Autonomy and Arctic Analog Testing for Planetary Drills

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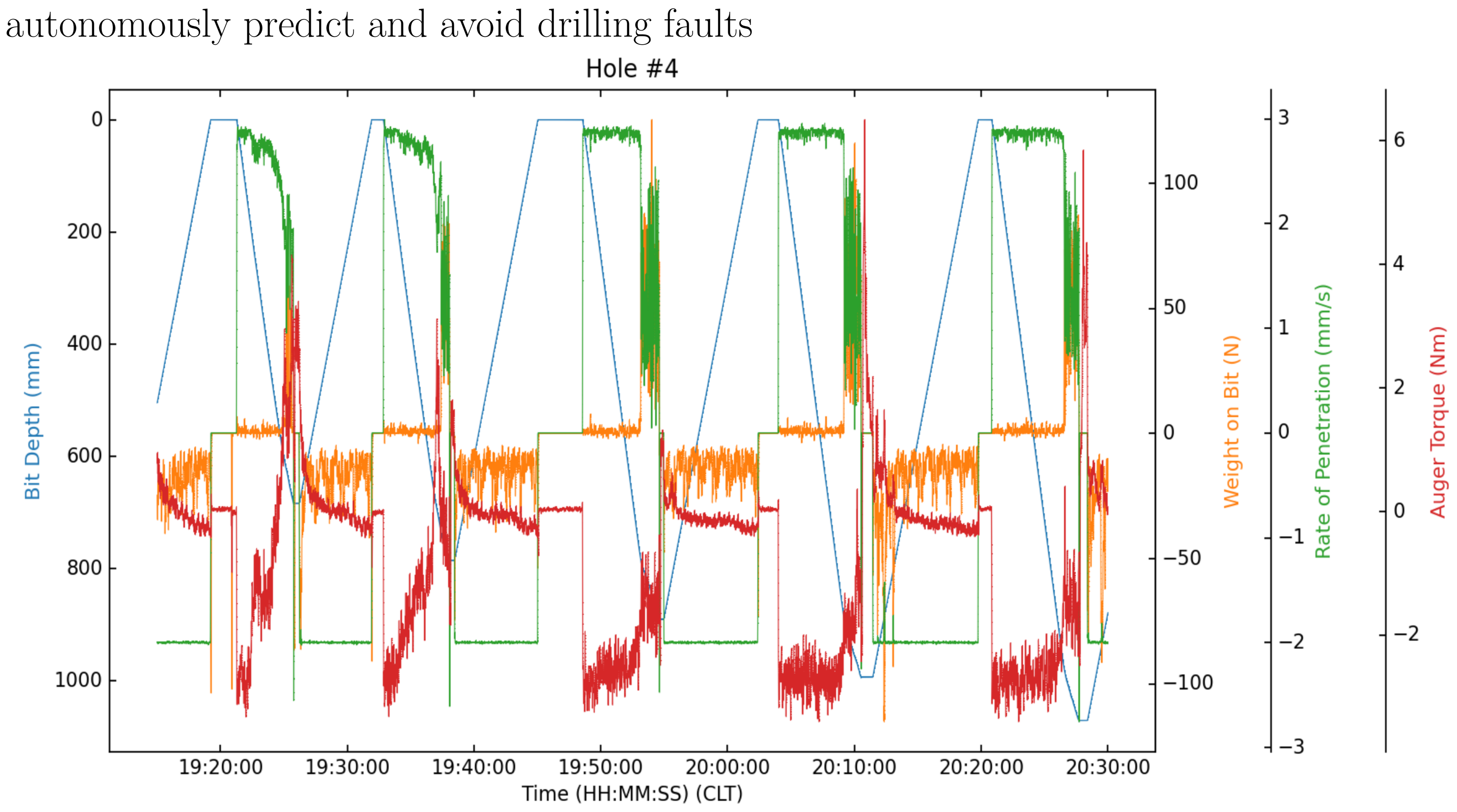
Abstract

In extreme planetary environments, robotic drills must either respond to or reason through potential indicators of fault to prevent structural failure and allow clean acquisition of subsurface samples for later study. This necessitates development of autonomous drilling techniques and robust analog testing in arctic planetary-analog sites. Past fieldwork in Haughton Crater has given us clues to what techniques could be used to better identify and prevent drilling faults for The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), a 1 meter rotary percussive drill manufactured by Honeybee Robotics.

