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USING ACOUSTICS TO INFER NEAR-SURFACE TURBULENCE S. Maurice¹, B. Chide^{2,1}, P. Blanc-Benon³, T. Bertrand⁴, X. Jacob², J. Lasue¹, R. D. Lorenz⁵, F. Montmessin⁶, N. Murdoch⁷, M. Gillier⁷, J. Pla-Garcia⁸, F. Seel⁹, S. Schröder⁹, A. E. Stott⁷, M. de la Torre Juarez¹⁰, and R. C. Wiens¹¹. ¹IRAP (Univ. Toulouse 3, CNRS, CNES), 9 av. Colonel Roche, Toulouse, France. sylvestre.maurice@irap.omp.eu. ²IMFT (Univ. Toulouse 3, INP, CNRS) Toulouse, France. ³LMFA (CNRS, ECL, INSA Lyon, Univ. Lyon 1) Ecully, France. ⁴LEISA (Obs. Paris, Univ. PSL, Sorbonne Univ., CNRS) Meudon, France. ⁵Space Exploration Sector, Johns Hopkins APL, Laurel, Maryland, USA. ⁶LATMOS (CNRS, Univ. Saint-Quentin-en-Yvelines, Sorbonne Univ.) Guyancourt, France. ⁷ISAE (Univ. Toulouse) Toulouse, France. ⁸Centro de Astrobiología, Madrid, Spain. ⁹IOSS, German Aerospace Center, Berlin, Germany. ¹⁰JPL, California Institute of Technology, Pasadena, California, USA. ¹¹Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana, USA.

Introduction: Turbulence within the lower atmosphere of Mars in direct contact with the surface drives the transport of heat, dust, and trace gases, all of which have a global impact on the overall dynamics of the atmosphere [1]. Detailed knowledge of the turbulent processes on all spatial and time scales is, therefore, key to understanding the overall Mars climate system.

The NASA Perseverance rover, which landed on Mars on Feb. 18, 2021, carries a scientific microphone for the first time, which has highlighted the great potential of acoustic investigations to study Mars atmosphere (see a review by Chide et al. [4]). The main artificial sound recorded by the microphone is created when the SuperCam pulsed laser generates a plasma, whose optical emission is used to measure elemental composition [5]. As the plasma expands, it creates a shock wave [6], resulting in an N-shaped acoustic wave that is recorded between 2 kHz and 25 kHz by the microphone.

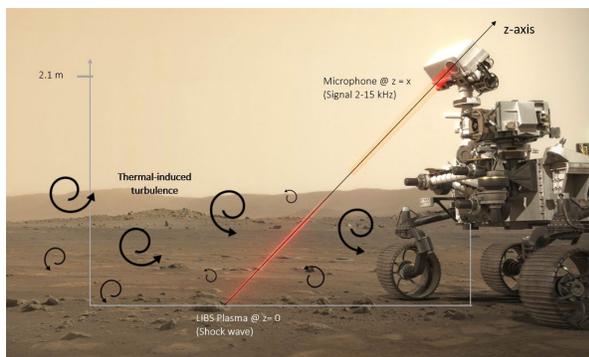


Figure 1. Geometry of the SuperCam microphone recordings of the laser-induced-acoustic signal, where the propagation path (2–8 m) along the z-axis goes through the thermal turbulence generated in the atmospheric surface layer of Mars.

We report on the first real acoustic experiment ever performed on Mars. Despite certain limitations of the setup, which lead to various simplifications (diffraction effects, wind speed is ignored, etc.), original results on the power spectrum of turbulent eddies near the surface of Mars can be deduced. First results have been

published [7] focusing on turbulence around noon local time. This study extends them to other local times for a better track of its diurnal and annual evolution.

Acoustic scintillation: The microphone is mounted at about 2.1 m above the ground, where the laser beam is fired (Fig. 1). The N-shaped acoustic waves propagate from the ground to the microphone, over distances that vary from target to target. Each N-wave acoustic wave is scattered by the many heterogeneities of the turbulent atmosphere along its propagation path.

SuperCam operates its laser at 3 Hz by bursts of 30 shots, 29 of which are recorded by the microphone at 100 kHz. Per burst, the first three shots are discarded because they may be potentially affected by surface dust. Hence, for targets between 2 m and 8 m, more than 3000 sets of 26 recordings have been acquired.

