# Properties of Common Focus Point Gathers

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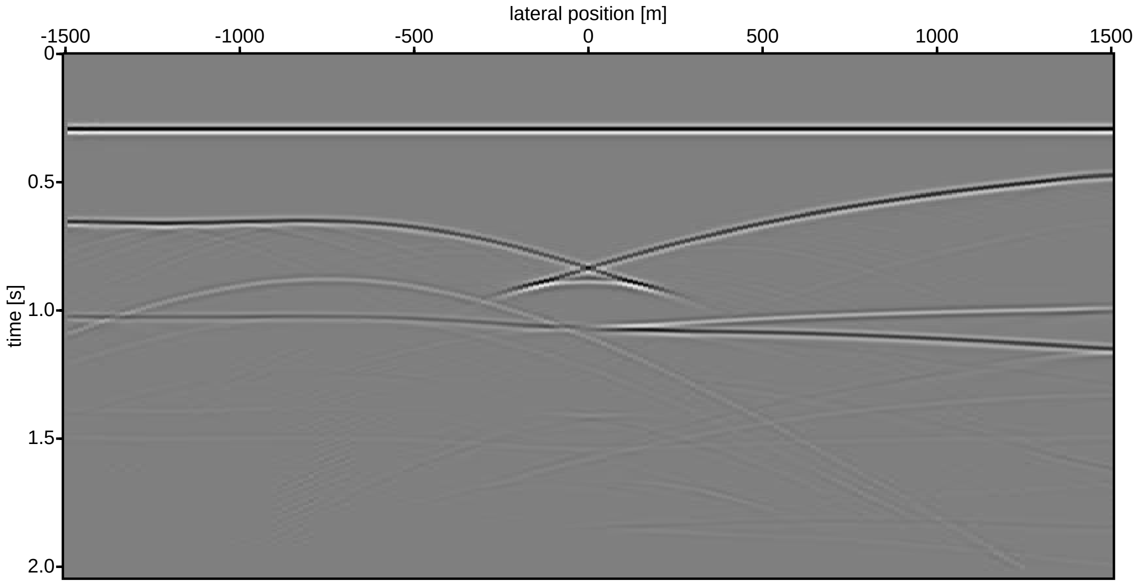
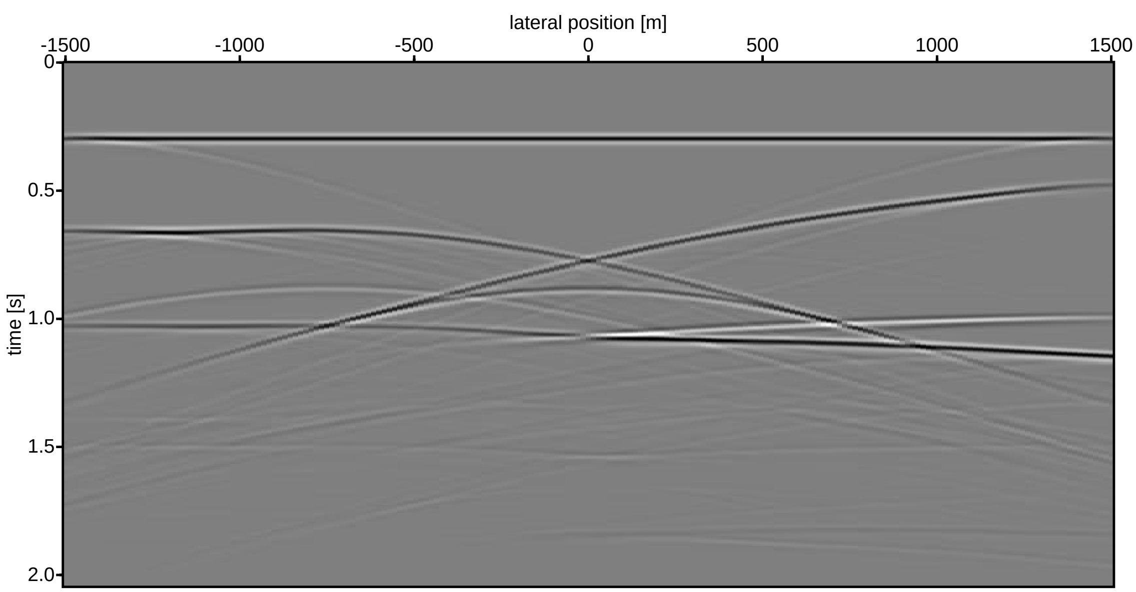
## Contents

- CFP gathers
- Velocity/operator analysis
- AVO and CFP
- Regularization
- Efficient imaging

# Areal Shot Record (Walter Rietveld)



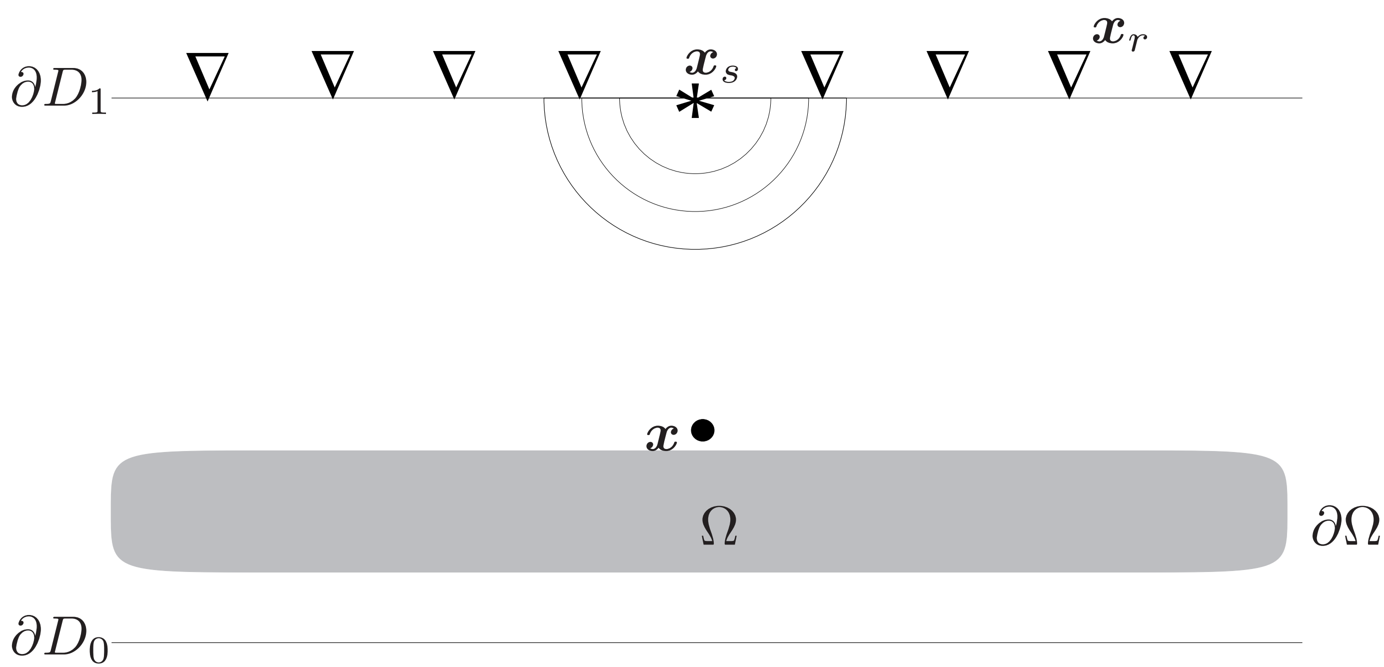

Zero-offset gather (201 traces)




Areal shot record: plane wave at surface (all data)

# Focusing integral for receiver array

$$P^{-,s}(\boldsymbol{x},\boldsymbol{x}_s) = \int_{\partial D_1} W_p^{+,*}(\boldsymbol{x},\boldsymbol{x}_r) P^{-,s}(\boldsymbol{x}_r,\boldsymbol{x}_s) \mathrm{d}^2\boldsymbol{x}_r,$$



# Focusing matrix for receiver array

Focusing result:

$$\tilde{\boldsymbol{P}}_i^-(z_m, z_s) = \tilde{\boldsymbol{F}}_i^-(z_m, z_r)\mathbf{P}(z_r, z_s)$$

with operator

$$\tilde{\boldsymbol{F}}_i^-(z_m, z_r) \approx \tilde{\boldsymbol{I}}_i^-(z_m)\left[\mathbf{W}^+(z_m, z_r)\right]^*$$

$$\tilde{\boldsymbol{F}}_i^-(z_m, z_r)\mathbf{W}^-(z_r, z_m) = \tilde{\boldsymbol{I}}_i^-(z_m)$$

and forward model

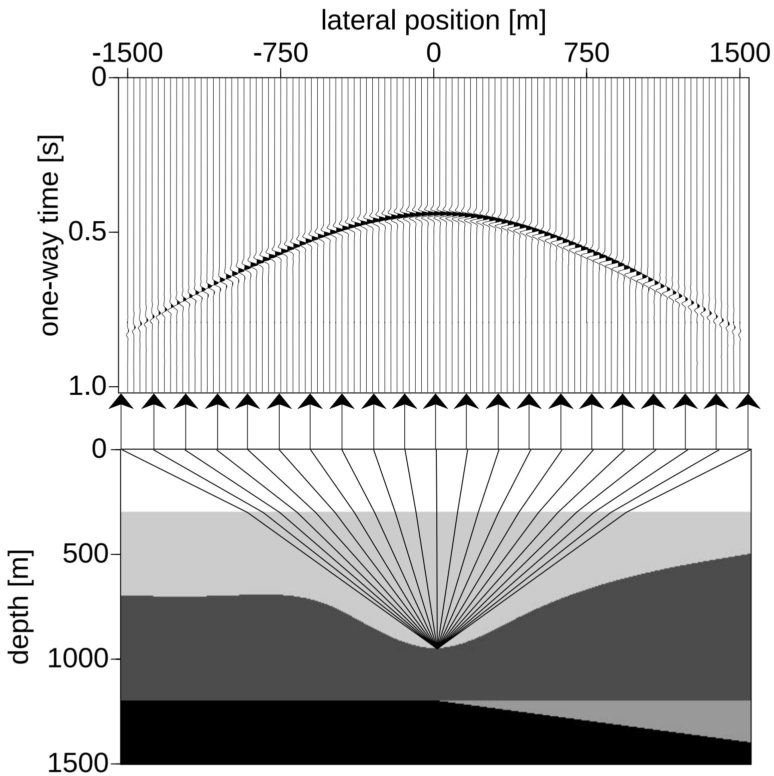
$$\mathbf{P}(z_r, z_s) = \mathbf{W}^-(z_r, z_m)\mathbf{R}^+(z_m)\mathbf{W}^+(z_m, z_s)\mathbf{S}(z_s)$$

gives

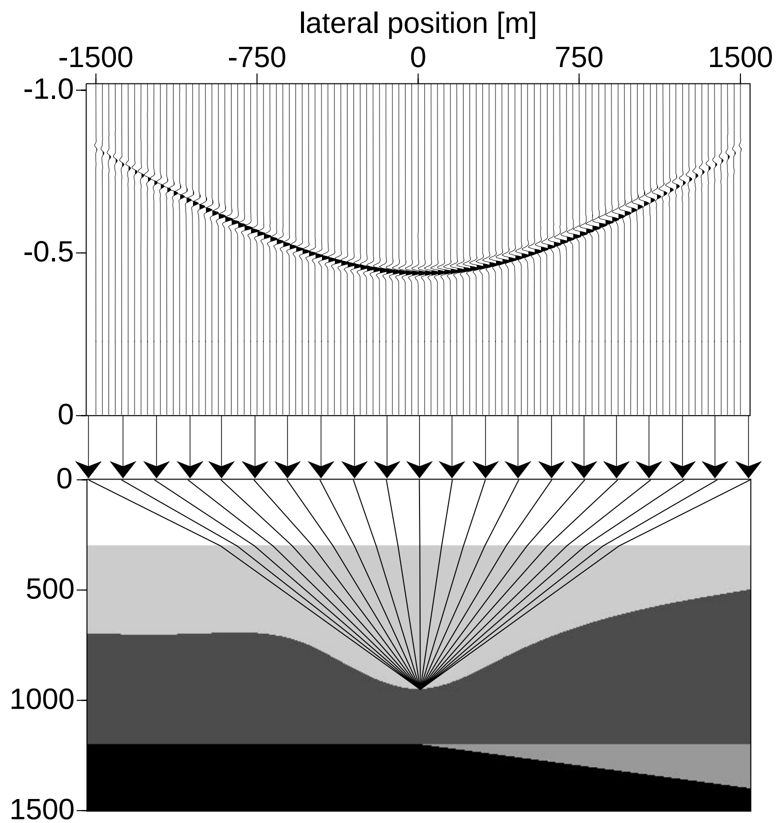
$$\tilde{\boldsymbol{P}}_i^-(z_m, z_s) = \tilde{\boldsymbol{I}}_i^-(z_m)\mathbf{R}^+(z_m)\mathbf{W}^+(z_m, z_s)\mathbf{S}(z_s)$$

