Estimating velocities and layer thickness changes from diving waves

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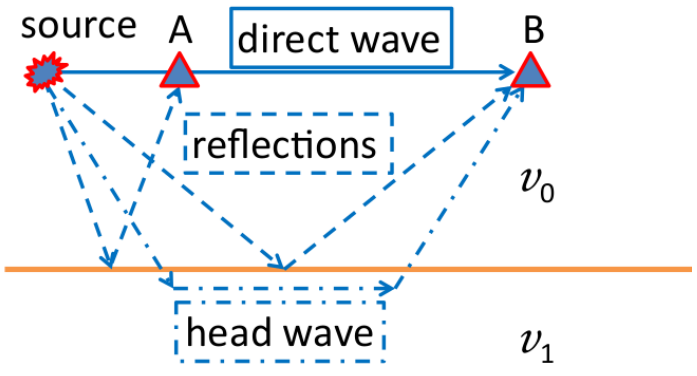
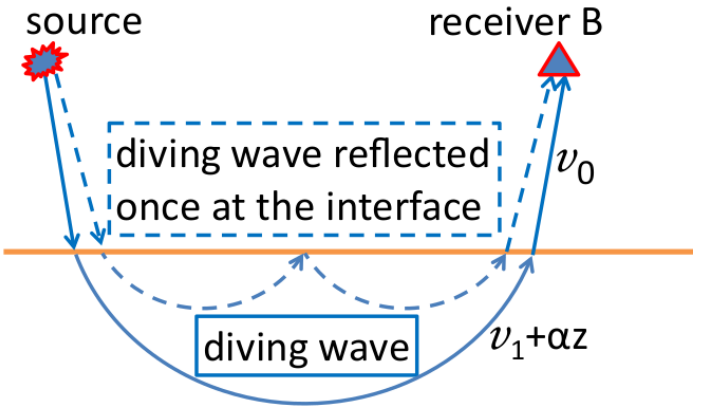
Diving wave and head wave



(a)



(b)

(Source: Kazei et al. [1])

