The feasibility of detecting CO_2 leaks using passive seismic monitoring

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1. University of Bristol
2. University of Edinburgh
3. University of Cambridge
4. Geological Survey Canada

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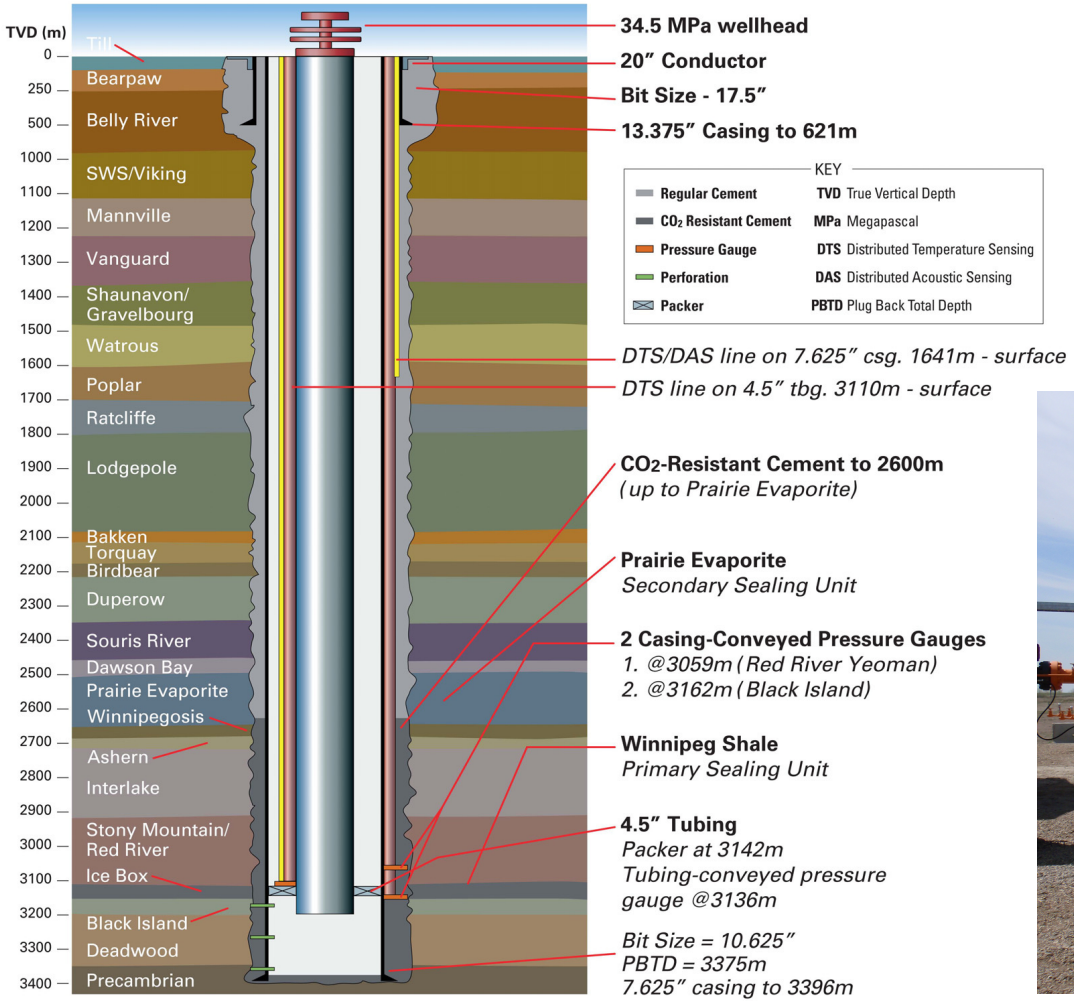
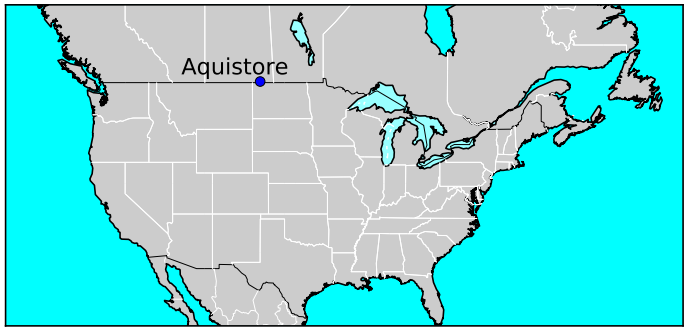
How useful is seismic monitoring in the event of a leak from a CO_2 storage site?

- Carbon capture and storage is only effective if stored for 1000s years with <~1% leakage rate.
- Potential for seismic events and seismic velocity changes with leak.

