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An oversimplified picture of the climate behavior based on a single process can lead to distorted conclusions

Richard S. Lindzen[a] (iD)

Alfred P. Sloan Professor of Atmospheric Sciences, Emeritus, Massachusetts Institute of Technology, Cambridge, USA

Abstract The nature of the climate system is reviewed. We then review the history of scientific approaches to major problems in climate, noting that the centrality of the contribution of carbon dioxide is relatively recent, and probably inappropriate to much of the Earth's climate history. The weakness of characterizing the overall climate behavior using only one physical process, globally averaged radiative forcing, is illustrated by considering the role of an equally well-known process, meridional heat transport by hydrodynamic processes which, by changing the equator-to-pole temperature difference, also impact global mean temperature.

1 Introduction

The present picture for the global warming issue presented to the general public hinges on the fact that CO_2 absorbs and emits in the infrared, and that adding it to the atmosphere must, therefore, lead to some warming. Indeed, the earth has been warming since the end of the Little Ice Age, and the level of CO_2 has indeed been increasing, but this hardly constitutes proof. However, the fact that large scale computer models can be made to replicate the warming with increasing CO_2 is held to be strong confirming evidence. Beyond this, is the claim that any warming at all is indicative of catastrophe, especially if higher than the politically defined goal of + 1.5 °C (of which over 1 °C has already occurred), and demands major reductions in fossil fuel use [1].

Although it is often noted that greenhouse warming has long been found in the climate literature, it turns out that this was not generally considered a major cause of climate change until the 1980s. In this paper, we present a description of the climate system in order to place the role of greenhouse warming into a proper context. We then look at how climate was viewed in the earlier literature (as well as some more recent work), and compare this with the current approach. It is shown that there are substantive reasons to regard the present publicly accepted explanation as improbable.

[a] e-mail: rlindzen@mit.edu (corresponding author)

2 The climate system

The following is a totally non-controversial description of the climate system.

  i. The core of the system we are looking at consists in two turbulent fluids (the atmosphere and oceans) interacting with each other.
 ii. The two fluids are on a rotating planet that is differentially heated by the sun.

   What this refers to is simply that solar radiation is directly incident at the equator while it barely skims the earth at the poles. The uneven heating drives the circulation of the atmosphere, and these motions are responsible for meridional heat transport.

iii. The oceanic component has circulation systems with timescales ranging from years to millennia, and these systems carry heat to and from the surface.

   The forcing of the ocean is complex. In addition to differential heating, there is forcing by wind, and fresh water injections. Because of the higher density of water with respect to air, circulations are much slower in the ocean and the circulations can have very long timescales. The fact that these circulations carry heat to and from the surface means that the surface is never in equilibrium with space.

iv. In addition to the oceans, the atmosphere is interacting with a hugely irregular land surface.

   The airflow is strongly distorted by passing over major topographic and thermal inhomogeneities of the surface which excites planetary scale waves that strongly impact remote regional variations in climate which, it turns out, are generally inadequately described in models [2].

 v. A vital constituent of the atmospheric component is water in the liquid, solid and vapor phases, and the changes in phase have vast energetic ramifications. Each is also radiatively important.

   The release of heat when water vapor condenses drives thunder clouds (known as cumulonimbus) is substantial. Moreover, clouds consist of water in the form of fine droplets and ice in the form of fine crystals. Normally, these fine droplets and crystals are suspended by rising air currents, but when these grow large enough, they fall through the rising air as rain and snow. Not only are the energies involved in phase transformations important, so is the fact that both water vapor and clouds (both ice- and water-based) strongly affect radiation. The two most important greenhouse substances by far are water vapor and clouds. Clouds are also important reflectors of sunlight. These matters are discussed in detail in the IPCC WG1 reports, each of which openly acknowledge clouds as major sources of uncertainty in climate modeling.

vi. The energy budget of this system involves the absorption and reemission of about 240 W/m^2. Doubling CO_2 involves a perturbation a bit less than 2% to this budget (4 W/m^2) [3]. So do changes in clouds and other features, and such changes are common.

