Comparison of Viking Lander Descent Data and MOLA Topography Reveals Kilometre-scale Offset in Mars Atmosphere Profiles

Author 1: Paul Withers. Affiliation: University of Arizona.

Mailing Address: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA. Telephone: +1 520 621 1507. Fax: +1 520 621 4933. Email: withers@lpl.arizona.edu

Author 2: R. D. Lorenz. Affiliation: University of Arizona.

Mailing Address: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA. Telephone: +1 520 621 5585. Fax: +1 520 621 4933. Email: lorenz@lpl.arizona.edu

Author 3: G. A. Neumann. Affiliation: Massachusetts Institute of Technology.

Mailing Address: Code 920, Laboratory for Terrestrial Physics, NASA Goddard Spaceflight Center, Greenbelt, MD 20771, USA. Telephone: +1 301 614 6019. Fax: +1 301 614 6015. Email: neumann@tharsis.gsfc.nasa.gov

Also at the Earth, Atmospheric, and Planetary Sciences Department, Massachusetts Institute of Technology, MA 02139, USA

Number of pages: 15

Number of figures: 2

Number of tables: 1

Proposed Running Head: VIKING AND MOLA ALTIMETRY

Correspondence Address:

Paul Withers

Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA.

withers@lpl.arizona.edu

Abstract

Each Viking Lander measured a topographic profile during entry. Comparing to MOLA, we find a vertical offset of 1 – 2 km in the Viking trajectory. Hence Viking atmospheric densities and pressures at a given altitude are 10 – 20 % too large.

Keywords:

ATMOSPHERES, STRUCTURE

MARS, ATMOSPHERE

Summary

Comparison of the martian topographic profile measured by Viking Lander 1 beneath its atmospheric entry trajectory and high-resolution topographic data generated by the Mars Orbiter Laser Altimeter (MOLA) instrument on the Mars Global Surveyor (MGS) spacecraft reveals a vertical offset of over one km in the Viking profile. The Viking profile, generated from accelerometer and radar altimeter measurements during descent through the martian atmosphere, is a major constraint on derived vertical profiles of atmospheric density, pressure, and temperature. These atmospheric profiles have been at the heart of the Mars Reference Atmosphere for two decades. The error in the topographic profile causes previously published values of atmospheric density and pressure at a given altitude to be too large by a systematic and correctable offset of 10 – 20 %.

Introduction

During its descent through the martian atmosphere, Viking Lander 1 experienced aerodynamic deceleration. Regular measurements of this deceleration were used with an initial entry state and knowledge of the martian gravitational field to reconstruct the spacecraft's trajectory to landing. They were then combined with knowledge of the spacecraft's aerodynamic characteristics to deduce profiles of atmospheric density, pressure, and temperature. Additional data sets, including radar altimeter measurements of altitude above the spatially-varying martian topography, were used to constrain the reconstructed trajectory and atmospheric profiles (Seiff and Kirk 1977a).

Altimetry from the Viking Landers

A by-product of this analysis was a profile of planetary radius relative to the landing site as a function of distance from the landing site, where distance is measured beneath the spacecraft trajectory (Seiff, 1993; Seiff and Kirk, 1977b). The Viking 1 profile was published by Seiff (1993, Figure 13). Using the spacecraft trajectory, archived at the National Space Science Data Center as dataset PSPA-00269, and the landing site coordinates (22.272 +/- 0.002 ^{o}N, 47.94 +/- 0.2 ^{o}W, Viking-era areocentric coordinates) we converted distance beneath the trajectory into areocentric latitude and longitude (Mayo *et al.* 1977). West areocentric longitudes, when subtracted from 360 degrees, give east areocentric longitudes. 0.2 degrees was then subtracted from the Viking-era east longitudes to convert them into MGS-era (1991 IAU) east longitudes used by MOLA (Smith *et al.* 1998; 1999). We used these latitudes and longitudes in the MOLA 1/16 degree resolution planetary radius dataset to obtain corresponding MOLA values for planetary radius relative to the landing site as a function of distance from the Viking 1 landing site.

