Mariner 9 Television Limb Observations of Dust and Ice Hazes on Mars

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ABSTRACT

Over 3000 Mariner 9 television reflectance profiles crossing the limb of Mars were analyzed statistically during the period from the decaying phase of a global dust storm (southern summer) until southern winter solstice. Most of the profiles were obtained during the first 100 days of the mission. The "top" of the dust, as defined by the inflection point in the reflectance profiles, decreased with time during the decay of the dust storm, but more rapidly in the higher latitudes of both hemispheres than in the tropics. The inflection point due to dust haze remained above 20 km in the tropics throughout the period. These variations support the hypothesis that the diurnal tide is the primary agent of vertical dust transport. Scale heights of the upper portion of the dust cloud were highest in the tropics early in the mission, decaying with time and/or depth in the atmosphere. If interpreted in terms of vertical eddy diffusion, the scale heights suggest diffusion coefficients of order $10^3 \text{ m}^2 \text{ s}^{-1}$ in the 40–60 km height range. Distribution, color and polarization of higher limb hazes were also analyzed. These are interpreted as condensate layers associated with convective overshoot from the dusty lower atmosphere. A long internal gravity wave revealed by one of these layers is discussed.

1. Introduction

During the Mariner 9 orbiter mission to Mars, over 7000 television (vidicon) images were received and processed by the Image Processing Laboratory (IPL) of the Jet Propulsion Laboratory, the facility which managed and operated the mission. Images containing the planetary limb are potential sources of information about the atmosphere, and this particular set is unique in its coverage in time and space, even in the post-Viking era. Over 700 usable limb images were obtained. Although such vidicon systems cannot generally be used for photometry (Young, 1974), the distributional aspects of the data can usefully complement the photometric measurements obtained with the Mariner 9 Ultraviolet Spectrometer (Ajello and Hord, 1973; Ajello et al., 1973, 1976), the Mariner 9 Infrared Interferometer Spectrometer (Toon et al., 1977), and the Viking Lander imaging system (Pollack et al., 1977). In this paper we utilize this data set to infer some statistical properties of the upper portion of the Martian dust haze and of the thin haze layers which frequently lie above it. In addition, polarization characteristics of the thin high hazes are inferred from the data, and are used to bound the particle sizes in these layers. A more detailed account of the analyses described here can be found in Anderson (1977).

2. Limb data set

Salient aspects of the imaging system and image processing are discussed by Thorpe (1973). Further details can be found in Masurky et al. (1970), and in technical memoranda by Cutts (1974), Koskela (1972) and Koskela et al. (1972), available at the Jet Propulsion Laboratory. Television images which contained the limb received additional processing by the IPL. Profiles of reduced data-number\(^1\) versus pixel number were plotted along paths normal to the limb in geometrically corrected images. The reduced data-number incorporated the preflight calibration corrections to the raw reflectance data, but further corrections were found to be necessary due to nonlinearities discovered in a limited set of in-flight calibration images (Thorpe, 1972, 1973; Young, 1974). Although photometric distortion is not a major concern in our analysis, we have applied Thorpe's corrections to

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\(^1\) Reduced data-number is used here to signify "reduced data record data number (RDR-DN) in the Mariner 9 nomenclature (e.g., Noland et al., 1973)."
reduce the influence of nonlinearities on the profile shapes. These corrections, defined at five points distributed over each frame, were used to define smoothed correction surfaces over the frame. The correction obtained for the orange filter (filter 2) was also applied to the other color filters of the wide-angle camera (A camera). A separate correction, suggested by Thorpe, was applied to all A camera polarization filter images (filters 3, 5, 7) based on in-flight calibration data obtained with filter 5. The narrow-angle camera (B camera) also had a separate correction based on in-flight data. Each image contained from one to nine profiles, but the average number was five. Distribution of profiles in time are given in Table 1, in space during the early part of the mission in Fig. 1, and the distribution by filter is given in Table 2.
3. Distribution of the dust haze