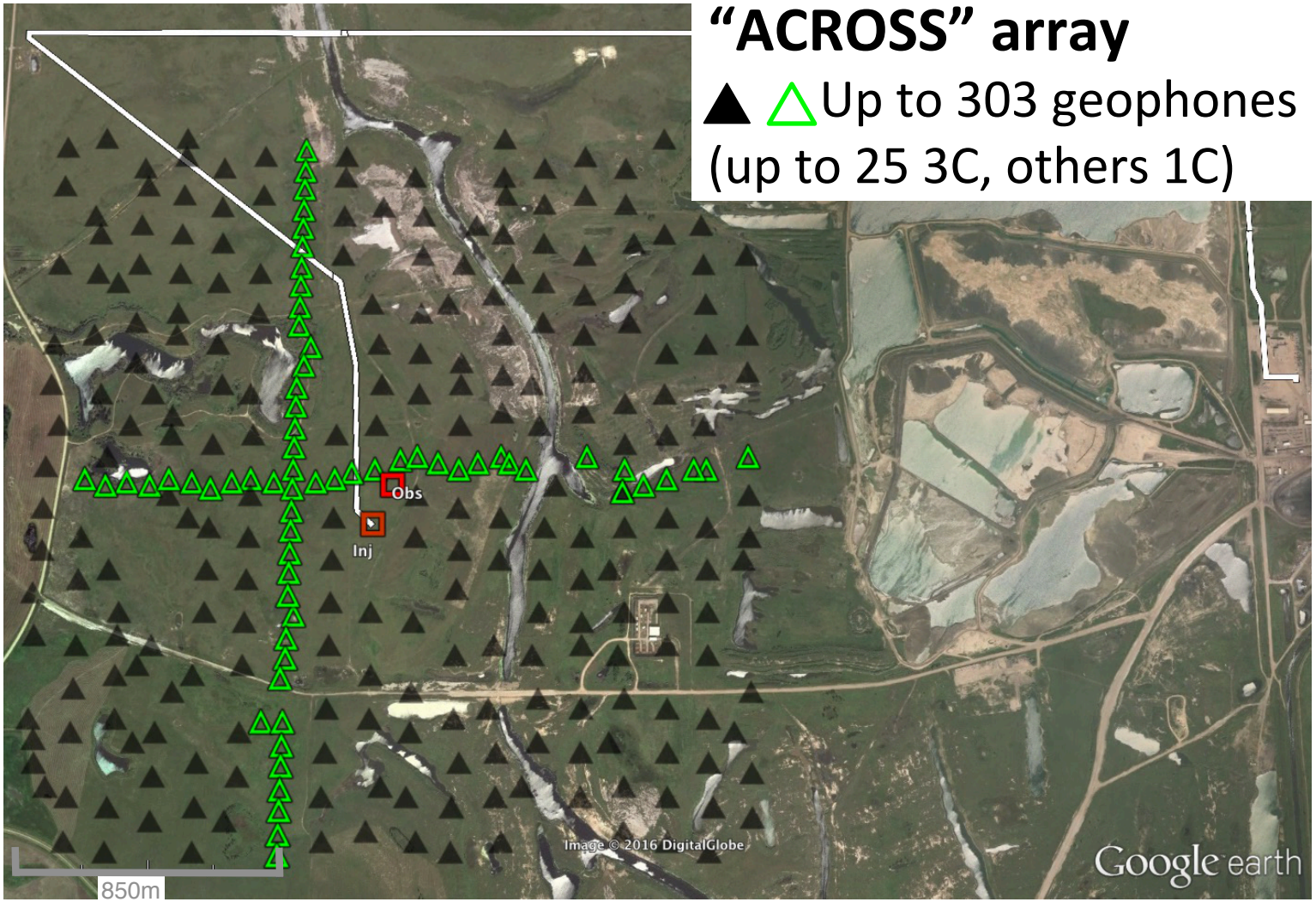
BOUNDARY DAM - AQUISTORE CO_2 INJECTION PROJECT

World's first commercial power plant CCS project





- Potential for induced seismicity
  - Fluid-flow modelling to determine whether fracture pressure will be exceeded.
- Potential to observe seismic velocity change
  - Ambient noise interferometry (ANI),
  - Tomographic inversion.

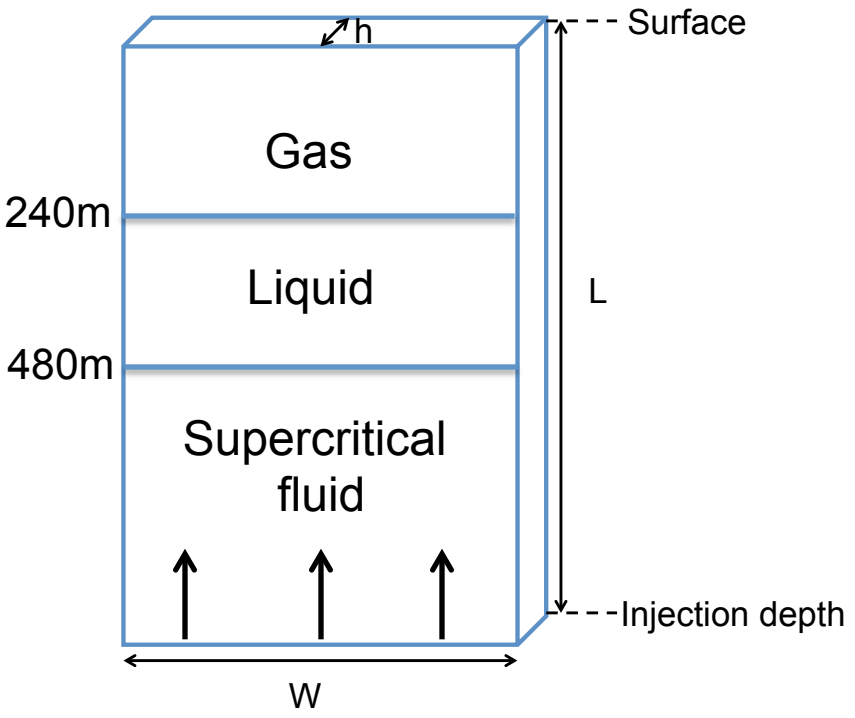


“ACROSS” array

▲ △Up to 303 geophones
(up to 25 3C, others 1C)

Fluid flow modelling methods

- Fault with pathway to surface
- Assume Darcy flow
- Viscous, laminar flow
- Incompressible fluid >240m
  - Constant viscosity
- Compressible gas <240m deep



