Seismic monitoring with continuous seismic sources

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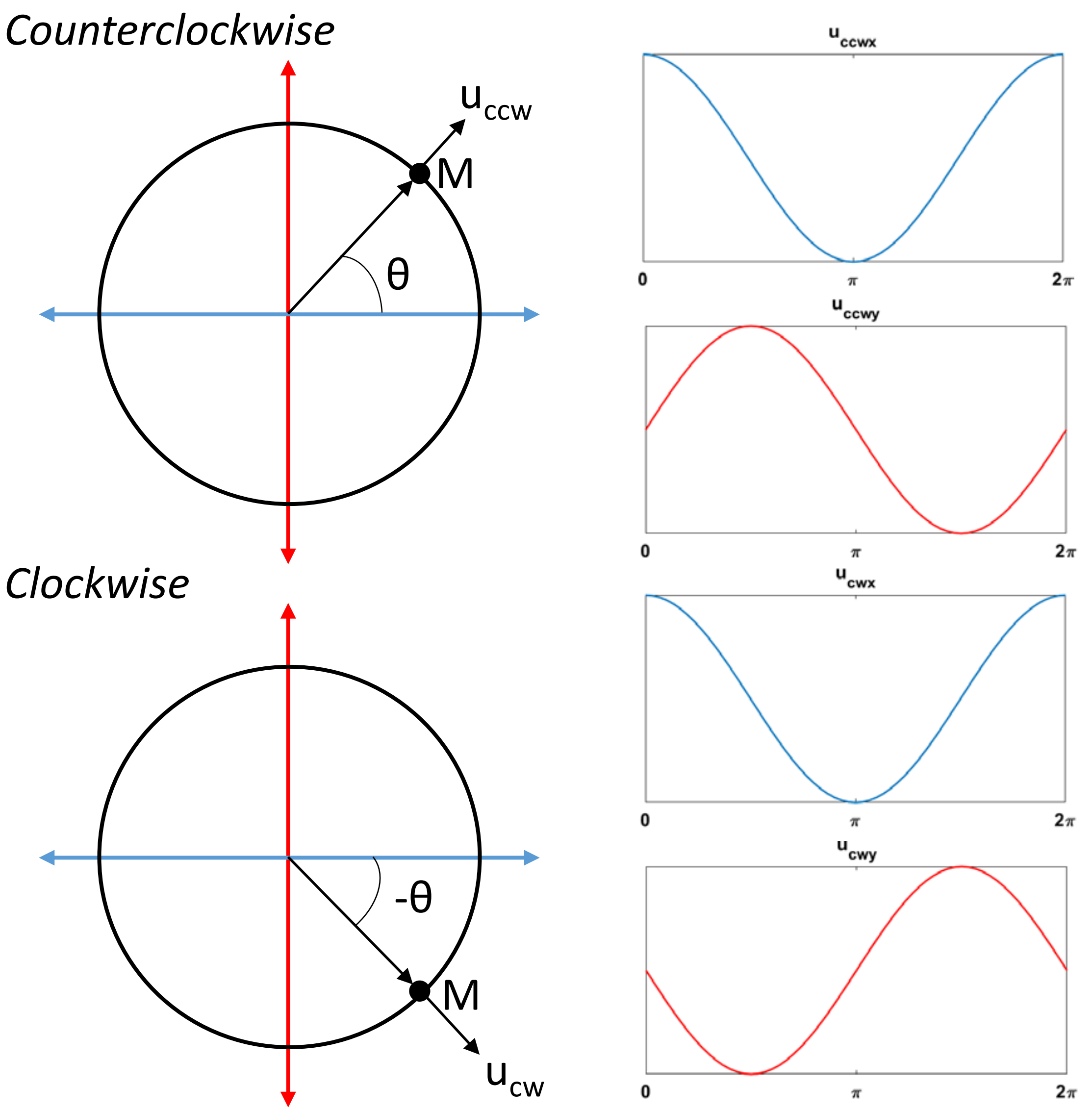
Motivations

- Active source monitoring (4D seismic) has many applications related to fluid injection & extraction:
  - Waterfloods
  - Steam chamber monitoring
  - Caprock integrity
  - CO_2 sequestration
- Two major issues with conventional 4D acquisition:
  1. Survey repeatability
  2. Time intervals between surveys
- Continuous seismic sources address both of these issues

Background

- Sources operate by rotating an eccentric mass around an axle which is fixed to the ground
- Source signature easily modelled by sinusoidal function
- Component of particle displacement can be boosted or cancelled by reversing rotation direction, then taking the sum or difference of the resulting data



Background

Analogy: washing machine

- Clothes inside machine form eccentric mass
- Causes vibration of entire machine

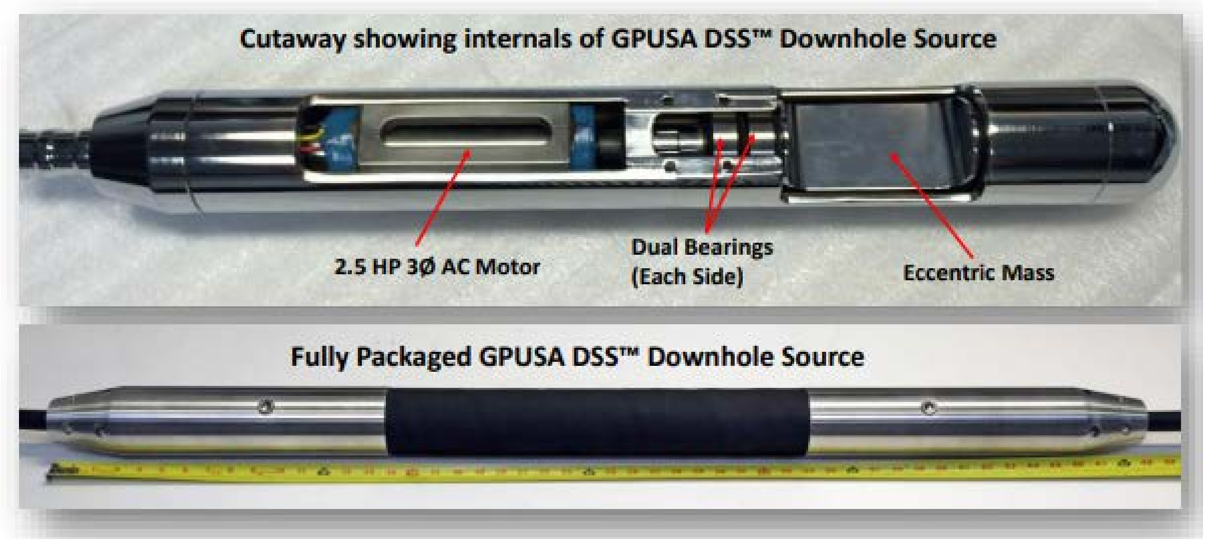
choice.com.au

realsimple.com

Background

- GPUSA orbital vibrators for continuous monitoring
- Installed in fixed location (surface, wells) and used in conjunction with permanent geophone array or DAS

