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A semi-automatic cepstral method for seismic event depth estimation

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POSTER

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OBJECTIVE

We investigate optimal processing of large SNR explosions with the goal to:

- Implement an automatic set of algorithms for depth estimation that is based on Cepstral Analysis.
- Evaluate the most promising of a set of 15 metrics to provide a reliable statistical assessment of the measured confidence and errors.

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INTRODUCTION

THE CEPSTRAL ANALYSIS :

- Uses Complex and Power Cepstrae, versus Power Cepstrum only.
- Homomorphic deconvolution allows comparison with the initial signal, deconvolution of the initial signal, phase delay and polarity check.
- Metrics are developed, tested and used to stabilize and statistically evaluate the depth estimates:

$$\text{TOTAL METRIC} = \prod [\, PMETRIC(i) x\, WEIGHT(i)]$$

- New semi-automatic approach: Process a large number of signal windows at a single station. Choose the optimal analysis window and the optimal cepstral liftered sample.

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INTRODUCTION

Automatic Cepstral Analysis Tool Modules

Seismic Input Parameter Estimation Module

- Preliminary location, depth range, mechanism
- Seismic phase arrival time and waveform prediction
- Source, path, receiver seismic velocity models
- P-phase arrival time and frequency content

Cepstral Analysis Tool

At each station

- Choose a set of analysis windows
- Signal – echo time delay
- Signal and echo waveforms
- Best liftered sample solution score

Seismic Solution Validation Module

- Array/network pP phase/echo validation
- Station/Network depth and depth error estimate

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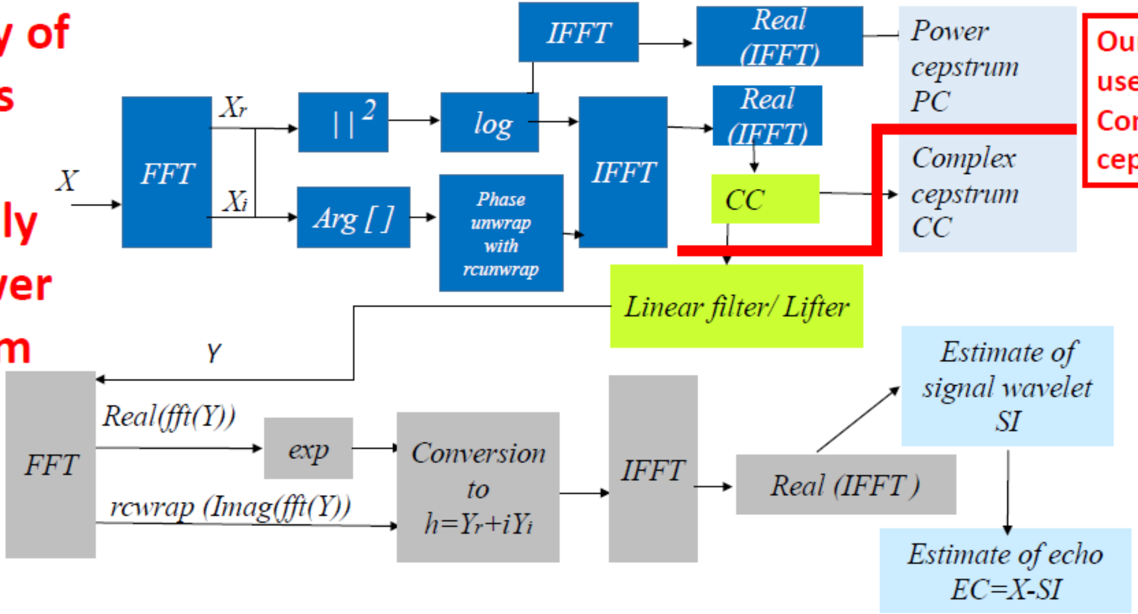
METHOD

Cepstral Process Flow Chart

The majority of previous studies used only the power cepstrum



Our method uses Power and Complex cepstrae

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DATA WINDOW DESCRIPTION

The waveform windows, measured in seconds used in this study are named:

- The IAW, which is the Initial Analyzed Waveform window. Six metrics are applied in this window named METRIC[1-6]_IAW.
- The QAW, the Quefrency Analysis Window, which is the CC quefrency window in which liftering is performed. Nine metrics are applied in this window named METRIC[7-15]_QAW.

