MVA demonstration activities at an EOR site with surface geodetic and geochemical techniques

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- Surface monitoring techniques are a potential low cost approach to MVA (Monitoring, Verification and Accounting)

- We have tested 4 techniques at an EOR site in south Texas:
  - Passive seismic
  - Geochemical (soil gas)
  - InSAR
  - GPS

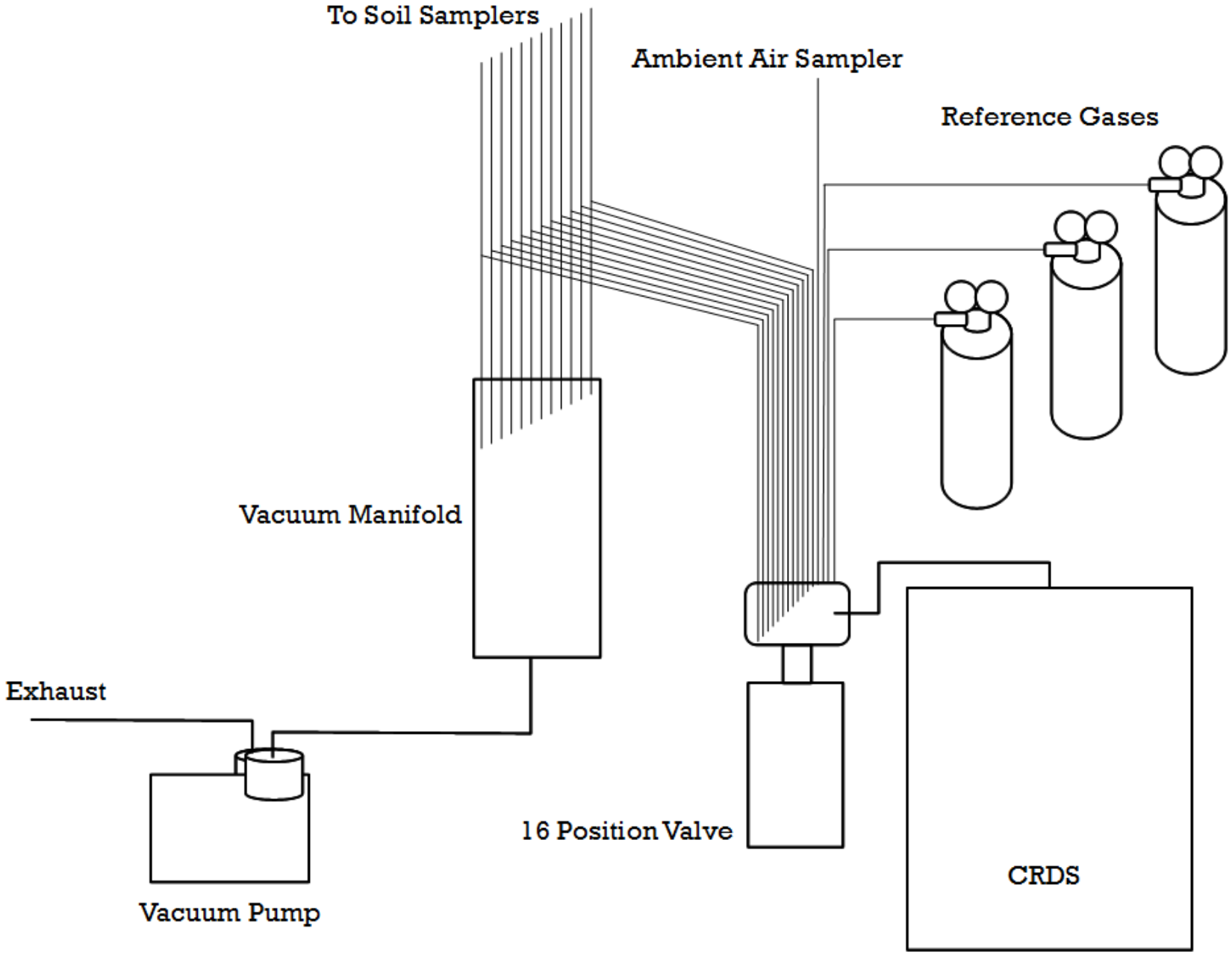
Geochemistry

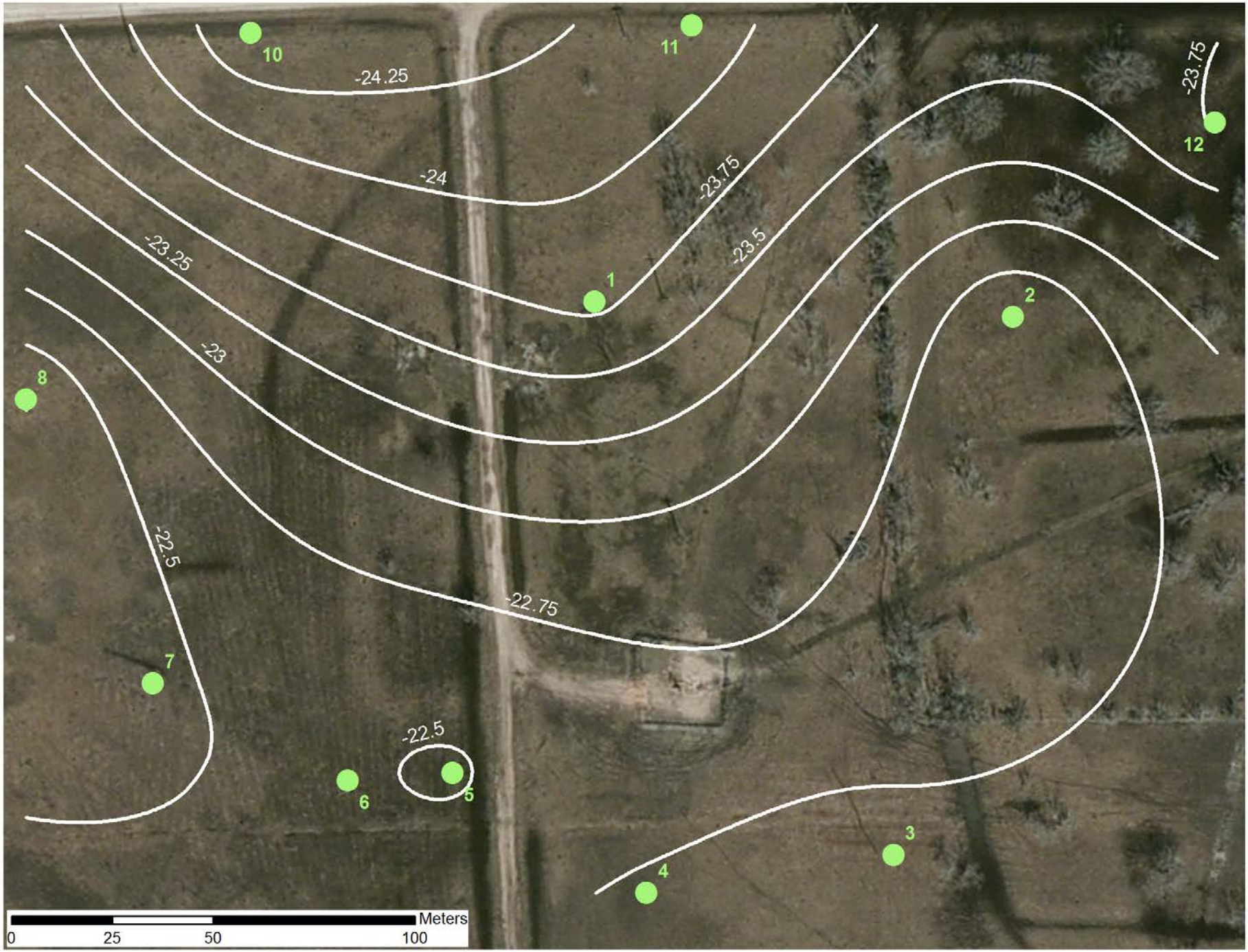
- Examining changes in soil gas composition over a CO_2 reservoir may reveal if gas is leaking to the surface.

