Accuracy vs. speed in 1D and 1.5D internal multiple prediction

Pan Pan
panp@ucalgary.ca

Supervisor: Dr. Kris Innanen

Outline

- Introduction
- Basic principles of IM prediction algorithms
- A study of prediction accuracy in 1D
- A study of prediction accuracy in 1.5D
- Conclusions and recommendations
- Acknowledgements

Introduction

The problems with internal multiples:

- ❑ Events which can be misinterpreted as primaries
- ❑ Events which can interfere with primaries
- ❑ Events which can obscure the task of interpretation

Task:

- ❑ Predict quantitatively which events are internal multiples, and interpret or remove

2D, 3D internal multiple prediction:

- ❑ Accurate but slow

1D internal multiple prediction:

- ❑ Fast but exposed to error

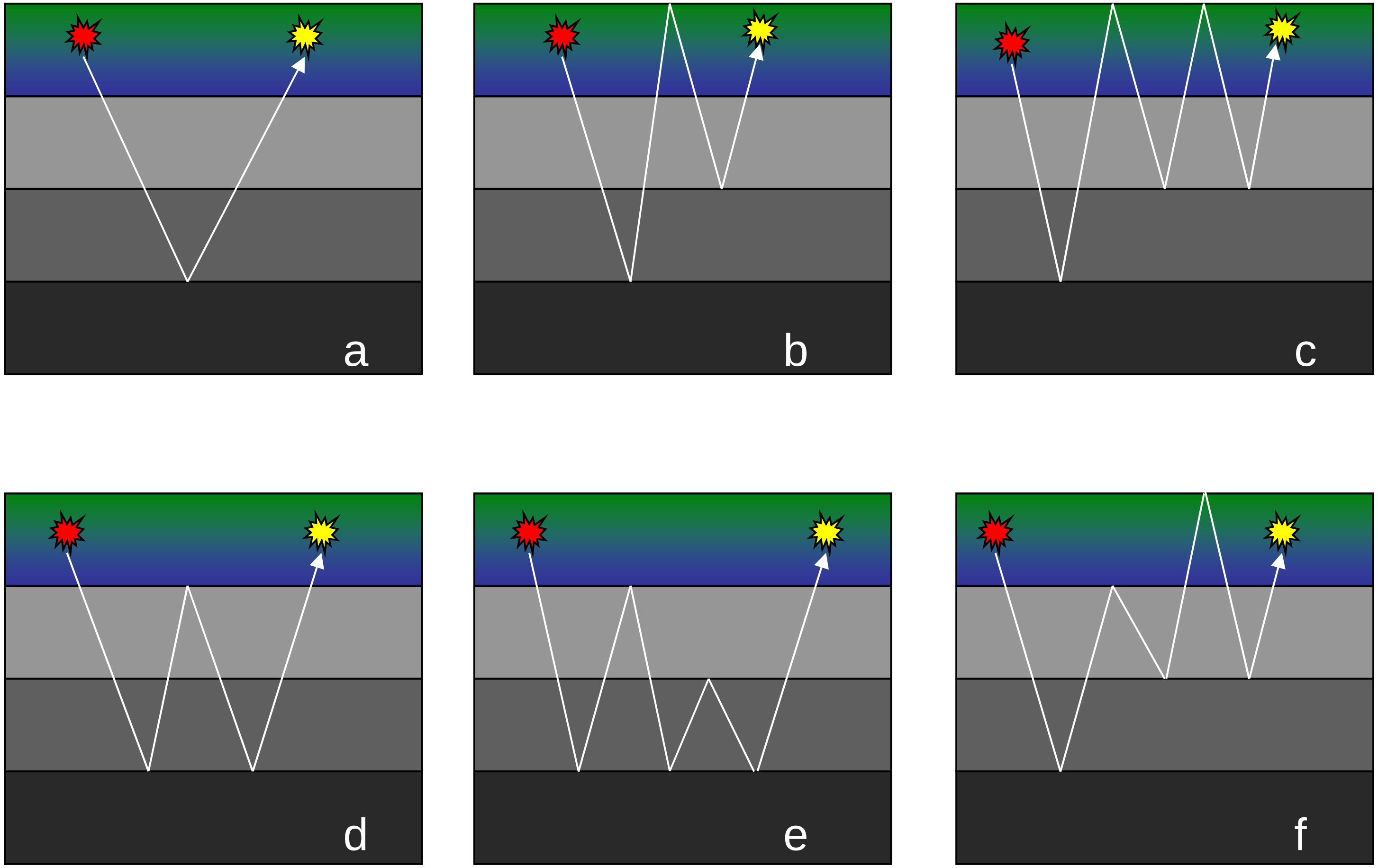
Question: under what circumstances, can the speed of 1D methods add value in a multidimensional world?

Basic principles

- Primaries: events which have experienced one upward reflection and no downward reflections during their history.

- FSMs: 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.



Primaries and multiples (after Weglein and Dragoset, 2005)

2D IM prediction algorithm

The prediction algorithm given by Weglein et., 1997 is

$$b_{3IM}(k_g, k_s, q_g + q_s) = \left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} dk_1 dk_2$$

$$\times \int_{-\infty}^{\infty} dz e^{i(q_g+q_1)z} b_1(k_g, k_1, z) \int_{-\infty}^{z-\epsilon} dz' e^{-i(q_1+q_2)z'} b_1(k_1, k_2, z')$$

$$\times \int_{z'+\epsilon}^{\infty} dz'' e^{i(q_2+q_s)z''} b_1(k_2, k_s, z'').$$

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

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 $k_z = 2\omega/c_0$.

1.5D IM prediction algorithm

If the data have offset but the Earth is nearly layered, in which

$$k_g = k_s,$$

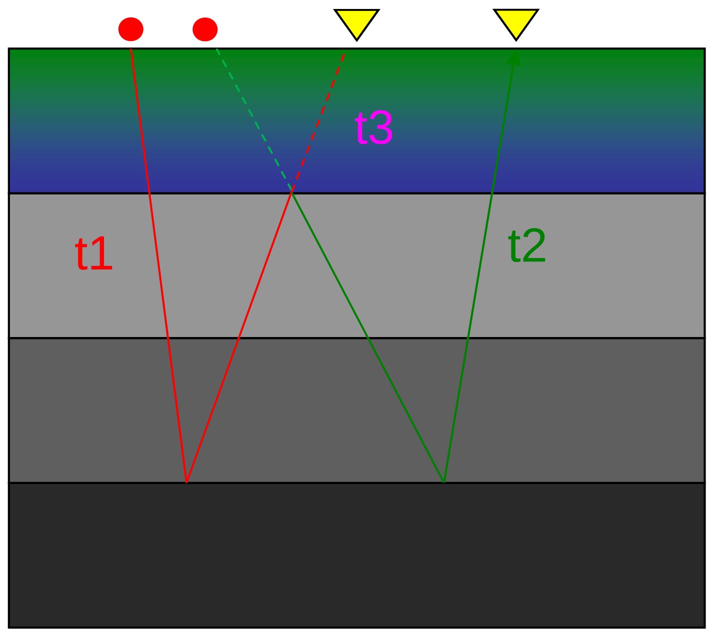
We obtain the 1.5D algorithm,

$$b_{3IM}(k_g,\omega) = \int_{-\infty}^{\infty} dz e^{ik_z z} b_1\left(k_g,z\right) \int_{-\infty}^{z-\epsilon} dz' e^{-ik_z z'} b_1\left(k_g,z'\right)$$

