Internal multiple prediction in the continuous wavelet transform domain

Kris Innanen
k.innanen@ucalgary.ca

UNIVERSITY OF CALGARY

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Outline

- Quick mention of AVO and FWI
- Review of Hernandez thesis results (2012)
  - Internal multiple prediction on noisy land data
- Continuous wavelet transform maxima
  - Continuous wavelet transforms
  - Processing with CWT maxima
  - Internal multiple prediction in the CWTM domain

AVO and FWI

CREWES research priority (Margrave et al., 2013)

Support & pre-condition iterative seismic inversion with existing standard methodologies

$$\delta\mathbf{s} = -\mathbf{H}^{-1}\mathbf{g}$$

update

amplitude correction ?

amplitude-compromised migration

AVO and FWI

FWI for short offset (pre-critical) reflection data?

Will involve AVO info & updates in 3 parameters

$$\delta \mathbf{s} = -\mathbf{H}^{-1}\mathbf{g}$$

update in V_P, V_S, ρ

amplitude correction ?

amplitude-compromised migration

AVO and FWI

A combined discrete-continuous formulation

determinant

gradients

$$\begin{bmatrix} \delta s_\kappa(\mathbf{r}) \\ \delta s_\rho(\mathbf{r}) \end{bmatrix} = \int d\mathbf{r}' \mathcal{H}_2^{-1}(\mathbf{r},\mathbf{r}') \int d\mathbf{r}'' \begin{bmatrix} -H_{\rho\rho}(\mathbf{r}',\mathbf{r}'') & H_{\rho\kappa}(\mathbf{r}',\mathbf{r}'') \\ H_{\kappa\rho}(\mathbf{r}',\mathbf{r}'') & -H_{\kappa\kappa}(\mathbf{r}',\mathbf{r}'') \end{bmatrix} \begin{bmatrix} g_\kappa(\mathbf{r}'') \\ g_\rho(\mathbf{r}'') \end{bmatrix}$$

Hessian functions

$$\mathcal{H}_2(\mathbf{r},\mathbf{r}') = \int d\mathbf{r}'' \left[H_{\kappa\kappa}(\mathbf{r},\mathbf{r}'')H_{\rho\rho}(\mathbf{r}'',\mathbf{r}') - H_{\rho\kappa}(\mathbf{r},\mathbf{r}'')H_{\kappa\rho}(\mathbf{r}'',\mathbf{r}') \right]$$

AVO and FWI

Allowing a range of approximate Newton steps

cross-talk suppression

amplitude correction

$$\begin{bmatrix} \delta s_\kappa(\mathbf{r}) \\ \delta s_\rho(\mathbf{r}) \end{bmatrix} \approx -\underbrace{\frac{1}{\Gamma_{\kappa\kappa}(\mathbf{r})\Gamma_{\rho\rho}(\mathbf{r}) - \Gamma_{\rho\kappa}(\mathbf{r})\Gamma_{\kappa\rho}(\mathbf{r})}} \begin{bmatrix} \Gamma_{\rho\rho}(\mathbf{r}) & -\Gamma_{\rho\kappa}(\mathbf{r}) \\ -\Gamma_{\kappa\rho}(\mathbf{r}) & \Gamma_{\kappa\kappa}(\mathbf{r}) \end{bmatrix} \begin{bmatrix} g_\kappa(\mathbf{r}) \\ g_\rho(\mathbf{r}) \end{bmatrix}$$

