Towards full-waveform inversion of the near surface in exploration seismic

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The growing importance of near surface signals

- Industry often considers ground roll as noise
- Near surface can distort deeper signals
- New technology makes high-fidelity land-seismic surveys possible

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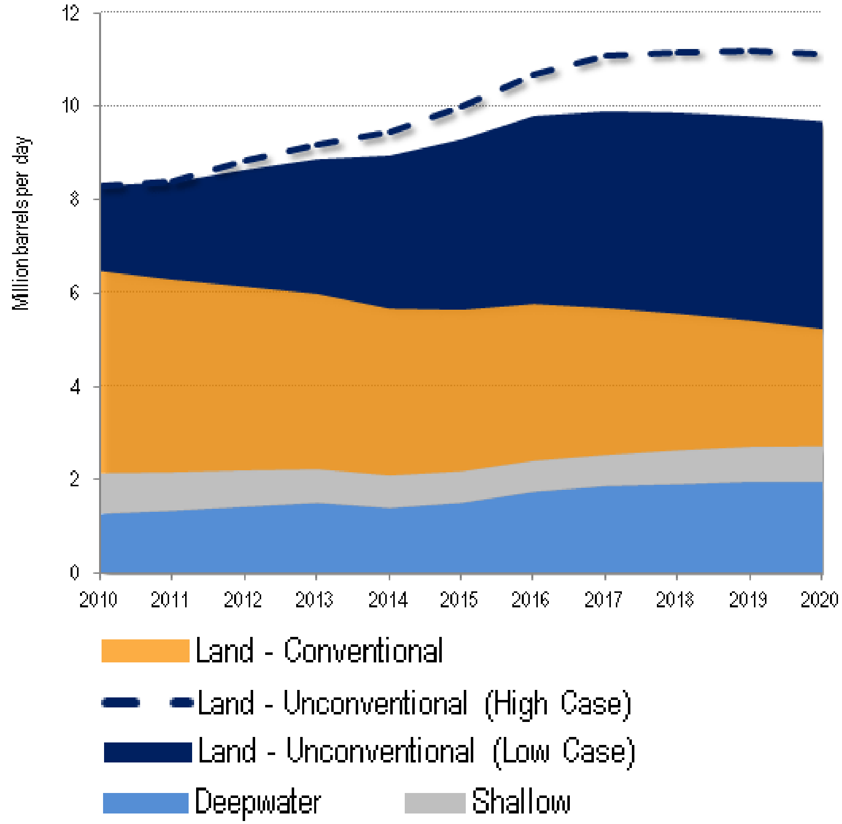
- Near surface can distort deeper signals
- New technology makes high fidelity land-seismic surveys possible

- Characterisation and exploitation of unconventional reservoirs like shale gas/oil need very good (surface) velocity models to compensate for near-surface effects

North American crude production by asset type, 2010-2020

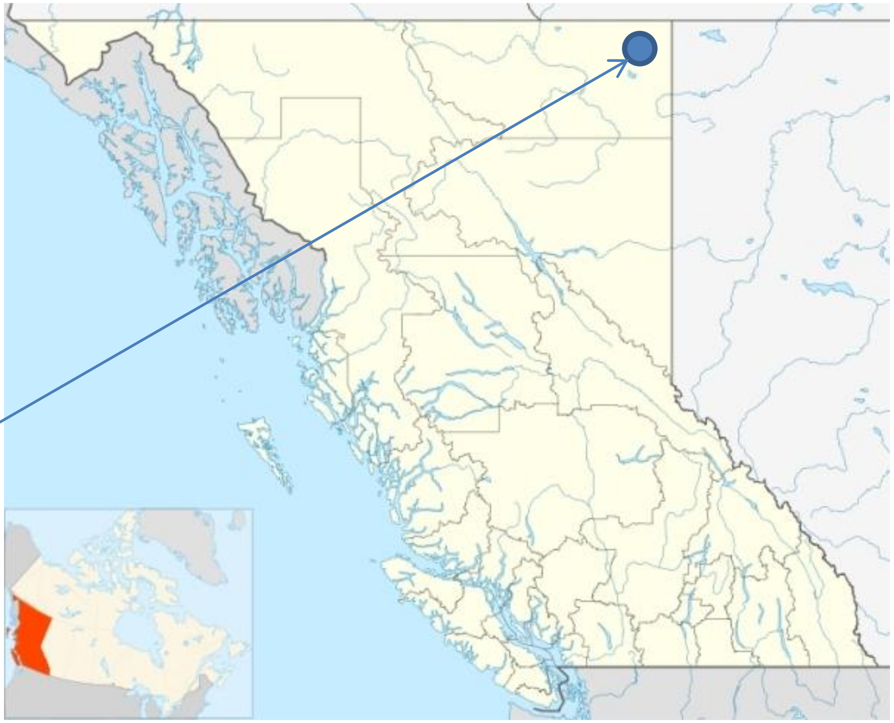


Source: IEA, IHS CERA, Business Monitor International, PFC Energy, SLB analysis

Survey location

North-east British Columbia

- shale gas rich area
- shale gas exploitation booming for the last decade
- reservoirs 2000-2500m depth



