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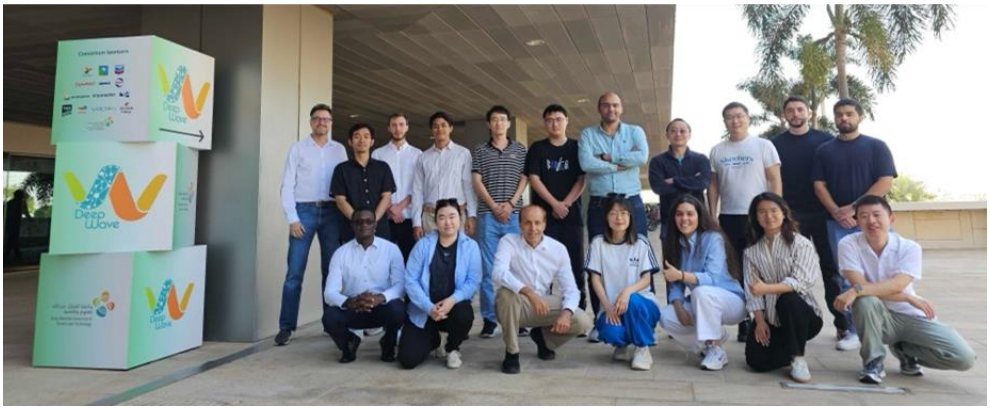
# BIANNUAL NEWSLETTER


## IN THIS ISSUE




# Overview

Welcome to the Spring 2025 issue of the DeepWave Consortium Newsletter! We're excited to share the latest developments, milestones, and insights from our vibrant team.

In this issue, turn to page 3 for a spotlight on **standout research projects** that reflect the creativity and determination of our team in tackling complex geophysical challenges.

On page 6, you'll find a curated selection of **recent publications** authored by our members, underscoring our collective commitment to advancing scientific knowledge in our disciplines.

Be sure to check out the **news** roundup on page 7, where we highlight recent events, important announcements, and updates from across the consortium. On page 8, we share some information on a new open **Faculty position** at KAUST for ML+geophysics.

We hope this edition leaves you informed, inspired, and connected to the momentum driving our work forward. Happy reading!

Find more about our consortium by either contacting us via e-mail [deepwave@kaust.edu.sa] or by visiting the DeepWave website [deepwave.kaust.edu.sa].

DeepWave is an industry funded research consortium at King Abdullah University of Science and Technology (KAUST), which focuses on the application of machine (deep) learning numerical algorithms to wave-equation-based processing, imaging, and inversion.

The application of these techniques extends to objectives ranging from global Earth discovery, to natural resources exploration, to subsurface monitoring as well as non-destructive testing and medical imaging.

## Goal

To be a leading center for the research and development of machine learning algorithms on waveform data with applications ranging from the exploration and discovery of the Earth to reservoir characterization and monitoring for oil and gas, geothermal, and CO2 storage purposes.

