Real-World Constraints on Global Warming

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Often lost in the heat of debate over global warming is the fact that the greenhouse effect of CO₂ is not in question: rising carbon dioxide concentrations, in and of themselves, do indeed have a tendency to enhance the thermal-blanketing properties of the atmosphere. Opinions diverge, however, about what happens when this phenomenon begins to operate, for practically nothing in nature happens in isolation, and numerous feedbacks—both positive and negative—severely cloud the issue.

Proponents of the theory that a dangerous level of CO₂-induced global warming is likely to occur believe that positive feedbacks that enhance the initial rise in temperature produce the major portion of whatever temperature increase ultimately occurs (or is predicted to occur). Detractors of the theory that a dangerous level of CO₂-induced global warming is likely to occur believe that negative feedbacks are capable of drastically reducing the initial impetus for warming. Some, like myself, believe that such feedbacks can negate totally the initial warming impetus; and it is the evidence for this latter position that I will discuss in this small treatise.
Negative feedbacks

There are at least three major categories of negative feedback mechanisms that are germane to the issue of CO₂-induced global warming. First—and most recognized—are the mechanisms by which rising temperatures may strengthen the cooling properties of clouds by purely physical means. Second are the mechanisms by which rising temperatures intensify biological processes that eventually lead to an enhancement of some of the same cloud-cooling properties. Third are the mechanisms by which some of these biological processes are directly enhanced by the “aerial fertilization effect” of increased concentrations of atmospheric CO₂ so that they are not dependent upon an initial warming to set the ultimate cloud-cooling processes in motion. In the following subsections, I shall describe these three types of negative feedbacks briefly and give illustrations of their great cooling power.

Feedbacks using physical processes

It has long been recognized that the presence of clouds has a strong cooling effect on earth’s climate (Barkstrom 1984; ERBE Science Team 1986; Nullet 1987; Nullet and Ekern 1988; Ramanathan et al. 1989). In fact, it has been calculated that a mere one percent increase in planetary albedo (i.e. the ratio of light reflected by the earth to that received by it) would be sufficient to counter totally the entire greenhouse warming that is typically predicted to result from a doubling of the atmosphere’s CO₂ concentration (Ramanathan 1988).

Within this context, it has been independently demonstrated that a 10 percent increase in the amount of low-level cloud could also completely cancel the warming that is typically predicted to occur as a result of a doubling of the air’s CO₂ content, again by reflecting more solar radiation back to space (Webster and Stephens 1984). In addition, Ramanathan and Collins (1991), by the use of certain “natural experiments,” have shown how the warming-induced production of high-level clouds over the equatorial oceans almost totally nullifies the powerful greenhouse effect of water vapor there. In fact, Kiehl (1994) has described how the presence of high-level clouds in this area dramatically increases from close to 0 percent coverage when temperatures at the sea’s surface are 26°C to fully 30 percent coverage when they are 29°C. The implication of this strong negative feedback mech-
anism is that “it would take more than an order-of-magnitude increase in atmospheric CO₂ to increase the maximum sea surface temperature by a few degrees” (Ramanathan and Collins 1991: 32). They acknowledge that this estimate is a considerable departure from the predictions of most general circulation models of the atmosphere but I will shortly show it to be in complete harmony with a variety of real-world observations.

In addition to increasing their areal coverage of the planet—as they typically do in response to an increase in temperature (Henderson-Sellers 1986a, 1986b; McGuffie and Henderson-Sellers 1988; Dai et al. 1997)—clouds in a warmer world would likely have greater liquid-water content than they do now (Paltridge 1980; Charlock 1981, 1982; Roeckner 1988). And, as the heat-conserving greenhouse properties of low- to mid-level clouds are already close to the maximum they can attain (Betts and Harshvardhan 1987) while their reflectances for solar radiation may yet rise substantially (Roeckner et al. 1987), an increase in the liquid-water content of clouds would tend to counteract an impetus for warming even in the absence of an increase in cloud cover. In fact, by incorporating just this one negative feedback mechanism into a radiative-convective climate model, the warming predicted to result from a doubling of the air’s CO₂ content has been shown to fall by fully 50 percent (Somerville and Remer 1984) while a 20 percent to 25 percent increase in liquid water in clouds has been shown, in a three-dimensional general circulation model of the atmosphere, to negate totally the typically predicted warming due to a doubling of the air’s CO₂ content (Slingo 1990).

