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The benefit of Using Higher Sampled Regional Seismic Data for Depth Estimation

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ABSTRACT

During the GSETT-3 experiment, and in the early days of the CTBT, discussions were held regarding the appropriate specifications for the International Monitoring System (IMS) primary and auxiliary seismic stations. Communications cost and digital storage availability were two reasons for specifying the relatively low rate of 40 samples per second (sps) for the collection and the storage of the seismic data. In fact, several of the legacy array stations were allowed to remain at 20 sps. Since that time, the sample rates have increased at a number of open stations to 100 sps, and even 200 sps.

Cepstral analysis applied to higher and lower sample rate data indicate that better event depth information is obtained from higher sampled data.

Here we present results from processing modeled data, shock wave data from an Israeli explosion designed to test the CTBTO-IMS system (1000 sps vs 100 sps) and a Nevada Test Site nuclear explosion, JUNCTION, recorded at PFO (250 sps vs 20 sps). In each case, we compute the event spectrum, the power cepstrum and the complex cepstrum for the two sample rates, and compare the differences in the results obtained from the processing of the two related complex cepstrums.

DATA

- **Shock wave data from an explosion designed to test the CTBTO-IMS system (1000 sps vs 100 sps). The tests were conducted at the surface, in February 2011 and recorded at an array of six infrasound sensors located at 29.9N, 34E. Here we present an analysis of records at station NS2A.**

- **A Nevada Test Site underground (622m depth) nuclear explosion, JUNCTION, occurred on March 26 1992, 16:30:00 UT, in the NTS area U19bg, at 37.27N and 116.36W, of 100kt yield. This explosion was recorded at the station AZ.PFO, at 402.2 km distance (250sps and 20 sps).**

OBJECTIVE

To improve shallow depth estimates of events of interest using Cepstral methods, should we be using data samples at rates higher than 40 sps? If the answer is “yes”, the next questions are

1) **What sample rate is appropriate?**
2) **Under what circumstances?**
3) **What should we require from further investigations?**

MOTIVATION

Utilizing Complex Cepstrum necessitates the use of phase information, which requires phase unwrapping and linear phase component removal. As observed in the literature, these are not trivial problems, except perhaps for the minimum-phase case, which is an ideal case and not typical for actual seismic signals. However, we have observed on some explosion data, that the phase unwrap problem is reduced, or eliminated, when we process events at very high sample rates.

METHOD

Cepstral analysis of seismic events attempts to provide answers the following questions:

- **What is the depth of the event?**
- **Is the event a single, or multiple explosion (ripple fire)?**
- **What is the best estimate of the event yield?**
- **Is the event located underground or at the surface, natural or man-made?**
- **How reliable are the above estimates?**

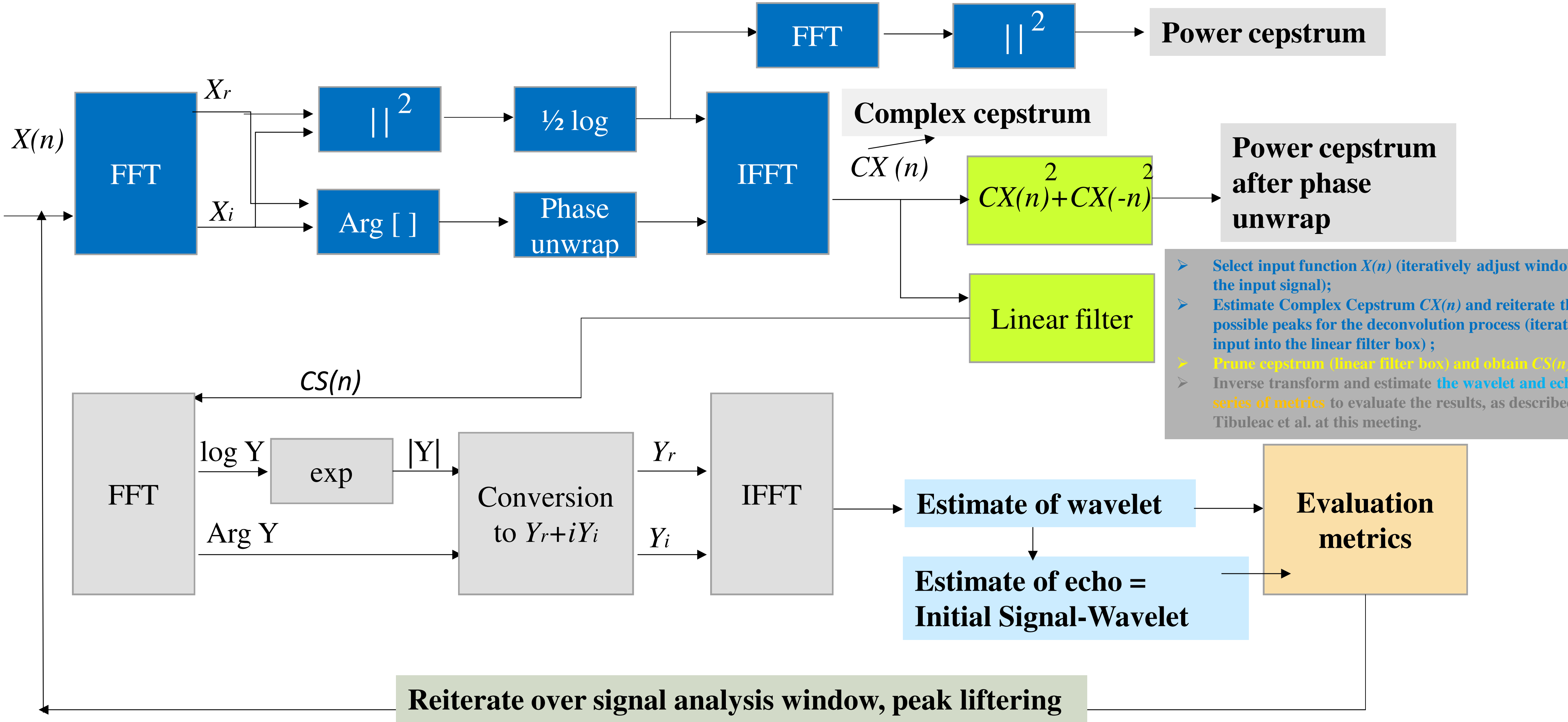
METHOD

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 used here use a set of concepts also addressed in several poster presentations at this conference (Kemerait and Tibuleac, Tibuleac et al., Saikia et al.) and explained in detail by Childers et al. (1977):

