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CORNELL UNIVERSITY

Center for Radiophysics and Space Research

ITHACA, N. Y.

FINAL REPORT FOR NASA-AMES-CORNELL
CONSORTIUM JOINT RESEARCH INTERCHANGE

"Early Climate on Earth-Reduced Gas Models and
Early Climate on Mars-Reduced
Gas and Obliquity Models"

NCA2-OR175-702

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Owen B. Toon/Carl Sagan

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Summary:

Early in the grant period, studies of the reduced gas climates of Earth and Mars were performed by Sagan (1977) and Pollack, (1978, in press). Further progress beyond these studies could not be made until more advanced atmospheric chemistry studies were completed by other investigators. Hence, during the grant period we concentrated on the portion of our proposal concerning the obliquity model of Mars climate. A number of significant discoveries were made during this study. We found that at high obliquity Martian polar ground temperatures could exceed the melting point of ice for considerable periods of time (∿90 Earth days), and that under special conditions ice itself might melt. CO_2 adsorbed on the Martian regolith is not expected to buffer the seasonal pressure wave except in the unlikely event that the soil pore size is very large (50 μm). For a basaltic soil composition the maximum CO_2 that could be desorbed over obliquity time scales due to thermal forces is a few millibars. At low obliquities the atmospheric pressures may drop, desorbing the soil. The only means to achieve higher CO_2 pressures is to have much higher (>20-30°K) planet wide temperatures due to some greenhouse effect, or to be at an epoch before the regolith or carbonates formed. The importance of a significant clay soil component to the CO_2 desorption has not yet been fully considered due to lack of data. The water ice budget between north and south polar caps has been considered and summer sublimation rates imply that the ice could be exchanged between the poles during obliquity cycles. The major difficulty is understanding how water reaches the winter pole. It is possible that both poles exchange with the low latitude regolith rather than with each other. A critical factor in the polar cap water budget is the interaction of water and dust. The origin of the Martian polar laminae is probably due to variations in this interaction.

Research:

The leading explanation for terrestrial ice ages is that they are caused by variations in the solar insolation due to changes in the Earth's orbit about the sun (e.g. Hays et al., 1978). Ward (e.g. 1978) has shown that the Martian orbit is subject to much greater variations than the Earth's. Hence it is important to investigate the climatological implications of these variations for Mars. Previous work (e.g. Gierasch and Toon, 1973) considered the annual average effects of the orbital variations for Mars, assuming Mars had permanent CO_2 polar caps. Viking data has shown that Mars does not have permanent CO_2 polar caps invalidating this assumption. Hence a seasonal model of Martian climate has been constructed which considers in turn: 1) The climate with CO_2 exchanging only between poles and atmosphere, 2) the climate with CO_2 also exchanging with the regolith, 3) the climate with water exchanging between poles and atmosphere, and 4) the climate with water also exchanging with the regolith. All these models are basically local heat balance models in which the thermal and mass diffusion into the soil are considered.

A full report on the findings of the study is in preparation. Some of the highlights are illustrated in Figures 1 and 2. It is seen that at high obliquities very large polar ground temperatures can occur for extensive periods of time, and that high polar ice temperatures can also be reached. An important problem for the CO_2 budget is the exchange of CO_2 between the regolith and atmosphere. By considering the annual average temperatures from Figure 1 it can be shown that very little CO_2 can be removed from the soil due to obliquity driven temperature changes. At low obliquity, however, the CO_2 atmosphere may condense at the polar cap reducing the atmospheric pressure and strongly desorbing the ground. If there were no regolith, or if the carbonates in the soil had not formed, atmospheric pressures would be higher.

The high polar ice temperatures in Figure 2 lead to large amounts of ice being sublimed from the polar caps. Without considering atmospheric dust or regolith interactions it is not possible for this ice to reach the winter pole due to the low atmospheric temperatures. Hence in order to understand the presence of H_2O ice caps we are forced to conclude that water does interact seasonally with the regolith or with atmospheric dust particles. The polar laminae are almost certainly a combination of windborne dust and water ice. Hence, their formation must be due to the interaction between the atmospheric water and dust.

Research into these problems is continuing under different support. The greenhouse effect due to water vapor-CO_2-cloud atmospheres will be considered, and geologic features on Mars will be interpreted in terms of the CO_2 and H_2O budget ideas in the present work. Following these added studies, a full report will be published.

