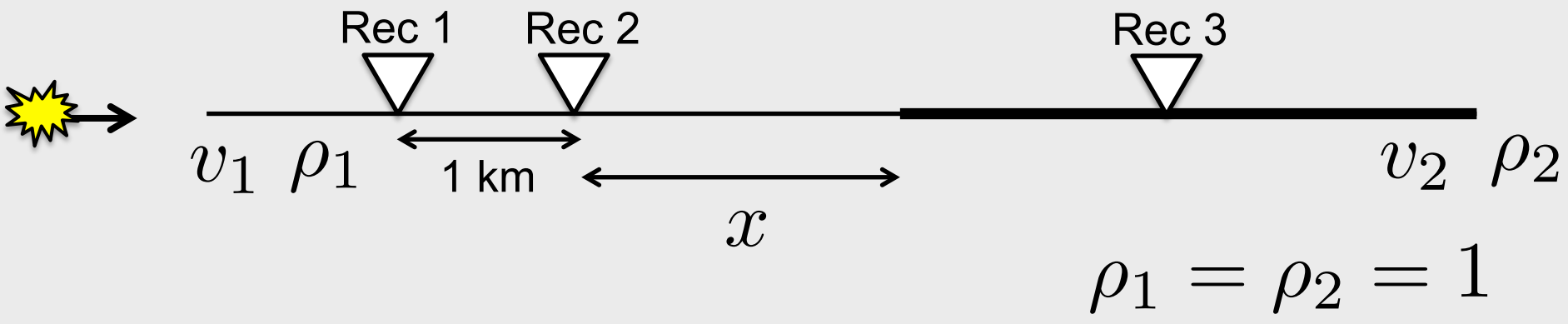
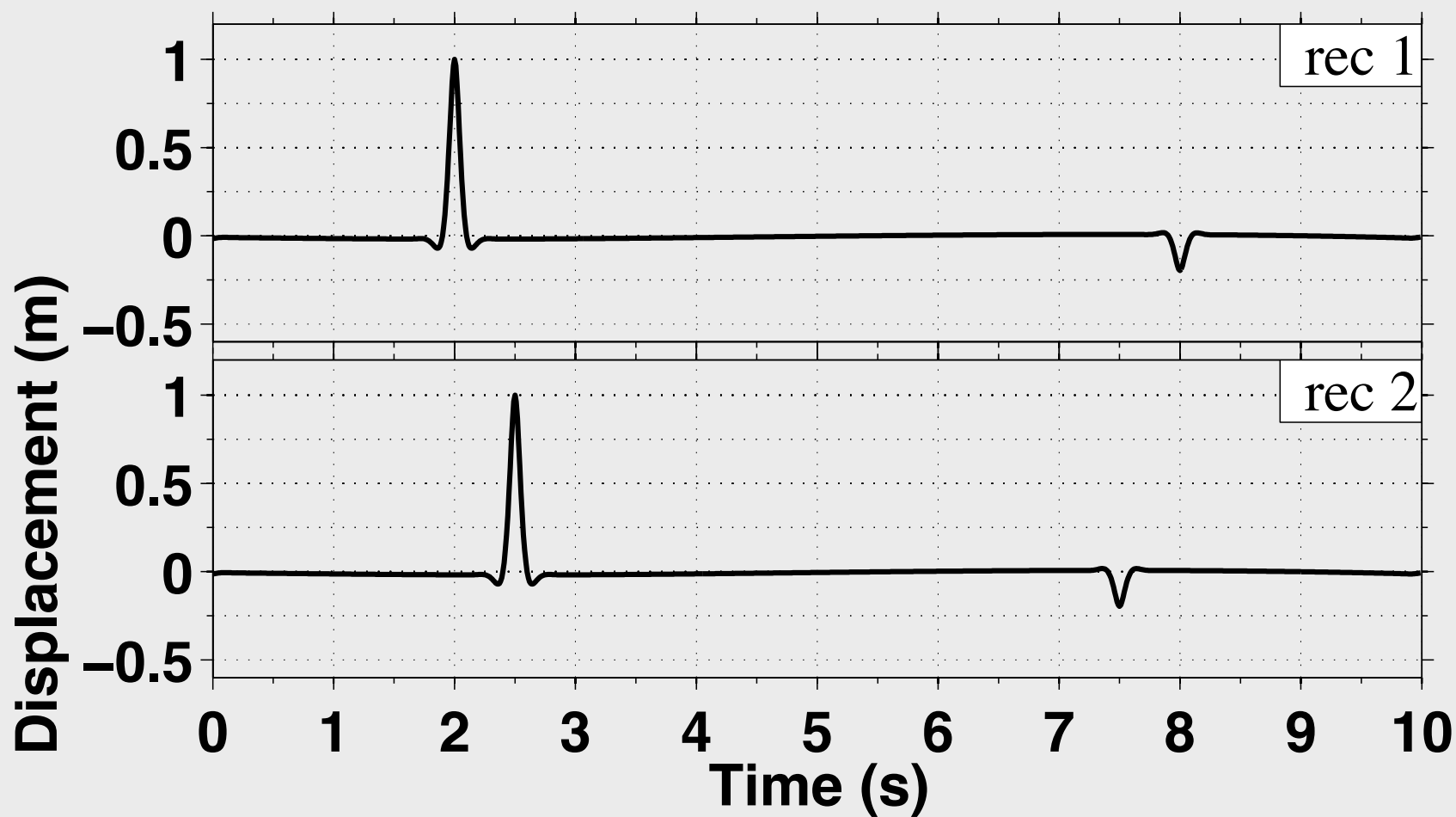
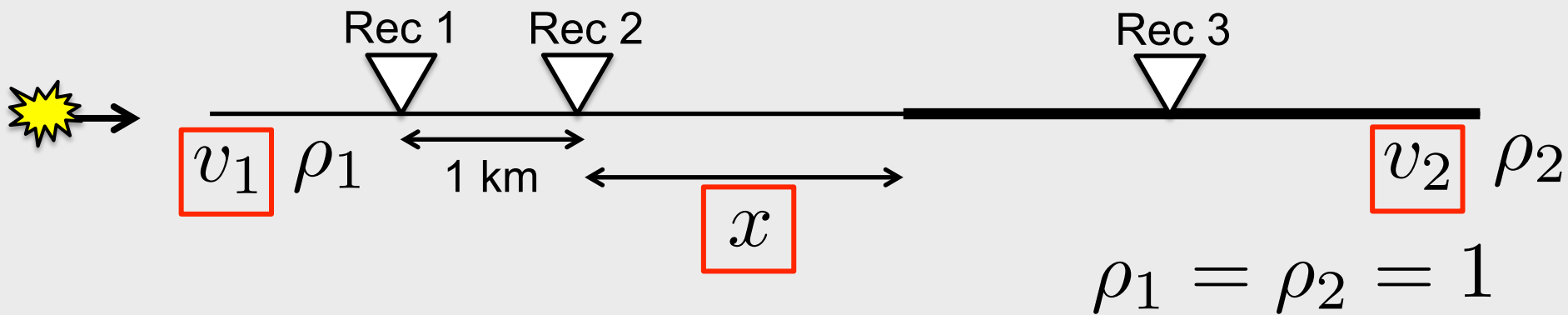


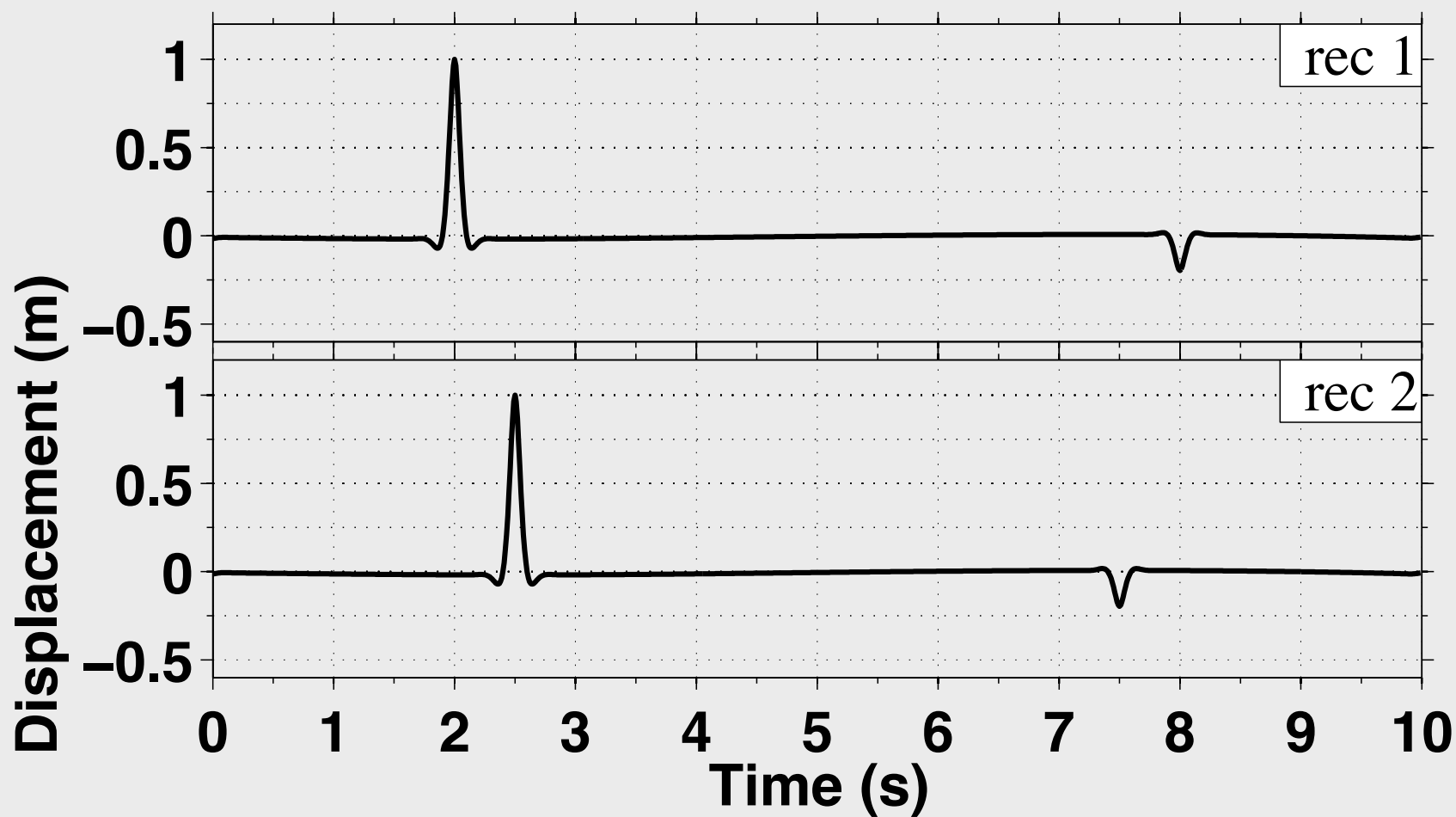
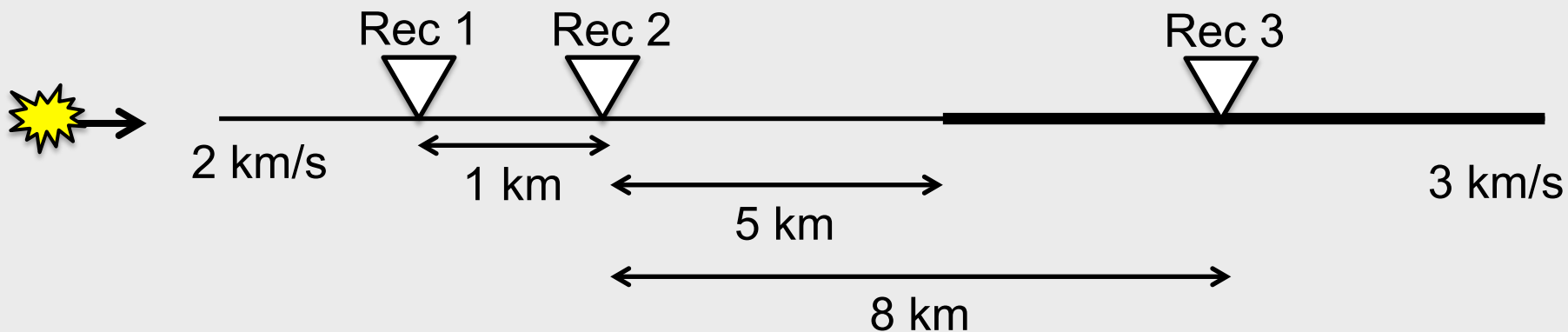
Waves, Waves on string

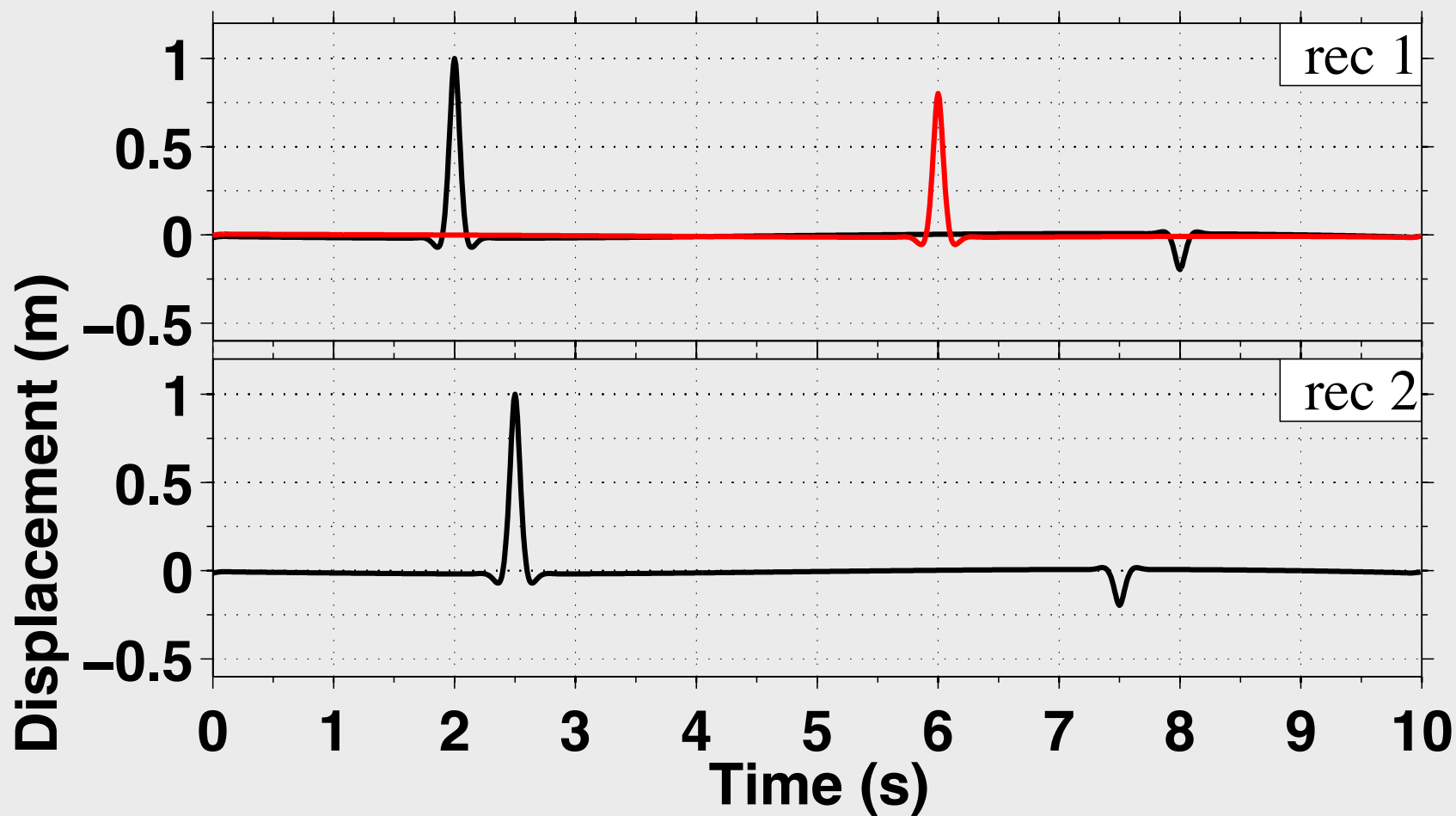
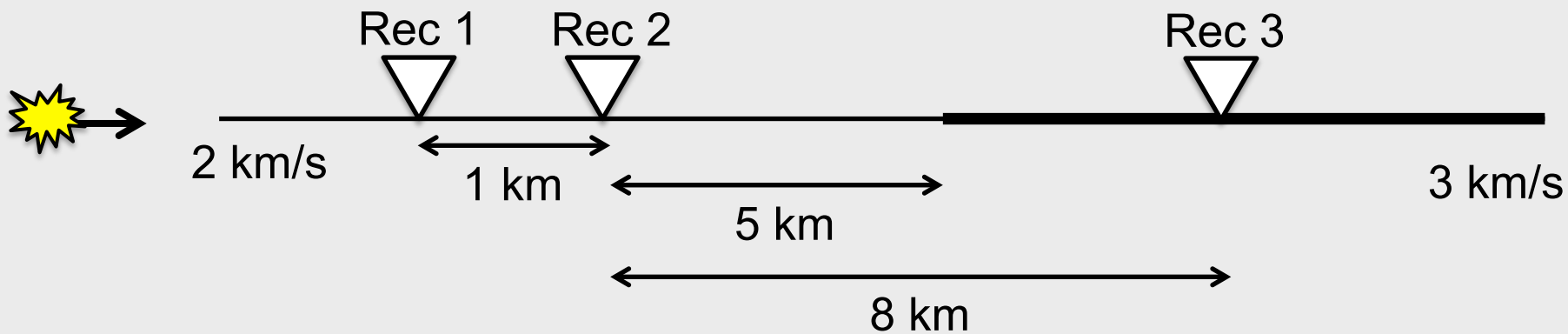
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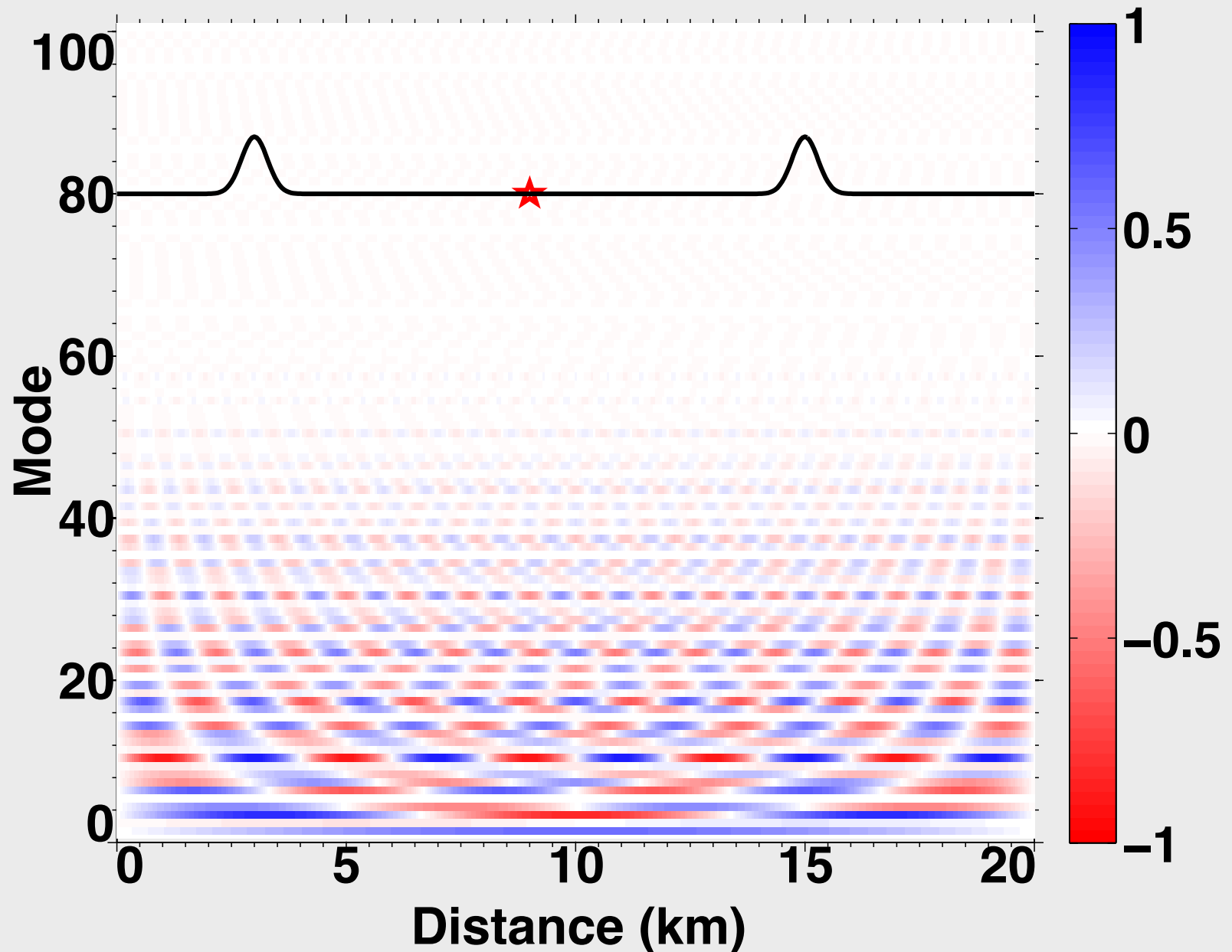




