Displacement and fling using the wavelet transform with ICEARRAY data

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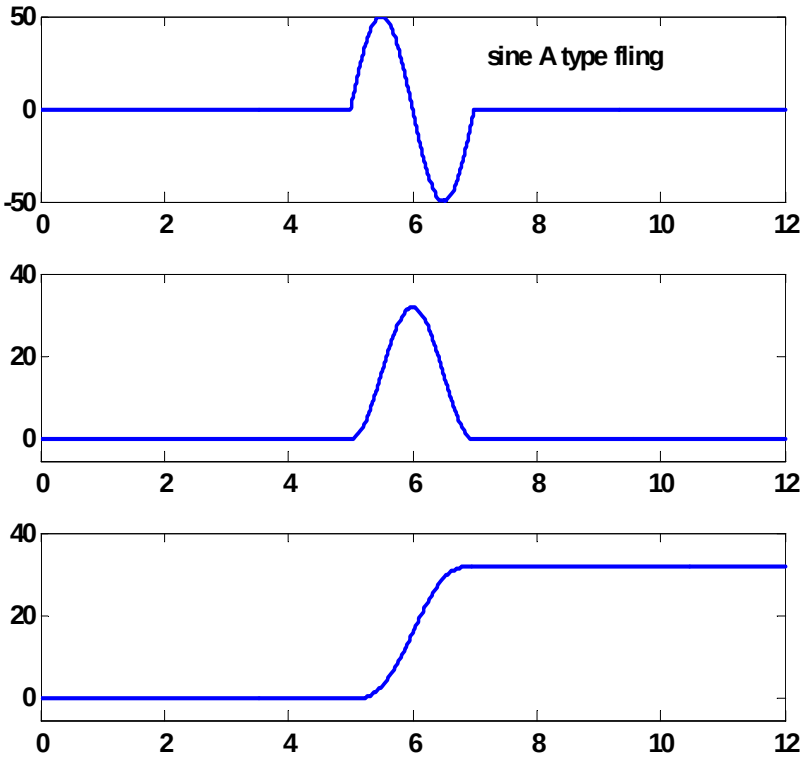
Our Paper

- **"Obtaining estimates of low frequency 'fling', instrument tilts and displacement timeseries using wavelet decomposition''**
- **Nicholas Alexander, University of Bristol**
- **Andrew Chanerley, University of East London**
- **Submitted to the Bulletin of European Earthquake Engineering in Dec 2008**

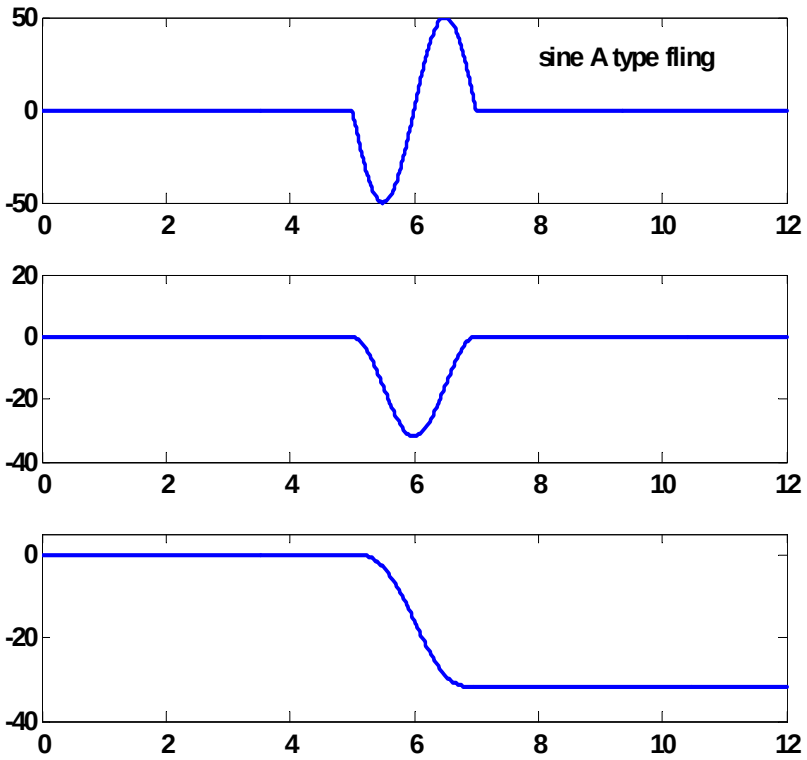
Objectives

- Method should correct and automate the integration from acceleration to displacement
- Method should be transparent from the point of view of earthquake type i.e. minimize expert opinion
- Method should extract the low-frequency fling

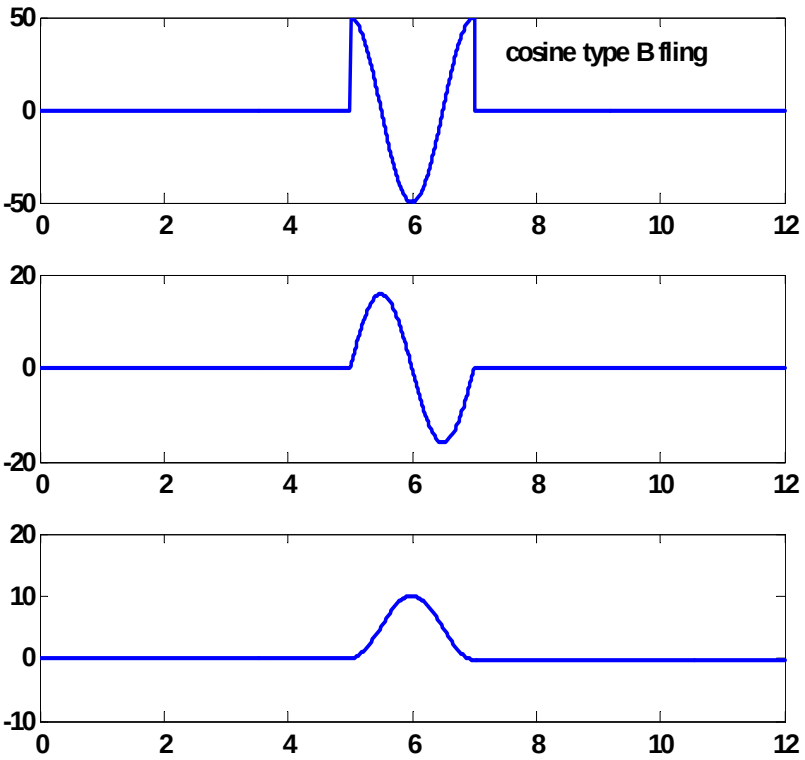
Sine A type fling(s)



