Seismic Conference 2024

May 2024

Aberdeen

ETLP Phase 8

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"Pre-Stack" Time-Shifts

New Paradigm for 4D Geomechanical History Matching

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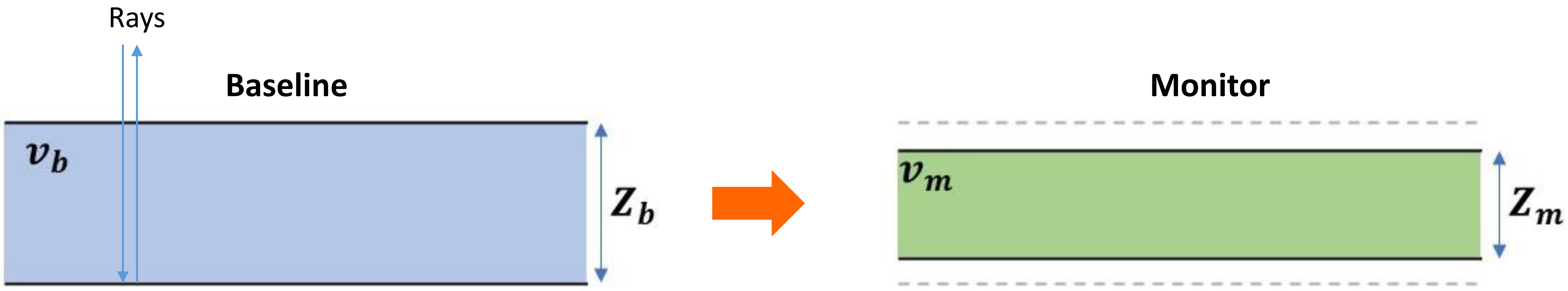
Post-Stack R-Factor Model

