Playa del Rey, California

InSAR Ground Deformation Monitoring

Master Document

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GEOSPATIAL SERVICES

SUBMITTED TO:

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EXECUTIVE SUMMARY

This Master Document report describes the methodology and results used to monitor and quantify potential ground deformation at the Southern California Gas Company (SoCalGas) Playa del Rey Gas Storage Field area in California using satellite radar interferometry. Surrounding areas are also included in the analysis and will be referred to generally as the main Area of Interest (AOI) throughout this report. The purposes of capturing areas outside of the Playa del Rey area is to show the effectiveness of the technology in the case where no movement has occurred at the Playa del Rey Gas Storage Field area but has occurred in the outlying areas.

This AOI will be monitored using the satellite radar technology for the next five (5) years. The RADARSAT-2 satellite passes over SoCalGas' AOI every 24 days at an elevation of approximately 500 miles. The acquired RADARSAT-2 imagery is being used for the generation of deformation maps of the AOI. The results of the deformation data will be presented to SoCalGas every six (6) month period. The accuracy of each deformation map is estimated to be in the order of 0.02 ft. Over time, it is expected that the accumulated deformation data will show in great detail any potential ground deformation and the context of these deformation signals.

For this deliverable, Milestone 1, two (2) deformation maps are produced from scheduled RADARSAT-2 Ultra-Fine ascending radar imagery. The current deformation data produced from May 27 to December 5, 2008 time period are reviewed as part of this report. For this initial time period, no significant deformation patterns above the noise floor can be detected within SoCalGas' AOI.

The following summarizes key features for this deliverable:

- Satellite radar data were scheduled for acquisition from May 2008 through to December 2008. For this deliverable, five (5) consecutive RADARSAT-2 Ultra-Fine ascending radar data images were scheduled and analyzed.

- All available data are evaluated and the highest quality deformation maps are generated. The time periods selected are from May 27, 2008 to August 31, 2008 (Pair A) and August 31, 2008 to December 5, 2008 (Pair B).

- The delivered products are georeferenced with a horizontal accuracy better than 65 ft. Areas of insufficient quality are masked out in the final products. The measurements in the AOI are of good quality.

- No significant deformation is observed in the AOI in the considered time span. The estimated precision for the Pair A deformation map is 0.031 ft with a 95% confidence interval, while the estimated precision for Pair B deformation map is 0.032 ft with a 95% confidence interval.

This document is referred to as the "Master Document". The document identifies the project overview, the Milestones for this contract, and conventional InSAR deformation processing. It also includes the results for the May to December 2008 time period. Future Milestone deliverables will be referred to as "Interim Report" and will focus primarily on results for the specified time period. At the end of the five (5) year contract, all results will be presented and discussed in a Final Report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

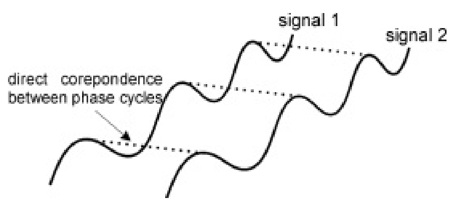
SYMBOLS, ACRONYMS AND DEFINITIONS

γ **Coherence**

Is the degree of similarity of the backscatter response, as measured by the SAR sensor, between corresponding ground cells in both SAR images of an InSAR pair.

ϕ **Phase**

When the sine wave starts to repeat itself (phase angle > 360 degrees), one cycle of phase has occurred. If we collect two separate images from exactly the same satellite position (same range), but at different times with nothing in the target area changing, one would expect the two sine waves from each image to be the same and in phase with each other (they would appear as one if at right-angles to the plane of the signal).



The phase difference is sensitive to both the viewing geometry and the height of the point above the reference surface

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λ **Wavelength**

Electromagnetic radiation consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c). Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the wavelength and frequency. The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests.

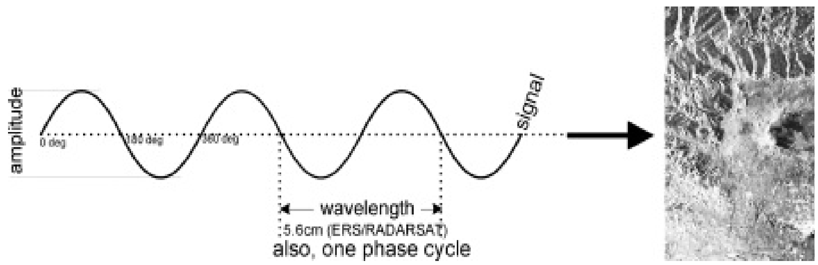
Wavelength and frequency are related by the following formula:

$$c = \lambda \nu$$

where:

λ = wavelength (m)
ν = frequency (cycles per second, Hz)
c = speed of light (3×10^8 m/s)

Therefore, the two are inversely related to each other. The shorter the wavelength, the higher the frequency. The longer the wavelength, the lower the frequency.



B

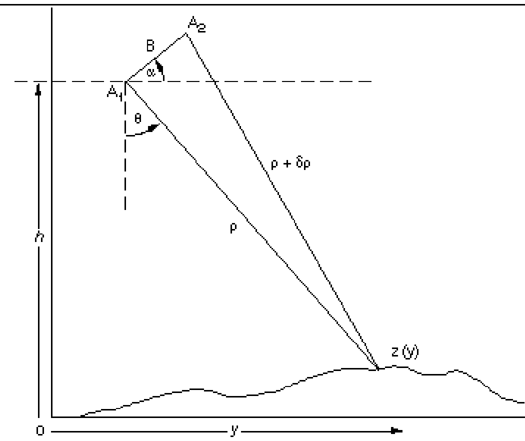
Baseline

The perpendicular baseline (Bperp, or across-track separation between the two satellite positions) is the difference between the position of the satellite in pass 1 and the position of the satellite in pass 2 of an interferometric pair.

ρ

Range

Consider two radar antennas, A1 and A2, simultaneously viewing the same surface and separated by a baseline vector B with length B and angle α with respect to horizontal. A1 is located at height h above some reference surface. The distance between A1 and the point on the ground being imaged is the range ρ, while $\rho+\delta\rho$ is the distance between A2 and the same point.



AOI	**Area of Interest**
DEM	**Digital Elevation Model** A digital elevation model is a digital representation of ground surface topography or terrain. Digital elevation models are gray scale images wherein the pixel values are actually elevation numbers. The pixels are also coordinated to world space (longitude and latitude), and each pixel represents some variable amount of that space (foot, meter, mile, etc.) depending on the purpose of the model and land area involved.
GSI	**MacDonald Dettwiler and Associates Geospatial Services Inc.**
InSAR	**Interferometric Synthetic Aperture Radar** SAR interferometry makes use of the phase information by subtracting the phase value in one image from that of the other, for the same point on the ground. This is, in effect, generating the interference between the two phase signals and is the basis of interferometry.
LOS	**Line-of-Sight** Line-of-sight between sensor and observed pixel in the terrain.
MDA	**MacDonald, Dettwiler and Associates Ltd.**
RADAR	**Radio Detection and Ranging** RADAR is the acronym for **RA**dio **D**etection **A**nd **R**anging, which essentially characterizes the function and operation of

	a radar sensor. It is the most common form of imaging active microwave sensors is RADAR. The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal. The strength of the backscattered signal is measured to discriminate between different targets and the time delay between the transmitted and reflected signals determines the distance (or range) to the target.
SAR	**Synthetic Aperture Radar** The Radar sends out a pulse of radio waves which bounces off the object to be depicted. The scattered pulses then return to the radar, where they are captured by the receiving antenna. The antenna is the radar's aperture, or its opening on the world. SAR antennas are a type of radar antenna designed to take advantage of their satellite's movement, thus creating a "synthetic" aperture or opening.
SRTM	**Shuttle Radar Topography Mission**
	Georeferencing Georeferencing is the process of assigning pixels within an image (raster), with ground co-ordinates, e.g., latitude and longitude. A georeferenced image may then be transformed to match a particular map projection system where each pixel represents a specific location and distance on the ground. Before georeferencing, SAR images consist of arrays of pixels fixed into a geometry corresponding to the acquisition parameters of the satellite–the image is said to be in slant range. The act of georeferencing and transforming into a map projection puts the image into ground range.
	Phase Noise Differential phase noise is caused by changes in microwave reflective properties over time. They result in a reduced ability to use the differential phase for accurate measurements of changes in line of sight.
	Temporal Decorrelation Changes in the Earth’s surface that make it difficult to compare “before” and “after” images. The problem of low coherence regions can be exacerbated as the time of separation is increased between two scenes of an InSAR pair.

1 INTRODUCTION

This document is referred to as the "Master Document". The document identifies the project overview, the Milestones for this contract, and conventional InSAR deformation processing. The SoCalGas Playa del Rey Gas Storage Field Area of Interest (AOI) as well as surrounding areas in California will be monitored using the satellite radar technology for the next five (5) years. The results of the deformation data will be presented to SoCalGas every six (6) month period. The accuracy of each deformation map is estimated to be in the order of 0.02 ft.

This report gives a brief introduction to the InSAR deformation mapping technology and provides detailed processing. The report also includes the results for the May 2008 to December 2008 time period. Future Milestone deliverables will be referred to as "Interim Report" and will focus primarily on results for the specified time period. At the end of the five (5) year contract, all results will be presented and discussed in a Final Report.

