ATMOSPHERIC OBSERVATIONS FROM THE MARS INSIGHT MISSION

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Introduction:

NASA's Discovery Program InSight mission is scientifically focused on the seismicity of Mars and its interior structure and heat flow. However, to understand when winds preclude good seismology and to possibly remove meteorological effects from the seismic signals, InSight will carry a complement of meteorological sensors that can add to the record of atmospheric observations at the surface of Mars. We will discuss the capabilities of InSight for atmospheric observations, and present the current plans for how its sensors will be used in operations. We will also discuss some of the recent scientific projects that are building in anticipation of using InSight's unique data sets.

InSight Goals:

The InSight mission's highest level goal is to understand the processes of formation and differentiation that have occurred on Mars, and thus the structure of the interior of the planet. Additionally, InSight will also study tectonic activity and meteorite impacts on Mars. To achieve these goals, InSight carries a set of seismometers, a heat flux probe and Doppler receiver/transponder to detect rotation variations. Supporting these primary instruments are cameras to ensure safe and proper placement of the seismometer and heat flow sensors on the ground, as well as a meteorology package to characterize the effects the atmosphere may have on the primary sensors.

Meteorological Support of Seismology:

The Viking seismology experiments demonstrated that winds can have a significant effect on seismometry (e.g., Nakamura and Anderson, 1979). InSight will mitigate this effect to a much larger degree than did Viking by placing its seismometers directly in contact with the ground, isolating them from the lander via a tether, and covering the seismometers with a wind and thermal shield. Nevertheless, it is expected that local wind and pressure perturbations will influence the observed seismic signals. For this reason, InSight carries basic wind and air temperature sensors (a variant of the wind and air temperature sensors from MSL REMS), as well as a highly sensitive pressure sensor (a Tavis pressure sensor, an improved version of those used on the Viking and Pathfinder missions). The pressure sensor is also equipped with a quad-disk inlet, adapted from those used in terrestrial infrasound detectors, to isolate atmospheric pressure changes from wind-induced dynamic pressure fluctuations. Because InSight will be monitoring for Martian seismicity essentially continuously, the operational plans also call for it to monitor the meteorology on a continuous basis.

Because the InSight mission is solar powered, and thus power availability is dependent on intensity of the sunlight received on its solar panels, InSight will use its arm-mounted camera to determine the atmospheric opacity.

Meteorological Sensor Performance:

The meteorological instrumentation on InSight was not chosen to be optimized for addressing MEPAG atmospheric goals. Rather it was selected to enable the key science goals for InSight, the seismic investigation of the planet. As such, InSight's meteorological investigation may be incremental rather than transformational, but there will be avenues in which it should make substantial scientific contributions. In particular, the continuous nature of the observations will provide a more complete catalog of atmospheric phenomena on Mars than has previously been obtained.

Pressure sensor performance. The pressure sensor will be sampled at 20Hz with a response time of at least several Hz, and have a noise level on the order of 10 mPa. This is roughly two orders of magnitude more sensitive than its predecessors, and will be sampled about 1 order of magnitude higher than its predecessors as well. We expect that this may open up possibilities to detect infrasound events from bolide impacts or other events as-yet unforeseen. Note that is sensor's absolute calibration and its temporal drift are not as fine as its noise level, as this was not a driver for Insight's seismic goals. The absolute calibration is still to be completed and it is unclear if there will be budget to assess its temporal drift.

Wind sensor performance. The wind sensor is a repackaged version of the MSL REMS wind sensors. In the specific implementation for InSight, the two wind sensor booms will be separated and mounted independently on the lander deck, facing outward on roughly opposite sides of the lander. This placement allows one boom to sense least perturbed wind flows in nearly any azimuth wind. Operational plans for the wind sensors for InSight will switch between these two booms based on the experience of previous Sols and the expected regular variation of the wind with local time. If energy allows, both booms may be operated continuously.

The wind sensor will be sampled at 1 Hz matching its physical response time. The wind sensor accuracy is about +/-40% for winds <3.5m/s, decreasing to +/-15% for stronger winds.

The air temperature sensor will be sampled at 1 Hz, but its physical response time is 30-90s. The sensor accuracy is 5K but measurements are recorded with a resolution of 0.1K.

Optical Depth Measurements. The arm-mounted camera is akin to a MER NAVCAM. The MER rovers have executed many sets of simultaneous standard "tau" observations, using the Pancam camera directly observing the sun through a solar filter) with so-called "InSight tau" observations, using the Navcam as it will be used on InSight to prove the technique and calibrate its performance. Performance is expected to yield optical depths to an accuracy of about 0.1, with a likely cadence of weekly or more infrequently.

Entry, Descent, and Landing (EDL) Profiles Profiling of the Mars atmosphere (density, temperature) using entry probe flight instrumentation (accelerometers, gyroscopes, cf. Van Hove and Karatekin, MAMO 2014) will be carried out – similarly to previous retrievals during lander and rover's EDLs. Given the Ls=295° season of landing, propitious to local or global dust storm activity, this new EDL profile will provide a crucial complement to the existing dataset obtained at clearer seasons.

Meteorological Goals:

With a nearly continuous data set of pressure, air temperature and wind speed and direction, InSight will be the most complete record of meteorological conditions at a Mars landing site. The possibility of identifying anomalous events (e.g., dust devils, bolides) is better with InSight than its predecessors due to its continuous observation capability and the sensitivity of its pressure sensor. This original event-driven approach, entailed by the main geophysical goals of the InSight mission – and the seimic measurements of possible marsquakes – will be complemented with Non-Event Meteorological Observations (NEMOs) to provide the community with meteorological datasets as extended as possible.

