Absence of Scientific Basis

RICHARD LINDZEN

Given normal climate variability, we may reasonably expect that there will be future climates both warmer and colder than the present regime. This, however, hardly supports the current fear that increasing greenhouse gases in the atmosphere will lead to catastrophic warming. The Intergovernmental Panel on Climate Change (IPCC) Scientific Assessment as well as the current update\textsuperscript{11,12} both recognize that temperature changes over the past century (a net warming of 0.45°C ± 0.15°C) are consistent with natural variability and smaller than would be expected for models predicting >−1.3°C equilibrium warming for a doubling of CO\textsubscript{2}—assuming all the change over the past century were due to CO\textsubscript{2}. This, of course, seems unlikely since the bulk of the warming occurred before 1940. Thus, the data neither suggest nor support current warming scenarios. Neither do simple greenhouse considerations. All other factors remaining constant, the equilibrium greenhouse warming, resulting from a doubling of CO\textsubscript{2}, is estimated to be between 0.5°C and 1.2°C.\textsuperscript{11,16,18,27}

These values may seem small, but CO\textsubscript{2} is only a minor greenhouse gas. If all CO\textsubscript{2} were removed from the atmosphere, water vapor and clouds would still provide almost all of the present greenhouse effect. Predictions of larger equilibrium warming depend crucially on positive feedbacks from water vapor, cloud cover, and surface albedo (due to snow cover). Of these model feedbacks, water vapor is by far the largest. As it turns out, the physics of the water-vapor budget is largely absent in current models. Indeed, in most (if not all) models the water-vapor feedback is readily identifiable with a calculational error. Thus, there is no theoretical basis for the catastrophic warming scenarios, as well. Indeed, there are reasons to believe the feedbacks are negative, suggesting the equilibrium response to CO\textsubscript{2} doubling may well be much smaller than the direct response.\textsuperscript{27,28}

Finally, the term equilibrium should be explained. It refers to the response achieved over an infinite time. In point of fact, the actual response time (largely determined by heat transport into the ocean) increases proportionally to the expected equilibrium response.\textsuperscript{9} In fact, a model predicting a 4.8°C equilibrium warming for a doubling of CO\textsubscript{2} would only have reached 2/3 of this warming in ~160 years. It is interesting, in this regard, to note that the models examined in the IPCC Scientific Assessment produce warming by 2100 almost equal to the equilibrium response of these models to a doubling of CO\textsubscript{2}; in these models, however, effective CO\textsubscript{2} has quadrupled by 2100. Had it only doubled, the predicted warming would have been much less.

Current concerns over significant global warming are based on simple, plausible physical arguments that increasing CO\textsubscript{2} levels will lead to some warming. Model predictions of large warming depend on projected large increases in atmospheric CO\textsubscript{2}, and mechanisms within the models which act to greatly amplify the climate response to increasing CO\textsubscript{2}. The projections depend on questionable economic, population, and energy scenarios; they also depend on clearly inadequate chemical models which serve to exaggerate the fraction of emitted CO\textsubscript{2} remaining in the atmosphere. The amplification mechanisms (positive feedbacks) depend on what is likely to be a severe misrepresentation of the relevant physical processes: moistening of the atmosphere and cloud formation. Recent data suggest that these processes may be acting in a manner opposite to what current models produce. Under the circumstances, the possibility of large warming, while not disproven, is also without a meaningful scientific basis.
Figure 1.
Atmospheric CO₂ increase in the past 250 years, as indicated by measurements of air trapped in ice from Siple Station, Antarctica (purple) and by direct atmospheric measurements at Mauna Loa, Hawaii (blue).¹¹

Figure 2.
Expected CO₂ in the atmosphere according to various emissions scenarios.¹⁰

**CO₂**

Before even discussing “greenhouse theory,” it may be helpful to begin with the issue that is almost always taken as a given: namely, that CO₂ will inevitably increase to values double and even quadruple present values. Before 1958, the record is based on the analysis of ice cores. After 1958, it is based on direct atmospheric sampling. Clearly, CO₂ has been increasing (Figure 1). Before 1800 the density was ~275 ppmv (parts per million by volume). Today it is ~355 ppmv. The increase is generally believed to be due to the combination of increased burning of fossil fuels (Figure 3) and (mostly before 1905) to deforestation. The total source is estimated to have been increasing exponentially with a characteristic time of 45 years—at least until 1973. From 1973 until 1990 the rate of increase has been slower. About half the production of CO₂ has appeared in the atmosphere.