METHOD DEVELOPMENT STAGES:

Cepstral Waveform Analysis Method 1.0 (CWAM1.0):

- Analyst – chosen IAW
- 15 metrics applied on a limited number of events

NEW Cepstral Analysis Tool 1.0 (CAT1.0):

- Semi-automatically chosen IAW
- 15 metrics evaluated on well located events.

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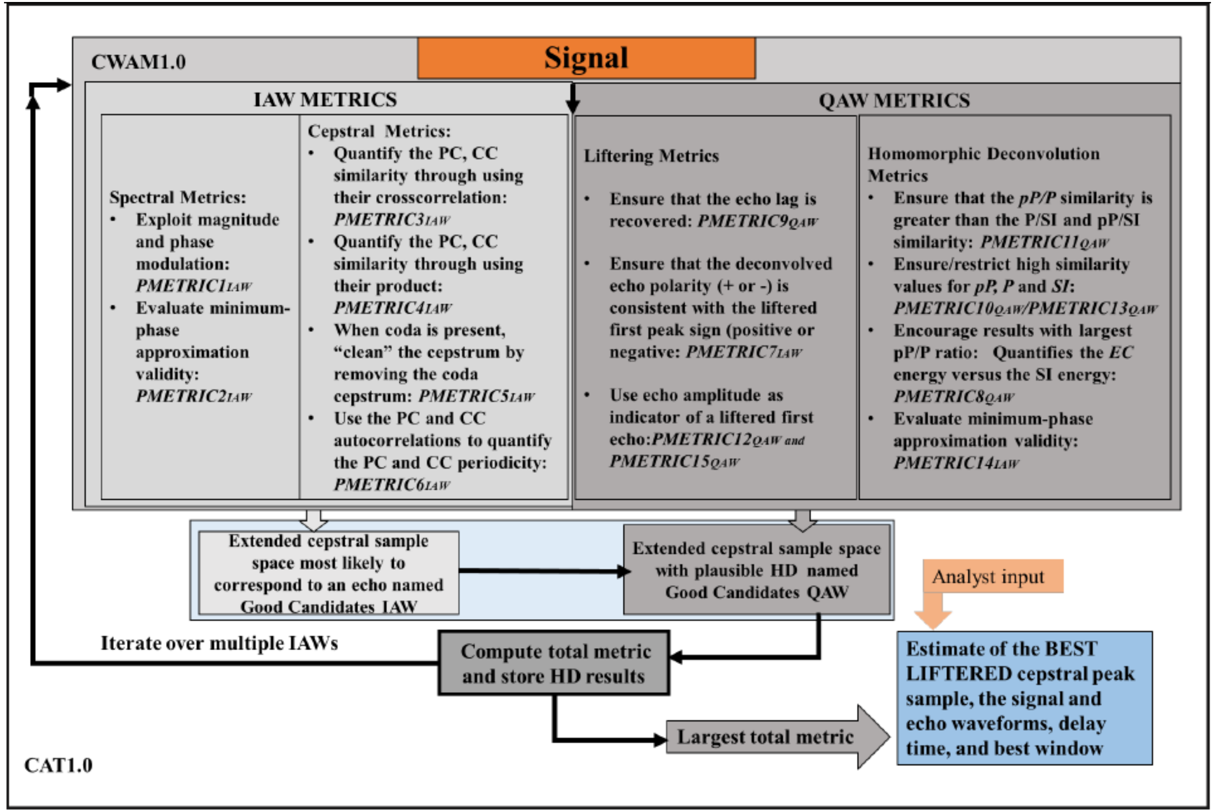
METHOD



