## Ab ac

**Ke d : Ac c a,e e a de , F e d ffe e ce e , d e e a e e ,**

## 2 P e Me d f De e e FD C effic e S a a S ace

$f(x)$ ... $f(x)$ ... $N$

$$\frac{\partial f}{\partial x} = \frac{}{\Delta x}\sum_{n=}^{N} c_n(f_n - f_{-n}),$$

$f_n = f(x+n\Delta x)$ $\Delta x$ ... $x$ ... $c_n$ ... $n$

... $x$ ...

$$k_x\Delta x = \sum_{n=}^{N} c_n \quad (nk_x\Delta x),$$

$k_x$ ... $k_x\Delta x$

$f(x)$ ... $N$

$$\frac{\partial f}{\partial x} = \frac{}{\Delta x}[c \ f + \sum_{n=}^{N} c_n(f_{-n}+f_n)]$$

$c_n$ ... $n$

$f(x)$ ... $x$

$$-(k_x\Delta x) = c + \sum_{n=}^{N} c_n (nk_x\Delta x)$$

$k_x$

$k_x\Delta x$

fi $f(x)$

$$c_n = -\frac{}{n} (n\pi) w_n^{\ N}, n = \pm \ , \pm \ , \cdots, \pm N,$$

$$c = -\sum_{n=}^{N} (c_{-n} + c_n),$$

$w_n^{\ N} = \frac{C_N^{N+n}}{C_N^N}$ $C_m^l = \frac{m!}{l!(m-l)!}$ $m \geq l$.

$w_n^{\ N}$

$w_n^{\ N+M}$

$$c_n = -\frac{}{n}( \ n\pi) w_n^{\ N+M}, n = \pm \ , \pm \ , \cdots, \pm N,$$

$M$

# 3 Ne Me d f De e e FD C effic e

## 3.1 D e - e a - e e FD e a : fi de a e 1D ca e

$$r = \frac{k_u \Delta x}{\pi} = \frac{f}{v/\Delta x},$$

$f$ $v$ $k_u$

$\Delta x$

$k_u \Delta x$

$\pi,$ $k_u \Delta x$ $\pi.$

$r =$

**Re a 1** *With our approach, if we consider a too high upper limit for the wavenumber for a given scheme order and grid spacing, large numerical dispersion will appear at low frequencies; while if we consider a too small upper limit for the wavenumber, large numerical dispersion will appear at high frequencies. Percentage of $k_u\Delta x$ to $\pi$ is given by $f/(v/(\ \Delta x))$.*

$N$

$$\begin{bmatrix} (k_x(\ )\Delta x) & (\ k_x(\ )\Delta x) & \cdots & (Nk_x(\ )\Delta x) \\ \vdots & \vdots & \vdots & \vdots \\ (k_x(N)\Delta x) & (\ k_x(N)\Delta x) & \cdots & (Nk_x(N)\Delta x) \end{bmatrix} \begin{bmatrix} c \\ \vdots \\ c_N \end{bmatrix} = \begin{bmatrix} k_x(\ )\Delta x \\ \vdots \\ k_x(N)\Delta x \end{bmatrix},$$

$k_x(n)\Delta x$ $n = \ ,\ ,\cdots,N$ $r\pi/N$ $r\pi.$

## 3.2 D e - e a - e e FD e a : ec d de a e 1D ca e

$N+$

$$\begin{bmatrix} & (k_x( \ )\Delta x) & \cdots & (Nk_x( \ )\Delta x) \\ \vdots & \vdots & \vdots & \vdots \\ & (k_x(N)\Delta x) & \cdots & (Nk_x(N)\Delta x) \end{bmatrix} \begin{bmatrix} c \\ \vdots \\ c_N \end{bmatrix} = \begin{bmatrix} -[k_x( \ )\Delta x] \\ \vdots \\ -[k_x(N+ \ )\Delta x] \end{bmatrix}.$$

fi

ffi

## 3.3 D e - e a - e e FD e a f e -d e a ac c a e e a

$$\frac{\partial \ p}{\partial x} + \frac{\partial \ p}{\partial z} = \frac{}{v} \frac{\partial \ p}{\partial t},$$