# The focusing operator

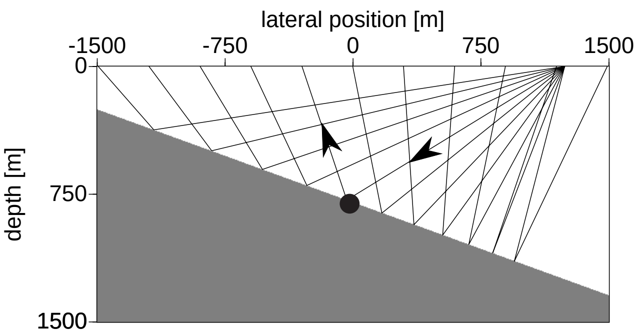
## modeling



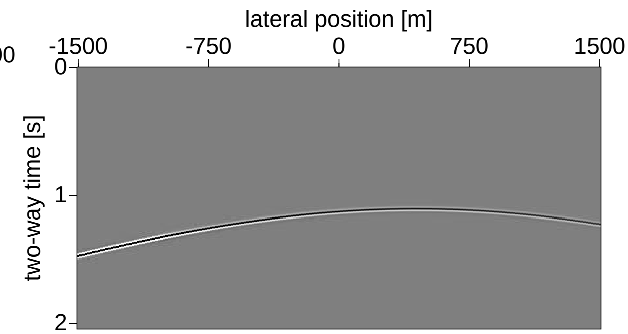

## focusing



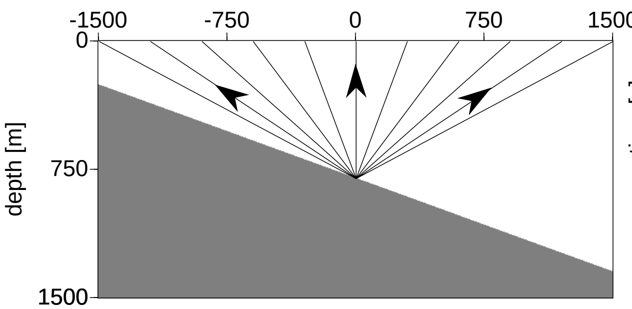
# Construction of a CFP trace



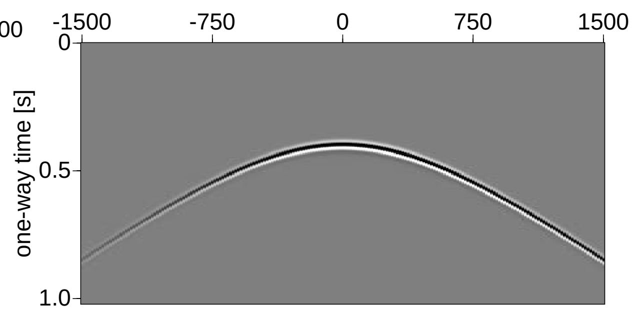

rays for shot record



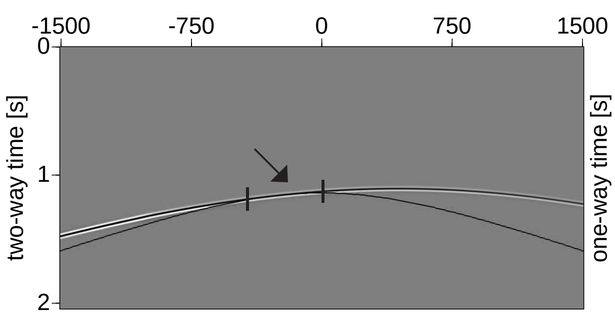

shot at $x_s = 1250$



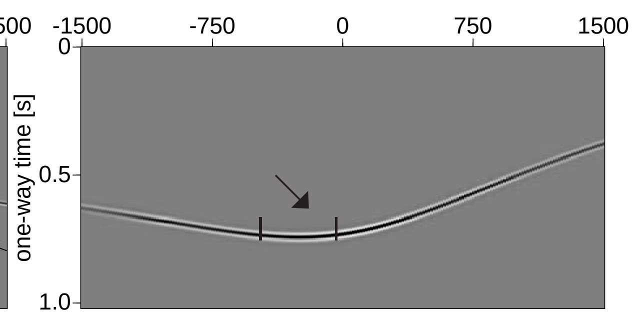

rays for focusing operator



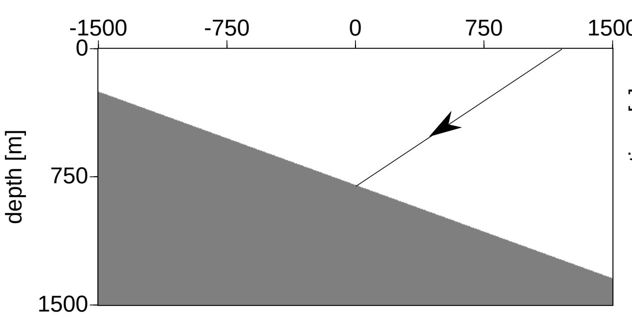

time reversed operator



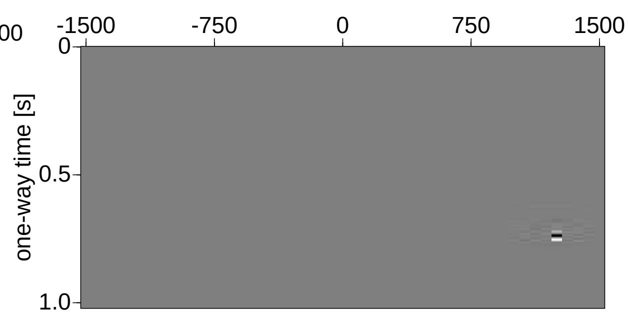

overlay of operator on shot




CFP corrected shot record

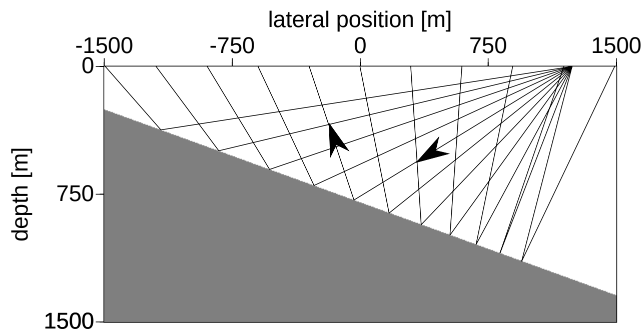



traveltime path

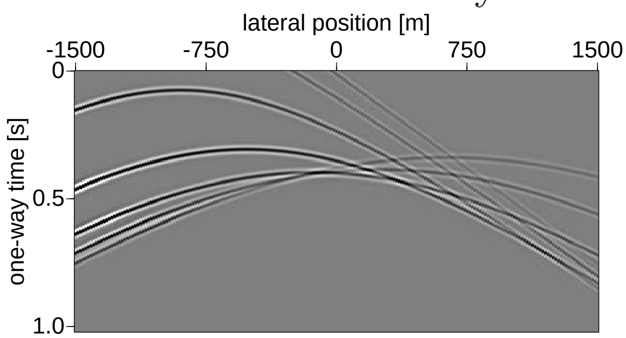



CFP trace

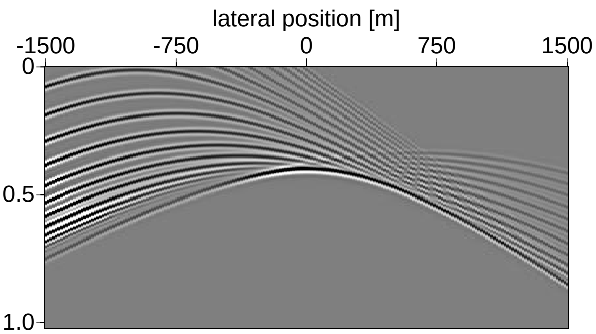
# Construction of a CFP gather



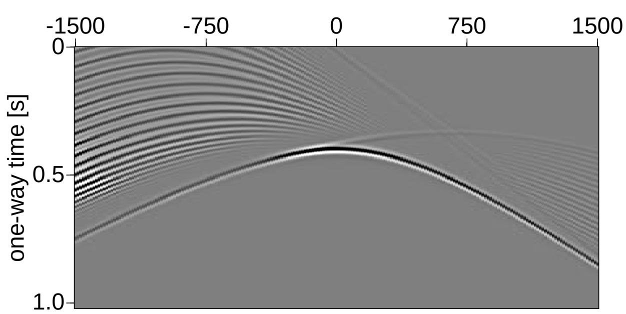

rays for shot record



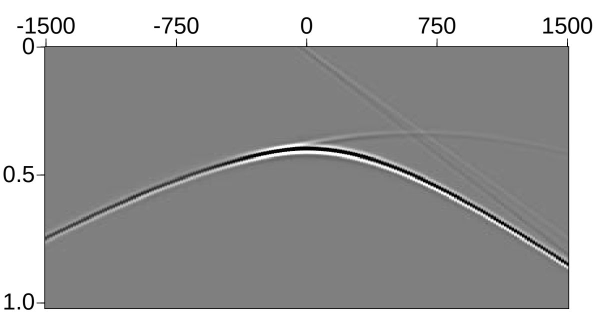

7 receivers per shot



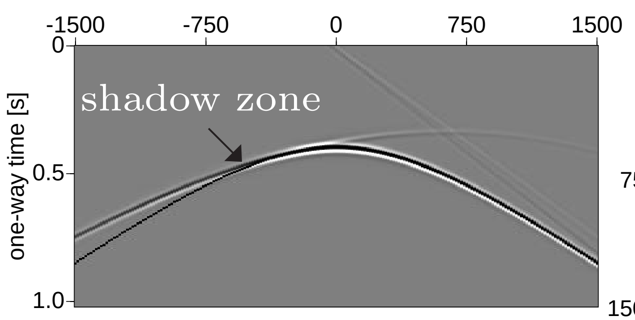

21 receivers per shot



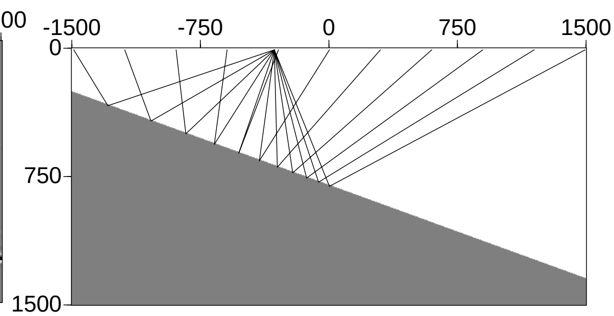

41 receivers per shot




201 receivers per shot

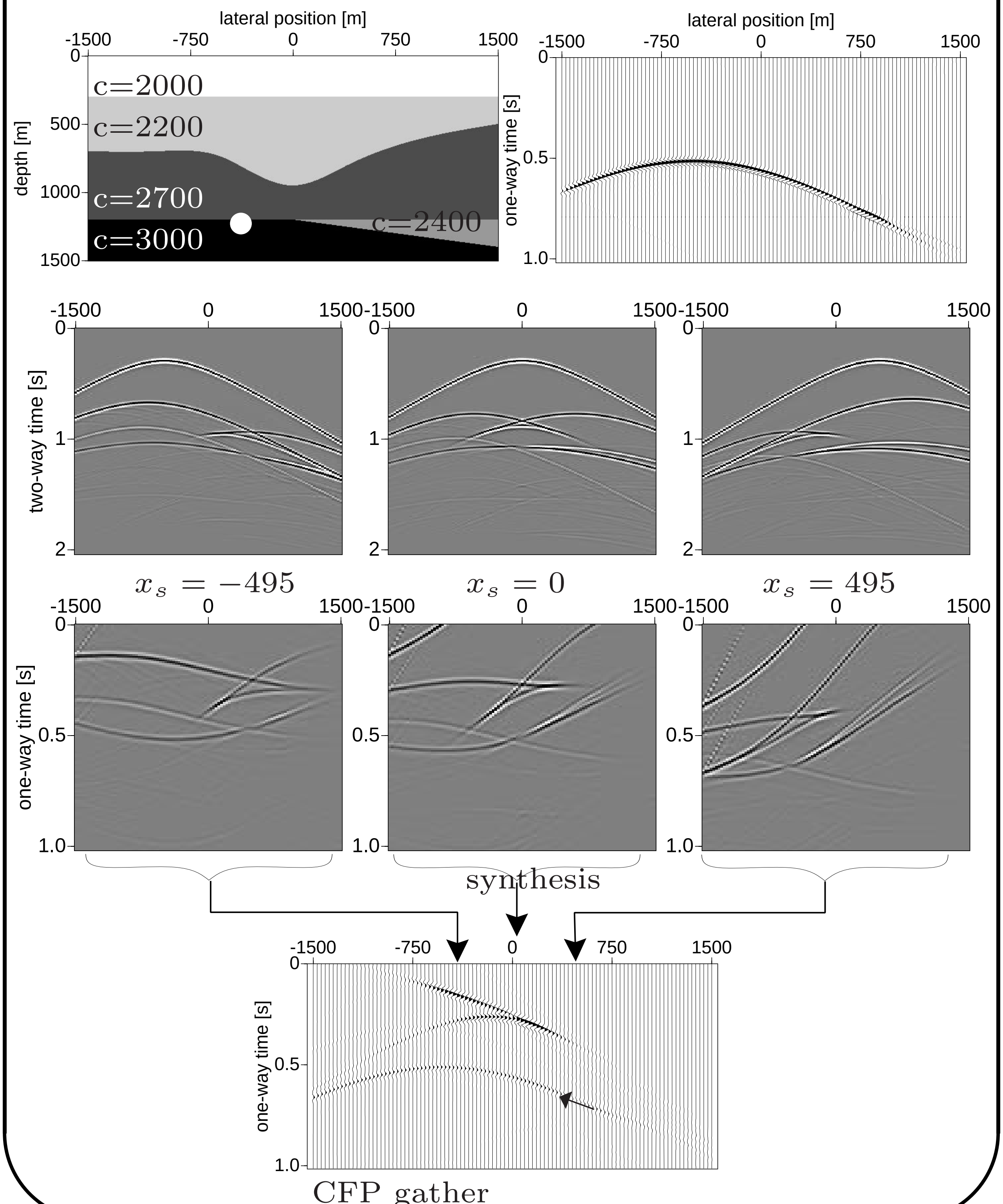



overlay operator and CFP

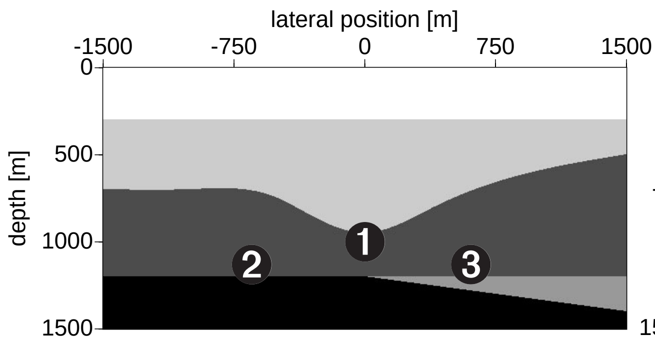



shadow zone in aperture

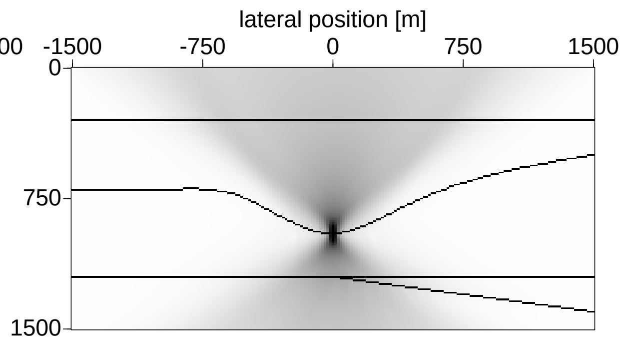
# Construction of a CFP gather



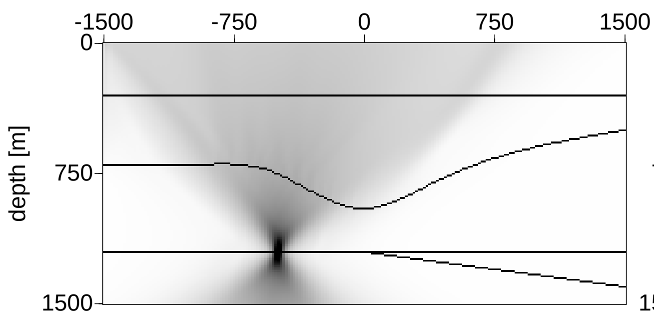
# Focusing beams



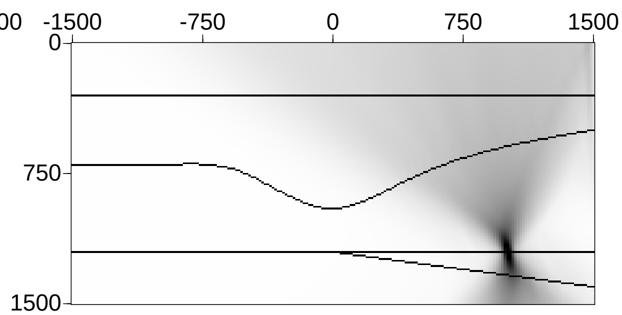
subsurface model



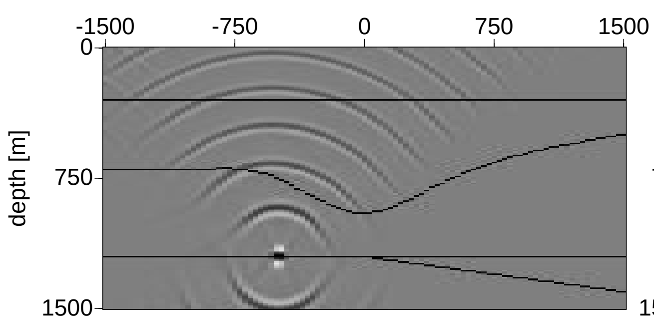