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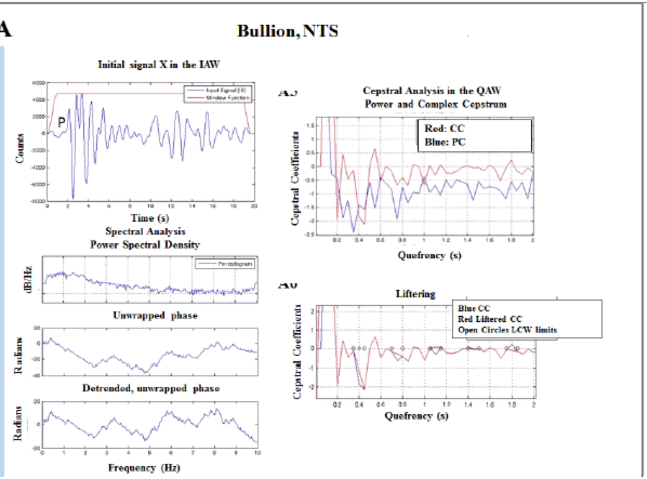
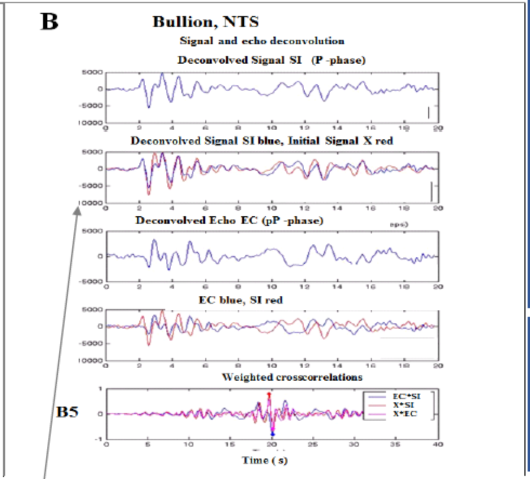
EXAMPLE OF CWAM1.0 ANALYSIS of the NTS nuclear explosion BULLION at station KONO, Kongsberg Norway

Initial Signal → Cepstral Analysis and Metric Evaluation → Estimated Depth

No visible depth phase for very shallow events





Note the P and SI amplitude difference which may affect yield estimates.

Reported Depth of Burial: 674 m

Our Estimate: 680 m

Estimated Echo Time Delay: 0.4 seconds

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DATA

Nuclear events at Nevada Test Site*

#	Name	Date	Time	Lat(deg)	Lon(deg)	Dob(m)	Dob(ft)	Yield
1.	ATRISCO	8/5/1982	14:00:00.090	37.08	-116.01	-640	-2099	138 kt
2.	AZUL	12/14/1979	18:00:00.090	37.14	-116.06	-205	-672	< 20 kt
3.	BASEBALL	1/15/1981	20:25:00.090	37.09	-116.05	-564	-1850	20 – 150 kt
4.	BENHAM	12/19/1968	16:30:00.040	37.23	-116.47	-1402	-4600	1.15 Mt
5.	BRISTOL	11/26/1991	18:35:00.070	37.10	-116.07	457	1500	< 20 kt
6.	BULLION	6/13/1990	15:59:59.330	37.26	-116.42	-674	-2211	20 – 150 kt
7	CHANCELLOR	9/1/1983	14:00:00.080	37.27	-116.36	-624	-2046	143 kt
8	DIVIDER	9/23/1992	15:04:00.000	37.02	-116.00	-340	-1115	< 20 kt

* US Nuclear Tests, July 1945 through September 1992, DOE/NV-209-REV 16, September 2015

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PRELIMINARY RESULTS

- TWTT is the two-way travel time
- DOB is the depth of burial
- The interquartile range is the difference of the 75 and 25 percentile of the data

#	NAME	Location	Expected TWTT to the source (sec)	CAT1.0 Estimated Median TWTT (sec)	Velocity at the source (Vs) (km/sec)	DOB (m)	Estimated Median DOB* (m)	DOB half interquartile range (m)	Containment Type	Source Rock	Density (gm/cm^3)
1.	ATRISCO	Yucca Flats	0.313	0.325	4.09	640	664	25	Shaft	Tuff	1.90
2.	AZUL	Yucca Flats	0.204	0.214	2.01	205	214	0	Shaft	Alluvium	1.78
3	BASEBALL	Yucca Flats	0.478	0.416	2.36	564	491	28	Shaft	Tuff	1.98
4	BENHAM	Pahute Mesa	0.600	0.523	4.67	1402	1223	417	Shaft	Tuff	2.30
5	BRISTOL	Yucca Flats	0.404	0.340	2.26	457	384	158	Shaft	Tuff	1.87
6	BULLION	Pahute Mesa	0.417	0.525	3.23	674	840	320	Shaft	Tuff	1.84
7	CHANCELLOR	Pahute Mesa	0.391	0.320	3.19	624	510	123	Shaft	Rhyolite	2.22
8	DIVIDER	Yucca Flats	0.318	0.339	2.14	340	362	64	Shaft	Tuff	1.73