- ***Homomorphic deconvolution*** **(the use of the Complex Cepstrum and its phase information for echo detection and wavelet recovery);**
- ***Blind deconvolution*** **(deconvolution without explicit knowledge of the impulse response function used in the convolution);**
- ***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);**
- ***Minimum – phase signal*****: A signal whose Z-transform has no poles or zeros outside the unit-circle, or no Complex Cepstrum at negative frequencies;**
- ***Maximum –phase signal*****: A signal whose Z-transform has no poles or zeros inside the unit-circle, or no Complex Cepstrum at positive frequencies;**
- ***Mixed-phase sequence*****: A real signal with minimum and maximum phase sequences, with positive and negative values of Complex Cepstrum.**

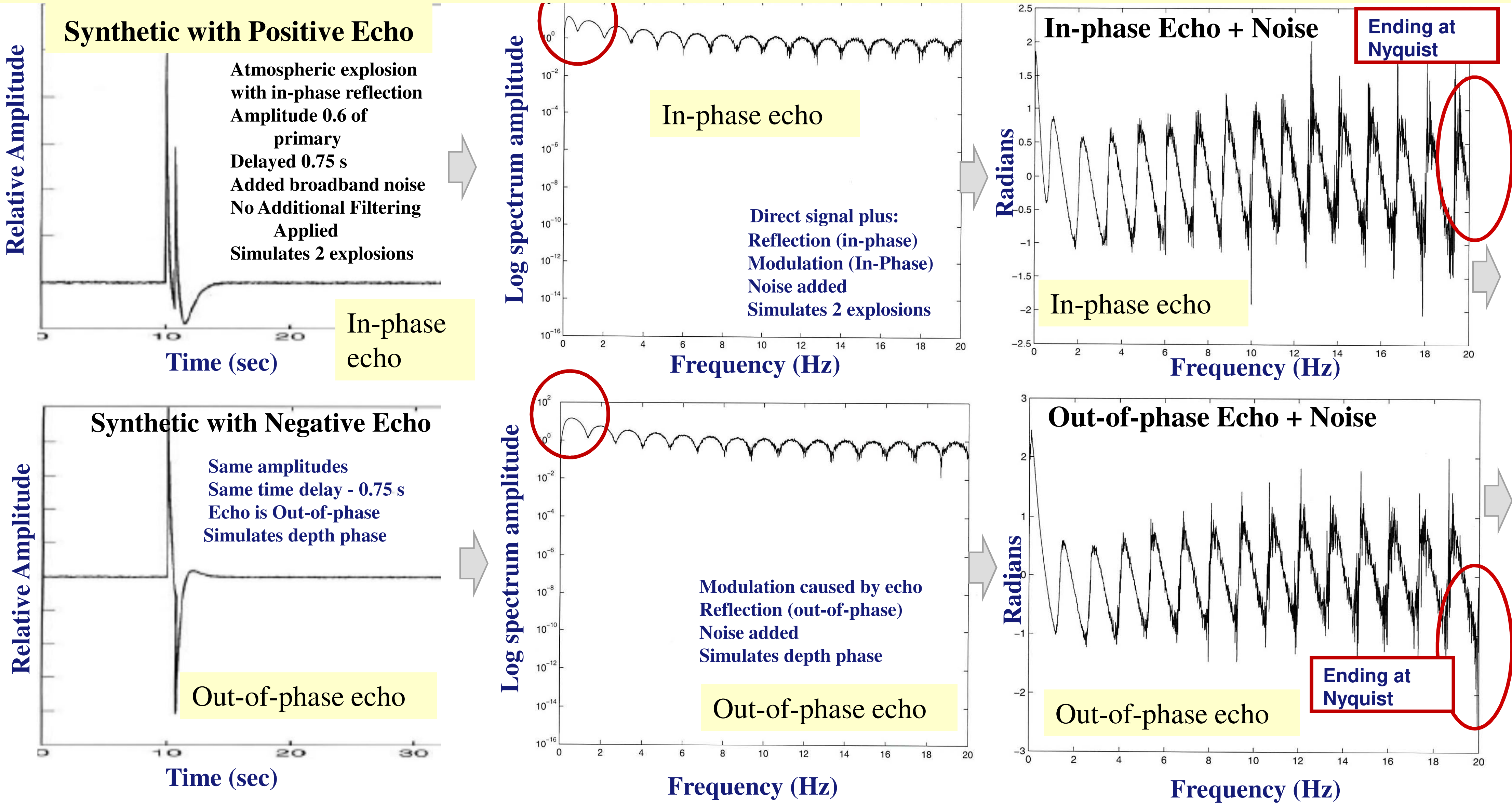
Cepstral Analysis Steps, Block diagram



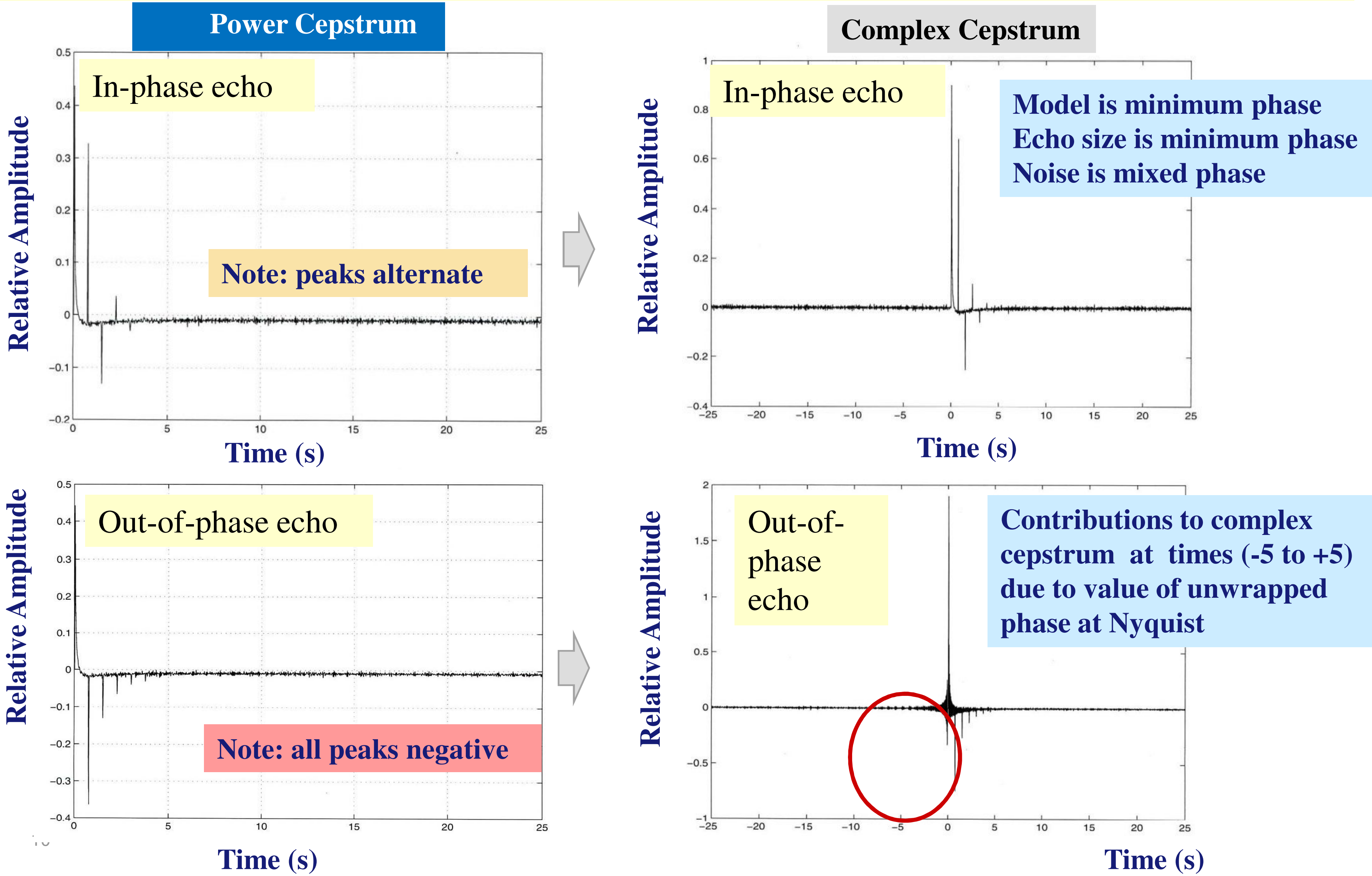
- Select input function *X(n)* (iteratively adjust windo
  the input signal);
- Estimate Complex Cepstrum *CX(n)* and reiterate th
  possible peaks for the deconvolution process (iterat
  input into the linear filter box) ;
- Prune cepstrum (linear filter box) and obtain *CS(n*
- Inverse transform and estimate the wavelet and ech
  series of metrics to evaluate the results, as describe
  Tibuleac et al. at this meeting.