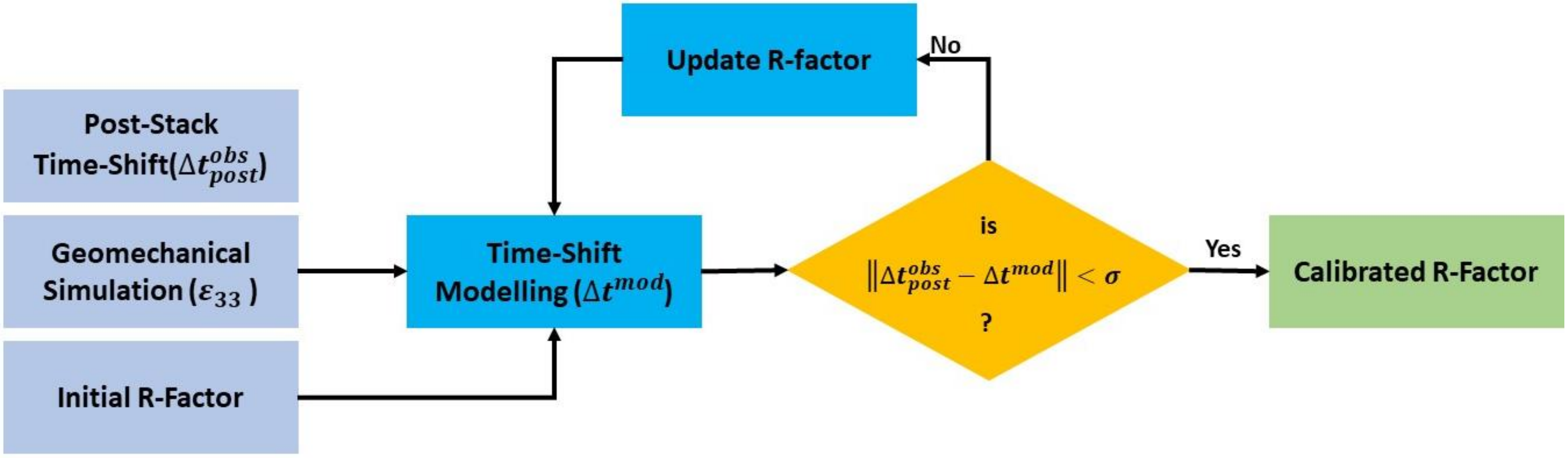


$$\frac{\Delta v}{v} = -R\varepsilon_{zz}$$

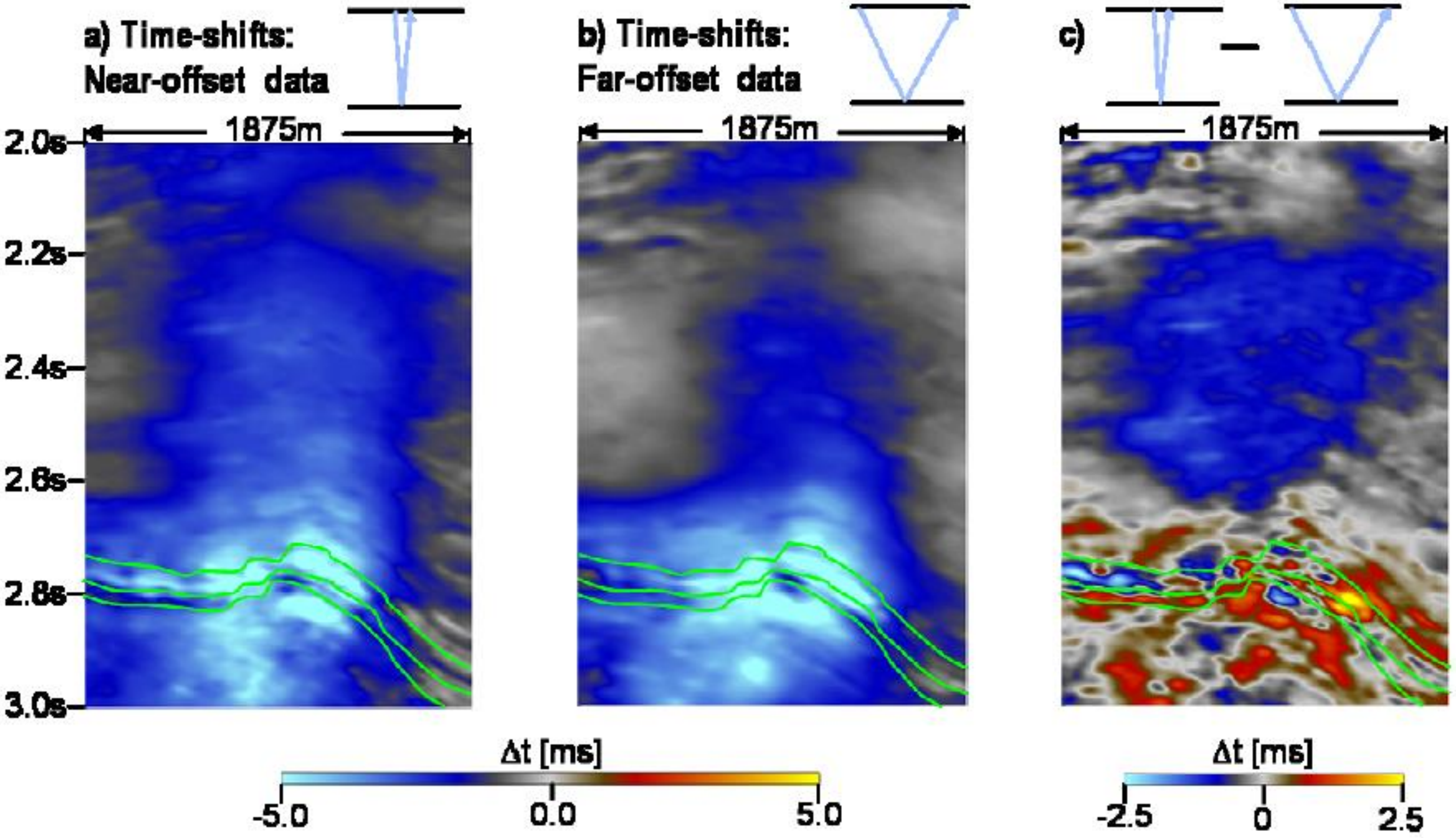
- Vertical Rays
- Vertical Strain
- Isotropic

