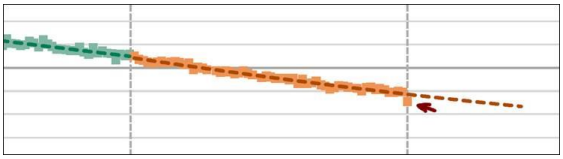
Westlake US 2
Received 5/30/2023

SNT Satellite Update
InSAR Subsidence
May 25, 2023

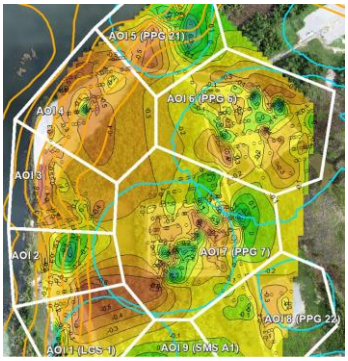
Lonquist comment:

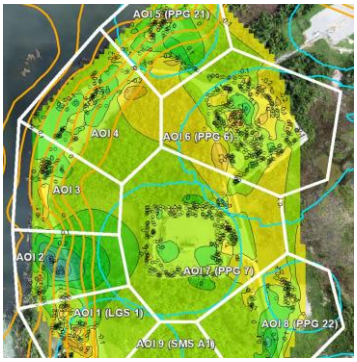
Both the SNT satellite (12-day revisit) and the TSX satellite from the TSX/PAZ constellation (4 & 7-day revisit) passed by Sulphur on Thursday May 25. We received the dataset Saturday and a preliminary evaluation revealed a greater than normal increase in the negative displacement values in AOI 4 in the SNT data (chart below). No indication of the same was observed in the TSX data from the same date. This is believed to be related to the data precision range in the SNT data. The next few datasets will be reviewed to confirm that measurements in that area have returned to trend.

AOI 4



The below maps have been provided for reference on this supplementary evaluation in addition to the standard reports (attached). The two maps below show the change in displacement values in inches between the 5/25 satellite image and the average of the displacement values from the prior month of images. Map 1 shows the SNT data and Map 2 shows the TSX/PAZ data. An area of negative displacement values in Map 1 stretching across AOI 3, 4, & 5 is not seen in Map 2 with similar datapoint coverage. A negative displacement region in Map 1 between AOI 1, 2 & 7 was also noted but it is created by a small number of datapoints and is also assumed to be related to data precision. The below comparison also highlights the difference in measurement precision between the SNT and TSX/PAZ data generally, which is related to the different resolution of the satellites. More spatial consistency and smaller magnitudes of change are shown in the TSX/PAZ data.





Submitted by: Nathaniel Byars (Lonquist)

Submitted by: Nathaniel Byars (Lonquist)

SNT Satellite Update

Continuous InSAR Monitoring of
Ground Displacement
Near Western Caverns and Dome Flank

Sulphur Mines Salt Dome

Prepared for:
Westlake Chemical

Prepared by:
Lonquist & Co., LLC
8591 United Plaza Blvd., Suite 280
Baton Rouge, LA 70809

Dataset
Satellite Source
Sentinel-1 (SNT)
Most Recent Image Date
Thursday, May 25, 2023

Analysis Report Date:

May 30, 2023

Dataset Information

Satellite Source	Sentinel-1 (SNT)
Revisit Frequency	12 days
Most Recent Image Date	Thursday, May 25, 2023
Dataset Image Count	178
Dataset Time Range	October 4, 2016 - May 25, 2023
Dataset Length	6.64 Years
Satellite Line-of-Sight (LOS)	43° West of Vertical (Viewing site from the West)

Analysis Methodology

Time Series Charts

Trend lines were calculated for the averaged displacement values within each AOI. Quadratic regression was used to determine Velocity and Acceleration of LOS displacement. Trends calculated for the AOI point groups are depicted for each AOI in the Time Series section of this report.

Contour Maps

A quadratic trend was also calculated for each individual measurement point across the analysis region. Trend values for each point were used to generate Velocity and Acceleration contour maps to depict the spatial distribution of the movement trends. Negative velocity values indicate subsidence. Negative acceleration values indicate increasing rates of subsidence and positive acceleration values indicate slowing rates of subsidence.

Recent vs. Historical Data

The multi-year SNT dataset timeframe allows for Recent data to be evaluated separately from Historical data and for trends from the two timeframes to be compared. The change in the velocities and accelerations from the two timeframes are provided in the Time Series and Contour Map sections. Velocity values are calculated for the final date in either the Recent or Historical datasets.

Observations

To-date there has been no material deviation from established subsidence trends in the areas investigated.

A larger than typical change in negative displacement was noted in AOI 4, but review of the TSX/PAZ dataset from the same date showed no indication of the same. This is believed to be related to the data precision range and the next dataset will be evaluated to confirm that measurements return to the trend.

The comparison of Recent to Historical trends in the SNT data does imply a minor increase in the negative velocity of LOS displacement in AOI 2 as well as a minor increase in both negative velocity and negative acceleration in AOI 6 (PPG 6), AOI 7 (PPG 7), and AOI 8 (PPG 22). This suggests that marginal increases in subsidence rates may be occuring in these areas in recent years.

Mapped contours of the change in recent vs. historical subsidence rates mostly show minor fluctuations around 0, intermittently distributed within the AOIs. This suggests that statistically relevant areas of change may not yet be apparent

Date Signed: May 30, 2023
Austin, TX

Nathaniel L. Byars, P.E.
Principal Engineer
Louisiana License No. 40697

InSAR Data Sources

InSAR Data

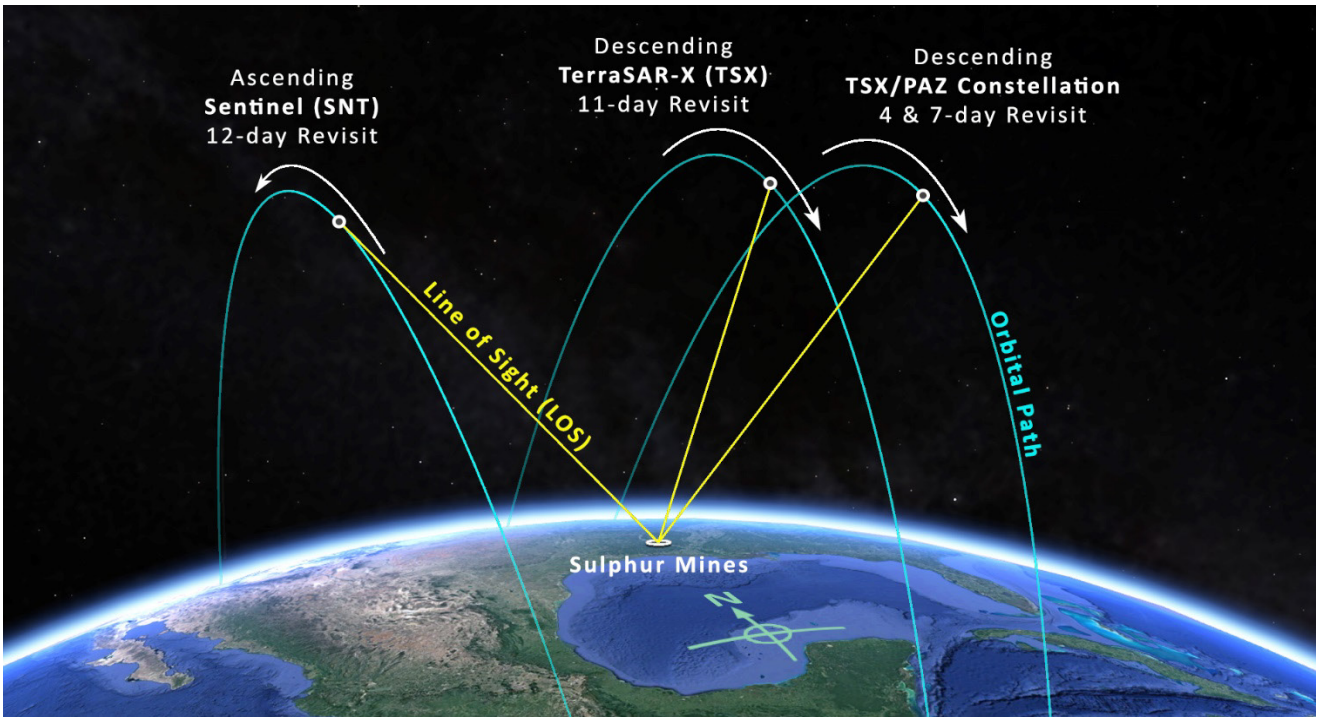
Interferometric Synthetic Aperture Radar (InSAR) is the most well established method to continually evaluate small, normally undetectable, ground movement over a large area. Radar imagery collected via satellites over successive orbital passes is used to identify and define measurement points on the ground. Objects or ground features providing a stable reflection of radar energy such as buildings, roads, and infrastructure produce the highest quality measurement points. InSAR analysis identifies the change in distance between the satellite and each measurement point over time relative to a stable reference point within the imaged area.

Satellite Sources

Two InSAR datasets are being used to evaluate subsidence over the Sulphur Mines Salt Dome. These datasets provide Line-of-Sight (LOS) displacment measurements from both ascending and descending orbits. An ascending orbit denotes the satellite's longitudinal course from south to north as it passes over the site, while a desceding orbit denotes the satellite is moving from north to south.

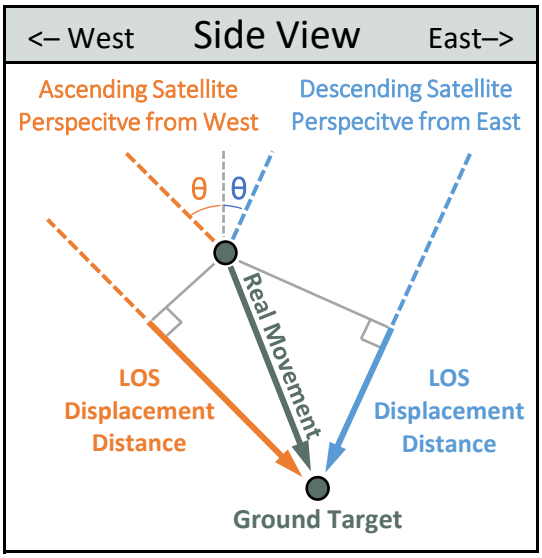
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a high-resolution TerraSAR-X (TSX) satellite on a descending orbit that captures data from the east of the site on an 11-day frequency. This dataset will be replaced in May 2023 by data from a pair of high resolution satellites that share the same descending orbit. These are a second TSX satellite and the PAZ satellite (TSX/PAZ constellation), both with an 11-day revisit frequency. Their orbits are offset with the PAZ satellite passing over the site 4 days after the TSX satellite. This transition is being made for the increased data frequency that will result from a 4 and 7-day revisit period. The image below depicts the orbital paths of the satellites in relation to the Sulphur Mines Salt Dome.