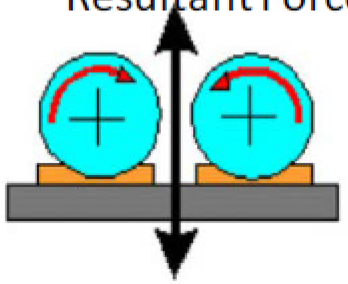
Borehole continuous source for crosswell monitoring



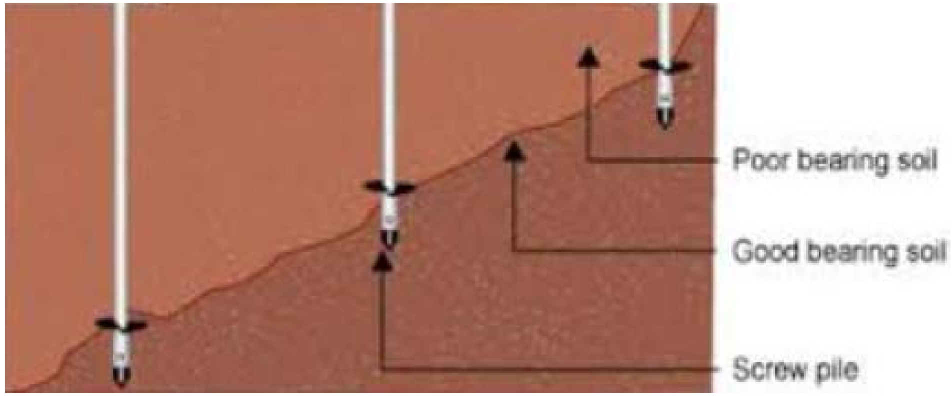
Photos courtesy GPUSA

✓ Survey repeatability

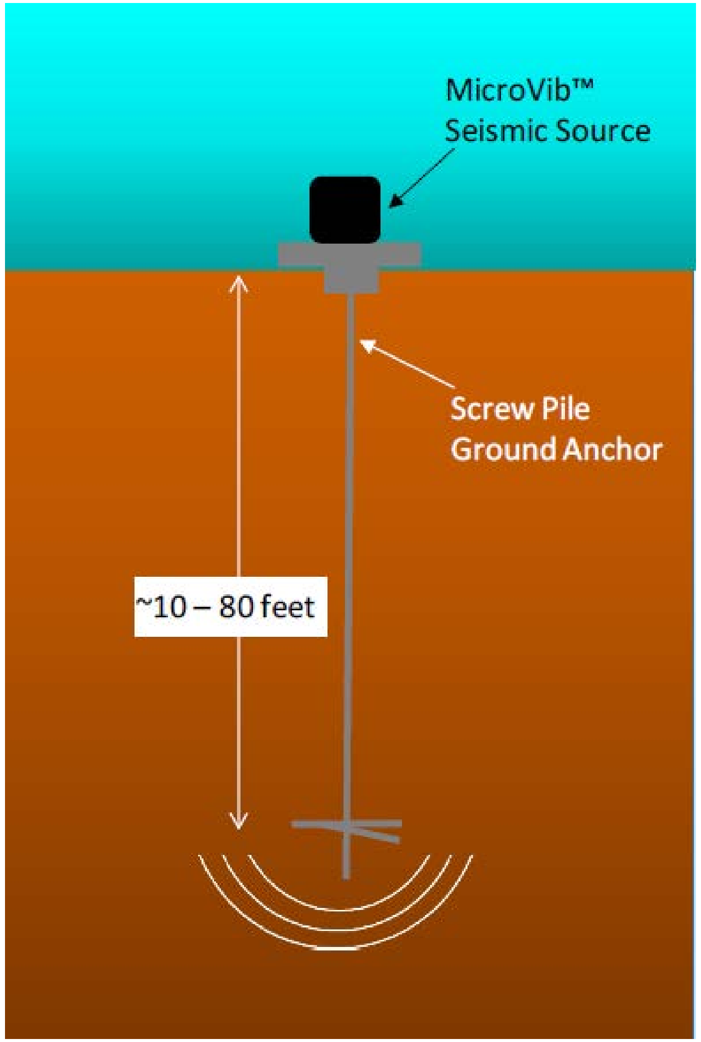
Linear vibrators installed at surface



Background



Images courtesy GPUSA

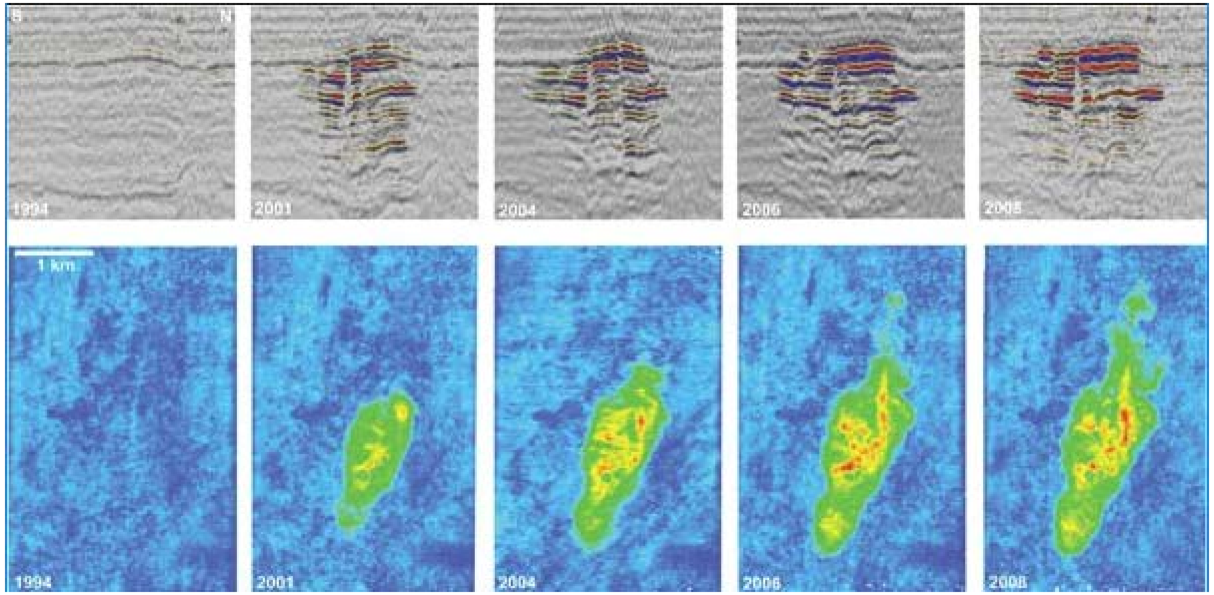


- Surface sources anchored below near surface layers to reduce attenuation