## Mission

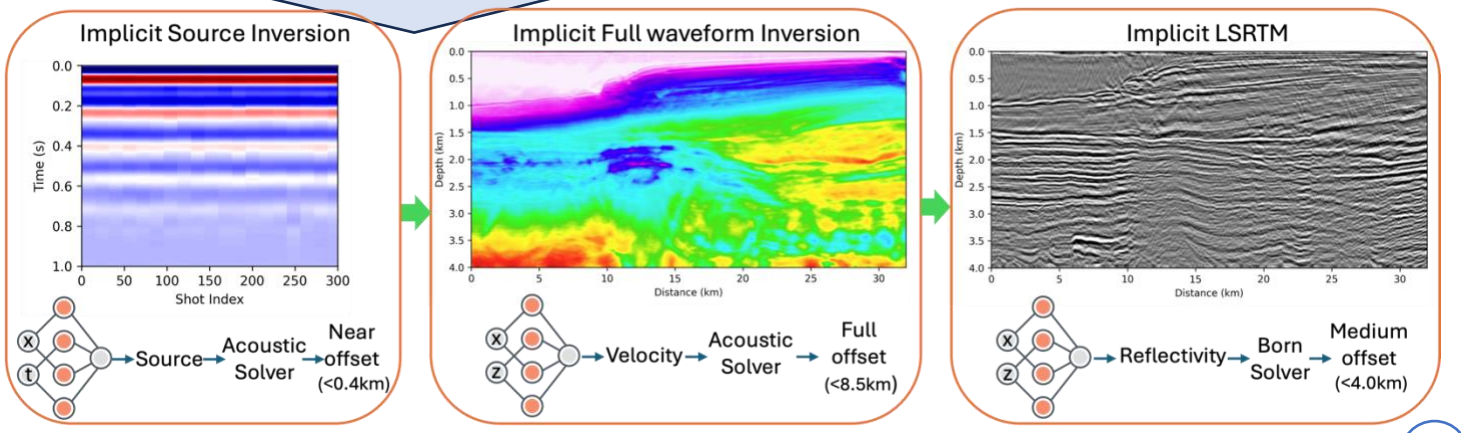
To foster an environment of effective research for the students and researchers that promotes seamless interaction with our sponsors.

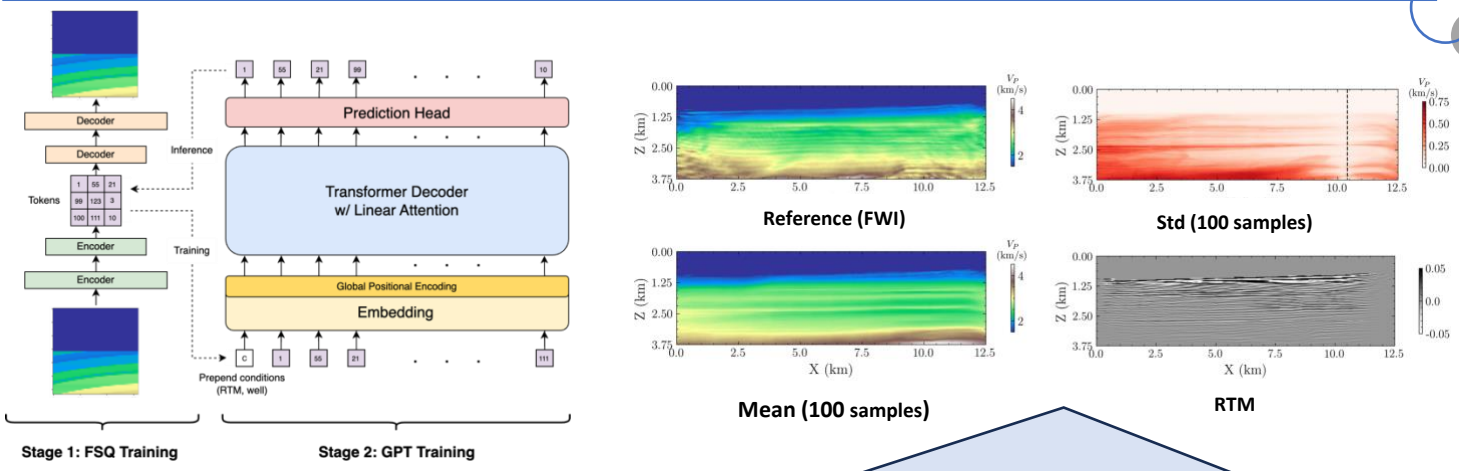
# Samples of DeepWave Research

## Accelerating implicit velocity model building and imaging

*Shaowen Wang, Matteo Ravasi, Tariq Alkhalifah*

An implicit neural representation-based workflow is proposed for seismic velocity model building and imaging. In this approach, the source wavelet, velocity model, and reflectivity model are each represented as the weights of neural networks, forming the basis for implicit source inversion (**ISI**), implicit full waveform inversion (**IFWI**), and implicit least-squares reverse time migration (**ILSRTM**). To accelerate convergence, **pseudo-Hessian** gradients correction and **multi-resolution hash encoding** are introduced at appropriate stages of the inversion process. Field dataset from Viridien demonstrate the robust inversion performance of the proposed workflow.