SYNTHETIC EXAMPLE

Unwrapped, trend removed Phase Spectrum



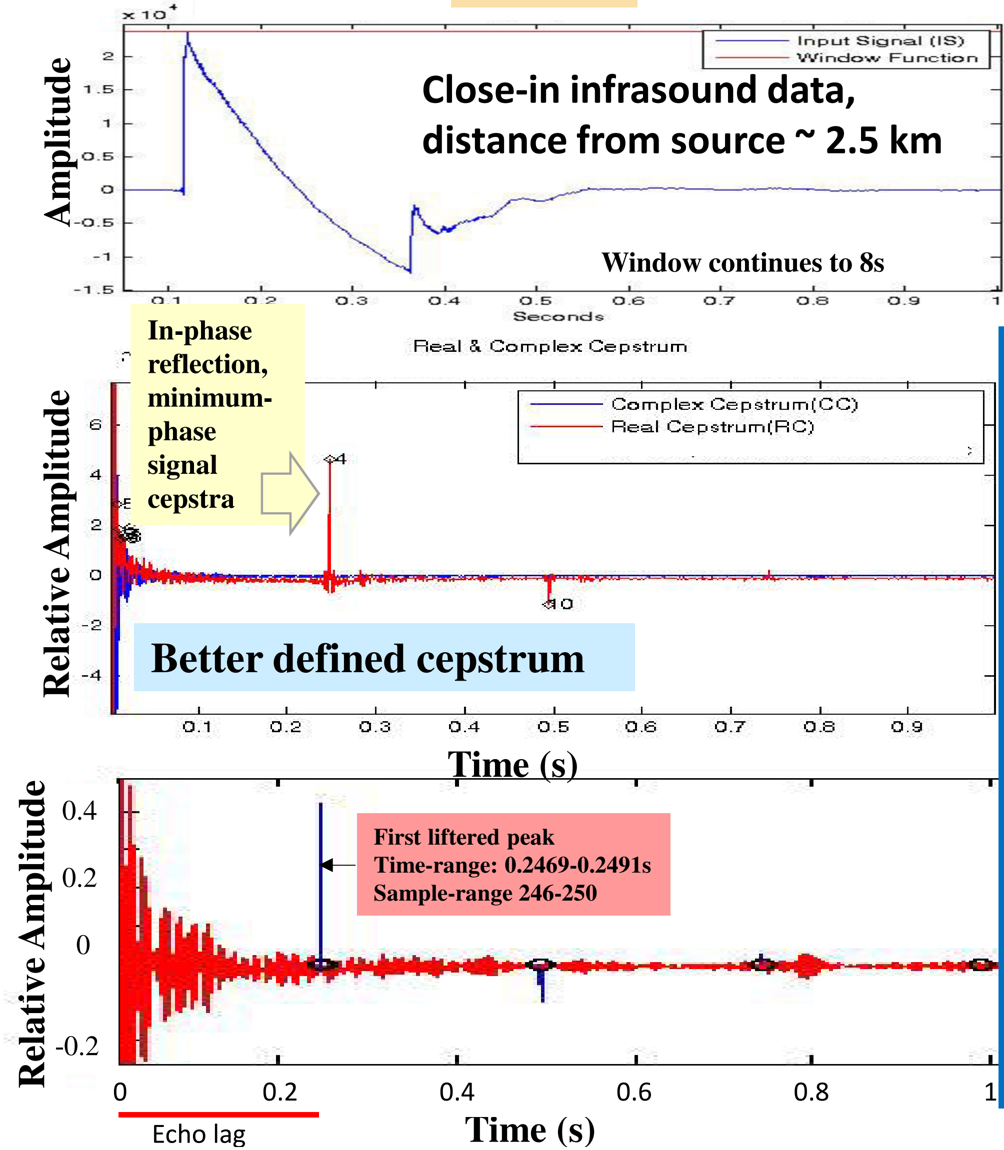
Comparison of Resulting Cepstrums



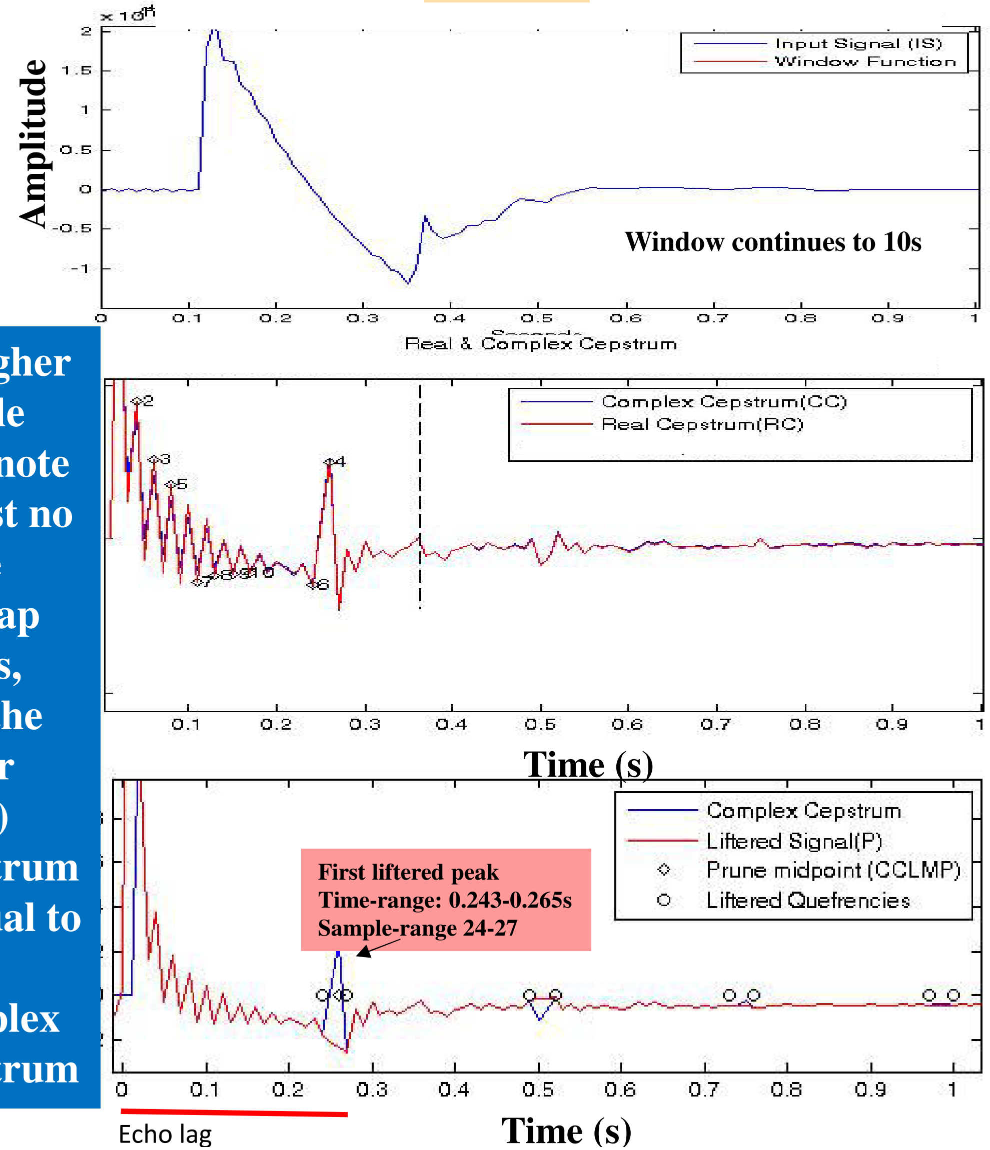
Close-in infrasound data 10-ton surface