Real-Time Data Simulator for the Qualification of DAS Passive Seismic Geothermal Monitoring Systems

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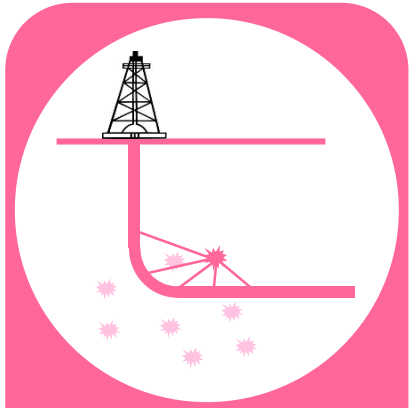
SLB

Microseismic Monitoring 101
Geometries of acquisition

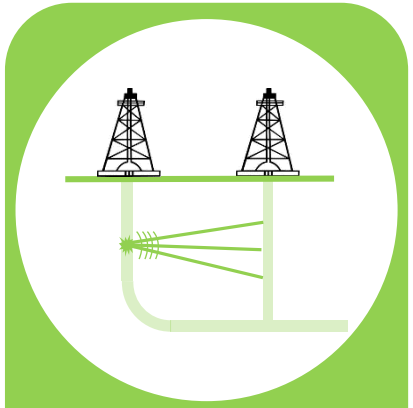


DH - SW

Single well downhole microseismic monitoring using VSI. Superior clamping, quantifiable coupling using proprietary shaker. Decoupled, GAC sensor and leading manufacturing tolerances result in superior signal to noise data.

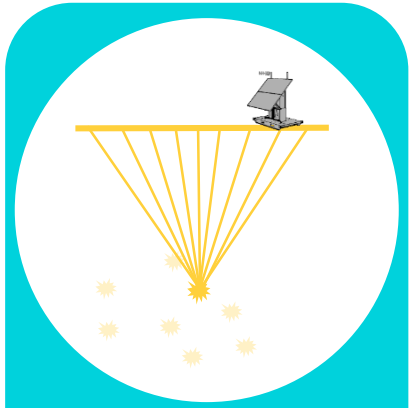
DH - MW

Multi well downhole microseismic monitoring using VSI. Superior clamping, quantifiable coupling using proprietary shaker. Decoupled, GAC sensor and leading manufacturing tolerances result in superior signal to noise data.



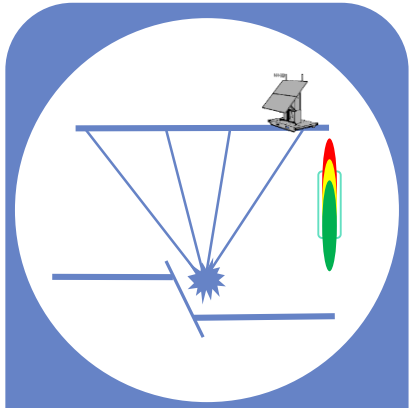
DLCS

High energy, low impact, downhole source, high frequency imaging, 4D drainage mapper, HFM velocity model calibration. Combinable with VSI & hDVS for complete monitoring and imaging versatility.



Surface HFM

Surface microseismic processing of shallow well grid or patch deployment.



Induced Seismicity Monitoring

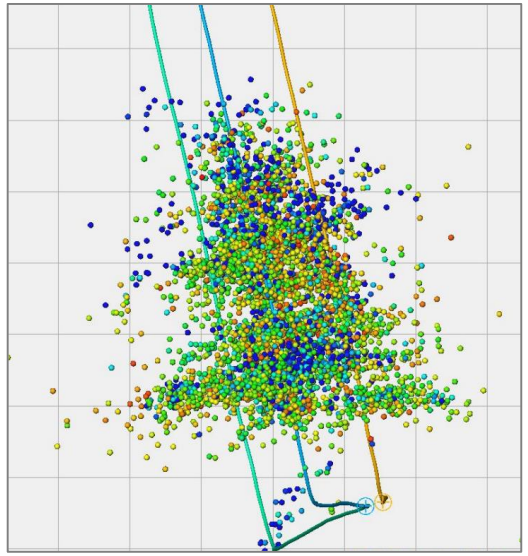
Real time surface monitoring of large magnitude events in response to regulatory requirements. Reservoir & monitoring applications including EOR and subsidence.

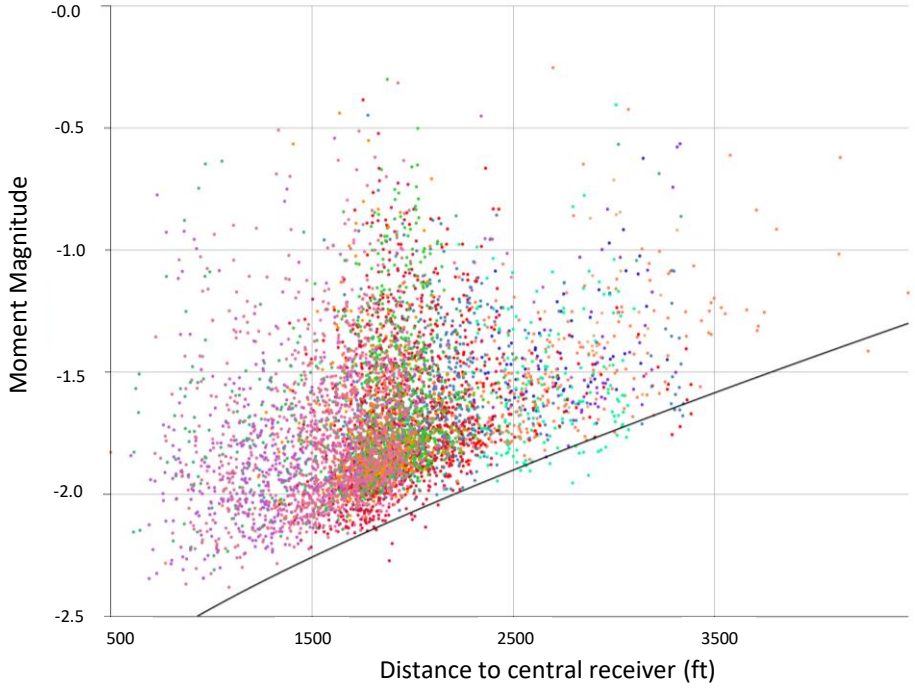
Microseismic Monitoring 101
Definition of a microseismic event

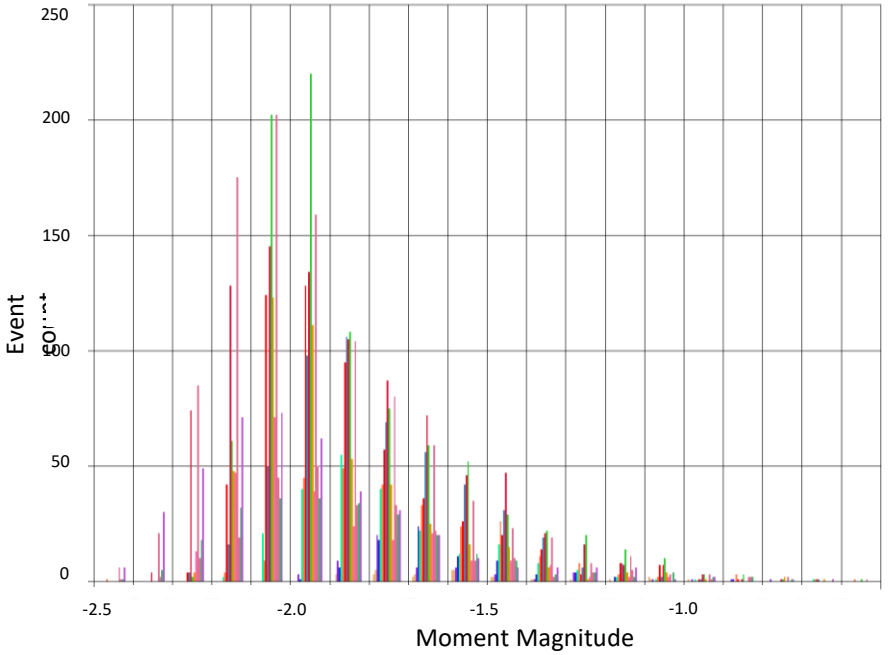
- In principle, **microseismic** describes any events or methods pertaining to *microseisms* — faint earth tremors with natural or human causes. Since about 2000, however, the term has become strongly associated with passive seismic monitoring of production effects, borehole-related phenomena, and especially hydraulic fracture stimulation or *fracking*. **(SEG wiki)** (and geothermal, carbon capture, etc.)

- Microseismic monitoring can tell us when and where a microseismic event occurred and how big it was (measured on the moment magnitude scale).

- Microseismic monitoring can also tell us how the rock failed, what was the mechanism, shear or tensile (i.e. slipping or opening and closing) ?