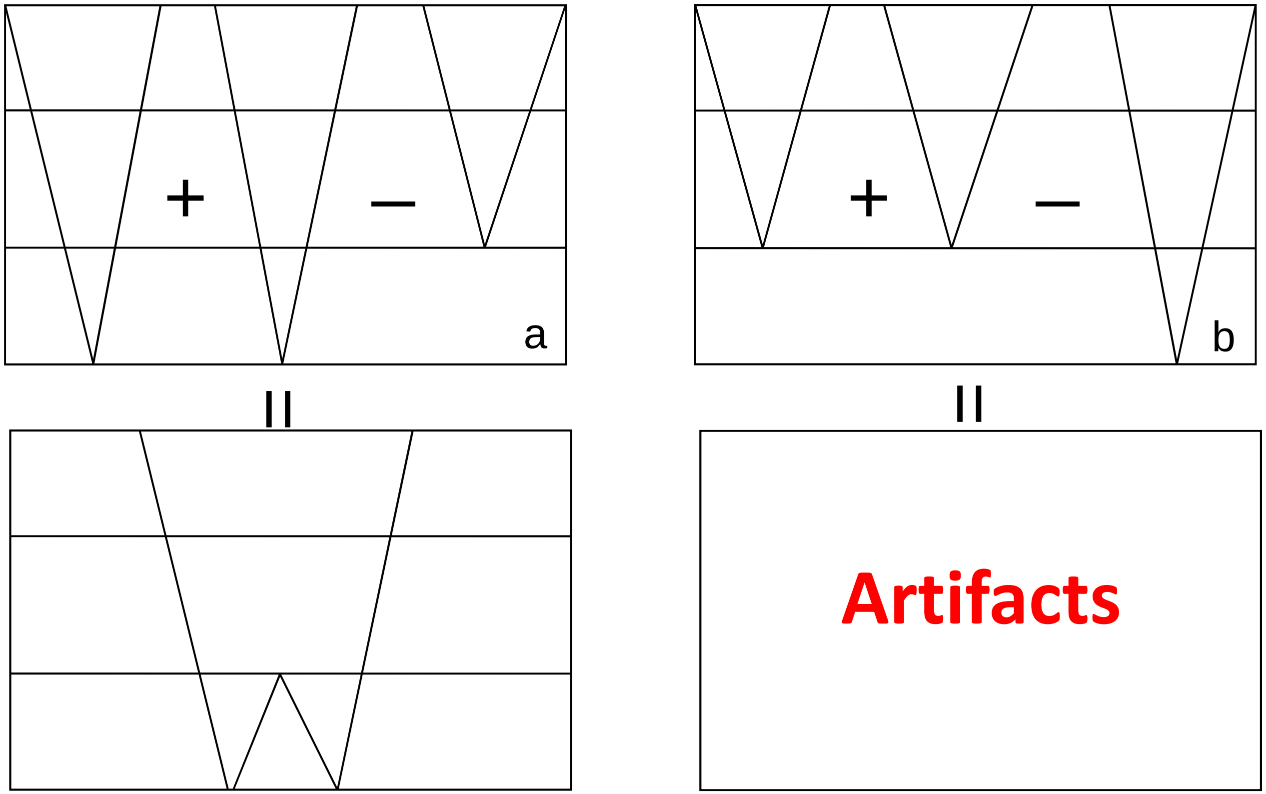
$$\times \int_{z'+\epsilon}^{\infty} dz'' e^{ik_z z''} b_1(k_g,z'')$$

where $k_z = 2q_g$.

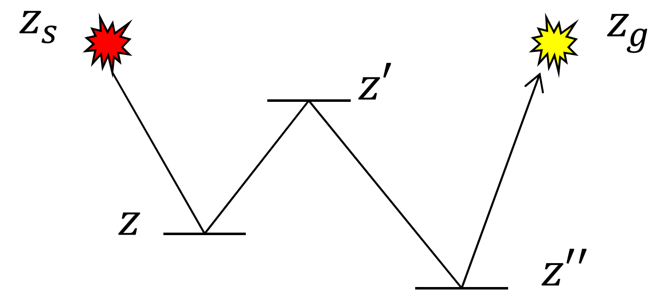
Lower-higher-lower relationship



Construction of the travel times of an internal multiple



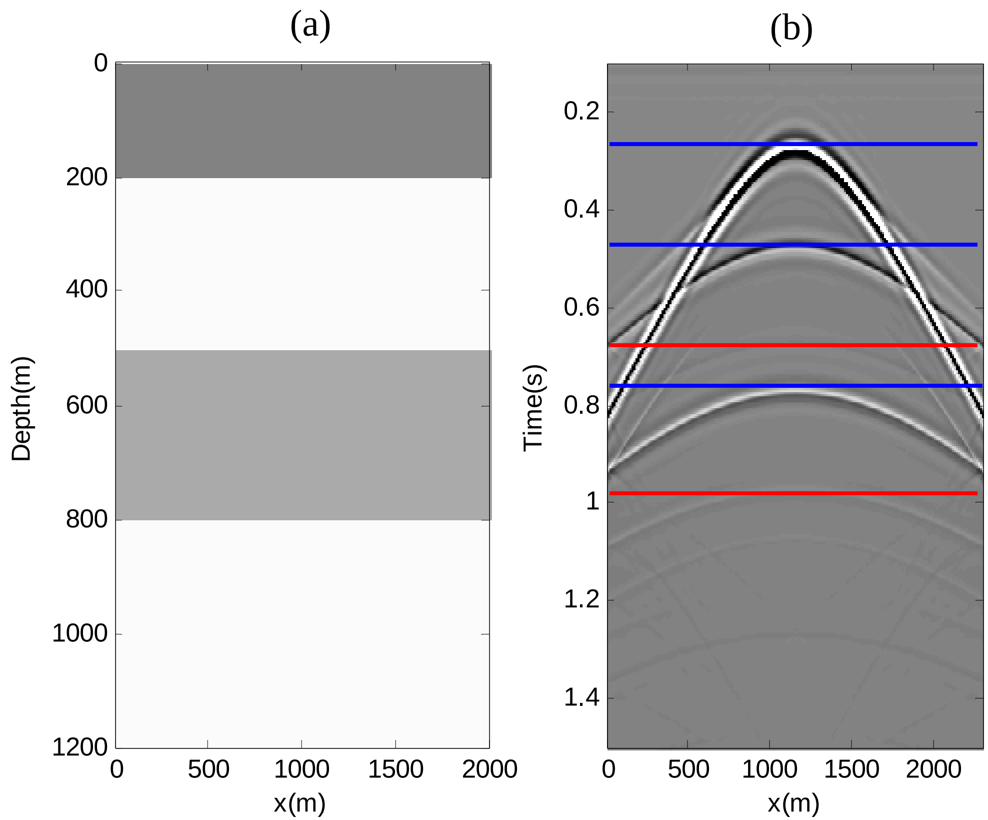
Two combinations of sums and differences