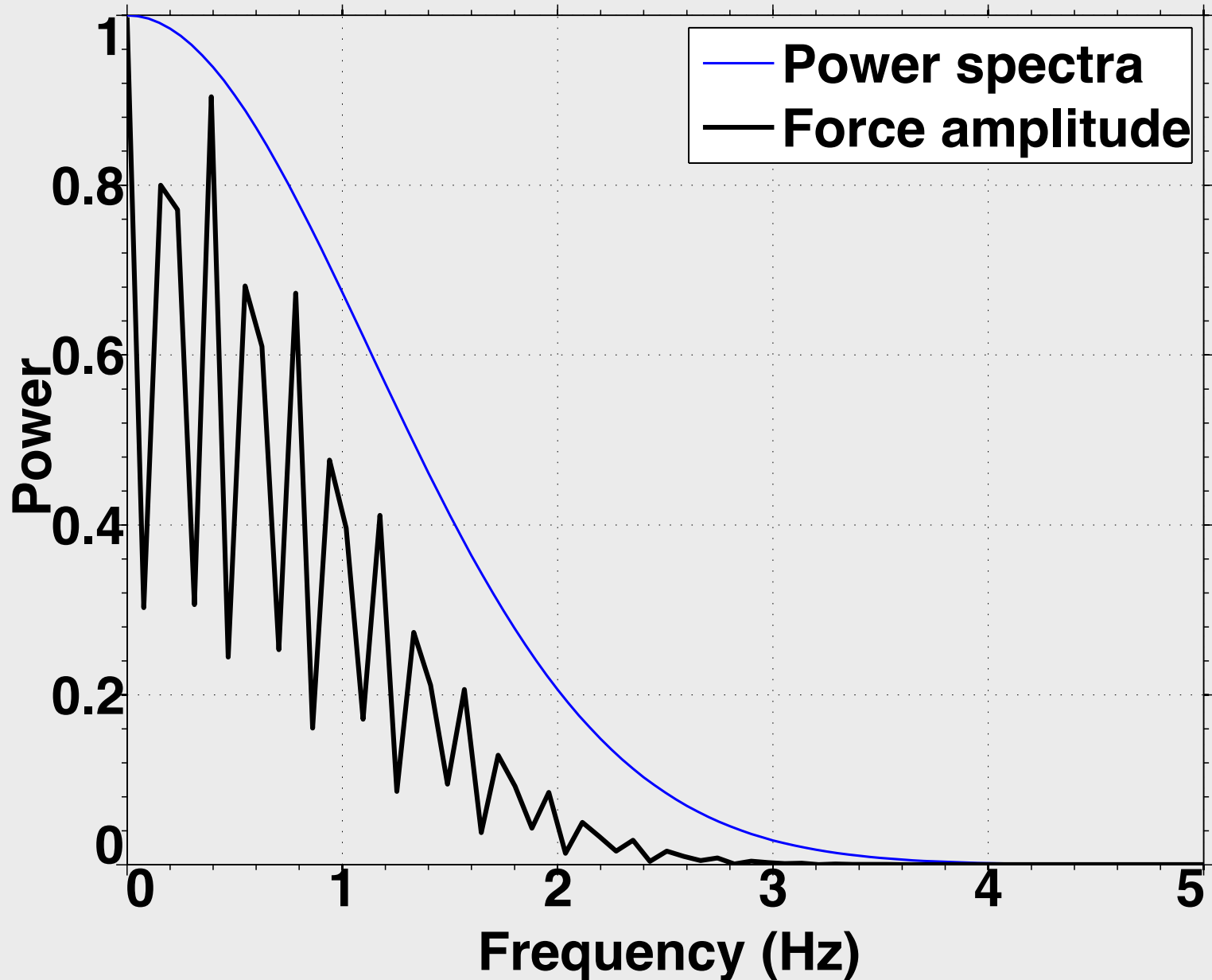




Normal modes



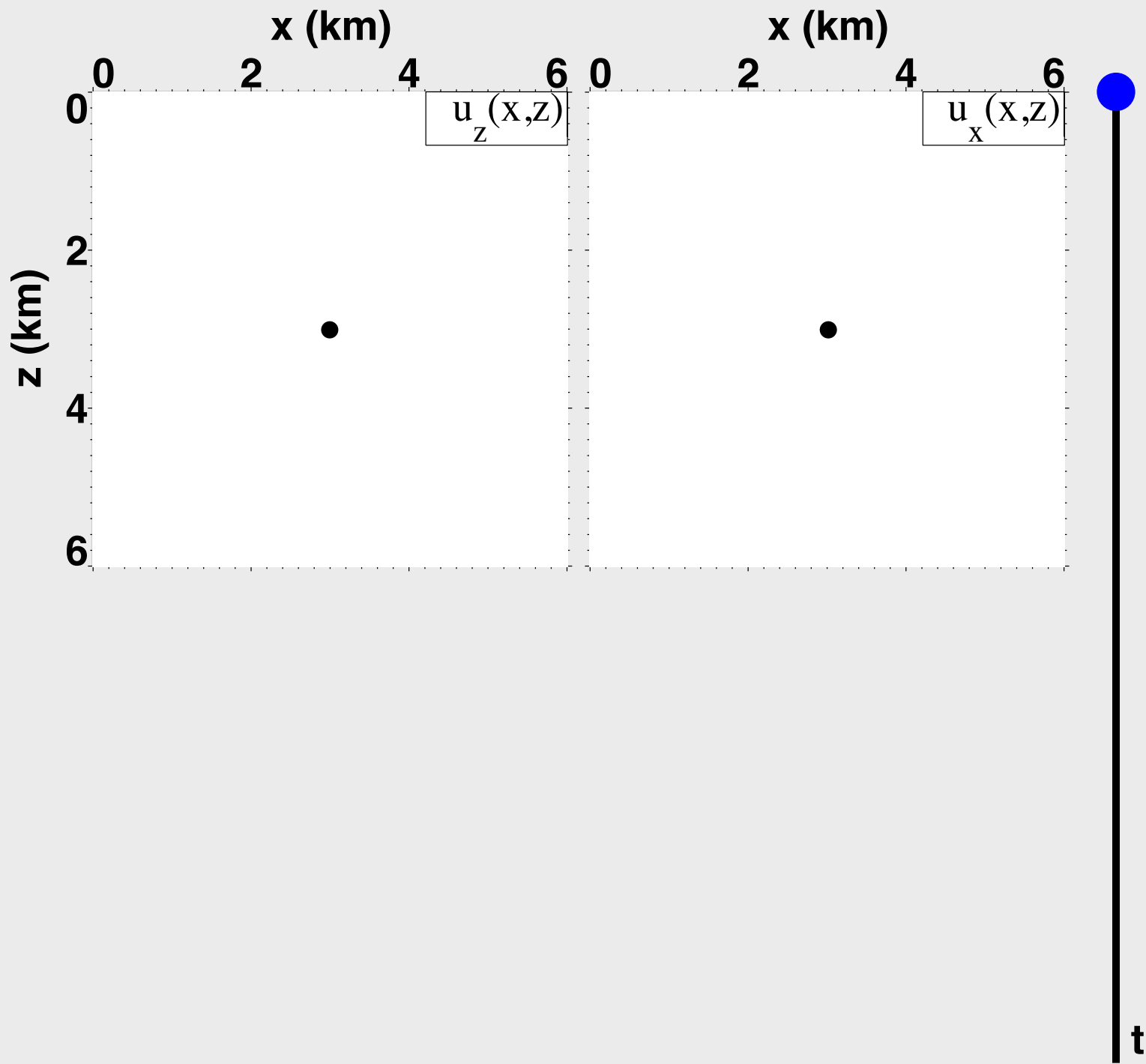
Fourier transform

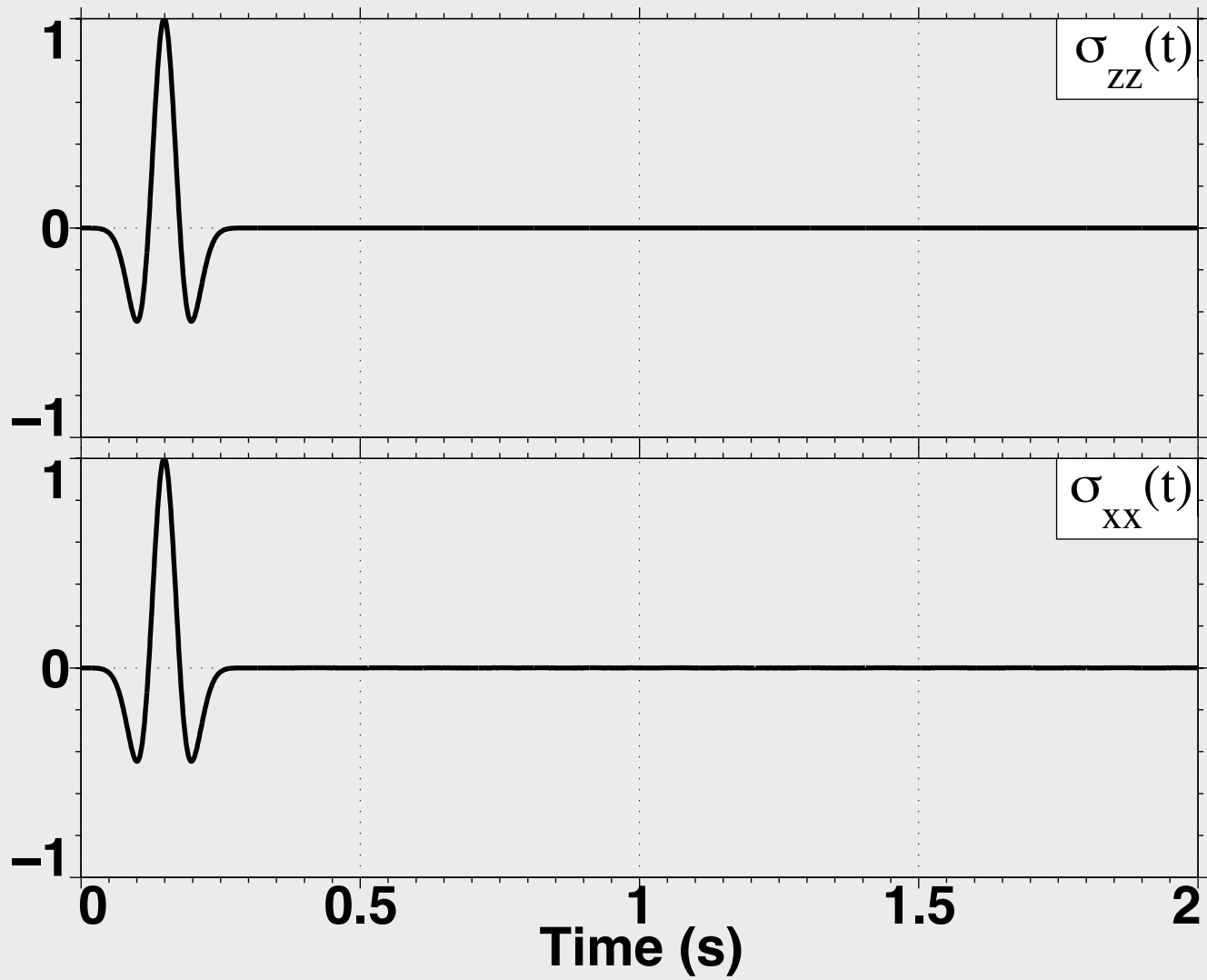


Body waves

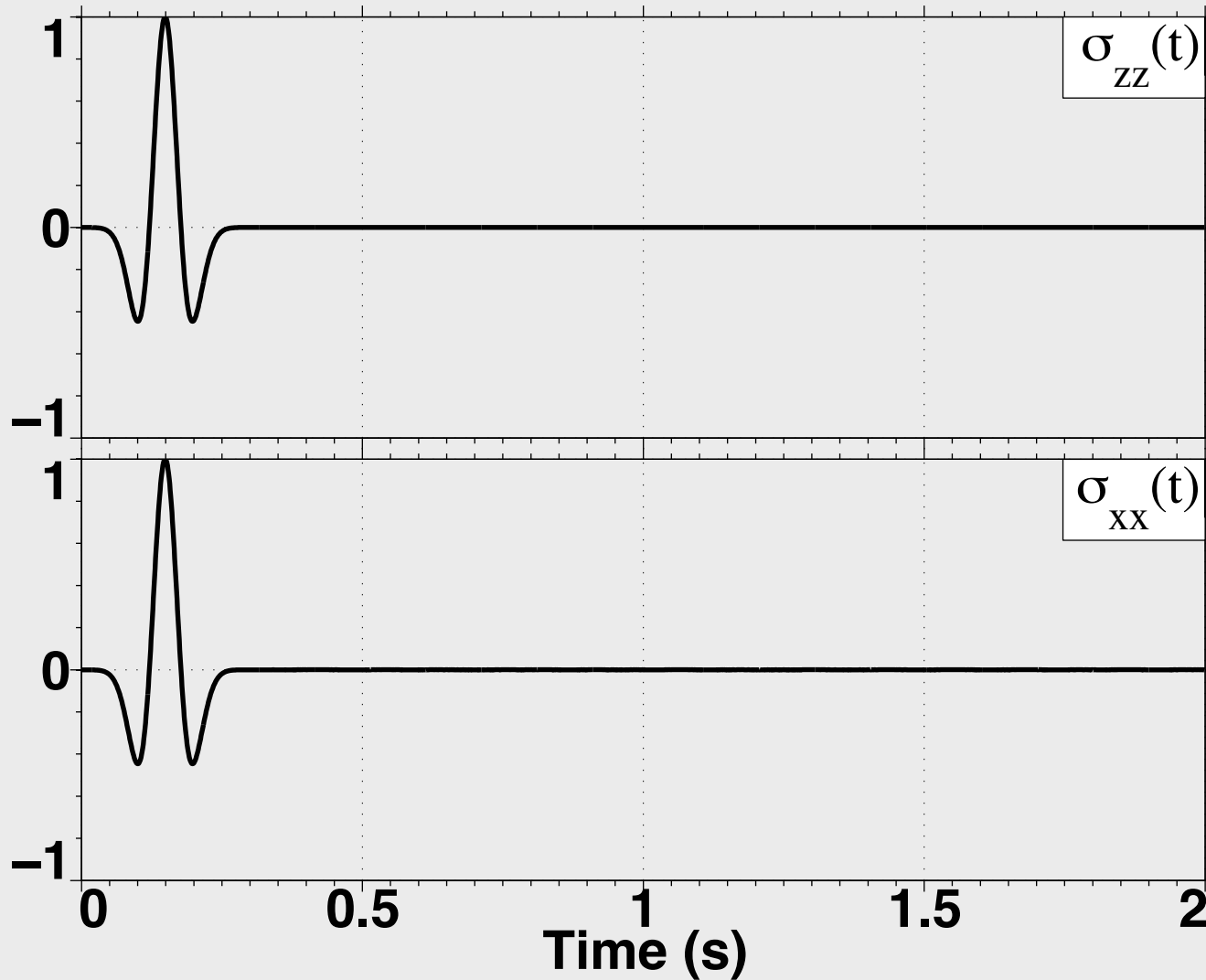
Nori Nakata

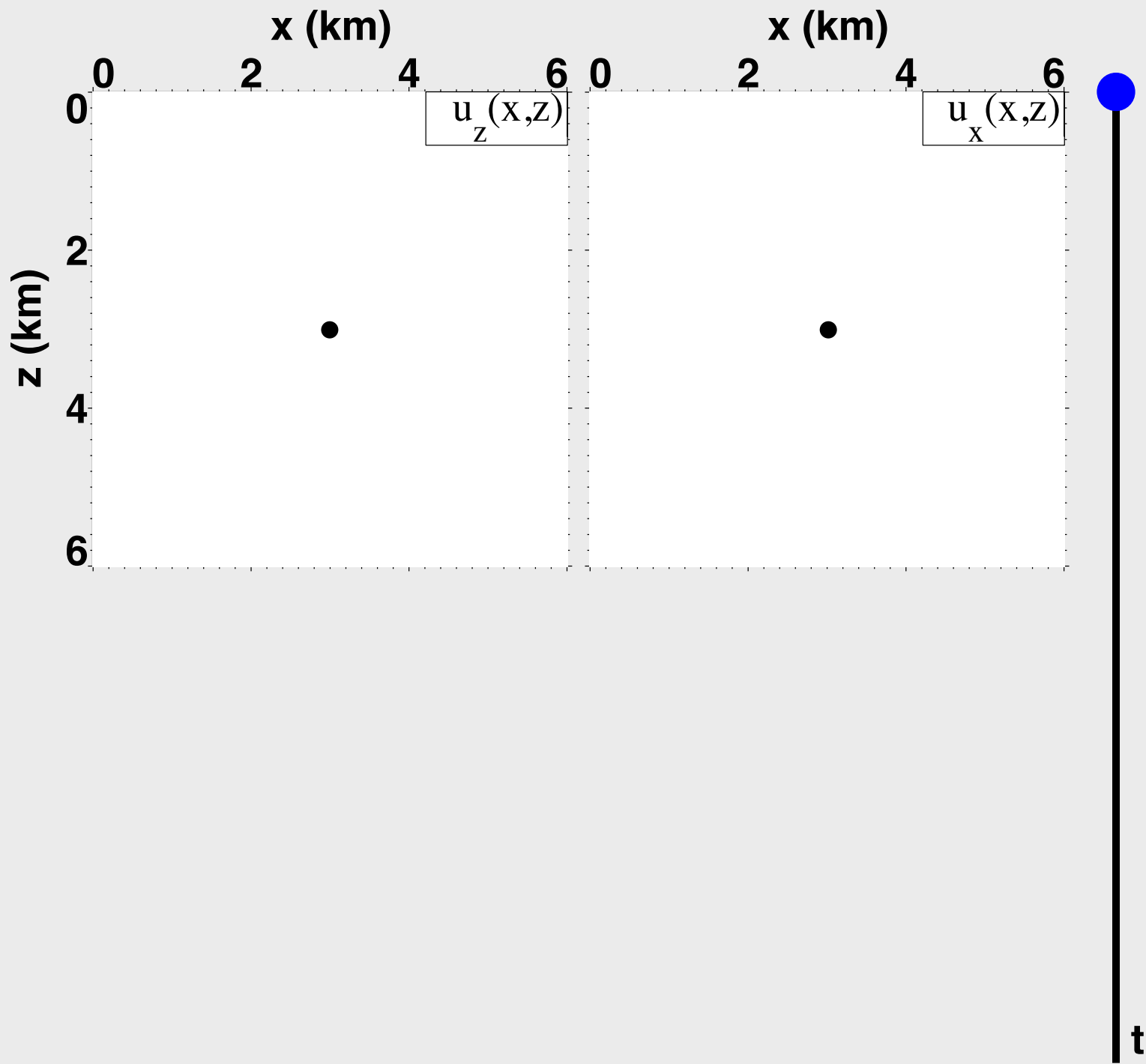
Stanford University

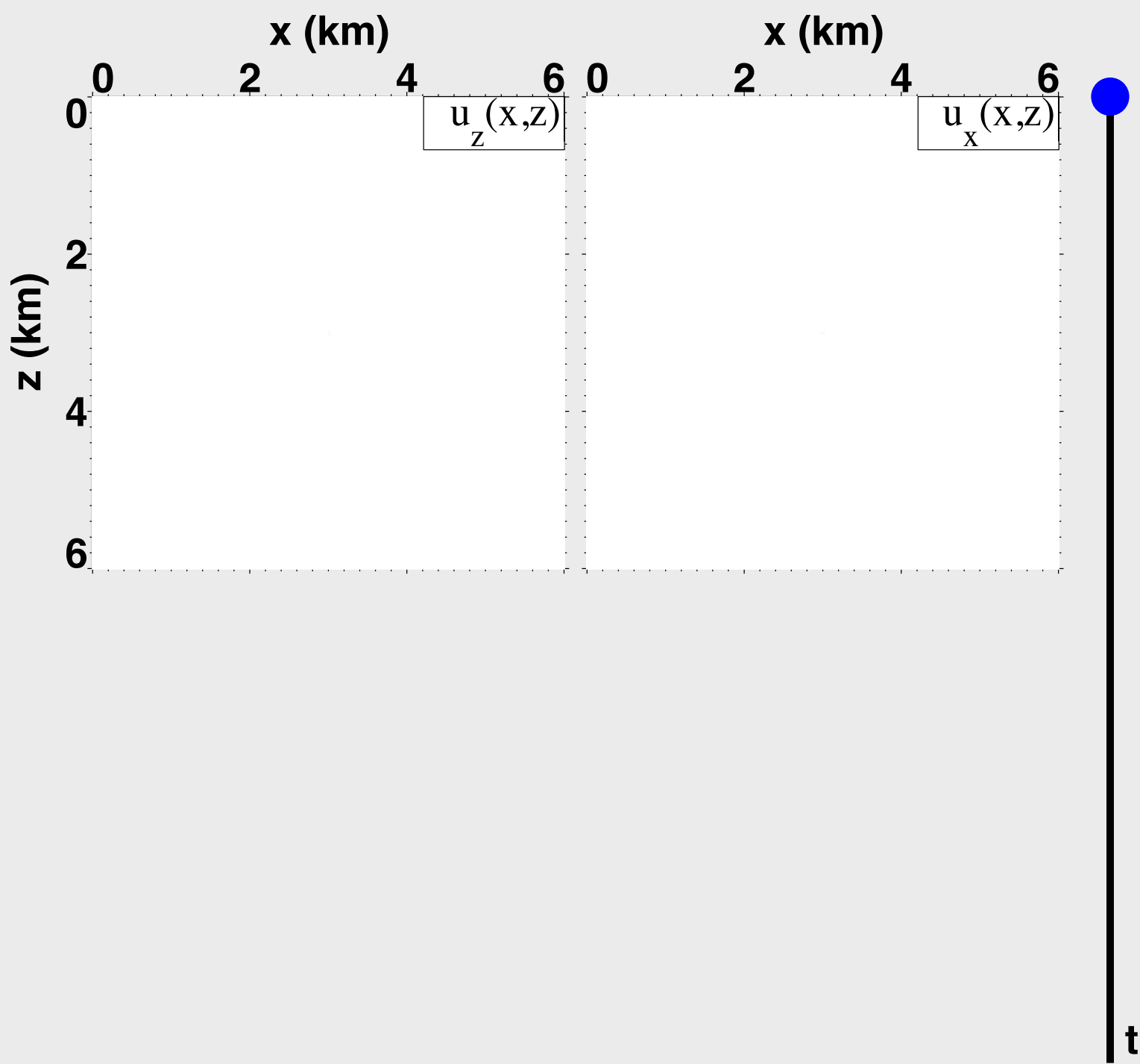


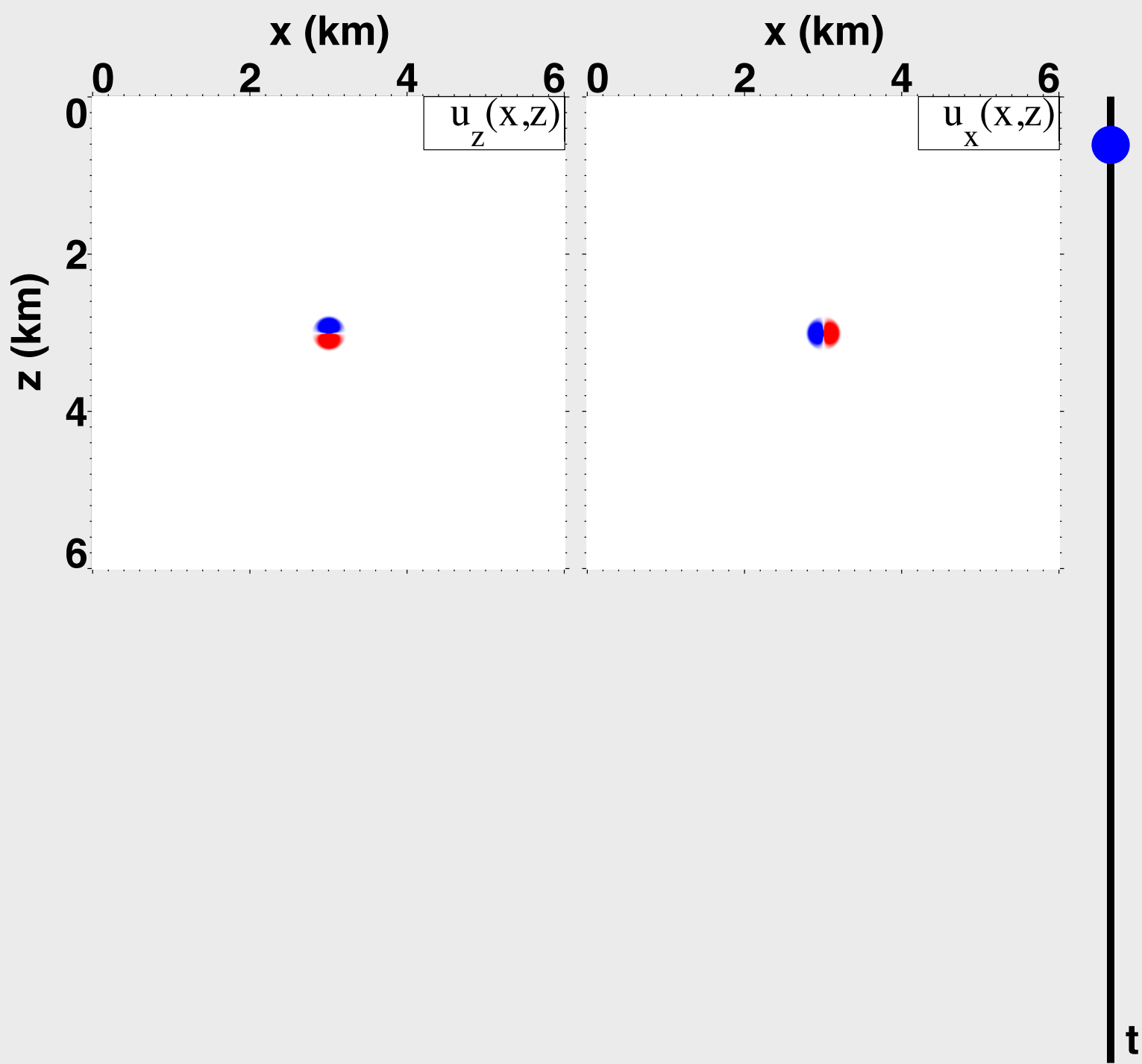


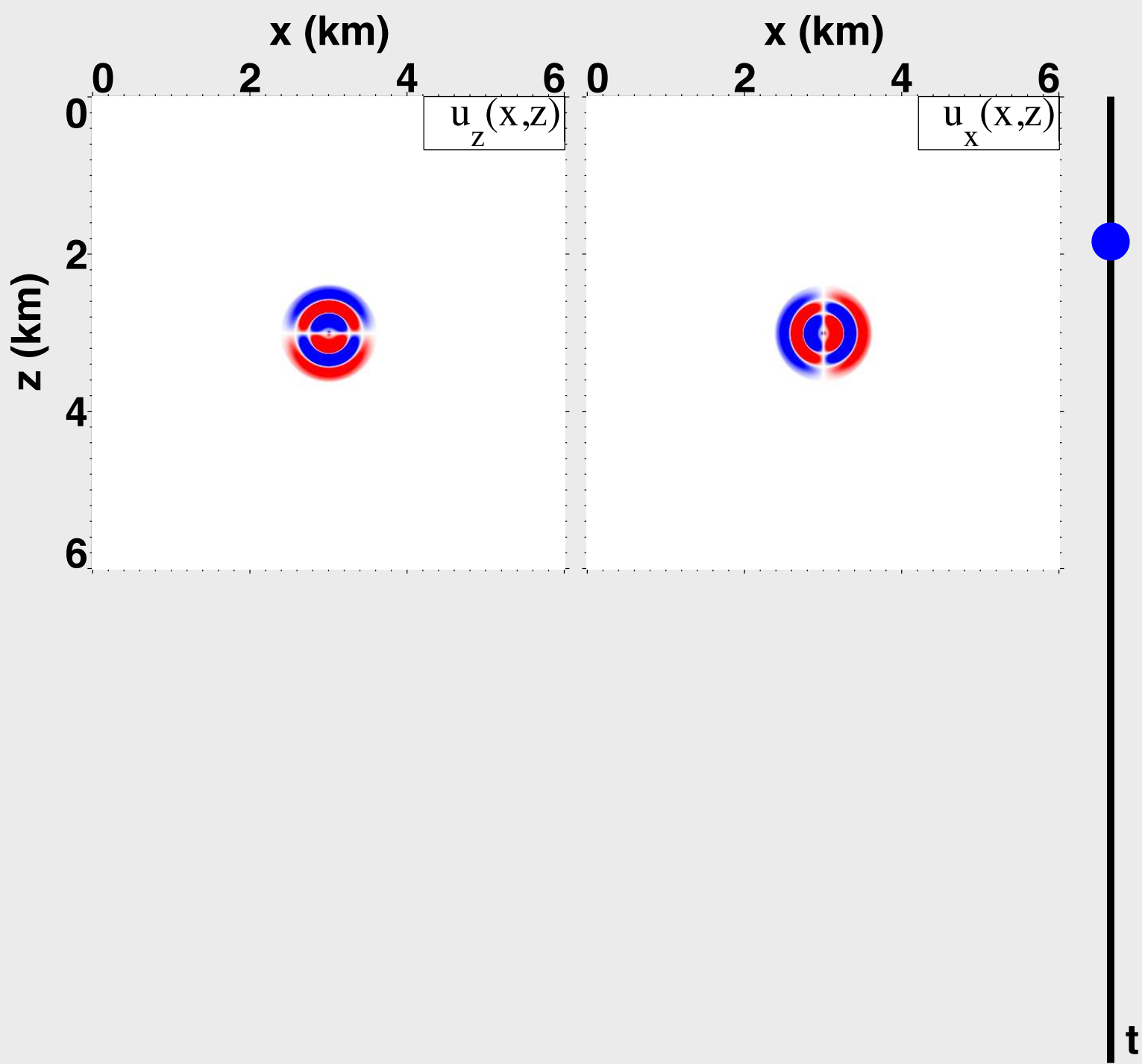
Explosive source

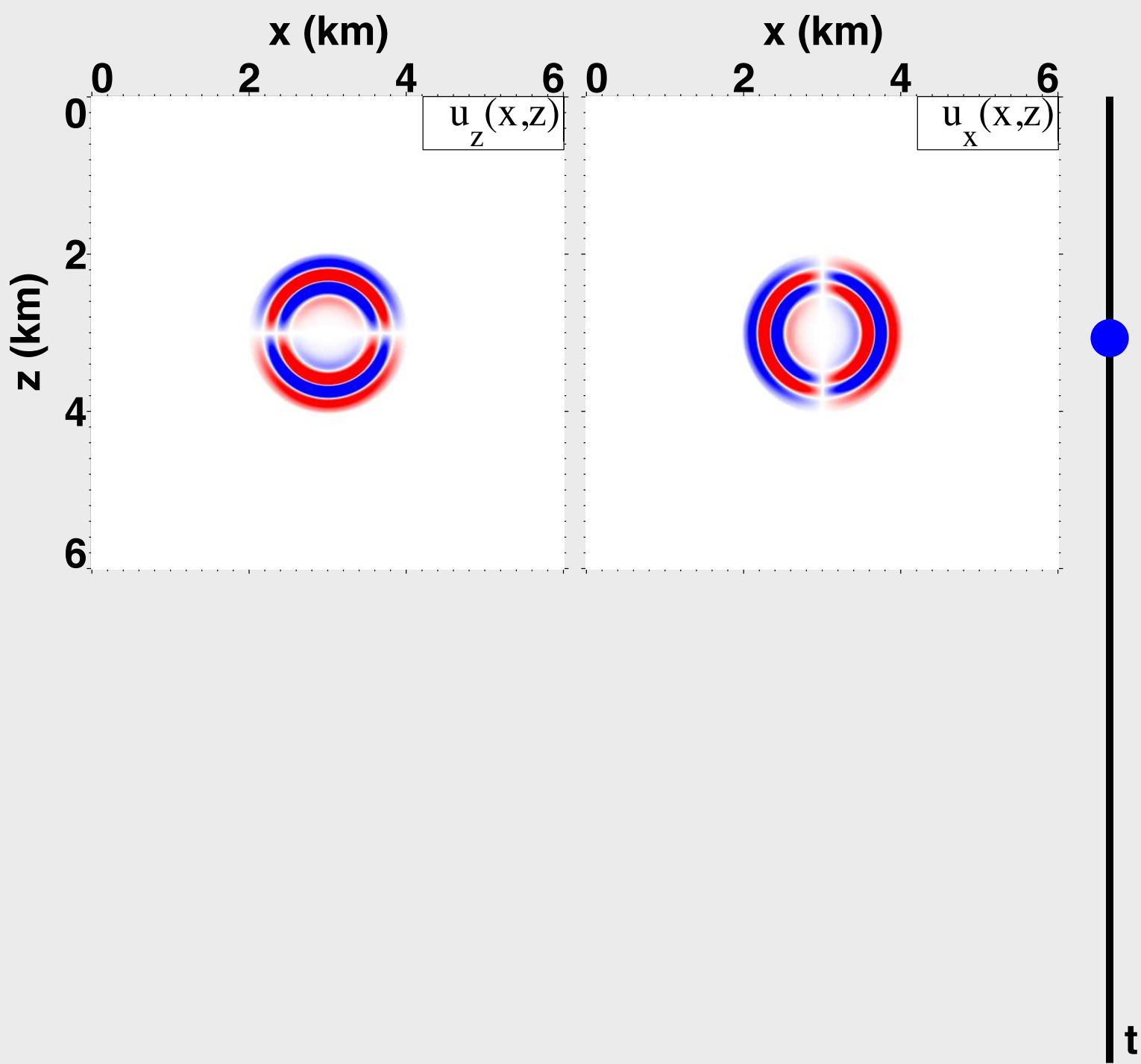


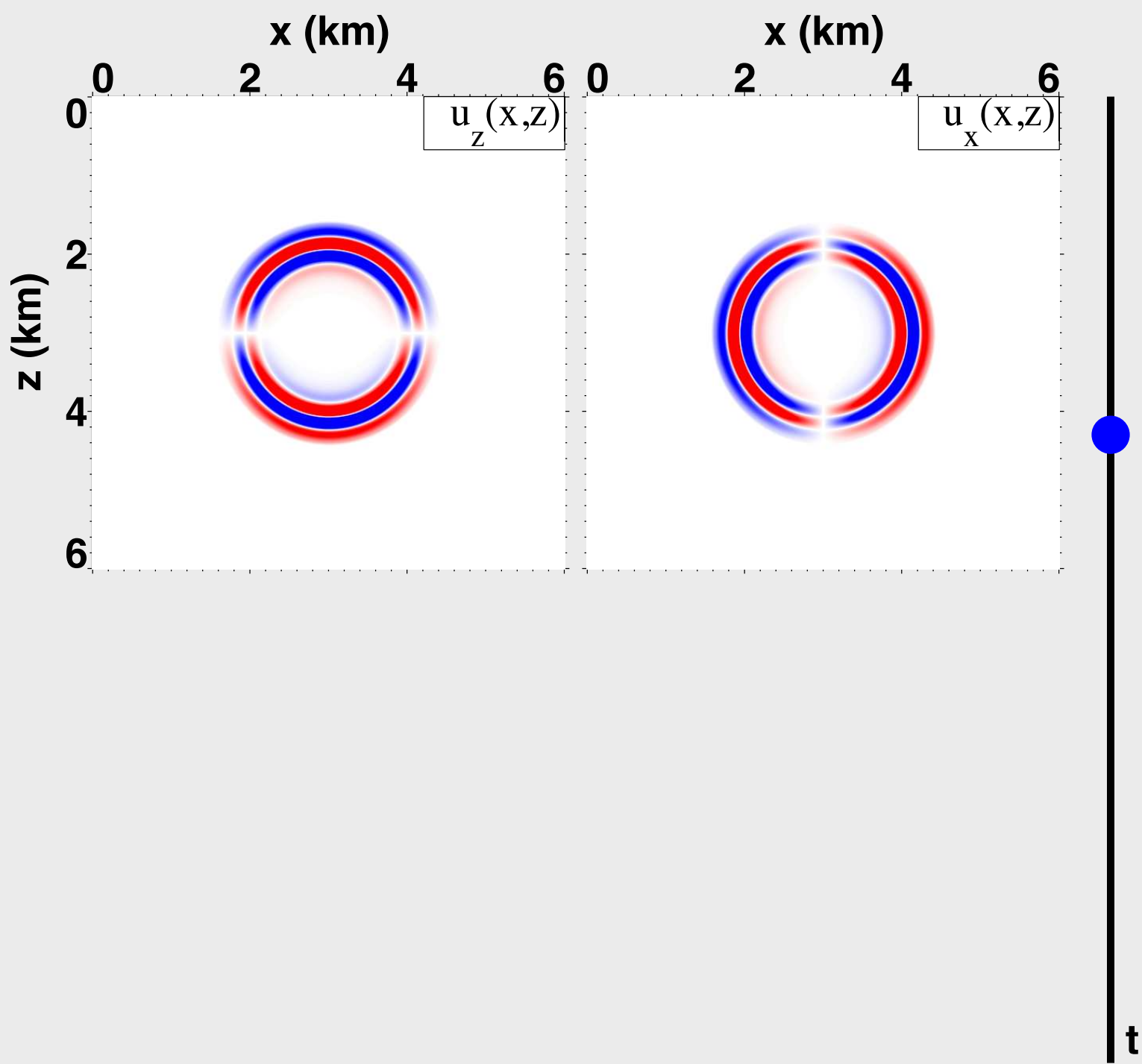


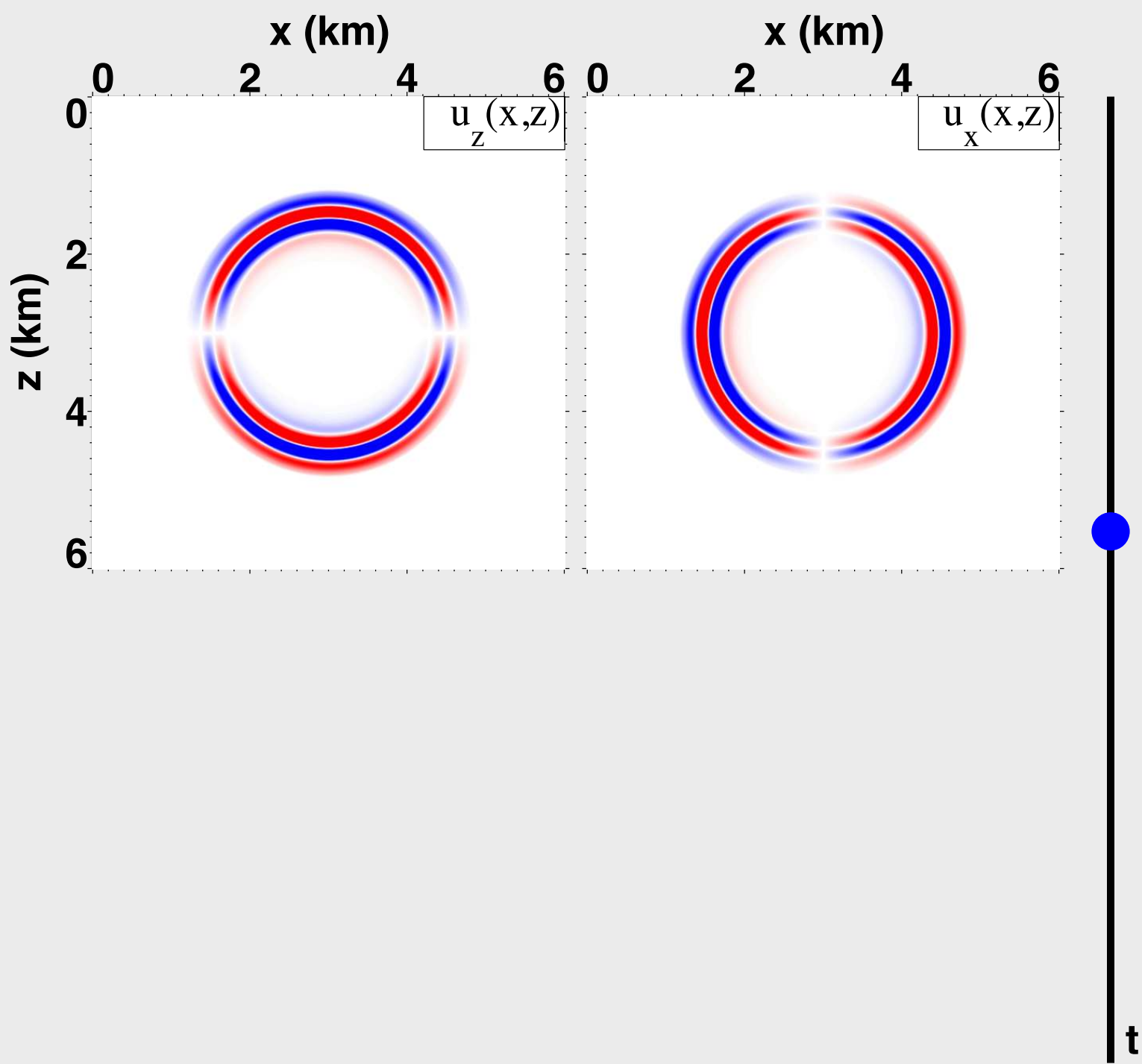


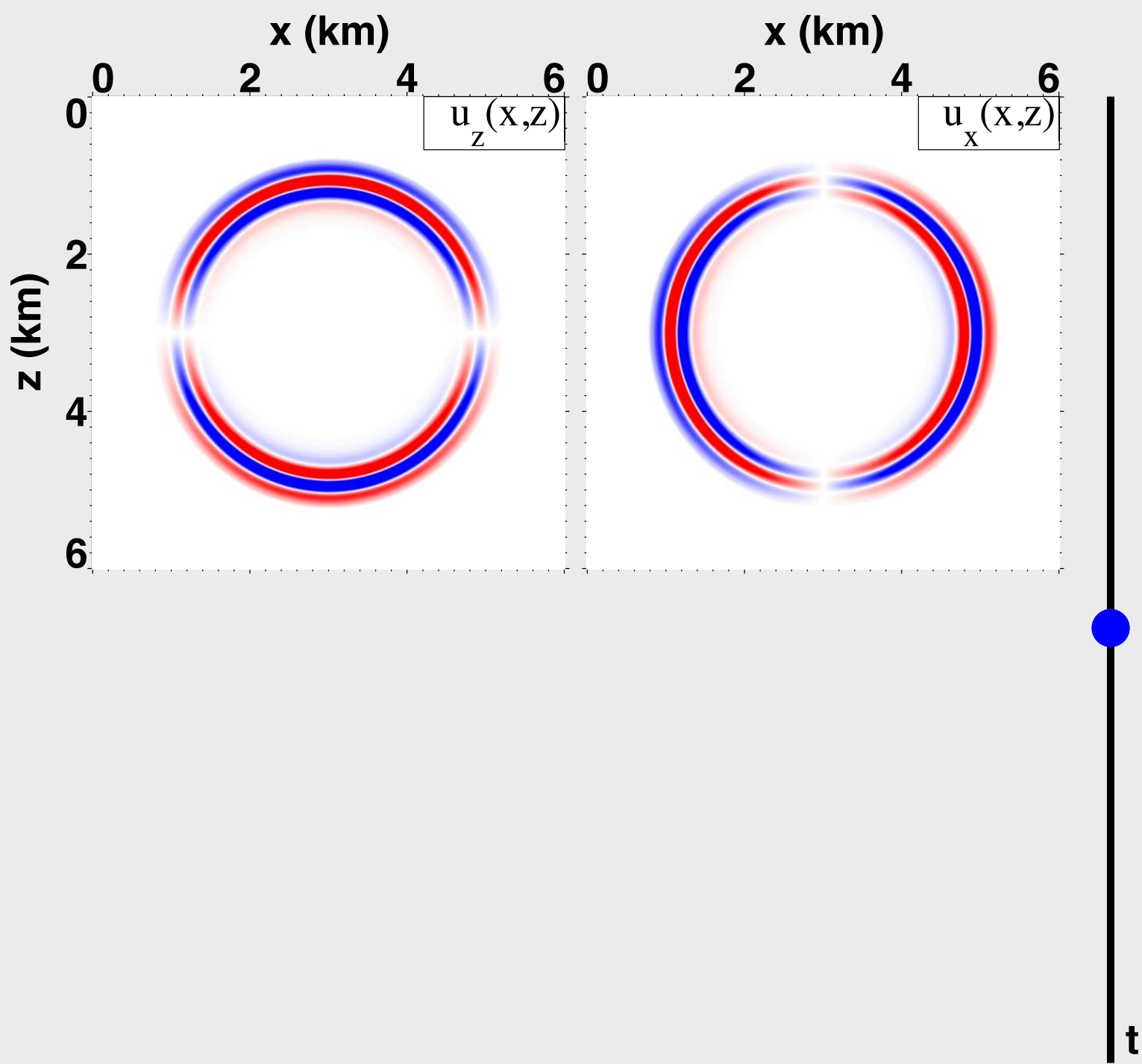


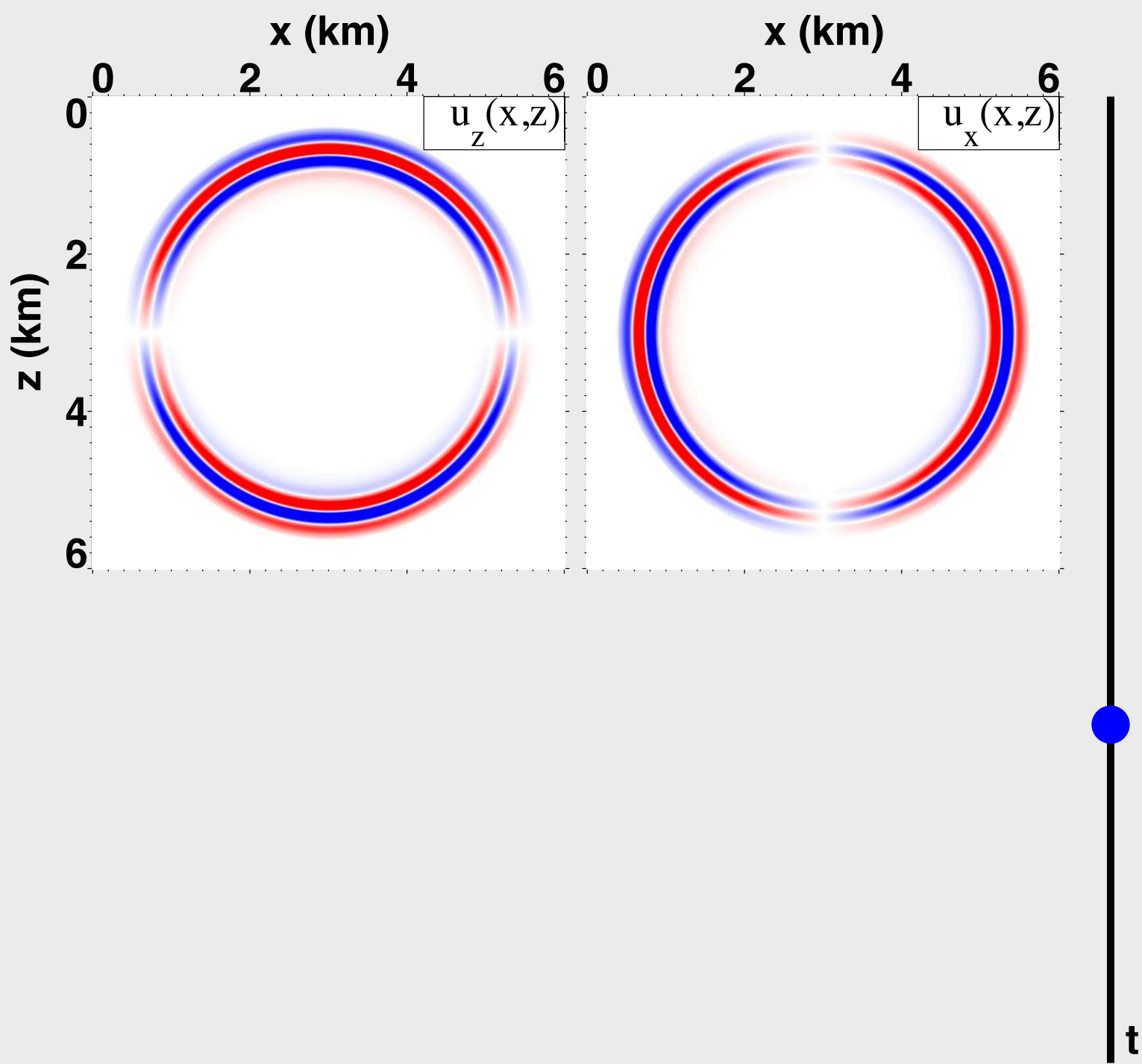


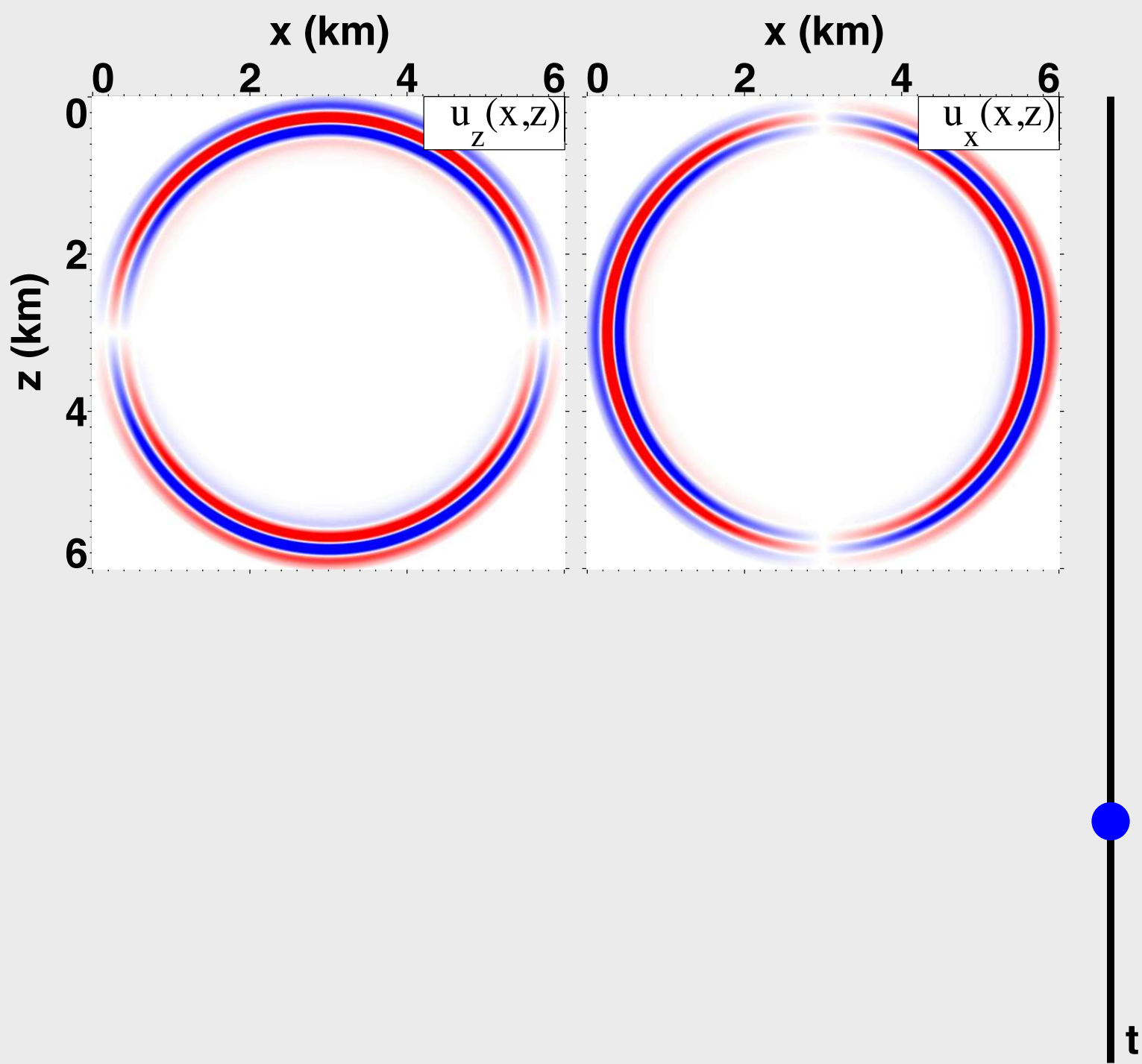


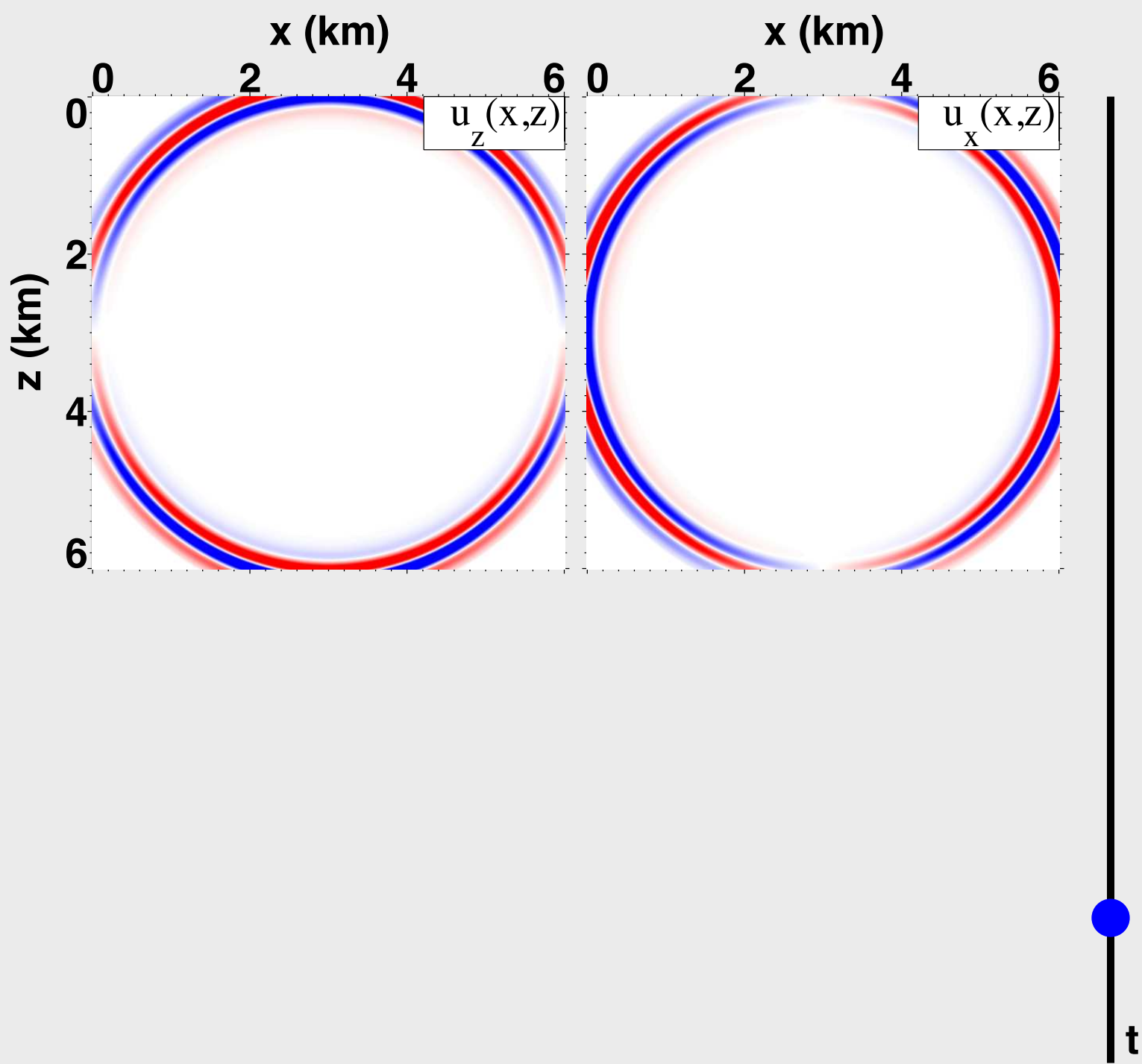


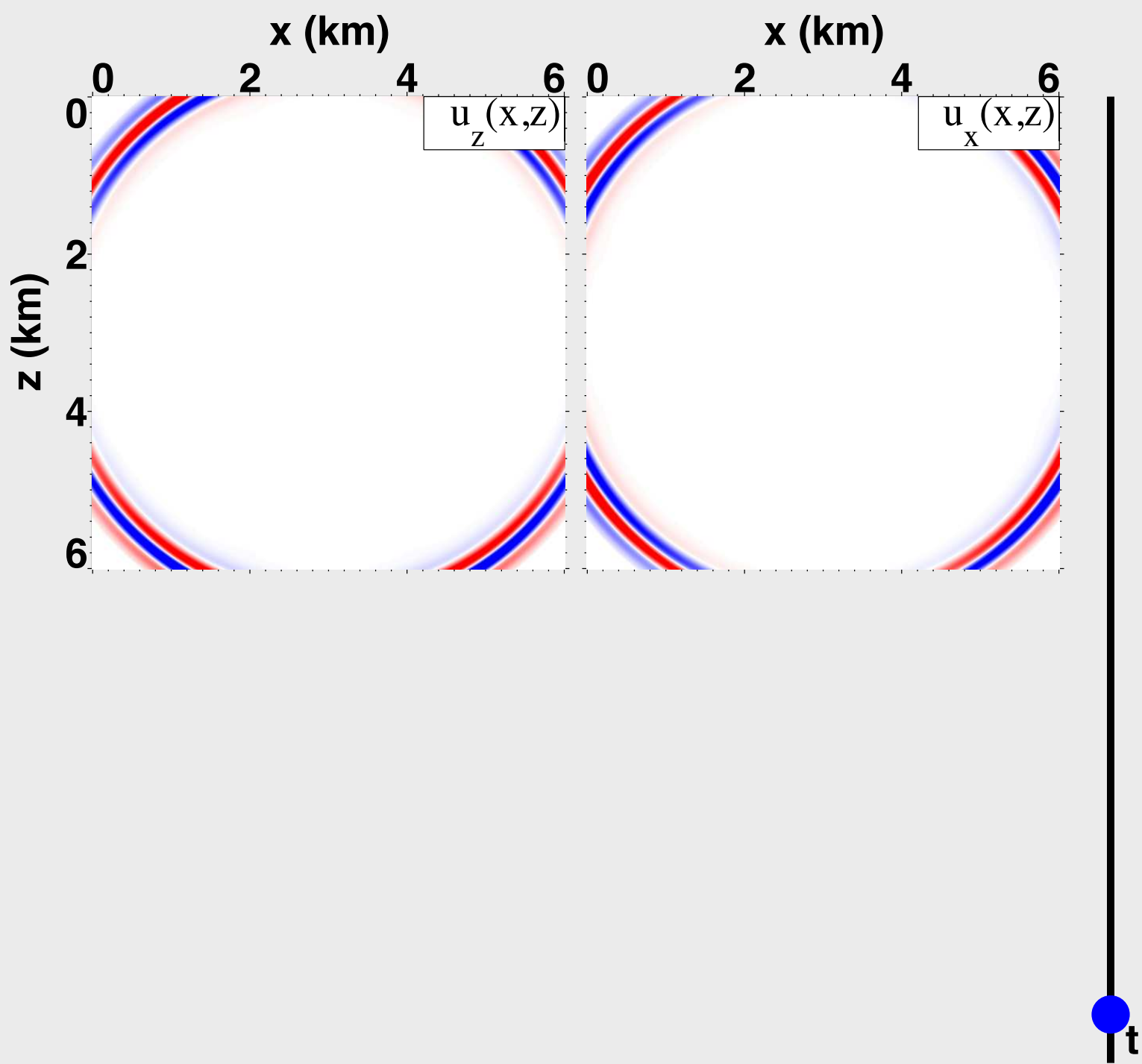




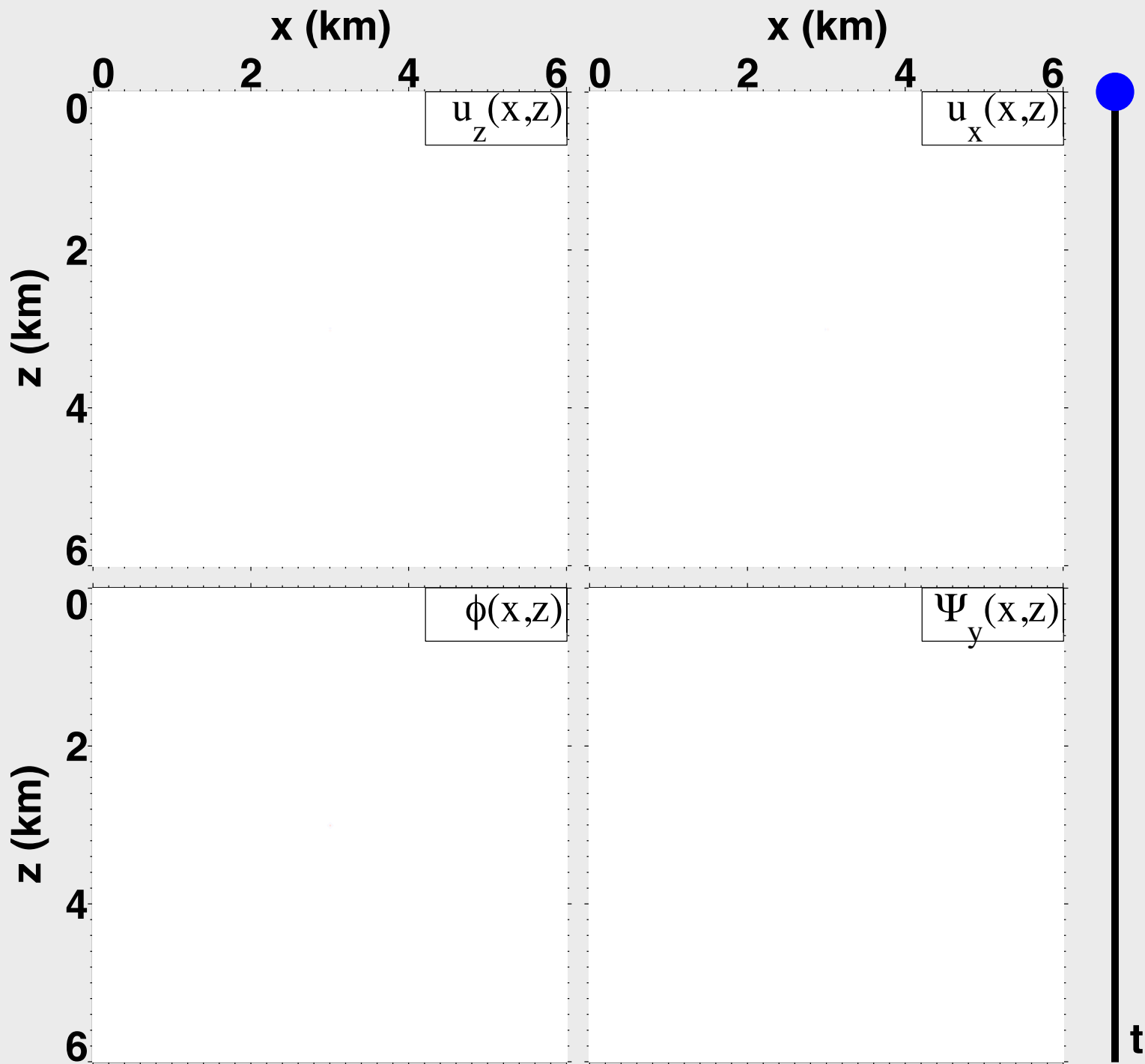


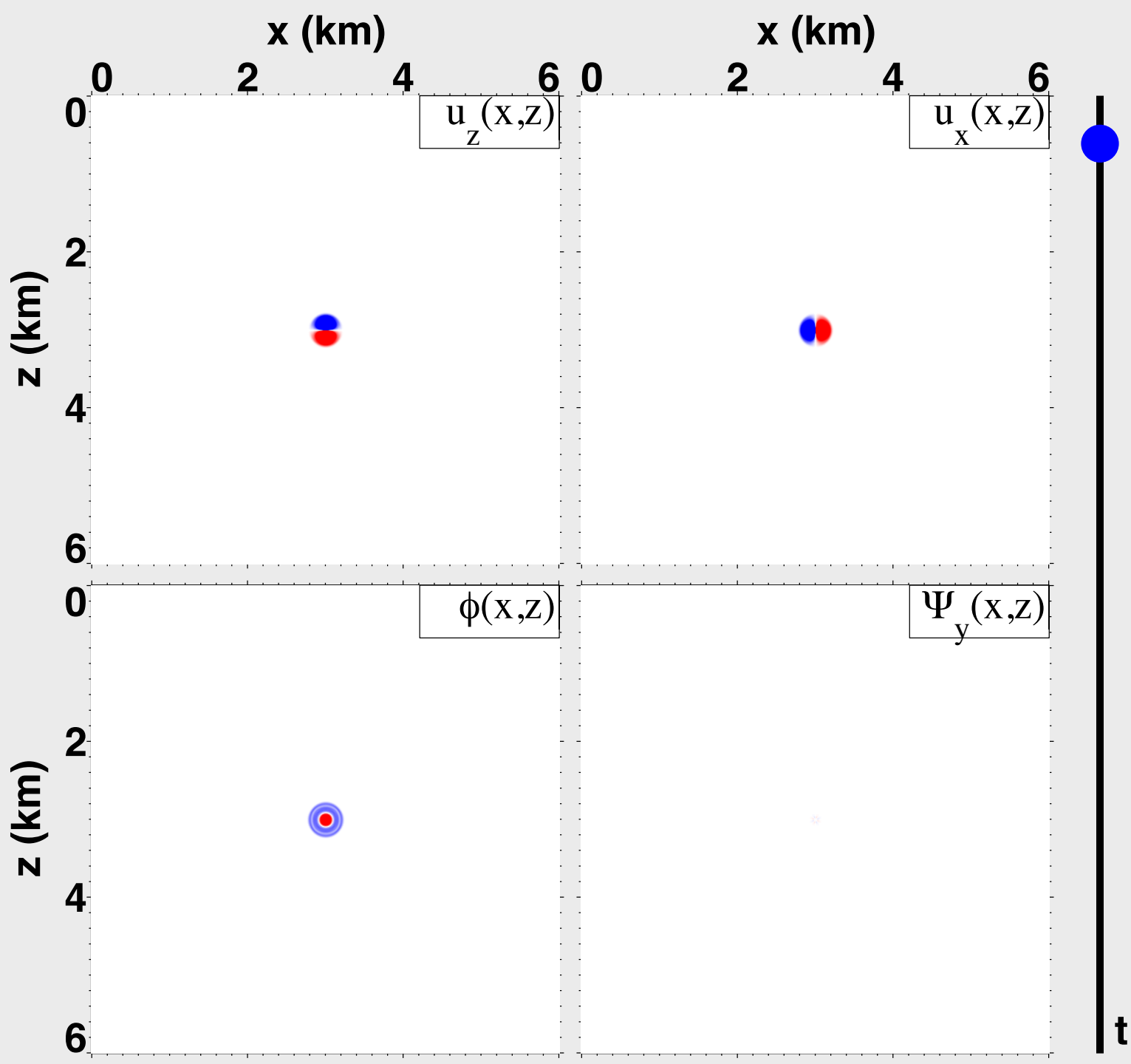


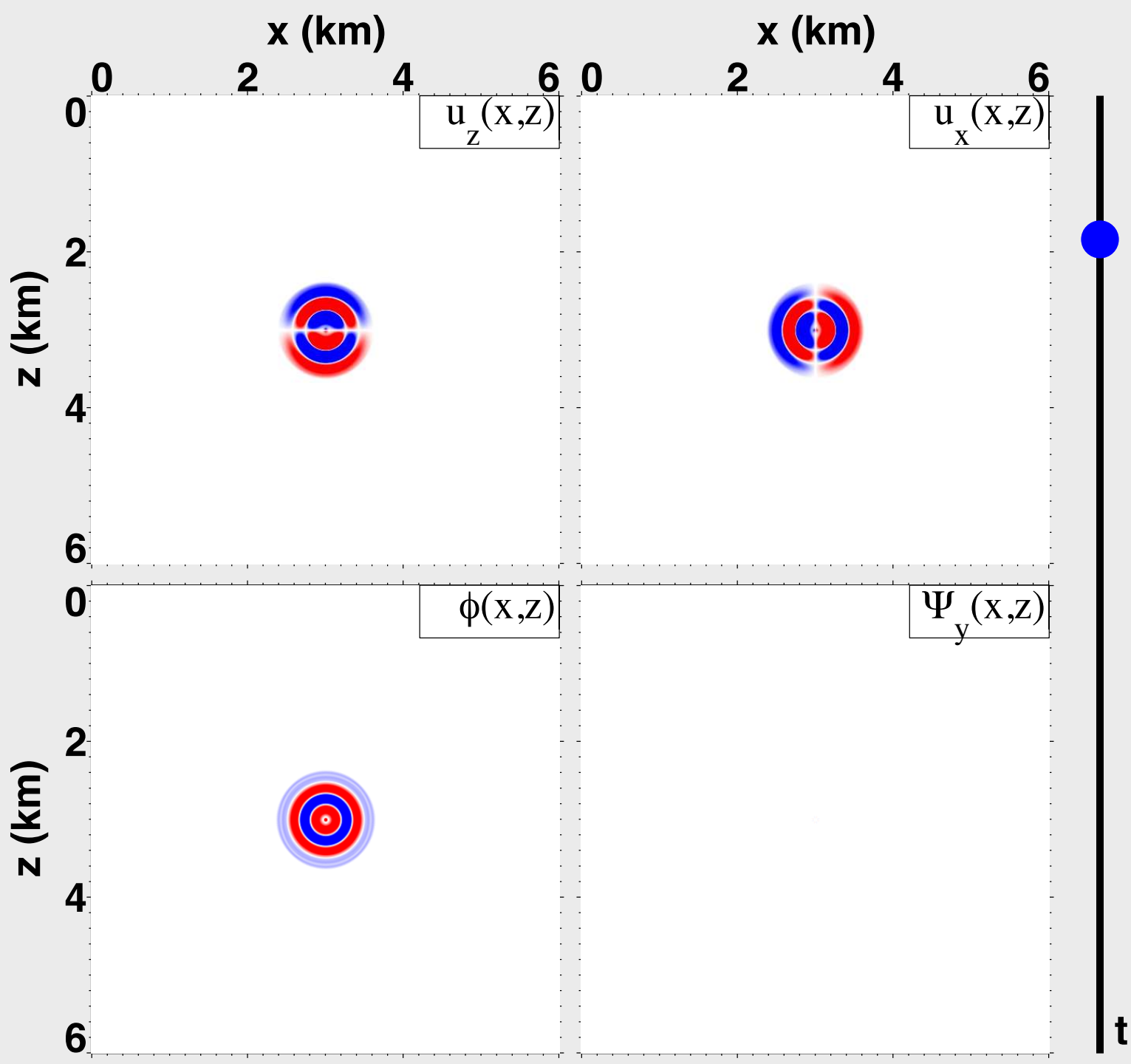


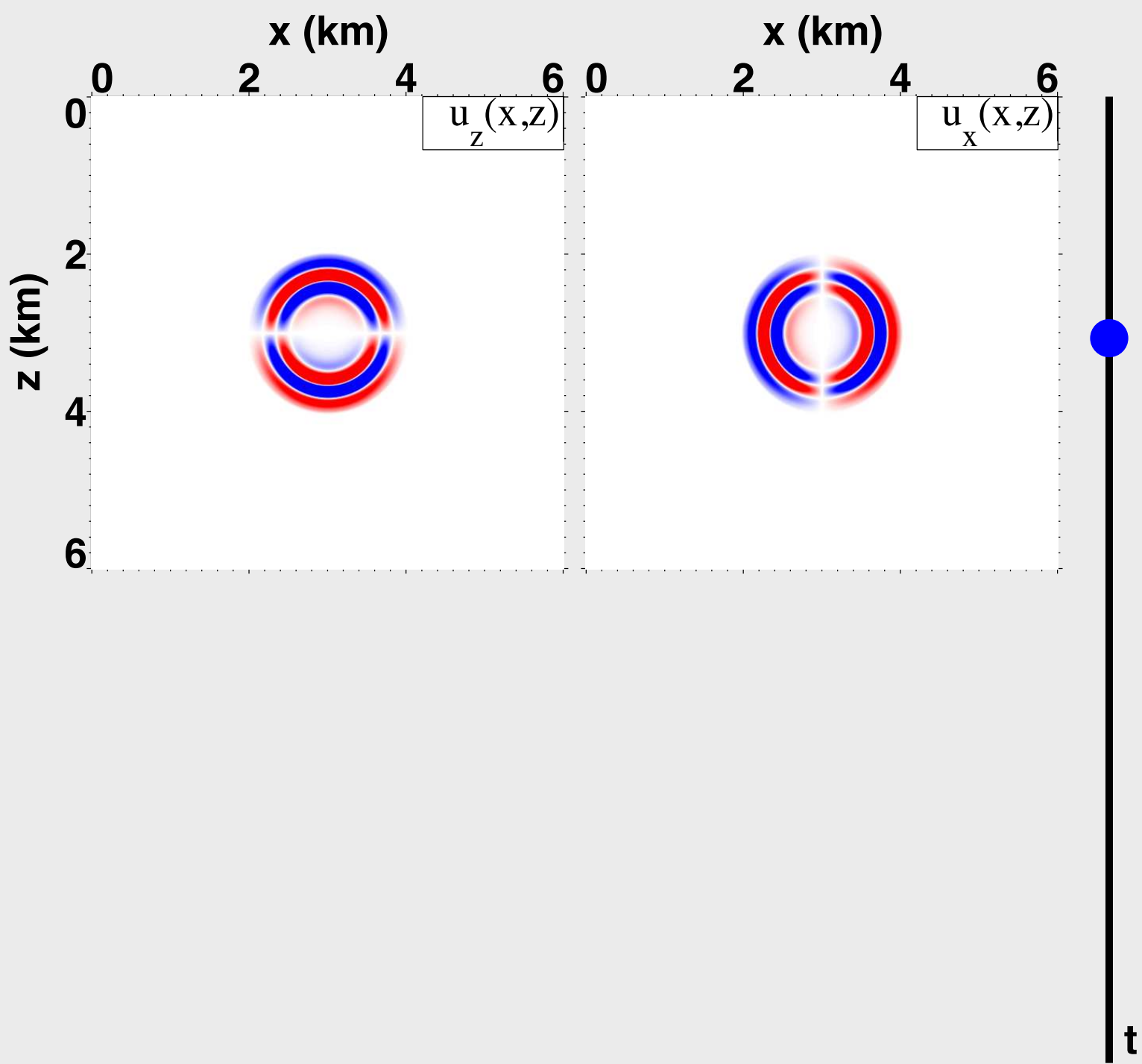


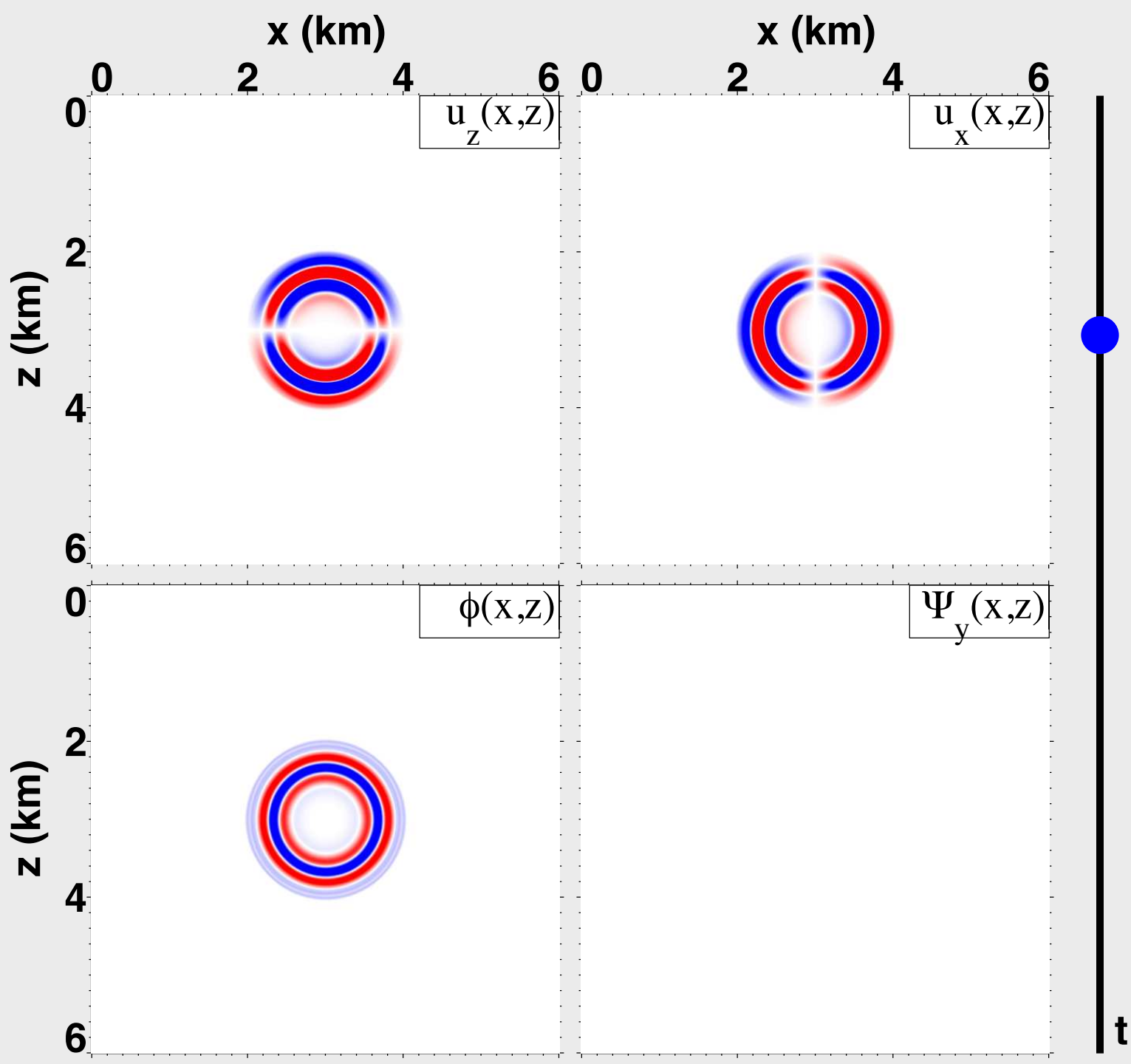
Potentials

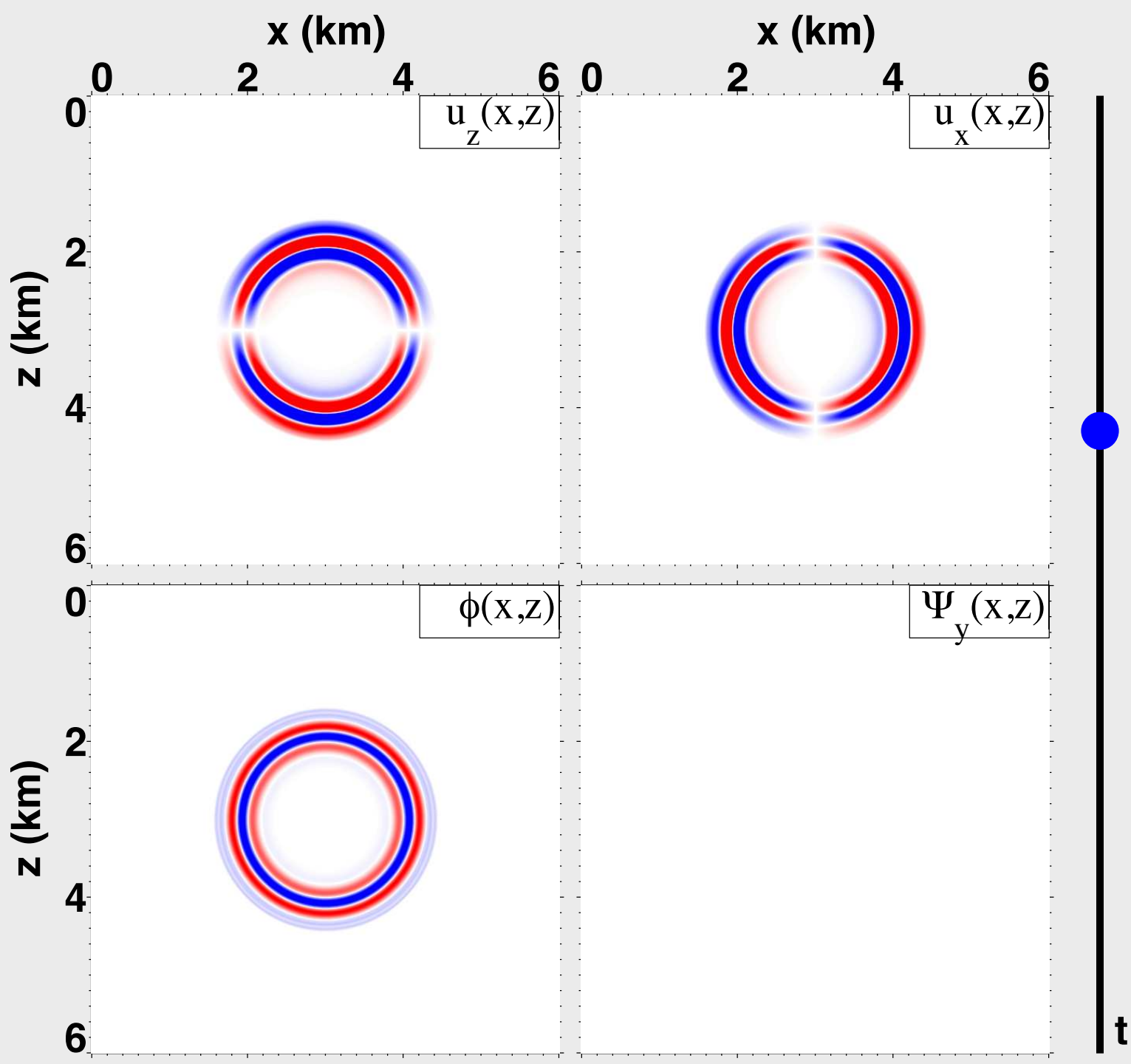


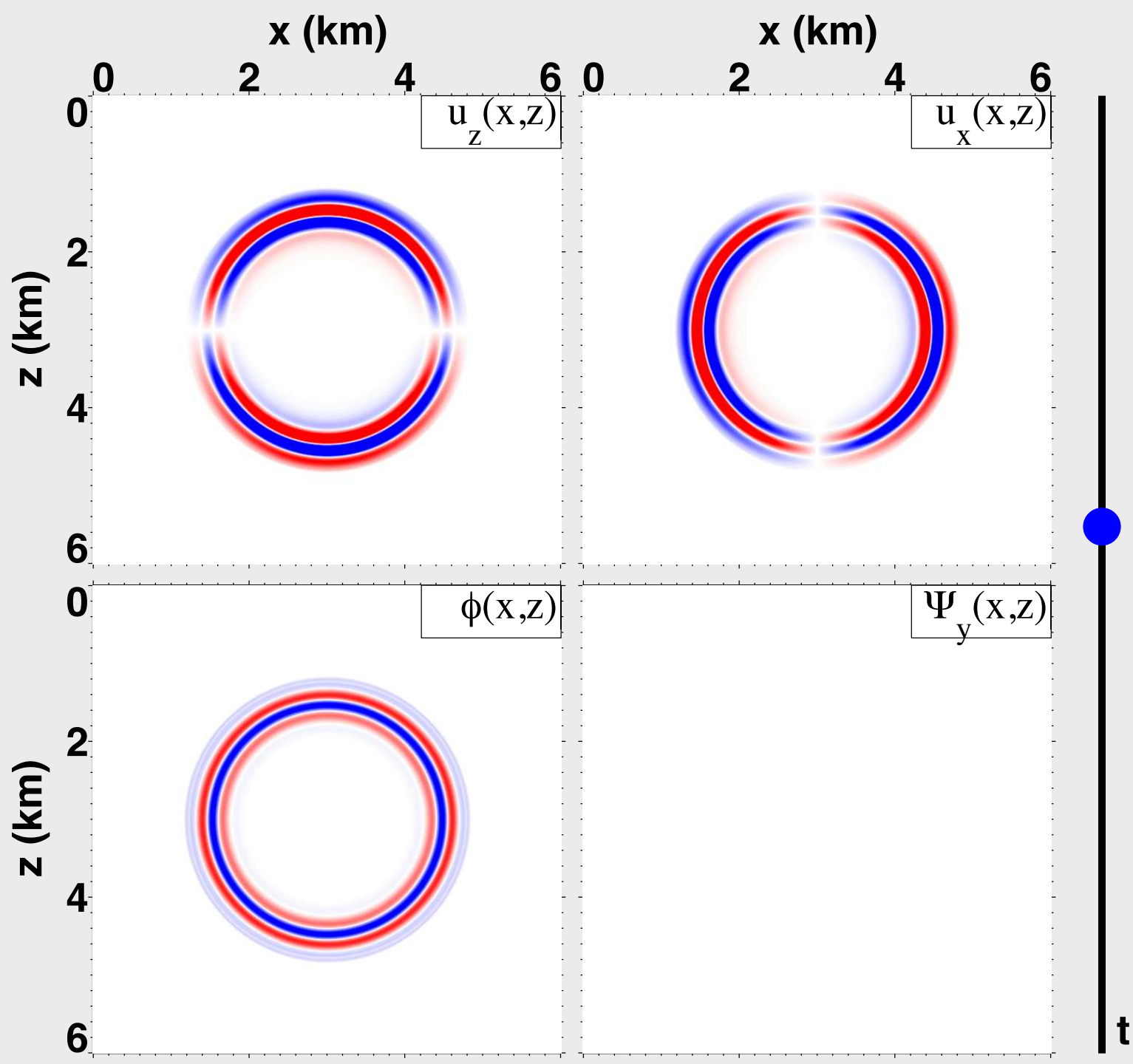


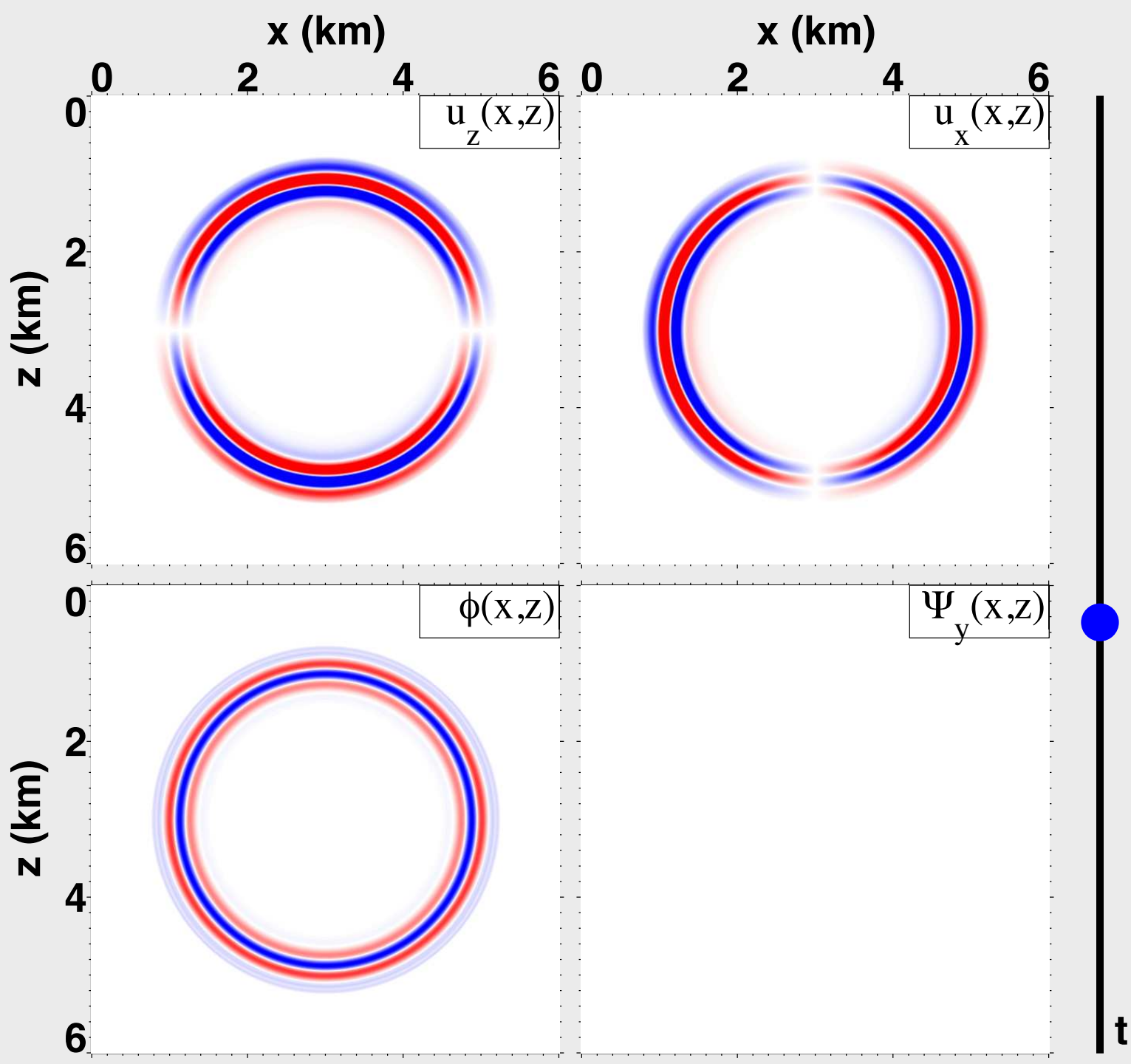


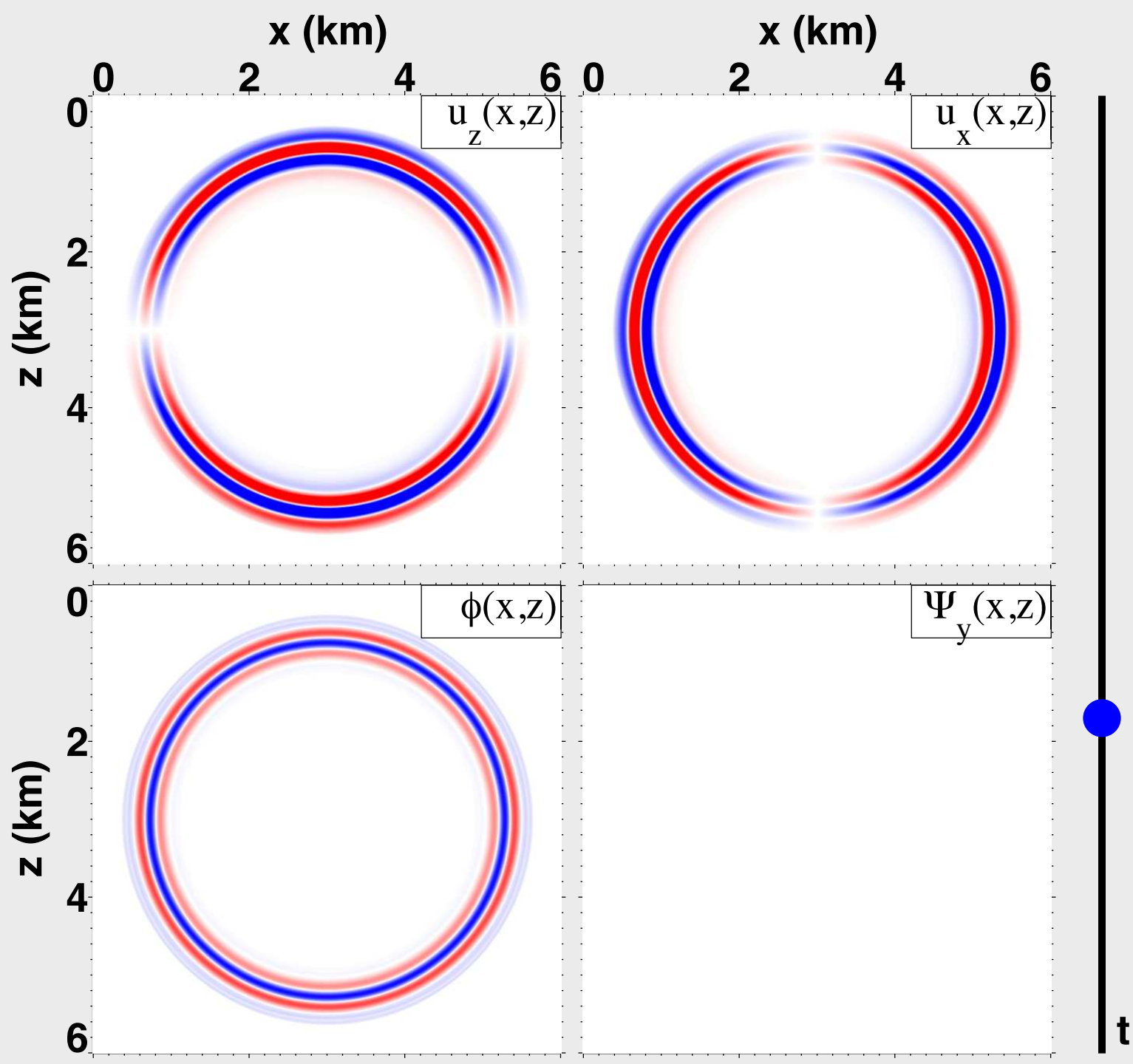


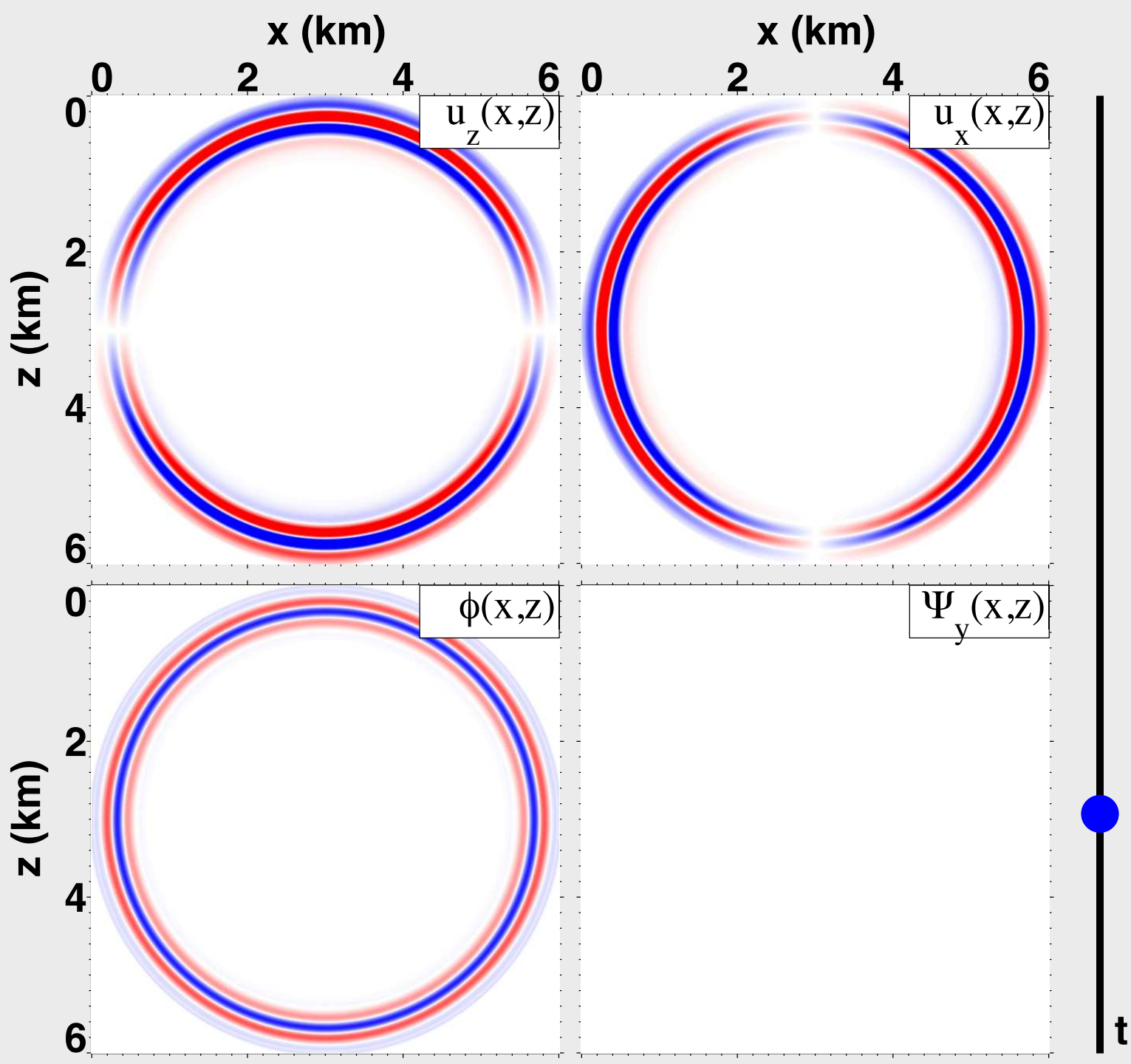


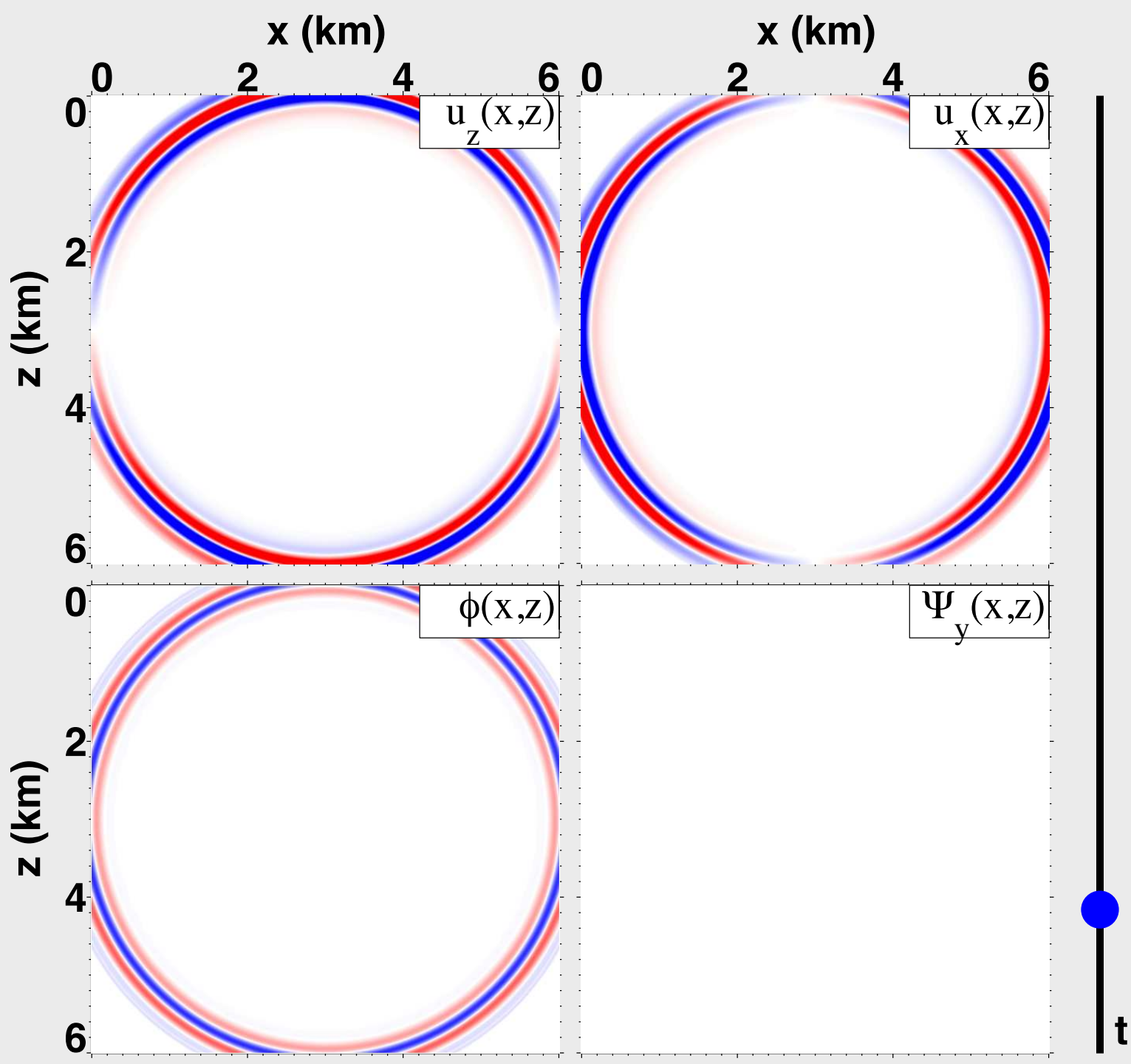


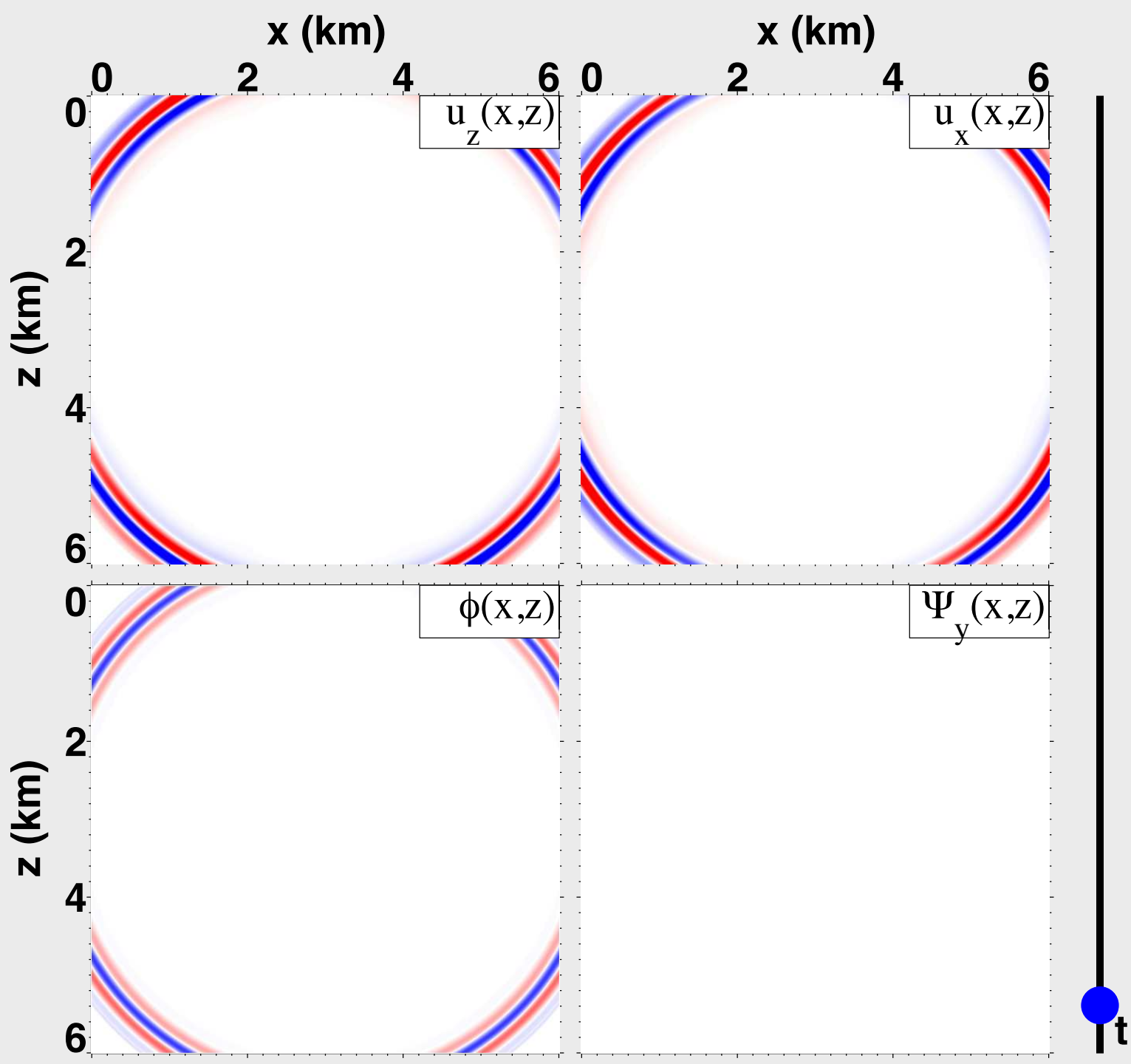




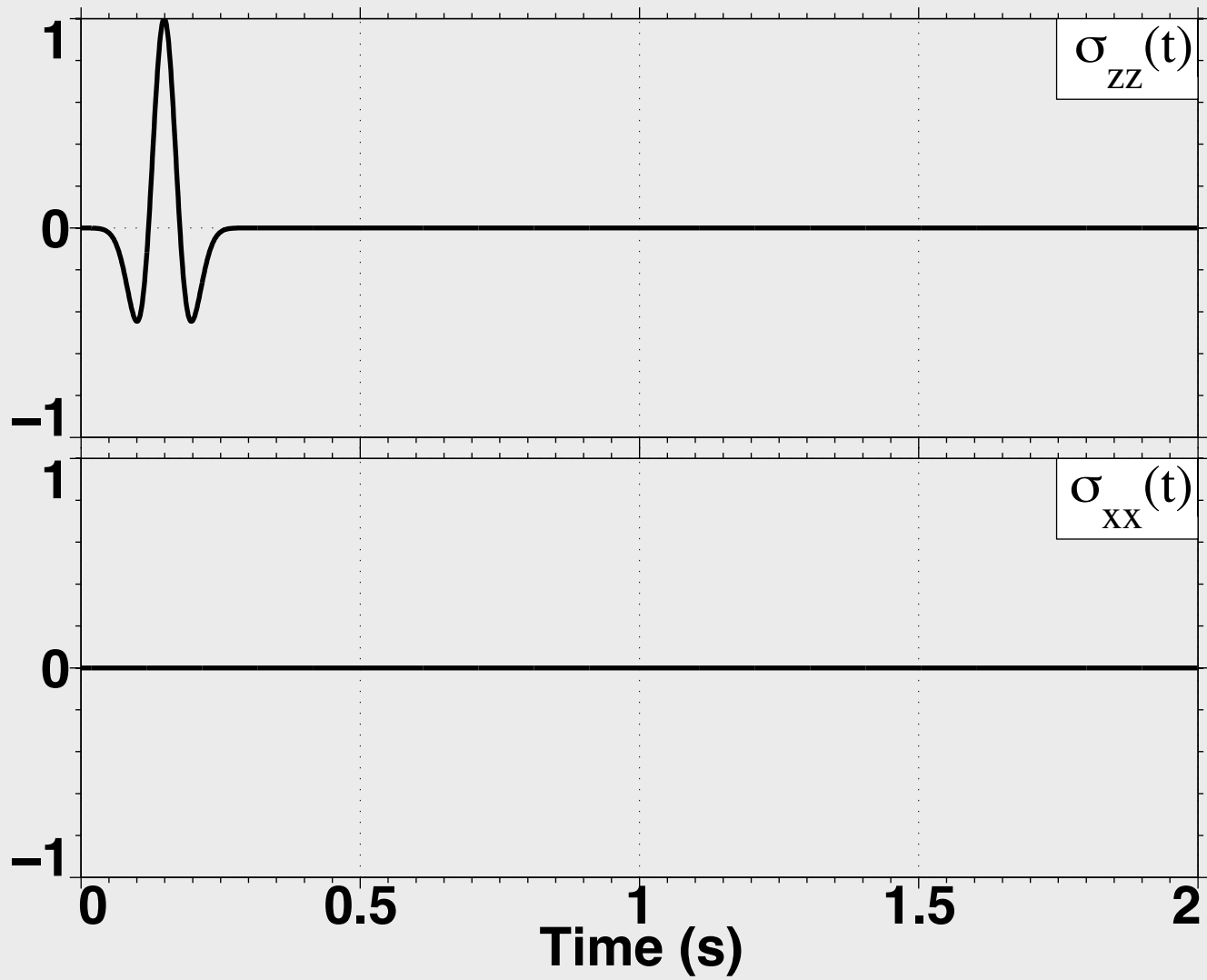




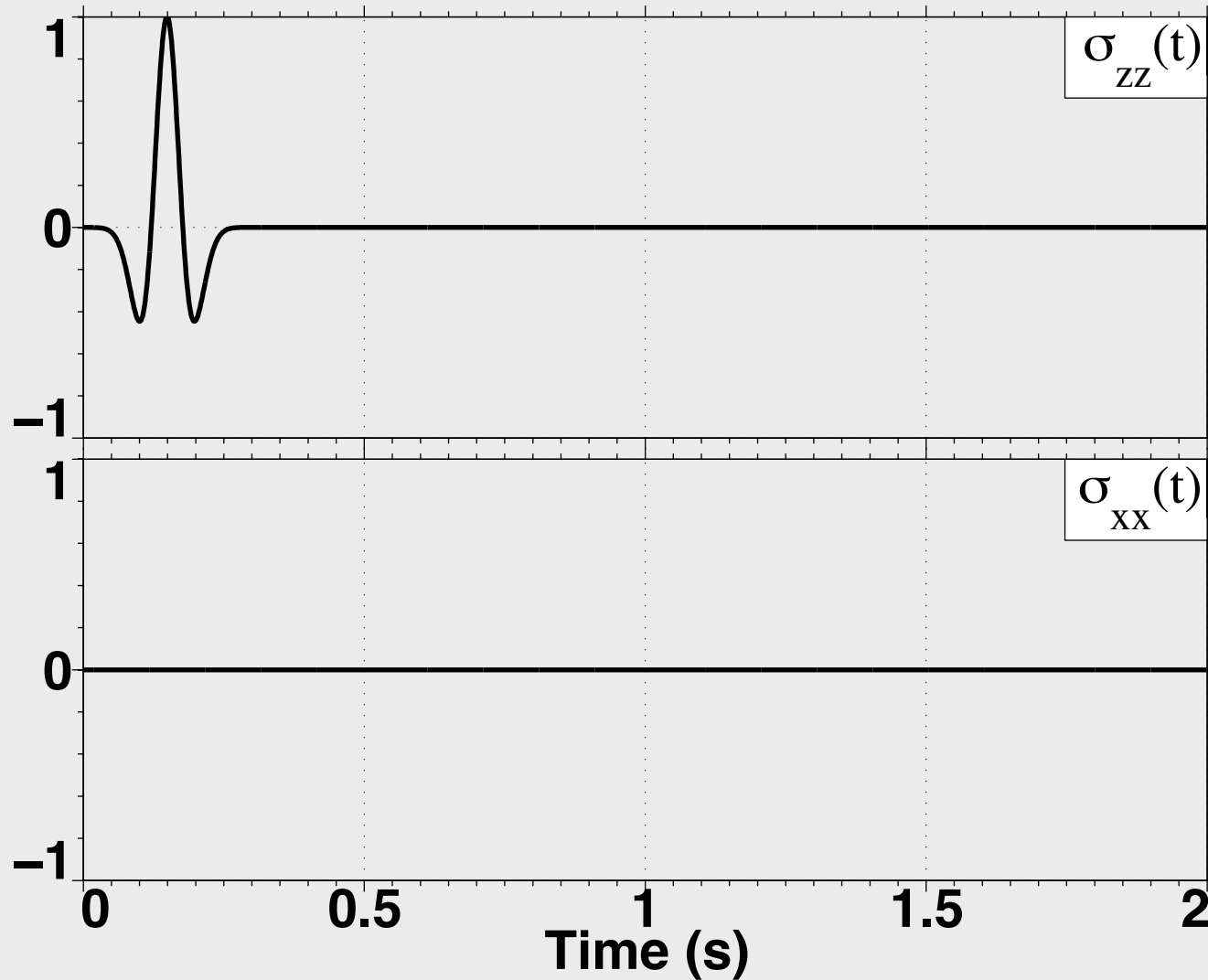


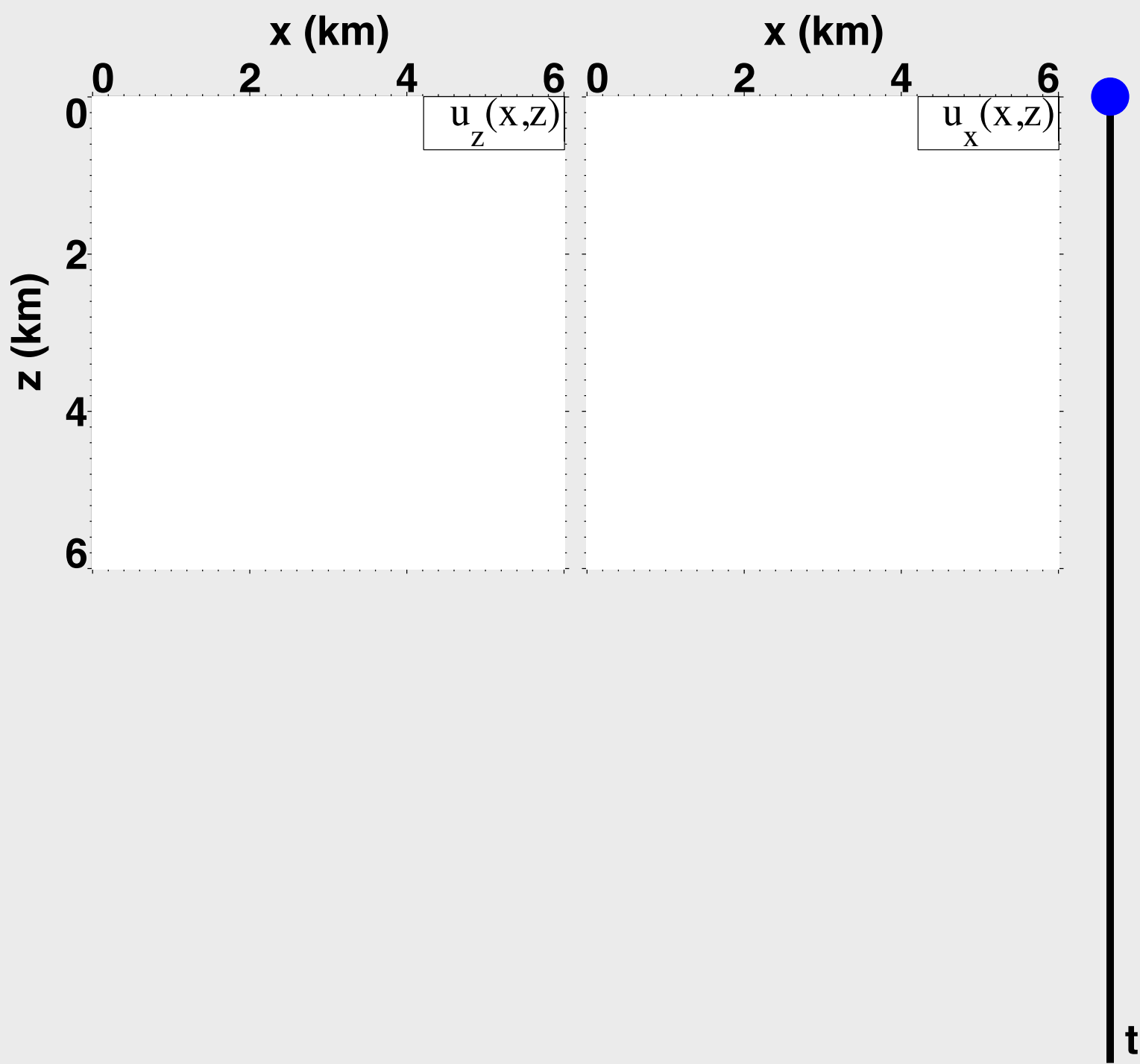


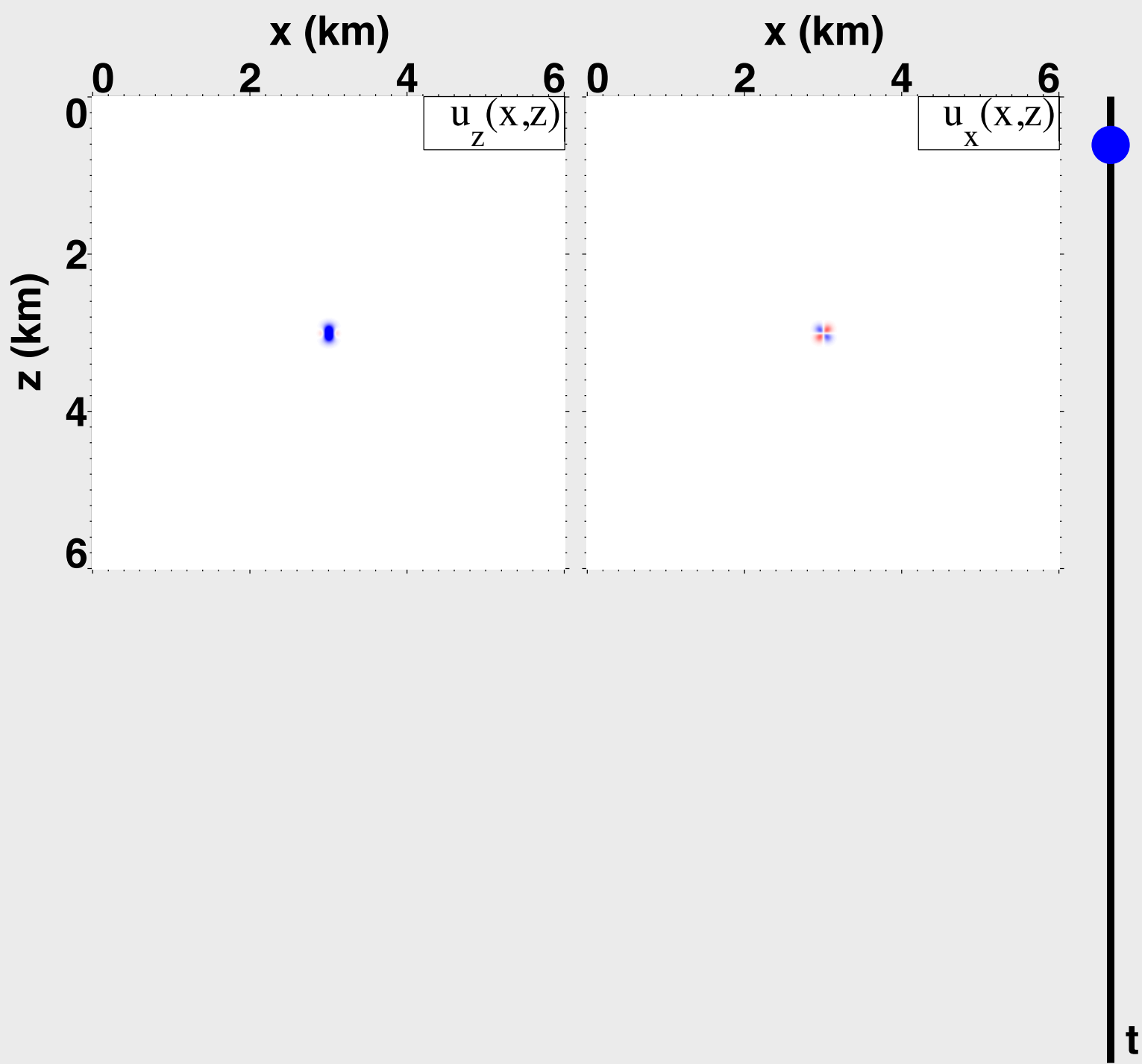
Another source

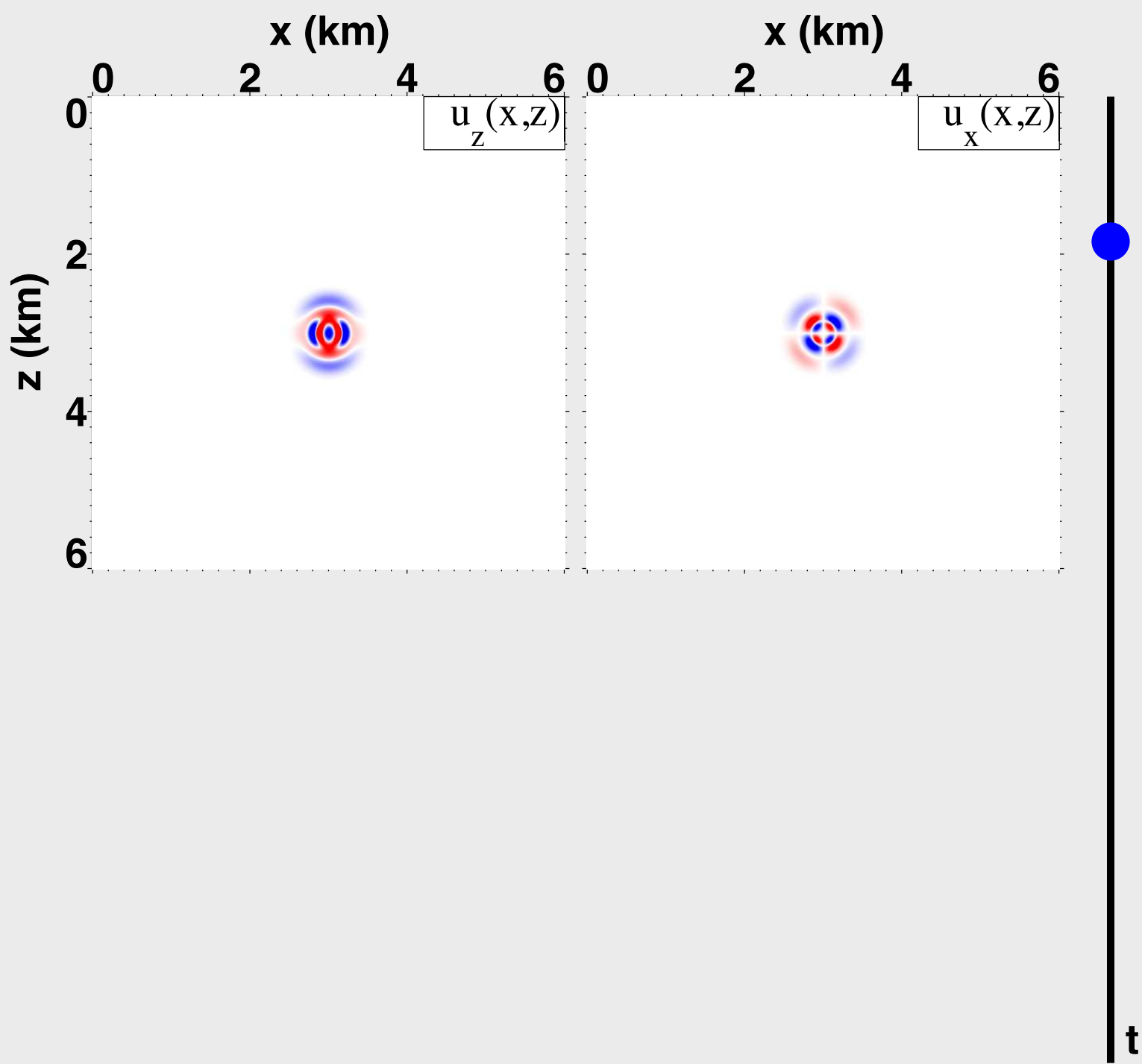


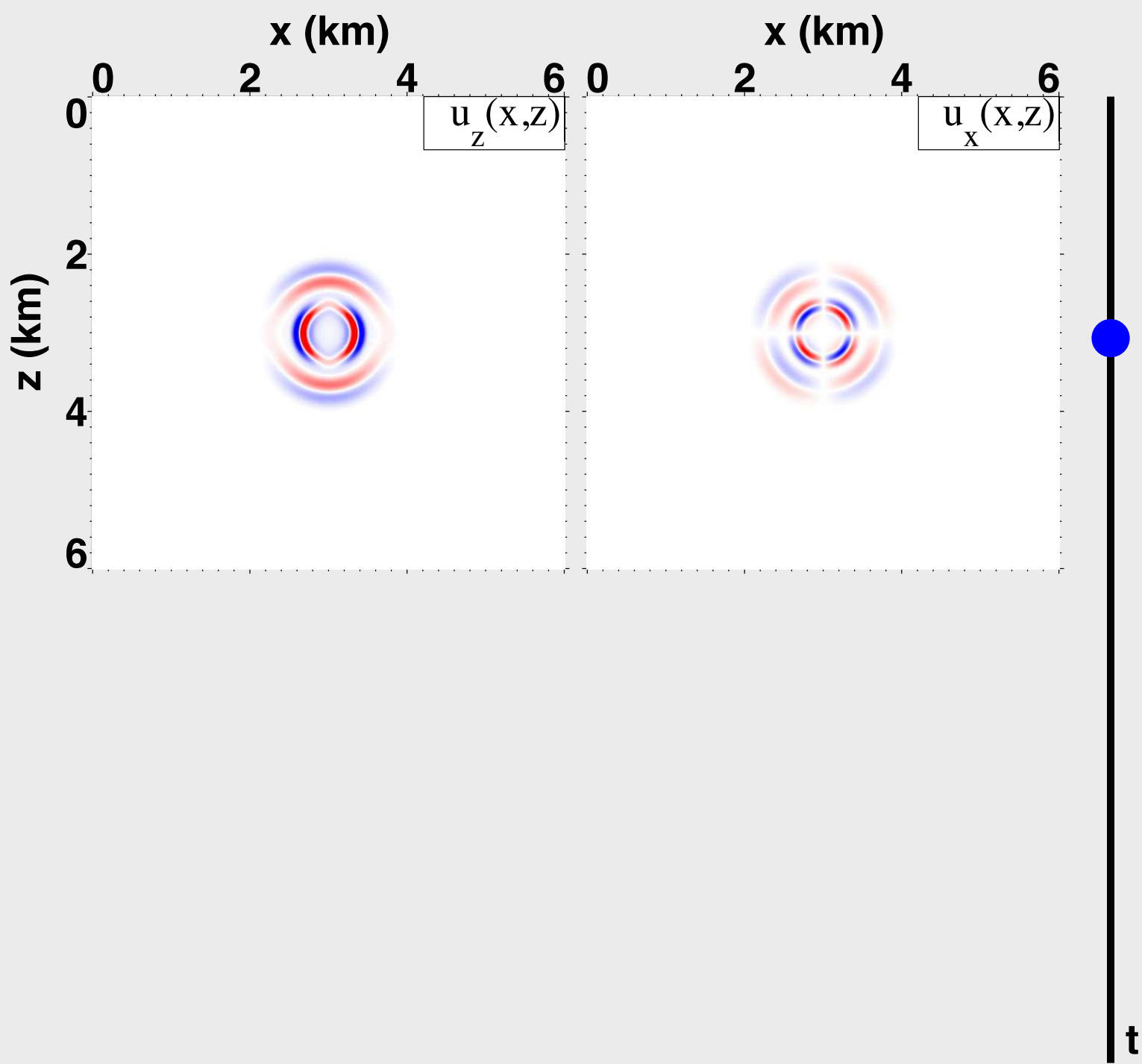
Directional source

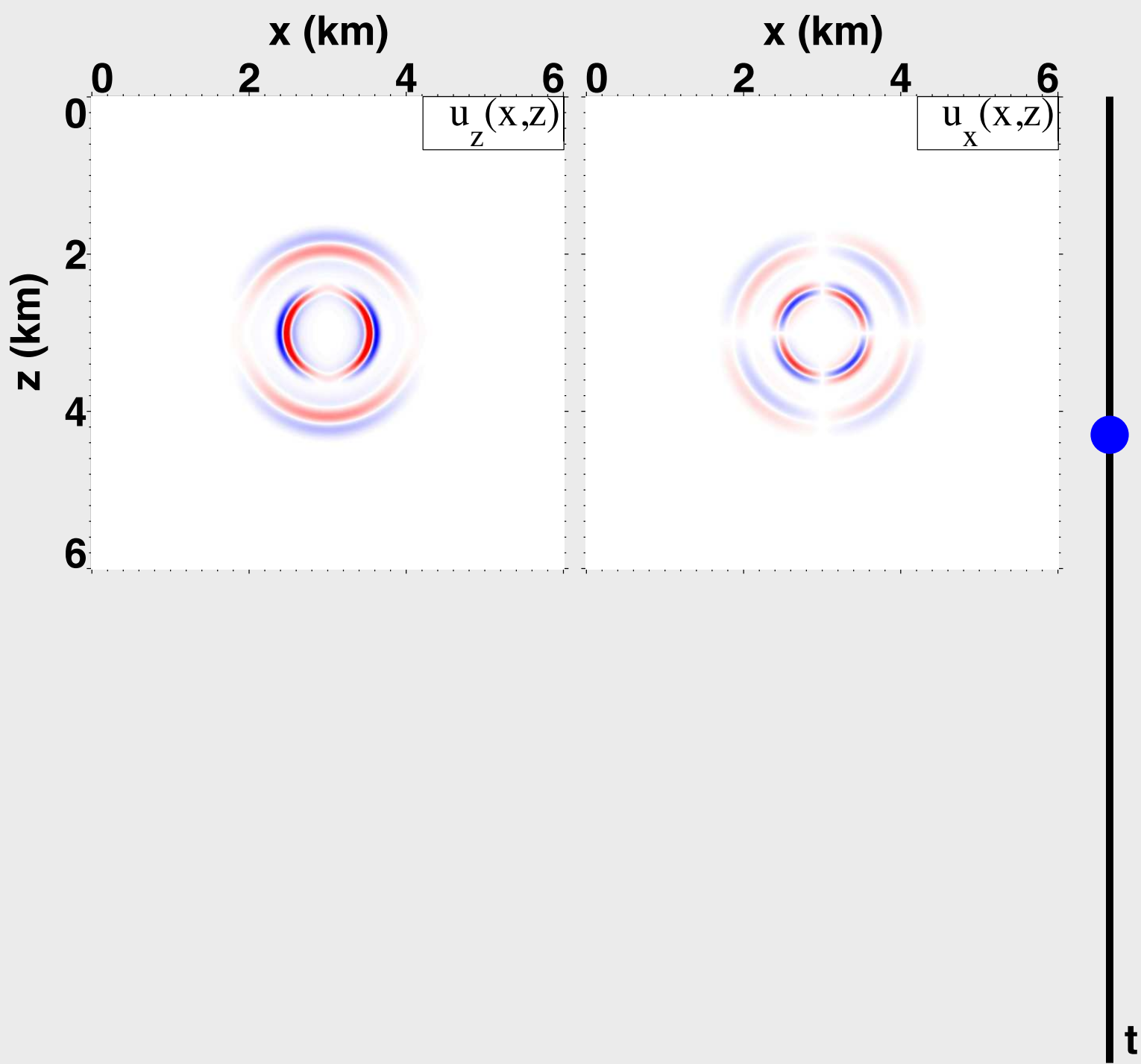


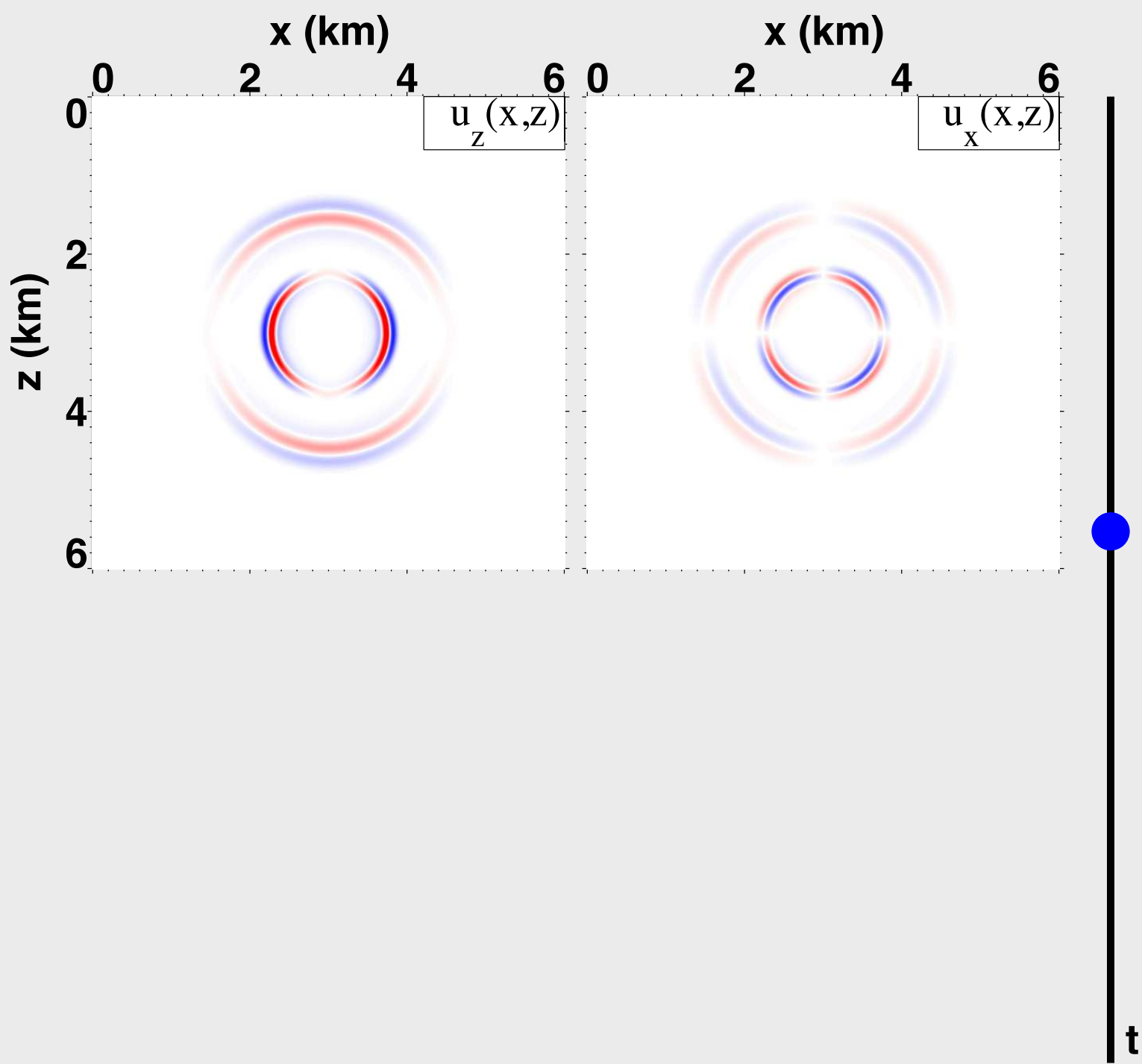


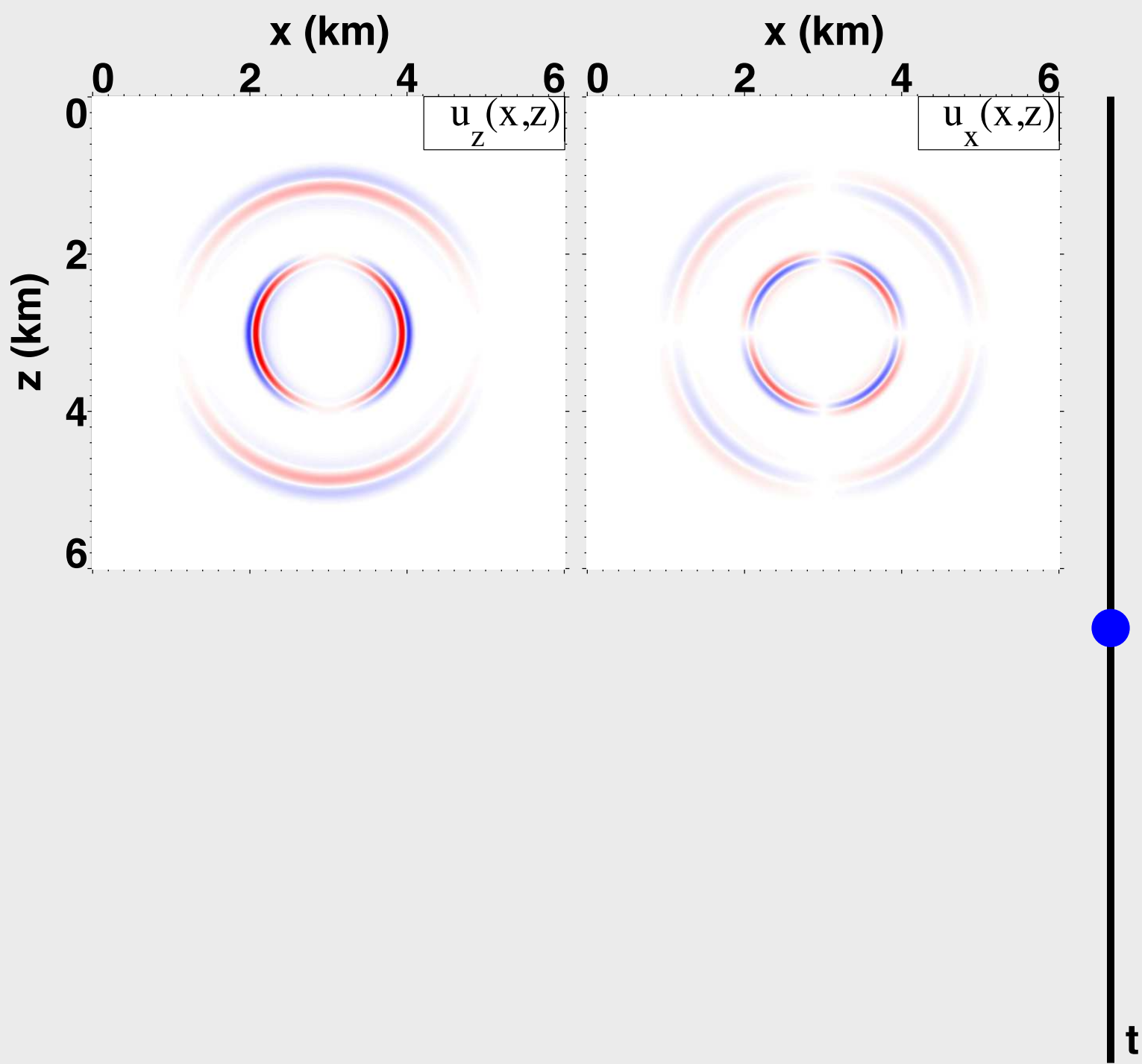


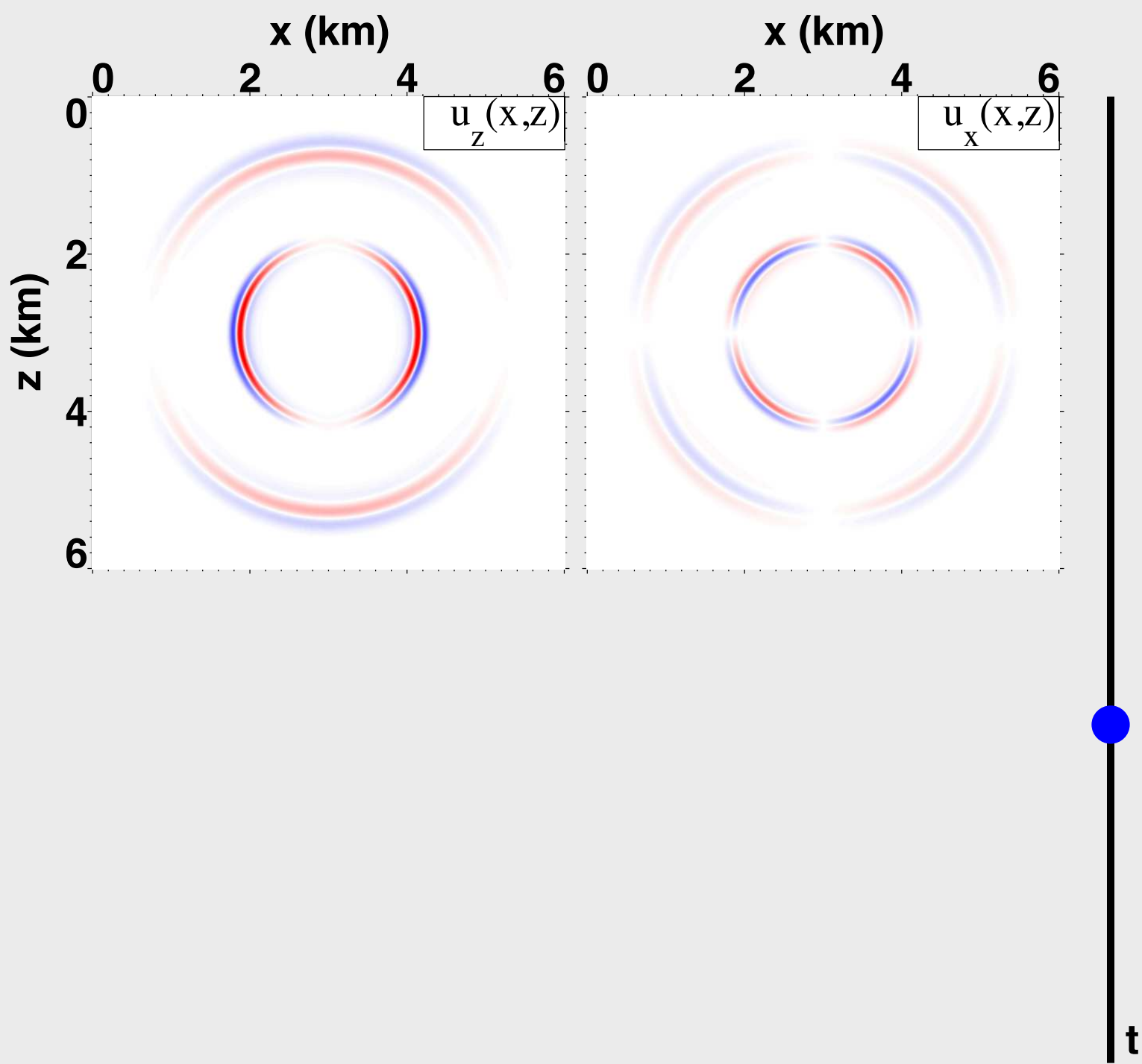


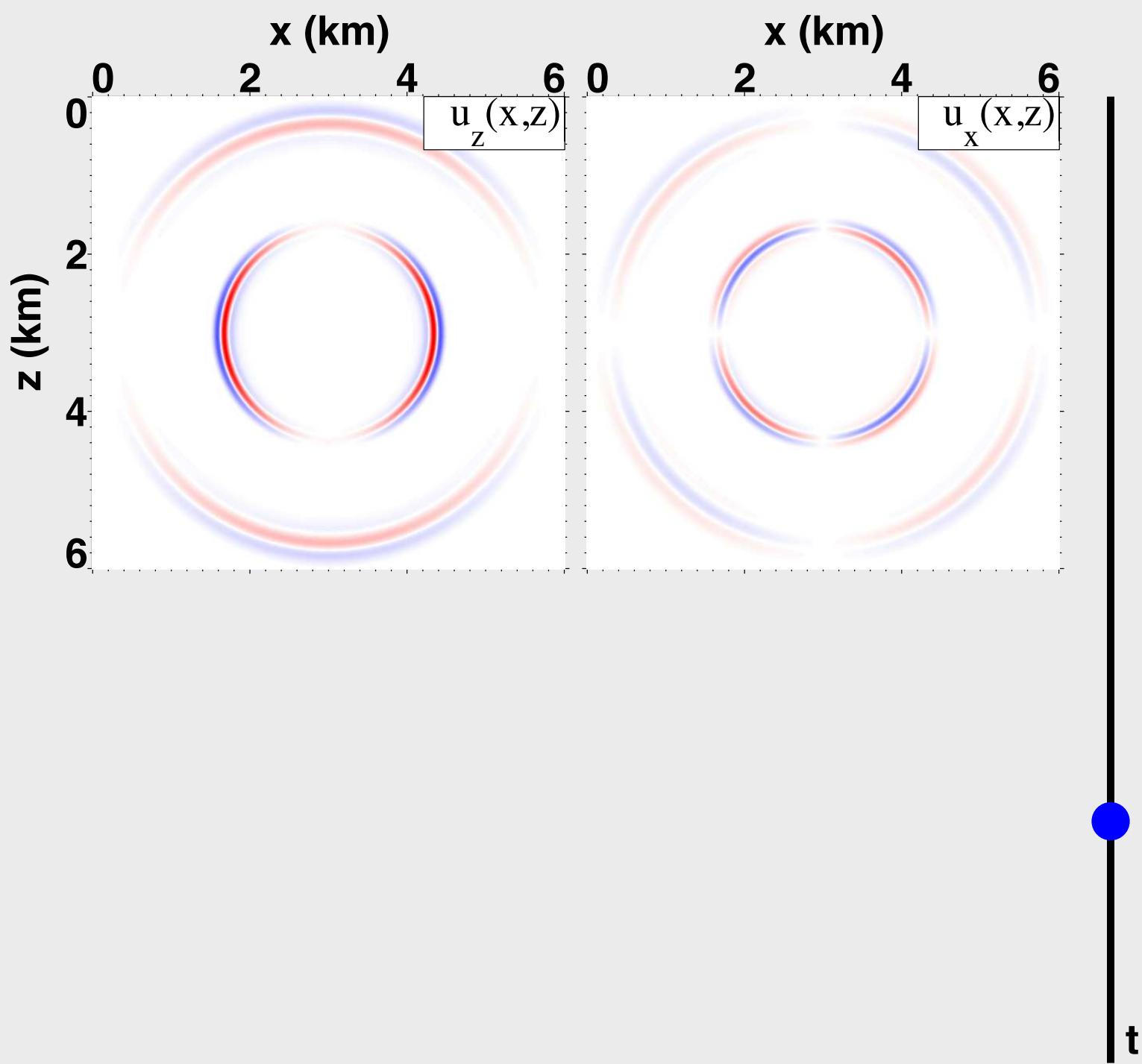


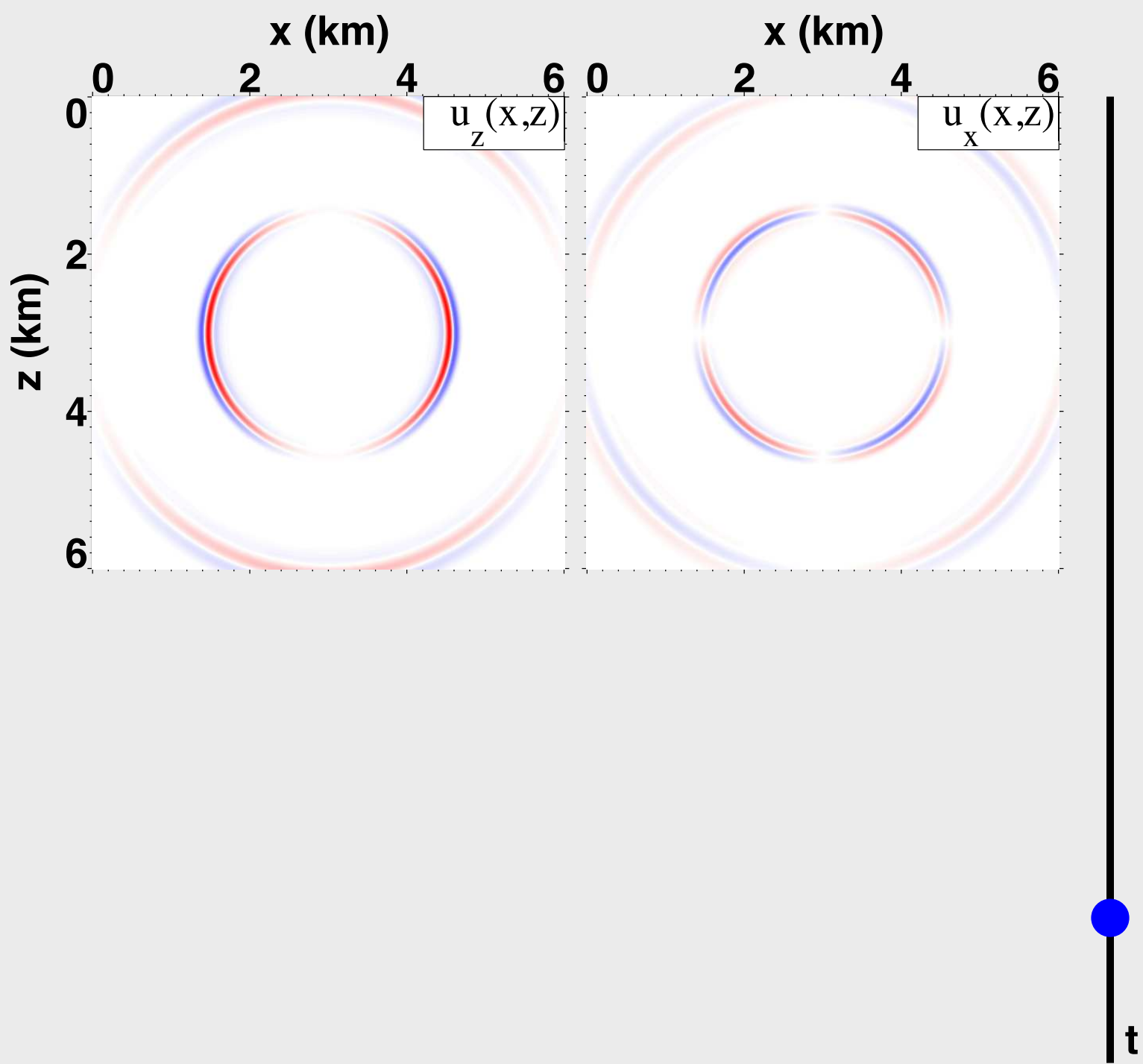


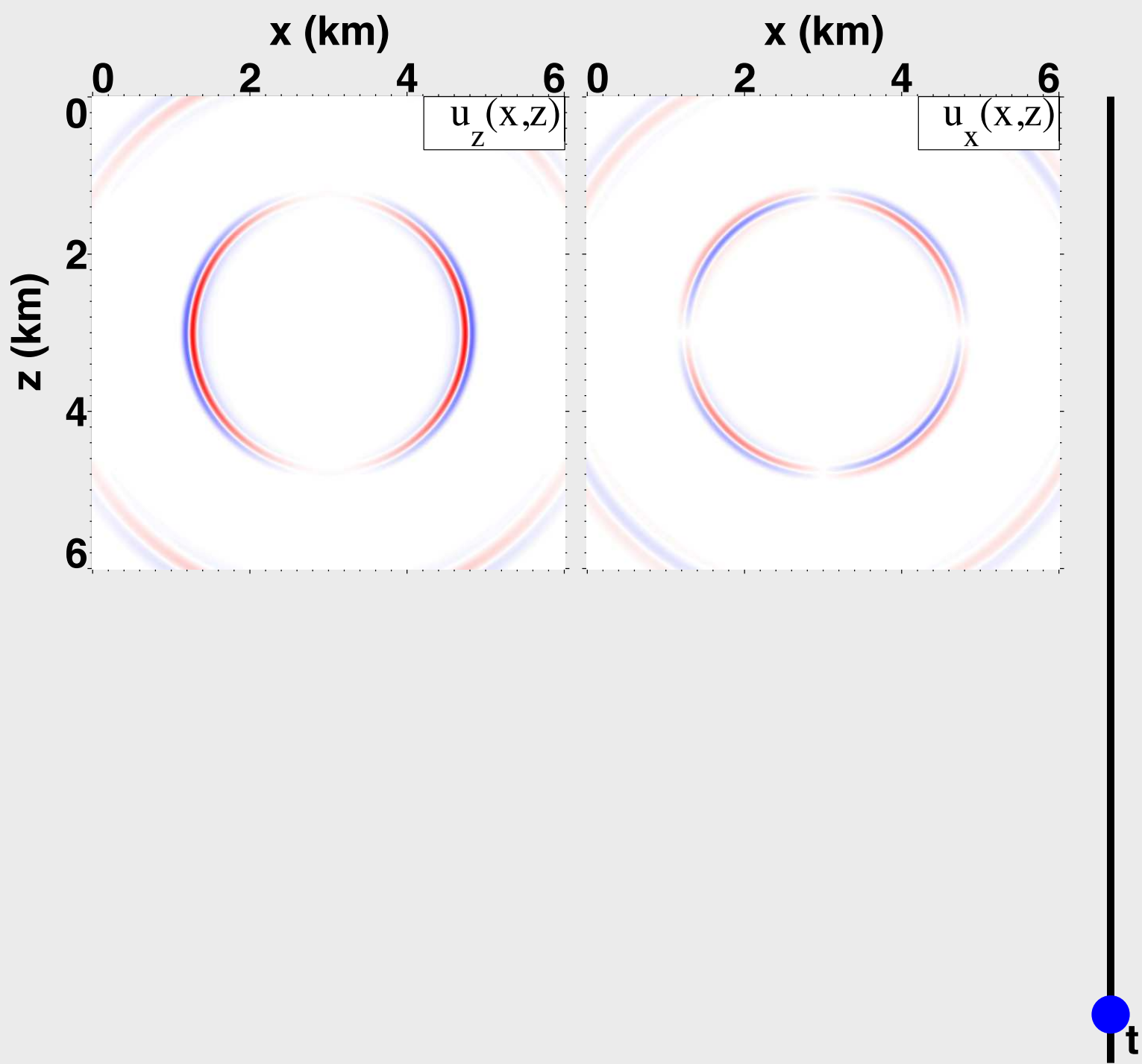




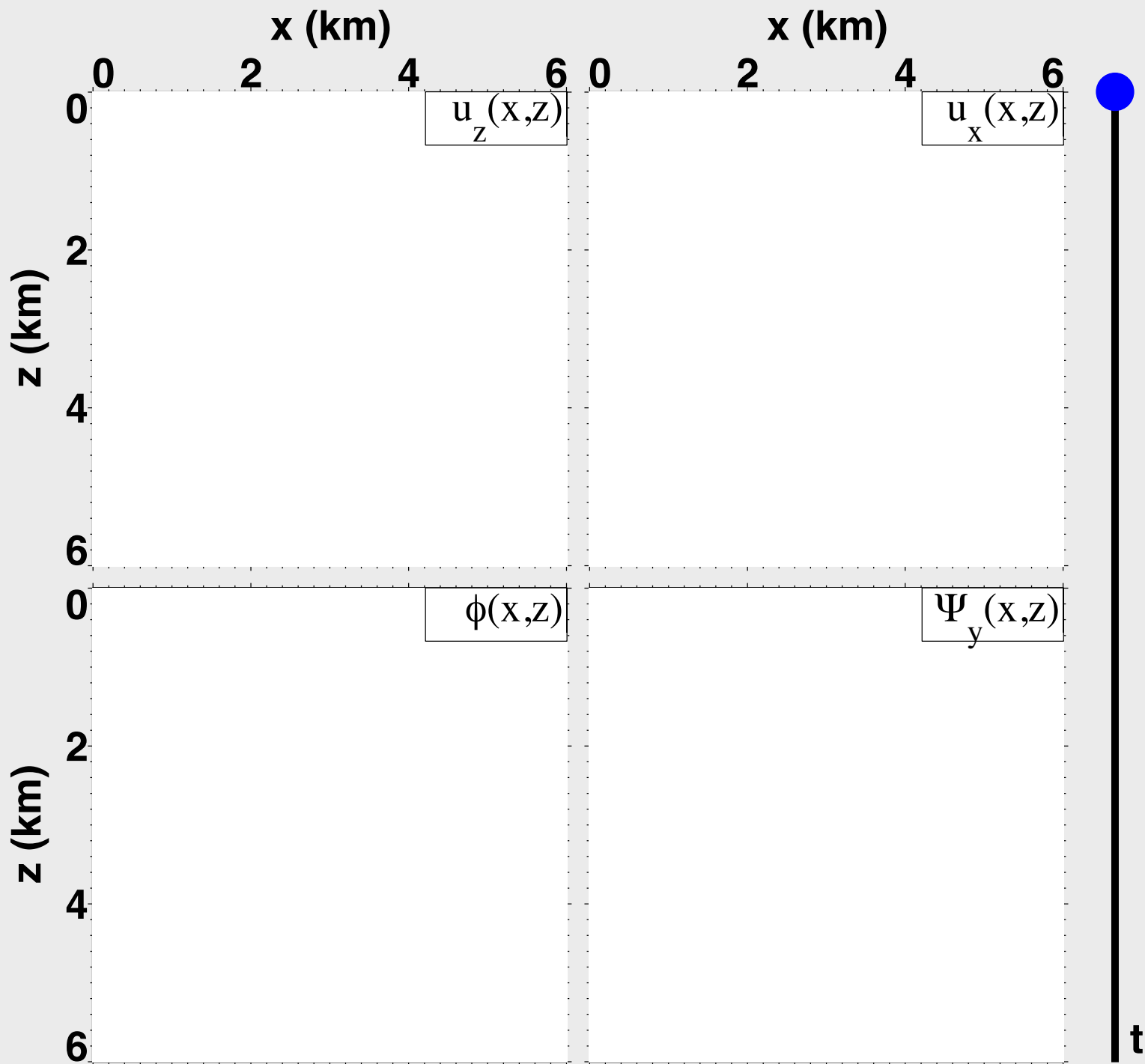


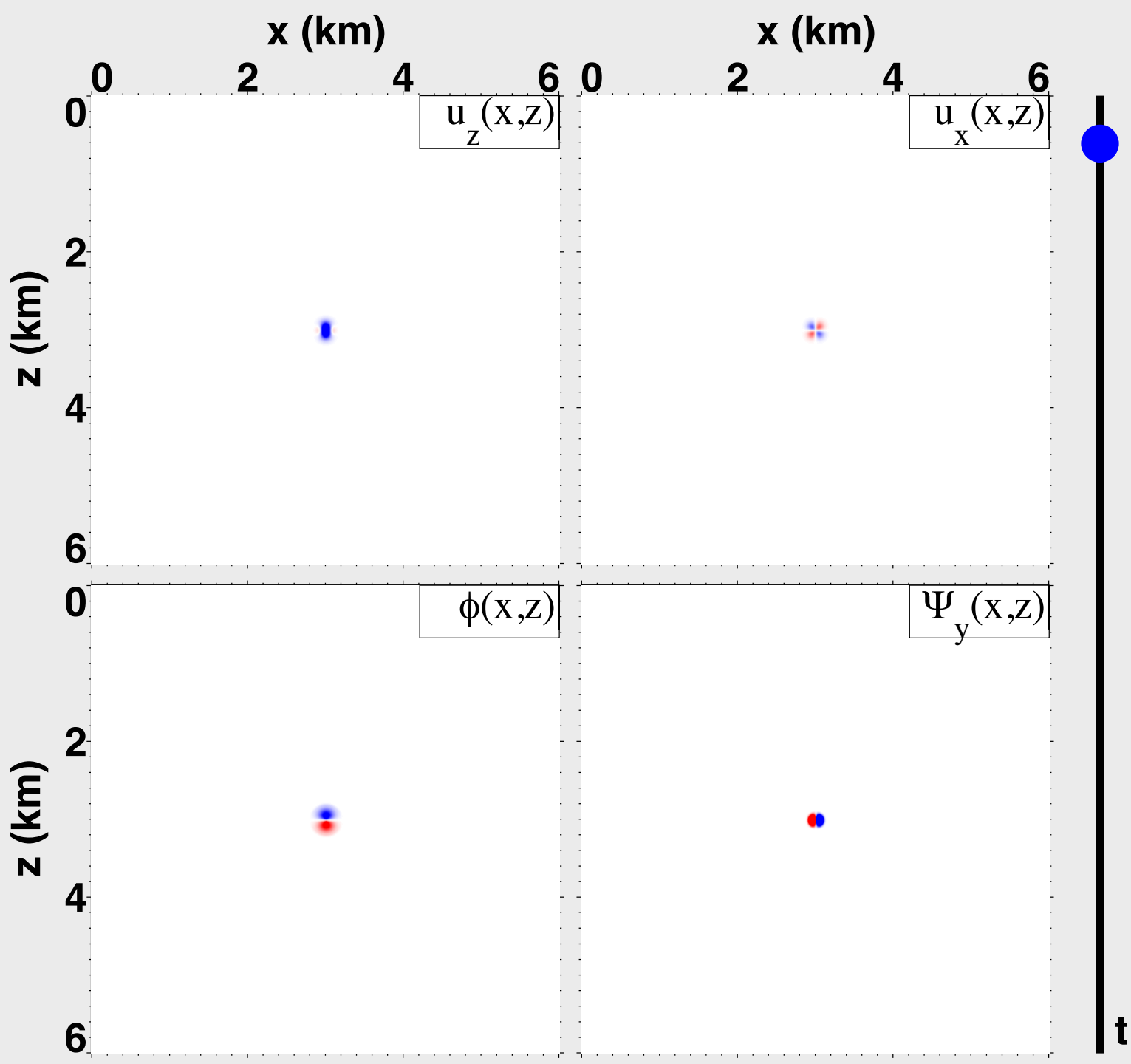