explosion test of the CTBTO-IMS, 2011

1000 sps

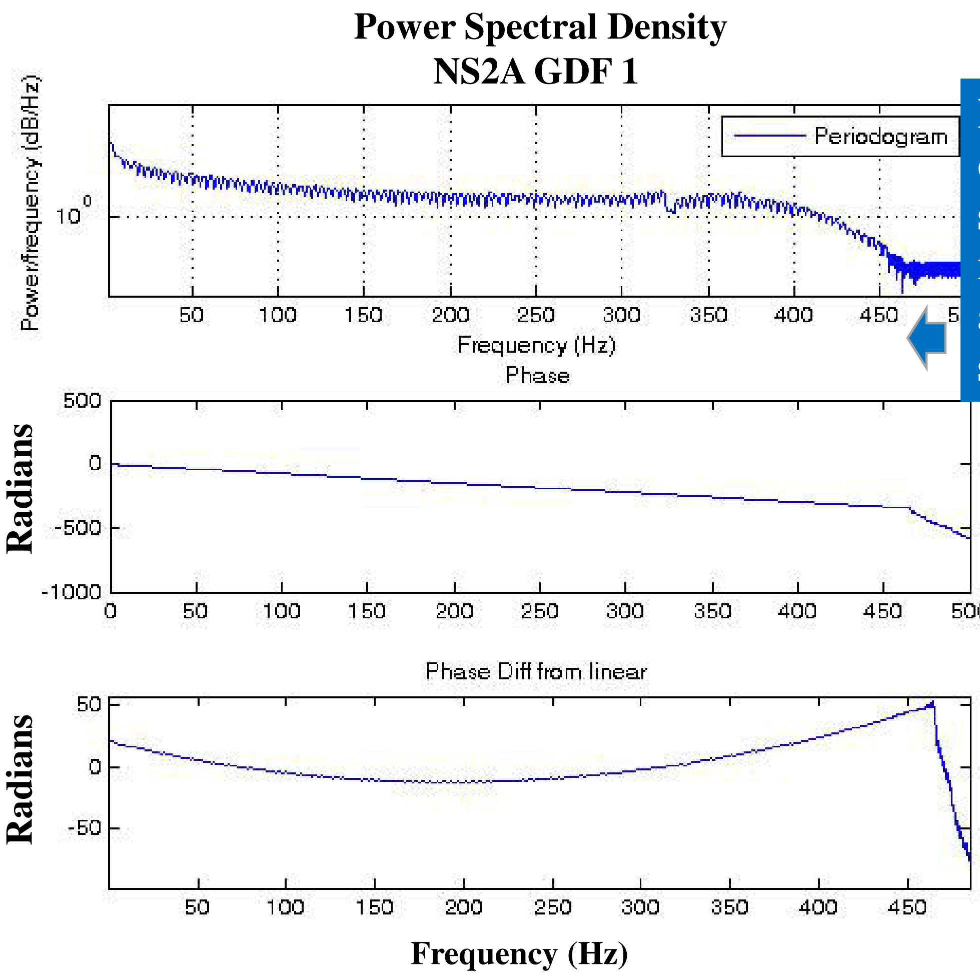
100 sps



At higher sample rate, note almost no phase unwrap errors, thus the Power (Real) Cepstrum is equal to the Complex Cepstrum

