

T3.7-P9



# Enhancement of Cepstral Methods for the Improved Processing of Seismic Data

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# ABSTRACT

**One of the challenges of automatic depth estimation is event of interest screening. We present research in progress to improve shallow depth estimates and event recognition by addition of new Complex Cepstrum algorithm capabilities, including:**

- 1) The use of the Mel Cepstrum (taken from the speech literature) for discrimination by quickly identifying ripple fire events, thus reducing the analyst work load;**
- 2) The effectiveness of the lifter to the Complex Cepstrum in recognizing and removing a second explosion from the seismogram, when a double-event is recorded;**
- 3) The use of seismic array data versus single station data for depth estimation.**

**This research is part of a series of coordinated efforts, discussed in multiple presentations at this conference (Kemerait et al., Tibuleac et al., Saikia et al.), to prepare this method for automation of depth estimation.**

# OBJECTIVE

**We investigate optimal processing of multiple types of events with the goal to implement an automatic set of algorithms for depth estimation, based on Cepstral analysis, and to significantly reduce the US NDC analyst work load.**

# DATA

- **Hand-digitized atmospheric explosion waveforms from the 1962 Operation Dominic series of atmospheric nuclear tests; Additional atmospheric nuclear explosions, bolides and surface chemical explosions;**
- **An example waveform consisting of superposed, delayed and scaled waveforms from a real event;**
- **A very shallow earthquake sequence, occurred in Mogul, west of Reno, Nevada USA, with a main shock of Mw 5 at 2.7 km depth, is investigated at TXAR short period elements and at the array element TX31 (40 sps), at a distance of 1867.7 km.**

# METHOD

**We believe that the deconvolution process utilizing the Complex Cepstrum iteratively is one of the optimum methods for identifying the associated depth seismic phases.**

**The Cepstral Algorithms use concepts also addressed in several presentations at this conference (Kemerait and Tibuleac, Kemerait et al., Saikia et al.) and explained in detail by Childers et al. (1977):**

- ***Complex Cepstrum* (the Inverse Fourier Transform of the logarithm (with unwrapped phase) of the Fourier Transform of the signal);**
- ***Liftering of the Complex Cepstrum* (“filtering” the echo peaks out of the Complex Cepstrum);**
- ***Power Cepstrum* (the Inverse Fourier Transform of the complex logarithm of the Fourier Transform of the signal);**

# MEL CEPSTRA

**Mel-cepstra coefficients were extracted from a number of infrasonic hand-digitized atmospheric explosion waveforms from the 1962 Operation Dominic series of nuclear tests. These explosions were shown to have a distinctive pattern of Mel-cepstral coefficients which can be modeled with synthetically generated waveforms. Here we show a preliminary investigation on how the Mel-cepstrum identifies underground nuclear and chemical explosions which are also detected by one, or more infrasound arrays.**

# MELCEPSTRAL FEATURE EXTRACTION METHOD

- ❑ Remove mean and apply Hamming window to the signal;
- ❑ Compute the power spectral density (PSD) of the signal;
- ❑ Mel-frequency scaling applied to the PSD according to  $S_m(k) = a \log_e [b S(k)]$ ;
- ❑ Given  $S_m(k)$  from the previous step, the discrete inverse cosine transform is taken to yield:

$X_m(n) = \left(\frac{1}{N}\right) \sum_{k=0}^{N-1} \left(S_m \cos \frac{2\pi kn}{N}\right)$ , for  $n=0,1,2,\dots,N-1$  where  $N$  is the total number of time domain samples;

- ❑ Take the derivative (using the difference operator) of the sequence  $X_m(n)$ , ie  $X_m'(n)$ ;
- ❑ Concatenate the derivative sequence,  $X_m'(n)$ , with the cepstral sequence,  $X_m(n)$  to form the augmented sequence  $X_m^a = [X_m'(n) | X_m(n)]$ ;
- ❑ Scale the entire data set with respect to the largest amplitude;
- ❑ Take the log of the previous step.

# A theoretical example of Melcepstra application

**The Berlage Function**

**Melcepstra from the single  
Berlage Function**

**Melcepstra from the two-pulse, 5  
sample delay Berlage Function**

# Test sites and the Infrasound Station Network

# The Tanana Nuclear Explosion recorded at SF (Micronesia)

**Raw waveforms**

**Melcepstrum**

**Power spectra**

# **The Mel Cepstrum shows differences between infrasonically detected atmospheric nuclear explosions, bolides and surface explosions**