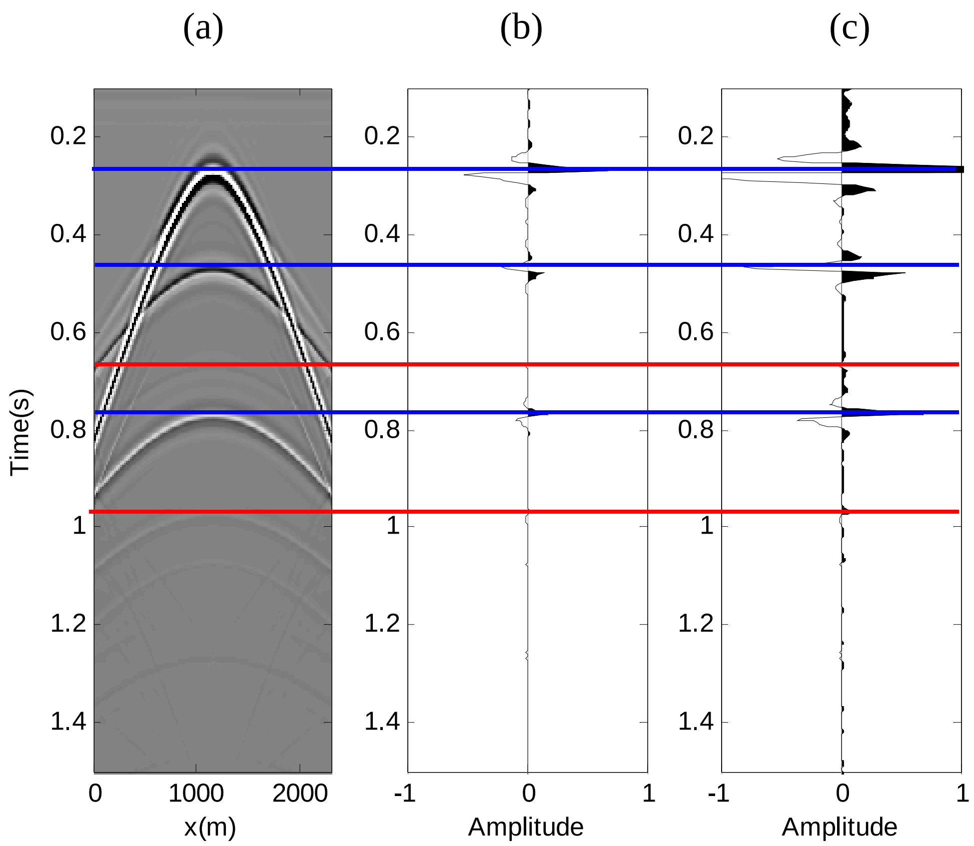
$\epsilon > 0$ ensures that $z'' > z'$ and $z > z'$

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

A study of prediction accuracy in 1D



(a) Four-layer velocity model. (b) Shot record.



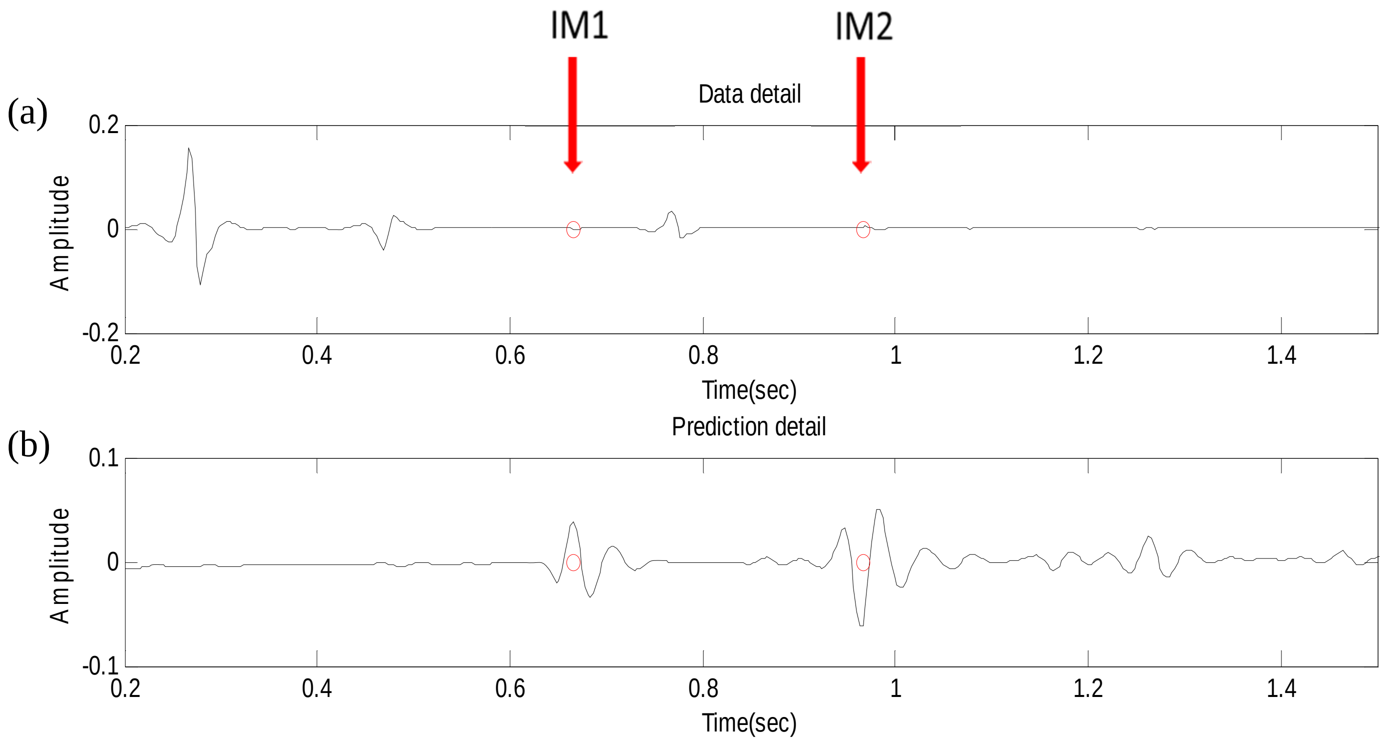
(a) Shot record. (b) Zero offset trace. (c) The same trace with a larger scale.

Decreases edge effects

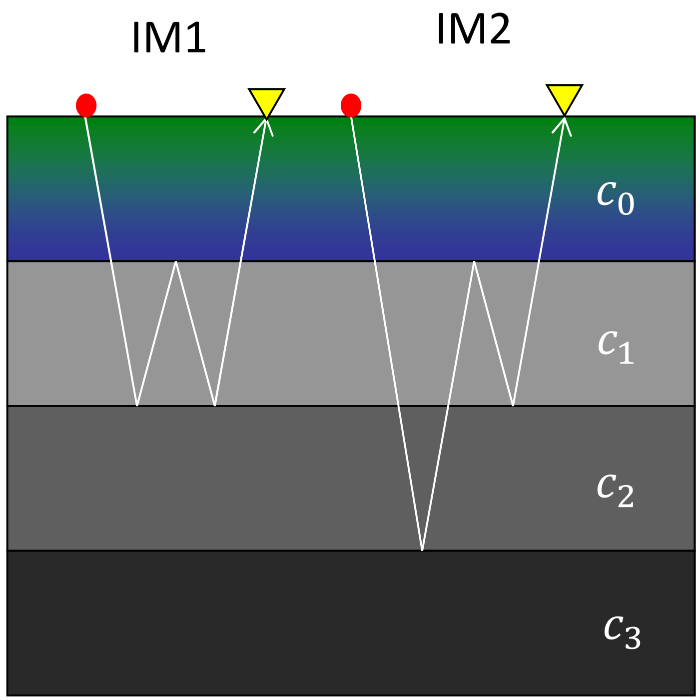
PARAMETER	VALUE
Number of *t*	1024
Number of *x*	1024
Number of *z*	1024
Interval sample time	3*ms*
Velocity and depth of the first interface	3000*m/s* at 200*m*
Velocity and depth of the second interface	2000*m/s* at 500*m*
Velocity and depth of the third interface	3000*m/s* at 800*m*
Wave speed of 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