## Synthesizing realistic-scale seismic velocity models using a spatially-aware generative model

*Randy Harsuko, Shijun Cheng, and Tariq Alkhalifah*

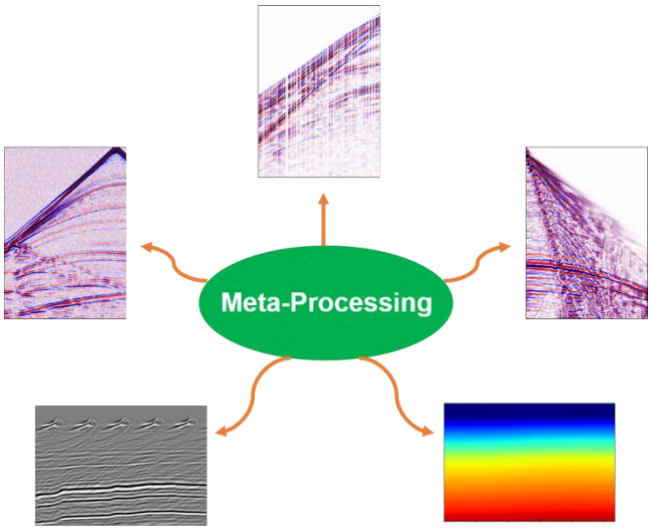
VelocityGPT is a next-generation approach to generate seismic velocity models from top to bottom, inspired by the GPT family of autoregressive transformers. By adopting a simpler yet more powerful way to quantify velocity patches and reworking the GPT design to span a broader context, the new version of VelocityGPT is scalable and excels at generating realistic velocity profiles. When tested on a real dataset, it integrates well data and reverse-time migration (RTM) images to yield accurate, coherent velocity samples. It also naturally captures uncertainty that matches our expectation. All in all, the improved VelocityGPT shows its capability to learn robust velocity priors for seismic velocity model building while seamlessly offering a way to measure uncertainty.

# Samples of DeepWave Research

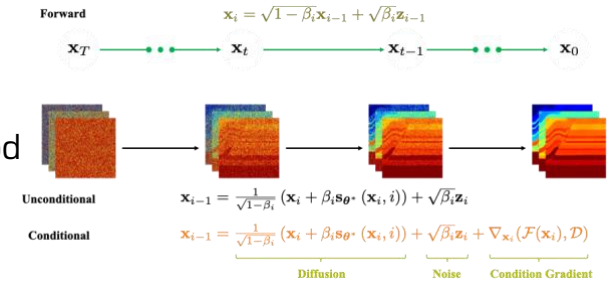
## Meta-Processing: A robust framework for multi-tasks seismic processing

*Shijun Cheng, Randy Harsuko, Tariq Alkhalifah*

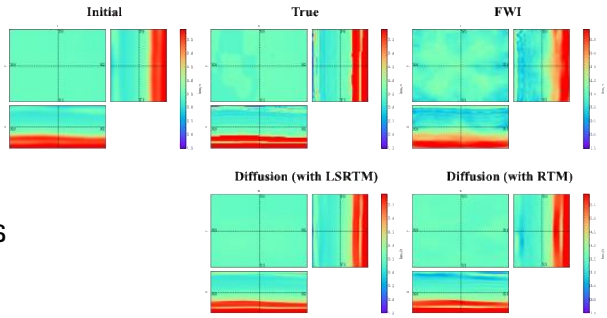
Meta-Processing is a unified framework that use meta-learning to overcome the limitations of traditional, task-specific seismic processing methods by learning a robust network initialization from limited training data. In this approach, seismic processing tasks, including denoising, interpolation, ground-roll attenuation, imaging enhancement, and velocity estimation, are addressed using a **two-stage strategy**: the **meta-training phase** uses a bilevel gradient descent method to optimize network parameters across various tasks by splitting training data into support and query sets, thereby capturing the common, inherent features of seismic data; the **meta-testing phase** then rapidly fine-tunes this pre-trained model on specific tasks with minimal additional training, resulting in much faster convergence and enhanced prediction accuracy compared to models with random initialization. Experimental results on both synthetic and field data demonstrate its potential to achieve high performance despite the scarcity of labeled data, marking a significant paradigm shift in seismic data processing.




