

# Weak-Signal Reconstruction under Strong Noise in Borehole Transient Electromagnetics

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## Motivation

Late-time signal loss  
limits exploration depth



01

02

03

04

05

## Reconstruction Framework

Ultra-pyramid fusion  
and noise-aware gating

## Conclusions & Outlook

Toward deeper, more reliable  
BTEM exploration

## Mathematical Rationale

Non-stationary decay  
And time-frequency evolution

## Validation & Analysis

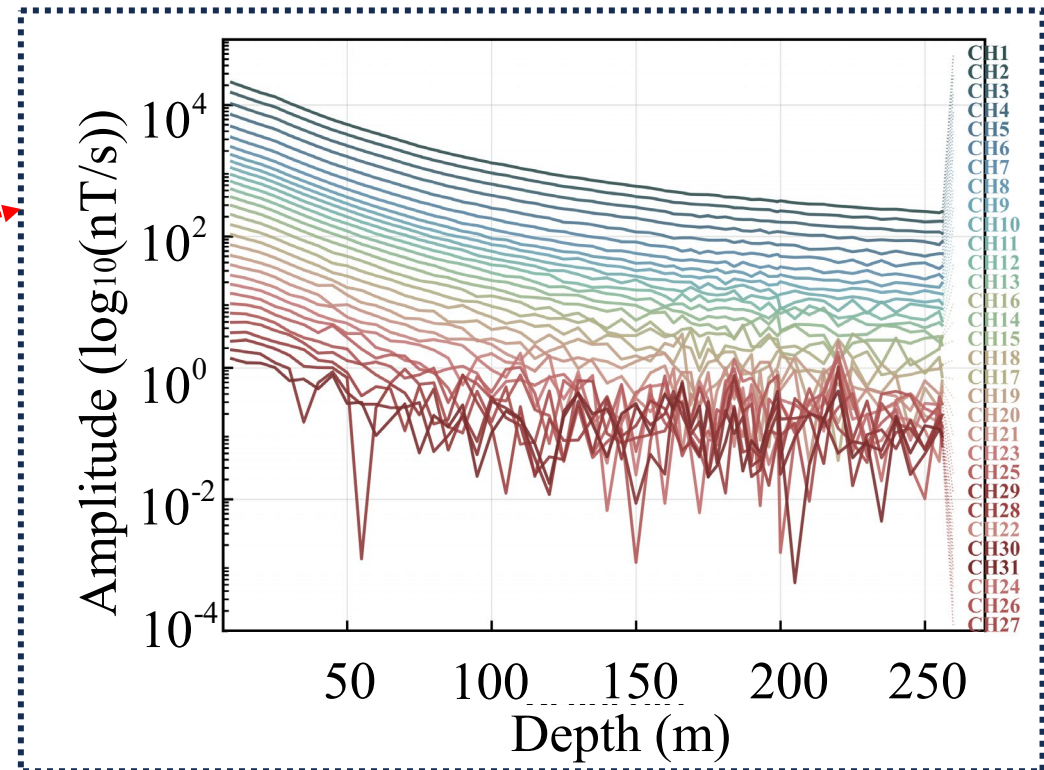
Synthetic benchmarks  
and field data evidence

**CURRENT SECTION** Why late-time weak responses become the bottleneck for reliable deep exploration.

# 1. Motivation



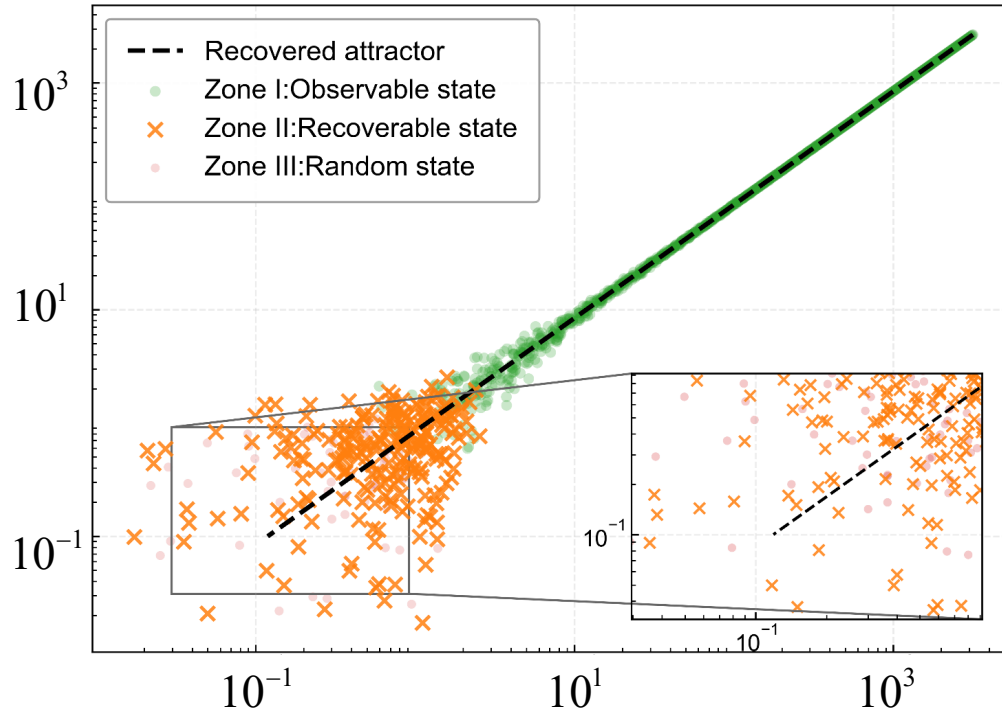
BTEM field operation site in Gansu, China