MDA Geospatial Services Inc. has executed hundreds of projects using InSAR technology since 1997. This experience has led to the development of software solutions tailored to the specific types of monitoring required by the oil and gas and mining sectors. The main objective of these projects has been to create very accurate surface deformation maps using space borne radar technology

1.1 REPORT ORGANIZATION

This report is organized as follows:

- Section 1 provides the introduction and report organization.
- Section 2 describes the scope of the project, the AOI, and the available data for the current monitoring time period.
- Section 3 illustrates the basic InSAR processing steps.

- Section 4 describes the processing and results for the two (2) delivered deformation maps.
- Section 5 provides a summary and conclusions.
- Appendix A lists the deliverables.

2 PROJECT OVERVIEW

This section briefly describes the scope of the project, the location and setting of the project area, and the RADARSAT-2 data used.

2.1 PROJECT OBJECTIVE AND SCOPE

The objective of this project is to provide SoCalGas with measurements of the ground deformation that occurred within the project's AOI using conventional InSAR monitoring. Five (5) RADARSAT-2 Ultra-Fine ascending satellite data, acquired from May 2008 to December 2008 were examined. For this Milestone, two (2) conventional InSAR deformation maps quantifying ground movement that occurred from May 2008 to December 2008 have been generated.

This deliverable pertains to the first deliverable of a five (5) year InSAR Monitoring Program, as shown in Table 1.

Table 1: Milestone Deliverables.

Milestone	Description of Services and Monitoring Period	Document Name	Delivery Date
Milestone 1	Two (2) Deformation Maps May to December 2008	Master Document	January 2009
Milestone 2	Two (2) Deformation Maps December 2008 to June 2009	Interim Report A	July 2009
Milestone 3	Two (2) Deformation Maps June 2009 to December 2009	Interim Report B	January 2010
Milestone 4	Two (2) Deformation Maps December 2009 to June 2010	Interim Report C	July 2010

Milestone 5	Two (2) Deformation Maps June 2010 to December 2010	Interim Report D	January 2011
Milestone 6	Two (2) Deformation Maps December 2010 to June 2011	Interim Report E	July 2011
Milestone 7	Two (2) Deformation Maps June 2011 to December 2011	Interim Report F	January 2012
Milestone 8	Two (2) Deformation Maps December 2011 to June 2012	Interim Report G	July 2012
Milestone 9	Two (2) Deformation Maps June 2012 to December 2012	Interim Report H	January 2013
Milestone 10	Two (2) Deformation Maps December 2012 to June 2013	Final Report	July 2013

2.2 STUDY AREA

The Playa del Rey Gas Storage Field AOI and surrounding area, in Los Angeles, California, is outlined by the red polygon as seen in Figure 1. The corner coordinates for the polygon are approximately given by a rectangle with coordinates 34º 01' 58"N 118º 28' 5"W and 33º 56' 56"N 118º 20' 4"W.

Figure 1: Playa del Rey AOI and surrounding area in Los Angeles, as outlined by red polygon (radar amplitude image).

2.3 DATA SELECTION

Table 2 lists the RADARSAT-2 Ultra-Fine data used to generate the deliverables for this project. These data were scheduled and acquired between the months of May 2008 to December 2008. All acquired data have been analyzed and the best Pairs of data were selected in order to create the most accurate products.

Table 2: RADARSAT-2 Ultra-Fine data acquired over Playa del Rey Gas Storage Field, CA

Acquisition #	Acquisition Date	Orbit Number	Comments
1	May-27-08	2351	Acquired
2	Jun-20-08	2694	Lost due to satellite anomaly
3	Aug-7-08	3380	Acquired
4	Aug-31-08	3723	Acquired
5	Nov-11-08	4752	Acquired
6	Dec-5-08	5095	Acquired

In large part, the Pair selection depended upon the resulting perpendicular baseline of the data, where a larger baseline could result in poor coregistration between pixels which leads to residual topographic phase noise.

In order to select the data that contain most value for the client, all data are evaluated, i.e., the Pairs that result in the largest area with good quality deformation measurements, and with the best deformation signal-to-noise level. When generating a deformation map from an interferogram, phase induced by constant topography needs to be removed from the interferogram. It is important to realize that the topographic height is never known exactly, which implies that residual topographic signal remains in the interferogram as phase. This can in turn be interpreted incorrectly as deformation signal. The phase due to the error of the Digital Elevation Model (DEM) is sensitive to the perpendicular baseline (the distance between the imaging positions at the time of acquisition) of the interferogram Pair. An interferogram with a small baseline is less sensitive to the error of the DEM. To minimize the error, it is important to select Pairs with smaller baselines.

The two (2) InSAR deformation maps generated are listed in **Error! Reference source not found.**. On these dates the SAR data were of best quality with suitable baselines. The two maps are generated using the August 31, 2008 acquisition as the shared data, which allows for a comparison between them and an improvement in the precision by summation of the two maps.

Table 3: Selected RADARSAT-2 data for the InSAR analysis. (The pairing numbers refer to the acquisition number in Table 2)

Interferogram Pair	Acquisition Date Master	Slave	Perpendicular Baseline (meters)
A (1-5)	May-27-08	Aug-31-08	399
B (5-9)	Aug-31-08	Dec-5-08	84

3 INSAR PROCESSING OVERVIEW

Spaceborne Synthetic Aperture Radar (SAR) systems transmit an electromagnetic signal to the earth's surface. The energy interacts with objects on the earth, and is scattered back to the sensor. Both the magnitude and the phase of microwave energy backscattered are accurately recorded. The magnitude is usually associated with a remotely sensed image. It indicates the “brightness” of the surface as detected by the SAR (See also Figure 2). The phase represents the combination of two factors: (i) the distance from the SAR to the surface, and (ii) the surface scattering effect on the incident electromagnetic wave. Given that this scattering effect is independent from point-to-point on the ground, the phase of a single SAR image is, in general, random, and of no practical purpose on its own.

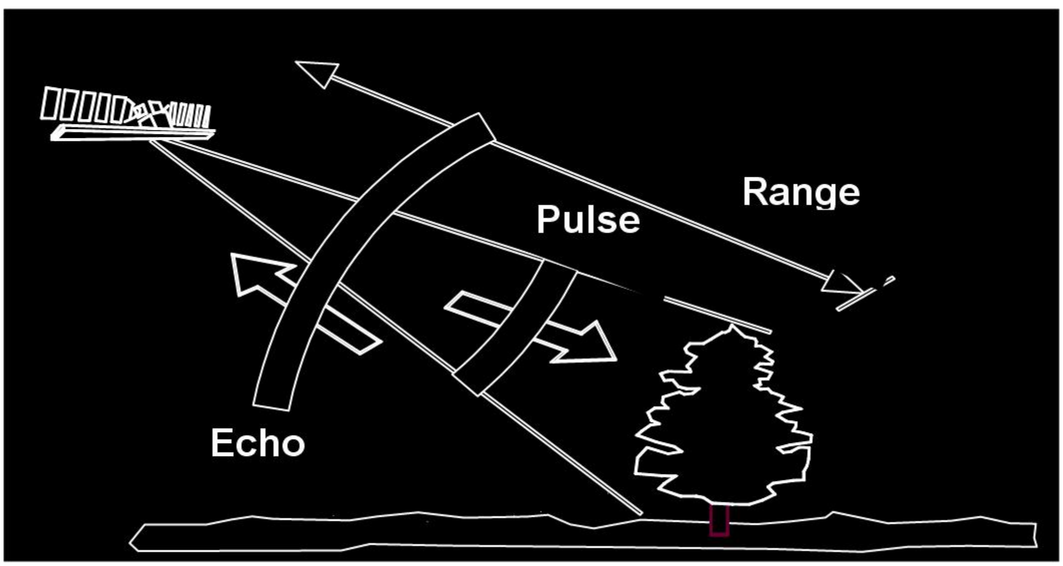


Figure 2: Radar Imaging Principle.