Fig. 2 illustrates the shapes of limb profiles for cases with and without high-level hazes. In all cases without high hazes, and in most cases with high hazes, an inflection point closest to the limb could be unambiguously identified. This point generally lies in the dusty haze which is the dominant contributor to opacity, and it approximately defines the level at which the optical path along the line-of-sight is unity (normal incidence optical depth of order 0.02). We identify this point with the approximate "top" of the dusty layer and attempt to characterize the time and space variations of its height and of the logarithmic slope, or scale height, in its vicinity, by a least-squares fit to the profiles. In a few cases, mainly in profiles near the terminator or just over it, a clearcut inflection point could not be identified, and these profiles were not used. The difficulty in this analysis is that the precise location of the hard limb or planetary surface is not known in the profiles because of orbital errors and errors in our knowledge of spacecraft orientation or scan platform pointing. The latter errors are dominant, and they are essentially random with a standard deviation of 0.25°, equivalent to 9–39 km depending on range. We assumed that the actual inflection point heights remained rather constant in large groups of profiles within small ranges of latitude and time and simply tried to reduce the uncertainties in mean inflection point height within these ranges by using many profiles from many images. An alternative procedure for identifying the hard limb location based on identification and location of landmarks in the images could not be applied here because of the obscuration of most surface features by dust haze. Fortunately, the inflection point heights proved to be...
Fig. 4a. Distribution of inflection point height (km), and standard deviations by latitude and time in mission. The peculiar arrangement of blocks for which the values correspond arise from the groupings of limb images throughout the mission. Numbers in parentheses are the numbers of profiles going into the statistics. Fig. 4b. Least-squares fit to the data in 4a. The standard error of the fit is ±12.9 km.

remarkably high, so that even this crude method of determination leads to significant results.

Fig. 3 shows an example of the distribution of inflection point heights for Mariner 9 revs 1–65\(^2\) and latitudes 0–30°S. The approximately Gaussian distribution and the standard deviation of 9 km are consistent with the hypothesis that the variability within this group of profiles is due primarily to random pointing errors. The distribution of mean heights for all analyzed profiles is shown in Fig. 4a. The heights are given with respect to an oblate spheroid of equatorial radius 3394 km and polar radius 3376 km (de Vaucouleurs et al., 1973) which differs little from the triaxial ellipsoid of Cain et al. (1972). Fig. 4b depicts a least-squares fit to the data of Fig. 4a which is third order in both latitude and rev number.

The extraordinary height of the dust haze during the early decay phase of the dust storm has been reported previously (Leovy et al., 1972) and is confirmed by ultraviolet spectrometer observations using a different technique (Ajello et al., 1976). The new result from Fig. 4 is that the dust height was greatest at all times in the equatorial zone, and that it decayed

\(^2\) A rev is an orbital revolution. Since there is 1 rev per 12 h, there are 2.05 revs per Martian solar day.
most rapidly with time in high latitudes of both hemispheres. The rate of decay of the height in the equatorial zone during the first 80 revs was quite consistent with the rate of decay of the dust heating inferred by Conrath (1975), but the subsequent altitude decay rate in equatorial latitudes appears to have been much slower. Even at the end of the mission, the equatorial inflection point height appears to exceed 20 km. Because of the small number of profiles involved, no great significance can be attributed to this last data point, but the result is consistent with the findings of Pollack et al. (1977) based on Viking Lander data obtained at the beginning of the Viking mission ($L_a=90-120$).

Lindzen (1970) has suggested that thermally driven atmospheric tides are important mixing agents in the Martian atmosphere. The time-latitude distribution of the top of the dust is very consistent with the distribution expected if mixing originates with the diurnal tides, since this tide is characterized by vertically propagating components in the latitude belt $\pm 30^\circ$, and vertically trapped components elsewhere (Chapman and Lindzen, 1970). The vertically propagating tidal components are expected to be efficient vertical mixing agents, either due to direct transport or because of associated turbulent transport arising from wave breaking when tidal amplitudes become large enough to cause the Richardson Number instability criterion to be exceeded. In his theoretical analysis of Martian tides, Zurek (1976) has shown that both effects are likely to be important in the Martian tropics above 35 km. Entry temperature profiles (Seiff and Kirk, 1976) and surface diurnal pressure variations (Hess et al., 1977) both provide convincing evidence that the diurnal tide is at least as strong as that calculated by Zurek. The inflection height observations can be interpreted as strong support for Lindzen’s original hypothesis that the diurnal tide is indeed the primary mixing agent on Mars, at least during the decaying phase of a global dust storm.