[Fig 1]

Comparison with MOLA Altimetry

Figure 1 shows the Viking 1 profile, as scanned and manually digitized, and the corresponding MOLA profile (Seiff 1993). No vertical offset has been applied. Many features in one profile can be seen at the same distance along the other profile. This suggests that the radar altimeter was working well during atmospheric entry. A vertical offset is present between the two profiles. The Viking 1 profile is 2.3 km too high at 640 km distance from the landing site. The spacecraft is at approximately 130 km altitude at

this time. This offset decreases, approximately linearly, to 0.8 km at 140 km distance from the landing site. The spacecraft is at approximately 30 km altitude at this time. This offset in the Viking topographic profile must also be present in the altitude scale for the atmospheric profiles. Figure 2 shows a shaded relief map of the MOLA 1/16 degree resolution planetary radius dataset. Topographic features along the ground track can be matched to features on the profiles in Fig. 1. Smoothed contour intervals are also shown on this figure. No region 6 km above the Viking 1 landing site is closer than about 1000 km to the landing site, significantly further away than the 600 km or so inferred from Seiff's figure. This provides a quick and simple way of discovering the offset in the Viking topographic profile.

[Fig 2]

The direction of the offset can be calculated in the following manner. When the Viking Lander radar altimeter measures that it is 120 km above the terrain below, the original trajectory reconstruction, primarily from the accelerometer data, locates the spacecraft at 126 km above, and some 600 km horizontally from, the landing site. This puts the underlying terrain at this point along the ground track at 6 km above the landing site, as shown in Fig. 1. The radar altimeter value of 120 km is correct but, due to uncertainties in the trajectory reconstruction, the trajectory reconstruction value of 126 km is not correct. Since accurate MOLA data show that the underlying terrain is only 4 km above the landing site, the spacecraft is only 124 km above the landing site. This is 2 km below the original trajectory reconstruction. The original density profile has a value of about 10^{-8} kg m^{-3} at 126 km altitude. This density value is actually valid is 124 km altitude, 2 km *below* where it was originally located. Consequently, the density value reassigned to 126

km altitude is a *lower* value than it was originally. Altitudes as a function of density are too large and densities as a function of altitude are also too large. The same altitude scale is used for the pressure and temperature profiles, so the same corrections apply.

Implications for Viking Atmospheric Structure Results

The close correspondence between the small-scale structures in the Viking and MOLA profiles in Fig. 1 suggests that the errors in latitude and longitude for the trajectory reconstruction are less than a few tenths of a degree, which is very small compared to the lengthscale for changes in atmospheric properties. Constraining these horizontal offsets further using a scanned figure is not really practical. A vertical offset of 1 – 2 km is present in the Viking Lander 1 entry and atmospheric structure reconstruction. Using a scale height of 10 km, this corresponds to previously published densities and pressures at a given altitude being systematically too large by approximately 10 – 20 % (Seiff and Kirk 1977a). Atmospheric temperatures are minimally affected. Since these atmospheric profiles have been at the heart of the Mars Reference Atmosphere for the past two decades, the error is significant (Seiff 1982). However, it is correctable.

Correcting the Viking Atmospheric Structure Results

The best possible correction to the Viking Lander 1 trajectory and atmospheric structure reconstruction would be to rederive it from the original accelerometer and radar altimeter data using the newly available MOLA data as a constraint. This requires access to, and detailed understanding of the uncertainties in, large amounts of Viking science and engineering data. This would be a major undertaking. A first-order correction can be

made by altering the altitude scale to which the atmospheric profiles are referenced to compensate for the offset in Fig. 1.