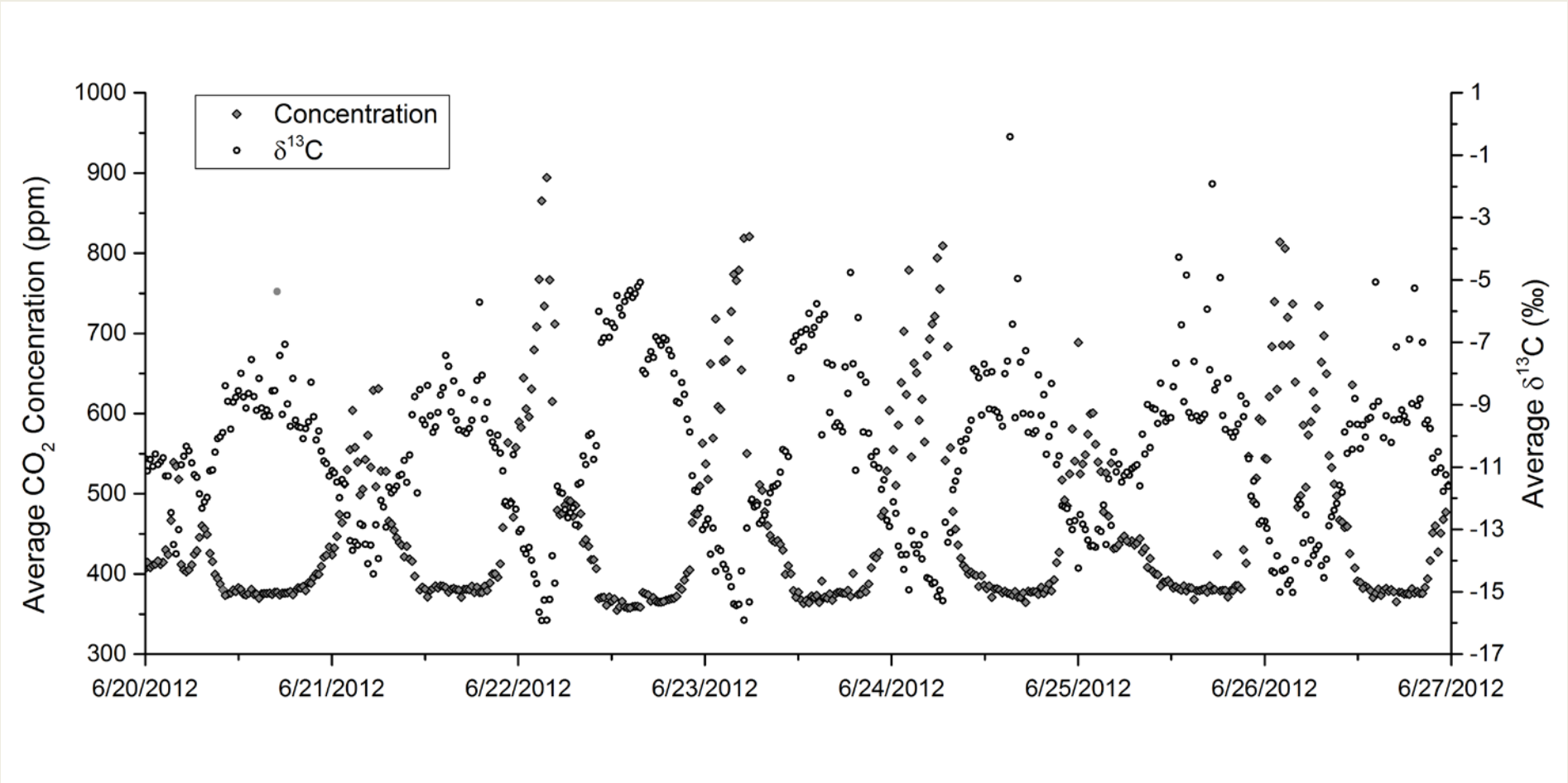
- CO_2 concentrations vary naturally due to soil biological activity, and with anthropogenic activity; Isotopic studies using $\delta^{13}C$ can help reveal the source of CO_2.

- While Mass Spectrometry has advanced since the 1940's, it still requires cryogens and careful attention for accurate isotopic measurements

- The Cavity Ringdown Spectrometer, an optical instrument, is suitable for field operations


To Soil Samplers
Ambient Air Sampler
Reference Gases
Vacuum Manifold
Exhaust
16 Position Valve
CRDS
Vacuum Pump


10
11
12
-24.25
-24
-23.75
-23.5
-23.25
-23
-22.5
-22.75
-23.75
-22.5
1
2
3
4
5
6
7
8
Meters
0
25
50
100



Diurnal variation – plant and soil microbial activity
Weekely variation - anthropogenic

Operational Concept

- Surface geochemistry system using 1 CRDS system (concentrations PLUS isotopic data) provides leak monitoring for ~ 1 km square

- Relatively low cost:

~100K plus analysis/maintenance

Surface Deformation - Background

- Surface deformation (measured by GPS or InSAR) is sensitive to pressure changes in the reservoir at depth
- Can be used to monitor plume location/ migration IF pressure changes are sufficiently large

- Challenge – separating signal from a variety of noise sources

Deformation sources in the Gulf Coast (partial list)

Signal →

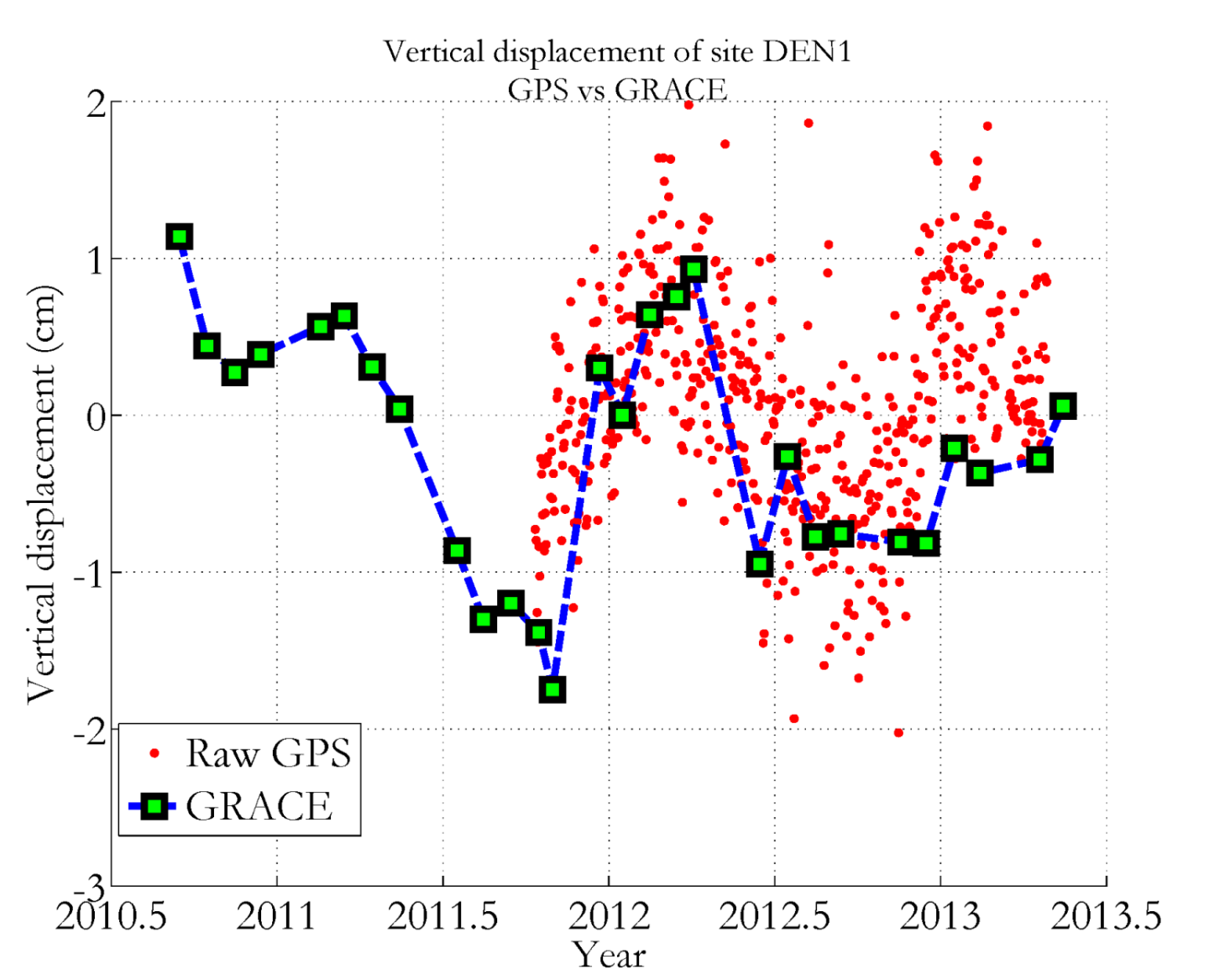
- CO_2 or saline water injection, oil extraction at the site of interest