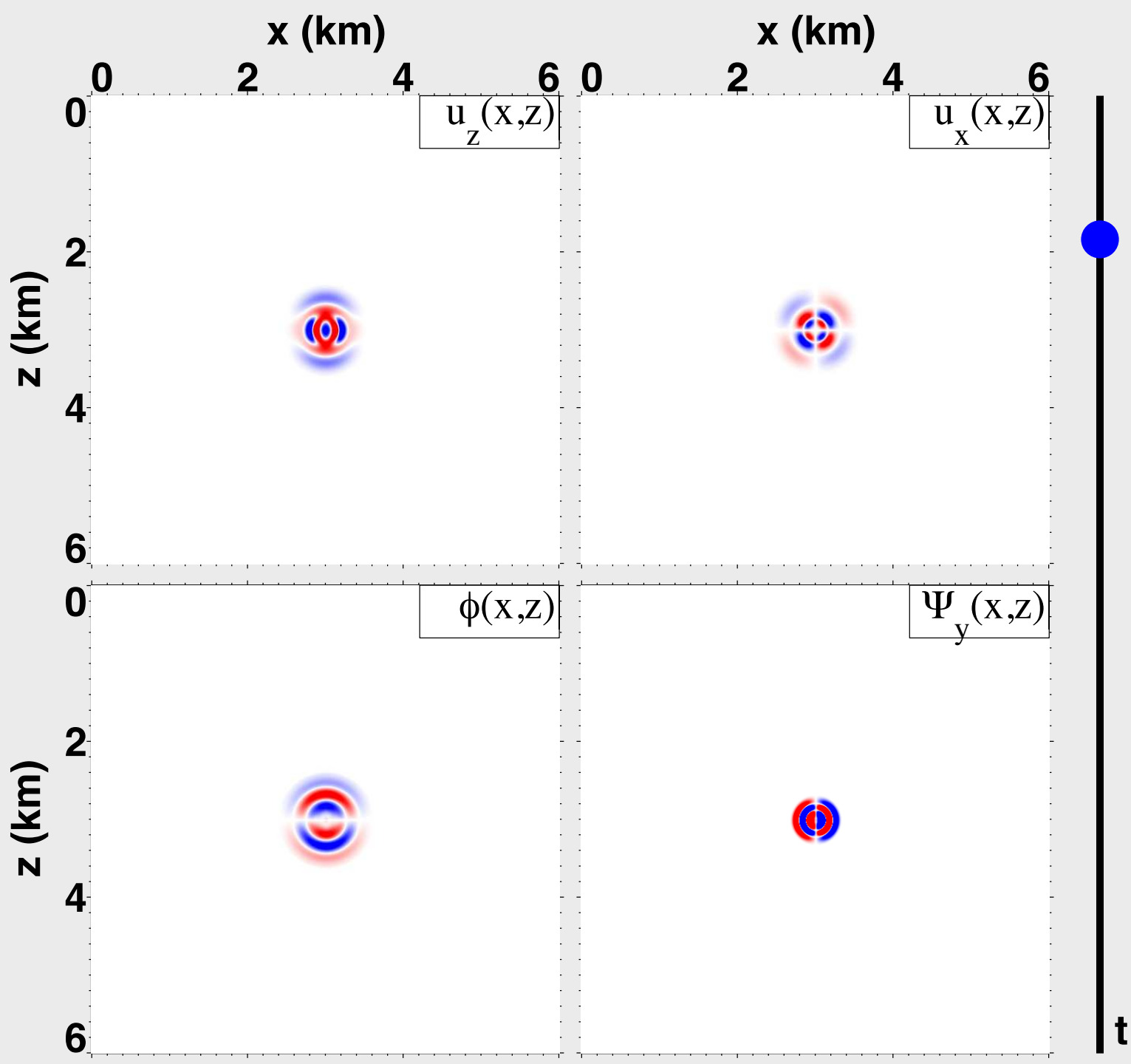


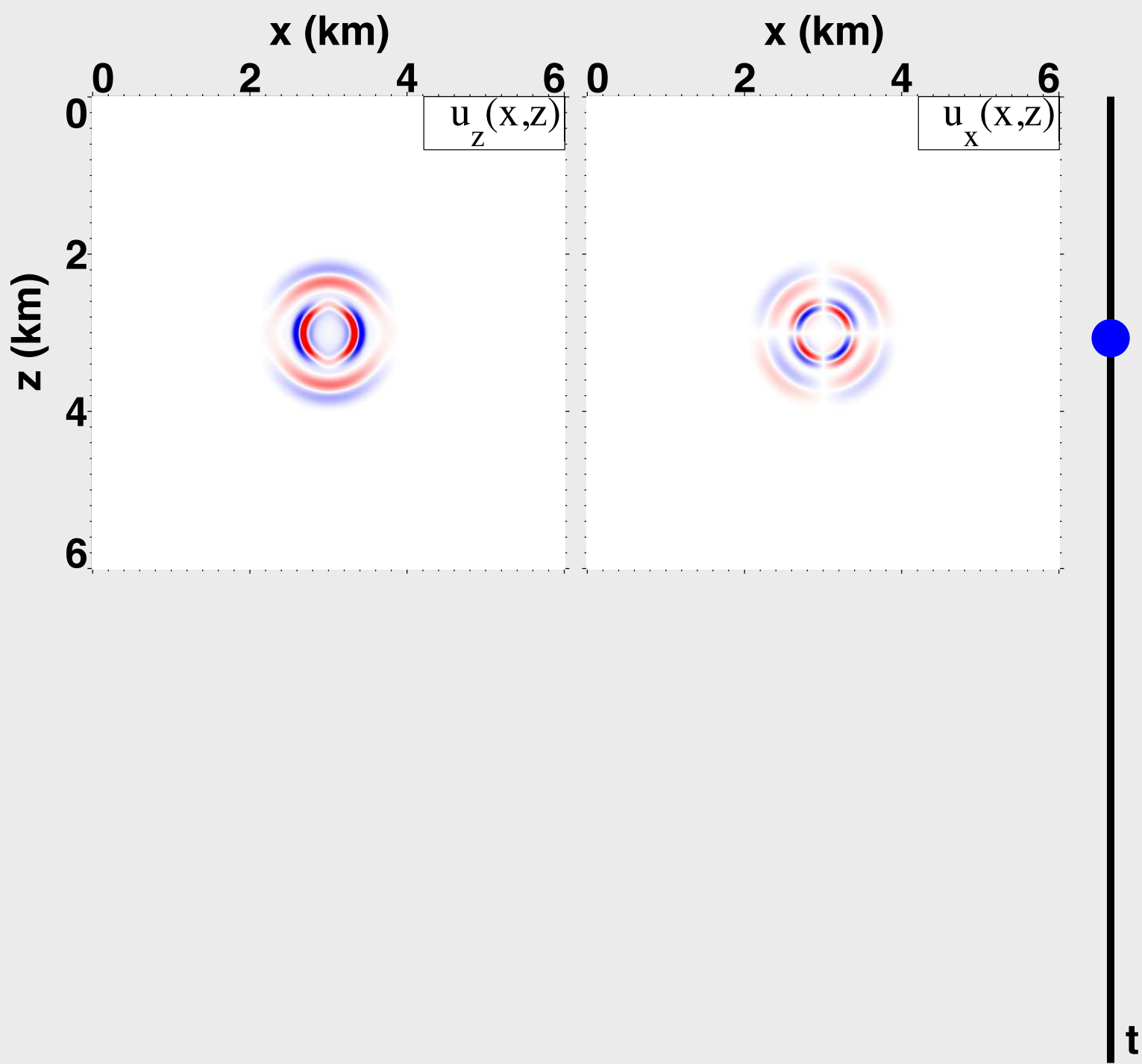


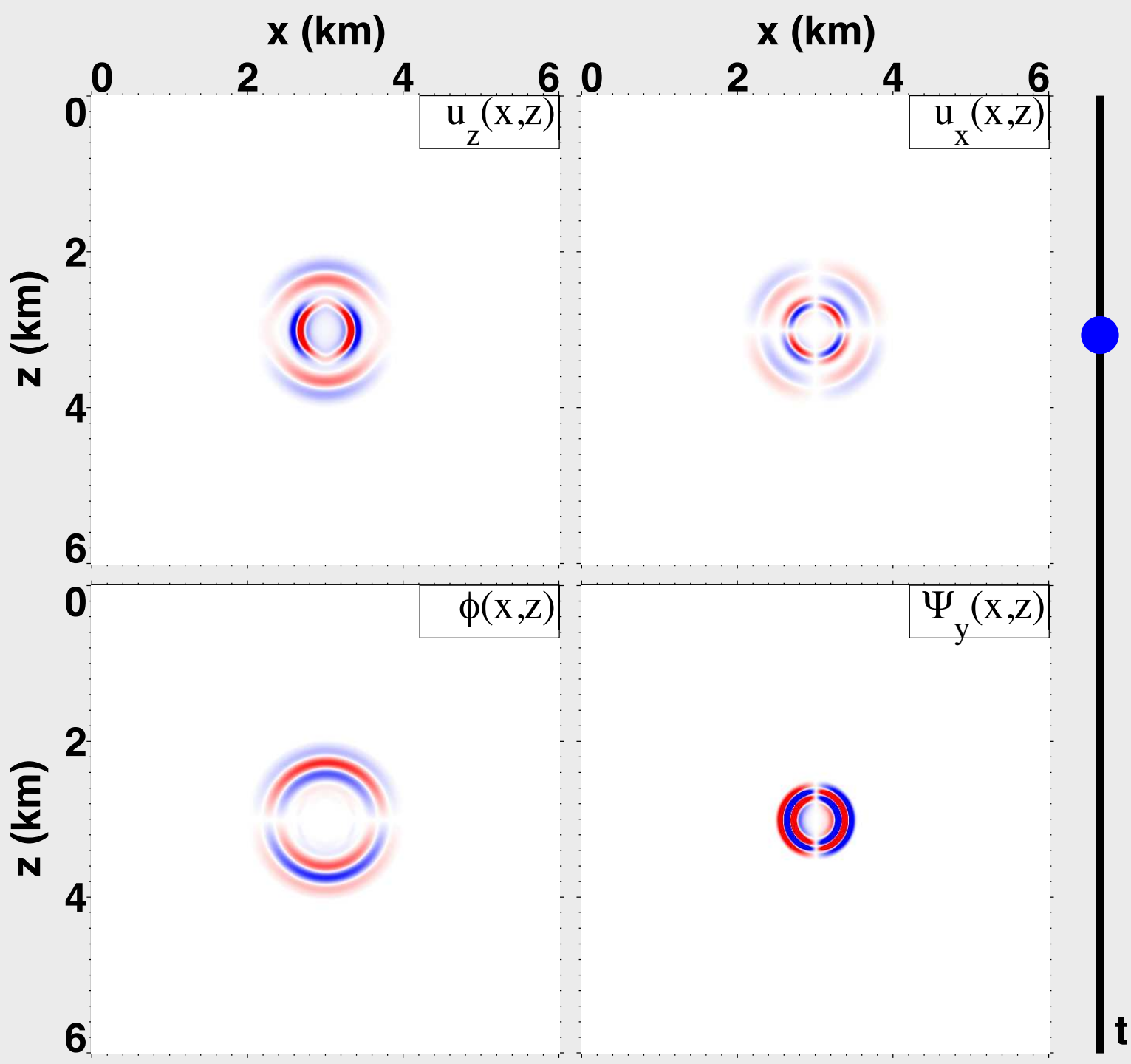
Potentials

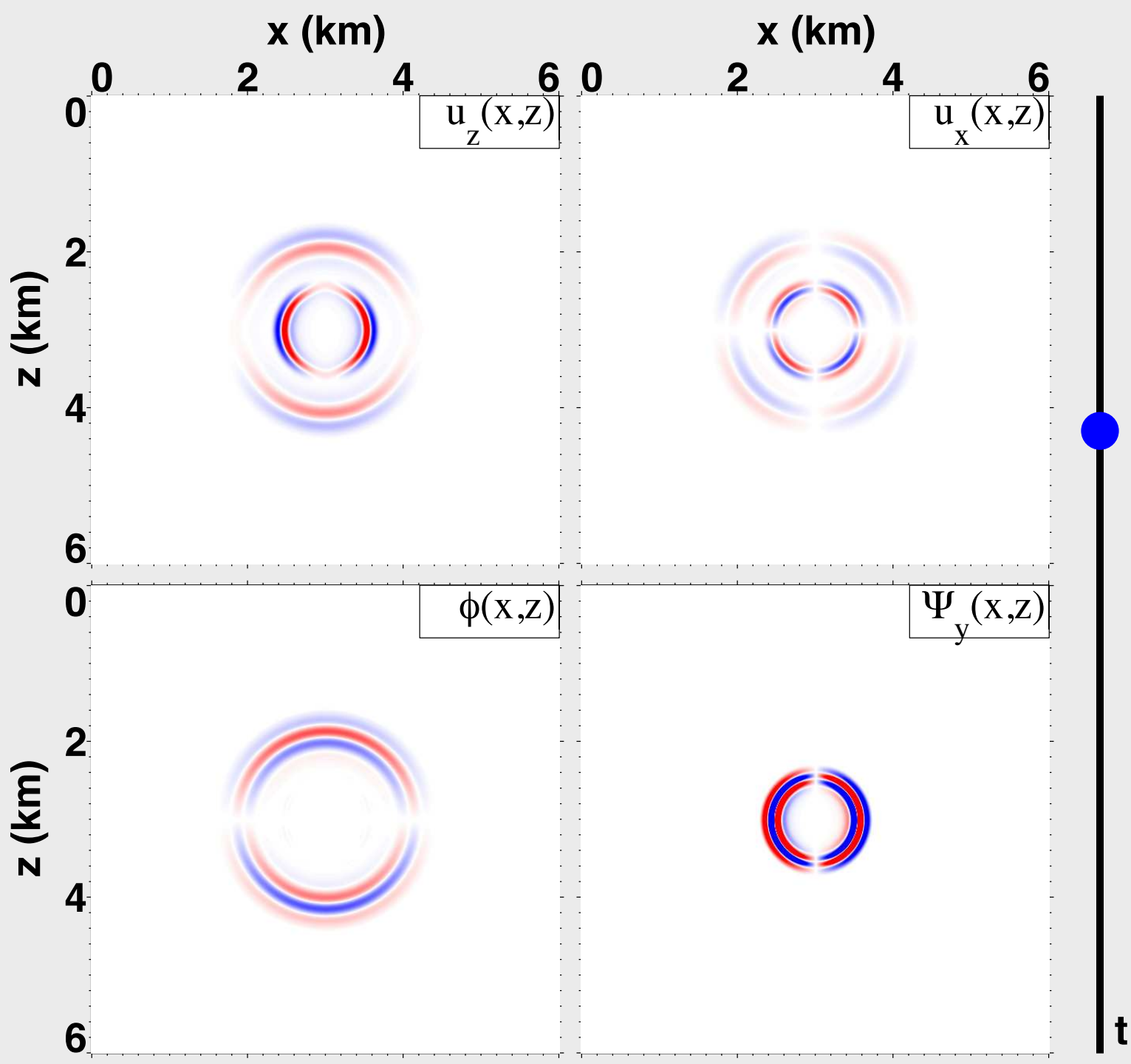


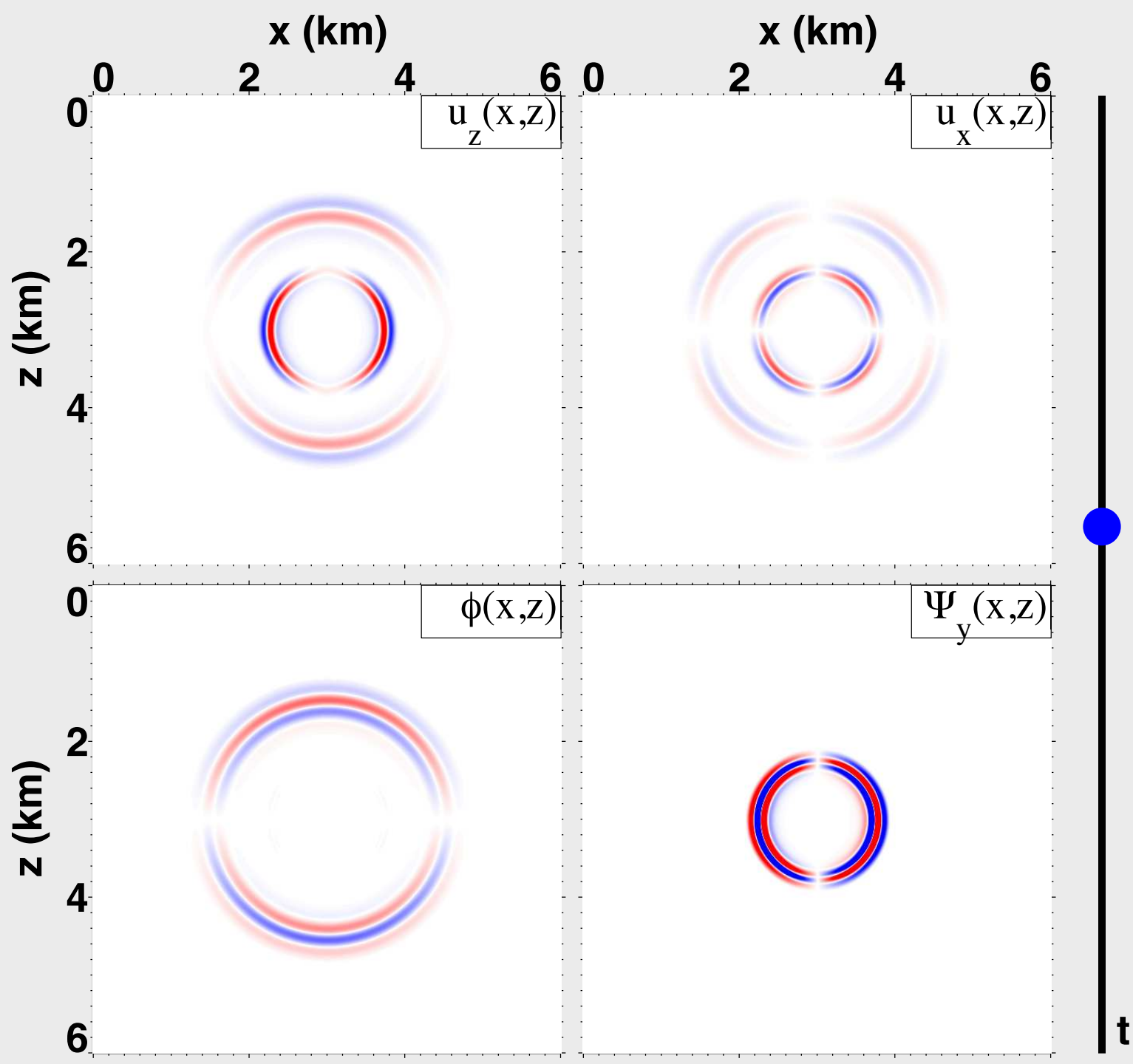


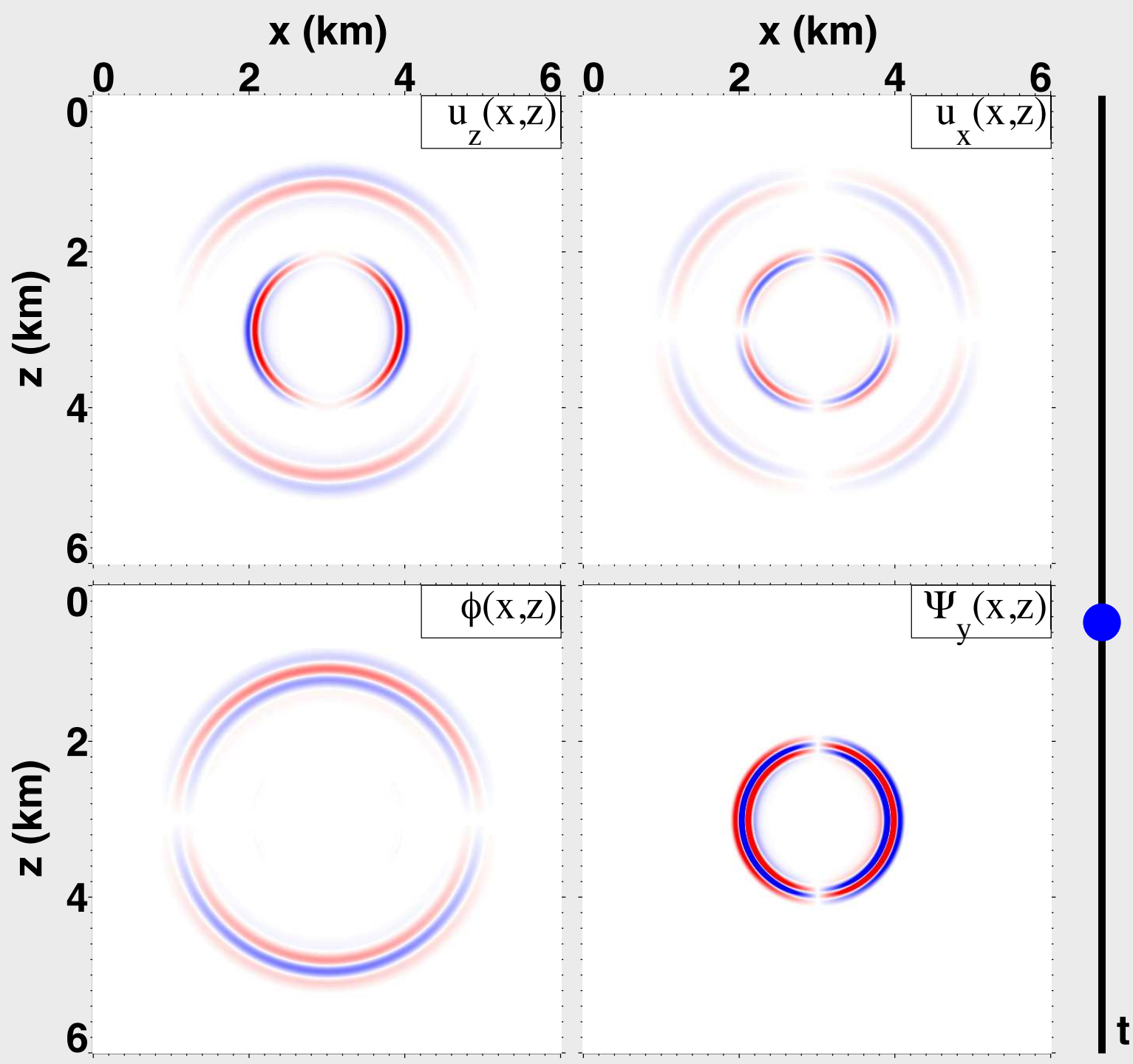


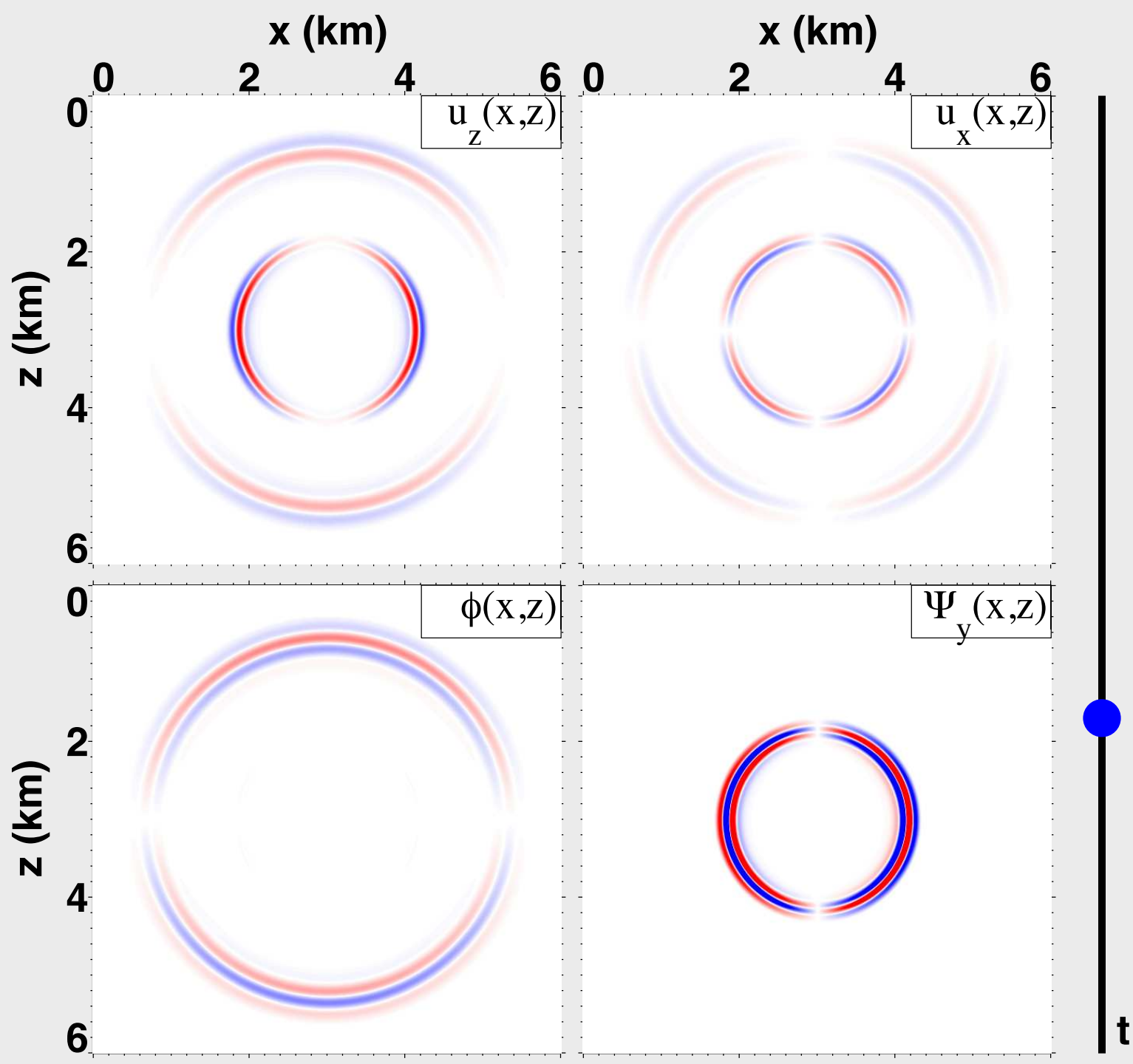


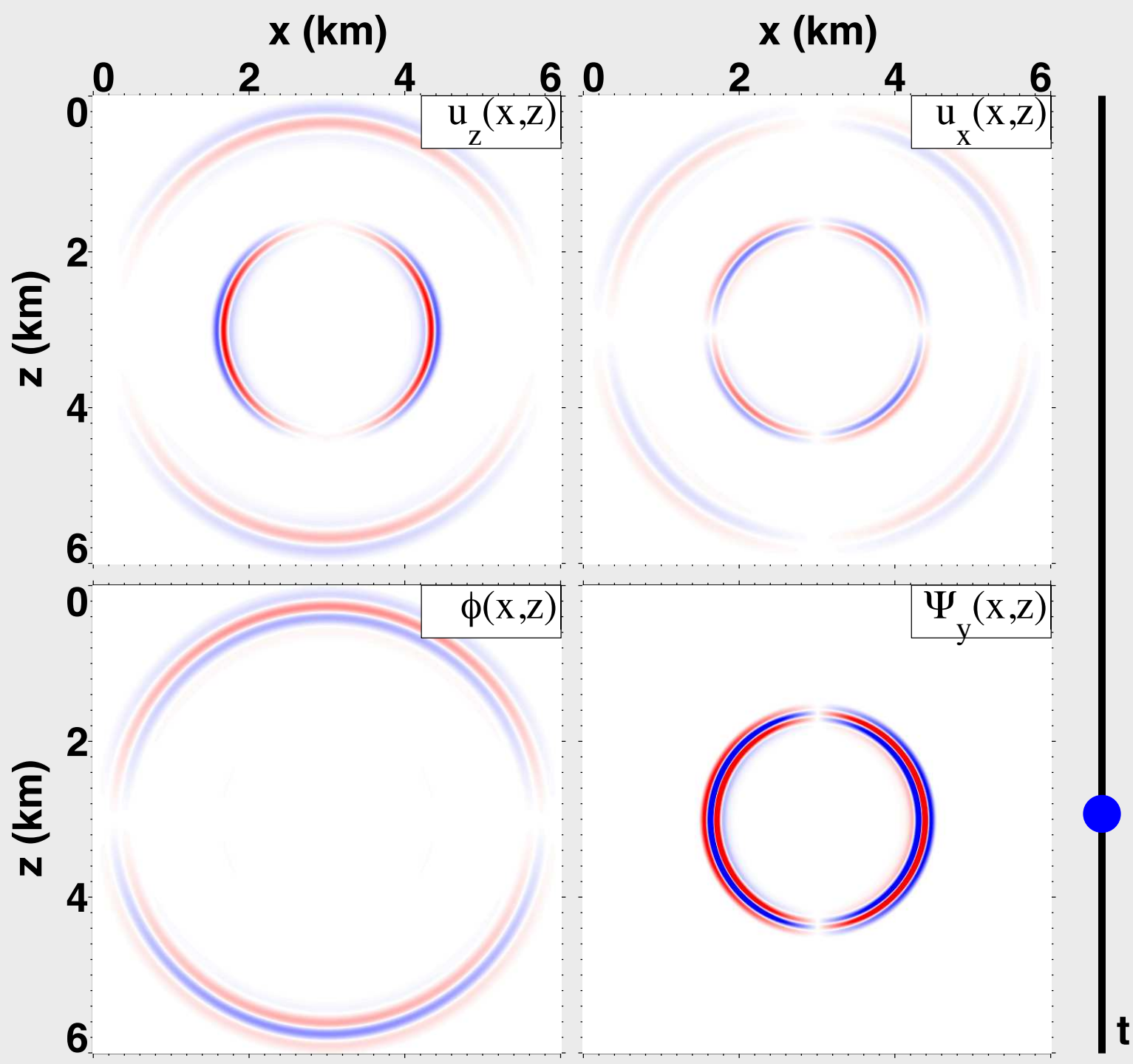


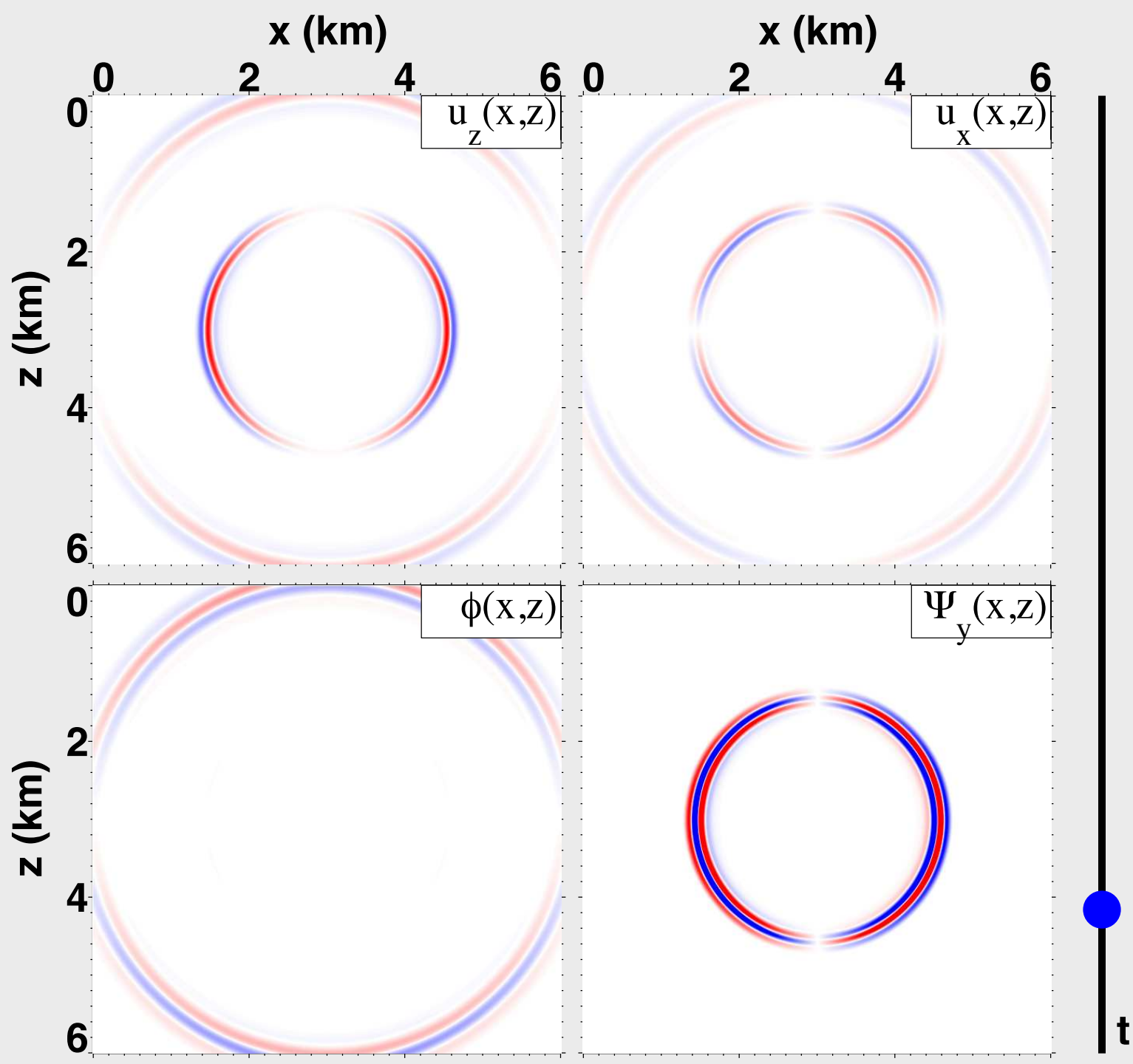


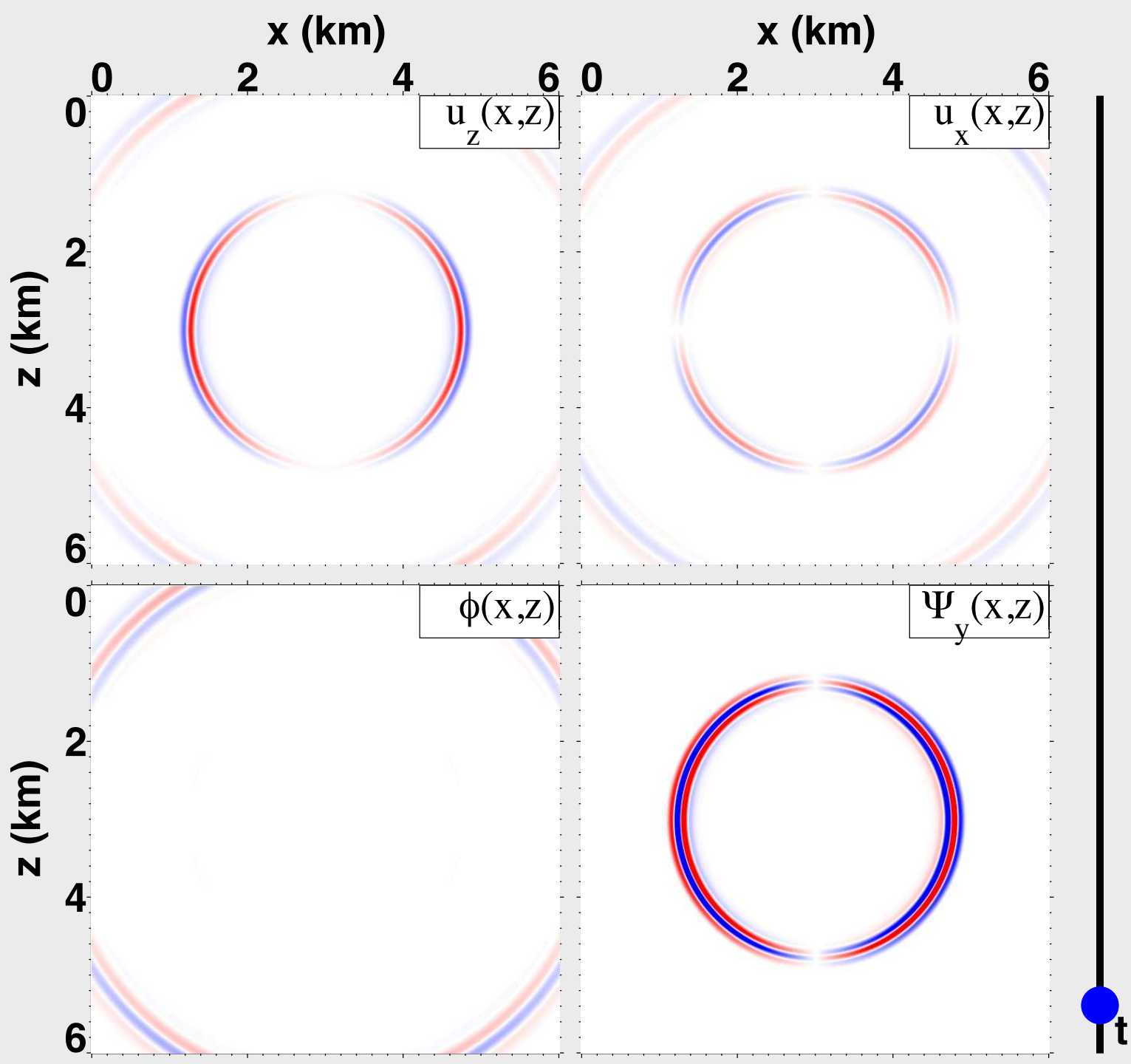






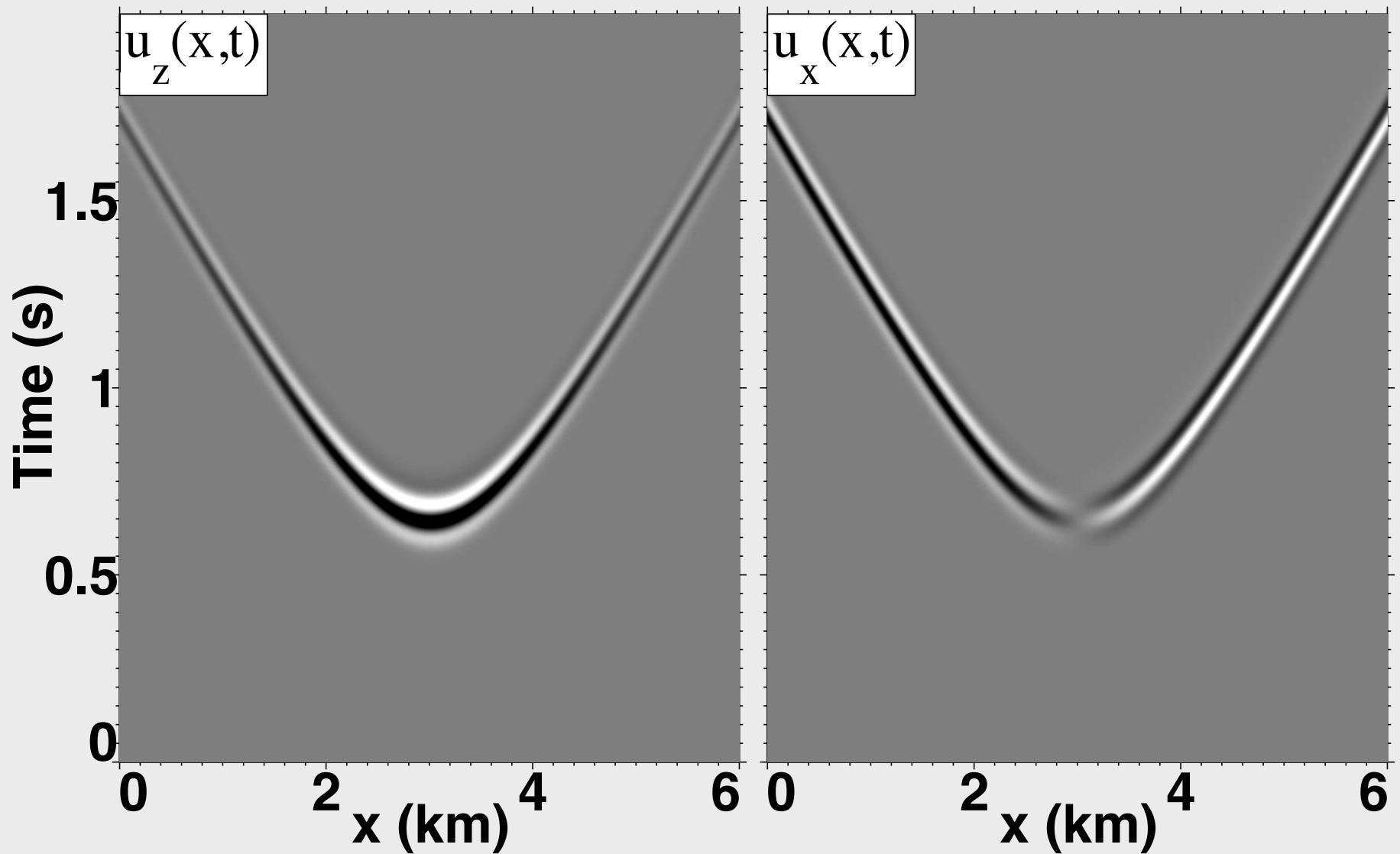




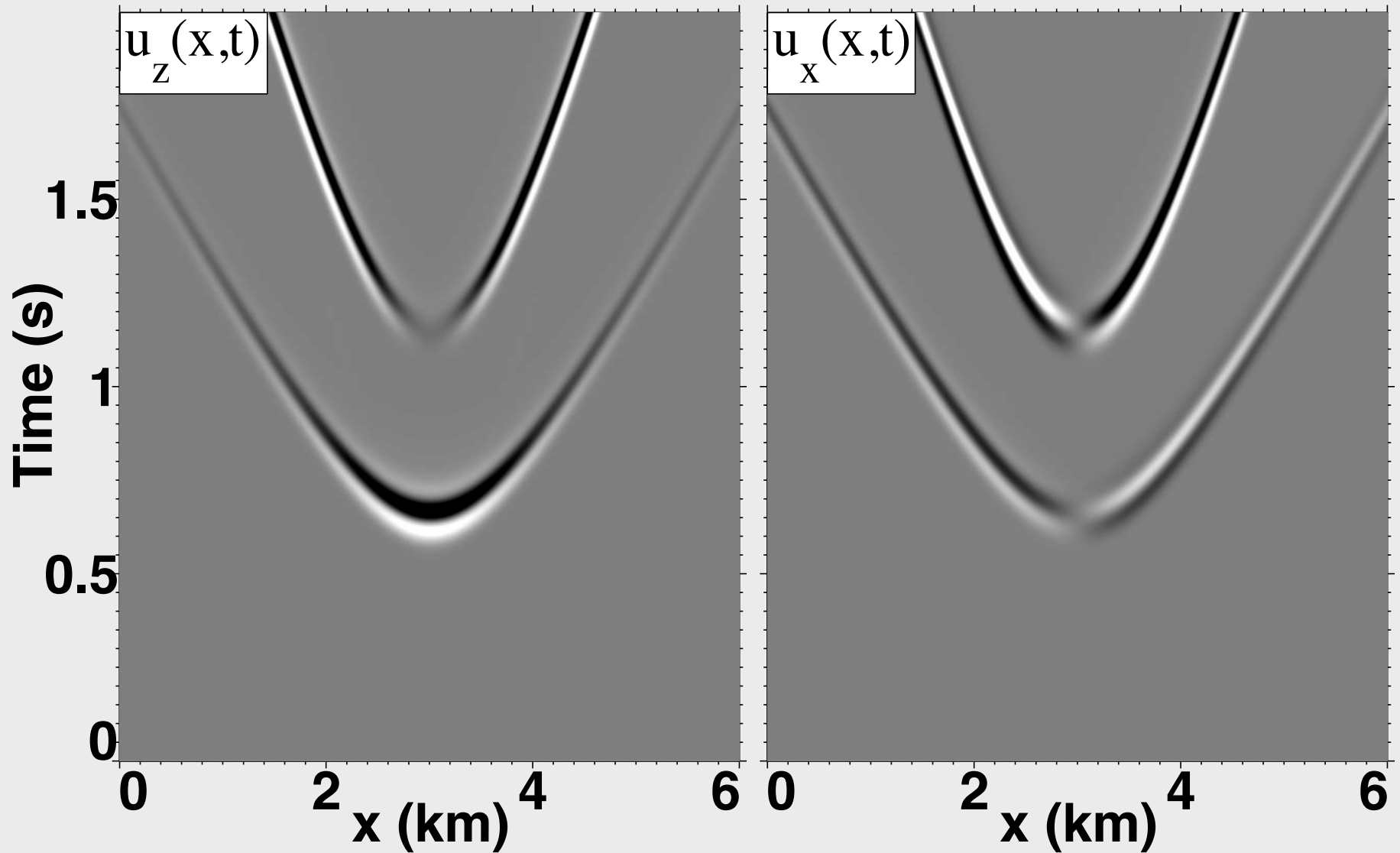


Observed data

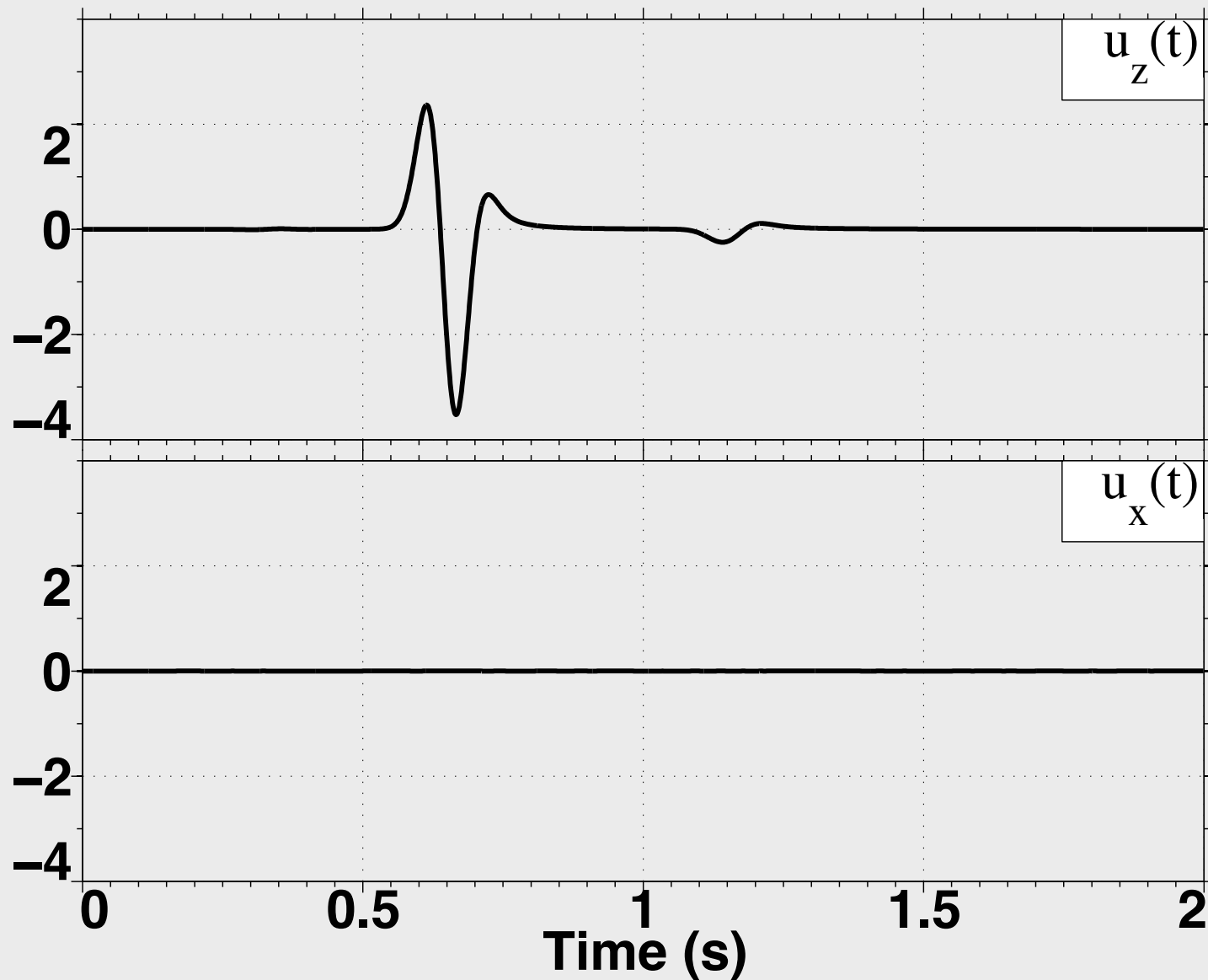
Explosive source



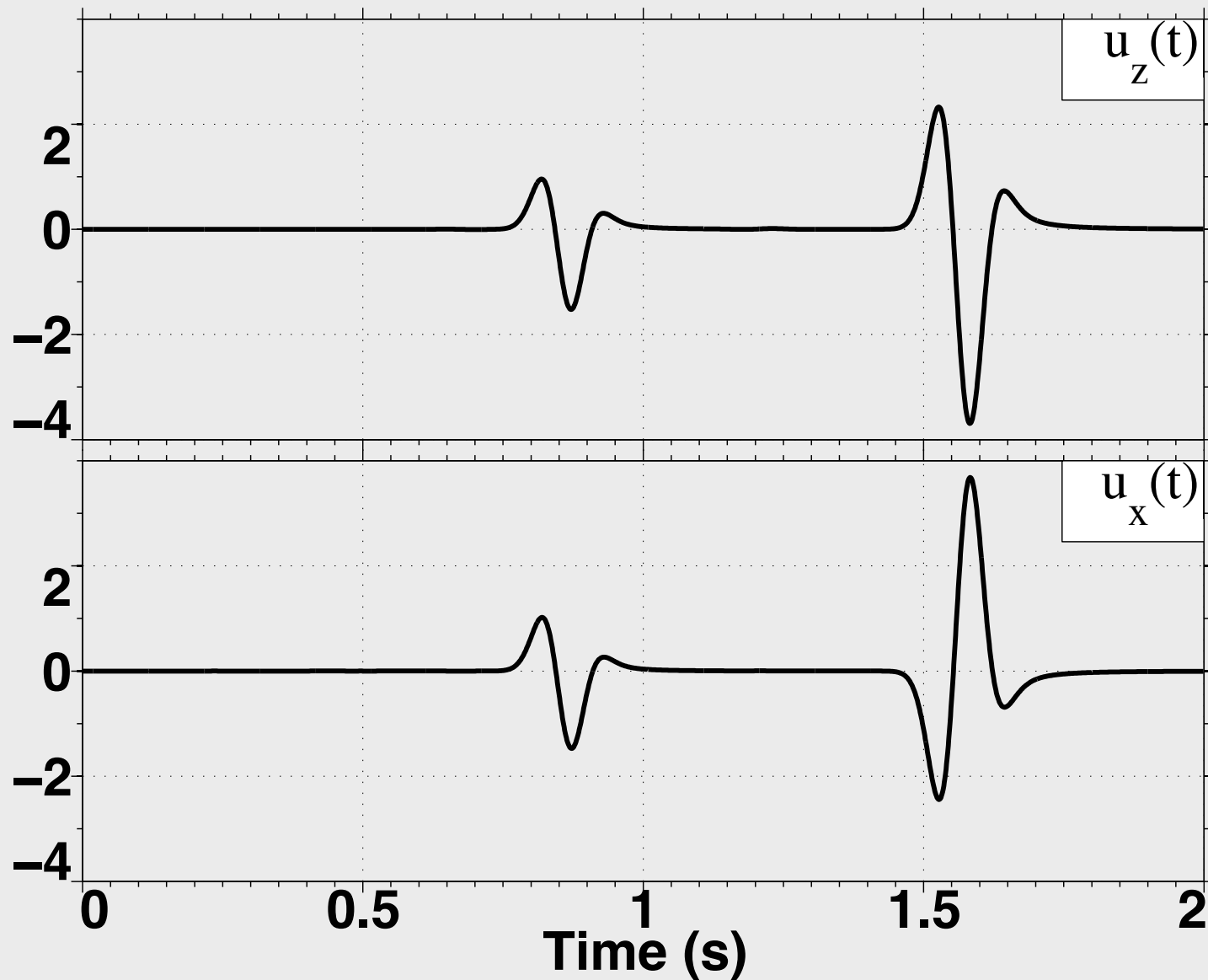
Directional source



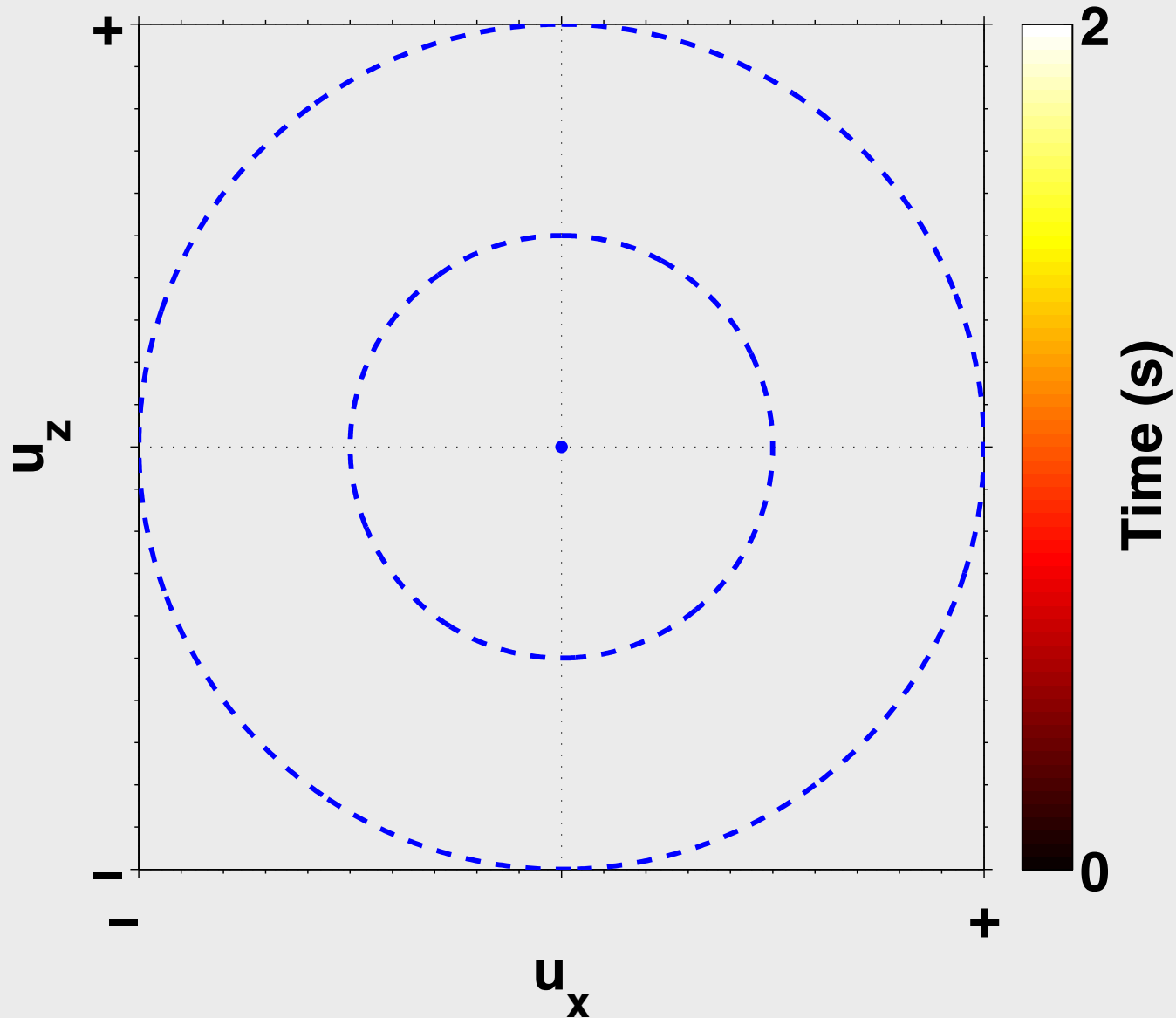
Trace (x:3.0 km)



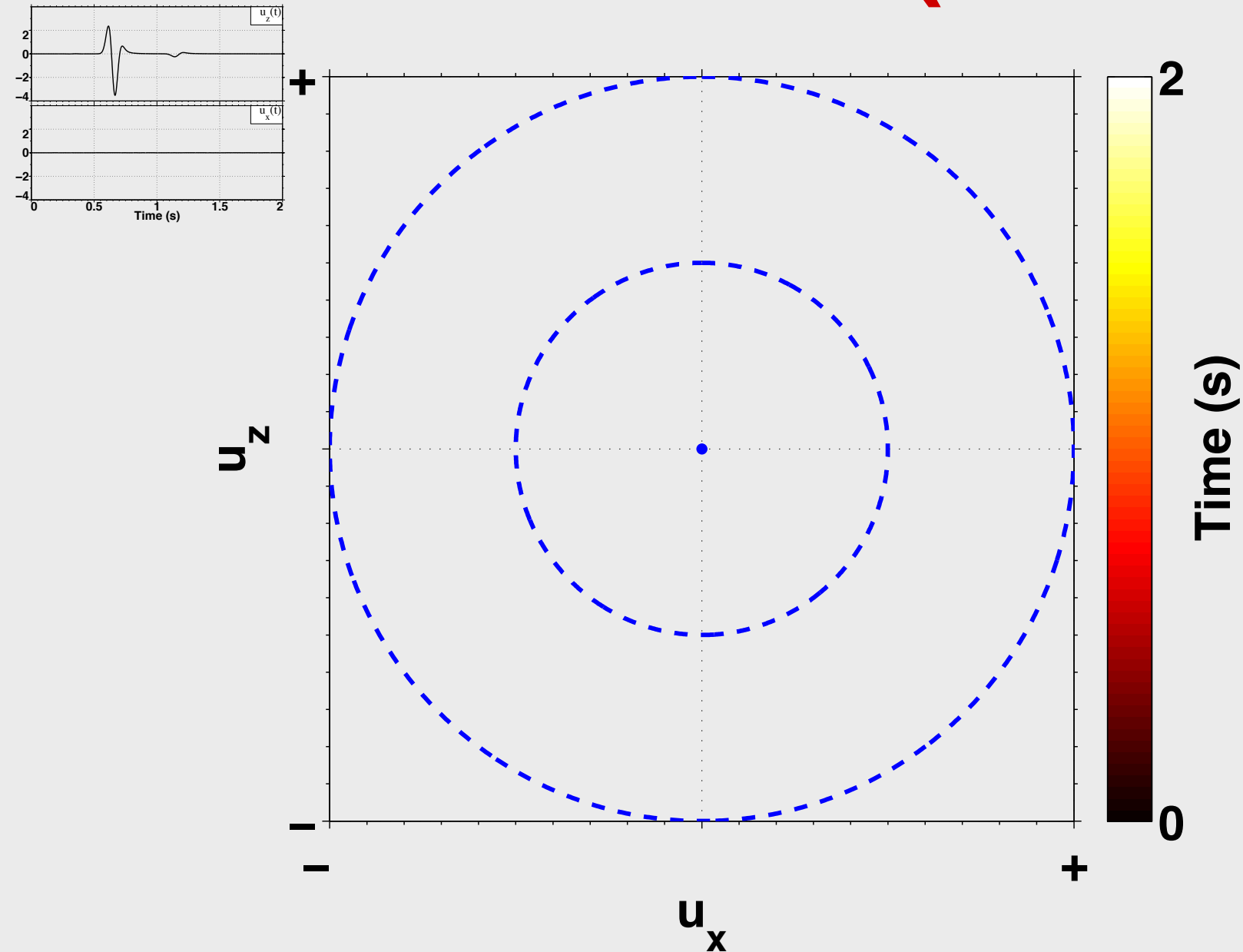
Trace (x:2.0 km)



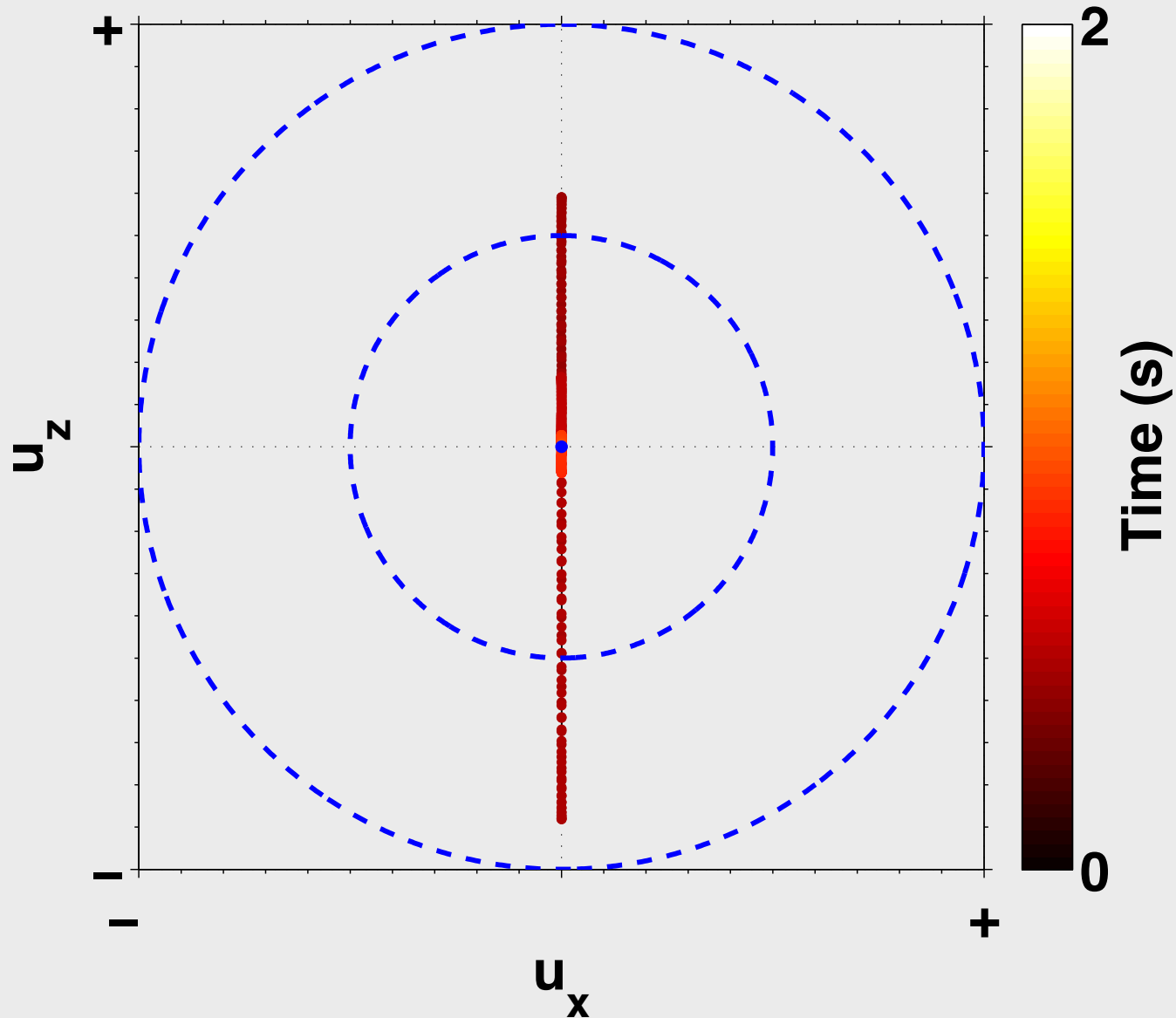
Particle motion



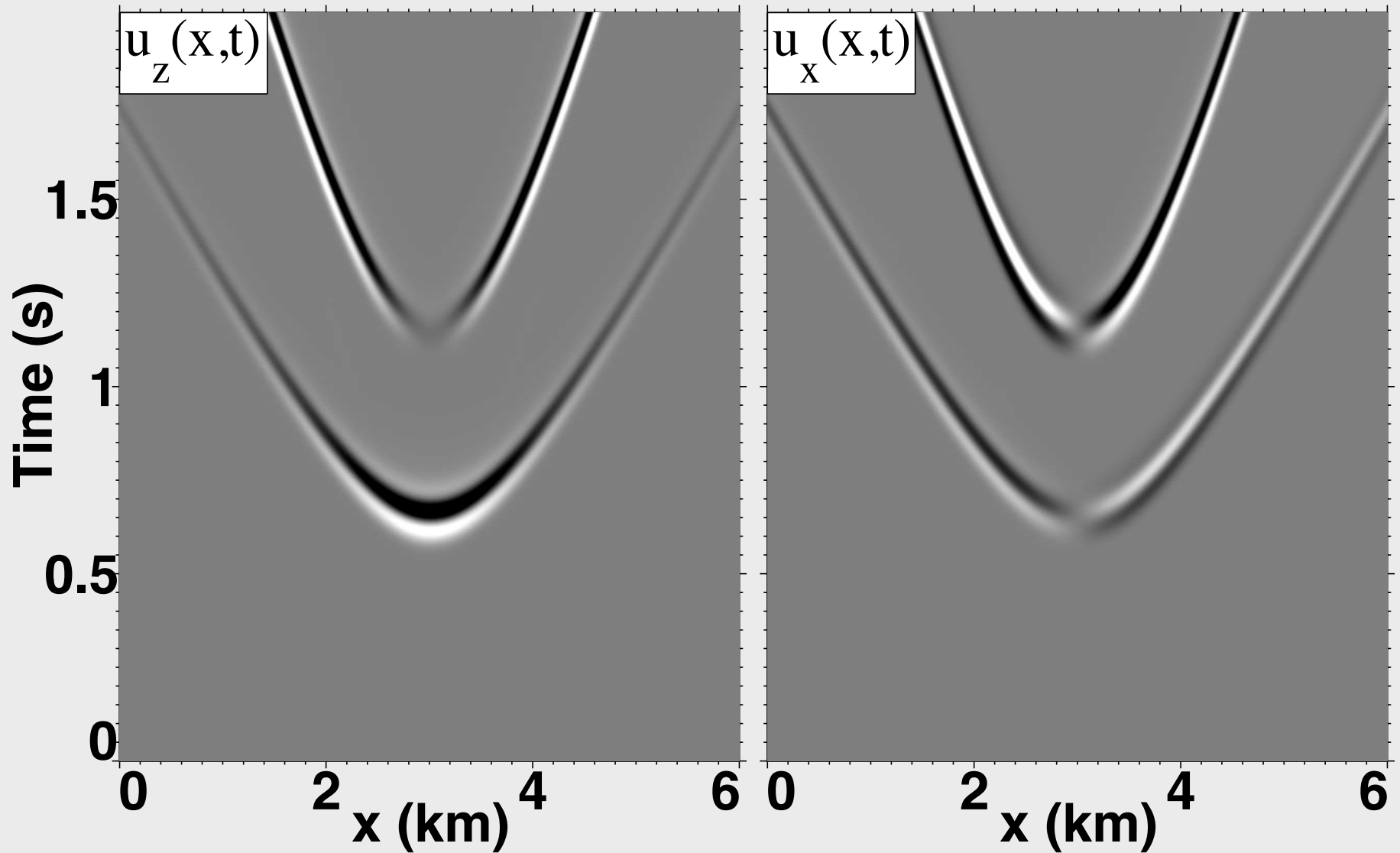
Particle motion (x:3.0 km)



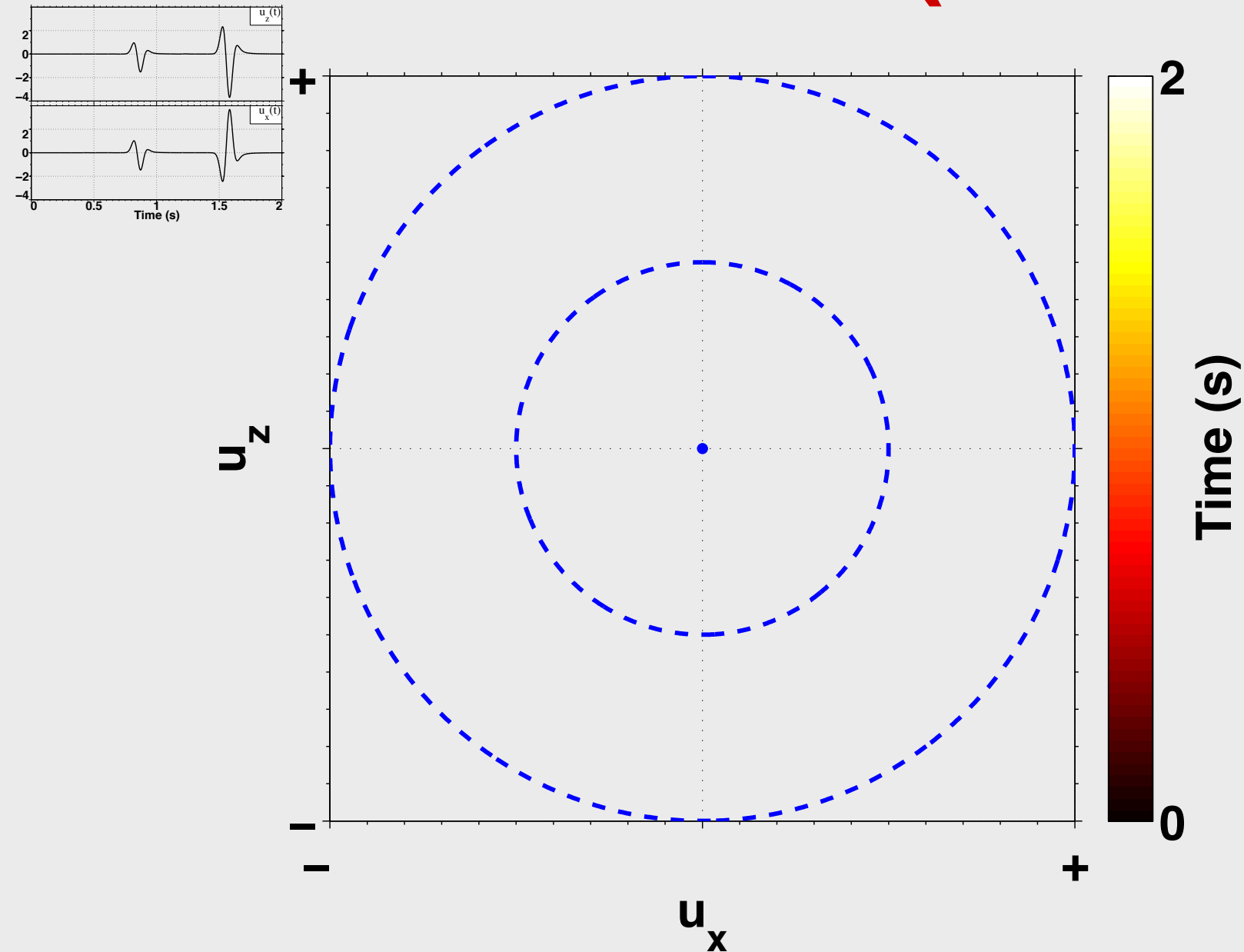
Particle motion (x:3.0 km)



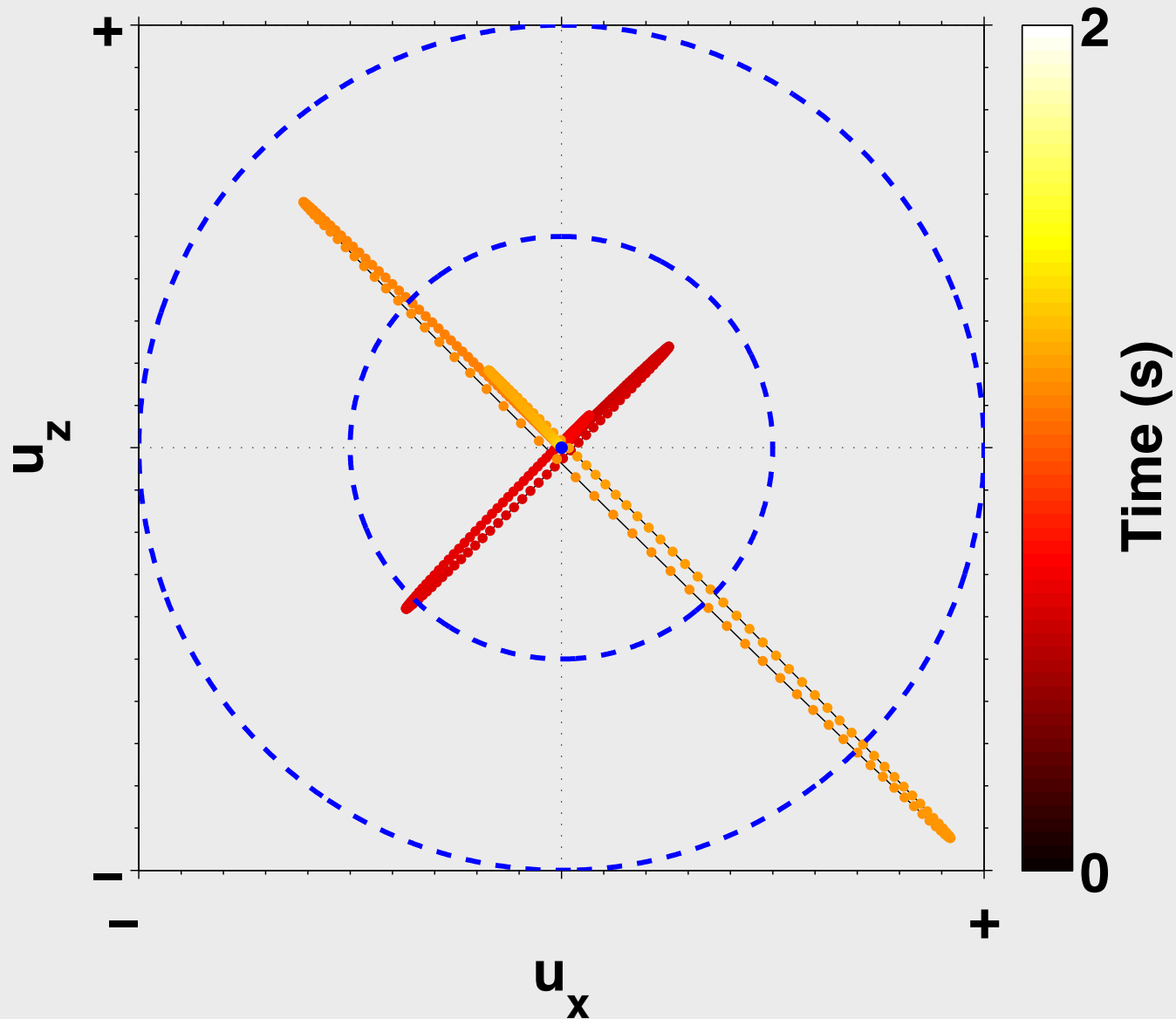
Directional source



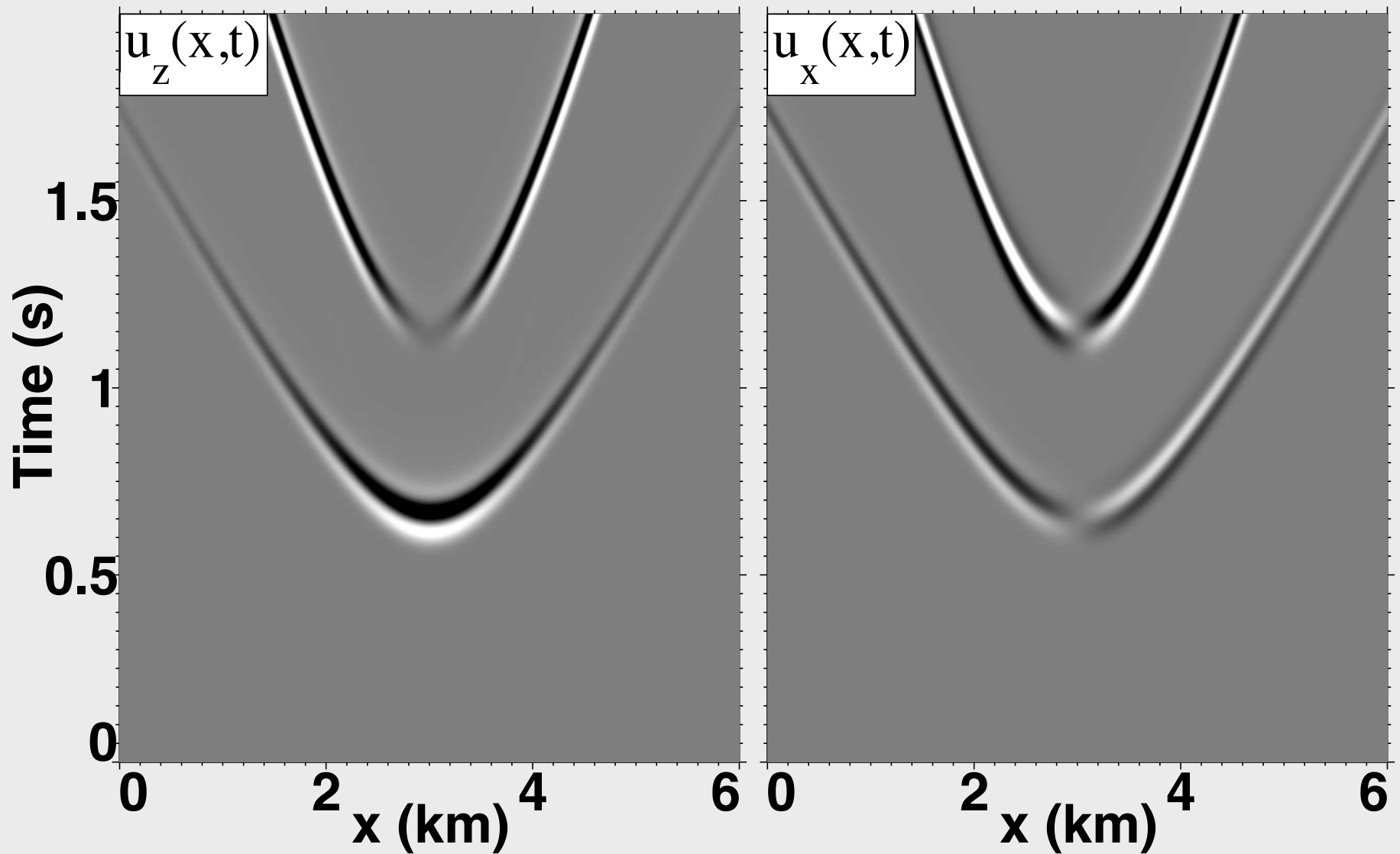
Particle motion (x:2.0 km)



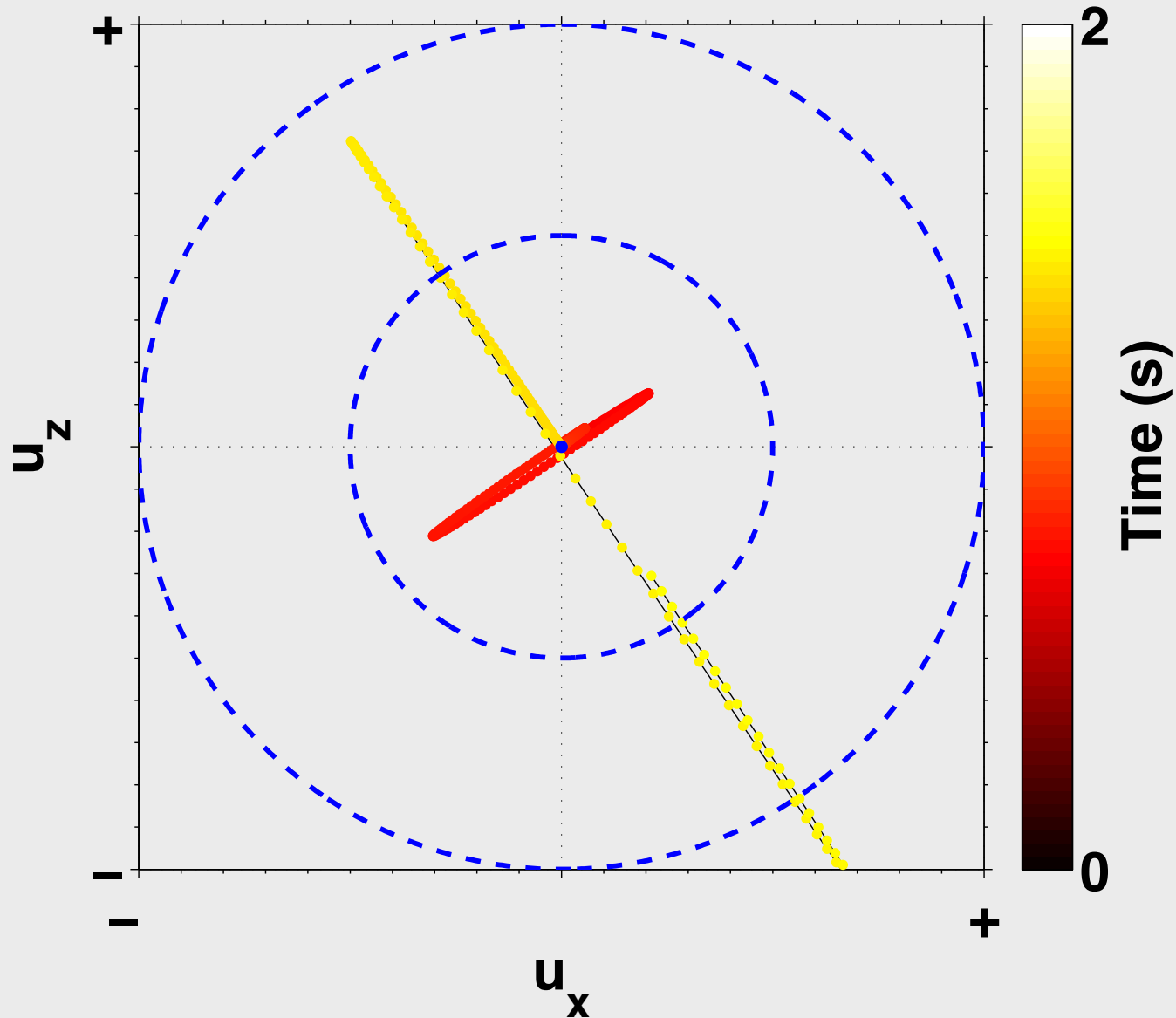
Particle motion (x:2.0 km)



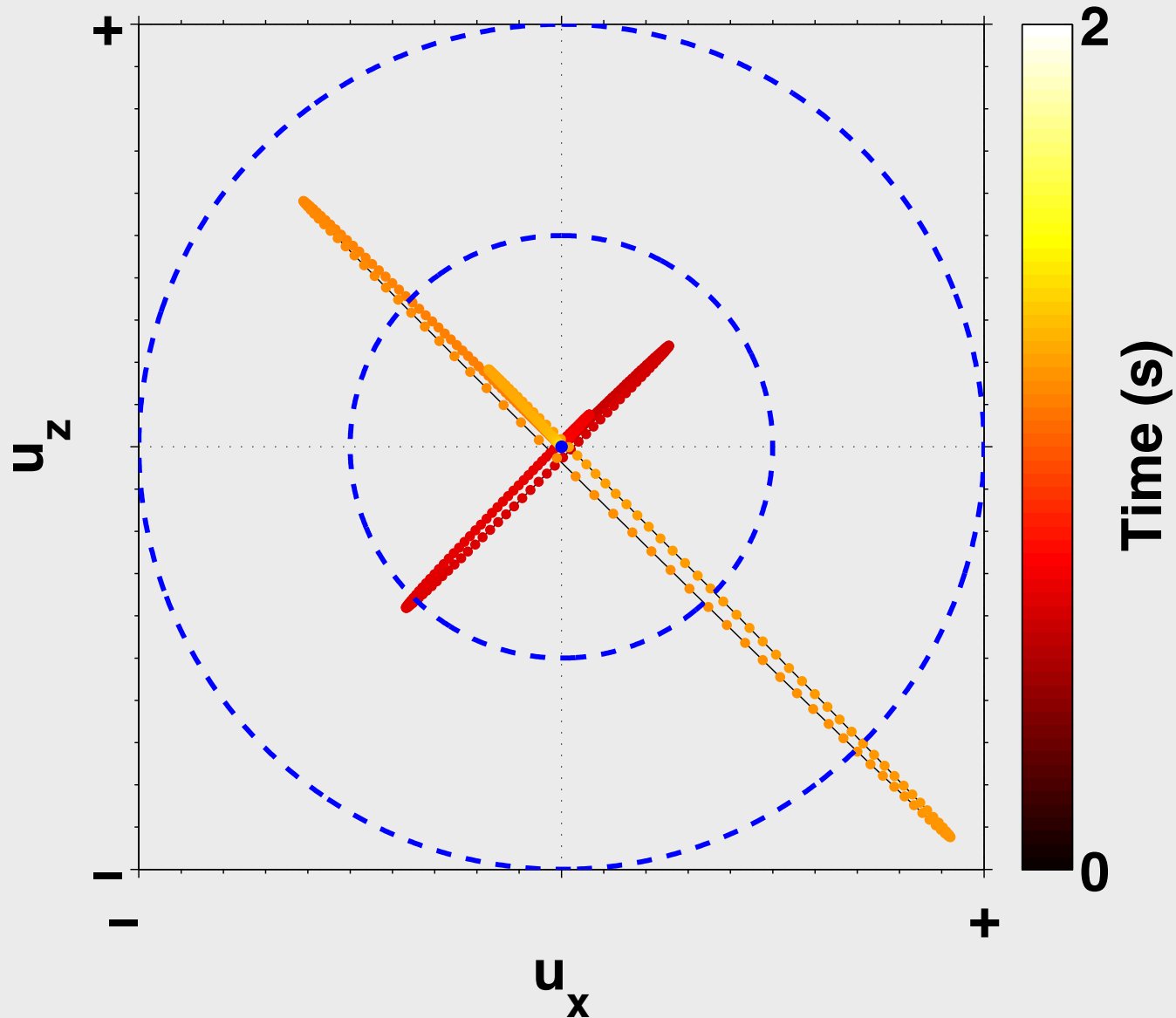
Directional source



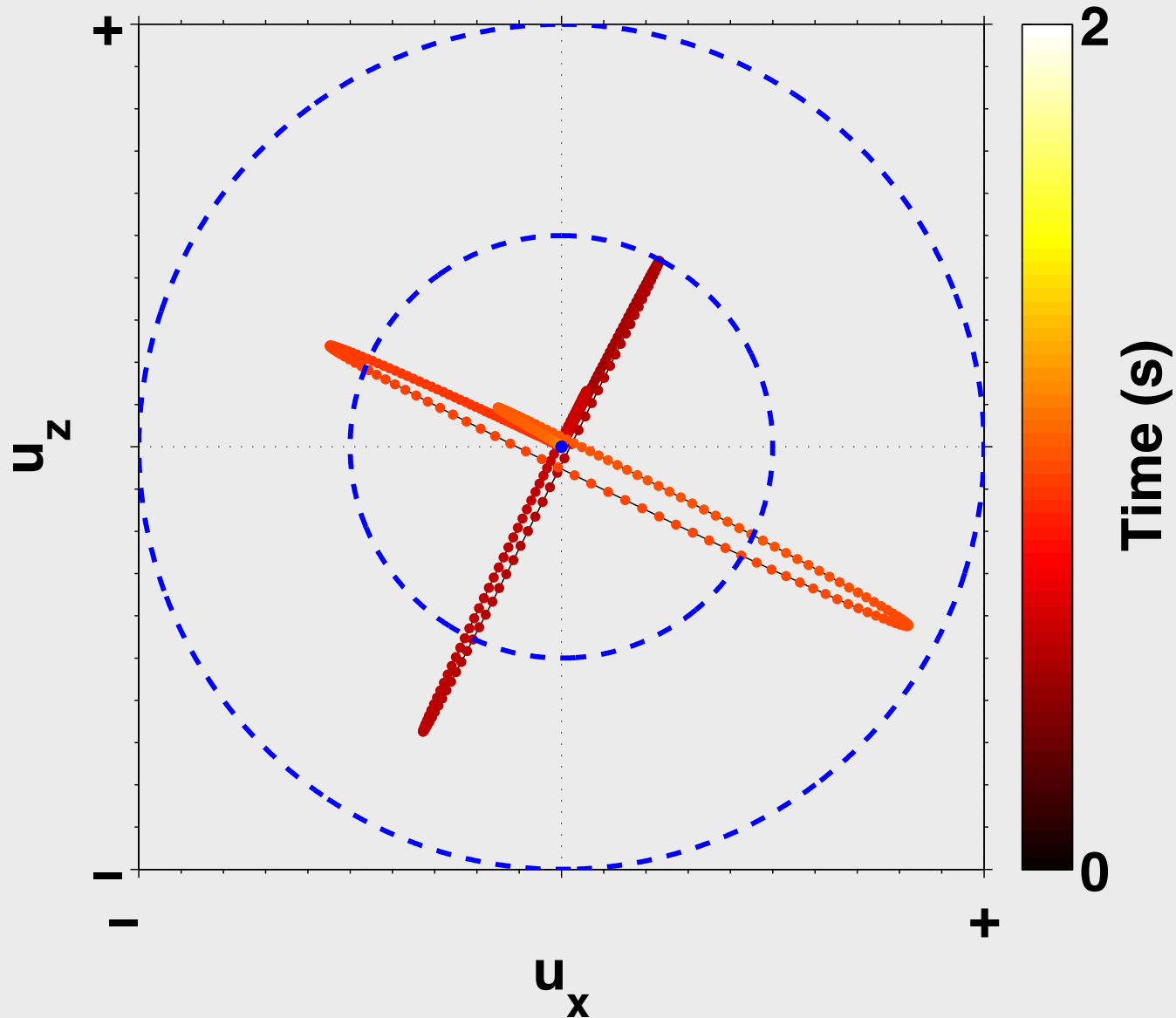
Particle motion (x:1.5 km)



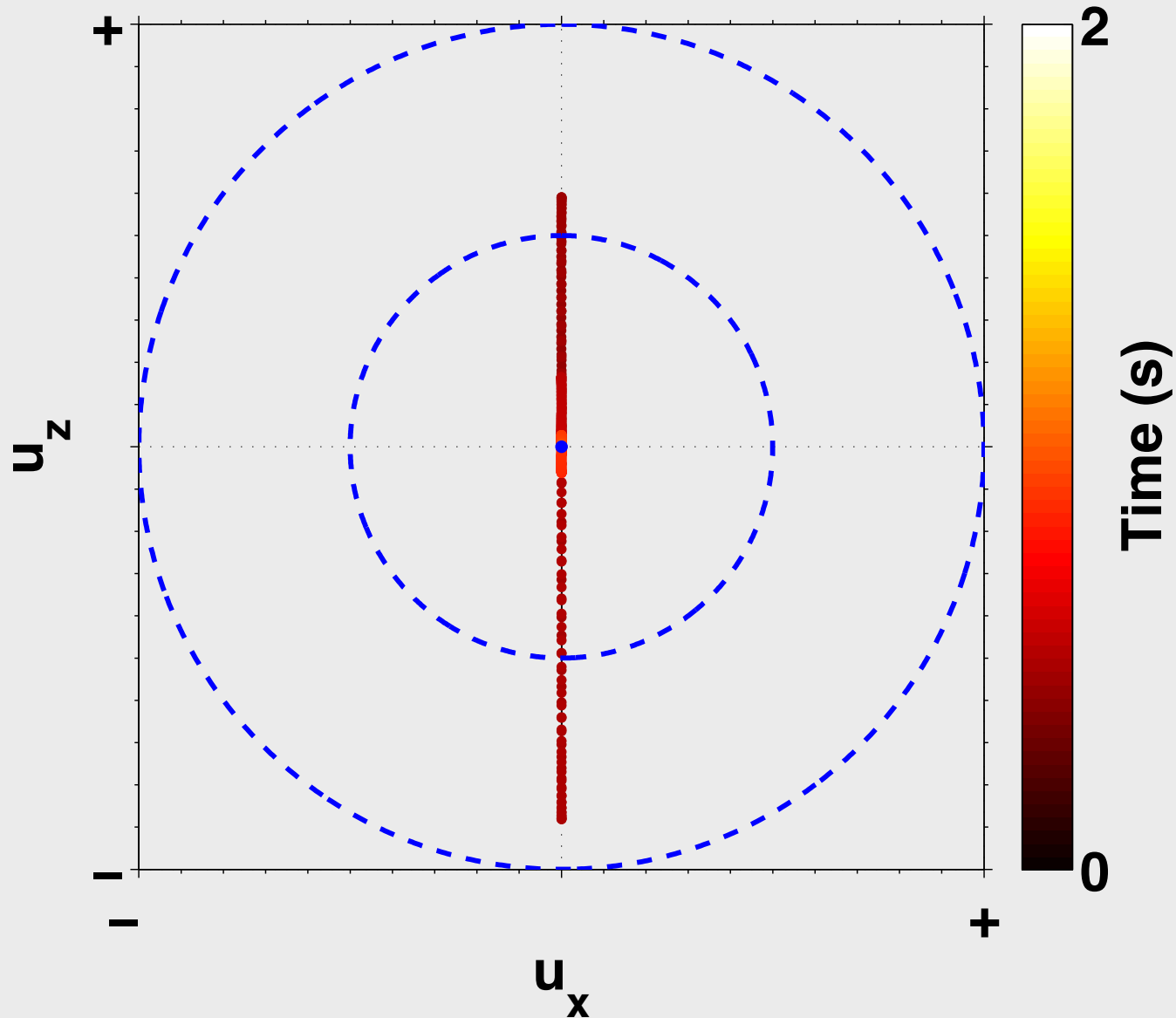
Particle motion (x:2.0 km)



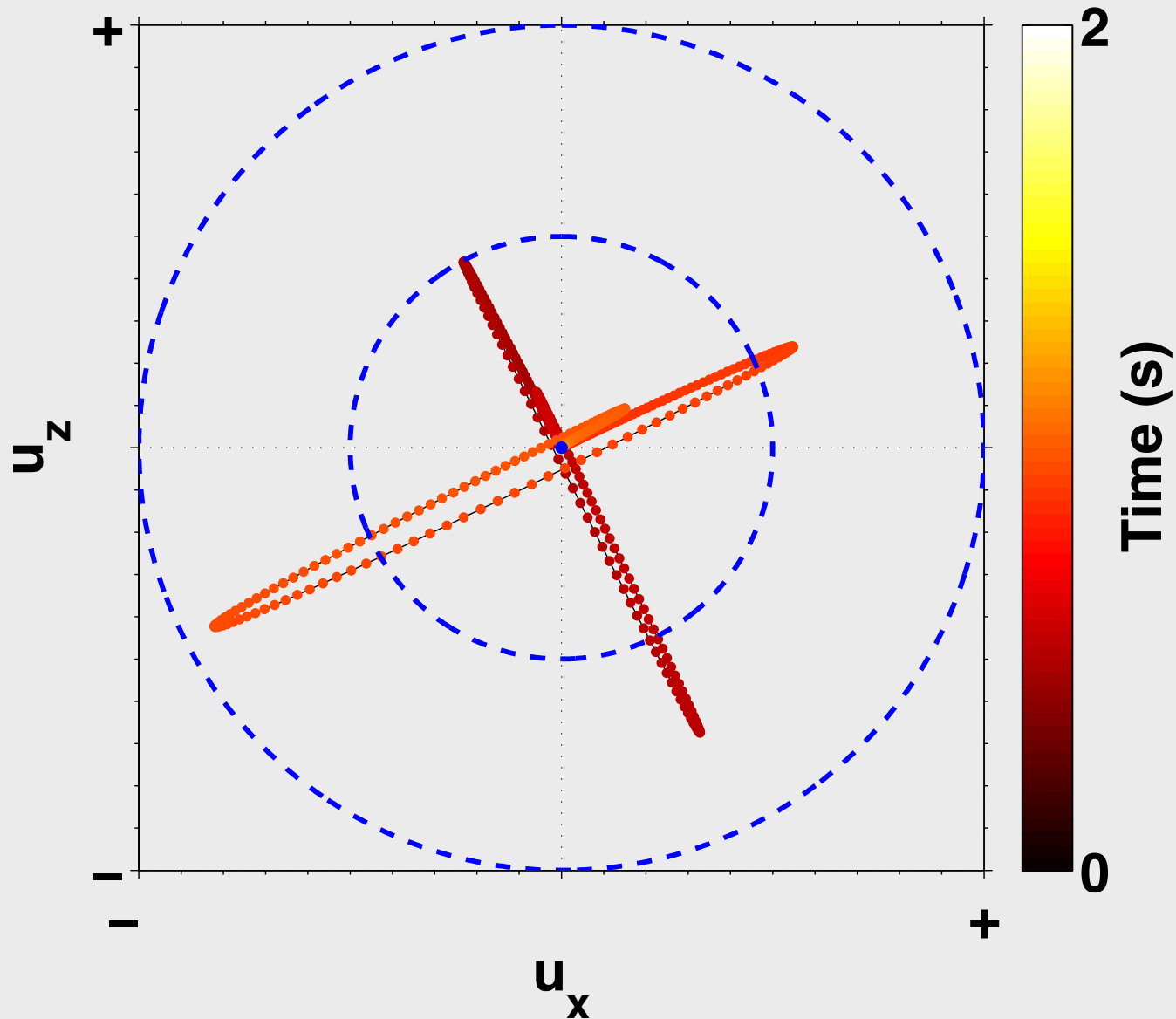
Particle motion (x:2.5 km)



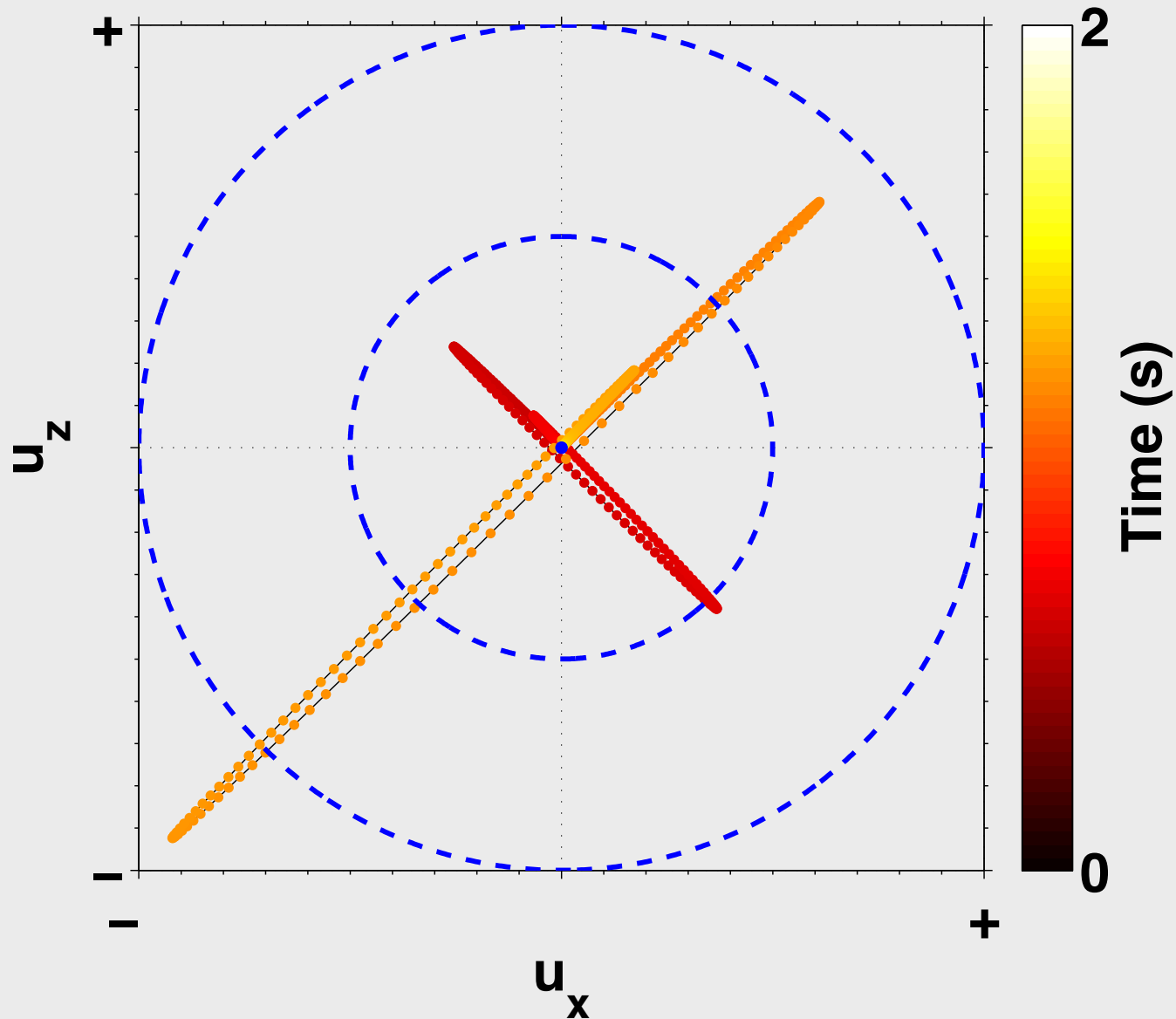
Particle motion (x:3.0 km)



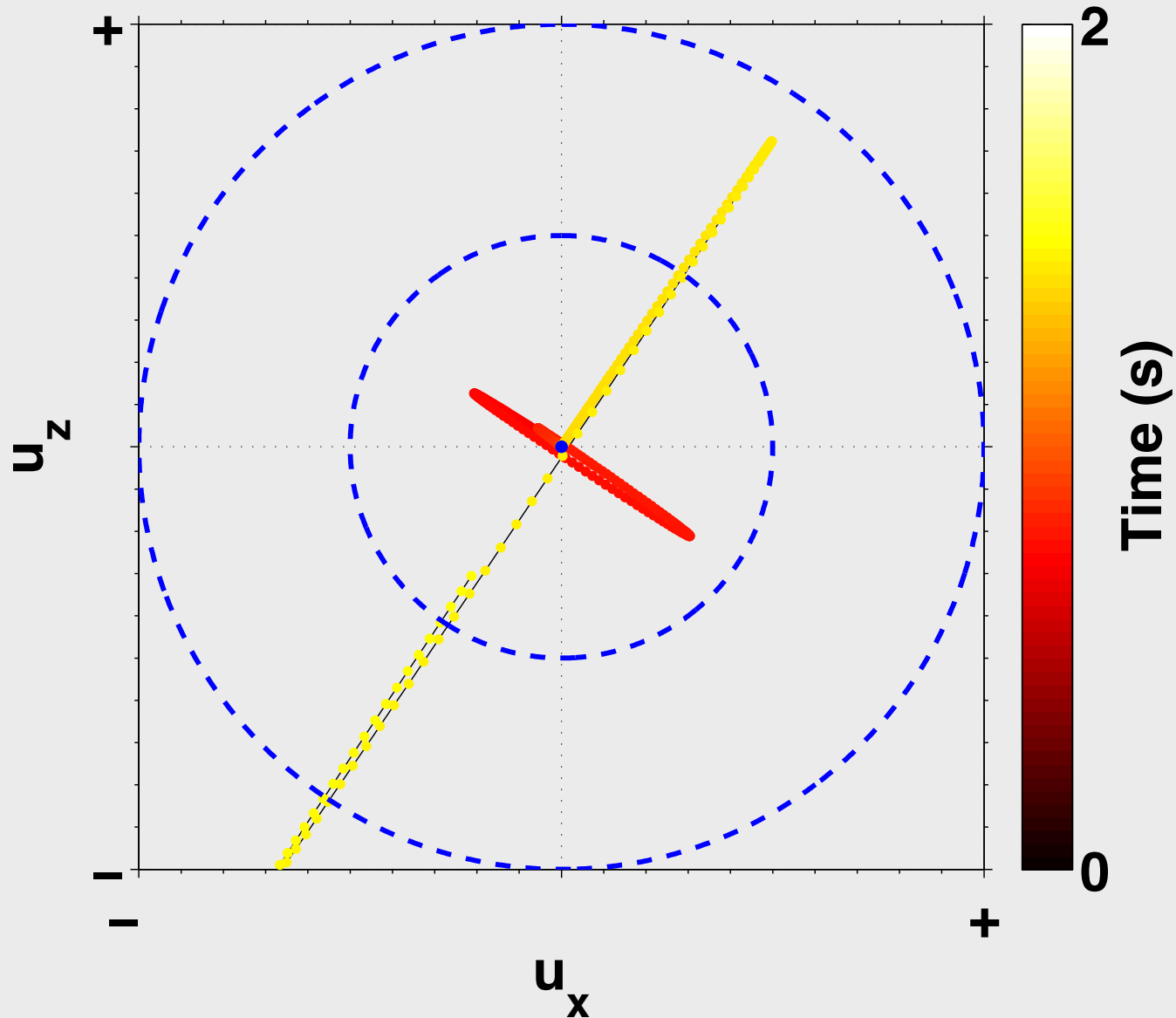
Particle motion (x:3.5 km)



Particle motion (x:4.0 km)



Particle motion (x:4.5 km)

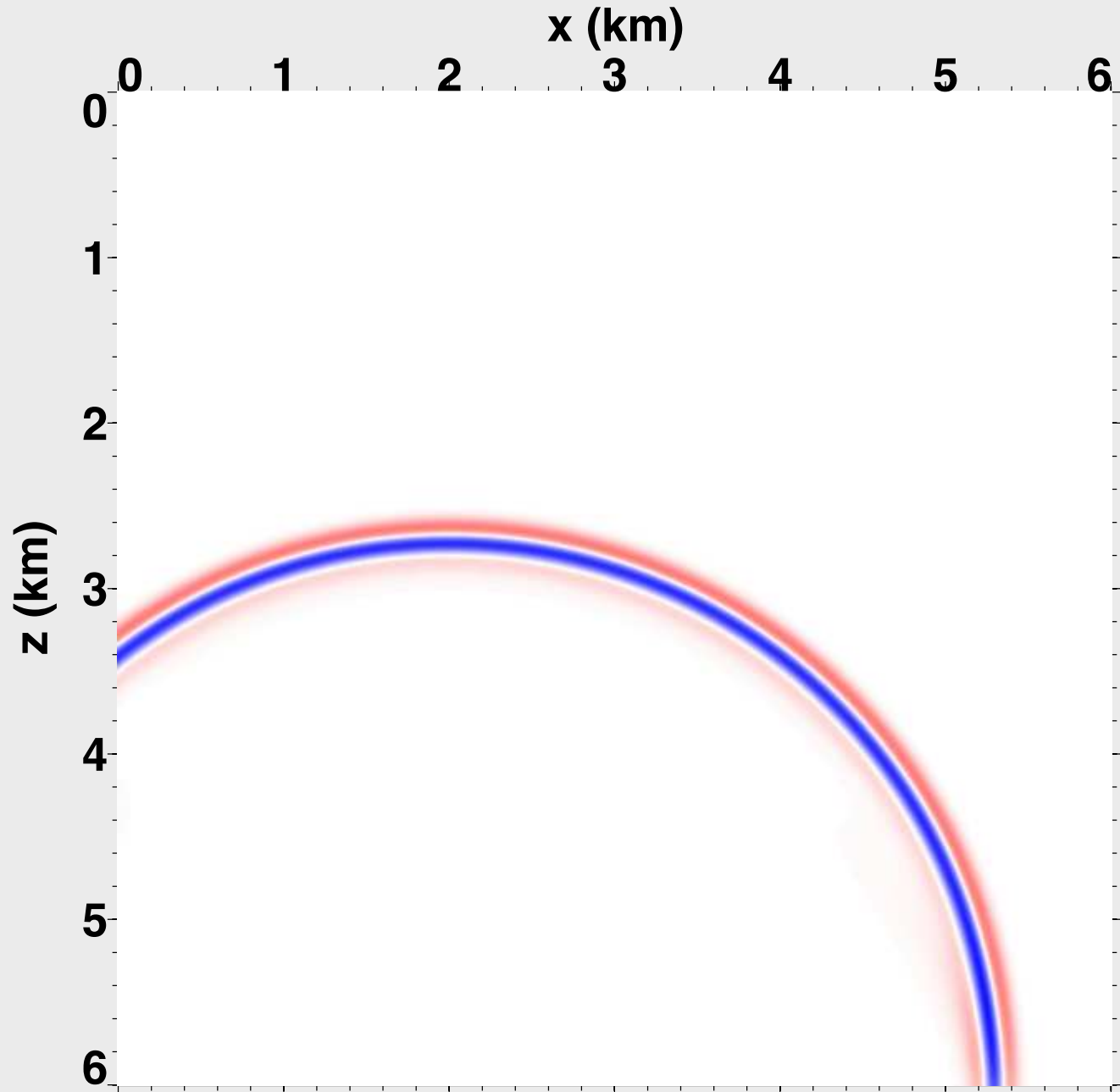


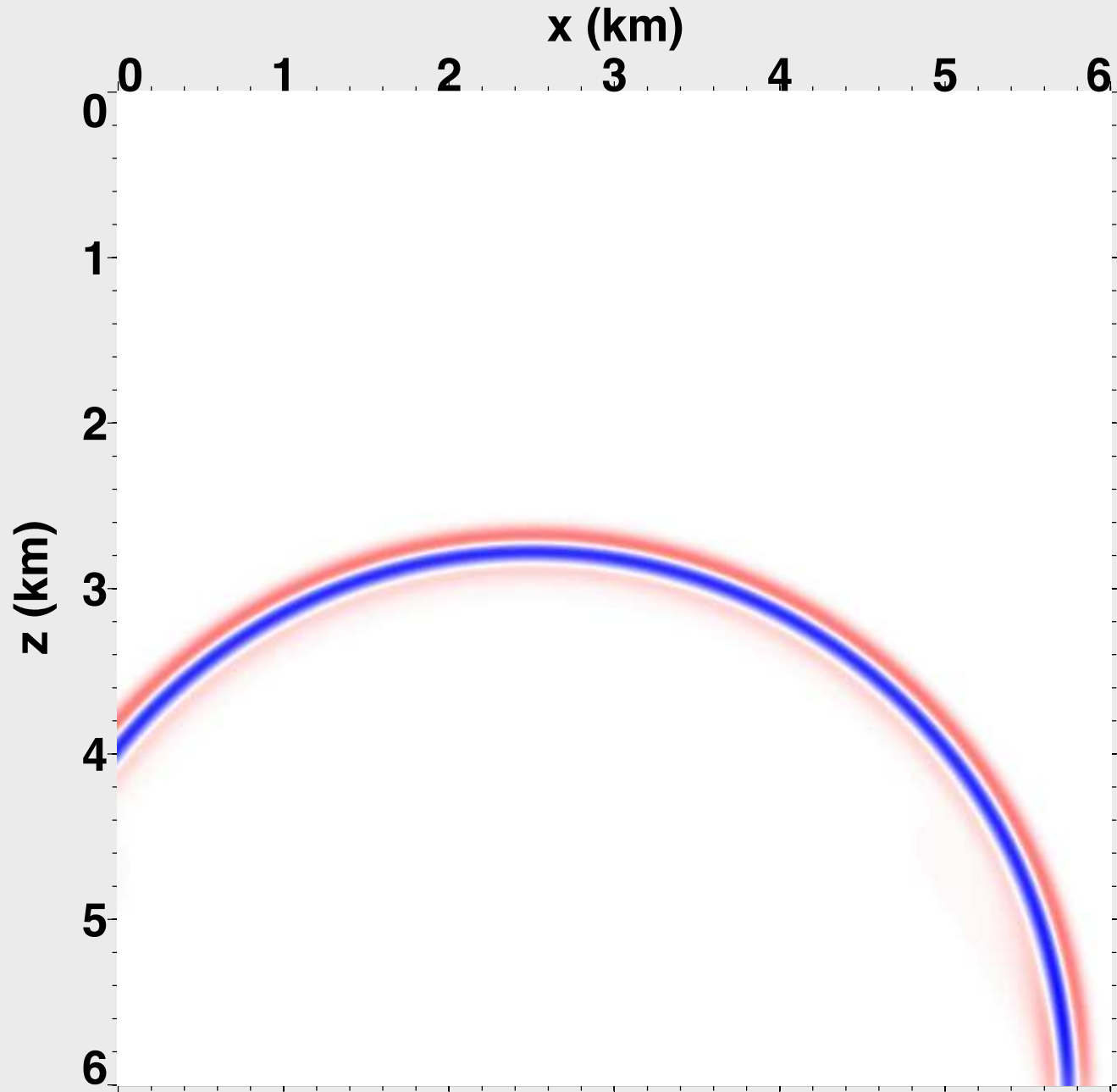
Snell's law

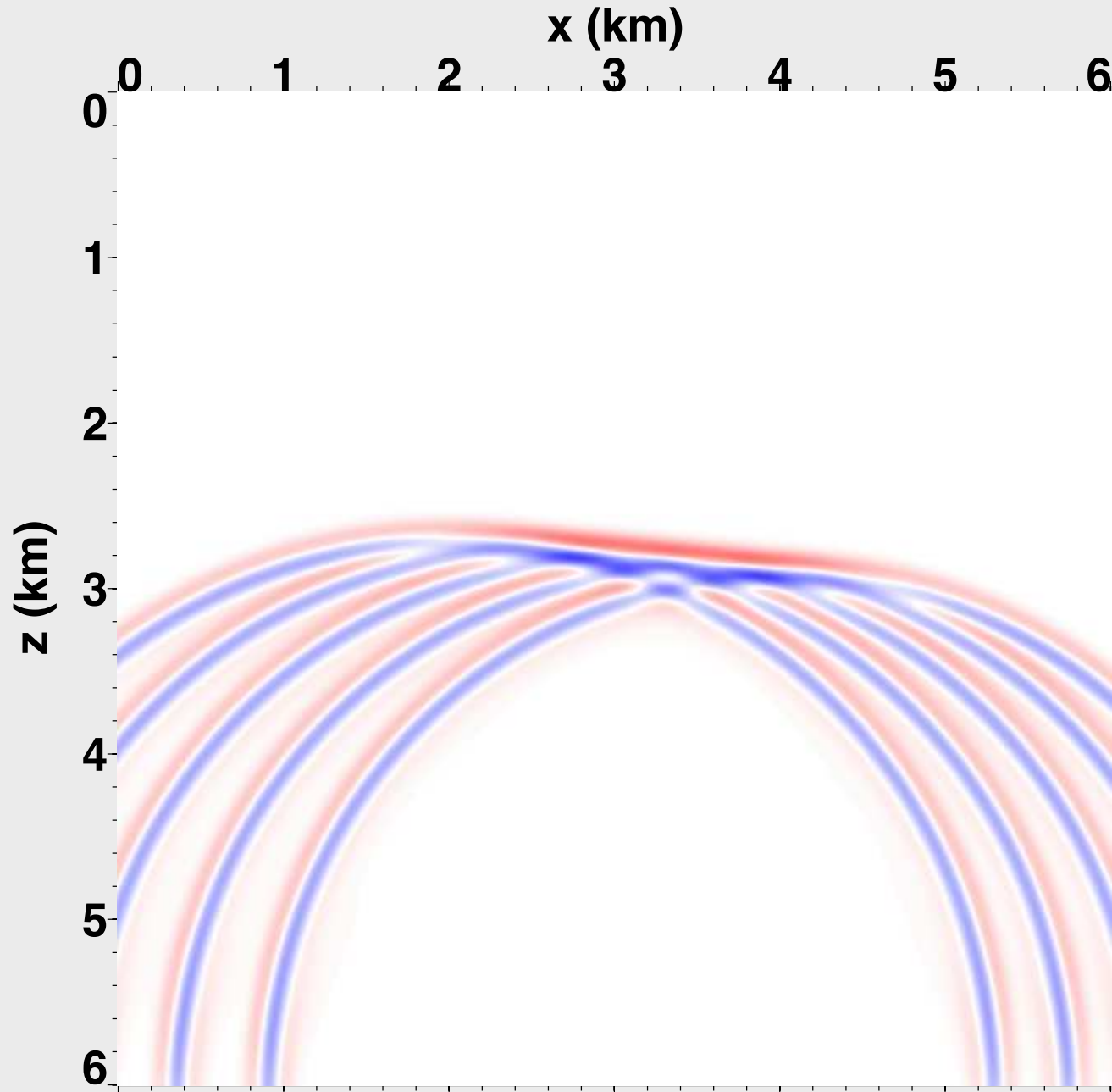
Reflection & Transmission

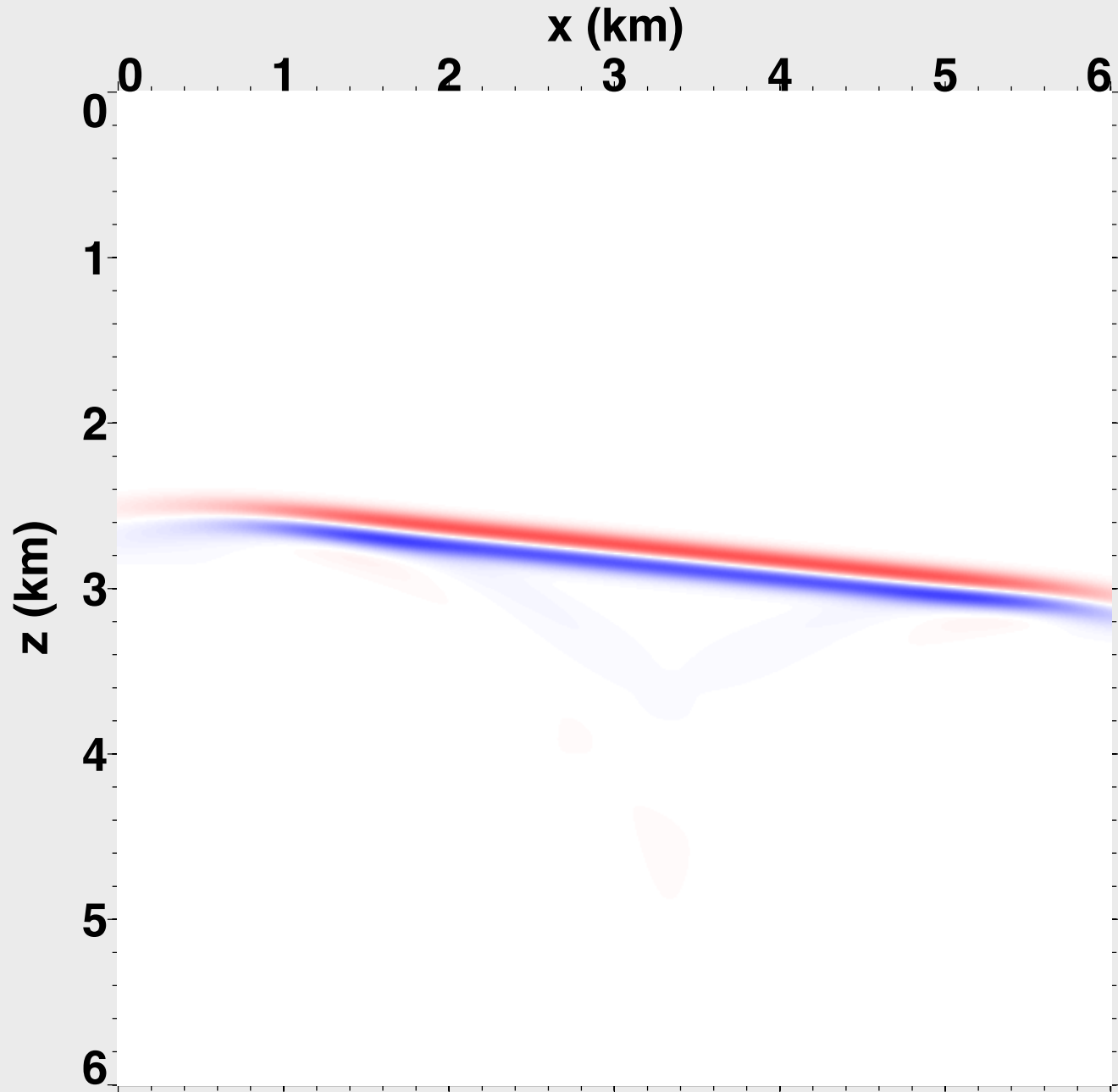
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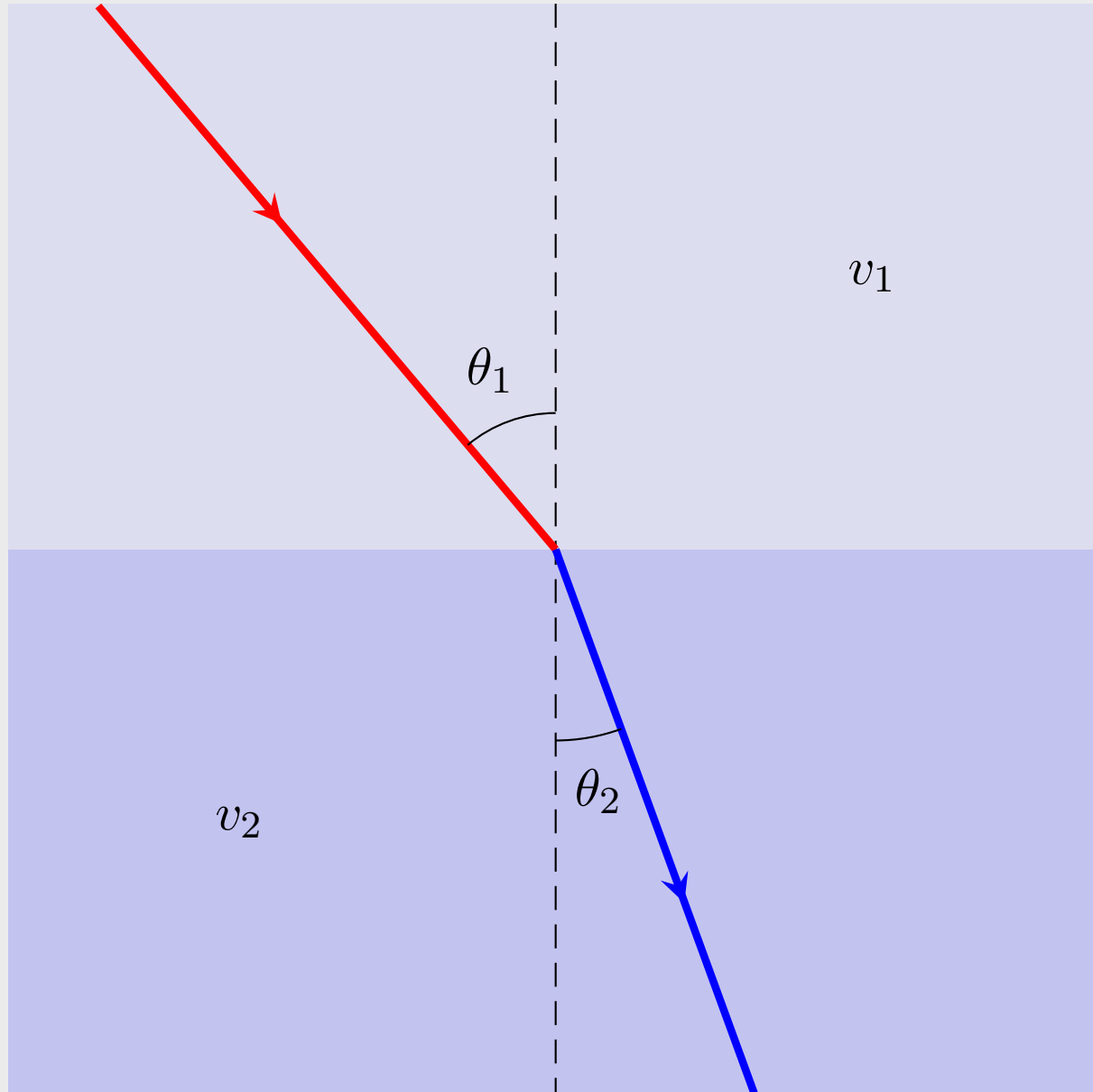