- Install several screw piles around survey area for multiple source points
- Impact of screw pile on source location/signature?

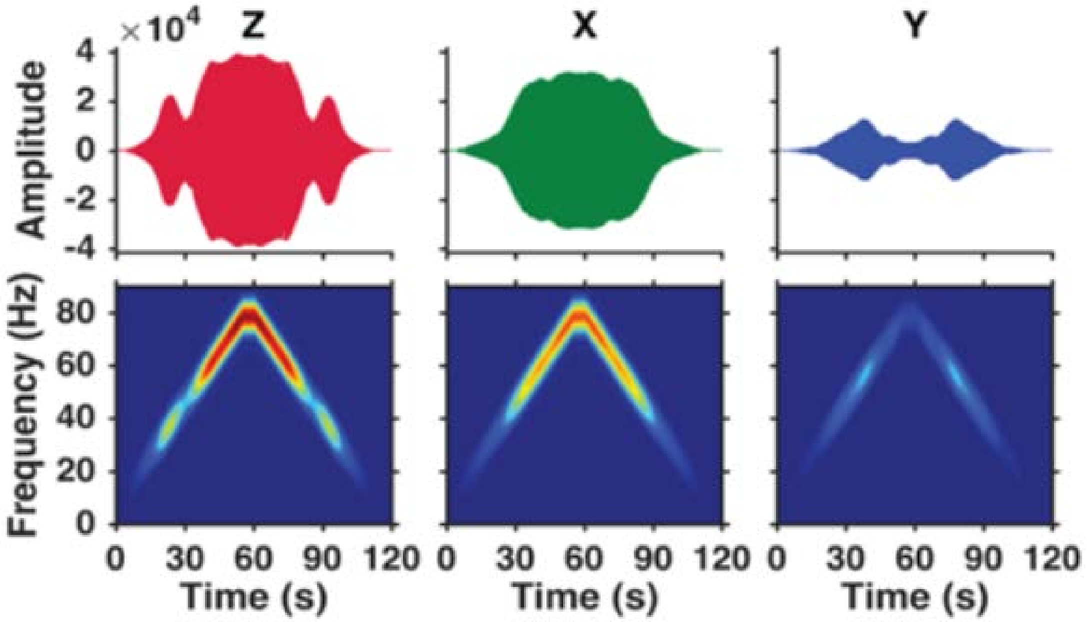
Background

“Conventional” 4D seismic program:
- 1+ years between surveys
- Survey geometry that attempts to recreate baseline

Continuous source 4D seismic program:
- Create daily/weekly/monthly stacks
- Permanent source & receiver geometry