Diving wave and head wave

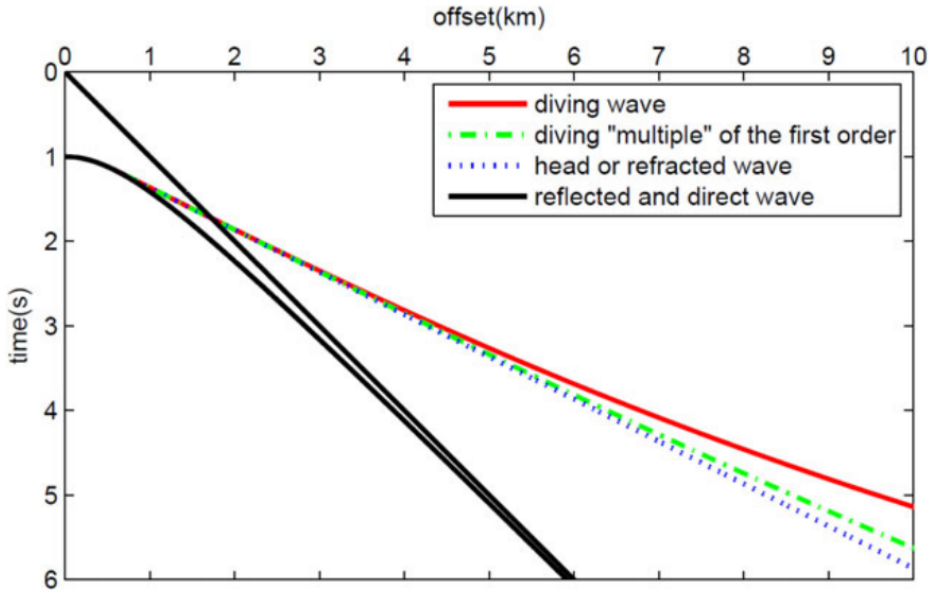
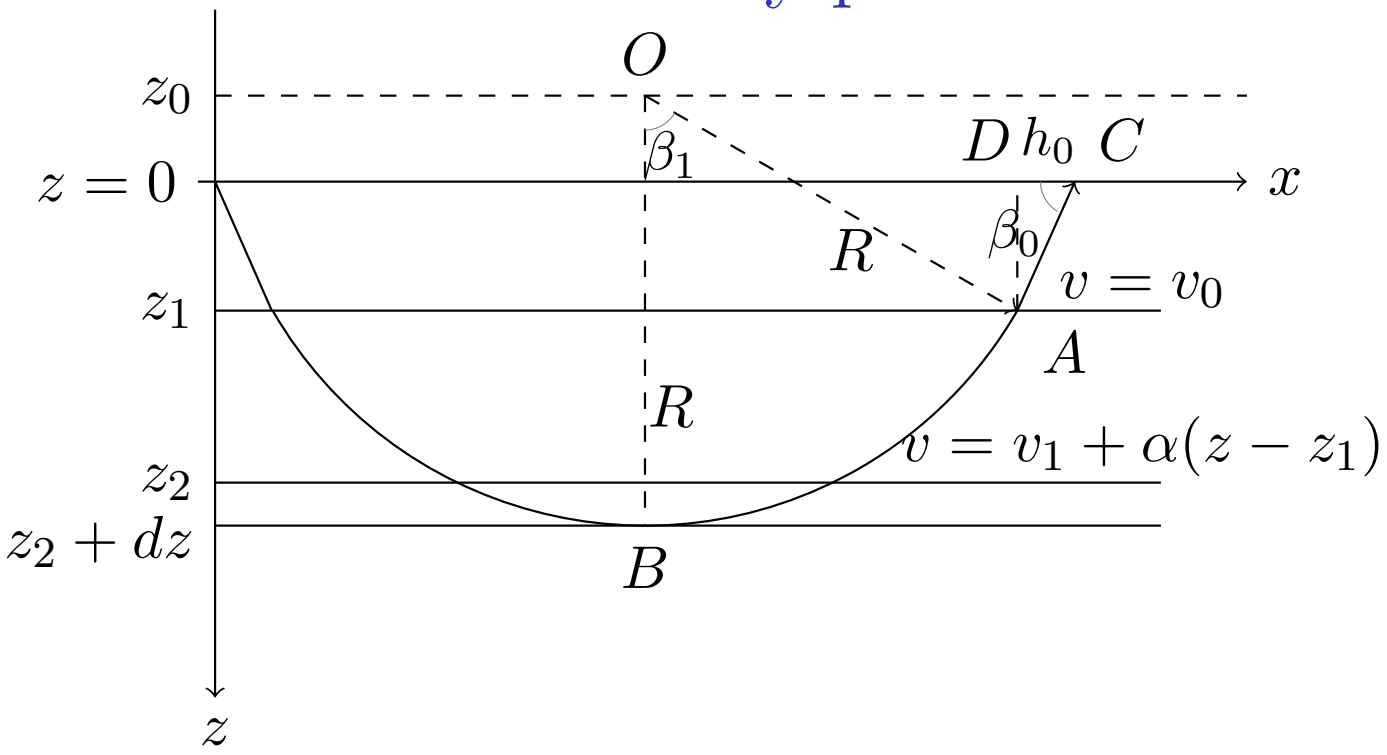


Figure 5 Traveltime curves for direct and reflected waves (black), a diving wave (red), head wave (blue) and a wave that has been reflected once at the interface between the shallower and deeper half-space (green).

(Source: Kazei et al. [1])

- Can we use diving wave for monitoring the subsurface? How?

Ray path



$$v = v_1 + \alpha(z - z_1)$$
$$\downarrow$$
$$z_0 = z_1 - v_1/\alpha;$$

Geometry:

$$\cos\beta_1 = \frac{v_1/\alpha}{R}$$
$$\tan\beta_0 = \frac{z_1}{h_0};$$

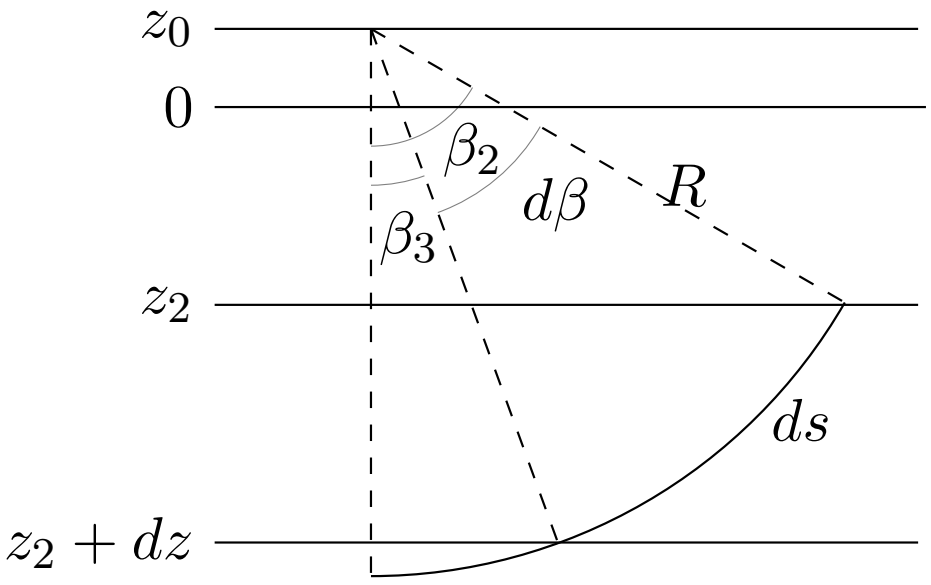
Snell's law with cosine:

$$\cos\beta_0 = \frac{v_0}{v_1}\cos\beta_1 = \frac{v_0}{\alpha R}$$

Trigonometry:

$$R = \frac{v_0}{\alpha}\sqrt{\left(\frac{z_1}{h_0}\right)^2 + 1}$$

Time shift



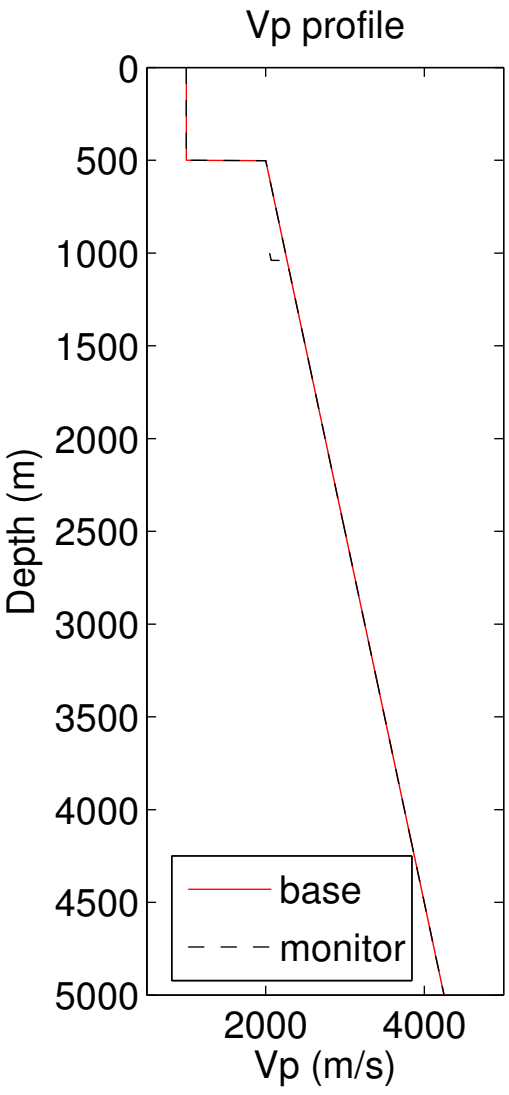
$$d\beta = \arccos\left(\frac{z_2 + |z_0|}{R}\right) - \arccos\left(\frac{z_2 + |z_0| + dz}{R}\right)$$