*Hatchell and Bourne (2005); Roste et al. (2006)

Post-Stack 4D Geomechanics

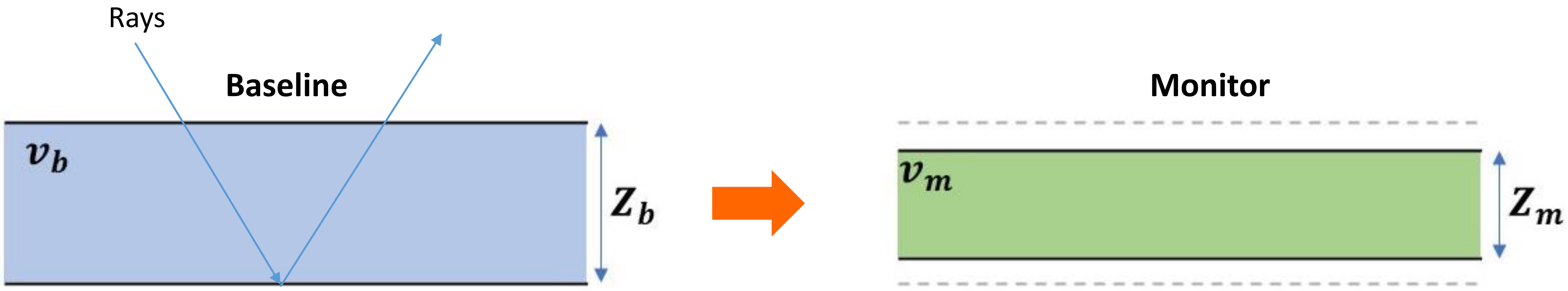


Why Pre-Stack Domain?



*Herwanger et al. (2007)

Pre-Stack R-Factor Model

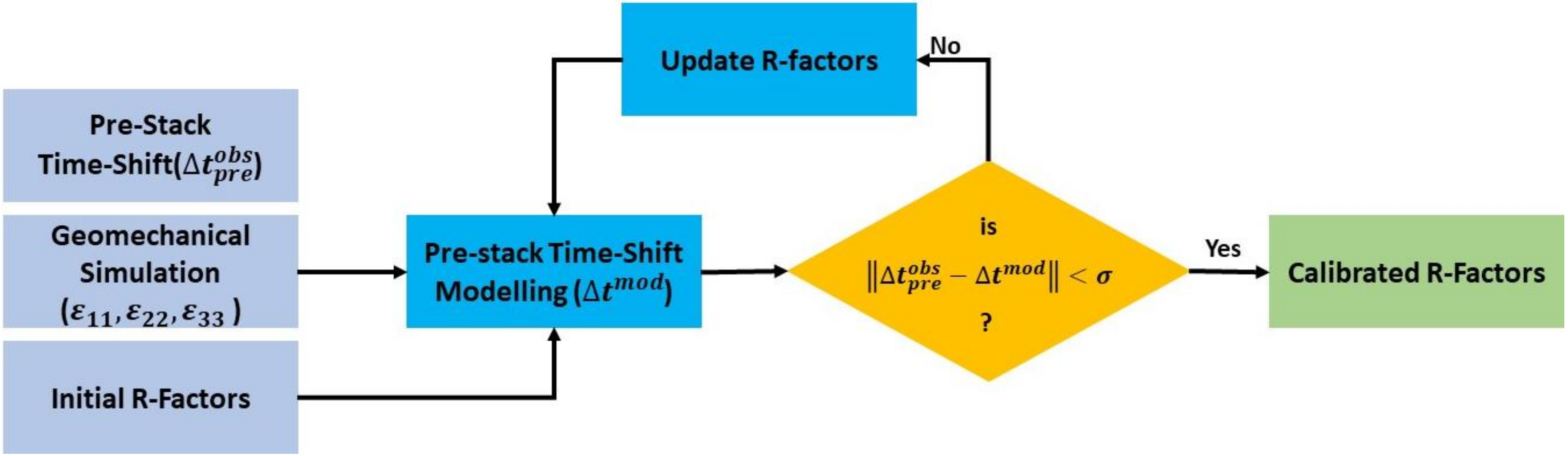


$$\frac{\Delta v}{v}(\theta) = [-(R_1 - R_2)\varepsilon_{zz} - R_2\varepsilon_{vol}] + [(R_1 - R_2)(\varepsilon_{zz} - \varepsilon_h) + (R_1 - R_2)\varepsilon_{vol}]sin^2(\theta)cos^2(\theta) + [(R_1 - R_2)(\varepsilon_{zz} - \varepsilon_h)]sin^4(\theta)$$