$p = p(x,z,t)$ fi ffi $x$ $z$

$$\begin{cases} \frac{\partial \ p}{\partial x} \approx \frac{\delta \ p}{\delta x} = \frac{}{h}(c \ p \ , \ + \sum_{m=}^{N} c_m(p_{-m,} \ + p_{m,} \ )), \\ \frac{\partial \ p}{\partial z} \approx \frac{\delta \ p}{\delta z} = \frac{}{h}(c \ p \ , \ + \sum_{m=}^{N} c_m(p \ _{,-m} + p \ _{,m})), \end{cases}$$

$p^j_{m,n} = p(x+mh, z+nh, t+j\tau)$ $h$ $x$ $z$ $\tau$ $N$

$$-k \ h \ \approx \ c \ + \sum_{m=}^{N} c_m( \quad (mkh \quad \theta) + \quad (mkh \quad \theta)).$$

, fi ff ,

f , f

f , $N+$ ,

f , fi

f ,

$$\sum_{\theta-}^{\pi}\begin{bmatrix} \vdots & a^h_{k\ ,l,} & \cdots & a^h_{k\ ,l,N} \\ \vdots & \vdots & \vdots & \vdots \\ & a^h_{k_{N+\ },l,} & \cdots & a^h_{k_{N+\ },l,M} \end{bmatrix}\begin{bmatrix} c \\ \vdots \\ c_N \end{bmatrix} = -\sum_{\theta-}^{\pi}\begin{bmatrix} -k(\ )\ h \\ \vdots \\ -k(N+\ )\ h \end{bmatrix},$$

fi $a^h_{k_l\,m}-\ (mk_xh)+\ (mk_zh)$ $m=\ ,\cdots,N$ $k_{i,l}$ $i=\ ,\cdots,N+$ $i$ f $k_l$

$l=x,z$ $k_x=k\ \ \theta$ $k\ =k\ \ \theta$ $\theta$ , , f $\theta=\frac{j}{}\pi$ $j=\ ,\ ,\cdots,\ )$.

f fi ,

ffi .

## 3.4 D e - e a - e e , FD e a f e ee-d e a ac - c a, e e a

$$\frac{\partial\ p}{\partial x}+\frac{\partial\ p}{\partial y}+\frac{\partial\ p}{\partial z}=\frac{}{v}\frac{\partial\ p}{\partial t},$$

$p=p(x,y,z,t)$ fi . , ffi f $x$ $y$ $z$

f , ff

$$\begin{cases} \frac{\partial\ p}{\partial x}\approx\frac{\delta\ p}{\delta x}=\frac{}{h}(c\ \ p_{\ ,\ ,\ }+\sum_{m=}^{N}c_m(p_{-m,\ ,\ }+p_{m,\ ,\ })), \\ \frac{\partial\ p}{\partial y}\approx\frac{\delta\ p}{\delta y}=\frac{}{h}(c\ \ p_{\ ,\ ,\ }+\sum_{m=}^{N}c_m(p_{\ ,-m,\ }+p_{\ ,m,\ })), \\ \frac{\partial\ p}{\partial z}\approx\frac{\delta\ p}{\delta z}=\frac{}{h}(c\ \ p_{\ ,\ ,\ }+\sum_{m=}^{N}c_m(p_{\ ,\ ,-m}+p_{\ ,\ ,m})), \end{cases}$$

$c_i$ f $i$ ffi $p^j_{m,n,l}=p(x+mh,y+nh,z+lh,t+j\tau)$ $h$ ,

, $\tau$ $m$ , f

.

$$-k\ h \approx c + \sum_{m=}^{N} c_m( \quad (mkh \quad \theta \quad \phi) + \quad (mkh \quad \theta \quad \phi) + \quad (mkh \quad \theta)),$$

$k$ $k = \sqrt{k_x + k_y + k_z}$ $\theta$

$\phi$

$N+$

fi

$$a^h_{k_l\, m} - \quad (mk_x h) + \quad (mk_y h) + \quad (mk_z h), \quad (m = \ , \cdots, N)$$