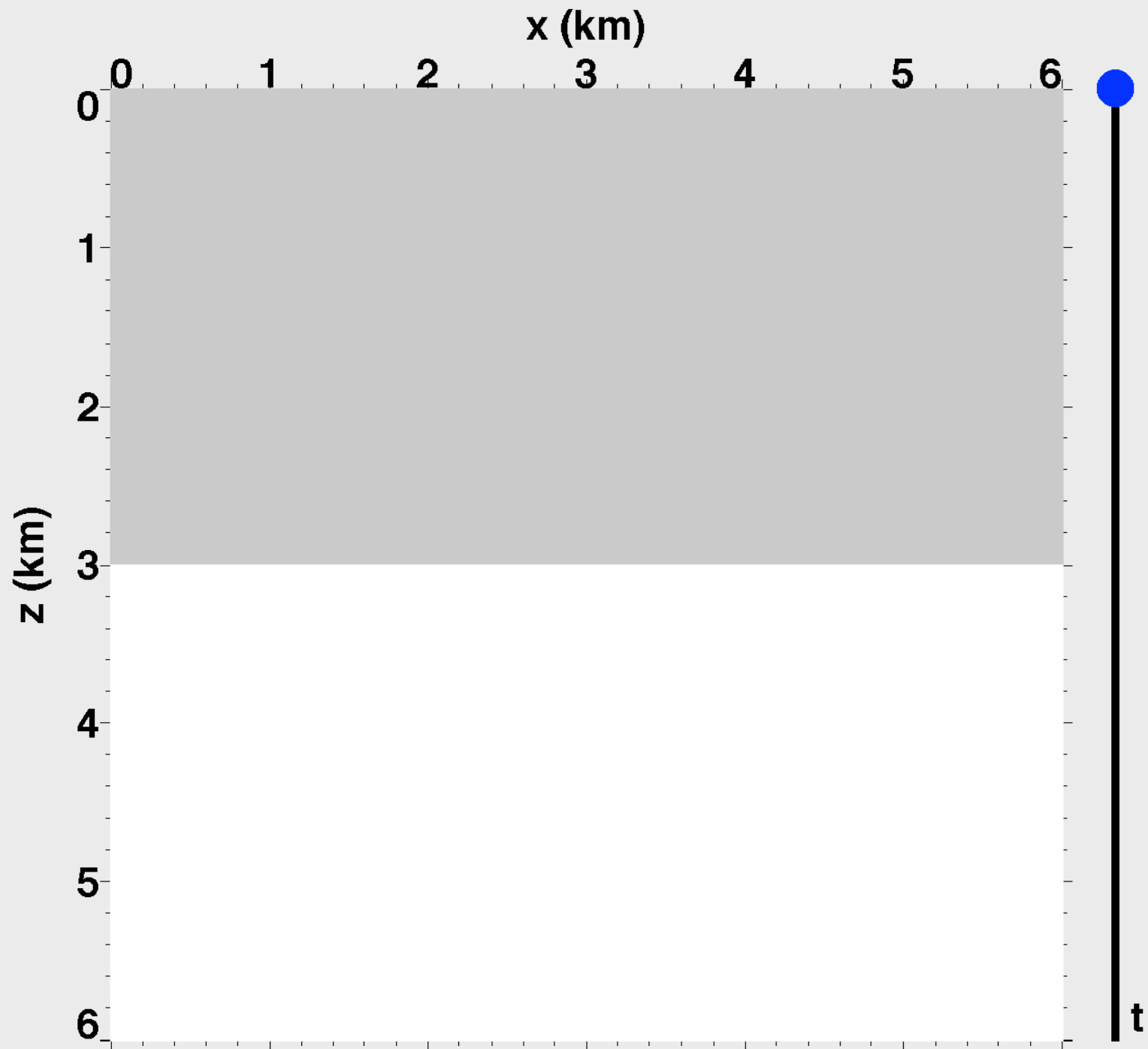


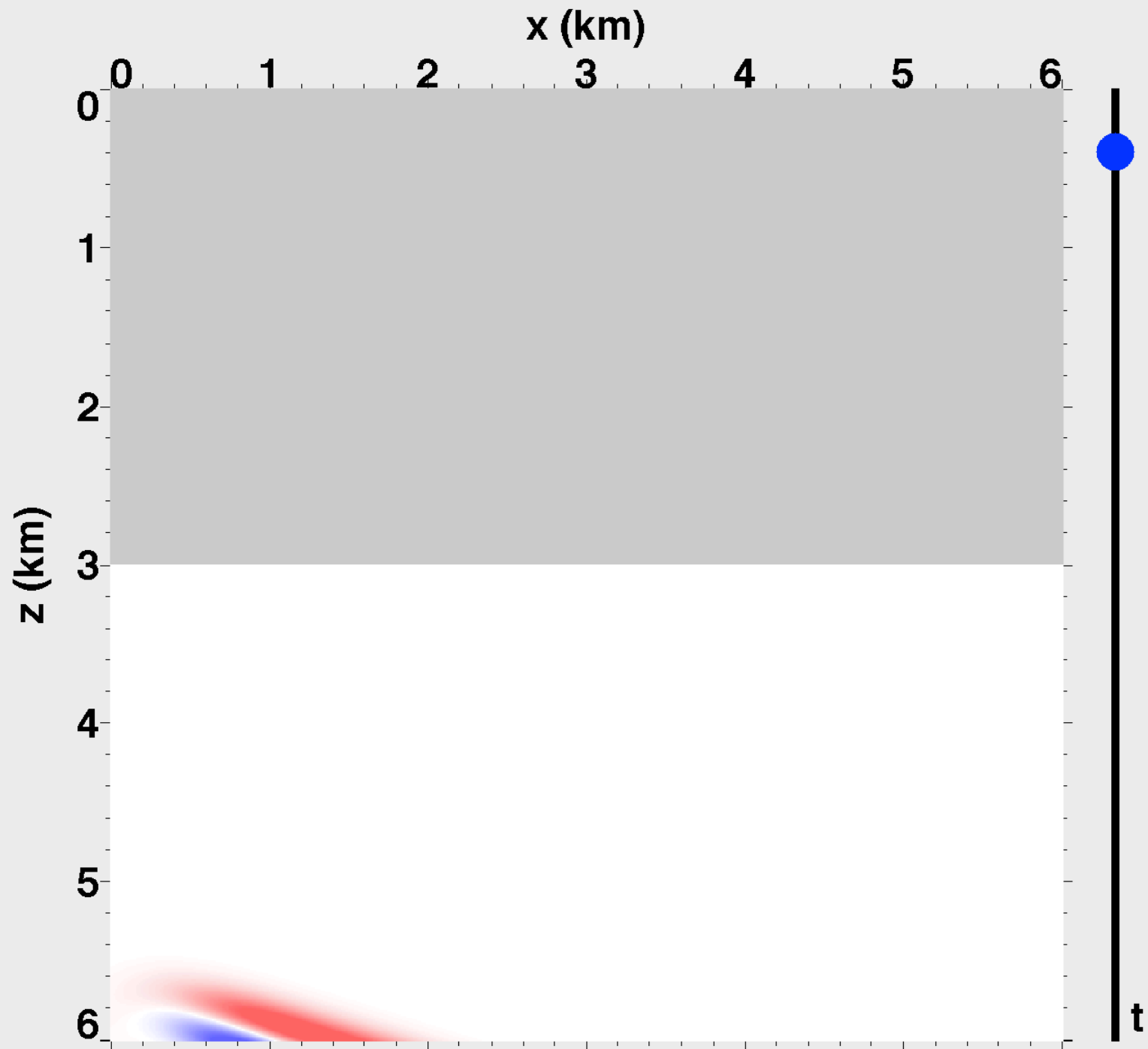


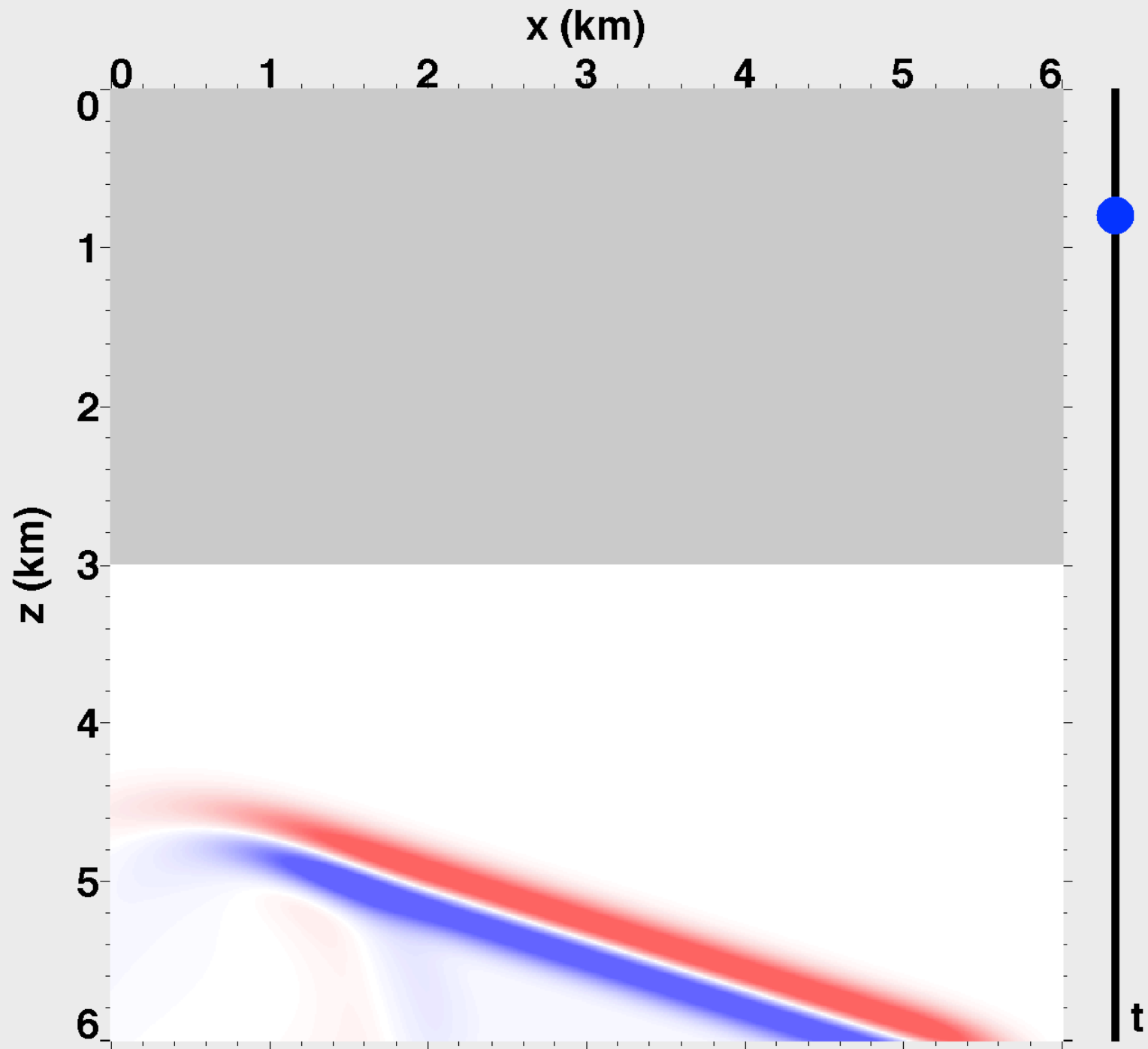
Snell's law

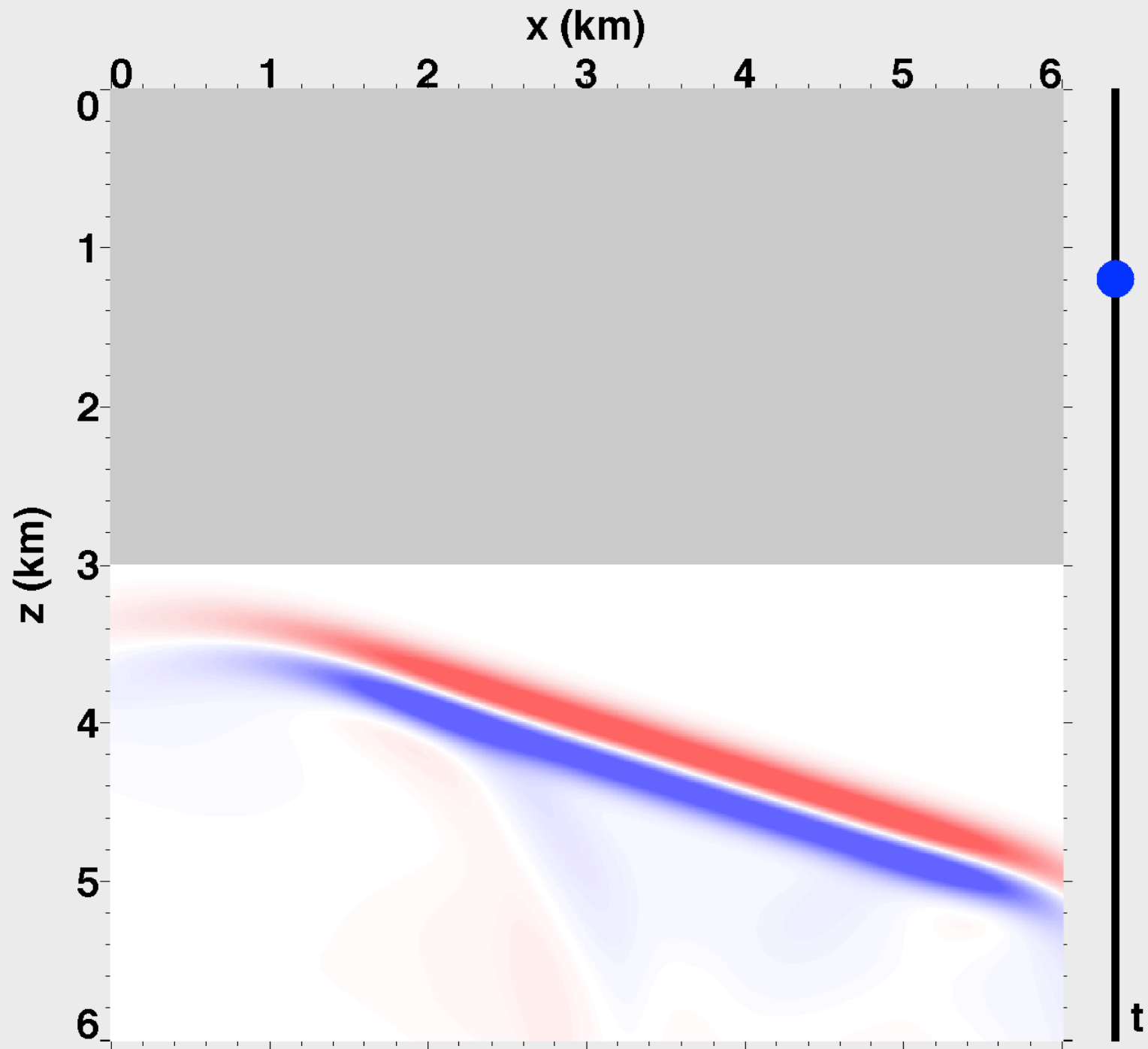


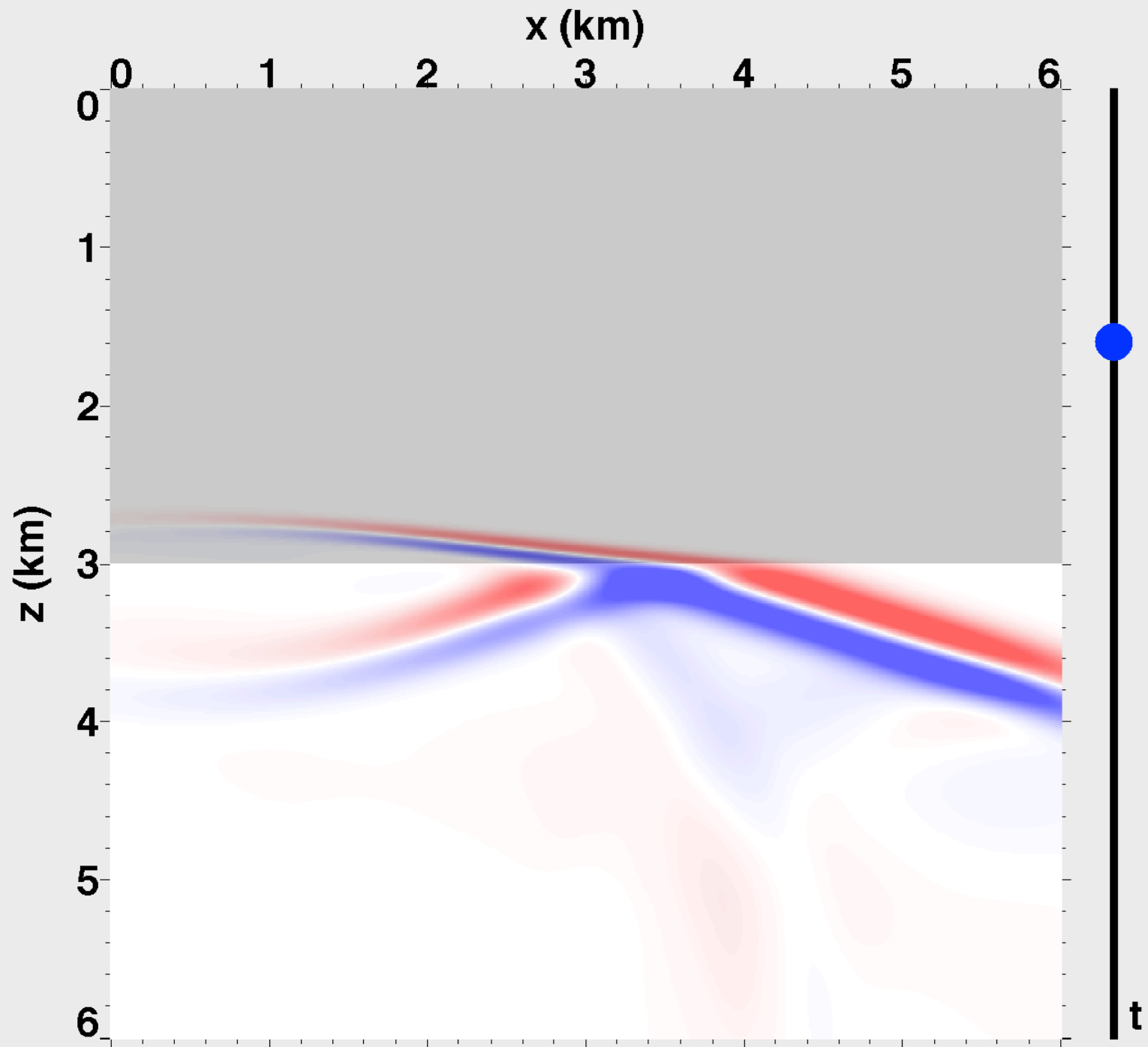
**Change propagating
direction**

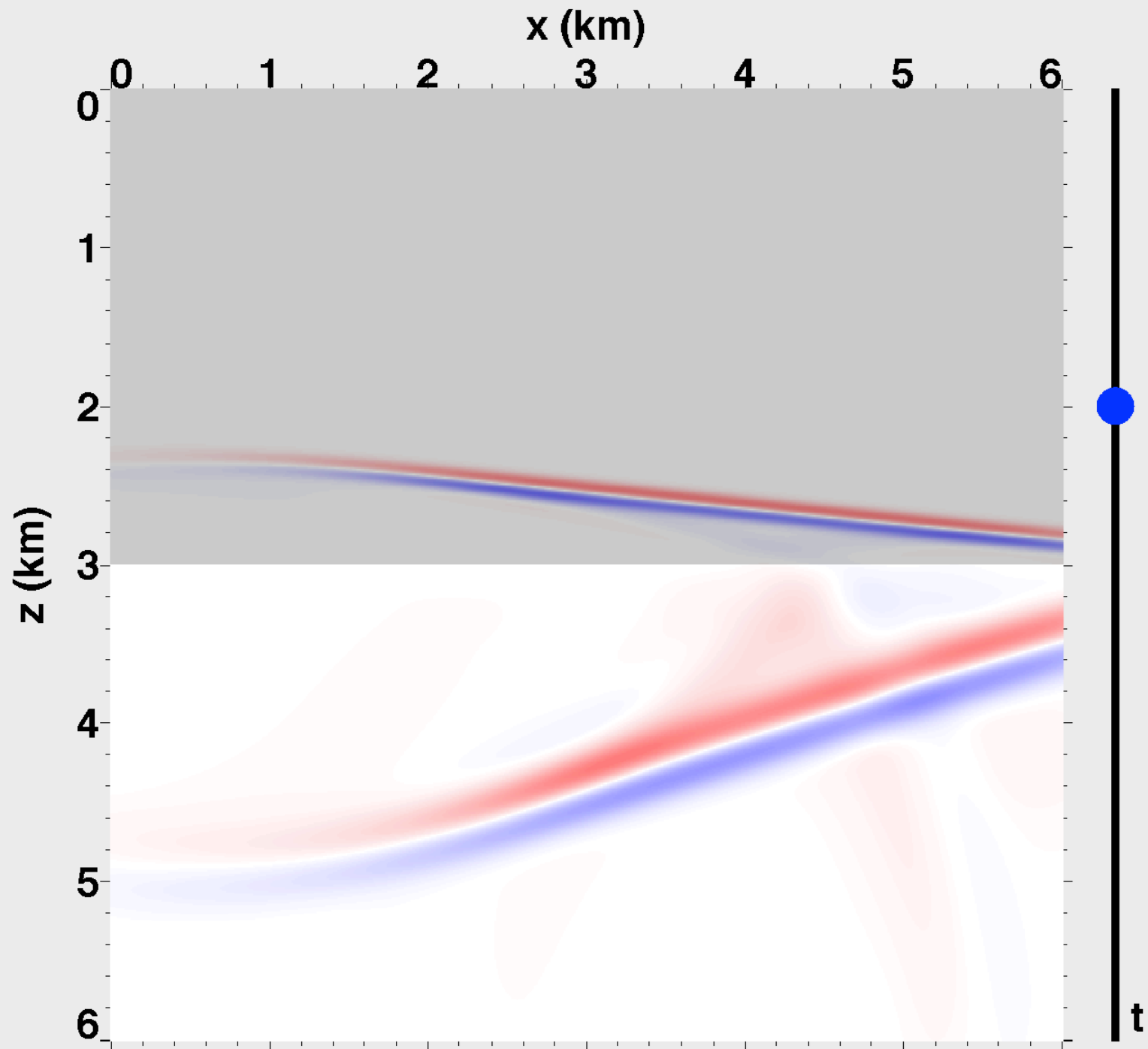


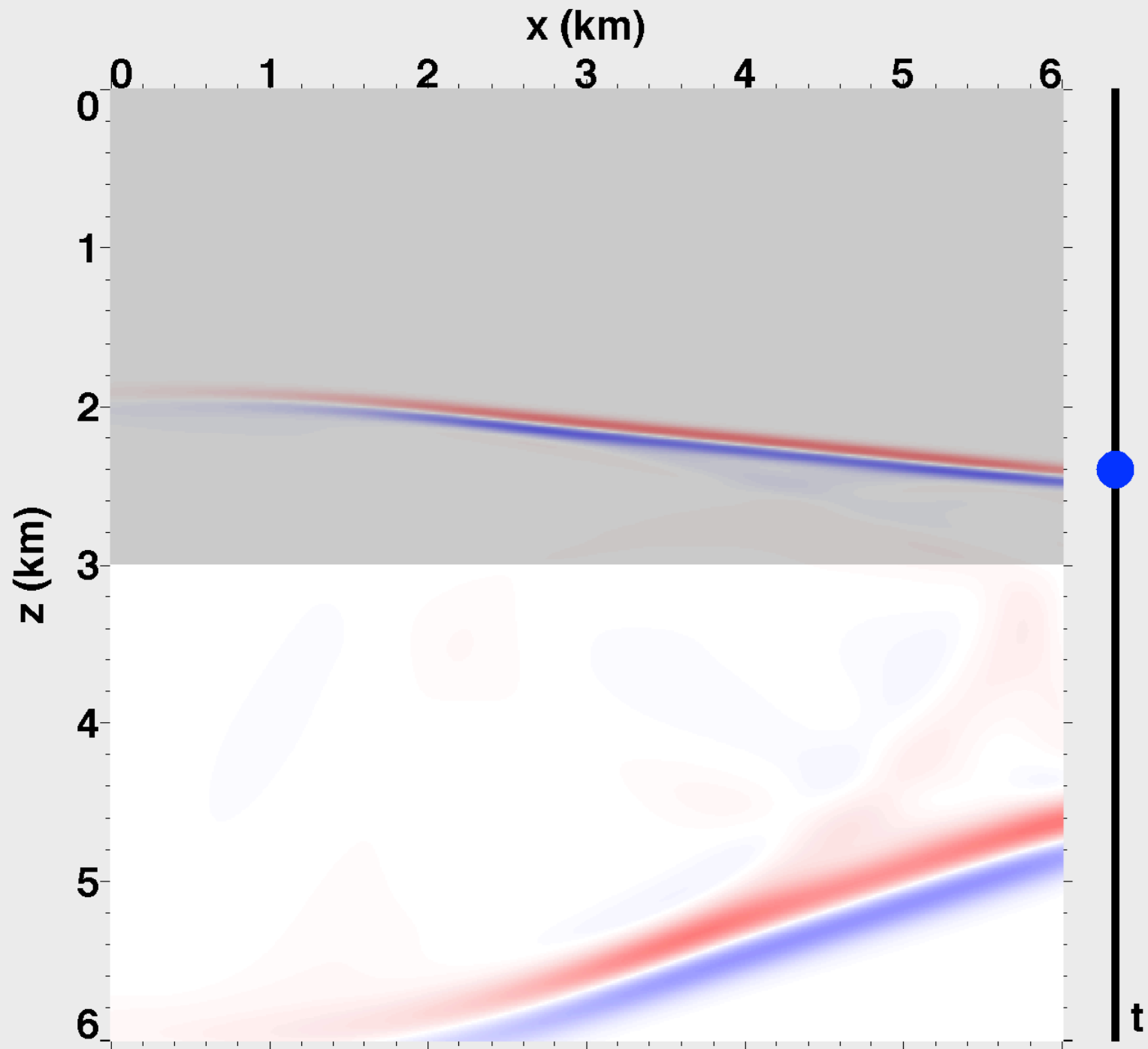


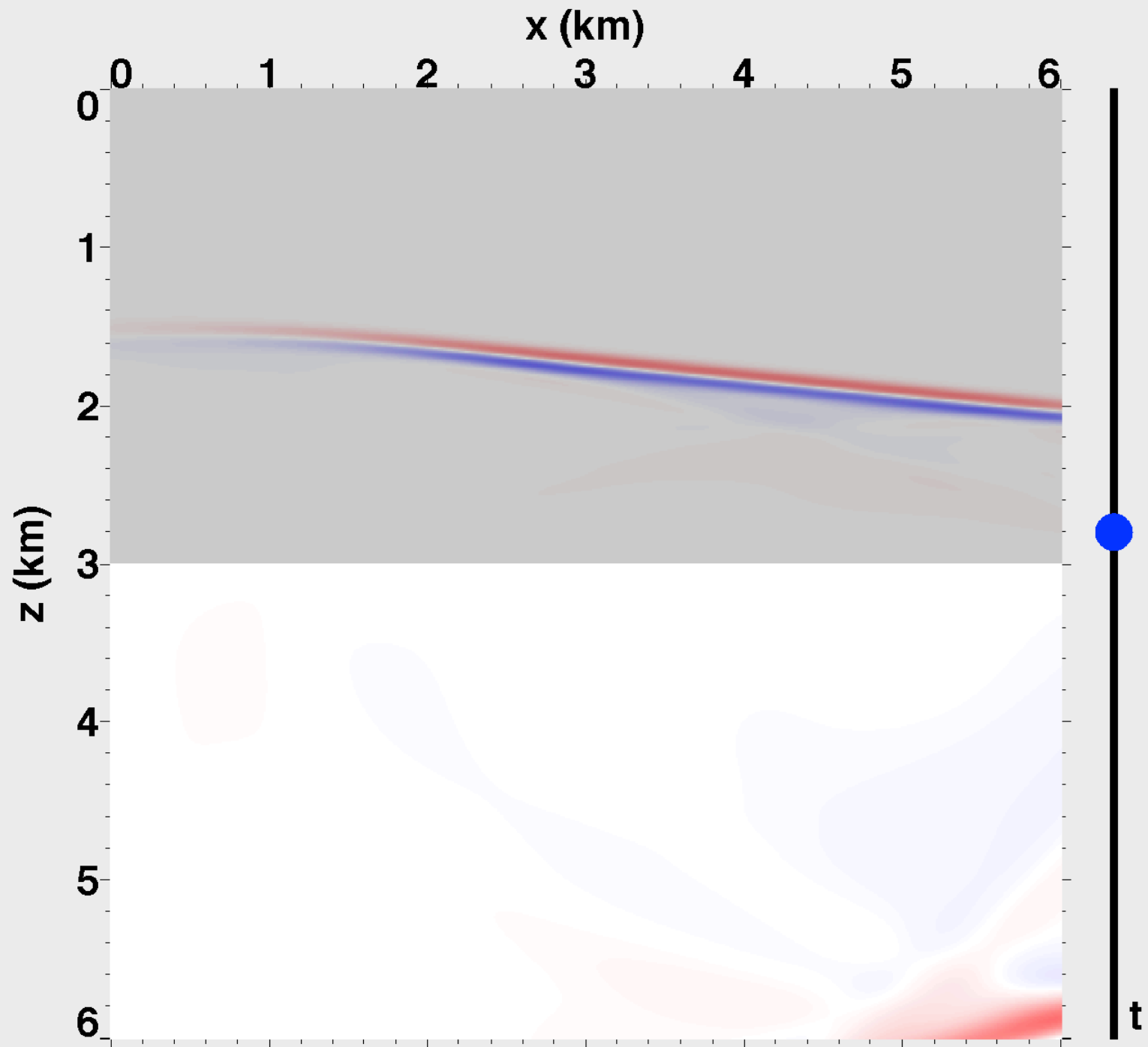


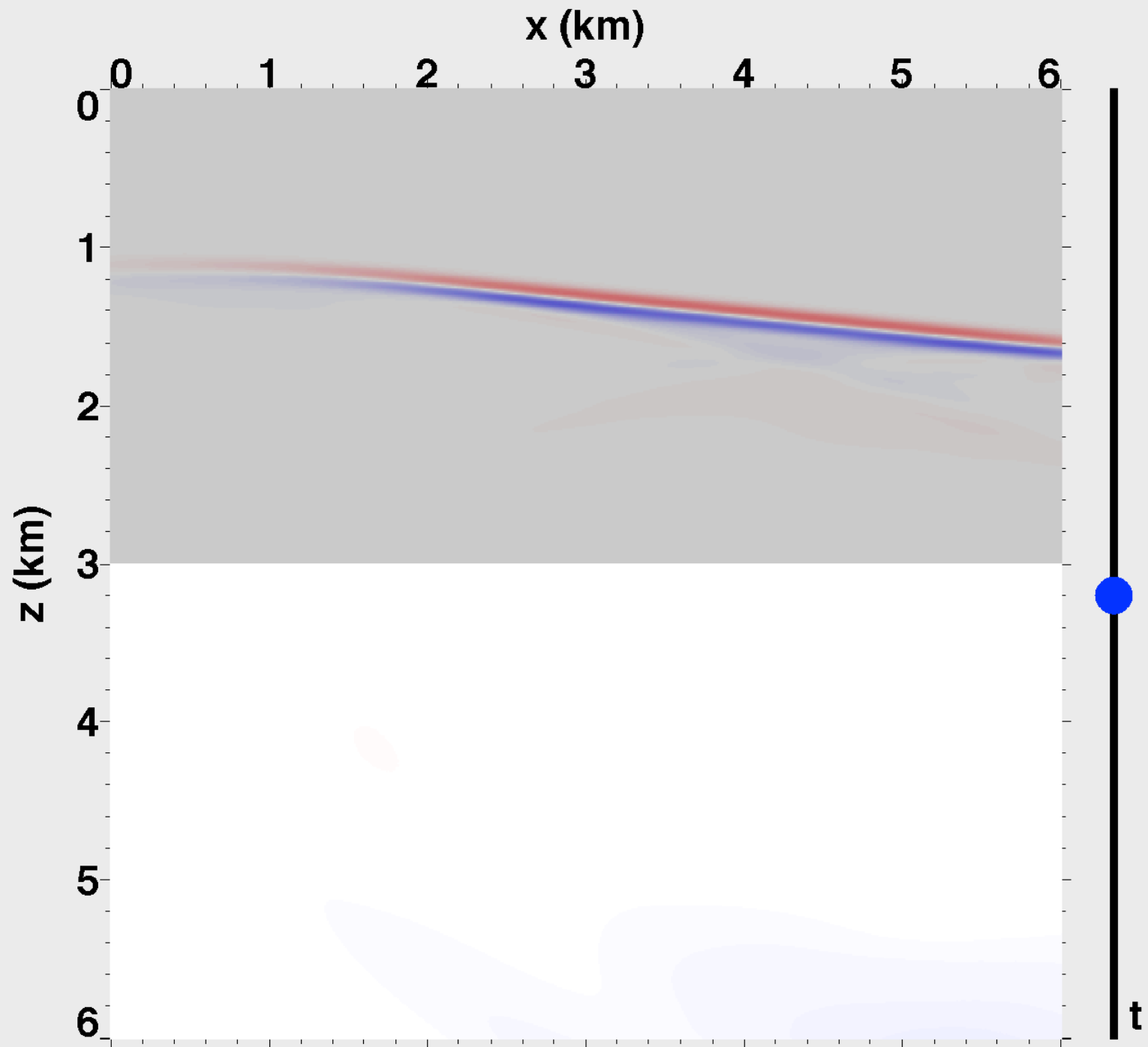


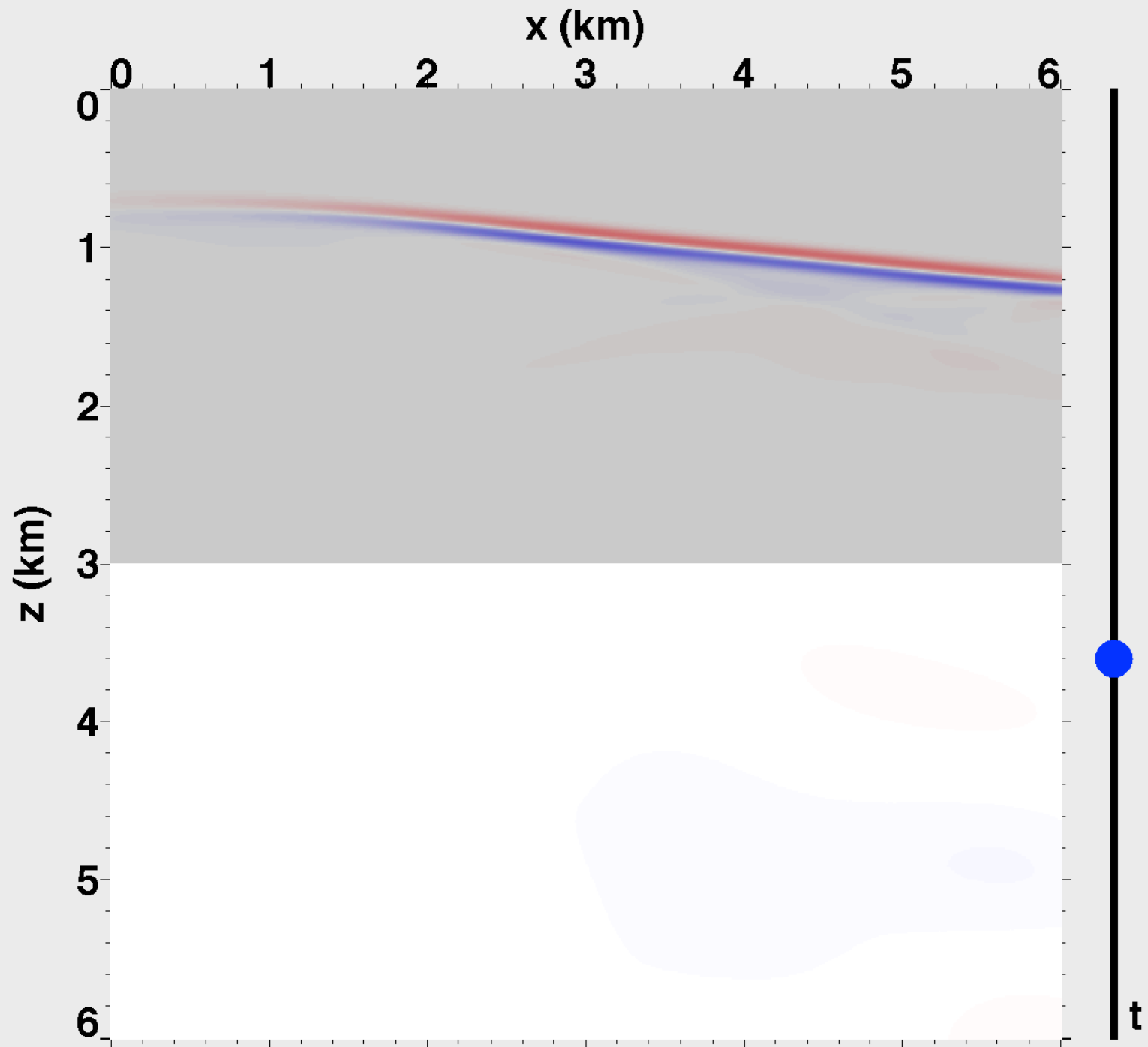


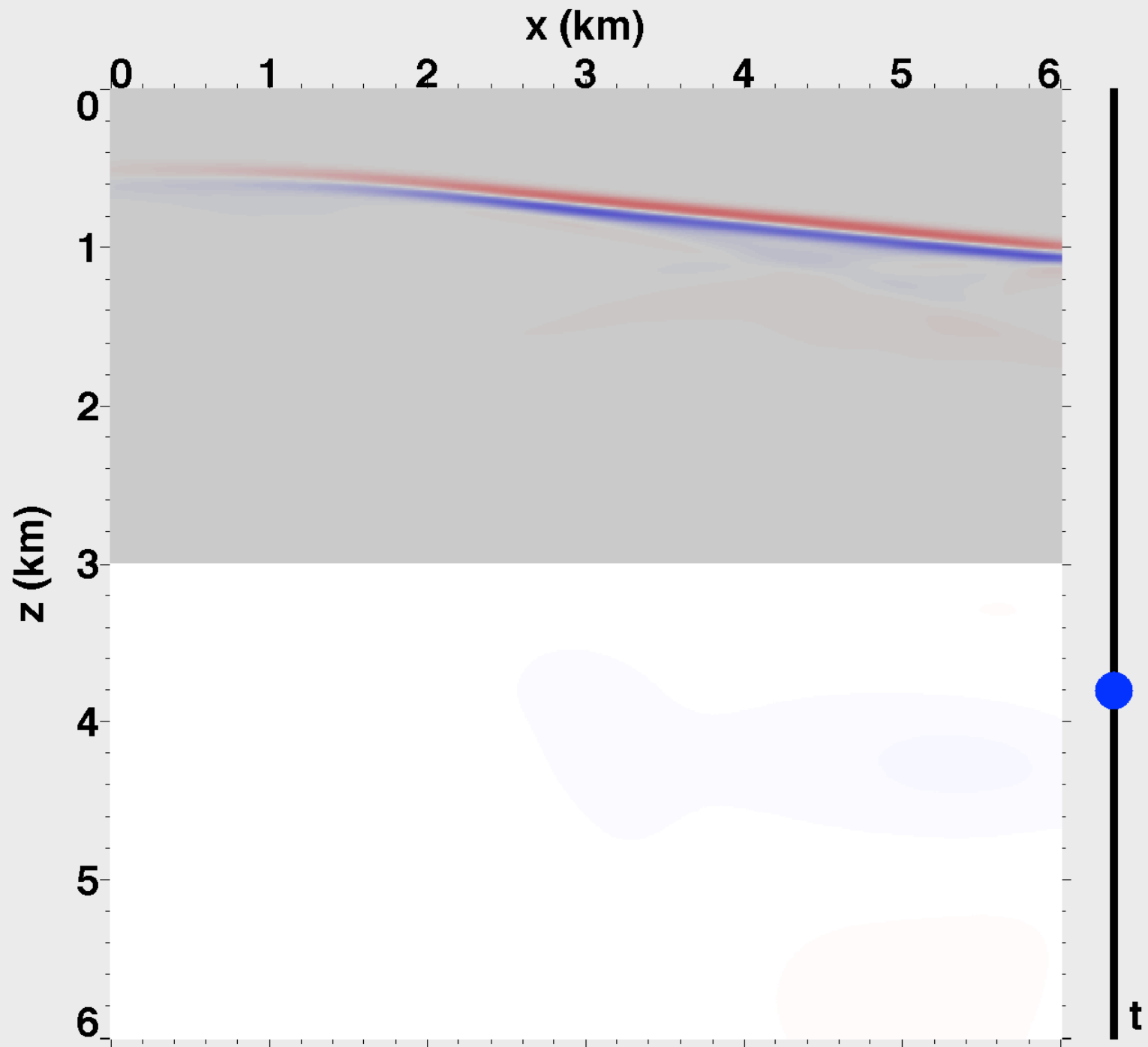






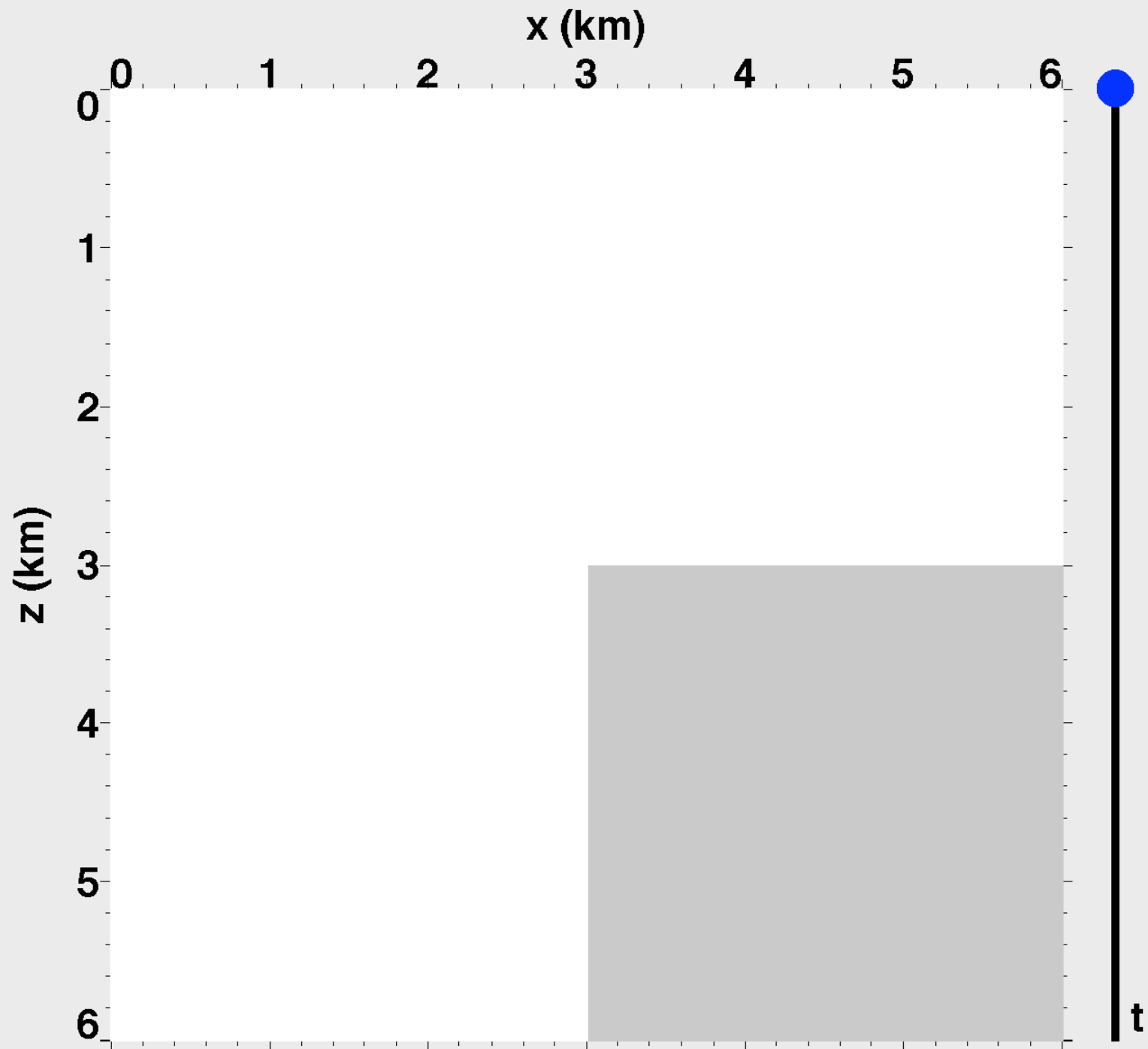


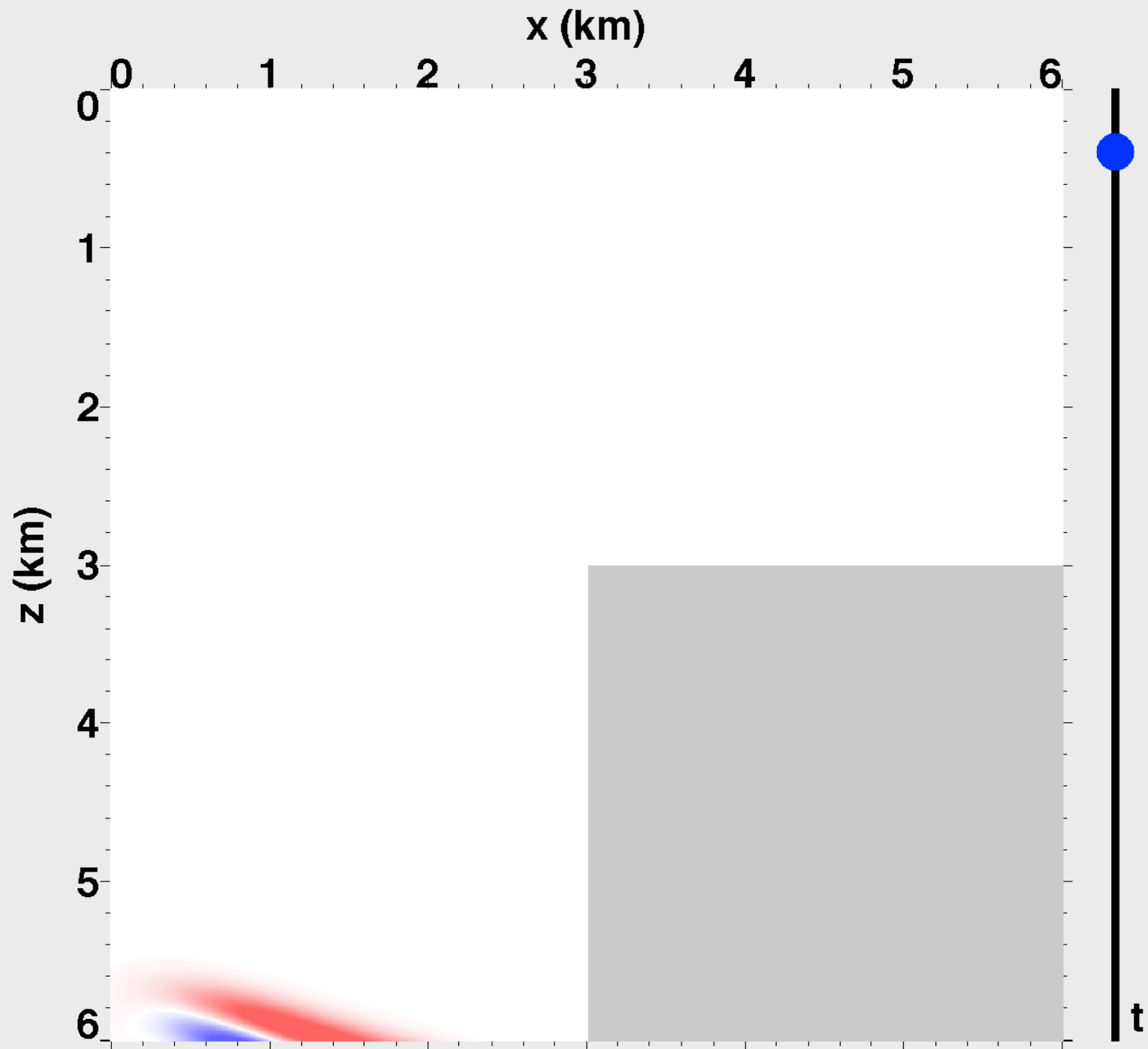


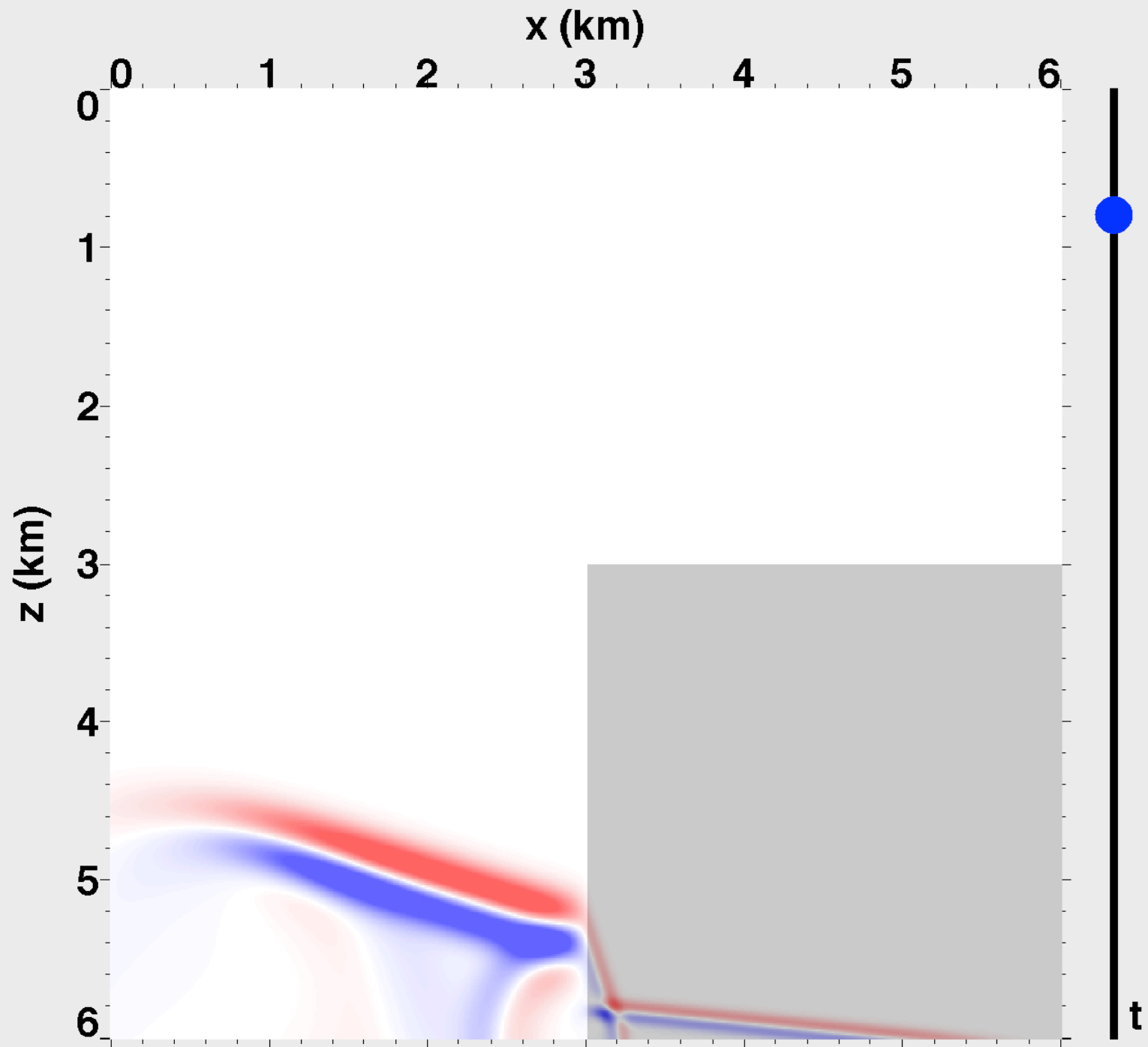


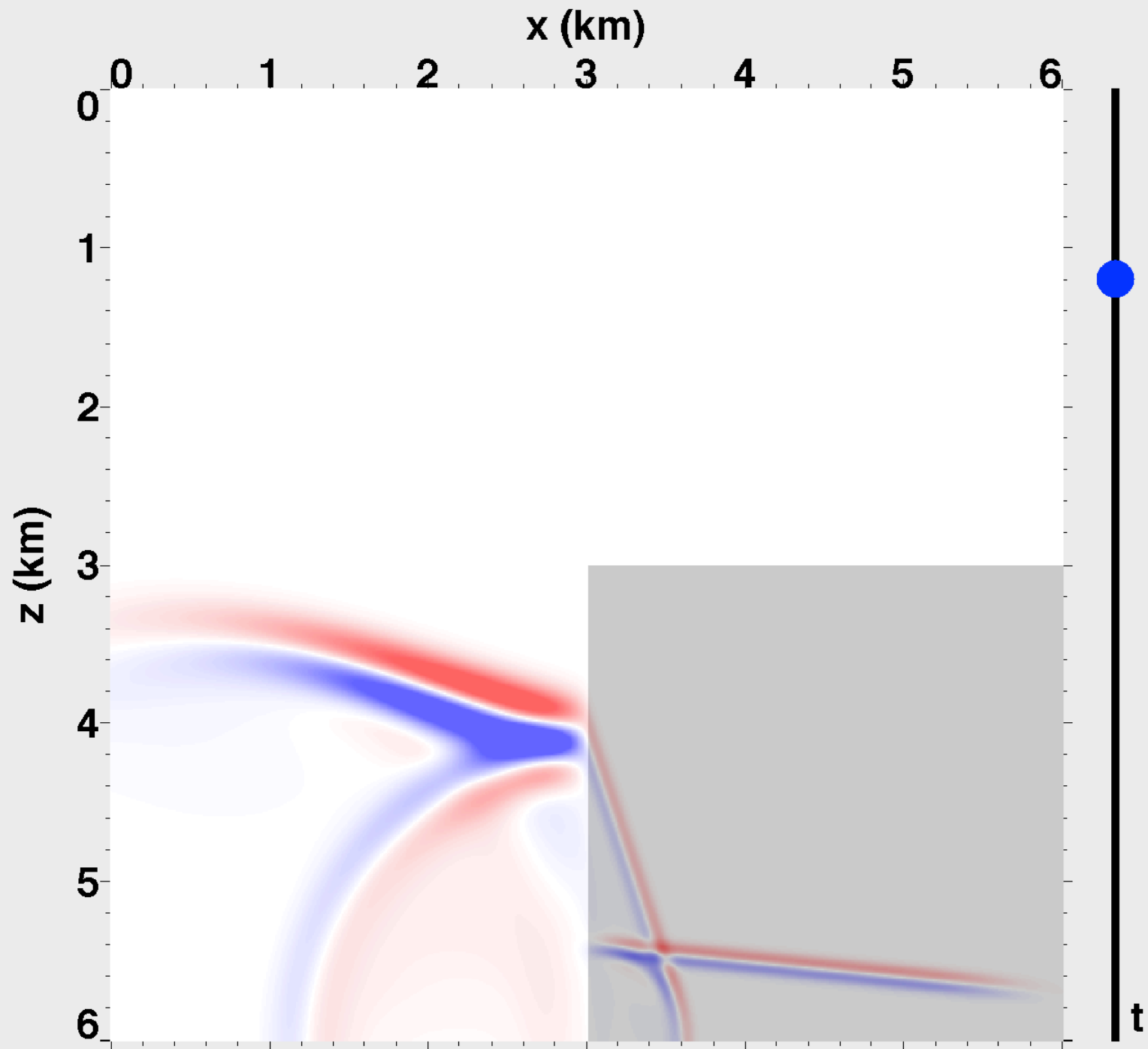
Change propagating direction

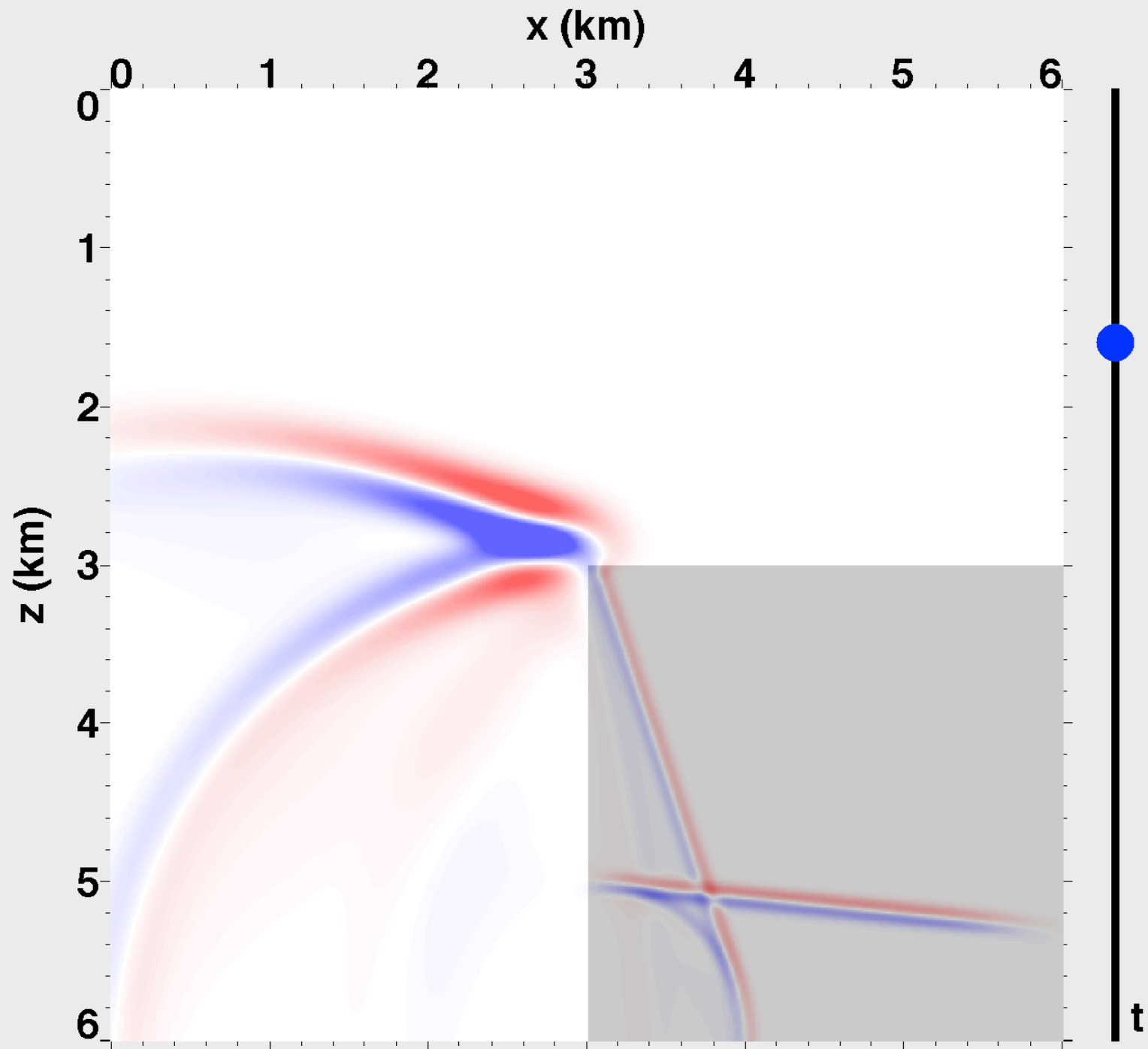
another example

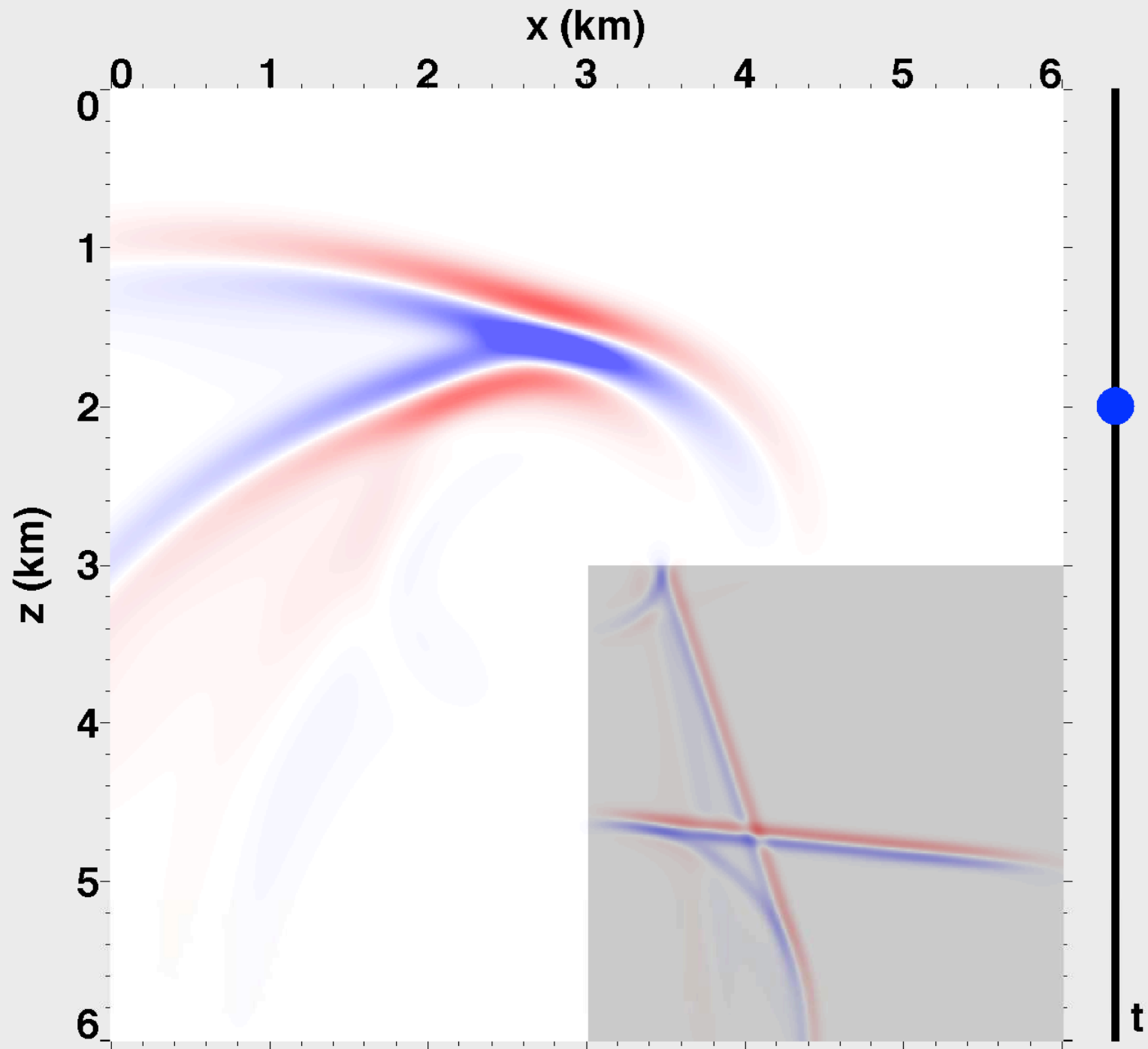


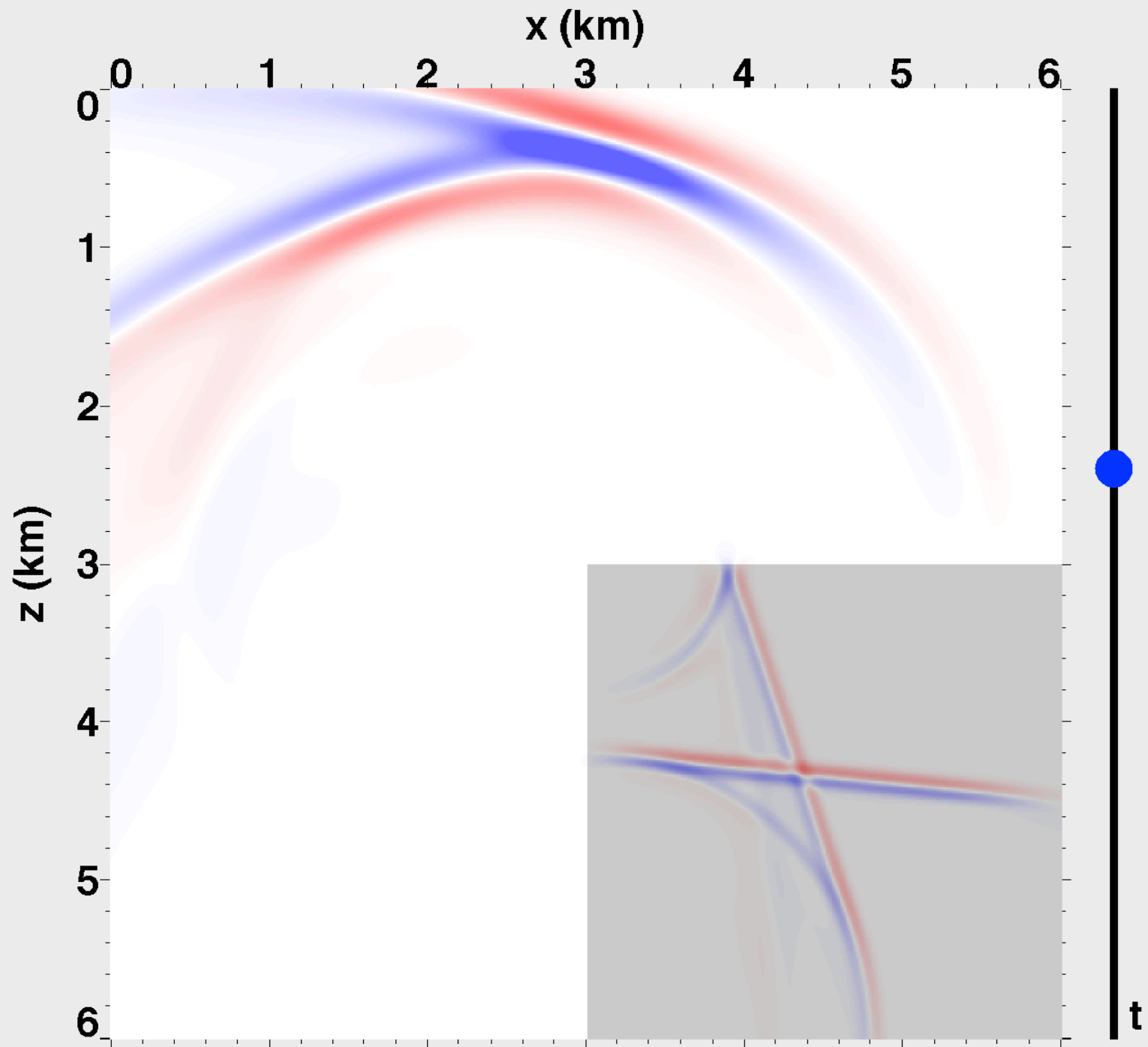


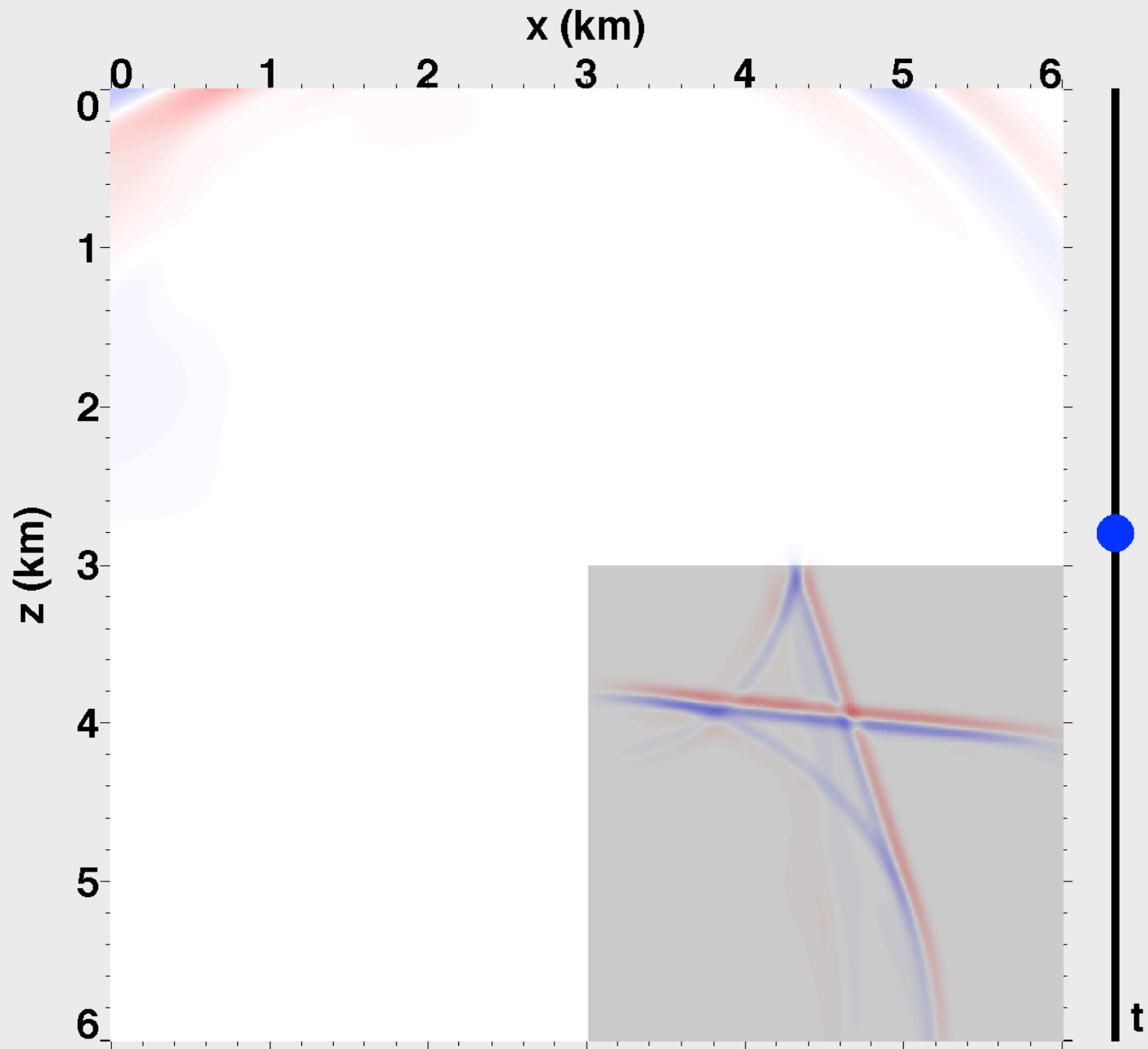


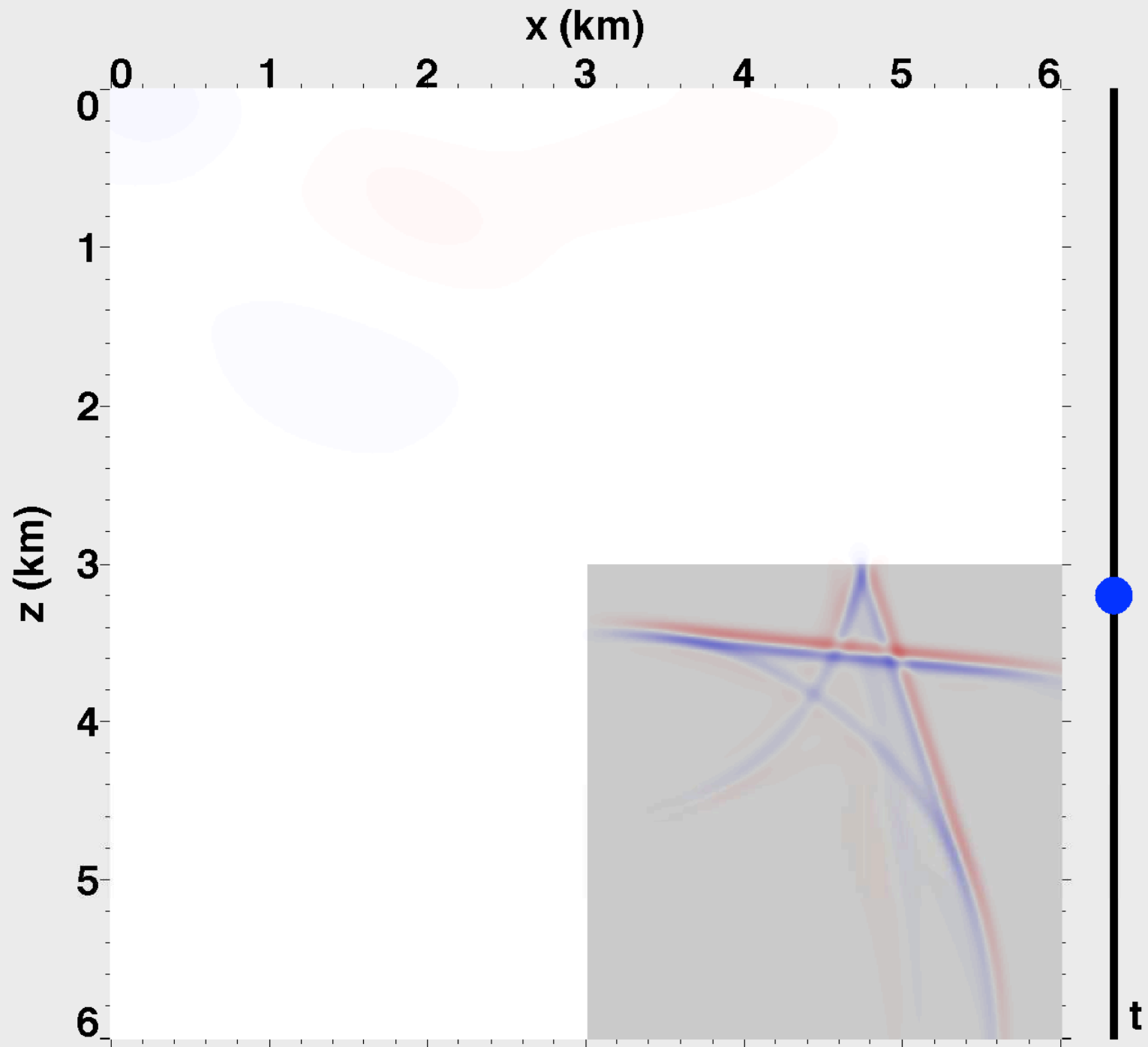


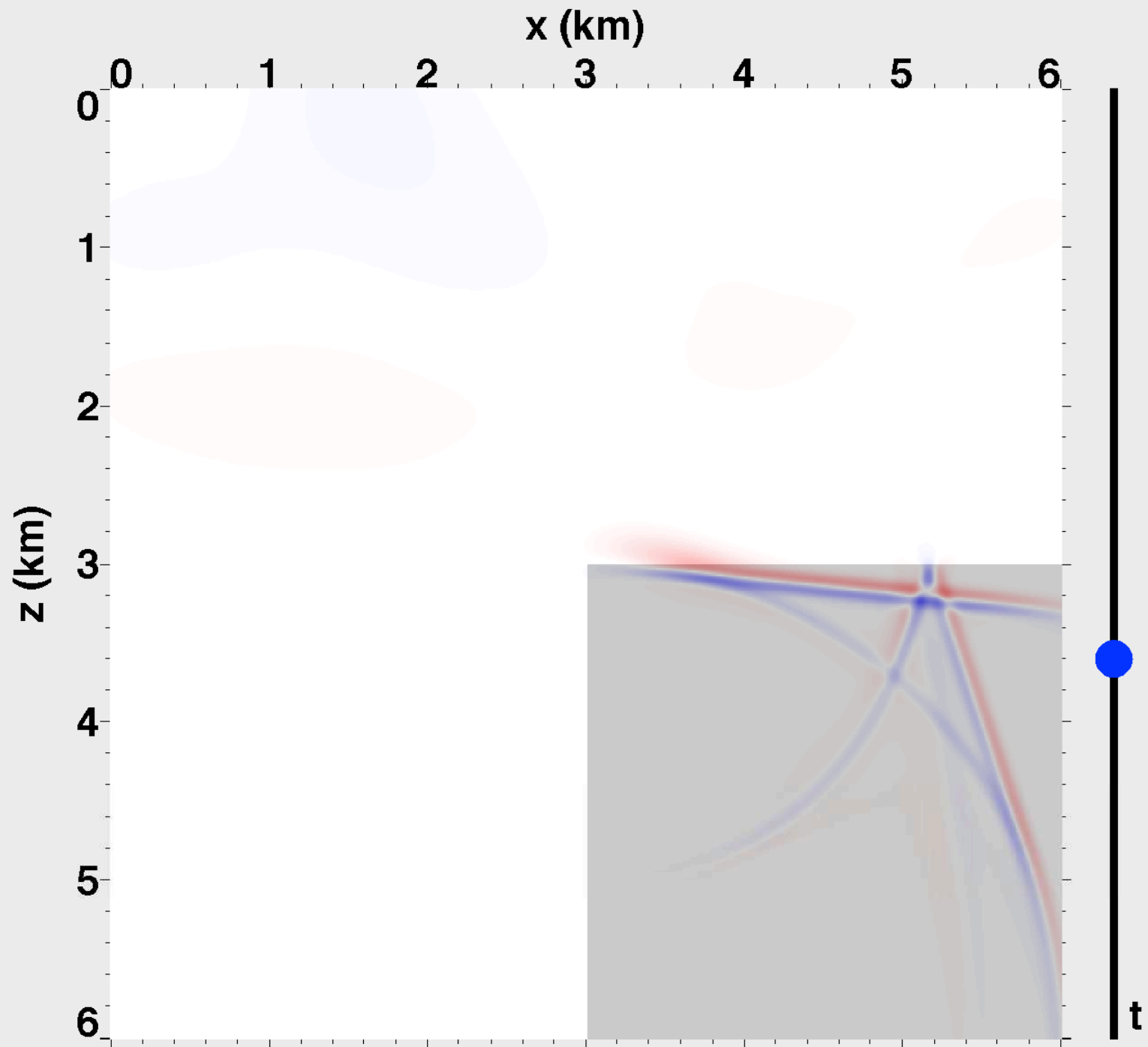


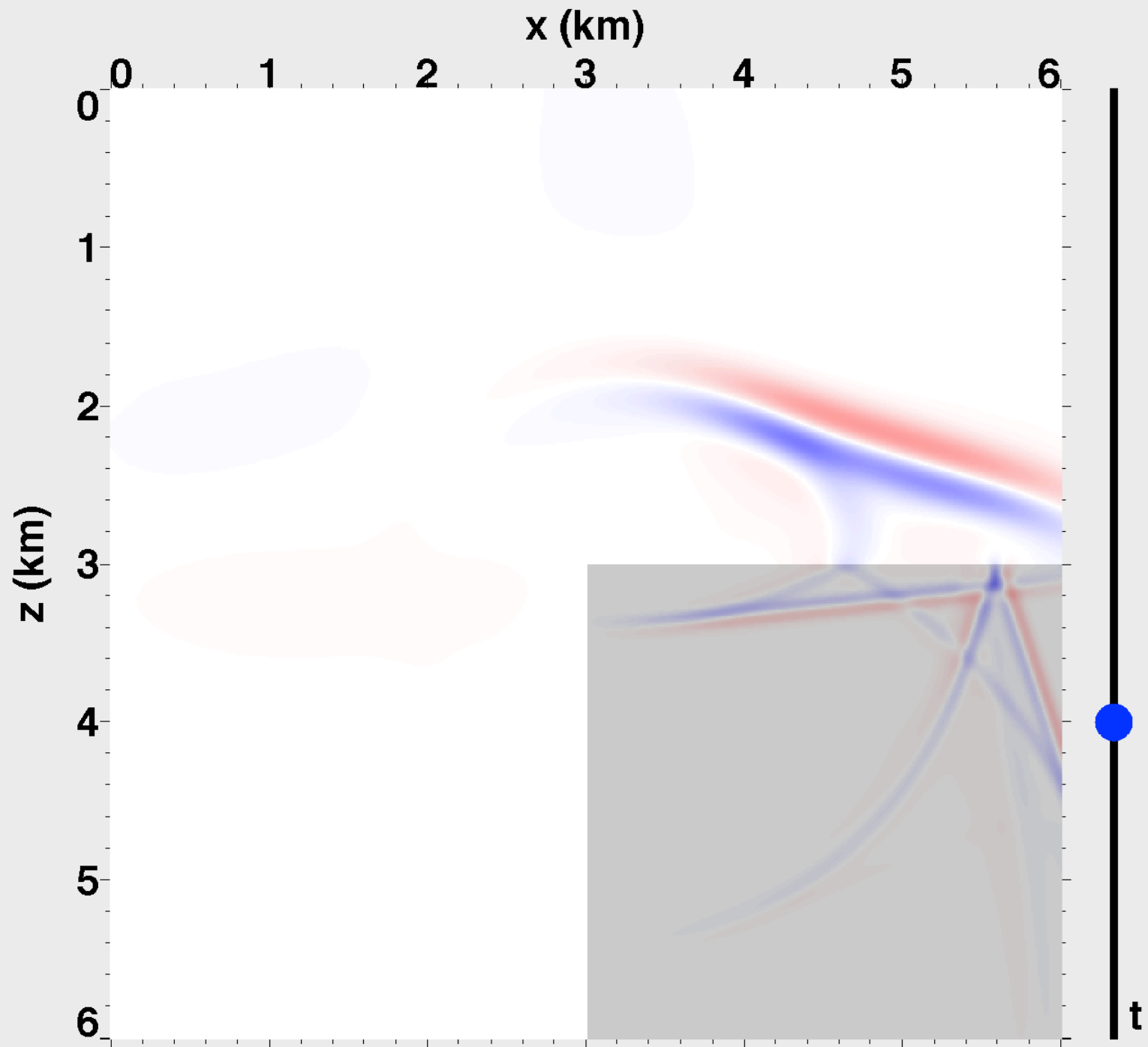


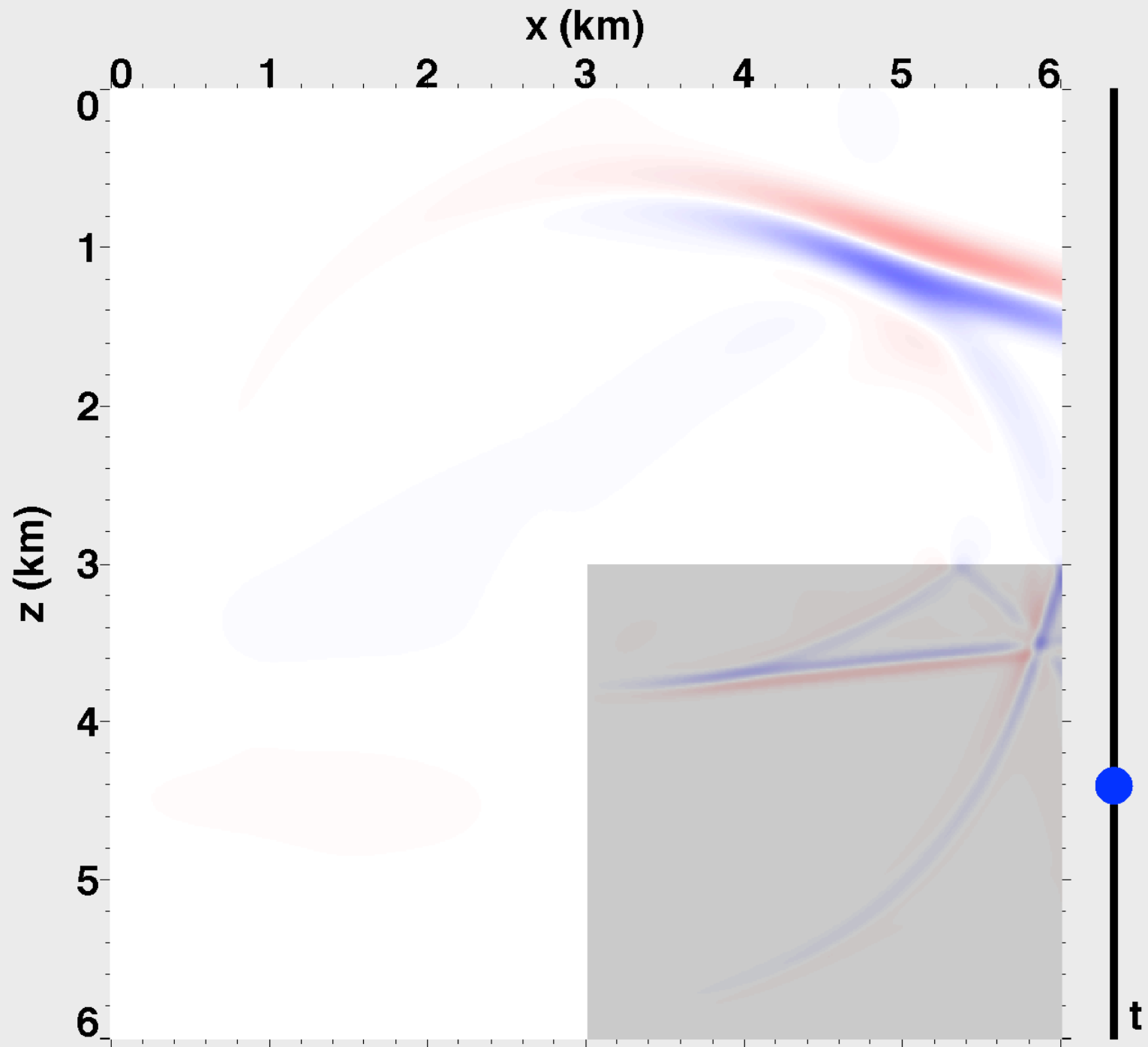


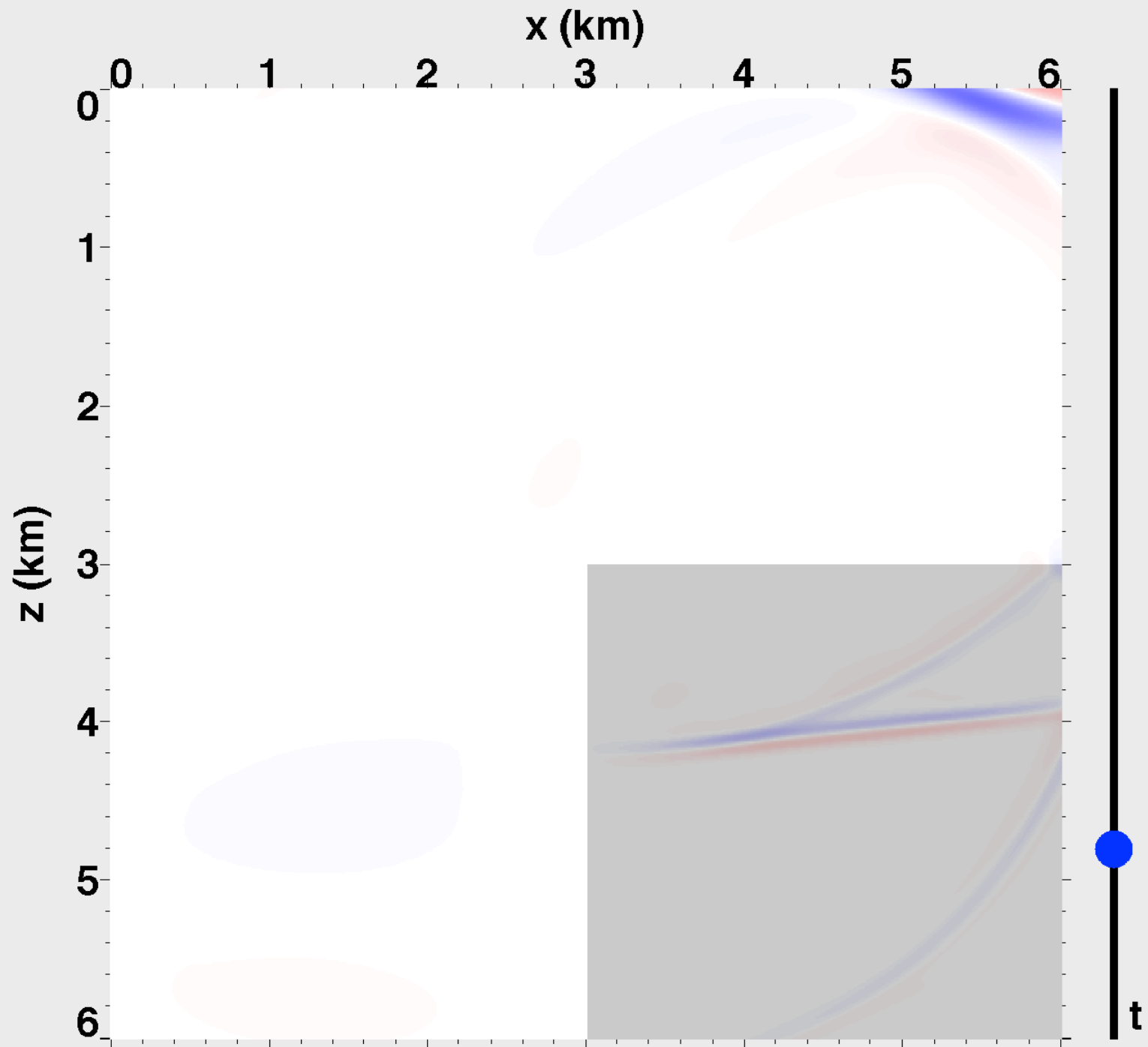


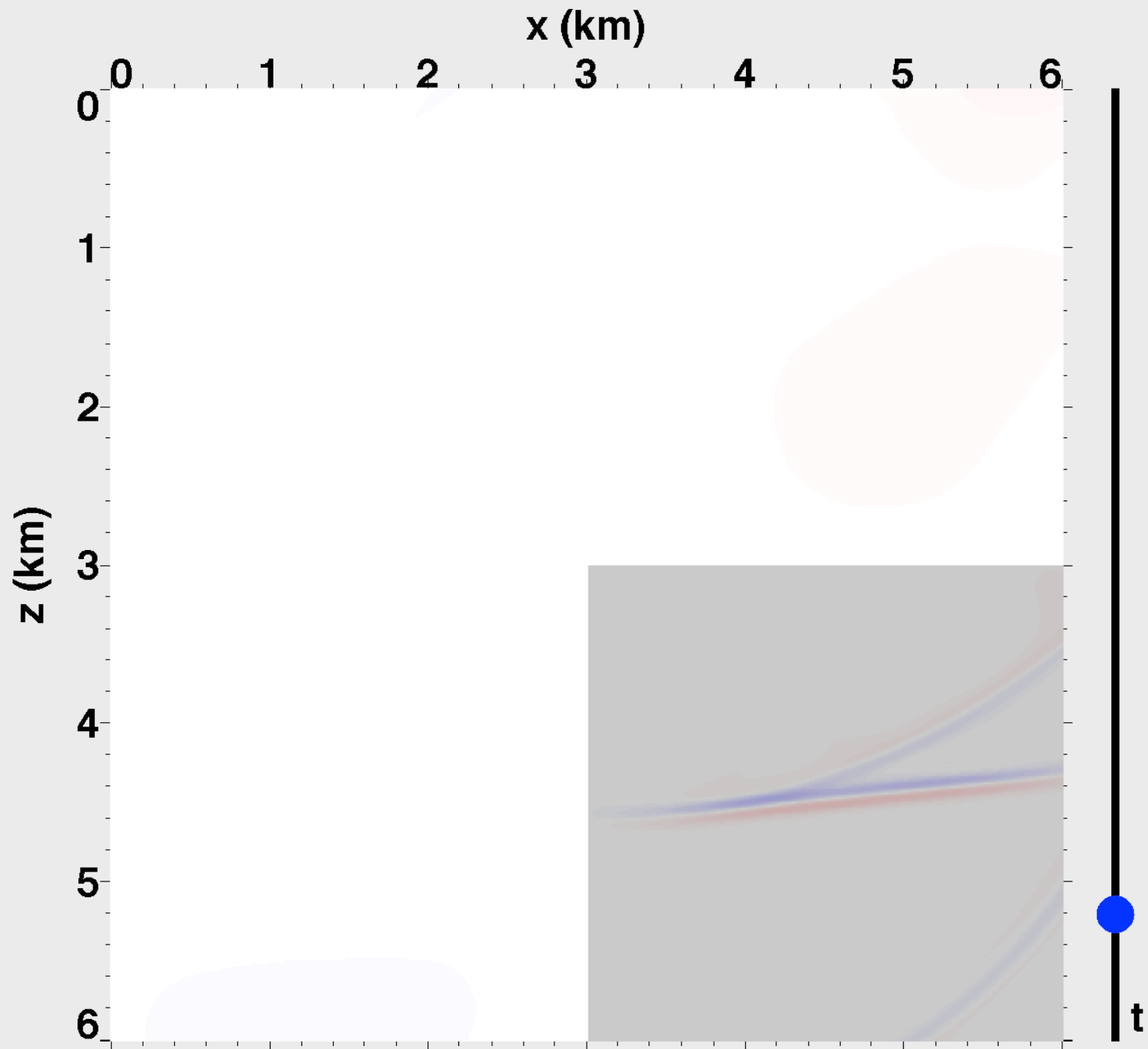


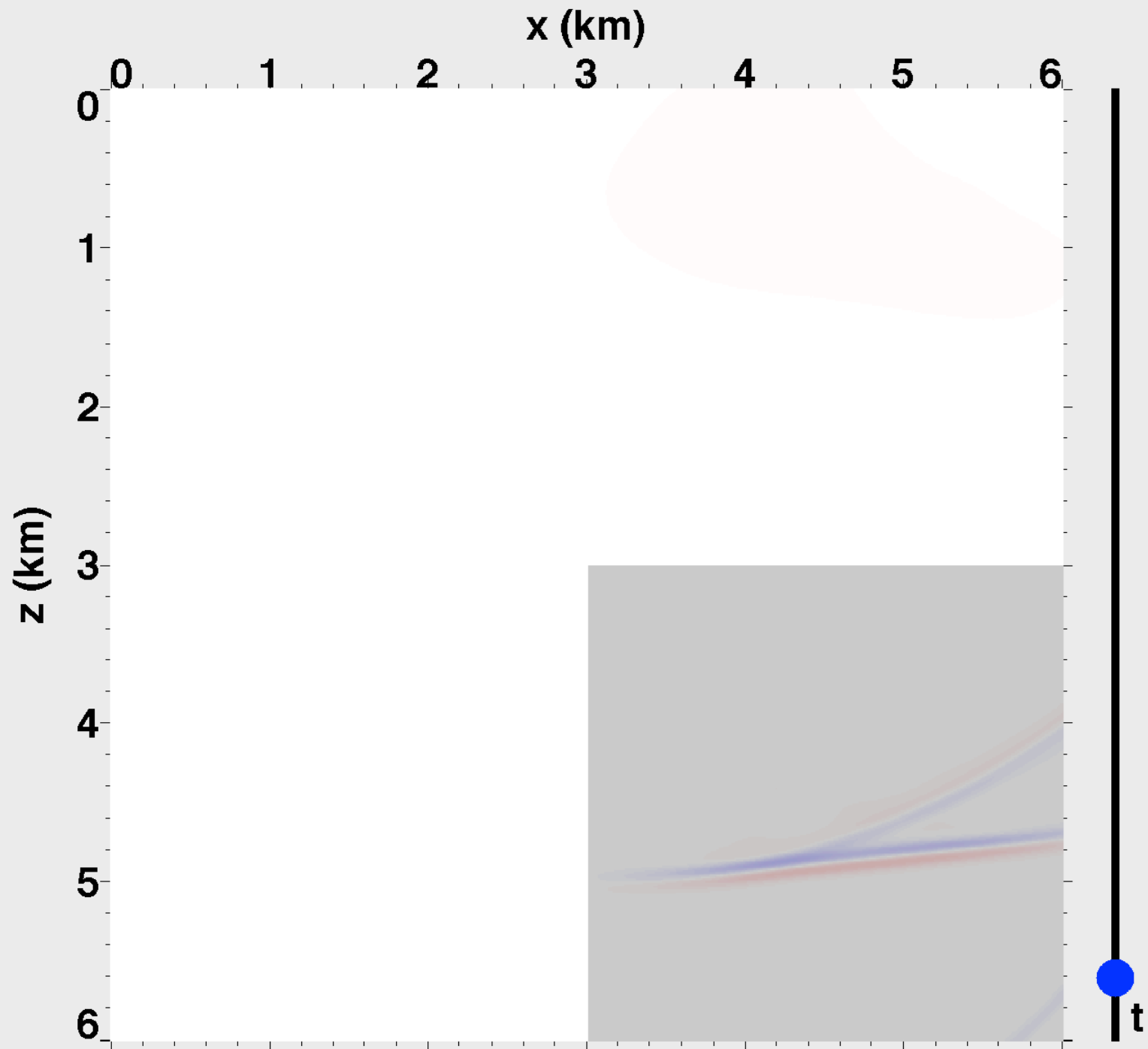








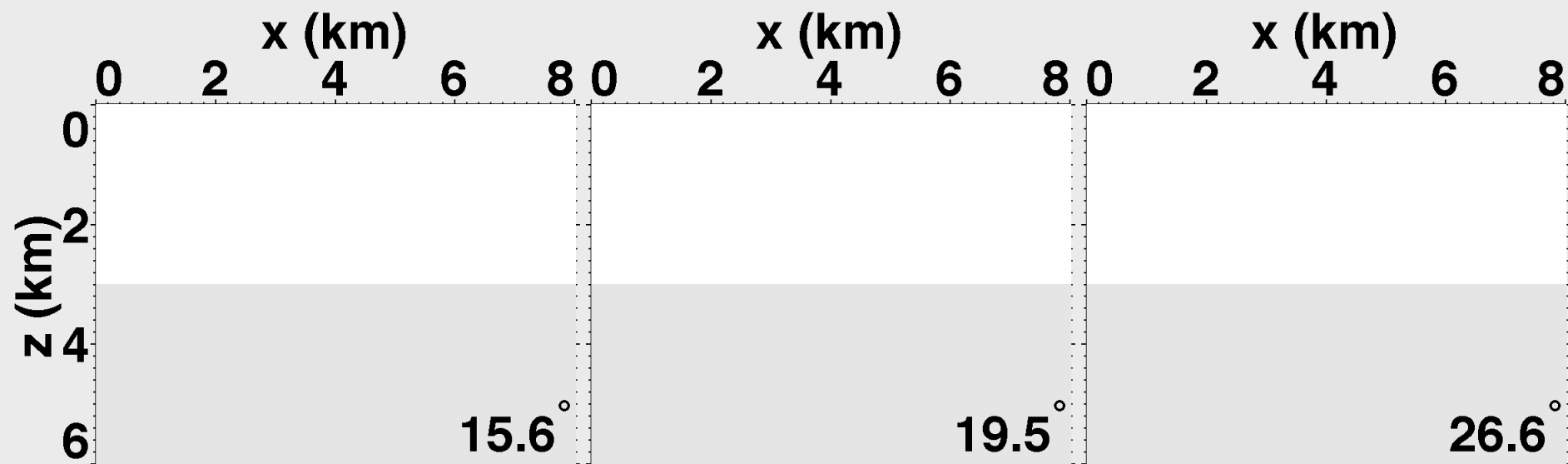
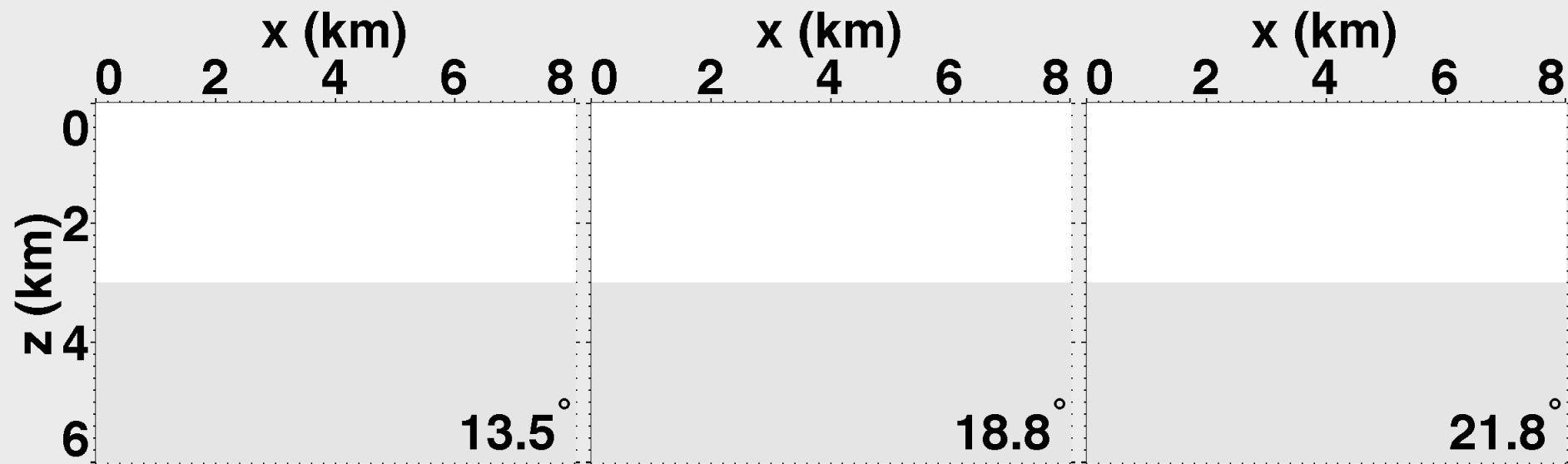


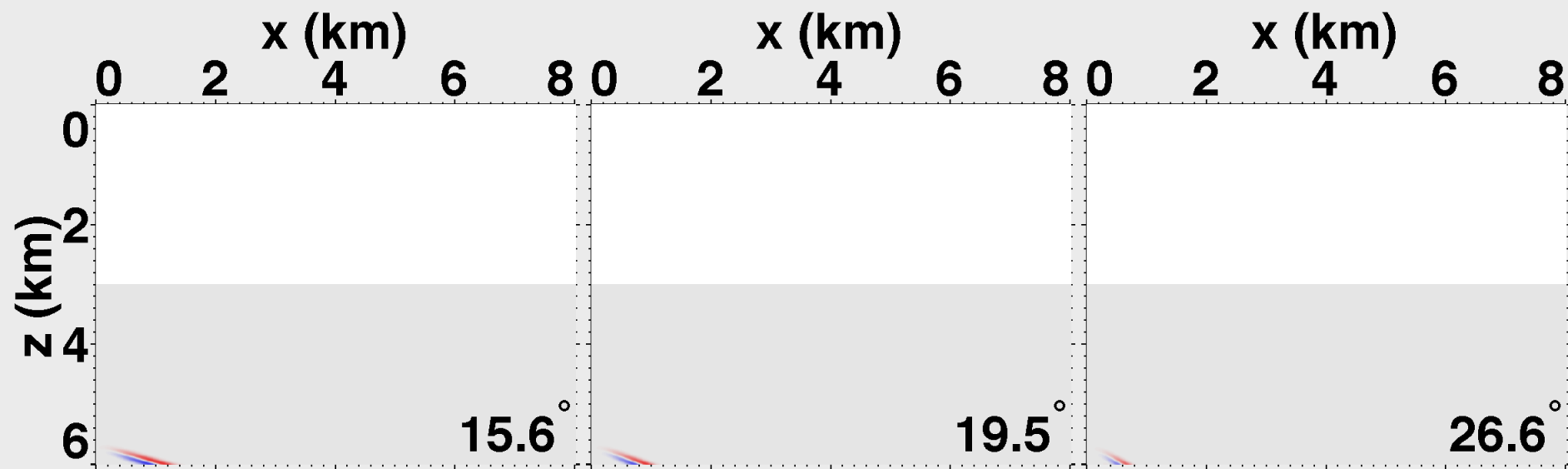
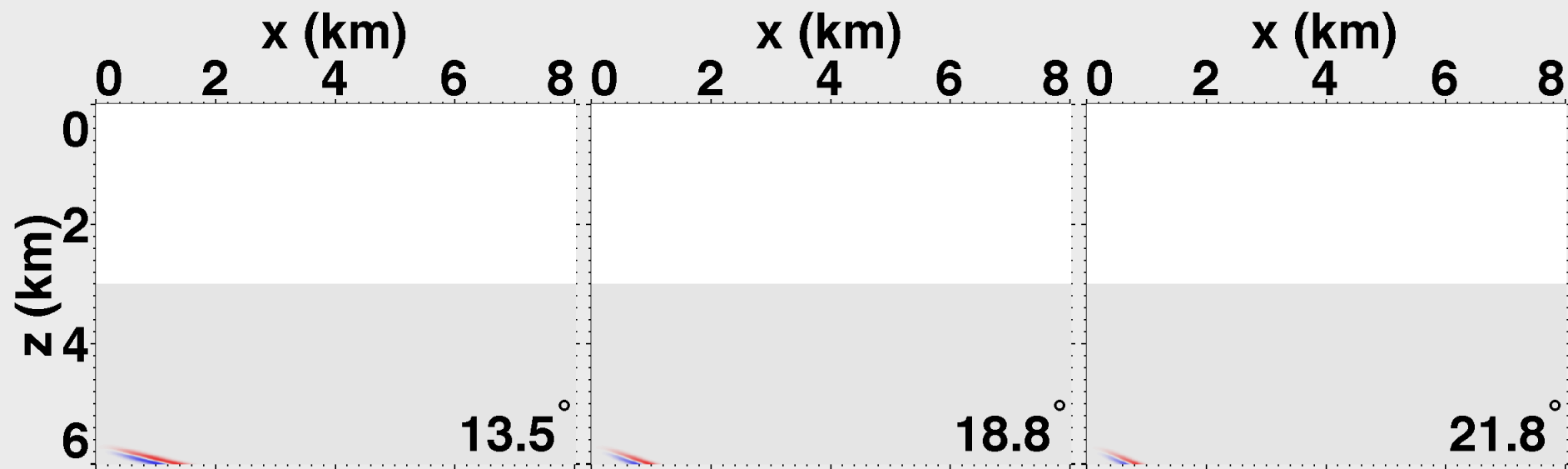


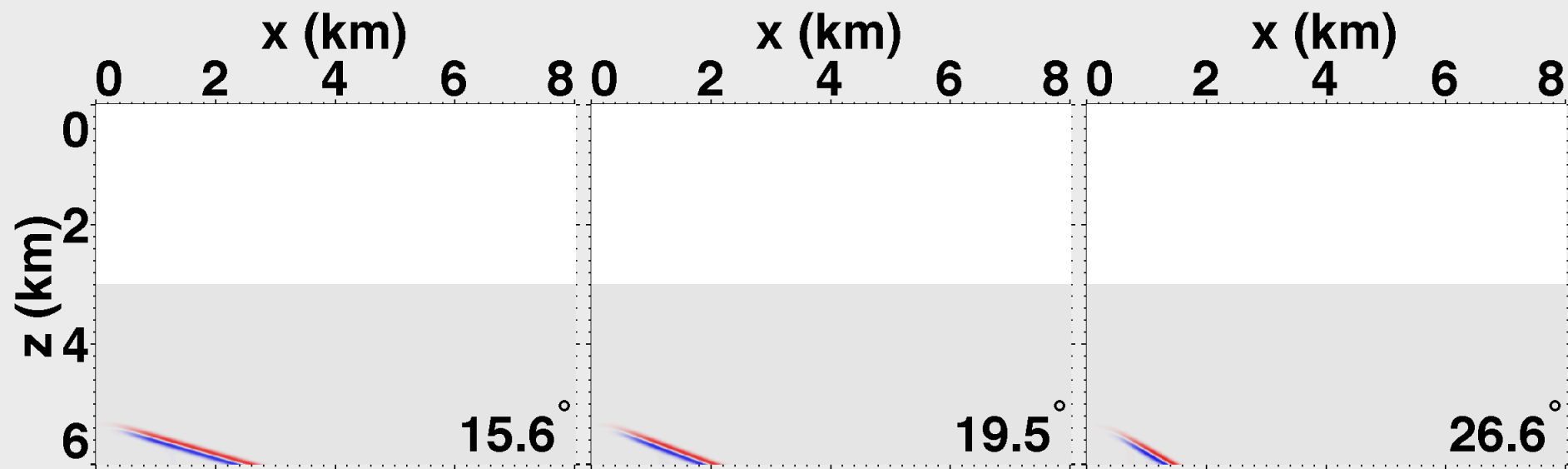
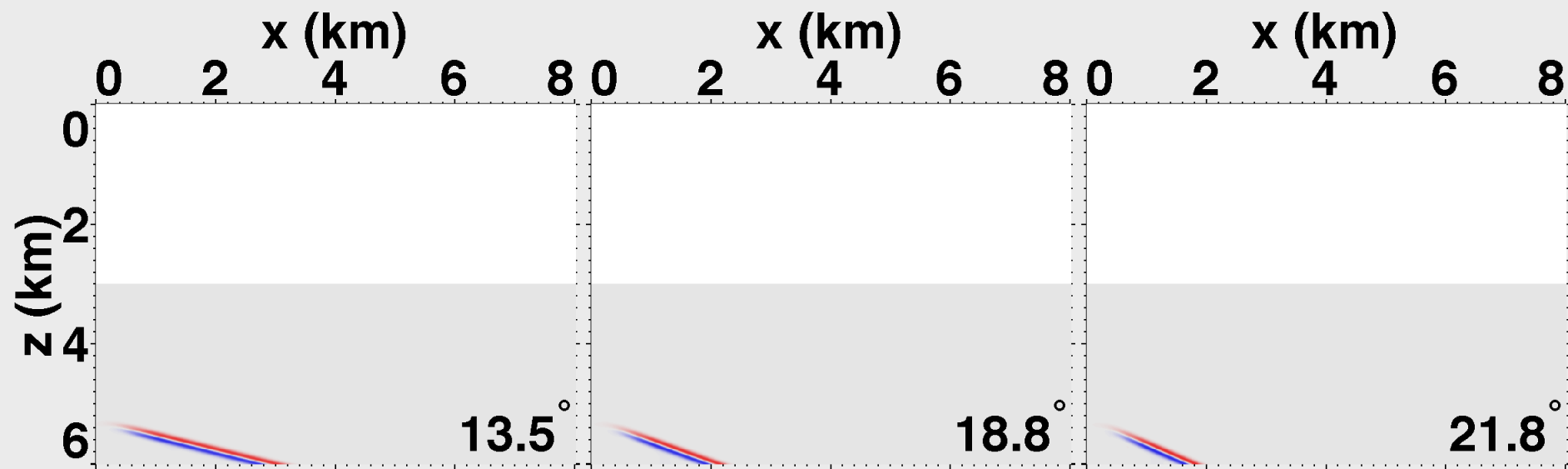
$$\begin{aligned}
\rho \begin{pmatrix} \frac{\partial^2 u_1}{\partial t^2} \\ \frac{\partial^2 u_2}{\partial t^2} \\ \frac{\partial^2 u_3}{\partial t^2} \end{pmatrix} &= (\lambda + 2\mu) \begin{pmatrix} \frac{\partial}{\partial x_1} \left(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2} + \frac{\partial u_3}{\partial x_3} \right) \\ \frac{\partial}{\partial x_2} \left(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2} + \frac{\partial u_3}{\partial x_3} \right) \\ \frac{\partial}{\partial x_3} \left(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2} + \frac{\partial u_3}{\partial x_3} \right) \end{pmatrix} \\
&\quad - \mu \begin{pmatrix} \frac{\partial}{\partial x_2} \left(\frac{\partial u_2}{\partial x_1} - \frac{\partial u_1}{\partial x_2} \right) - \frac{\partial}{\partial x_3} \left(\frac{\partial u_1}{\partial x_3} - \frac{\partial u_3}{\partial x_1} \right) \\ \frac{\partial}{\partial x_3} \left(\frac{\partial u_3}{\partial x_2} - \frac{\partial u_2}{\partial x_3} \right) - \frac{\partial}{\partial x_1} \left(\frac{\partial u_2}{\partial x_1} - \frac{\partial u_1}{\partial x_2} \right) \\ \frac{\partial}{\partial x_1} \left(\frac{\partial u_1}{\partial x_3} - \frac{\partial u_3}{\partial x_1} \right) - \frac{\partial}{\partial x_2} \left(\frac{\partial u_3}{\partial x_2} - \frac{\partial u_2}{\partial x_3} \right) \end{pmatrix}
\end{aligned}$$

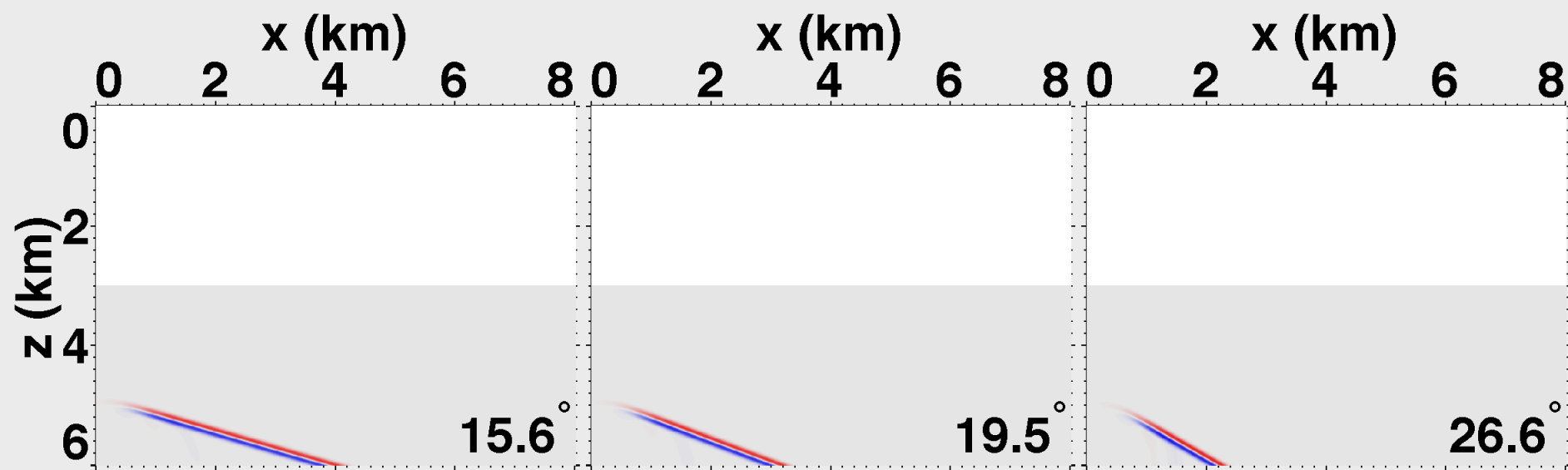
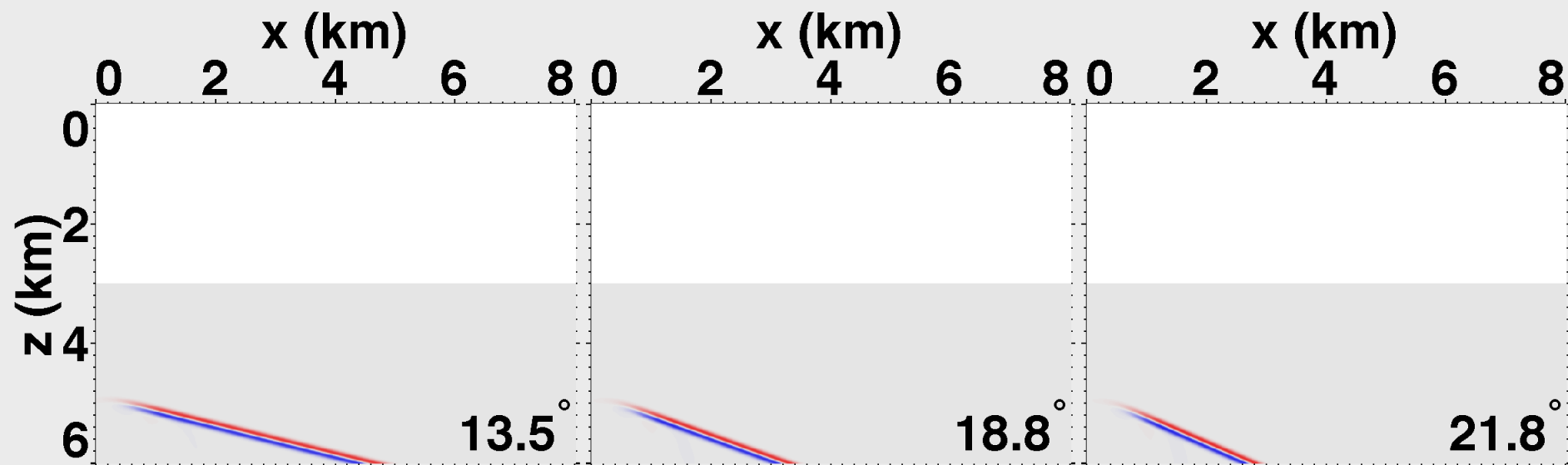
$$\begin{aligned}
\rho \begin{pmatrix} \frac{\partial^2 u_1}{\partial t^2} \\ \frac{\partial^2 u_2}{\partial t^2} \\ \frac{\partial^2 u_3}{\partial t^2} \end{pmatrix} &= (\lambda + 2\mu) \begin{pmatrix} \frac{\partial}{\partial x_1} \left(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_3}{\partial x_3} \right) \\ 0 \\ \frac{\partial}{\partial x_3} \left(\frac{\partial u_1}{\partial x_1} + \frac{\partial u_3}{\partial x_3} \right) \end{pmatrix} \\
&\quad + \mu \begin{pmatrix} \frac{\partial}{\partial x_3} \left(\frac{\partial u_1}{\partial x_3} - \frac{\partial u_3}{\partial x_1} \right) \\ \frac{\partial^2 u_2}{\partial x_3^2} + \frac{\partial^2 u_2}{\partial x_1^2} \\ \frac{\partial}{\partial x_1} \left(\frac{\partial u_1}{\partial x_3} - \frac{\partial u_3}{\partial x_1} \right) \end{pmatrix}
\end{aligned}$$

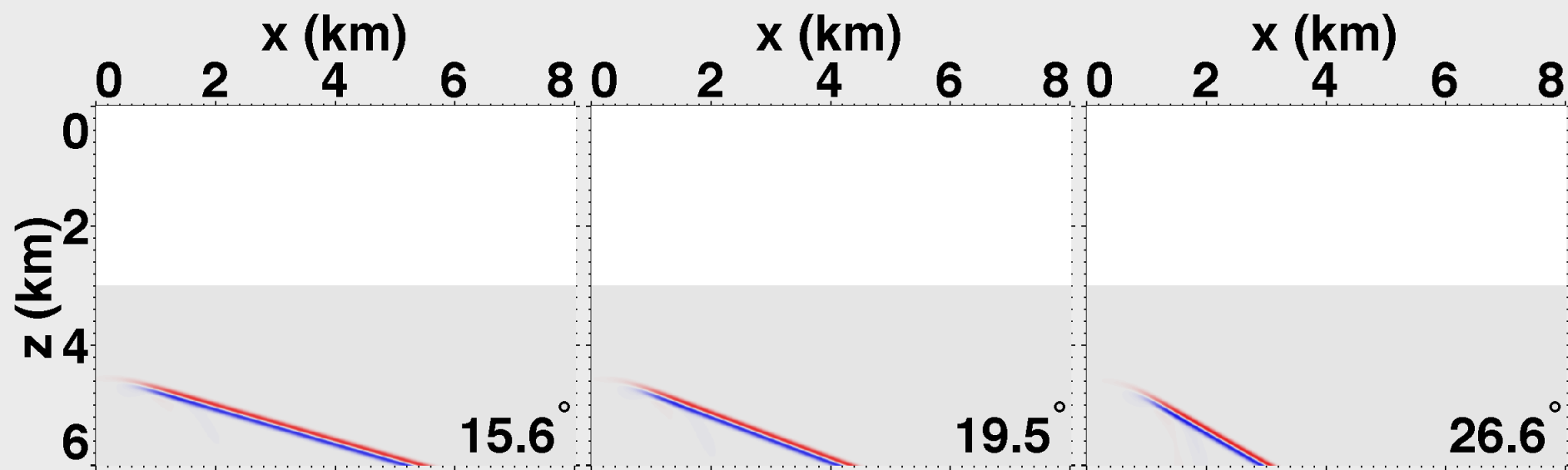
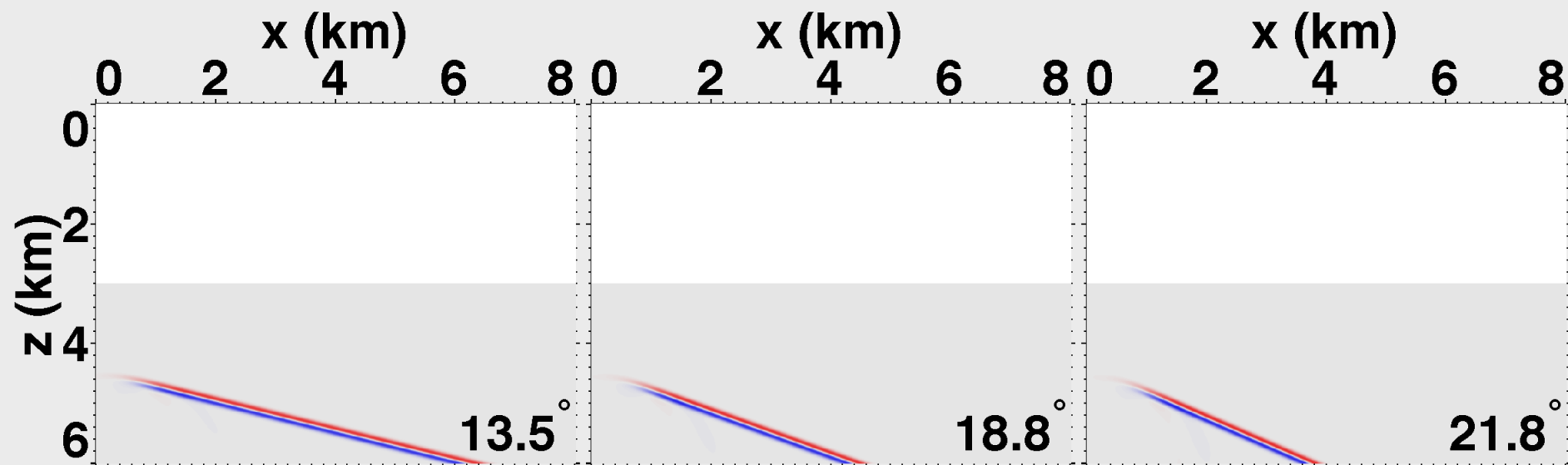
Postcritical waves

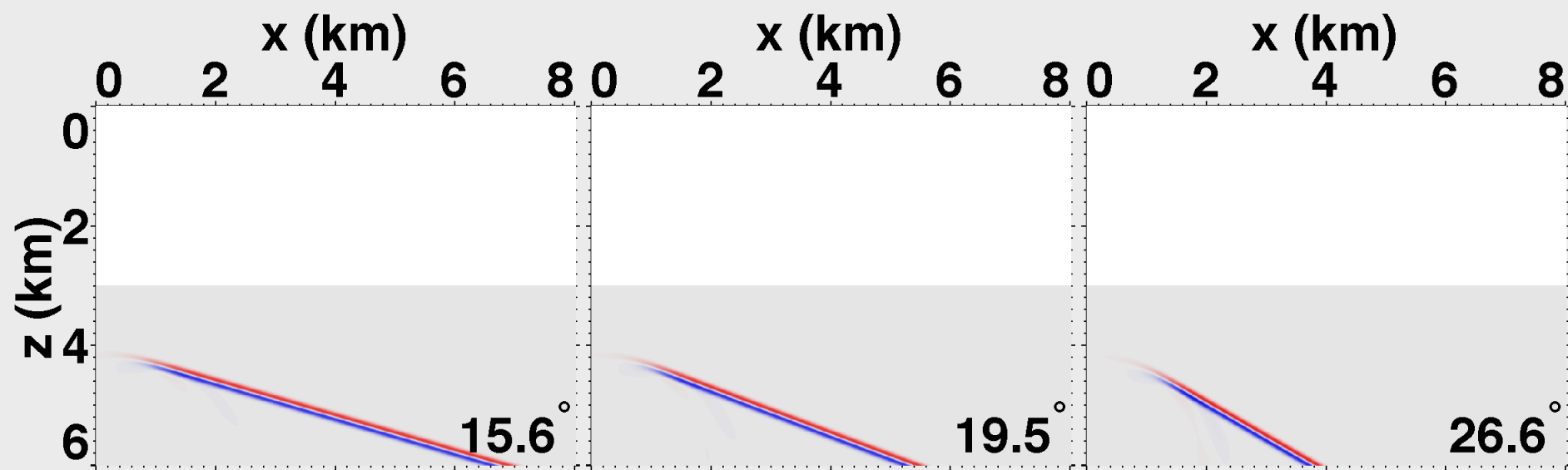
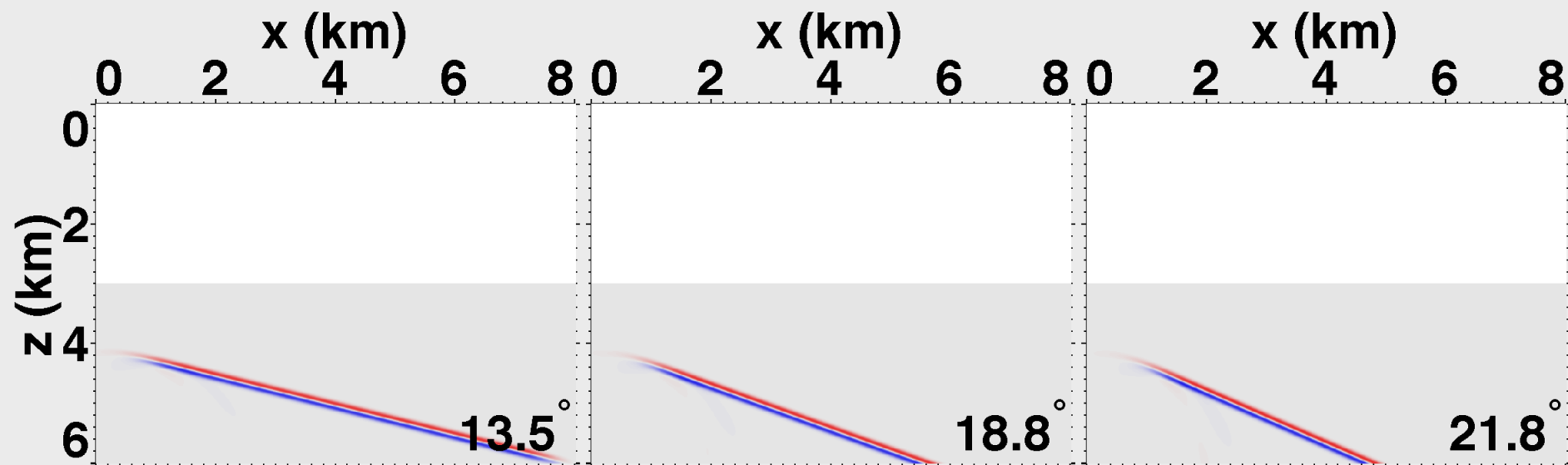


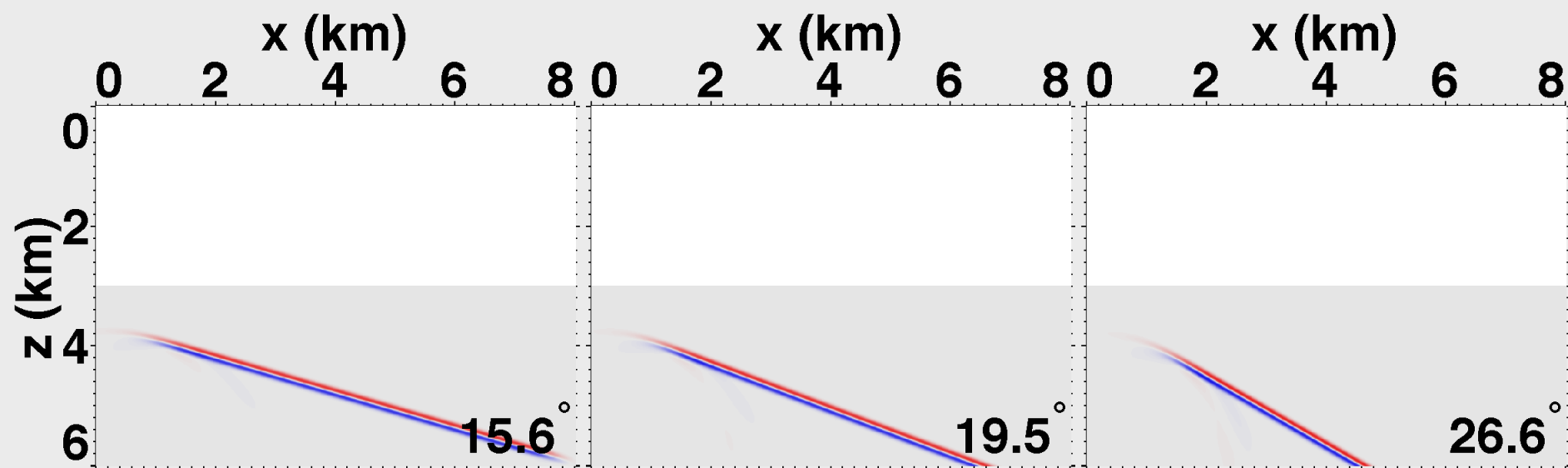
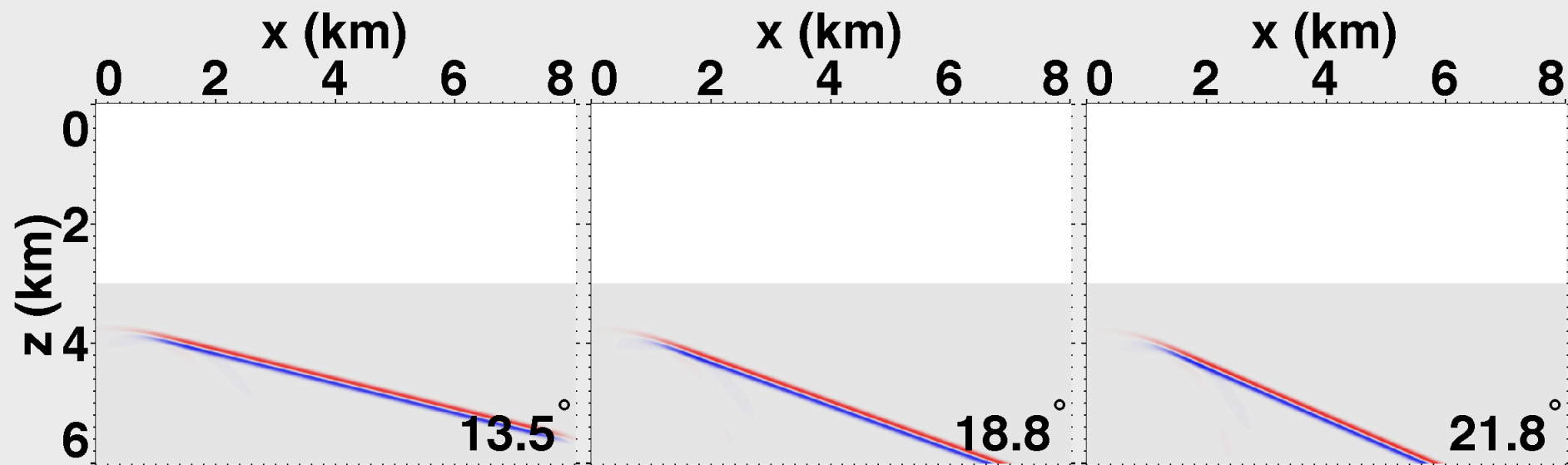


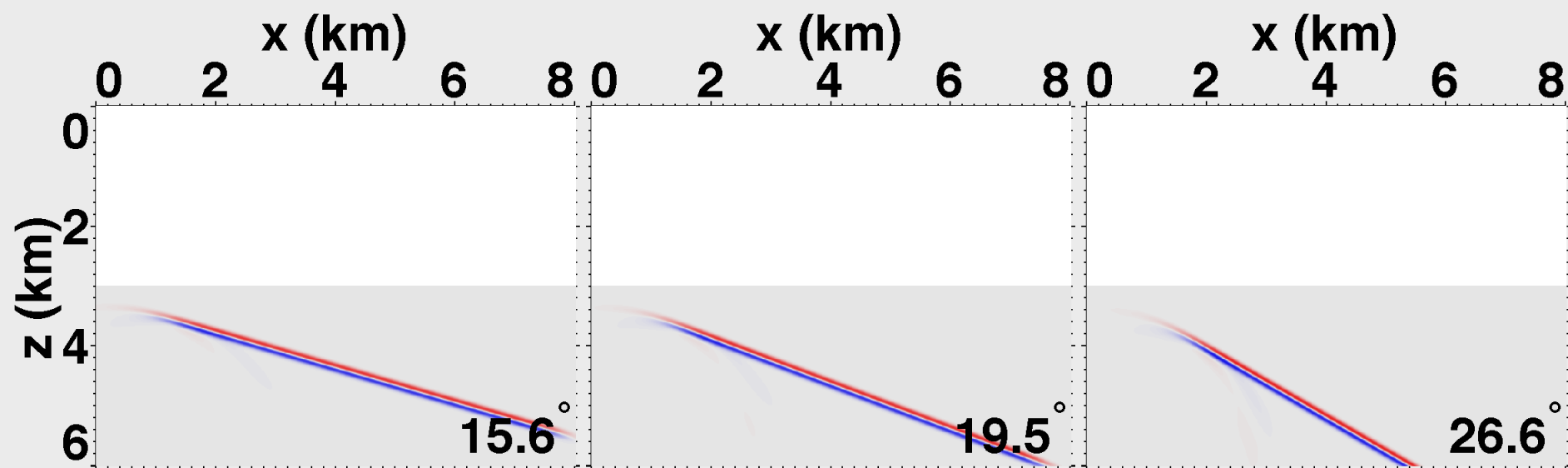
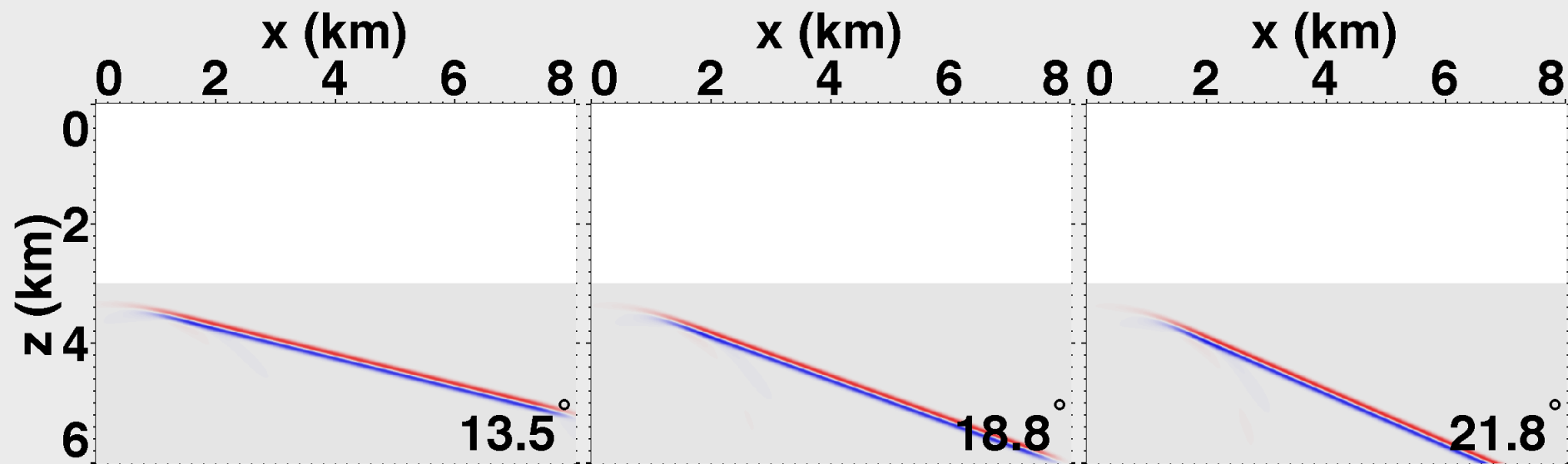


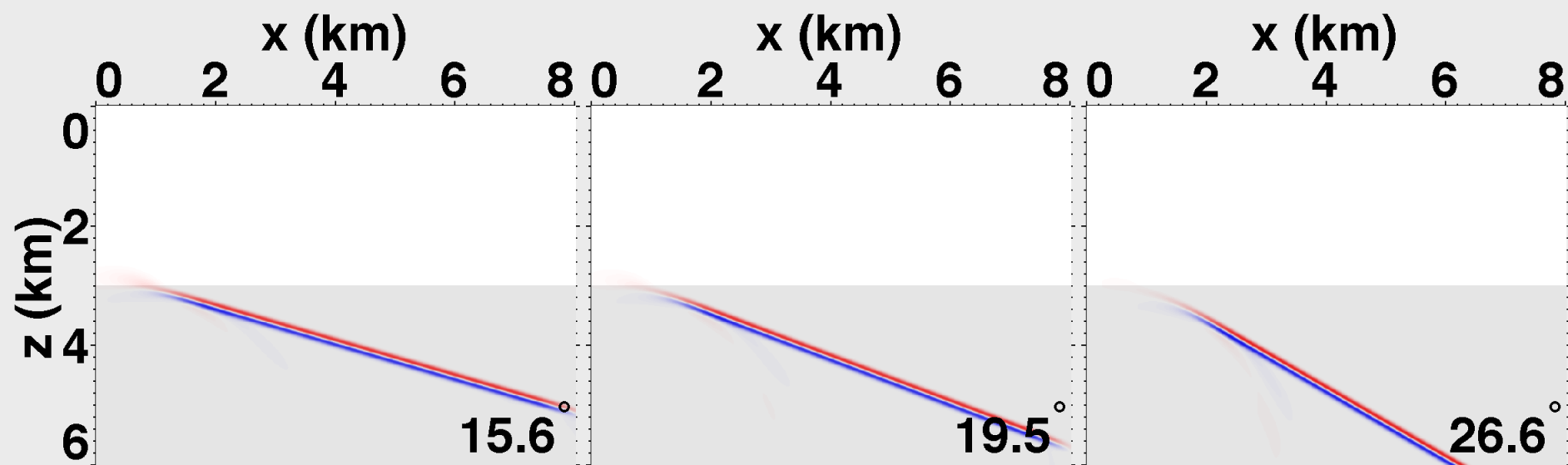
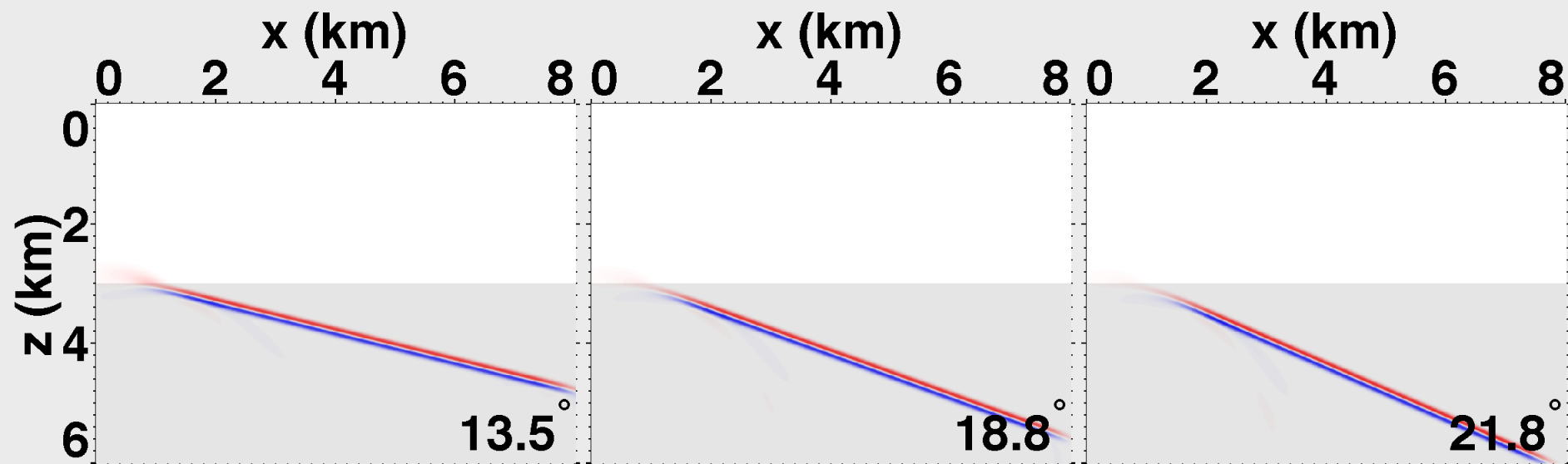


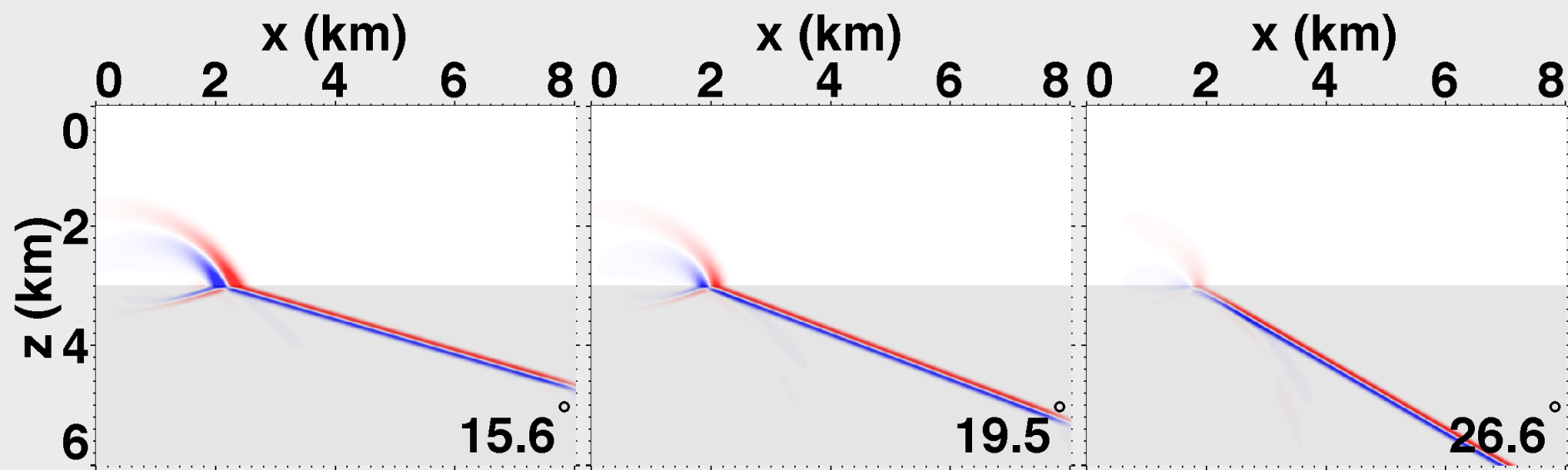
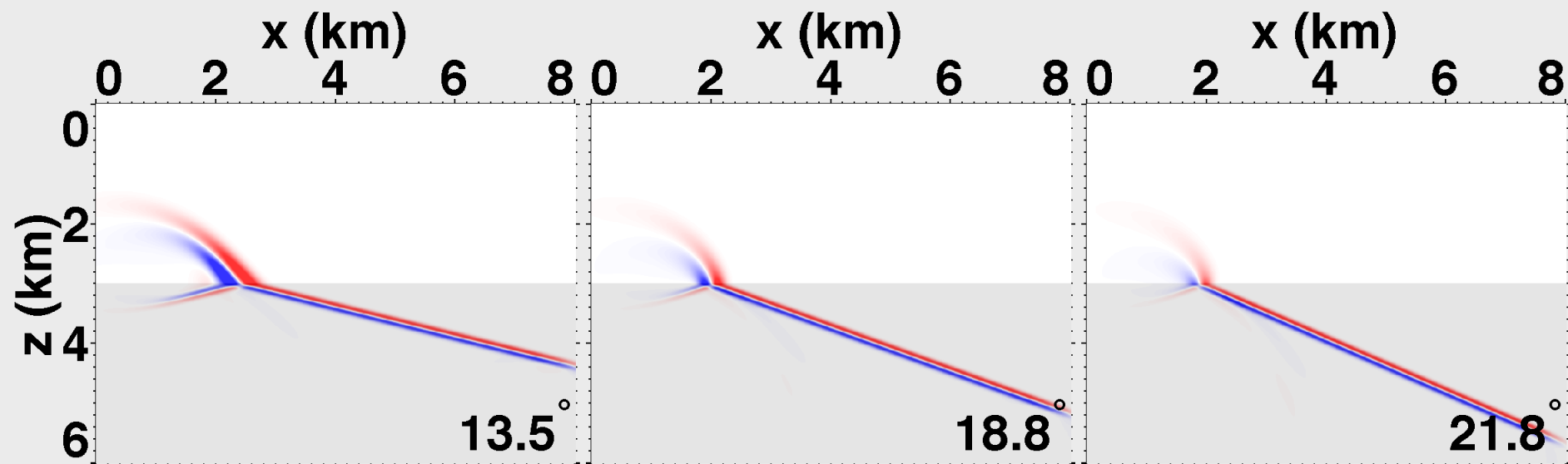


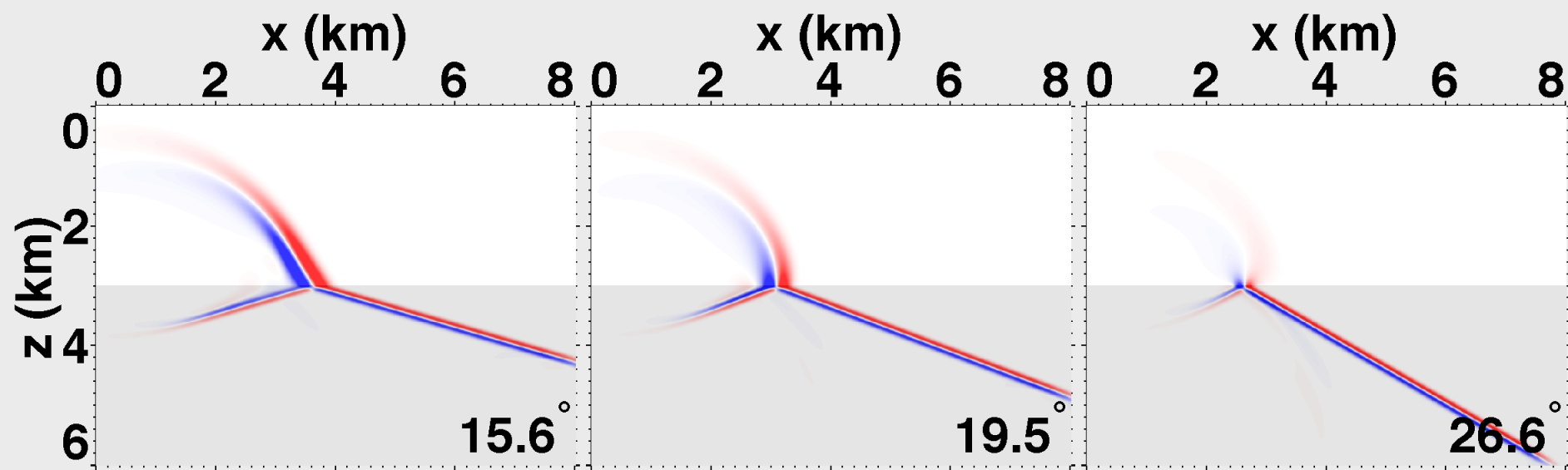
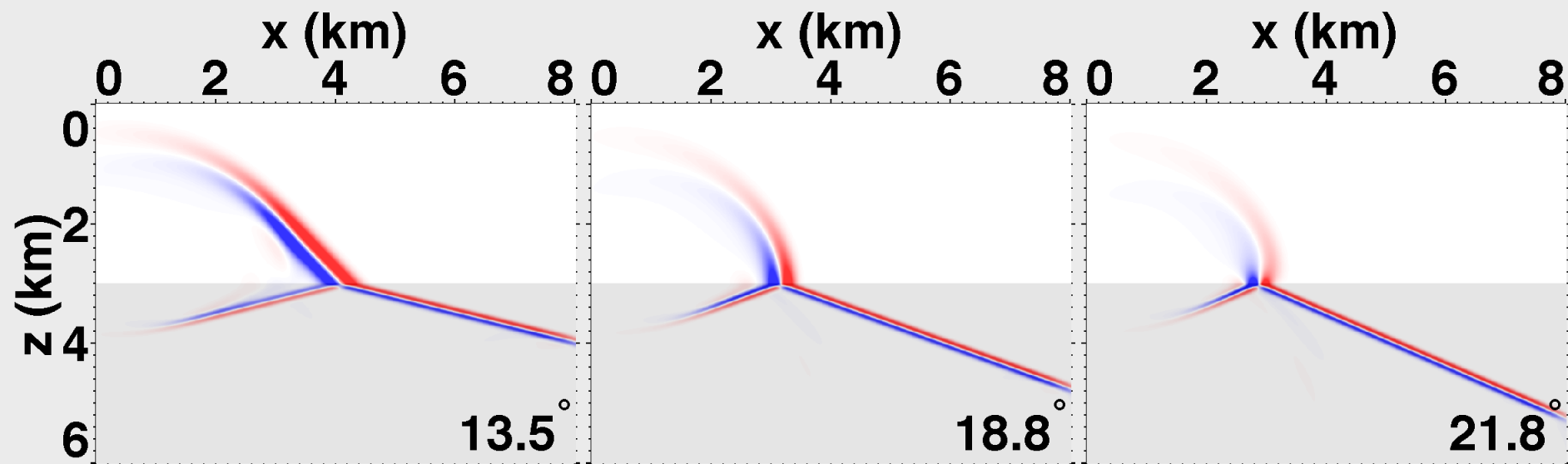


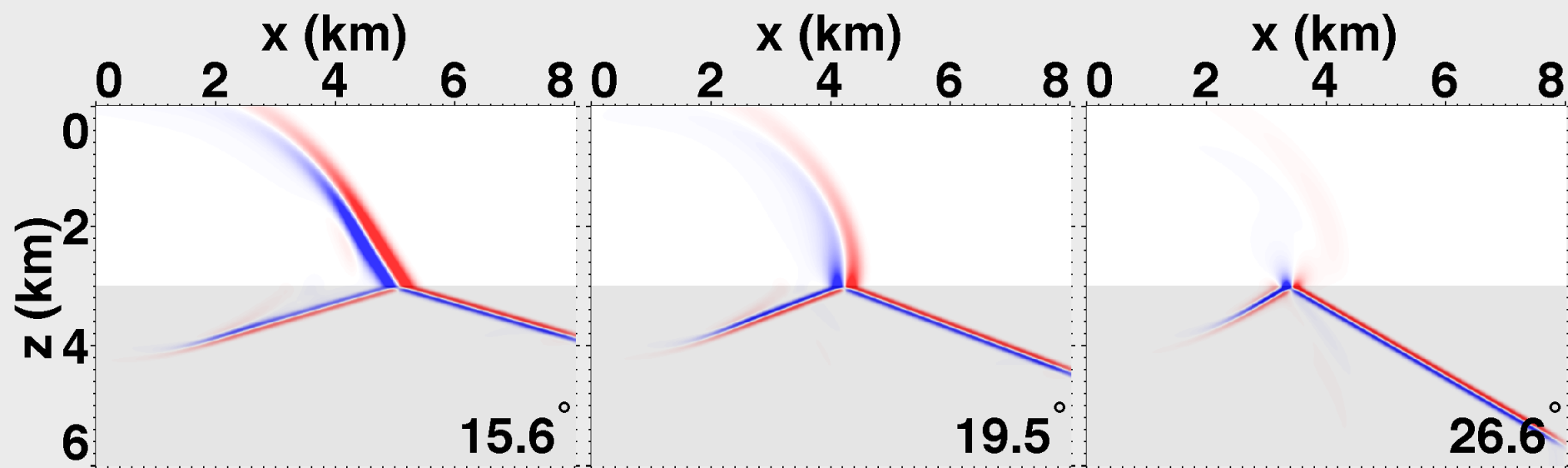
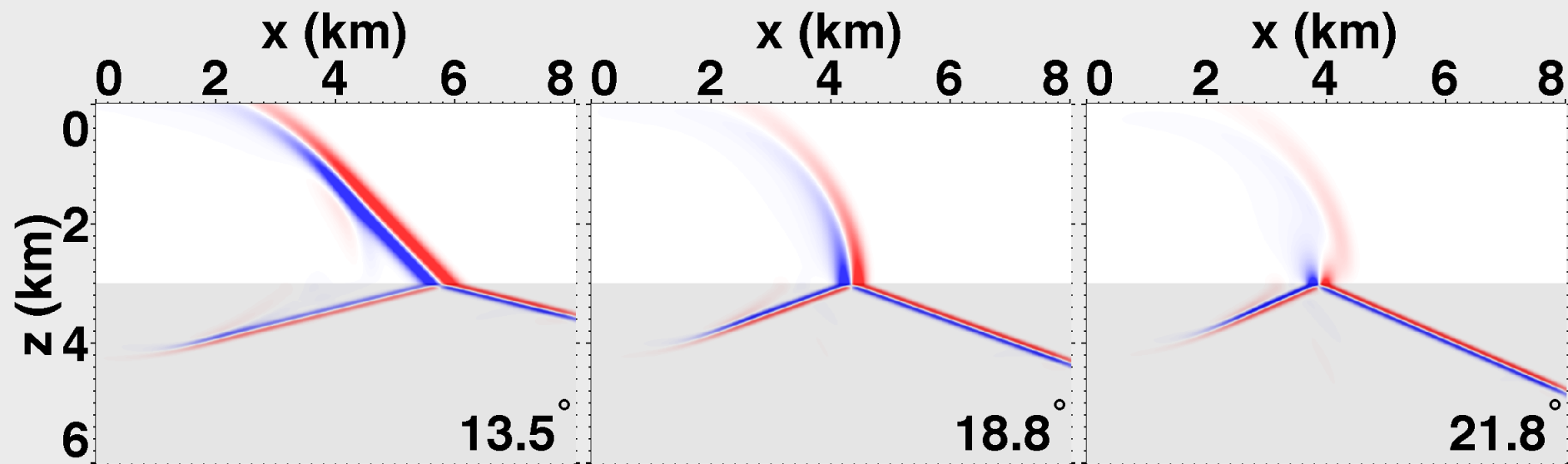


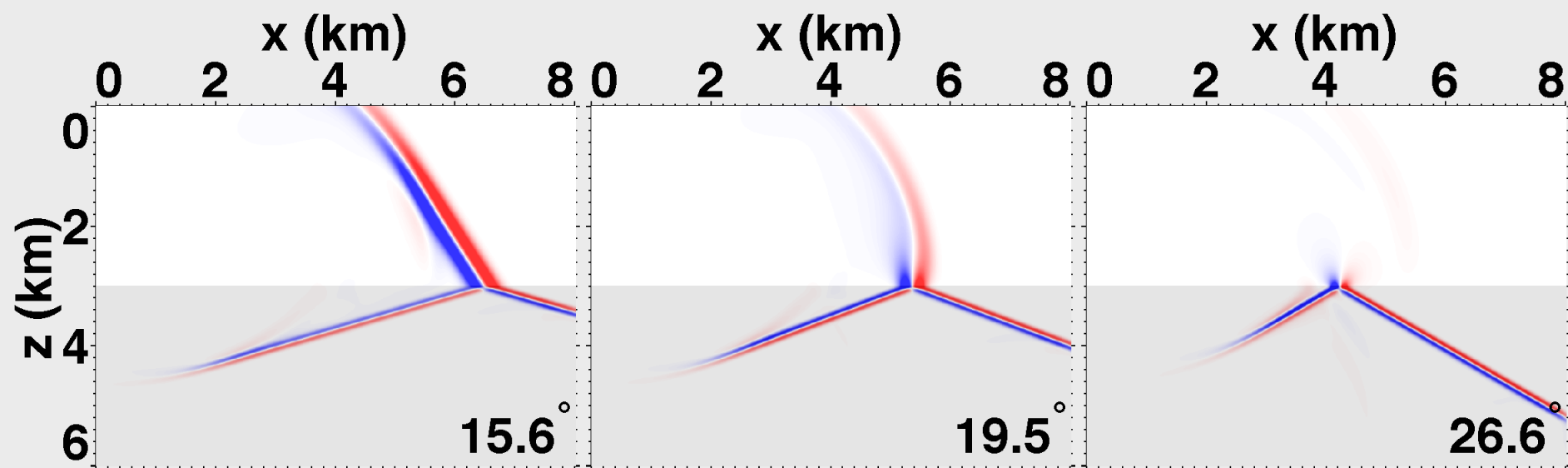
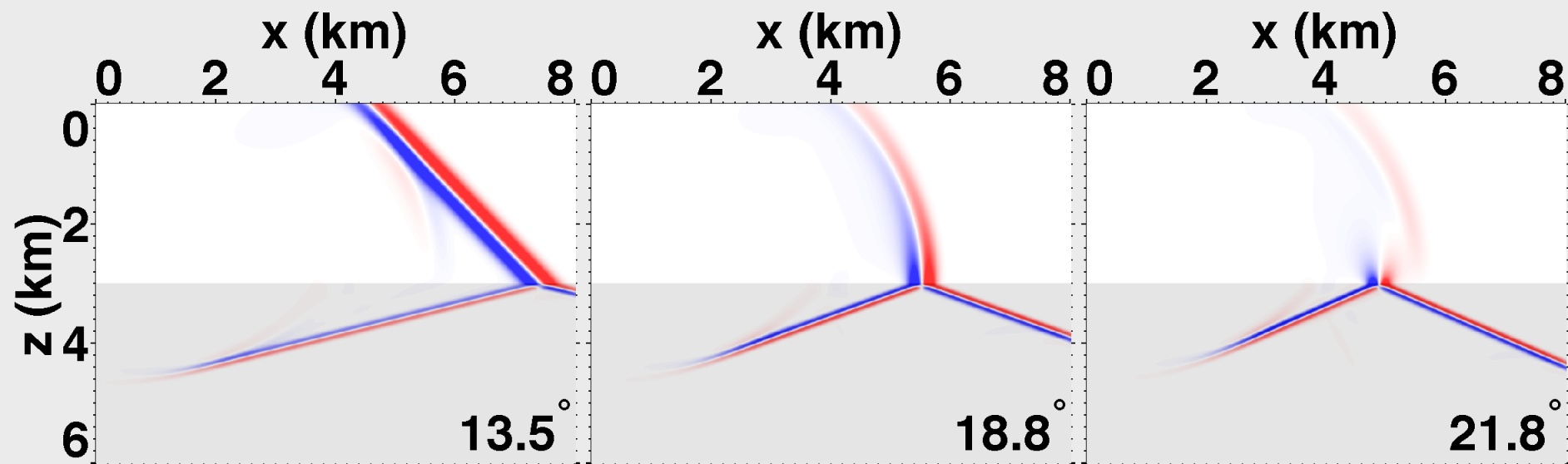


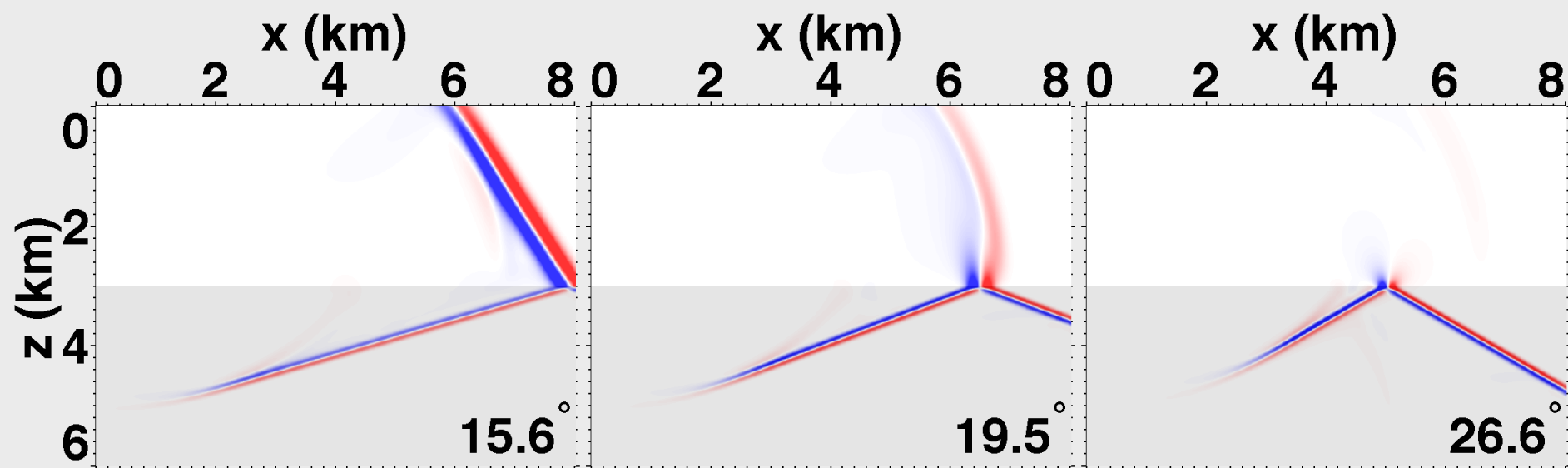
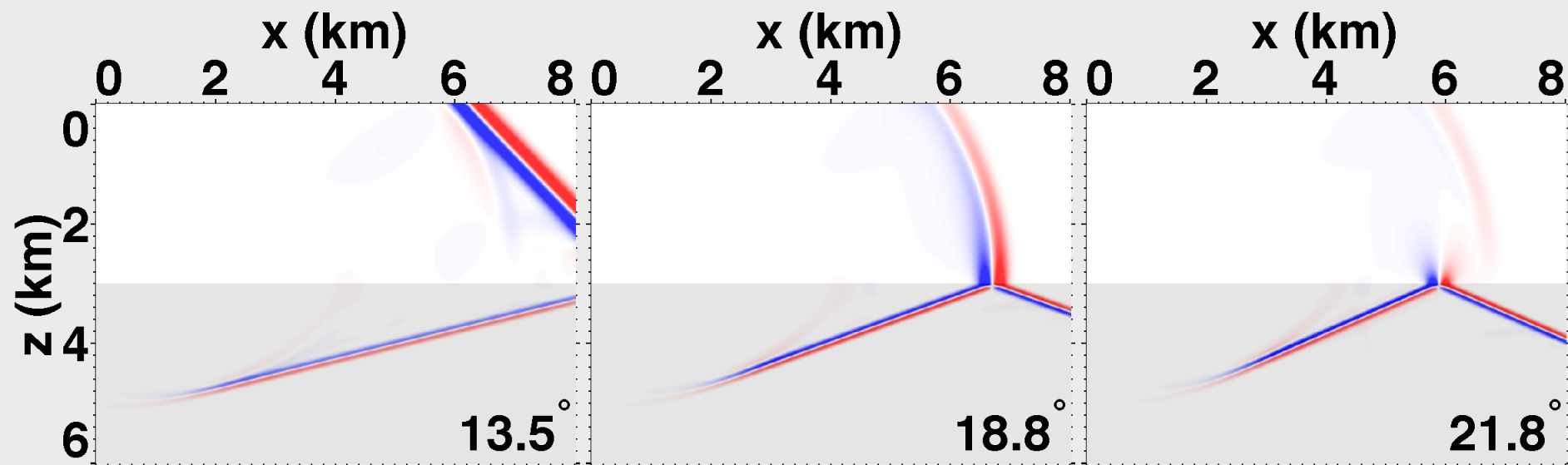


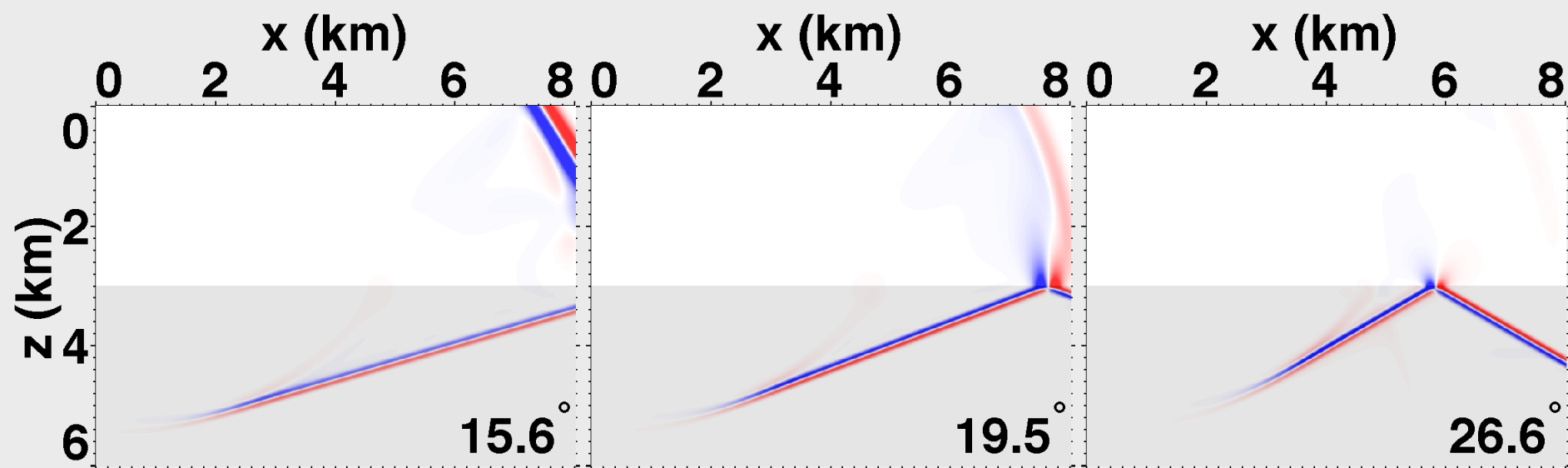
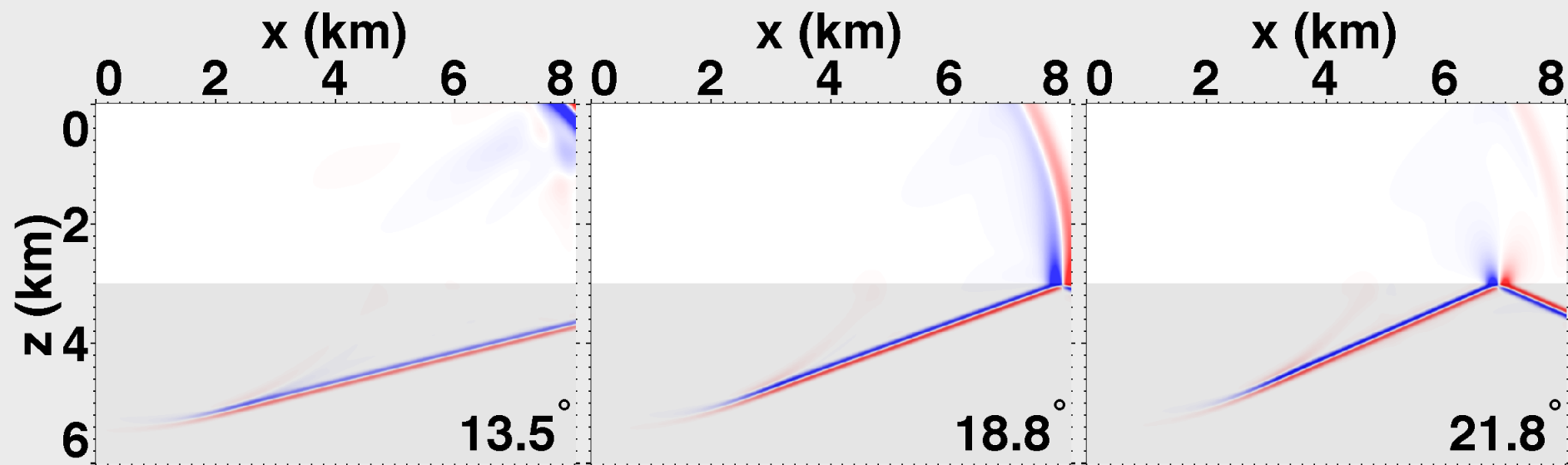