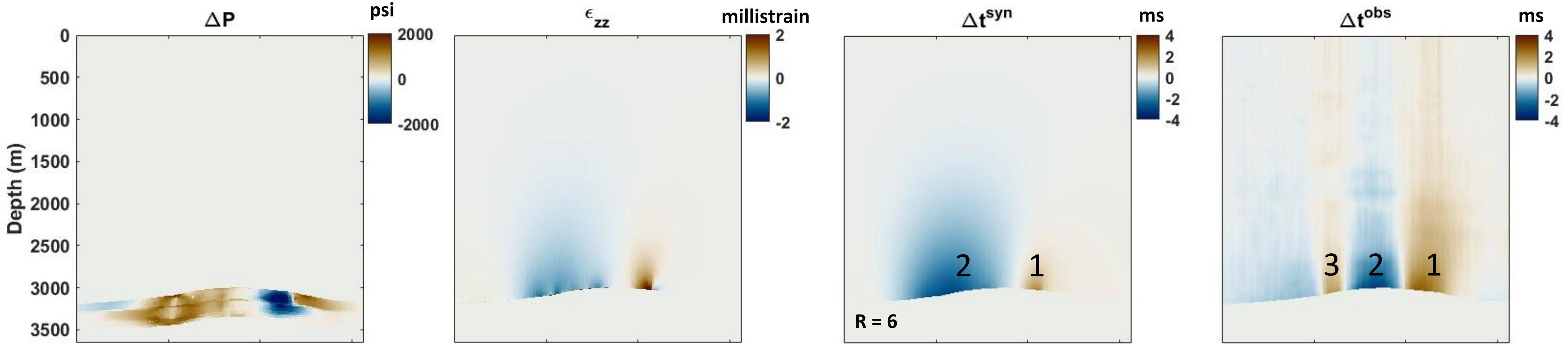
- **Non-vertical Rays**
- **Lateral & Vertical Strain**
- **Anisotropic**
- **Two R-Factors**

*Izadian and MacBeth (2022)