Noise

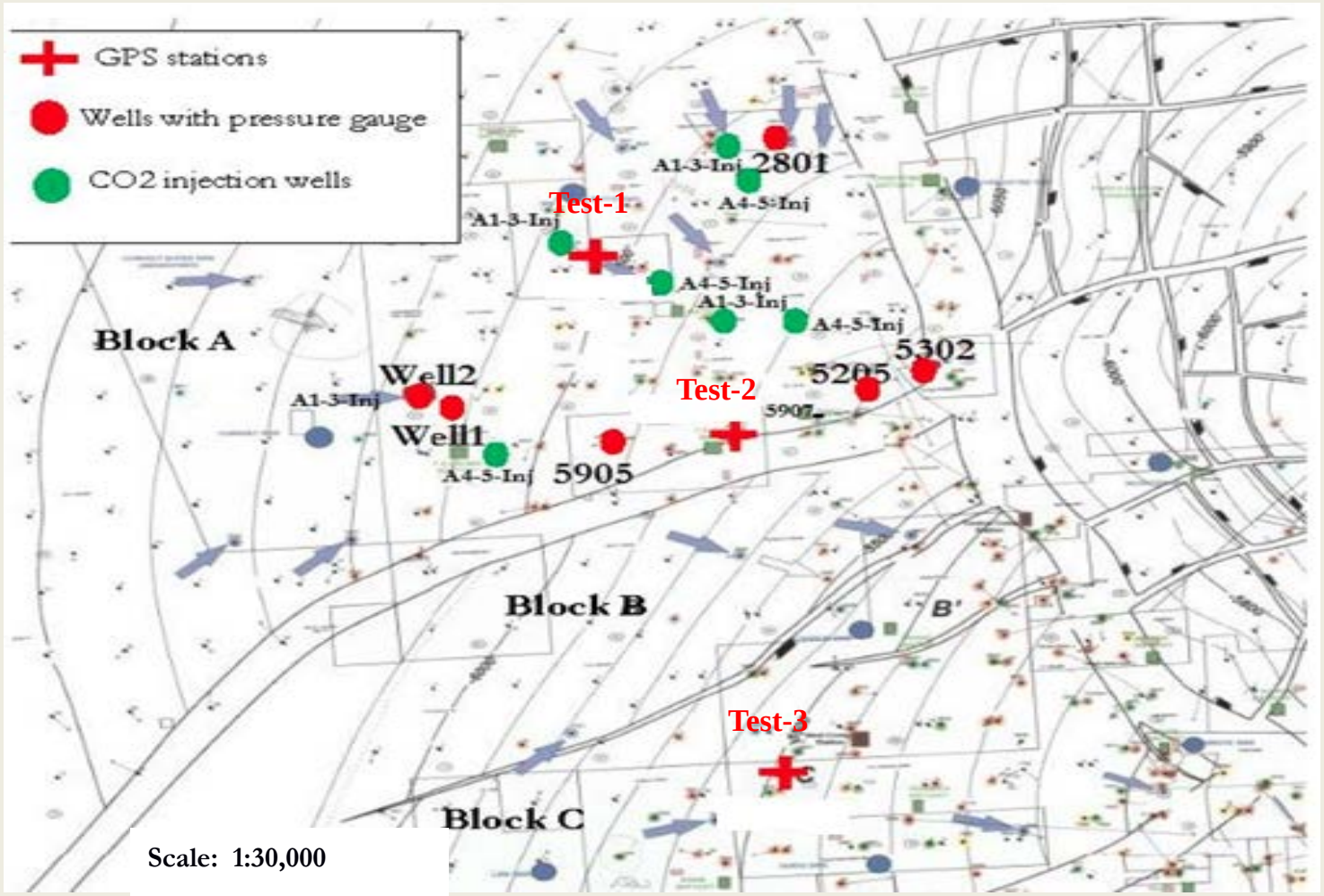
- Regional ground water table variation associated with wet/dry season
- Local ground water variation due to pumping
- Extraction of oil, natural gas from adjacent fields
- Salt tectonics

Comparison of GPS and GRACE satellite time series

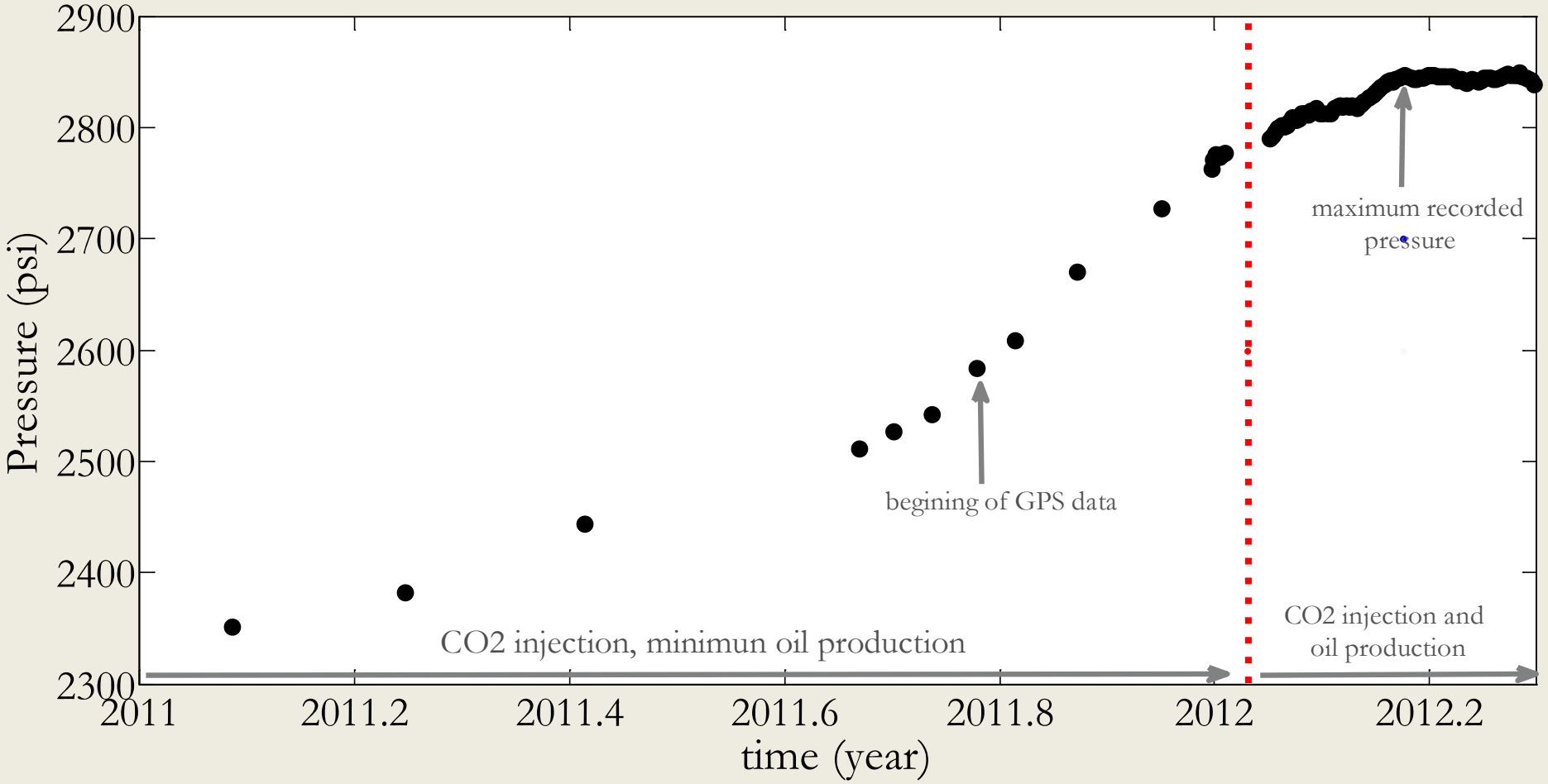
Indicator of regional groundwater loading