Cordova Embayment

Typical surface characteristics in the Cordova Embayment area

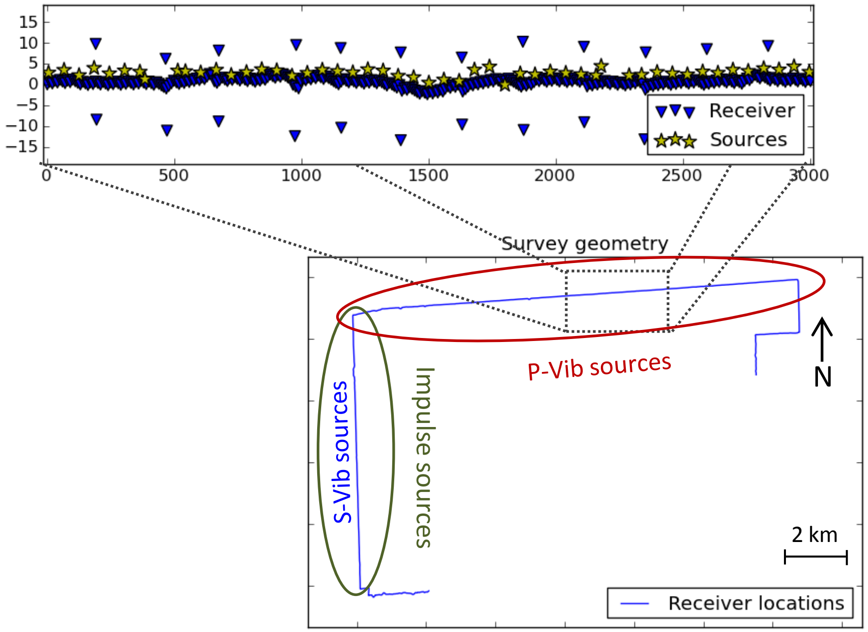
Source: Photos by Garth Lenz

Survey characteristics

- Number of shots in total : 868
- Three kinds of shots

  S-Vib sources / P-Vib source / Impulse source
- Vibration data, correlated

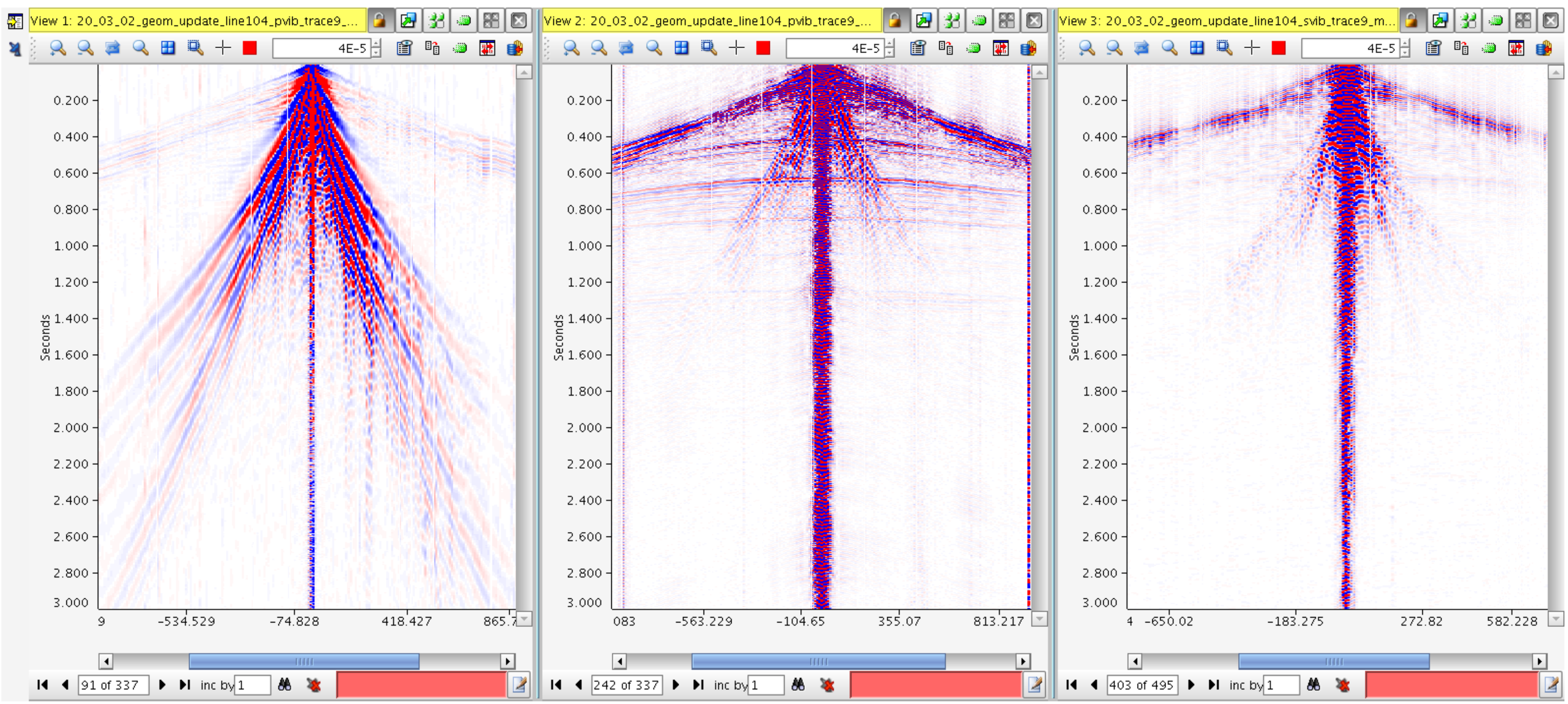
  Klauder wavelet as effective source wavelet
- Shot spacing : ~ 60m
- Receiver spacing : ~10m
- 3-comp acceleration data
- 2ms time sampling
- 6s record length



Influence of the source-time function

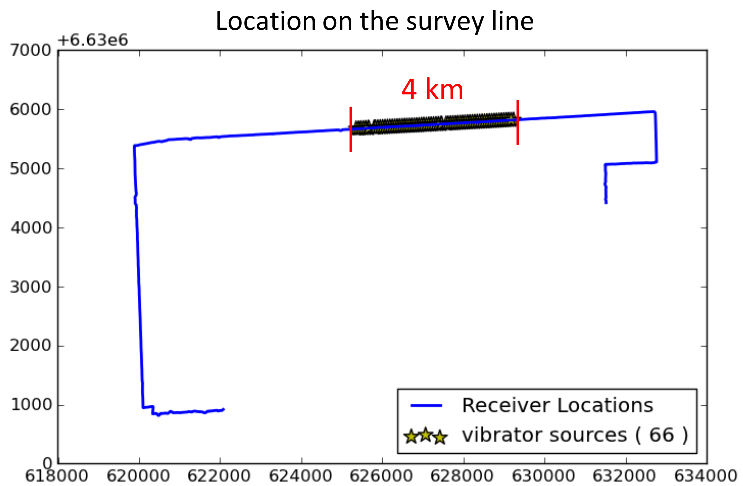
The *source-time-function* (time-dependent amplitude of the force applied at the source) can have a large impact on the recorded seismograms

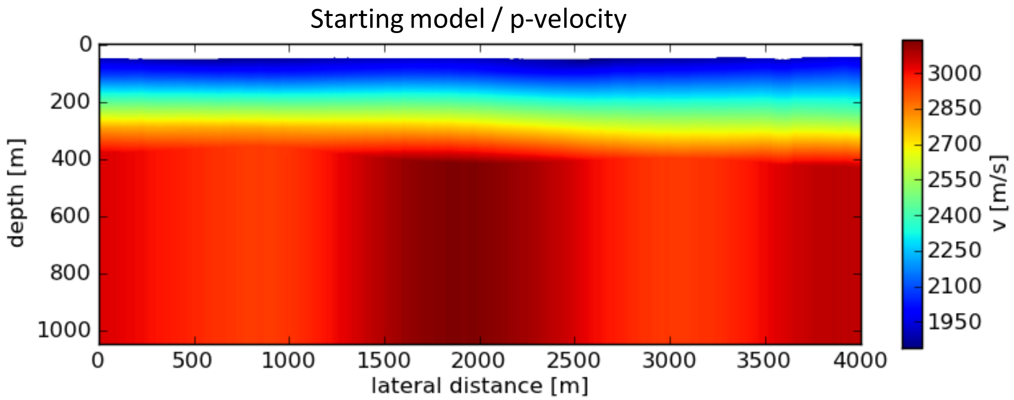
Impulse source | Vertical vib source | Horizontal(SH) vib source

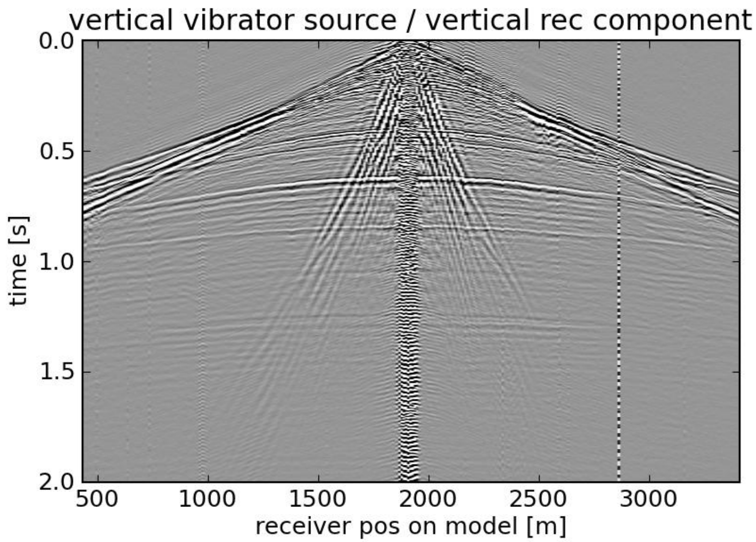


Investigated part of survey

- Lateral extent: 4km
- Number of shots: 66
- Number of receivers per shot: ~300
- offset per shot : -1500m to 1500m
- P-Vib source (~8-120 Hz)