**Feedbacks using biological processes**

Charlson et al. (1987) have described another negative feedback mechanism involving clouds, which has been calculated to be of the same strength as the typically predicted greenhouse effect of CO₂ (Lovelock 1988; Turner et al. 1996). These investigators suggest that the productivity of oceanic phytoplankton will increase in response to an initial impetus for warming, with the result that one of the ultimate by-products of the enhanced algal metabolism—dimethyl sulfide (DMS)—will be produced in significantly greater quantities. Diffusing into the atmosphere, where it is oxidized and converted into particles that function as cloud-condensation nuclei, this augmented flux of DMS has
been projected to create additional clouds and/or clouds with a higher albedo. This should reflect more solar radiation back to space, thereby cooling the earth and countering the initial im- petus for warming (Shaw 1983, 1987).

There is much evidence—700 papers in the past 10 years (Andreae and Crutzen 1997)—to support the validity of each link in this conceptual chain of events. First, there is the demonstrated propensity for oceanic phytoplankton to increase their productivity in response to an increase in temperature (Eppley 1972; Goldman and Carpenter 1974; Rhea and Gotham 1981); this propensity is clearly evident in latitudinal distributions of marine productivity (Platt and Sathyendranath 1988; Sakshaug 1988). Second, as oceanic phytoplankton photosynthesize, they produce a substance called dimethylsulfonio propionate (Vairavamurthy et al. 1985), which disperses throughout the surface waters of the oceans when the phytoplankton die or are eaten by zooplankton (Nguyen et al. 1988; Dacey and Wakeham 1988) and decomposes to produce DMS (Turner et al. 1988). Third, it has been shown that part of the DMS thus released to the earth’s oceans diffuses into the atmosphere, where it is oxidized and converted into sulfuric and methanesulfonic acid particles (Bonsang et al. 1980; Hatakeyama et al. 1982; Saltzman et al. 1983; Andreae et al. 1988; Kreidenweis and Seinfeld 1988) that function as cloud-condensation nuclei (CCN) (Saxena 1983; Bates et al. 1987). Fourth, more CCN can clearly stimulate the production of new clouds and dramatically increase the albedos of pre-existent clouds by decreasing the sizes of the clouds’ component droplets (Twomey and Warner 1967; Warner and Twomey 1967; Hudson 1983; Coakley et al. 1987; Charlson and Bates 1988; Durkee 1988). This latter phenomenon then tends to cool the planet by enabling clouds to reflect more solar radiation back to space (Idso 1992b; Saxena et al. 1996). In fact, it has been calculated that a 15 percent to 20 percent reduction in the mean droplet radius of earth’s boundary-layer clouds would produce a cooling influence that could completely cancel the typically predicted warming due to a doubling of the air’s CO₂ content (Slingo 1990).

Another way in which the enhanced production of CCN may retard global warming via a decrease in size of droplets in clouds is by reducing drizzle from low-level marine clouds, which length-
ens their life span and thereby expands their coverage of the planet (Albrecht 1988). In addition, since drizzle from stratus clouds tends to stabilize the atmospheric boundary layer by cooling the sub-cloud layer as a portion of the drizzle evaporates (Brost et al. 1982; Nicholls 1984), a CCN-induced reduction in drizzle tends to weaken the stable stratification of the boundary layer, enhancing the transport of water vapor from ocean to cloud. As a result, clouds containing extra CCN tend to persist longer and perform their cooling function for a longer period of time.

The greater numbers of CCNs needed to enhance these several cooling phenomena are also produced by biological processes on land (Went 1966; Duce et al. 1983; Roosen and Angione 1984; Meszaros 1988) and in the terrestrial environment, the volatilization of reduced-sulfur gases from soils is particularly important in this regard (Idso 1990). Here, too, one of the ways in which the ultimate cooling effect is set in motion is by an initial impetus for warming. It has been reported, for example, that soil DMS emissions rise by a factor of two for each 5°C increase in temperature between 10°C and 25°C (Staubes et al. 1989) and, as a result of the enhanced microbial activity produced by increasing warmth (Hill et al. 1978; MacTaggart et al. 1987), there is a 25-fold increase in soil-to-air sulfur flux between 25°N and the equator (Adams et al. 1981). Of perhaps even greater importance, however, is the fact that increased concentrations of atmospheric CO₂ alone can initiate the chain of events that leads to cooling.