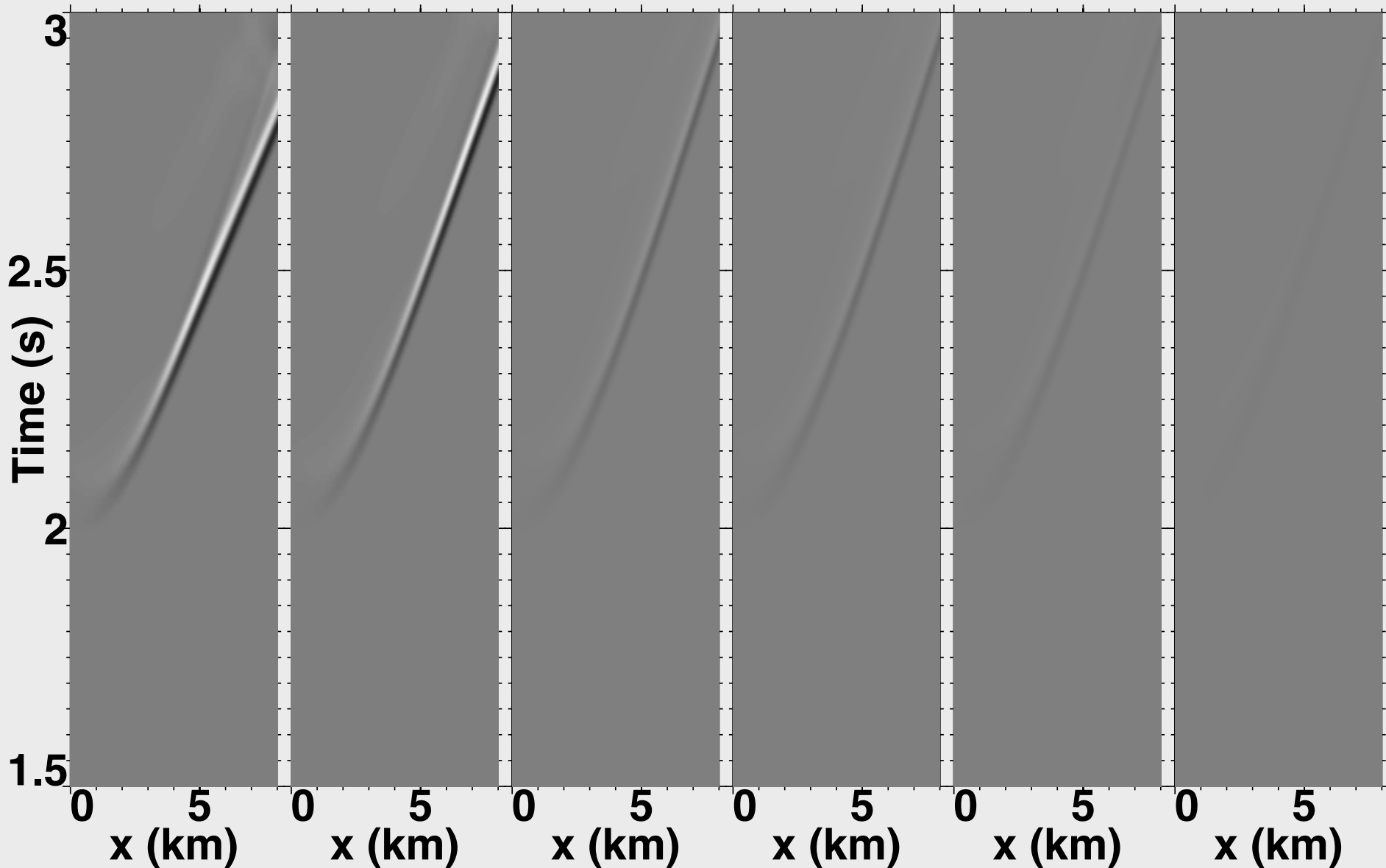








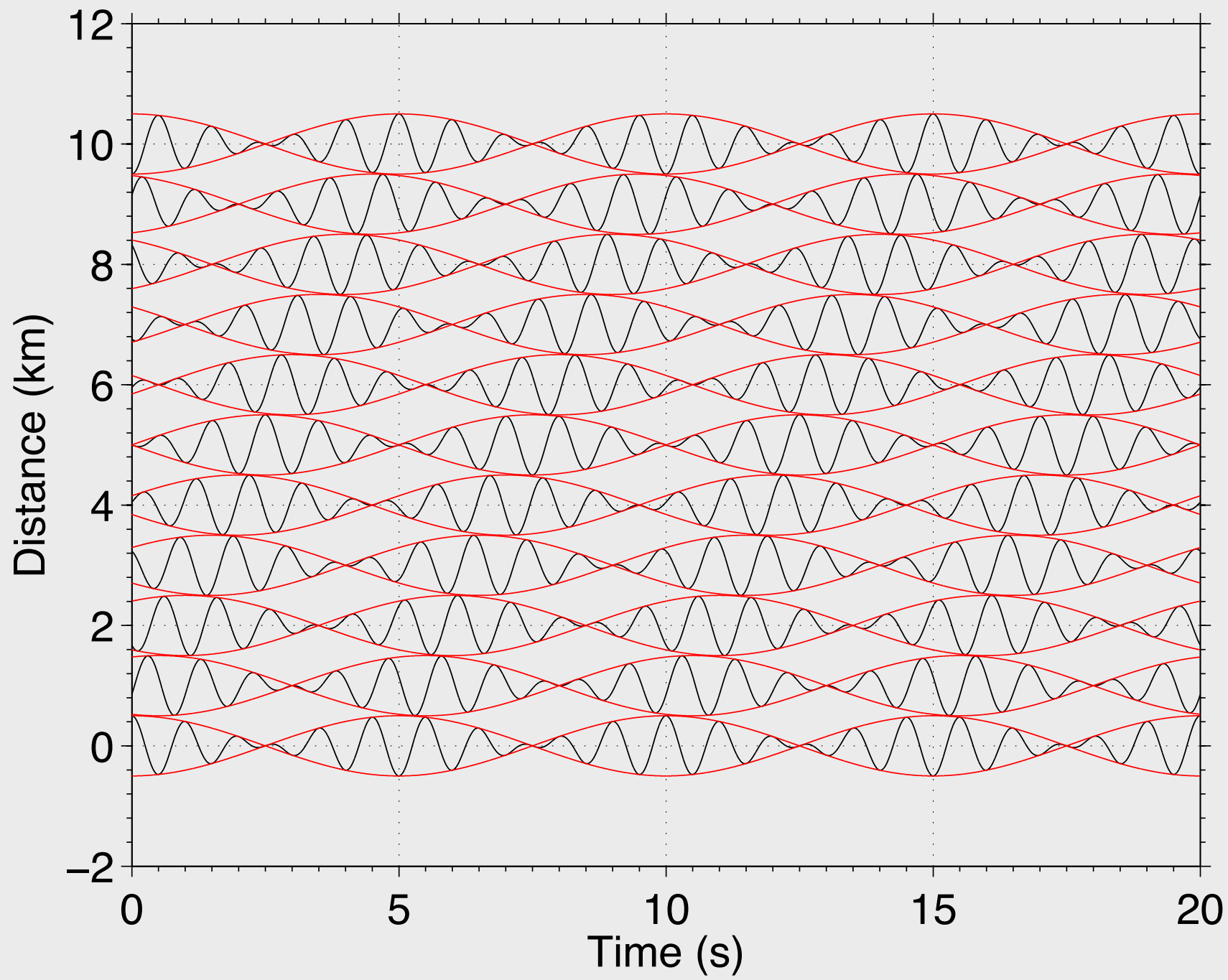
Shot gather

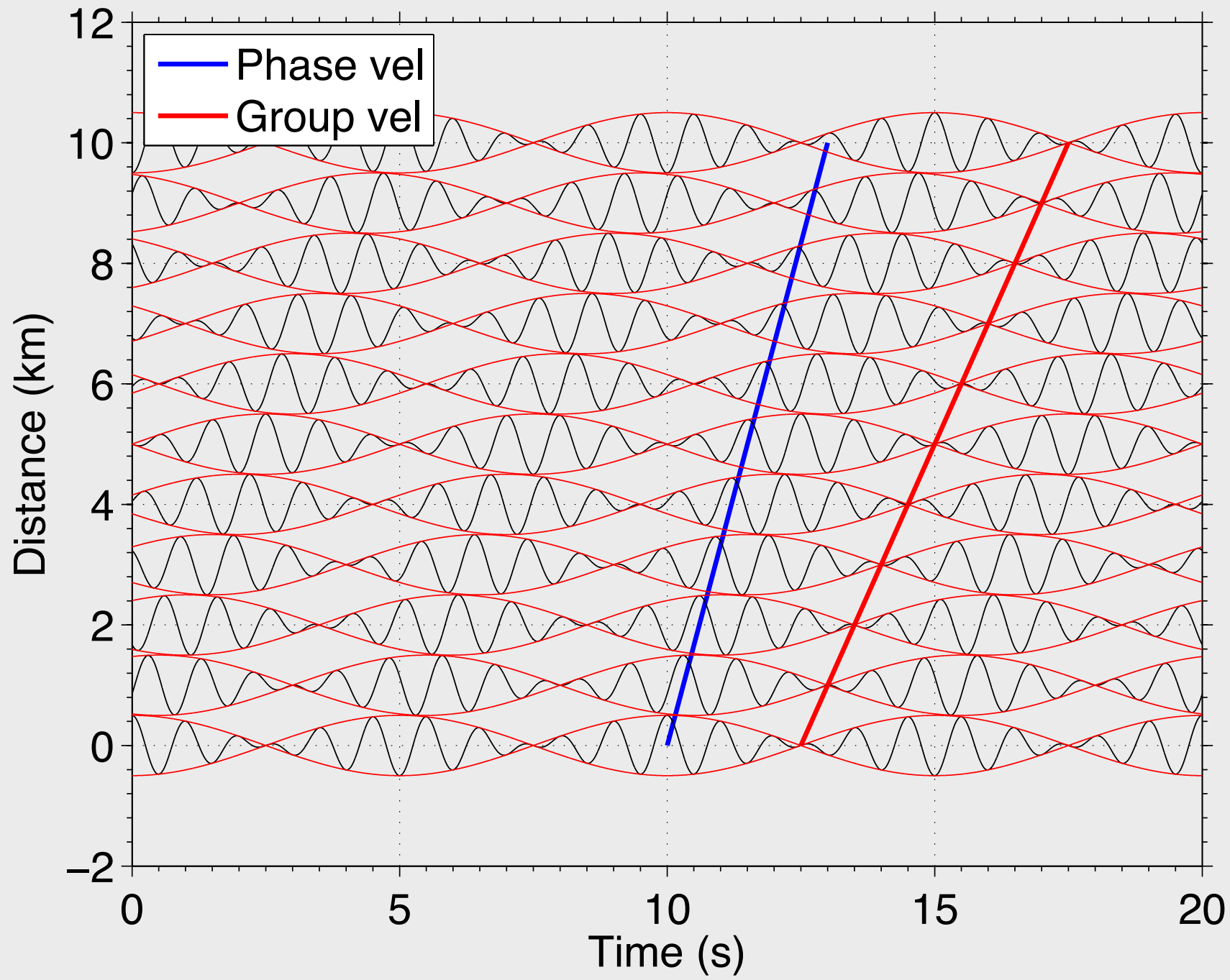


Surface waves

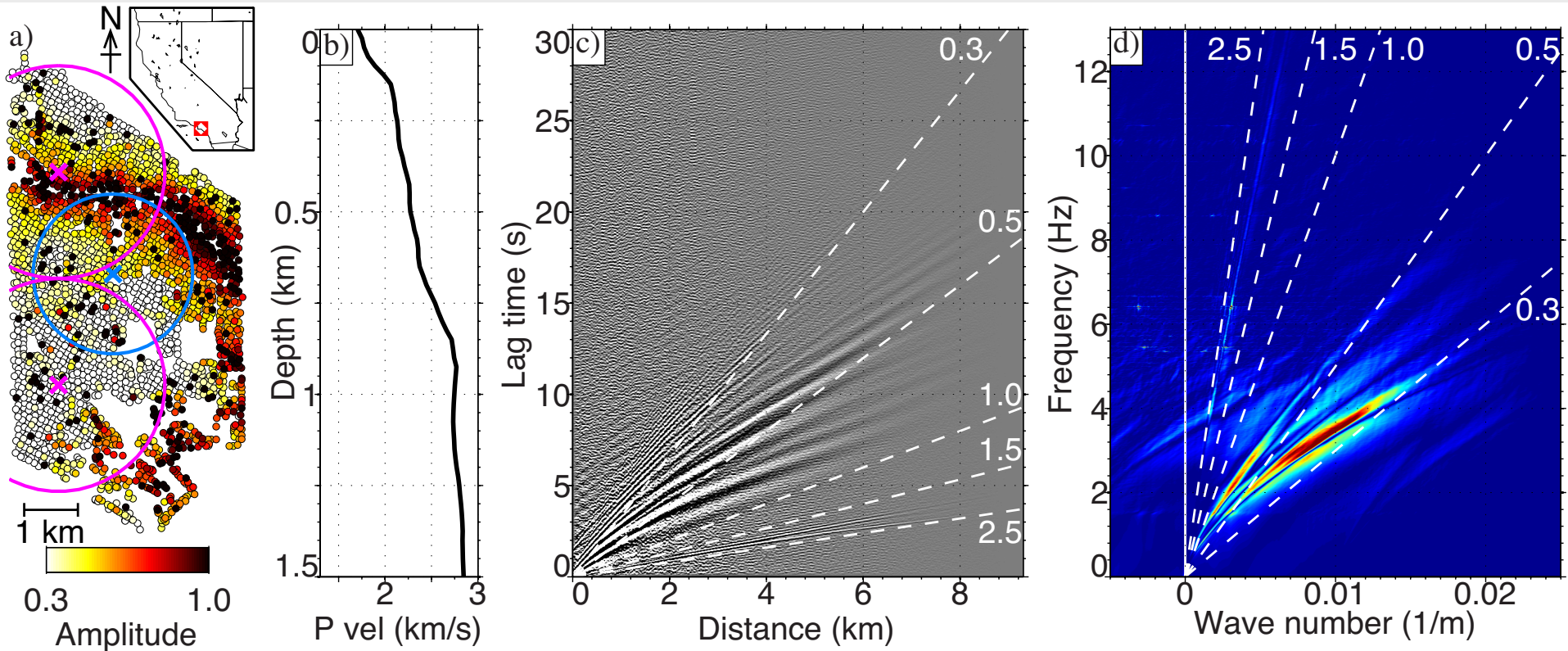
Nori Nakata

Stanford University

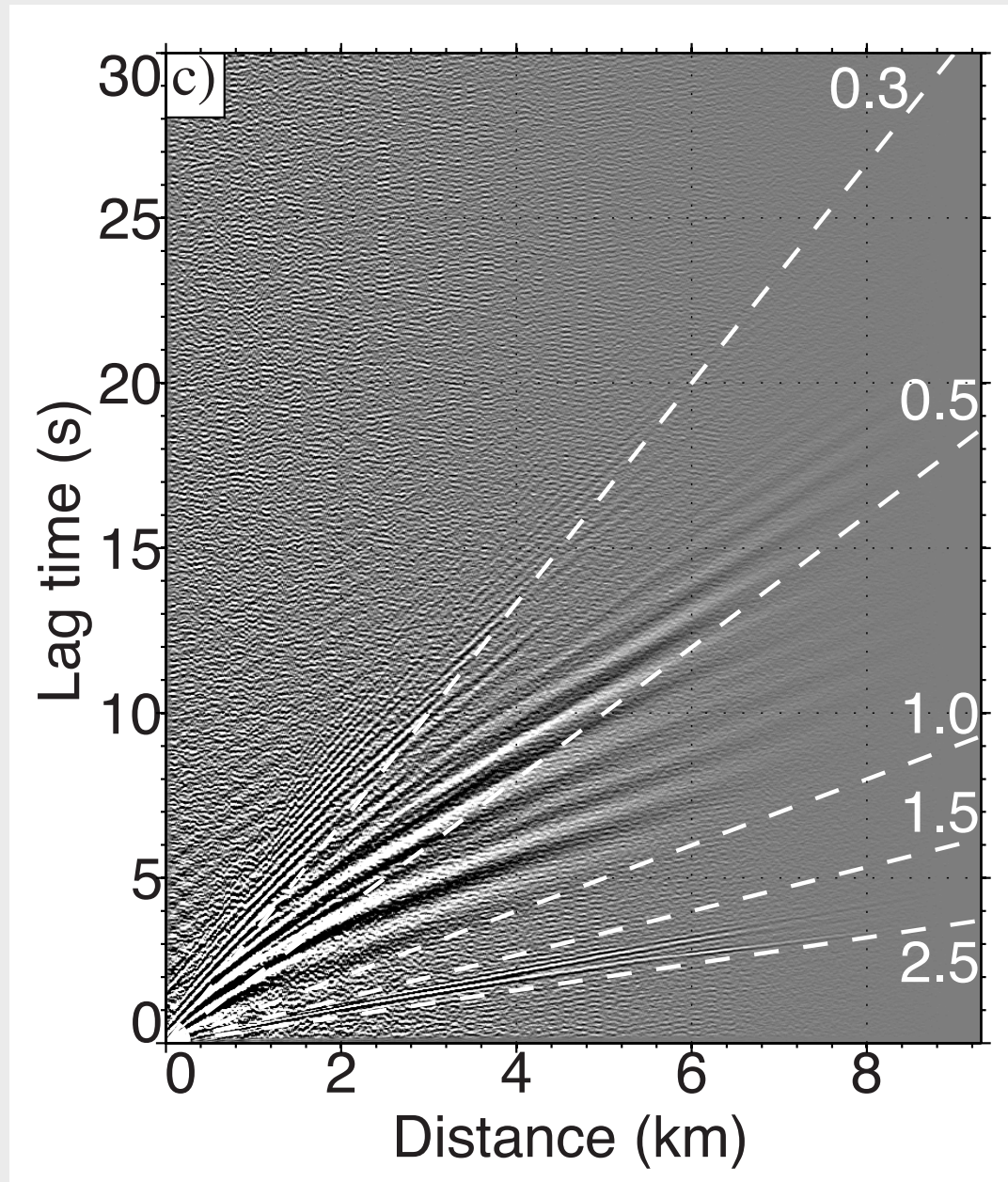




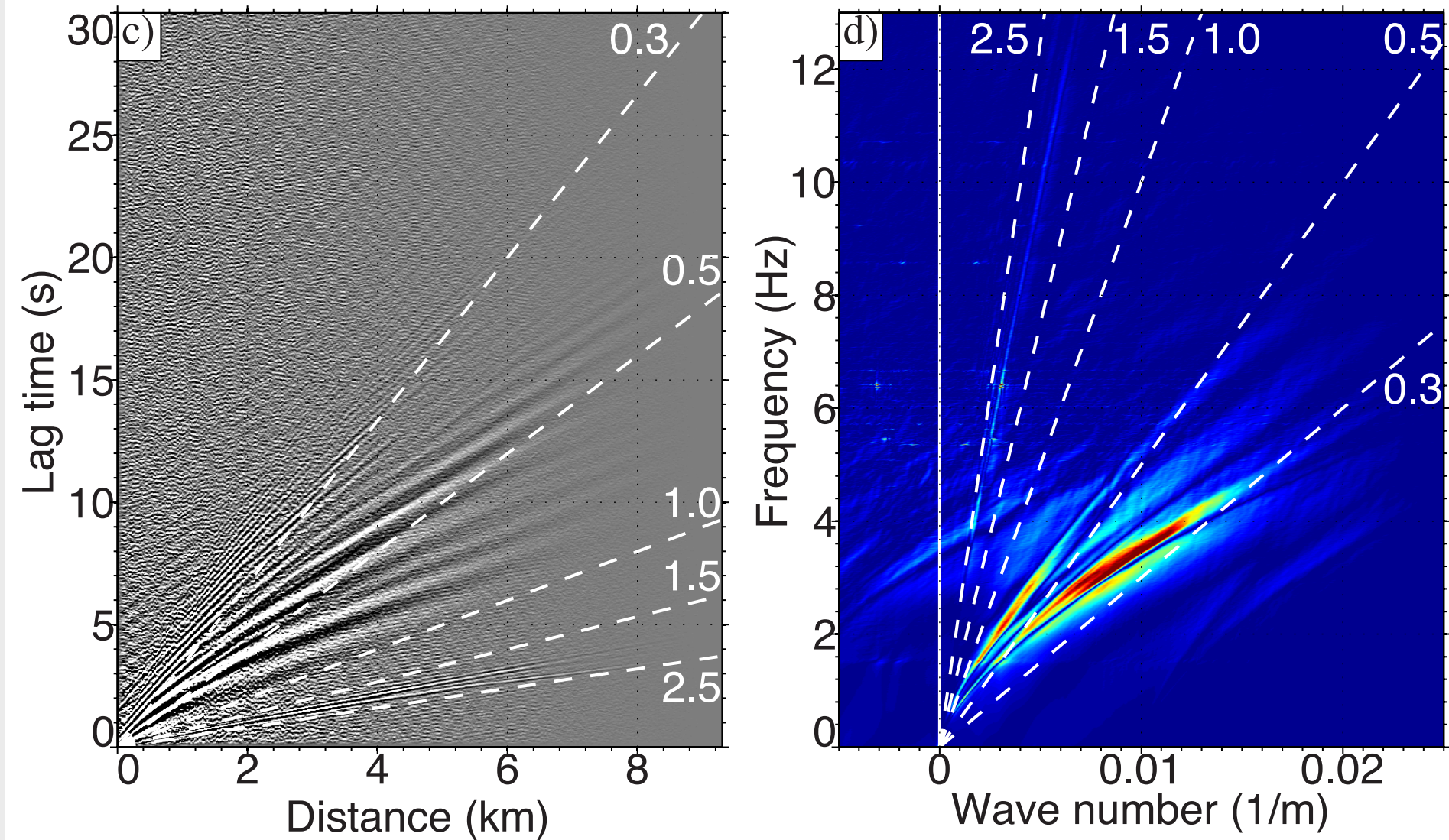
Surface wave velocities



Surface wave velocities



Surface wave velocities



Earth structure

Nori Nakata

Stanford University

Reflection and refraction seismology

Nori Nakata
Stanford University

Active sources



Receivers

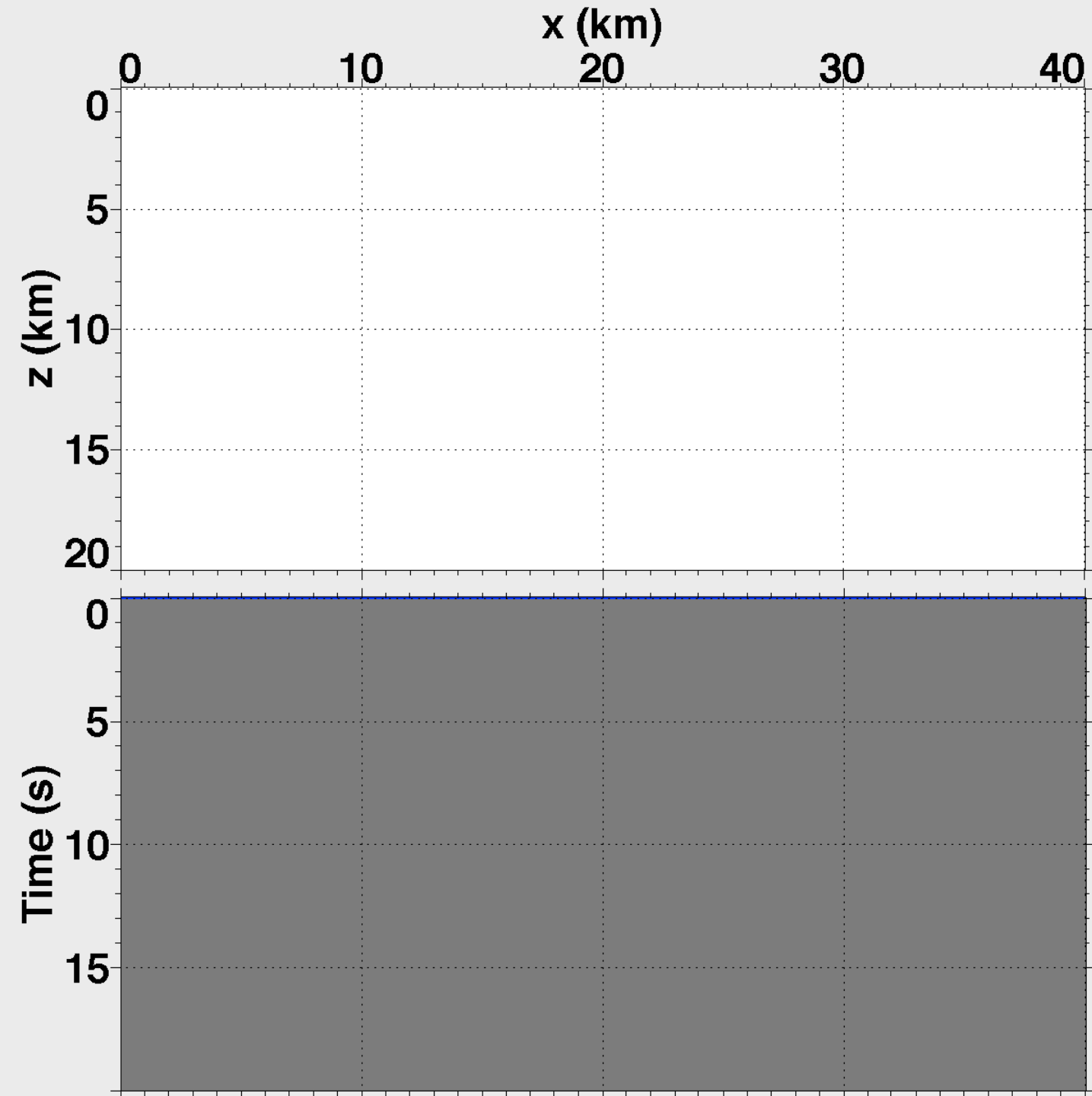


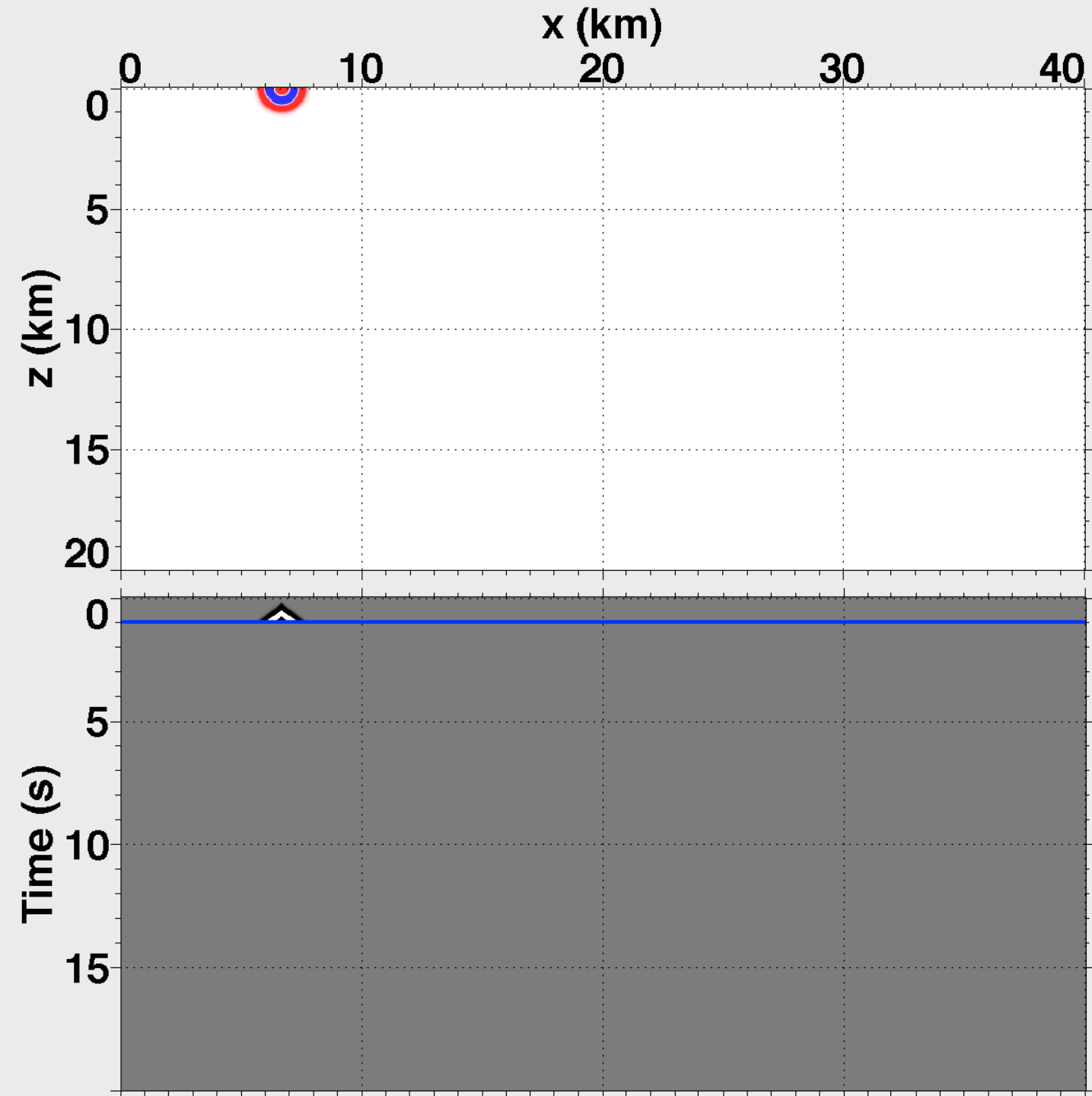
Numerical study

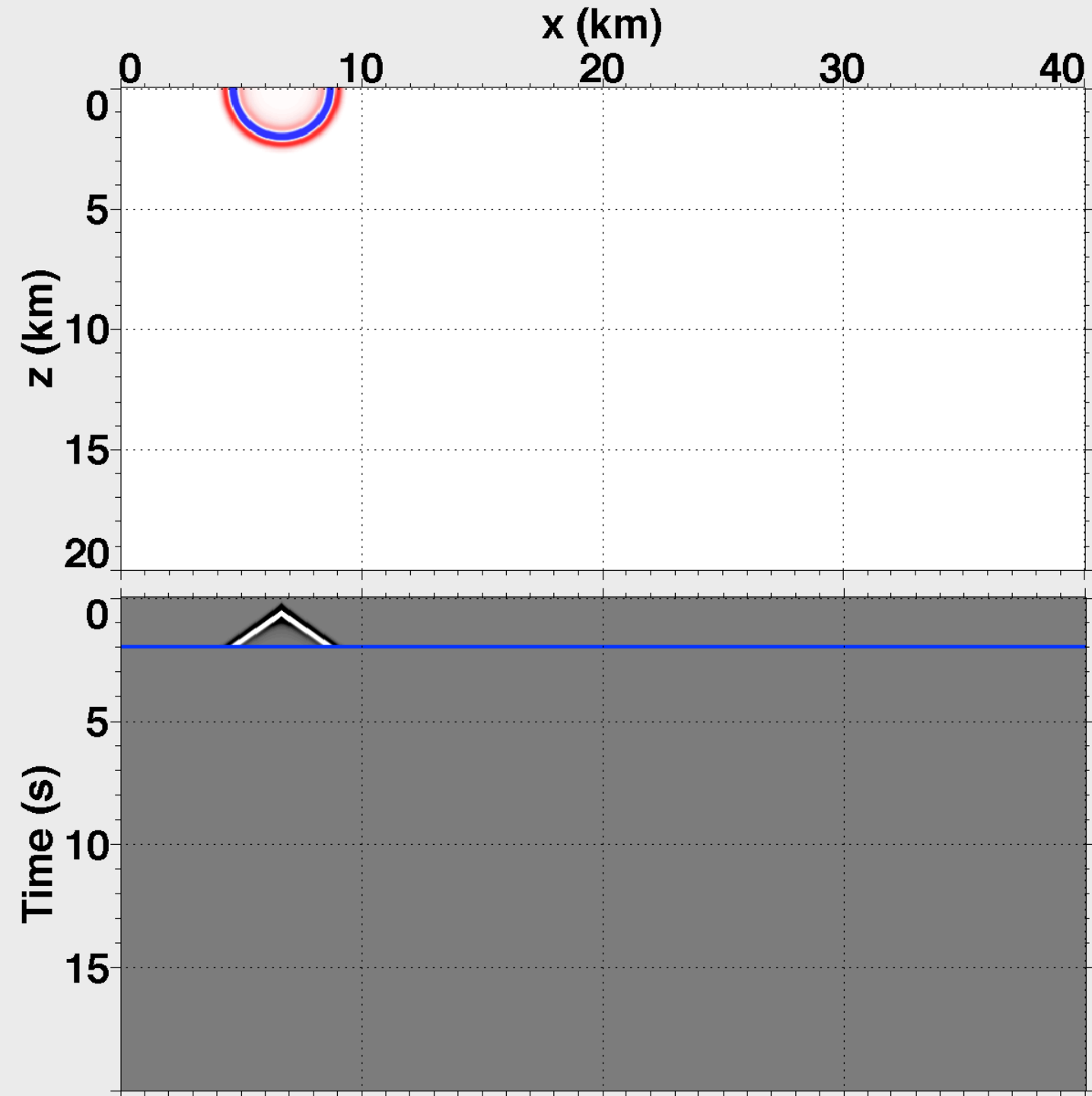
Nori Nakata

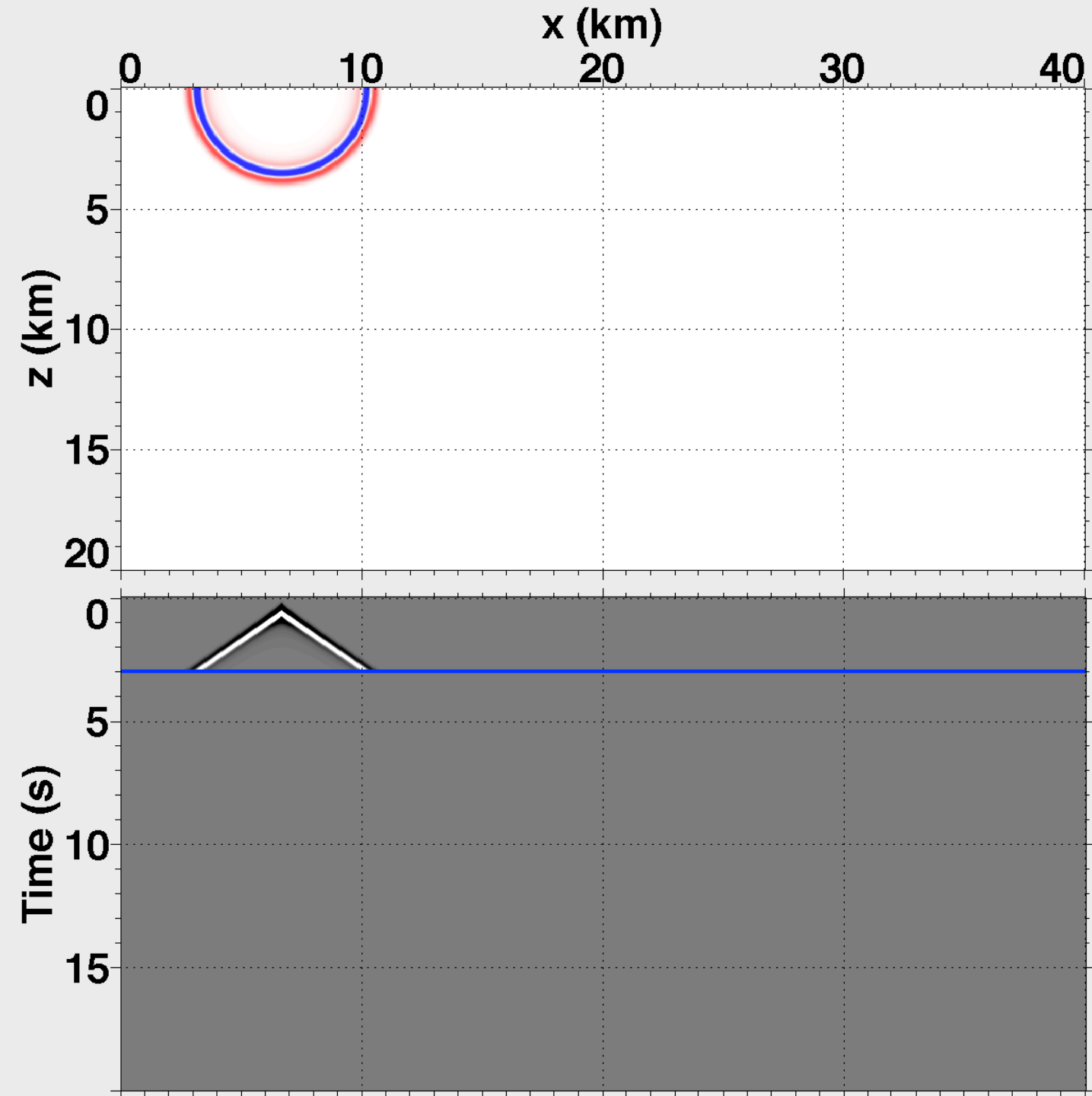
Stanford University

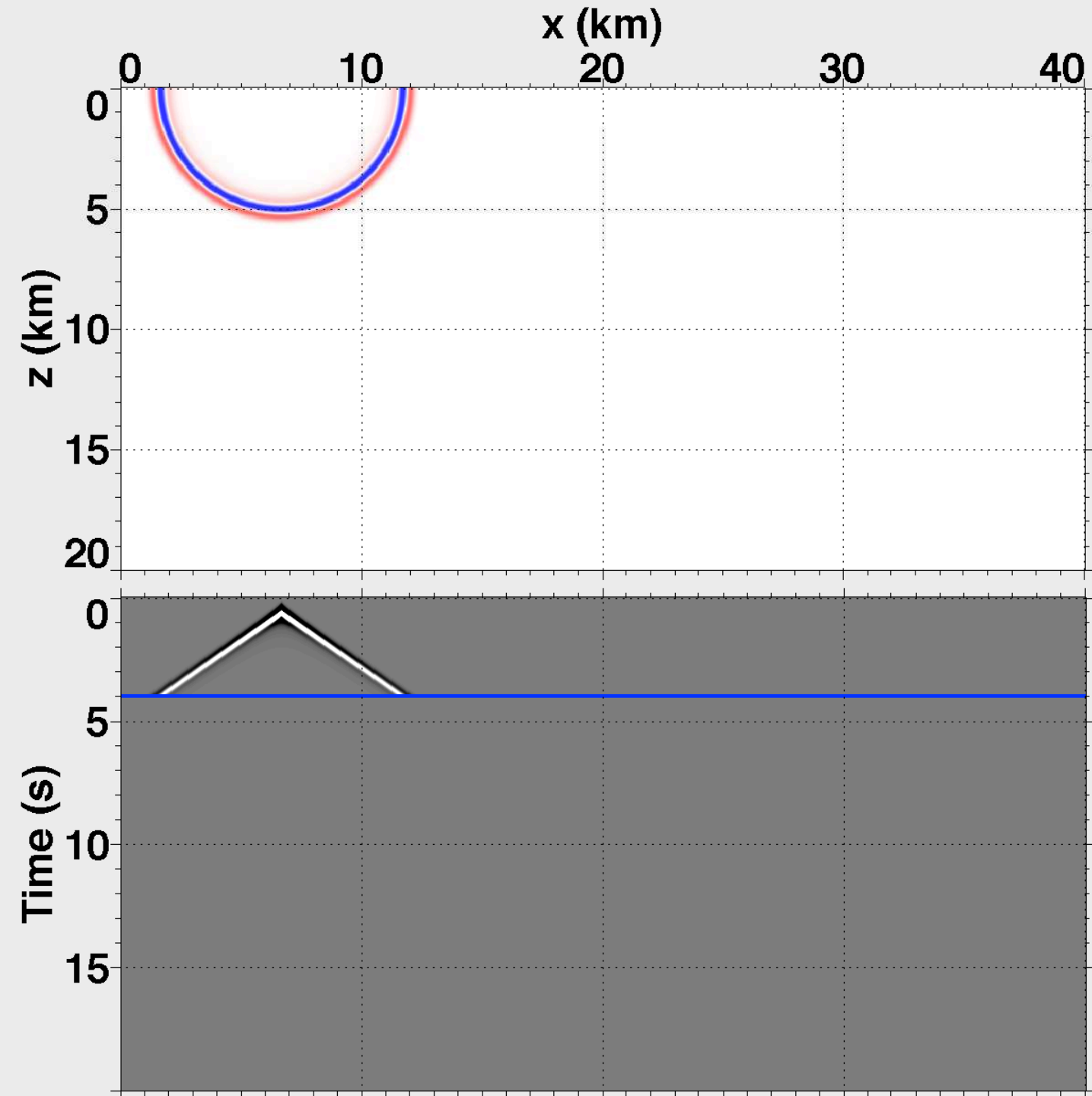
Halfspace

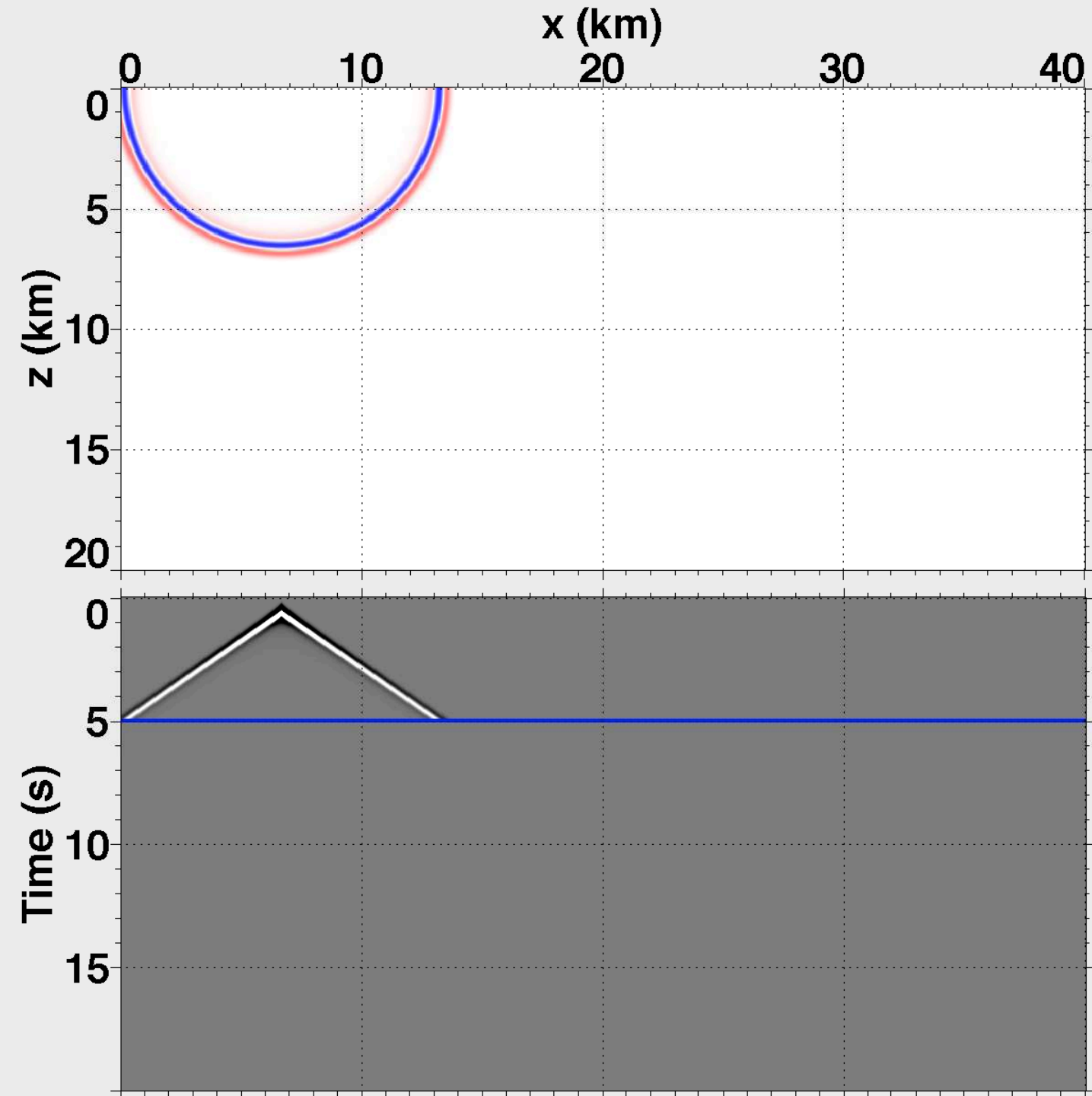


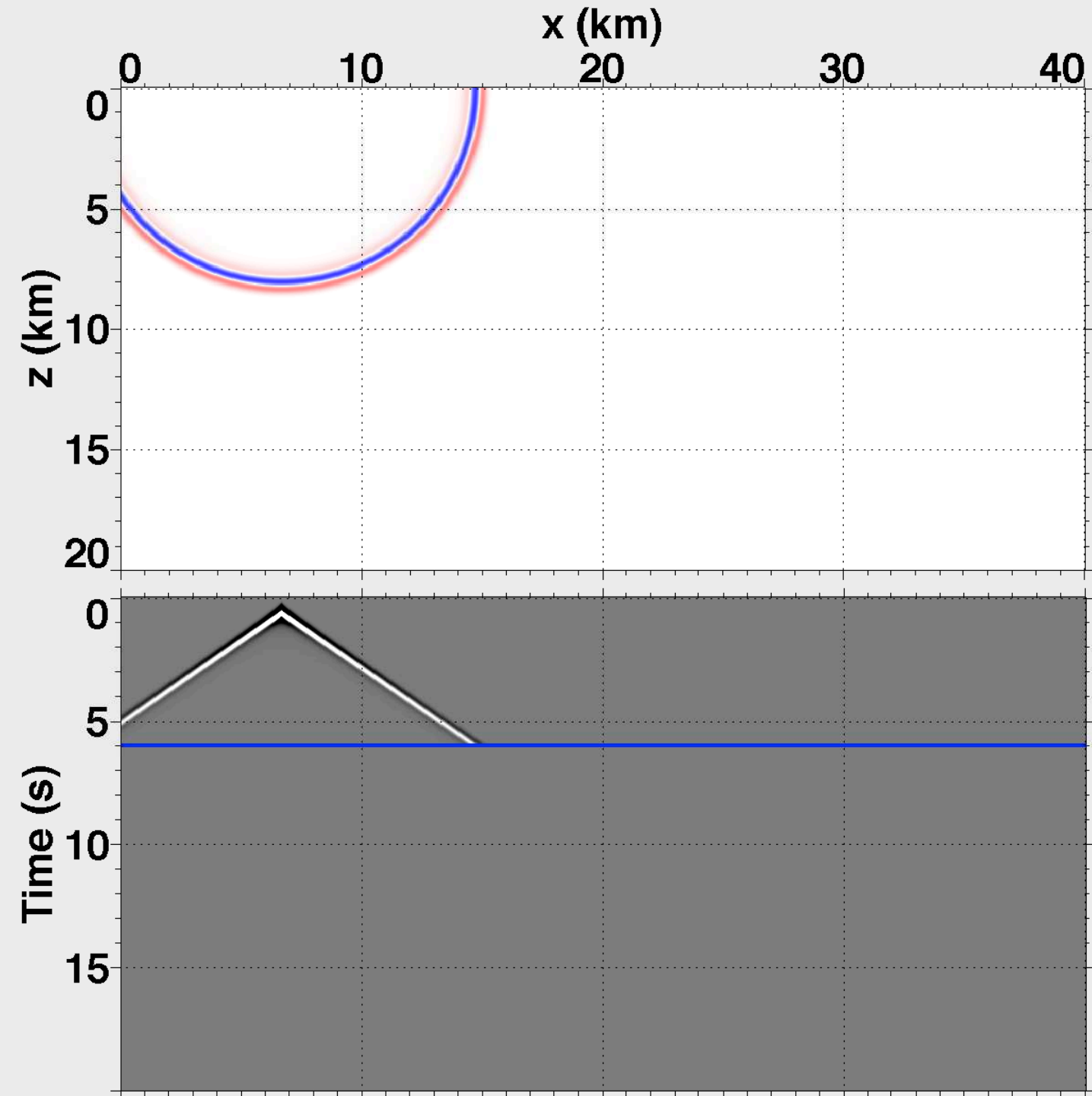


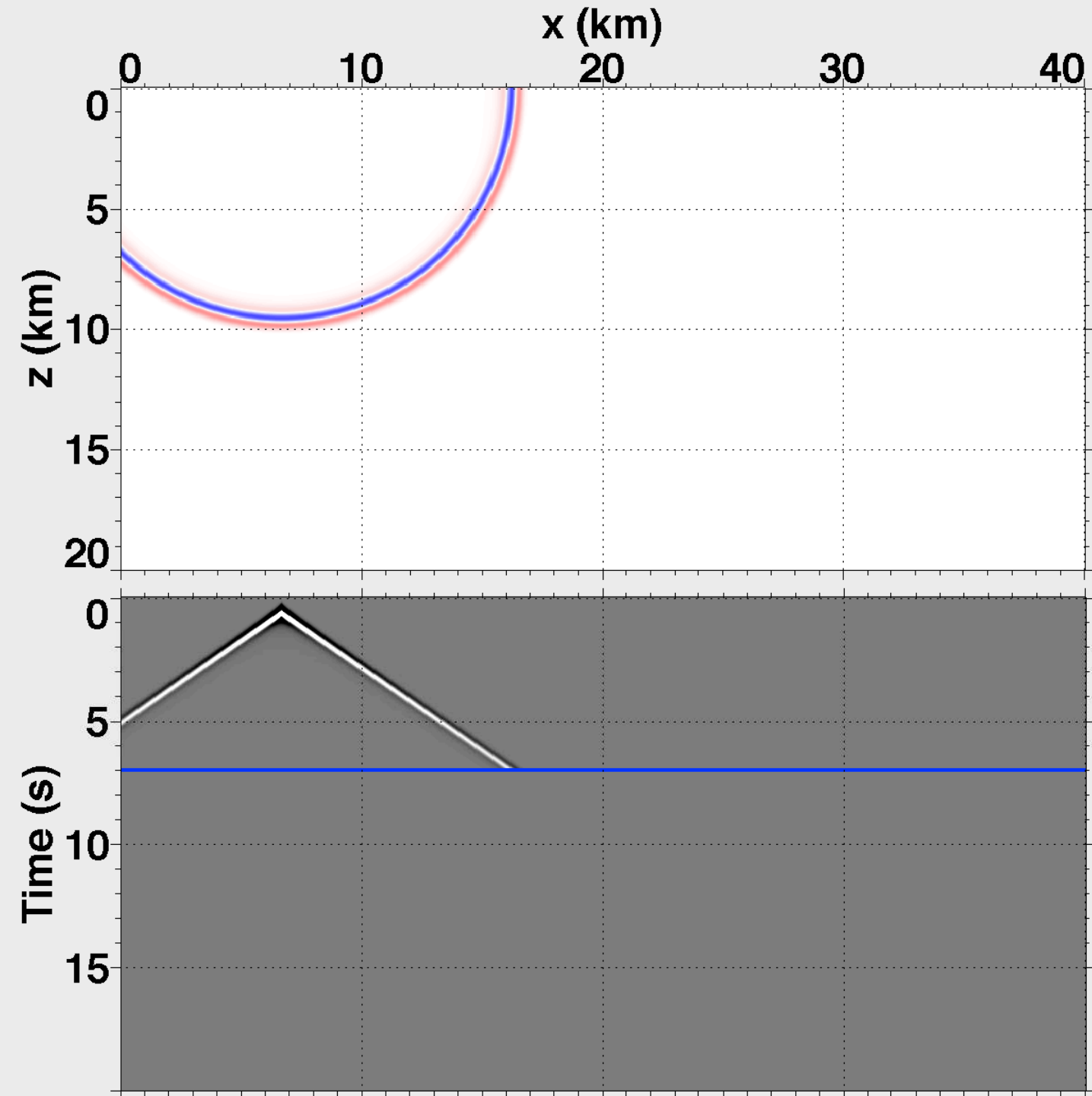


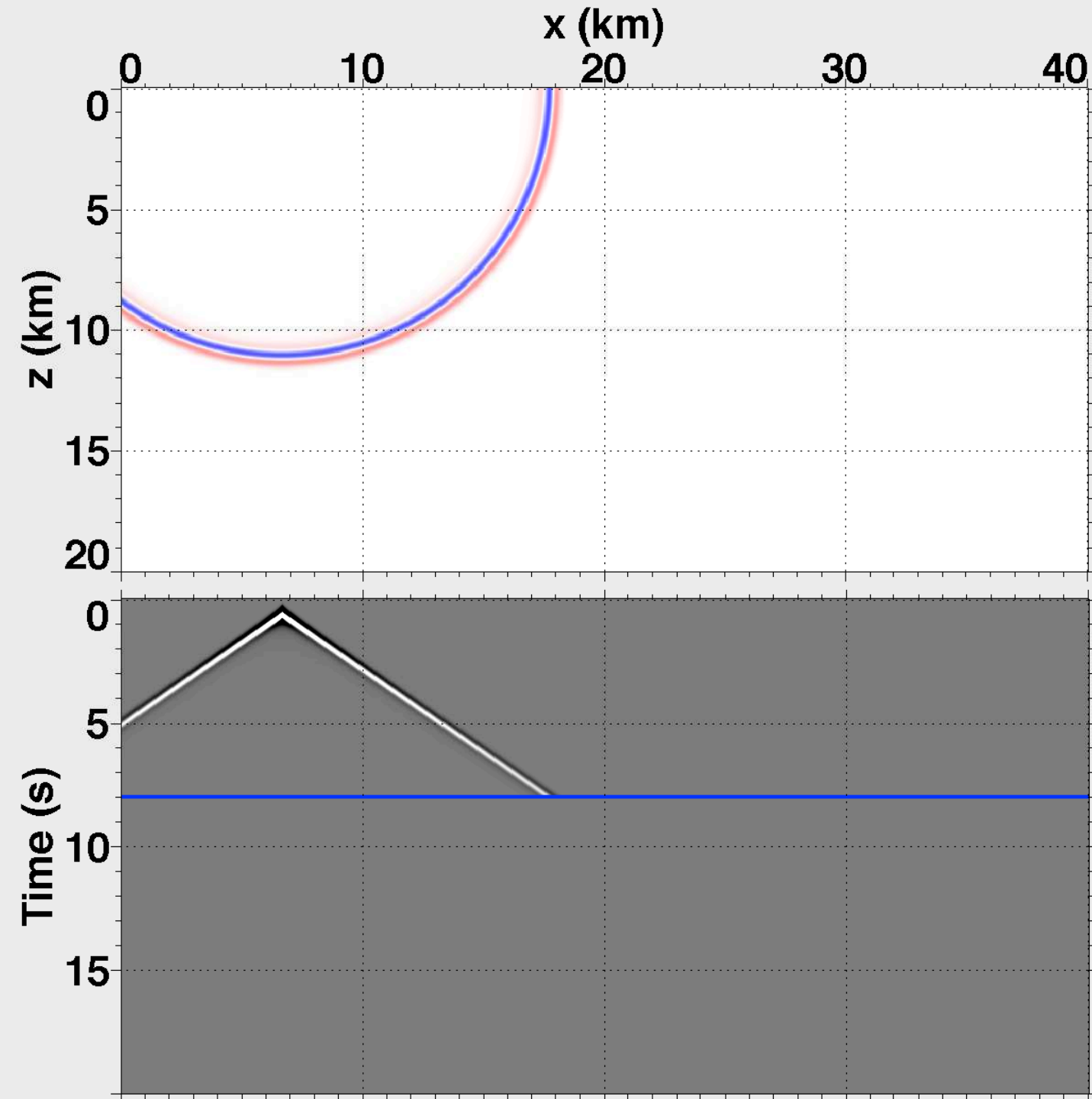


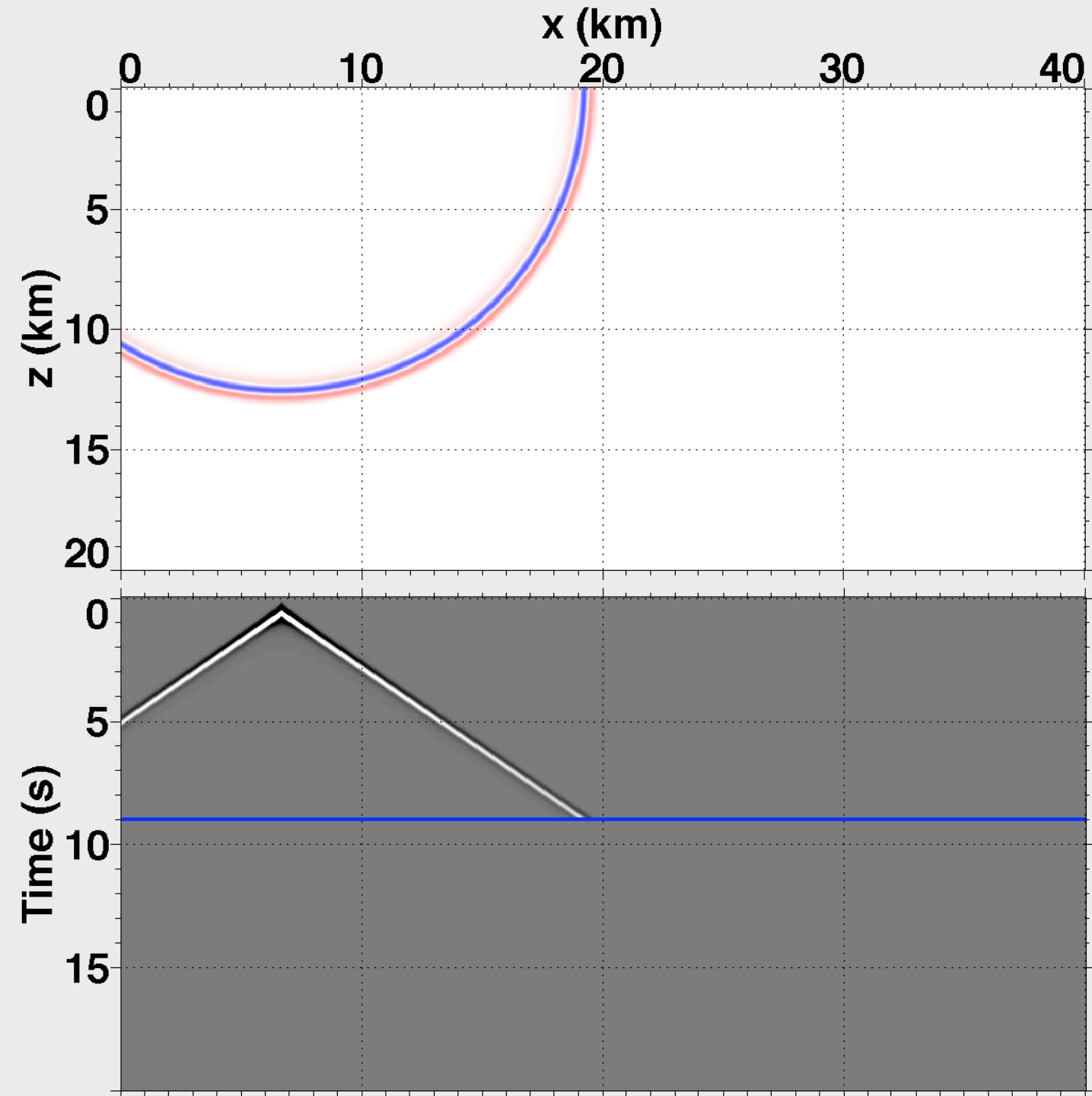


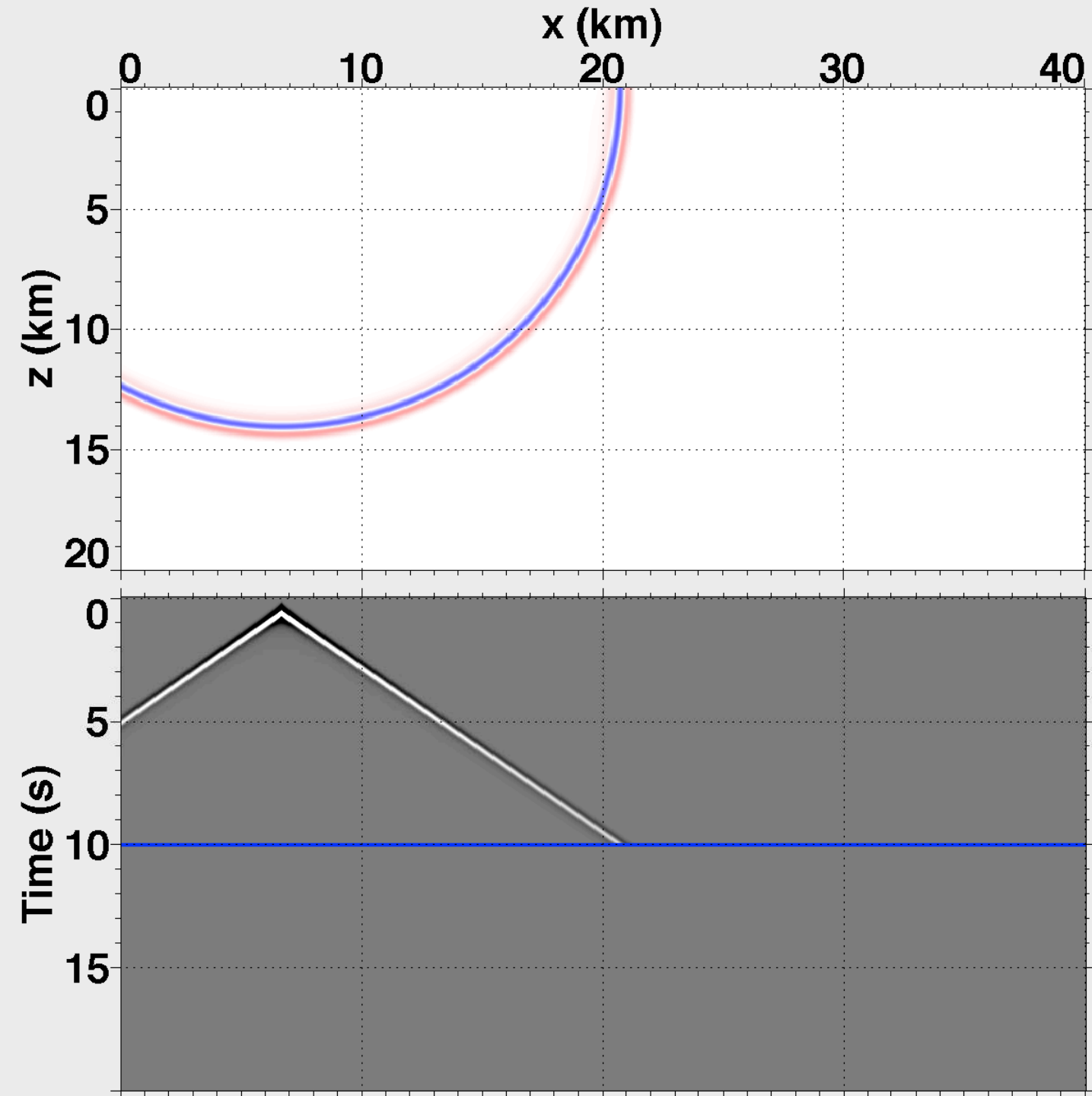


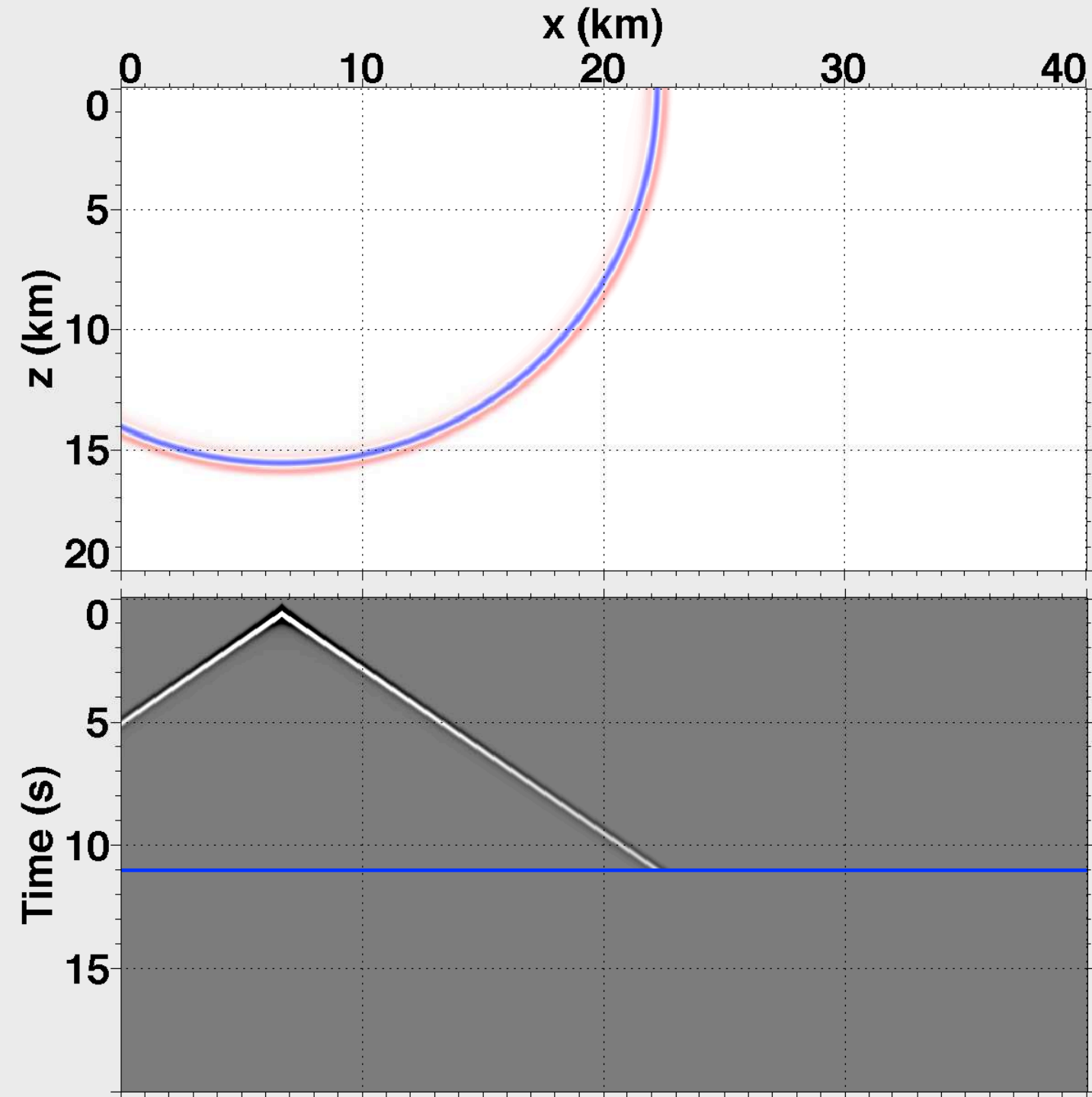


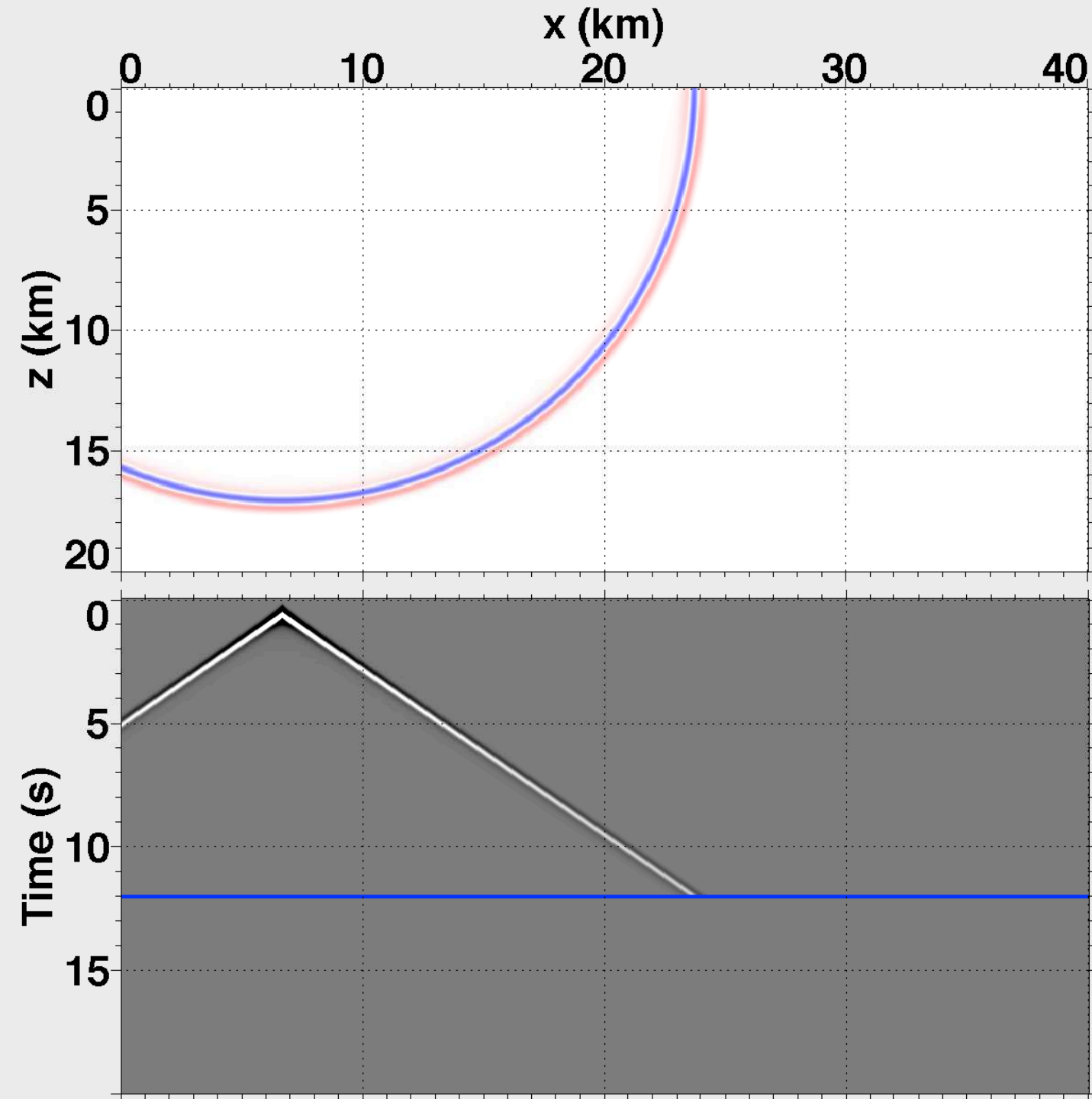


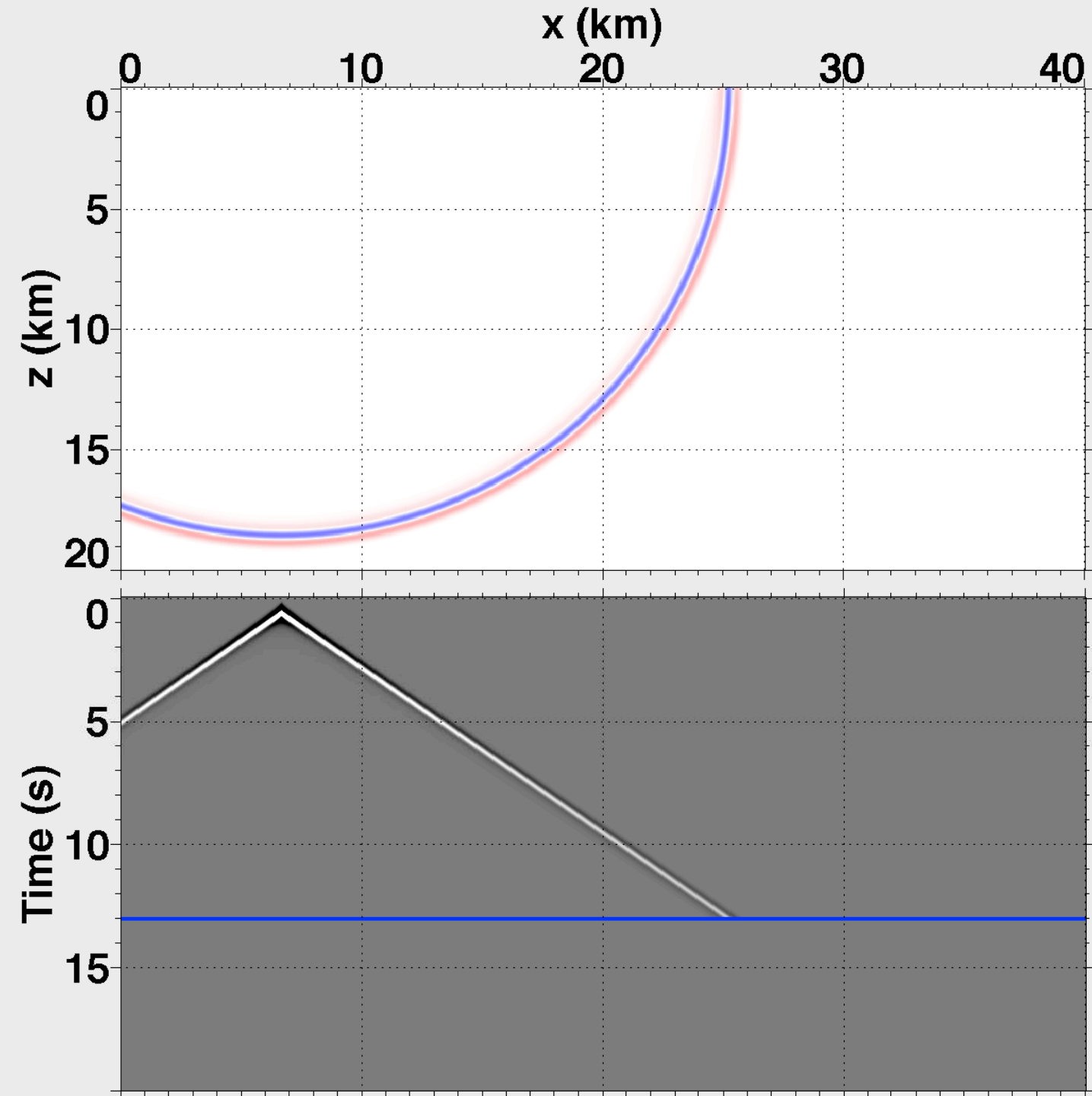


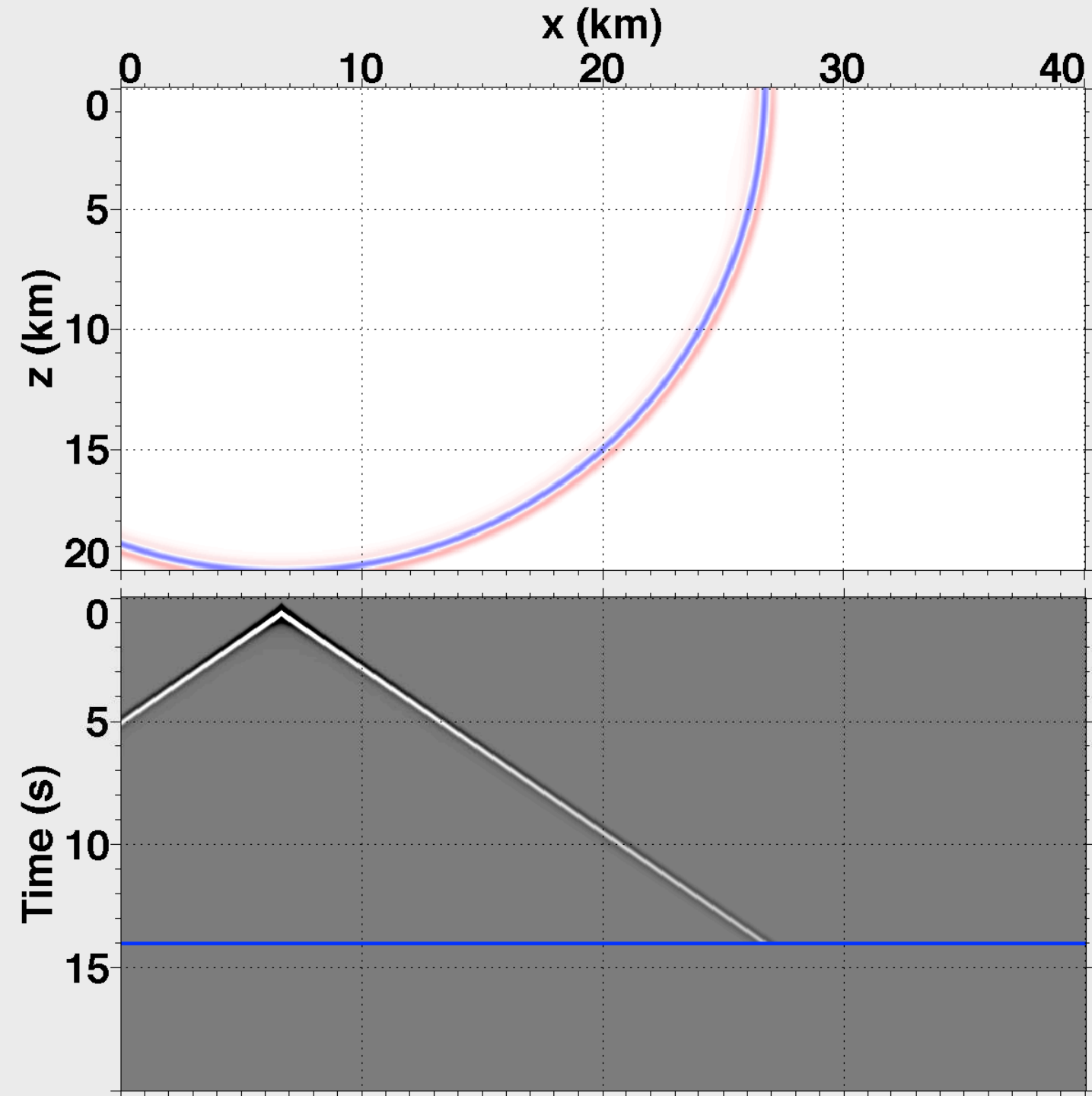


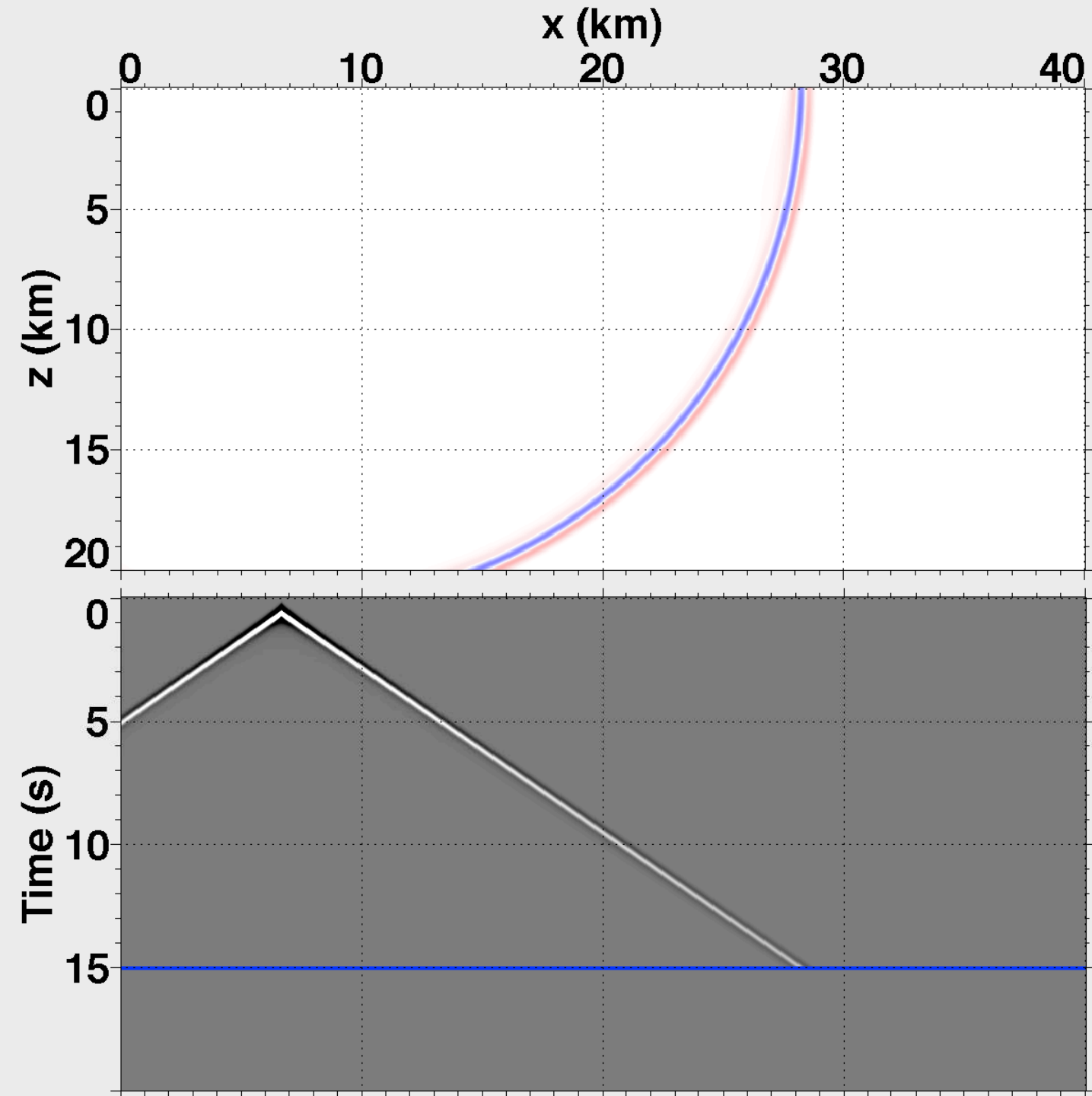


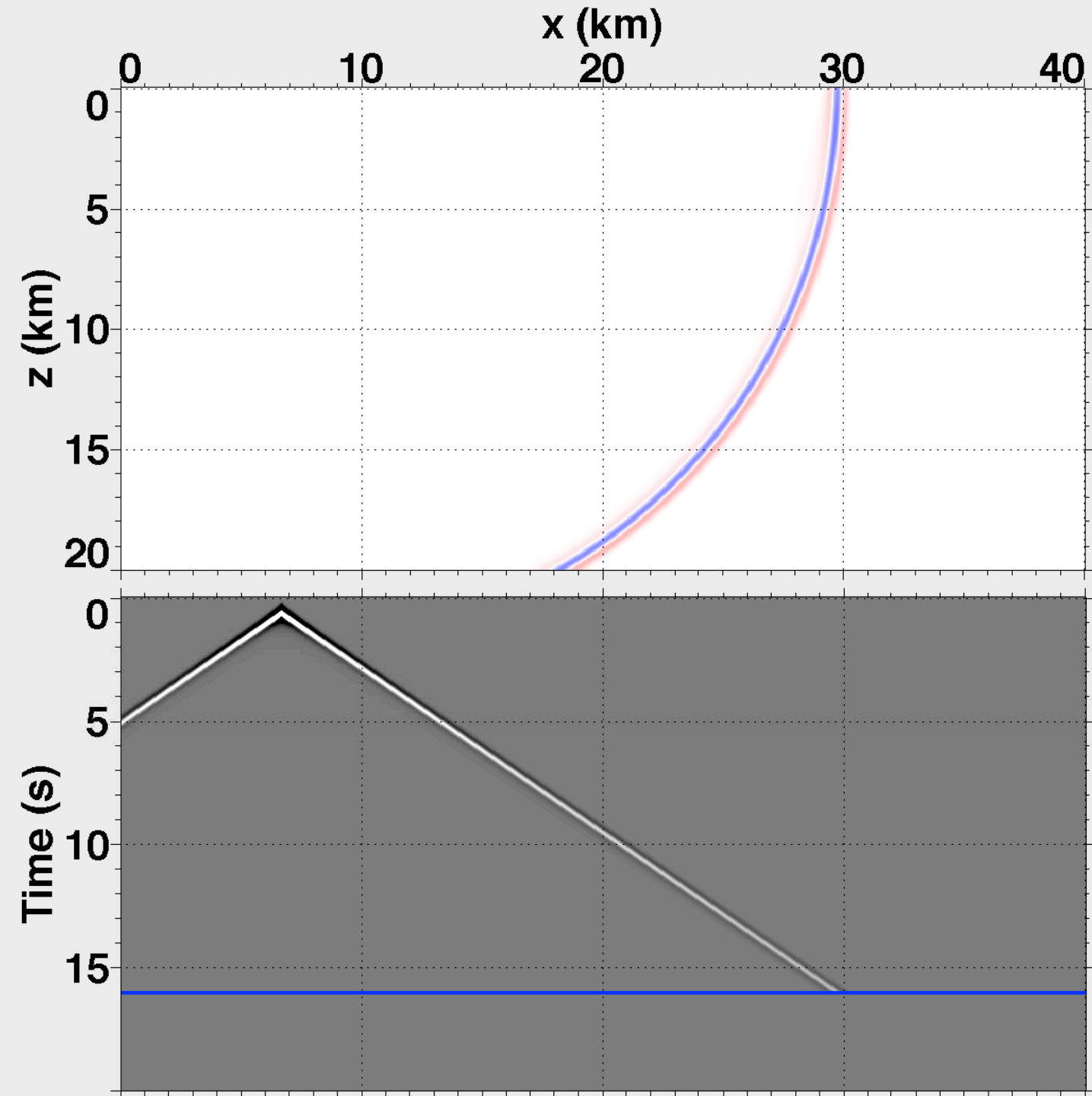


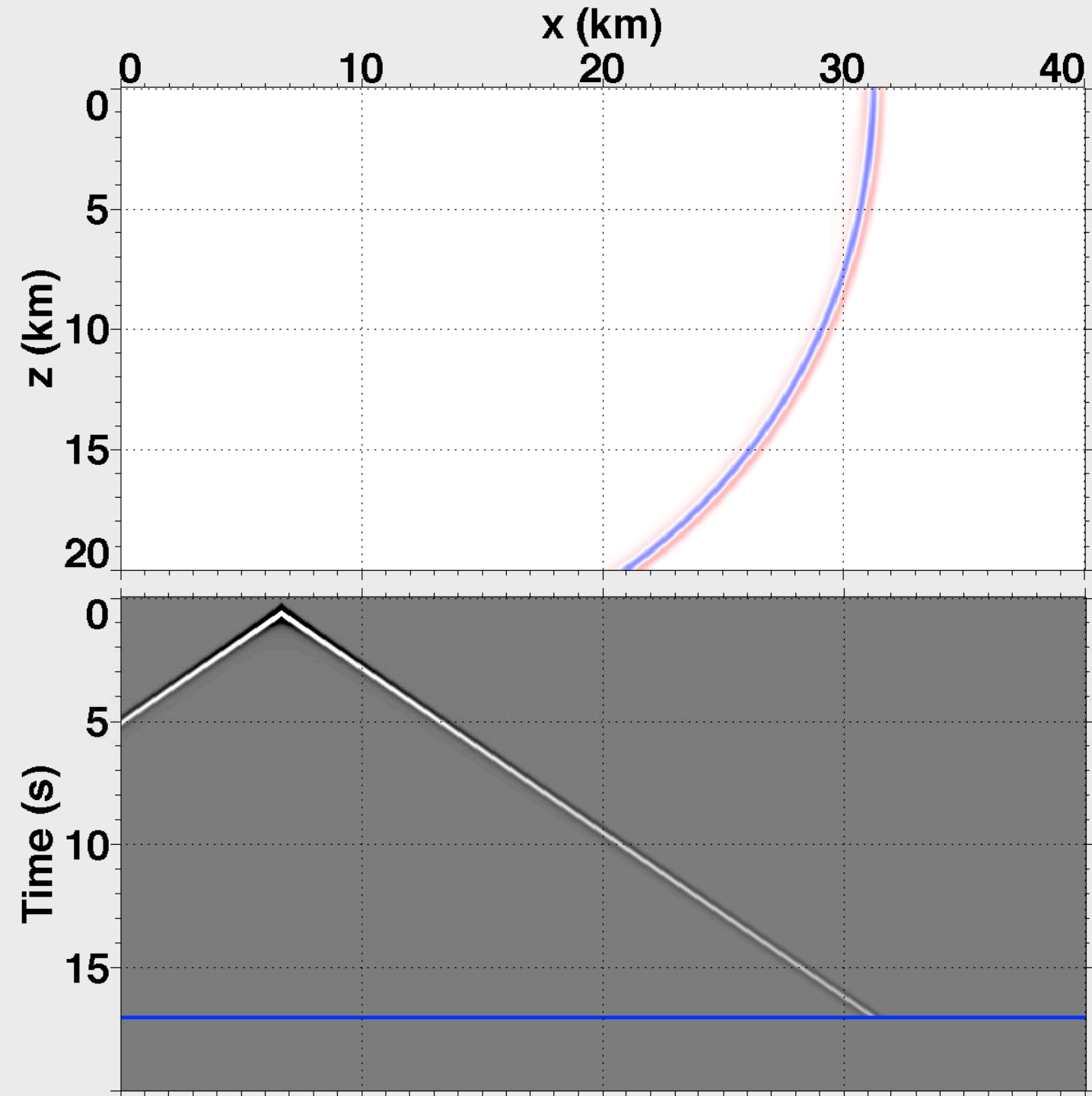


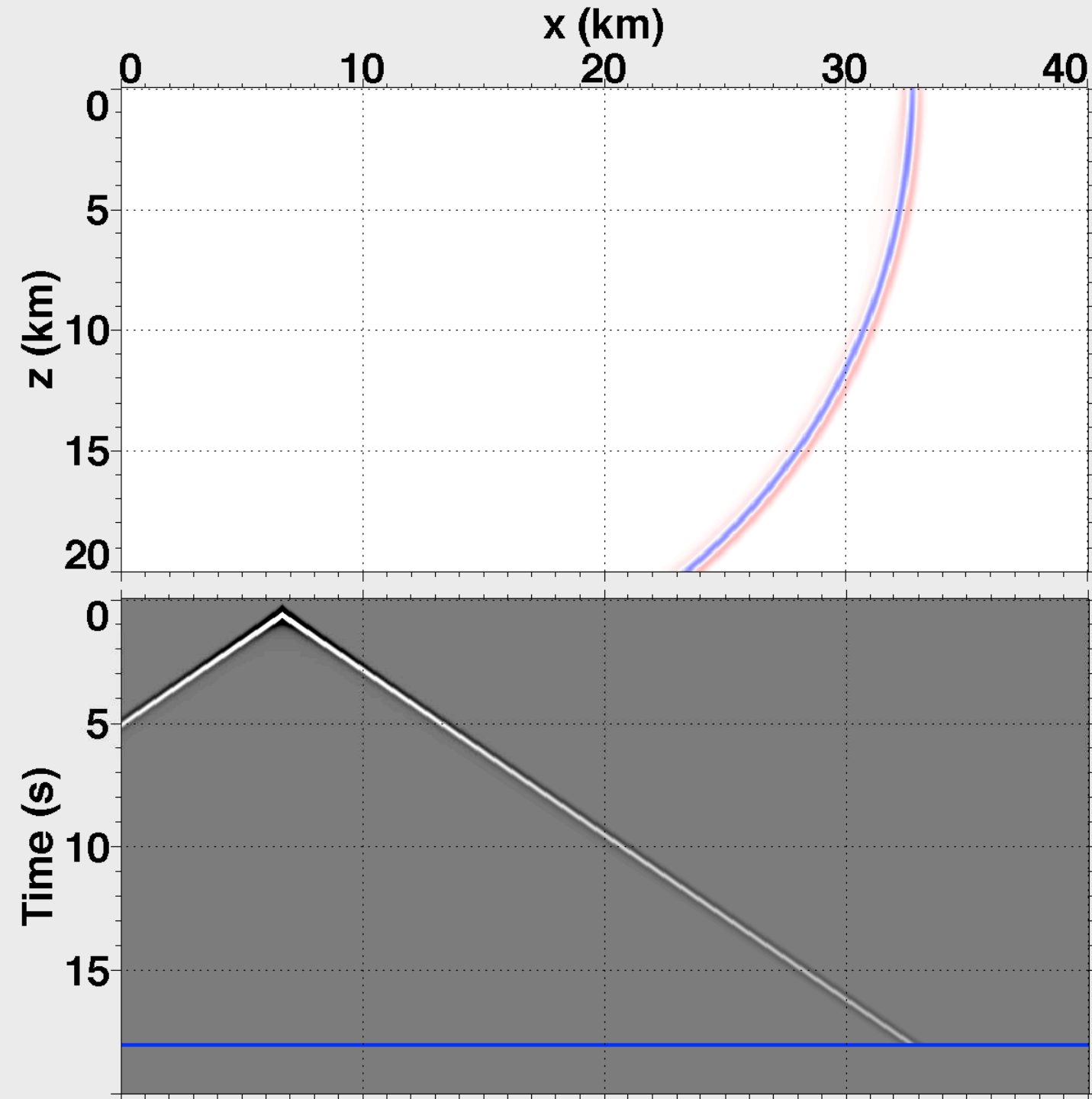


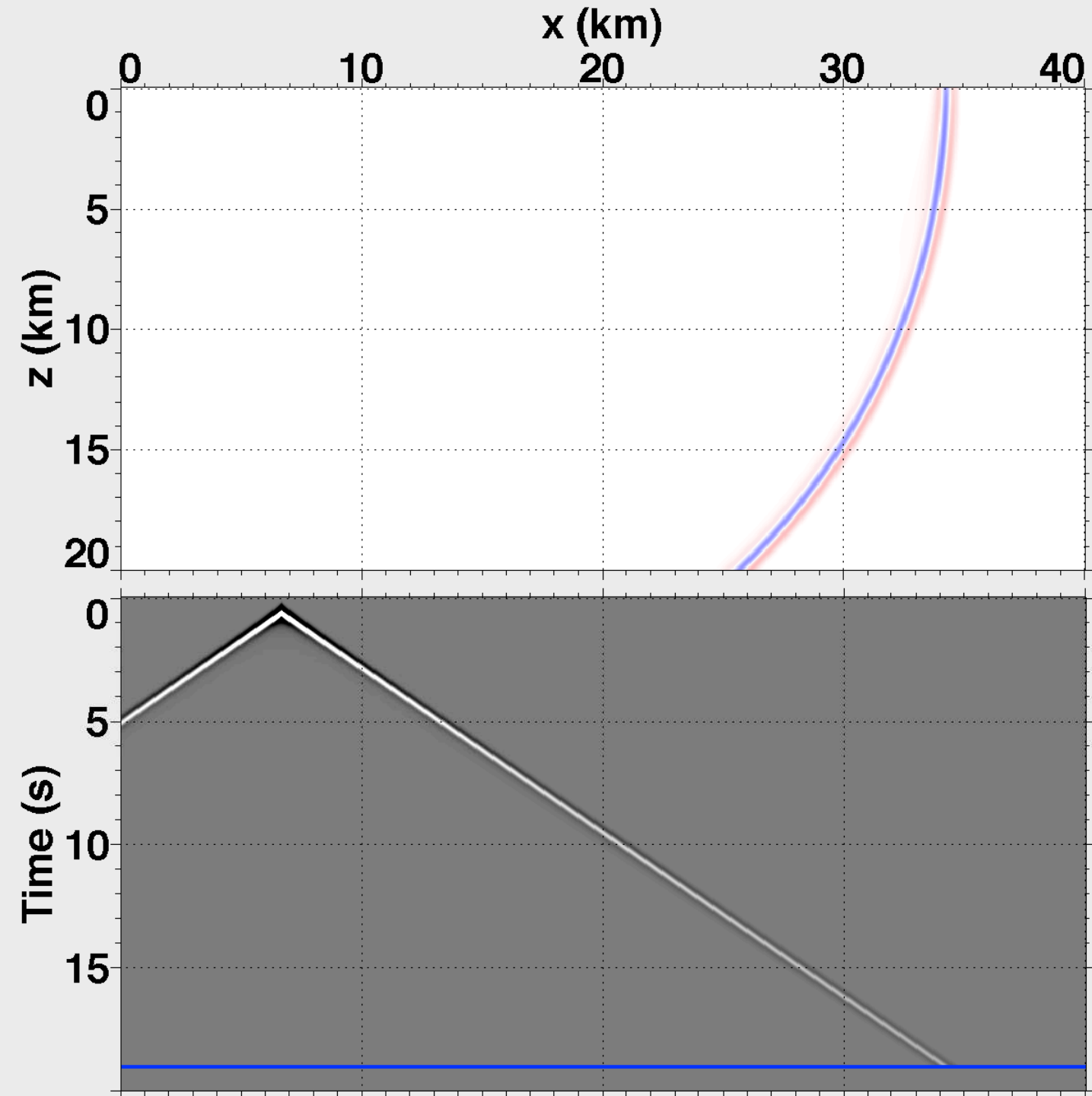




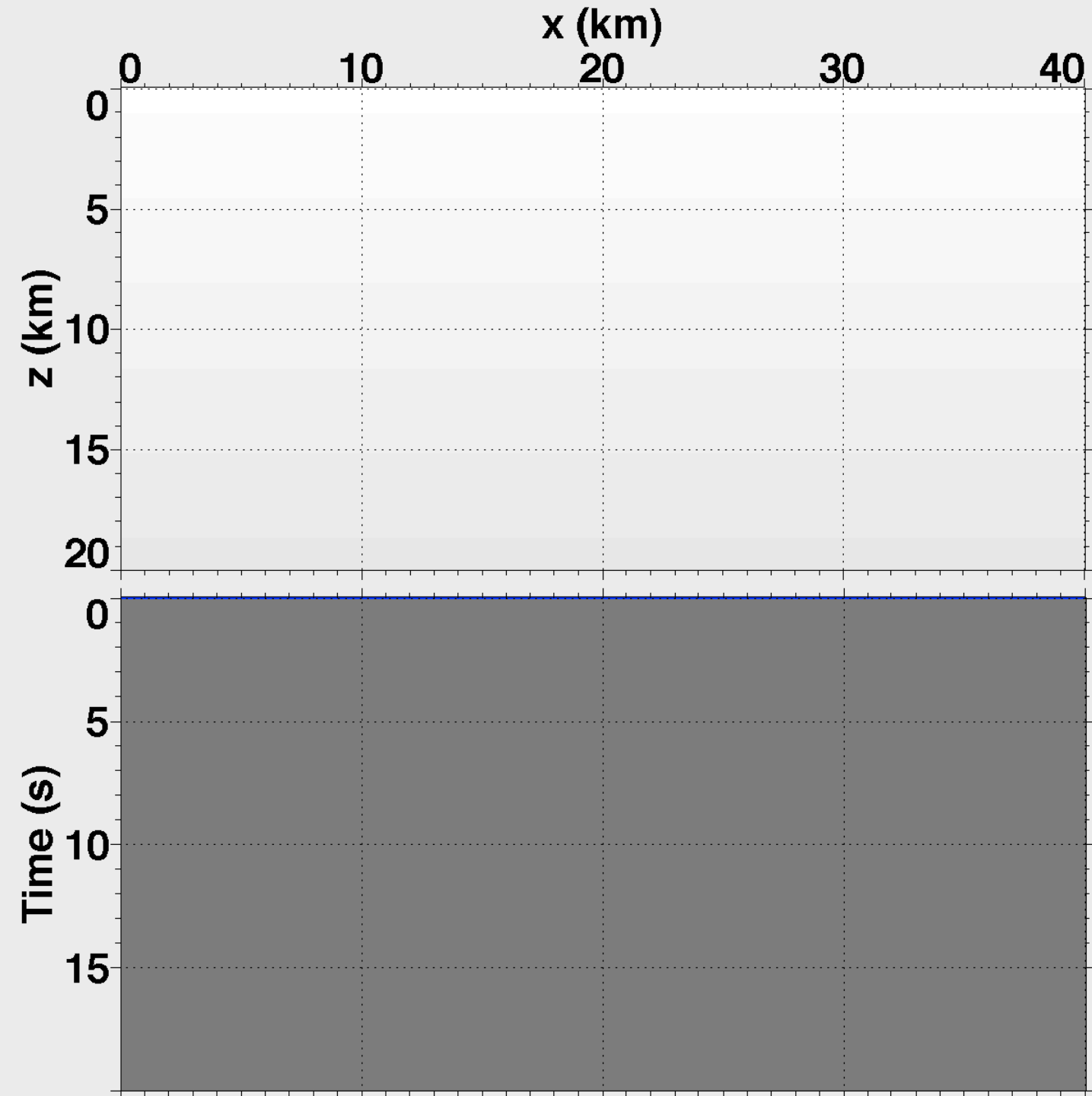


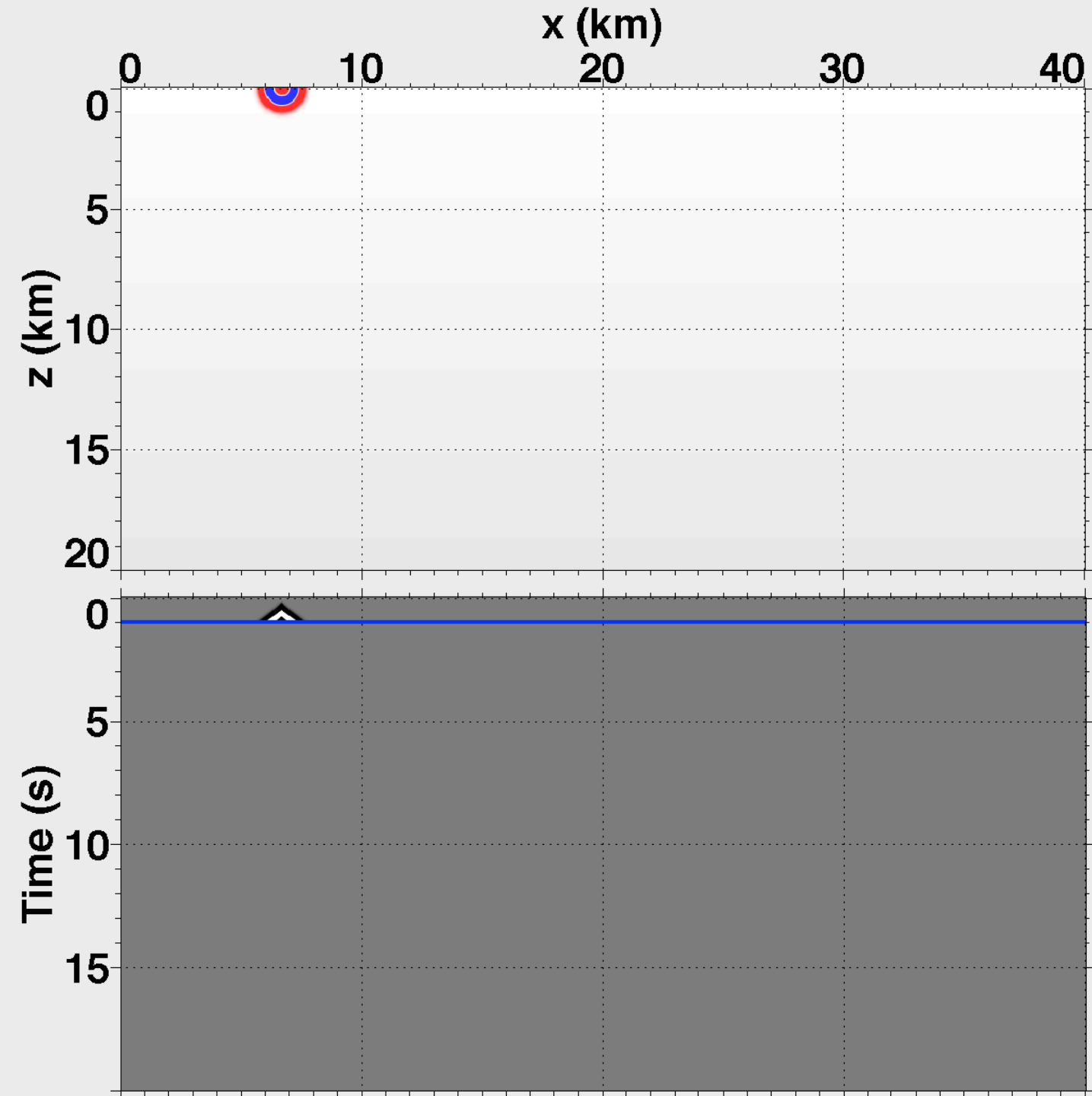


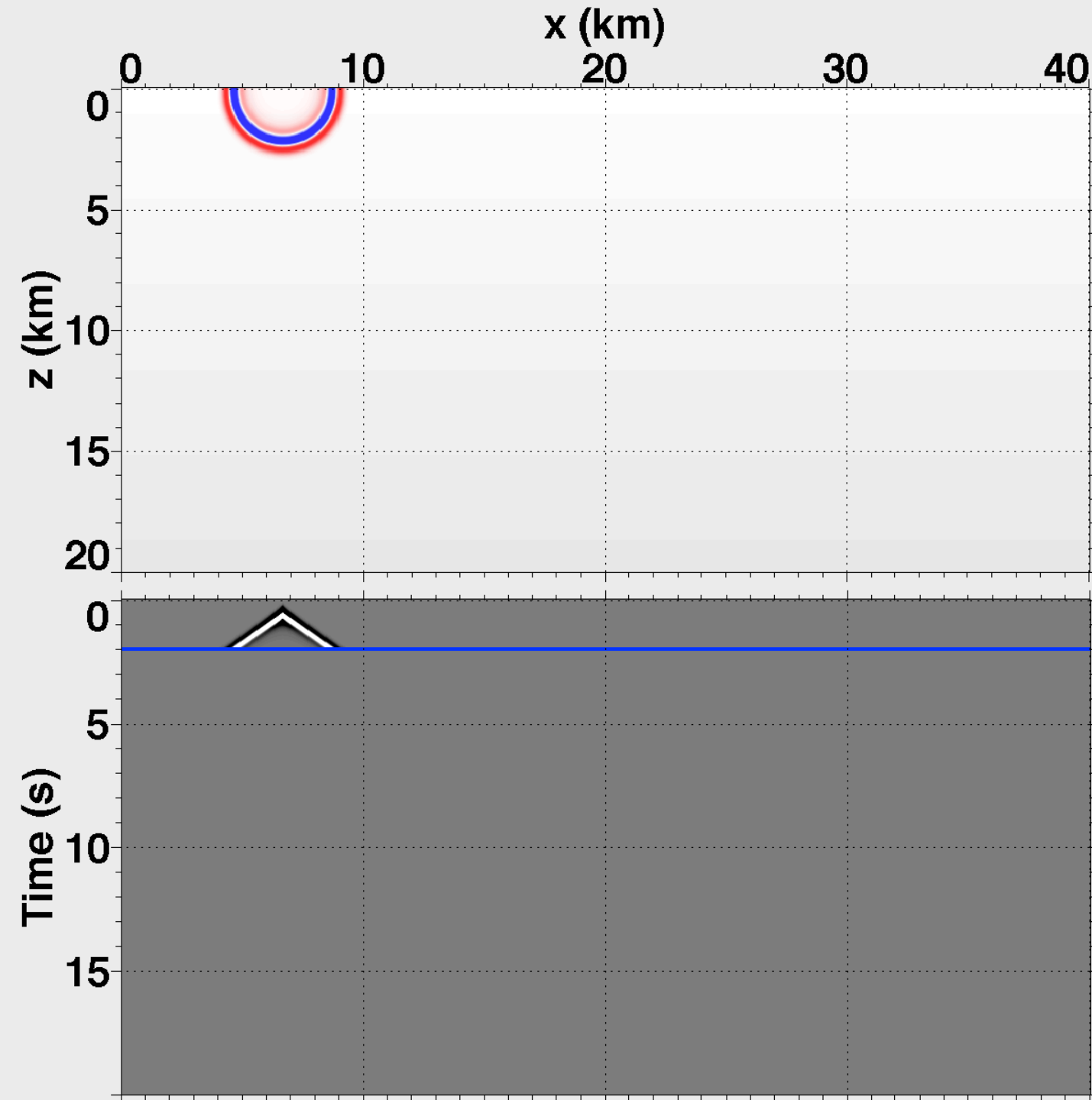


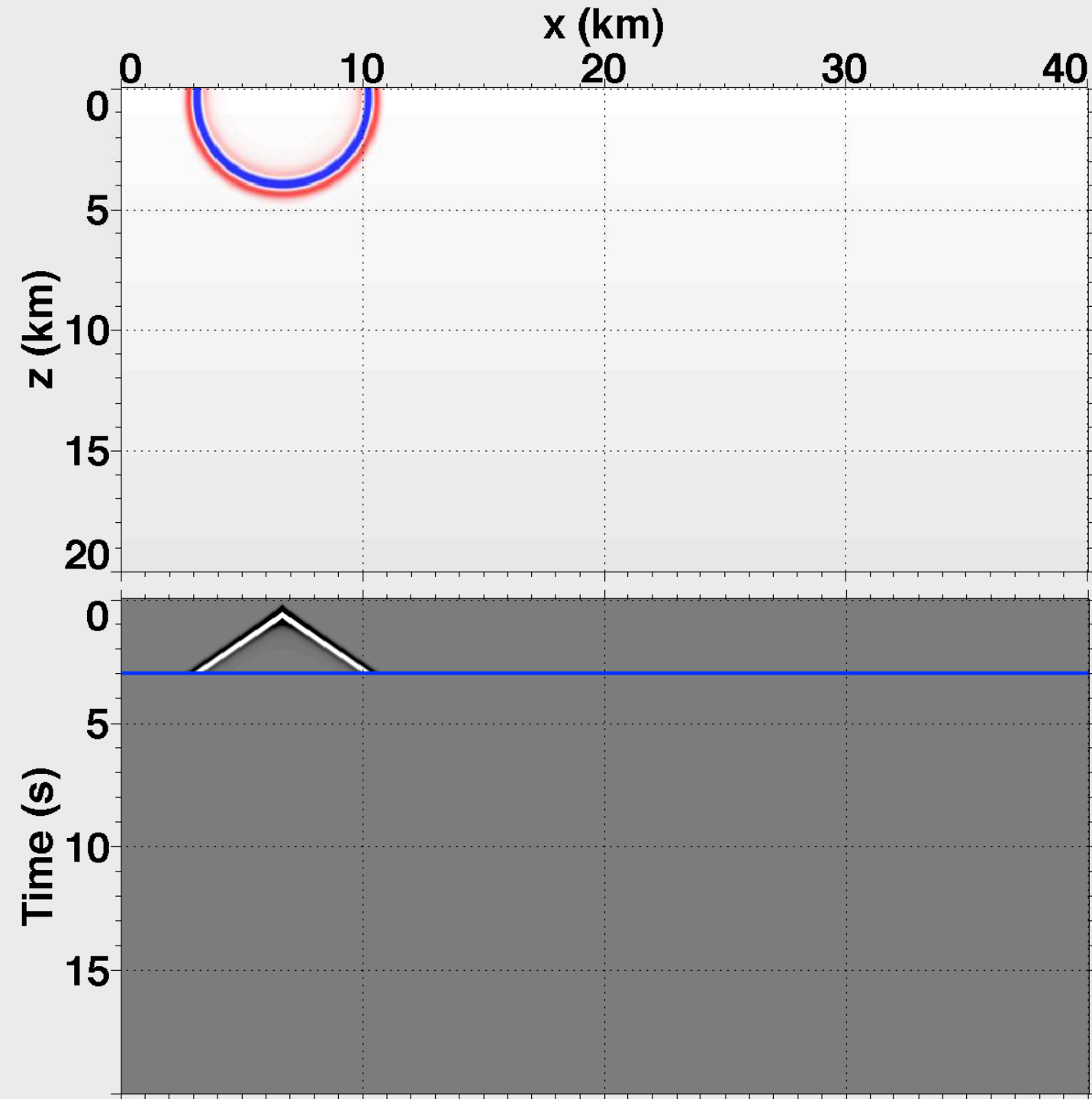


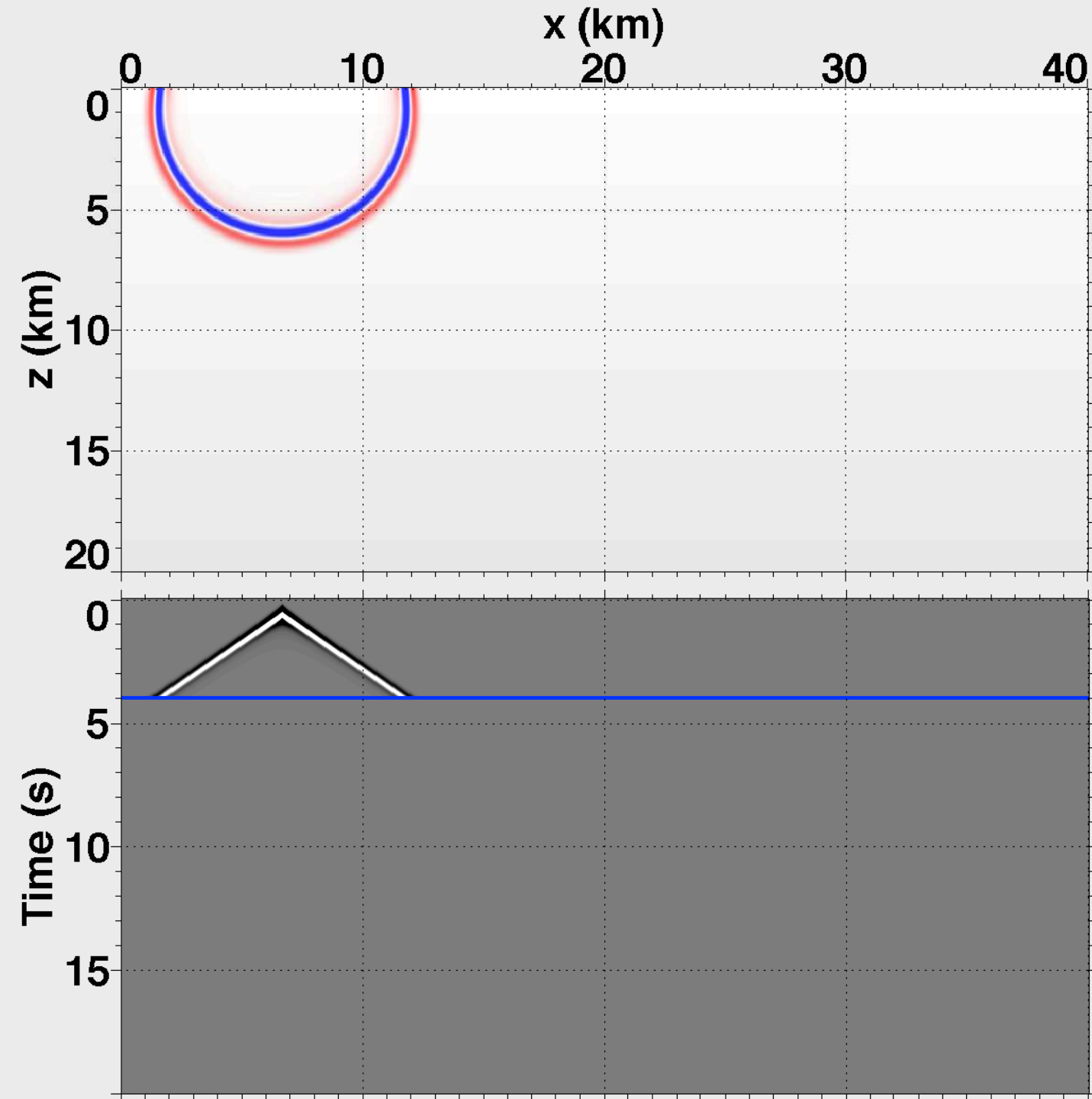
**Gradually increase
velocity**

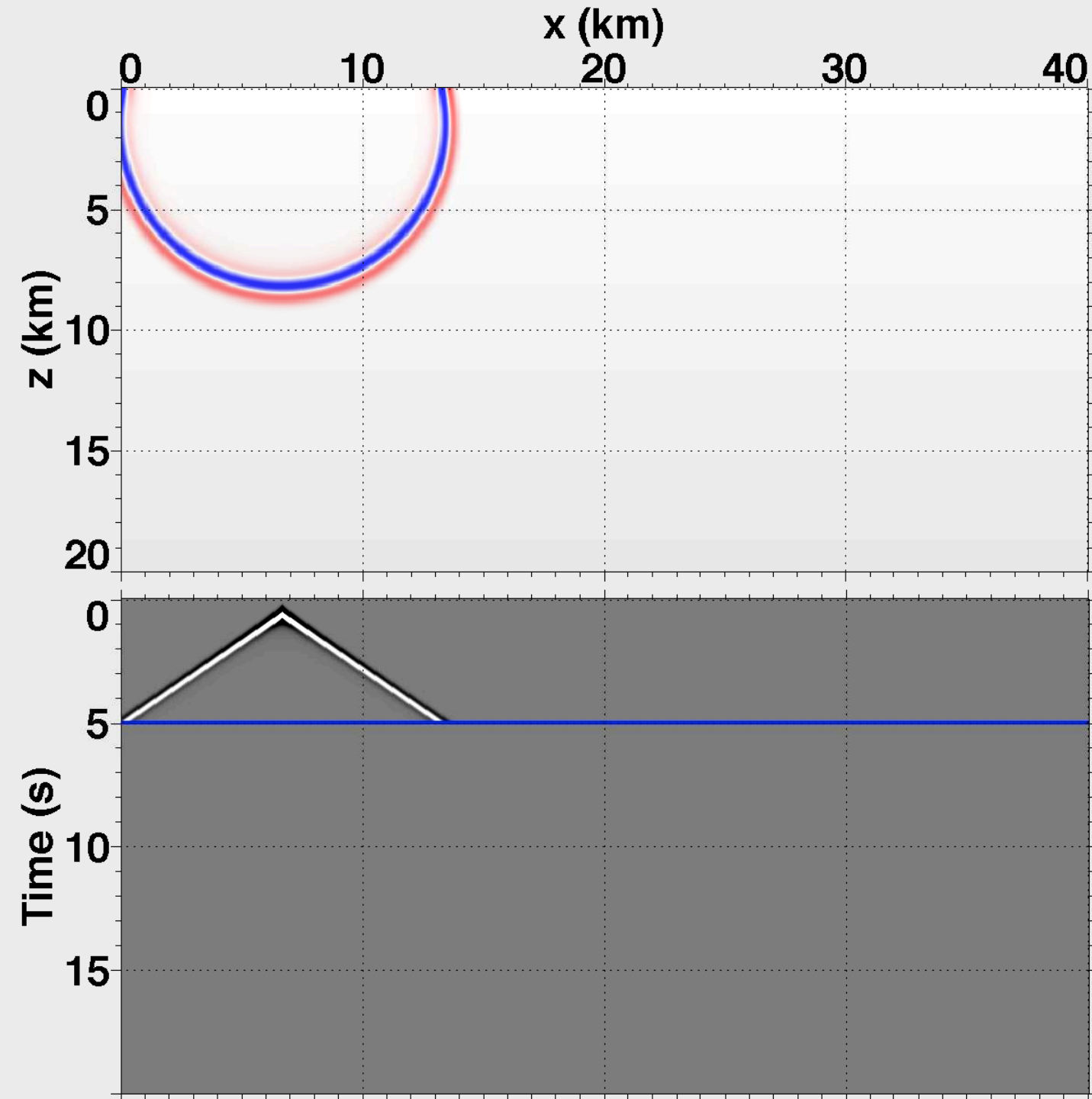


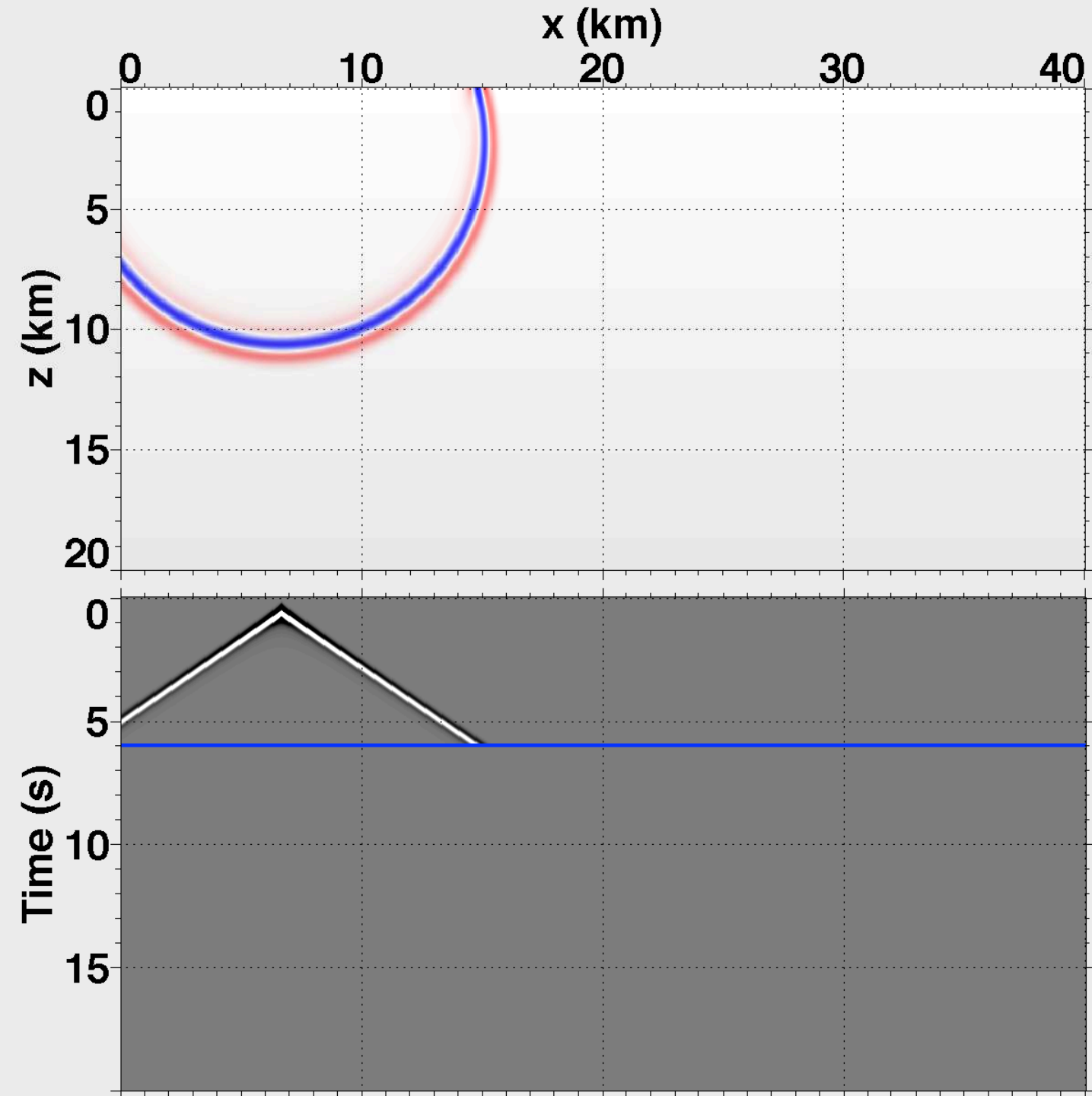


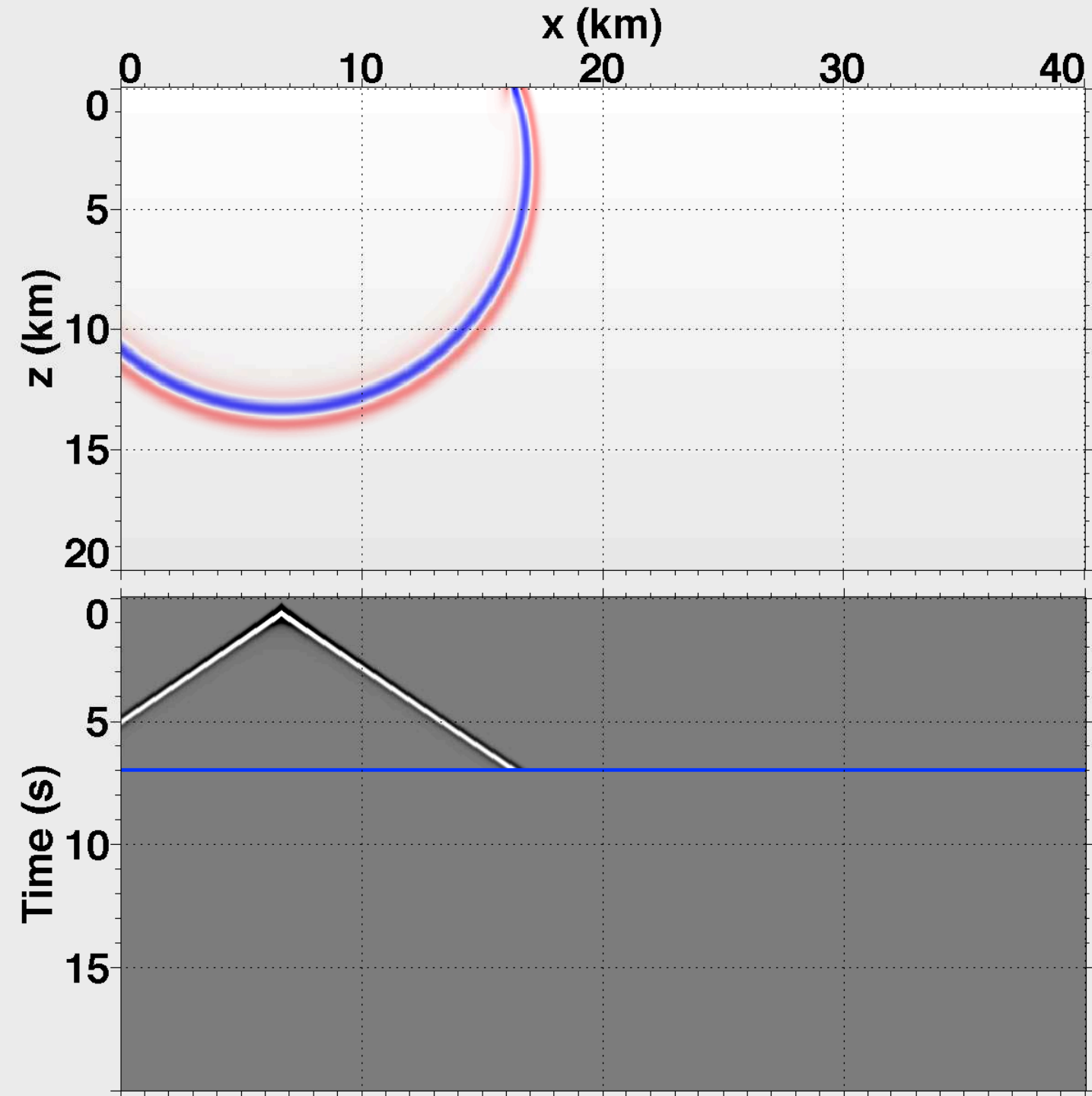


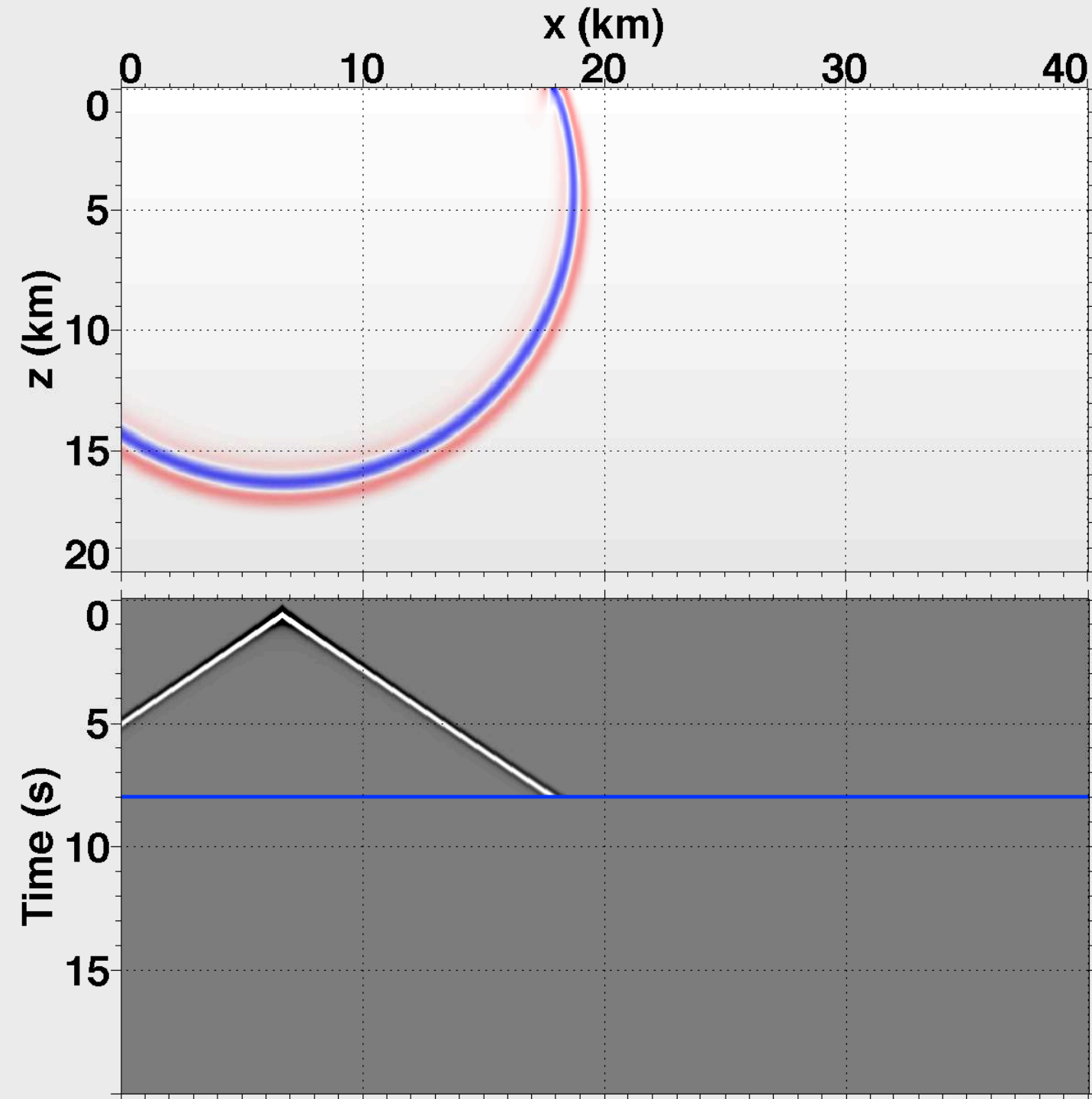


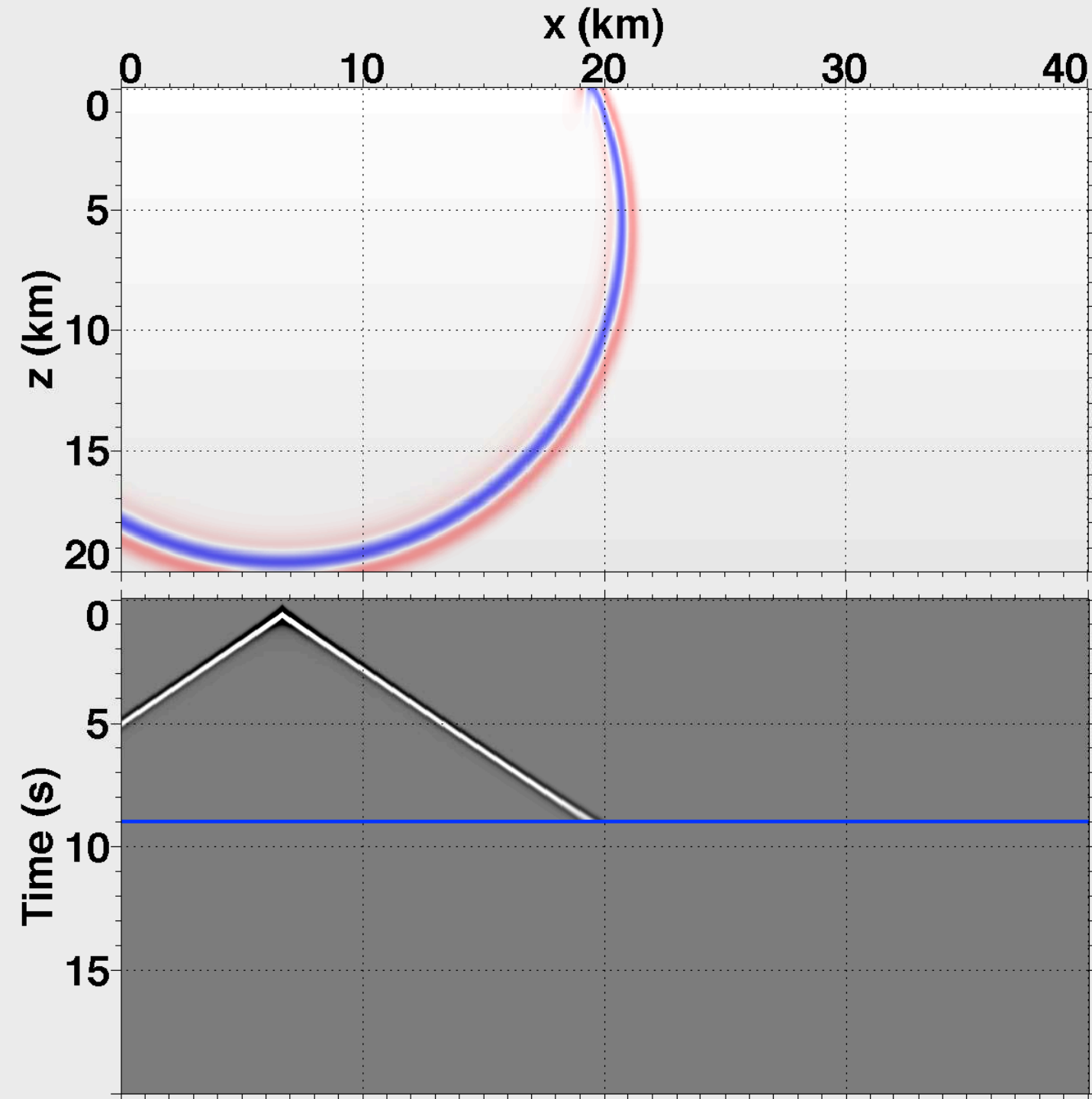


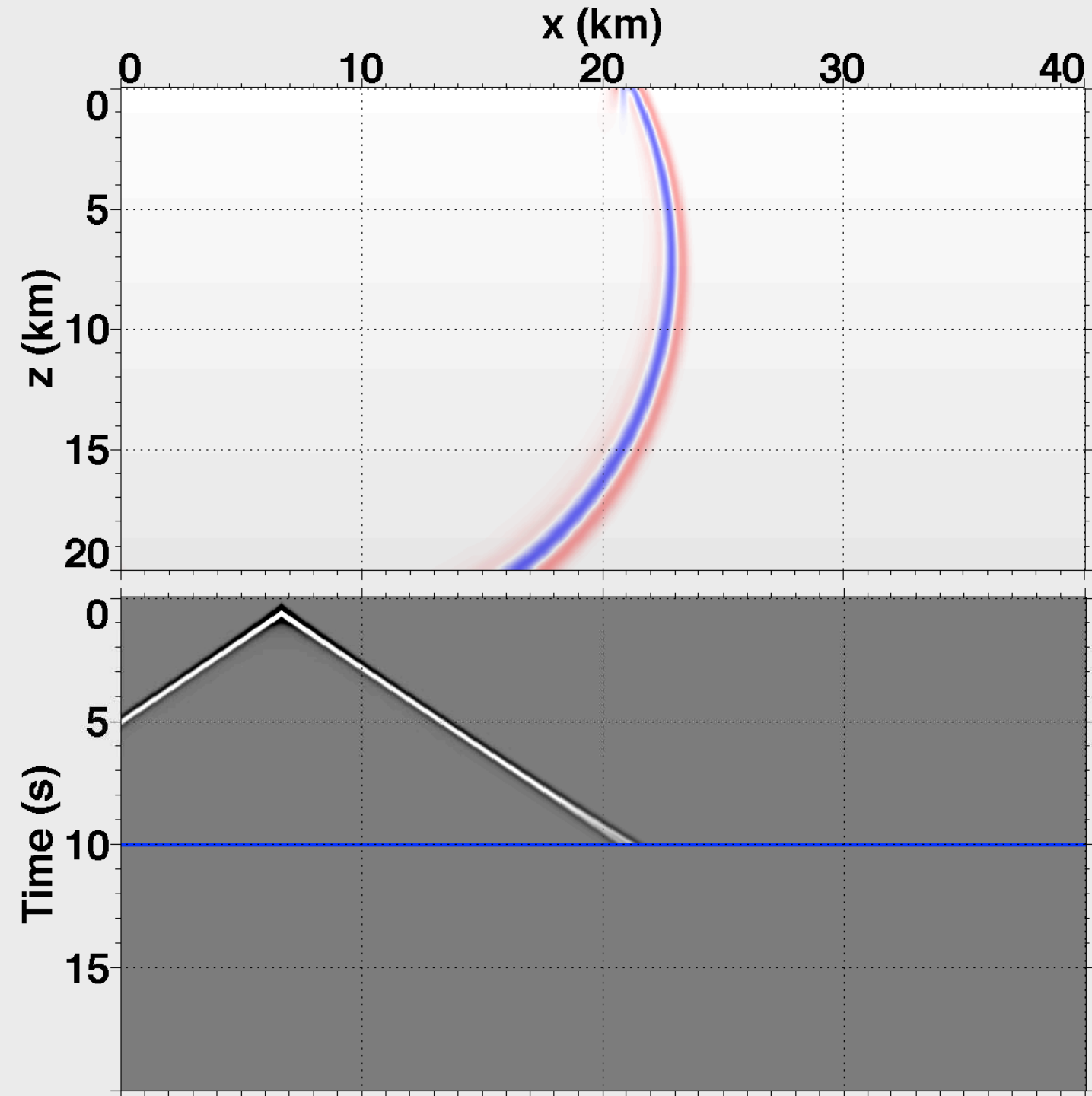


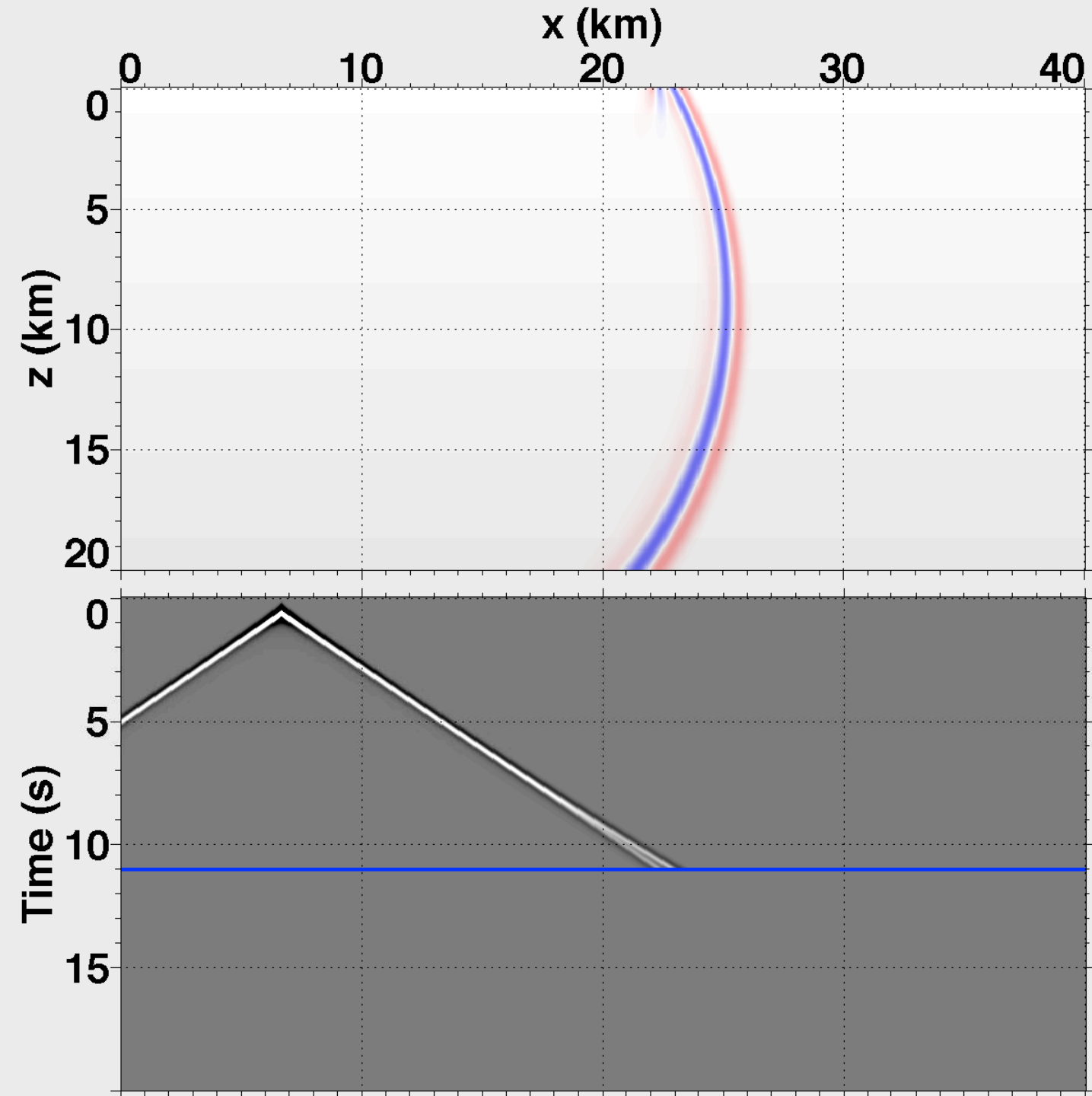


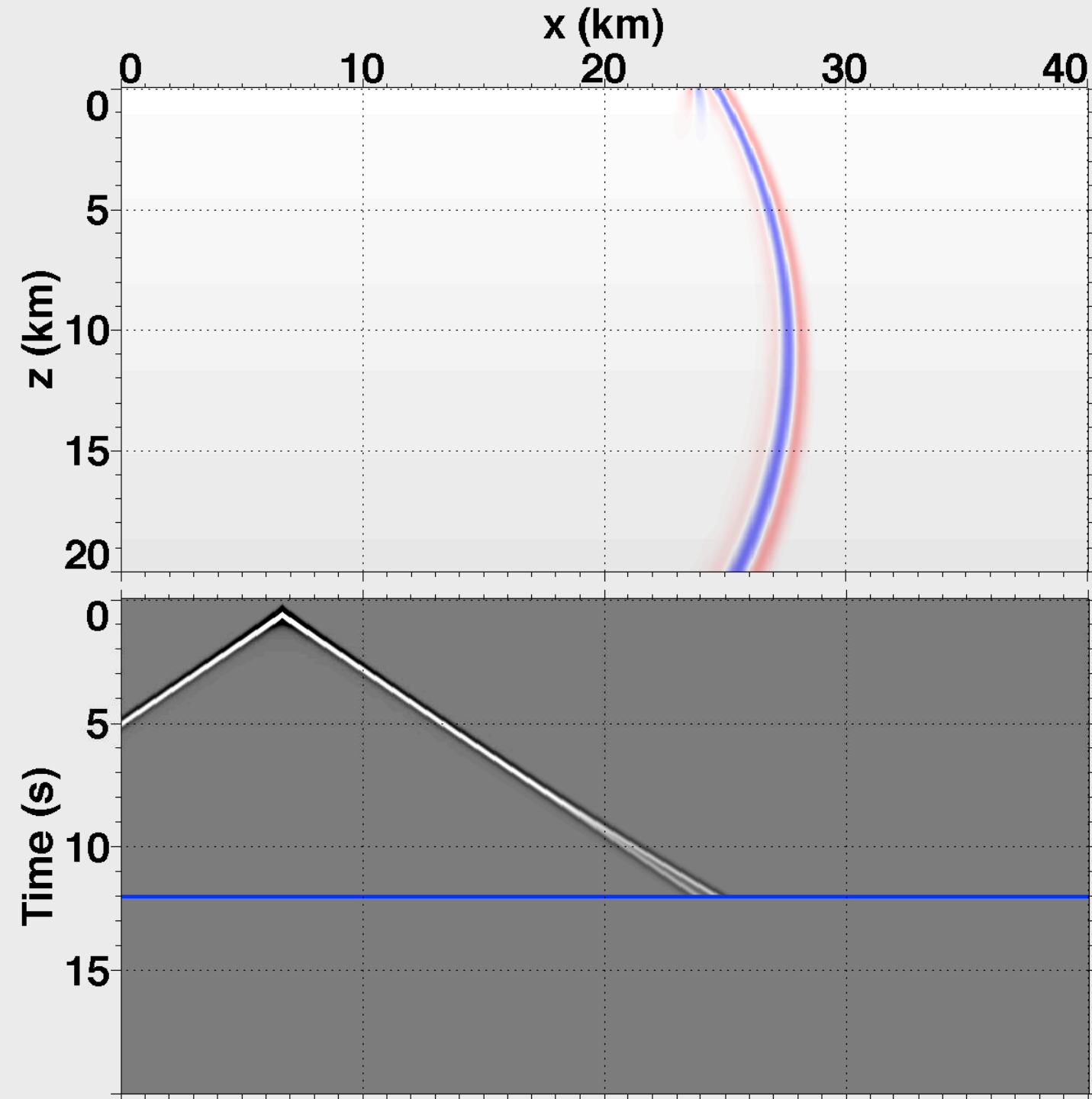


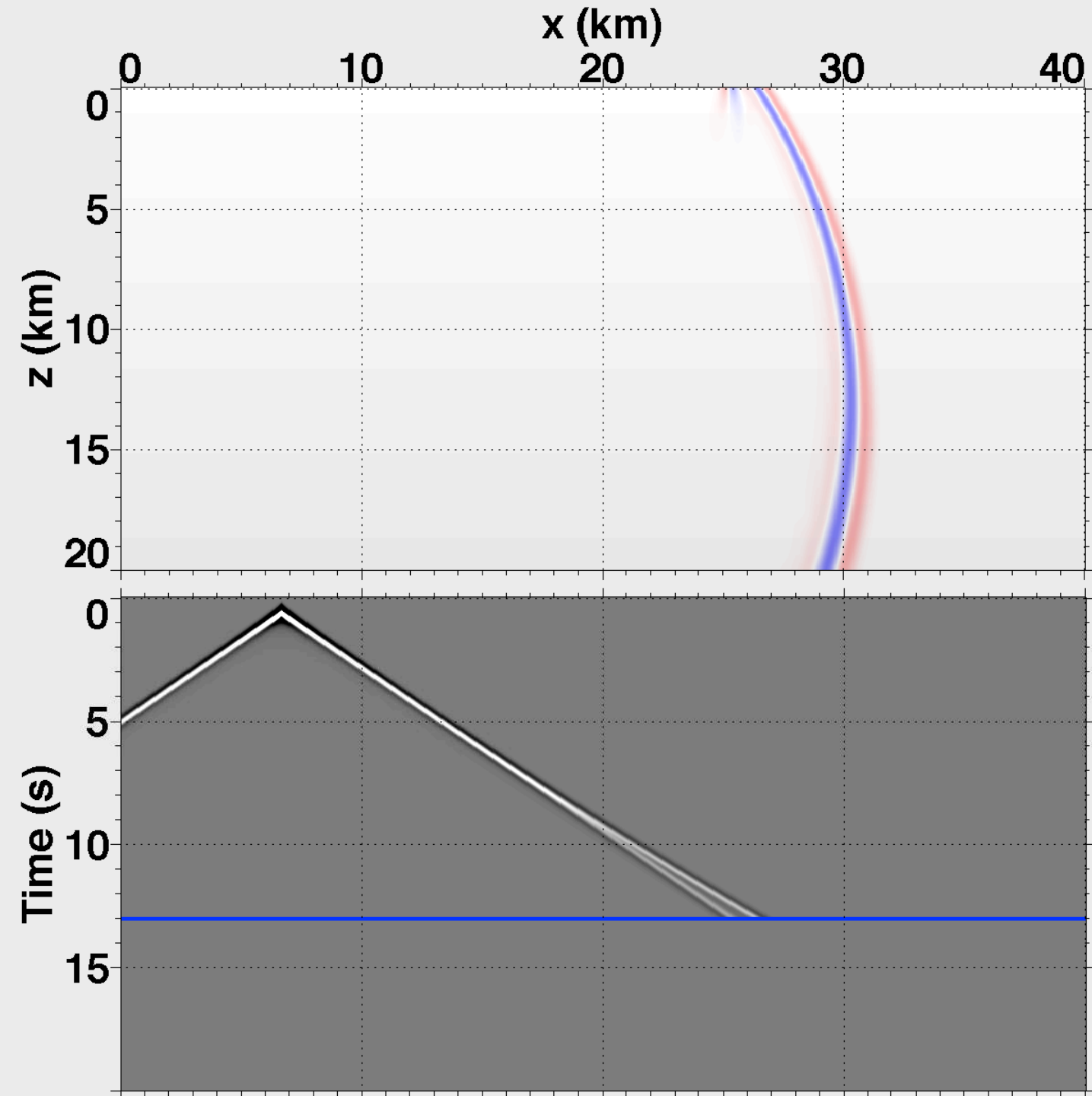


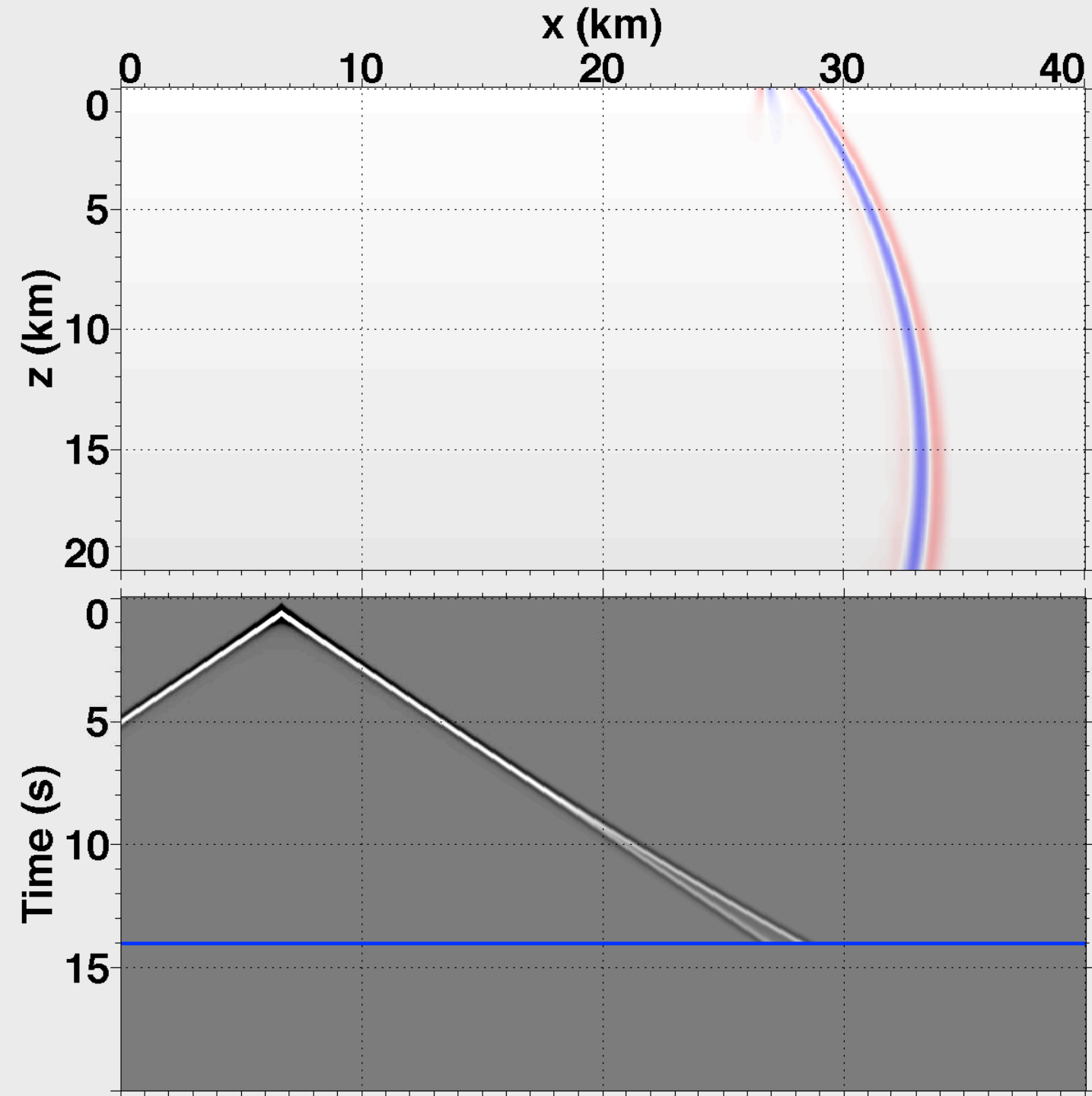


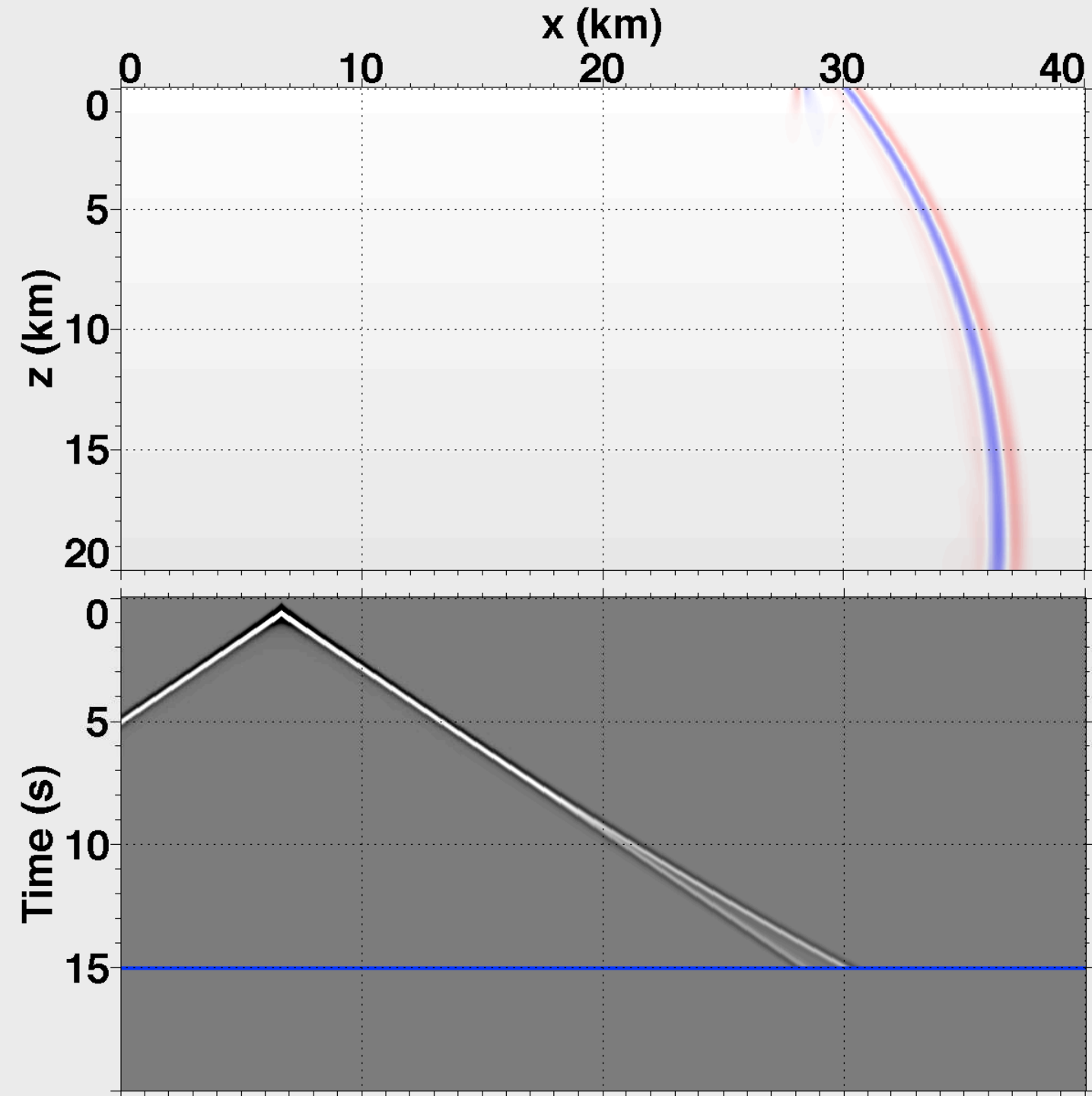


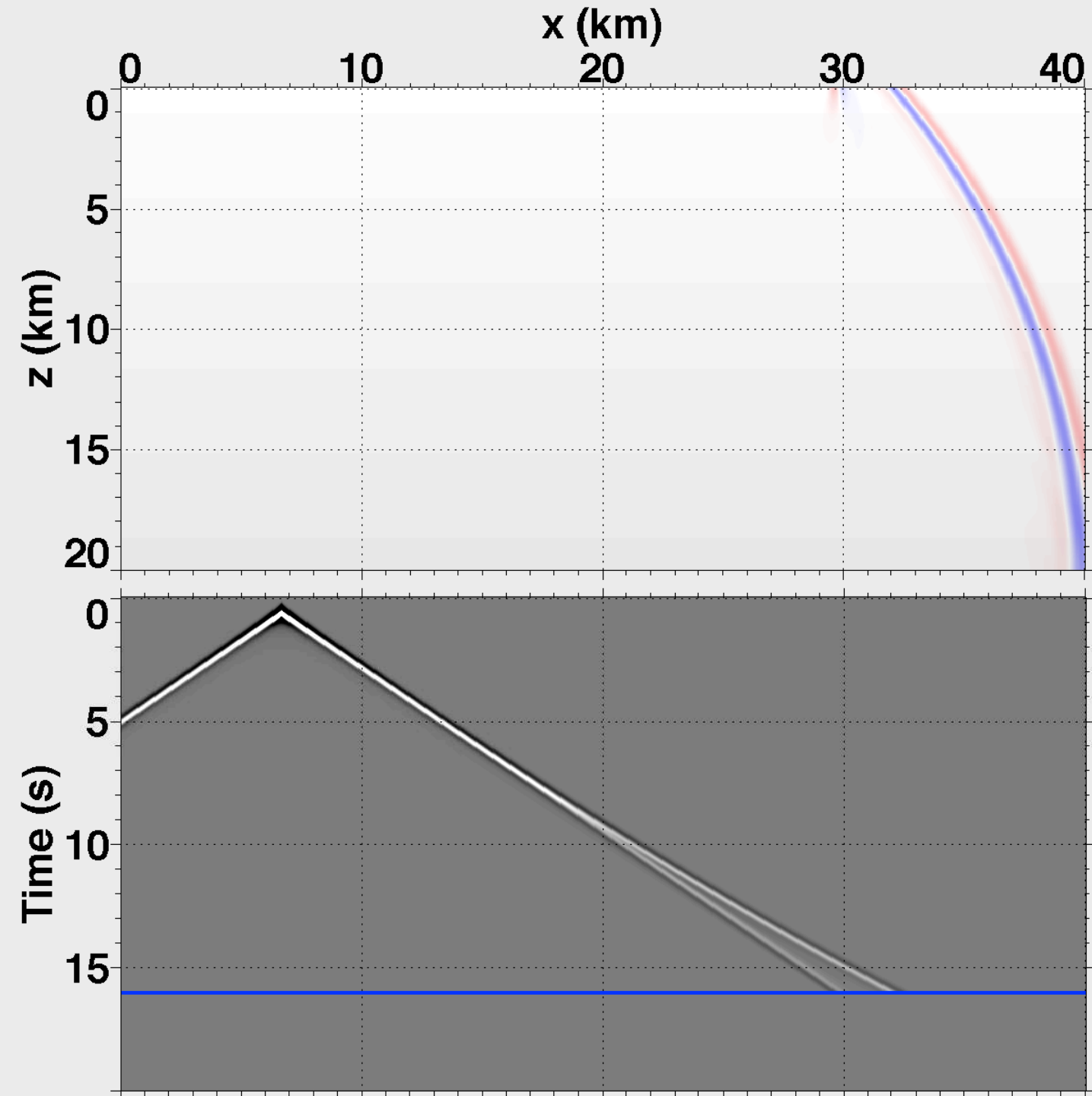


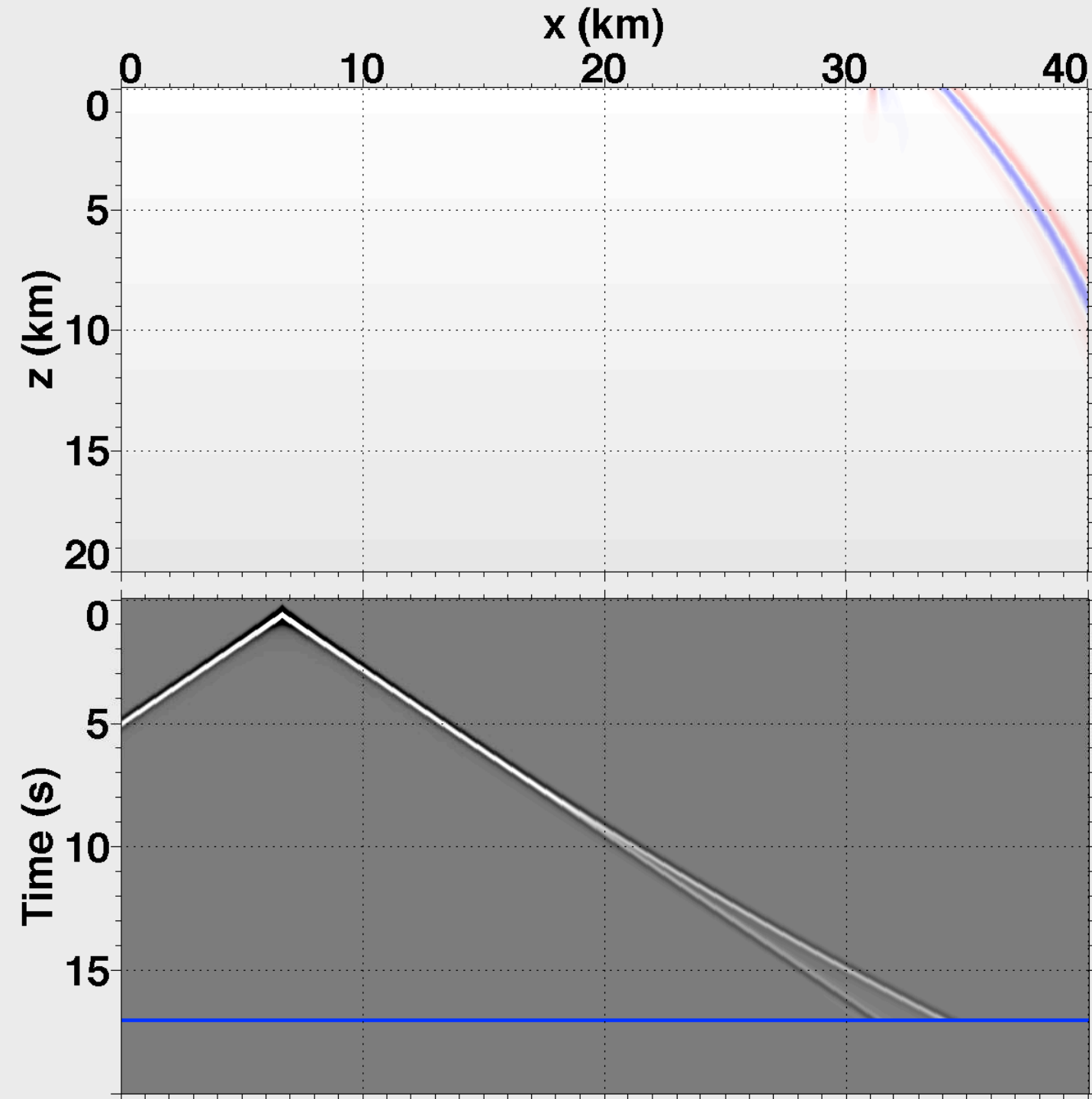


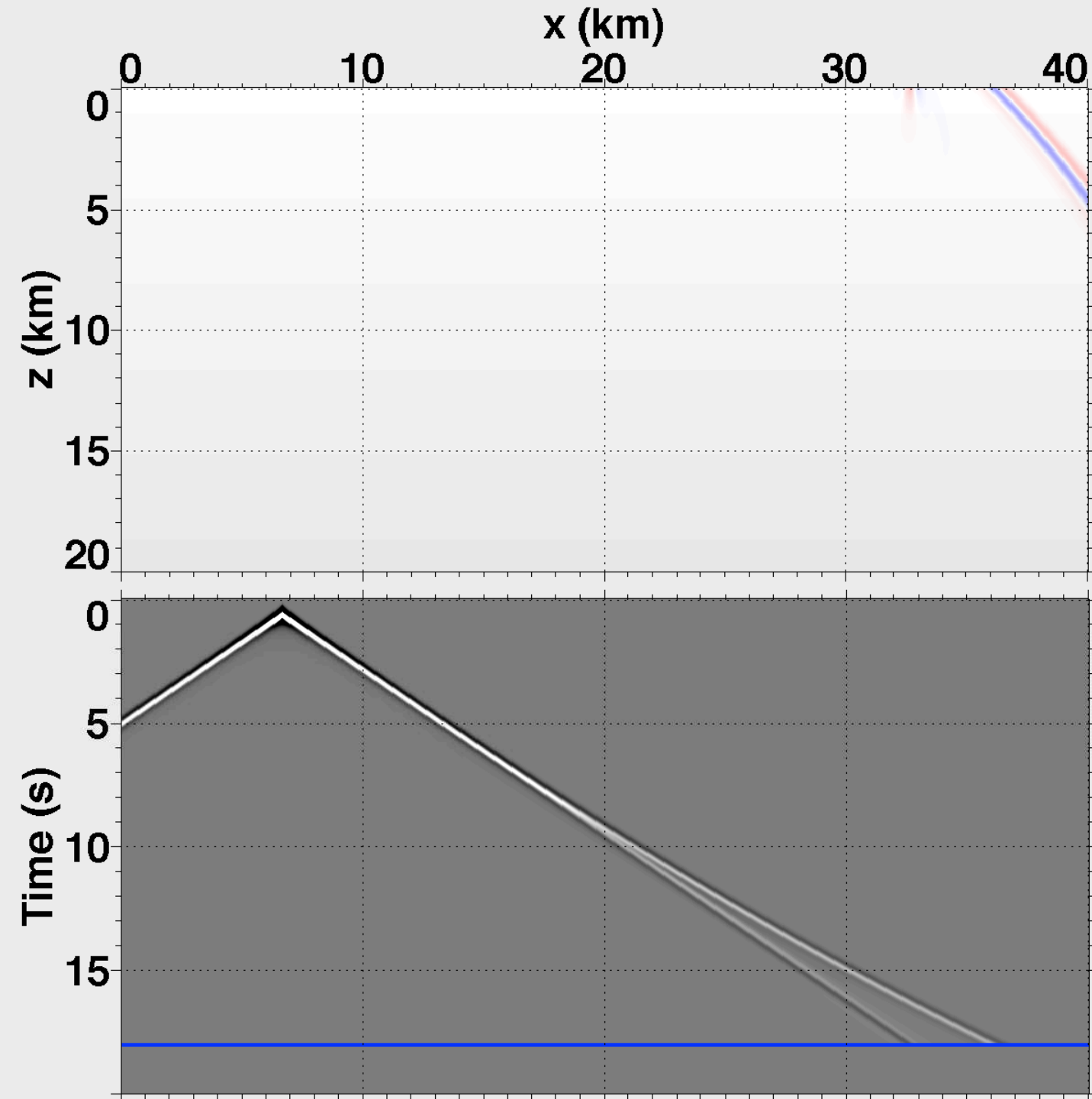


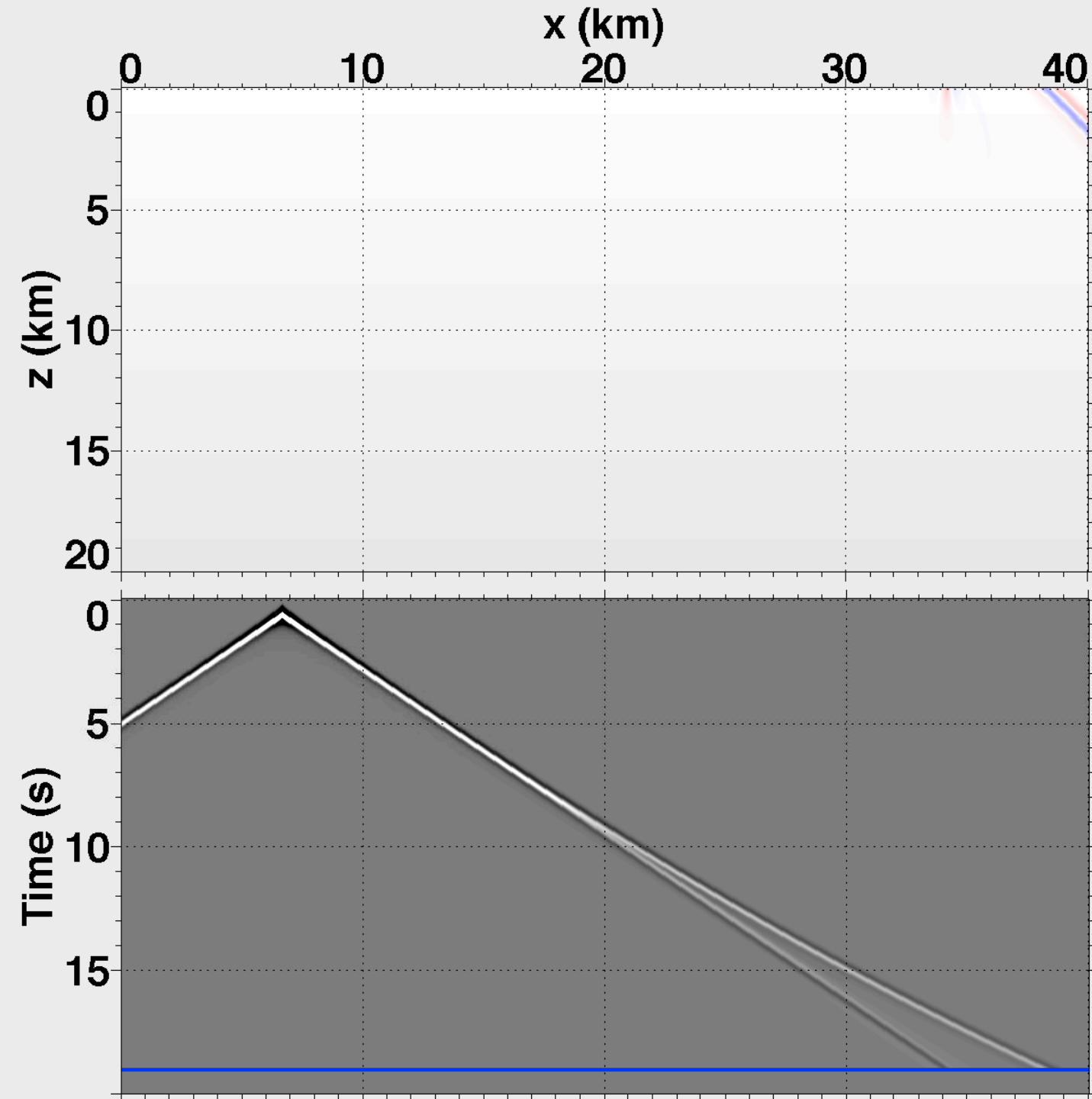




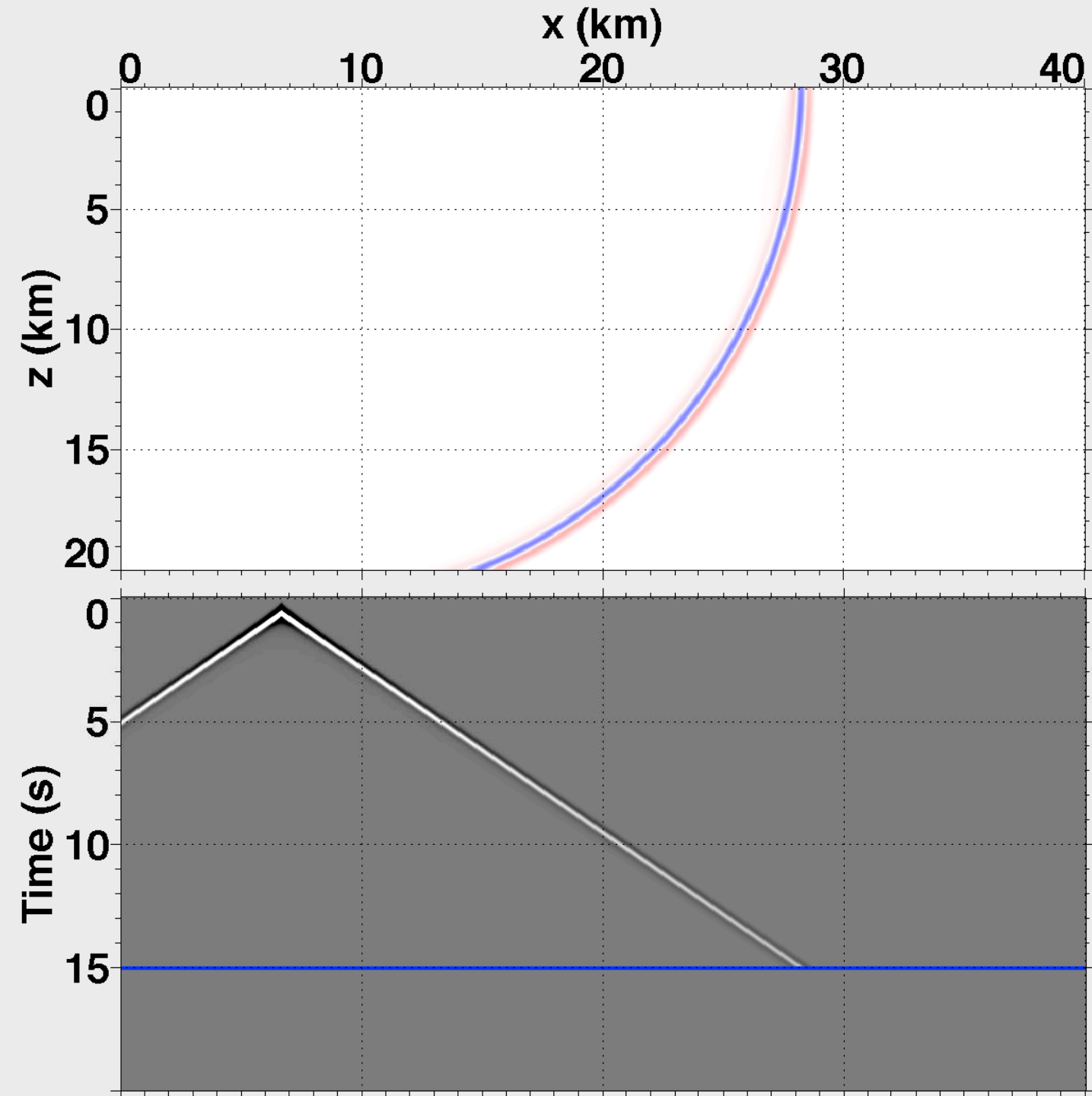


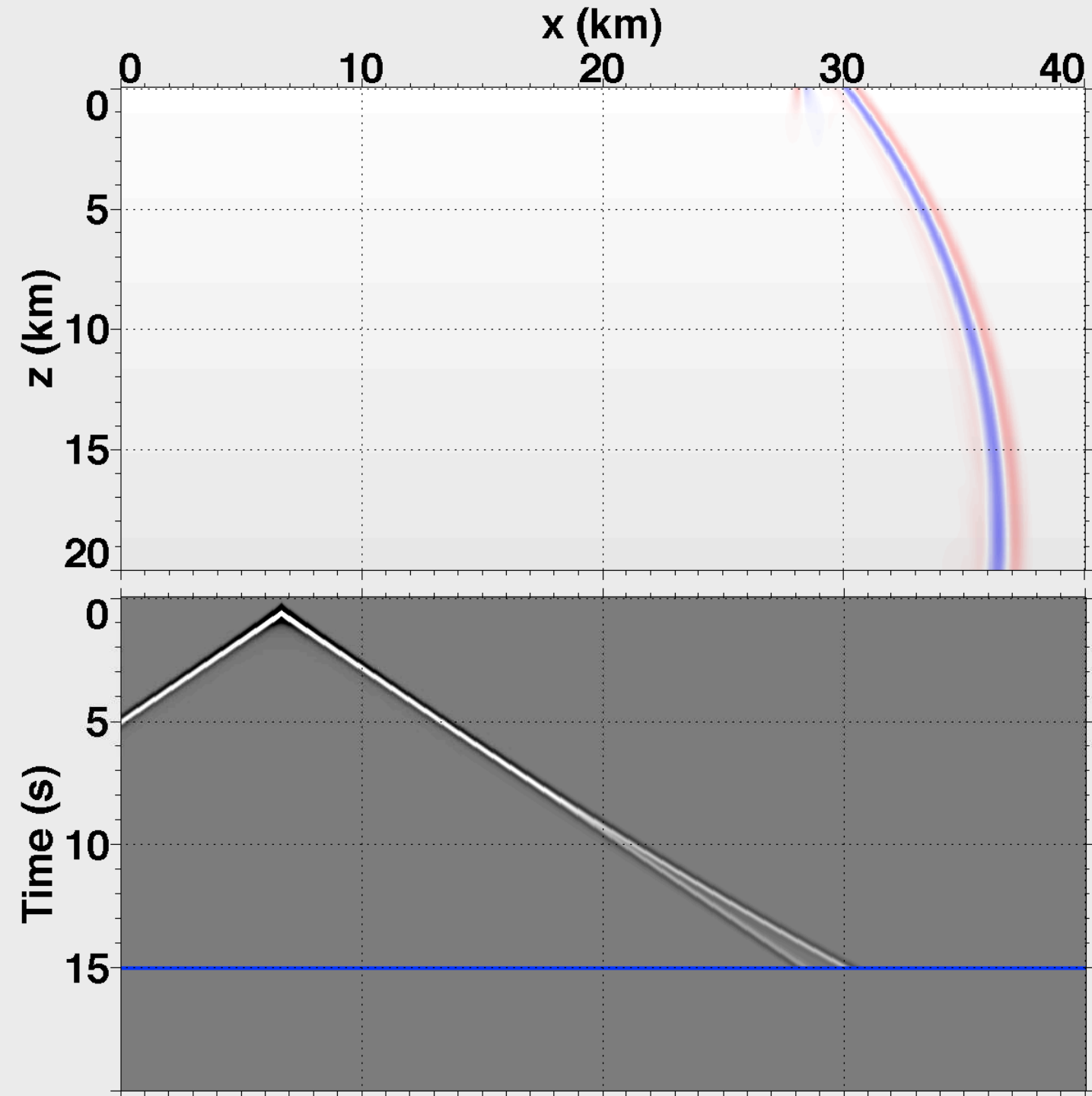




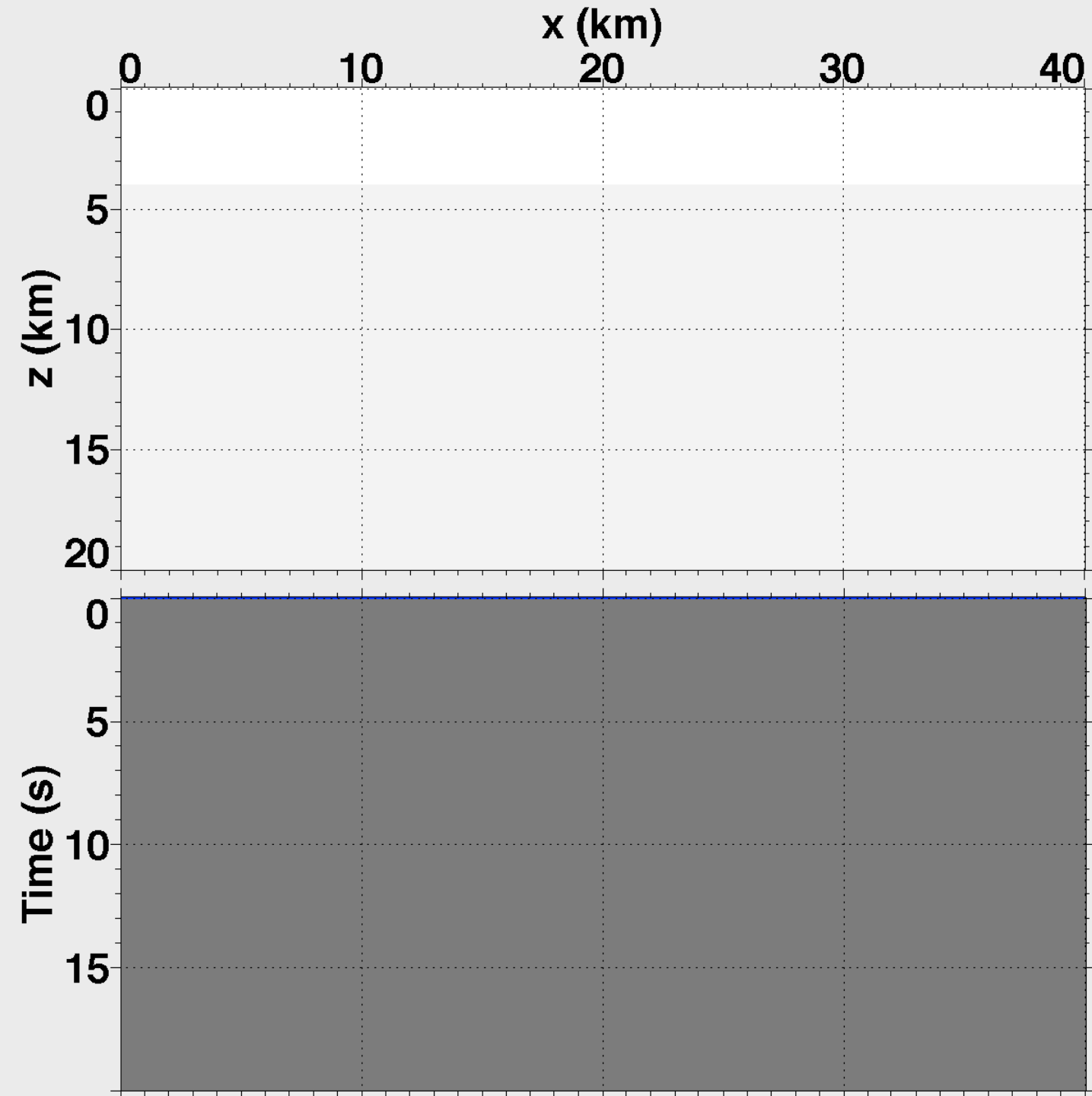


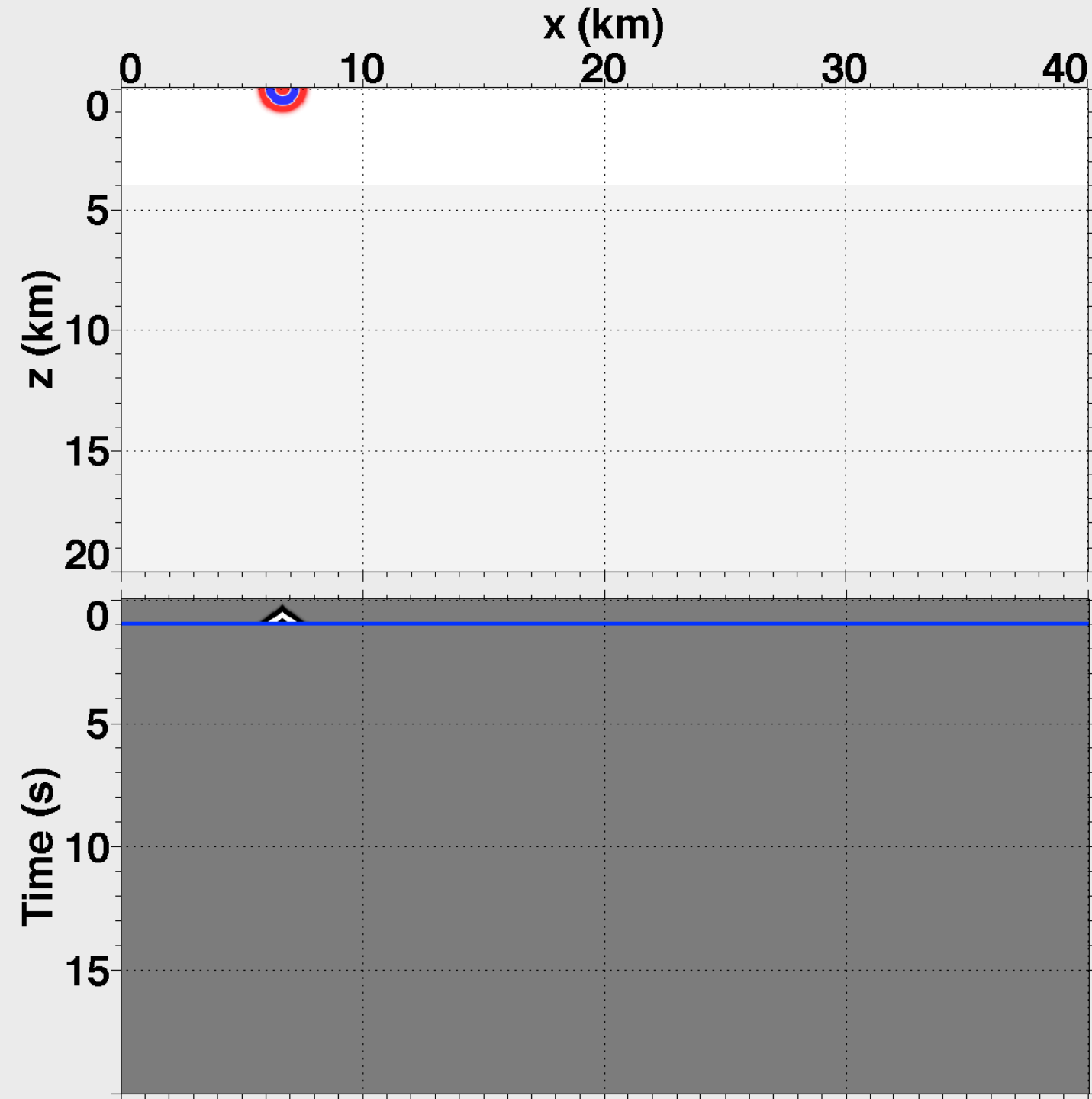
Comparison

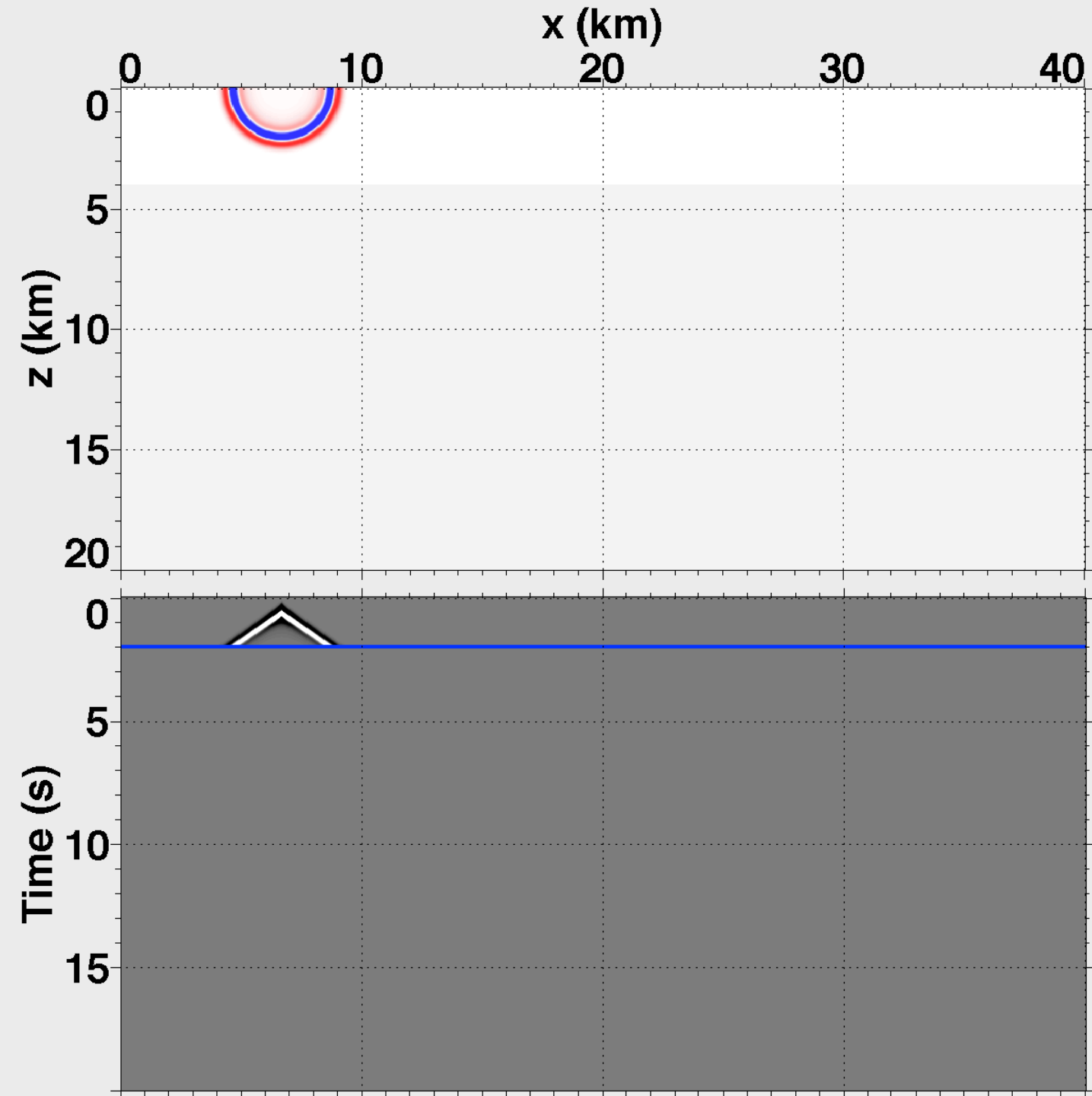


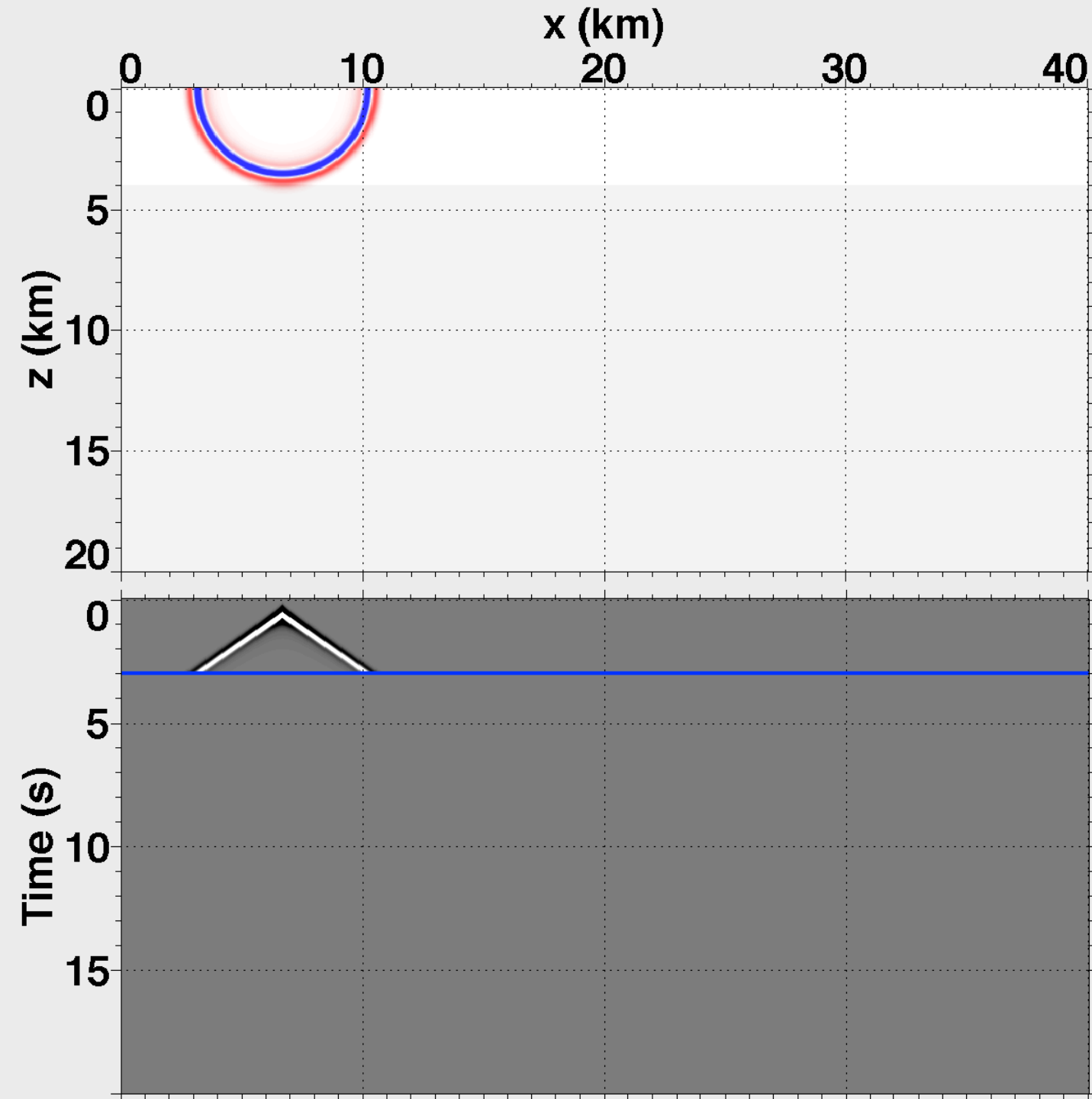


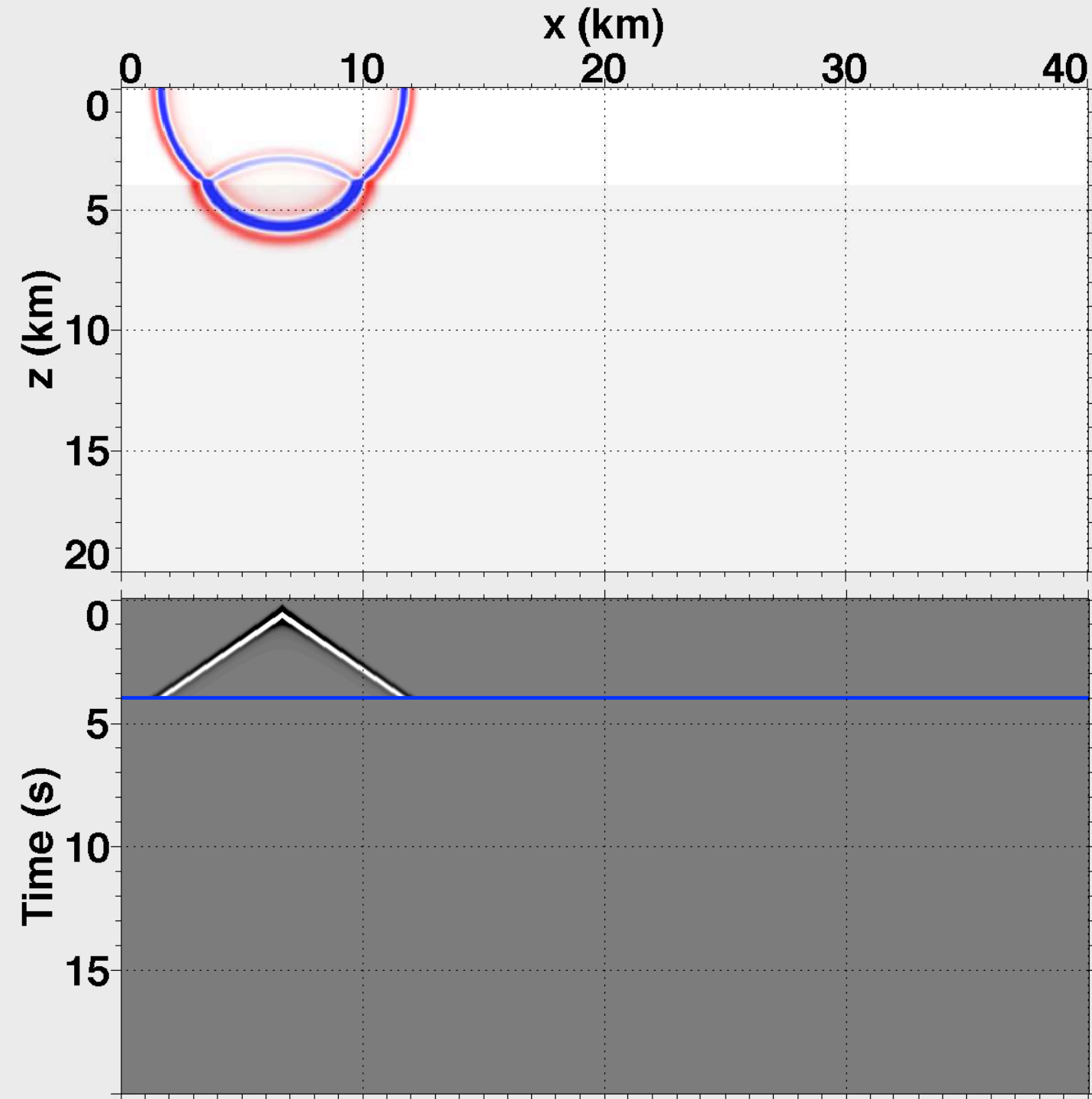
A layer + halfspace

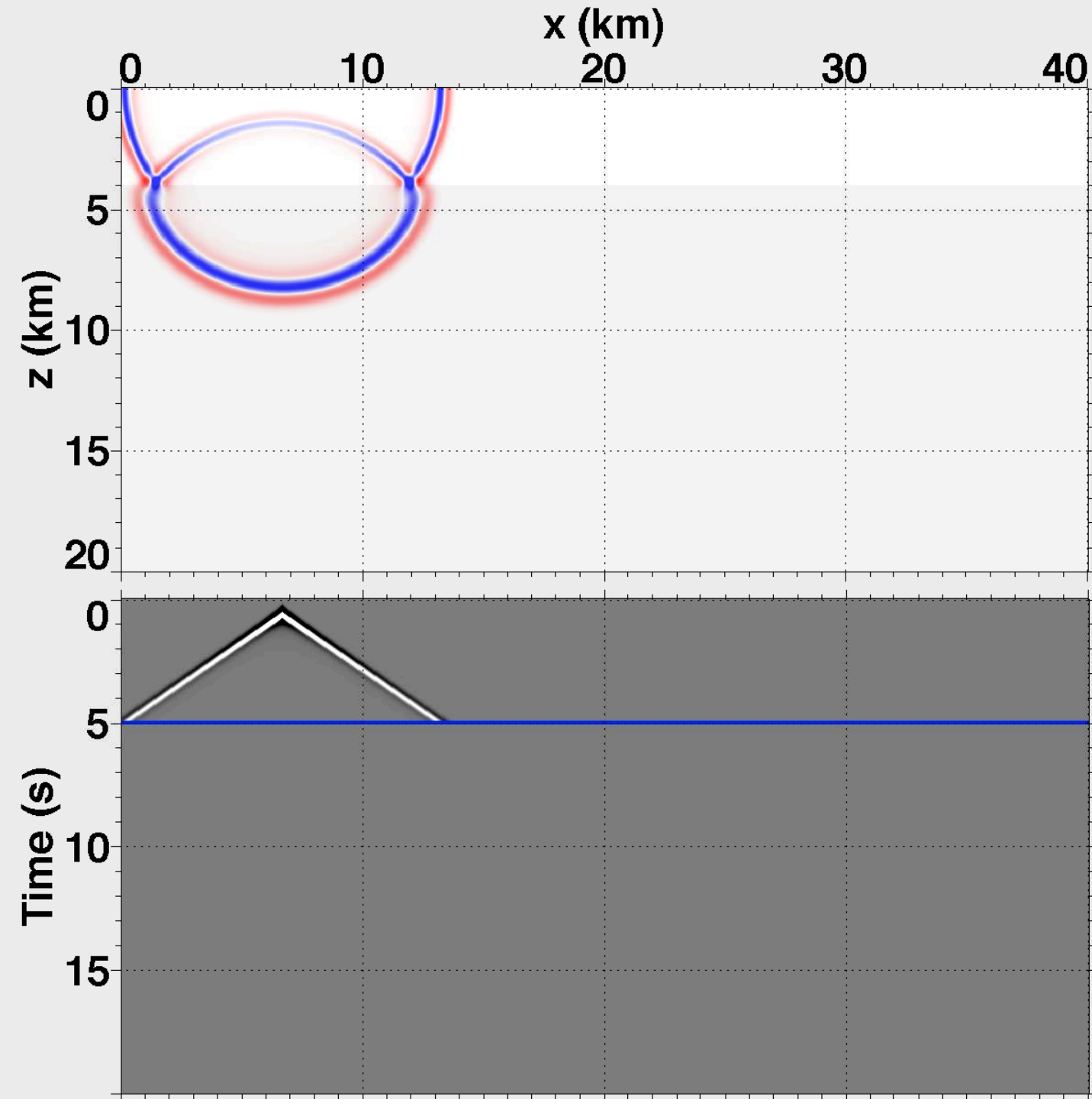


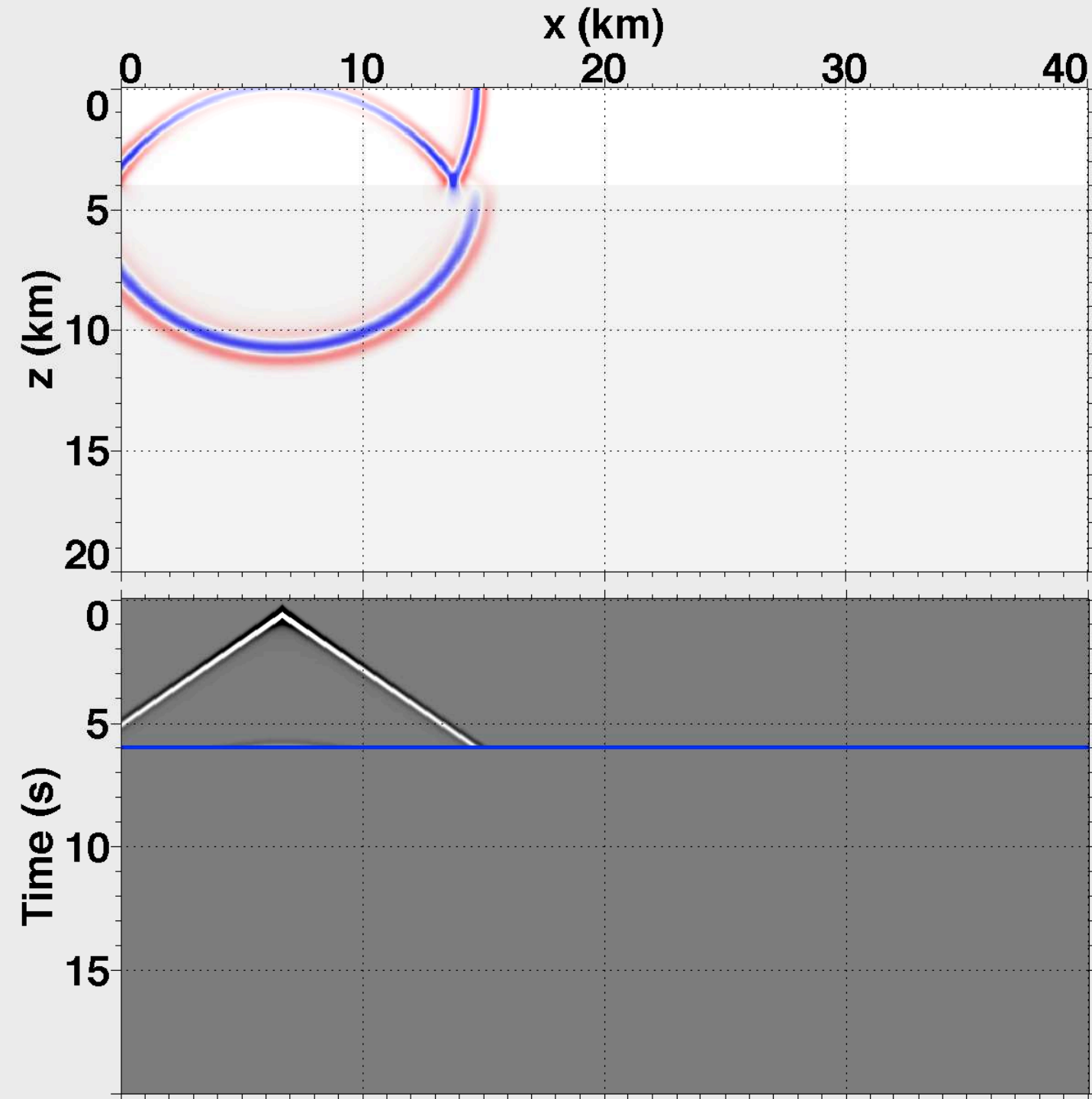


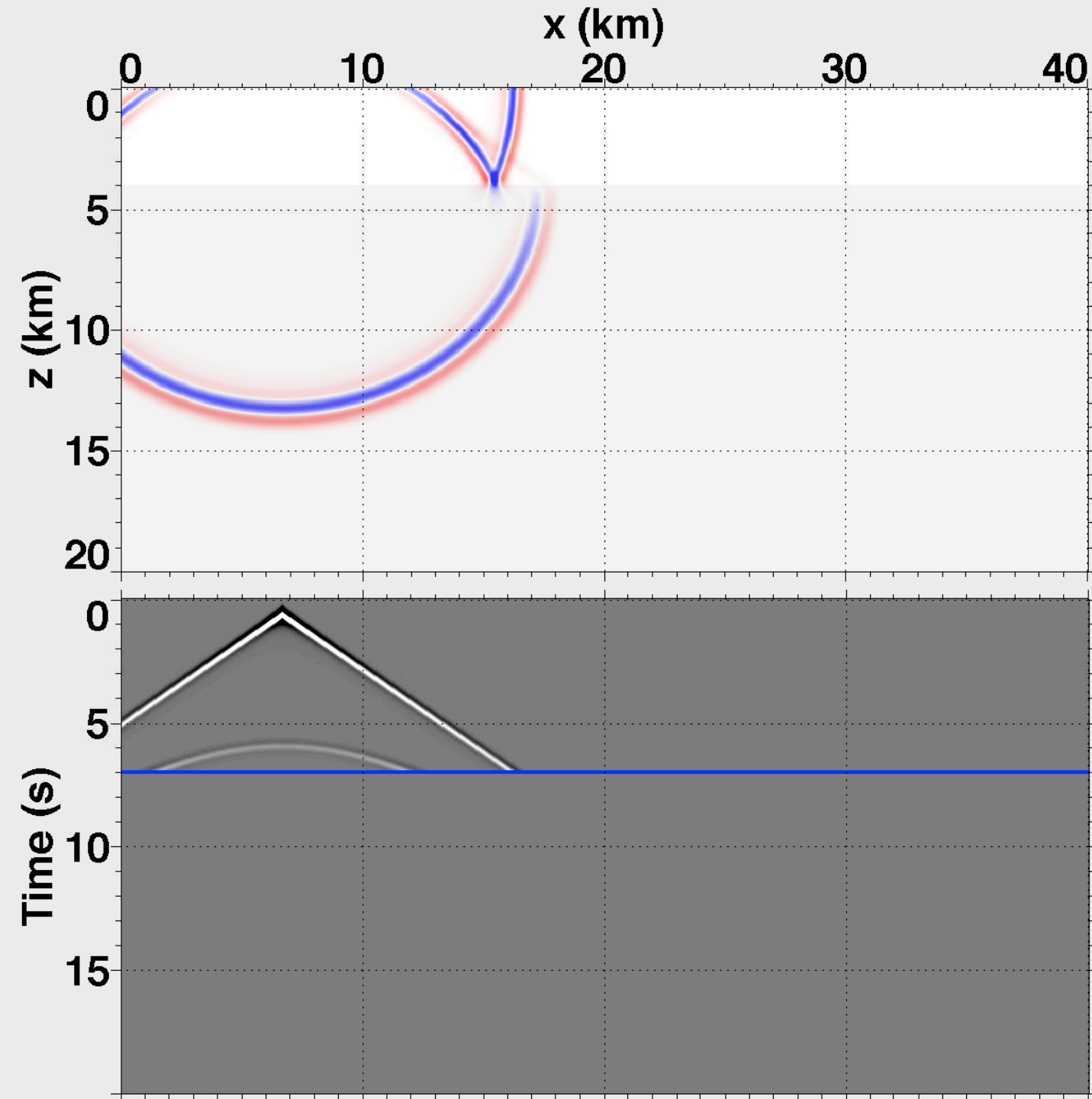


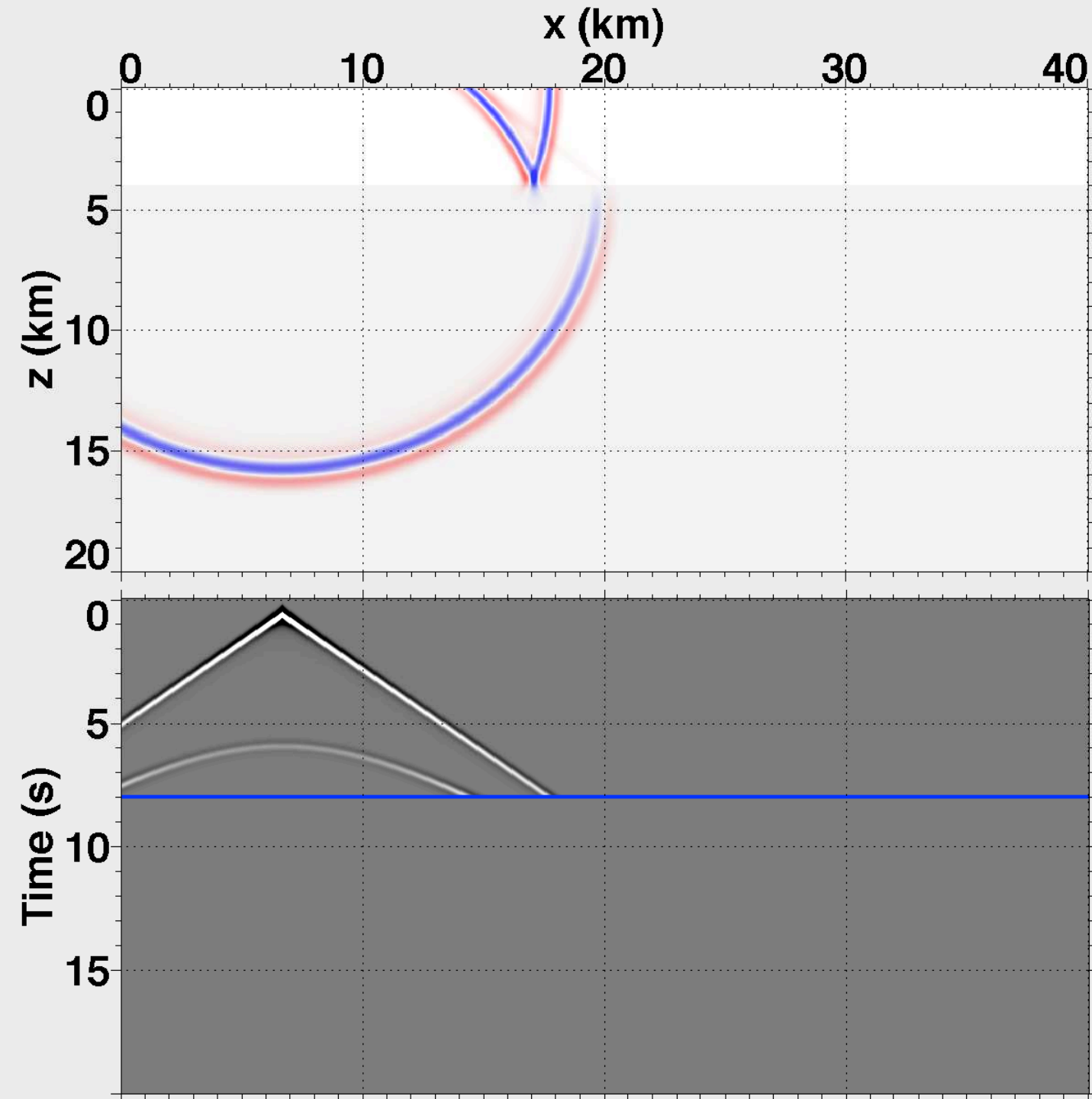


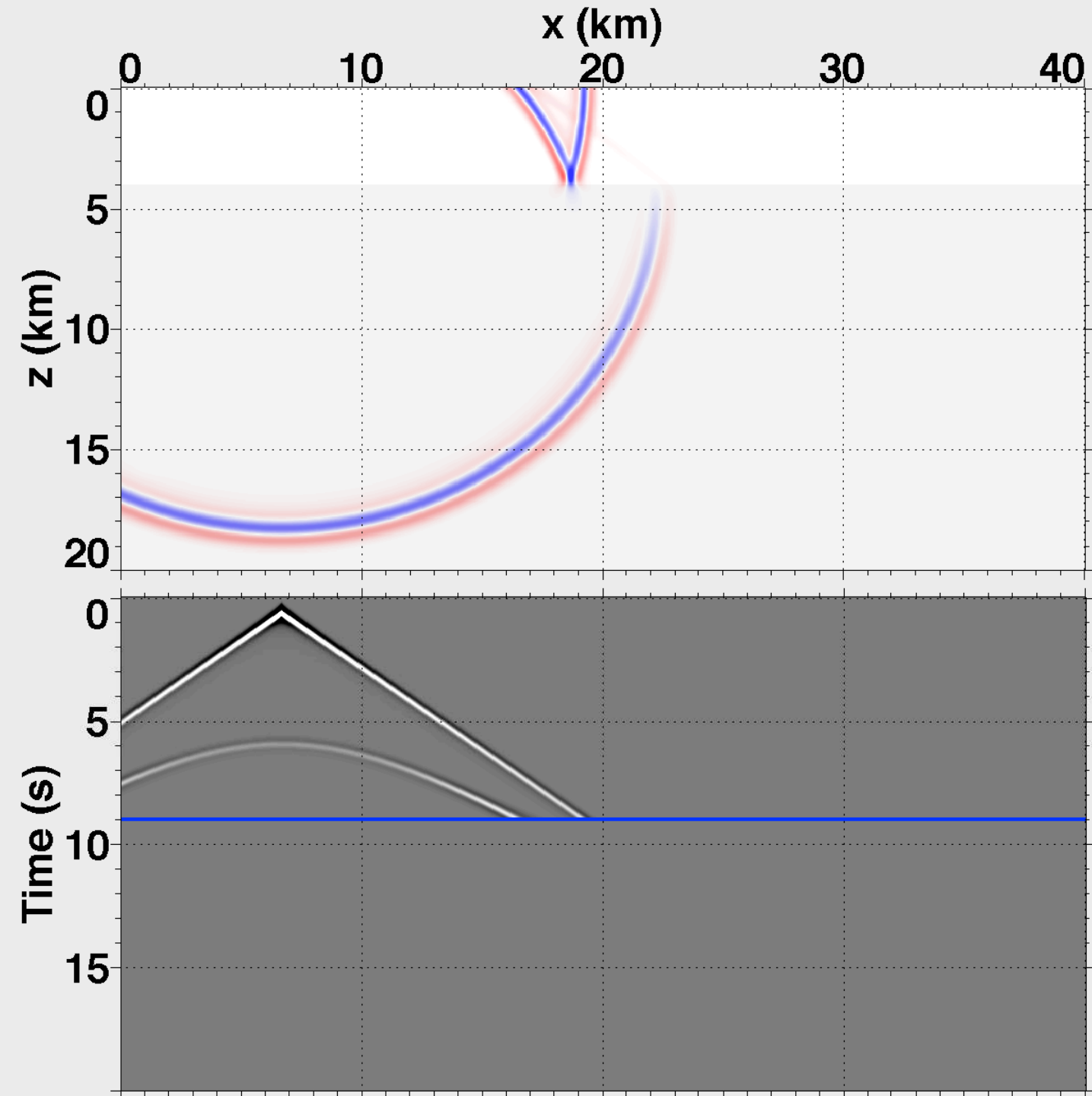


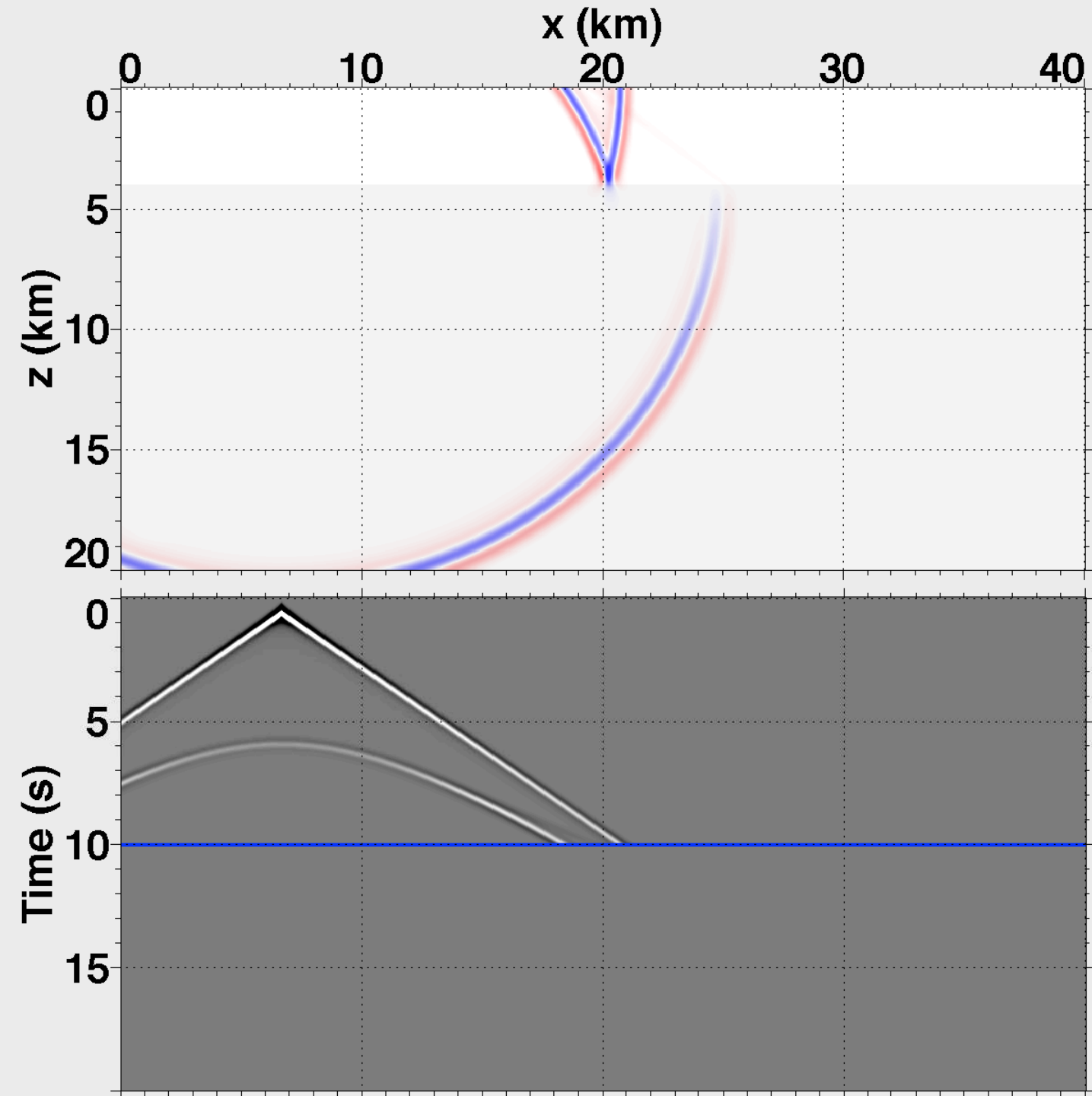


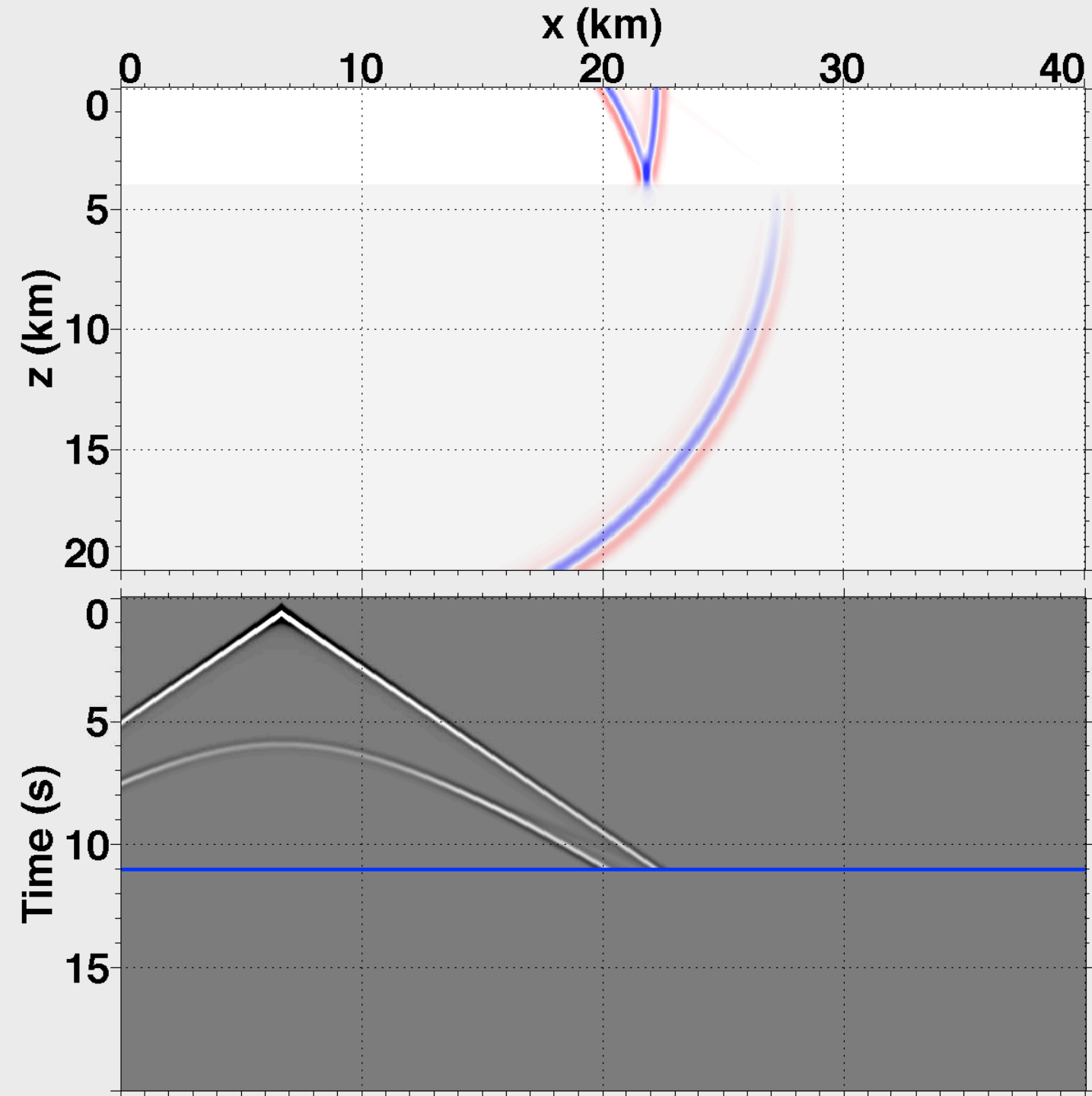


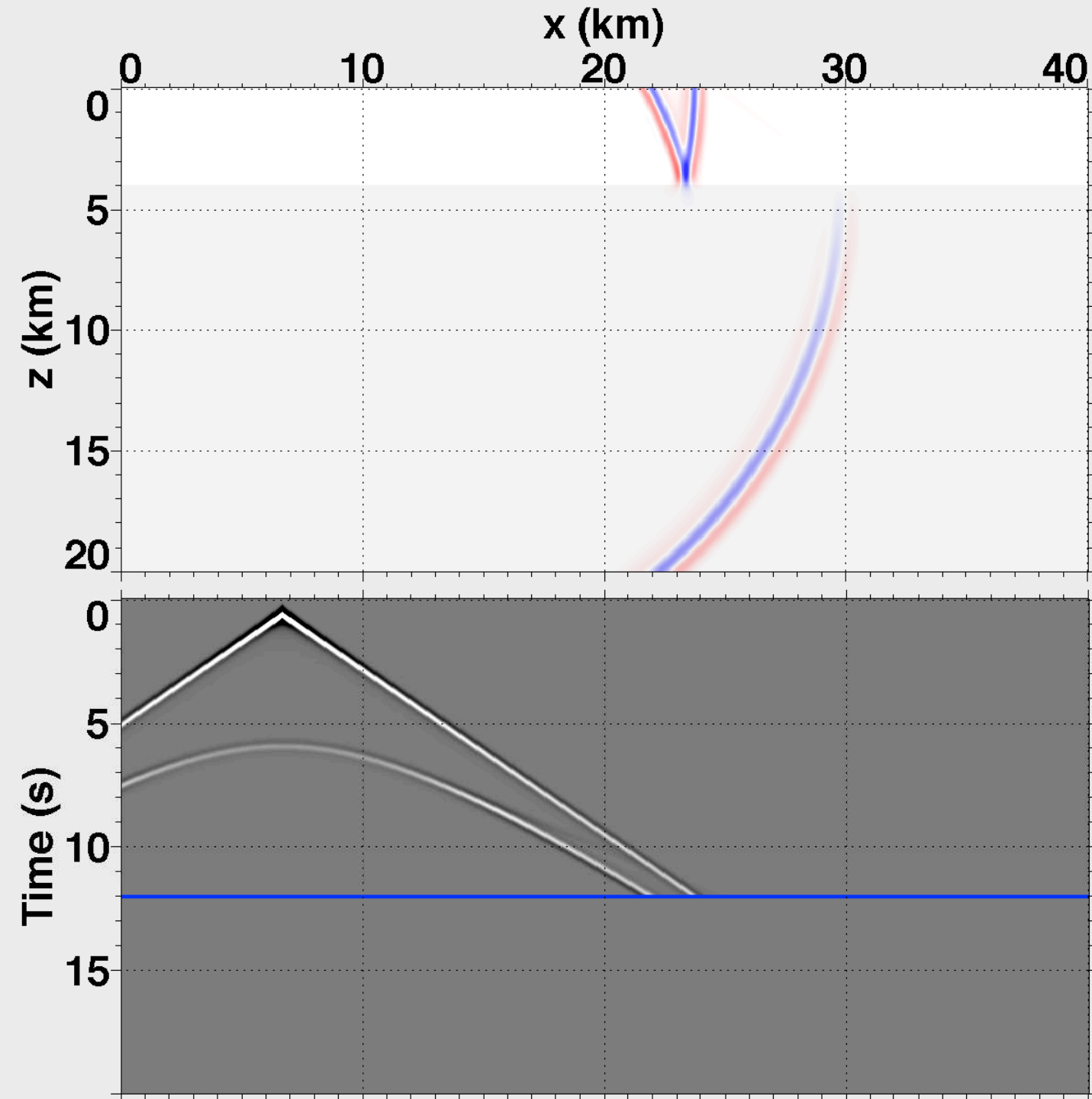


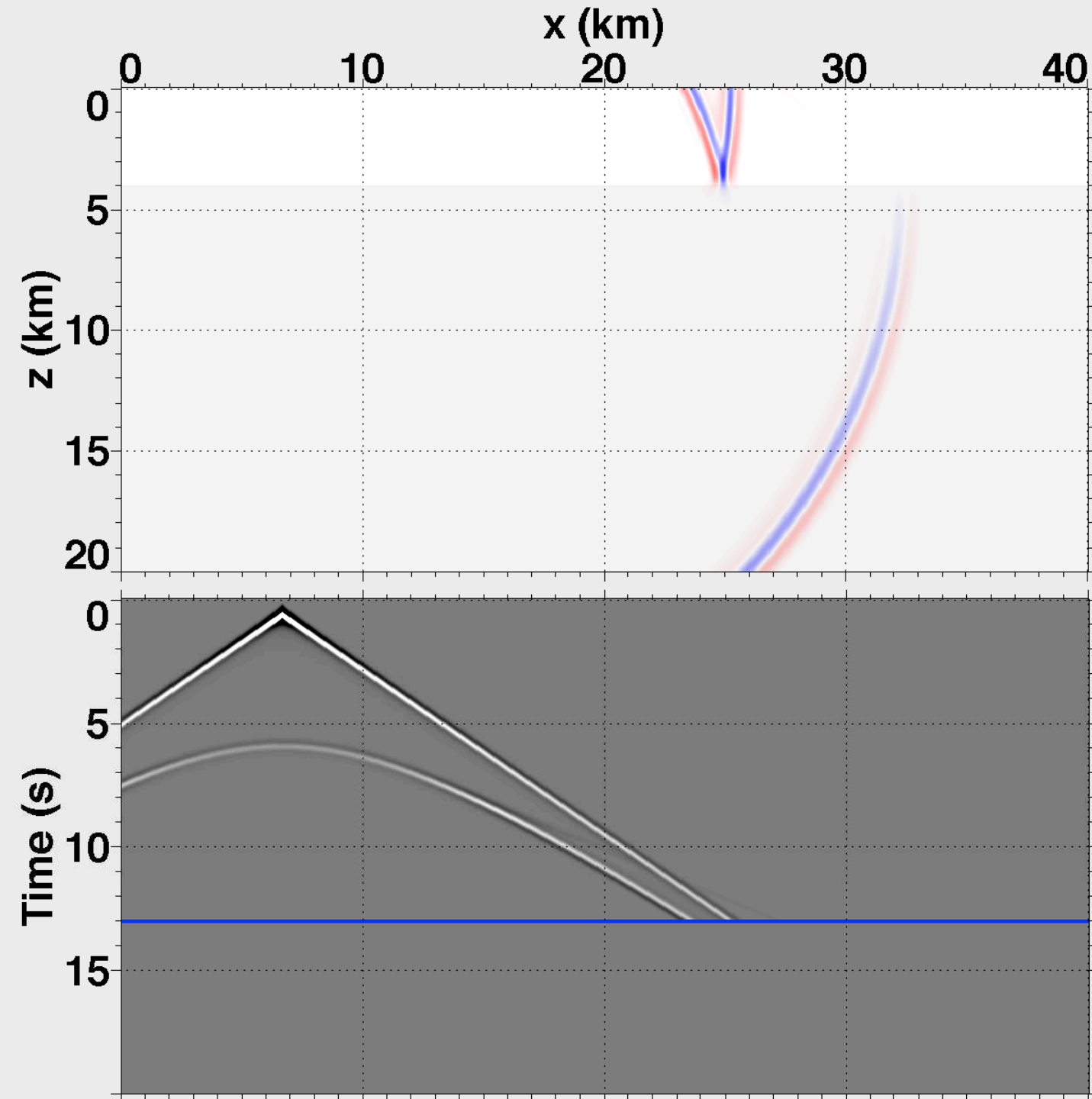


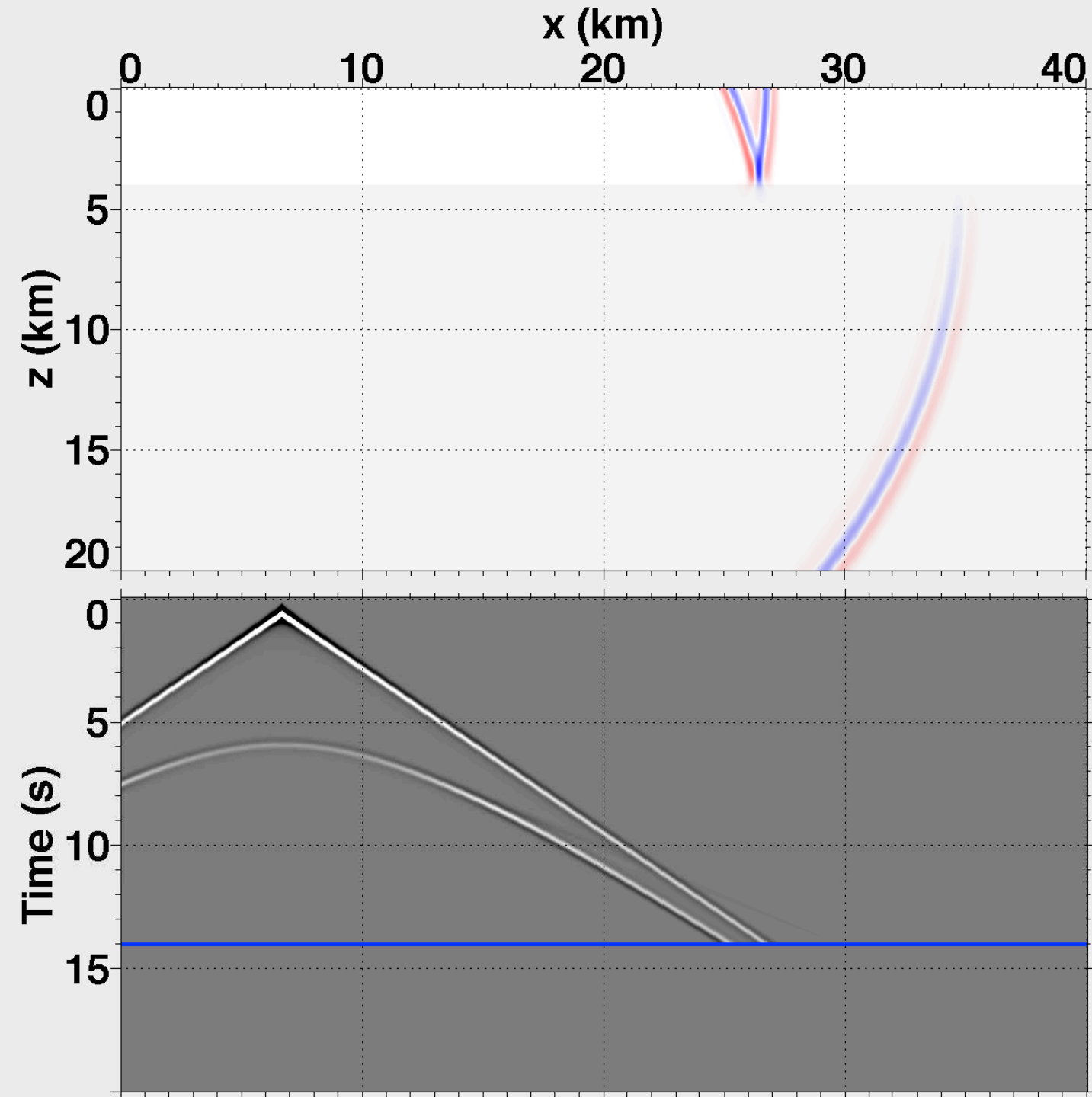


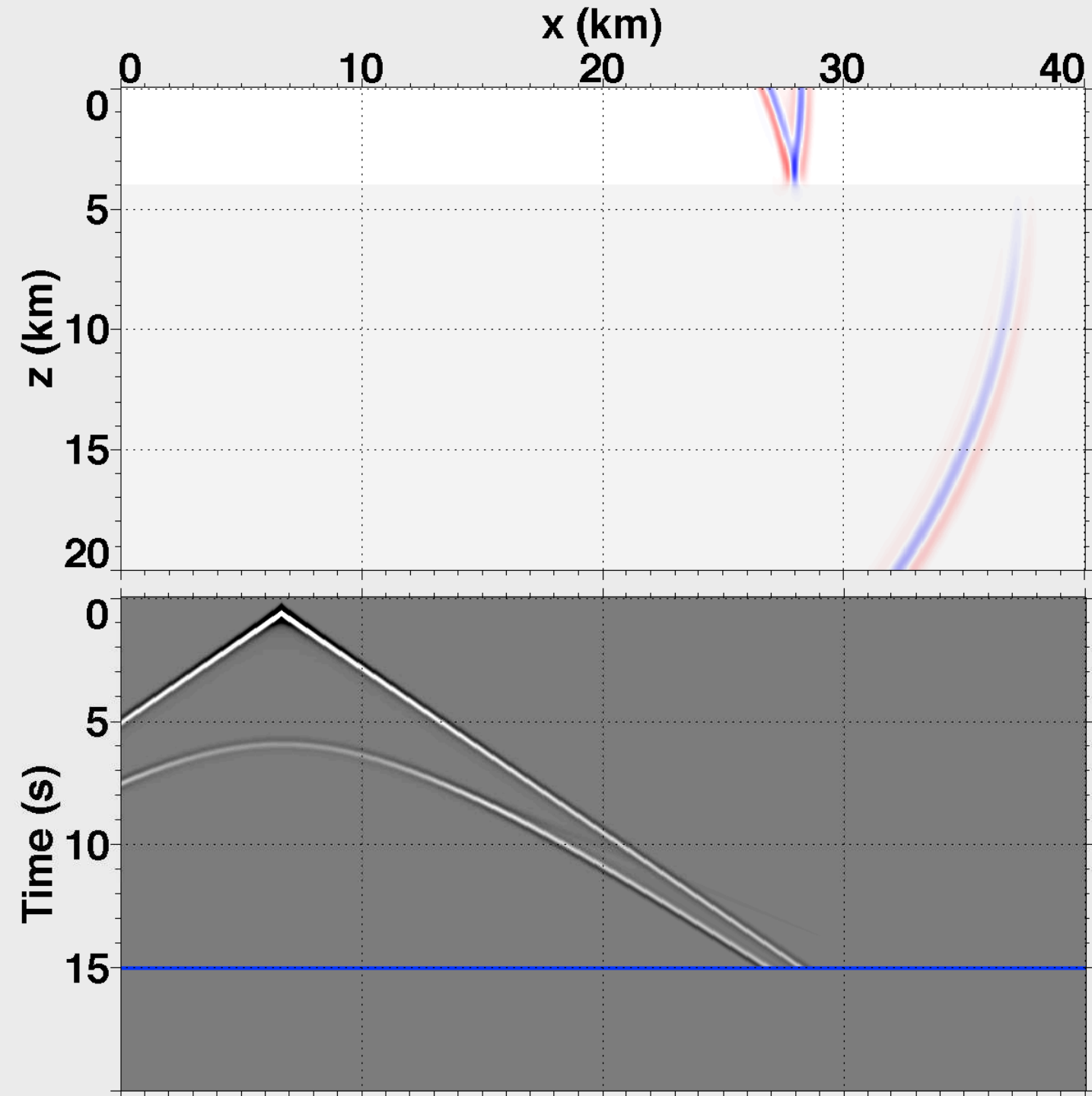


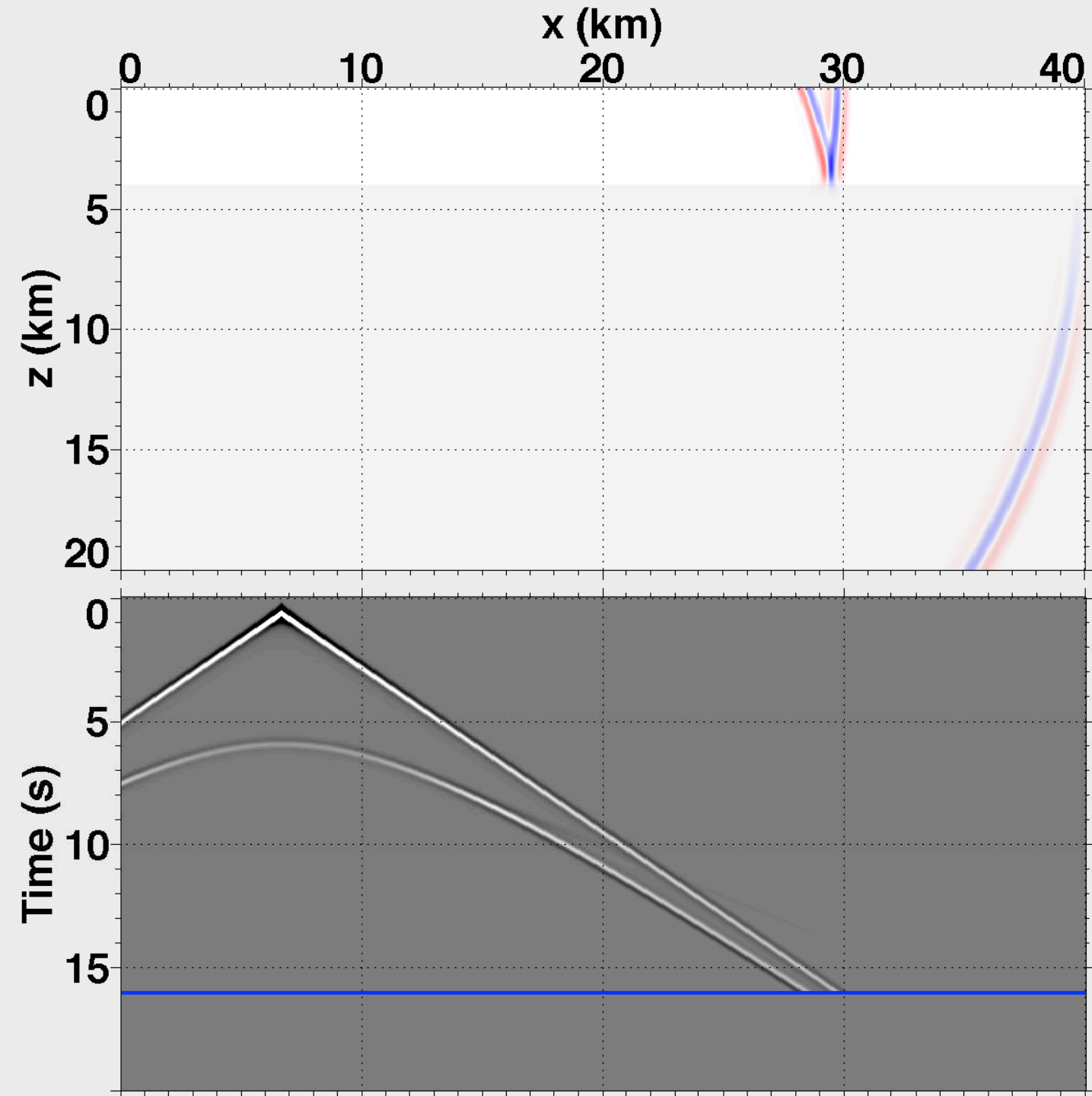


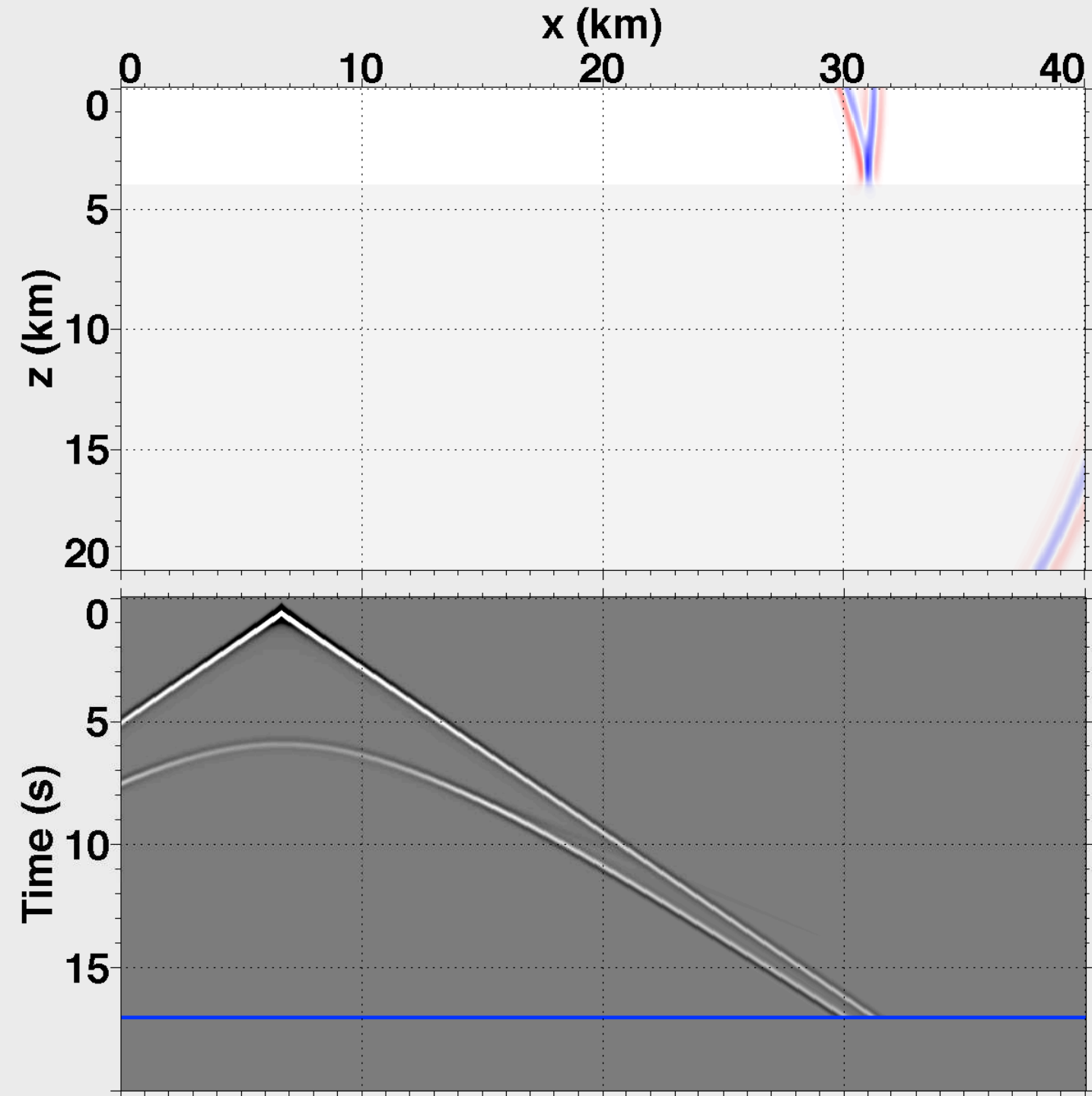


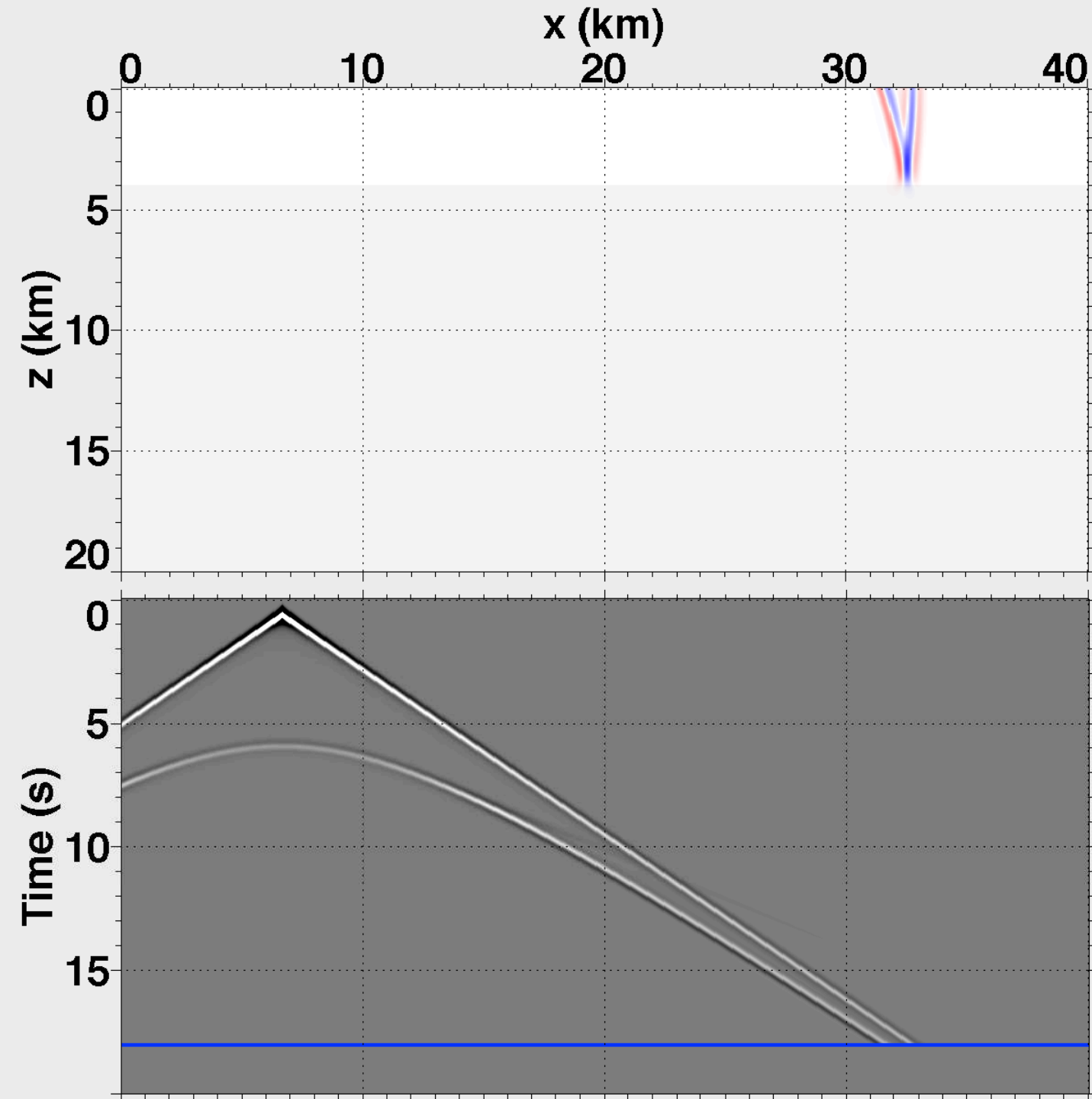


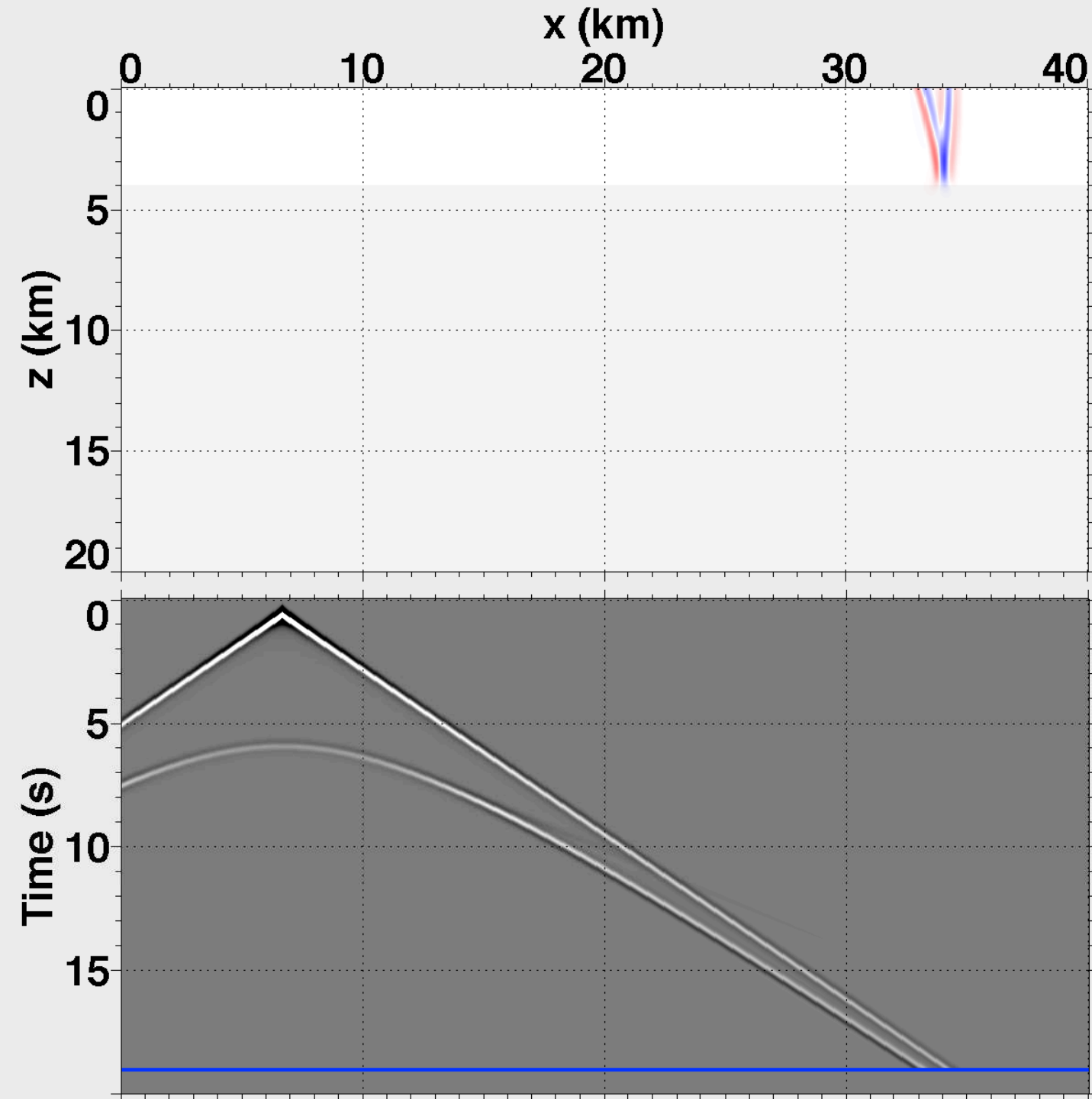




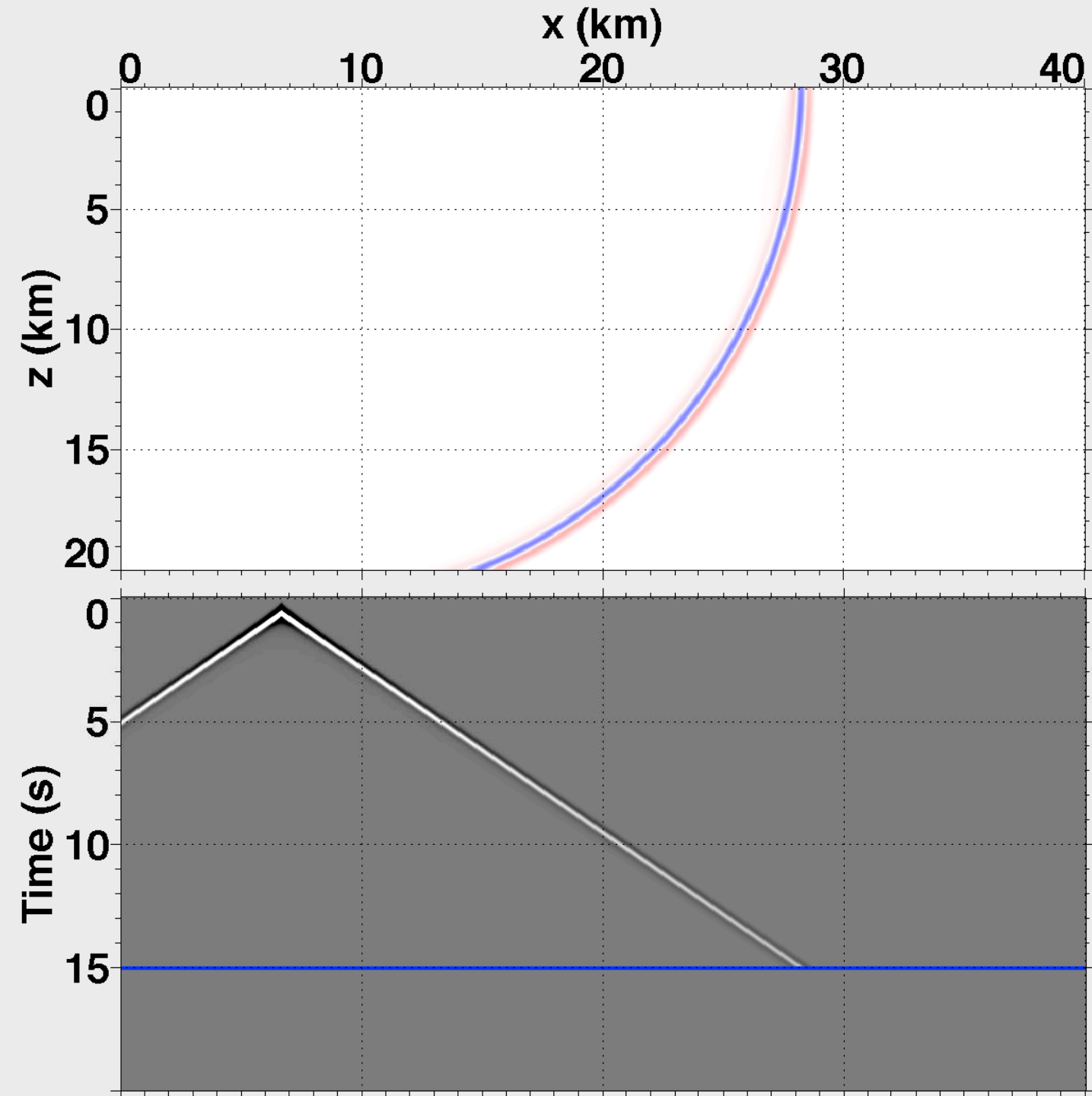


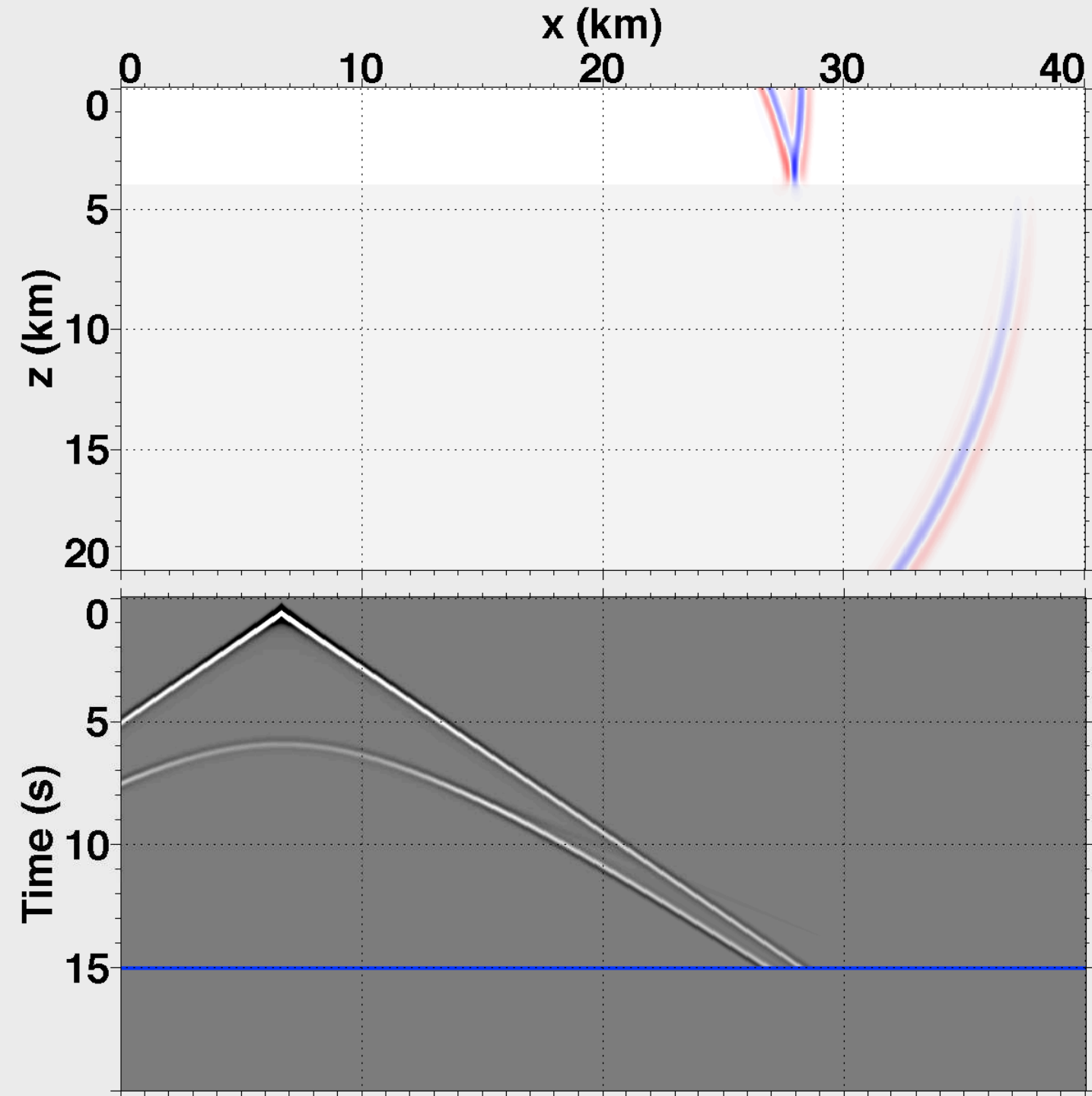




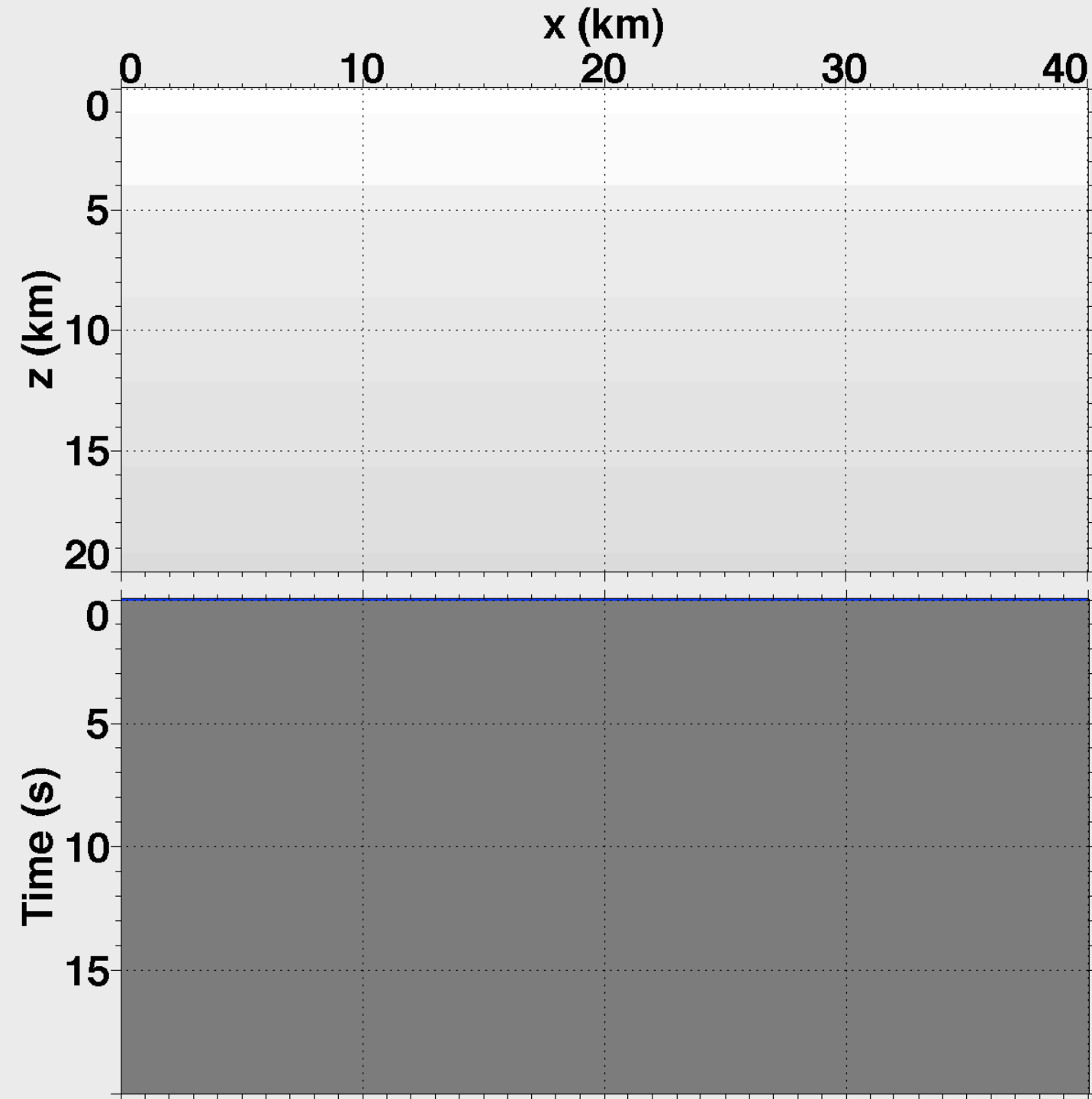


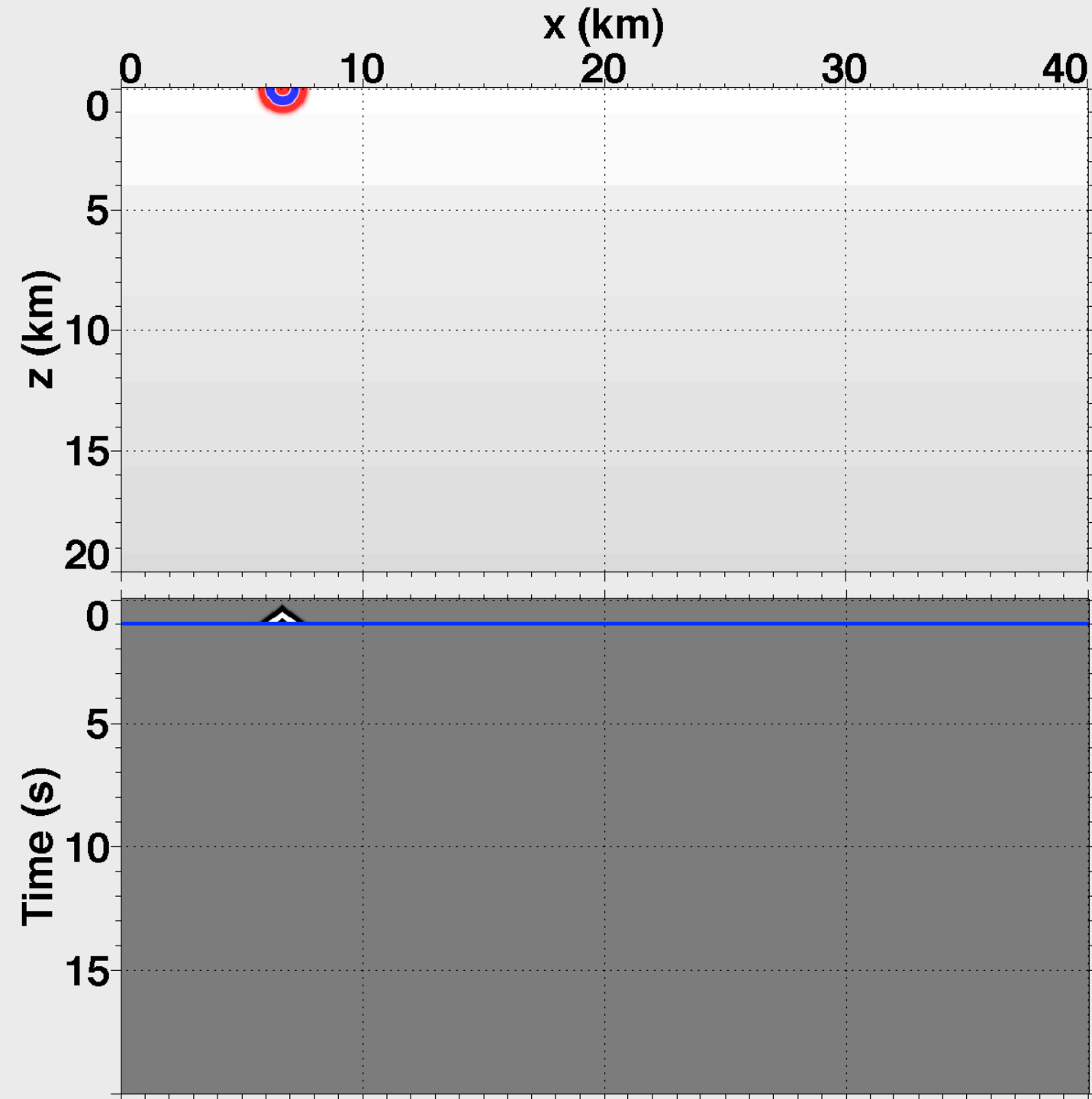
Comparison

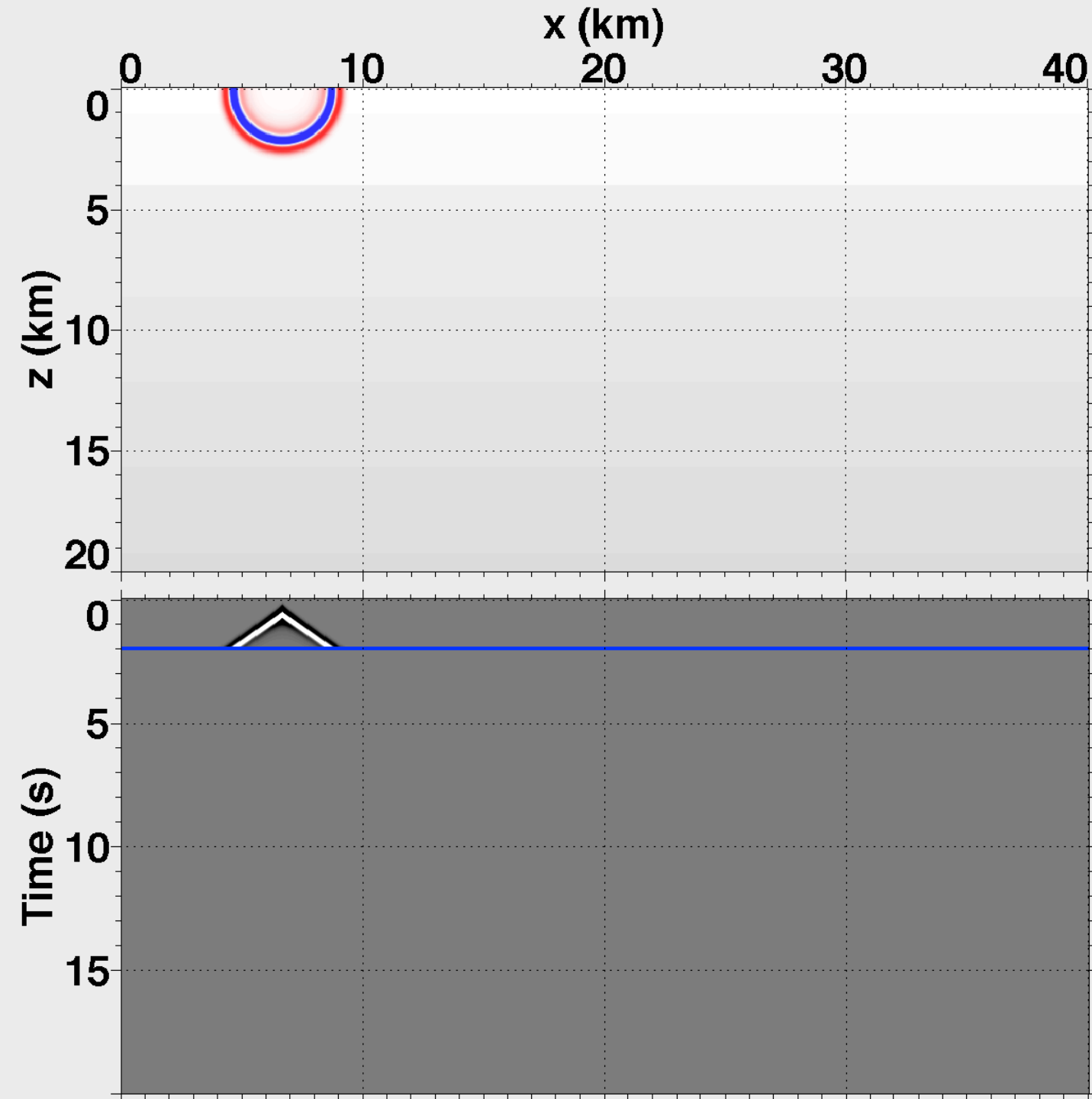


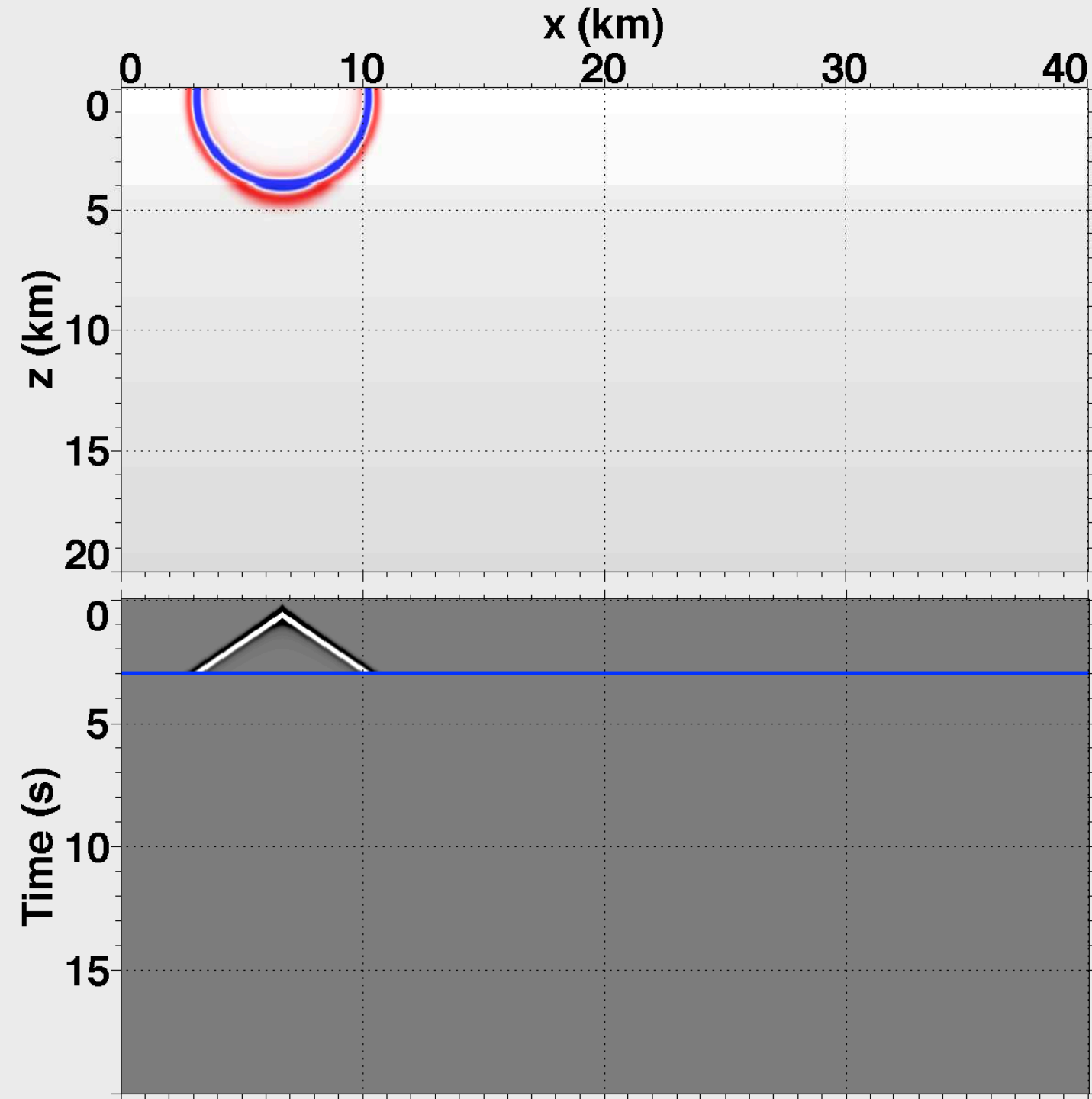


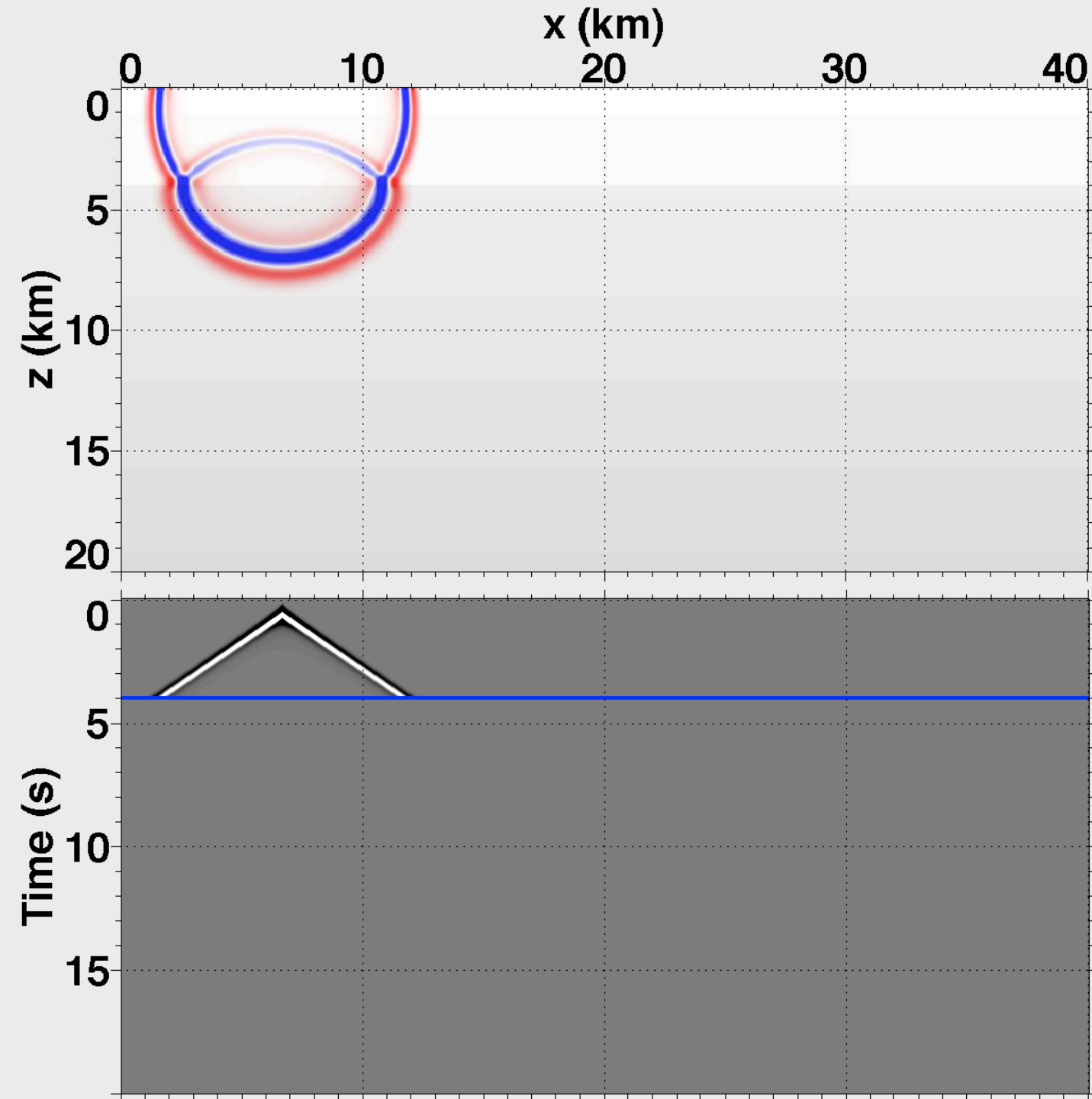
**One layer + half space +
gradually increasing
velocity**