These observations also close a paradox of long standing in the ground-based observations of Mars. It is well known that the optical oblateness exceeds the dynamical oblateness (Darwin, 1876). This analysis shows that the effect is due to the nonuniform distribution of haze, confirming a hypothesis of de Vaucouleurs (1964).

The logarithmic derivative of the reflectance profile at the inflection point was used to determine the dust scale height $H$, under the assumption that the dust is approximately exponentially distributed in that altitude region. Near the top of the dust, the single scattering approximation is a good one, and the reflectivity $R$ at height $z$ is given by

$$R(z) = A \{ 1 - \exp[-\tau(z)] \},$$

where $\tau(z)$ is the optical path length along the line of sight, and $A$ is a constant involving the single scattering albedo, phase function, solar irradiance, reflectivity of the underlying atmosphere and the spectral response function of the imaging system. For an exponential distribution of scatterers

$$\tau(z) = \tau_0 \exp(-z/H),$$

where $\tau_0$ is the line-of-sight optical path at the zero-point of height. Hence,

$$dR/dz = -A \exp[-\tau(z)] \tau(z)/H.$$  

At the inflection point $z_i$,

$$\frac{d^2R}{dz^2} = \frac{A \tau(z_i)}{H^2} \exp[-\tau(z_i)] \left[ 1 - \tau(z_i) \right] = 0,$$

or $\tau(z_i) = 1$. Hence, near $z_i$, by logarithmic differentiation of (1), we have

$$H = \left[ 1/(e-1) \right] R(z_i) \left( \frac{dR}{dz} \right)_z = 0,$$

and the logarithmic derivative of the reflectance at the inflection height is inversely proportional to the local dust scale height. Statistics of $H$ evaluated in this way were treated statistically in a manner similar to the inflection point height.

For A-camera images at ranges beyond 3000 km, a correction had to be applied for the spatial resolution function of the imaging system (this is usually referred to as the modulation transfer function or MTF). The preflight MTF calibration data were used to simulate a limb profile taken from the relatively great range of 8000 km. This simulation indicated that an exponential scattering profile would produce an apparent scale height larger by a factor $0.68^{-1}$ than the actual one as a result of the MTF. When A-camera profiles at an average range of 2800 km, where the MTF effect is negligible, were compared with those at an average range of 8200 km, the latter appeared to have average scale heights larger than those of the former by a factor 0.72. This was sufficiently close to the correction factor obtained by simulation that a simple linear correction to scale height yielding this factor at 8000 km was employed for all A-camera images at ranges beyond 3000 km. A check on this simple procedure was obtained by comparison of A-camera scale heights with those obtained using the B-camera at various ranges. The B-camera resolution was 10 times better than that of the A-camera, so that MTF was not a problem in B-camera images of the limb. No systematic differences in scale heights determined by the B-camera or by the A-camera employing this correction were found, nor were there any systematic differences.
between scale heights or inflection heights obtained with the various A-camera filters. A further precaution was necessary in the scale-height analysis. Profiles with high limb hazes were excluded from the set in order to eliminate possible biases due to these profile distortions.

Results of the dust scale-height analysis are displayed in Fig. 5. Scale heights are initially largest in the equatorial region and the Southern Hemisphere, which is the hemisphere in which the dust storm was initially most active, at least in terms of its atmospheric heating effects (Conrath et al., 1973). Scale height decreases with time or with depth in the atmosphere within each latitude belt, and there is some indication that it decreases most rapidly in the higher latitudes.

Under steady-state conditions, the loss of dust particles due to fallout just balances the local gain due to vertical mixing. If the latter can be described by an eddy mixing coefficient $K$, which is approximately constant near the inflection point, this balance is given by

$$ w = \frac{1}{KH} + \frac{1}{H_a}, $$

where $w$ is the mean fall velocity of the particles and $H_a$ the scale height of the molecular component of the atmosphere. Under the free molecular flow conditions prevailing at these heights