focusing beam ❶



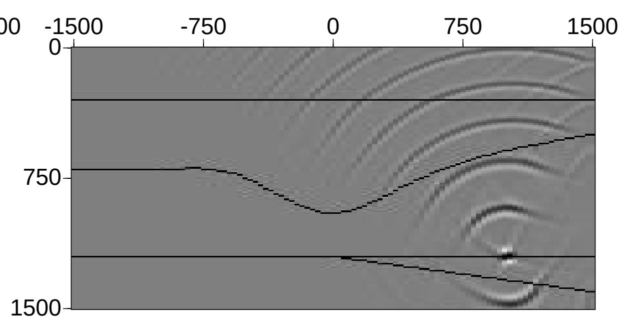
focusing beam ❷



focusing beam ❸



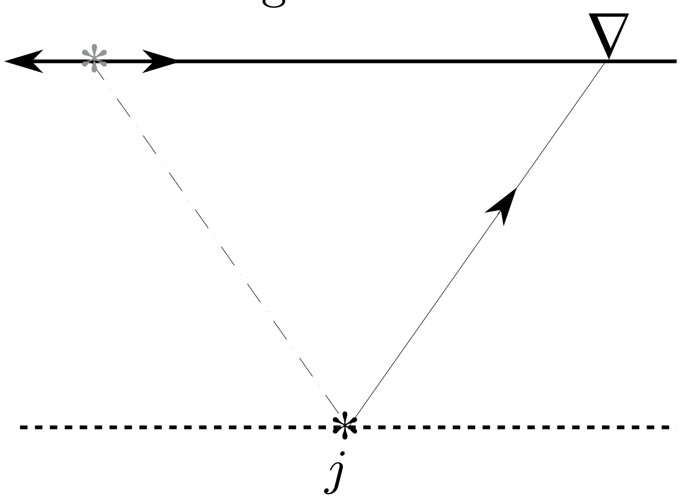
snapshots ❷



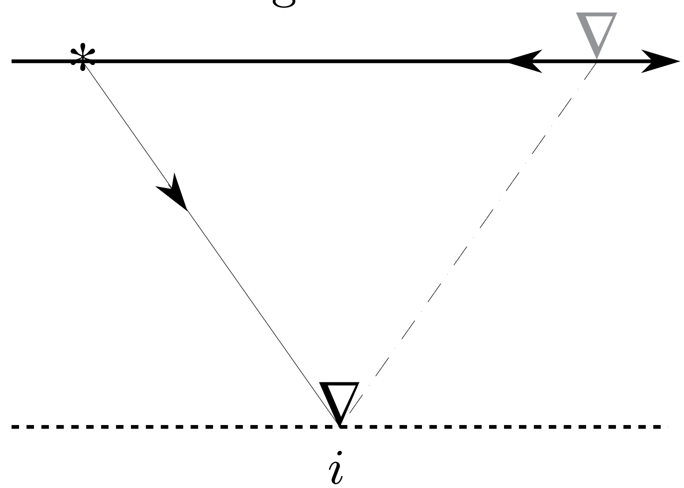
snapshots ❸

$$\tilde{\boldsymbol{F}}_j^+(z_s, z_m) = \left[\mathbf{W}^-(z_s, z_m)\right]^* \tilde{\boldsymbol{I}}_j^+(z_m) \qquad \boldsymbol{F}_i^-(z_m, z_r) = \tilde{\boldsymbol{I}}_i^-(z_m) \left[\mathbf{W}^+(z_m, z_r)\right]^*$$

focusing in emission

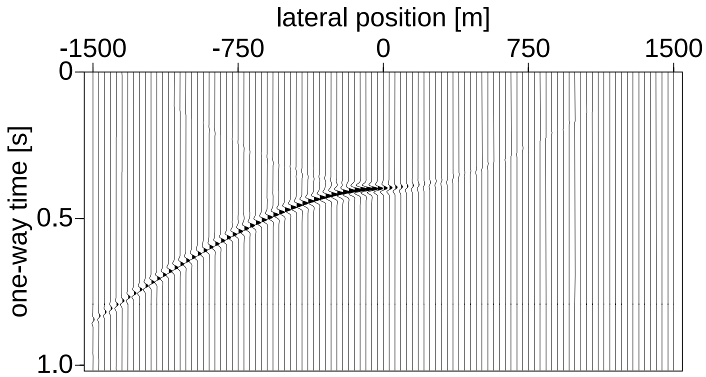



focusing in detection

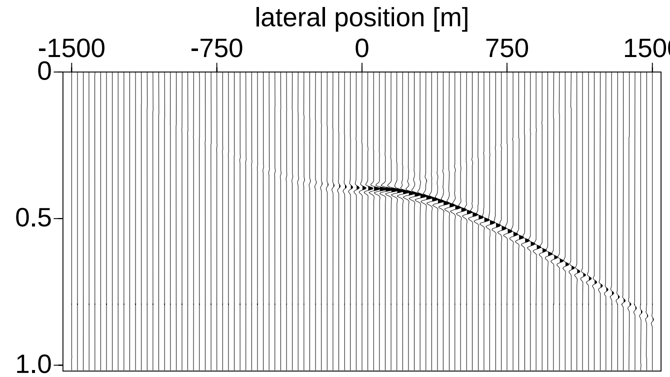



$$\tilde{\boldsymbol{P}}_j(z_r, z_m) = \mathbf{W}^-(z_r, z_m)\tilde{\boldsymbol{R}}_j^+(z_m) \qquad \tilde{\boldsymbol{P}}_i^-(z_m, z_s) = \tilde{\boldsymbol{R}}_i^+(z_m)\mathbf{W}^+(z_m, z_s)$$

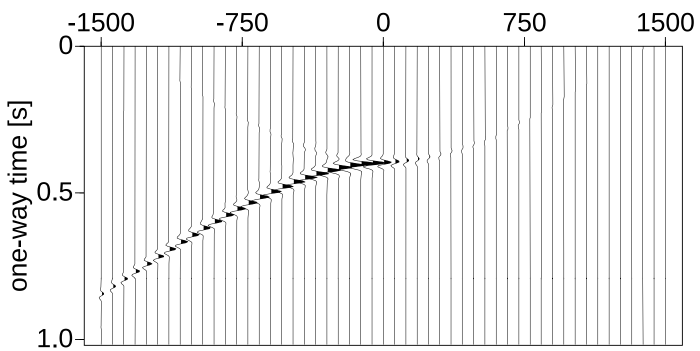
# Focusing in Emission and Detection



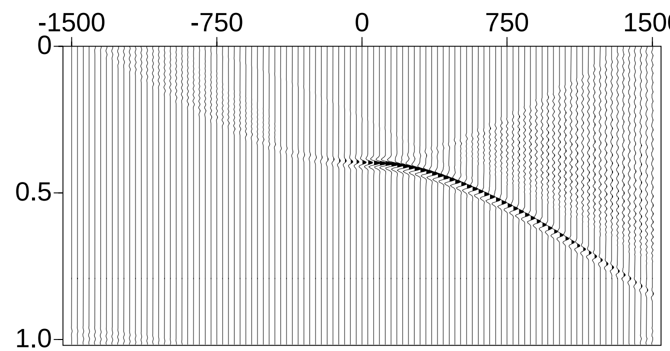

detection $\Delta x_s = 30$ m




emission $\Delta x_s = 30$ m




detection $\Delta x_s = 60$ m




emission $\Delta x_s = 60$ m

# Focusing for receiver array

Correct operator:

$$\tilde{\boldsymbol{F}}_i^-(z_m, z_0) = \tilde{\boldsymbol{I}}_i^-(z_m)\left[\bar{\mathbf{W}}^+(z_m, z_0)\right]^*,$$

CFP gather:

$$\tilde{\boldsymbol{P}}_i^-(z_m, z_0) = \tilde{\boldsymbol{I}}_i^-(z_m)\mathbf{R}^+(z_m)\mathbf{W}^+(z_m, z_0)S_0,$$

# Erroneous operator

Model:

$$\mathbf{W}^-(z_0, z_m) = \bar{\mathbf{W}}^-(z_0, z_m)\Delta\mathbf{W}(z_m),$$

Operator:

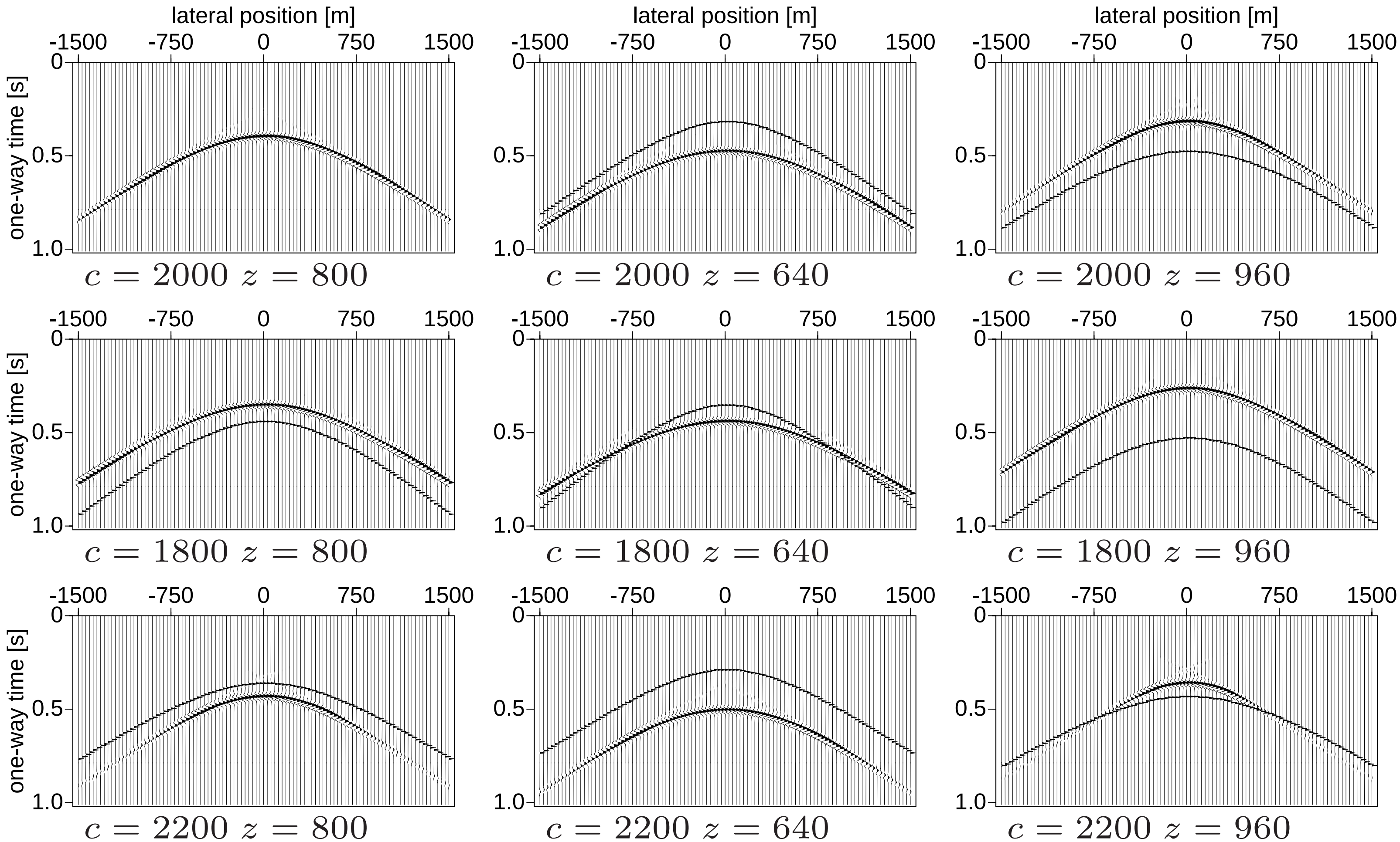
$$\left[\tilde{\boldsymbol{F}}_i^-(z_m, z_0)\right]^* = \tilde{\boldsymbol{I}}_i^-(z_m)\left[\Delta\mathbf{W}(z_m)\right]^* \mathbf{W}^+(z_m, z_0),$$

CFP gather:

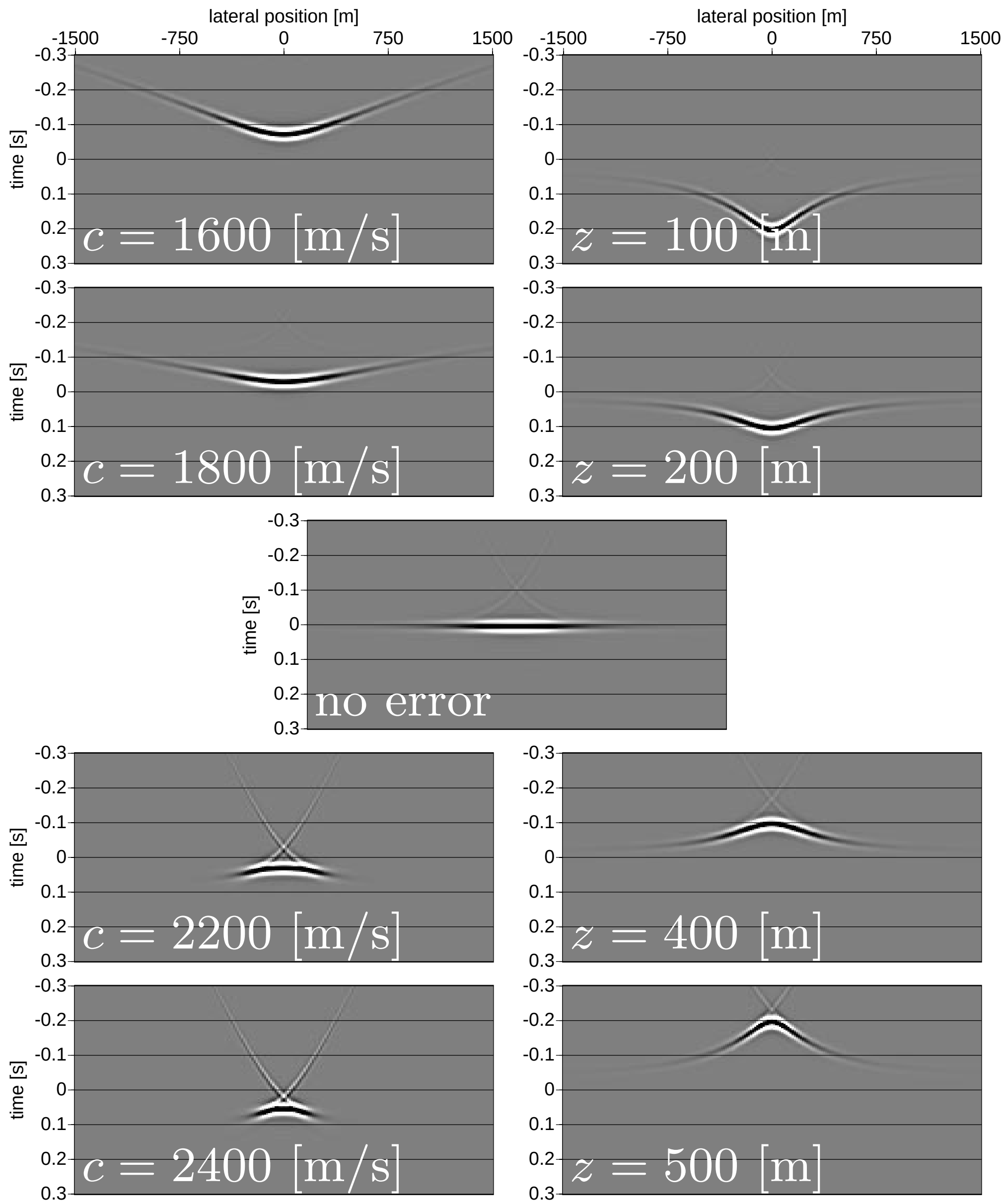
$$\tilde{\boldsymbol{P}}_i^-(z_m, z_0) = \tilde{\boldsymbol{I}}_i^-(z_m)\Delta\mathbf{W}(z_m)\mathbf{R}^+(z_m)\mathbf{W}^+(z_m, z_0)S_0,$$

$$\tilde{\boldsymbol{P}}_i^-(z_m, z_0) = \tilde{\boldsymbol{R}}_i^+(z_m)\Delta\mathbf{W}(z_m)\mathbf{W}^+(z_m, z_0)S_0,$$

# Erroneous operator and CFP gather



# Move out Panels



## Operator updating

traveltime updating:

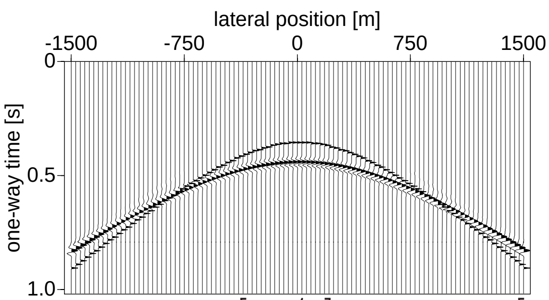
$$\bar{T}_s^1(x_r) = \bar{T}_s^0(x_r) + T_c(x_r)$$

traveltime correction:

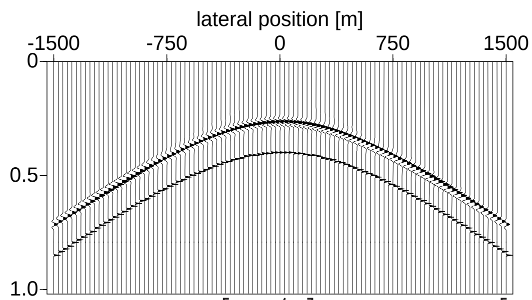
$$T_c(x_r) = \frac{T_{cfp}(x_r) - \bar{T}_s^0(x_r)}{2}$$

# Focusing operator updating

updating in offset



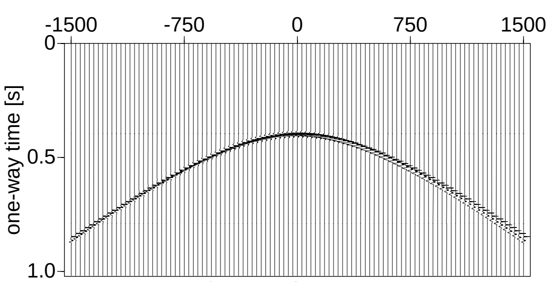

$c = 1800$ [m/s] $z = 640$ [m]



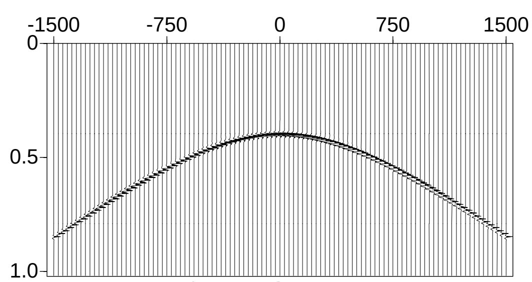

$c = 1800$ [m/s] $z = 960$ [m]

$\Downarrow$ update

$\Downarrow$ update

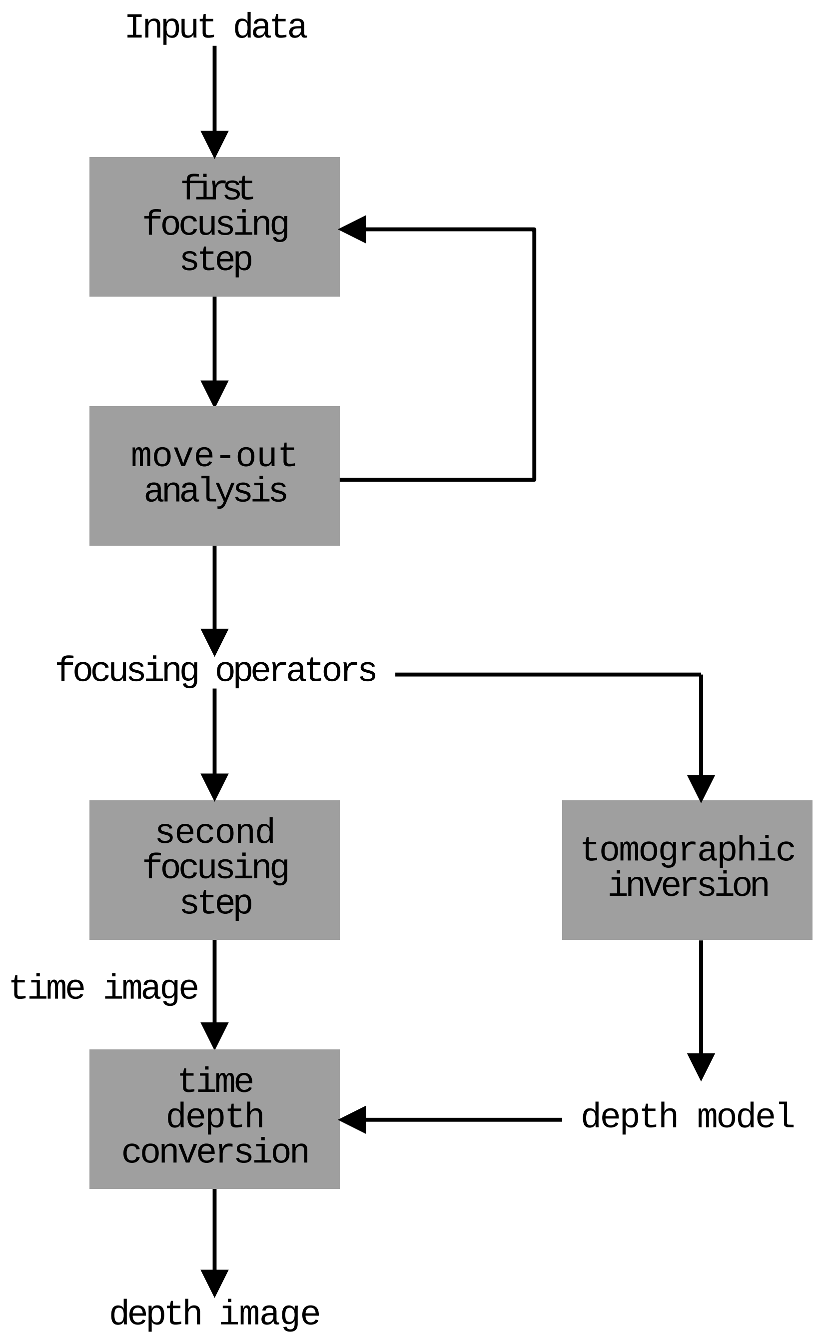



result after first update




result after first update

# Summary


Input data
first focusing step
move-out analysis
focusing operators
second focusing step
tomographic inversion
time image
time depth conversion
depth model
depth image