**The Swordfish Nuclear  
Explosion recorded at station  
MF (Alaska)**

**Bolide November 21, 2009  
recorded at I35**

**Bolide March 9, 2002 recorded  
at I57**

**Bolide February 15. 2013,  
recorded at I31KZ**

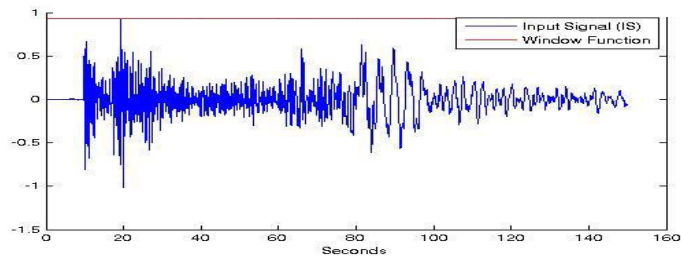
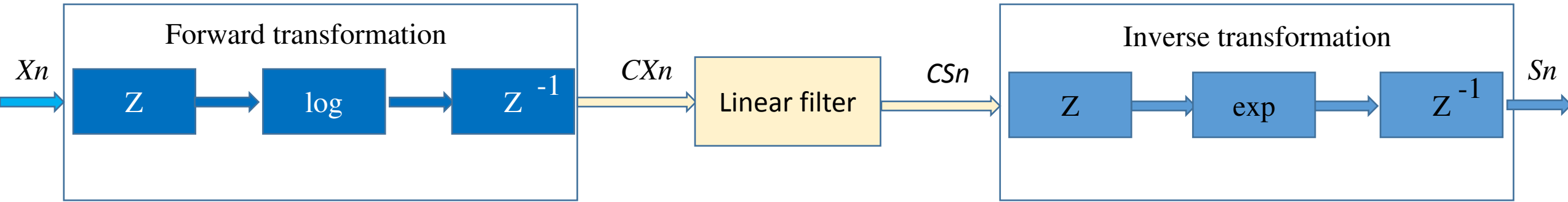
# Possible causes for Mel-cepstra differences:

- Time delays of the secondary phases cause scalloping in the spectra, thus changing the Mel-cepstra;
- Nuclear explosion source models are represented by a single isotropic source at a single point in space and time;
- Bolides are a moving infrasound and seismic source in time, and may be represented as more than one explosion;
- Surface explosions are reflected off surrounding source topography.

*Thus our hypothesis, yet to be confirmed, is that the observed differences in Mel-cepstra are due to more complicated source model for surface events and bolides, when compared to atmospheric nuclear explosions.*

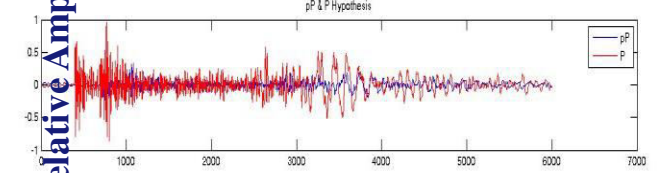
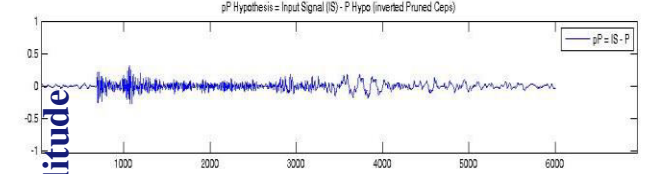
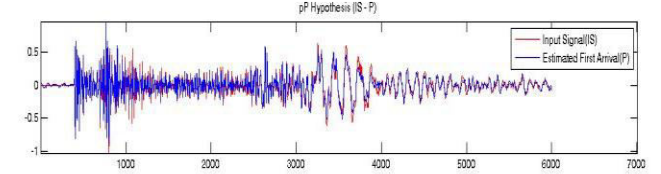
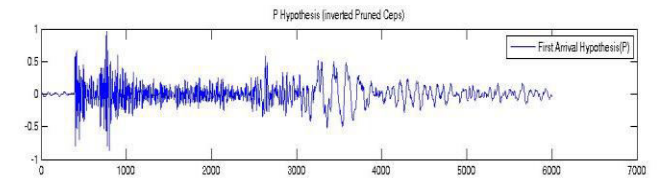
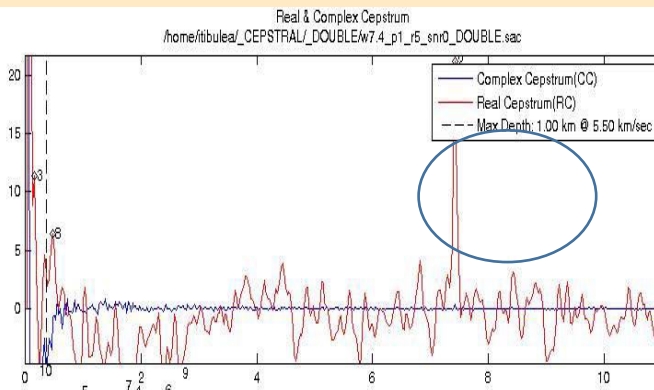
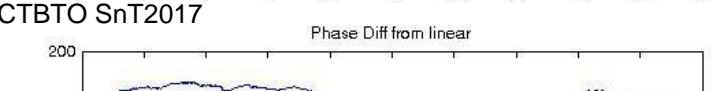
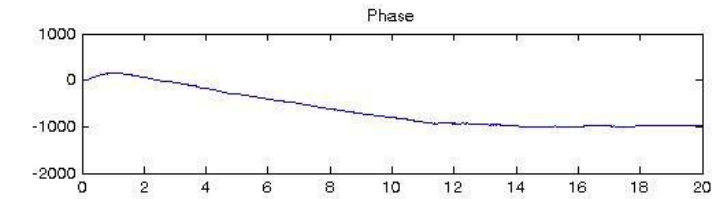
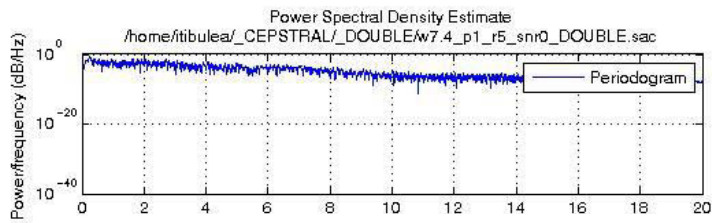
# true delay 7.4 s, second signal amplitude ratio 0.5