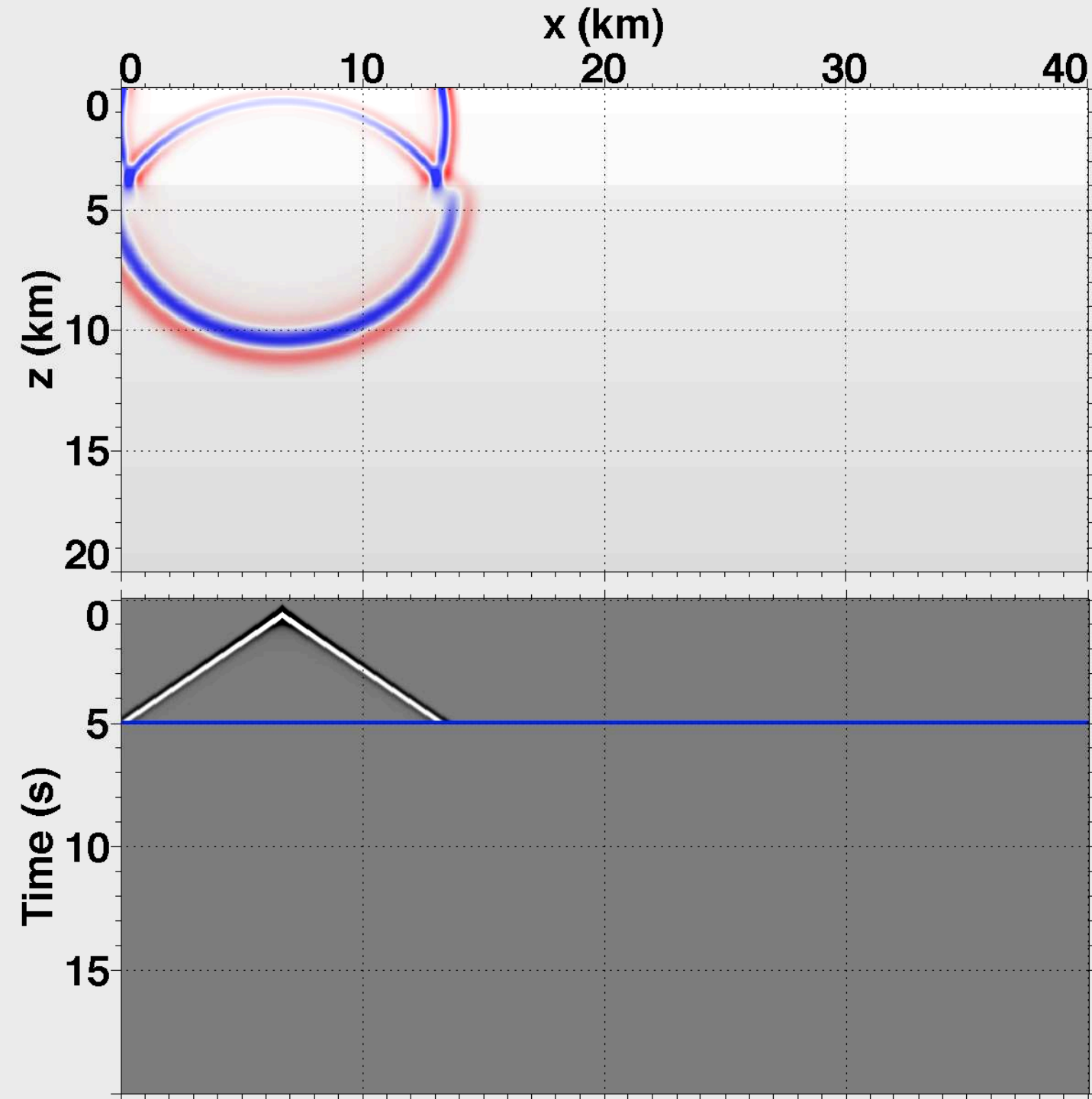


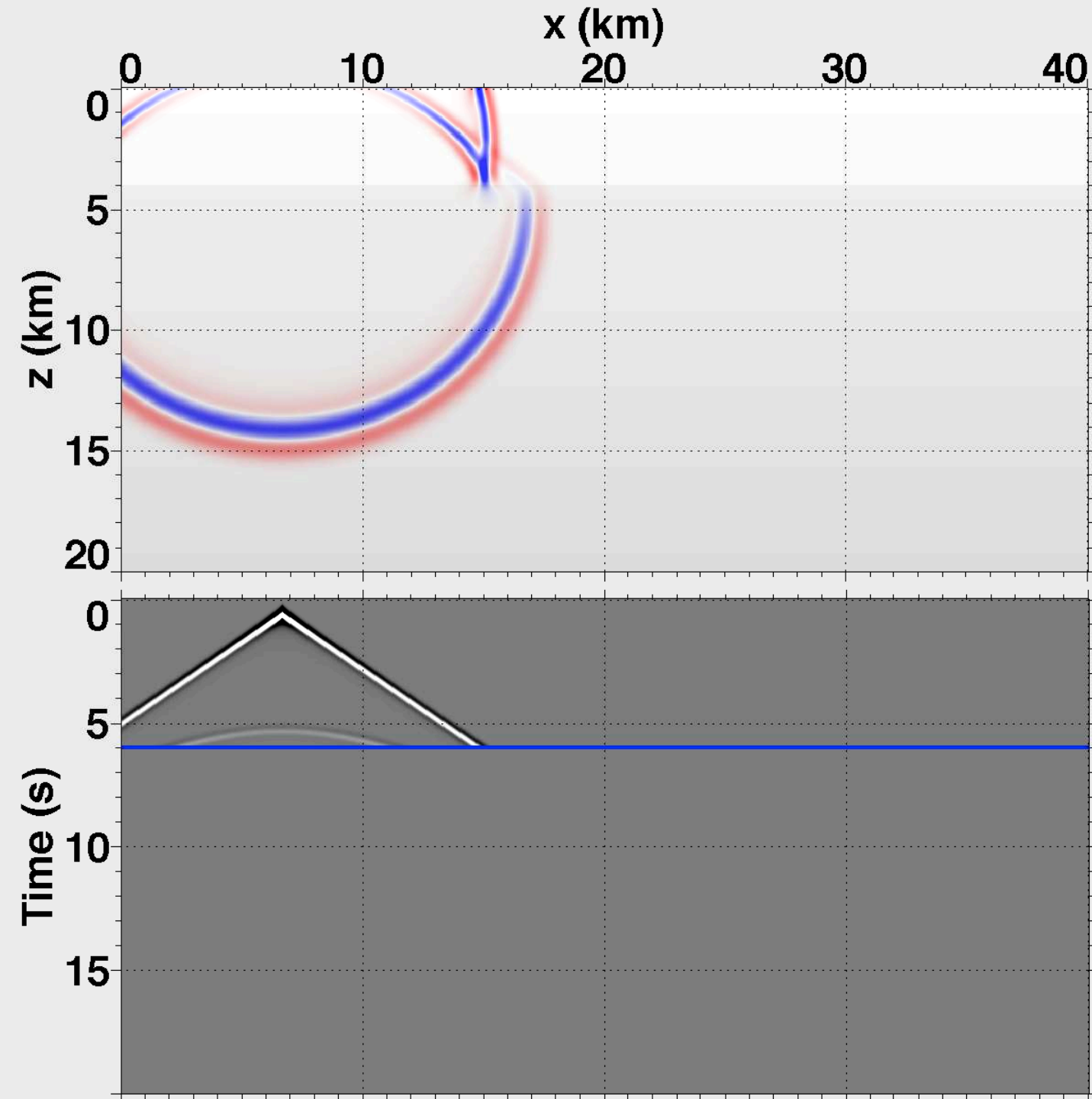


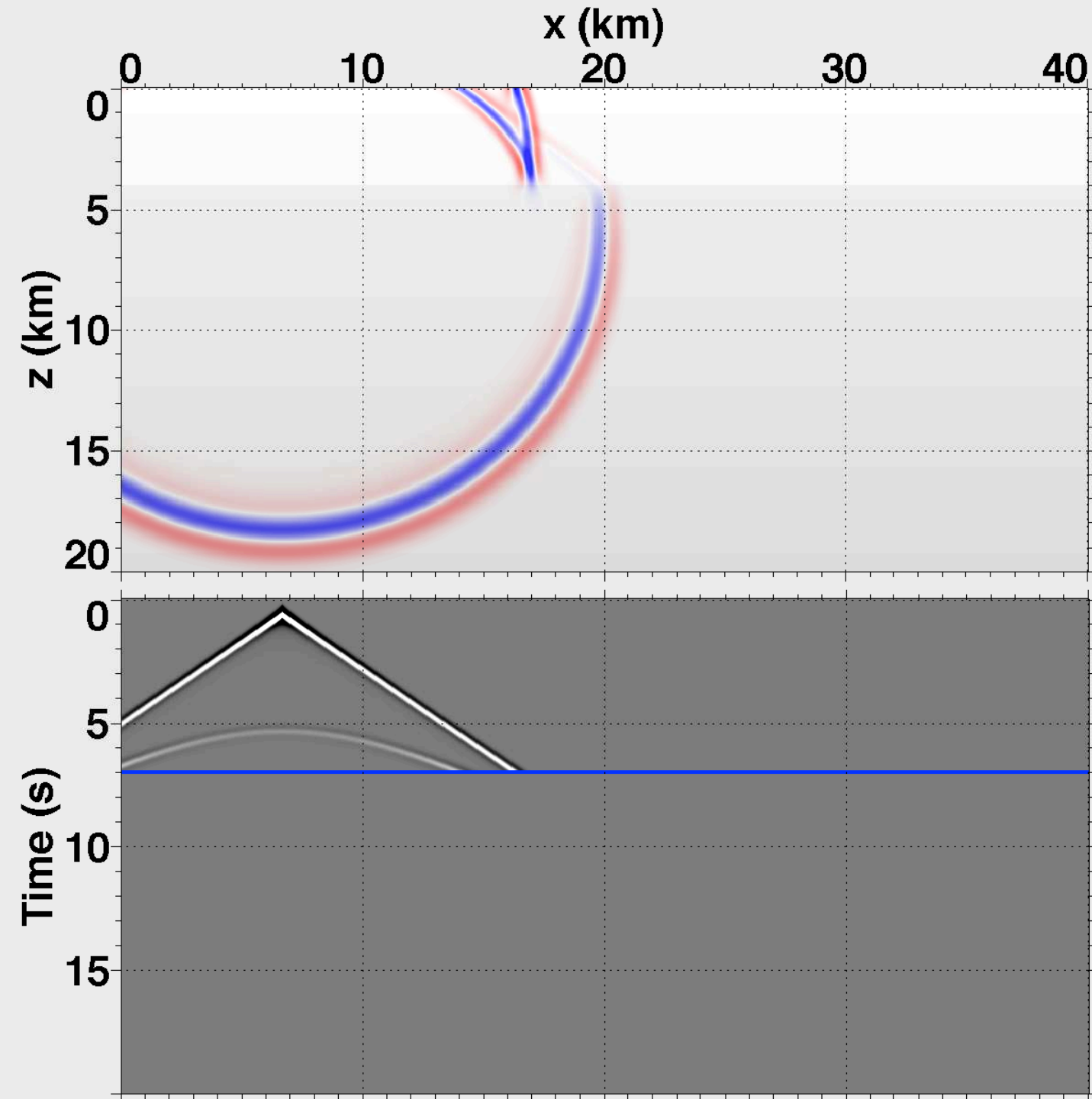


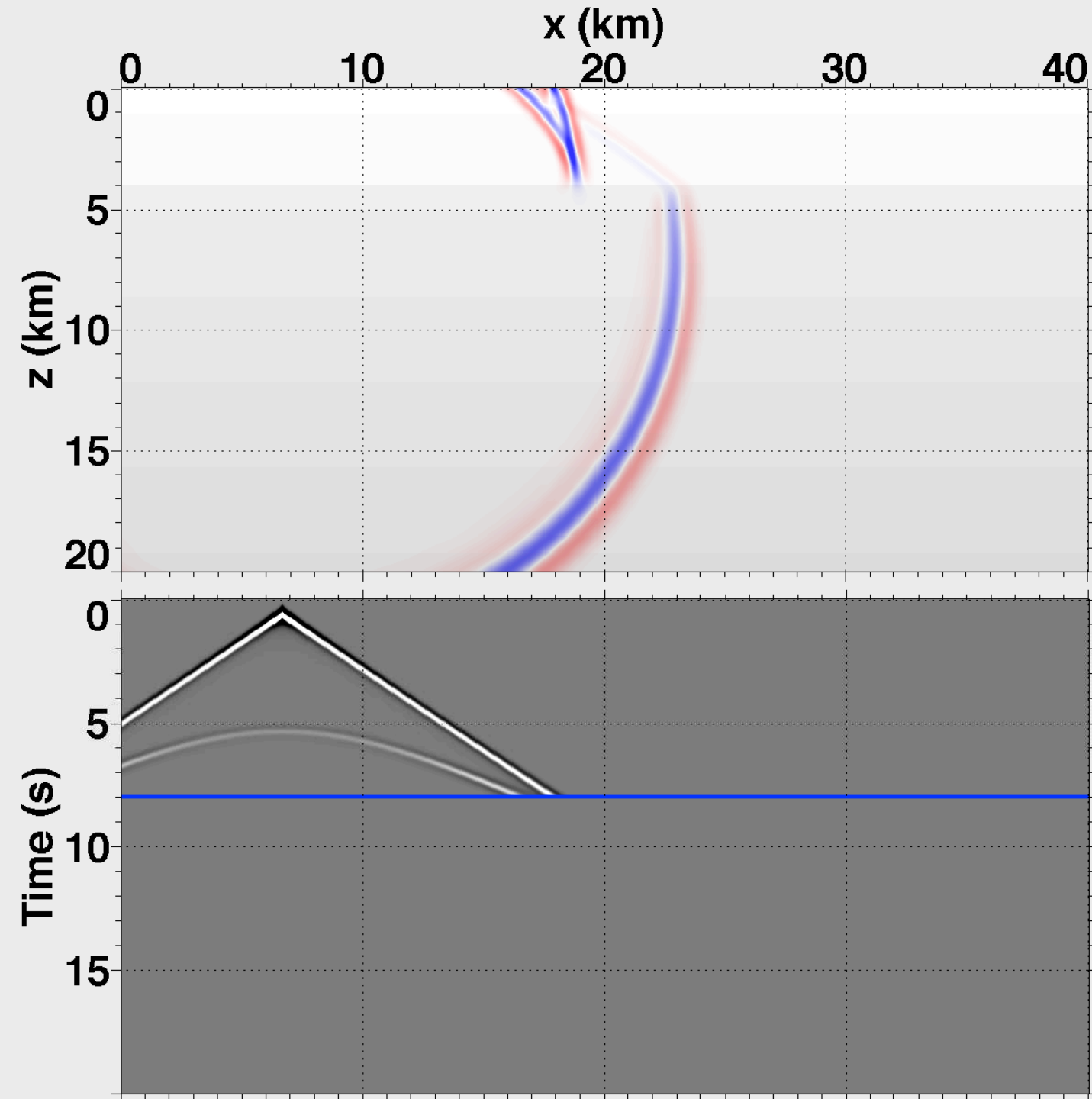


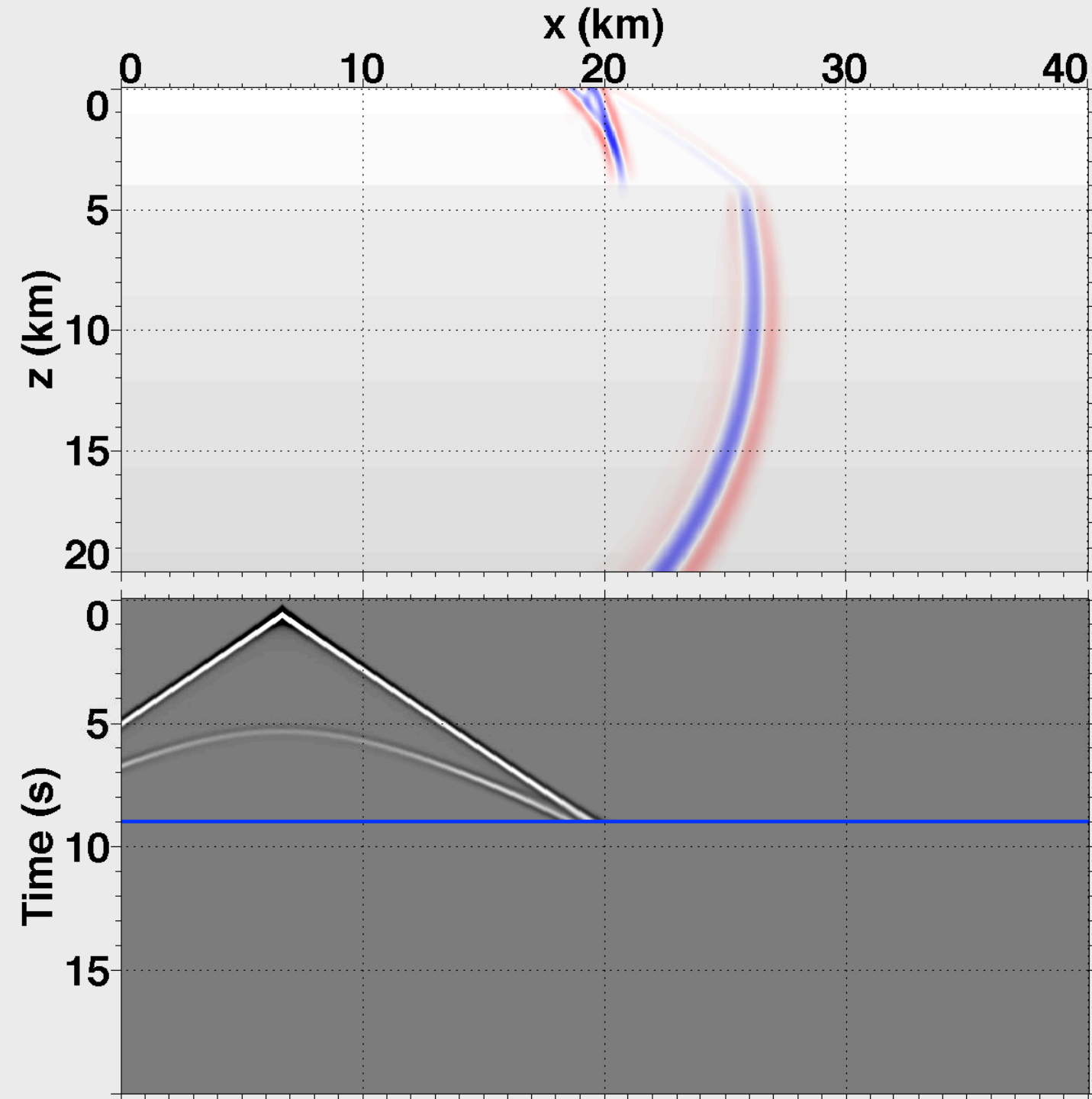


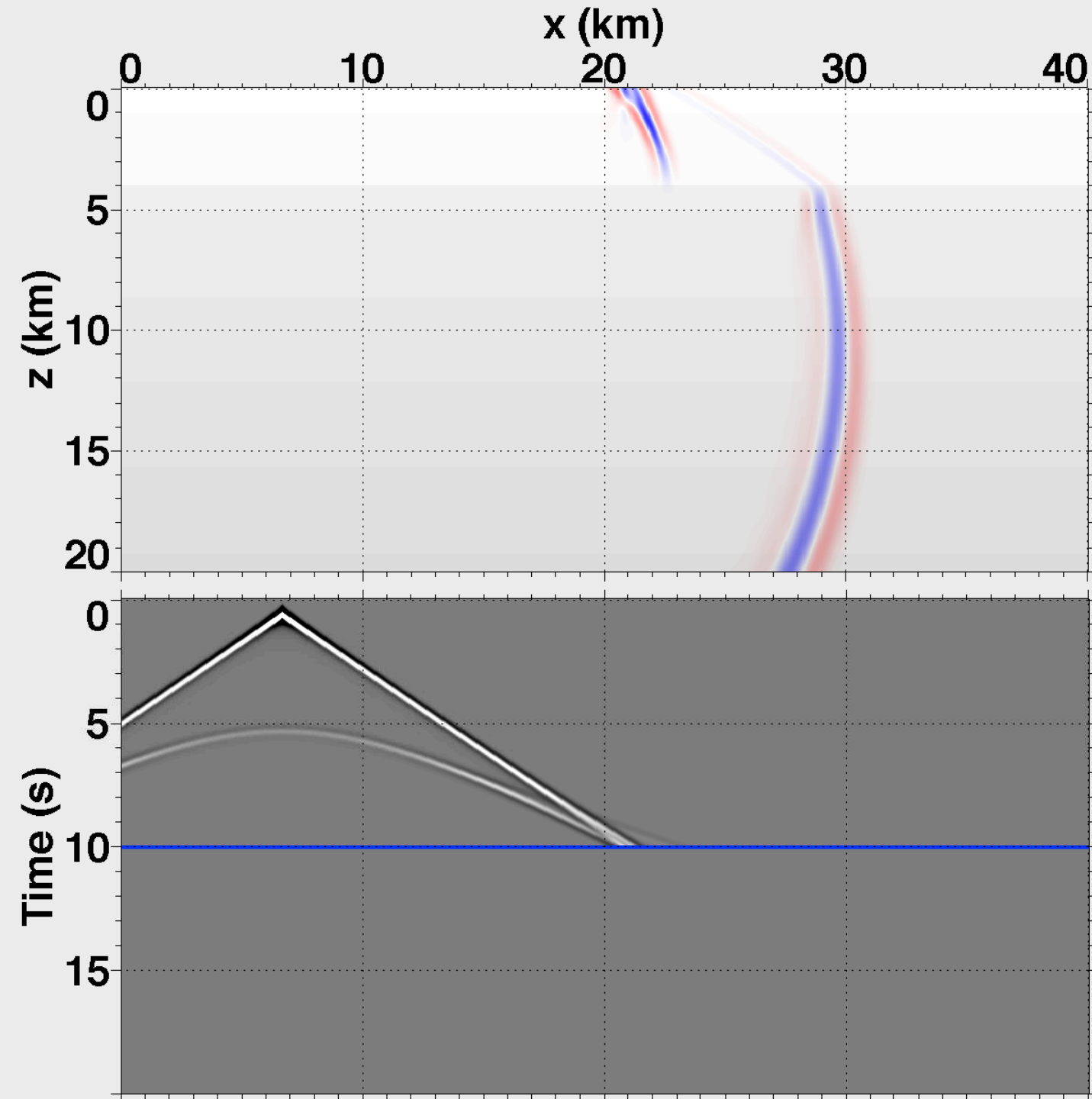


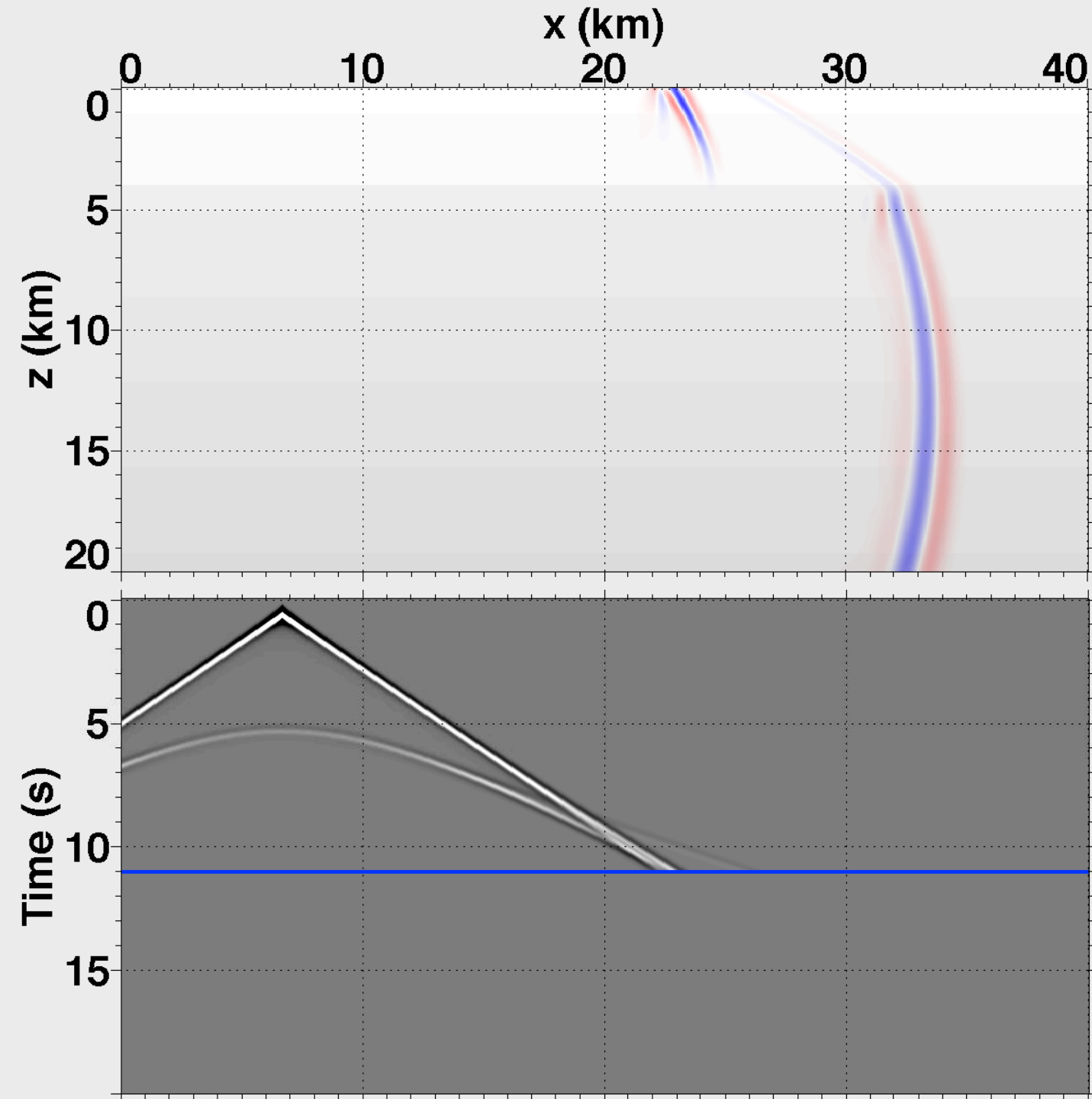


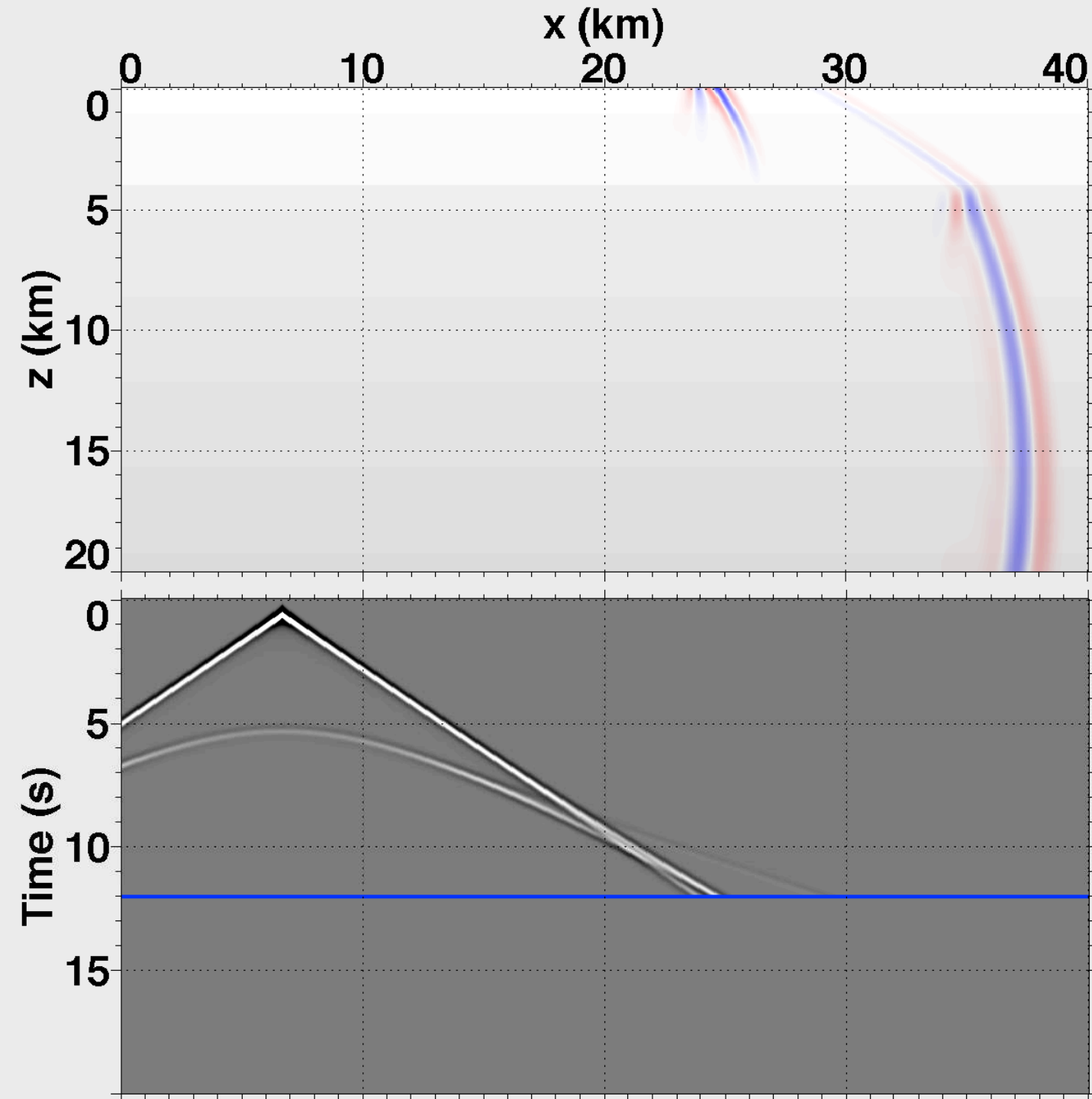


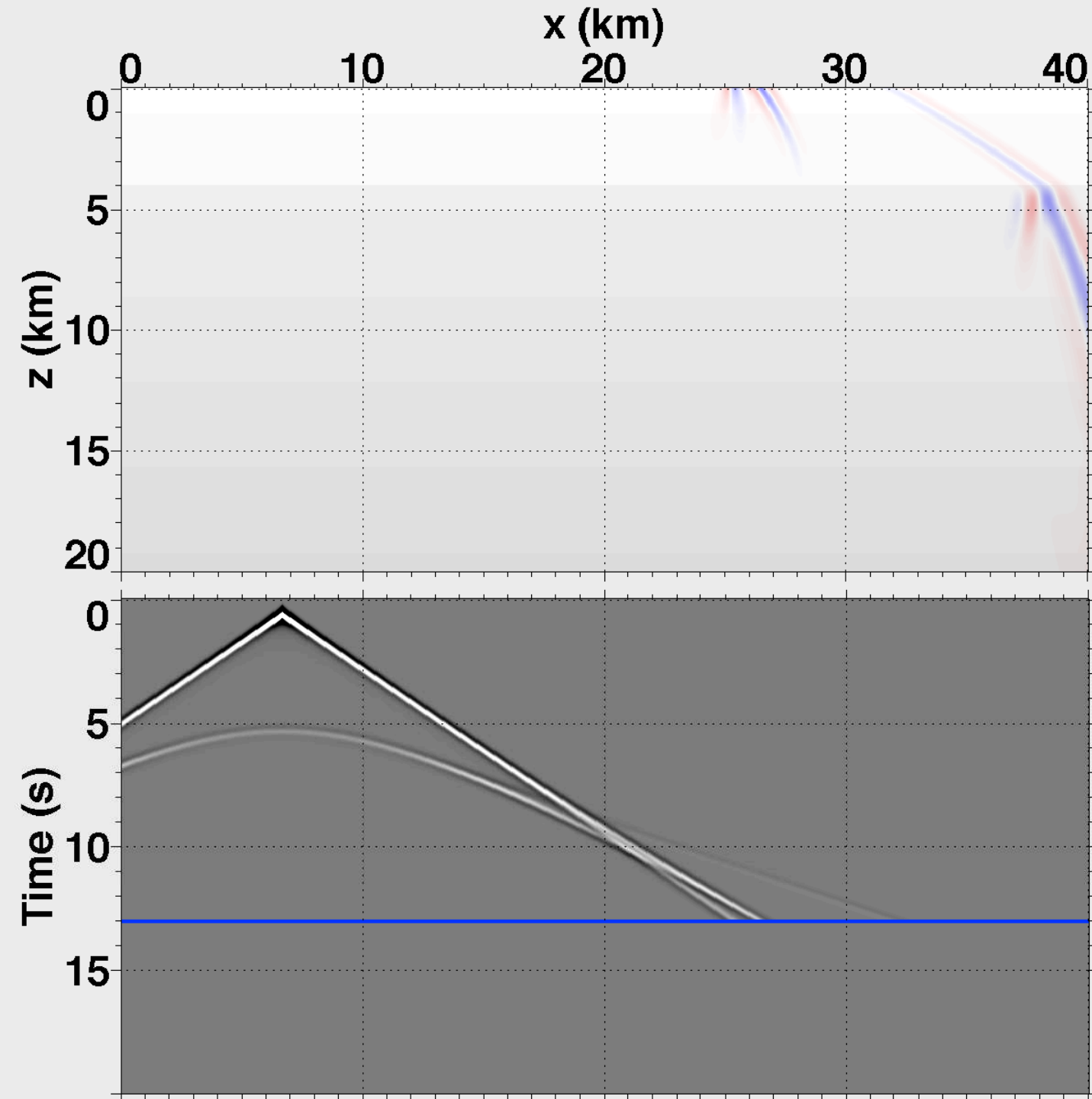


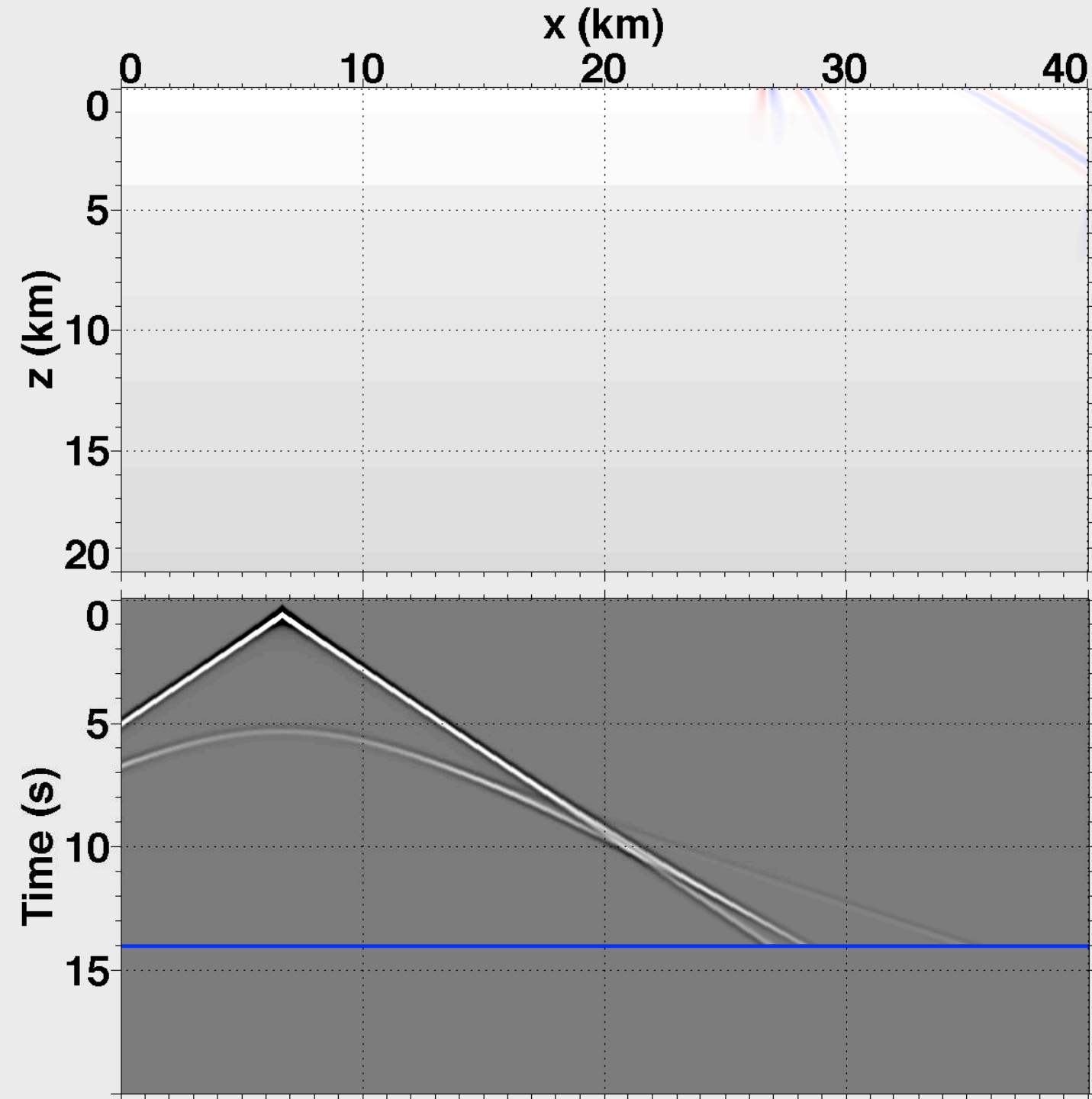


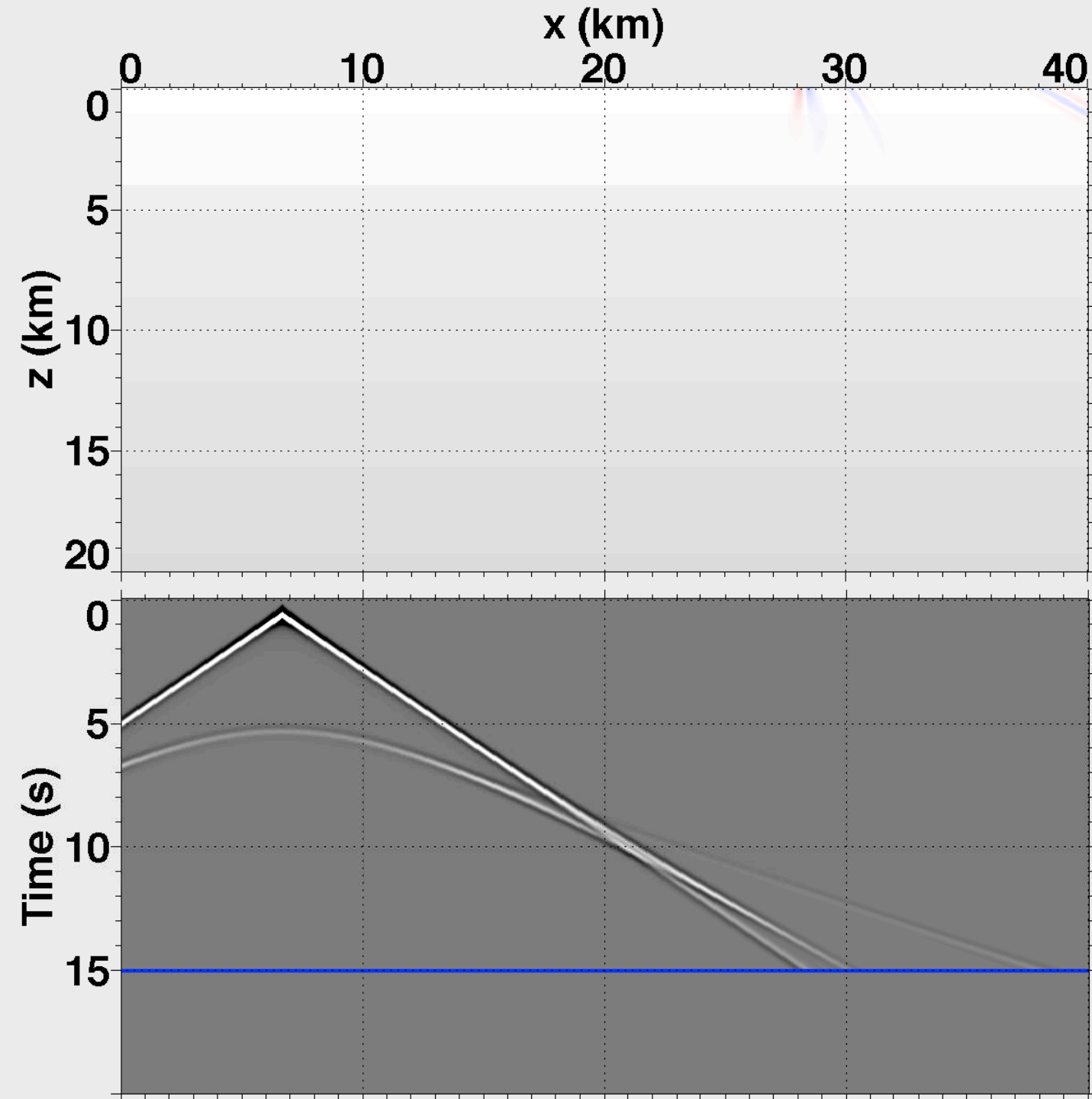


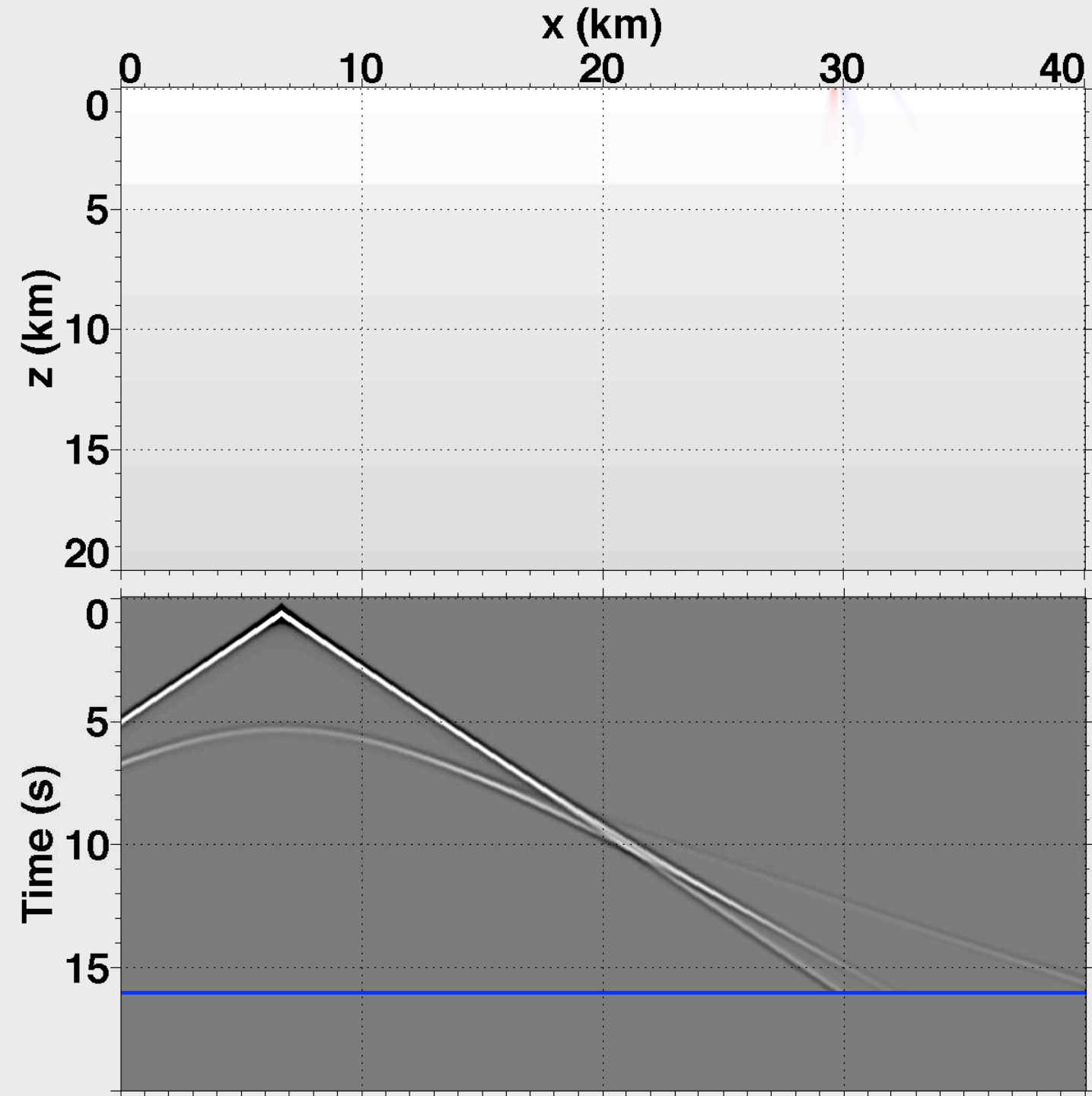


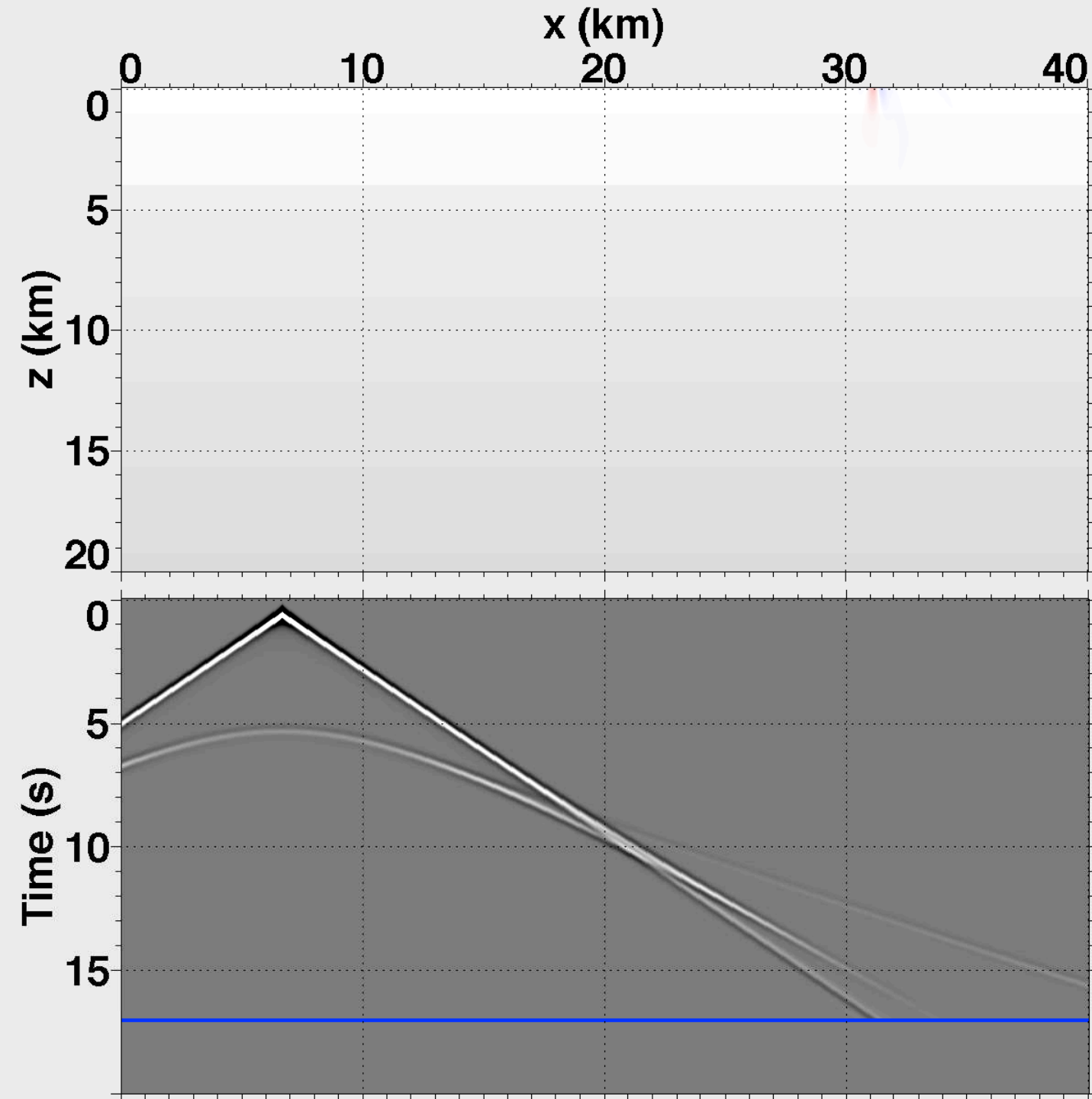


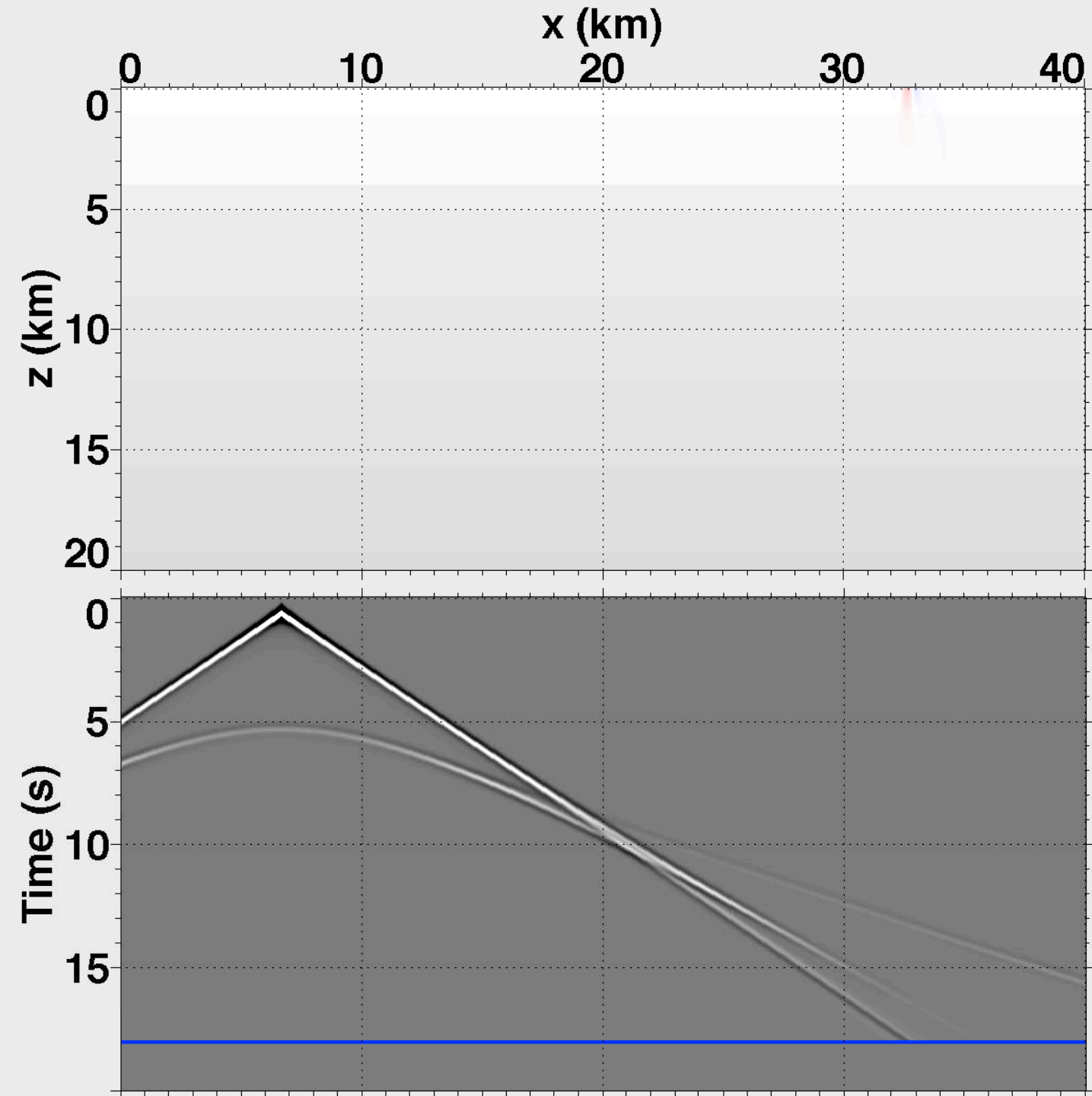


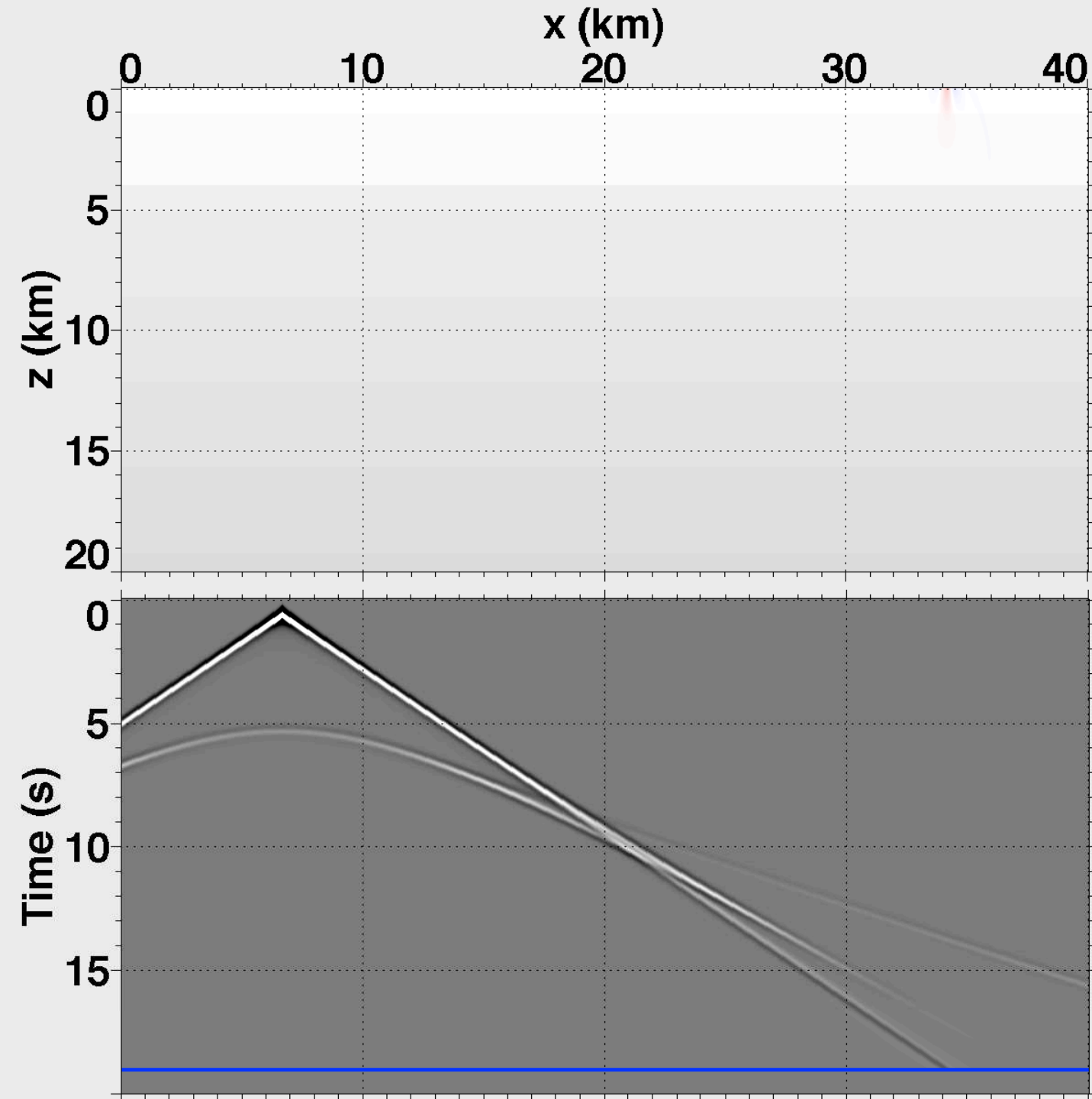




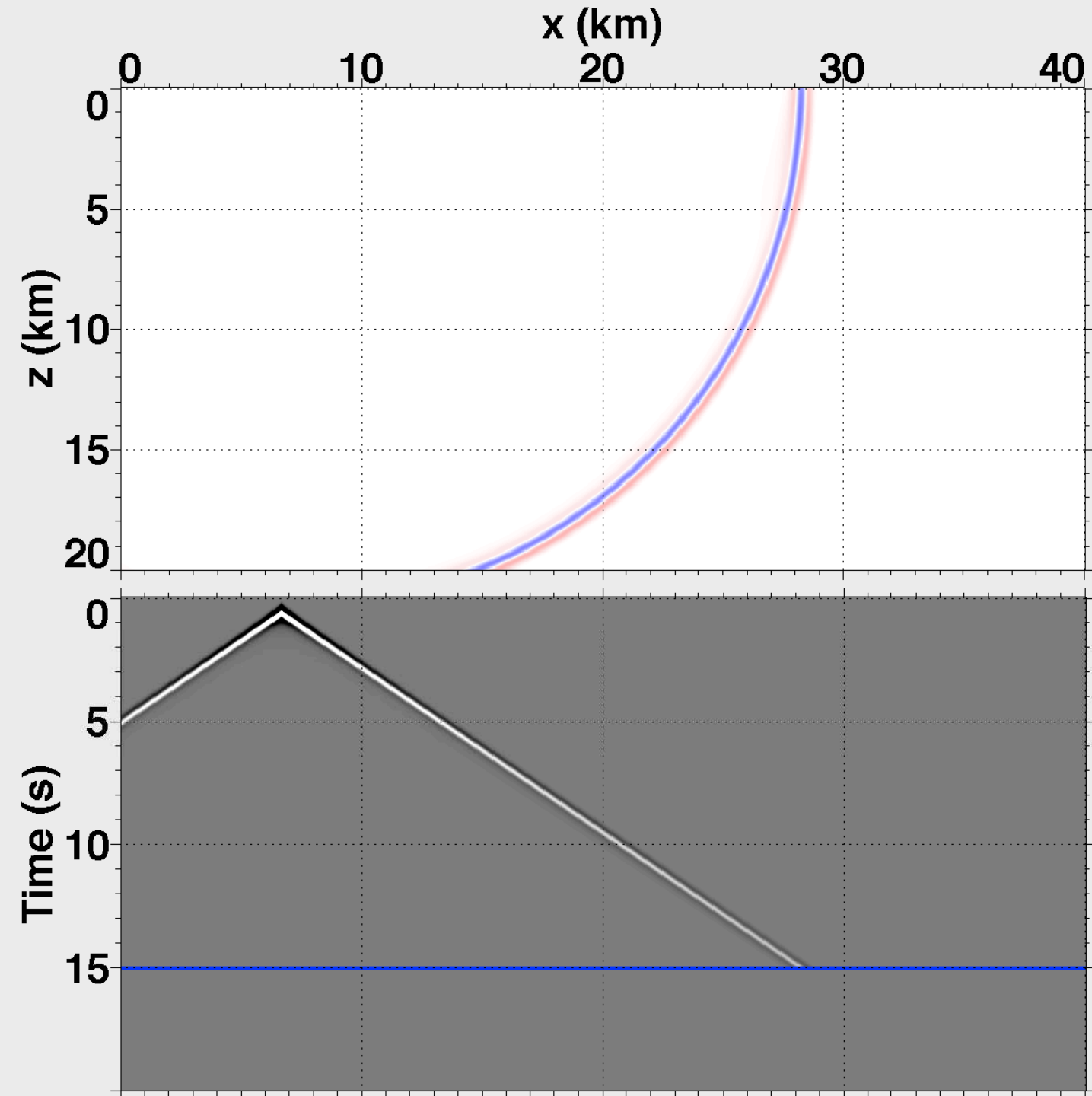


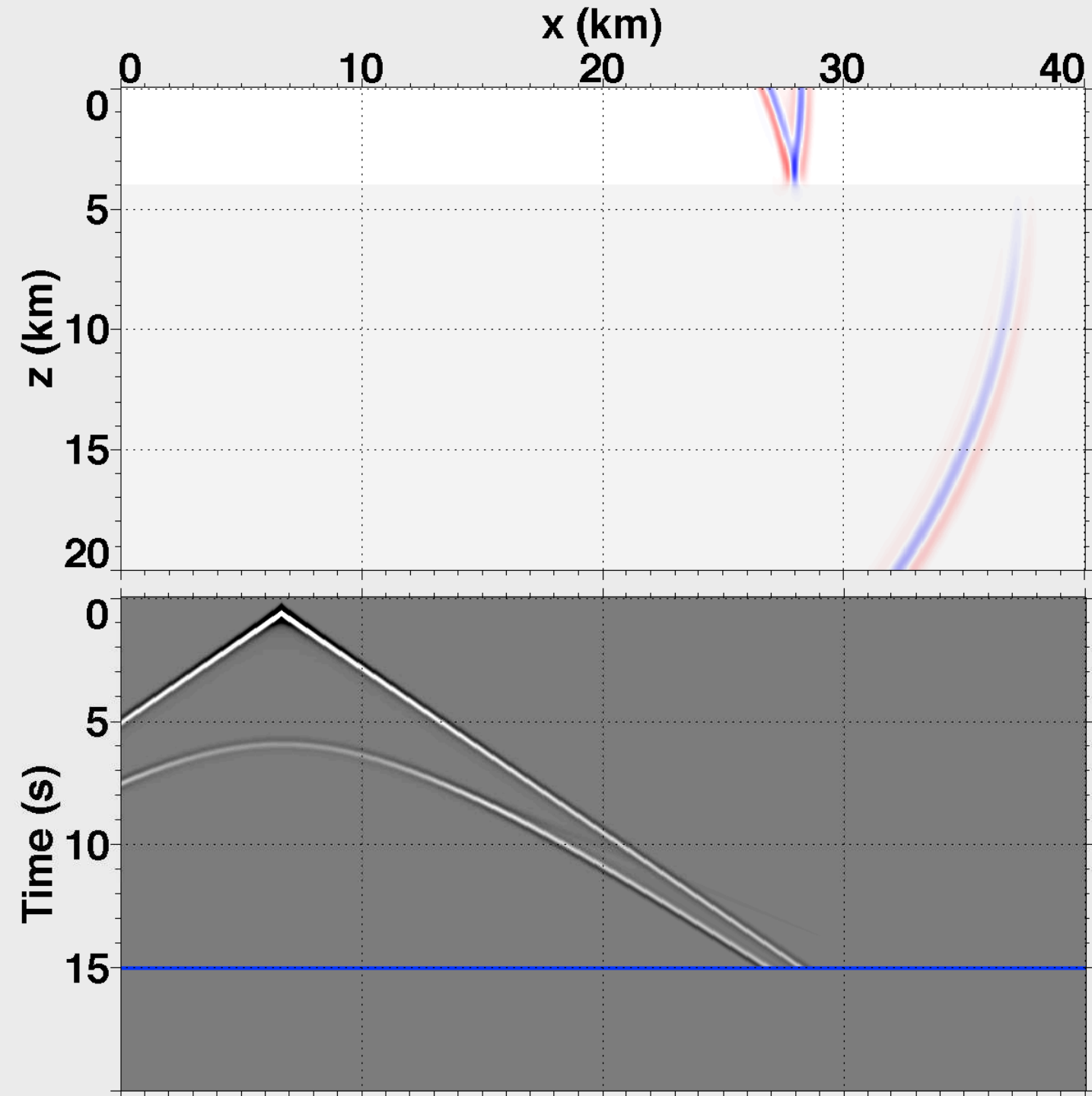


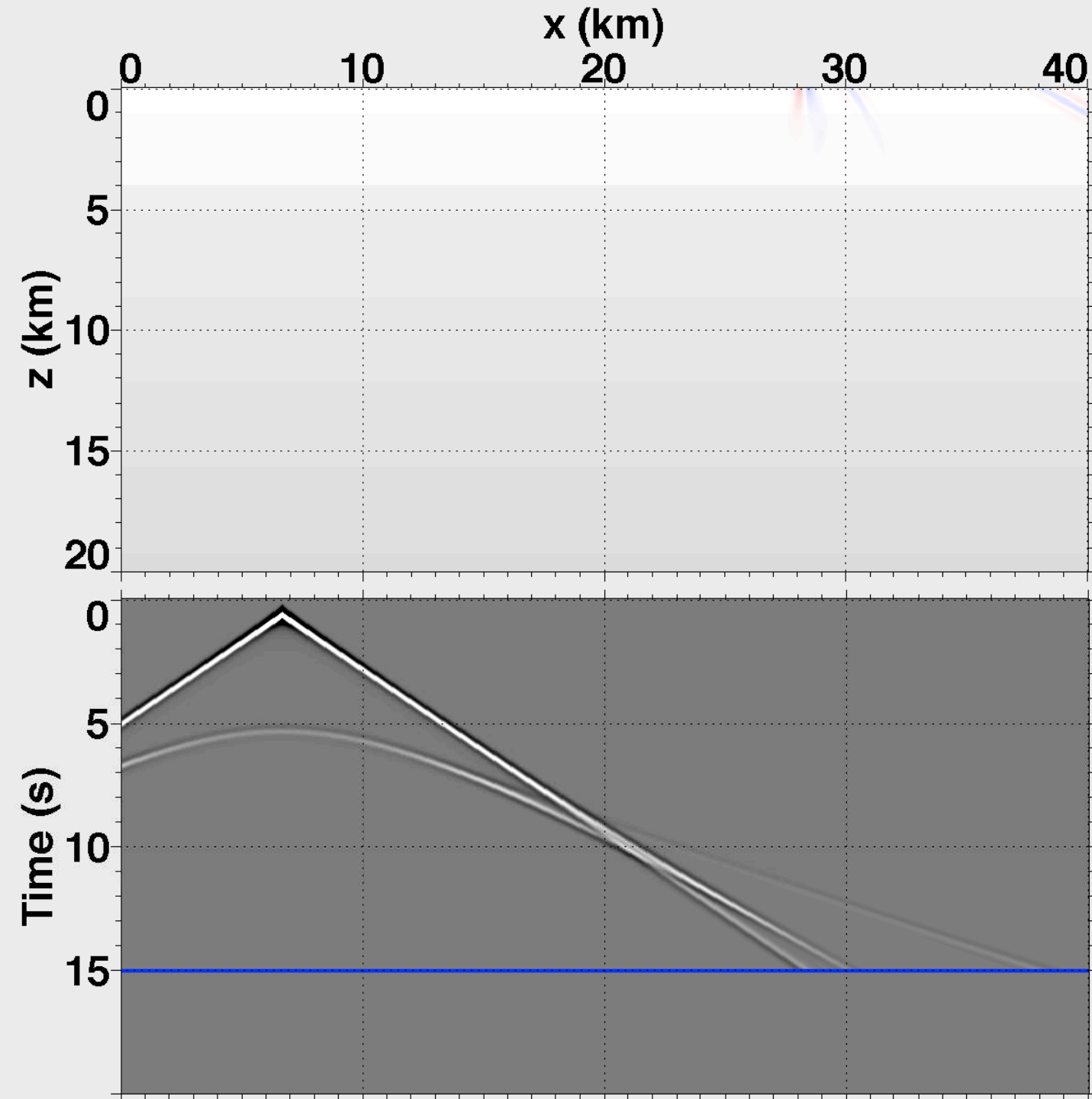


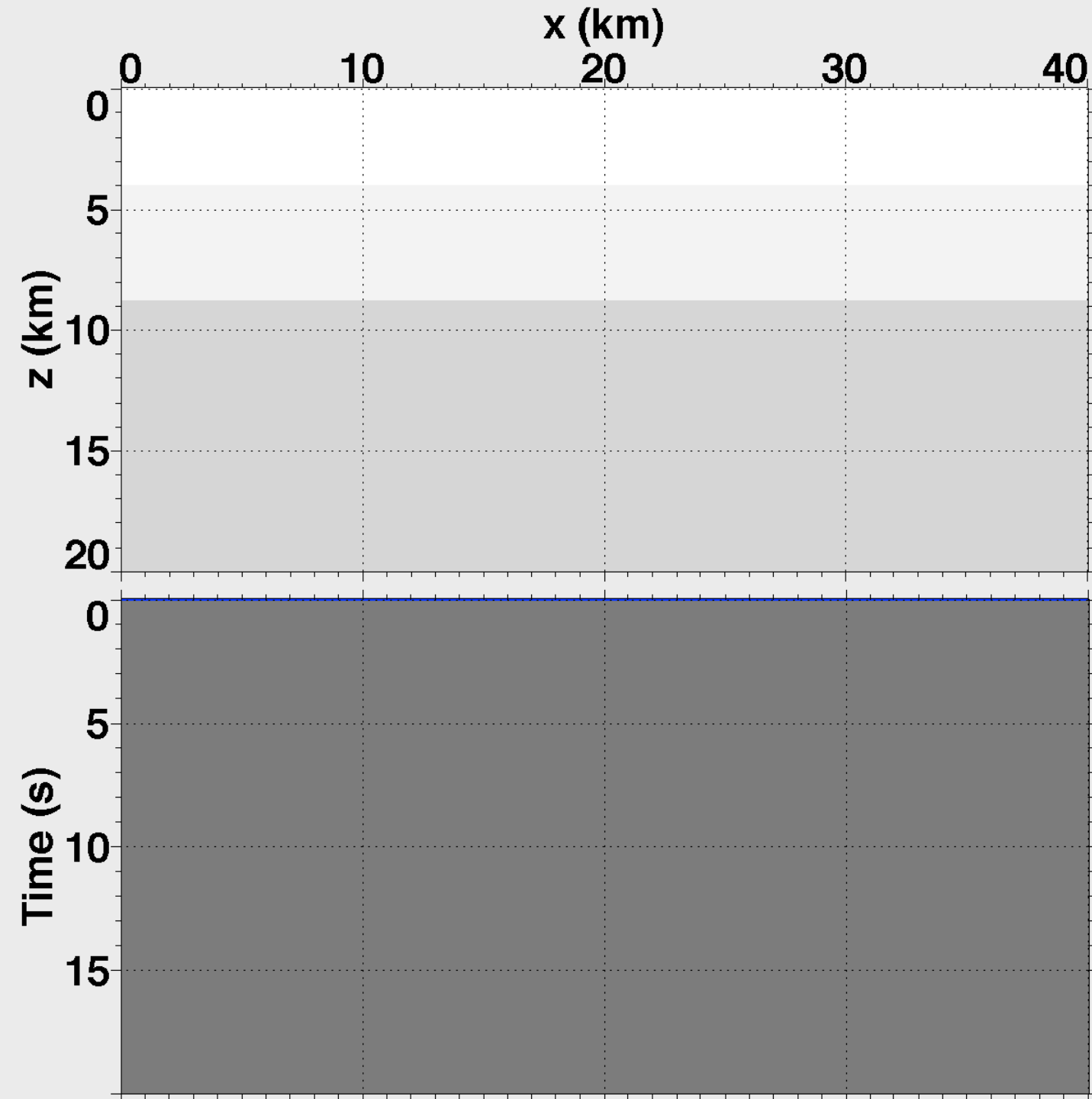


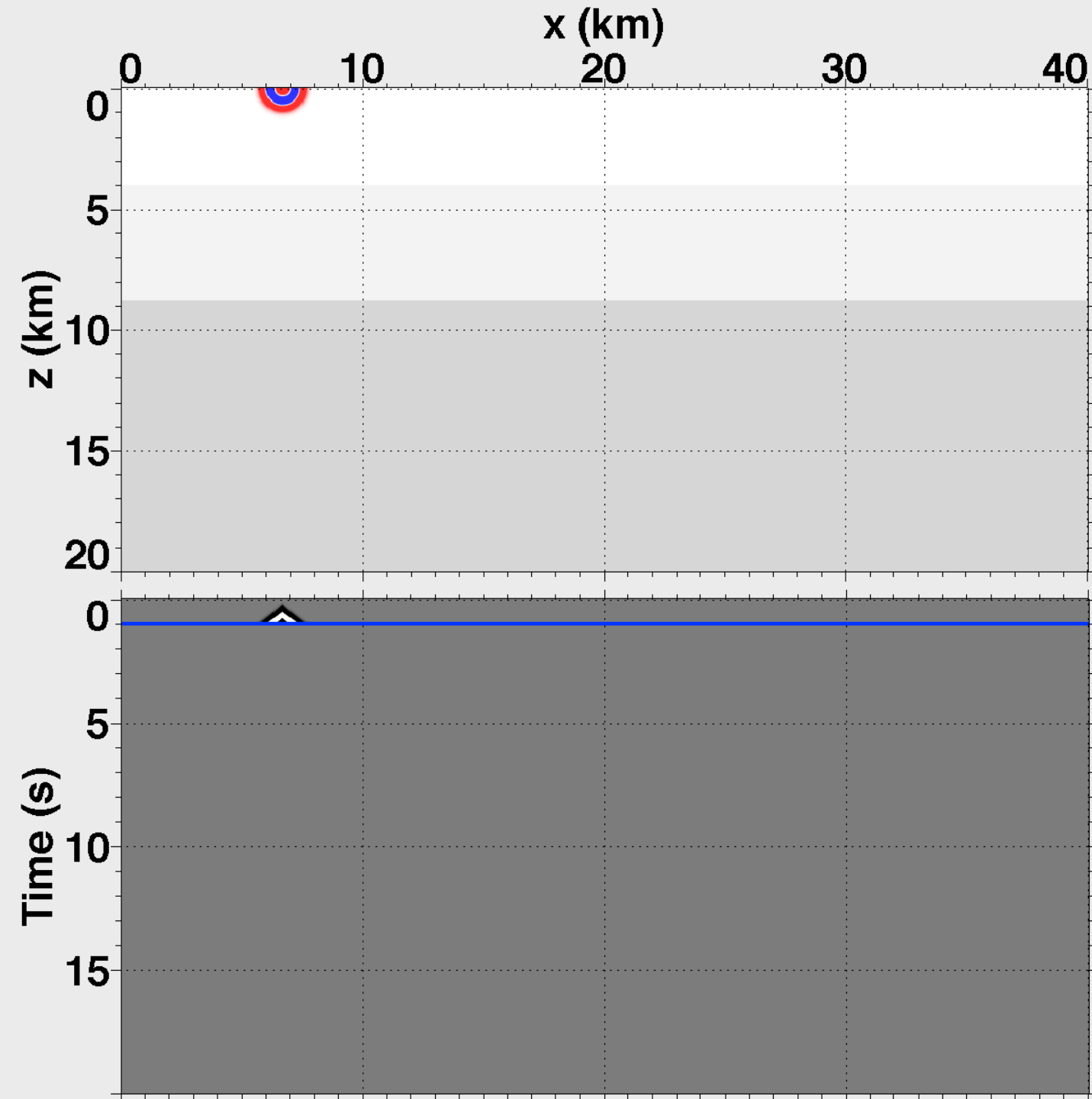
Comparison

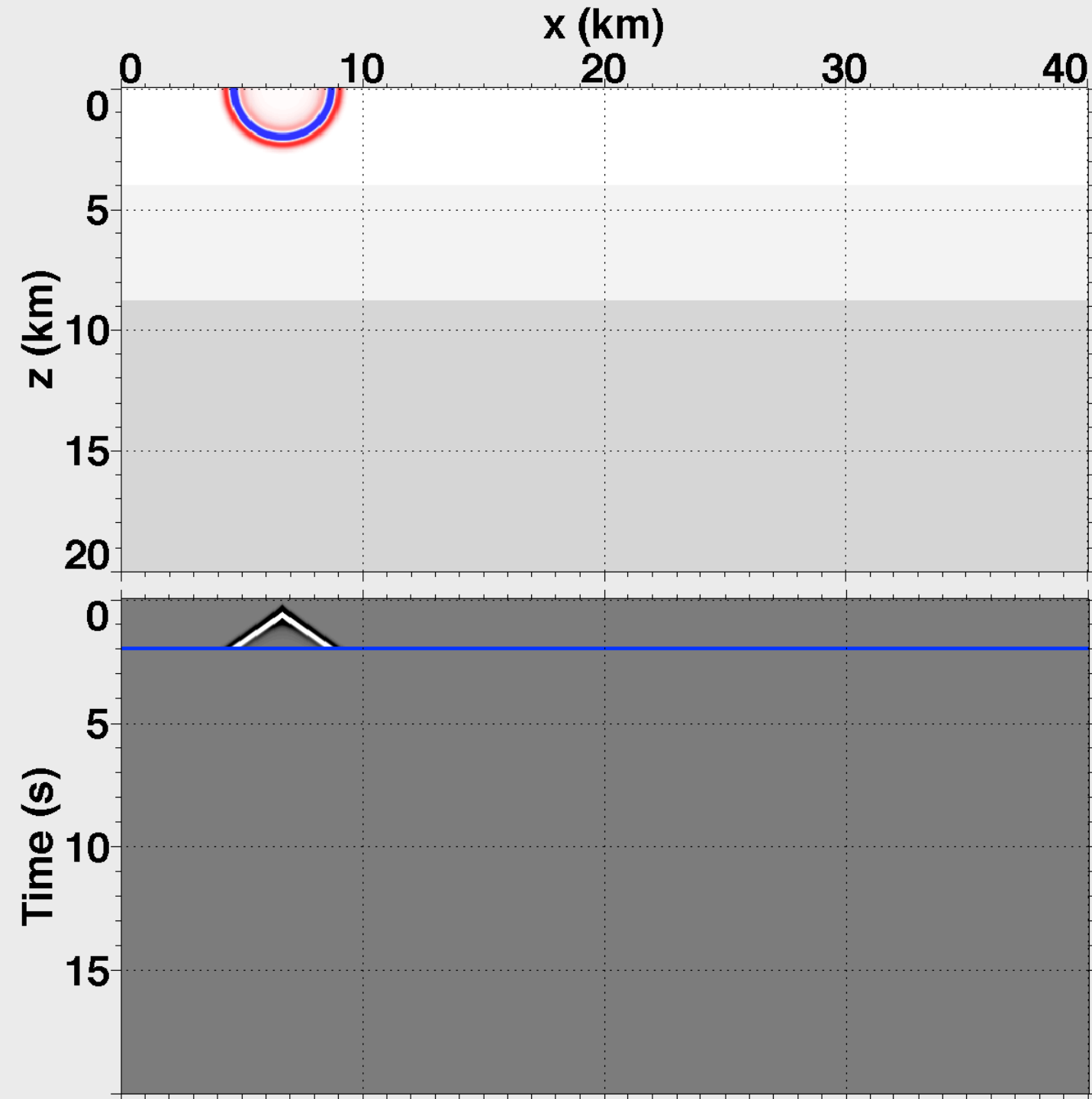


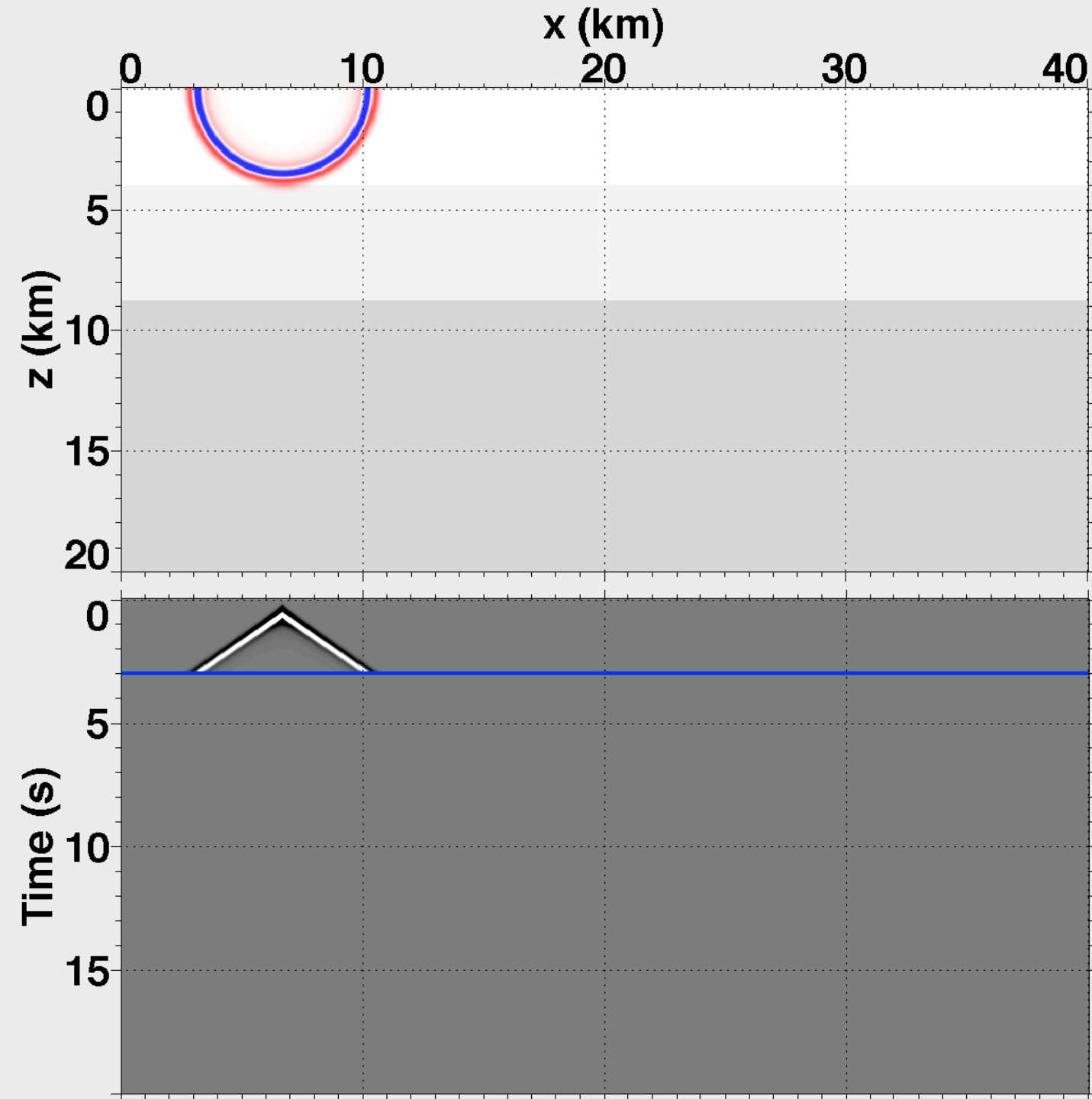


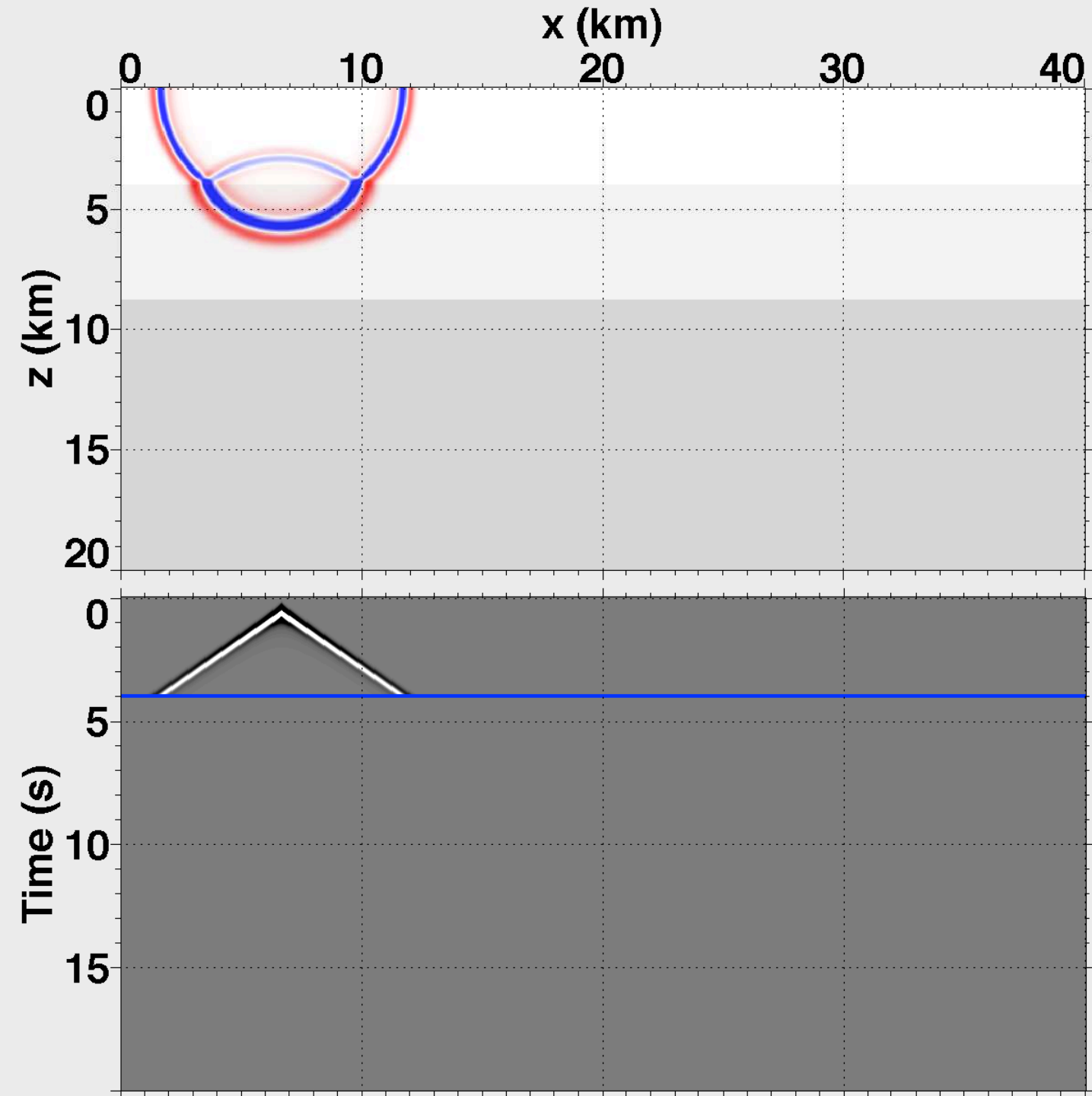


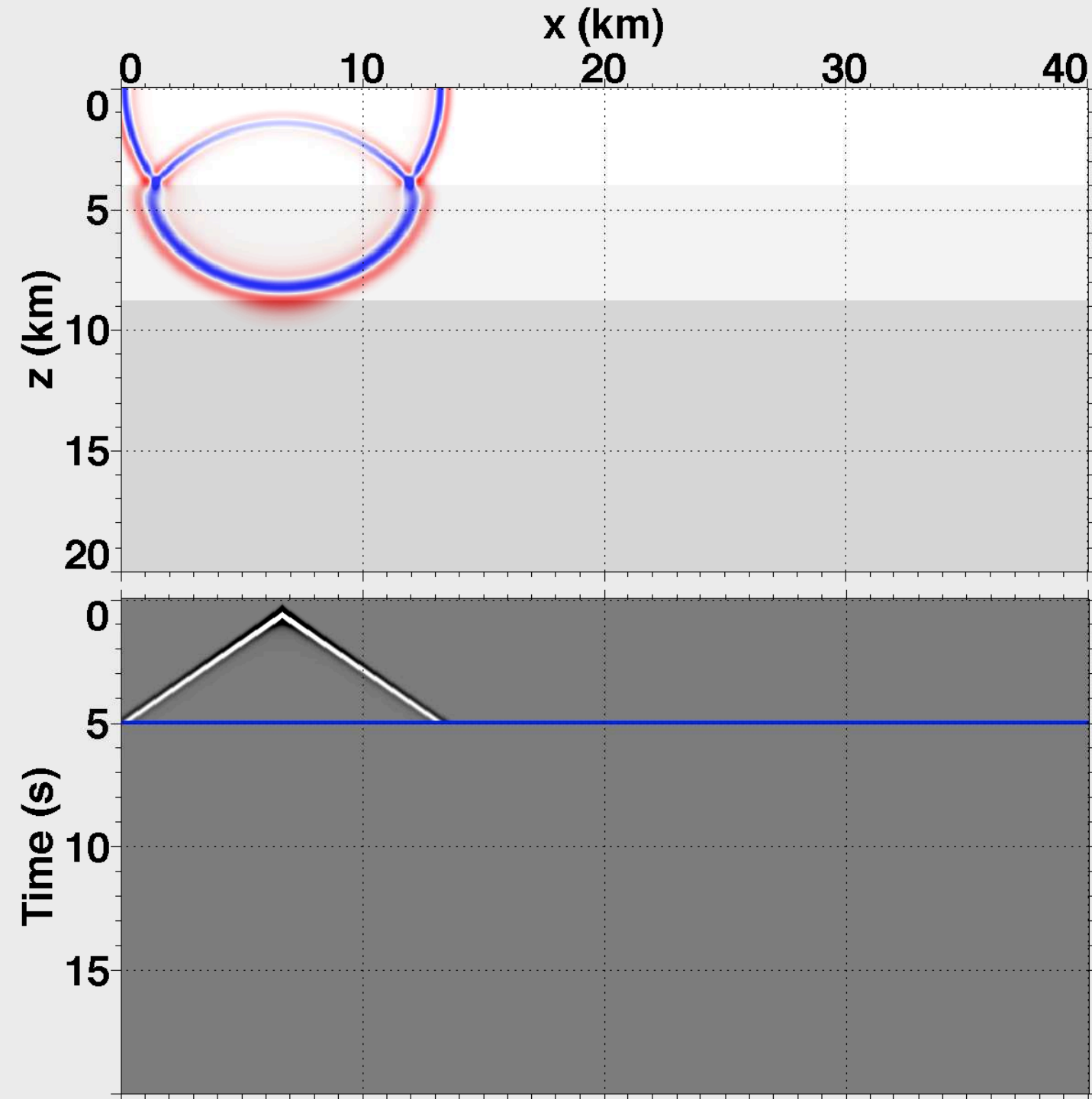


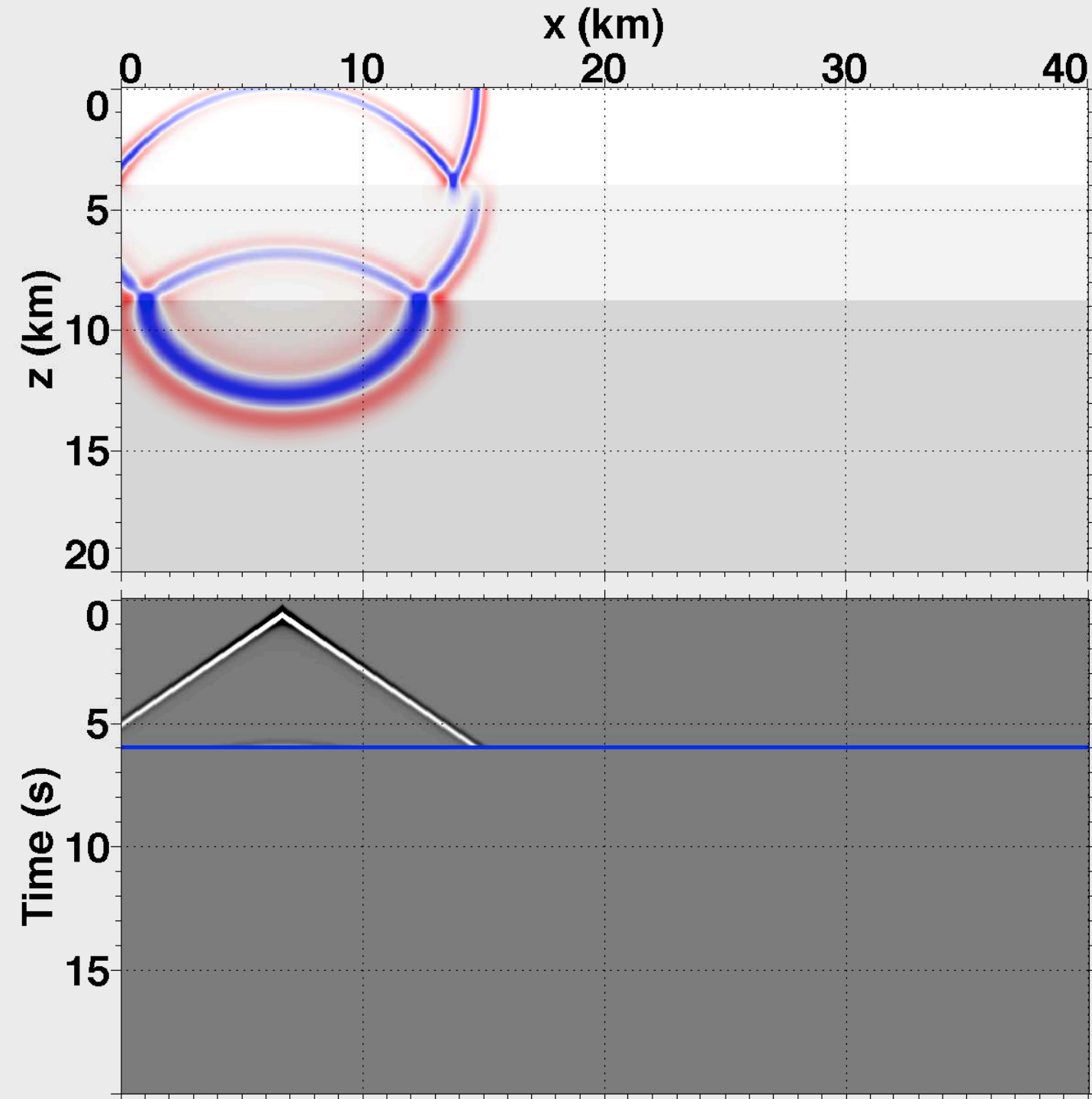


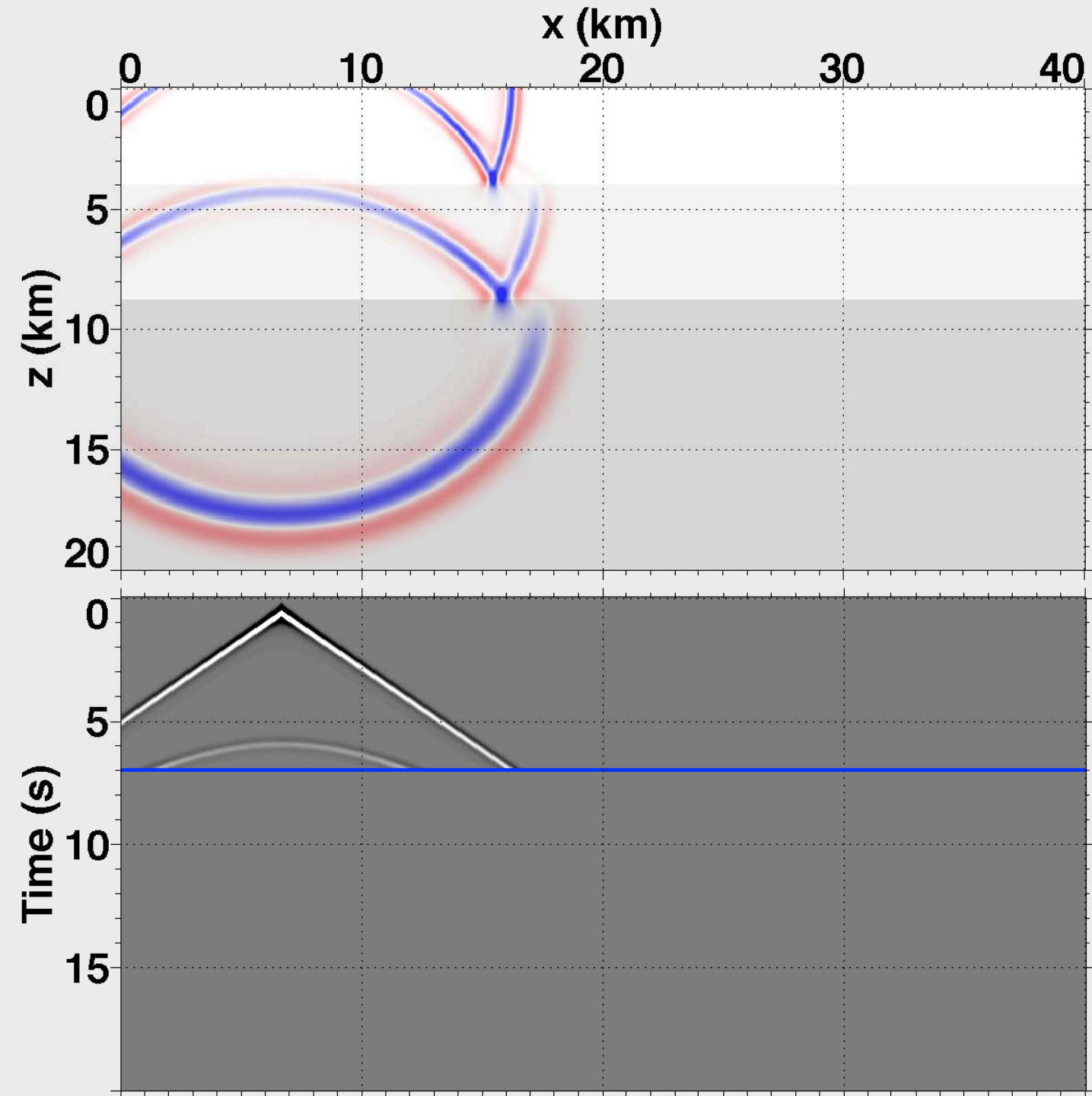


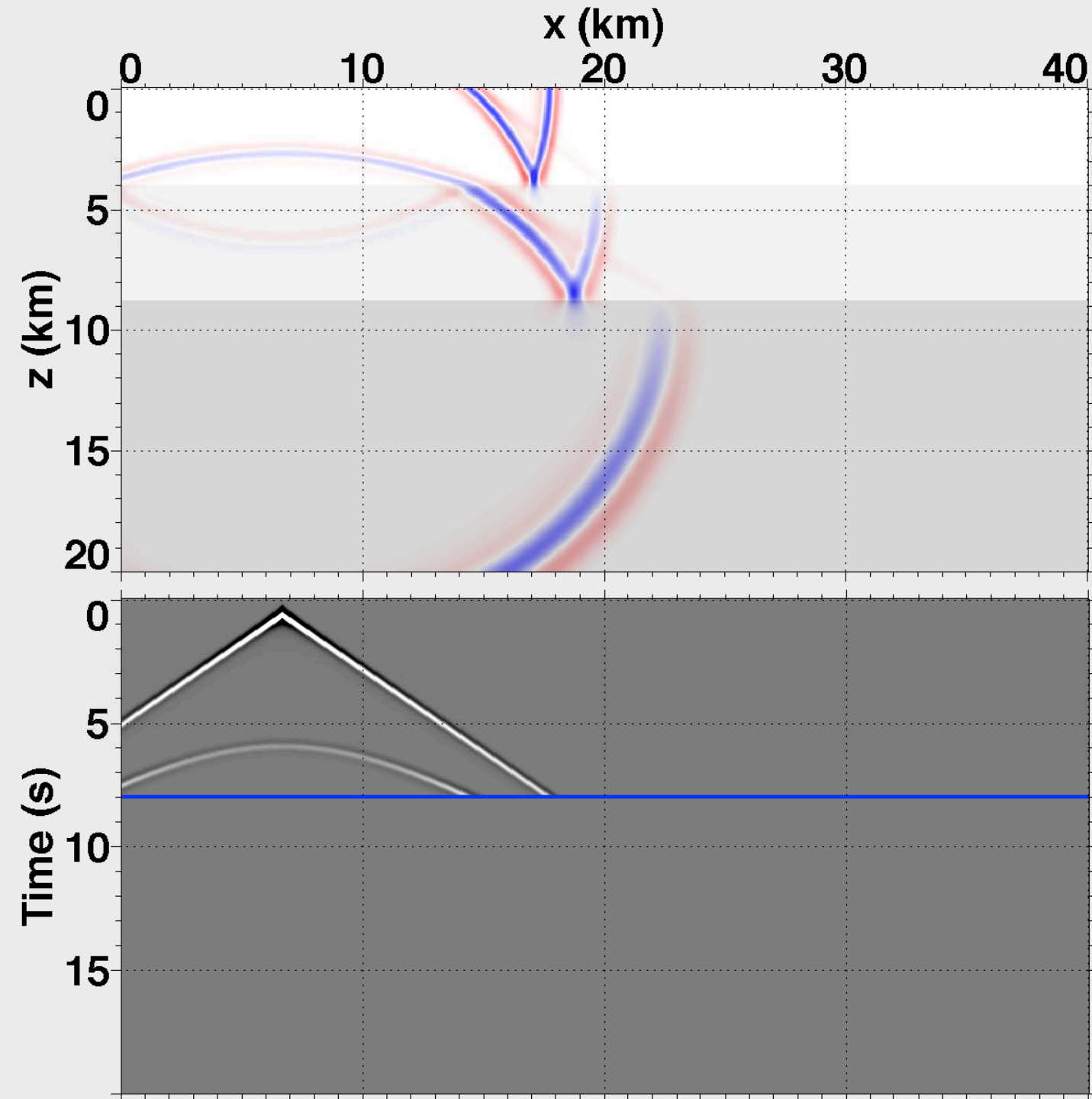


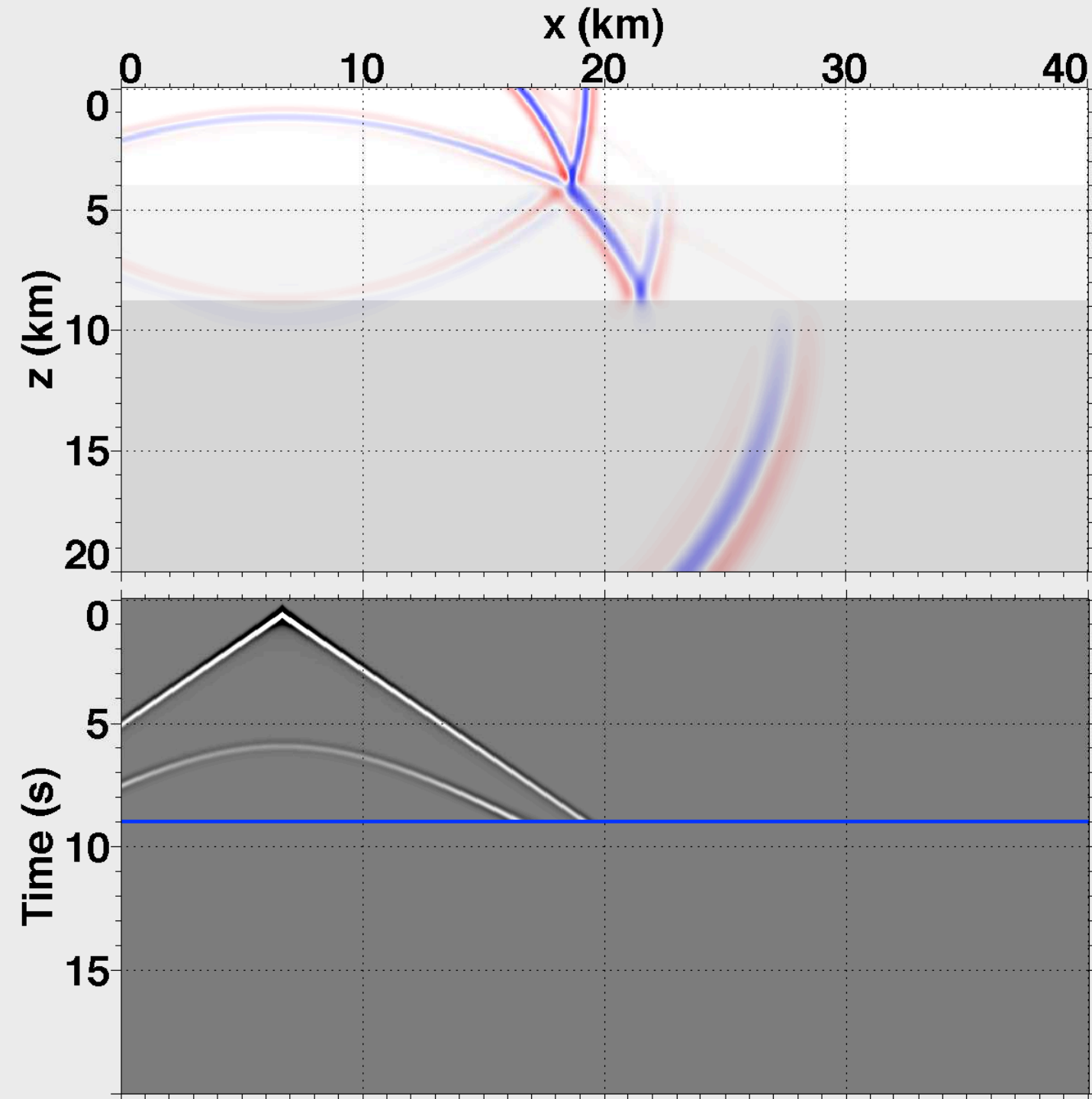


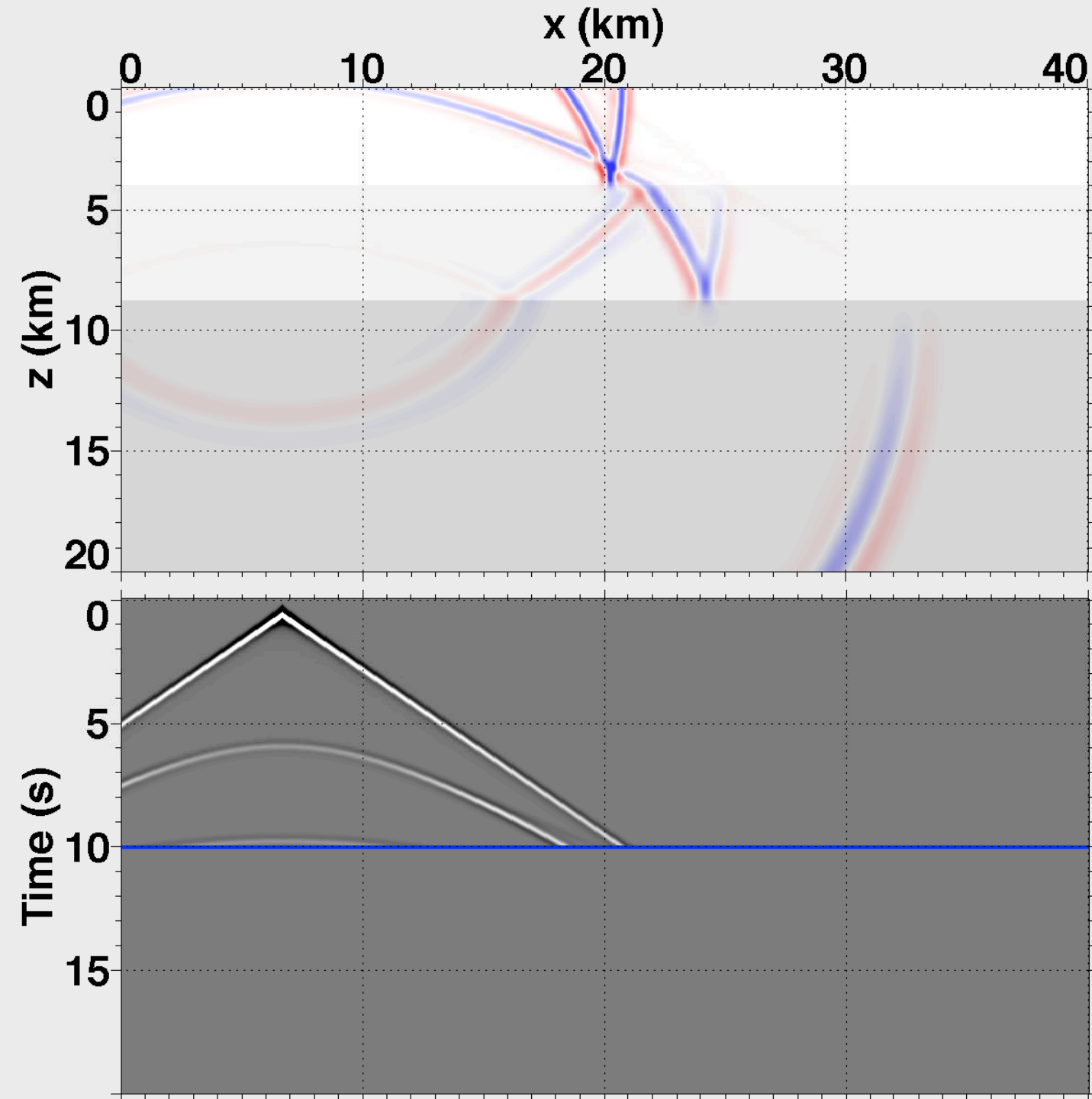


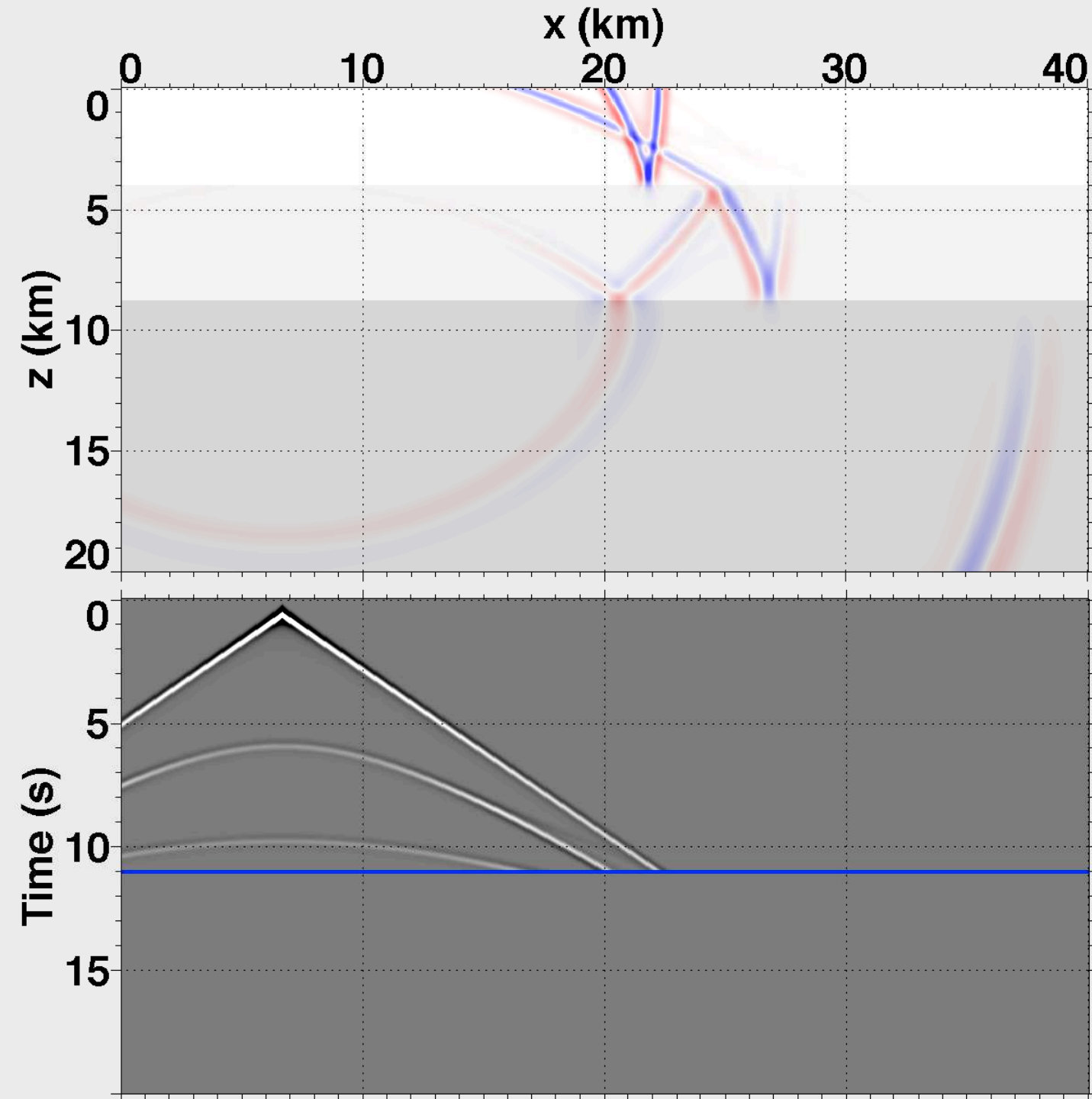


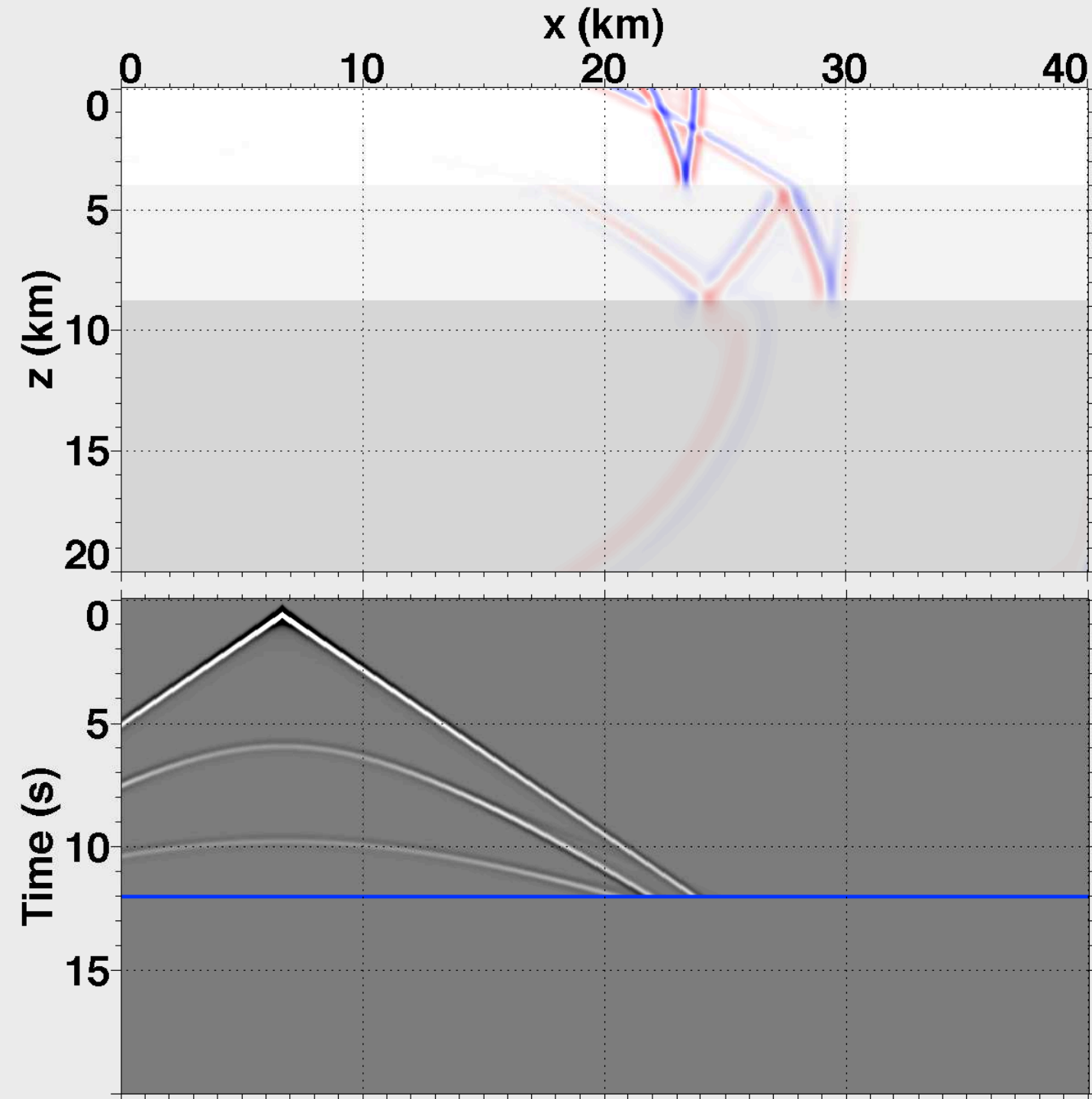


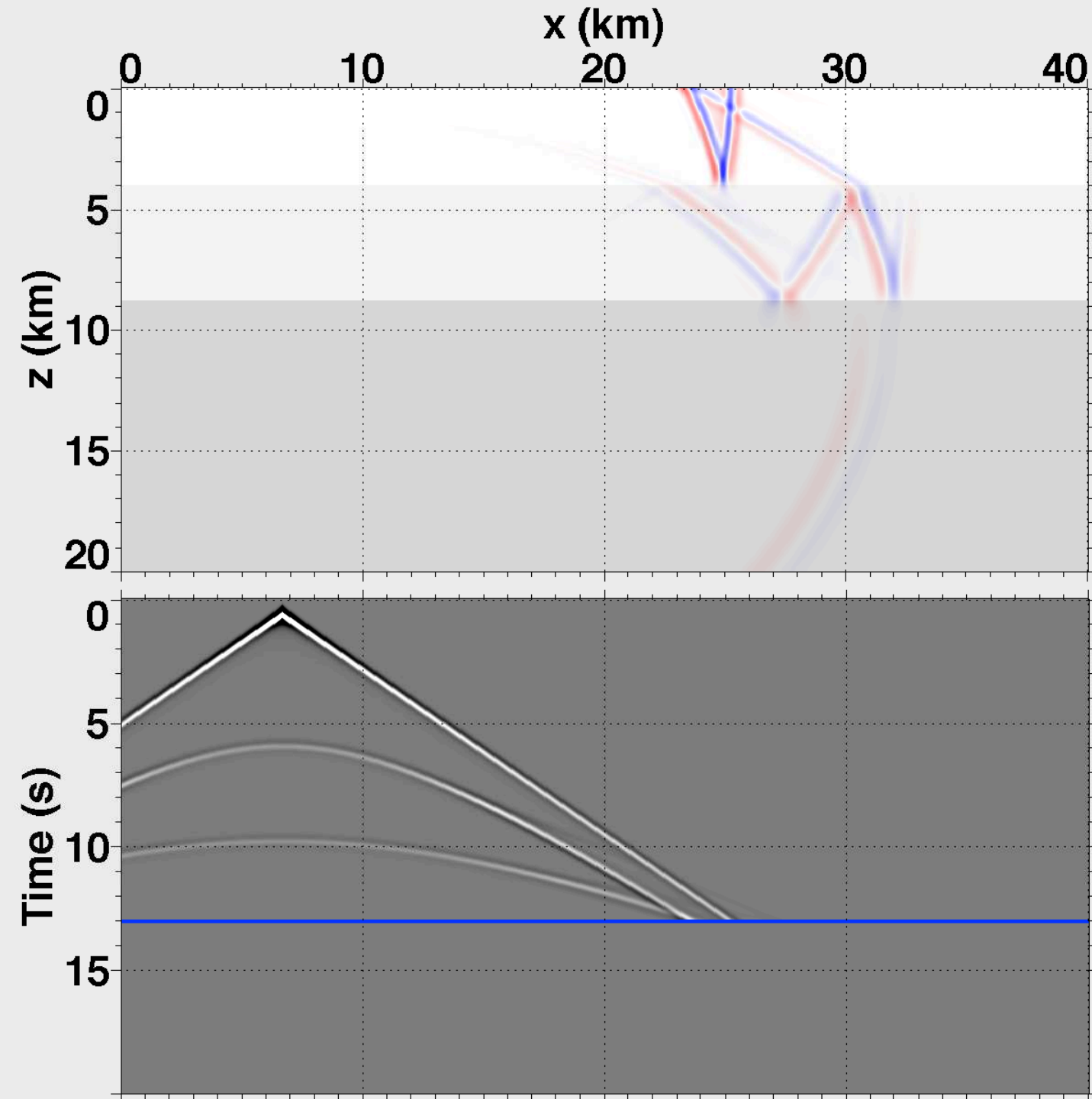


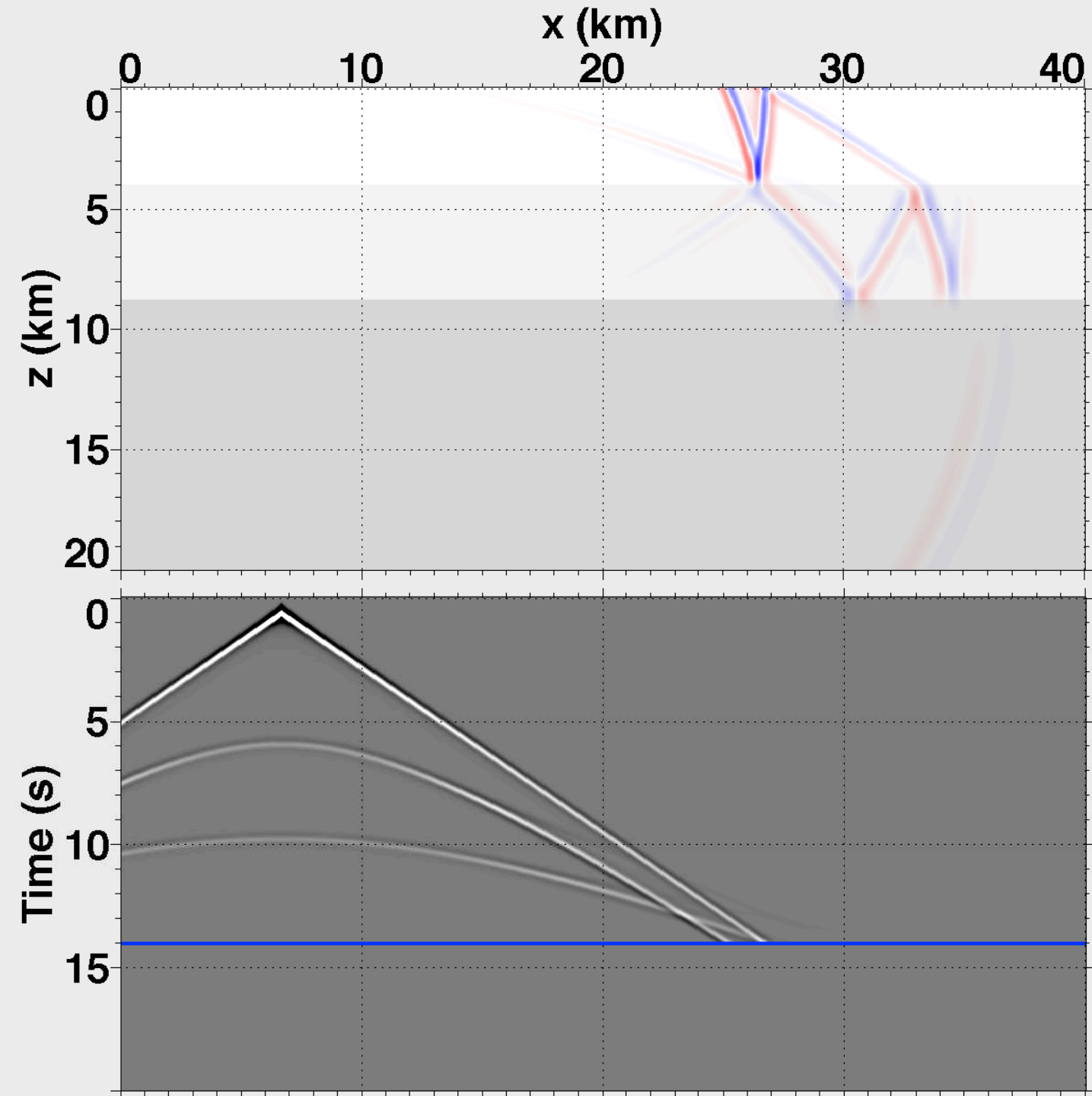


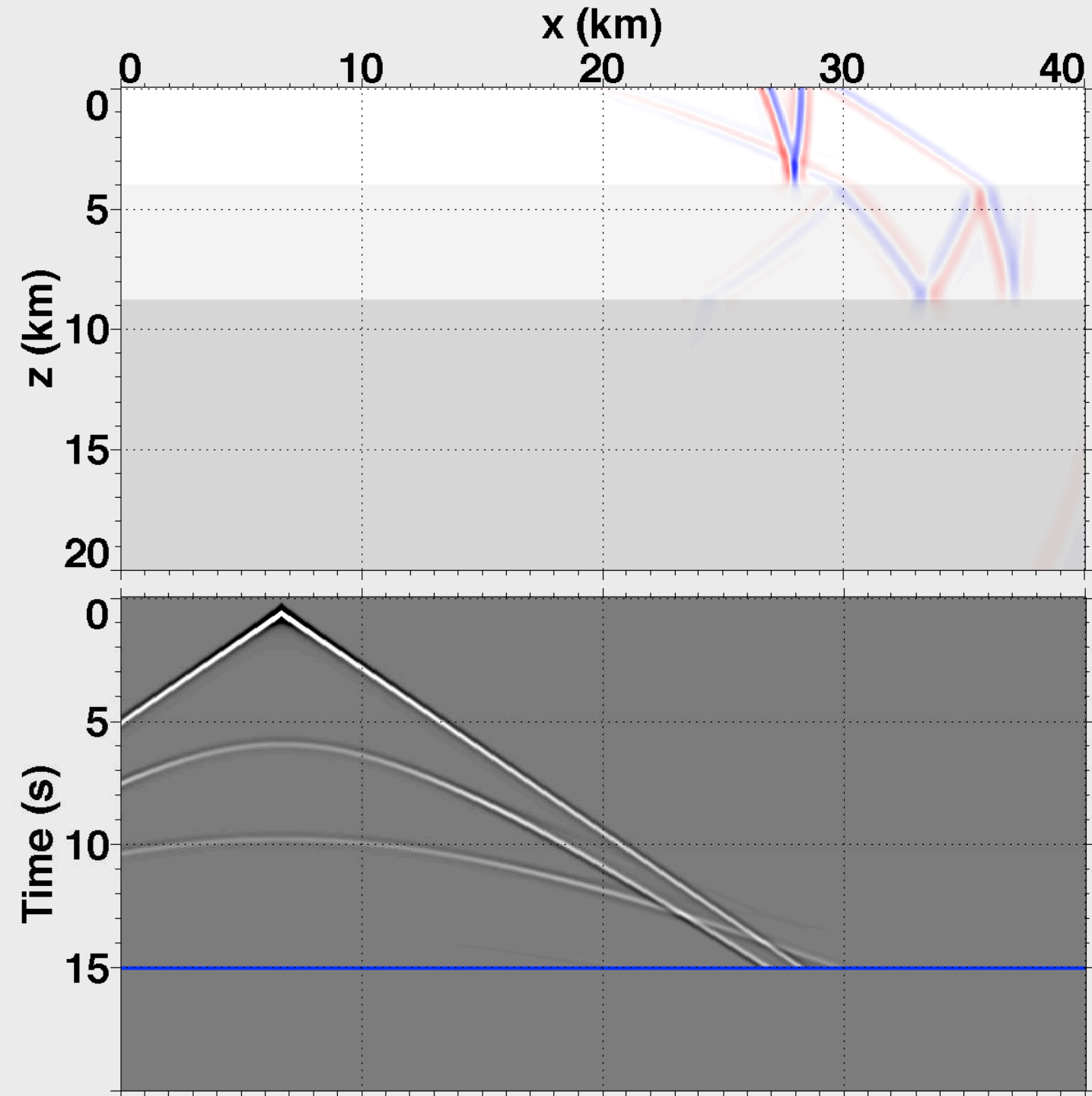


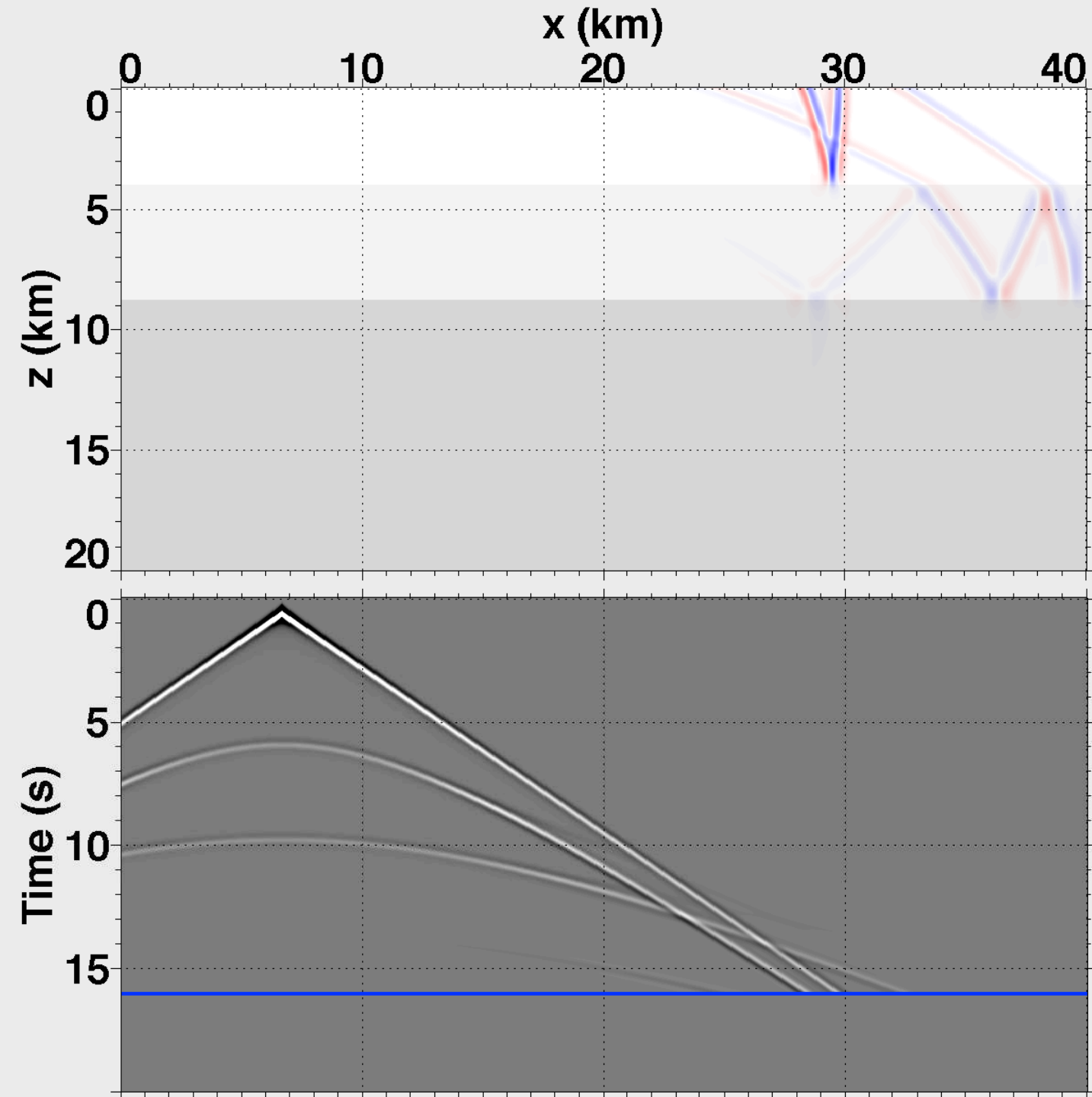


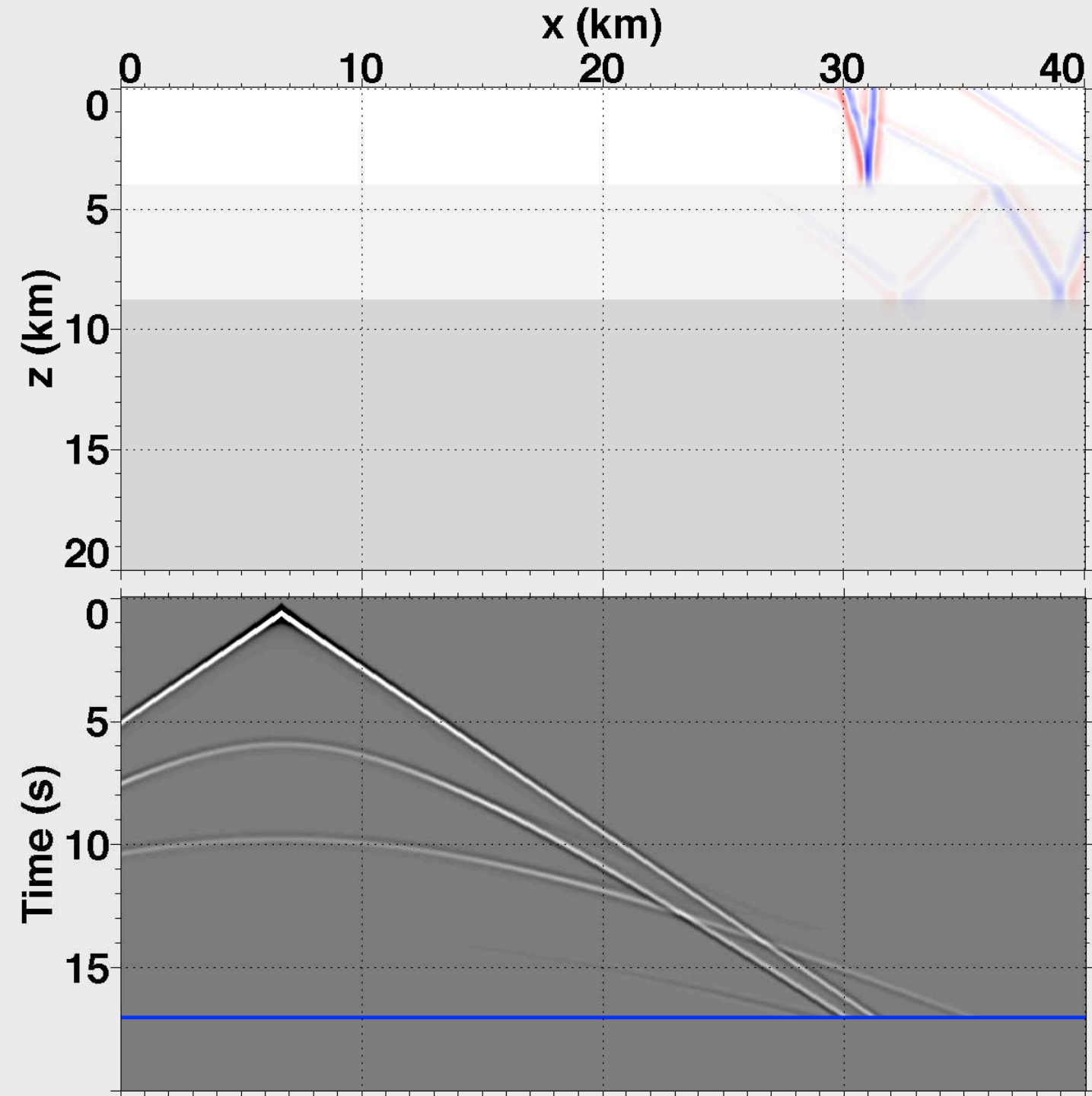


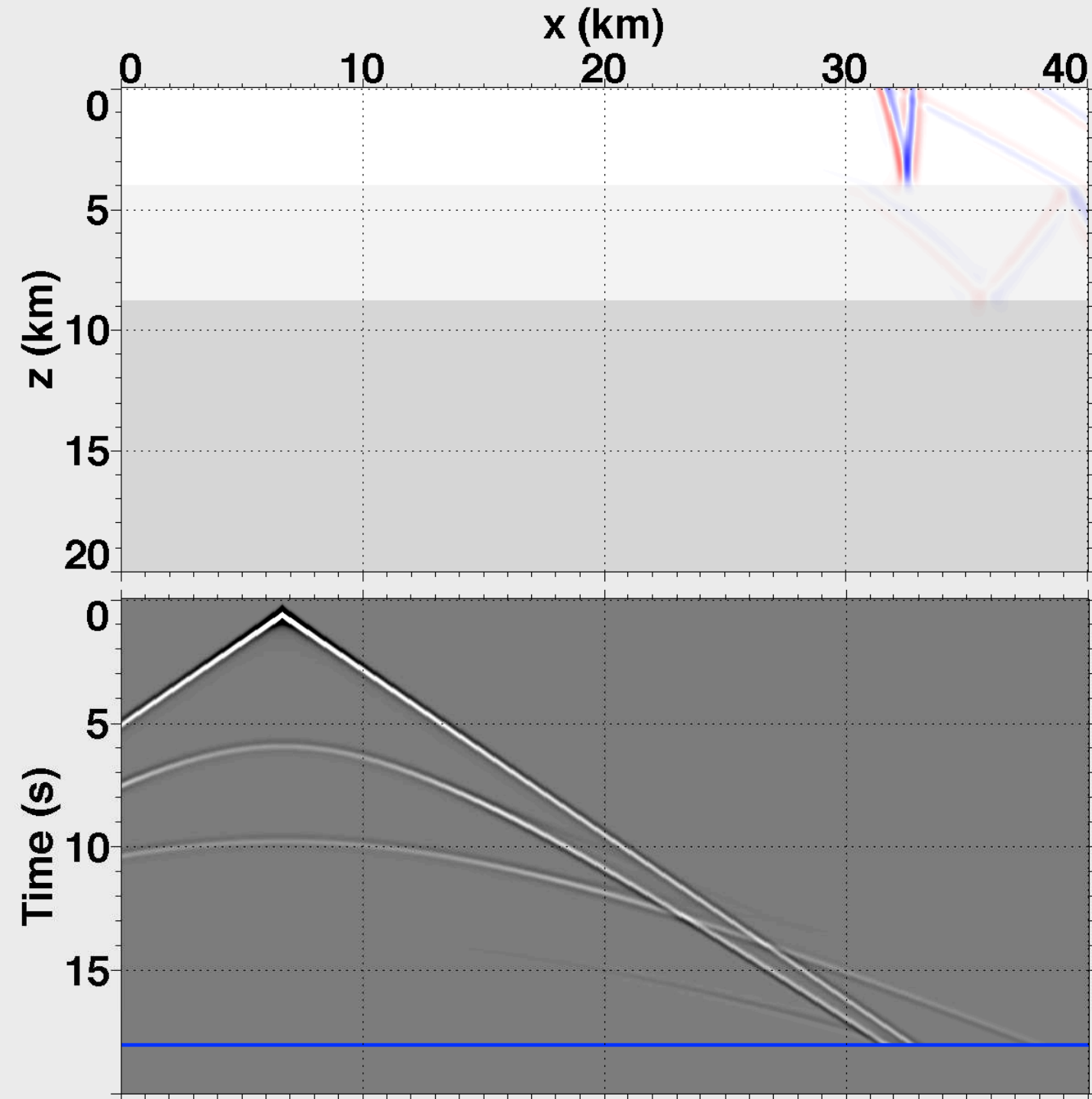


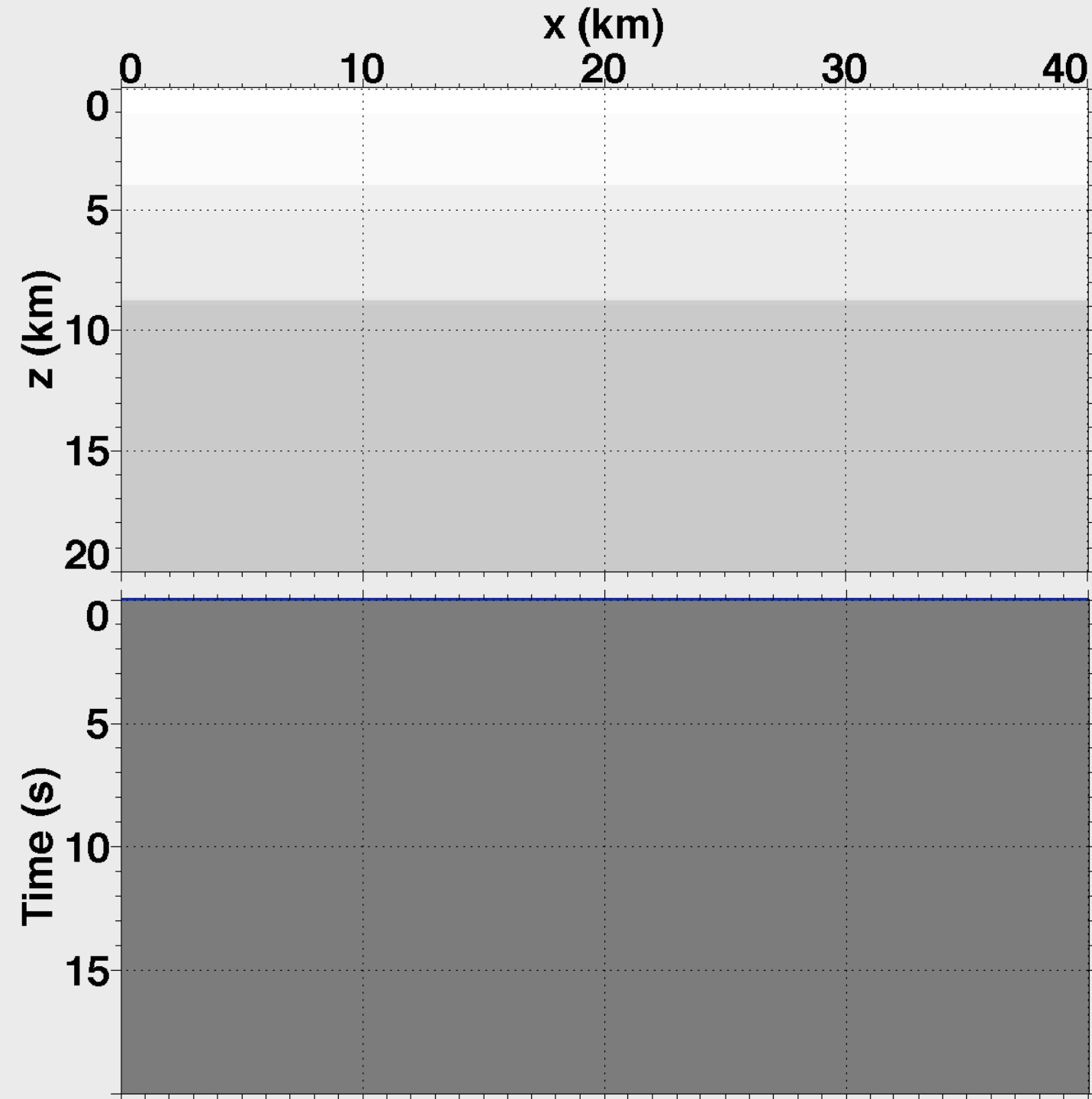


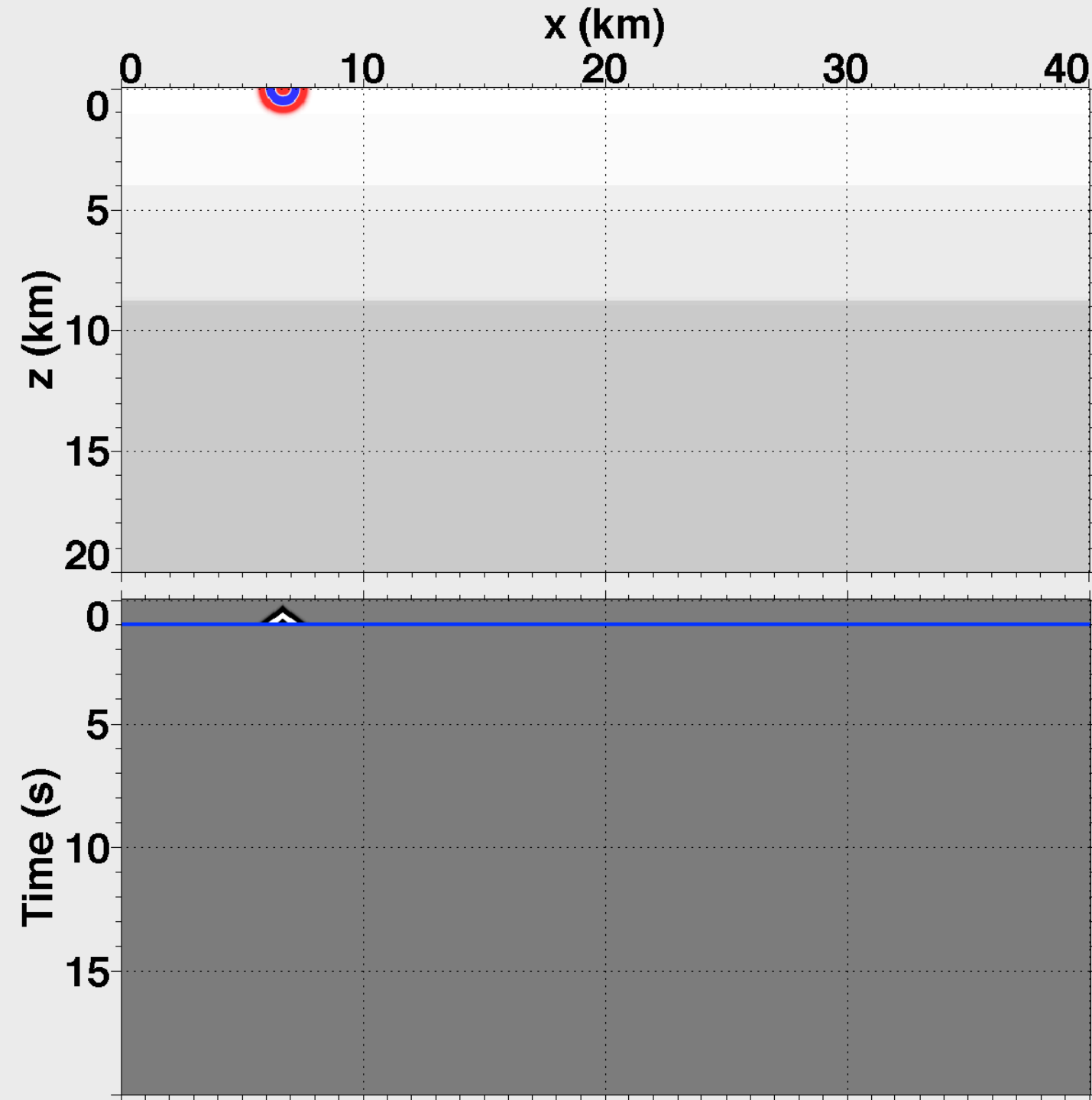


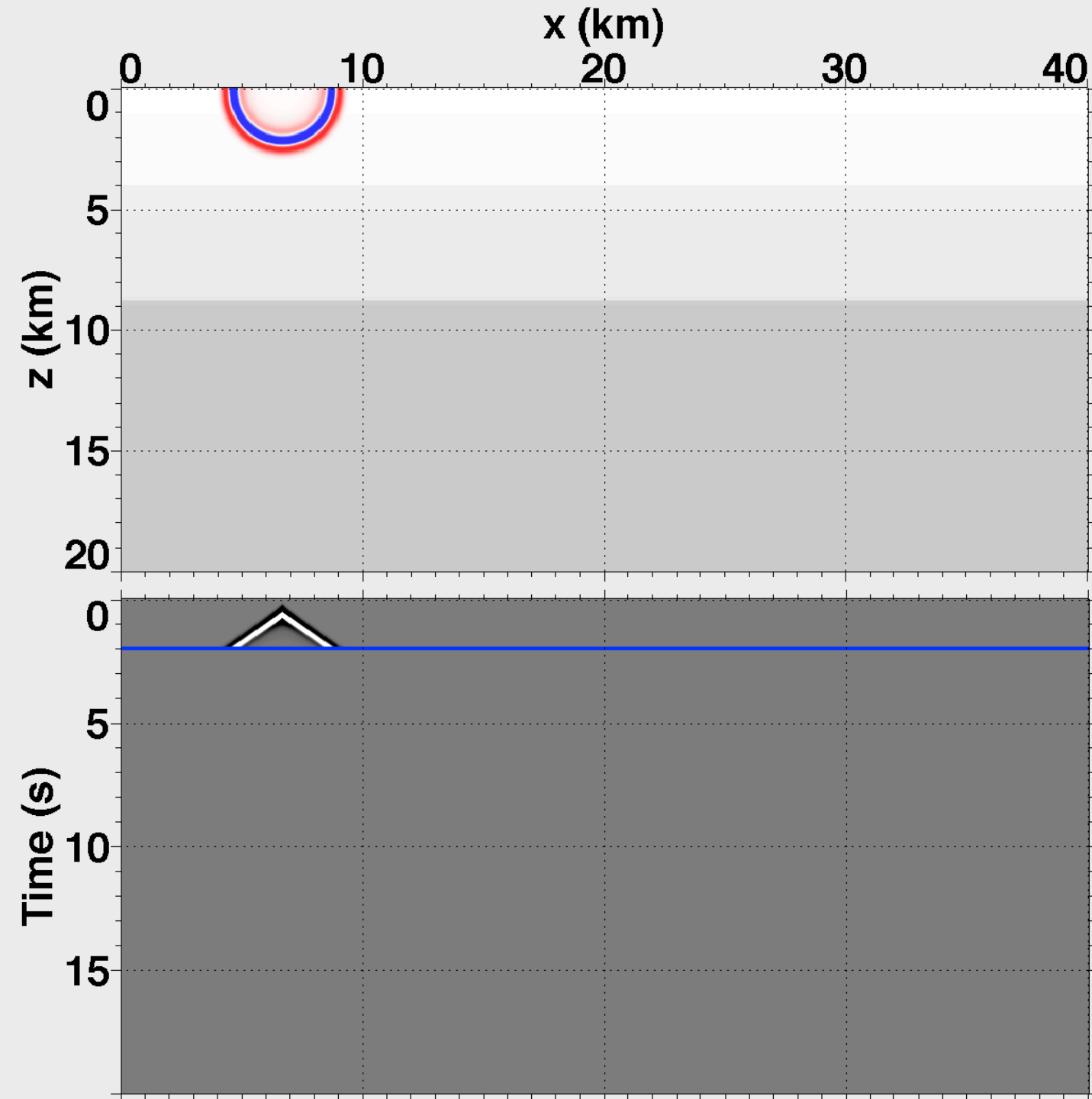


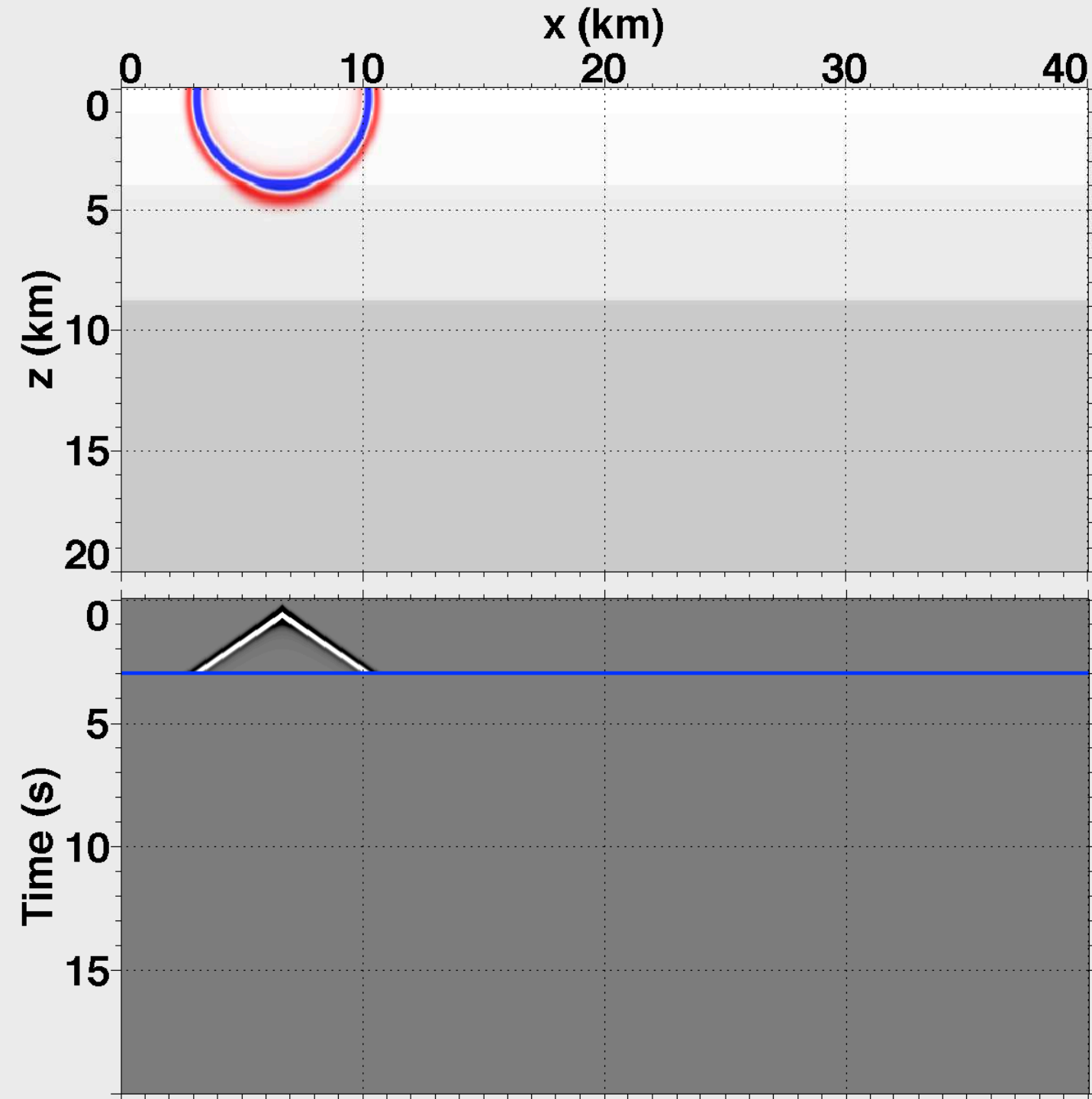


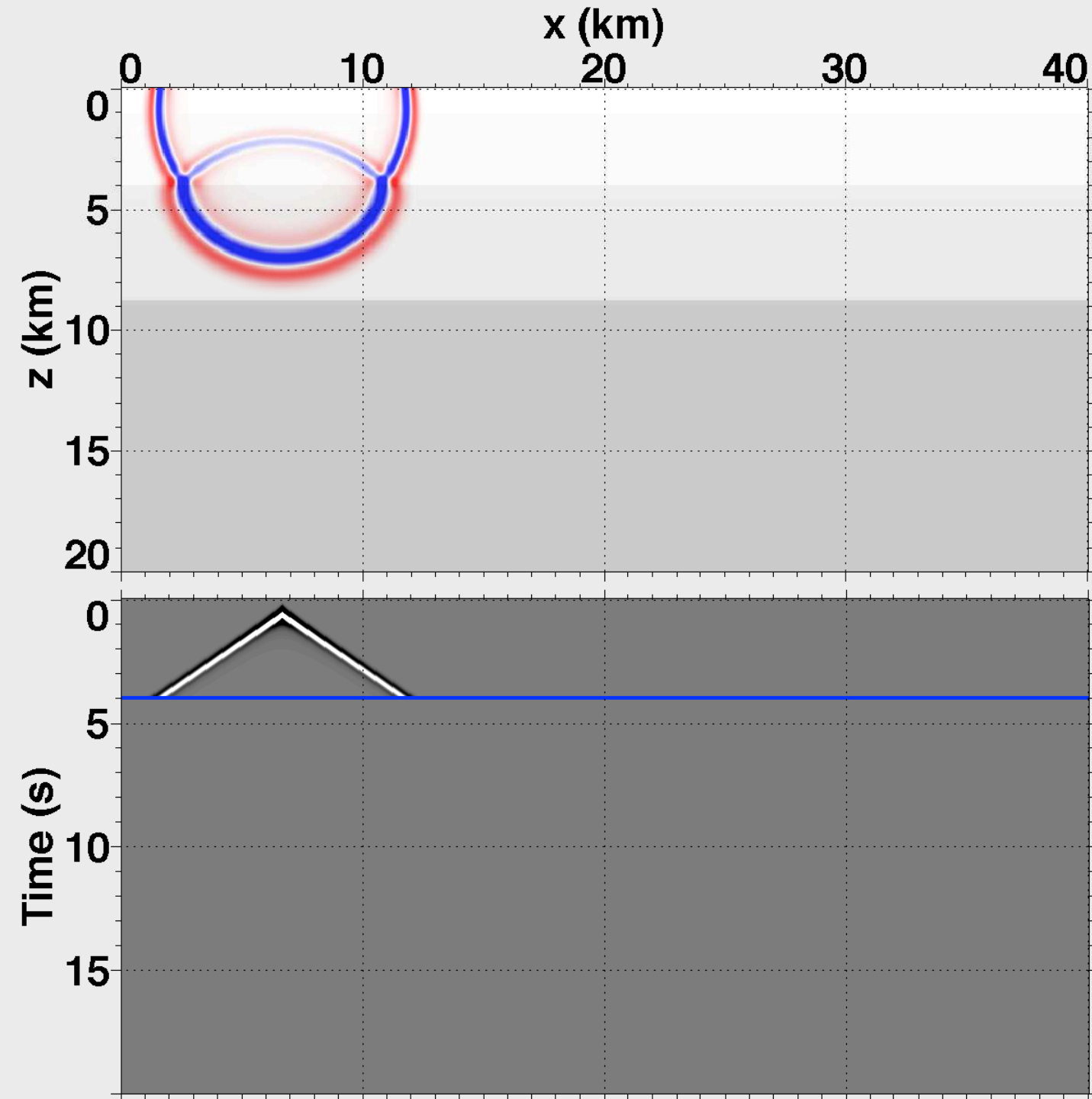


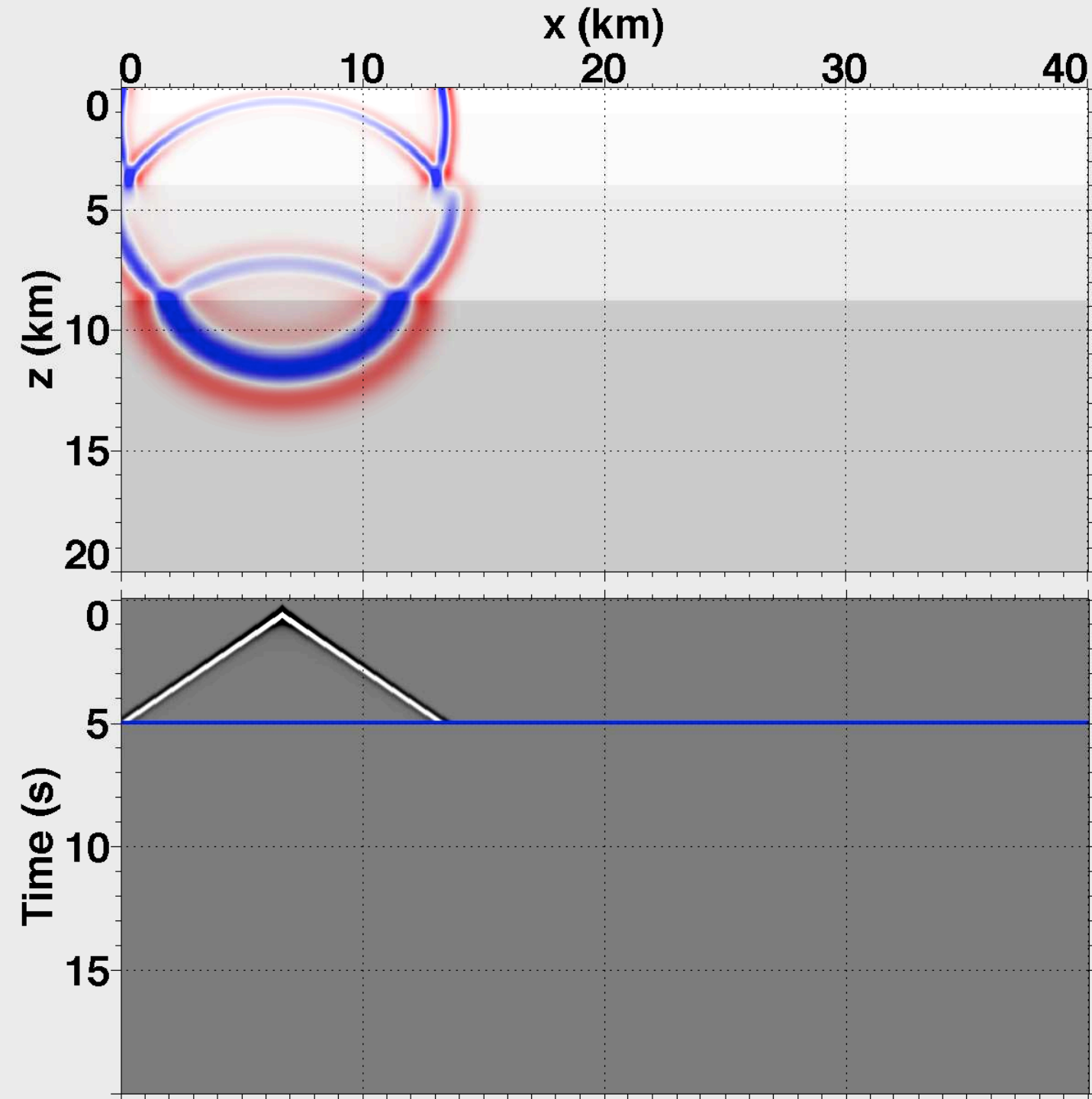


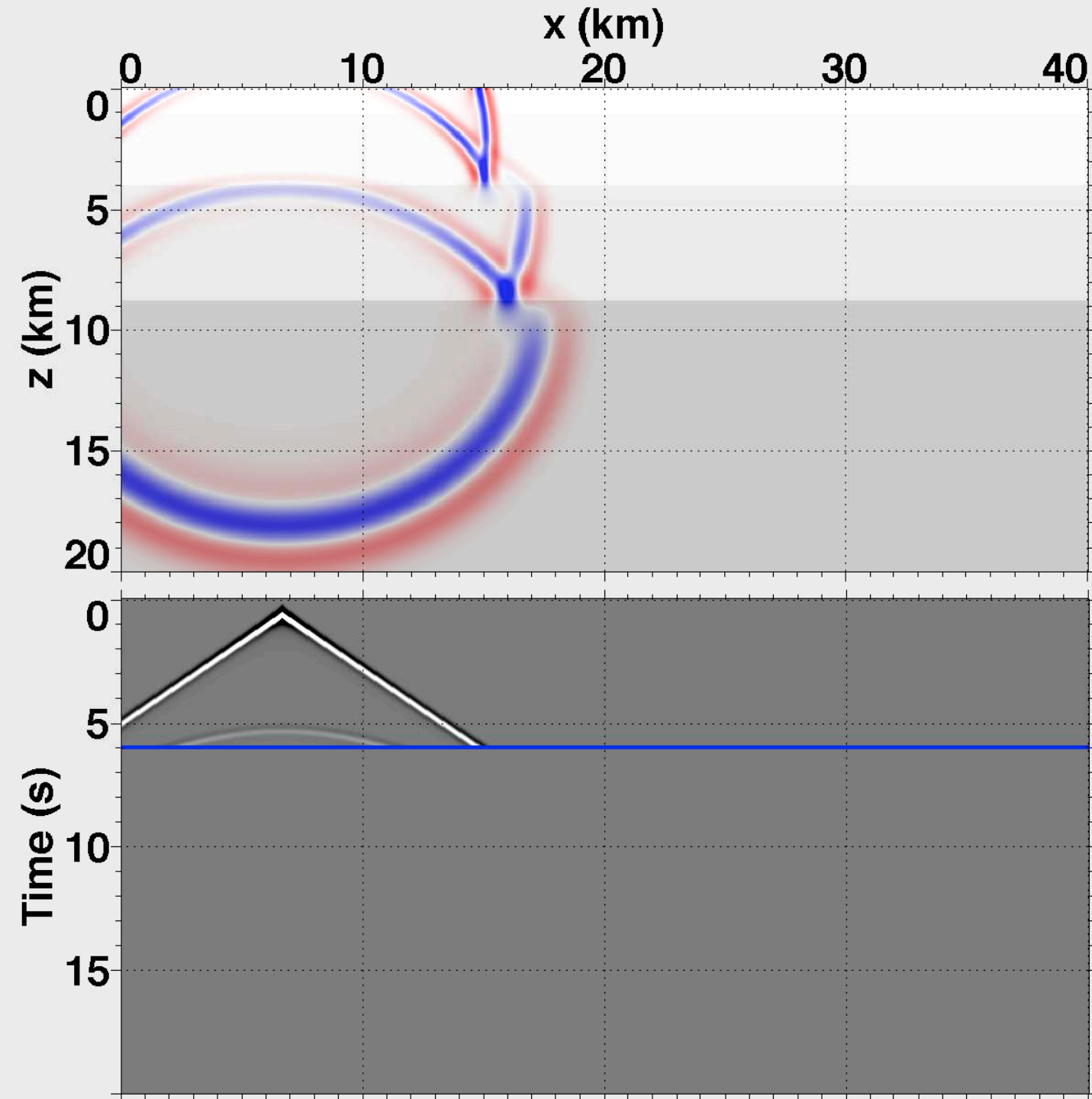


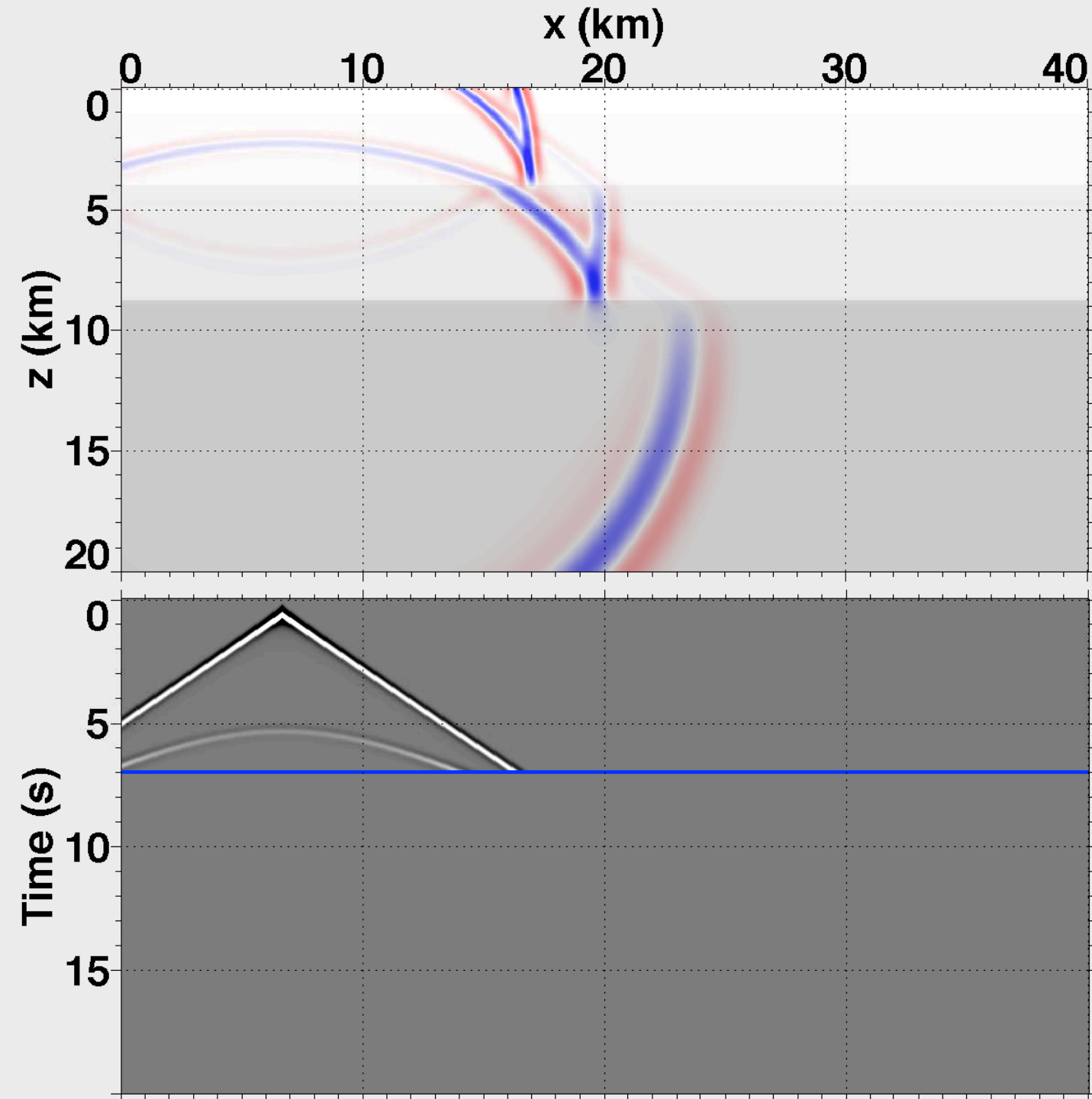


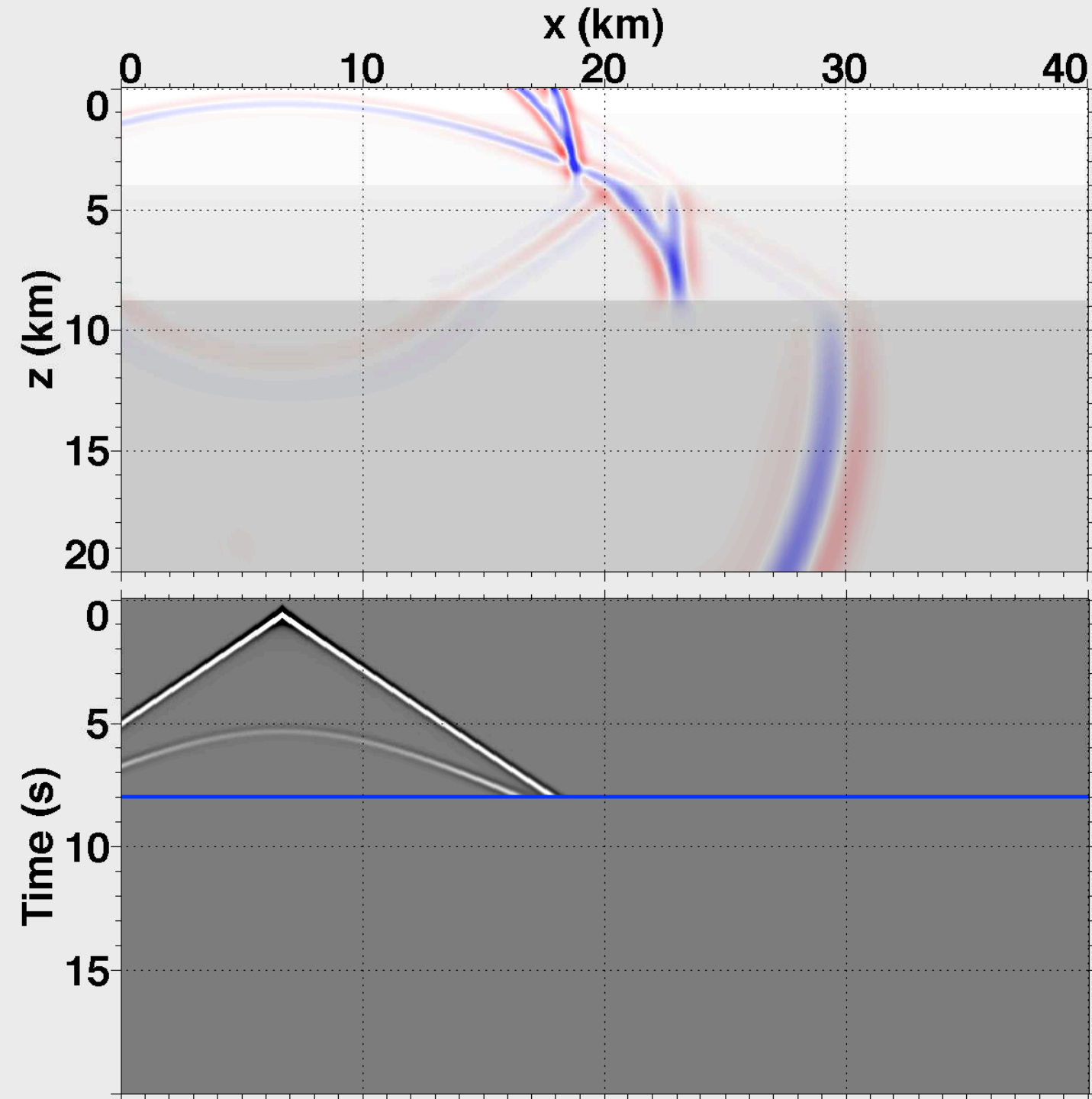


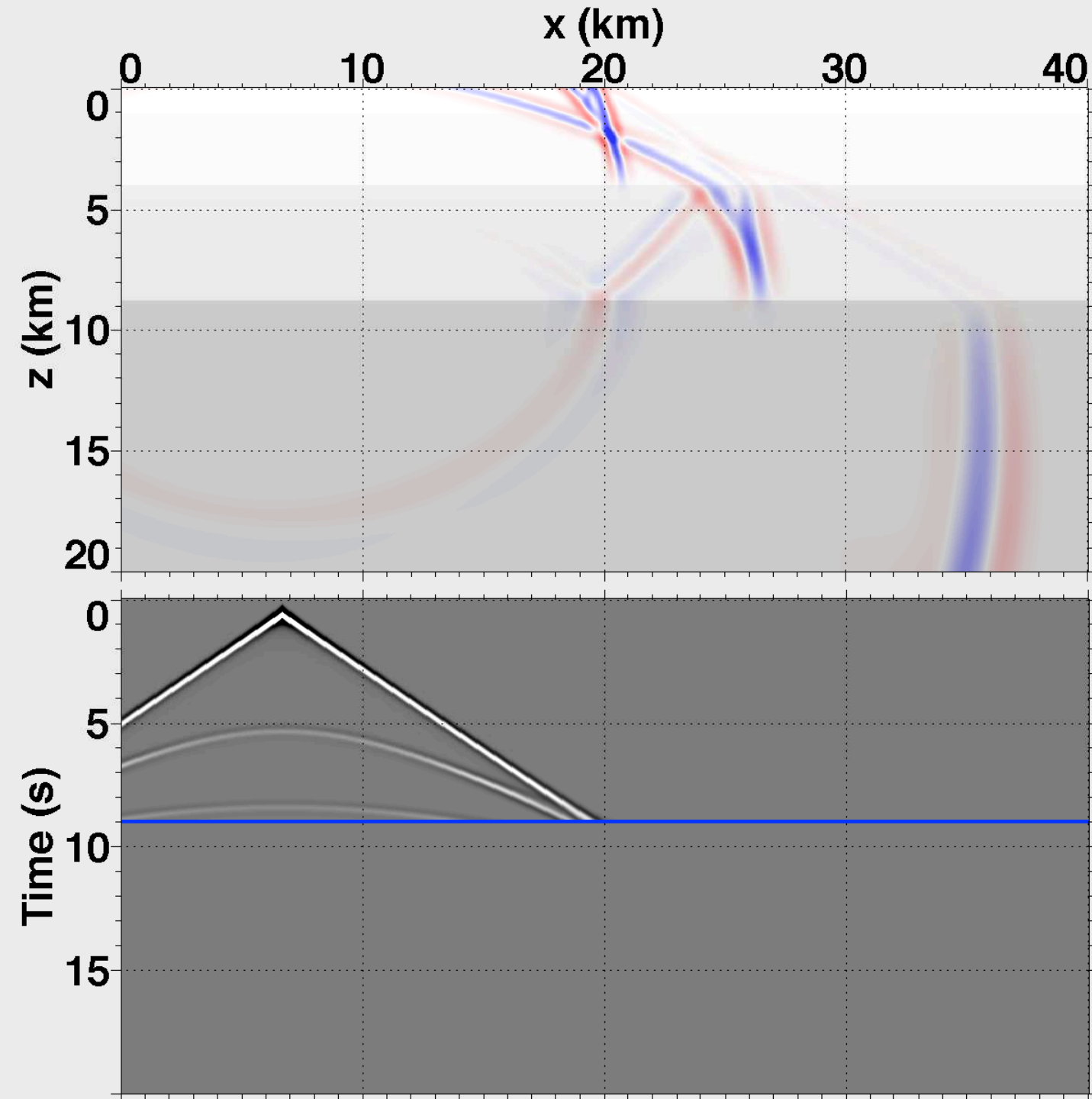


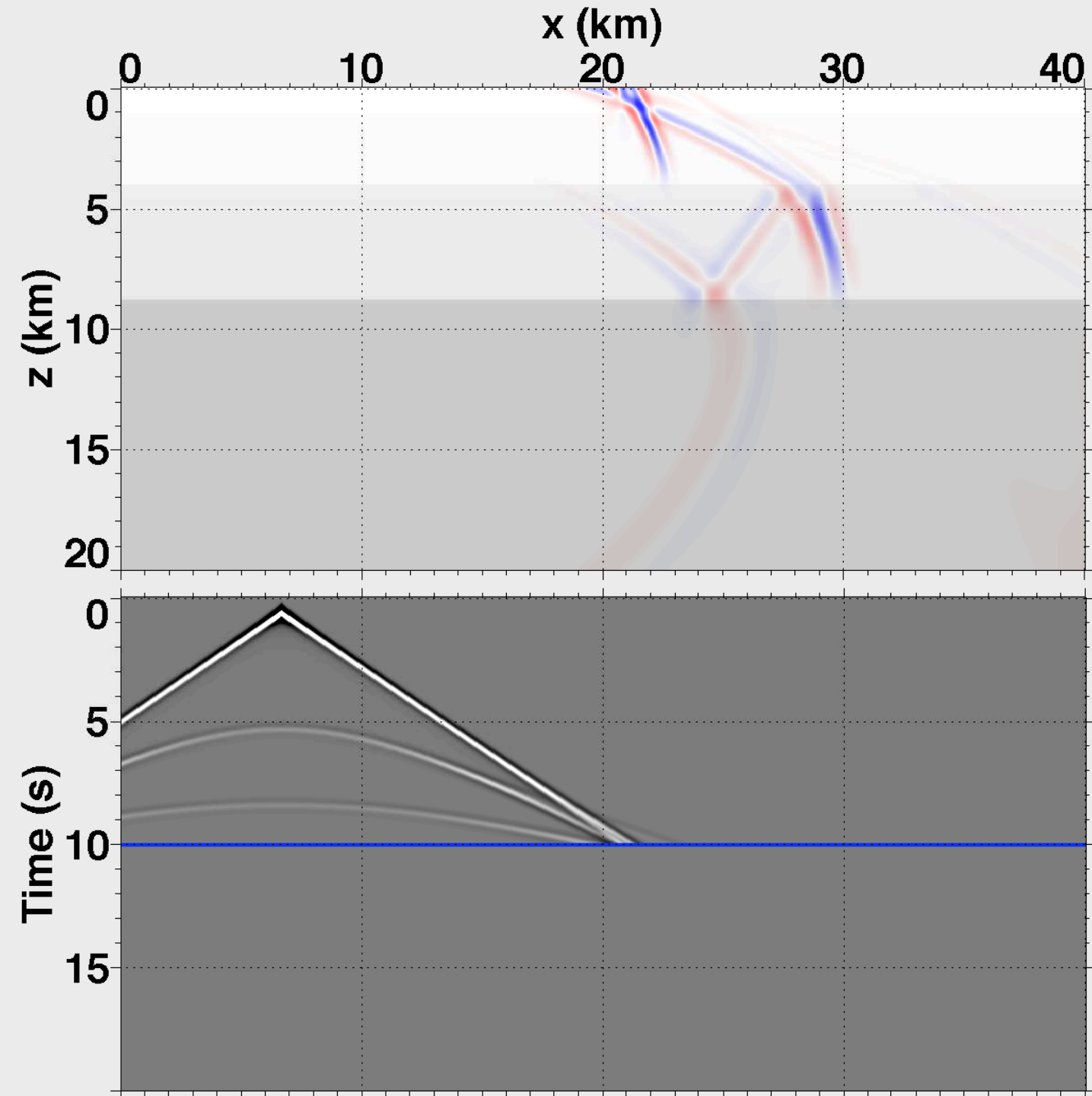


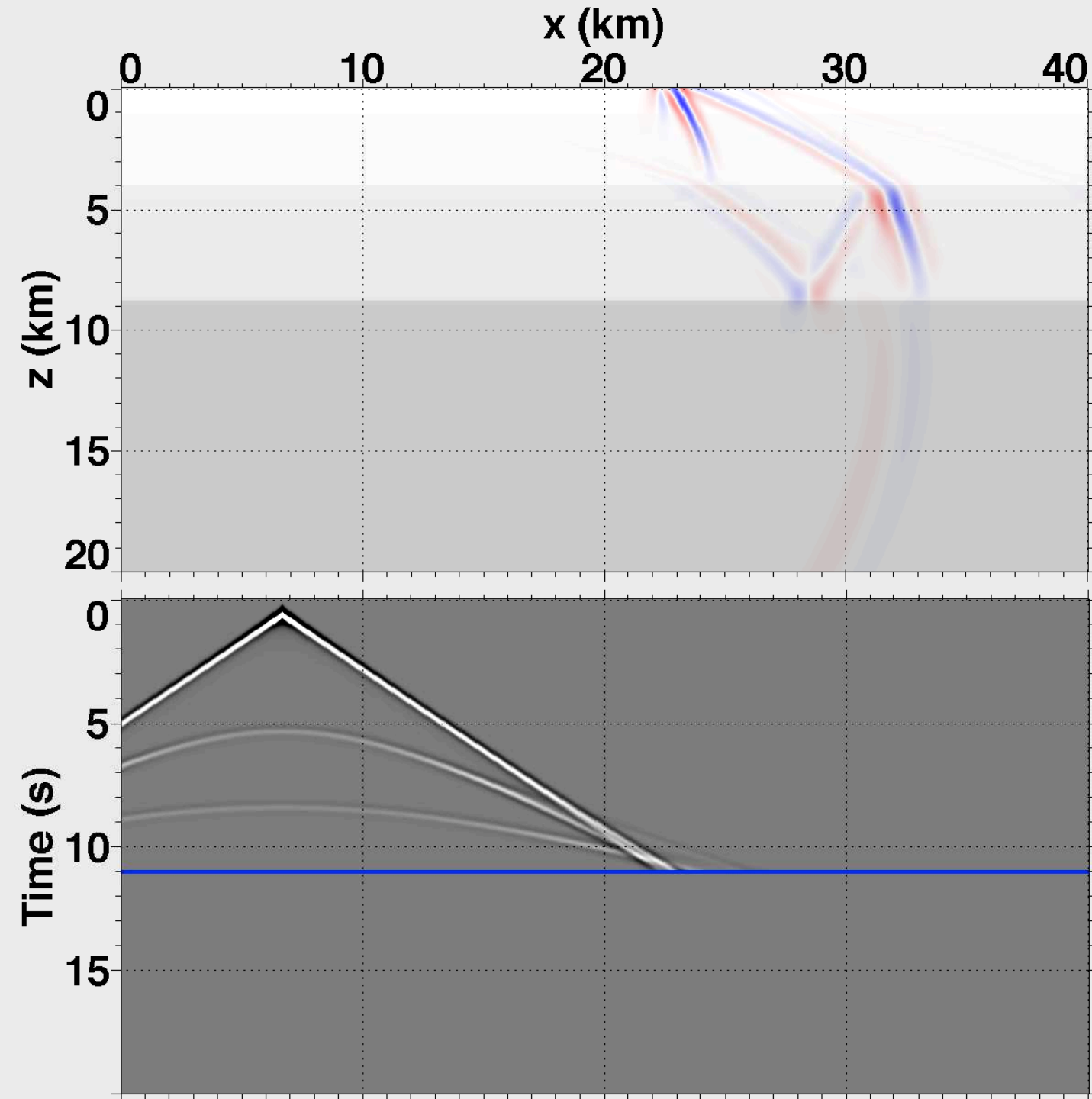


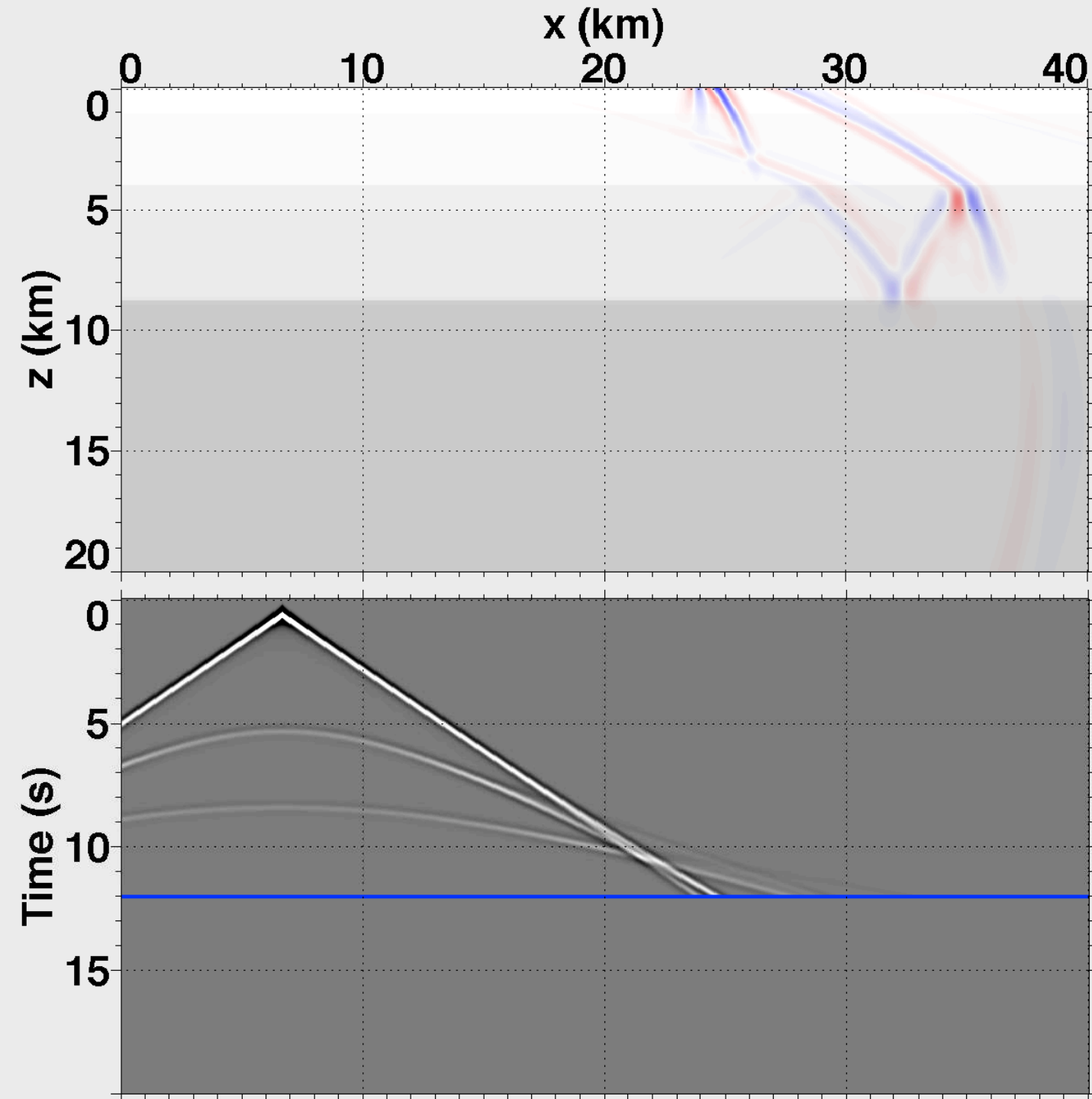


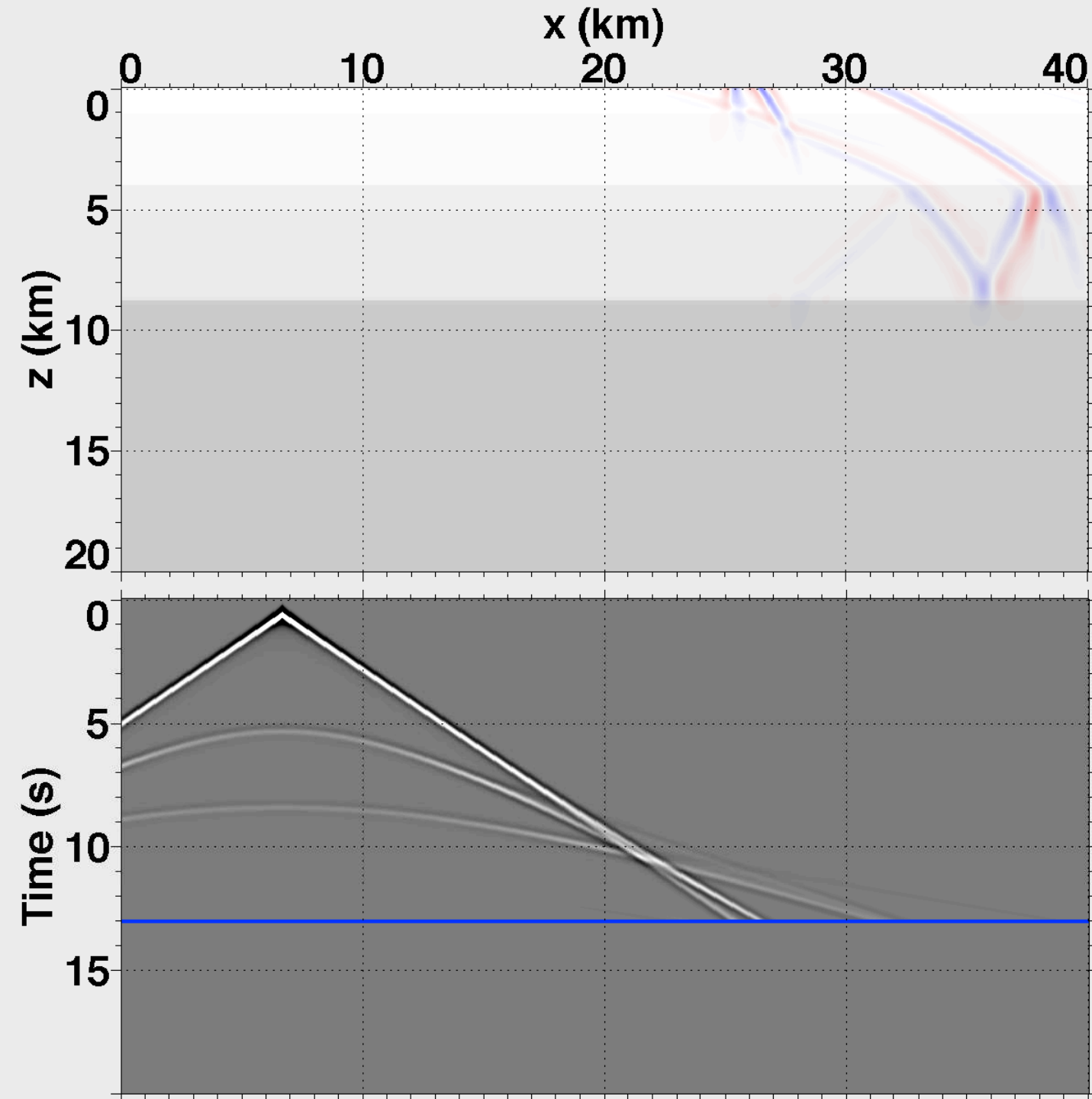


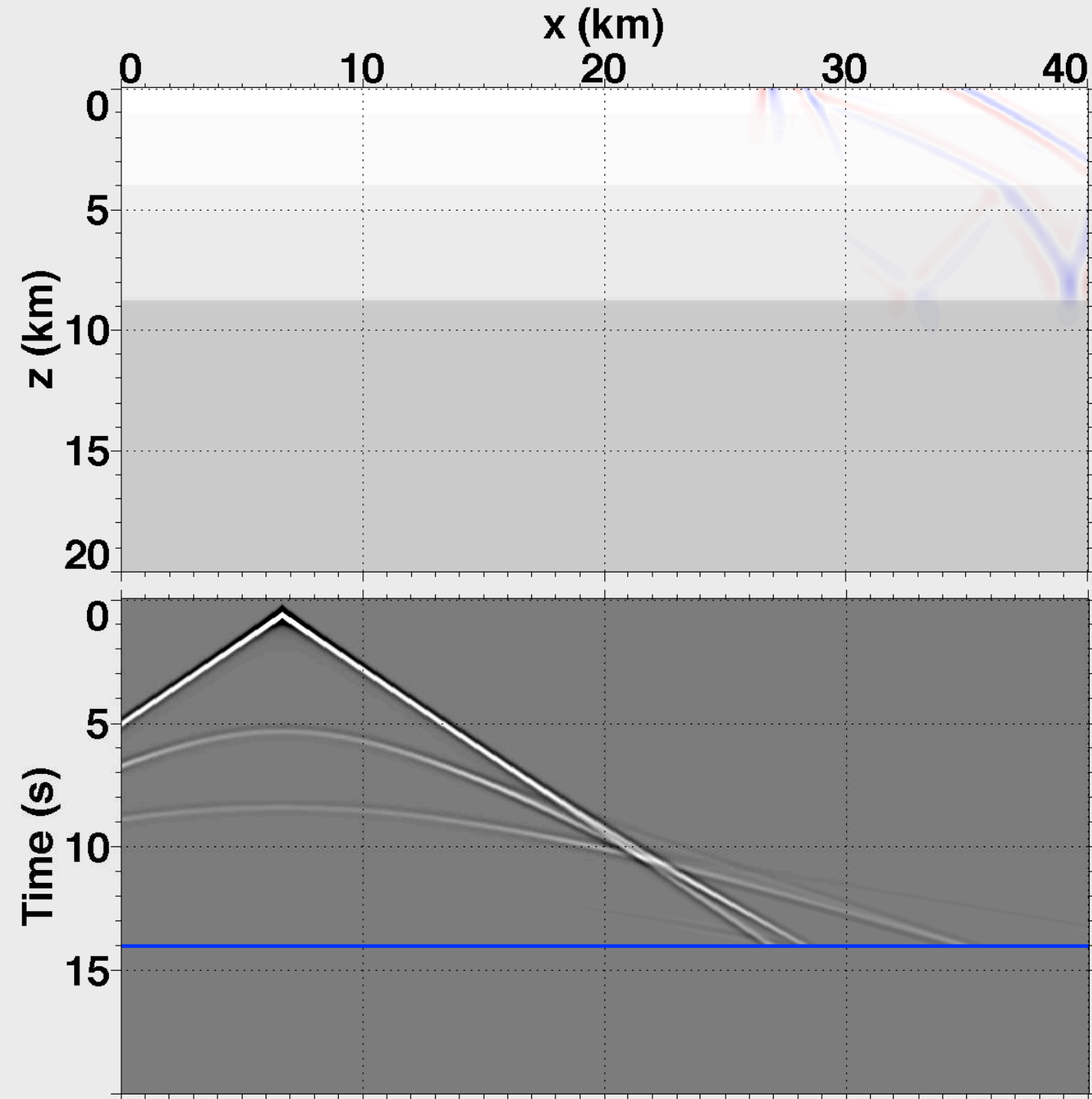


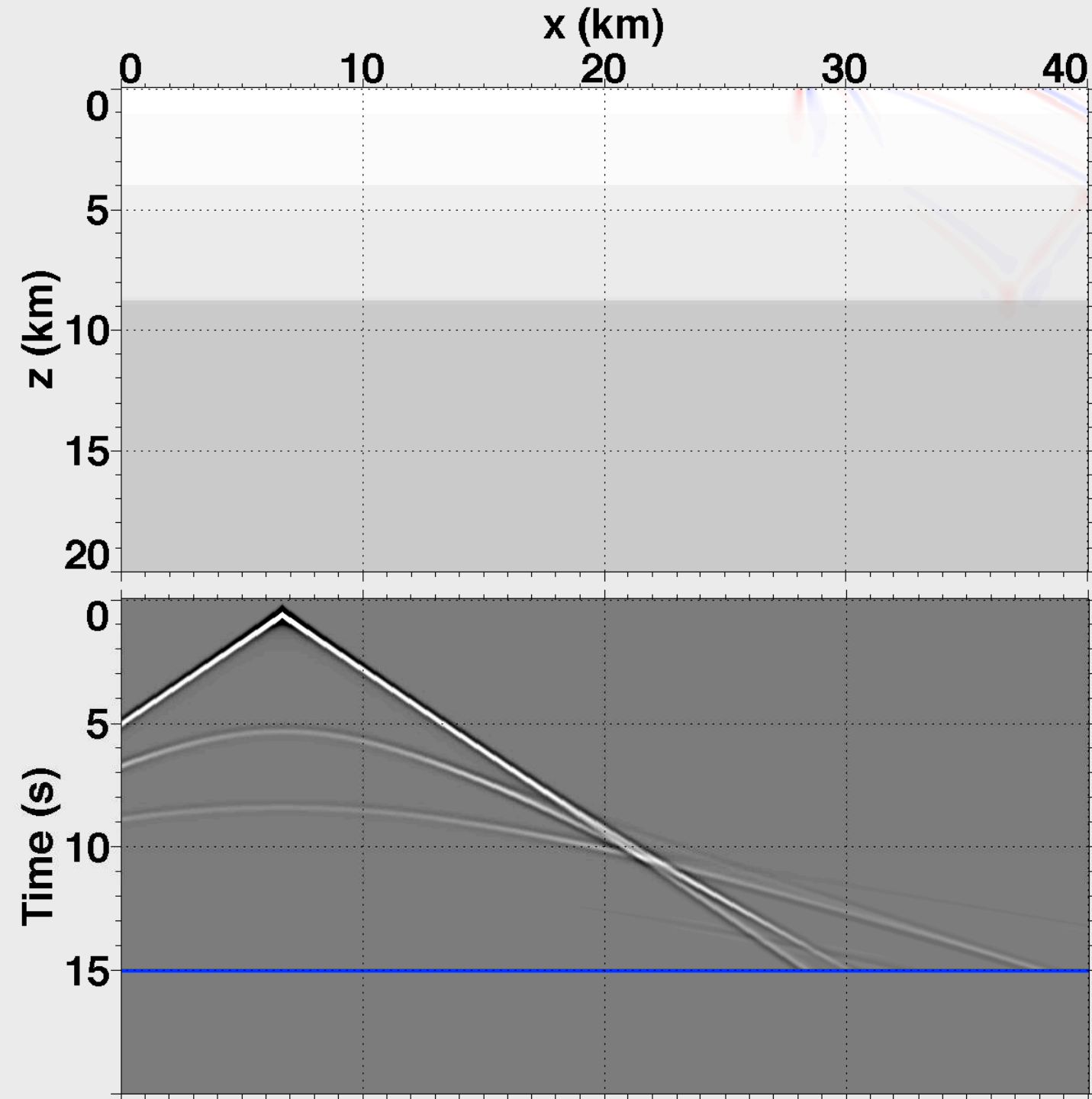


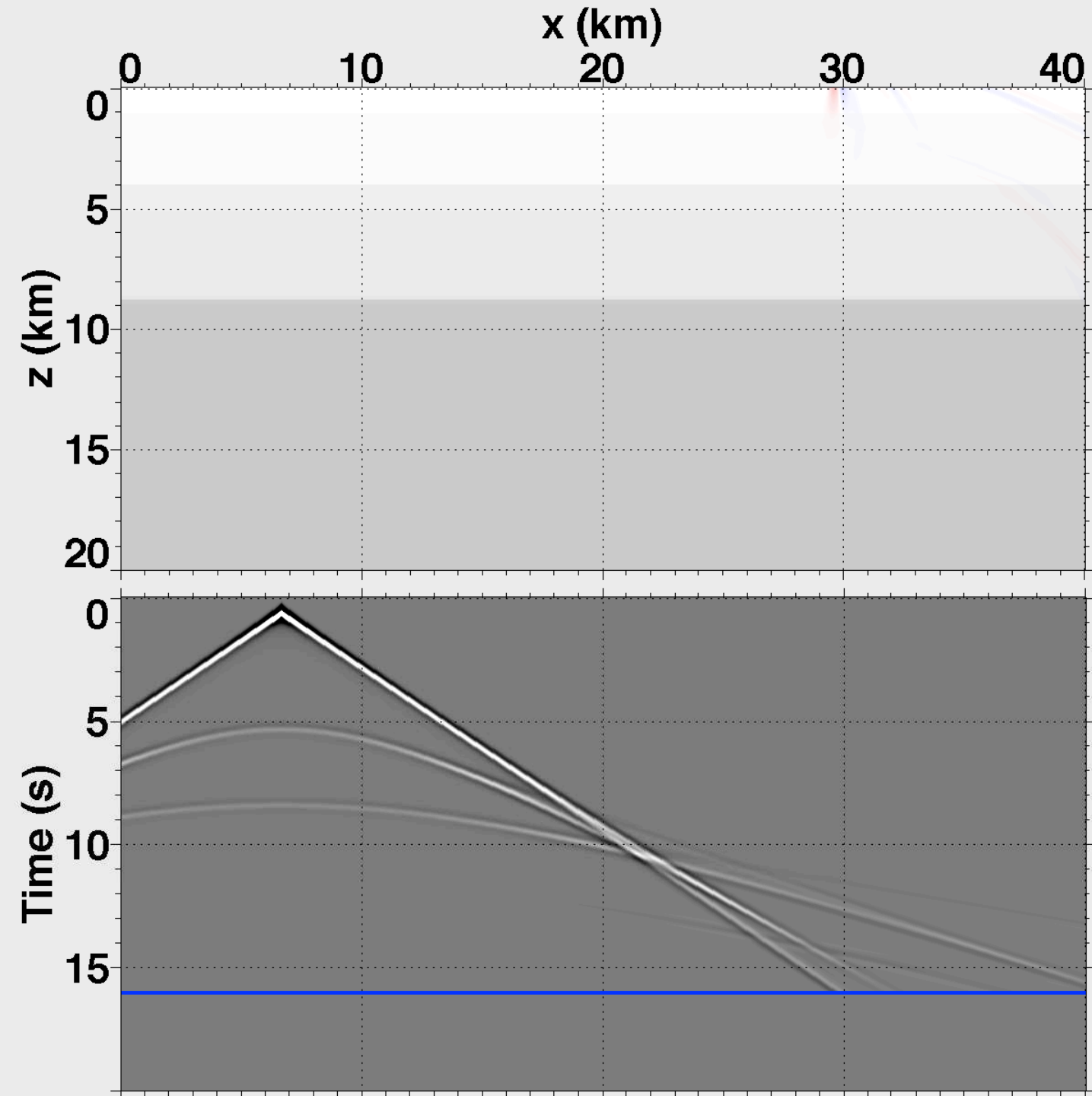


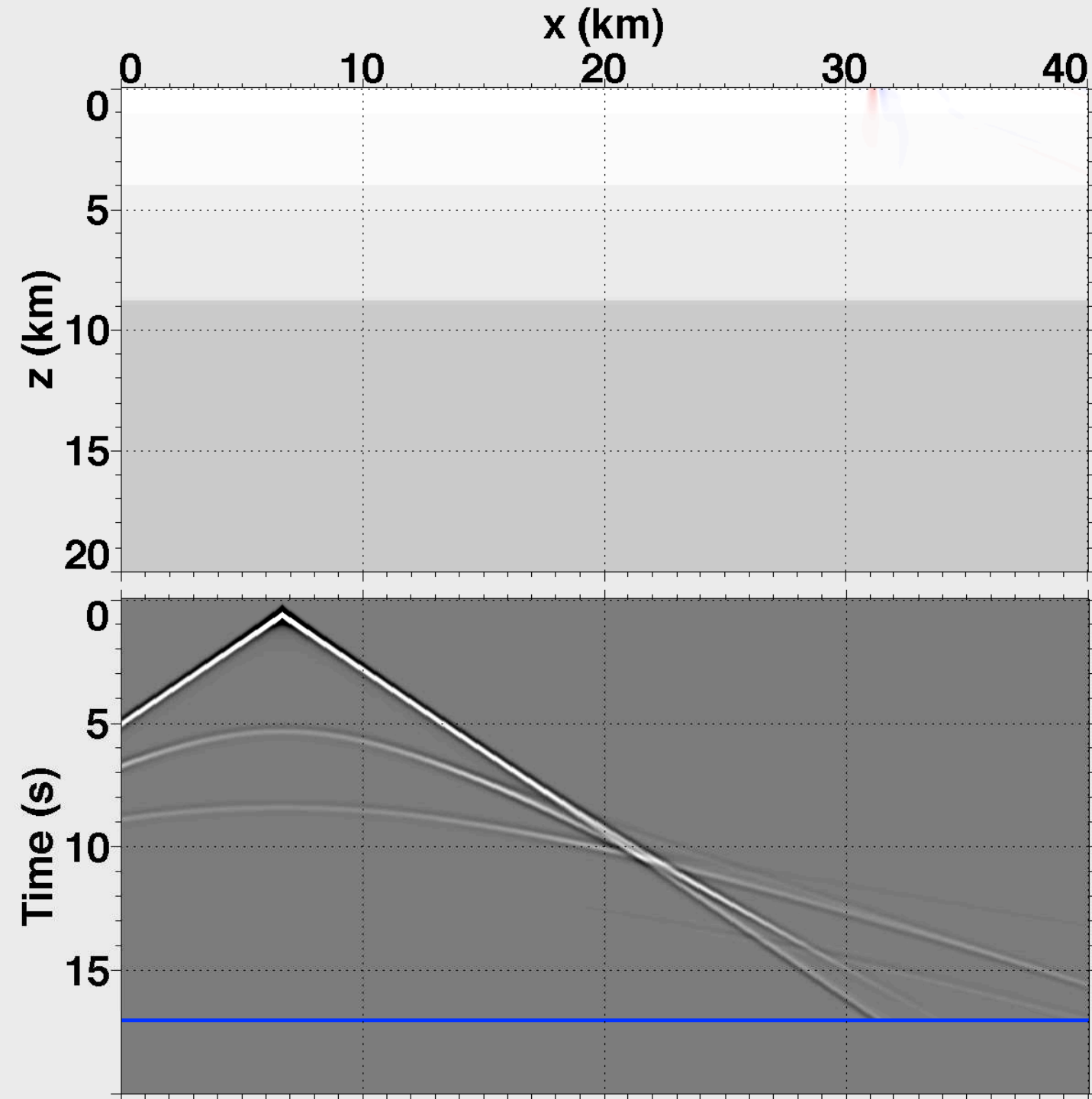


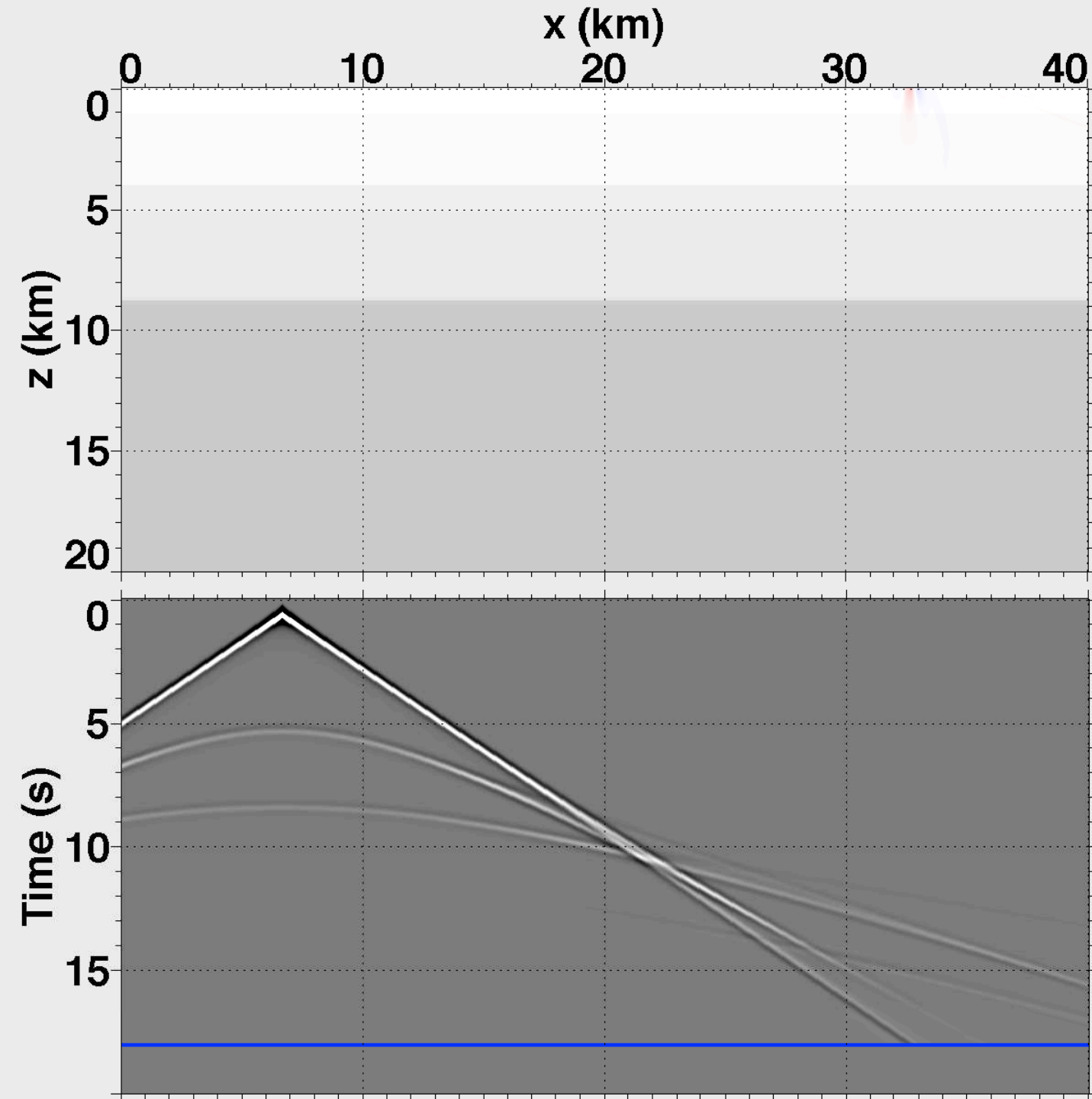


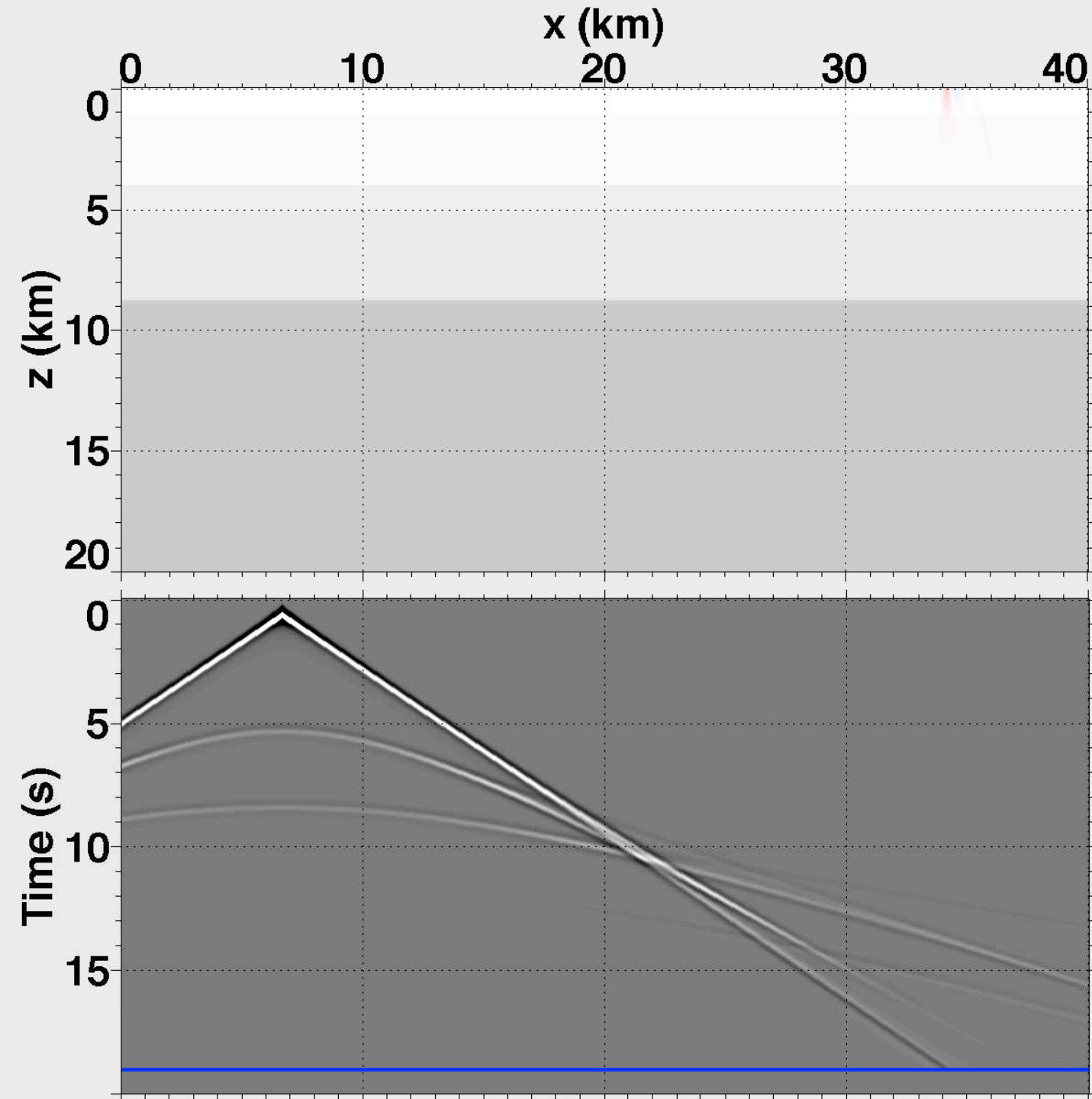


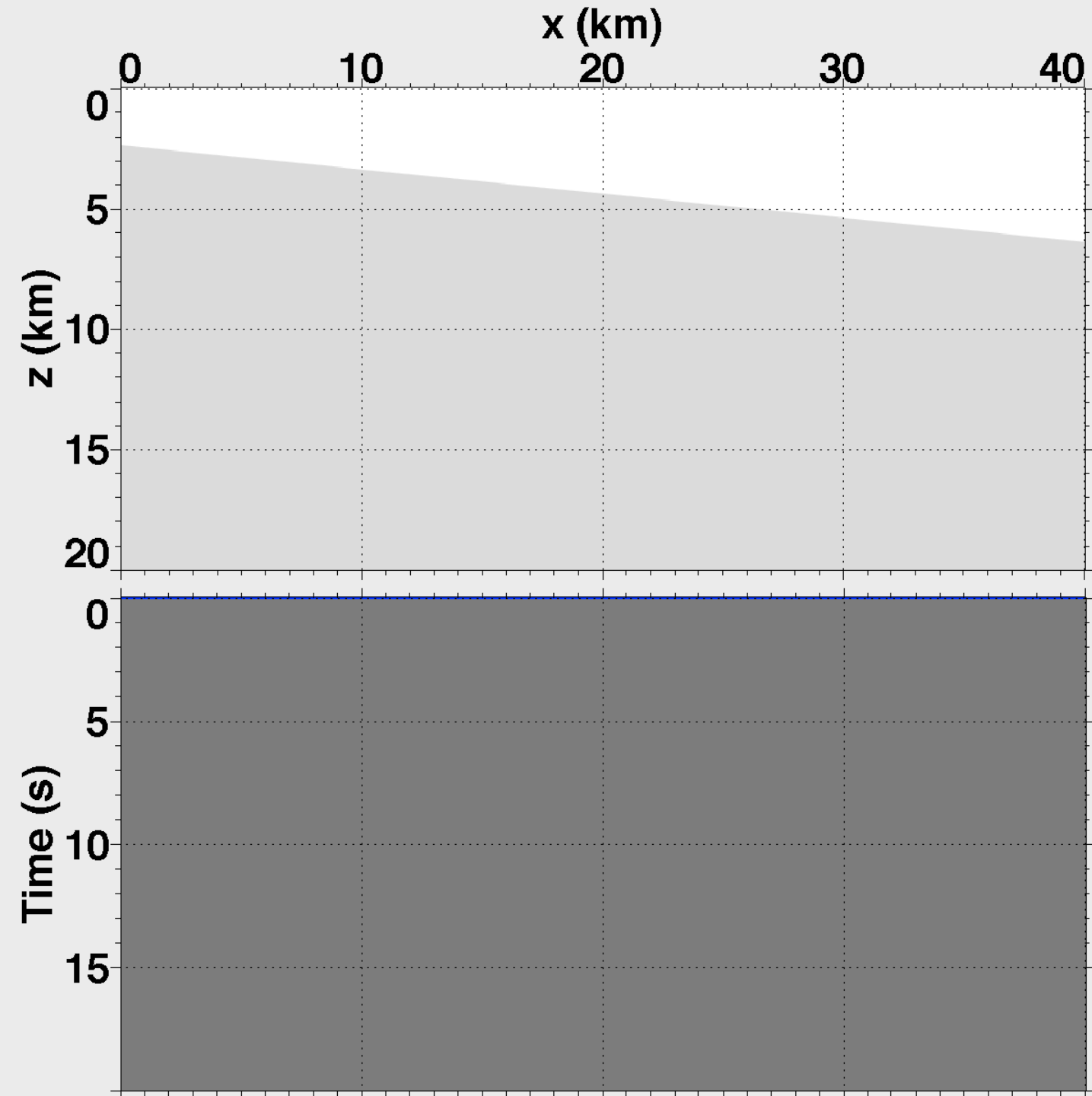


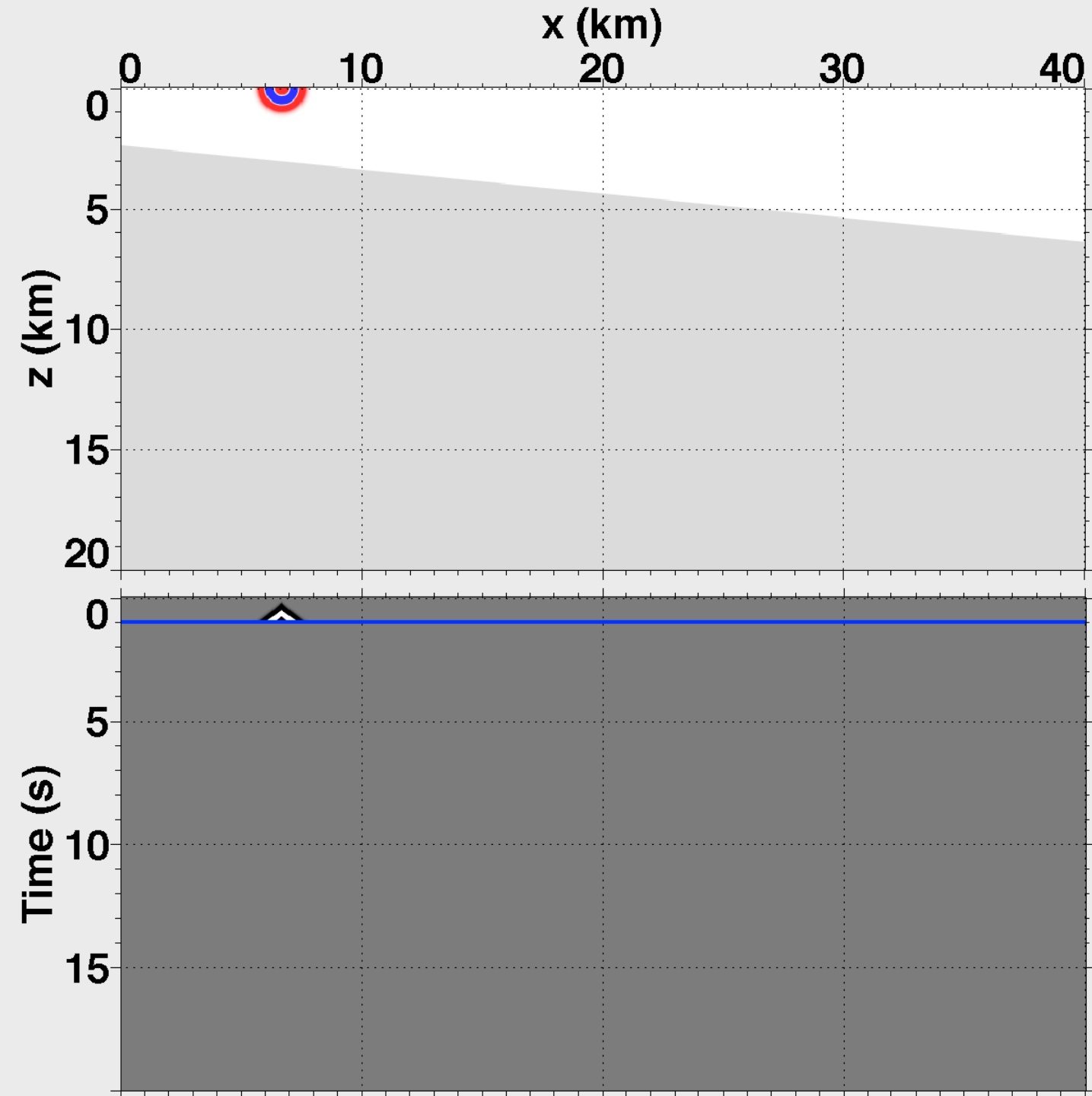


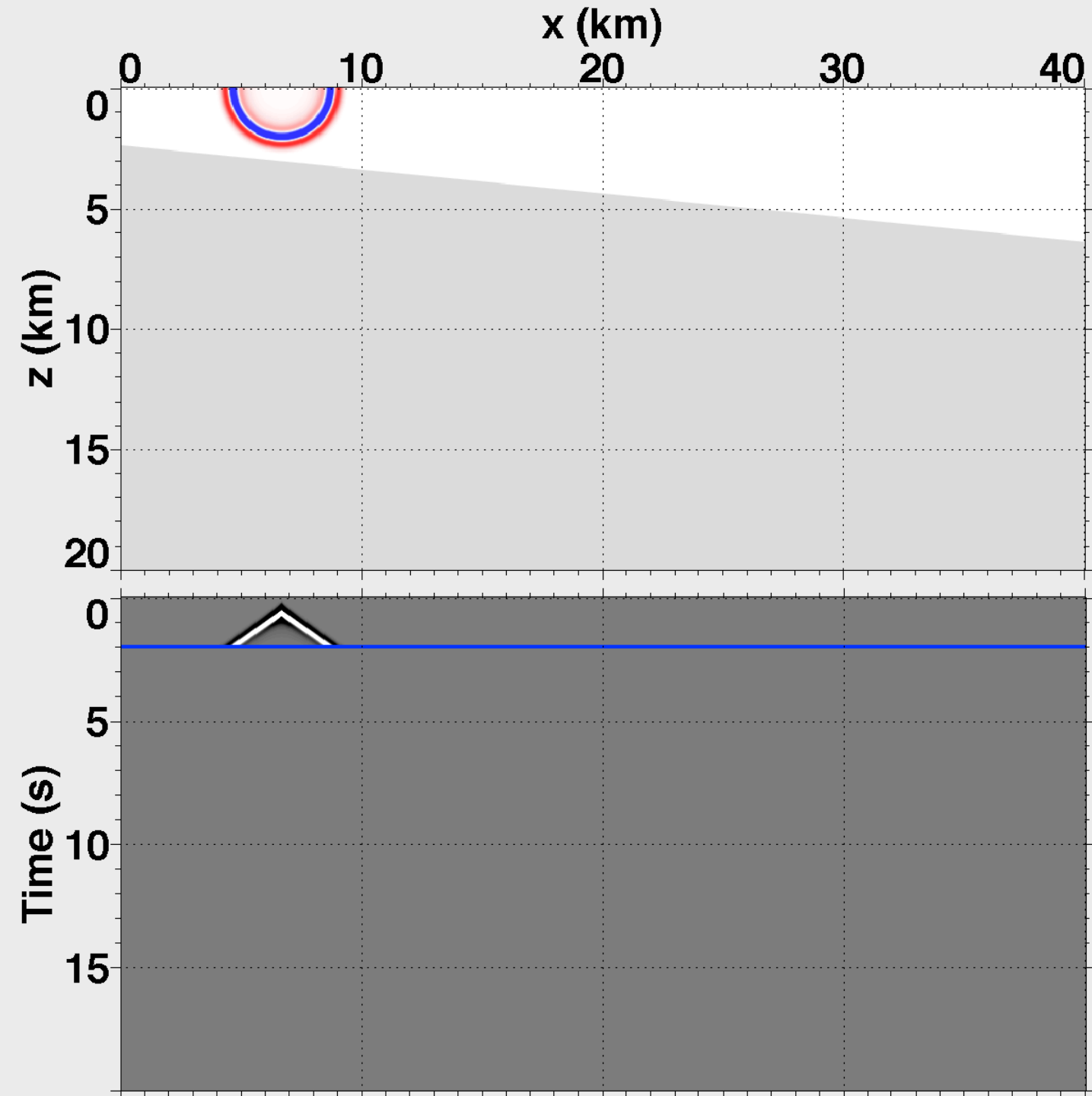


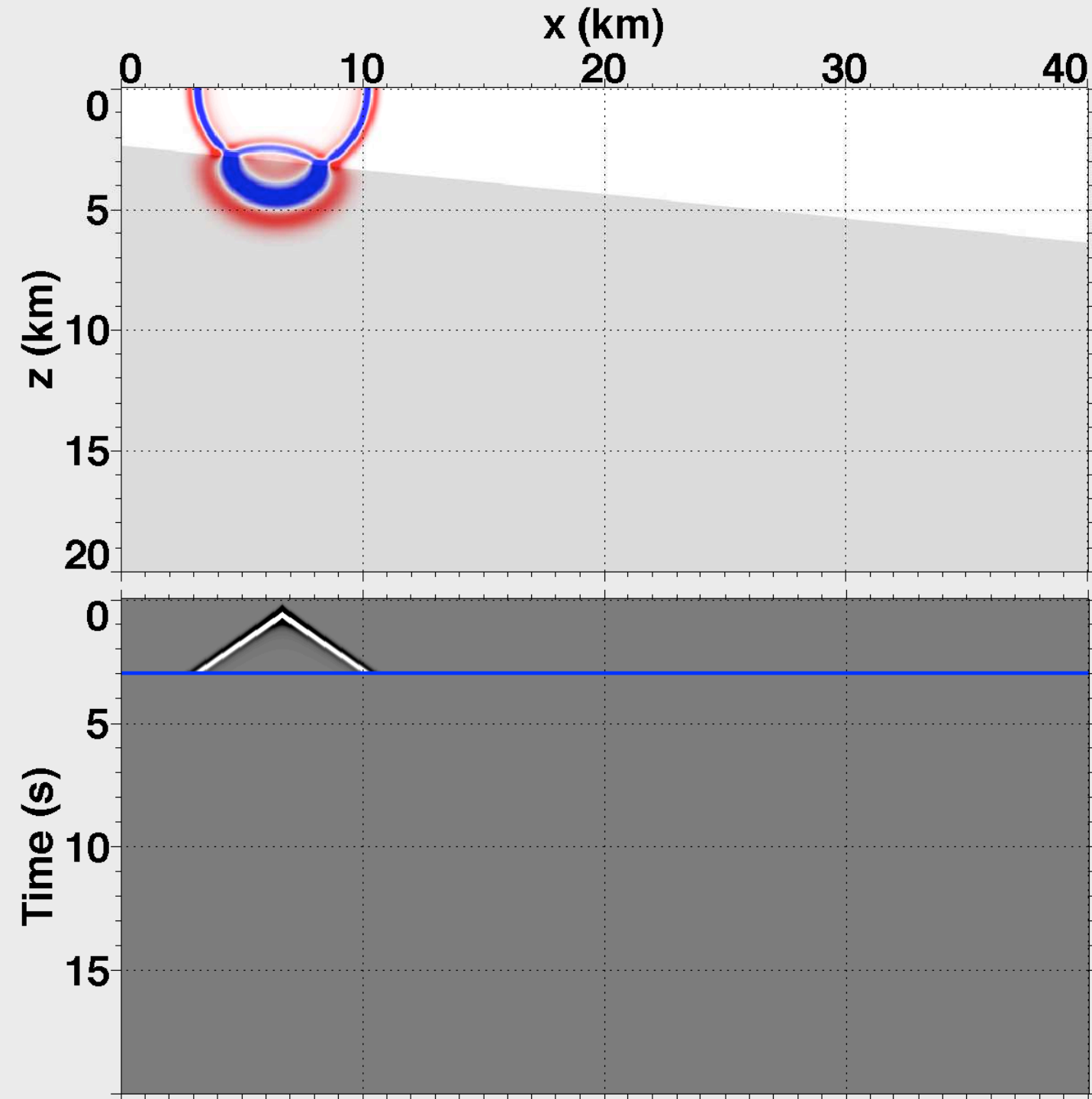


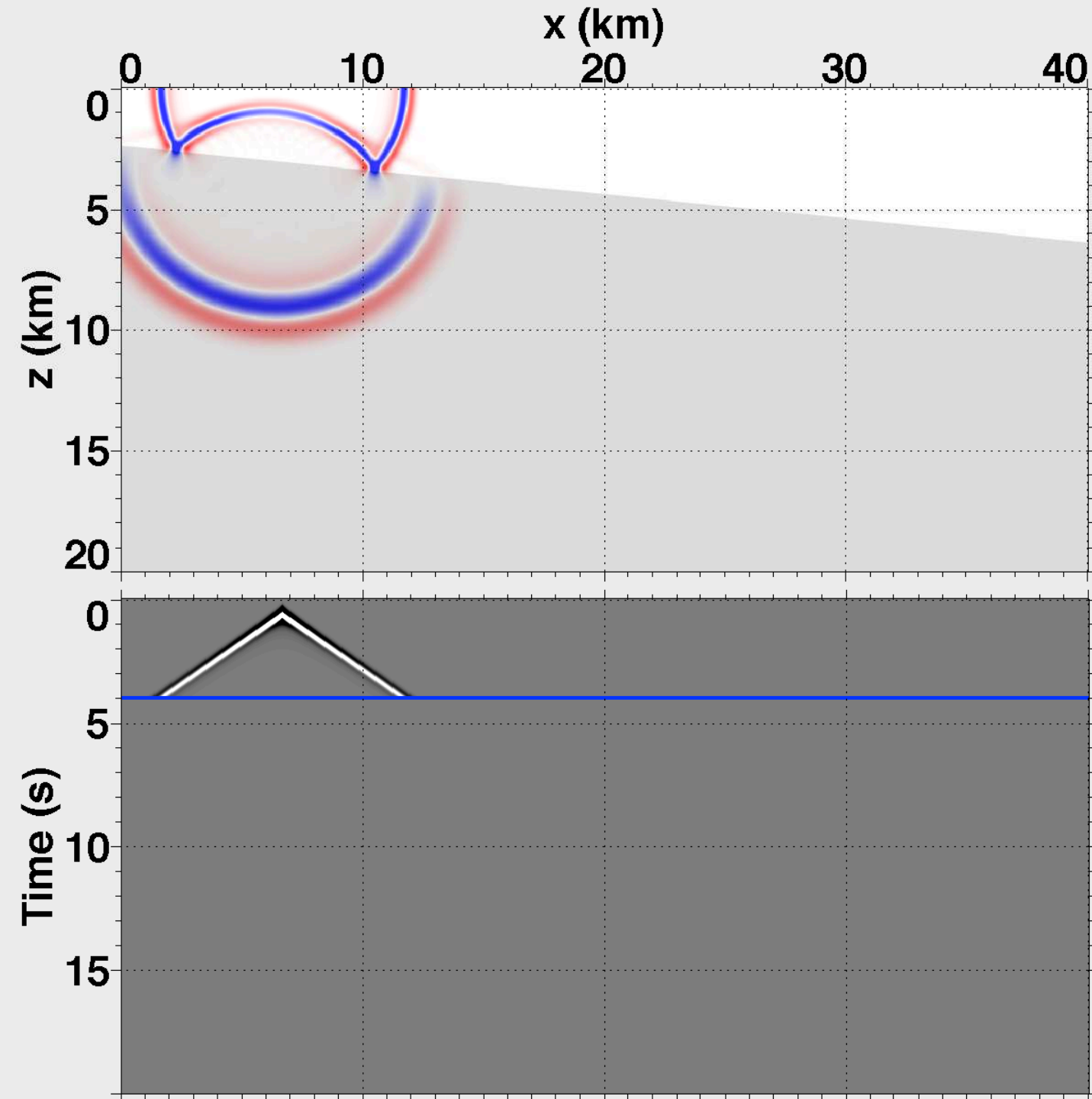


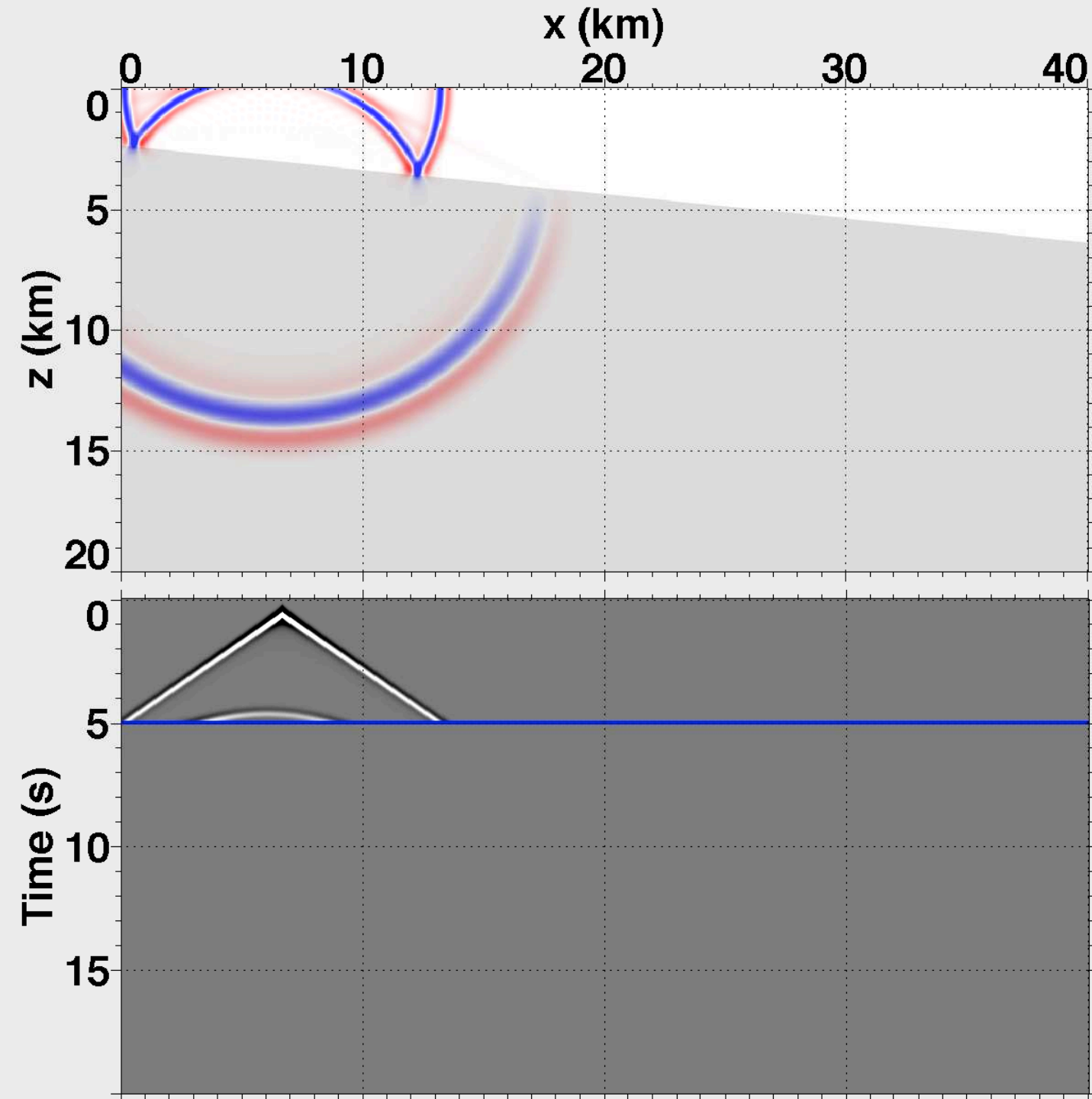


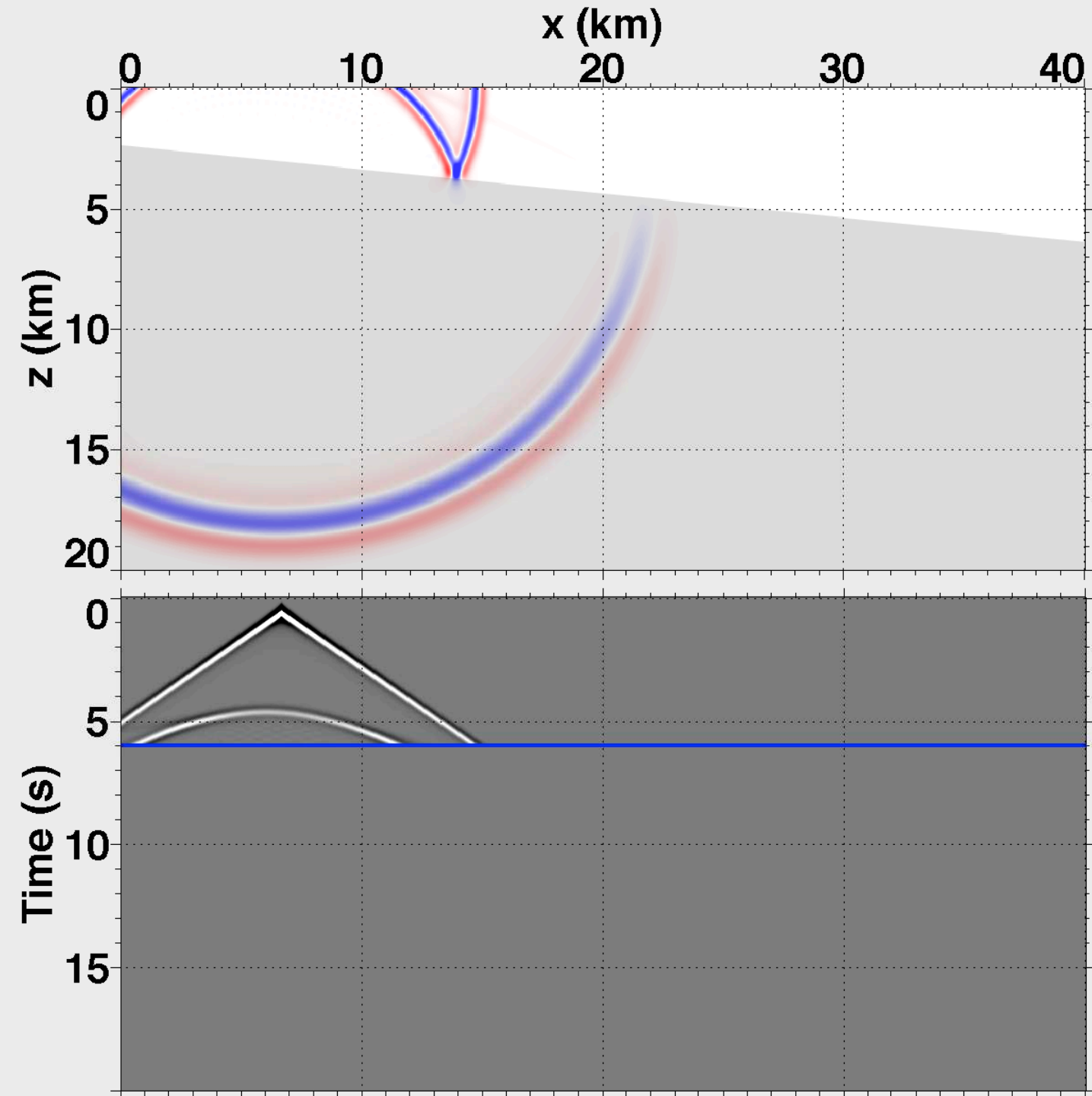


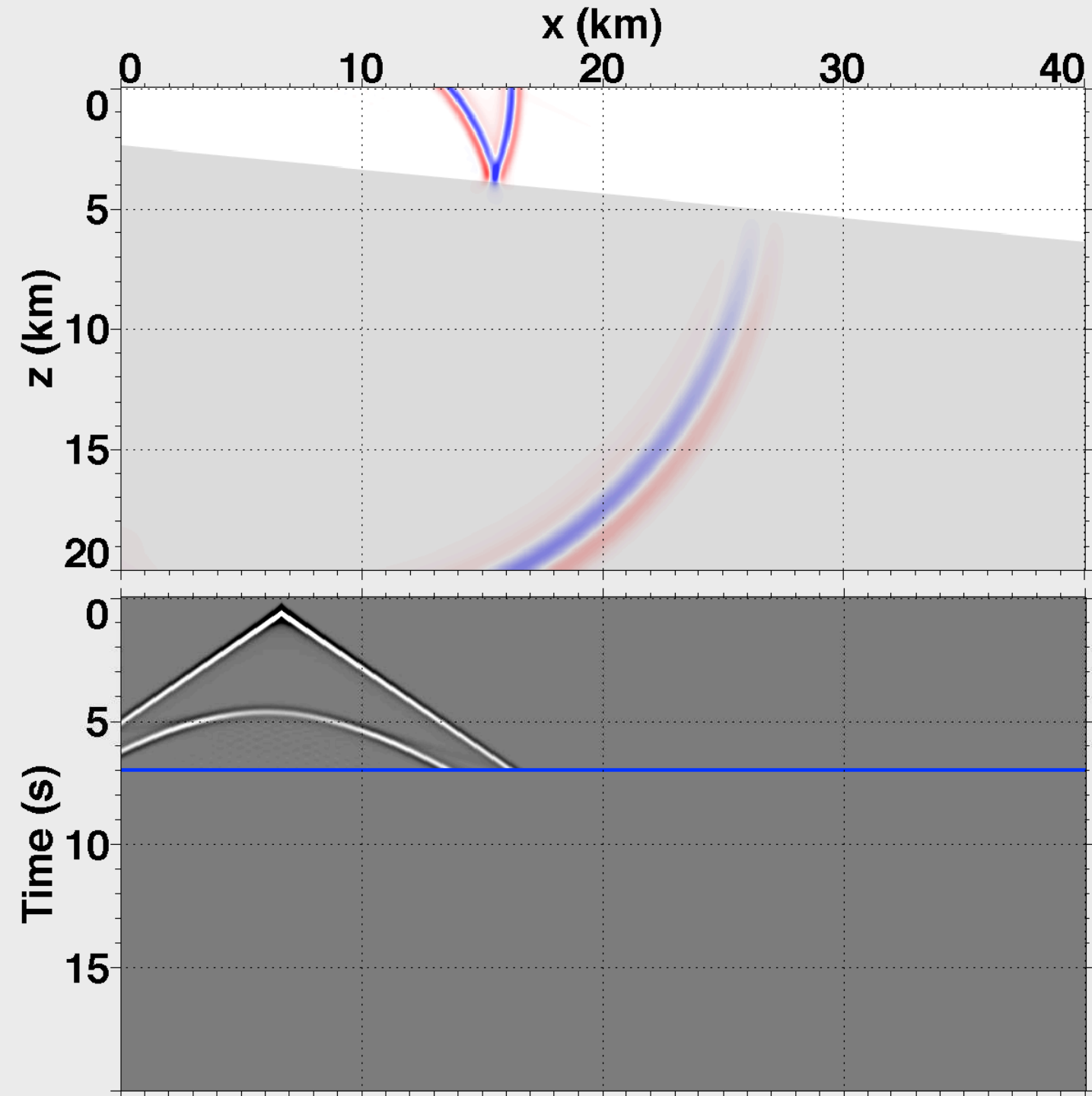


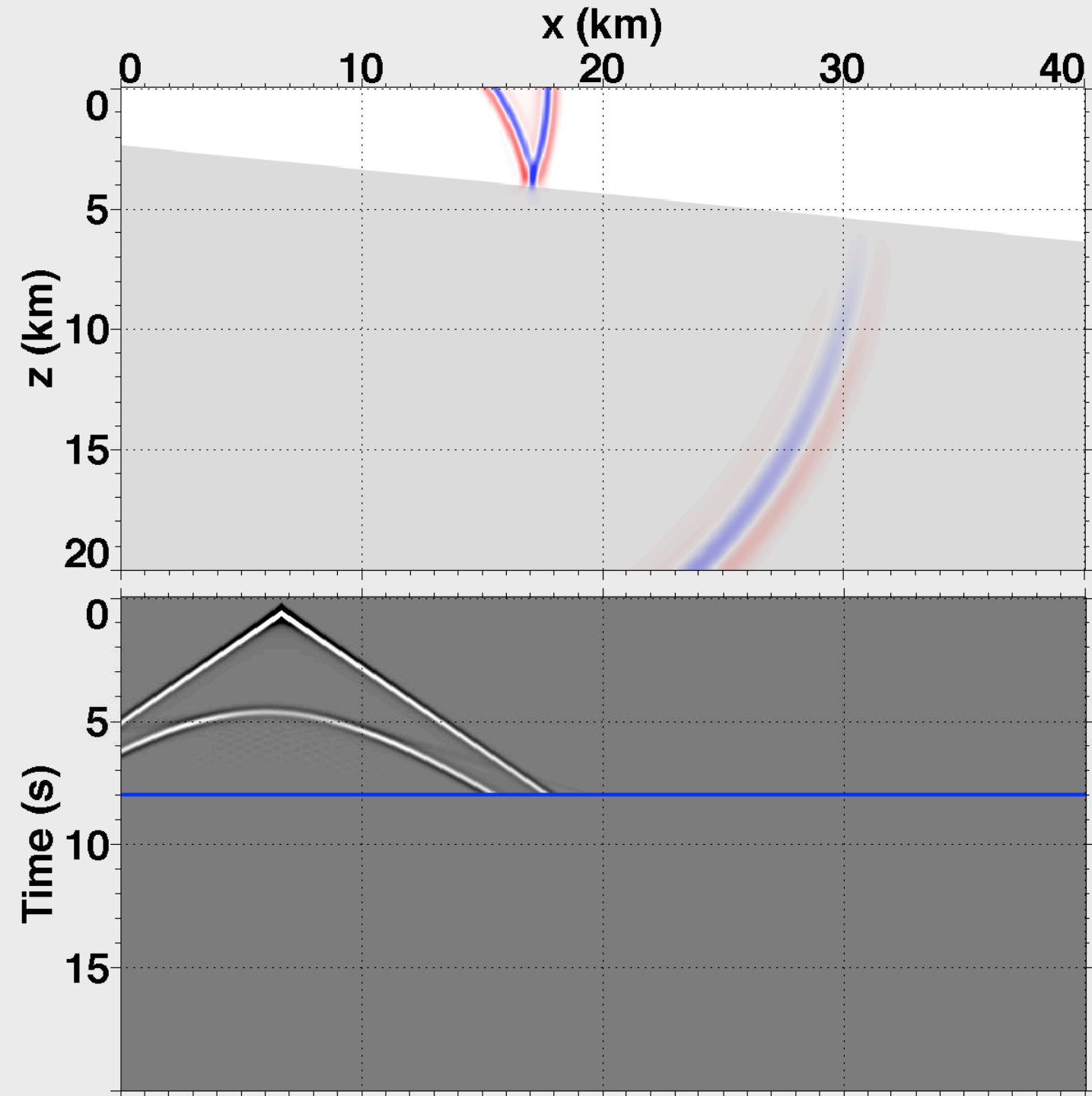