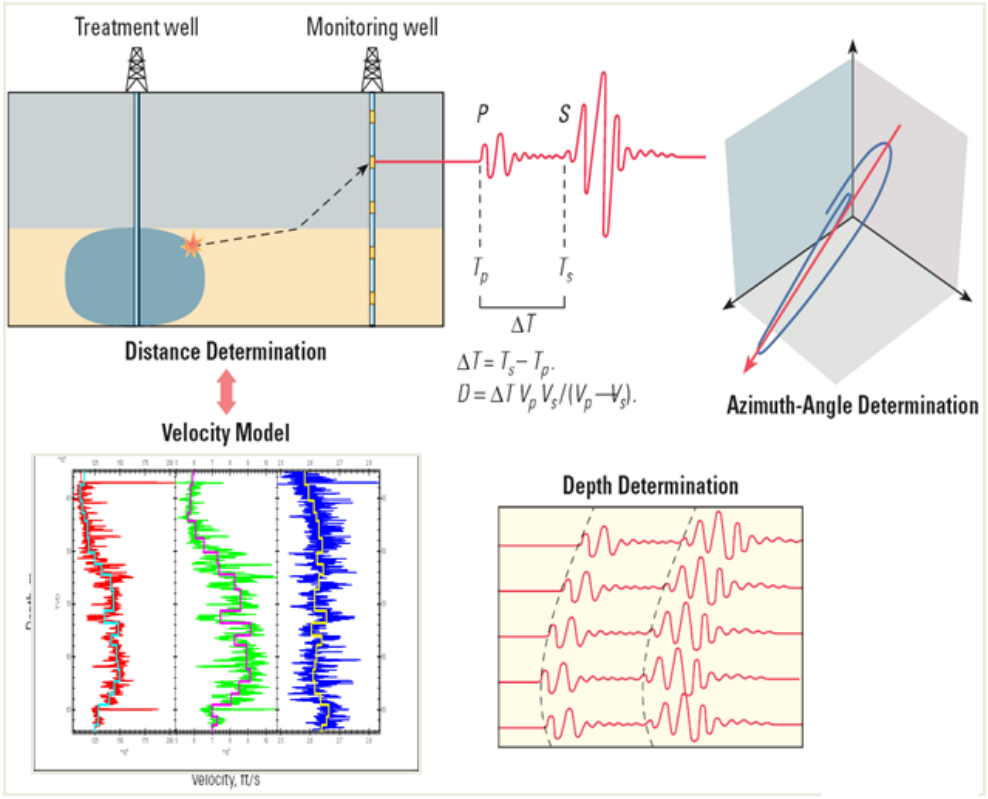


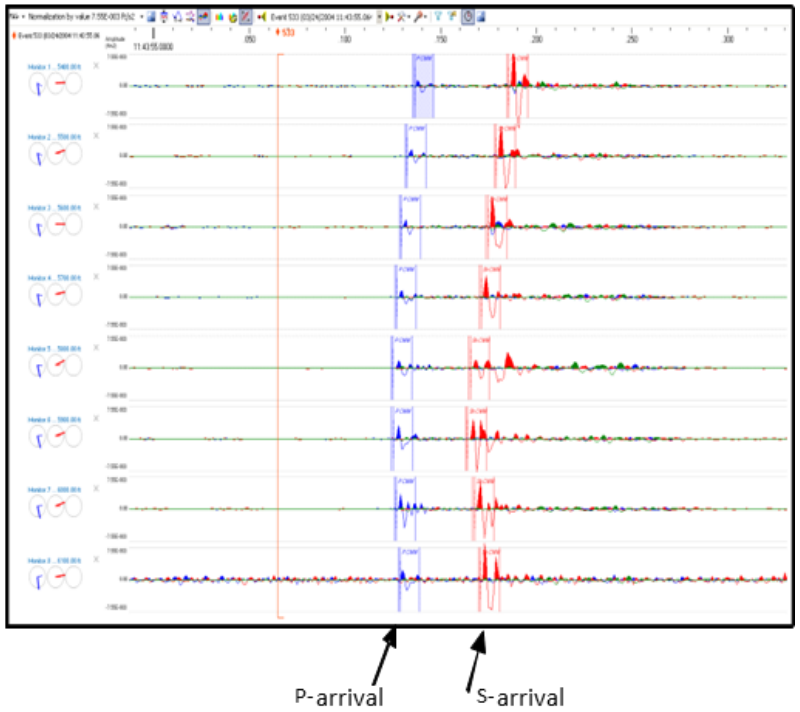




Microseismic Monitoring 101
Definition of a microseismic event

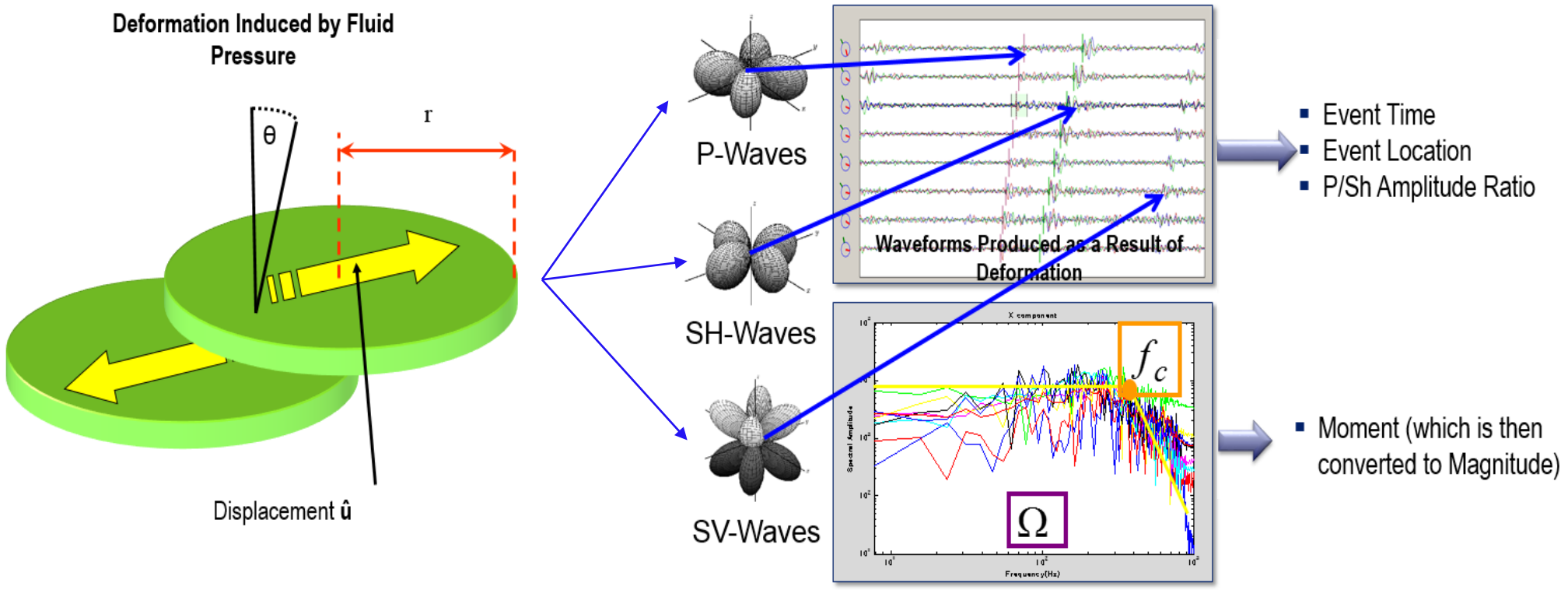
- Rock will deform (crack) when pressure increases beyond its failure criteria
- Energy is released and measured (either downhole or on the surface)
- When (time), where (spatially), and how (mechanism), this occurred can be mapped





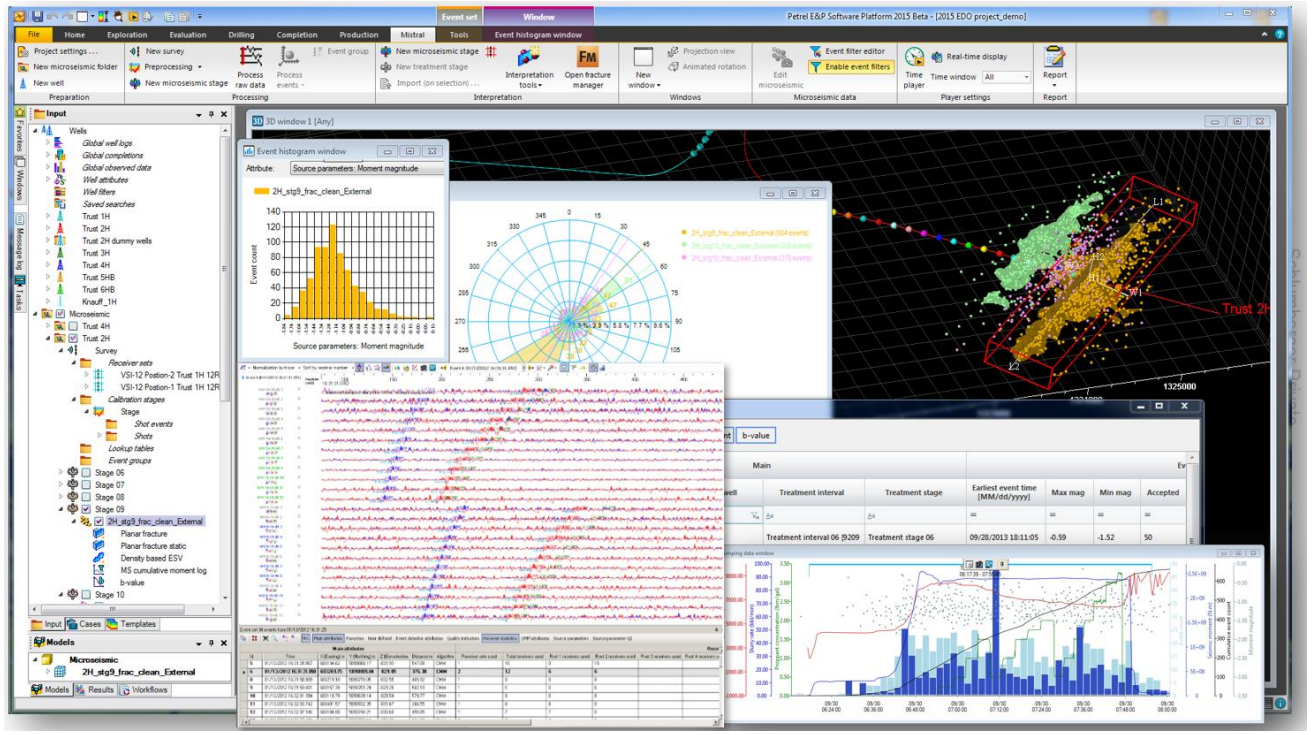
Microseismic Monitoring 101
Definition of a microseismic event

