Seismic-to-well ties by smooth dynamic time warping

Tianci Cui and Gary Margrave

Outline

- **Introduction**
- **Smooth dynamic time warping**
- **Seismic-to-well ties on Hussar field data**
- **Conclusions**
- **Acknowledgements**

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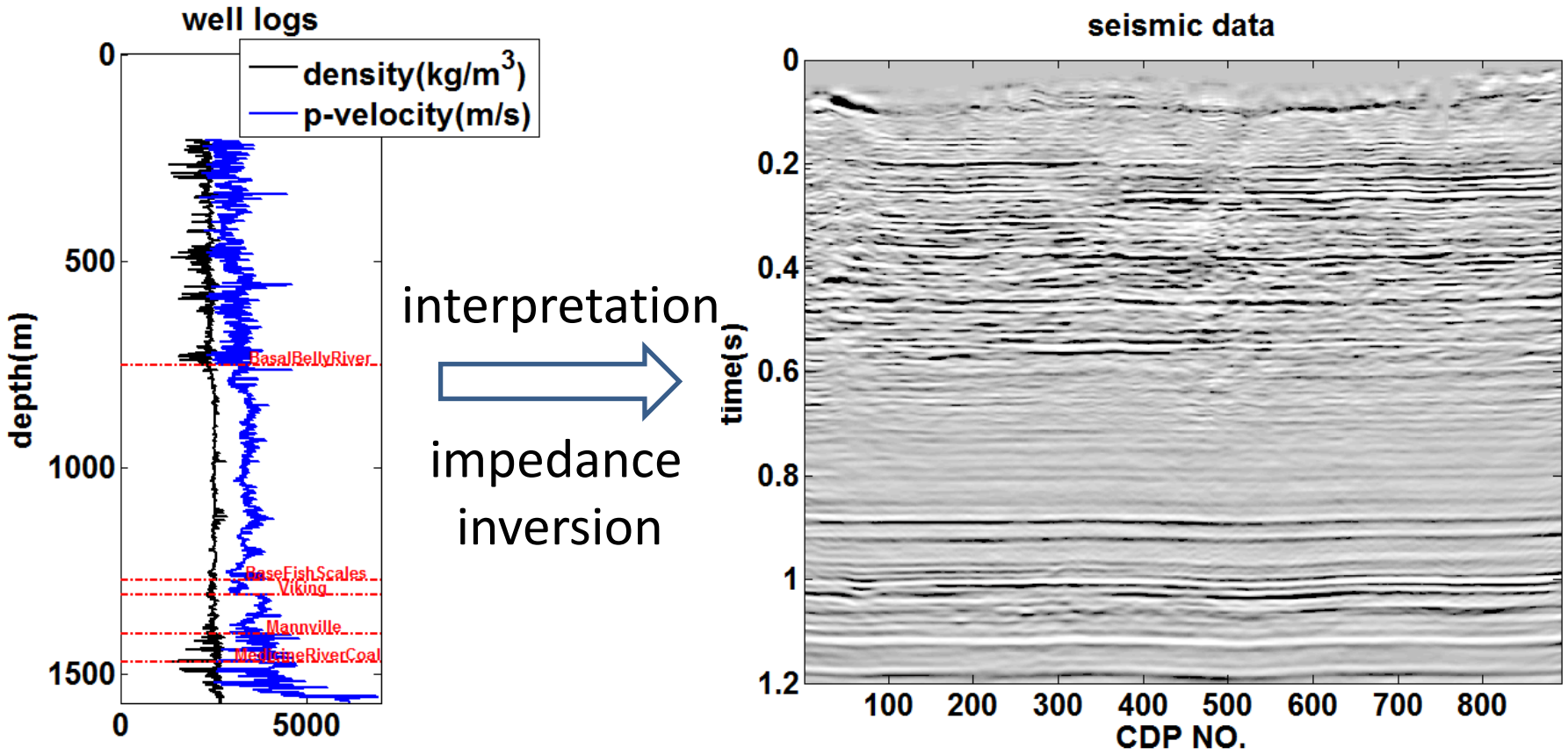
Introduction

What are seismic-to-well ties for?



Introduction

How to tie wells to seismic?

1. Edit well logs and process seismic data
2. Calibrate sonic times to seismic times (Anelastic attenutation)
   - Q
   - Check-shot/VSP survey
   - Manually stretch and squeeze ➡ Smooth dynamic time warping
3. Estimate wavelet and calculate reflectivity to create synthetic seismogram
4. Rotate the seismic trace by a single constant-phase
   ➡ Time-variant constant-phase rotation

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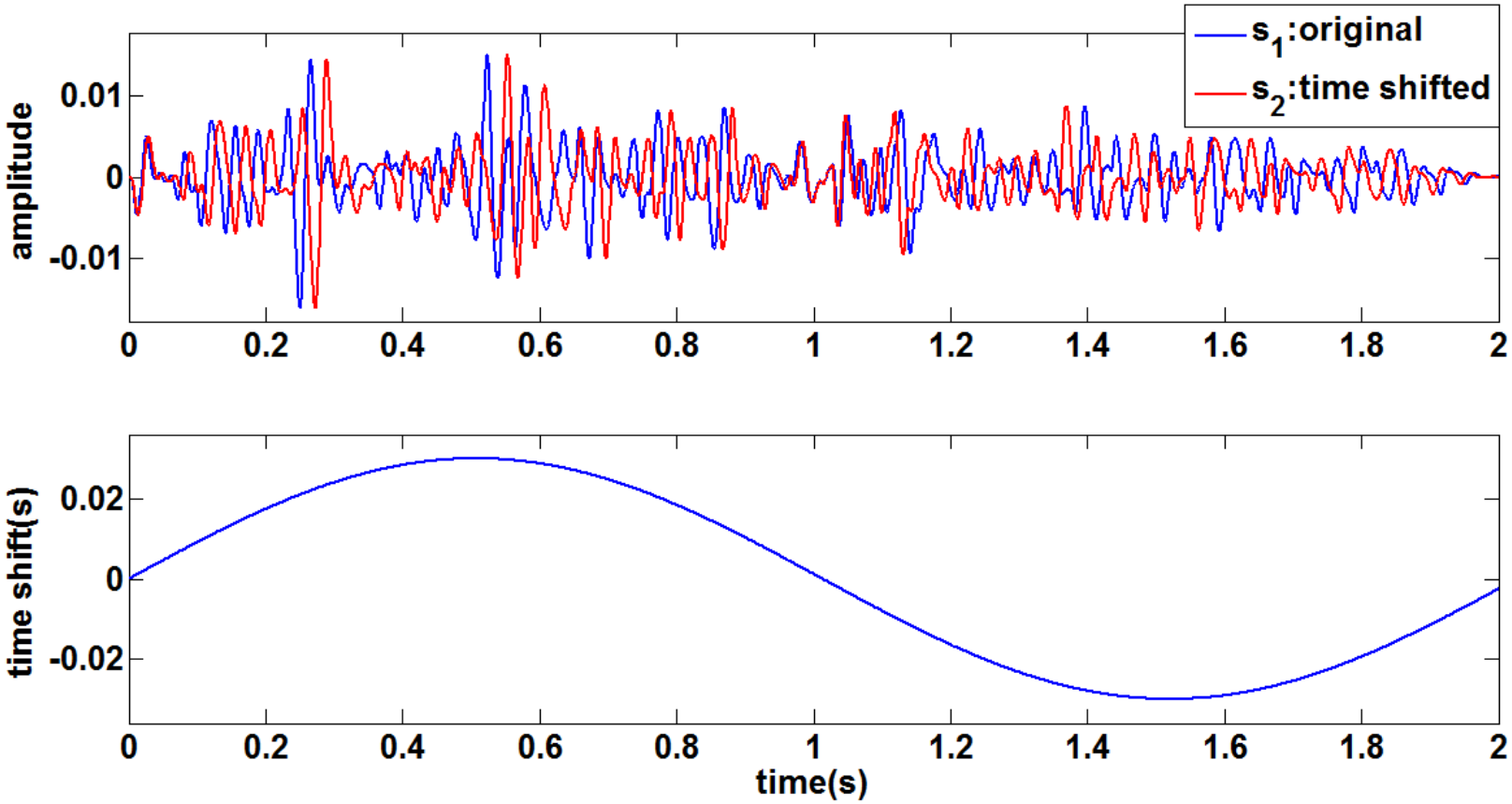
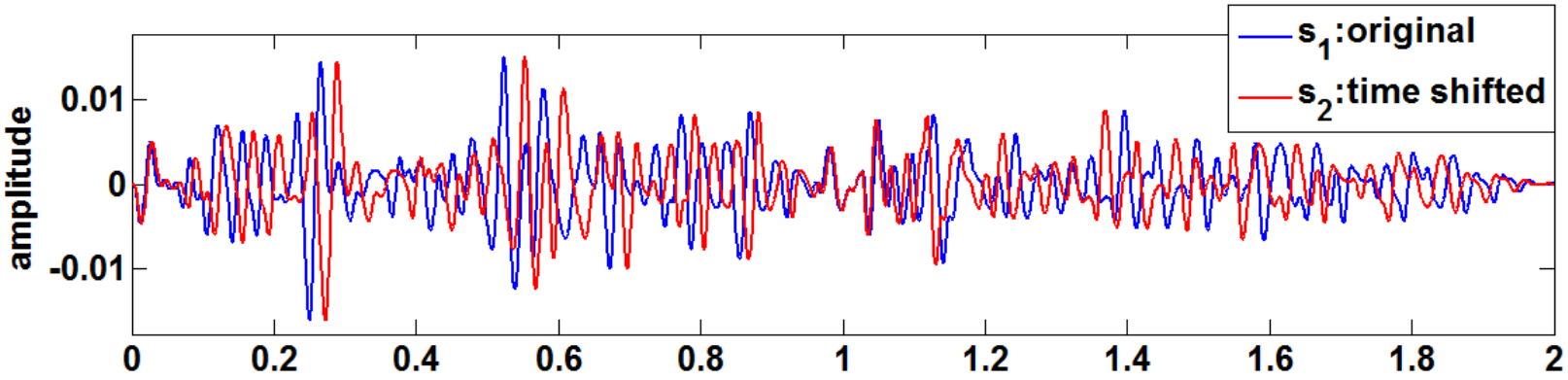
Dynamic time warping