## Synthetic example (same scaled event added with a time delay)



Waveforms (40sps) filtered at 0.75-3 Hz were tapered in a window 150s long and filtered from 0.75 to 5 Hz.

Below is the Power Cepstrum as a function of time (sec), with a clear peak at 7.4 s, however the peak is not observed in the Complex Cepstrum.

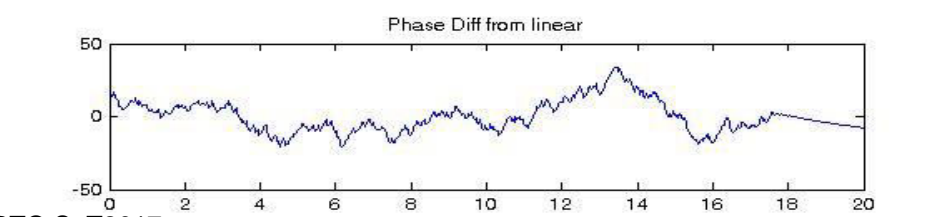
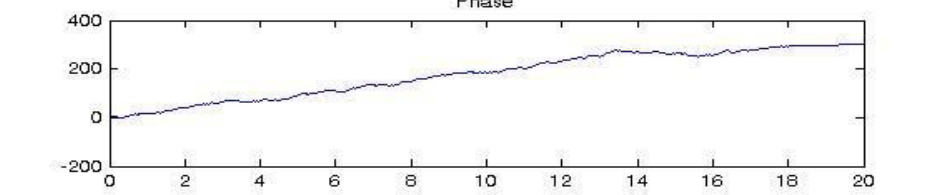
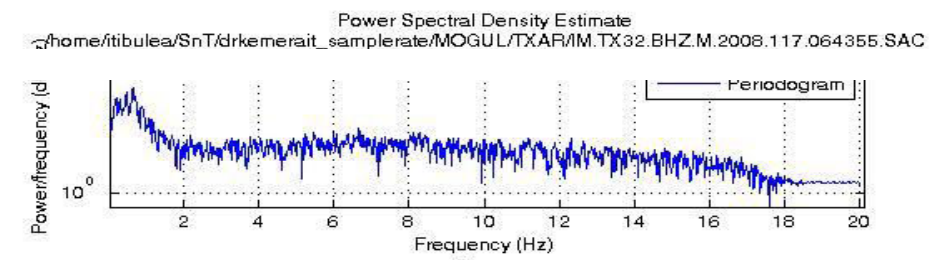
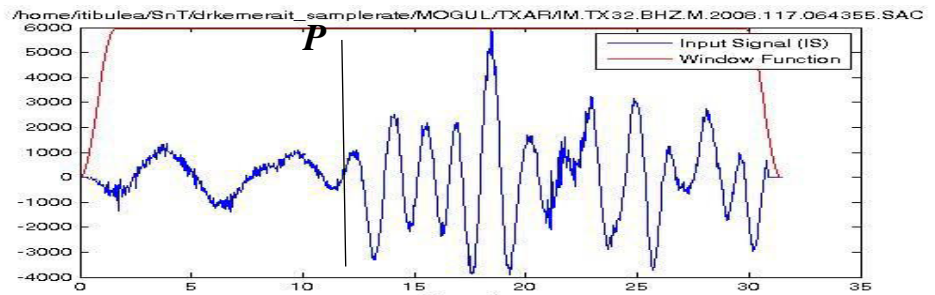


Relative Amplitude

Time (samples at 40 cps)

