The Influence of Ozone on Martian Atmospheric Temperature

W. R. KUHN, S. K. ATREYA, AND S. E. POSTAWKO

Department of Atmospheric and Oceanic Science, University of Michigan, Ann Arbor, Michigan 48109

Radiative equilibrium temperature calculations indicate that ozone, although a minor constituent in the Martian atmosphere, may play a significant role in determining the deposition of carbon dioxide.

INTRODUCTION

The climatological studies of Mars have hitherto ignored the role of ozone. Although ozone is a minor species in the atmosphere of Mars, its total column abundance in some seasons is nonetheless comparable to, or greater than, the ozone abundance above the stratopause in the earth's atmosphere. It is well known that the temperature maximum at the terrestrial stratopause is the result of absorption of solar radiation by ozone. The results of radiative equilibrium temperature calculations discussed here show that ozone has an influence on the Martian temperature structure and consequently on the deposition of carbon dioxide. Furthermore, there appears to be a possibility that the permanent ice cap of dry ice in the southern hemisphere of Mars may also be related to the abundance of ozone.

The Martian atmosphere contains small amounts of ozone primarily at high latitudes during late summer through winter when the polar hood is prominent. The ozone then decreases during spring and is below the limit of detectability during summer; it has not been observed in equatorial latitudes during any season.

The maximum amount of ozone measured was 57 μm [*Barth*, 1974] over the polar hood during winter. Over the polar cap itself the ozone amount was 16 μm. During summer less than 3 μm is present in the atmosphere.

Although the Martian ozone abundance is less than 1/100 of that found in the earth's atmosphere its total column abundance is about 4 times the abundance above the terrestrial stratopause. Not only is the ozone amount important in determining its effect on temperature but also the available solar energy and the background number density with which the ozone molecules partition their energy. The ultraviolet radiation incident on the Martian atmosphere is about 43% of the ultraviolet radiation incident on earth, while the number density at the height of the terrestrial stratopause is about one-tenth of the number density at the Martian surface (surface temperature of 160°K). Both would tend to reduce the importance of ozone to the temperature structure, and we would not expect to find a temperature increase of about 55°K such as found at the earth's stratopause. However, since the Martian high-latitude temperatures and pressures are close to those corresponding to carbon dioxide ice vapor equilibrium, even a small change in temperature could be important to carbon dioxide deposition.

METHODOLOGY

The model used to calculate radiative equilibrium temperatures was previously described [*Kuhn et al.*, 1978] and will only be outlined here. From an assumed initial temperature profile [*Kong and McElroy*, 1977] and fixed surface temperature of 160°K, radiative heating and cooling rates were determined for 18 levels in the Martian atmosphere extending from the surface to 40 km. The temperature profile was modified by the heating/cooling rates, and the calculations repeated until the rates were less than 0.001°K/d and radiative equilibrium was essentially reached.

The transmission functions for planetary (infrared) radiation for carbon dioxide and ozone and the transmission functions for the solar radiation for carbon dioxide were determined from spectral line data from *McClatchey et al.* [1973]. The infrared spectrum was divided into 11 intervals for carbon dioxide (500–862 cm^{-1}) and 8 intervals for ozone (934–1190 cm^{-1}), while 9 intervals (500–8500 cm^{-1}) were used for solar absorption by carbon dioxide. The ultraviolet and visible spectrum was divided into 106 intervals (1525–7600 Å) with ozone cross sections taken from *Ackerman* [1971] as well as the solar photon flux.

The line shape was represented by a Voigt profile, and the temperature dependence of the line strengths was included. Pressure and temperature in the nonhomogeneous paths were represented by the Curtis-Godson approximation. The diffusivity factor was 1.667.

The calculations were carried out for a latitude of 57°N for winter conditions (solar declination −5°). The mean solar zenith angle was calculated to be 79°. The ozone column abundance was 57 μm, and the ozone profile was from *Kong and McElroy* [1977]. Surface pressure and temperature are 7.2 mb and 160°K, respectively.

We also made calculations for two other hypothetical ozone distributions to determine the sensitivity of the calculated temperatures to the ozone profiles. In one case the ozone mixing ratio was held constant at 6.7×10^{-7}, and in the other the mixing ratio decreased exponentially with height with surface value of 1.8×10^{-6}. Both profiles have the same total column abundance of 57 μm.

We have not attempted to include the influence on the thermal structure of the polar hood. Little is known about the optical thickness and size distributions. We have made one calculation in which the dust scattering (optical depth 0.1) was included. Also, we have allowed for solar reflection of visible and near infrared radiation from the polar cap (albedo of 60%).

RESULTS

Radiative equilibrium temperature profiles for 57°N latitude winter conditions are shown in Figure 1. The dashed curve does not include ozone, while the solid curve has a total ozone amount of 57 μm and distribution with height as given by *Kong and McElroy* [1977]. The equilibrium between CO_2 ice and vapor is also shown.