Predicting what will happen to CO₂ over the next century is a rather uncertain matter. By assuming a shift toward coal, advances in the 3rd World’s standard of living, large population increases, and a reduction in nuclear and other non-fossil fuels, one can generate an emissions scenario that will lead to a doubling of CO₂ by 2030—if we use a particular model for the chemical response to CO₂ emissions. This was referred to as the “business-as-usual” scenario by the IPCC Working Group I. As it turns out, the chemical model used was inconsistent with the past century’s record; it would have predicted that we would already have ~380 ppmv. An improved model developed at the Max Planck Gesellschaft in Hamburg shows that the so-called business-as-usual scenario does not even double CO₂ by the year 2100.¹⁰ Their model shows that under other scenarios, we may not even get much more CO₂ than is already in the atmosphere (Figure 2). Personally speaking, it seems unlikely that the indefinite future of energy belongs to coal. I also find it difficult to believe that technology will not lead to improved nuclear reactors within 50 years. As the IPCC update notes, scenarios are not predictions. Given our present “crystal ball” technology, predictions for 50 to 100 years are more than anyone would rationally attempt.

Nevertheless, we have already seen a significant increase in CO₂ which
has been accompanied by increases in other minor greenhouse gases as well (CH₄, CFC, etc). Indeed, in terms of greenhouse potential, we have had the equivalent of a 50% increase in CO₂ over the past century. The effects of these increases are certainly worth studying—quite independent of any uncertain future scenarios. Similarly, given past trends, it is not at all unreasonable to expect substantial increases. The remainder of this paper will focus on the basis for the expectation that warming will accompany these changes in atmospheric composition.

The common popular presentation of the greenhouse effect is that the atmosphere is transparent to sunlight (apart from the very significant reflectivity of clouds and the surface) which heats the Earth’s surface (Figures 4&11). The surface attempts to balance this heating by radiating in the infrared. The infrared radiation increases with increasing surface temperature, and the temperature adjusts until balance is achieved. If the atmosphere were also transparent to infrared radiation, then the infrared radiation produced by an average surface temperature of -18°C would balance the incoming solar radiation (less that amount reflected back to

Figure 3.
Belchatow mine, Belchatow, Poland. The lignite deposit in this coal strip mine was discovered in 1960 and the mine has been in operation since 1975. A 3 Krupp Bucket Wheel Excavator removes the coal. A bulldozer next to the base of the excavator shows the size of the machine (1987).

JAMES L. STANFIELD
It is interesting to note that these estimates of the greenhouse effect assume that in the absence of greenhouse gases we still have clouds to reflect sunlight. If we were to also assume that in the absence of water vapor there would be no clouds, then the resulting temperature would be much closer to what it is now. However, the atmosphere is not transparent in the infrared, and so the Earth must heat up somewhat more to deliver the same flux of infrared radiation to space. This is what is called the greenhouse effect. The fact that the Earth's average surface temperature is 15°C rather than -18°C is attributed to this effect. The main absorbers of infrared in the atmosphere are water vapor and clouds. As already noted, even if all other greenhouse gases (like CO₂ and CH₄) were to disappear, we would still be left with almost all of the current greenhouse effect. Nevertheless, it is presumed that increases in CO₂ and other minor greenhouse gases will lead to significant increases in temperature. As we have seen, CO₂ is increasing. So are other minor greenhouse gases. A widely held, but questionable, contention is that these increases will continue along the path they have followed for the past century.

