Reports

The Climatological Significance of a Doubling of Earth's Atmospheric Carbon Dioxide Concentration

Abstract. *The mean global increase in thermal radiation received at the surface of the earth as a consequence of a doubling of the atmospheric carbon dioxide content is calculated to be 2.28 watts per square meter. Multiplying this forcing function by the atmosphere's surface air temperature response function, which has recently been determined by three independent experimental analyses to have a mean global value of 0.113 K per watt per square meter, yields a value of ≤ 0.26 K for the resultant change in the mean global surface air temperature. This result is about one order of magnitude less than those obtained from most theoretical numerical models, but it is virtually identical to the result of a fourth experimental approach to the problem described by Newell and Dopplick. There thus appears to be a major discrepancy between current theory and experiment relative to the effects of carbon dioxide on climate. Until this discrepancy is resolved, we should not be too quick to limit our options in the selection of future energy alternatives.*

According to the CO_2 theory of climatic change, an increase in the earth's atmospheric CO_2 concentration will tend to raise surface air temperatures as a result of the moderating influence of CO_2 on the loss of terrestrial surface radiation to space. There is practically universal scientific assent about this potential temperature increase (*1*). There is a greater latitude of opinion about the magnitude of the effect, with estimates of the increase in the mean global surface air temperature resulting from a doubling of the atmospheric CO_2 concentration ranging from a low of less than 1 K to a high of almost 10 K (*2*).

Since many important decisions related to the development of future energy sources must soon be made that will have a major impact on the rate of increase in atmospheric CO_2, it is imperative that this extreme range of predictions be narrowed. Although a consensus in the range of 2 to 4 K is beginning to emerge for a doubling of the CO_2 concentration (*3*), safety is not necessarily to be found in numbers in this instance, for the studies that predict effects in this range are all too similar to be regarded as independent routes to a common solution. Indeed, practically all such studies during the past decade have been carried out by means of theoretical numerical models, generally of the radiative-convective type introduced by Manabe and Wetherald (*4*). Thus, I attempt here to provide a fresh outlook on the problem by breaking with this tradition and using a truly independent experimental approach. The answer I obtain casts grave doubts upon the common result of the many theoretical numerical models.

The problem has two major aspects. One is to determine the magnitude of the forcing function for surface air temperature change that results from an increase in atmospheric CO_2 concentration, and the other is to determine the magnitude of the surface air temperature response function of the atmosphere; the product of these two numbers will yield the desired change in surface air temperature.

Solution of the first part of the problem is begun by utilizing the experimental data of Staley and Jurica (*5*) to determine the change in the effective emittance of the cloudless atmosphere exhibited at ground level that would occur as a consequence of increasing the mean atmospheric CO_2 concentration from 300 to 600 parts per million (ppm). The answer is 0.0175, but, because there is an overlap in the radiative effects of CO_2 and H_2O vapor, the net effective result is considerably smaller.

To evaluate the magnitude of the required overlap correction, it is necessary to know the mean global surface H_2O vapor pressure. Sellers (*6*) lists a value of 2.47 cm for the mean global precipitable water content of the atmosphere. Converting this value to a surface H_2O vapor pressure by the relation of Idso (*7*) yields 1.55×10^3 Pa, whereas the relation of Monteith (*8*) yields 1.64×10^3 Pa. The mean value of 1.60×10^3 Pa, when used with the data of Staley and Jurica, gives an H_2O-CO_2 overlap correction that conservatively indicates that the net change in total atmospheric emittance induced by a doubling of the CO_2 concentration is only one-half of the 0.0175 previously calculated, or 0.00875.

