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

Award # FE0001580

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RSMAS/University of Miami

Goal

- Develop integrated, low-cost methods to assess fate of CO_2 injected into various geologic reservoirs.

- Demonstrate the applicability of these methods at one of DOE's Phase 3 carbon sequestration test sites.

Actors

PIs

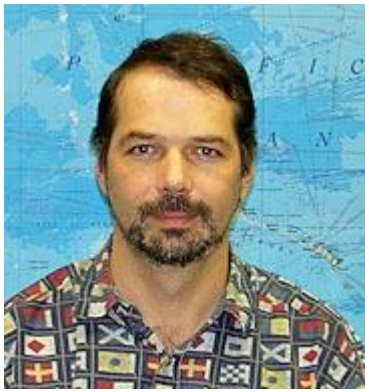
Tim Dixon (GPS)

Guoqing Lin (Seismology)

Dan Riemer (Atmospheric Geochemistry)

Peter Swart (Carbonate and Fluid Geochemistry)

Falk Amelung (InSAR)



Supporting Cast

5 Students

- **InSAR**
  - TBD
- **GPS**
  - TBD
- **Seismology**
  - TBD
- **Atmospheric Chemistry**
  - TBD
- **Fluid Modeling and Rock Interactions**
  - Caitlin Augustin

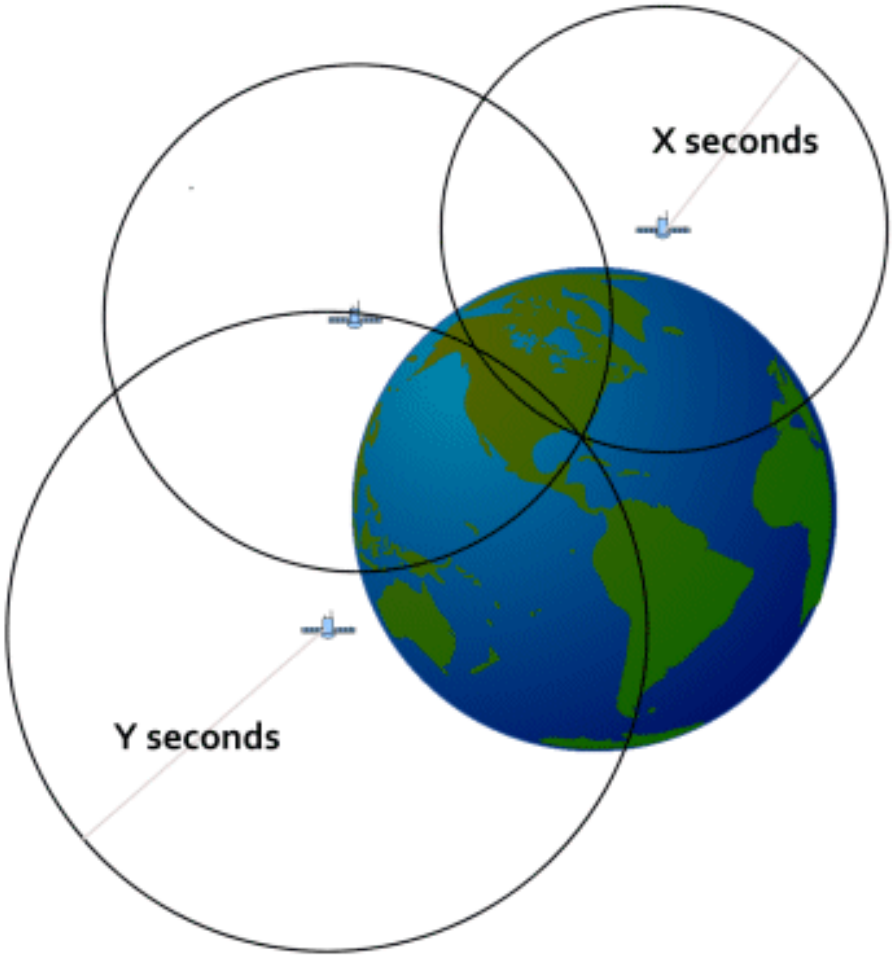
Three Components

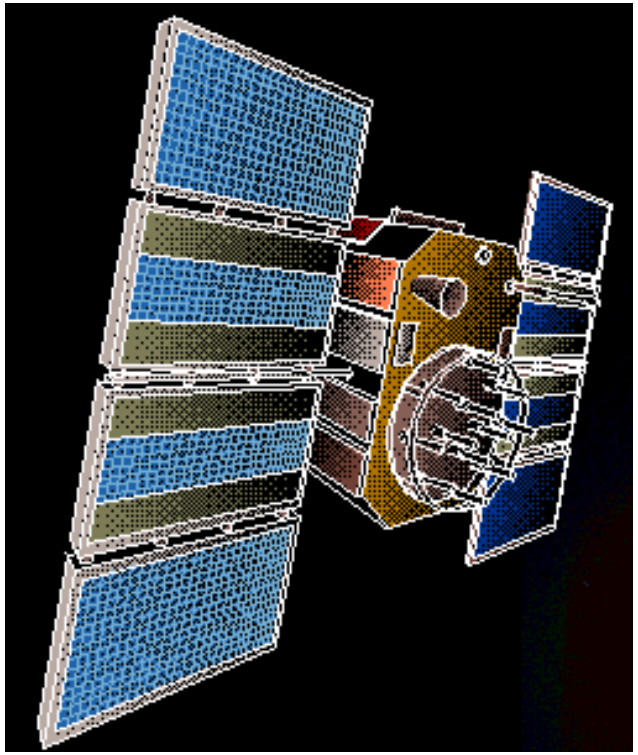
- **Space Geodesy (InSAR, GPS)**
  - Measure surface deformation at selected test site
- **Seismology**
  - Measure Vp/Vs at selected test site
- **Geochemistry**
  - Measure key geochemical parameters at test site
- Integrate data from all three areas in a numerical model that includes geochemical reactions, reservoir geometry, and pressure changes in reservoir associated with CO_2 pumping

Space Geodesy (GPS/InSAR)

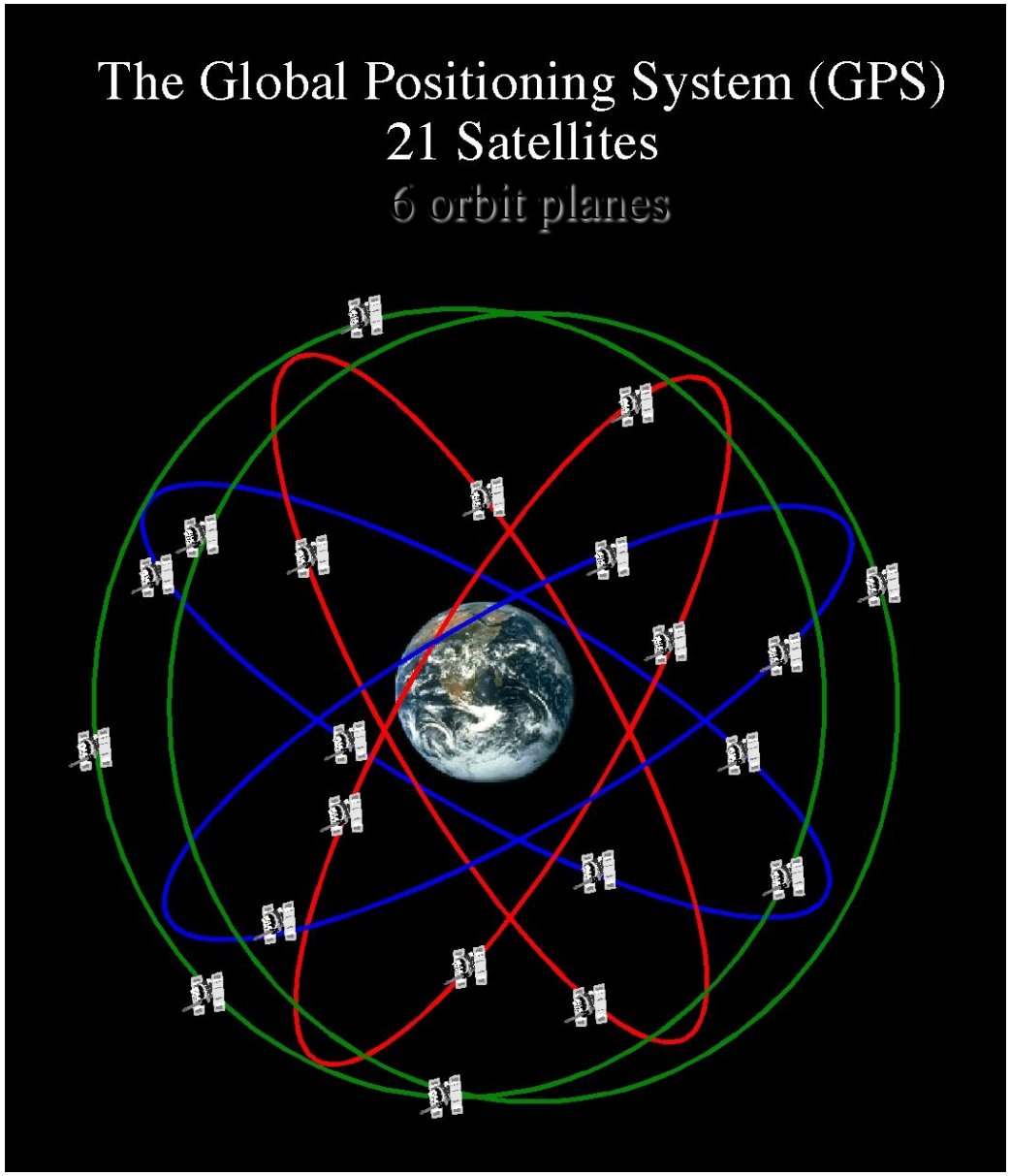
- **Principle**: adding CO_2 to reservoir increases pressure, leads to measurable uplift; short term leakage leads to subsidence
- New tools (GPS and InSAR) for deformation measurement (last one-two decades)
- GPS (point positions, high temporal resolution) and InSAR (high spatial resolution) provides ideal combination for long term monitoring of sequestration sites
- University of Miami has significant ability using these methods particularly for monitoring deformation from the emplacement of fluids in volcanic events and earthquakes