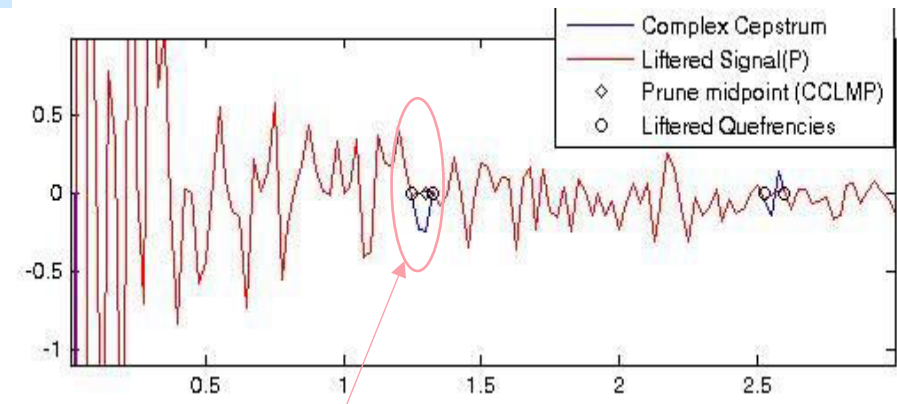
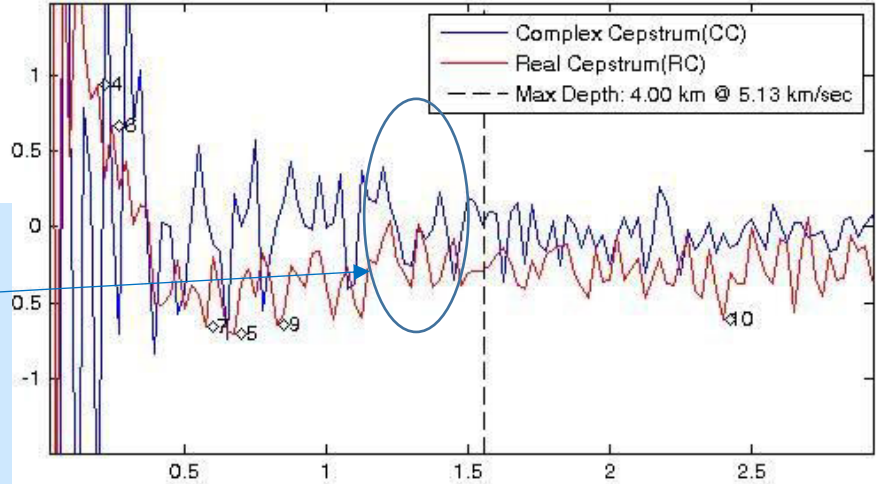
# Cepstral Analysis of array data versus single station data for depth estimation:

## Single station TX32 Cepstral Analysis of a very shallow earthquake in Mogul, west of Reno, (depth 2.7 km, GT 1), distance 1867km from TX32



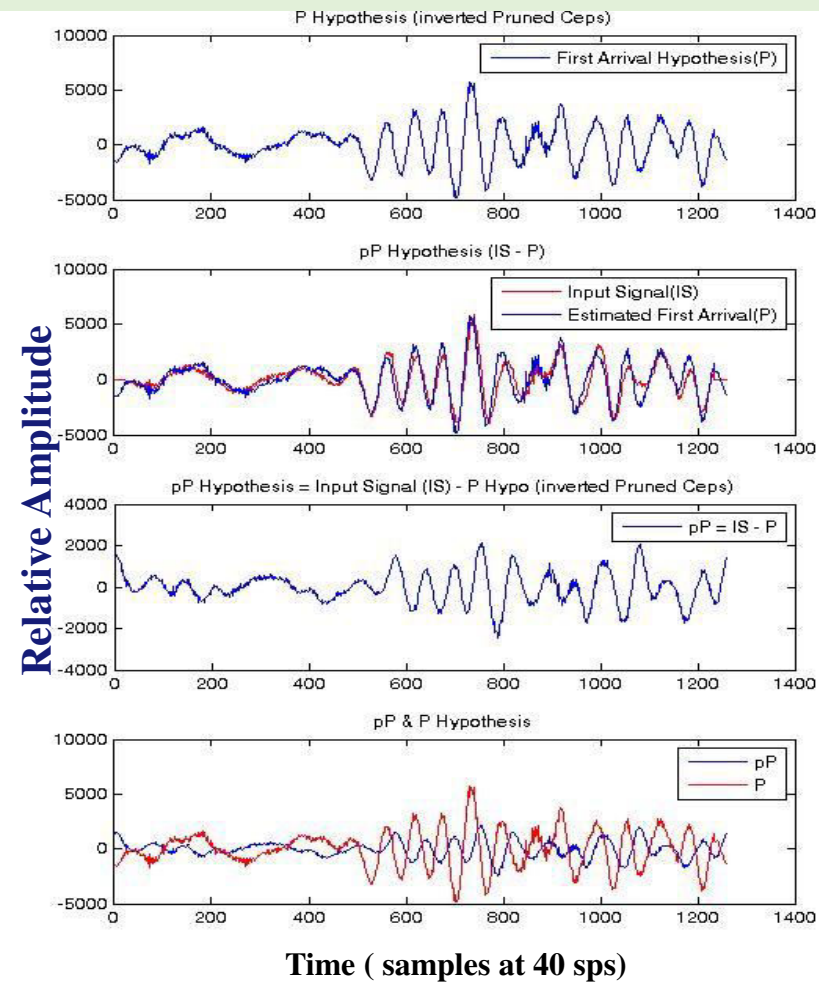
CTBTO SnT2017

Note correspondence of the Power and Complex Cepstrums, however, not associated with the highest cepstral peak



The first and second liftered peak signs are consistent to the pP assumption.