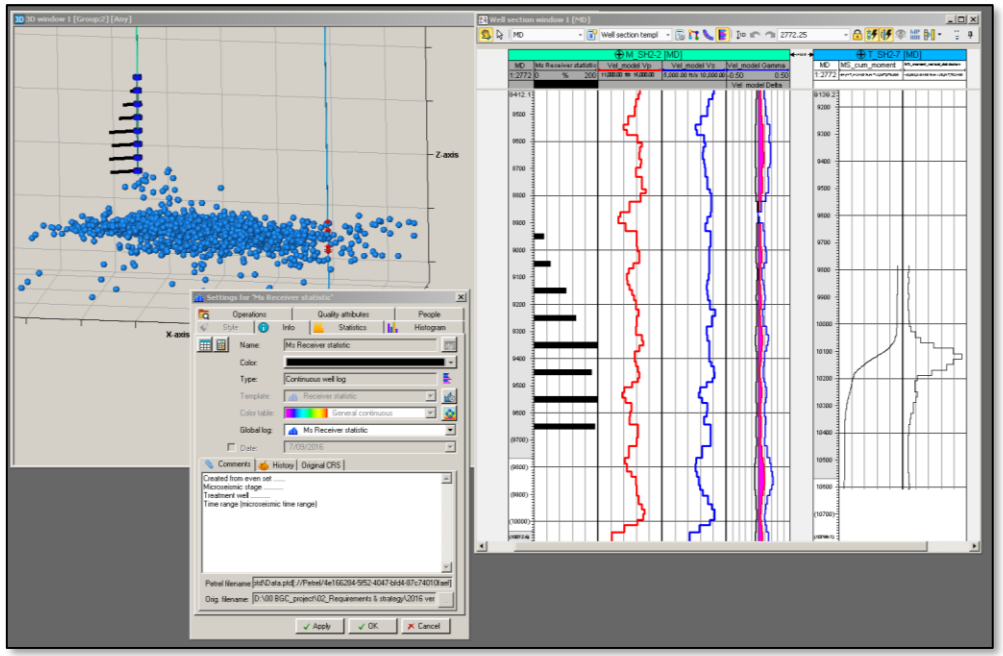
- The energy of a microseismic event is expressed as a magnitude similar to the Richter (log) scale used to measure earthquakes
- Microseismic events are typically magnitudes -1 to -4
- An event of magnitude -2 is roughly equivalent to dropping a bag of sugar from the countertop

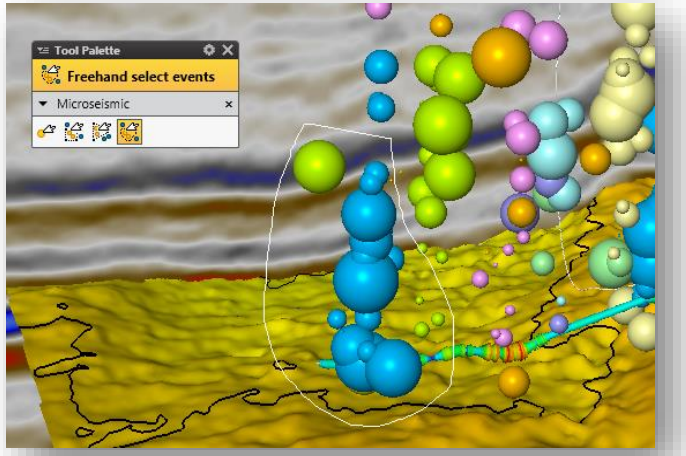


Microseismic Monitoring 101

How to use a microseismic event

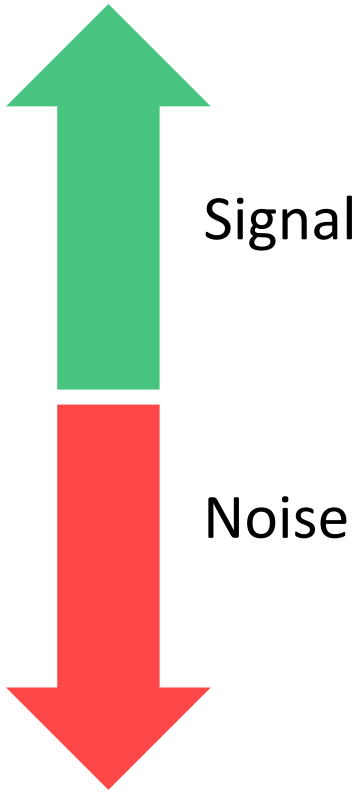


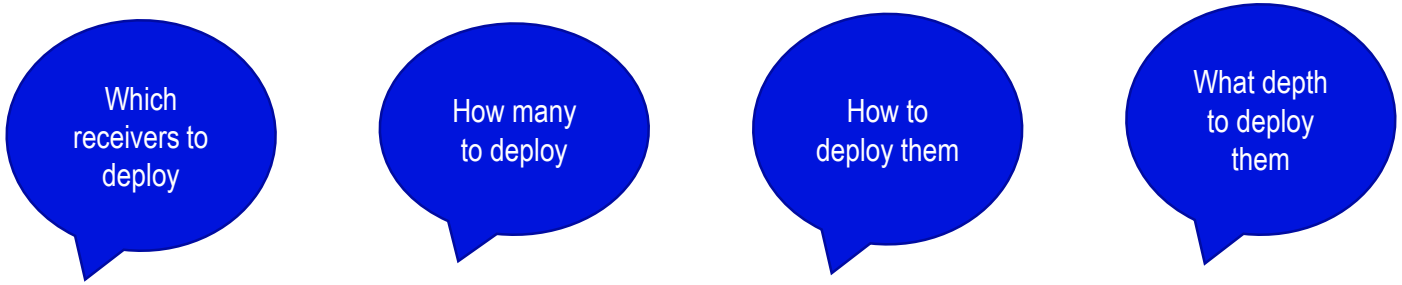




Microseismic Monitoring 101
Requirement for optimal hypocenter mapping

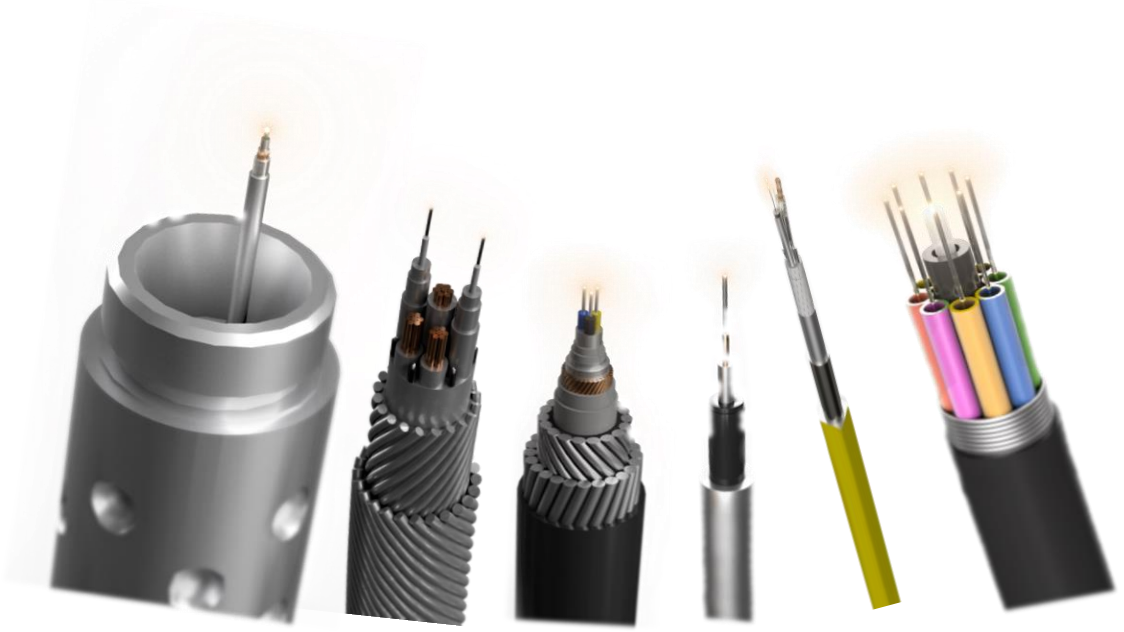
- Optimal placement of geophones
- Accurate wellbore surveys
- Sufficient energy at geophones to generate microseisms
- Accurate estimate of velocity and anisotropy
- Unbiased wideband 3-component sensor response
- Vector fidelity
- Optimal & stable Acoustic Coupling





Fiber Optic

Different types, deployment methods, purposes

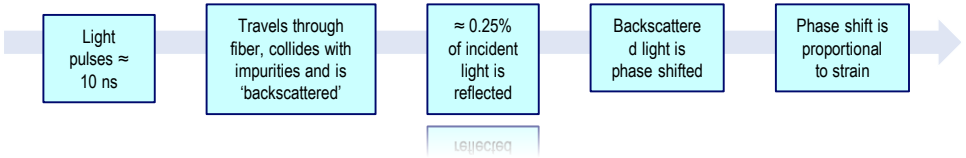


Temporary Deployment

Permanent Deployment

Fiber Optic
Relying on Sound Physics, Hardware and Processing

Sound Physics

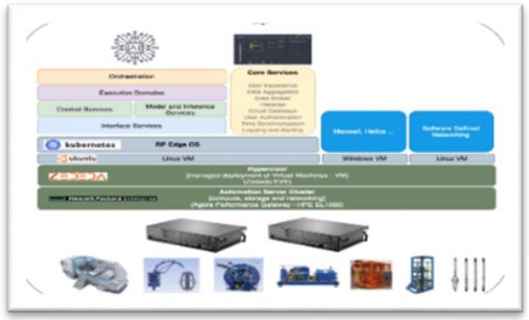


Hardware

Acquisition box

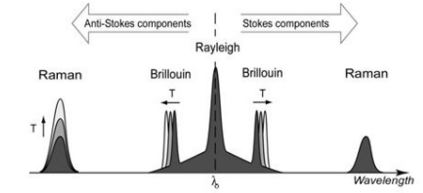
Cables

Digital



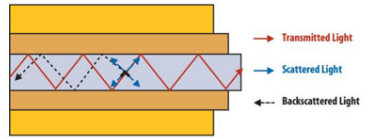
Interrogator	Principle	Measurement	Fiber Type	Sample Applications
DTS	Raman	Temperature	MMF	Flow Monitoring
DAS	Rayleigh	Acoustics (Dynamic Strain)	SMF (best), MMF	Borehole Seismic Flow Monitoring
DSTS	Brillouin	Static Strain & Temperature	SMF	Pipeline Integrity

