1D internal multiple prediction in a multidimensional world: errors and recommendations

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Outline

- Introduction to some important concepts
- Basic principles of IM prediction algorithm
- Systematic study of the prediction errors
- Recommendations
- Acknowledgements

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Concepts

- Primaries: events which have experienced one upward reflection and no downward reflections during their history.
- FSMs: any events that reflected from the free surface.
- IMs: events which experienced at least one downward reflection in the subsurface, and never interact with the free surface.

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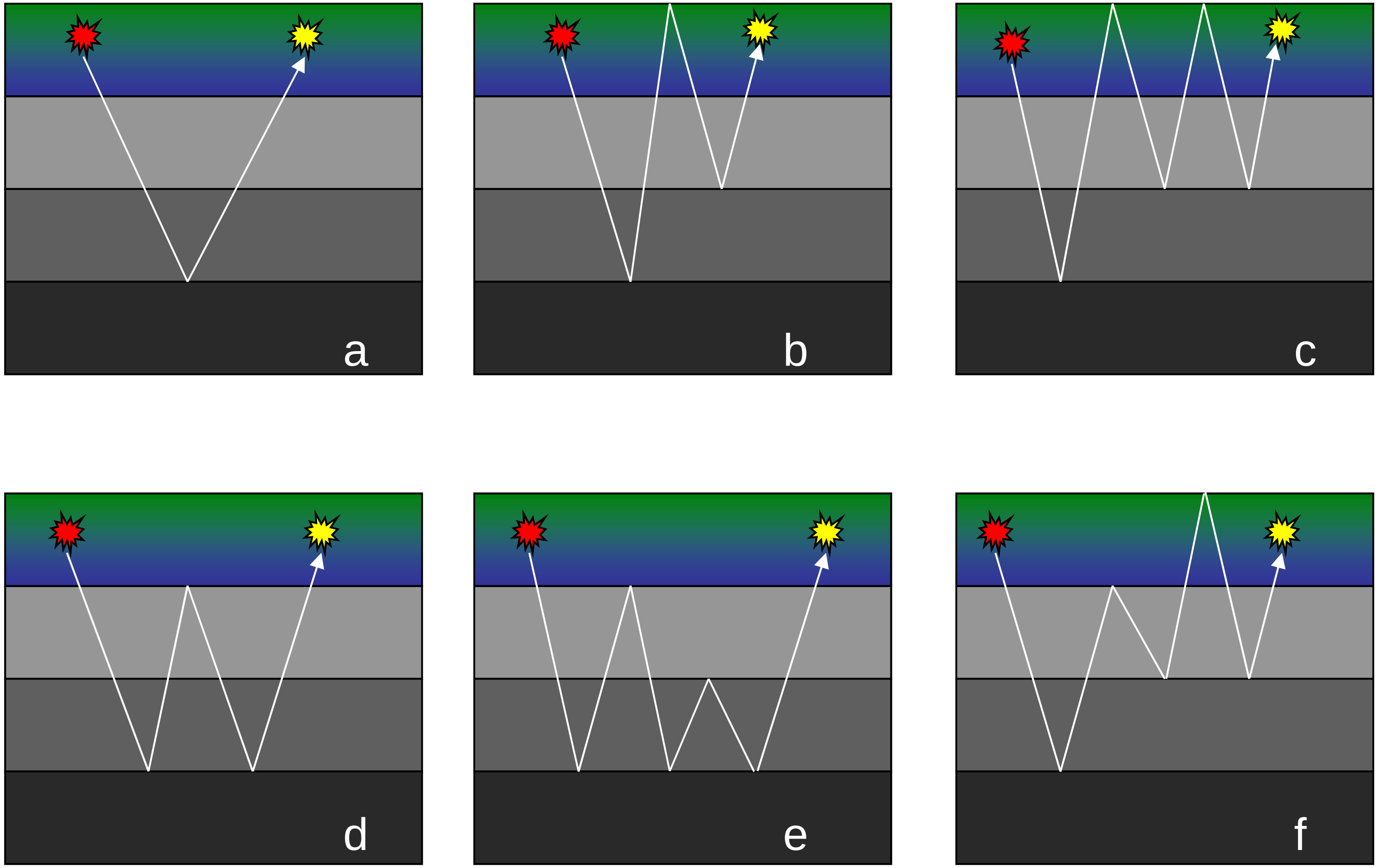

Figure 1. Primaries and multiples

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2D IM prediction algorithm

The prediction algorithm given by Weglein et., 1997 is

$$b_{3IM}\left(k_g,k_s,q_g+q_s\right)=\left(\frac{1}{2\pi}\right)^2\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}dk_1dk_2$$
$$\times\int_{-\infty}^{\infty}dze^{i\left(q_g+q_1\right)z}b_1(k_g,k_1,z)\times\int_{-\infty}^{z-\epsilon}dz'e^{-i(q_1+q_2)z'}b_1(k_1,k_2,z')$$
$$\times\int_{z'+\epsilon}^{\infty}dz''e^{i(q_2+q_s)z''}b_1(k_2,k_s,z'').$$

And $q_x=\frac{\omega}{c_0}\sqrt{1-\frac{k_x^2c_0^2}{\omega^2}}$ are vertical wave numbers.

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The procedure for getting the input was given by Innanen (2012):

Begin with a data set $d(x_g, x_s, t)$.

Fourier transform to the frequency domain

$$d(x_g, x_s, t) \rightarrow D(k_g, k_s, \omega).$$

Change from ω to k_z

$$D(k_g, k_s, \omega) \rightarrow D(k_g, k_s, k_z),$$

where $k_z = q_g + q_s$.

