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Third EAGE Seabed Seismic Today Workshop

SEABED SEISMIC: EVOLUTION THROUGH INNOVATION

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Bringing high density seismic to Transition Zone

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Outline

- Sampling needs in Transition Zone
- Transition Zone systems: a history of leakage and synchronization challenges
  - Bay cables, Wireless nodes, Land nodes, Seabed nodes
- Review of clock solutions
- Experiment results
- Conclusion

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Spatial sampling

Land seismic

- Noise, near-surface unhomogeneities, low velocities, high data complexity

Need high density of sensors

- Earlier through geophone arrays, because of technical limitations and affordability issues
- Now with high density nodal systems

Seabed seismic

- Better data quality

Single node every 25 / 50 / 100 m

Transition Zone

Complex:

- Noise, near-surface variations, diverse sources and receivers
- We have often been trying to acquire high complexity data with sparse seabed geometries

⇒ No wonder Transition Zone can have a bad data quality reputation

We do this for economical reasons: we cannot afford proper sampling

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Source effort in Transition Zone

Difficult terrain:

- Access is usually impossible for vibroseis
- Airguns can sometimes be used

⇒ Only option is usually dynamite

- Slow and expensive

⇒ Another reason for densifying receivers

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Dense TZ: it works

- Most TZ surveys are acquired with seabed geometries

Some exceptions

- Dukhan 3D survey in Qatar in 2010
- The TZ part was recorded with the same dense geometry than the land part: 7.5 m sampling

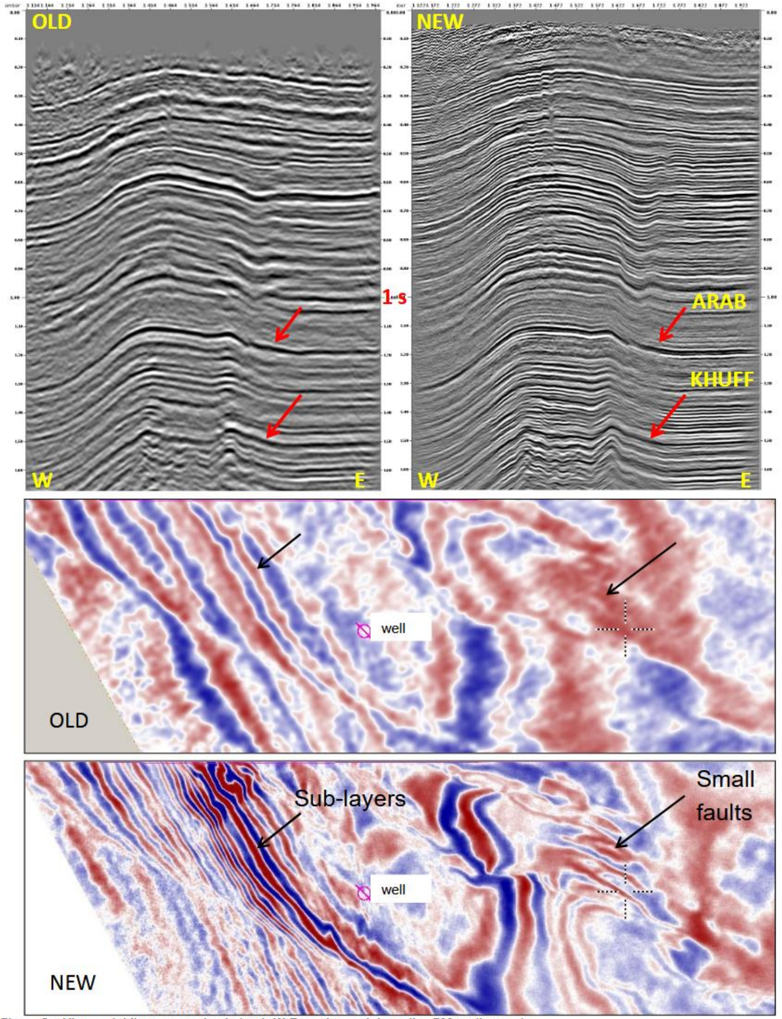

Figure 2a: Vintage (old) vs. new seismic (top); W-E section and time slice 700ms (bottom)

Seeni S., Al-Mohammadi J., Kermoal P., Sauzedde P. and F. Clow [2011]. Dukhan 3D, Ultra High Density Full Wide Azimuth Seismic Survey-Transition Zone and Sabkha Acquisition, *Conference Proceedings 73rd EAGE Conference and Exhibition*, cp-238-00306

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Transition Zone acquisition equipment

What do we need?

