First results of continuous GPS monitoring of surface deformation at the Aquistore underground CO2 storage site

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1. INTRODUCTION

- Aquistore is a demonstration project for the underground storage of CO2
- Location: Estevan, Saskatchewan, Canada
- Storages depth: ~3350 m below surface

Project Objective

- Obtain quantitative estimates of change in subsurface fluid distributions, pressure changes and associated surface deformation
- Design, adapt and test non-seismic monitoring methods not systematically utilized to date for monitoring CO2 storage
- Integrate data from various monitoring tools
- Monitoring methods include satellite-, surface- and wellbore-based monitoring systems, such as:
  - Controlled-source electromagnetic systems
  - Absolute gravimetry
  - GPS
  - Synthetic aperture radar interferometry (InSAR)
  - Tiltmeter array analysis
  - Chemical tracer studies
- This is the first analysis with one year or more of GPS data to determine the natural rates of surface deformation before CO2 injection begins in 2015

2. DEFORMATION MONITORING NETWORK

- Covers a 1.7 x 3.8 km area (see Fig. 1 inset map)
- NE area is an old open pit coal mine reclaimed to a depth of ~20-25 m
- 13 multi-technique sites were planned with additional 6 tiltmeter-only sites
- Only 9 multi-technique monitoring sites and 1 tiltmeter site installed: 5 in 2012 & 4 in 2013 (see Fig. 1)
- Instruments mounted on or installed in 5-9 “t” dia. well casings, most to a depth of 30 m to get below the reclaimed area
- Drilling in well casings very difficult and expensive at some sites
- This analysis focuses only on the GPS monitoring using 2 years of data at 5 sites and 1 year at 4 sites

3. GPS DATA PROCESSING

Data Used

- 5 inner sites (SITE, NE01, NW01, SE01, SW01) with 2 years of data
- 4 outer sites (NE02, NW02, SE02, SW03, SW01) with 1 year of data
- 4 IGS stations (DUBO, FLIN, PRDS, SASK) define reference frame

Daily Solutions

- Bernese GPS Software v5.2 & current IGS processing guidelines using:
  - Absolute gravimetry
  - Synthetic aperture radar interferometry (InSAR)
  - Tiltmeter array analysis
  - Chemical tracer studies

Multi-Day (Velocity) Solution

- Simultaneously aligned and combined daily solutions into a 4D solution for velocities and chemistries using new SINEX combination software
- Daily and combined solutions aligned to IG08 (ITRF2008)
- Variance factors estimated for each daily solution and outliers removed
- NEU RMS of fit of daily & combined solutions: 1.5, 1.4, 4.0 mm
- NEU RMS of fit of combined solution to IG08: position 3, 3, 5 mm, velocity 0.5, 0.7, 0.4 mm/y

4. GPS & INSAR MONUMENT STABILITY

- Examined time series of short GPS baselines from SITE to other Aquistore monuments
- SITE selected as reference due to best stability of absolute coordinate time series
- GPS antennas also installed on InSAR monuments at SITE (2012) & SE01 (2013) to assess stability of shallow ~4 m deep InSAR monuments versus deep 30 m GPS monuments (Fig. 7)

2012 Monuments (left side of Fig. 8)

- Currently stable to ±1 mm with exception of NW01 (small split-off with respect to site)

2013 Monuments (right side of Fig. 8)

- Most show significant vertical settlement until spring 2014
- Likely a result of large horizontal motions (well casings had to be braced into vertical or may be drifting back)
- NE02 exhibited a strange systematic pattern of motion - horizontal exhibited the same pattern (the cause)
- All monuments appear to have stabilized except for shallow InSAR at SE01 – but larger noise due to 2012 one

6. COMPARISON WITH INSAR

- InSAR results in Fig. 10 based on RADARSAT-2 using the methodology of Samsonov et al. (see G41A-0467)
- Linear deformation relative to the selected stable reference area “R” in Fig. 10
- Deformation estimated for a 5 x 5 m footprint at each site

- InSAR time series agrees fairly well with GPS, following the same basic pattern except during initial monument settlement of new 2013 sites (right side of Fig. 8)

7. SUMMARY & FUTURE WORK

- Fairly good agreement of GPS with regional velocity field and InSAR
- Need longer time series (first year not really useable because of monument settlement at new sites)
- Need to use more IGS stations to determine reference frame more reliably

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