It is worth noting immediately that the usual picture of the greenhouse mechanism is seriously oversimplified. Many of us were taught in elementary school that heat is transported by radiation, convection, and conduction. The above picture only refers to radiative transfer. As it turns out, if there were only radiative heat transfer, the greenhouse effect would warm the Earth to ~77°C rather than to 15°C. In fact, the greenhouse effect is only ~25% of what it would be in a pure radiative situation. The reason for this is the presence of convection (heat transport by air motion), which bypasses much of the radiative absorption (Figure 5). The surface of the Earth is cooled in large measure by air currents (in various forms including deep clouds) which carry heat upward and poleward. One con-
sequence of this picture is that it is the greenhouse gases well above the Earth's surface that are of primary importance in determining the temperature of the Earth. This is especially important for water vapor whose density decreases by about a factor of 1000 between the surface and 10 km above it. Another consequence is that we cannot even calculate the temperature of the Earth without models that accurately reproduce the motions of the atmosphere. Indeed, present models have large errors here (some 50%-26) and, not surprisingly, these models cannot correctly calculate either the present average temperature of the Earth or the equator-pole temperature distribution. Rather, the models are adjusted (or tuned) to get these quantities appropriately right.

Having said all this, it is still of interest to ask what we would expect a doubling of CO$_2$ to actually do. As already noted, if this were all that happened, we might expect a warming of from 0.5 to 1.2°C. The general consensus is that such warming would present few if any problems. However, the climate is a complex system where it is impossible for all other factors to remain constant. In present models, these other factors (commonly referred to as feedbacks) act as destabilizing factors that amplify the effects of increasing CO$_2$, leading to predictions of warming in the neighborhood of 4 to 5°C. The most important of these factors in current climate models is due to water vapor. In all current models, upper tropospheric (3 to 12 km above the Earth's surface) water vapor, the major greenhouse gas, increases as surface temperatures increase. Without this feedback, no current model would predict warming in excess of 1.7°C—regardless of any other feedback. Unfortunately, the way these factors (like clouds and water vapor) are handled in present models is disturbingly arbitrary. In many instances the underlying physics is simply not known. In other instances there are identifiable errors. Even computational errors play a major role. For example, existing models have only 10 to 20 levels in the vertical, which is inadequate for predicting the behavior of a substance like water vapor which varies immensely with height. The difficulty leads to model predictions of negative water vapor in some parts of the atmosphere. The arbitrary filling routines used to correct this obviously unrealistic behavior play a major role in the model water vapor budgets. In fact, evidence is compelling that all the known “destabilizing” feedbacks in the models are actually stabilizing (negative) feedbacks. In that case, we would expect the response to CO$_2$ doubling alone to diminish.

Water-vapor Feedback

The issue of deep clouds (cumulonimbus towers) and water vapor is rather technical; it is also crucial to the issue. These towers are the main mechanism for surface air to communicate with the interior atmosphere. Moist air rises in these towers. As this air rises to levels of lower pressure, it expands and cools (as does refrigerator coolant). As air cools, its capacity to hold water vapor diminishes. The excess water vapor condenses into liquid water or ice (depending on the temperature). In the simplest models of cumulonimbus towers, all the condensed vapor falls out as rain. When the cloud reaches its top altitude (in this simple model), it merges into the atmosphere as saturated (100% relative humidity) air at cloud-top temperature. As the surface warms, cloud air becomes more buoyant and would reach higher top levels where the air would be colder and thus hold

Figure 5. The role of dynamic heat transport in modifying greenhouse warming. Infrared opacity is greatest at the ground over the tropics, and diminishes as one goes poleward and upward. Air currents bodily carry heat to regions of diminished infrared opacity where the heat is radiated to space—balancing absorbed sunlight.

The update suggests that the expected warming was to some extent cancelled by cooling resulting from cloud brightening by sulfates. The update, therefore, suggests that the past record might be consistent with an equilibrium response to CO$_2$ doubling of almost 2°C. While this is also not a catastrophically large warming, the IPCC estimate is based on the work of RJ Charlson and colleagues which probably overestimates sulfate loading by a factor of 3 to 4. We are, therefore, sticking with the "uncorrected" value of 1.3°C from the original IPCC Scientific Assessment.
Figure 6.
Snowcapped Payachata Volcano seen beyond Lake Chungara, Chile.
GEORGE F MOBLEY

less water vapor.\textsuperscript{14,15} Hence, the supply of water vapor to the interior atmosphere would be diminished in a warmer climate. However, since water vapor is the main greenhouse gas in the atmosphere, this reduction would act to restrain the warming—i.e., provide a negative feedback.