- Low channel cost
- Low operational cost

Address specific TZ issues

  - Reliability; avoid leakage
  - Easy deployment
  - Data synchronization solution

Bay cables

Evolution of land cable systems

Data synchronization through cable telemetry

- Cumbersome deployment
- Channel count limitations
- Prone to leakage

Wireless nodes

Already in the 90's, radio wireless systems were developed for TZ: Digiseis FLX

- Data transmission and synchronization via radio

- Limited channel count
- Leakage issues: sensor connected to the node via a cable and a connector
- Very heavy

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Land nodes

Seismic data recorded in the node

Still need an antenna to receive GNSS signal for synchronization. Cannot be under water

- Cable and connector: leakage risk
- Need to connect every sensor package to the surface

Seabed nodes

They have become the default choice in many TZ jobs

Internal clock solution without need for GNSS

No cable or connector

But:

- Limited channel count (cost)
- Very heavy
- Expensive

Ideal TZ equipment

What does the industry need:

- A small light-weight and low-cost integrated node with a clocking solution that can work when GNSS is not available

Highly reliable, flexible to operate

Clock types

Atomic clocks

- **CSAC** Chip Scale Atomic Clock
  - Very Expensive

Oscillators

- **OCXO**
  - **Oven Controlled Oscillator**
    - Very high power
    - Used in some seabed nodes
- **TCXO**
  - **Temperature Compensated Oscillator**
    - Analog or digital compensation
    - Already used in land seismic nodes
    - Often the same oscillator than in OCXO
    - Much lower power

Clocking solution

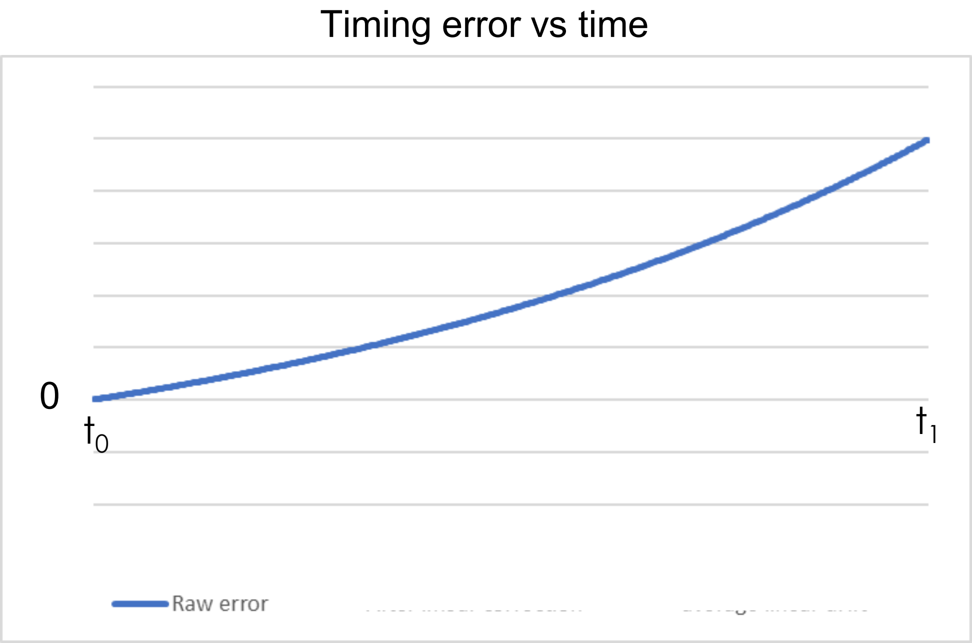
Two main methods: GNSS disciplined clocks and free-running clocks with resampling

Disciplined clock: you use time sync events from the GNSS to adjust the clock frequency

Resampling: you record every GNSS time sync event during acquisition and use them to post-process the data: resample the recorded data after data harvesting