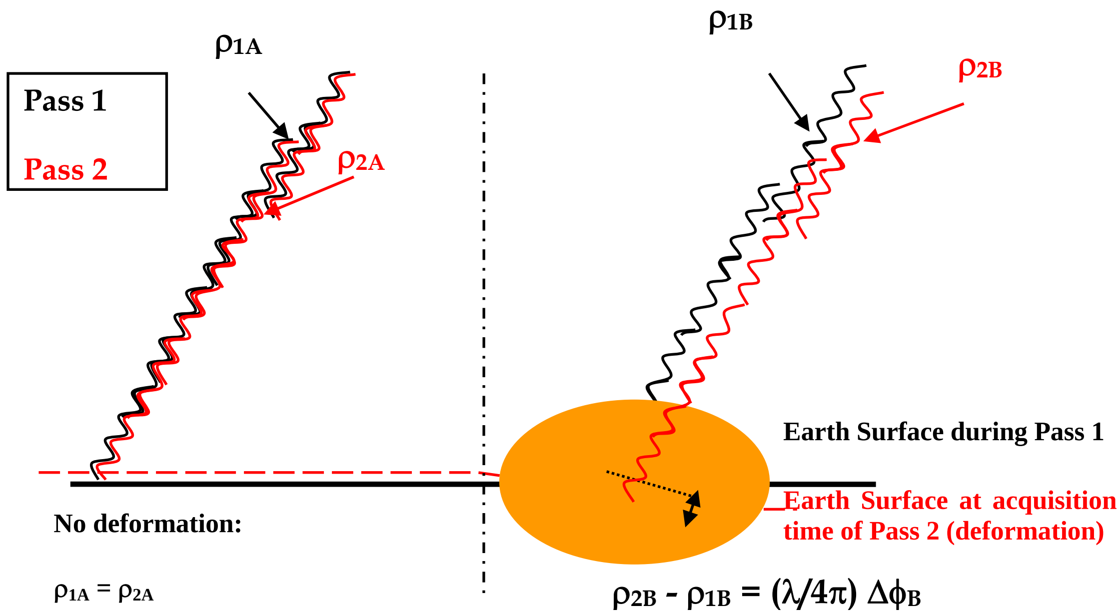


Figure 3: Illustration of interferometric phase measurements. The left panel represents a pixel (A) in the interferogram where the surface did not undergo deformation in the time between the acquisitions of Pass 1 (black) and Pass 2 (red), resulting in a zero interferometric phase. The distances ρ1A and ρ2A are equal. The right panel shows a pixel (B) where the terrain has subsided: the interferometric phase difference ΔφB that can be measured is related to the change in distance of the terrain to the sensor ρ2B - ρ1B, between Pass 1 and Pass 2, and to the wavelength λ.

Interferometric SAR (InSAR) makes use of the phase information by subtracting the phase value in one image from that of the other, for the same point on the ground. (See also Figure 3). If the distance, called the baseline, between the two locations of the SAR platform in space is small, then the surface scattering effects will be the same for the two images and are thus cancelled in the formation of the interferogram. Therefore, the interferogram exhibits information related to the difference in distances from the surface to the two SAR locations. Knowing the geometry involved, topographic heights can be computed from this information. It has been shown that the sensitivity of the phase to height is proportional to the baseline, i.e., there will be more interferometric phase induced by topography if the baseline is larger. The precisions of terrain height measurements are typically 1 to 10 meters, depending on the value of the baseline and phase noise.

If surface deformation occurred between the acquisition times of the two imaging passes of the SAR platform, then the interferogram phase represents a combination of topographic information and surface change. If the topography for the area is known with sufficient precision, it can be used to remove the topographic phase information from the interferogram, leaving only the surface change phase. The sensitivity of the phase to surface change is in the order of a fraction (~1/100) of the wavelength of the transmitted electromagnetic wave, which is ~5.6 centimeters for the C-Band SAR used in this project. Thus, the precision of the surface change measurement is at the millimeter level.

The general processing steps that have been used to produce the deformation maps using InSAR techniques are the following:

1. Historic SAR data set selection or future acquisition scheduling.

2. Raw SAR data processing: Two SAR scenes are processed to a product that includes magnitude information and phase information.

3. Image coregistration: Both scenes are very accurately co-registered (lined up) to sub-pixel accuracy.

4. Interferogram generation: The interferogram is an image of the phase difference between corresponding pixels of the two (2) images.

5. Topographic phase removal: An external Digital Elevation Model (DEM) is used to remove effects of stationary topography.

6. Phase unwrapping: For the generation of a quantitative deformation product, it is crucial to create a map of "absolute phase" from "wrapped phase" values. This process is called "phase unwrapping".

7. Terrain distortion correction (ortho-rectification): This process removes specific image distortions due to the radar geometry.

8. Ground control point collection and position refinement: This process is required as the inherent geo-referencing of the SAR data is not accurate enough. Ground control points from standard topographical maps are generally sufficient to achieve horizontal position accuracies of ~65 ft.

9. Deformation map generation in the client specified format and projection/datum.

4 RADAR INTERFEROMETRY DEFORMATION MAPPING

The conventional differential interferometry technique is extremely powerful to measure subtle displacement on the earth's surface over large areas. Radar interferometric deformation measurements of the natural terrain, however, are limited by temporal decorrelation and other sources of noise. Temporal decorrelation is noise resulting from small (~centimeter) incoherent changes of the relative positions of many individual scattering elements in the observed resolution cell. The longer the time between acquisitions the more likely it is that these changes will occur, and so the higher the probability that the data contains more noise. Additionally, atmospheric water vapor is another important error source as it influences the measurements, such that over larger areas the precision decreases, depending on the atmospheric conditions during image acquisition.

Upon completing the analysis and evaluation of all available sequential data combinations, two (2) interferometric Pairs are selected for the generation of deformation maps:

- Pair A for the time period between May 27, 2008 to August 31, 2008 (96 days)

- Pair B for the time period between August 31, 2008 to December 5, 2008 (96 days)

These data are selected because the generated interferograms are of high quality at these dates and are least affected by noise and DEM error. This is related to the amount of temporal decorrelation in these Pairs, the atmospheric circumstances at the acquisition times and the perpendicular baseline, which is an important parameter for sensitivity to topographic height. For this study, SRTM (Shuttle Radar Topography Mission) DEM is used for the topographic phase removal. Note that InSAR measures the Line-of-Sight (LOS) component of the actual displacement vector in the terrain. If the motion is assumed to be vertical (subsidence or uplift), it can be estimated from the change of the LOS (vertical deformation map).

Atmospheric effects are removed using a dedicated filter. A mask is applied in incoherent areas, caused by e.g., water surfaces. The root-mean-square of the observed values in the deformation map is indicative of the precision of the deformation map. To obtain a 95% confidence interval a factor of two is used. Table 4 and Table 5 show the summary of the estimation of noise level for Pairs A and B.

Table 4: Summary of Pair A

Date	Time Span	Noise Level standard deviation [ft]	95% Confidence interval [ft]
May-27-08 to Aug-31-08	96 days	0.0154	0.0308

Table 5: Summary of Pair B

Date	Time Span	Noise Level standard deviation [ft]	95% Confidence interval [ft]
Aug-31-08 to Dec-5-08	96 days	0.0157	0.0318

The following sections present the results for both Pairs A and B.

4.1 PAIR A – MAY 27, 2008 TO AUGUST 31, 2008

The deformation in the Playa del Rey Gas Storage Field is observed for the time period between May 27, 2008 and August 31, 2008.

In order to extract reliable information from the generated deformation products, a low coherence mask is generated and applied to the deformation map. This mask is created by thresholding the coherence image. Coherence (γ) values, $\gamma < 0.3$, are considered areas of low coherence and are masked out with values set to -999 (NODATA).

No significant deformation is observed in the Playa del Rey Gas Storage Field area, as can be seen from the deformation map shown in Figure 4. The resulting vertical deformation map products of the main AOI are illustrated in Figure 5 and Figure 6. All measurements are close to zero within the estimated precision. The average of the estimated deformation at these locations is within +/-0.39 inches, i.e., well below the noise level.

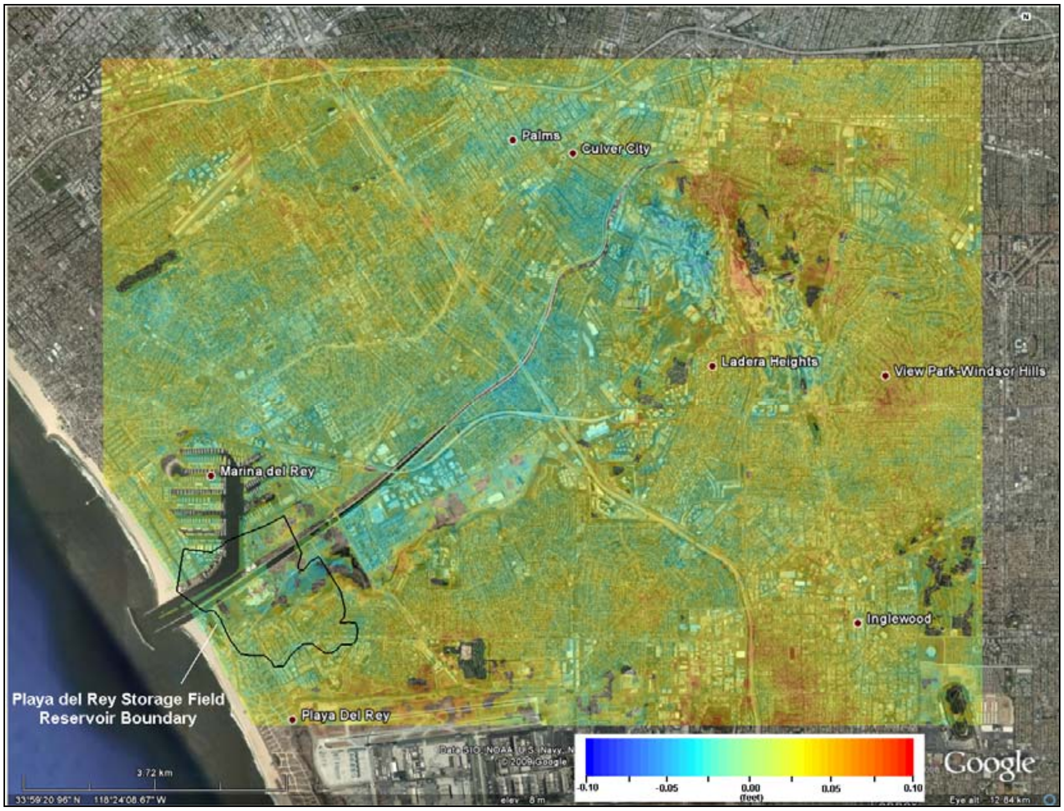


Figure 4: Zoom-in colour representation of the vertical deformation from May 27, 2008 to August 31, 2008 superimposed onto Google Earth.