   The earth receives about 340 W/m^2 from the sun, but about 100 W/m^2 is simply reflected back to space by both the earth's surface and, more importantly, by clouds. This would leave about 240 W/m^2 that the earth would have to emit in order to establish balance. The sun radiates in the visible portion of the radiation spectrum because its temperature is about 6000 K. If the Earth had no atmosphere at all (but for purposes of argument still was reflecting

100 W/m^2), it would have to radiate at a temperature of about 255 K, and, at this temperature, the radiation is mostly in the infrared.

Of course, the Earth does have an atmosphere and oceans and this introduces a host of complications. Evaporation from the oceans gives rise to water vapor in the atmosphere, and water vapor very strongly absorbs and emits radiation in the infrared. The water vapor essentially blocks infrared radiation from leaving the surface, causing the surface and (via conduction) the air adjacent to the surface to heat, and convection sets on. The combination of the radiative and the convective processes results in decreasing temperature with height. To make matters more complicated, the amount of water vapor that the air can hold decreases rapidly as the temperature decreases. Above some height there is so little water vapor remaining that radiation from this level can now escape to space. It is at this elevated level (around 5 km) that the temperature must be about 255 K in order to balance incoming radiation. However, because the temperature decreases with height, the surface of the Earth now has to actually be warmer than 255 K. It turns out that it has to be about 288 K (which is indeed the average temperature of the earth's surface). The addition of other greenhouse gases (like CO$_2$) increases further the emission level and causes an additional increase of the ground temperature. Doubling CO$_2$ is estimated to be equivalent to a forcing of about 4 W/m^2 which is a little less than 2% of the net incoming 240 W/m^2.

The situation can actually be more complicated if upper-level cirrus clouds are present. They are very strong absorbers and emitters of infrared radiation and effectively block infrared radiation from below. Thus, when such clouds are present above about 5 km, their tops, rather than 5 km determine the emission level. This makes the ground temperature (i.e., the greenhouse effect) dependent on the cloud coverage. Quantification of this effect can be found in Rondanelli and Lindzen [4].

Many factors, including fluctuations of average cloud area and height, snow cover, ocean circulations, etc. commonly cause changes to the radiative budget comparable to that of doubling of CO$_2$. For example, the net global mean cloud radiative effect is of the order of $-$20 W/m^2 (cooling effect). A 4 W/m^2 forcing, from a doubling of CO$_2$, therefore corresponds to only a 20% change in the net cloud effect.

vii. It is important to note that such a system will fluctuate with timescales ranging from seconds to millennia even in the absence of explicit forcing other than a steady sun.

Much of the popular literature (on both sides of the climate debate) assumes that all changes must be driven by some external factor. Of course, the climate system is driven by the sun, but even if the solar forcing were constant, the climate would still vary. Moreover, given the massive nature of the oceans, such variations can involve timescales of millennia rather than milliseconds. El Nino is a relatively short example involving years, but most of these internal time variations are too long to even be identified in our relatively short instrumental record. Nature has numerous examples of autonomous variability including the approximately 11-year sunspot cycle and the reversals of the Earth's magnetic field every couple of hundred thousand years or so. In this respect, the climate system is no different from other natural systems; that is to say, it can exhibit autonomous variability. Well-known examples include the quasi-biennial oscillation of the tropical stratosphere, El Nino/Southern Oscillation, the Atlantic Multi-decadal oscillation, and the Pacific Decadal Oscillation.

viii. Of course, such systems also do respond to external forcing, but such forcing is not needed for them to exhibit variability.

Restricting ourselves to matters that are totally uncontroversial does mean that the above description is not entirely complete, but it does show the heterogeneity, the numerous degrees of freedom, and the numerous sources of variability of the climate system.

The 'consensus' assessment of this system is today the following:

In this complex multifactor system, the climate (which, itself, consists in many variables—especially the temperature difference between the equator and the poles) is described by just one variable, the globally averaged temperature change, and is controlled by the 1–2% perturbation in the energy budget due to a single variable (any single variable) among many variables of comparable importance. We go further and designate CO_2 as the sole control. Although we are not sure of the budget for this variable, we know precisely what policies to implement in order to control it.