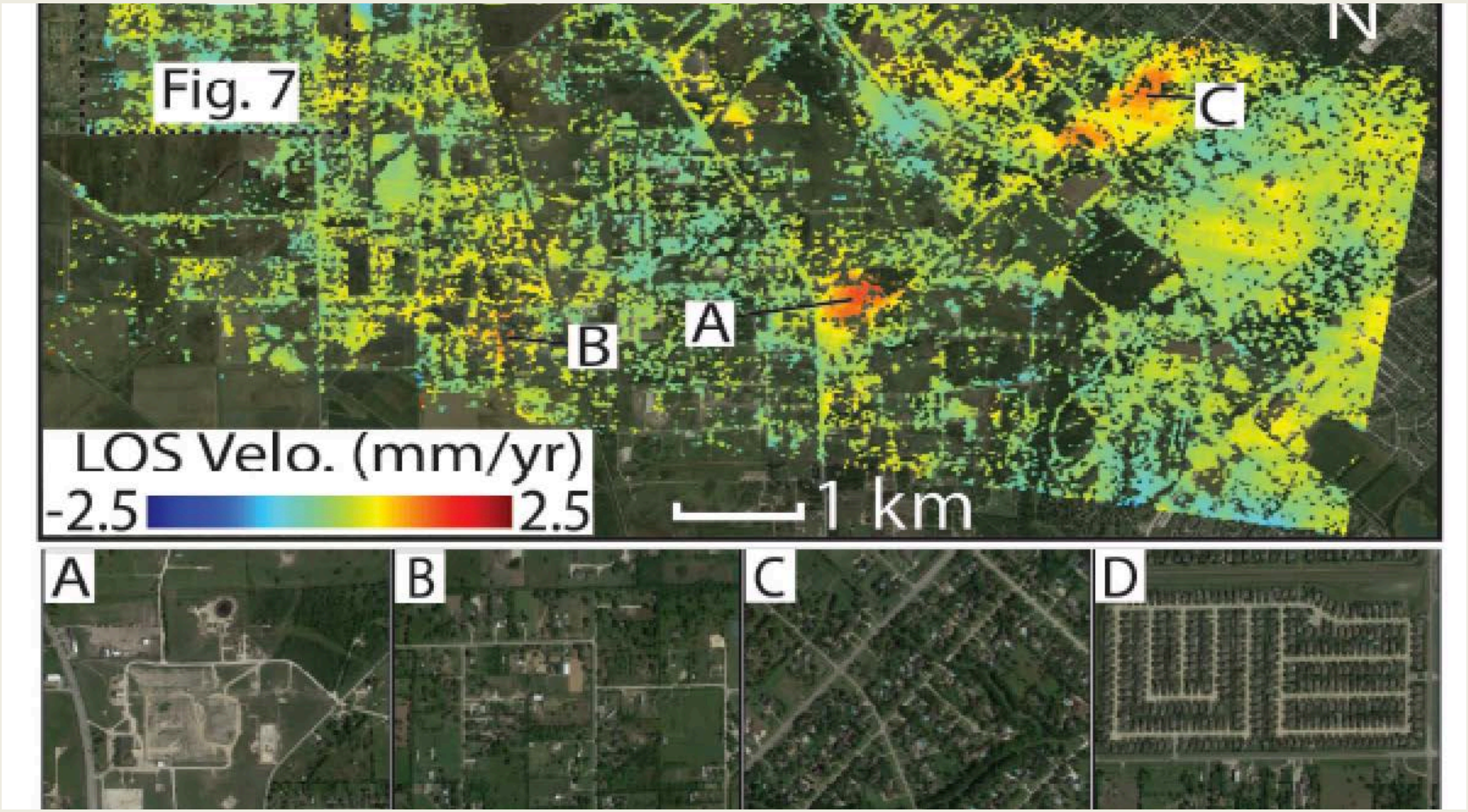
Study Site: Hastings, Texas



Reservoir Pressure History



InSAR: 2012-2013



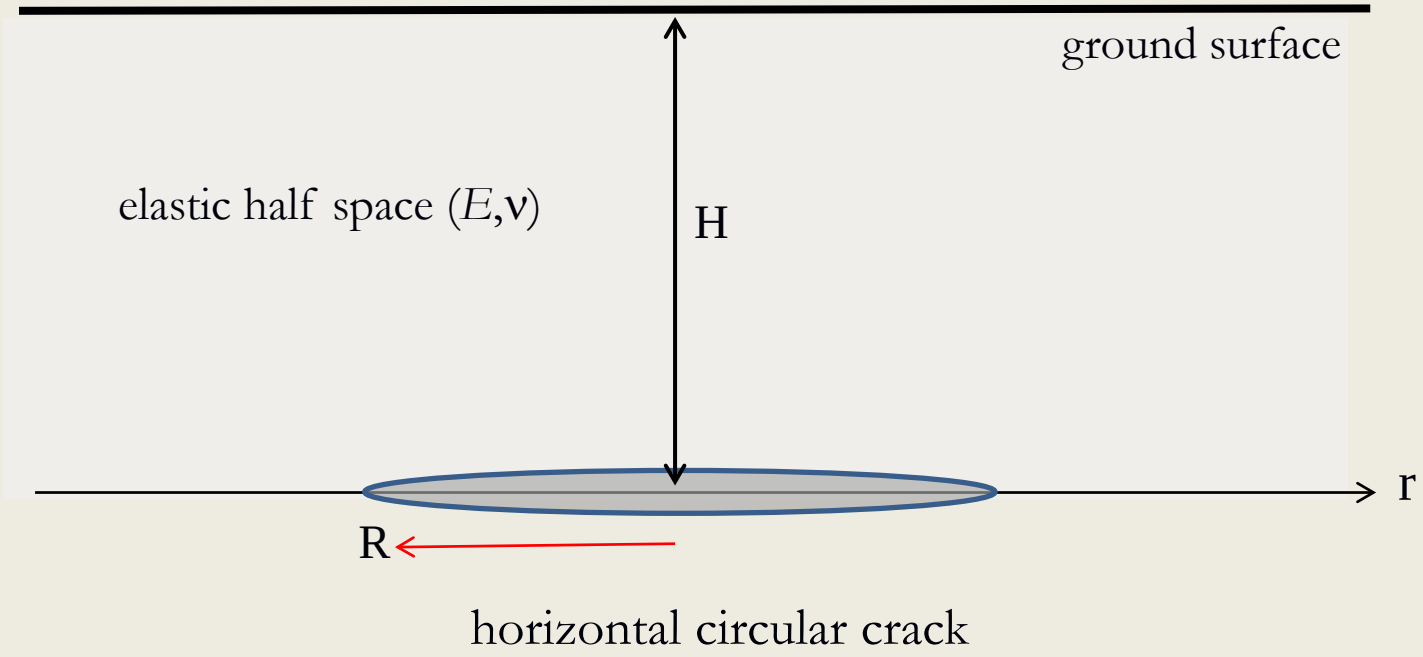

10/26/2011

GPS Noise Reduction Approach

- Use nearby GPS stations as reference to define and subtract common mode (regional) signal
- Problem: some nearby stations also respond to local deformation sources (eg groundwater pumping)
- Solution: correlation analysis distinguishes local vs. regional signals
- Use stations whose signals correlate with many other stations

