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AVA analysis and geological dip estimation via two-way wave-equation based extended images

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Motivation

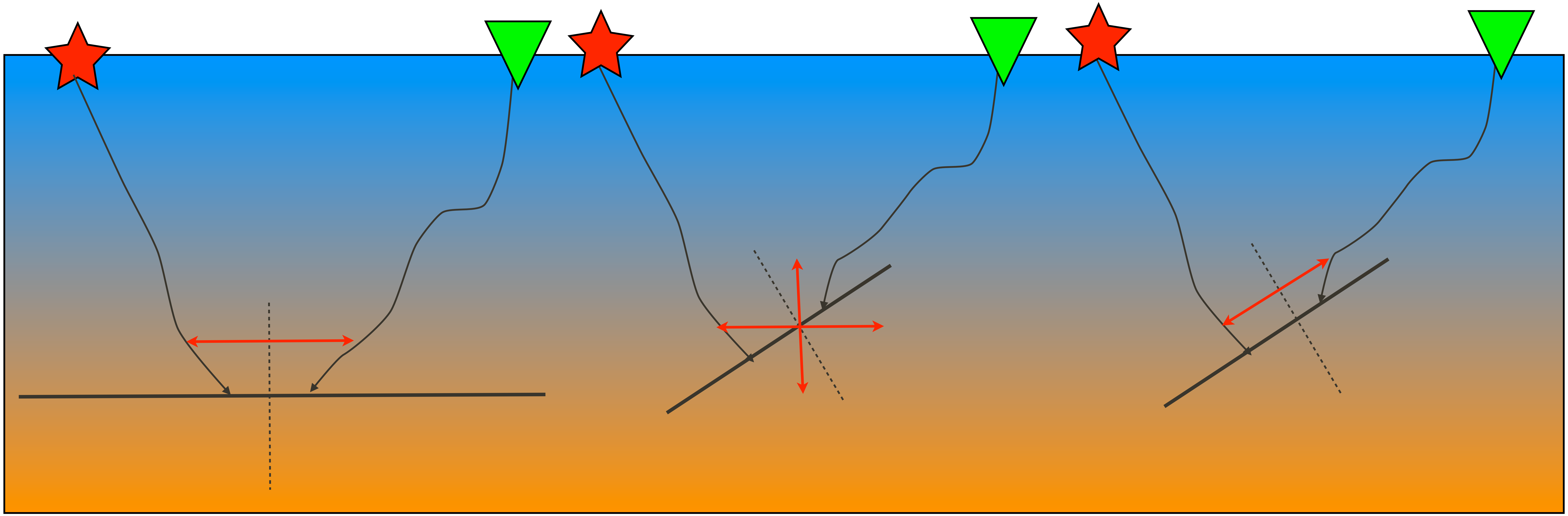
Computation of *full*-subsurface offset volumes is computationally *prohibitively* expensive
(storage & computation time)

Full-subsurface *offset* volumes allow us to conduct

- AVA w/ geologic *dip* corrections
- MVA

using information from *all* directions.

[Biondo & Symes, '04 ;Sava & Vasconcelos, '11]

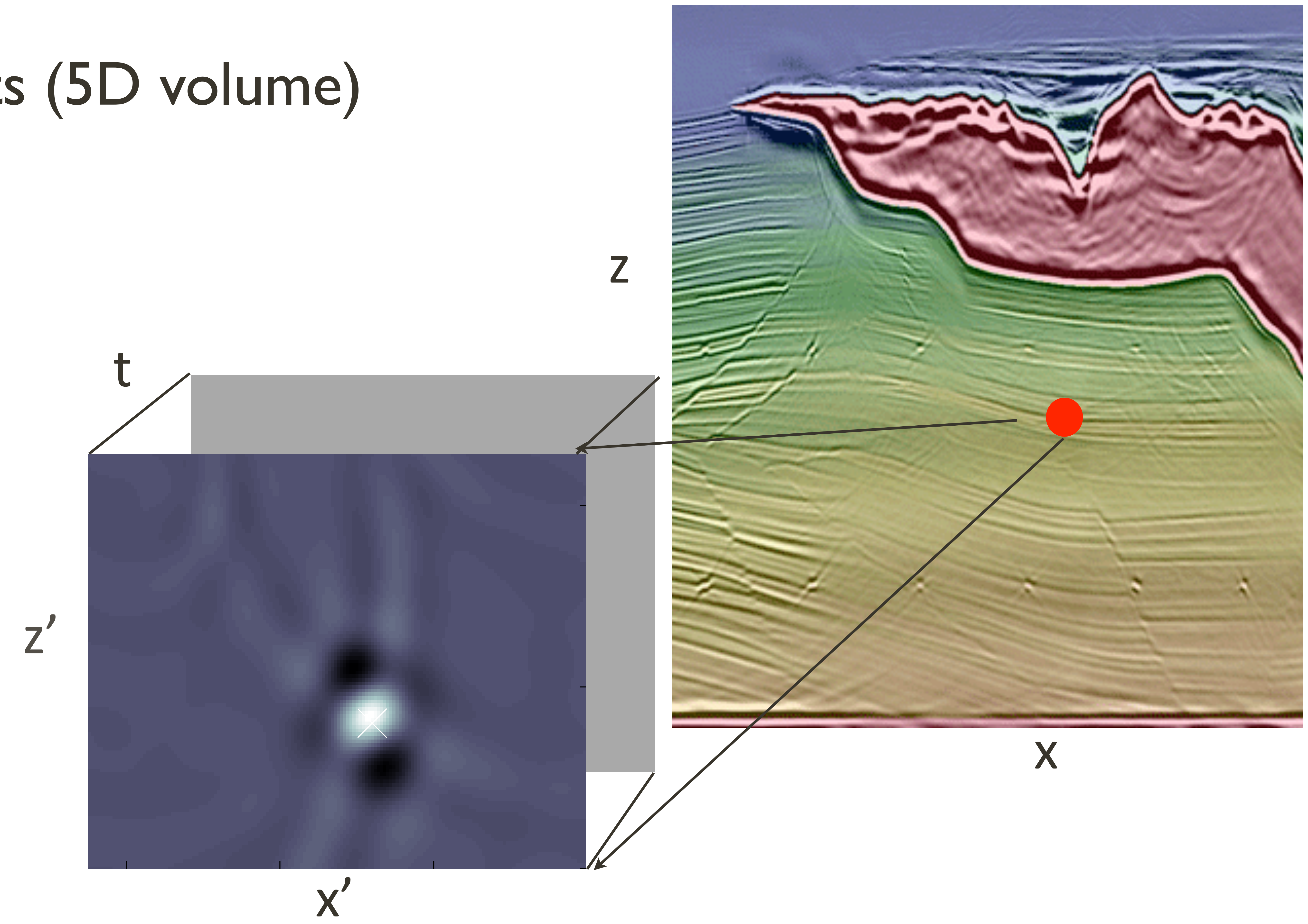


horizontal offset

horizontal +vertical offset

all offsets

- use *all* subsurface offsets (5D volume)
- 2-way wave-equation



but.... we can *never* hope to *compute* or *store* such an *extended* image volume!
Can we work with the *extended* volume *implicitly* ?

Outline

- Anatomy
- Computation
- Dip Angle Gather
- Application
- Conclusions

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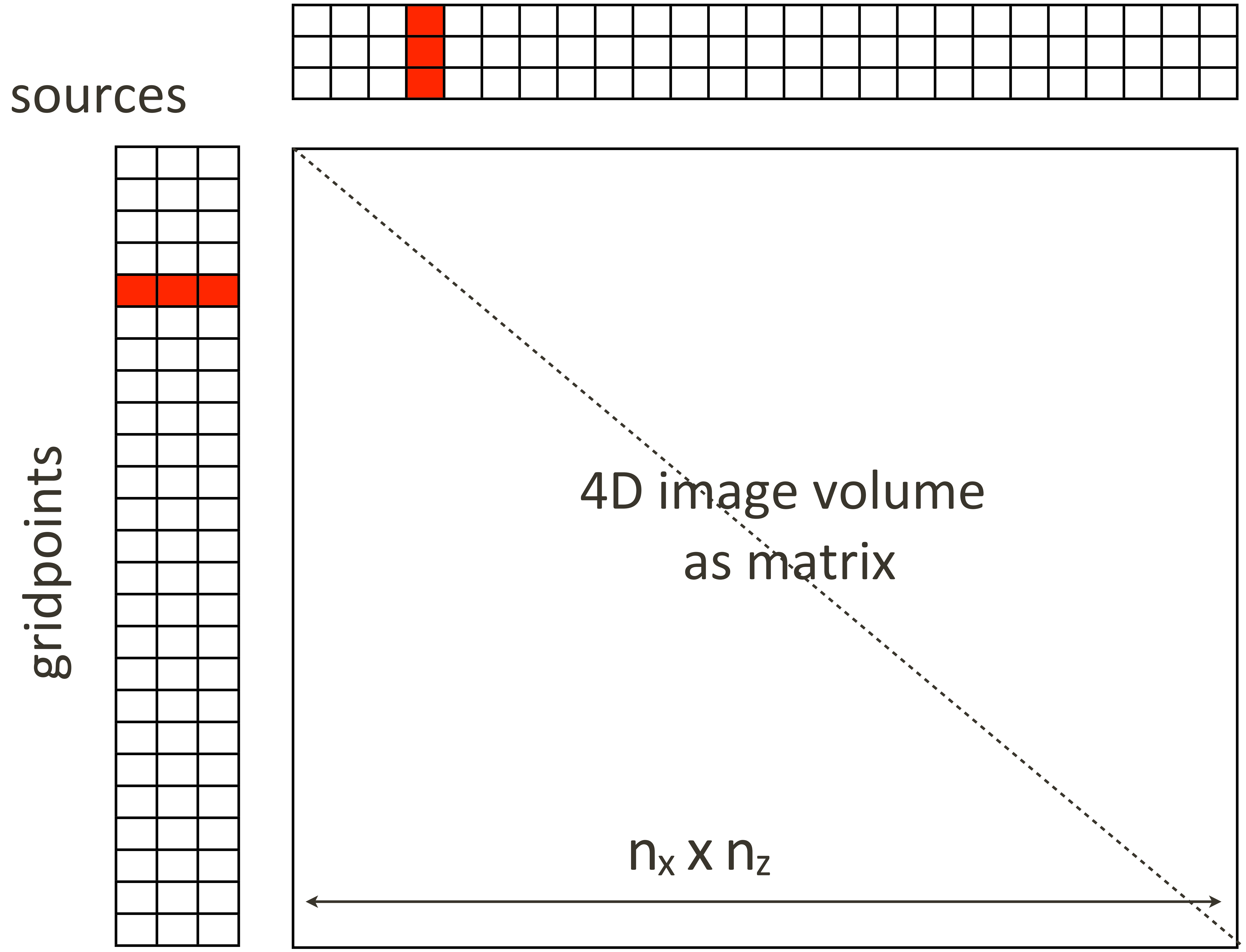
Anatomy

$$e(\omega, \mathbf{x}, \mathbf{x}') = \sum_i u_i(\omega, \mathbf{x}) v_i(\omega, \mathbf{x}')^*$$