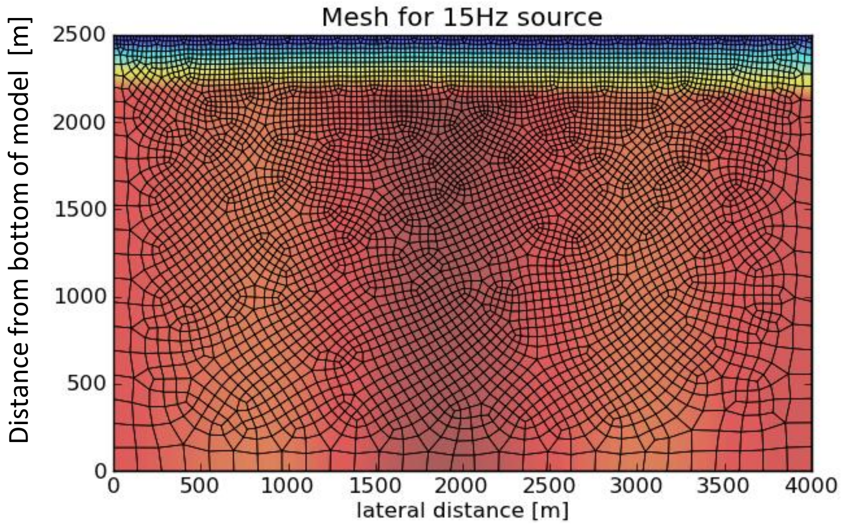






Calculating synthetics with SEM method

Mesh for the SEM calculations



Guideline for accuracy :

$$\frac{v_{min}}{f_{max}} \approx \triangle h$$

Stability criterion for time marching:

$$\triangle t \approx 0.3 \cdot \left(\frac{\triangle \hat{h}_{point}}{v} \right)_{\min}$$

Typical parameter values for on forward simulation at $f_{\max}$ = 15Hz:

$$\triangle h_{\max} = 104m \qquad \triangle t = 3.0 \cdot 10^{-4} s$$

$$\triangle h_{\min} = 23m$$

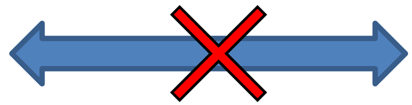
5519 elements

Simulation time on 8 processors : ~ 2 min

Compare recorded data to synthetics

Numerically generated data : synthetics

- 2D wave propagation
- displacement
- perfectly straight line



Recorded data

- 3D wave propagation
- acceleration
- irregular line

Compare recorded data to synthetics

Numerically generated data : synthetics

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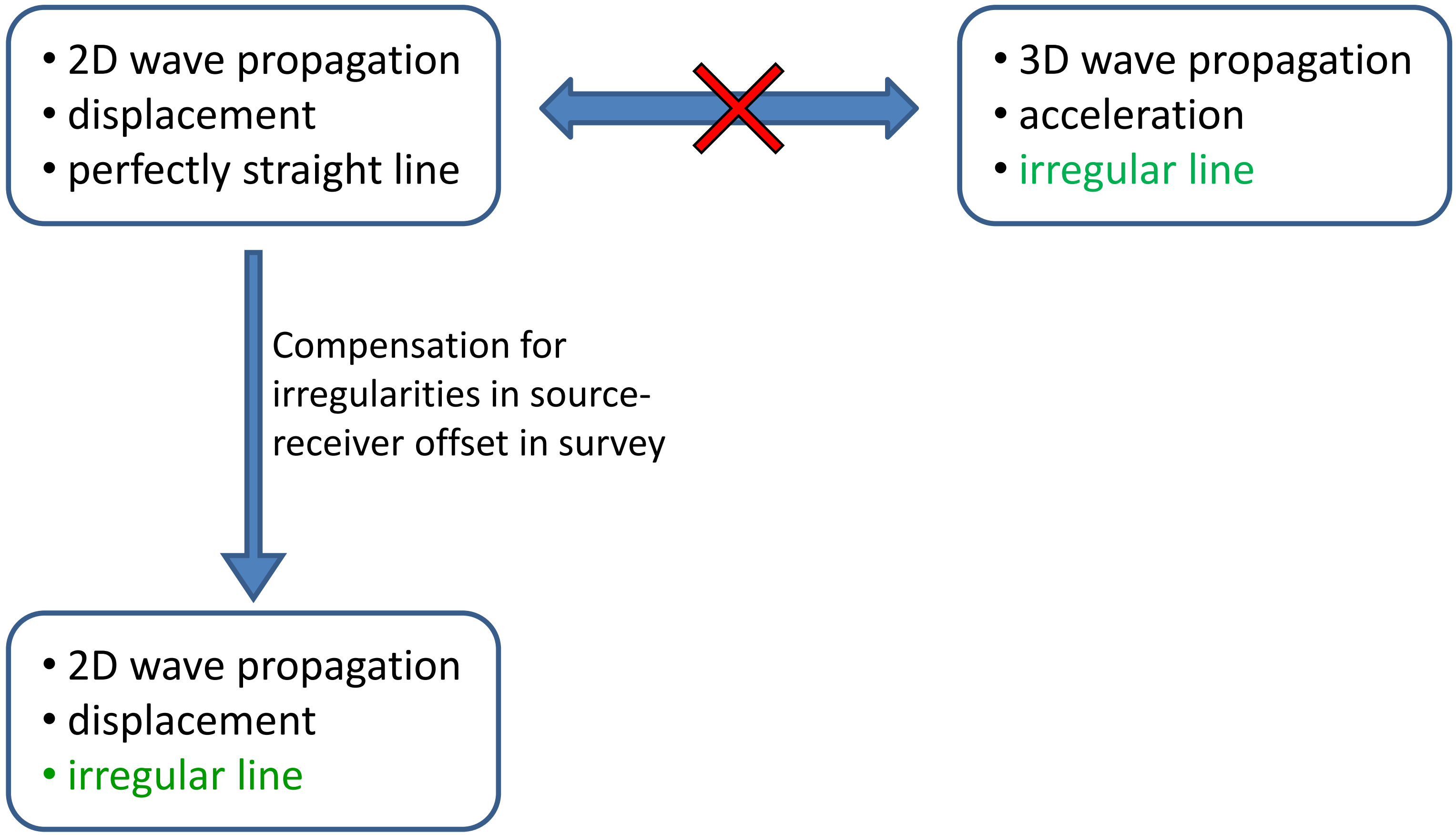
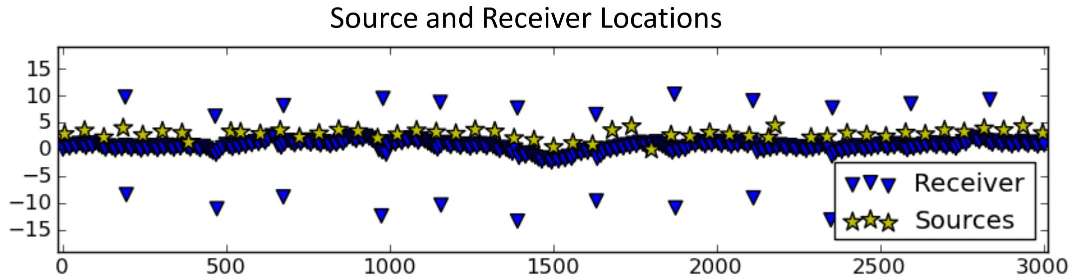