Surface displacement model

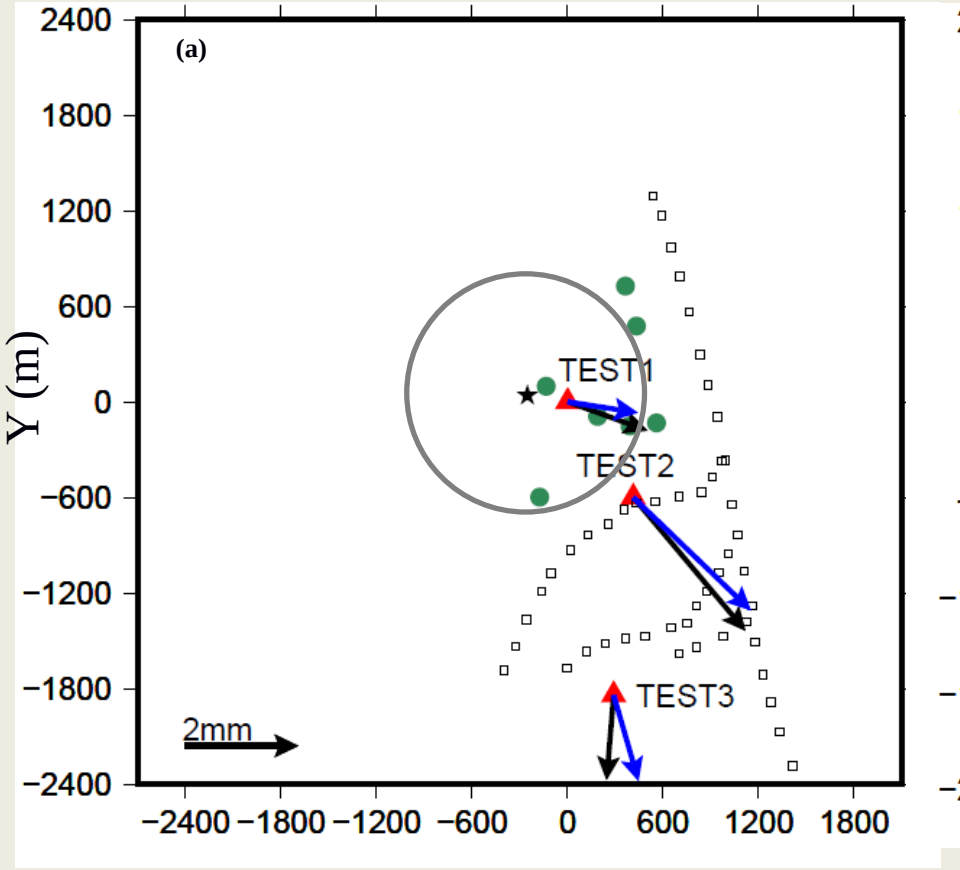
Simple elastic half space, ”penny-shaped crack”

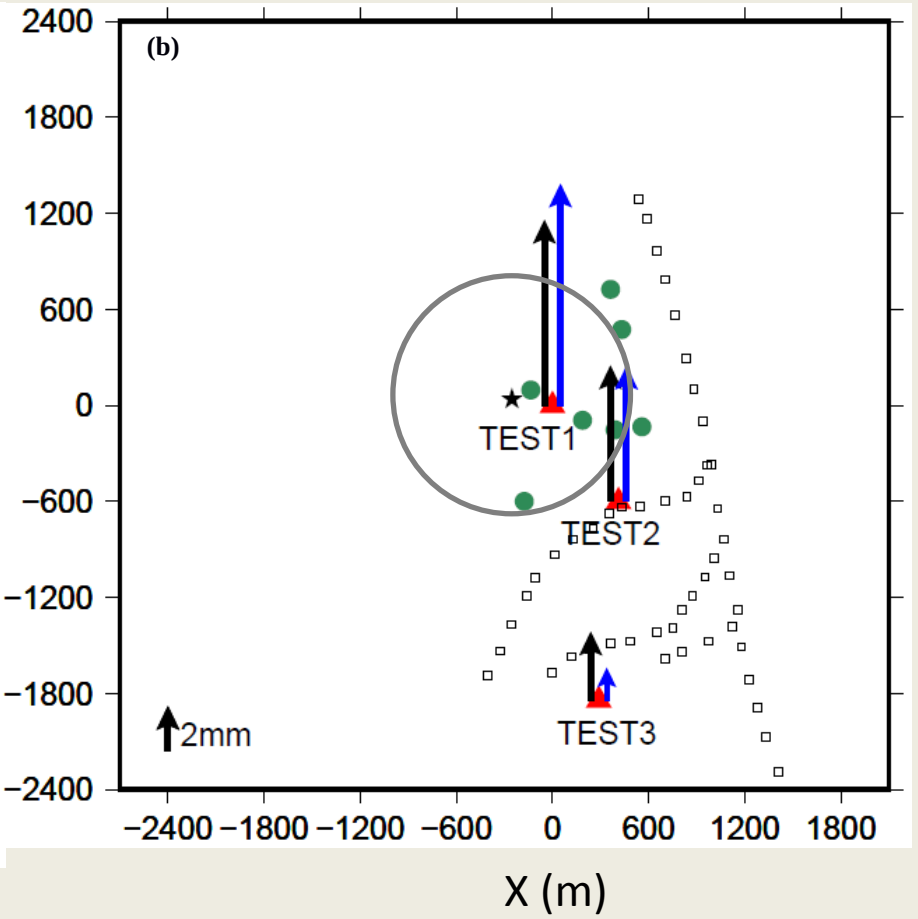


Model vs Data (map view)

Horizontal
(post-fit rms <1.3 mm)

Vertical
(post-fit rms <2.9 mm)