Publication of Results:

Full publication of the results is expected in the near future.

An abstract of this work for a poster session talk has been submitted for the October 1978 Division of Planetary Sciences meeting in Pasadena, California.

References:

1) Hays, J.D., J. Imbrie, and N.J. Shackleton, Variations in the Earth's orbit: Pacemaker of the ice ages, Science, 194, 1121, 1976.

2) Gierasch, P.J. and O.B. Toon, Atmospheric pressure variations and the climate of Mars, J. Atmos. Sci., 30, 502, 1973.

3) Pollack, J.B., Climatic change on the terrestrial planets, submitted to Icarus, 1978.

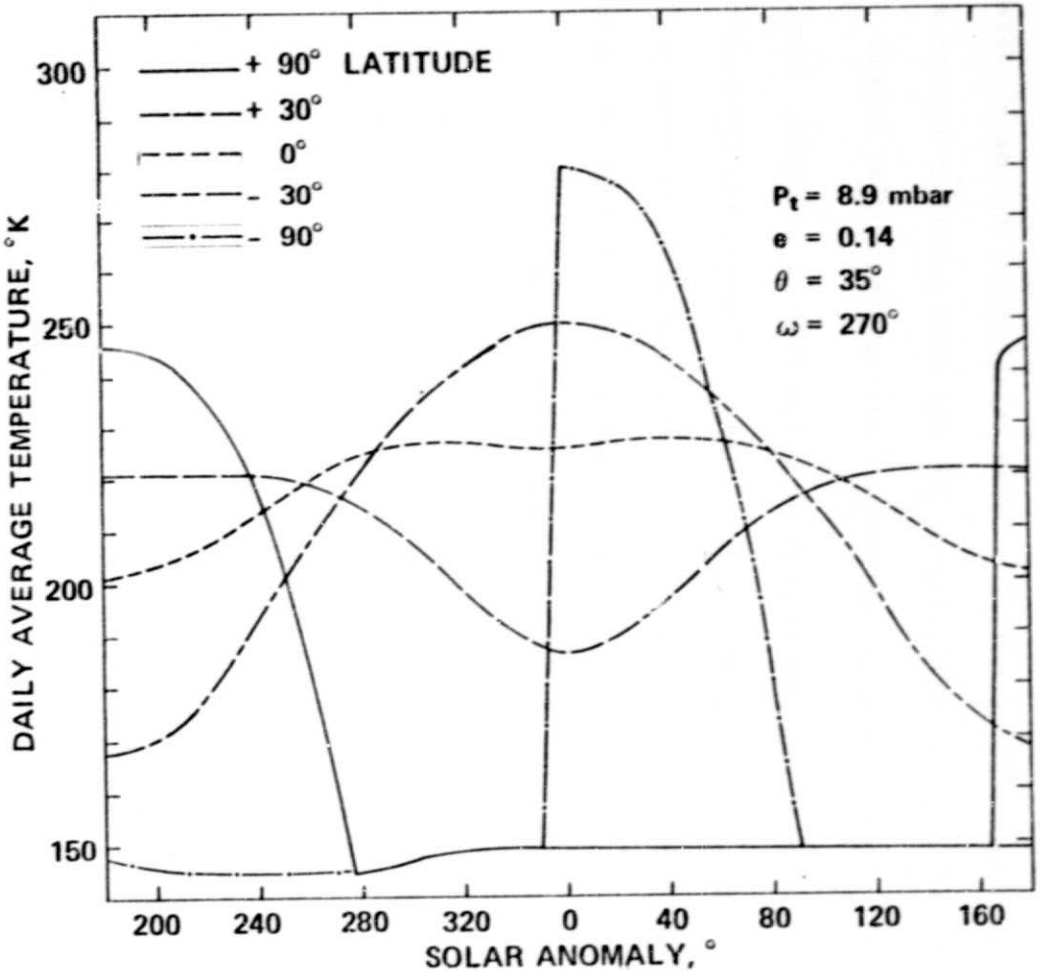
4) Sagan, C., Reducing greenhouses and the temperature history of Earth and Mars, Nature, 269, 224, 1977.

5) Ward, W.R., 1. Present obliquity oscillations of Mars: Fourth order accuracy in orbital e and I, in press, J. Geophys. Res., 1978.