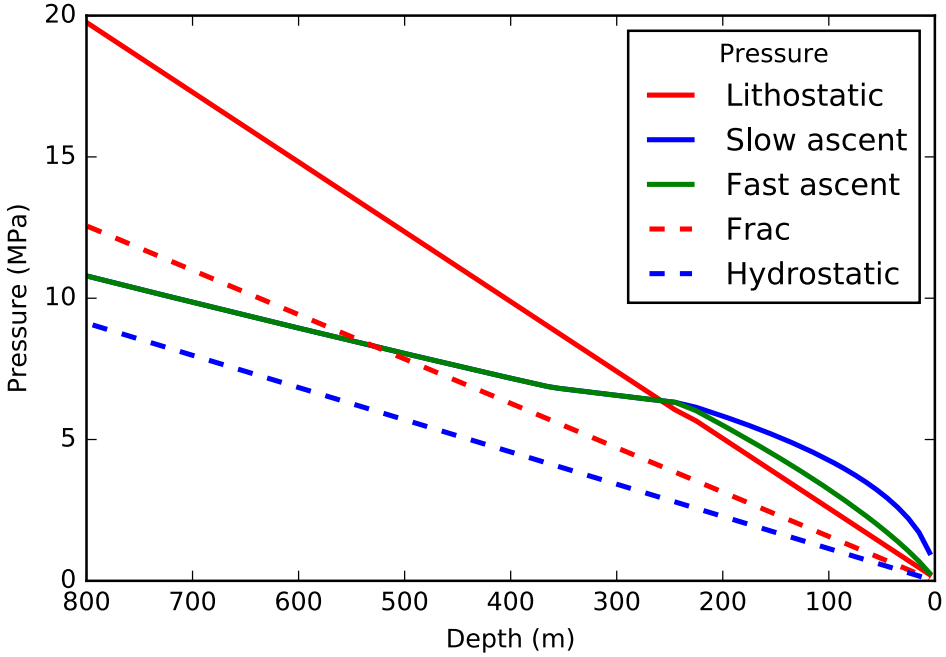
CO_2 pressure

Incompressible fluid

- Constant volume & density
- Pressure from data tables

Compressible gas

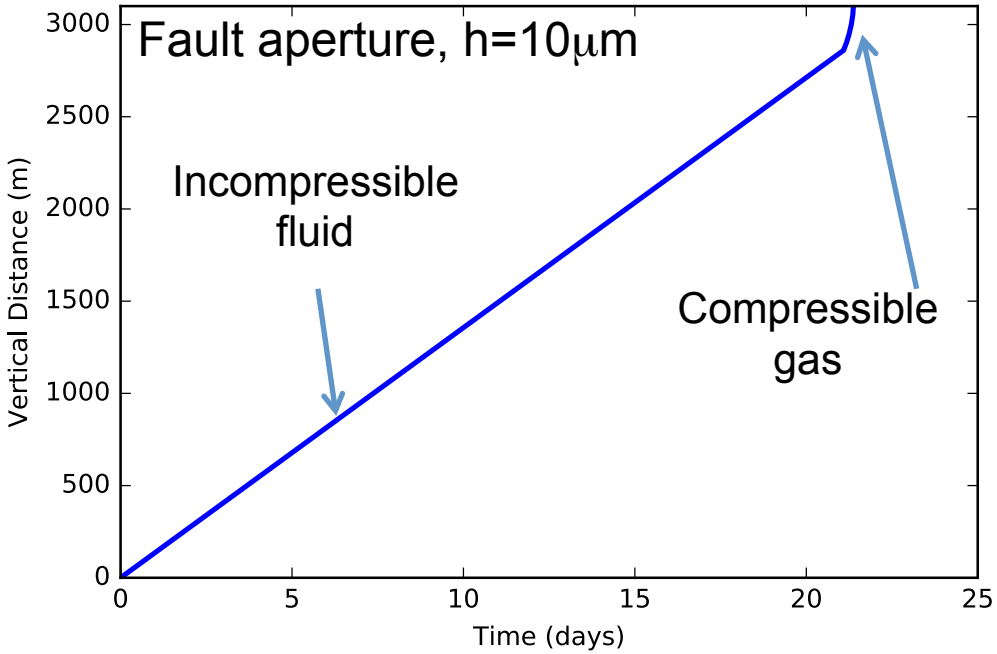
- Equations from Huppert & Sparks, J. Fl. Mech., 2016



Stork et al., in rev.

Frac pressure exceeded at depths <500m.

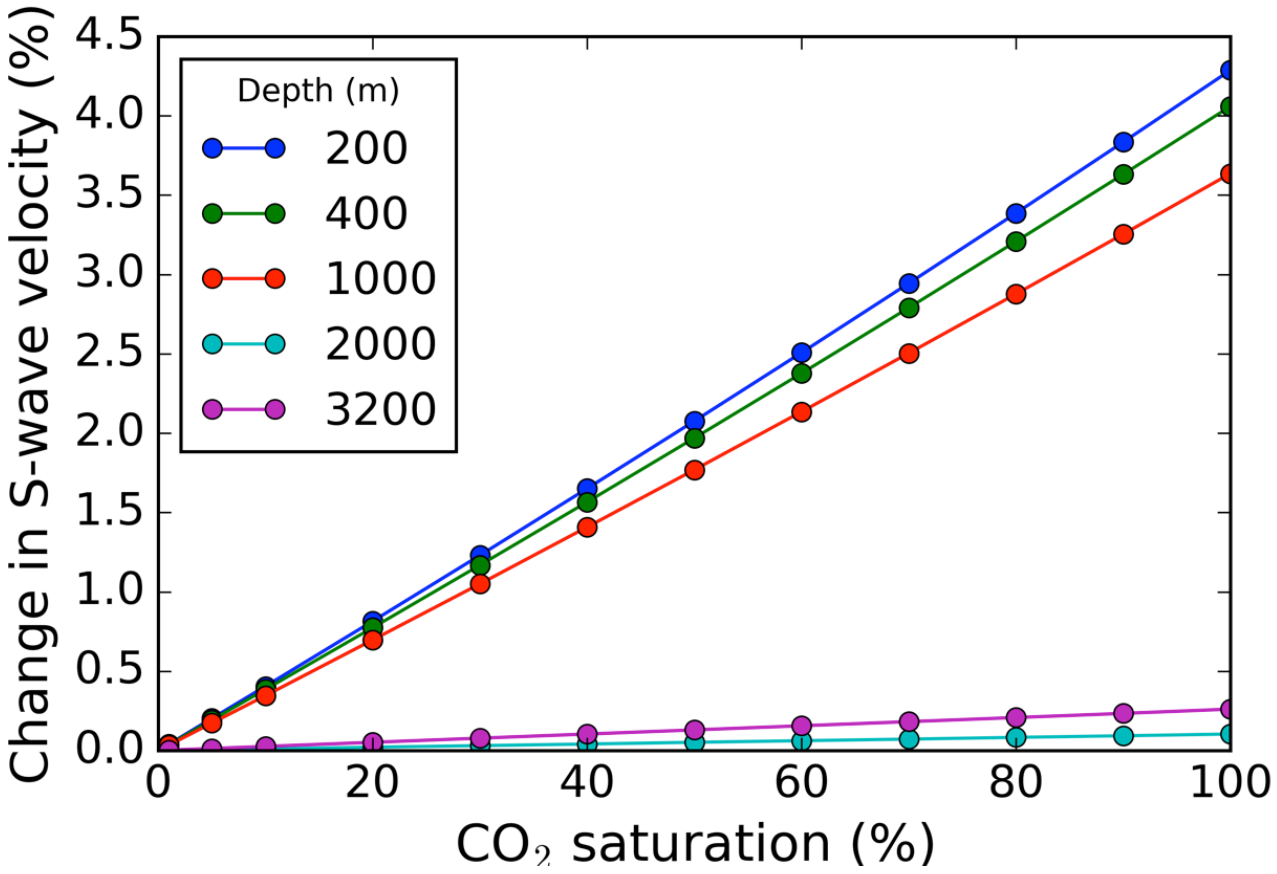
Travel-time to surface



Stork et al., in rev.

