Double-wavelet double-difference time-lapse waveform inversion

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Outline

- Well-control waveform inversion
- Time-lapse inversion strategies
- Double-wavelet double-difference time-lapse waveform inversion (DWDDWI)
- Conclusions

Waveform inversion

1) Data residuals $\delta d = d_0 - d_m$

2) Reflectivity residual $\delta R = Stk[Mig(\delta d)]$

3) Gradient $g = Imp(\delta R)$

4) Velocity perturbation $\delta m = \lambda g$

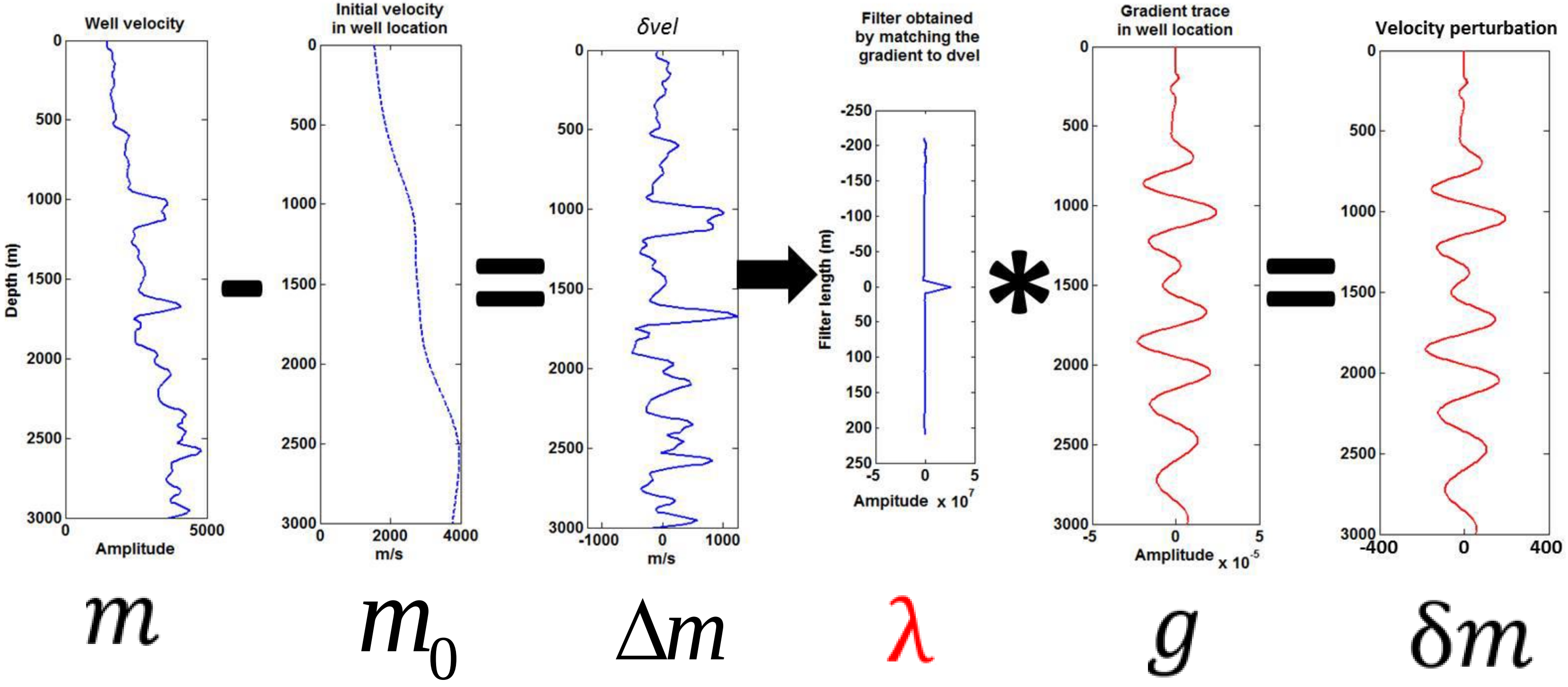
5) Velocity update $m_{k+1} = m_k + \delta m$

(Margrave et al., 2010; Romahn, 2019)

Log validation

$$\delta m = \lambda g$$

- Log calibration
- Minimize difference between the gradient & δvel in the well



(Romahn and Innanen, 2016)