# AVO analysis

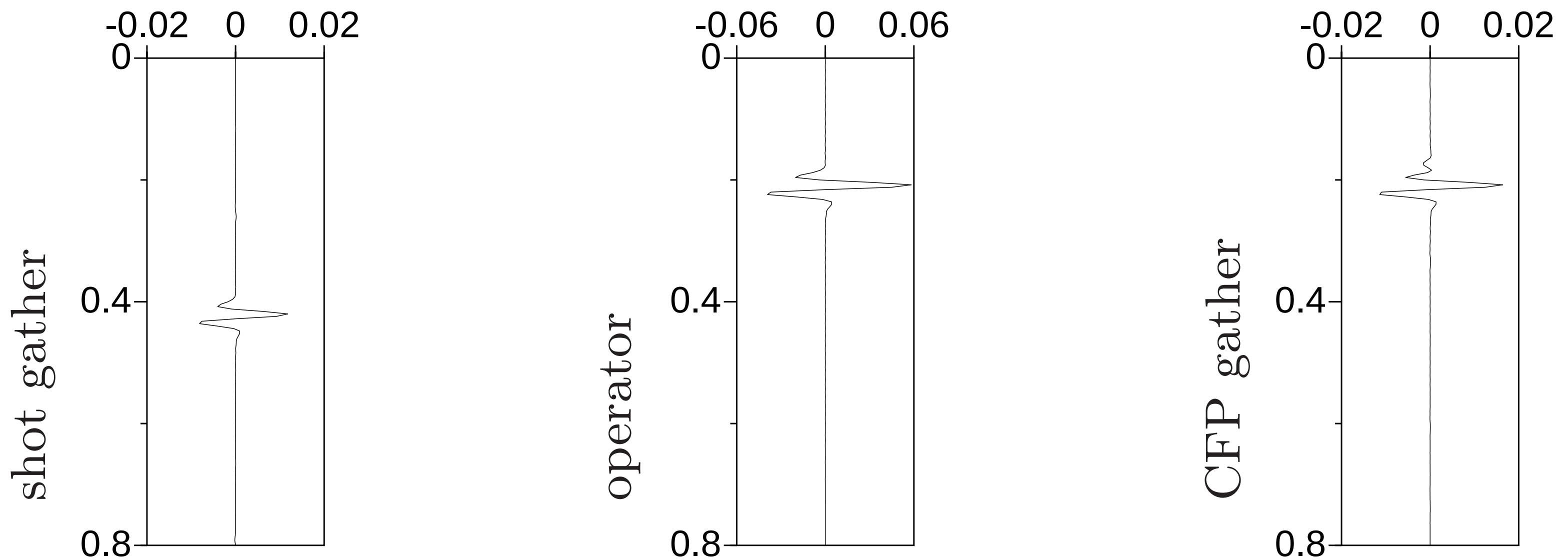
Operator:

$$\tilde{\boldsymbol{F}}_i^{-}(z_m, z_0) = \tilde{\boldsymbol{I}}_i^{-}(z_m)\left[\mathbf{W}^{+}(z_m, z_0)\right]^{*}$$

CFP gather:

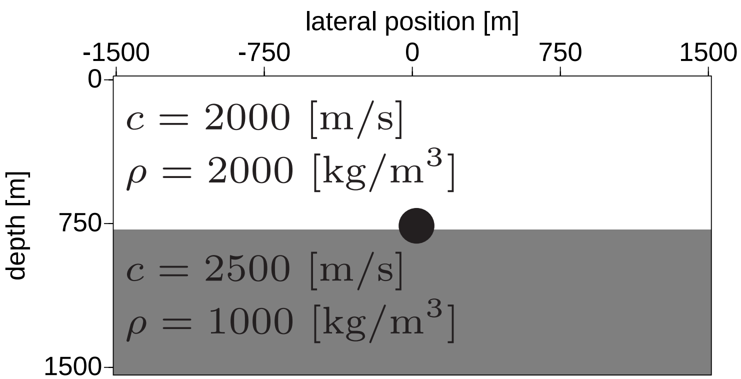
$$\tilde{\boldsymbol{P}}_i^{-}(z_m, z_0) = \tilde{\boldsymbol{I}}_i^{-}(z_m)\mathbf{R}^{+}(z_m)\mathbf{W}^{+}(z_m, z_0)\mathbf{S}(z_0)$$

# AVO

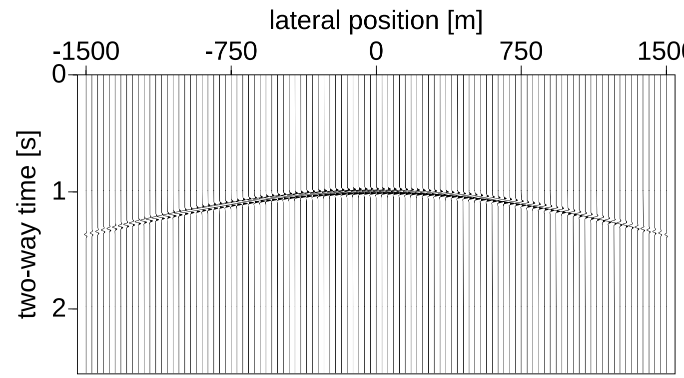



$$A \simeq \frac{RS}{\sqrt{2r}} \qquad A \simeq \frac{S}{\sqrt{r}} \qquad A \simeq \frac{RS}{\sqrt{r}}$$

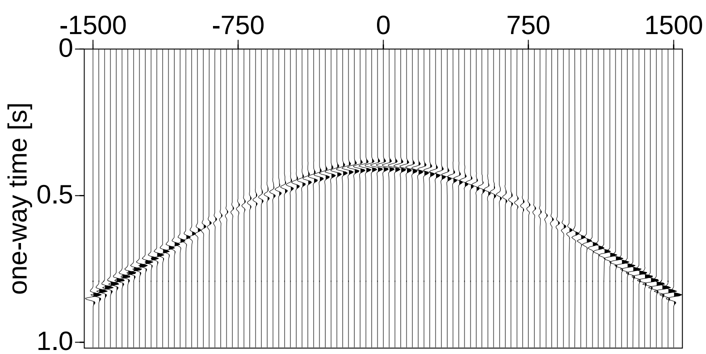
# AVO



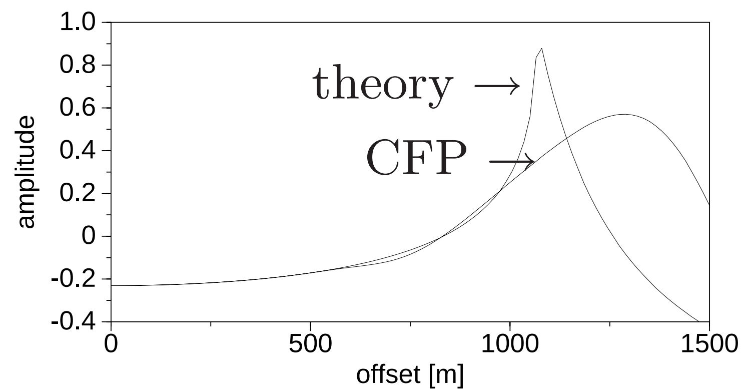

flat reflector model




shot record with $x_s = 0$

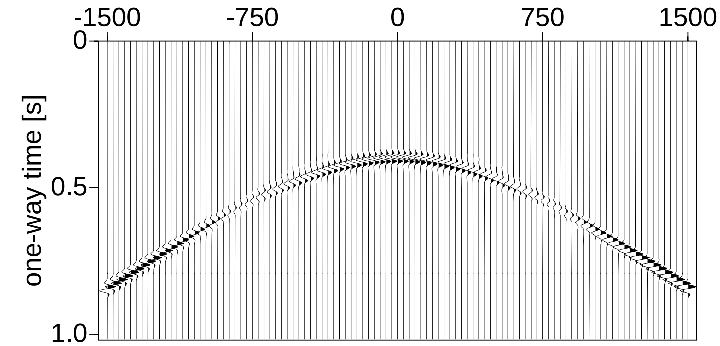



CFP gather

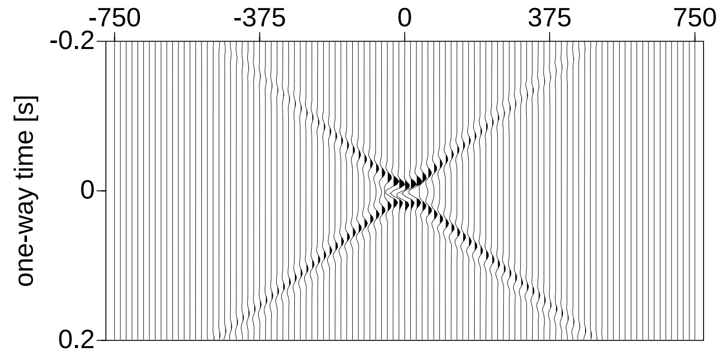



amplitude versus offset curve

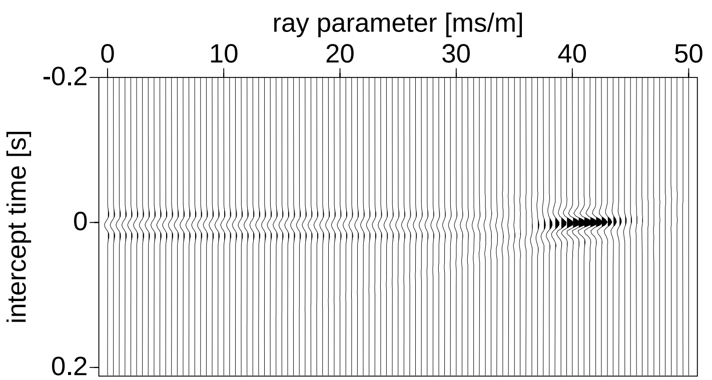
# AVO



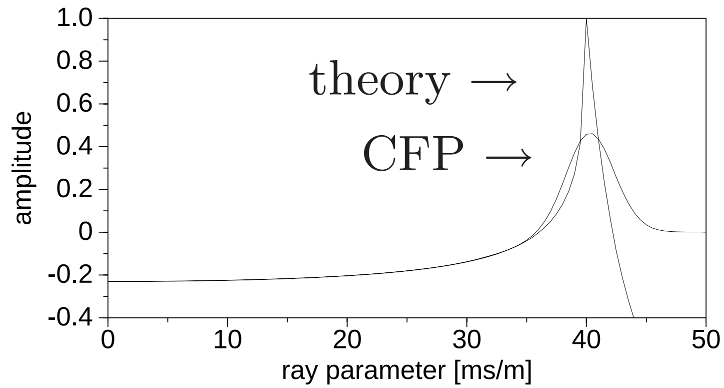

CFP gather




2D cross-correlation

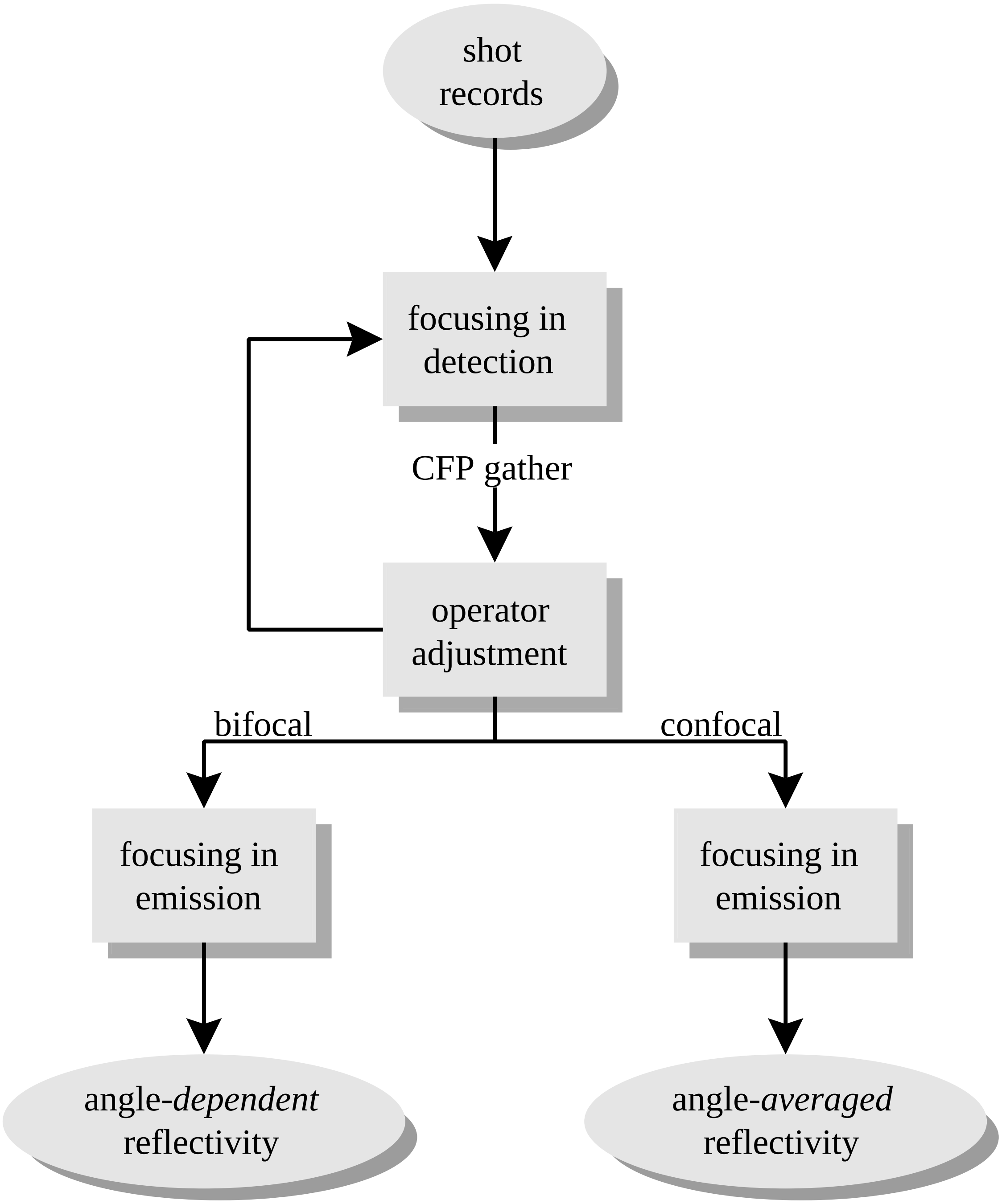



$\tau - p$ )