Frac pressure exceeded at depths <500m.
Potentially days before CO_2 reaches surface.

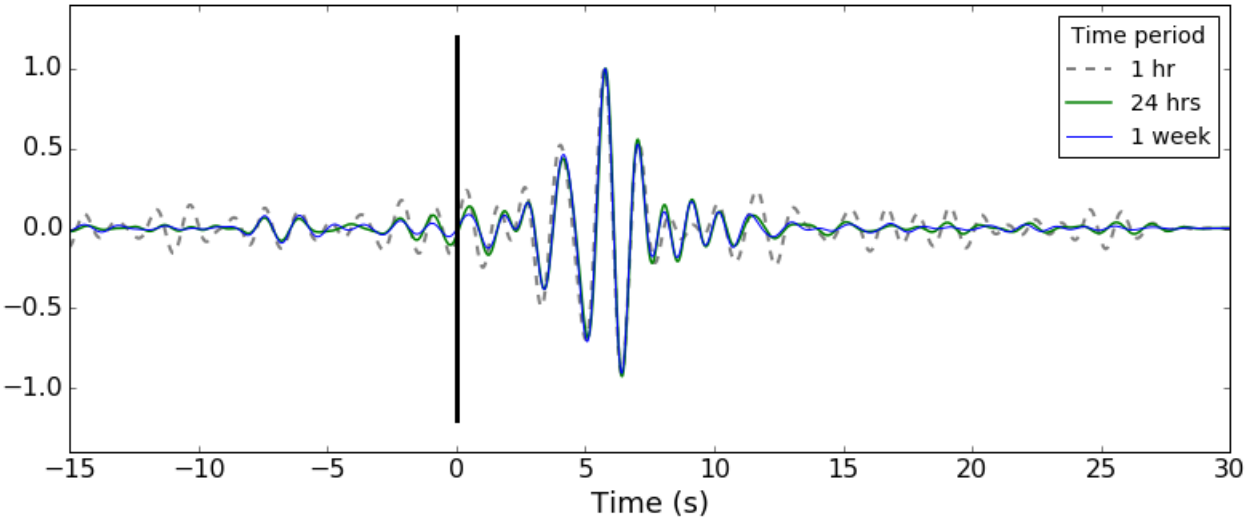
Predicted velocity changes with CO_2 influx



- Biot-Gassmann fluid substitution
- Brine pore fluid

Detecting velocity changes

- Ambient noise interferometry (e.g. Curtis et al., 2006)
  - Cross-correlation of noise recordings
  - 1 week April 2015 (pre-injection)
  - 1 week June 2015 (during injection)



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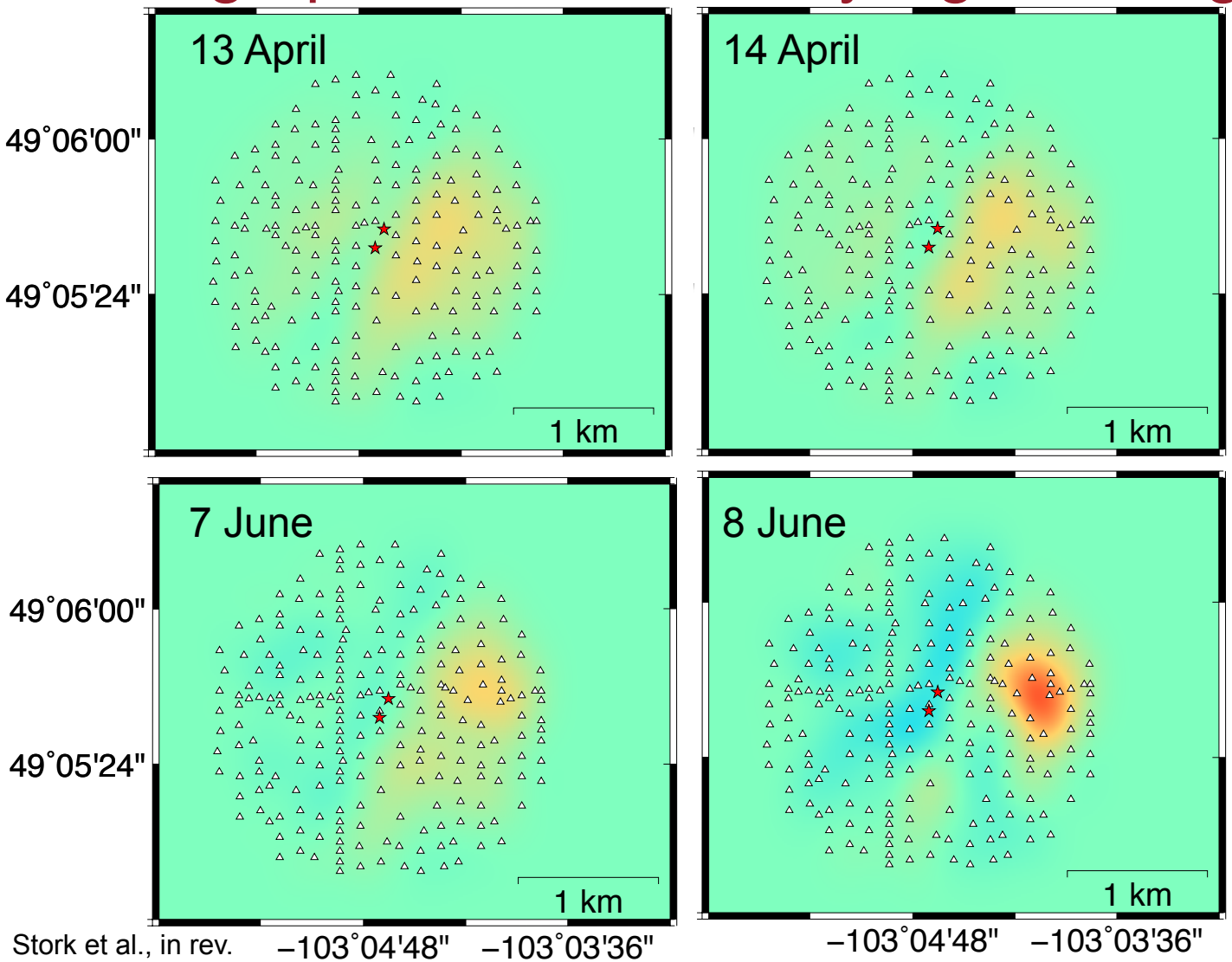
Tomographic inversion: Rayleigh wave group velocity