DTS : Distributed Temperature Sensing
DSTS : Distributed Strain and Temperature Sensing
DTGS: Distributed Temperature Gradient Sensing
DAS: Distributed Acoustic Sensing
SMF: Single Mode Fiber
MMF: Multi Mode Fiber

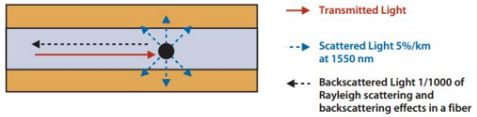


Spectrum of Backscattered Laser Light in SMF

MMF

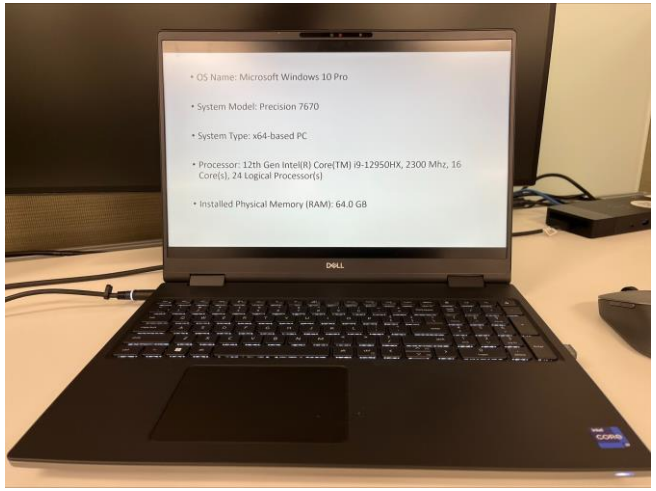


SMF

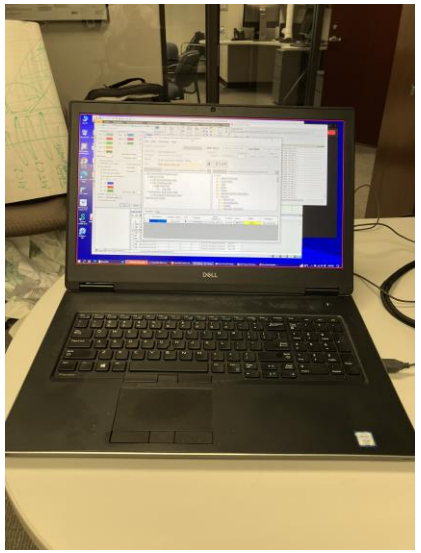


(Source: Reference Guide to Fiber Optic Testing by JDSU)

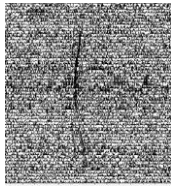
Background

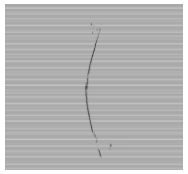


Acquisition Simulator



Any substitute for initial testing?



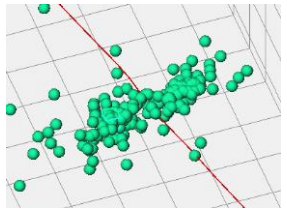


Real-time DAS Recording

Machine Learning Signature Detection

Detection

Event Location and Magnitude Estimation



Seismicity Catalog

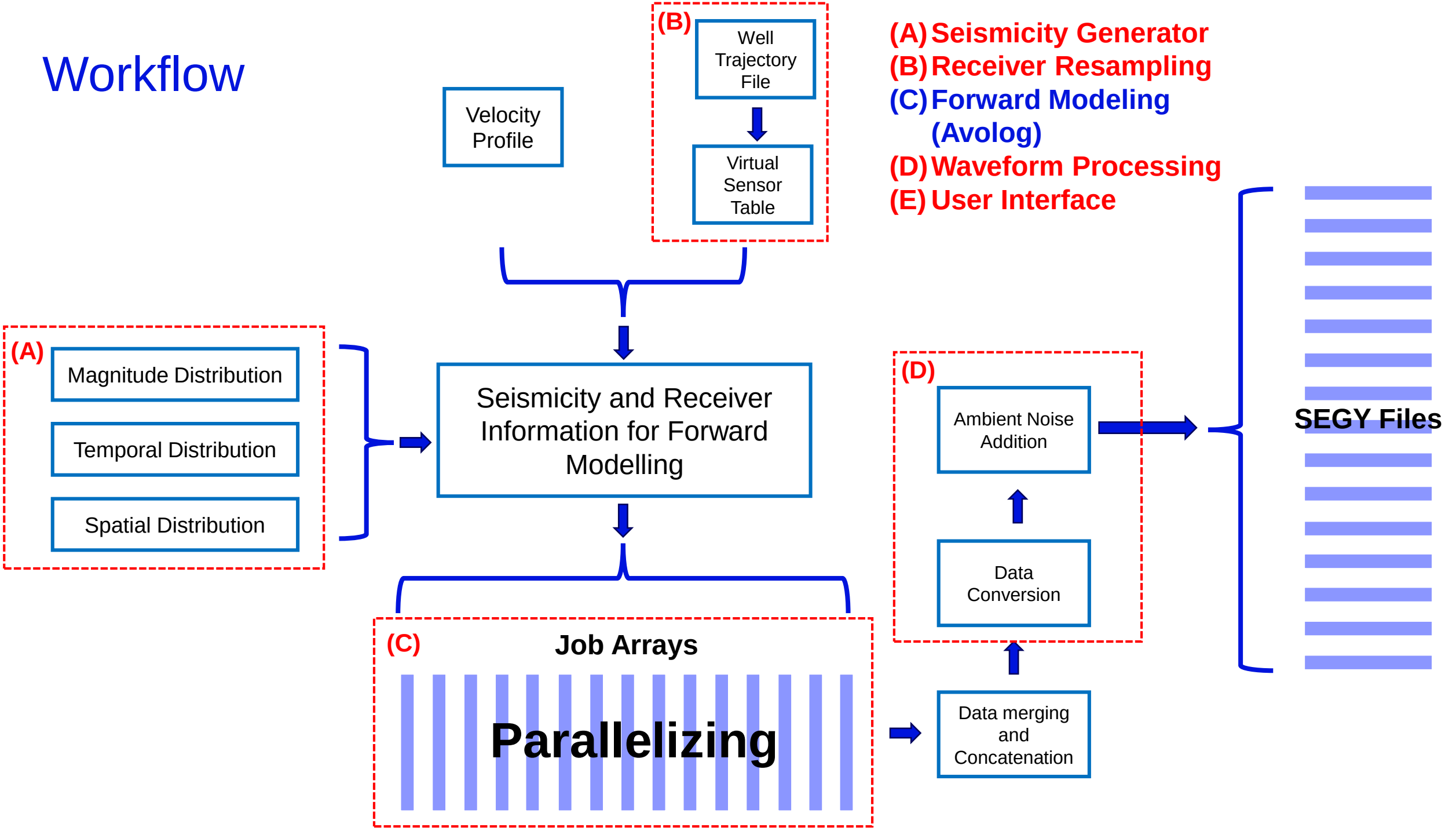
Challenges

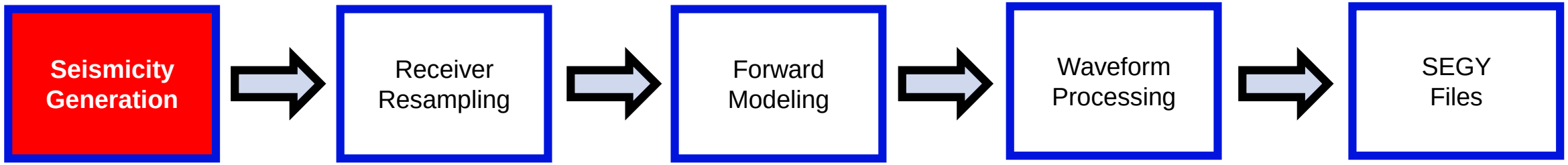
- **Seismicity simulation with a scientific rationale**
- **Earthquake waveform modeling and noise modeling**
- **Data format and metadata handling**
- **Capability of simulating data with different settings**
- **Robustness and speed of real-time simulation**

Potential Solutions

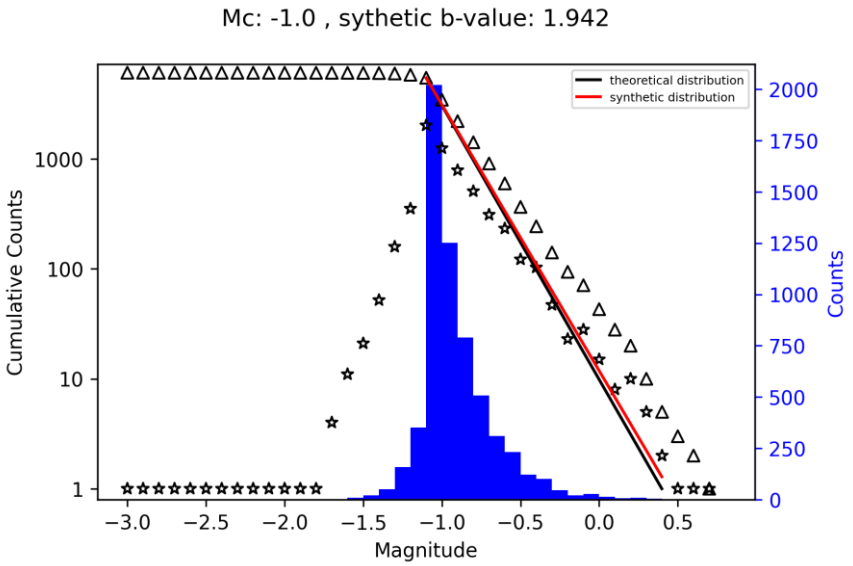
- **Empirical studies**
- **Synthetic generator and data modeling**
- **SEGY header handler**
- **Code generalization**
- **Parallelization and testing**

