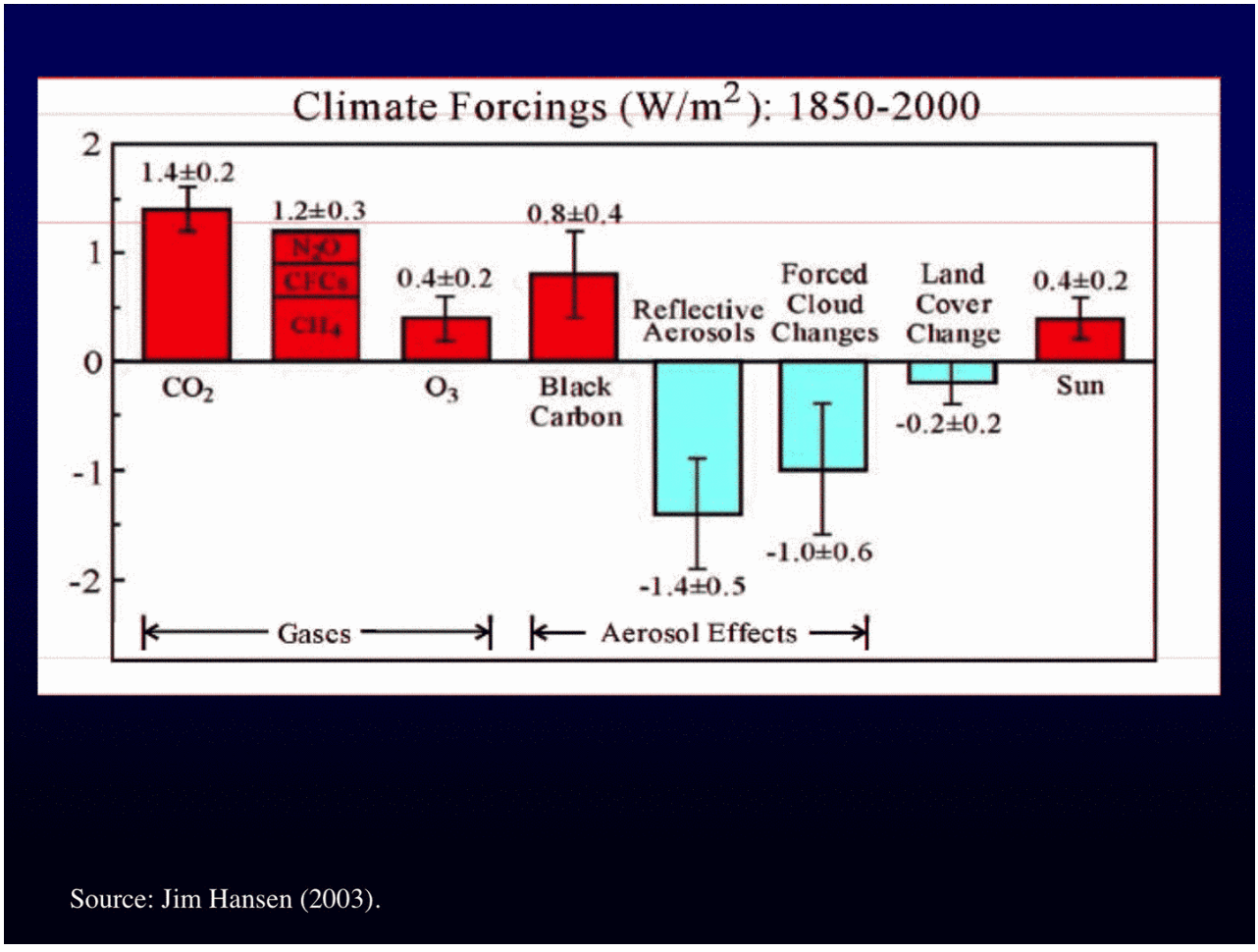
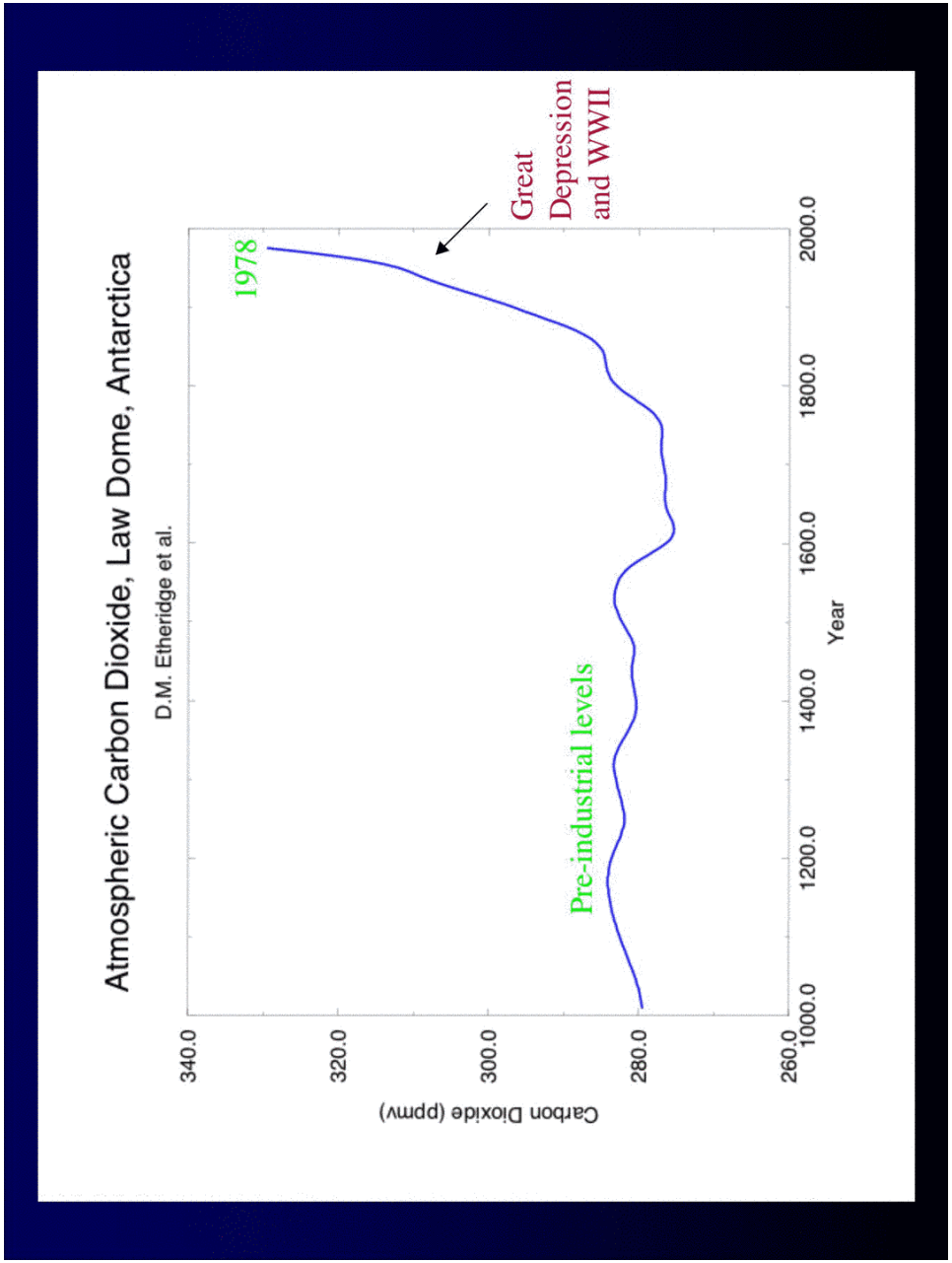


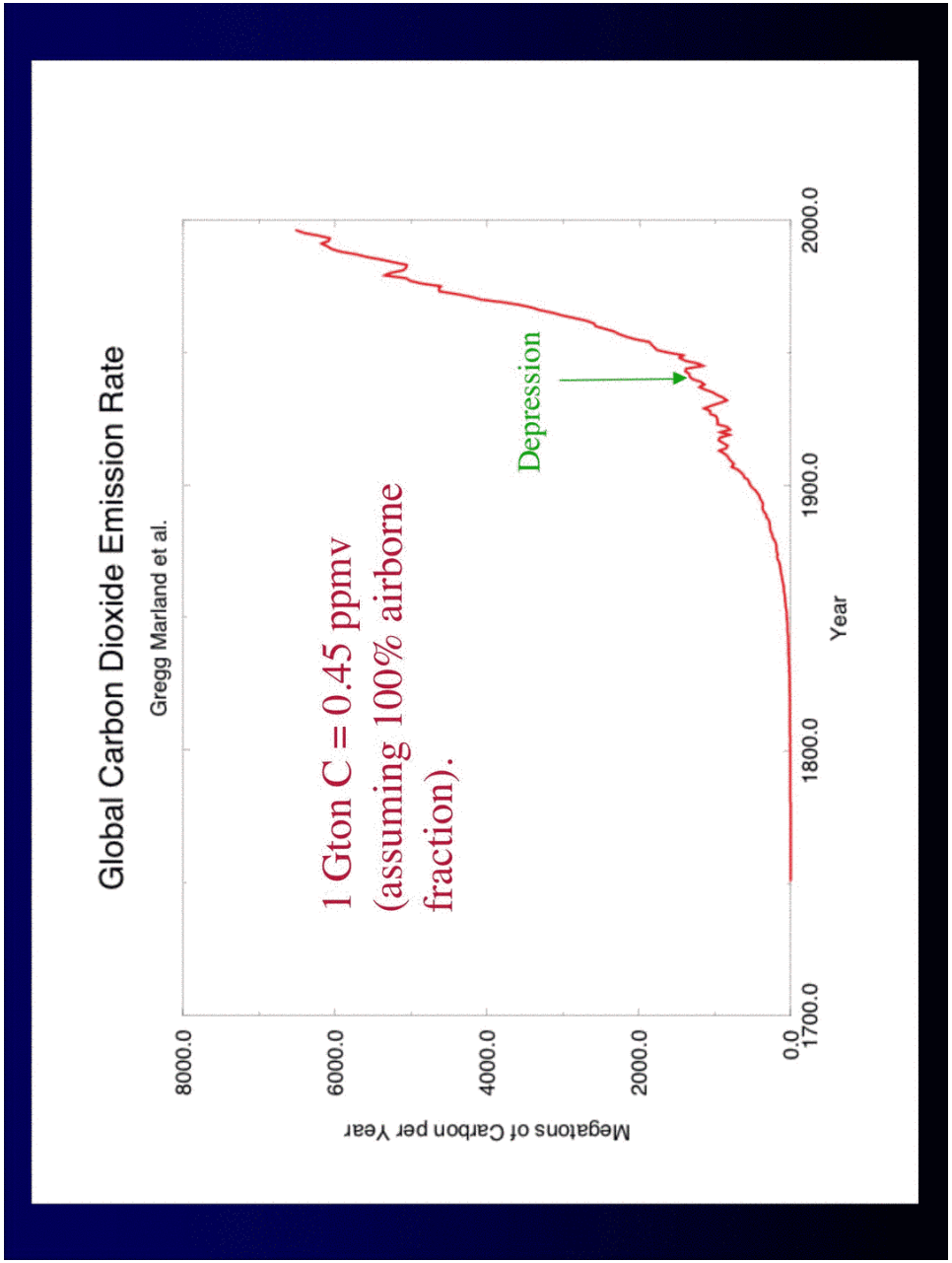
Fig 2. Global radiative forcings during the last ice age relative to the current interglacial period. The total forcing is -6.6 ± 1.5 W/m^2. Thus, the 5°C cooling of the ice age implies a climate sensitivity of 0.75°C per 1 W/m^2 forcing.