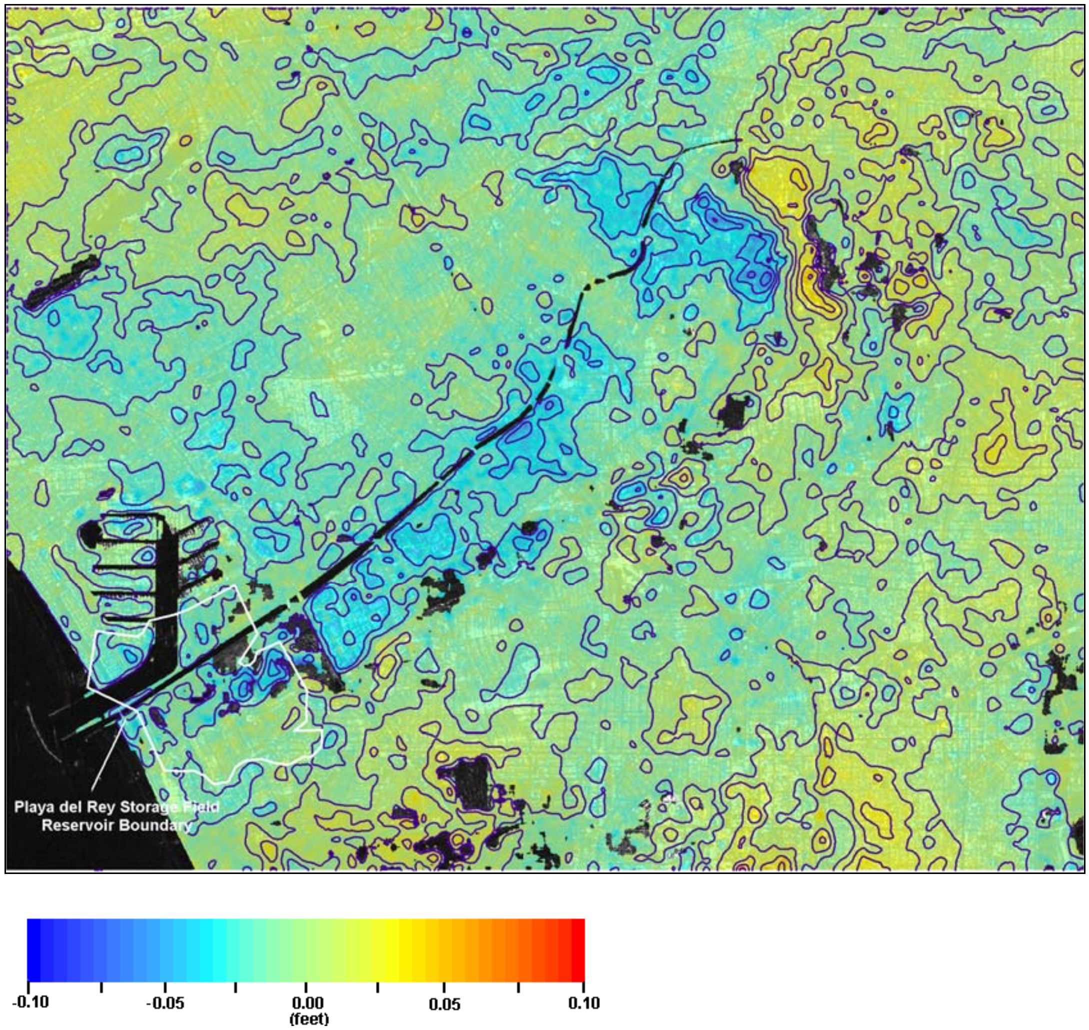


Figure 5: Zoom-in Vertical deformation map of AOI for the time period May 27, 2008 to August 31, 2008 with 0.01ft contours.

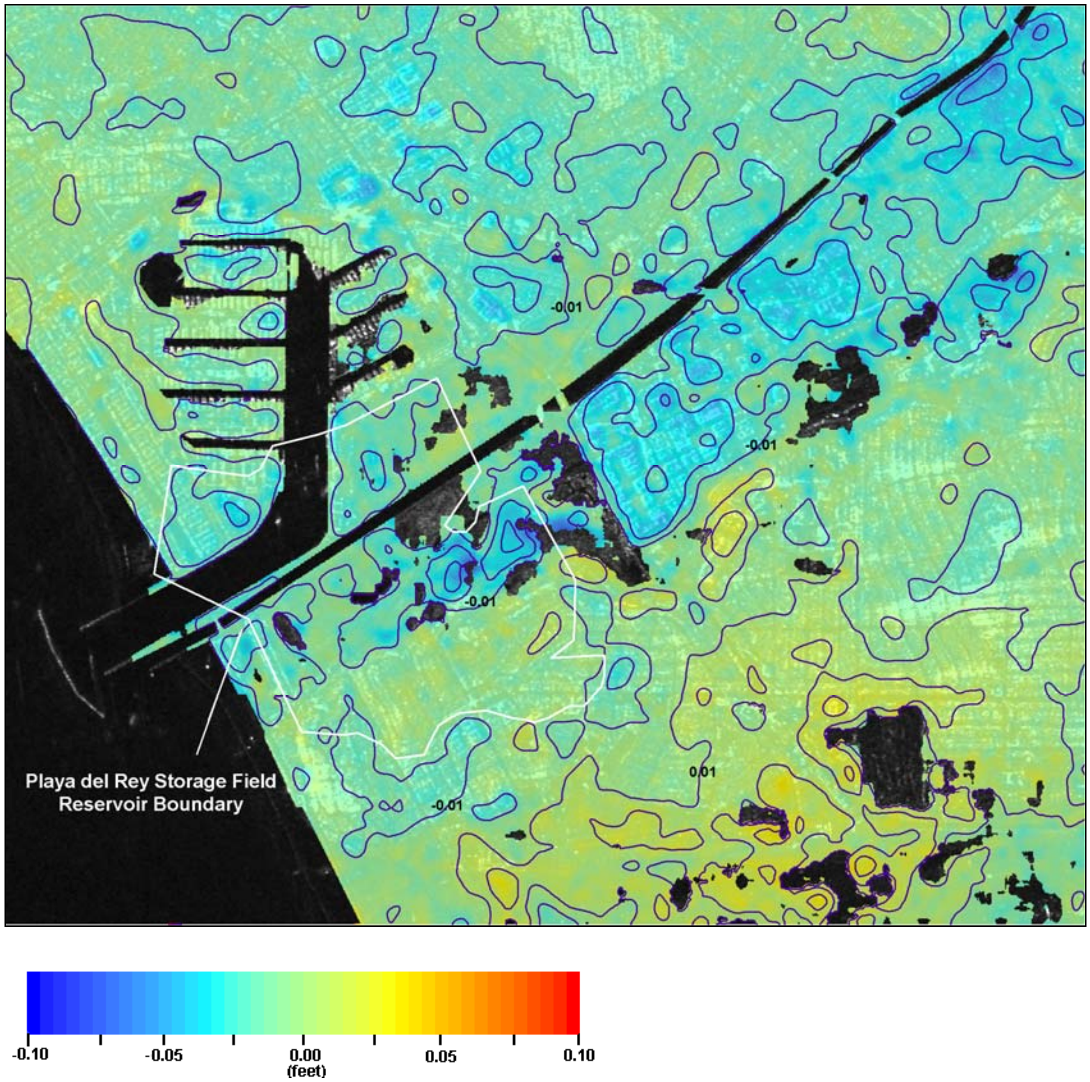


Figure 6: Zoom-in of Playa del Rey Gas Storage Field. Colour representation of the summation of vertical deformation maps from May 27, 2008 to August 31, 2008, superimposed onto SAR image with 0.01ft contours.

4.2 PAIR B – AUGUST 31, 2008 TO DECEMBER 5, 2008

The deformation in the Playa del Rey Gas Storage Field is observed for the time period between August 31, 2008 and December 5, 2008.

In order to extract reliable information from the generated deformation products, a low coherence mask is generated and applied to the deformation map. This mask is created by thresholding the coherence image. Coherence (γ) values, $\gamma < 0.3$, are considered areas of low coherence and are masked out with values set to -999 (NODATA).

No significant deformation is observed in the Playa del Rey Gas Storage Field area, as can be seen from the deformation map shown in Figure 7. The resulting vertical deformation map products of the main AOI are illustrated in Figure 8 and Figure 9. All measurements are close to zero within the estimated precision. The average of the estimated deformation at these locations is within +/-0.39 inches, i.e., well below the noise level.