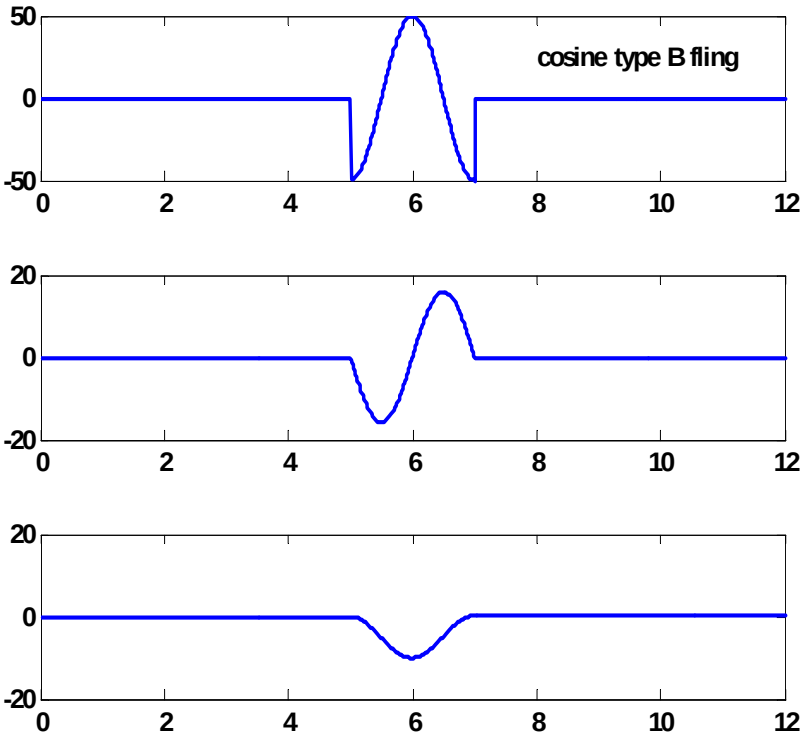
More model fling(s)



cosine type B fling(s)



cosine type B fling



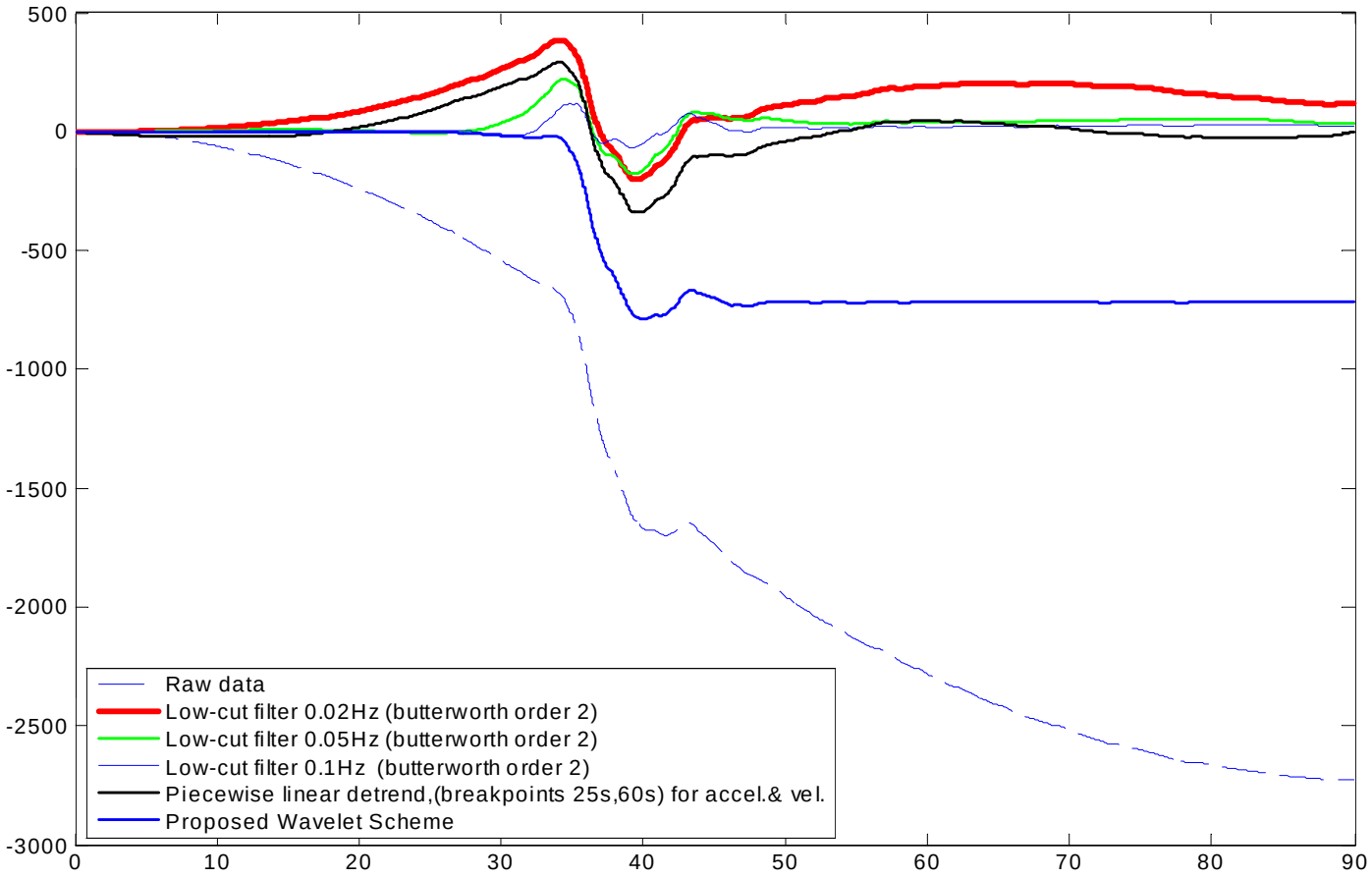
Fling summary

- **Fling model(s) are easy to integrate**

How do we extract Fling model ?

- **Answer: not with standard filtering**

Standard filtering methods



So what did we do?

