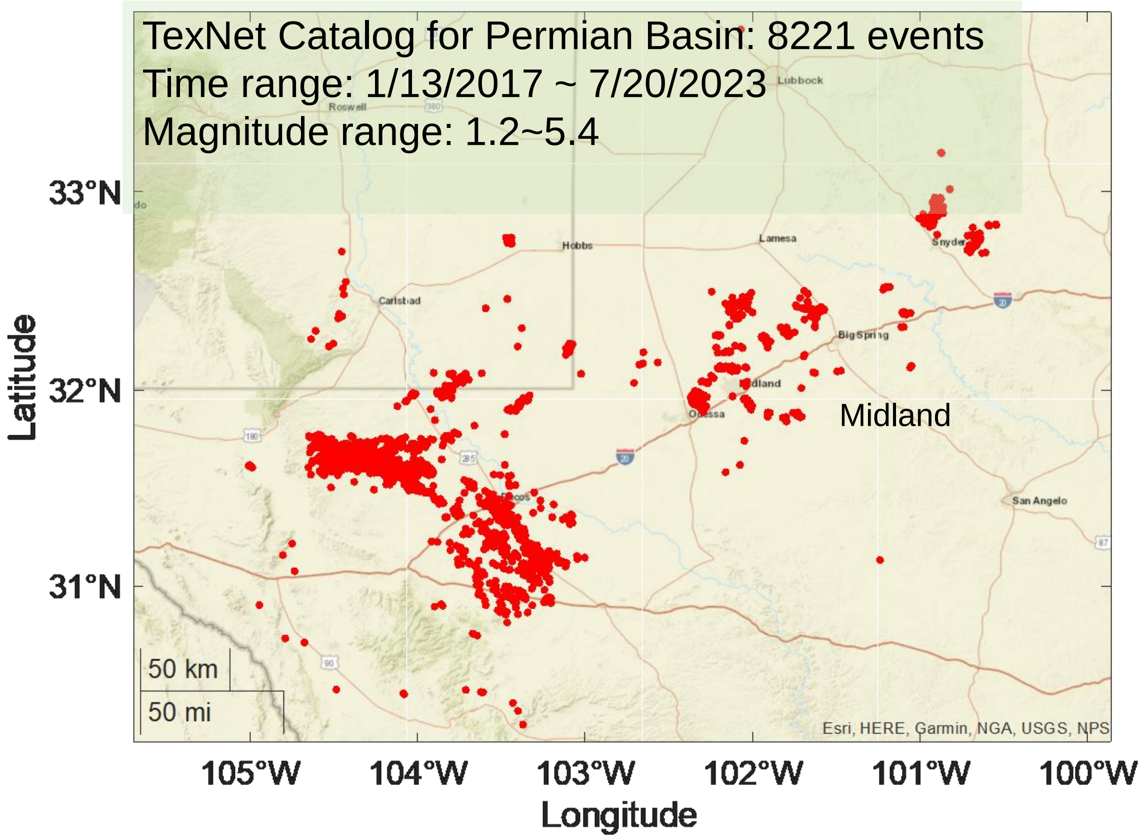
Induced Seismicity in Howard County IV:

Numerical Investigation of Wave Propagation in a Complex Layered Sedimentary Basin Velocity Field and the Impact on Travel Paths and Event Locations

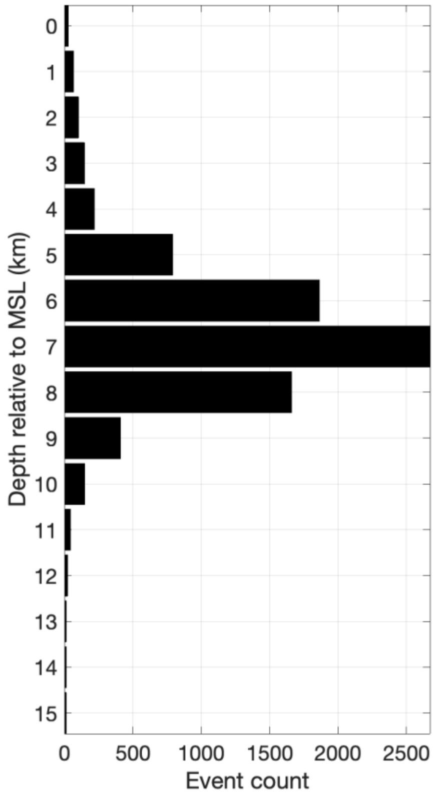
Xinding Fang, Tianrun Chen, Siwei Li, Nick Brooks, George Knapo - SensorEra Inc
Alan R. Huffman - HighPeak Energy
Tony Lupo - SM Energy
Rachel Storniolo - Birch Resources

International Meeting for Applied Geoscience & Energy

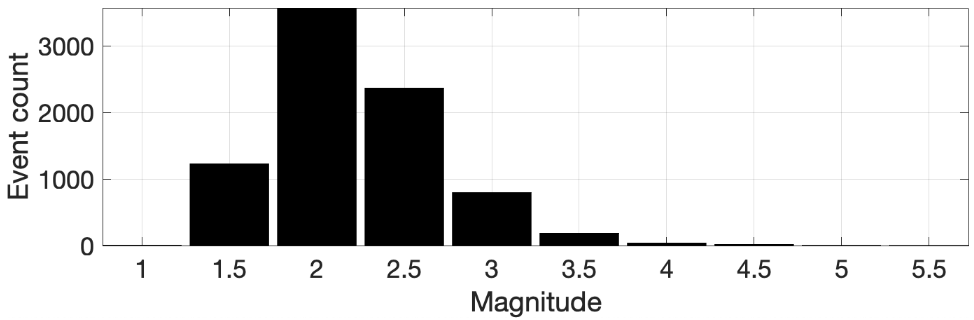
Motivation – frequent reports of events much deeper than known injection depth of disposal fluids



Event depth



Event magnitude distribution



~46% of events' depths are deeper than 7km.

Can fluid injection at shallow layers really generate so many deep events or any other explanation?

Can the estimated event depths be biased by velocity model or station locations used in the inversion?