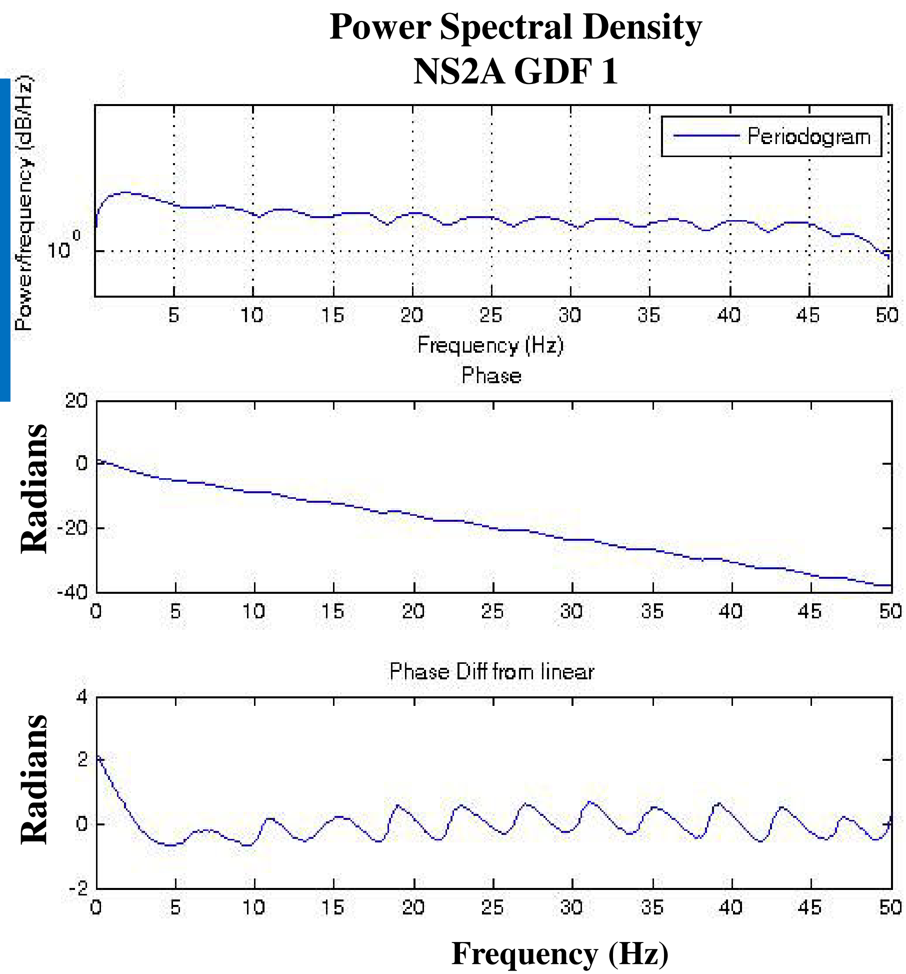


1000 sps



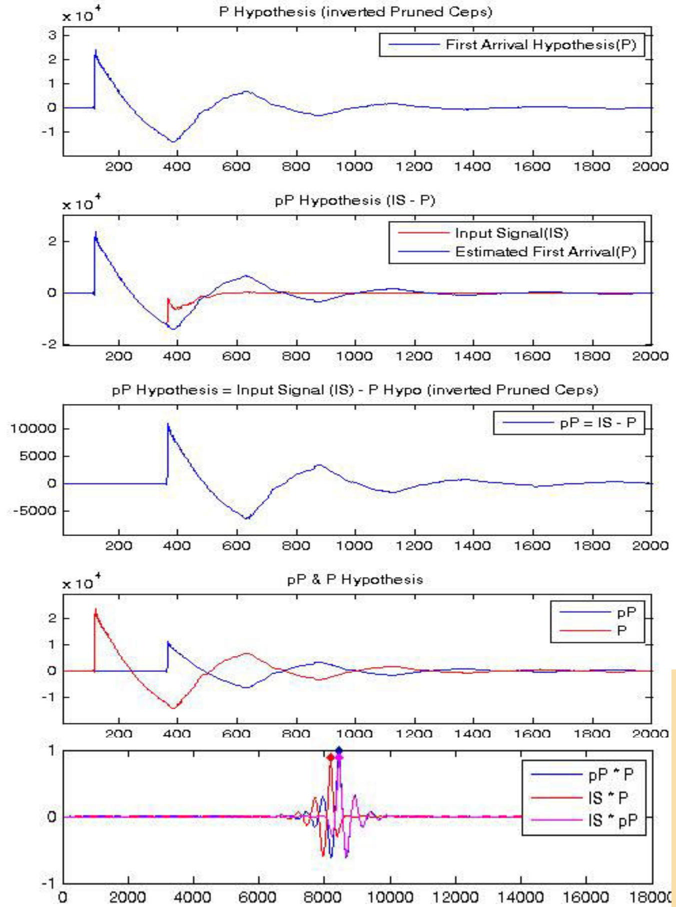
Note enhanced spectral information at higher sample rate