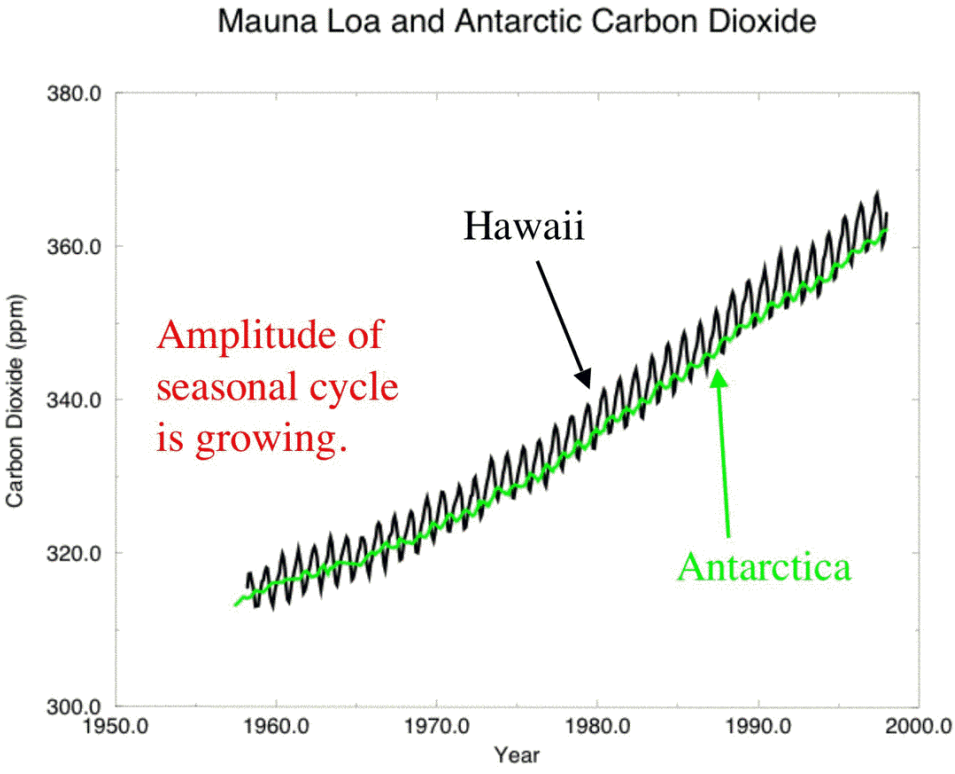
Hansen, J. et al., The missing climate forcing, Phil. Trans. R. Soc. London. B, 352, 231-240, 1997.



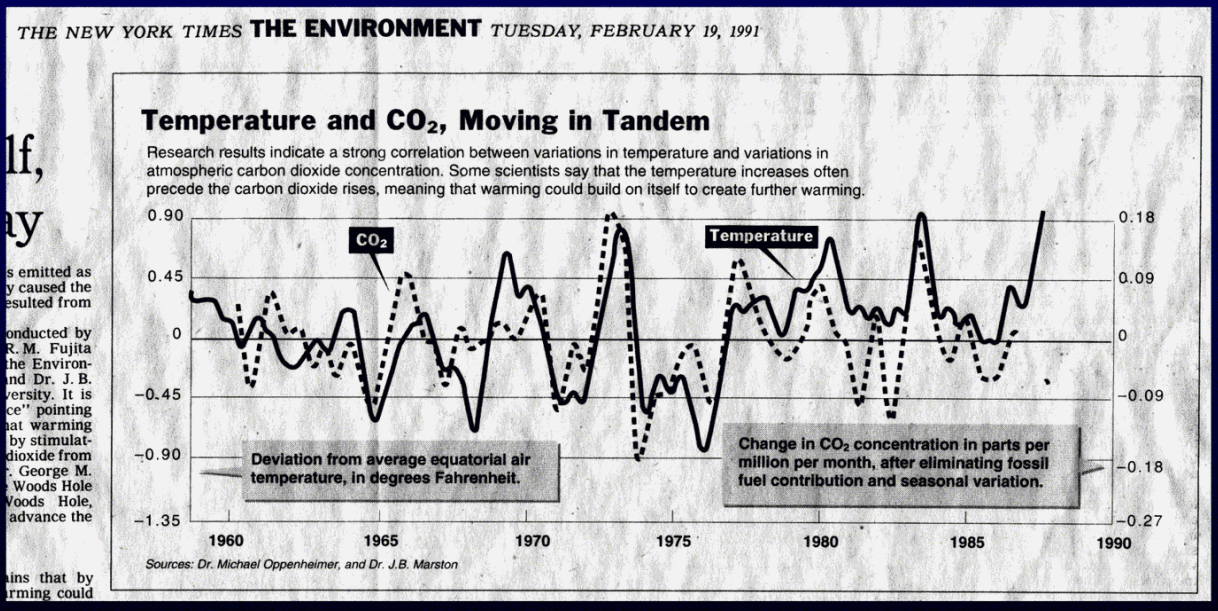
Source: Jim Hansen (2003).


Atmospheric Carbon Dioxide, Law Dome, Antarctica
D.M. Etheridge et al.
1978
Great Depression and WWII
Pre-industrial levels
Carbon Dioxide (ppmv)
340.0
320.0
300.0
280.0
260.0
1000.0
1200.0
1400.0
1600.0
1800.0
2000.0
Year


Global Carbon Dioxide Emission Rate
Gregg Marland et al.
1 Gton C = 0.45 ppmv
(assuming 100% airborne
fraction).
Depression
Megatons of Carbon per Year
8000.0
6000.0
4000.0
2000.0
0.0
1700.0
1800.0
1900.0
2000.0
Year



Positive CO_2 Feedback Could Worsen Warming



THE NEW YORK TIMES **THE ENVIRONMENT** TUESDAY, FEBRUARY 19, 1991

Temperature and CO_2, Moving in Tandem

Research results indicate a strong correlation between variations in temperature and variations in atmospheric carbon dioxide concentration. Some scientists say that the temperature increases often precede the carbon dioxide rises, meaning that warming could build on itself to create further warming.

0.90 0.45 0 −0.45 −0.90 −1.35

0.18 0.09 0 −0.09 −0.18 −0.27

CO_2

Temperature

Deviation from average equatorial air temperature, in degrees Fahrenheit.

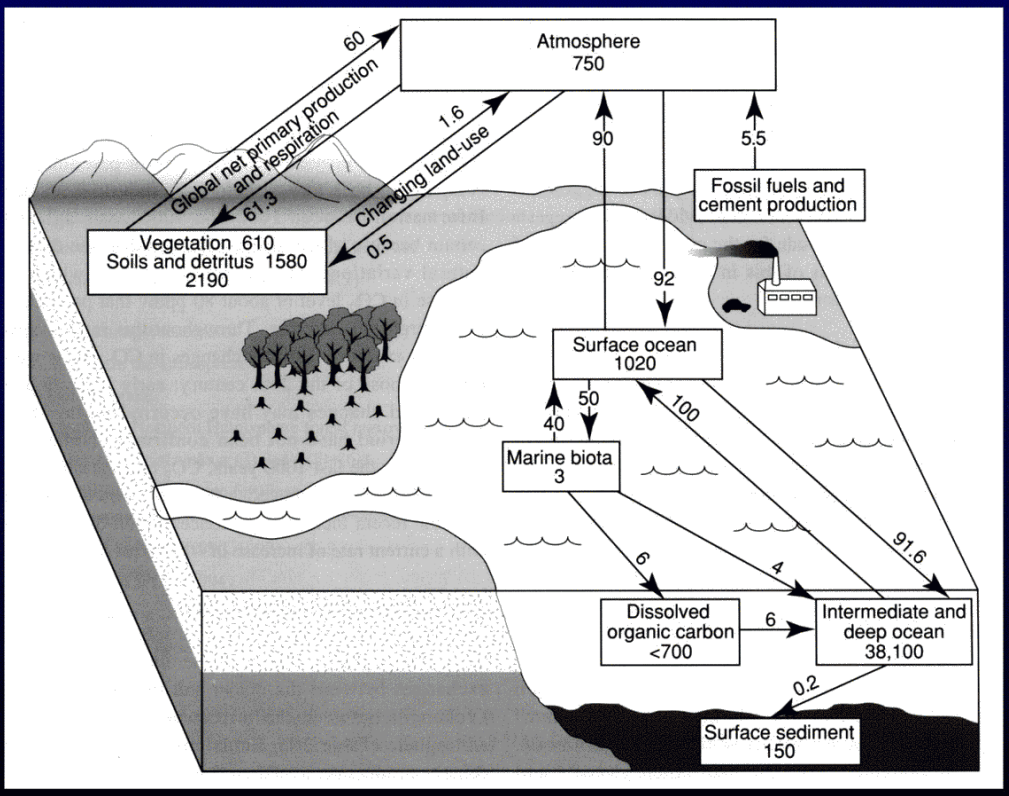
Change in CO_2 concentration in parts per million per month, after eliminating fossil fuel contribution and seasonal variation.

1960 1965 1970 1975 1980 1985 1990

Sources: Dr. Michael Oppenheimer, and Dr. J.B. Marston

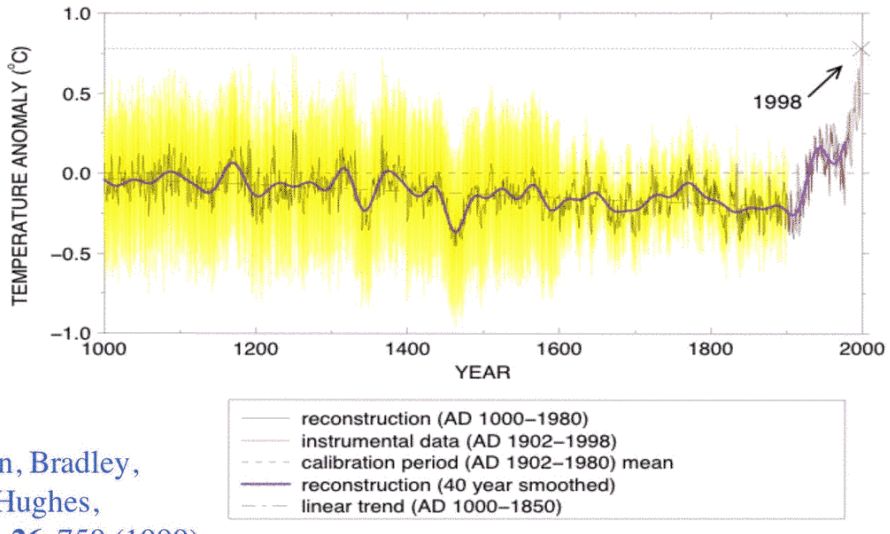
J. B. Marston, M. Oppenheimer, R. M. Fujita, and S. R. Gaffin, "CO_2 and temperature" Nature **349**, 573 (1991).