Satellite Orbital Diagram



InSAR Line-of-Site (LOS) Data

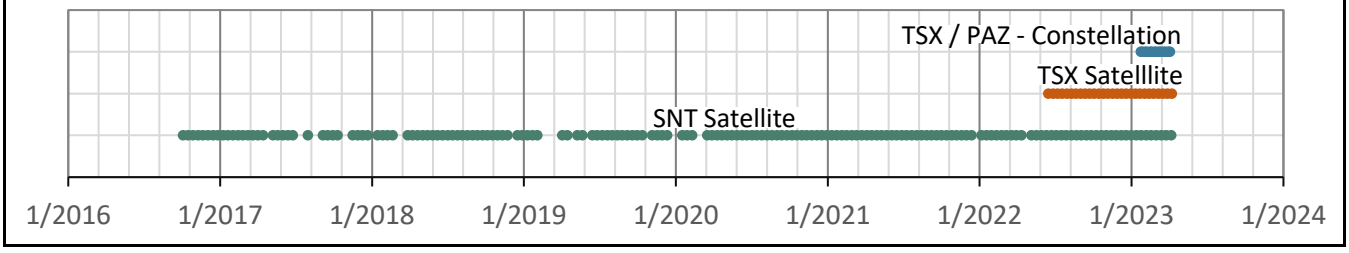
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR satellites view the site from eastward and westward positions so LOS measurements are understood to convey a movement distance that is not purely vertical. The diagram to the right illustrates the geometric relationship between the theoretical Real movement of a ground target and LOS displacement measurements from two different satellite viewing directions.



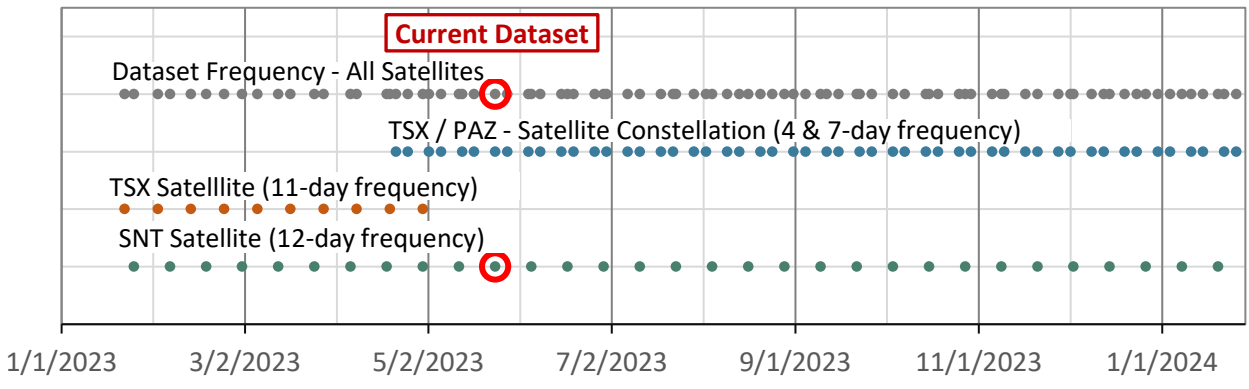
Satellite Properties & Image Frequency

Satellite and Data Properties	SNT	TSX	TSX/PAZ Constellation
Band (Wavelength)	C-band (2.20 in)	X-band (1.22 in)	X-band (1.22 in)
Track	T136	T29	T67 & T120
Pixel resolution	65 x 16 ft	3 x 3 ft	3 x 3 ft
Revisit frequency	12 days	11 days	4 & 7 days
Orbit (LOS Angle, θ)	Ascending (43°)	Descending (17°)	Descending (37°)
Data Start Date	10/4/2016	6/16/2022	1/24/2023
Measurement error range	± 0.20 in	± 0.03 in	± 0.03 in

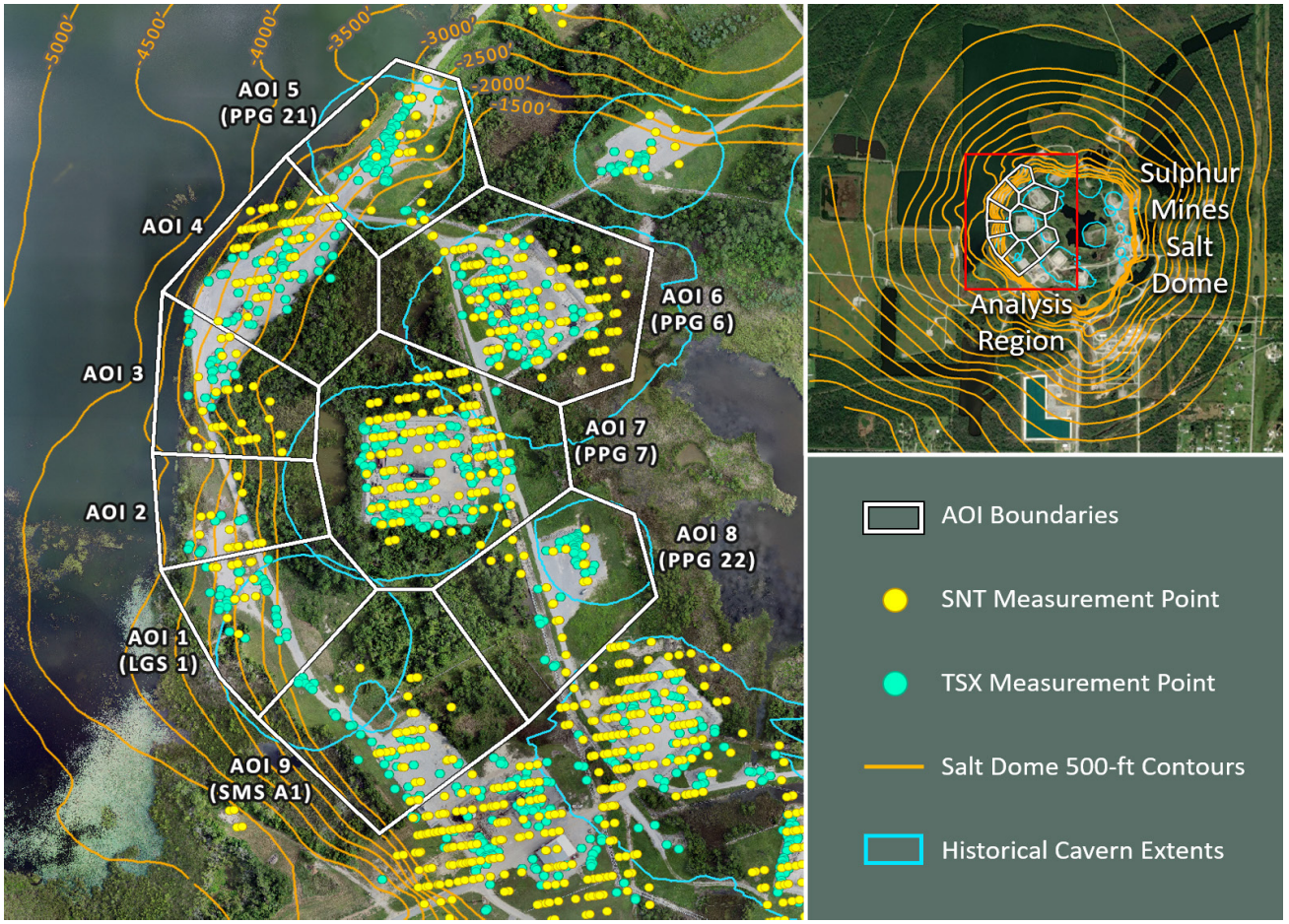
Dataset Measurement History



Dataset Update Frequency



AOI Boundaries & InSAR Measurement Points

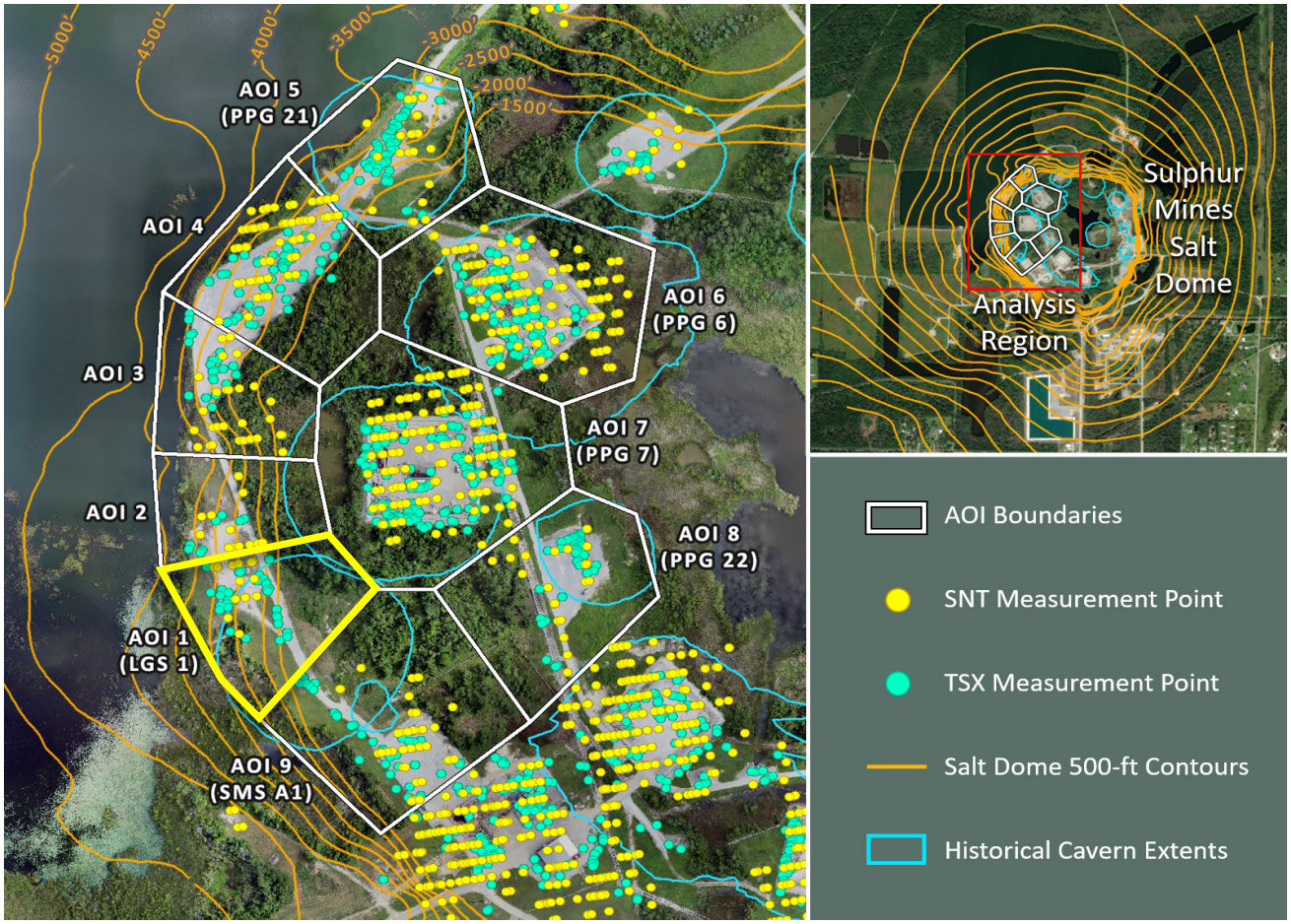


Subsidence Monitoring Areas of Interest (AOIs)