100 sps



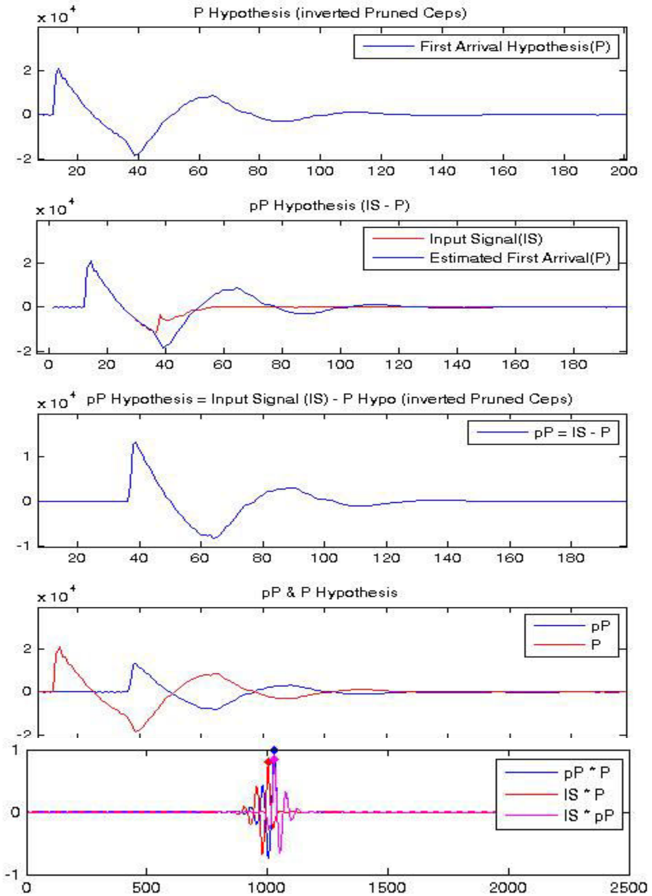
1000 sps

Relative Amplitude



Time (samples at 1000sps)

100 sps



Time (samples at 100sps)

P : First arrival hypothesis based on Complex Cepstrum Lifter;
IS : Original signal;
pP : (IS - P) First echo hypothesis.

Note deconvolved waveform similarity at all sample rates, however, enhanced detail at higher sample rate;

Deconvolved waveform similarity evaluation metrics are slightly better at higher sample rate.

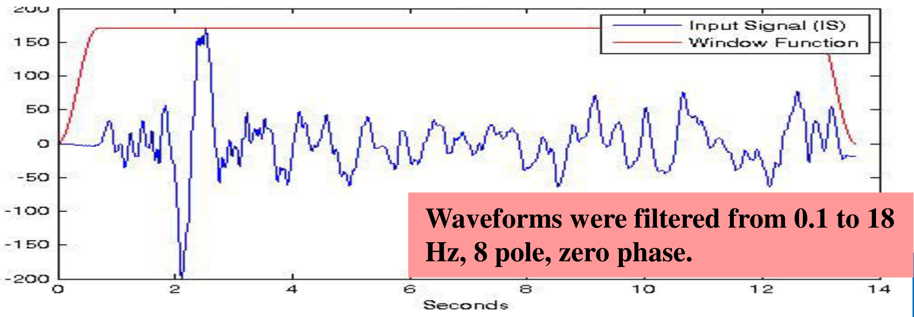
Correlation IS*P: 0.89
Correlation pP*P : 0.9
Correlation pP*IS: 0.8
power(pP)/ power(xcor_P)= 0.46

Correlation IS*P: 0.79
Correlation pP*P: 0.98
Correlation pP*IS: 0.84
power(pP)/ power(xcor_P)= 0.61

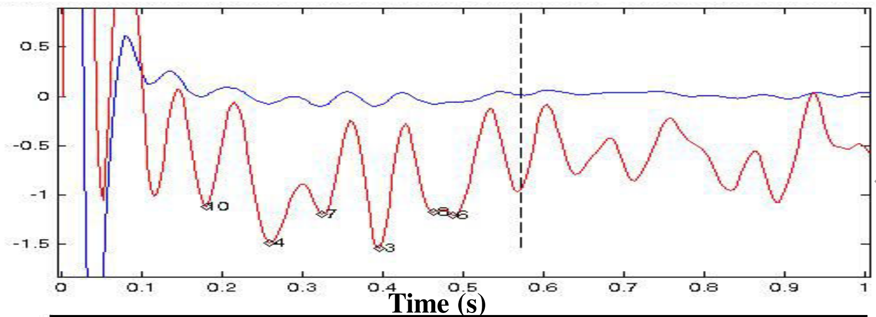
The input and estimated echo lag corresponds within two sample points for both sample rates.

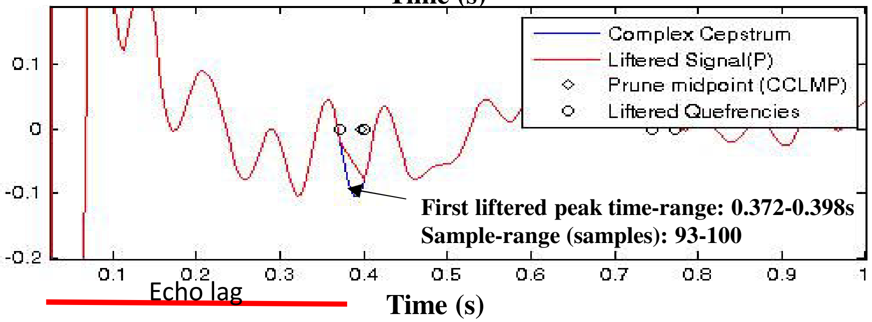
1992 March 26 16:30, NTS nuclear explosion, AZ.PFO

