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CLIMATIC EFFECTS OF ENHANCED CO_2 LEVELS IN MARS' EARLY ATMOSPHERE;

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The existence of branching valley networks in ancient, heavily cratered Martian terrain probably implies a much warmer and wetter Martian climate in the past (1,2). The most likely mechanism for bringing this about is greatly enhanced atmospheric CO_2 pressures. Calculations of the amount of CO_2 necessary to warm the early climate have been made previously using 1-D, radiative-convective models. For present solar luminosity, Pollack (3) predicted that about 2 bars of CO_2 would be required to elevate Mars' average surface temperature (T_s) above the freezing point. Cess et al. (4) repeated the calculation with what they claimed was a more sophisticated radiative model and concluded that only about 0.7 bar of CO_2 would be required to bring T_s above freezing. Their model also predicted warmer temperatures for early Earth than did other 1-D climate models (5,6,7). Subsequently, Cess et al. have discovered that their original model contained an error that caused their predicted surface temperatures to be too high (V. Ramanathan, private communication, 1985). New calculations described here confirm Pollack's earlier results and show that the climatically plausible range of CO_2 pressures for early Mars is 1 to 5 bars.

The radiative-convective model used here is described in references (8) and (9). Absorption coefficients for H_2O and CO_2 in 55 different spectral intervals were derived by fitting synthetic spectra generated from the AFGL tape (10). Band models (Goody model for H_2O, Malkmus model for CO_2) were used in the infrared; exponential sum fits were used in the visible and near-IR. Approximate Doppler corrections were applied to the band models, and the effective broadening pressure was modified to account for the increased efficiency of collisions involving H_2O or CO_2. The absorption coefficients used here are particularly appropriate for modeling the dense early Martian atmosphere because they were derived for CO_2 column densities as high as those on Venus. A δ 2-stream scattering approximation was used to calculate solar energy deposition. Rayleigh scattering cross sections were calculated by the method of Vardavas and Carver (11). The Rayleigh scattering coefficient for CO_2 is a factor of 2.5 times higher than that of air; this is climatically important because it enhances the planetary albedo and provides a negative feedback on surface temperature at high CO_2 levels.

Other parameters in the model were treated in the following manner: The moist adiabatic lapse rate was used in the troposphere. The tropospheric relative humidity was assumed to follow a Manabe/Wetherald (12) profile, with a surface value of 0.77. Above the convective region, the relative humidity was allowed to increase upwards, provided that the water vapor mixing ratio did not increase with altitude. Clouds were assumed to be absent in all cases. The surface albedo was fixed at 0.215; this choice produced a planetary albedo of 0.212 for the present Martian atmosphere, in good agreement with the measured value of 0.214 (13). The present solar flux was assumed to be 0.43 times the flux at Earth's orbit; the surface gravity was set at 373 cm s^{-2}; and the present surface pressure (p_s) was assumed to be 6 mbar.

Calculated surface temperatures (T_s) and planetary albedos (A_p) for different surface pressures and present solar flux are shown in Figure 1. Both T_s and A_p increase slowly at first as p_s is increased, then more rapidly at pressures exceeding a few tenths of a bar. The surface pressure

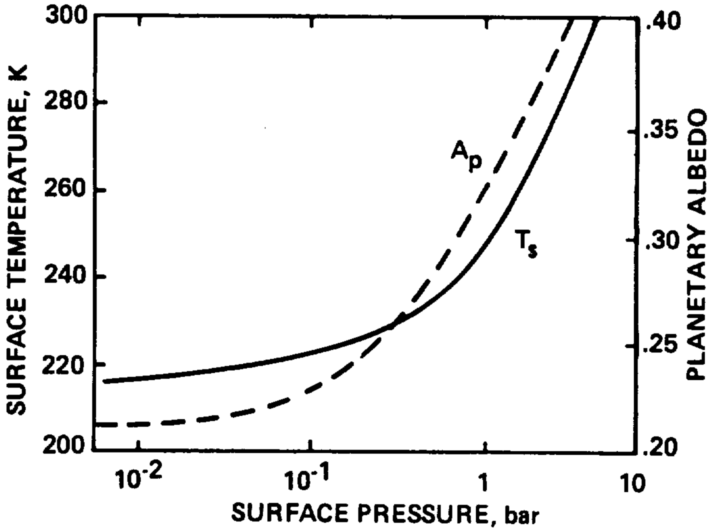

Fig. 1 Calculated surface temperature T_s and planetary albedo A_p as a function of surface pressure. A pure CO_2 atmosphere and present solar flux are assumed.