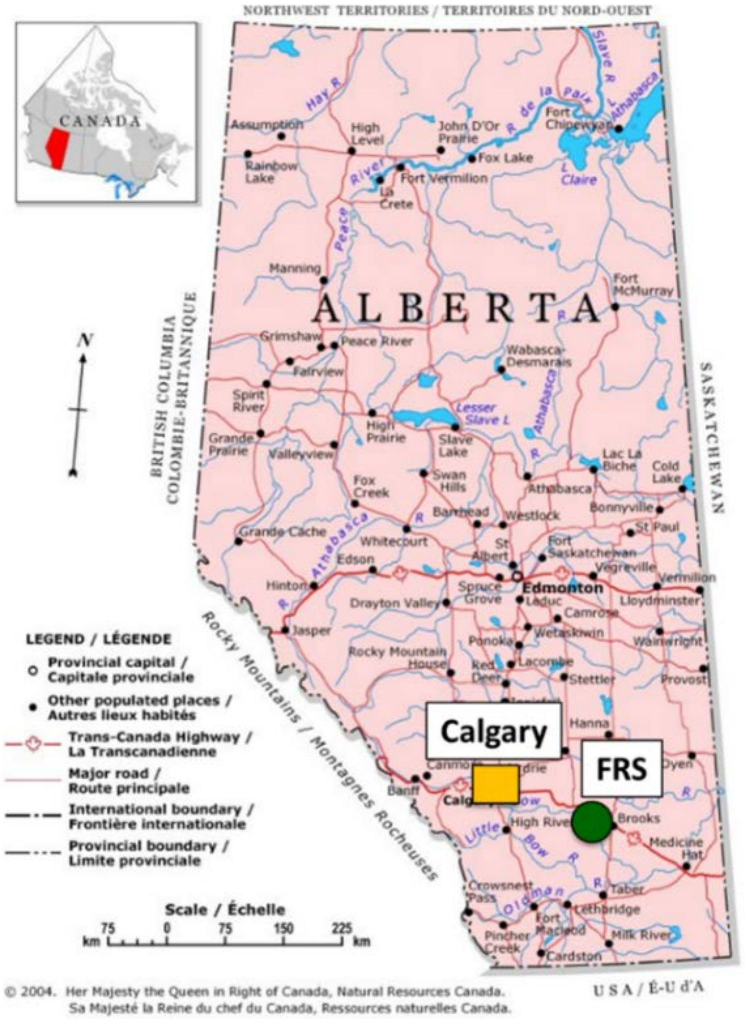
Chadwick et al., 2010



Freifeld et al., 2016

✓ Time interval between survey

Field work


NORTHWEST TERRITORIES / TERRITOIRES DU NORD-OUEST
CANADA
ALBERTA
BRITISH COLUMBIA
COLOMBIE-BRITANNIQUE
SASKATCHEWAN
Rocky Mountains / Montagnes Rocheuses
N
Calgary
FRS
Edmonton
LEGEND / LÉGENDE
Provincial capital / Capitale provinciale
Other populated places / Autres lieux habités
