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# Automated Detection of Dust-Devil Induced Pressure Signals

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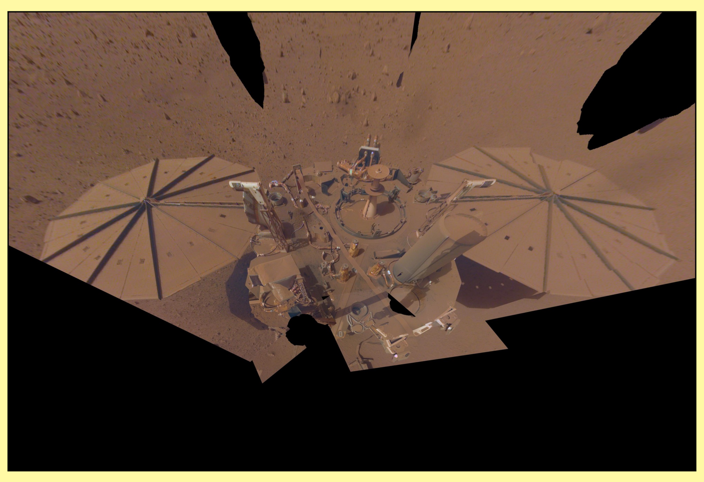
## What are dust devils and why are they important for Mars?

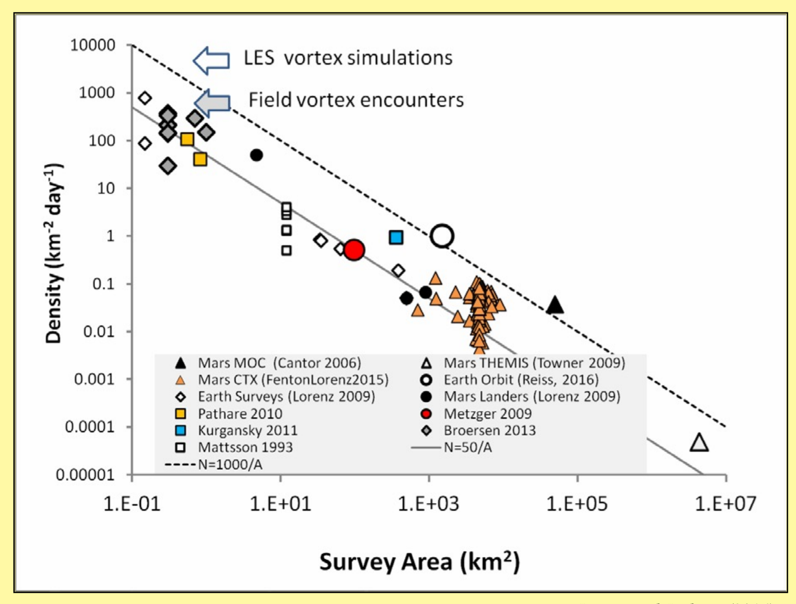
*Lorenz et al. (2016)*

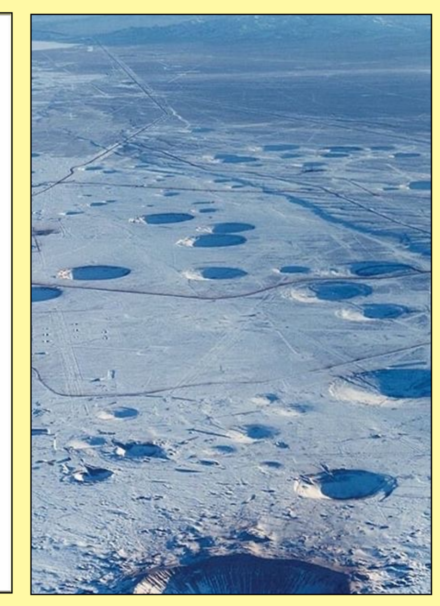


*InSight Final Selfie (NASA/JPL-Caltech)*

- Dust devils are formed by the sun heating up the ground and forming hot pockets of air. As the hot air rises, cooler air rushes in to restore equilibrium. Given the right conditions, convective vortices with pressure dips at their center form.
- Convective vortices are defined as being at least a meter in height and lasting at least 10 seconds (Oke et al, 2007). Dust devils are unique convective vortices in that they are dust-laden.
- Dust devils occur on Mars at high frequencies of around 1 per every square kilometer.
- Dust loading plays a primary role in the Martian atmosphere, altering the albedo and weather patterns in certain areas.
- Understanding dust devils could play an import role for future missions, with wind erosion possibly affecting biosignatures on rocks, and convective vortices cleaning dust off of the solar panels of rovers and landers.