- **Decided to try the wavelet transform**

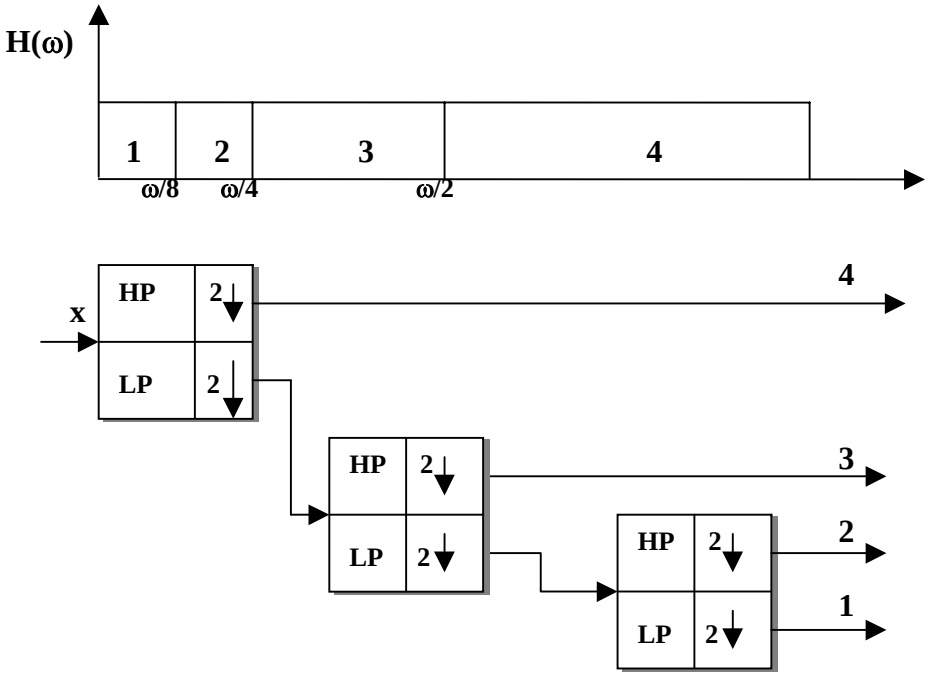
Wavelet transform

- Ingrid Debauchies, *Ten Lectures on Wavelets*: Philadelphia, PA: SIAM 1992

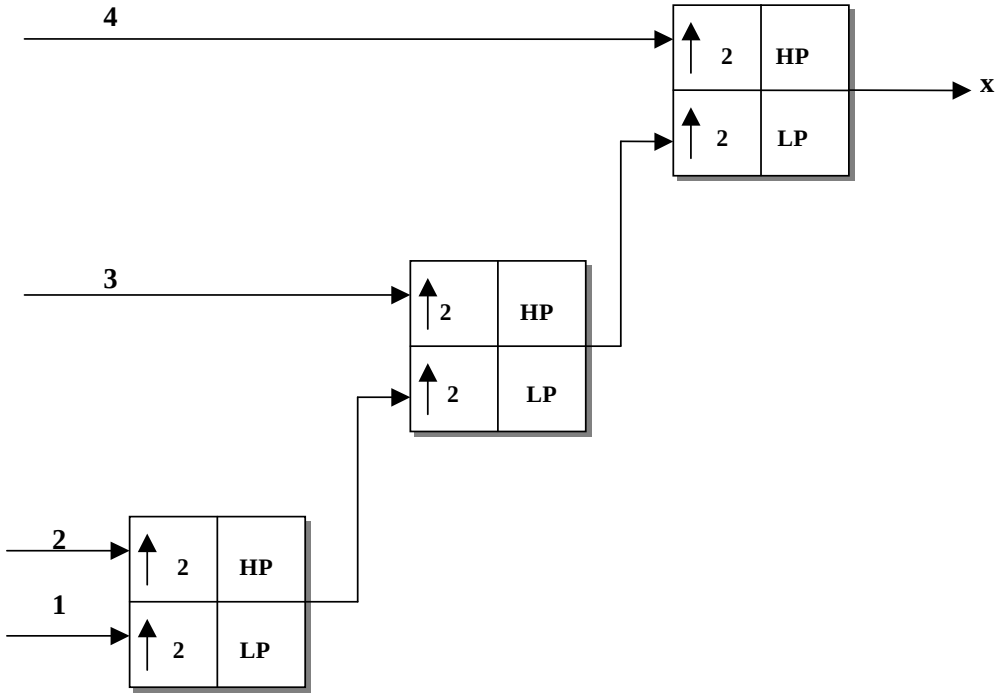
- Sums, averages, differences, similar to low-pass and high-pass filters

- Easiest to consider the transform as a set of filter banks similar to octave equalizers used in audio

Wavelet transform->decomposition filter banks



Re-construction filter banks

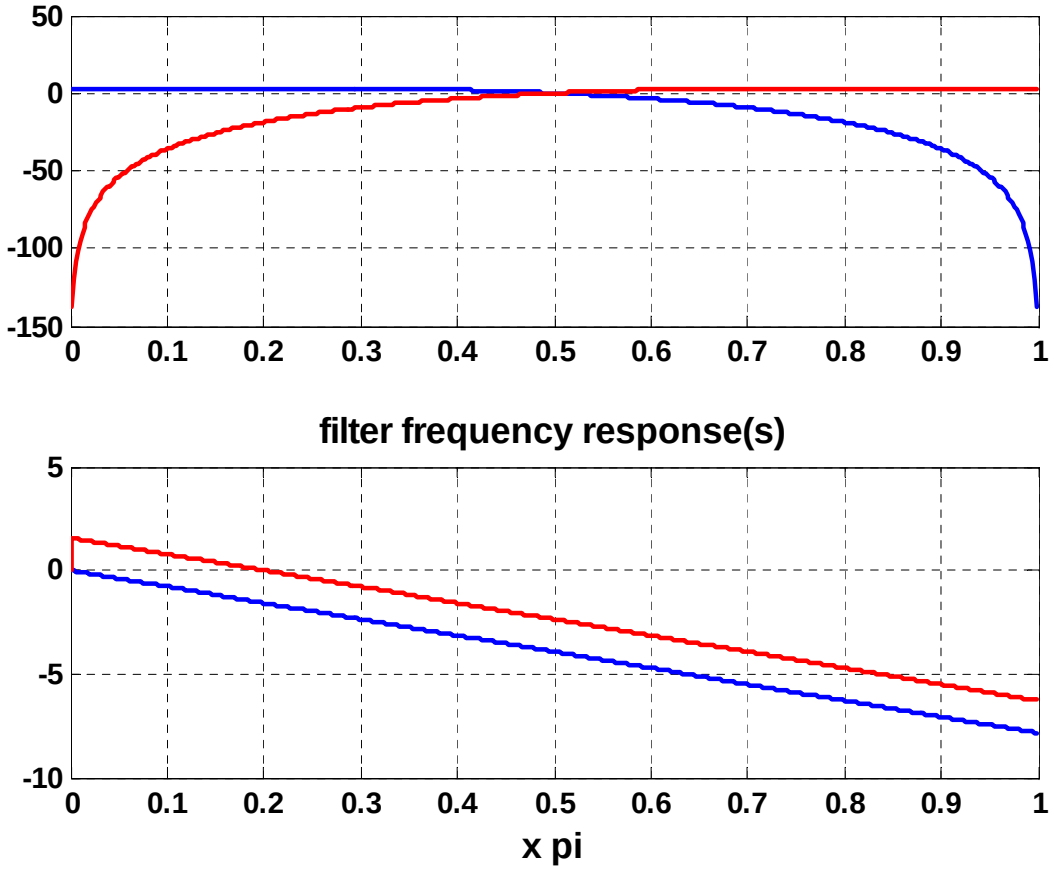


Filter matrices for decomposition & reconstruction

$$Y = \begin{bmatrix} h_o & h_1 & h_2 & h_3 & & & & & & & & \\ h_3 & -h_2 & h_1 & -h_0 & & & & & & & & \\ & & h_0 & h_1 & h_2 & h_3 & & & & & & \\ & & h_3 & -h_2 & h_1 & -h_0 & & & & & & \\ & & & & & & h_0 & h_1 & h_2 & h_3 & & \\ & & & & & & h_3 & -h_2 & h_1 & -h_0 & & \\ h_2 & h_3 & & & & & & & h_1 & h_2 & & \\ h_1 & -h_0 & & & & & & & h_3 & -h_2 & & \end{bmatrix}$$