To visually convey and evaluate trend consistency for the displacement time series of each ground target, measurment points were grouped and their displacement values were averaged. The point groups are referred to as Areas of Interest (AOIs) in this analysis and their boundaries are depicted on the above map. The below table lists the trend values calculated in each AOI for the dataset evaluated in this report.

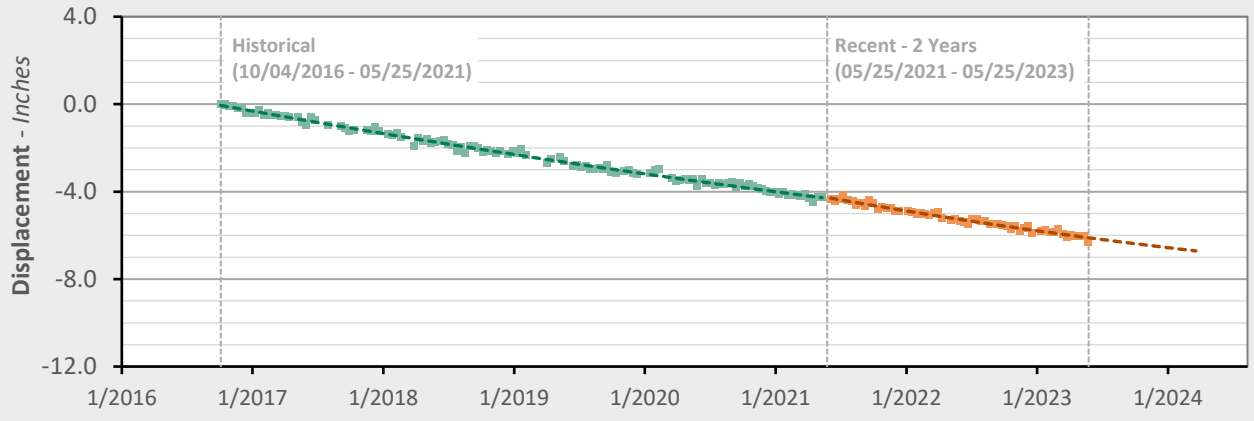
AOI Name	SNT (5/25/2023)	LOS Velocity *(in/yr)*			LOS Acceleration *(in/yr^2)*		
	Point Count	Historical	Recent	Change	Historical	Recent	Change
AOI 1 *(LGS 1)*	13	-0.76	-0.79	-0.03	+0.07	+0.13	+0.06
AOI 2	15	-0.69	-0.84	-0.15	+0.12	+0.14	+0.02
AOI 3	29	-0.72	-0.49	+0.23	+0.02	+0.24	+0.22
AOI 4	62	-0.70	-0.68	+0.02	+0.03	+0.11	+0.08
AOI 5 *(PPG 21)*	25	-0.71	-0.71	+0.00	+0.01	-0.04	-0.04
AOI 6 *(PPG 6)*	134	-0.89	-1.03	-0.14	+0.07	-0.05	-0.12
AOI 7 *(PPG 7)*	140	-0.99	-1.12	-0.13	+0.10	-0.01	-0.10
AOI 8 *(PPG 22)*	21	-1.10	-1.27	-0.17	+0.14	+0.03	-0.11
AOI 9 *(SMS A1)*	39	-0.82	-0.73	+0.09	+0.11	+0.21	+0.10

AOI 1 *(LGS 1)* - Location Map



AOI 1 *(LGS 1)* - Displacement Time Series

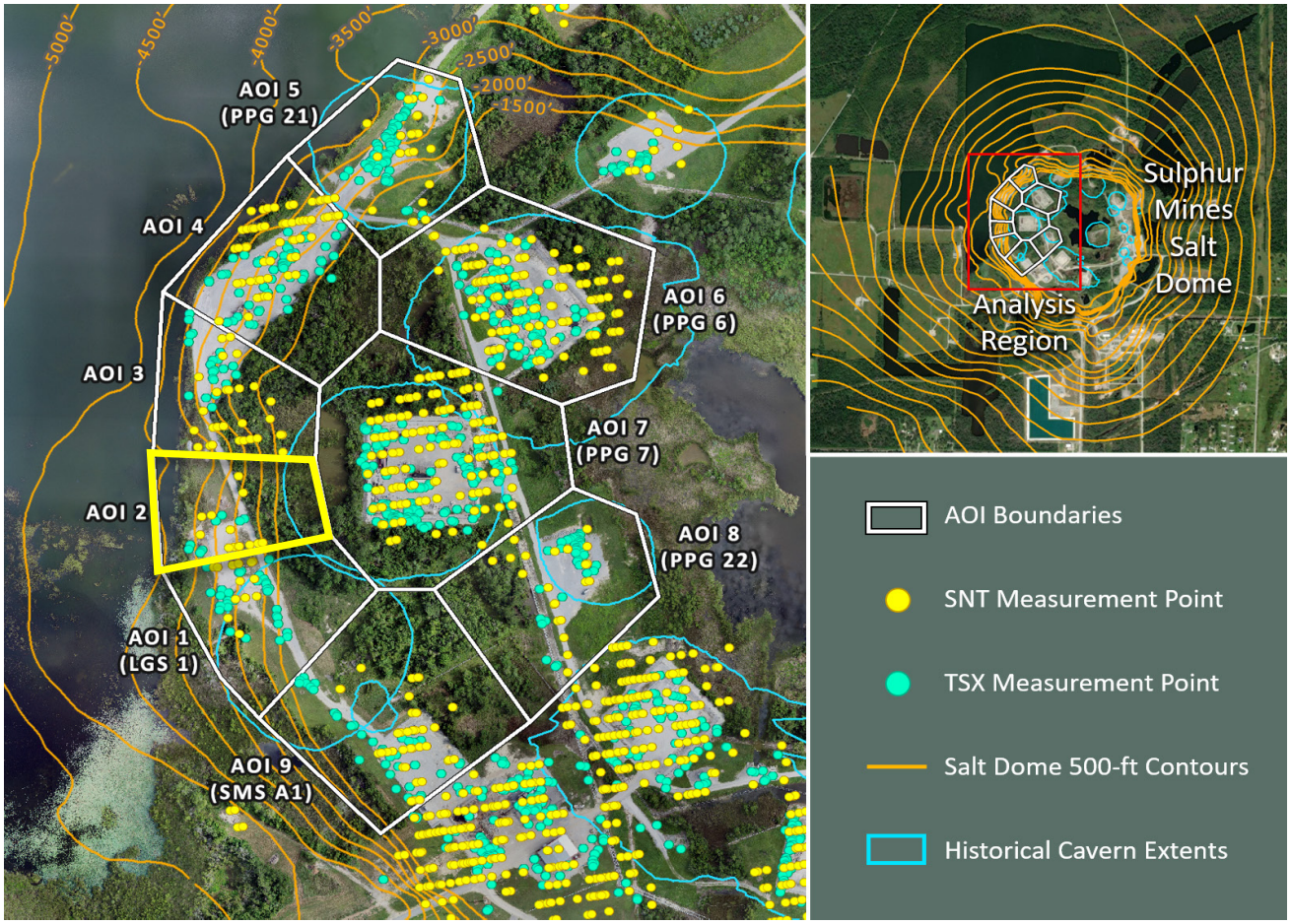
SNT (5/25/2023) Point Count: **13**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.76 in/yr	-0.79 in/yr	-0.03 in/yr
Acceleration:	+0.07 in/yr^2	+0.13 in/yr^2	+0.06 in/yr^2

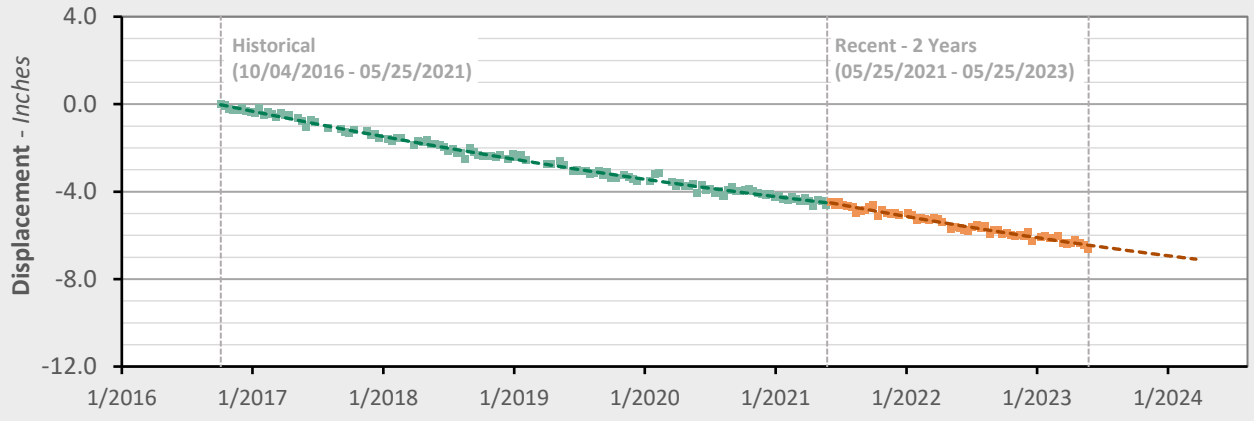
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 2 - Location Map



