



Fig. 3. Synthetic spectra as would be observed by spacecraft for atmospheres with no cloud or dust and 30 $\mu\text{m-atm O}_3$ (solid line), vertical opacities of dust and cloud of 0.3 and 1.0, respectively, and 30 $\mu\text{m-atm O}_3$ (dashed line), and vertical opacities of dust and cloud of 0.3 and 1.0, respectively, and 100 $\mu\text{m-atm O}_3$ (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 $\mu\text{m-atm}$ 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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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

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

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 10x 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.

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ESCAPE OF MARS ATMOSPHERIC CARBON THROUGH TIME BY PHOTOCHEMICAL MEANS. J. G. Luhmann¹, J. Kim², and A. F. Nagy³, ¹Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA 90024-1567, USA, ²KARI, Seoul, Korea, ³Space Research Laboratory, University of Michigan, Ann Arbor MI 48109, USA.

Luhmann et al. [1] recently suggested that sputtering of the martian atmosphere by reentering O⁺ pickup ions could have provided a significant route of escape for CO₂ and its products throughout Mars' history. They estimated that the equivalent of C in a ~140-mbar CO₂ atmosphere should have been lost this way if the Sun and solar wind evolved according to available models. Another source of escaping C (and O) that is potentially important is the dissociative recombination of ionospheric CO⁺ near the exobase [2]. We have evaluated the loss rates due to this process for "ancient" solar EUV radiation fluxes of 1, 3, and 6× the present flux in order to calculate the possible cumulative loss over the last 3.5 Gyr. (Earlier estimates of loss by McElroy [2] used the present-day rates and thus represent underestimates.) The inputs and assumptions for this calculation are the same as used by Zhang et al. [3] for an evaluation of historical O escape by dissociative recombination of ionospheric O₂⁺. We find loss rates of C that are at least comparable to the sputtering loss rates, thereby potentially accounting for another 100 mbar or more of Mars' original atmosphere.

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525-91 ABS. ON
MIGHT IT BE POSSIBLE TO PREDICT THE ONSET OF MAJOR MARTIAN DUST STORMS? L. J. Martin¹, P. B. James², and R. W. Zurek³, ¹Lowell Observatory, Flagstaff AZ 86001, USA, ²University of Toledo, Toledo OH 43606, USA, ³Jet Propulsion Laboratory and California Institute of Technology, Pasadena CA 91109, USA.

This was done very successfully by the late "Chick" Capen in 1971, but we now believe that the chance of having a planet-encircling storm in any given Mars year is less than 50% [1]. Capen suggested that these storms begin around the time of perihelion. More recent storms have extended this season to nearly one-third of a martian year, during the same interval that the south polar cap is receding [2]. There is no observational evidence that storms of this size have occurred outside of that period, although smaller dust storms have been observed throughout most of the martian year. The circumstances that allow a limited storm to become a runaway or encircling storm are not well understood. Seasonal effects are apparently just one aspect of these circumstances, but apparently a critical one. Dust activity seen by Viking near the edges of the receding cap and data showing that the cap may be receding at a faster rate prior to these storms suggest that the seasonal south cap may be influencing dust activity.

We have also determined that the north polar hood recedes during major dust storms, but it is not clear whether impending storms might have an effect upon this atmospheric phenomenon. Viking images do show local storm clouds near the hood prior to the first 1977 planet-encircling dust storm, but the hood is such a dynamic feature that minor changes may not be meaningful. We are, however, continuing to analyze these data.

Several datasets indicate that Mars' atmosphere was less clear before the first 1977 encircling storm, although we cannot discount the possibility that this was merely a seasonal change. Data from other Mars years are less detailed and comprehensive, but the 1977 Viking data from both imaging [3] and infrared [4] suggest that dust in the atmosphere was increasing prior to the storm. Peter Boyce found that, prior to the 1971 planet-encircling storm, there was "violet haze" present on Mars. He attributed this to the impending storm, which may have been correct, but this condition, which could be due in part to atmospheric dust on Mars, is not uncommon at times when no storm is on the way. This may also be true for other indicators of increasing atmospheric dust mentioned above.

Capen also believed that smaller, precursor storms occurred before a planet-encircling storm. This generally seems to be the case, although the data are not conclusive. These earlier storms certainly provide a good vehicle for raising dust into the the atmosphere and regional dust storms may be a sign of an impending larger storm. However, many of these storms occur without any subsequent dust activity, even during the dust storm "season."

Investigations of dust-storm observations show that that the Hellas Basin is the most active area on Mars for all sizes of storms [2]. This area is probably their primary dust source.

Earth-based observations suggest that, during the expansion phase of planet-encircling storms, diurnal cycles often begin at Hellas, presumably with a new load of dust, as mountain climbers return to a base camp for more supplies to be cached along their route. Each day the storms carry an increasing supply of dust farther to the west, until Hellas is reached from the east, completing the