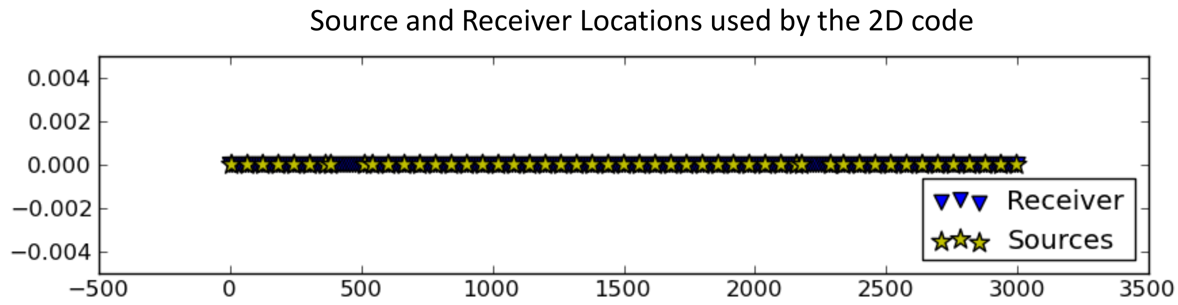
Preparations for correct modeling

Receiver and source locations:

-> Remove receiver locations which are not on the main receiver line

-> Calculate corrected source and receiver distances on 2D Line





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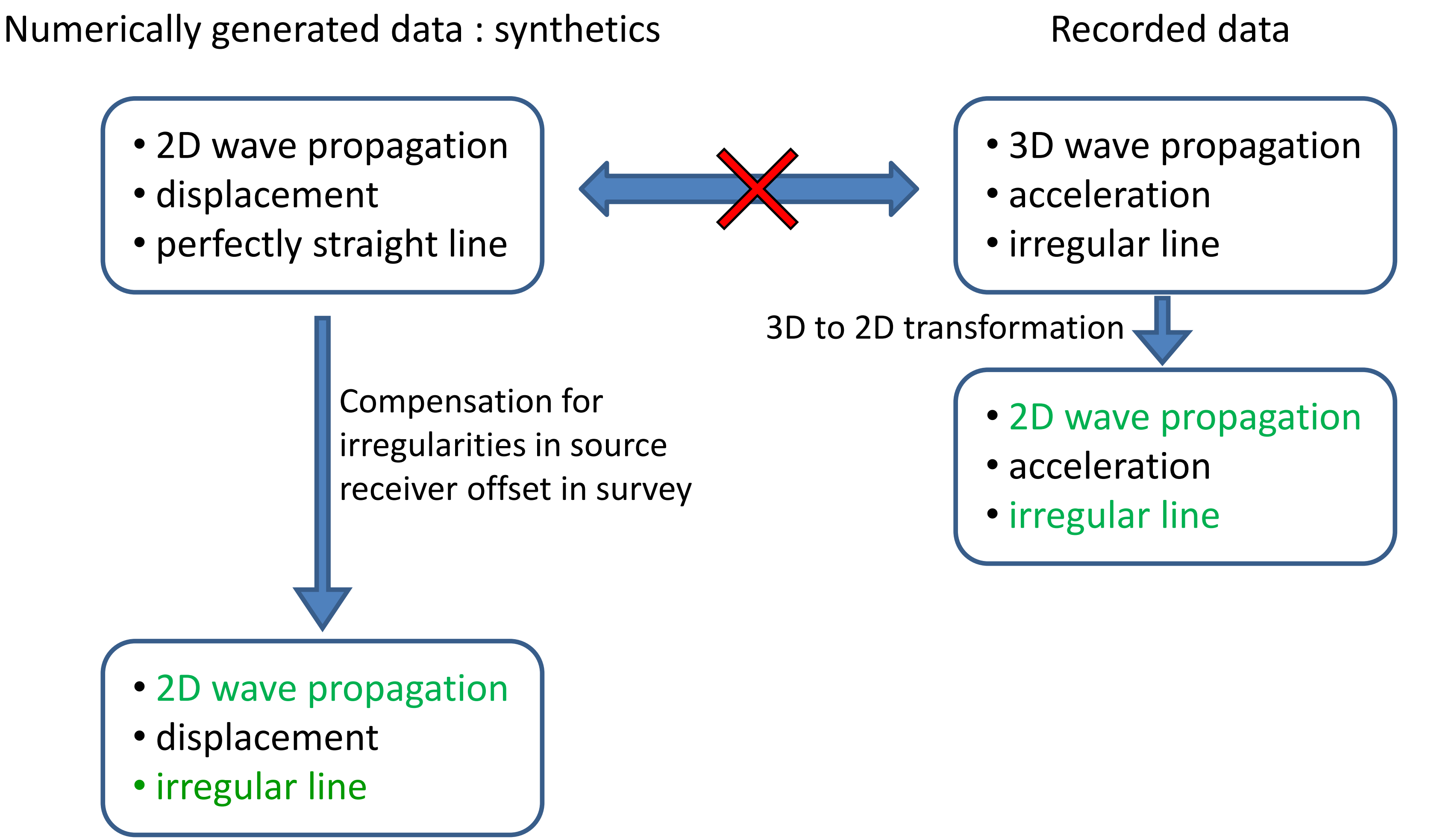
Compensation for irregularities in source receiver offset in survey

- 2D wave propagation
- displacement
- irregular line

Compare recorded data to synthetics



2D Simulation of 3D Data

Wave propagation excited by a point source is different in 2D and 3D

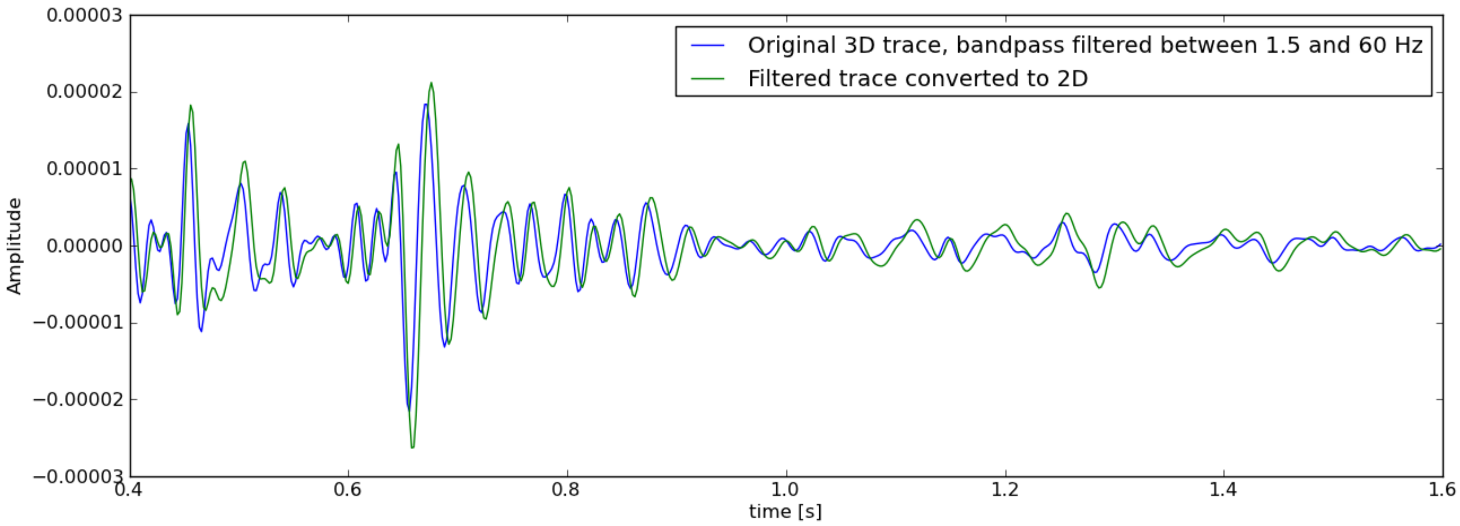
To compare 2D synthetics with 3D data it is necessary to transform the recorded 3D data to 2D