SEG | AAPG image

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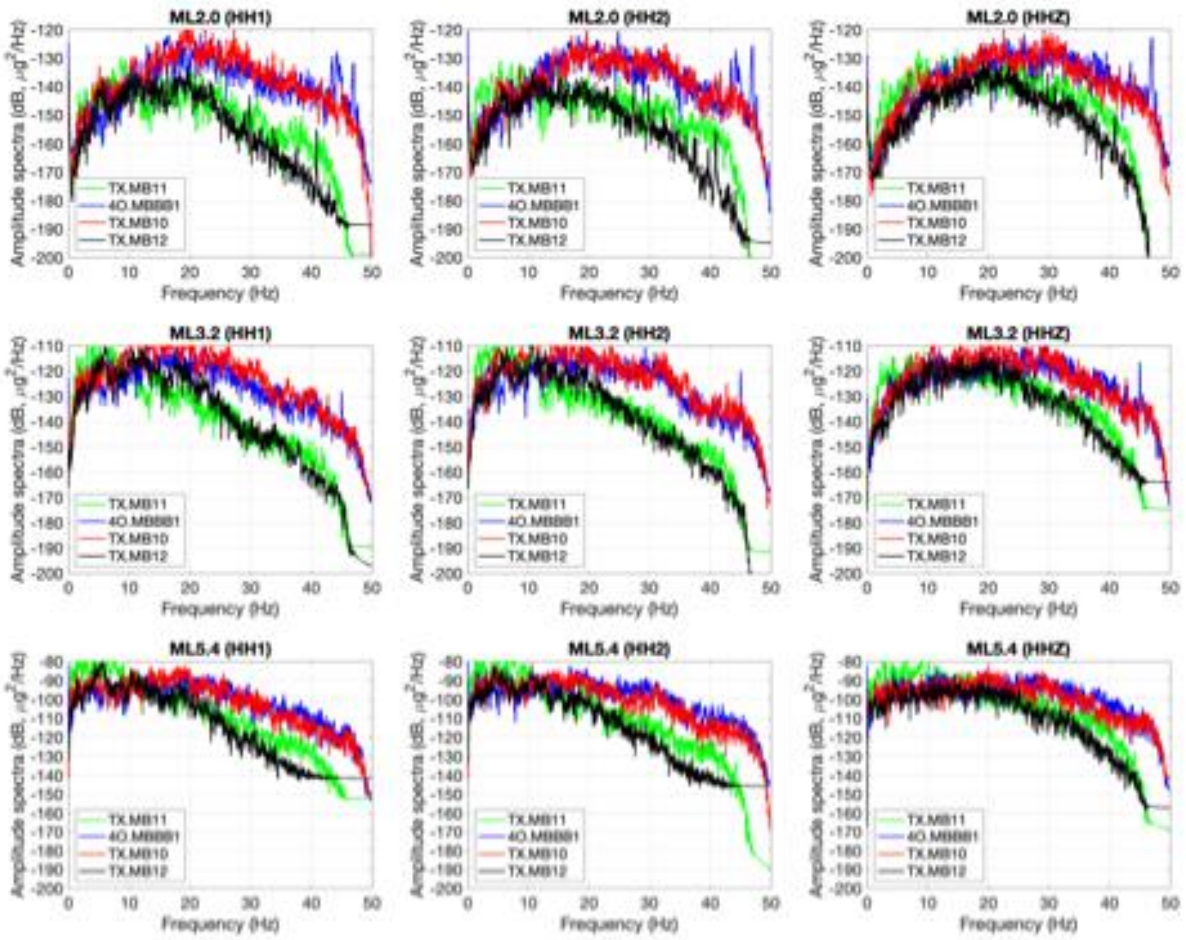
Motivation – improve our understanding of induced seismic data

- **Dominant frequency bandwidth: ~10s Hz**

This is similar to the frequency of conventional exploration seismology, implying that the propagation of induced seismic waves can be strongly influenced by basin's shallow sedimentary structure.

- **Recording distance: ~ 10s km**

This is much larger than the acquisition offset in conventional surface seismic exploration. The long recording distance affects the travel time and amplitude of seismic waves, alters their sensitivity to the earth's structures, and leaves a strong free surface footprint on seismic data.



Frequency spectra of the data for 3 induced events (ML2.0, ML3.2, ML5.4) recorded at 4 different stations at distances varying from about 15km to 50km.

Outline

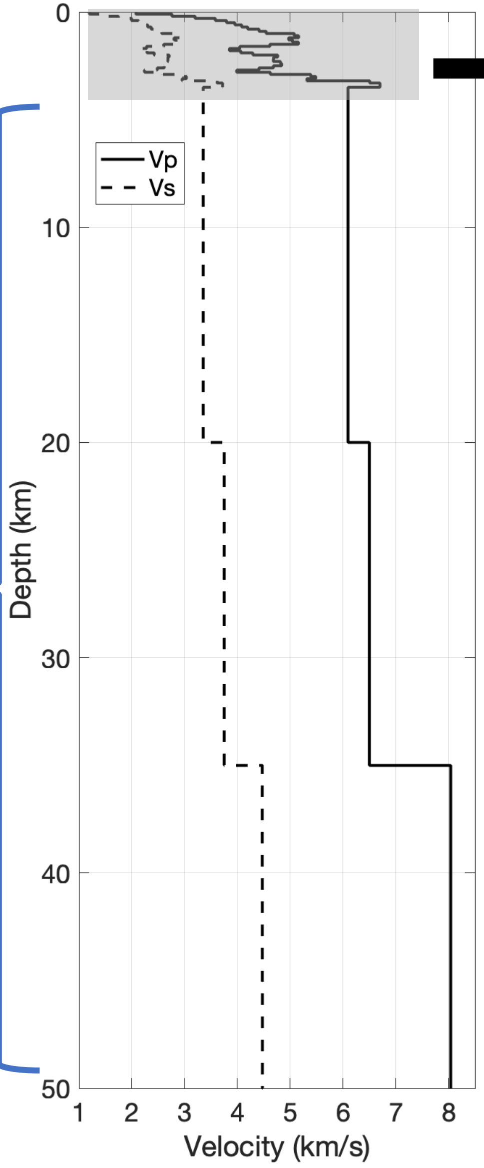
- **Numerical modeling to understand**
  - Complex wave propagation in Permian Howard County area
  - Influence of station-to-event distance on event depth inversion
  - Investigation of hypocenter inversion using the IASP91 model