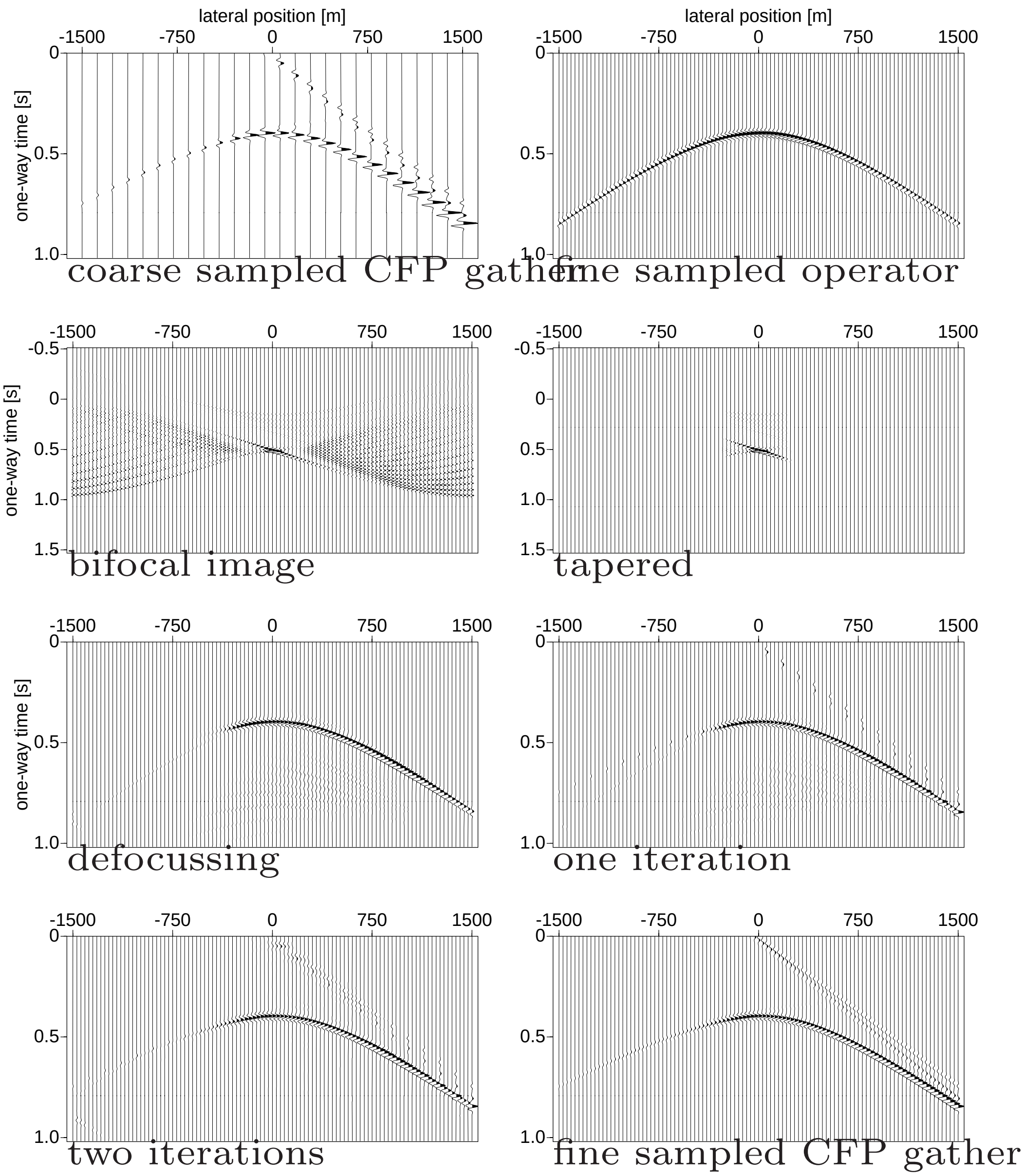



amplitude versus $p$ curve

# Computation scheme



# Regularization



# CFP Imaging

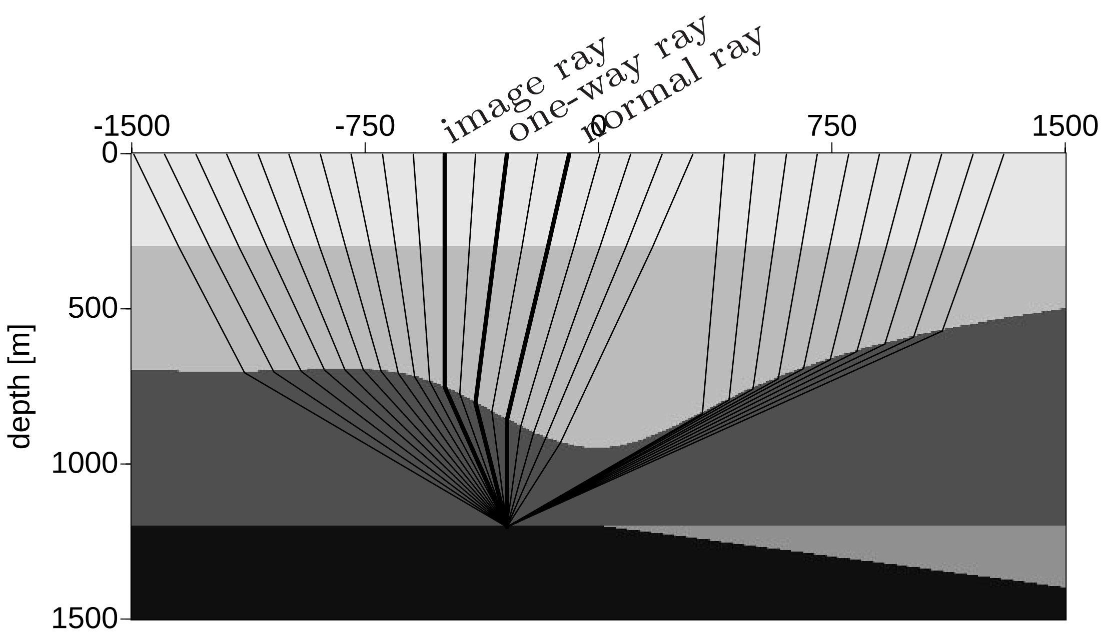
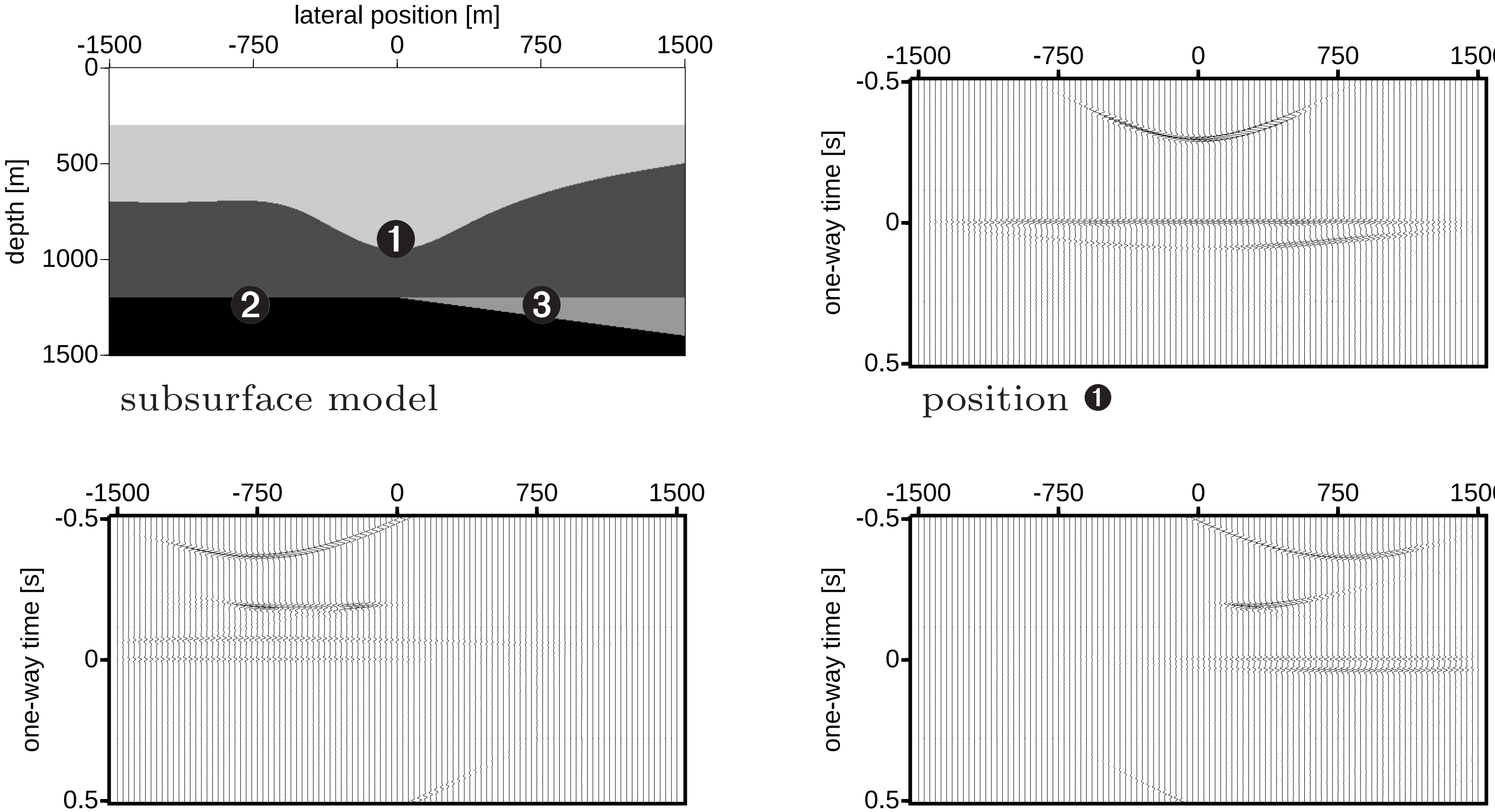


image ray
one-way ray
normal ray
-1500
-750
0
750
1500
0
500
1000
1500
depth [m]