Vast Reservoirs of Carbon & Enormous Fluxes



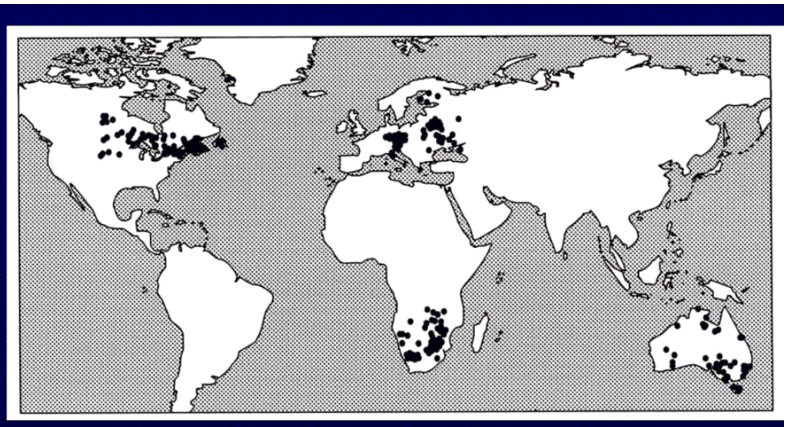
Source: *Climate Change 1995*

Temperature of Northern Hemisphere

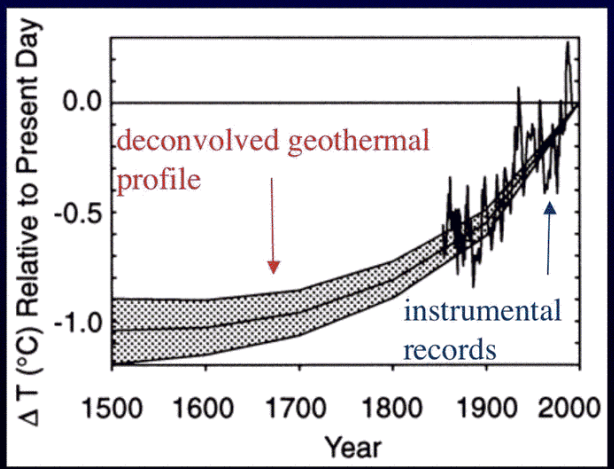


Mann, Bradley, and Hughes, GRL **26**, 759 (1999)

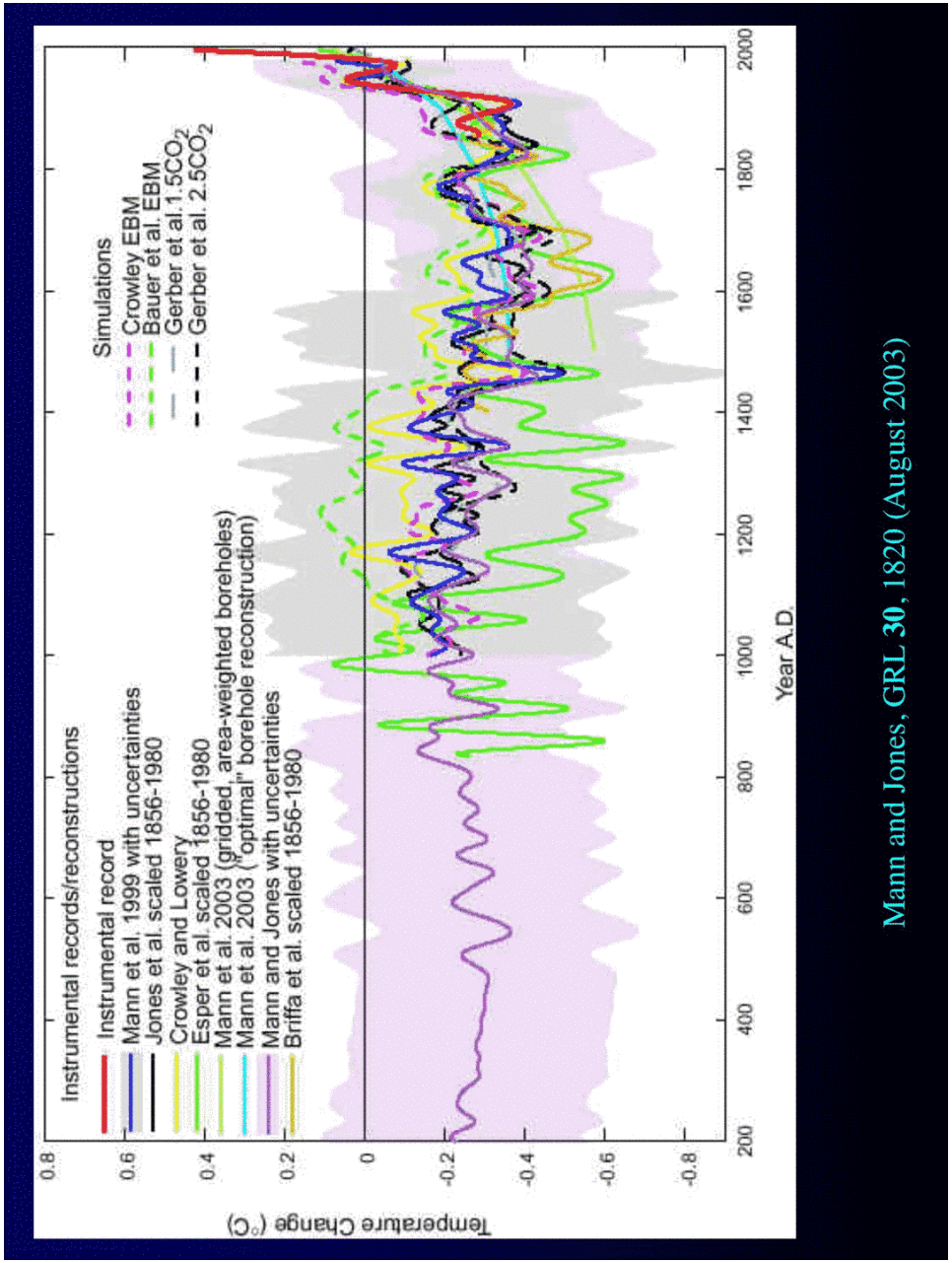
A Different Method To Extract Past Temperature: Geothermal Boreholes

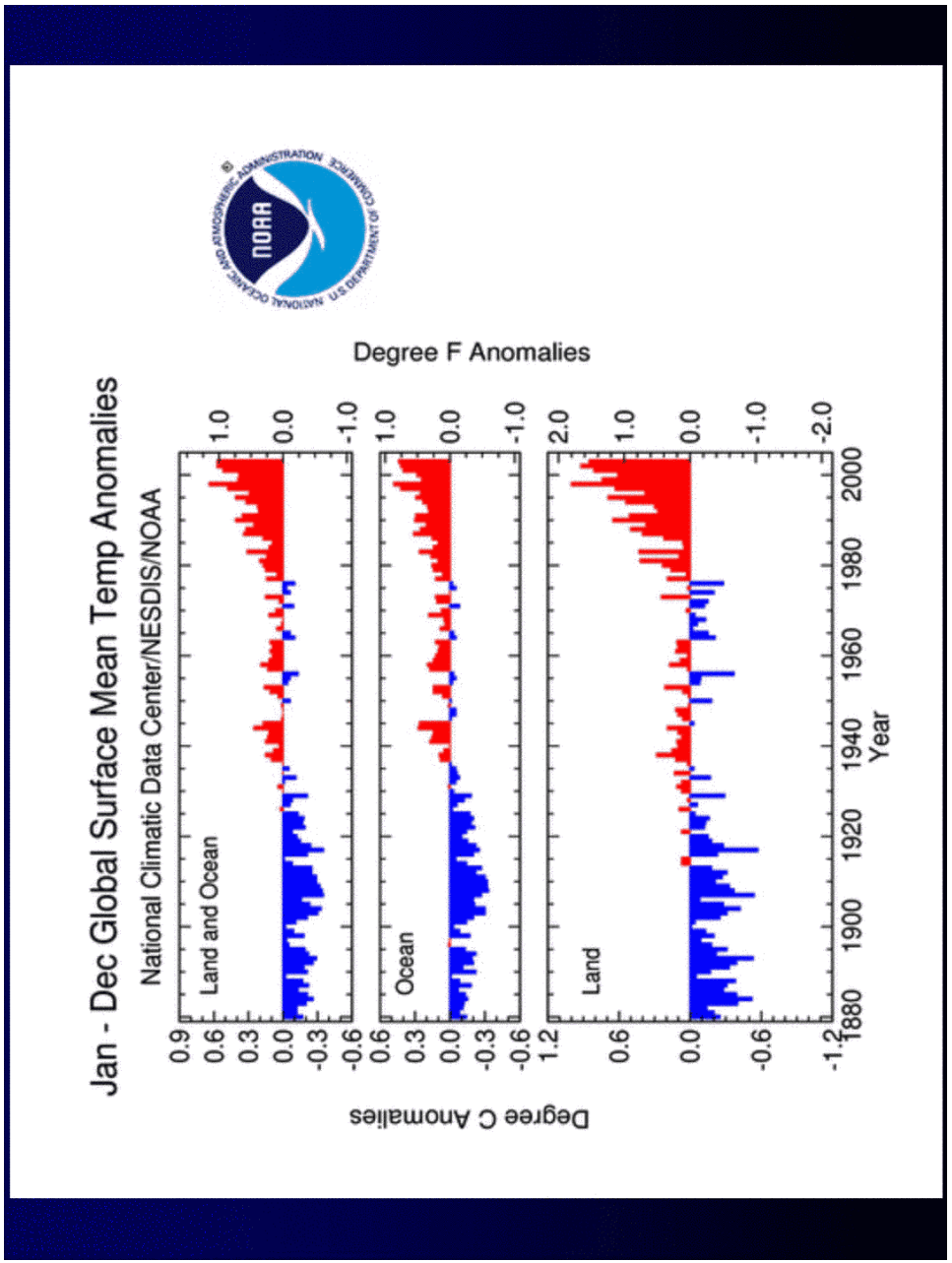


Heat flow due to geothermal gradient of 0.03 K/m is $I = 0.1\ W/m^2$ since $K_{granite}$ = 3 J/(m s K). **Negligible.**



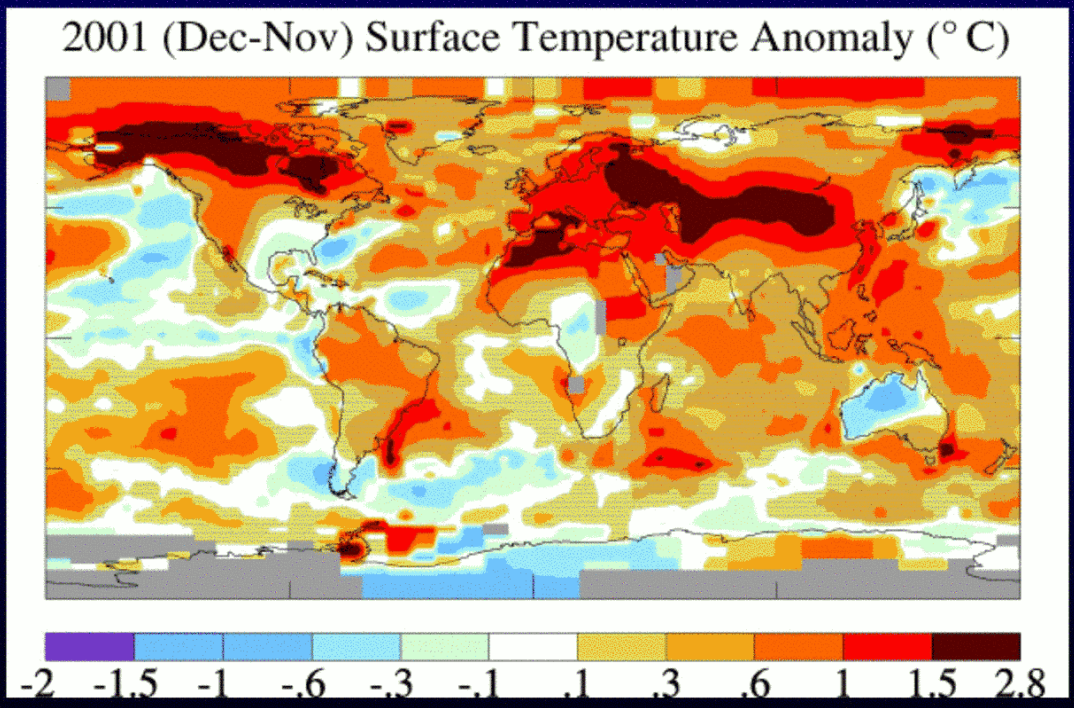
(Huang, Pollack, and Shen, Nature **403, 756 (2000)**)


