Combining Space Geodesy, Seismology, and Geochemistry for Monitoring Verification and Accounting of CO_2 in Sequestration Sites

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Developing the Technologies and Building the Infrastructure for CO_2 Storage

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Presentation Outline

- Benefit to program
- Goals & objectives
- Preliminary InSAR results (site selection phase)
- Project location
- Project installed equipment
- Specific project results
- Summary

Benefit to the Program

- Focused on monitoring, verification, and accounting (MVA)
- If successful, our project will demonstrate the utility of low cost, surface observations, to complement higher cost industry, in-situ observations
- Can be done by academic groups, independent of industry
- Important for public confidence in CCS process

Project Overview: Goals and Objectives

- develop an integrated, low cost methodology for assessing the fate of CO_2 pumped into geologic reservoirs.
- integrate data from space geodesy, seismology and geochemistry in a straightforward series of procedures and algorithms, and assess the cost and efficacy of these procedures for long term tracking of CO_2 .
- Long term goal is to increase public confidence in the utility, safety and efficacy of CCS

Space Geodesy (GPS/InSAR)

•**Principle**: adding CO_2 to reservoir increases pressure, leads to measurable uplift; short term leakage leads to subsidence

•GPS (point positions, high temporal resolution) and InSAR (high spatial resolution) provides ideal combination for long term monitoring of sequestration sites

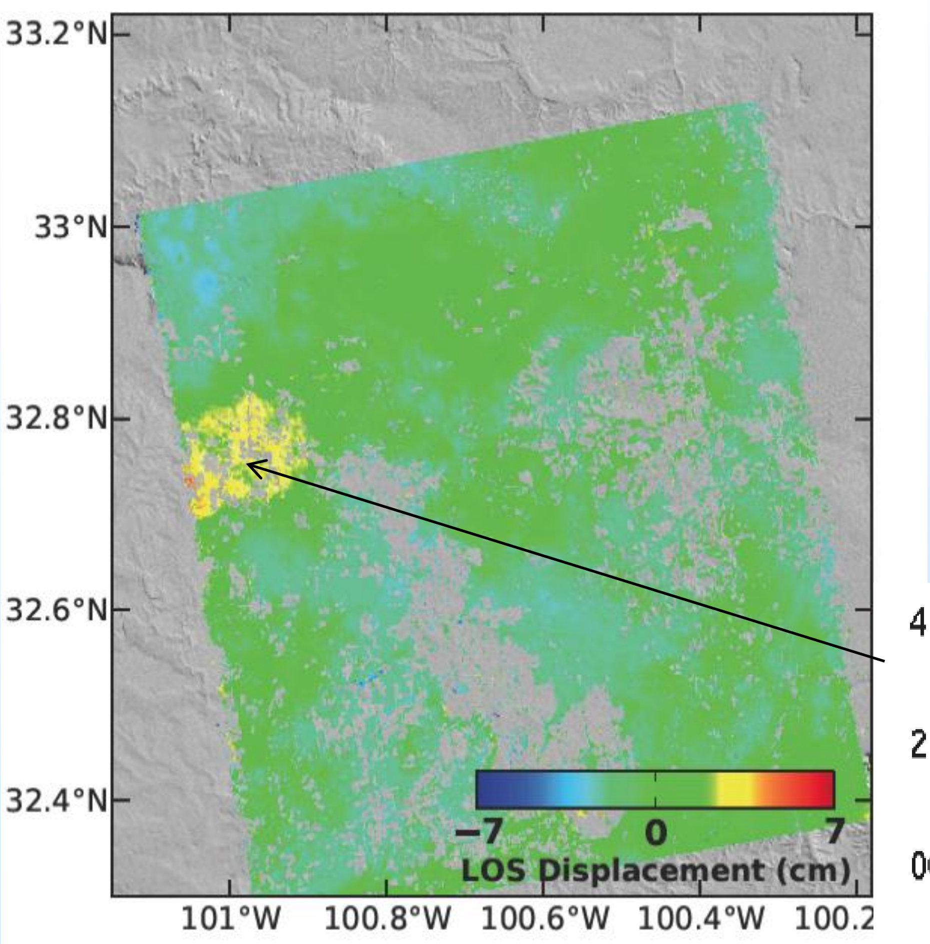
•InSAR demonstrated for CCS at InSalah, Algeria (dry)