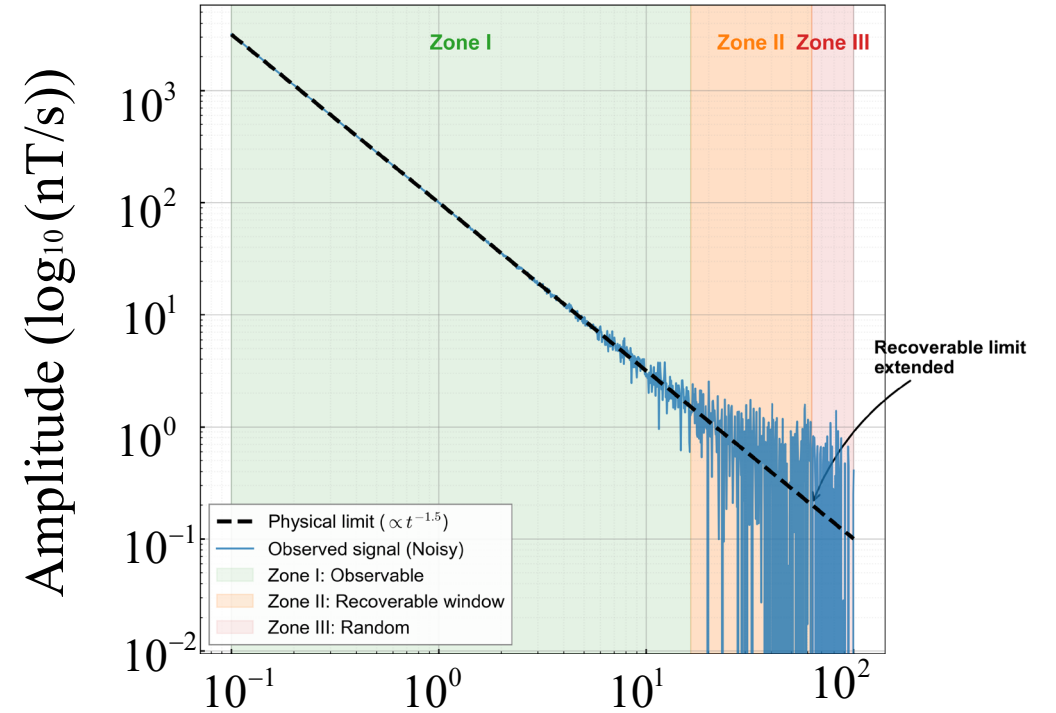
Raw field BTEM profile responses

Field BTEM data from Gansu show that complex survey-site noise severely degrades weak late-time responses, limiting the reliable detection of deep conductive targets.

# 1. Motivation



Recoverable State Manifold under Low SNR



Recoverability Limit of Late-Time BTEM Decay

Noise collapses the late-time interpretation window; the objective is to reconstruct the recoverable physical decay structure that supports deeper BTEM sensing.

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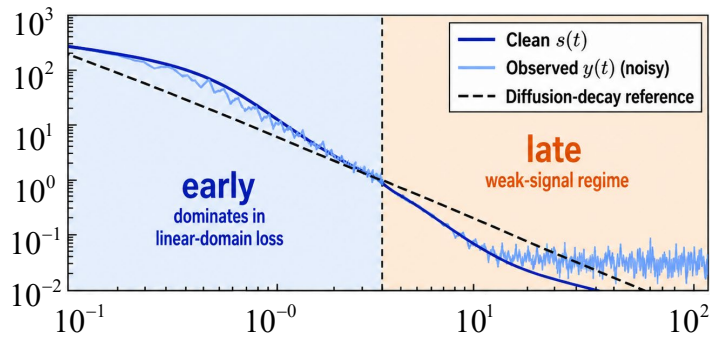
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**CURRENT SECTION** How non-stationary BTEM decay structures provide a basis for time–frequency reconstruction.