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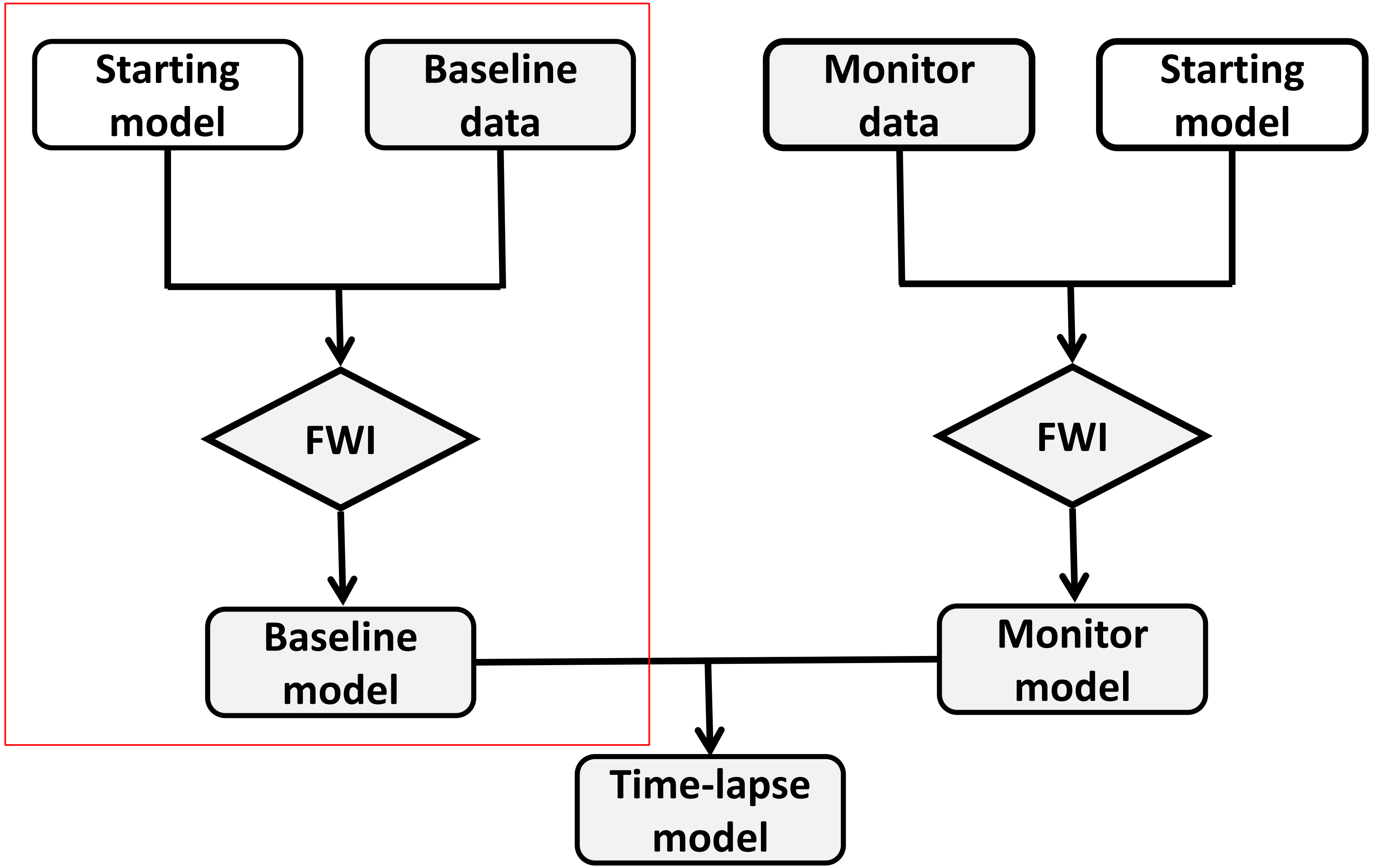