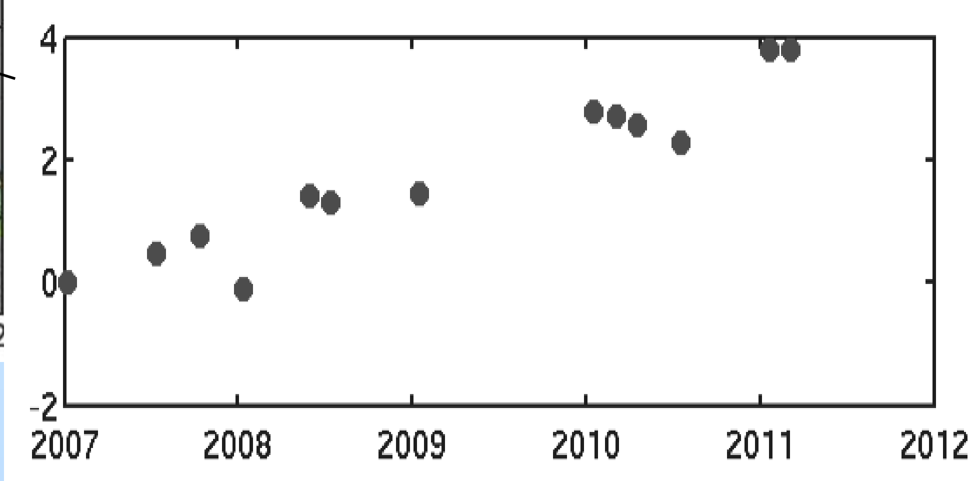
•InSAR not yet demonstrated for CCS in humid, vegetated areas

•We have made significant strides at development of InSAR for vegetated areas, and used it to assess possible sites for more detailed study