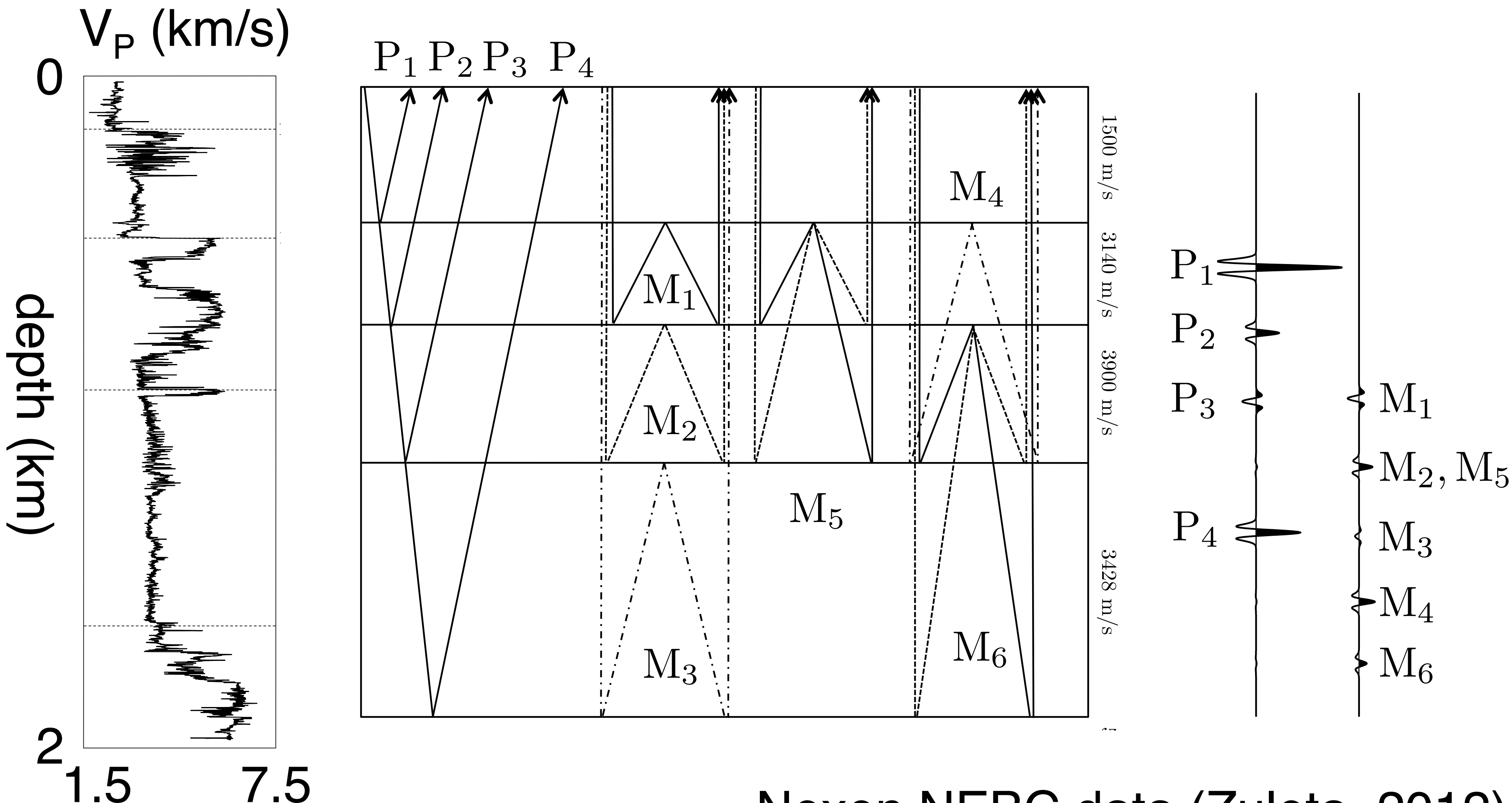
angle-dependence suppression

cross-talk suppression

Internal multiple prediction

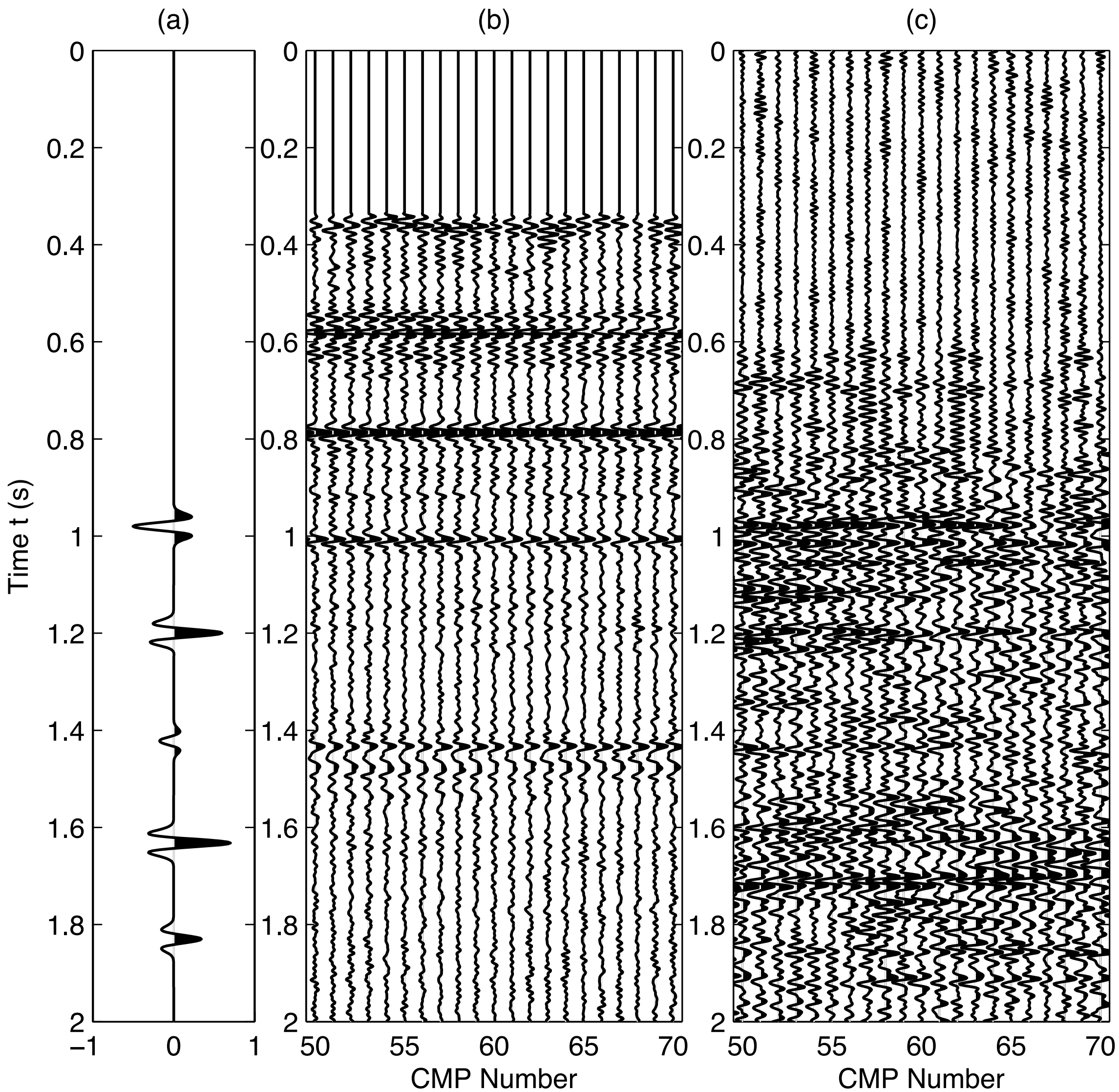
On noisy land traces

(Hernandez, 2012; following Weglein et al., 1997)



Nexen NEBC data (Zuleta, 2012)

Internal multiple prediction



(Hernandez & Innanen, 2013)

Conclusions

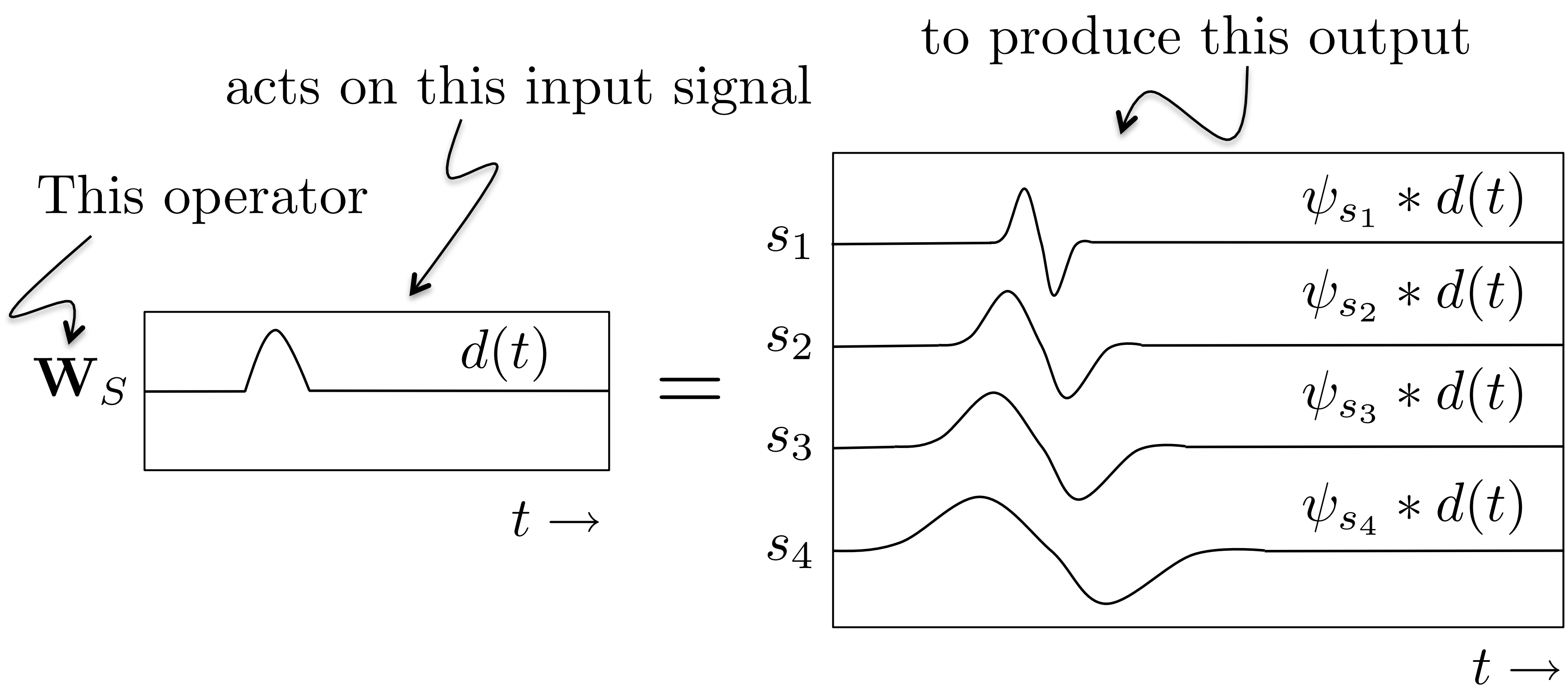
Predictions correlate very well with modelled traces