Pre-Stack 4D Geomechanics

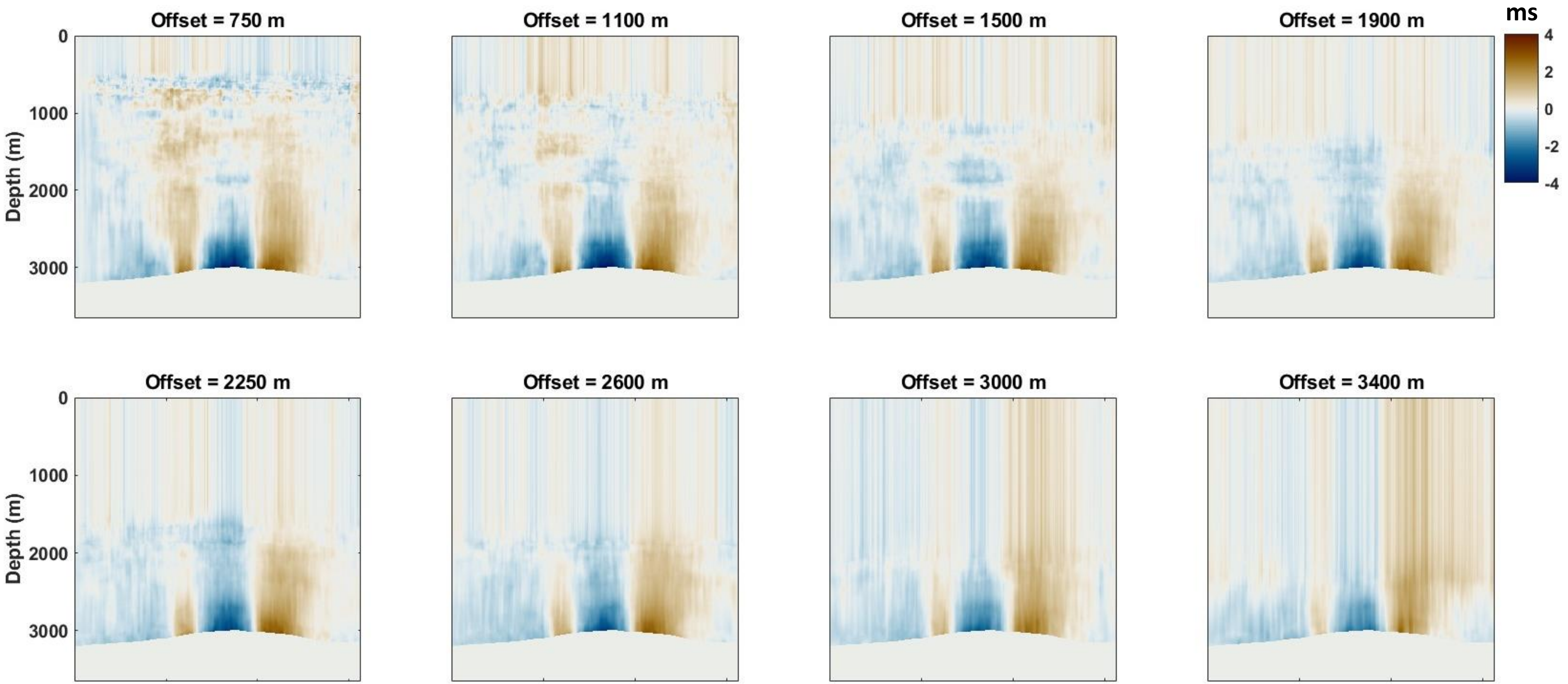


Application to North Sea Data

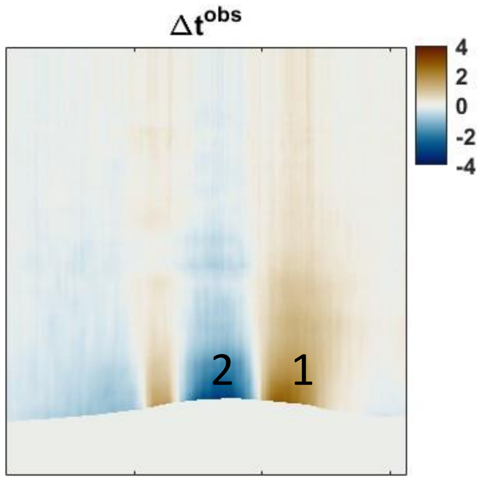


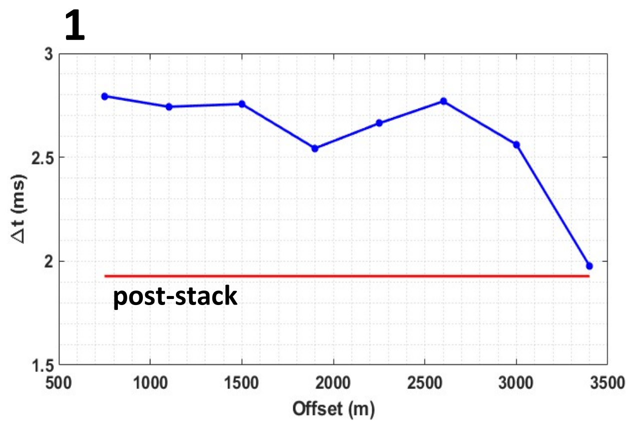
- Compacting reservoir.
- Pressure from flow simulation.
- Vertical strain from geomechanical simulation.
- Seismic and pressure may differ.
- R-factor measurement is semi-quantitative.

