Mariner 9 Ultraviolet Spectrometer Experiment: Seasonal Variation of Ozone on Mars

Abstract. *Ozone is observed to be present in the polar regions of Mars and to have a seasonal variation. In the summer, the amount present in the polar atmosphere is less than 3 micrometer-atmospheres. In the fall, ozone increases in amount and is found in association with the formation of the polar hood. In winter, the maximum amount of ozone is present, 57 micrometer-atmospheres over the polar hood and 16 over the polar cap. In spring, the amount over the polar cap decreases monotonically until by the beginning of summer the ozone disappears. Ozone is not observed in the equatorial region during any season.*

Between 14 November 1971 and 27 October 1972 systematic observations of ozone on Mars were made with the Mariner 9 ultraviolet spectrometer. This time period covered almost half of a martian year or two complete seasons in each hemisphere. Since Mariner 9 made observations in both hemispheres, summer and fall were observed in the south, winter and spring in the north. An important result is that ozone is present in the atmosphere in the polar regions (poleward of 45° latitude) and that the amount varies with the changing season. Within the detection limits of the ultraviolet spectrometer, no ozone was found in the equatorial region (equatorward of 45° latitude). A somewhat simplified description of the seasonal variation in the polar regions is as follows: Early in summer, there is no ozone in the atmosphere. In late summer and early fall, ozone begins to appear both over the polar cap and in association with the formation of the polar hood. In winter, the entire polar region from 45° latitude to the pole is covered by the polar hood. It is at this time that the maximum amount of ozone is observed over the polar cap. As the season progresses, less and less ozone is present until by the beginning of summer, ozone disappears from over the polar cap and the entire polar region.

Ozone is measured by the ultraviolet spectrometer experiment by observing the Hartley absorption continuum between 2000 and 3000 Å in the ultraviolet light reflected from the planet. The ultraviolet solar radiation that is reflected from Mars arises from Rayleigh scattering, from scattering by large particles in the polar hood, and from reflection from the bright polar cap (*1*). A great deal of information about the polar hood and polar cap of Mars has been acquired by several of the Mariner 9 instruments. In this report, the following operational model of these two martian phenomena will be used. The polar hood is a fog or cloud bank of water ice crystals that covers most of the winter hemisphere poleward of 45°. It begins to form in the fall and portions of it remain until the spring. The polar cap is primarily composed of frozen carbon dioxide and may also contain water ice.

The behavior of ozone in the polar region between 50°S and 75°S during the southern summer and fall is demonstrated in Fig. 1A. During most of the summer, no ozone was observed in this latitude region. Toward the end of summer, before the polar hood became visible, ozone began to appear in the atmosphere near 60°S. At the end of summer, the amount increased from the detection limit of 3 μm-atm to an amount greater than 10 μm-atm (*2*). During these summer measurements, the ultraviolet spectrometer was able to make continuous observations over a range of latitudes. The maximum amounts of ozone observed in the latitude range 50°S to 75°S are plotted in Fig. 1A. When Mariner 9 observations were made in the middle of the southern fall, the polar hood was visible and the amount of ozone was observed to have increased to more than 30 μm-atm. The final three measurements were made at specific targets in the southern hemisphere and, hence, are not necessarily the maximum values in this latitude band.