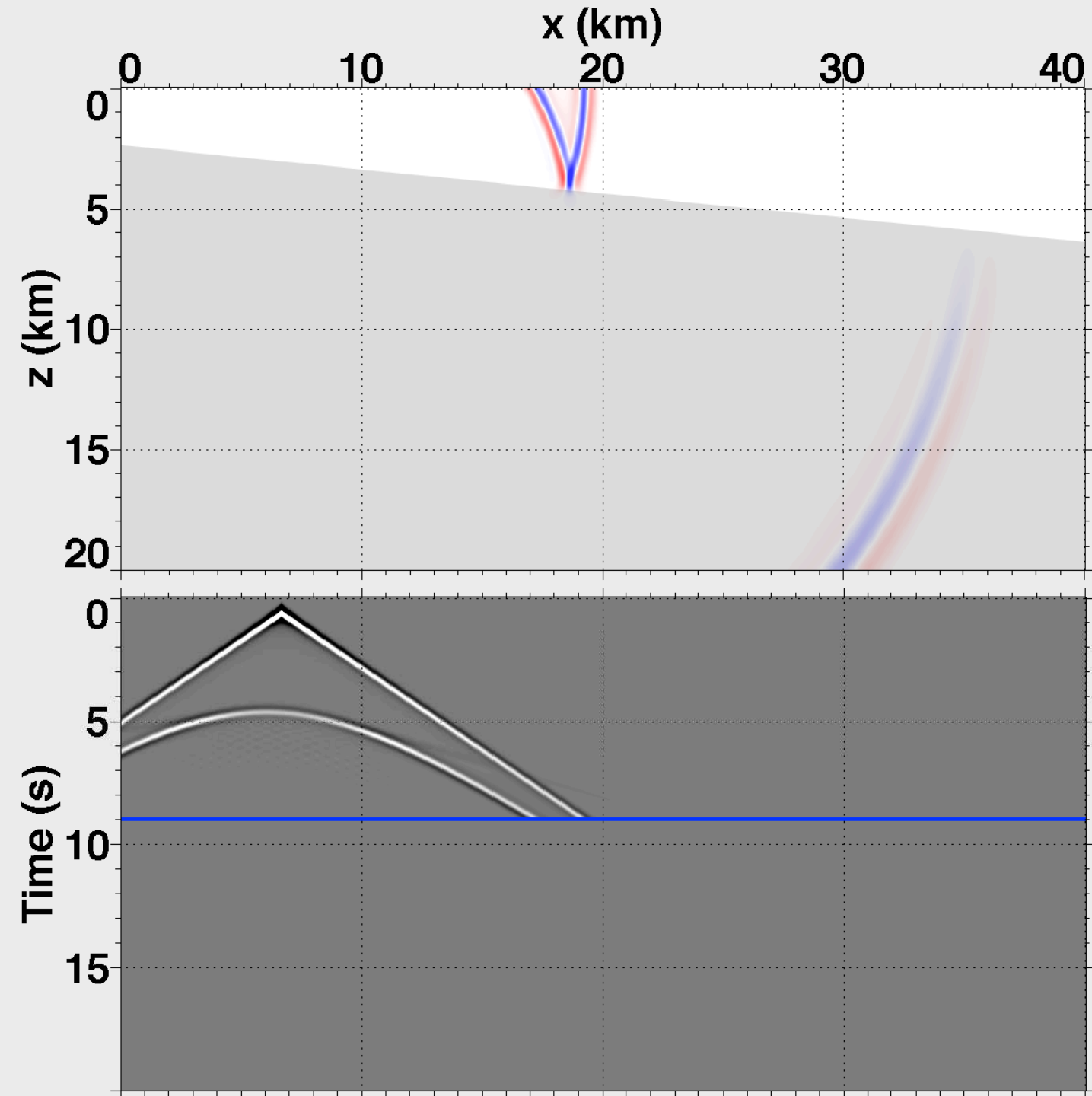


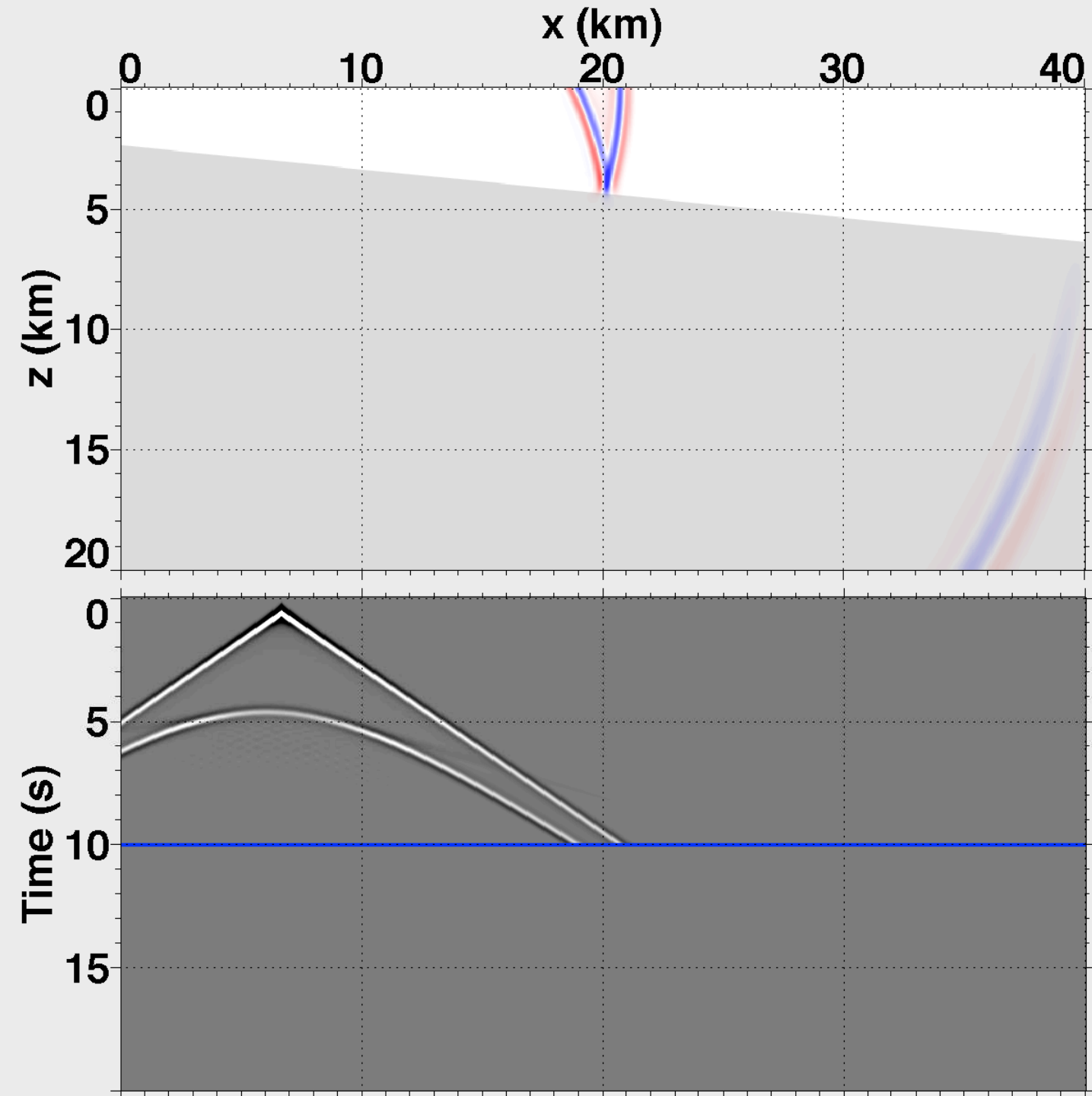


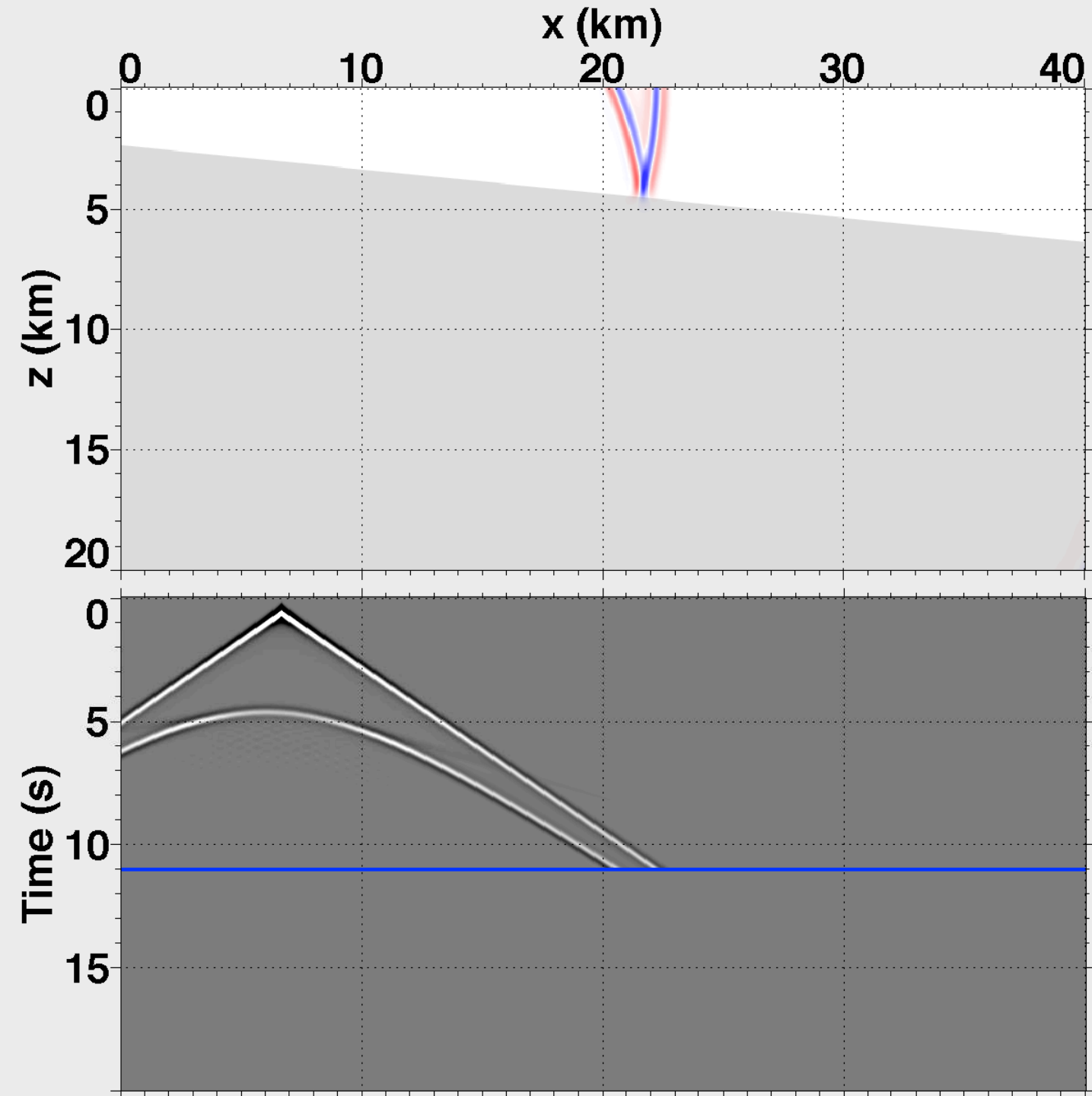


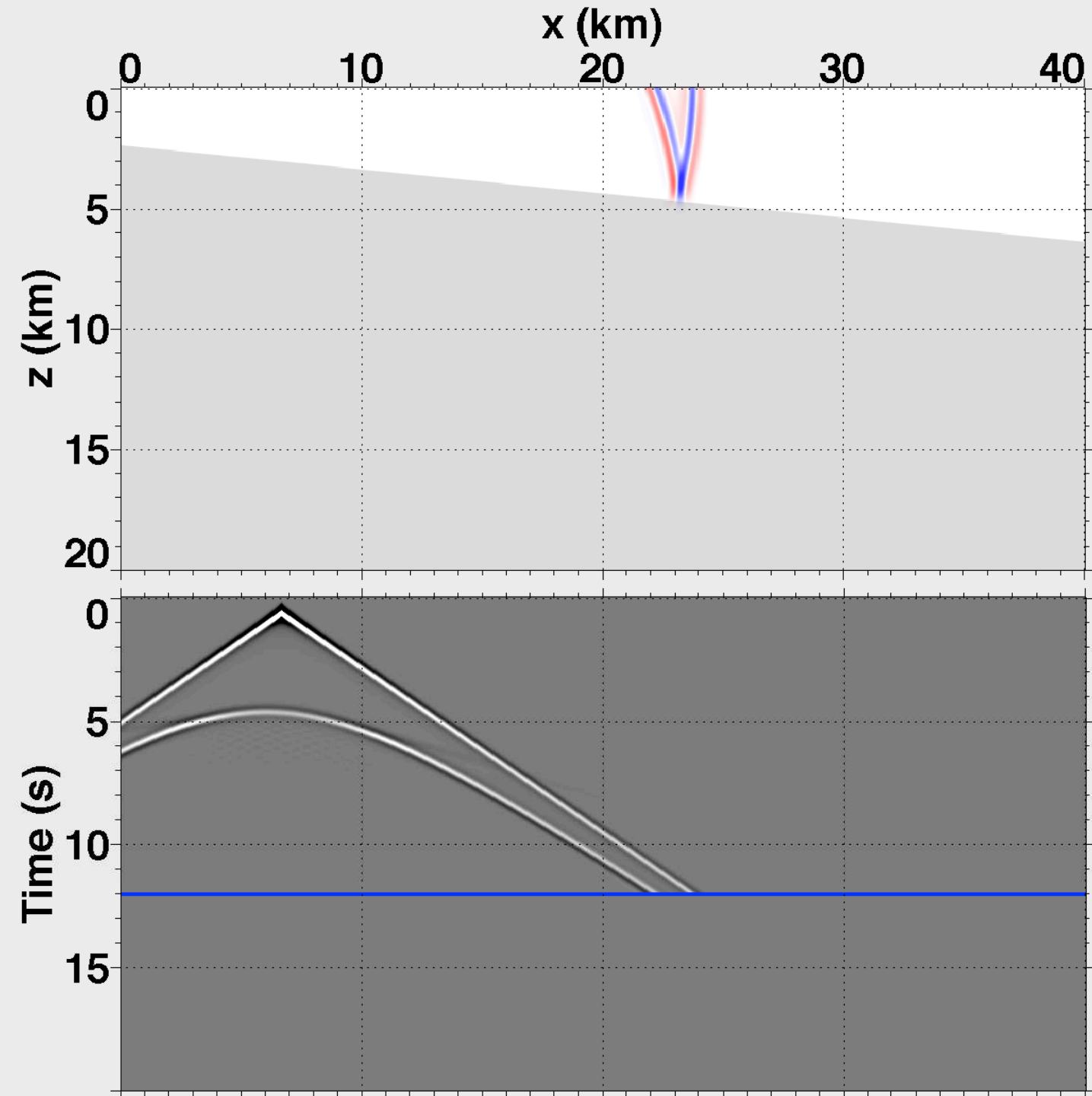


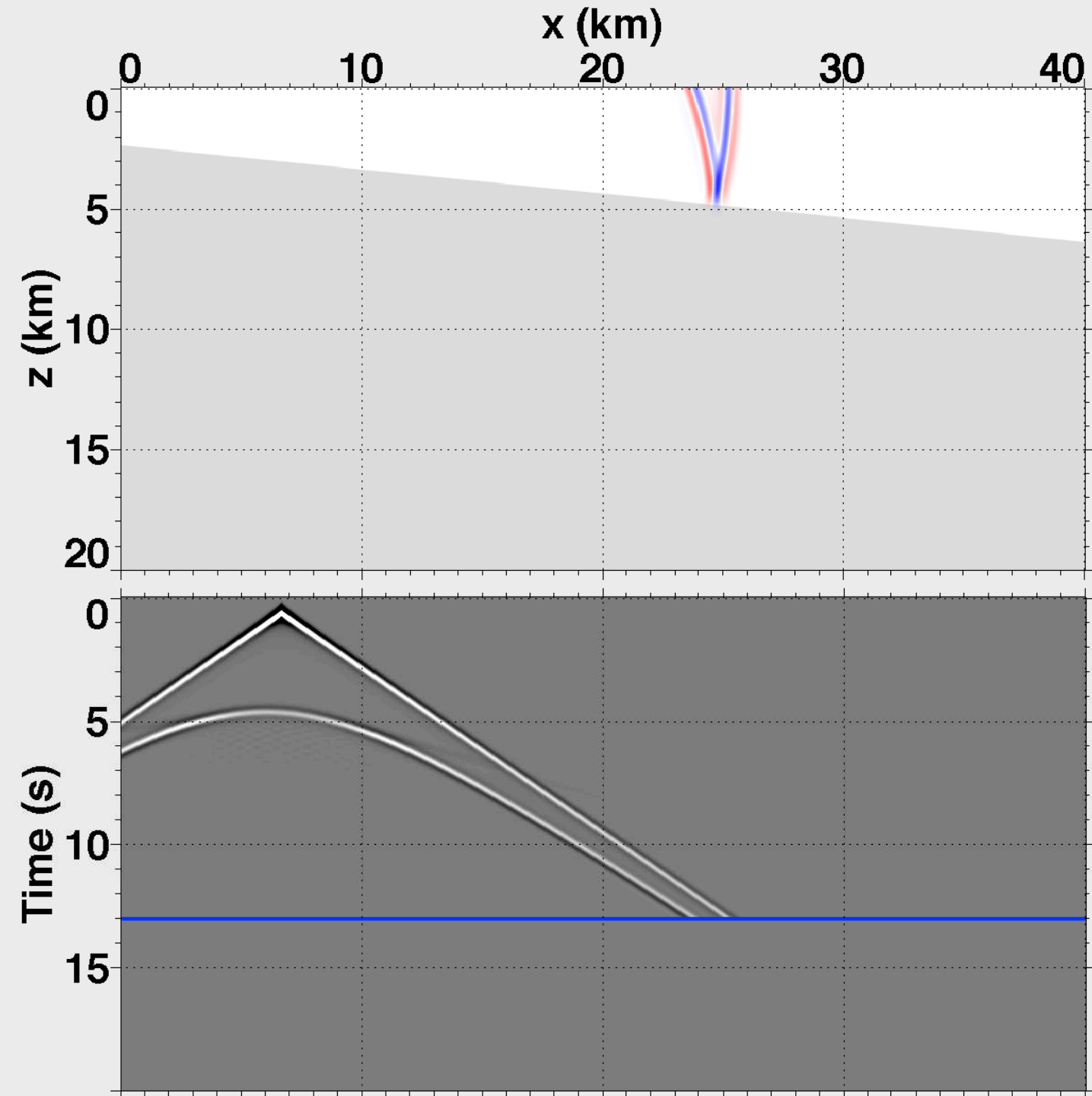


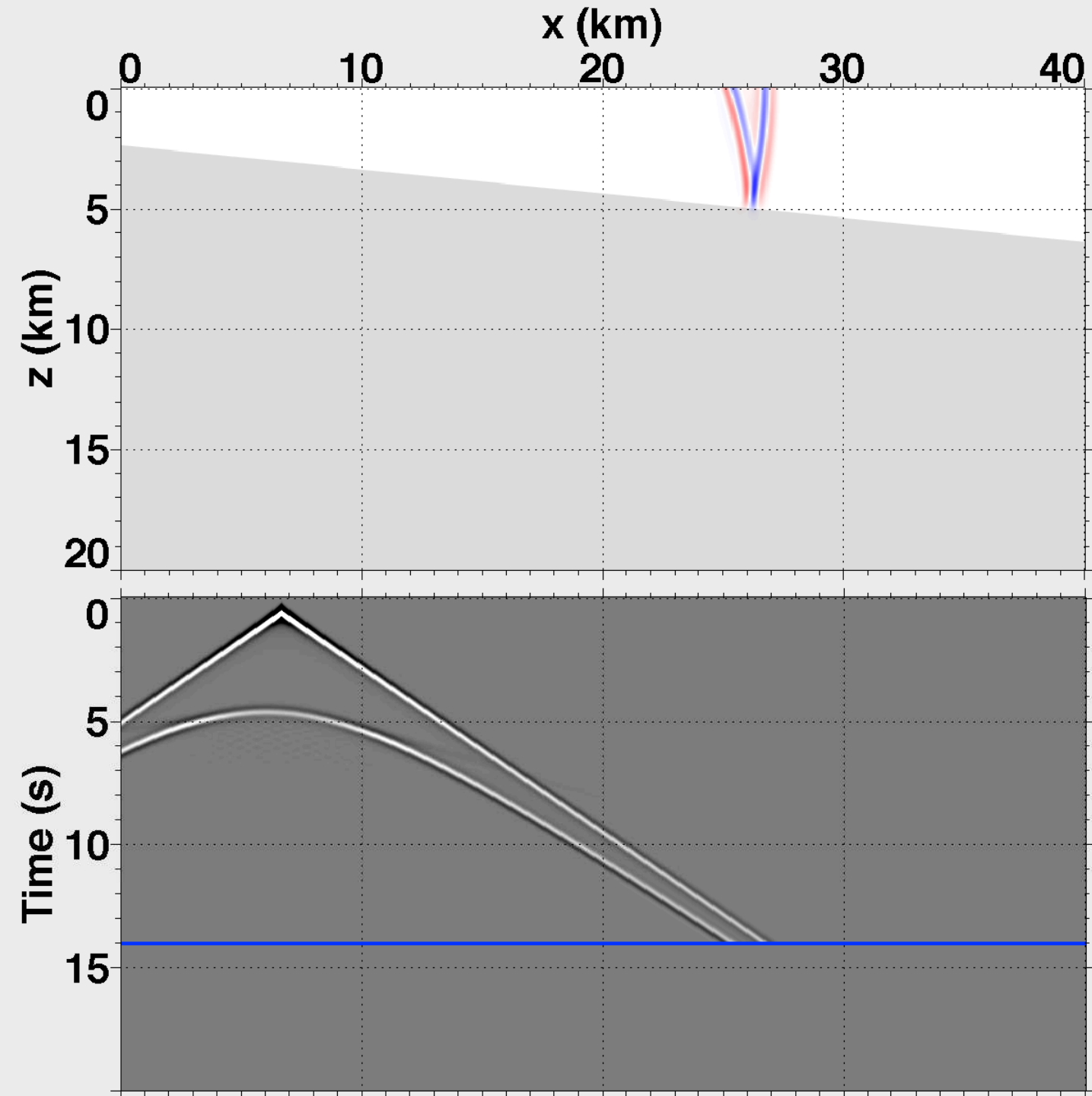


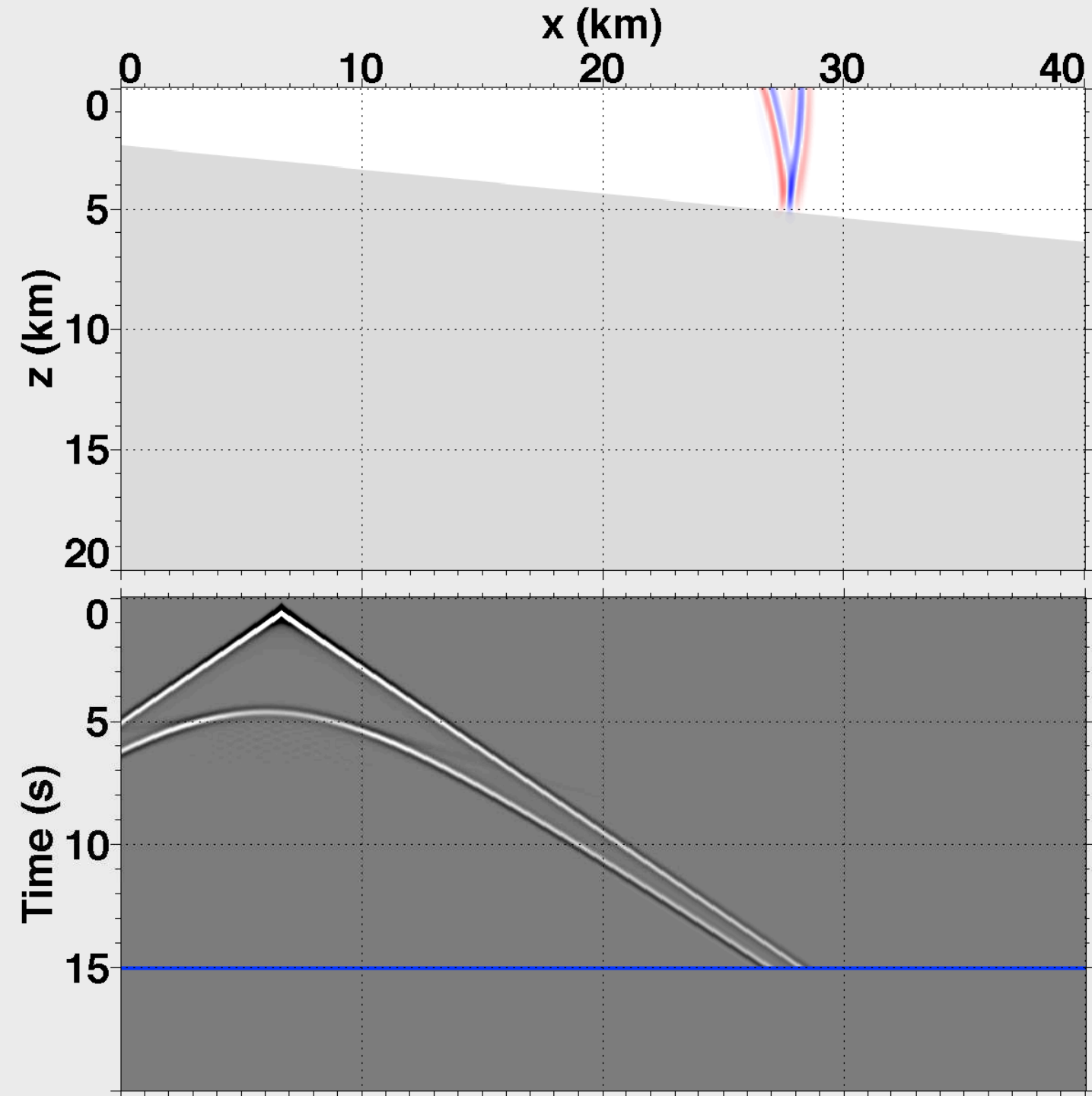


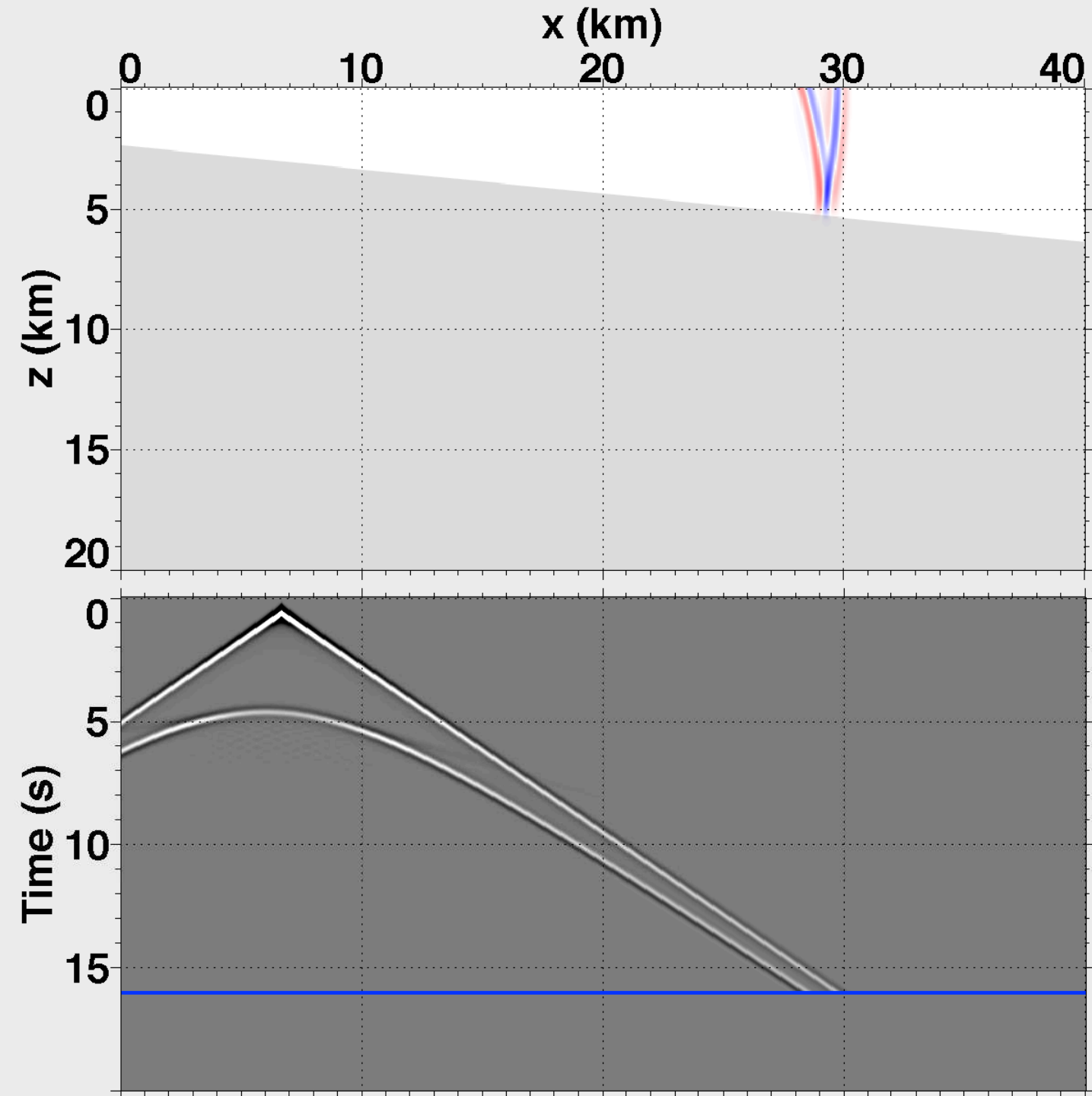


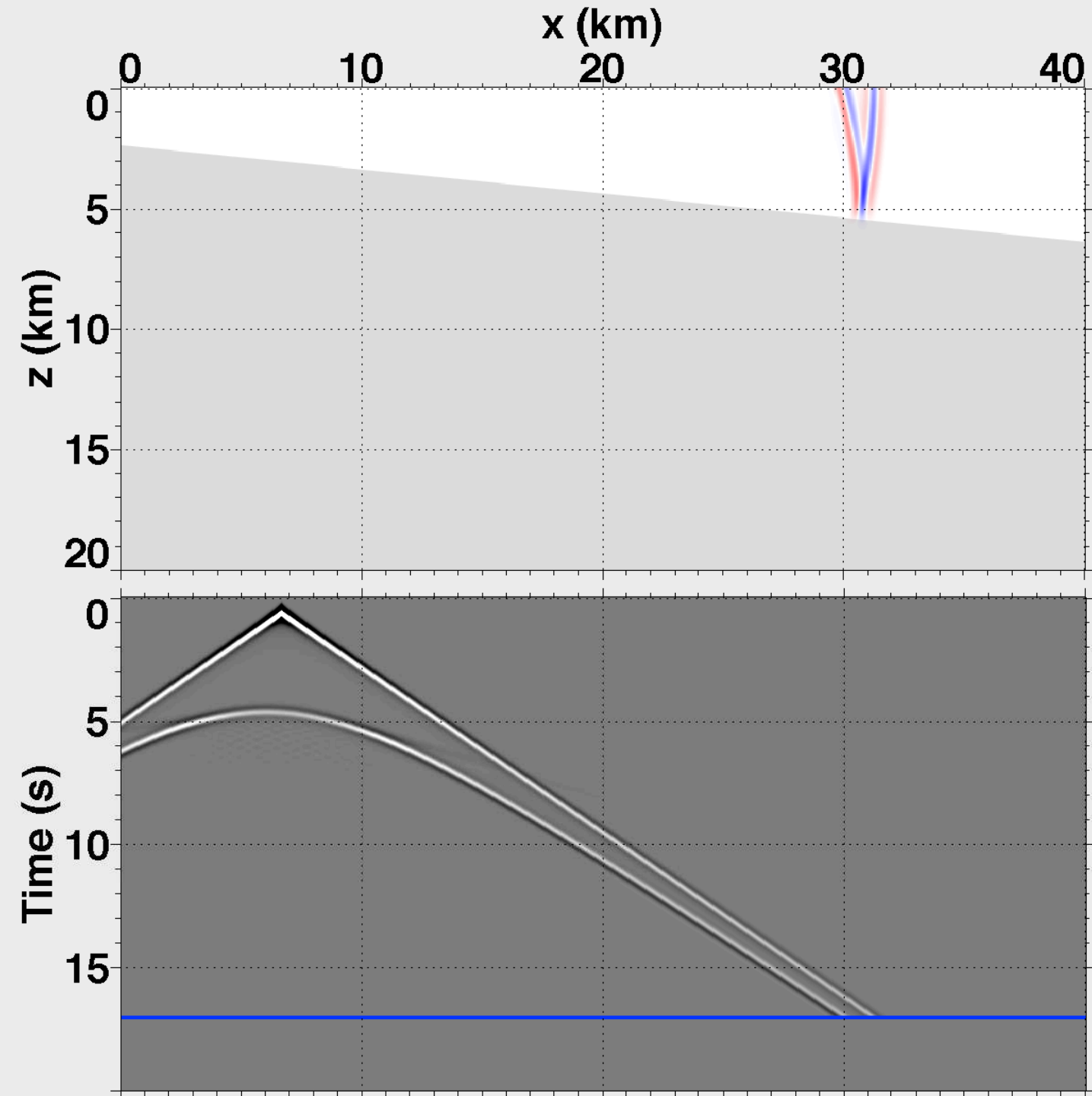


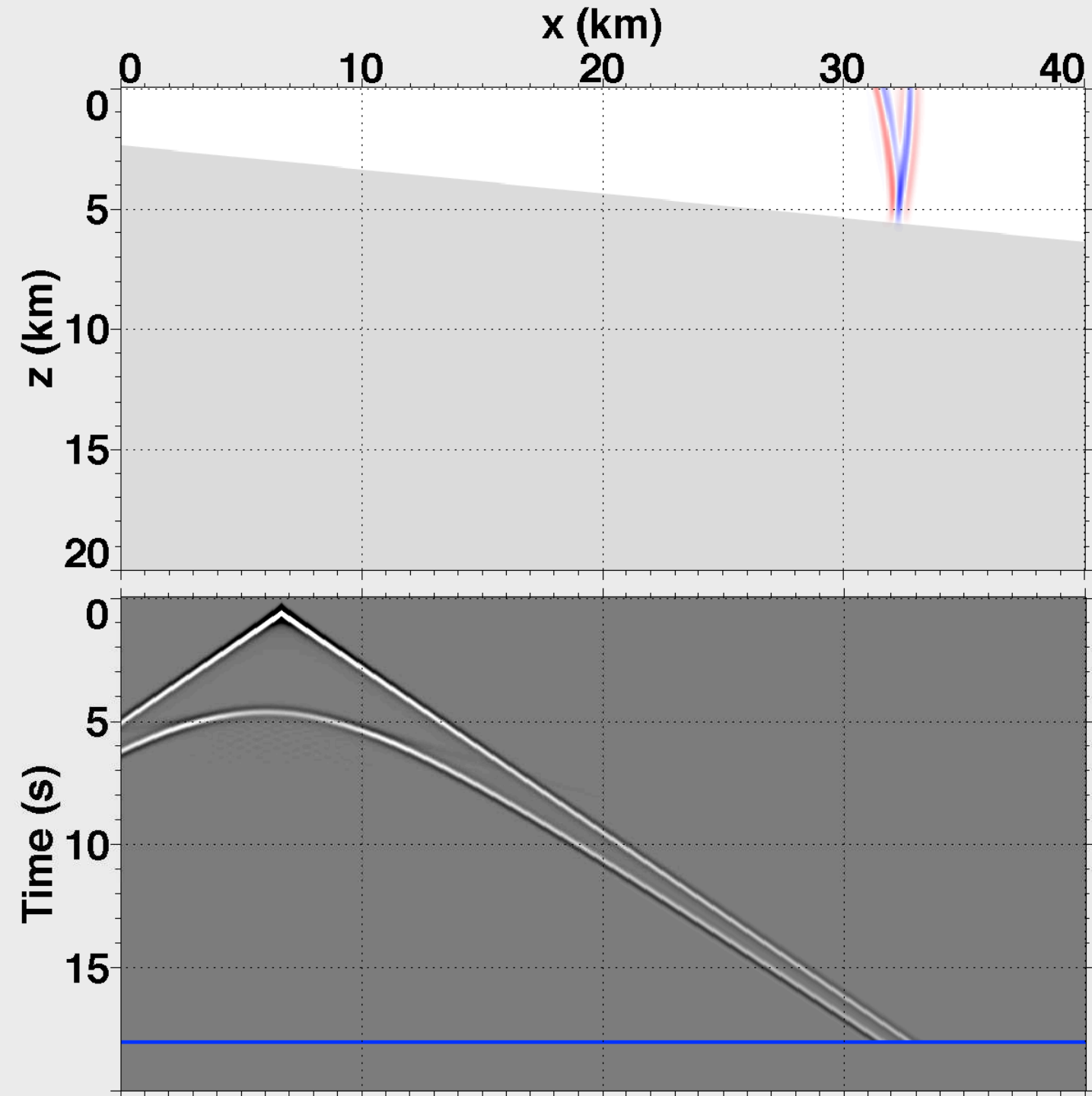


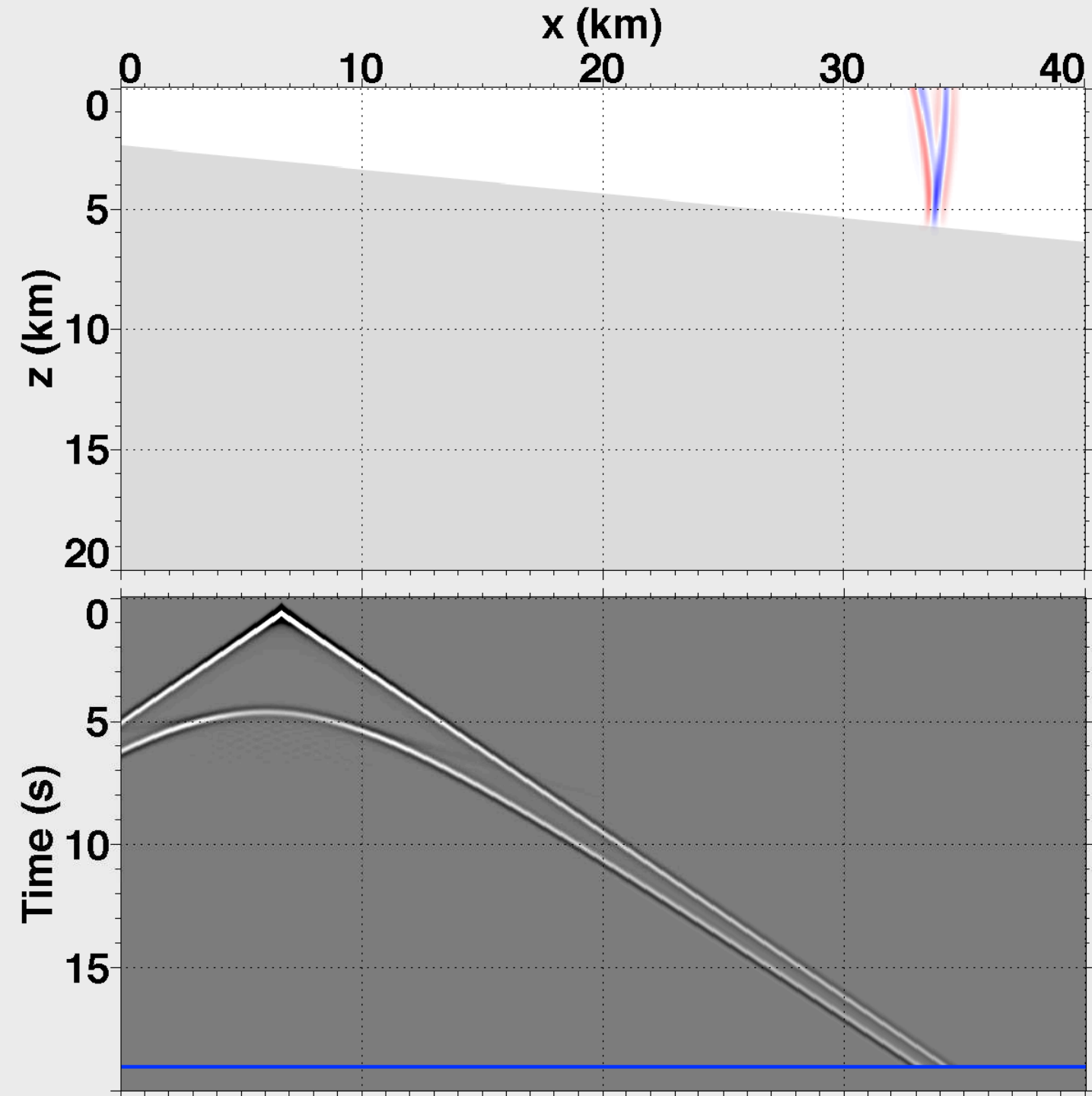


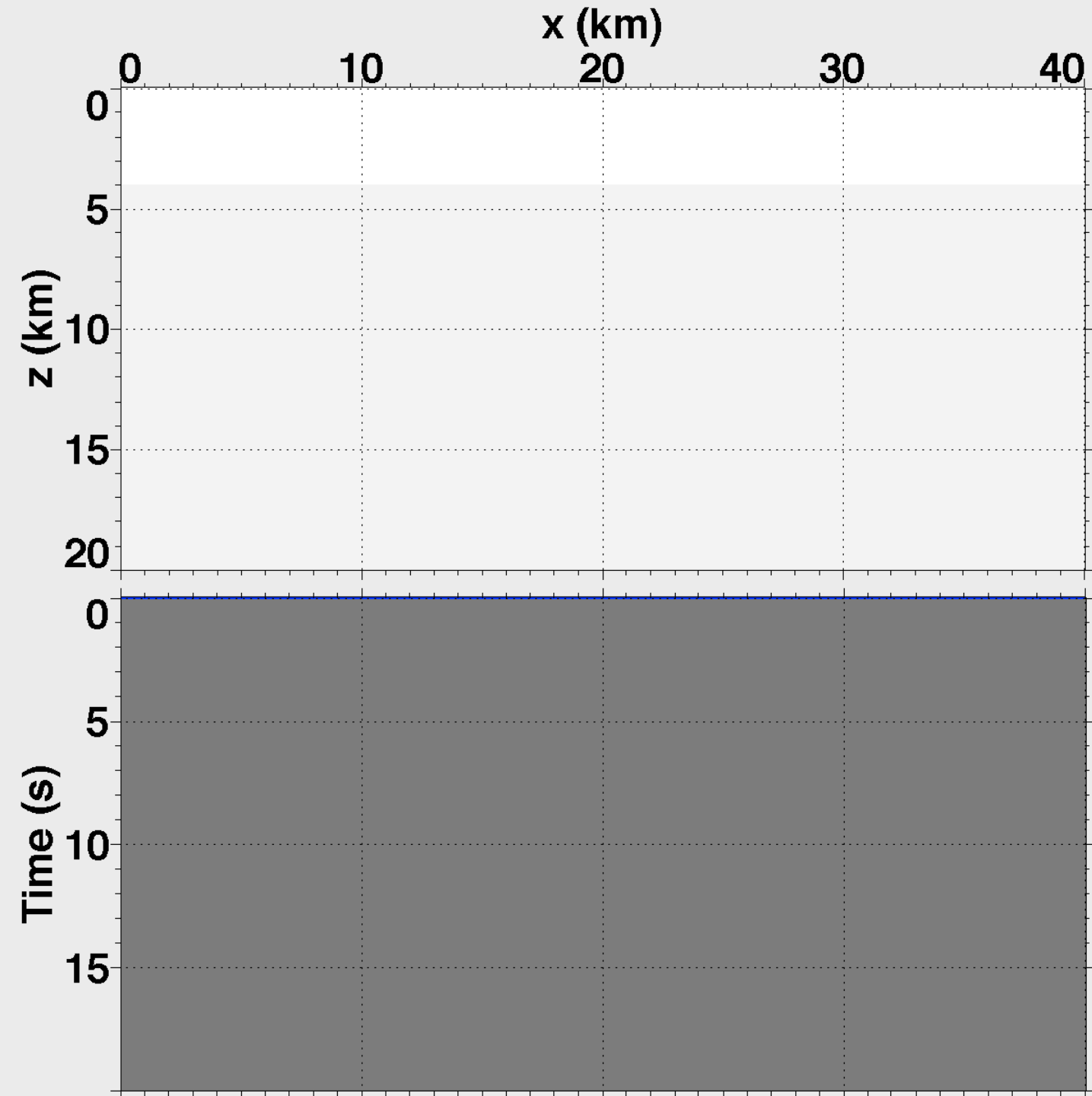


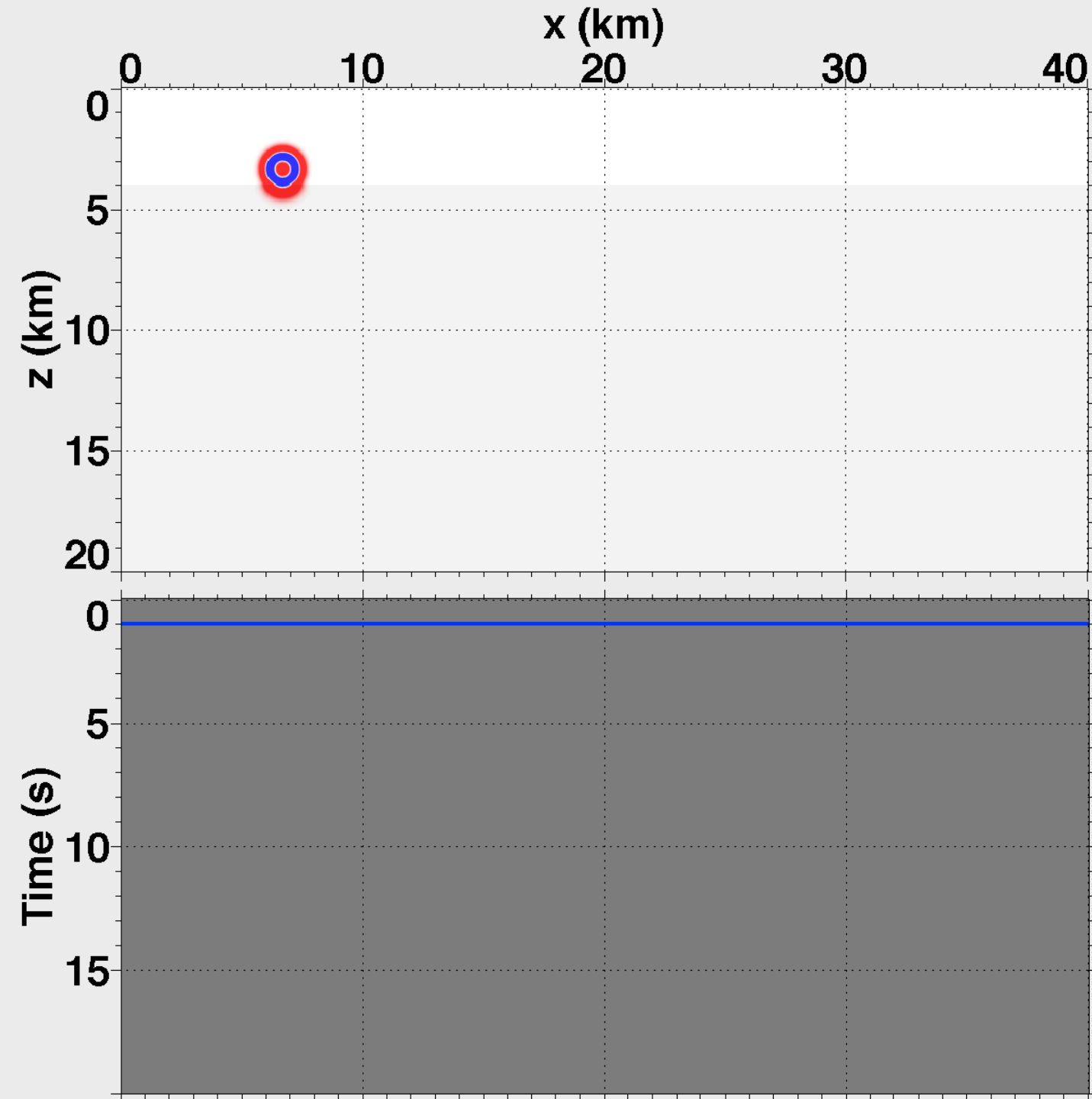


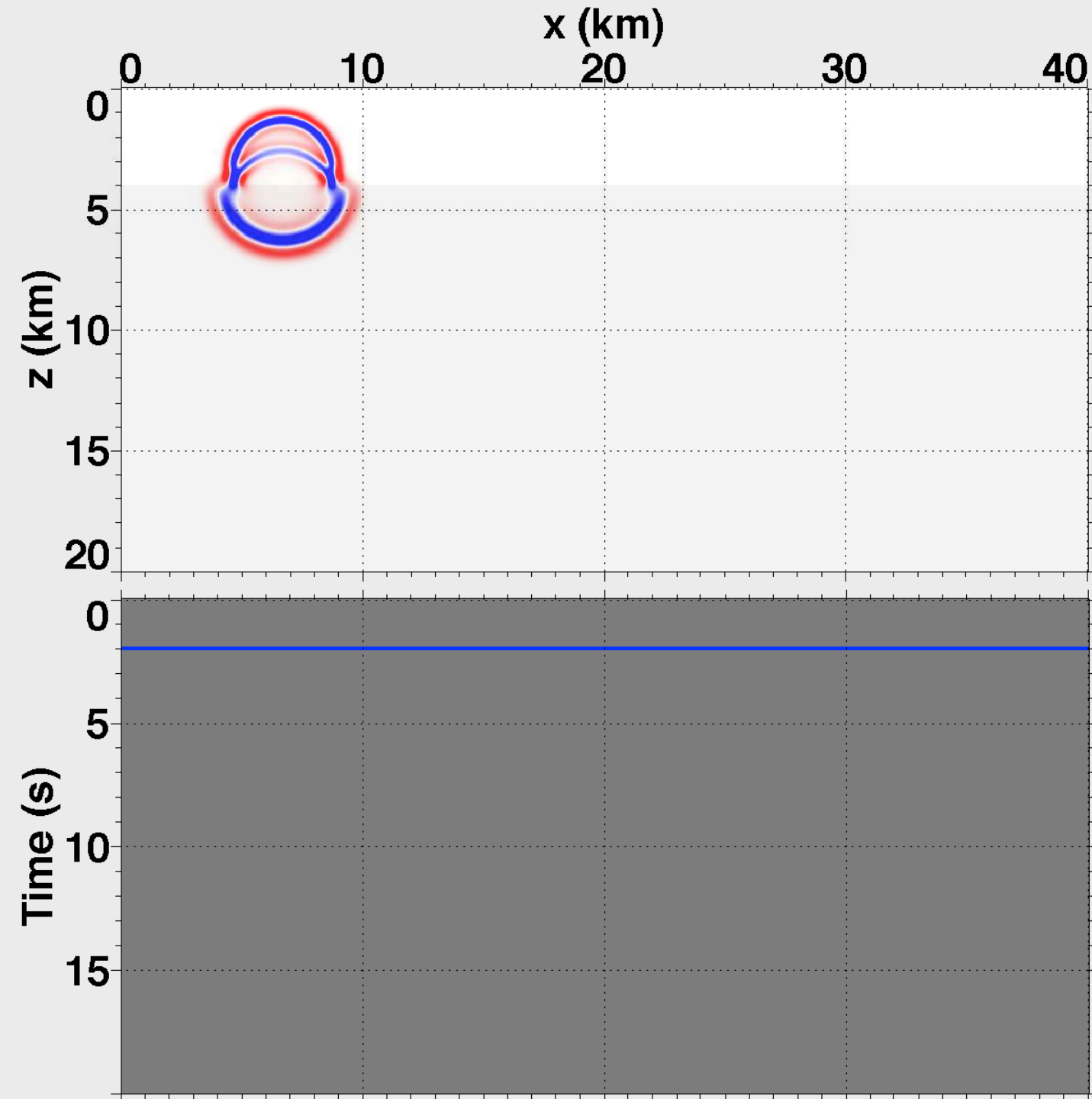


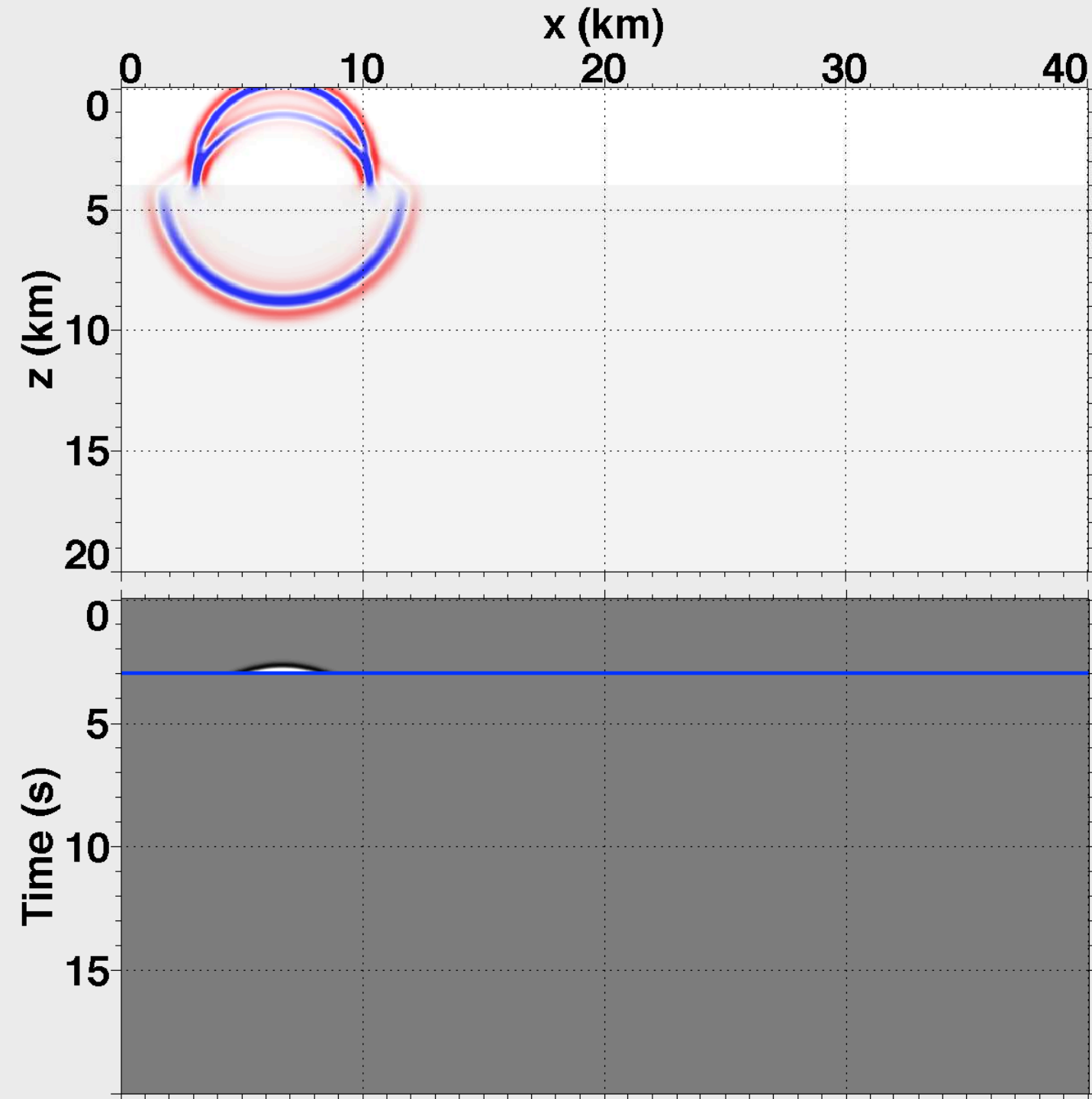


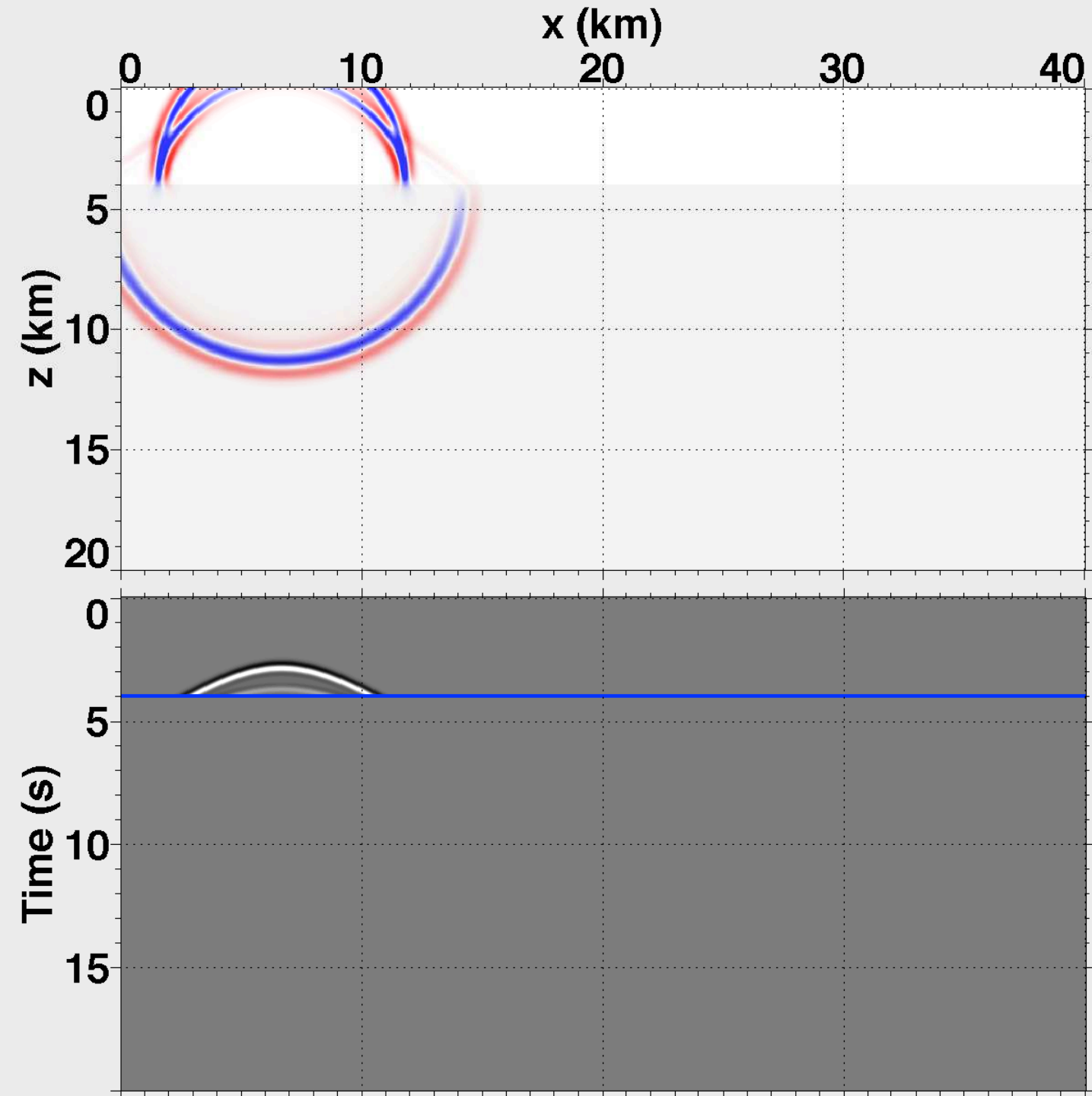


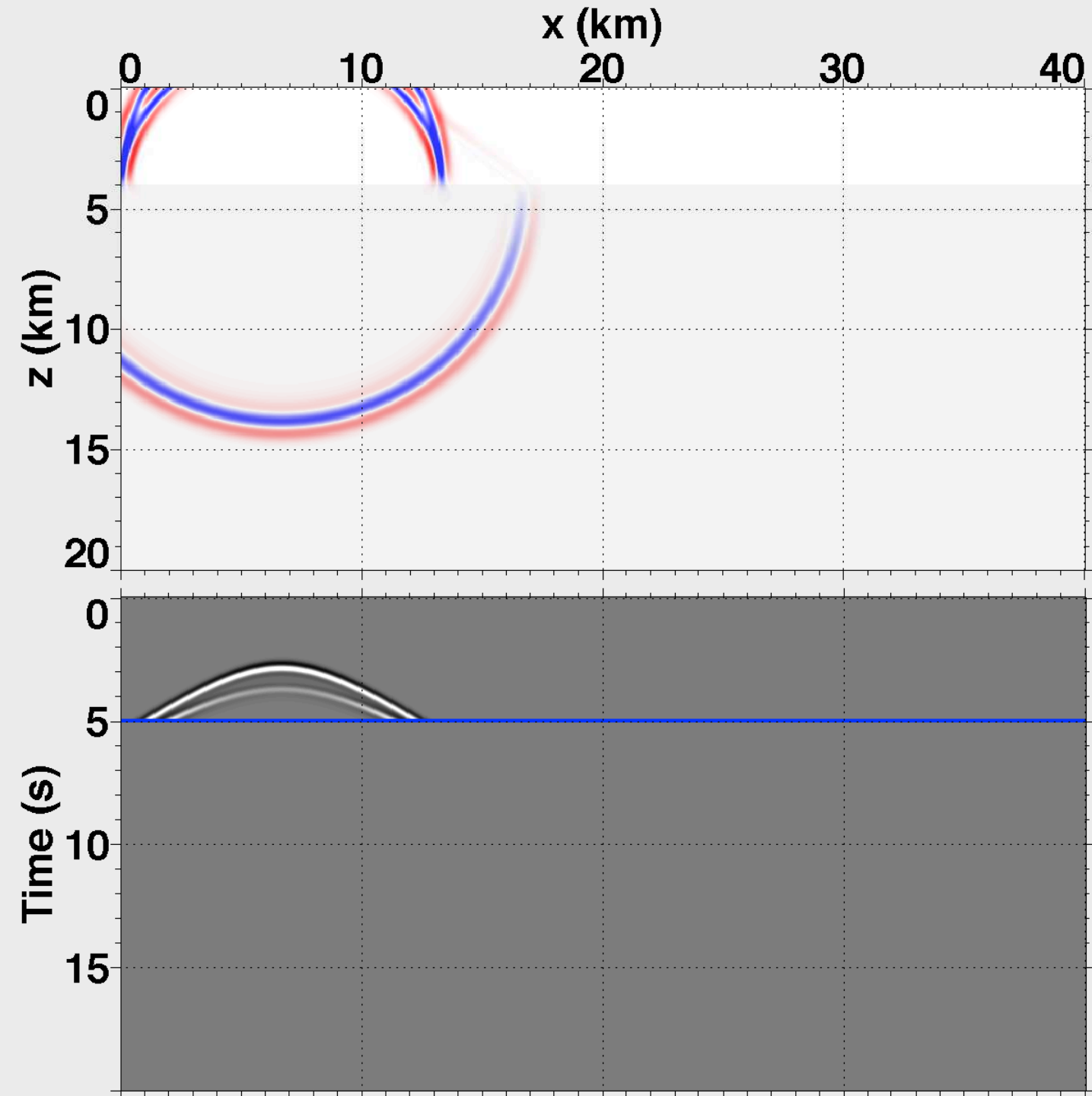


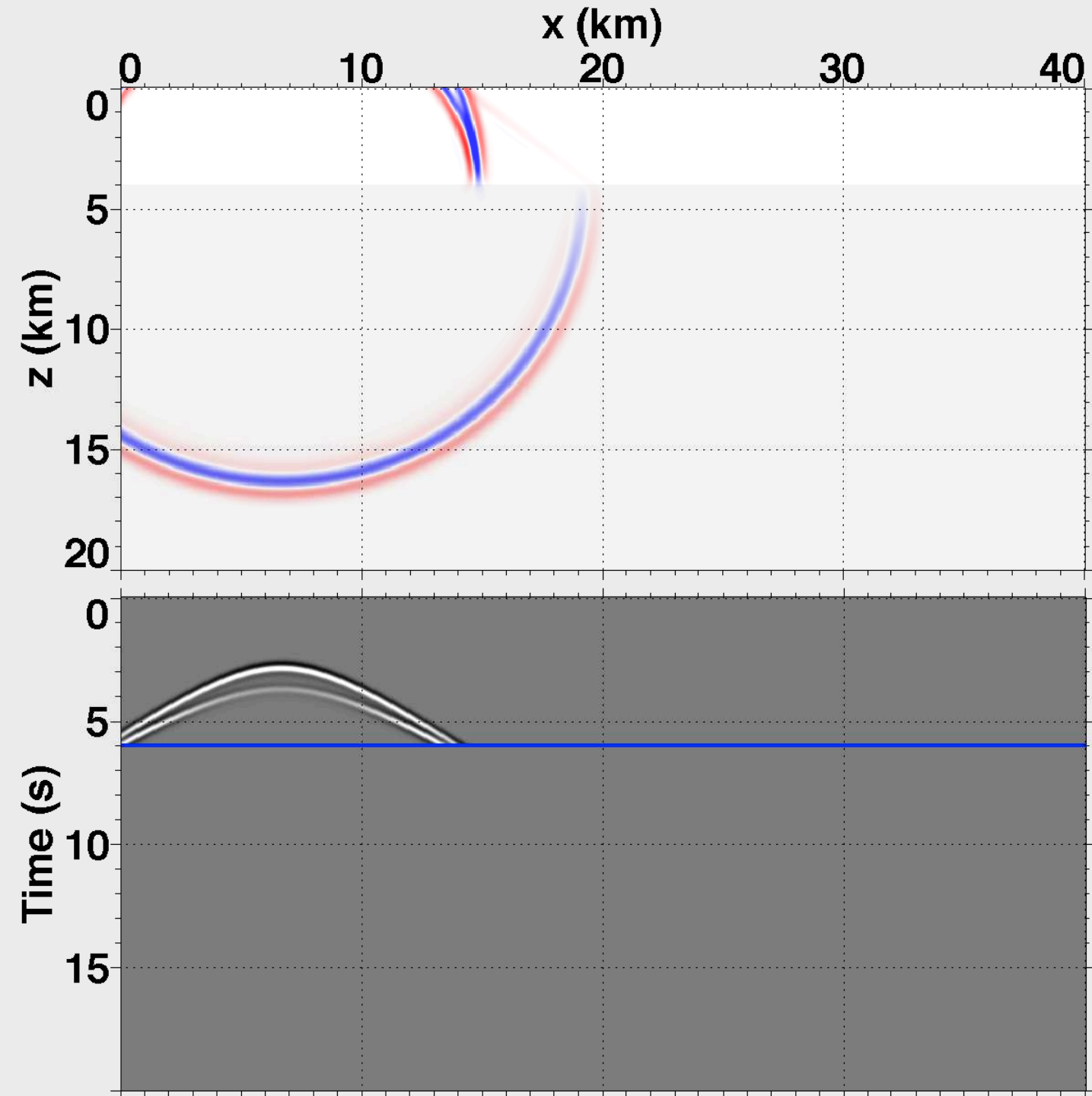


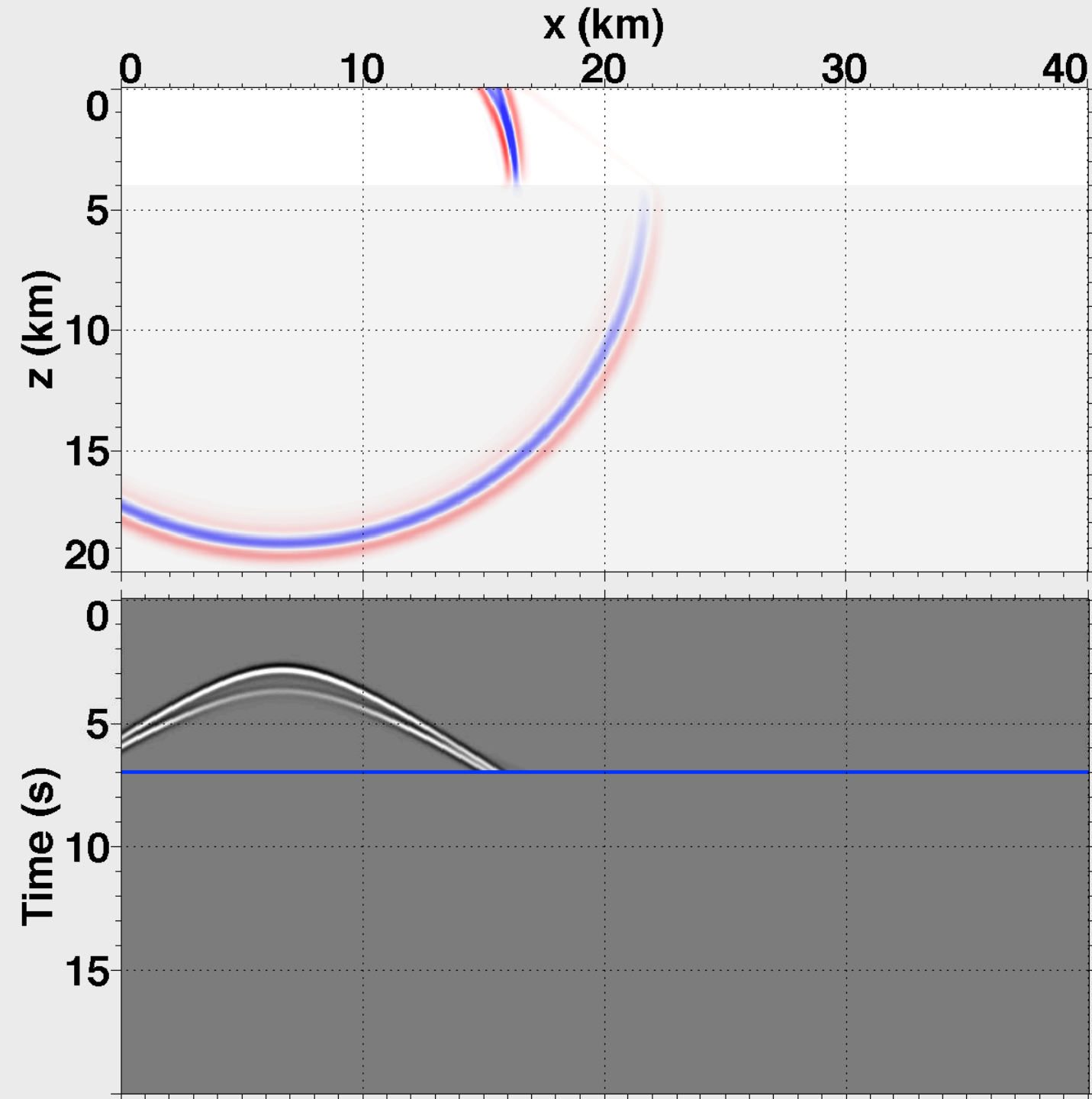


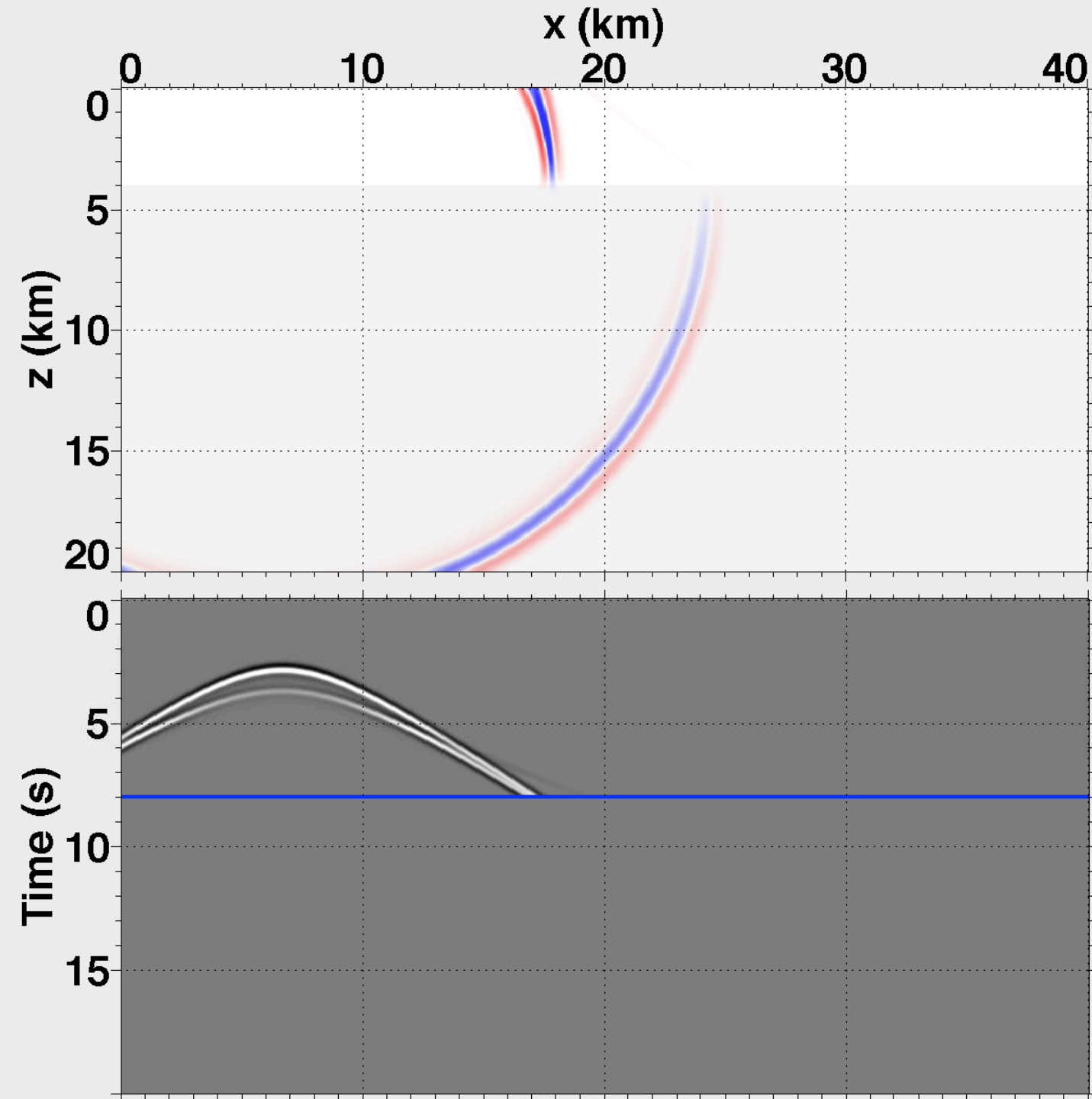


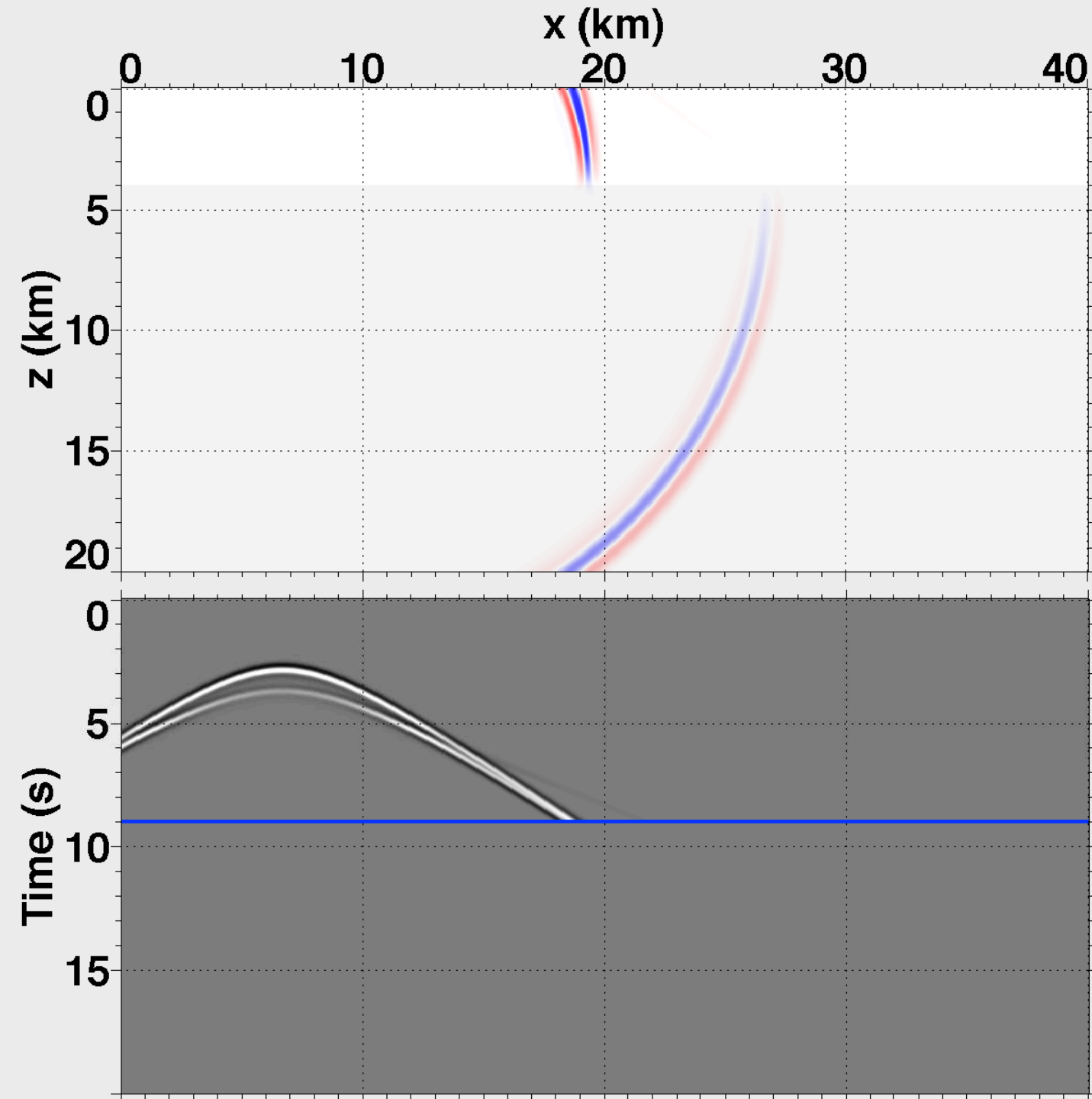


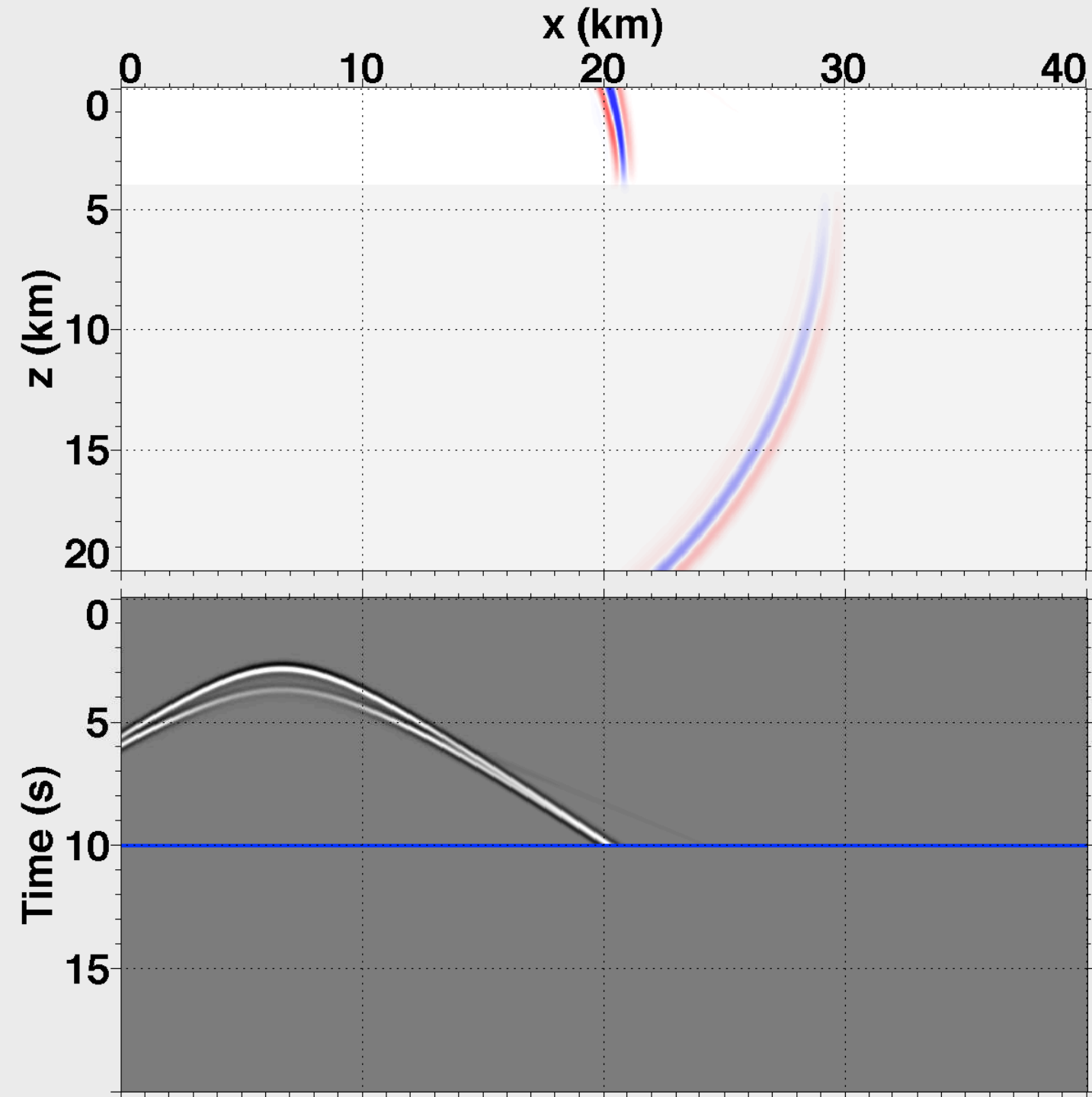


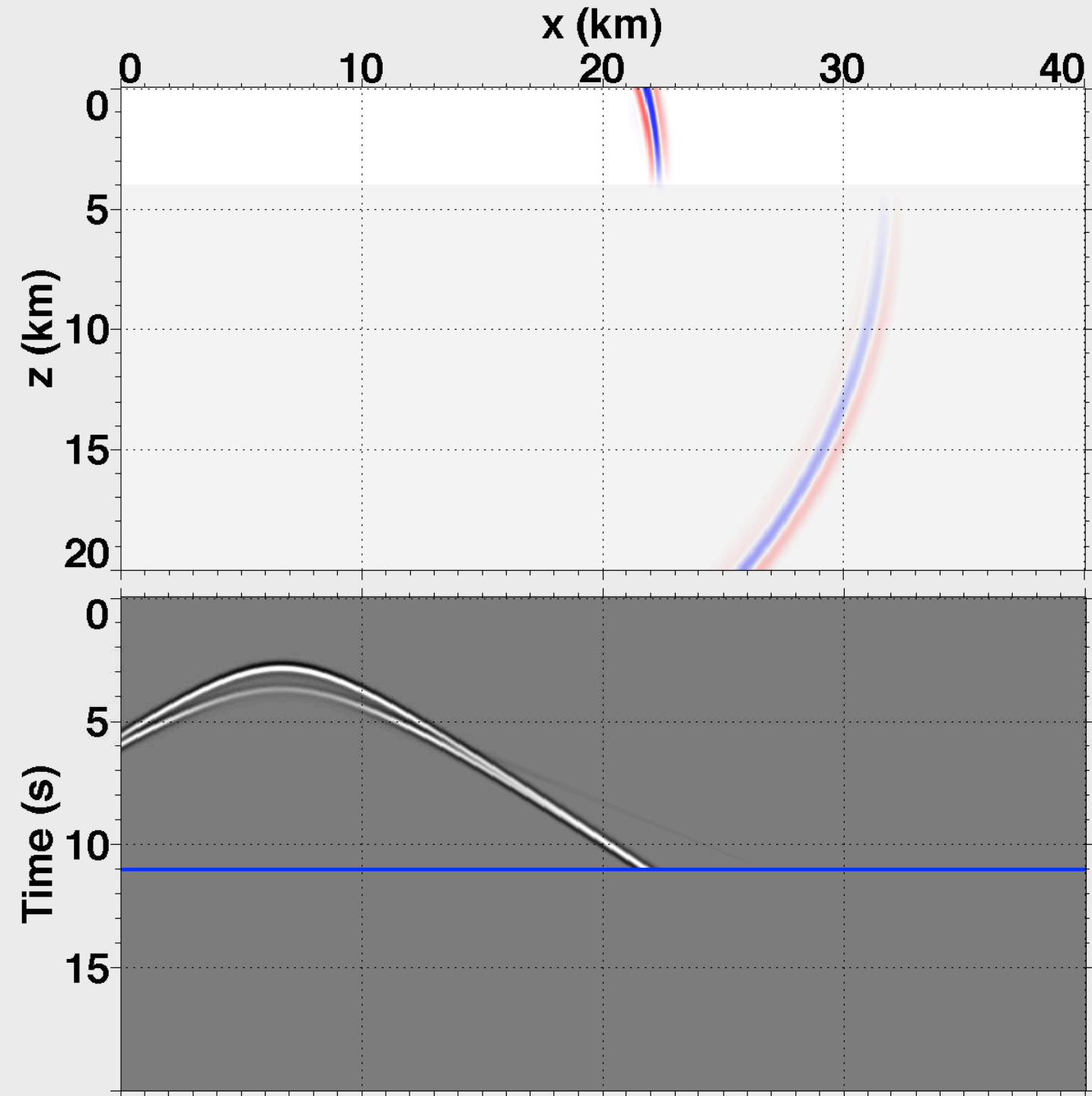


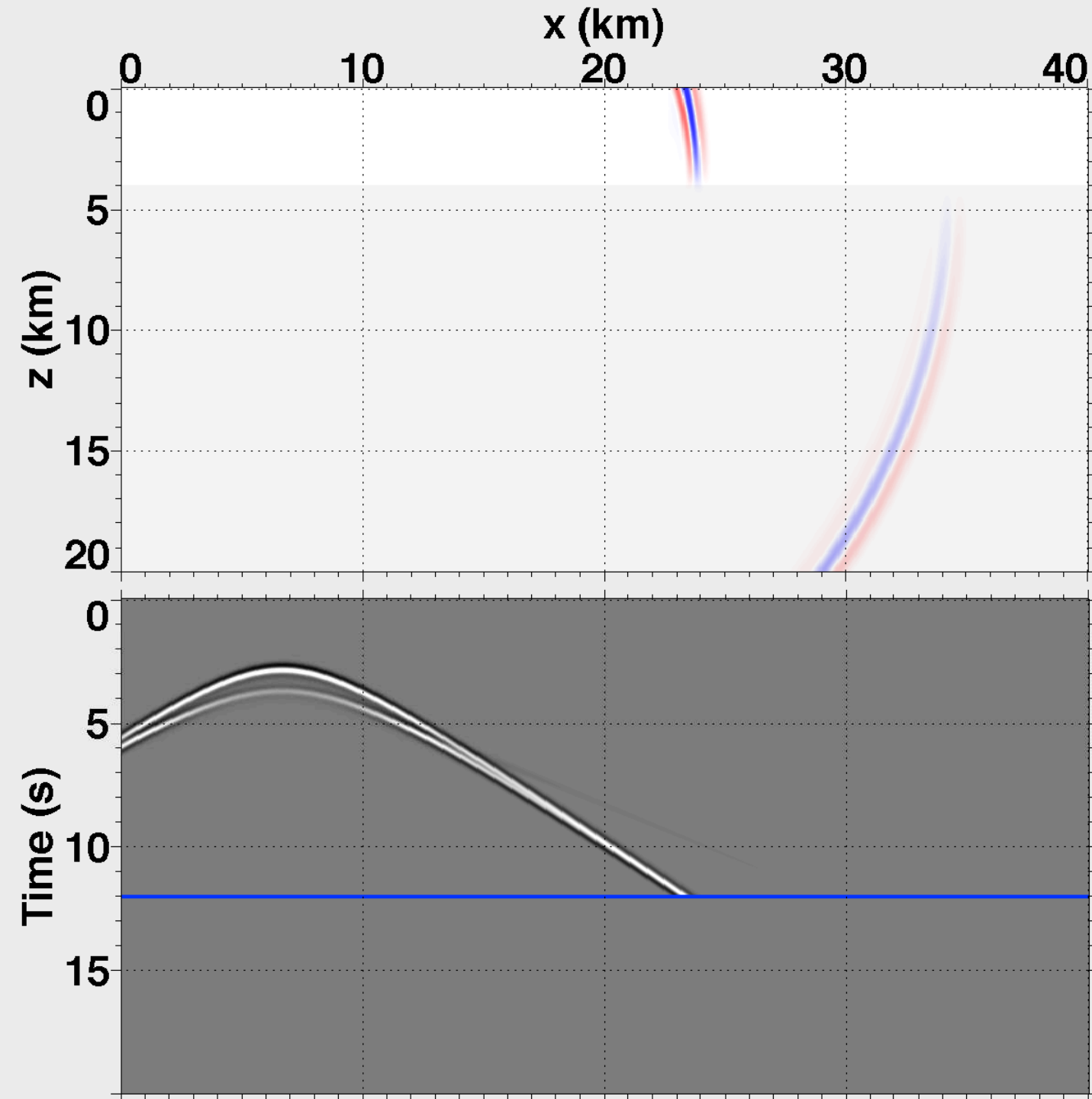


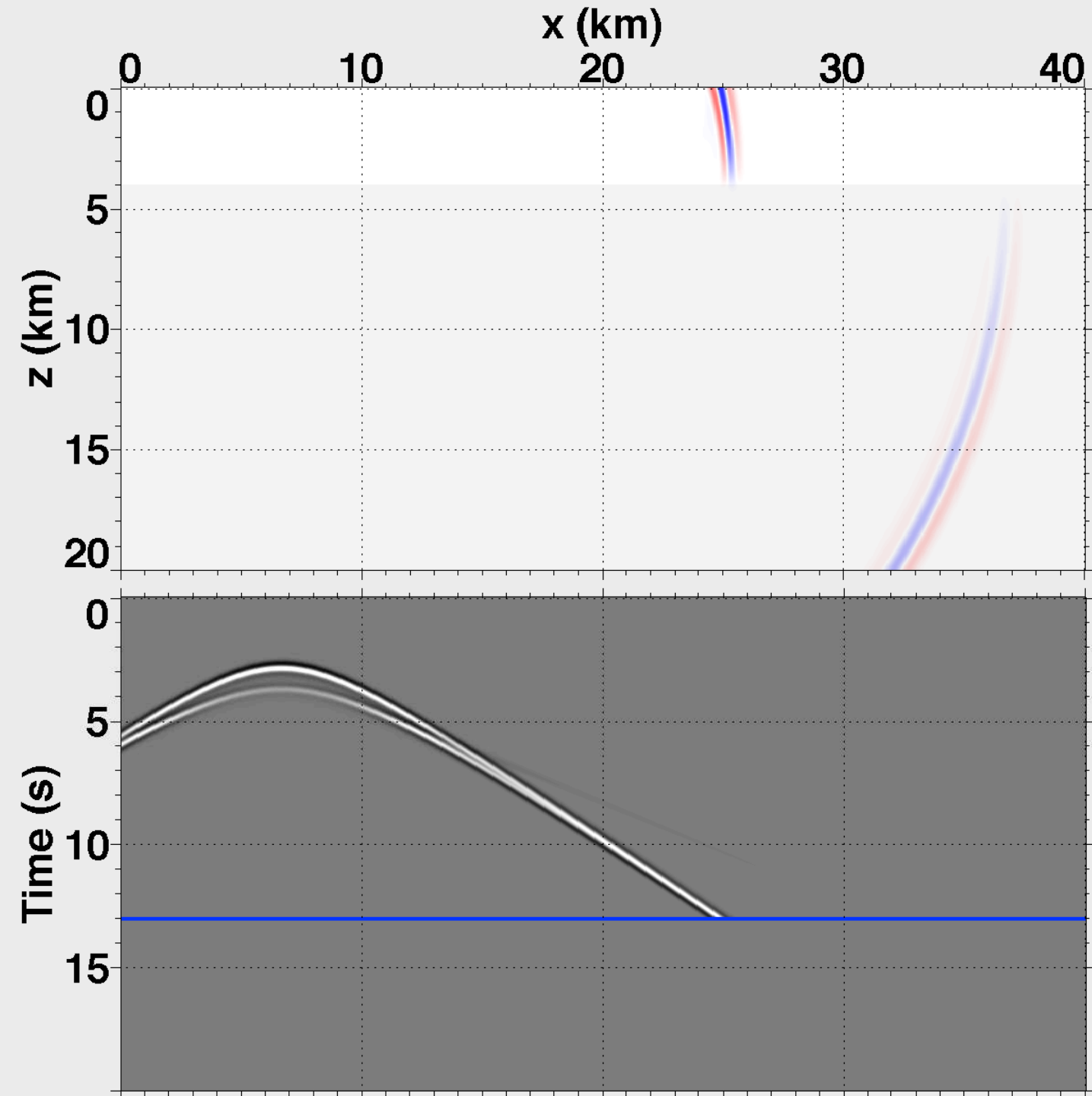


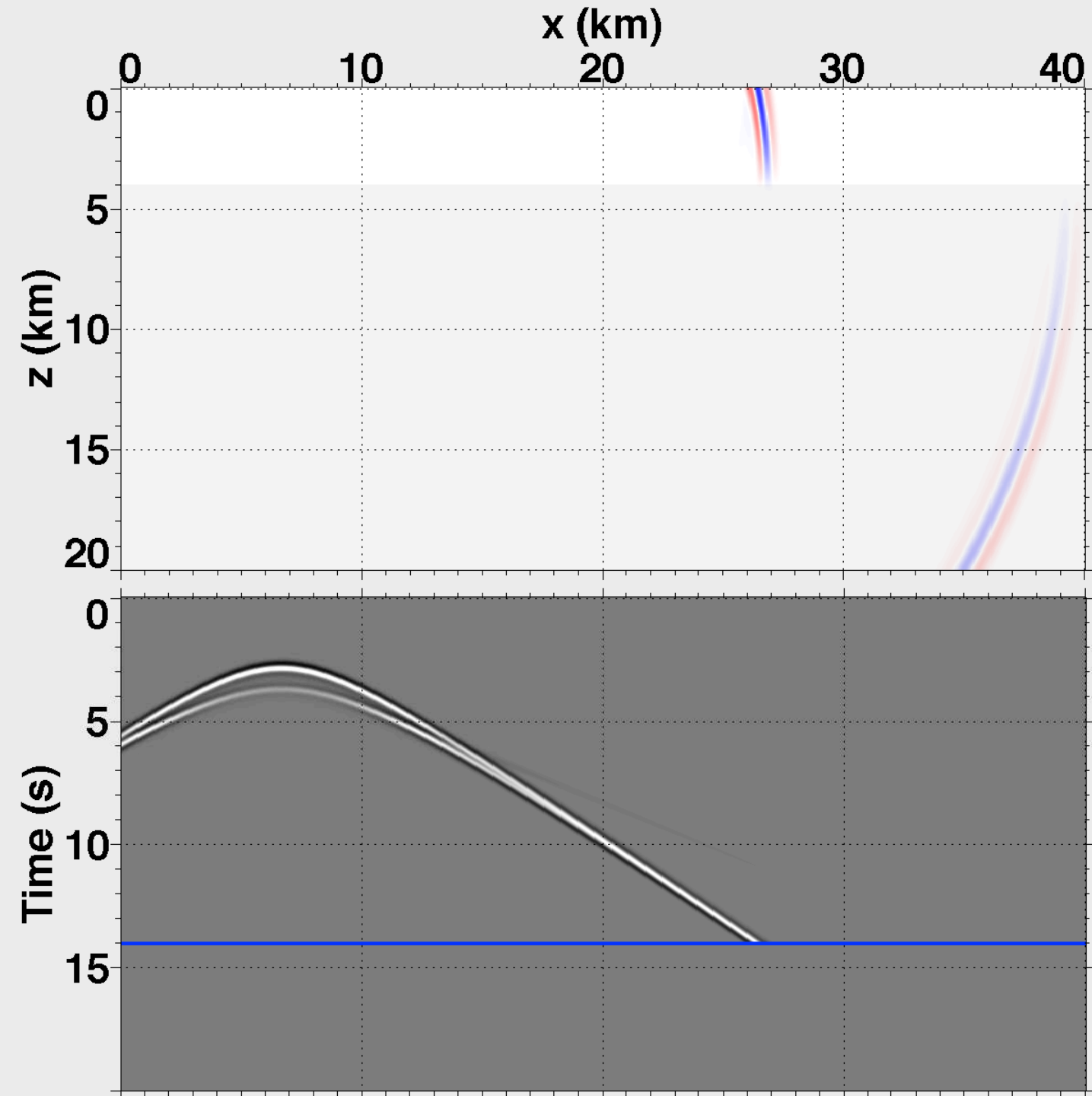


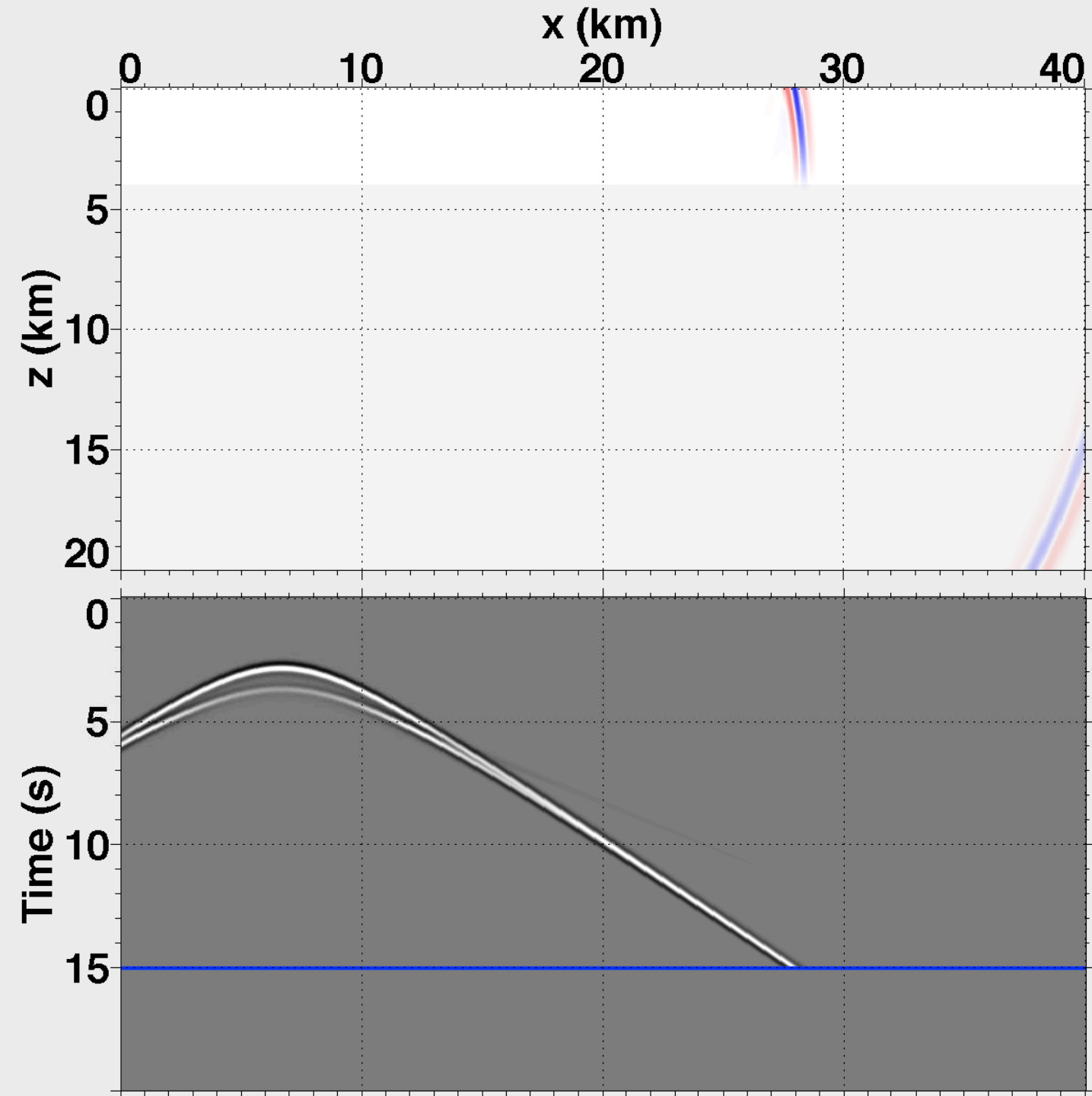


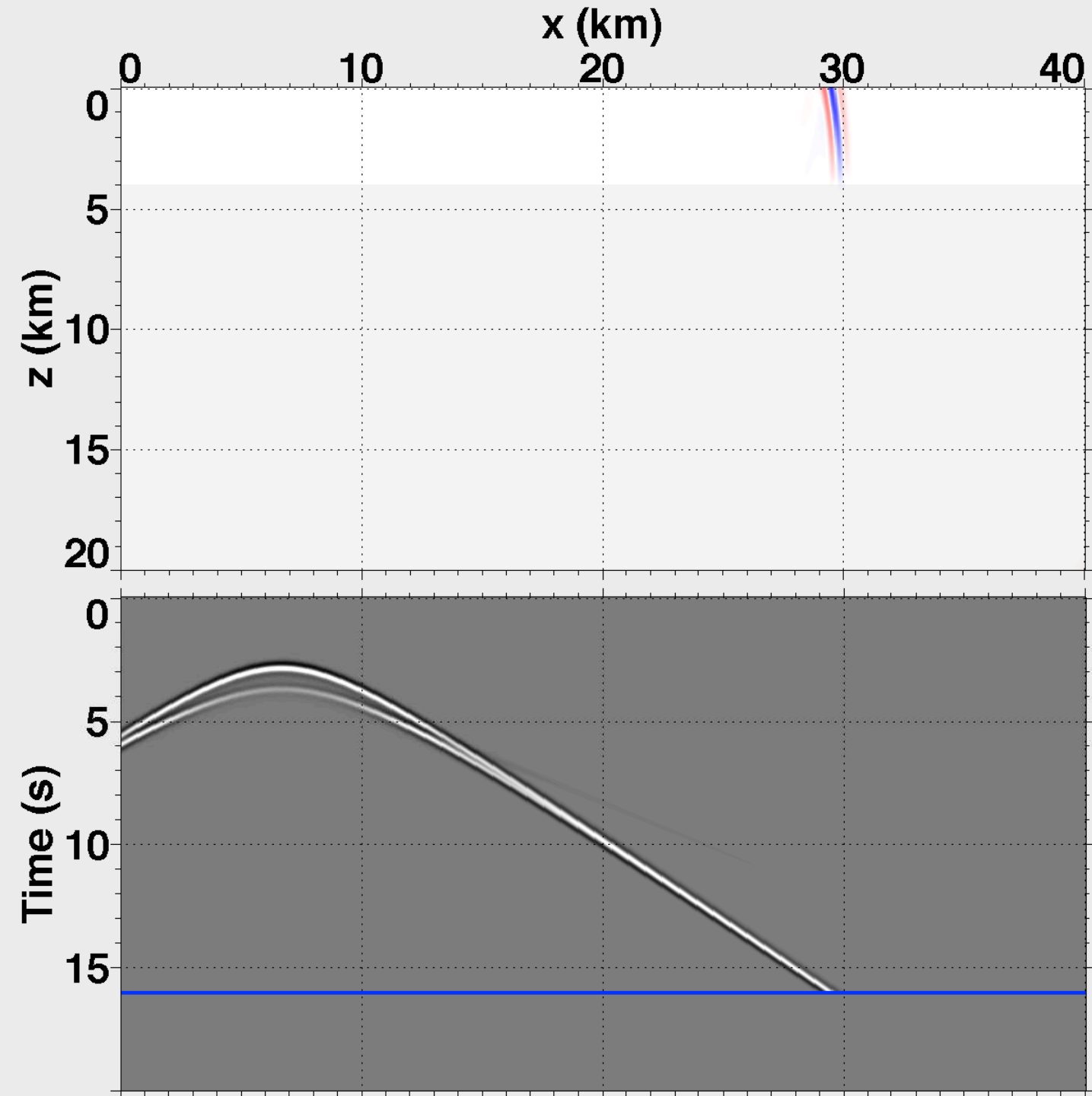


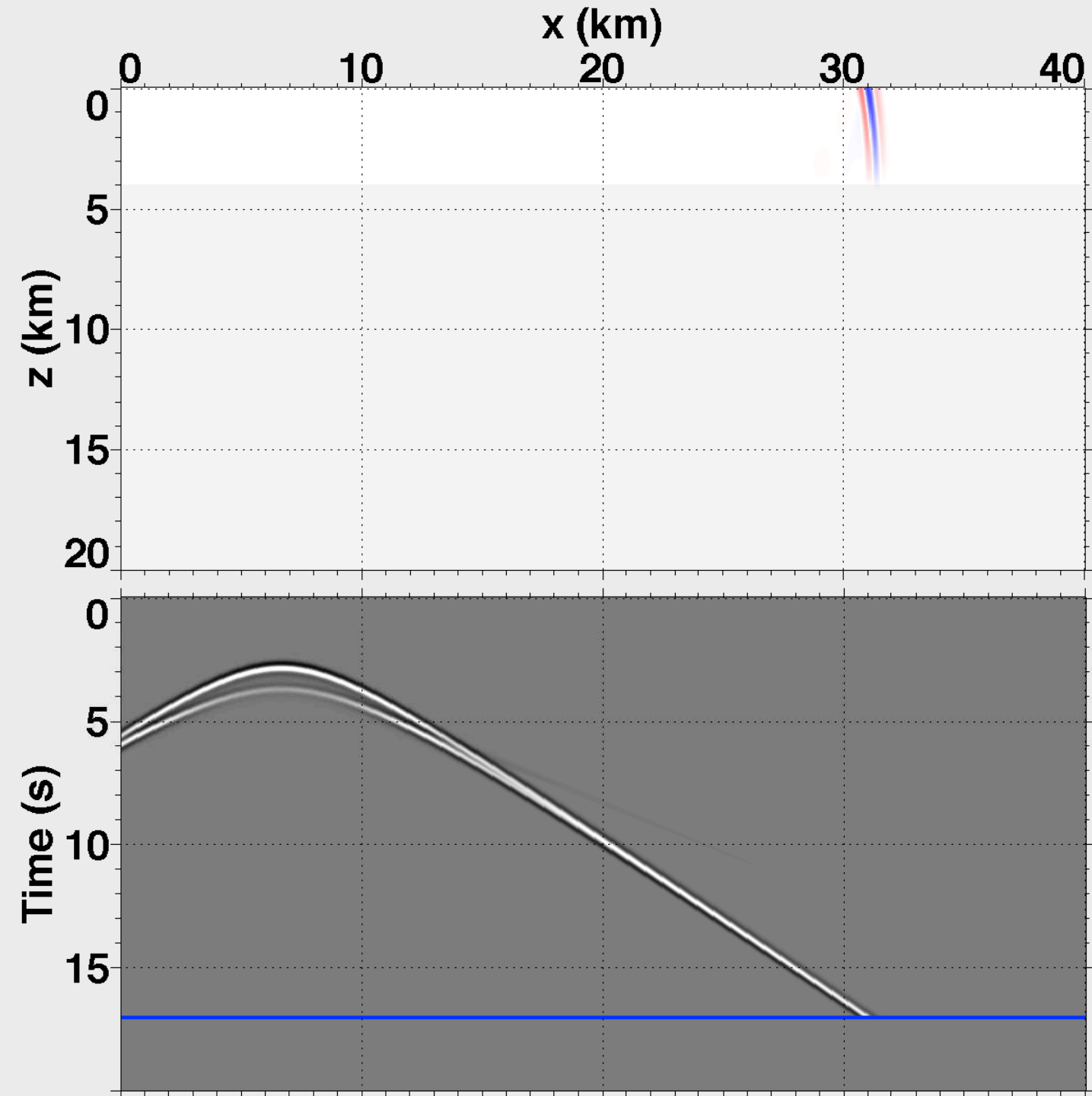


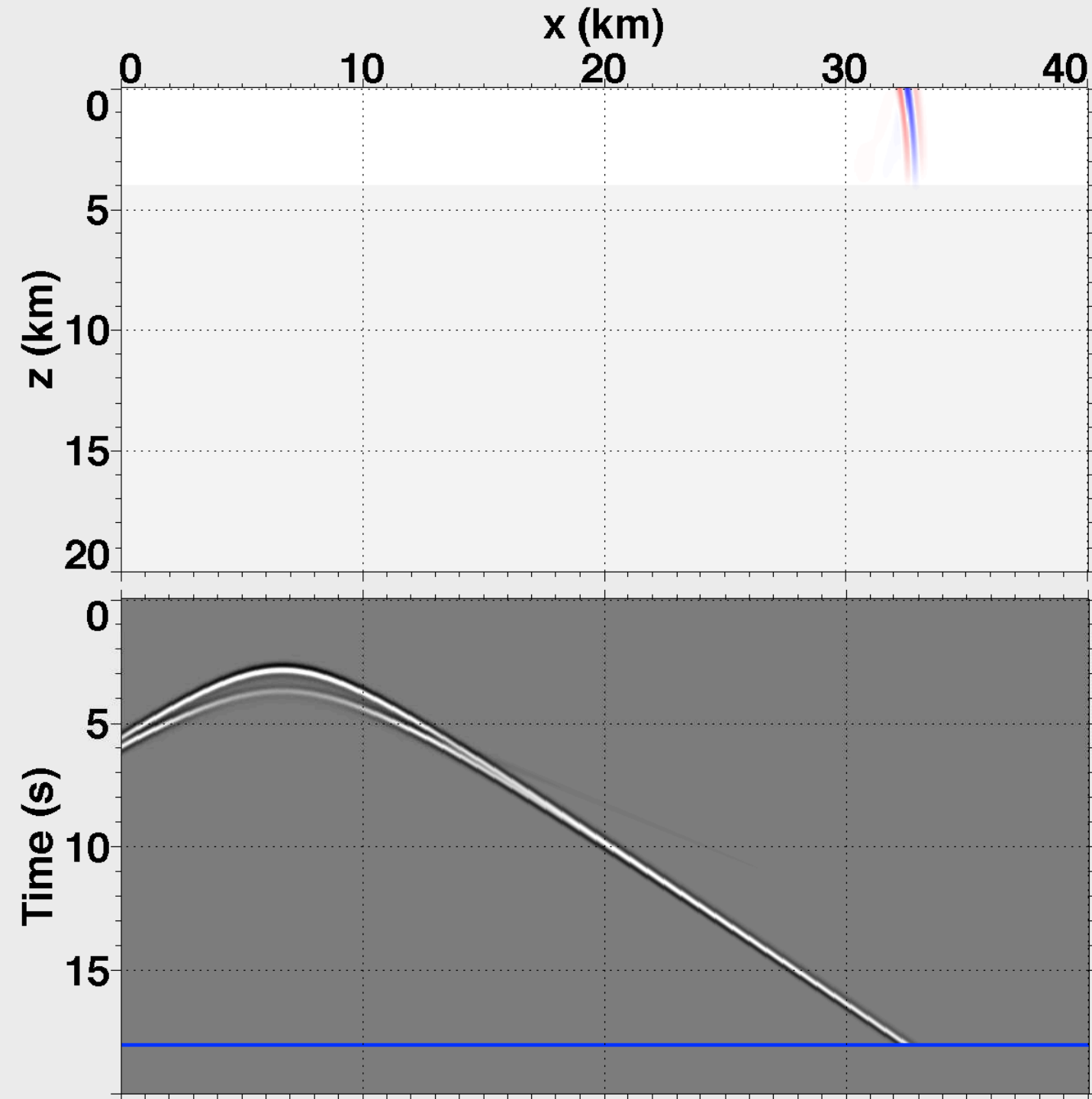


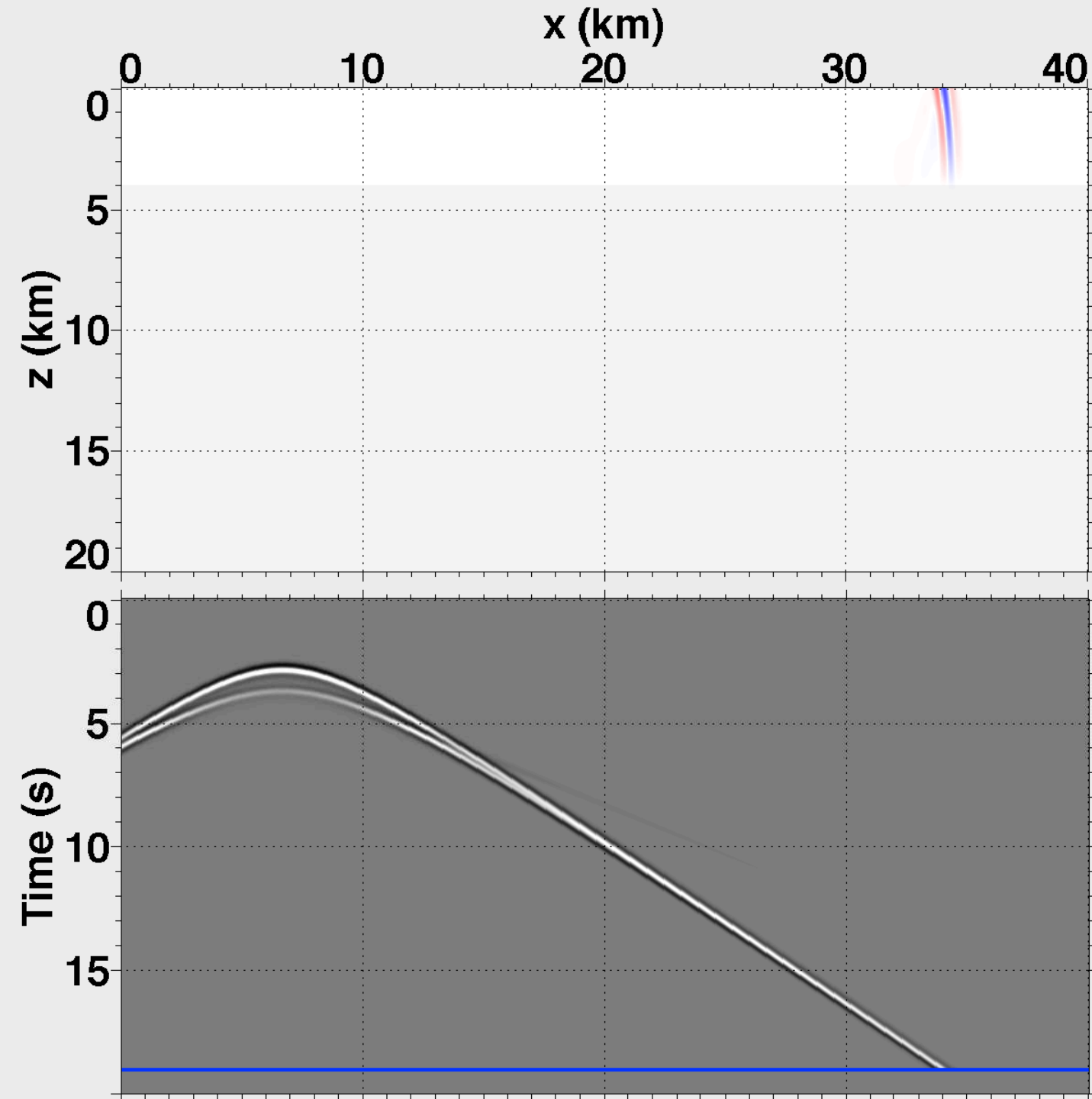










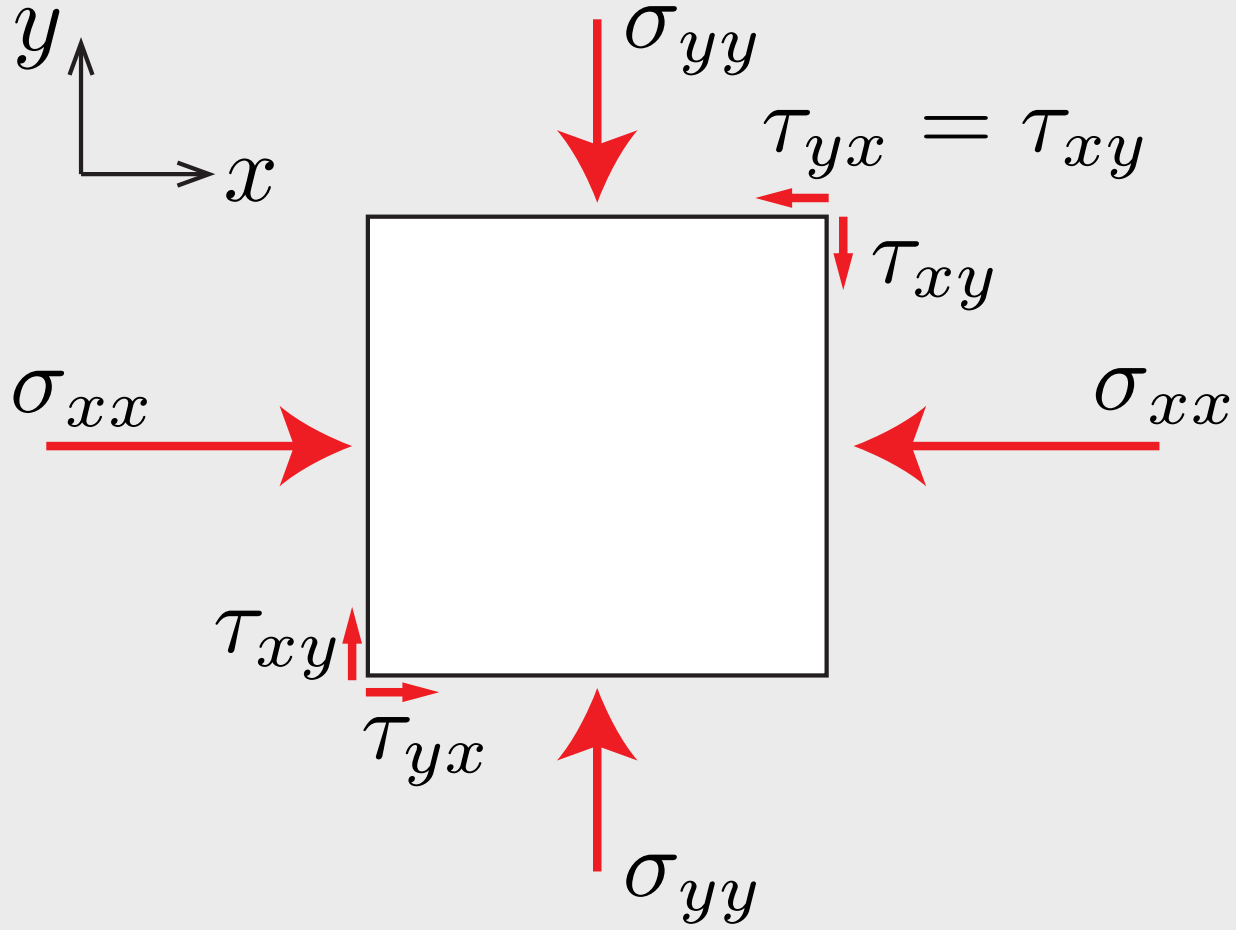


Source mechanisms

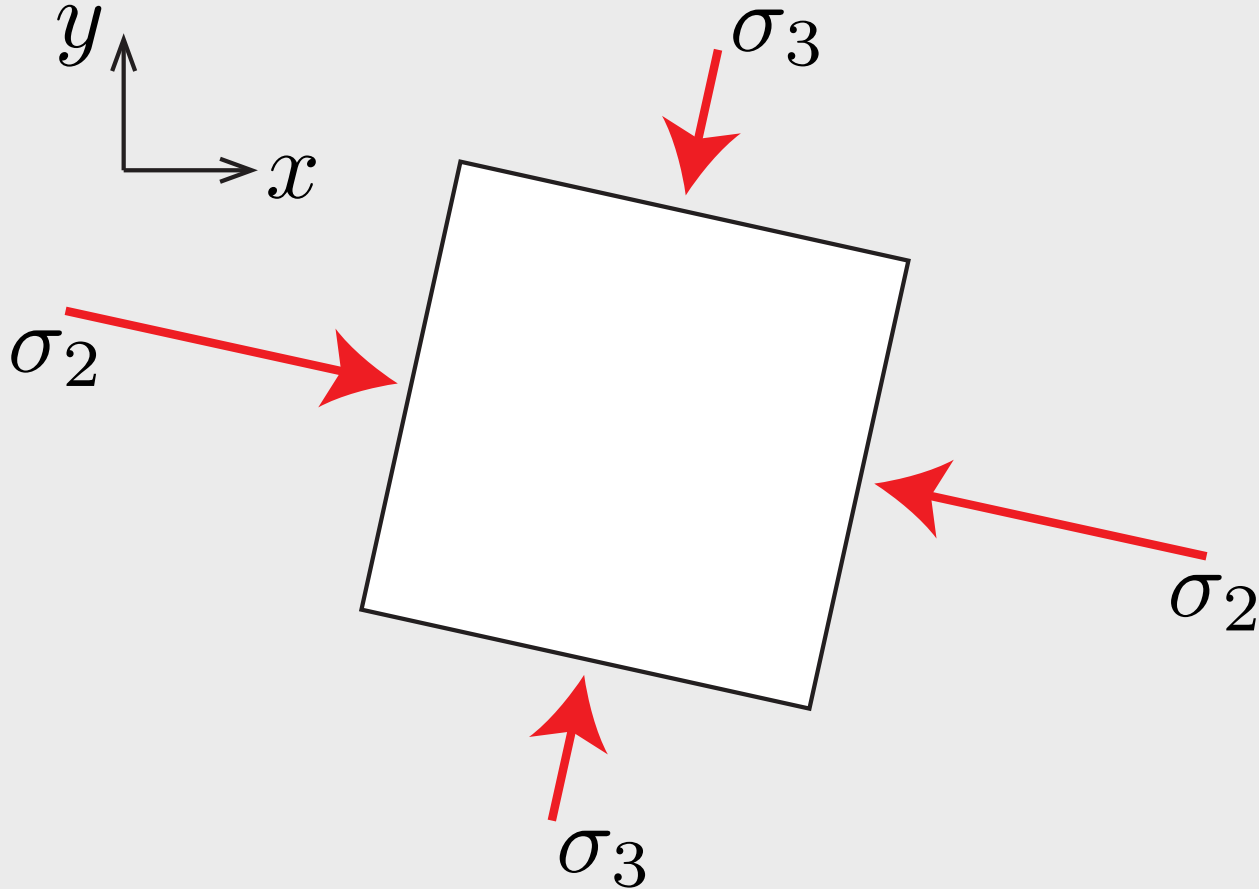
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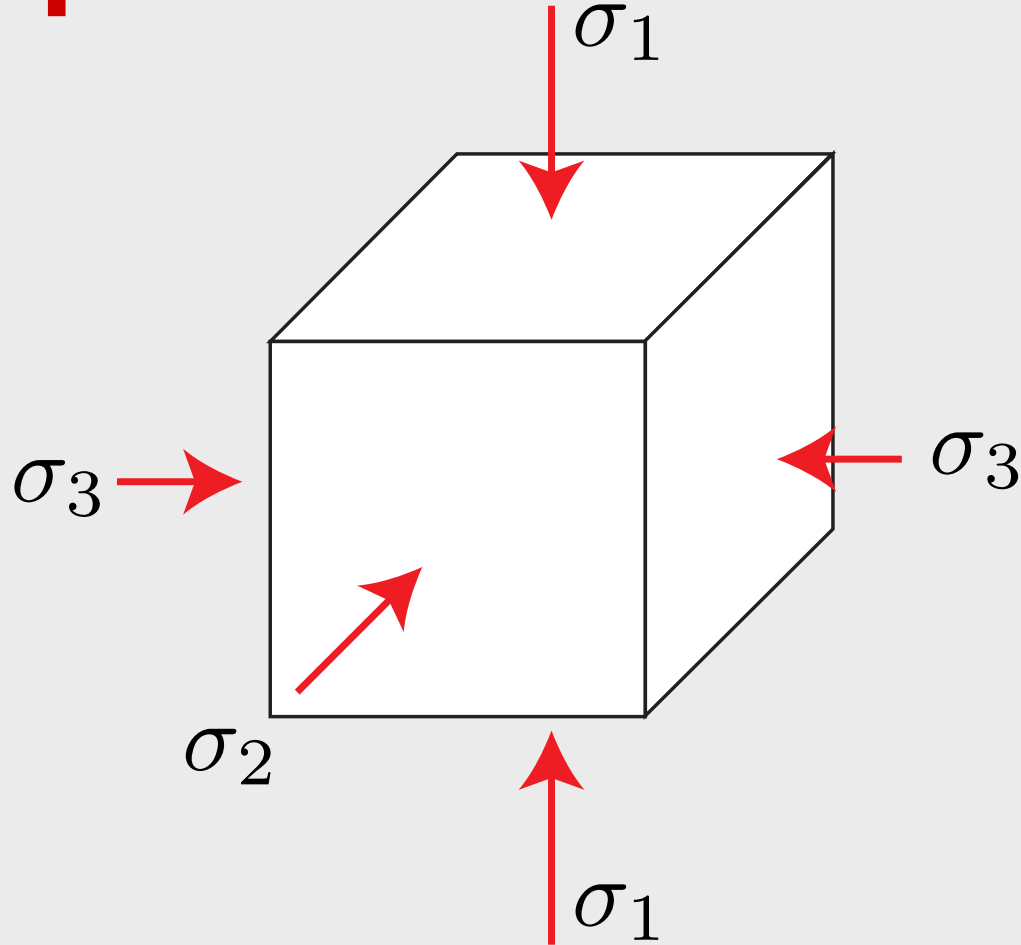
Stress orientation



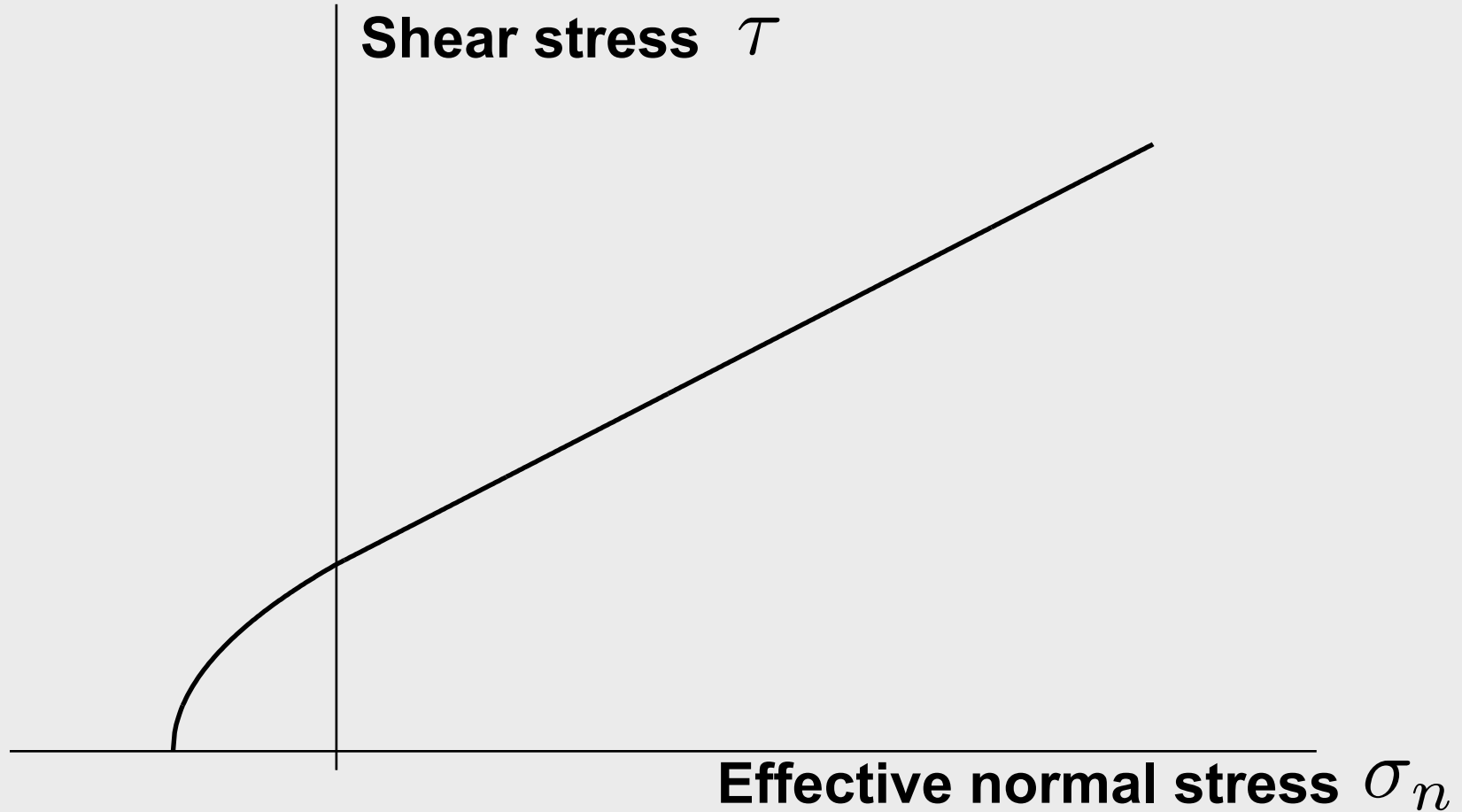
Principle stress orientation



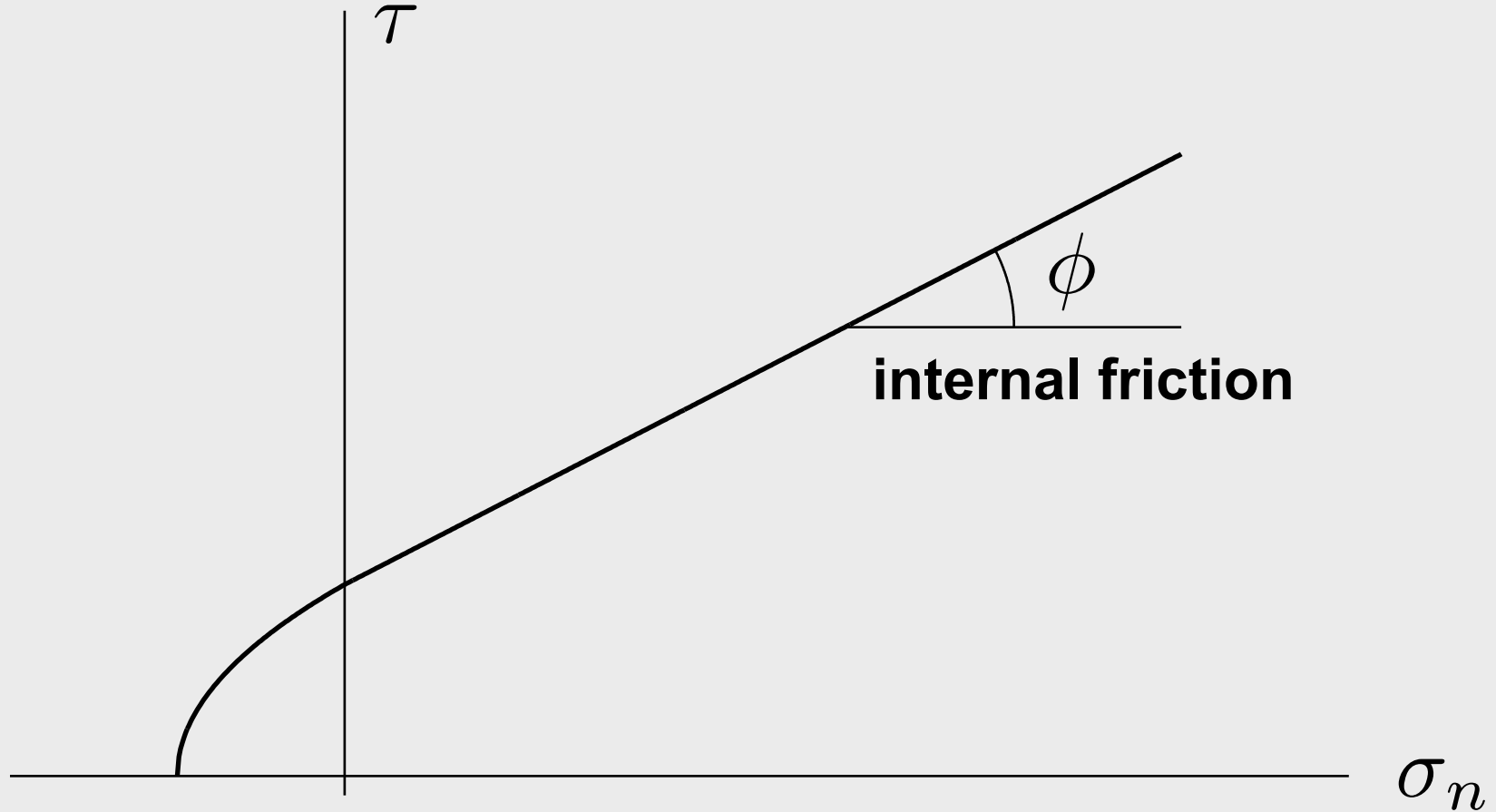
Principle stress orientation



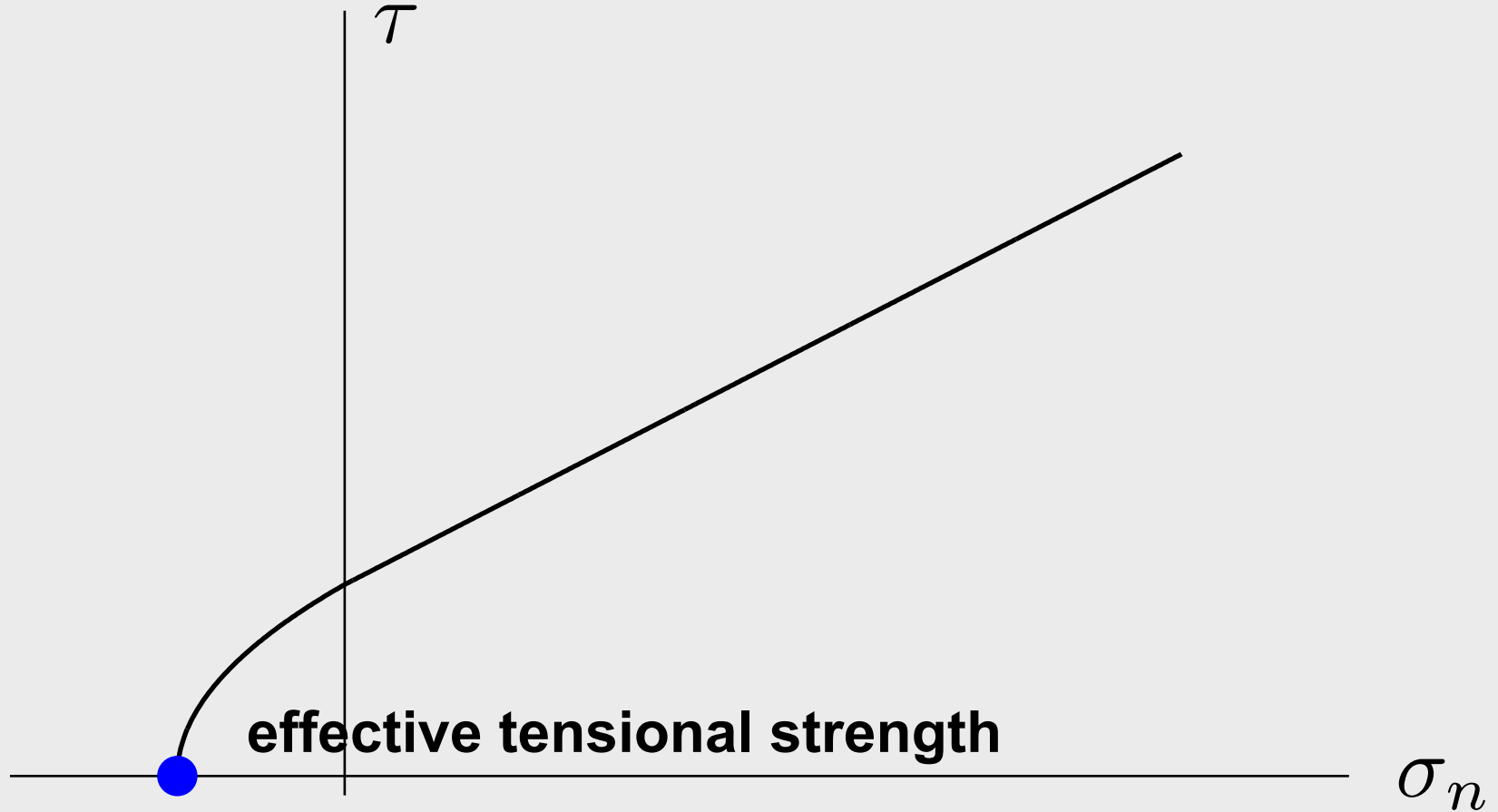
Coulomb/Griffith failure criteria



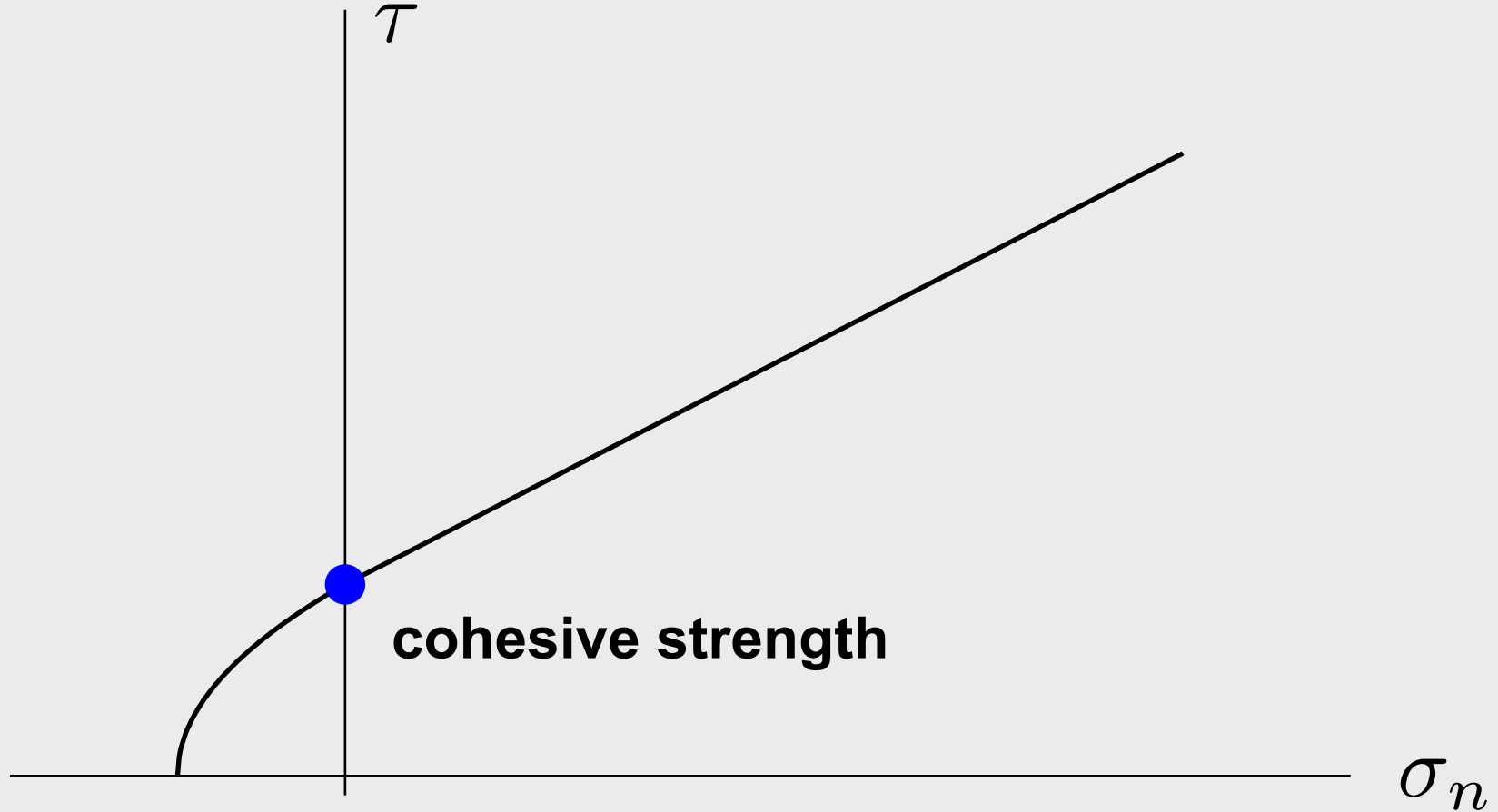
Coulomb/Griffith failure criteria



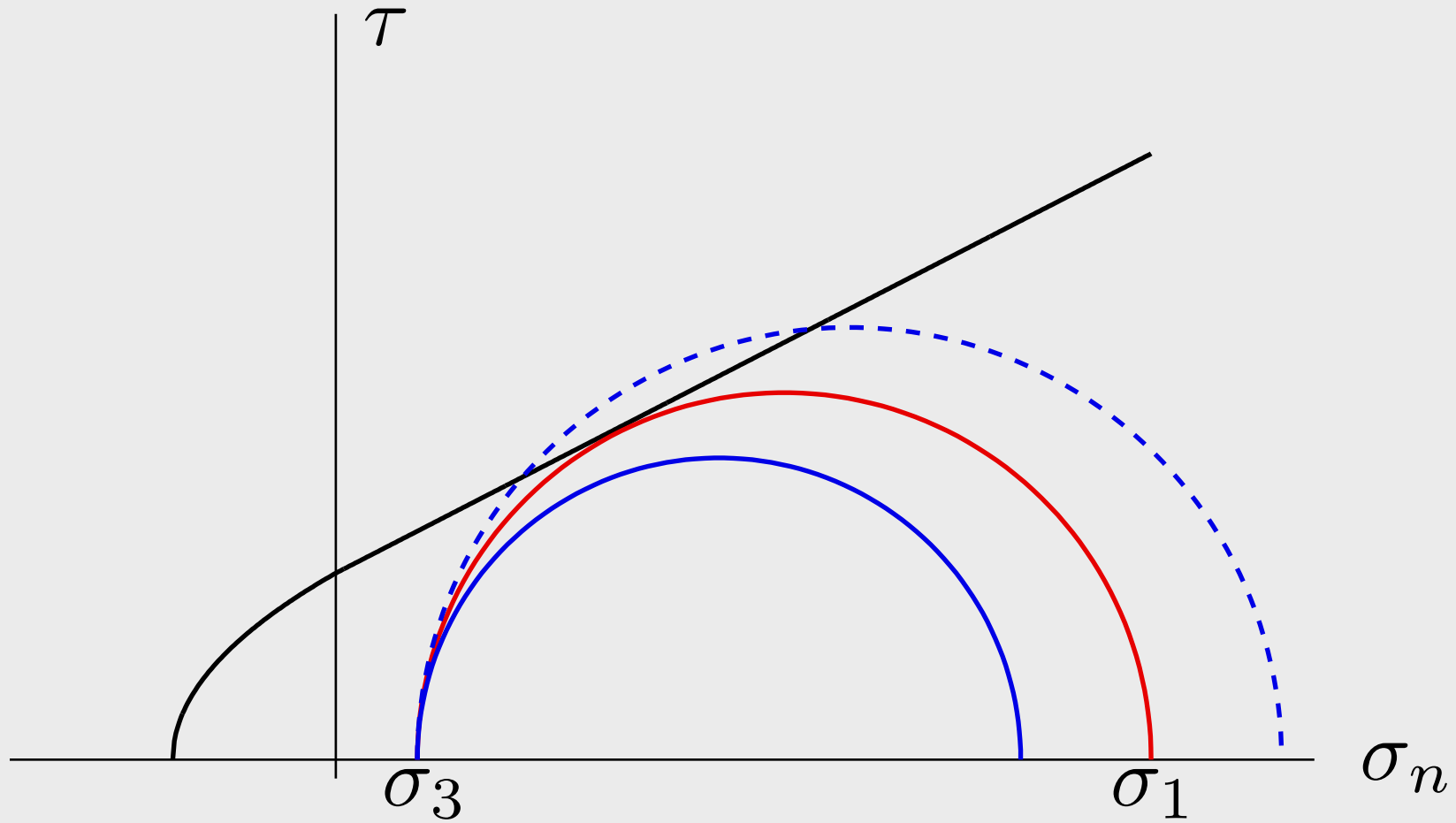
Coulomb/Griffith failure criteria



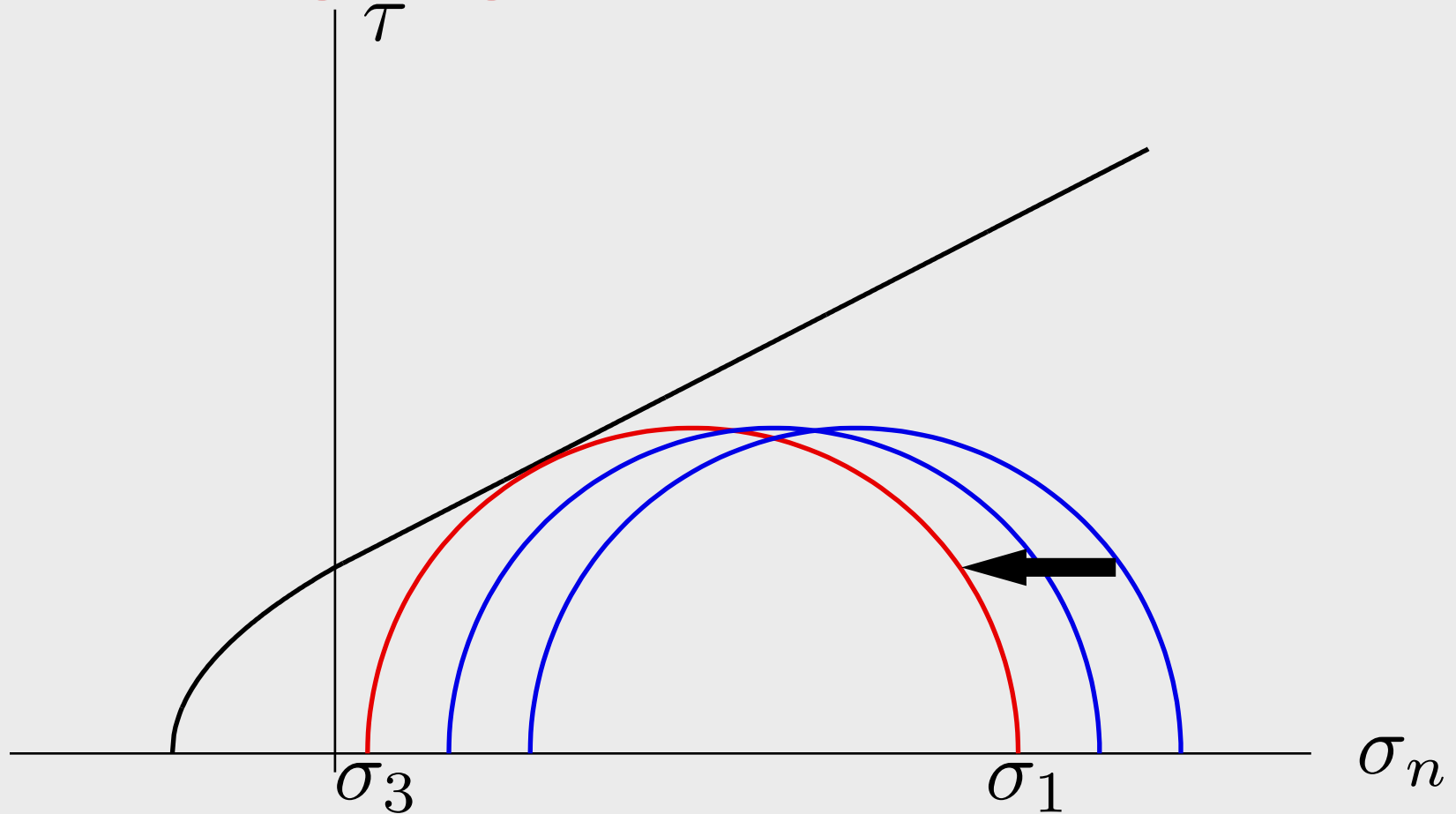
Coulomb/Griffith failure criteria



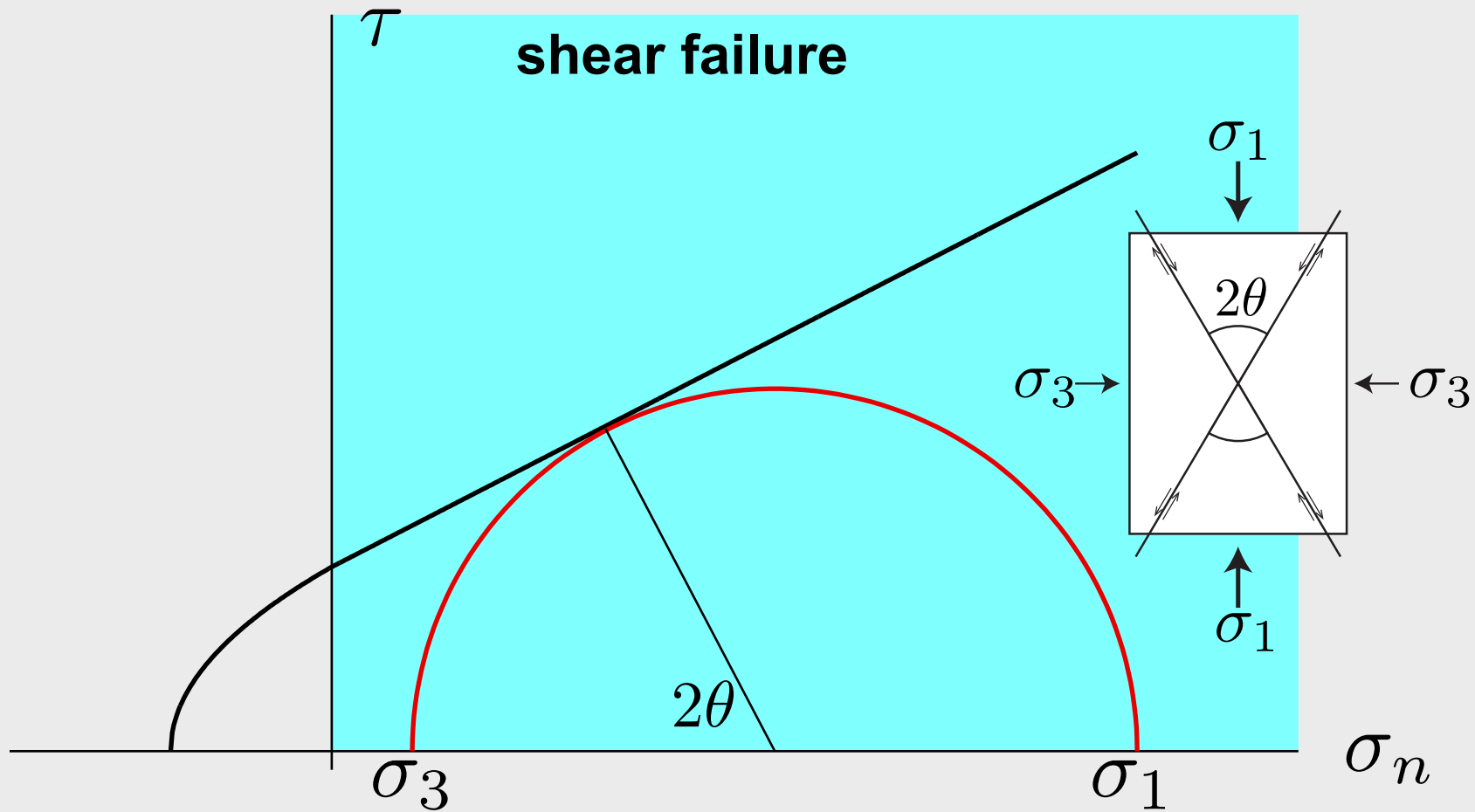
Mohr circle



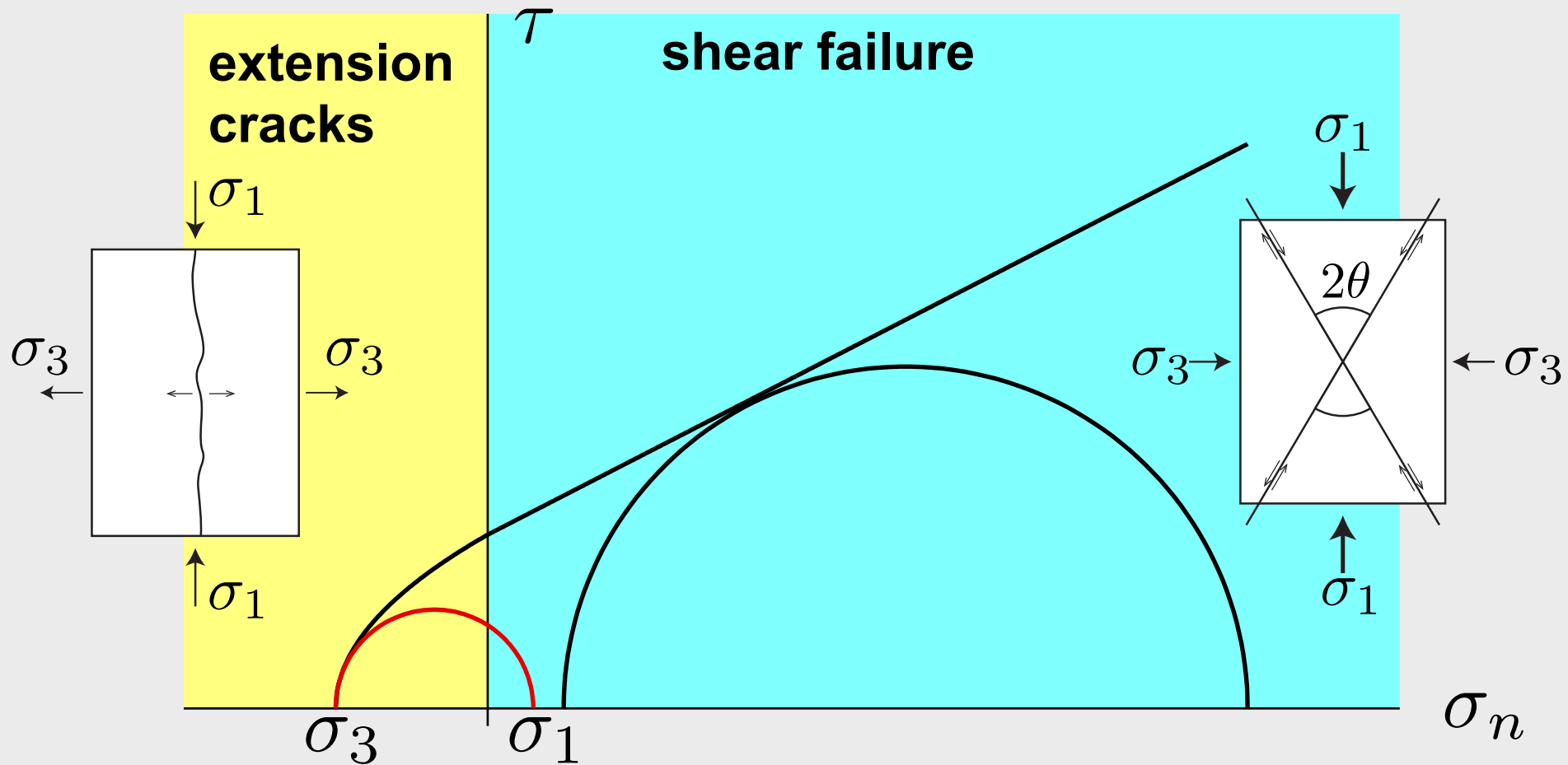
Changing pore pressure



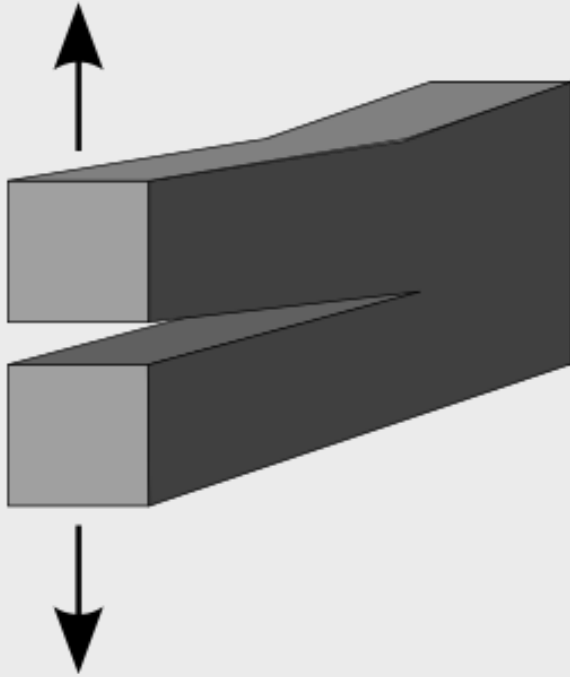
Failure



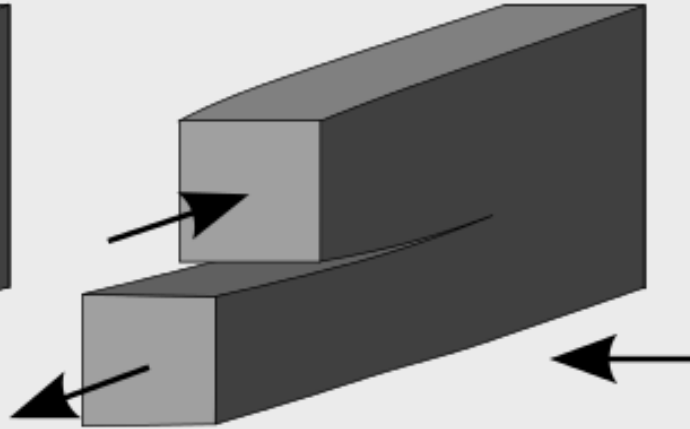
Failure



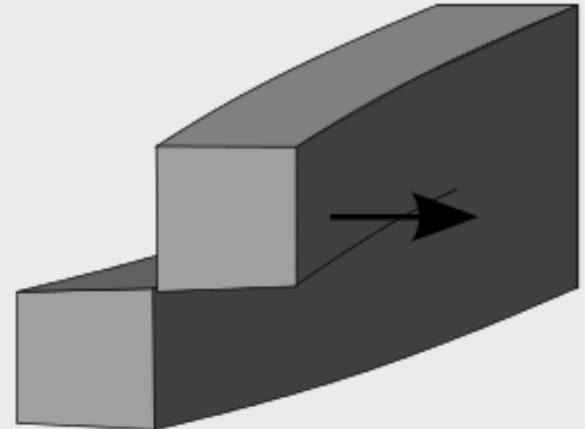
Fracture mechanisms



Mode I
Opening

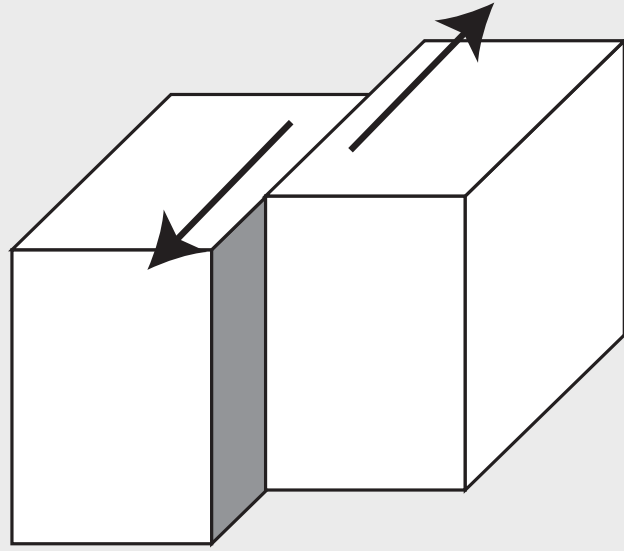


Mode II
Shearing

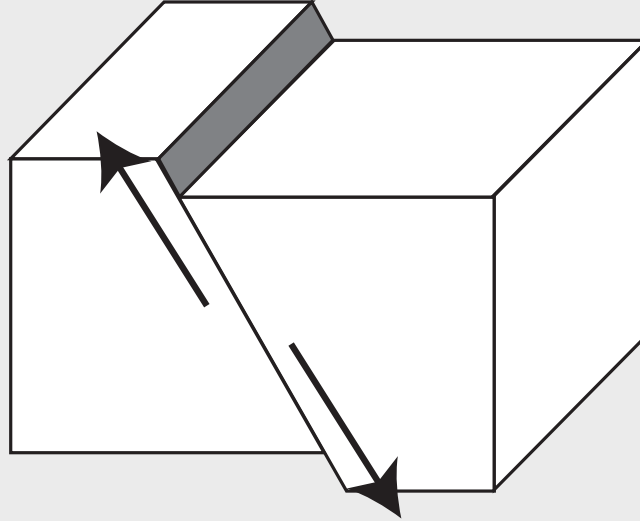


Mode III
Tearing

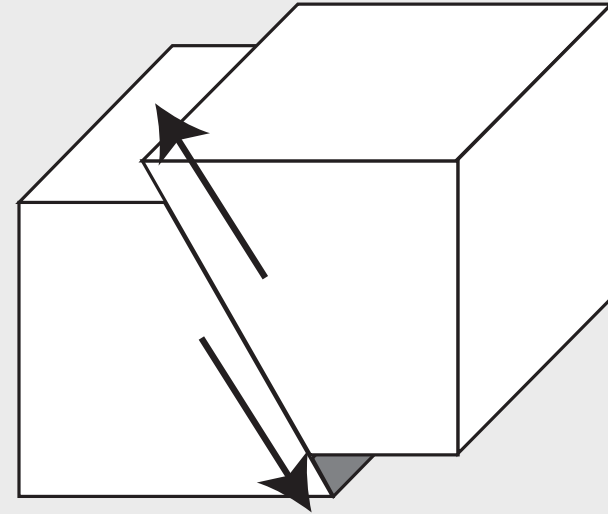
Faulting



Strike slip

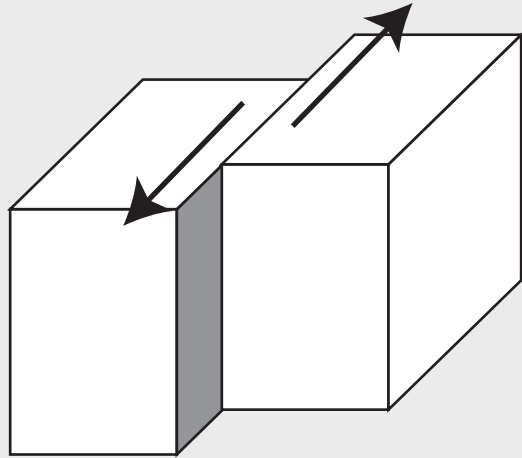


Normal

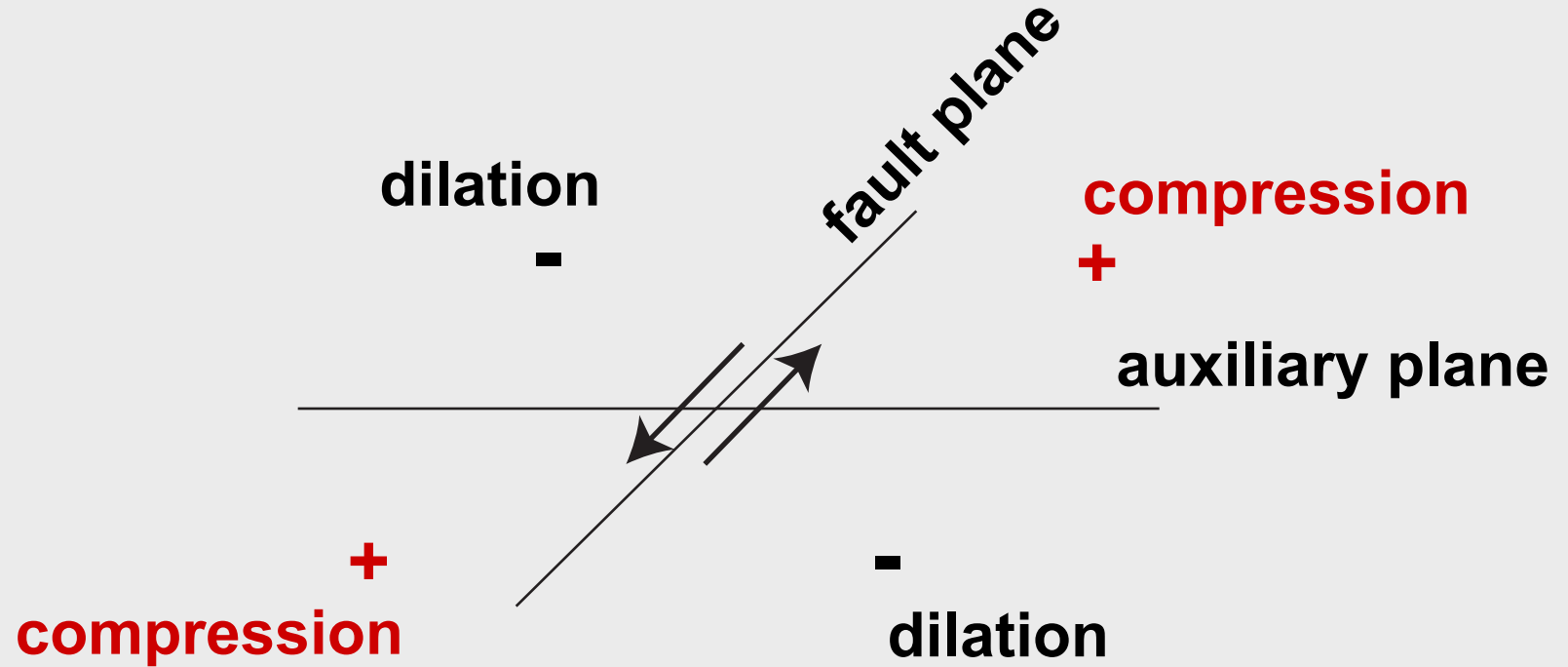


Reverse

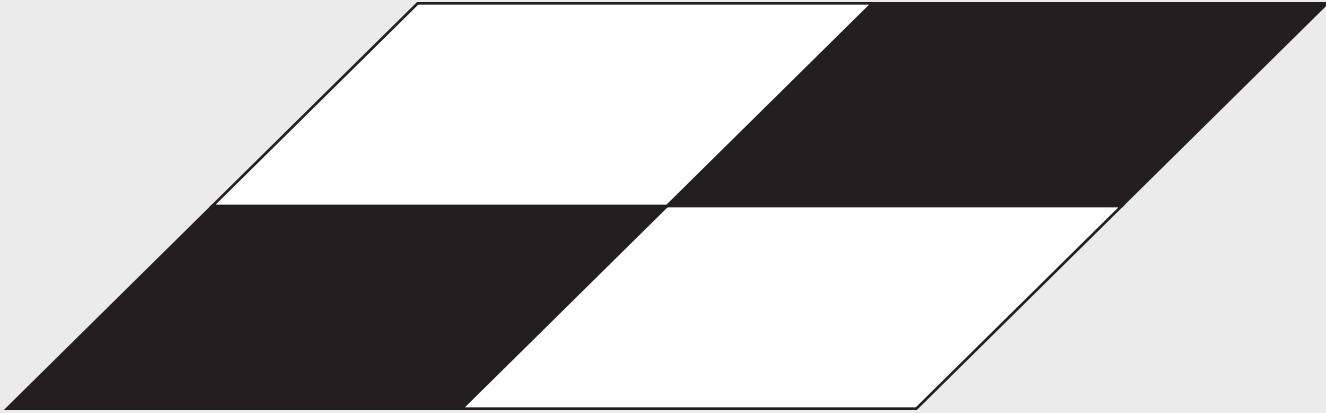
Faulting



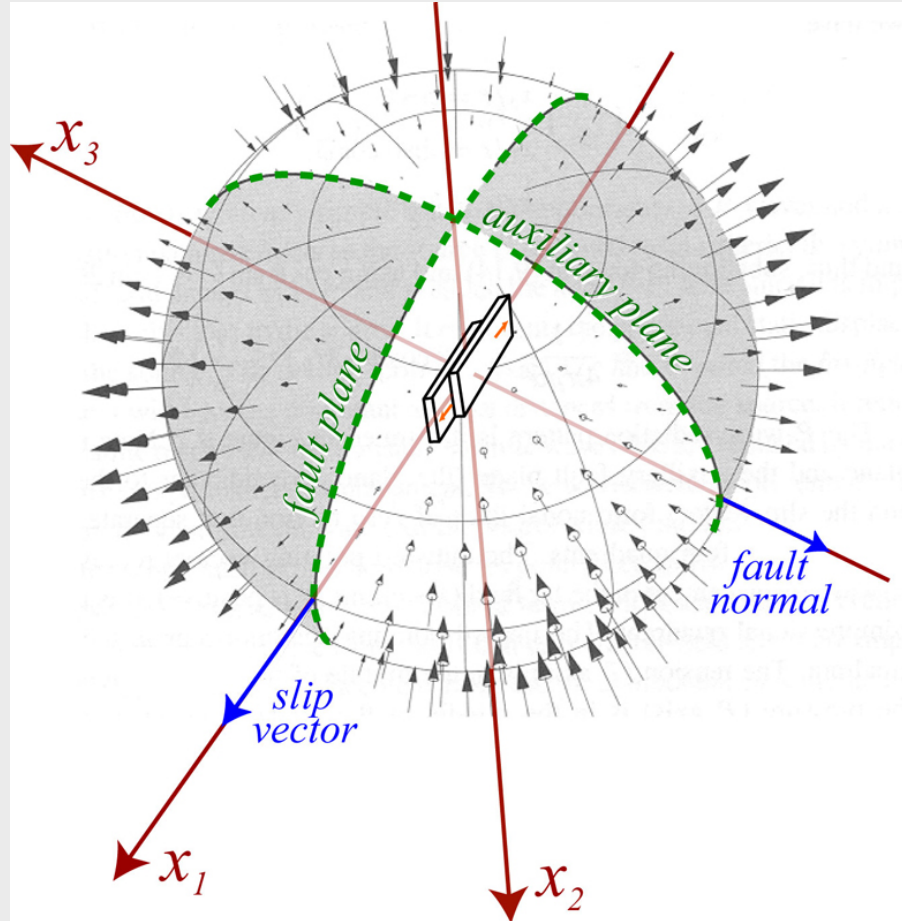
Faulting



Faulting



Seismic wave



Seismic wave

$$\mathcal{L}\mathbf{u}(x) = \mathbf{F}(x)$$

u Displacement

F Force (related to stress)