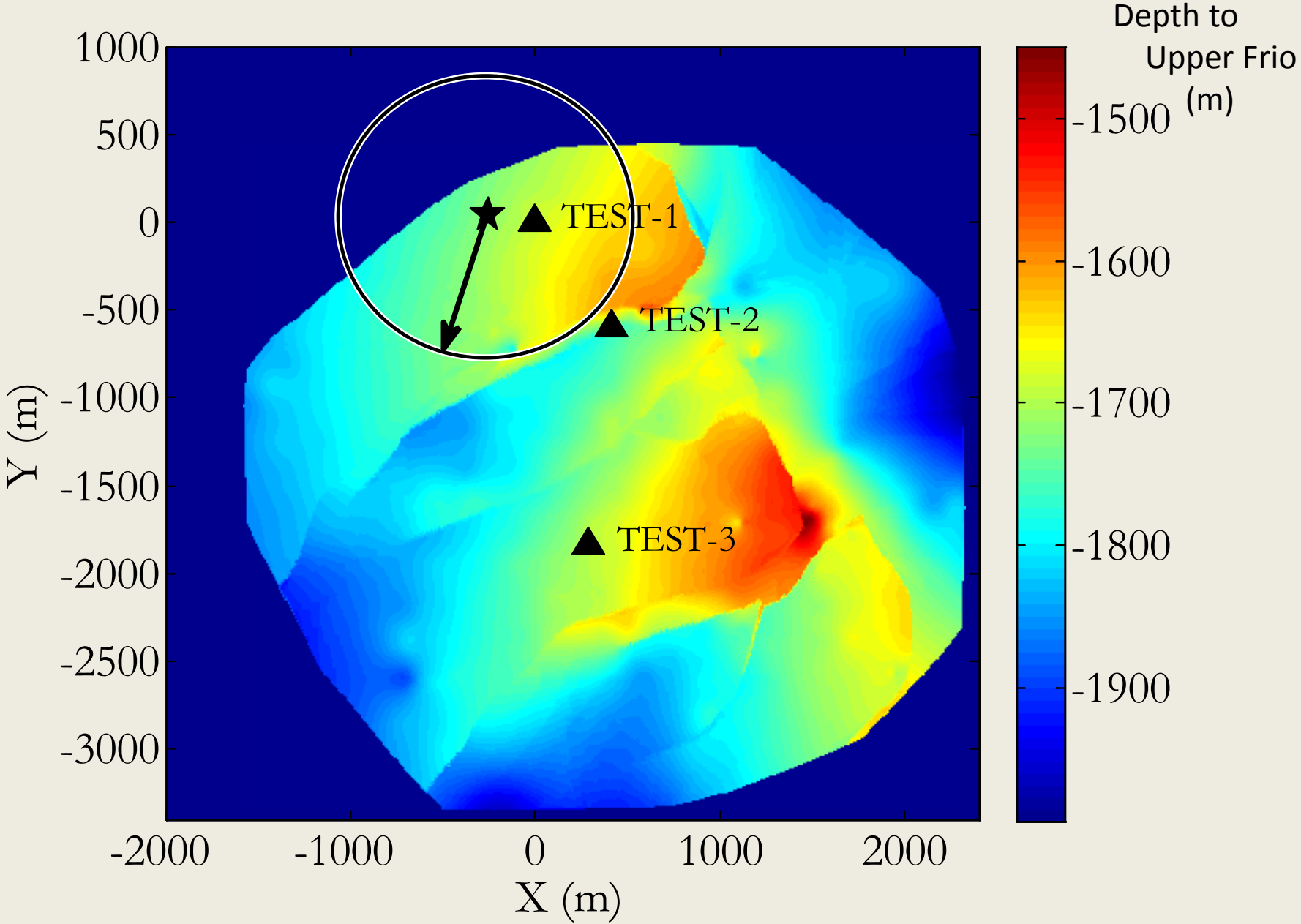




GPS=Black

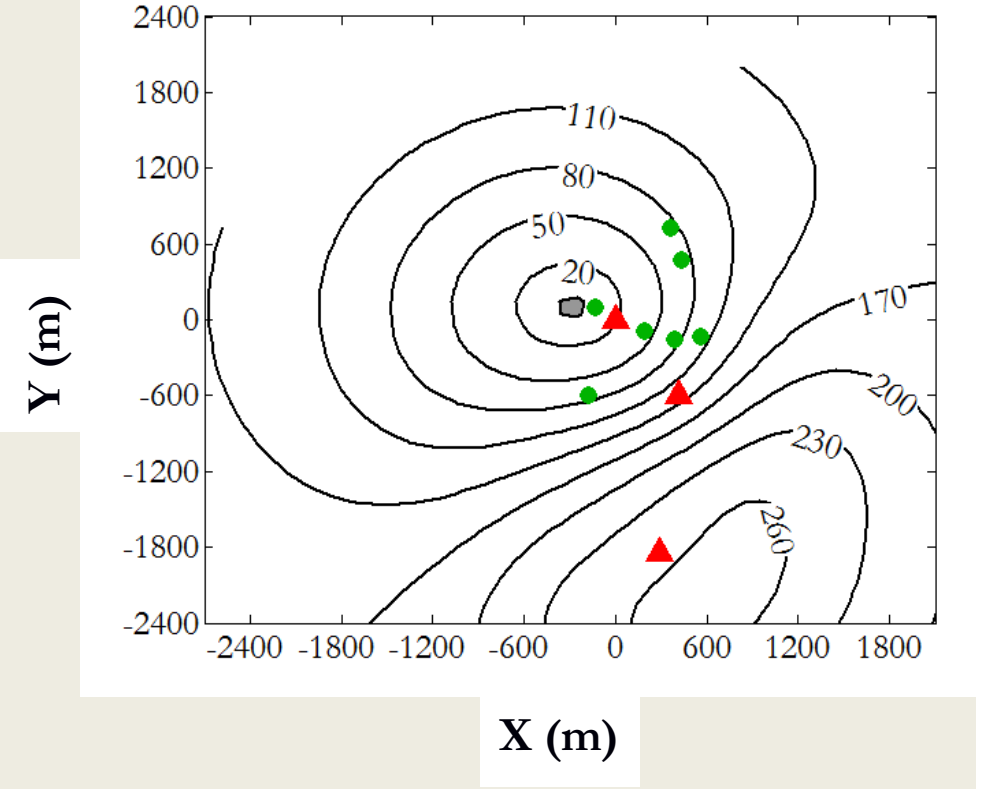
Model=Blue

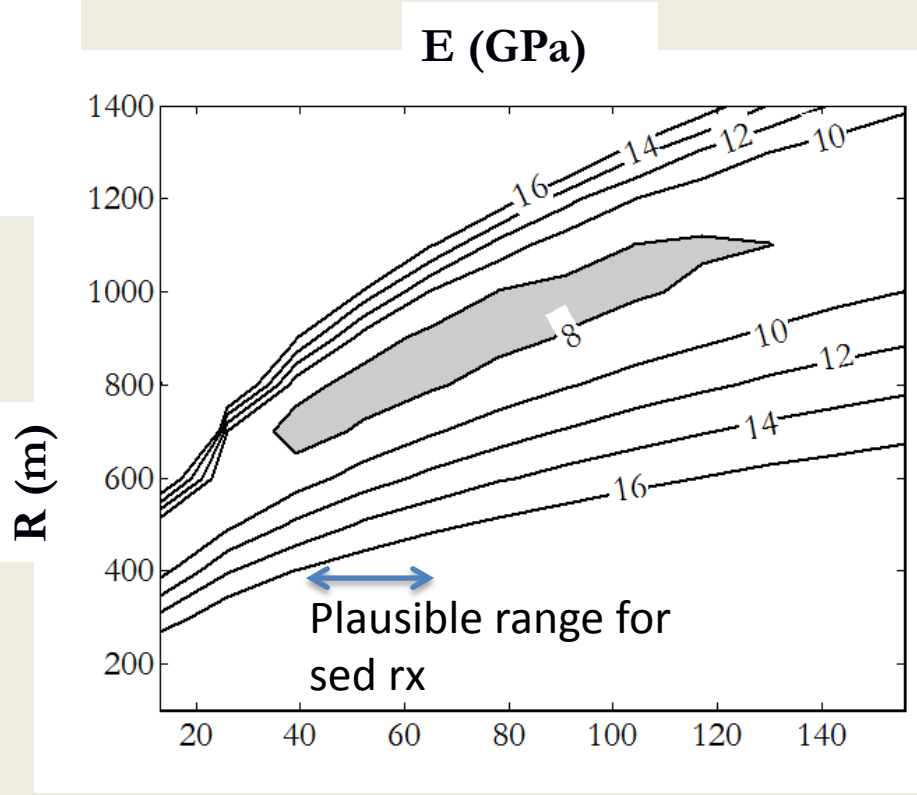
GPS data on plume extent consistent with block integrity (sealing fault) during initial injection phase