$i$ $k_l$ $l = x, y, z$ $k_{i,l}$ $i = \ , \cdots, N+$ $k_x = k \quad \theta \quad \phi$ $k_y = k \quad \theta \quad \phi$ $k_z = k \quad \theta$ $\theta$ $\phi$ $\theta, \phi = \frac{j}{}\pi$ $j = \ , \ , \cdots,$

$$\sum_{\phi=}^{\pi} \sum_{\theta=}^{\pi} \begin{bmatrix} / & a^h_{k\ ,l,} & \cdots & a^h_{k\ ,l,N} \\ \vdots & \vdots & \vdots & \vdots \\ / & a^h_{k_{N+}\ ,l,} & \cdots & a^h_{k_{N+}\ ,l,N} \end{bmatrix} \begin{bmatrix} c \\ \vdots \\ c_N \end{bmatrix} = -\sum_{\phi=}^{\pi} \sum_{\theta=}^{\pi} \begin{bmatrix} -k(\ )\ h \\ \vdots \\ -k(N+\ )\ h \end{bmatrix}.$$

$N+$

ffi

## 3.5 S

fi ff

$A$ fi ffi

$(A)$ $A$ $(A)$

$O(\ )$ ffi $N =$ , $N =$ $(A)$

ffi

$(A)$ $O(\ )$ $N =$ , $N =$ $(A)$ $O(\ )$

ffi

# 4 N e ca d e e a a

ff

$$E = \sum_{n=}^{N} c_n \quad (nk_x\Delta x) - k_x\Delta x$$

$$E = -[c + \sum_{n=}^{N} c_n \quad (nk_x\Delta x)] - (k_x\Delta x)$$

fi

$E$ $E$

ff

fi $r$

ff $N$

$. \times \ -$

$kh$ $[\ ,\ .\ \pi]$

$kh$

$kh$

ff

$kh$ [ , . $\pi$]