Interpretation tool? Probability map of contamination with IMs

Subtraction? Need a way of combating noise…

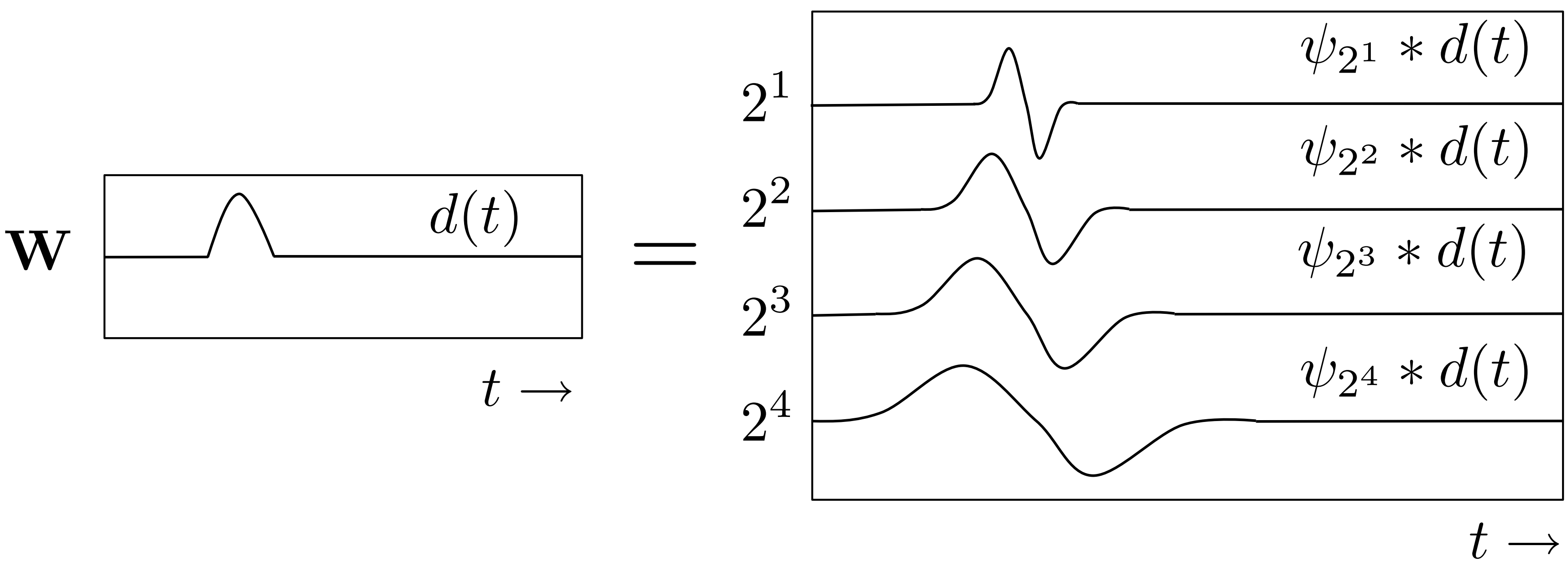
Continuous wavelet transform

Define the operator W_S



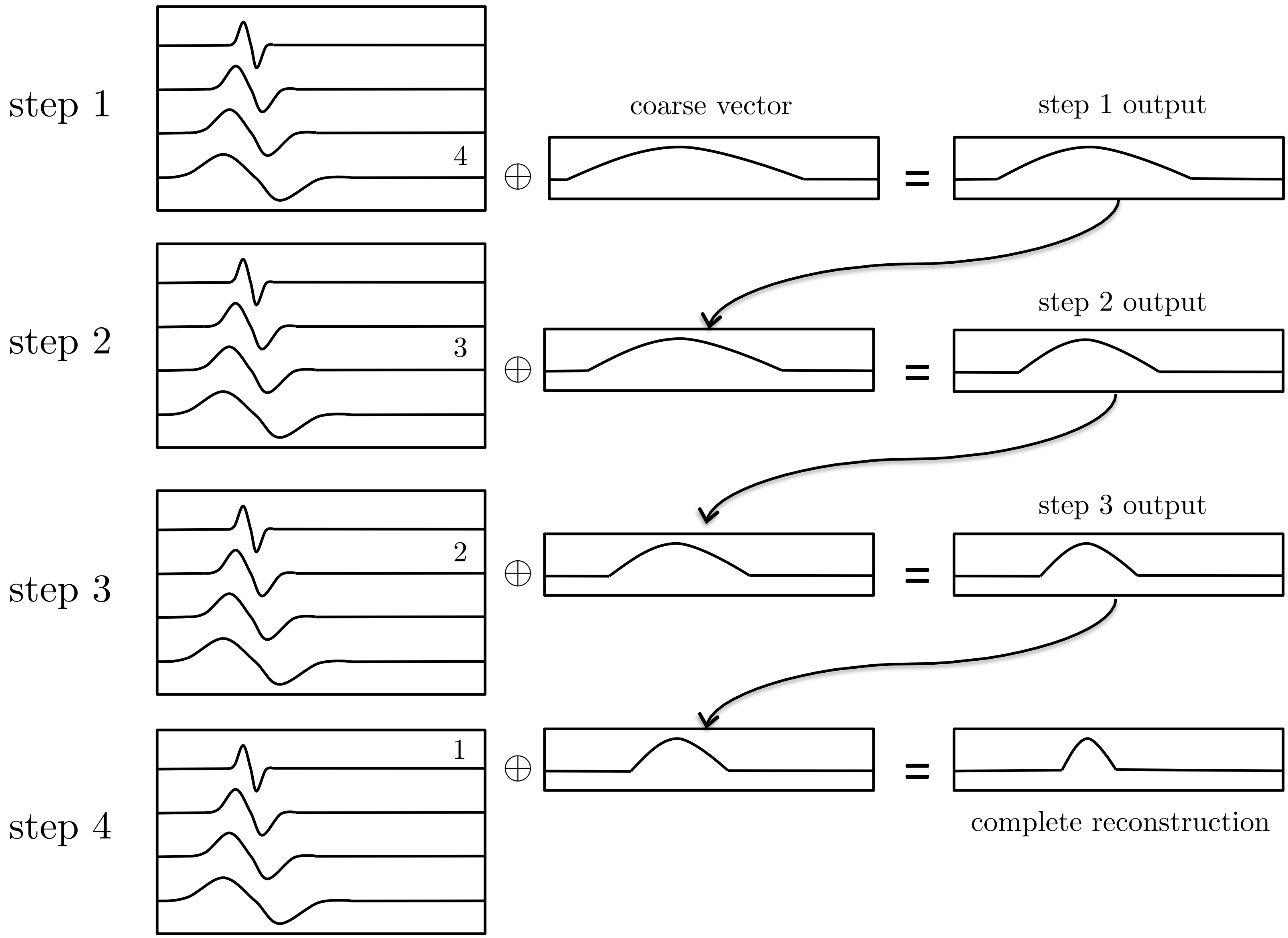
Continuous wavelet transform

Define the operator W

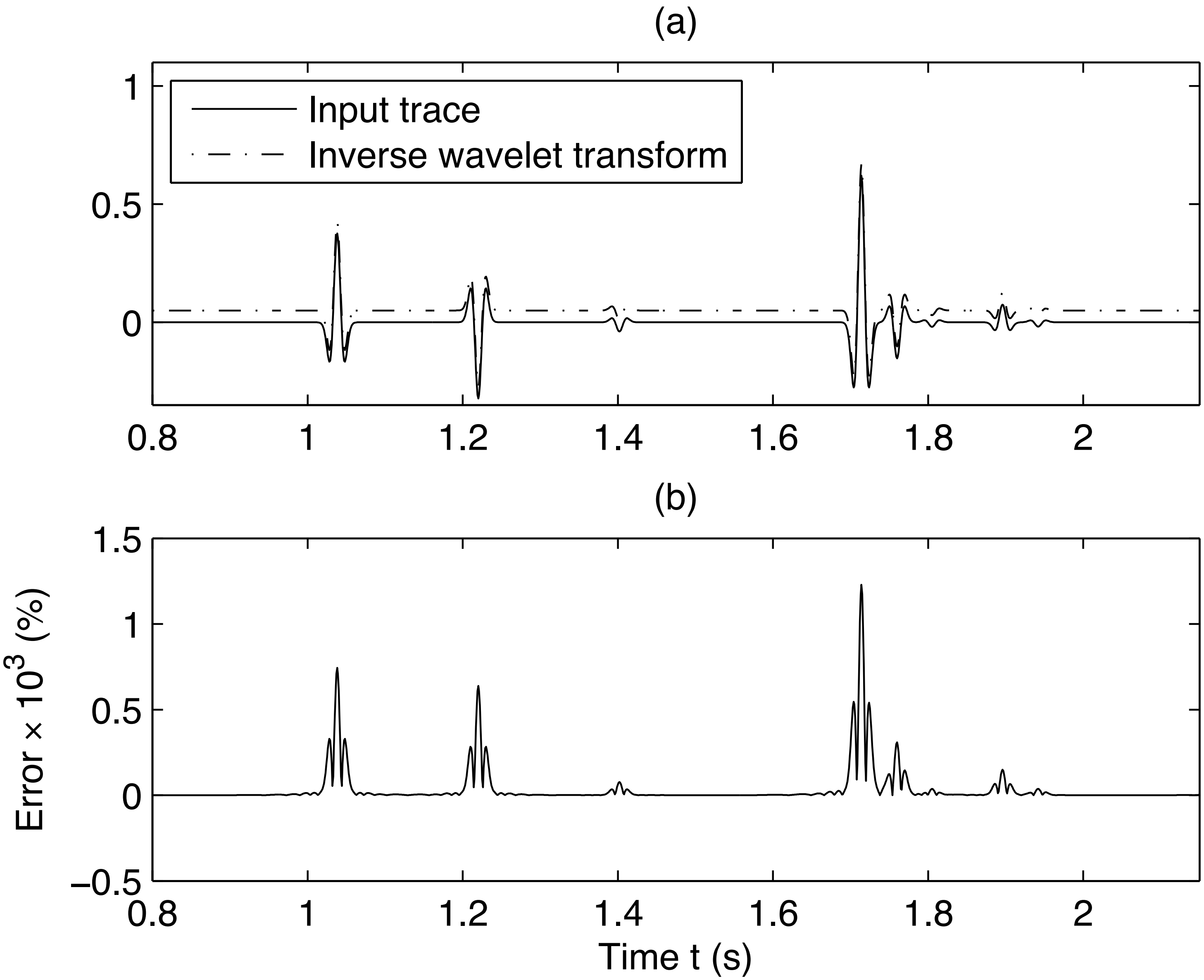


+ a “coarse” signal

Inversion W^{-1}

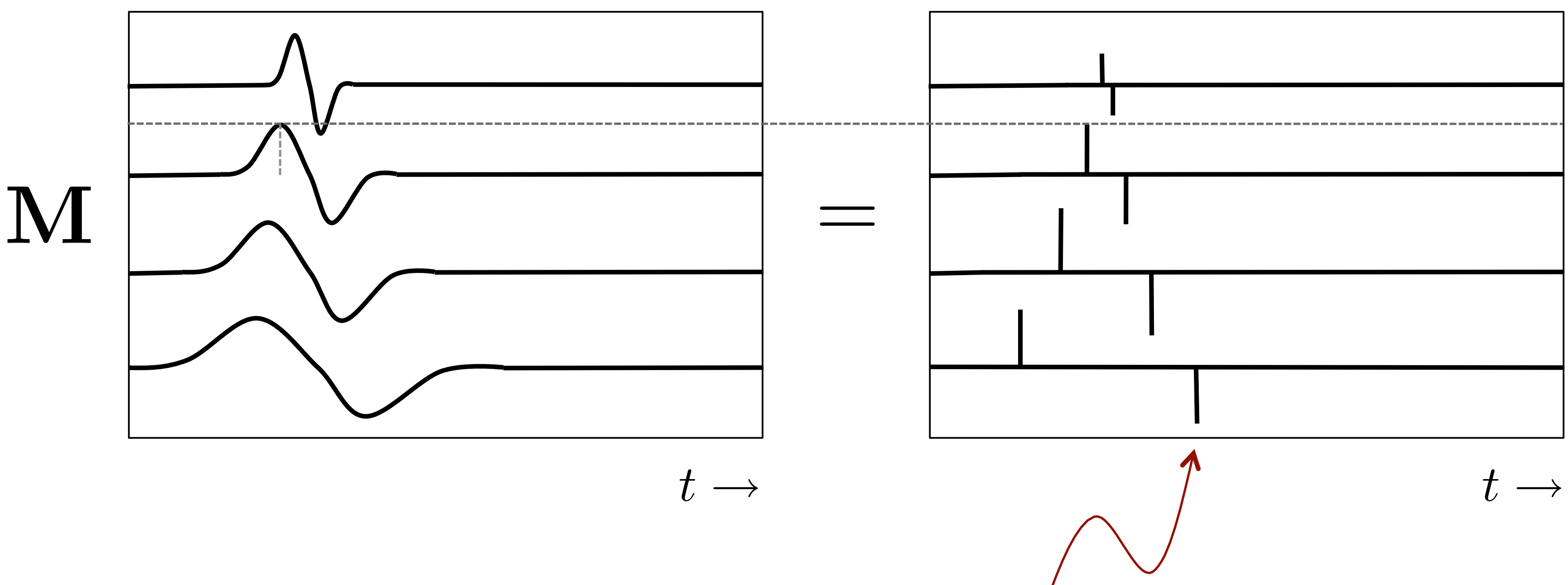


Inversion W^{-1} accuracy