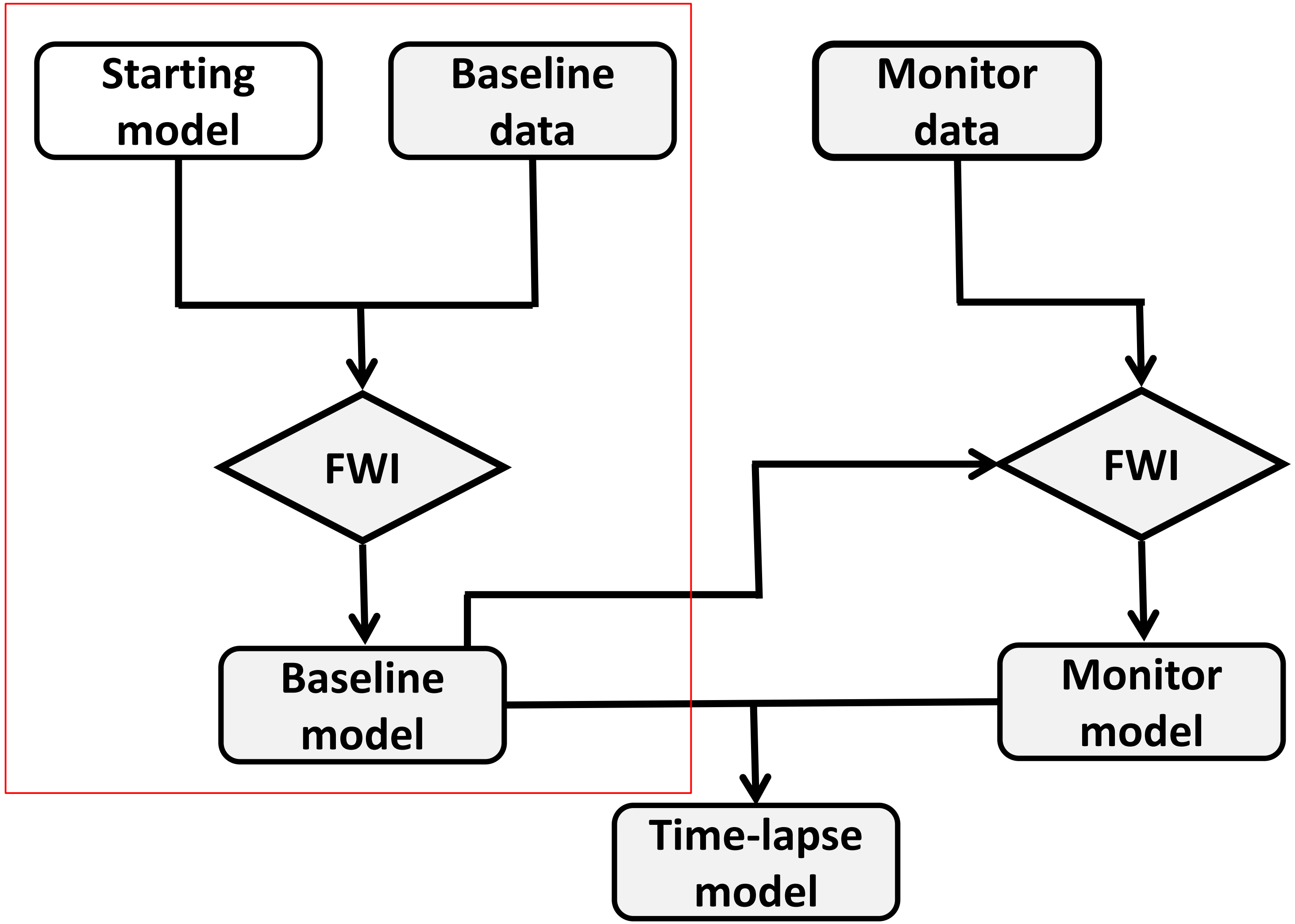
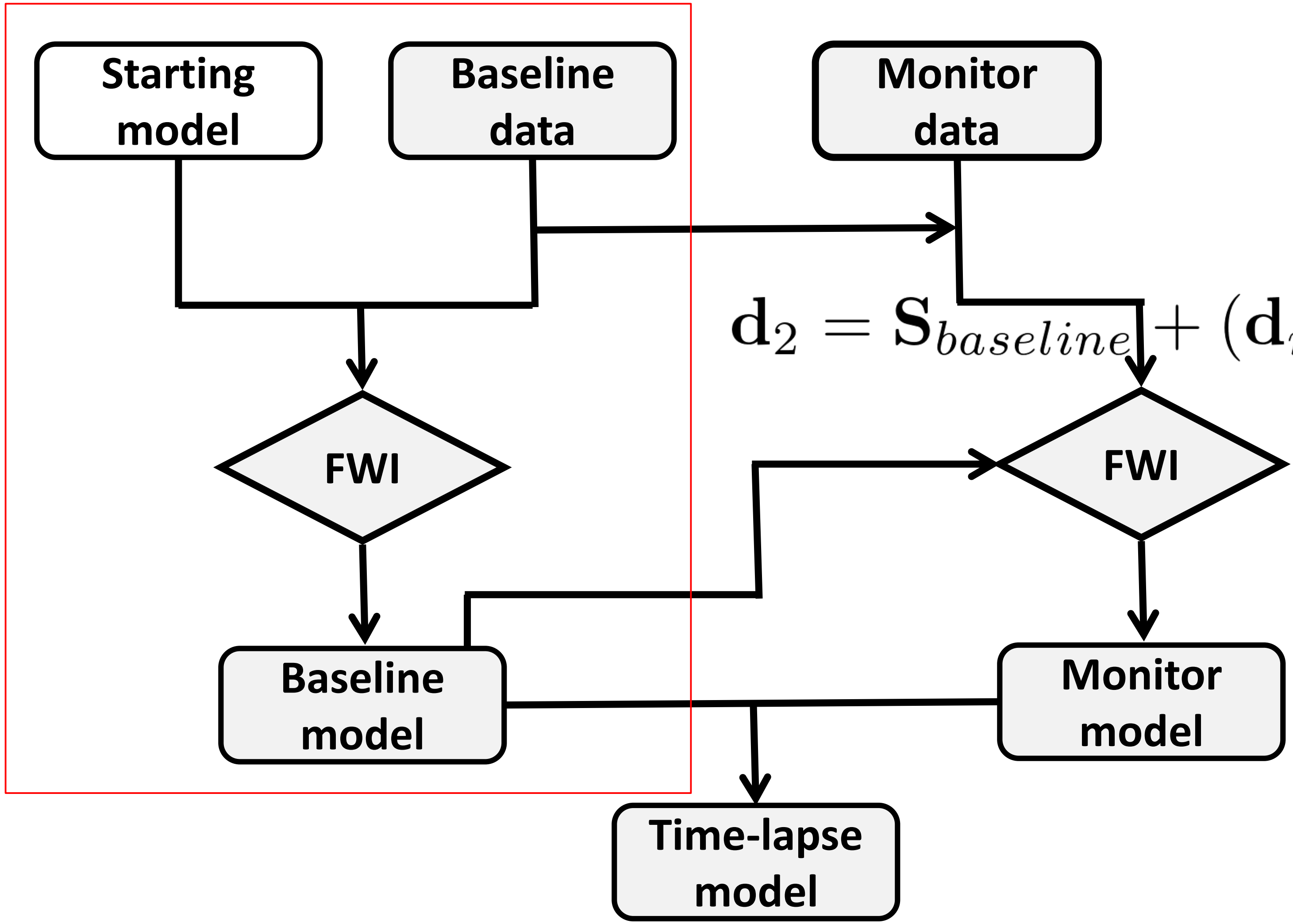
Parallel difference strategy