Scaled by $-i2q_s$,

$$b_1(k_g, k_s, k_z) = (-i2q_s)D(k_g, k_s, k_z).$$

Inverse Fourier transform, appearing in the pseudo-depth domain as

$$b_1(k_g, k_s, k_z) \rightarrow b_1(k_g, k_s, z).$$

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1D IM prediction algorithm

Now we will reduce the algorithm to 1D, using the replacement:

$$k_g = k_s = 0,$$

Then we can obtain the prediction algorithm in 1D normal incidence case,

$$b_{3IM}(k_z) = \int_{-\infty}^{\infty} dz e^{ik_z z} b_1(z) \int_{-\infty}^{z-\epsilon} dz' e^{-ik_z z'} b_1(z') \int_{z'+\epsilon}^{\infty} dz'' e^{ik_z z''} b_1(z'')$$

where $k_z = 2\omega/c_0$.

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Lower-higher-lower relationship

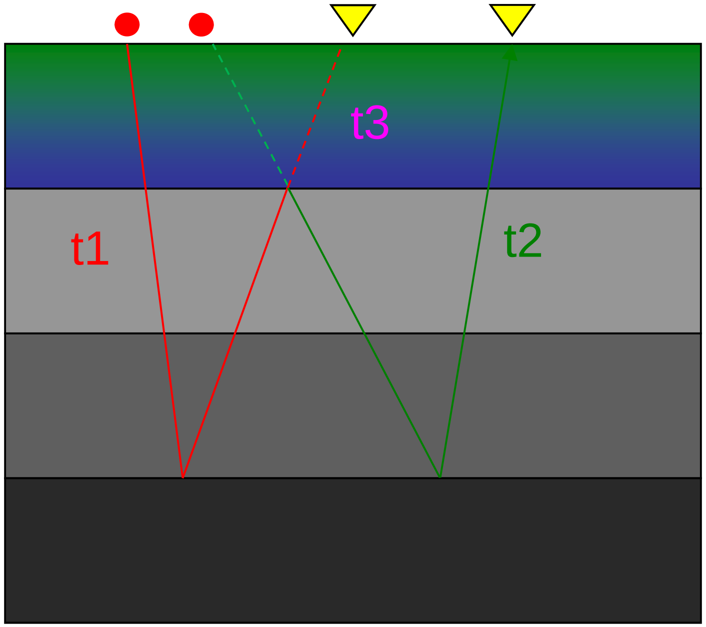


Figure 2. Construction of the travel times of an internal multiple

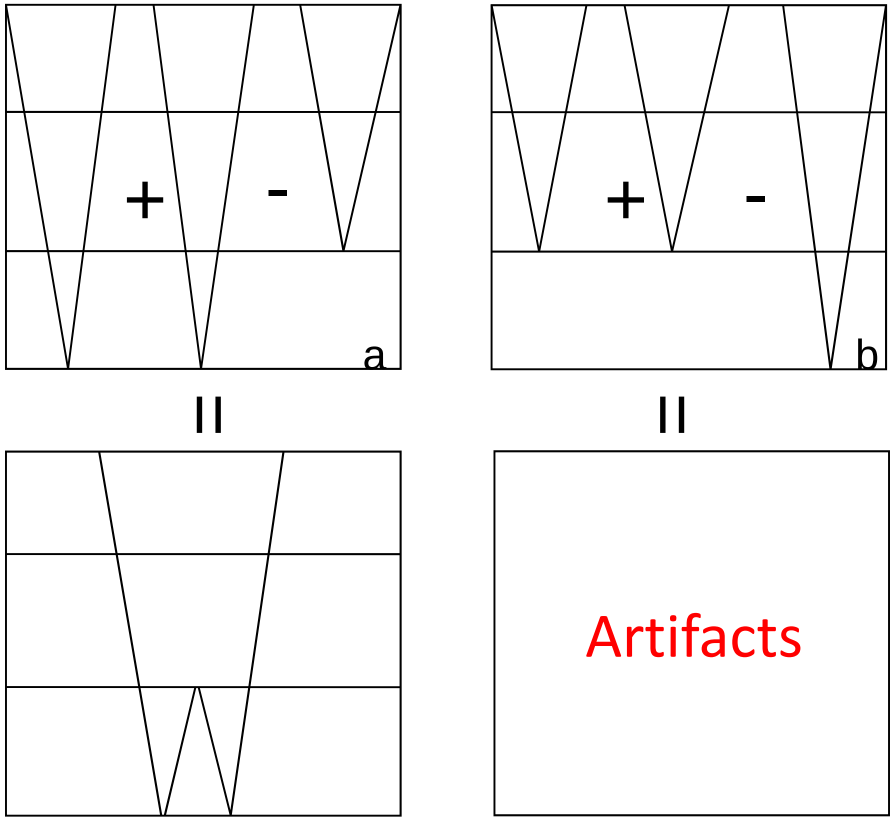
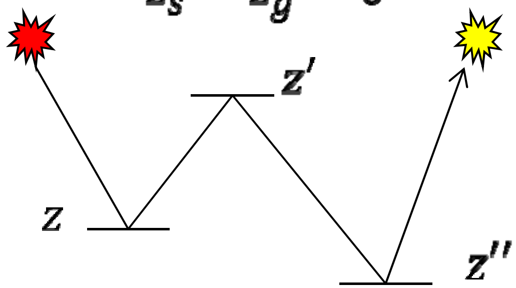