$$Y^{-1} = Y^T = \begin{bmatrix} h_o & h_3 & & & & & & & & & & \\ h_1 & -h_2 & & & & & & & & & & \\ h_2 & h_1 & h_0 & h_3 & & & & & & & & \\ h_3 & -h_0 & h_1 & -h_2 & & & & & & & & \\ & & & & h_2 & h_1 & h_0 & h_3 & & & & \\ & & & & h_3 & -h_0 & h_1 & -h_2 & & & & \\ & & & & & & h_2 & h_1 & h_0 & h_3 & & \\ & & & & & & h_3 & -h_0 & h_3 & -h_2 & & \end{bmatrix}$$

Associated low pass and high pass filters and their phase. Note that these QMFs are maximally flat



de-noising

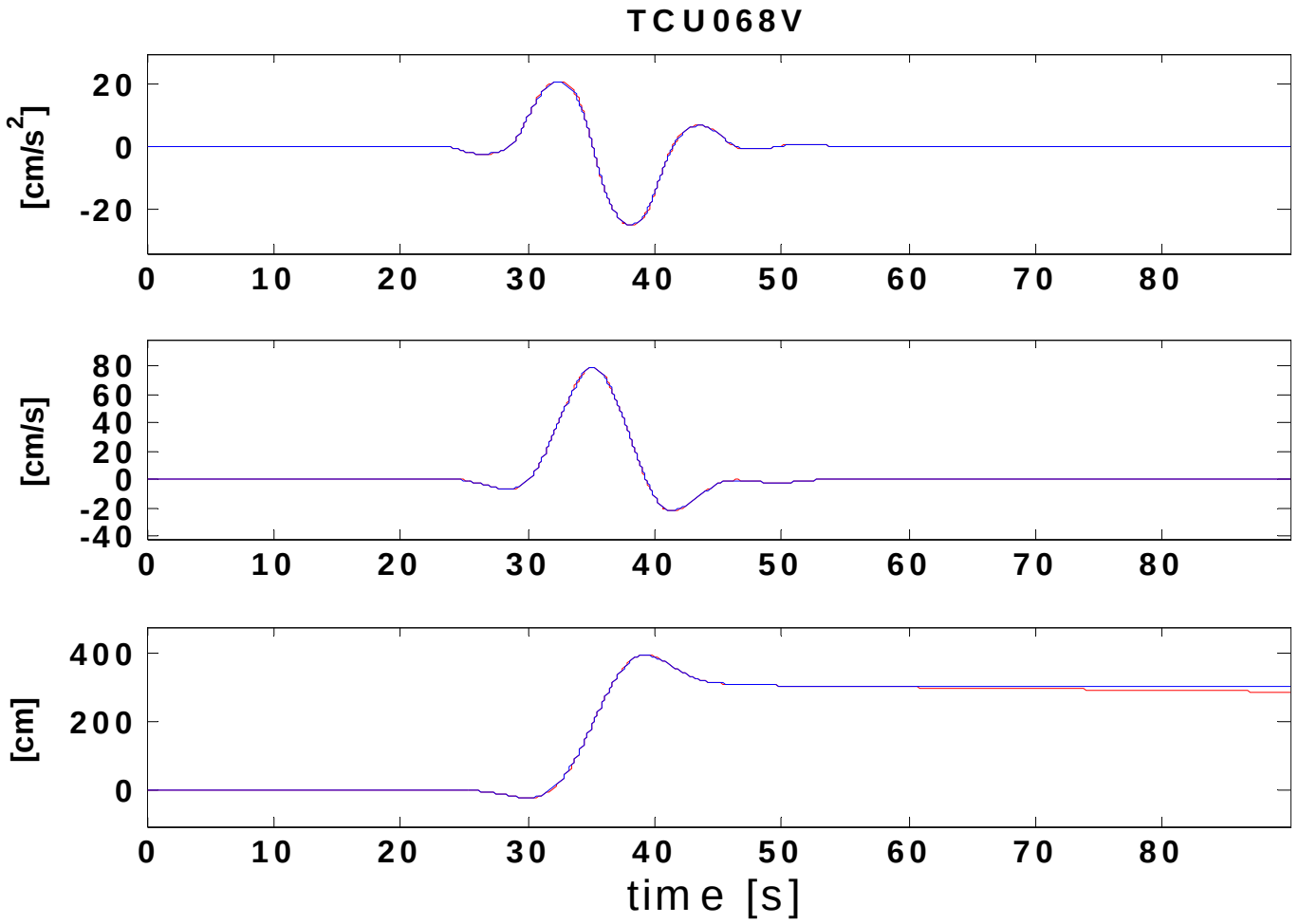
- Thresholding involves the setting to zero wavelet coefficients (i.e. the transformed data values), whose absolute values are below a certain threshold. This type of thresholding is called ‘hard’
- HT leaves discontinuities in a signal, which could lead to unwanted and spurious oscillations
- ‘Soft’ thresholding still removes absolute values below a threshold, and gradually sets to zero the discontinuities, i.e. smoothing, so is a better procedure to apply.