GPS

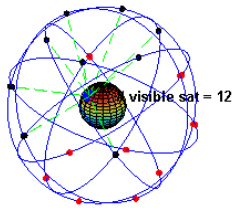




High Precision Geodesy with GPS



- Range to four or more satellites gives 3D position + clock error
- Precise phase and pseudo- range data estimates range between satellite and ground point
- Geophysical models estimate and correct major error sources (orbits, troposphere)
- Dual frequency gives first order ionosphere correction

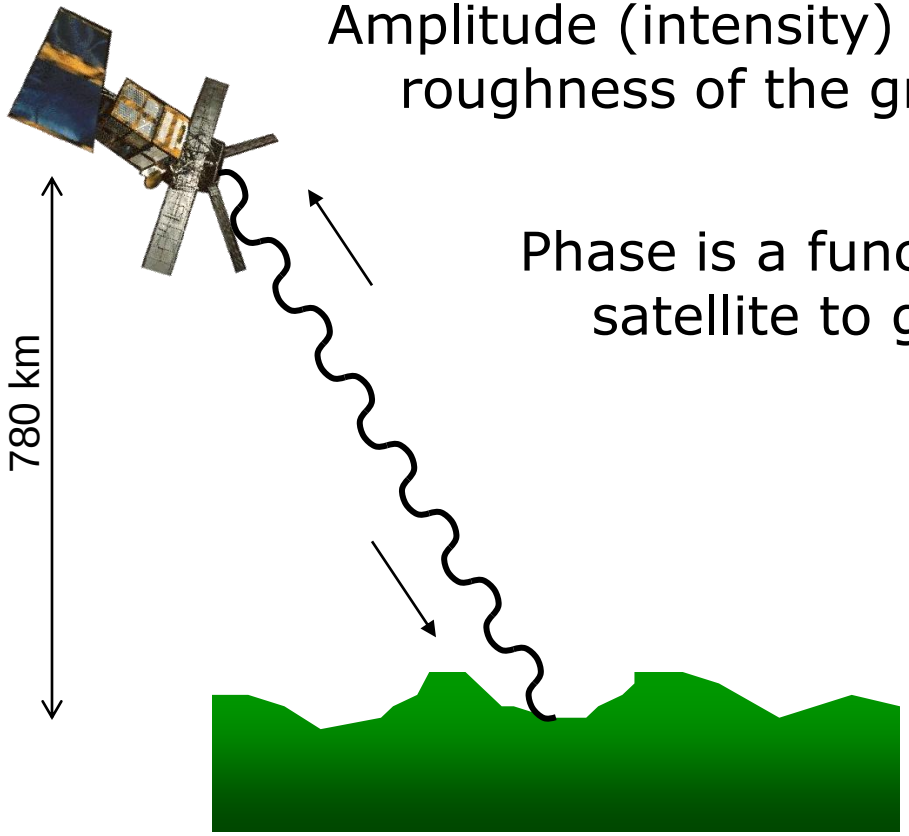


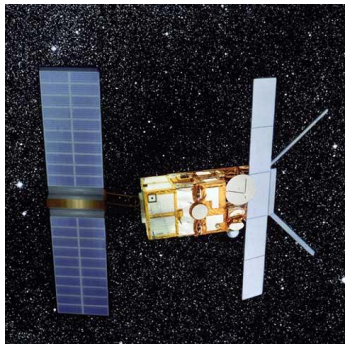
How it works: InSAR

Transmit a pulse of e-m radiation (typically microwave-band) and measure amplitude and phase of returns

Amplitude (intensity) is a function of the roughness of the ground

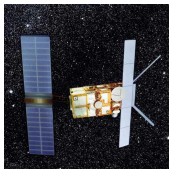
Phase is a function of distance from satellite to ground ('range')





Satellite: ERS-2 (1995–)

How it works: InSAR



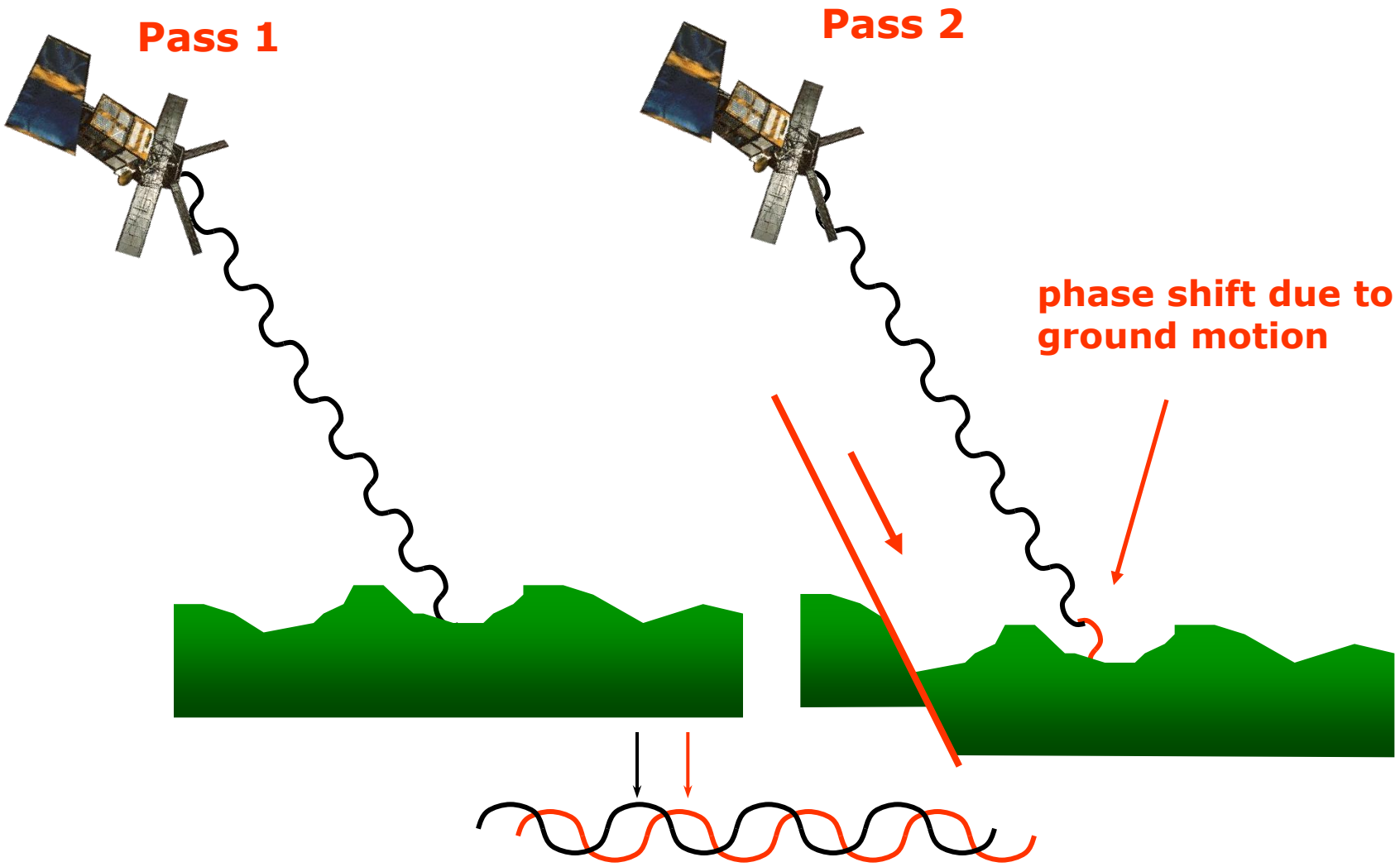
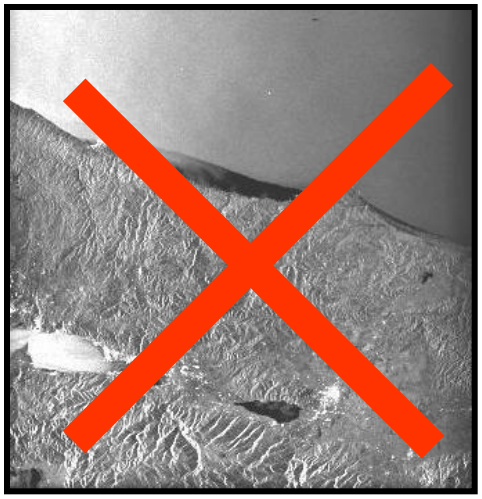
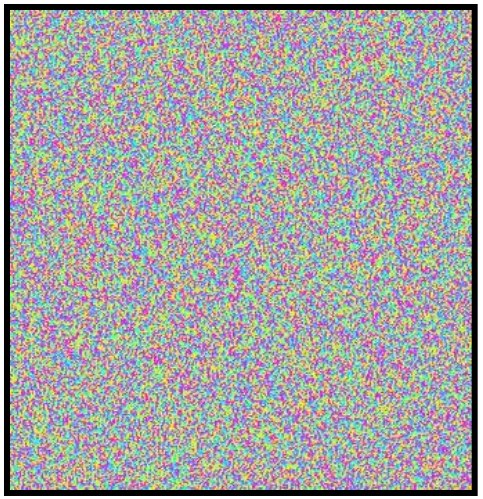
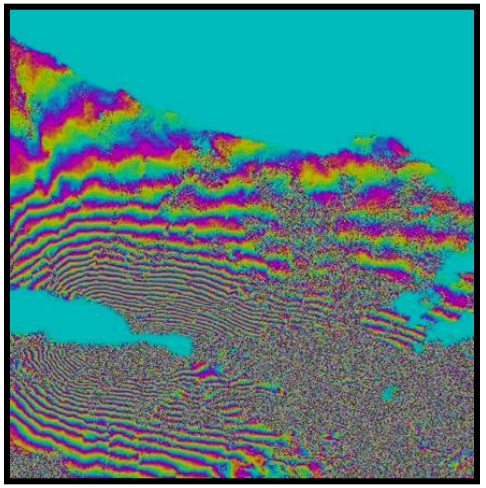