$kh$

$kh$

fi

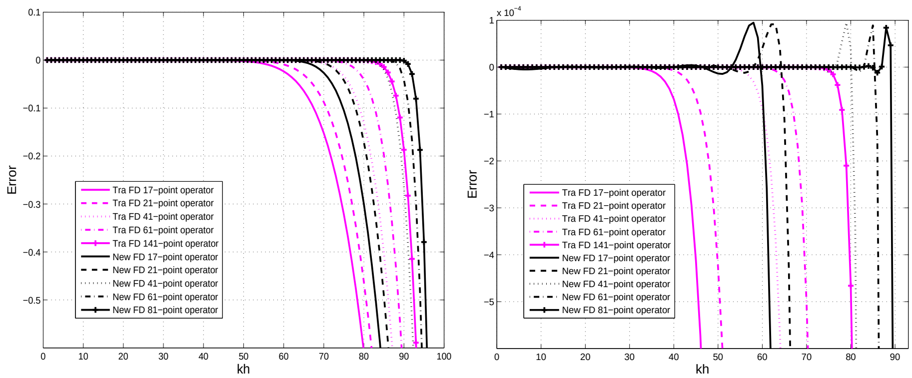
$N >$

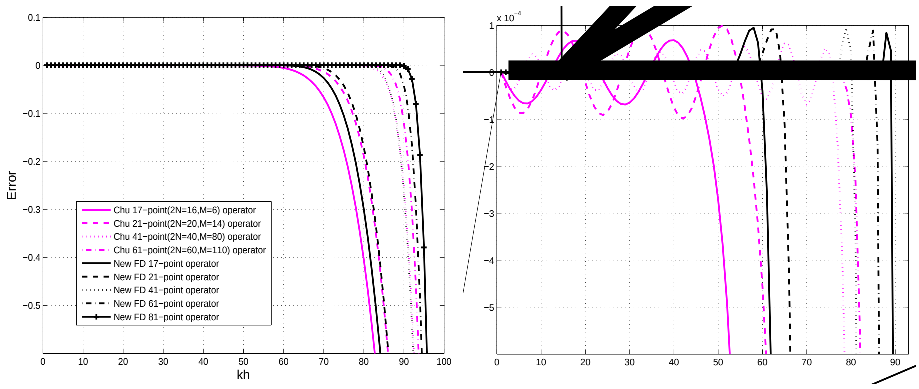
ffi

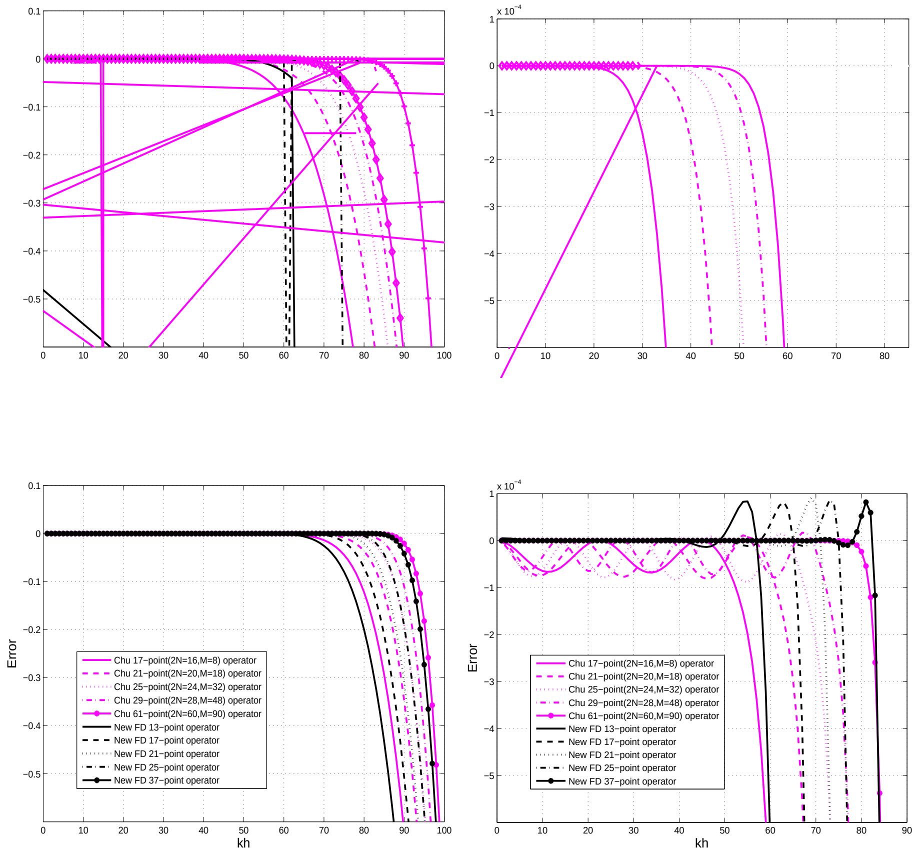
$$E = -[\, c + \sum_{n=}^{N} c_n \quad (nk \quad (\theta)h) + \sum_{n=}^{N} c_n \quad (nk \quad (\theta)h)] - (kh) \; .$$

$E$

$N =$

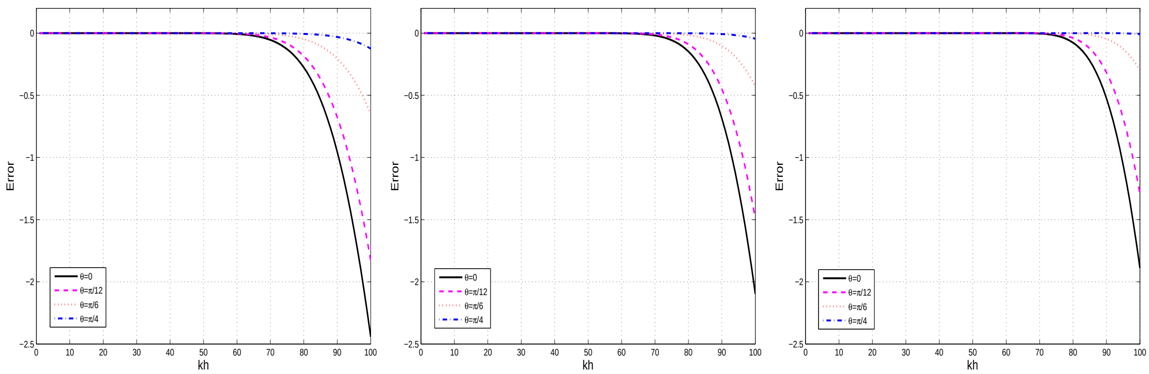

Error
kh
x 10^-4
Tra FD 17−point operator
Tra FD 21−point operator
Tra FD 41−point operator
Tra FD 61−point operator
Tra FD 141−point operator
New FD 17−point operator
New FD 21−point operator
New FD 41−point operator
New FD 61−point operator
New FD 81−point operator