How did such a naïve seeming picture come to be accepted, not just by the proponents of this issue, but also by most skeptics? After all, we spend much of our effort arguing about global temperature records, climate sensitivity, etc. In brief, we are guided by this line of thought.

3 History

In fact, this view on climate was initially opposed by many leading figures including the director of Scripps Institute of Oceanography,[1] the director of the European Centre for Medium Range Weather Forecasting,[2] the head of the World Meteorological Organization,[3] the head of the Climate Research Unit at the University of East Anglia,[4] the former head of the British Meteorological Office,[5] a former president of the US National Academy of Science,[6] the leading Soviet climate scientists,[7] etc. Even in 1988, when James Hansen presented his famous US Senate testimony, *Science Magazine* reported widespread skepticism in the then small climate science community. However, all these individuals were from an older generation, and many are now dead.

Between 1988 and 1994, things changed radically. In the USA, funding for climate increased by about a factor of 15. This led to a great increase in the number of people interested in working as 'climate scientists', and the new climate scientists understood that the reason for the funding was the 'global warming' alarm.

In France, in the 60s, there was essentially one theoretical meteorologist, Queney. Today, there are hundreds involved with models if not theory, and it is largely due to 'global warming.' Is it unreasonable to wonder whether or not a political movement has succeeded in capturing a scientific field?

What was the previous situation? For most of the twentieth century, climate was a small subset of the small fields of meteorology and oceanography with important contributions from a handful of geologists. Almost no major scientists working on aspects of climate referred to themselves as 'climate scientists.' Within meteorology, the dominant approach to climate was dynamic meteorology (though the greenhouse effect was well known).

A good example of what were regarded as the basic problems in climate in 1955 can be found in Pfeffer [5]. This is the proceedings of a conference that took place in 1955 at

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[1] William Nierenberg.

[2] Lennard Bengtsson.

[3] Aksel Wiin-Nielsen.

[4] Hubert Lamb.

[5] Basil John Mason.

[6] Frederick Seitz.

[7] Mikhail Budyko, Yuri Izrael and Kiril Kondratiev.

the Institute for Advanced Studies at Princeton University where John von Neumann had begun numerical weather prediction. The contributors to this volume included J. Charney, N. Phillips, E. Lorenz, J. Smagorinsky, V. Starr, J. Bjerknes, Y. Mintz, L. Kaplan, A. Eliassen, among others (with an introduction by J. Robert Oppenheimer). The contributors were generally regarded as the leaders of theoretical meteorology. Only one article dealt with radiative transfer, and it did not focus on the greenhouse effect, though increasing CO_2 was briefly mentioned. To be sure, Callendar [6] had suggested that increasing CO_2 might have caused the warming from 1919 to 1939, but the leading English meteorologists of the period, Simpson and Brunt, pointed out the shortcomings of his analysis in the comments that followed Callendar's paper.

4 Earlier approach to climate versus current approach

By the 1980s, with advances in paleoclimatology, several aspects of climate history emerged with increased clarity. We began to see more clearly the cyclic nature of glaciation cycles of the past million years or so [7]. Warm periods like the Eocene (50 million years ago) became better defined [8]. The data suggested that for both glacial periods and the warm periods, equatorial temperatures did not differ much from present values, but the temperature difference between the tropics and high latitudes varied greatly. The following are the temperature differences:

Eocene:	$\Delta T \approx 20$C [8]
Glacial maximum:	$\Delta T \approx 60$C [9]
Today:	$\Delta T \approx 40$C

The variations in equatorial temperatures were much smaller than the above differences. Interestingly, however, the original estimates were that the equatorial temperature during the Eocene was a little colder than it is today [8], while the equatorial temperature during the last glacial maximum (LGM) was a little warmer than it is today. Of course, this is not what one would expect for greenhouse forcing, and there were intense efforts to 'correct' the equatorial temperatures. Today, the commonly claimed Eocene equatorial temperature is commonly taken to be indistinguishable from today's [10], while equatorial temperature for the LGM are commonly believed to have been about 2C colder than they are today. As far as this discussion goes, the changes in equatorial temperature are still small. The above situation leads to some exciting and important questions concerning climate. We will look at three of these questions.