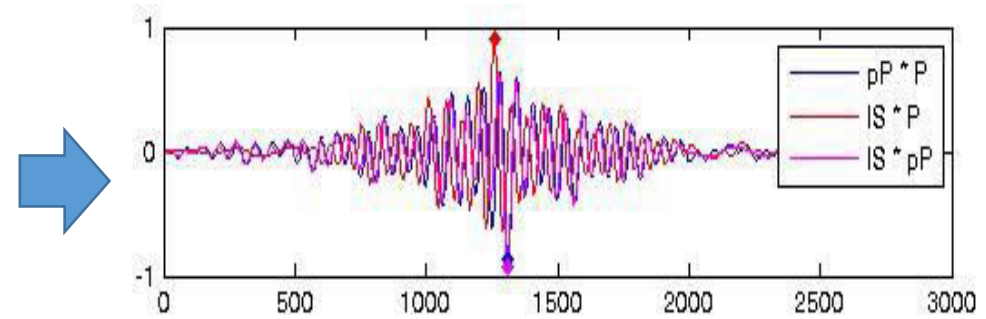
# Deconvolution of the P and pP waveforms



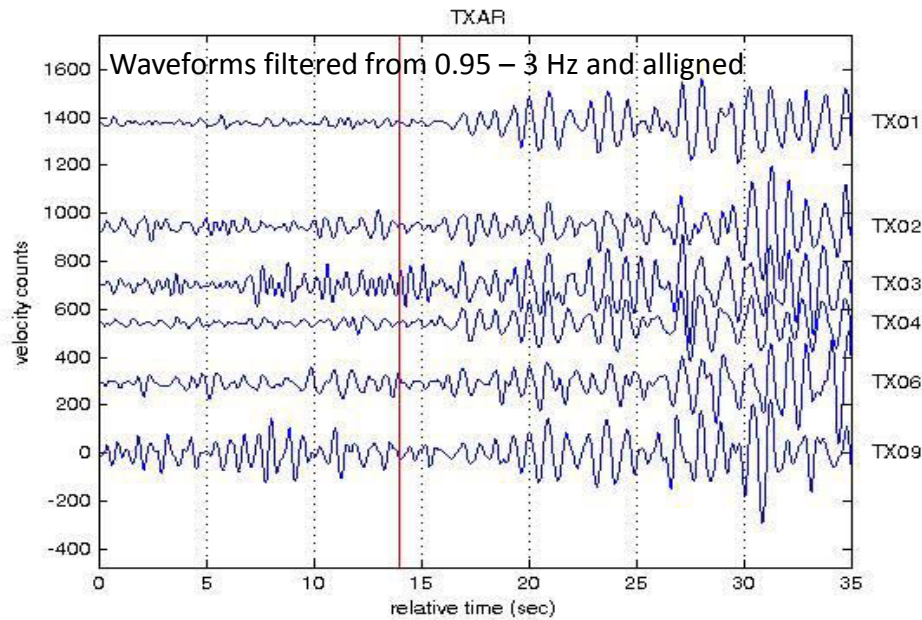
**Estimated Depth (km) :**  
**3.2-3.3**  
**GT1 depth main shock:**  
**2.7 km**  
**Sample Range:50-53**  
**Time Range:1.25-1.31**  
**Velocity at epicenter :**  
**5.13 km/sec**  
**Correlation IS\*P : 0.91**  
**Correlation pP\*P : -0.86**  
**Correlation pP\*IS: -0.91**  
**Power Ratio**  
**pP\_hypo/**  
**power(xcor\_P\_hypo)= 0.45**

**Note that the P-pP delay estimated at TX32 is larger than the “true” value 1.1s. We are investigating the possibility of refining the measurement using the whole array.**

