HOW WELL WAS TOTAL OZONE ABUNDANCE INFERRED WITH MARINER 9?

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Ozone is a key to understanding atmospheric chemistry on Mars. Over 20 photochemical models of the martian atmosphere have been published, and O_3 is often used as a benchmark for these models[1-3]. O_3 abundance has been inferred from instrumentation on several spacecraft, with the most complete coverage provided by Mariner 9[3,4]. The Mariner 9 UV spectrometer scanned from 2100 to 3500 Angstroms with a spectral resolution of 15 Angstroms and an effective field-of-view of approximately 300 km^2 [4]. The only atmospheric absorption in the 2000 to 3000 Å wavelength region was previously assumed to come from the Hartley band system of ozone[4], which has an opacity of order unity at winter polar latitudes[3]. Therefore the amount of ozone was inferred by fitting this absorption feature with laboratory data of ozone absorption, as shown in Fig. 1[4]. Mars O_3 shows strong seasonal and latitudinal variation, with column abundances ranging from 0.2 μm-atm at equatorial latitudes to 60 μm-atm over northern winter polar latitudes[4] (1 μm-atm is a column abundance of 2.689×10^{15} molecules cm^{-2}). However, the O_3 abundance is never great enough to significantly affect atmospheric temperatures[5] or surface temperatures and frost amounts[6]. Figure 2 shows some of the previously-inferred O_3 abundances[7].

A radiative transfer computer model is used to re-examine the Mariner 9 UV spectra. Assuming a constant mixing ratio for O_3 and no chemical or radiative interaction between O_3 and clouds/dust, Fig. 3 shows that when typical amounts of dust and cloud are present that significant underestimation of O_3 abundance occurs. A factor of 3 times as much O_3 is needed to generate the same spectrum the spacecraft would measure for a cloudy, dusty atmosphere as for a clear atmosphere. If the scattering properties of martian clouds and dust were well known, then their appearance would not be a problem, as a model would be capable of retrieving the O_3 abundance. However, these properties are not well known, which raises doubts about the effectiveness of the UV reflectance spectroscopy technique for measuring O_3 abundance on Mars. The simulations shown in Fig. 3 are repeated for a range in solar zenith angle (50°-90°), ground albedo (0.3-0.8),

altitude distribution of O_3, satellite viewing geometries, and cloud, dust and O_3 abundances. A factor of 3 underestimation is typical, with greater underestimation for high ground albedo or high dust opacities. Even if scattering by clouds is properly accounted for (as previously done with Mariner 9 data reduction in [4]), masking by dust can easily result in factor of 2 underestimation. Results are not strongly dependent on solar zenith angle.

Spatial and temporal variability in temperature and water vapor have been claimed to account for the scatter of the data points in Fig. 2[8]. A decrease in temperature results in a decrease in water vapor, if saturated as expected at prevalent temperatures. A decreased water vapor abundance decreases the availability of odd hydrogen (H, OH, and HO_2), which converts CO and O into CO_2 catalytically, decreasing the abundance of O needed to form O_3. However, water vapor is a small source of odd hydrogen in the winter polar atmosphere compared to H_2, and may not account for most of the variability in Fig. 2[3]. Masking by clouds and dust may also account for some of the observed O_3 variability, because the nature and opacity of the clouds and dust at winter polar latitudes change significantly spatially and temporally. As the maximum O_3 abundance resides near the surface[3], spacecraft must be able to observe through the entire cloud and dust abundance in order to measure the total O_3 column abundance. If reflectance spectroscopy is used, as on Mariner 9, then the cloud and the airborne dust must be traversed twice; first by the incoming solar flux down to the surface, and then once again upon reflection from the surface out to the spacecraft. In addition, the large solar zenith angles at winter polar latitudes mean several times the vertical opacity of cloud and dust must be traversed. Indeed, part of the observed latitudinal variation in O_3 abundance in Fig. 2 may be due to the inability of the spacecraft to observe through the increasing effective optical depths as one goes poleward.

By using a photochemical model which included multiple scattering of solar radiation, Lindner[3] showed that the absorption and scattering of solar radiation by clouds and dust should actually increase O_3 abundances at winter polar latitudes. Hence, regions with high dust and cloud abundance could contain high O_3 abundances (heterogeneous chemistry effects have yet to be fully understood[2,9]). It is quite possible that the maximum O_3 column abundance observed by

Mariner 9 of 60μm-atm is common. In fact, larger quantities may exist in some of the colder areas with optically thick clouds and dust. As the Viking period often had more atmospheric dust loading than did that of Mariner 9, the reflectance spectroscopy technique may even have been incapable of detecting the entire O_3 column abundance during much of the Mars year that Viking observed, particularly at high latitudes. The behavior of O_3 is virtually unknown during global dust storms, in polar night, and within the polar hood, leaving large gaps in our understanding.

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FIGURE CAPTIONS

Figure 1. Ultraviolet spectrum measured by Mariner 9 at 57°N latitude on orbit 144[7]. To enhance the O_3 absorption feature, this spectrum was divided by one obtained at 20°N latitude on orbit 144, where O_3 abundances are minimal[7].

Figure 2. Measurements of the O_3 column abundance previously inferred from the Mariner 9 UV spectrometer data during the northern winter, $L_s = 330\text{-}360°$, in the northern hemisphere[4].

Figure 3. Synthetic spectra as would be observed by spacecraft for atmospheres with no cloud or dust and 30 μm-atm O_3 (solid line), vertical opacities of dust and cloud of 0.3 and 1.0, respectively, and 30 μm-atm of O_3 (dashed line), and vertical opacities of dust and cloud of 0.3 and 1.0, respectively, and 100 μm-atm of O_3 (dotted line). All cases assume a solar a zenith angle of 75° (typical for winter polar observations), and a polar cap albedo of 0.6.

ORBIT 144

UV SPECTRUM AT "B"
57°N

$RATIO\left(\frac{57°\ N}{20°N}\right)$

RELATIVE INTENSITY

WAVELENGTH (Å)

2100   2500   3000   3500

Relative Intensity

2100   2400   2700   3000

Wavelength (in Angstroms)