Time-lapse EFWI of CO_2 injection at CaMI FRS using VSP: a feasibility study

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UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
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Carbon Management Canada

Motivation

Full waveform inversion of DAS field data from the 2018 CaMI VSP survey (Eaid et. al.,2021)

Full waveform inversion of VSP accelerometer data from the CAMI field site (Keating et. al., 2021)

Motivation

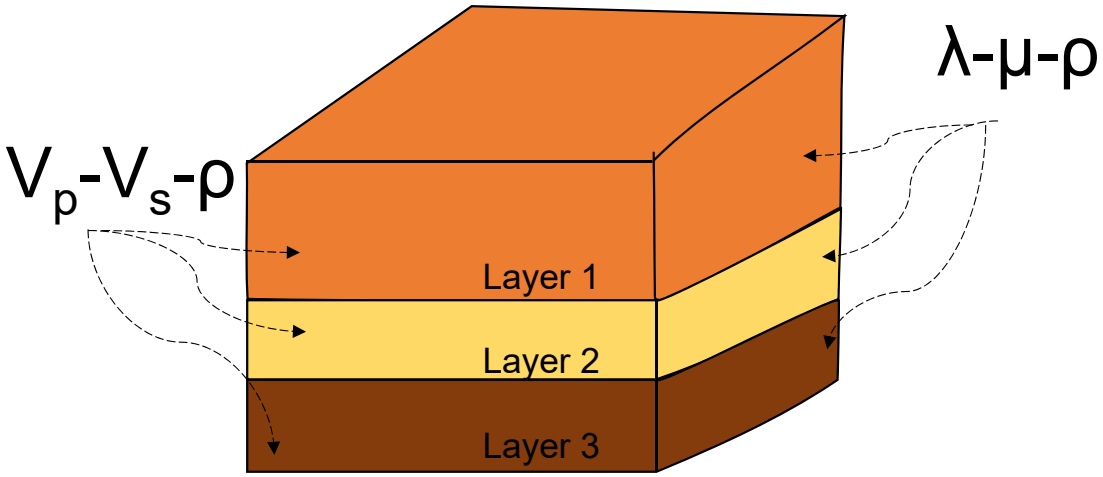
(1) Can we use EFWI to monitor reservoir changes due to CO_2?

(2) Is there an inversion strategy that can help us to accomplish (1) better?

Elastic medium and seismic

Describe with:

Equivalent description



From seismic:

V_p- V_s- ρ ≠ λ- μ- ρ

V_p - V_s ≠ I_p- I_s

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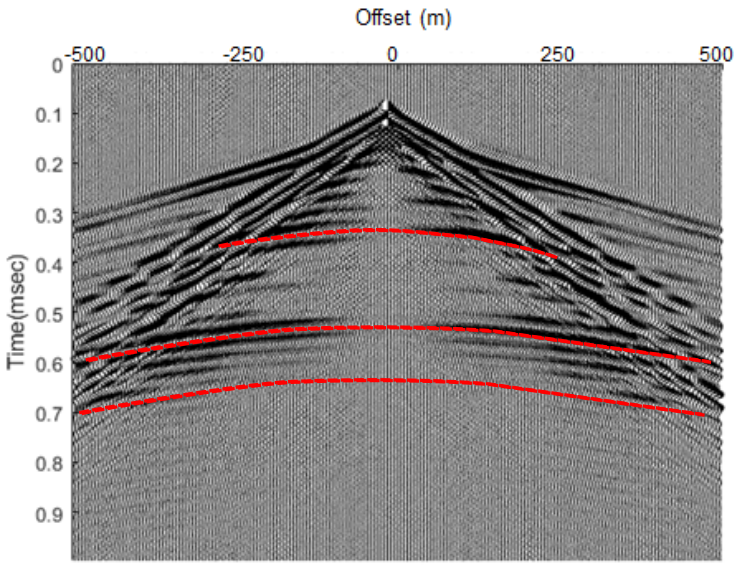
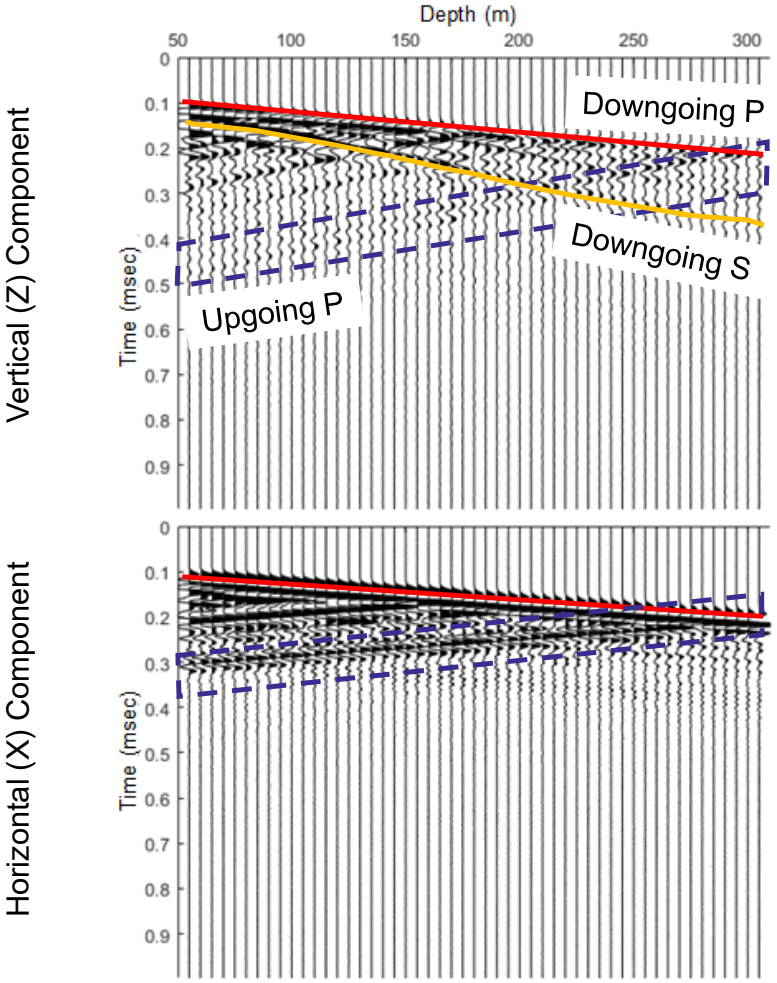
Seismic records and elastic parameters

Surface Seismic

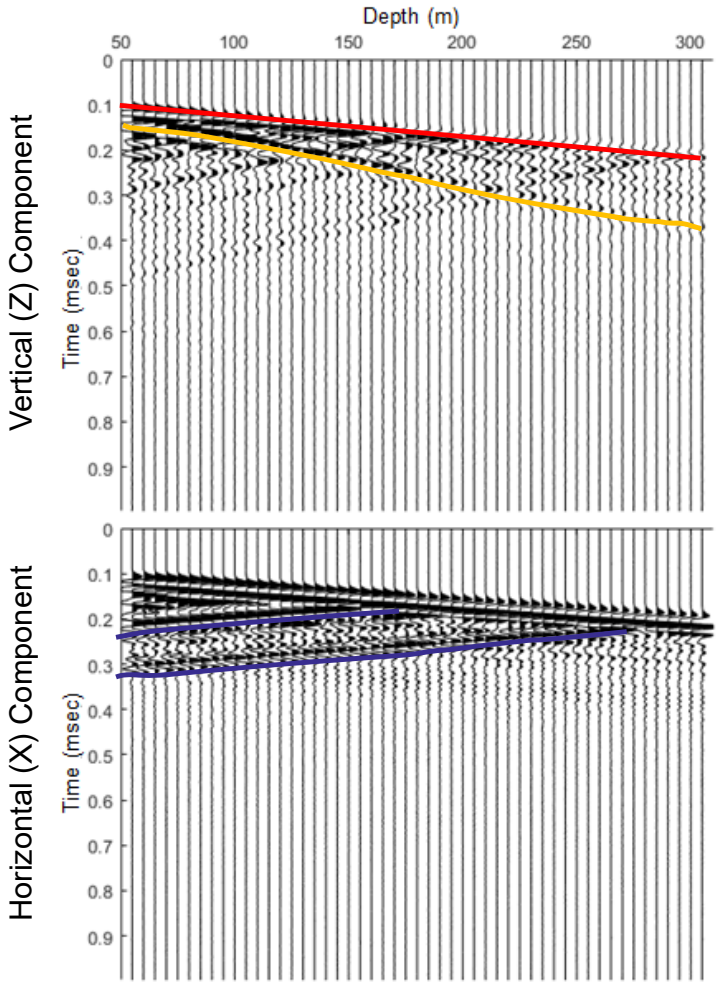


-- Reflections

VSP

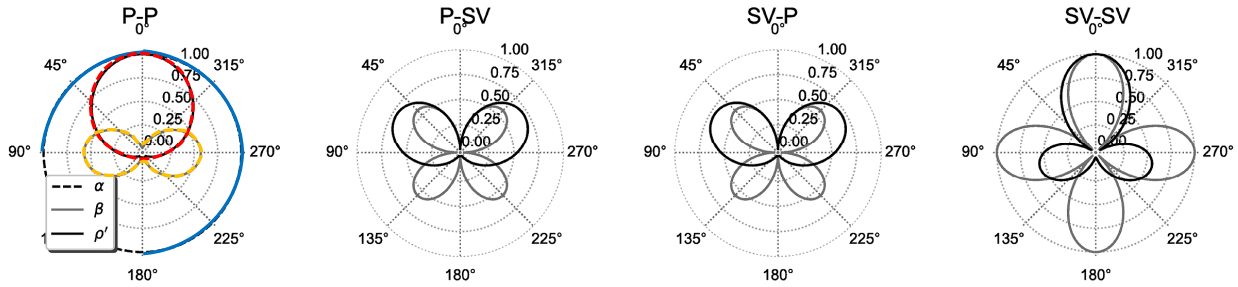


Seismic records and elastic parameters

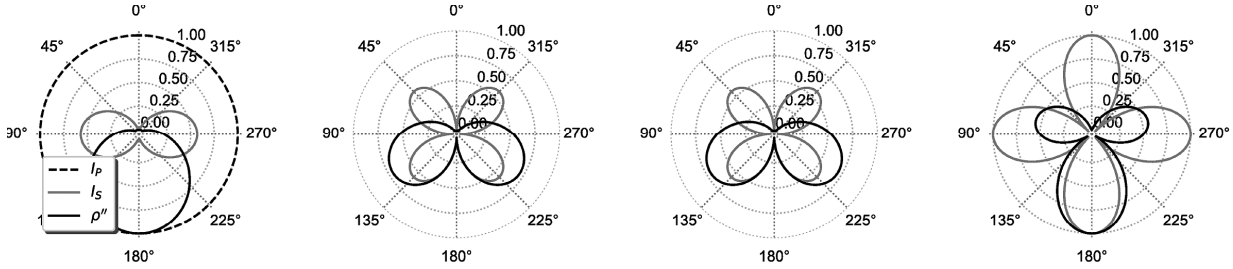


Suggested parameterizations:

V_p-V_s-ρ



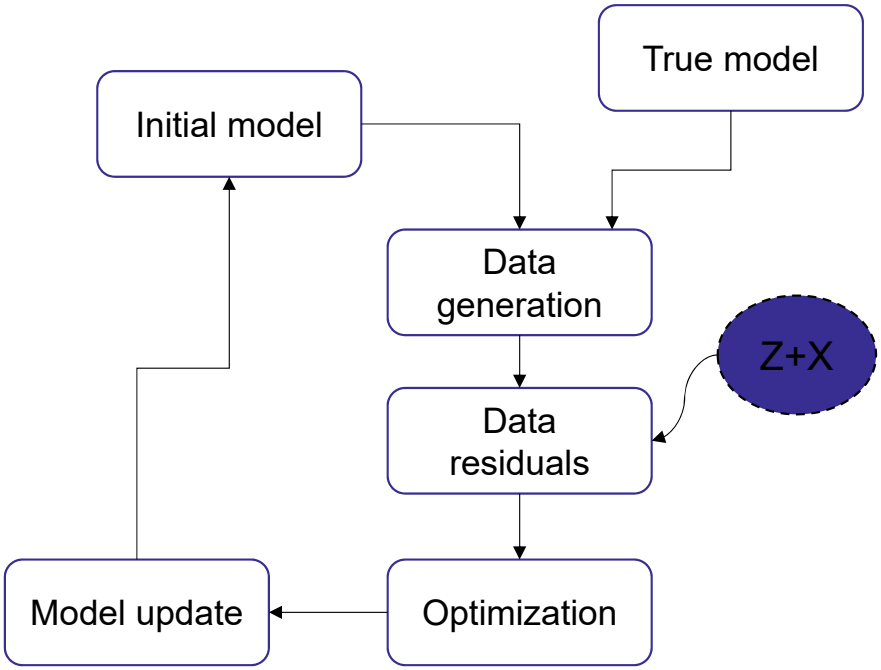
I_p-I_s- ρ



Pan *et al.*, 2018

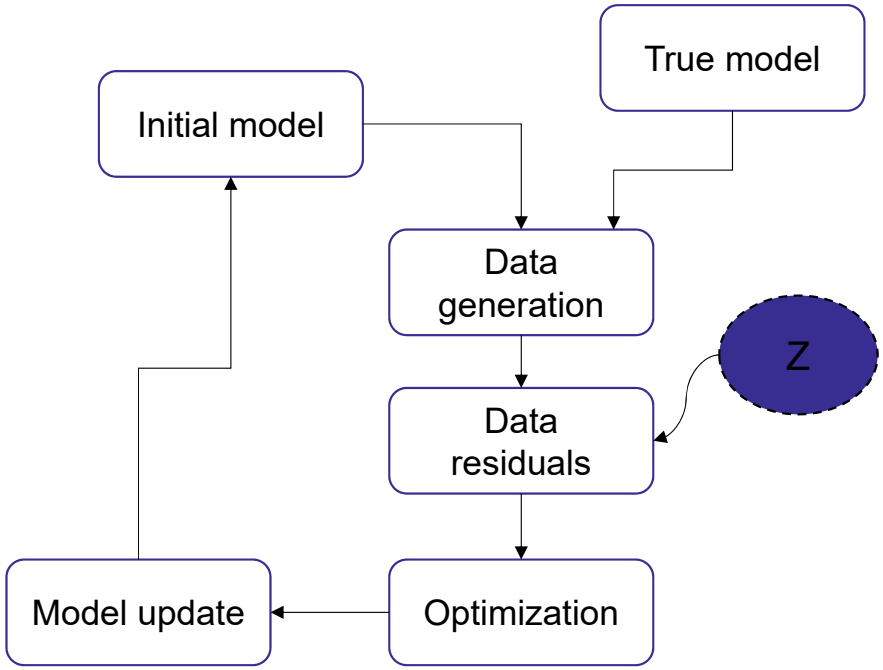
FWI Workflow

Inversion Z+X Components



[4-26 Hz]

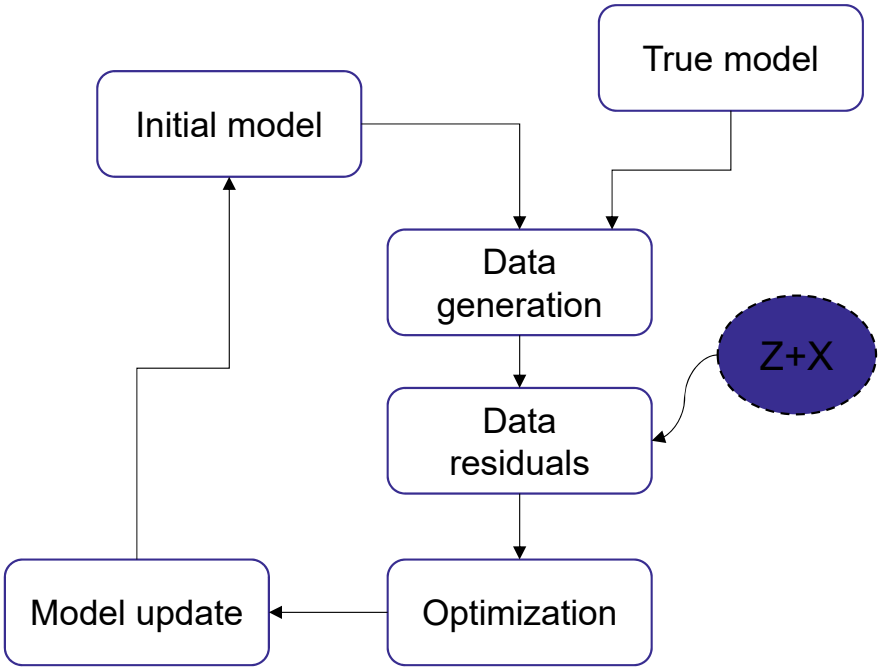
Inversion (1) Z and (2) Z+X Components



[4-24 Hz]