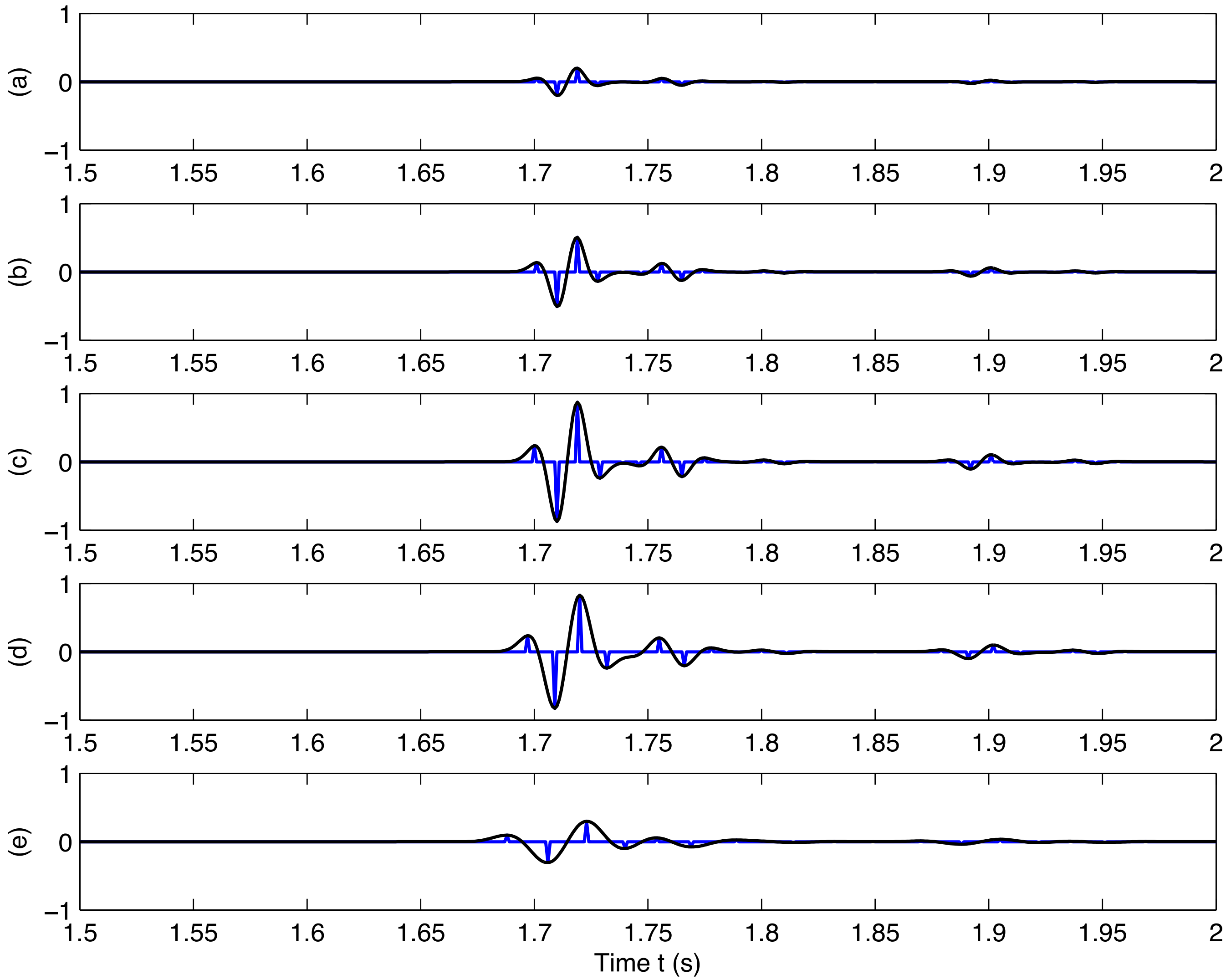
CWT modulus maxima

Define the operator M



Analysis: e.g., Q estimation
(Izadi et al., 2011, 2012)

CWT modulus maxima



Reconstruction from CWT maxima

Question

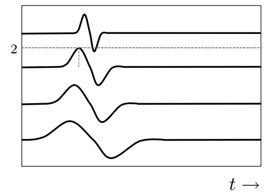
Is there a stable and accurate $(MW)^{-1}$?

Answer

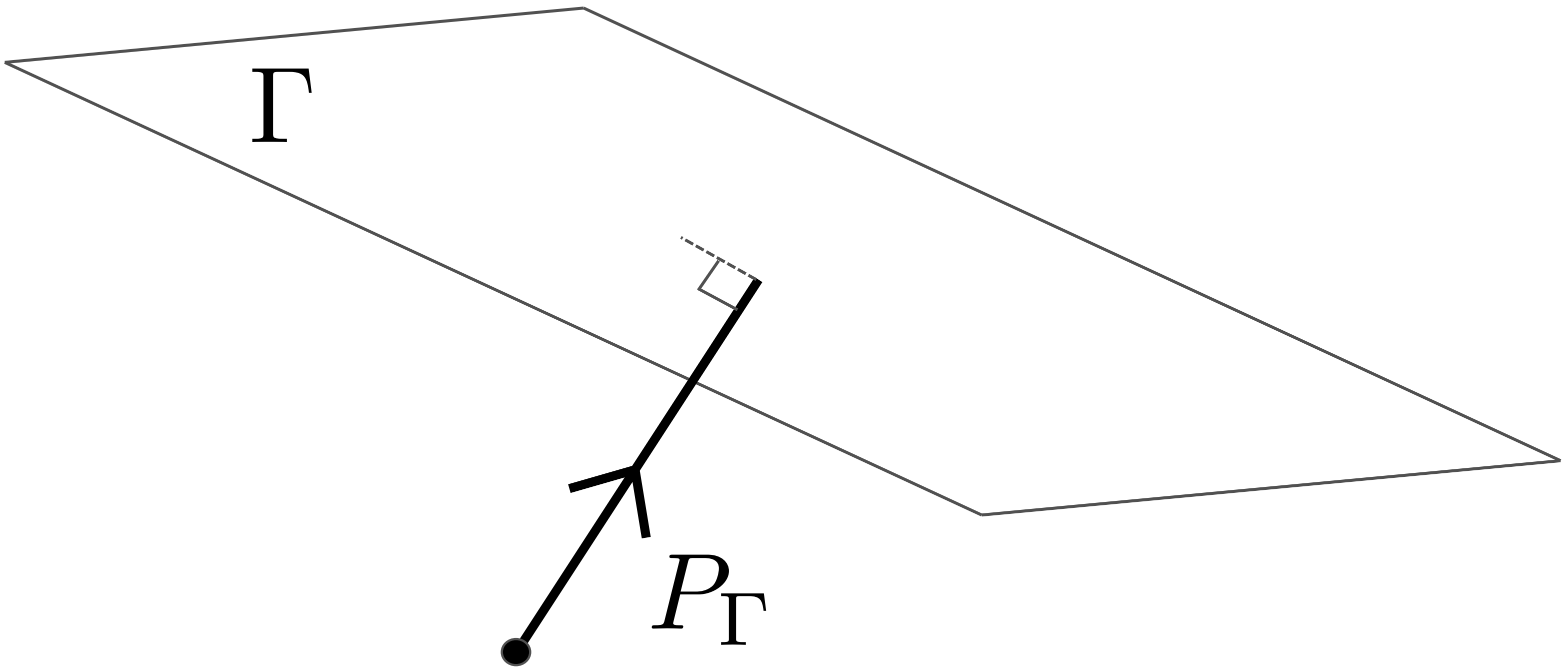
Yes! …approximately…

To find it, we need to define two spaces, Γ and V, and two operators, P_Γ and P_V.