Sequential difference strategy



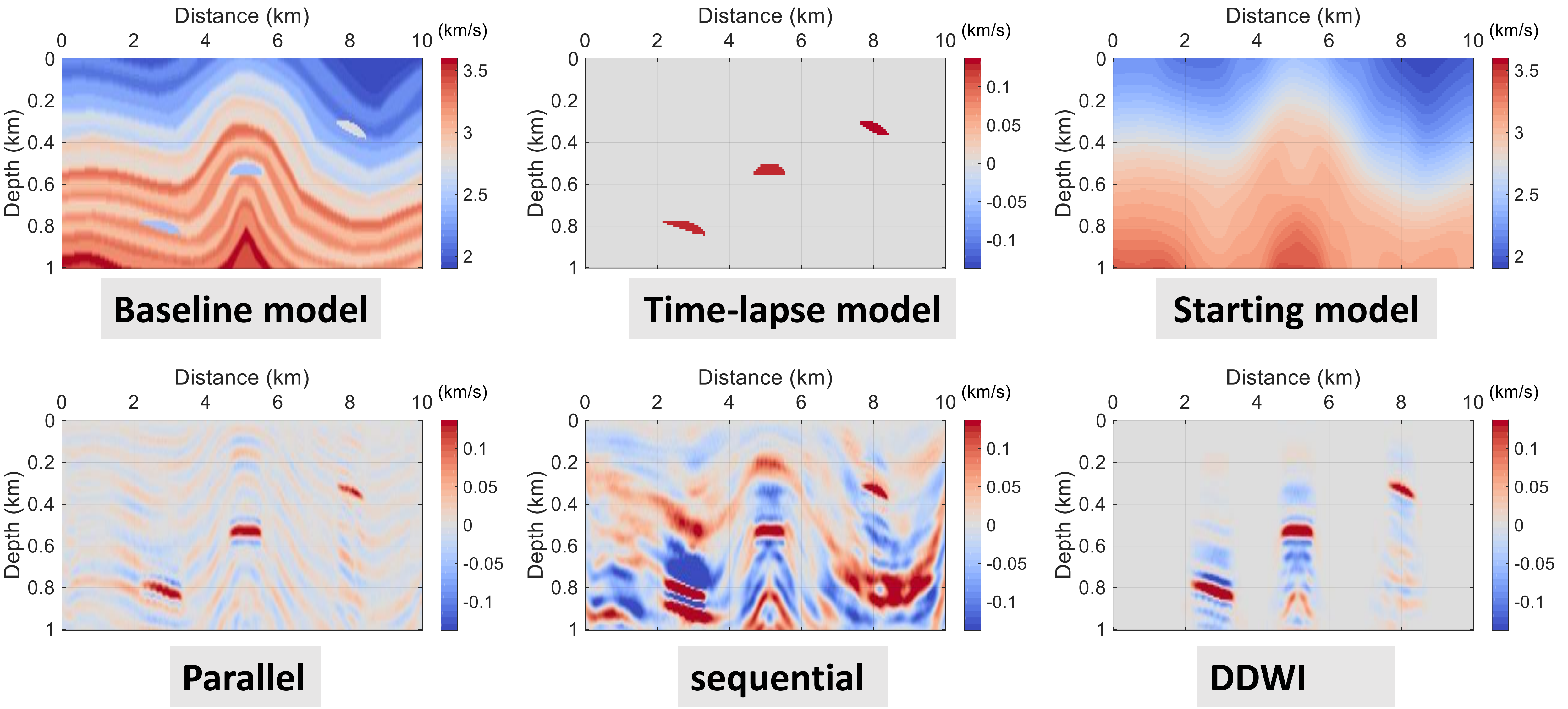
Double-difference strategy (DDWI)



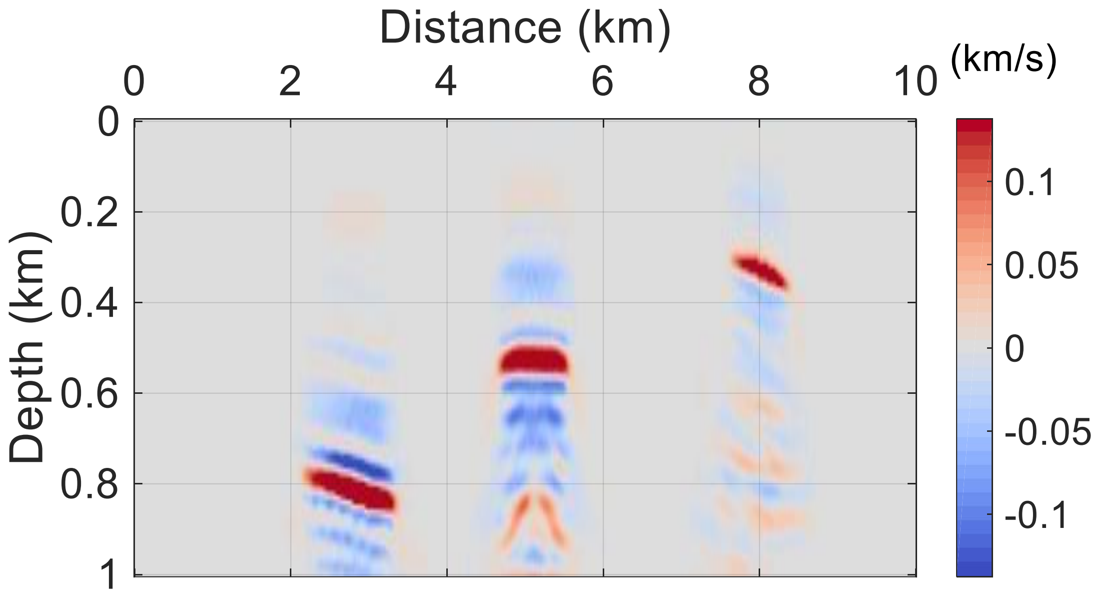
$$\mathbf{d}_2 = \mathbf{S}_{baseline} + (\mathbf{d}_{monitor} - \mathbf{d}_{baseline})$$

$$E_{DDWI} = \frac{1}{2}\|\mathbf{d}_2 - \mathbf{S}_2\|^2 = \frac{1}{2}\|(\mathbf{d}_{monitor} - \mathbf{S}_{monitor}) - (\mathbf{d}_{baseline} - \mathbf{S}_{baseline})\|^2$$

