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PHYSICS & SOCIETY

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EDITOR'S COMMENTS

With this issue of *Physics & Society*, we kick off a debate concerning one of the main conclusions of the International Panel on Climate Change (IPCC), the UN body which, together with Al Gore, recently won the Nobel Prize for its work concerning climate change research. There is a considerable presence within the scientific community of people who do not agree with the IPCC conclusion that anthropogenic CO2 emissions are very probably likely to be primarily responsible for the global warming that has occurred since the Industrial Revolution. Since the correctness or fallacy of that conclusion has immense implications for public policy and for the future of the biosphere, we thought it appropriate to present a debate within the pages of P&S concerning that conclusion. This editor (JJM) invited several people to contribute articles that were either *pro* or *con*. Christopher Monckton responded with this issue's article that argues against the correctness of the IPCC conclusion, and a pair from Cal Poly San Luis

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IN THE APRIL WEB ISSUE

NEWS FROM THE FORUM

Message from the Chair

You are holding in your hands the very last paper copy of our newsletter, "Physics and Society." The idea of going to a fully electronic version, readable on your computer or readily sent to your local printer was something that the Executive Committee first discussed in 2001 when we dropped down from four printed copies a year to our current mix of two printed and two electronic. The advantages of electronic printing are obvious: the Forum saves significant money (each printing costs approximately $4,000) and the environmental impact of an electronic version is small. In addition, the money saved can be used to support other programs (e.g. student internships and travel for invited speakers of an FPS-sponsored session at an APS meeting) and give us the freedom to explore new programmatic ideas of interest to our membership.

What about the disadvantages of electronic printing? In 2001, there was legitimate concern about downloading a large document with the connection speed of a telephone modem. Fortunately, that is rarely an issue for the vast majority of our membership. Another general concern is that electronic newsletters lead to longer, but not necessarily better articles, and that the writing and the editing quality are automatically lessened. Our editors have heard this concern in the past and I have no doubt that these will be addressed as we move forward. Finally, several hundred libraries currently receive paper copies and that is an invaluable resource for the Forum. There's no way to tell how many patrons "stumble" upon a copy of the newsletter, but we want to ensure that this continues by printing a small number of copies for the libraries.

I hope you had a chance to attend some of the FPS-sponsored sessions at the recent March/April meetings. There were two excellent sessions at the March meeting in New Orleans: "Understanding Hurricanes and Severe Storms" and "Lessons learned from Katrina … " The April meeting sessions were outstanding and ranged from the technical (Nuclear Forensics) to the general (How to Run for Public Office). My thanks to the organizers and to the speakers at each of our Sessions. Our 2009 Program Chair, Don Prosnitz, is already putting together a variety of interesting topics for next year's meetings.

We're in the second year of sponsoring a FPS summer student fellowship in collaboration with the Society of Physics Students. The Selection Committee is chaired by Bo Hammer. The Fellow for 2008 was just chosen and will look at energy savings from light pipes. We expect to see an article in this newsletter from the student some time next year.

New offerings like this student fellowship program is the type of initiative that we plan to explore as we look for exciting ways to increase and improve the activities of the Forum. Our Past Chair, Lawrence Krauss did a great job last year, we have an excellent Executive Committee and it will be a pleasure to work with them as I serve as the Chair of FPS.

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Message from the Former Chair

I am pleased to address this note to the membership as outgoing chair of the Forum on Physics and Society. My experience has been an interesting and rewarding one, and one that convinces me that the forum continues to play an important and useful role in the Society. Our newsletter is a widely read source of information, and our other primary activity, involving organizing sessions at the two annual APS meetings remain of interest, with broad attendance. Over the past two years our sessions ranged widely, from thematic presentations on energy issues, and nuclear proliferation to sessions on how to support students and physics departments in the event of a natural disaster like hurricane Katrina, and a session on how to run for political office.

The leadership of the forum is continuing to explore other mechanisms to address important issues in Physics and Society, including co-organizing public meetings on science issues, and cooperating with groups like the AAAS to prepare sessions at national meetings. As we continue to witness attacks on science in the schools, urgent national defense issues that are being ignored or mishandled, and the persistent lack of public and political recognition of the importance of sound science in government, it is clear that the need for physicists to discuss these issues, and act on them, remains strong.

Finally, I would like to thank all those on the executive committee of the forum, and all the other individuals who have helped organize sessions for our meetings and have written pieces for our newsletter, for their largely unsung time and effort to keep the forum moving in the right direction.

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Future Meetings

Planning is under way for the March and April meetings. To submit suggestions for FPS program sessions or help with the planning, please contact Don Prosnitz at dprosnit@rand.org.

A Tutorial on the Basic Physics of Climate Change

David Hafemeister and Peter Schwartz

The following article has not undergone any scientific peer review, since that is not normal procedure for American Physical Society newsletters. The American Physical Society reaffirms the following position on climate change, adopted by its governing body, the APS Council, on November 18, 2007: "Emissions of greenhouse gases from human activities are changing the atmosphere in ways that affect the Earth's climate."

Abstract: ***In this paper, we have used several basic atmospheric–physics models to show that additional carbon dioxide will warm the surface of Earth. We also show that observed solar variations cannot account for observed global temperature increase.***

The Intergovernmental Panel on Climate Change (IPCC) has projected a likely temperature rise of 3 °C (2 to 4.5 °C) from a doubled CO_2 of 560 ppm in this century.[i] Many believe that a rise of 2–2.5 °C will cause a "dangerous anthropogenic interference with climate." Earth has already had a rise of 0.8 °C in less than one-half century, and it is projected to rise another 0.6 °C as the planet adjusts to the present level of CO_2. Scientists have accumulated compelling evidence besides the temperature data to document a warming Earth. The observations include the shrinking of the northern ice cap (40% thinner in 30 years, and a considerable loss in surface area in the last year) and Greenland's glaciers, lakes are frozen a shortened time by about two weeks, and summer is two weeks longer as determined by animal and plant cycles. The discussion sensibly moves to two main questions: "Are non-anthropogenic causes of warming significant" and "how much warmer will Earth become?"

We will not review the scientific literature, as that path is well trod. Rather, we present some basic physics models, to shore up basic understandings.[ii] Put a blanket over a light bulb, and you will have a fire. For the full power of the light bulb to pass through the blanket, the inner temperature must rise considerably. The atmosphere is not a mere thermal resistor, but the analogy is illuminating. Svante Arrhenius, a Swedish physicist, first suggested in 1896 that increases in atmospheric CO_2 would lead to global temperature rises. Below, we conduct an analysis in a similar fashion.

The naturally occurring greenhouse gases (present before industrialization) cause the earth to be 33 °C warmer than if there was no infrared trapping by the atmosphere. One can attribute 21 °C of that warming to the IR trapping of water vapor, 7 °C to CO_2 and 5 °C to other gases. If we add even more CO_2, we should expect it to increase the surface temperature. There are also feedbacks, but IPCC has observed that feedbacks are more positive than negative, meaning they will further increase warming. It is our belief that "theory leads experiment" on climate change because all well-accepted atmospheric models predict a temperature rise. The data over the past decade is now solidifying in general agreement with theory. General Circulation Models (GCM) and our basic models connect cause and effect. Some critics believe that the warming is "directly linked to two distinctly different aspects of solar dynamics: the short-term statistical fluctuations in the Sun's irradiance and the longer–term solar cycles."[iii] We will show that observed solar fluctuations cannot be responsible for the presently observed global climate changes.

The carbon released worldwide from burning carbon and deforestation has recently been about 7.1 Gt/yr. The number of CO_2 molecules released is

$$N_{CO2} = (7.1 \times 10^{15}\ \text{g/yr})(6.02 \times 10^{23}/\text{mole})/(12\ \text{g/mole}) = 3.6 \times 10^{38}\ \text{molecules } CO_2/\text{yr} \quad (1)$$

The mass of the atmosphere is the surface area of Earth times the atmospheric pressure of 10^5 Pascal divided by g:

$$M_{atmos} = PA/g = (10^5\ \text{Pa})(4\pi)(6.4 \times 10^6\ \text{m})^2/(9.8\ \text{m/sec}^2) = 5.3 \times 10^{18}\ \text{kg.} \quad (2)$$

The number of O_2 and N_2 molecules in the atmosphere is

$$N_{atmos} = (5.3 \times 10^{21}\ \text{g})(6.02 \times 10^{23}/\text{mole})/(29\ \text{g air/mole}) = 1.1 \times 10^{44}\ \text{molecules.} \quad (3)$$

This gives the rate of increase in concentration of CO_2 molecules,

$$c_{CO2} = N_{CO2}/N_{atmos} = (3.6 \times 10^{38}\ CO_2/\text{yr})/(1.1 \times 10^{44}\ \text{air}) = 3.3\ \text{ppm/yr.} \quad (4)$$

This is more than twice the atmospheric CO_2 rise of 1.4 ppm/yr (325 ppm in 1970 to 354 ppm in 1990 to 370 ppm in 2000). Thus, about half of the CO_2 remains in the atmosphere, the other half goes into sinks in the oceans and on land.

CO_2 Before Industrialization. The pre-industrial CO_2 level was 280 ppm in 1800. By 1959, the level had grown to 316 ppm. We can estimate total change in concentration by integrating backwards in time. Using a rate of 0.9 ppm/yr in 1959 and a global carbon rate growth rate of about l = 3%/year, the increase in CO_2 concentration between 1800 and 1959 should be about

$$\Delta c_{CO2} = \int_{-\infty}^{0} (0.9)\, e^{\lambda t}\, dt = 0.9(e^0 - e^{\infty})/l = 0.9/0.03 = 30\ \text{ppm.} \quad (5)$$

Subtracting this from the 1959 value of 316 ppm gives a pre-industrial CO_2 level of 285 ppm, close to the accepted value of 280 ppm.

CO_2 in the 21st Century. 2050 CO_2 levels may be obtained by projecting 60 years growth onto the 1990 level of 354 ppm.

Energy Information Agency estimated a business-as-usual approach will give 2%/yr global growth in fossil fuels, for a 2050 concentration of

$$c_{CO_2} = \int_0^{60} (1.4 \text{ ppm/yr})\, e^{0.02t}\, dt + 354 \text{ ppm} = 162 \text{ ppm} + 354 \text{ ppm} = 516 \text{ ppm} \quad (6)$$

This figure is consistent with most business-as-usual projections.

Upper-Atmospheric Temperature T_a. Earth's temperature is determined from a heat balance between absorbed energy from solar flux $s_o = 1367$ W/m^2 and infrared emission to space. The solar power intercepted by the area of Earth's disk ($\pi R_E^2 s_o$) is distributed over the entire spherical area ($4\pi R_E^2$), giving an average solar flux of $s_o/4 = 1367/4 = 342$ W/m^2. Of this, 70% is absorbed by the Earth, and 30% is reflected (Earth's albedo $a = 0.3$ in the visible), giving an *average flux absorbed by surface and atmosphere*,

$$s_{absorbed} = (1 - a)(s_o/4) = (1 - 0.3)(1367/4) = 239 \text{ W/m}^2. \quad (7)$$

Absorption by clouds and atmosphere reduces solar flux at the surface to an average of about 200 W/m^2. The energy absorbed by Earth's surface is sent upward by infrared, evaporation and air currents, which is captured by the atmosphere or passes directly to space. In our first model, we assume that *all the absorbed* energy is *reradiated to space as IR from a thin surface* at the top of the atmosphere. The power balance at the top of the Earth's *upper* atmosphere is

$$P_{in} = (1 - a)(\pi R_E^2 s_o) = P_{out} = \varepsilon\sigma T_a^4 (4\pi R_E^2) \quad (8)$$

where temperature at the top of the atmosphere T_a is in Kelvin, σ is the Stefan–Boltzmann constant, 5.67×10^{-8} W/m^{2}K^4, and ε is emissivity (about 1 for 10–micron infrared). Solving for the upper atmosphere temperature,

$$T_a = [(1 - a)s_o/4\varepsilon\sigma]^{1/4} = [239 \text{ W/m}^2/\sigma\varepsilon]^{1/4} = 255 \text{ K} = -18^{o}\text{C} = 0^{o}\text{F} \quad (9)$$

The temperature in the middle of the troposphere is 255 K at 5 km above the surface (and at 50 km.) This is 32 K colder than the observed average surface temperature of 287 K (14.0 ^{o}C with 1997 averages of 14.6^{o}C in the northern hemisphere and 13.4^{o}C in the southern hemisphere). As a comparison we calculate $T_{a\text{-}V}$ for Venus, which has a higher solar flux since the radius of its orbit is only 60% that of Earth:

$$s_{o\text{-}V} = s_o(r_E/r_V)^2 = (1367 \text{ W/m}^2)(1.50 \times 10^8 \text{ km}/1.08 \times 10^8 \text{ km})^2 = 2610 \text{ W/m}^2. \quad (10)$$

However, Venus's higher albedo of 0.76 reflects a greater fraction of sunlight, greatly reducing the average absorbed flux to

$$(1 - a)s_{o\text{-}V}/4 = (1 - 0.76)(2610 \text{ W/m}^2)/4 = 157 \text{ W/m}^2 \quad (11)$$

which is smaller than Earth's 239 W/m^2. The upper atmospheric temperature of *hot* Venus,

$$T_{a\text{-}V} = [157 \text{ W-m}^{-2}/\text{s}]^{1/4} = 229 \text{ K} \quad (12)$$

is 26 K *colder* than Earth's 255 K. However, Venus's higher CO_2 concentration traps IR, giving it a surface temperature of 750 K, three times Earth's surface temperature of 287 K.