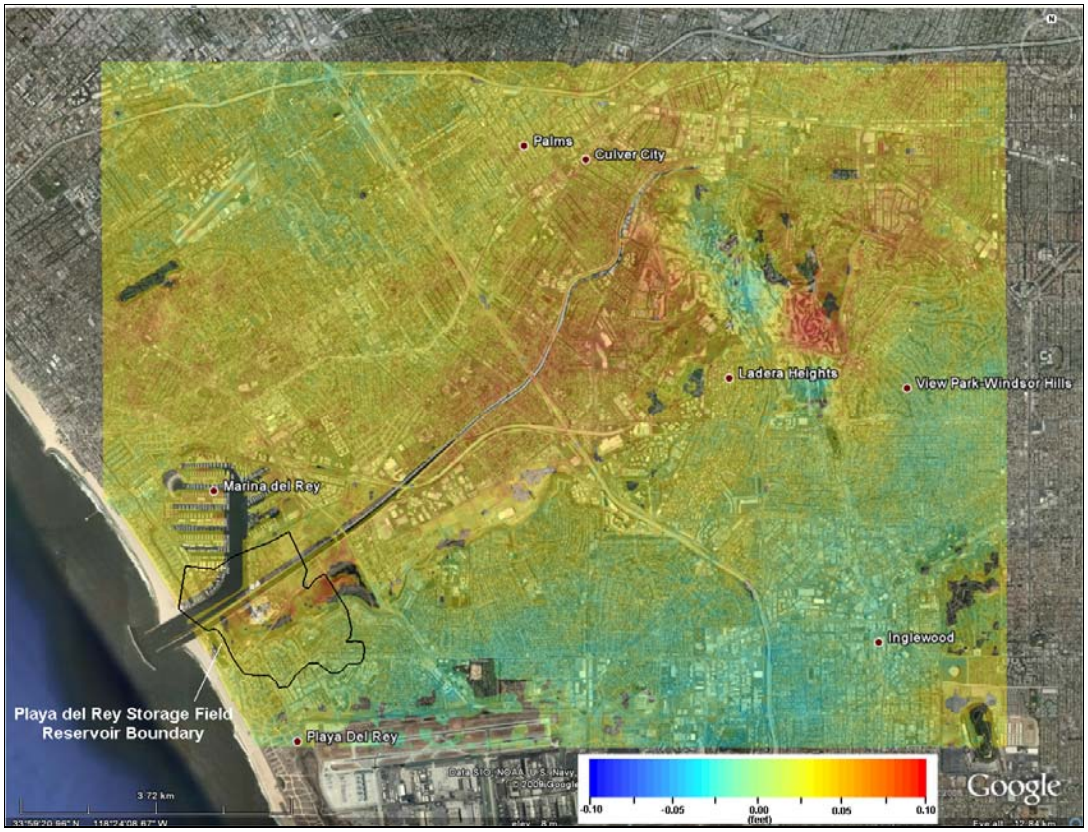


Figure 7: Zoom-in colour representation of the vertical deformation from August 31, 2008 to December 5, 2008 superimposed onto Google Earth.

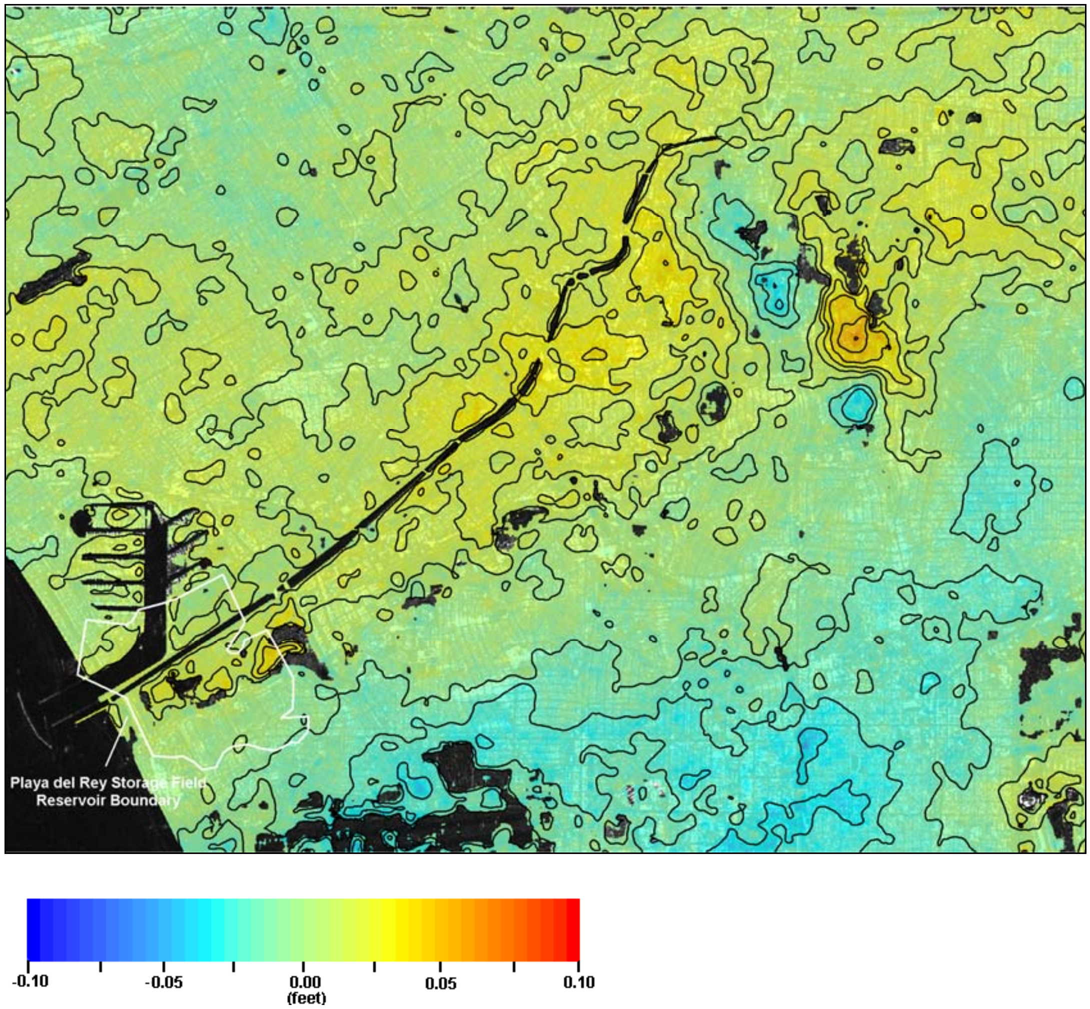


Figure 8: Zoom-in vertical deformation map of AOI for time period August 31, 2008 to December 5, 2008 with 0.01ft contours.

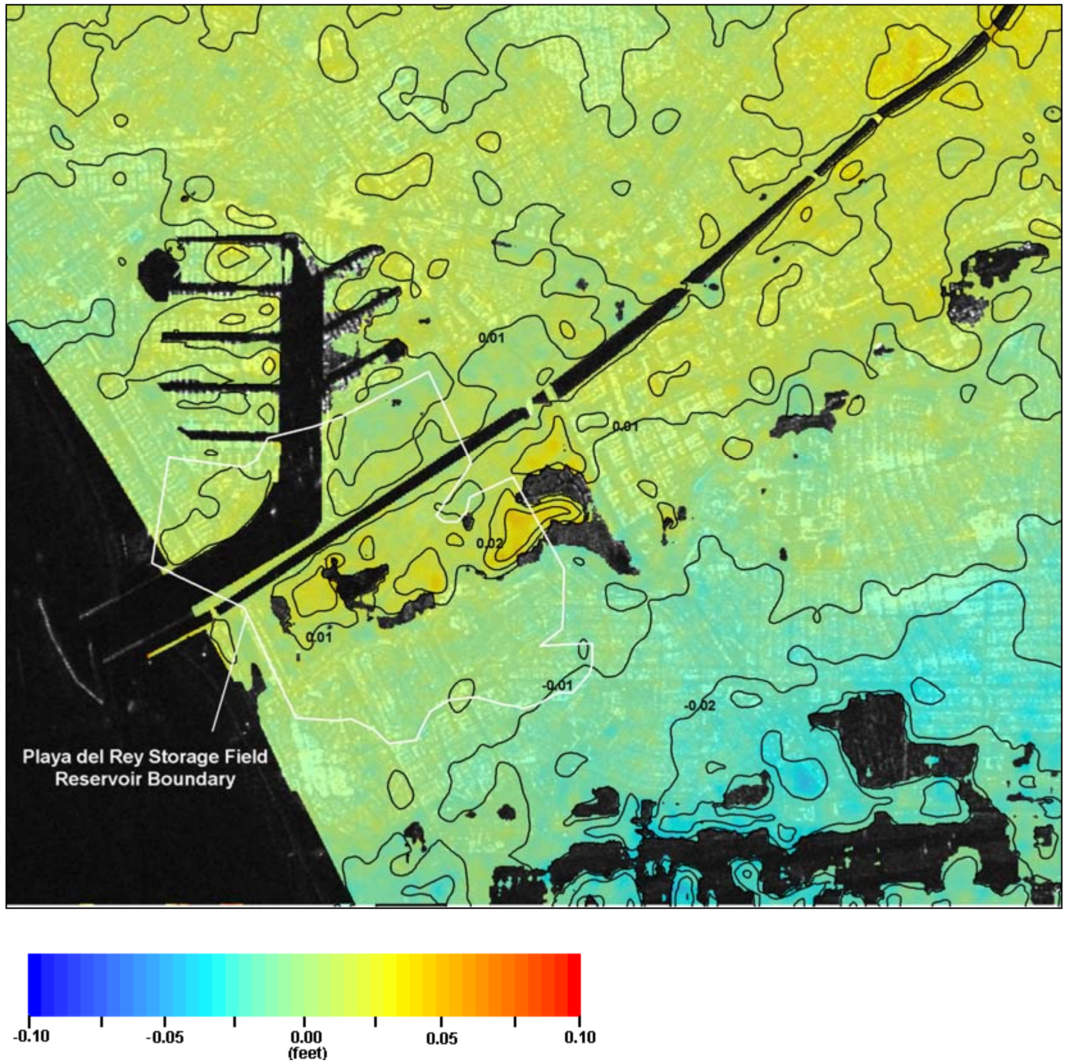


Figure 9: Zoom-in of Playa del Rey Gas Storage Field. Colour representation of the summation of vertical deformation maps from August 31, 2008 to December 5, 2008 superimposed onto SAR image with 0.01ft contours.