AOI 2 - Displacement Time Series

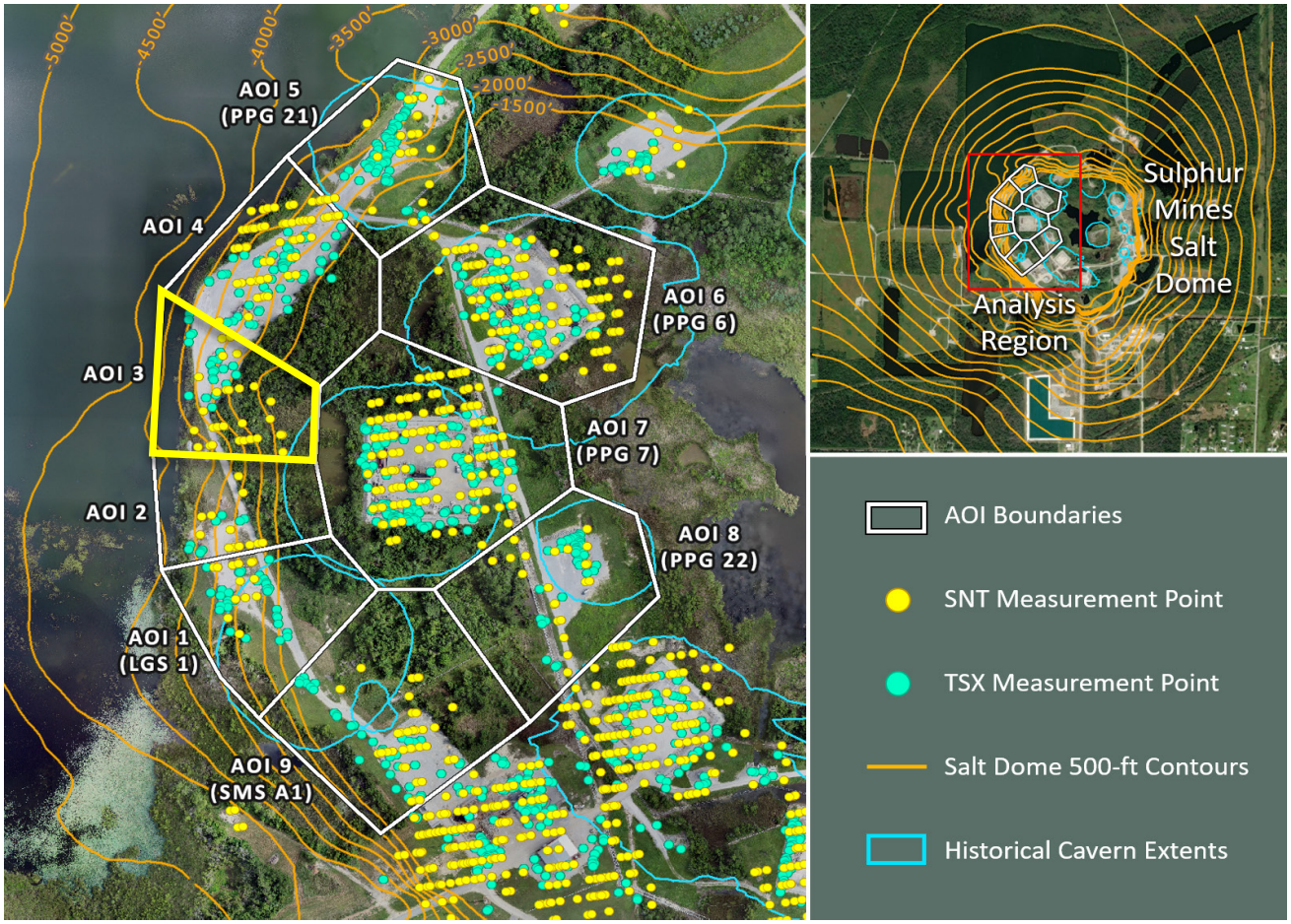
SNT (5/25/2023) Point Count: **15**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.69 in/yr	-0.84 in/yr	-0.15 in/yr
Acceleration:	+0.12 in/yr^2	+0.14 in/yr^2	+0.02 in/yr^2

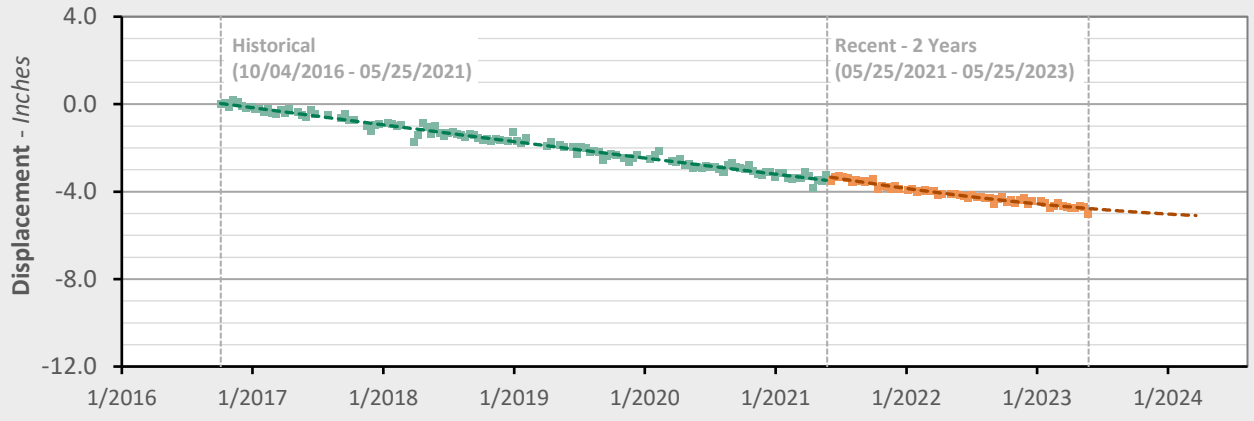
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 3 - Location Map



AOI 3 - Displacement Time Series

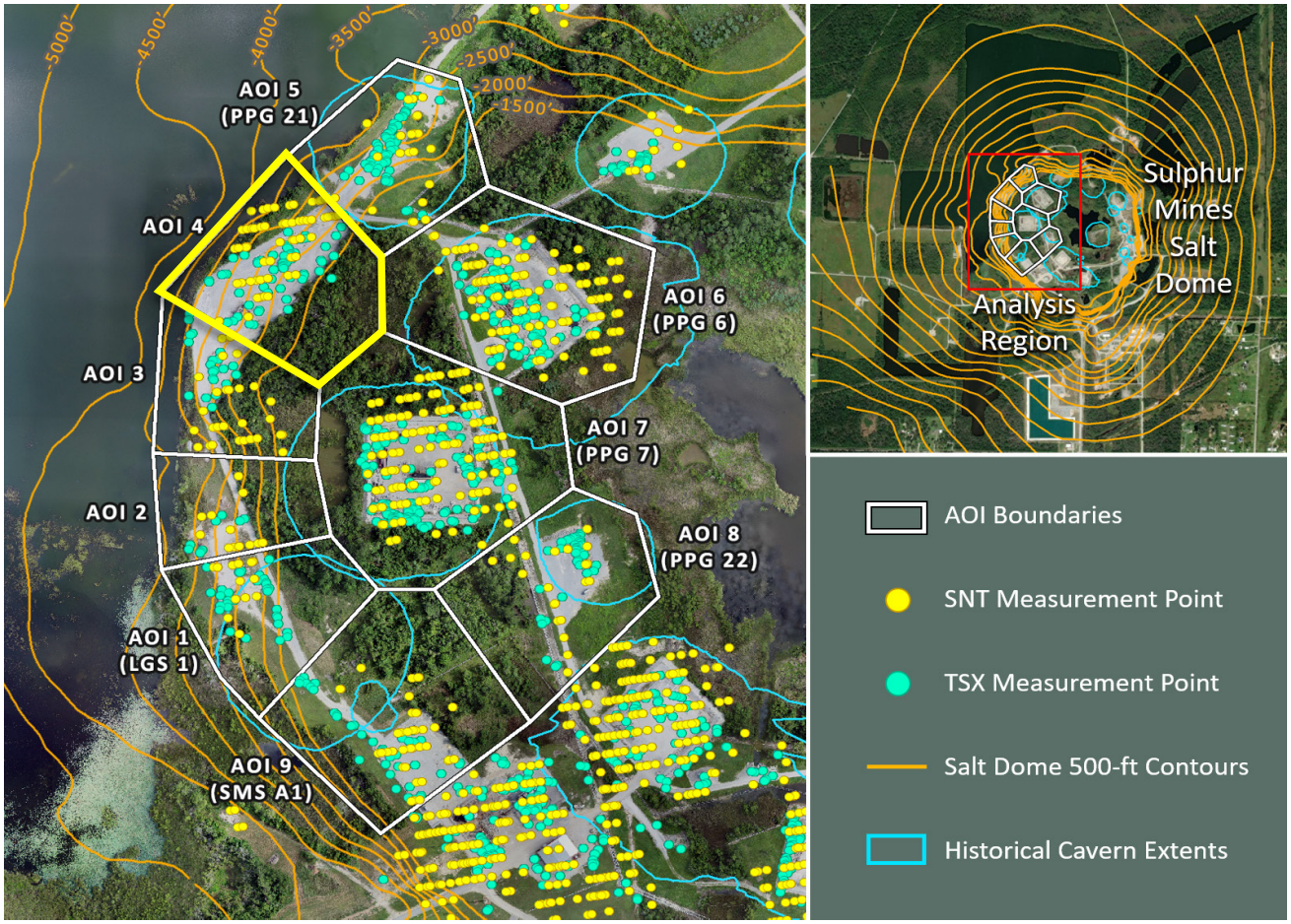
SNT (5/25/2023) Point Count: **29**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.72 in/yr	-0.49 in/yr	+0.23 in/yr
Acceleration:	+0.02 in/yr^2	+0.24 in/yr^2	+0.22 in/yr^2