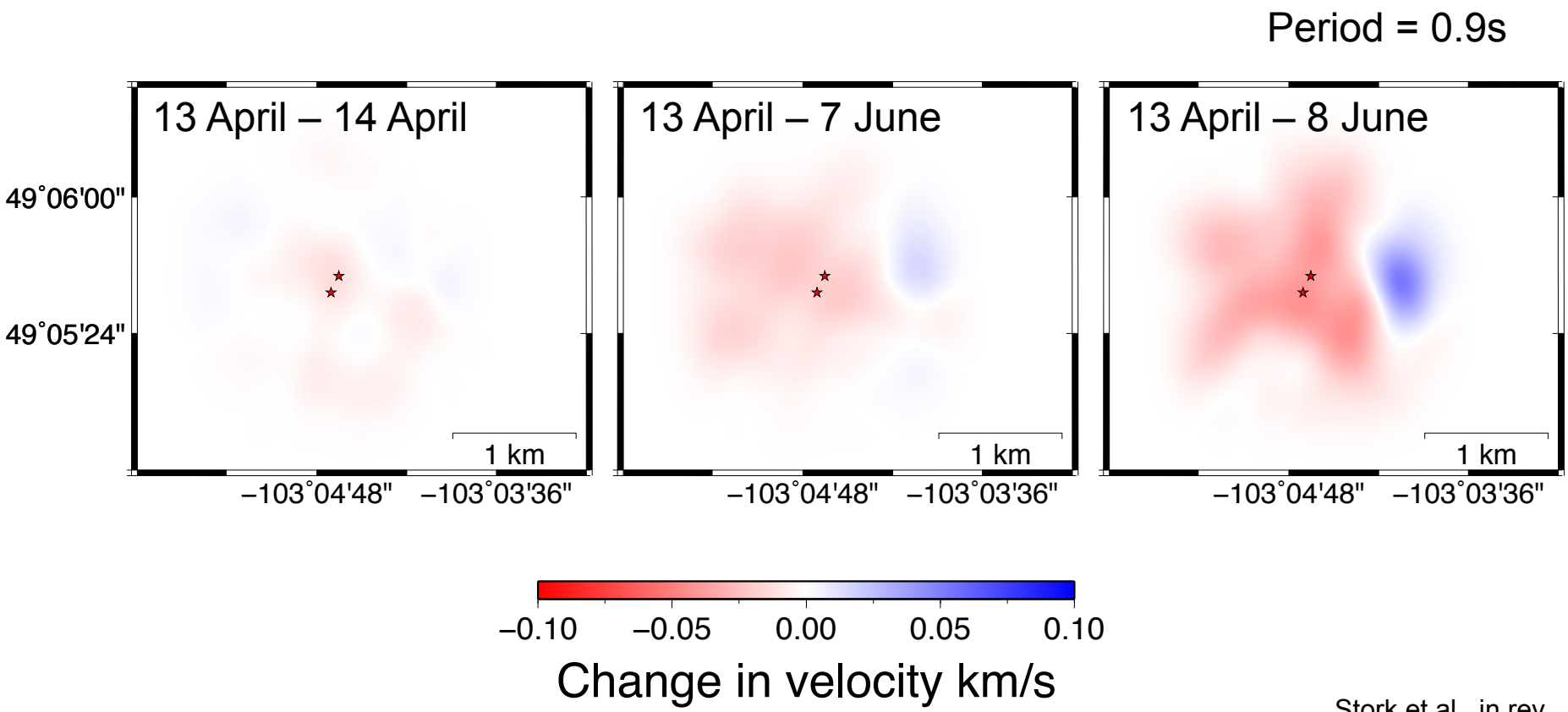
Period = 0.9s

0.2 0.3 0.4 0.5
Velocity km/s

(FMST, Rawlinson 2005)