# 2. Mathematical Rationale

## 1 Dynamic-range compression

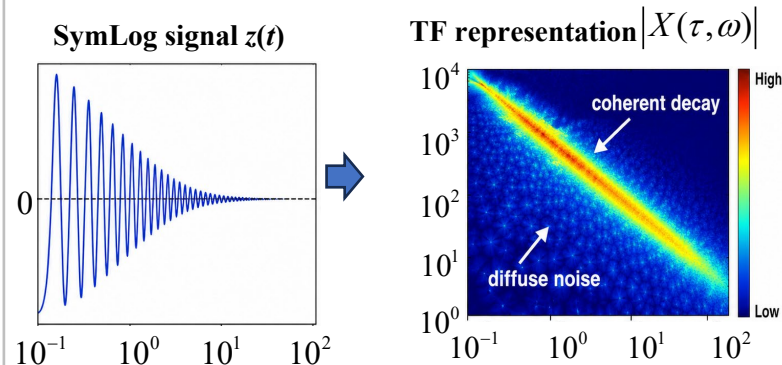


$$y(t) = s(t) + n(t)$$

$$z(t) = \text{sgn}(y) \log\left(1 + \frac{|y|}{s_0}\right)$$

SymLog makes weak late-time responses visible to optimization

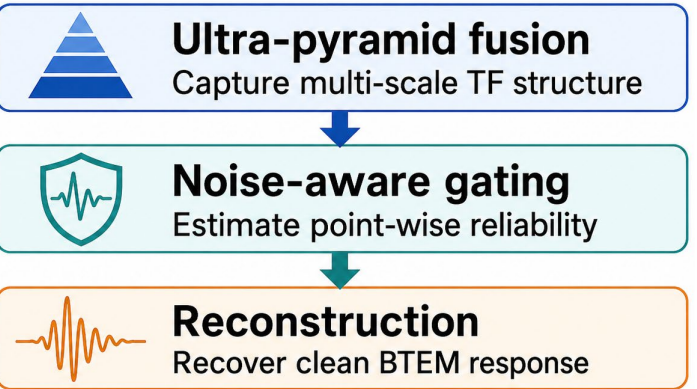
## 2 Time-frequency separability



$$X(\tau, \omega) = \text{STFT}[z(t)]$$

Recoverable signals preserve local TF coherence; noise becomes diffuse

## 3 Multi-scale reconstruction



$$\tilde{F} = F_{\theta}^{TF}(y) \odot G_{\theta}(y)$$

$$\hat{s} = R_{\theta}(\tilde{F})$$

Multi-scale TF features and point-wise reliability improve late-time recovery

The recoverability of weak late-time BTEM responses arises from stabilized decay dynamics, coherent time–frequency structure, and reliability-guided multi-scale reconstruction.

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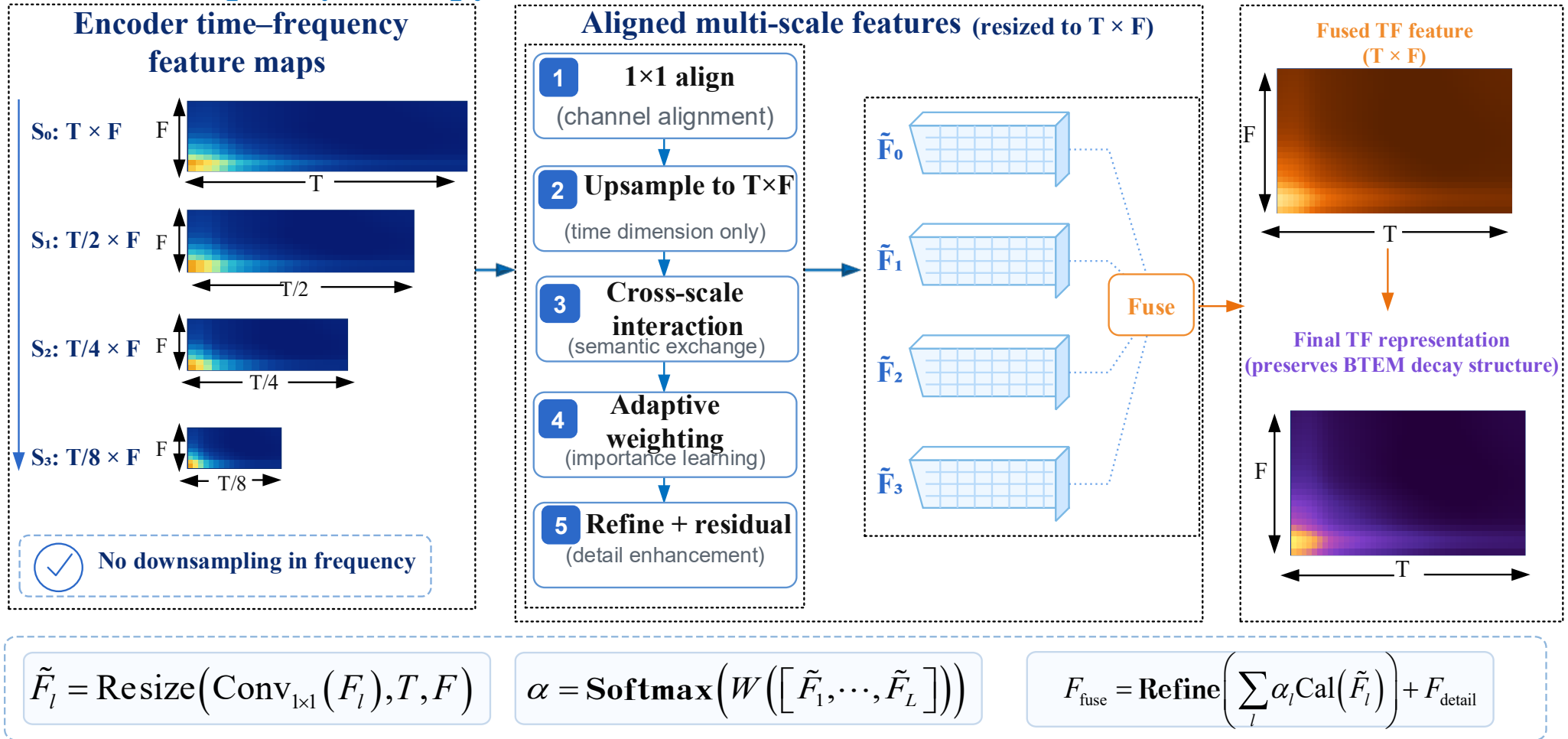
## Validation & Analysis