Now this is the increase to be expected in clear sky atmospheric emittance; for the entire globe, allowance must be made for the mitigating effects of clouds. This is accomplished by writing an expression for the mean emittance of the global atmosphere (ϵ_m) in terms of the clear sky atmospheric emittance (ϵ_a), cloudy sky emittance (ϵ_c), and the mean earth fractional cloud cover (n):

$$\epsilon_m = (1 - n)\,\epsilon_a + n\,\epsilon_c \qquad (1)$$

Since the atmosphere is nearly black outside of the window region, ϵ_c can be expressed as ϵ_a plus the ratio of transmitted blackbody radiation from the cloud base divided by the blackbody flux density at screen-level air temperature, as follows:

$$\epsilon_c = \epsilon_a + \frac{(1 - \epsilon_a)\sigma T_c^4}{\sigma T_0^4} = \epsilon_a + (1 - \epsilon_a)\left(\frac{T_c}{T_0}\right)^4 \qquad (2)$$

where σ is the Stefan-Boltzmann constant, T_c is the temperature of the cloud base, and T_0 is the surface air temperature.

Utilizing data in Paltridge and Platt (*9*) to calculate the mean global cloud height and a consequent T_c of 255 K and using a value of 288 K for T_0, Eq. 2 reduces to

$$\epsilon_c = 0.614 + 0.386\,\epsilon_a$$

Substituting this expression for ϵ_c in Eq. 1 and using the value for n of 0.54 given by Sellers (*6*) then yields

$$\epsilon_m = 0.332 + 0.668\,\epsilon_a$$

Thus, the calculated $\Delta\epsilon_a$ of 0.00875, which was derived for a doubling of the global atmospheric CO_2 concentration from 300 to 600 ppm, results in a $\Delta\epsilon_m$ of only 0.0058.

One thus evaluates the forcing function for the change in T_0 by multiplying this value of $\Delta\epsilon_m$ by the blackbody energy flux at the mean global T_0 value of 288 K. The final result is 2.28 W m^{-2}.

What are the consequences on the surface air temperature of such an increase in thermal radiant heat flux to the earth's surface? To find out, it is necessary to solve the second part of the problem and

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numerically determine the surface air temperature response function of the atmosphere. Fortunately, this response function has recently been evaluated by three independent experimental means (*10*). The value obtained over land is 0.175 K per watt per square meter, whereas over the ocean it appears to be at least 50 percent smaller. Thus, for the entire globe, which has 70 percent of its surface area covered by oceans, the mean value of the surface air temperature response function is 0.113 K per watt per square meter or less.

The rise in surface air temperature to be expected from a doubling of the earth's atmospheric CO_2 concentration is consequently determined to be $\leq$ (0.113 K W^{-1} m^2) (2.28 W m^{-2}) = $\leq$ 0.26 K. For the entire planet, a doubling of the atmospheric CO_2 concentration would produce a change in T_0 practically indistinguishable from climatic "noise," fully an order of magnitude less than the predictions of the theoretical numerical models in vogue today. However, this result is virtually identical to the value of $\leq$ 0.25 K obtained by Newell and Dopplick (*11*). Since these two completely independent experimental studies produce a common result so much lower than previous theoretical estimates, a serious reconsideration of the whole CO_2-climate problem seems imperative.

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References and Notes

1. One possible exception to this consensus is the recent paper by B. Choudhury and G. Kukla [*Nature (London)* **280**, 668 (1979)], wherein the authors investigate the effects of increased atmospheric CO_2 on the solar radiation available for absorption by water and snow; the resultant energy deficit, when not compensated by enhanced downwelling atmospheric thermal radiation, may delay the recrystallization of snow and the dissipation of pack ice to yield a cooling rather than a warming effect. Calculations by Newell and Dopplick (*11*), however, indicate that the thermal radiation enhancement is indeed much larger than the solar radiation reduction, basically negating the possibility raised by Choudhury and Kukla.
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Core Drilling Through the Ross Ice Shelf (Antarctica) Confirmed Basal Freezing

Abstract. *New techniques that have been used to obtain a continuous ice core through the whole 416-meter thickness of the Ross Ice Shelf at Camp J-9 have demonstrated that the bottom 6 meters of the ice shelf consists of sea ice. The rate of basal freezing that is forming this ice is estimated by different methods to be 2 centimeters of ice per year. The sea ice is composed of large vertical crystals, which form the waffle-like lower boundary of the shelf. A distinct alignment of the crystals throughout the sea ice layer suggests the presence of persistent long-term currents beneath the ice shelf.*