Localized wavelet

Parameters of the velocity model and shot record

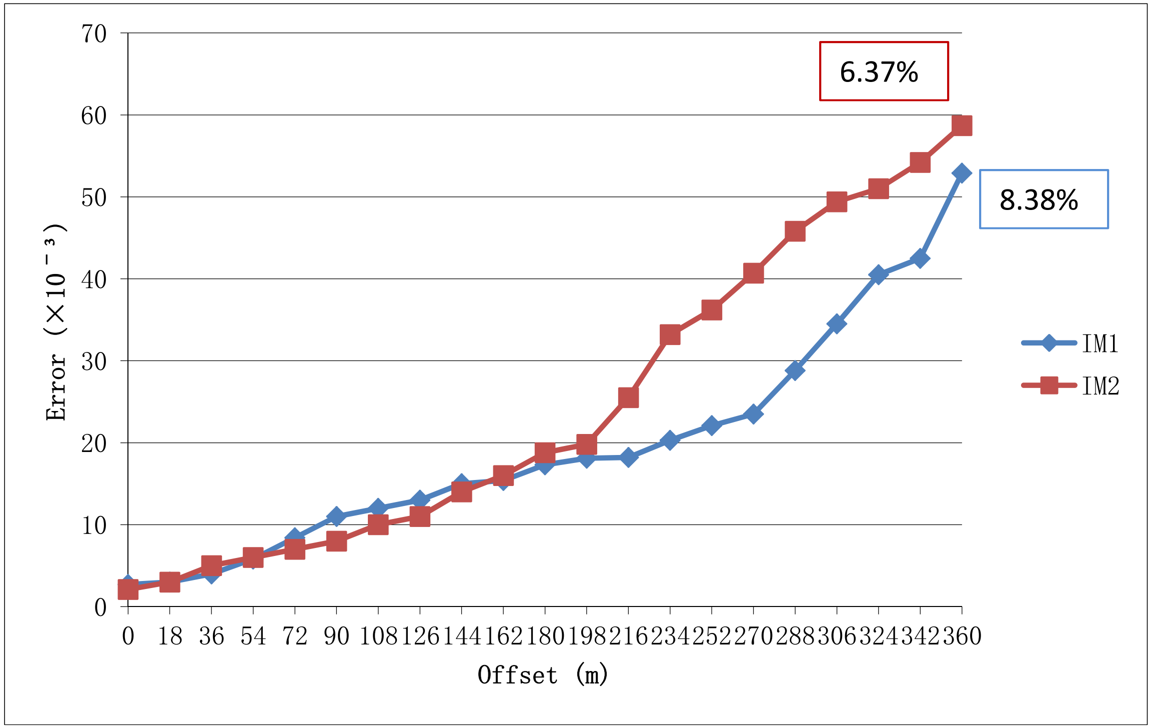


(a) Input data. (b) Prediction output.



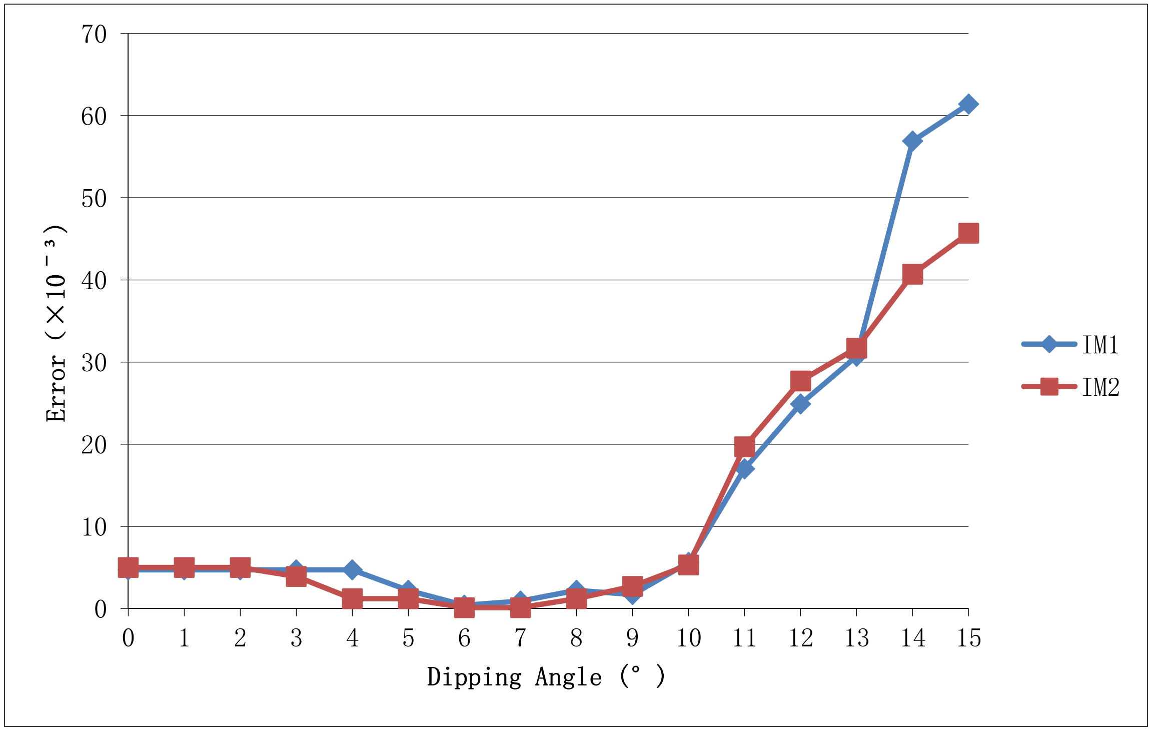
The paths of the two internal multiples

The influence of offset



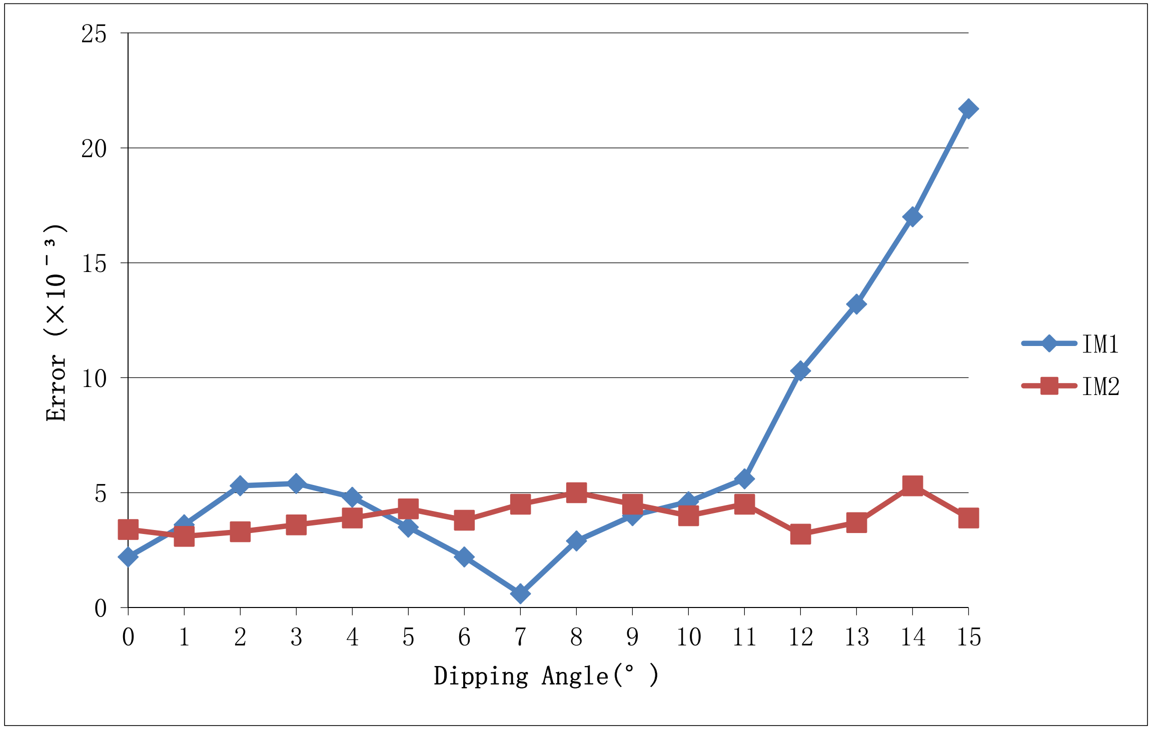
Prediction errors plotted against an increasing series of offsets

