A machine learning framework for geophysical and atmospheric monitoring in planetary science missions

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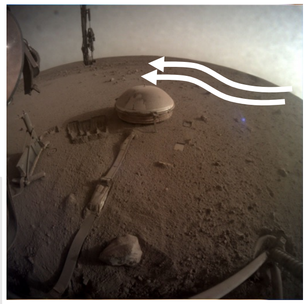


Images credit: Caltech/JPL NASA

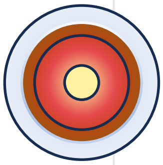
1. How do planets work?

The structure and how does it vary?

- Interior layer constraints
- Global variation – crustal and mantle heteorogeneities

Ongoing dynamic activity?

- The atmospheric system
- Tectonic/impact features and spatial distribution



2. Goals:

- Understand the seismicity and structure of Mars
  - What is the origin and distribution of marsquakes?
  - What is the interior structure of Mars?
- Characterise atmospheric turbulence at the surface of Mars
  - How does turbulence vary over the sol at the season?
  - What drives turbulence?

3. How can a machine learning framework help?:

- We can improve dataset quality to discover new and clean informative signals
- We can extract descriptive features
- We can create new datasets to study and new ways to operate future missions

Inputs:
- Wind
- Pressure
- Temperature
- Magnetic field
- Seismic

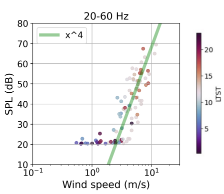
→ Sensor/system transfer function - Mixes inputs → Machine learning retrieval algorithm → Unmixed and clean signals

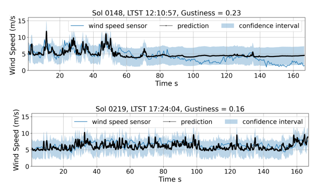
Wind and turbulence with the NASA Mars 2020 Perseverance microphone

Project:

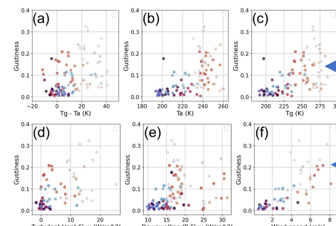
- The microphone records pressure fluctuations associated with the wind
- We implemented Gaussian process regression to convert the microphone signal to a wind speed
- This wind speed is sensitive to fast fluctions – good for atmospheric turbulence
- We can calulate statistics (i.e. gustiness) on the wind speed to characterise turbulence and try to discover its driving forces

1. Sensitivity of microphone to wind speed → 2. Calibration to wind speed using Gaussian process regression → 3. Statistic to describe turbulent intensity Gustiness = $\frac{\text{Standard deviation}}{\text{Mean}}$ → 4. Characterisation and control of turbulence



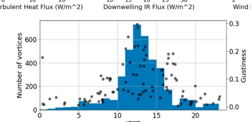


Figures from Stott et al. 2023a



Temperature control – radiative forcing?

Heat flux control?



Similar distrubution of pressure drops (a turbulence marker) and gustiness

Findings:

1. We can study the fastest variations of the Martian atmosphere using the Perseverance microphone and machine learning
2. We observe correlations of the turbulent instensity with pressure drops, diurnal temperature and heat fluxes
3. Future work with a combined analysis of other datasets can highlight dominant relationships at different times

Wind and turbulence with InSight's seismometer

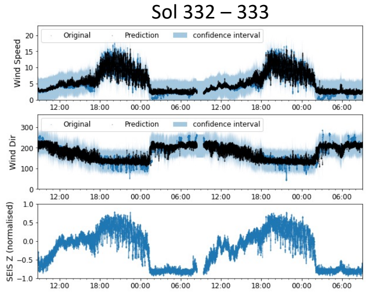
Project:

- The InSight seismometer is sensitive to wind-induced vibrations
- We predict the wind speed and direction from the InSight seismic data using machine learning algorithms
- This produces a more complete wind catalogue as the wind sensor was often off due to power

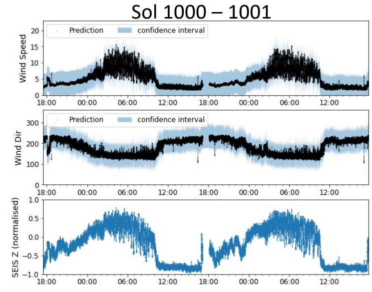
Findings:

- We can produce the most continuous in situ wind catalogue over 2 Mars years
- Work ongoing to study interannual variaiton

Sol 332 – 333



Sol 1000 – 1001



Machine learning for seismology on InSight and future missions

- As shown, the seismic noise level is dependent on the atmosphere
- We can use InSight data to infer noise levels for future missions for a variety of different seismic deployments for future missions – create more mission opportunities
- The seasonal variation of noise must be taken into account – the deployment data were taken at a noisy time of year

Future seismic deployment	InSight data analogue
Geophysical observatory	Final InSight installation
Ground or penetrator	Before wind and thermal shield
On deck of rover/lander	Short period on the deck

The converse problem – ongoing work

- We can use machine learning to clean seismic signals
- Ongoing work to extract features to categorise events
- This leads to determination of seismicity (event source and location) and structure

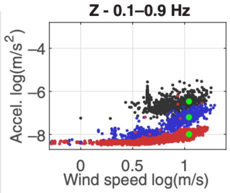
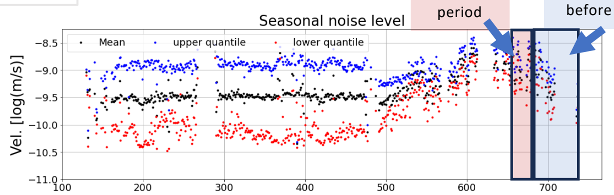


Figure from Stott et al. 2021

Noise variation: Not a stationary problem



Conclusions and outlook

- We have implemented machine learning to expand wind data sets to higher frequencies and continuity than ever before on Mars
- This leads to a new characterisation of turbulence and atmospheric variation
- We can use the information from InSight to infer future mission noise levels
- This highlights that we should think of conjoining machine learning with instrumentation in mission design
- Work is ongoing to clean the InSight seismic data and analyse event features to extract information on Mars' structure and event origins

References

[1] Stott et al (2023a), "Wind and turbulence observations with the Mars microphone on Perseverance", *JGR:Planets*

[2] Stott et al (2021), "The site tilt and lander transfer function from the short-period seismometer of InSight on Mars", *BSSA*

[3] Stott et al (2023b), "Using InSight data to inform sensing opportunities for future seismology and meteorology missions", *IPPW*