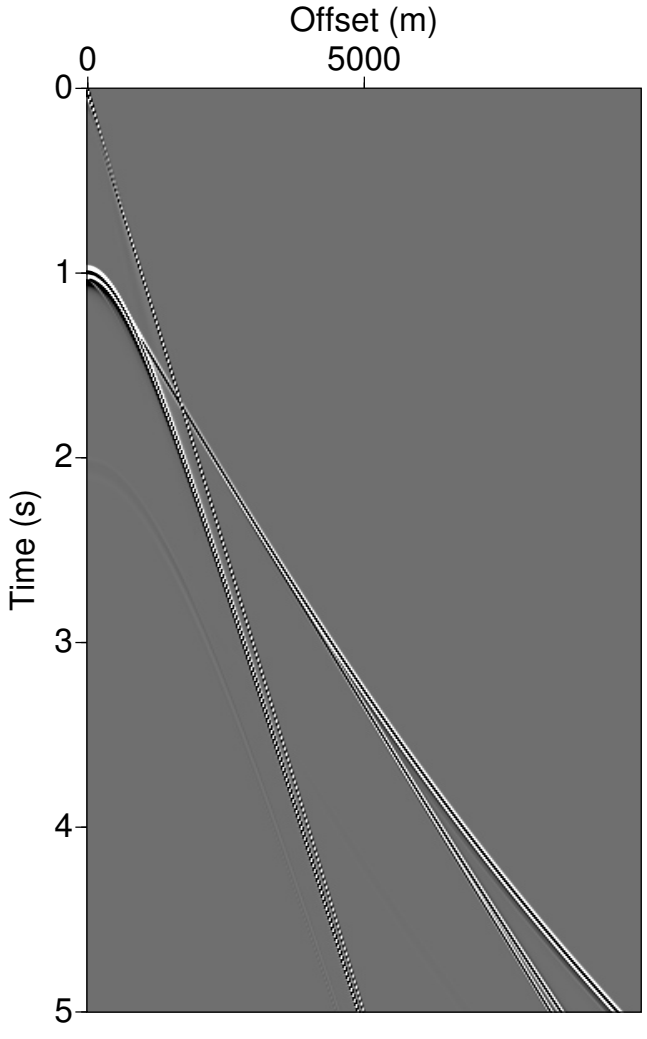
$$ds = R d\beta$$

Time shift:

$$dt = 2\left(\frac{ds}{v+dv} - \frac{ds}{v}\right)$$

Vp model and data





Ray tracing: visualization of ray path change

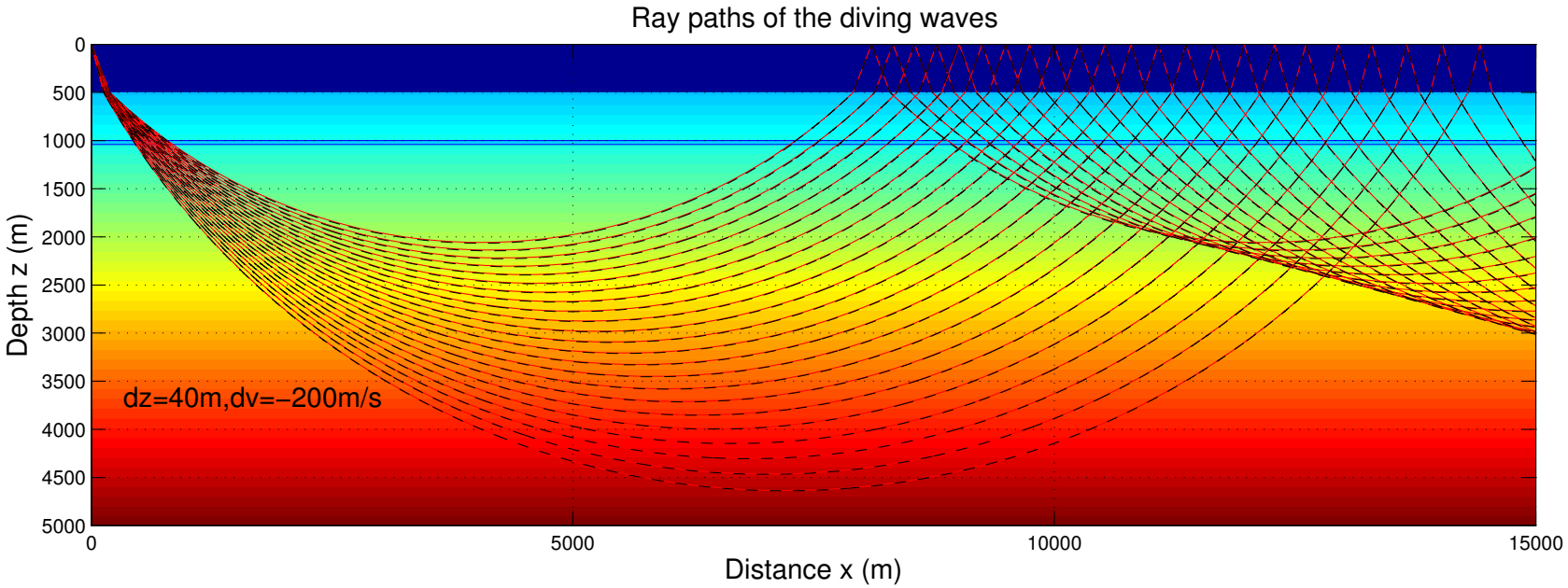


Figure: Overview of the ray paths (base and monitor) of diving waves.The actual layer thickness dz and velocity change dv are written on the lower left corner.

Verify the time shifts observed

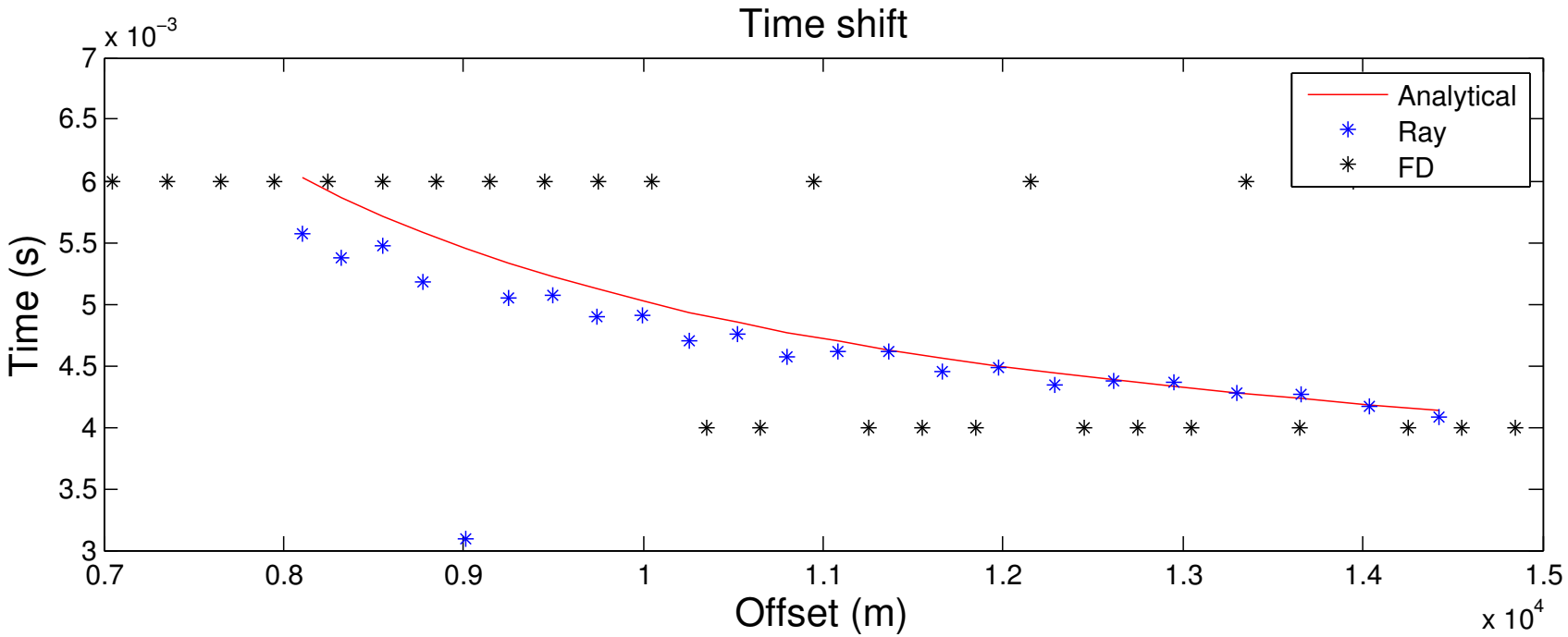


Figure: Comparison of the analytical time shifts. The deviation of the FD values from the analytical ones is within the limitation of the sampling rate (2 ms) and the wavelet used (Ricker 20 Hz). The values by ray tracing deviates slightly from the red line because the rays do not arrive at the exact same position at the surface for the base and monitor survey.