**Feedbacks resulting from increased levels of atmospheric CO₂**

Consider the fact—impressively supported by literally hundreds of laboratory and field experiments (Lemon 1983; Cure and Acock 1986; Mortensen 1987; Lawlor and Mitchell 1991; Drake 1992; Poorter 1993; Idso and Idso 1994; Strain and Cure 1994)—that nearly all plants are better adapted to concentrations of atmospheric CO₂ higher than those of the present, and that the productivity of most herbaceous plants rises by 30 percent to 40 percent in the presence of a 300 ppm to 600 ppm increase in the air’s CO₂ content (Kimball 1983; Idso 1992a), while the growth of many woody plants rises even more dramatically (Idso and Kimball 1993; Ceulemans and Mousseau 1994; Wullschleger et al. 1995, 1997). Because of this stimulatory
effect on plant growth and development, the productivity of the biosphere has been rising hand in hand with the recent rise in the air’s CO₂ content (Idso 1995); this is evident in (1) the ever increasing amplitude of the seasonal cycle of the air’s CO₂ concentration (Pearman and Hyson 1981; Cleveland et al. 1983; Bacastow et al. 1985; Keeling et al. 1985, 1995, 1996; Myneni et al. 1997), (2) the upward trends in a number of long tree-ring records that mirror the progression of the Industrial Revolution (LaMarche et al. 1984; Graybill and Idso 1993; Idso 1995), and (3) the accelerating growth rates of numerous forests on nearly every continent of the globe over the past several decades (Kauppi et al. 1992; Phillips and Gentry 1994; Pimm and Sugden 1994; Idso 1995).

In consequence of this CO₂-induced increase in plant productivity, more organic matter is returned to the soil (Leavitt et al. 1994; Jongen et al. 1995; Batjes and Sombroek 1997), where it stimulates biological activity (Curtis et al. 1990; Zak et al. 1993; O’Neill 1994; Rogers et al. 1994; Ineichen et al. 1997; Ringelberg et al. 1997; Godbold and Berntson 1997) that results in the enhanced emission of various sulfur gases to the atmosphere (Staubes et al. 1989), whereupon more CCNs are created (as described above), which tend to cool the planet by altering cloud properties in ways that result in the reflection of more solar radiation back to space. In addition, many non-sulfur biogenic materials of the terrestrial environment play major roles as both water- and ice-nucleating aerosols (Schnell and Vali 1976; Vali et al. 1976; Bigg 1990; Novakov and Penner 1993; Saxena et al. 1995; Baker 1997); and the airborne presence of these materials should also be enhanced by increased concentrations of atmospheric CO₂.

Analogous CO₂-induced cooling processes likely operate at sea as well. It is well established, for example, that increased concentrations of atmospheric CO₂ stimulates the growth of both macro-aquatic plants (Titus et al. 1990; Sand-Jensen et al. 1992; Titus 1992; Madsen 1993; Madsen and Sand-Jensen 1994) and micro-aquatic plants (Raven 1991, 1993; Riebesell 1993; Shapiro 1997). In addition, it has been demonstrated in a major experimental program (Coale et al. 1996) that adding iron to the high-nitrate low-chlorophyll waters of the equatorial Pacific significantly stimulates the productivity of oceanic phytoplankton (Behrenfeld et al. 1996) and this surrogate for a CO₂-induced in-
crease in marine productivity has been observed to increase surface-water DMS concentrations greatly (Turner et al. 1996). There is also evidence to suggest that a significant fraction of the ice-forming nuclei of maritime origin are composed of organic matter (Rosinski et al. 1986, 1987); and the distribution of these nuclei over the oceans (Bigg 1973) has been shown to be strongly correlated with surface patterns of biological productivity (Bigg 1996; Szyrmer and Zawadzki 1997). Hence, it is clear that there exists an entire suite of powerful planetary cooling forces that can respond directly to the rising carbon dioxide content of the atmosphere over both land and sea. And these CO$_2$-induced cooling forces could negate a large portion (or even all) of the primary warming effect of a rise in atmospheric CO$_2$, leading to little or no net change in mean global air temperature.

**Evidence for muted global warming**

The power of nature’s negative feedbacks, like the theory of CO$_2$-induced global warming, must be evaluated against real-world evidence. Hence, in the subsections that follow, I make such evaluations for 4 global climatic situations that incorporate all the real-world phenomena that combine to produce the equilibrium results derived therein.