We undertook 2 studies to check these ideas. In the 1st, we used some data showing the descent of the mountain snowlines (Figure 6) during the last major glacial period (18 000 years ago\textsuperscript{13}) to see whether the colder atmosphere of those times had more water vapor.\textsuperscript{27} Our study showed that almost certainly it did, thus confirming the notion of a negative feedback.

Our 1st study did not, however, tell us what mechanism was actually responsible for the negative feedback. Our 2nd study undertook to examine the atmosphere's water-vapor budget in greater detail.\textsuperscript{28} Here we con-
firmed that our original mechanism had a significant problem. (This had been noted by A K Betts.3) Saturated air from cloud tops constituted too small a source to maintain present levels of humidity. The problem, it turned out, was our assumption that all condensed water vapor in the cloud fell out as rain. Significant amounts are, in fact, carried aloft in the cloud and thrown out into the atmosphere, mainly as ice crystals (leading to extensive cirrus cloud cover). The main source of water vapor for the atmosphere proves to be falling droplets and ice crystals that reevaporate into the environment. What causes a cloud to loft more water substance is not totally known, but it appears to be related (not surprisingly) to how fast cloud air is rising. Our 1st study did, in fact, show why cloud air would rise faster in a colder climate. These results appear to conflict with recent studies by A Raval and V Ramanathan21 and D Rind and coworkers22 purporting to “prove” positive water-vapor feedback on the basis of satellite observations. Both papers incorporate many serious problems,17,28 but they share 1 fatal problem. They both assume that water vapor above the turbulent surface layer (approximately the bottom 2 km) is uniquely determined by surface temperatures immediately below. They, therefore, take local surface temperatures determined by geometry and season as surrogates for climate. Unfortunately, over the bulk of the atmosphere (99.9% in the tropics), air gently subsides in order to compensate the rapid ascent in the active cumulus towers (which occupy ~0.1% of the area). Thus the air above the surface layer is decoupled from the surface immediately below.

An appropriate observational test would consist in comparing the time histories of global average temperature and of global averaged specific humidity (ie, water-vapor density) in the upper troposphere (above 2 to 3 km or, in meteorological parlance, 800 to 700 mb). Such a study is being undertaken by Abraham Oort at Princeton University (A Oort, conversation 1992). His preliminary results suggest that the global warming of the late 1970s and early 1980s was accompanied with decreasing globally averaged specific humidity in the upper troposphere. The reduction at 300 mb (~9 km above the surface) amounts to almost 20%. The implications of this result are truly profound. If it holds up, it unambiguously implies such a strong negative feedback as to hold all changes from increasing CO2 to a small fraction of a degree.27 Recent results from European satellite measurements have added further support for the upper tropospheric drying mechanism, and have identified model errors in connection with this mechanism (J Schmetz and L van de Berg, correspondence 1992).

It is commonly suggested that society should not depend on negative feedbacks to spare us from a “greenhouse catastrophe.” This is a peculiar perversion of science, if the negative feedbacks are a sound consequence of scientific knowledge. Moreover, what is omitted from such suggestions is that current models depend heavily on artificial “positive” feedbacks to predict high levels of warming. The positive feedback from clouds has been receiving the closest scrutiny. This is not unreasonable. Cloud cover in models is poorly treated and inaccurately predicted.13 Yet clouds reflect ~75 W/m2. Given that a doubling of CO2 will change the surface flux by only 2 W/m2, it is evident that a small change in cloud cover can strongly affect the response to CO2.

The situation is complicated by the fact that clouds at high altitudes can also supplement the greenhouse effect. Indeed, the effects of clouds in
reflecting light and in enhancing the greenhouse effect are roughly in balance. Their actual effect on climate depends both on the response of clouds to warming, and on the possible imbalance of their cooling and heating effects. Similarly, feedbacks involving the contribution of snow cover to reflectivity serve, in current models, to amplify warming due to increasing CO₂. What happens seems reasonable enough; warmer climates presumably are associated with less snow cover and less reflectivity (Figure 7)—which, in turn, amplifies the warming. However, it snows in winter when incident sunlight is minimal. Moreover, clouds shield the sun from the surface and minimize the response to snow cover. Indeed, evidence is growing that clouds accompany diminishing snow cover to such an extent as to turn this feedback negative.⁹