Workflow

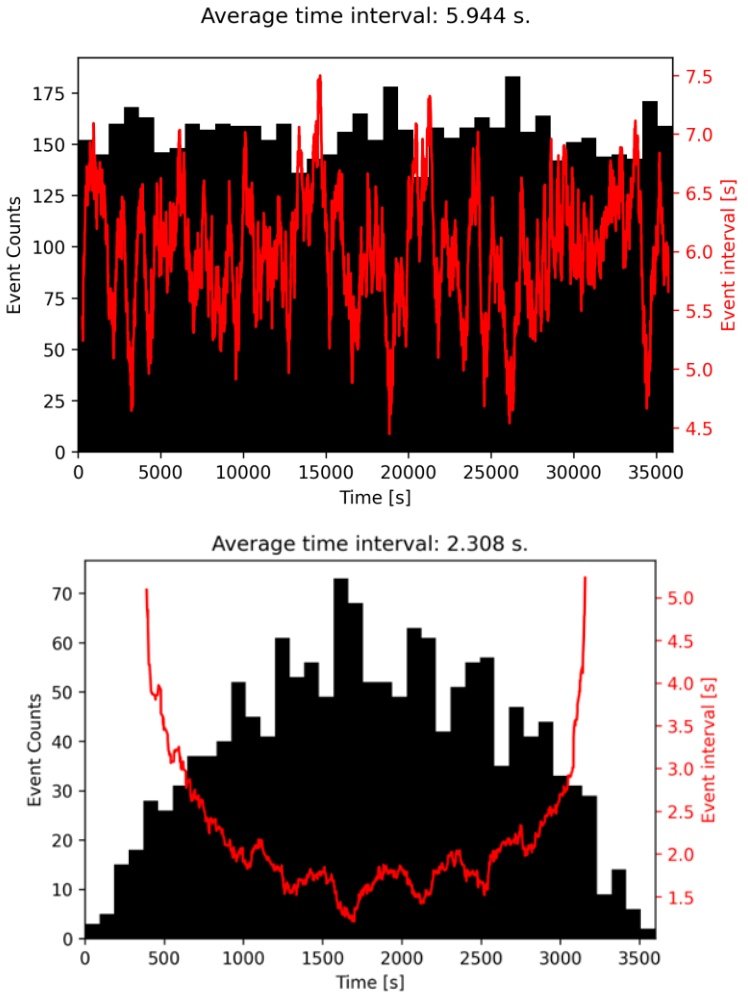

(A) Seismicity Generator
(B) Receiver Resampling
(C) Forward Modeling (Avolog)
(D) Waveform Processing
(E) User Interface
(B)
Well Trajectory File
Virtual Sensor Table
Velocity Profile
(A)
Magnitude Distribution
Temporal Distribution
Spatial Distribution
Seismicity and Receiver Information for Forward Modelling
(C)
Job Arrays
Parallelizing
(D)
Ambient Noise Addition
Data Conversion
Data merging and Concatenation
SEGY Files



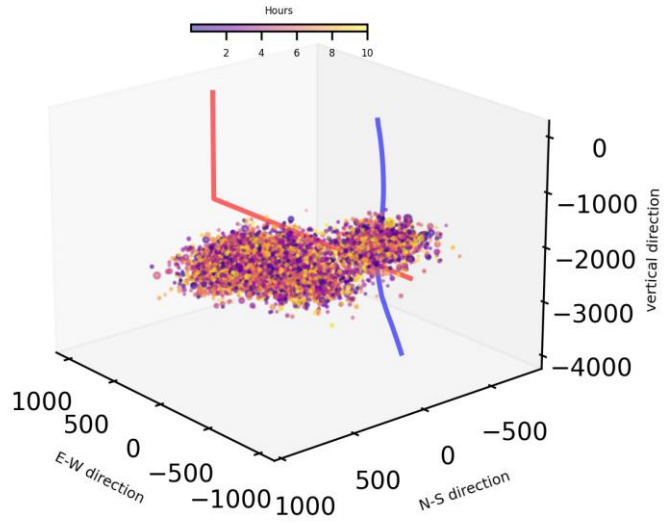
Magnitude distribution: GR-Law

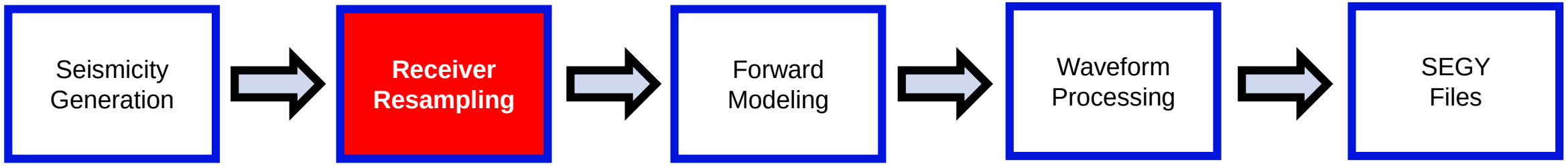


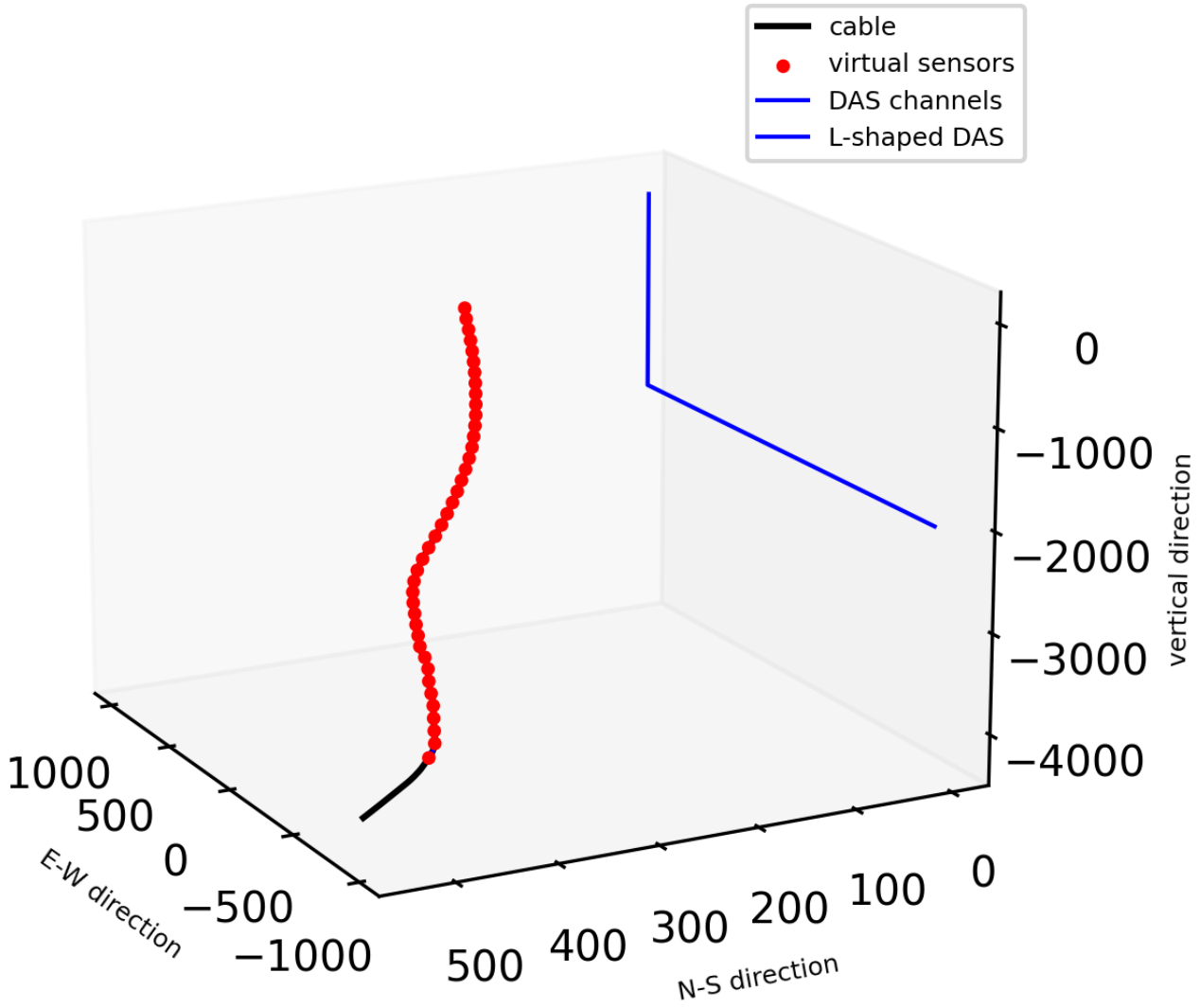
Temporal distribution: (Non)Homogeneous Poisson



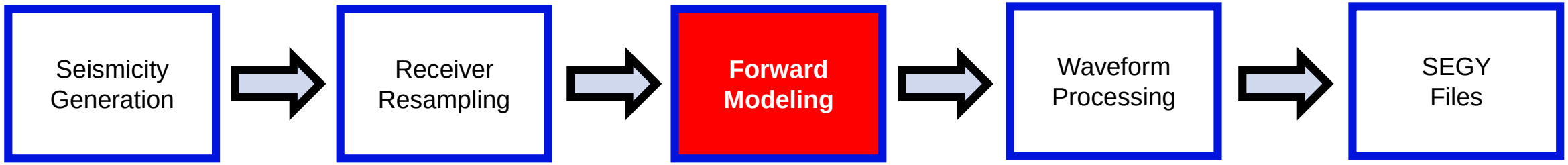
Spatial distribution: EQ clusters







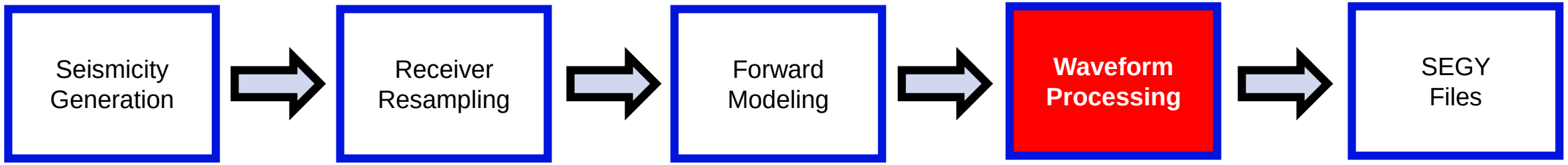
- Geophone receiver table (L-shaped well):
  - 2000 DAS channels
- Well trajectory file (smooth well path)
  - 2000 DAS channels
  - Constant spatial interval
  - Spatial integration and resampling