$$ w = -174 r T^3 \exp(z/H_a) \, [m \, s^{-1}], $$

where $r$ is the dust particle radius (m) and $T$ the atmospheric temperature (Green and Lane, 1964). In deriving this expression, an isothermal atmosphere with surface pressure 6.1 mb has been assumed. Using $H_a = 10$ km, consistent with the data of Conrath et al. (1973), we derive the $K$ values for 1 pm radius particles at the inflection point height shown in Table 3. The 1 pm radius is close to the value deduced by Pollack et al. (1977) for suspended Martian dust, but according to Eq. (6) particle fall rates are proportional to the radius and hence $K$ is inversely proportional to radius. Interpreted in terms of this simple mixing model, the vertical distribution of dust near the inflection point implies a decrease in mixing rate with time and/or with depth in the atmosphere.
at all latitudes. For reasonable particle radii (0.3–3 μm), the deduced mixing coefficients are of order $10^6 \text{m}^2 \text{s}^{-1}$ between 40 and 60 km. This magnitude is consistent with that required by current photochemical models in order to yield atmospheric composition consistent with observations (McElroy and Kong, 1976). It is consistent with the values estimated by Zurek from tidal theory. Although the inflection point height data strongly points to tides as the primary mixing agent, it is not clear whether the direct action of tides or secondary turbulence generated by the tides is responsible for the dust structure near the inflection height.

4. Distribution and color of high thin hazes

The entire set of limb profiles was surveyed for the signature of high limb hazes (Fig. 2). Although these occasionally occurred as multiple layers, in most cases only a single distinct layer could be identified. Multiple layers occurred relatively more often late in the mission, and were observed frequently very near the terminator. However, we consider here only the distribution and orange/violet ratio of the single layers. Fig. 6 depicts the distribution by latitude belt and time in the mission of the height of the peak of such high haze layers above the inflection point. The striking feature of these distributions is the very sharp peak in the equatorial distributions at 20 km above the inflection point in the regions and time range in which the dust storm was most active, i.e., revs 1–120 in the equatorial region and Southern Hemisphere. In the later decay phase of the dust storm, the high haze occurrences are almost as sharply peaked, but in this case they fall mainly about 10 km above the inflection height. By contrast, hazes in the higher northern latitudes occur over a broad range of heights. This is apparently a reflection of the fact that the north was less influenced by the dust storm, but was subject to the irregular weather patterns of winter (Briggs and Leovy, 1974). Variable high hazes then can result from variable condensation phenomena or from dust layers advected northward from lower latitudes.

Early in the mission, two-color (orange/violet, filter 2/filter 8) imaging of the limb occurred quite frequently (see Fig. 1). Color ratio distributions for these two color sequences are depicted in Fig. 7. No attempt is made to relate these ratios to true color because of uncertainties in the absolute calibration of the imaging system. Moreover, there was never exact overlap of the limb as seen by the different filters. Image pairs were sometimes separated by several hundred kilometers. Nevertheless, almost all of the high hazes were much “bluer” (or perhaps more accurately, much less red) than the underlying planet and dusty atmosphere which had orange/violet ratios generally near 2. We conclude that the particles comprising these layers were much less red than those in the dust particles at lower levels. We shall show in a subsequent section that they were also smaller. There is a tendency for the earliest equatorial and southern hazes to be particularly blue, and for a general reddening with time as the haze layers drop in altitude. A very significant point in this figure is the persistence of these hazes in the equatorial region over all revs between 1 and 118, and the nearly complete absence of high hazes in the northern latitudes early in the period and in southern latitudes late in the period. In other words, the high hazes are most frequent and persistent where the dust storm is most active, or where the dust reaches the greatest altitudes.

The high layers were almost always optically thin, since their reflectivities were substantially less than the reflectivity of the planet. The ratio of high haze reflectivity to the reflectivity on the adjacent planet varied considerably, but averaged less than 20% at 0.61 μm. They were also geometrically thin in most cases. Uniformly low layer thickness was particularly evident in the equatorial and Southern Hemisphere regions during the first 80 revs. A typical example, a B-camera image on rev 42, could be matched well to an exponential layer with a sharp lower boundary and a scale height of 3–4 km. On Mars, the relationship between the tangent path optical depth $\tau$, and the normal incidence optical depth $\tau$ for an expo-
ential layer with scale height $H$ (km) is

$$\tau_s = \tau 146 H^{-1}.$$

On this basis, we estimate that most of the observed high hazes had $\tau$ values in the range 0.001 to 0.01. The smaller of these values is the approximate detectability threshold for the Mariner 9 television cameras under the exposure conditions of most of the limb images.