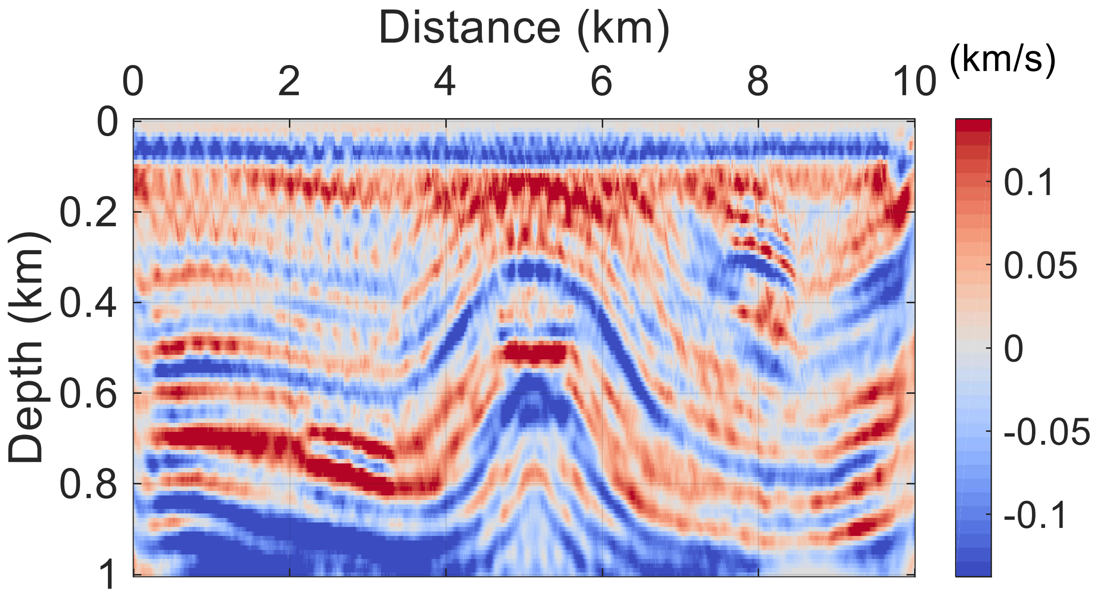
Numerical example



Double-difference strategy (DDWI)



DDWI
Wavelets for baseline and monitor data are the same



DDWI
Wavelets for baseline and monitor data are different

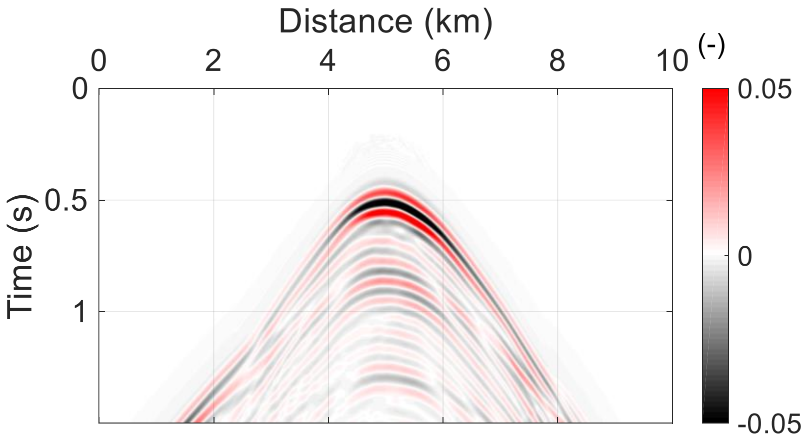
Double-difference strategy (DDWI)

DDWI $$\mathbf{d}_2 = \mathbf{S}_{baseline} + (\mathbf{d}_{monitor} - \mathbf{d}_{baseline})$$

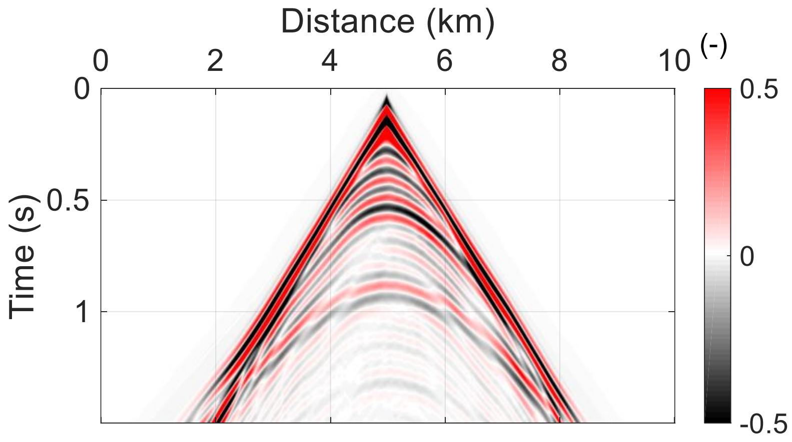
$$= \mathbf{S}_{baseline} + (\mathbf{W}_{monitor} * \mathbf{G}_{monitor} - \mathbf{W}_{baseline} * \mathbf{G}_{baseline})$$

when $\mathbf{W}_{monitor} = \mathbf{W}_{baseline} = \mathbf{W}$

$$\mathbf{d}_2 = \mathbf{S}_{baseline} + \mathbf{W} * (\mathbf{G}_{monitor} - \mathbf{G}_{baseline})$$



$\mathbf{W}_{monitor} = \mathbf{W}_{baseline}$



$\mathbf{W}_{monitor} \neq \mathbf{W}_{baseline}$

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Double-wavelet double-difference time-lapse waveform inversion (DWDDWI)

DDWI $$\mathbf{d}_2 = \mathbf{S}_{baseline} + (\mathbf{d}_{monitor} - \mathbf{d}_{baseline})$$

$$= \mathbf{S}_{baseline} + (\mathbf{W}_{monitor} * \mathbf{G}_{monitor} - \mathbf{W}_{baseline} * \mathbf{G}_{baseline})$$