Surface Temperature T_s. Our zero-dimensional box model did not take into account the following variable factors: Reflection, absorption and emission by air, aerosols, clouds and surface; Convection of sensible and latent (evaporation) heat; Coupling to oceans and ice; Variations in three dimensions; and Variable solar flux.

Next, we estimate the surface temperature T_s without considering T_a. We assume that all the solar flux that is not reflected is transmitted through the air and totally absorbed by the Earth's surface $f_{absorbed} = (1 - a)s_o/4$. The warmed surface radiates as a blackbody, and also loses heat through rising in air currents or evaporated moisture. We allow a fraction of the light radiated from the earth, f_{IR} to be absorbed by the atmosphere, which is mostly in the infrared. The atmosphere radiates 50% of the IR absorbed flux to space and 50% to Earth, giving an IR flux downward of $(f_{IR}/2)f_{absorbed}$. Again, a fraction f_{IR} of this energy is absorbed in the atmosphere again and 50% of this radiates downward and is absorbed by the surface, $(f_{IR}/2)(f_{IR}/2)f_{absorbed}$. This process gives an infinite sum in the energy balance:

$$f_{absorbed} + (f_{IR}/2)f_{absorbed} + (f_{IR}/2)^2 f_{absorbed} + (f_{IR}/2)^3 f_{absorbed} + \cdots + (f_{IR}/2)^n f_{absorbed} = \sigma T_s^4. \quad (13)$$

After manipulation, this becomes

$$f_{absorbed}/[(1 - (f_{IR}/2)] = \sigma T_s^4. \quad (14)$$

We obtain Earth's surface temperature of $T_s = 287$ K with $f_{IR} = 0.76$. For the extreme case of *no IR* absorption in the atmosphere ($f_{IR} = 0$), we obtain $T_s = 255$ K, the temperature of the upper atmosphere. For the other extreme case of *100% IR absorption* in the atmosphere ($f_{IR} = 1$), we obtain $T_s = 303$ K, consistent with the next calculation.

T_a and T_s Together: Next, we assume that all sunlight is transmitted through the air and absorbed by the Earth's surface. We vary the one free parameter, the emissivity of the atmosphere ε_a, but retain the surface of Earth as a blackbody with $\varepsilon_E = 1$. Equation 15 *balances heat flow in the single layer of air*. The left side doubles the infrared flux emitted by Earth's atmosphere, since IR goes both up into space and down to Earth's surface, essentially doubling the radiating surface area. This is balanced with IR flux emitted from Earth's blackbody surface and absorbed by the gray body atmosphere.

$$2\varepsilon_a \sigma_o T_a^4 = \varepsilon_a \sigma T_s^4 \tag{15}$$

Equation 16 is an *energy balance at Earth's surface*. The left side is the *sum* of solar energy absorbed at the surface and the absorbed downward flow of IR from the atmosphere, which is balanced with upward IR flux from the surface,

$$(1 - a)s_o/4 + \varepsilon_a \sigma T_a^4 = \sigma T_s^4. \tag{16}$$

Solving equations 15 and 16 gives

$$T_s = 2^{1/4} T_a \text{ and } \sigma T_s^4 = (1 - a)s_o/4(1 - \varepsilon_a/2). \tag{17}$$

If the air layer is a blackbody ($\varepsilon_a = 1$, considerable CO_2), the atmosphere is $T_a = 255$ K (as before) and the surface is $T_s = 303$ K (16 K warmer than actual value of 287 K). If $\varepsilon_a = 1/2$ (from less CO_2), the atmosphere is too cold at $T_a = 230$ K and the surface is also too cold at $T_s = 274$ K. By adjusting ε_a to 0.76, we obtain the "correct" surface temperature, $T_s = 287$ K.

Multi-Layer Atmosphere. Next we divide the planetary atmosphere into n zones, layered vertically. By using several layers, the temperature gradient in each layer is reduced, smoothing the temperature profile to become more continuous. The thickness of a layer is such that almost all incident IR on a layer is just absorbed in that layer, which then radiates it upwards and downwards. Planets with small amounts of CO_2 and H_2O have less than one zone, while Venus has many zones. Due to lack of space, we leap to the answer:

$$T_0 = [(1 - a)s_o/4\sigma]^{1/4} \text{ and } T_s = (n + 1)^{1/4} T_0 \tag{18}$$

where n is the number of IR absorption layers Earth has. Earth's $s_o = 1367$ W/m^2 and $a = 0.3$ gives $T_0 = 255$ K, $T_1 = 303$ K, $T_{10} = 464$ K, $T_{20} = 546$ K and $T_{75} = 753$ K. The answer depends greatly on the amount of greenhouse gasses in the atmosphere. Earth's surface temperature of 287 K is somewhat colder than that for one full layer ($n = 1$) at 303 K. The number of layers for the Earth's atmosphere is obtained by solving for n, giving

$$n = (T_s/T_0)^4 - 1 = (287 \text{ K}/255 \text{ K})^4 - 1 = 0.6. \tag{19}$$

It is not surprising that Earth's atmosphere contains only 60% of an IR layer since O_2 and N_2 hardly absorb IR, leaving the task of IR absorption to trace amounts of CO_2 and H_2O. Venus, on the other hand, has a large temperature difference between the upper atmosphere at $T_0 = 229$ K and the surface at $T_s = 750$ K. These temperatures give 74 IR layers for CO_2 rich Venus!

Solar Variations. We might expect solar variations of 0.2% are possible since that is twice the present 11-year solar variation. The 0.2% variation gives a surface temperature variation of

$$\Delta T_s = T_s(\Delta s/s_o)/4 = (287 \text{ K})(2 \times 10^{-3})/4 = 0.14 \text{ K}. \tag{20}$$

Correlation has been discovered between number of sunspots and surface temperature of Earth. However, for solar variations to explain climate change, there remains to be identified an additional solar heating mechanism beyond that already described. General circulation model calculations show extra heating in summer warms the stratosphere, strengthening easterly winds and changing wind patterns. However, the GCM changes predicted from solar variations are smaller than the observed changes. Other GCM calculations, which include interactive stratospheric chemistry with ozone, had more success in predicting an 11-year climate cycle. A theoretical link between solar variation and climate change needs a more active sun to emit considerably more ultraviolet. Extra UV would interact with ozone, raising stratosphere temperatures, but this would only raise the *surface temperature* at high latitudes by only a few tenths of a degree. Our calculation supports the IPCC findings that the contribution of solar variations to increased temperatures is not significant. Figure 3 in the paper by Judith Lean indicates that the cyclical amplitude of Earth's surface temperature is about 0.1 K, so the solar variational effect is not significant.[iv] On the other hand, our calculations, the GCMs, and Arrhenius can explain the observed global temperature rises with the observed increases in greenhouse gases.

Conclusion: Earth is getting warmer. Basic atmospheric models clearly predict that additional greenhouse gasses will raise the temperature of Earth. To argue otherwise, one must prove a physical mechanism that gives a reasonable alternative cause of warming. This has not been done. Sunspot and temperature correlations do not prove causality.

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Endnotes

i *Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Basis, Cambridge University Press, New York (2007), http://www.ipcc.ch.*

ii *D. Hafemeister, Physics of Societal Issues: Calculations on National Security, Environment and Energy, Springer, New York, 2007.*

iii *N. Scafetta and B. West, "Is Climate Sensitive to Solar Variability," Physics Today 61, 50–51 (2008).*

iv *J. Lean, "Living with a Variable Sun," Physics Today 58, 32–38 (2005).*

Climate Sensitivity Reconsidered

Christopher Monckton of Brenchley

The following article has not undergone any scientific peer review, since that is not normal procedure for American Physical Society newsletters. The American Physical Society reaffirms the following position on climate change, adopted by its governing body, the APS Council, on November 18, 2007: "Emissions of greenhouse gases from human activities are changing the atmosphere in ways that affect the Earth's climate."

Abstract: The Intergovernmental Panel on Climate Change (IPCC, 2007) concluded that anthropogenic CO_2 emissions probably caused more than half of the "global warming" of the past 50 years and would cause further rapid warming. However, global mean surface temperature T_S has not risen since 1998 and may have fallen since late 2001. The present analysis suggests that the failure of the IPCC's models to predict this and many other climatic phenomena arises from defects in its evaluation of the three factors whose product is climate sensitivity:

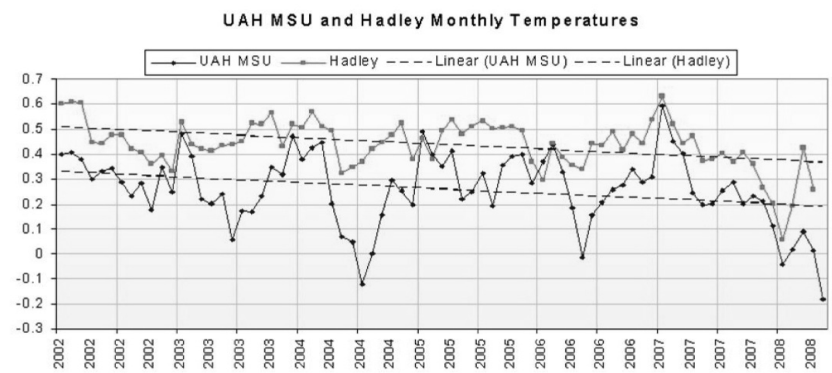
1) Radiative forcing ΔF; 2) The no-feedbacks climate sensitivity parameter κ; and 3) The feedback multiplier f.

Some reasons why the IPCC's estimates may be excessive and unsafe are explained. More importantly, the conclusion is that, perhaps, there is no "climate crisis", and that currently-fashionable efforts by governments to reduce anthropogenic CO_2 emissions are pointless, may be ill-conceived, and could even be harmful.

The context

Globally-averaged land and sea surface absolute temperature T_S has not risen since 1998 (Hadley Center; US National Climatic Data Center; University of Alabama at Huntsville; etc.). For almost seven years, T_S may even have fallen (Figure 1). There may be no new peak until 2015 (Keenlyside et al., 2008).

Figure 1: Mean global surface temperature anomalies (°C), 2001-2008

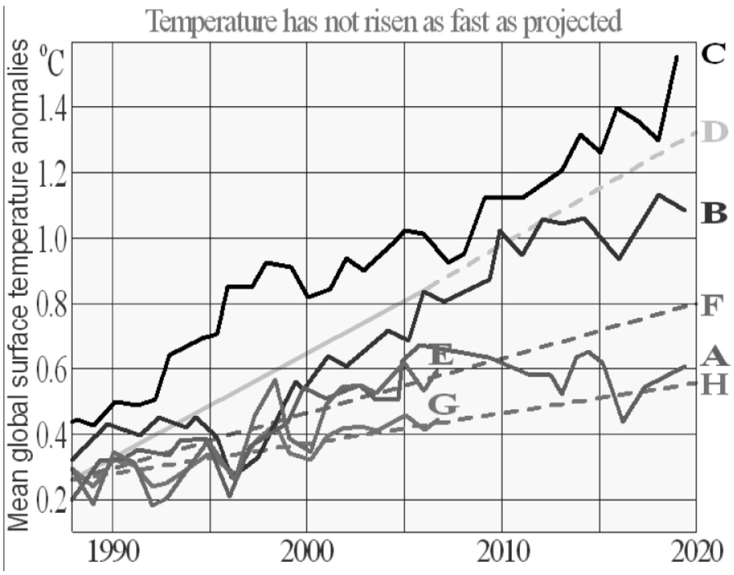


Since the phase-transition in mean global surface temperature late in 2001, a pronounced downtrend has set in. In the cold winter of 2007/8, record sea-ice extents were observed at both Poles. The January-to-January fall in temperature from 2007-2008 was the greatest since global records began in 1880. Data sources: Hadley Center monthly combined land and sea surface temperature anomalies; University of Alabama at Huntsville Microwave Sounding Unit monthly lower-troposphere anomalies; Linear regressions.