**Note crosscorrelation “ringing” due to the narrow band signal recorded at regional distance**

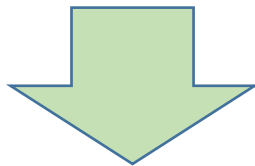


# TXAR Array Cepstral Analysis of a very shallow earthquake in Mogul, west of Reno

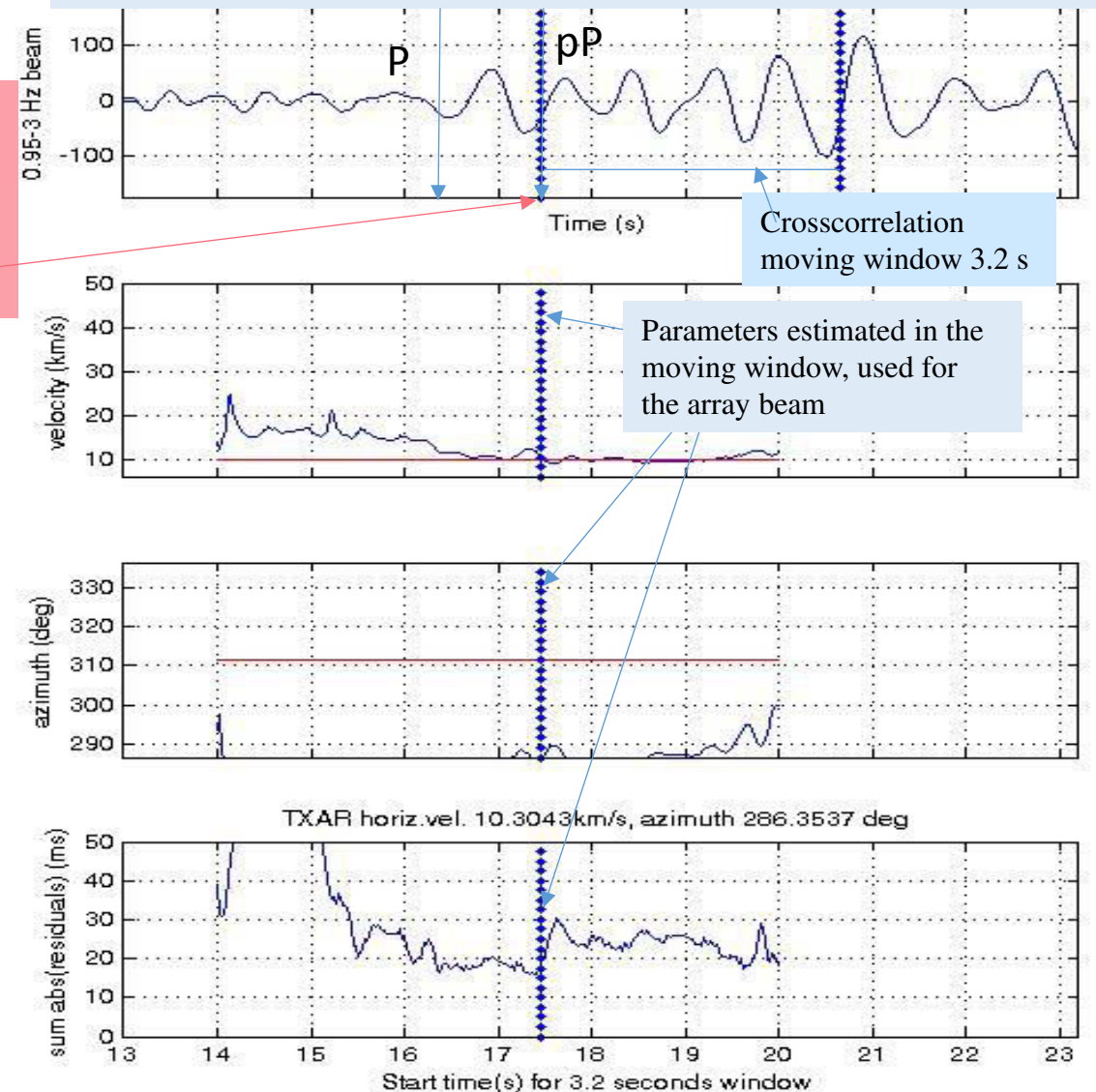


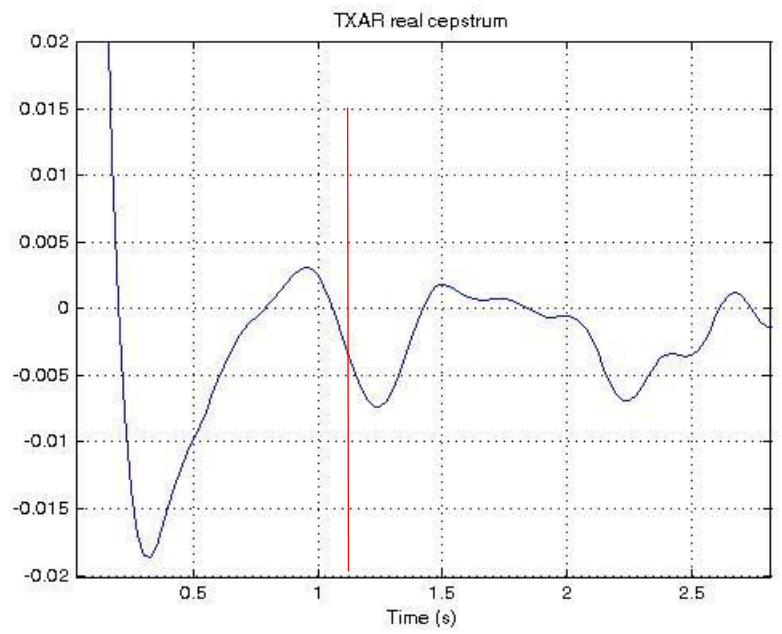
Note that the array beam was estimated for pP and not for P parameters.

Using crosscorrelation in time domain (Tibuleac and Herrin, 1997) the waveforms were stacked on the pP phase. Results from application of the complex cepstral analysis to the array beam and separately at each station are discussed below.