When the N-wave hits the microphone, its arrival time and intensity are carefully measured. Then, over 26 shots, their respective mean and variance are derived. The original publication [7] shows how the mean travel time and its variance can constrain the size distribution of eddies near the surface of Mars (Gaussian, Kolmogorov, Von Karman profiles). Oscillations of the wave intensity are worked in terms of the normalized variance of the signal intensity [8], renamed “acoustic scintillation” by analogy with optics:

$$SI = \frac{\langle (I - \langle I \rangle)^2 \rangle}{\langle I \rangle^2} = \frac{\langle p^4 \rangle - \langle p^2 \rangle^2}{\langle p^2 \rangle^2}.$$

SI is driven by turbulence. A first insight to the turbulence variation with local time is shown Fig. 2: SI values are lower at dusk and dawn than at midday. Moreover, SI increases with distance: the farther away the targets are, the more turbulence cells the acoustic.

This study provides new insight to this important relationship with local time. In the case of small perturbations, the original publication [7] showed that variations in SI with distance can constrain the type of turbulence, favoring a generalized Von Karman field as opposed to a pure Kolmogorov cascade. Based on this

model, SI values can be corrected for distance biases, such as those observed around noon in Fig. 2. Here we still assume that the laws for such a correction are valid at other local times.

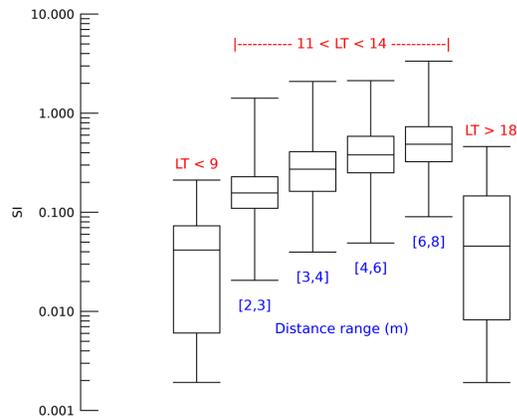


Figure 2. Variations of acoustic scintillation (SI) with local true sol time (LTST) and distance to the target

As new data are added to the study, a new sketch of daytime turbulence has emerged (Fig. 3). It follows the diurnal evolution of the turbulence on Mars: strong turbulence during daytime and a more stratified atmosphere during nighttime [9]. SI values expand over 2 orders of magnitude which makes them a very reliable indicator of the turbulence on Mars. 5-point average on the same target are performed to reduce the dispersion, but not changing the interpretation.

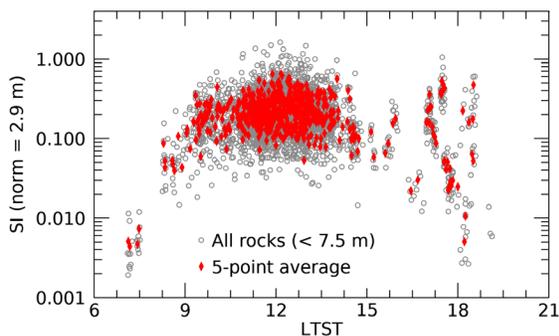


Figure 3. Variations of acoustic scintillation (SI) with local true sol time (LTST), for values normalized at a distance $x = 2.9$ m.

Turbulence is very low at dawn and increases rapidly until 10:00 LTST. It then stabilizes until 14:00 LTST. Later it appears to be very variable until dusk around 19:00 LTST. It appears that the turbulence decreases rapidly between 17:00 and 18:30 LTST, but with a lot of variability. The integrity of the data has been checked, and standard deviations of over 2-orders of magnitude (Fig. 2) are real.

Discussion: The Perseverance rover is carrying out an original active acoustic experiment to infer, for the first time, the characteristics of the near-surface acoustic turbulence on Mars at different local times. More data will be collected, including at night in the near future. When enough data have been collected, variations with Mars solar longitude (L_s) are expected. Both effects will be presented at the meeting.

We conclude that the scintillation SI is a new parameter to describe the variations of the Martian near-surface turbulence at 3 Hz (the repetition rate of the laser shots) in a well-defined configuration (e.g. the microphone is, by definition, always pointing in the direction of the incoming acoustic wave). More generally, measuring the speed of sound on another planet provides a new method of determining atmospheric temperature independently of traditional thermocouple sensors. It sheds light on large temperature variations over a very short time scale, ± 5 K/s on average and up to 10 K/s [4,10]. Such temperature excursions had been seen occasionally by atmospheric sensors, but were usually dismissed and attributed to thermal contamination from the rover, when they are natural; the power of cross-validation.

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