- Forward modeling with existing tool

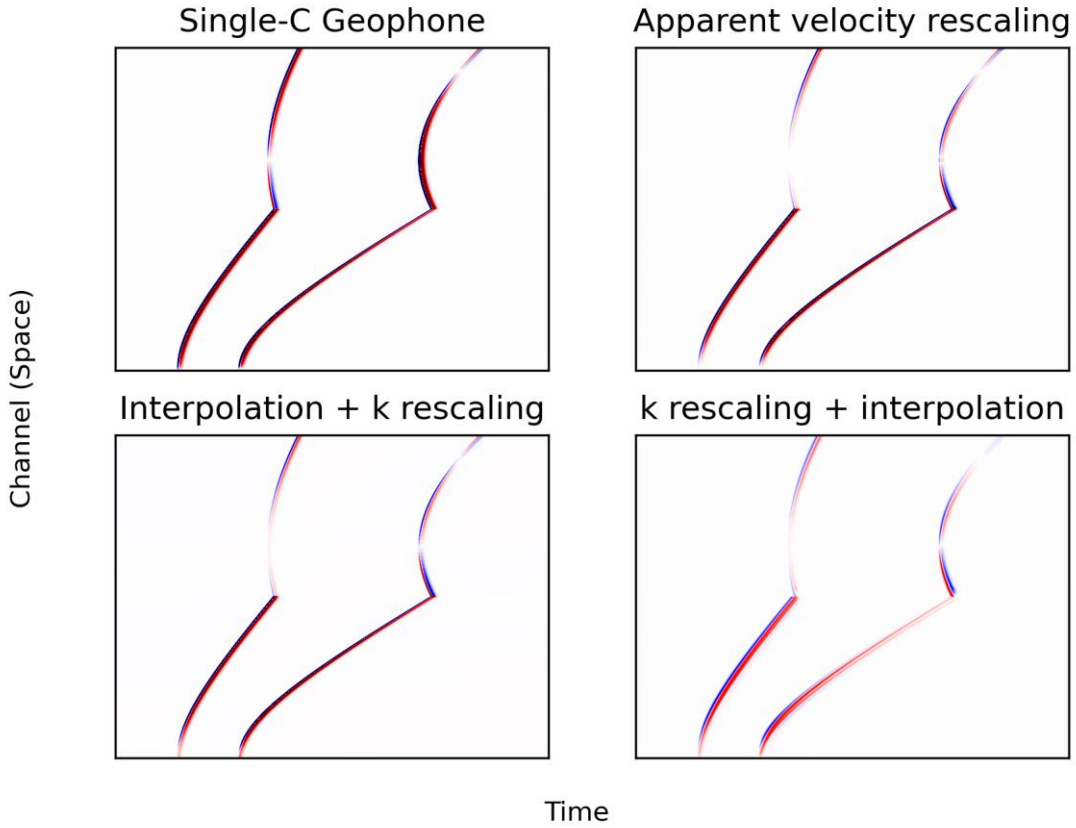
- To achieve real-time simulation scheme:
  - Parallelize waveform modeling with multiple standalone executables
  - Spatial downsampling
  - Interpolation
  - Calculating theoretical arrival time (with homogeneous model) and fine-shifting

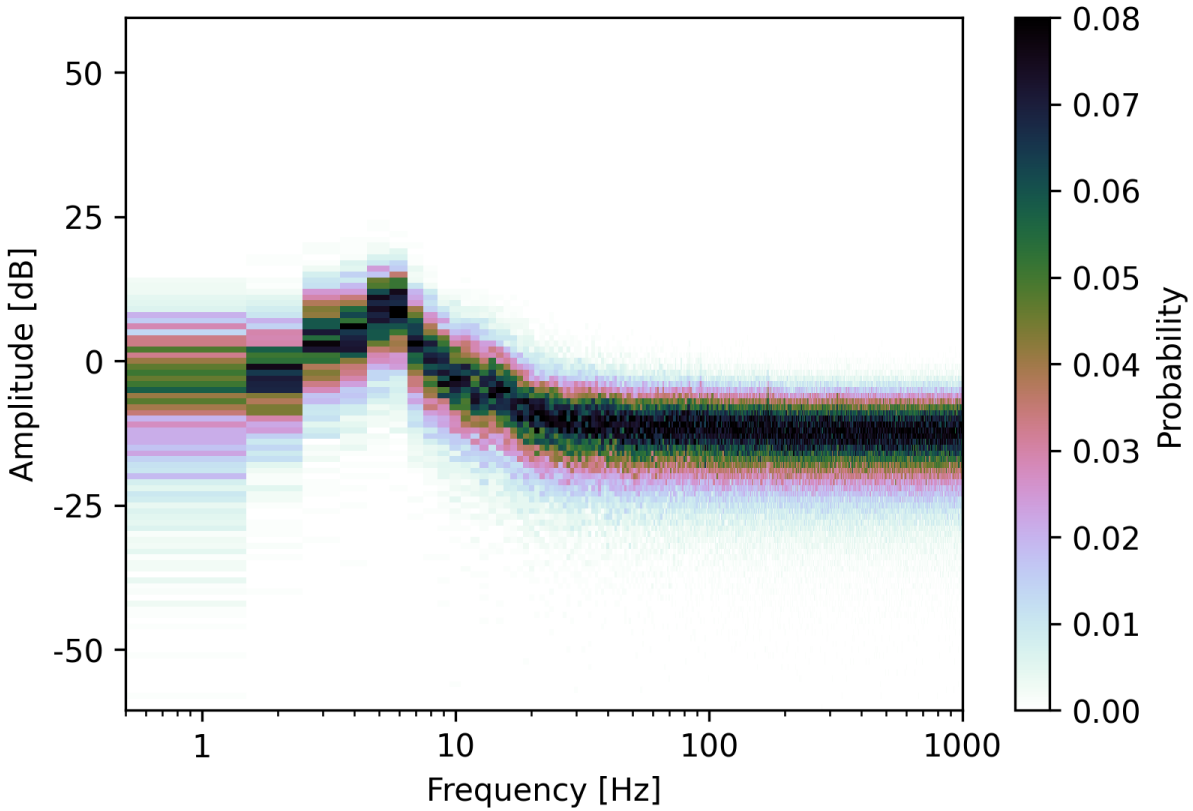
- Data concatenation

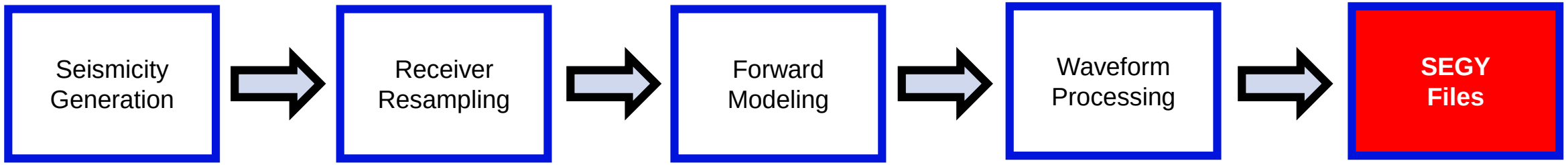


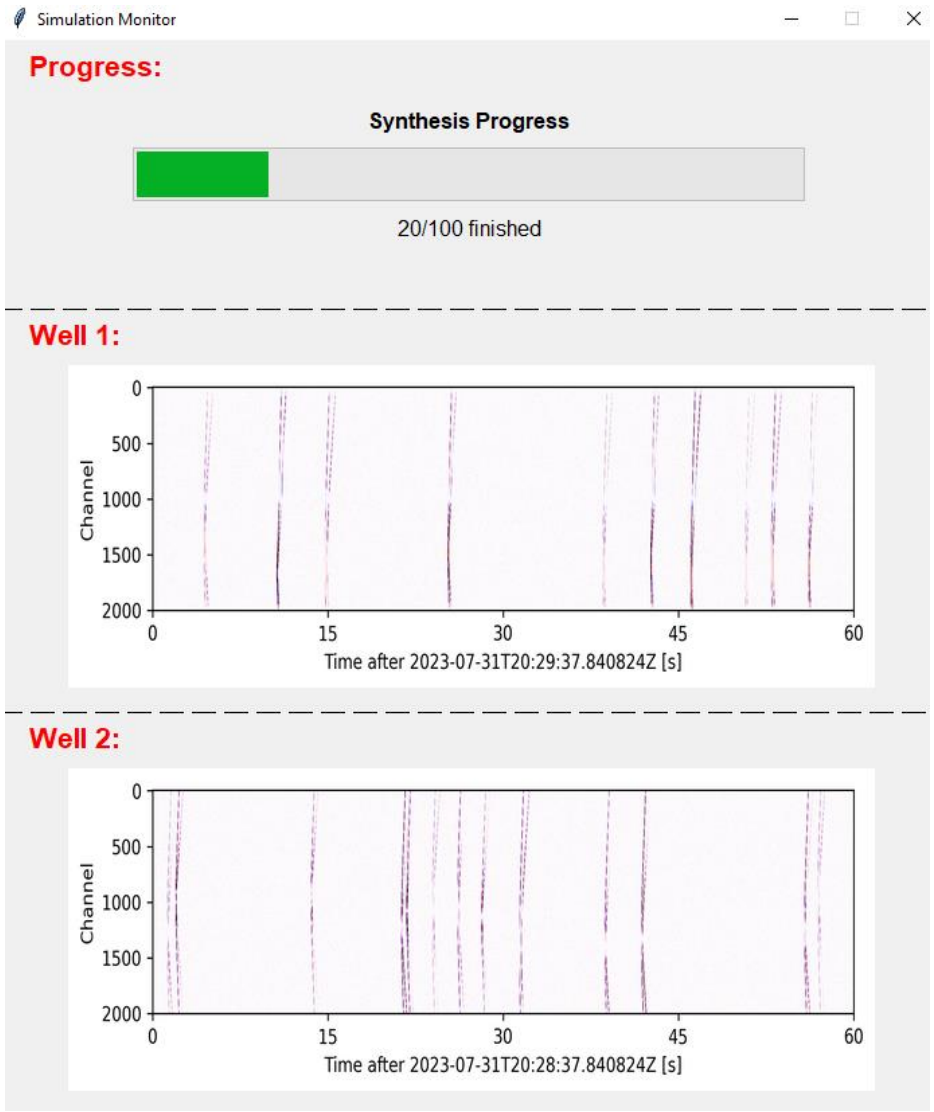
- Measurement conversion (From velocity /displacement to strain):
  - Apparent velocity rescaling
  - Wavenumber rescaling / …

