from ***Environmental Science and Technology***
Volume 24, pages 424 - 427

Some Remarks on Global Warming

Richard S. Lindzen
Center for Meteorology and Physical Meteorology
M.I.T., Cambridge, MA 02139

A consideration of the issue of increasing atmospheric carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons and the possibility of consequent global warming presents us with a variety of questions and problems. The gases mentioned all absorb in the infrared portion of the electromagnetic spectrum, and hence are capable of inhibiting the radiative cooling of the Earth. In this brief essay, I will focus on the role of CO_2 – but the other gases are comparably important.

The thought that CO_2 is a polluting gas is particularly daunting. After all, CO_2 is a product of virtually all burning – including breathing. Increasing CO_2 is closely related to increasing population and standard of living. Although the United States contributes proportionally more per capita to CO_2 emission than other parts of the world, its contribution is only about 20% of the total (1). That CO_2 is increasing is not open to serious question. It is currently estimated that the preindustrial concentration of CO_2 was about 280 ppmv. The concentration of CO_2 since 1800 is crudely given by the following simple formula (2):

$$CO_2 = 278.8ppmv + 1.17ppmv \times e^{((year-1800)/45years)}$$

In fact, the e-folding scale has not been all that constant, and the simple extrapolation of future CO_2 from the above formula would be imprudent. However, there is little question that CO_2 has increased about 25% over the last century, and that it will double by some time in the next century. Insofar as the combustion of all fossil fuel resources will lead to an approximate quadrupling of atmospheric CO_2, the above equation must certainly break down within some time period on the order of a century – at which point a major problem may be the depletion of fossil fuels. For many individuals, the increase in CO_2 due to man's activities is of and by itself a matter for concern; there is a common presupposition that such changes *must* do something bad. However, the determination of what this 'something bad' is is a vastly more difficult and uncertain matter. The current candidate is 'global warming'[1].

[1] Exactly how 'bad' both increased CO_2 and warming would be is, itself, extremely unclear and controversial – but that is a matter for another essay.

The idea here is *deceptively* simple: CO_2 absorbs in the infrared and reradiates heat downward, thus heating the earth. Doubling CO_2 adds about 4 watts/m^2 (3) to the downward heat flux – which in the absence of this extra CO_2 would be about 327 watts/m^2 (4). This alerts us to the fact that there is something more important than CO_2 in the infrared absorption spectrum. Indeed, both atmospheric water vapor, and clouds, themselves, are much more important than CO_2 . The fact that both water vapor and cloud cover are both highly variable adds to the complexity of the situation. Small percentage changes in either are fully capable of changing the infrared flux more than the changes induced by increased CO_2 . There is an even more important complication in the simple picture of the 'greenhouse effect': namely, the surface of the earth cools primarily by means of processes other than radiation. These processes are evaporation and turbulent heat exchange. Both the sensible and latent heat are carried away from the surface boundary layer by convective processes including convection by tall cumulonimbus towers which carry the heat deep into the atmosphere where the infrared optical depth is much less. Heat is also transported laterally from regions of high water vapor to colder regions with less water vapor. These processes greatly reduce greenhouse warming. For instance, for existing water vapor and cloud cover, pure radiative equilibrium would lead to an average surface temperature of 350 K – as opposed to the equivalent black body temperature of 255 K which would exist in the absence of an atmosphere (5). The actual average surface temperature is only about 288 K due to the effects of transport. It should be noted that 288 K is much closer to the equivalent black body temperature than to the pure greenhouse temperature – especially when one considers that surface infrared fluxes go as T^4! None of this is meant to suggest that the greenhouse effect is not real (288 K is, after all, warmer than 255 K); the effect, however, is neither simple nor pure.