Trans-Canada Highway / La Transcanadienne
Major road / Route principale
International boundary / Frontière internationale
Provincial boundary / Limite provinciale
Scale / Échelle
75 0 75 150 225
km
USA / É-U d'A
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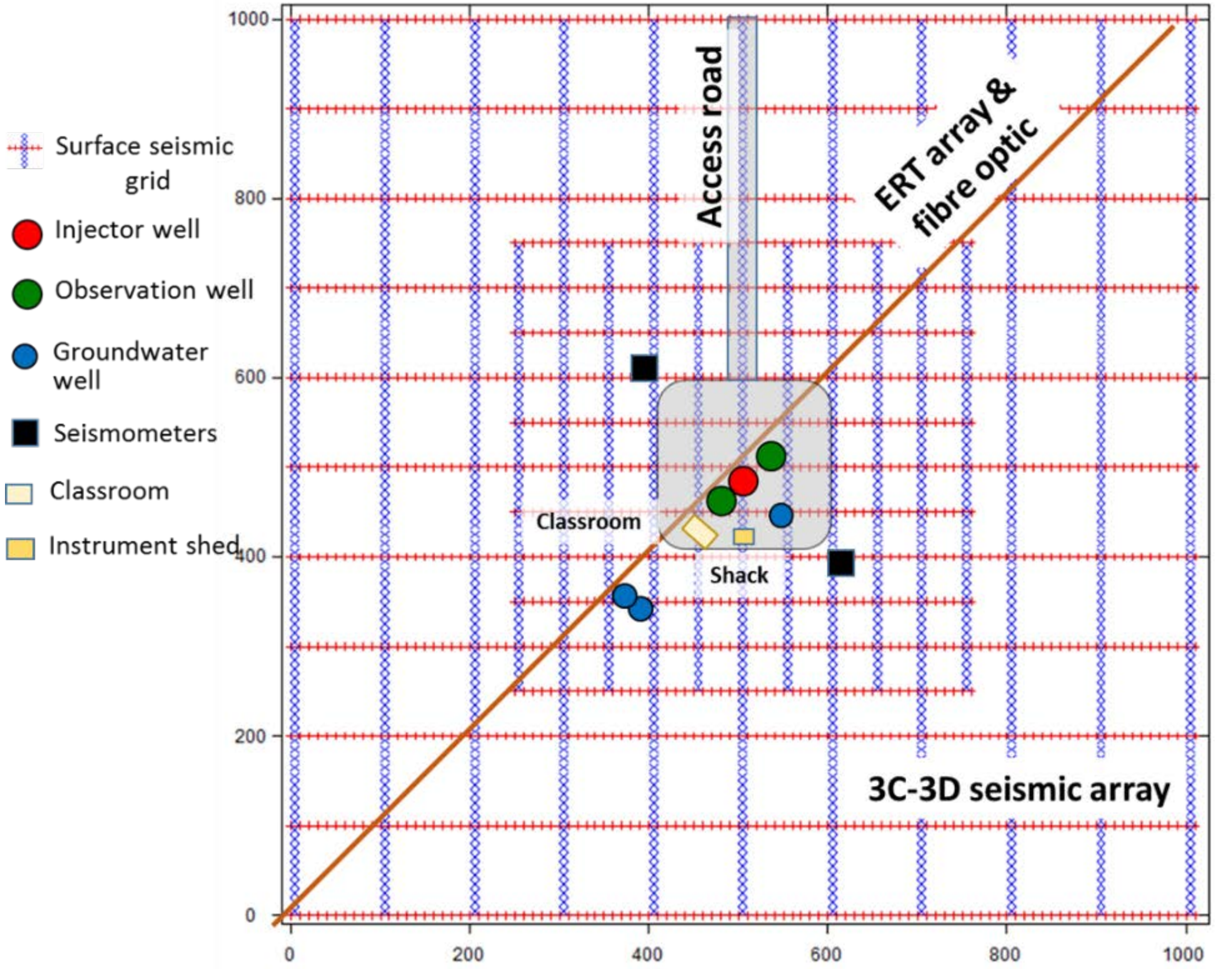
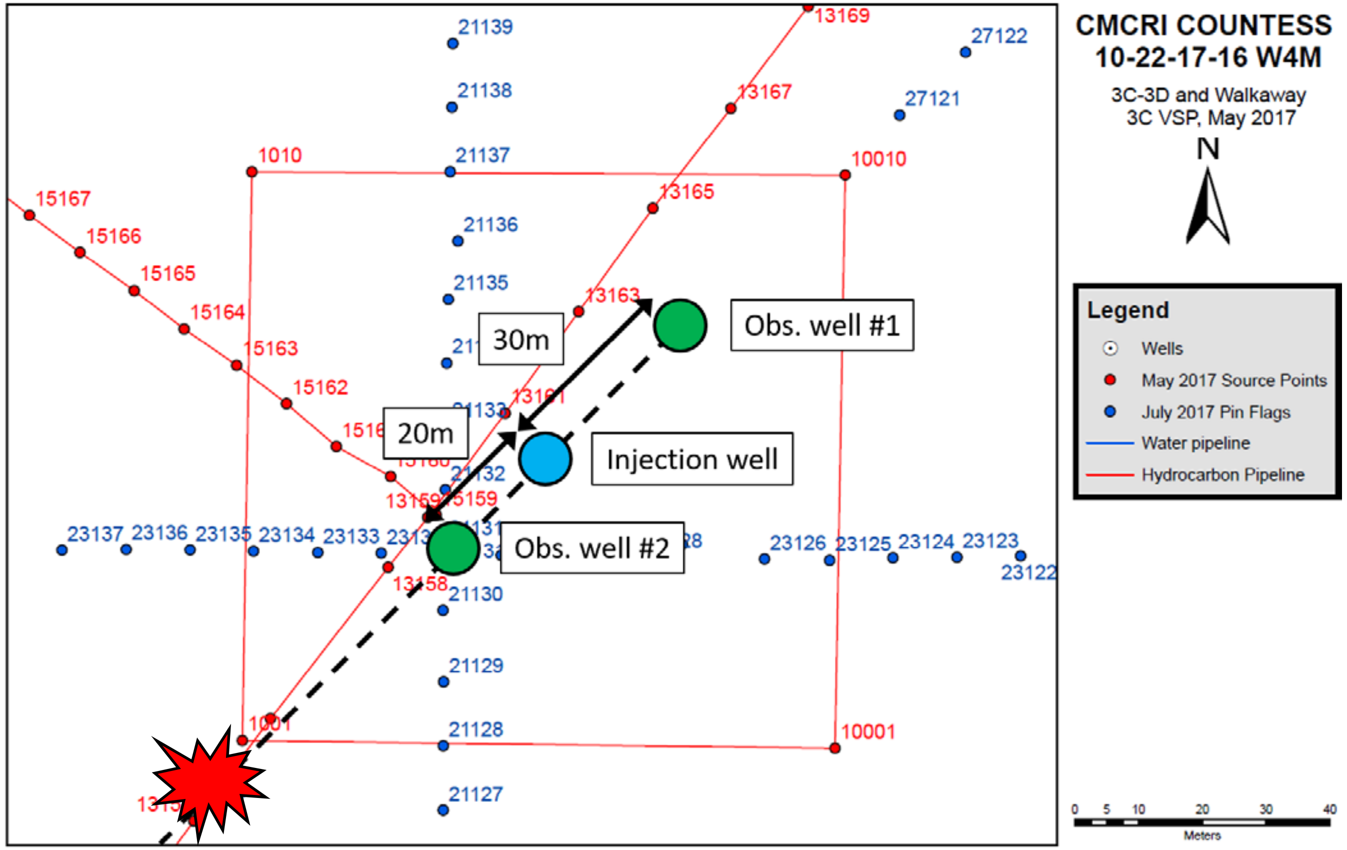
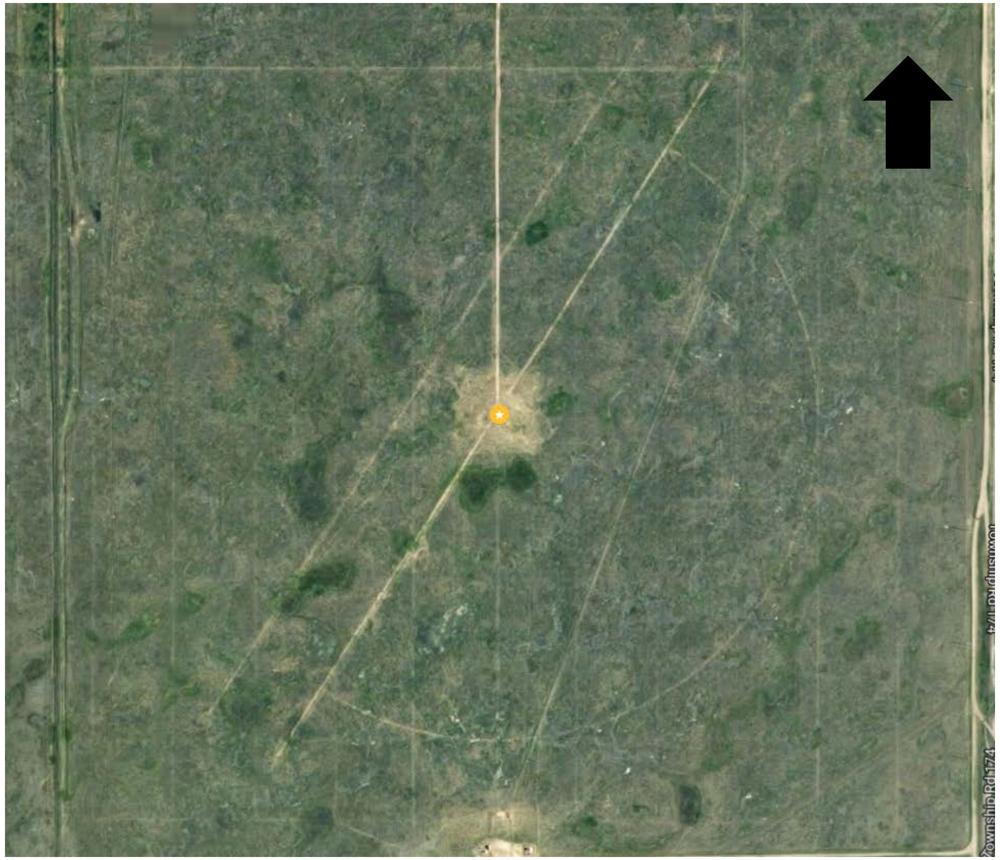