The models heavily relied upon by the Intergovernmental Panel on Climate Change (IPCC) had not projected this multidecadal stasis in "global warming"; nor (until trained ex post facto) the fall in T_S from 1940-1975; nor 50 years' cooling in Antarctica (Doran et al., 2002) and the Arctic (Soon, 2005); nor the absence of ocean warming since 2003 (Lyman et al., 2006; Gouretski & Koltermann, 2007); nor the onset, duration, or intensity of the Madden-Julian intraseasonal oscillation, the Quasi-Biennial Oscillation in the tropical stratosphere, El Nino/La Nina oscillations, the Atlantic Multidecadal Oscillation, or the Pacific Decadal Oscillation that has recently transited from its warming to its cooling phase (oceanic oscillations which, on their own, may account for all of the observed warmings and coolings over the past half-century: Tsonis et al., 2007); nor the magnitude nor duration of multi-century events such as the Mediaeval Warm Period or the Little Ice Age; nor the cessation since 2000 of the previously-observed growth in atmospheric methane concentration (IPCC, 2007); nor the active 2004 hurricane season; nor the inactive subsequent seasons; nor the UK flooding of 2007 (the Met Office had forecast a summer of prolonged droughts only six weeks previously); nor the solar Grand Maximum of the past 70 years, during which the Sun was more active, for longer, than at almost any similar period in the past 11,400 years (Hathaway, 2004; Solanki et al., 2005); nor the consequent surface "global warming" on Mars, Jupiter, Neptune's largest moon, and even distant Pluto; nor the eerily- continuing 2006 solar minimum; nor the consequent, precipitate decline of ~0.8 °C in T_S from January 2007 to May 2008 that has canceled out almost all of the observed warming of the 20th century.

An early projection of the trend in T_S in response to "global warming" was that of Hansen (1988), amplifying Hansen (1984) on quantification of climate sensitivity. In 1988, Hansen showed Congress a graph projecting rapid increases in T_S to 2020 through "global warming" (Fig. 2):

Figure 2: Global temperature projections and outturns, 1988-2020



Hansen (1988) projected that global temperature would stabilize (A) if global carbon dioxide concentration were controlled from 1988 and static from 2000: otherwise temperature would rise rapidly (B-C). IPCC (1990) agreed (D). However, these projections proved well above the National Climate Data Center's outturn (E-F), which, in contrast to the Hadley Center and UAH records (Fig. 1), show a modest rise in temperature from 1998-2007. If McKitrick (2007) (G,H) is correct that temperature since 1980 has risen at only half of the observed rate, outturn tracks Hansen's CO2 stabilization case (A), although emissions have risen rapidly since 1988.

To what extent, then, has humankind warmed the world, and how much warmer will the world become if the current rate of increase in anthropogenic CO_2 emissions continues? Estimating "climate sensitivity" – the magnitude of the change in T_S after doubling CO_2 concentration from the pre-industrial 278 parts per million to ~550 ppm – is the central question in the scientific debate about the climate. The official answer is given in IPCC (2007):

> *"It is very likely that anthropogenic greenhouse gas increases caused most of the observed increase in [T_S] since the mid-20th century. … The equilibrium global average warming expected if carbon dioxide concentrations were to be sustained at 550 ppm is likely to be in the range 2-4.5 °C above pre-industrial values, with a best estimate of about 3 °C."*

Here as elsewhere the IPCC assigns a 90% confidence interval to "very likely", rather than the customary 95% (two standard deviations). There is no good statistical basis for any such quantification, for the object to which it is applied is, in the formal sense, chaotic. The climate is "a complex, non-linear, chaotic object" that defies long-run prediction of its future states (IPCC, 2001), unless the initial state of its millions of variables is known to a precision that is in practice unattainable, as Lorenz (1963; and see Giorgi, 2005) concluded in the celebrated paper that founded chaos theory –

> *"Prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly. In view of the inevitable inaccuracy and incompleteness of weather observations, precise, very-long-range weather forecasting would seem to be non-existent.".*

The *Summary for Policymakers* in IPCC (2007) says:

> *"The CO_2 radiative forcing increased by 20% in the last 10 years (1995-2005)."*

Natural or anthropogenic CO_2 in the atmosphere induces a "radiative forcing" ΔF, defined by IPCC (2001: ch.6.1) as a change in net (down minus up) radiant-energy flux at the tropopause in response to a perturbation. Aggregate forcing is natural (pre-1750) plus anthropogenic-era (post-1750) forcing. At 1990, aggregate forcing from CO_2 concentration was ~27 W m^{-2} (Kiehl & Trenberth, 1997). From 1995-2005, CO_2 concentration rose 5%, from 360 to 378 W m^{-2}, with a consequent increase in aggregate forcing (from Eqn. 3 below) of ~0.26 W m^{-2}, or <1%. That is one-twentieth of the value stated by the IPCC. The absence of any definition of "radiative forcing" in the 2007 Summary led many to believe that the aggregate (as opposed to anthropogenic) effect of CO_2 on T_S had increased by 20% in 10 years. The IPCC – despite requests for correction – retained this confusing statement in its report.

Such solecisms throughout the IPCC's assessment reports (including the insertion, after the scientists had completed their final draft, of a table in which four decimal points had been right-shifted so as to multiply tenfold the observed contribution of ice-sheets and glaciers to sea-level rise), combined with a heavy reliance upon computer models unskilled even in short-term projection, with initial values of key variables unmeasurable and unknown, with advancement of multiple, untestable, non-Popper-falsifiable theories, with a quantitative assignment of unduly high statistical confidence levels to non-quantitative statements that are ineluctably subject to very large uncertainties, and, above all, with the now-prolonged failure of T_S to rise as predicted (Figures 1, 2), raise questions about the reliability and hence policy-relevance of the IPCC's central projections.

Dr. Rajendra Pachauri, chairman of the UN Intergovernmental Panel on Climate Change (IPCC), has recently said

Table 1: Evaluation of ΔF_{2x} from the IPCC's anthropogenic-era forcings

Forcing agent (yellow: values from IPCC, 2007)	*1750-2005*	*1750-2xCO$_2$*	*Method*
CO_2 anthropogenic-era radiative forcing ΔF_{2xCO2}	1.66 W m^{-2}	3.71 W m^{-2}	From Eqn. (3)
LLGHGs: CH_4 0.48; NO_2 0.16; Halocarbons 0.34	0.98 W m^{-2}		
SLGHGs: O_3 0.30; CH_4 water vapor 0.07	0.37 W m^{-2}		
All GHGs' anthropogenic-era forcings	3.01 W m^{-2}	4.95 W m^{-2}	3.71 / 75%
Contrails 0.01; Surfc.albedo –0.10; Aerosol –1.20	–1.29 W m^{-2}	–1.29 W m^{-2}	Held constant
Total anthropogenic-era forcings ΔF_{2x} …	1.72 W m^{-2}	3.66 W m^{-2}	
… adjusted for IPCC probability-density function:	1.60 W m^{-2}	3.41 W m^{-2}	3.35 x 1.60 / 1.72

Anthropogenic-era radiative forcings from CO_2, from long-lived (LLGHG) and short-lived (SLGHG) greenhouse gases are added to other forcings to yield total anthropogenic-era forcings ΔF_{2x}, which are then reduced by a probability-density function. The column for 1750-2005 summarizes the values given in IPCC (2007). The column for forcings from 1750 to CO_2 doubling proceeds differently, since IPCC (2007) does not publish projected values for individual forcings at CO_2 doubling other than that for CO_2 itself. However, IPCC (2001) projected that CO_2 forcings by 2050-2100, when CO_2 doubling is expected, would represent 70-80% of all greenhouse-gas forcings. That projection is followed here, while non-greenhouse-gas forcings (which are strongly net-negative) are conservatively held constant. To preserve the focus on anthropogenic forcings, the IPCC's minuscule estimate of the solar forcing during the anthropogenic era is omitted.

that the IPCC's evaluation of climate sensitivity must now be revisited. This paper is a respectful contribution to that re-examination.

The IPCC's method of evaluating climate sensitivity

We begin with an outline of the IPCC's method of evaluating climate sensitivity. For clarity we will concentrate on central estimates. The IPCC defines climate sensitivity as equilibrium temperature change ΔT_λ in response to all anthropogenic-era radiative forcings and consequent "temperature feedbacks" – further changes in T_S that occur because T_S has already changed in response to a forcing – arising in response to the doubling of pre-industrial CO_2 concentration (expected later this century). ΔT_λ is, at its simplest, the product of three factors: the sum ΔF_{2x} of all anthropogenic-era radiative forcings at CO_2 doubling; the base or "no-feedbacks" climate sensitivity parameter κ; and the feedback multiplier f, such that the final or "with-feedbacks" climate sensitivity parameter $\lambda = \kappa f$. Thus –

$$\Delta T_\lambda = \Delta F_{2x}\, \kappa\, f = \Delta F_{2x}\, \lambda, \tag{1}$$

$$\text{where } f = (1 - b\kappa)^{-1}, \tag{2}$$

such that b is the sum of all climate-relevant temperature feedbacks. The definition of f in Eqn. (2) will be explained later. We now describe seriatim each of the three factors in ΔT_λ: namely, ΔF_{2x}, κ, and f.

1. RADIATIVE FORCING ΔF_{CO2}, where (C/C_0) is a proportionate increase in CO_2 concentration, is given by several formulae in IPCC (2001, 2007). The simplest, following Myrhe (1998), is Eqn. (3) –

$$\Delta F_{CO2} \approx 5.35 \ln(C/C_0) \implies \Delta F_{2xCO2} \approx 5.35 \ln 2 \approx 3.708 \text{ W m}^{-2}. \tag{3}$$

To ΔF_{2xCO2} is added the slightly net-negative sum of all other anthropogenic-era radiative forcings, calculated from IPCC values (Table 1), to obtain total anthropogenic-era radiative forcing ΔF_{2x} at CO_2 doubling (Eqn. 3). Note that forcings occurring in the anthropogenic era may not be anthropogenic.

From the anthropogenic-era forcings summarized in Table 1, we obtain the first of the three factors –

$$\Delta F_{2x} \approx 3.405 \text{ W m}^{-2}. \tag{4}$$

2. THE BASE OR "NO-FEEDBACKS" CLIMATE SENSITIVITY PARAMETER κ, where ΔT_κ is the response of T_S to radiative forcings ignoring temperature feedbacks, ΔT_λ is the response of T_S to feedbacks as well as forcings, and b is the sum in W m^{-2} °K^{-1} of all individual temperature feedbacks, is –

$$\kappa = \Delta T_\kappa / \Delta F_{2x} \text{ °K W}^{-1}\text{ m}^2\text{, by definition;} \tag{5}$$

$$= \Delta T_\lambda / (\Delta F_{2x} + b\Delta T_\lambda) \text{ °K W}^{-1}\text{ m}^2. \tag{6}$$

In Eqn. (5), ΔT_κ, estimated by Hansen (1984) and IPCC (2007) as 1.2-1.3 °K at CO_2 doubling, is the change in surface temperature in response to a tropopausal forcing ΔF_{2x}, ignoring any feedbacks.

ΔT_κ is not directly measurable in the atmosphere because feedbacks as well as forcings are present. Instruments cannot distinguish between them. However, from Eqn. (2) we may substitute 1 / (1 – bκ) for f in Eqn. (1), rearranging terms to yield a useful second identity, Eqn. (6), expressing κ in terms of ΔT_λ, which is measurable, albeit with difficulty and subject to great uncertainty (McKitrick, 2007).

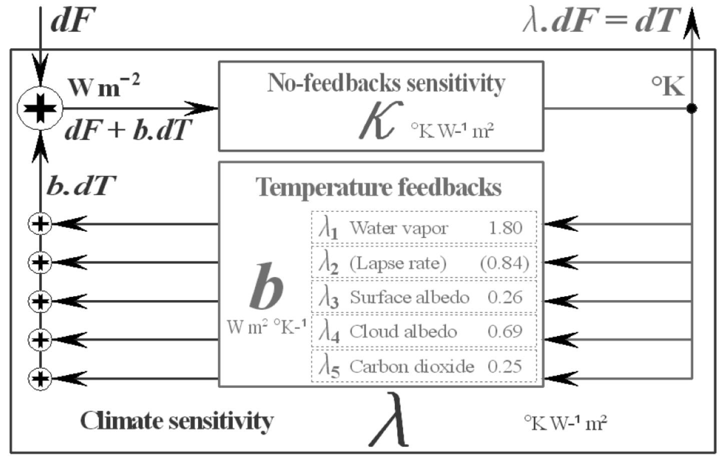
IPCC (2007) does not mention κ and, therefore, provides neither error-bars nor a "Level of Scientific Understanding" (the IPCC's subjective measure of the extent to which enough is known about a variable to render it useful in quantifying climate sensitivity). However, its implicit value $\kappa \approx 0.313$ °K W^{-1} m^2, shown in Eqn. 7, may be derived using Eqns. 9-10 below, showing it to be the reciprocal of the estimated "uniform-temperature" radiative cooling response –

"Under these simplifying assumptions the amplification [f] of the global warming from a feedback parameter [b] (in W m^{-2} °C^{-1}) with no other feedbacks operating is 1 / (1 – [bκ^{-1}]), where [–κ^{-1}] is the 'uniform temperature' radiative cooling response (of value approximately –3.2 W m^{-2} °C^{-1}; Bony et al., 2006). If n independent feedbacks operate, [b] is replaced by ($\lambda_1 + \lambda_2 + \ldots \lambda_n$)." (IPCC, 2007: ch.8, footnote).

$$\text{Thus, } \kappa \approx 3.2^{-1} \approx 0.313 \text{ °K W}^{-1} \text{ m}^2. \tag{7}$$

3. THE FEEDBACK MULTIPLIER *f* is a unitless variable by which the base forcing is multiplied to take account of mutually-amplified temperature feedbacks. A "temperature feedback" is a change in T_S that occurs precisely because T_S has already changed in response to a forcing or combination of forcings. An instance: as the atmosphere warms in response to a forcing, the carrying capacity of the space occupied by the atmosphere for water vapor increases near-exponentially in accordance with the Clausius-Clapeyron relation. Since water vapor is the most important greenhouse gas, the growth in its concentration caused by atmospheric warming exerts an additional forcing, causing temperature to rise further. This is the "water-vapor feedback". Some 20 temperature feedbacks have been described, though none can be directly measured. Most have little impact on temperature. The value of each feedback, the interactions between feedbacks and forcings, and the interactions between feedbacks and other feedbacks, are subject to very large uncertainties.