InSAR survey: 1. Snyder, Texas

2007-2011

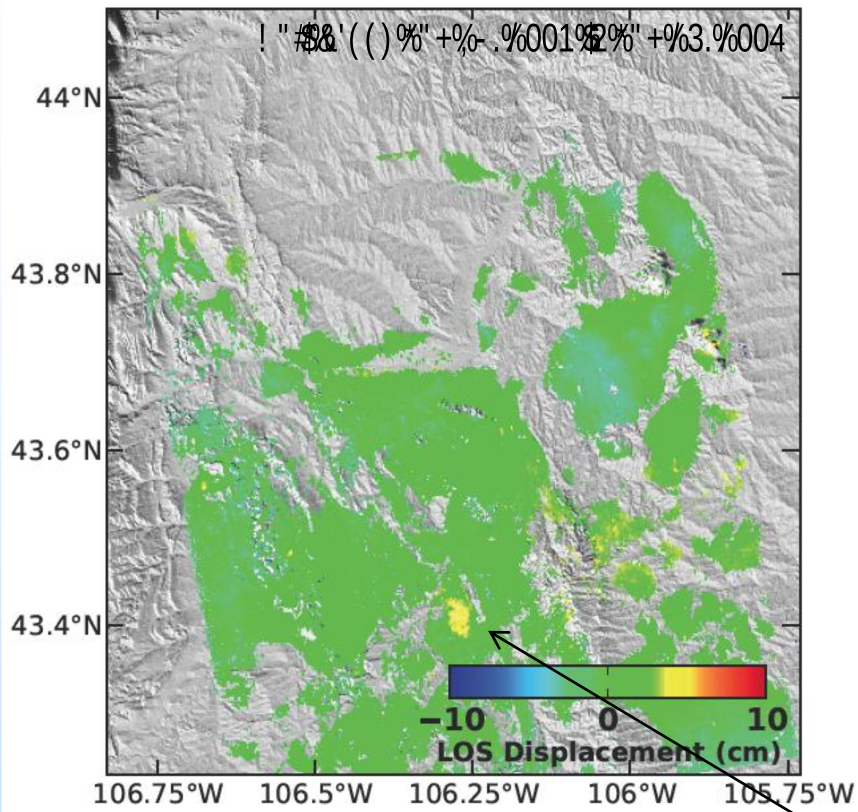




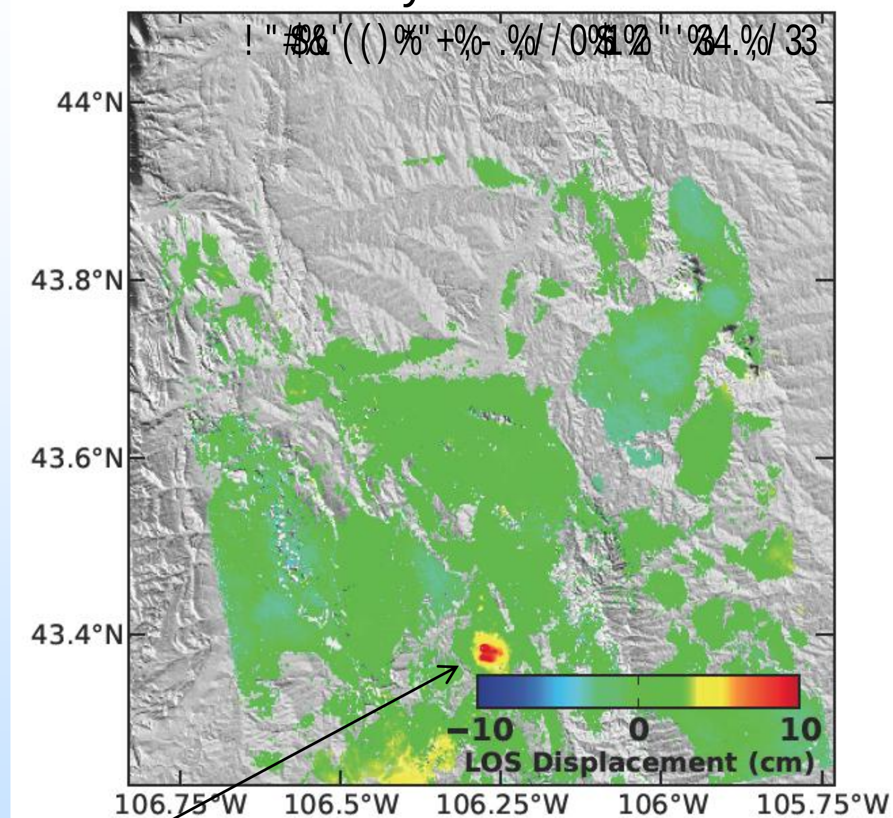
ALOS satellite

InSAR survey: 2. Salt Creek, Wyoming

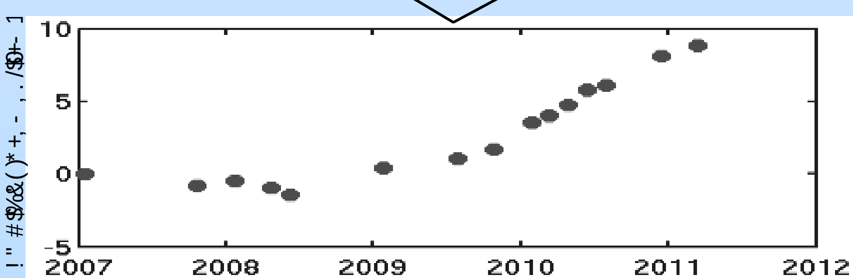
Before January 2009



After January 2009



ALOS satellite



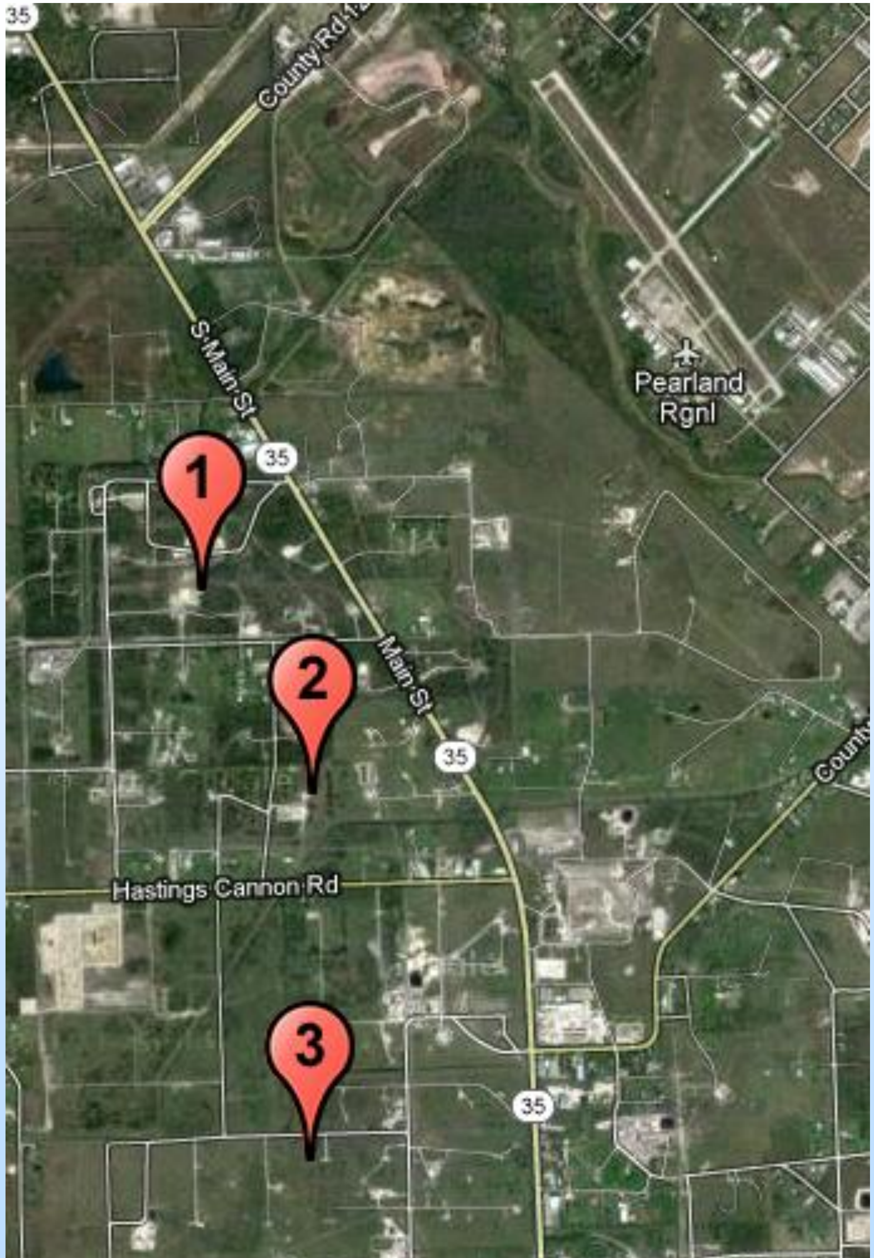
Technical Status

- Project site chosen
- Equipment installed, operating, and data are being analyzed
- Preliminary results show clear deformation and geochemical signals