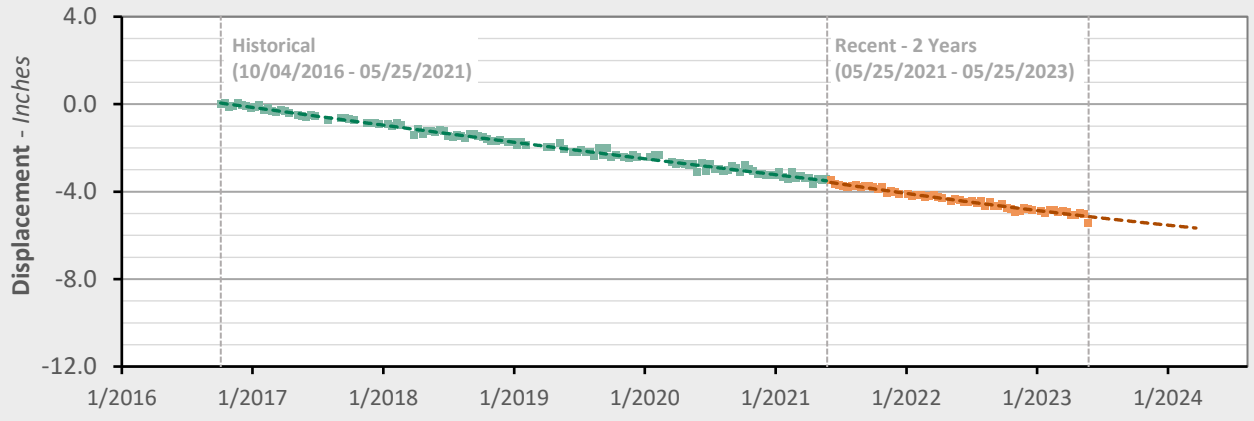
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 4 - Location Map



AOI 4 - Displacement Time Series

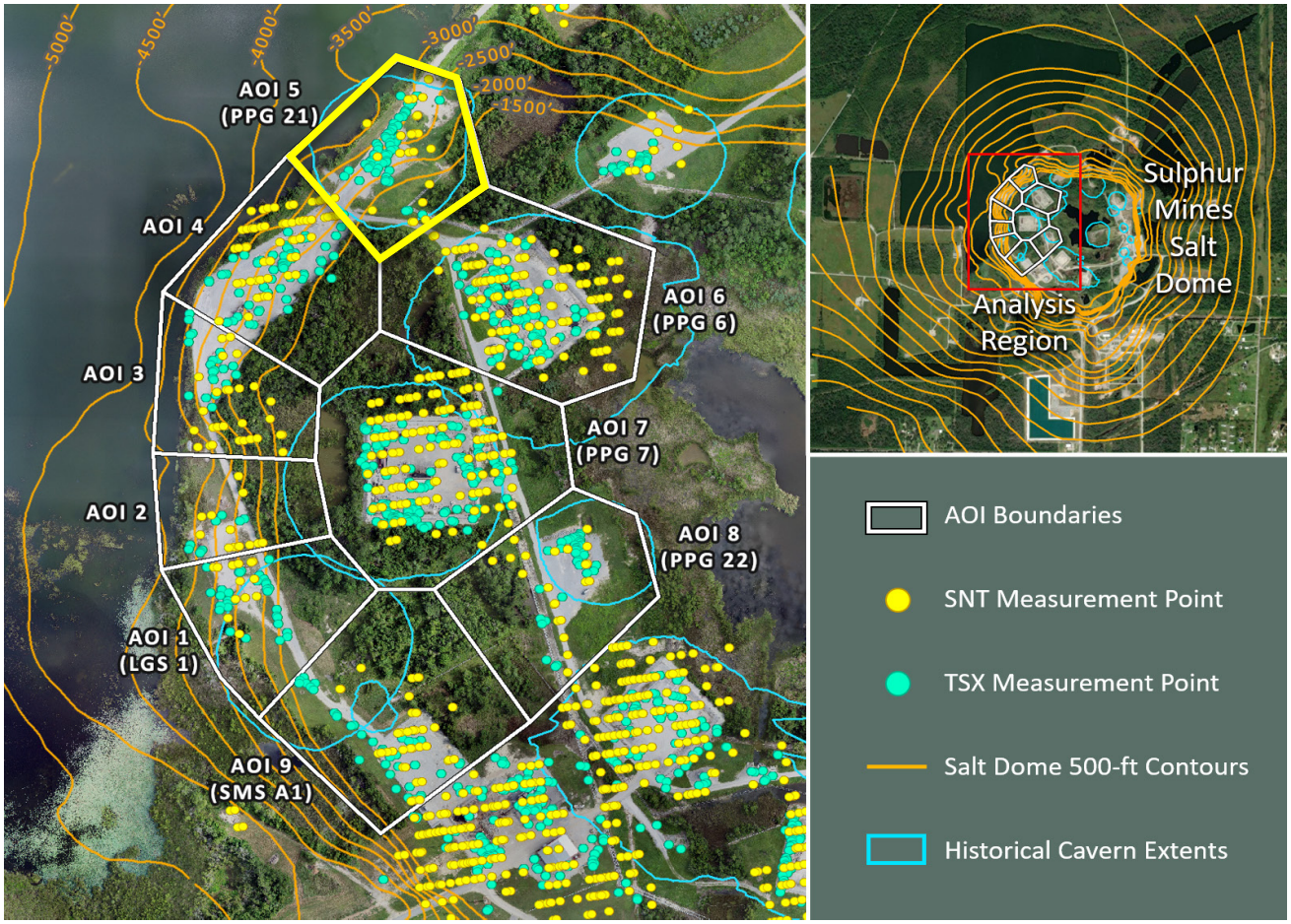
SNT (5/25/2023) Point Count: **62**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.70 in/yr	-0.68 in/yr	+0.02 in/yr
Acceleration:	+0.03 in/yr^2	+0.11 in/yr^2	+0.08 in/yr^2

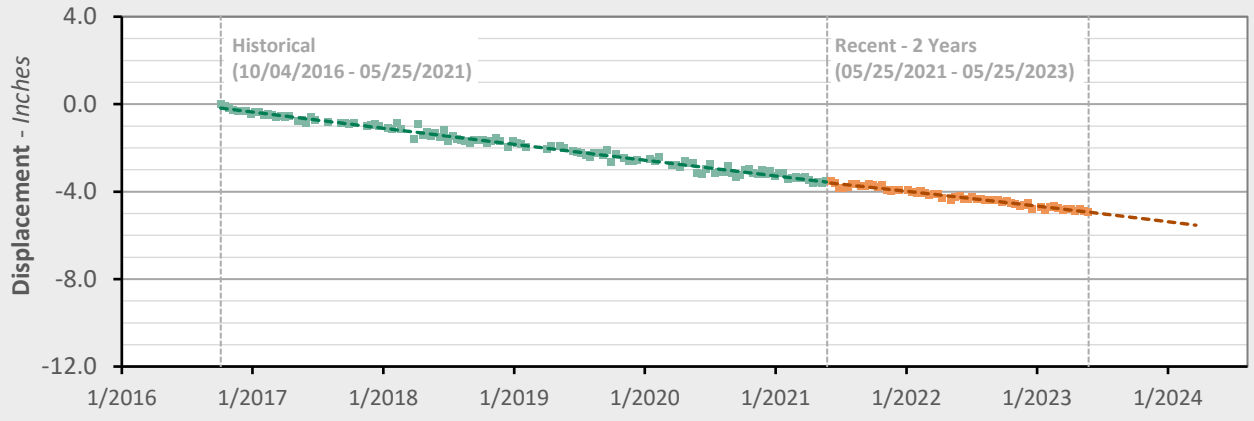
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 5 *(PPG 21)* - Location Map



AOI 5 *(PPG 21)* - Displacement Time Series

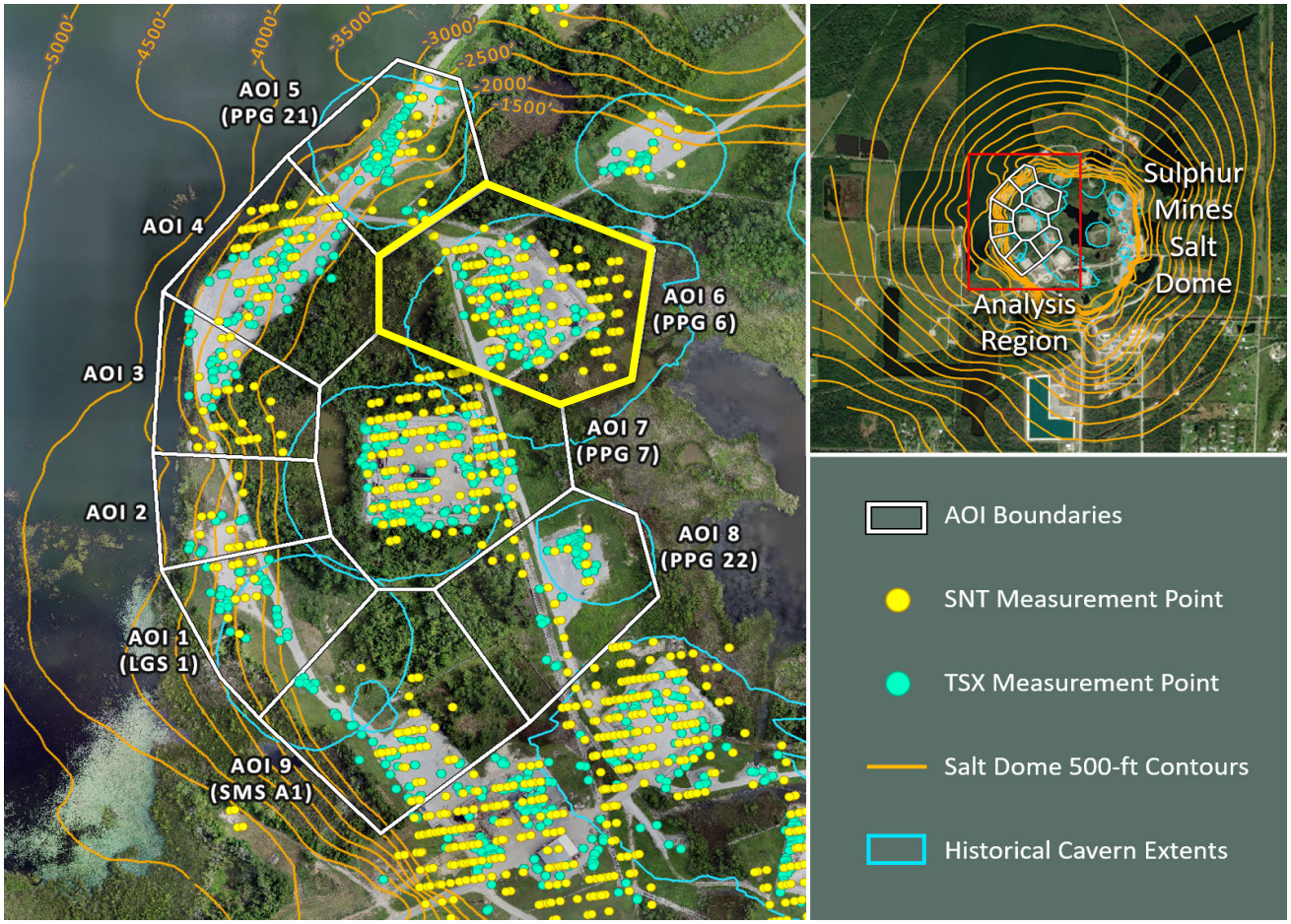
SNT (5/25/2023) Point Count: **25**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.71 in/yr	-0.71 in/yr	+0.00 in/yr
Acceleration:	+0.01 in/yr^2	-0.04 in/yr^2	-0.04 in/yr^2