Error
kh
x 10^-4
Chu 17−point(2N=16,M=6) operator
Chu 21−point(2N=20,M=14) operator
Chu 41−point(2N=40,M=80) operator
Chu 61−point(2N=60,M=110) operator
New FD 17−point operator
New FD 21−point operator
New FD 41−point operator
New FD 61−point operator
New FD 81−point operator

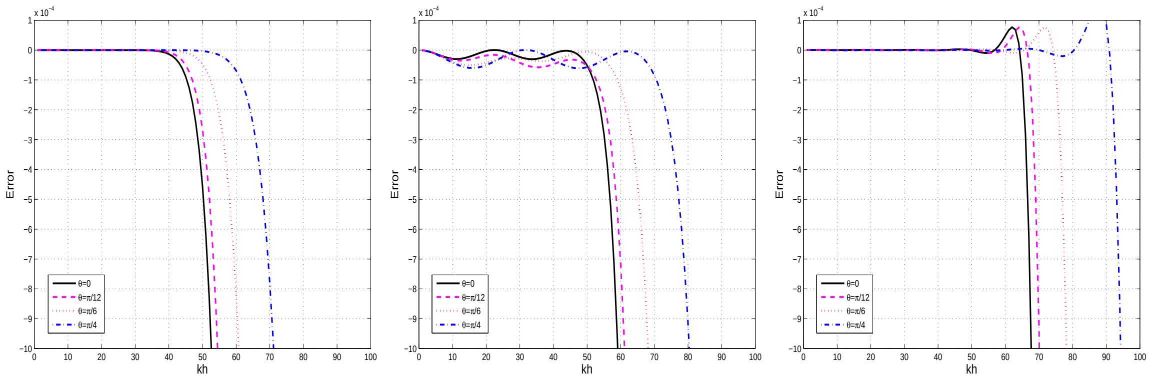


Error
kh
x 10^-4
Chu 17−point(2N=16,M=8) operator
Chu 21−point(2N=20,M=18) operator
Chu 25−point(2N=24,M=32) operator
Chu 29−point(2N=28,M=48) operator
Chu 61−point(2N=60,M=90) operator
New FD 13−point operator
New FD 17−point operator
New FD 21−point operator
New FD 25−point operator
New FD 37−point operator

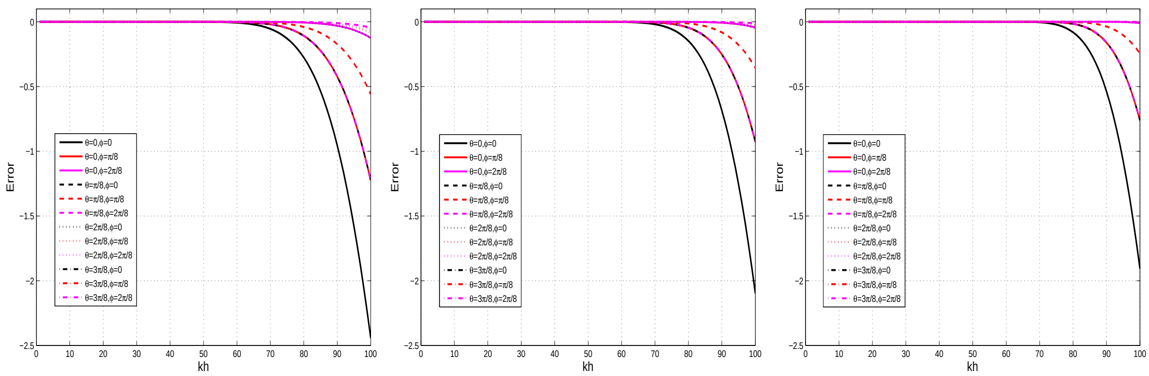
[illegible]


0
−0.5
−1
−1.5
−2
−2.5
Error
0 10 20 30 40 50 60 70 80 90 100
kh
θ=0
θ=π/12
θ=π/6
θ=π/4

[illegible] $kh$ [illegible]


x 10⁻⁴
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
Error
0 10 20 30 40 50 60 70 80 90 100
kh
θ=0
θ=π/12
θ=π/6
θ=π/4