This can be done by convolving the recorded traces with the function:

$$H(t) \cdot t^{-\frac{1}{2}}$$

where $H(t)$ denotes the step function

(Chapman, GJRAS, 1978)



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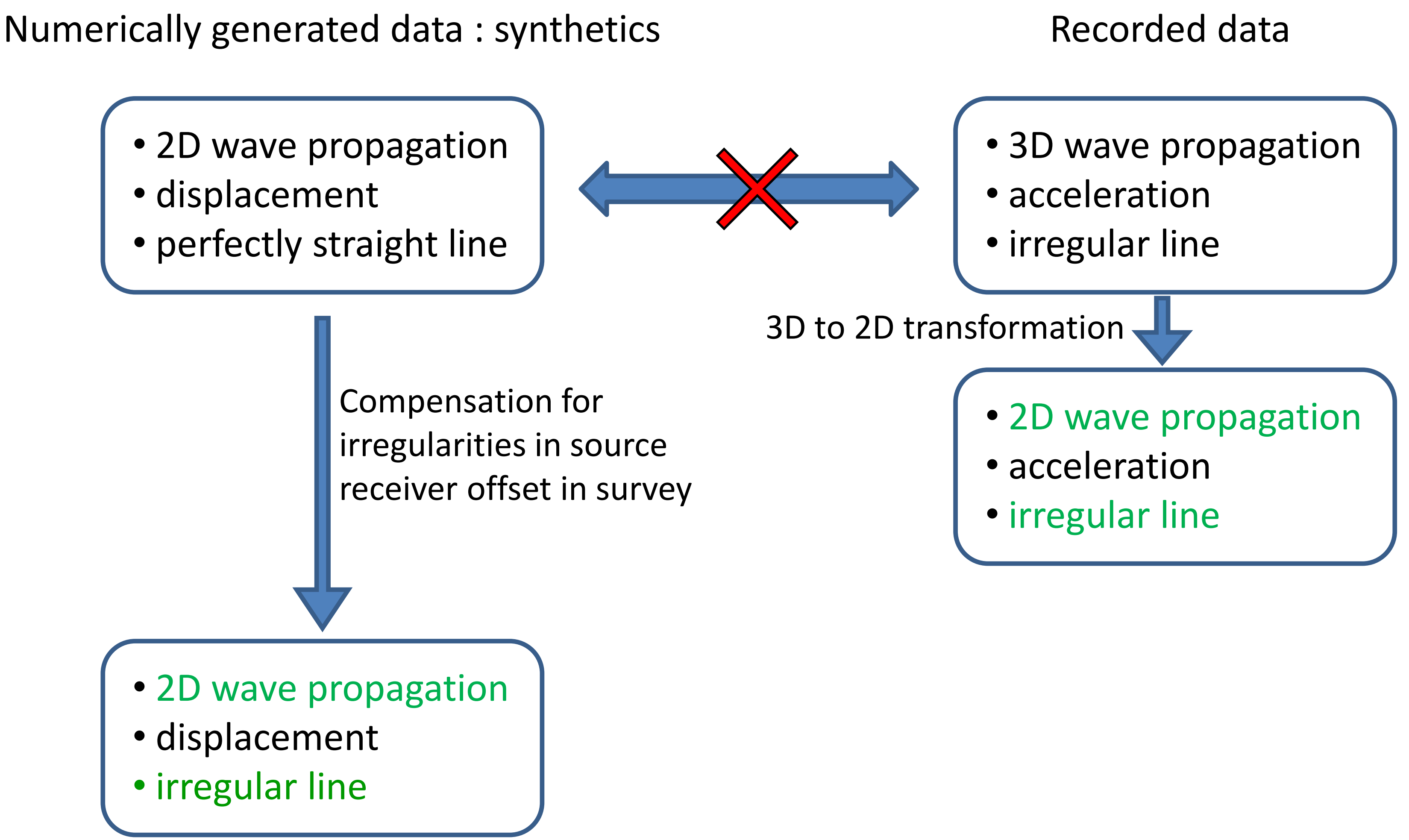