Figure 3. Two combinations of sums and differences

$z_s = z_g = 0$



$\epsilon > 0$ ensure that $z'' > z'$ and $z > z'$

$$b_{3IM}(k_z) = \int_{-\infty}^{\infty} dz e^{ik_z z} b_1(z) \int_{-\infty}^{z-\epsilon} dz' e^{-ik_z z'} b_1(z') \int_{z'+\epsilon}^{\infty} dz'' e^{ik_z z''} b_1(z'')$$

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A study of prediction errors

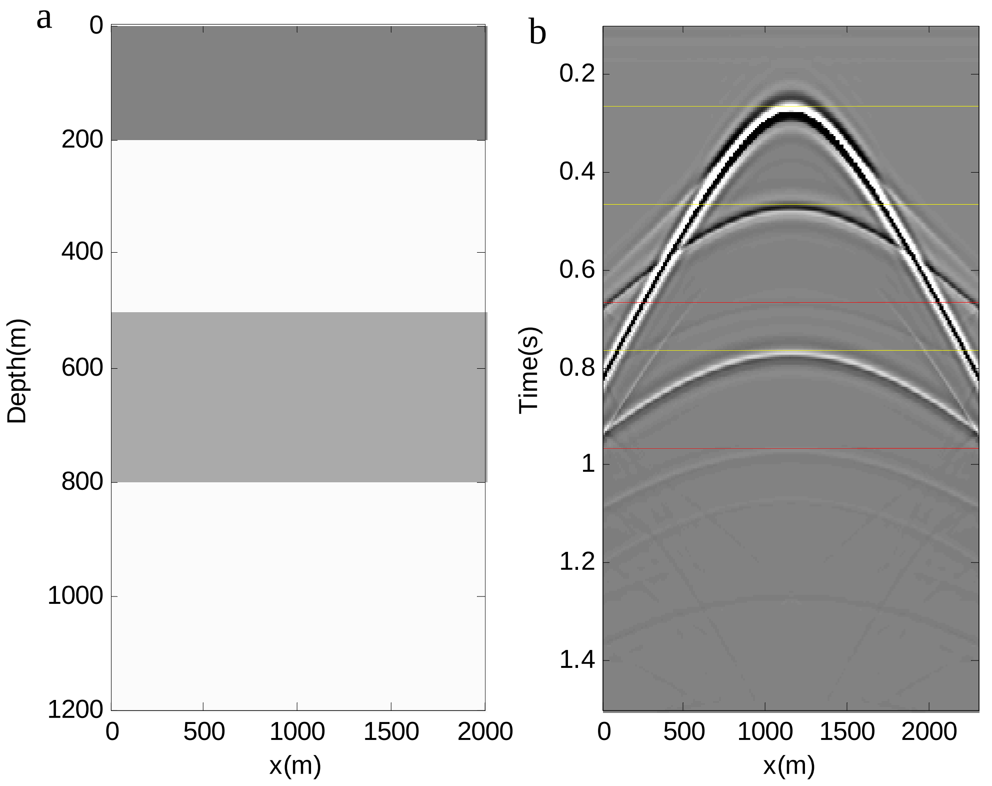

Figure 4. (a) Three layers velocity model. (b) Shot record

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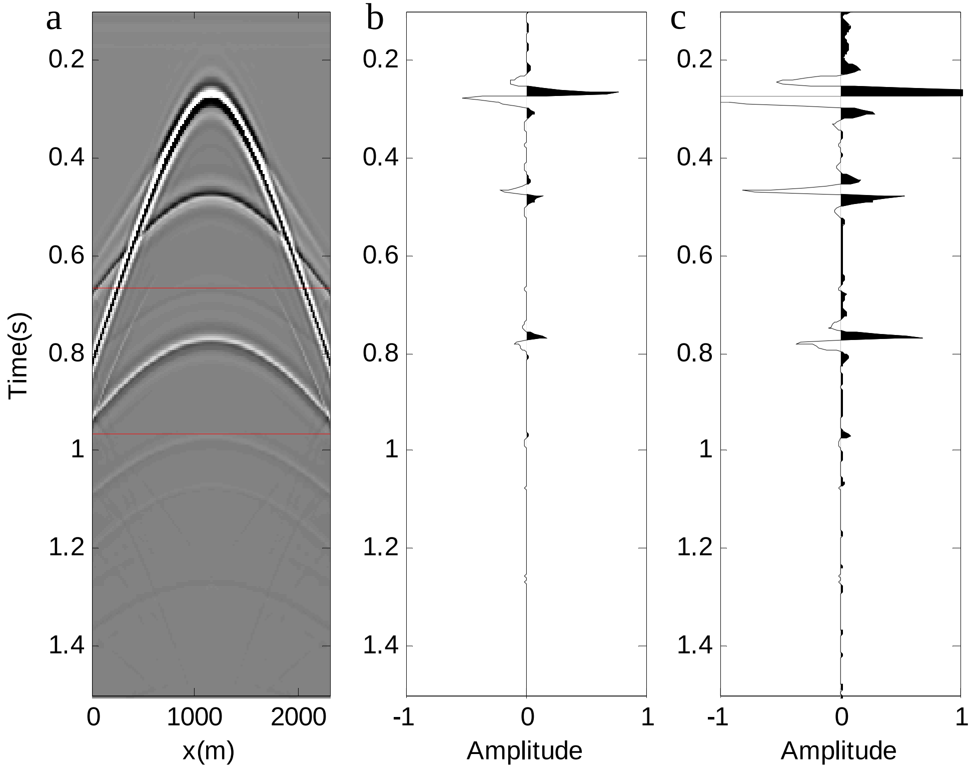

Figure 5. (a) Shot record. (b) Zero offset trace. (c) The same trace with a lager scale.