The behavior of ozone in association

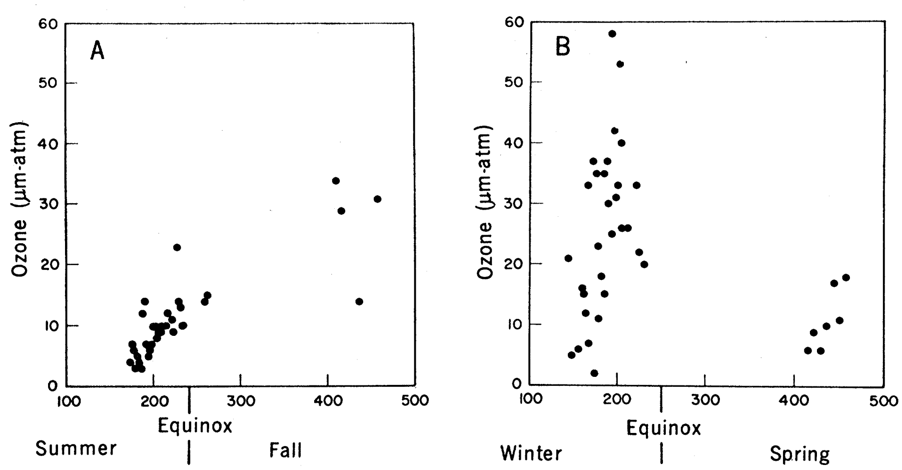

Fig. 1. (A) Amount of ozone observed in the southern polar region during the summer and fall. The numerical values along the abscissa correspond to the Mariner 9 orbit numbers. The amount of ozone plotted corresponds to the maximum value found between 50°S and 75°S, except for the last three points. (B) Amount of ozone observed in the northern polar region during the winter and spring. The ordinate is the maximum amount of ozone found between 50°N and 75°N.

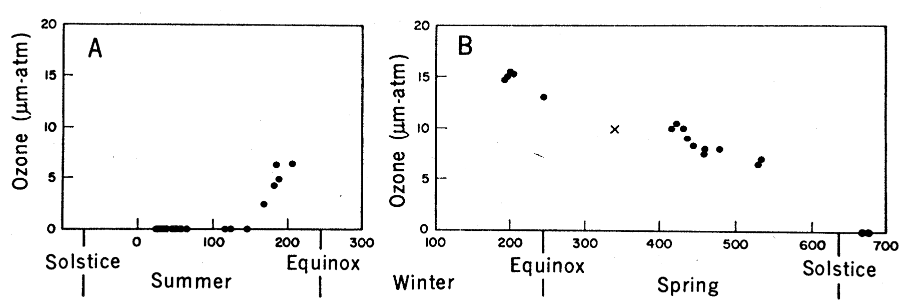

Fig. 2. (A) Amount of ozone observed over the south polar cap during the summer. (B) Amount of ozone observed over the north polar cap during the winter, spring, and beginning of summer. The cross refers to the Mariner 7 measurement which was made over the south polar cap in 1969. The ordinates and abscissas are defined as in Fig. 1.

with the northern polar hood is shown in Fig. 1B. On all occasions when observations were made north of 45°N during winter, ozone was measured and the polar hood was always visible. The data plotted in Fig. 1B are the maximum amounts of ozone observed in the latitude range 50°N to 75°N. The amount measured varied, ranging all the way from the detection limit of 3 μm-atm up to the largest value observed on Mars by Mariner 9, 57 μm-atm. In spring when measurements were made of specific targets in the north, there was less ozone than in the winter and the polar hood was not readily visible.

The behavior of ozone over the south polar cap in summer is shown in Fig. 2A. Throughout the summer, the Mariner 9 observations show that there was no ozone over the remnant of the cap. Near the end of the summer the amount of ozone increased above the detection limit, reaching a value of 6 μm-atm. Favorable viewing conditions were not attained during the fall in the south.

The behavior of ozone over the north polar cap during the winter and spring is shown in Fig. 2B. Toward the end of winter, when the polar hood cleared sufficiently to permit the cap to be seen by the Mariner 9 instruments, the amount of ozone measured was 16 μm-atm. In the middle of spring the quantity of ozone above the polar cap was 10 μm-atm, and its magnitude decreased monotonically during the latter half of the northern spring. During the last two orbital operations of Mariner 9, just after the northern summer solstice, observations of the north polar cap showed that the ozone had disappeared.