- Modeling in progress

Project Location

- Denbury Resources, Hastings site, ~ 30 miles south of Houston Texas
- Enhanced Oil Recovery site
- Injection of CO_2 from natural source began in 2011
- Oil extraction began in 2012

Project Location



Regional Airport providing weather data

Denbury Offices

Installed Equipment

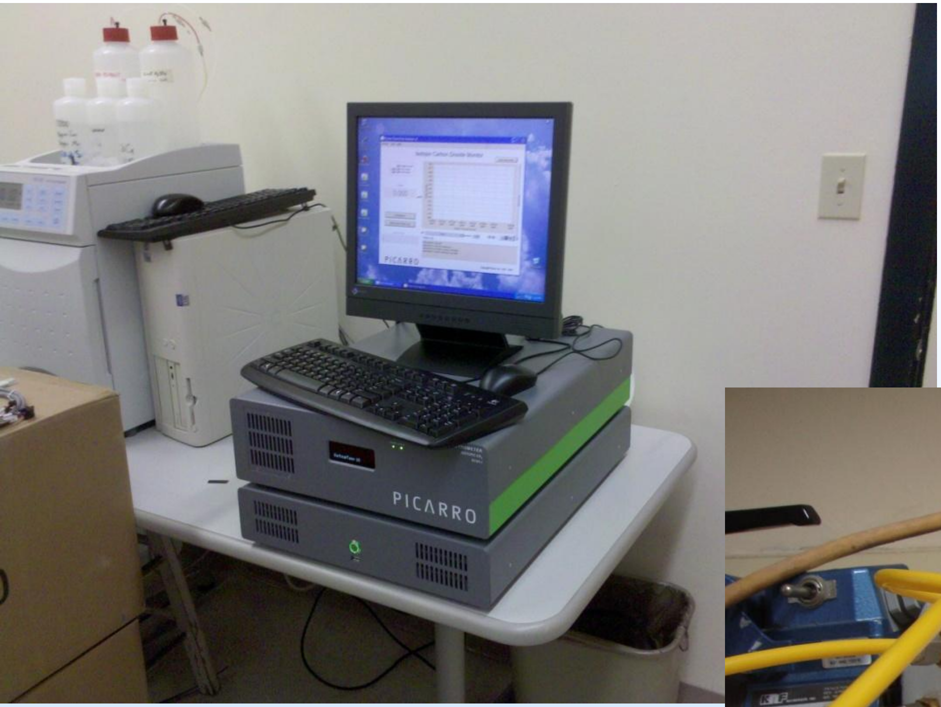
- High precision GPS at all three sites
- Broadband seismometer at all three sites
- Cavity ring-down spectrometer at Site #3