- Similar to what is done in Seabed but with more sync events

Clocking methods: disciplined



- At t_0, you just had a GNSS time fix and your timing error is zero
- Then, as the clock frequency is not perfect and varies, you start having a timing error
- At t_1, you get a new GNSS time fix. In a disciplined system, you adjust the clock frequency (the data sampling rate) to bring back the error towards zero

Clocking methods: resampling

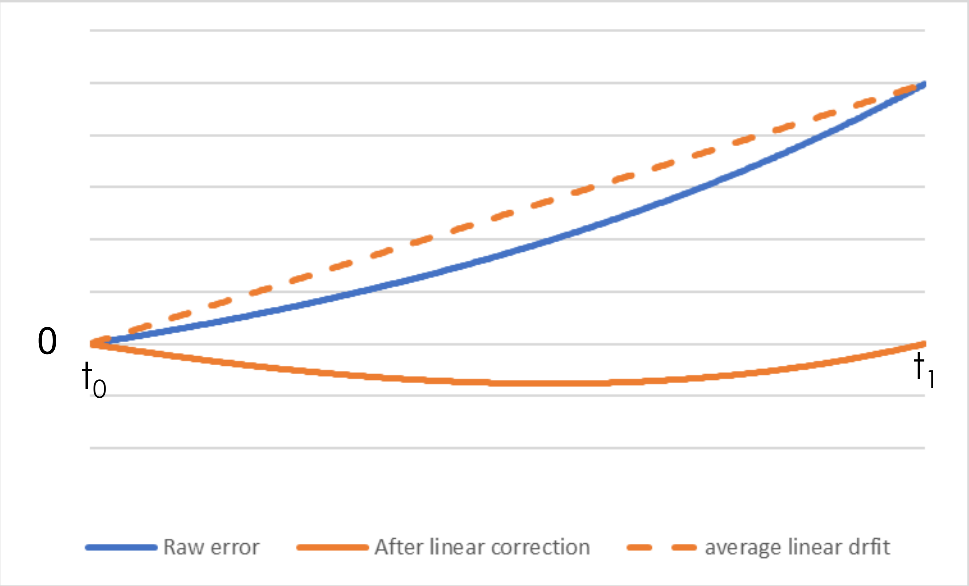
Timing error vs time

- In a resampling after harvesting scenario, you can calculate the average frequency shift between t_0 and t_1 once you have downloaded the data, and compute from it the average linear drift during this period (and between any two GNSS time events during acquisition)

Clocking methods: resampling

- You then subtract the linear shift

Timing error vs time



- Your timing error is smaller
- There is no jitter in the sampling period
- Any constant frequency shift will be corrected for: there is no need to adjust the clock frequency during acquisition

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Next step: better clock model

- You know the average clock frequency between any two GNSS
  - You also record a lot of metadata in the node:
    - Node internal parameters
    - Environmental factors
- Can you use this to model and predict the behaviour of the clock?
- We have collected data during normal use of the nodes and fed them to a machine learning algorithm
  - It gave us a correction model for each node