Instrumental records/reconstructions
Instrumental record
Mann et al. 1999 with uncertainties
Jones et al. scaled 1856-1980
Crowley and Lowery
Esper et al. scaled 1856-1980
Mann et al. 2003 (gridded, area-weighted boreholes)
Mann et al. 2003 ("optimal" borehole reconstruction)
Mann and Jones with uncertainties
Briffa et al. scaled 1856-1980
Simulations
Crowley EBM
Bauer et al. EBM
Gerber et al. 1.5CO2
Gerber et al. 2.5CO2
Temperature Change (°C)
Year A.D.
Mann and Jones, GRL 30, 1820 (August 2003)

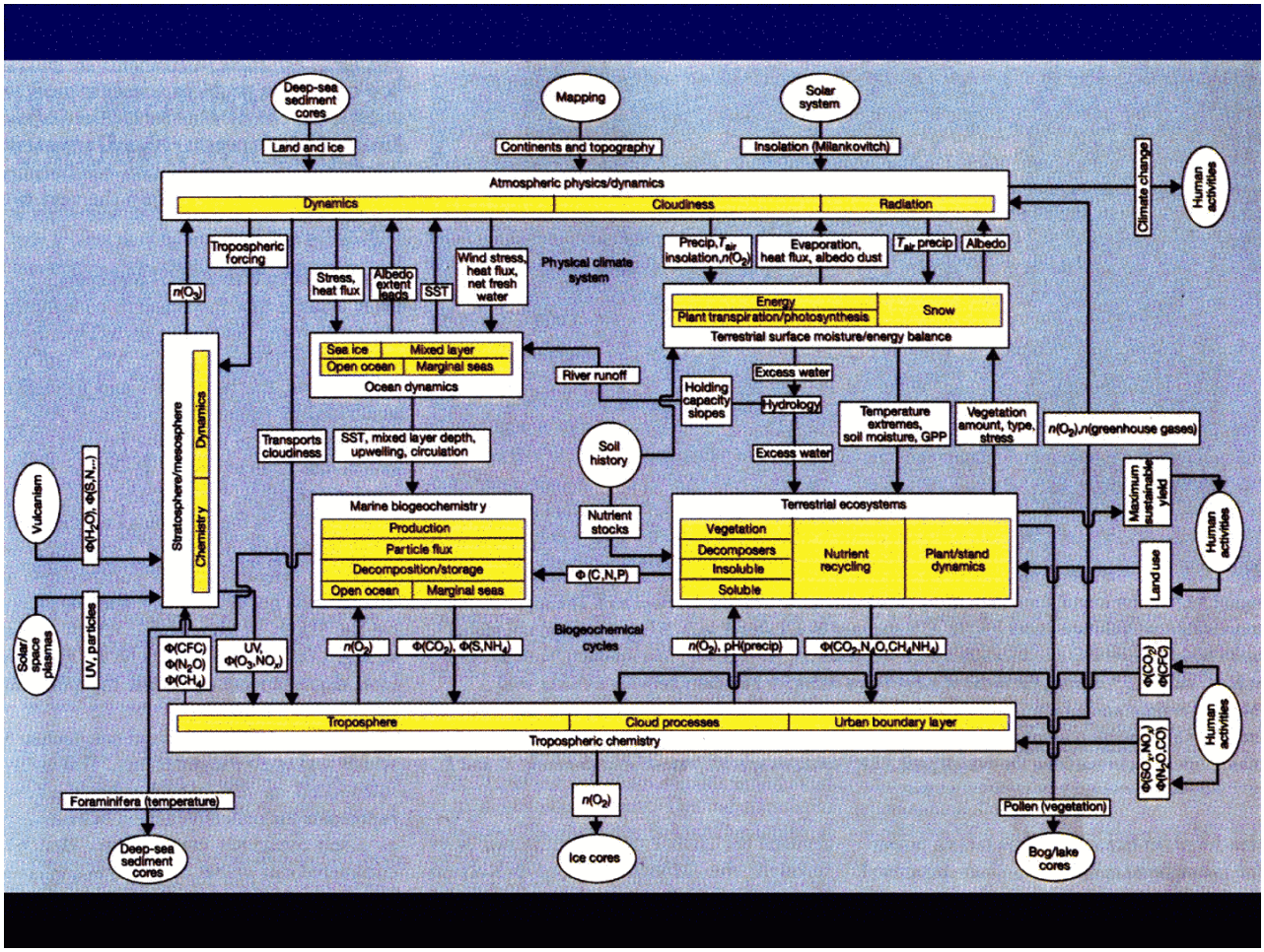

Jan - Dec Global Surface Mean Temp Anomalies
National Climatic Data Center/NESDIS/NOAA
Degree F Anomalies
Land and Ocean
Ocean
Land
Degree C Anomalies
Year

Other Signs of Warming

- Glaciers are melting all over the world, with only a few exceptions.
- Sea level is rising, 1 to 2 mm/year, due to thermal expansion and influx of melt water.
- Arctic ice is thinning. Warming is greater in north polar region, consistent with greenhouse effect.



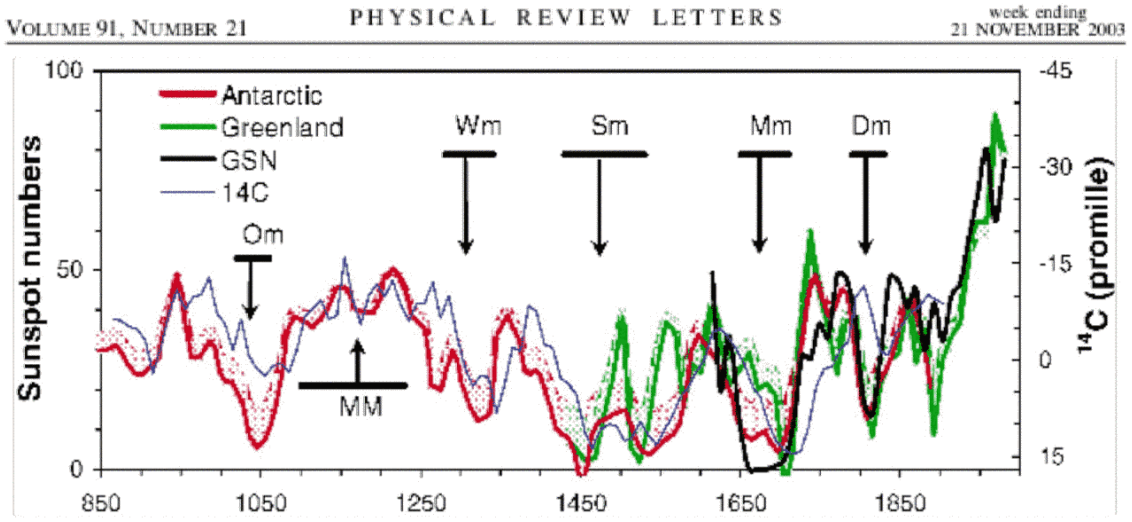
Source: J. Hansen, NASA GISS



Uncertainties in Models

- 16 orders of magnitude of length scales: 40,000 km (circumference of earth) to 10 nm (aerosol particles). Enormous range of time scales too.
- Changes in clouds: positive or negative feedback?
  - Cumulus clouds have net cooling effect.
  - Cirrus clouds have net warming effect.
  - Simple argument: Empirically, the relative humidity stays roughly constant over the course of a year --> same cloudiness, but more water vapor when hot --> **positive feedback.**
  - Recent satellite observations support positive feedback.
- Role of natural and anthropogenic dust, soot, and aerosols?
- Fluctuations in the solar activity? Solar constant larger during solar maximum, when there are more sunspots.
- Indirect effects via cosmic rays -- nucleation?

Usoskin *et al*. "Millennium-Scale Sunspot Number Reconstruction: Evidence for an Unusually Active Sun since the 1940's," PRL **91**, 211101 (2003)



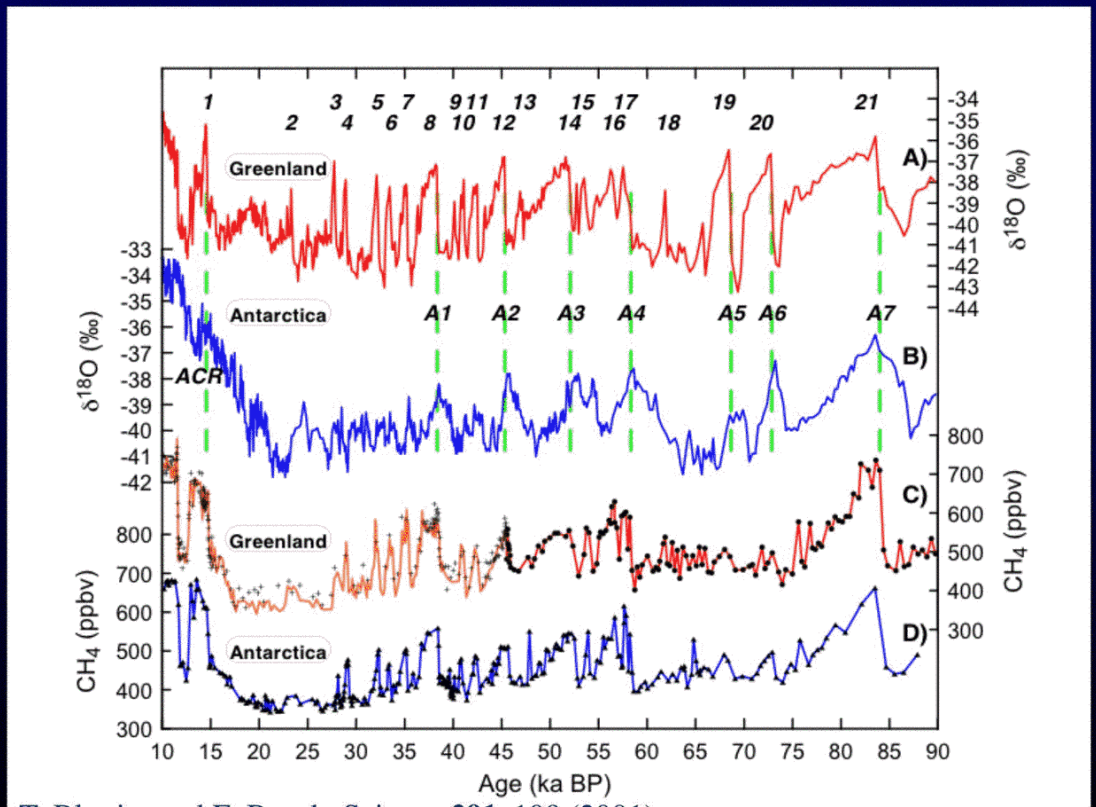
Uncertainties in Models (continued)

- Interactions between atmosphere and oceans, coupling processes with very different time scales?
- Changes in land use: deforestation, asphalt, agriculture.
- Future emissions of greenhouse gases.
- Potential for nonlinear response: Abrupt changes in oceanic circulation? Example: The Younger-Dryas event.
- Etc., Etc., Etc.