Top Left: Location of summer 2024 fieldwork. Top Middle: Field camp view in Haughton Crater Top Right: Drill operation at Haughton Crater Bottom: View from field camp on analog site

Introduction

- TRIDENT gives indicators, visually or otherwise, of a failure well before it happens. Data indicates a failure has a high likelihood of prediction, but the necessary components to intelligently monitor actions do not exist yet.
- We propose building on previous work with online time-series subspace analysis methods and percussive beat frequency detection to develop a Markov Decision Process to autonomously predict and avoid drilling faults



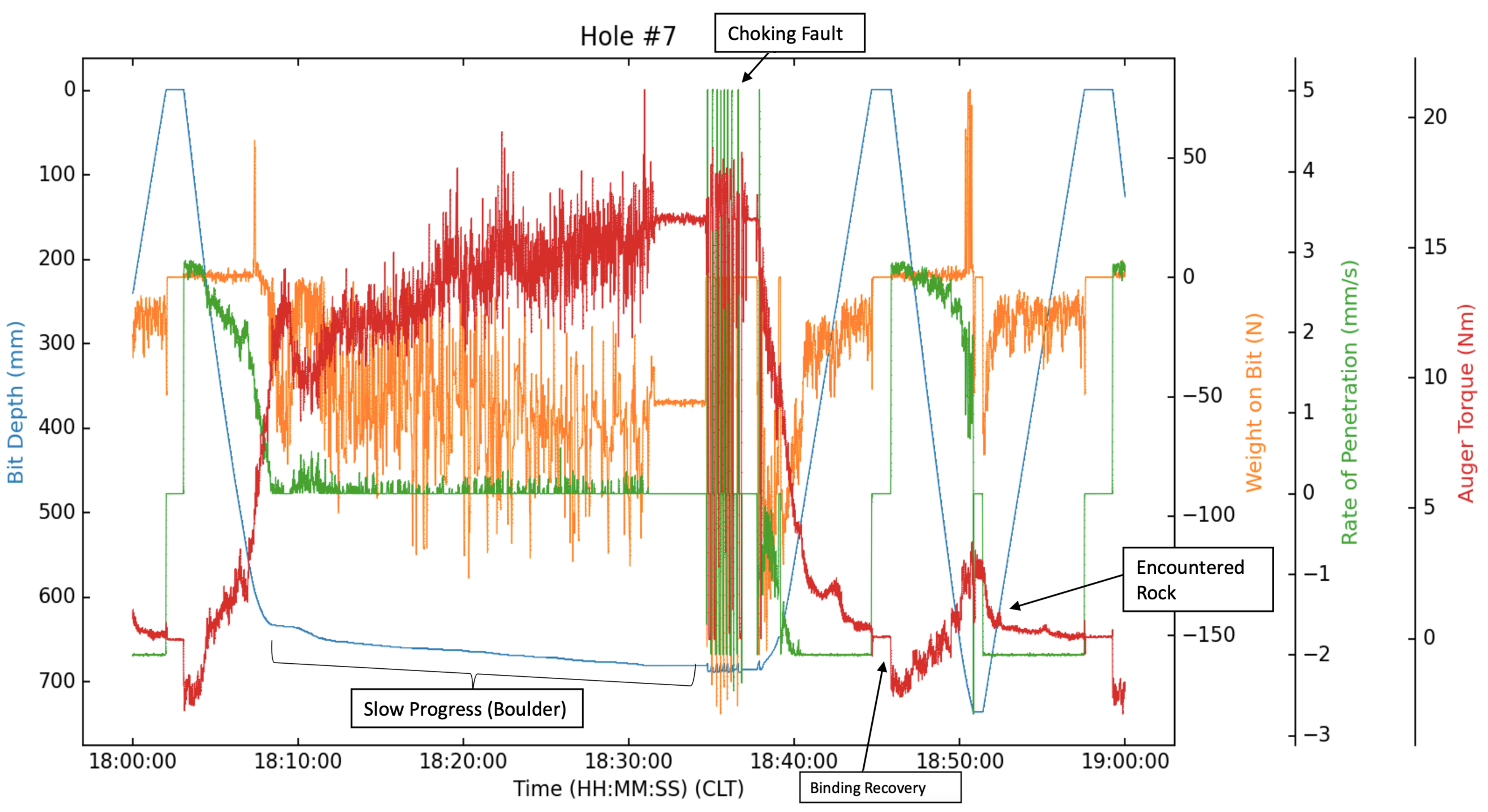
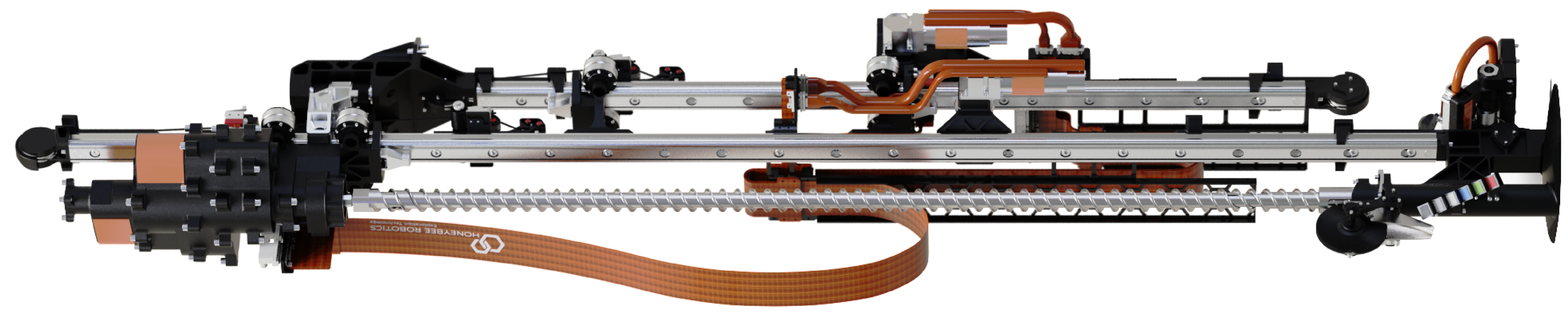
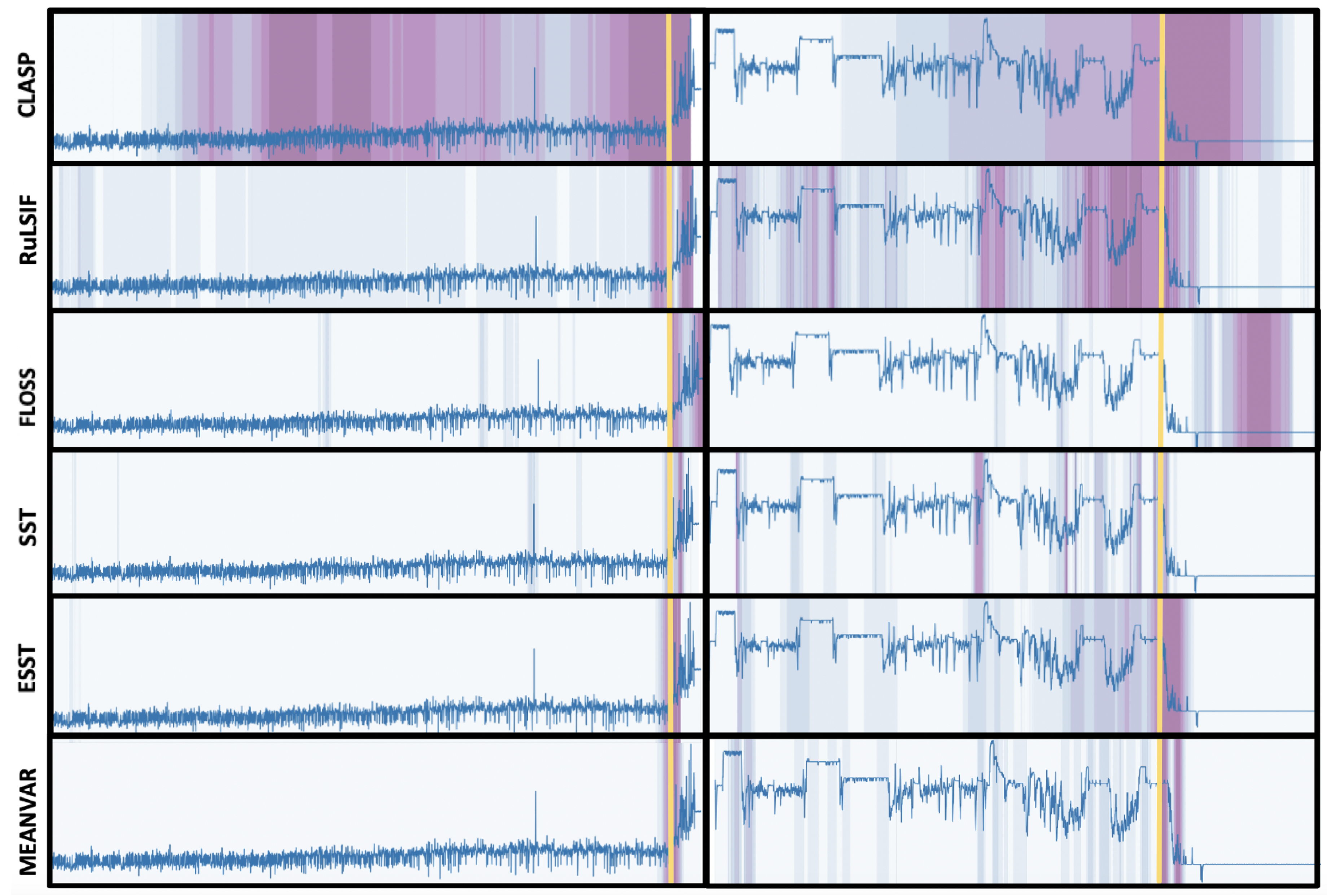