New monitor data New baseline data

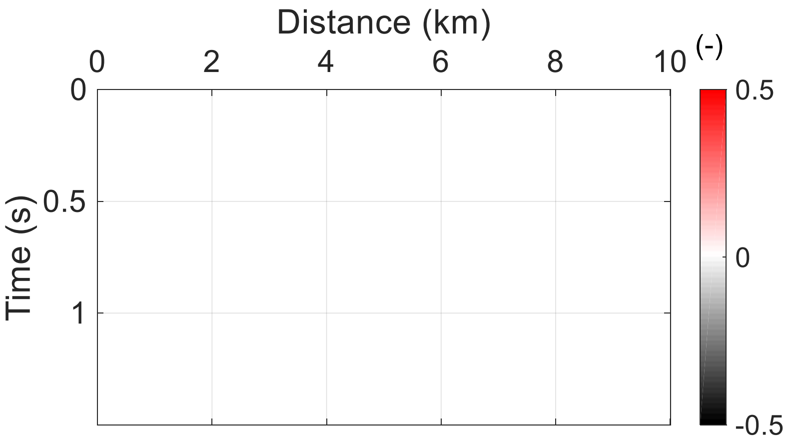
DWDDWI $$\mathbf{d}'_2 = \mathbf{S}'_{baseline} + (\mathbf{W}_{baseline} * \mathbf{d}_{monitor} - \mathbf{W}_{monitor} * \mathbf{d}_{baseline})$$

$$= \mathbf{S}'_{baseline} + (\mathbf{W}_{baseline} * \mathbf{W}_{monitor} * \mathbf{G}_{monitor} - \mathbf{W}_{monitor} * \mathbf{W}_{baseline} * \mathbf{G}_{baseline})$$

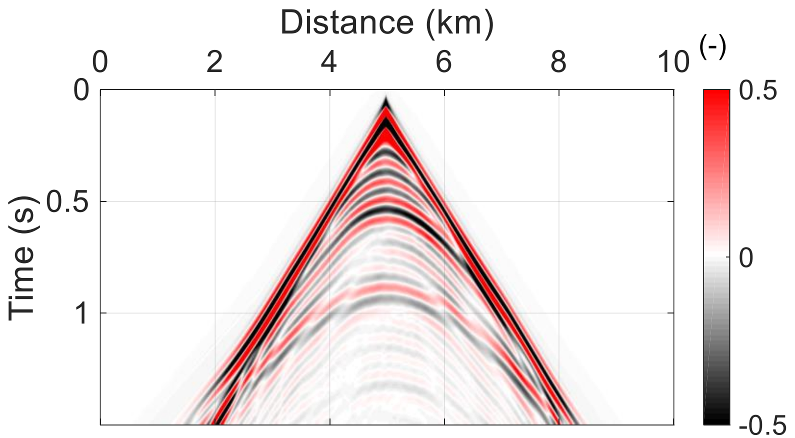
$$= \mathbf{S}'_{baseline} + \mathbf{W} * (\mathbf{G}_{monitor} - \mathbf{G}_{baseline})$$

where $\mathbf{W}_{baseline} * \mathbf{W}_{monitor} = \mathbf{W}_{monitor} * \mathbf{W}_{baseline} = \mathbf{W}$

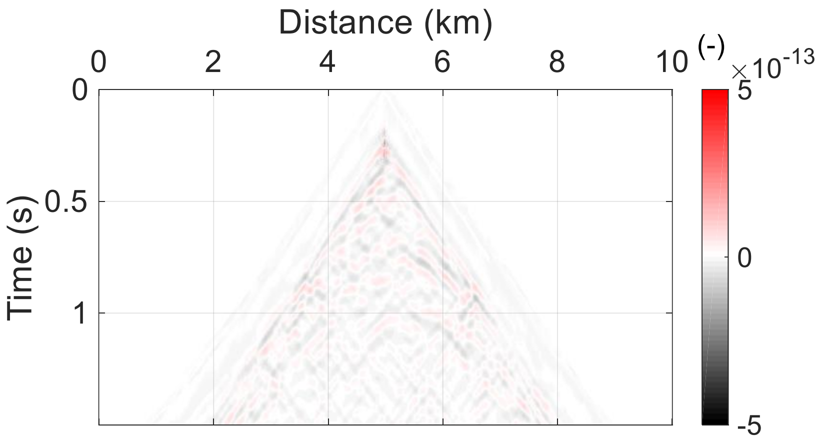
Data difference



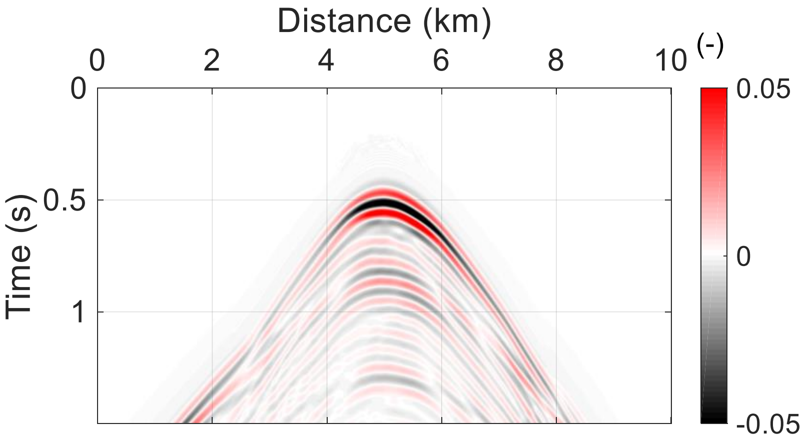
$$\mathbf{d}_{baseline}(10Hz) - \mathbf{d}_{baseline}(10Hz)$$