Figure 3: Bode (1945) feedback amplification schematic



A forcing dF is input by multiplication to the final or "with-feedbacks" climate sensitivity parameter λ = ϰf, yielding the output dT = dFλ = dFϰf. To find λ = ϰf, the base or "no-feedbacks" climate sensitivity parameter ϰ is successively amplified round the feedback-loop by feedbacks summing to b.

Each feedback, having been triggered by a change in atmospheric temperature, itself causes a temperature change. Consequently, temperature feedbacks amplify one another. IPCC (2007: ch.8) defines f in terms of a form of the feedback-amplification function for electronic circuits given in Bode (1945), where b is the sum of all individual feedbacks before they are mutually amplified:

$$f = (1 - b\kappa)^{-1} = \Delta T_\lambda / \Delta T_\kappa \tag{8}$$

Note the dependence of f not only upon the feedback-sum b but also upon κ –

$$\begin{aligned}
\Delta T_\lambda &= (\Delta F + b\Delta T_\lambda)\kappa \\
\Longrightarrow\ \Delta T_\lambda (1 - b\kappa) &= \Delta F\kappa \\
\Longrightarrow\ \Delta T_\lambda &= \Delta F\kappa(1 - b\kappa)^{-1} \\
\Longrightarrow\ \Delta T_\lambda / \Delta F &= \lambda = \kappa(1 - b\kappa)^{-1} = \kappa f \\
\Longrightarrow\ f &= (1 - b\kappa)^{-1} \approx (1 - b / 3.2)^{-1} \\
\Longrightarrow\ \kappa &\approx 3.2^{-1} \approx 0.313 \text{ °K W}^{-1} \text{ m}^2.
\end{aligned} \tag{9}$$

Equivalently, expressing the feedback loop as the sum of an infinite series,

$$\begin{aligned}
\Delta T_\lambda &= \Delta F\kappa + \Delta F\kappa^2 b + \Delta F\kappa^2 b^2 + \ldots \\
&= \Delta F\kappa(1 + \kappa b + \kappa b^2 + \ldots) \\
&= \Delta F\kappa(1 - \kappa b)^{-1} \\
&= \Delta F\kappa f \\
\Longrightarrow\ \lambda &= \Delta T_\lambda / \Delta F = \kappa f
\end{aligned} \tag{10}$$

For the first time, IPCC (2007) quantifies the key individual temperature feedbacks summing to *b*:

"In AOGCMs, the water vapor feedback constitutes by far the strongest feedback, with a multi-model mean and standard deviation … of 1.80 ± 0.18 W m^{-2} K^{-1}, followed by the negative lapse rate feedback (–0.84 ± 0.26 W m^{-2} K^{-1}) and the surface albedo feedback (0.26 ± 0.08 W m^{-2} K^{-1}). The cloud feedback mean is 0.69 W m^{-2} K^{-1} with a very large inter-model spread of ±0.38 W m^{-2} K^{-1}." (Soden & Held, 2006).

To these we add the CO_2 feedback, which IPCC (2007, ch.7) separately expresses not as W m^{-2} °K^{-1} but as concentration increase per CO_2 doubling: [25, 225] ppmv, central estimate q = 87 ppmv. Where p is concentration at first doubling, the proportionate increase in atmospheric CO_2 concentration from the CO_2 feedback is o = (p + q) / p = (556 + 87) / 556 ≈ 1.16. Then the CO_2 feedback is –

$$\lambda_{CO2} = z \ln(o) / dT_\lambda \approx 5.35 \ln(1.16) / 3.2 \approx 0.25 \text{ W m}^{-2} \text{ K}^{-1}. \quad (11)$$

The CO_2 feedback is added to the previously-itemized feedbacks to complete the feedback-sum b:

$$b = 1.8 - 0.84 + 0.26 + 0.69 + \underline{0.25} \approx 2.16 \text{ W m}^{-2}\,^{\circ}\text{K}^{-1}, \quad (12)$$

so that, where κ = 0.313, the IPCC's unstated central estimate of the value of the feedback factor f is at the lower end of the range f = 3-4 suggested in Hansen et al. (1984) –

$$f = (1 - b\kappa)^{-1} \approx (1 - 2.16 \times 0.313)^{-1} \approx 3.077. \quad (13)$$

Final climate sensitivity ΔT_λ, after taking account of temperature feedbacks as well as the forcings that triggered them, is simply the product of the three factors described in Eqn. (1), each of which we have briefly described above. Thus, at CO_2 doubling, –

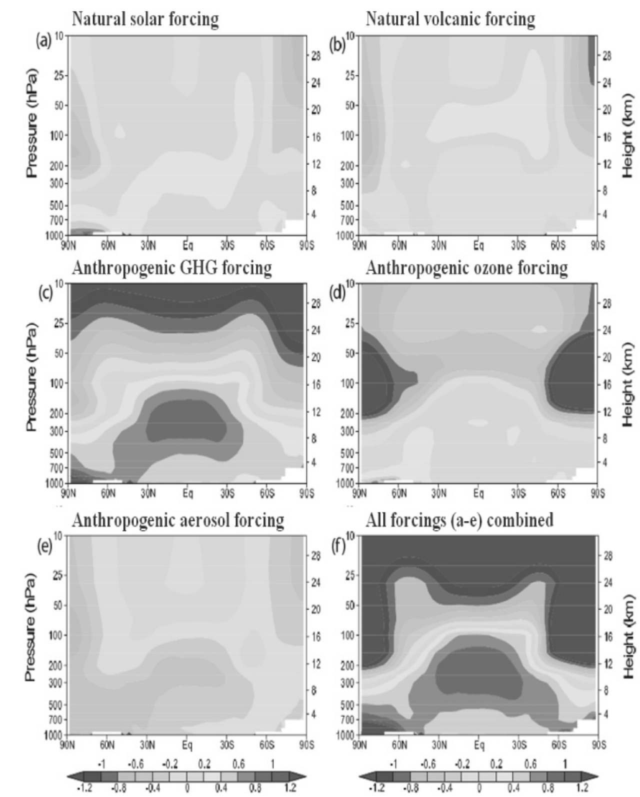
$$\Delta T_\lambda = \Delta F_{2x}\, \kappa\, f \approx 3.405 \times 0.313 \times 3.077 \approx 3.28\ ^{\circ}\text{K} \quad (14)$$

IPCC (2007) gives dT_λ on [2.0, 4.5] °K at CO_2 doubling, central estimate $dT_\lambda \approx 3.26$ °K, demonstrating that the IPCC's method has been faithfully replicated. There is a further checksum, –

$$\Delta T_\kappa = \Delta T_\lambda / f = \kappa\, \Delta F_{2x} = 0.313 \times 3.405 \approx 1.1\ ^{\circ}\text{K}, \quad (15)$$

sufficiently close to the IPCC's estimate $\Delta T_\kappa \approx 1.2$ °K, based on Hansen (1984), who had estimated a range 1.2-1.3 °K based on his then estimate that the radiative forcing ΔF_{2xCO2} arising from a CO_2 doubling would amount to 4.8 W m^{-2}, whereas the IPCC's current estimate is ΔF_{2xCO2} = 3.71 W m^{-2}

Figure 4: Temperature fingerprints of five forcings



Modeled zonal mean atmospheric temperature change (ºC per century, 1890-1999) in response to five distinct forcings (a-e), and to all five forcings combined (f). Altitude is in hPa (left scale) and km (right scale) vs. latitude (abscissa). Source: IPCC (2007).

(see Eqn. 2), requiring a commensurate reduction in ΔT_κ that the IPCC has not made.

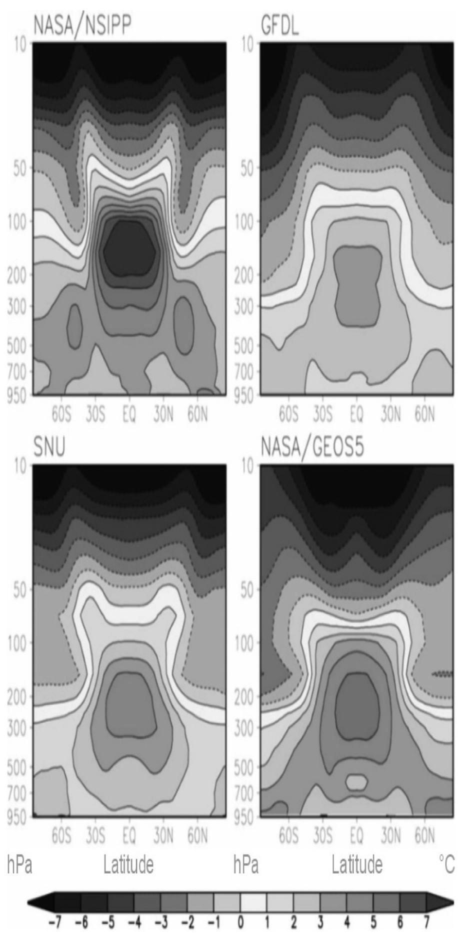
A final checksum is provided by Eqn. (5), giving a value identical to that of the IPCC at Eqn (7):

$$\begin{aligned}\kappa &= \Delta T_\lambda / (\Delta F_{2x} + b\Delta T_\lambda) \\ &\approx 3.28 / (3.405 + 2.16 \times 3.28) \\ &\approx 0.313\ ^{\circ}\text{K W}^{-1} \text{ m}^2. \end{aligned} \quad (16)$$

Having outlined the IPCC's methodology, we proceed to re-evaluate each of the three factors in dT_λ. None of these three factors is directly measurable. For this and other reasons, it is not possible to obtain climate sensitivity numerically using general-circulation models: for, as Akasofu (2008) has pointed out, climate sensitivity must be an input to any such model, not an output from it.

In attempting a re-evaluation of climate sensitivity, we shall face the large uncertainties inherent in the climate object, whose complexity, non-linearity, and chaoticity present formidable initial-value and boundary-value problems. We cannot

Figure 5: Fingerprints of anthropogenic warming projected by four models



Zonal mean equilibrium temperature change (°C) at CO_2 doubling (2x CO_2 – control), as a function of latitude and pressure (hPa) for 4 general-circulation models. All show the projected fingerprint of anthropogenic greenhouse-gas warming: the tropical mid-troposphere "hot-spot" is projected to warm at twice or even thrice the surface rate. Source: Lee et al. (2007).

measure total radiative forcing, with or without temperature feedbacks, because radiative and non-radiative atmospheric transfer processes combined with seasonal, latitudinal, and altitudinal variabilities defeat all attempts at reliable measurement. We cannot even measure changes in T_S to within a factor of two (McKitrick, 2007).

Even satellite-based efforts at assessing total energy-flux imbalance for the whole Earth-troposphere system are uncertain. Worse, not one of the individual forcings or feedbacks whose magnitude is essential to an accurate evaluation of climate sensitivity is measurable directly, because we cannot distinguish individual forcings or feedbacks one from another in the real atmosphere, we can only guess at the interactions between them, and we cannot even measure the relative contributions of all forcings and of all feedbacks to total radiative forcing. Therefore we shall adopt two approaches: theoretical demonstration (where possible); and empirical comparison of certain outputs from the models with observation to identify any significant inconsistencies.