*The greenhouse effect in the earth’s whole atmosphere*

The current greenhouse effect of earth’s entire atmosphere warms the surface of the planet by approximately 33.6°C as the result of a surface-directed thermal radiation flux of approximately 348Wm$^{-2}$ (Watts per square metre) (Idso 1980, 1982). Dividing the first of these numbers by the second yields what could be called a surface air-temperature sensitivity factor, which for this particular situation has a value of 0.097°C/Wm$^{-2}$. Multiplying this factor by 4Wm$^{-2}$—the value by which the flux of thermal radiation to the earth’s surface is expected to rise as a result of a 300 ppm to 600 ppm increase in the air’s CO$_2$ concentration (Smagorinsky et al. 1982; Nierenberg et al. 1983; Shine et al. 1990)—yields a mean global warming of 0.39°C, which is but one-tenth to one-third of the warming that has been predicted for this scenario by the majority of the general-circulation models of the atmosphere that have been applied to this problem (Kacholia and Reck 1997).
**Latitudinally-dependent greenhouse effect**

A second evaluation of the likely warming to be expected from a doubling of the air’s CO$_2$ content can be derived from the annually averaged equator-to-pole air-temperature gradient that is sustained by the annually averaged equator-to-pole gradient of total radiant energy absorbed at the surface (Idso 1984). Mean surface air-temperatures and water-vapor pressures required for this calculation can be obtained for each five-degree latitude increment stretching from 90°N to 90°S from information reported by Warren and Schneider (1979) and Haurwitz and Austin (1944). From these data, I calculated values of clear-sky atmospheric thermal radiation (Idso 1981) incident upon the surface of the earth at the midpoints of each of the specified latitude belts. Then, from information about the latitudinal distribution of cloud cover (Sellers 1965) and the ways in which clouds modify the clear-sky flux of downwelling thermal radiation at the earth’s surface (Kimball *et al.* 1982), I appropriately modified the clear-sky thermal radiation fluxes and averaged the results over both hemispheres. Similarly averaged fluxes of surface-absorbed solar radiation (Sellers 1965) were then added to the thermal-radiation results to produce 19 annually averaged total surface-absorbed radiant-energy fluxes stretching from the equator to 90°N/S, against which I plotted the corresponding average values of mean surface air temperature.

This operation produced two distinct linear relationships—one of slope 0.196°C/Wm$^{-2}$, which extended from 90°N/S to approximately 63°N/S, and one of slope 0.090°C/Wm$^{-2}$, which extended from 63°N/S to the equator. I thus weighted the two results according to the percentages of earth’s surface area to which they pertained (12 percent and 88 percent, respectively) and combined them to obtain a mean global value of 0.103°C/Wm$^{-2}$. Multiplying this result, as before, by 4Wm$^{-2}$ then yields a mean global warming of approximately 0.41°C, which is essentially the same amount of warming I derived from the prior whole-atmosphere calculation.

**The greenhouse effect from an increased concentration of atmospheric CO$_2$ over geologic time**

The same result may also be obtained from the standard resolution of the paradox of the faint early sun (Sagan and Mullen 1972; Owen *et al.* 1979; Kasting 1997), a dilemma (Sagan and
Chyba 1997; Longdoz and Francois 1997) that is most often posed by the following question: how could earth have supported life nearly 4 billion years ago when, according to well-established concepts of stellar evolution (Schwarzschild et al. 1957; Ezer and Cameron 1965; Bahcall and Shaviv 1968; Iben 1969), the luminosity of the sun was probably 20 percent to 30 percent less than it is now (Newman and Rood 1977; Gough 1981), so that, all else being equal, nearly all of earth’s water should have been frozen and unavailable for sustaining life (Schopf and Barghourn 1967; Knauth and Epstein 1976; Schopf 1978; Lowe 1980; Schidlowski 1988)?

Most who have studied the problem feel that the answer to this question resides primarily in the large greenhouse effect of earth’s early atmosphere, which is believed to have contained much more CO₂ than it does today (Hart 1978; Holland 1984; Wigley and Brimblecombe 1981; Walker 1985). Consequently, based on the standard assumption of a 25 percent reduction in solar luminosity 4.5 billion years ago, I calculated the strength of the CO₂ greenhouse effect required to compensate for the effects of reduced solar luminosity at half-billion year intervals from 3.5 billion years ago—when we are confident of the widespread existence of life (Mojzsis et al. 1996; Eiler et al. 1997)—to the present. I plotted the results as a function of the atmospheric CO₂ concentration derived from a widely accepted atmospheric CO₂ history for that period of time (Lovelock and Whitfield 1982). Using the relationship derived from that exercise to calculate the effects of a 300 ppm to 600 ppm increase in the air’s CO₂ concentration, I once again obtained a mean global warming of only 0.4°C (Idso 1988).