Surface seismic grid
Injector well
Observation well
Groundwater well
Seismometers
Classroom
Instrument shed
Access road
ERT array & fibre optic
Classroom
Shack
3C-3D seismic array
0
200
400
600
800
1000
0
200
400
600
800
1000

Field work

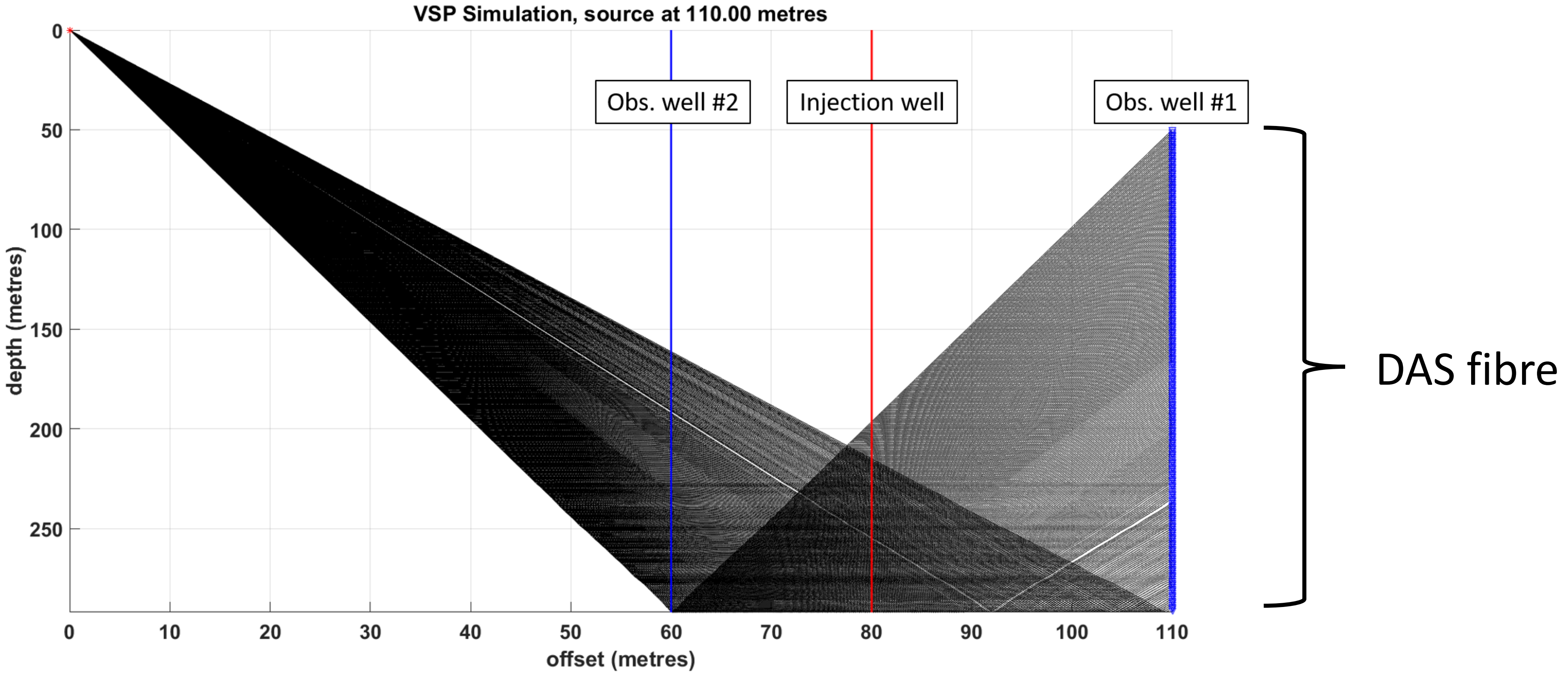
Objective: determine ideal location for continuous seismic source for acquiring VSP in observation well #1



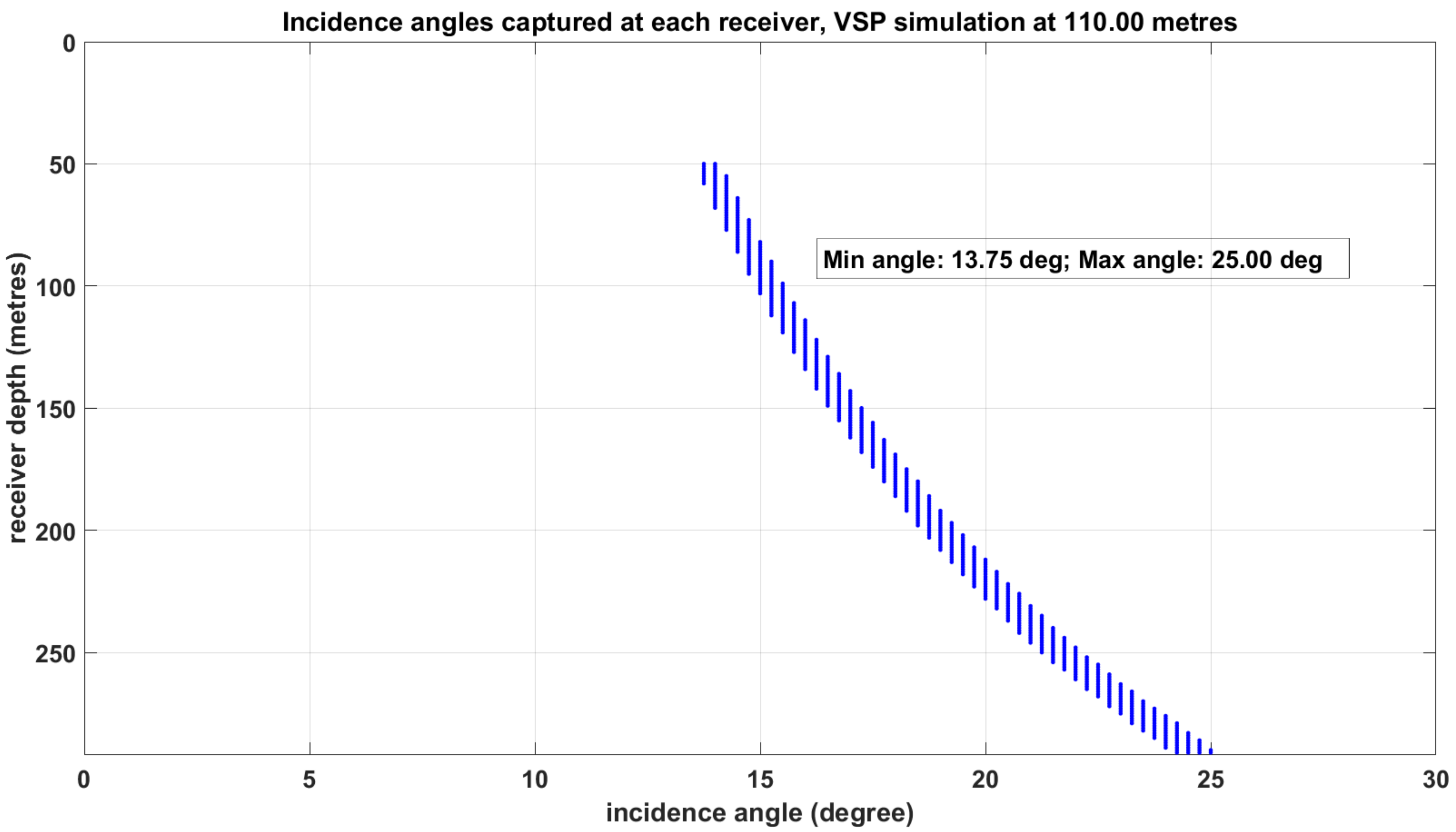


Google, 2017.