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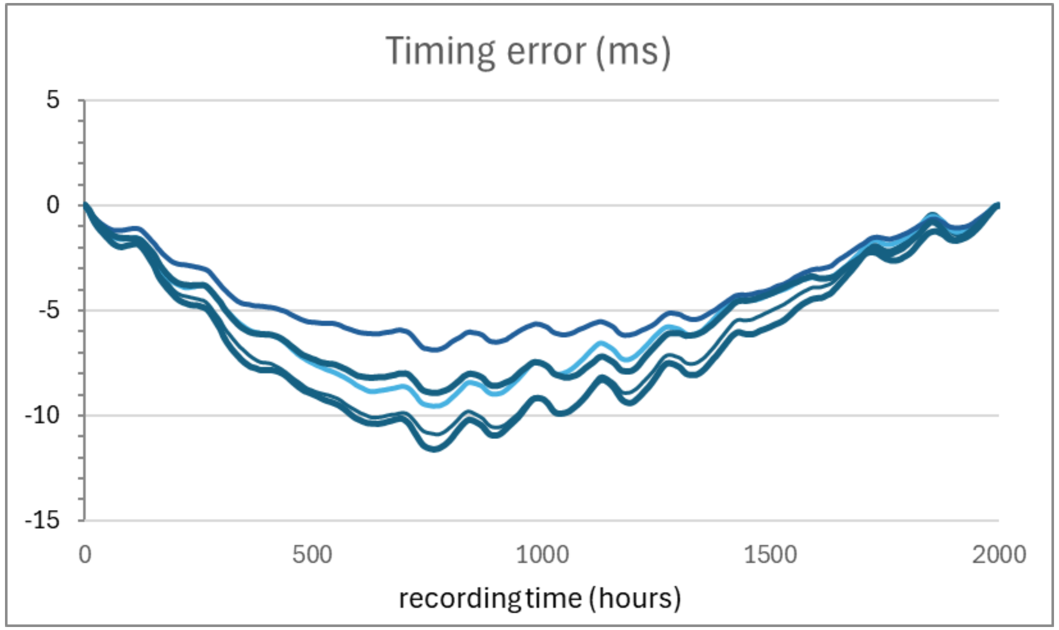
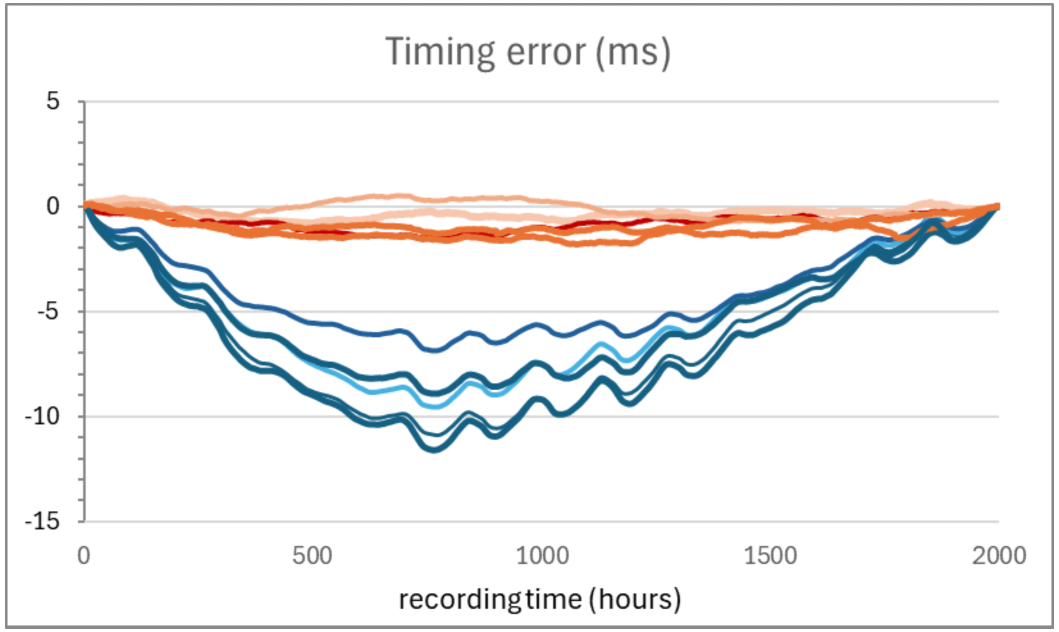
Experiment 1: 2 weeks in the lab

- The nodes record frequent GNSS fixes, so we know the exact timing
- Then we only keep the first and last GNSS time sync, and apply a linear correction for the average frequency shift for each of the 5 nodes shown here
- We get the timing errors vs time shown here (blue lines)