$\mathcal{L}$ Wave-propagation operator
(e.g., $\nabla^2 + \omega^2/v_p^2$)

Seismic wave

wave propagation

mechanics

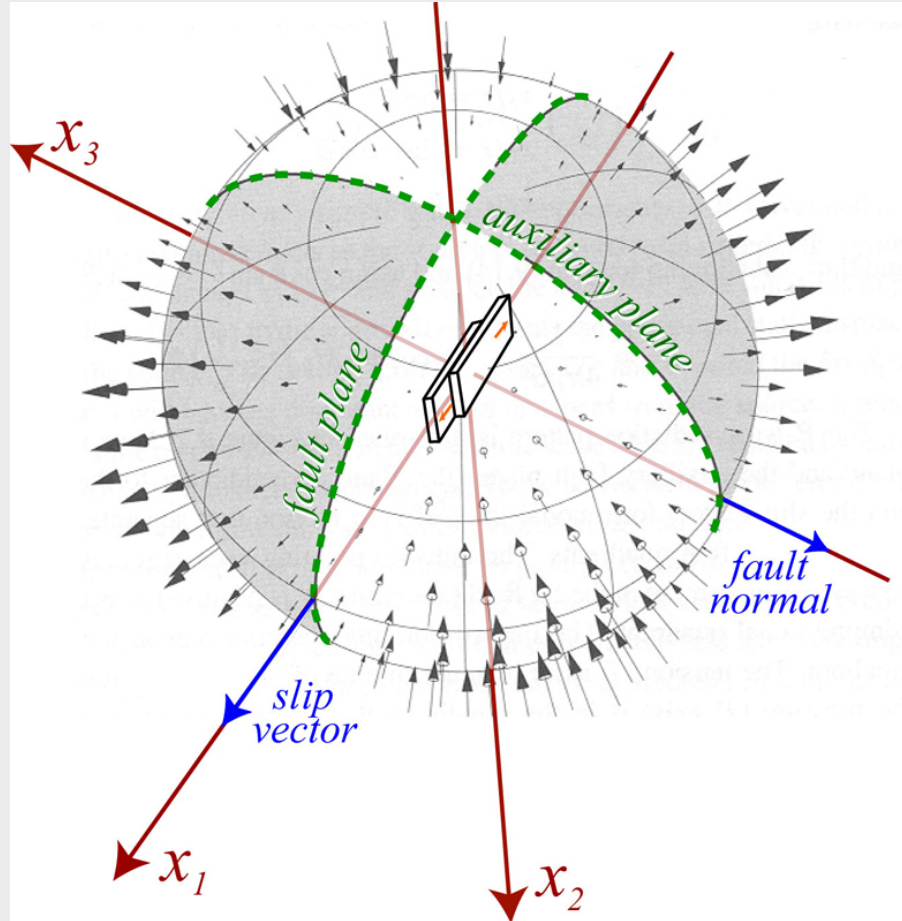
$$\boxed{\mathcal{L}} \underbrace{\mathbf{u}(x)}_{\text{data}} = \boxed{\mathbf{F}(x)}$$

u Displacement

F Force (related to stress)

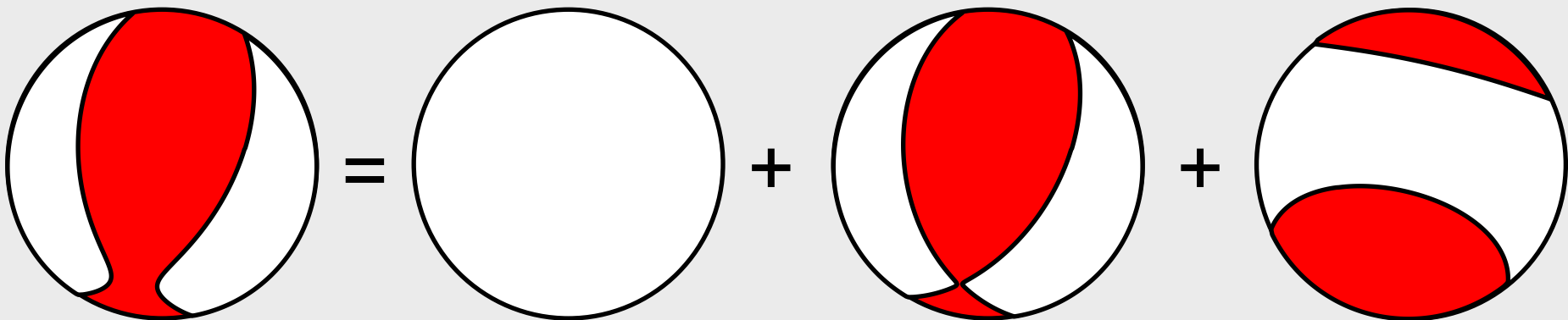
L Wave-propagation operator
(e.g., $\nabla^2 + \omega^2/v_p^2$)

Seismic wave



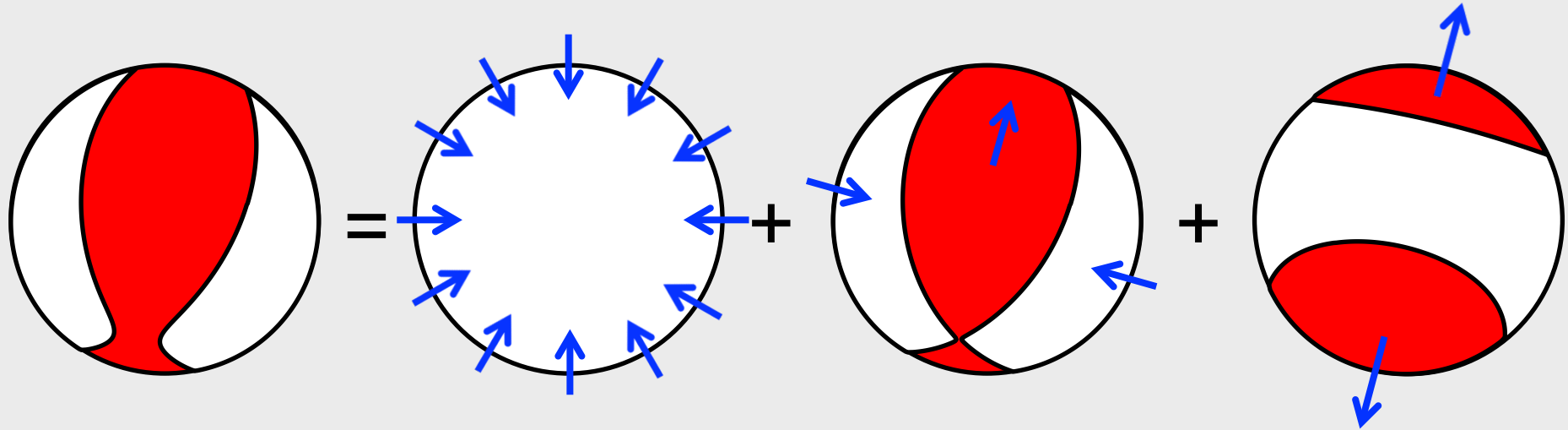
Moment tensor

$$\mathbf{M} = \mathbf{M}^{\text{ISO}} + \mathbf{M}^{\text{DC}} + \mathbf{M}^{\text{CLVD}}$$



Moment tensor

$$\mathbf{M} = \mathbf{M}^{\text{ISO}} + \mathbf{M}^{\text{DC}} + \mathbf{M}^{\text{CLVD}}$$



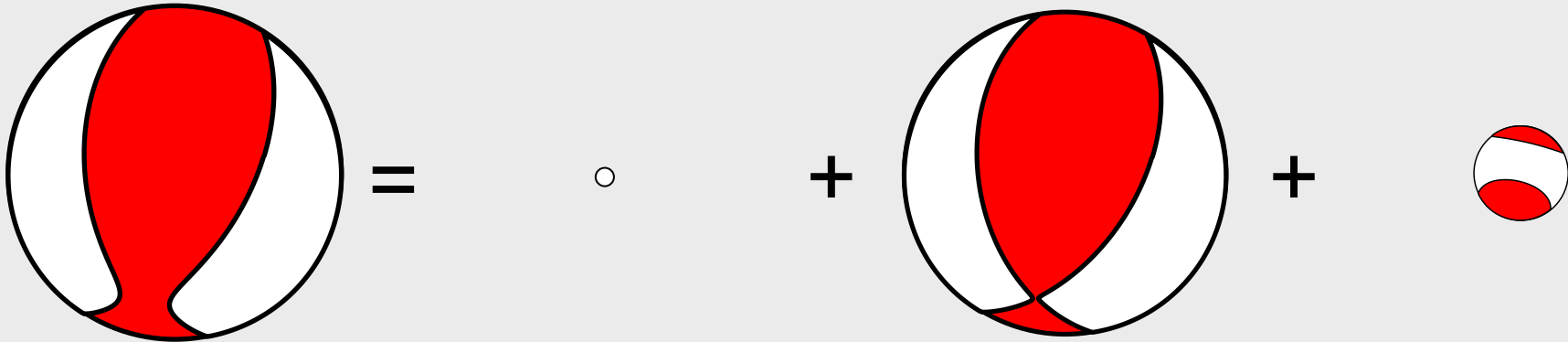
Moment tensor

$$\mathbf{M} = \mathbf{M}^{\text{ISO}} + \mathbf{M}^{\text{DC}} + \mathbf{M}^{\text{CLVD}}$$

0.01%

99%

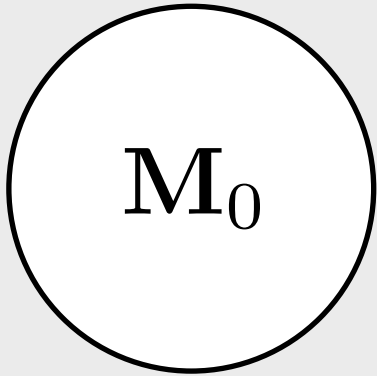
1%





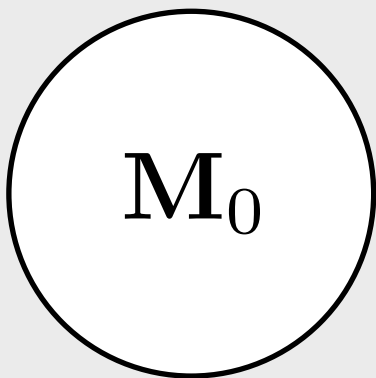
Magnitude

$$M_w = \frac{2}{3} (\log_{10} M_0 - 9.1)$$



Magnitude

$$M_w = \frac{2}{3}(\log_{10} M_0 - 9.1)$$

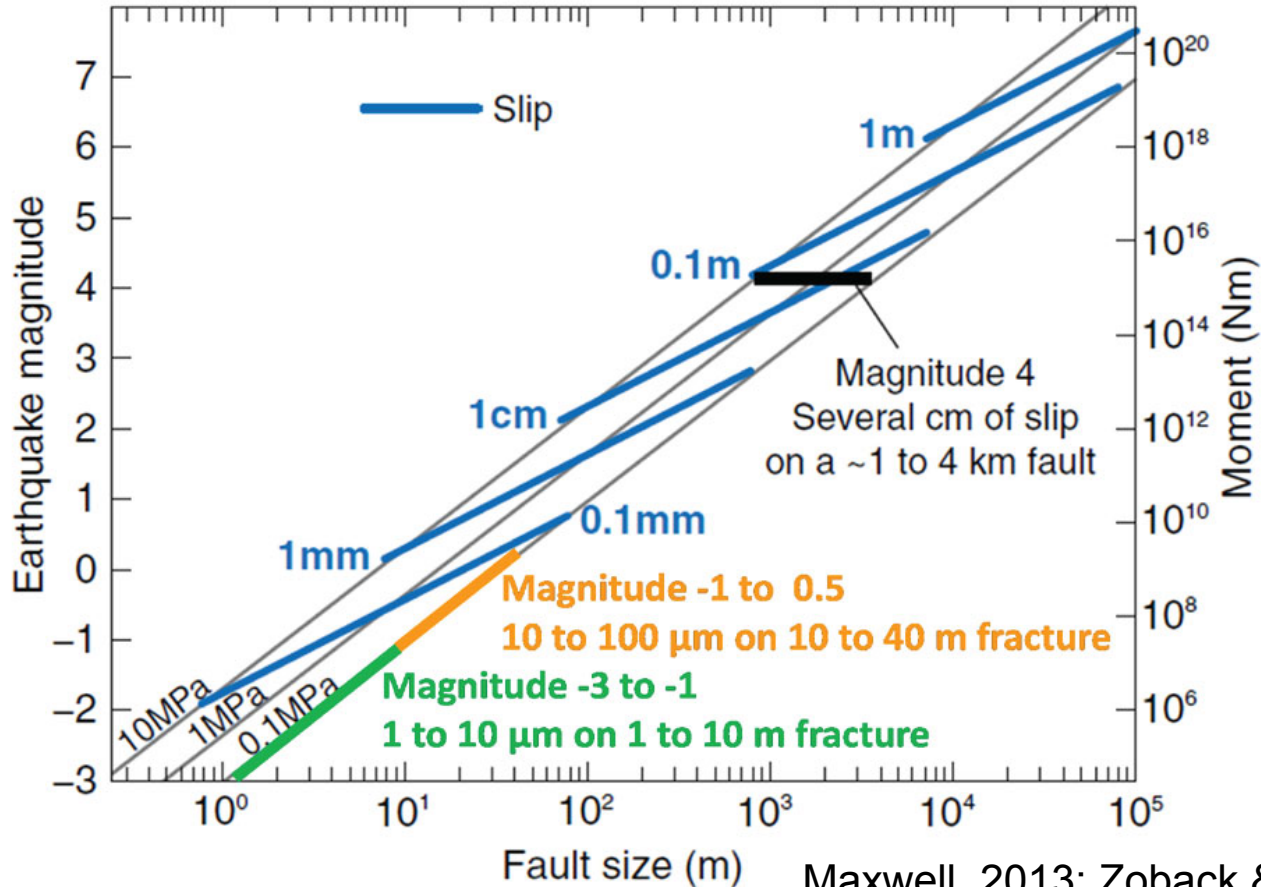


$$M_w \rightarrow M_w + 1$$

$\parallel$

$$M_0 \rightarrow 32M_0$$

Magnitude - scale

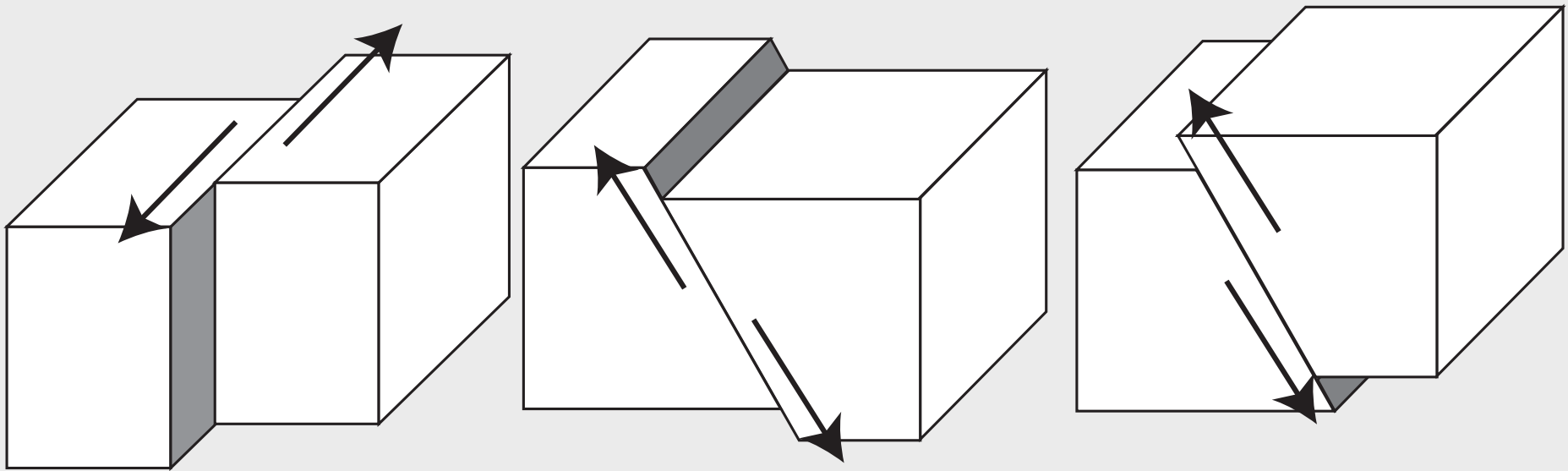


Focal mechanisms

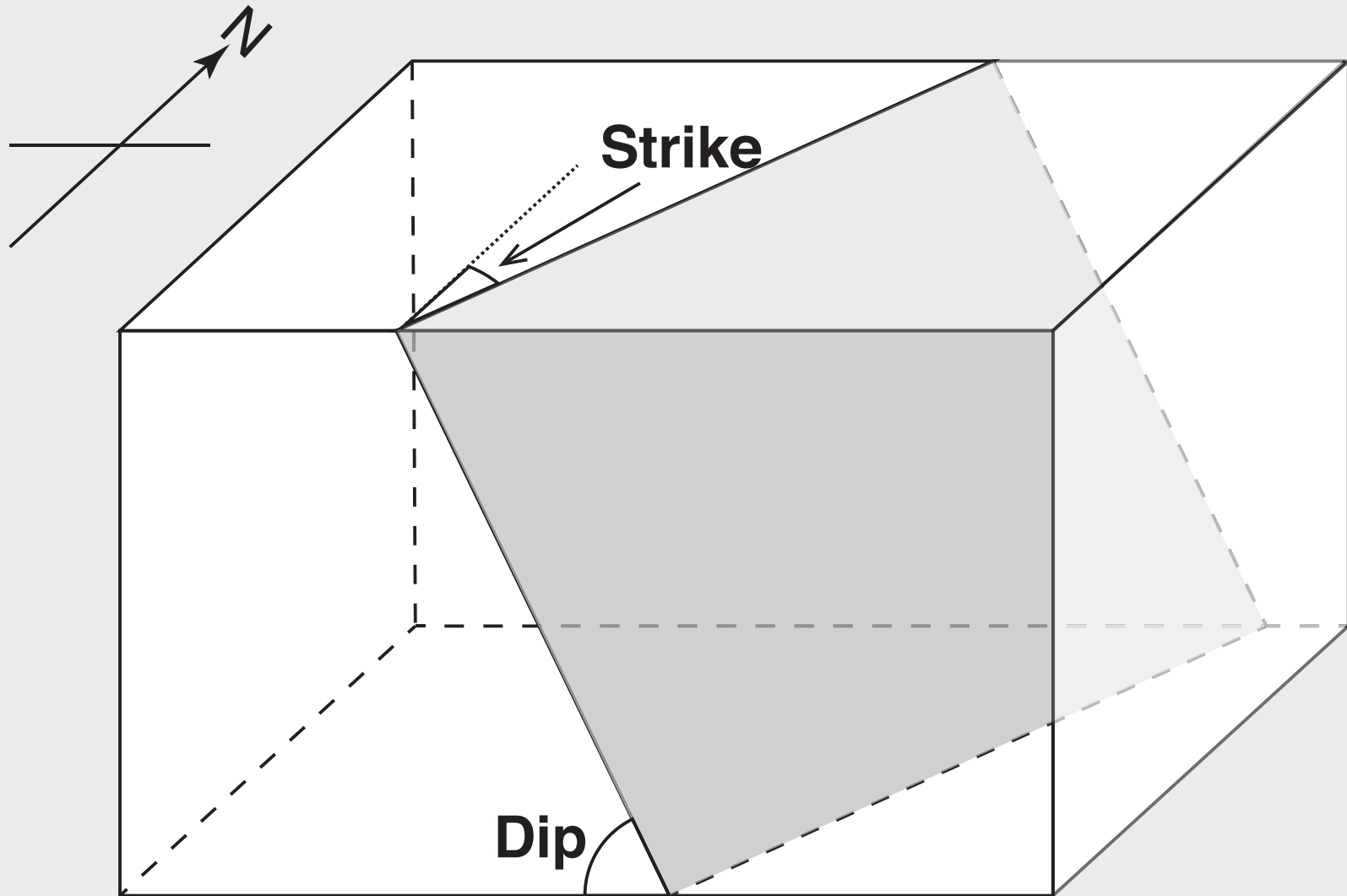
Nori Nakata

Stanford University

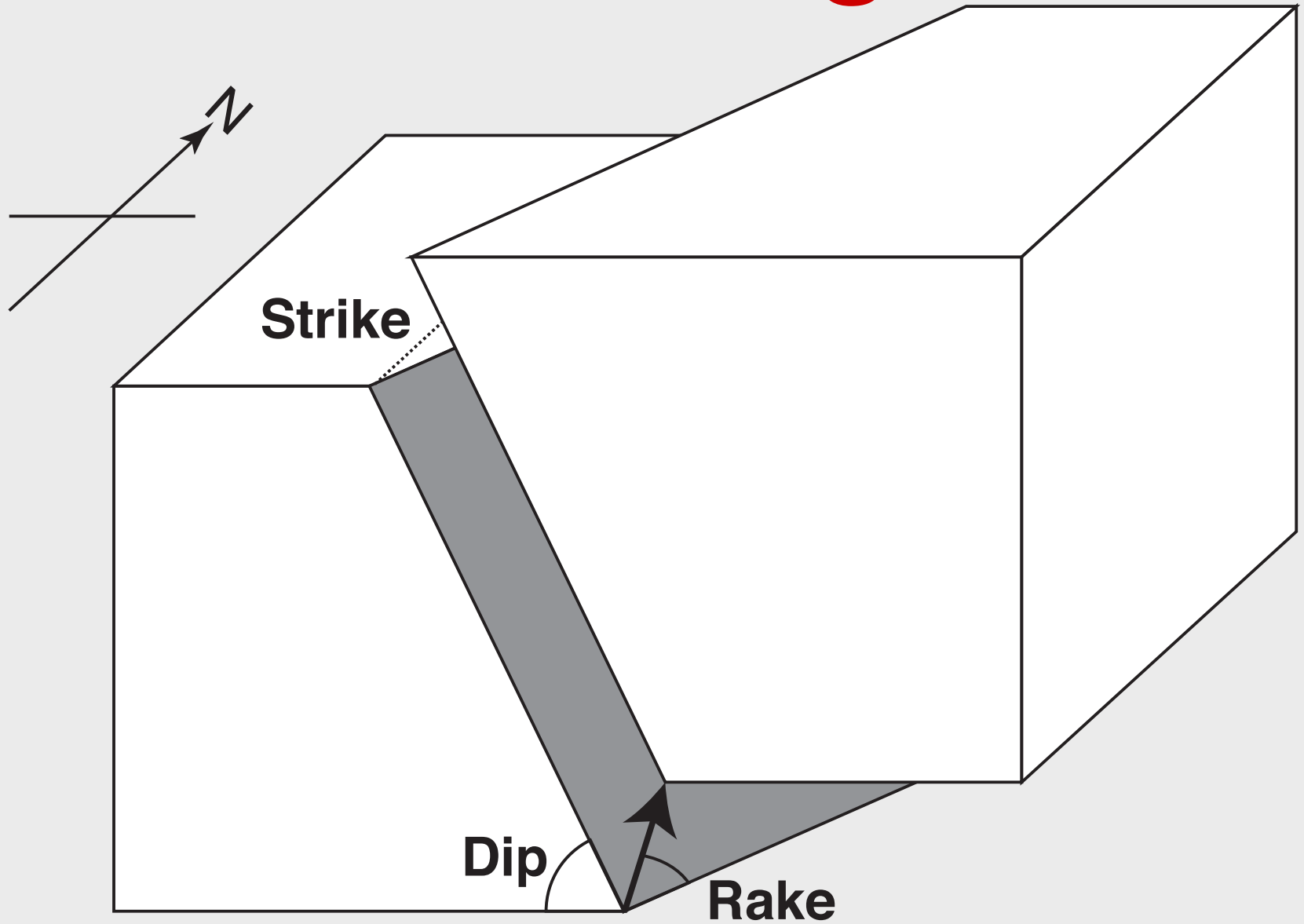
Faulting



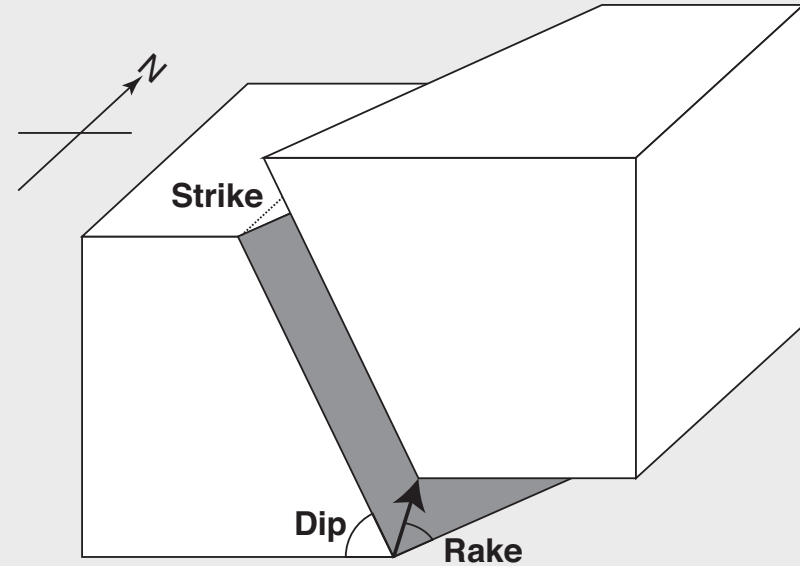
Faulting



Faulting



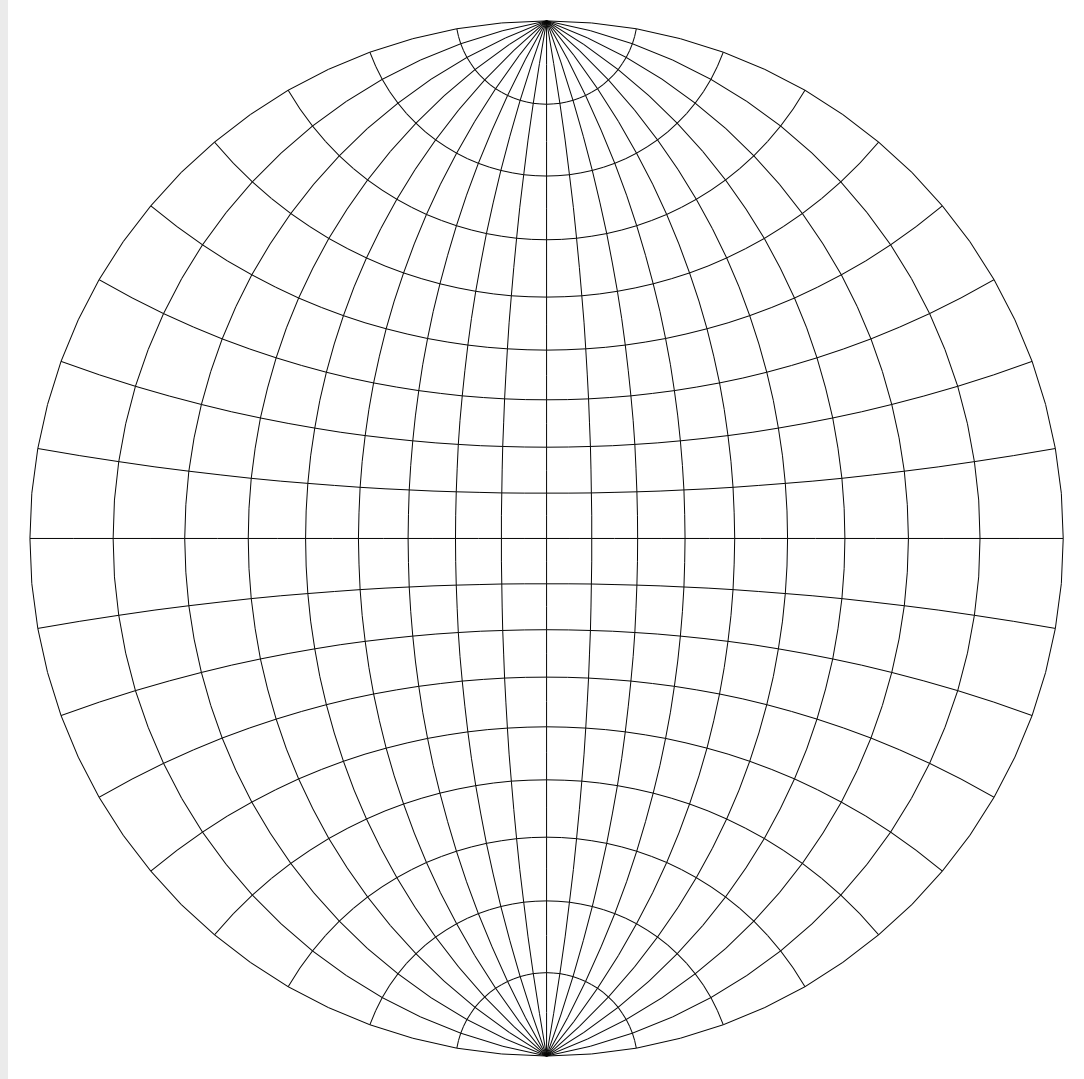
Focal mechanism



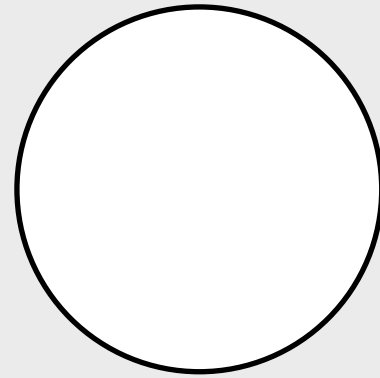
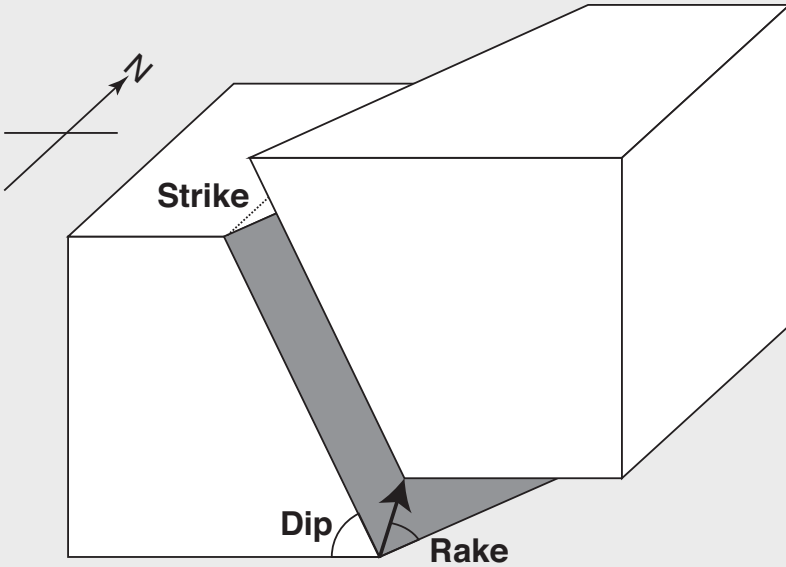
Strike: 0-360

Dip: 0-90

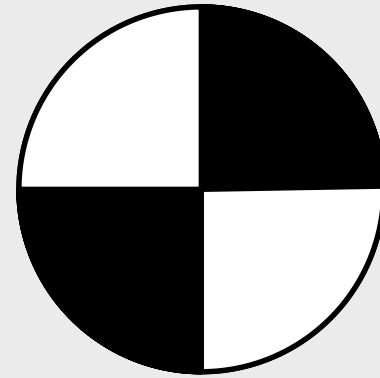
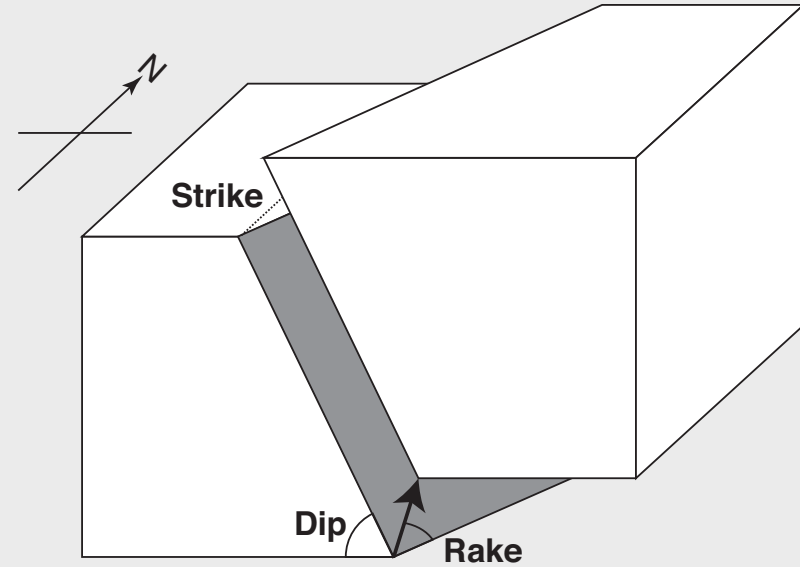
Rake: 0-360



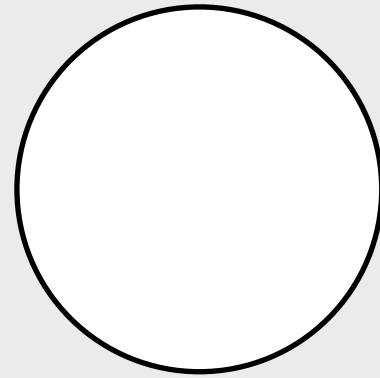
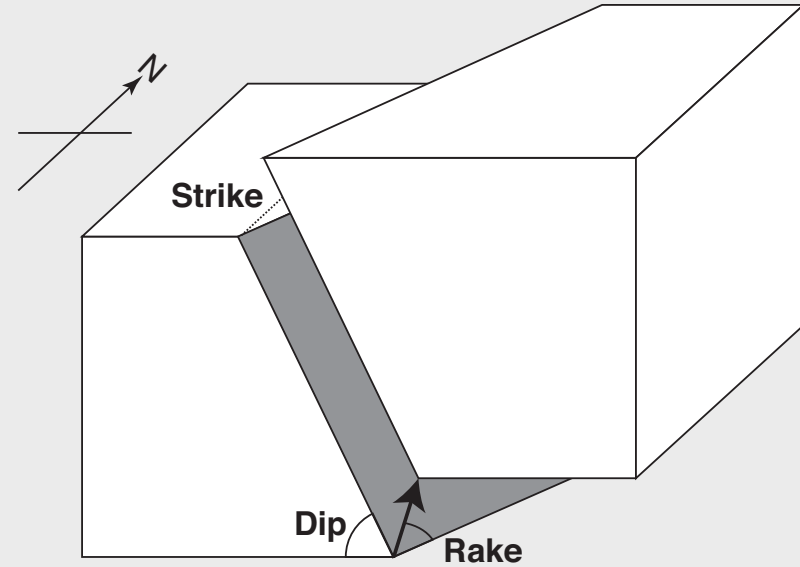
$[s, d, r]=[0,90,0]$



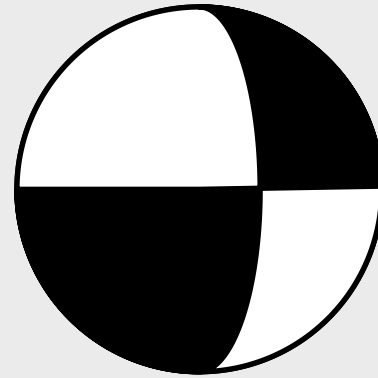
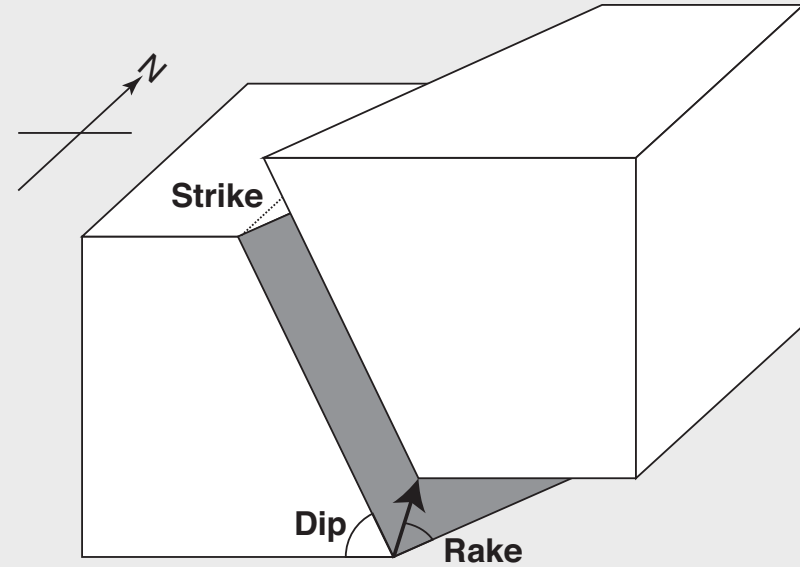
$[s, d, r]=[0,90,0]$



$[s, d, r]=[0,60,0]$

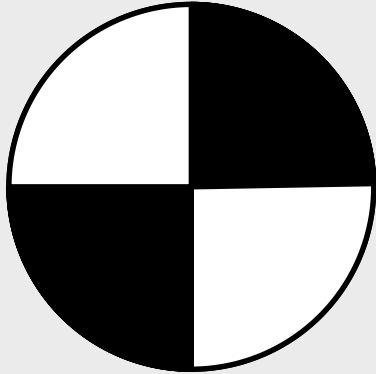


$[s, d, r]=[0,60,0]$

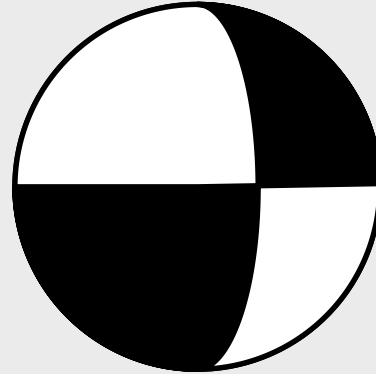


$$[s, d, r]=[0,90-0,0]$$

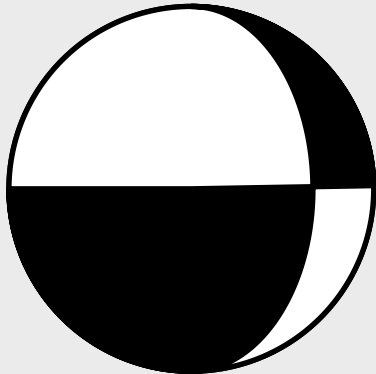
90



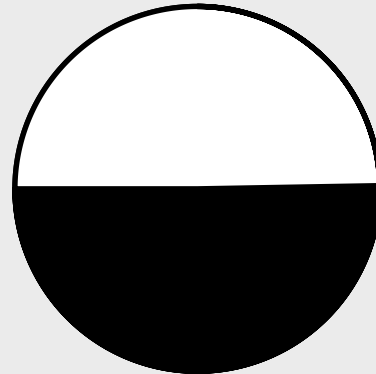
60



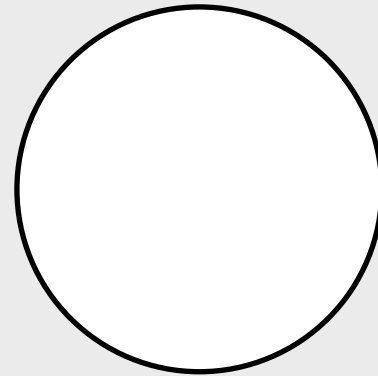
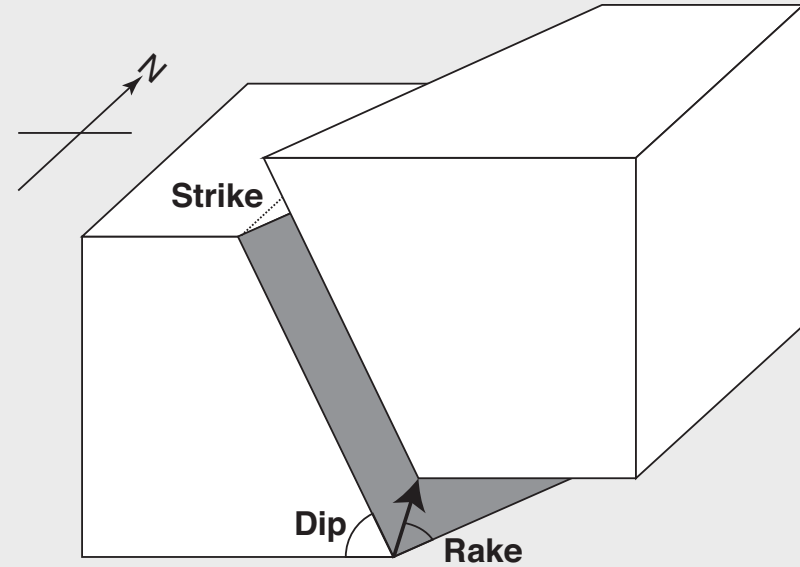
30



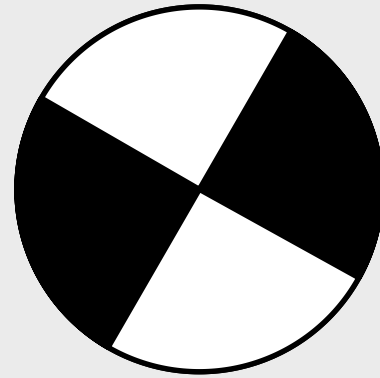
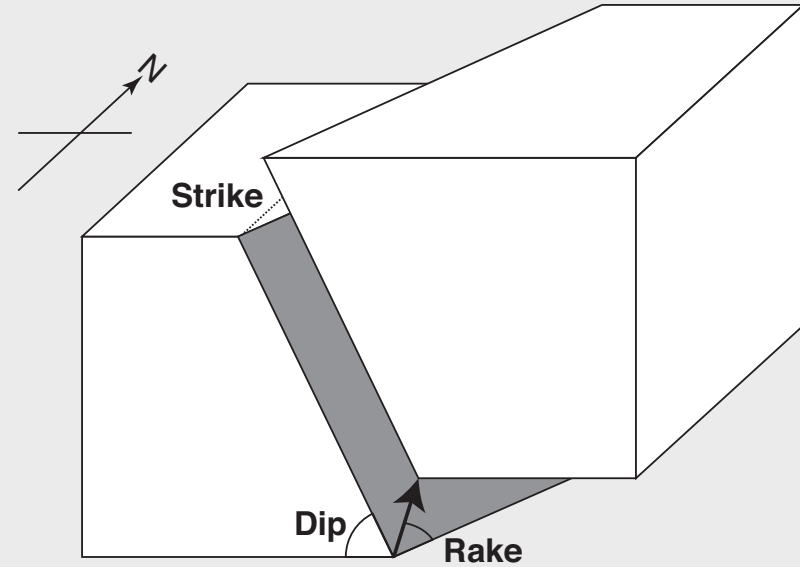
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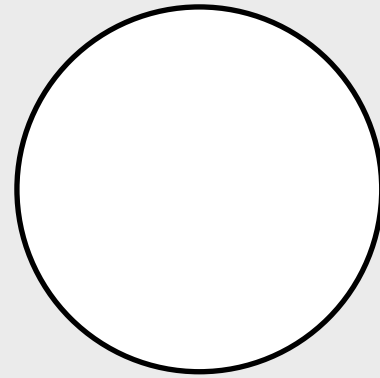
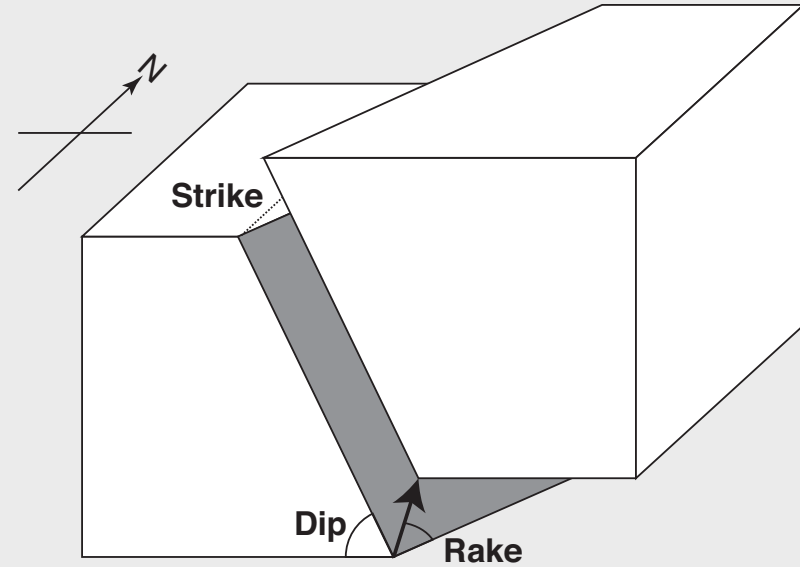
$[s, d, r]=[30,90,0]$



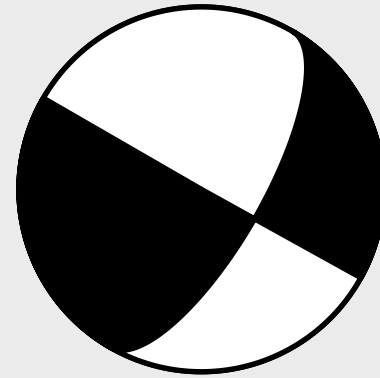
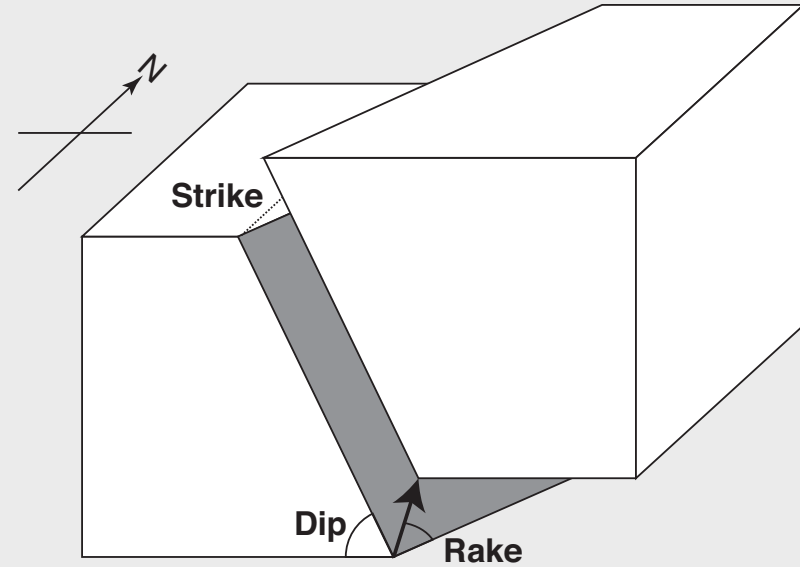
$[s, d, r]=[30, 90, 0]$



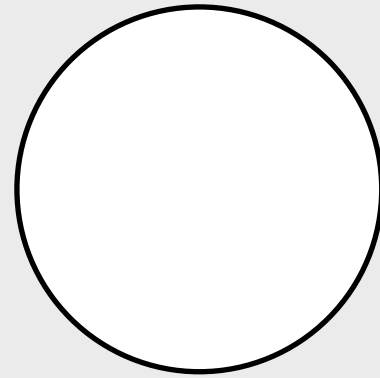
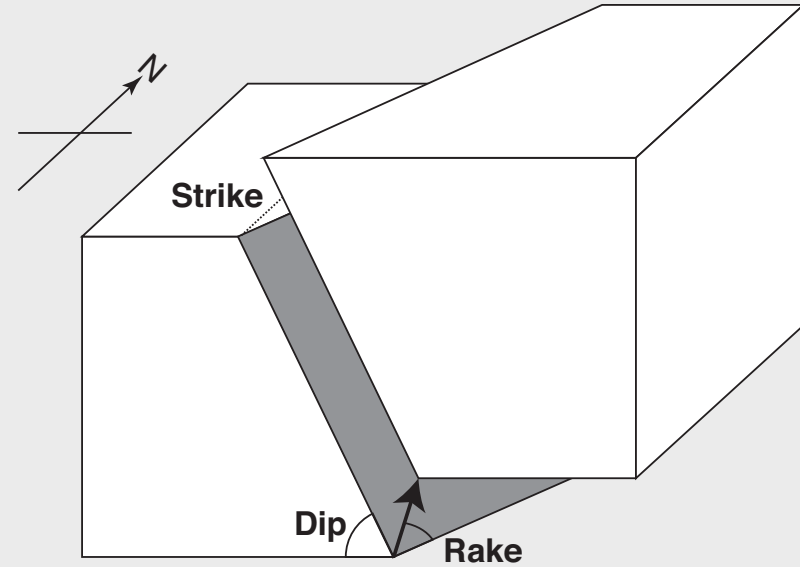
$[s, d, r]=[30, 60, 0]$



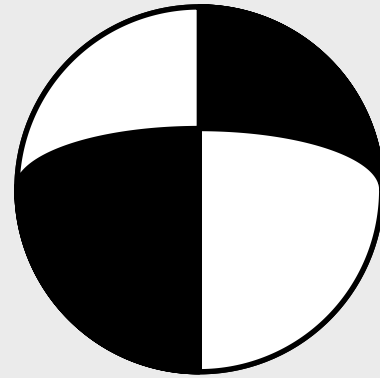
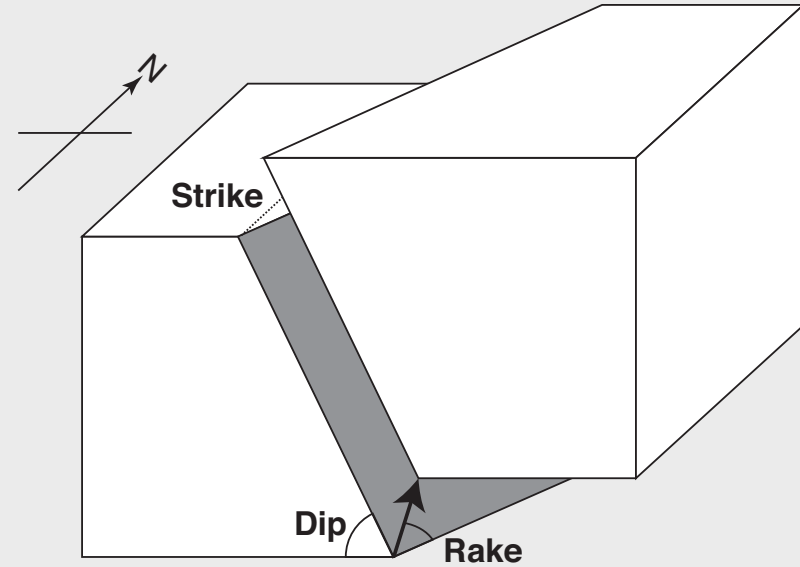
$[s, d, r]=[30, 60, 0]$



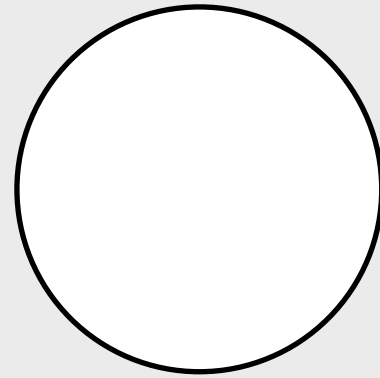
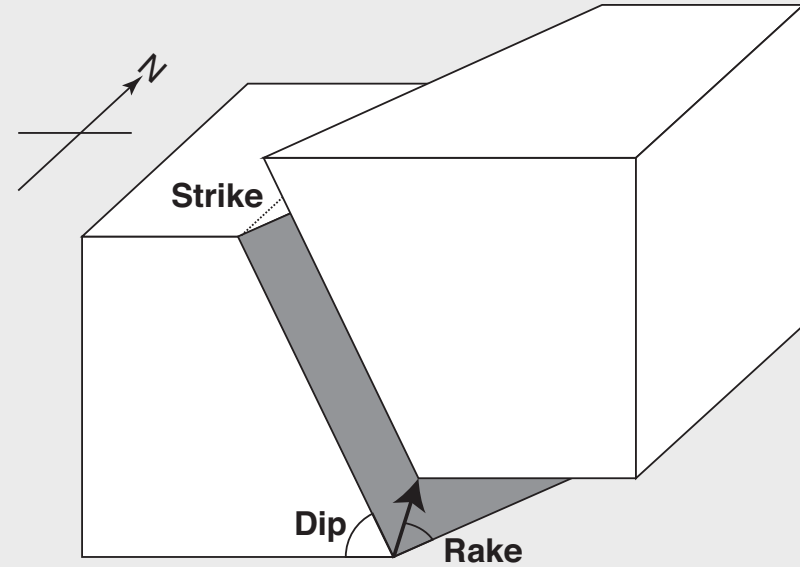
$[s, d, r]=[0,90,30]$



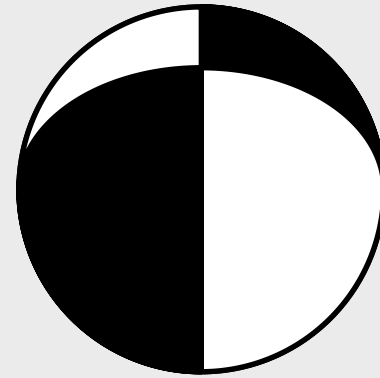
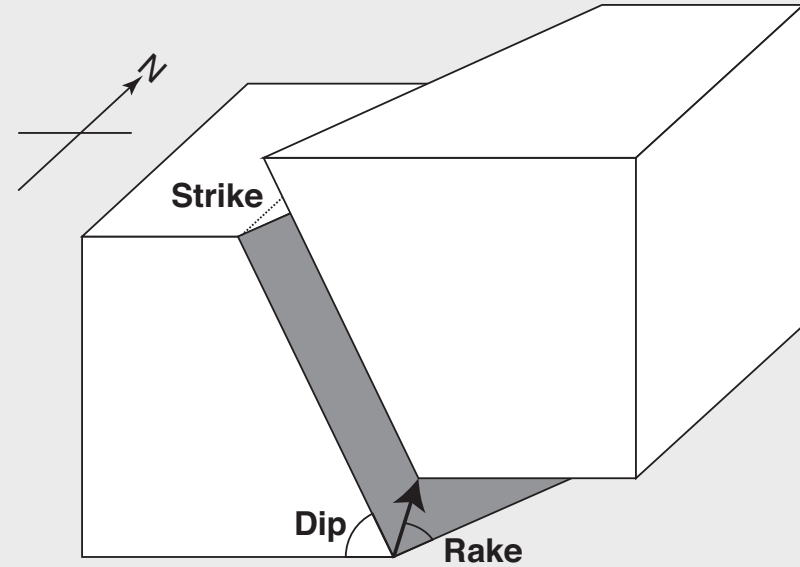
$[s, d, r]=[0,90,30]$



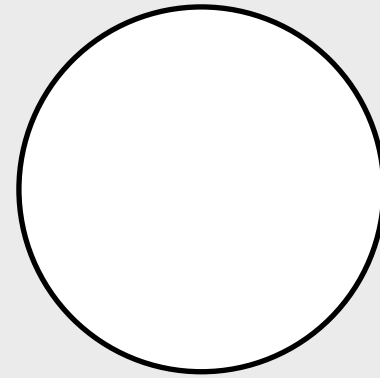
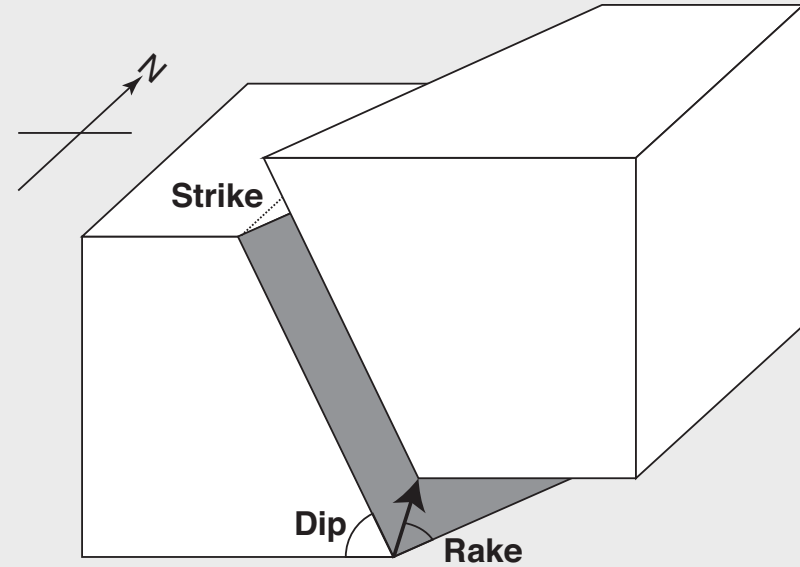
$[s, d, r]=[0,90,60]$



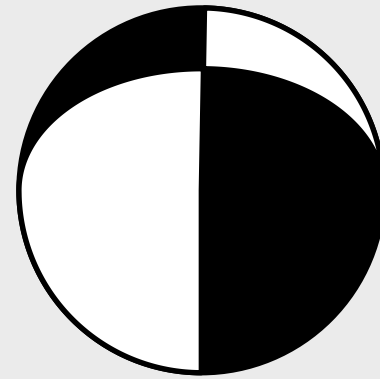
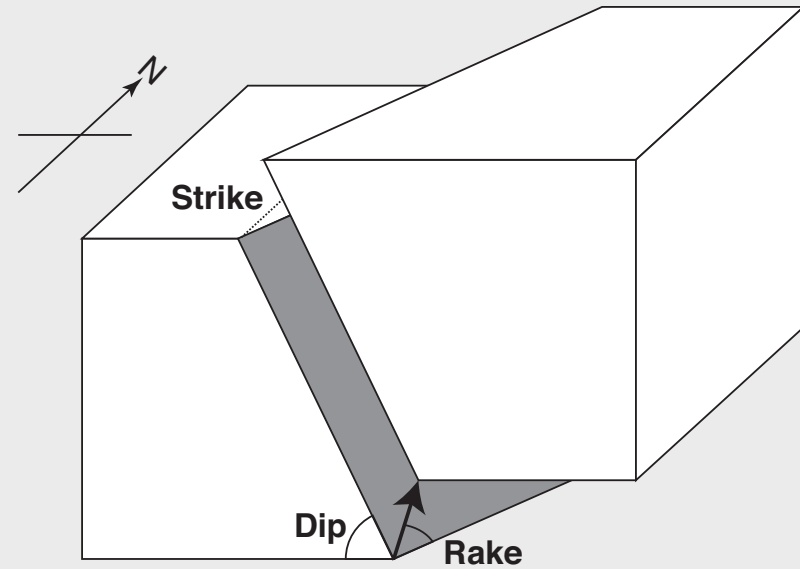
$[s, d, r]=[0,90,60]$



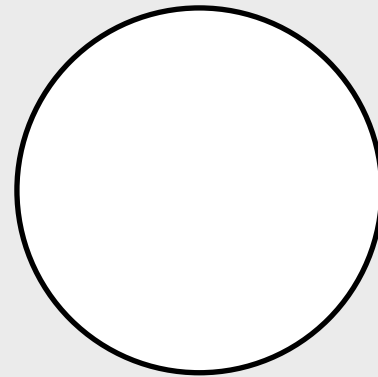
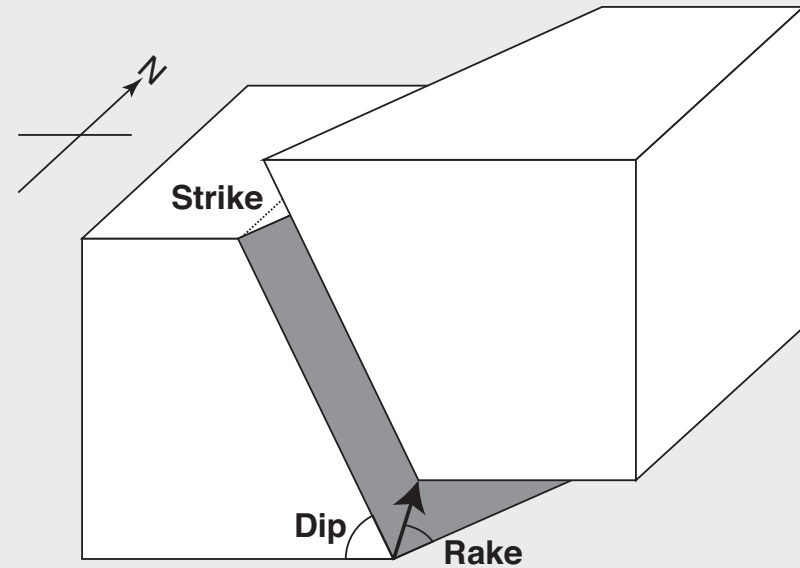
$[s, d, r]=[270, 30, 0]$



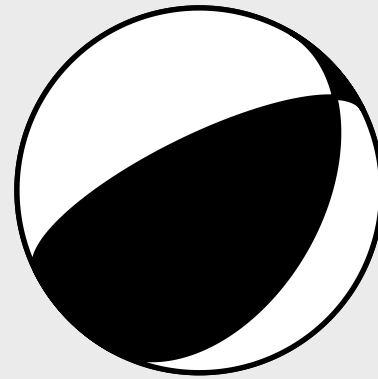
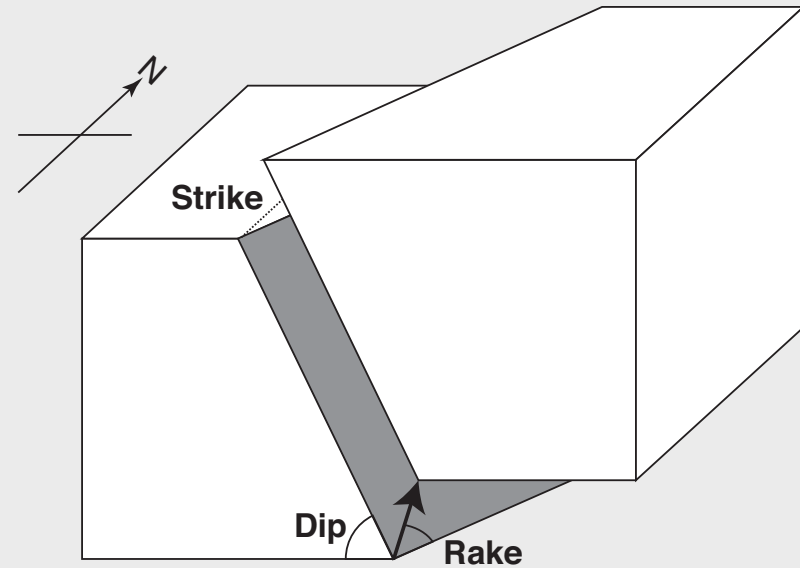
$[s, d, r]=[270, 30, 0]$



$[s, d, r]=[30,30,60]$

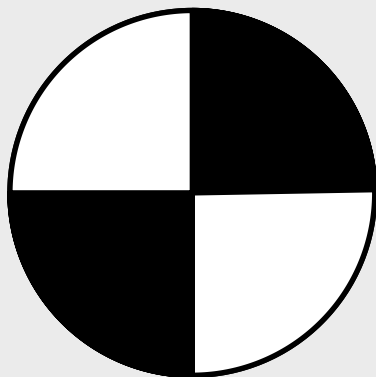


$[s, d, r] = [30, 30, 60]$

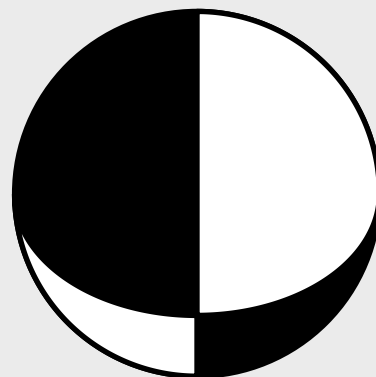
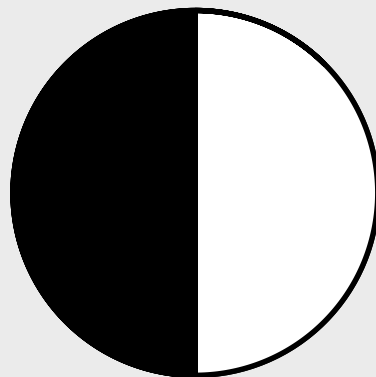
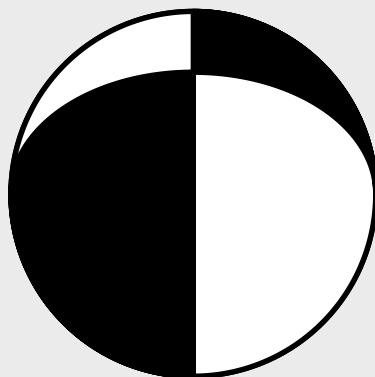
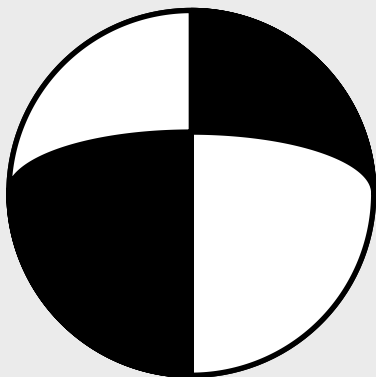


[s, d, r]=[0,90,0-270]

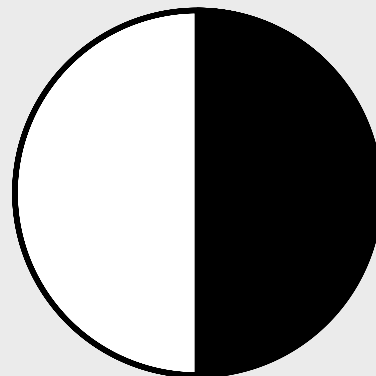
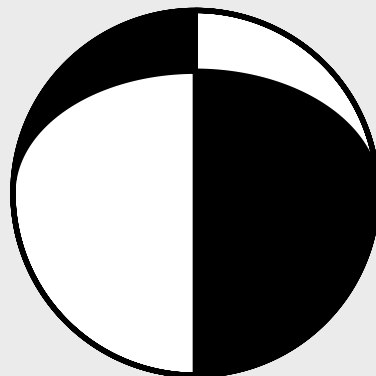
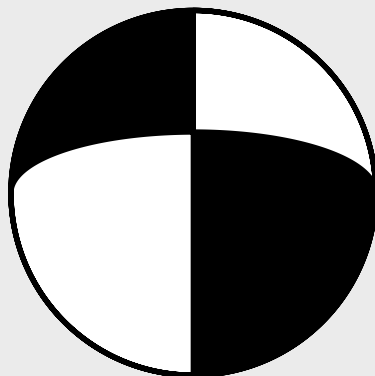
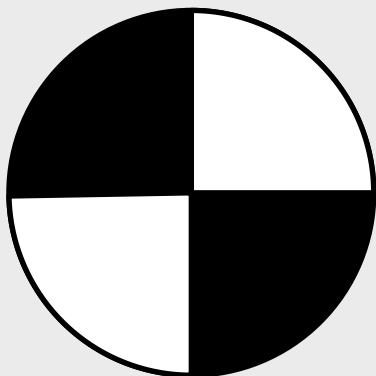
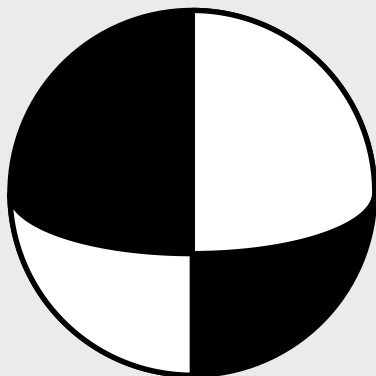
0



120



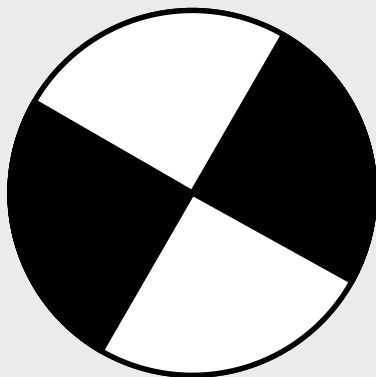
150



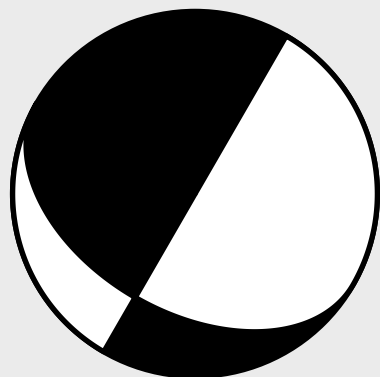
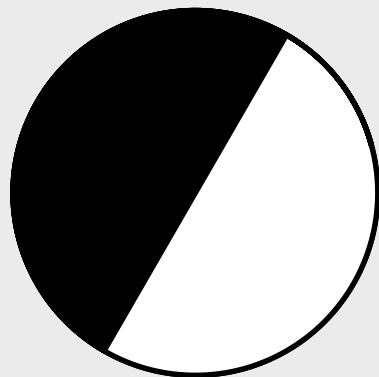
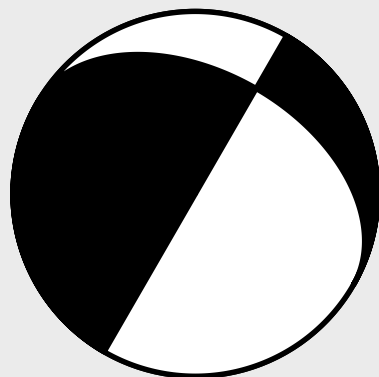
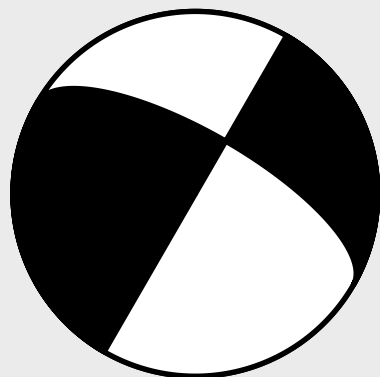
270

[s, d, r]=[30,90,0-270]

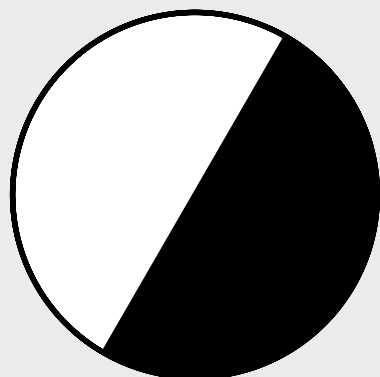
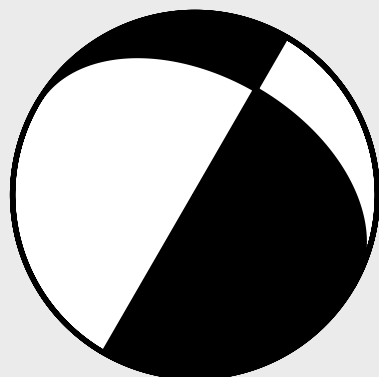
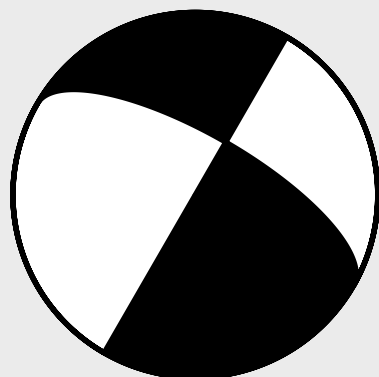
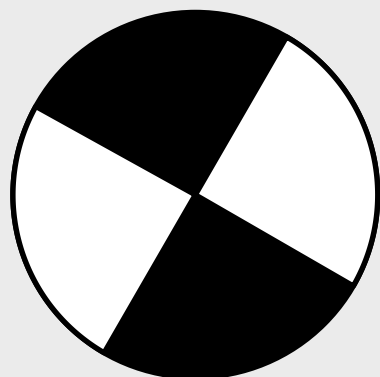
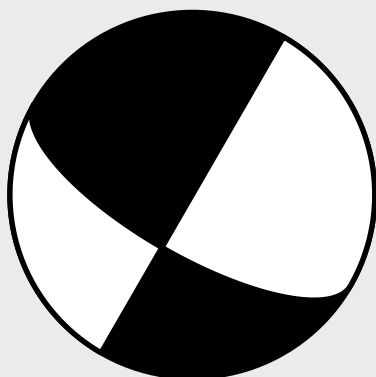
0



120



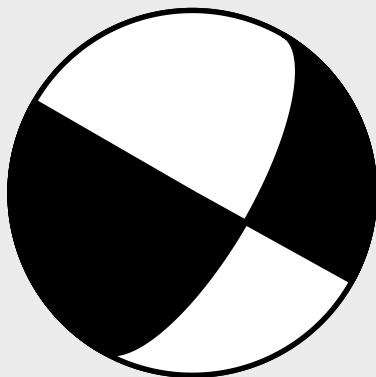
150



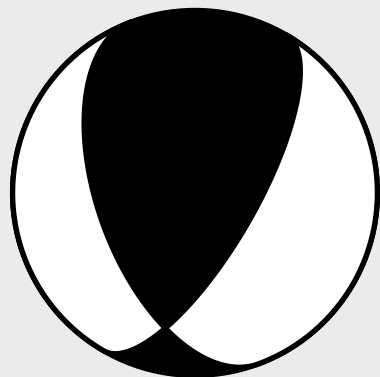
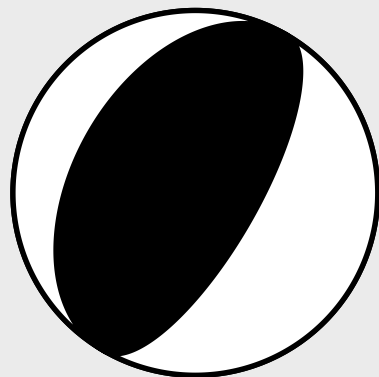
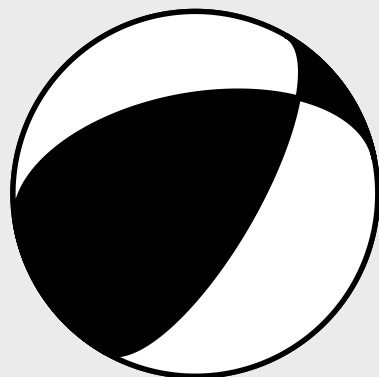
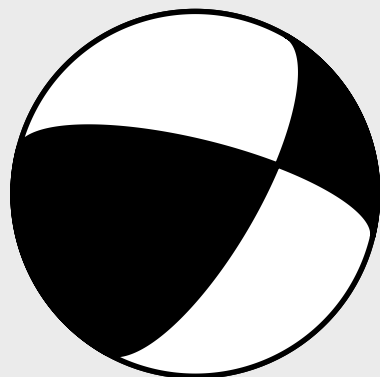
270

$[s, d, r]=[30, 60, 0-270]$

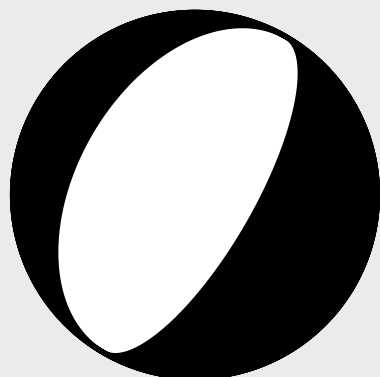
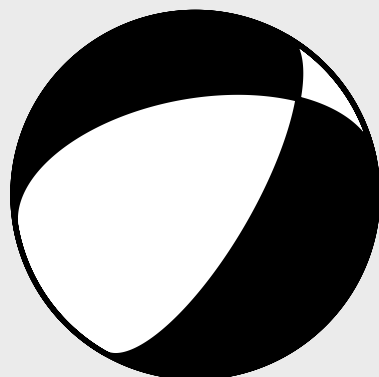
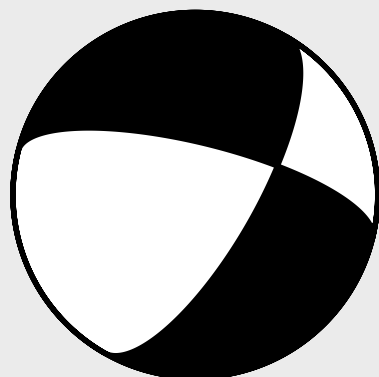
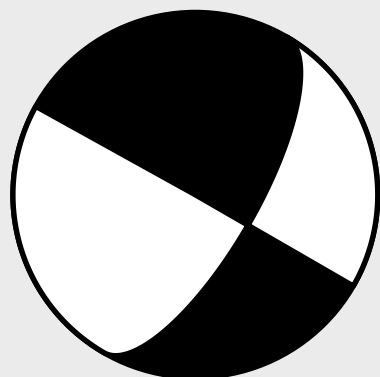
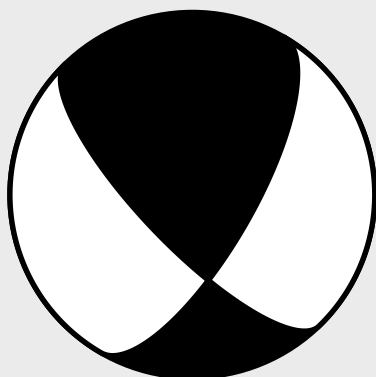
0



120

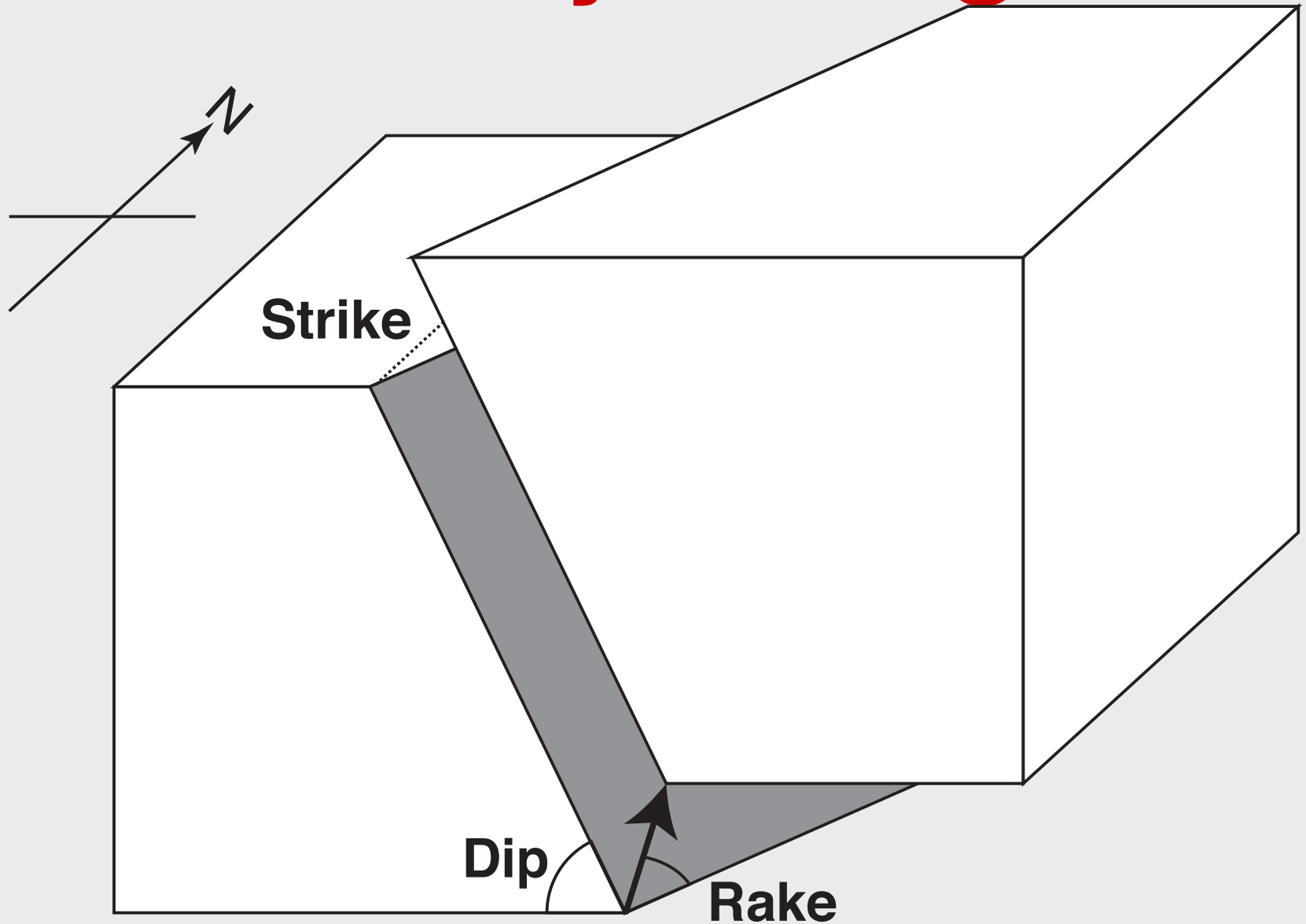


150



270

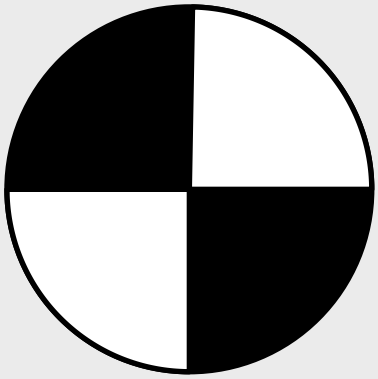
Are they enough?



Are they enough?

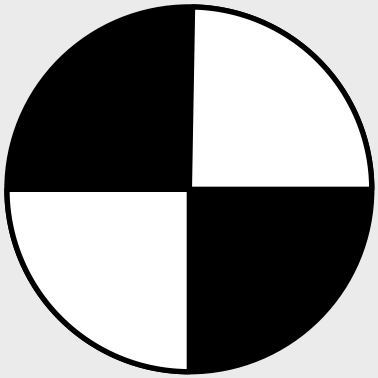


Moment tensor



Moment tensor

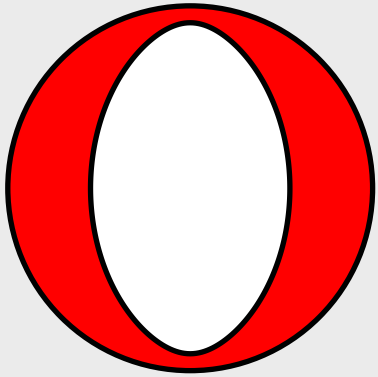
$$[s,d,r]=[0,90,0]$$



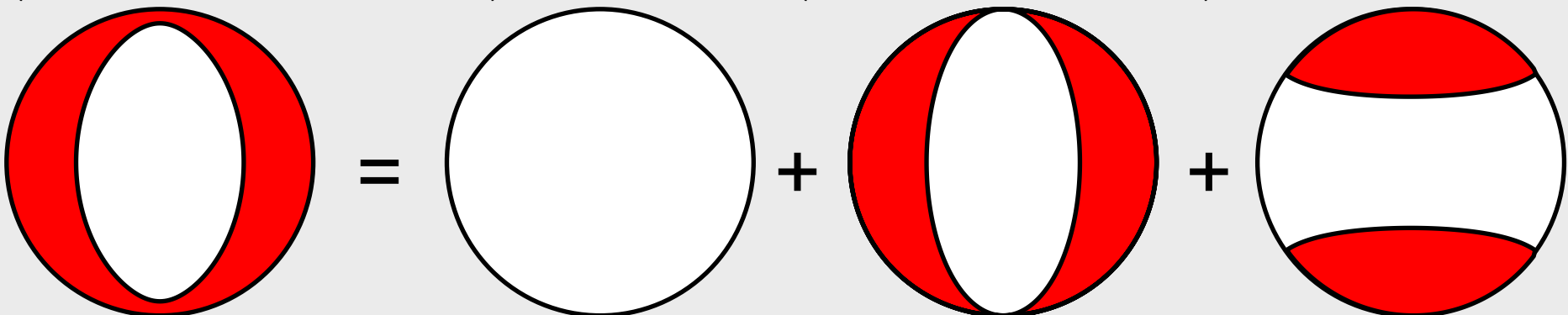
$$\frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Moment tensor

$$\begin{pmatrix} 0.0566 & 0 & 0 \\ 0 & 1.7015 & 0 \\ 0 & 0 & -1.758 \end{pmatrix}$$

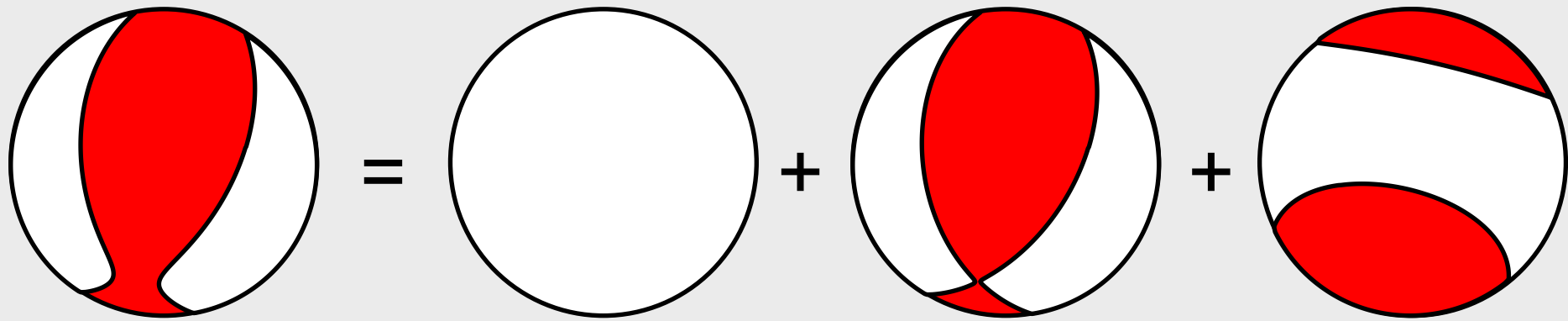


Moment tensor

$$\begin{pmatrix} 0.0566 & 0 & 0 \\ 0 & 1.7015 & 0 \\ 0 & 0 & -1.758 \end{pmatrix} \quad \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1.7298 & 0 \\ 0 & 0 & -1.7298 \end{pmatrix}$$


$$= \begin{pmatrix} -7.4e-17 & 0 & 0 \\ 0 & -7.4e-17 & 0 \\ 0 & 0 & -7.4e-17 \end{pmatrix} \quad \begin{pmatrix} 0.0566 & 0 & 0 \\ 0 & -0.0283 & 0 \\ 0 & 0 & 0.0283 \end{pmatrix}$$

Moment tensor

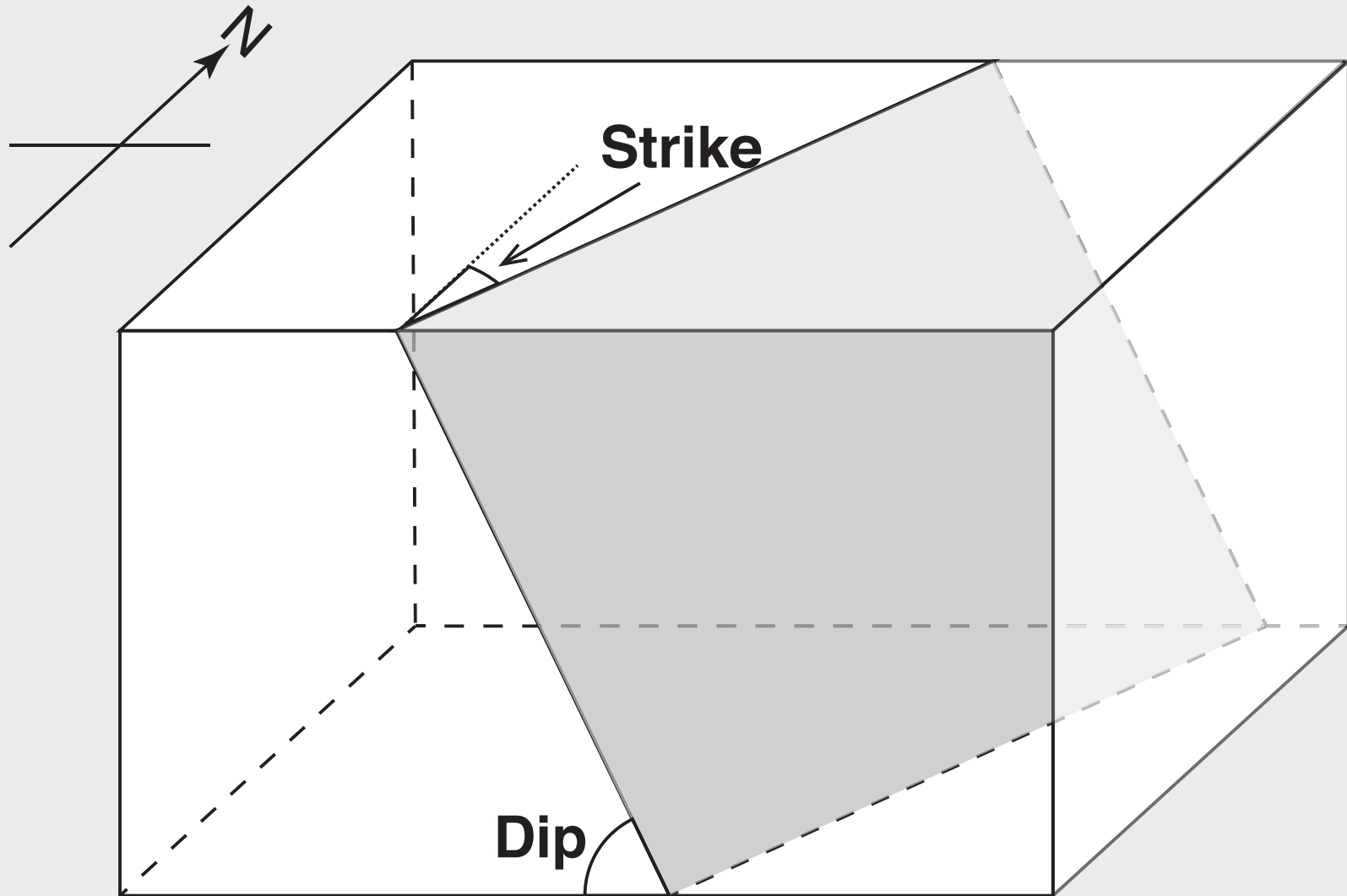


Moment magnitude

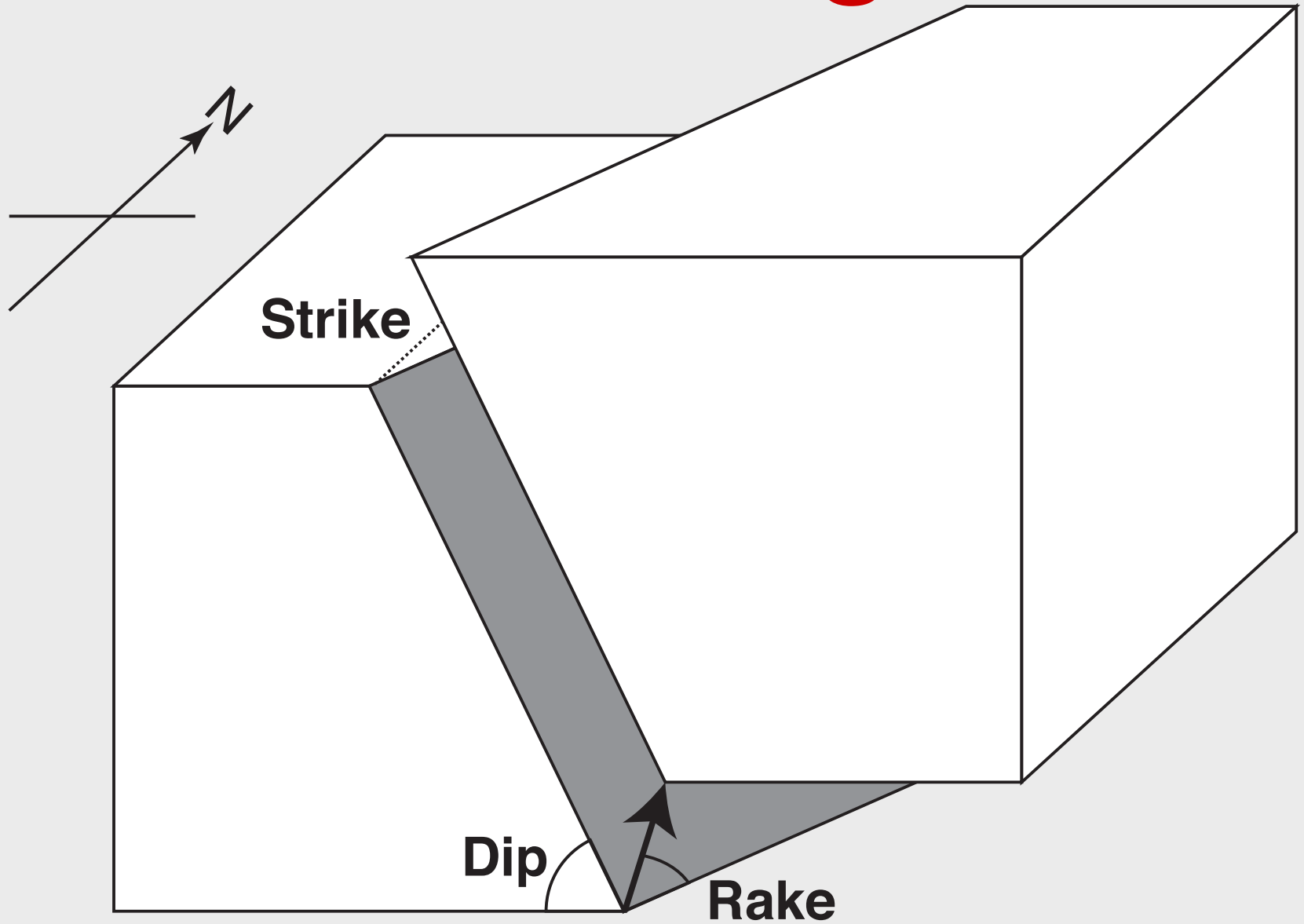
$$\mathbf{M}_0 = \frac{1}{\sqrt{2}} \left(\sum_{ij} \mathbf{M}_{ij}^2 \right)^{1/2}$$

$$\mathbf{M}_w = \frac{2}{3} (\log_{10} \mathbf{M}_0 - 9.1)$$

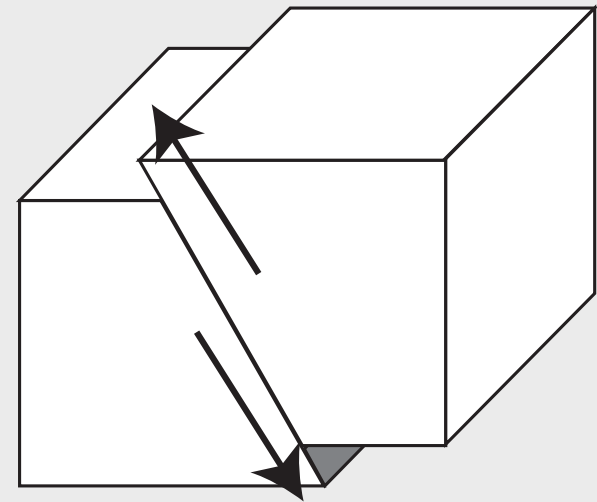
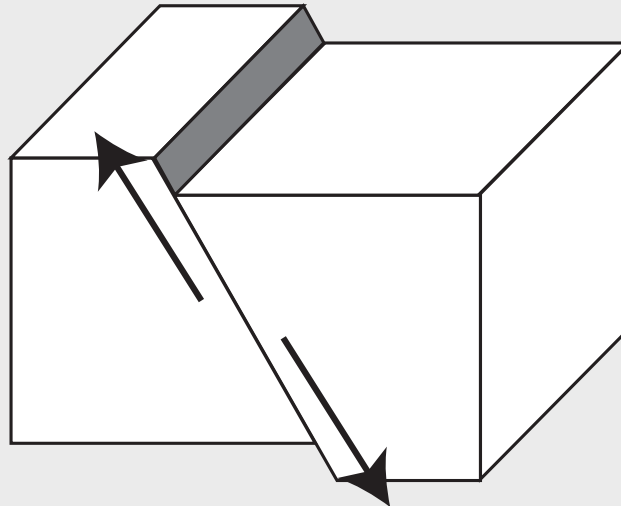
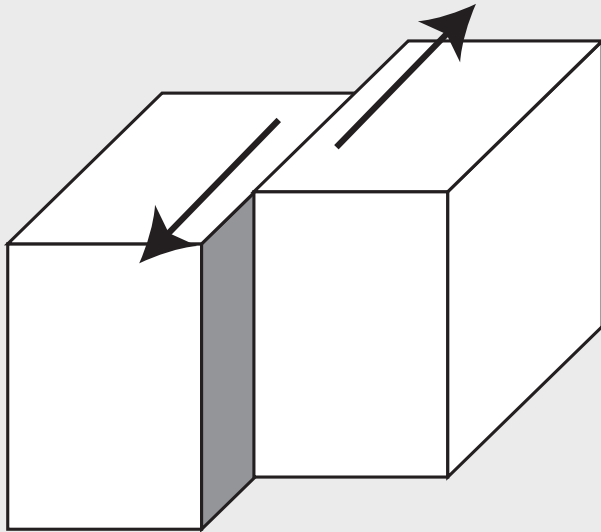
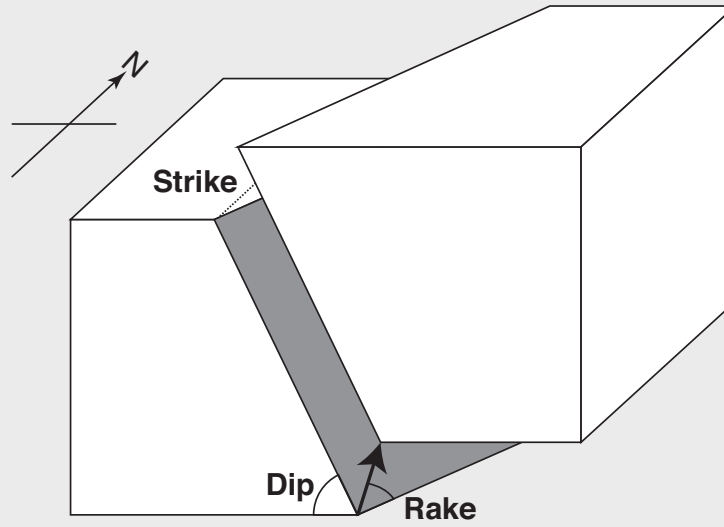
Faulting



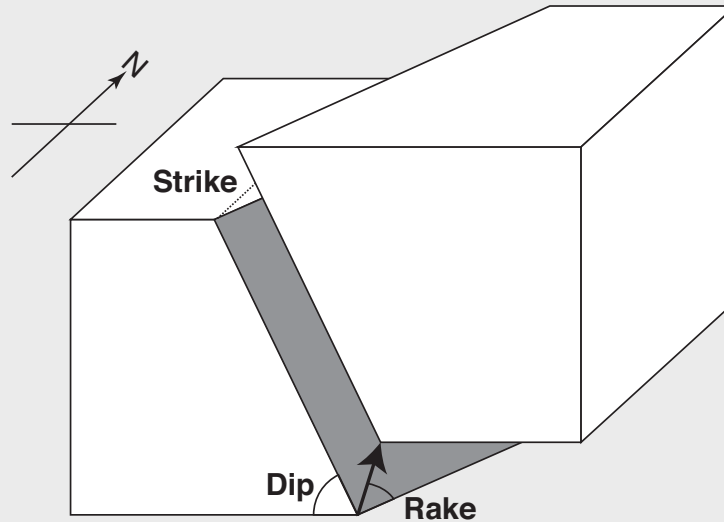
Faulting



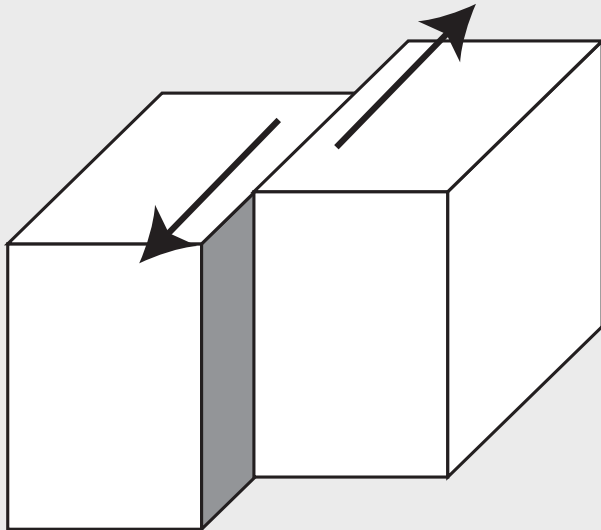
Faulting



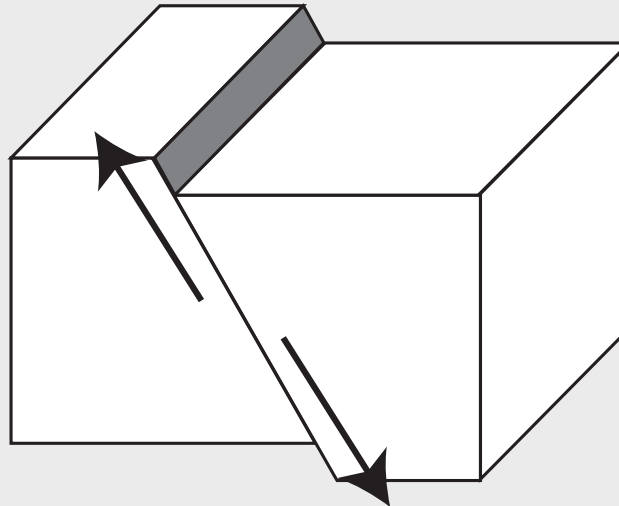
Faulting



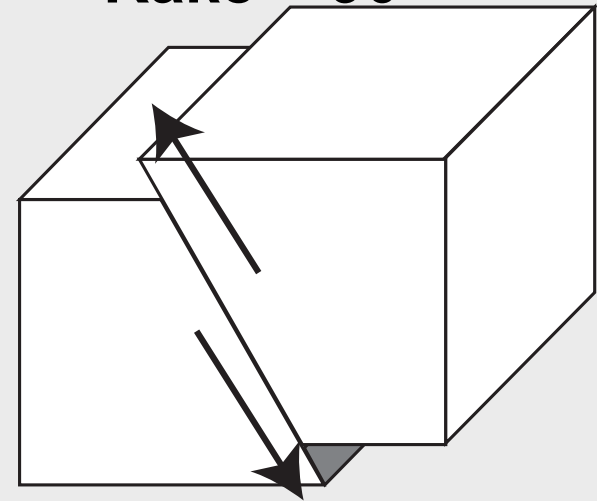
Rake = 0 (left)
180 (right)



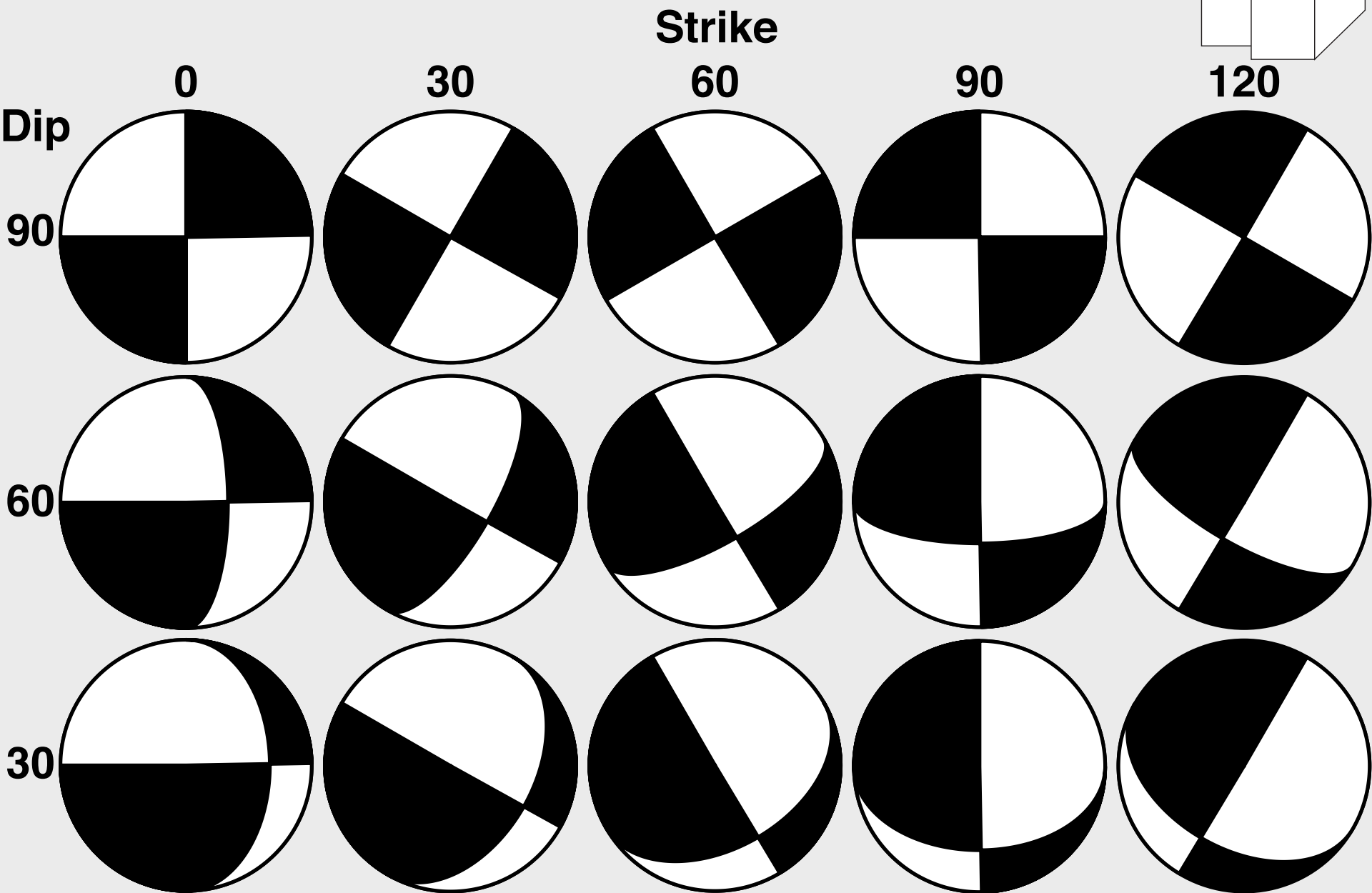
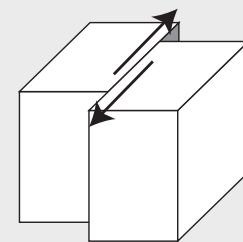
Rake = 270



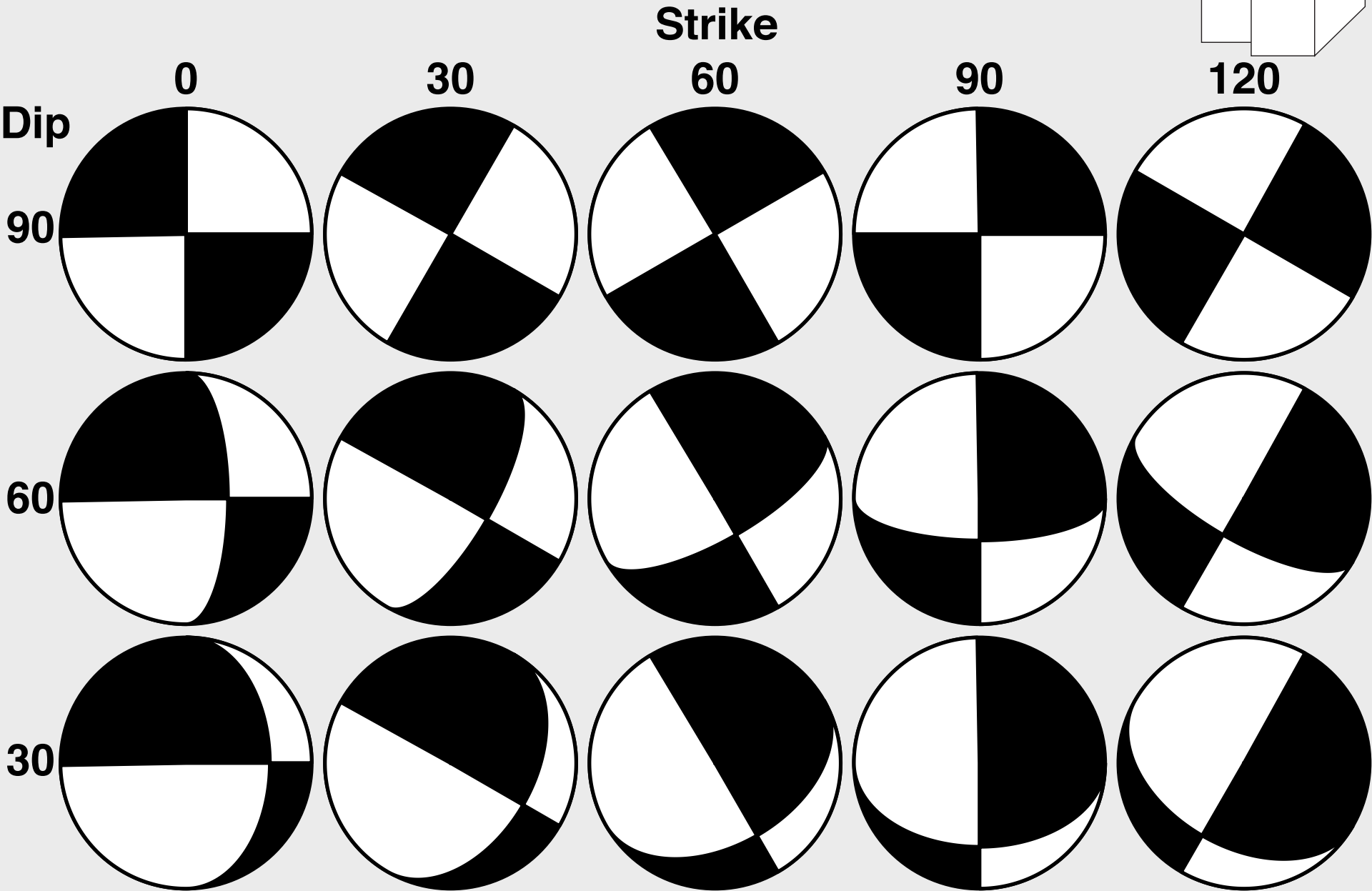
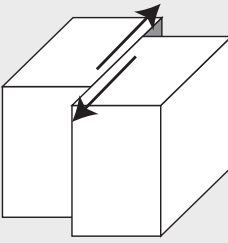
Rake = 90



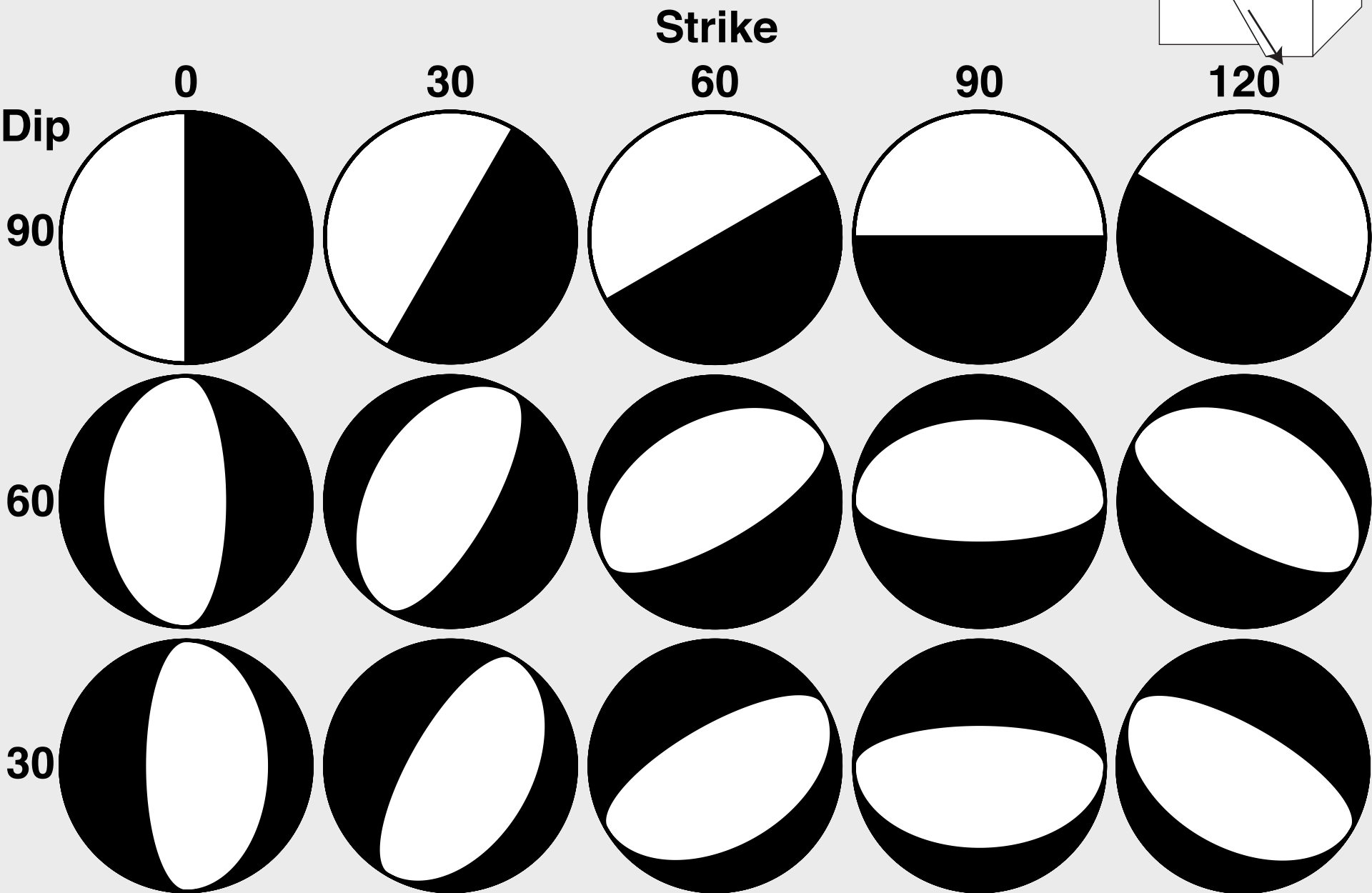
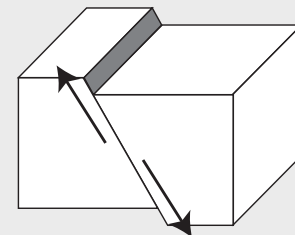
Left-lateral strike slip (rake=0)



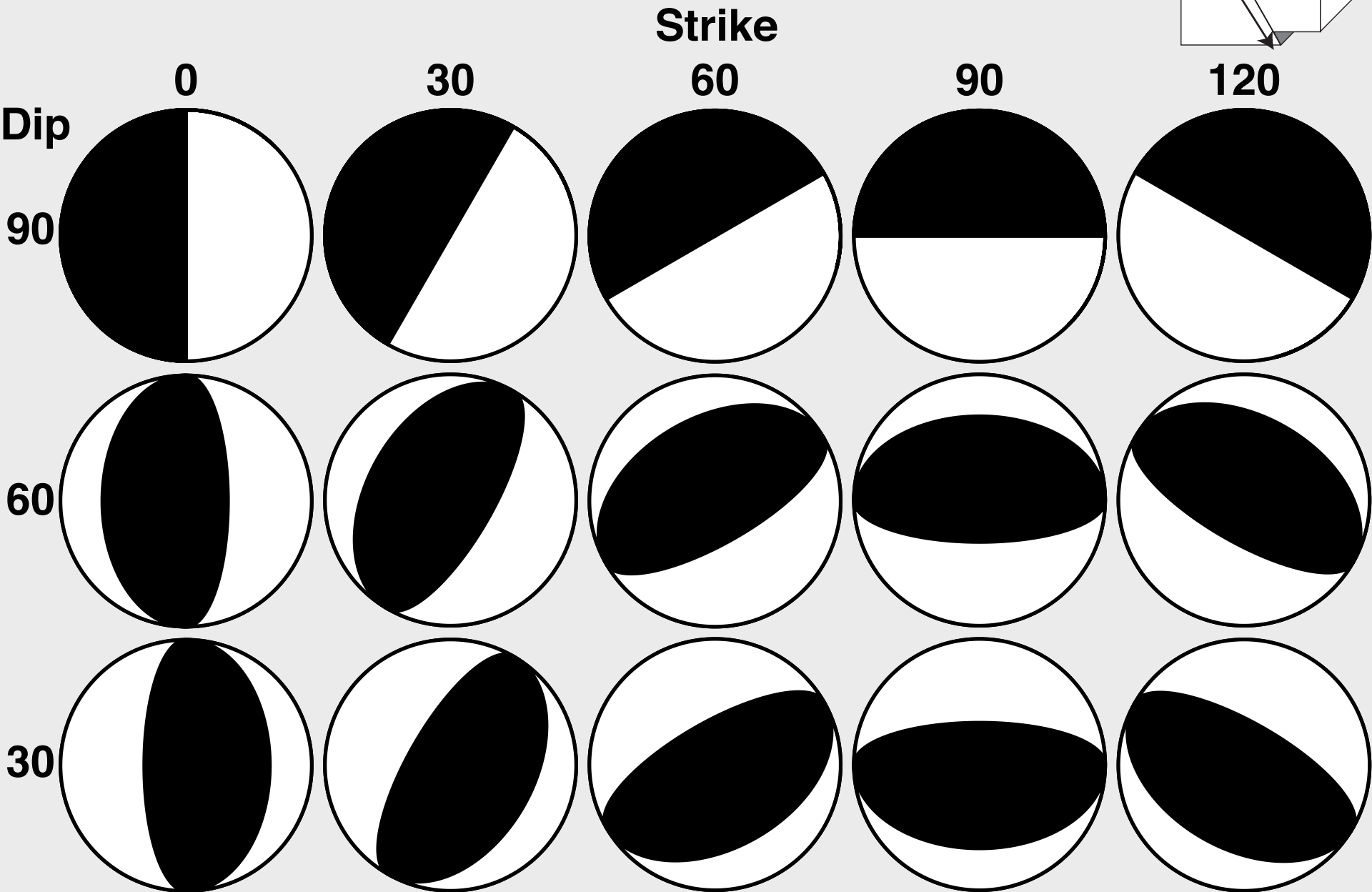
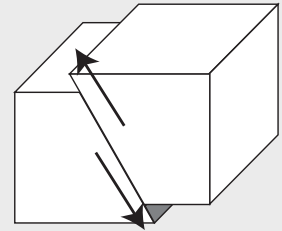
Right-lateral strike slip (rake=180)



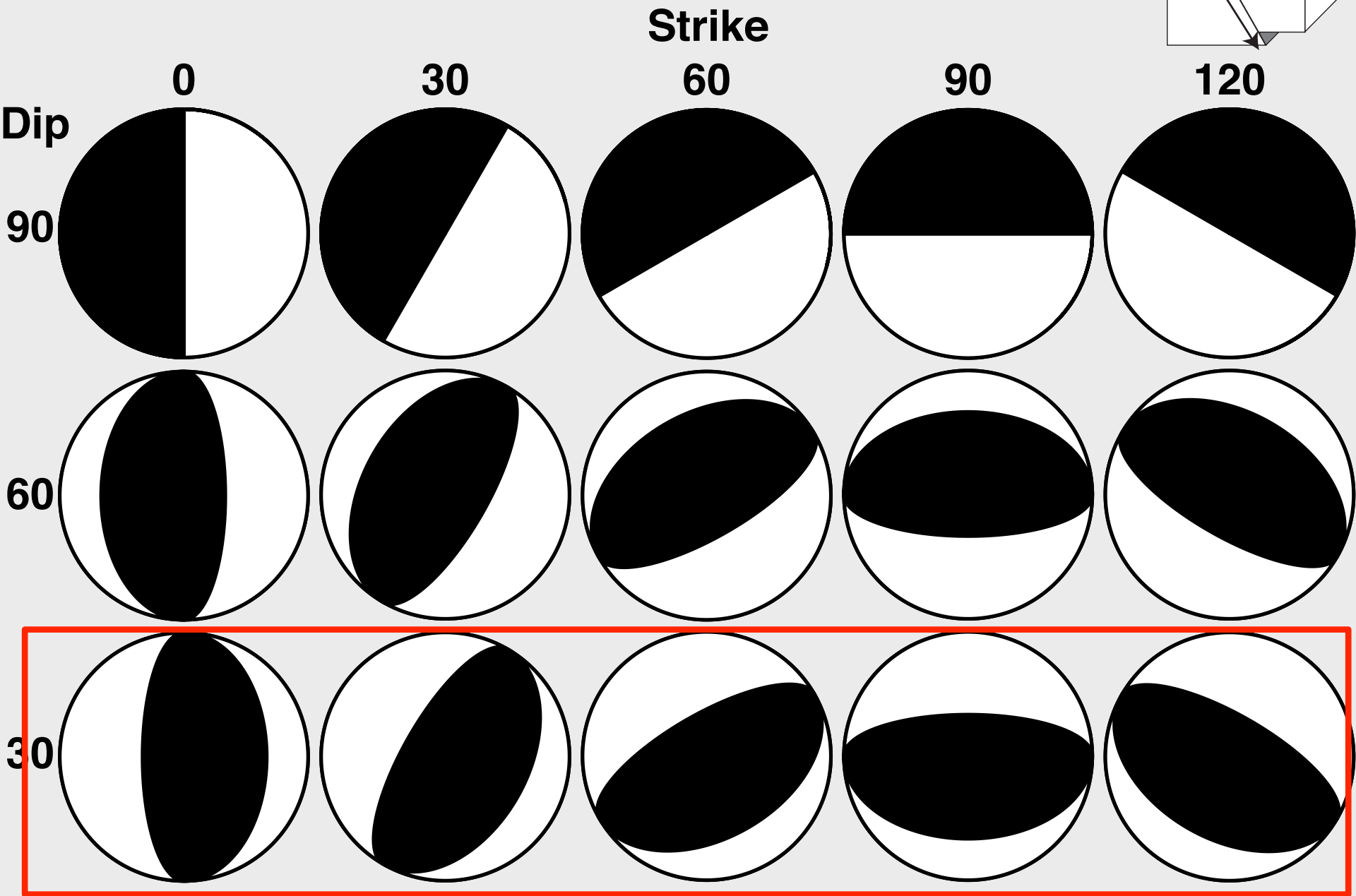
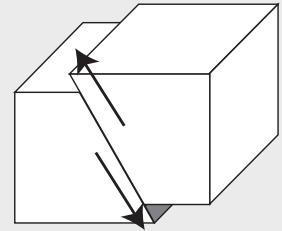
Normap-dip slip (rake=270)



Reverse-dip slip (rake=90)



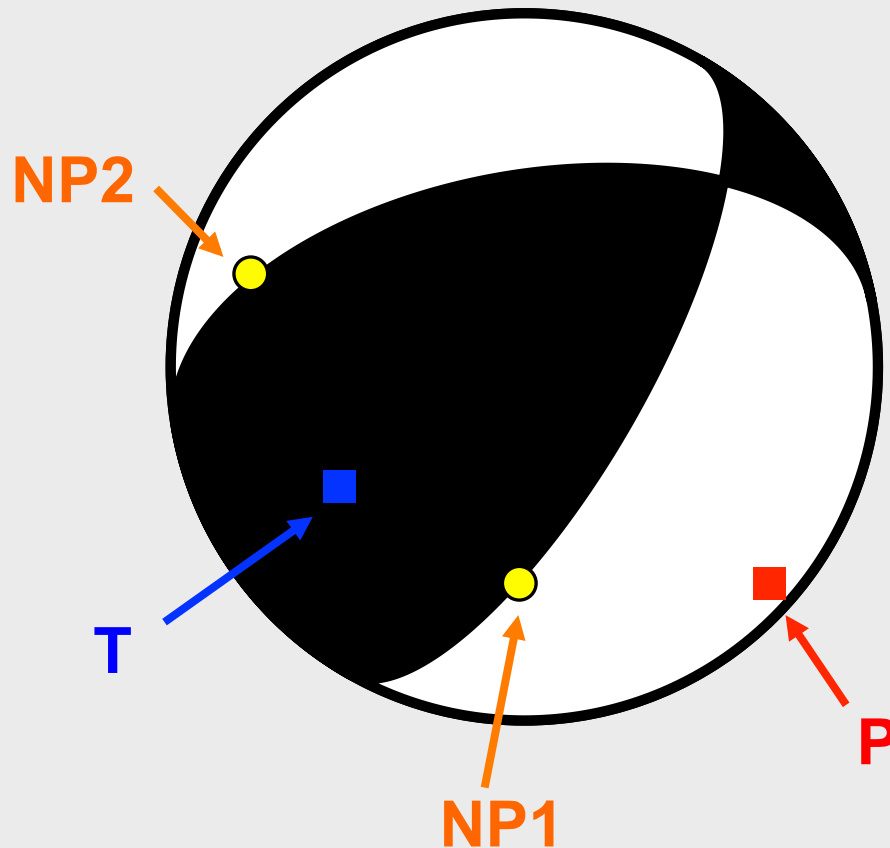
Reverse-dip slip (rake=90)



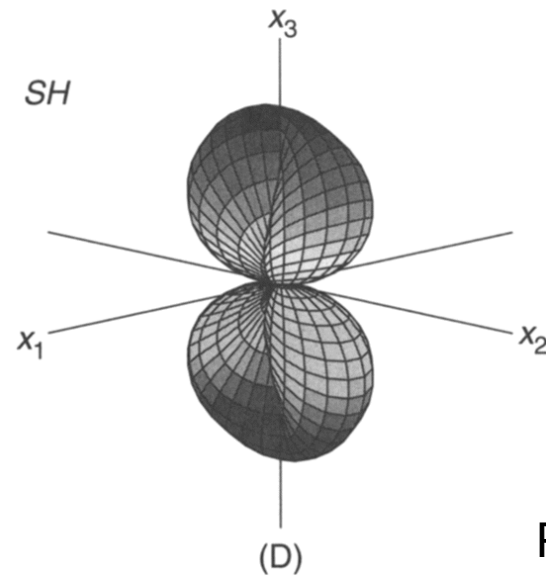
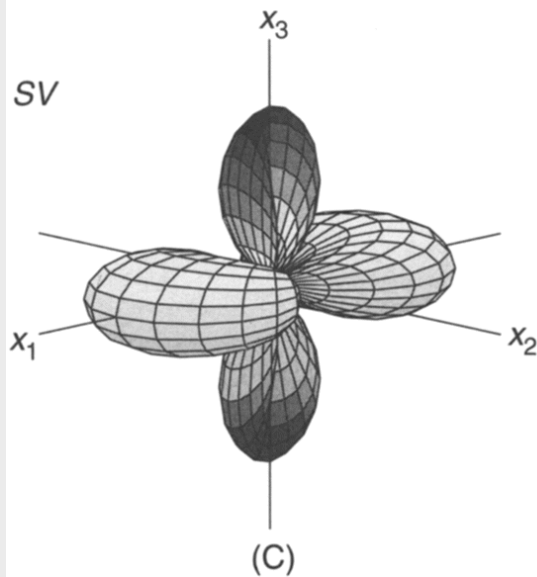
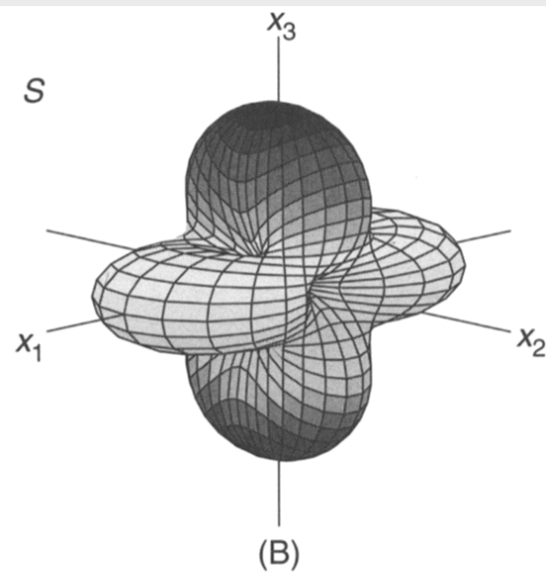
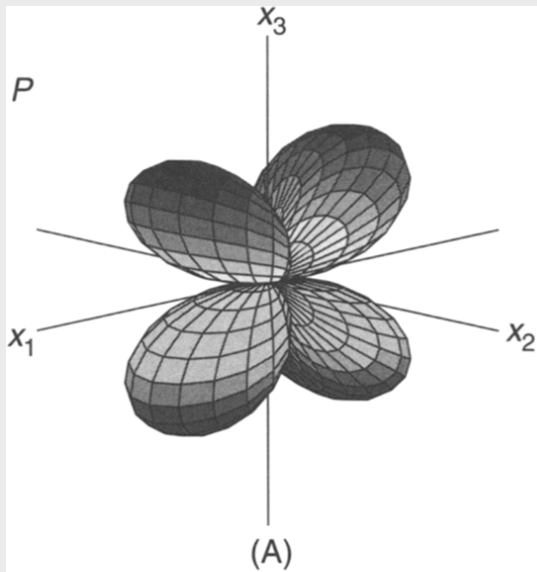
P and T axes

P: maximum compressive principal stress

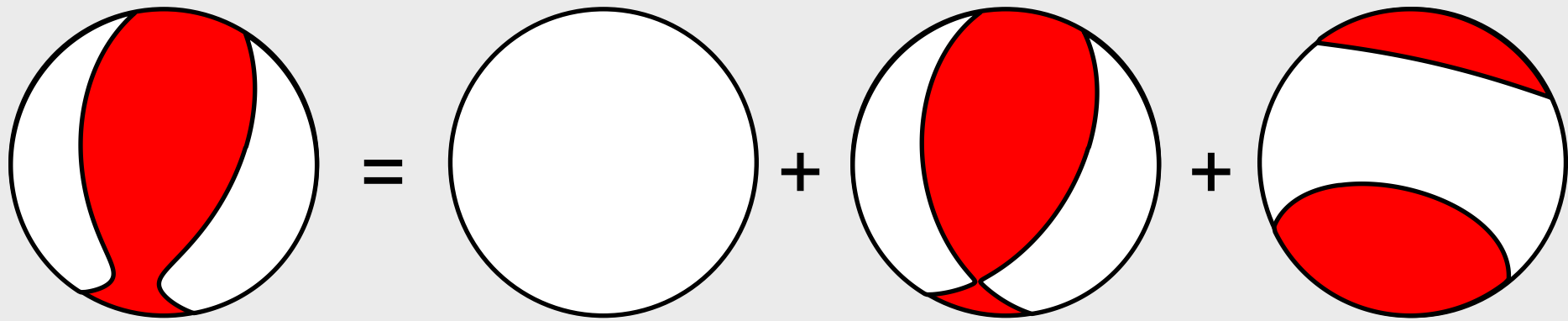
T: minimum compressive principal stress



Radiation pattern



Moment tensor



Characterize earthquake

What kind of faulting?

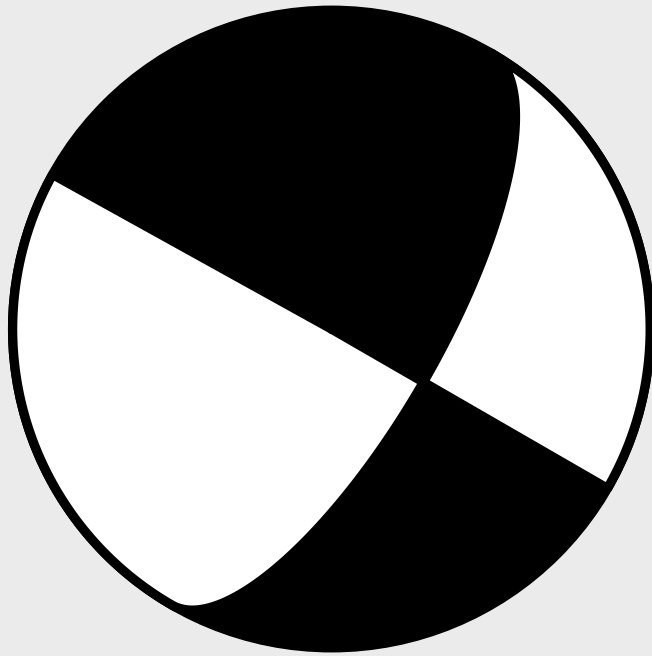
Is the dip shallow or steep?

Is the mechanism deviatoric?

...

Characterize earthquake

$[s,d,r]=[30,60,180]$



What kind of faulting?

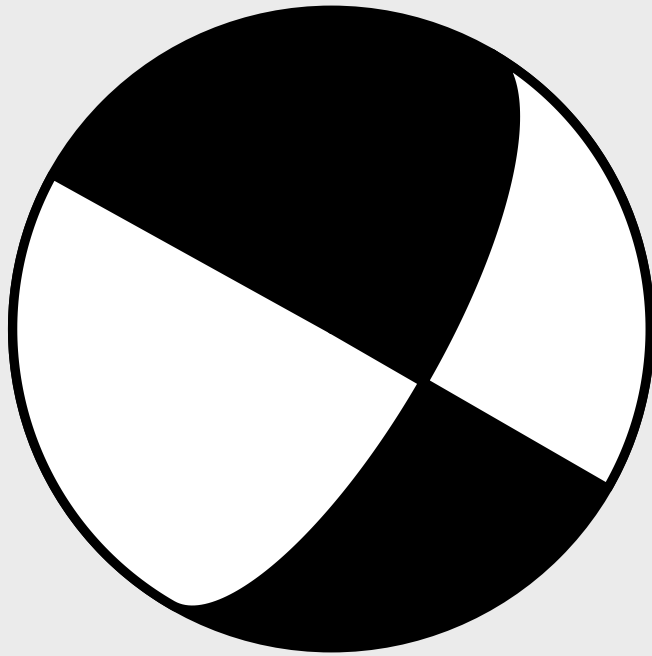
Is the dip shallow or steep?

**Is the mechanism
deviatoric?**

**What is the horizontal
direction of faulting?**

Characterize earthquake

$[s,d,r]=[30,60,180]$



What kind of faulting?

Right lateral strike slip

Is the dip shallow or steep?

Steep

Is the mechanism
deviatoric?

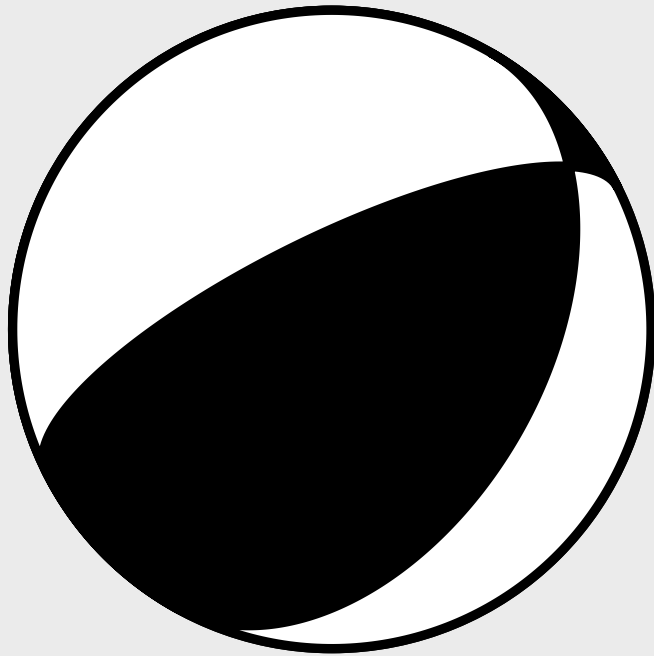
Yes

What is the horizontal
direction of faulting?

30 degrees from North

Characterize earthquake

$[s,d,r]=[30,30,60]$



What kind of faulting?

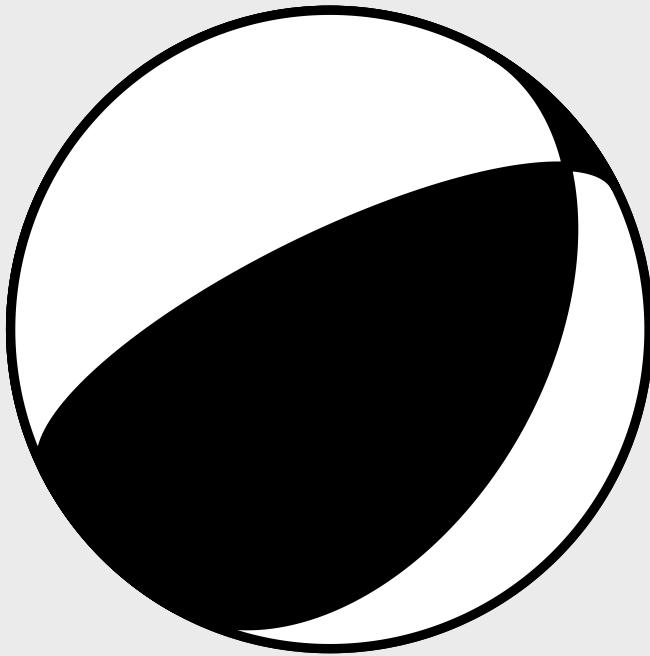
Is the dip shallow or steep?

**Is the mechanism
deviatoric?**

**What is the horizontal
direction of faulting?**

Characterize earthquake

$[s,d,r]=[30,30,60]$



What kind of faulting?

**Mostly reverse-dip slip with
some left-lateral strike slip**

Is the dip shallow or steep?

Shallow

Is the mechanism
deviatoric?

Yes

What is the horizontal
direction of faulting?

30 degrees from North

EASTERN TURKEY

11/10/23 10:41:21.73

Epicenter: 38.710 43.446
MW 7.3

USGS CENTROID MOMENT TENSOR

11/10/23 10:41:44.50

Centroid: 39.451 43.354

Depth 16 No. of sta: 159

Moment Tensor; Scale 10^{19} Nm

Mrr= 5.89 Mtt=-6.13

Mpp= 0.24 Mrt= 7.73

Mrp= 1.60 Mtp=-0.51

Principal axes:

T Val= 9.83 Plg=63 Azm=344

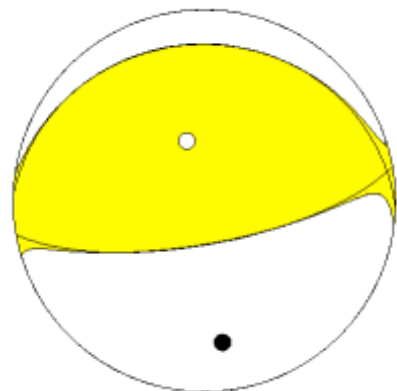
N 0.22 4 81

P -10.05 26 173

Best Double Couple: $M_0=9.9 \times 10^{19}$

NP1: Strike= 80 Dip=71 Slip= 86

NP2: 272 19 101



<http://earthquake.usgs.gov/earthquakes/>

What kind of faulting?

**Is the dip shallow or steep
(closer to 0 or 90 degrees)?**

**Is the mechanism
deviatoric?**

**What is meant by
“centroid”?**

OKLAHOMA

11/11/06 03:53:10.53

Epicenter: 35.537 -96.747
MW 5.6

USGS/SLU REGIONAL MOMENT TENSOR

Depth 7 No. of sta: 32

Moment Tensor; Scale 10^{17} Nm

Mrr=-0.17 Mtt= 3.22

Mpp=-3.05 Mrt=-0.07

Mrp=-0.28 Mtp=-1.09

Principal axes:

T Val= 3.40 Plg= 0 Azm=190

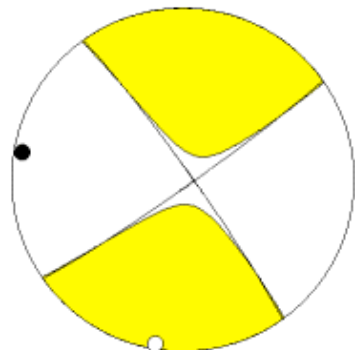
N -0.14 85 95

P -3.26 5 280

Best Double Couple: $M_0 = 3.3 \times 10^{17}$

NP1: Strike= 55 Dip=87 Slip=-176

NP2: 324 86 -3



What kind of faulting?

What is the strike?

**Is the mechanism
deviatoric?**

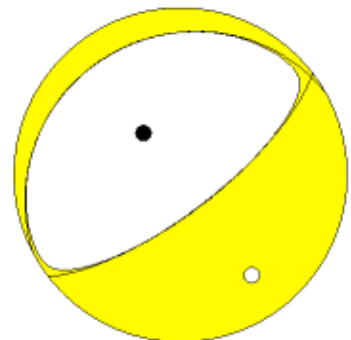
SOUTHERN TEXAS

11/10/20 12:24:40.58

Epicenter: 28.803 -98.154
MW 4.8

USGS/SLU REGIONAL MOMENT TENSOR
Depth 5 No. of sta: 22
Moment Tensor; Scale 10^{**16} Nm
Mrr=-1.05 Mtt= 0.73
Mpp= 0.32 Mrt=-1.14
Mrp=-0.91 Mtp= 0.46
Principal axes:
T Val= 1.78 Plg=27 Azm=145
N 0.03 3 53
P -1.80 63 318

Best Double Couple: $M_0=1.8 \times 10^{**16}$
NP1: Strike= 53 Dip=72 Slip= -93
NP2: 241 18 -82



What kind of faulting?

What is the dip?

**Is the mechanism
deviatoric?**

NEAR EAST COAST OF HONSHU, JAPAN

11/03/11 05:46:23.82

Epicenter: 38.308 142.383
MW 9.0

USGS CENTROID MOMENT TENSOR

11/03/11 05:47:47.20

Centroid: 38.486 142.597

Depth 10 No. of sta: 151

Moment Tensor; Scale 10^{22} Nm

Mrr= 2.03 Mtt=-0.16

Mpp=-1.87 Mrt= 2.06

Mrp= 3.49 Mtp=-0.60

Principal axes:

T Val= 4.57 Plg=58 Azm=306

N -0.05 5 208

P -4.52 32 115

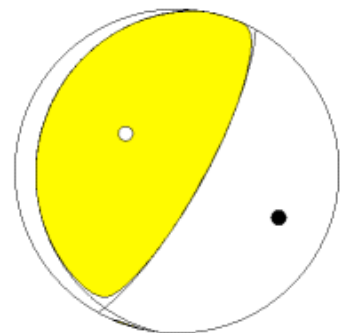
Best Double Couple: $M_0 = 4.5 \times 10^{22}$

NP1: Strike= 29 Dip=77 Slip= 95

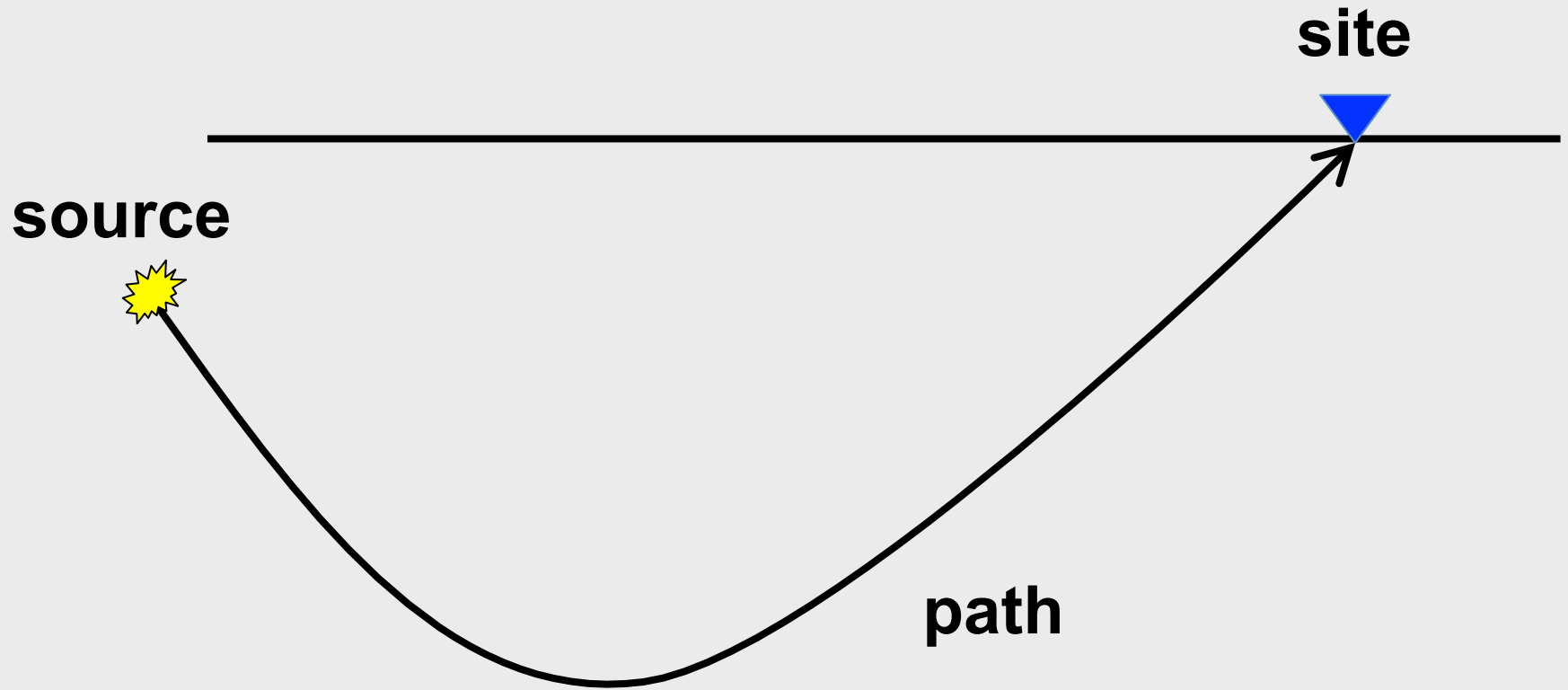
NP2: 187 14 68

What kind of faulting?

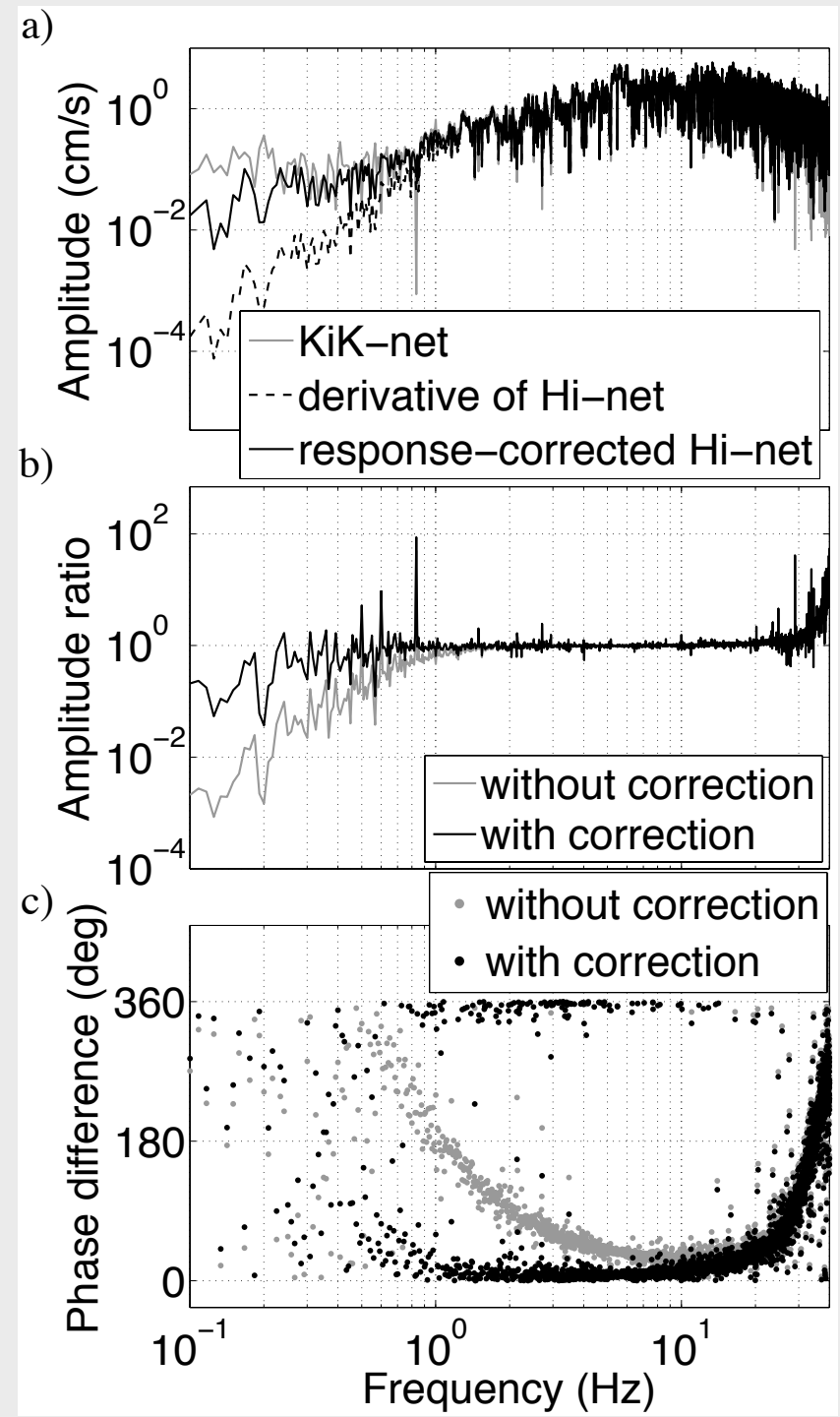
Which is the fault plane?



Records



Instrument response



Nakata (2013)

Magnitude

Nori Nakata
Stanford University

Local magnitude

Richter scale

$$M_L = \log A + 2.76 \log \Delta - 2.48$$

A : amplitude of signal

Δ : distance

$\log = \log_{10}$

Body-wave magnitude

$$m_b = \log(A/T) + Q(h, \Delta)$$

A : amplitude of signal

T : dominant period

h : depth

Δ : distance

Surface-wave magnitude

$$M_s = \log(A/T) + 1.66 \log \Delta + 3.3$$

$$M_s = \log A_{20} + 1.66 \log \Delta + 2.0$$

A : amplitude of signal

T : dominant period

h : depth

Δ : distance

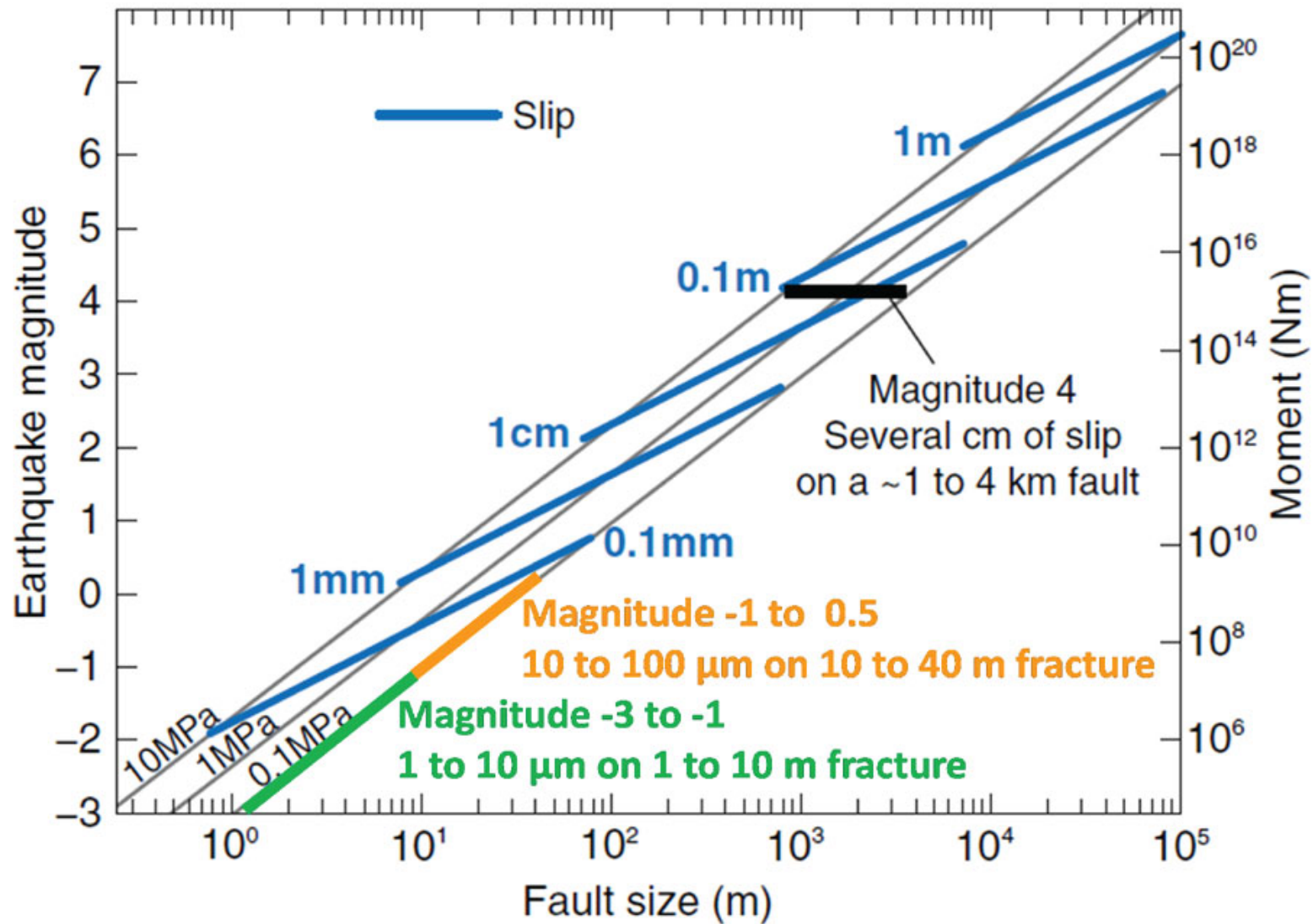
Moment magnitude

$$M_w = \frac{\log M_0}{1.5} - 10.73$$

M_0 : scalar seismic moment [dyn-cm]

$$1N = 10^5 dyn$$

Magnitude - scale



Earthquake statistics

Nori Nakata

Stanford University

***b* value**

$$\log_{10} N = a - bM$$

N : number of earthquakes with magnitudes greater than M

a : total number of earthquakes

b : ratio between large and small earthquakes
(usually 0.8-1.2)