Lydprofilinterpolasjon i rom og tid

Sound velocity profile interpolation in space and time – a way to overcome one of the nightmares of multi-beam processing?

S. Roemer, D. A. Hodnesdal, A. E. Ofstad,
Kartverket Sjødivisjonen

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Introduction – Motivation

Inconsistencies at sea-bed becomes apparent in overlapp zones and are often caused by sound-velocity problems:

- inhomogeneous/erroneous profiles?
- insufficient observation frequency (in space & time)?
- ... 
- insufficient profile handling (switchover between profiles)
- typical interpolation/collocation problem

<table>
<thead>
<tr>
<th>depth</th>
<th>≈ 500m</th>
</tr>
</thead>
<tbody>
<tr>
<td>swath width</td>
<td>≈ 1000m</td>
</tr>
<tr>
<td>discrepancies</td>
<td>≈ 5m</td>
</tr>
</tbody>
</table>
Introduction – Overview, goal

**Interpolation ’water level’**

- originally designed for 'water-level interpolation'
  (simultaneously observed time series related to a fixed position)
in space and time
- interpolation 'longitude', 'latitude' & *time* (linear interpolation in time)
- Simultaneous observations from different tide gauges are used to estimate
  the water level 'somewhere' in between (but at the same time).

**Interpolation ’sound velocity profiles’**

- adapted for e.g. 'sound velocity profile interpolation'
  (time series observed at different locations and at different times)
in space, time and depth
- interpolation in 'longitude', 'latitude', *depth* + *time*
- Estimates the sound velocity for a desired position, depth & time
  by using time shifted observations from other locations & depths.

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\(^1\) time vs. instantaneous water level, MSL, chart datum, . . .
\(^2\) depth or pressure vs. sound speed, density, temperature, salinity, . . .
Generel information

- Projection: 'sinusoidal projection' (constant east–west scale throughout the map and along the central meridian) is used to transform from [°] to [m]
- Equidistance: not necessary neither in space nor time
- Interpolation by computing a weighted mean between time series
- Weights: function of distance (in space or/and time)
- ...
- Main problem: What kind of weighting is meaningful?
Distance based weighting: What is ‘distance’?

‘Distance’ – geometric, spatial ‘distance’
- shortest distance at sea (‘sea distance’) approximated by the shortest distance using the sinusoidal projection
- possible to consider coast lines
- without coast line: ‘sea distance’ = ‘air-line distance’
- with coast line: ‘sea distance’ ≥ ‘air-line distance’
- possible to manipulate the distances to consider oceanographical phenomena

‘Distance’ – distance in time
- sound velocity profile
Distance based weighting – From distance to weight

[Maps and data visualizations showing distance based weighting.

6.30697 km]
Distance based weighting: Distance in space and time

**Vertical axis:**
relative sea distance
\[ = f(\text{lat, lon, coast line, . . .})\]
between two positions

- obs. position SV profile \( P_i \)
- obs. position SV profile \( P_j \)
- 'wanted' position \( P_n \) which profiles has to be interpolated to

**Horizontal axis:**
rel. distance in time between different obs. epochs

- observation epoch SV profile \( P_i \)
- observation epoch SV profile \( P_j \)
- 'wanted' epoch \( P_n \) which profiles has to be interpolated to
Distance based weighting – Weighting functions

Weighting functions

- different weighting functions\(^3\) are implemented
- **distance-based weighting function** (distance in space):
  each series\(^4\) can handle an individual weighting function
- **time-distance-based weighting function** (distance in time):
  each 'sound profile' can handle an individual weighting function
  - same type of function backward and forward in time
  - different function parameters possible
    (different 'livetime' backward and forward)
  - manual or automatic mode
- individual scaling of weights per station to control both 'livetime' and 'living space'
- possibility for low-pass filtering
  (interpolating signal, minimizing noise)

\(^3\) inverse distance, exponential functions
\(^4\) both 'water level' and 'sound profile'
Weighting functions – Determination

Which functions should be used? (We do not yet!)

- should be ‘optimal’ in sense of least squares
- auto- and cross-correlation & spectral analysis to analyse and
discribe the data distribution as a function of distance i time,
space and depth
- least-squares collocation
  - prediction (interpolation, extrapolation)
  - filtering (noise)
  - parameter estimation (systematical effects like biases)
  - variance propagation
Weighting functions – Determination

Which functions and function parameters were used?

- instinct based guessing
- $1/distance$ (both in space and time, 'logic' parameter definition)
- first/last SV profile long lifetime backward/forward
  (there is no alternative in time)
- flexible lifetime (based on time distance between sequential profiles and by defining the maximum weight of a profile at the observation time of the neighbouring profile) to find a compromise between minimizing 'smearing effects between profiles' and 'minimizing errors and noise'
- same 'living space' for all SV profiles (e.g. $1/distance \ [m^5]$)
  - larger smearing effects by shorter distances (profiles with short distance should be identical and should be averaged)
- finally weight is a compromise: 'nearest in time and space'

\[^5\text{not so important as long equal for all profiles}\]
Practice – How does it work?

Vertical precision requirement: in 500m

\[ d_{\text{depth}} = 0.2m + 0.004 \times \text{depth}[m] \]

\[ d_{500m} = 2.2m \]

Without interpolation (outside requirement)

Interpolation interval: 1min (≈200m) (inside requirement)
Practice – How does it work?

\[ \approx 5m \text{ systematic discrepancy between two lines reduces to . . .} \]
Practice – How does it work?

... a more randomly variation ($\sigma < \pm 1m$, visually estimated)
Practice – How does it work?

Data from the corridor. The pink line is surveyed with wrong sound velocity profile.
Conclusions and outlook

- Interpolation works in principle, but the determination of the weights and weighting functions is non-professional/scientific
- Part of the standard processing (Kartverket)
  - easy to use (e.g. 100 profiles in – 8000 profiles out)
  - FFI, Kongsberg, CARIS
- SV still major element of uncertainty in multi-beam processing
  therefor: Observe sound velocity...
  - ... close to the first and to the LAST ping!
  - ... sufficient frequency (in time and space)
  - ... in context with conditions like depth, sea state, currents
  - ... maybe continuously
  to ensure that interpolation produces meaningful results

- Room for improvement
  - automated quality check of the raw data (sound velocity)
  - data analysis of the SV-profiles to obtain well-founded and provable statistical information
  - least squares collocation (filtering, prediction, variance propagation, maybe parameter estimation)
  - visualisation of the results
  - (quantitative) verification of the improvements