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Simulating the seismic pressure noise on Mars

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Abstract

The atmospheric pressure fluctuations on Mars will induce an elastic response in the ground that will create a ground tilt, detectable as a seismic signal on SEIS. We use Large Eddy Simulations of the wind and surface pressure at the InSight landing site, combined with ground deformation models to investigate the atmospheric pressure signals on SEIS. Full results have been reported in [1].

1. Introduction

The InSight mission, selected under the NASA Discovery program for launch in 2018, will perform the first comprehensive surface-based geophysical investigation of Mars. The objectives of the InSight mission are to advance our understanding of the formation and evolution of terrestrial planets and to determine the current level of tectonic activity and impact flux on Mars. SEIS (Seismic Experiment for Internal Structures) is the critical instrument for delineating the deep interior structure of Mars, including the thickness and structure of the crust, the composition and structure of the mantle, and the size of the core [2].

Meeting the performance requirements of the SEIS instrument is vital to successfully achieve the InSight mission objectives. However, there are many potential sources of noise on seismic instruments [3]. Also, the different environment on Mars compared to the Earth results in different noise conditions for the Martian seismometer. Meteorological activities induce noise on the seismometer through various mechanisms, such as the dynamic pressure due to the wind acting directly on the seismometer [4], and ground motion due to the interaction of the wind shield or the lander and the Martian winds [5]. The atmospheric pressure fluctuations on Mars induce an elastic response in the ground that creates ground tilt, vertical displacement, and surface pressure changes. Near, and at, the InSight seismic station, medium-scale atmospheric pressure variations (100s of m to kms) will generate ground deformations and, therefore, noise on the seismic records.

This pressure noise has been studied on Earth as a noise source at long-periods of 1-10 mHz, which is below the oceanic micro-seismic bands [6,7]. However, the situation is likely to be more severe on Mars due to the fact that the seismometer will be installed on top of the ground and on a soft regolith layer. Indeed, in addition to non-coherent seismic waves generated by the interaction of the planet's atmosphere with the ground and interior, the ground tilt due to atmospheric pressure fluctuations is expected to be one of the major contributors to the seismic noise recorded by the SEIS instrument [3]. The investigation of this atmospheric seismic signal is the primary goal of this paper.

2. Seismic pressure noise on Mars

3.1 Large Eddy Simulations

The investigation of the ground tilt caused by the local pressure field around the seismic station requires the thorough description of the regional pressure field. This is made possible by using turbulence-resolving Large-Eddy Simulations (LES) to describe the atmospheric environment of Mars at the InSight landing site and to model the excitation source, i.e., the surface-pressure field. [8] detail the LES model used in this study; in particular, the physical parametrizations, including radiative transfer, are adapted to the Martian conditions. The horizontal resolution of the model is 50 m, and the grid covers a region of 14.4 km by 14.4 km. This value is about three times the maximum expected height of the Planetary Boundary Layer (4.5 km, according to [9]), ensuring the development of convective cells [10]. The simulation starts at 8 am local time, and the vertical temperature profile is initialized according to the predictions of the Mars Climate Database [11]. With an output every 6 seconds, the simulation lasts until 9 pm local time, and thus covers the development and the collapse of the PBL convection as well as part of the calm nighttime period. Moreover, a West-to-East ``background'' horizontal wind of 10 m/s mimics the effects of regional-scale circulation and advects convective cells and vortices towards the East.

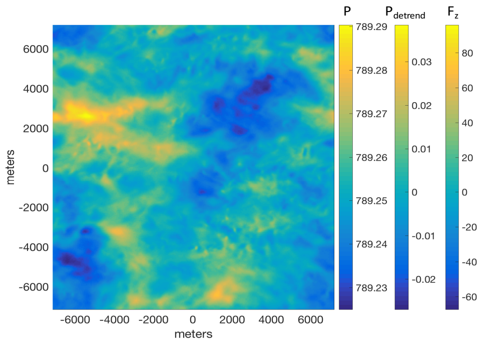

Figure 1. Large Eddy Simulations. The pressure (P, in Pa), detrended pressure ($P_{detrend}$, in Pa) and vertical force (F_z, in N) variations across the LES grid at one instant in time. North is aligned with the y-axis and East is aligned with the x-axis.

3.2. Ground deformation simulations

A point-load ground deformation approach, validated via comparison with in-situ seismic and pressure measurements of terrestrial dust devils [12], is used to calculate the displacement of the ground at the SEIS feet. The ground is modeled as an elastic half-space with properties of a Martian regolith [13]. For every section of the LES grid, the variation of the vertical force exerted on the ground at the center of the section of the grid can be given by the detrended value of the pressure of the grid section times the surface area of the grid section (Fig. 1). Then, the displacement of the ground at the seismometer feet will be a sum of the displacements caused by each section of the grid (each considered to be a point source in Green's function approximation). A detailed comparison of the Green's function approach has also been performed with two other independent methods: a spectral approach using the entire pressure field [14], and a single-station approach based on Sorrells' theory [15,16] using only the co-located seismic and pressure measurements. Results of the first of these two comparisons are shown in Fig. 2.

4. Results and Conclusions

The horizontal acceleration as a result of the ground tilt due to the LES turbulence-induced pressure fluctuations are found to be typically ~2 - 40 nm/s^2 in amplitude, whereas the direct horizontal acceleration is two orders of magnitude smaller and is thus negligible in comparison. The vertical accelerations are found to be ~0.1 - 6 nm/s^2 in amplitude (Fig. 2). These are expected to be worst-case estimates for the seismic pressure noise as we use a half-space approximation; the presence at some (shallow) depth of a harder layer would significantly reduce quasi-static displacement and tilt effects.

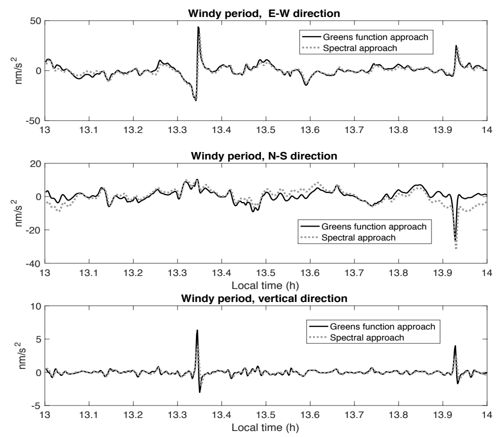

Figure 2. Comparison of the E-W, N-S and vertical accelerations calculated using Green's function method (black) and the spectral approach (grey dotted) for 1h during the most turbulent LES period.

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