EMPIRICAL PREDICTIONS OF MARTIAN SURFACE PRESSURE IN SUPPORT OF THE LANDING OF MARS SCIENCE LABORATORY

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ABSTRACT

Landing a spacecraft on Mars is tough. Unlike the Moon, Mars has enough atmosphere to require extensive thermal protection systems, such as heatshields. Unlike Venus and Titan, Mars has too tenuous an atmosphere for low-Mach parachutes alone to provide enough deceleration for a safe landing. Hence complicated landing systems, such as that used by Mars Science Laboratory, are required. A critical input to the design of Mars EDL systems is the surface pressure, which is essentially the mass of the atmospheric column. Here we explore ways to predict the surface pressure for the EDL of Mars Science Laboratory.

1. INTRODUCTION

The aim of this work is to develop an empirical expression for diurnal mean martian surface pressure in support of the landing of Mars Science Laboratory. We evaluate the consistency of surface pressure measurements from four landers, Viking Lander 1, Viking Lander 2, Mars Pathfinder, and Phoenix, and one radio occultation experiment, Mars Global Surveyor. With the exception of Mars Pathfinder, whose measurements are 0.1 mbar smaller than expected, all are consistent. We assume that the diurnal mean surface pressure is a separable function of altitude and season, neglecting dependences on time of day, latitude, and longitude, and use the Viking Lander 1 dataset to characterize the seasonal dependence as a harmonic function of season with annual and semi-annual periods. We characterize the exponential dependence of surface pressure on altitude using Mars Global Surveyor radio occultation measurements widely-distributed below +1 km altitude and within 45 degrees of the equator. Our empirical expression for diurnal surface pressure, p_{dm}, is $p_{0,VL1} \exp\left(-\left(z - z_{0,VL1}\right)/H_0\right) \left(1 + s_{1,VL1} \sin\left(1L_s\right) + c_{1,VL1} \cos\left(1L_s\right) + s_{2,VL1} \sin\left(2L_s\right) + c_{2,VL1} \cos\left(2L_s\right)\right)$ where z is altitude, L_s is season, the reference pressure, $p_{0,VL1}$, is 7.972 mbar, the altitude of Viking Lander 1, $z_{0,VL1}$, is -3.63 km, the reference scale height, H_0, is 11 km, and the harmonic coefficients are s_1 = -0.069, c_1 = 0.060, s_2 = 0.045, and c_2 = -0.050. We validate this expression against the available datasets and predict, with a 1-σ confidence level of 2%, a diurnal mean surface pressure of 7.30 mbar at Gale Crater, the Mars Science Laboratory landing site, at $L_s = 150^\circ$.

2. OTHER APPLICATIONS

The operational implications of simple and accurate methods for predicting martian surface pressure extend beyond MSL. From an operational perspective, other mission design efforts can use the work reported here to make first-order estimates of surface pressure for candidate landing sites and times. They can also use it as a straight-forward “reality-check” on the predictions of more complex models.

There are also potential scientific applications, such as the determination of the total atmospheric mass. Variations in the total mass of the martian atmosphere with time are important for several research areas, including the martian rotational state and the martian gravitational field. The atmospheric mass per unit area is the surface pressure divided by the acceleration of gravity. Using our empirical expression for diurnal surface pressure, we find that the predicted mean total atmospheric mass is approximately 2.4×10^{16} kg. The predicted difference between the maximum and minimum atmospheric mass is 6.6×10^{15} kg, or 27% of the mean atmospheric mass. If this mass difference were uniformally deposited in one hemisphere at latitudes poleward of 75° (or 65°) with a density of 910 kg m^{-3}, then the resultant seasonal polar cap would have a height of 3 m (or 1 m). These estimates of total atmospheric mass, range in atmospheric mass, and seasonal elevation changes are broadly consistent with earlier publications which builds confidence in our empirical expression.

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