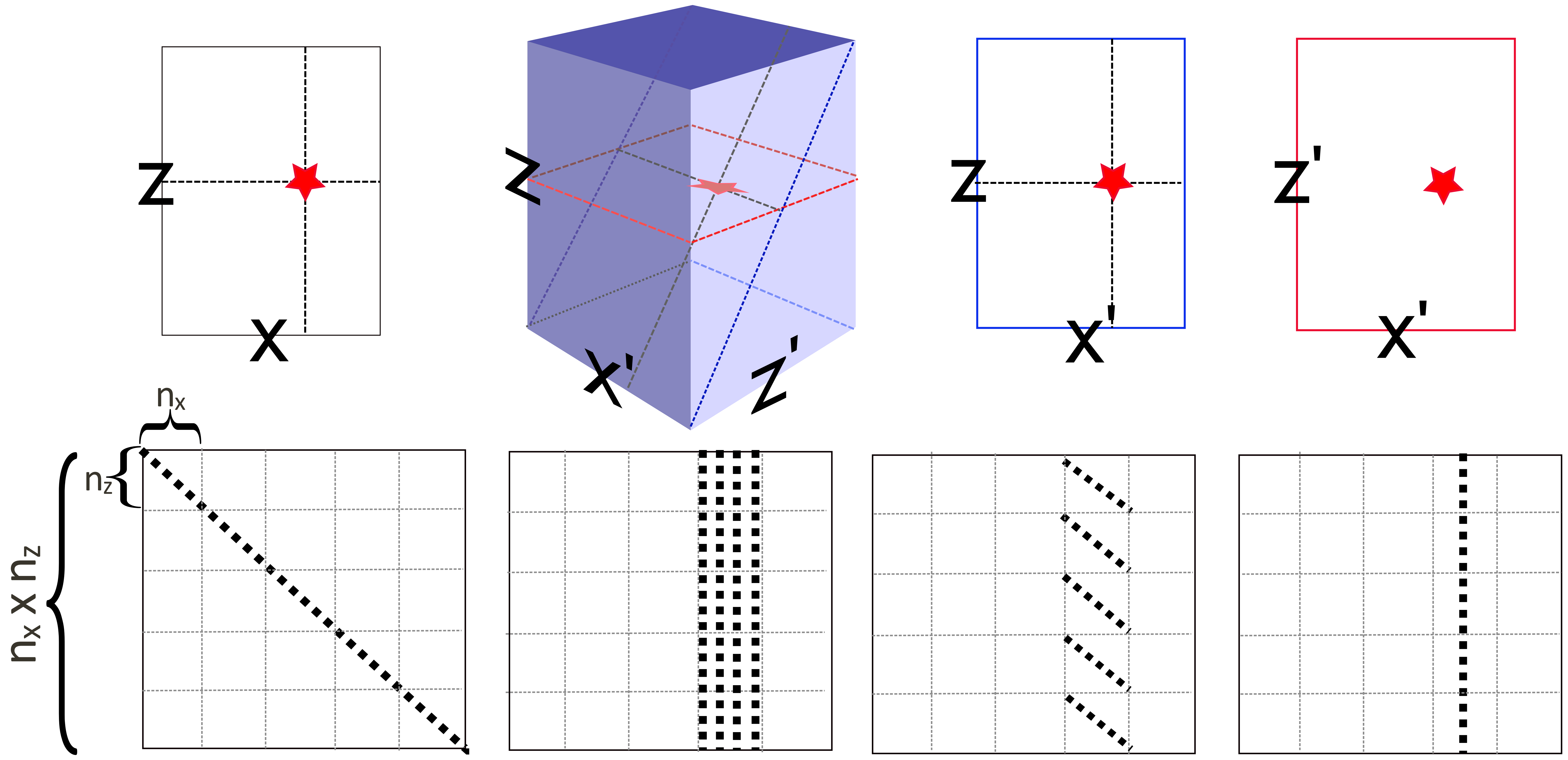
- Organize wavefields in monochromatic *data matrices* [Berkhout, 84]
- *Express* image volume *tensor* as *matrix*