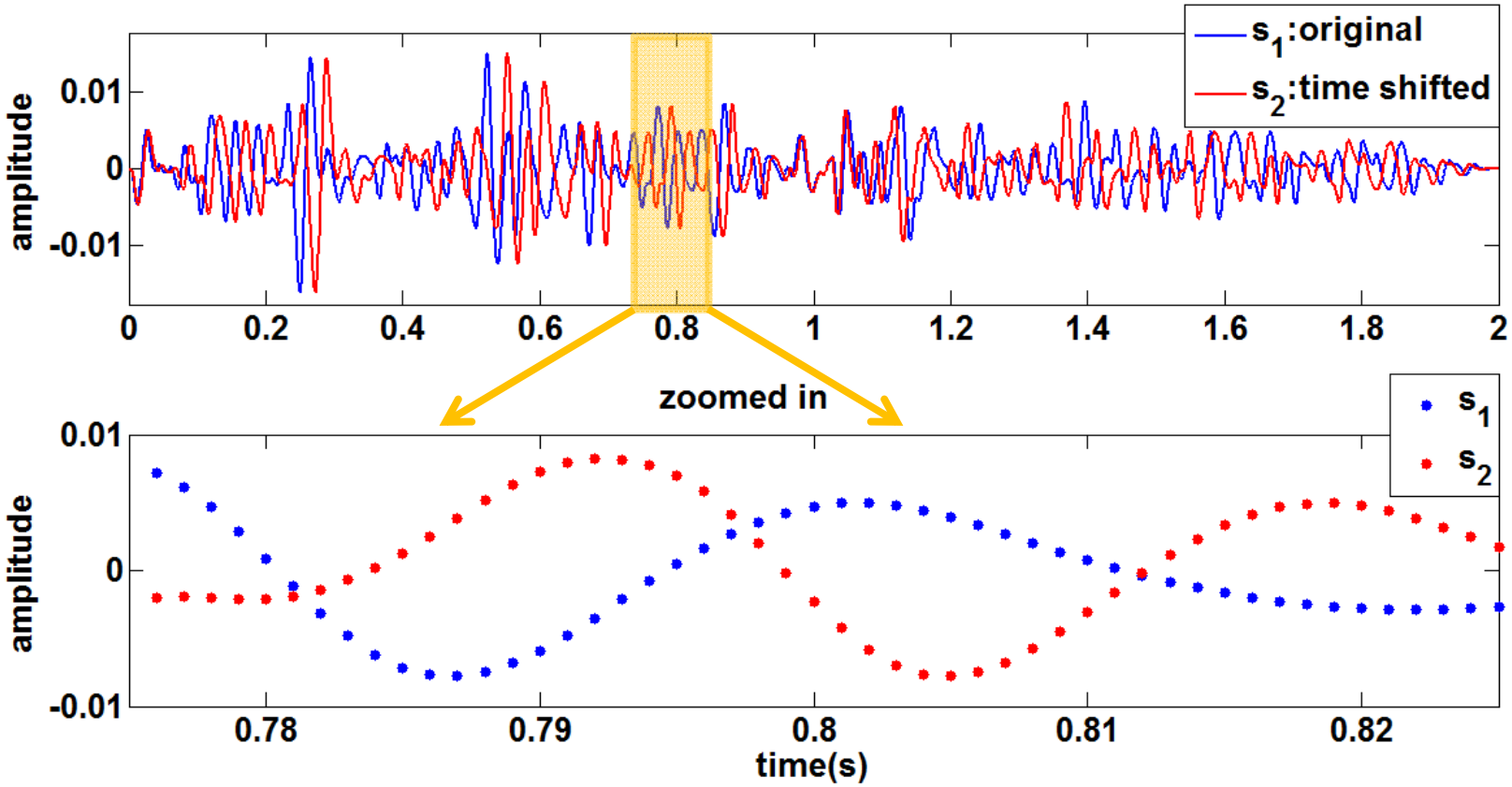


Hale, D., 2013, Dynamic warping of seismic images: Geophysics

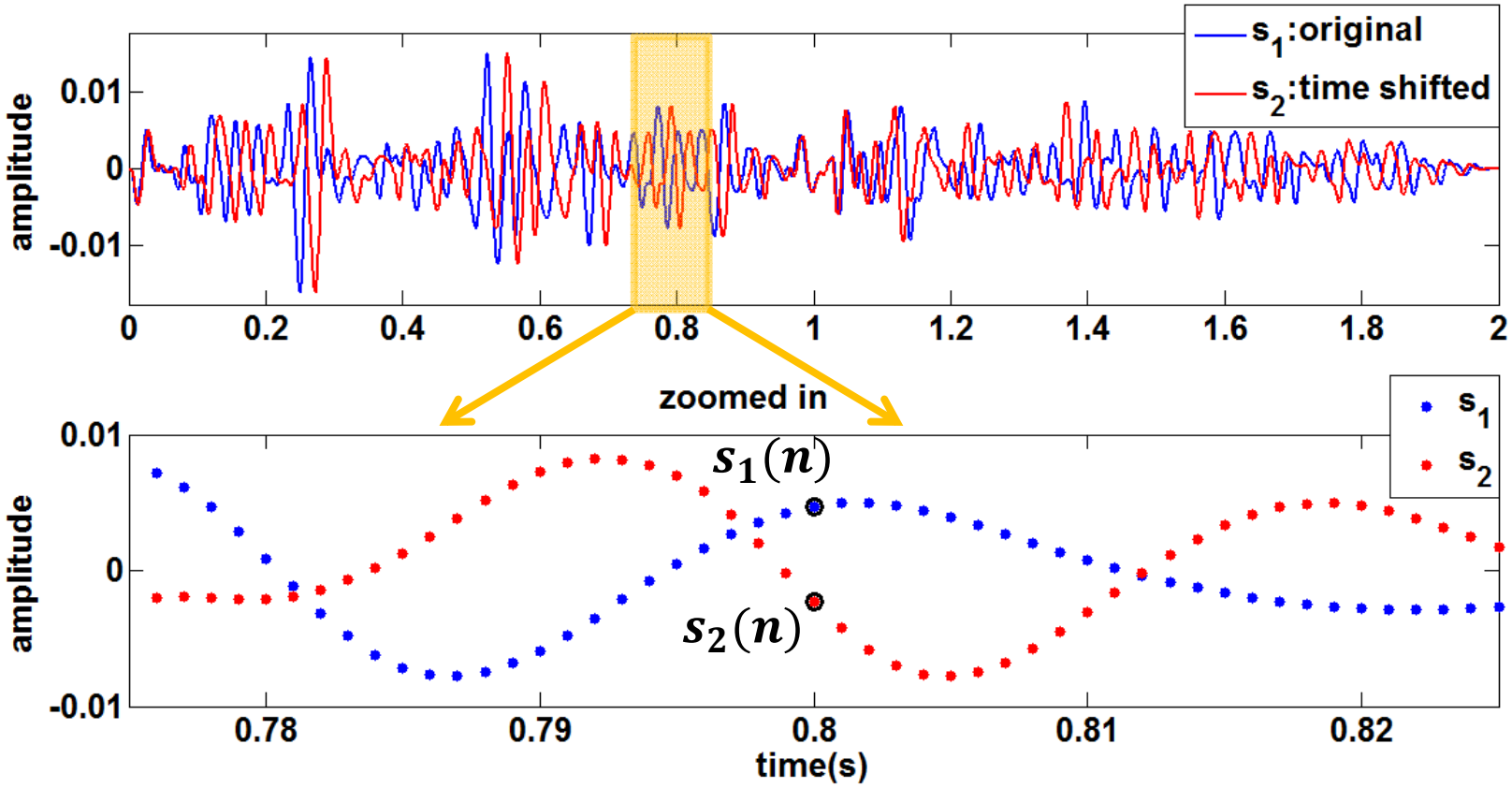
Dynamic time warping



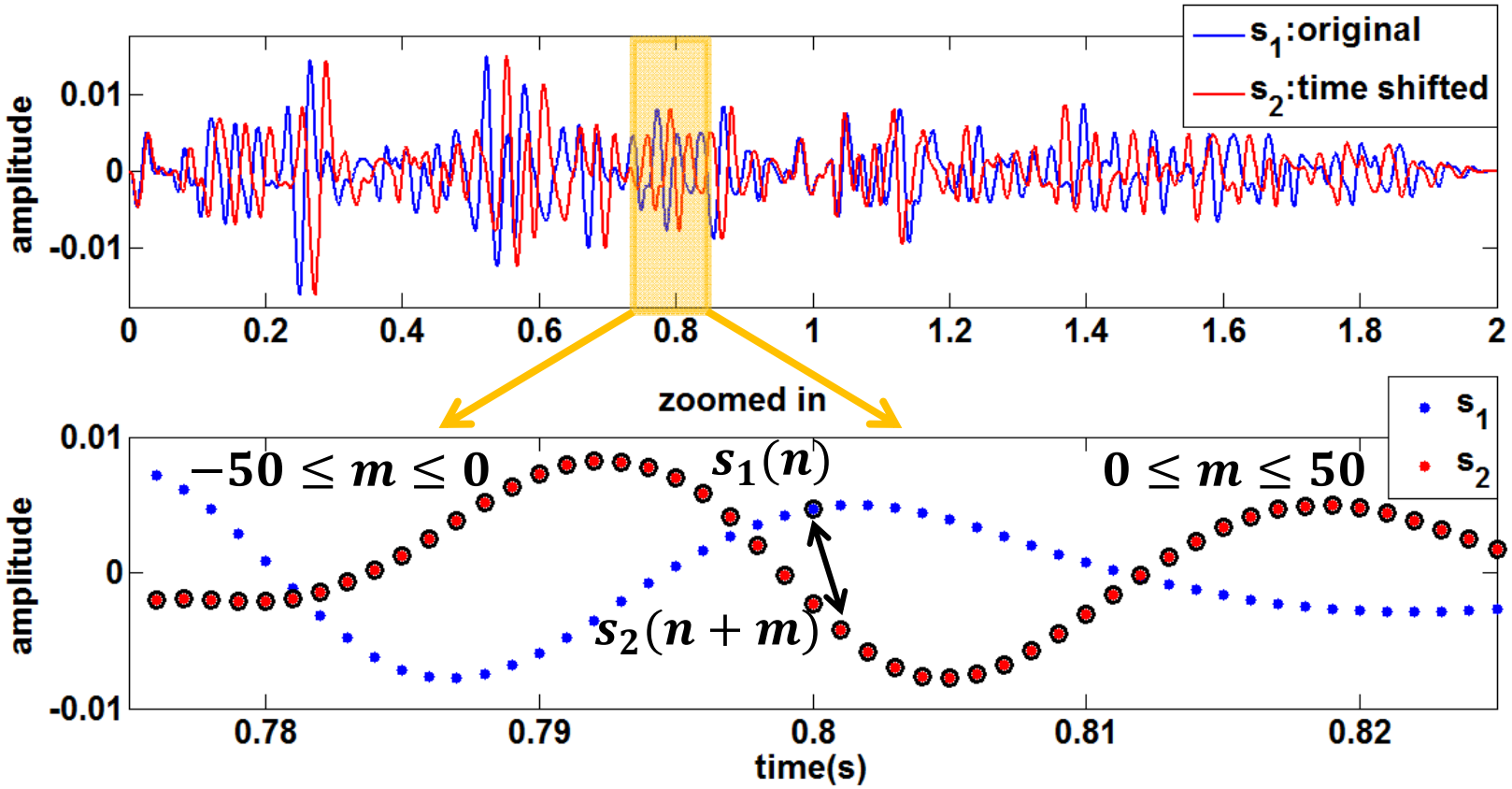
Dynamic time warping



Dynamic time warping

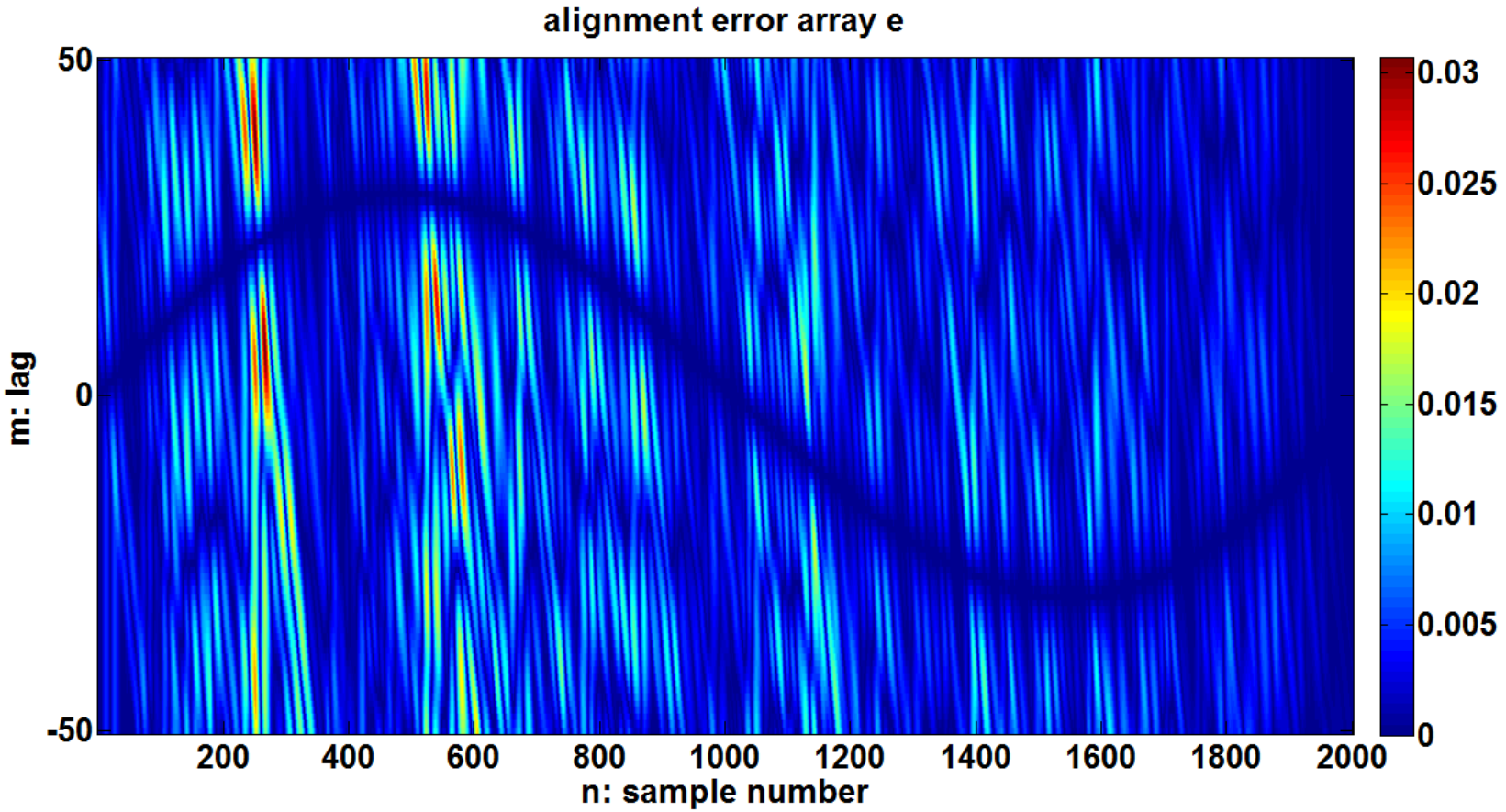


Dynamic time warping



$$e(m,n) = [s_1(n) - s_2(n+m)]^2 \qquad n = 1, 2, \dots, 2000$$

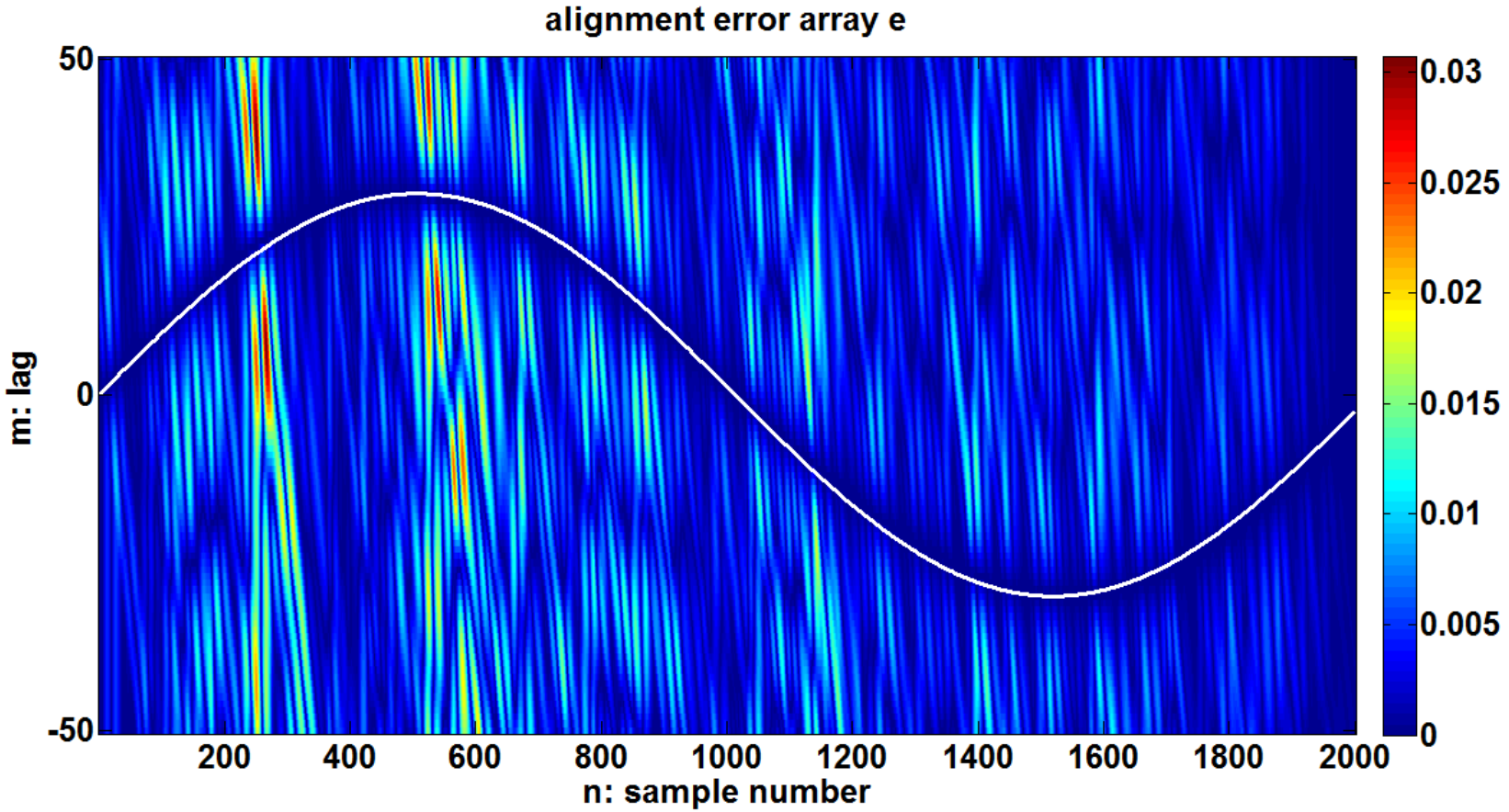
Dynamic time warping



Dynamic time warping

$101^{2000} \Rightarrow$ infinite

Constraint: $|m(n) - m(n-1)| \leq 1$



Dynamic programming

Alignment error array e

m				
	2	**4**	**7**	**3**
	1	**1**	**8**	**4**
	0	**3**	**5**	**8**
	-1	**6**	**5**	**9**
	-2	**2**	**8**	**1**
		1	2	3
			n	

125 possible paths

Dynamic programming: accumulation

Alignment error array e

m		1	2	3
	2	**4**	**7**	**3**
	1	**1**	**8**	**4**
	0	**3**	**5**	**8**
	-1	**6**	**5**	**9**
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n

Distance array d

m		1	2	3
	2	**4**	**?**	
	1	**1**		
	0	**3**		
	-1	**6**		
	-2	**2**		

n

125 possible paths

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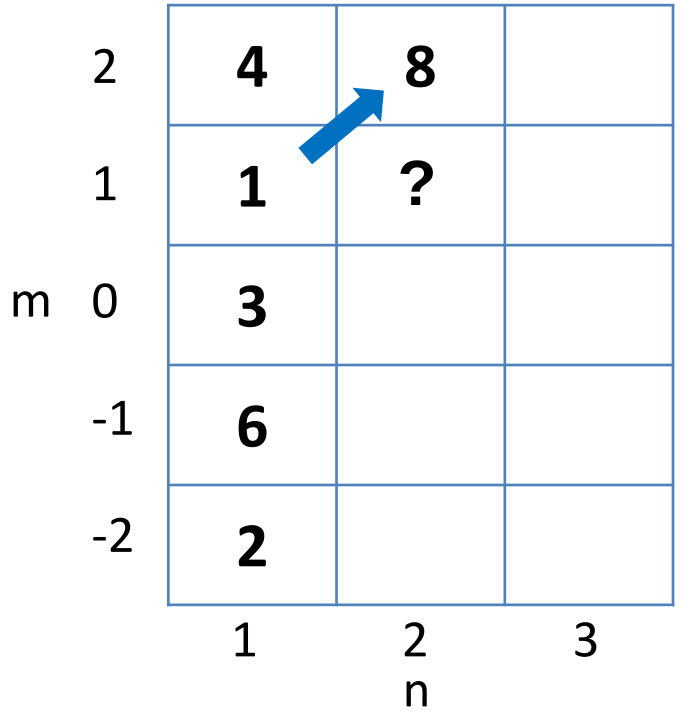

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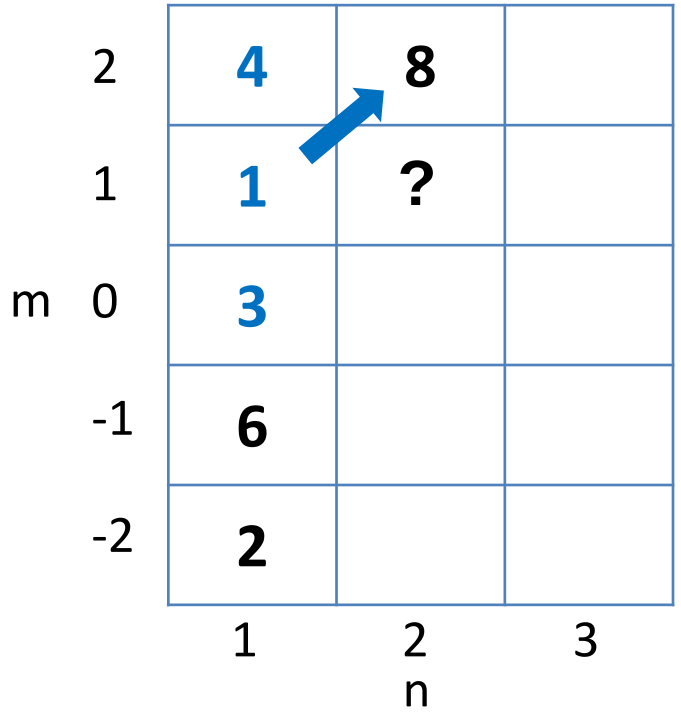
n

Distance array d



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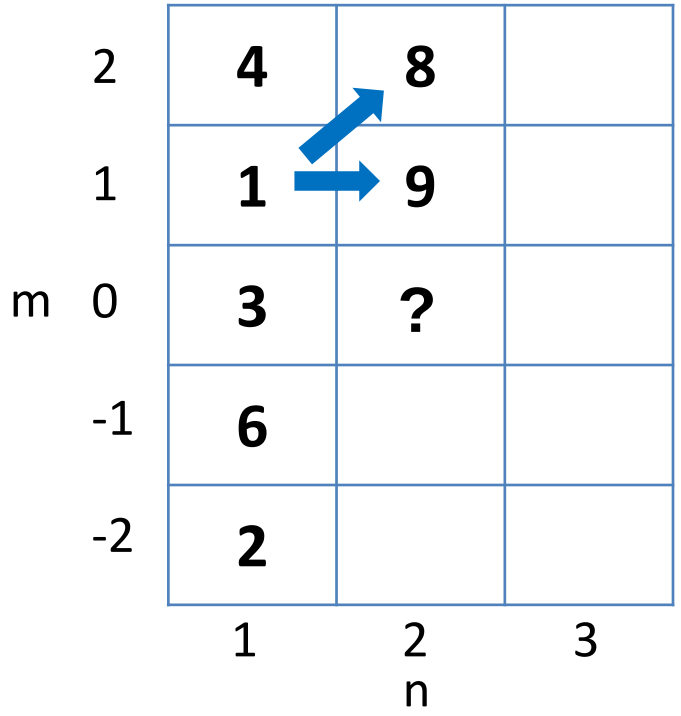

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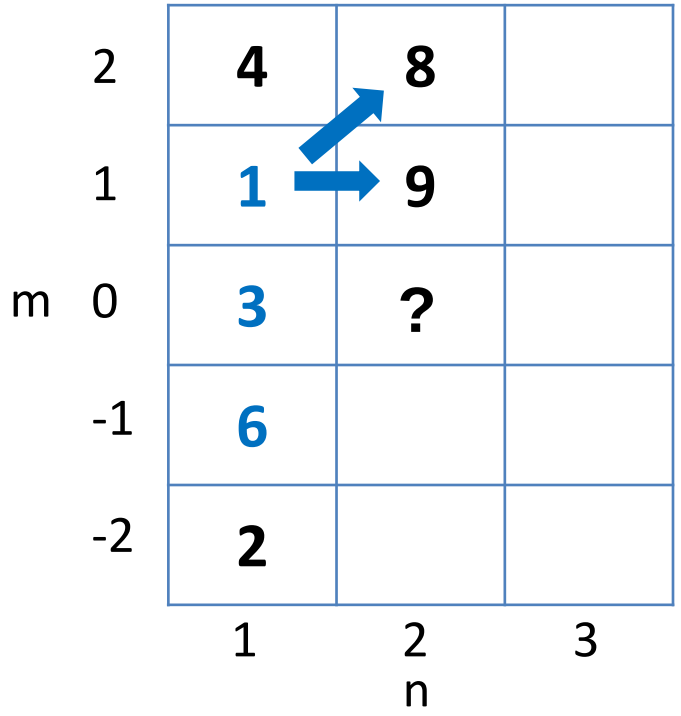

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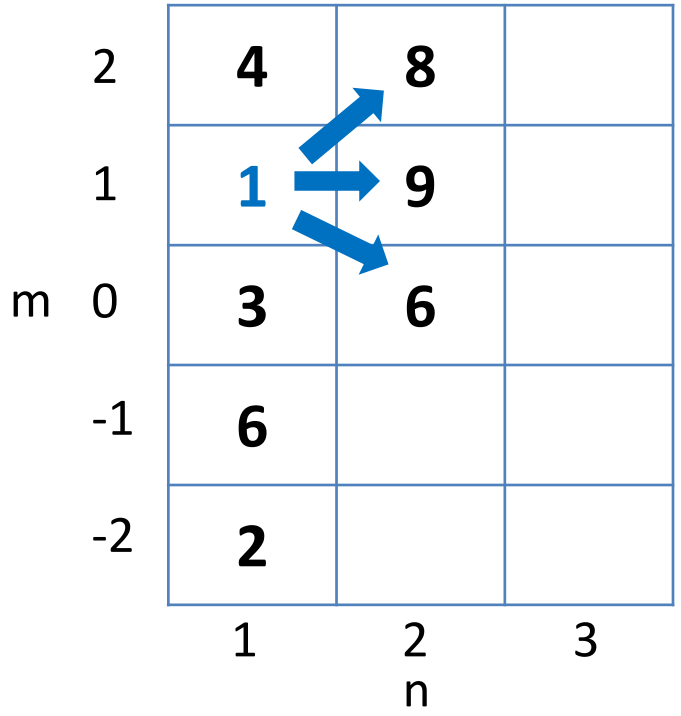