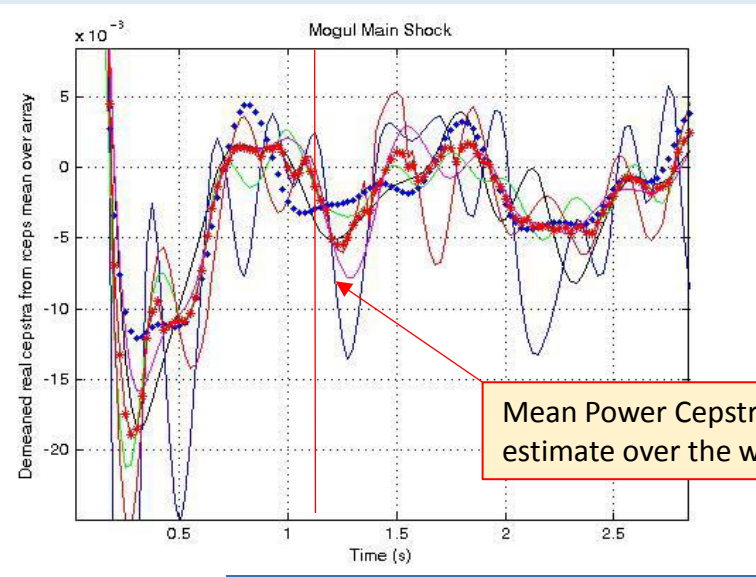
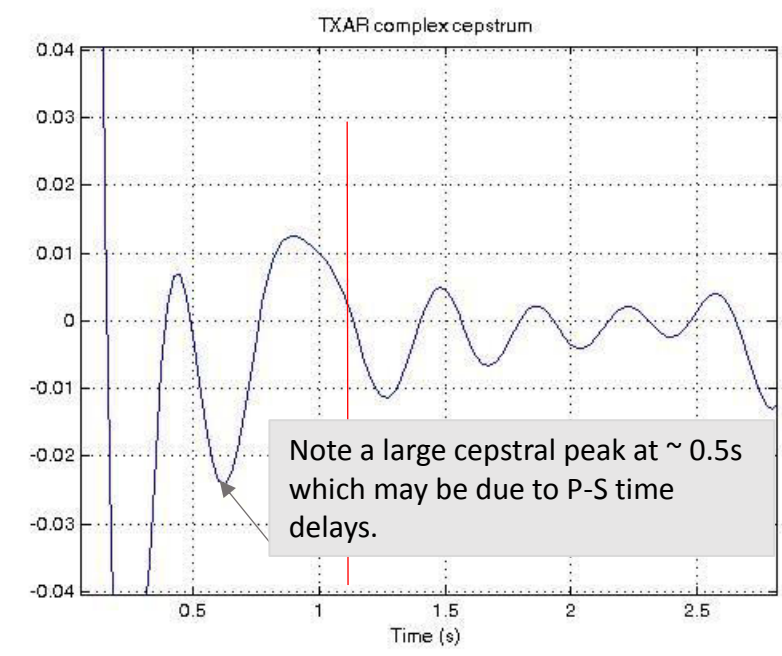


TXAR array beam estimated using the parameters at the time lags shown below.

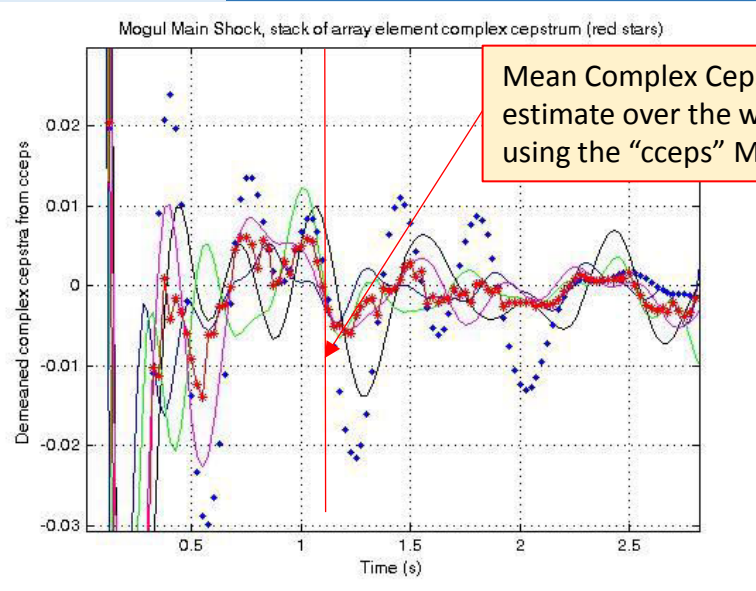




The “true” P-pP delay time was 1.1s for 2.7km GT1 depth at 5.13 km/s (vertical red bar in all plots)