[illegible] $kh$ [illegible]




$kh$

$$E = - c - \sum_{m=}^{N} c_m( \quad (mkh \quad \theta \quad \phi) + \quad (mkh \quad \theta \quad \phi) + \quad (mkh \quad \theta)) - k \; h \; .$$

$E$

$N =$

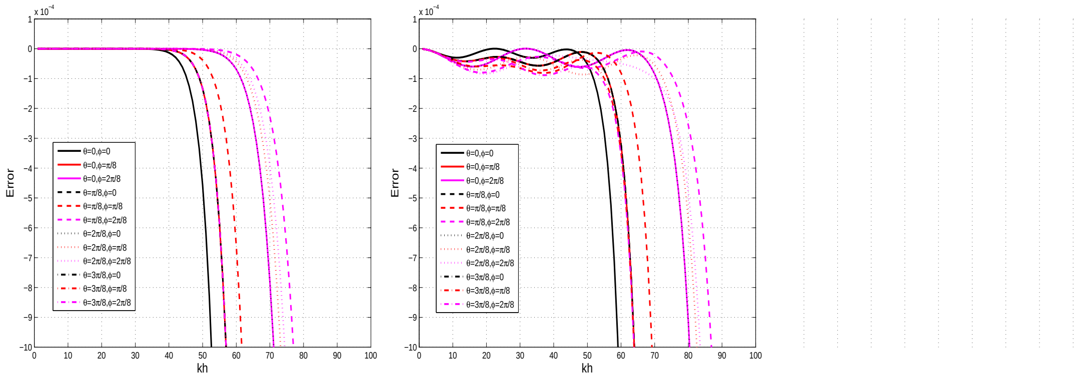
$- . \times {}^{-} \quad . \times {}^{-}$

