

Double-wavelet double-difference time-lapse waveform inversion

Xin Fu*, Sergio Romahn, Kris Innanen

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- ❑ 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

$$\delta R = \text{Stk}[\text{Mig}(\delta d)]$$

3) Gradient

$$g = \text{Imp}(\delta R)$$

4) Velocity perturbation

$$\delta m = \lambda g$$

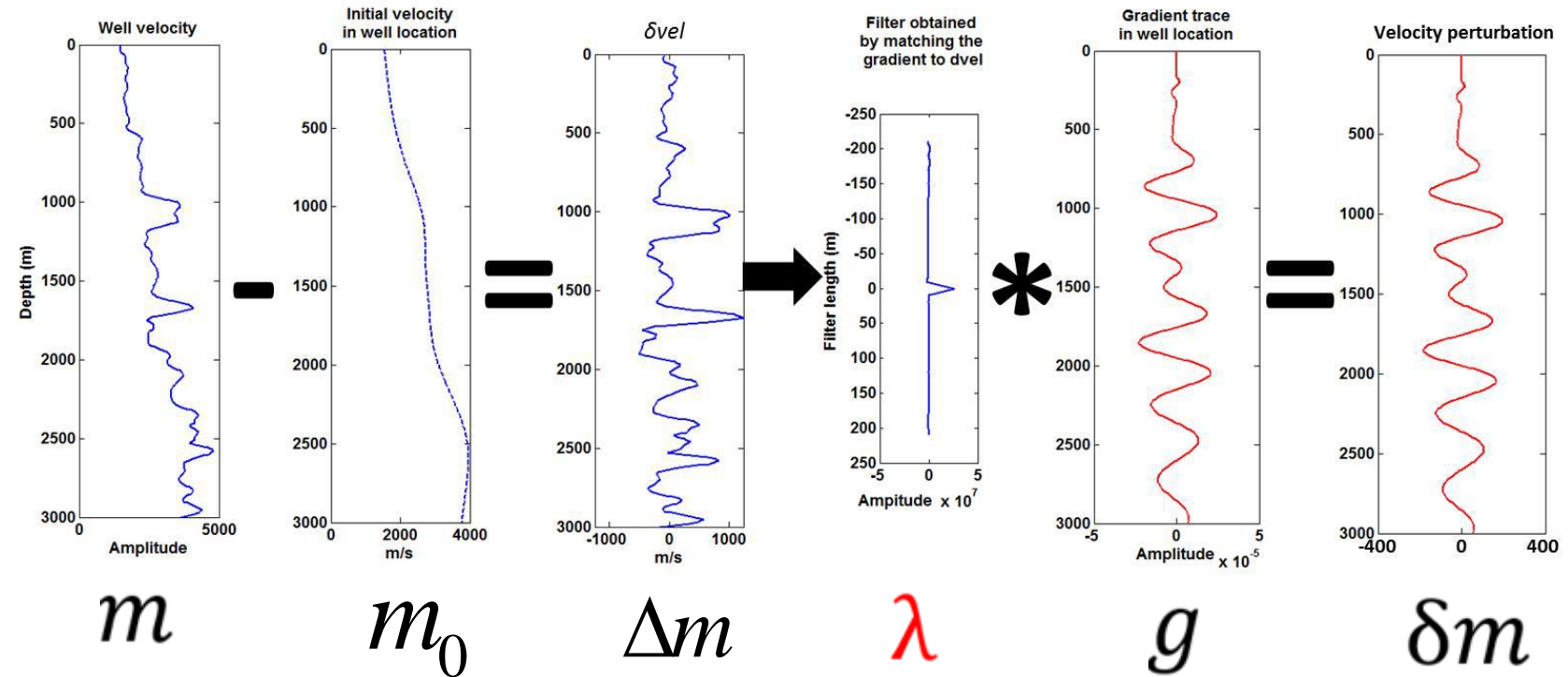
5) Velocity update

$$m_{k+1} = m_k + \delta m$$

Log validation

$$\delta m = \lambda g$$

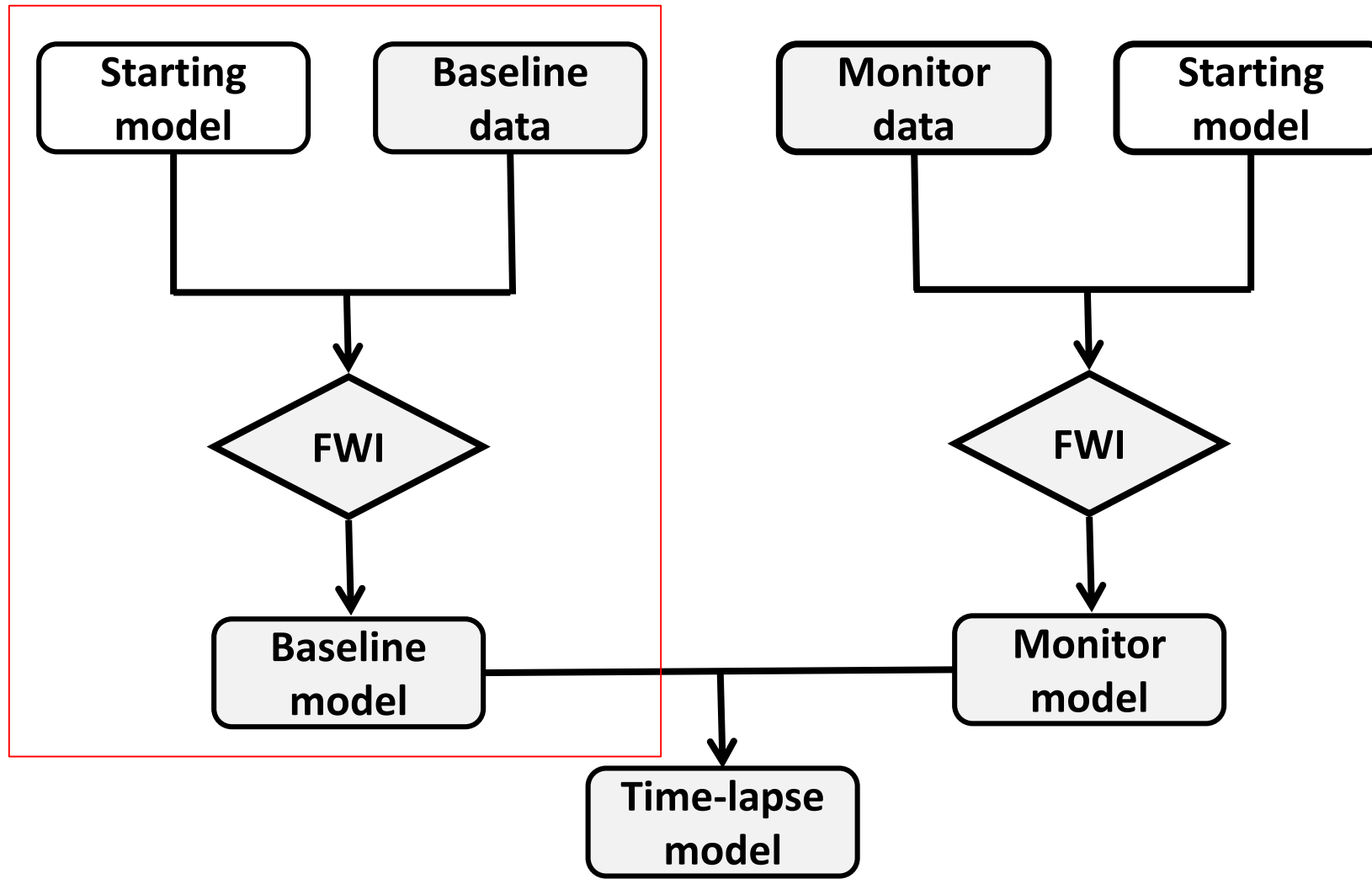
- Log calibration
- Minimize difference between the gradient & δvel in the well

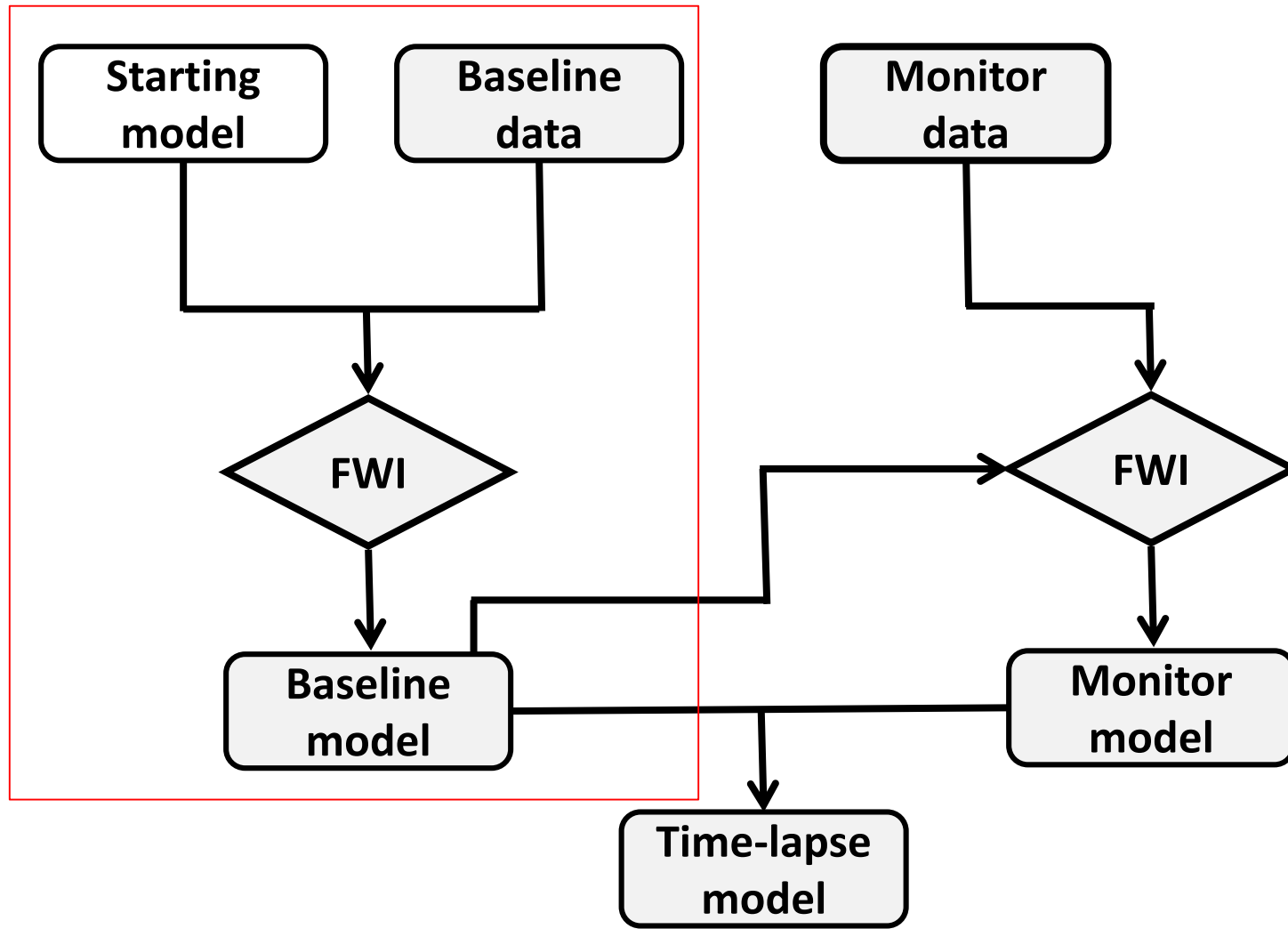


(Romahn and Innanen, 2016)