The greenhouse effect from increased concentration of atmospheric CO₂ on Mars and Venus

Consider, finally, what we can learn from our nearest planetary neighbors, Mars and Venus. In spite of the tremendous differences that exist between them, and between them and the earth, their observed surface temperatures have been said to confirm “the existence, nature, and magnitude of the greenhouse effect” ((Smagorinsky et al. 1982: 5; Nierenberg et al. 1983: 274) by two select committees of the United States National Research Council, a conclusion that also appears to be accepted by the Intergovernmental Panel on Climate Change (Trenberth et al. 1996).
Venus exhibits a greenhouse warming of approximately 500°C (Oyama et al. 1979; Pollack et al. 1980) that is produced by a 93-bar atmosphere of approximately 96 percent CO₂ (Kasting et al. 1988); Mars exhibits a greenhouse warming of 5 to 6°C (Pollack 1979; Kasting et al. 1988) that is produced by an almost pure CO₂ atmosphere that fluctuates over the Martian year between 0.007 and 0.010 bar (McKay 1983). Plotting the two points defined by these data on a log-log coordinate system of CO₂-induced global warming versus the partial pressure of atmospheric CO₂ and connecting them by a straight line produces a relationship that, when extrapolated to CO₂ partial pressures characteristic of present-day earth, once again yields a mean global warming of only 0.4°C for a 300 ppm to 600 ppm increase in the air’s CO₂ content (Idso 1988). And no other simple line that can be drawn through these real-worlds data produces any greater warming.

**Summary and conclusions**

Earth’s climate system possesses a number of highly effective negative feedback mechanisms that tend to inhibit CO₂-induced global warming. Some of these phenomena are driven by purely physical forces and they begin to exert their cooling influence in response to an initial rise in temperature. Others have a biological origin, but also respond to increasing warmth. The scientific literature provides several demonstrations of their individual capacities to negate totally the ultimate equilibrium warming that is typically predicted to result from a doubling of the atmosphere’s carbon dioxide concentration.

To this arsenal of powerful climate-stabilizing forces can be added yet a third set of real-world brakes on CO₂-induced global warming: cooling forces that have their origins in biological phenomena that are directly enhanced by the aerial fertilization by increased concentrations of atmospheric CO₂. Operating with or without an initial impetus for warming, these forces have the potential to lead to a cooling of the planet, since any of the warming-induced negative feedbacks could nullify the greenhouse effect of a rise in atmospheric CO₂, leaving the CO₂-induced cooling forces to drive temperatures down even further.

Solid support for these feedback scenarios comes from a number of real-world climatic observations. First and foremost are the empirically based evaluations that I have made of the ulti-
mate warming likely to be produced by an increase in downward-directed thermal radiation equivalent to that expected to be received at the surface of the earth as a result of a doubling of the air’s CO$_2$ content, warming that is only one-tenth to one-third of what has typically been predicted for this situation by most of the general-circulation models of the atmosphere that are currently in vogue. Secondary support is provided by the suite of recent observational studies that have revealed that contemporary climate models have long significantly underestimated the cooling power of clouds (Cess et al. 1995; Ramanathan et al. 1995; Pilewskie and Valero 1995; Heymsfield and McFarquhar 1996), even when demonstrating the abilities of cloud-related cooling forces to negate totally the large global warming that is generally predicted to result from a doubling of the atmosphere’s CO$_2$ concentration.

In view of these facts, I find no compelling reason to believe that the earth will necessarily experience any global warming as a consequence of the ongoing rise in the atmosphere’s carbon dioxide concentration. There could be a CO$_2$-induced increase in mean global air temperature, but it would have to be small—no more than 0.4°C for a 300 ppm to 600 ppm increase in the air’s CO$_2$ content. Then, again, it is even possible that the planet could cool somewhat in response to a rise in atmospheric CO$_2$. Our current understanding of the planet’s complex climate system is just not sufficient to draw any more detailed conclusions.

References