250 sps



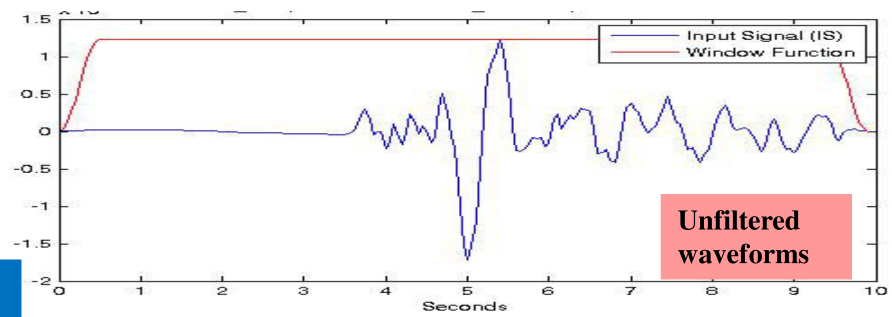
Real and Complex Cepstrum



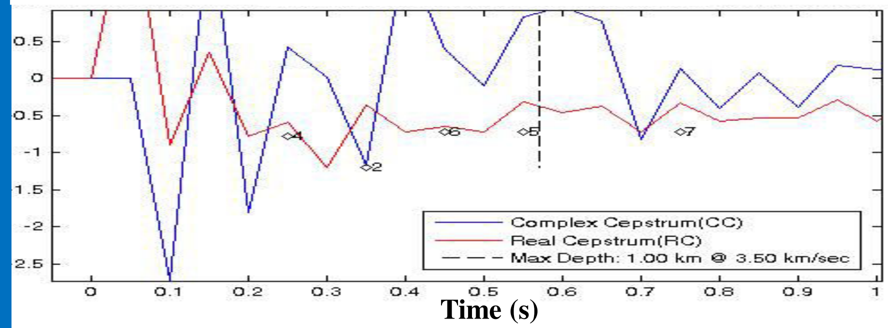


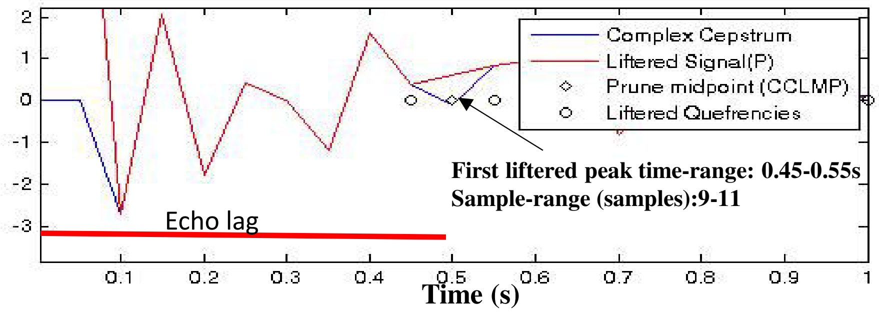
Note enhanced cepstral peak detail at higher sample rates and correspondence of the Power and Complex Cepstrums at the chosen echo lag time

20 sps

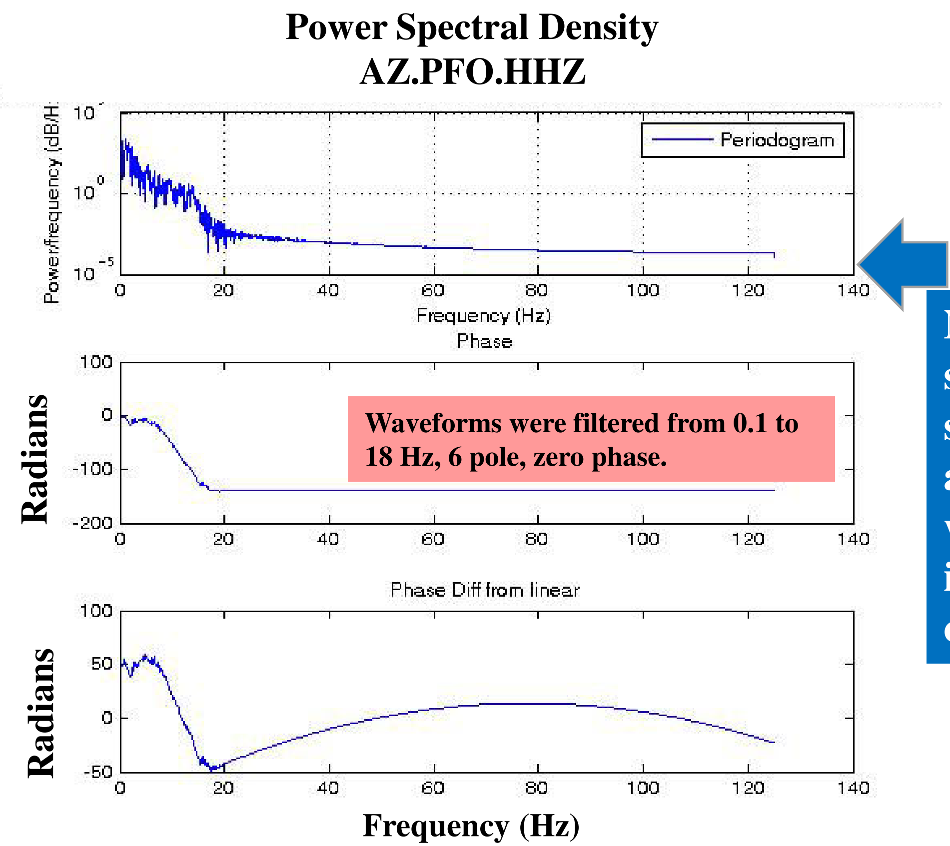


Real and Complex Cepstrum



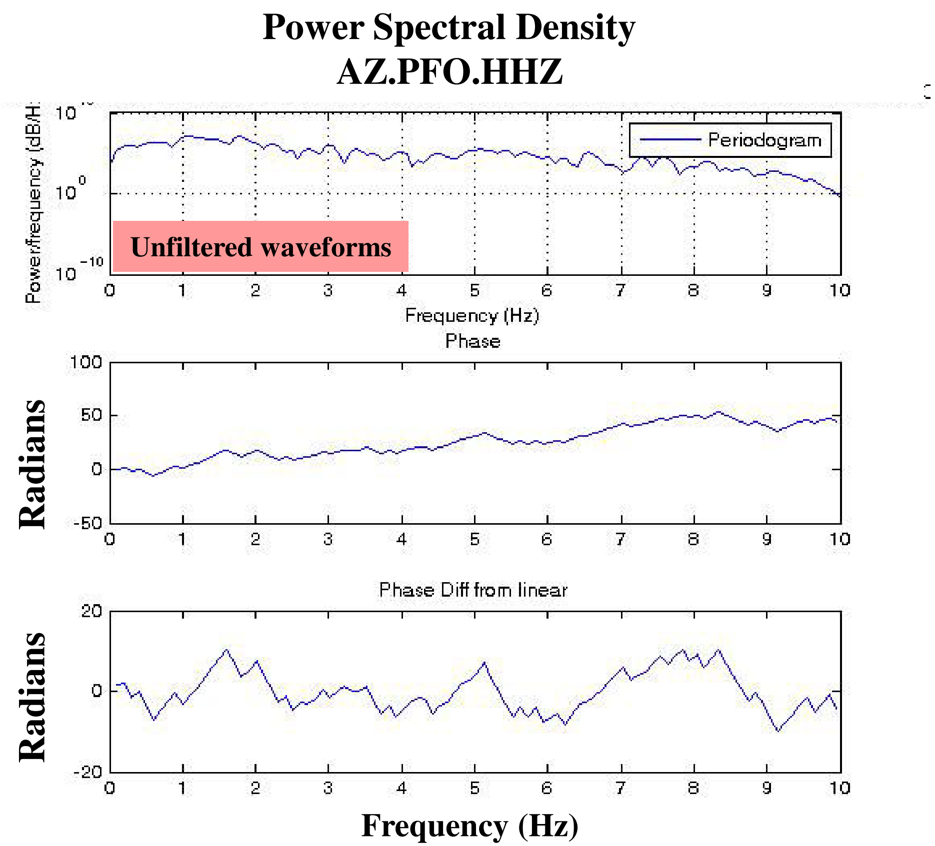


250 sps



Note enhanced spectral sampling at 250 sps, which results in higher cepstral detail.