Reconstruction from CWT maxima

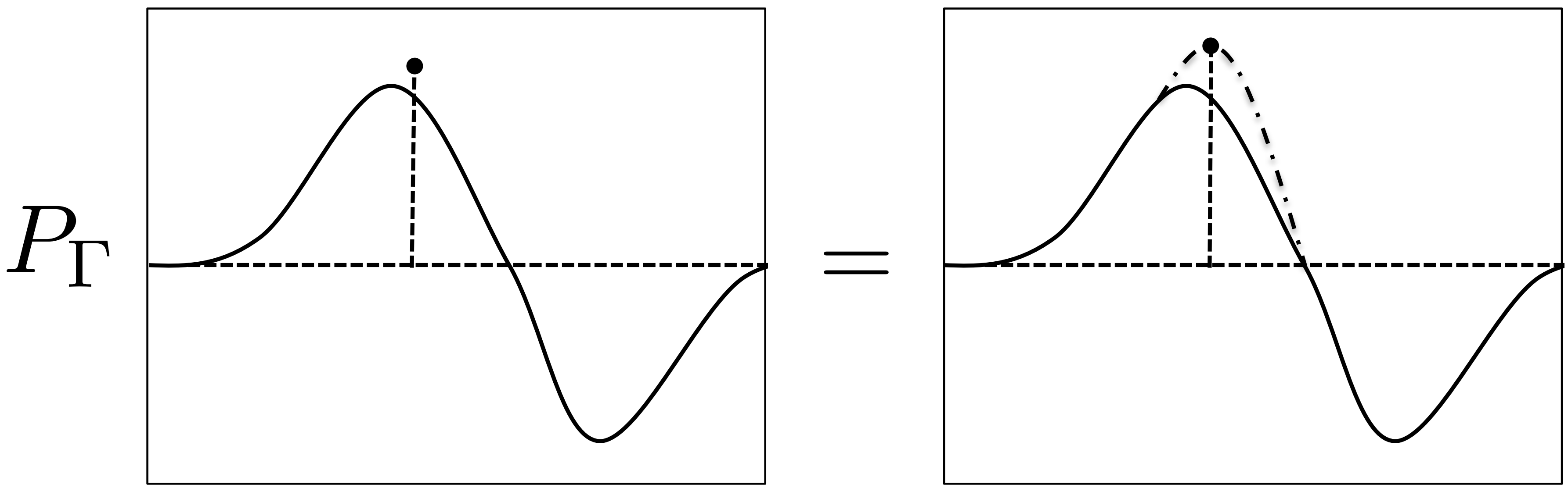
Γ: all matrices 

with the same maxima



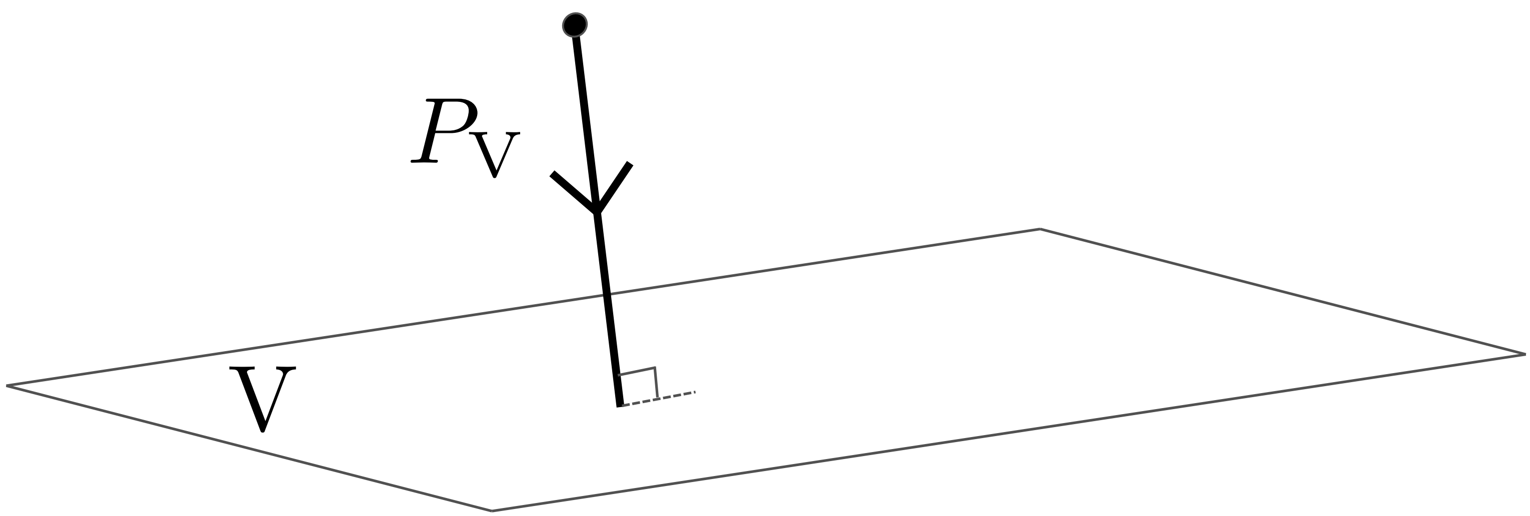
Reconstruction from CWT maxima

P_Γ: projection onto “nearest” element of Γ



Reconstruction from CWT maxima

V: all legitimate CWTs



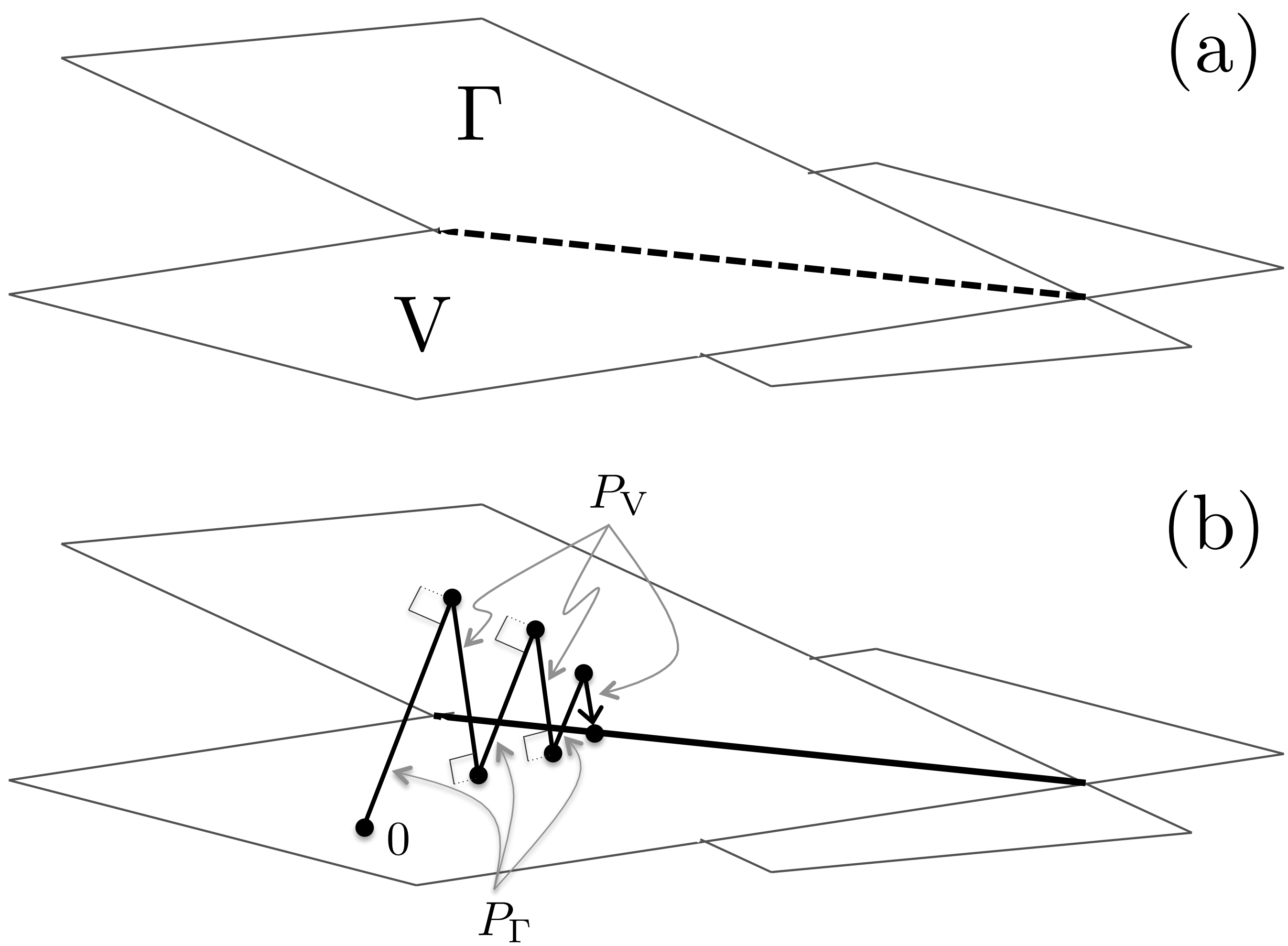
Reconstruction from CWT maxima