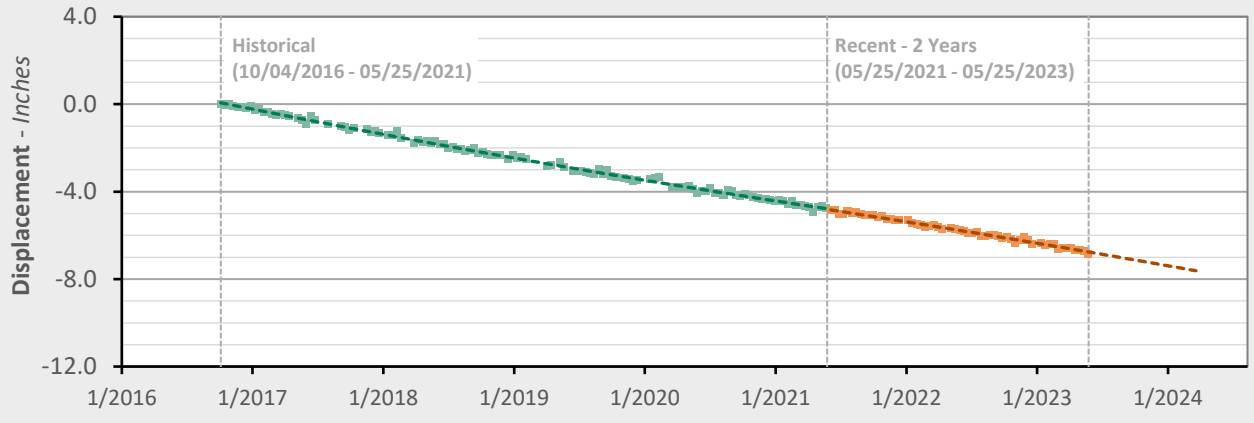
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 6 *(PPG 6)* - Location Map



AOI 6 *(PPG 6)* - Displacement Time Series

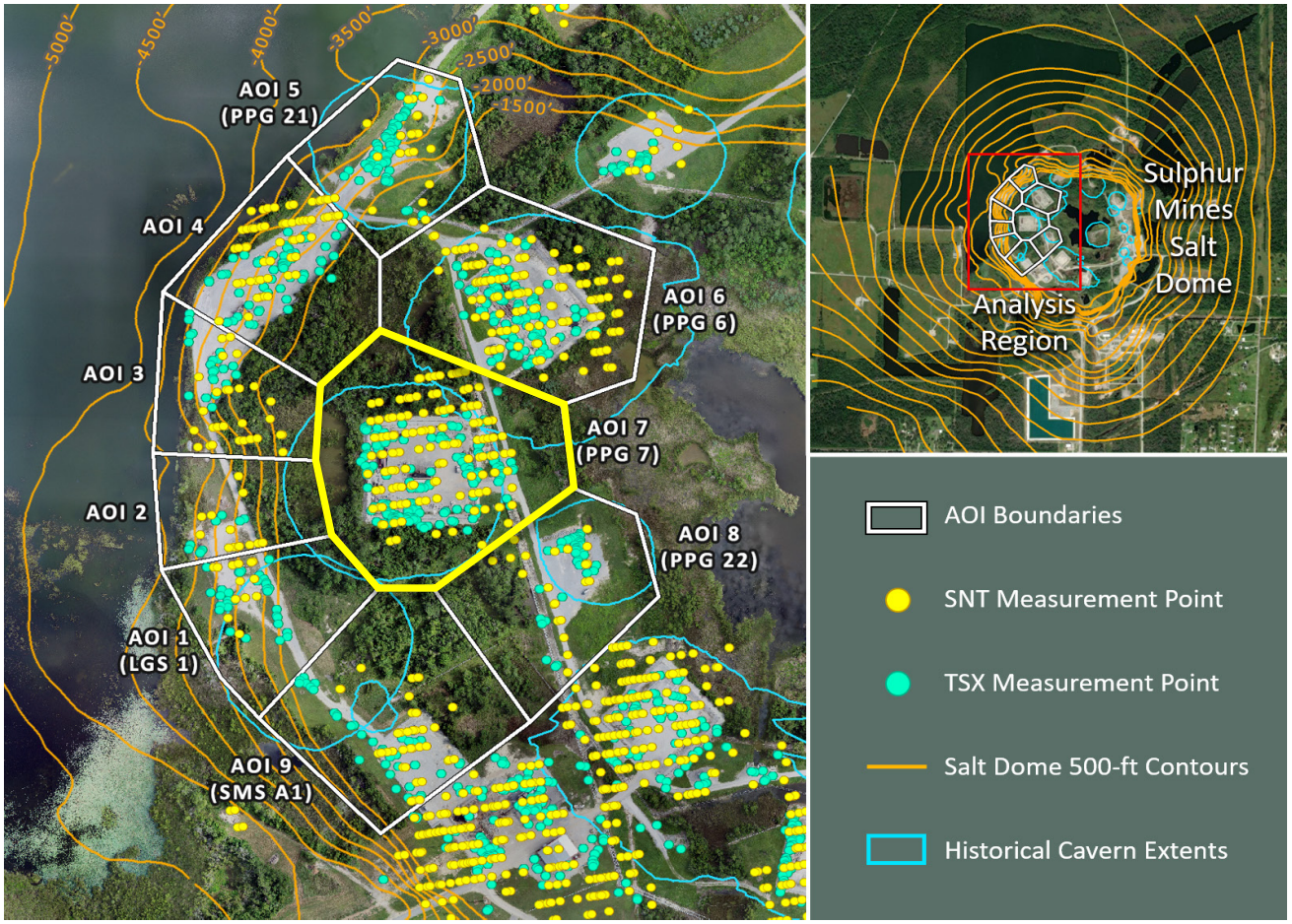
SNT (5/25/2023) Point Count: **134**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.89 in/yr	-1.03 in/yr	-0.14 in/yr
Acceleration:	+0.07 in/yr^2	-0.05 in/yr^2	-0.12 in/yr^2

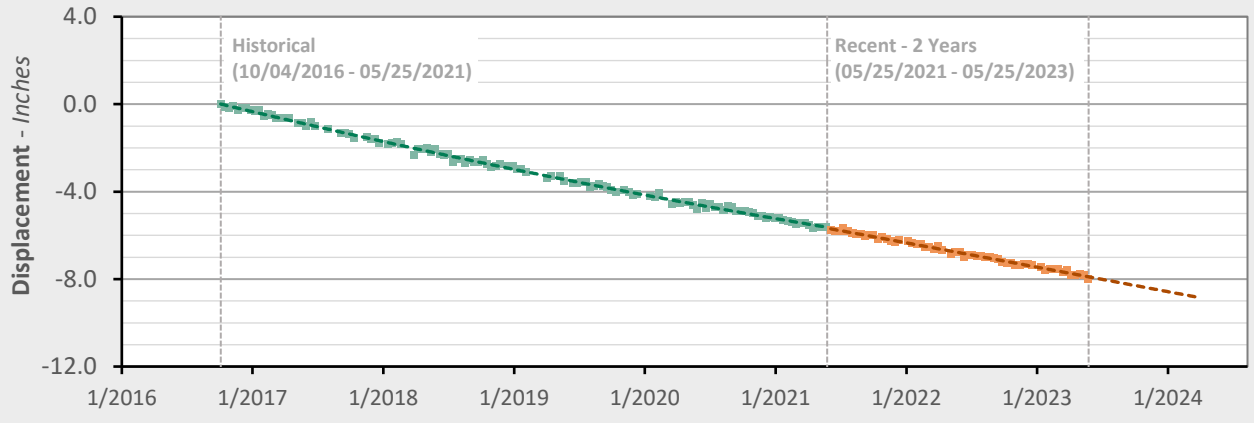
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 7 *(PPG 7)* - Location Map