Synthetic benchmarks  
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**CURRENT SECTION** How ultra-pyramid fusion and noise-aware gating translate signal physics into reconstruction.

# 3. Reconstruction Framework

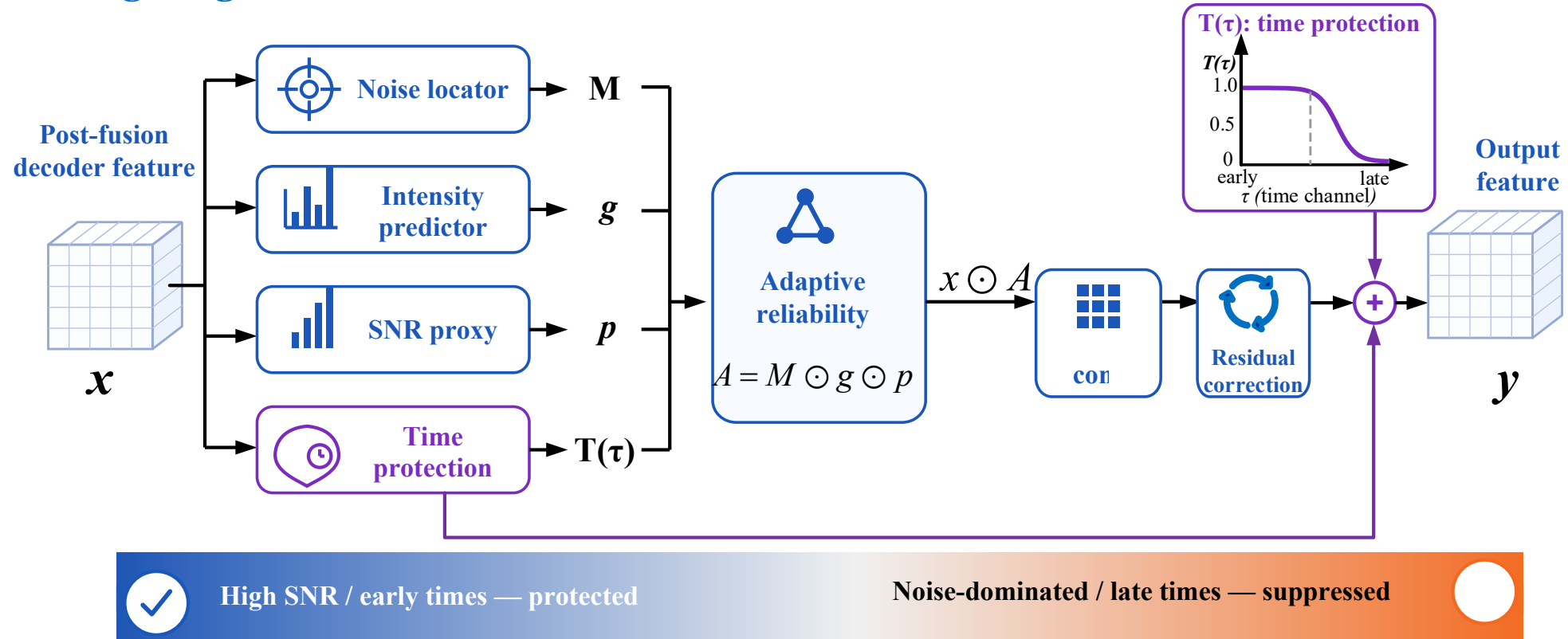
## 3.1 Asymmetric time-frequency ultra-pyramid fusion



The **asymmetric ultra-pyramid** preserves **frequency-resolved decay structure** and integrates **multi-scale temporal context** to enhance late-time BTEM recoverability.