Radiative forcing ΔF_{2x} reconsidered

We take the second approach with ΔF_{2x}. Since we cannot measure any individual forcing directly in the atmosphere, the models draw upon results of laboratory experiments in passing sunlight through chambers in which atmospheric constituents are artificially varied; such experiments are, however, of limited value when translated into the real atmosphere, where radiative transfers and non-radiative transports (convection and evaporation up, advection along, subsidence and precipitation down), as well as altitudinal and latitudinal asymmetries, greatly complicate the picture. Using these laboratory values, the models attempt to produce latitude-versus-altitude plots to display the characteristic signature of each type of forcing. The signature or fingerprint of anthropogenic greenhouse-gas forcing, as predicted by the models on which the IPCC relies, is distinct from that of any other forcing, in that the models project that the rate of change in temperature in the tropical mid-troposphere – the region some 6-10 km above the surface – will be twice or thrice the rate of change at the surface (Figure 4):

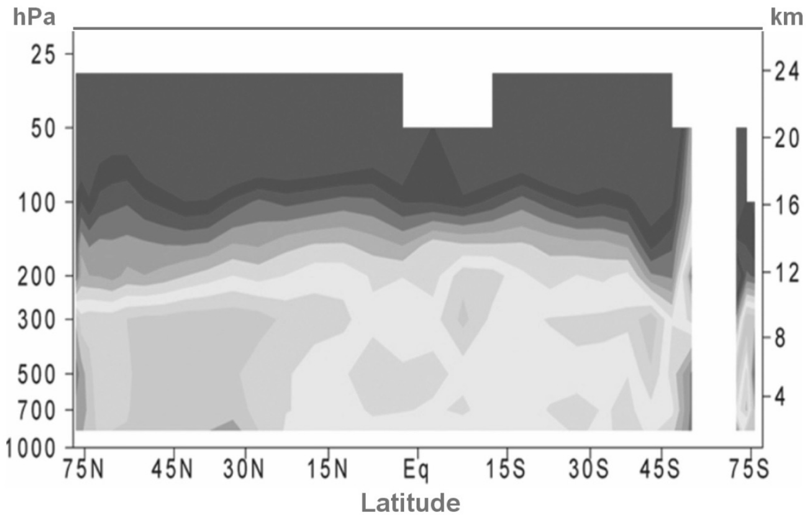
The fingerprint of anthropogenic greenhouse-gas forcing is a distinctive "hot-spot" in the tropical mid-troposphere. Figure 5 shows altitude-vs.-latitude plots from four of the IPCC's models:.

However, as Douglass et al. (2004) and Douglass et al. (2007) have demonstrated, the projected fingerprint of anthropogenic greenhouse-gas warming in the tropical mid-troposphere is not observed in reality. Figure 6 is a plot of observed tropospheric rates of temperature change from the Hadley Center for Forecasting. In the tropical mid-troposphere, at approximately 300 hPa pressure, the model-projected fingerprint of anthropogenic greenhouse warming is absent from this and all other observed records of temperature changes in the satellite and radiosonde eras:

None of the temperature datasets for the tropical surface and mid-troposphere shows the strong differential warming rate predicted by the IPCC's models. Thorne et al. (2007) suggested that the absence of the mid-tropospheric warming might be attributable to uncertainties in the observed record: however, Douglass et al. (2007) responded with a detailed statistical analysis demonstrating that the absence of the projected degree of warming is significant in all observational datasets.

Allen et al. (2008) used upper-atmosphere wind speeds

Figure 6: The absent fingerprint of anthropogenic greenhouse warming



Altitude-vs.-latitude plot of observed relative warming rates in the satellite era. The greater rate of warming in the tropical mid-troposphere that is projected by general-circulation models is absent in this and all other observational datasets, whether satellite or radiosonde. Altitude units are hPa (left) and km (right). Source: Hadley Centre for Forecasting (HadAT, 2006).

as a proxy for temperature and concluded that the projected greater rate of warming at altitude in the tropics is occurring in reality. However, satellite records, such as the RSS temperature trends at varying altitudes, agree with the radiosondes that the warming differential is not occurring: they show that not only absolute temperatures but also warming rates decline with altitude.

There are two principal reasons why the models appear to be misrepresenting the tropical atmosphere so starkly. First, the concentration of water vapor in the tropical lower troposphere is already so great that there is little scope for additional greenhouse-gas forcing. Secondly, though the models assume that the concentration of water vapor will increase in the tropical mid-troposphere as the space occupied by the atmosphere warms, advection transports much of the additional water vapor poleward from the tropics at that altitude.

Since the great majority of the incoming solar radiation incident upon the Earth strikes the tropics, any reduction in tropical radiative forcing has a disproportionate effect on mean global forcings. On the basis of Lindzen (2007), the anthropogenic-year radiative forcing as established in Eqn. (3) are divided by 3 to take account of the observed failure of the tropical mid-troposphere to warm as projected by the models –

$$\Delta F_{2x} \approx 3.405 / 3 \approx 1.135 \text{ W m}^{-2}. \quad (17)$$

The "no-feedbacks" climate sensitivity parameter κ reconsidered

The base climate sensitivity parameter κ is the most influential of the three factors of ΔT_λ: for the final or "with-feedbacks" climate sensitivity parameter λ is the product of κ and the feedback factor f, which is itself dependent not only on the sum b of all climate-relevant temperature feedbacks but also on κ. Yet κ has received limited attention in the literature. In IPCC (2001, 2007) it is not mentioned. However, its value may be deduced from hints in the IPCC's reports. IPCC (2001, ch. 6.1) says:

> *"The climate sensitivity parameter (global mean surface temperature response ΔT_S to the radiative forcing ΔF) is defined as $\Delta T_S / \Delta F = \lambda$ {6.1} (Dickinson, 1982; WMO, 1986; Cess et al., 1993). Equation {6.1} is defined for the transition of the surface-troposphere system from one equilibrium state to another in response to an externally imposed radiative perturbation. In the one-dimensional radiative-convective models, wherein the concept was first initiated, λ is a nearly invariant parameter (typically, about 0.5 °K W^{-1} m^2; Ramanathan et al., 1985) for a variety of radiative forcings, thus introducing the notion of a possible universality of the relationship between forcing and response."*

Since $\lambda = \kappa f = \kappa(1 - b\kappa)^{-1}$ (Eqns. 1, 2), where $\lambda = 0.5$ °K W^{-1} m^2 and $b \approx 2.16$ W m^{-2} °K^{-1} (Eqn. 12), it is simple to calculate that, in 2001, one of the IPCC's values for f was 2.08. Thus the value f = 3.077 in IPCC (2007) represents a near-50% increase in the value of f in only five years. Where f = 2.08, $\kappa = \lambda / f \approx 0.5 / 2.08 \approx 0.24$ °K W^{-1} m^2, again substantially lower than the value implicit in IPCC (2007). Some theory will, therefore, be needed.

The fundamental equation of radiative transfer at the emitting surface of an astronomical body, relating changes in radiant-energy flux to changes in temperature, is the Stefan-Boltzmann equation –

$$F = \varepsilon \sigma T^4 \text{ W m}^{-2}, \quad (18)$$

where F is radiant-energy flux at the emitting surface; ε is emissivity, set at 1 for a blackbody that absorbs and emits all irradiance reaching its emitting surface (by Kirchhoff's law of radiative transfer, absorption and emission are equal and simultaneous), 0 for a whitebody that reflects all irradiance, and (0,

1) for a graybody that partly absorbs/emits and partly reflects; and $\sigma \approx 5.67 \times 10^{-8}$ is the Stefan-Boltzmann constant.

Differentiating Eqn. (18) gives –

$$\kappa = dT / dF = (dF / dT)^{-1} = (4 \varepsilon \sigma T^3)^{-1} \text{ °K W}^{-1} \text{ m}^2. \qquad (19)$$

Outgoing radiation from the Earth's surface is chiefly in the near-infrared. Its peak wavelength λ_{max} is determined solely by the temperature of the emitting surface in accordance with Wien's Displacement Law, shown in its simplest form in Eqn. (20):

$$\lambda_{max} = 2897 / T_S = 2897 / 288 \approx 10 \ \mu\text{m}. \qquad (20)$$

Since the Earth/troposphere system is a blackbody with respect to the infrared radiation that Eqn. (20) shows we are chiefly concerned with, we will not introduce any significant error if $\varepsilon = 1$, giving the blackbody form of Eqn. (19) –

$$\kappa = dT / dF = (4 \sigma T^3)^{-1} \text{ °K W}^{-1} \text{ m}^2. \qquad (21)$$

At the Earth's surface, $T_S \approx 288$ °K, so that $\kappa_S \approx 0.185$ °K W^{-1} m^2. At the characteristic-emission level, Z_C, the variable altitude at which incoming and outgoing radiative fluxes balance, $T_C \approx 254$ °K, so that $\kappa_C \approx 0.269$ °K W^{-1} m^2. The value $\kappa_C \approx 0.24$, derived from the typical final-sensitivity value $\lambda = 0.5$ given in IPCC (2001), falls between the surface and characteristic-emission values for κ.

However, the IPCC, in its evaluation of κ, does not follow the rule that in the Stefan-Boltzmann equation the temperature and radiant-energy flux must be taken at the same level of the atmosphere. The IPCC's value for κ is dependent upon temperature at the surface and radiant-energy flux at the tropopause, so that its implicit value $\kappa \approx 0.313$ °K W^{-1} m^2 is considerably higher than either κ_S or κ_C.

IPCC (2007) cites Hansen et al. (1984), who say –

> *"Our three-dimensional global climate model yields a warming of ~4 ºC for … doubled CO_2. This indicates a net feedback factor f = 3-4, because [the forcing at CO_2 doubling] would cause the earth's surface temperature to warm 1.2-1.3 ºC to restore radiative balance with space, if other factors remained unchanged."*

Hansen says dF_{2x} is equivalent to a 2% increase in incoming total solar irradiance (TSI). Top-of-atmosphere TSI $S \approx 1368$ W m^2, albedo $\alpha = 0.31$, and Earth's radius is r. Then, at the characteristic emission level Z_C,

$$F_C = S(1 - \alpha)(\pi r^2 / 4\pi r^2) \approx 1368 \times 0.69 \times (1/4) \approx 236 \text{ W m}^{-2}. \qquad (22)$$

Thus a 2% increase in F_C is equivalent to 4.72 W m^{-2}, rounded up by Hansen to 4.8 W m^{-2}, implying that $\kappa \approx 1.25 / 4.8 \approx 0.260$ °K W^{-1} m^2. However, Hansen, in his Eqn. {14}, prefers 0.29 W m^{-2}.

Bony et al. (2006), also cited by IPCC (2007), do not state a value for κ. However, they say –

> *"The Planck feedback parameter [equivalent to κ^{-1}] is negative (an increase in temperature enhances the long-wave emission to space and thus reduces R [the Earth's radiation budget]), and its typical value for the earth's atmosphere, estimated from GCM calculations (Colman 2003; Soden and Held 2006), is ~3.2 W m^2 ºK^{-1} (a value of ~3.8 W m^2 ºK^{-1} is obtained by defining [κ^{-1}] simply as $4\sigma T^3$, by equating the global mean outgoing long-wave radiation to σT^4 and by assuming an emission temperature of 255 ºK)."*

Bony takes $T_C \approx 255$ °K and $F_C \approx 235$ W m^{-2} at Z_C as the theoretical basis for the stated prima facie value $\kappa^{-1} \approx T_C / 4F_C \approx 3.8$ W m^2 ºK^{-1}, so that $\kappa \approx 0.263$ ºK W^{-1} m^2, in very close agreement with Hansen. However, Bony cites two further papers, Colman (2003) and Soden & Held (2006), as justification for the value $\kappa^{-1} \approx 3.2$ W m^2 ºK^{-1}, so that $\kappa \approx 0.313$ ºK W^{-1} m^2.

Colman (2003) does not state a value for κ, but cites Hansen et al. (1984), rounding up the value $\kappa \approx 0.260$ °K W^{-1} m^2 to 0.3 °K W^{-1} m^2 –

> *"The method used assumes a surface temperature increase of 1.2 °K with only the CO_2 forcing and the 'surface temperature' feedback operating (value originally taken from Hansen et al. 1984)."*

Soden & Held (2006) likewise do not declare a value for κ. However, we may deduce their implicit central estimate $\kappa \approx 1 / 4 \approx 0.250$ °K W^{-1} m^2 from the following passage –

> *"The increase in opacity due to a doubling of CO2 causes [the characteristic emission level Z_C] to rise by ~150 meters. This results in a reduction in the effective temperature of the emission across the tropopause by ~(6.5K/km)(150 m) ≈ 1 K, which converts to 4 W m^{-2} using the Stefan-Boltzmann law."*

Thus the IPCC cites only two papers that cite two others in turn. None of these papers provides any theoretical or empirical justification for a value as high as the $\kappa \approx 0.313$ °K W^{-1} m^2 chosen by the IPCC.

