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Short Communication

THE CO_2 GREENHOUSE EFFECT ON MARS, EARTH, AND VENUS*

SHERWOOD B. IDSO

U.S. Water Conservation Laboratory, 4331 East Broadway, Phoenix, AZ 85040 (U.S.A.)

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ABSTRACT

A simple comparative analysis of the mean surface air temperatures and atmospheric pressures and compositions of Mars and Venus suggests that the greenhouse warming due to a 300–600 ppm doubling of the CO_2 concentration of Earth's atmosphere should be only about 0.4°C. The legitimacy of this conclusion is supported by several independent considerations.

In two separate assessments of the magnitude of the CO_2 greenhouse effect, the U.S. National Research Council (NRC, 1982, 1983) has concluded that the likely consequence of a 300–600 ppm doubling of the Earth's atmospheric CO_2 concentration would be a 3 ± 1.5°C increase in the planet's mean surface air temperature. Coincident with these assessments, the committees responsible for the two reports stated emphatically — as indicated by their use of italics in both publications — that "*observed surface temperatures of Mars, Earth, and Venus confirm the existence, nature, and magnitude of the greenhouse effect.*" Clearly, this statement must be true. What is not clear, however, and what the NRC committees have never demonstrated, is that the evidence to which they refer is supportive of the particular magnitude which they have attributed to the CO_2 greenhouse effect on Earth. I will herein show that this assumption is not supported by the data, and that the NRC committees have overestimated the strength of the greenhouse effect on our planet by almost a full order of magnitude.

Consider what is known. The greenhouse warming of Venus is approximately 500°C (Oyama et al., 1979; Pollack et al., 1980; Kasting et al., 1988), while that of Mars is about 5 or 6° (Pollack, 1979; Kasting et al., 1988). On Venus, the large surface air temperature elevation is maintained by a massive 93-bar atmosphere which is composed of about 96% CO_2 (Kasting et al., 1988). Similarly, the much smaller greenhouse warming of Mars is also maintained by an atmosphere of almost pure CO_2. In this case, however, the atmosphere is

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much more tenuous, oscillating over the Martian year between surface pressures of only 0.007 and 0.010 bar (McKay, 1983).

If we plot the two points defined by these data on a log–log scale, we obtain the solid-line relationship depicted in Fig. 1. Extended to the two CO_2 concentrations which are the primary focus of our investigation, it can be seen that this relationship suggests that a 300–600 ppm doubling of the Earth's atmospheric CO_2 concentration could only raise the mean surface air temperature of our planet by about 0.4°C, which is nearly an order of magnitude less than what has consistently been predicted by the U.S. National Research Council over the last decade.

But why should one believe this result, particularly in view of its departure from the consensus view of so many prior studies?

Consider, first, the basic mechanism of the greenhouse effect. The fact that higher surface air temperatures are maintained by an enhanced receipt of thermal radiation at the planetary surface (originating with the greenhouse gas) implies that the surface air temperature rise produced by an increase in atmospheric CO_2 should be proportional to the increase in thermal radiation which it produces at the planet's surface. Now for a 300–600 ppm doubling of Earth's atmospheric CO_2 concentration, the U.S. National Research Council (1983) has estimated this latter radiative enhancement to be about $4\ W\ m^{-2}$. In addition, the current mean surface air temperature of the Earth is about 15°C; and since its current mean downward-directed emittance is approximately 0.89