Figure 1: Upper image shows normal drilling operations during testing in Devon Island, Canada. [1]. Bottom image illustrates choking fault during testing in Devon Island, Canada [1]. In both images, Torque is red, Rate of Penetration is green, and Weight on Bit is Orange. From observing plots with field notes, we inferred that choking and binding faults will tend to raised Torque and Weight on Bit while the Rate of Penetration is roughly zero



Change Point Detection

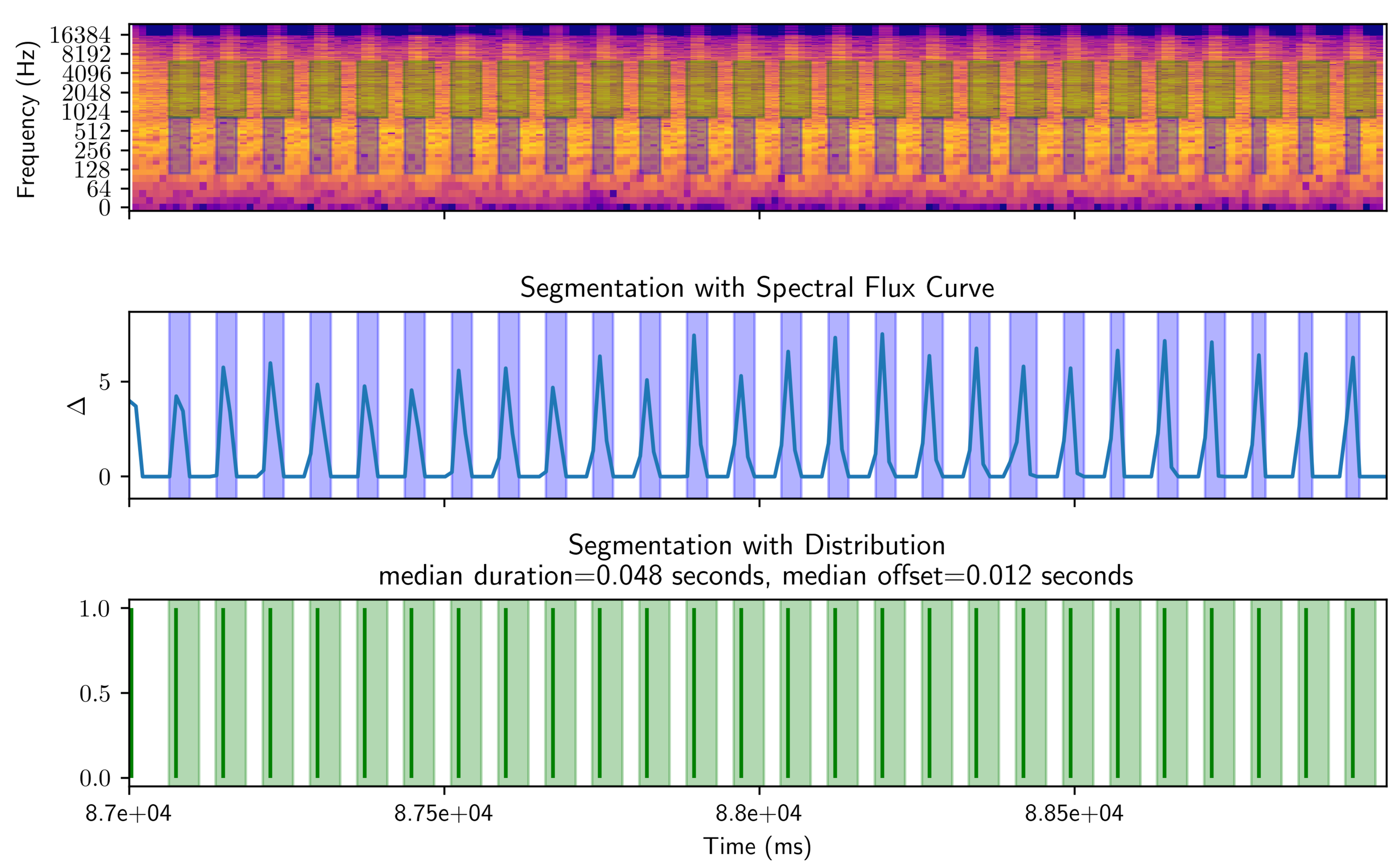
Using fault detection techniques like ESST [2], we can monitor the Torque and Weight on Bit change score, which often spike to indicate faulty conditions for Torque or WOB. We can also consider the Rate of Penetration (ROP), to monitor stalled or slowed progress approaching a velocity of zero. Percussion indicates hard or differing material composition with active percussion.



A sampling of visual results from evaluated algorithms for two datasets. [2] Dark background indicates the change point score of the methods. The yellow vertical line indicates a drilling fault.

Beat Detection

