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Measurement of Martian boundary layer winds by the displacement of jettisoned lander hardware

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ABSTRACT

Martian boundary layer wind speed and direction measurements, from a variety of locations, seasons and times, are provided. For each lander sent to Mars over the last four decades a unique record of the winds blowing during their descent is preserved at each landing site. By comparing images acquired from orbiting spacecraft of the impact points of jettisoned hardware, such as heat shields and parachutes, to a trajectory model the winds can be measured. We start our investigations with the Viking lander 1 mission and end with Schiaparelli. In-between we extract wind measurements based on observations of the Beagle 2, Spirit, Opportunity, Phoenix and Curiosity landing sites.

With one exception the wind at each site during the lander's descent were found to be <8 m s^{-1}. High speed winds were required to explain the displacement of jettisoned hardware at the Phoenix landing site. We found a tail wind (>20 m s^{-1}), blowing from the north-west was required at a high altitude (>2 km) together with a gust close to the surface (<500 m altitude) originating from the north. All in all our investigations yielded a total of ten unique wind measurements in the PBL. One each from the Viking landers and one each from Beagle 2, Spirit, Opportunity and Schiaparelli. Two wind measurements, one above about 1 km altitude and one below, were possible from observations of the Curiosity and Phoenix landing site.

Our findings are consistent with a turbulent PBL in the afternoon and calm PBL in the morning. When comparing our results to a GCM we found a good match in wind direction but not for wind speed. The information provided here makes available wind measurements previously unavailable to Mars atmosphere modellers and investigators.

1. Introduction

Horizontal winds on Mars are an important property of the Martian atmosphere as they can influence the weather (Savijärvi, 2012; Kass et al., 2008) occasionally with dramatic results as observed during dust storms. The winds also sculpt the surface and transport material around the planet (Day and Kocurek, 2016). The near-surface winds, i.e. less than 2 m altitude, have been measured in situ by a number of surface missions (Chamberlain et al., 1976; Seiff et al., 1997; Gunnlaugsson et al., 2008) however the winds within the PBL have been measured only sporadically mostly by remote techniques e.g. Tamppari et al. (2010). More wind measurements are required especially those within the PBL as they are valuable for verifying the physics of Martian atmospheric models (Justus et al., 2004), understanding dust and volatile transport (Spiga and Lewis, 2010), help with the detection of trace gases and for planning landings (Michaels and Rafkin, 2008; Kauhanen et al., 2008).

Modelling of the Martian atmosphere on scales of 10 to 100 km (Spiga and Lewis, 2010) and investigations of sand dunes (Parteli et al., 2009; Liu and Zimbelman, 2015; Jackson et al., 2015) suggest topographic control of the near-surface winds. At smaller scales (1–10 km) the influence of turbulence on the wind patterns becomes important. Dust devils, a significant form of turbulence, are seen to be blown across the surface by the flow in the PBL (Stanzel et al., 2008).

In Section 2, background on the images of the jettisoned hardware used in our analysis is provided. Additionally some relevant atmospheric modelling details are provided relevant to this study. In Section 3, we describe our measurement technique and how the measurement uncertainties are obtained. In Section 4, we determine the wind speed, direction and some limited information on the vertical structure of the Martian winds. In Section 5, these results are discussed in the context of the Martian PBL.

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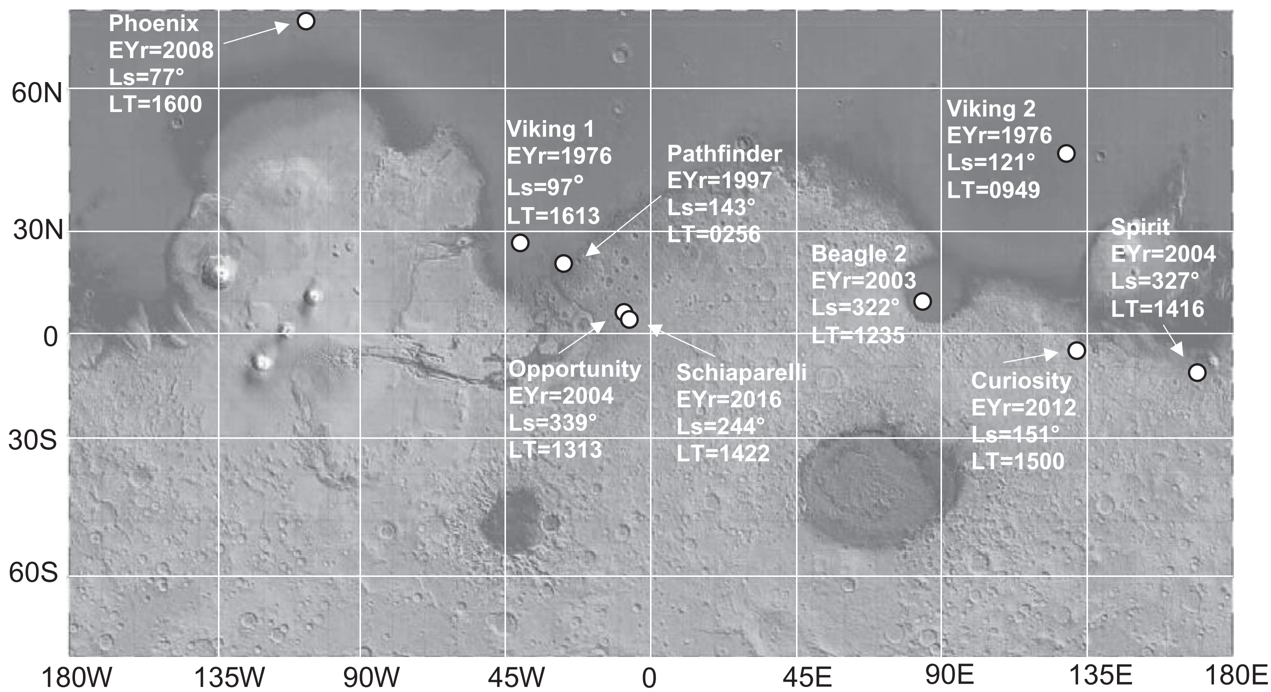