Image A - 12 August 1999





Interferogram =
Phase A - Phase B



"Change map"

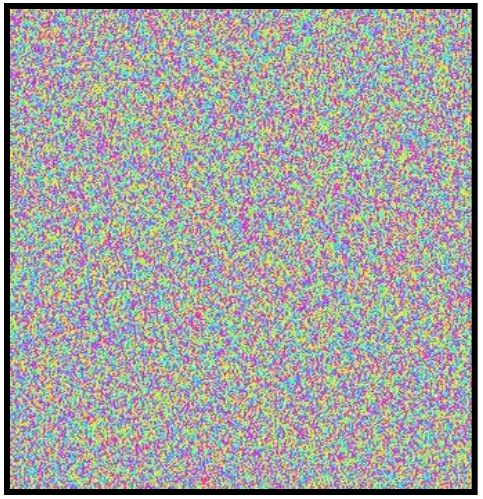


Image B - 16 September 1999

Remove phase from
topography
satellite positions
earth curvature

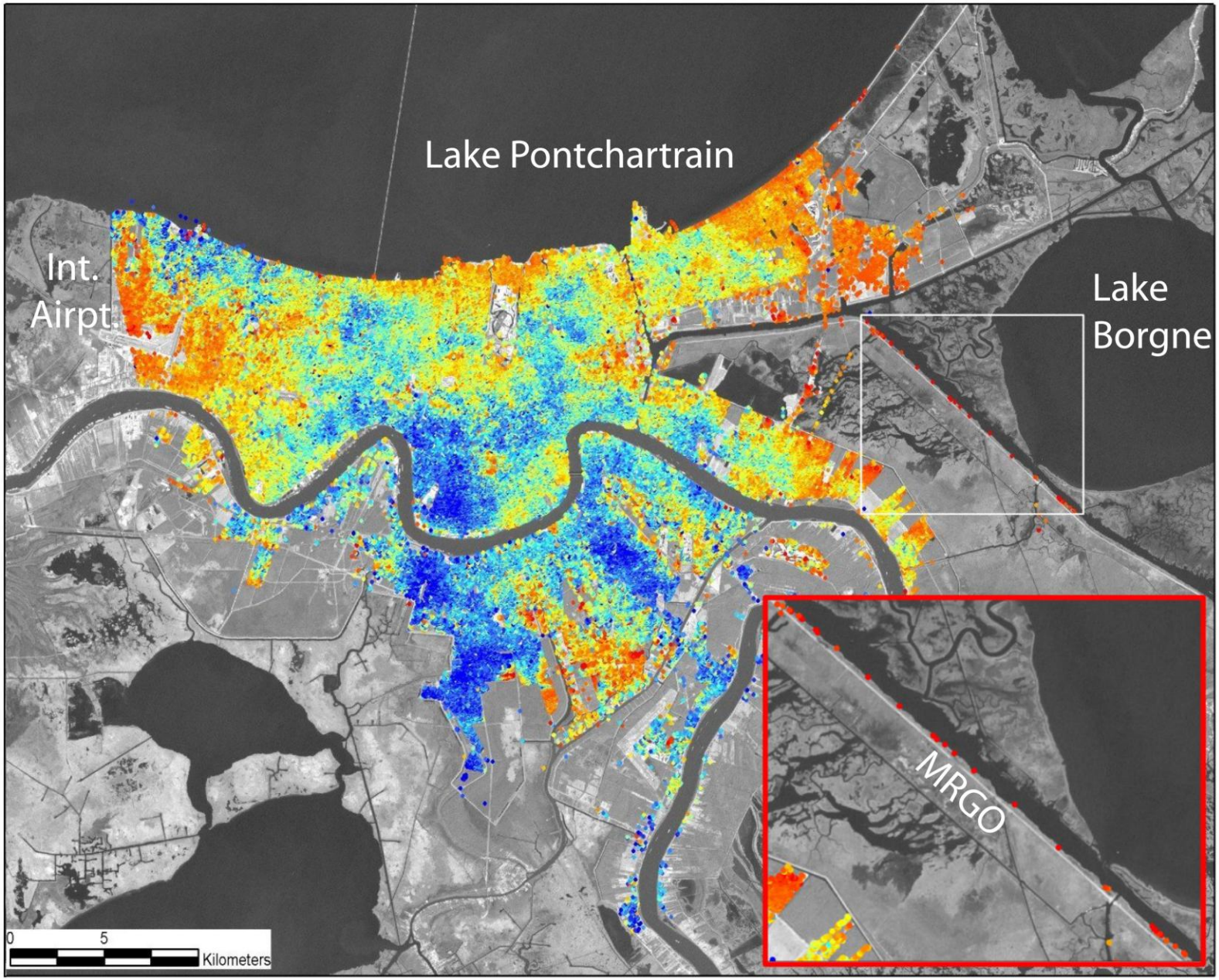
Space Geodesy:Application Examples

New Orleans example:combined GPS and InSAR for “absolute” velocity; Forensics example; why did levees fail?

Tungarahua example: non-standard shallow source (analogous to CO_2 problem?)

Bakersfield example:enhance recovery, shallow source (analogous to CO_2 problem?)

New Orleans


Lake Pontchartrain
Int.
Airpt.
Lake
Borgne
MRGO
0
5
Kilometers
Legend
NEW ORLEANS
VEL [mm/year]
-28.60 - -17.60
-17.59 - -13.54
-13.53 - -10.20
-10.19 - -8.90
-8.89 - -8.10
-8.09 - -7.50
-7.49 - -7.00
-6.99 - -6.60
-6.59 - -6.30
-6.29 - -6.00
-5.99 - -5.70
-5.69 - -5.50
-5.49 - -5.30
-5.29 - -5.10
-5.09 - -4.90
-4.89 - -4.70
-4.69 - -4.50
-4.49 - -4.30
-4.29 - -4.00
-3.99 - -3.70
-3.69 - -3.40
-3.39 - -3.10
-3.09 - -2.80
-2.79 - -2.40
-2.39 - -1.80
-1.79 - 10.30