# 3. Reconstruction Framework

## 3.2 Noise-aware gating module



$$y = x + \text{GuidedConv}(x \odot A) \odot A \odot T$$

**Pointwise reliability gating** separates **recoverable late-time decay** from noise-dominated fluctuations, enabling **physically consistent BTEM** reconstruction.

## Motivation

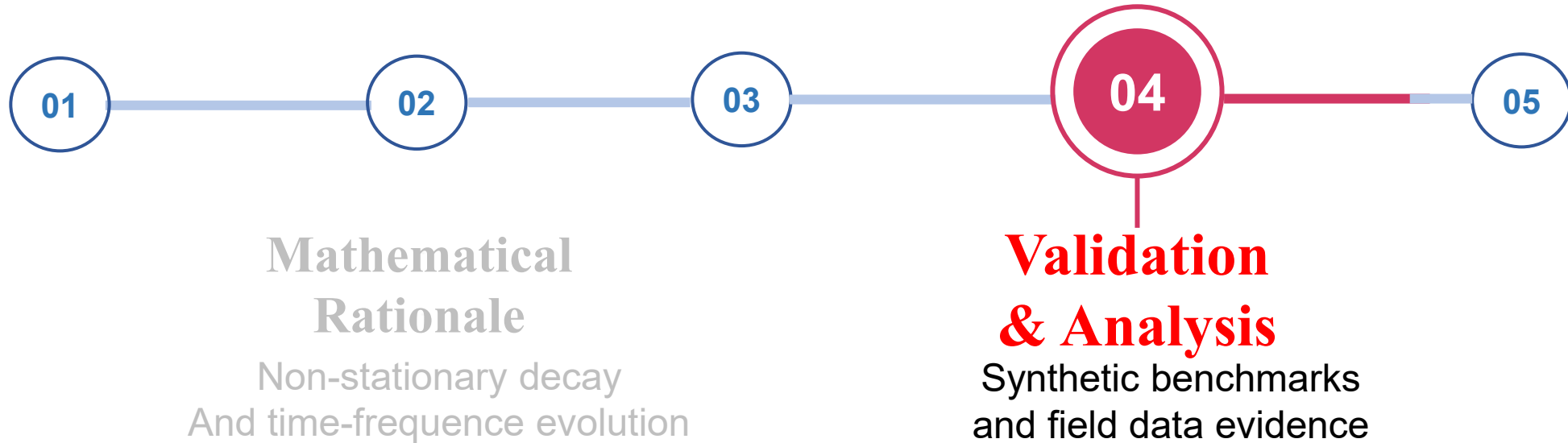
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## Reconstruction Framework

Ultra-pyramid fusion  
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## Conclusions & Outlook

