**Mars Atmospheric Science from NASA's InSight Lander.** D. Banfield[1], A. Spiga[2], C. Newman[3], R. Lorenz[4], F. Forget[2], M. Lemmon[5], D. Viudez-Moreiras[6], J. Pla-Garcia[6], N. Teanby[7], N. Murdoch[8], R. Garcia[8], P. Lognonne[9], B. Kenda[9], C. Perrin[9], S. Rodriguez[9], A. Lucas[9], T. Kawamura[9], D. Mimoun[8], O. Karatekin[10], S. Lewis[11], W.T. Pike[12], J. McClean[12], C. Charalambous[12], N. Mueller[13], E. Millour[2], L. Mora-Sotomayor[6], S. Navarro[6], J.-A. Rodriguez-Manfredi[6], J. Torres[6], J. Maki[14], S. Smrekar[14], W.B. Banerdt[14], and the InSight Team, [1]Cornell Center for Astrophysics and Planetary Science, Cornell University, Ithaca, NY, USA, (banfield@astro.cornell.edu) [2]Laboratoire de Meteorologie Dynamique (LMD), Sorbonne University, Centre National de la Recherche Scientifique, Paris, France, [3]Aeolis Research, Pasadena, CA, USA, [4]Johns Hopkins Applied Physics Lab, Laurel, MD, USA, [5]Space Science Institute, USA, [6]Centro de Astrobiologia (CAB), Madrid, Spain, [7]University of Bristol, United Kingdom, [8]Institut Superieur de l'Aeronautique et de l'Espace (ISAE), Toulouse, France, [9]Institut de Physique du Globe de Paris (IPGP), France, [10]Royal Observatory of Belgium, Brussels, Belgium, [11]Open University, Milton Keynes, United Kingdom, [12]Imperial College, London, United Kingdom, [13]DLR Institute of Planetary Research, Berlin, Germany, [14]Jet Propulsion Laboratory, Pasadena, CA, USA.

**Introduction:** NASA's Mars InSight Spacecraft landed on Nov 26, 2018 ($L_s$=295°) in Elysium Planitia (~4.5°N, 136°E) with the main scientific purpose of investigating the interior structure and heat flux from Mars. However it is also equipped with a very capable meteorological station. To help remove environmental noise from the seismic signals, InSight has a very precise pressure sensor (PS). To aid in removing the atmospheric pressure-induced seismic noise, and to identify periods when wind-induced seismic noise may reduce sensitivity, InSight also carries a pair of Wind and Air temperature sensors (TWINS)[1]. Complementing these are a radiometer in the $HP^3$ suite to measure surface radiance, the seismic measurements of SEIS which can record interesting atmospheric phenomena, and the InSight cameras to image clouds and dust devils and estimate atmospheric opacity from dust or clouds. The Lander also carried accelerometers that can be used to reconstruct the atmospheric structure during descent. We will discuss results drawn from atmospheric measurements on board InSight from the ~8 months of operation, highlighting the new perspectives permitted by the novel high-frequency, and continuous nature of the InSight data acquisition. Pre-landing scientific perspectives for atmospheric science with InSight are found in [2].

**Description of APSS-PS & TWINS:** InSight's pressure sensor is a fast-response, high precision instrument compared to previous Mars pressure sensors. It is sampled at 20Hz continuously and has a single observation noise level of about 10 mPa. The absolute calibration is accurate to about 1.5 Pa with expected drift over the 1 Mars year of the mission of <~1.5 Pa. It is equipped with a special inlet designed to reduce wind-induced dynamic pressure perturbations [1].

The wind and air temperature sensors for InSight have high heritage from the REMS sensors from the Curiosity rover [3], with specific improvements to their ability to operate under cold conditions. The two booms face opposite directions near the edge of the lander deck to minimize wind and air temperature perturbations from the lander itself. The resolution of the air temperature measurements is about 0.1K (with an absolute accuracy of <5K). The wind sensors are able to distinguish wind directions with an angular resolution of <22°, and wind speed to <0.4 m/s for low wind speeds, rising to <2 m/s for higher wind speeds [1].

**Operational Aspects:** To enable identification of Mars quakes that may happen anytime, InSight continuously records data from its seismometers as well as the APSS-PS & TWINS sensors. These data are then downlinked to Earth after down-sampling to fit within downlink data volume allocations. Selected data snippets that are expected to be scientifically interesting based on the down-sampled continuous data could then be requested and downlinked at higher sampling rates (up to the full sampling rate). For the first ~6 months of the mission, pressure was obtained continuously at 2Hz and wind and air temperature continuously at 0.1Hz, but extensive periods of data for pressure, air temperature and winds have been downlinked at the full sampling rates. After 6 months, the continuous data rates were increased.