The influence of dipping angle (generator)



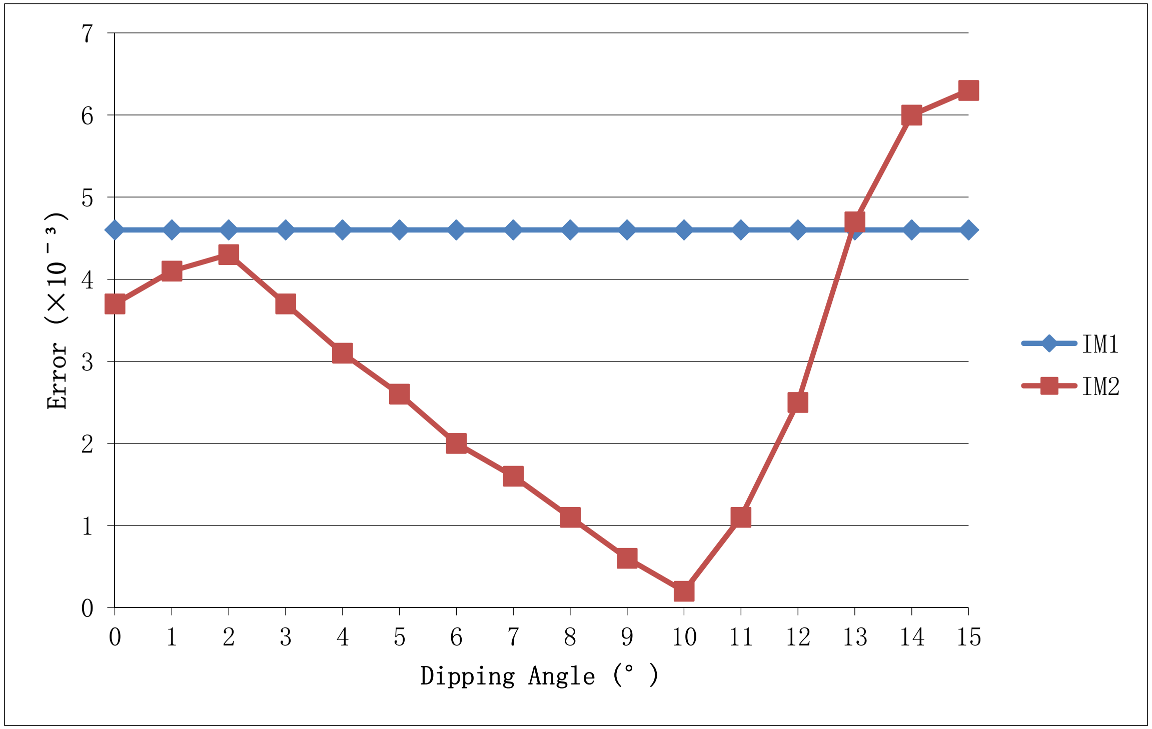
Prediction errors in the zero offset trace plotted against an increasing series of dipping angles.

The influence of dipping angle (second interface)



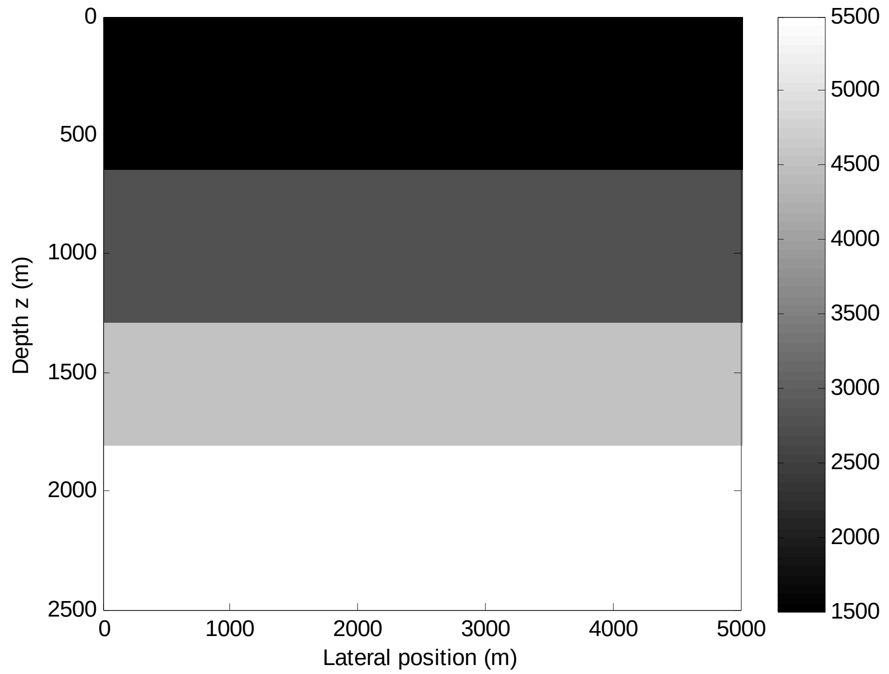
Prediction errors in the zero offset trace plotted against an increasing series of dipping angles.

The influence of dipping angle (third interface)