## Why are dust devils on Mars hard to study? How can we overcome this difficulty?



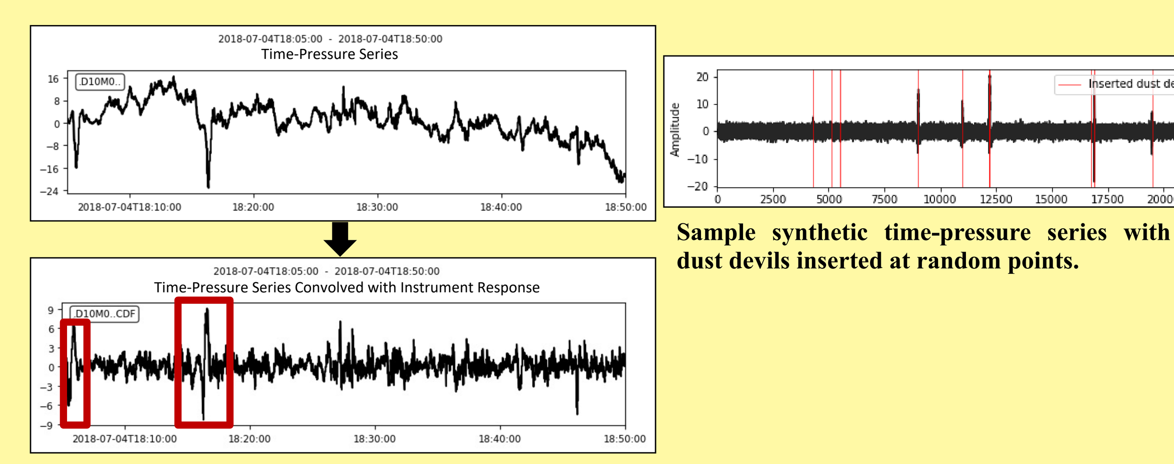
*Lorenz and Jackson (2016)*

- Low station density prevents an extensive record of dust devils on Mars, despite their prevalence. makes their behavior hard to study.
- Formation characteristics of convective vortices can be studied through the development of an extensive catalog of Earth-based dust devils.
- The Nevada National Security Site (NNSS) contains 10,000 station days of infrasound data in a desert environment filled with craters across varied topography. There are thousands of dust devil signatures in this data record. This is an excellent Mars analog site.
- We can study dust devils at the NNSS in hopes of understanding dust devils on Mars. While environmental conditions are different, the atmospheric physics governing the strength of dust devils can be extrapolated using background pressure and temperature conditions (Renno et al, 2004).

## How can we extract thousands of dust devils from 10,000 days of data?

**Not** manually.

- Our dataset is too large for a human to scan and identify dust devil signatures. We need an automated algorithm to identify dust devils. We also need to test this algorithm and understand how often it yields false positives and false negatives.
- When a dust devil passes over an infrasound sensor, the distinctive dip in pressure at their centers are detected.
- When convolved with a sensor's instrument response, this pressure dip is recorded as a unique "heartbeat" signature.
- Prior research indicates that dust devils tend to occur within the $10^{-3}$ to $10^{-1}$ Hz frequency band. The unique heartbeat signature lends itself well to detection through correlation with templates.
- However, correlation-based detection is very computationally expensive. We need to make this process efficient to analyze the full dataset.

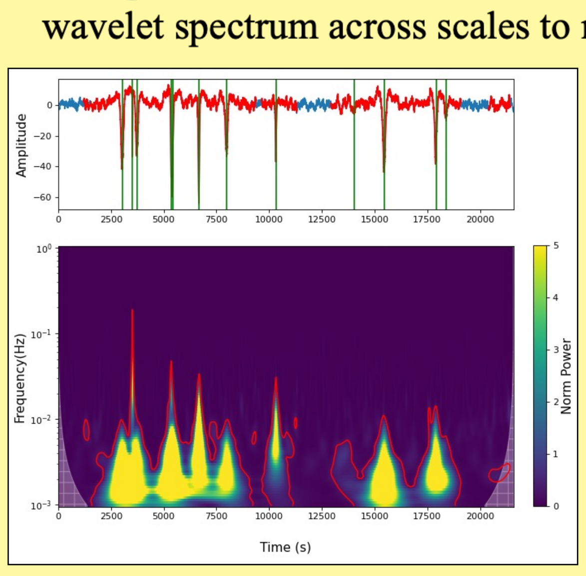



**Sample synthetic time-pressure series with dust devils inserted at random points.**

## How do we make our dust devil detector efficient?

**By reducing the search space.**

- We use wavelet transforms to identify regions in our signal where there is higher energy **not created by background noise.**
- We first remove the instrument response from the recorded signal. The signal is now the physical pressure dip and not the heartbeat signature.
- We the compare the power in the wavelet spectrum $W_n(s)$with the power in a background signal of white noise $P_k$ and compare it with a $\chi^2$ distribution to find areas in the signal that are peaks **not created by background noise at the 95% confidence level.** We also smooth the wavelet spectrum across scales to make our detector more robust.