Tungarahua

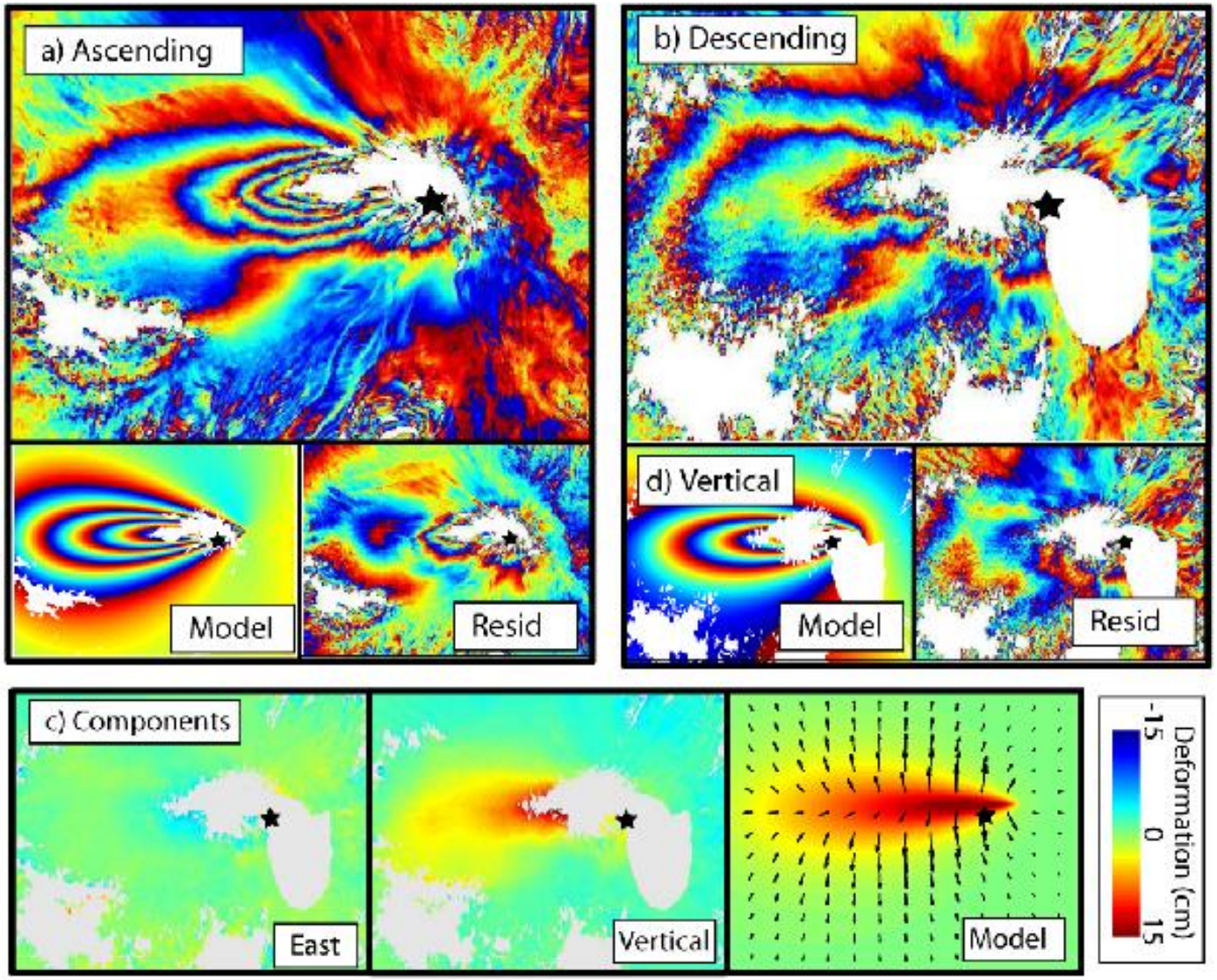
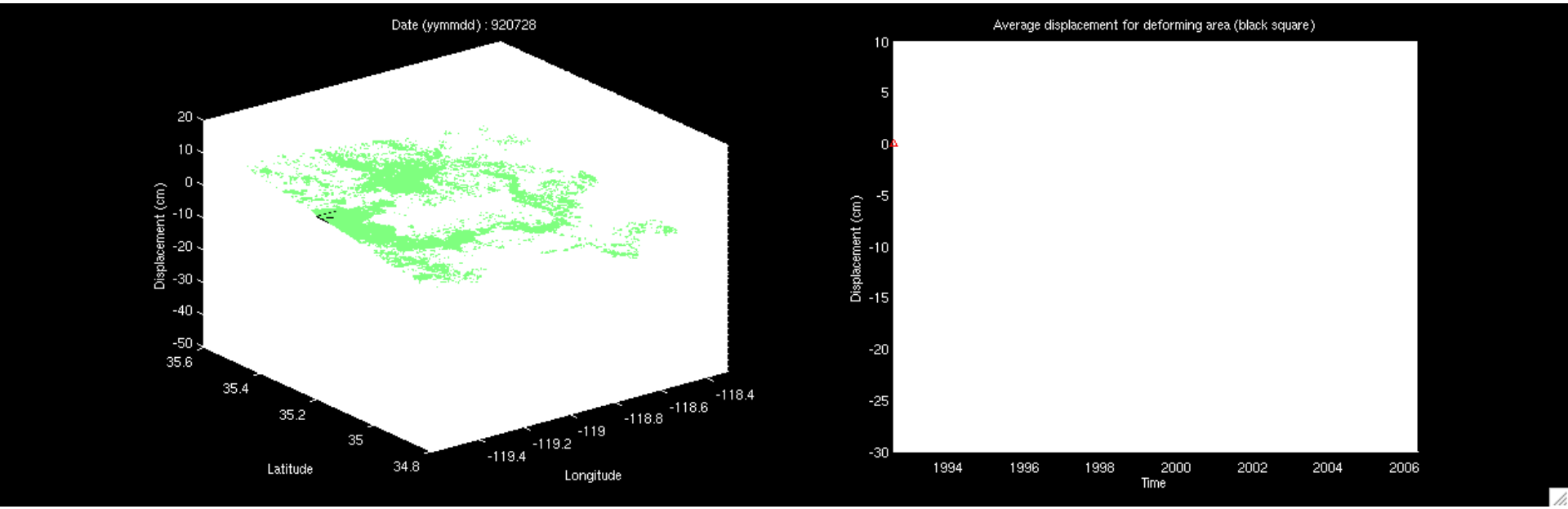
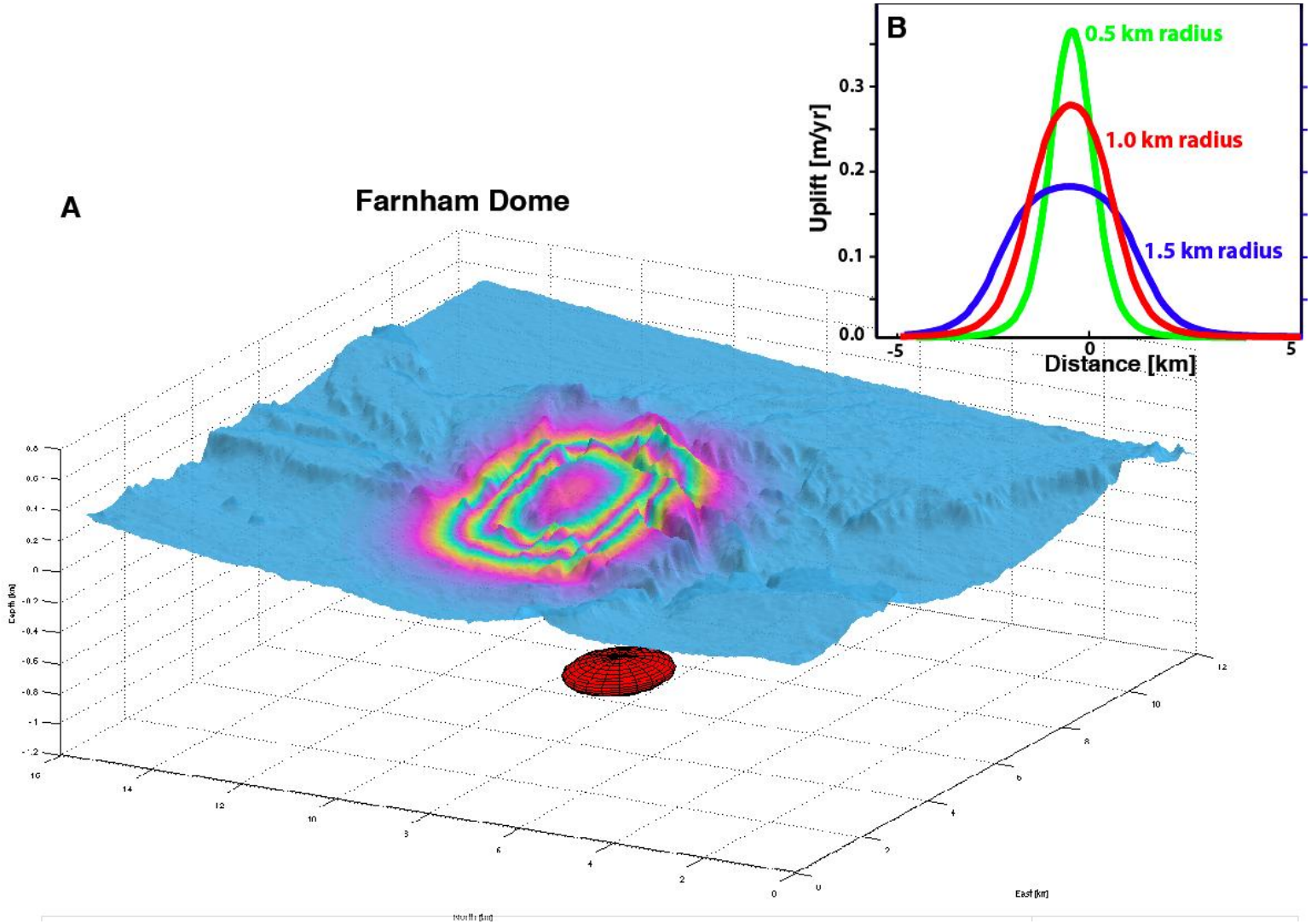


Figure 3. ALOS Interferograms spanning December 2007 - March 2008. a) Stack of two independent interferograms from an ascending line of sight; b) Single interferogram from a descending line of sight. Both interferograms are re-wrapped to 2.8cm fringes to make the deformation pattern clearer. c,d) deformation decomposed into east and north components respectively based on the assumption that the northward component has a negligible contribution to the line-of-sight deformation. The peak is 17.5 cm of uplift with little horizontal motion.

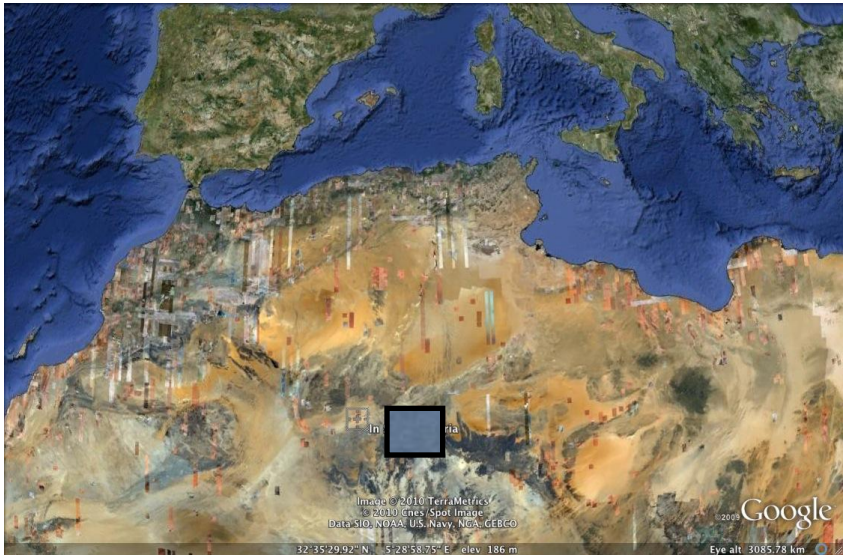
Space Geodesy and Sequestration: The Movie