Surface changes induced by Aeolian processes will be detectable using the arm-mounted camera, and can be correlated to the continuously observed winds to yield a good understanding of the wind environment during the time when the Aeolian changes may occur.

Perspectives for atmospheric science with InSight with indirect measurements also include

- evaluating the Atmospheric Angular Momentum from the Rotation and Interior Structure Experiment (RISE),
- detecting acoustic and gravity wave events with APSS and SEIS,
- obtaining turbulent spectra for winds (and the daily cycle thereof) with APSS and SEIS
- retrieving a cloud climatology with the cameras on board InSight
- estimating surface layer gradients with a combination of TWINS and HP3rad measurements

At the time of writing, the feasibility of those indirect measurements is still yet to be determined.

We cannot fully anticipate what the meteorological investigations on InSight will reveal. The continuous data set may turn up new (rare) phenomena, or characterize expected ones in greater detail. The much greater sensitivity of the pressure sensor may reveal a wealth of infrasound sources, for which we are preparing to analyze. The observational strategy for meteorological data taking on InSight is designed with the possibility of serendipity and the unexpected in mind.

Published Science Activities: Atmospheric Science with InSight seismometers

Three studies submitted to the InSight special issue of *Space Science Reviews* discussed in details the links between atmospheric science and seismic investigation with InSight:

- Kenda et al. (*submitted*) show, by combining a Sorrell formalism with atmospheric Large-Eddy Simulations (LES), that convective vortices (giving birth to dust devils when dust is lifted and transported in the vortex) cause pressure fluctuations leading to, through quasi-static surface deformation, detectable ground-tilt effects by the InSight SEIS VBB seismometers. High-frequency records exhibit a significant excitation corresponding to dust devil episodes : not only because of direct wind noise associated with the dust devil, but also because shallow surface waves arise from atmosphere-surface coupling. The latter phenomenon would allow for using dust devils as a passive source for seismic profiling down to a 50m depth. InSight / SEIS should be able to detect the signal from a convective vortex up to a distance of a few hundreds meters from the vortex, which shall allow for a more detailed investigation of the statistics of convective vortices than enabled by previous landers and rovers on the surface of Mars.
- Murdoch et al. (*submitted*) complement the study by Kenda et al. by adressing the elastic response in the ground as a result of all atmospheric pressure fluctuations associated with boundary-layer turbulence (not only convective vortices). They couple a Green function ground deformation model to the results of atmospheric LES (which is shown to yield results close to the Sorrells formalism). The dominant seismic signal caused by atmospheric fluctuations is the horizontal acceleration associated with the ground tilt (compared to the vertical acceleration, about an order of magnitude smaller, and the direct horizontal acceleration, about two orders of magnitude smaller). This seismic noise would be reduced in the presence at some shallow depth of a harder layer. The correlation between the seismic signal (as measured by SEIS) and the pressure signal (as measured by APSS) is found to be higher in windiest period because the seismic pressure noise reflects the atmospheric structure close to the InSight seismometer. Using the synthetic seismic noise derived from LES, Murdoch

et al. demonstrate that it is possible to decorrelate the atmospheric noise from the seismic signal measured by SEIS by using the pressure measurements of APSS. The decorrelation technique they propose entails a factor of 5 reduction on the horizontal tilt noise and the vertical noise caused by atmospheric circulations.

– Garcia et al. (*in press*) applied a 2D finite-difference model simulating the propagation of acoustic and gravity waves in planetary atmospheres to the case of surface explosions analogous to meteor impacts on Mars – in various conditions of ambient wind and attenuation by CO_2. They show that acoustic waves generated by impacts can refract back to the surface on wind duct at high altitude. Furthermore, the strong nighttime near-surface temperature gradient associated with radiative cooling on Mars cause a trapping of the acoustic waves in a waveguide close to the surface. This will allow for the night-side detection of impacts by InSight at large distances in Mars plains.

Summary:
InSight carries a suite of meteorological sensors that is similar to those that have flown before, except in its pressure sensitivity and the fact that it will record data nearly continuously. In addition to that, indirect diagnostics useful for atmospheric science will be available from the other instruments – including the SEIS seismometer on board InSight. InSight's meteorological capabilities will allow it to make a contribution to our understanding of the atmospheric boundary layer on Mars and, more generally, to the properties of the Mars atmosphere and climate. We recognize that we don't know all that we should expect to see from InSight's meteorological sensors, and welcome input and ideas for how best to conduct the InSight meteorological investigations.

References:

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Finite-Difference Modeling of Acoustic and Gravity Wave Propagation in Mars Atmosphere: Application to Infrasounds Emitted by Meteor Impacts

Garcia R., Q. Brissaud, L. Rolland, R. Martin, D. Komatitsch, A. Spiga, P. Lognonné, W. B. Banerdt

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http://link.springer.com/article/10.1007/s11214-016-0324-6

Modeling of ground deformation and shallow surface waves generated by Martian Dust Devils and perspectives for near-surface structure inversion

Kenda B., P. Lognonné, A. Spiga, T. Kawamura, S. Kedar, W. Banerdt, R. Lorenz

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Estimations of the seismic pressure noise on Mars determined from Large Eddy Simulations and demonstration of pressure decorrelation techniques for the InSight mission

Murdoch N., B. Kenda, T. Kawamura, A. Spiga, D. Mimoun, P. Lognonné

Space Science Reviews (submitted)