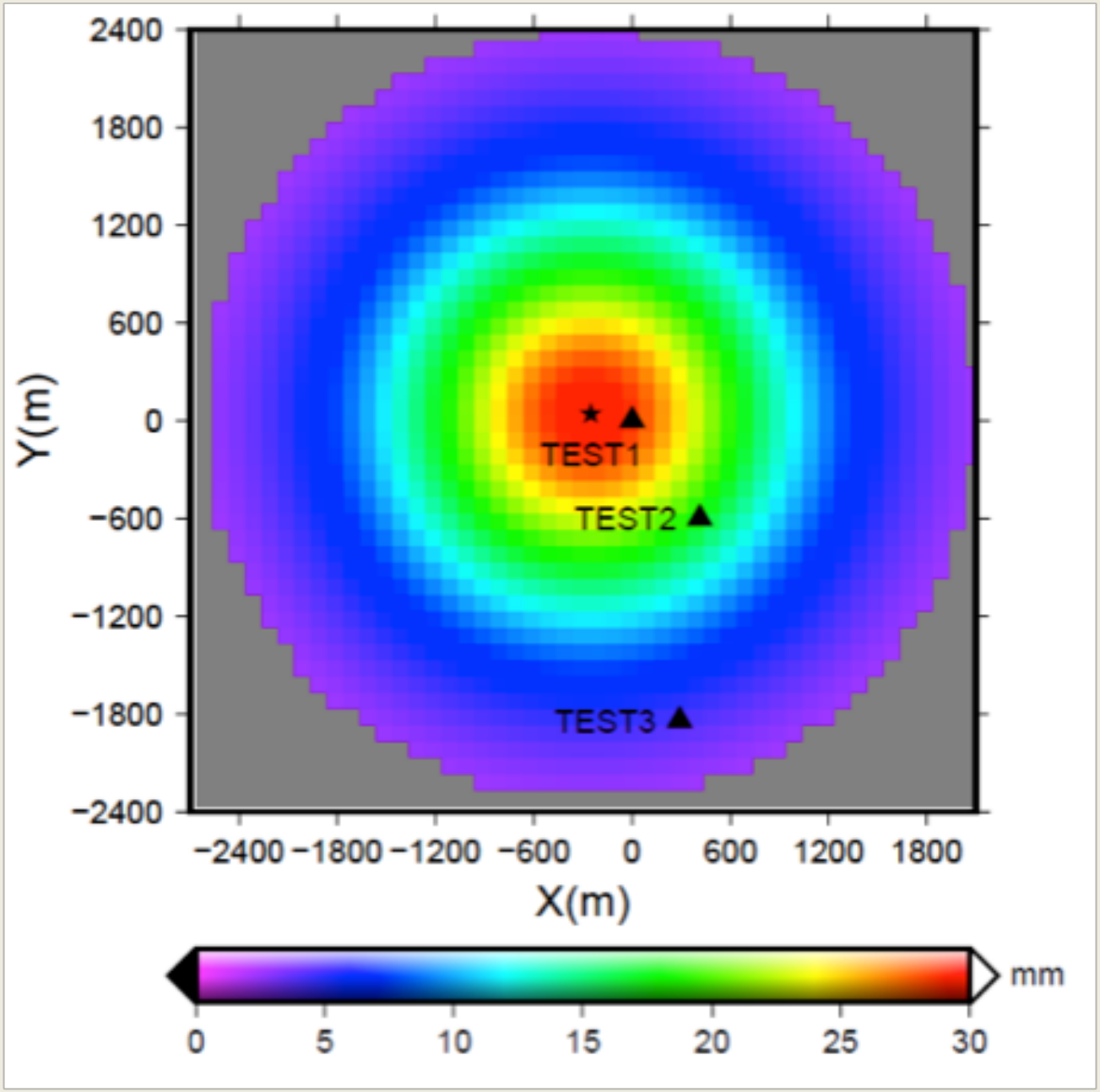
Model Resolution:

Parameter trade-offs shown by contoured misfit (grey=acceptable models)

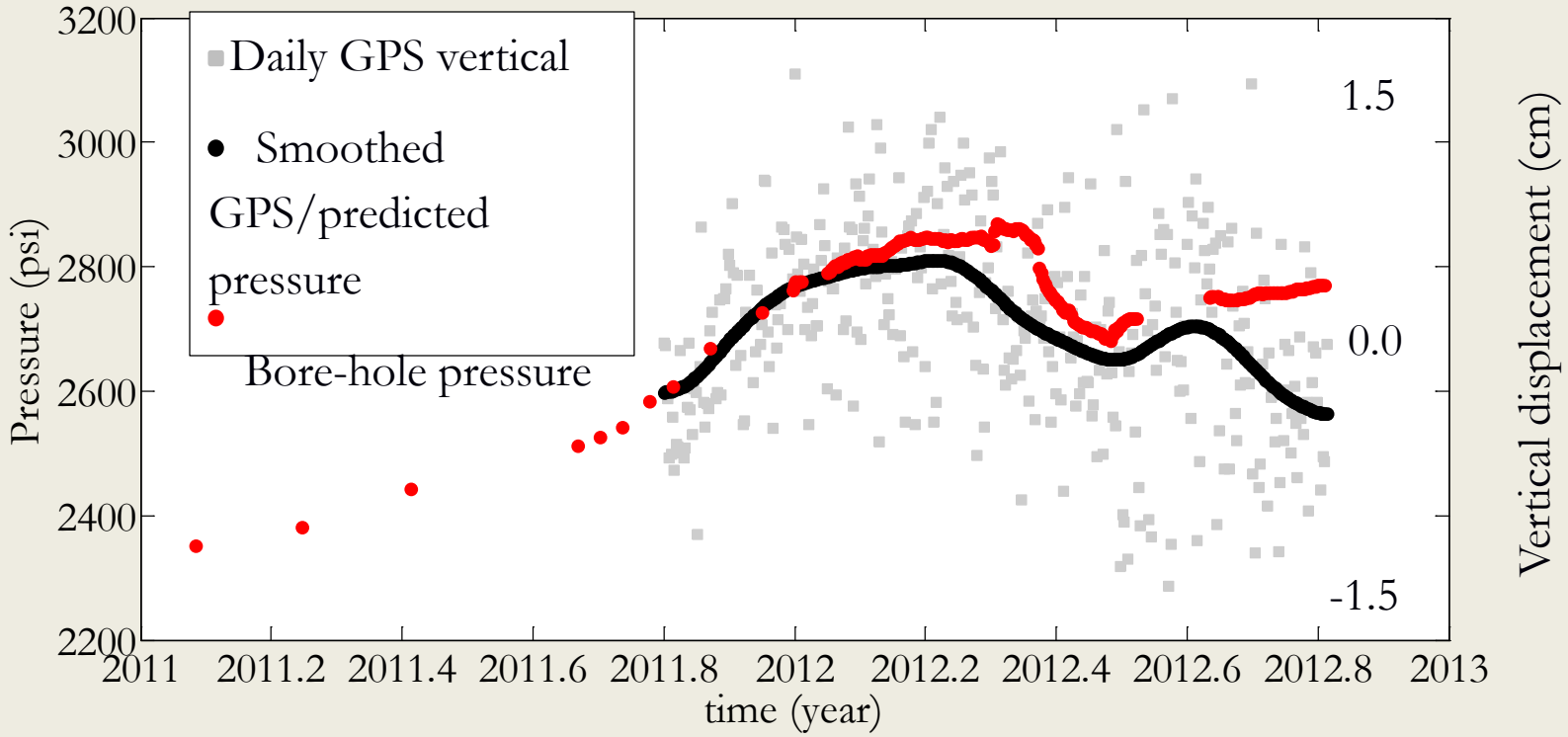




Predicted Total Uplift (Year 1)