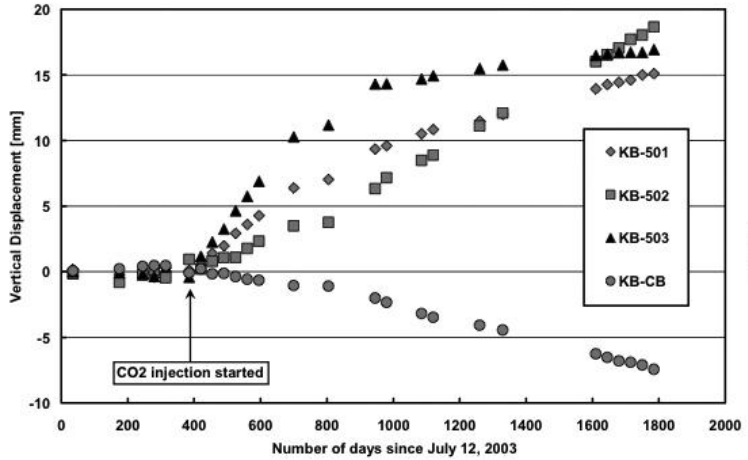
Farnham Dome Simulation

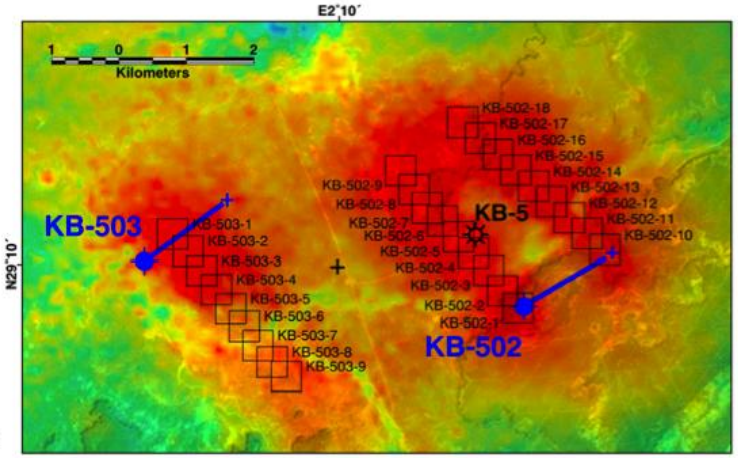


In Salah, Algeria test site: verify U of M InSAR processing



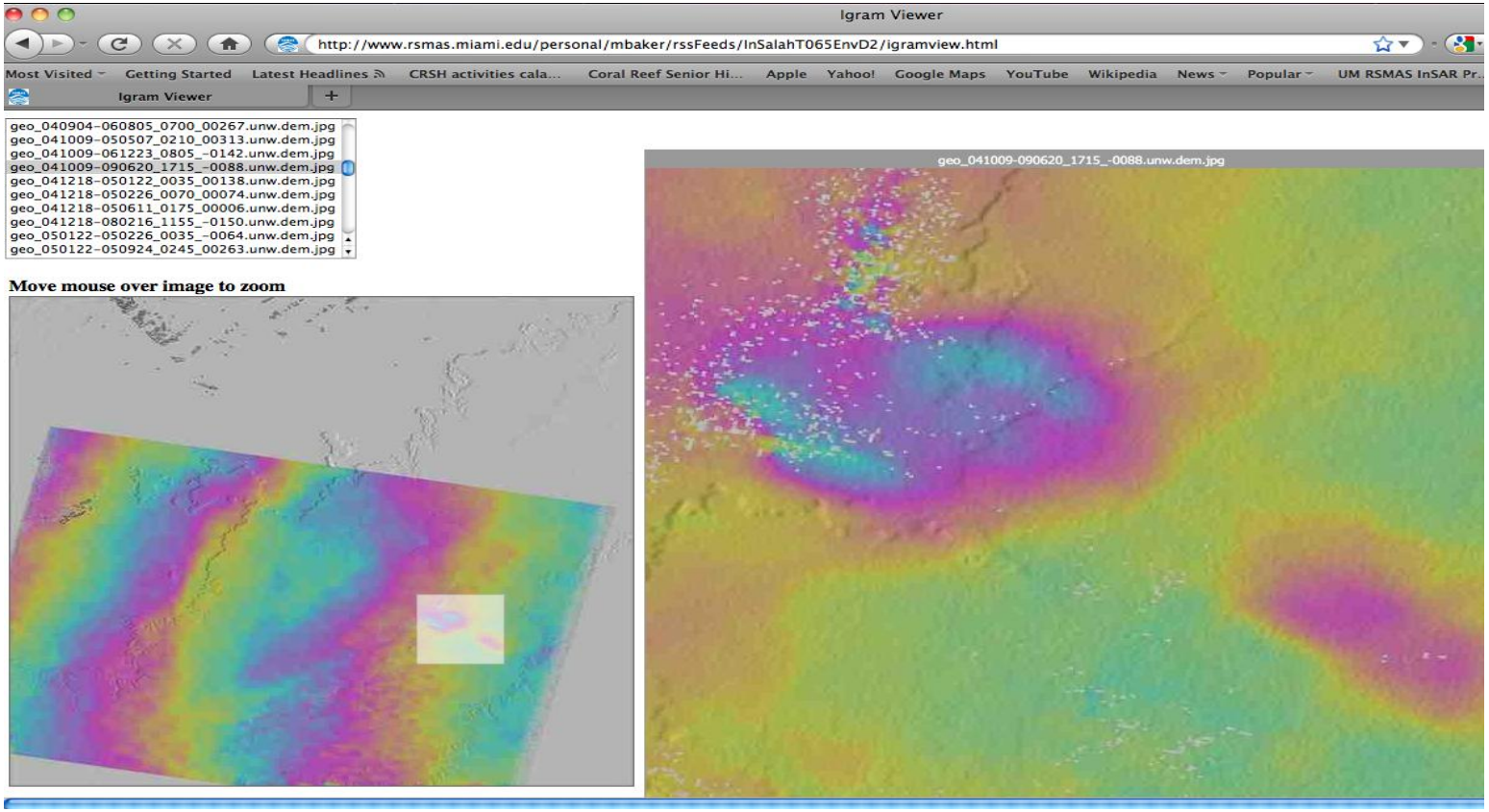
published work at In Salah showed that time-dependent uplift related to CO_2 injection can be monitored with InSAR



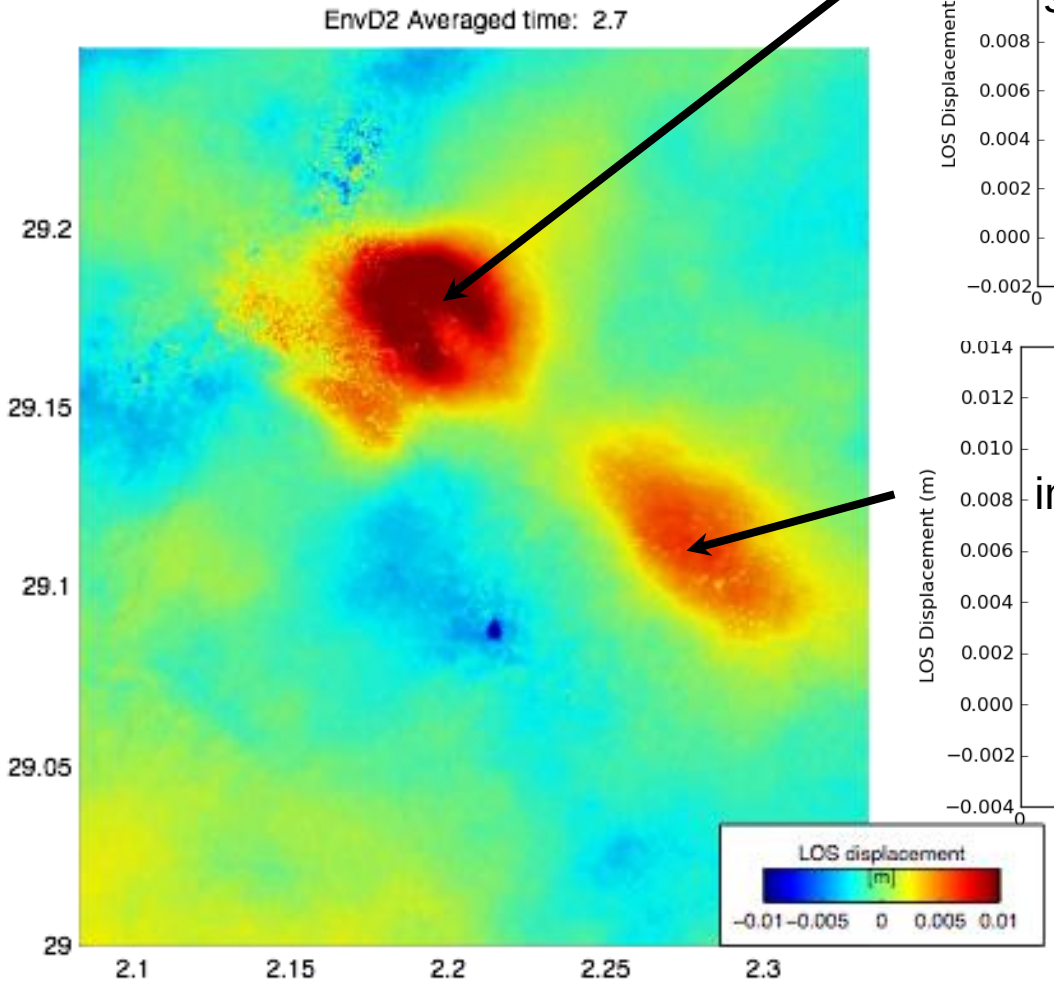


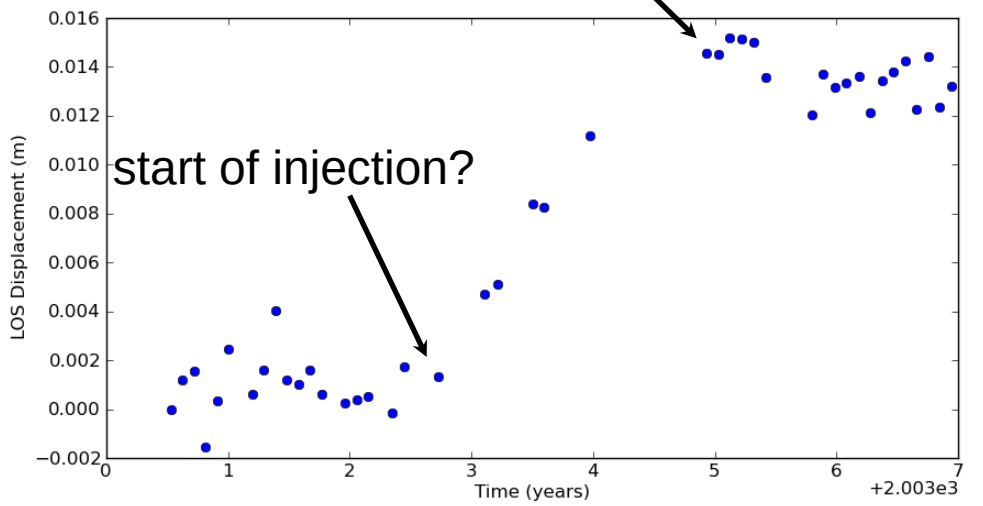
From Onuma and Ohkawa, Energy Procedia, 2009