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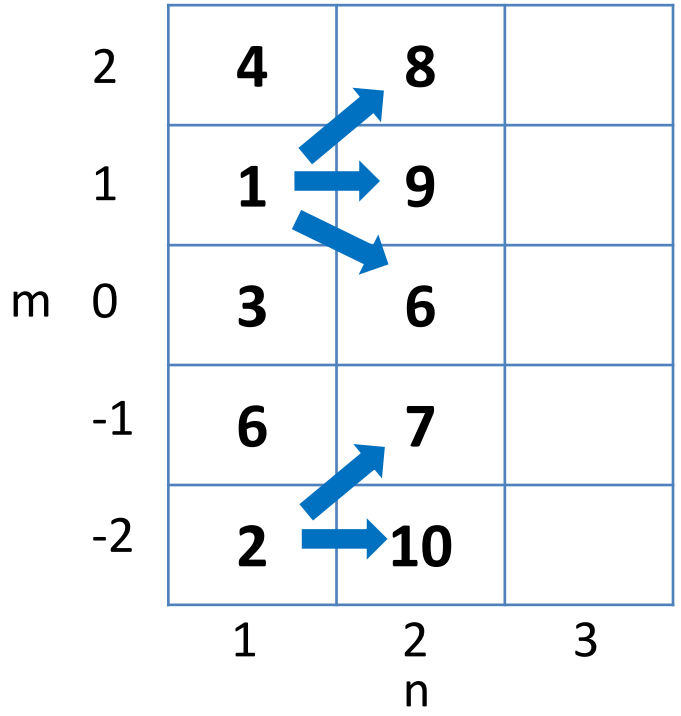

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			n	

Distance array d

m				
	2	**4**	**8**	**11**
	1	**1**	**9**	**10**
	0	**3**	**6**	**14**
	-1	**6**	**7**	**15**
	-2	**2**	**10**	**8**
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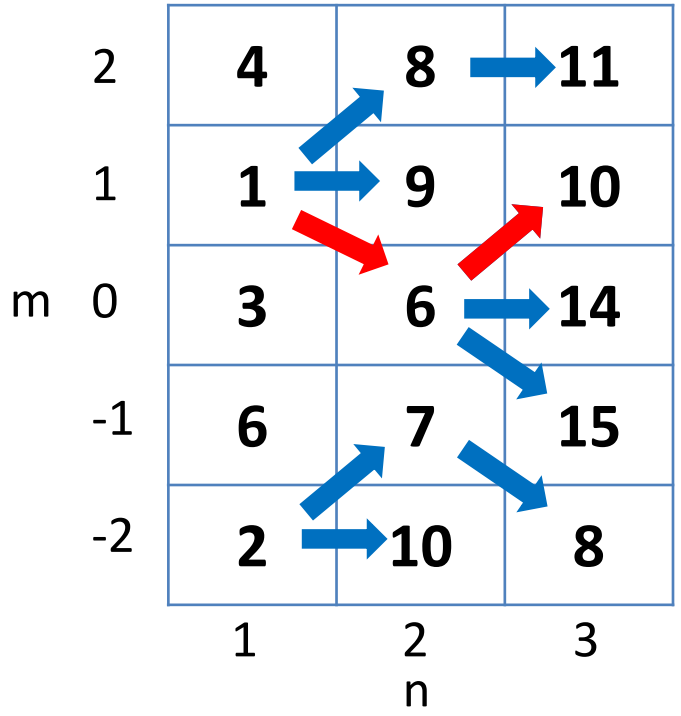

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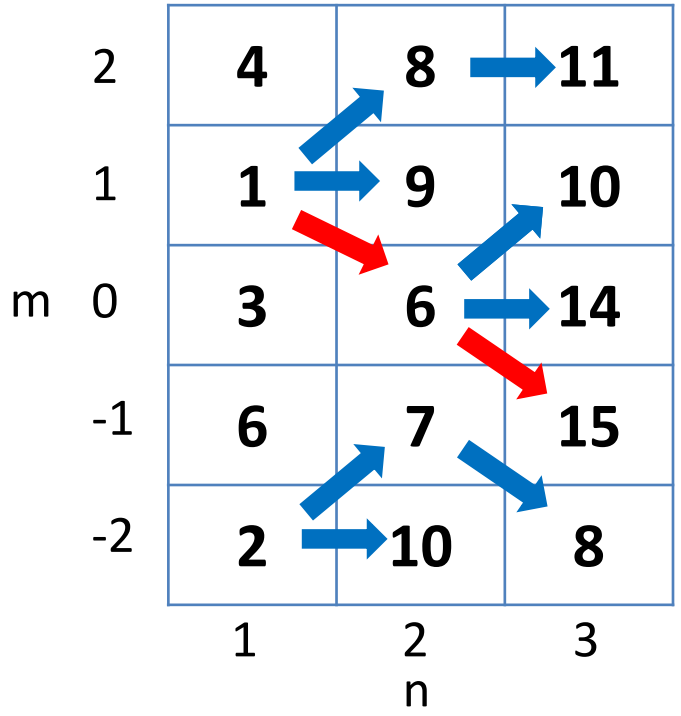

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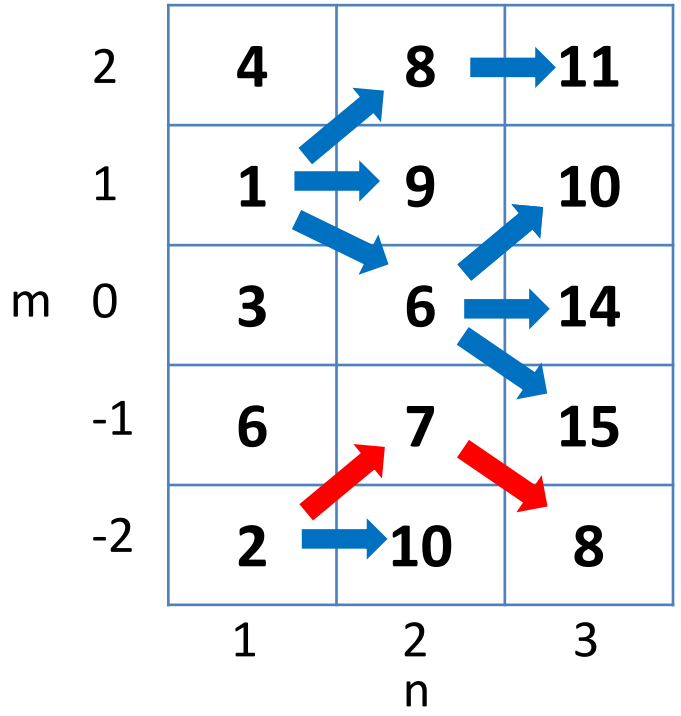
125 possible paths

Distance array d



5 possible paths

Constraint: $|m(n) - m(n-1)| \leq 1$

Dynamic programming: backtracking

Alignment error array e

m		n=1	n=2	n=3
	2	**4**	**7**	**3**
	1	**1**	**8**	**4**
	0	**3**	**5**	**8**
	-1	**6**	**5**	**9**
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125 possible paths

Distance array d

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	1	**1**	**9**	**10**
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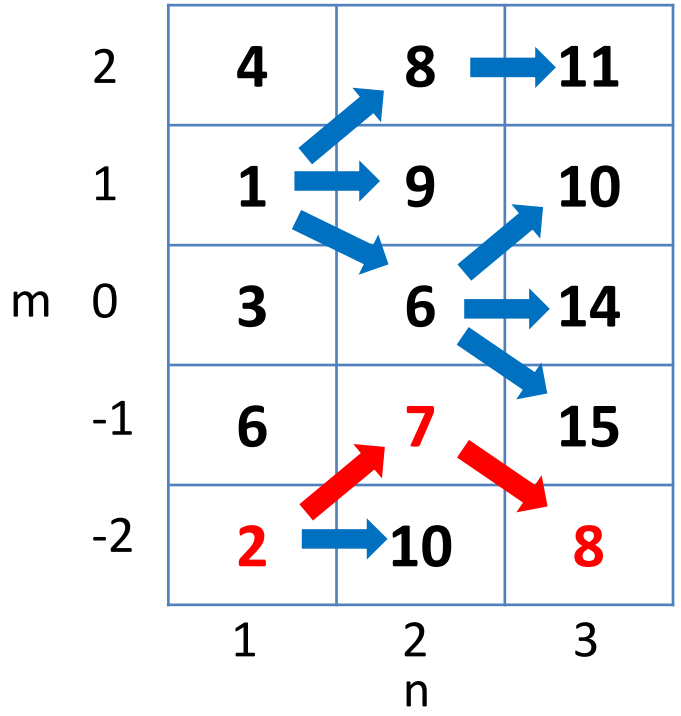
	-2	**2**	**8**	**1**
		1	2	3
			n	