1. What accounted for the glaciation cycles of the past 700 thousand years?

Milankovitch [11] early on put forward an insightful suggestion for this: namely that orbital variations led to powerful variations in summer insolation in the arctic and this determined whether winter snow accumulations melted or persisted through the summer. Imbrie and others found a rather poor correlation between the peaks in the orbital forcing and the arctic ice volume. However, Roe [12] and Edvardsson et al. [13] showed that when one compared the time derivative of the ice volume rather than the ice volume itself, the correlation with the summer insolation was excellent. This is what is shown explicitly Fig. 1 (taken from Roe [12]. This figure shows the best fit of the orbital parameters to the time derivative of the ice volume, and this is almost identical to the Milankovitch parameter. Note that insolation is varying locally by about 100 W/m^2. Edvardsson et al. [13], showed that the variations in
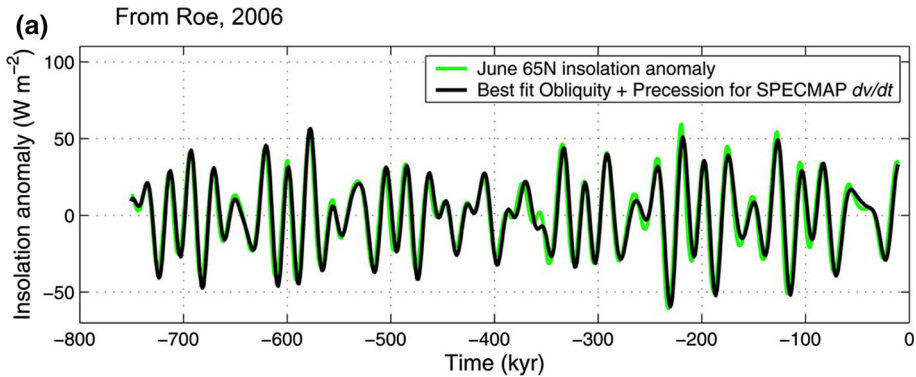
Fig. 1 Comparison of insolation anomaly (green curve) during June at 65 N with the best fit of change of ice volume to the orbital variations (dv/dt; black curve) from Roe [12]

insolation were quantitatively consistent with the melting and growth of ice. This seems to constitute strong evidence for the correctness of Milankovitch's proposal.

It is interesting to note how the present mainstream view deals with this issue (Ruddiman [14], https://www.yaleclimateconnections.org/2007/10/common-climate-misconceptions-co2-as-a-feedback-and-forcing-in-the-climate-system/; see also Genthon et al. [15]. No mention is made of the remarkable success of the independent efforts of Edvardsson et al. [13] and Roe [12]. Moreover, Roe had to include a caveat that his work had no implications for the role of CO_2, in order to get his paper published (personal communication).

The present official approach [16] is as follows: the arctic summer insolation is ignored; rather, only the globally and annually averaged insolation is taken into account, and this varies about two orders of magnitude less than the arctic summer insolation. A causal role for CO_2 cannot be claimed since its variations (between 180 and 280 ppmv—corresponding to a change in radiative forcing of about 1 W/m^2) follow rather than lead the temperature changes. So it is maintained that orbital variations 'pace' the glaciation cycles, and that the resulting changes in CO_2 provide the necessary 'amplification'. This interpretation is a direct consequence of considering the global insolation as the driver of the changes. In reality, as Roe (and Milankovitch) note, the Arctic responds to radiation in the Arctic, and the changes in the Arctic are much larger than those associated with global mean insolation. To be fair, it is worth mentioning that more recent analyses tend to corroborate this more realistic picture of the high latitude response to insolation (for example Abe-Ouchi et al. [17] or Ganopolski and Brovkin [18]).