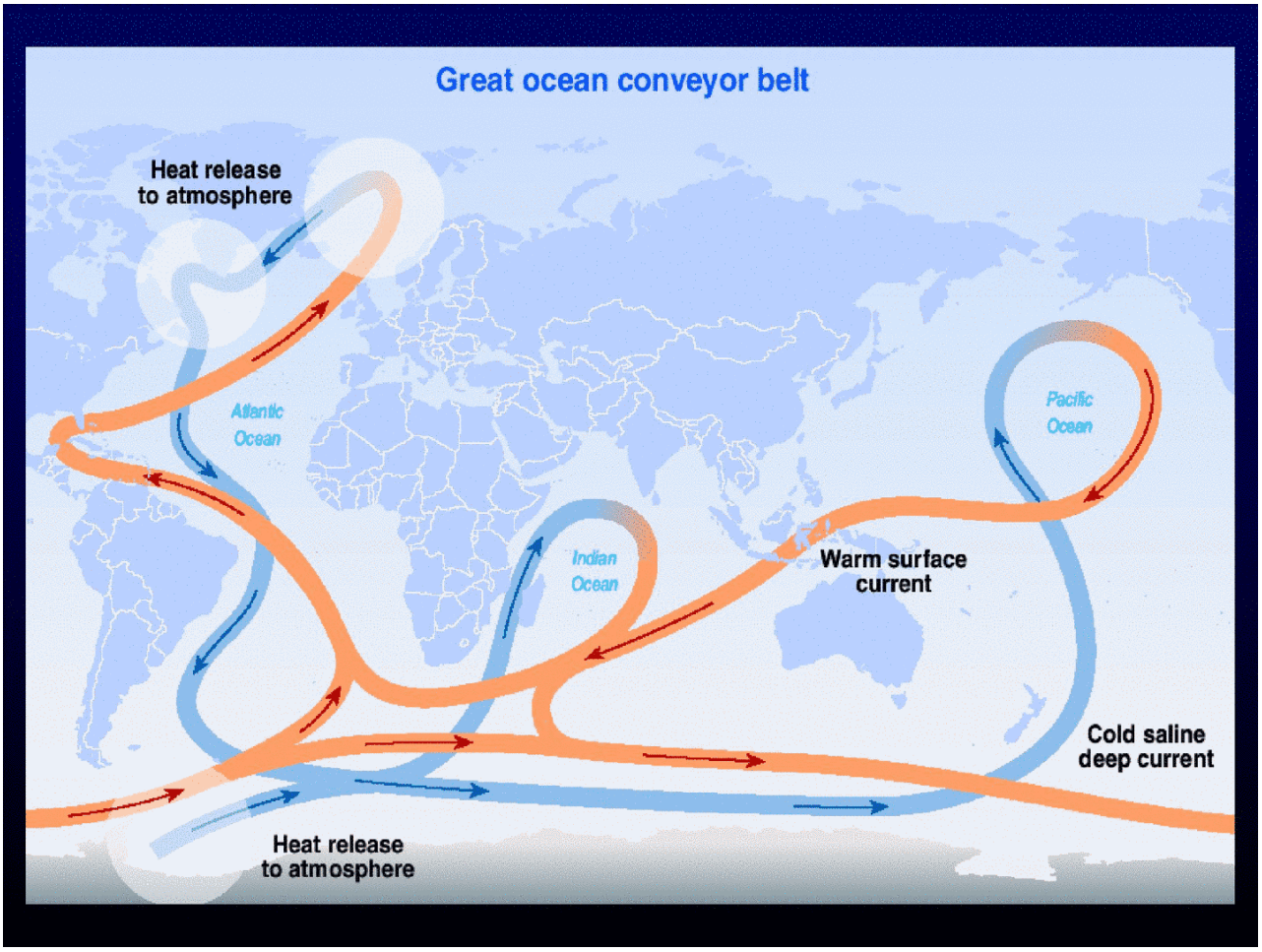
Upshot: Simplest (Manabe, 1983) *and* most complex computer models find that a doubling of CO_2 will cause globally averaged temperature to rise by a few degrees centigrade. IPCC (2001): 1.4 to 5.8^{o}C by year 2100.

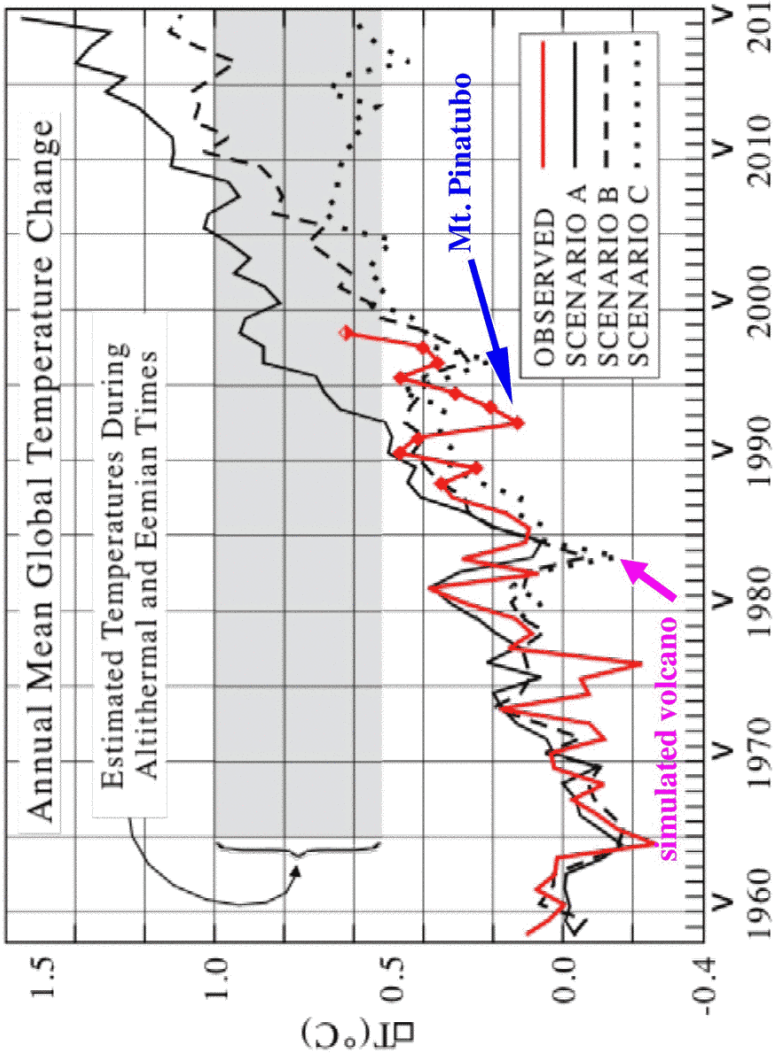
Big Problems Likely

Sudden Swings in Climate Have Happened Before

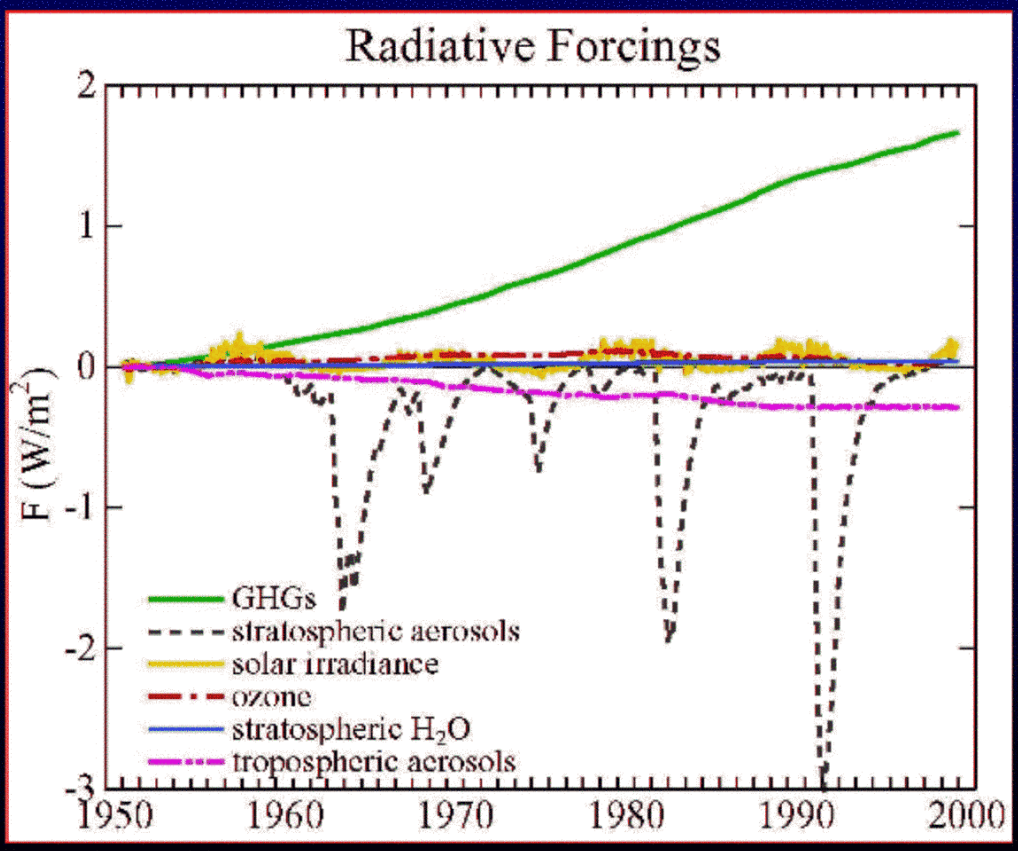


T. Blunier and E. Brook, Science **291**, 109 (2001)



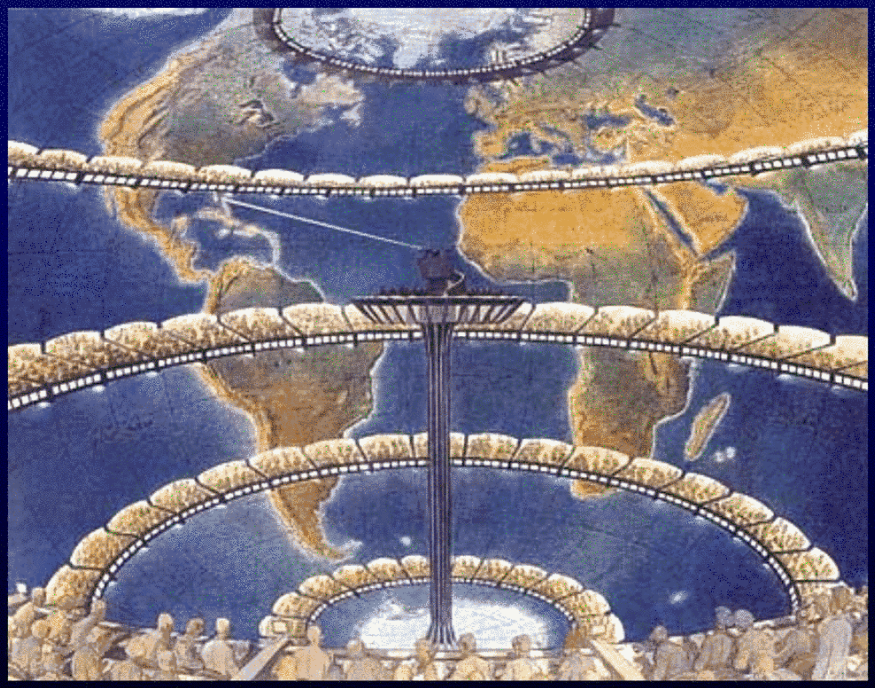


Climate model calculations reported by J. Hansen et al. (1988) with new data added.