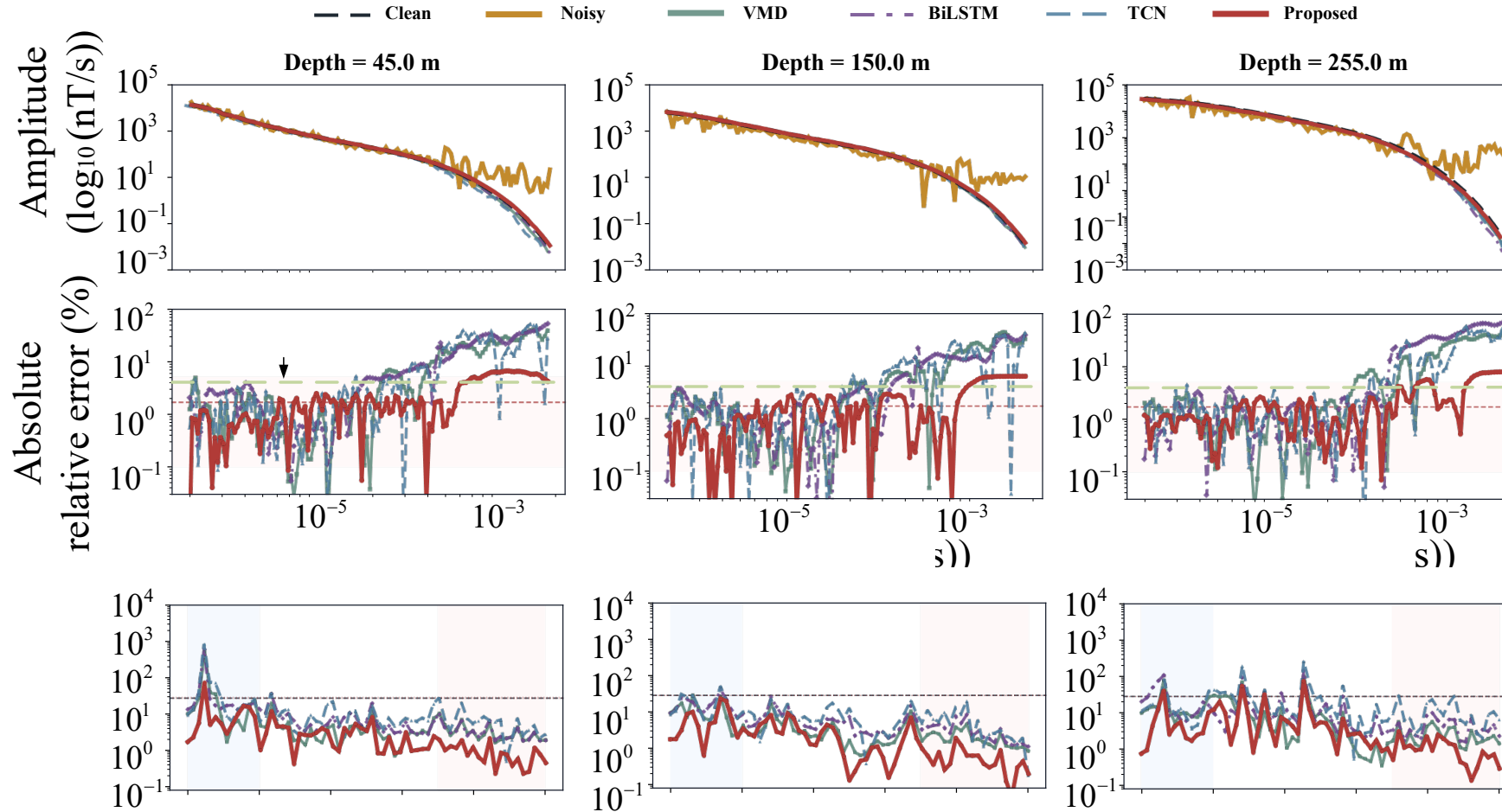
Toward deeper, more reliable  
BTEM exploration