B_{skip} represents training from different beat detection methods. These begin with calculating a novelty curve corresponding to an increase in spectral energy of the vibration signal, not different from change point detection methods. Then, an algorithm is used to pick which points in the novelty curve correspond to beats. Beat bounds are found from the local minima of the novelty curve. After applying the Fourier transform to beats, features like frequency peaks, and overall energy are used to determine if the beat denotes a fault or nominal operation. Analysis of test data shows that non-faulting beats typically have a frequency peak around 6 kHz, and faulting beats tend to have higher frequency peaks and more overall energy. We can use this to help detect potentially faulty beats.



Results of novelty curve segmentation (middle), distribution based segmentation with beat duration scaled by 1.5 (bottom) and a direct comparison of both methods overlaid on a spectrogram of the audio (top).

References

[1] B. Glass, C. Stoker, H. Battah, S. Boelter, C.Fortuin, I. King, T. Stevenson, and T. Stucky, "TRIDENT Drill Validation at Mars Analog Field Sites," in *55th Lunar and Planetary Science Conference (LPSC)*, 2024.

[2] S. Boelter, L. Weber, R. Lenz, B. Glass, and M. Gini, "Fault prediction in drilling using subspace analysis techniques," *Intelligent Autonomous Systems 19, Proc. 19th Int'l Conf IAS-19, accepted*, 2025.