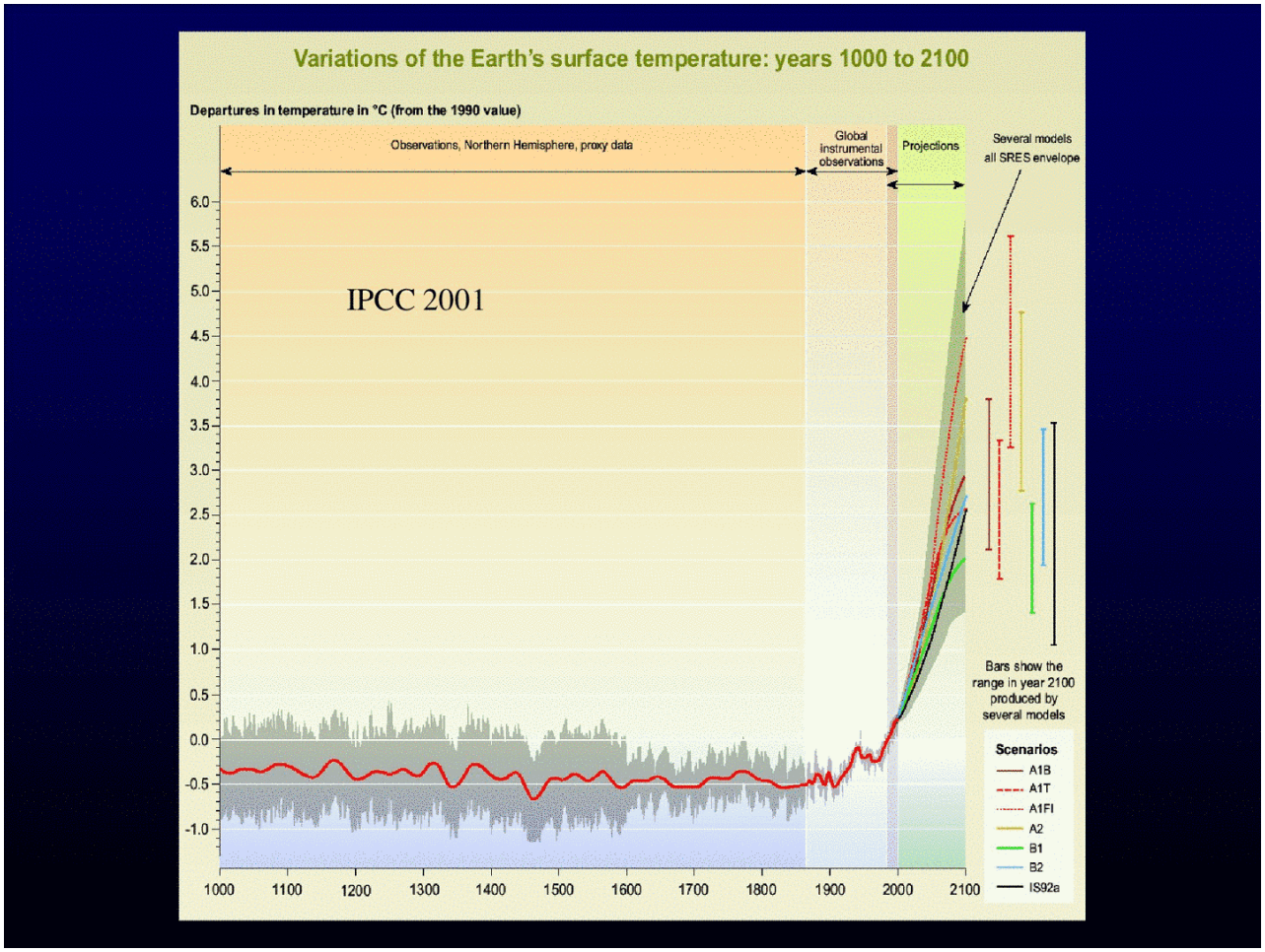


Source: Jim Hansen (2003).

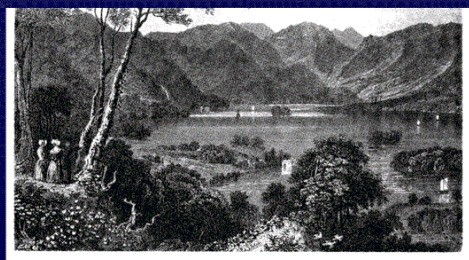
Richardson's Human Weather Computer (1917 --1922)



"Lewis Fry Richardson's imaginary `forecast factor' would have employed some 64,000 human computers to keep up with the pace of the weather, The workers sit in tiers inside a great spherical theater; the director, atop a pedestal in the middle, shines a beam of light on those places where the calculation is getting ahead or falling behind." [Brian Hayes, *American Scientist* **80**, 10 -- 14 (2001).]



Providence Journal, 9/12/2001



Warming makes a better world

PATRICK J. MICHAELS

WASHINGTON

FOR MORE THAN A DECADE, many industry groups have maintained that putting carbon dioxide in the air would produce a general "greening" of the planet. In fact, that's the thesis of a famous 1992 video, *The Greening of Planet Earth*, which riled the environmental community more than just about anything else that business has done in its own defense on this issue.

"Greening" was put out by energy-industry activists (you can get your own copy by contacting http://www.greeningearthsociety.org), who discovered that several big-name scientists were willing to appear and argue that carbon dioxide will *enhance* global plant growth by directly stimulating plants and by warming the coldest air of winter. These scientists were confident because the growth stimulation had been observed in literally thousands of controlled lab experiments and reported in the scientific literature.

At the same time, the climate data were pouring in showing that "global" warming was much more "winter" warming, and of the coldest air, which was sure to lengthen the growing season for plants.

Next Sunday, industry will be vindicated with a vengeance in the Journal of Geophysical Research, when Liming Zhou and five co-authors publish their paper demonstrating a profound greening of the planet poleward of latitude 40 degrees, or north of a circle passing through New York City.

Using a satellite designed to measure changes in vegetation, they found that the time of active growth has advanced as much as 18 days a year in Eurasia. (The freeze-free period averages around 170 days at latitude 40 degrees.)

In North America, the results are more spotty, with a few areas increasing by up to 12 days. On our continent, the results are confounded by the well-known (to scientists, not to newspaper readers) cooling trend in northeastern North America that has been going on for about 70 years.

Zhou *et al.* attribute this "greening" (their word) to "global warming," because it matches areas that show maximum warming since 1980 in land-based climate records. In fact, the winter warming in the dead of Siberia has been quite striking for decades, and, everything else being equal, this will lengthen the growing season. (Last year's record cold merely proves that climate is a very variable thing.) Summer warming in Siberia has been less profound, a fact not generally disseminated because it doesn't support the popular global-warming-as-disaster paradigm.

What isn't noted in the paper or the brief flurry o news reports — there would probably be a bit more coverage if Zhou had written "global warming is killing the North Woods" — is that the beginning o their satellite record, in 1981, corresponds in the Northern Hemisphere to the end of the coolest era of the last 70 years. The fact is that all analyses show a cooling of our hemisphere from roughly the mid-1940s to the late 1970s. During this climatic spasm, "global cooling" became popular. So this paper starts at an unusual point, but, unfortunately, that is when the satellite went up. If the satellite went up in, say, 1950, the changes it would have found in the growing season would have been much smaller.

The contra is also true: According to Zhou's findings, if we had continued down that cooling spiral, the world north of 40 degrees would now be much more barren than it was 20 years ago. It's quite reasonable to ask if human-induced global warming has saved the world from a food crisis.

What really ticked off the greens about *The Greening of Planet Earth* were the many soundbites from prominent agricultural scientists about how the future atmosphere would be much more conducive for food production. But look at what NASA, which funded this study, now says about Zhou's work: "The pattern of high growth is especially noteworthy in boreal [northern] Eurasia. This includes the grasslands and croplands of south central Russia."

In other words, dreaded global warming will produce more food for Russia.

Russians rightfully fear the cold. In 1972, near the bottom of the mid-century cooling (and around the height of global cooling fear), they were so short of food that they purchased just about every kernel available of American grain. This sent grocery store prices here to alarming levels. By the end of the crop year 1972, world grain reserves stood at a stunningly low 19 days. Since we warmed up, those fears have become a thing of the past. Now food shortages are largely local and political, and commodity prices have been in the tank for years, reflecting vast supply compared with demand.

So is this what global warming has wrought? It appears to have created a more comfortable planet with more food. The video was right. The greens were wrong. The world is greener.

Patrick J. Michaels is senior fellow in environmental studies at the Cato Institute, author of The Satanic Gases, *and an adviser to the Greening Earth Society in Washington, D.C.*

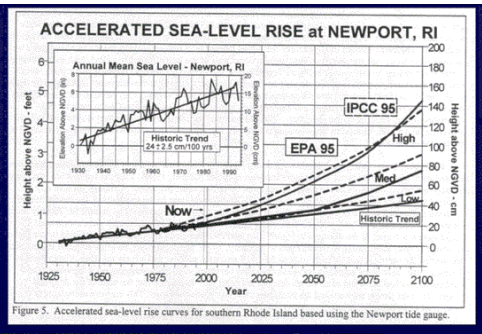
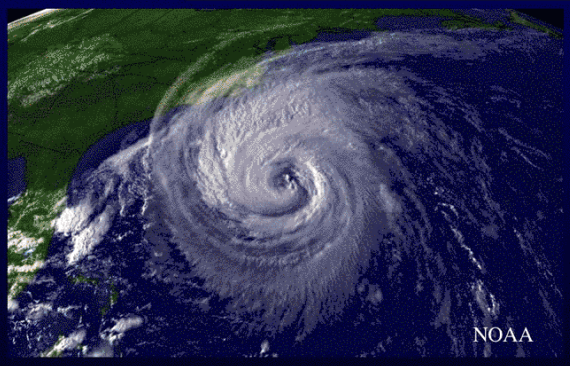
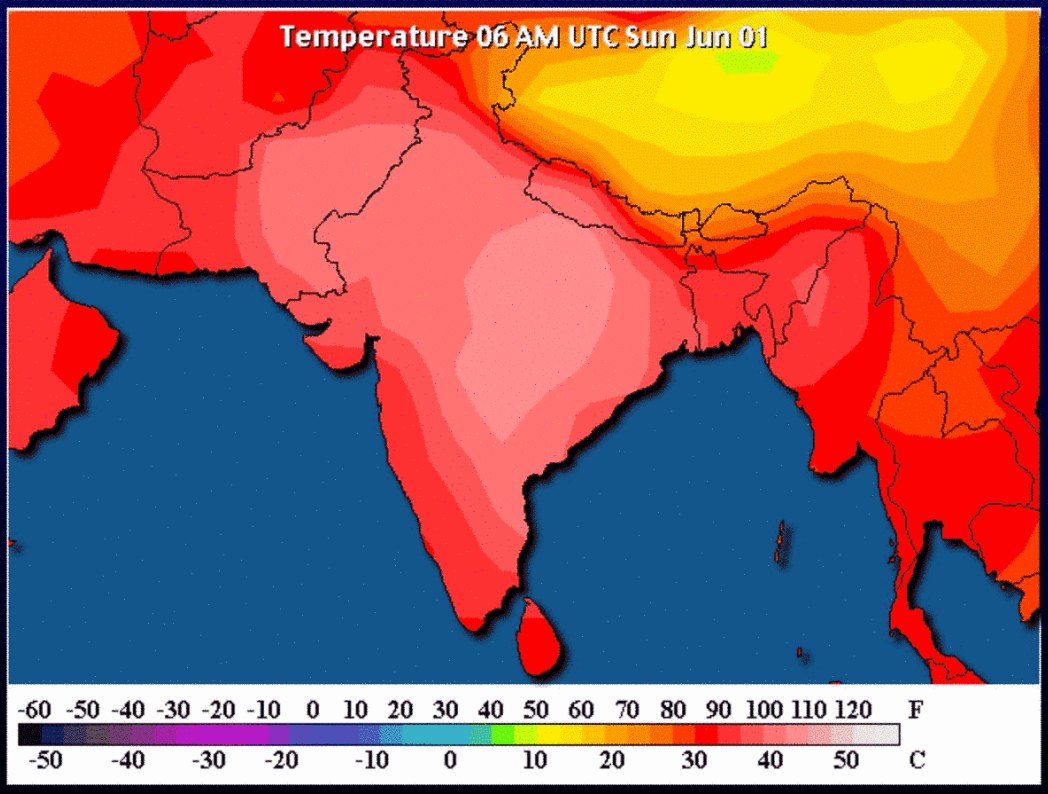
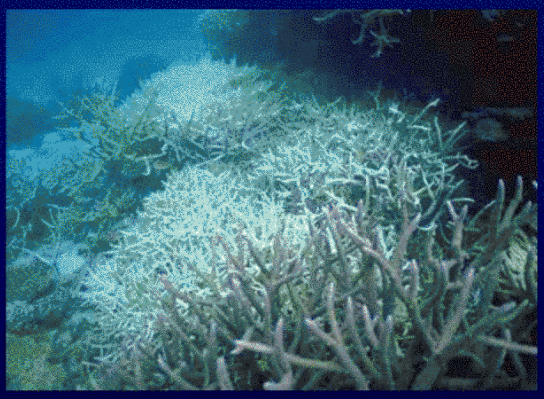


Figure 5. Accelerated sea-level rise curves for southern Rhode Island based using the Newport tide gauge.