Table 2: Values of the "no-feedbacks" climate sensitivity parameter κ

Source	*Value of κ*	*Ratio*	*How derived*	*$\lambda = \kappa(1 - 2.16\kappa)^{-1}$*	*Ratio*
Ramanathan (1988), cited in IPCC (2001)	0.240 °K W^{-1} m^2	1.000	From λ = 0.500	0.500 °K W^{-1} m^2	1.000
Soden & Held (2006)	0.250 °K W^{-1} m^2	1.042	1 °K / 4 W m^{-2}	0.543 °K W^{-1} m^2	1.086
Bony et al. (2006)[1]	0.263 °K W^{-1} m^2	1.096	$(3.8)^{-1}$	0.609 °K W^{-1} m^2	1.218
Bony et al. (2006)[2]	0.269 °K W^{-1} m^2	1.121	T_C / [S(1 – α)]	0.642 °K W^{-1} m^2	1.284
Hansen et al., (1984)[2]	0.290 °K W^{-1} m^2	1.208	Hansen eqn. {14}	0.776 °K W^{-1} m^2	1.552
Colman (2003, appendix)	0.300 °K W^{-1} m^2	1.250	Rounded up	0.852 °K W^{-1} m^2	1.704
Kiehl (1992); Hartmann (1994)	0.305 °K W^{-1} m^2	1.271	288 / (4 x 236)	0.894 °K W^{-1} m^2	1.788
Bony et al. (2006)[3], cited in IPCC (2007)	0.313 °K W^{-1} m^2	1.304	$(3.2)^{-1}$	0.966 °K W^{-1} m^2	1.932

The range of values for κ in the IPCC's assessment reports and in the papers which it cites is substantial. The value of κ implicit in IPCC (2007) is some 30% above that which is implicit in IPCC (2001): consequently, the value of the climate-sensitivity parameter λ is almost doubled. Though it is usual to assume a constant temperature lapse-rate, and hence to use the value of κ that obtains at the characteristic-emission level, where inbound and outbound radiative fluxes balance by definition, the the IPCC's current value for κ assumes that the lapse-rate increases as temperature rises. Also, the IPCC does not sufficiently allow for latitudinal asymmetry in distribution of the values of κ.

Kiehl (1992) gives the following method, where F_C is total flux at Z_C:

$$\kappa_S = T_S / (4F_C) \approx 288 / (4 \times 236) \approx 0.305\ °K\ W^{-1}\ m^2. \tag{23}$$

Hartmann (1994) echoes Kiehl's method, generalizing it to any level J of an n-level troposphere thus:

$$\begin{aligned}\kappa_J &= T_J / (4F_C) \\ &= T_J / [S(1 - \alpha)] \\ &\approx T_J / [1368(1 - 0.31)] \approx T_J / 944\ \ °K\ W^{-1}\ m^2.\end{aligned} \tag{24}$$

Table 2 summarizes the values of κ evident in the cited literature, with their derivations, minores priores. The greatest value, chosen in IPCC (2007), is 30% above the least, chosen in IPCC (2001). However, because the feedback factor f depends not only upon the feedback-sum b ≈ 2.16 W m^{-2} $°K^{-1}$ but also upon κ, the 30% increase in κ nearly doubles final climate sensitivity:

The value of κ cannot be deduced by observation, because temperature feedbacks are present and cannot be separately measured. However, it is possible to calculate κ using Eqn. (6), provided that the temperature change ΔT_λ, radiative forcings ΔF_{2x}, and feedback-sum b over a given period are known. The years 1980 and 2005 will be compared, giving a spread of a quarter of a century. We take the feedback-sum b = 2.16 W m^{-2} $°K^{-1}$ and begin by establishing values for ΔF and ΔT:

CO_2 concentration:
338.67 ppmv 378.77 ppmv $\Delta F = 5.35 \ln (378.77/338.67) = \mathbf{0.560\ W\ m^{-2}}$

Anomaly in T_S:
0.144 °K 0.557 °K $\Delta T = \mathbf{0.412\ °K}$ (NCDC)

Anomaly halved:
$\Delta T = \mathbf{0.206\ °K}$ (McKitrick) (25)

CO_2 concentrations are the annual means from 100 stations (Keeling & Whorf, 2004, updated). T_S values are NCDC annual anomalies, as five-year means centered on 1980 and 2005 respectively. Now, depending on whether the NCDC or implicit McKitrick value is correct, κ may be directly evaluated:

NCDC:
$\kappa = \Delta T / (\Delta F + b\Delta T) = 0.412 / (0.560 + 2.16 \times 0.412) = \mathbf{0.284\ °K\ W^{-1}\ m^2}$

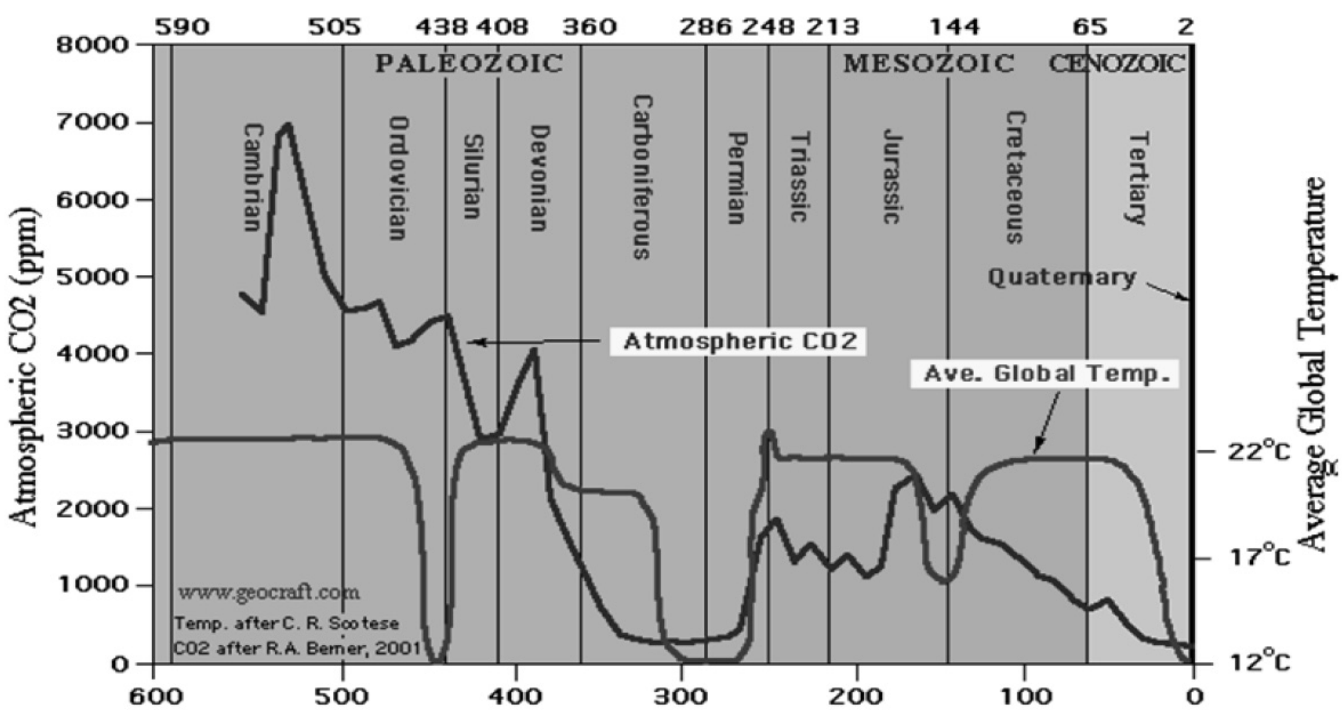
McKitrick:
$\kappa = \Delta T / (\Delta F + b\Delta T) = 0.206 / (0.599 + 2.16 \times 0.206) = \mathbf{0.197\ °K\ W^{-1}\ m^2}$

Mean:
$$\kappa = (0.284 + 0.197) / 2 = \mathbf{0.241\ °K\ W^{-1}\ m^2} \tag{26}$$

We assume that Chylek (2008) is right to find transient and equilibrium climate sensitivity near-identical; that all of the warming from 1980-2005 was anthropogenic; that the IPCC's values for forcings and feedbacks are correct; and, in line 2, that McKitrick is right that the insufficiently-corrected heat-island effect of rapid urbanization since 1980 has artificially doubled the true rate of temperature increase in the major global datasets.

With these assumptions, κ is shown to be less, and perhaps considerably less, than the value implicit in IPCC (2007). The method of finding κ shown in Eqn. (24), which yields a value very

Figure 7: Fluctuating CO_2 but stable temperature for 600m years (millions of years before present)



Throughout the past 600 million years, almost one-seventh of the age of the Earth, the mode of global surface temperatures was ~22 °C, even when carbon dioxide concentration peaked at 7000 ppmv, almost 20 times today's near-record-low concentration. If so, then the instability inherent in the IPCC's high-end values for the principal temperature feedbacks has not occurred in reality, implying that the high-end estimates, and by implication the central estimates, for the magnitude of individual temperature feedbacks may be substantial exaggerations. Source: Temperature reconstruction by C.R. Scotese; CO_2 reconstruction after R.A. Berner; see also IPCC (2007).

close to that of IPCC (2007), is such that progressively smaller forcing increments would deliver progressively larger temperature increases at all levels of the atmosphere, contrary to the laws of thermodynamics and to the Stefan-Boltzmann radiative-transfer equation (Eqn. 18), which mandate the opposite.

It is accordingly necessary to select a value for κ that falls well below the IPCC's value. Dr. David Evans (personal communication, 2007) has calculated that the characteristic-emission-level value of κ should be diminished by ~10% to allow for the non-uniform latitudinal distribution of incoming solar radiation, giving a value near-identical to that in Eqn. (26), and to that implicit in IPCC (2001), thus –

$$\kappa = 0.9\, T_C / [S(1 - \alpha)] \approx 0.9 \times 254 / [1368(1 - 0.31)] \approx 0.242\ °K\ W^{-1}\ m^2 \qquad (27)$$

The feedback factor f reconsidered

The feedback factor f accounts for two-thirds of all radiative forcing in IPCC (2007); yet it is not expressly quantified, and no "Level Of Scientific Understanding" is assigned either to f or to the two variables b and κ upon which it is dependent.

Several further difficulties are apparent. Not the least is that, if the upper estimates of each of the climate-relevant feedbacks listed in IPCC (2007) are summed, an instability arises. The maxima are –

Water vapor feedback	1.98 $W\ m^{-2}\ K^{-1}$	
Lapse rate feedback	–0.58 $W\ m^{-2}\ K^{-1}$	
Surface albedo	feedback 0.34 $W\ m^{-2}\ K^{-1}$	
Cloud albedo feedback	1.07 $W\ m^{-2}\ K^{-1}$	
CO_2 feedback	0.57 $W\ m^{-2}\ K^{-1}$	
Total feedbacks b	3.38 $W\ m^{-2}\ K^{-1}$	(28)

Since the equation $[f = (1 - b\kappa)^{-1}] \to \infty$ as $b \to [\kappa^{-1} = 3.2\ W\ m^{-2}\ K^{-1}]$, the feedback-sum b cannot exceed 3.2 $W\ m^{-2}\ K^{-1}$ without inducing a runaway greenhouse effect. Since no such effect has been observed or inferred in more than half a billion years of climate, since the concentration of CO_2 in the Cambrian atmosphere approached 20 times today's concentration, with an inferred mean global surface temperature no more than 7 °K higher than today's (Figure 7), and since a feedback-induced runaway greenhouse effect would occur even in today's climate where b >= 3.2 $W\ m^{-2}\ K^{-1}$ but has not occurred, the IPCC's high-end estimates of the magnitude of individual temperature feedbacks are very likely to be excessive, implying that its central estimates are also likely to be excessive.

Since absence of correlation necessarily implies absence of causation, Figure 7 confirms what the recent temperature record implies: the causative link between changes in CO_2 concentration and changes in temperature cannot be as strong as the IPCC has suggested. The implications for climate sensitivity are self-evident. Figure 7 indicates that in the Cambrian era, when CO_2 concentration was ~25 times that which prevailed in the IPCC's reference year of 1750, the temperature was some 8.5 °C higher than it was in 1750. Yet the IPCC's current central estimate is that a mere doubling of CO_2 concentration compared with 1750 would increase temperature by almost 40% of the increase that is thought to have arisen in geological times from a 20-fold increase in CO_2 concentration (IPCC, 2007).

How could such overstatements of individual feedbacks have arisen? Not only is it impossible to obtain empirical confirmation of the value of any feedback by direct measurement; it is questionable whether the feedback equation presented in Bode (1945) is appropriate to the climate. That equation was intended to model feedbacks in linear electronic circuits: yet many temperature feedbacks – the water vapor and CO_2 feedbacks, for instance – are non-linear. Feedbacks, of course, induce non-linearity in linear objects: nevertheless, the Bode equation is valid only for objects whose initial state is linear. The climate is not a linear object: nor are most of the climate-relevant temperature feedbacks linear. The water-vapor feedback is an interesting instance of the non-linearity of temperature feedbacks. The increase in water-vapor concentration as the space occupied by the atmosphere warms is near-exponential; but the forcing effect of the additional water vapor is logarithmic. The IPCC's use of the Bode equation, even as a simplifying assumption, is accordingly questionable.

IPCC (2001: ch.7) devoted an entire chapter to feedbacks, but without assigning values to each feedback that was mentioned. Nor did the IPCC assign a "Level of Scientific Understanding" to each feedback, as it had to each forcing. In IPCC (2007), the principal climate-relevant feedbacks are quantified for the first time, but, again, no Level of Scientific Understanding" is assigned to them, even though they account for more than twice as much forcing as the greenhouse-gas and other anthropogenic-era forcings to which "Levels of Scientific Understanding" are assigned.