Method




Results




## Guiding unconditional diffusion models through data reconstruction for high-fidelity velocity model building

*Mohammad. H. Taufik, and Tariq Alkhalifah*

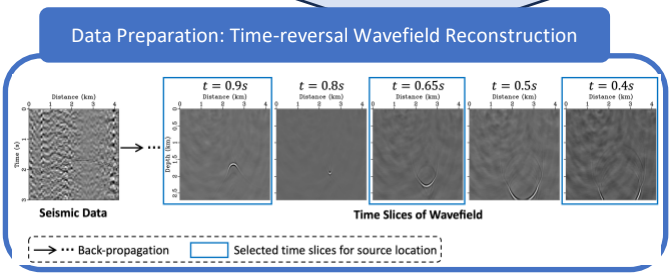
We introduce reconstruction guidance loss to perform conditional diffusion model sampling from our prior expectations of the Earth. With this guidance, we can incorporate different types of data modality to guide the diffusion sample toward a desirable velocity model without including conditions during the diffusion model training. Courtesy of the image reconstruction guidance, we demonstrate that the trained diffusion model can generate an unseen (in training), completely out-of-distribution, velocity model information. The general velocity trend is injected by starting the reverse diffusion with the initial (background accurate) velocity model. Thus, with only an estimate of the background velocity (like migration velocity) and the resulting image, the diffusion model admits reasonably accurate velocity models.

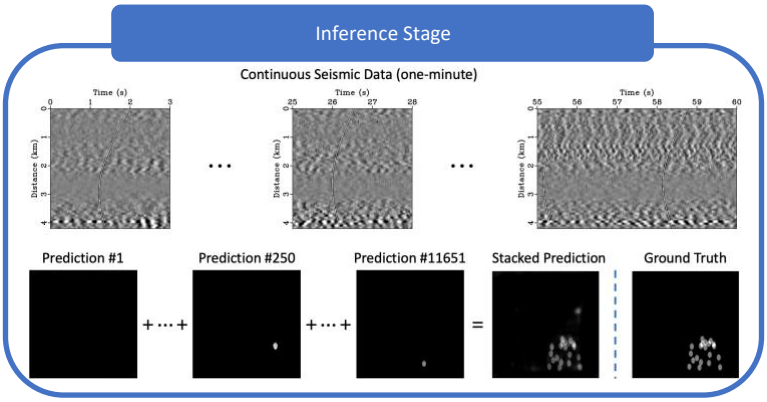
# Samples of DeepWave Research

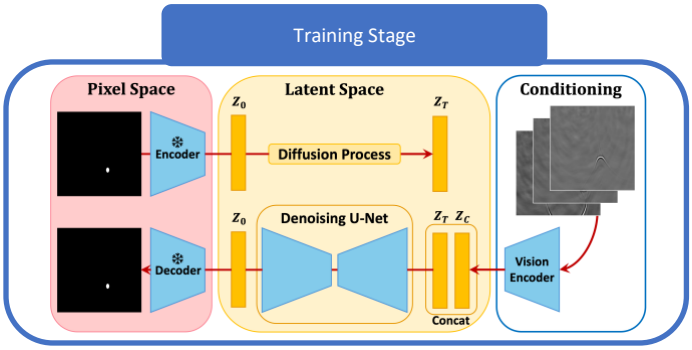
## Real-time Microseismic Event Location Using a Latent Diffusion Model

*Yuanyuan Yang, Omar M. Saad, Tariq Alkhalifah*

We propose a real-time microseismic event location framework that leverages a latent diffusion model as an imaging condition applied to time-reversal seismic wavefield. Conventional methods for locating events typically require prior event detection to ensure that the subsequent location algorithms only operate on event-containing segments. Our approach eliminates the need for pre-defined time windows with detected events, and operates directly on the raw, continuous seismic recordings. By conditioning the model on three time snapshots of the time-reversal wavefield, it instantly infers event locations (if there is any) without prior knowledge of source origin times. The figure of inference stage demonstrates a successful example of accurately detecting and locating 20 events from one-minute continuous seismic recording.