Pre-Stack Time-Shifts

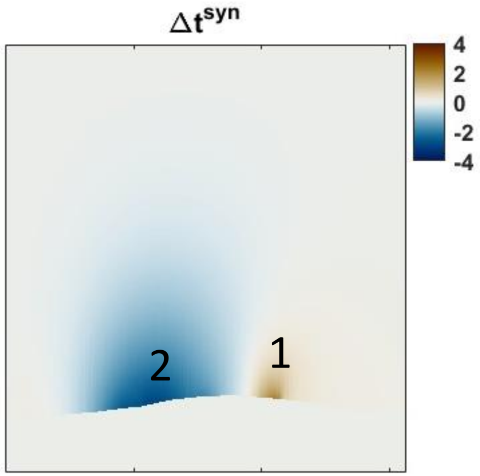


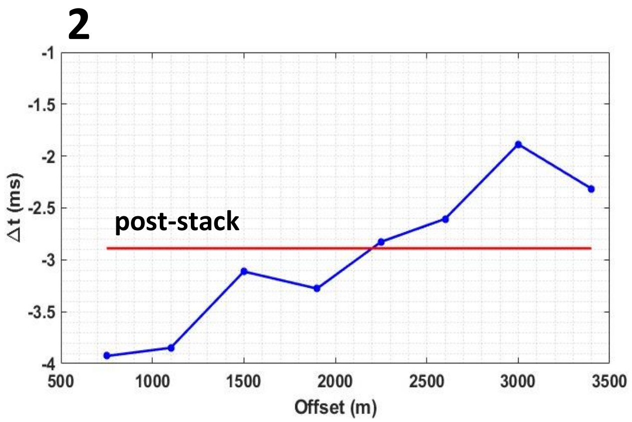
Post-Stack Time-Shift vs Pre-Stack Time-Shift





- Massive drop in time-shift at far offsets (1.5 ms).
- Very non-linear behaviour.
- Post-stack time-shift is far from average.





- Massive increase in time-shift (2 ms) from near to far offsets.
- Post-stack time-shift is close to average.
- Post-stack time-shift is controlled by mid offsets.