The amount of ozone that was measured over the south polar cap in 1969, by the Mariner 7 ultraviolet spectrometer, was 10 μm-atm (*1*). The season on Mars at that time was southern spring. This value is plotted in Fig. 2B at the corresponding seasonal time for comparison with the Mariner 9 data for the 1972 northern spring.

When ozone was observed in association with the polar hood in the fall and winter seasons, the ultraviolet spectrometer also detected increased reflectivity in the region from 3000 to 3500 Å compared to the reflectivity of the clear atmosphere. This increased reflectivity presumably is produced by the ice crystals of the polar hood. We have suggested elsewhere that this correlation of the appearance of ozone with the appearance of the polar hood is experimental evidence for the suppression of ozone in the presence of water vapor (*3*). Current theoretical treatments (*4*) suggest that not only water vapor, but also hydrogen peroxide (which is a by-product of the photolysis of water vapor by sunlight in the presence of molecular oxygen) should have this effect. However, a full explanation of the present results will probably involve the effects of variations in atmospheric temperature and of the global transport of water vapor, in addition to photochemical considerations.

Achieving an understanding of the presence and variation of ozone in the martian atmosphere is important for our knowledge of current conditions on Mars and the state of evolution of its atmosphere. In addition, this understanding of ozone photochemistry in a planetary atmosphere is relevant to the earth's atmosphere, where questions as to the stability of the earth's ozone in the presence of added impurities arise. On Mars, the Mariner observations show a 20-fold variation in the amount of ozone, depending on the presence or absence of another minor constituent, water vapor, in the atmosphere. In the evolution of the earth's primitive atmosphere, the formation of an ozone layer may have played an important role in the prebiotic chemistry that took place on the surface. The seasonal formation and disappearance of ozone in the contemporary martian atmosphere may be of consequence in any prebiotic chemistry that may be occurring there.

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References and Notes

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2. The amount of ozone is expressed in terms of micrometer-atmospheres, the thickness of the ozone column in micrometers when compressed to standard pressure and temperature on the earth; 1 μm-atm = 1×10^{-4} cm-atm = 2.69×10^{15} molecules per square centimeter. The amount of ozone in the earth's atmosphere is approximately 0.3 cm-atm.
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4. T. D. Parkinson and D. M. Hunten, *J. Atmos. Sci.* **29**, 1380 (1972); M. B. McElroy and T. M. Donahue, *Science* **177**, 986 (1972).
5. The development of the ideas presented here was greatly stimulated by many conversations with all of the participants in the Mariner 9 mission. This research was supported by the National Aeronautics and Space Administration.

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Ice and Snow in Eolian Sand Dunes of Southwestern Wyoming

Abstract. *Snow becomes incorporated in eolian sand dunes of southwestern Wyoming when snow cornices on dune crests begin to melt, slide down the lee slope, and are covered by sand during subsequent lee-slide deposition. In some cases burial is rapid enough to provide the insulation necessary to preserve the ice and snow within the dune throughout the year. Deformed laminae associated with the incorporated snow are preserved, and these features may be of value as paleoclimatic indicators in ancient sandstone.*

Ice and snow are preserved throughout the year in eolian dunes in the Killpecker dune field approximately 25 km east of Eden, Wyoming. Buried snow occurs as lenticular bodies whose maximum and intermediate axes lie in a plane more or less parallel with the major internal bedding of the dune. In September 1972, 4 months after the last snowfall in the area, two separate snow lenses were observed in one trench approximately 10 m downhill from the crest of a transverse dune 30 m high. The snow lens shown in Fig. 1 is 25 cm thick, extends 2.5 m laterally parallel to the crest of the dune, and is only 1.5 m beneath the dune surface. It is surrounded by relatively undisturbed laminae which, above the lens, conform to the convex upward boundary between sand and snow. A larger and somewhat more irregular body of snow was discovered in the same trench approximately 2.0 m below the dune surface, but its exact geometry and size are not known. A zone of completely frozen sand 10 cm thick surrounds this lens, and the adjacent laminae are