It is not possible to unambiguously distinguish the composition or the formation mechanism on the basis of these observations alone, but the evidence does point toward a condensate layer whose formation is directly related to the dust storm below. Condensation of carbon dioxide as a consequence of convective overshoot seems to us to be the most plausible explanation, at least for those haze layers which occur very high, very early in the mission, and over the equatorial and Southern Hemisphere regions. In these regions, and at these times, solar heating produces daytime temperatures of order 210 K in the 30–40 km altitude range (Comrath et al., 1973). Between 40 and 60 km, this high temperature must relax, either because the heated dust particles can no longer transfer their energy to the tenuous atmosphere or because, as we have seen, the particle fall velocity becomes so large that mixing can no longer support them effectively. The relaxation layer may be rather thin, probably only of order one scale height in thickness, and at its top, radiative processes would tend to force the temperature toward its radiative equilibrium value of $\sim 145$ K for the dust free case (Gierasch and Goody, 1968; Seiff and Kirk, 1977). A rapid vertical transition from 210° to 145° would generate an unstable lapse rate and convective overturning. From the point of view of the upper atmosphere temperature structure, the situation resembles raising the ground to the level of the top of the dust haze. Vigorous overturning would produce substantial overshoot, and could well yield CO$_2$ condensation temperatures ($\sim 110$ K) at heights of order 20 km above the relaxation level. The lower hazes occurring during later
phases of the dust storm may be H₂O ice rather than CO₂ ice, but they also appear to form as a result of convective overshoot. Goody (1957) hypothesized that such a high-level convective layer would form on Mars, but as a result of vibrational relaxation of CO₂ rather than dust heating relaxation.

5. Polarization of the high hazes

The three A-camera polarization filters (filters 3, 5, 7) had virtually identical spectral characteristics and filter response factors differing by no more than 5%. Thus, despite possible uncalibrated nonlinearities in the imaging system, the relative responses for each filter should be nearly identical for unpolarized light. Noland et al. (1973) have discussed the use of the polarization data and have carried out a number of consistency checks in their effort to assess the polarization of Phobos and Deimos. They estimate systematic errors of less than 0.04 in degree of polarization for moderate values of reduced data number (DN). Unfortunately, the high hazes occur at relatively low DN levels (reduced data numbers of 20–40); nevertheless, they fall in the range of one somewhat underexposed Phobos image sequence. This sequence yielded a Phobos polarization which was quite consistent with that obtained at much higher exposure levels. The previously described photometric correction procedure based on Thorpe’s evaluation of in-flight data was applied to these profiles together with filter factors determined by the IPL. An additional problem in the present analysis is the need for precise alignment of adjacent profiles with respect to vertical scale. In cases with high haze layers, this was achieved by matching identifiable small-scale features in the high haze. In general this could be done with errors no larger than 2 km. Errors in alignment lead to small errors in polarization near the peak of the haze layer and on the planet, but they may produce significant errors in the transition zone between the lower dusty atmosphere and the high haze. In those cases where no such alignment was possible because of the absence of high layer structure, no information on polarization in the upper part of the dust haze could be obtained. Overall we believe that errors in degree of polarization near the peak of the high haze layers are well below 0.10 (<50% relative error). All of the polarization sequences were taken in the narrow phase angle range 76°–82°.