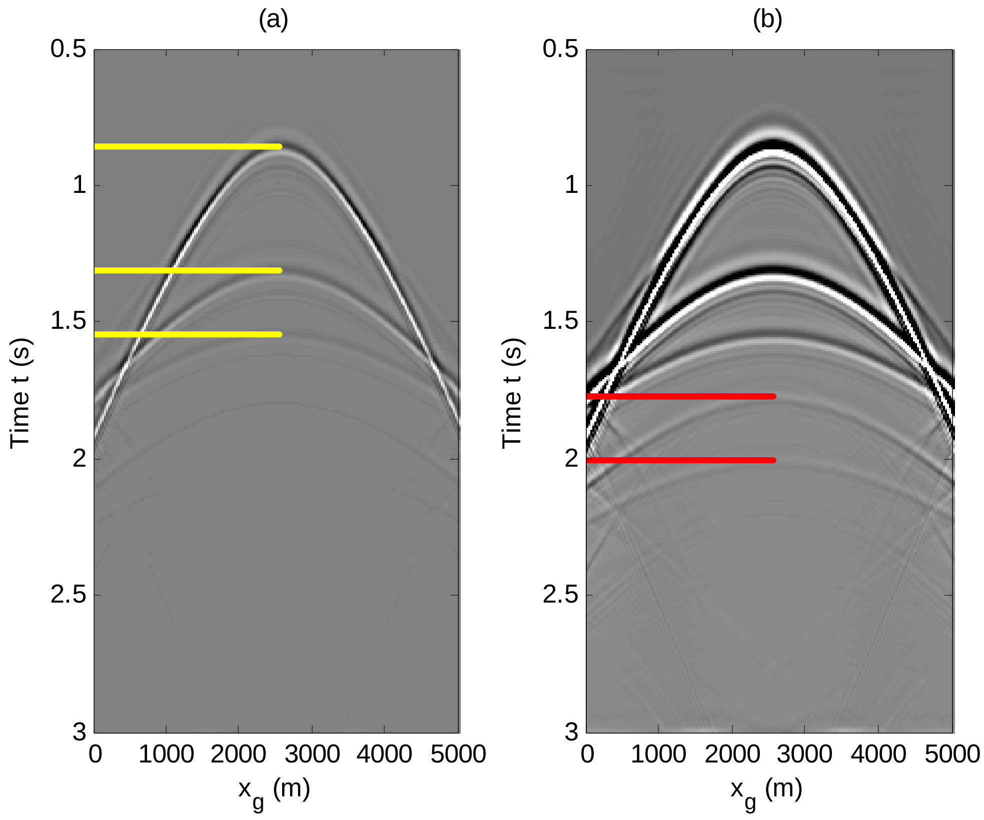


Prediction errors in the zero offset trace plotted against an increasing series of dipping angles.

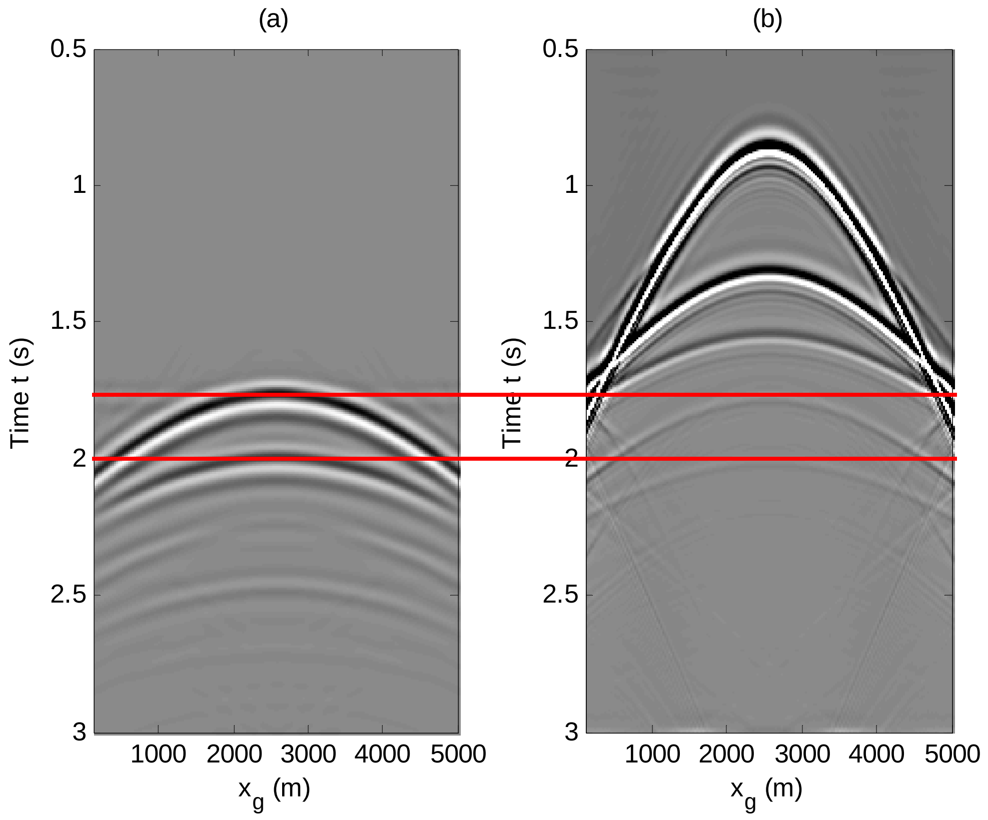
A study of prediction accuracy in 1.5D



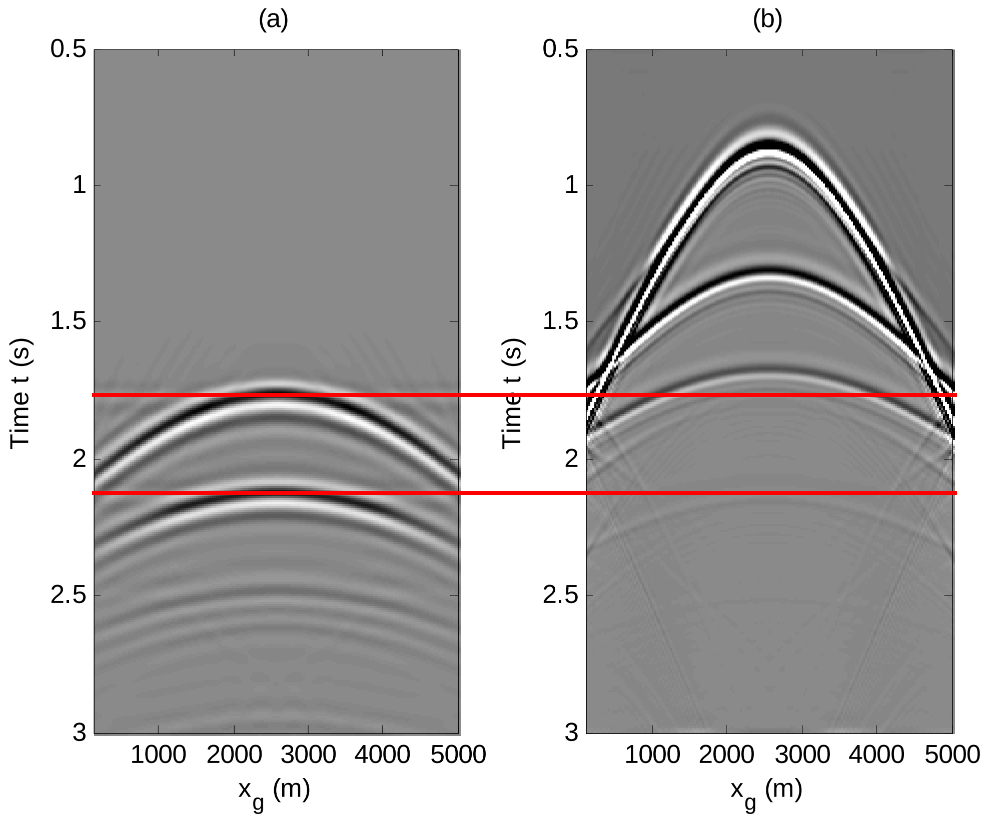
Four-layer velocity model used to generate synthetic data and test the 1.5D internal multiple prediction algorithm.



Shot record in which primaries are indicated in yellow and internal multiples are indicated in red.