4.3 PAIR C – SUMMATION MAY 27, 2008 TO DECEMBER 5, 2008

Figure 10**Error! Reference source not found.**, Figure 11 and Figure 12 illustrate the summation products for the AOI. These summation products are created from the individually estimated deformation results for the two time periods – May to August 2008 and August to December 2008. The summation product provides an enhanced estimate of the actual deformation that occurred within this time period. Each Pair has different atmospheric noise levels independent of each other; by taking the average of the two, it provides a better estimate of the actual deformation while minimizing the atmospheric noise.

It is clear from these results that there is no apparent deformation occurring in the Playa del Rey Gas Storage Field area, as can been seen in Figure 13 and Figure 14. However, deformation is observed over an area situated between Ladera Heights and Culver City, center coordinate 34º 0' 16"N 118º 22' 41"W. Deformation in this area is in the order of 0.05 to 0.08 ft as seen in Figure 15 and Figure 16.

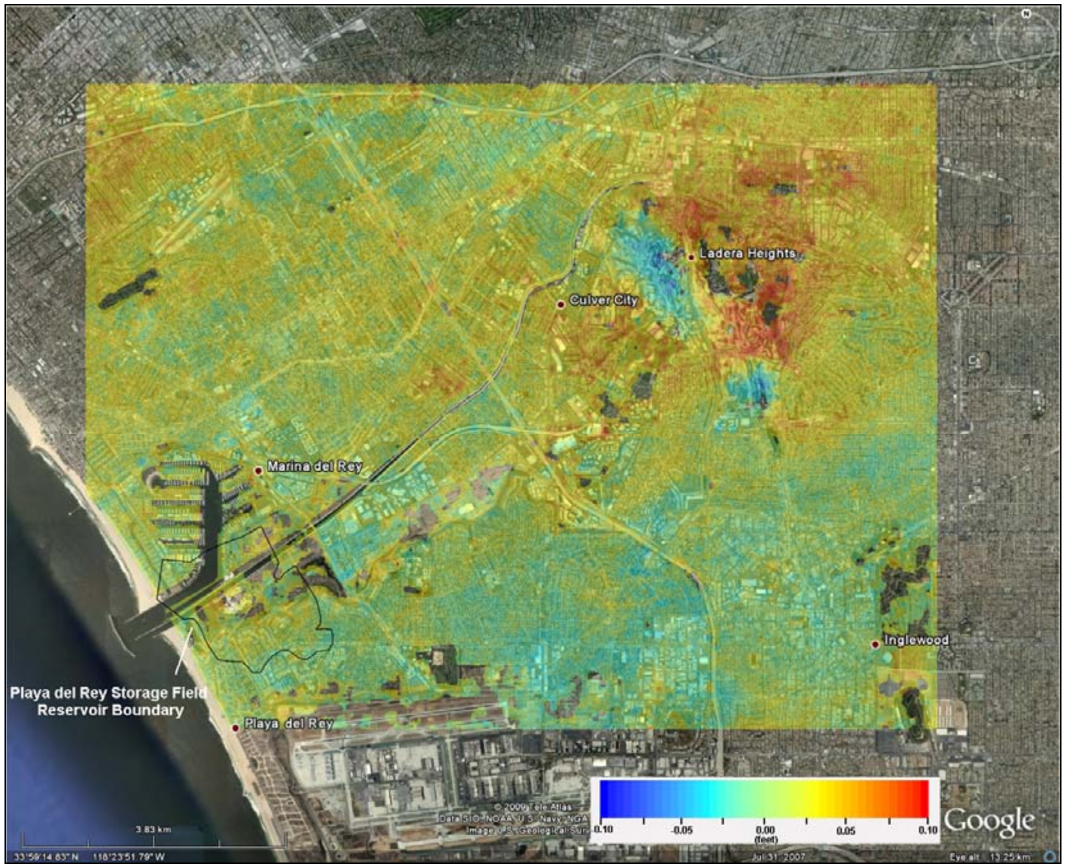


Figure 10: Zoom-in colour representation of the summation of vertical deformation maps from May 27, 2008 to August 31, 2008 and from August 31, 2008 to December 5, 2008 superimposed onto Google Earth.

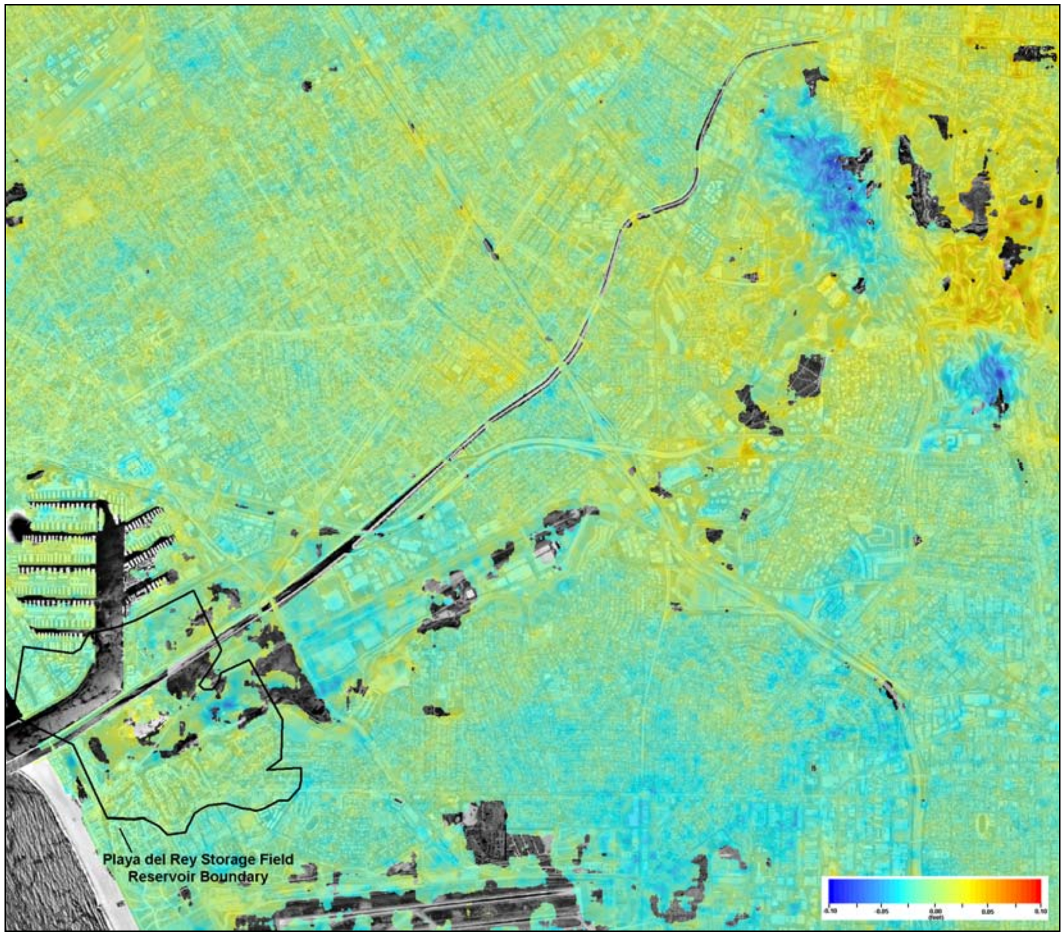


Figure 11: Zoom-in summation of vertical deformation maps where blue represents subsidence and red represents uplift for May 27 to August 31, 2008 and August 31to December 5, 2008.