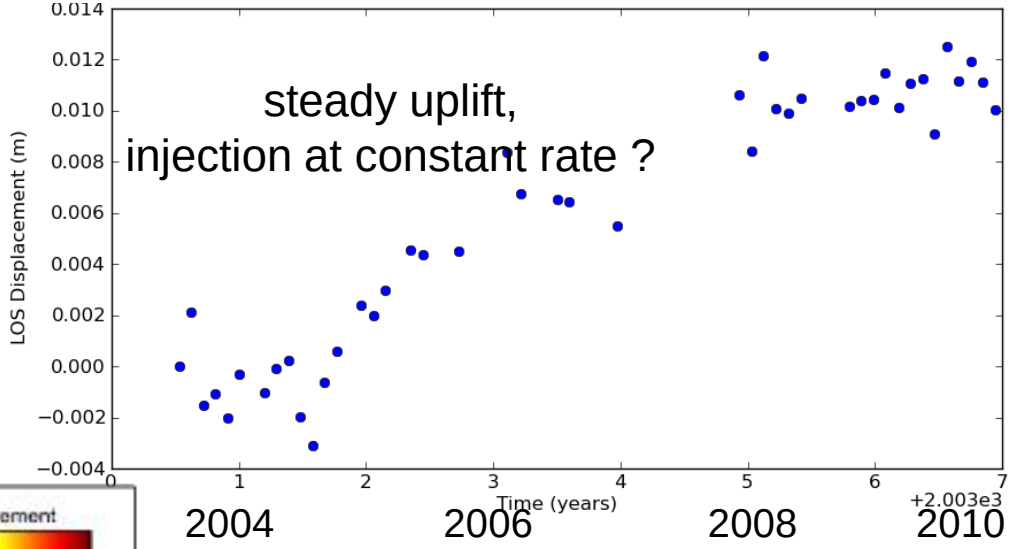
- In Salah: 44 Envisat images 2003-2010
- 98 interferograms
- Ingestion of processed data into U of M-developed interferogram viewer



In Salah, Algeria results







Time-series InSAR detects changes in surface uplift

Typical GPS Station Installation by Unavco:

GPS + seismic Network in Costa Rica for UM Earthquake Experiment

Seismology

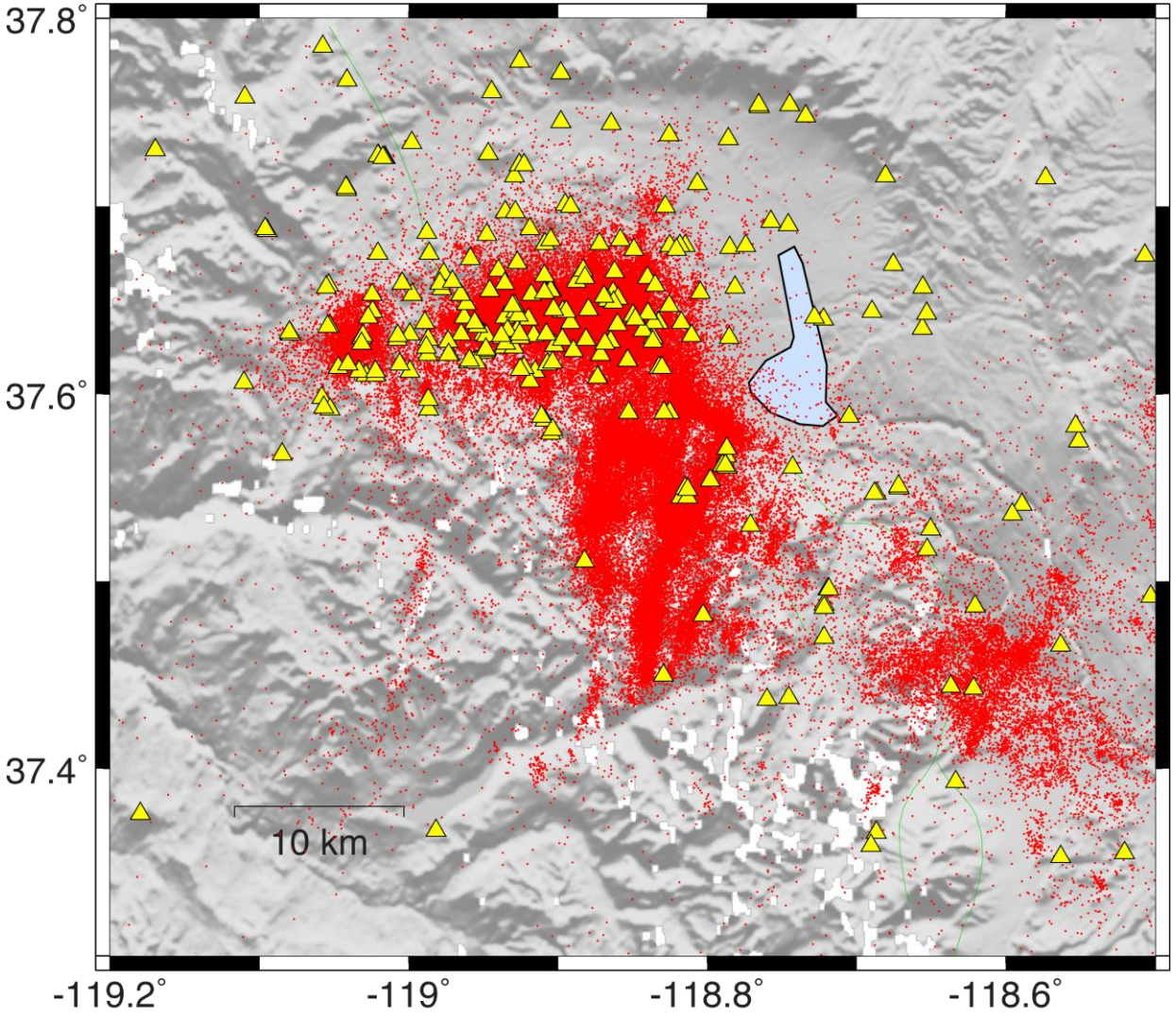
•**Principle:** Emplacement of CO_2 both can cause seismic activity and can be imaged using seismic waves

• Seismic tomography (Vp, Vs)

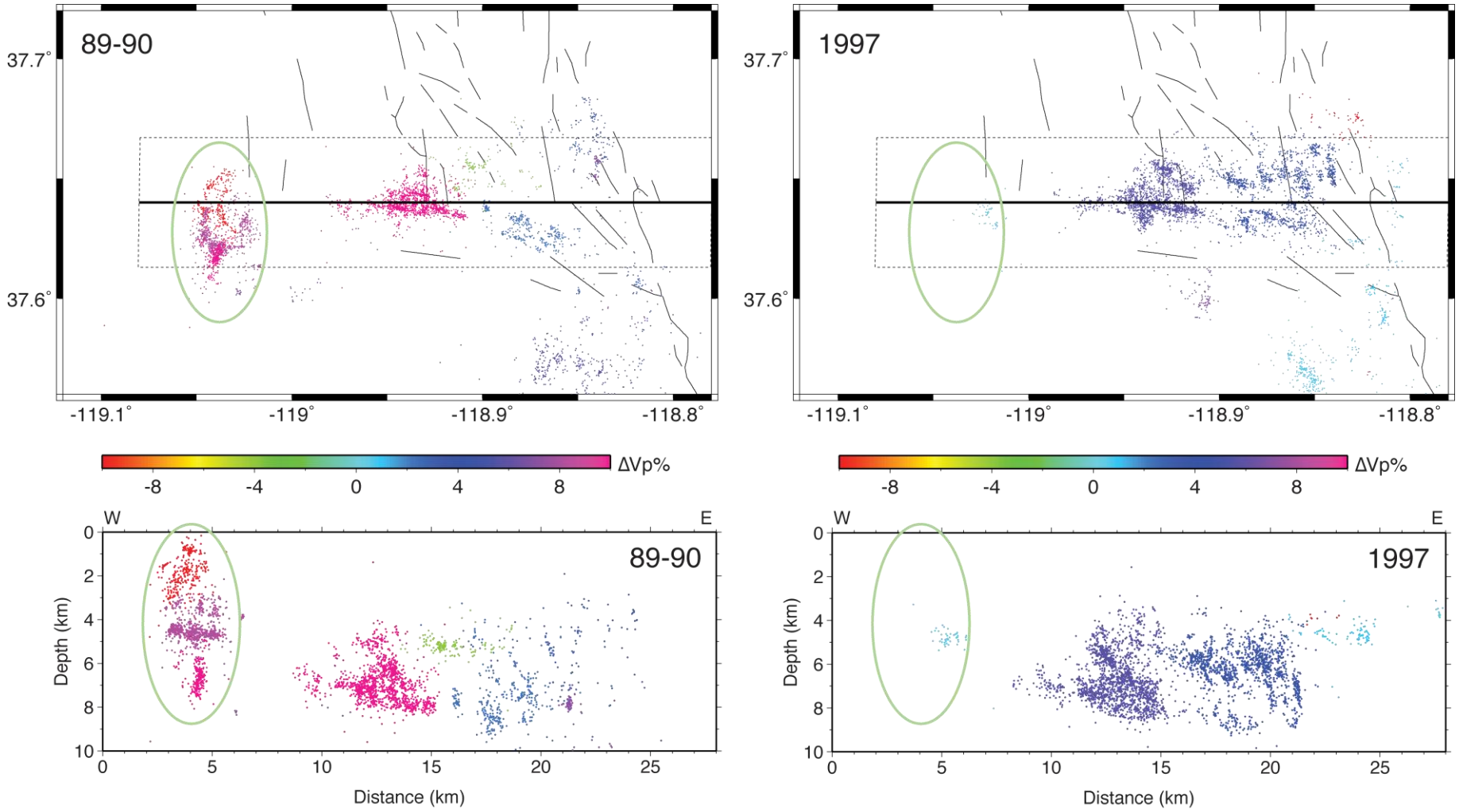
• *In-situ* high-resolution Vp/Vs ratio (~ Poisson's ratio)