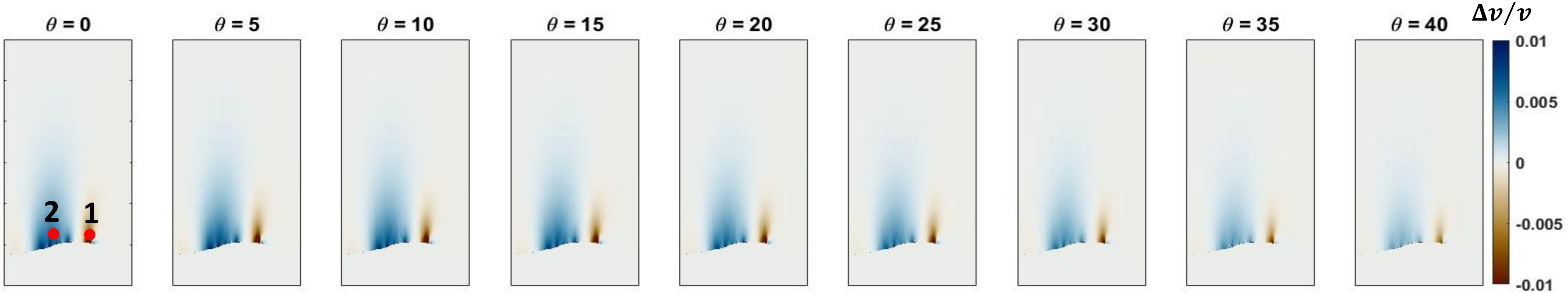
Pre-Stack R-Factors

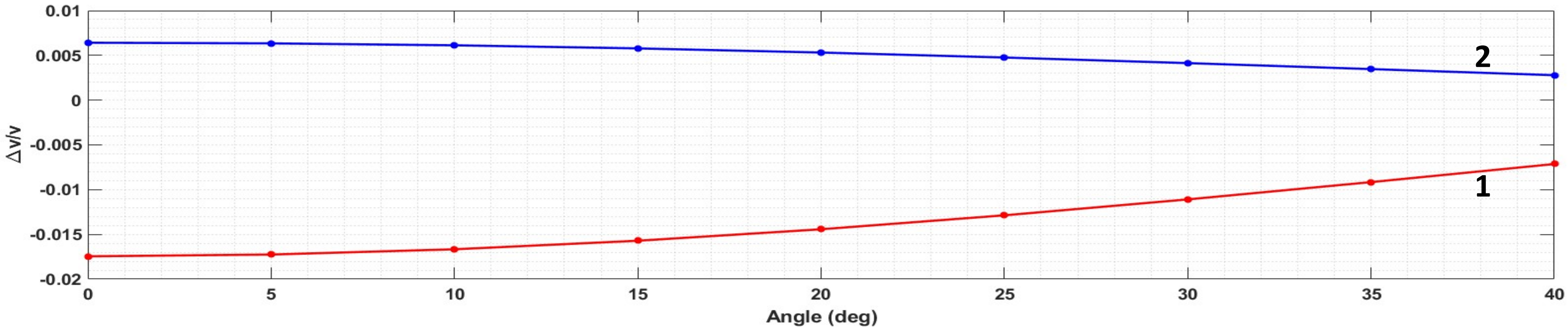
R_1	R_2	R_3	$R_1:R_3$	$R_2:R_3$	$\Delta\delta$	$\Delta\varepsilon$	Lithology	Reference
227	96	−116	−1.9	−0.8	0.1	0.1	North Sea Shale	Prioul et al. (2004)
207	38	−16	−12.9	−2.4	0.2	0.2	Colton Sandstone	Prioul et al. (2004)
626	−24	−21	−29.4	1.1	0.6	0.6	Berea Sandstone	Sarkar et al. (2003)
363	53	−8	−46.0	−6.8	0.3	0.3	Buff Sandstone	Winkler and Liu (1996)
465	144	55	8.5	2.6	0.3	0.3	Hanson Sandstone	Winkler and Liu (1996)
2536	545	154	16.5	3.5	2.0	2.0	Massilon Sandstone	Winkler and Liu (1996)
140	39	17	8.0	2.2	0.1	0.1	Portland Sandstone	Winkler and Liu (1996)
1237	348	19	66.0	18.6	0.9	0.9	Westerly Sandstone	Winkler and Liu (1996)
843	162	−156	−5.4	−1.0	0.7	0.7	Berea Sandstone (a)	Winkler and Liu (1996)
1686	402	121	13.9	3.3	1.3	1.3	Berea Sandstone (b)	Winkler and Liu (1996)

- **Lab measurements can be orders of magnitude larger than field measurements.**
- **R2 is a fraction of R1.**

*MacBeth and Bachkheti (2022)

Anisotropic $\Delta v/v$





3 R-Factor Models

1) Post-Stack:

$$\frac{\Delta v}{v} = -R\varepsilon_{zz}$$

2) Pre-Stack, Isotropic:

$$\frac{\Delta v}{v} = -(R_1 - R_2)\varepsilon_{zz} - R_2\varepsilon_{vol}$$

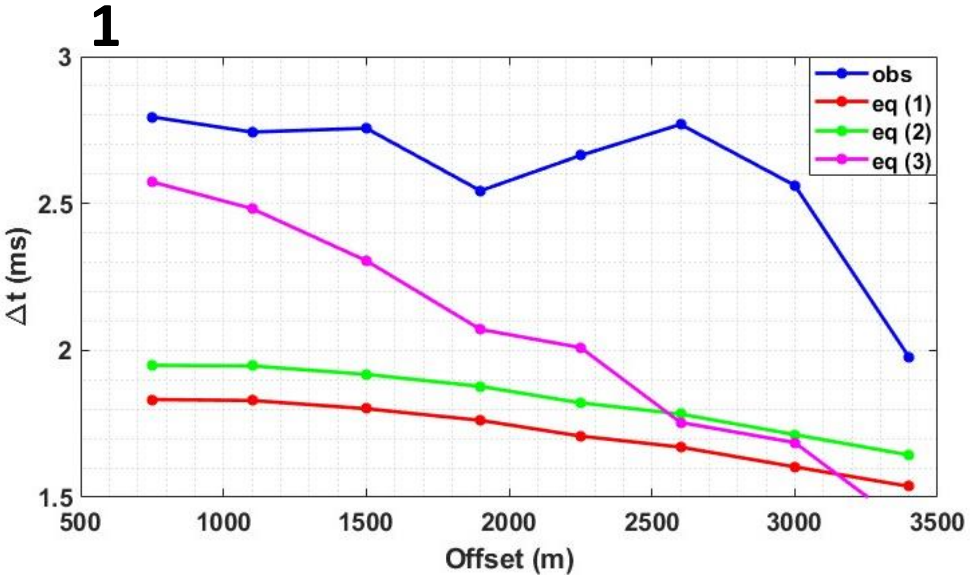
3) Pre-Stack, Anisotropic:

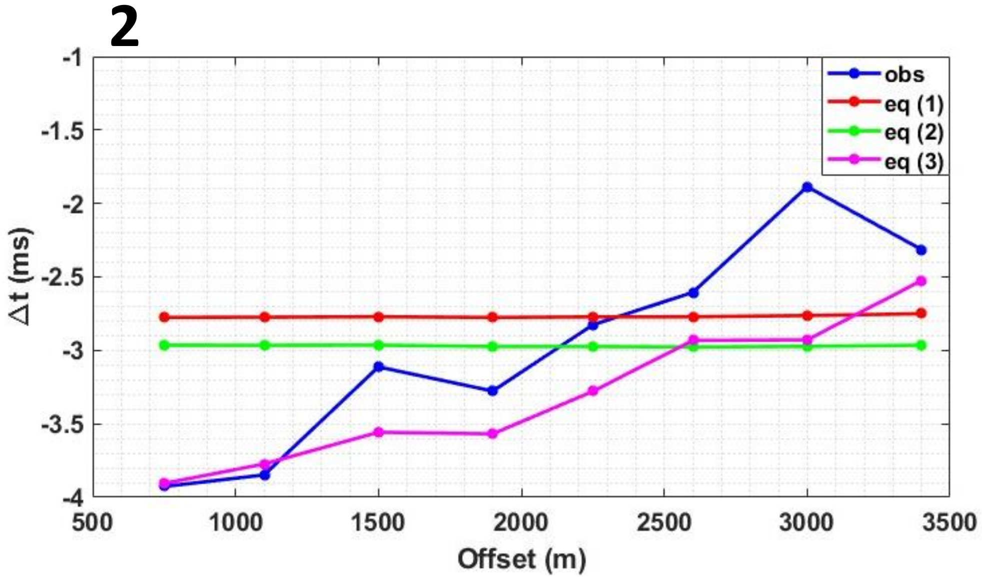
$$\frac{\Delta v}{v}(\theta) = [-(R_1 - R_2)\varepsilon_{zz} - R_2\varepsilon_{vol}] +$$

$$[(R_1 - R_2)(\varepsilon_{zz} - \varepsilon_h) + (R_1 - R_2)\varepsilon_{vol}]sin^2(\theta)cos^2(\theta) +$$

$$[(R_1 - R_2)(\varepsilon_{zz} - \varepsilon_h)]sin^4(\theta)$$

Pre-Stack R-Factor Measurement





	R1	R2	R
Post-Stack	-	-	6
Pre-Stack Isotropic	8	2	-
Pre-Stack Anisotropic	10.5	3.5	-

- $R_1 - R_2 \approx R$
- **R2 is a fraction of R1.**

Conclusions

- **Time-lapse changes are indeed anisotropic.**
- **Lateral strain changes affect the 4D velocity changes.**
- **The proposed R-factor model captures the anisotropy in 4D changes.**

Acknowledgements

We thank the sponsors of the Edinburgh Time-Lapse Project, Phase VIII (ADNOC, AkerBP, BHP, BP, CNOOC, ConocoPhilips, ENI, Equinor, ExxonMobil, Harbour Energy, Neptune Energy, Petoro, Petrobras, Sharp Reflections, Shell, TAQA, Tullow Oil, Woodside) for supporting this research.

Thank You

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