125 possible paths

Distance array d

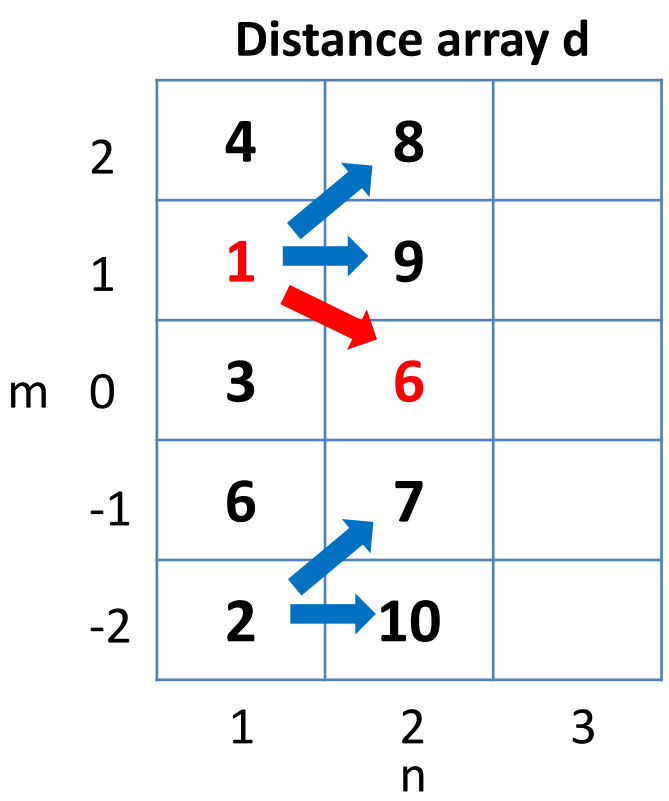


5 possible paths

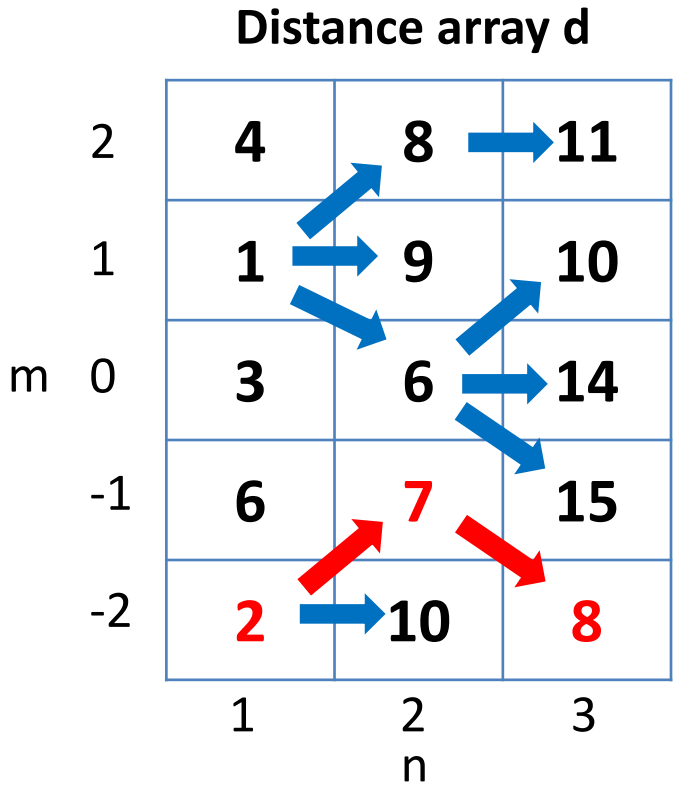
Constraint: $|m(n) - m(n-1)| \leq 1$

Estimated lag sequence: $m(n) = [-2, -1, -2]$

Dynamic time warping



$m(n) = [1, 0]$



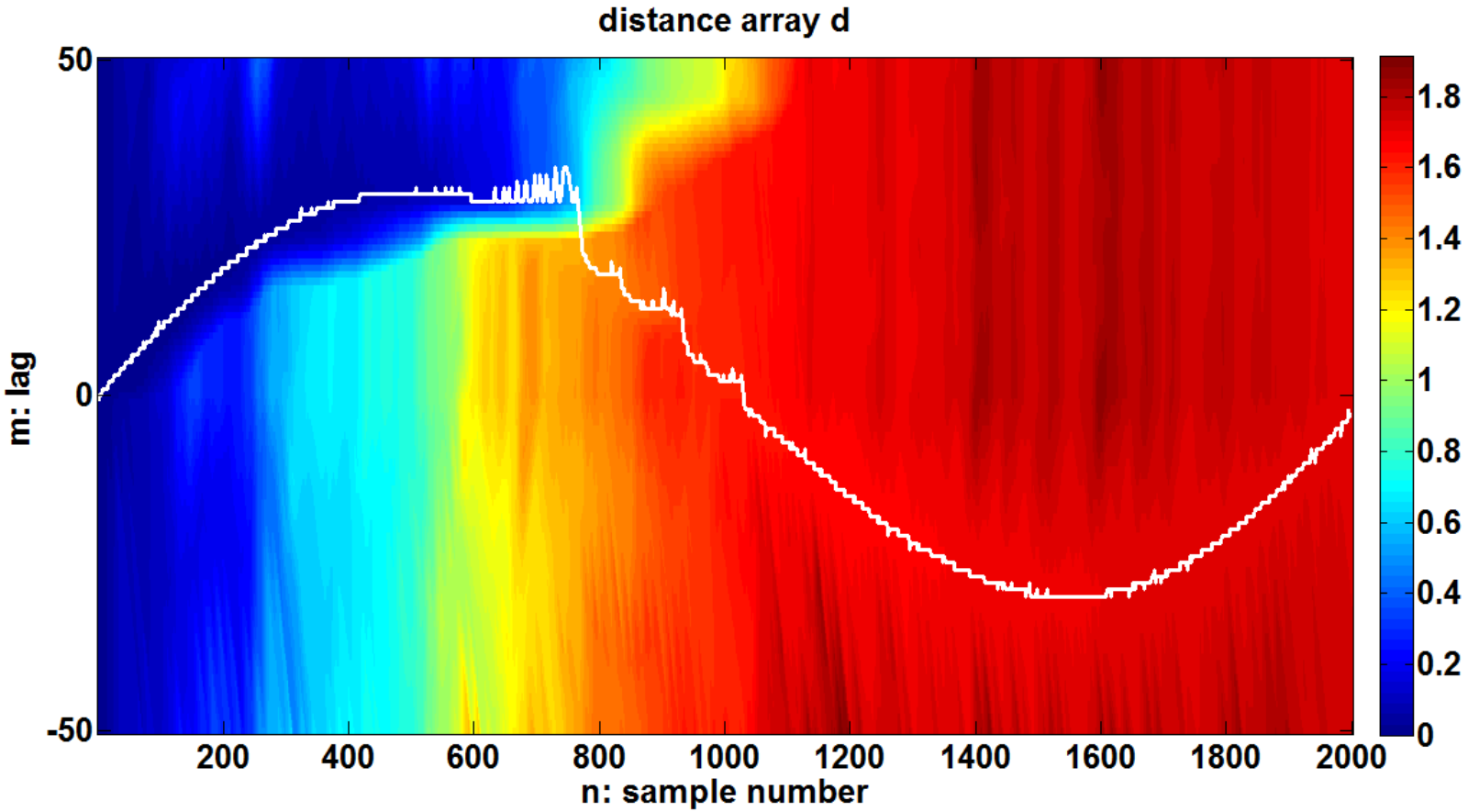
$m(n) = [-2, -1, -2]$

Dynamic: optimal path varies at different stages

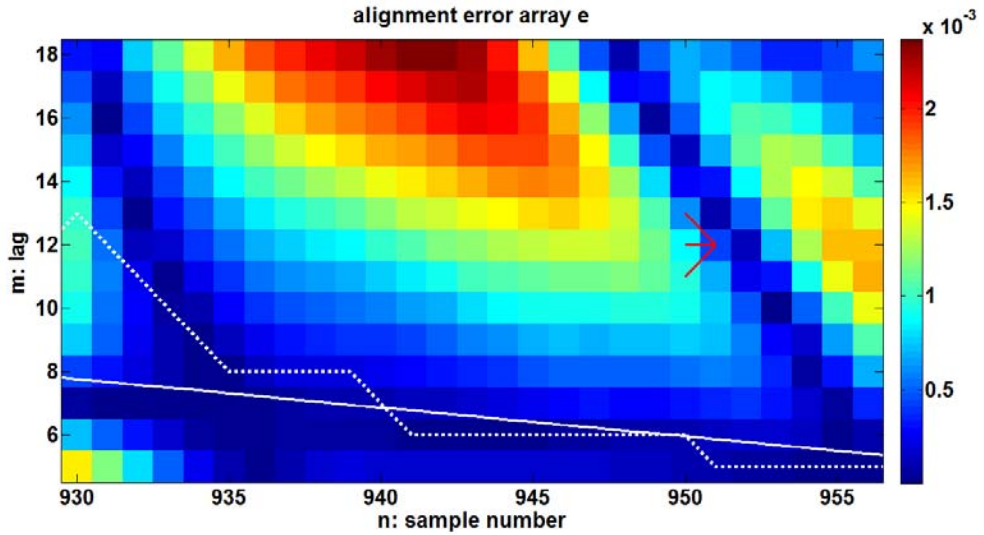
Warping path: lag sequence

Dynamic time warping

CREWES Matlab toolbox function: *DTW*



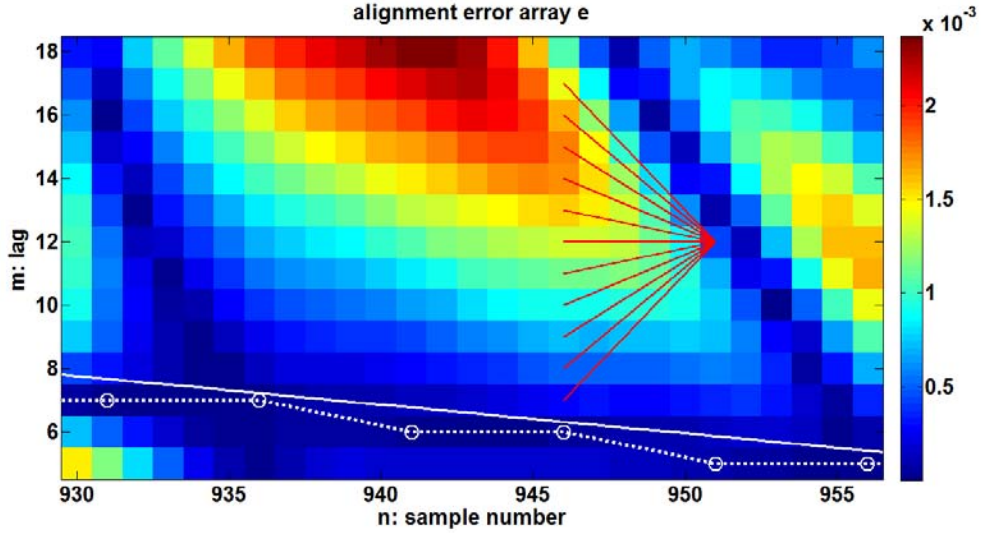
Smooth dynamic time warping



Constraint: $|m(n) - m(n-1)| \leq 1$

Dynamic time warping

$\boldsymbol{h = 1}$



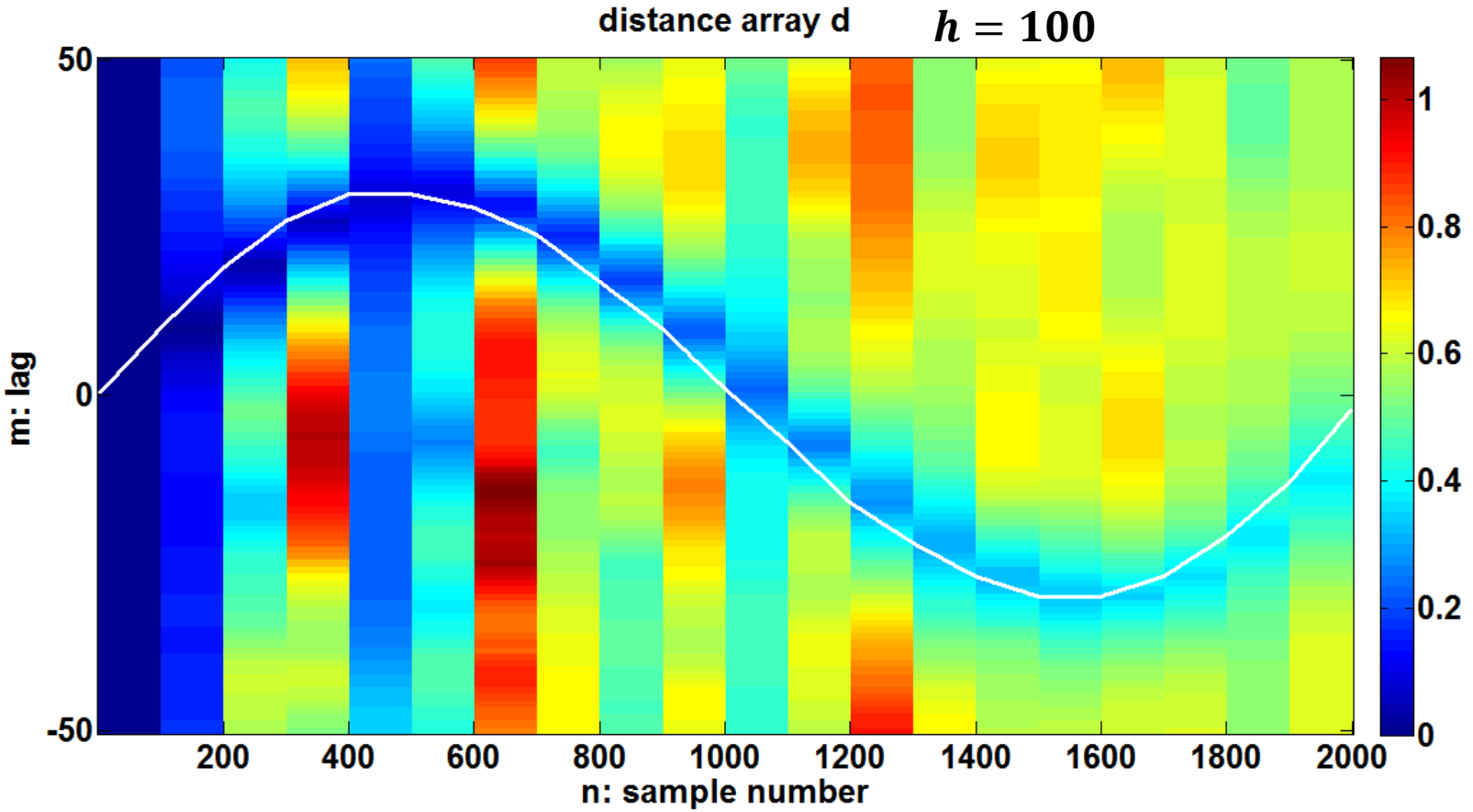
Smooth dynamic time warping

Coarse sampling interval $\boldsymbol{h = 5}$

Compton, S., and Hale, D., 2014, Estimating V-P/V-S ratios using smooth dynamic image warping: Geophysics

Smooth dynamic time warping

CREWES Matlab toolbox function: *DTWs*



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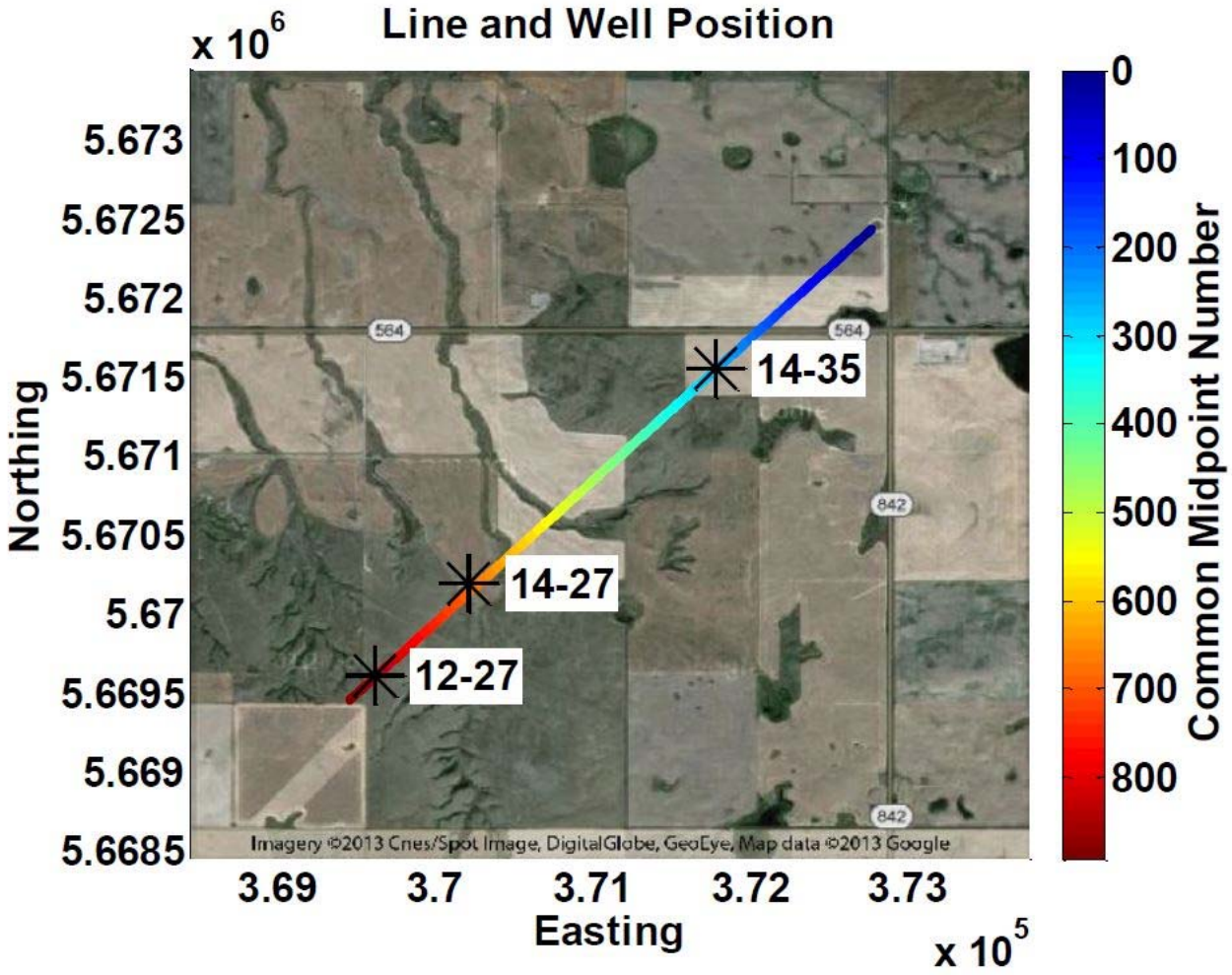
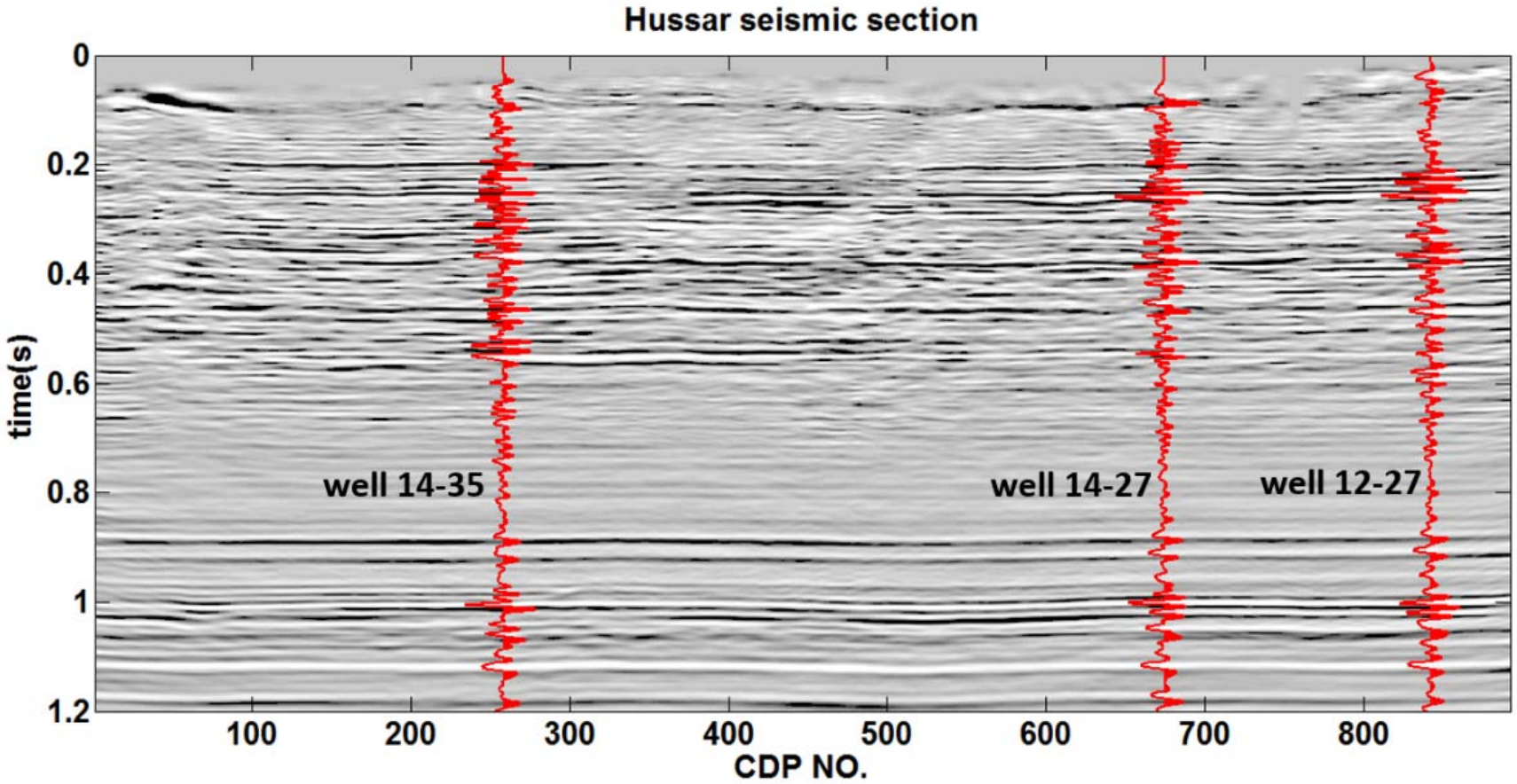
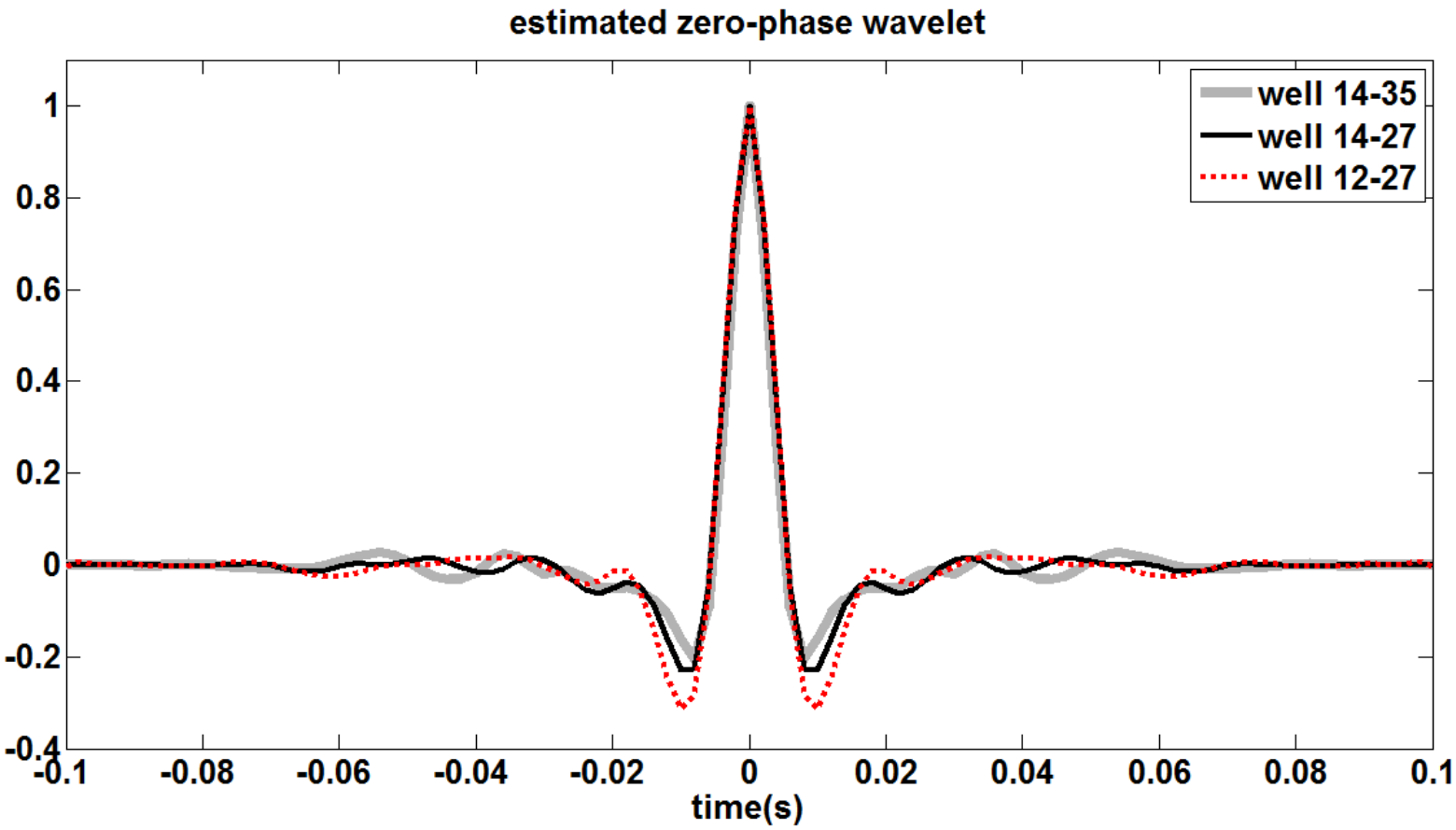
Hussar experiment