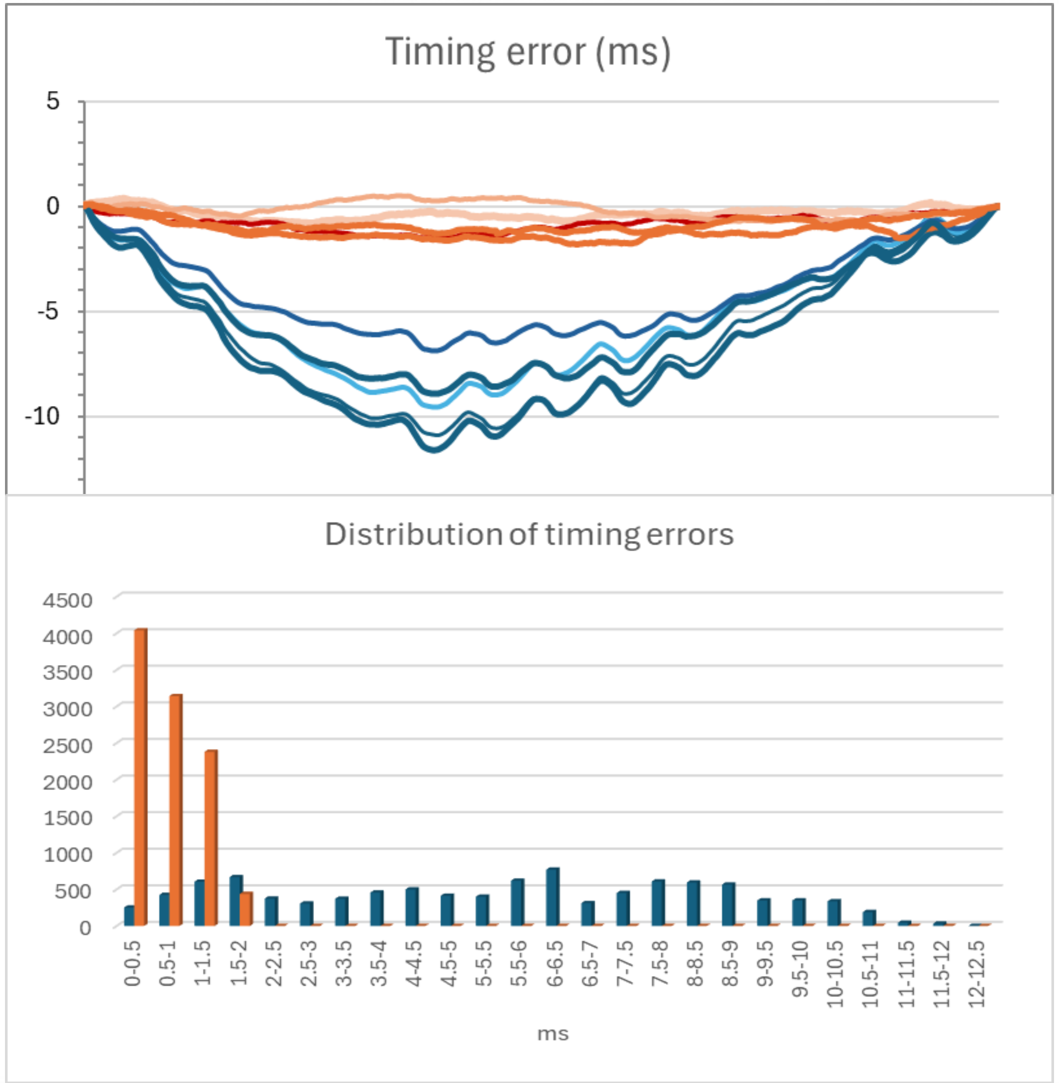
Experiment 1: 2 weeks in the lab

- We then apply the clock model obtained from machine learning for each node instead of the linear correction
- The timing errors are vastly reduced (orange lines)