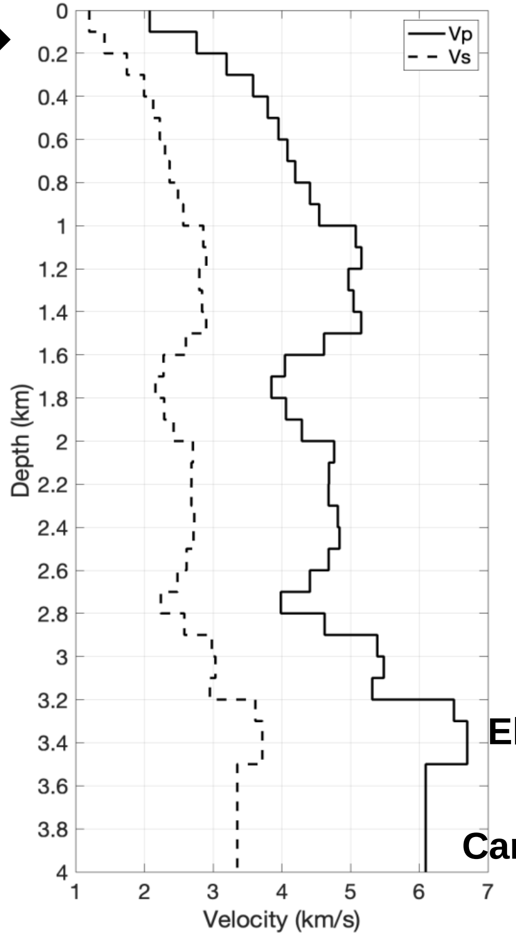
- **Summary of learning & findings**

Numerical modeling - model setup

Our numerical modeling is conducted based on a local 1D velocity model: **Howard County 1D model** (**HC1D**), which is extracted from a high resolution 3D velocity model generated by HighPeak Energy

The basement layer extends to 20km and then switches to the IASP91 model.



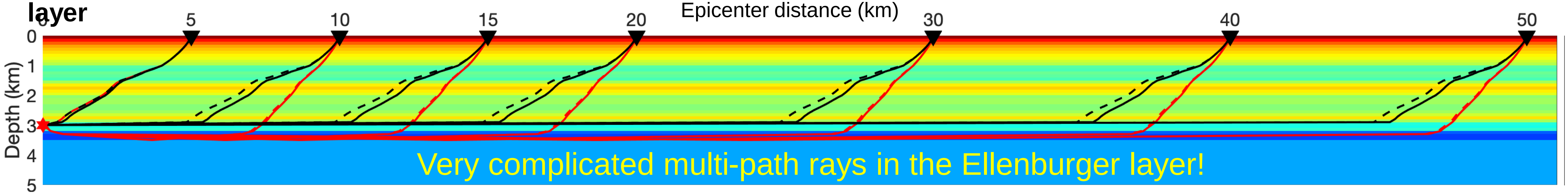


<u>Full-wave simulations</u>:
A generalized reflection and transmission coefficient method (Fang & Tang, 2021) is used to generate full-wave synthetic waveforms produced by a double-couple source in a 3D layered model with free surface boundary condition.

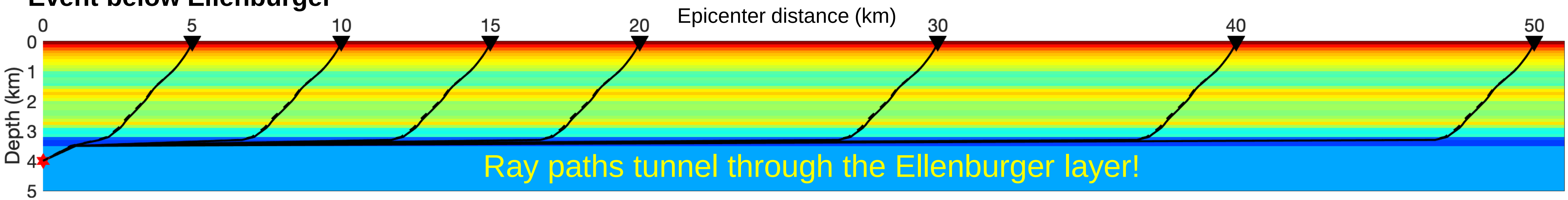
<u>Source mechanism</u>:
Strike-slip double-couple source with 10Hz Ricker wavelet.

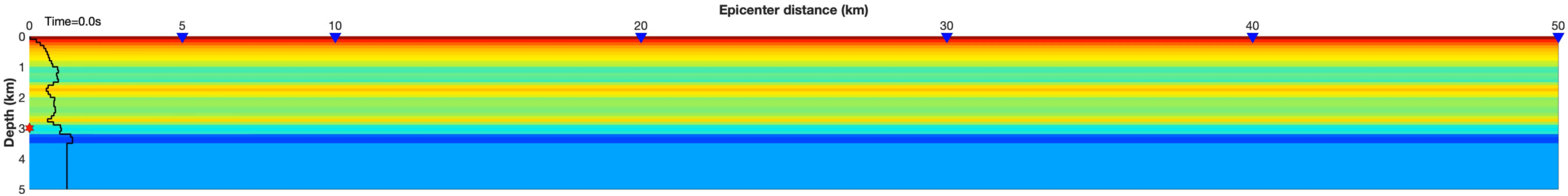
Numerical modeling – raytracing & full-wave modeling