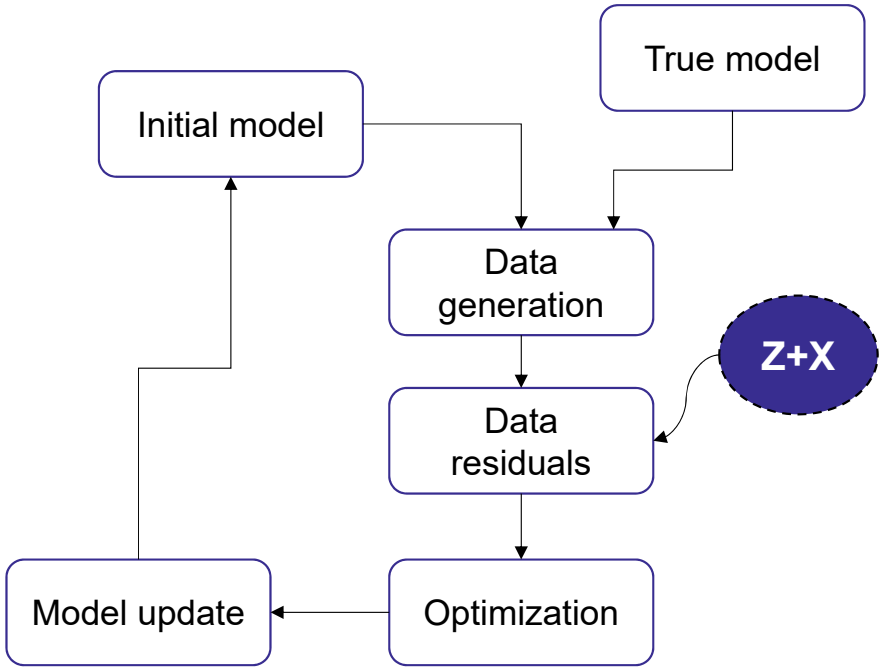
FWI Workflow

Inversion Z+X Components



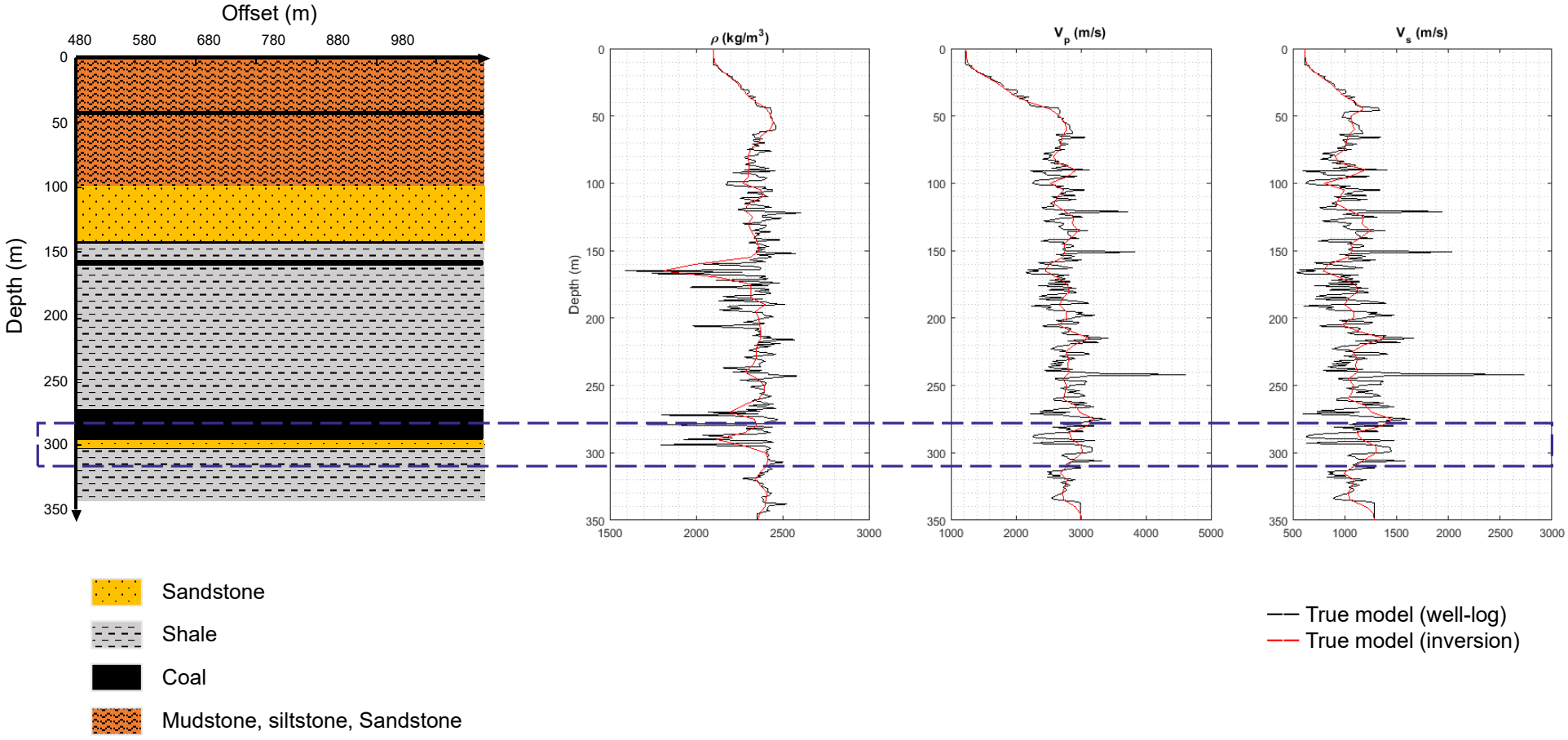
[4-26 Hz]

Inversion (1) Z and (2) Z+X Components

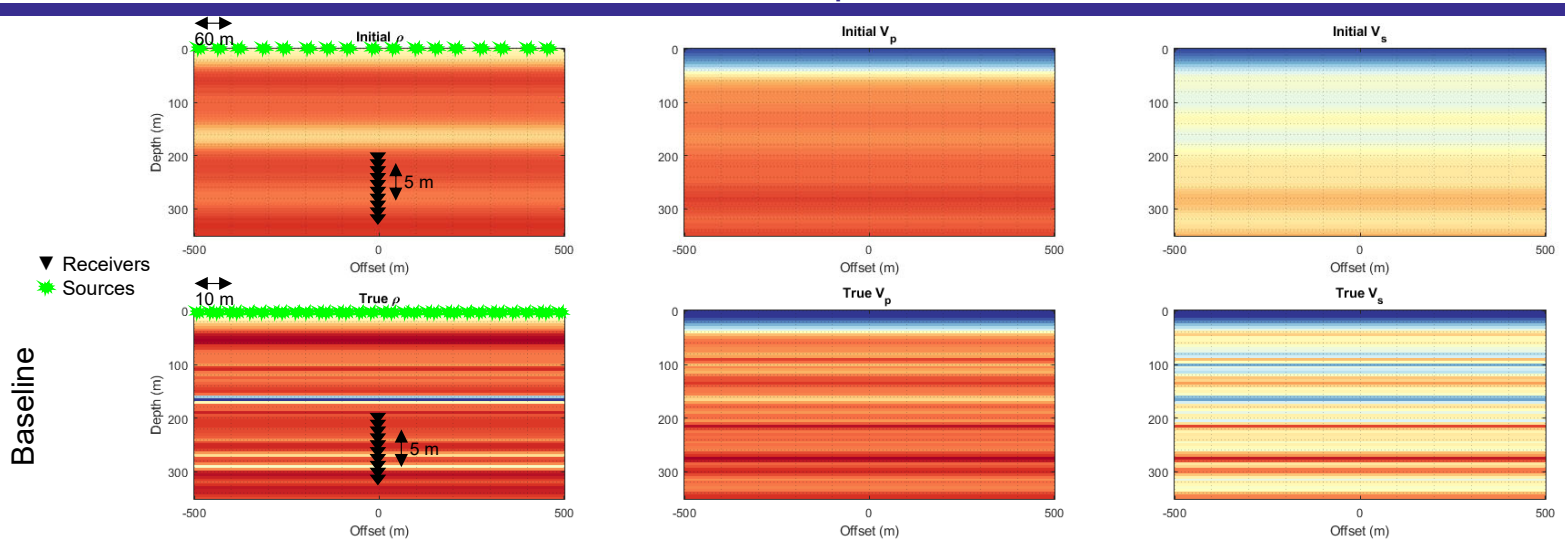


[4-30 Hz]

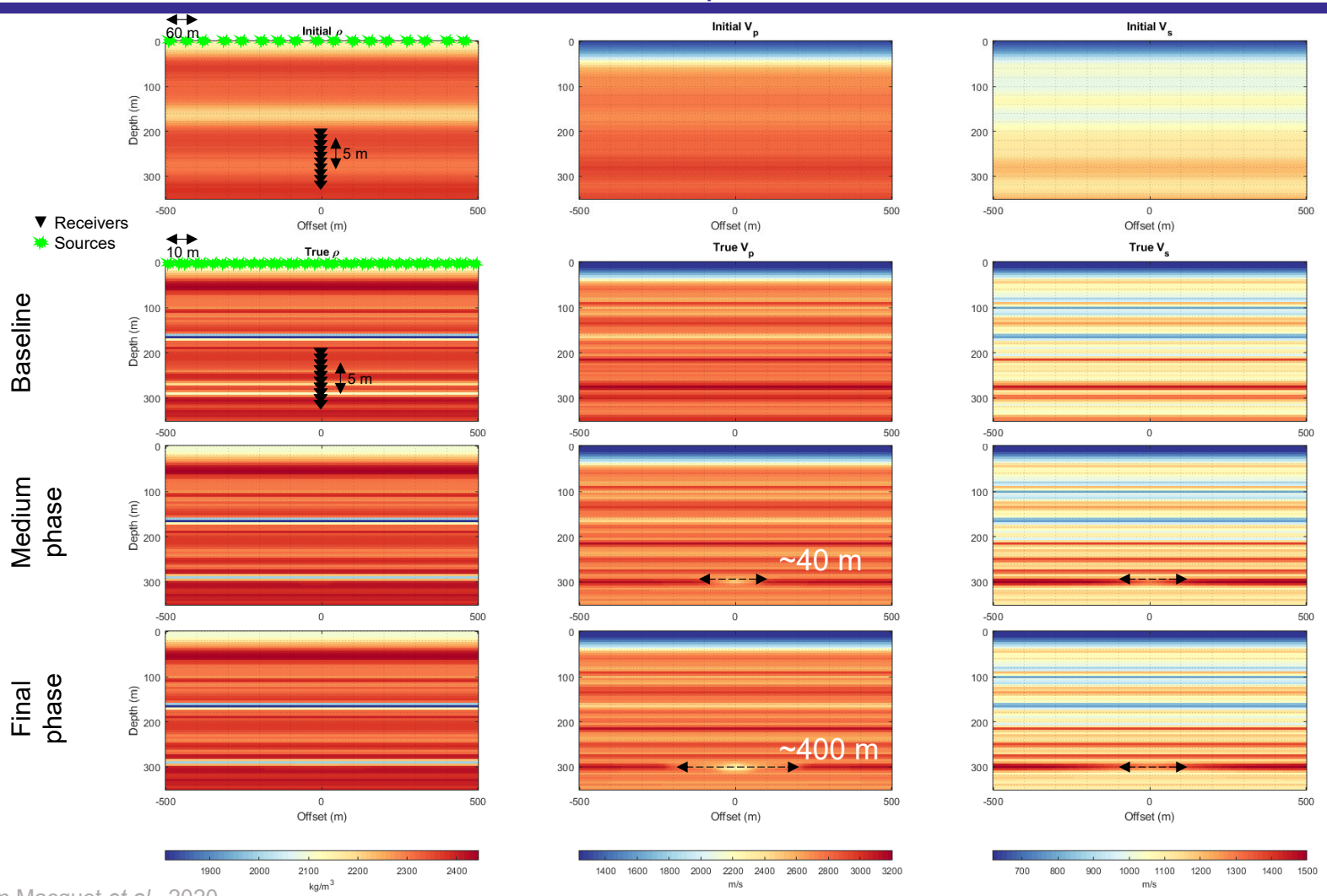
Containment and Monitoring Institute Field Research Station