•We will use natural seismic waves as well as detect seismic event induced by the injection

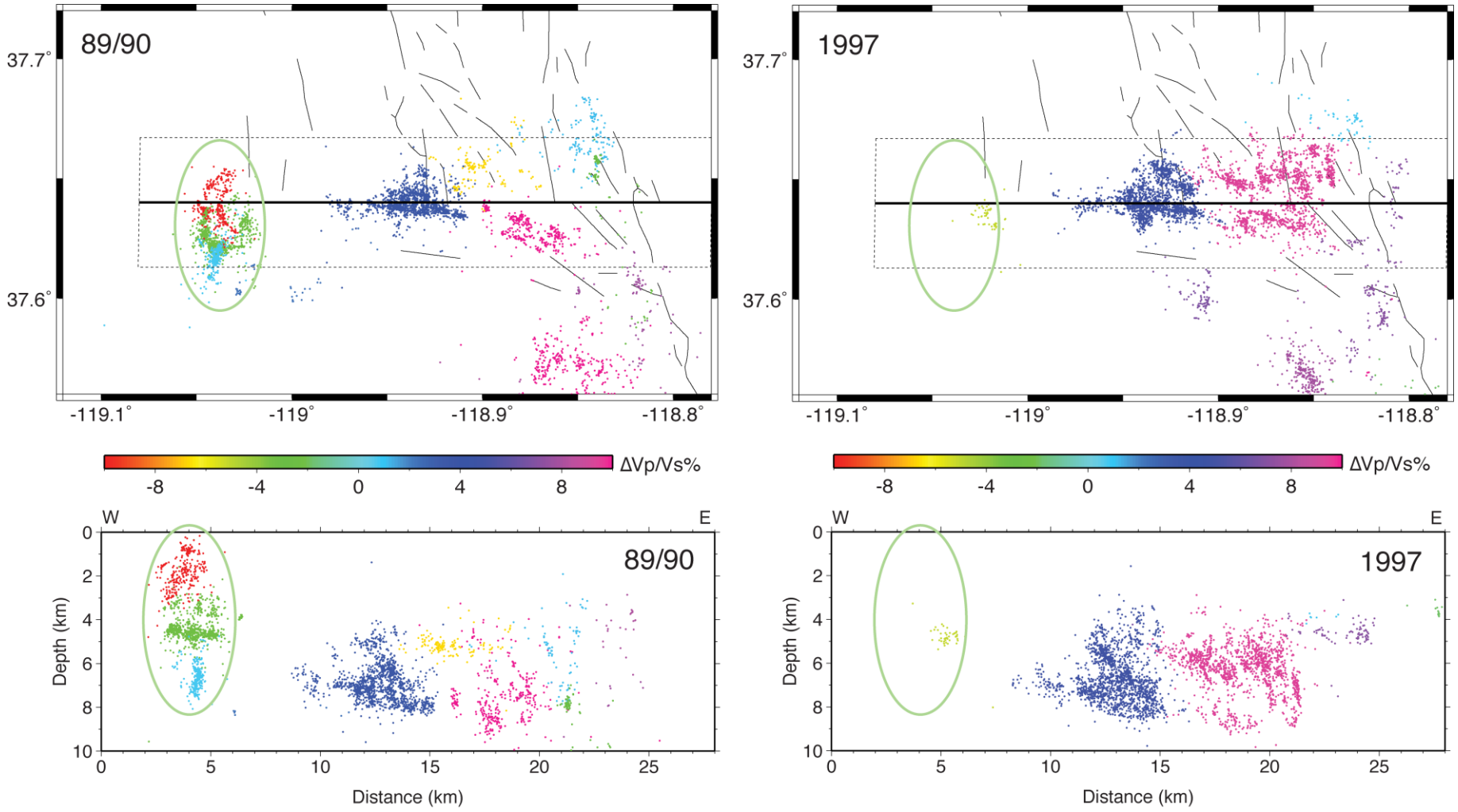
Example: Long Valley Caldera



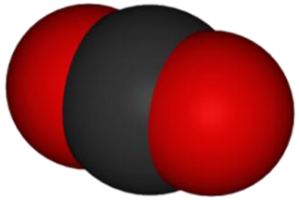
Temporal Variations in Vp



Temporal Variations in Vp/Vs



Geochemical Aspects



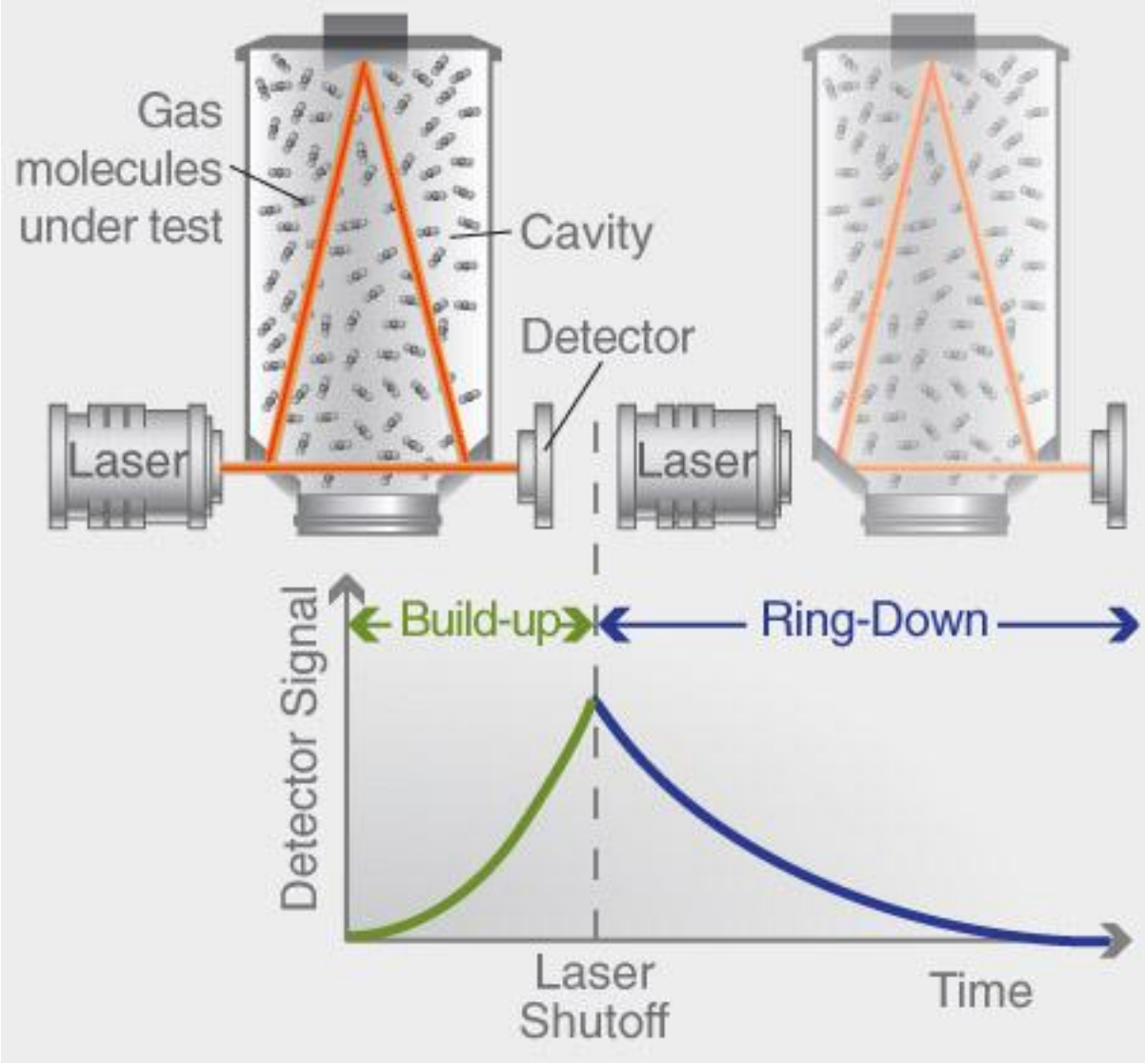
- Monitoring of CO_2 escaping from reservoir
  - Concentration measurements- (Riemer, Swart & student)
  - Isotopic composition ($^{13}C/^{12}C$) of CO_2 (Swart, Riemer & student)
- Reactions in Reservoirs
  - Direct Observations (Swart and students)
  - Modeling (Swart, Dixon & students)

Identification of CO_2 Source

- Step 1: Recognition of concentrations of CO_2 above baseline ambient concentrations
  - High speed, high precision, infrared gas analyzer deployed at several sites around the target area.
  - Measurement of soil gas fluxes and subsurface gases

- Step 2: Deployment of a cavity ring spectrometer allowing for rapid and continuous isotopic characterization of emissions
  - After identification of potential sites a cavity ring spectrometer will be deployed.