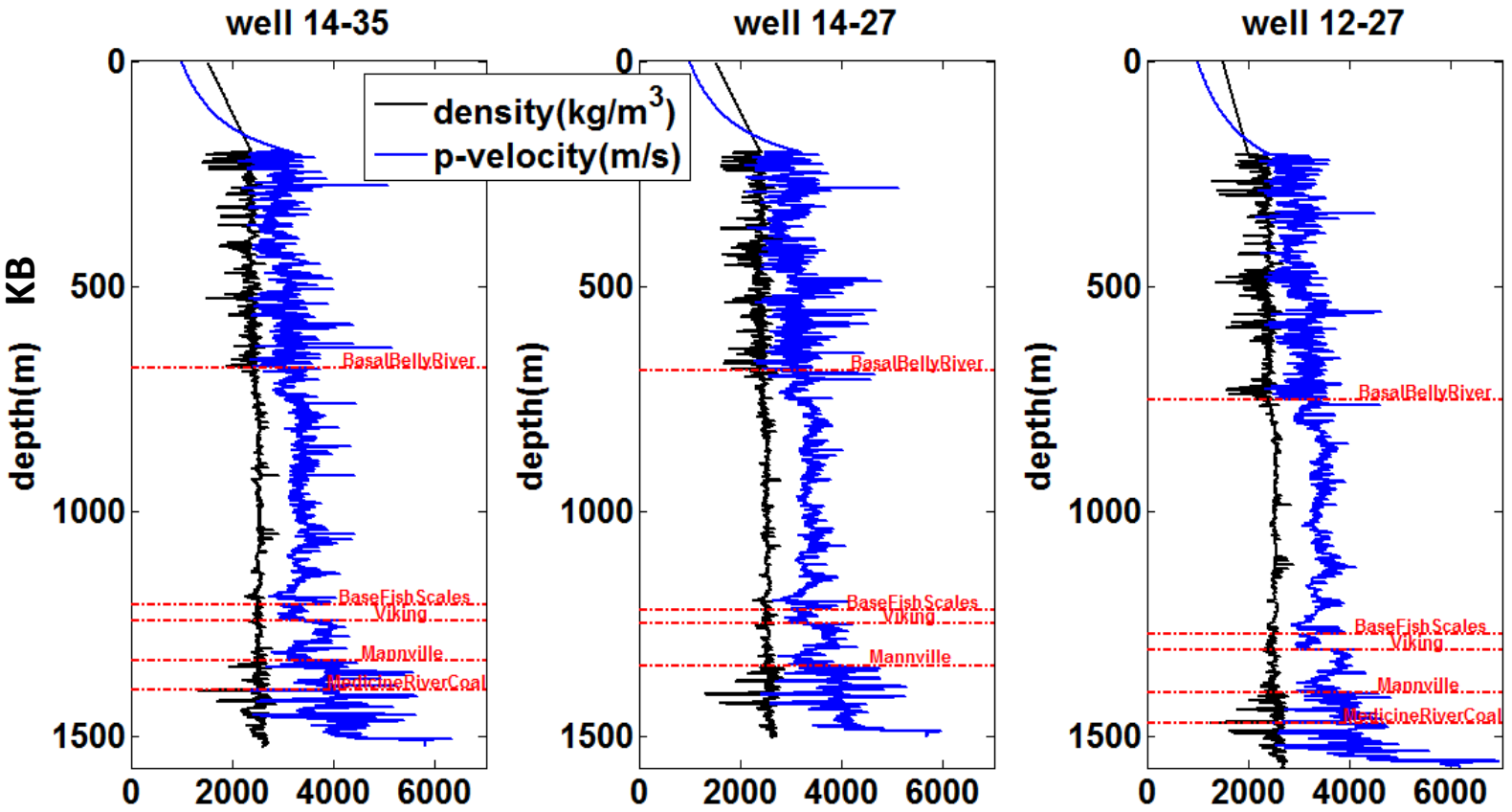
Zero-offset seismic section



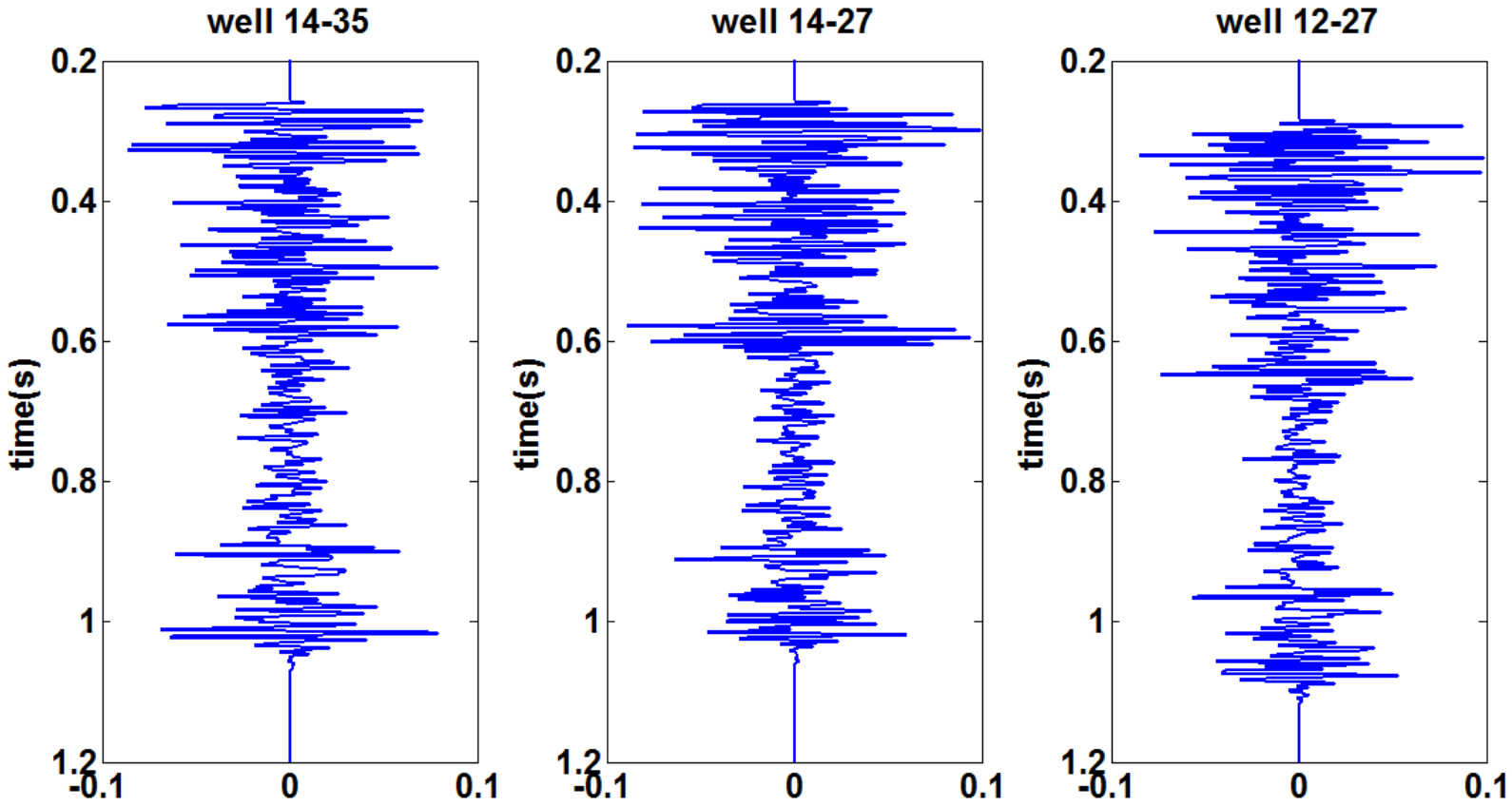
Estimate seismic wavelet



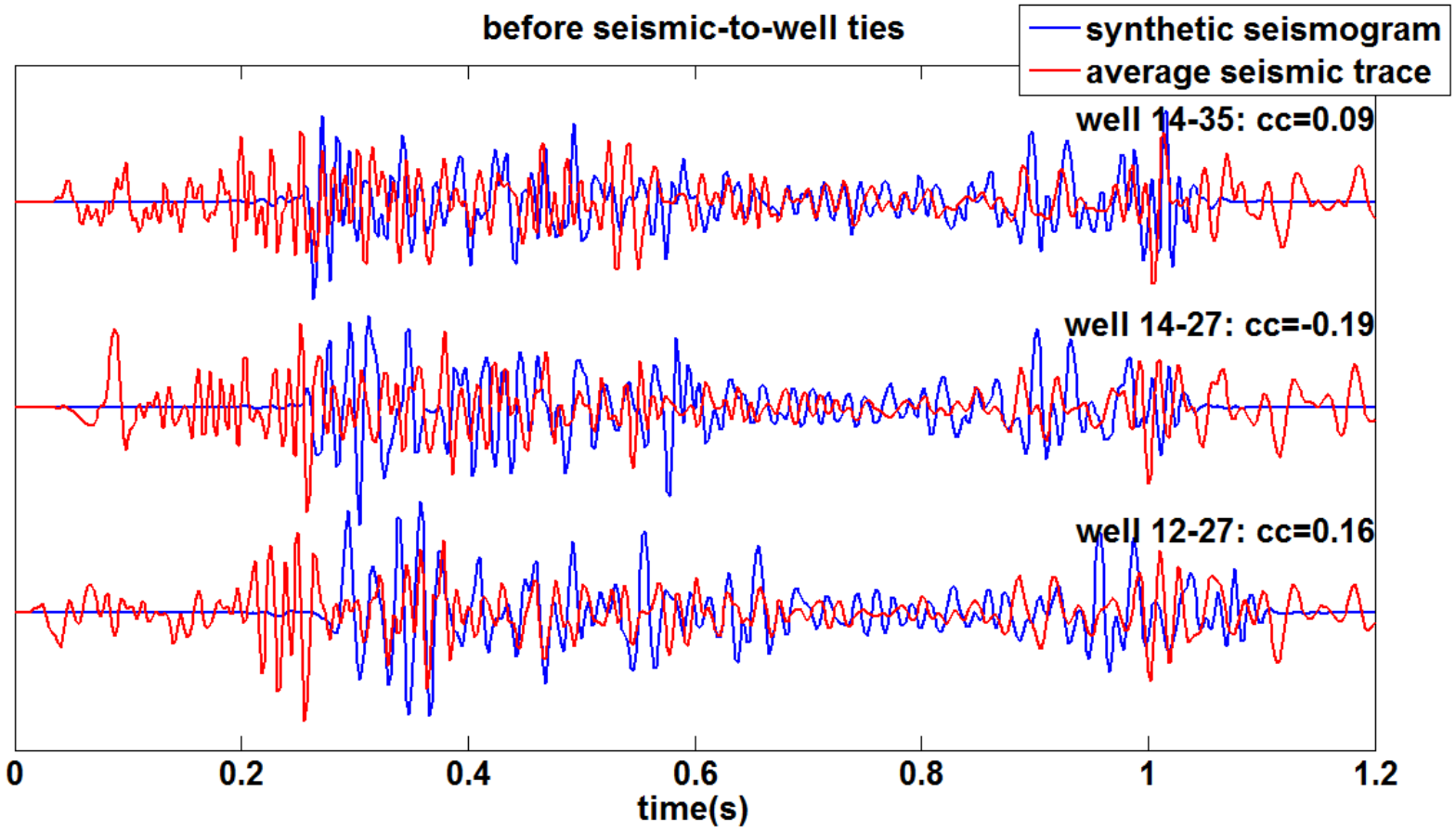
Well logs after editing



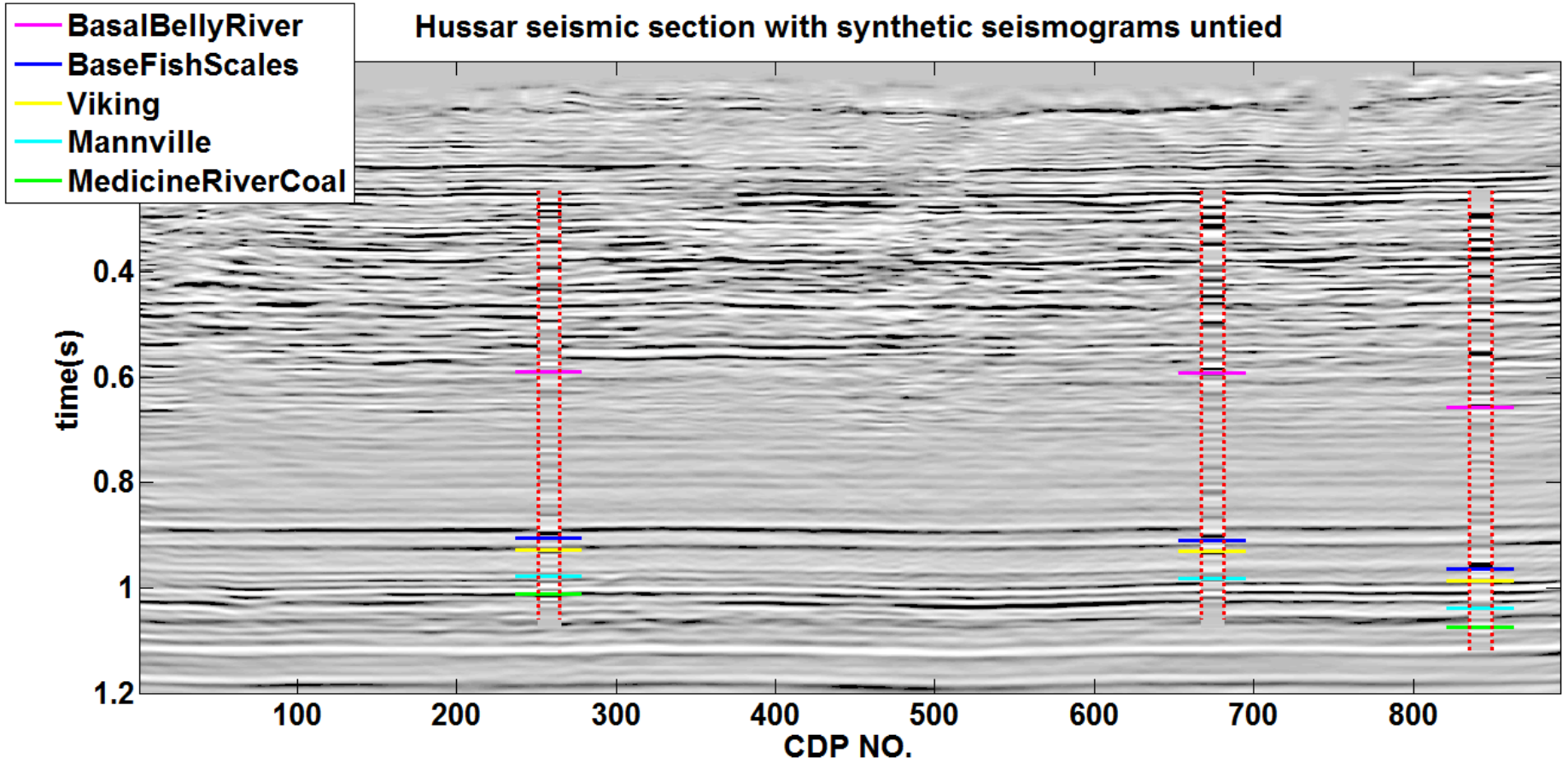
Well reflectivity



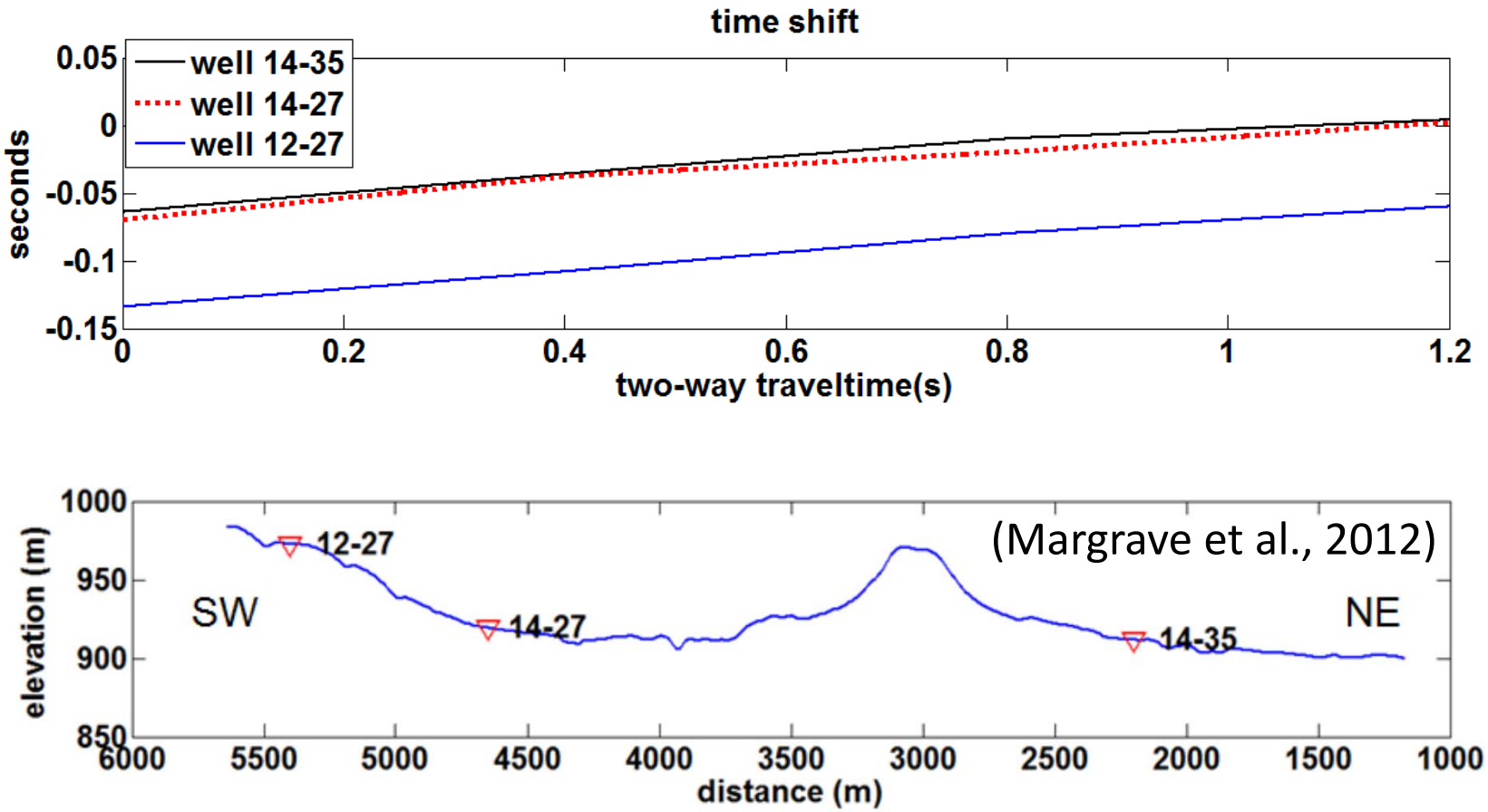
Construct synthetic seismogram



Before seismic-to-well ties

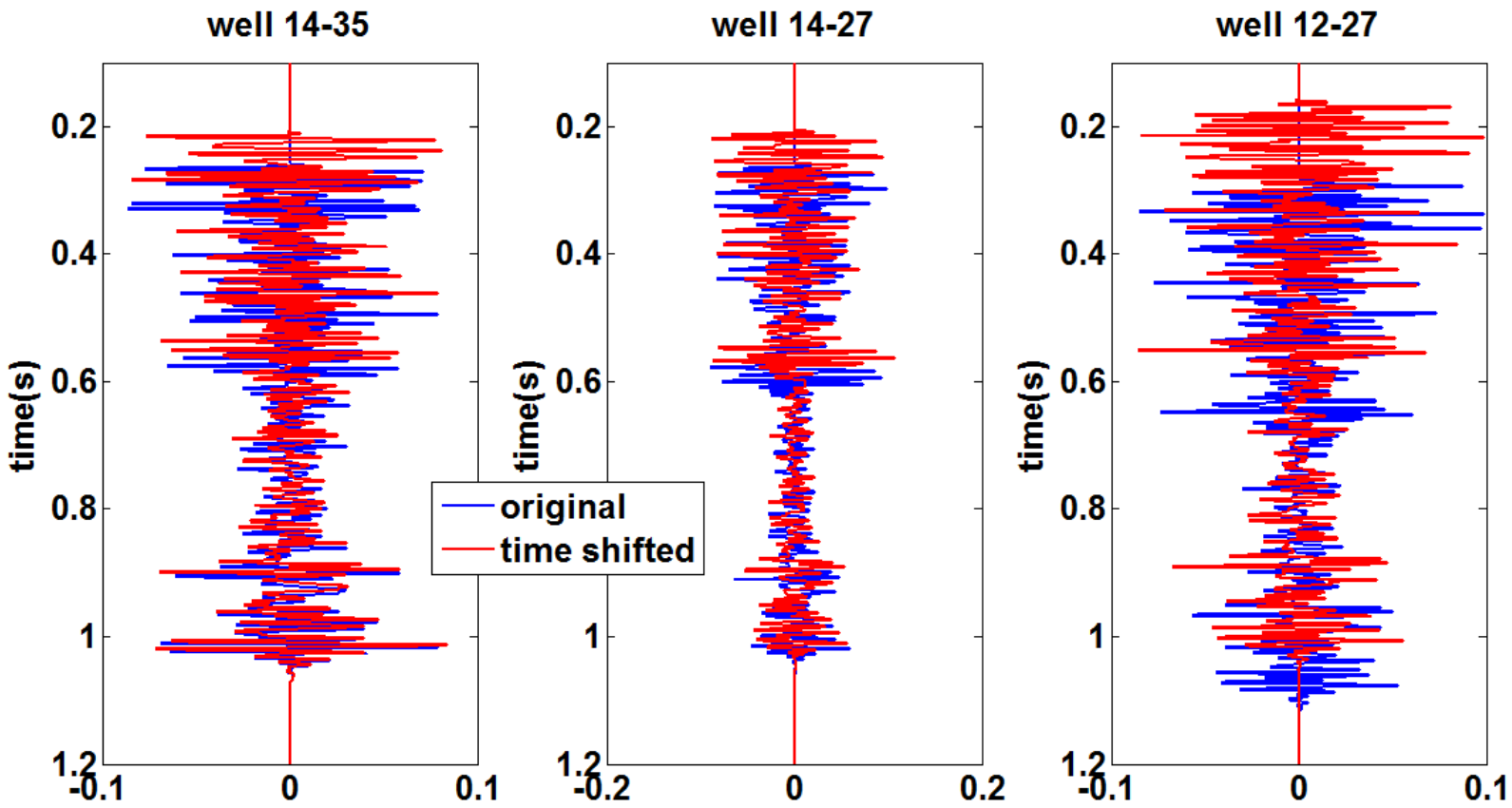


Estimate time shift by SDTW

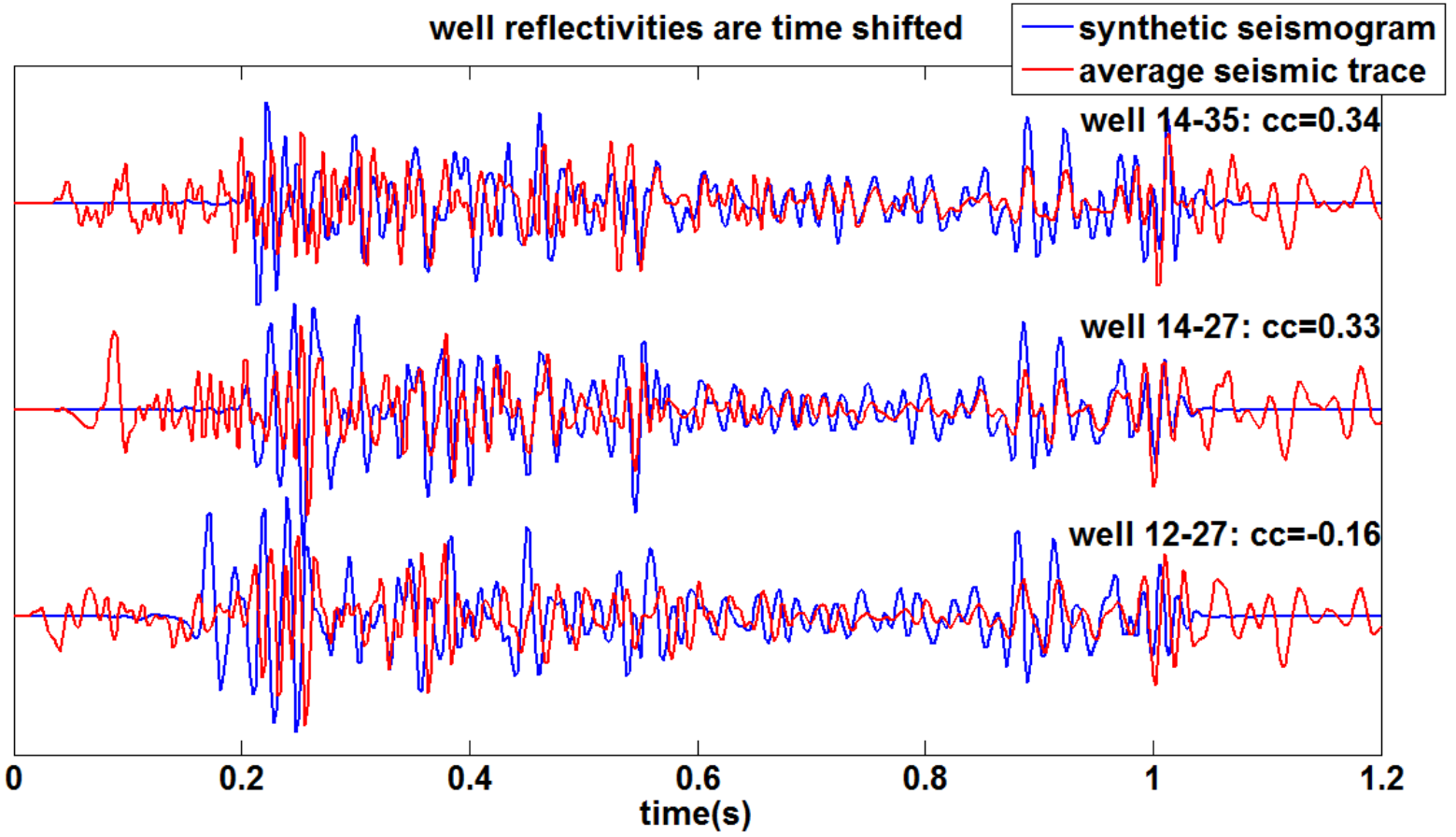


(Margrave et al., 2012)