Models and experiment design, V_p-V_s-ρ Parameterization

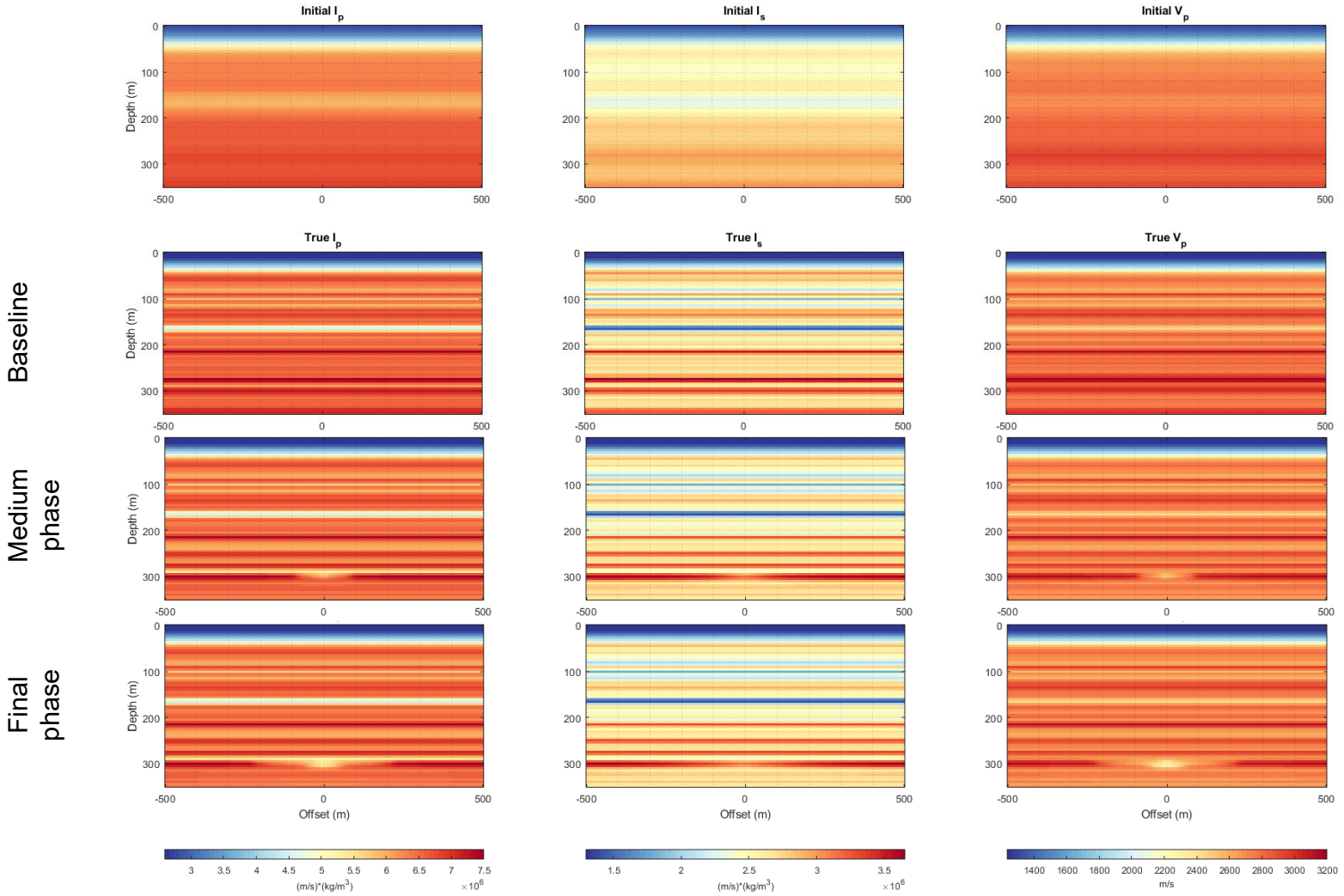


Models and experiment design, V_p-V_s-ρ Parameterization



Adapted from Macquet *et al.*, 2020

I_p-I_s-V_p Parameterization

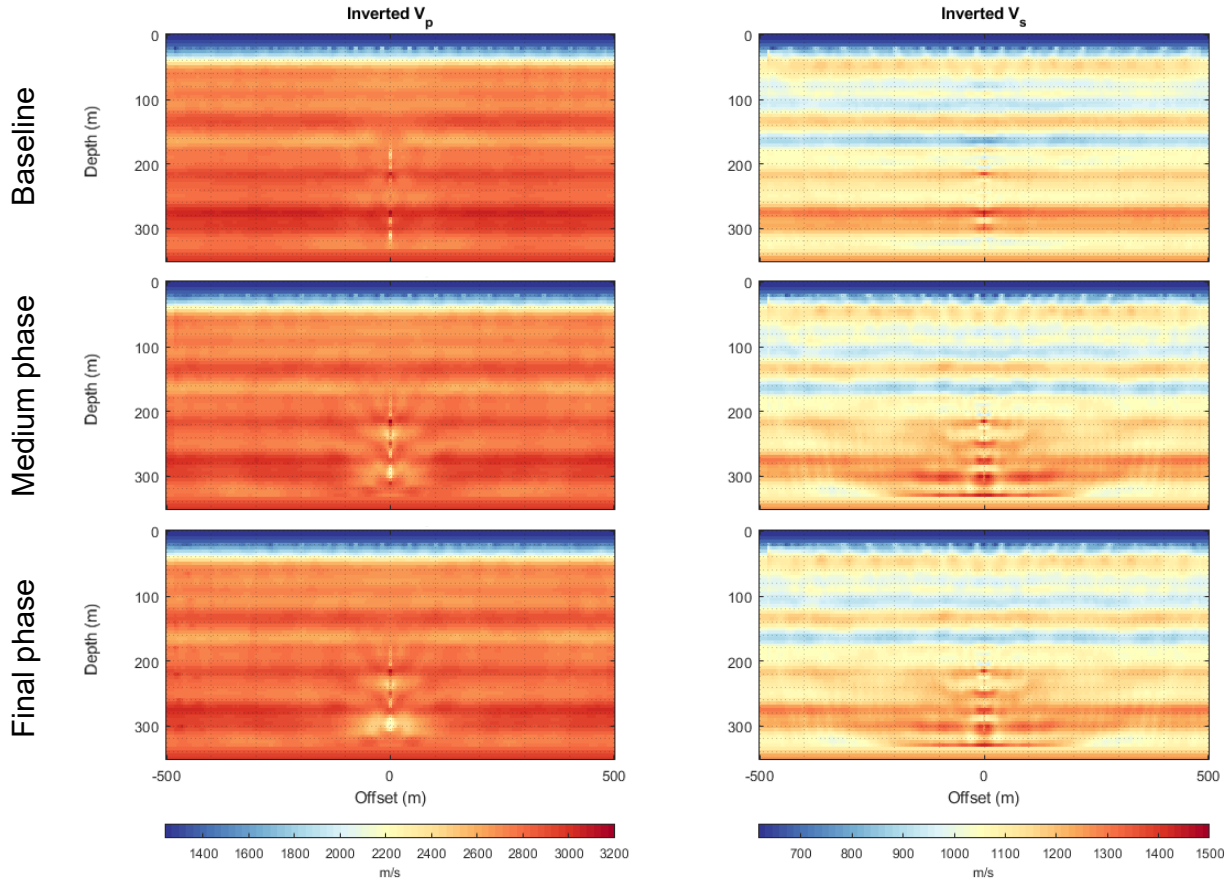


(1) Can we use EFWI to monitor reservoir changes due to CO_2?

Inversion of Z+X components

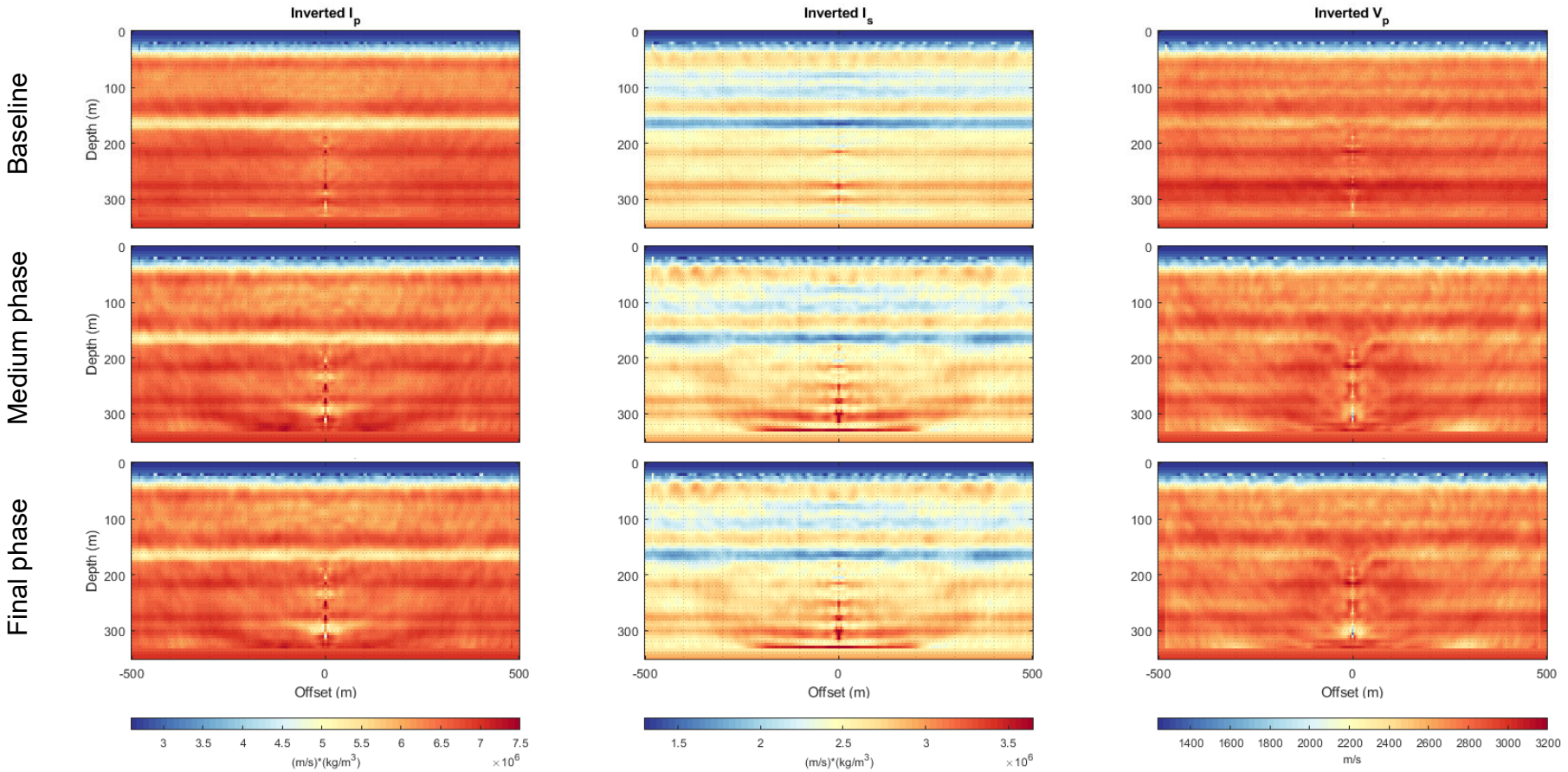
(2) Is there an inversion strategy that can help us to accomplish (1) better?