Event above Ellenburger layer

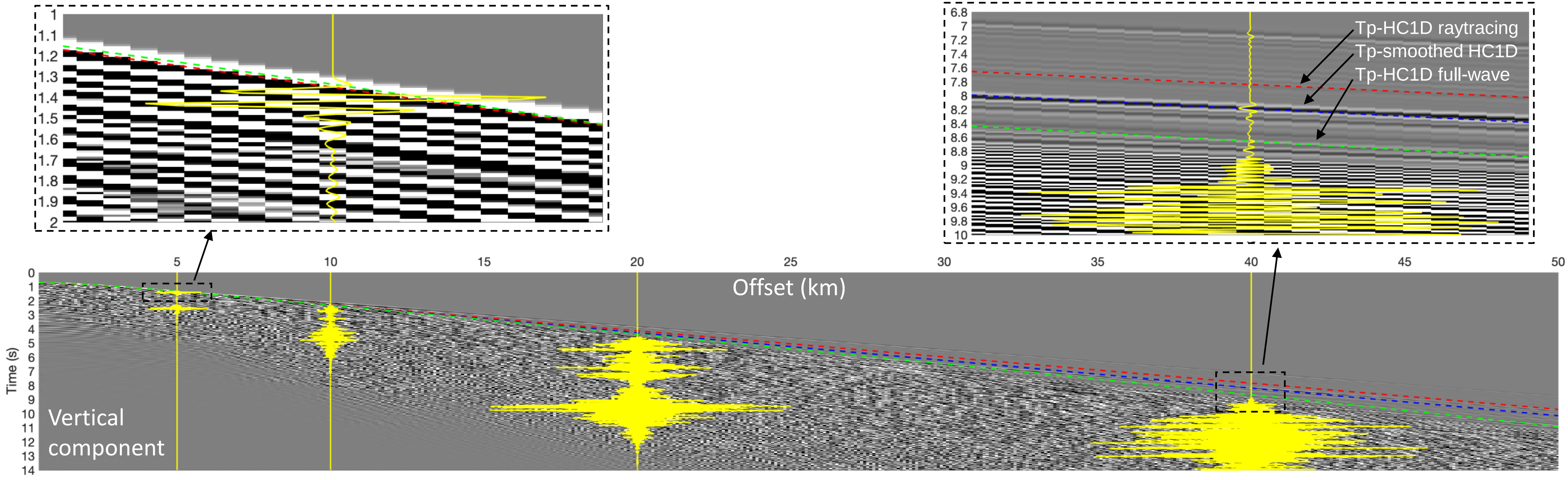


Event below Ellenburger



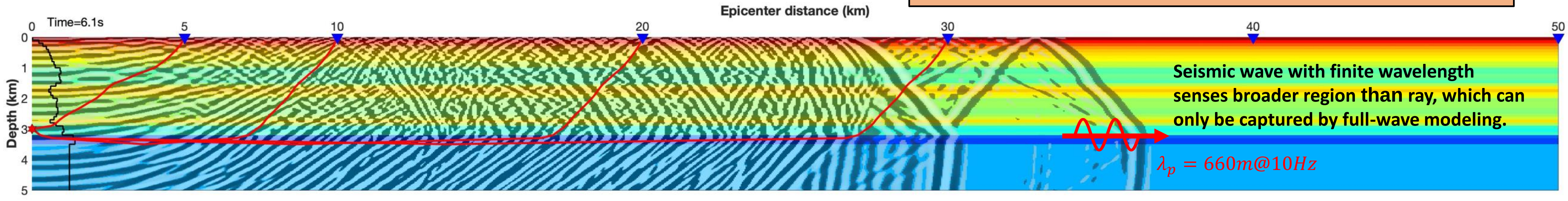


Numerical modeling – first arrivals at near and far stations



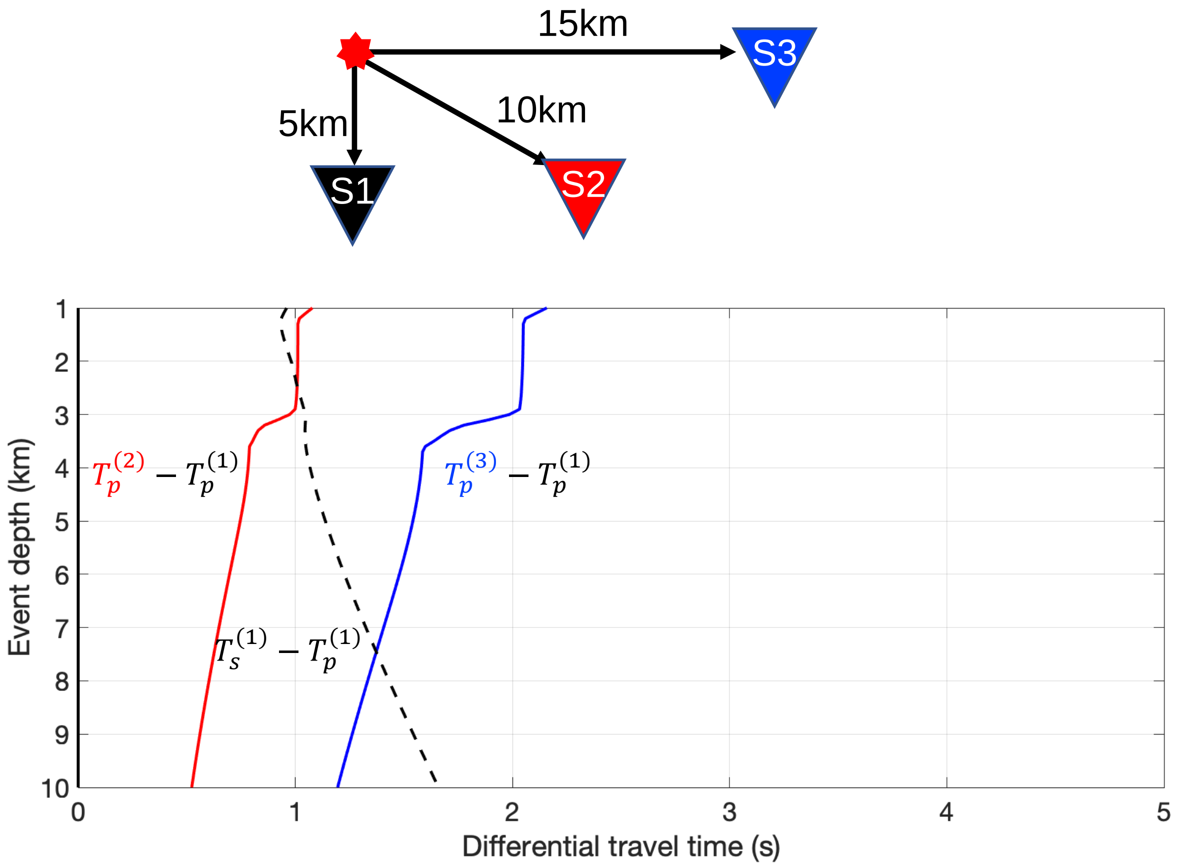
Direct P and S-waves are clear at near offsets and easy to pick.
No ambiguity!

- Both P and S first breaks are weak at 20km and 40km offsets
- Dispersive waveforms make it difficult to pick P and S first break
- Raytraced Tp & Ts are inconsistent with full-wave waveforms