PARAMETER	**VALUE**
Number of *t*	1024
Number of *x*	1024
Number of *z*	1024
Interval sample time	3*ms*
Velocity and depth of the first interface	3000*m/s* at 200*m*
Velocity and depth of the second interface	2000*m/s* at 500*m*
Velocity and depth of the third interface	3000*m/s* at 800*m*
Wave speed of the source/ receiver medium	1500*m/s*
Time step	0.4*ms*
Maximum time of the shot record	3.07*s*
Location of the source	(1, 512)
Frequency band (*Hz*)	[10 20 80 100]
Epsilon	60

Table 1. Parameters of the velocity model and shot record

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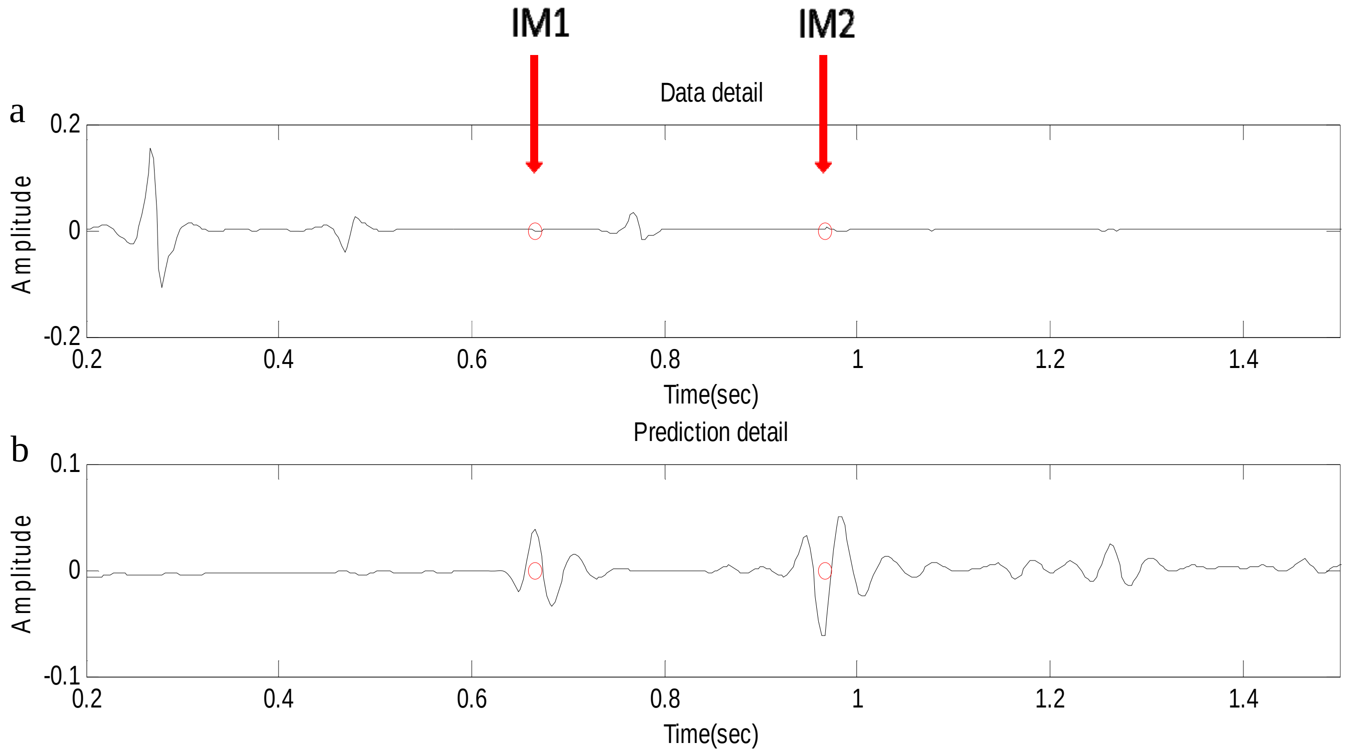

Figure 6. (a) Input data (b) Prediction output

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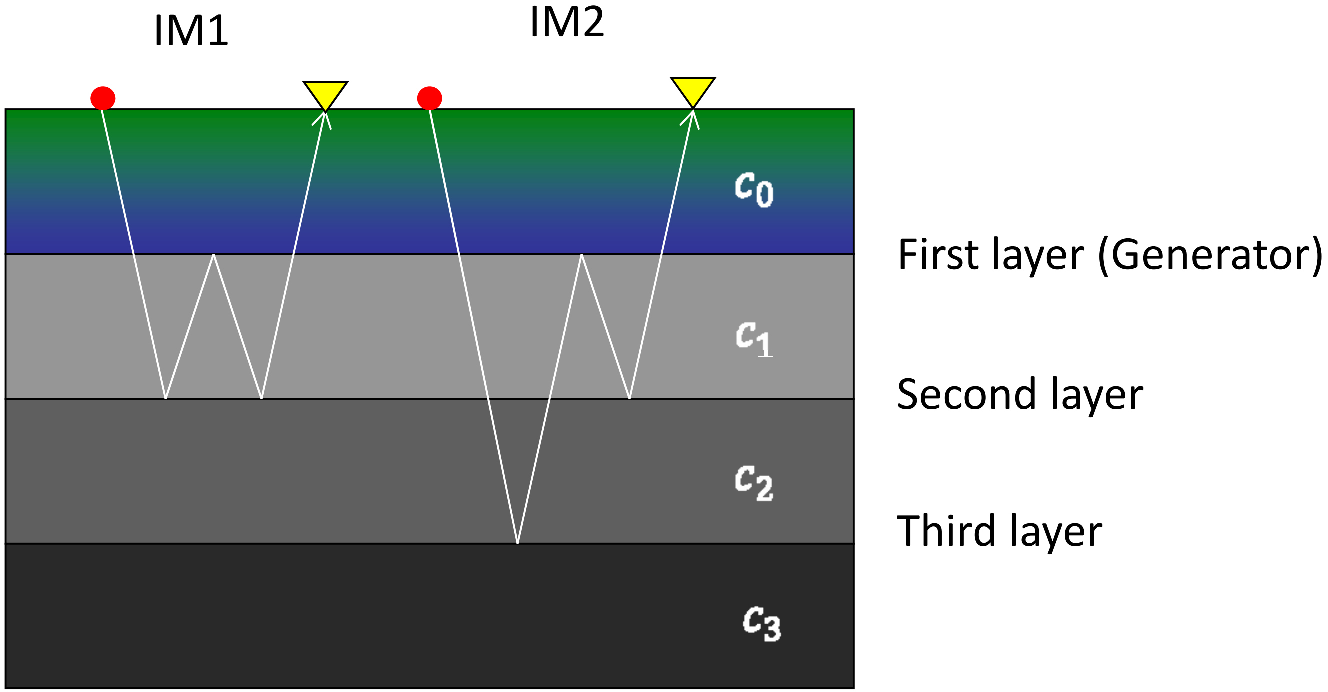