Fig. 1. Lander locations on a topographical map of Mars (Smith et al., 2001). EYr is the Earth year that the lander arrived at the surface of Mars. Ls is the solar longitude. LT is the local time.

2. Background

Wind profiles in the PBL have been determined from landers on the parachute descending through the Martian atmosphere using Doppler measurements such as with the Viking landers (Seiff, 1993a) and Schiaparelli (Ferri et al., 2017). Instrumentation has been developed specifically for making high resolution wind speed and direction measurements up to an altitude of 10 km (Montmessin, 2014; 2017) using Doppler wind lidar and will hopefully be deployed on the surface sometime soon. Moores et al. (2010, 2015) have used lander imagers to investigate atmospheric dynamics over the landing site by tracking dust and cloud features. Moores et al. (2016) modelled the trajectories of hardware jettisoned by Curiosity to verify their mesoscale modelling results.

2.1. Wind-blown lander hardware

The distribution of lander hardware on the surface such as heat shields and parachutes on the surface will be sensitive to the winds aloft in the Planetary Boundary Layer (PBL), e.g. see Paton (2017). A way to determine wind speed, direction and limited information on the vertical structure on Mars is from trajectory modelling of jettisoned lander hardware (Moores et al., 2016). As there have been a number of landings on Mars over a number of years and at a variety of locations, images of these sites could provide useful information on the variability of the Martian winds. Fig. 1 shows the distribution of landers across Mars all of which, apart from VL-2 and Pathfinder, have landed in the afternoon when the atmosphere is most turbulent. In some cases strong turbulence (Seiff, 1993a) and gusts (Cheng et al., 2004) appear to have had a significant effect on the lander's motion during descent.

Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) have imaged landers along with their jettisoned EDLS components on the surface of Mars. The images are all available via the HiRISE or MOC websites. The landers that have been imaged are Vikings 1 and 2, Pathfinder, the MER rovers Spirit and Opportunity, Phoenix and Curiosity. Attempts to image failed missions have been attempted. So far ESA's Beagle 2 (Merrifield, 2015) and Schiaparelli (see HiRISE website) have been spotted.

As can be seen in Table 1 the identification of jettisoned lander hardware are more certain when imaged up to a year or two after landing, i.e. from Spirit onwards in Table 1. Older lander parts are presumably covered in Martian dust which makes spotting them difficult. For example the Viking lander 1 and 2 backshells have been observed but the parachutes have proved difficult to identify presumably because they are covered in dust. In some more recent cases EDL hardware has been imaged in situ by the lander. The HiRISE images of the Phoenix hardware, its heat shield and parachute are particularly clear and the certainty of their origin has been strengthened with images returned from the surface by the lander itself (image PIA11172).

Fig. 2 shows a generic EDL architecture representing a lander-type using powered descent. Similar lander architectures were used for the Viking landers, Phoenix and Curiosity. For Viking the parachute was deployed at around 5 km above the landing site (Cooley and Lewis, 1977), 13 km altitude for Phoenix (Desai et al., 2011) and 12 km altitude for Curiosity (Cruz et al., 2014). The heat shield is jettisoned soon after the parachute is deployed, triggered by a timer, and then falls relatively quickly to the surface impacting the surface before the touchdown of the lander. The next relevant event for our analysis is when the lander separates from the backshell-parachute. This normally occurs around an altitude of 1 km. After being released the lander performs a powered descent while the parachute and the connected backshell drift down to the surface. Other types of landing system have been used on Mars, i.e. Pathfinder, MER rovers. These differ in that they used a combination of solid propellant retrorockets and airbags for the final stage of the landing to bring the lander to rest. Beagle 2 was light enough that retrorockets were not required and airbags could be used to absorb the energy from the impact with the surface. See Tables A.5 and A.6 for lander EDLS properties and EDL trajectory parameters, respectively.