- Test a range of offsets to find the optimum balance between:
  1. Maximizing spatial coverage of injected CO_2 plume
  2. Maximizing angle content to capture potential AVO/AVA effects

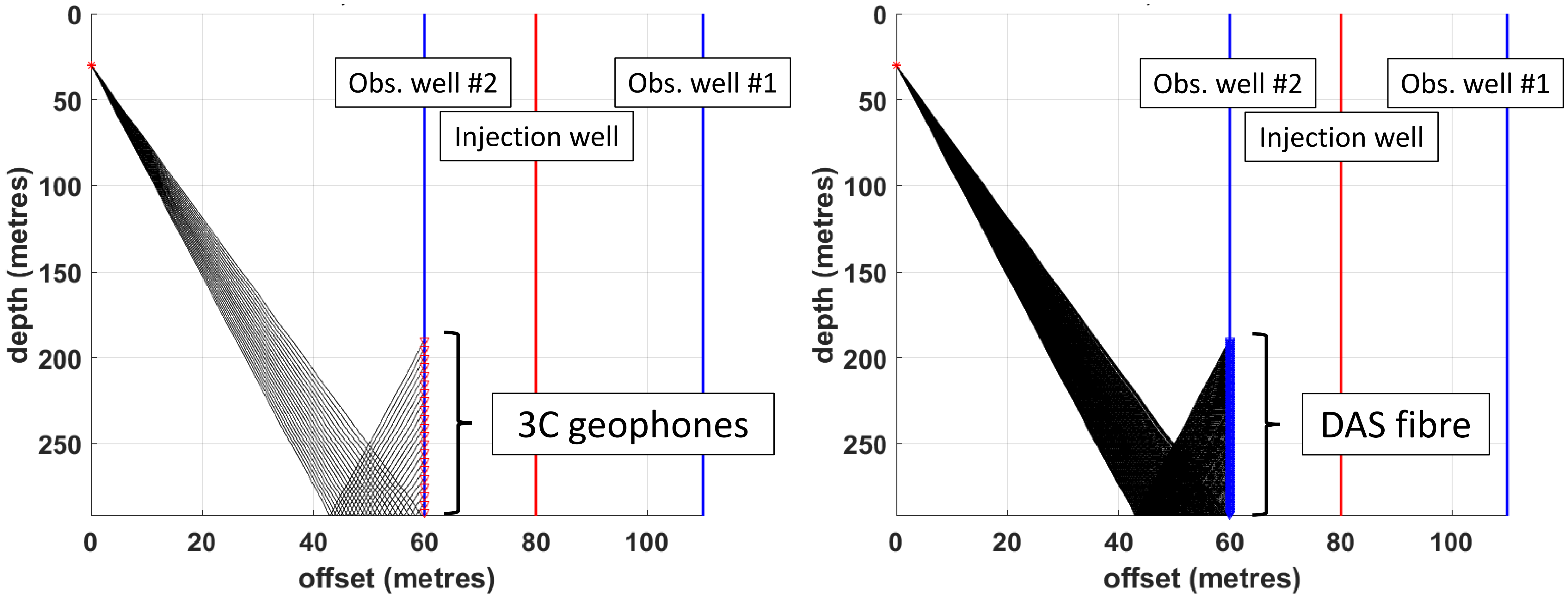


Field work


Incidence angles captured at each receiver, VSP simulation at 110.00 metres
Min angle: 13.75 deg; Max angle: 25.00 deg
receiver depth (metres)
0
50
100
150
200
250
incidence angle (degree)
0
5
10
15
20
25
30

Field work

- Observation well #2: DAS fibre, geophones at ~190m



Field work

- Mateeva et al. (2012): recorded amplitude in straight DAS fibre varies as $\cos^2(\theta)$, where θ is the angle between the incident ray and the fibre

- From raytracing with source at 110m offset, incidence angles at the fibre:

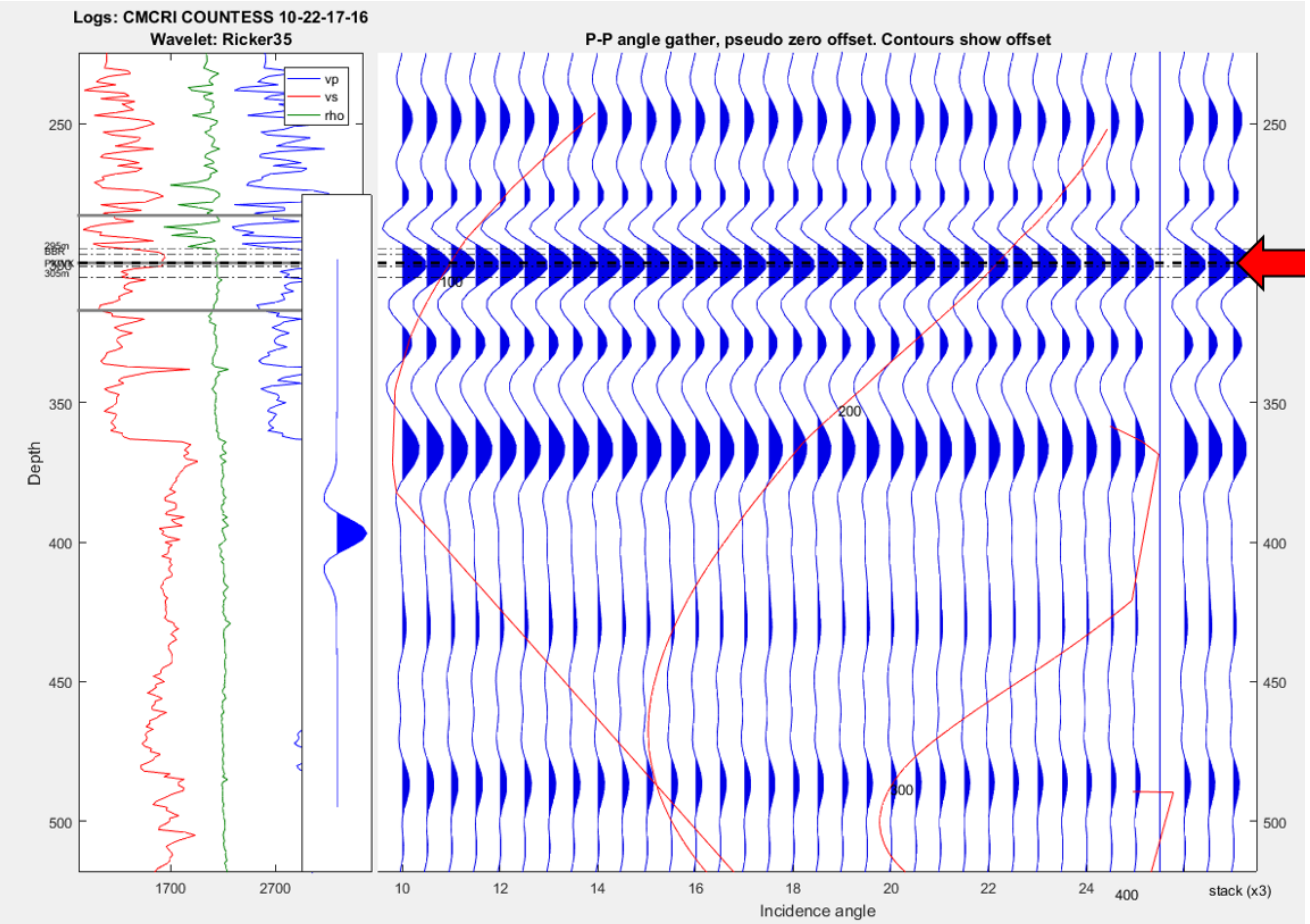
	Angle (degrees)	$\cos^2(\theta)$ scalar
Minimum	11.5	0.96
Maximum	24.5	0.83

