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Atmospheric opacity, surface insolation, and dust lifting over 3 Mars years with the Mars Exploration Rovers

M.T. Lemmon and the Athena Science Team
Dept. of Atmospheric Sciences, Texas A&M University, College Station, Texas, USA (lemmon@tamu.edu).

Abstract

The Mars Exploration Rover optical depth record [4] now spans >3 Mars years at each of two sites. The record provides ground truth for orbital remote sensing, context for rover-based observations and for rover operations, and a measurement of a key component in atmospheric dynamics. Dust devil activity in Gusev is seen to be controlled by surface insolation, which is controlled by seasonal effects and dust opacity.

1. Introduction

Dust plays a fundamental role in the behavior and evolution of the Martian atmosphere. It has a direct effect on both surface and atmospheric heating rates, which are drivers of atmospheric dynamics. In turn, resulting atmospheric motions influence the distribution of the dust itself; setting up a complex feedback [e.g., 5]. Prior to the Mars Exploration Rover (MER) mission, the record of surface observations comprised ~1.3 Martian years of data at each of the two Viking Lander sites [2] and ~0.1 Martian year of data at the Pathfinder site [6].

In January 2004, a new era of surface-based atmospheric observations began with the arrival of the Mars Exploration Rover (MER) missions. The two rovers, MER-A and MER-B (or Spirit and Opportunity) landed shortly before the Southern autumn equinox on opposite sides of the planet in Gusev crater (14.6°S, 184.5°W) and in Meridiani Planum (1.9°S, 2.5°W), respectively. Each of the two rovers has accumulated more than 2000 sols (a sol is a Martian solar day, about 1.027 Earth solar days) of data as of this writing.

2. Observations

The MER atmospheric optical depth archive [4], which now spans over 3 Martian years for each rover, is based on Pancam images. Pancam has two cameras (eyes) per rover, each with a CCD detector, a filter wheel, and optics that map a 16x16 degree field of view onto 1024x1024 pixels [1]. Low-transmission solar filters are position eight in each filter wheel. The nominal wavelengths are 440 nm (L8) and 880 nm (R8); comparable Viking observations were done at 670 nm [2], and Pathfinder observations were made at 440, 670, 880, and 990 nm [6].

3. Optical depth calibration

Conversion of solar images into an optical depth measurement is fundamentally simple: following the Beer-Lambert law,

$$F = F_{TOA}\, e^{-\tau \eta} \qquad (1)$$

where F is the measured flux, F_{TOA} is the top-of-atmosphere flux, τ is the desired normal incidence optical depth, and η is the airmass, or ratio of slant path optical depth to normal optical depth. Derivation of atmospheric transmittance, F/ F_{TOA}, is done via a relative calibration, similar to that in the Mars Pathfinder analysis [6].

Substantial dust accumulation occurred near sol 1250. The window extinction came to exceed atmospheric extinction for parts of the mission. The identification and correction of dust events relies simply on a continuous reapplication of the Beer-Lambert Law. The transmission of atmospheric dust decreases with airmass, while the transmission of dust on the window is independent of airmass, and mimics a lower value for F_{TOA}.

4. Discussion

The optical depth record of the mission is shown in Fig. 1. Values in both filters are nearly the same. The rovers' initial 90-sol mission included the southern autumnal equinox (L_S 0) that began Mars Year (MY) 27, during a time of moderate but declining optical depths (Lemmon *et al.* 2004). Elevated and variable optical depths were seen each southern summer, while relatively low and steady optical depths (0.2 at Gusev, 0.4 at Meridiani) were seen each winter (until about sols 300, 1000, 1700). The seasonal and weather context and the implications of optical depth for surface heating will be discussed.

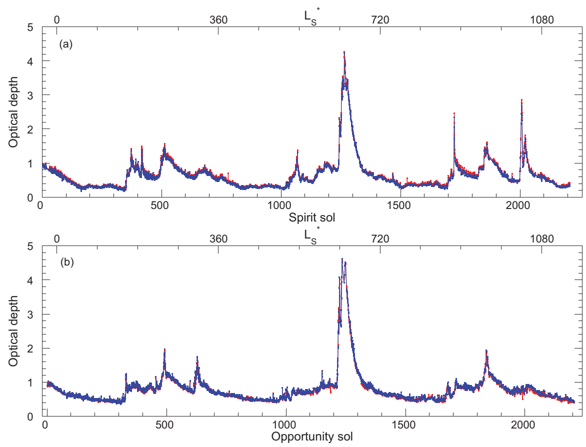

Figure 1: The MER optical depth record for (a) Spirit and (b) Opportunity is shown as a function of sol. Opacity observed in L8 (blue) and R8 (red) is shown. All valid measurements are presented. An approximate L_S scale is along the top axis modified to increase through the mission (successive northern spring equinoxes are at 0°, 360°, 720°, and 1080°).

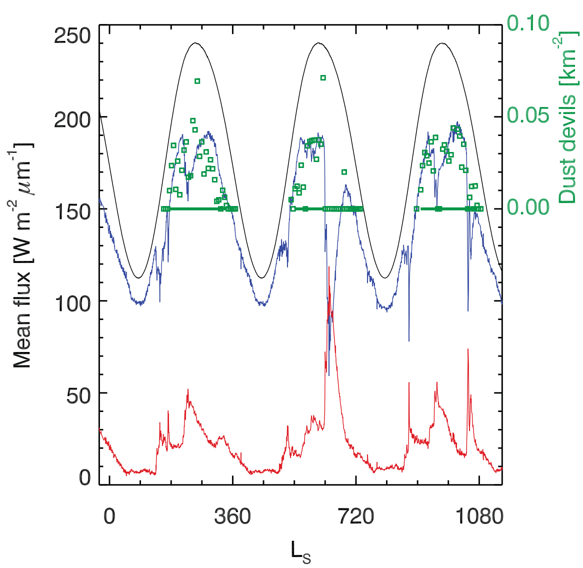

Figure 2: The MER optical depth record for (a) Spirit and (b) Opportunity is shown as a function of sol. Opacity observed in L8 (blue) and R8 (red) is shown. All valid measurements are presented. An approximate LS scale is along the top axis modified to increase through the mission (successive northern spring equinoxes are at 0°, 360°, 720°, and 1080°).

In particular, surface insolation (direct solar plus diffuse) at the Spirit site (Fig. 2) is of interest. Dust devils were seen and their density tracked over three southern summers [3]. For this site, there appears to be a threshold sol-average insolation of ~150 W m^{-2}; dust devil activity increases in proportion to the excess insolation above this threshold.

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