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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 Å with a spectral resolution of 15 Å and an effective field of view of approximately 300 km² [4]. The only atmospheric absorption in the 2000–3000-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 reexamine 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, 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, 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
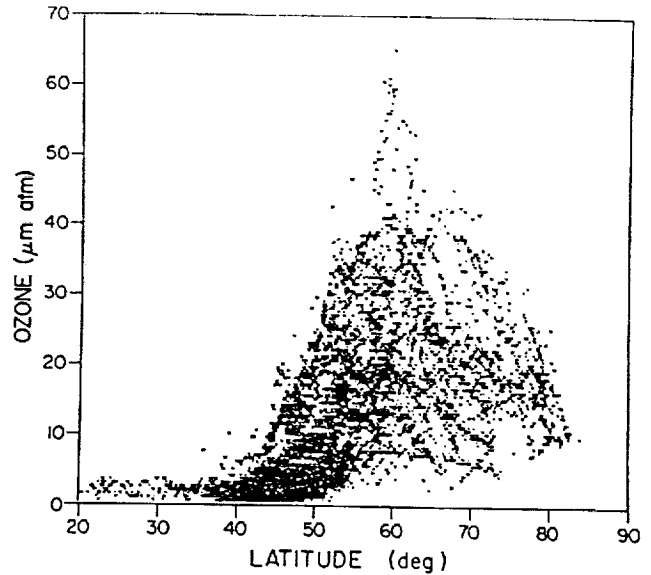
Fig. 2.   Measurements of the O_3 column abundance previously inferred from the Mariner 9 UV spectrometer data during the northern winter, $L_s = 330°-360°$, in the northern hemisphere [4].

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 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
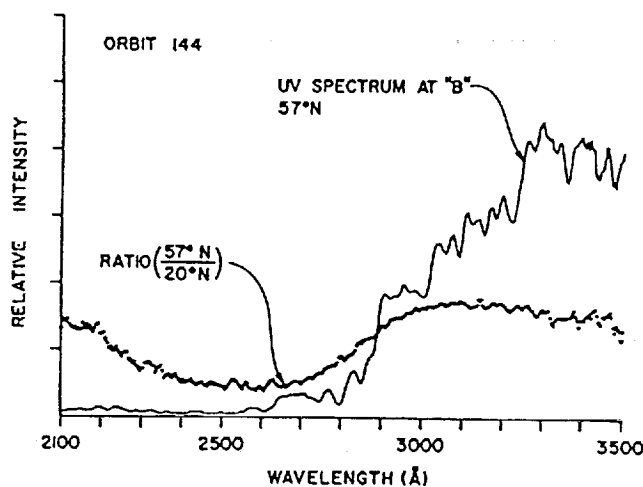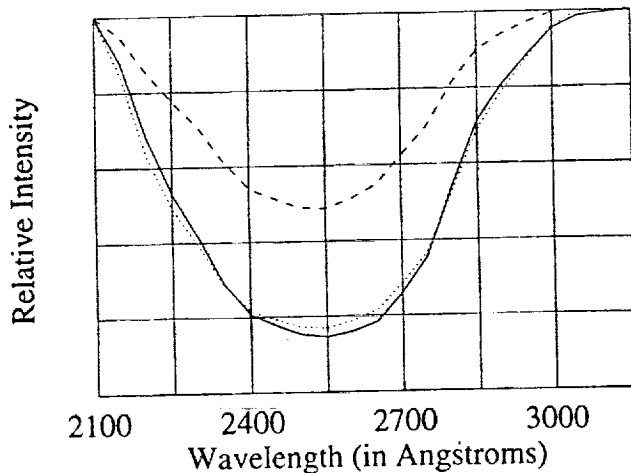

Fig. 1.   Ultraviolet spectrum measured by Mariner 9 at 57°N latitude on orbit 144 [7]. To enhance the O_3 absorption feature, this spectrum was divided by one obtained at 20°N latitude on orbit 144, where O_3 abundances are minimal [7].

Fig. 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 zenith angle of 75° (typical for winter polar observations), and a polar cap albedo of 0.6.

to observe through the increasing effective optical depths as one goes poleward.

By using a photochemical model that 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 60 μm-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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References: [1] Shimazaki T. (1989) *J. Geomag. Geoelectr.*, *41*, 273–301. [2] Krasnopolsky V. A. (1993) *Icarus, 101*, 313–332. [3] Lindner B. L. (1988) *Planet. Space Sci.*, *36*, 125–144. [4] Barth C. A. et al. (1973) *Science, 179*, 795–796; Lane A. L. et al. (1973) *Icarus, 18*, 102–108. [5] Lindner B. L. (1991) *Icarus, 93*, 354–361; Lindner B. L. (1993) *Publ. Astron. Soc. Japan*, submitted. [6] Lindner B. L. (1990) *JGR, 95*, 1367–1379; Lindner B. L. (1992) *GRL, 19*, 1675–1678; Lindner B. L. (1993) *JGR, 98*, 3339–3344. [7] Barth C. A. (1985) in *The Photochemistry of Atmospheres. Earth, Other Planets, and Comets* (J. Levine, ed.), Academic, Florida. [8] Barth C. A. and Dick M. L. (1974) *Icarus, 22*, 205–211. [9] Atreya S. K. and Blamont J. E. (1990) *GRL, 17*, 287–290.

THE EFFECT OF POLAR CAPS ON OBLIQUITY. B. L. Lindner, Atmospheric and Environmental Research, Inc., 840 Memorial Drive, Cambridge MA 02139, USA.

Rubincam [1] has shown that the martian obliquity is dependent on the seasonal polar caps. In particular, Rubincam analytically derived this dependence and showed that the change in obliquity is directly proportional to the seasonal polar cap mass. Specifically, Rubincam showed

$$d\psi/dt = 3 \times 10^{-10} \, M(t)/M(0) \quad \text{degrees/Earth year} \quad (1)$$

where ψ is the obliquity and M is the mass of the seasonal polar caps, with time t of 0 being the present. This expression assumes uniformly thick spherical caps with identical angular radii of 45°. However, even if a very different polar cap mass distribution is used, Rubincam estimates the total uncertainty in the constant in equation (1) to be less than a factor of 2. Using the current mass of the seasonal polar cap as typical over geologic time, Rubincam calculates that the amount that the obliquity would secularly change is only 1.4°. Considering that the current obliquity of Mars is 25°, Rubincam concludes that seasonal friction does not appear to have changed Mars' climate significantly.

Using a computer model for the evolution of the martian atmosphere, Haberle et al. [2,3] have made a convincing case for the possibility of huge polar caps, about 10× the mass of the current polar caps, that exist for a significant fraction of the planet's history. Given the large uncertainties in input parameters and in the model itself, the results must be regarded as speculative. Also, the Haberle et al. results have been unable to favor or rule out a large polar cap scenario vs. a small polar cap scenario.

Nonetheless, since Rubincam showed that the effect of seasonal friction on obliquity is directly proportional to polar cap mass, a scenario with a ten-fold increase in polar cap mass over a significant fraction of the planet's history would result in a secular increase in Mars' obliquity of perhaps 10° (using equation (1)). Hence, the Rubincam conclusion of an insignificant contribution to Mars' climate by seasonal friction may be incorrect. Furthermore, if seasonal friction is an important consideration in the obliquity of Mars, this would significantly alter the predictions of past obliquity as presented by Ward [4–6], Murray et al. [7], Ward et al. [8], Rubincam [9], Chao and Rubincam [10], Bills [11], Ward and Ruby [12], Touma and Wisdom [13], and Laskar and Robutel [14]. That in turn would significantly alter the predictions of past climate, which are based on obliquity predictions [15–20]. The mechanics of the polar cap system also depend on obliquity [21–26]. If obliquities were often much smaller than at present, that could have implications for past atmospheric composition [27].

Given the enormity of the implications, the effect of the polar caps on the obliquity of Mars should be given more attention and study. Perhaps further modeling of obliquity could be used to rule out the possibility of large polar caps for extended times, which would assist modeling of atmospheric evolution. Similarly, modeling of atmospheric evolution should be given more attention and study because of the implications for obliquity history, and therefore climate history.