Figure 7. The paths of two internal multiples

The influence of offset

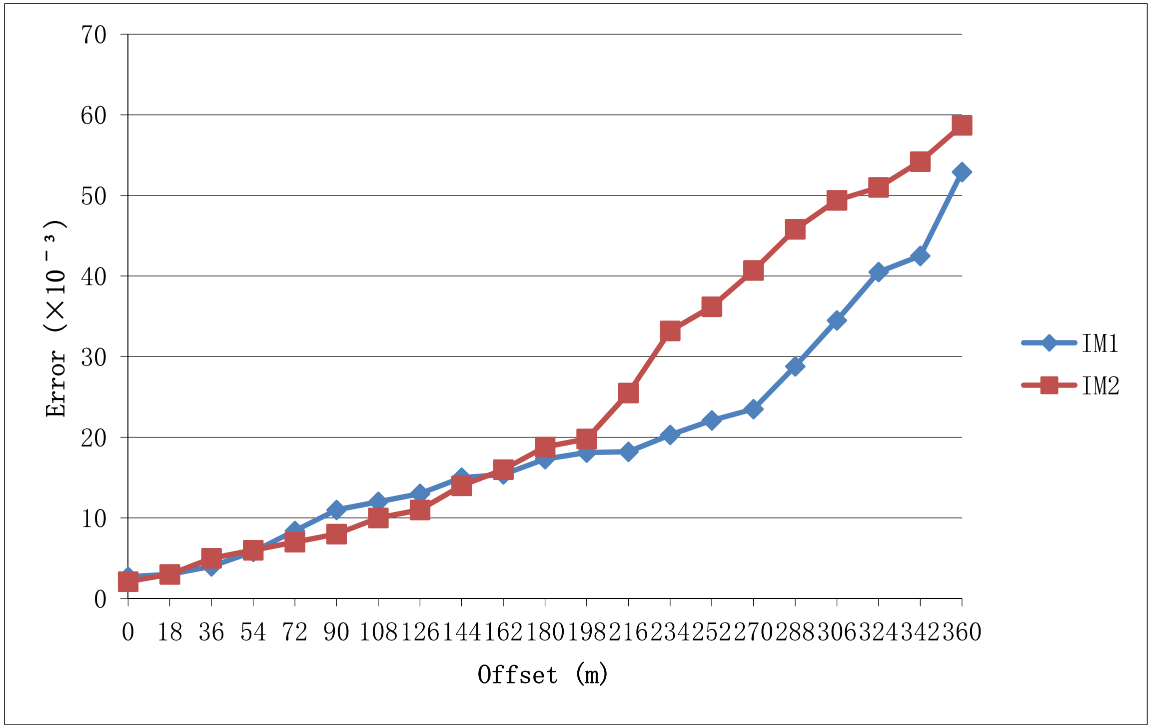

Figure 8. Prediction errors plotted against an increasing series of offset

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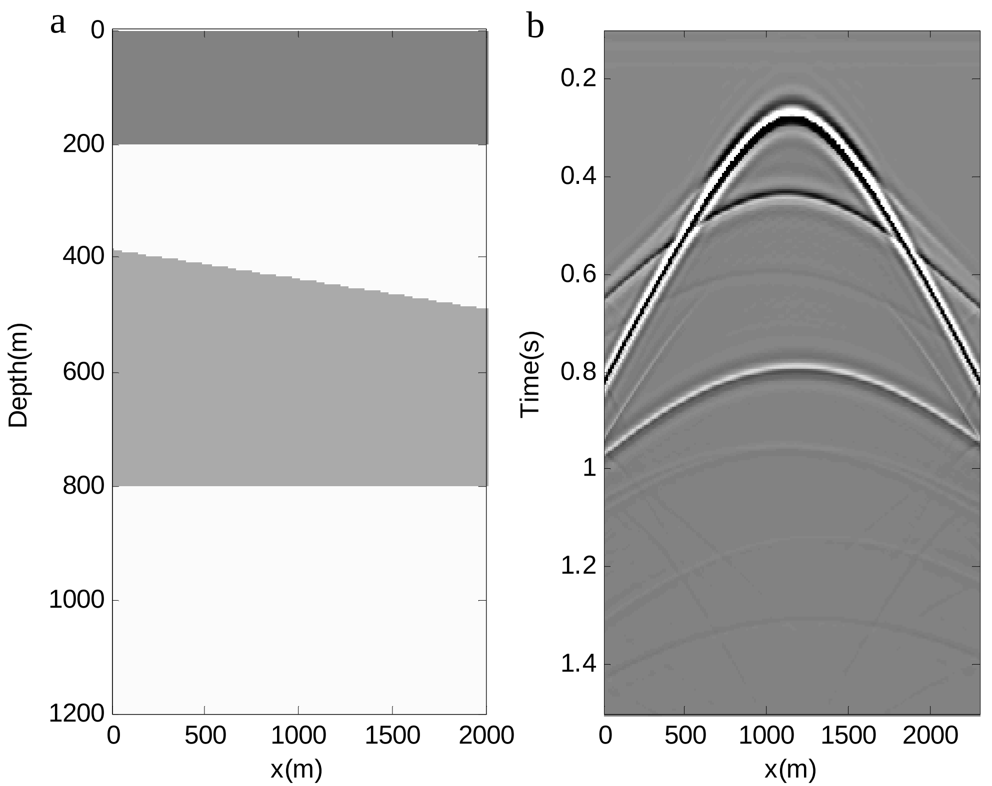