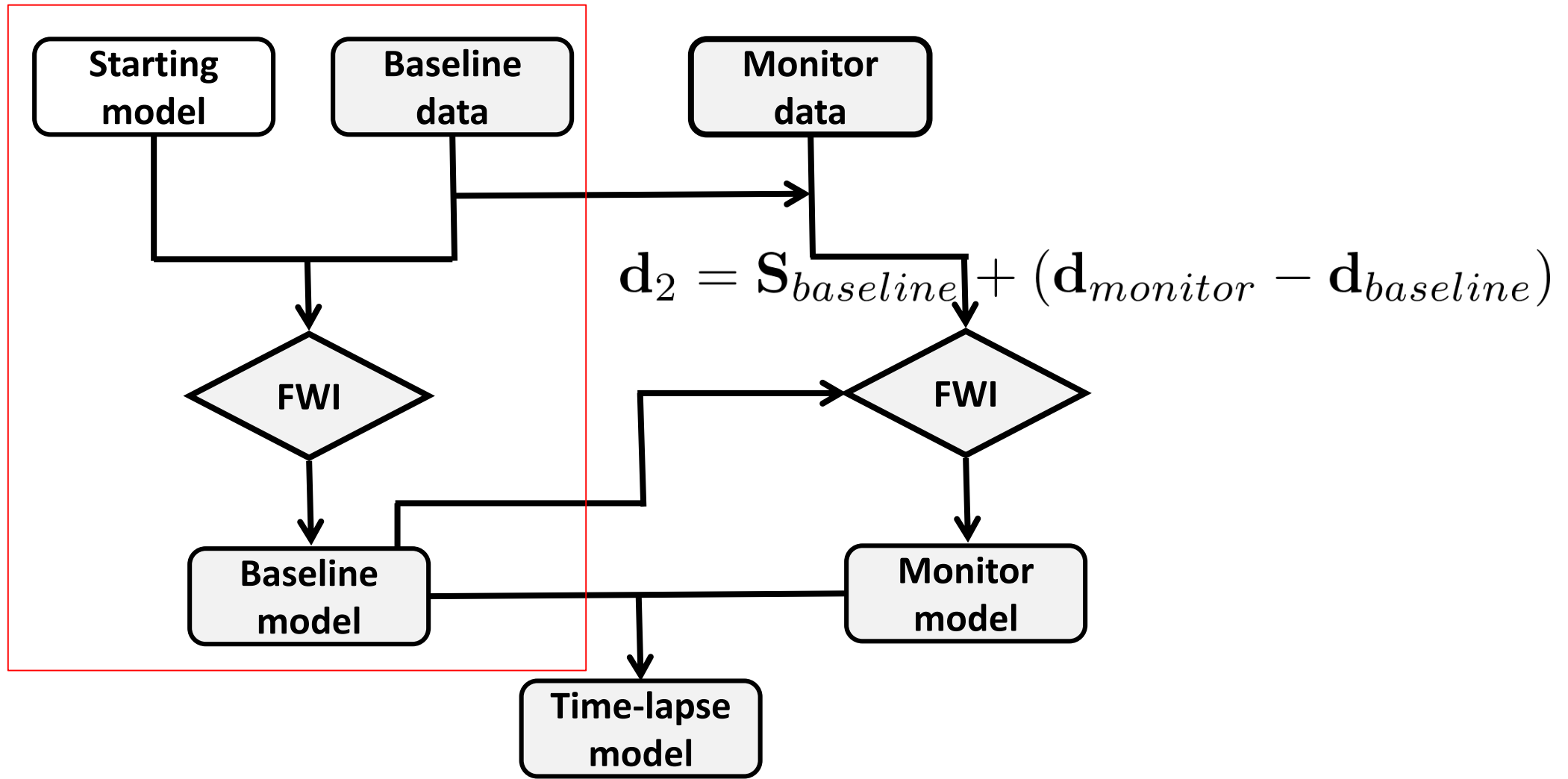
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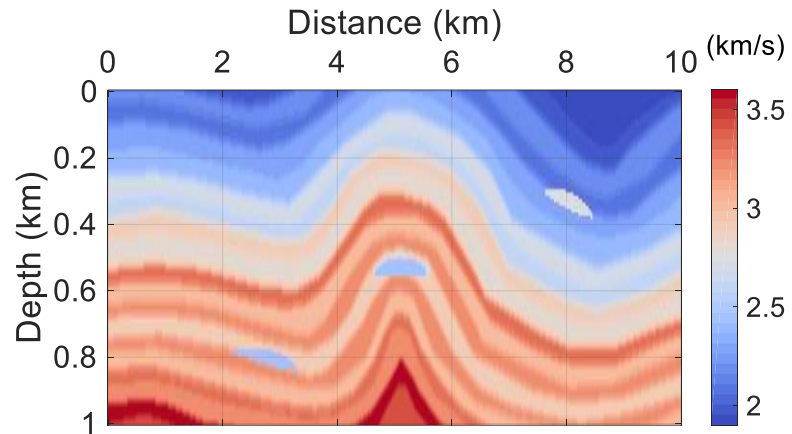
Double-difference strategy (DDWI)



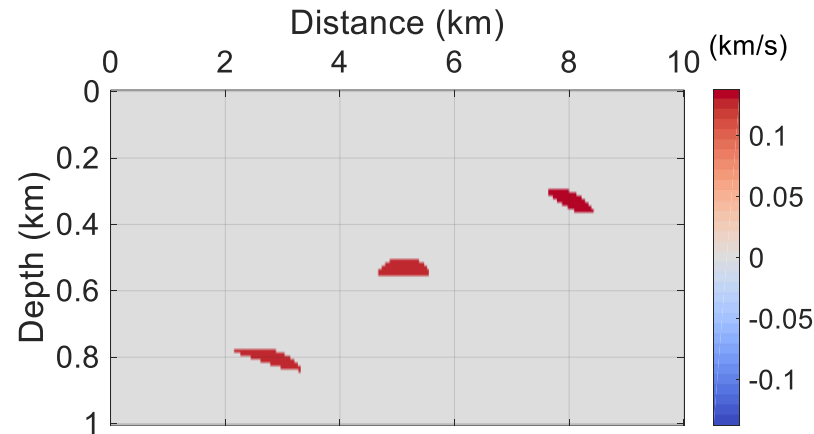
$$E_{DDWI} = \frac{1}{2} \|\mathbf{d}_2 - \mathbf{S}_2\|^2 = \frac{1}{2} \|(\mathbf{d}_{monitor} - \mathbf{S}_{monitor}) - (\mathbf{d}_{baseline} - \mathbf{S}_{baseline})\|^2$$



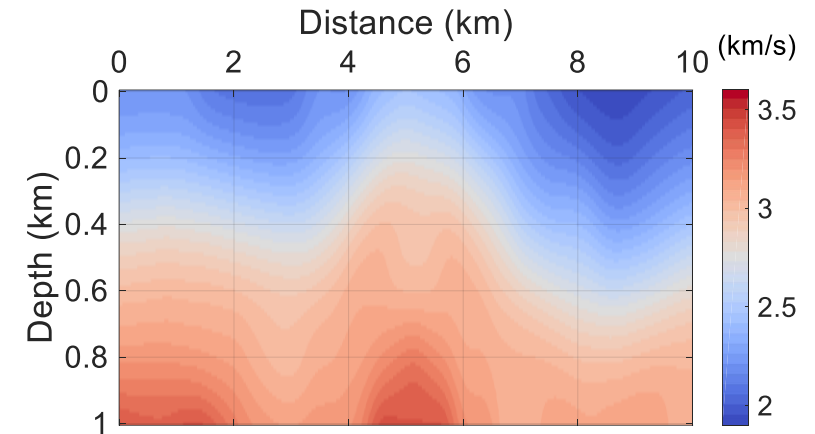
Numerical example



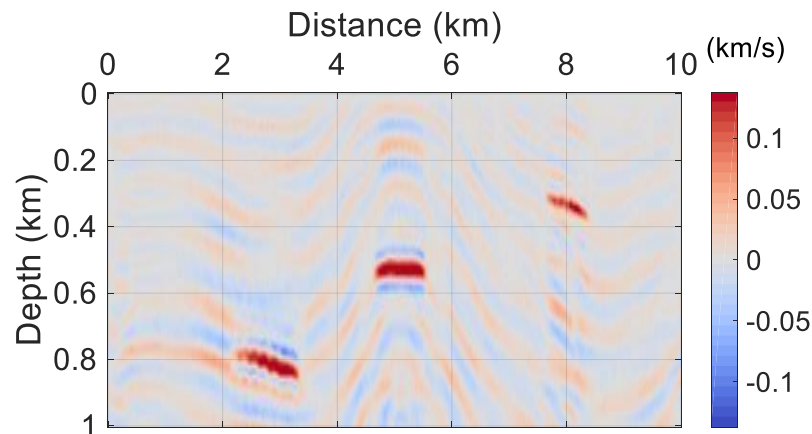
Baseline model



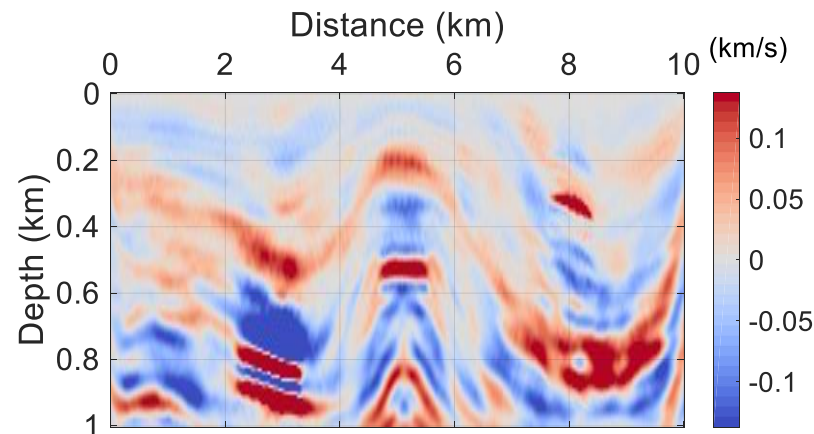
Time-lapse model



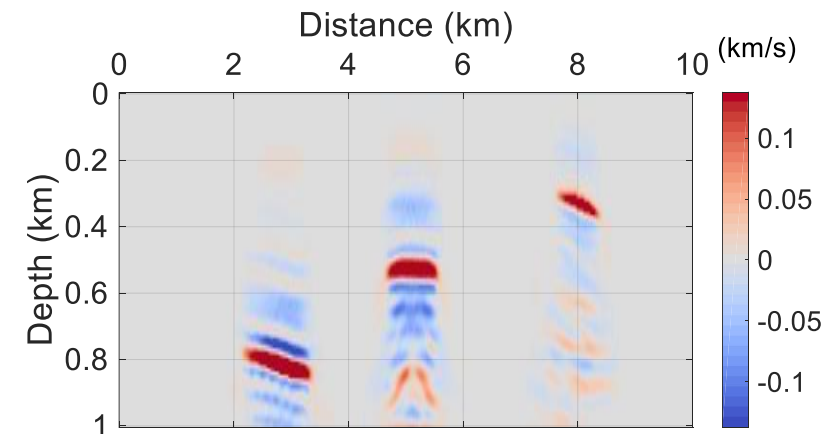
Starting model



Parallel



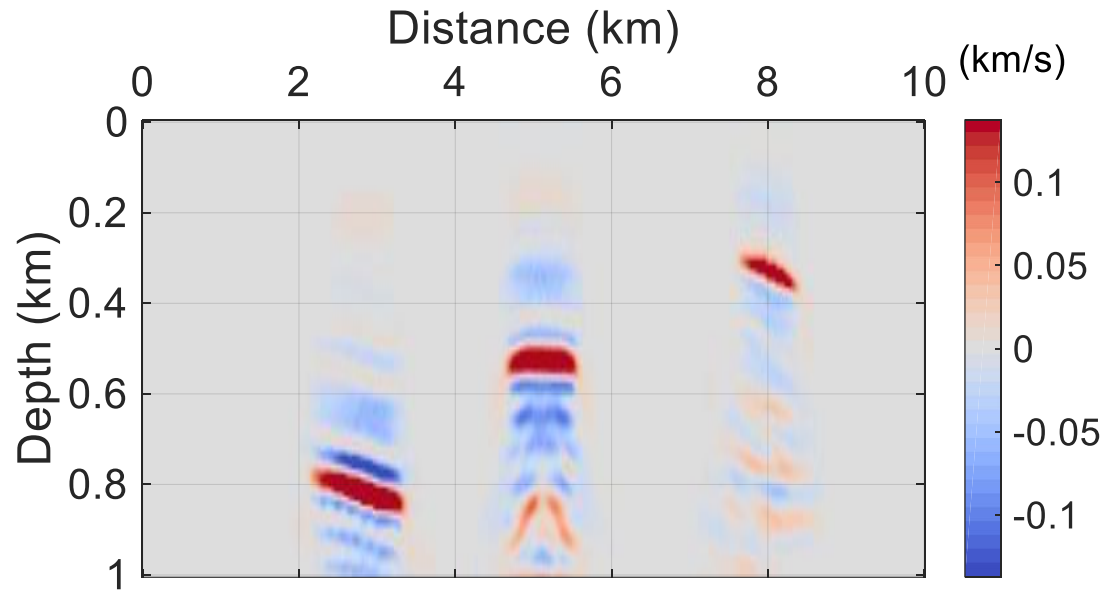
sequential



DDWI

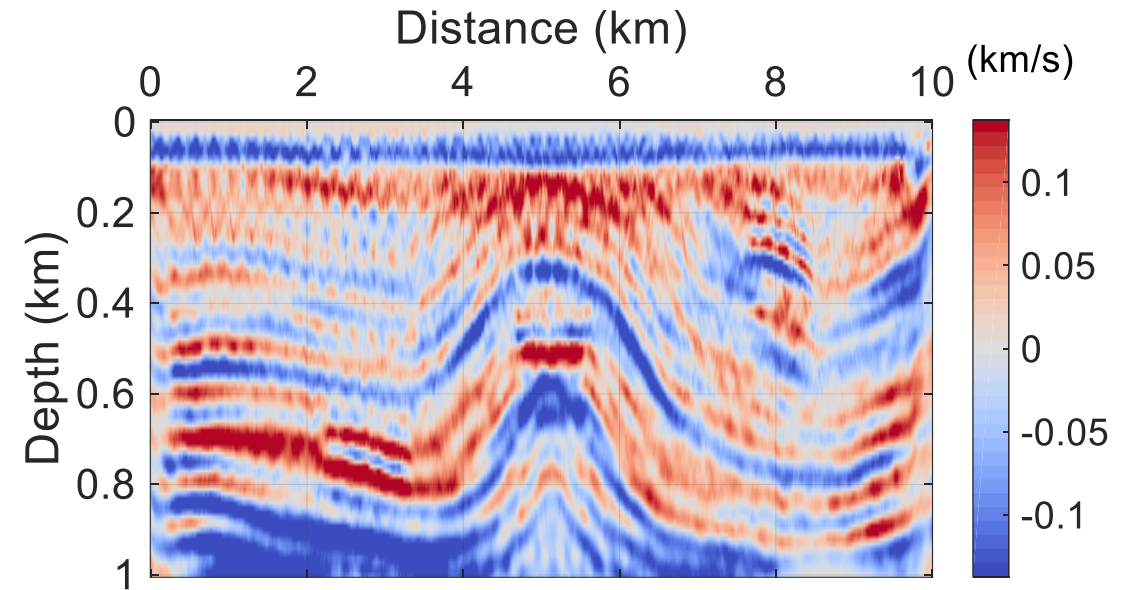


Double-difference strategy (DDWI)



DDWI

Wavelets for baseline and monitor data are the **same**



DDWI

Wavelets for baseline and monitor data are **different**



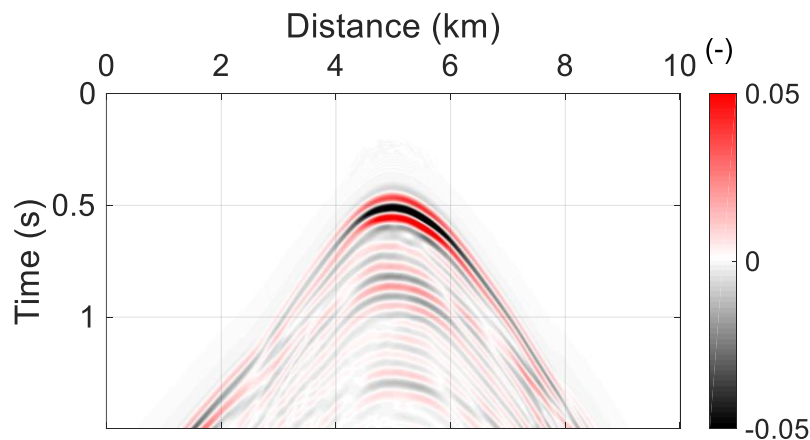
Double-difference strategy (DDWI)

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

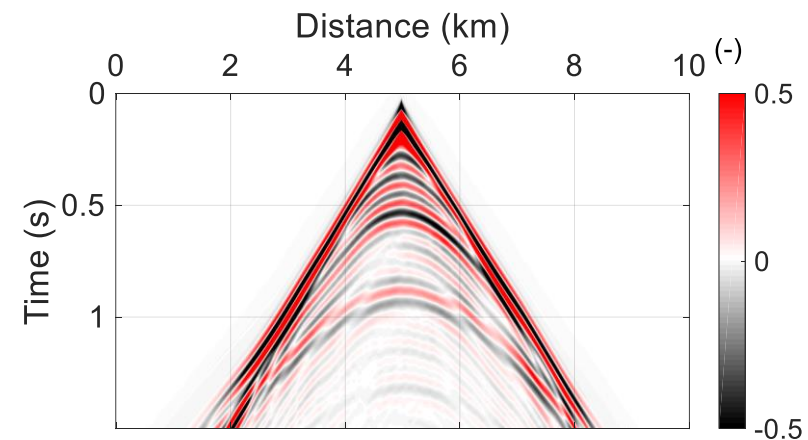
$$= \mathbf{S}_{baseline} + (\mathbf{W}_{monitor} * \mathbf{G}_{monitor} - \mathbf{W}_{baseline} * \mathbf{G}_{baseline})$$

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

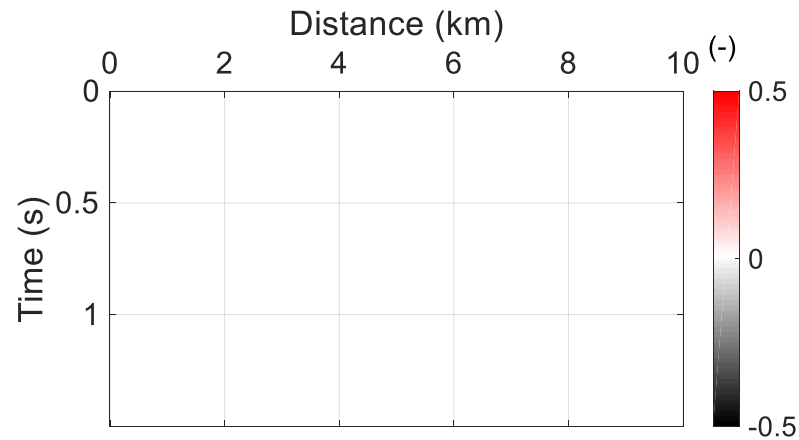
$$= \mathbf{S}'_{baseline} + (\mathbf{W}_{baseline} * \mathbf{W}_{monitor} * \mathbf{G}_{monitor} - \mathbf{W}_{monitor} * \mathbf{W}_{baseline} * \mathbf{G}_{baseline})$$

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

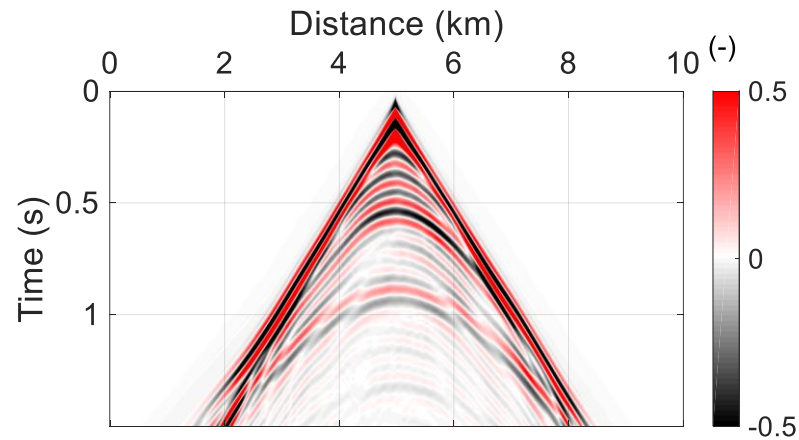
where $\mathbf{W}_{baseline} * \mathbf{W}_{monitor} = \mathbf{W}_{monitor} * \mathbf{W}_{baseline} = \mathbf{W}$



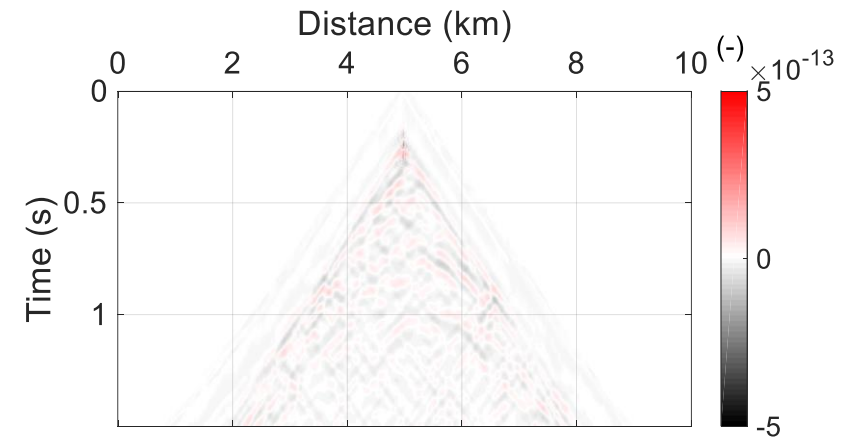
Data difference



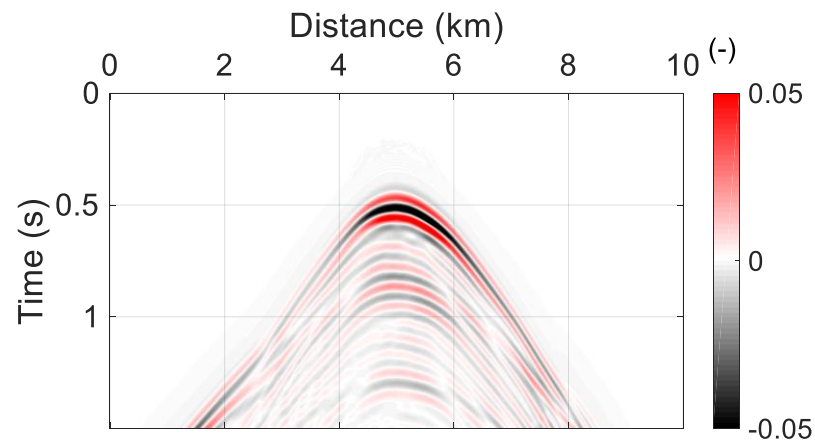
$$\mathbf{d}_{baseline}(10Hz) - \mathbf{d}_{baseline}(10Hz)$$



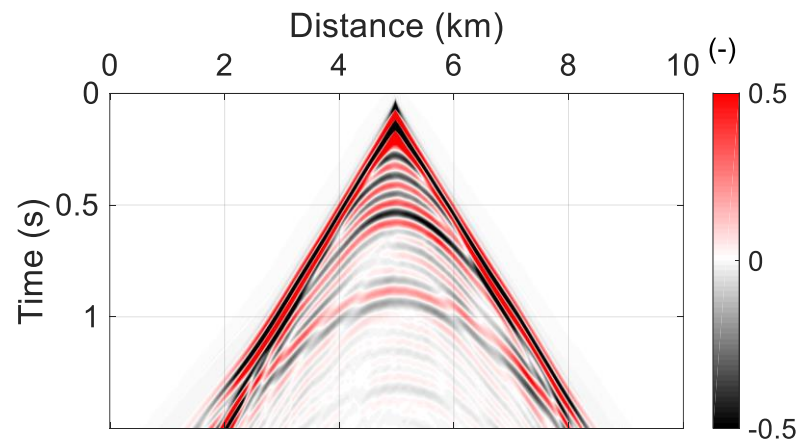
$$\mathbf{d}_{baseline}(10Hz) - \mathbf{d}_{baseline}(8Hz)$$



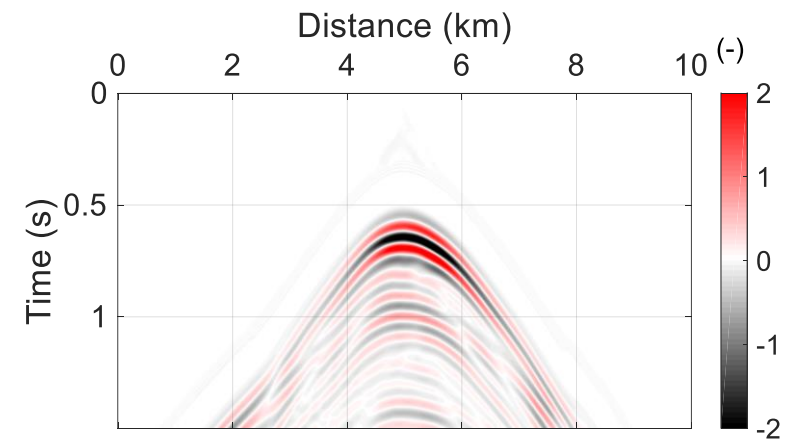
$$\mathbf{w}(8Hz) * \mathbf{d}_{baseline}(10Hz) - \mathbf{w}(10Hz) * \mathbf{d}_{baseline}(8Hz)$$



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



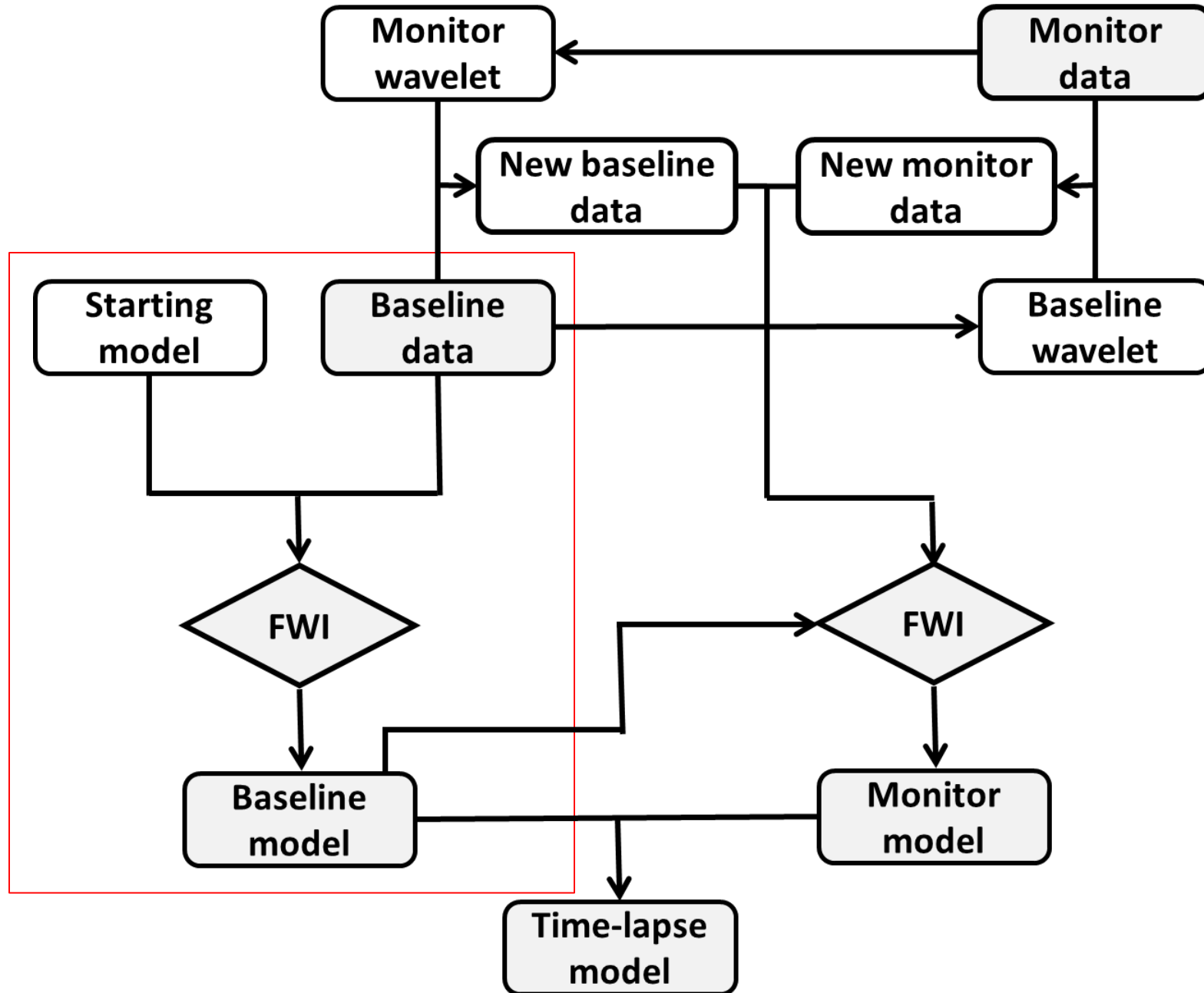
$$\mathbf{d}_{monitor}(10Hz) - \mathbf{d}_{baseline}(8Hz)$$



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

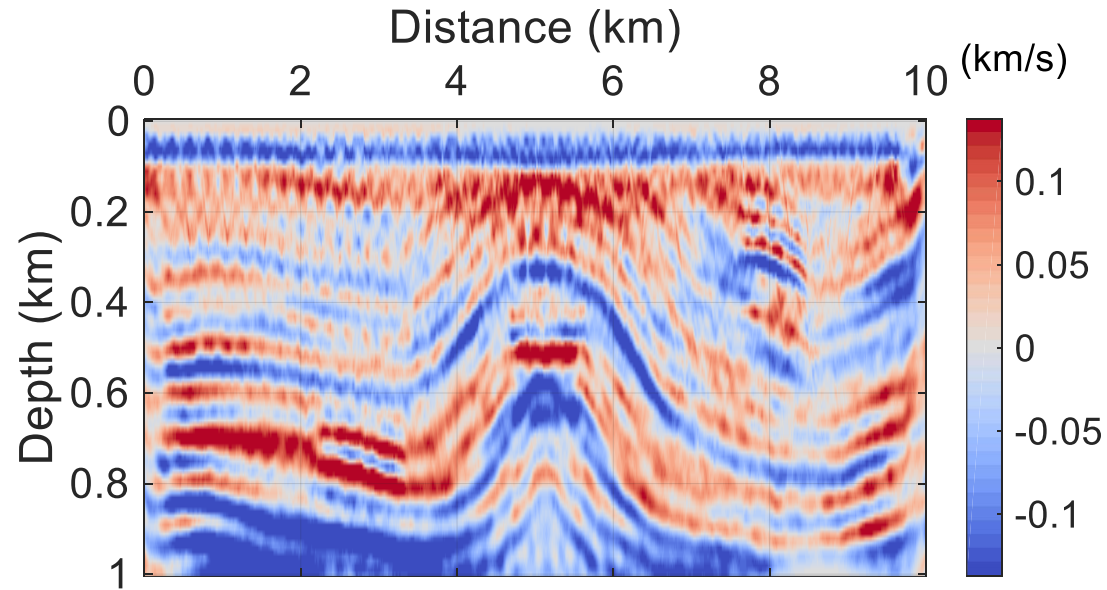


Double-wavelet double-difference strategy (DWDDWI)



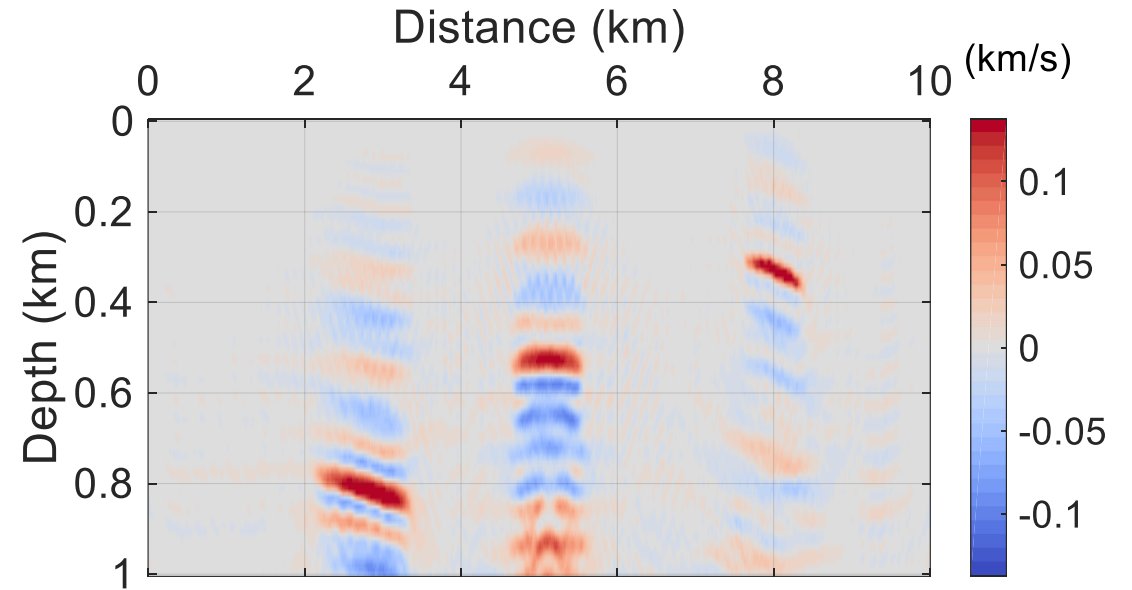


Different wavelets



DDWI

Wavelets for baseline and monitor data are **different**



DWDDWI

Wavelets for baseline and monitor data are **different**



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- ✓ 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



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Thank you!