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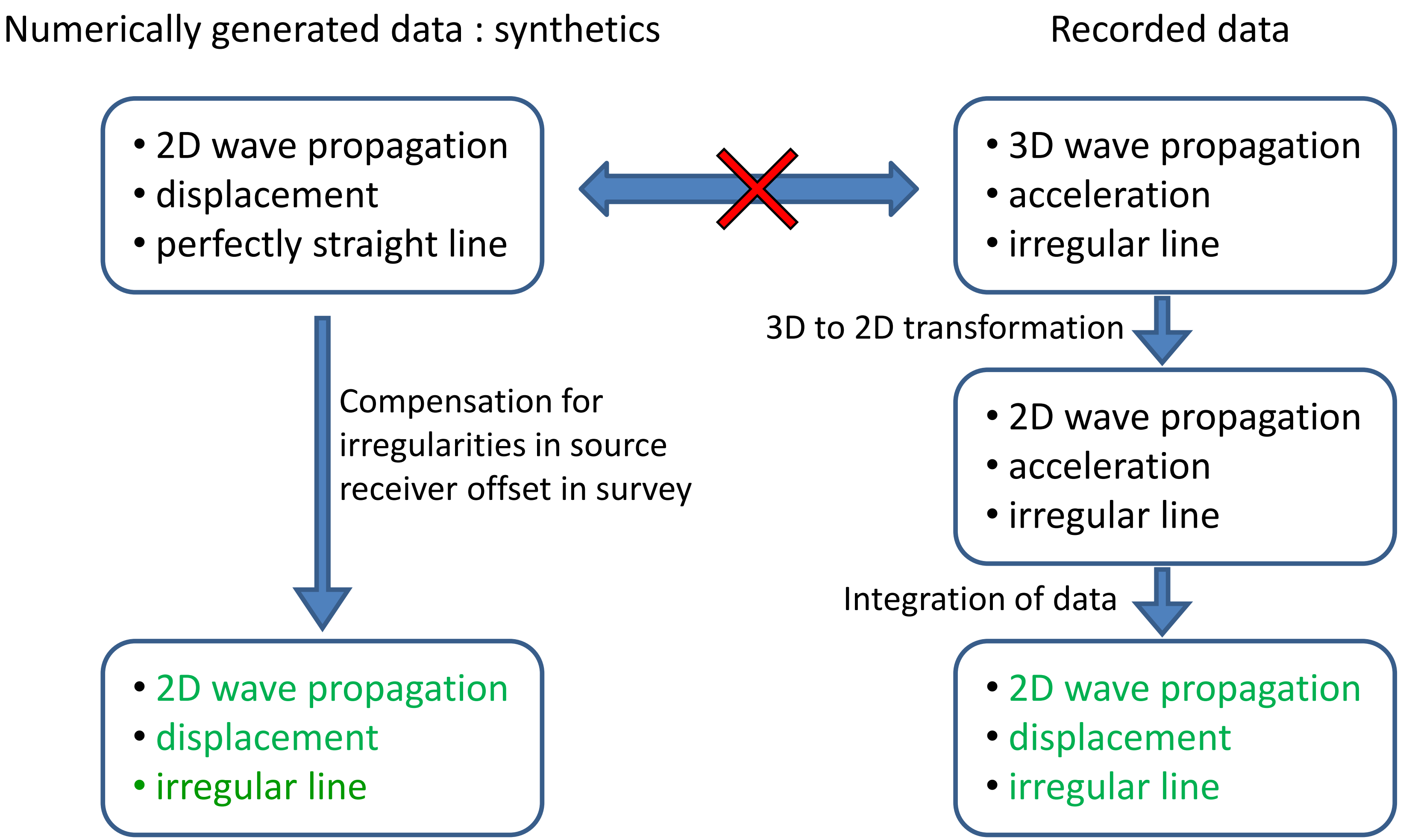
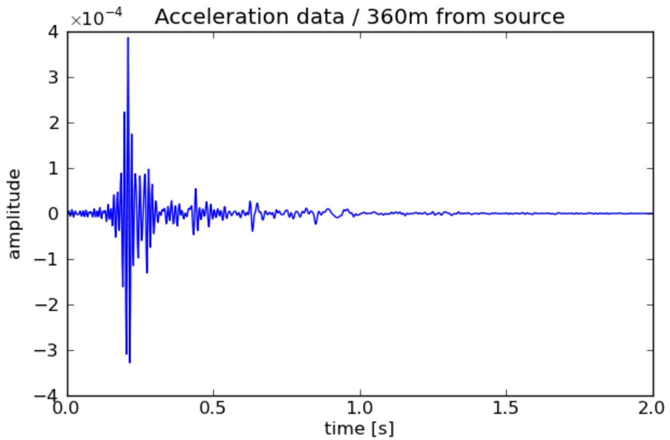
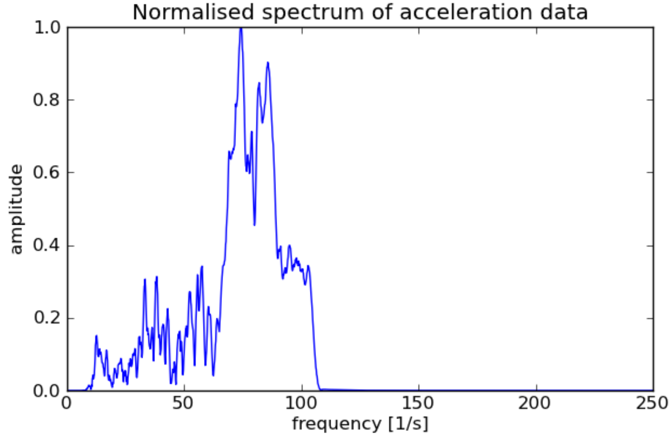


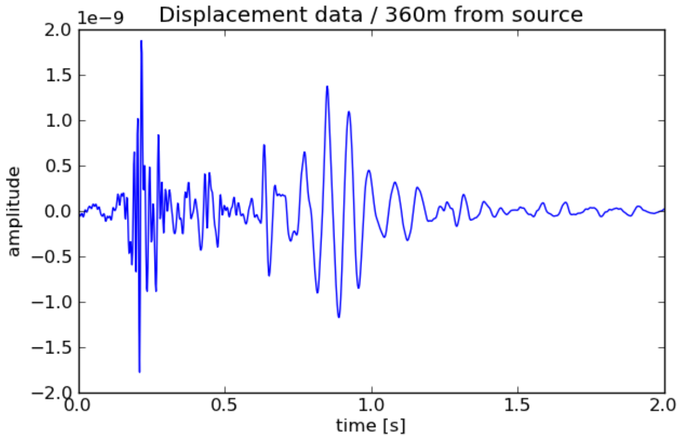
Impact of integration on seismograms

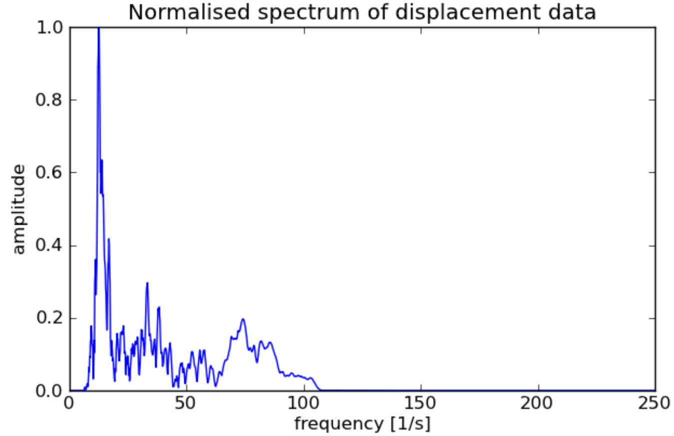
Trace as recorded (acceleration)





Trace after integration (displacement)





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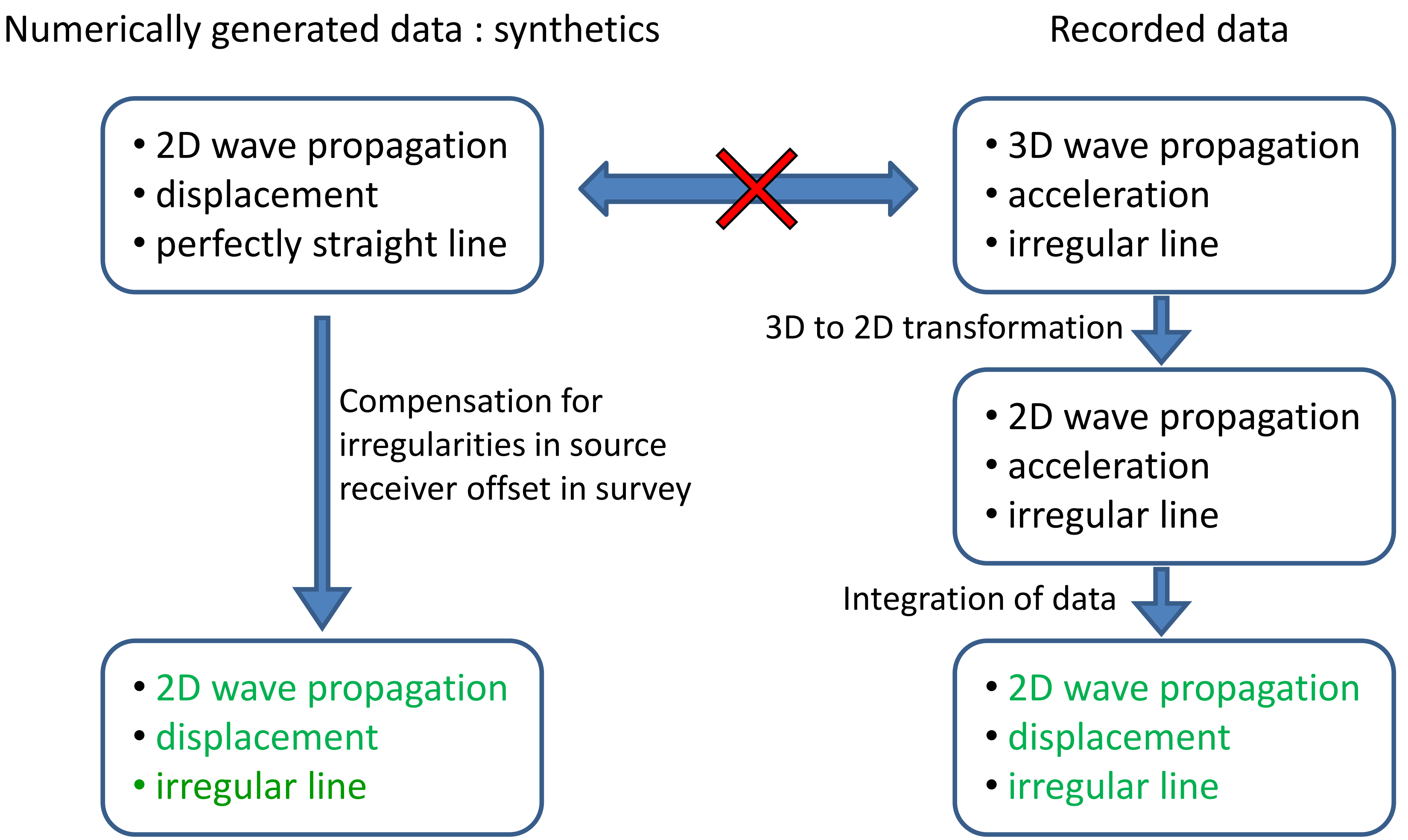