$$z_{corrected} = z_{original} + offset(z_{original})$$

The original altitude values, $z_{original}$, to which the density, pressure, and temperature measurements were matched are offset from their actual values, $z_{corrected}$. The offset, a function of $z_{original}$, equals the Viking-derived planetary radius at the corresponding latitudes and longitudes subtracted from the MOLA planetary radius at the same locations. This correction is not complete because the atmospheric properties derived from the accelerometer measurements depend on the trajectory. However, the additional corrections that are needed should be smaller than this initial correction and so we neglect them here. Using the archived values for the spacecraft's trajectory (altitude, latitude, and longitude) and the two profiles in Fig. 1, we find that the offset is effectively linear with altitude.

$$offset(z_{original}) = z_{original} \times (-0.012) - 1.00 \text{ km}$$

The Viking Lander 1 atmospheric profiles are tabulated in Seiff and Kirk (1977a) at 4 km intervals. We reproduce them here in Table I with the addition of our corrected altitude scale.

[Table 1]

Conclusions

A kilometre-scale offset in the altitude of the Viking Lander 1 reconstructed entry trajectory has been identified by comparison between MOLA topography and data from the Viking Lander 1 radar altimeter. This causes the results for atmospheric density and pressure at a given altitude that were derived from the Viking Lander 1 entry to be 10 – 20% too large. This is a significant source of error for the Mars Reference Atmosphere. This error can now, in principle, be corrected using MOLA topographic data and we have made a first-order correction to the atmospheric profiles. There is also the possibility of evaluating the performance of the Viking radar altimeter, which has interesting engineering implications.

Acknowledgments

Dave Smith, Maria Zuber, the MOLA Science Team, John Wilson, and two reviewers.

References

Mayo, A. P., W. T. Blackshear, R. H. Tolson, W. H. Michael Jr., G. M. Kelly, J. P. Brenkle, and T. A. Komarek 1977. Lander locations, Mars physical ephemeris, and solar system parameters: Determination from Viking lander tracking data. *J. Geophys. Res.* **82**, 4297-4303.

Seiff, A. 1982. Post-Viking models for the structure of the summer atmosphere of Mars. *Adv. Space Res.* **2**(2), 3-17.

Seiff, A. 1993. Mars atmospheric winds indicated by motion of the Viking landers during parachute descent. *J. Geophys. Res.* **98**, 7461-7474.

Seiff, A., and D. B. Kirk 1977a. Structure of the atmosphere of Mars in summer at mid-latitudes. *J. Geophys. Res.* **82**, 4363-4378.

Seiff, A., and D. B. Kirk 1977b. Viking Lander Altimeter update. In *Minutes of the second meeting of the Viking Mars Physical Properties Working Group* (assembled by J. W. Meredith), pp. 26-30, JPL.

Smith, D. E., M. T. Zuber, H. V. Frey, J. B. Garvin, J. W. Head, D. O. Muhleman, G. H. Pettengill, R. J. Phillips, S. C. Solomon, H. J. Zwally, W. B. Banerdt, and T. C. Duxbury 1998. Topography of the Northern Hemisphere of Mars from the Mars Orbiter Laser Altimeter. *Science* **279**, 1686-1690.

Smith, D. E., G. A. Neumann, P. Ford, R. E. Arvidson, E. A. Guinness, and S. Slavney 1999. Mars Global Surveyor Laser Altimeter Initial Experiment Gridded Data Record, NASA Planetary Data System, MGS-M-MOLA-5-lEGDR-L3-V1.0.