P_V: projection onto “nearest” element of V

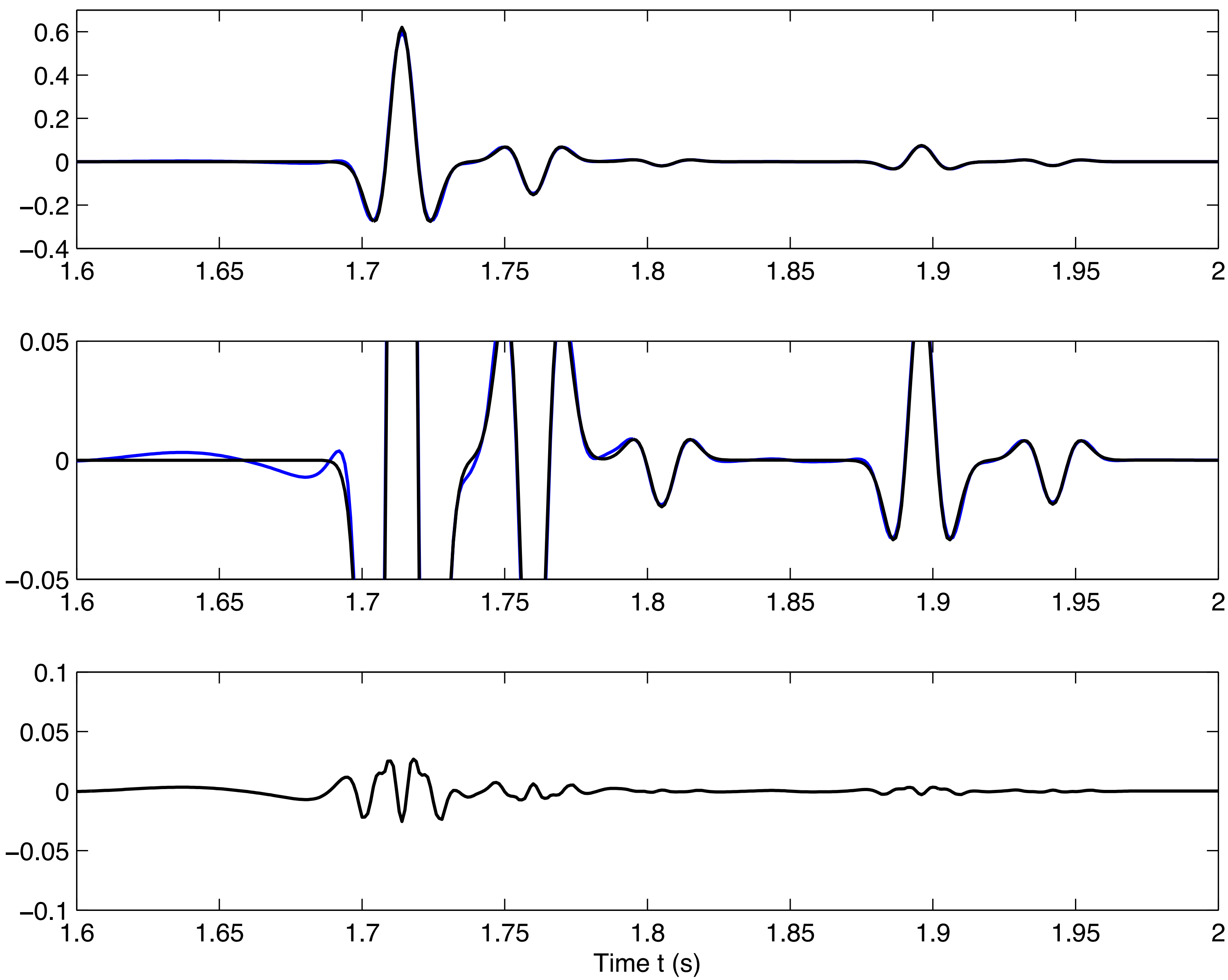
$$P_V = \mathbf{W}\mathbf{W}^{-1}$$

Reconstruction from CWT maxima

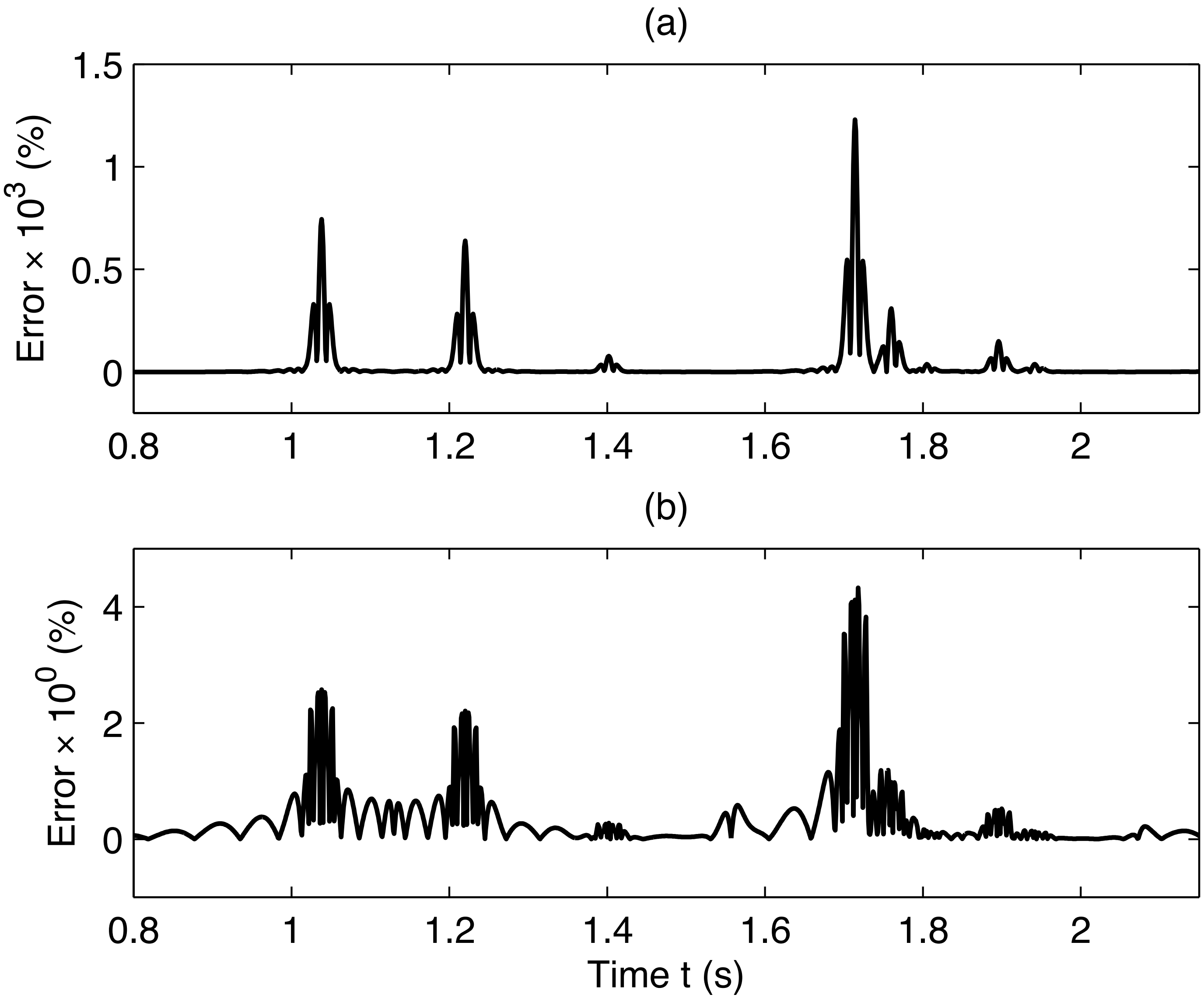
Iterative reconstruction



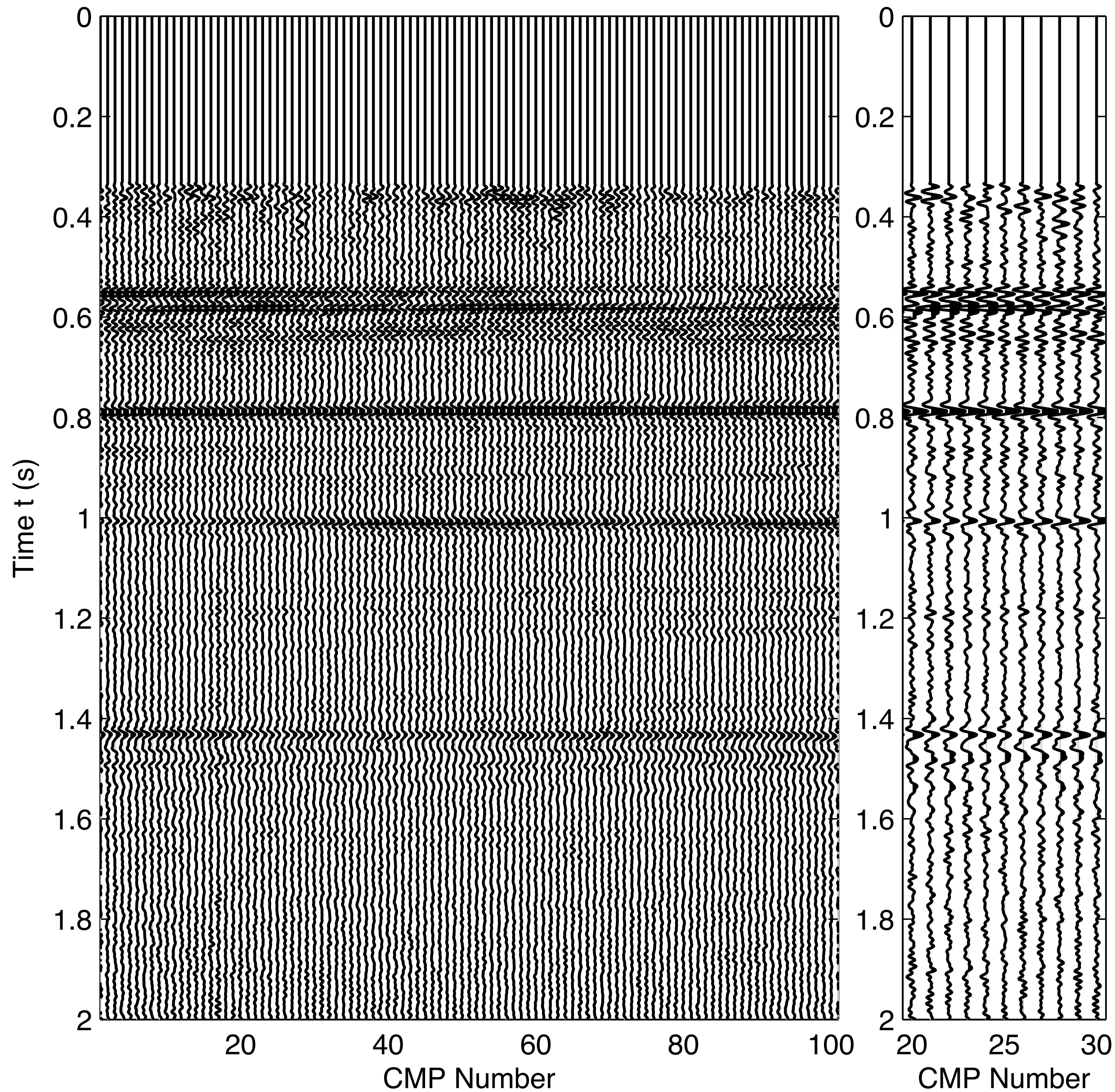
Reconstruction from CWT maxima



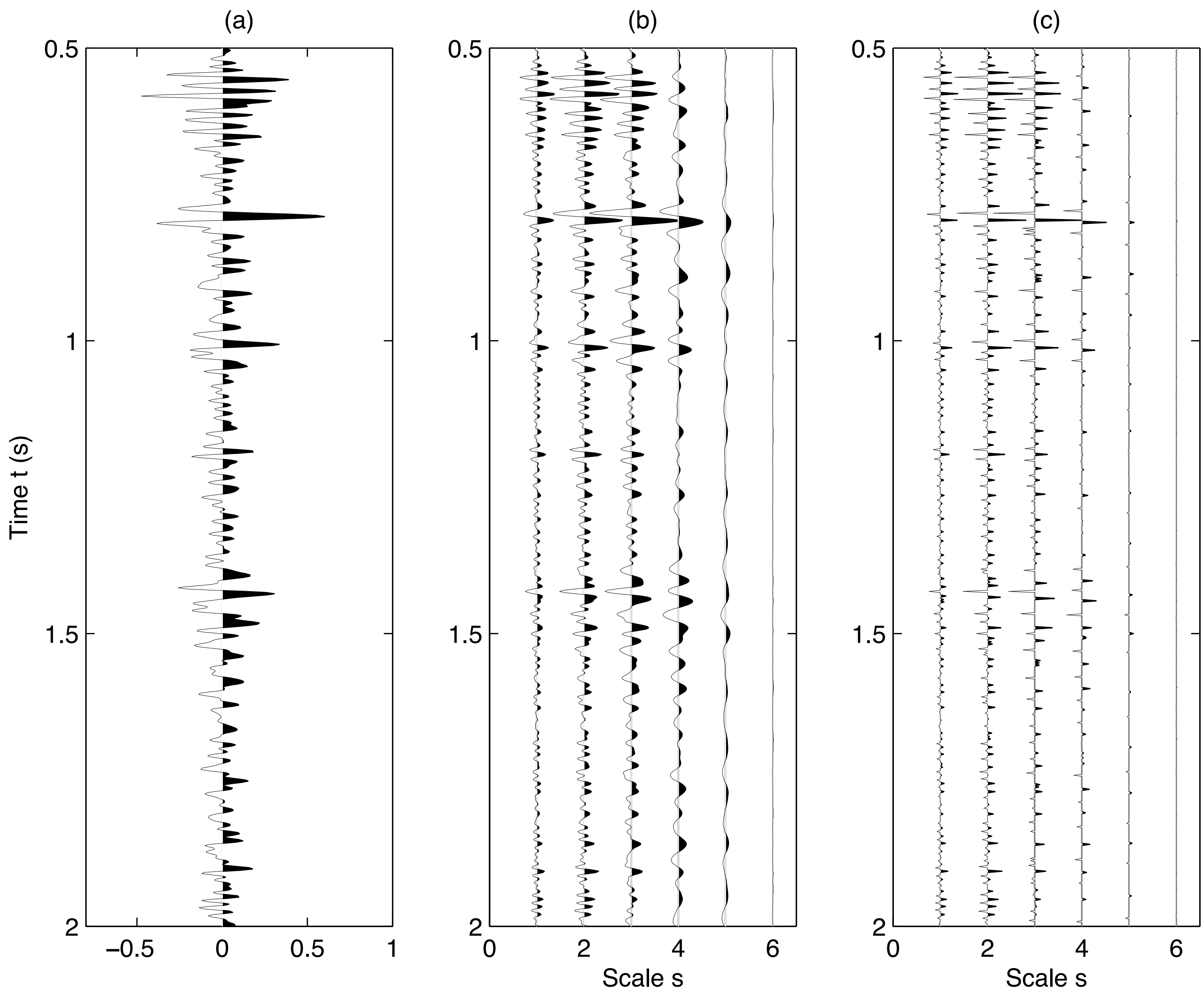
Reconstruction from CWT maxima



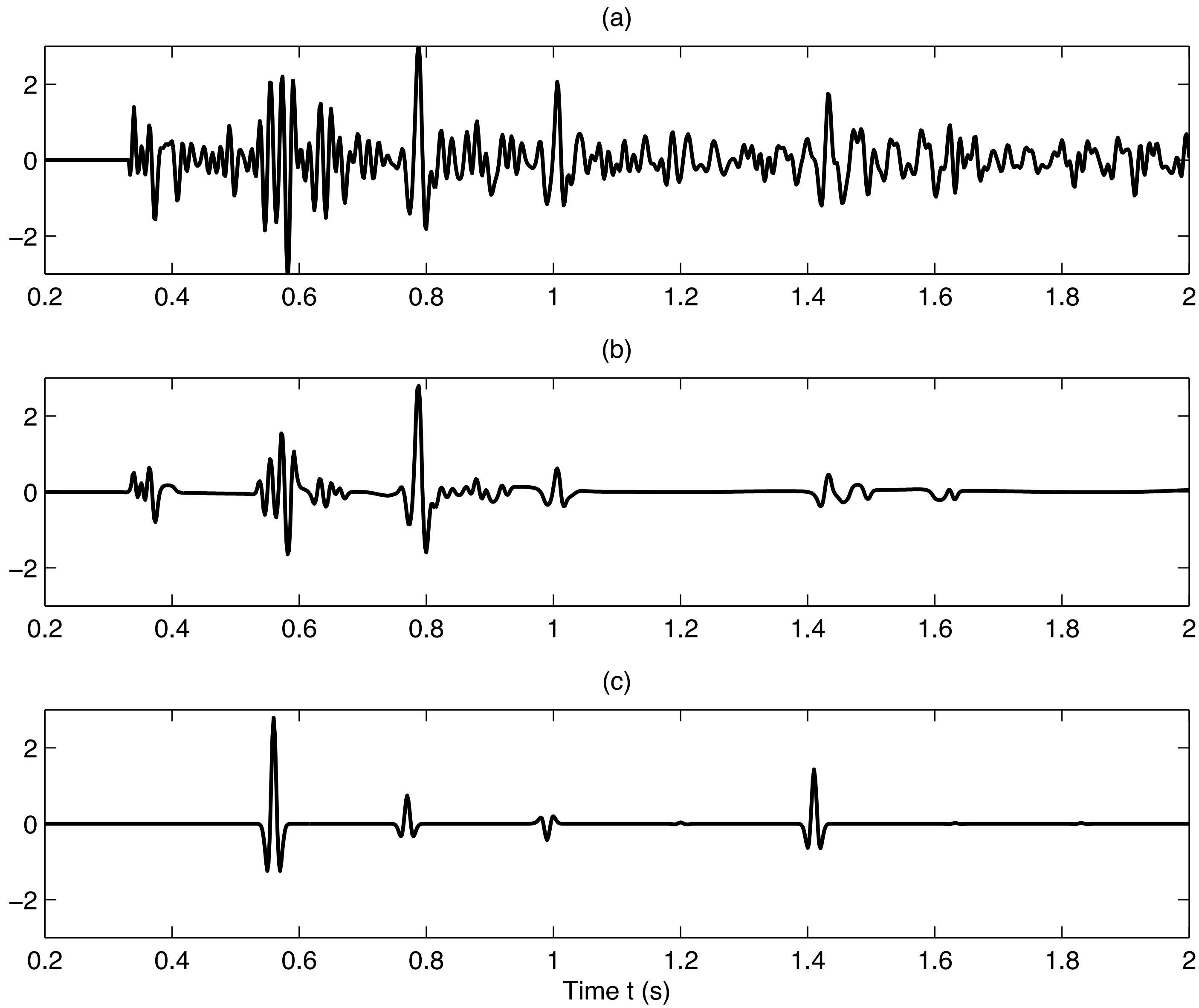