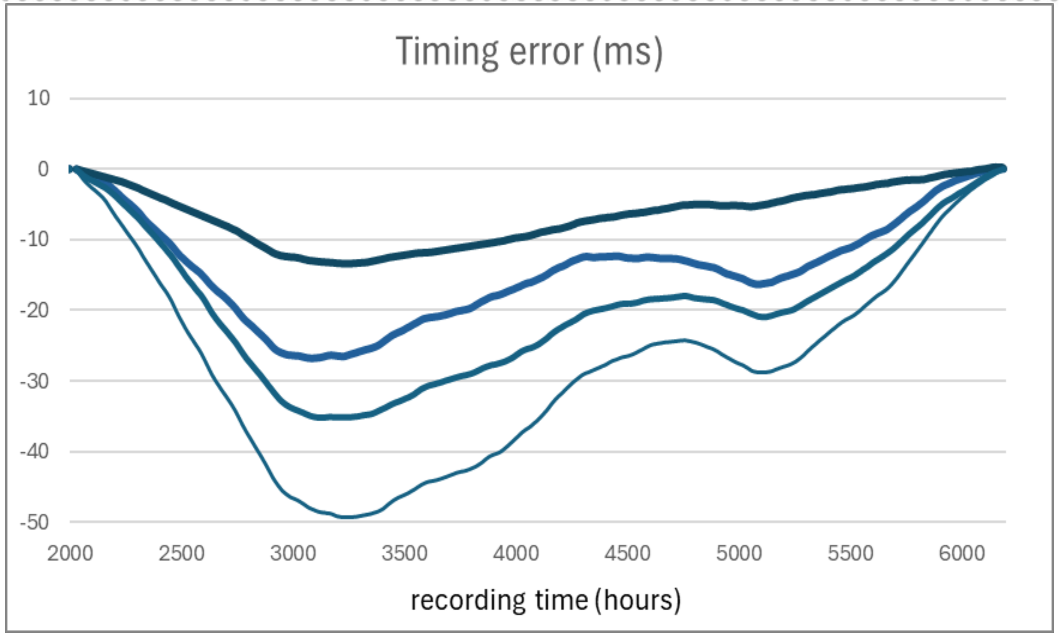
Experiment 1: 2 weeks in the lab

- We then apply the clock model obtained from machine learning for each node instead of the linear correction
- The timing errors are vastly reduced (orange lines)
- No timing error larger than the sampling rate
- Over 95% below 1.5 ms



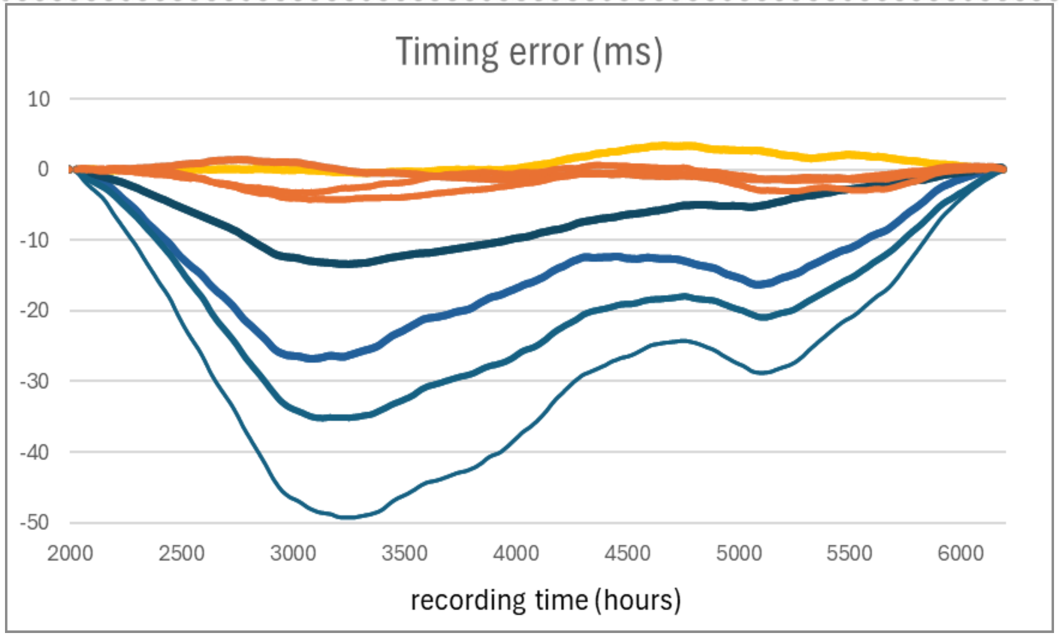
Experiment 2: 4 weeks buried in soil

- Same type of experiment: larger timing errors with linear correction



Experiment 2: 4 weeks buried in soil

- Applying the machine learning model dramatically reduces the timing errors



Further work:

- Testing better TCXO
- More data for improved model
  - Can also integrate data from current deployment

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Conclusion

- Transition Zone needs affordable light weight high-density acquisition systems
- Always relying on GNSS for timing is introducing heavy operational constraints
- We have shown that acceptable timing is achievable using low power TCXO clocks by better modelling their behaviour
- We keep working towards a commercial solution

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THANK YOU.

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