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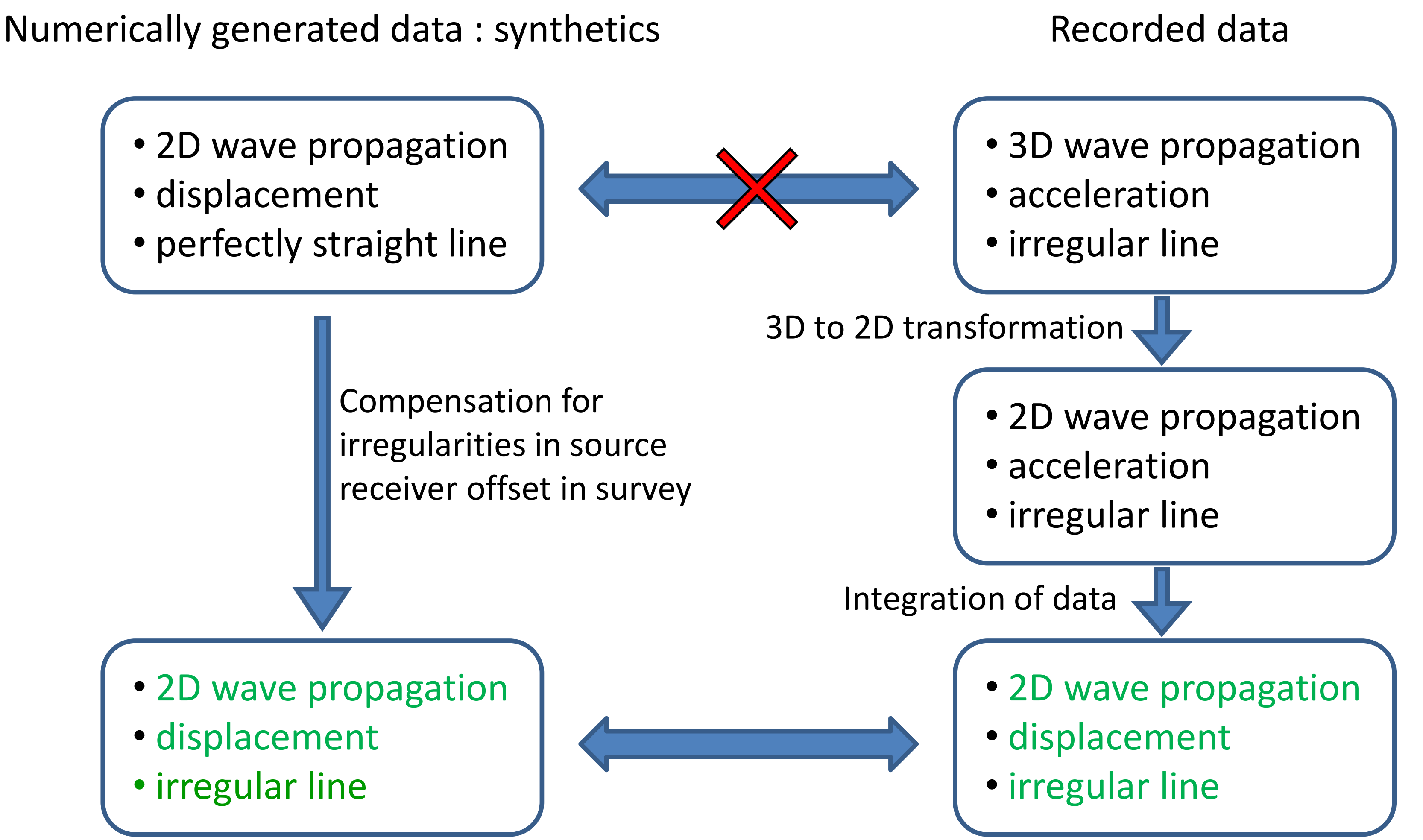
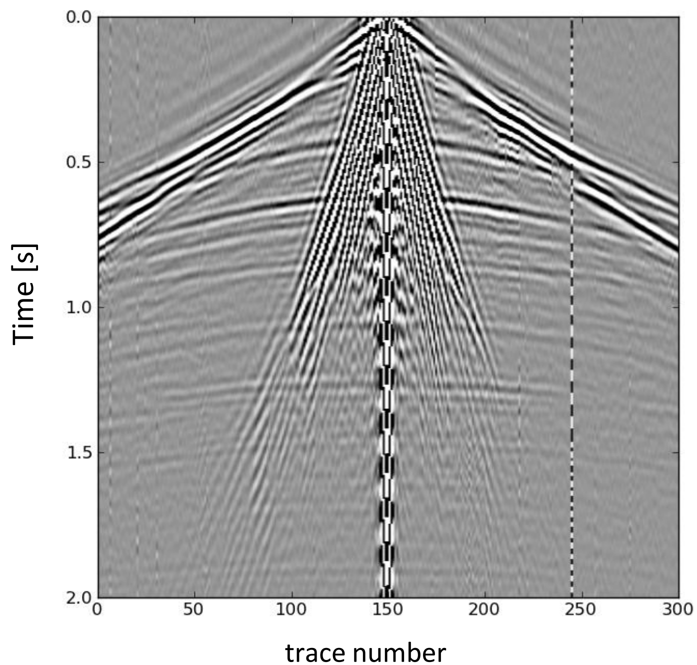
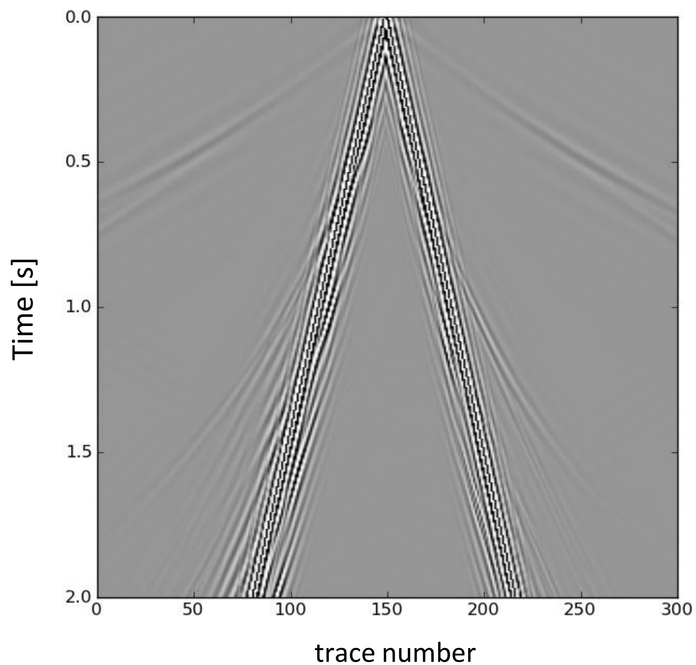