Tables

Table I

Original Altitude (km)	Corrected Altitude (km)	Atmospheric Density (kg m^{-3})	Atmospheric Pressure (mbar)	Atmospheric Temperature (K)
120.00	117.61	1.60E-8	4.14E-6	136.3
116.00	113.65	2.42E-8	6.91E-6	149.2
112.00	109.70	3.95E-8	1.12E-5	148.6
108.00	105.75	6.59E-8	1.84E-5	146.4
104.00	101.79	1.06E-7	3.03E-5	149.4
100.00	97.84	1.67E-7	4.94E-5	154.8
96.00	93.89	2.88E-7	8.02E-5	145.9
92.00	89.93	5.39E-7	1.38E-4	133.6
88.00	85.98	8.33E-7	2.33E-4	146.7
84.00	82.03	1.40E-6	3.87E-4	144.2
80.00	78.07	2.57E-6	6.70E-4	136.6
76.00	74.12	4.66E-6	1.16E-3	130.5
72.00	70.17	7.70E-6	2.05E-3	139.1
68.00	66.21	1.17E-5	3.43E-3	152.9
64.00	62.26	1.88E-5	5.55E-3	154.6
60.00	58.31	3.19E-5	9.11E-3	149.5
56.00	54.35	5.96E-5	1.56E-2	136.8
52.00	50.40	9.56E-5	2.67E-2	146.3
48.00	46.44	1.57E-4	4.45E-2	148.6
44.00	42.49	2.65E-4	7.46E-2	147.5
40.00	38.54	4.10E-4	1.23E-1	157.4
36.00	34.58	6.25E-4	1.98E-1	166.1
32.00	30.63	9.32E-4	3.12E-1	175.1
28.00	26.68	1.38E-3	4.83E-1	183.8

Read 1.60E-8 as 1.60×10^{-8}

These altitudes are radial distances above the landing site

Figure Captions

Figure 1: Topographic profiles beneath the Viking Lander 1 entry trajectory as derived by Viking Lander 1 and by MOLA.

Figure 2: Shaded relief map of 1/16 degree resolution MOLA planetary radius data, referenced to the Viking 1 landing site. Smoothed contours are drawn in black at one kilometre intervals. The portion of the ground track shown in Fig. 1 is marked in white, as is the landing site.

Figures

Figure 1:

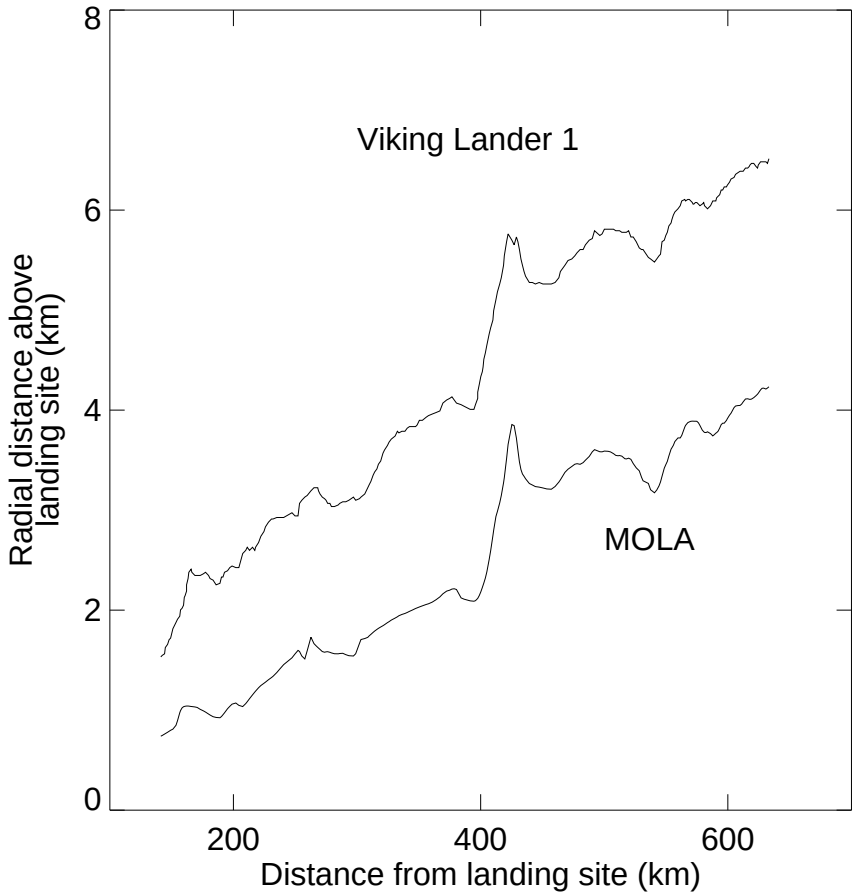
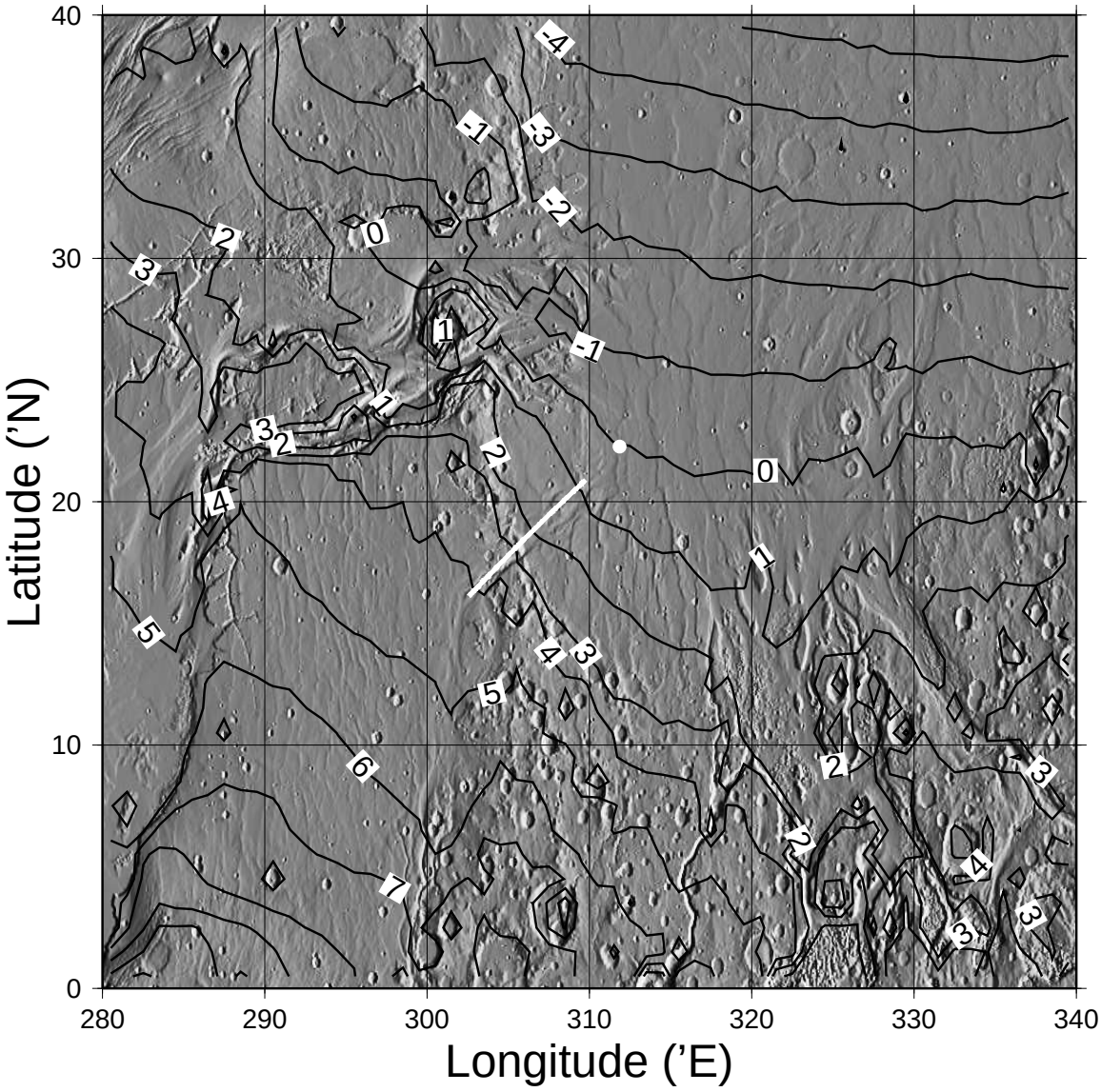
Figure 2: