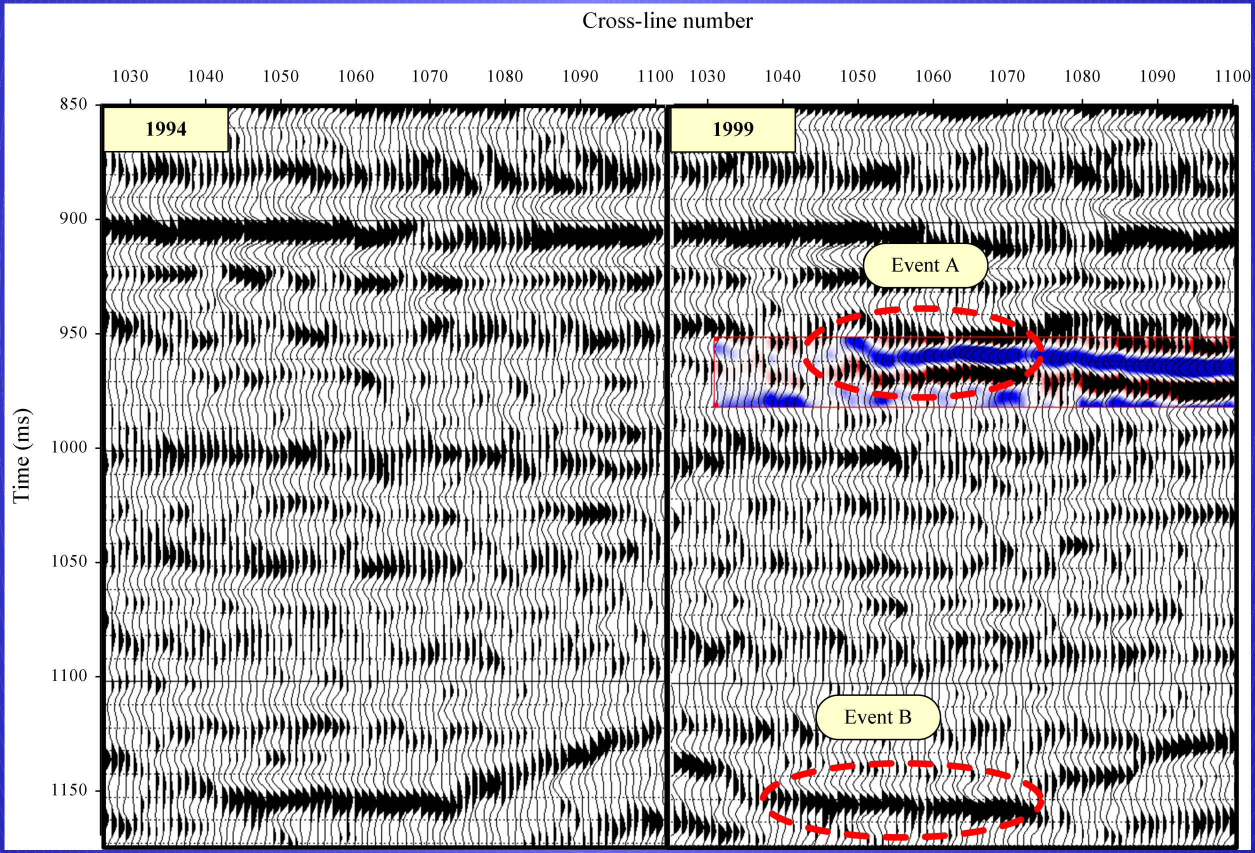
Velocity and thickness estimation of thin CO_2-layers with uniform and patchy saturations

Amir Ghaderi, Martin Landrø

Rose Meeting 2010

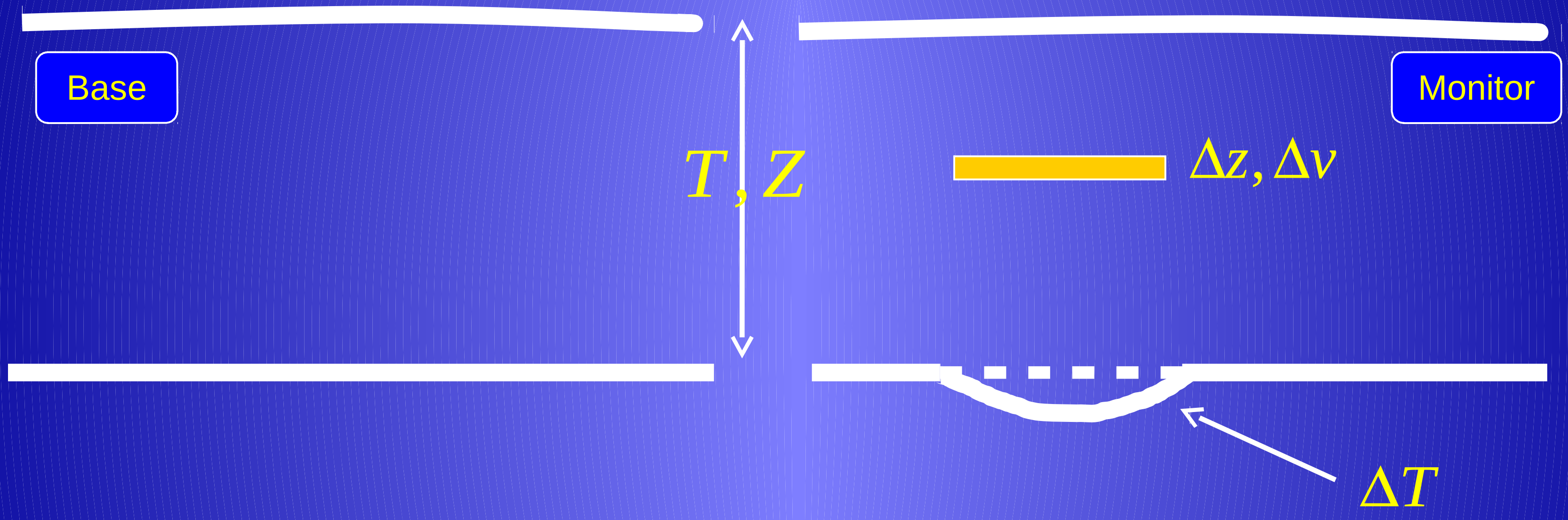
The Problem

Real seismic data anomaly



A section from Utsira formation
Ghaderi & Landrø, Geophysics 2009

The Problem



For the 4D seismic anomaly, we are interested in an estimate of

- thickness: Δz
- change in velocity : Δv
- a quantitative measure of saturation $S_{anomaly}$

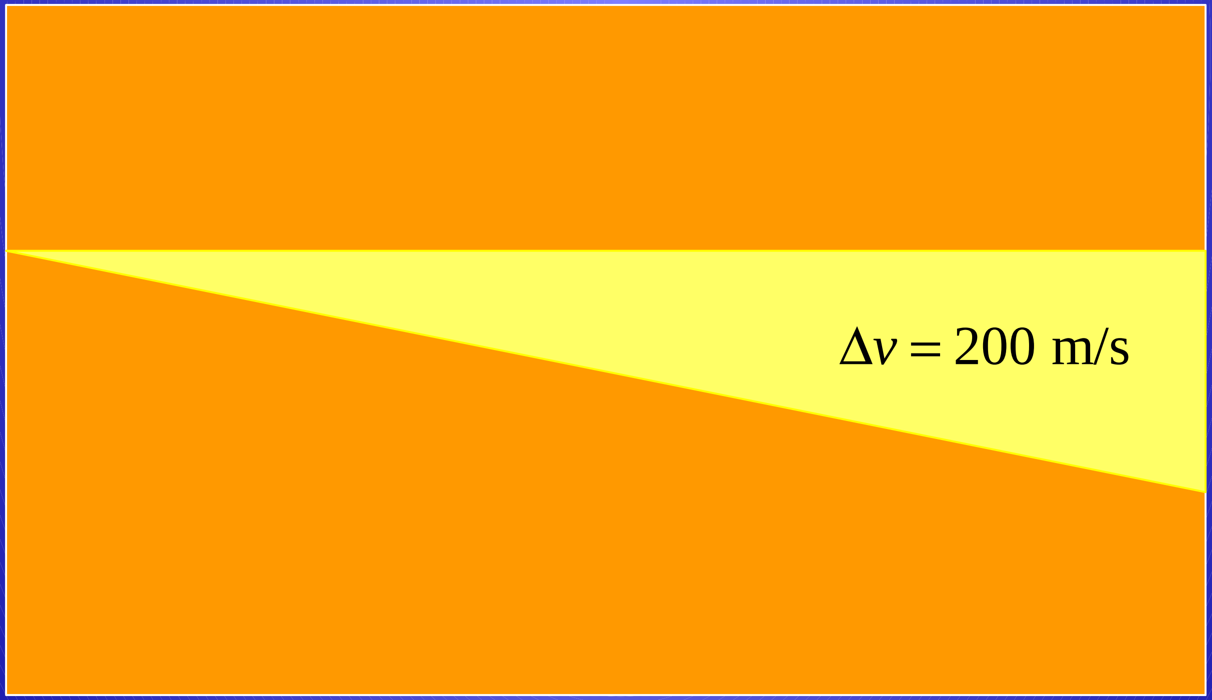
An estimate for solution

Assuming known Δv (some rock physics model, well log), Ghaderi & Landrø (geophysics 2009), propose to estimate Δz by

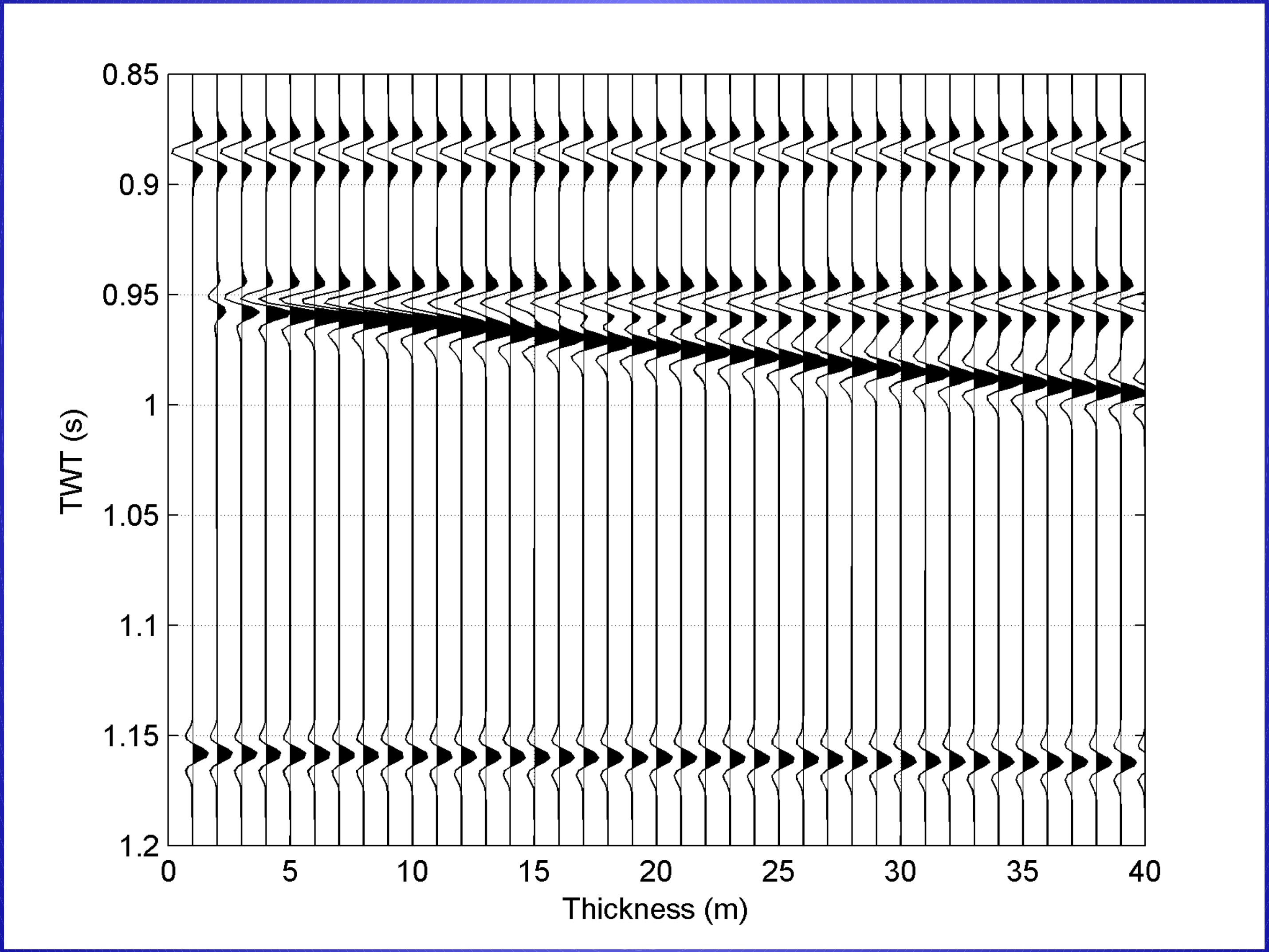
$$\frac{\Delta T}{T} = -\frac{\Delta v}{v}\frac{\Delta z}{z}$$

Synthetic test of the model

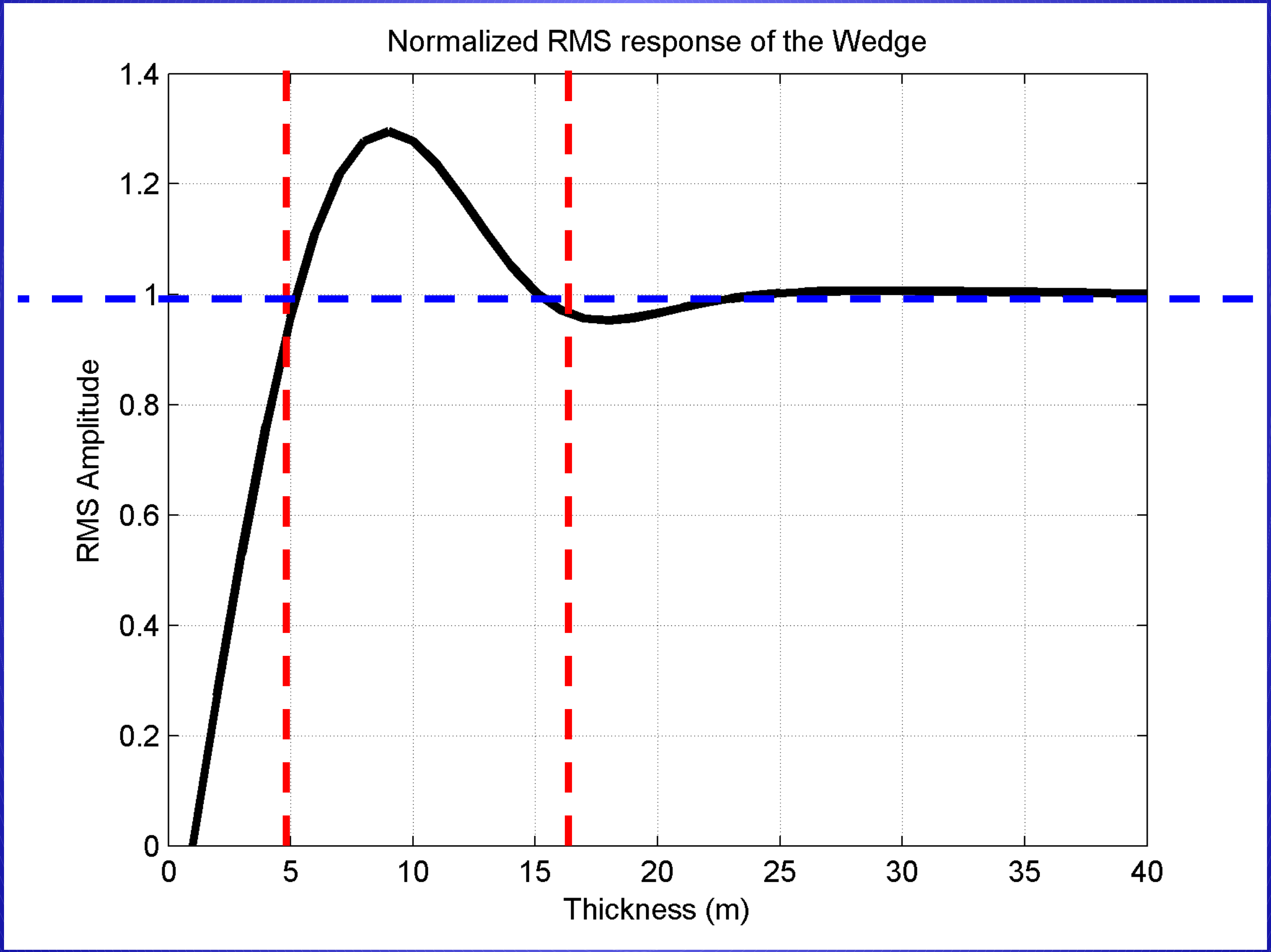
- Wedge model as a basis for testing the proposed estimate on synthetic data



Convolution model (primaries only)
– homogenous saturation distribution



The Amplitude response of wedge model



Estimation of thickness Δz, given Δv

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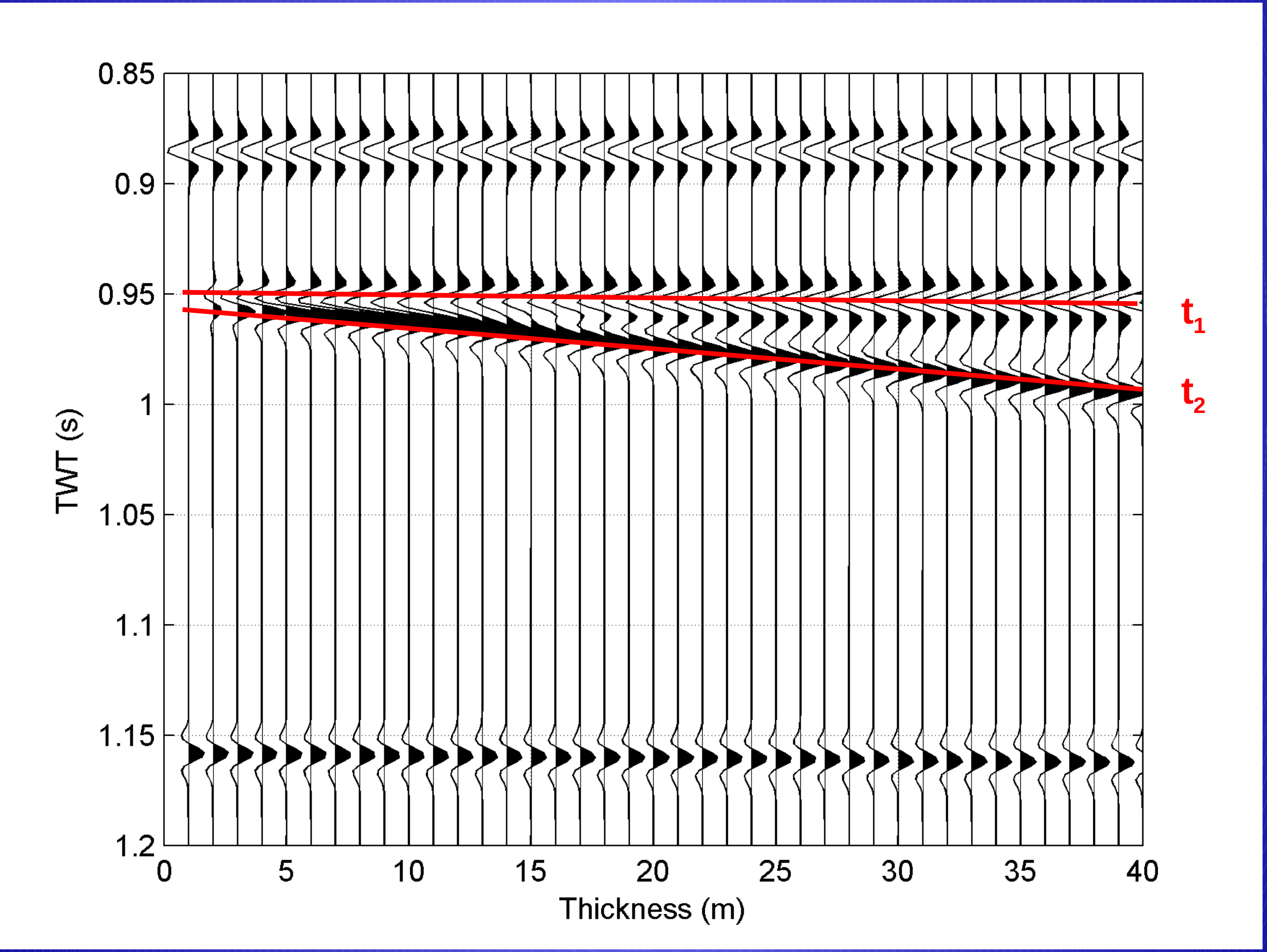


Estimation of thickness Δz, given Δv

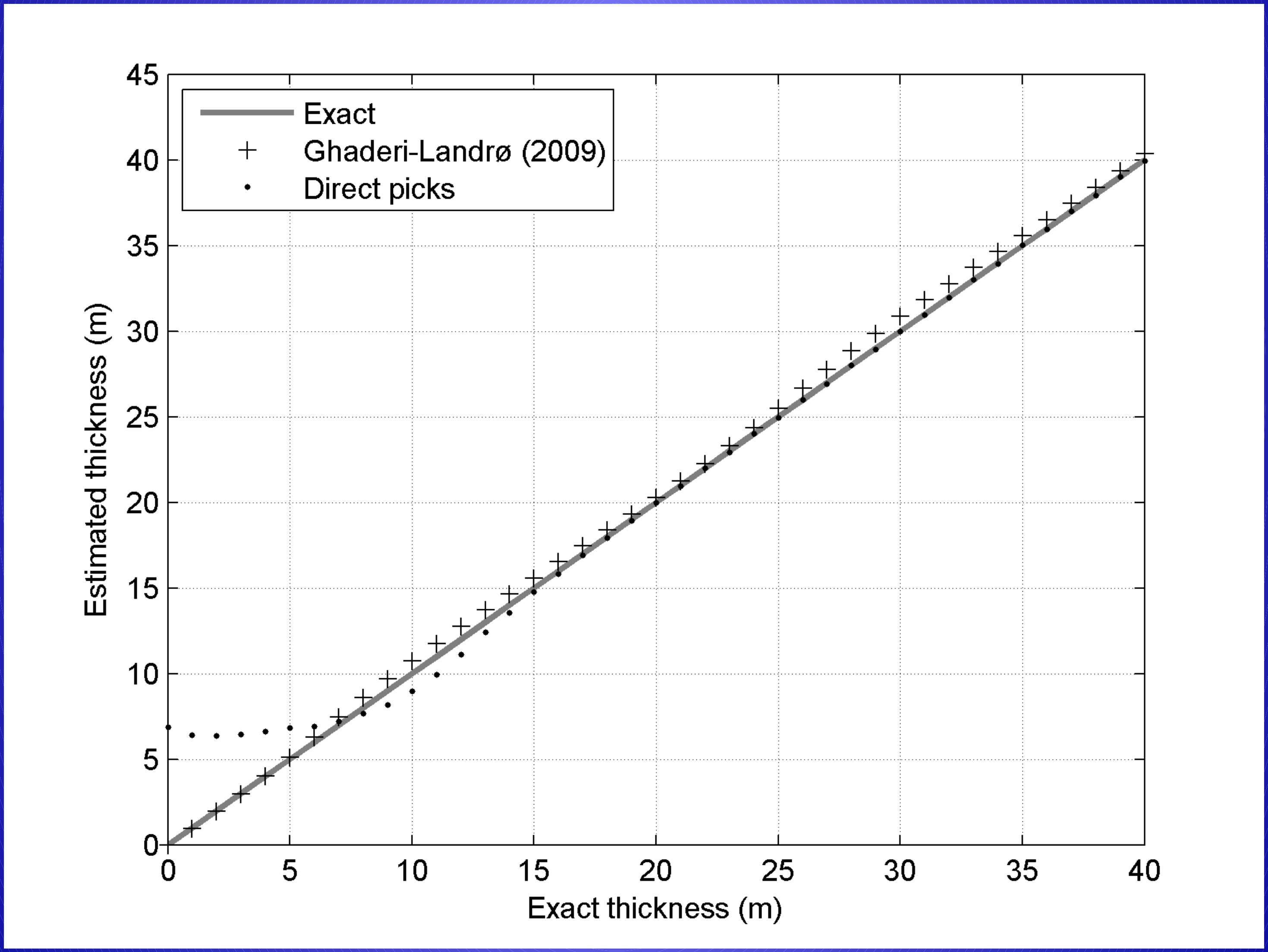
- One simple thickness estimate is based on direct picks and:

$$\Delta z = \left(t_2 - t_1 \right) \Delta v$$

- Using Ghaderi & Landrø estimate:

$$\Delta z = -z \frac{v}{\Delta v} \frac{\Delta T}{T}$$

Estimation of thickness, given Δv



Observations

- Direct picking on the wedge leads to
  - an underestimate for a limited range of thicknesses above the tuning thickness
  - For thicknesses below the tuning thickness, it tend to a minimum as the Wedge gets thinner, leading to a gross overestimate.
- Ghaderi & Landrø method:
  - The result is better by picking traveltime below the event.
  - Knowing velocity change, measurements of travel time below the 4D seismic anomaly, can predict the thickness below tuning.

Simultaneous estimation of Δv and Δz

Ghaderi & Landrø, Geophysics (2009)

4D amplitude response of a thin layer :

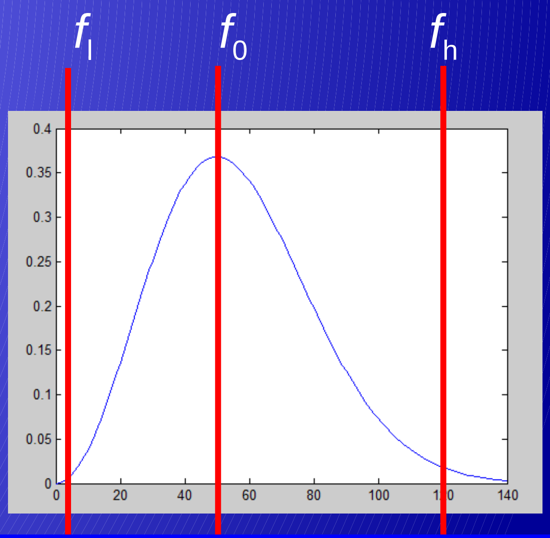
$$S_d(f_0) = -\frac{|P(f_0)|}{v_1 \cos^3\theta}\frac{\Delta T}{T} \times \mathrm{sinc}\left(-\frac{\Delta T}{T}\frac{z_1 2\pi f_0}{\Delta v \cos\theta}\right)$$

Measure S_d and ΔT => Δv

Propose to extend to all frequencies

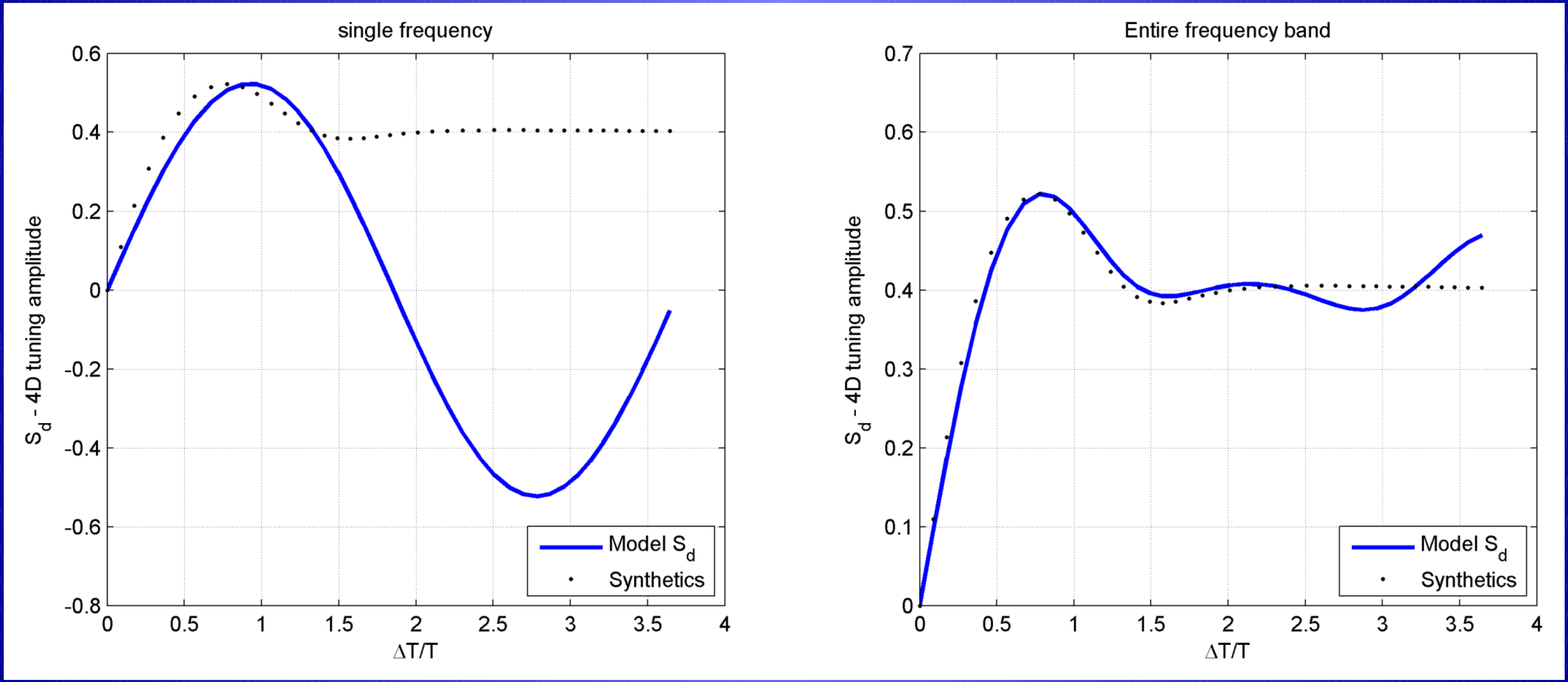
$$S_d(f) = \left(\int_{f_l}^{f_h} S_d^{\,2}(f)\,df\right)^{\frac{1}{2}}$$

Modified expression from A.Barns, SEG Ext. Abs. 2004



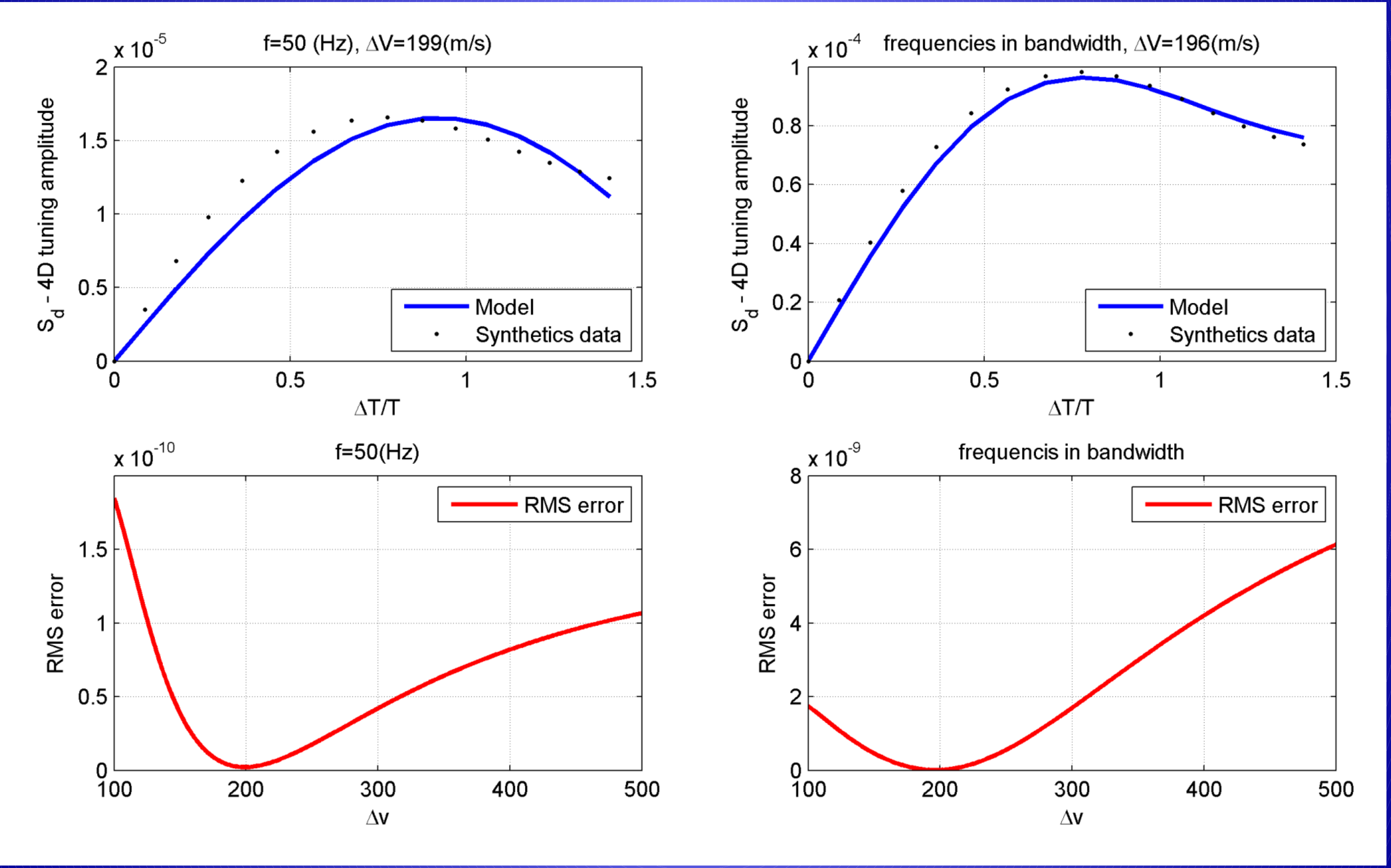
Frequency spectrum of Ricker, 50 Hz

Comparing S_d with synthetic modeling of the wedge

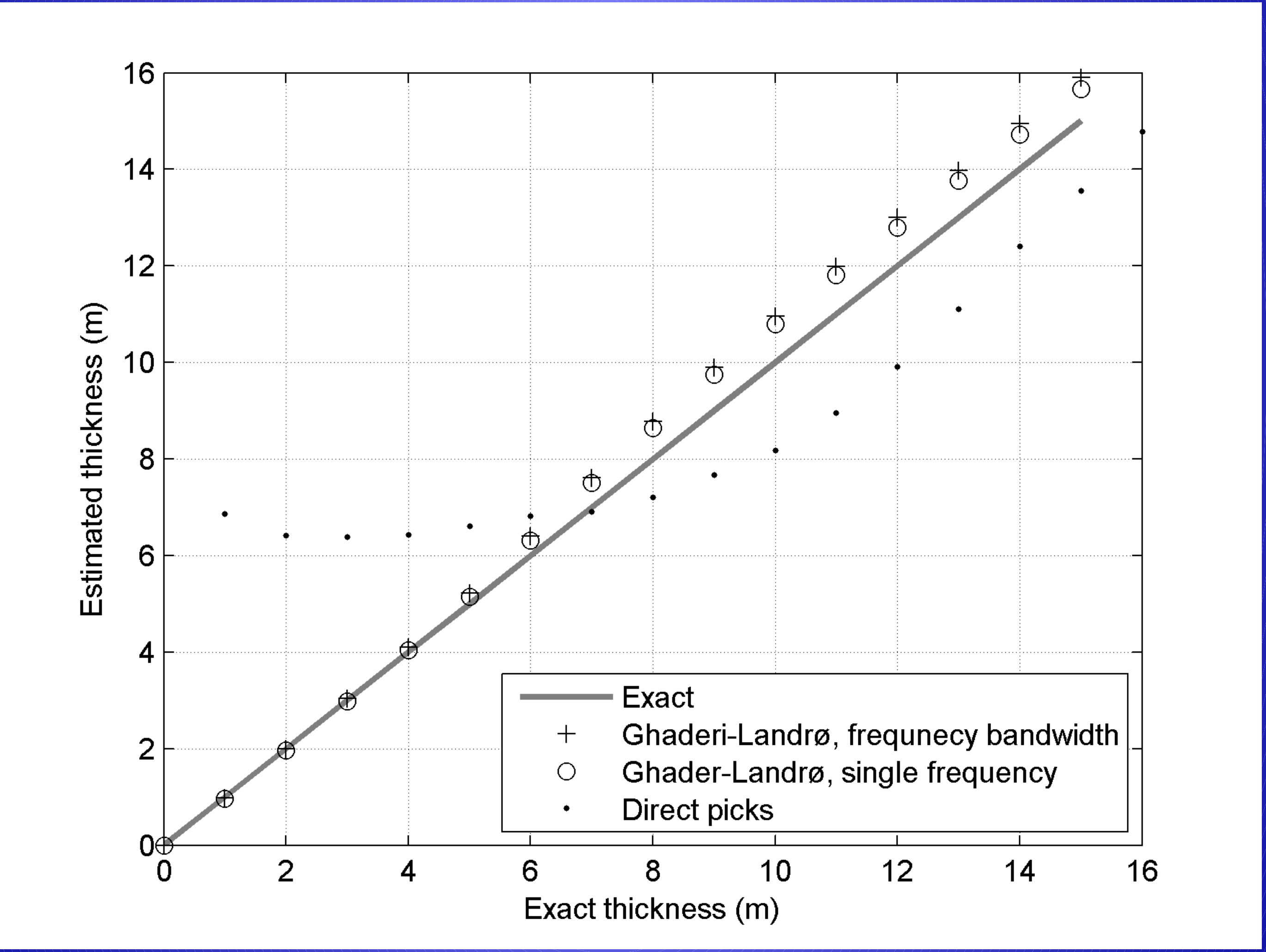


Inverting for Δv (exact answer: 200 m/s)

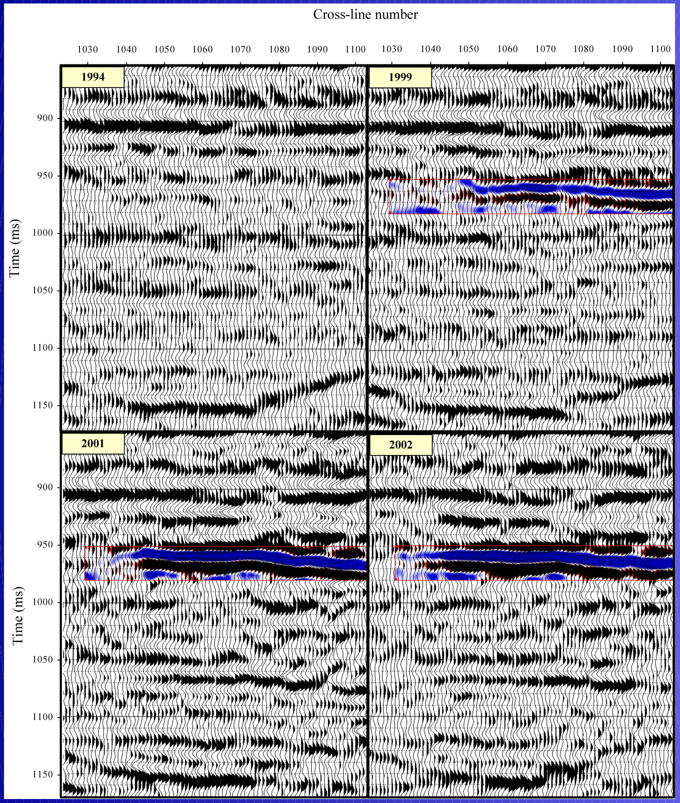
Least square method

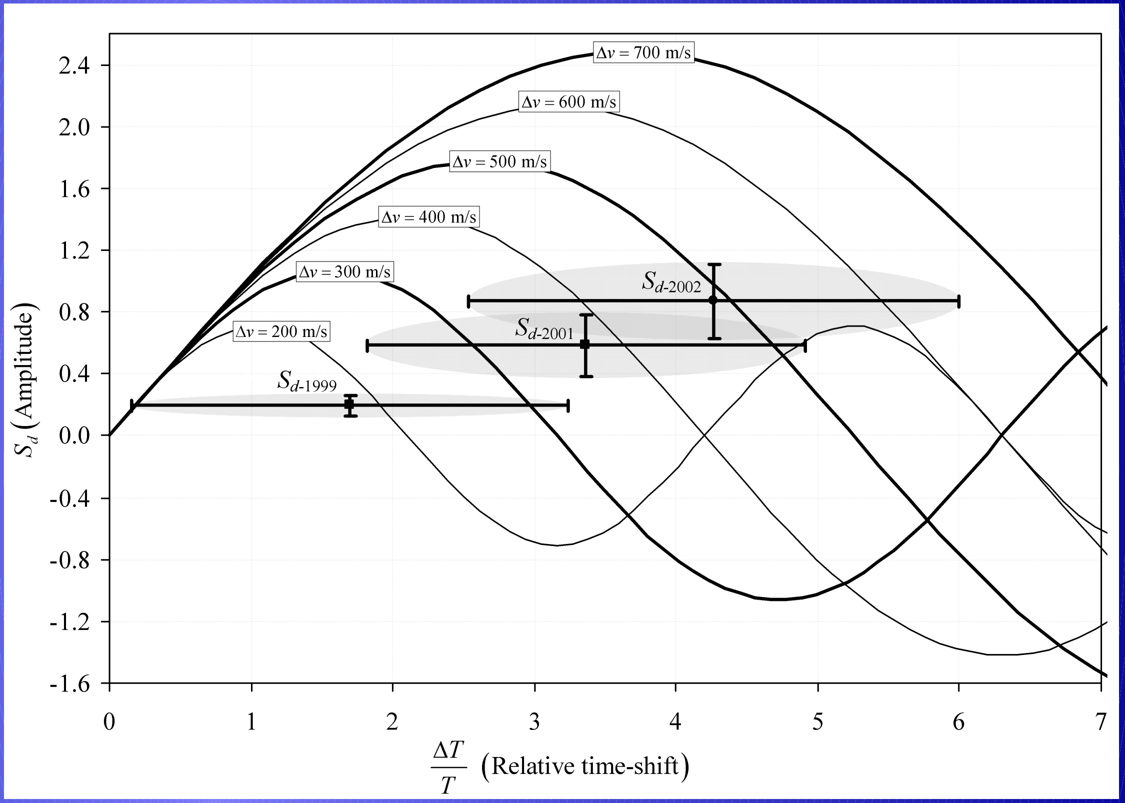


Estimated thicknesses from inversion



Application to real data



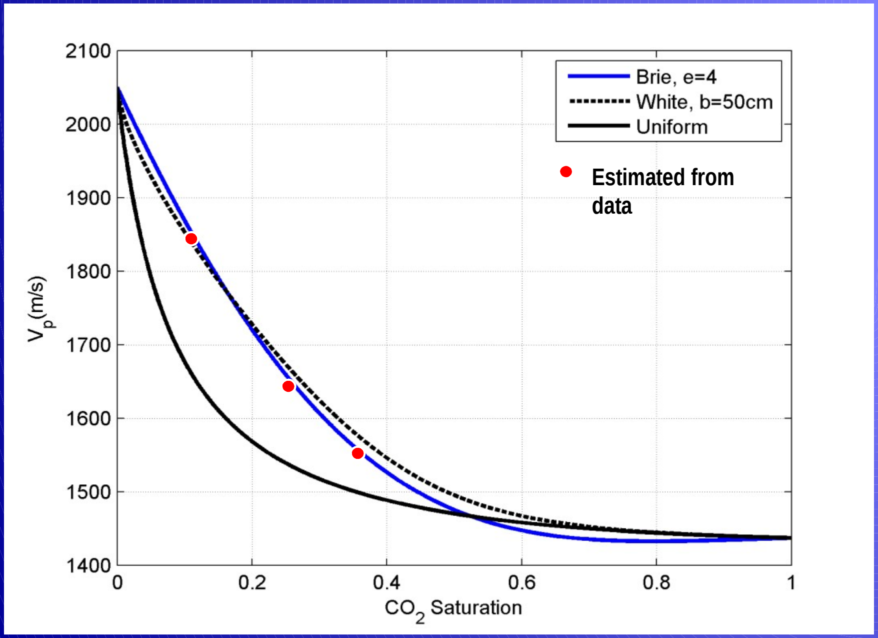


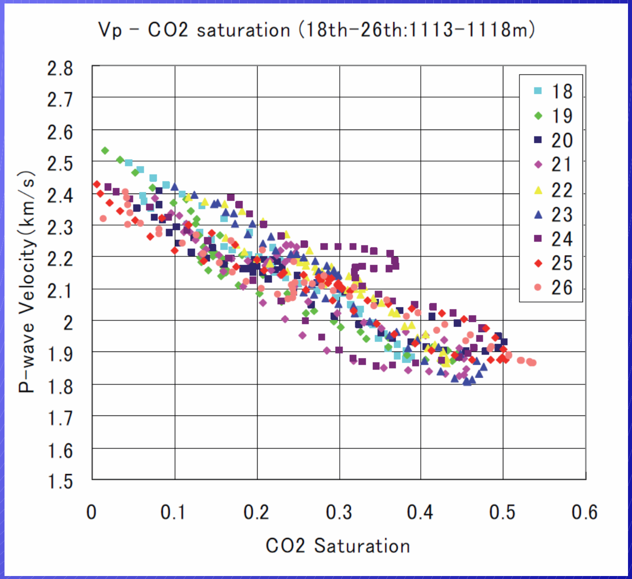
- Estimates of Δv and Δz
  - According to Ghaderi&Landrø
  - Values in parenthesis based on Gassmann and picked timeshifts

Monitor year	Δv (m/s)	Δz (m)
1999	200	15 (4)
2001	400	15 (8)
2002	500	15 (10)

So, what is happening?

- Look at some rock physics models
  - Brie, describing the patchy saturation distribution
  - Gassmann-Wood, the uniform distribution
- Calibrating the patchy saturation with White's model

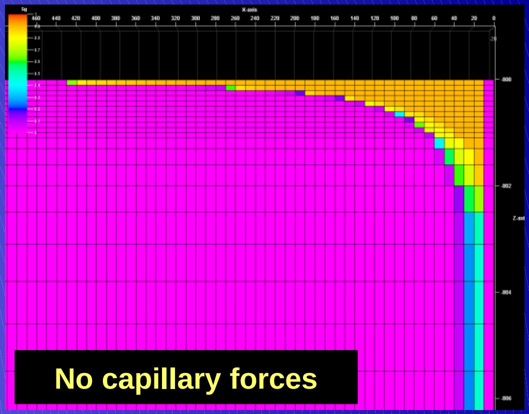


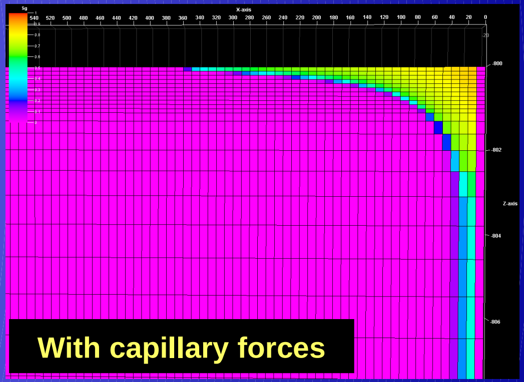


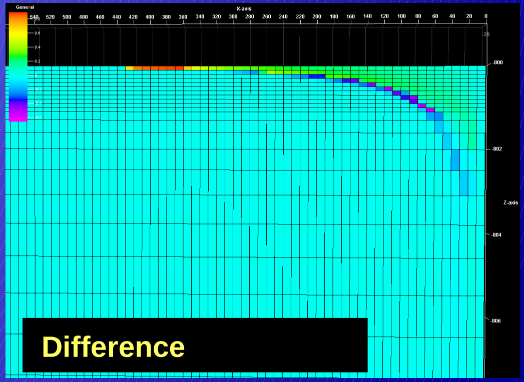
P-wave velocity and CO_2 saturation from Nagaoka field, Konishi et al, EAGE 2008

CO_2 distribution under thin shale layers

- Ongoing work
  - Ghaderi, Landrø and Lindeberg
- Mapping of the CO_2 'finger' propagation, and variation of the thicknesses under shale
- Effect of capillary pressure on saturation distribution







Capillary pressure and transition zone

- Capillary pressure:
  - *Difference between the two phase pressure*

$$P_c = P_{fl_2} - P_{fl_1}$$

- Capillary transition zone:
  - *The mixing zone that occurs between two phases (due to capillary pressure)* when the fluids are immiscible

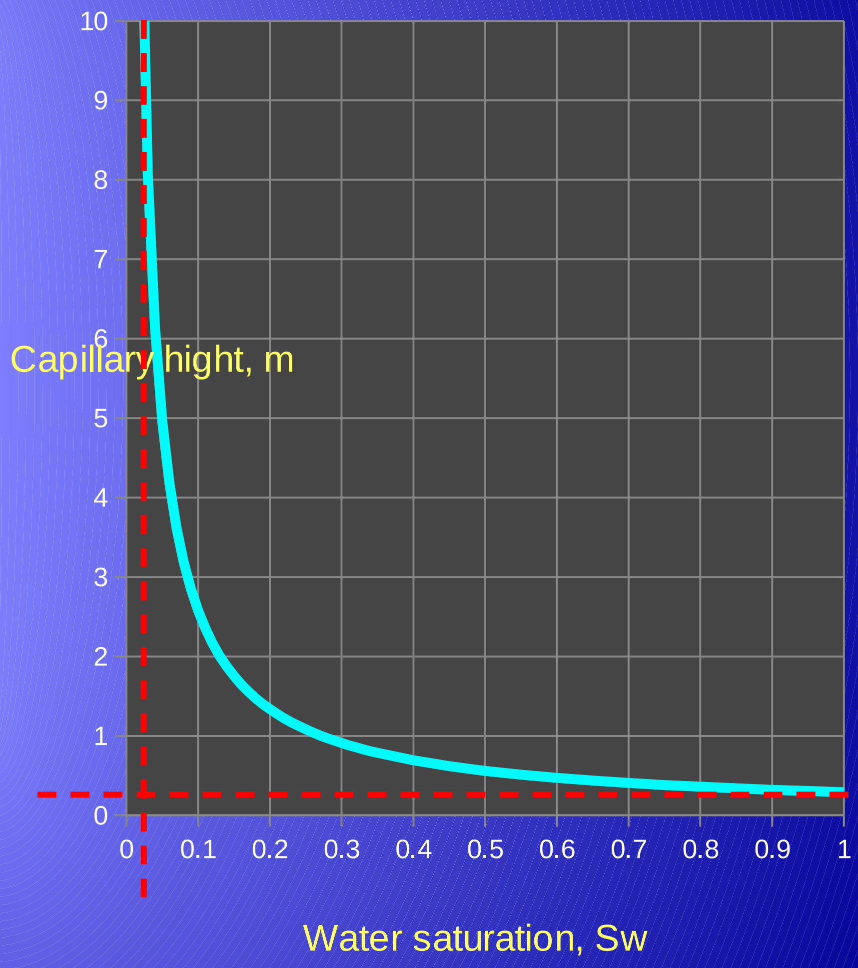
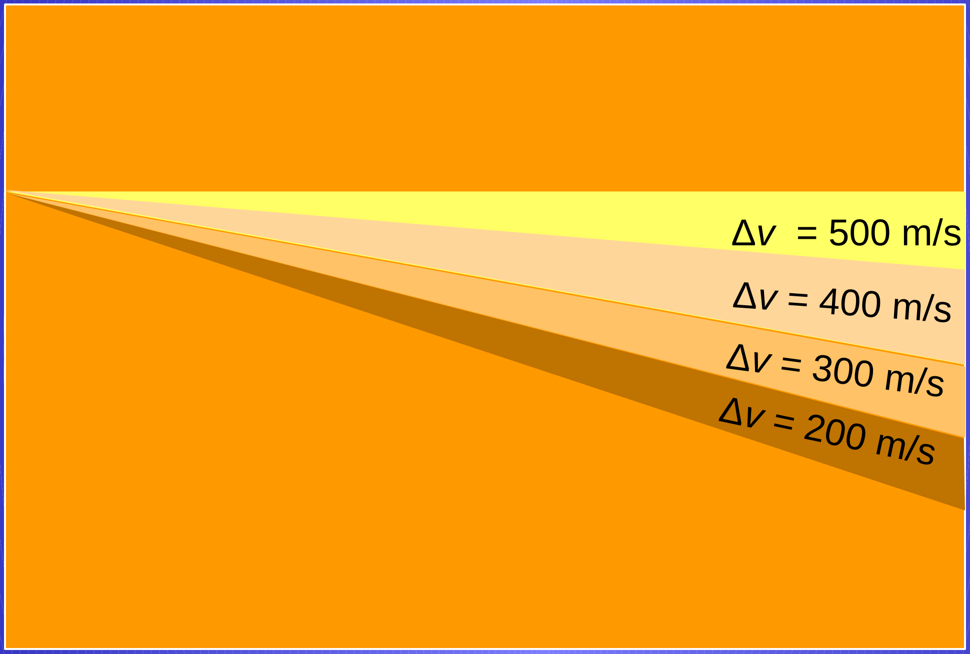


Figure: Erik Lindeberg, unpublished data Utsira

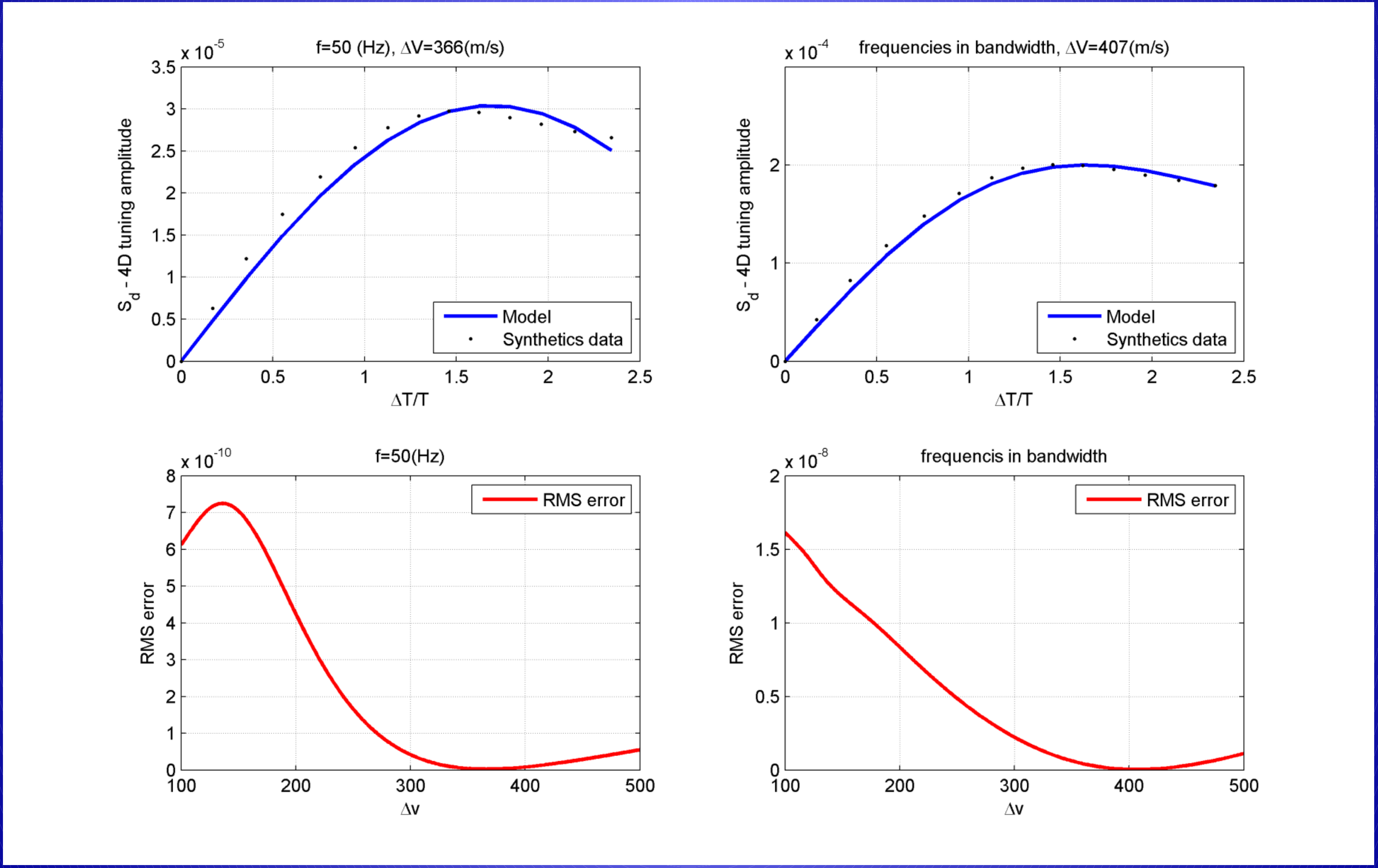
Modeling the transition zone



- 4 layer wedge model
- Progressively lower CO_2 saturations further down the model
- Average velocity change = 350 m/s

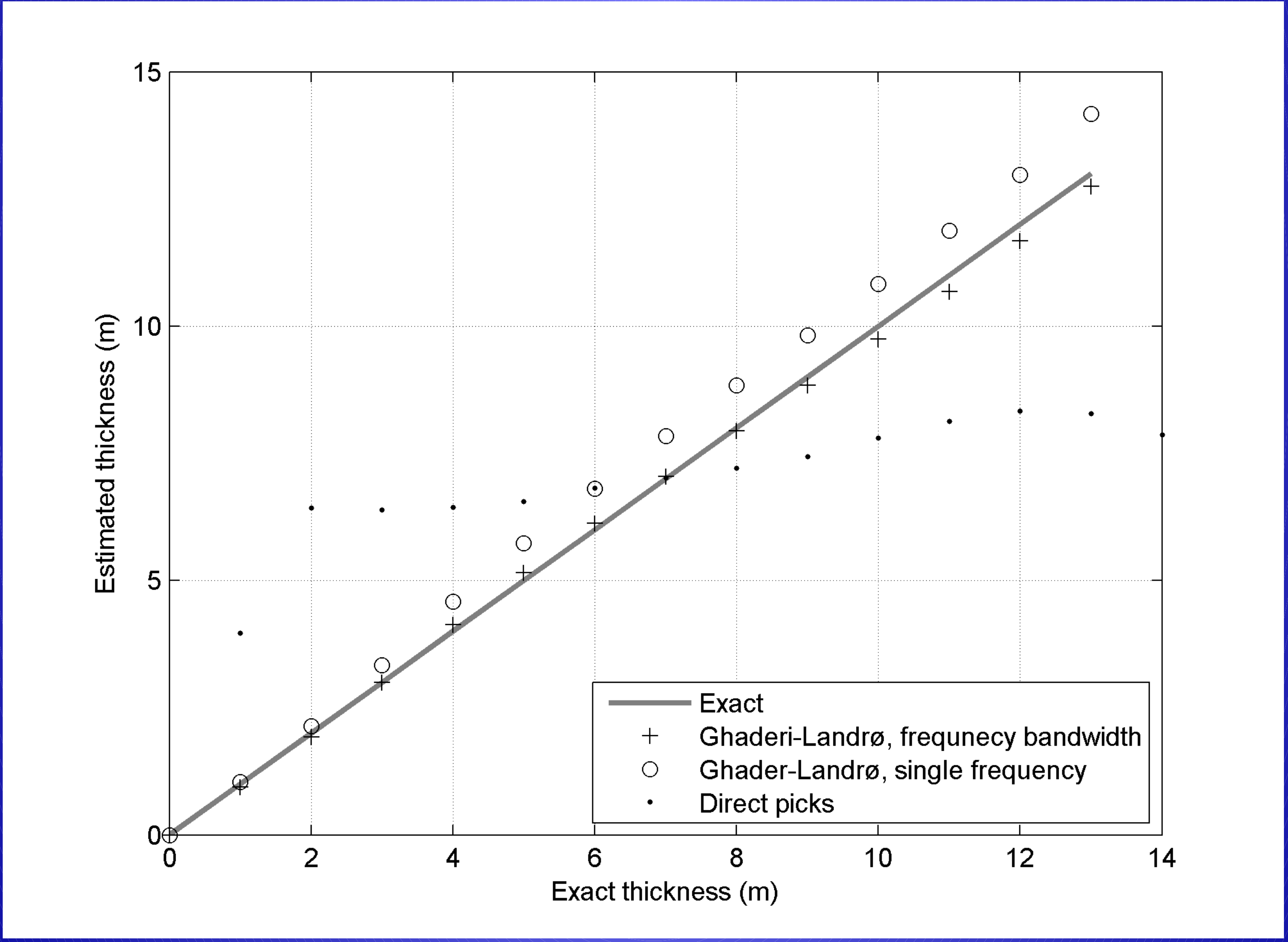
Inverting for Δv (average = 350 m/s)

Patchy saturation (4 layer model)



Estimated thicknesses from inversion

Patchy saturation (4 layer model)



Conclusion

- An efficient model is provided for estimating changes in velocity and thickness for CO_2 layers within and below the tuning thicknesses.
- A good match for homogenous saturation distribution
- A reasonable estimation with patchy saturation
- The scaling factor between the model and the data plays an important role in the RMS error estimation

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