Let us now return to the remaining two questions.

2.   What accounted for the stability of tropical temperatures?

Radiative-convective processes (including the greenhouse effect) are generally held to play a major role in determining tropical temperature. The fact that these temperatures seem to have changed little in radically different climate regimes is consistent with low sensitivity to greenhouse forcing [19]. Indeed, there is strong evidence that about 2.5 billion years ago, equatorial ground temperatures were about the same as they are today despite the solar constant being 20–30% less than it is today. Sagan and Mullen [20] referred to this as the Early Faint Sun Paradox. Most attempts to explain this have relied on improbably high levels of various greenhouse gases, but, as Rondanelli and Lindzen [4] showed, it is readily accounted

for by negative feedbacks from upper level cirrus clouds as was found earlier by Lindzen et al. [21].

3. What determined the equator-to-pole ground temperature differences?

Here, it was generally thought that the dynamic process responsible for north–south heat transfer was implicated. The process is what is called baroclinic instability [22–24], and essentially every textbook on geophysical fluid dynamics), and the conventional thinking was that the temperature difference resulted from the equilibration of this instability wherein the mean state comes close to a state that is neutral with respect to this instability. The puzzle, however, was how there could be different equilibrations for different climates. The first attempt to determine the equilibrated state used what is called the two-layer approximation wherein the atmosphere is approximated by 2 layers. In rotating systems like the earth, there is a strong proportionality between vertical wind shear and horizontal temperature gradient. This is referred to as the thermal wind relation. Within the two-layer model, there is a critical shear for baroclinic instability and an associated meridional temperature difference between the tropics and the pole which turned out to be 20C [25] which is the Eocene value. In the presence of snow and ice, the vertical temperature profile displays what is referred to as the *arctic inversion* where instead of the usual decrease of temperature with altitude, the temperature actually increased with altitude. This inversion greatly increases the static stability of the atmosphere below the tropopause and, as suggested by Held and Suarez [26], this should reduce meridional heat transport. This would appear to explain the greater tropics-to-pole temperature differences during the present and during the major glaciations.

The situation when we consider a continuous atmosphere instead of the two-level model is much more difficult to treat. Equilibration, in this case, determines the slope of the isentropic surface connecting the tropical surface to the polar tropopause [27] while leaving ambiguous the temperature field below this surface. Equilibration simply refers to the state which the baroclinic instabilities attempt to produce. Entropy in the atmosphere is described by what is called potential temperature. This is the temperature that a parcel of air would have if it were adiabatically lowered to the surface (where the pressure is higher). An isentrope originating at the surface in the tropics will rise as one approaches the pole, and will essentially determine the temperature at the tropopause over the pole. According to Jansen and Ferarri [27], this, in turn, determines the tropics-to-pole temperature difference at the height of the polar tropopause (ca 6 km), and that value is about 20C. When one looks at today's climate, we see that the equator-pole temperature difference at the altitude of the polar tropopause is, in fact, approximately 20C [28]. The existence of the arctic inversion causes the surface temperature differences between the tropics and the pole to be larger than they are at the tropopause.

Again, the currently widespread explanation takes a different view of this situation. The physics came to be associated exclusively with the greenhouse effect amplified by the alleged positive water vapor feedback. The change in equator-to-pole temperature difference was attributed to some imaginary '**polar amplification**,' whereby the equator-pole temperature automatically followed the mean temperature [29]. Although the analogy is hardly exact, this is not so different from assuming that flow in a pipe depends on the mean pressure rather than the pressure gradient. Indeed, it has been noted that some important models barely display this polar amplification [30], while attempts to model the Eocene by simply cranking up CO_2 often end up with today's equator-to-pole temperature distribution that is uniformly increased [31, 32]. With respect to the Eocene, this led to much greater equatorial warming in models than was observed.