Effect of layer thickness change (dz)

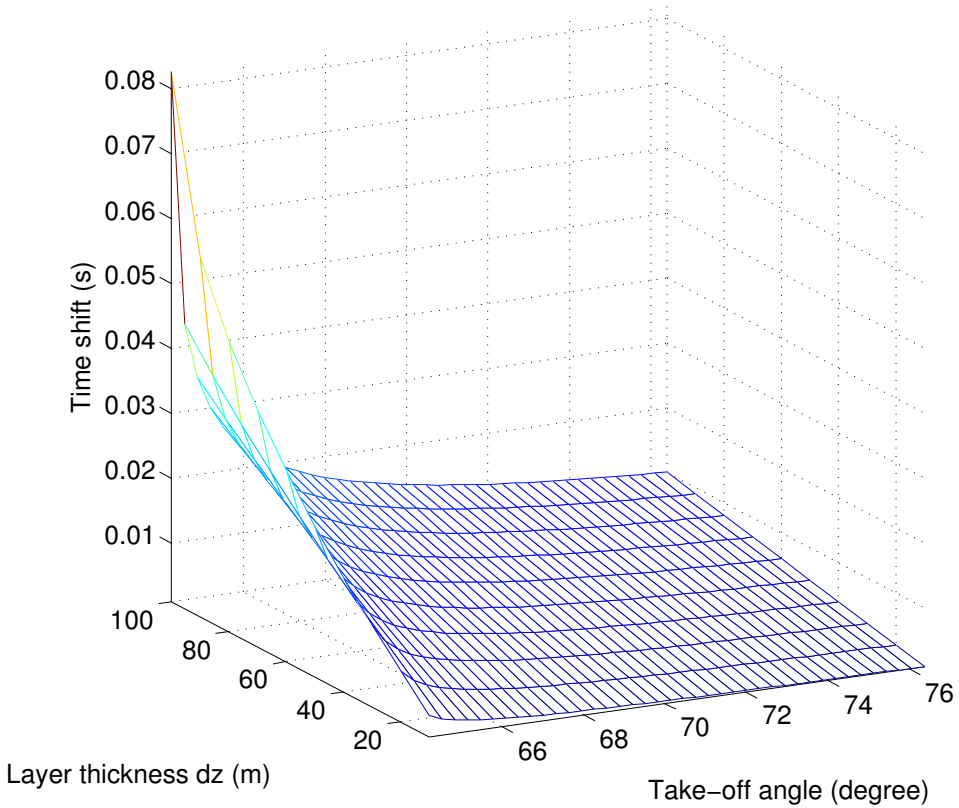


Figure: The effect of dz on time shift, as a function of offsets (ray take-off angle β_0). The time shift sensitivity to the layer thickness increases drastically with the decrease of offsets.

Effect of velocity change (dv)