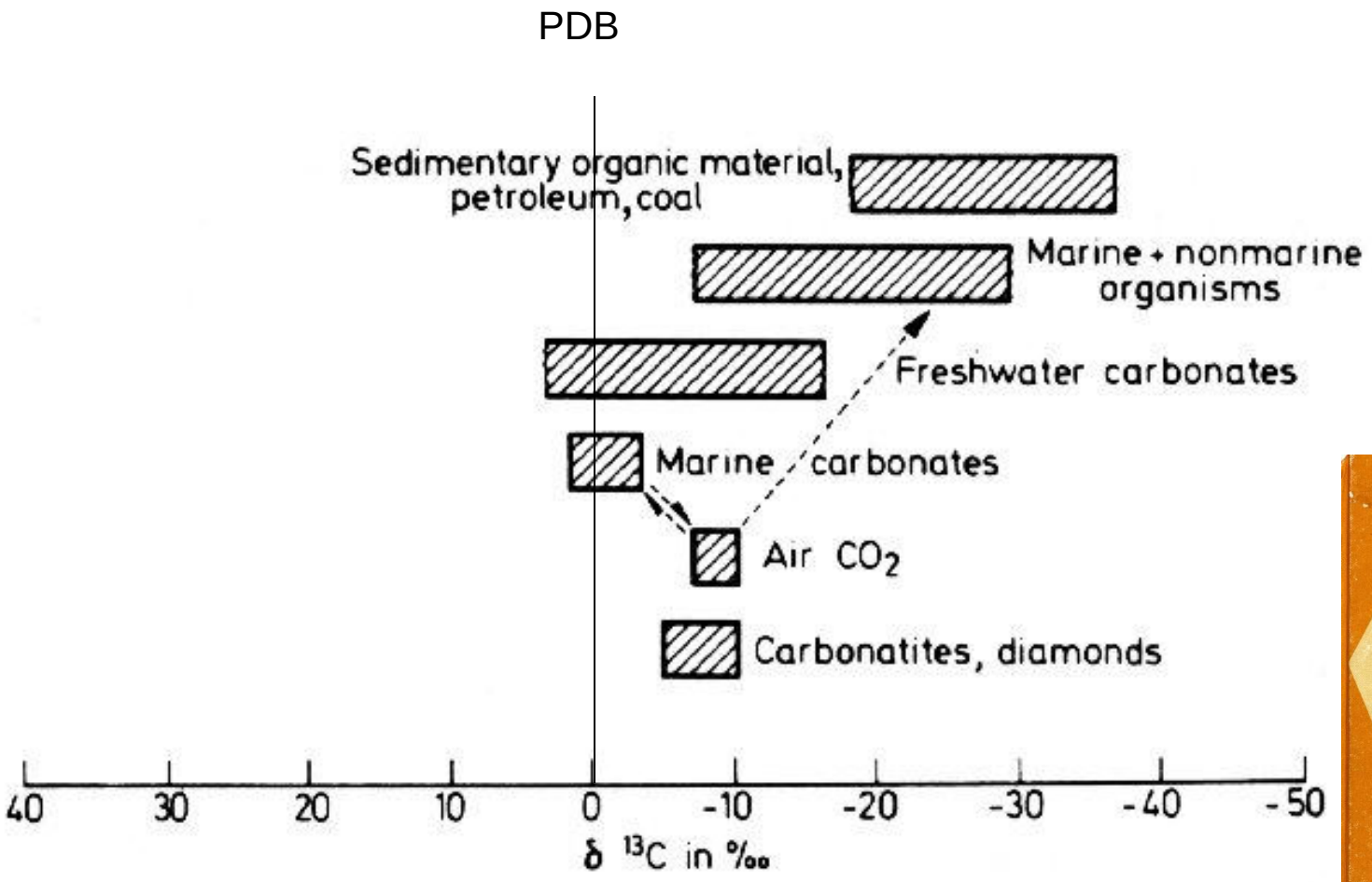

MAT 251

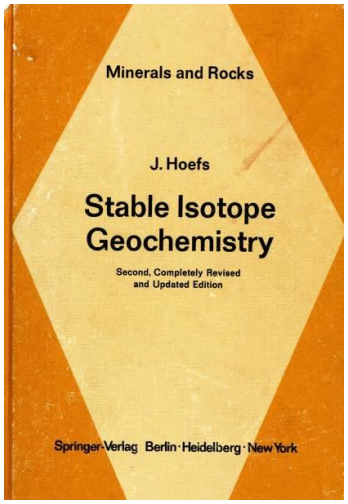

Gas
molecules
under test
Cavity
Detector
Laser
Laser
Build-up
Ring-Down
Detector Signal
Laser
Shutoff
Time

Cavity Ring Spectrometers

- Portable
  - Operated using an inverter in a car and therefore can obtain spatial data
  - Postioned in the field
- Rapid
- Fairly sensitive (5 mins for 0.1 per mille)
- Few moving parts

Range of Carbon Isotope Values





Hoefs 1982

Look at the Rocks and Fluids

- Direct Observation
  - Geochemical Measurements
    - Stable Isotopes
    - X-ray Diffraction
    - SEM
    - Other?

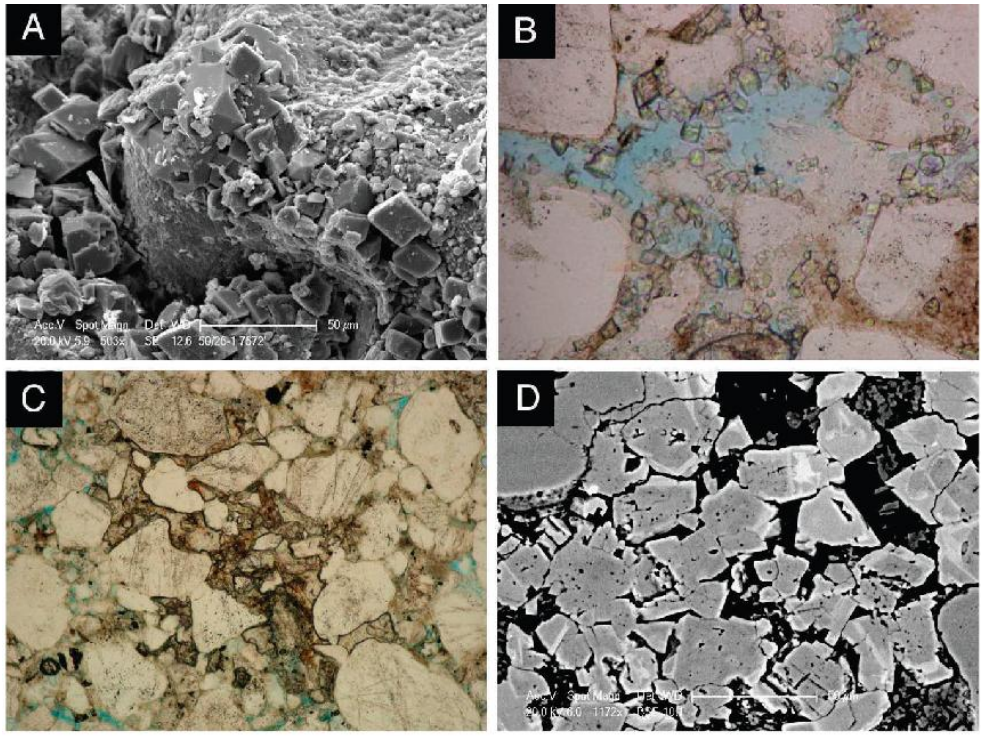


Fig. 6.— A) Pore-lining dolomite cement typical of the upper parts of the Rotliegend section. B) Thin-section view of the pore-lining cement. FOV 5 2.5 mm. C) Dolomite mini-concretion from the lower part of the Rotliegend section. F OV 5 2.5 mm. D) SEM-CL image of dolomite from the Orwell Field, which is very similar to that in the Fizzy accumulation. FOV 5 190 microns.

Modeling

- Modeling
  - Reactive Chemical Simulator (Finite Element Modeling)
  - Equilibrium and Kinetic Modeling (Geochemist Workbench)

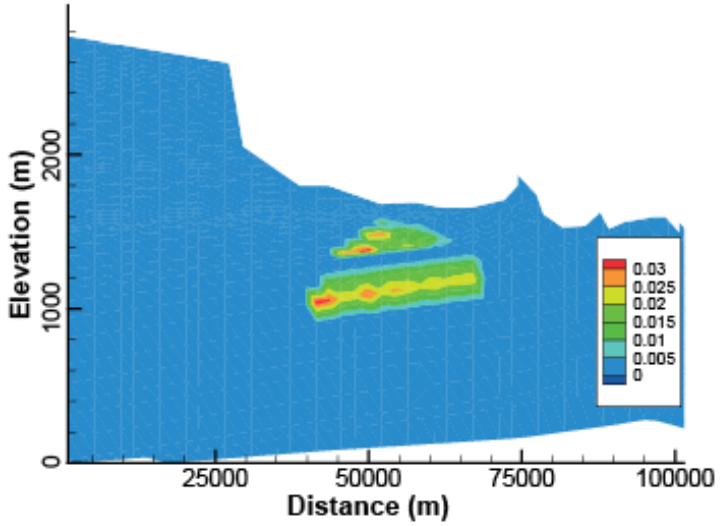


Fig. 15. Change in dawsonite density 950 years after the beginning of CO_2 injection (units are mol dm^{-3}).

Questions?