RESULTS

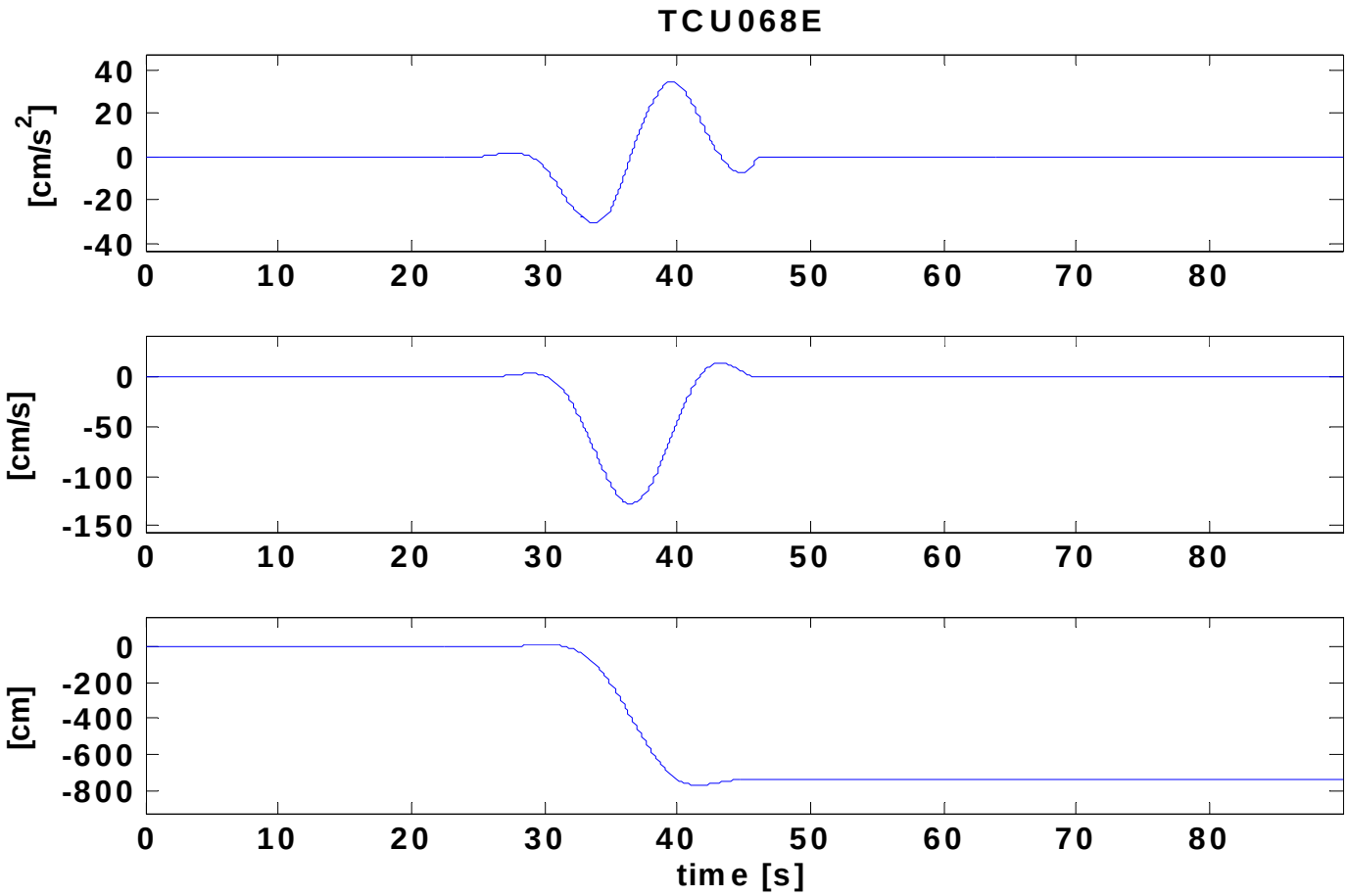
Chi-Chi Event 1999

ICEARRAY 29th May 2008

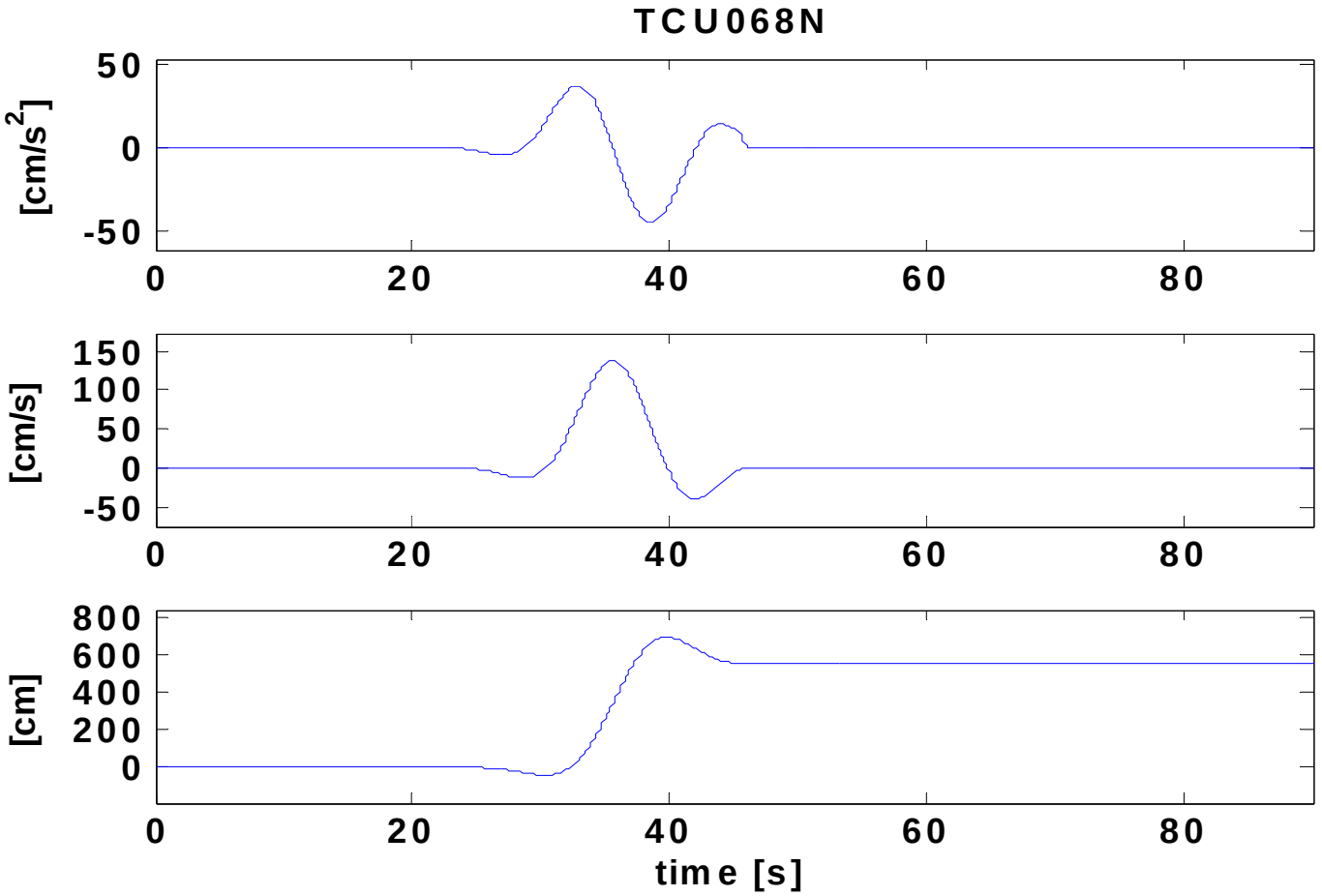
TCU068V low frequency sub-band



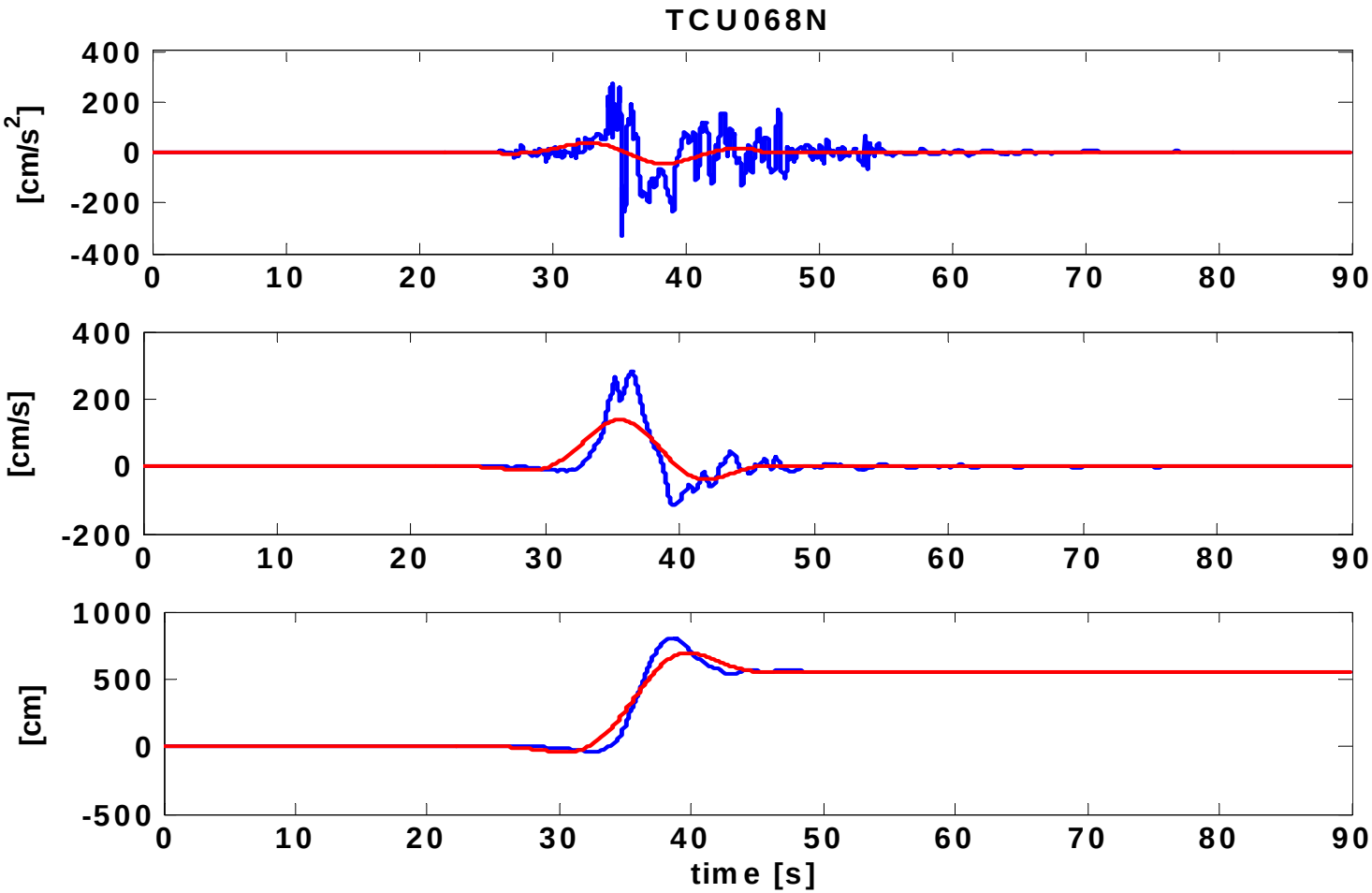