V_p-V_s-ρ, Inversion of Z+X components, ds = 60 m



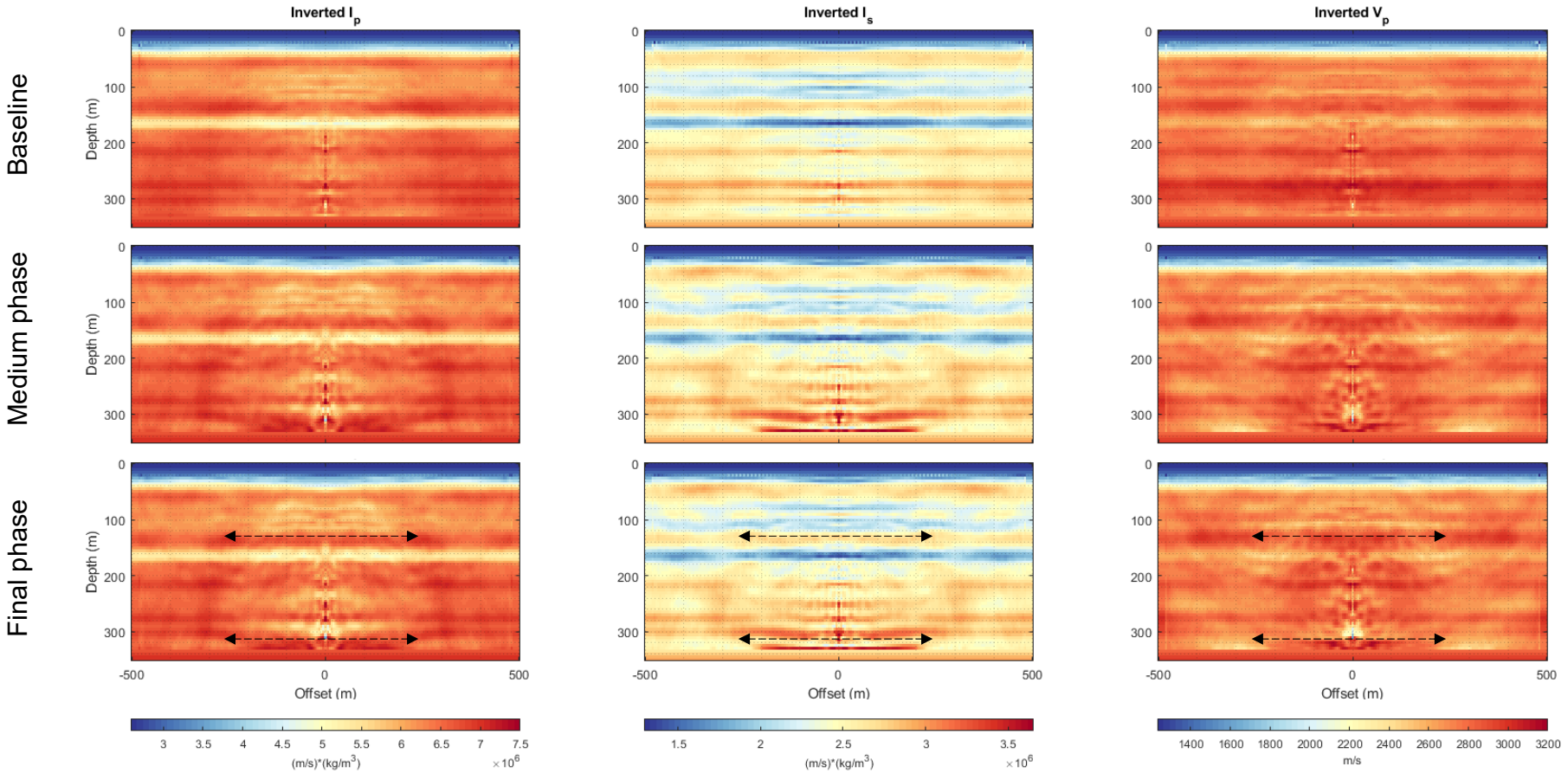
[4-26 Hz]

I_p-I_s-V_p, Inversion of Z+X components, ds = 60 m



[4-26 Hz]

I_p-I_s-V_p, Inversion of Z+X components, ds = 10 m



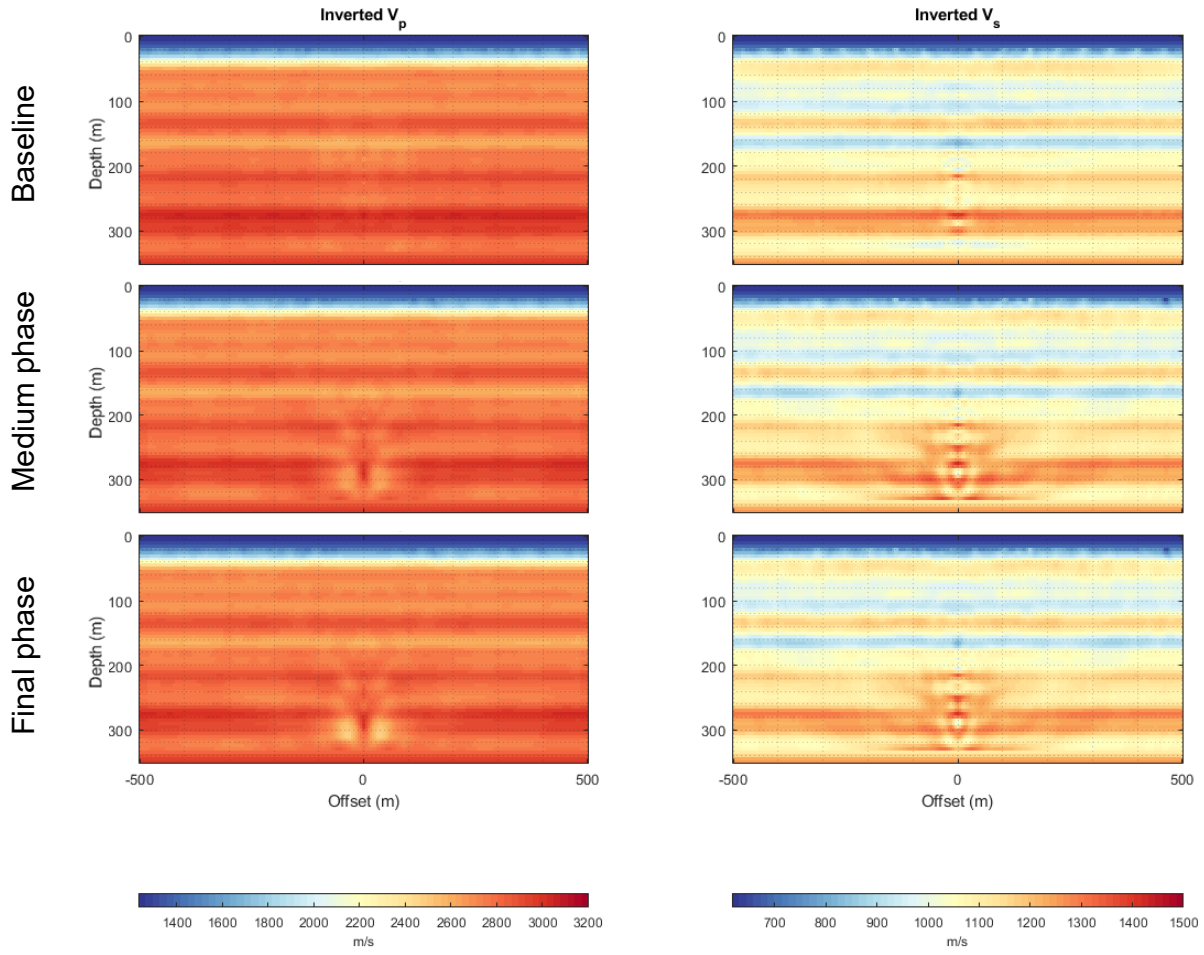
[4-26 Hz]

(1) Can we use EFWI to monitor reservoir changes due to CO_2?

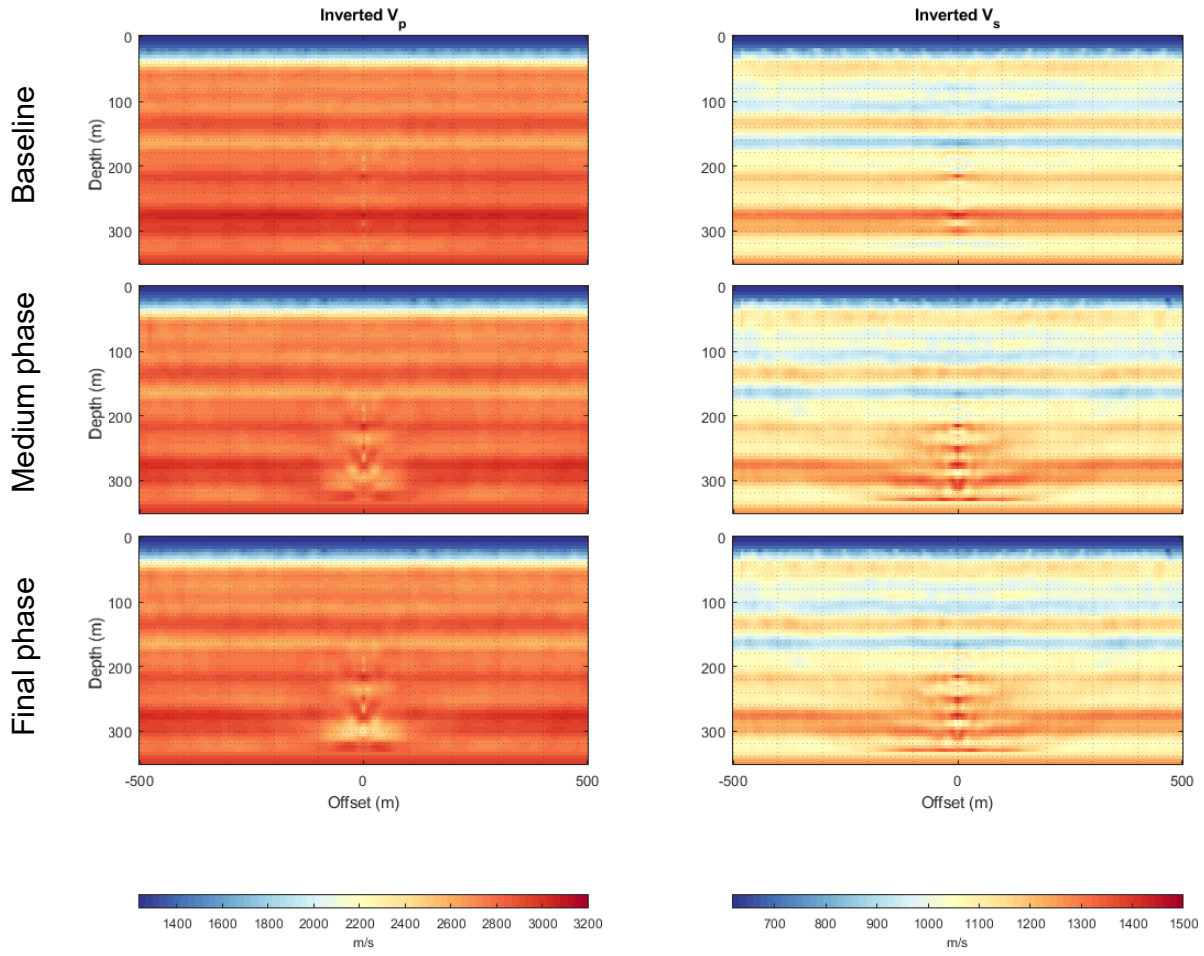
Inversion of Z and then, Z+X components

(2) Is there an inversion strategy that can help us to accomplish (1) better?