## Recent Publications

**Alfarhan M.; Ravasi M.; Chen F.; Alkhalifah T.**, "*Robust full waveform inversion with deep Hessian deblurring*", 2025, Geophysical Journal International, 10.1093/gji/ggae378.

**Brandolin F.; Ravasi M.; Alkhalifah T.**, "*Slope assisted Physics Informed Neural Networks for seismic signal separation with applications on ground roll removal and interpolation*", 2025, Geophysical Prospecting, 10.1111/1365-2478.70004.

**Cheng S.; Alkhalifah T.**, "*Discovery of Physically Interpretable Wave Equations*", 2025, Surveys in Geophysics, 10.1007/s10712-024-09857-5.

**Cheng S.; Alkhalifah T.**, "*Meta Learning for Improved Neural Network Wavefield Solutions*", 2025, Surveys in Geophysics, 10.1007/s10712-024-09872-6.

# Recent Publications (cont'd)

**Cheng S.; Zhang H.; Alkhalifah T.**, "*Self-Supervised Seismic Resolution Enhancement*", 2025, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2025.3528414.

**Corrales M.; Berti S.; Denel B.; Williamson P.; Aleardi M.; Ravasi M.**, "*Annealed stein variational gradient descent for improved uncertainty estimation in full-waveform inversion*", 2025, Geophysical Journal International, 10.1093/gji/ggaf096.

**Harsuko R.; Cheng S.; Alkhalifah T.**, "*Propagating the prior from shallow to deep with a pre-trained velocity-model generative transformer network*", 2025, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000408.

**Mu X.; Alkhalifah T.; Huang J.**, "*Attenuation-compensated viscoelastic reverse time migration with finite-difference operators*", 2025, Geophysics, 10.1190/geo2024-0295.1

**Park J.-Y.; Saad O.M.; Oh J.-W.; Alkhalifah T.**, "*Transformer-Based Seismic Image Enhancement: A Novel Approach for Improved Resolution*", 2025, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2024.3510863.

**Saad O. M.; Alkhalifah T.**, "*F-SiameseFWI: A Novel Deep Learning Framework for Multi-Source Full Wave Inversion*", 2025, Geophysics, 10.1190/geo2024-0785.1.

**Taufik M.H.; Alkhalifah T.**, "*Wavenumber-aware diffusion sampling to regularize multiparameter elastic full waveform inversion*", 2025, Geophysical Journal International, 10.1093/gji/ggae437.

**Cheng S.; Wang Y.; Zhang Q.; Harsuko R.; Alkhalifah T.**, "*A self-supervised learning framework for seismic low-frequency extrapolation*", 2024, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000157.

**Saad O. M.; Harsuko R.; Alkhalifah T.**, "*SiameseFWI: A deep learning network for enhanced full waveform inversion*", 2024, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000227.

**Taufik M.H.; Huang X.; Alkhalifah T.**, "*Multiple Wavefield Solutions in Physics-Informed Neural Networks Using Latent Representation*", 2024, IEEE Geoscience and Remote Sensing Letters, 10.1109/LGRS.2024.3397873

**Wang F.; Huang X.; Alkhalifah T.**, "*Controllable seismic velocity synthesis using generative diffusion models*", 2024, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000153.

**Yang Y.; Saad O. M.; Alkhalifah T.**, "*Deep learning-based 3D microseismic event direct location using simultaneous surface and borehole data*", 2024, Journal of Geophysical Research: Machine Learning and Computation, 10.1029/2024JH000365.