TCU068E low frequency sub-band



TCU068N low-frequency sub-band



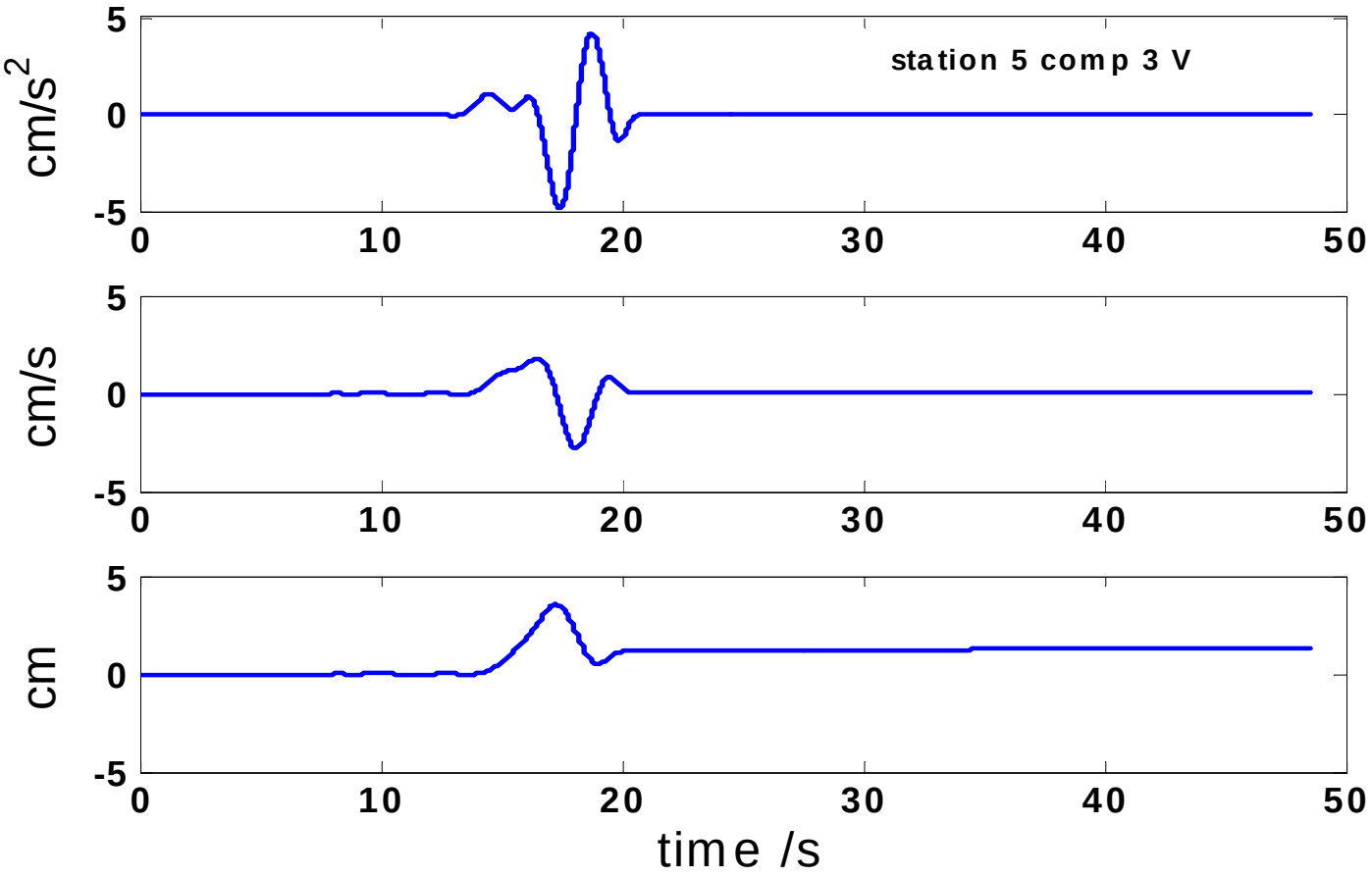
TCU068N re-integrated after correction



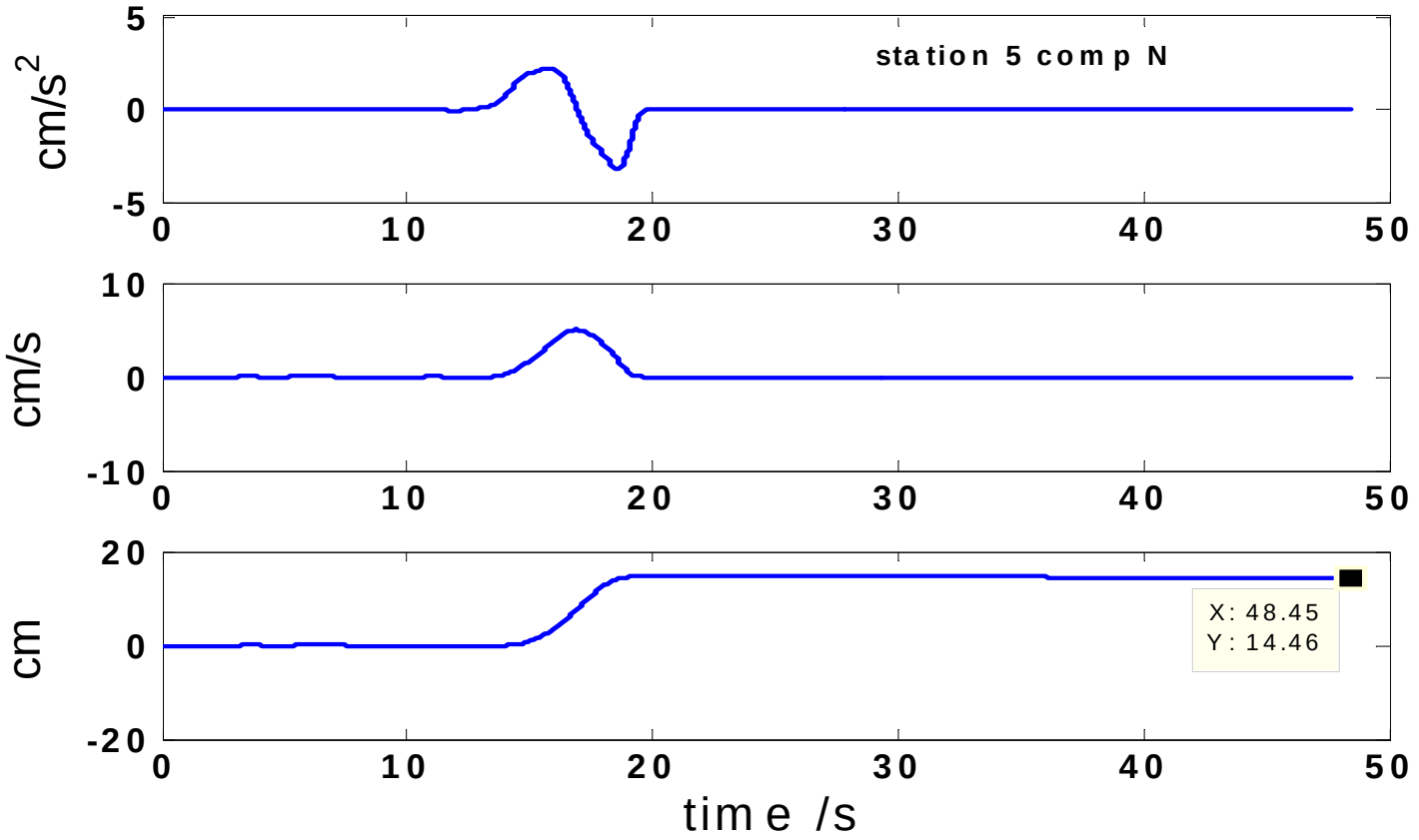
ICEARRAY

- ICEARRAY: small aperture array in Hveragerdi
- 11 x CUSP stations
- 33 x components
- wavelet transform processing completed for all 33 components
- low frequency sub-bands isolated and integration completes to yield velocity and displacement