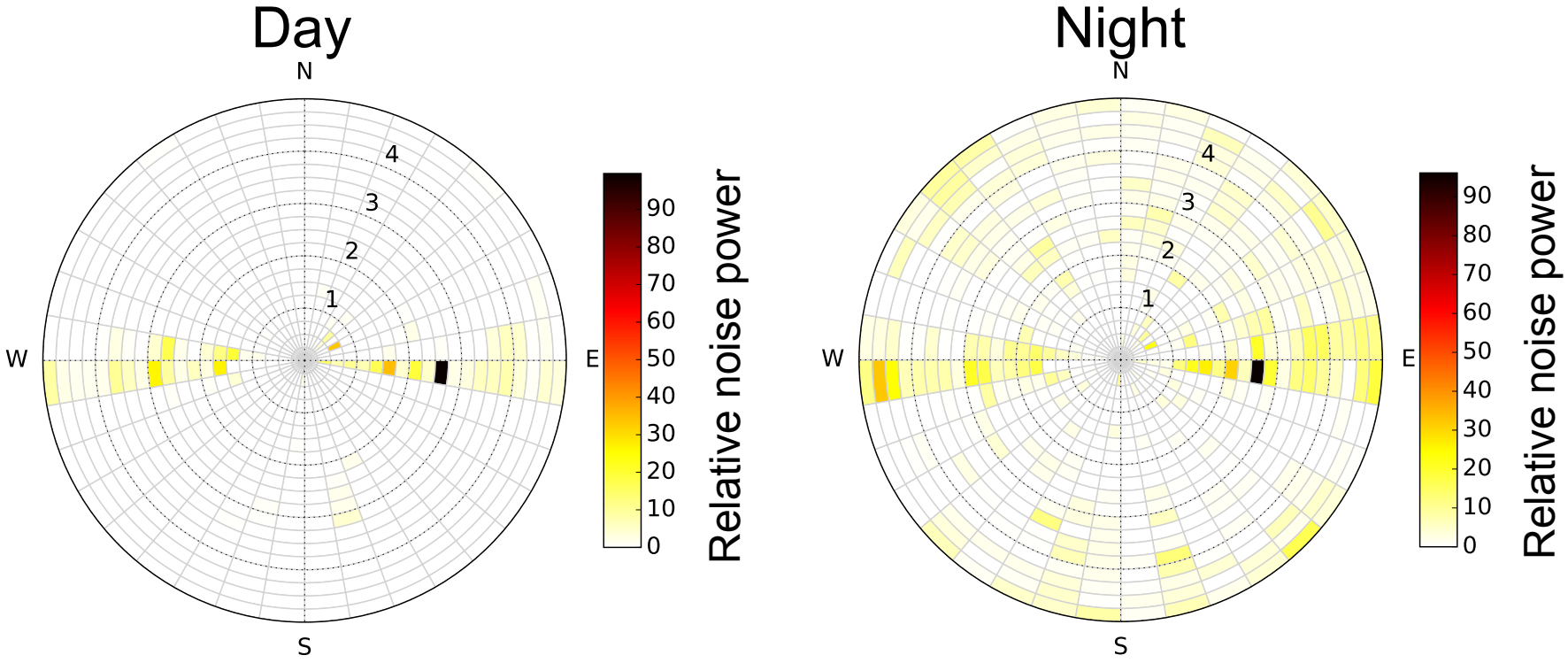
Stork et al., in rev.

Velocity differences

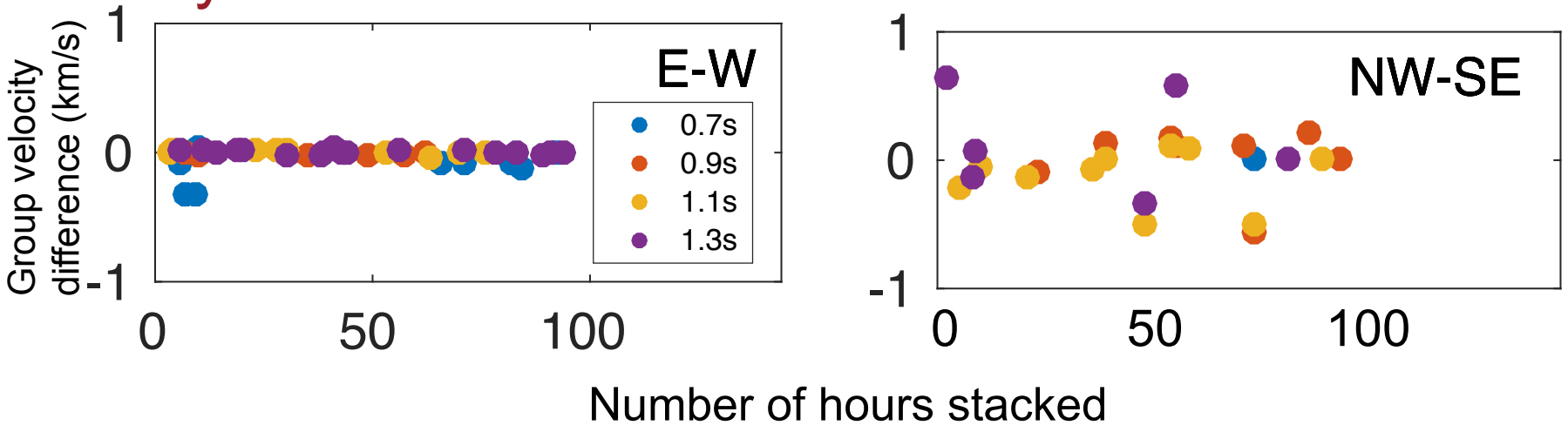


Stork et al., in rev.

Ambient noise



Velocity variation with stacked data



Conclusions

- Assessment of seismic monitoring as CO_2 leakage detection tool at Aquistore.
- Seismic events predicted if CO_2 <500m deep.
- Ambient noise interferometry currently unable to detect leak at Aquistore due to
  - Array aperture
  - Noise characteristics
  - Picking uncertainties
- In general, ANI could provide cost-effective, near real-time monitoring.