Warming is a subject riddled by uncertainty. Although much argument currently centers on those feedbacks which may either augment or suppress the direct thermal effects of CO_2 , even those estimates of the effect of doubling CO_2 on globally averaged temperature in the absence of feedbacks vary between 0.6 K and 1.2 K. The larger numbers, commonly cited (1.5 K to 5 K), result from positive feedbacks in models. What is generally agreed on, however, is that the warming effect of increasing CO_2 increases only logarithmically with CO_2 (3). Thus, the effect of the 25% increase of CO_2 over the last century is expected to be proportionally greater than the effect of doubling CO_2 in the next several decades. Based on equilibrium calculations, temperature increases ranging from about 0.6 K (no feedbacks) to 2.5 K (from models predicting 5 K warmings from a doubling of CO_2) should have occurred over the last century based on the known increases in minor greenhouse gases. Of course, the climate system is not in equilibrium. The response time depends on heat transport between the ocean surface and underlying layers, and the degree of feedback in the atmosphere – matters which are in the realm of gross uncertainty. However, all models –

even models with very long response times – still predict that at least 0.5 K of warming should have occurred over the last century. This is probably the main reason for the intense scrutiny of historical climate records for evidence of small warming trends.

Some evidence for such a warming trend (between 1880 and the present) is indeed claimed on the basis of land based thermometric measurements (6). Unfortunately, this record suffers from a number of severe problems. The record displays irregular (and probably natural) variability of the same magnitude (0.5 K) on all time scales – including time scales that probably exceed the length of the record. The 0.5 K increase almost totally occurs by 1940 – before the bulk of CO_2 and other minor greenhouse gases were added. The individual records are significantly affected by urbanization, shifts of measurement sites, etc. Corrections are highly uncertain and of the order of the sought for effect. Finally, it is questionable whether the existing array of land based measuring sites is adequate for sampling a global change. These doubts are reenforced by the fact that the (comparably uncertain) record of sea surface temperature taken from ship measurements shows no change of temperature between the nineteenth century and the present (7). Similarly, the dense and carefully corrected record of temperature for the continental U.S. shows almost no significant warming since 1900 (8). Finally, globally averaged satellite measurements over the past decade correlate poorly with the land based record (9) – adding to the suspicion of sampling problems. The existing data is completely compatible with the possibility that no warming has occurred over the past century (which would demand significant negative feedbacks). It is also compatible with the possibility of some warming – in line with the smallest model predictions. Compatibility with the larger model predictions demands very long thermal lag times – but these too cannot be rejected on the basis of current knowledge.

Finally, we must turn to the models. It is from model results that our fear of profound greenhouse warming arises. There are currently five large scale climate models, and these models currently predict warmings of from 1.5 K to 5 K arising from a doubling of CO_2 . Dependence on these models is an awkward situation to be in. As we have already noted, the doubling of CO_2 will increase the downward infrared flux at the surface by about 4 watts/m^2/sec; the solar flux in existing models must be adjusted by many times this quantity simply in order to get the present day global temperature correct. Further, as we have seen, the thermal effect of doubling CO_2 alone is modest. The predictions are larger because of positive feedbacks in the models – primarily involving water vapor and clouds (the major greenhouse constituents in the atmosphere). The treatment of water vapor and clouds are among the weakest and most uncertain features of these models. Modest changes in these treatments are known to dramatically affect the model predictions (10, 11). Moreover, the treatment of clouds and water vapor depend implicitly (and explicitly) on many of the other weak points in present models: boundary layer turbulence, interactions with vegetation, air-sea exchange, etc. It is even likely that there are processes we haven't yet considered. One can only conclude that the current state of large scale climate models precludes their credible use in predicting the thermal effects of increasing CO_2 .

Where then does this leave us? How do we respond to unobserved changes predicted by models operating beyond the limits of their credible performance? As it turns out, there is one thing that we do know – despite all the uncertainties. It is easy to see that every suggested policy designed to prevent warming will have almost no effect on warming. Certainly if there is no warming, the policies will have no effect, but even if the most pessimistic models prove to be right (unlikely as that may be), the effect will not be significantly greater. Given the logarithmic dependence of warming on CO_2 , the *elimination* of America's 20% contribution to CO_2 production will merely reduce warming by a fraction of a degree – a reduction that would be wiped out in a few years. Even with international cooperation, the draconian sacrifices that would be required of much of the world are unlikely to be made – and perhaps should not. Indeed, if the most pessimistic models were to be right, much of the warming is already 'in the pipeline'. Dealing with situations like this in a responsible manner will be a worthy challenge for environmentalism in the 90's.

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