Now that the IPCC has published its estimates of the forcing effects of individual feedbacks for the first time, numerous papers challenging its chosen values have appeared in the peer-reviewed literature. Notable among these are Wentz et al. (2007), who suggest that the IPCC has failed to allow for two-thirds of the cooling effect of evaporation in its evaluation of the water vapor-feedback; and Spencer (2007), who points out that the cloud-albedo feedback, regarded by the IPCC as second in magnitude only to the water-vapor feedback, should in fact be negative rather than strongly positive.

It is, therefore, prudent and conservative to restore the values $\kappa \approx 0.24$ and $f \approx 2.08$ that are derivable from IPCC (2001), adjusting the values a little to maintain consistency with Eqn. (27). Accordingly, our revised central estimate of the feedback multiplier f is –

$$f = (1 - b\kappa)^{-1} \approx (1 - 2.16 \times 0.242)^{-1} \approx 2.095 \qquad (29)$$

Final climate sensitivity

Substituting in Eqn. (1) the revised values derived for the three factors in ΔT_λ, our re-evaluated central estimate of climate sensitivity is their product –

$$\Delta T_\lambda = \Delta F_{2x}\, \kappa\, f \approx 1.135 \times 0.242 \times 2.095 \approx 0.58\ °K \qquad (30)$$

Theoretically, empirically, and in the literature that we have extensively cited, each of the values we have chosen as our central estimate is arguably more justifiable – and is certainly no less justifiable – than the substantially higher value selected by the IPCC. Accordingly, it is very likely that in response to a doubling of pre-industrial carbon dioxide concentration T_S will rise not by the 3.26 °K suggested by the IPCC, but by <1 °K.

Discussion

We have set out and then critically examined a detailed account of the IPCC's method of evaluating climate sensitivity. We have made explicit the identities, interrelations, and values of the key variables, many of which the IPCC does not explicitly describe or quantify. The IPCC's method does not provide a secure basis for policy-relevant conclusions. We now summarize some of its defects.

The IPCC's methodology relies unduly – indeed, almost exclusively – upon numerical analysis, even where the outputs of the models upon which it so heavily relies are manifestly and significantly at variance with theory or observation or both. Modeled projections such as those upon which the IPCC's entire case rests have long been proven impossible when applied to mathematically-chaotic objects, such as the climate, whose initial state can never be determined to a sufficient precision. For a similar reason, those of the IPCC's conclusions that are founded on probability distributions in the chaotic climate object are unsafe.

Not one of the key variables necessary to any reliable evaluation of climate sensitivity can be measured empirically. The IPCC's presentation of its principal conclusions as though they were near-certain is accordingly unjustifiable. We cannot even measure mean global surface temperature anomalies to within a factor of 2; and the IPCC's reliance upon mean global temperatures, even if they could be correctly evaluated, itself introduces substantial errors in its evaluation of climate sensitivity.

The IPCC overstates the radiative forcing caused by increased CO_2 concentration at least threefold because the models upon which it relies have been programmed fundamentally to misunderstand the difference between tropical and extra-tropical climates, and to apply global averages that lead to error.

The IPCC overstates the value of the base climate sensitivity parameter for a similar reason. Indeed, its methodology would in effect repeal the fundamental equation of radiative transfer (Eqn. 18), yielding the impossible result that at every level of the atmosphere ever-smaller forcings would induce ever-greater temperature increases, even in the absence of any temperature feedbacks.

The IPCC overstates temperature feedbacks to such an extent that the sum of the high-end values that it has now, for the first time, quantified would cross the instability threshold in the Bode feedback equation and induce a runaway greenhouse effect that has not occurred even in geological times despite CO_2 concentrations almost 20 times today's, and temperatures up to 7 ºC higher than today's.

The Bode equation, furthermore, is of questionable utility because it was not designed to model feedbacks in non-linear objects such as the climate. The IPCC's quantification of temperature feedbacks is, accordingly, inherently unreliable. It may even be that, as Lindzen (2001) and Spencer (2007) have argued, feedbacks are net-negative, though a more cautious assumption has been made in this paper.

It is of no little significance that the IPCC's value for the coefficient in the CO_2 forcing equation depends on only one paper in the literature; that its values for the feedbacks that it believes account for two-thirds of humankind's effect on global temperatures are likewise taken from only one paper; and that its implicit value of the crucial parameter κ depends upon only two papers, one of which had been written by a lead author of the chapter in question, and neither of which provides any theoretical or empirical justification for a value as high as that which the IPCC adopted.

The IPCC has not drawn on thousands of published, peer-reviewed papers to support its central estimates for the variables from which climate sensitivity is calculated, but on a handful.

On this brief analysis, it seems that no great reliance can be placed upon the IPCC's central estimates of climate sensitivity, still less on its high-end estimates. The IPCC's assessments, in their current state, cannot be said to be "policy-relevant". They provide no justification for taking the very costly and drastic actions advocated in some circles to mitigate "global warming", which Eqn. (30) suggests will be small (<1 °C at CO_2 doubling), harmless, and beneficial.

Conclusion

Even if temperature had risen above natural variability, the recent solar Grand Maximum may have been chiefly responsible. Even if the sun were not chiefly to blame for the past half-century's warming, the IPCC has not demonstrated that, since CO_2 occupies only one-ten-thousandth part more of the atmosphere that it did in 1750, it has contributed more than a small fraction of the warming. Even if carbon dioxide were chiefly responsible for the warming that ceased in 1998 and may not resume until 2015, the distinctive, projected fingerprint of anthropogenic "greenhouse-gas" warming is entirely absent from the observed record. Even if the fingerprint were present, computer models are long proven to be inherently incapable of providing projections of the future state of the climate that are sound enough for policymaking. Even if per impossibile the models could ever become reliable, the present paper demonstrates that it is not at all likely that the world will warm as much as the IPCC imagines. Even if the world were to warm that much, the overwhelming majority of the scientific, peer-reviewed literature does not predict that catastrophe would ensue. Even if catastrophe might ensue, even the most drastic proposals to mitigate future climate change by reducing emissions of carbon dioxide would make very little difference to the climate. Even if mitigation were likely to be effective, it would do more harm than good: already millions face starvation as the dash for biofuels takes agricultural land out of essential food production: a warning that taking precautions, "just in case", can do untold harm unless there is a sound, scientific basis for them. Finally, even if mitigation might do more good than harm, adaptation as (and if) necessary would be far more cost-effective and less likely to be harmful.

In short, we must get the science right, or we shall get the policy wrong. If the concluding equation in this analysis (Eqn. 30) is correct, the IPCC's estimates of climate sensitivity must have been very much exaggerated. There may, therefore, be a good reason why, contrary to the projections of the models on which the IPCC relies, temperatures have not risen for a decade and have been falling since the phase-transition in global temperature trends that occurred in late 2001. Perhaps real-world climate sensitivity is very much below the IPCC's estimates. Perhaps, therefore, there is no "climate crisis" at all. At present, then, in policy terms there is no case for doing anything. The correct policy approach to a non-problem is to have the courage to do nothing.

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NEWS

DOE Files Yucca Mountain Nuclear Waste Repository Application

"Today's application begins a new phase for the Yucca Mountain Project." - Secretary of Energy Samuel Bodman

It will be at least three years before the Nuclear Regulatory Commission decides whether it will grant the Department of Energy a construction and operation license for the proposed Yucca Mountain nuclear waste repository in Nevada. The review process was initiated last week with the filing of an 8,600-page application by DOE.

An FYI written last year about a hearing before the House Budget Committee noted, "The first witness to testify was Edward Sproat, Director of the DOE Office of Civilian Radioactive Waste Management. Sproat . . . left little doubt that he would meet or beat his deadline to submit a Yucca Mountain construction license application to the Nuclear Regulatory Commission by June 30, 2008."

Sproat beat his deadline. On June 3, Energy Secretary Samuel Bodman told an audience in Washington: "I'm pleased to announce that this morning the Department of Energy submitted a license application to the U.S. Nuclear Regulatory Commission seeking authorization to build America's first national repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada. We are confident that the NRC's rigorous review process will validate that the Yucca Mountain repository will provide for the safe disposal of spent nuclear fuel and high-level radioactive waste in a way that protects human health and our environment."

It has been 20 years since the Department of Energy began what has turned out to be a $10 billion examination of the feasibility of locating a nuclear waste repository 1,000 feet below the crest of Yucca Mountain. The site is located on federally-owned land adjacent to the Nevada Test Site, approximately 100 miles northwest of Las Vegas. Congress selected Yucca Mountain in 1987 to be characterized as the site of the first permanent repository. This followed the 1982 passage of the Nuclear Waste Policy Act, which provided for the identification by DOE of a permanent geologic repository. In 2002, Congress and President Bush accepted DOE's determination that Yucca Mountain would be an appropriate location for the repository. See http://www.ocrwm.doe.gov/ym_repository/index.shtml#5 for more information on this proposed facility. DOE estimates there are now 47,500 metric tons of commercial and defense spent nuclear fuel, plus another 100 million gallons of liquid high-level radioactive waste being stored in temporary storage facilities in 39 states.

Congressional reaction to the Department's filing of the application was predictability mixed. House Science and Technology Committee Chairman Bart Gordon (D-TN) was supportive: "I welcome the Department of Energy's announcement today regarding its submittal of a license application to the Nuclear Regulatory Commission to construct a deep geologic repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain. This application is long overdue. As Congress begins to consider climate change legislation, there is wide recognition that nuclear power will continue to supply a significant part of our electricity needs. Even if our country advances new nuclear technologies such as spent fuel reprocessing, establishing and building a permanent high level waste storage facility at Yucca Mountain is critical to dealing with existing spent fuel and to the future of nuclear energy in our country." Senator Pete Domenici (R-NM) is a strong supporter of nuclear energy and spent fuel recycling, and his statement was more nuanced: "After years of debate, the suitability of the Yucca Mountain repository is now in the hands of the experts at the Nuclear Regulatory Commission. This action is consistent with the direction given by Congress and the President when the Yucca Mountain site was approved six years ago. It is my belief that America needs a solution to the nuclear waste question, and I believe that reprocessing could in fact be the best way to meet our nation's needs. Nevertheless, it is important that the NRC begin work on its review process for Yucca Mountain so that all of our options remain on the table."

A June 5 letter from Senate Majority Leader Harry Reid (D-NV) and the entire Nevada congressional delegation to the Commission was clear in its opposition to the project: "We have no doubt that the Department of Energy's decision to file its license application on June 3rd was a political decision. There are too many components missing from the license application to suggest that the Department is genuinely prepared to make its case for moving forward on the Yucca Mountain project. We strongly urge the Commission to reject the Department's approach and avoid making a decision that could have the appearance of bias." See http://reid.senate.gov/newsroom/pr_06-05-08_Delegation-Letter.cfmfor the entire text of this letter.

The Nuclear Regulatory Commission has a site devoted to the Yucca Mountain application process, with links to the DOE license application that were posted today. For the next ninety days, the Commission will study the completeness of the application, a process known as a docketing or "acceptance" review. A positive review does not indicate that the NRC will ultimately approve the application. The decision whether to approve the application is scheduled to take three years, although the NRC can request a one-year extension. Concurrent with this review is an examination of DOE's Final Environmental Impact Statement on the Yucca Mountain project that was first published in 2002. If the application is docketed, 100 NRC staff and contract employees in Maryland, Texas, and Nevada will review the application. Opportunities will be provided to request an adjudicatory hearing before the Atomic Safety and Licensing Board Panel. A much fuller explanation of this licensing process is available on the Commission's website at: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html (cut-and-paste both lines of URL) The NRC website provides a succinct statement regarding the application: "The NRC will issue a construction authorization only if DOE can demonstrate that it can safely construct and operate the repository in compliance with established regulations."

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Science, Evolution, and Creationism

National Academy of Sciences Institute of Medicine, The National Academy Press, Washington, D.C., 2008, 70 pages, ISBN 978-0-309-10586-6

Shelby Foote, in his engaging history of the Civil War, recounts the experience of a soldier who survived the Battle of Antietam, the bloodiest single-day event in American history with nearly 23,000 casualties. The soldier explains that he finally understood the meaning of the biblical passage that says the sun stood still at the Battle of Jericho. During the death and mayhem, this poor battle-scarred survivor was desperately hoping for an end to the horrific day and a chance to leave the battleground alive. But time seemed to stand still and the sun to take forever to pass across the sky.

As evocative and plausible as this interpretation is, we don't know if it is the biblical author's intended meaning. We can hope not all the Bible was written literally: it is a much richer text if it is infused with metaphor and subtle shades of meaning. We can hope our ancestors, who authored the Bible and related works, were not lacking in literary sophistication.