One of the most insidious results of assuming that the change in equator-to-pole temperature is an automatic consequence of global warming has been the claim that paleoclimate
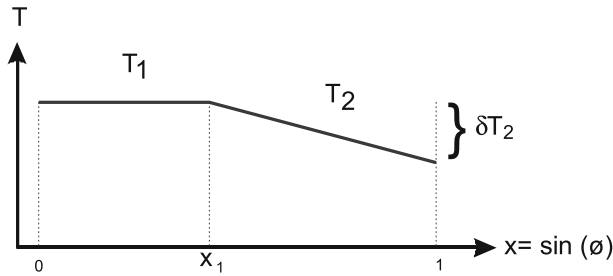
Fig. 2 Simplified picture of meridional temperature distribution between the equator ($\sin(\varphi) = 0$) and the pole ($\sin(\varphi) = 1$). See text for details

data implies very high climate sensitivity. A simplistic (schematic) treatment of the separate contributions of the greenhouse effect and dynamically produced changes to the equator-to-pole temperature difference to global mean temperature illustrates this problem. Figure 2 illustrates the situation where $x = \sin(\phi)$, ϕ = latitude, x_1 is the meridional extent of the Hadley circulation which effectively horizontally homogenizes tropical temperature [33], the tropics, and δT_2 = equator-to-pole temperature difference.

$$T = T_1 \text{ for } 0 \leq x \leq x_1 \quad T = T_2 \text{ for } x_1 \leq x \leq 1_2 = T_1 - \delta T_2(x - x_1)/(1 - x_1)$$
$$\bar{T} = T_1 - \delta T_2 \frac{1 - x_1}{2}$$
$$\Delta \bar{T} = \Delta T_1 - \Delta(\delta T_2)\frac{1 - x_1}{2}$$

Note that ΔT_1 is the warming of the tropics, while $\Delta(\delta T_2)$ is the change in the equator-to-pole temperature difference. While ΔT_1 reflects the sensitivity to greenhouse (i.e., radiative) forcing and feedbacks, $\Delta(\delta T_2)$ need not, especially when the latter is much greater than the former. All attempts to estimate climate sensitivity from paleo data (at least as far as I can tell) fail to distinguish between the two and attribute both contributions to greenhouse forcing in estimating climate sensitivity. This could be a major error.

For example, in the absence of greenhouse forcing, ΔT_1 might be zero, while there might still be a contribution from $\Delta(\delta T_2)$, which would of course lead to a change in global mean temperature. This, in turn, would lead to the false conclusion that sensitivity was infinite. More realistically, if climate sensitivity to radiative forcing were very small, contributions from $\Delta(\delta T_2)$ could still lead one to falsely conclude that the sensitivity was large [15].

5 Concluding remarks

As noted in Sect. 2, it is implausible that a system as complex as the climate system with numerous degrees of freedom should be meaningfully summarized by a single variable (global mean temperature anomaly) and determined by a single factor (CO_2 level in the atmosphere). As an example, we have shown in Sect. 4, that the different physics associated with tropical temperatures (i.e. radiative forcing including radiative feedbacks) and with the equator-to-pole temperature difference (i.e. hydrodynamic transport via baroclinic instabilities) both lead to changes in global mean temperature. However, this does not imply that changes in global mean temperature cause changes in the equator-to-pole temperature difference. This brief paper focussed on a single example of where the assumption of single variable

control can lead to a mistaken result. However, the issue of sensitivity even when restricted to radiation is still subject to numerous possibilities, and there is ample reason to suppose that the radiative component of the sensitivity is, itself, exaggerated in most current models. A separate discussion of this matter can be found in Lindzen [19].

Interestingly, even those of us rejecting climate alarm (including me) have focused on the greenhouse picture despite the fact that this may not be the major factor in historic climate change (except, in the case, of low sensitivity, to explain the stability of equatorial temperatures). That is to say, we have accepted the basic premise of the conventional picture: namely that all changes in global mean temperature are due to radiative forcing. Although capturing the narrative is a crucial element in a political battle, it should not be permitted to replace scientific reasoning.

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