A semi-automatic cepstral method for seismic event depth estimation

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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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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:

\[
\text{TOTAL METRIC}=\sum [PMETRIC(i) \times WEIGHT(i)]
\]

- **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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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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Cepstral Process Flow Chart

The majority of previous studies used only the power cepstrum.
**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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EXAMPLE OF CWAMI1.0 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

REPORTED DEPTH OF
Burial: 674 m
Our Estimate: 680 m
Estimated Echo Time Delay: 0.4 seconds

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

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<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Date</th>
<th>Time</th>
<th>Lat(deg)</th>
<th>Lon(deg)</th>
<th>Dob(m)</th>
<th>Dob(ft)</th>
<th>Yield</th>
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<td>8/5/1982</td>
<td>14:00:00.090</td>
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<td>-640</td>
<td>-2099</td>
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<td>20:25:00.090</td>
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<td>-1850</td>
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<td>BENHAM</td>
<td>12/19/1968</td>
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<td>-4600</td>
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<td>11/26/1991</td>
<td>18:35:00.070</td>
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<td>457</td>
<td>1500</td>
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<td>CHANCELLOR</td>
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<td>-116.00</td>
<td>-340</td>
<td>-1115</td>
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<table>
<thead>
<tr>
<th>#</th>
<th>NAME</th>
<th>Location</th>
<th>Expected TWT T to the source (sec)</th>
<th>CAT1.0 Estimated Median TWT (sec)</th>
<th>Velocity at the source (Vs) (km/sec)</th>
<th>DOB (m)</th>
<th>Estimated Median DOB£ (m)</th>
<th>DOB half interquartile range (m)</th>
<th>Containment Type</th>
<th>Source Rock</th>
<th>Density (gm/cm³)</th>
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<td>362</td>
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<td>1.73</td>
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</tbody>
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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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• 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.