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TOTAL

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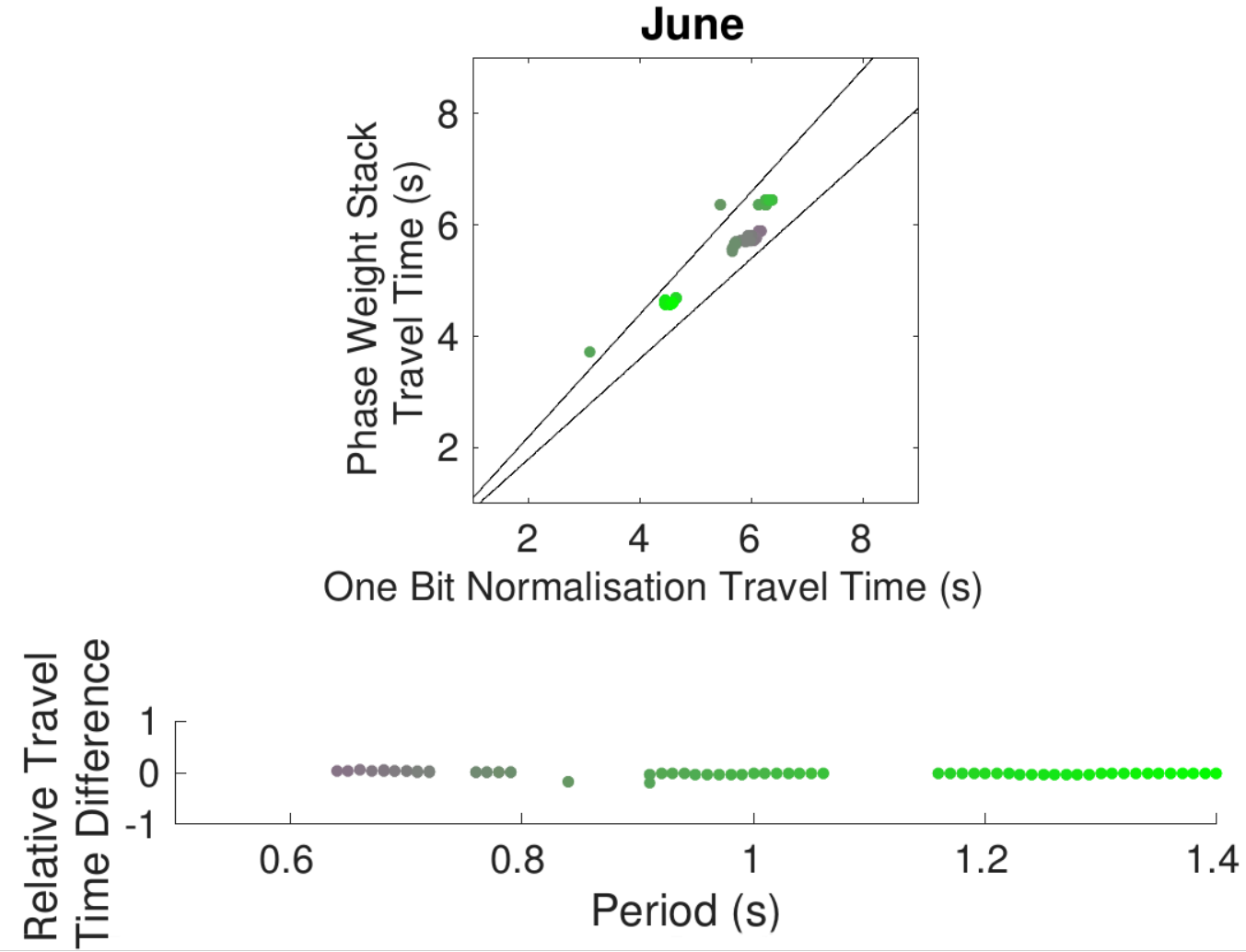
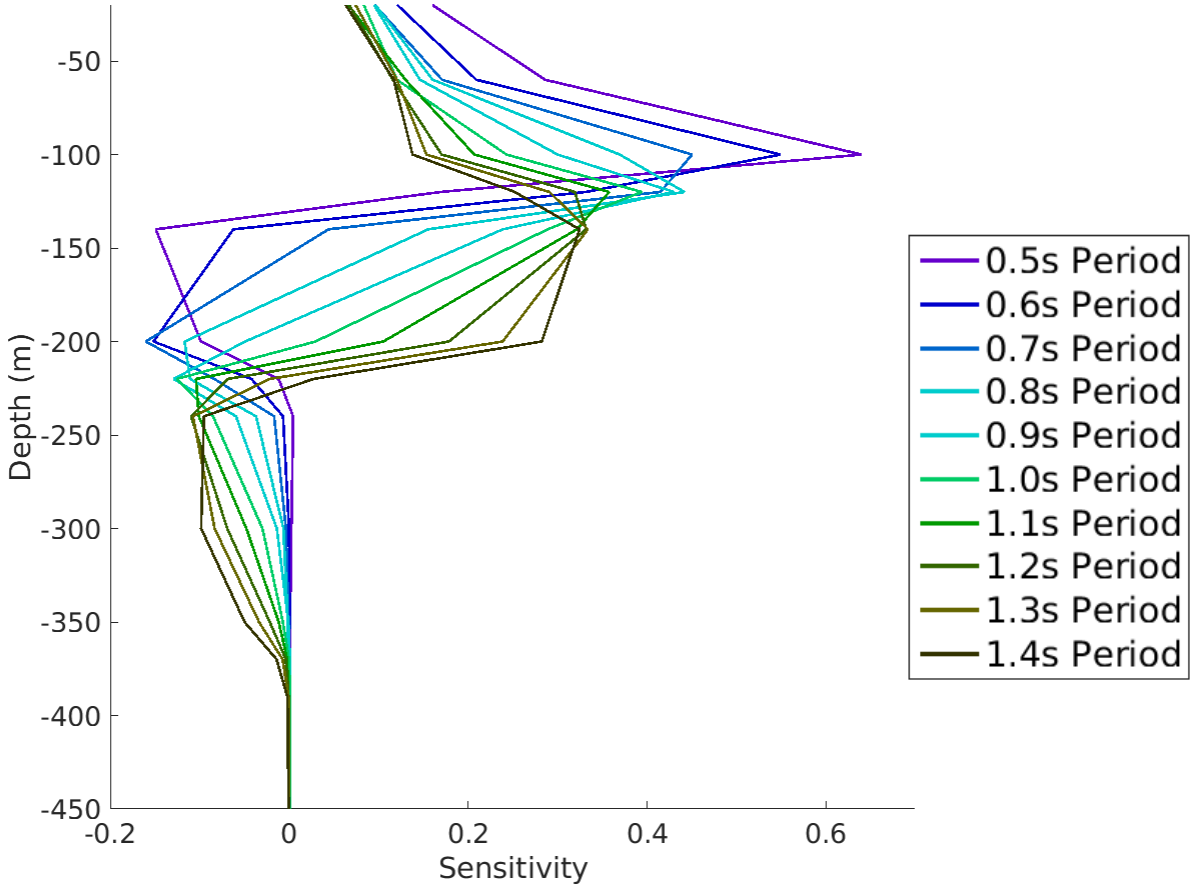
UKCCS RESEARCH CENTRE