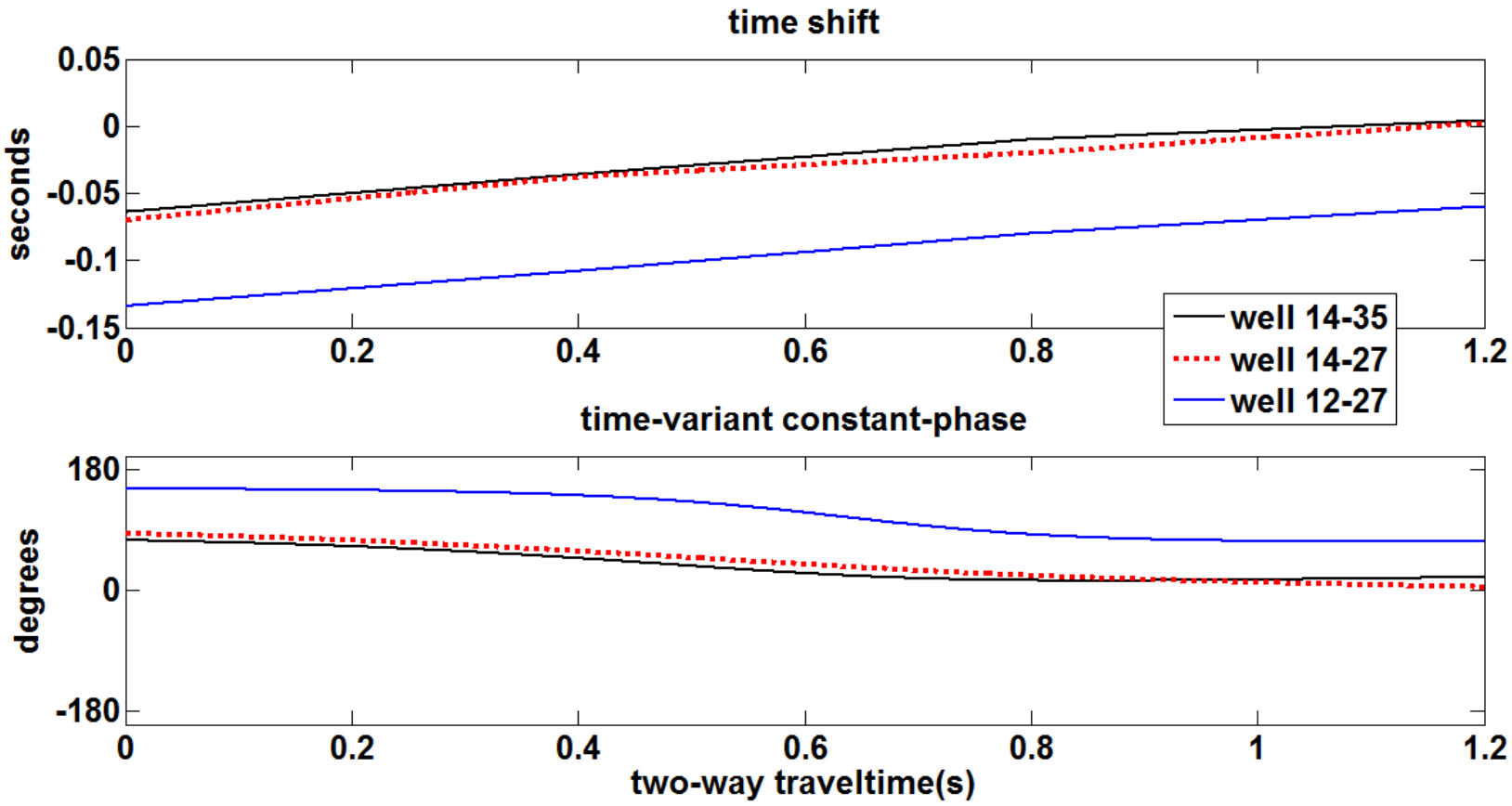
Time calibration of reflectivity



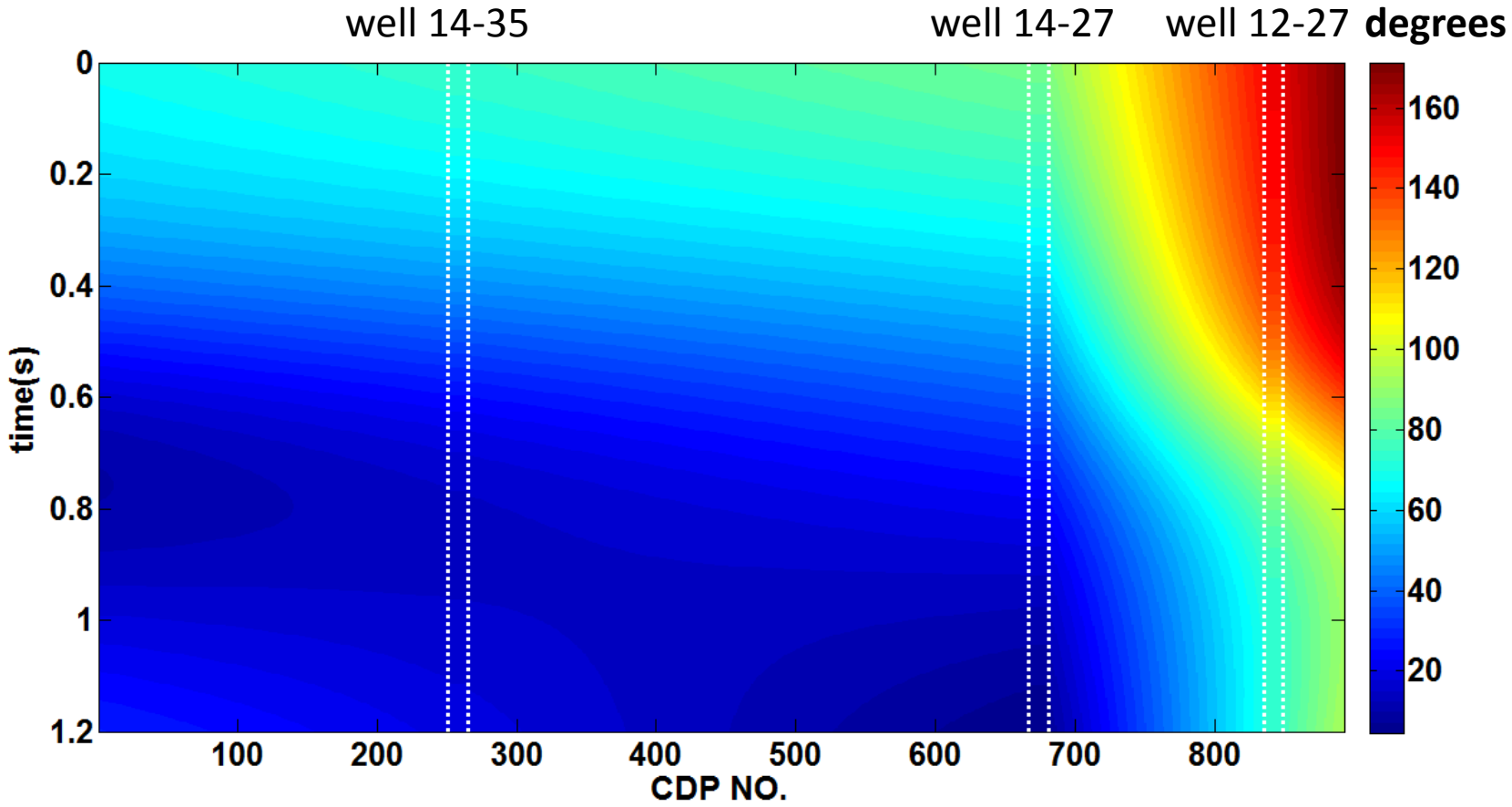
Reconstruct synthetic seismogram



Estimate time-variant constant-phase

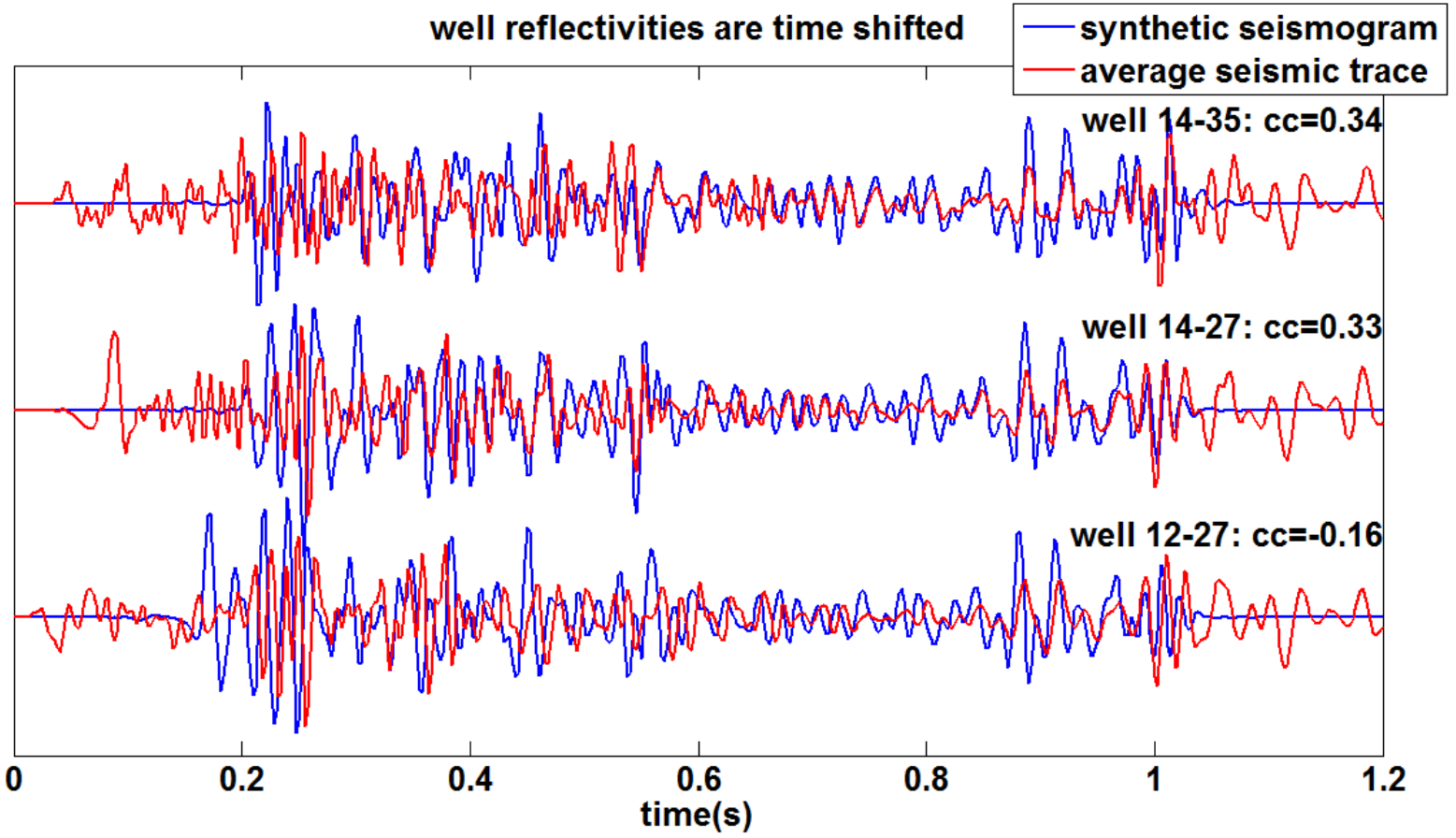


2-D time-variant constant-phase

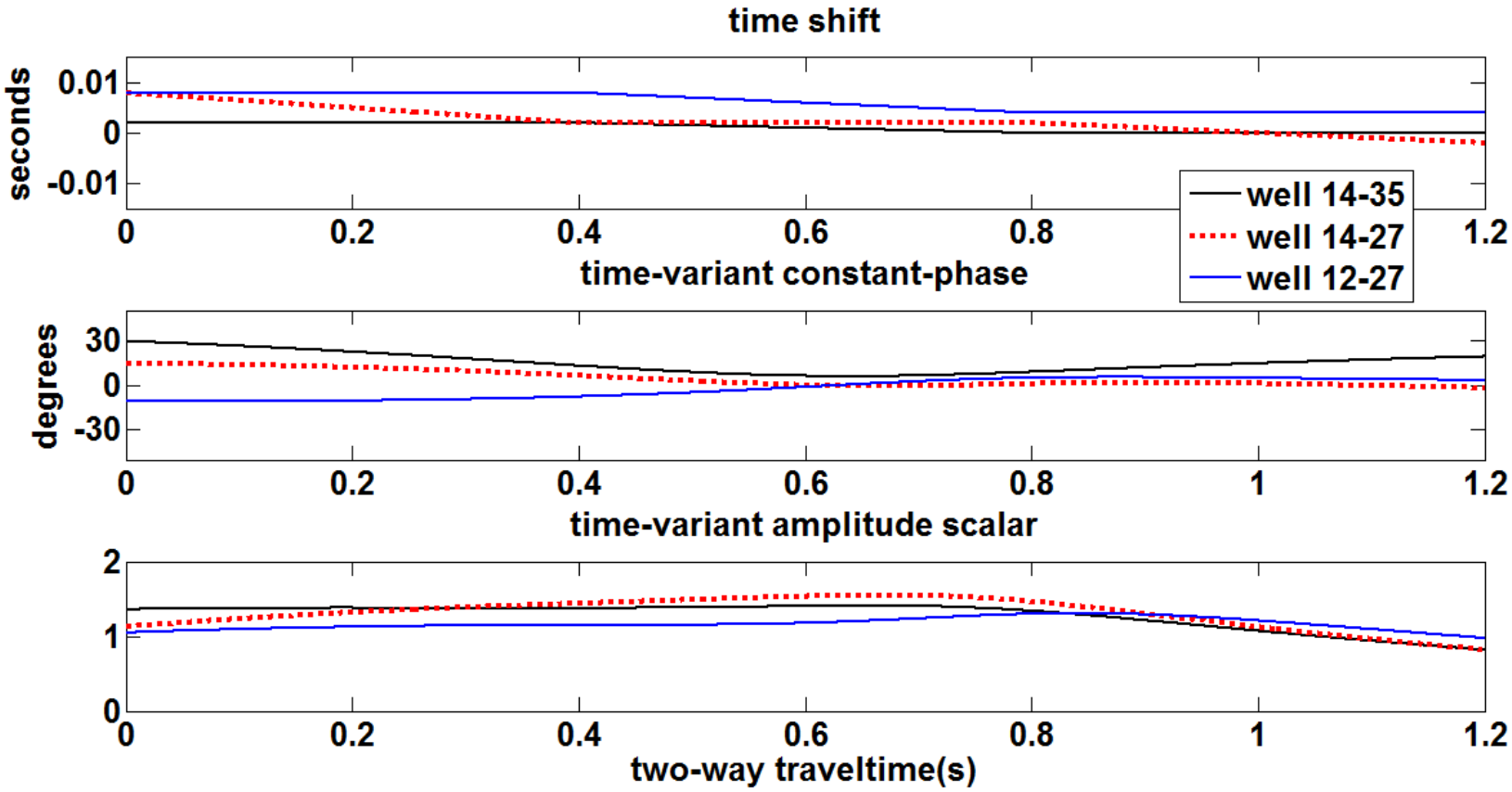


Second iteration of time calibration

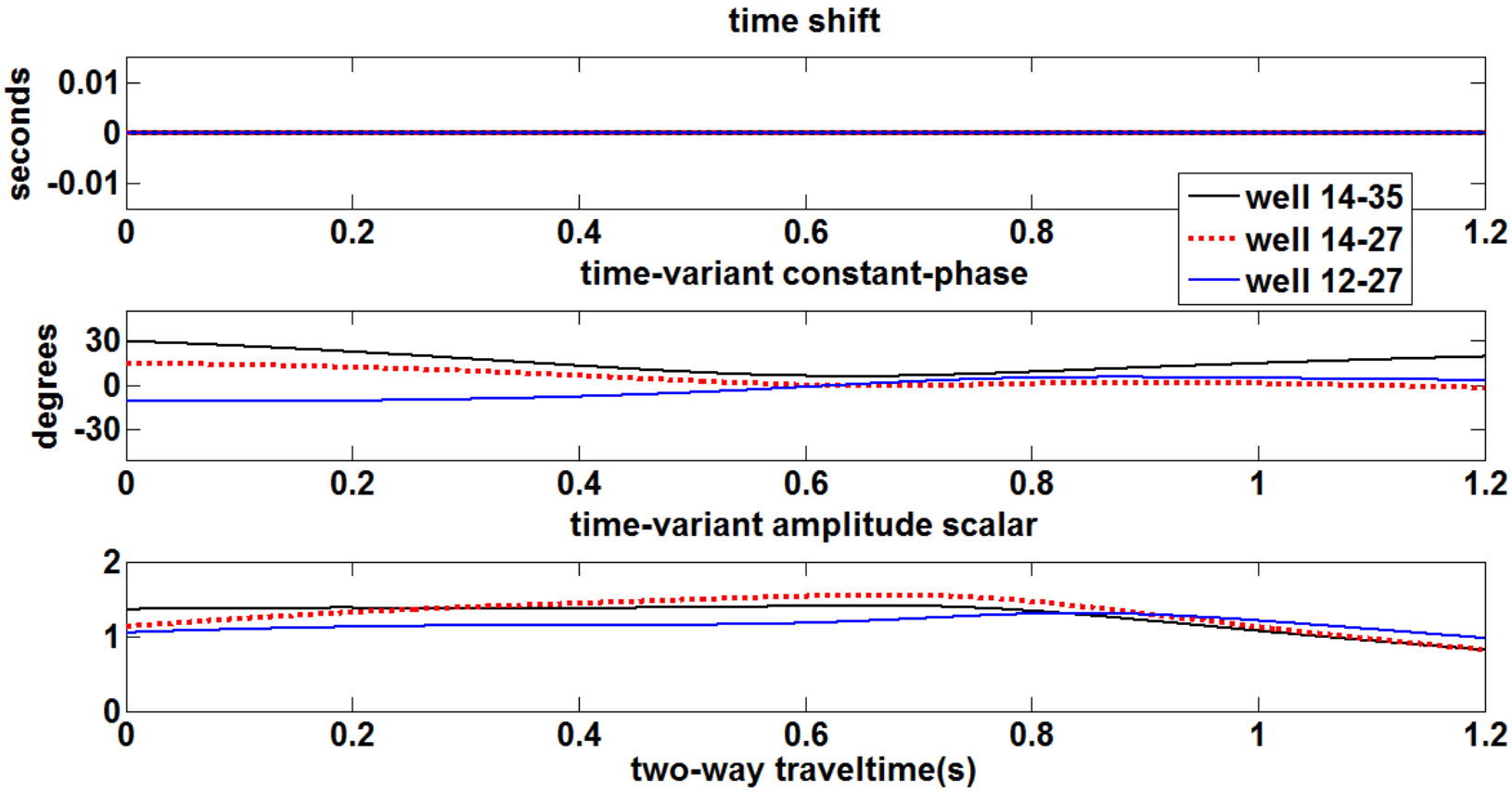
Synthetic seismogram after time calibration once