**CURRENT SECTION** How synthetic benchmarks and field data verify late-time recovery and profile consistency.

# 4. Validation and Analysis

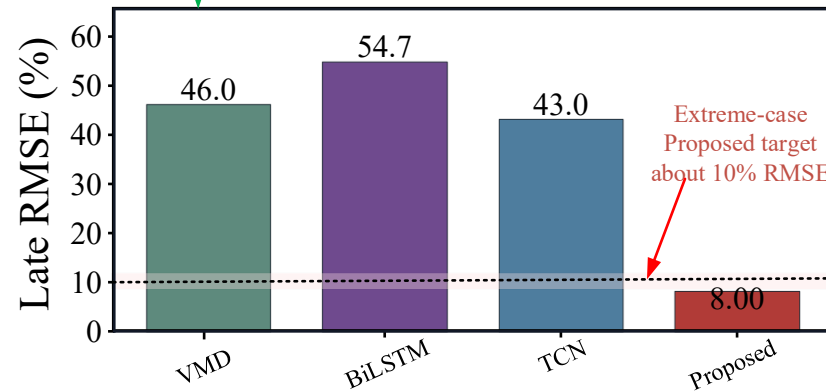
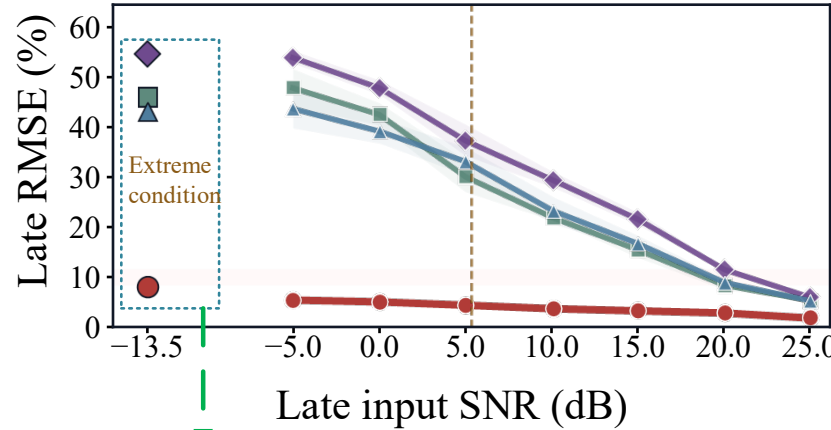
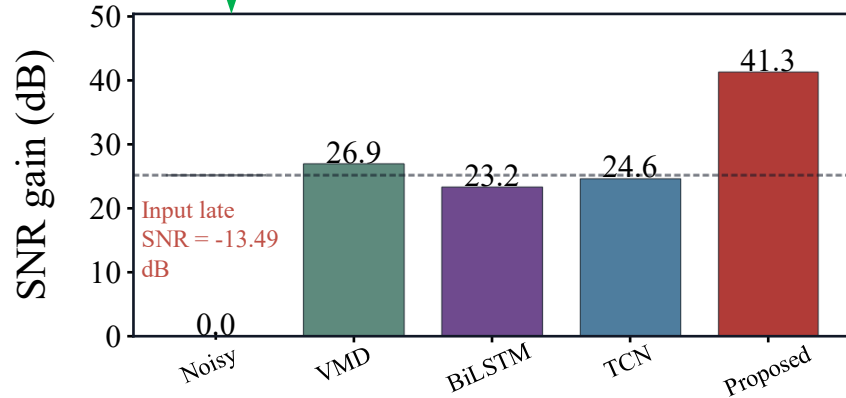
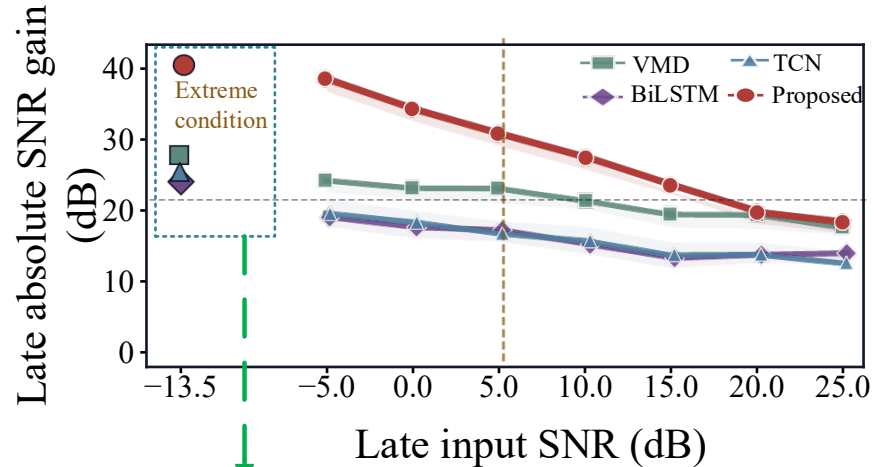
## 4.1 Simulated decay signals reconstruction



- ❖ **Temporal fidelity**  
Clean decay trends are recovered across depths
- ❖ **Late-time robustness**  
Weak late-time responses remain more stable
- ❖ **Spectral cleanliness**  
Residual noise energy is consistently reduced.

# 4. Validation and Analysis

## 4.2 Quantitative analysis of simulated response reconstruction



❖ **SNR-gain dominance**  
Highest late-time SNR gain across SNR regimes.

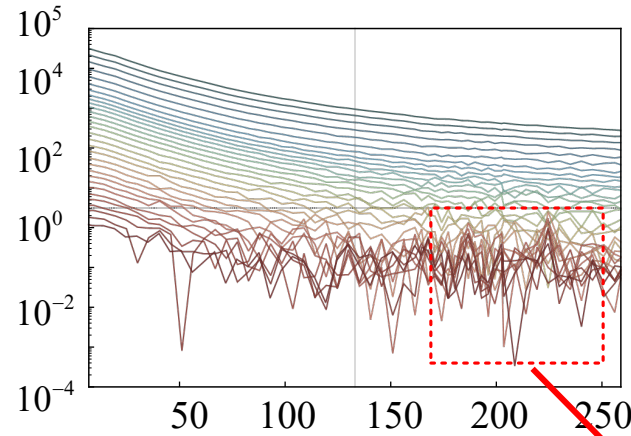
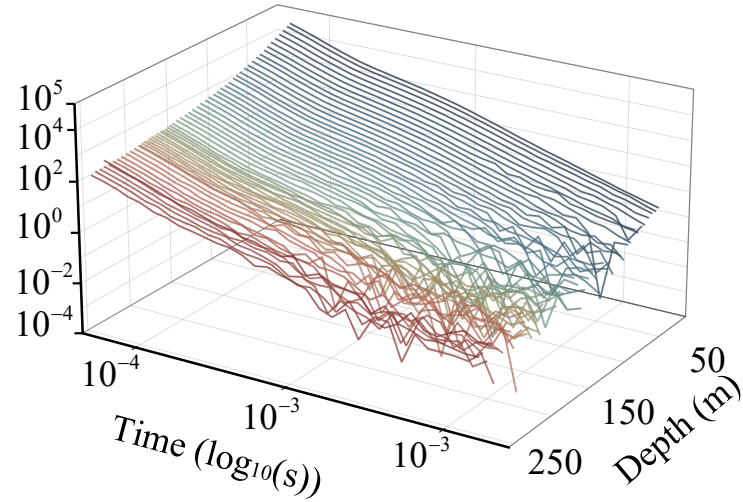
❖ **Extreme-SNR resilience**  
41.3 dB gain and 8.0% RMSE at -13.49 dB.