Figure 9. (a) Three layers velocity model with the second layer's dipping angle equals 3 degrees. (b) Shot record

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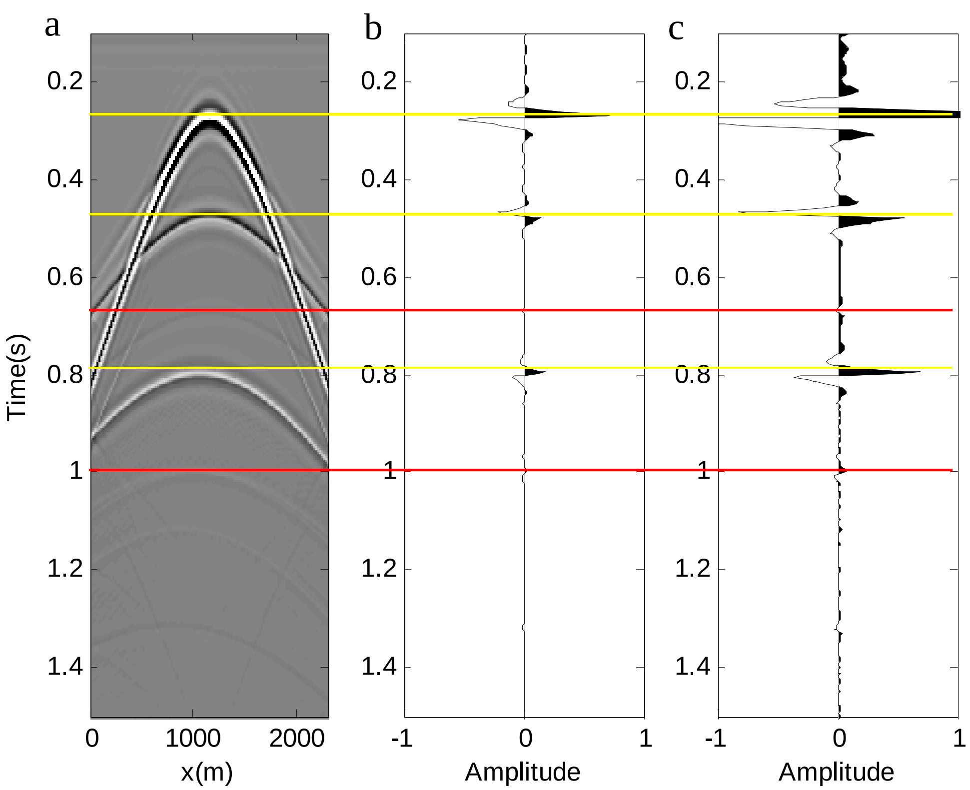

Figure 10. (a) Shot record. (b) Zero offset trace. (c) The same trace with a lager scale.