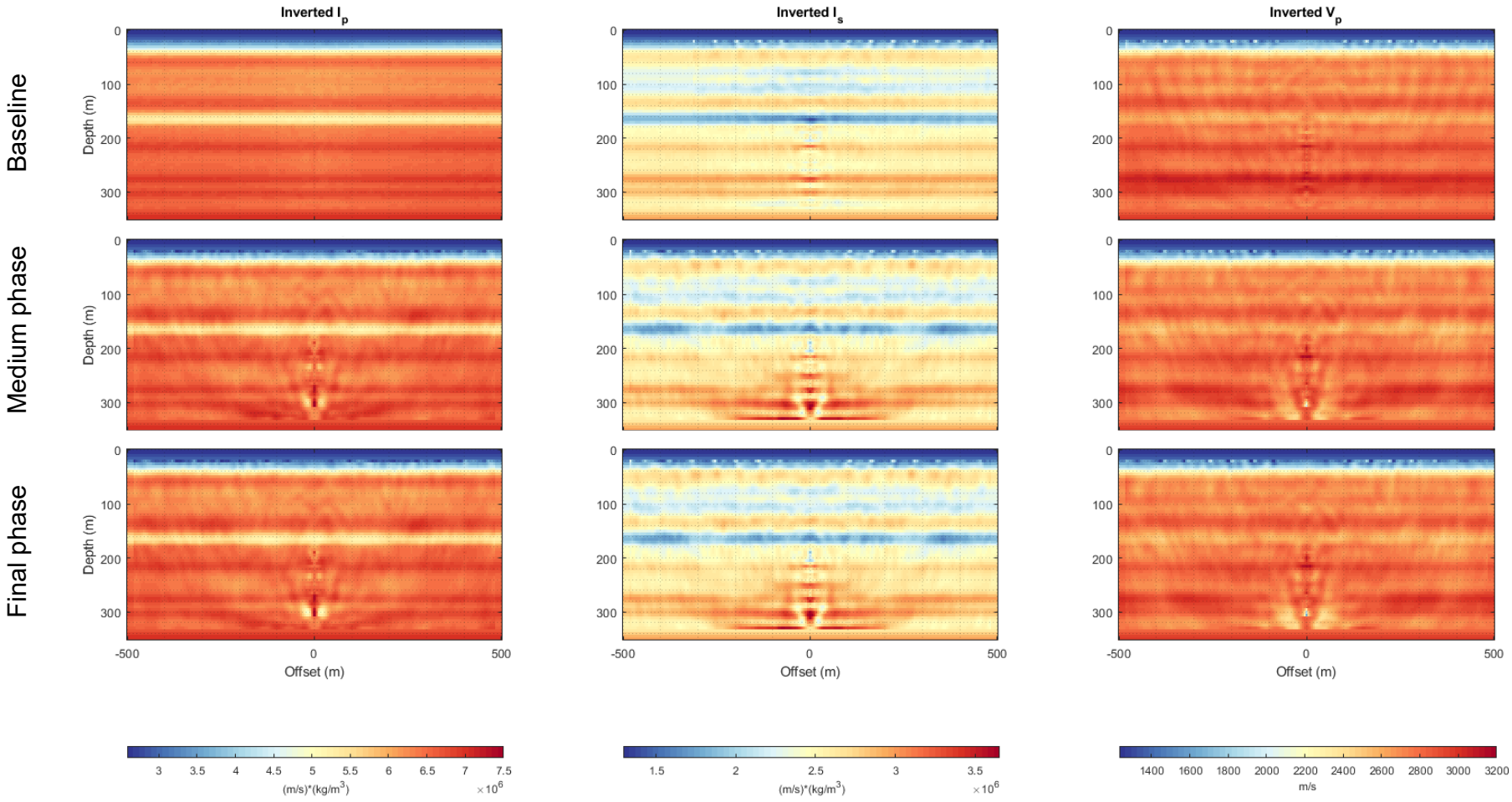
V_p-V_s-ρ, Inversion Z component, [4-24 Hz]



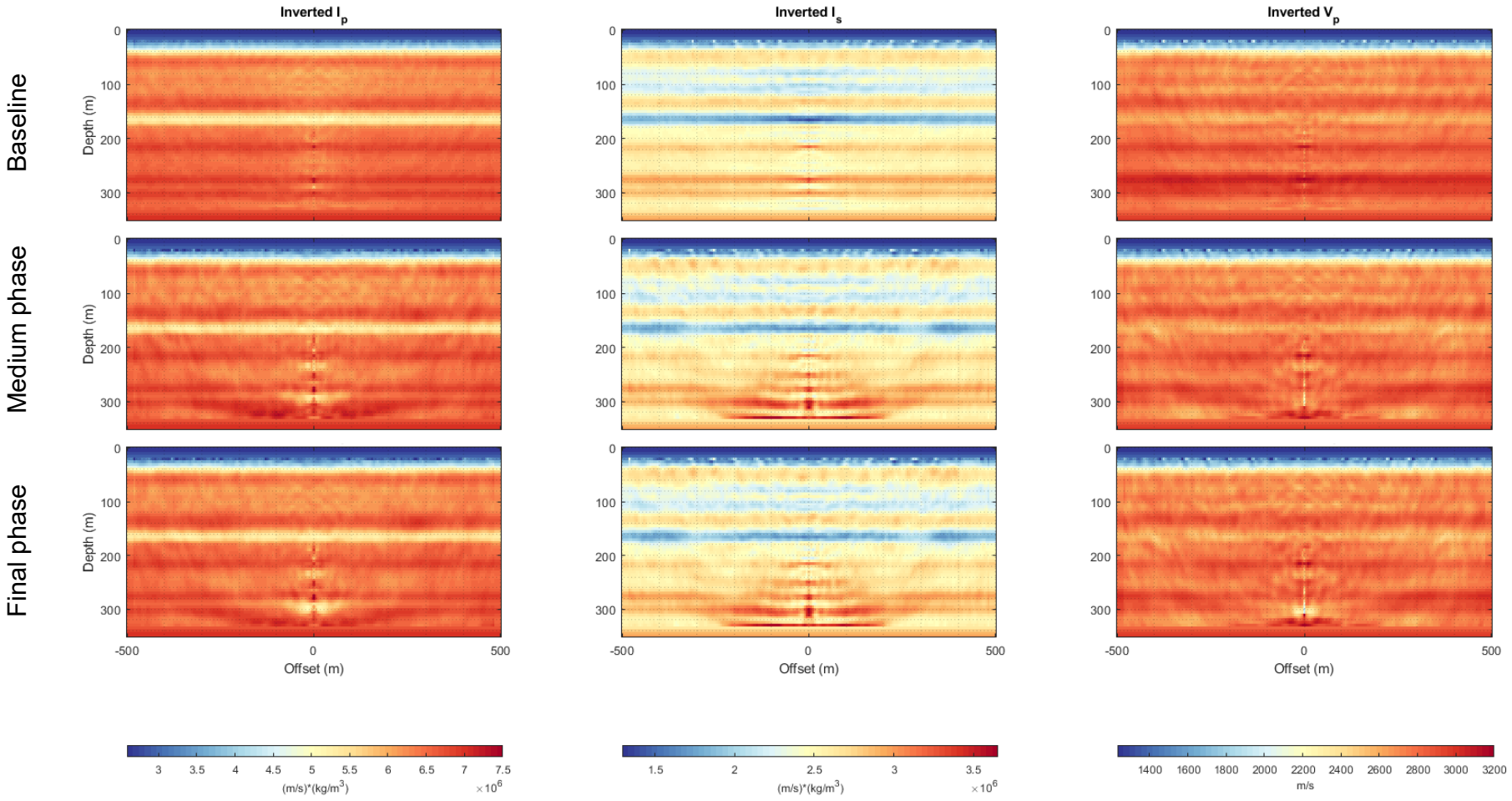
V_p-V_s-ρ, Inversion Z+X component [4-30 Hz]



I_p-I_s-V_p, Inversion Z component [4-24 Hz]



I_p-I_s-V_p, Inversion Z+X components [4-30 Hz]