Second iteration of time calibration

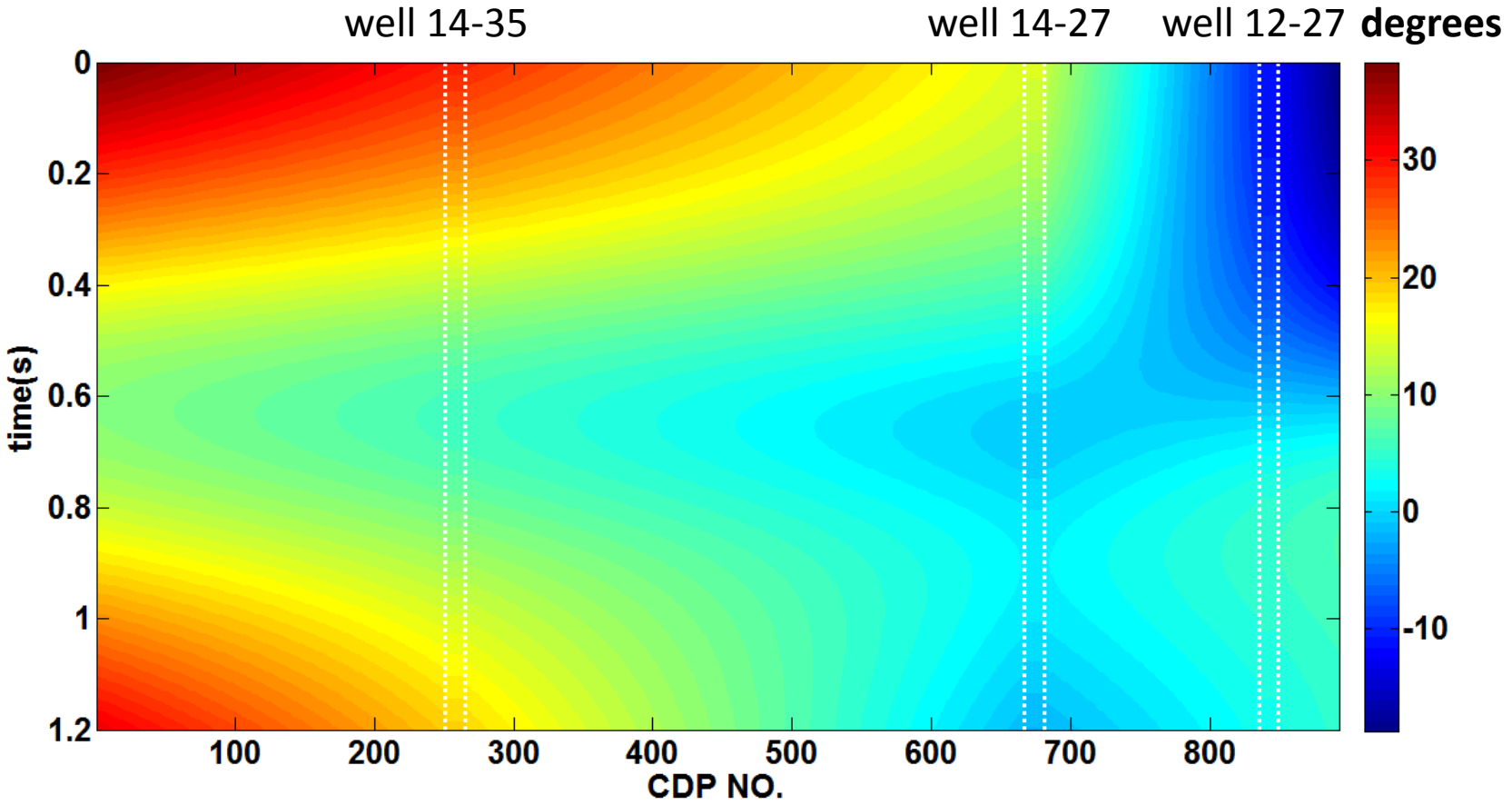


Third iteration of time calibration

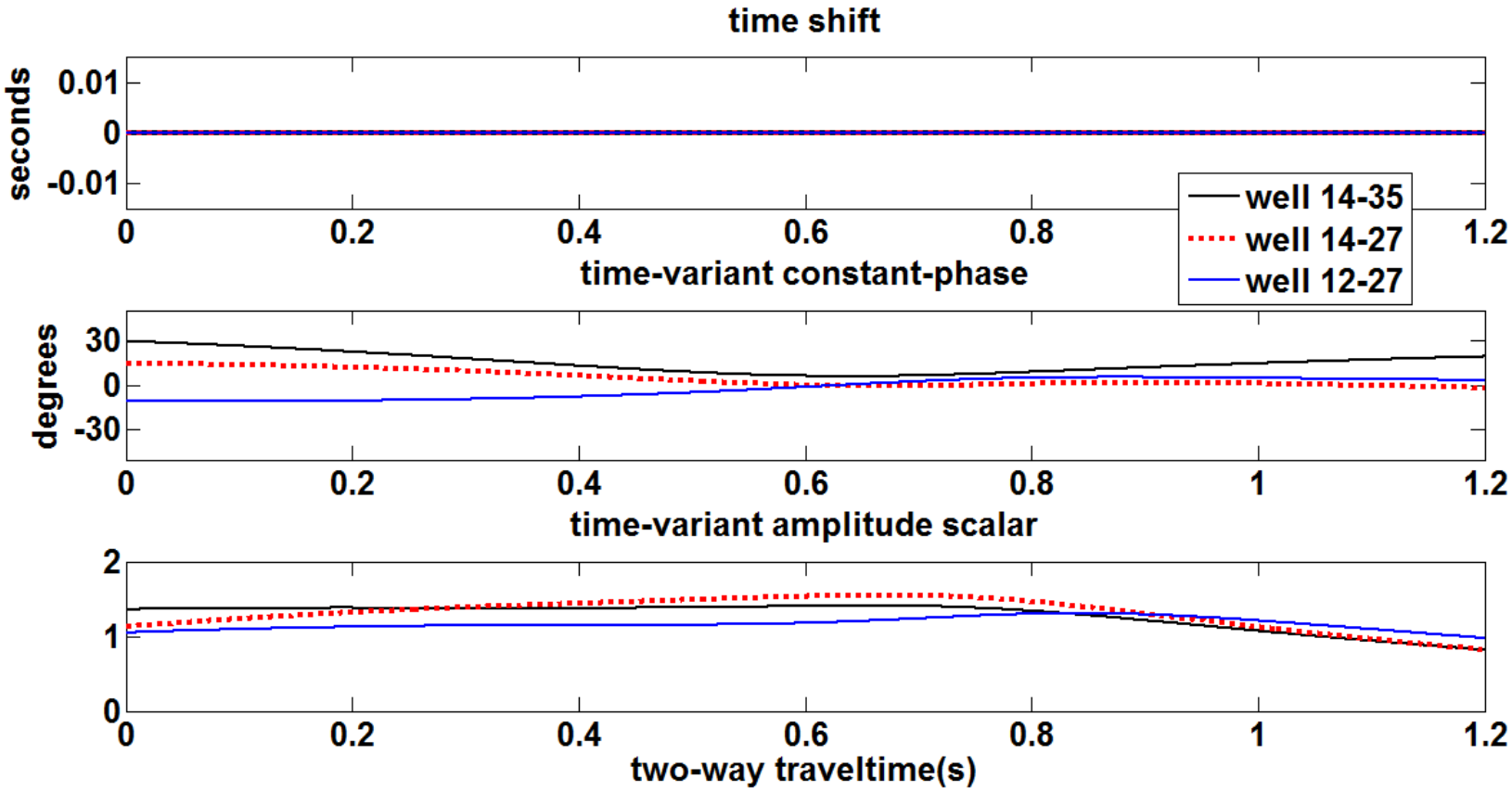


2-D time-variant constant-phase

Two iterations of time calibration

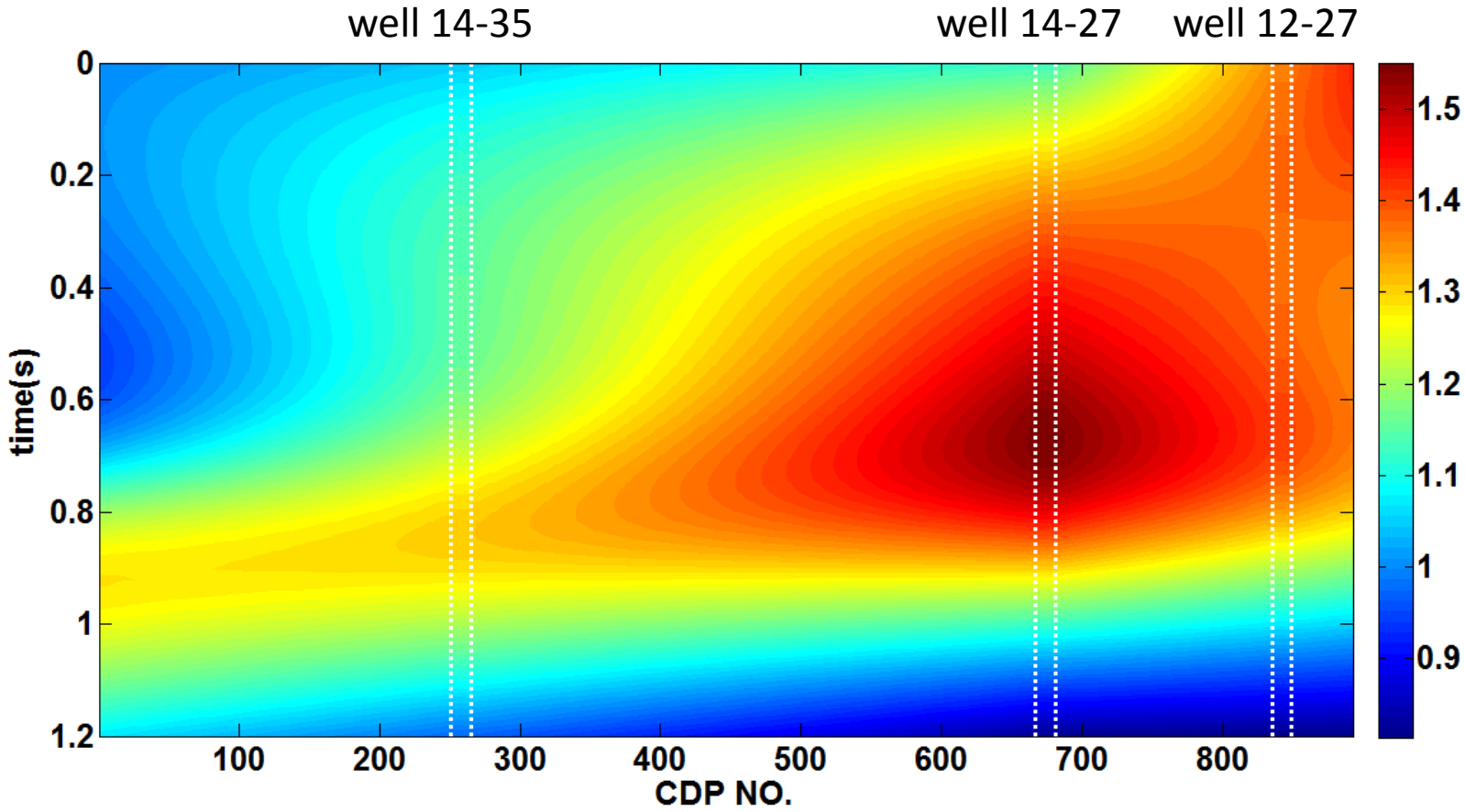


Third iteration of time calibration

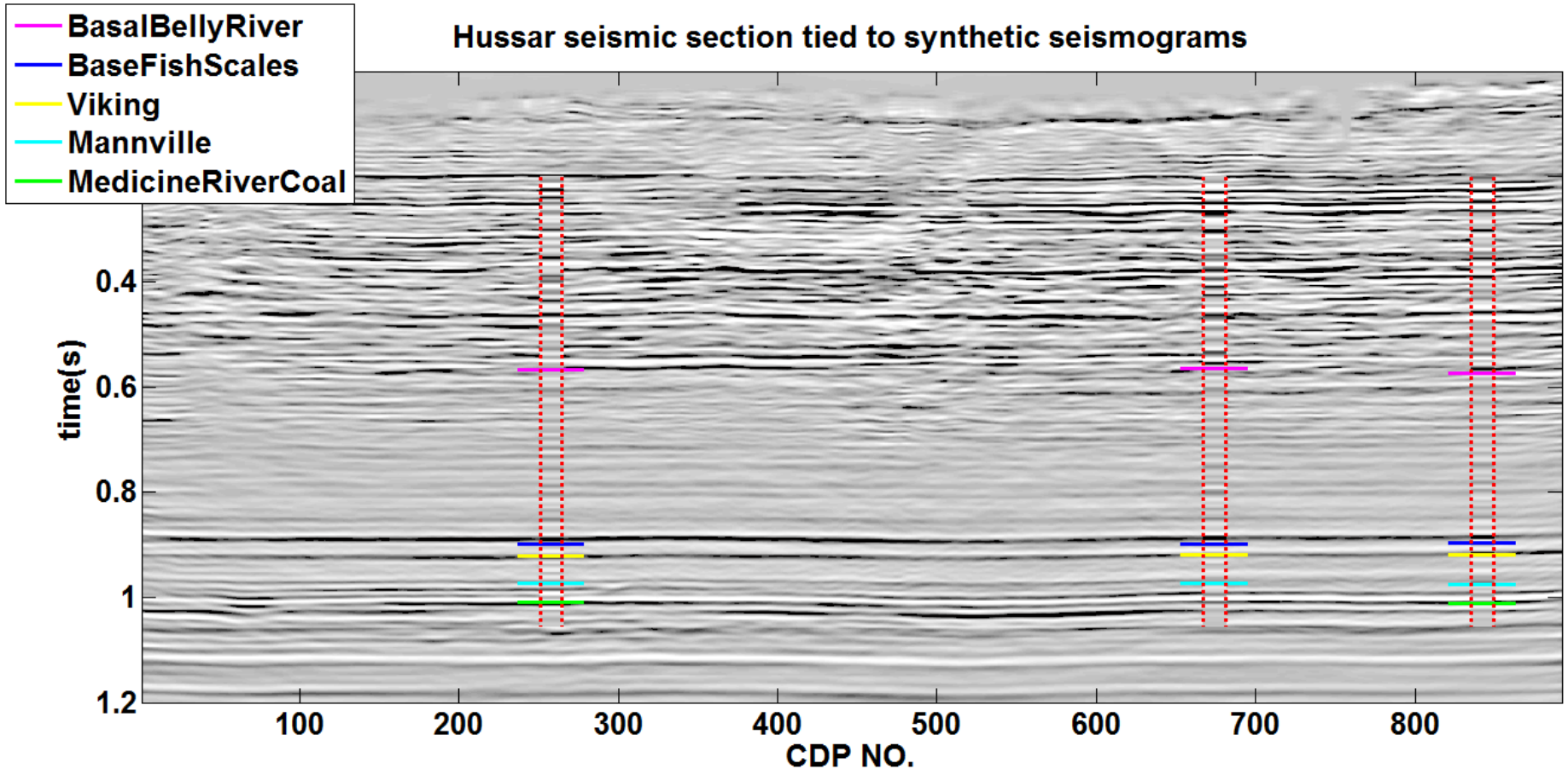


2-D time-variant amplitude scalar

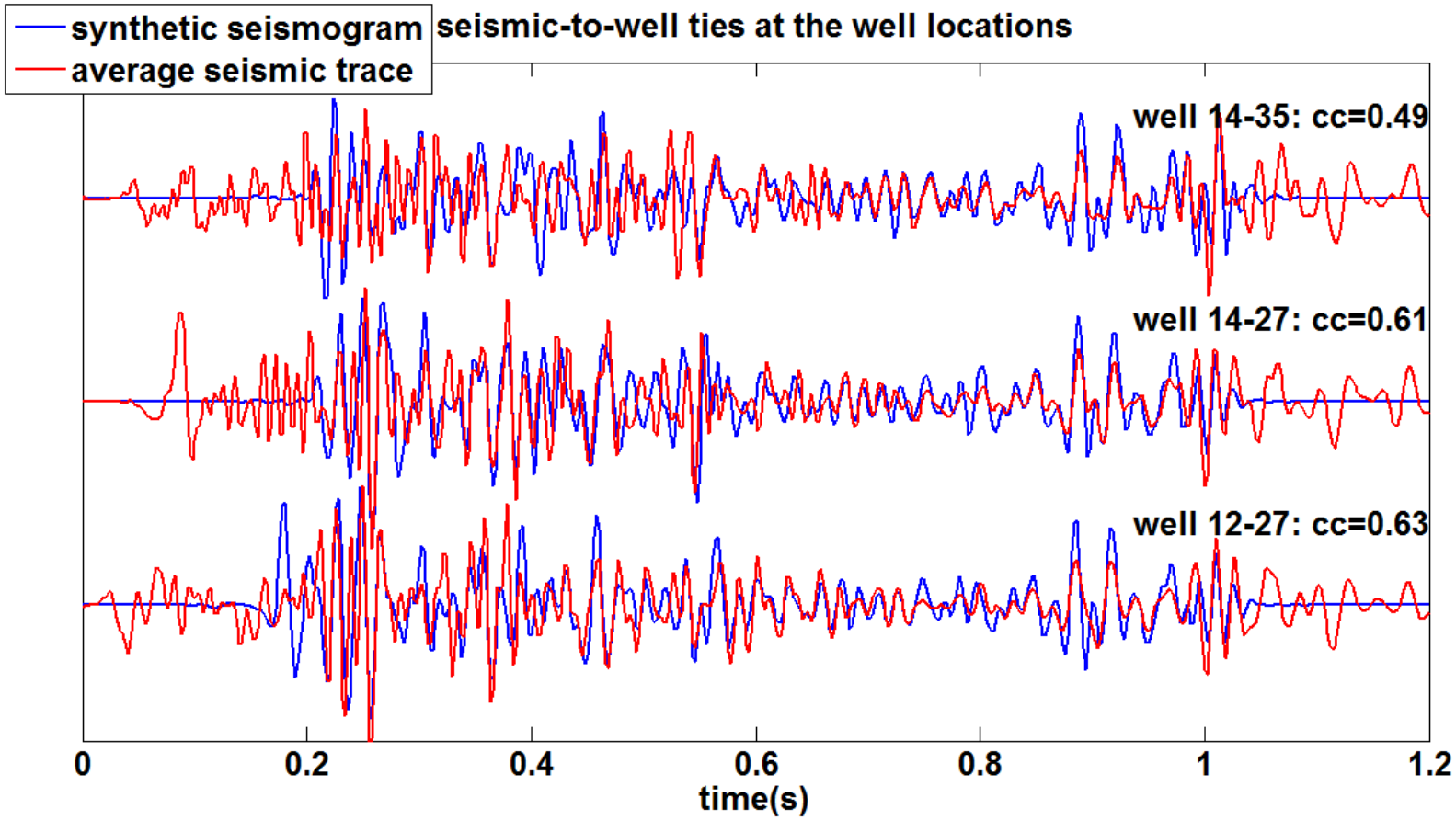
Two iterations of time calibration



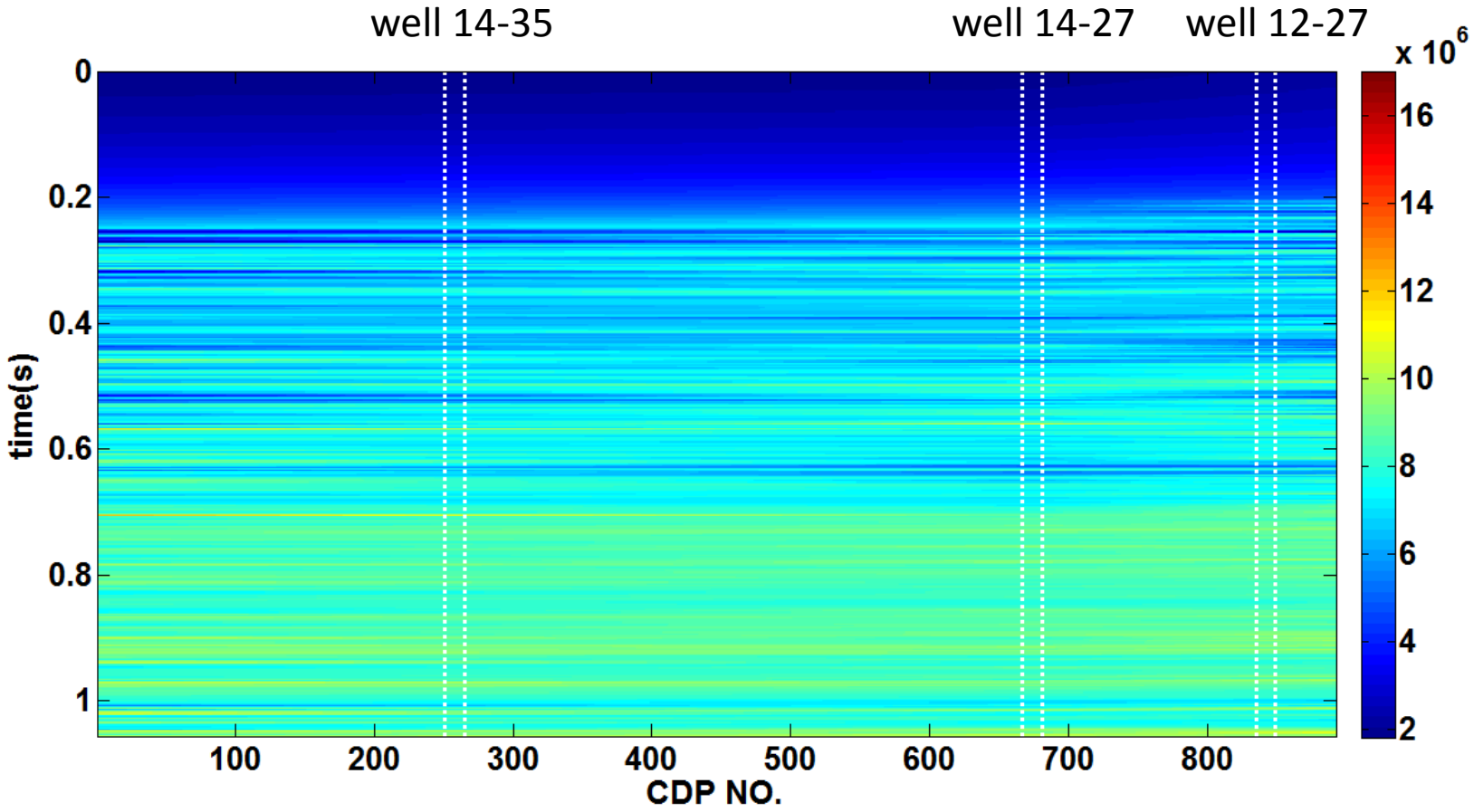
After seismic-to-well ties



After seismic-to-well ties



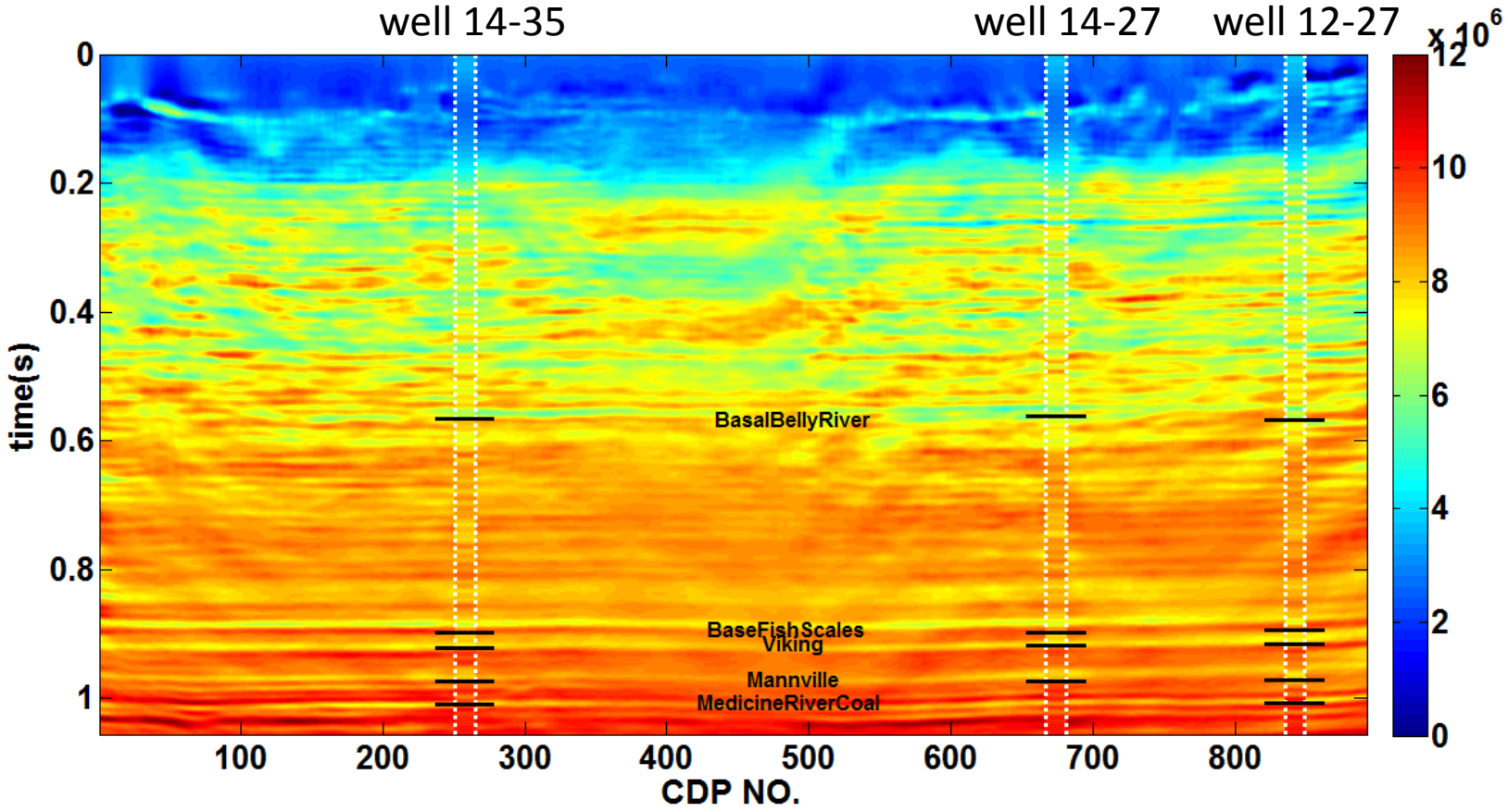
Interpolated well impedance



Bandlimited impedance inversion

One iteration of time calibration

Well: 0-3 Hz