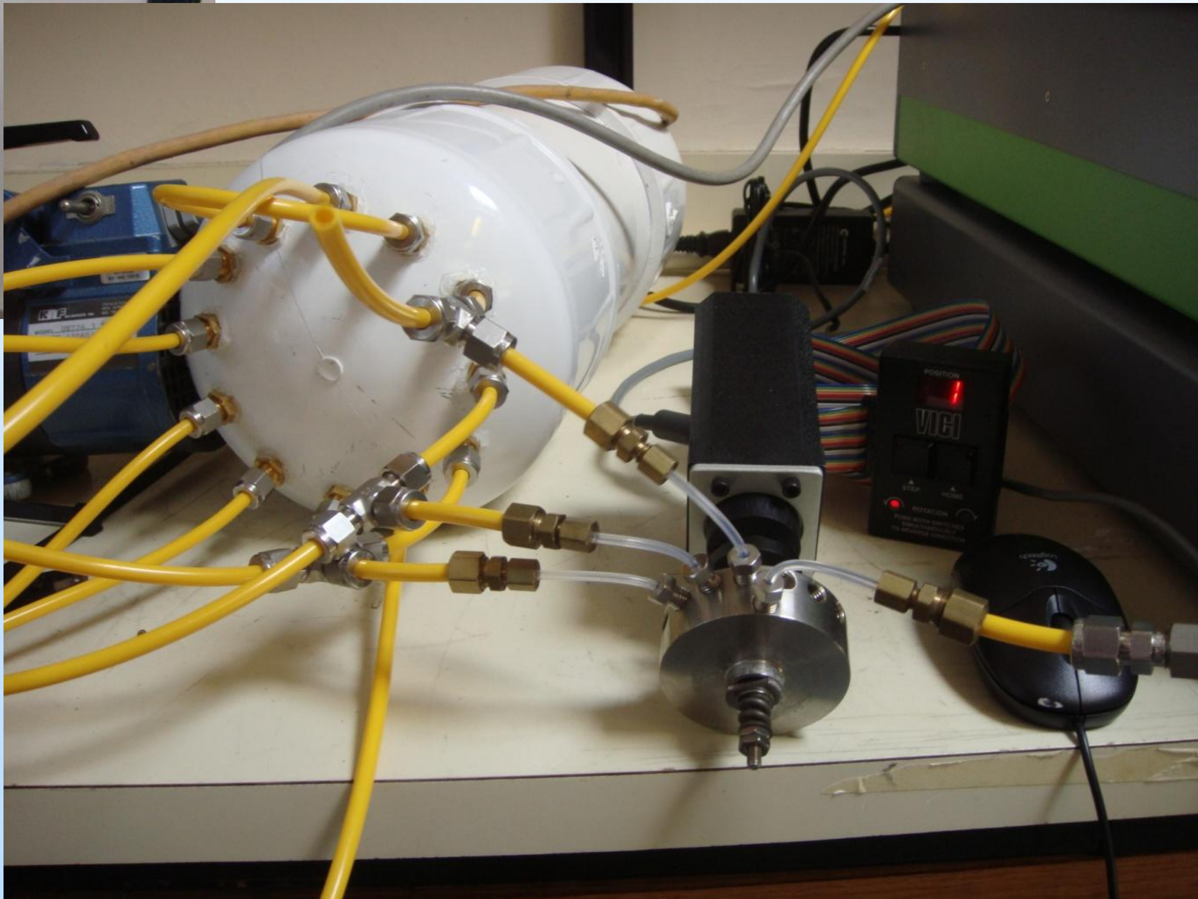
GPS and Seismic Station

Geochem Housing

Sample locations (total 12)