Obs. well #1

	Angle (degrees)	$\cos^2(\theta)$ scalar
Minimum	8.1	0.98
Maximum	13.8	0.94

Obs. well #2

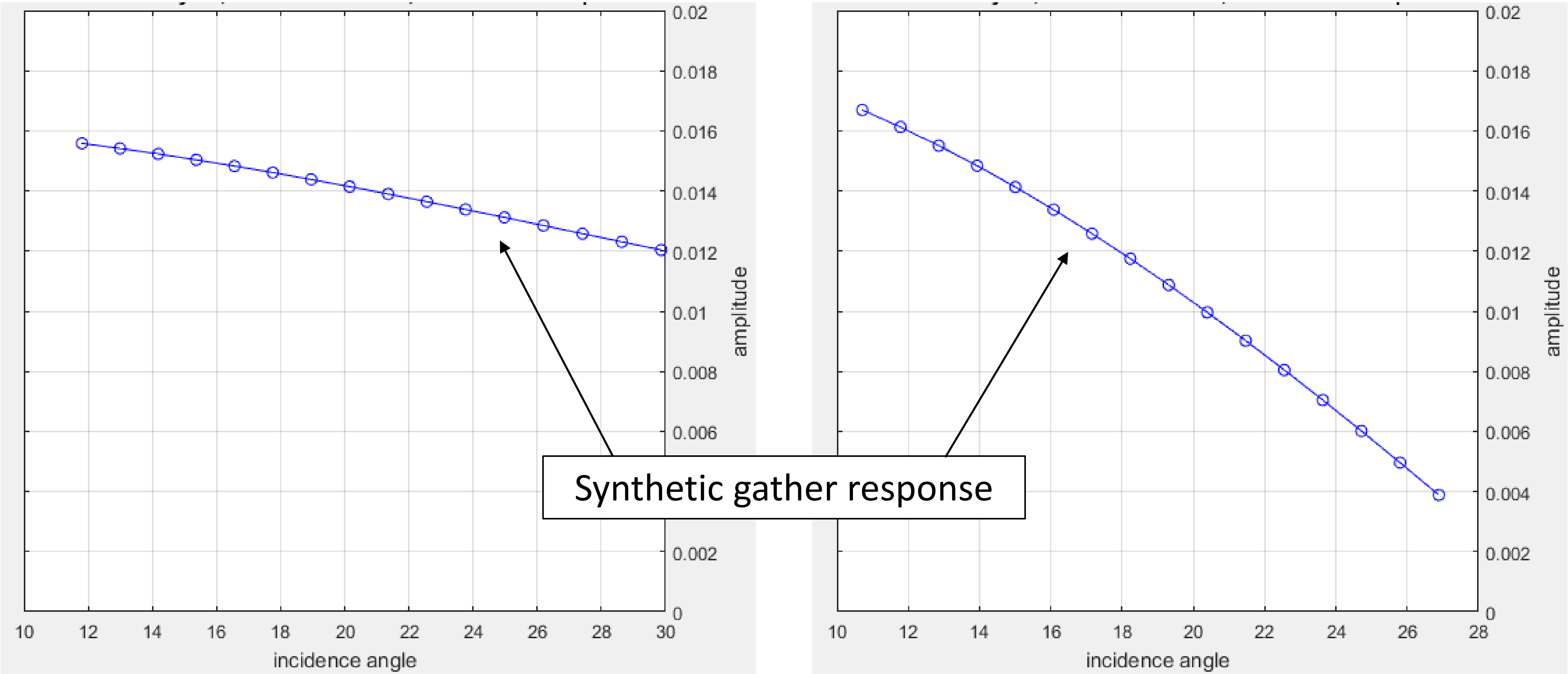
Field work



- Non-zero offset synthetics modeled using injector well logs
- Two endmembers: 100% water saturation, 100% CO_2 saturation
- Attempt to identify if there is potential for AVO anomalies

Field work

100% water saturation (pre-injection case) 100% CO_2 saturation (post-injection case)



Future work

- Begin acquisition using continuous sources in late 2017/early 2018
- Develop processing routine that requires minimal user inputs
- How to handle large quantities of data?

Conclusions

- Continuous seismic sources offer significant improvement over conventional 4D seismic programs in survey repeatability, time interval between surveys
- Continuous source data can be easily modelled using a sinusoidal source function, thus can boost or suppress a selected component of the data by reversing the rotation direction
- Offset of 110 metres between observation well #1 and continuous source provides optimal combination of:
  1. Spatial coverage of predicted high-saturation area around injector
  2. Angle content in recorded data
  3. Minimal reduction in amplitudes recorded in straight fibre

Acknowledgements

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Questions?