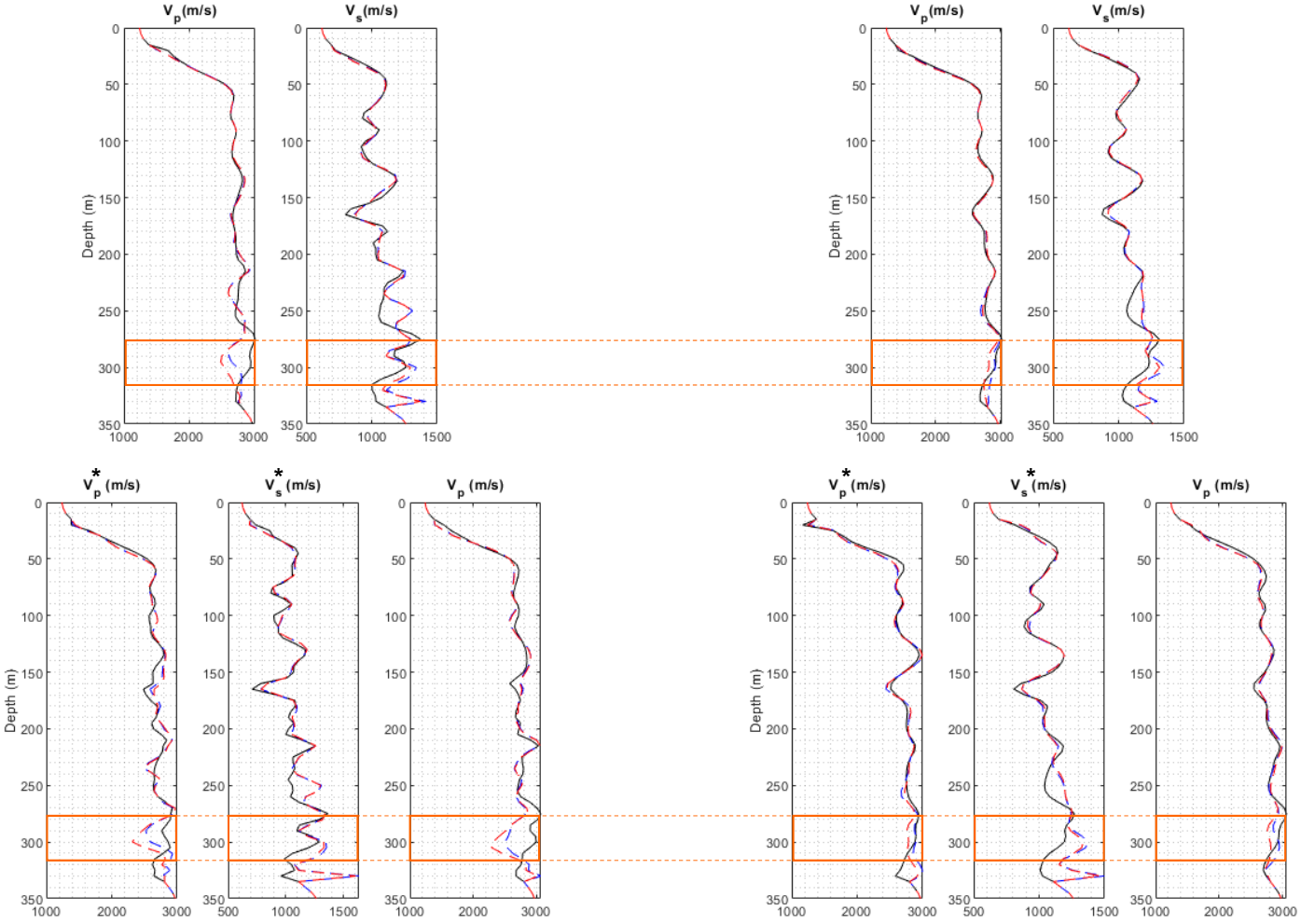
Time-lapse from inverted data, Z+X components

Near offset location

Far offset location

V_p-V_s-ρ

I_p-I_s-V_p



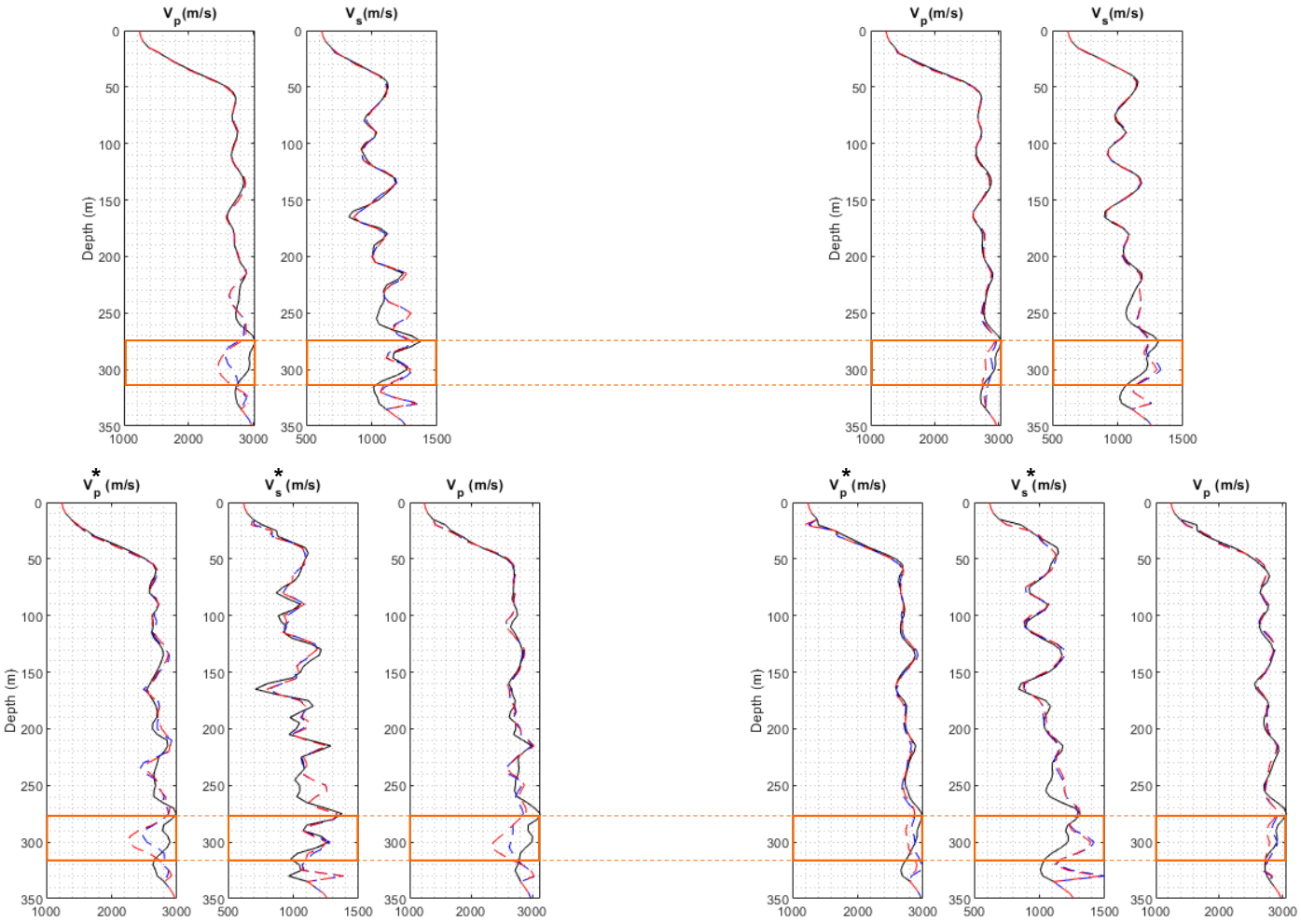
Time-lapse from inverted data, Z and Z+X Components

Near offset location

Far offset location

V_p-V_s-ρ

I_p-I_s-V_p



Time-lapse observations

Inversion of Z+X Components

Parameterization		Normalized residuals	Parameter variation (%)	
			Near offset	Far offset
V_p-V_s-ρ	V_p	0.6429	-15.18	-3.55
	V_s	0.8143	6.02	10.29
I_p-I_s-V_p	$I_p \rightarrow V_p$*	0.7805	-17.56	-3.29
	$I_s \rightarrow V_s$*	0.8642	3.03	12.25
	V_p	0.7109	-22.98	-4.57

Inversion of Z, then Z+X Components

Parameterization		Normalized residuals	Parameter variation (%)	
			Near offset	Far offset
V_p-V_s-ρ	V_p	0.6113	-16.41	-5.34
	V_s	0.8151	3.45	8.86
I_p-I_s-V_p	$I_p \rightarrow V_p$*	0.7338	-21.22	-4.78
	$I_s \rightarrow V_s$*	0.8254	-1.26	14.11
	V_p	0.6130	-20.77	-5.19

Conclusions

(1) Can we use EFWI to monitor reservoir changes due to CO_2?
Yes:

- Parameter variations are detected.
- I_p-I_s-V_p parameterization measures greater changes.
- Reliable P- and S-wave structures, but density inconclusive.

(2) Is there an inversion strategy that can help us to accomplish (1) better? **Inversion of Z, then Z+X Components:**

- Better model convergence.
- 21% P-wave reduction, S-wave 1% reduction and 14% increase.

Acknowledgements

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Sponsors, faculty, students and staff

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NSERC CRSNG

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Carbon Management Canada

Containment and Monitoring Institute

References

Eaid, M., Keating, S., and Innanen, K. A. H., 2021, Full waveform inversion of DAS field data from the 2018 CaMI VSP survey, **33**, 6.

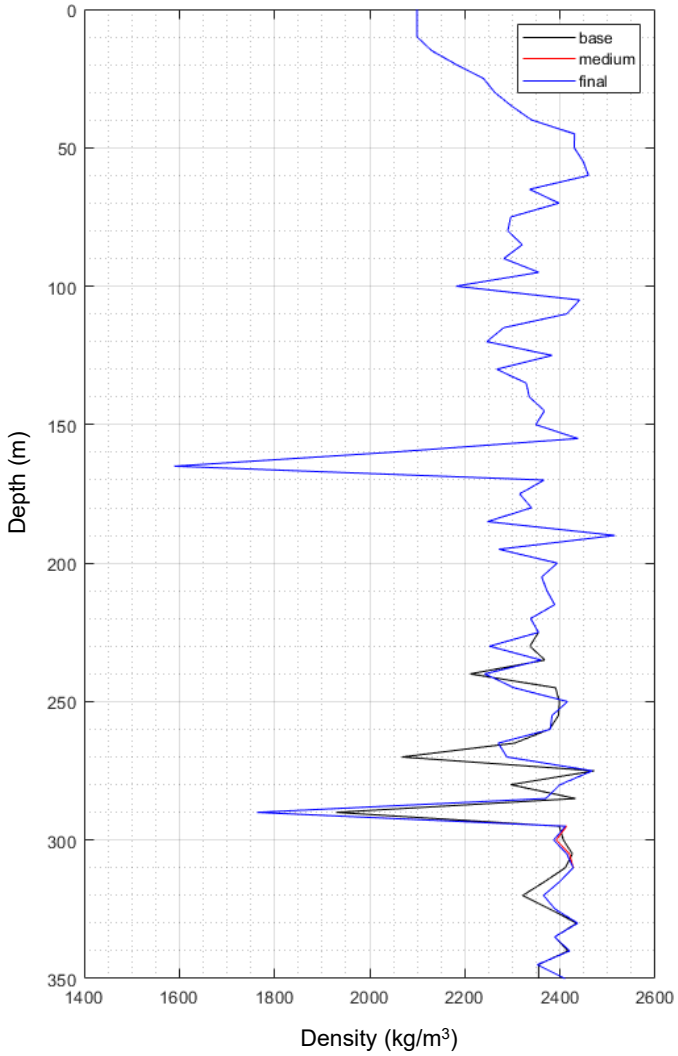
Keating, S., Eaid, M., and Innanen, K. A. H., 2021, Full waveform inversion of VSP accelerometer data from the CAMI field site, **33**, 28.