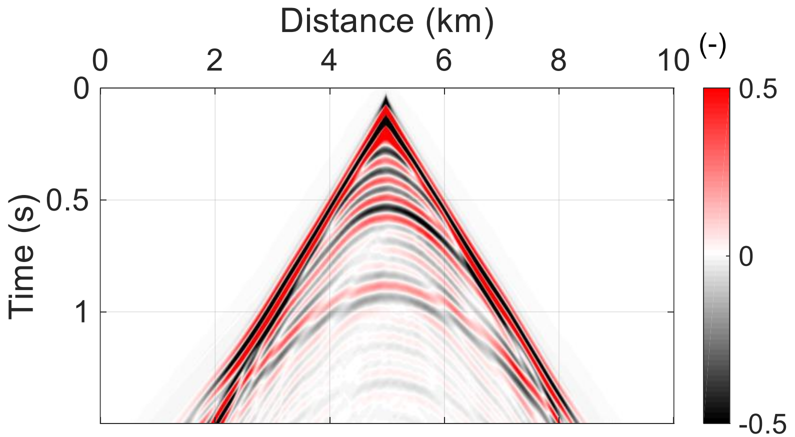
$$\mathbf{d}_{baseline}(10Hz) - \mathbf{d}_{baseline}(8Hz)$$



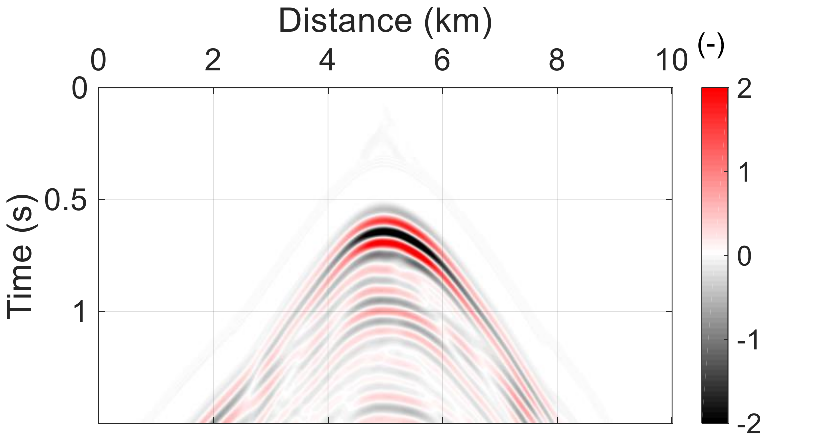
$$\mathbf{w}(8Hz) * \mathbf{d}_{baseline}(10Hz) - \mathbf{w}(10Hz) * \mathbf{d}_{baseline}(8Hz)$$