# CFP move-out panels



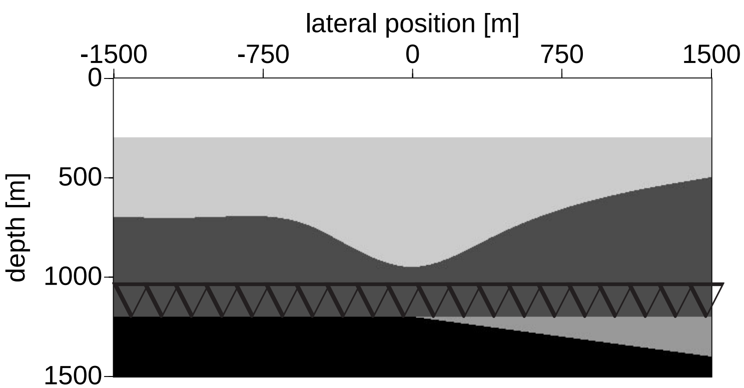

subsurface model

position ❶

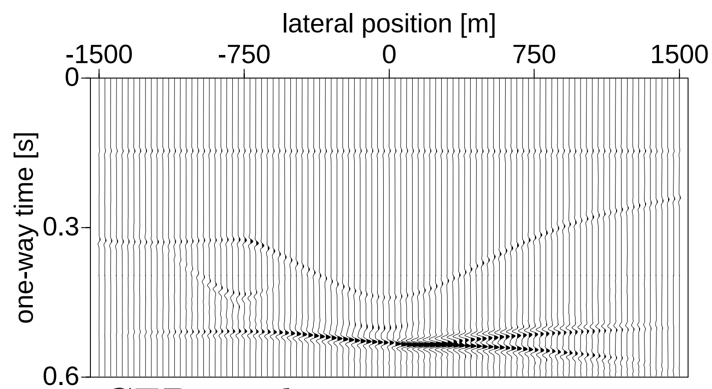
position ❷

position ❸

# Combining CFP images

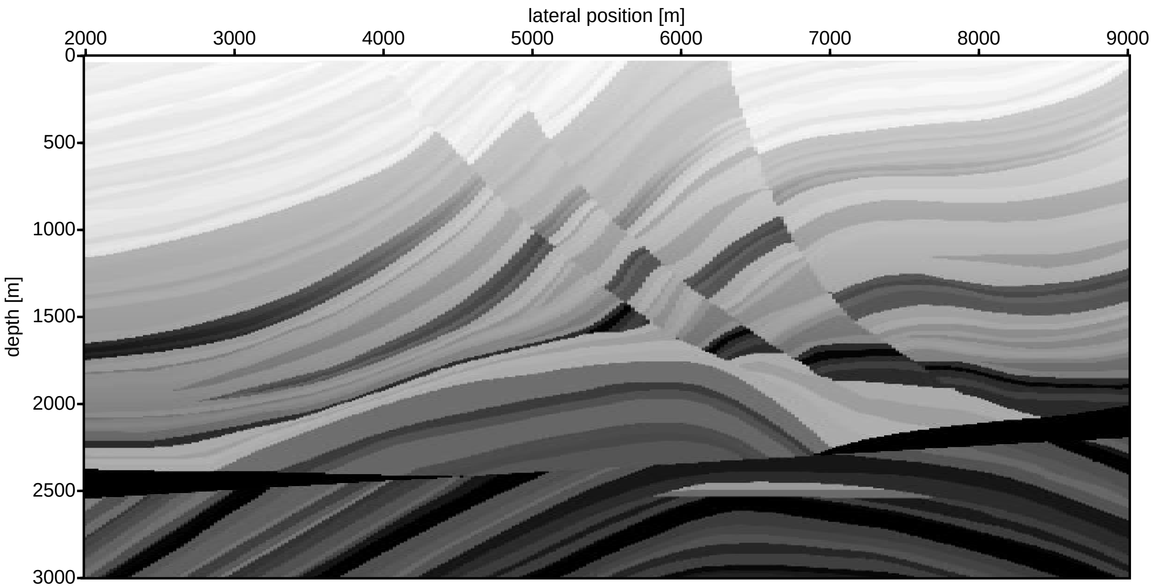



syncline model

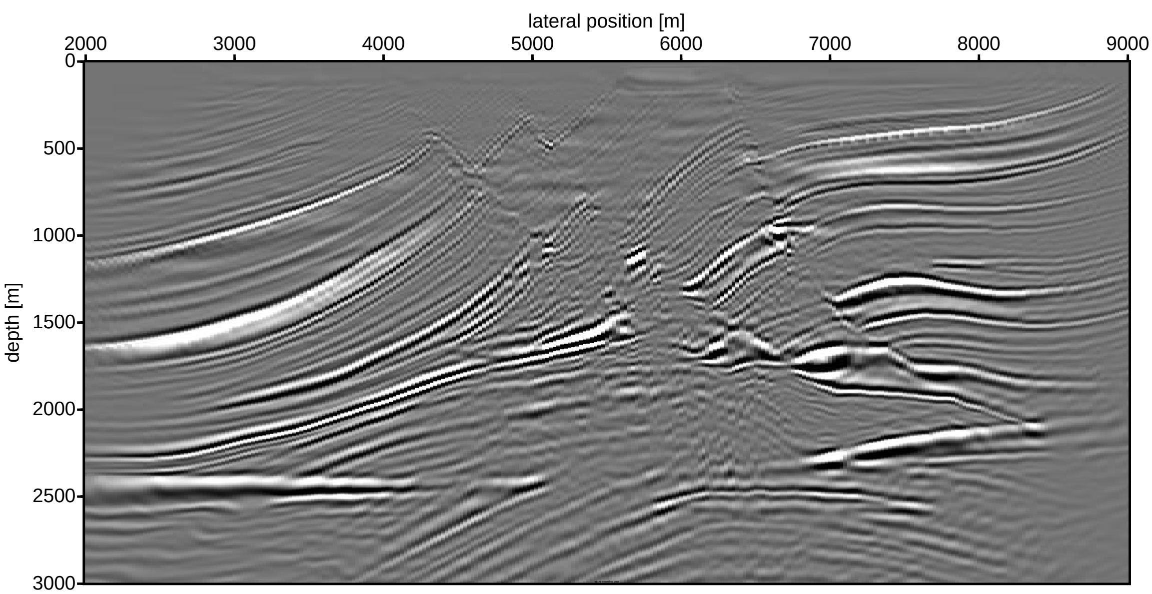



CFP-stack at $z = 1200$ m

# Marmousi model

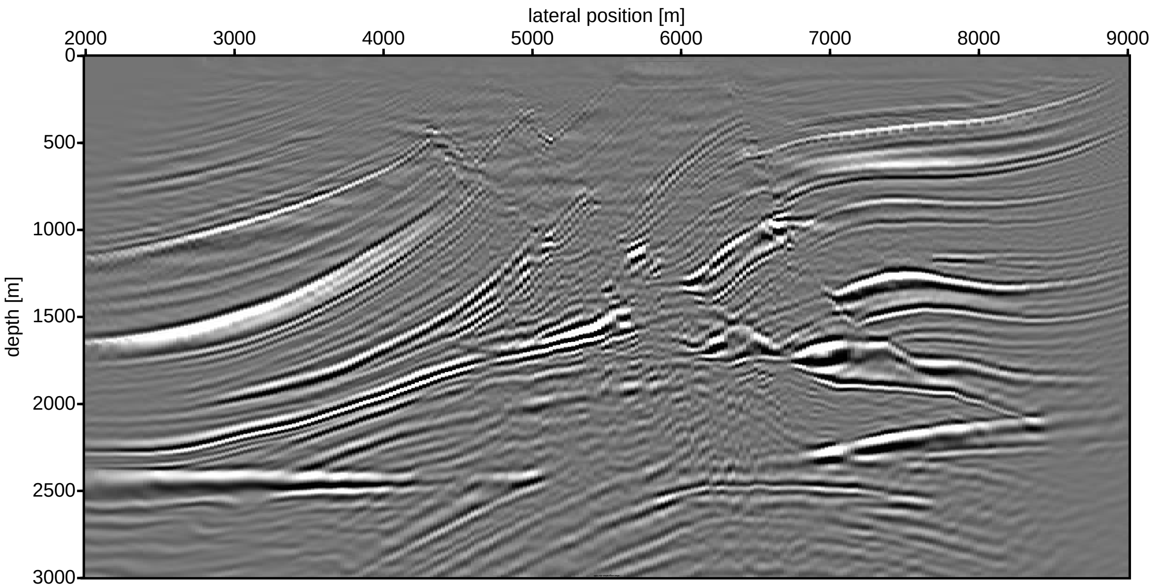



Marmousi model

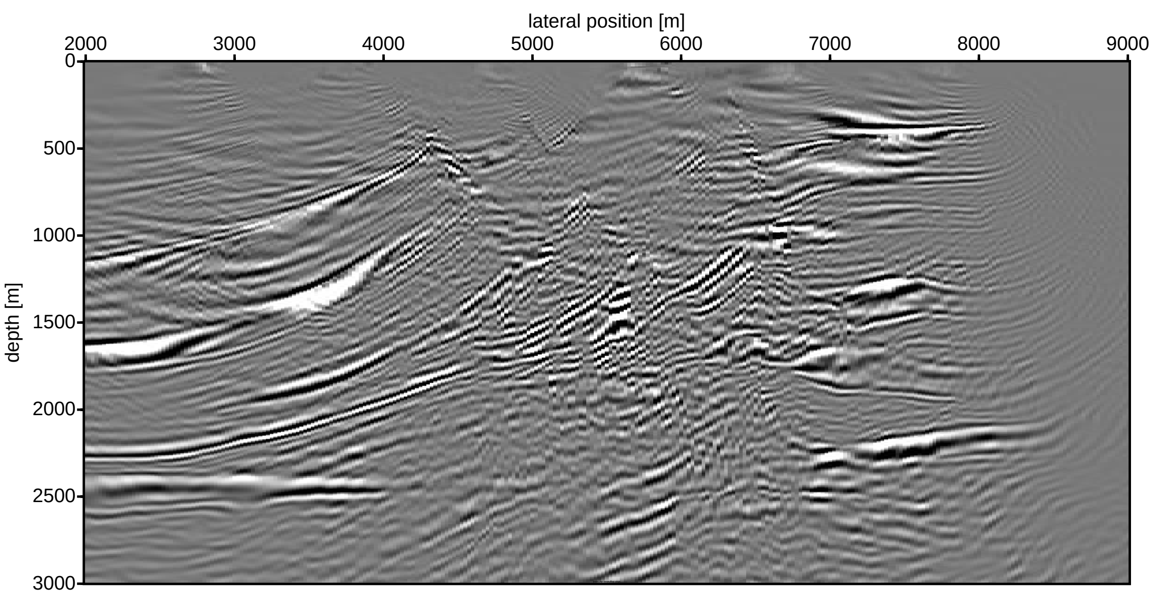



Shot record migration with $\Delta x_{src} = 25$ (all 240 shots)

# shot record migration

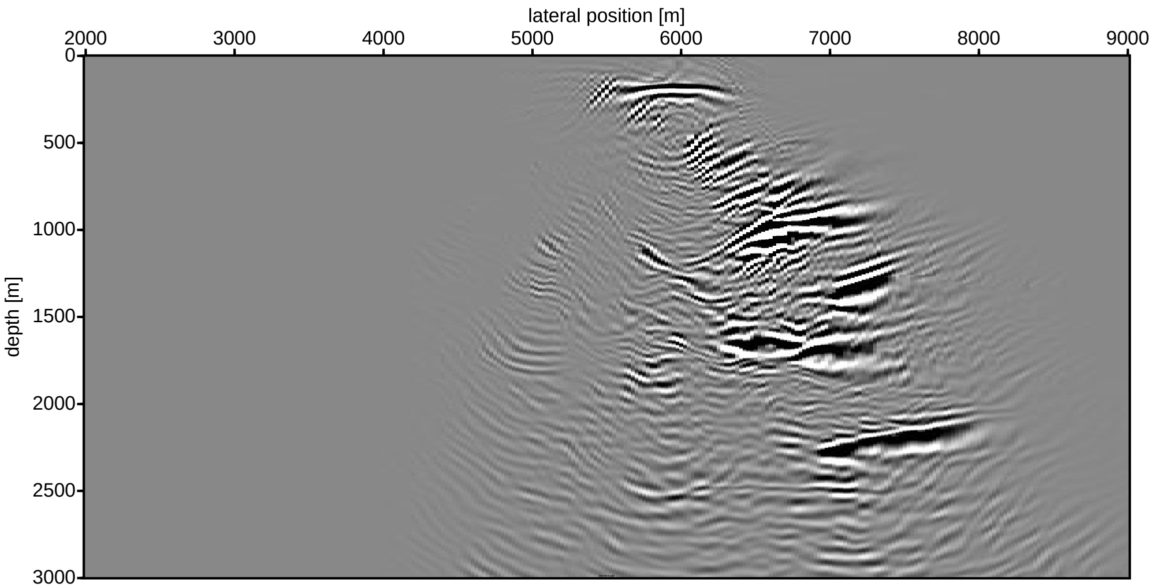



Shot record migration with $\Delta x_{src} = 100$ (61 shots)

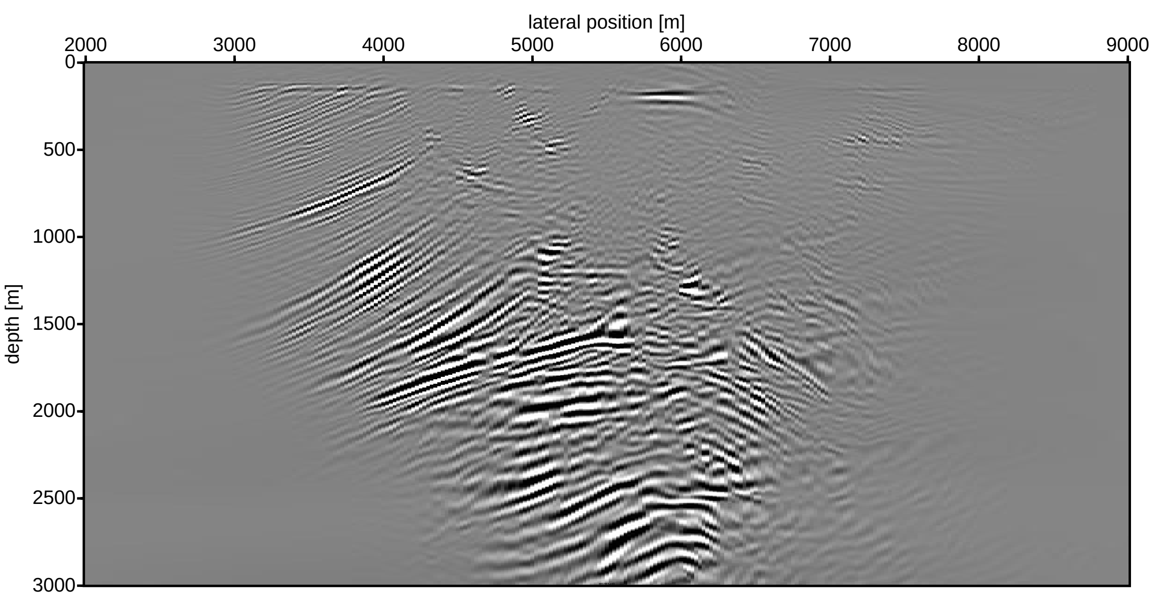



Shot record migration with $\Delta x_{src} = 1000$ (7 shots)