Predicted Reservoir Pressure from GPS Data



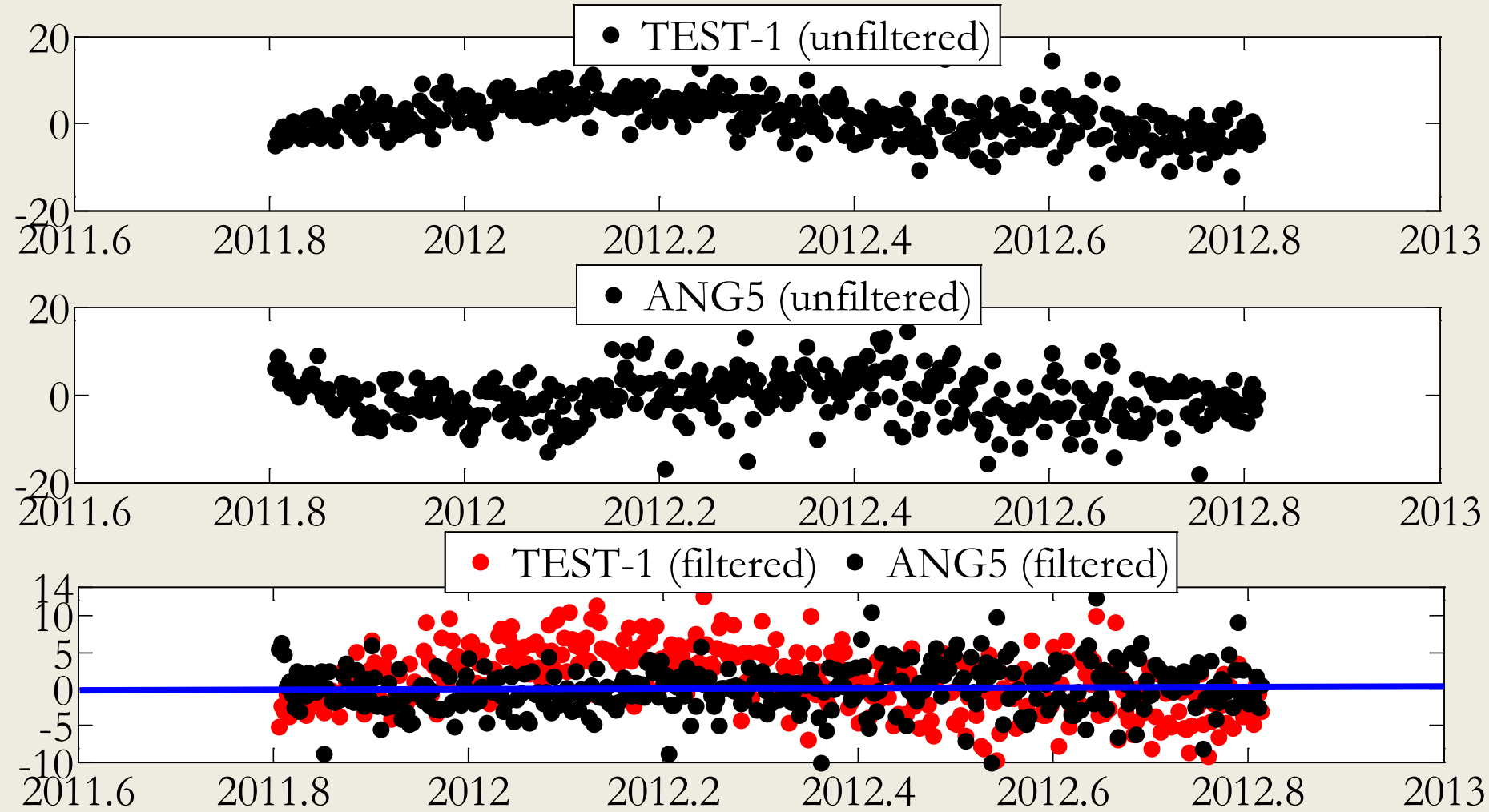
Conclusions

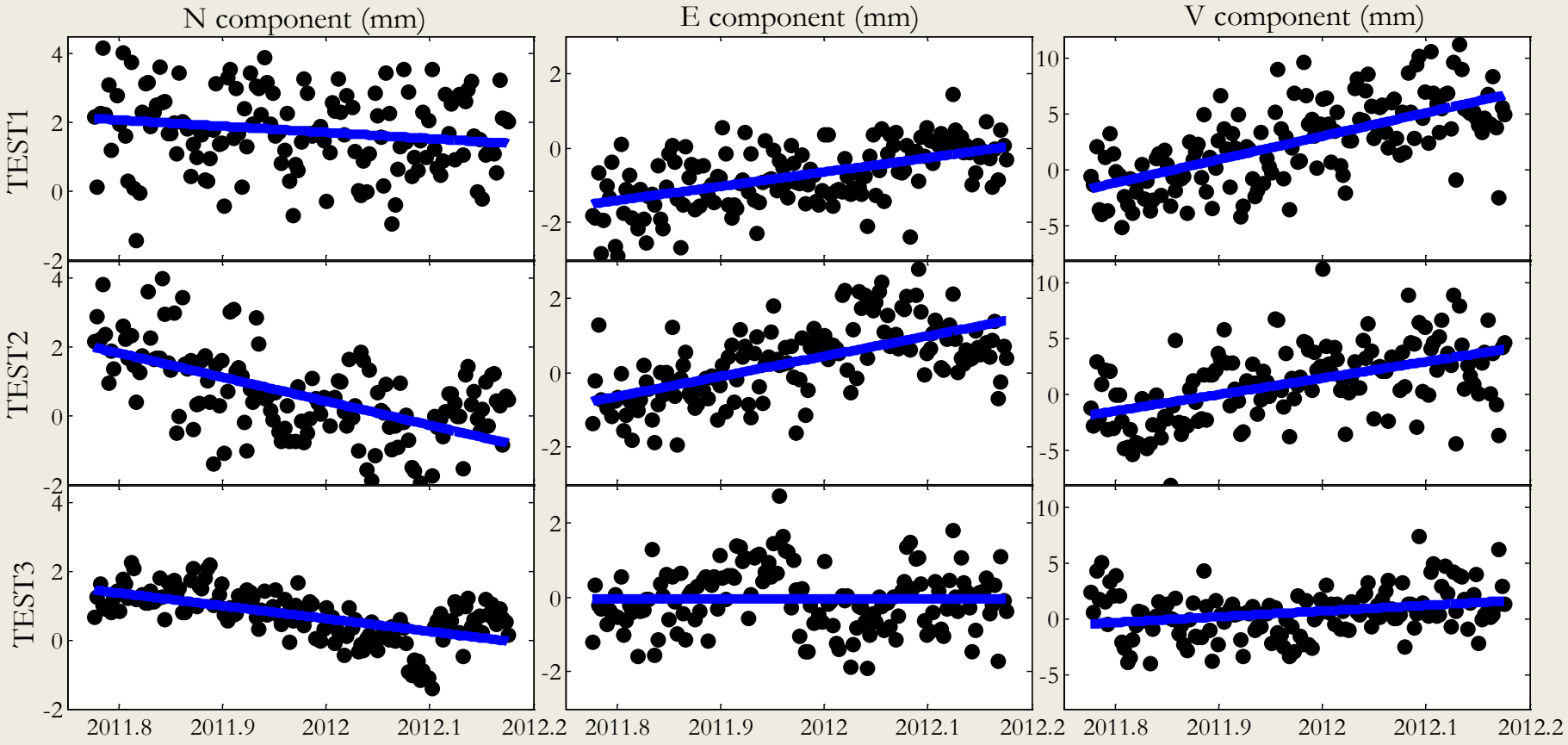
- Surface deformation can make useful contributions to MVA; low cost augmentation to downhole techniques
- High precision GPS provides information complimentary to InSAR (vector data, high time resolution, less sensitive to vegetation/water vapor effects)
- Caveats:
  - Annual hydrologic signal can be large; one-two yrs of baseline data is useful
  - Should be integrated with geomechanical information

Acknowledgements

- Supported by DOE
- Technical support from Texas Bureau of Economic Geology
- Site access and ancillary data from Denbury Resources

Questions?


TEST-1 (unfiltered)
20
0
-20
2011.6
2011.8
2012
2012.2
2012.4
2012.6
2012.8
2013
ANG5 (unfiltered)
20
0
-20
2011.6
2011.8
2012
2012.2
2012.4
2012.6
2012.8
2013
TEST-1 (filtered)
ANG5 (filtered)
14
10
5
0
-5
-10
2011.6
2011.8
2012
2012.2
2012.4
2012.6
2012.8
2013


N component (mm)
E component (mm)
V component (mm)
TEST1
TEST2
TEST3
2011.8
2011.9
2012
2012.1
2012.2