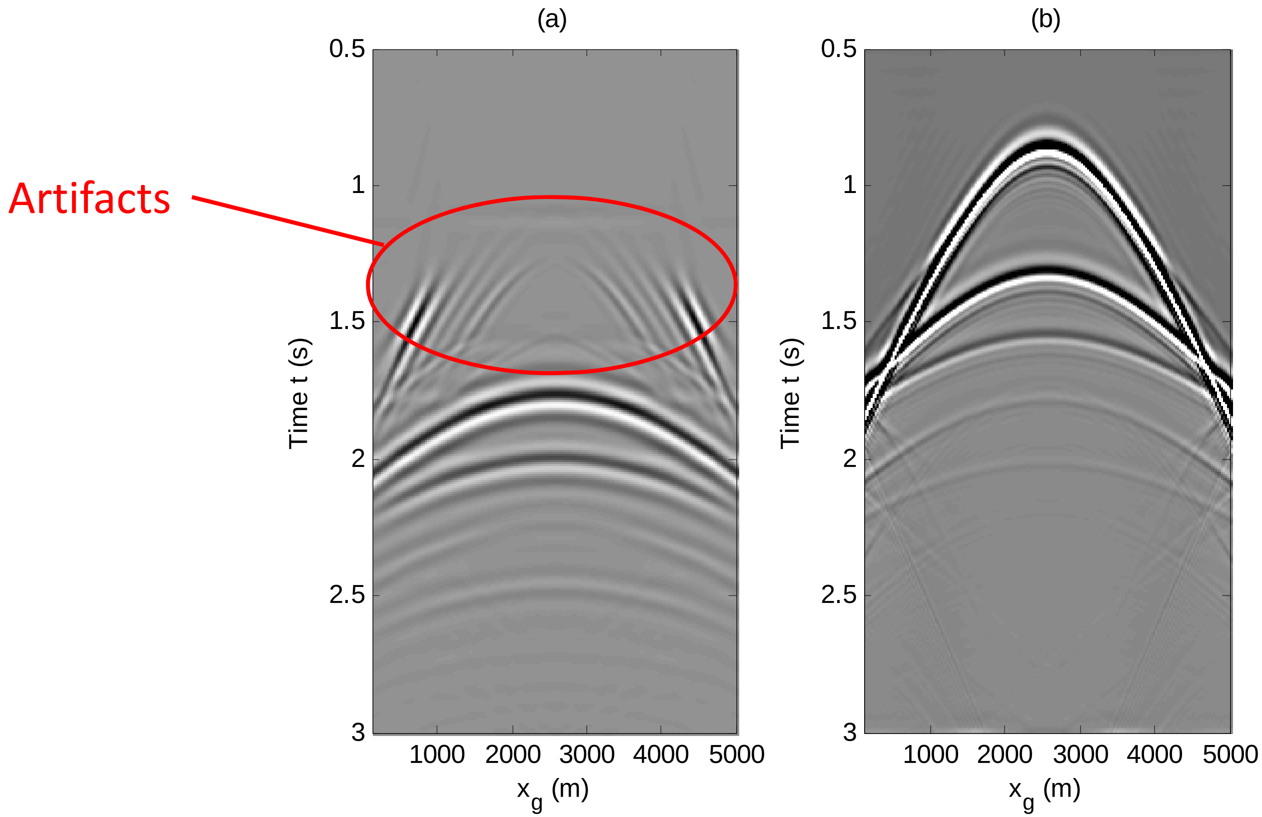


The output of the 1.5D internal multiple prediction with epsilon value equals 200.



The output of the 1.5D internal multiple prediction with epsilon value equals 200.

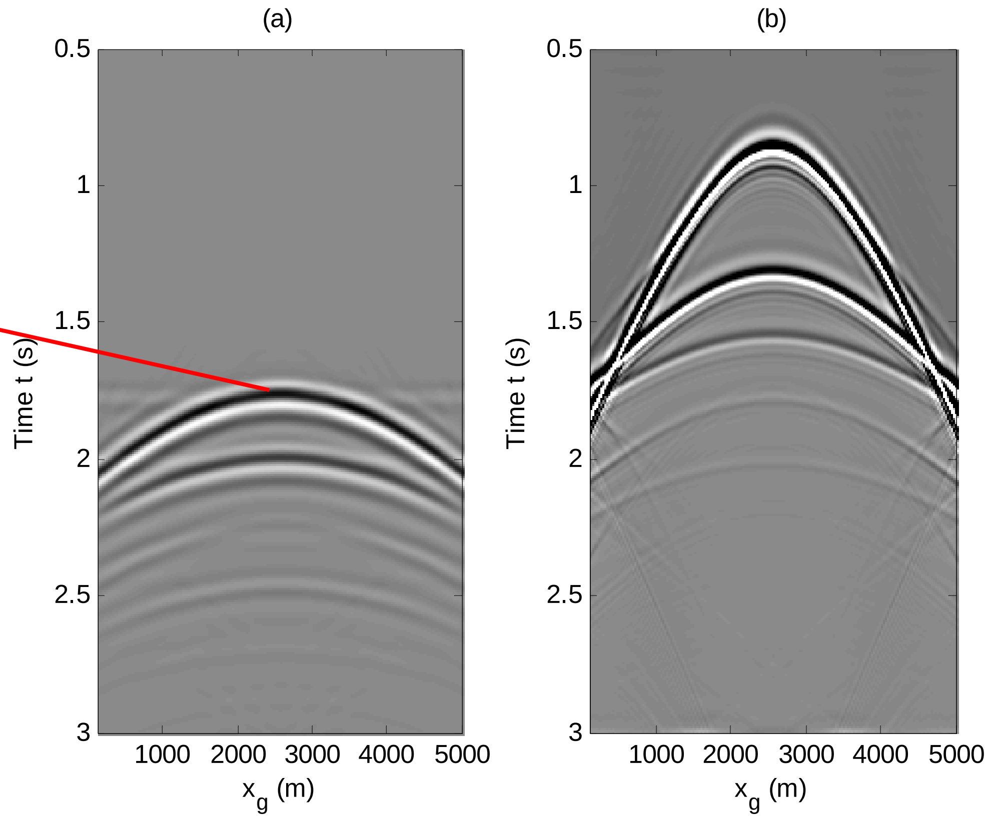
The influence of epsilon values $(\epsilon = 100)$



The output of the 1.5D internal multiple prediction with epsilon value equals 100.

The influence of epsilon values $(\epsilon = 200)$

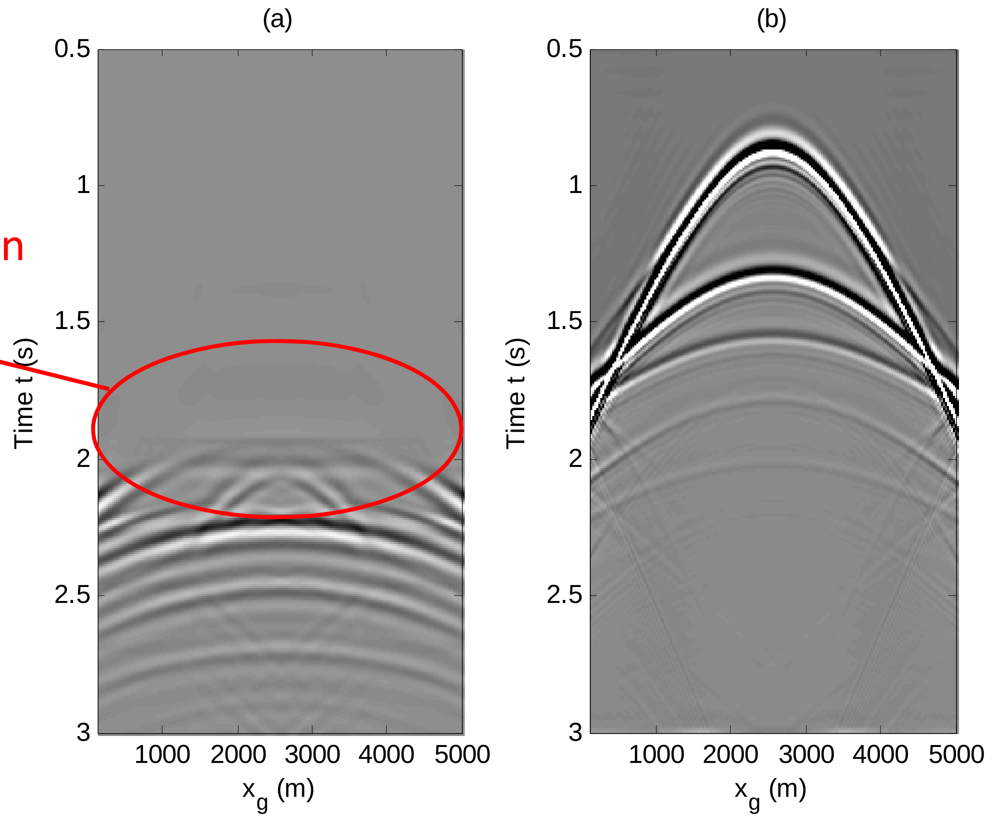
Optimal value



The output of the 1.5D internal multiple prediction with epsilon value equals 200.