Geochem equipment

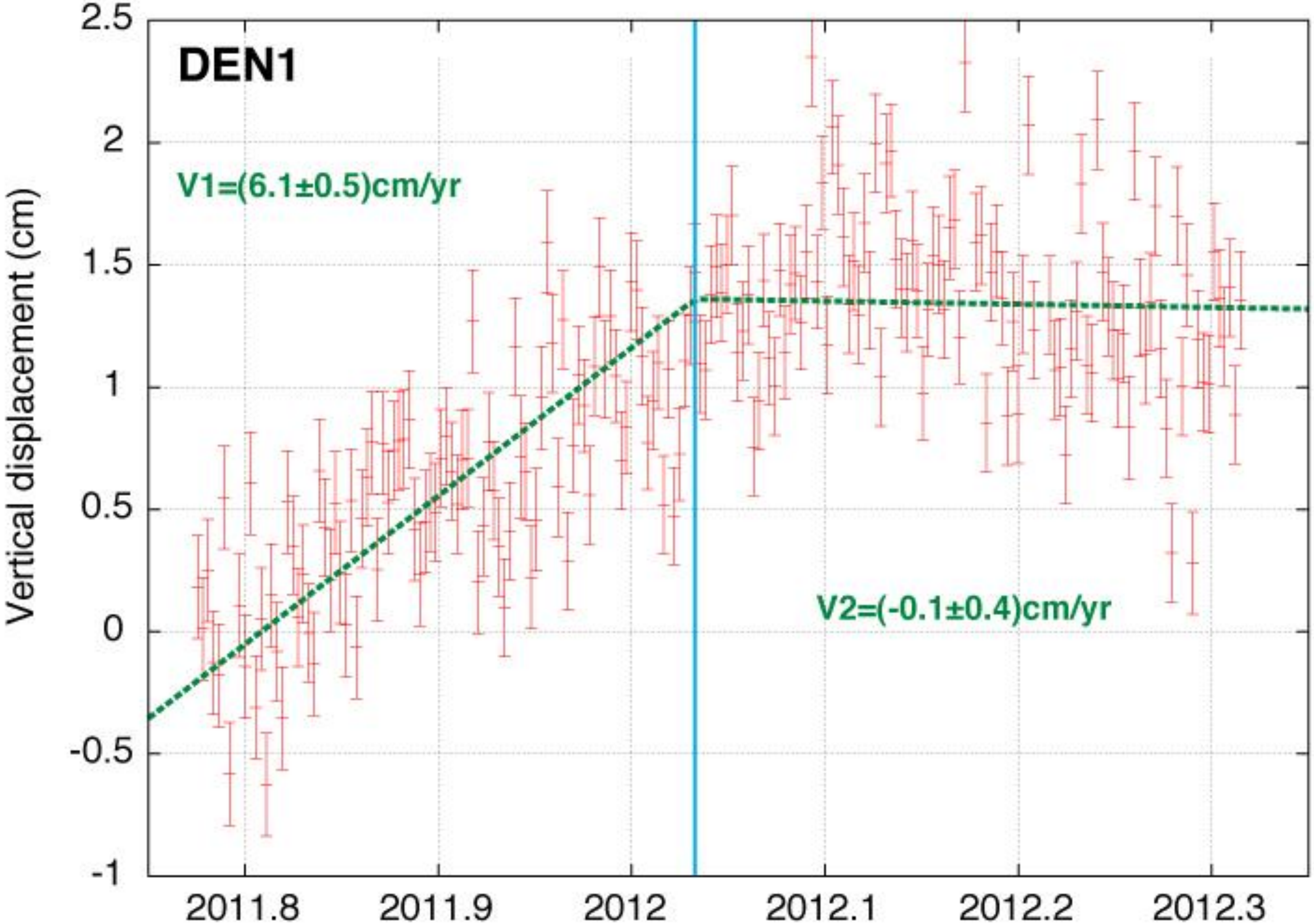




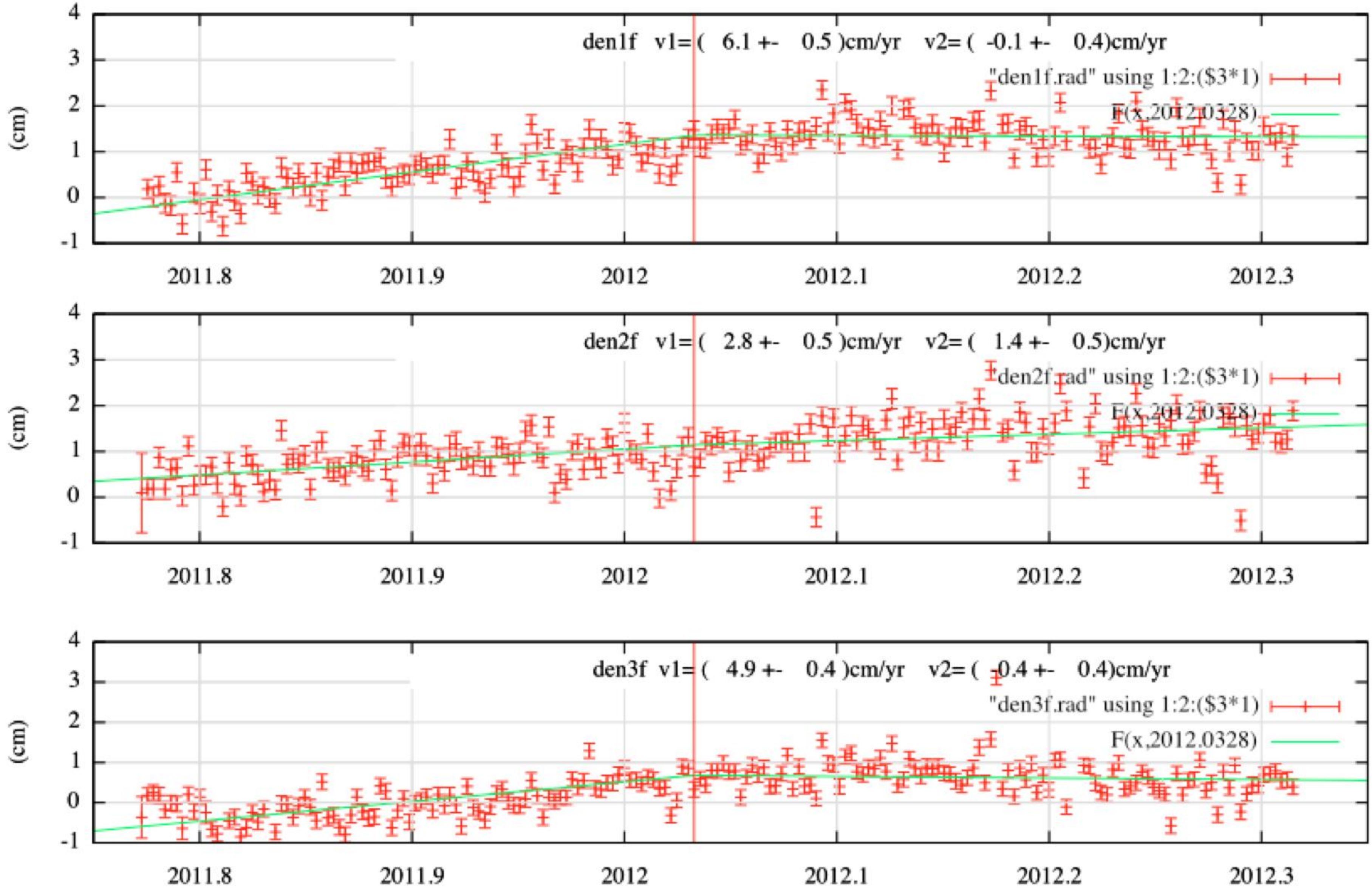
Core equipment consists of one CRDS instrument, 16 position valve, manifold, vacuum pump, and data connection.