I recently asked a refugee from a fundamentalist cult how the faithful could be so certain of their interpretation of the Bible when they are not even familiar with the ancient languages it is written in. I was told that God reveals the true meaning through prayer. At least this "theory" of interpretation is consistent with creationism; it is entirely antiscientific. No amount of evidence or Biblical scholarship can refute revelation.

What strategy should reasonable people, who accept the findings of empirical science, adopt in the culture war against fundamentalists who wish to impose their pernicious ideology on public education and discourse? The National Academy of Sciences Institute of Medicine tacitly answers this question with a well-written polemic entitled *Science, Evolution, and Creationism*. The intended audience is composed of frontline warriors embroiled in debates about evolution: school board members, science teachers, policy makers, and legal scholars. It is written at a high-school level and assumes no knowledge of science. The book also debunks "Intelligent Design" by arguing persuasively that it is not supported by scientific evidence.

I learned that in an outcropping of rock in far Northern Canada, paleontologists discovered a 375-million-year-old fossil of a creature that they named Tiktaalik. Tiktaalik forms a link between fish and early tetrapods, sharing features of both. This finding illustrates the unique strength of empirical science: quantitative predictive power. The discovery of Tiktaalik confirms a prediction of evolutionary biology that species emerged from the oceans 375 million years ago.

Though the information provided is valuable, entertaining and well worth learning, I suspect the book will have limited success toward winning the culture war. The approach is tactically sound but strategically questionable. The implicit message is that fundamentalism can be combated by reasoned argument based on facts. Certainly it is prudent to wear a Kevlar flak jacket of scientific facts when facing down a fundamentalist at high noon. A discussion of Tiktaalik may provide an appropriate riposte against creationists who rail at school board meetings about gaps in the fossil record. Facts are important to know and use. Nonetheless, I cannot help but think that due to its effort to maintain political correctness and not offend moderate religious believers, *Science, Evolution, and Creationism* is crucially off target.

In the highly useful section of Frequently Asked Questions at the end of the book, one answer reads in part, "Many scientists and theologians have written about how one can accept both faith and the validity of biological evolution." The book also contains a series of quotations from clergy and scientists who see no conflict between their faith and science. But there is a conflict between fundamentalism and empirical science. One cannot accept the Bible as literal truth and not be in conflict with science any more than one can believe the Earth is flat or resting on Atlas' shoulders. Adam and Eve did not exist as real people and Eve was not created from Adam's rib. The story of the Garden of Eden is a creation myth of a pre-scientific culture, equivalent to the myriad other myths created by many other cultures across the world. Myths may be poignant metaphors containing great wisdom, but they are not literally true. Fundamentalist beliefs contradict science.

Scientists need to be bold and intellectually honest. Rather than fighting a defensive holding action against the worshipers of ignorance, scientists need to go on the offensive. We need to deliver a truthful denunciation of factually incorrect religious beliefs. The strength of our nation and humankind depends on a scientifically educated citizenry that knows the difference between empirical fact and myth. We need to recognize fundamentalists for what they are—fanatics who are undermining our society and threatening the world. When religion is deeply destructive, it shouldn't be allowed to hide behind platitudes about faith and science not conflicting. Though important and useful, I find *Science, Evolution, and Creationism* far too timid in confronting the dangerous zealots who advocate creationism.

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The Science of Evolution and the Myth of Creationism, Knowing What's Real and Why it Matters

Ardea Skybreak, Insight Press, Chicago (2006), 338 pp. ISBN 0-97602360-5-2 (paperback, $24.95), ISBN 0-9760236-7-9 (hardcover).

The author of this book studied biology, but left before completing her Ph.D. dissertation because she "felt a compelling need for revolutionary change in the world." She understands the theory of evolution quite well and firmly believes it. According to her, there is no doubt about the scientific correctness of the theory, and those who would deny it are no more credible than those who believe in a flat earth.

Skybreak begins by describing Darwinian evolution, including mutations of genes and the idea of natural selection. She discusses the evidence in favor of evolution and the lack of any evidence against it. Later she points out that the evidence of Darwin's time has only increased in subsequent years, in large part because of our increasing understanding of DNA and our discovery of more fossils of intermediary species. Of course, the fossil record will never be complete, and some creationists use these gaps as evidence for the work of God. But "God of the gaps" is a poor argument, as God's role continually diminishes as more scientific evidence is accumulated. Skybreak has no quarrel with people believing in God or having religion, so long as they do not use religion to try to refute established science.

The author devotes chapters to the evidence for evolution and describing how evolution leads to entirely new species of plants and animals, including the evolution of the human species. She points out that Homo sapiens first appeared in Africa about 200,000 years ago. I did not count the number of times she offered this information, but I have the impression it was about half a dozen times throughout the book. She also repeated many other facts more often than I thought necessary, but I can understand that repetition reinforces memory.

Skybreak blasts creationists, both those who advocate a young earth (of about 6000 years) and those who admit an old earth but support intelligent design. She calls the latter people "Intelligent Design Creationists." Both kinds of creationists, she says, make "an assault on all of science in the name of god" [Skybreak consistently writes god rather than God]. She goes overboard when she says about the young-earth creationists, "These people will do anything in their power—distort the truth, spread outright lies, and even threaten and intimidate—to try to force people to accept and submit to a literal interpretation of the Biblical story of Creation, although all the scientific evidence which has accumulated over the past century and a half shows this doesn't hold water." My own opinion is that although some creationists may lie and intimidate, most of them are are telling the "truth" according to their beliefs. The power of faith in many people is much stronger than their understanding of science.

She also refutes the views of those advocating intelligent design. Here, the creationist argument is more subtle. Intelligent design proponents admit that the earth is 4.5 billion years old and life a few billion years old. However, they argue that some parts of living creatures have "irreducible complexity," and so couldn't evolve. For example, take away the optic nerve and the eye would not be functional. How could something like the eye evolve, they ask, if it would not be useful if any part of it was missing? The author refutes these claims by pointing out the evolutionary advantages of an animal having even a slight ability to detect light or motion with a primitive eye. She further remarks that parts of present complex systems might have had different functions when they first began to evolve. She gives other examples. Of course, an argument against evolution does not constitute scientific evidence for intelligent design.

The author rightly points out that "Social Darwinism," which has led to subjugation of supposedly inferior people and euthenasia, is not scientific and has nothing to do with Darwinian evolution. However, she occasionally lets her social activism intrude into her discussion, as when she briefly discusses Karl Marx and quotes a sentence of Mao Tsetung. The views of these people have little to do with evolution, and mentioning them detracts from the book.

In my opinion, the continuity of argument of the book is hurt by interruptions, in double column on gray paper, which describe certain points in more detail than in the regular text. I think the presentation would have been smoother if these sections had been woven into the narrative.

Skybreak concludes that "while the science of evolution is on solid scientific ground, the attacks on evolution are not going to stop...the Christian Fundamentalist movement in the United States today is well organized, well funded, and powerfully 'connected,' right up to the highest levels of government...There continues to be a pressing need to actively defend science."

Despite the flaws of this book, the author presents a well-reasoned defense of the science of evolution and a cogent attack on creationism. I therefore recommend the book to those who need to be convinced of evolution as well as those who want arguments to defend it against those who condemn it.

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The Essential Exponential! For the Future of Our Planet

Albert A. Bartlett with Robert G. Fuller, Vicki L. Plano Clark, and John A. Rogers, Center for Science, Mathematics, and Computer Education,University of Nebraska, Lincoln, NE, 2004

Professor Emeritus Albert Bartlett began his career in the physics department at the University of Colorado, Boulder in 1950. In 1969, he began delivering lectures on exponential growth and its often unintuitive results. The focus of his talks involved educating people about the consequences and arithmetic of steady growth, a centerpiece of domestic and global economies, and was motivated by the belief that "the greatest shortcoming of the human race is our inability to understand the exponential function." The talks evolved into a series of papers on the exponential function and its relation to the energy crisis, population growth, and nonrenewable resources. This book is a collection of these papers and also includes some additions by M. King Hubbert and L. David Roper regarding depletion theory.

Many of the papers in the book discuss continuous growth in energy usage. In such cases, the time required for the growing quantity to double in size is $T_2 = (\ln 2)/k$, where k is the fractional growth per year. If the size of the resource is R (e.g. tons of coal or barrels of oil), the exponential expiration time (time at which the total consumption is equal to the total resource size), is $EET = (1/k)\ln(kR/r_0 + 1)$, where r_0 is the current rate of consumption. Professor Bartlett then applies these equations to oil and coal usage to estimate the life expectancy for these energy reserves under several circumstances. For example, if the world crude oil production rate continues to rise by 7%/year, the world's known oil supply (crude oil and oil shale) will expire in 35 years. The simple model is also used to derive scenarios in which a finite resource can be extended indefinitely (e.g. "Sustained Availability") by decreasing the rate of extraction such that the total of all future extractions equals the size of the remaining resource at present. Many of these papers rely on a very simple exponential model in which the rate of extraction continues to grow at a fixed rate despite declining resources. Later in the book, this assumption is refined to include more sophisticated depletion theories by Hubbert and Roper, and more recent data (e.g. up to 2003) is used to show depletion of oil reserves. Additionally, Bartlett notes that several political projections for energy reserves rely on the "current rate of usage" and can thus be very misleading.

The book also includes a series of articles discussing the exponential function and its impact on population growth. Here, there are several interesting points on methods to achieve zero-growth populations (both voluntary and involuntary), the impact of overpopulation on the decline of democracy, and the marginalization of Thomas Malthus's original population growth analysis. Finally, the last chapter of the book contains 14 papers written for *The Physics Teacher* that detail the mathematics of exponential growth and additional simple applications to compound interest, inflation, and miles of highway.

The bulk of the work is presented at a very simple level that is easily comprehensible to undergraduates and advanced high school students. Since the book is collection of Professor Bartlett's papers on exponential growth, there is substantial redundancy in both the mathematics and the message. Moreover, many of the papers rely on an overly simplistic continuous growth model that may, without the proper caveats, lead to erroneous conclusions; however, the inclusion of Hubbert's and Roper's papers allow the interested reader to make more sophisticated calculations. Despite these criticisms, I would recommend the book for anyone interested in the current energy crisis or overpopulation as it provides a good background to simple models associated with these subjects.

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Editor's Comments, continued from page 1

Obispo, David Hafemeister and Peter Schwartz, responded with this issue's article in favor of the IPCC conclusion. We, the editors of P&S, invite reasoned rebuttals from the authors as well as further contributions from the physics community. Please contact me (jjmarque@sbcglobal.net) if you wish to jump into this fray with comments or articles *that are scientific in nature*. However, we will not publish articles that are political or polemical in nature. Stick to the science! *(JJM)*

Whether or not human produced carbon dioxide is a major cause of impending climate change (as is being debated in the two articles of this issue), the issue of energy "production" by our Earth-bound societies must be faced. Fossil fuel supplies may become unavailable in this century —or the next— but in a finite system, obeying the laws of thermodynamics, non-fossil energy sources will have to become available to mankind, sooner or later (within the foreseeable lifetime of our planet). One major energy resource, being much touted again, is that of the fissioning nucleus. Nuclear power faces three major drawbacks in the public eye: the possibilities of devastating accidents; the possibility of "proliferation" — the diversion of energy resources and technology into weaponry; the problem of protecting present and future generations from "nuclear ashes"— the long-lived radioactive byproducts of power generation by nuclear fission. For the most part, our society has "stuck its head in the sand" regarding these issues, but we have spent a great deal of money exploring one possible means of dealing with the third problem — burying nuclear wastes deep underground (out of sight, ergo out of mind). As the News item in this issue summarizes, the Federal government, after the expenditure of billions of dollars, seems to be ready to start sending long-lived wastes to be buried in Nevada. Many people there object — "not in my backyard"! As physicists interested in the impact of physics on society (and the converse), we are obligated to participate intensely in the public debate on this problem of waste disposal as well as the other two. The final resolutions will have to be political but hopefully they will be well informed by knowledge of the physical possibilities as well as constraints. For example, I am unaware of any public discussion about the practical possibilities of decreasing the amount of long-lived nuclear ashes via the use of fast neutron fission reactors for power generation. I hope to see much more discussion of these issues in the future "pages" of this journal. (I put quotation marks about the word "pages" since it now appears that we may no longer be communicating with you via the customary paper pages; what word(s) should we use?) We know that many of our readers are well informed on these topics and hope that they will share their physical insights with the rest of us – please submit articles, commentaries, letters, and enjoy the summer – whether its warmth is in line with past trends or represents a new climate. *(AMS)*

Physics and Society is the quarterly of the Forum on Physics and Society, a division of the American Physical Society. It presents letters, commentary, book reviews and reviewed articles on the relations of physics and the physics community to government and society. It also carries news of the Forum and provides a medium for Forum members to exchange ideas. Opinions expressed are those of the authors alone and do not necessarily reflect the views of the APS or of the Forum. Contributed articles (up to 2500 words, technicalities are encouraged), letters (500 words), commentary (1000 words), reviews (1000 words) and brief news articles are welcome. Send them to the relevant editor by e-mail (preferred) or regular mail.