$$E = UV^*$$

Extended images

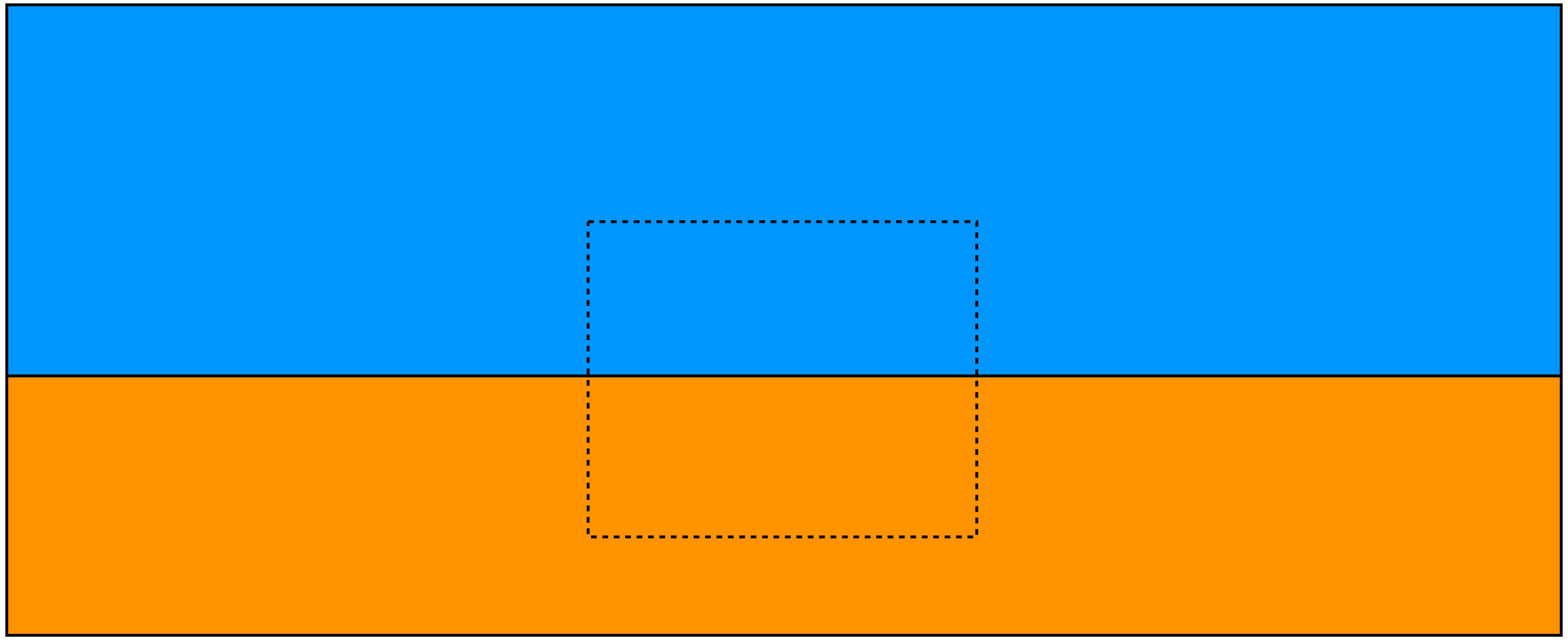


Extended images



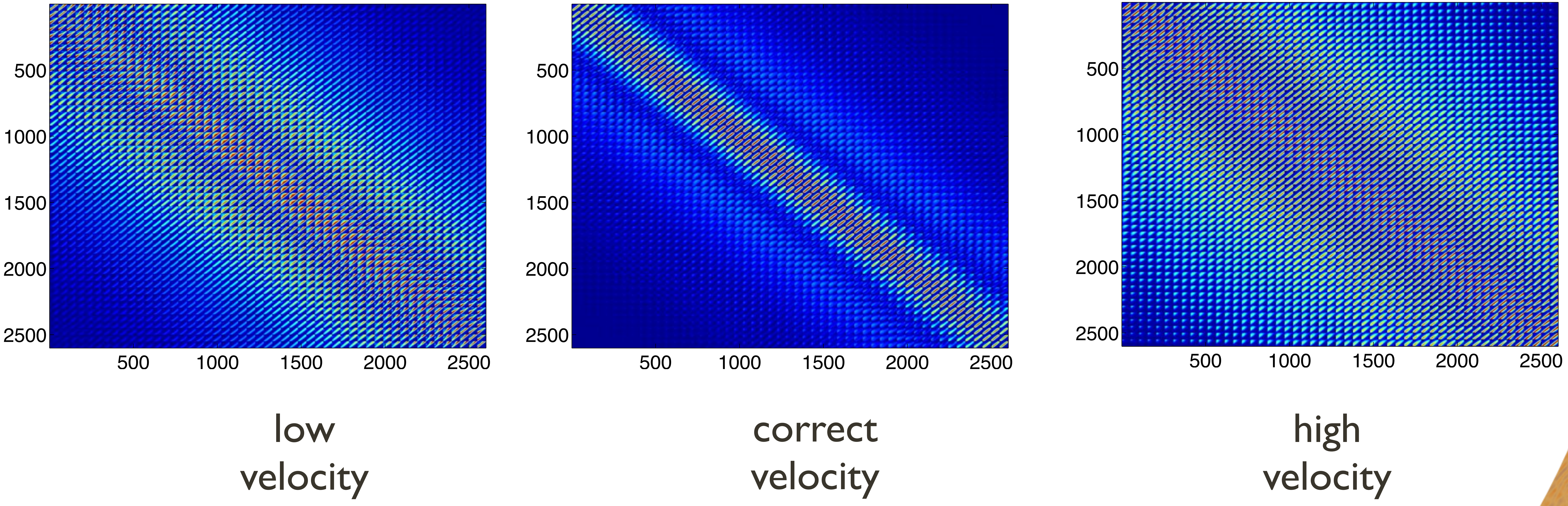
Extended images

example for *one* layer



Extended images

full matrix



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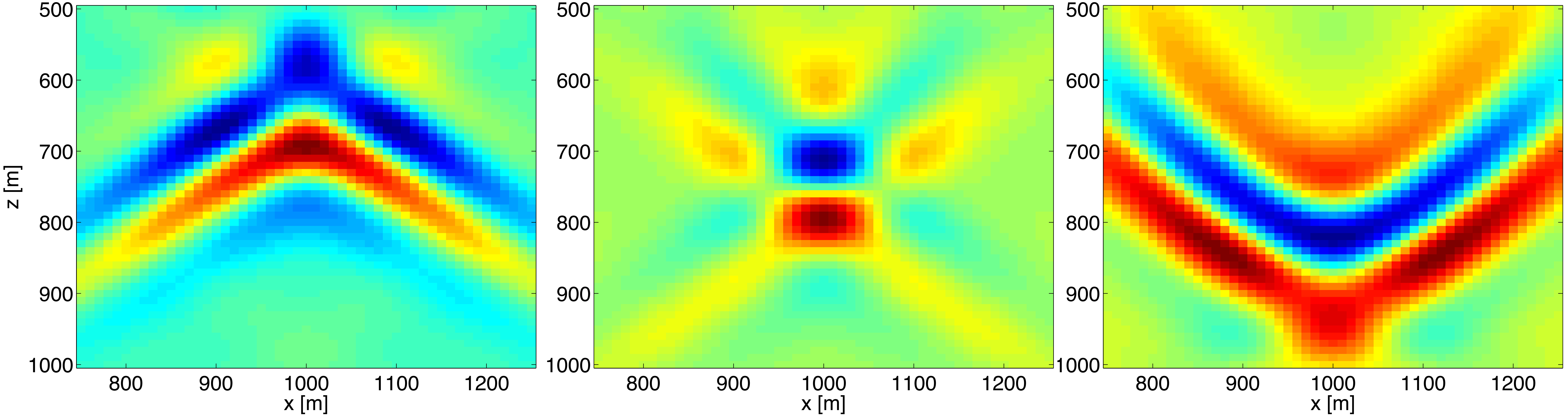
Extended images

one column



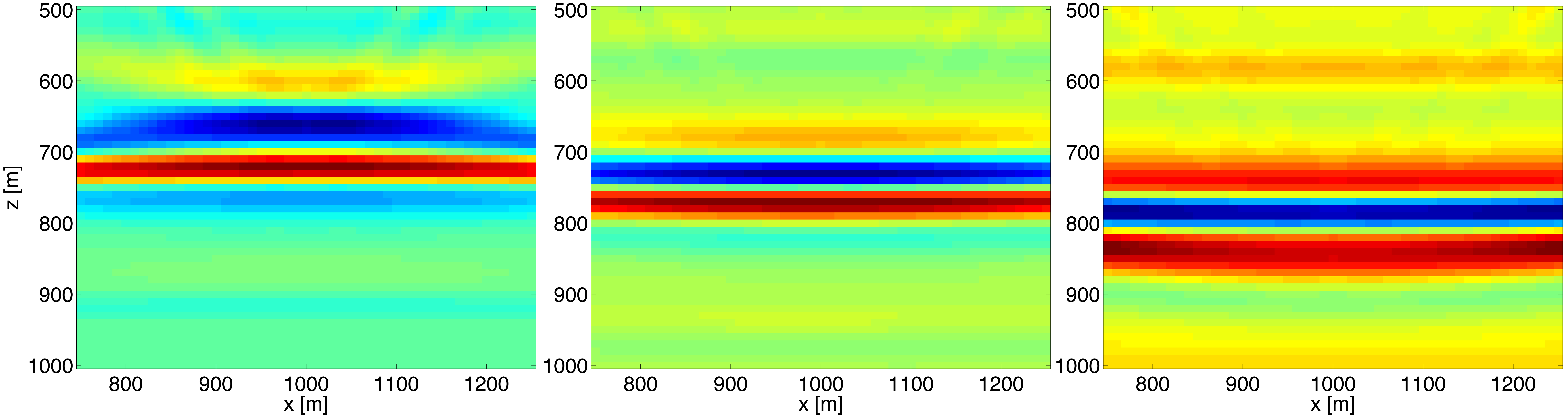
low velocity

correct velocity

high velocity

Extended images

diagonal



low velocity

correct velocity

high velocity

Computation

- *complete* image volume too *large* to form: $(n_x \times n_z)^2$
- instead, *probe* volume for information via *mat-vecs* $E\mathbf{y}$ [van Leeuwen and Herrmann, 12]
- $\mathbf{y}$ can be interpreted as subsurface (sim.) *source* function

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Computation

mat-vec with *extended* image:

$$\mathbf{e} = E\mathbf{y} = H^{-1}P_s^T Q D^* P_r H^{-1}\mathbf{y}$$

- $\widetilde{\mathbf{d}} = P_r H^{-1}\mathbf{y}$ *(one subsurface source)*
- $\widetilde{\mathbf{w}} = D^*\widetilde{\mathbf{d}}$ *(source weights)*
- $\mathbf{e} = H^{-1}P_s^T Q\widetilde{\mathbf{w}}$ *(one source)*

Computation

Are able to compute *full*-subsurface image gathers

- w/o *looping* over *all* sources
- probe image space w/ arbitrary *test* functions
  - *point* scatterers (one at location of subsurface point)
  - Gaussian weights (*simultaneous* source)

Computation

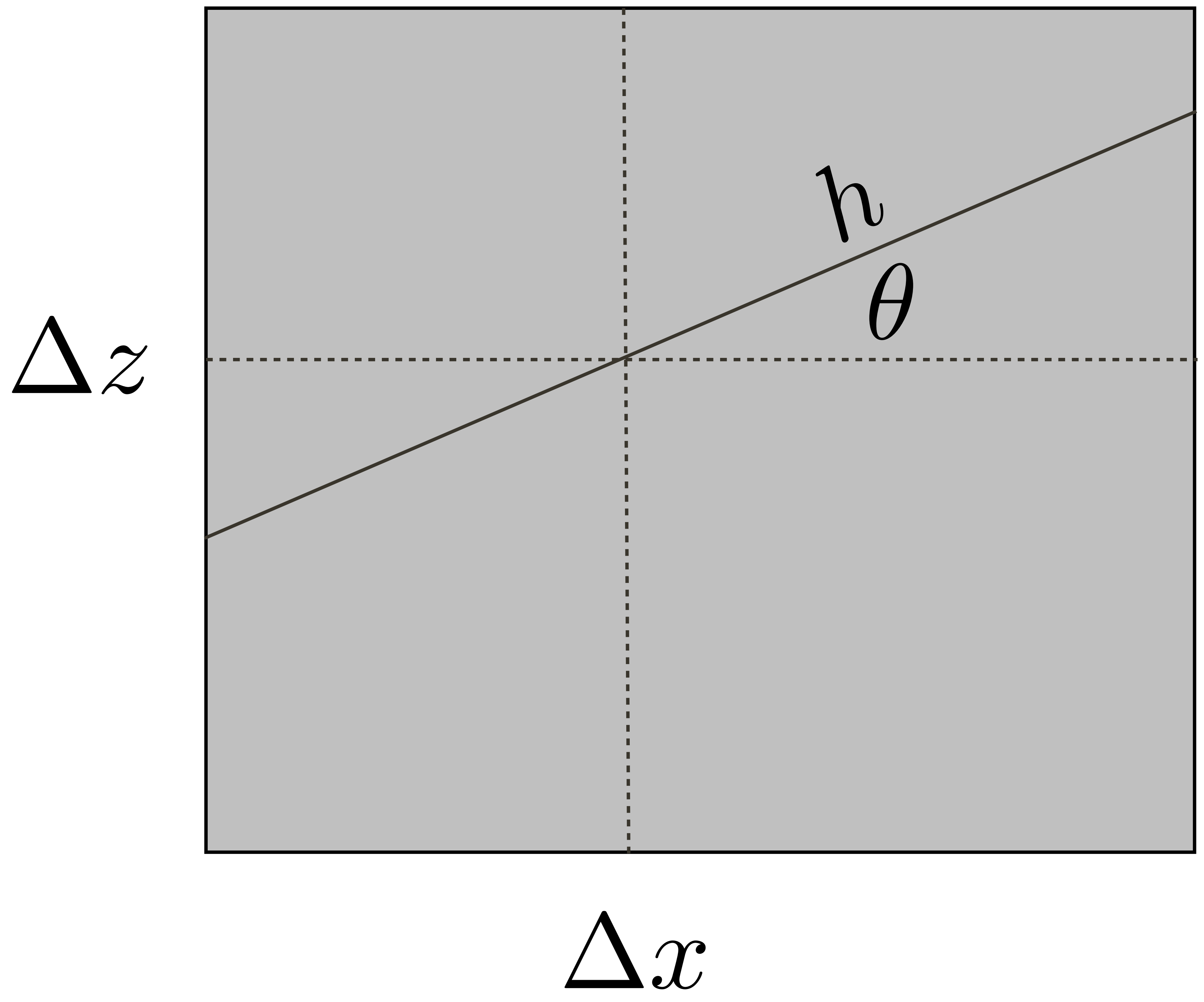
computation of an *image point gather*

	# of PDE solves	"flops for correlations"
conventional	$2N_s$	N_s x N_h
mat-vecs	$2N_x$	N_s x N_r

N_s - # of sources
N_r - # of receivers
N_h - # of subsurface offsets
N_x - # of sample points