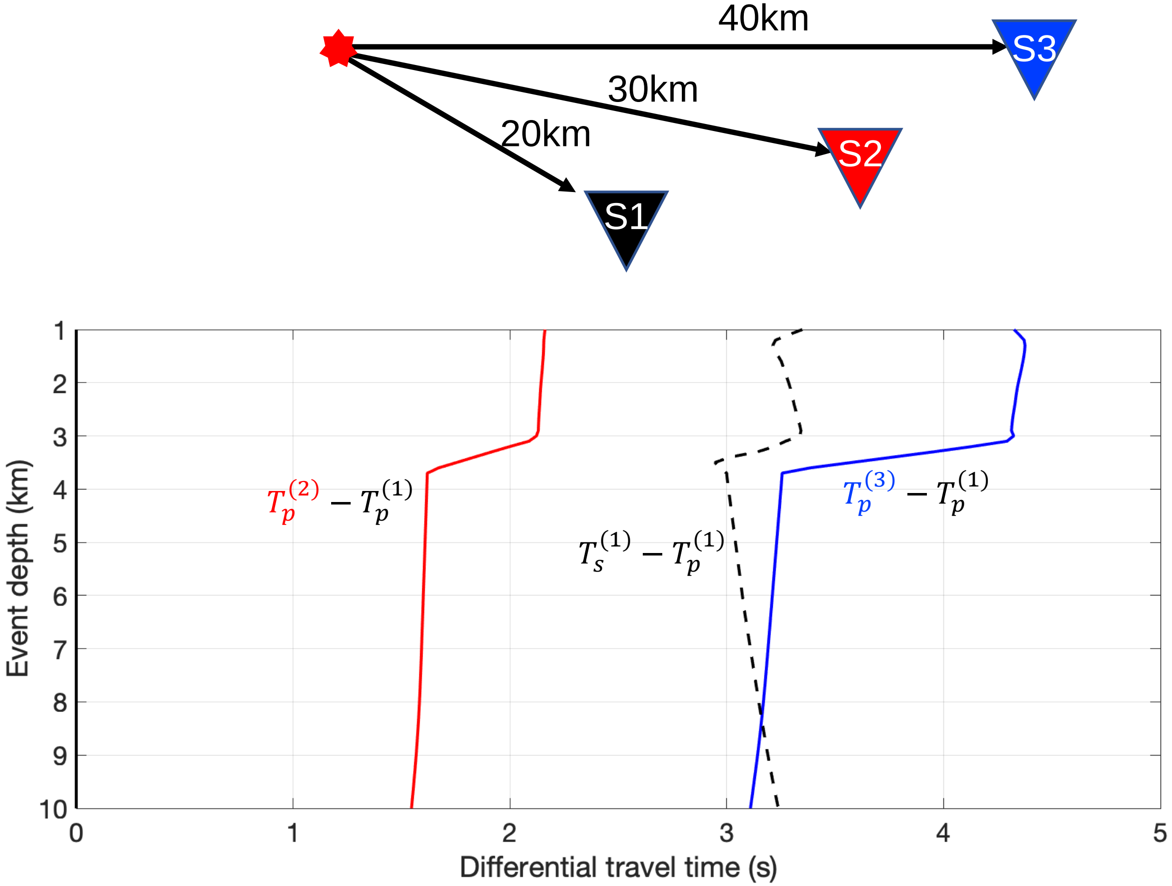
Far stations do not have much depth sensitivity from P-wave travel time

Near stations



Both P- and S- first arrivals at near stations have good sensitivity on event depth

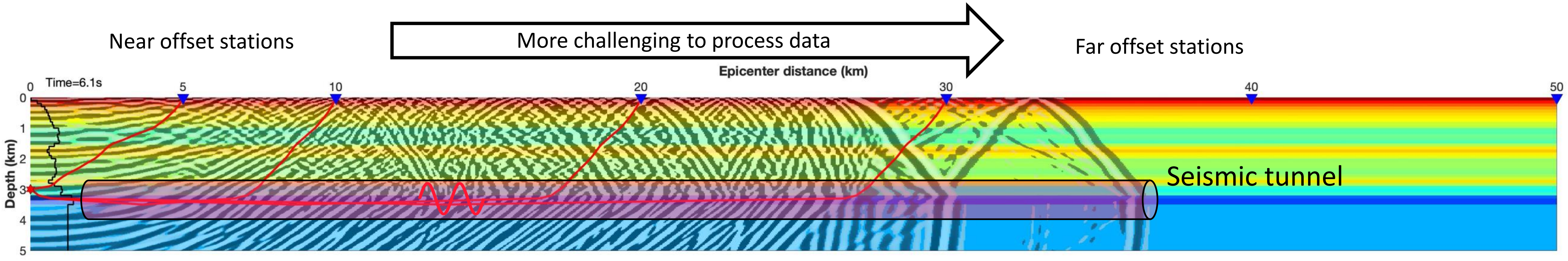
Far stations



Sensitivity of both P &S arrivals at far stations drop. Picking of P & S first break at far stations have large ambiguity.

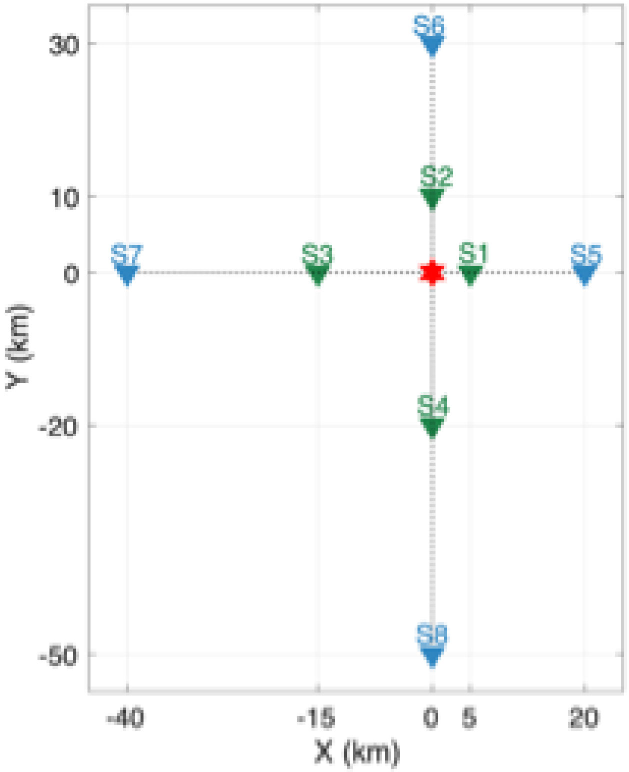
Near versus far stations

	Near stations	Far stations
P and S first arrivals' amplitude	Strong and clear	Weak
P and S first arrivals' picking	Easy and straightforward	Difficult and large picking ambiguity (particularly on S first arrivals)
Depth inversion sensitivity	High on P and S first arrivals	Low on both P and S first arrivals.
Timetable building for inversion	Raytracing works well	Raytracing may fail due to multi-pathing and finite wavelength effect. Picking from synthetic waveforms is required.