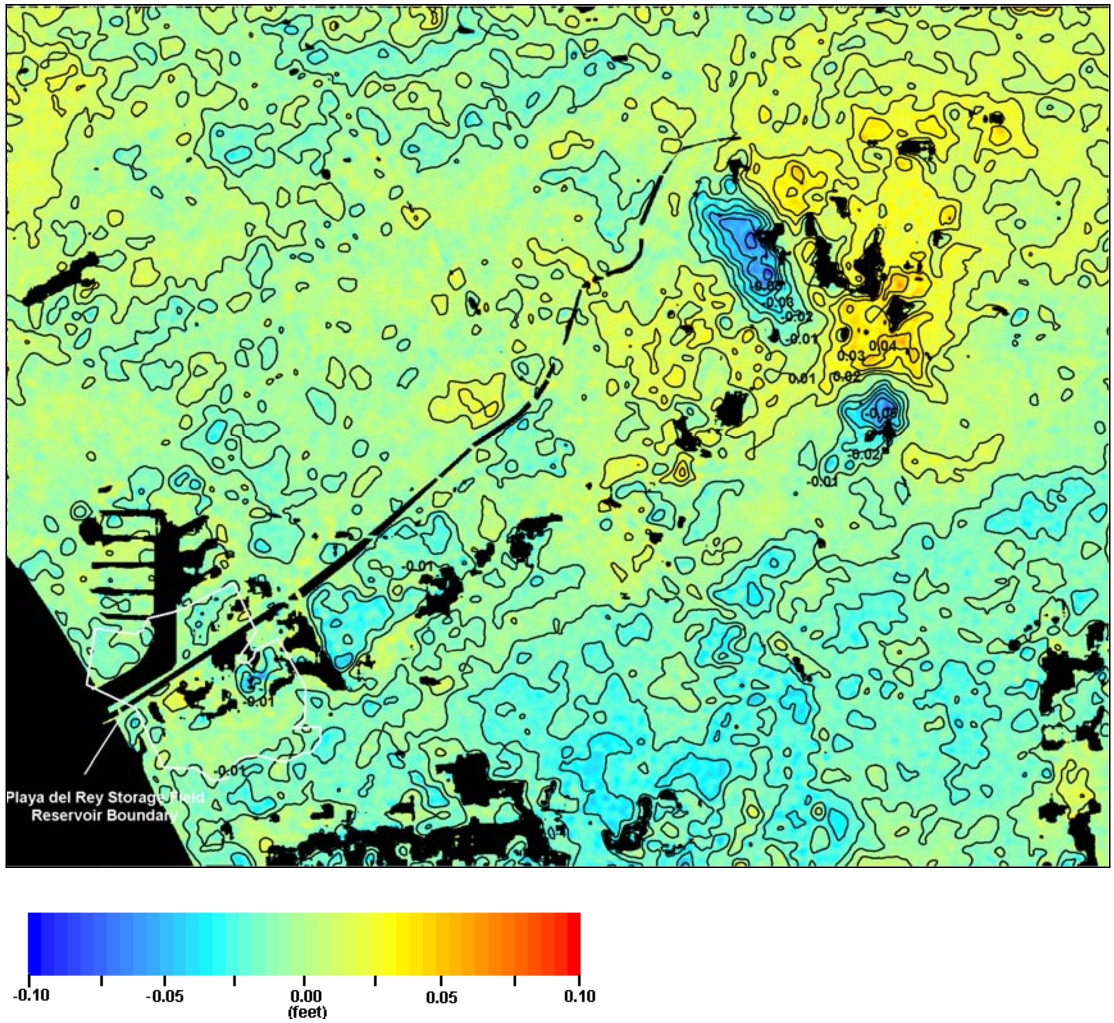


Figure 12: Zoom-in of the summation of the vertical deformation maps from May 27, 2008 to August 31, 2008 and from August 31, 2008 to December 5, 2008 with 0.01ft contours superimposed.

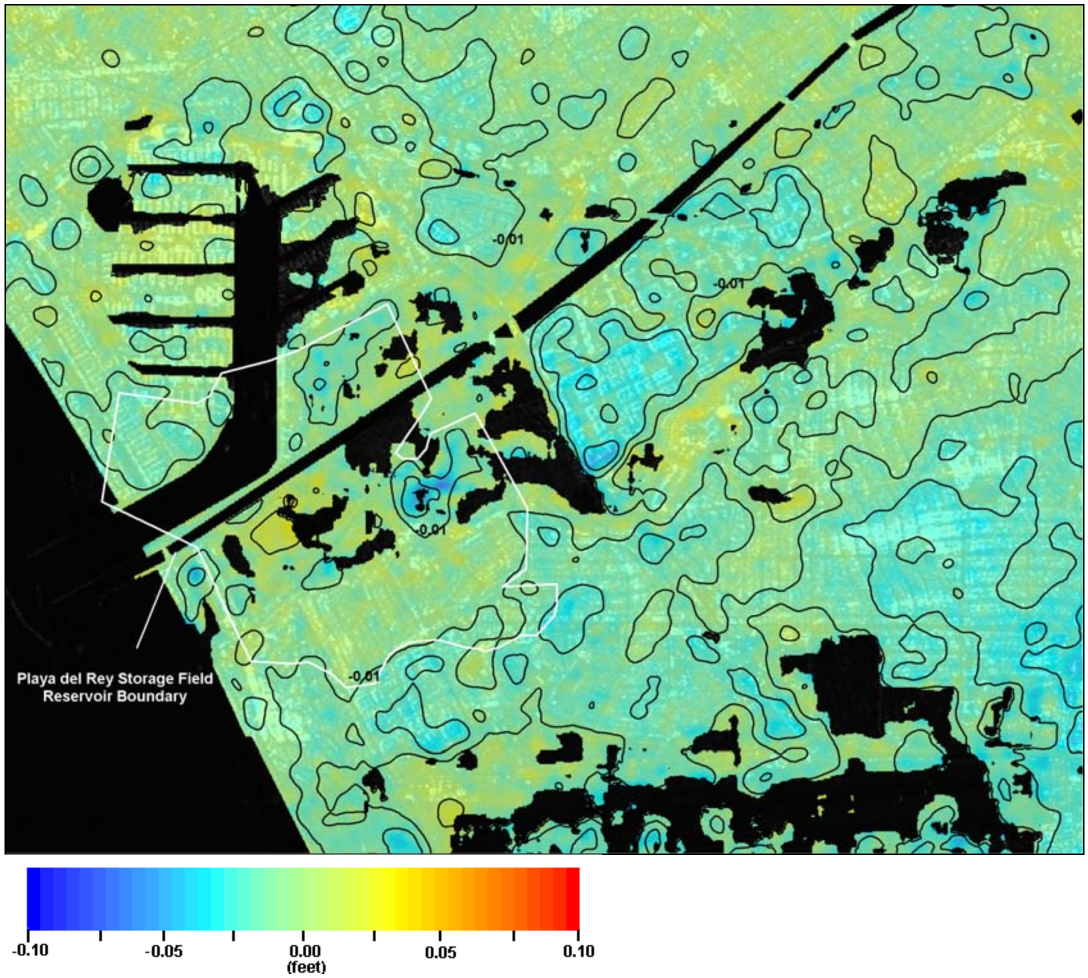


Figure 13: Zoom-in view of Playa del Rey Gas Storage Field. Colour representation of the summation of vertical deformation maps from May 27, 2008 to December 5, 2008 superimposed onto SAR image with 0.01ft contours.

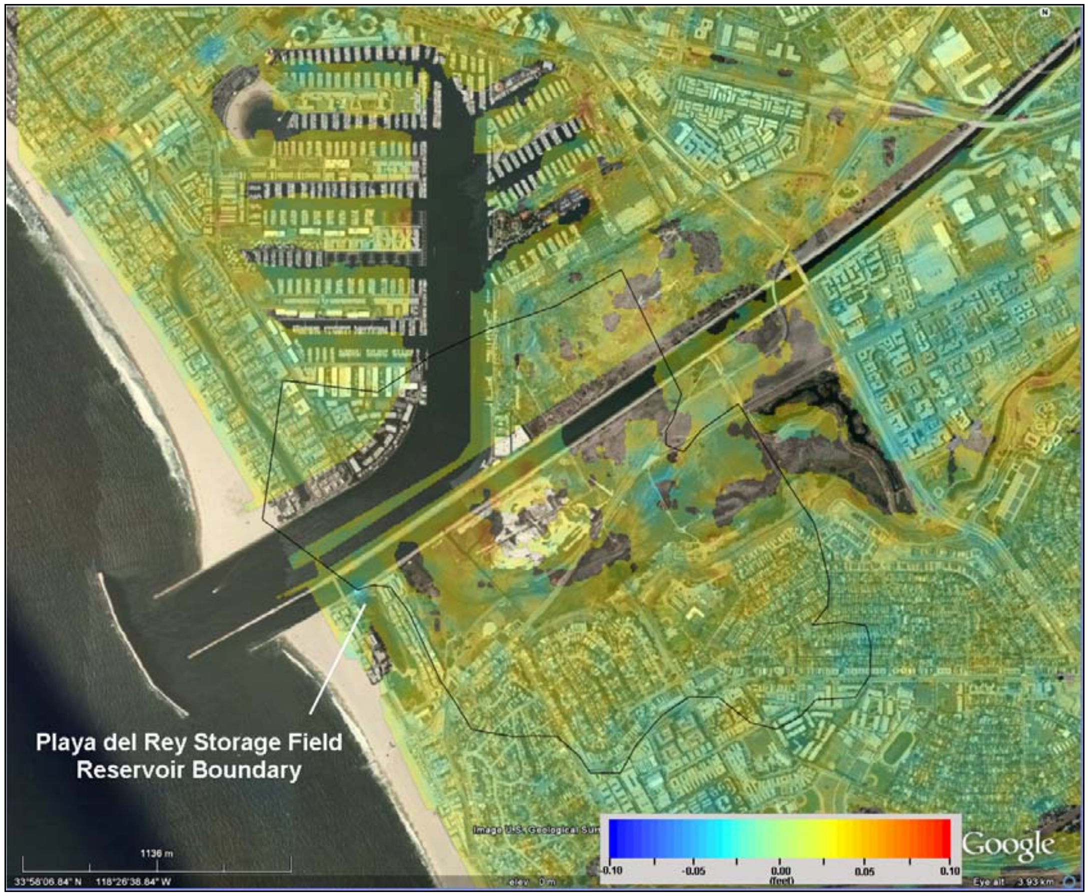


Figure 14: Zoom-in of summation deformation map superimposed onto Google Earth for the time period May 27, 2008 to December 5, 2008.