required to elevate T_s above freezing is 2.2 bars, in agreement with Pollack's earlier prediction (3). The calculated planetary albedo is in rough agreement with that predicted by Cess et al. (4), except that it does not exhibit the decrease near p_s = 1 bar caused by the large amount of water vapor in their model.

This calculation does not directly tell us about early Mars because the solar flux (S_o) was lower in the past by 25 to 30% (14,15). For a 30% reduction in S_o, the CO_2 pressure required to elevate Mars' average surface temperature above freezing is about 5 bars (Fig. 2). On the other hand, Mars' orbit is highly eccentric (e = 0.093); thus, at perihelion the incident solar flux is enhanced by some 22%. At Mars' maximum eccentricity of 0.14 (16), the enhancement in S_o at perihelion would be 35%. Furthermore, the equatorial regions are more strongly heated than the planet as a whole by about 40%. Thus, under favorable conditions (at the equator during perihelion), the local irradiation in certain areas on early Mars could have been as much as 30% higher than the present flux. The CO_2 pressure required to push T_s above freezing in this case is just 1 bar (Fig. 2). This value could be even further reduced to 0.8 bar if the surface albedo of (an unoxidized) early Mars was as low as 0.1 (dashed curve, Fig. 2).

In conclusion, Mars could have had surface temperatures above freezing in the past if the CO_2 pressure was above ~1 bar. Approximately 2 to 5 bars of CO_2 would have been required for widespread liquid water to exist. More detailed (3-dimensional) climate models could refine this prediction to some extent; however, large uncertainties would still remain because of the possible presence of other greenhouse gases and of clouds.

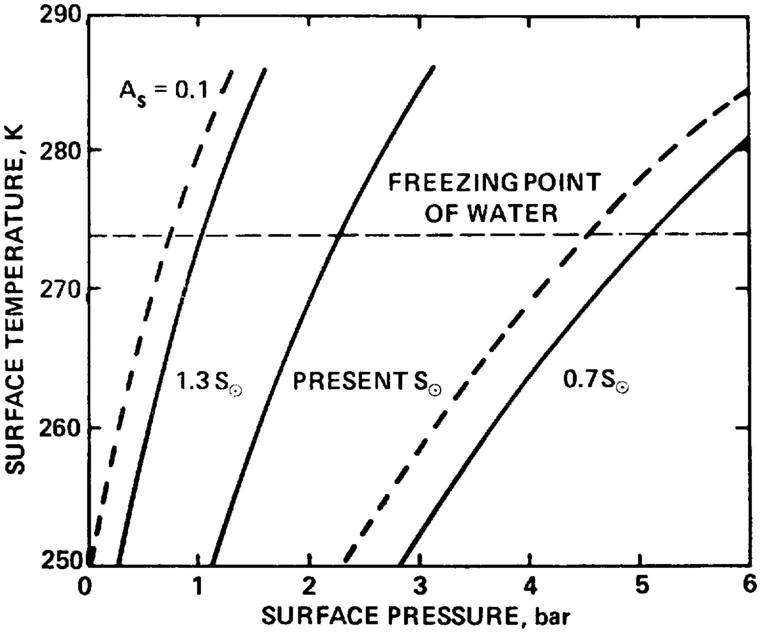

Fig. 2 Surface temperature as a function of surface pressure for different values of the incident solar flux. Solid curves are for a surface albedo A_s of 0.215; dashed curves are for A_s = 0.1.

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