GPS Processing

- High precision ephemeris data
- Sophisticated atmospheric model to reduce vertical component uncertainties
- Use ensemble of ~ 10 regional sites to define local reference frame
- Uncertainties are ~ 3 mm horizontal, 8 mm vertical



DEN1
V1=(6.1±0.5)cm/yr
V2=(-0.1±0.4)cm/yr
Vertical displacement (cm)
2.5
2
1.5
1
0.5
0
-0.5
-1
2011.8
2011.9
2012
2012.1
2012.2
2012.3


den1f v1= (6.1 +- 0.5)cm/yr v2= (-0.1 +- 0.4)cm/yr
"den1f.rad" using 1:2:($3*1)
F(x,2012.0328)
den2f v1= (2.8 +- 0.5)cm/yr v2= (1.4 +- 0.5)cm/yr
"den2f.rad" using 1:2:($3*1)
F(x,2012.0328)
den3f v1= (4.9 +- 0.4)cm/yr v2= (-0.4 +- 0.4)cm/yr
"den3f.rad" using 1:2:($3*1)
F(x,2012.0328)
(cm)
2011.8
2011.9
2012
2012.1
2012.2
2012.3

Vertical GPS Results

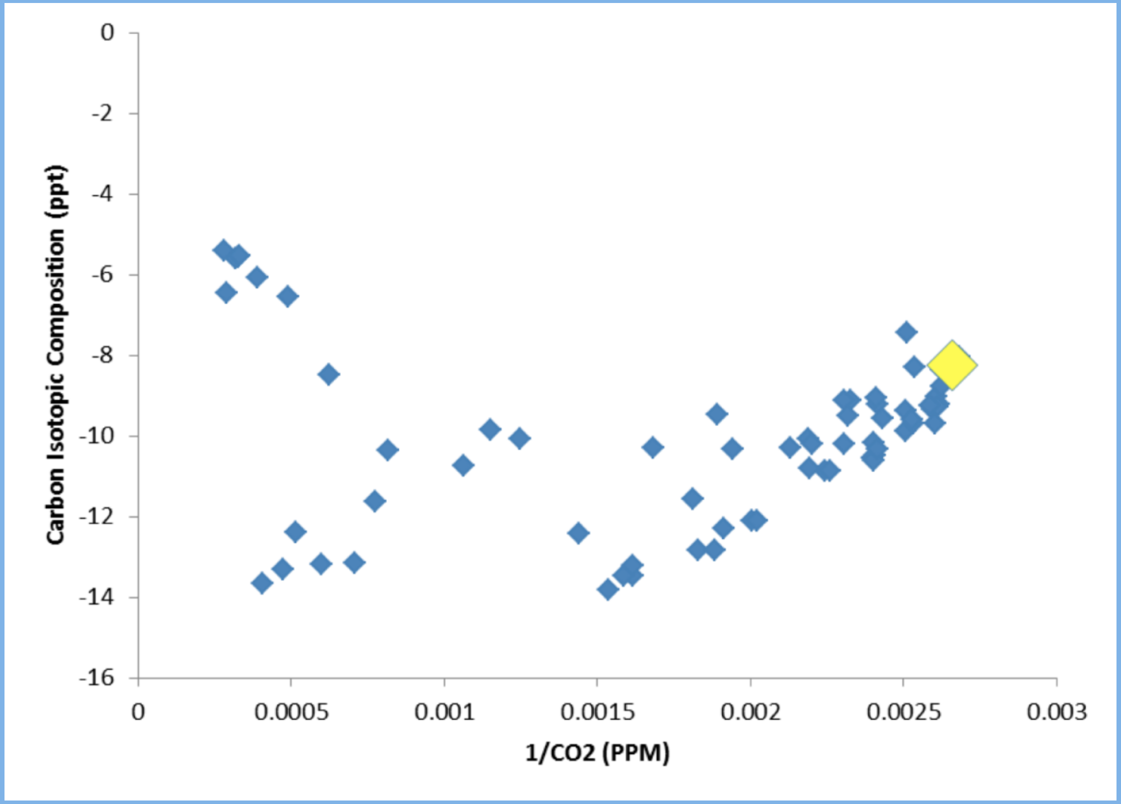
	Before	After
Den-1	6.1 cm/yr	-0.1 cm/yr
Den-2	2.8 cm/yr	1.4 cm/yr
Den-3	4.9 cm/yr	-0.4 cm/yr