- Ambient noise:
  - White noise
  - Modeled noise from borehole data
  - Noise level





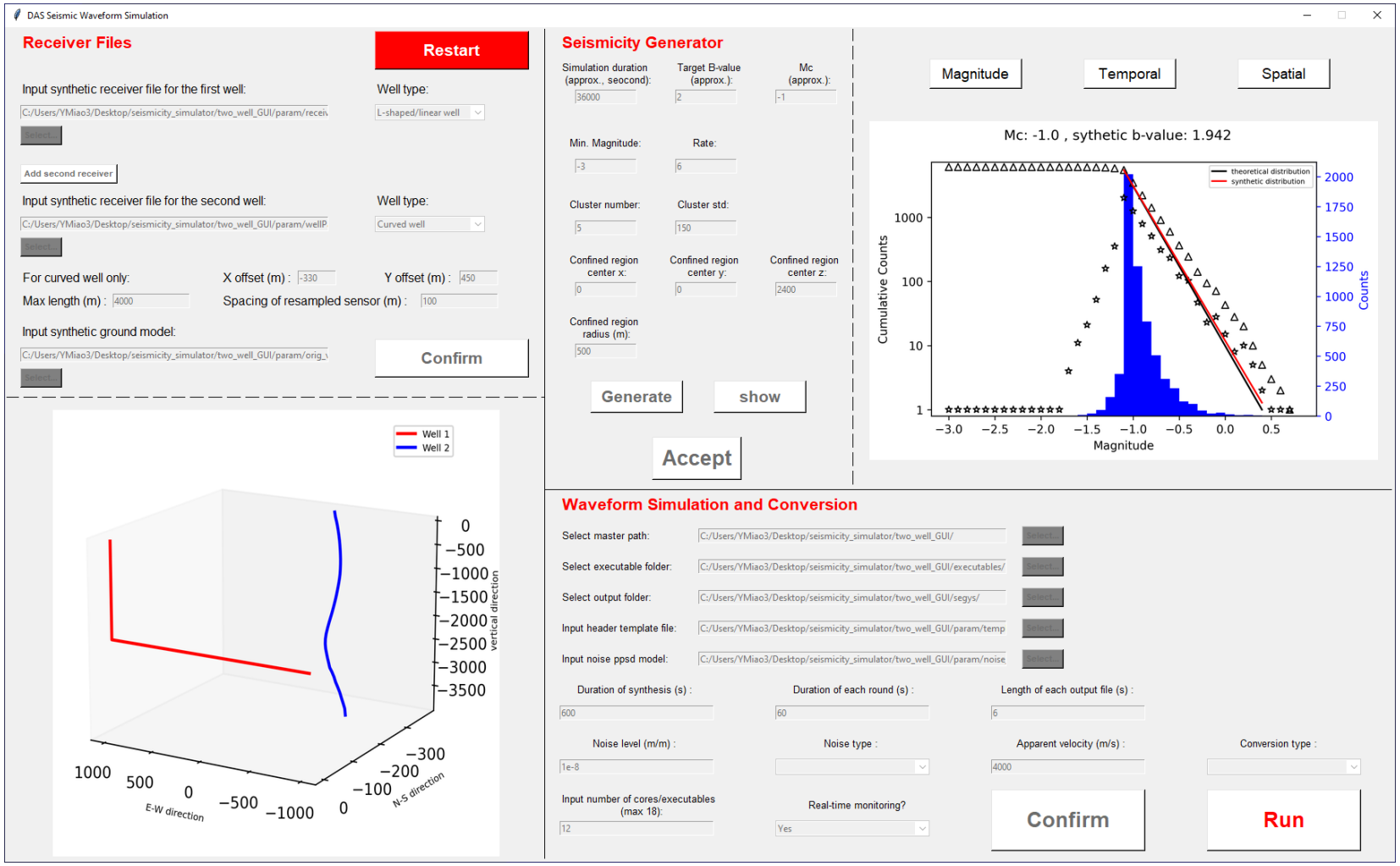




- Data output:
  - One-minute batch to optimize memo/CPU usage
  - 6-second files to adapt RTISA
  - Metadata internal handling
  - Progress monitoring and data visualization

Well number	Duration	Seismicity Rate (per minute)	Computation Time	Data Volume
1	1 min	12	24 second	1.35 GB
2	1 min	12	35 second	2.71 GB
2	1 min	20	~ 1 min	2.71 GB
2	1 day	12	~ 13 hour	3.81 TB

Real-time seismic data synthetis on virtual DAS array

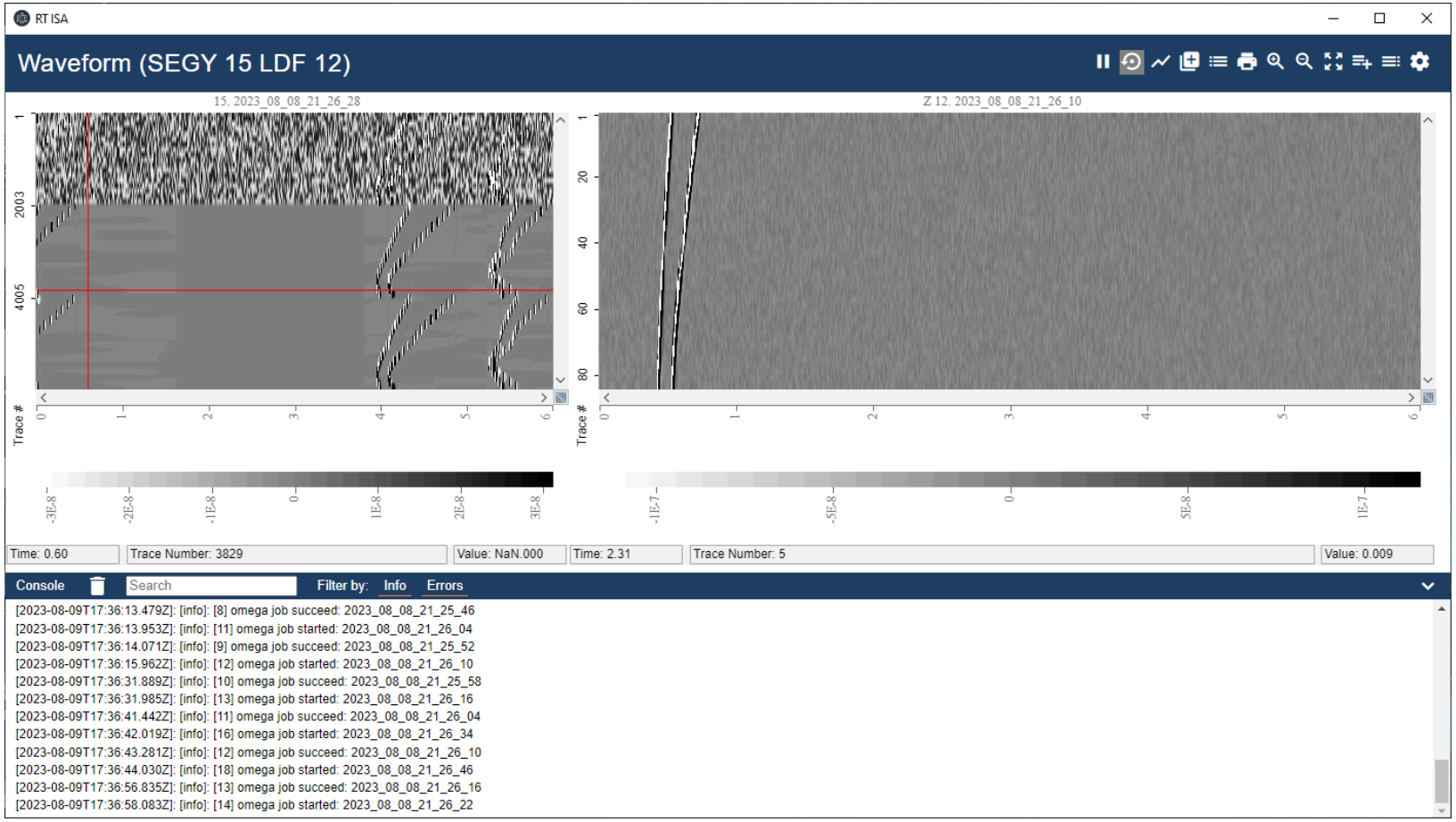


Real-time scheme

- To achieve real-time simulation scheme, it is not practical to simulate all channels:
  - Parallelize waveform modeling for each earthquake
  - Only sample tens of virtual sensors, the interpolation
  - Calculate theoretical arrival time then fine-shifting