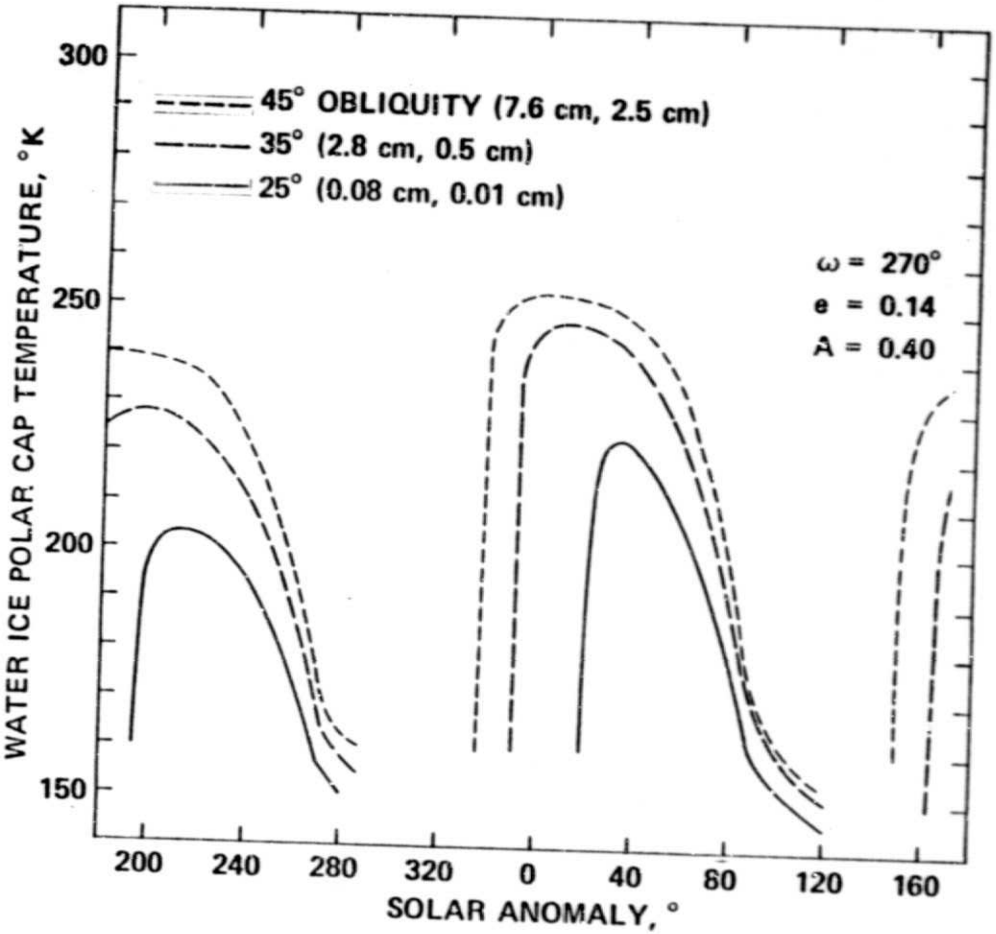
Figure Caption:

Figure 1: Ground temperatures as a function of latitude (various curves) and time of year (solar anomaly). These calculations assume an eccentricity of 0.14, an obliquity of 35° and that perhileon occurs at solstice. Note the high temperature during south polar summer.

Figure 2: Water ice polar cap temperature as a function of obliquity (various curves) and time of year (solar anomaly). The calculations assume an eccentricity of 0.14 a polar cap albedo of 0.4, and that perhelion occurs at solstice. The values in parenthesis give the thickness of ice lost during the entire summer at each cap.


+ 90° LATITUDE
+ 30°
0°
- 30°
- 90°
P_t = 8.9 mbar
e = 0.14
θ = 35°
ω = 270°
DAILY AVERAGE TEMPERATURE, °K
300
250
200
150
200
240
280
320
0
40
80
120
160
SOLAR ANOMALY, °

TOON



45° OBLIQUITY (7.6 cm, 2.5 cm)
35° (2.8 cm, 0.5 cm)
25° (0.08 cm, 0.01 cm)
ω = 270°
e = 0.14
A = 0.40
WATER ICE POLAR CAP TEMPERATURE, °K
300
250
200
150
200
240
280
320
0
40
80
120
160
SOLAR ANOMALY, °