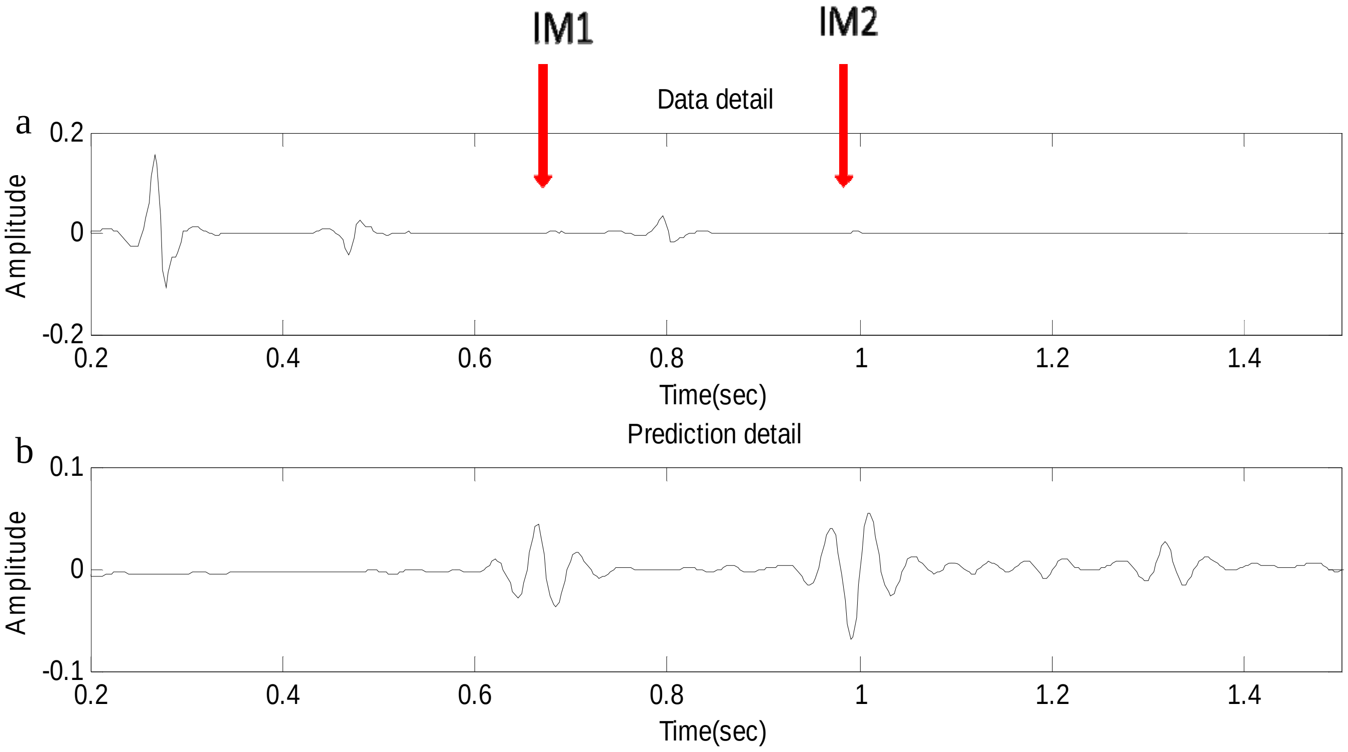

Figure 11. (a) Input data (b) Prediction output

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The influence of dipping angle (generator)

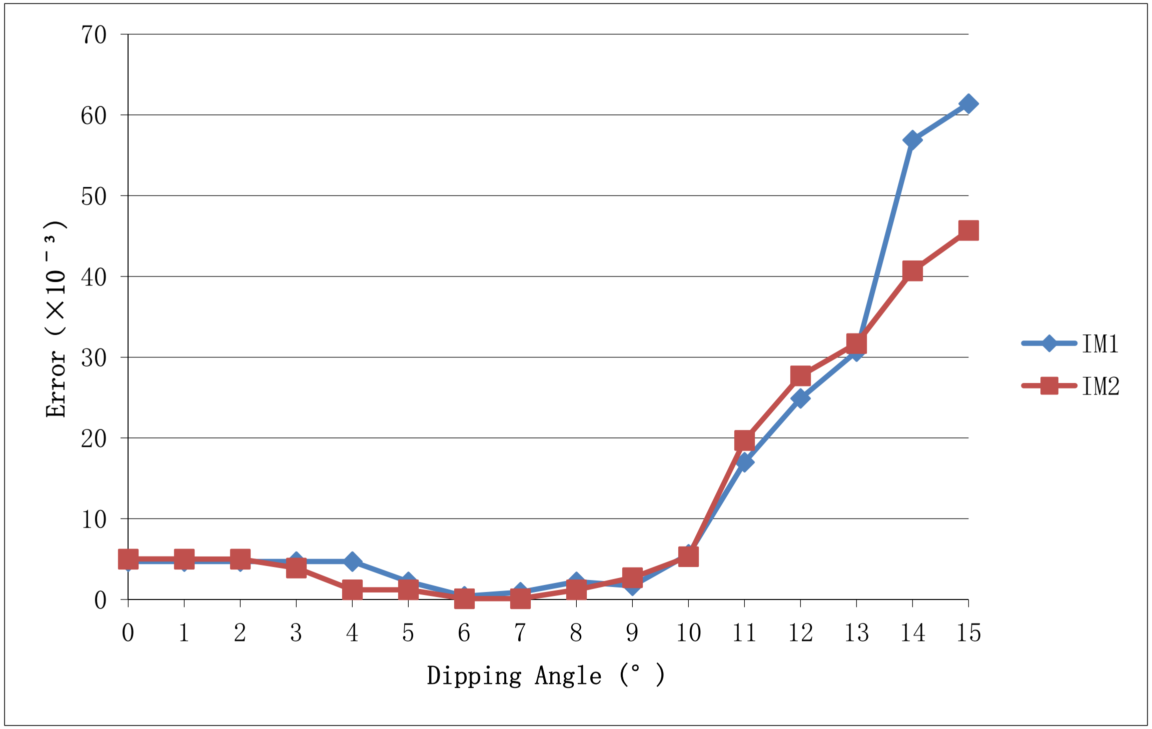

Figure 12. Prediction errors in the zero offset trace plotted against an increasing series of dipping angle.