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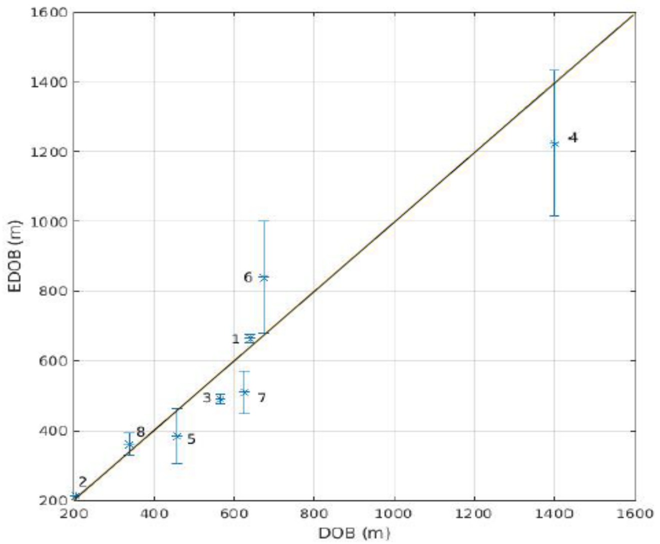
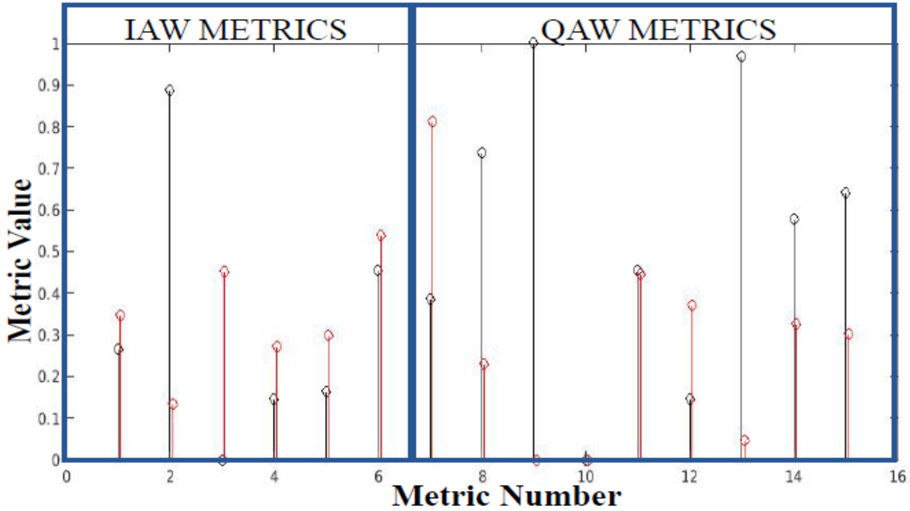
PRELIMINARY RESULTS

Estimated EDOB as a function of listed DOB. The length of the vertical bars is half of the interquartile (iqr) range.



Metric median values (black) and iqr (red) for the semi-automatically chosen IAW and for the optimal P-pP time delay at all the stations and for all the NTS events in this study. A metric value close to one and low iqr are the empirically required conditions for efficient metrics.



Best metrics: 2, 6, 7, 8, 9, 11, 13, 14 and 15
Less performant metrics: 3, 10
Metrics with variable performance as a function of event or station : 1, 3, 6, 7, 11

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SUMMARY

- CAT1.0 is a semi-automatic method developed for nuclear explosion analysis (depth < 1.5km);
- Using metrics, CAT1.0 estimates the liftered QAW sample most likely to result in an optimal echo in an optimal window (IAW). Currently CAT1.0 is semi-automatic because an analyst chooses the optimal result from a subset of best candidates.
- Fifteen metrics are evaluated in a semi-automatically chosen optimal IAW for the optimal liftered sample for eight underground nuclear explosions recorded at more than 40 stations. A preliminary evaluation indicates the best and least satisfactory metrics.
- Future work will include:
  - The analysis of twelve more NTS events;
  - Investigations to understand the cases of high metric variability and its dependence of DOB, epicentral distance and sample rate;
  - Finalization of the method evaluation by the choice and the application of the most useful metrics.