HYDERABAD, India (AP) -- Sunstroke and dehydration claimed another 160 lives in a southern Indian state, raising the death toll from a two-week heat wave to nearly 800.

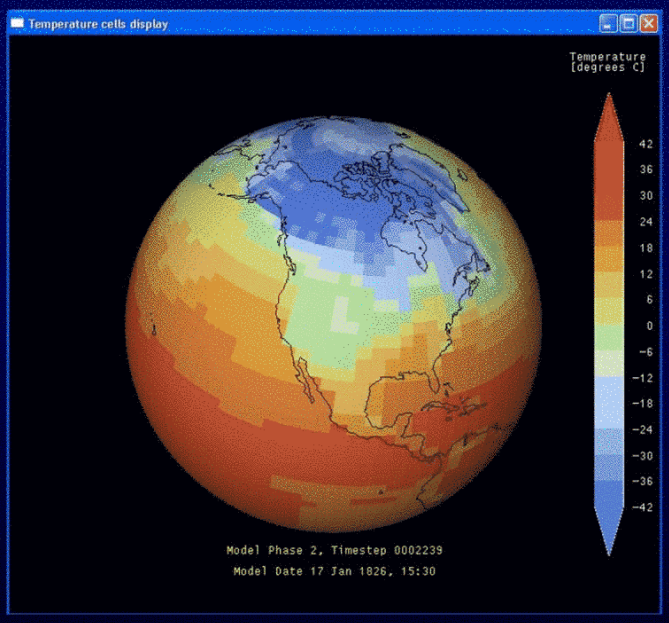




Research: A 4th Quantum Mechanical Aspect

- To study properties of a gas, it is neither useful nor practical to follow the trajectories of each of 10^{23} atoms. *Statistical* physics gets at the important questions right away (ideal gas law, etc.)
- Climate is statistical; weather is not. To model climate, it seems wasteful to compute averages by integrating the equations of motion that describe weather forward in time for long periods.
- Can we develop statistical methods to directly extract climate statistics, like average temperature, from models?
- *Linear Schrödinger-like equations govern Probability Distribution Function (PDF).*

climateprediction.net

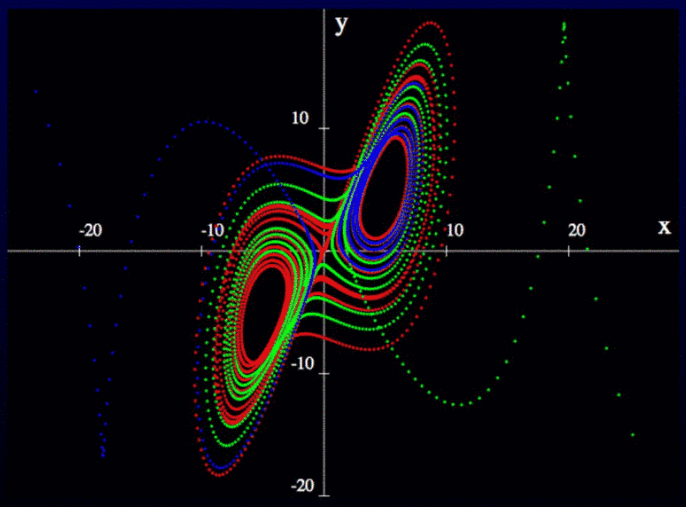


"More than any other theoretical procedure, numerical integration is also subject to the criticism that it yields little insight into the problem. The computed numbers are not only processed like data but they look like data, and a study of them may be no more enlightening than a study of real meteorological observations. An alternative procedure which does not suffer this disadvantage consists of deriving a new system of equations whose unknowns are the statistics themselves. This procedure can be very effective for problems where the original equations are linear, but, in the case of non-linear equations, the new system will inevitably contain more unknowns than equations, and can therefore not be solved, unless additional postulates are introduced." [Edward Lorenz, *The Nature and Theory of the General Circulation* (1967)]

Illustration: The Lorenz Attractor

Discovered in a highly simplified model of convection rolls in the atmosphere.

$$\frac{dx}{dt} = 3\,(y - x)$$
$$\frac{dy}{dt} = 26.5\,x - y - x\,z$$
$$\frac{dz}{dt} = x\,y - z$$



$\langle x \rangle = \langle y \rangle = 0$

$\langle z \rangle \approx 22.7$

$\langle z^2 \rangle - \langle z \rangle^2 \approx 43.8$

Log-Hopf Equation and Cumulant Expansion

Uriel Frisch, *Turbulence: The Legacy of A. N. Kolmogorov* (1995)

EOM $\frac{dx}{dt} = x^2$

$\Psi(t,u) \equiv e^{iux(t)}$ Generating Functional

$$i\frac{\partial}{\partial t}\Psi = u\frac{\partial^2}{\partial u^2}\Psi$$

Linear "Schrödinger equation"

$\bar{\Psi}(t,u) \equiv \langle \Psi(t,u) \rangle$ Average over initial conditions

$$i\frac{\partial}{\partial t}\bar{\Psi} = u\frac{\partial^2}{\partial u^2}\bar{\Psi}$$

$$\bar{\Psi}(t,u) \equiv \exp S(t,u)$$
$$S(t,u) = iu\langle x \rangle - \frac{1}{2!}u^2(\langle x^2 \rangle - \langle x \rangle^2) + \ldots$$

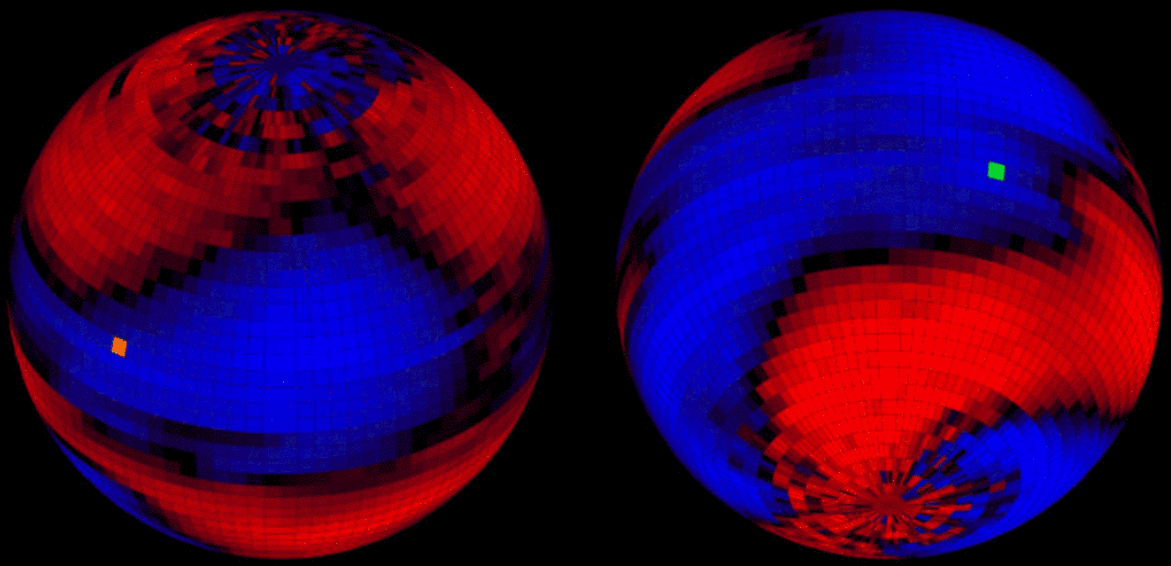
Cumulant Expansion

$\langle x \rangle = \langle y \rangle = 0$

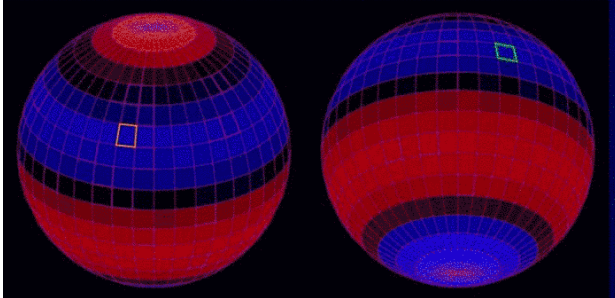
$\langle z \rangle = 23.37$

$\langle z^2 \rangle - \langle z \rangle^2 = 40.17$

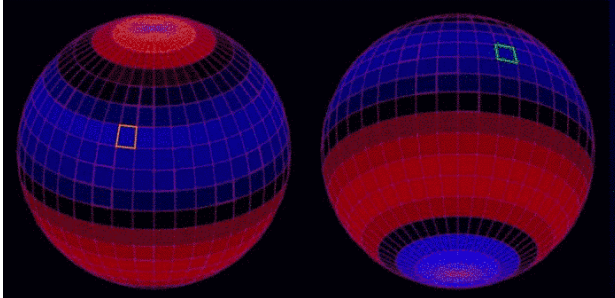
The Quantum Field Theory of Global Warming