Dip-angle gathers

align subsurface *offset* with local *dip*



Dip-angle gathers

1. compute *image*-point gather

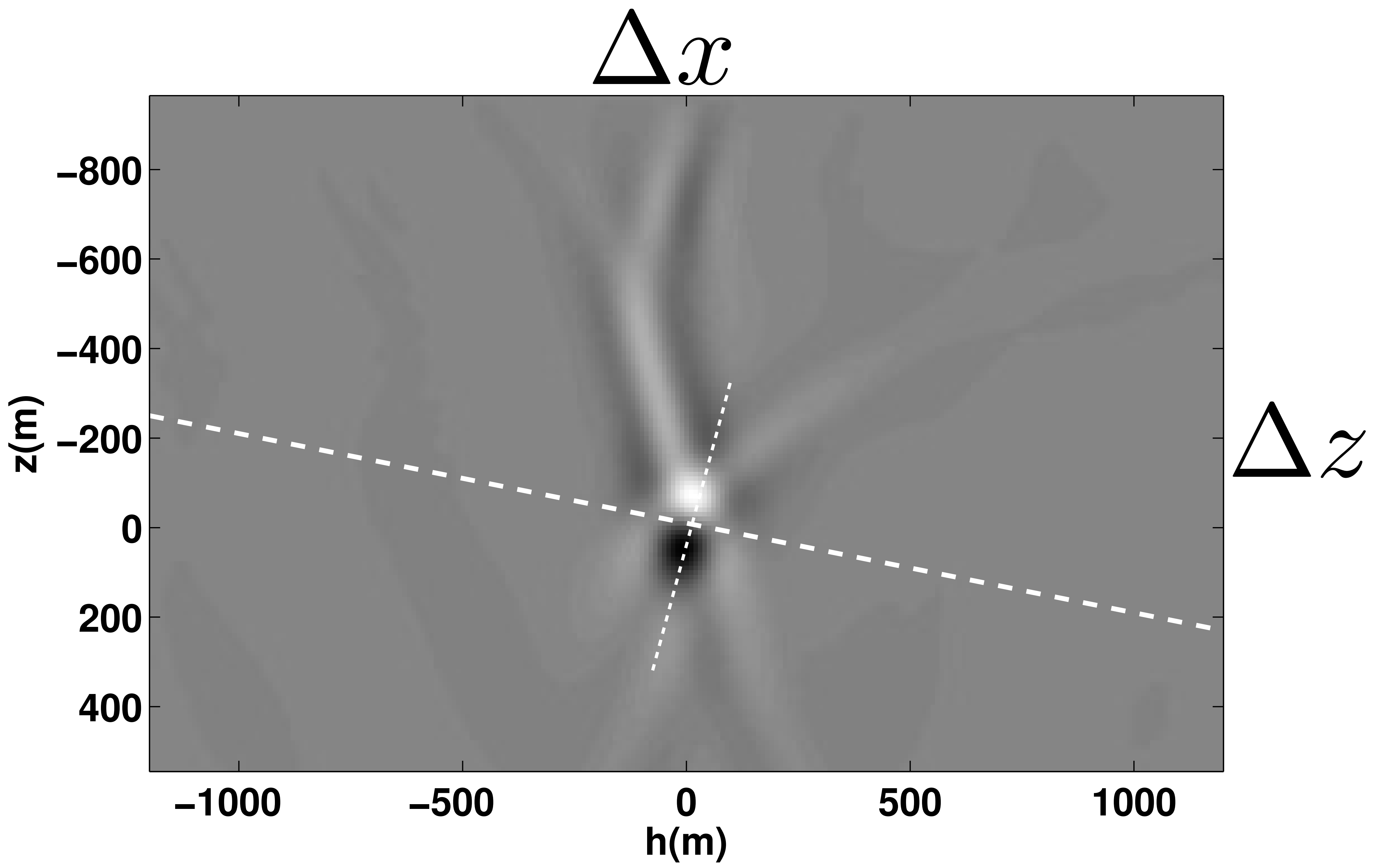
2. determine dip

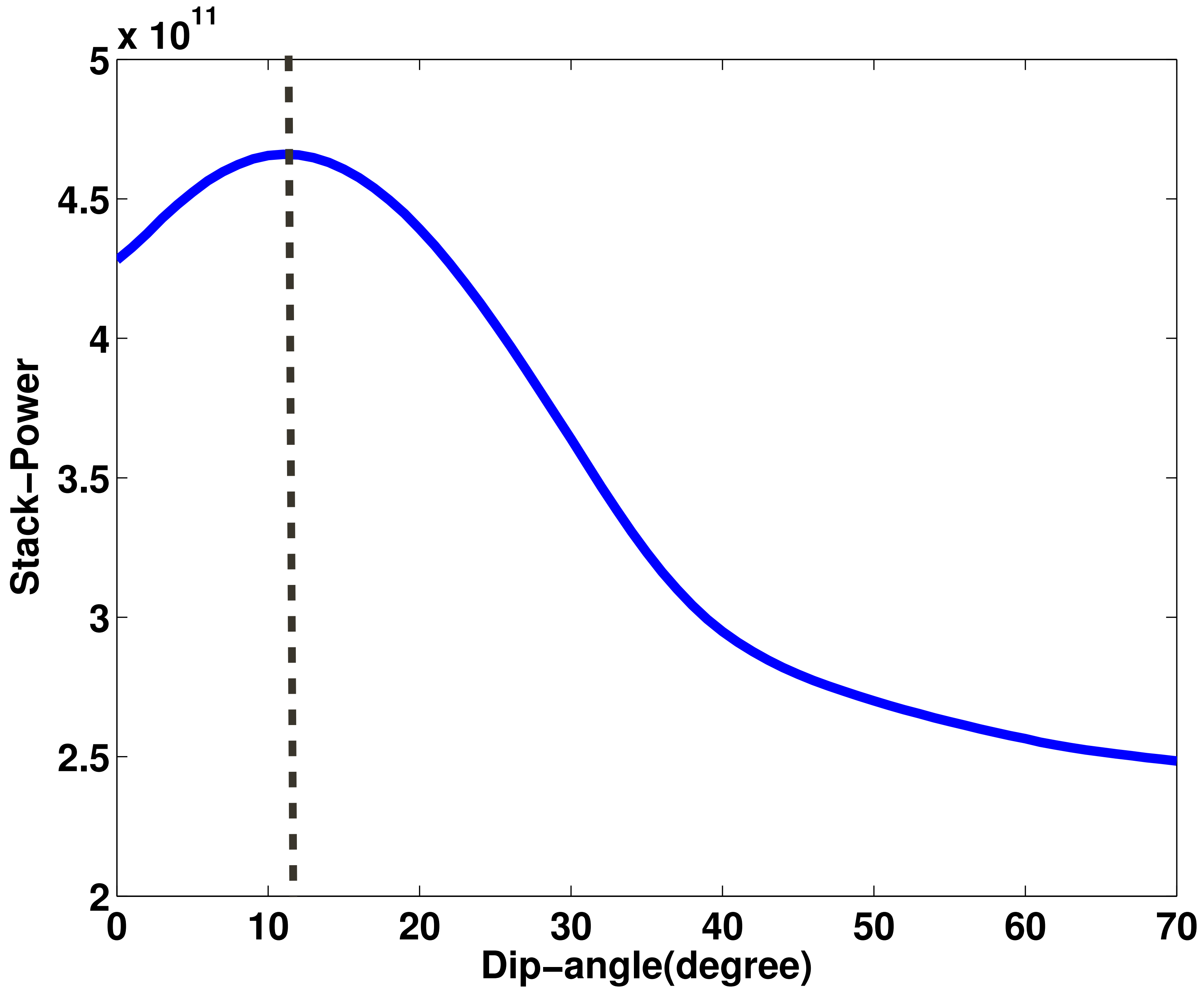
$$\tilde{\theta} = \arg\max_{\theta} \sum_{h} \left| \sum_{\omega} e(\omega, \mathbf{x}_i, \mathbf{x}(h, \theta + \pi/2)) \right|$$

3. extract *offset* along *dip*

Dip-angle gathers

the *dip* can be *detected* by measuring the *stackpower* normal to the *dip*





Dip-angle gathers

Radon transform to compute *angle* gather

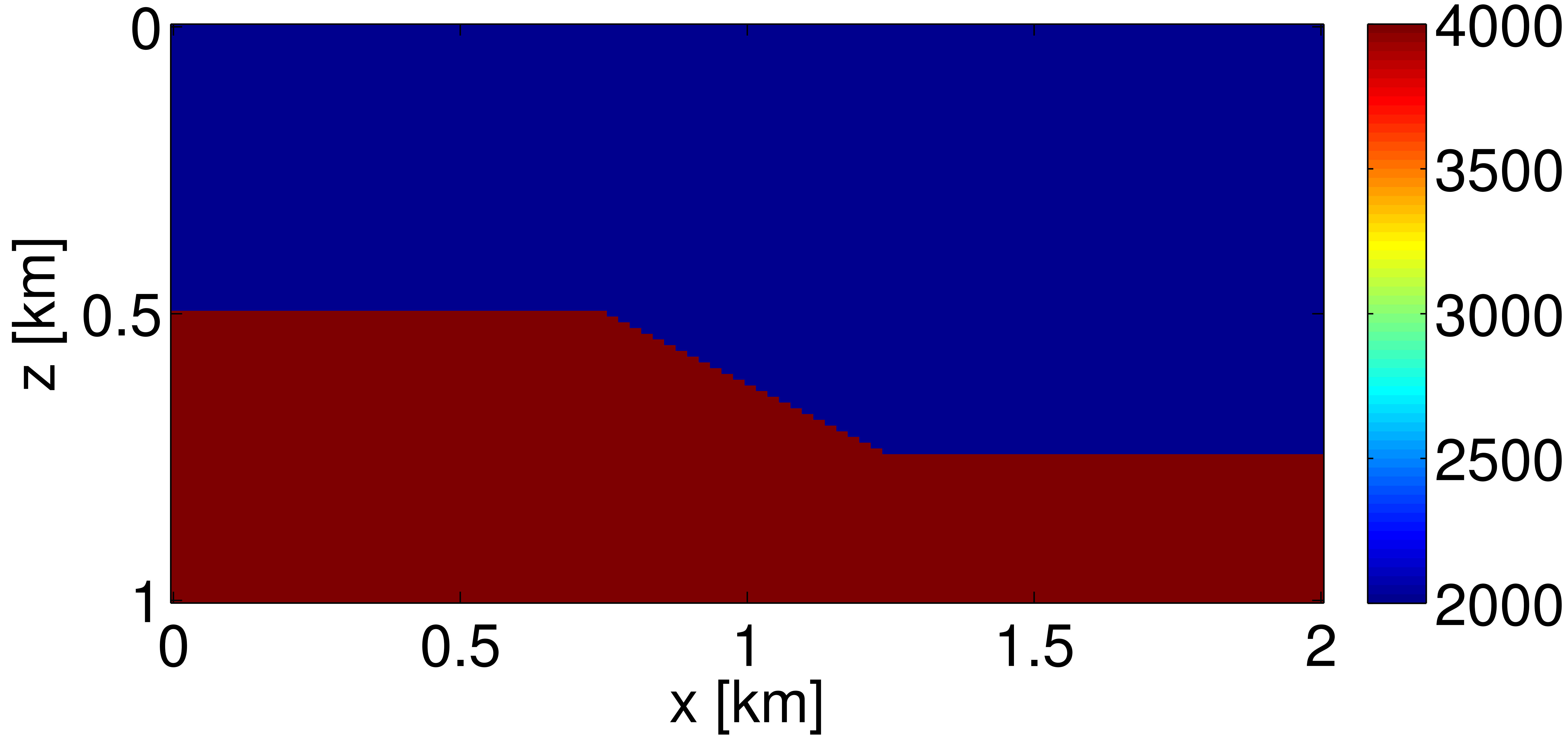
$$I(\mathbf{x}_i, p, \theta) = \sum_{\omega}\sum_{h} e(\omega, \mathbf{x}_i, \mathbf{x}(h, \theta))e^{\imath\omega p h}$$