Macquet, M., Lawton, D. C., Saeedfar, A., and Osadetz, K. G., 2019, A feasibility study for detection for detections thresholds of co2 at shallow depths at the cami field research station, Newell County, Alberta, Canada: Petroleum Geoscience, **25**, No. 4, 509–518.

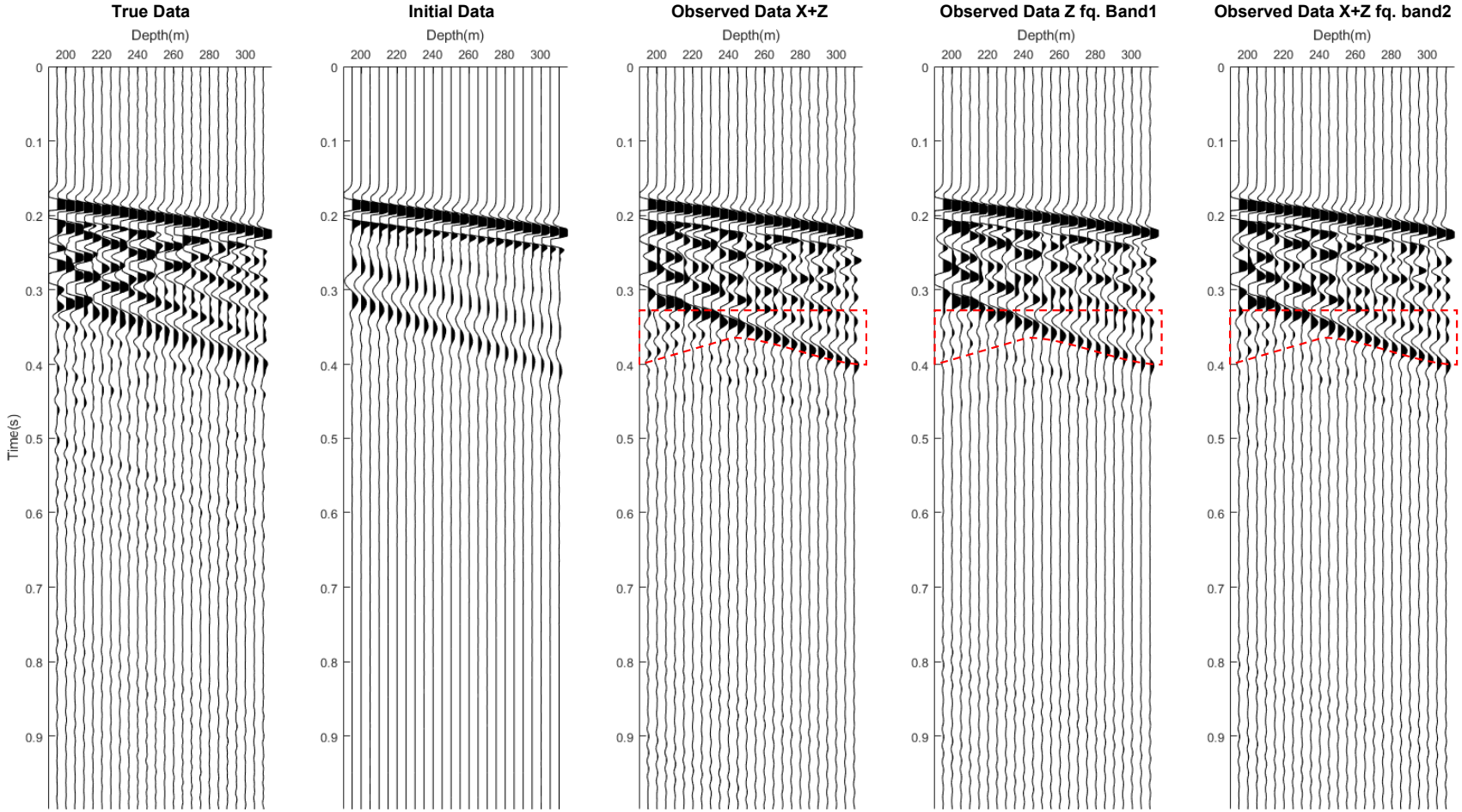
Pan, W., Innanen, K. A., and Geng, Y., 2018, Elastic full-waveform inversion and parametrization analysis applied to walk-away vertical seismic profile data for unconventional (heavy oil) reservoir characterization: Geophysical Journal International, **213**, No. 3, 1934–1968.

Changes of density (true models)

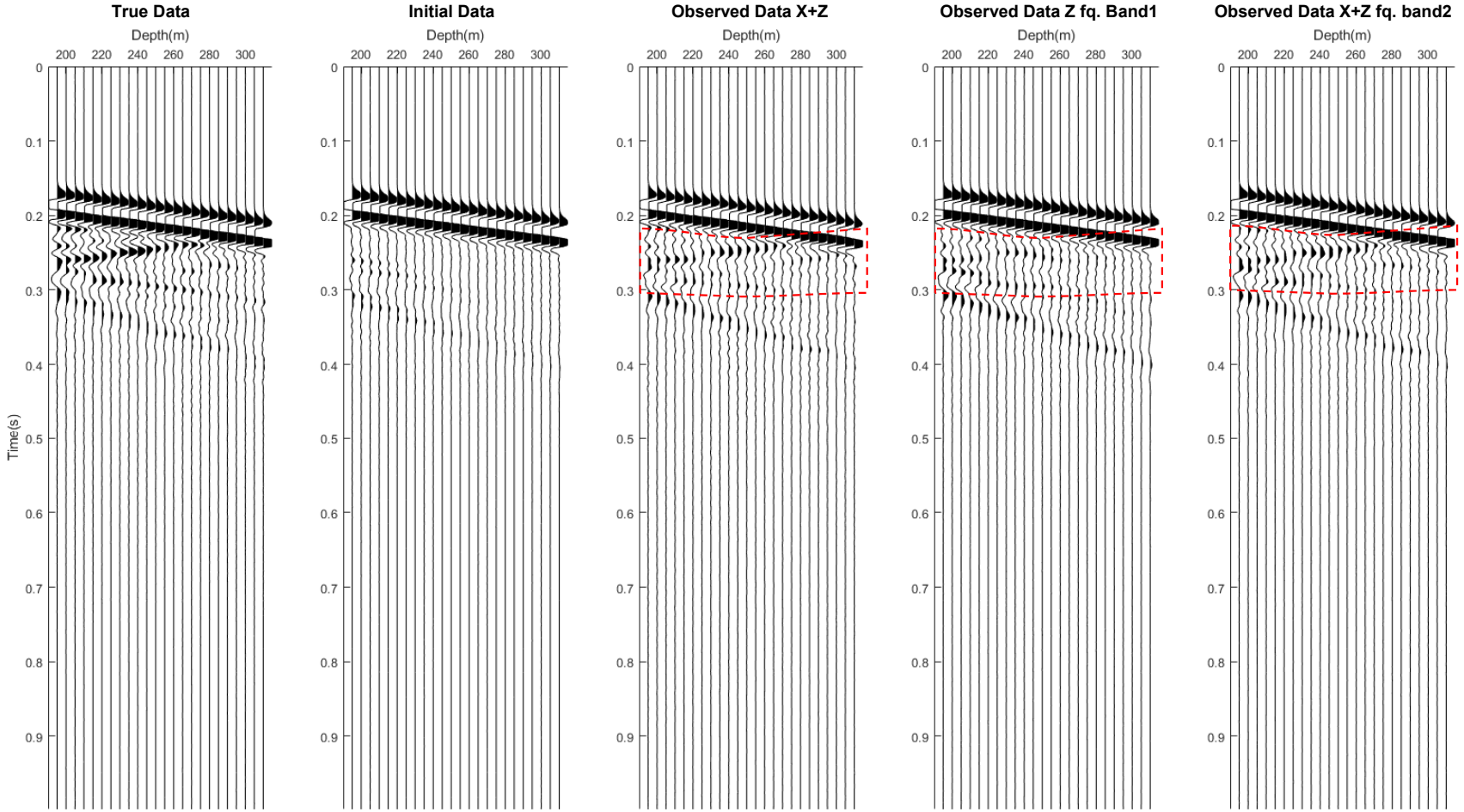
Profile at zero offset (wells area)



Synthetic data, Z component



Synthetic data, X component



Time-lapse observations (full)

Inversion of Z+X Components

Parameterization		Injection Stage	Normalized residuals	Parameter variation (%)	
				Near offset	Far offset
Vp-Vs-rho	Vp	Baseline	1.0785	0.00	0.00
	Vs		0.9279	0.00	0.00
	Vp	Medium	0.7905	-10.89	-1.03
	Vs		0.7862	2.52	7.05
	Vp	Final	0.6429	-15.18	-3.55
	Vs		0.8143	6.02	10.29
Ip-Is-Vp	Ip	Baseline	1.2040	0.00	0.00
	Is		0.9731	0.00	0.00
	Vp		1.0063	0.00	0.00
	Ip	Medium	0.9326	-9.41	0.49
	Is		0.8390	4.51	15.10
	Vp		0.8942	-16.39	-1.43
	Ip	Final	0.7805	-17.56	-3.29
	Is		0.8642	3.03	12.25
	Vp		0.7109	-22.98	-4.57

Time-lapse observations (full)

Inversion of Z, then Z+X Components

Parameterization		Injection Stage	Normalized residuals	Parameter variation (%)	
				Near offset	Far offset
Vp-Vs-rho	Vp	Baseline	1.0110	0.00	0.00
	Vs		0.9072	0.00	0.00
	Vp	Medium	0.7640	-12.49	-1.80
	Vs		0.8061	2.19	6.42
	Vp	Final	0.6113	-16.41	-5.34
	Vs		0.8151	3.45	8.86
Ip-Is-Vp	Ip	Baseline	1.1110	0.00	0.00
	Is		0.9120	0.00	0.00
	Vp		0.9538	0.00	0.00
	Ip	Medium	0.8862	-13.25	-1.55
	Is		0.7982	-1.26	16.24
	Vp		0.7576	-11.52	-1.26
	Ip	Final	0.7338	-21.22	-4.78
	Is		0.8254	-1.26	14.11
	Vp		0.6130	-20.77	-5.19