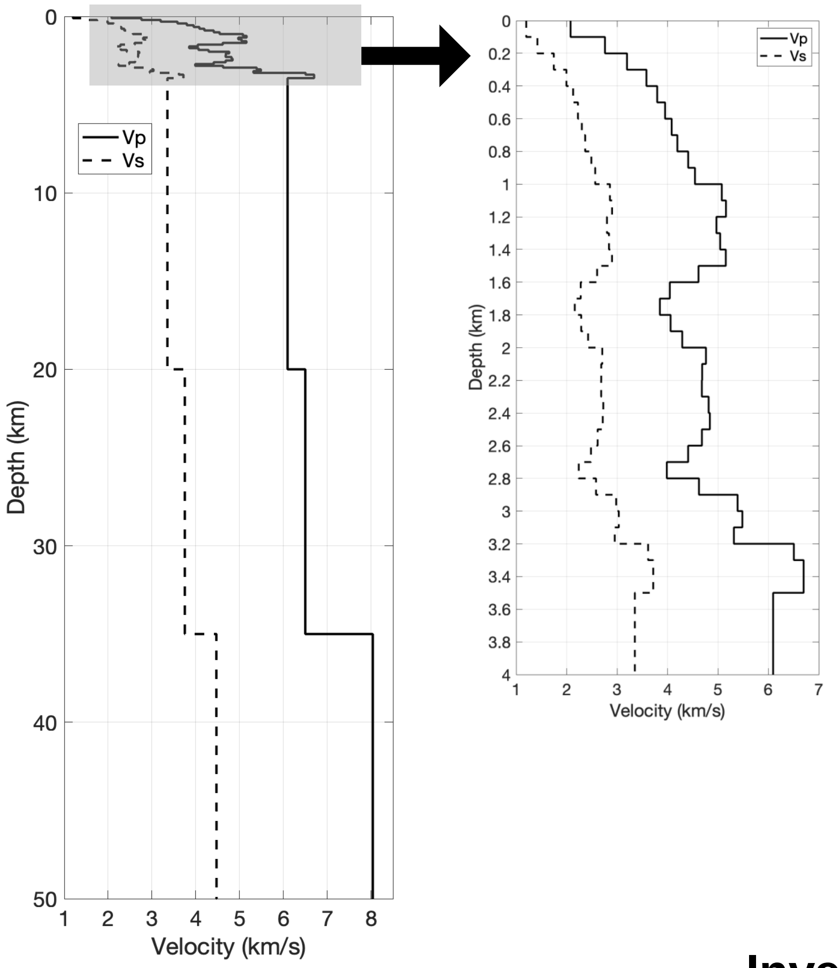


Investigation of hypocenter inversion using the IASP91 model

Acquisition geometry

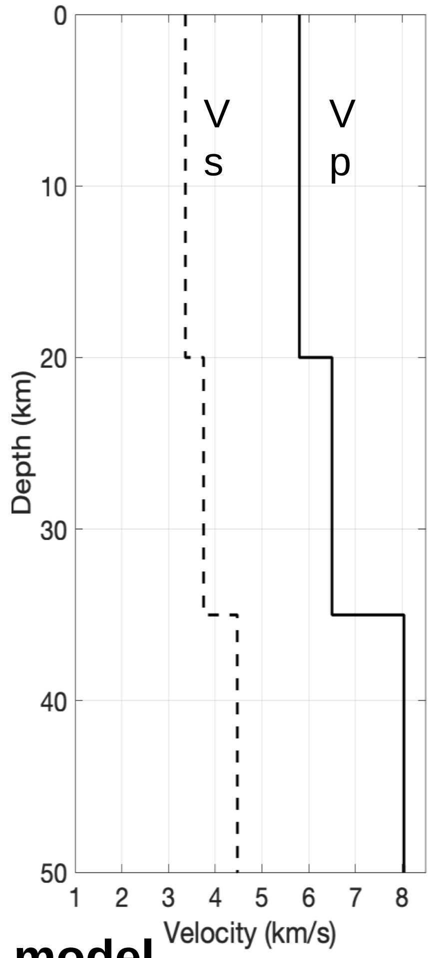


Howard County 1D (HC1D) model
A local velocity model



True model

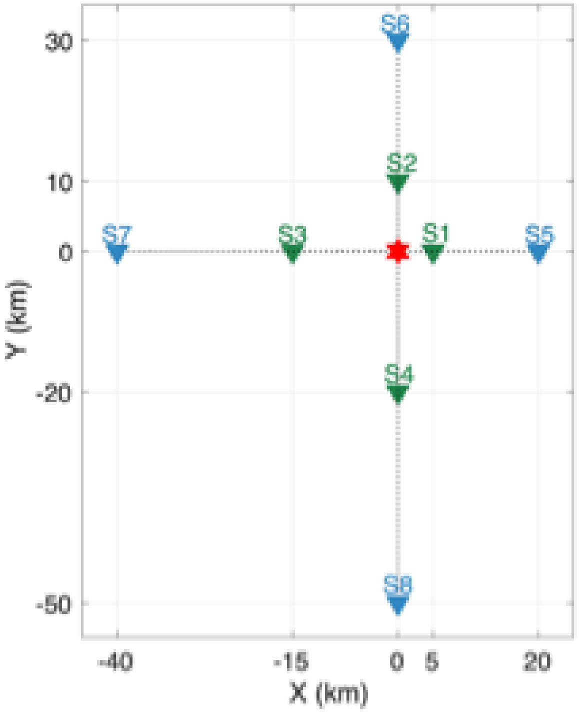
IASP91 model
A global model



Inversion model

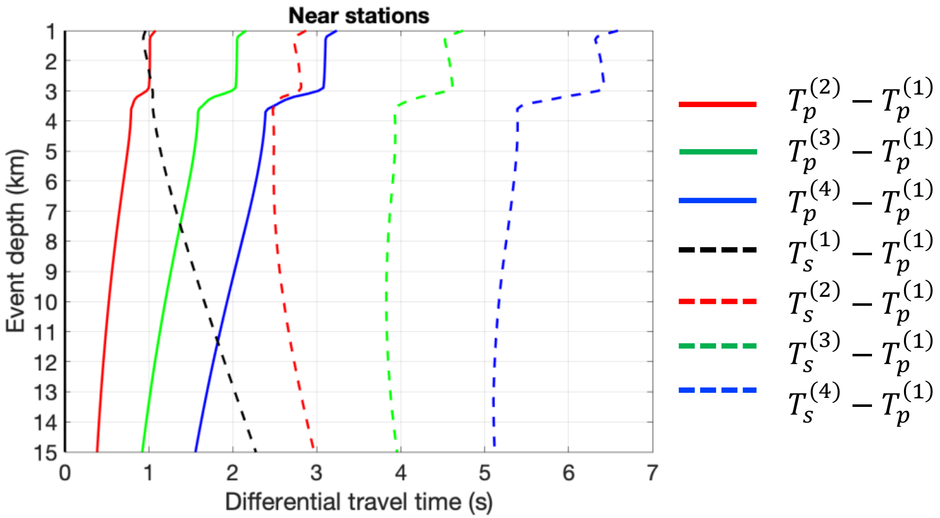
- Observed data: first breaks derived from the full-wave modeling results of the HC1D model
- Inversion model: IASP91 model