An example of a polarization sequence, analyzed in terms of Stokes parameters I, Q, U as well as in terms of the degree of polarization P and polarization angle θ, is shown in Fig. 8 (see Noland et al., for a discussion of the derivation of these quantities from the data)³. It can be seen that U is near zero at all heights, but Q changes substantially above the inflection point, so that polarization increases to above 20% near the peak of the haze layer. Values of θ are near 90°, i.e., the scattered light is partially polarized in the plane perpendicular to the scattering plane, as would be the case for a Rayleigh scattering contribution. Fig. 9 shows the limb traces and polarizations for all of the Mariner 9 limb polarization sequences. Here P_e is polarization measured at the peak of the high haze layer and P_d the polarization of light from the underlying dusty atmosphere and surface, i.e., from the flat part of profiles like those in Fig. 8. On profiles from revs 61, 66 and 102, there was no identifiable high haze layer. The rev 9 profiles show very high values for both P_d and P_e. These profiles were located very close to the corner of the image in a region where the calibration was particularly unreliable, and they should be considered accordingly. They also occurred very close to the terminator. The profiles for rev 102 were over the north pole, and this feature may indeed be highly polarized, although the individual profiles are not well registered for this case. The remaining cases are reasonably consistent, with values of P_d narrowly dispersed about 7% and values of P_e more widely dispersed, but averaging about 22%. The value of P_d found here is about 0.03 higher than the value obtained by Noland et al. for the dusty planet.

³Note, however, that the angle φ introduced in the discussion by Noland et al. (1973) is defined with respect to the vertical axis of the A-camera images and is thus inconsistent with the form of their Eq. (1) which assumes φ to be measured relative to the scattering plane.
We conclude that the high haze layers are significantly more polarized perpendicular to the scattering plane than the underlying dusty planet, with typical values of $P = 0.22 \pm 0.10$. Some increase in polarization is to be expected with increasing height as a consequence of the transition from a multiple-scattering to a single-scattering regime; however, in the highly absorbing Martian dust this effect could not account for the observed polarization increase. Polarization indicates that the high haze particles are different in composition or size from the dust haze particles. We have explored various combinations of refractive index and size parameters for log-normal particle size distributions using a Mie calculation in order to assess the constraints placed on these parameters by the observed polarization. It was found that for real refractive indices between 1.31 and 1.55, log-normal dispersions between 1.1 and 2.0, and any reasonable imaginary refractive index, log-normal mean radii lie in the range $0.05-0.3 \mu m$ for any polarization within $\pm 10\%$ of the nominal $22\%$. The reason that the mean radius is constrained despite such large ranges in the other parameters is because the measured perpendicular polarization is so high that the particle behavior must lie on the transition region between Rayleigh scattering behavior and behavior characteristic of particle sizes comparable to the wavelength. In this region, polarization varies quite rapidly with mean radius and relatively slowly with other parameters. However, as real refractive index or size dispersion increase, mean radius must decrease in order to yield the same polarization value. Of course, the assumption of spherical particles may not be correct, but for such small particles at the observed phase angles, it is unlikely to have a serious effect. We conclude that the high haze particles are generally smaller than the dust particles, that their mean radii are in the range...
6. Gravity waves

On a very few occasions, the high hazes showed evidence of wave structure, the best example of which is shown in Fig. 10. The parallel arcs show a complete arc structure in some places as a result of long horizontal bands following the planetary curvature and seen through the limb. In this case, there is a single well-defined wave train of wavelength 70 km occurring at an altitude of about 80 km. The feature is probably similar in origin to those seen early in the mission near the terminator (Masursky et al., 1972), and resembles noctilucent cloud structures (Witt, 1957, 1962). Evidently long internal gravity waves do reach the Martian upper atmosphere, at least occasionally.

7. Concluding remarks

The Mariner 9 limb imaging data produce great problems for interpretation of atmospheric phenomena. The problems are both photometric and geometric in nature. Nevertheless, the data set has unique properties, both in terms of the space-time coverage of the limb and the occurrence of relatively high-resolution polarization profiles. These unique features have encouraged us to attempt an analysis of the data, and they have allowed us to fill in some further details in the picture of post-dust-storm Martian hazes. During the decaying phase of the storm, the dust is maintained aloft to high elevations by vertical mixing primarily in the equatorial zone, apparently by the direct or indirect action of the diurnal tide. Consequently the dust decay is much faster in high latitude regions than near the equator. Mixing rates between 40 and 60 km are consistent both with expectations of tidal theory and with current photochemical models. Significant dust remains aloft in Martian equatorial regions long after the major dust storms have subsided. At the top of the dusty atmosphere, there is a region in which temperatures relax toward values expected for a dust-free CO₂ atmosphere; consequently, this is a region of convective overturning topped by thin condensation hazes resembling terrestrial noctilucent clouds. Like noctilucent clouds, the latter sometimes exhibit gravity wave structures.

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REFERENCES