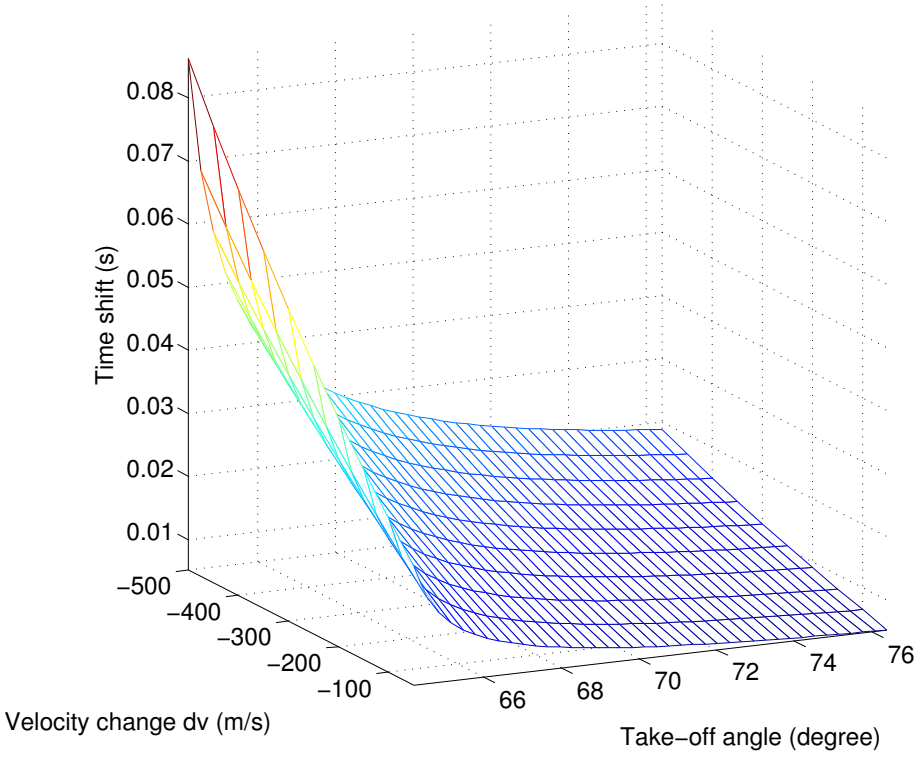


Figure: The effect of dv on time shift, as a function of offsets (ray take-off angle β_0). The time shift sensitivity to the layer velocity change increases drastically with the decrease of offsets.

Velocity change estimation

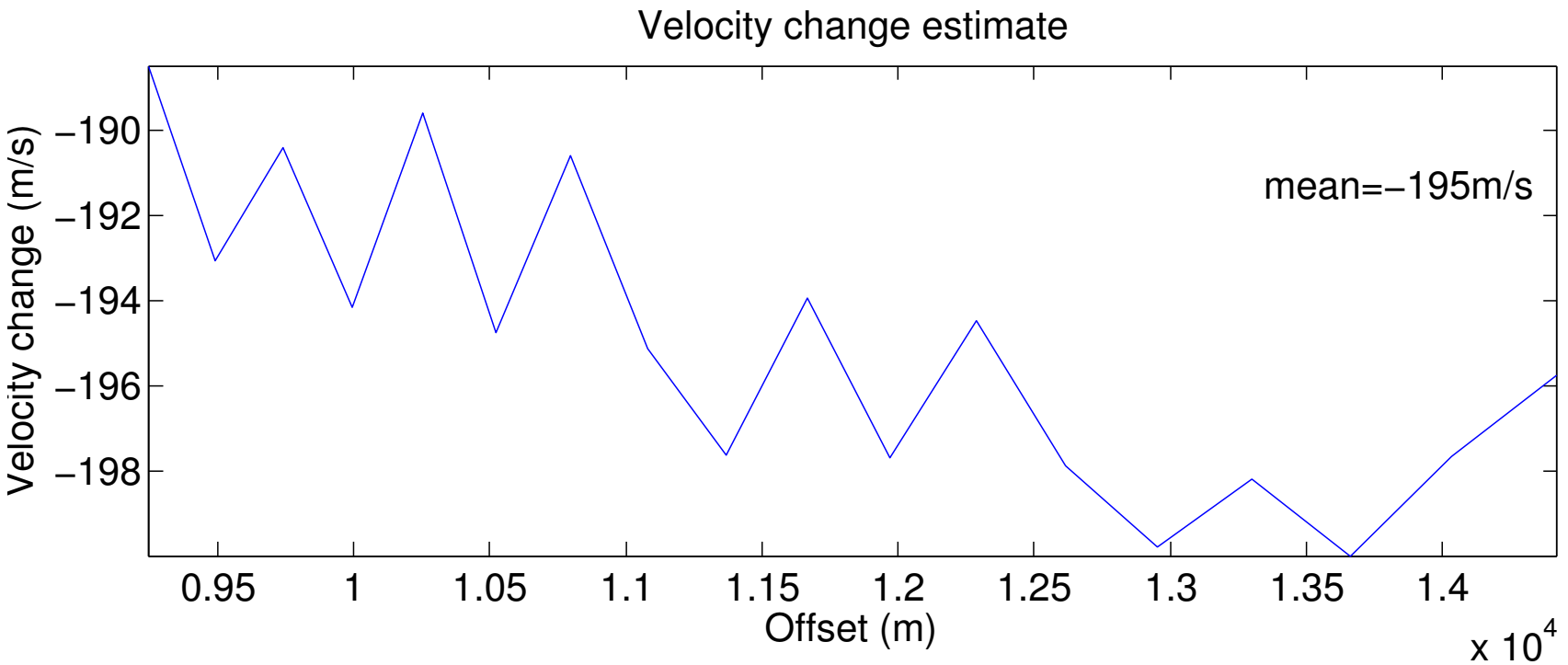


Figure: Velocity change estimation per offset. The values are calculated from the time shifts by ray tracing, and as a bench mark, the correct dz is used. The accuracy could be improved by tuning the degree of overshooting and undershooting. Most of the time shifts by ray tracing are slightly lower than the analytical values. The true dv is -200 m/s.