Seismic: 3-75 Hz



Bandlimited impedance inversion

Two iterations of time calibration

Well: 0-3 Hz
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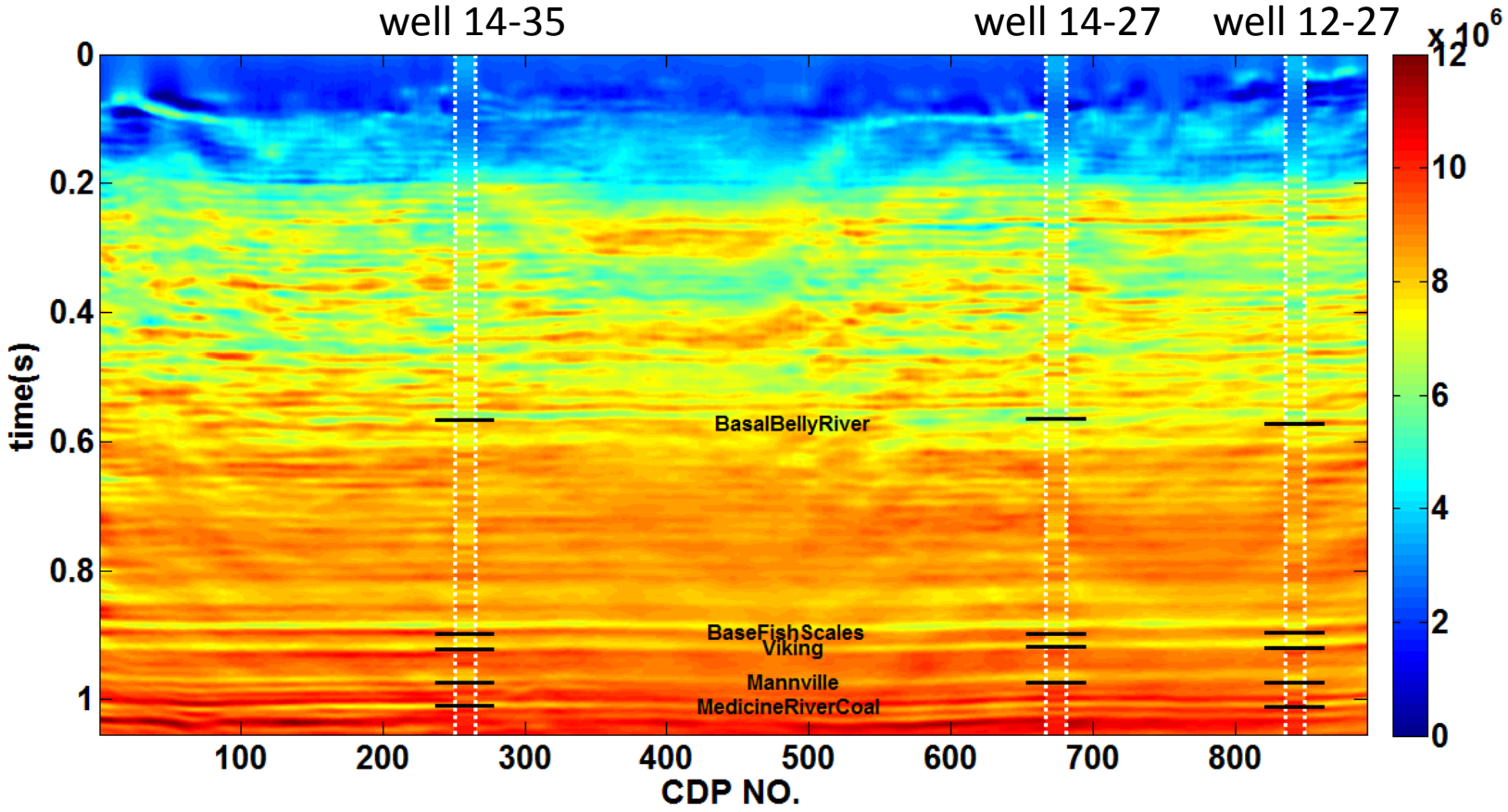
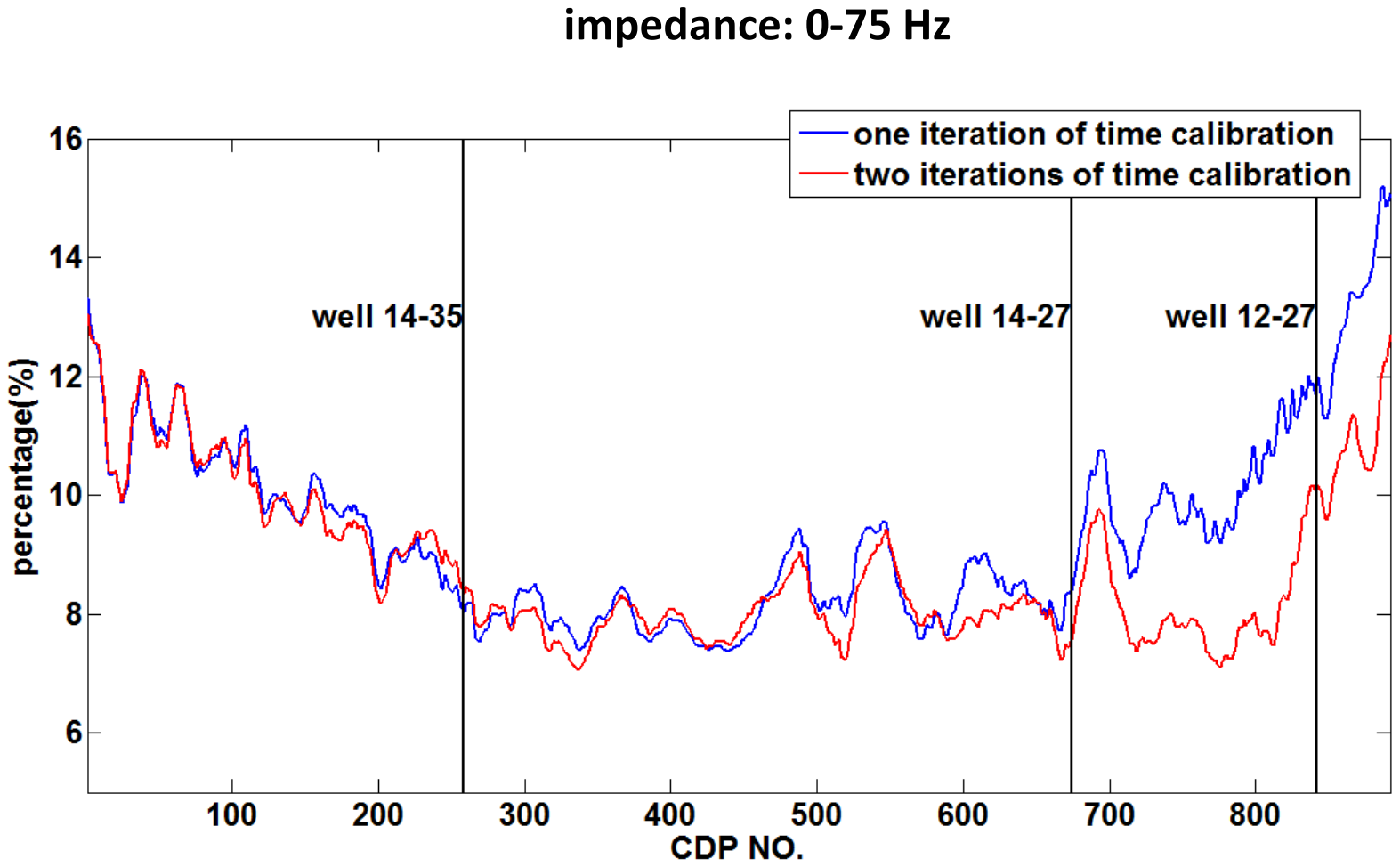


Errors between seismic and well impedance



Conclusions

- Smooth dynamic time warping can accurately estimate the smooth time shift between two traces.

- Smooth dynamic time warping takes the place of the manual stretch-squeeze process in the Hussar well tying.

- The second iteration of time calibration reduces inversion errors around the well 12-27, verifying better seismic-to-well ties.

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- **CREWES staff and students**

THANK YOU !