AOI 7 *(PPG 7)* - Displacement Time Series

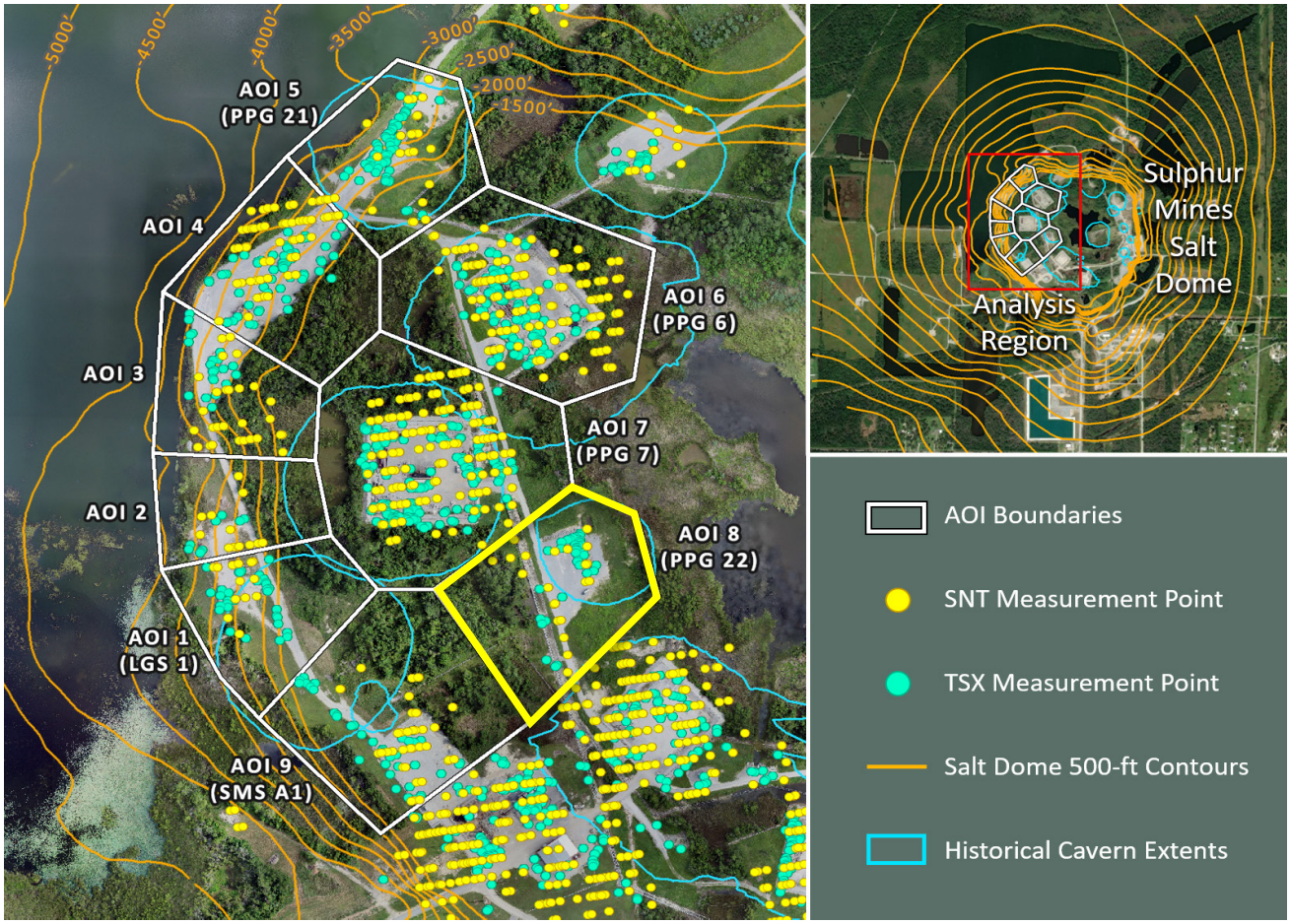
SNT (5/25/2023) Point Count: **140**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.99 in/yr	-1.12 in/yr	-0.13 in/yr
Acceleration:	+0.10 in/yr^2	-0.01 in/yr^2	-0.10 in/yr^2

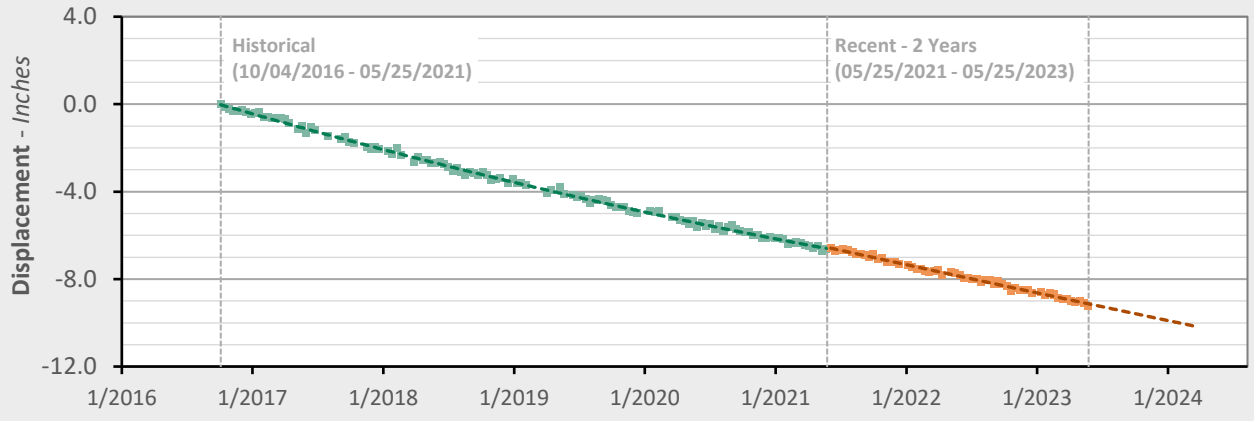
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 8 *(PPG 22)* - Location Map



AOI 8 *(PPG 22)* - Displacement Time Series

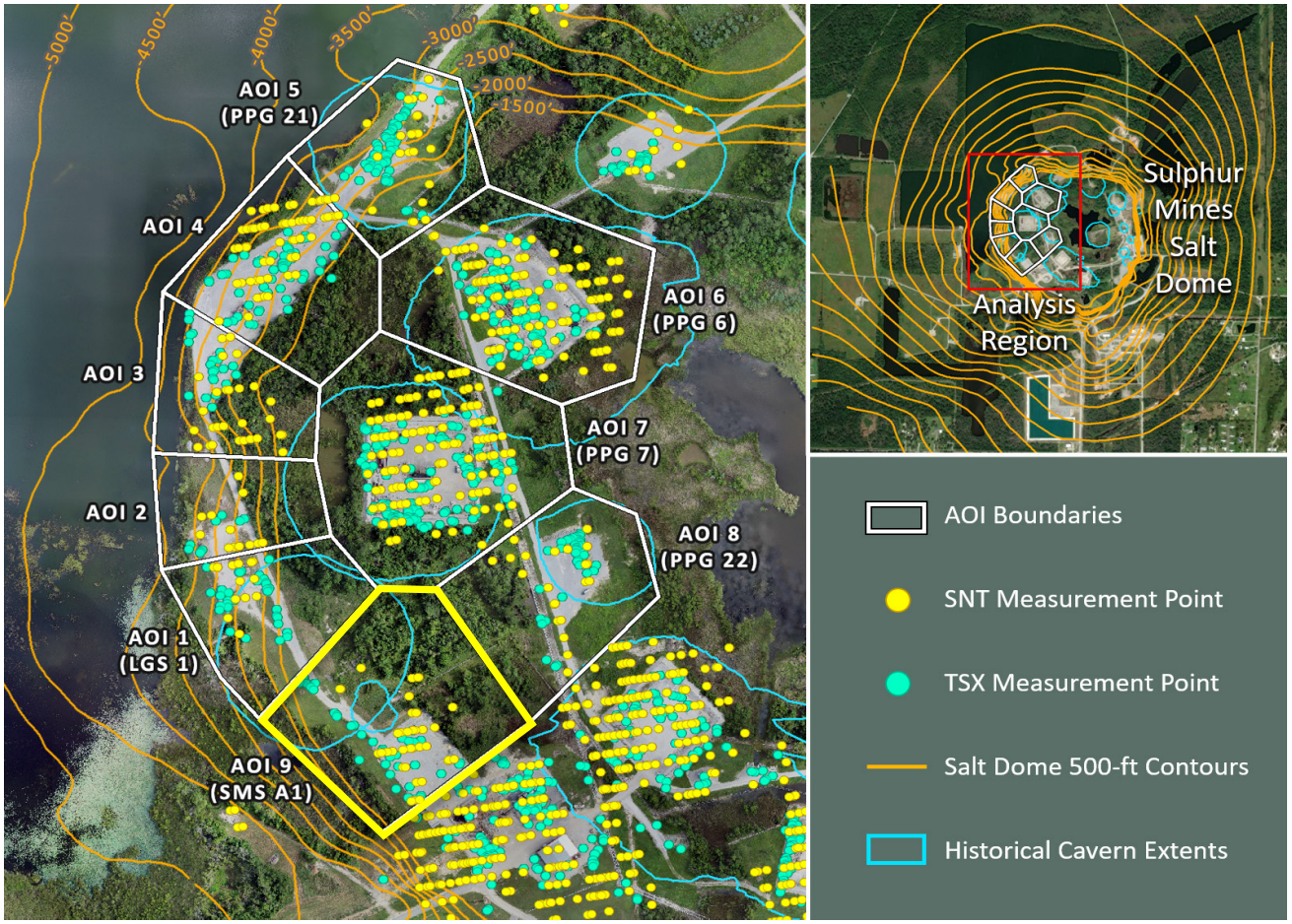
SNT (5/25/2023) Point Count: **21**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-1.10 in/yr	-1.27 in/yr	-0.17 in/yr
Acceleration:	+0.14 in/yr^2	+0.03 in/yr^2	-0.11 in/yr^2

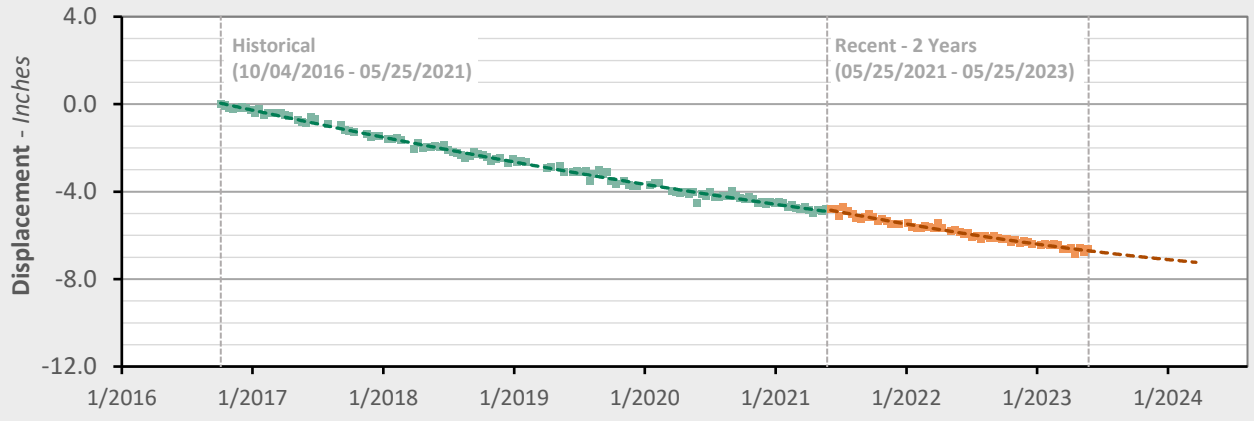
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 9 *(PPG A1)* - Location Map



AOI 9 *(SMS A1)* - Displacement Time Series

SNT (5/25/2023) Point Count: **39**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.82 in/yr	-0.73 in/yr	+0.09 in/yr
Acceleration:	+0.11 in/yr^2	+0.21 in/yr^2	+0.10 in/yr^2

Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

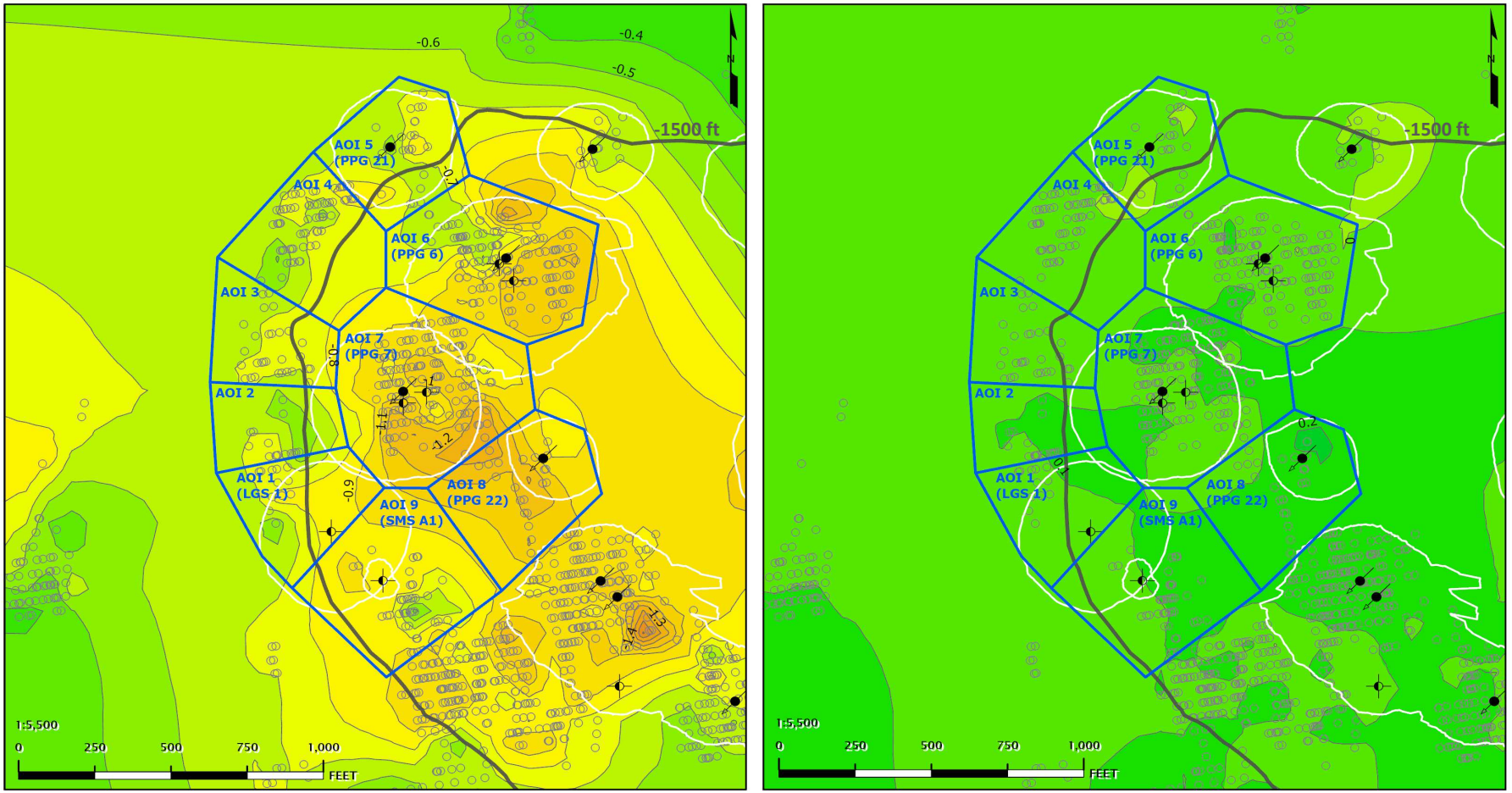
Historical SNT Data (10/04/2016 - 05/25/2021)

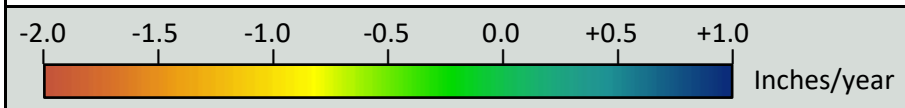
Velocity Contours

As of date: 05/25/2021

Acceleration Contours

Date range: 10/04/2016 - 05/25/2021





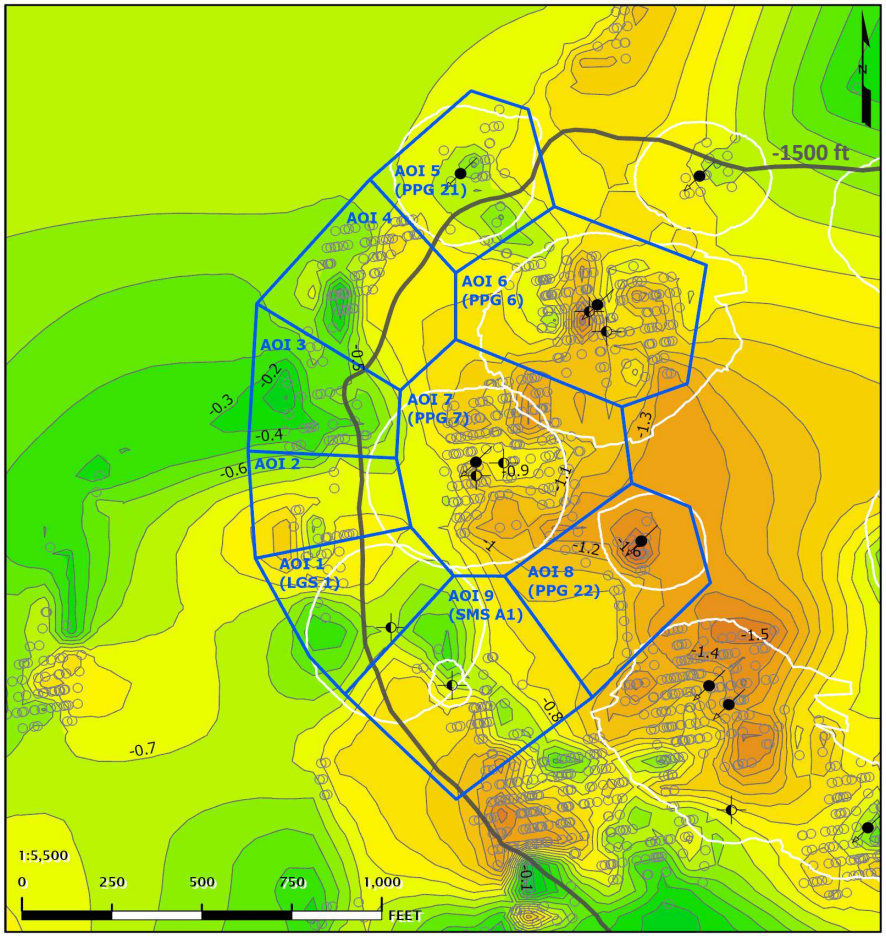
AOI Boundary | InSAR LOS Measurement Point | Contour (0.1) | Cavern Well Surface Locations

Historical Cavern Extent | Top of Dome (-1500 ft Contour) | 09 - Active - Injection | 29 - Dry and Plugged

Recent SNT Data - 2 Years (05/25/2021 - 05/25/2023)

Velocity Contours

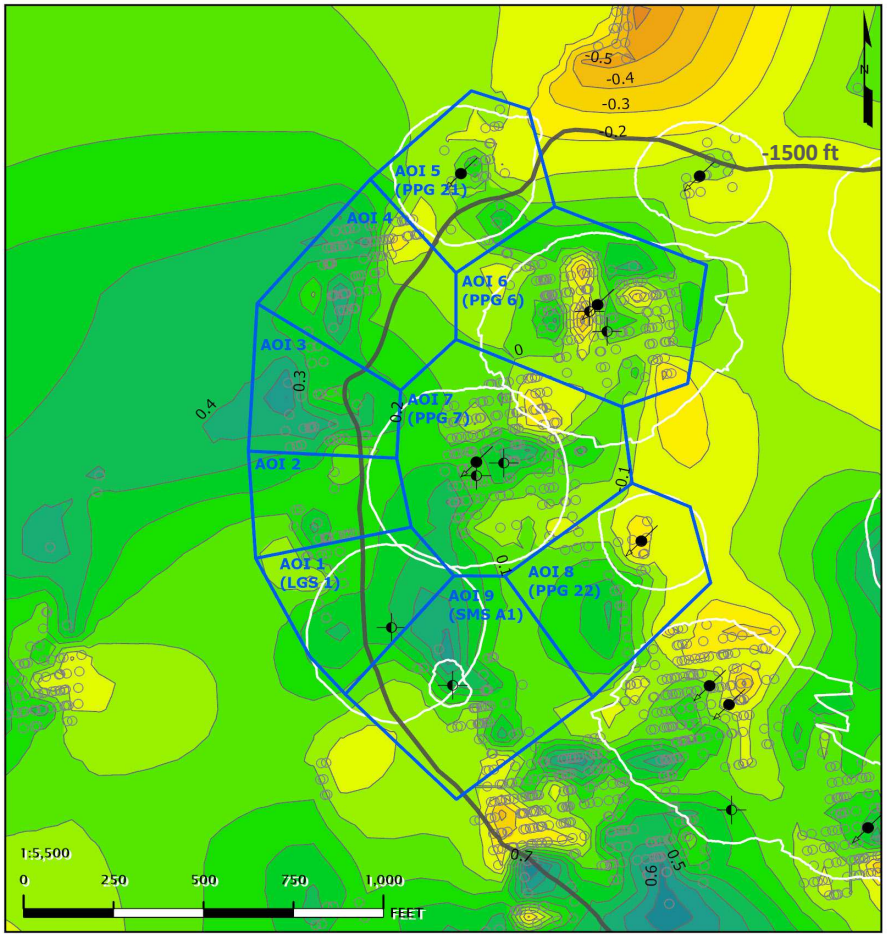
As of date: 05/25/2023



-2.0 -1.5 -1.0 -0.5 0.0 +0.5 +1.0 Inches/year

Acceleration Contours

Date range: 05/25/2021 - 05/25/2023



-1.0 -0.5 0.0 +0.5 +1.0 Inches/year^2

AOI Boundary
InSAR LOS Measurement Point
Contour (0.1)
Cavern Well Surface Locations
Historical Cavern Extent
Top of Dome (-1500 ft Contour)
09 - Active - Injection
29 - Dry and Plugged

Change from Historical to Recent SNT Data

Velocity Contours

Historical Velocity subtracted from Recent Velocity

Acceleration Contours

Historical Acceleration subtracted from Recent Acceleration