In 1978, as part of the Ross Ice Shelf Project (*1*), we obtained a core through the ice shelf in the area of Camp J-9 (82° 22′S, 168°37′W; Fig. 1a), using an antifreeze thermal-drilling method. This procedure, developed by V. A. Morev of the Arctic and Antarctic Research Institute, Leningrad, and one us (I.A.Z.), consisted of adding an antifreeze component to the melted water within the hole in order to keep it from freezing at low temperatures, instead of taking this water from the hole. The necessary drilling equipment was designed and built by Morev (*2*). Core drilling through the ice shelf began on 1 December 1978 (*3*) and was completed in 13 days. An ethyl alcohol-water solution was used as the antifreeze. Some 416 m of core, with a diameter of about 8 cm, was recovered, including a core from the very bottom of the ice shelf.

The core revealed no debris of any kind throughout the thickness of the ice shelf. The core consists of homogeneous bubbly glacial ice to a depth of 410 m. At this depth, abrupt changes in the appearance and properties of the ice occur. The 6-m-thick lower layer contains vertical brine channels and some brownish material. The salinity of the ice within this layer is much higher than that of the ice above 410 m (Fig. 1b) (*4*) and increases to the bottom of the ice shelf. These features are typical of ice formed by the freezing of seawater onto the bottom.

Large vertical crystals are observed throughout the 6-m layer. At the bottom of the shelf, the lower ends of these crystals protrude downward into the sea, giving rise to a waffle-like bottom surface (Fig. 2a) (*5*).

The bottom crystals show distinct alignment at the bottom of the Ross Ice Shelf (shown schematically in Fig. 1c). This alignment can be followed throughout the sea ice layer, showing strong preferred crystal orientation within the layer.

The same kind of alignment, but on a much smaller scale, is found in the growing fast ice of northern polar seas (*6, 7*). It indicates that there is active freezing at the bottom of the ice shelf at Camp J-9 at the present time. These structure alignments of fast ice were probably formed

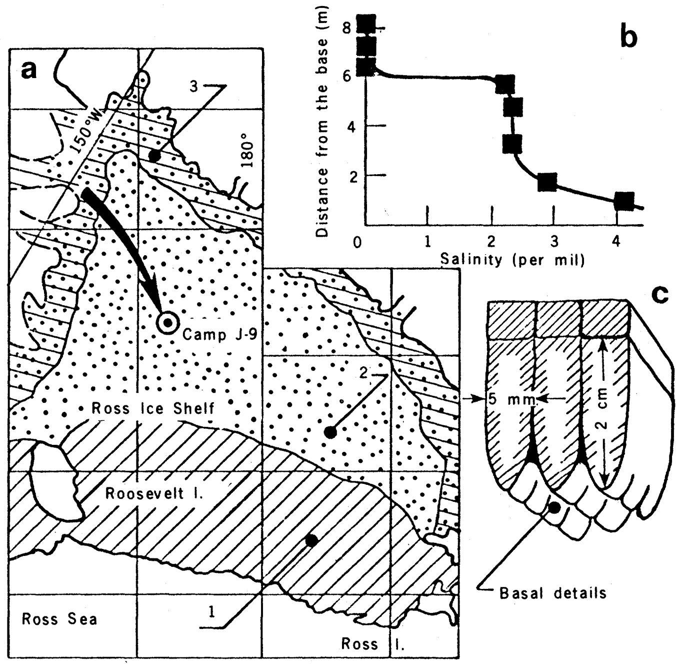

Fig. 1. (a) Map of the Ross Ice Shelf showing the location of Camp J-9 and the approximate stream line (arrow) of the ice shelf in an area of Camp J-9. Area 1, region of melting at the bottom (*8*); area 2, region of freezing governed by heat loss through the ice shelf; area 3, belt of freezing, influenced by a freshwater supply to the bottom of the ice shelf (*8*). (b) Salinity of the bottom part of the ice core. (c) Schematic of the crystal alignment at the base of the ice shelf.

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