where

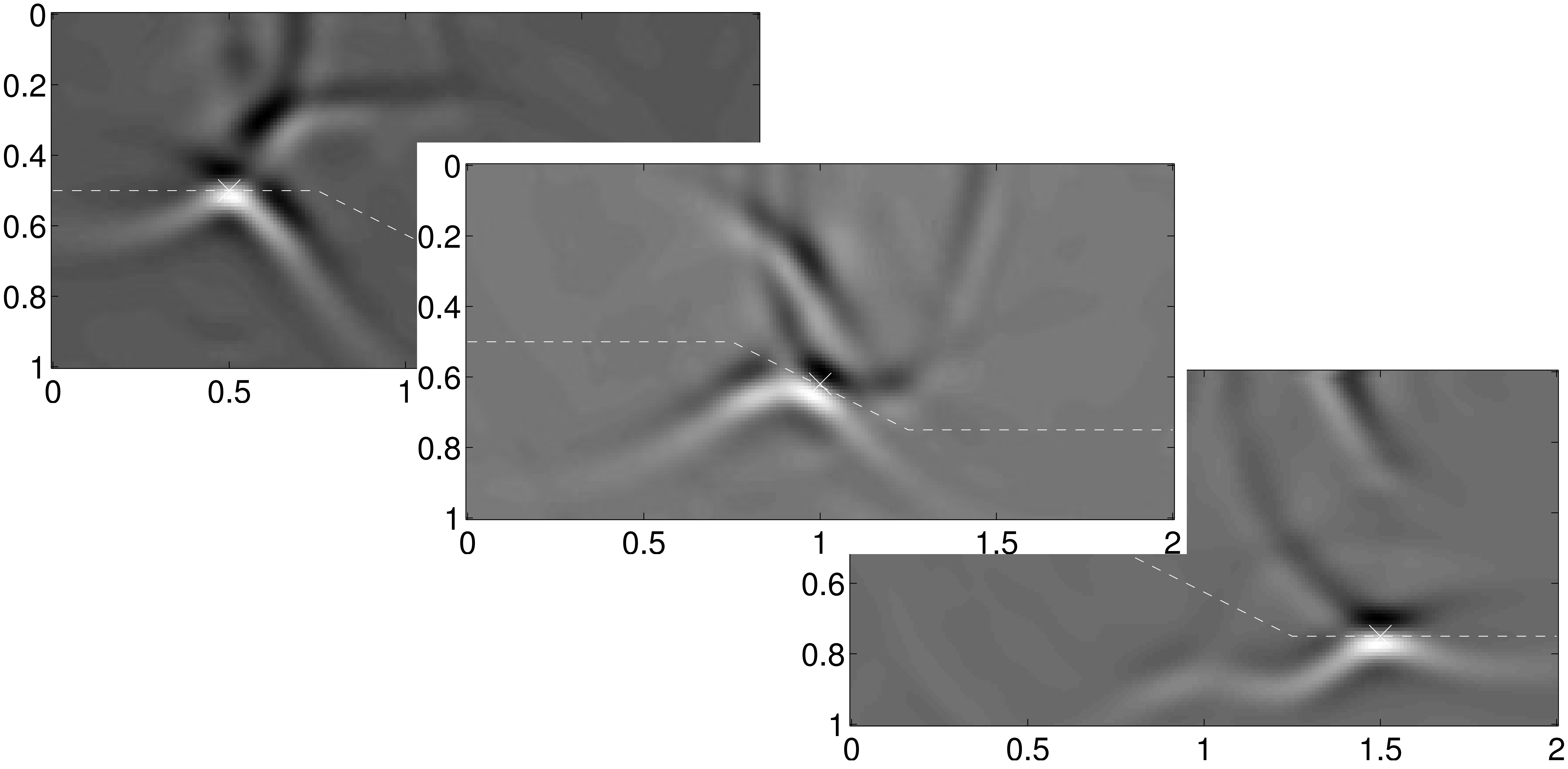
$$p = \frac{k_x}{\omega} = \frac{\sin(\alpha)}{v}$$

[de Bruin, 90]