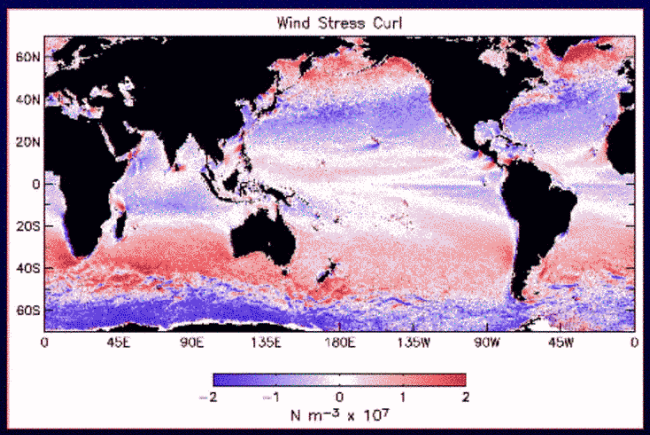
Direct Simulation



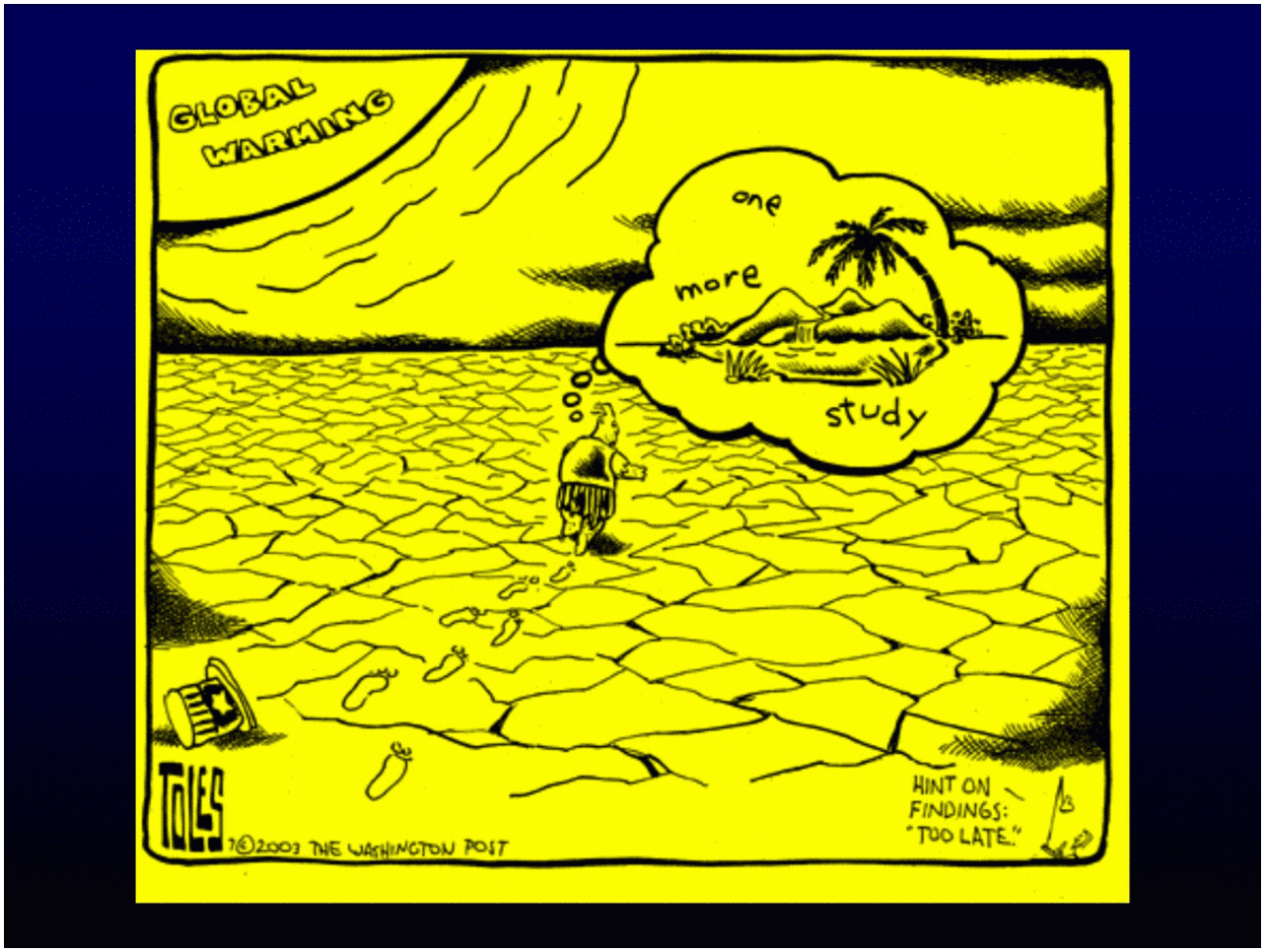
Cumulant Expansion



Observation (4 year mean)



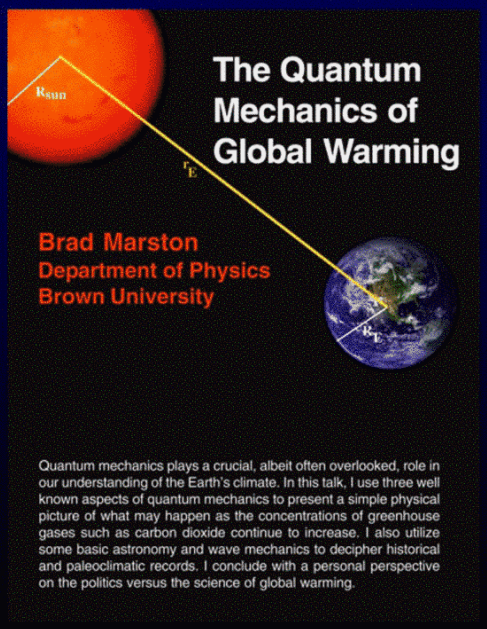
Chelton *et al.*, *Science* **303**, 978 (February 2004)

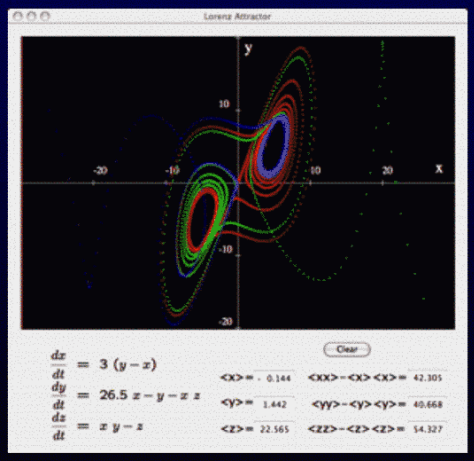


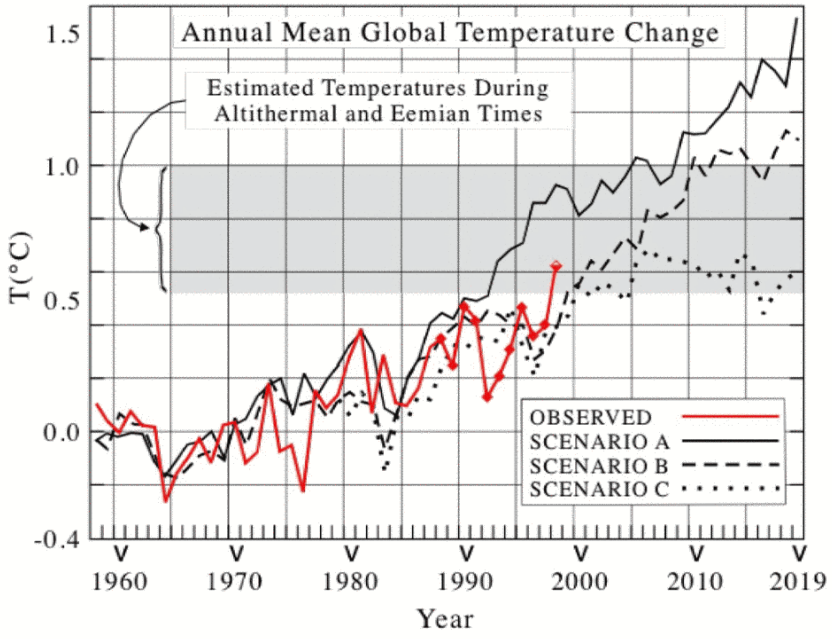
"Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years. (Revelle and Suess 1957)

References for further study:

homepage.mac.com/bradmarston/







'But when Pat Michaels testified to Congress in 1998 and showed our 1988 predictions (Fig. 1) he erased the curves for scenarios B and C, and showed the result only for scenario A. He then argued that, since the real world temperature had not increased as fast as this model calculation, the climate model was faulty and there was no basis for concern about climate change, specifically concluding that the Kyoto Protocol was "a useless appendage to an irrelevant treaty".'

Combating global warming would be a costly waste

ProJo 7/25/2003

SALLIE BALIUNAS

WASHINGTON

HUMANS RECORD historical events, Herodotus wrote, "in the hope of preserving from decay the remembrance of what men have done."

Nature also writes its own history. And when coupled with that written by men, it can ameliorate the tendency to sensationalize current trends in climate into something unusual or dangerous.

Recently, Sen. John Kerry of my home state of Massachusetts, and a leading Democratic presidential candidate, added to the alarmism over climate change. At an environmental conference in Washington, he compared the "threat of global warming" to that of the Cold War, indicating that it required the same mobilization of national resources as was needed to defeat Soviet communism.

In a similar vein, attorneys general from six states are suing the federal government to enforce reductions in carbon-dioxide emission, which is essential to life on the planet and has never been classified as a toxic pollutant, but is blamed by alarmists for warming the globe. New York and some other states are even considering legislation for the state to enforce reductions in the emission of CO_2, which arises mainly from burning fossil fuels.

These domestic calls for action echo a United Nations-sponsored worldwide plan, called the Kyoto Protocol. It requires signatories to reduce their greenhouse-gas emissions based upon the notion that the earth is dangerously warming.

The historical record — both man and nature's — doesn't support this view.

It is true that, according to thermometer measurements, the earth was warmer by some 0.6 degrees Celsius at the end of the 20th Century than it was in the second half of the 19th. And because the 20th Century also coincided with an increased concentration of human-made greenhouse gases in the air, it may be argued that the 20th Century's warmth — and future global warming — was and will be caused, at least in part, by the burning of fossil fuels.

But to get a proper estimate of the amount of human-made global warming, a demonstration is required that the 20th Century actually was unusually warm, and that the 19th Century was normal. Were they?

To find the answer, we must go back several centuries to a period when the amount of greenhouse gases emitted from human activities was minimal. At that time, the instrumentally measured record of global temperature change was insufficient to detail climate's natural fluctuations, as the record dates back only from the mid-19th Century.

Nature's record, however, goes back much further.

What makes up that record? It is natural indicators — or proxies — of climate information derived from glaciers, boreholes, coral, tree growth, sediments of pollen, insects, sea organisms, river effluvia, dune migration, stalactites and stalagmites, plus human documentary evidence such as weather diaries and crop accounts.

The technique of studying proxies isn't easy. There are many differences among proxies, so averaging across many proxies remains tricky. Another difficulty is that no one type of proxy is widely available to make a meaningful global average.

Because of these limitations, proxies are best viewed as records of local climate, with each accounted for in the context of its limits and uncertainties — in time, geographical extent and climate sensitivity.

Nonetheless, despite the problems, there is a wealth of climate information from proxies that can now be culled through modern technology to provide a history of climate at many locations worldwide.

And a recent review (http://cfa-www.harvard.edu/press/pr0310.html) by a team from Harvard University of more than 240 scientific articles by over 1,000 researchers using the various proxy data shows that the climate in most locations was not extreme or unusual during the 20th Century. Instead, the warmest, or most extreme, climate for those locations occurred in the Medieval Warm Period, between the 9th and 14th centuries.

That period of extreme climate — long before the air's increase in greenhouse-gas concentration from human activities — must have natural explanations. Whatever they are, the results of the warming, as far as man was concerned, in most cases appear to have been more beneficial than dangerous. Vikings made their way to Greenland and Newfoundland in that period. And England had productive vineyards.

H.H. Lamb, the founder of the climatic research unit at East Anglia University, found that England's climate was warm enough in the 12th and 13th centuries to support more than 30 vineyards, signifying that May frosts were rare. But natural swings in climate ended that environment, beginning with a period known as the Little Ice Age, lasting from about 1300 to 1900, during which Europe had more acute winters. The intensity of the Little Ice Age reached its peak from 1550 to 1700, bringing crop failures, disease and death. Many died of famine in Scotland during crop failures in seven of eight years at the end of the 18th Century.

That the last millennium has seen periods warmer than the 20th Century in many parts of the world where there is information means that the 20th Century was not unusual. Meanwhile, the 19th Century, where thermometer records begin, seems to have been the tail of an unusually cold period that had persisted for some centuries, perhaps as far back as the 14th Century in some areas. It was not so normal.

The scientific history drawn from nature and man's observations over the last millennium suggests that a strong trend of human-induced warming does not exist. The scientific facts indicate that costly policies to combat global warming are unlikely to mitigate any of climate's ever-present natural risks, but they could reduce society's economic ability to cope with them.

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"A flawed recent study [Soon and Baliunas, 2003] compels us to stress two points which might seem patently obvious: (1) It is essential to assess each proxy series for sensitivity to past temperature variability and not, as in SB03, to equate hydrological influences with temperature influences; (2) It is also essential to distinguish between regional anomalies, which often cancel in a hemispheric mean and not, as in SB03, to equate eg., the existence of asynchronous warm anomalies in different regions with a hemispheric mean warm anomaly." [Mann and Jones, GRL **30**, 1820 (2003)]

"The Bush administration took the unusual step of inserting a reference to the Soon-Baliunas paper in the EPA's recent report on the environment, replacing a statement that temperatures have risen significantly in recent decades." [Robert Park, APS, 8/1/2003]