Significant vertical uplift during injection phase, when reservoir pressure is increasing;

Negligible uplift after extraction starts, when reservoir pressure remains approximately constant

Geochemistry Results

- Most days indicate typical atmospheric values, modulated by soil/vegetation processes
- Some evidence of injected CO2


0
-2
-4
-6
-8
-10
-12
-14
-16
Carbon Isotopic Composition (ppt)
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
1/CO2 (PPM)

Summary of Accomplishments to Date

Demonstrated InSAR as an observation tool for some CCS sites

Demonstrated that high precision GPS measurements of surface deformation are sensitive to CO2 injection

Demonstrated that geochemical techniques have the sensitivity to detect anomalies

Summary

- Proposed observations have the sensitivity to meet project objectives
- Lessons: need to have early, baseline data; need to work closely with company for quantitative assessment (will be a challenge for development of independent MVA process)
- Future: Work with company to develop quantitative model relating observed deformation signal with actual injection/extraction volumes

Appendix

Investigators

- **Tim Dixon** (co-PI; GPS; modeling; management & reporting
- **Peter Swart** (co-PI; Carbonate and Fluid Geochemistry, modeling & reporting)
- **Falk Amelung** (Co-I; InSAR)
- **Guoqing Lin** (Co-I; Seismology)
- **Dan Riemer** (Co-I; Atmospheric Geochemistry)
- Students: Qian Yang (GPS), Wenling Zhou (InSAR), Peng Fang (Seismology), Ben Galfond (Geochemistry), Caitlin Augustin (modeling)

		10 Q1	10 Q2	10 Q3	10 Q4	11 Q1	11 Q2	11 Q3	11 Q4	12 Q1	12 Q2	12 Q3	12 Q4	13 Q1	13 Q2	13 Q3	13 Q4	14 Q1
Task	Sub task																	
Task 1.0 Project Management, Planning, Reporting		A1 A3				A2 B					C				D		W, X, Y	Z
Task 2.0 Investigation of InSar Data																		
Investigation of Legacy InSAR Data at DOEs Phase 2 Sites	2.1		F															
Initiation of InSAR Monitoring at Phase 3 Sites	2.2					G												
Investigation of InSAR data at Specified Phase 3 Test Site	2.3								H					I-1			I-2	
Task 3.0 Investigation of GPS Data																		
Investigation of Regional GPS Data at Legacy Sites	3.1					J												
Installation of New GPS Receivers at Test Site	3.2									K								
Analysis of New GPS Data at Test Site	3.3													L-1			L-2	
Strain Modeling	3.4													M				
Task 4.0 Investigation of Seismic Data																		
Refinement of Seismic Algorithm	4.1				N													
Installation of Seismic Equipment at Test Site	4.2									O								
Analysis of New Seismic Data at Test Site	4.3													P-1			P-2	
Task 5.0 Investigation of Geochemical Data																		
Construction of CO2 Monitoring Sub-systems	5.1						Q											
Deployment of CO2 Monitoring System at Test Site	5.2									R								
Field Isotope Measurement System	5.3						S											
Deployment of Field Isotope System	5.4									T								
Model Geochemical Data	5.5													U-1			U-2,V	

Bibliography

No peer reviewed publications as yet

Three in preparation