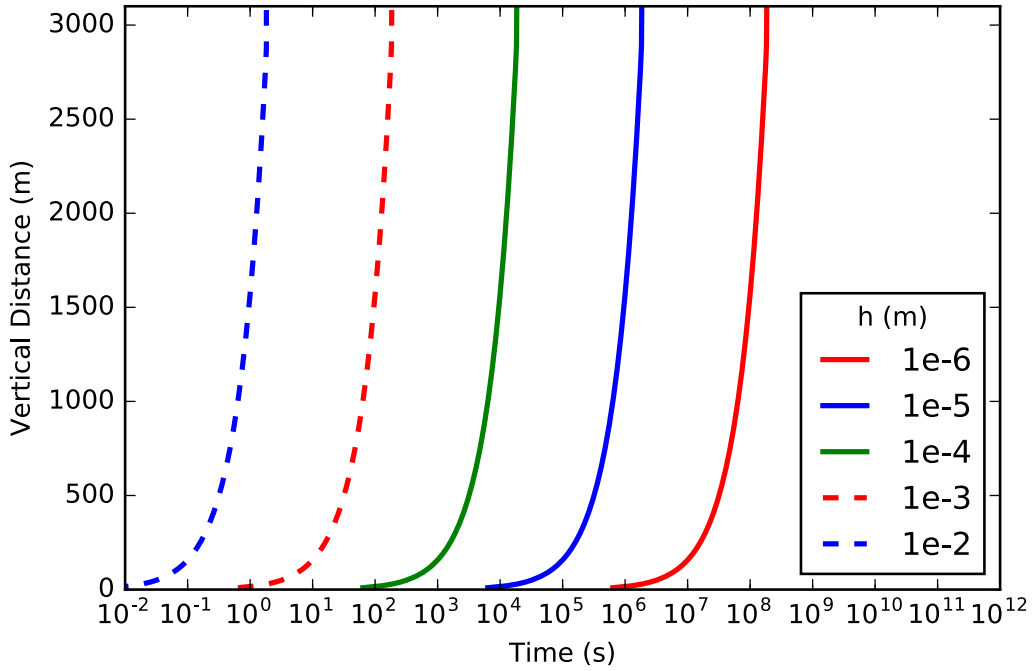
EPSRC
Engineering and Physical Sciences Research Council

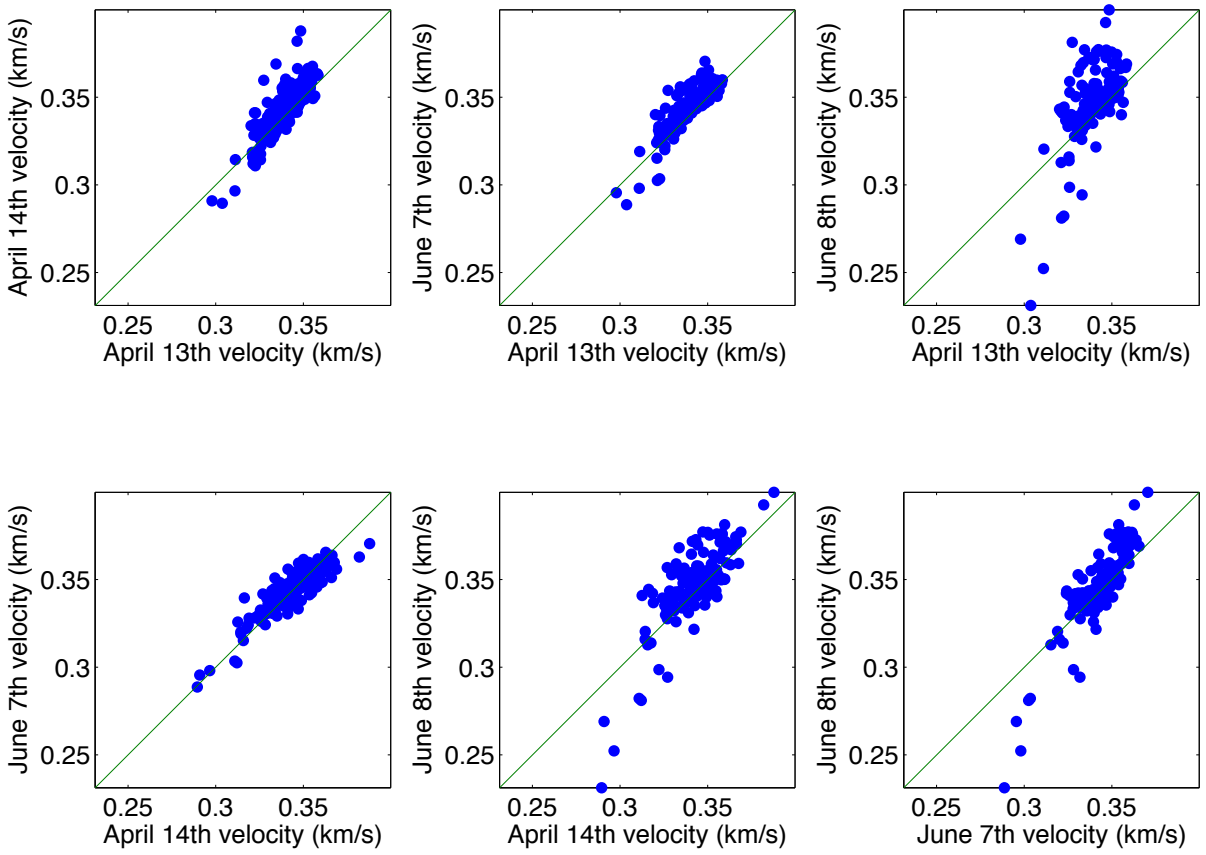
Thanks to the PTRC for providing permission to work with and present the data.

ptrc
Petroleum Technology Research Centre


June
Phase Weight Stack Travel Time (s)
2
4
6
8
2
4
6
8
One Bit Normalisation Travel Time (s)
Relative Travel Time Difference
1
0
-1
0.6
0.8
1
1.2
1.4
Period (s)


-50
-100
-150
-200
-250
-300
-350
-400
-450
Depth (m)
-0.2
0
0.2
0.4
0.6
Sensitivity
0.5s Period
0.6s Period
0.7s Period
0.8s Period
0.9s Period
1.0s Period
1.1s Period
1.2s Period
1.3s Period
1.4s Period


Vertical Distance (m)
3000
2500
2000
1500
1000
500
0
10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12}
Time (s)
h (m)
1e-6
1e-5
1e-4
1e-3
1e-2


April 14th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
April 13th velocity (km/s)
June 7th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
April 13th velocity (km/s)
June 8th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
April 13th velocity (km/s)
June 7th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
April 14th velocity (km/s)
June 8th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
April 14th velocity (km/s)
June 8th velocity (km/s)
0.35
0.3
0.25
0.25 0.3 0.35
June 7th velocity (km/s)

$$u_z = -(k/\mu)dp/dz$$