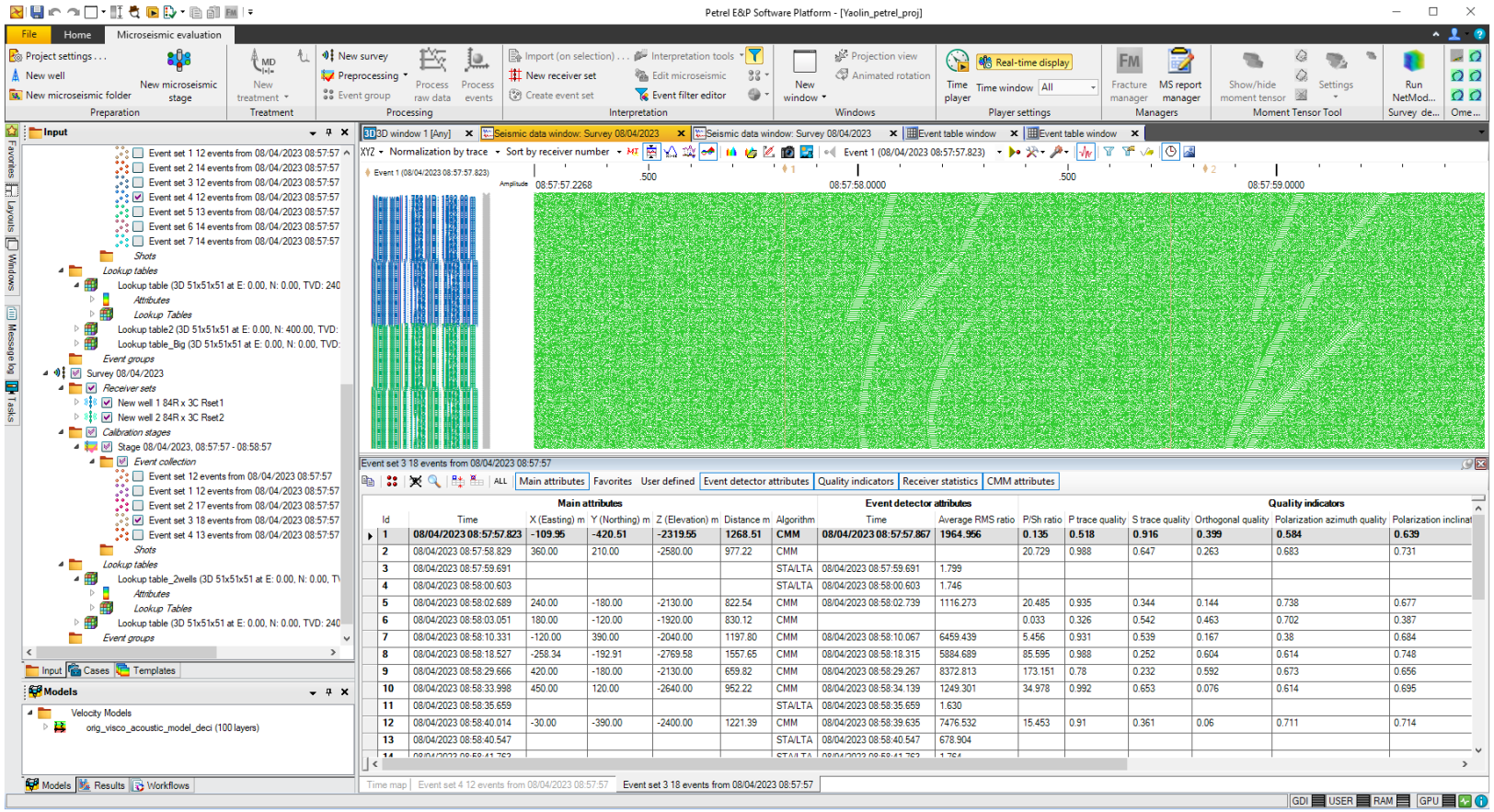
- Data is output every minute, and chunked into 6-second files:
  - Concatenate data of all earthquakes within one minute
  - Figures updating

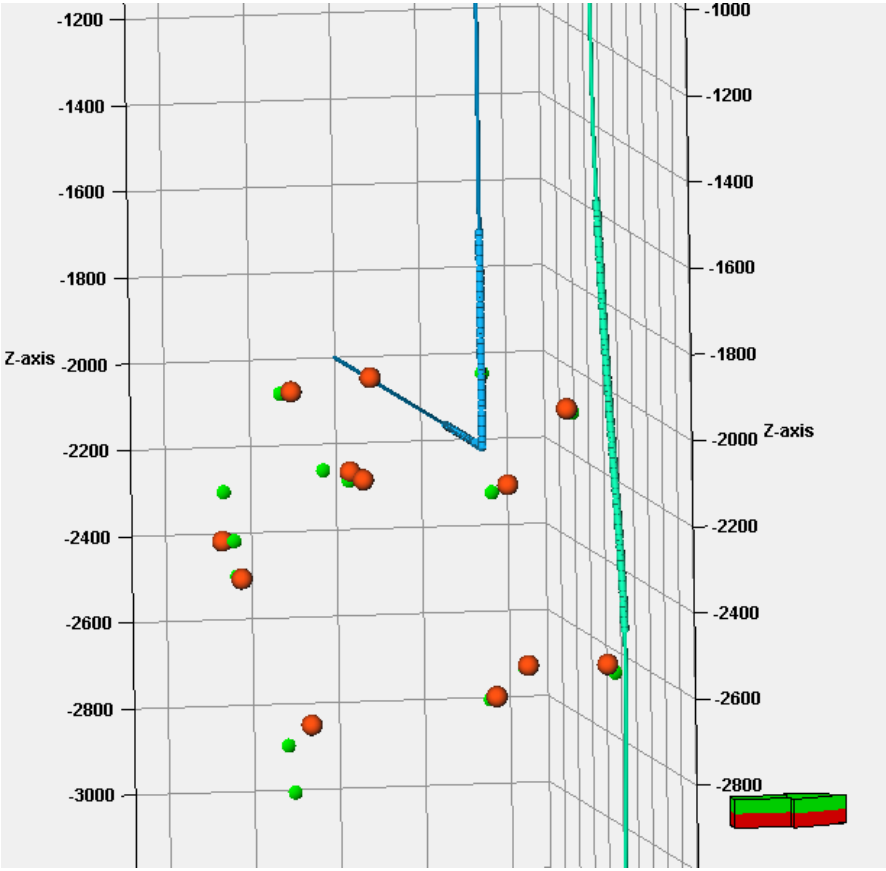
Testing with RT-ISA



Testing with Petrel

Green: True Location
Red: Petrel location

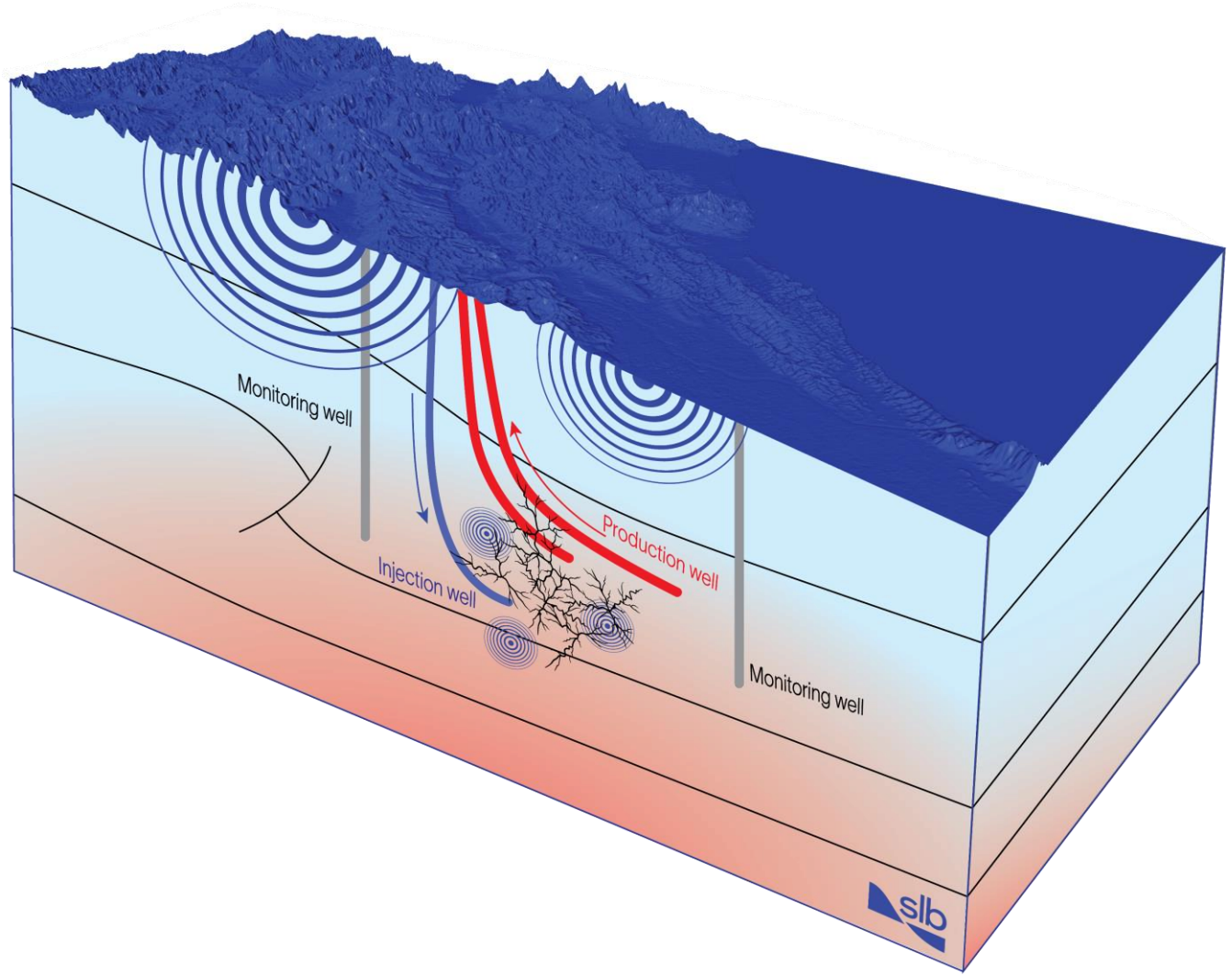




Conclusions

- In this project, we implement a workflow for real-time seismic data synthesis on virtual DAS arrays, which is used to perform initial testing on the fluid injection monitoring platform
- This workflow focusing on generating synthetic seismicity and taking the use of existing forward Modeler to simulate waveforms of synthetic earthquakes
- It has been tested to simulate two days of data within 25 hours with no issue
- It has been tested with RT-ISA and Petrel for event location
- Future plans:
  - Testing the robustness of the workflow
  - Simulate data for longer duration
  - Limitations…

Thank you


Monitoring well
Injection well
Production well
Monitoring well
slb