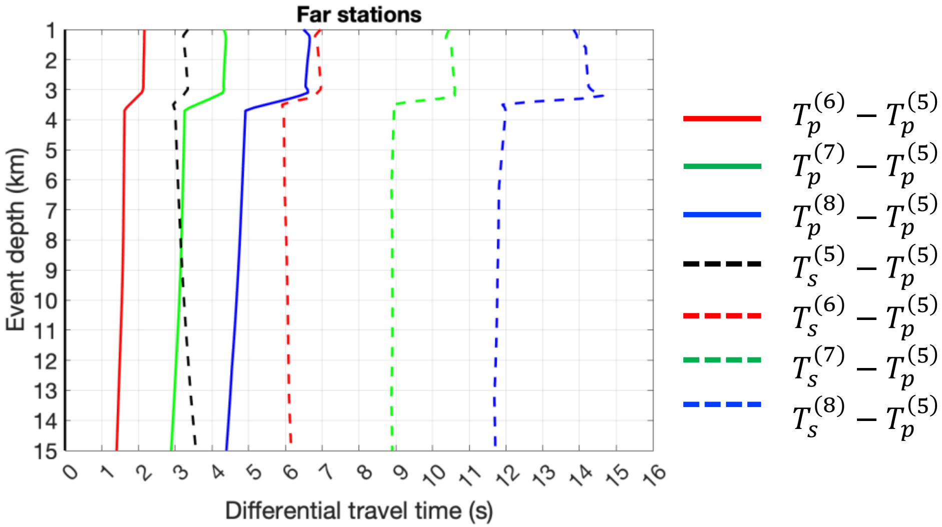
Investigation of hypocenter inversion using the IASP91 model



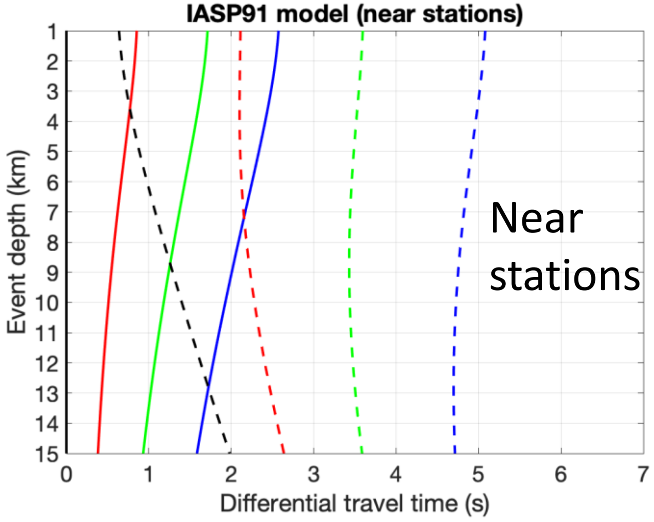
Near stations: S1-S4
Far stations: S5-S8

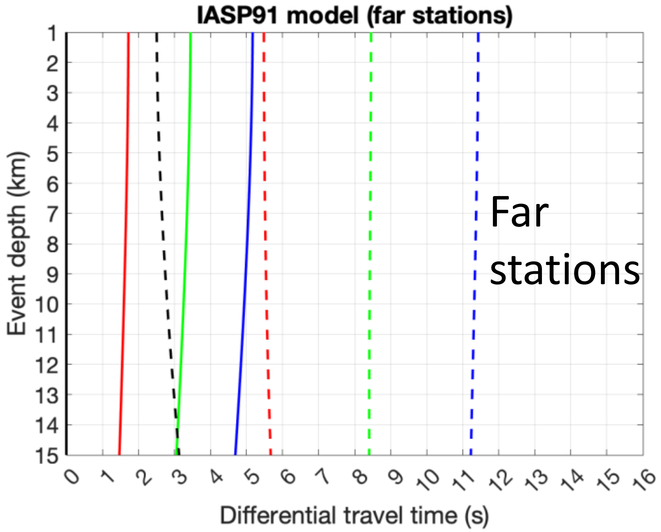
Travel time derived from full-wave modeling of the HC1D model



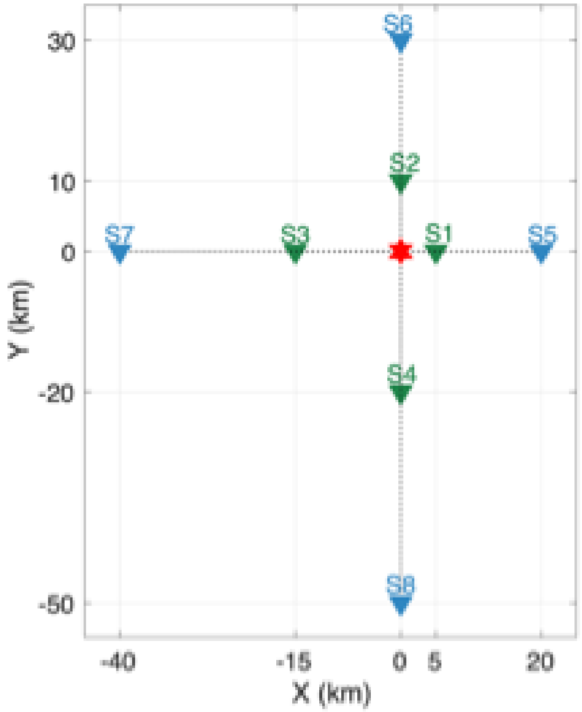


Travel time derived from raytracing of the IASP91 model



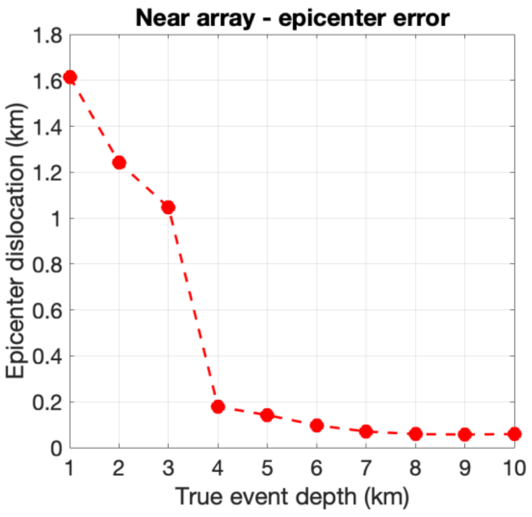


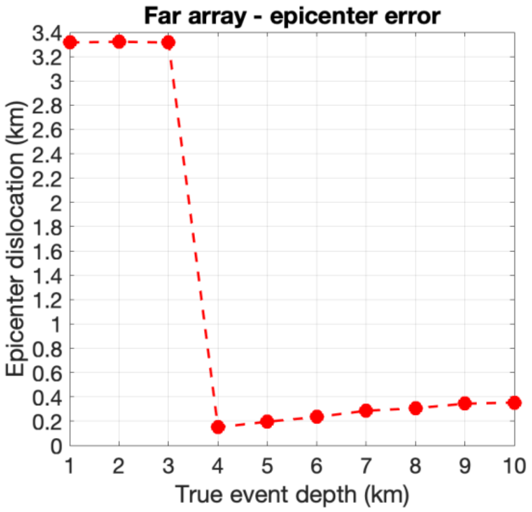
Investigation of hypocenter inversion using the IASP91 model