$$\mathbf{d}_{monitor}(10Hz) - \mathbf{d}_{baseline}(10Hz)$$

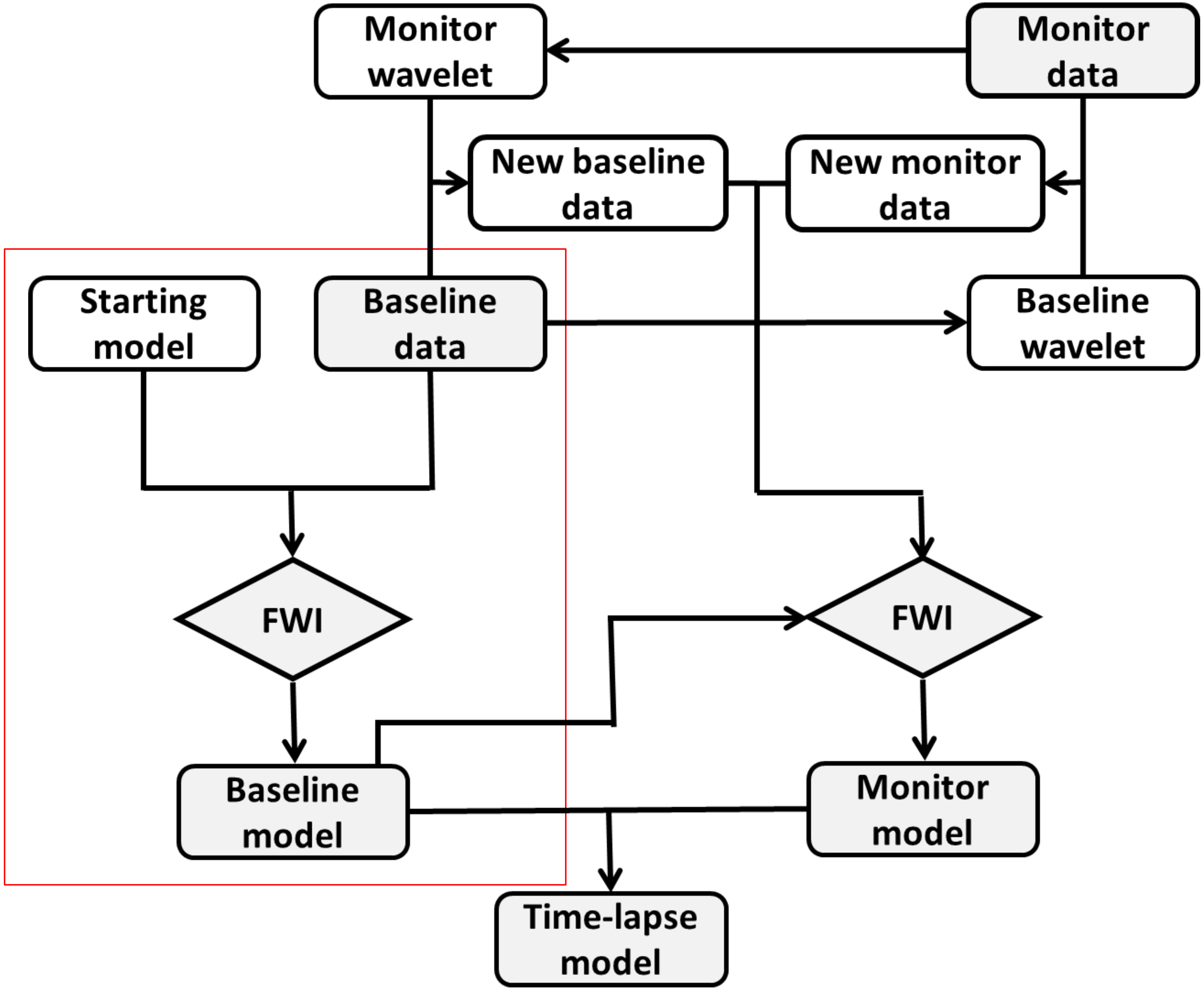


$$\mathbf{d}_{monitor}(10Hz) - \mathbf{d}_{baseline}(8Hz)$$

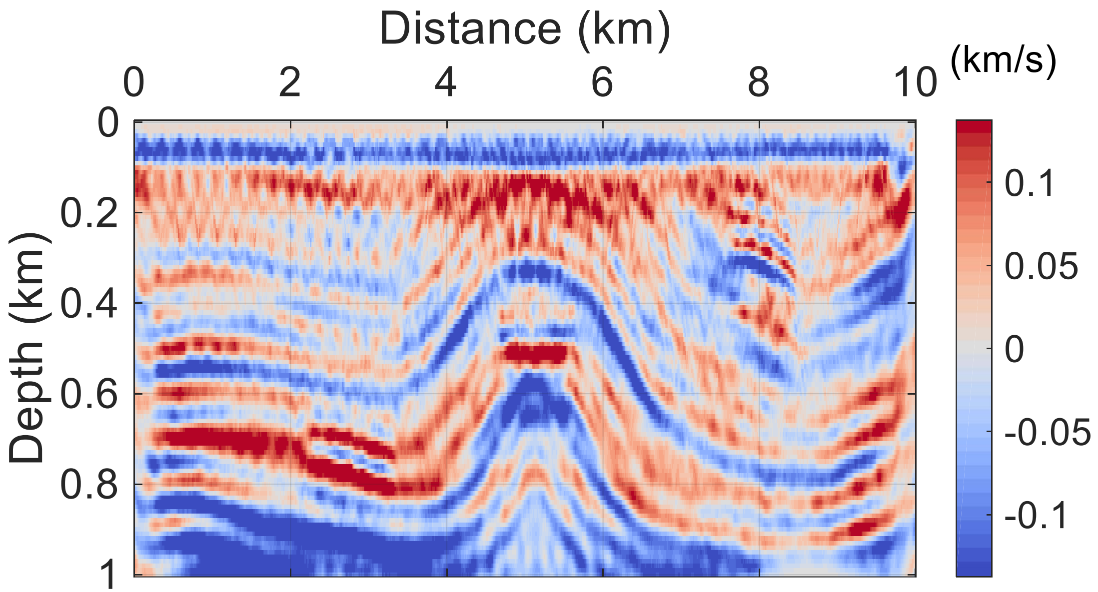


$$\mathbf{w}(8Hz) * \mathbf{d}_{monitor}(10Hz) - \mathbf{w}(10Hz) * \mathbf{d}_{baseline}(8Hz)$$

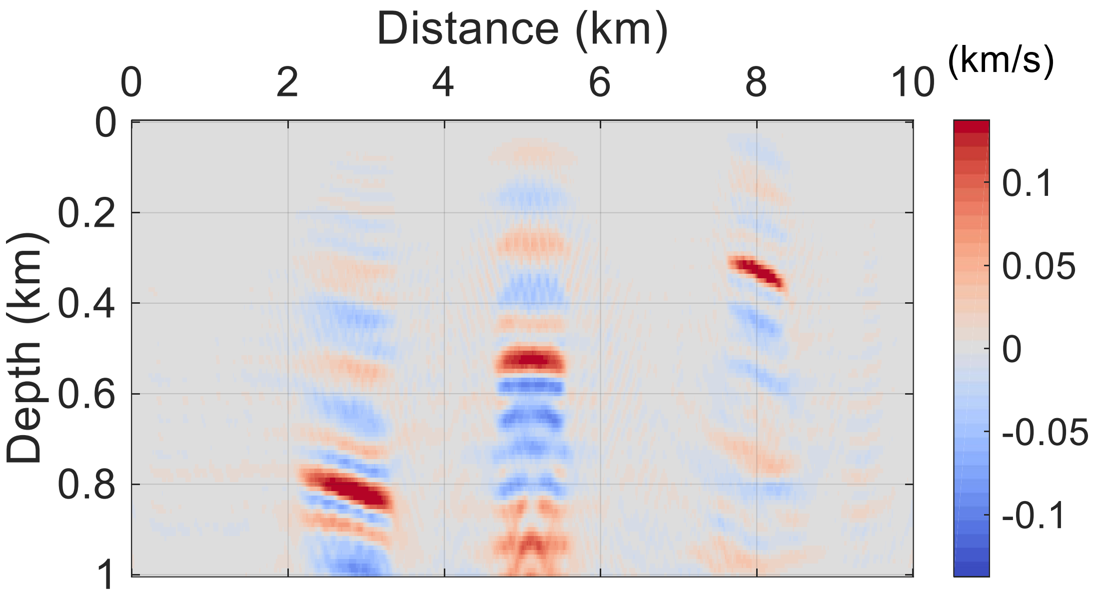
Double-wavelet double-difference strategy (DWDDWI)



Different wavelets



DDWI
Wavelets for baseline and monitor data are different



DWDDWI
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Conclusions

- ✓ DDWI is not easy to be affected by the different convergences of baseline and monitor inversions
- ✓ DDWI demands an almost perfect repeatability between the two surveys
- ✓ DWDDWI can handle well with the situation of wavelets for the two datasets are different
- ✓ DWDDWI works because the data difference caused by the wavelet difference is eliminated.
- ✓ The premise is that the two wavelets are known

Acknowledges

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Thank you!