# CFP gather migration

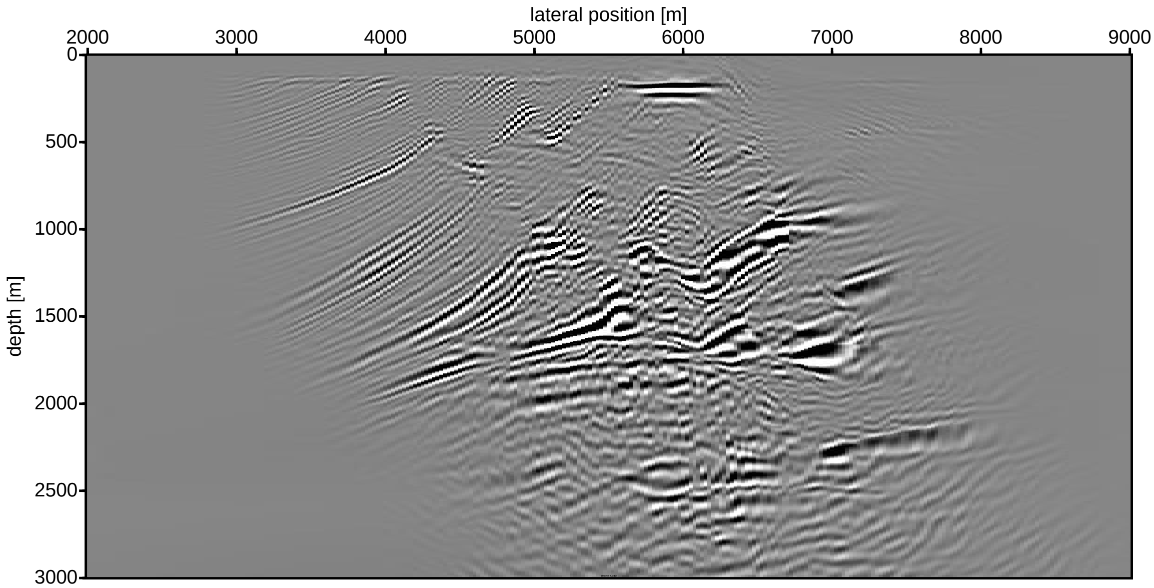



CFP gather migration with focus x=6000 and z=500

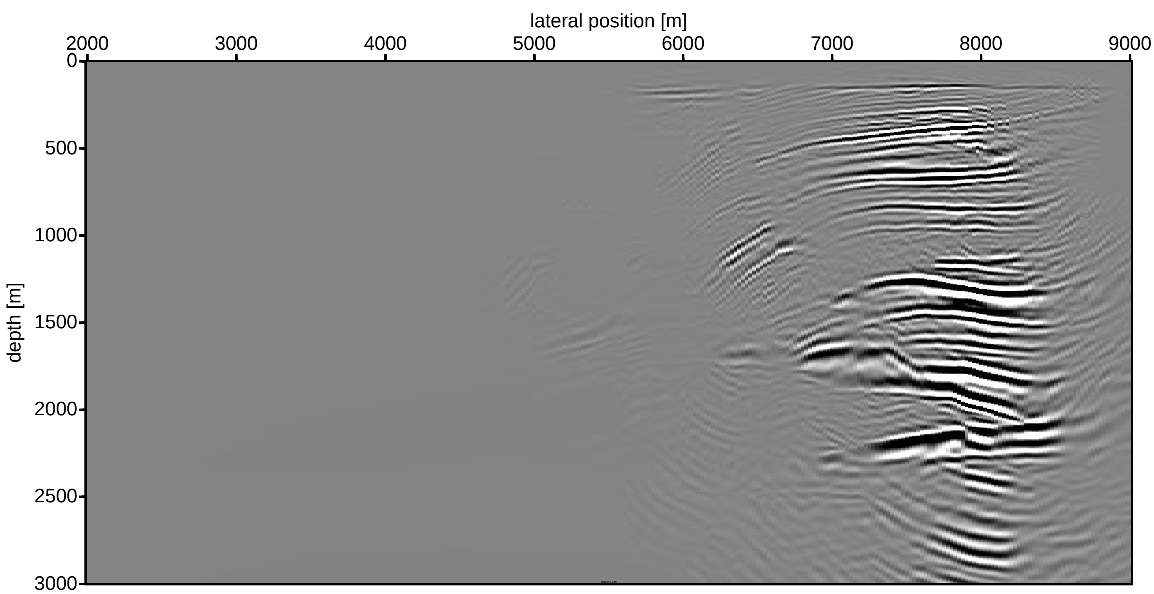



CFP gather migration with focus x=6000 and z=3000

# CFP gather migration

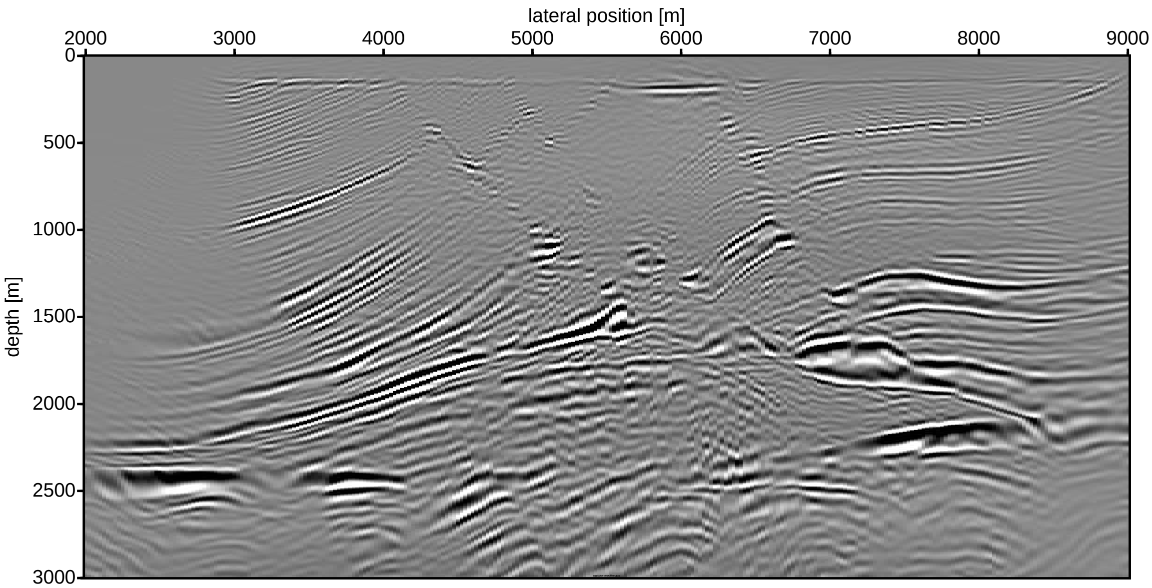



Focus at $x = 6000$ with $\Delta z = 500$ (6 gathers)

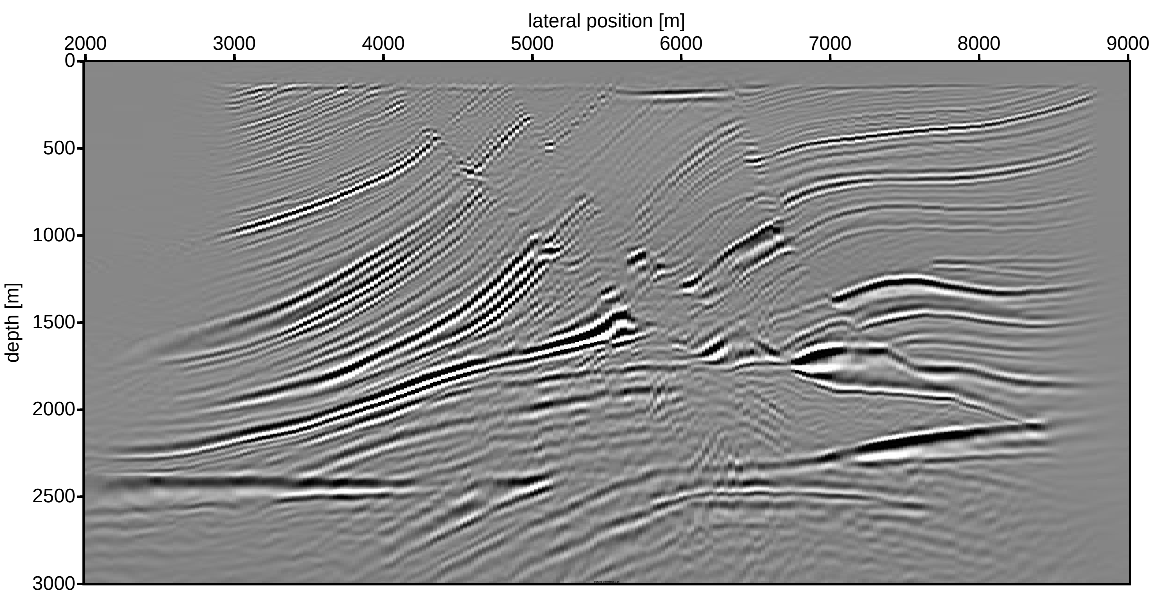



Focus at $x = 8000$ with $\Delta z = 500$ (6 gathers)

# CFP gather migration

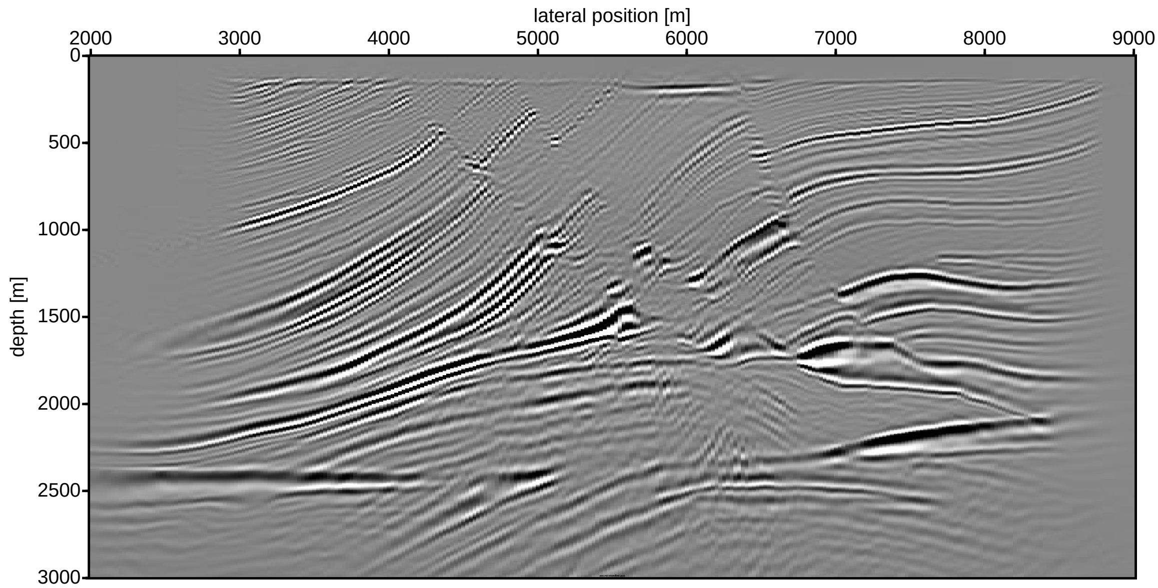



Focus at $z = 3000$ with $\Delta x_{cfp} = 1000$ (8 gathers)

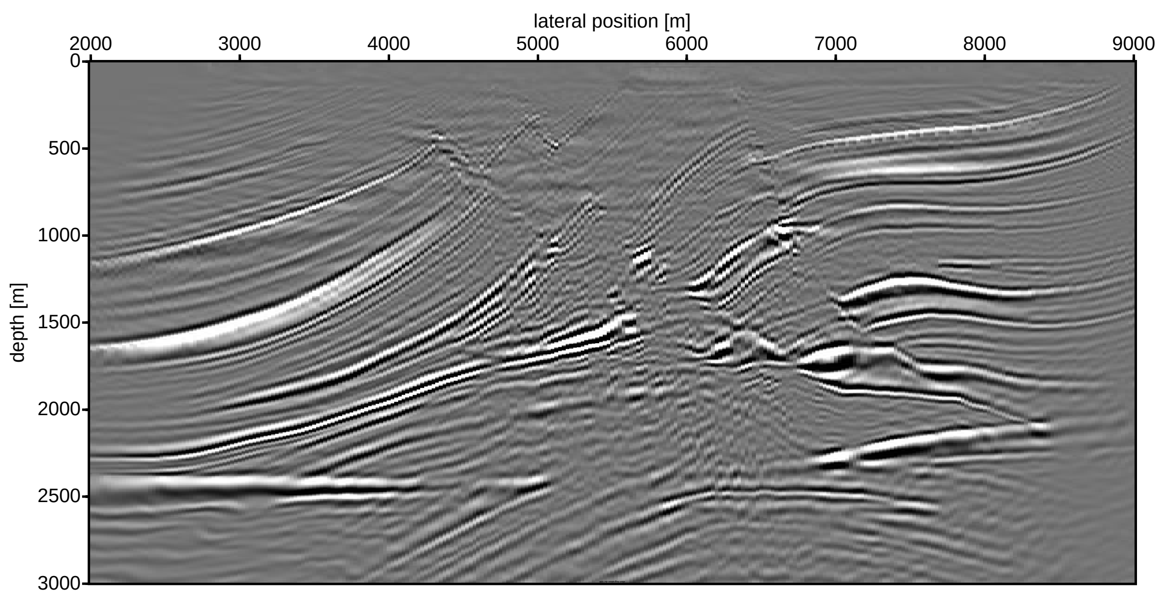



Focus at $z = 3000$ with $\Delta x_{cfp} = 250$ (29 gathers)

# CFP vs shot migration




CFP gather migration with $\Delta x_{cfp} = 100$ (60 gathers)




Shot record migration with $\Delta x_{src} = 100$ (60 shots)

## Concluding remarks

- CFP gathers are very well suited for velocity analysis.
- Efficient migration using CFP gathers looks promissing
- 3D extension continued within DELPHI project
- CFP has been used in surface and internal multiple elimination
- CFP used for (weathered) layer replacement