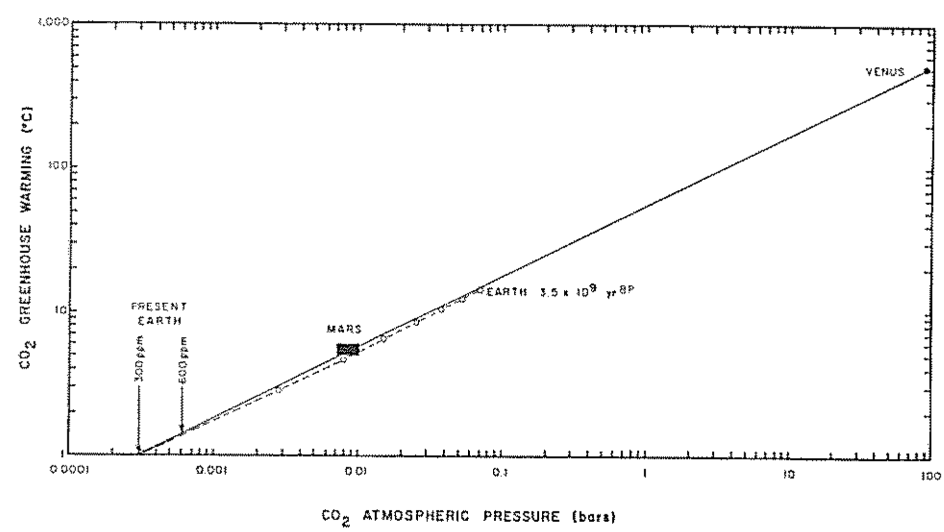

Fig. 1. A comparative planetary climatology relationship for Mars, Earth and Venus based on the greenhouse warmings of Mars and Venus, which are produced by their atmospheric partial pressures of CO_2 (solid line). Also shown is the almost identical relationship which derives from standard considerations related to the Earth's paleoclimatic record and the first early sun paradox (dashed line).

(Idso, 1982), it follows that the current mean flux of thermal radiation to the Earth's surface is about 347 W m^{-2}. Hence, a 300–600 ppm doubling of the Earth's atmospheric CO_2 concentration increases the flux of thermal radiation to the surface of the planet by (4 W m^{-2}/347 W m^{-2}) × 100% = 1.15%, which is essentially identical to the corresponding percentage increase in surface air temperature computed from Fig. 1: (0.4°C/35°C) × 100% = 1.14%, where the current 35°C greenhouse warming of Earth (Kasting et al., 1988) is that maintained by the current mean flux of thermal radiation to the Earth's surface.

Consider also the faint early sun paradox (Sagan and Mullen, 1972; Owen et al., 1979). Assuming the standard 25% reduction in solar luminosity at 4.5×10^9 year BP, along with a linear increase to present conditions, it is a simple matter to calculate a 13.4°C reduction in the mean surface air temperature of the Earth at 3.5×10^9 year BP. However, geological and biological evidence indicates that the climate of the Earth at that time was at least as warm as it is today (Schopf and Barghourn, 1967; Knauth and Epstein, 1976); and the 13.4°C greenhouse warming required to overcome the effects of the lower solar luminosity of that epoch is almost exclusively believed to be due to a higher atmospheric CO_2 concentration at that time (Wigley and Brimblecombe, 1981), which Hart (1978) calculates to be about 0.07 bar.

As shown in Fig. 1, the point defined by these two values falls right at the edge of the line determined by current conditions on Mars and Venus. Furthermore, if we make similar greenhouse warming calculations for every 0.5×10^9 year from that time to the present and plot the results as a function of atmospheric CO_2 partial pressure, determined as per the relationship employed by Lovelock and Whitfield (1982), we get the open-circle data points connected by the dashed line of Fig. 1. And, again, this entire relationship never departs from the solid-line relationship of Fig. 1 by more than a few tenths of a degree.

Consider, finally, the consistency of all of the preceding empirical data. Since water vapor is practically non-existent on Mars, intermediate on Earth, and large on Venus (in an absolute sense) — varying in much the same way that cloud amounts vary among the three planets — yet, as near-perfect results are obtained in all situations investigated here in terms of their accurate portrayal by the one simple relationship of Fig. 1, it follows that atmospheric CO_2 fluctuations influence surface air temperature largely independently of atmospheric moisture conditions. Hence, the long-espoused claim of a many-fold amplification of direct CO_2 effects by a positive water vapor feedback mechanism would appear to be rebuffed by this analysis. As a result, the final conclusion of immediate concern is almost inescapable: the current scientific consensus on the strength of the CO_2 greenhouse effect, as expressed in past reports of the U.S. National Research Council, is likely to be in error by nearly a full order of magnitude. Based on the comparative planetary climatology relationship of Fig. 1, a 300–600 ppm doubling of Earth's atmospheric CO_2 concentration should only warm the planet by about 0.4°C.

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