Dip-angle gathers

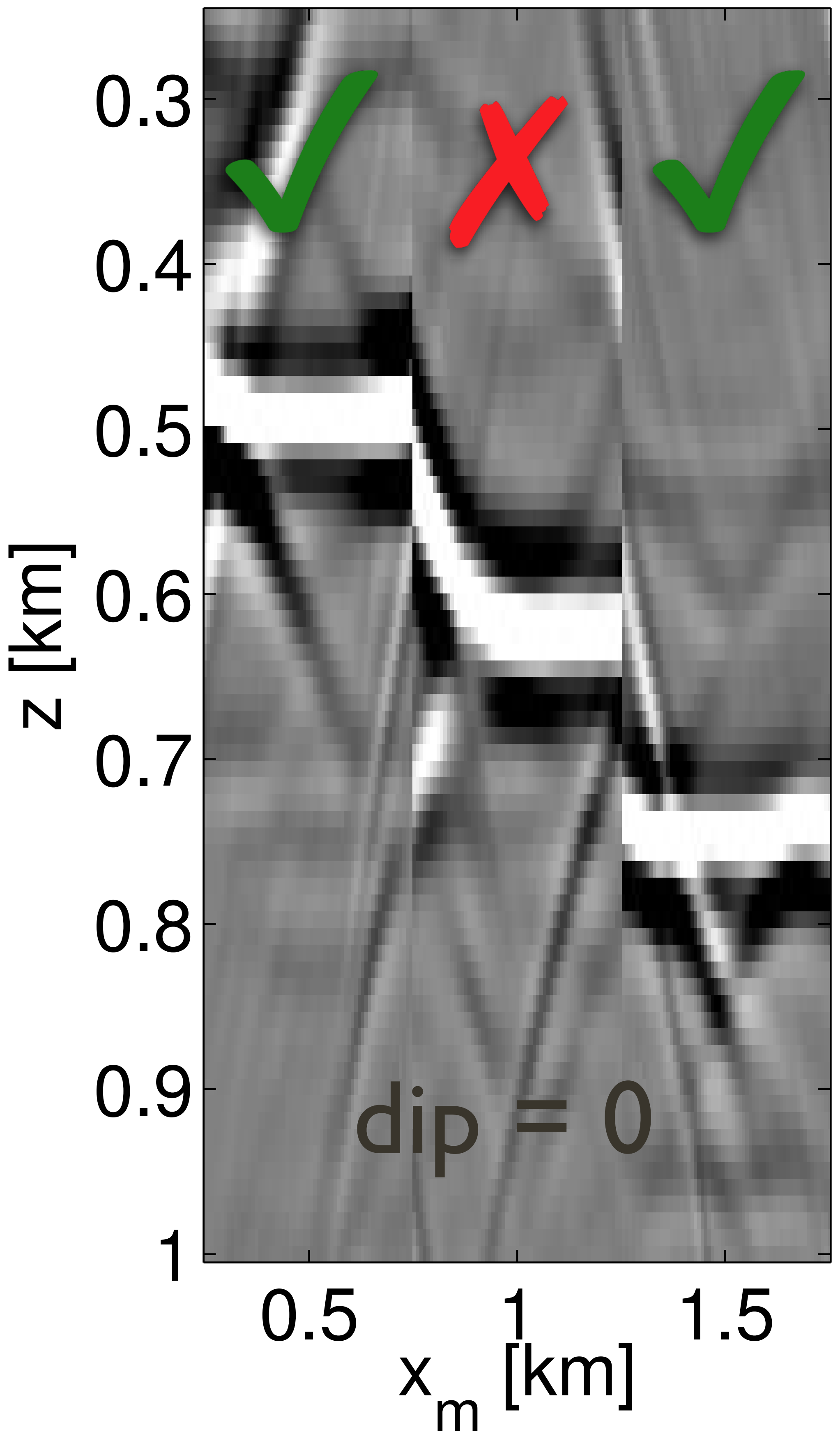


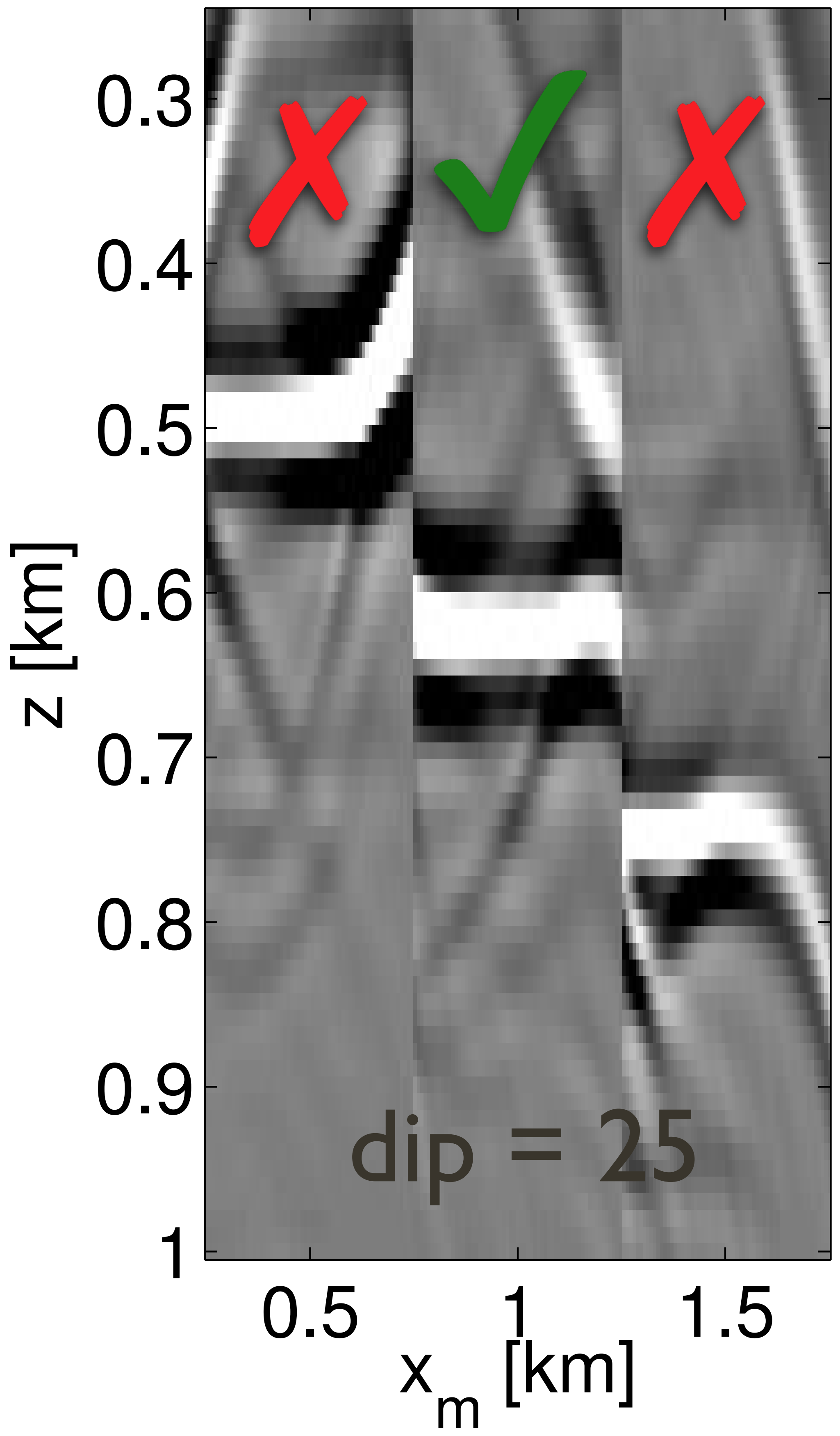
Dip-angle gathers



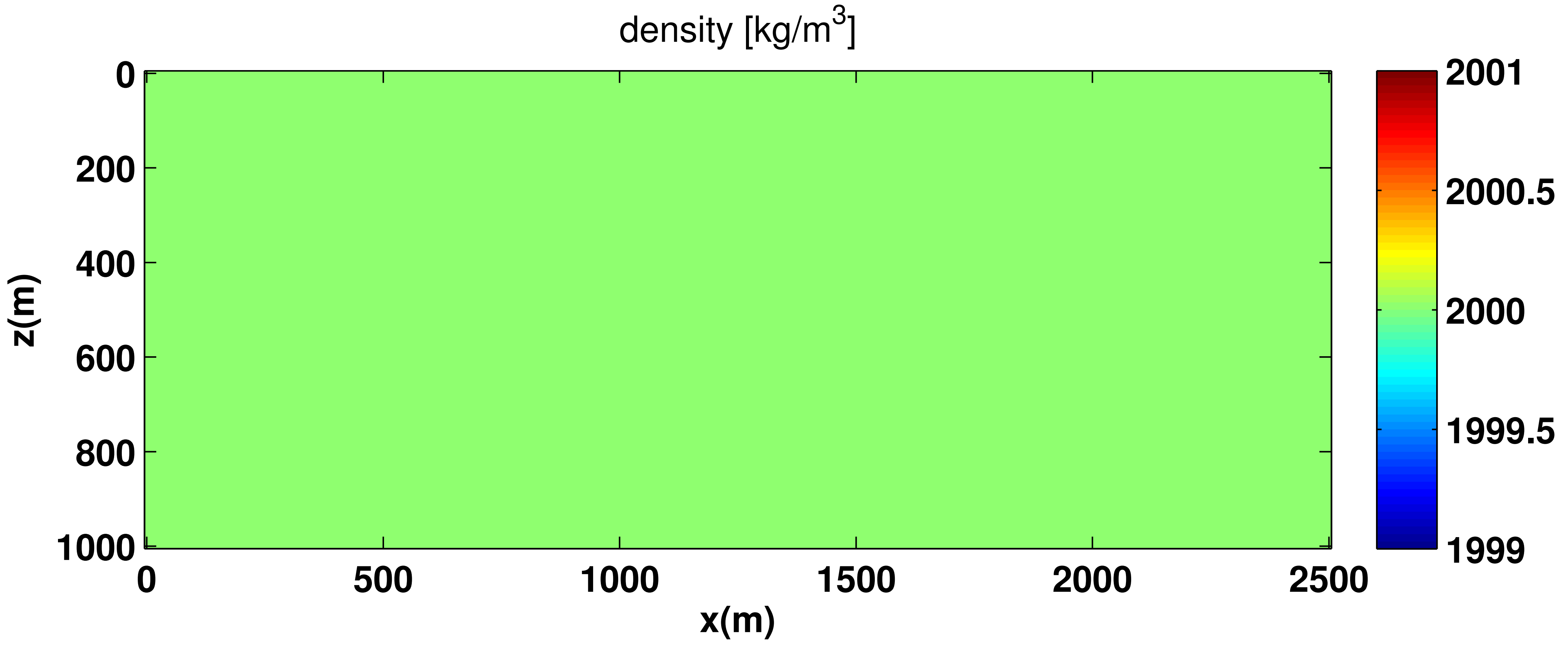
Dip-angle gathers

angle gathers for *correct* velocity, should all be *flat*

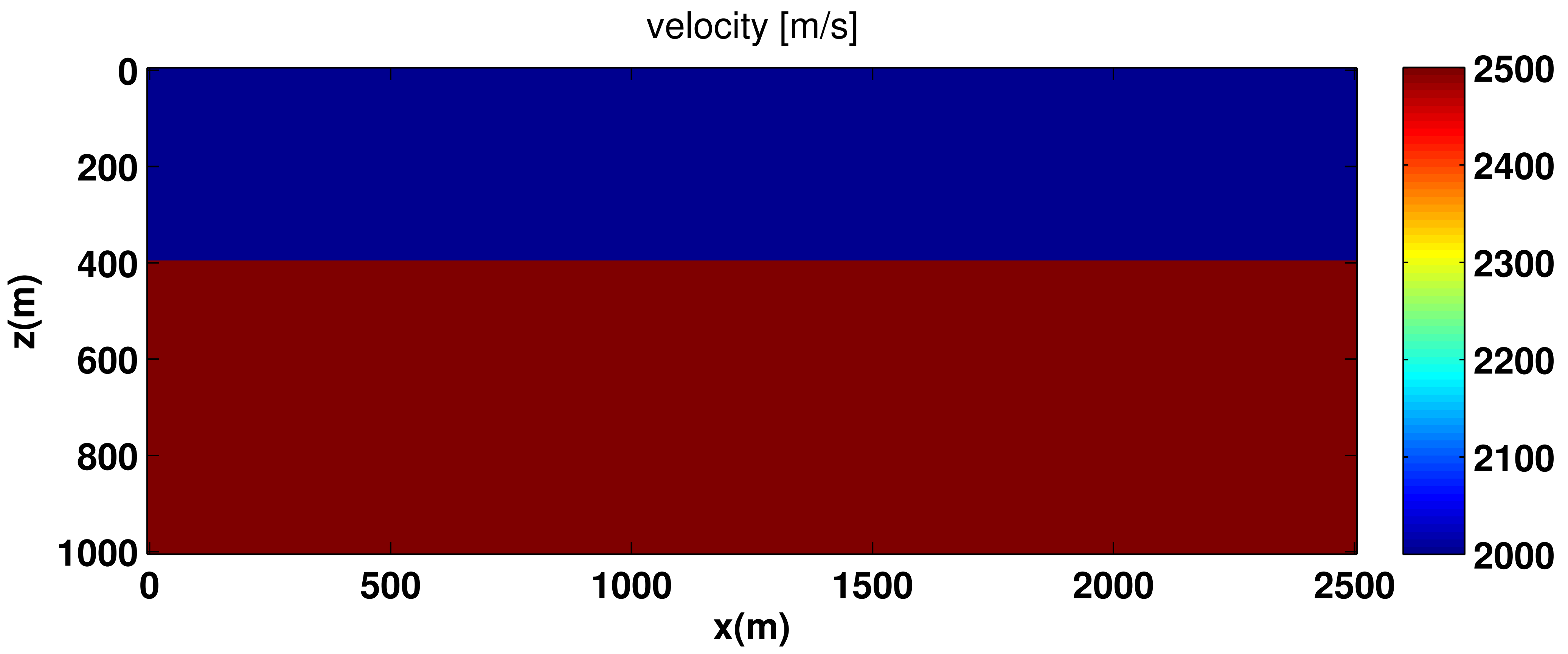




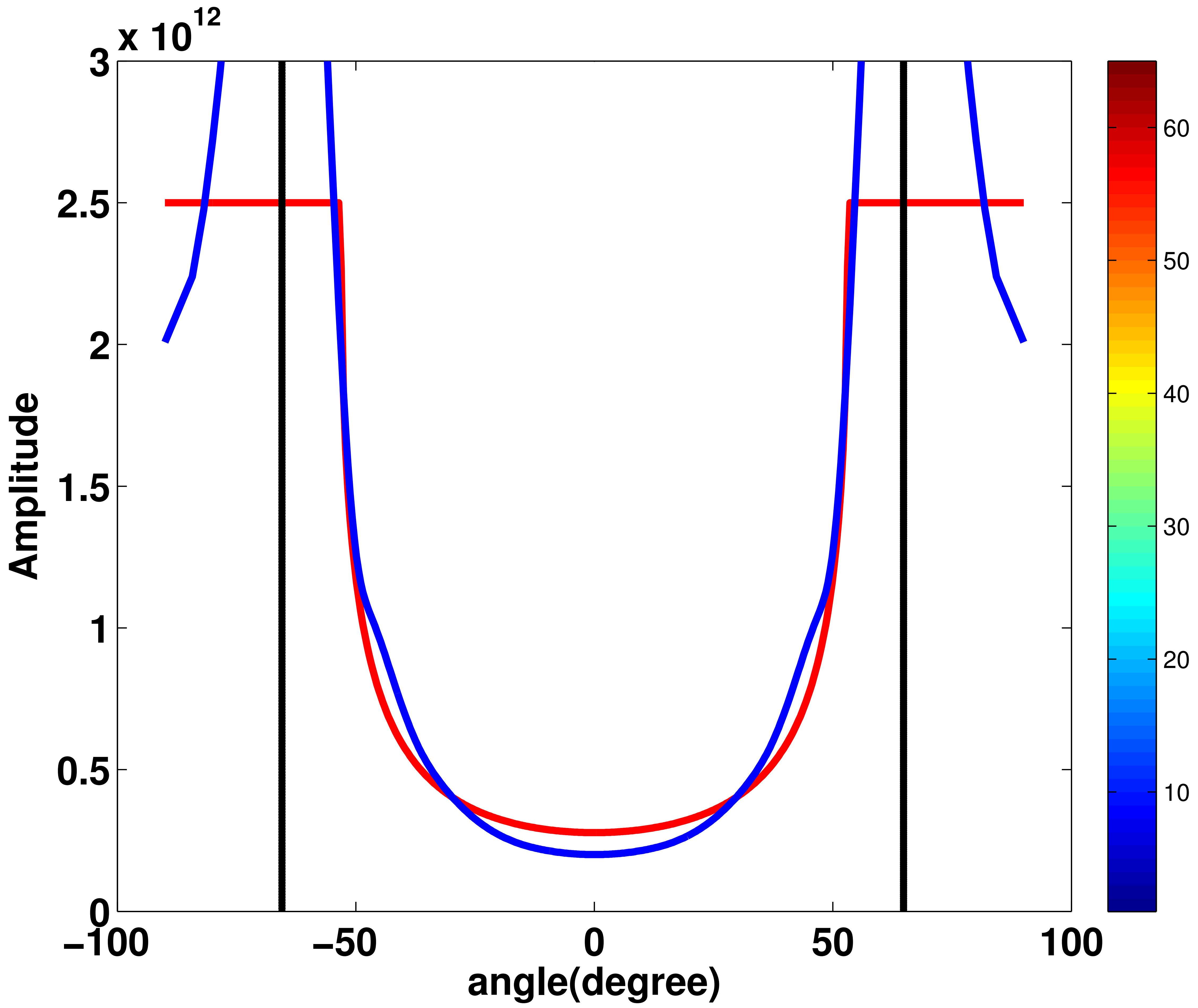
AVA
[1-layer]



density [kg/m3]
z(m)
x(m)
0
200
400
600
800
1000
0
500
1000
1500
2000
2500
2001
2000.5
2000
1999.5
1999