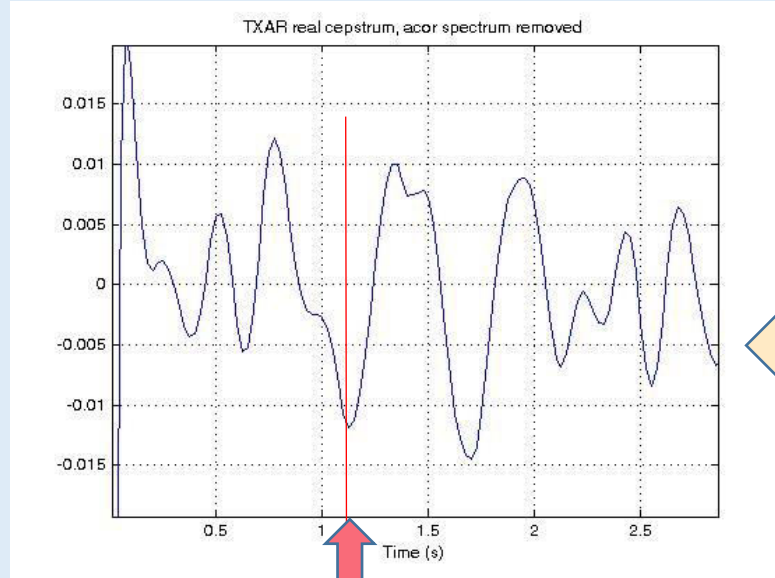


Note good correspondence of the Real and Complex cepstrums, which is an indicator of the first filtered peak.

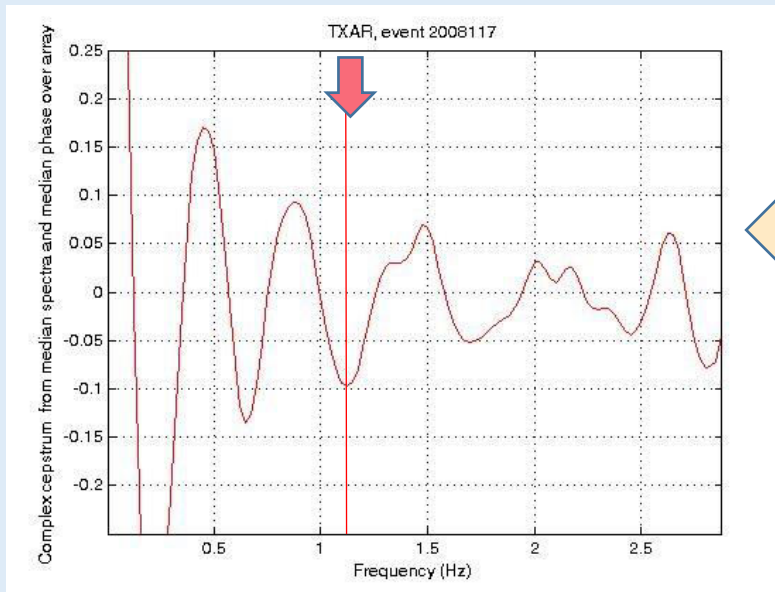


Cepstra estimated at each available element are shown with different colors

## Combined Cepstral analysis applied at the TXAR single elements



The “true” P-pP delay time was 1.1s for 2.7km GT1 depth at 5.13 km/s (vertical red bar in all plots)



The Power Cepstrum of the TXAR beam, after **the autocorrelation was removed** has only information on the P-pP delays.

The autocorrelation spectrum is approximately the spectrum of the wavelet, which is similar to the echo spectrum. Removing the wavelet/echo spectrum should enhance the cepstrum first peak at the time lag indicating the wavelet-echo delay.

The Complex Cepstrum of each TXAR element was estimated using the **median unwrapped phase** for all available elements of the array.

# SUMMARY

- **Mel-cepstra:** The Mel-cepstra discriminant has been shown to be a powerful discriminant for separating bolides and above ground explosions. The Mel-cepstra analysis is potentially very efficient in identifying multiple events, such as ripple fire explosions.
- **Multiple events:** Very promising results are obtained when the Complex Cepstrum method is applied to double events, in the synthetic case. In the case of real events, with slightly different waveforms, metric modification will be necessary.
- **Cepstral analysis applied to array data:** We have recently resurrected the power cepstral analysis of events utilizing array data, as compared with the results from using just the individual elements. The results are very promising. Caution must, however, be exercised in the case of very shallow earthquakes, where periodicity from P – S phase delays may be strongly observed in the cepstra. Echo delays estimated with array cepstra stacks are comparable to echo delays obtained from the array pP beam cepstra.

# Further investigations

- **Mel-cepstra:** Further research is on-going to ascertain the Mel-cepstra capability for discriminating shallow earthquakes from underground nuclear explosions.
- **Multiple events:** We are currently refining the cepstral parameters that will automatically identify ripple fire events in near-real time. We then intend to use these metrics on multiple explosions (non ripple fire events), and events with rarefaction phases, etc.
- **Cepstral analysis applied to array data:** Our goal is to better understand the effect of shallow event phases on the complex cepstrum and to fully use the advantages of new and existing seismic array processing techniques for cepstral echo enhancement at multiple event-station distances. Another goal is to develop a better phase unwrapping algorithm, thereby, improving the array Complex Cepstrum estimates.