❖ **Error-controlled recovery**  
Late-time errors remain within the target range.

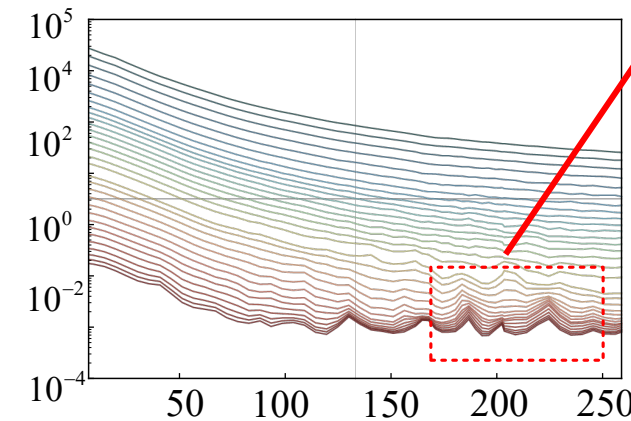
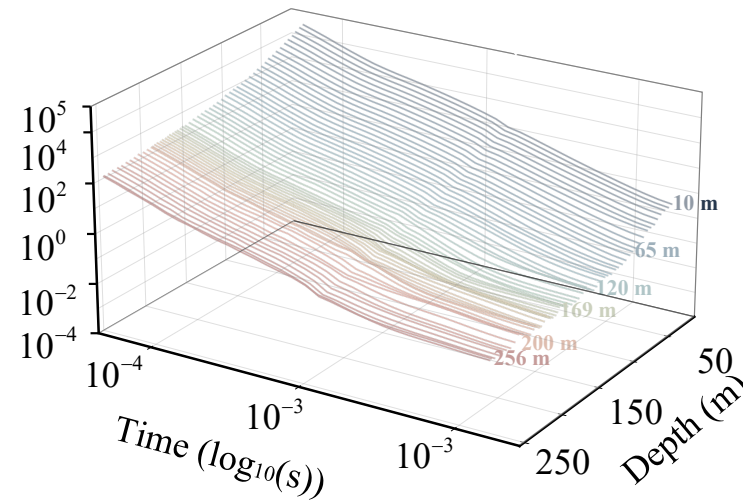
# 4. Validation and Analysis

## 4.3 Field response reconstruction validation

### ❖ Method effectiveness in field data



The proposed reconstruction method suppresses late-time random fluctuations and restores physically coherent BTEM decay responses in real measurements.



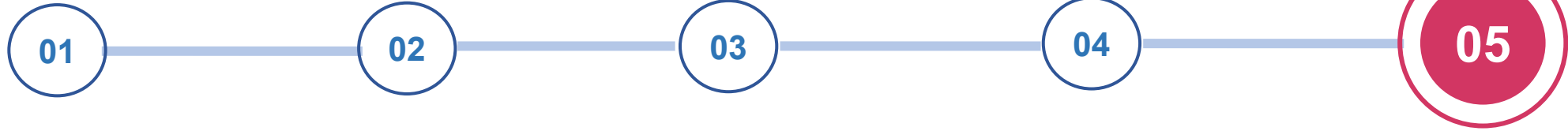
Drilling confirms the reconstructed anomalous interval.

### ❖ Drilling-validated interpretation

The recovered anomalous interval is confirmed by drilling data, demonstrating the geological reliability of the proposed method.

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**CURRENT SECTION** What this framework contributes to deeper BTEM exploration and future physics-guided reconstruction.

### 5.1 Conclusion

- **BTEM reconstruction challenge:** late-time weak responses are strongly degraded by field noise, shortening the interpretable time window and reducing profile traceability.
- **Method contribution:** the proposed method combines time–frequency ultra-pyramid fusion and noise-aware gating to recover multi-scale decay features with higher point-wise reliability.
- **Geophysical contribution:** simulated and field results show improved late-time SNR gain, lower RMSE, and enhanced profile continuity, providing a more robust signal basis for deep geophysical exploration.

### 5.2 Outlook

- **Reconstruction-to-inversion integration:** couple the reconstructed BTEM responses with resistivity inversion to quantify improvements in deep-target interpretation.
- **Field generalization:** extend validation to multi-survey, multi-component, and complex geological datasets to assess transferability under broader survey conditions.

# Thank you

## Questions & Discussion

### Weak-Signal Reconstruction under Strong Noise in Borehole Transient Electromagnetics

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