Aggressive denoising with thresholds



Aggressive denoising with thresholds



Aggressive denoising with thresholds



Internal multiple prediction

$$\mathrm{PREDICTION} = \mathrm{DATA} \times \mathrm{DATA} \times \mathrm{DATA}$$

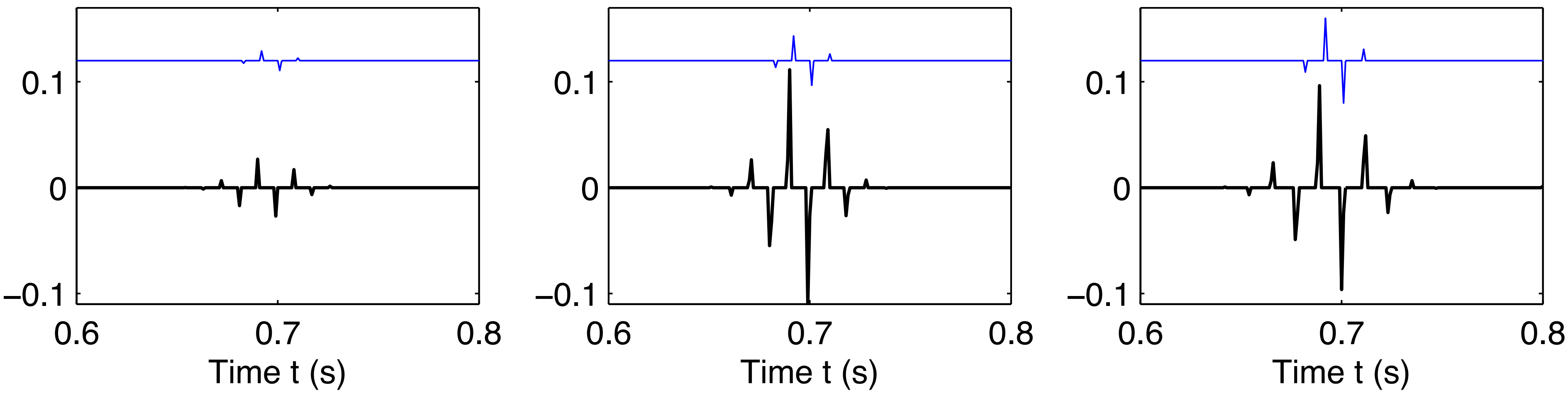
…nonlinear. Question:

prediction of wavelet maxima

=

wavelet maxima of prediction?