20 sps

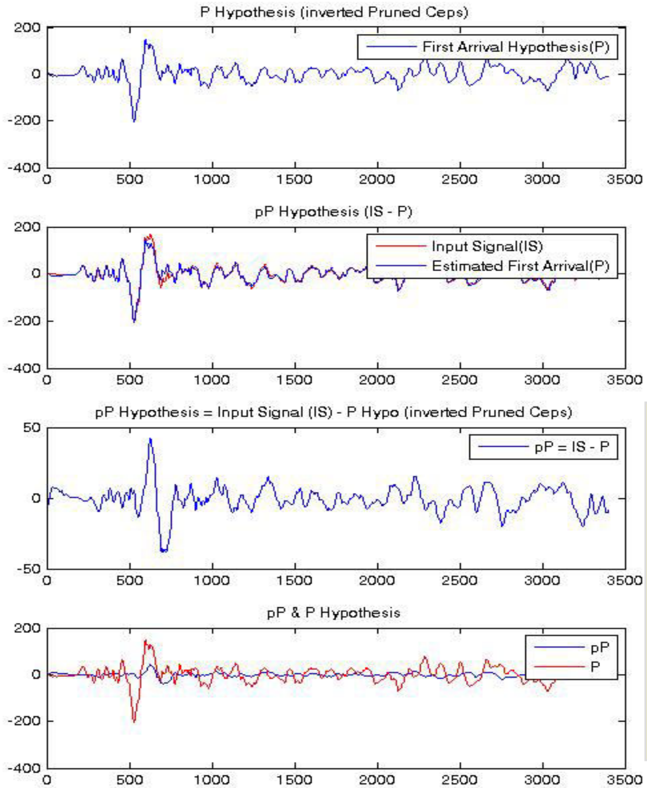


250 sps

20sps

Note improved, more stable P, pP waveform deconvolution at higher sample rate

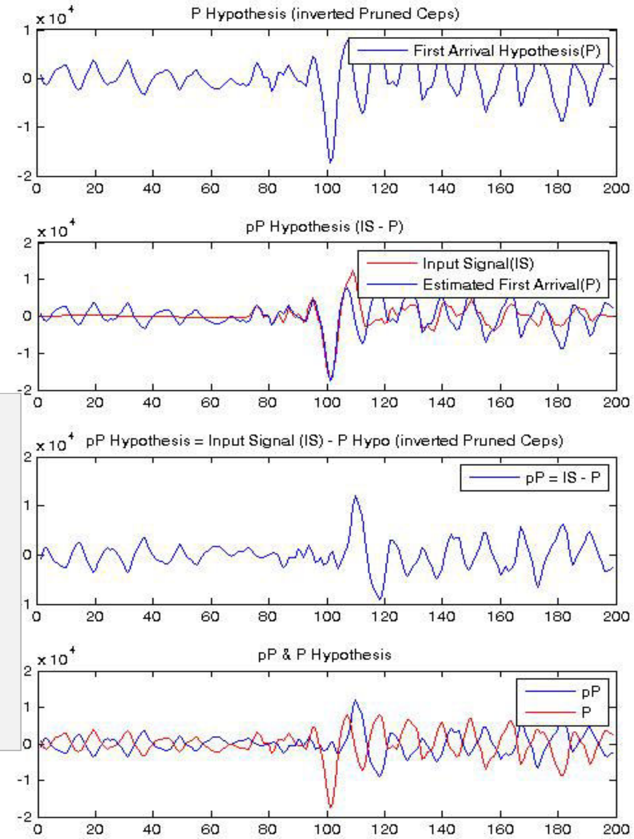
Note improved IS-P and IS-pP correlation at higher sample rate.



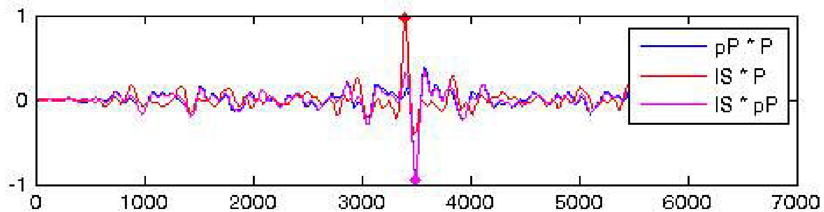
Time (samples at 250sps)

First liftered peak time-range: 0.243-0.258s
Correlation IS*P: 0.97
Correlation pP*P : -0.94
Correlation pP*IS: -0.96
power(pP_hypo)/ power(xcor_P_hypo)= 0.24
Estimated Depth @ 3.5km/s: 0.65 - 0.69 km
True Depth: 0.622 km

First liftered peak time-range: 0.3-0.33s
Correlation IS*P: 0.65
Correlation pP*P :-0.69
Correlation pP*IS -0.79
power(pP_hypo)/ power(xcor_P_hypo)= 0.77
Estimated Depth @3.5km/s: 0.78-0.96 km
True depth: 0.622 km

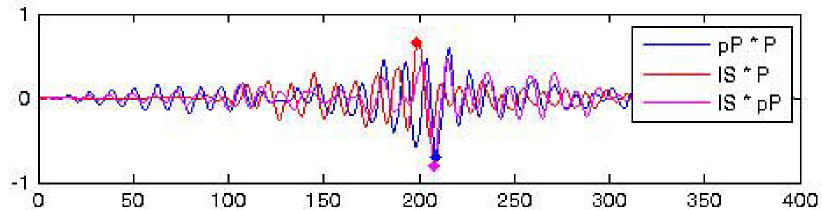


Time (samples at 20sps)



Time (samples at 250sps)

The input and estimated echo lag corresponds within three sample points for both sample rates.



Time (samples at 20sps)

SUMMARY

- A higher sample rate better samples the spectra, and results in enhanced cepstral detail;
- The phase unwrapping errors decrease with the increase of sample rate;
- A challenge to address in the future will be ambient noise phase distortion at higher sample rates and low Signal-to-Noise ratios. Preliminary investigations show that filtering is a possible solution to this problem.
- We recommend further investigation of a comprehensive event database in multiple scenarios to unequivocally determine the gains and limitations of enhanced sample rate usage.