# News

## Farewell to Matteo Ravasi

Recently Matteo Ravasi has embarked on an exciting new journey by joining Shearwater. Matteo has been instrumental in the creation of our consortium and has played a key role in numerous important research projects during his years at KAUST, either leading or contributing significantly to them. Beyond his professional contributions, Matteo has been a valued mentor and a good friend to all of us at KAUST. We are deeply grateful for his dedication and impact and we warmly wish him all the best in his new endeavors!

## New Sponsors

We are pleased to announce that **Woodside Energy** and **Eni** have recently joined the Consortium as our newest sponsors. Their addition strengthens our commitment to advancing innovation and fostering collaboration across our initiatives. We look forward to working closely with them and leveraging their expertise in our upcoming projects. Welcome to the team!

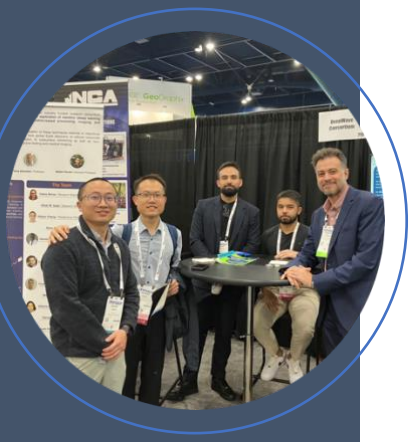
## Mid-year Meeting 2025

The Consortium's Mid-Year 2025 Meeting took place on February 10–11, 2025, at KAUST. Organized in a hybrid format, the event featured five focused sessions covering *Imaging and Processing*, *Full-Waveform Inversion (FWI)*, *Reservoir and Microseismic studies*, and *Generative Regularization*. We were pleased to welcome over 80 online participants, along with 8 colleagues attending in person, which fostered lively discussions and valuable feedback during the Q&A sessions. Next stop: the Annual Meeting in Houston (Aug. 2025).

## DeepWave gets a new home


The Deepwave team has recently relocated to a dedicated workspace designed to spark closer collaboration and spontaneous idea exchange among its members. This new environment not only supports more frequent and productive brainstorming sessions but also creates a stronger sense of focus and team identity.

# News (cont'd)



## Conferences

DeepWave is gearing up for a strong presence at the upcoming **EAGE** conference in Toulouse, where our members will deliver *24 oral presentations* and showcase *2 posters*. At the **IMAGE** conference in Houston, we will continue sharing our latest research with the broader geoscience community. In addition to technical presentations, the consortium will host a dedicated **booth** at the IMAGE exhibition, offering a space to highlight recent achievements and connect with new collaborators and industry peers.

## Annual Report & Annual Meeting

The team is preparing to share all the exciting research produced during this last year with the consortium sponsors in the next volume of the Annual Report that will be ready at the start of June. Later, in August, we will be hosting the Annual Meeting where we'll have the chance to meet, present, and discuss to our colleagues from Sponsor companies.

## Student Internship in Oxy

Hasyim Taufik, a senior PhD student in our group, recently completed a fruitful 12-week internship placement in Oxy (Houston, US). Hasyim, whose research covers the topics of generative models and Bayesian full waveform inversion, had the chance to join the Oxy team and improve his understanding in tackling large-scale Bayesian full waveform inversion.

## DeepWave on Github

Our GitHub organization has expanded thanks to the contributions of our team, now proudly hosting *49 stable repositories* and *44 in development*. These repositories are designed to facilitate seamless code sharing between DeepWave researchers and Consortium sponsors. A total of *18 public repos* which are linked to published research have become available to the whole community after completing a privacy period of 6 months.

## Announcement

### Faculty opening at KAUST

KAUST has just announced an open faculty position in **computational science and engineering** with a focus on **geophysics**. The candidate should have some expertise in machine learning and computational methods applied to seismic imaging, inversion, earthquake monitoring, or subsurface characterization.

A Ph.D. in Geophysics, Computer Science, Applied Mathematics, or a closely related discipline is required.

To access the official site for more information and applications, use the following link: https://apply.interfolio.com/167350

We thank our **Industry Sponsors** for their support

## Scope of research

The Consortium aims to deliver the most effective solutions to waveform processing, imaging, and inversion challenges across multiple scales.



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