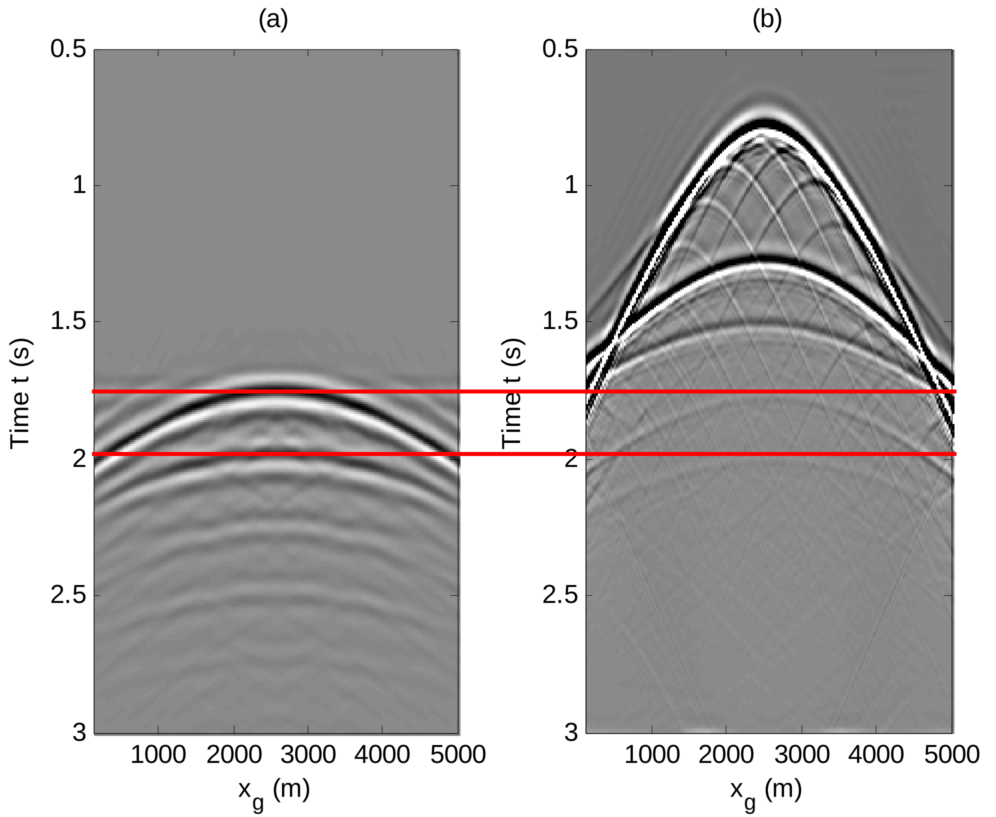
The influence of epsilon values $(\epsilon = 300)$

Important information has been damaged



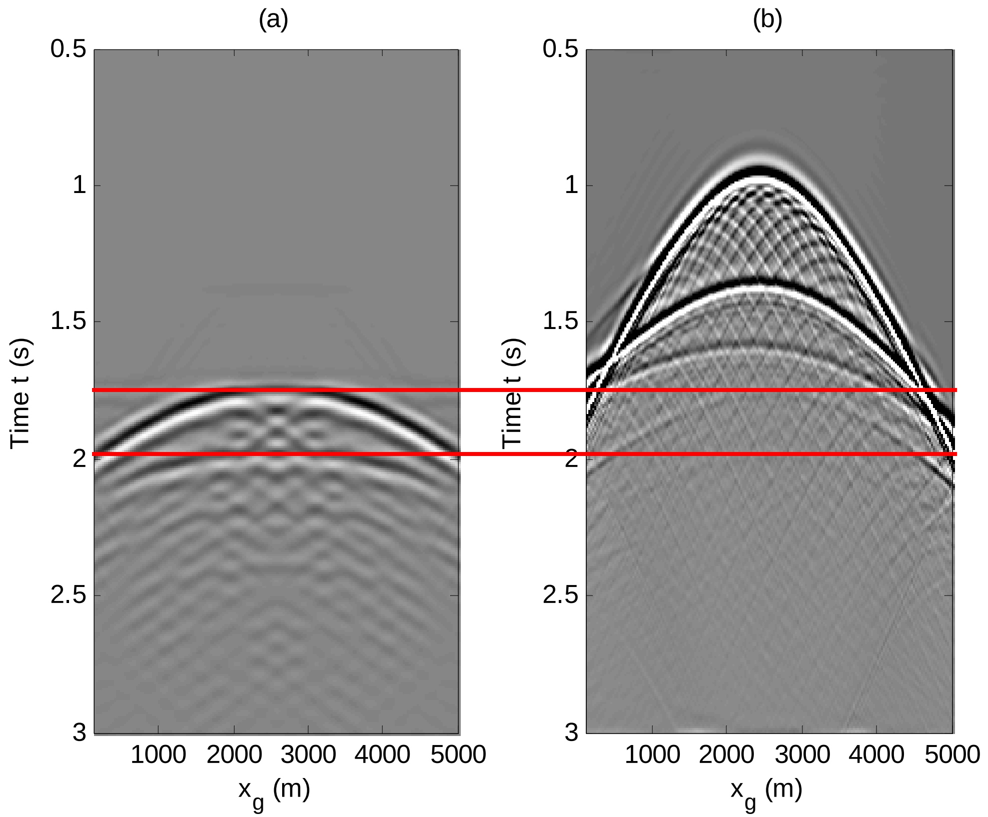
The output of the 1.5D internal multiple prediction with epsilon value equals 300.

The influence of dipping angles $(\boldsymbol{\theta = 2°})$



The output of the 1.5D internal multiple prediction with epsilon value equals 200.

The influence of dipping angles $(\theta = 5°)$



The output of the 1.5D internal multiple prediction with epsilon value equals 180.

Recommendations

Question: under what circumstances can the speed of 1D methods add value in a multidimensional world?

- ❑ We recommend applying 1D method when the offset is smaller than 300m.
- ❑ When we have information about the subsurface, all results up to 10 degrees show good results in 1D method.
- ❑ Even without any advanced knowledge of the multiple generators, we recommend using this method when the dipping angle is within 10 degrees.

Conclusions

- For small dipping angle layers, all results with dipping angle within 10 degrees show good results in 1D method.
- Compared to 2D method, the computation cost has been dramatically reduced in 1.5D method.
- According to the effects of various epsilon values, we can choose the epsilon value more efficiently.
- Our 1.5D method is demonstrated to be useful for situations where small dipping angles exist and primaries are mixed together with internal multiples.

Acknowledgements

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