Internal multiple prediction

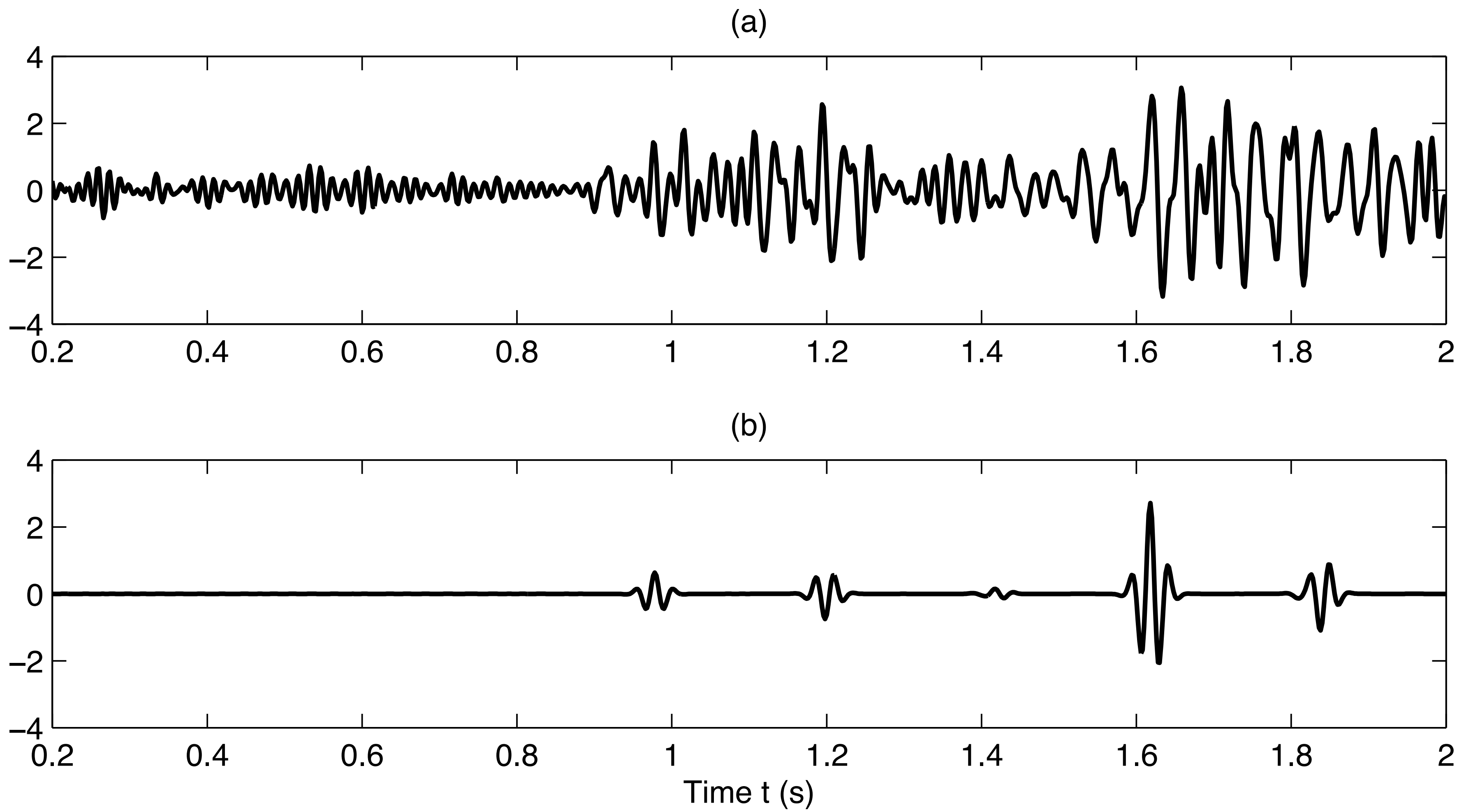


…yes, very close.

Opportunity for making IMP parameters vary with scale – surgical prediction

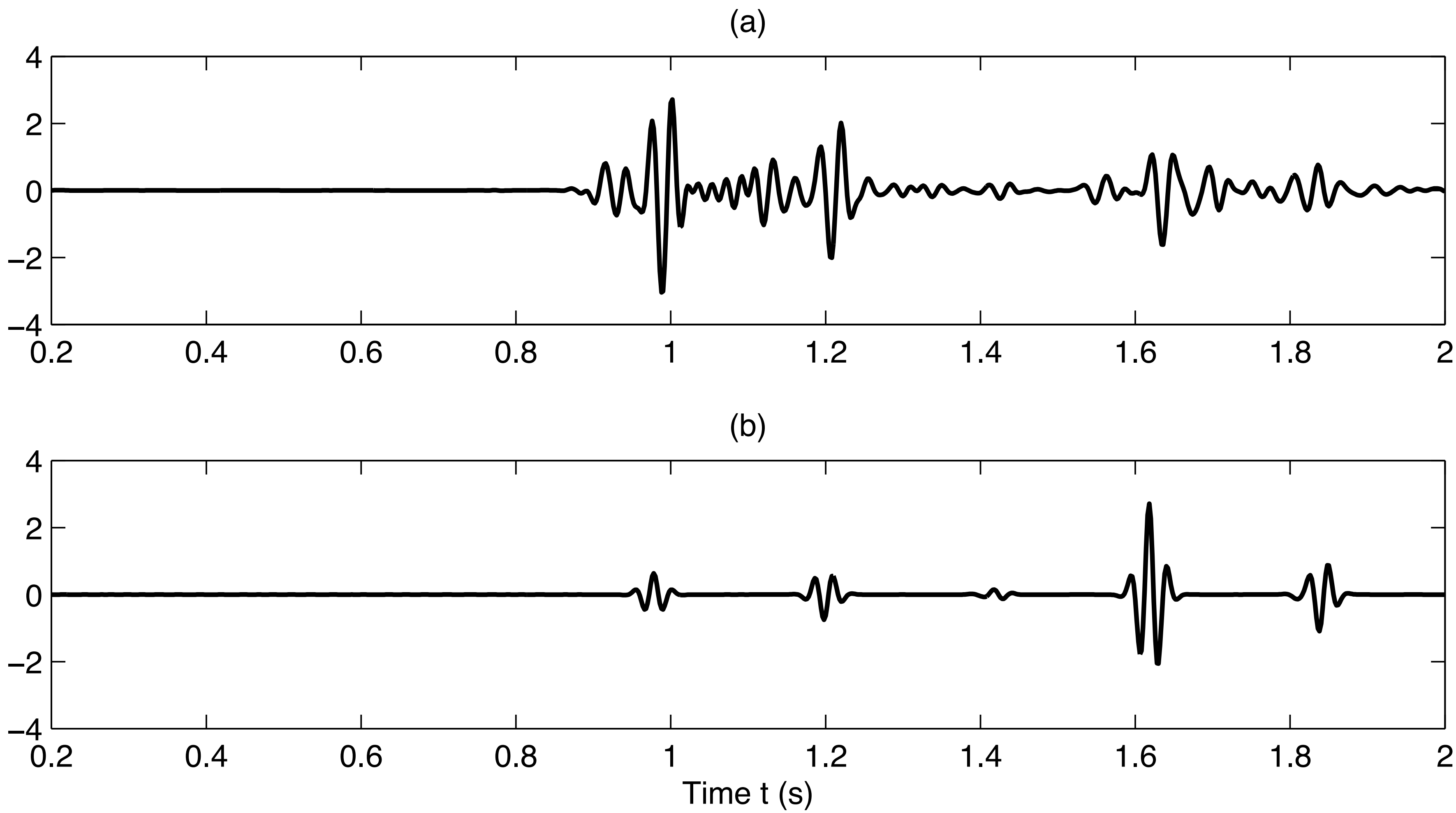
Internal multiple prediction

Aggressively denoised data in prediction operator



Internal multiple prediction

Aggressively denoised data in prediction operator



Codes

MATLAB 1D internal multiple prediction

2014 in CREWES toolbox
(standalone available upon request)

MATLAB 1.5D internal multiple prediction

2014

MATLAB continuous wavelet transform (W, W^{-1})

MATLAB reconstruction from maxima $(MW)^{-1}$

2014

Acknowledgments

CREWES

NSERC
CRSNG

Nexen

M. J. Hernandez, H. Izadi