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The influence of dipping angle (second interface)

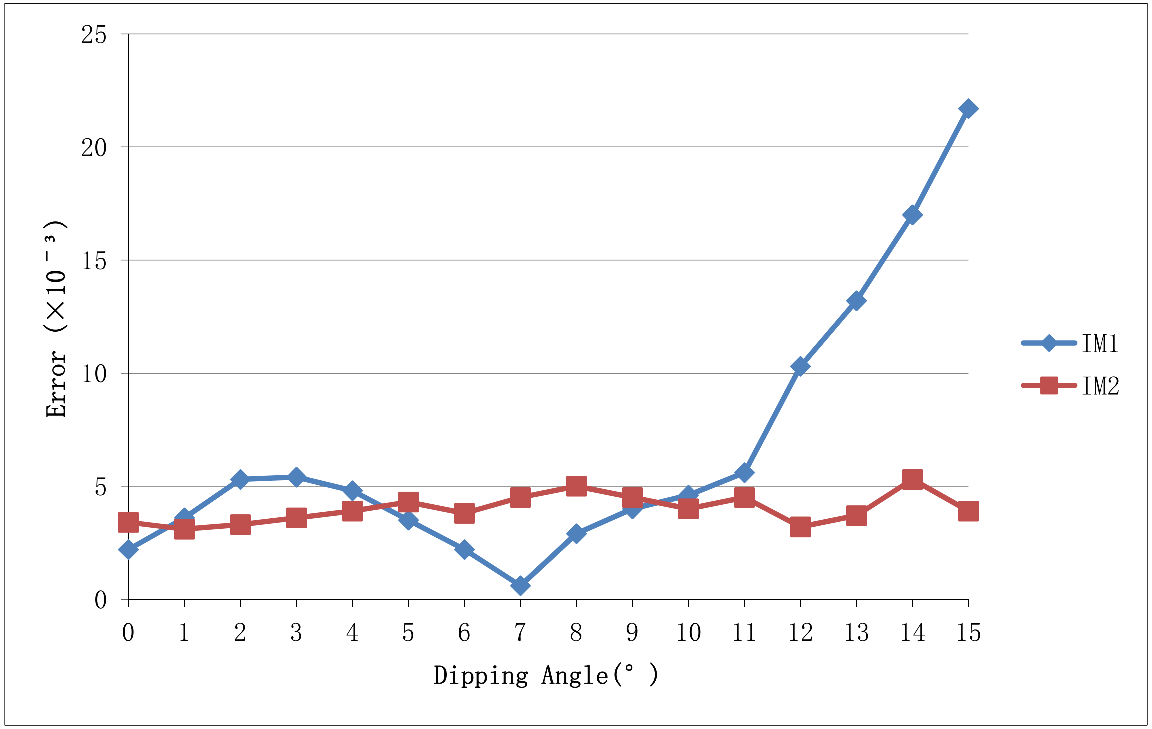

Figure 13. Prediction errors in the zero offset trace plotted against an increasing series of dipping angles.

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The influence of dipping angle (third interface)

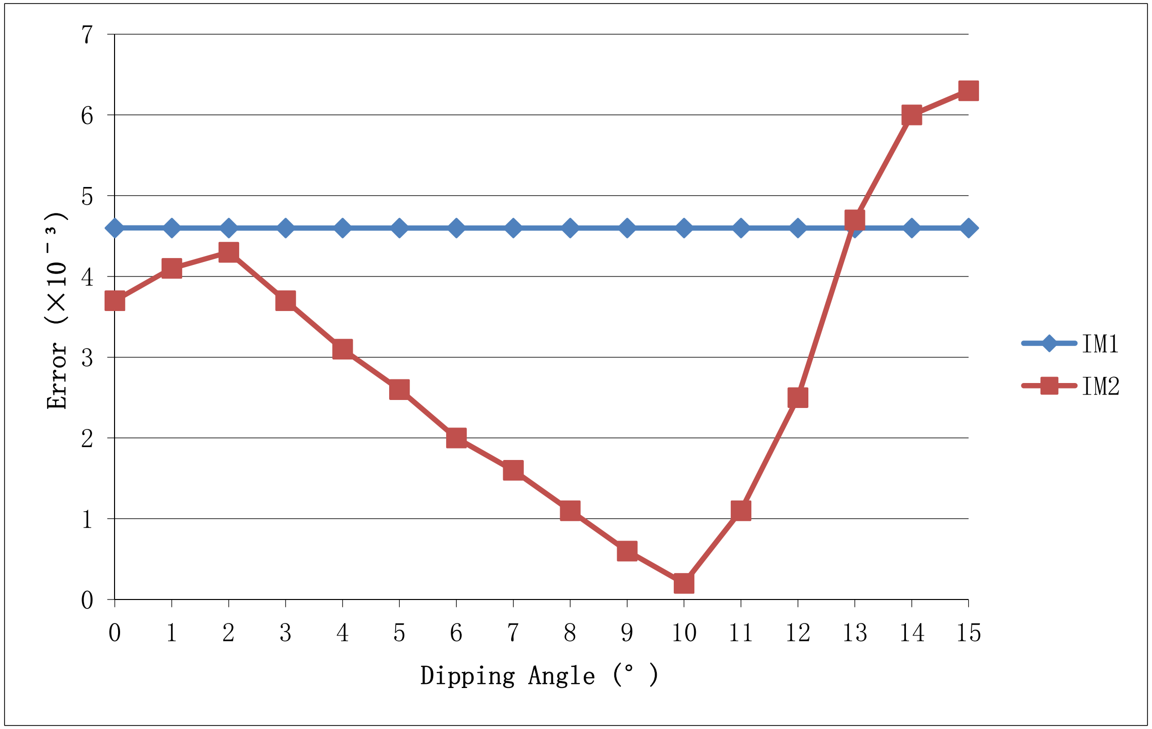

Figure 14. Prediction errors in the zero offset trace plotted against an increasing series of dipping angles.

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Recommendations

1) We do not recommend applying this method when the offset is greater than 300m.

2) When we have information about the subsurface.

- Generator: we recommend using this method when the dipping angel is within 10 degrees.
- Second layer: we recommend applying this method when the dipping angle is within 11 degrees.
- Third layer: we recommend applying this method at any dipping angle within 15 degrees.

3) Even without any advanced knowledge of the multiple generators, we recommend using this algorithm when the dipping angle is less than 10 degrees.

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