**Scientific Results:** InSight is observing meteorological phenomena at all scales from seasonal/global down to the boundary layer turbulence. At the longest timescales, InSight's pressure sensor is recording the annual pressure cycle with consistency with prior landed missions, but interesting, as-yet unexplained differences. On top of this there is also the expected diurnal pressure variation controlled by the diurnal and semidiurnal thermal tides [4]. A surprising addition to these diurnal variations are the 2.5-sol oscillations from baroclinic waves along the northern polar vortex. While waves like this were recently identified at the MSL location [5], their amplitude at InSight is much greater (as high as 7 Pa peak to peak). This may be due to amplification of the waves by the local topography near InSight (i.e., the dichotomy boundary to the South and Elysium Mons to the North).

InSight experienced a large regional scale dust storm starting around sol 40 ($L_s$~320°) where the local atmospheric opacity measured by IDC increased from ~0.8 to about 2.0 in ten sols. This increased the semi-diurnal pressure amplitude as expected [6], but more surprisingly changed the daily wind behavior. Prior to the dust storm, the winds were primarily from the NNW only varying by about 60 degrees azimuth throughout a sol. During the first 2 weeks of the dust storm, the winds changed to circulating all the way around the lander, the daytime wind speeds were increased, while nighttime wind speeds significantly decreased. Modeling suggests that the dust storm reduced a large-scale, steady wind component that allowed a moderate, diurnally reversing slope wind to then dominate the winds.

InSight's highly sensitive pressure sensor is the first to have detected frequent evening and night-time pressure oscillations (and occasionally associated wind speed, wind direction and air temperature oscillations) with periods between 300-1000s and pressure amplitudes of order 1 Pa. These oscillations are consistent with gravity waves in the strong night-time static stability and may be associated with mountain wave from relatively distant topography.

In addition to the gravity waves, InSight also regularly saw morning and evening pressure bumps (as large as 4 Pa) first notable during the dust storm. These evolved in terms of amplitude, and time of occurrence as the dust storm decayed. These pressure bumps were typically followed by long-period pressure oscillations (~1000s) and associated wind speed and direction changes, making them reminiscent of undular bores. In this case at Mars, this may be caused by katabatic flows from Elysium Mons.

During daytime, the active convective boundary layer produces large turbulent pressure (~0.5 Pa), air temperature (~10K) and wind speed fluctuations with timescale ranging up to 200-500s. These are likely the advection past the lander of Rayleigh-Benard convective cells with scales set by the diurnally evolving convective boundary layer.

InSight has also detected afternoon dust-devil-like vortices at a greater rate than previous landers (twice as many as Pathfinder and five times as many as Phoenix and Curiosity). The population of these vortices matches that found terrestrially with a power law exponent of 2.6 [7]. While InSight is an active site for vortices, we have not yet imaged an active dust devil by Sol 150 in spite of several intense imaging campaigns. The lack of visible dust devils in spite of the frequent occurrence of vortices may suggest that some component required for dust lifting is absent at the InSight Landing site. The largest vortex passage to date (Sol 65, 13:36 LTST, 9 Pa) appears to have caused a minor clearing of the solar panels, for the first time confirming that it is likely vortices that clean Martian solar panels (e.g., Spirit & Opportunity) rather than straight-line wind gusts.

Possible expressions of infrasound have been detected by InSight as well, with ~80s oscillations (too fast for gravity waves) in both pressure and wind. However, the expected expression of these possible infrasound waves on the seismometer do not match expectations, so their actual source is still uncertain. A second type of infrasound is also detected by InSight: <1s period oscillations embedded on top of the signature of some vortex passages. This may be noise induced by the vortex itself, perhaps asymmetry in the vortex, with the period indicating its rotation period.

The pressure power spectral density shows an expected -5/3 slope at frequencies below 0.1 Hz. However, between 0.1-2Hz the slope is closer to -1. The cause of this unexpected behavior of the smaller eddies is unclear, with one possible explanation being local enhancement of small scale eddy energy by the lander obstacles. Another possible explanation could be a transition zone in the spectrum between the buoyancy range at low frequencies and the inertial range at high frequencies [8]

As the aphelion cloud season starts, we have recently begun seeing clouds from InSight, with gravity-wave-like structures in their shapes. Illumination changes at sunset which may indicate their altitudes. From their angular speed across the sky, advecting wind estimates can be produced.

We have undertaken a long-term campaign to detect aeolian changes around the InSight Lander, and the characterize the wind speeds required to produce these changes. InSight's continuous and high sampling rate measurements are particularly suited to this purpose. To date we have seen changes in dust distributions and some grain motions, but large-scale aeolian change of soil has not been observed.

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