Synthetic vs. data gather

Data gather / horizontal component



Synthetic gather / horizontal component

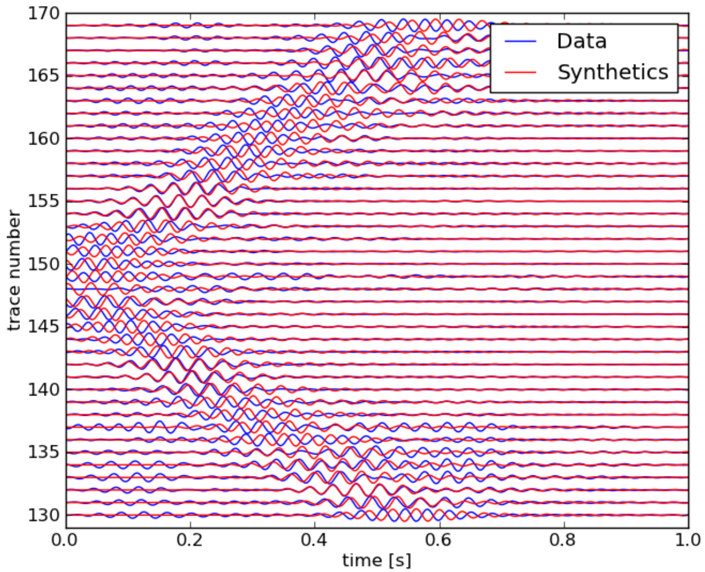


Certain parts of the gather can be matched using only small adjustments to the starting model

Much more information is contained in the data and will be included in the process as our synthetics match our data better and better

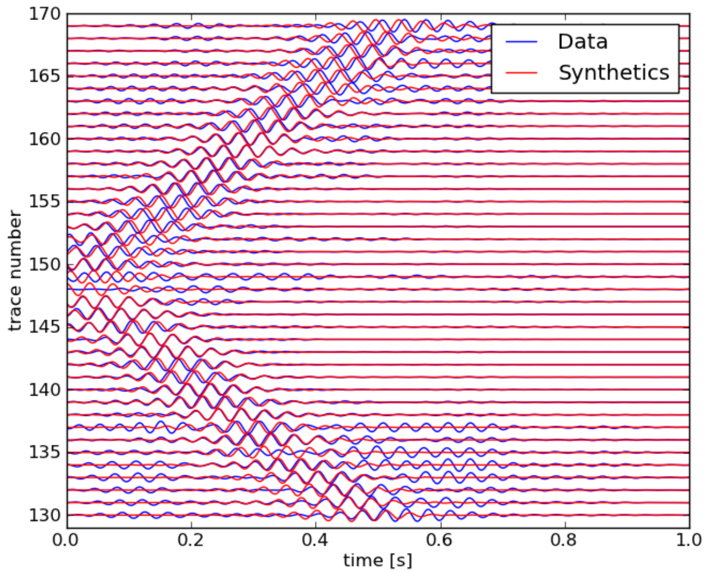
Band-passed data and synthetics

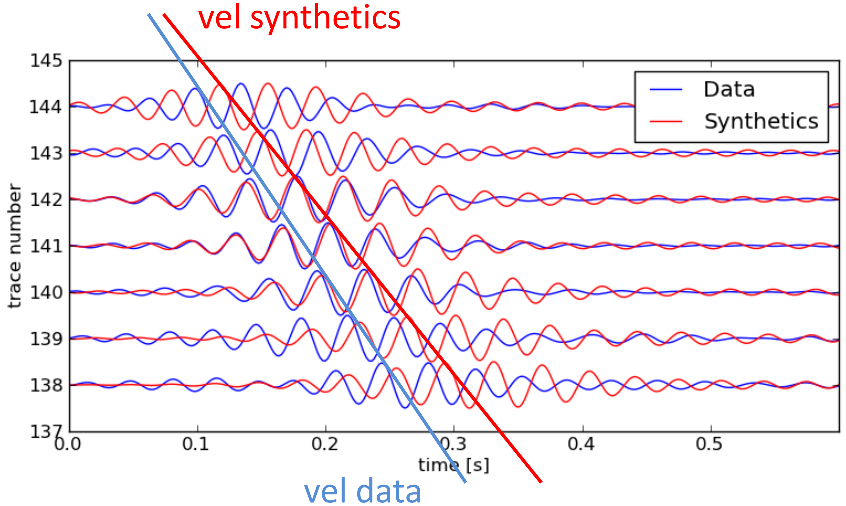
Rayleigh wave in band-passed (25-30Hz) data/synth

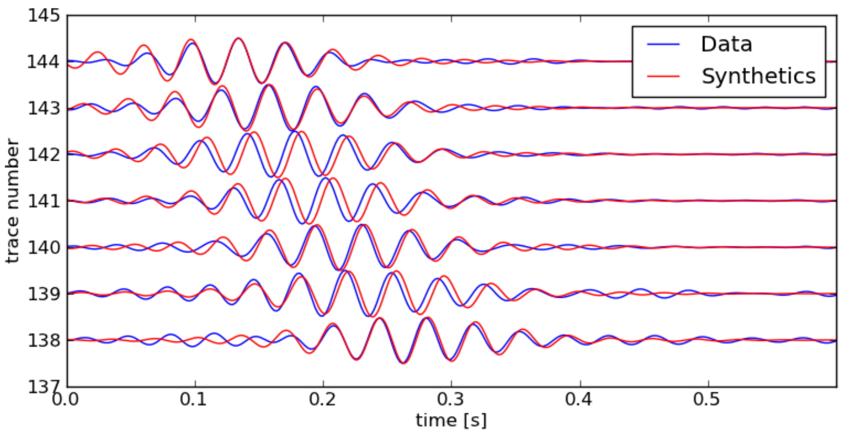


Velocity of near surface manually adjusted

Rayleigh wave in band-passed (25-30Hz) data/synth







Future work

- Iterative inversion of the data
  - Perform the inversion
  - Iterate through arrivals -> Full waveform
  - Try different misfit functions
    (time-frequency, polarisation)
  - Chose appropriate optimisation algorithm
- Validating results
  - Comparing with results of other methods
  - Use finite-difference code to compare synthetics

Thank you