If, however, we ask why current models predict that large warming will accompany increasing CO₂, the answer is mostly the water-vapor feedback. Current models all predict that warmer climates will be accompanied by increasing humidity at all levels (Figure 8). As already noted, this behavior is an artifact of the models, since they have neither the physics nor the numerical accuracy to deal with water vapor. As we have noted, recent studies of the physics of how deep clouds moisten the atmosphere strongly suggest that this largest of the positive feedbacks is not only negative, but very large,²⁷ and these results are supported by the latest data (A Oort, conversation 1992; J Schmetz and L van de Berg, correspondence 1992).

Conclusion

Clearly there are major reasons to believe that models are exaggerating climatic response to increasing CO₂. Perhaps even more significant, the models' predictions for the past century incorrectly describe the pattern of warming, and overestimate its magnitude. The temperature record is irregular and not without problems (Figure 9). However, it does show an average increase in temperature of ~0.45°C±0.15°C with most of the increase occurring before 1940, followed by some cooling through the early 1970s, and a rapid (but modest) temperature increase in the late 1970s. Now, as we have noted, we have already seen an increase in "equivalent" CO₂ of 50%. Thus, on the basis of models that predict a 4°C warming for a doubling of CO₂ we might expect to have seen 2°C already. However, if the delay imposed by the ocean's heat capacity is included, the expectation is reduced to ~1°C. This is still twice what we have actually seen. Moreover, most of what has been seen occurred before the bulk of the minor greenhouse gases was added to the atmosphere. The past record is most consistent with an equilibrium response to a doubling of ~1.3°C—assuming that all the observed warming was due to increasing CO₂. (For models with differing equilibrium sensitivities to a doubling of CO₂ see Figure 10.) However, there is nothing in the record that can be distinguished from the natural variability of the climate. If we consider the tropics, the situation is even more disturbing. There is ample evidence that the average equatorial sea surface has remained within ±1°C of its present temperature for billions of years,⁶ yet current models predict average warming of 2 to 4°C even at the equator. It should be noted that for much of the Earth's history, the atmosphere had much more CO₂ than is currently anticipated for centuries to come.

G L Stephens and coworkers²⁴ have noted a serious, and unexplained, difficulty with the contribution of layer clouds to greenhouse warming. Such warming involves heating the bottoms of these clouds leading to convective instability within the layer cloud. The resulting instability is incompatible with the observed lifetime of these clouds.

Figure 8.
Huge billowing monsoon cloud formations are backlit against a pink-tinted sky. The land is only dimly visible below in this aerial view.

STEVE MCCURRY
It is sometimes suggested that the time series of CO₂ and temperature obtained from the past 160 000 years from the Vostoc ice core "proves" the relation between CO₂ and climate. It is clear from these time series that during a period of high CO₂ concentration, a major glaciation set on with CO₂ decreasing after several thousand years. How this serves to prove that CO₂ determines climate is a matter of great bafflement.

Figure 9.
Combined land air and sea surface temperatures, 1861 to 1989, relative to 1951 to 1980.¹¹

In this brief paper, I have barely touched upon numerous and fundamental difficulties with present climate models (P Stone discusses such difficulties). Rather, I have focused on the specific reasons for current models to predict substantial global warming from increasing CO₂. It is clear that these reasons are essentially spurious. In addition, both observational and theoretical evidence implies that current predictions are substantially exaggerating the likely warming. None of this constitutes "proof" that significant warming is possible, but, in the unlikely event that it occurs, it most certainly will not be for the reasons currently put forth. Much of the debate on how society should respond to the purported danger of global warming hinges on one's interpretation of and response to "uncertainty." In point of fact, there is neither observational nor theoretical basis for expecting substantial warming. However, the possibility has been suggested. Whether the absence of a rigorous disproof of the possibility is a sufficient basis for action is a political question. "Action" under these circumstances does, however, present certain serious problems. Clearly, there will be no way to establish accountability for the effectiveness of any actions taken. Equally clearly, the inclination of society to respond to unfounded suggestions of alleged catastrophe cannot but impede its ability to respond to real problems.

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