$kh$

$kh$

$kh$

fi ff




fi $kh$

# 5 N e ca a

## 5.1 A e de

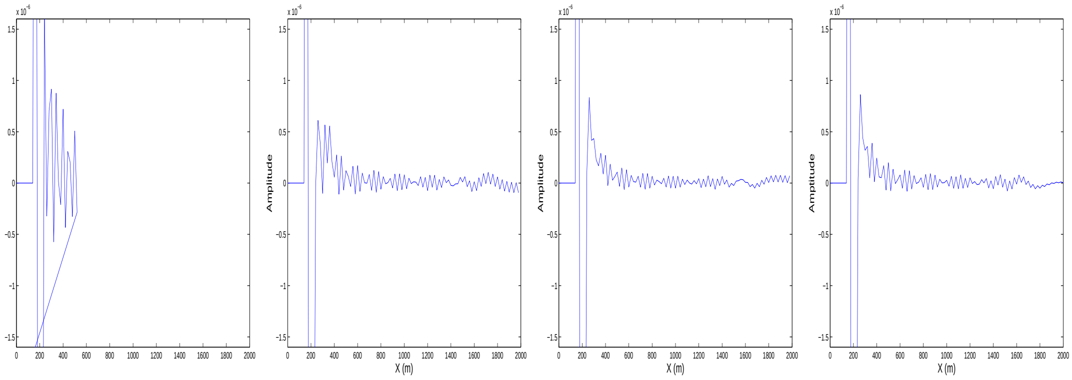
fi $N =$ fi

$$w(t) = \quad (-f\ (t-t\ )\ ),$$

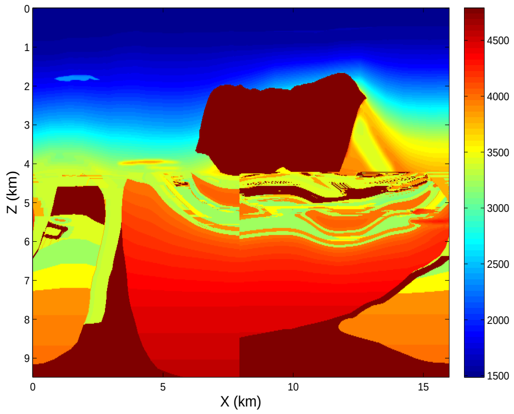
$f$ $t$ $/f$

ff

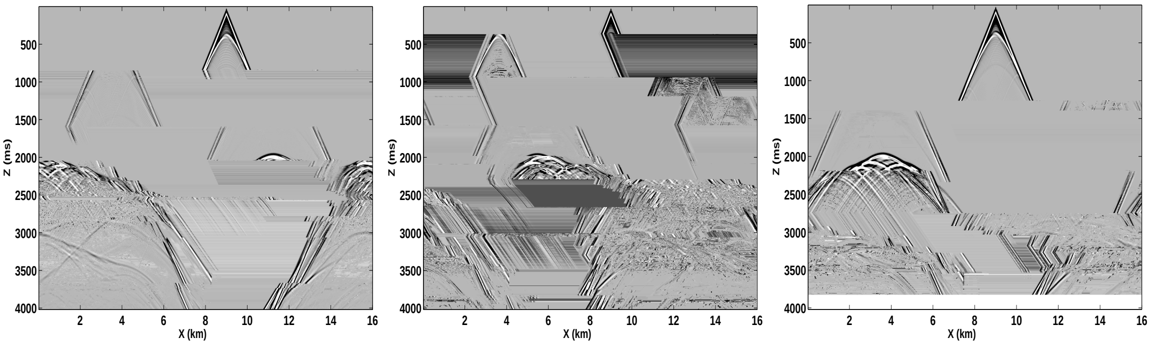
$N =$ $M =$ $r = .\ f$ fi

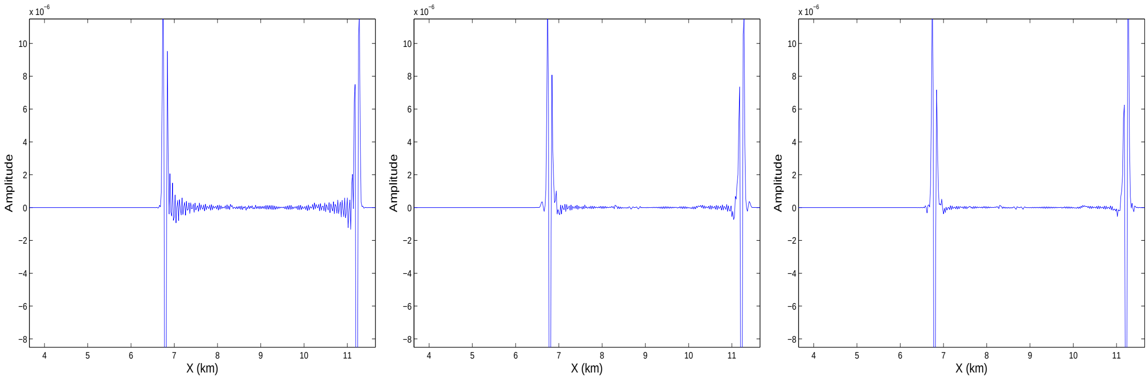



## 5.2 Sa de

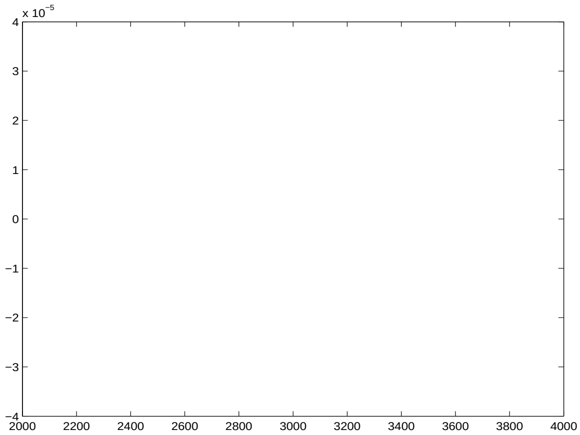

Z (km)
X (km)
0
1
2
3
4
5
6
7
8
9
0
5
10
15
4500
4000
3500
3000
2500
2000
1500

## 6 C c


Z (ms)
500
1000
1500
2000
2500
3000
3500
4000
2
4
6
8
10
12
14
16
X (km)


x 10^-6
Amplitude
10
8
6
4
2
0
-2
-4
-6
-8
4
5
6
7
8
9
10
11
X (km)

fi ff




## Ac ed e e

J fi

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fi ff

ff f

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fi ff

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