Absorption of solar radiation by ozone contributes approxi-

Paper number 9C1267.
0148-0227/79/009C-1267$01.00

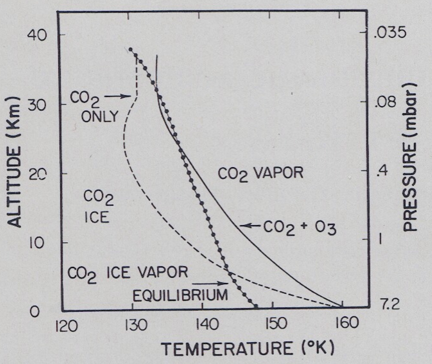

Fig. 1. Radiative equilibrium temperatures for a latitude of 57°N during winter.

mately 10° to the temperature between heights of about 10–25 km. Since these calculations were made with the maximum measured ozone in the atmosphere, it is doubtful that the temperature effect would be more than several degrees at most latitudes and seasons unless there occurs an as yet undetected ozone maximum or higher ozone concentrations at lower latitudes where there is more solar radiation. At 45°N latitude winter, for example, we find that ozone [*Kong and McElroy*, 1977] increases the temperature less than 1.5°K. More importantly, however, is the fact that the calculated temperatures are within 10° of phase equilibrium. In the absence of ozone, deposition of carbon dioxide occurs from about 8 to 35 km, while deposition only occurs in a narrow height range of 25–30 km when ozone is present. The actual distribution of ozone with height is not crucial to our discussion. For the two hypothetical ozone distributions given in the previous section, the temperatures were within a few degrees of that calculated with the *Kong and McElroy* [1977] distribution. Dust scattering with optical depth of 0.1 and reflection of visible and near infrared radiation from the polar cap changed the temperature less than 2°K.

For our calculations to be realistic, radiation must be a primary contributor to the atmospheric thermal profile. Indeed, *Goody and Belton* [1967] have shown that the relevant dynamical time constants are larger than the radiative time constant. In addition, *Zurek* [1976] has shown that tidal effects will not dominate the dynamics until a height of approximately 30 km is reached. We calculated the relaxation times for horizontal and vertical motion (see, e.g., *Goody and Belton* [1967] and *Gierasch and Goody* [1969]) on the basis of recent Mars data [*Leovy*, 1979] and find values of 19 and 3 days, respectively. Radiative relaxation times this large would require thermal disturbances to have wavelengths larger than two scale heights.

Our calculations, nevertheless, should only be interpreted qualitatively, since the data required for detail calculations are not available. Simultaneous measurements of the seasonal variations in the extent and thickness of the polar hood, ice caps, ozone height profile, and the vertical temperature profile would provide valuable data for establishing unambiguously the climatological impact of ozone. It is interesting to speculate, however, that ozone, although present in small amounts, may play a significant role in controlling the rate of carbon dioxide deposition and thus the atmospheric pressure. Furthermore, the infrared thermal mapping and water vapor mapping instruments on the Viking orbiters have established that the permanent ice caps, revealed after the recession of the polar hood, are composed of water ice in the northern polar region and dry ice in the southern polar region [*Farmer*, 1979]. The Mariner observations [*Barth*, 1974] indicate a larger ozone abundance in the high latitudes of the northern hemisphere than in the southern hemisphere. Our calculations show that the deposition of CO_2 may depend on ozone amount. It is possible that the larger amount of ozone in the northern hemisphere prevents CO_2 deposition during part of the winter, while the smaller ozone amount in the southern hemisphere may have little effect on the temperature and thus the deposition rate.

Acknowledgments. This work was supported by NASA Planetary Program grant NSG 7404 and the National Science Foundation, Atmospheric Sciences section.

REFERENCES

Ackerman, M., Ultraviolet solar radiation related to mesospheric processes, in *Mesospheric Models and Related Experiments,* edited by G. Fiocco, p. 149, D. Reidel, Hingham, Mass., 1971.

Barth, C. A., The atmosphere of Mars, *Annu. Rev. Earth Planet. Sci., 2,* 333, 1974.

Farmer, C. B., Seasonal water transport, paper presented at the Second International Colloquium on Mars, NASA, Pasadena, Calif., Jan. 15-18, 1979.

Gierasch, P. J., and R. M. Goody, Radiative time constants in the atmosphere of Jupiter, *J. Atmos. Sci., 26,* 979, 1969.

Goody, R. M., and M. J. S. Belton, Radiative relaxation times for Mars: A discussion of Martian atmospheric dynamics, *Planet. Space Sci., 15,* 247, 1967.

Kong, T. Y., and M. B. McElroy, The global distribution of O_3 on Mars, *Planet. Space Sci., 25,* 839, 1977.

Kuhn, W. R., D. Kraemer, R. J. Cicerone, and S. Liu, Radiative Equilibrium Temperatures in the Stratosphere and Mesosphere—A Comparison for the Stellar Occultation and BUV Ozone Data, *Geophys. Res. Lett., 5,* 365, 1978.

Leovy, C. B., Martian meteorology, *Annu. Rev. Astron. Astrophys., 17,* 387–413, 1979.

McClatchey, R. A., W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfee, K. Fox, L. S. Rothman, and J. S. Garing, AFCRL Atmospheric absorption line parameters compilation, *Environ. Res. Pap. 434,* Air Force Cambridge Res. Lab., Bedford, Mass., 1973.

Zurek, R. W., Diurnal tide in the Martian atmosphere, *J. Atmos. Sci., 33,* 321, 1976.

(Received April 9, 1979;
revised August 3, 1979;
accepted August 15, 1979.)