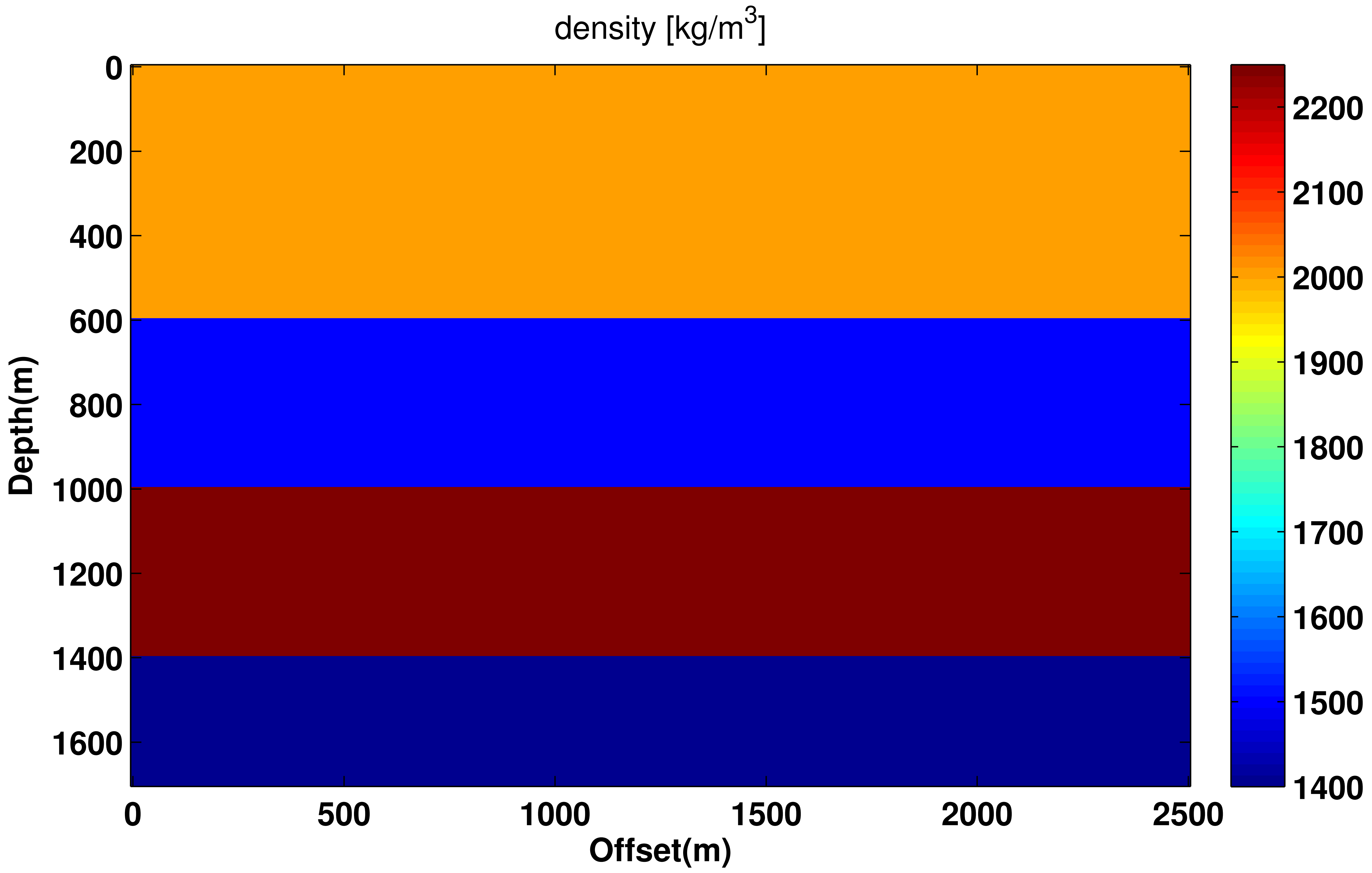


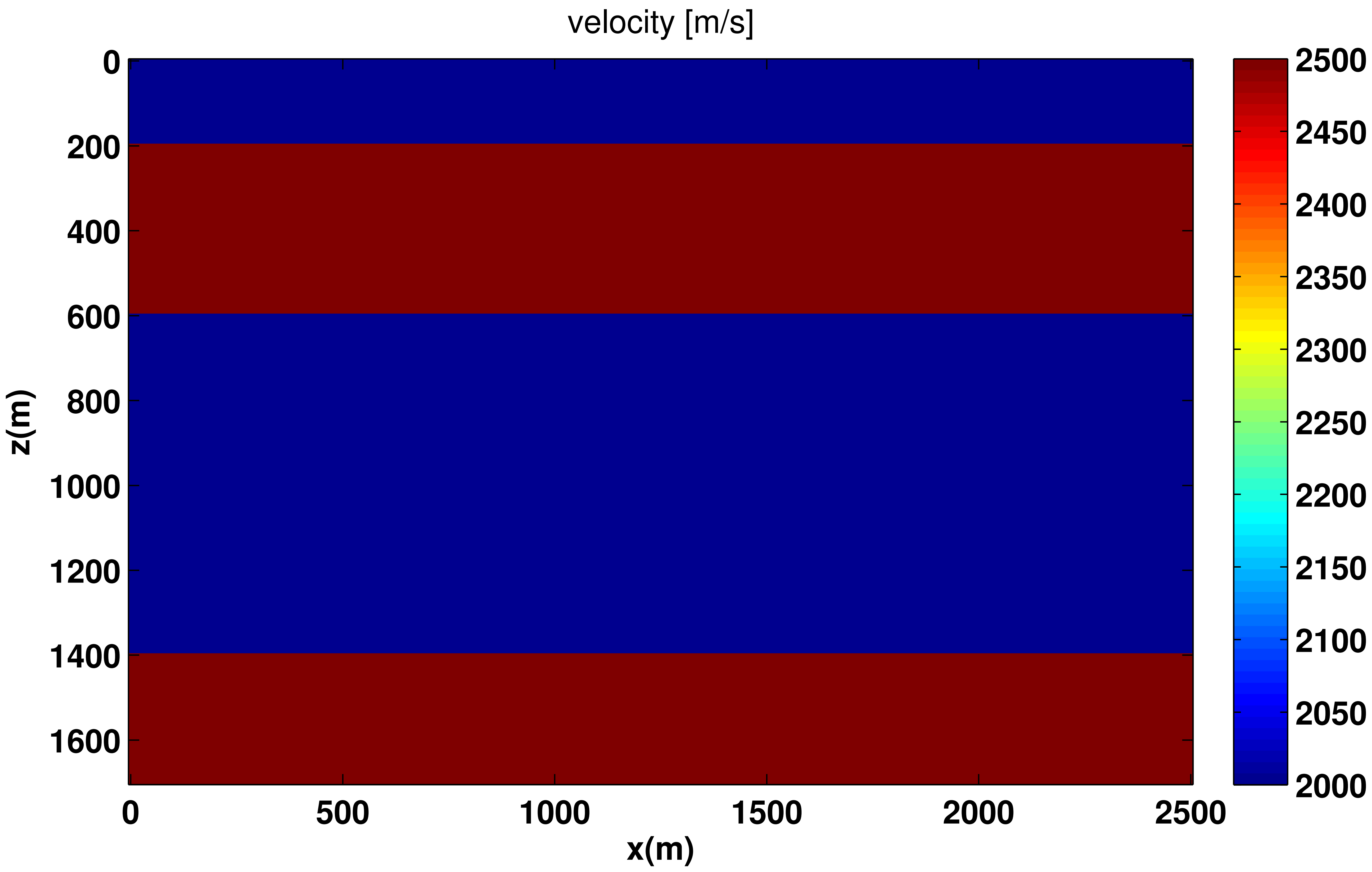
velocity [m/s]
z(m)
x(m)
0
200
400
600
800
1000
0
500
1000
1500
2000
2500
2500
2400
2300
2200
2100
2000



x 10^12
Amplitude
angle(degree)
3
2.5
2
1.5
1
0.5
0
−100
−50
0
50
100
60
50
40
30
20
10

AVA
[4-layer]


density [kg/m3]
Depth(m)
Offset(m)
0
200
400
600
800
1000
1200
1400
1600
0
500
1000
1500
2000
2500
2200
2100
2000
1900
1800
1700
1600
1500
1400


velocity [m/s]
z(m)
x(m)
0
200
400
600
800
1000
1200
1400
1600
0
500
1000
1500
2000
2500
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000