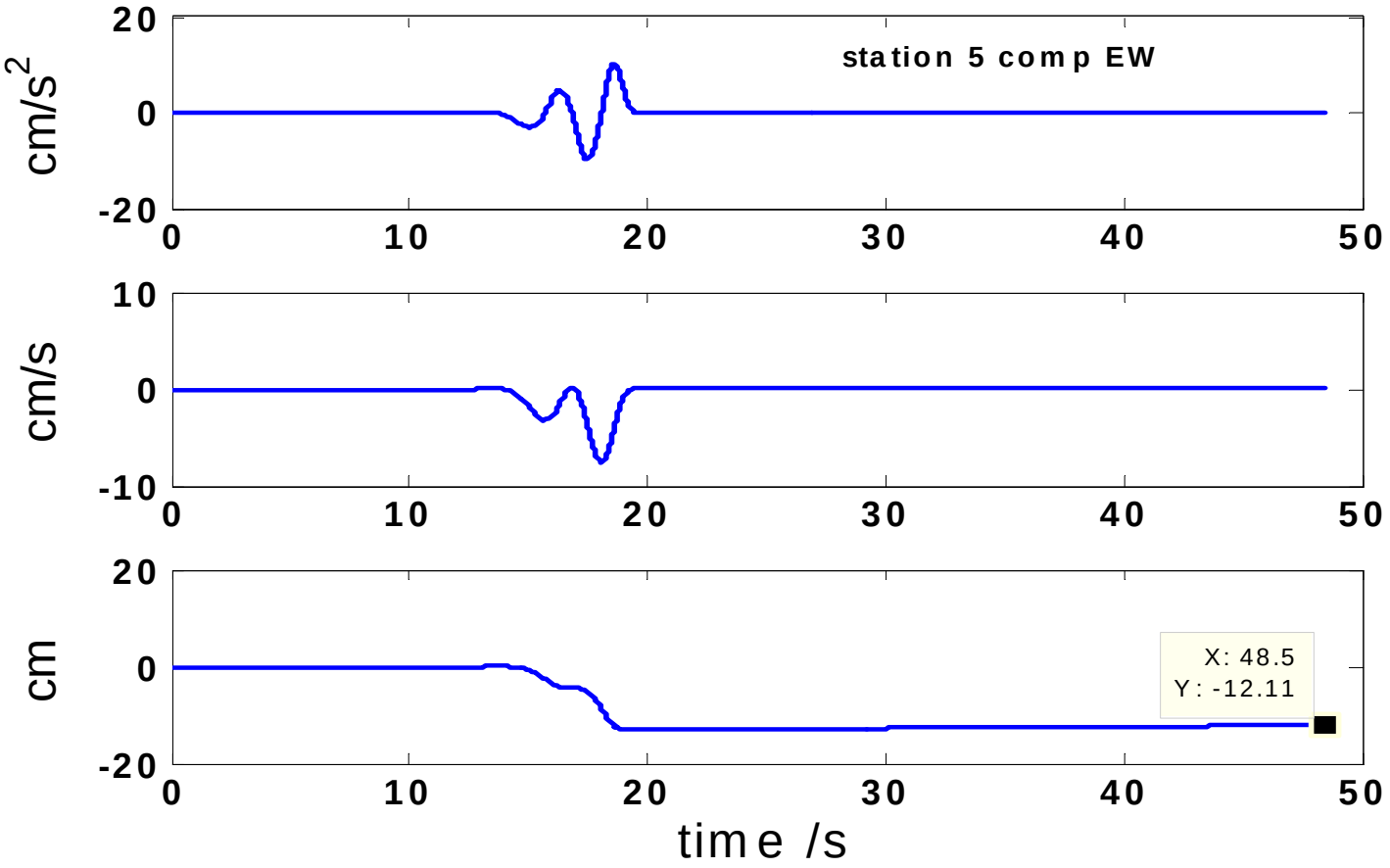
ICEARRAY stn5 comp V



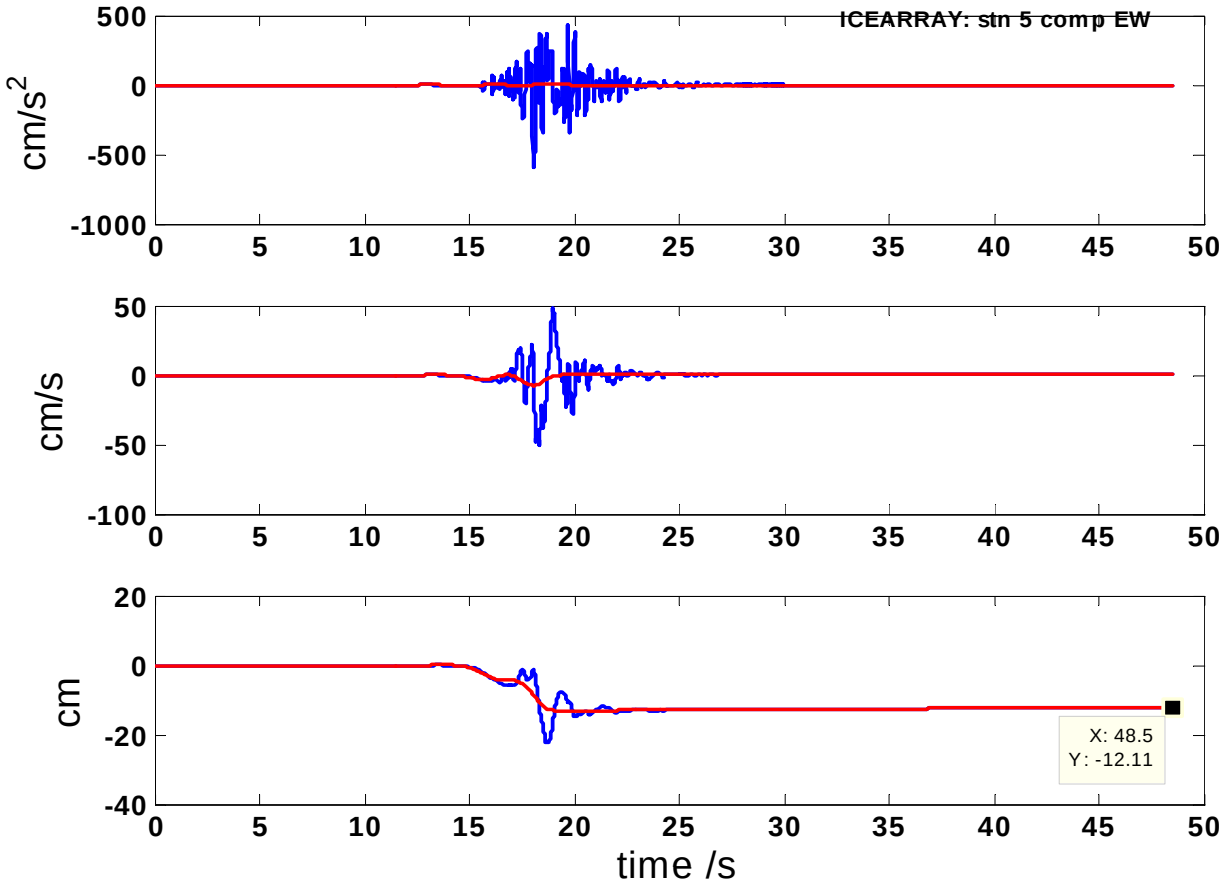
ICEARRAY: stn 5 comp N



ICEARRAY:stn 5 comp EW
Resultant: 18.86cm NW



ICEARRAY: stn 5 comp EW



Summary

- Wavelet transform methodology gives good performance
- identifies low-frequency sub-band fling, standard filtering cannot do this
- enables easier integration
- operates automatically and corrects for baseline
- same methodology applies (so far) to different earthquakes

[1] Trifunac MD, “Zero Baseline Correction of Strong Motion Accelerograms”, *BSSA*, 61, pp 1201-1211

[2] Wu Y-M., Wu C-F., “Approximate Recovery of Co-Seismic Deformation from Taiwan Strong-Motion Records”, *J. Seismology*, 11:159-170, 2007

[3] Iwan MD, Moser MA, Peng CY, “Some Observations on Strong-Motion Earthquake Measurements using a Digital Accelerograph”, *BSSA* 75:1222-1246, 1985

[4] Boore DM, “Effect of Baseline Correction on Displacement and Response Spectra for Several Recordings of the 1999 Chi-Chi, Taiwan, Earthquake,” *BSSA*, 91,5, pp1199-1211, 2001

[5] Chanerley AA, Alexander NA, “Correcting Data from an Unknown Accelerometer using Recursive Least squares and Wavelet De-noising”, *J. Computers and Structures*, 85, 1679-1692, 2007

[6] Chen, S-M, Loh C-H, “Estimates of Permanent Ground Displacements from Near-fault, Strong-Motion Acelerograms”, *1st European Conference of Earthquake Engineering & Seismology”*, paper 1631, Geneva, 3-8 Sept, 2006

[7] Bolt, B. A. (1971), “The San Fernando Valley, California earthquake of February 9, 1971: Data on seismic hazards,” *Bull. Seism. Soc. Am.* **61**, 501-510.