Effect of velocity change (dv)

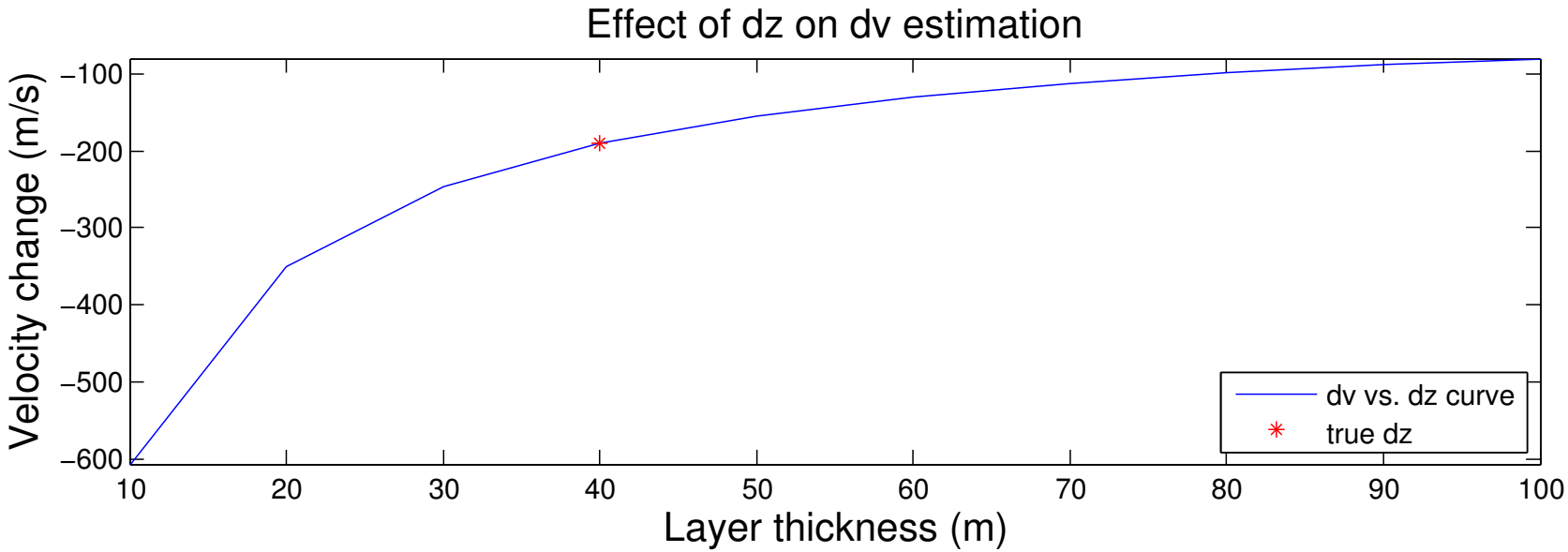


Figure: The velocity estimates without the correct dz. Each velocity value is the mean value from all offsets, and is plotted to the corresponding dz used. It is observed that the change in dv becomes smaller for the dz values larger than the correct dz.

- Proposed a way of using diving waves for monitoring small changes in the subsurface
- Acquiring large offset seismic data is beneficial in this context
  - helps extracting correct traveltimes
  - minimize the effects from an unknown layer thickness in estimating the velocity change.
- Encouraging results for estimating both velocity change and layer thickness
- Further research
  - Effects from an unknown macro-model, the depth of velocity change, the limiting applicability of the method, the test on field data and etc..

Acknowledgements

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References I

[1] Kazei, V., V. Troyan, B. Kashtan, and W. Mulder, 2013, On the role of reflections, refractions and diving waves in full-waveform inversion: Geophysical Prospecting, **61**, 1252–1263.