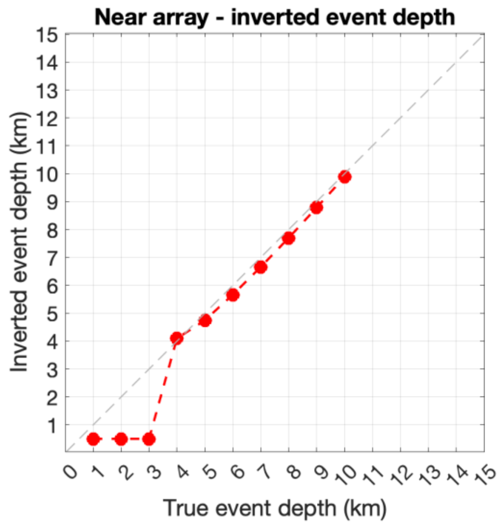
Near stations: S1-S4
Far stations: S5-S8

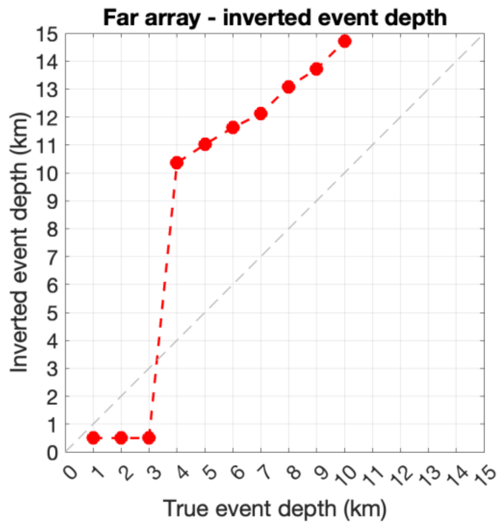
Epicenter error





Hypo depth error





IASP91 model underestimates the propagation velocity of seismic wave round the Ellenburger layer, leading to an overestimation of travel time for events within or below the Ellenburger. This would force the inversion to shift an event to a deeper depth in order to match the actual travel time data, resulting in over estimation of event depth by several kilometers.

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Summary of learning & findings

- The presence of the high velocity Ellenburger layer in the Permian Basin introduces a lot of complexities in the induced seismic wavefield, making it difficult to use conventional raytracing methods to predict the first break travel times. Thus full-wave modeling is required to build the correct travel time table.

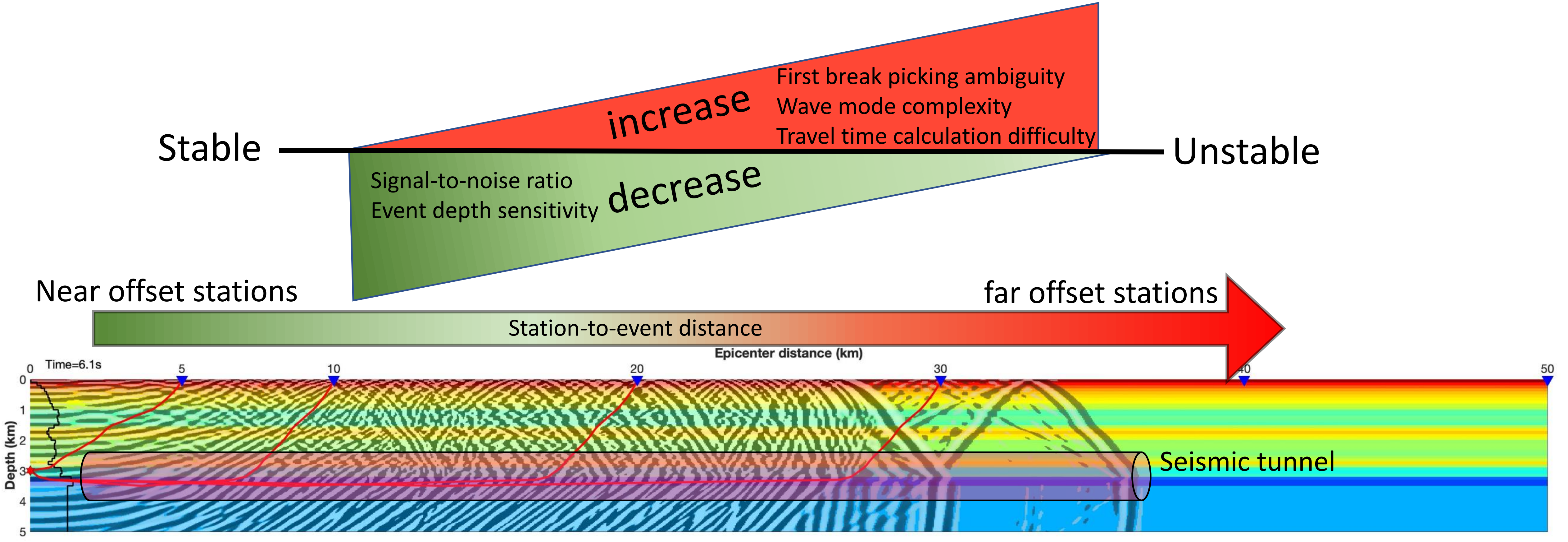
- Travel time data recorded at distant stations have little sensitivity to event depth, resulting in depth uncertainty on the order of kilometers. The drop in sensitivity also increases the inversion's susceptibility to noise and picking errors. The only way to get around this issue is to use local close stations.

- Regional crustal models (e.g., IASP91) without accurate shallow velocity structures fail to model the near field ray path distortions caused by head/reflected/guided waves, resulting in inaccurate estimation of event location. Therefore, it is crucial to use a robust local velocity model for hypocenter inversion.

Summary of learning & findings

In a nutshell:

- A good local velocity model is critical
- Near stations bring tremendous advantages over far stations for event hypocenter inversion
- Robust and reliable processing can be achieved with a good velocity model and near stations




SensorEra
Thank You