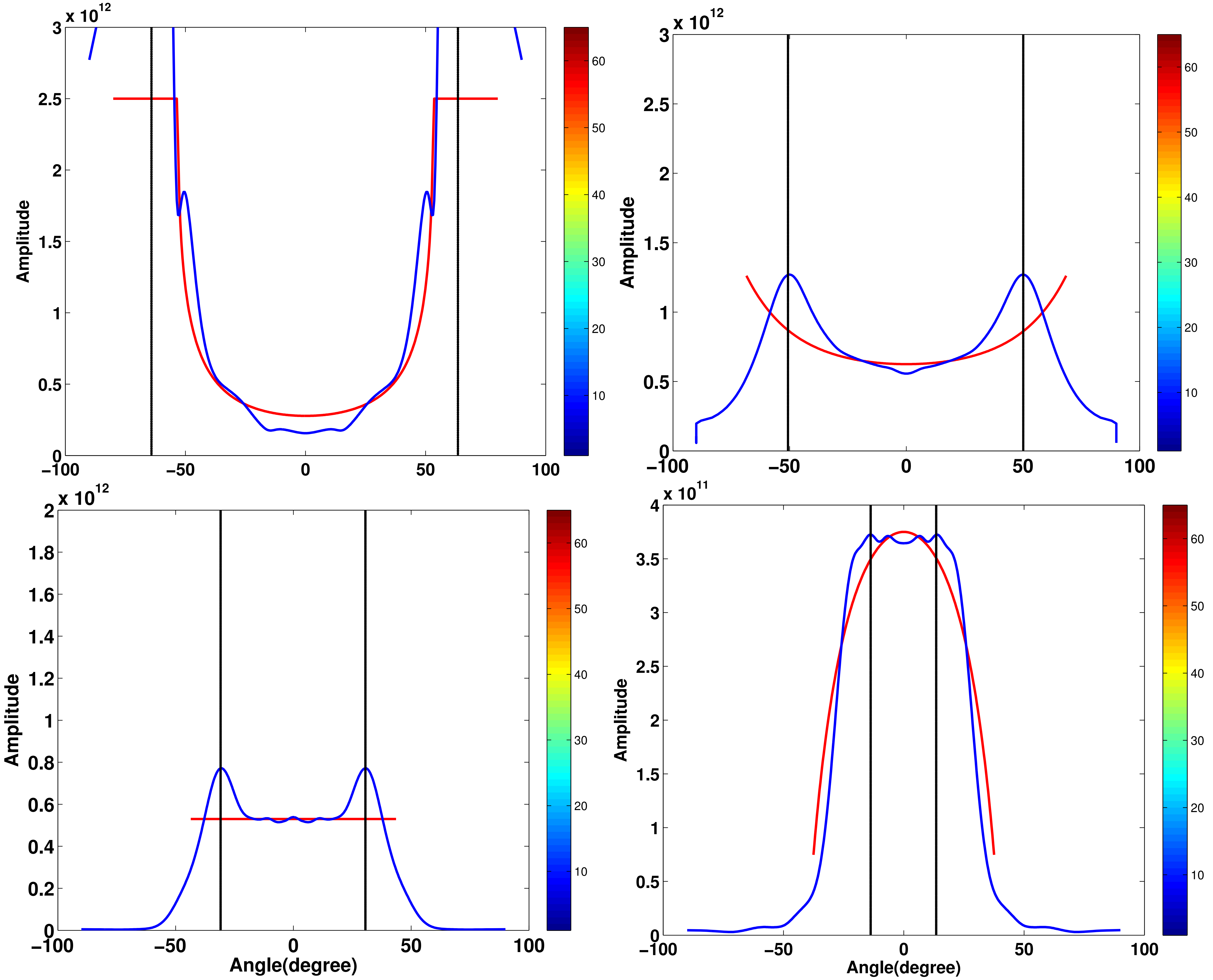
AVA
[4-layer]

1st layer

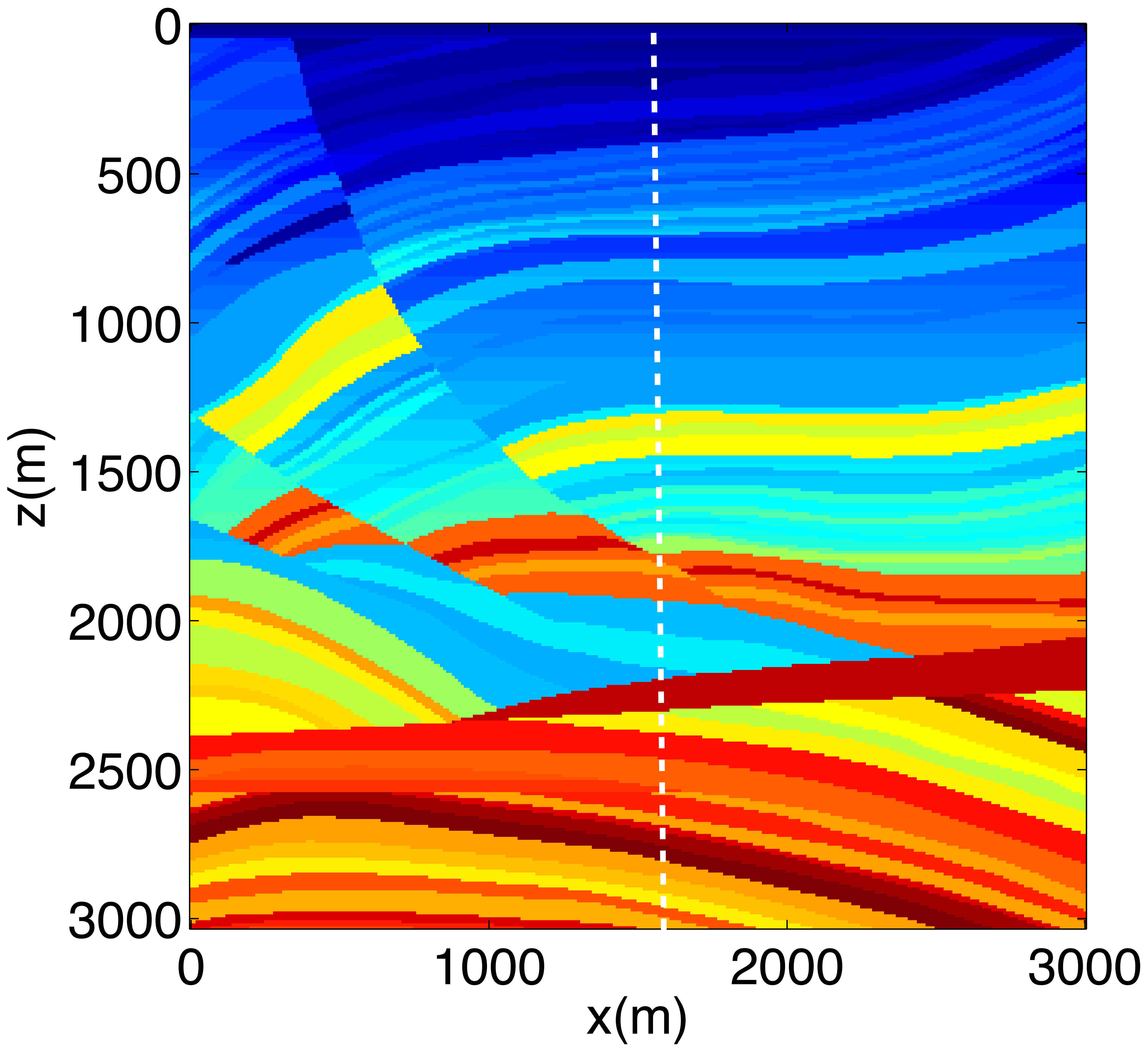
2nd layer

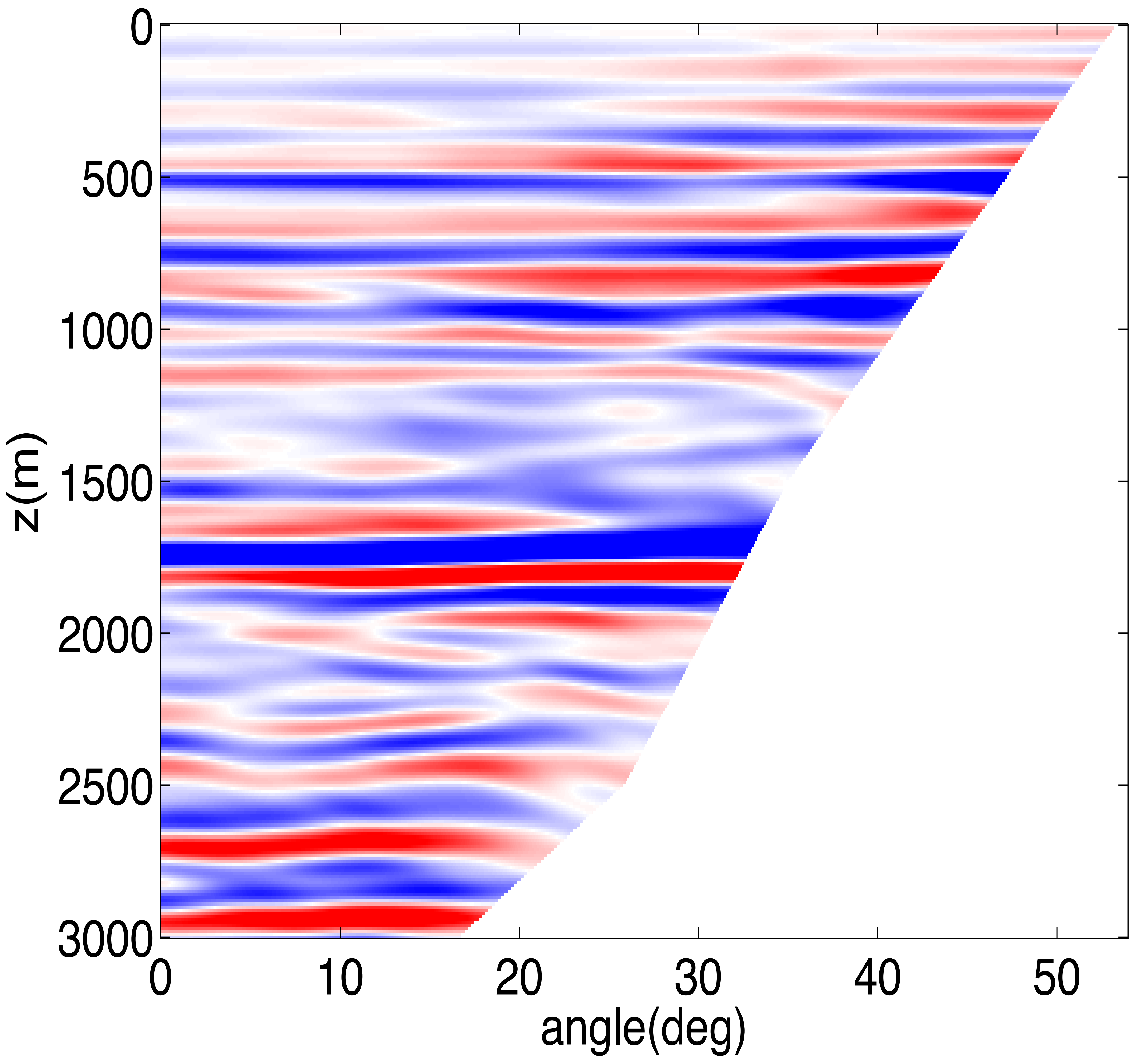
3rd layer

4th layer



AVA
[marmousi model]





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Conclusion

- *Probe* image volume with *mat-vecs*
- Use *full* subsurface offsets, no need to estimate *dips* a *priori*
- *Suitable* for AVA at targeted regions
- estimate dip *automatically*

Acknowledgements

Thank you for your attention !
https://www.slim.eos.ubc.ca/

W-11: Advances in Model Building, Imaging, and FWI,
Friday, 27 September
Title : Efficient WEMVA using extended images

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