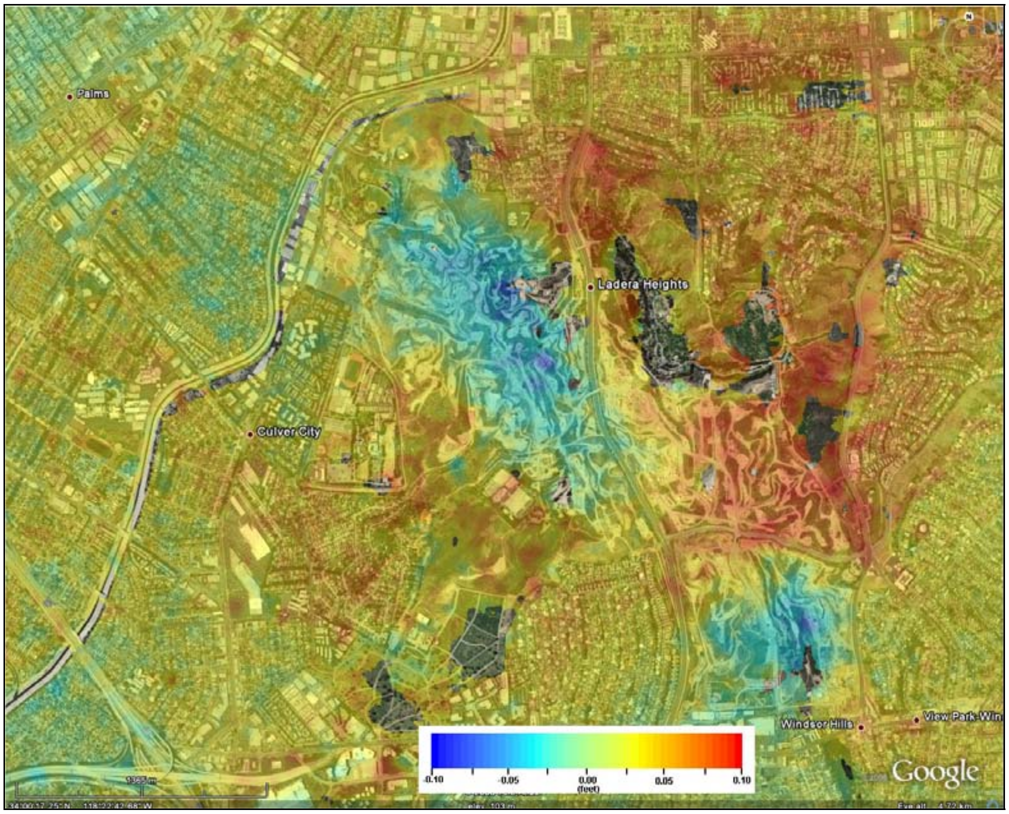


Figure 15: Colour representation of the vertical summation deformation product between Culver City and Ladera Heights superimposed onto Google Earth from May 27, 2008 to December 5, 2008.

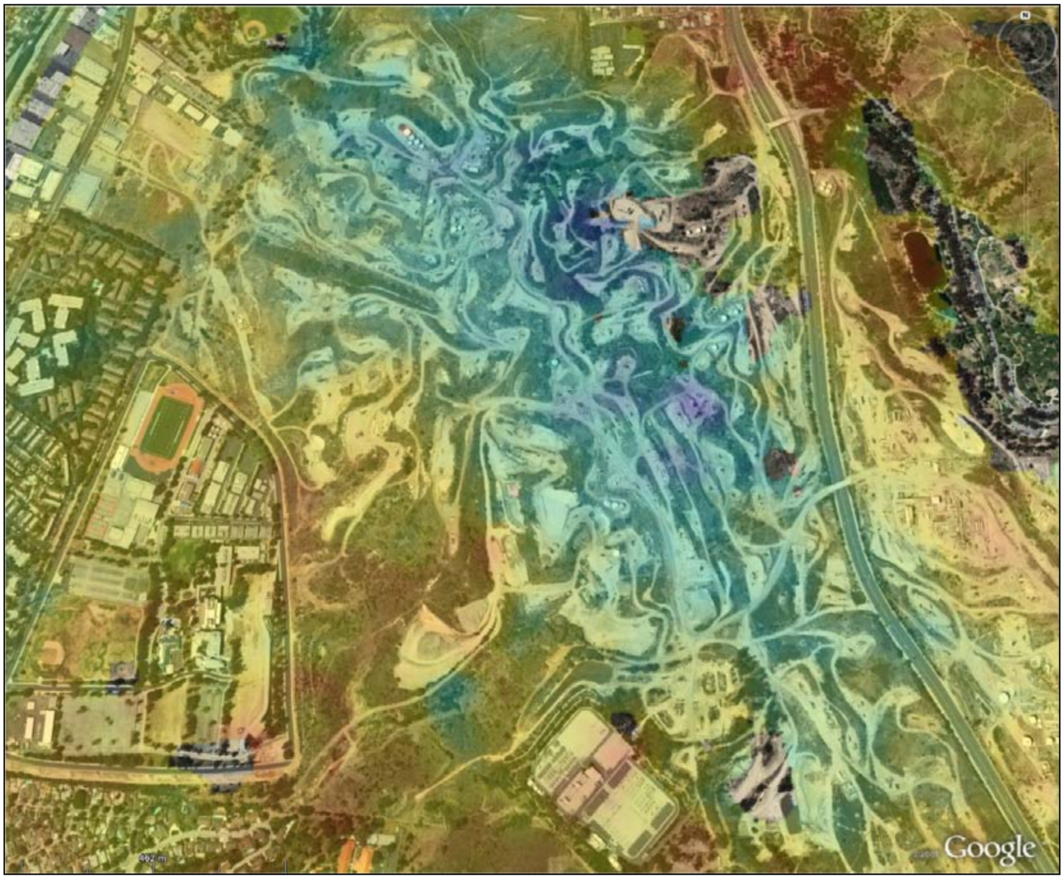


Figure 16: Zoom-in view showing summation deformation product from May 2008 to December 2008 in the area between Culver City and Ladera Heights.

5 CONCLUDING REMARKS

Vertical surface deformation measurements are made for the Playa del Rey Gas Storage Field and surrounding areas in California, using conventional radar interferometry (InSAR).

The following items describe the main findings:

- RADARSAT-2 Ultra-Fine ascending data were scheduled by MDA for acquisition. The acquired data, covering the period of May 2008 to December 2008, were analyzed and utilized as part of the deliverables.
- Two (2) deformation maps were generated as part of the first deliverable of a five (5) year monitoring program.
- The estimated precision for Pair A deformation map is 0.031 ft with a 95% confidence interval, while the estimated precision for Pair B deformation map is 0.032 ft with a 95% confidence interval.
- No significant deformation is observed in the Playa del Rey Gas Storage Field area.
- Deformation is observed in an area situated between Ladera Heights and Culver City, center coordinate 34º 0’ 16”N / 118º 22’ 41”W as shown in the summation product Figure 10. Deformation in this area is in the order of 0.05 to 0.08 ft.
- The summation map product, Pair C, has been computed and is included as a deliverable. This product provides increased precision.

This report, referred to as the “Master Document”, pertains to Milestone 1 of the current contract. The results included in Milestone 1 reflect the deformation occurring in the Playa del Rey Gas Storage Field and surrounding area from May 2008 to December 2008.

As per Section 2.1, a total of ten (10) Milestones reports will be delivered to SoCalGas on a bi-annual basis, as part of the contract, RV-14524. Milestones 2 to 9 will be referred to as Interim Report and will each cover a consecutive monitoring period of six (6) months. A Final Report, Milestone 10, will be delivered and will include results from December 2012 to June 2013. The Final Report will also include all previous results, overall summary and conclusions from the five (5) year monitoring program.

A. DELIVERABLES

The deliverables, which are included on CD-ROM for Milestone 1 are listed in **Error! Reference source not found.**. These delivered data are described in XYZ ASCII files and are in California US State Plane, NAD27, 65.62 ft spacing.

Table 6: Delivered Data

Deliverable file	**Description**
PlayadelRey_SoCalGas_MasterReport_2008.pdf	This report in PDF format.
Conventional Deformation map	
052708_083108_DEF.xyz 052708_083108_DEF.tif 083108_120508_DEF.xyz 083108_120508_DEF.tif SUM_052708_123108_DEF.xyz SUM_052708_123108_DEF.tif	ASCII files with location and vertical deformation measurements in feet. Coherence (γ) values, $\gamma < 0.3$, are considered areas of low coherence are masked out with values set to -999 (NODATA). Additional format supplied as GeoTiff.
Projection_Report.pdf	Describes the coordinate projection system of the delivered data.