Pressure time series and wavelet spectrum after instrument response removal. Areas included within the red contour and colored in red are parts of the signal not generated by white noise with 95% confidence.

$$\frac{|W_n(s)|^2}{\sigma^2 P_k} \to \frac{\chi_2^2}{2}$$

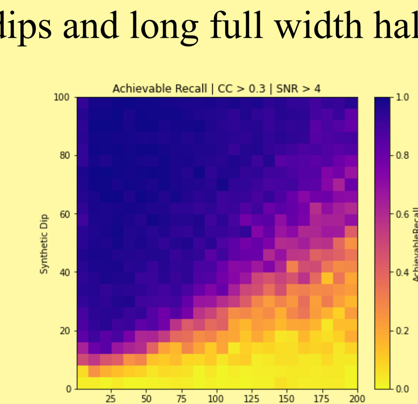
Relation from Torrence and Compo (1998) that allows for confidence testing in the frequency domain.

- The wavelet detector is agnostic to the actual source of the signal. We isolate parts of the signal identified by the wavelet detector and then apply the correlation detector to extract only the dust devil signatures. We correlate the time snippets with the heartbeat signal and identify times of correlation coefficient greater than 0.3. **But now, the correlation detector runs on a much smaller dataset.**

## How effective was our detector?

**It worked very well in trials.**

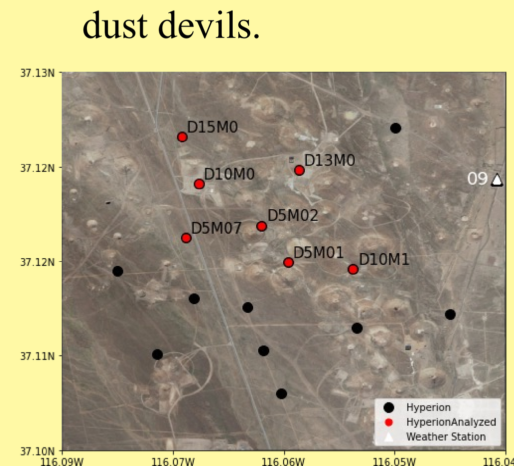
- We generated 10,000 6-hour-long synthetic windows with dust devils inserted at known locations to conduct recall and efficiency analysis on our detector. We chose various pressure dips (1-100 Pa) and full width half maxima (1-300 seconds) to parameterize our artificial dust devils.
- In our test, 91 percent of synthetic dust devils were detected with 99 percent precision.
- The detector had the most difficulty picking out synthetics with low dips and long full width half maximums.

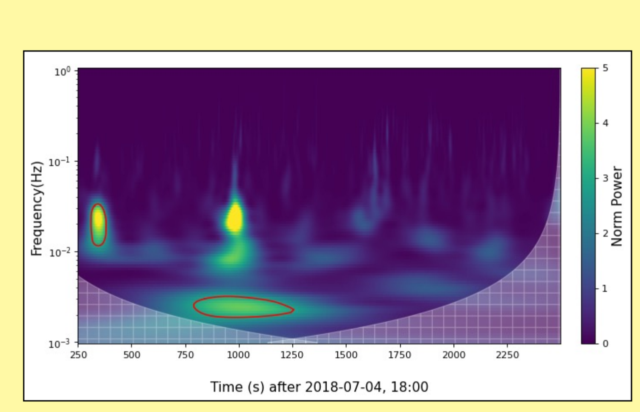



| Detector | Precision(%) | Recall (%) |
|---|---|---|
| Wavelet | 74 | 95 |
| Correlation | 98 | 83 |
| Wavelet+Correlation | 99 | 91 |

### Observational Data (NNSS)

- We also ran our detector on a subset of the larger NNSS catalogue.
- From 7 stations and 62 days of data, we made 5976 detections of dust devils.




## What comes next?

**Dust devil mining and analysis.**

*Martian dust devil captured by Spirit. Rover. NASA/JPL-Caltech*

- We have run our detector on a subset of the NNSS and generated promising results. We will now run through the full 7 years of data on the entirety of the infrasound array. We have developed a parallel implementation of our detector, which can be run on supercomputers to efficiently analyze the full dataset (~several TB in size).
- Our catalog will have tens of thousands of dust devils in topographically and atmospherically diverse settings with dense instrumentation. We can conduct analysis on the formation and dynamics of dust devils on a large N dataset and extrapolate results to Mars.
- We will release a catalogue of dust devils through the NASA Planetary Data System (PDS) Atmospheres node to the scientific community.

## Key Takeaways

- **Dust devils play an important role in the Martian environment, but are difficult to study because of the sparsity of stations on Mars.**
- **An equivalent analog densely populated with arrays containing over 10,000 sensor days of data is available for analysis.**
- **An automated detection scheme has been developed and characterized. This scheme will be used to identify tens of thousands of dust devils in the analog setting.**

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