Westlake US 2
Received 5/25/2024

SNT Satellite Update
InSAR Subsidence
May 19, 2024

Longuist comment:

The SNT satellite (12-day revisit) passed by Sulphur on Sunday May 19. We received the dataset Saturday and verified that none of the point groups within the review area are showing deviation from their respective trends. The attached report has been prepared for reference.

Regarding the SNT satellite pass that occurred on May 7, we were informed by TREA that Sulphur Mines was not in the ESA's acquisition plan and that the image was not acquired. The four prior SNT acquisitions have been successful since the last time this occurred.

Submitted by: Nathaniel Byars (Longuist)

SNT Satellite Update

Continuous InSAR Monitoring of Ground Displacement At Westlake Caverns and Western 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
Sunday, May 19, 2024

Analysis Report Date:

May 24, 2024

Dataset Information

Satellite Source	Sentinel-1 (SNT)
Revisit Frequency	12 days
Most Recent Image Date	Sunday, May 19, 2024
Dataset Image Count	201
Dataset Time Range	October 4, 2016 - May 19, 2024
Dataset Length	7.62 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 or eastward movement. Negative acceleration values indicate increasing rates of subsidence or eastward movement and positive acceleration values indicate slowing rates of subsidence or eastward movement.

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 have been no acute deviations from established subsidence trends in the areas investigated.

The comparison of Recent to Historical trends in the SNT data does imply a minor increase (≥ -0.10) in the negative velocity and/or negative acceleration of LOS displacement in 7 of the 15 AOI point groups. This suggests that marginal increases in subsidence rates may be occuring in these areas in recent years with the greatest velocity increases (in descending order) occuring in AOI 13 (PPG 18), AOI 10 (PPG 2), AOI 8 (PPG 22), and AOI 7 (PPG 7).

In the mapped contours of the change in recent vs. historical subsidence rates, the most notable negative rate change is seen to be occuring in AOI 1, AOI 10 (PPG 2), and AOI 13 (PPG 18) in the velocity and acceleration maps. This generally supports the average trend change values presented in the AOI Analysis Summary.

Date Signed: May 24, 2024
Austin, Texas

Nathaniel L. Byars, P.E.
Principal Engineer
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InSAR Data Sources

InSAR Data

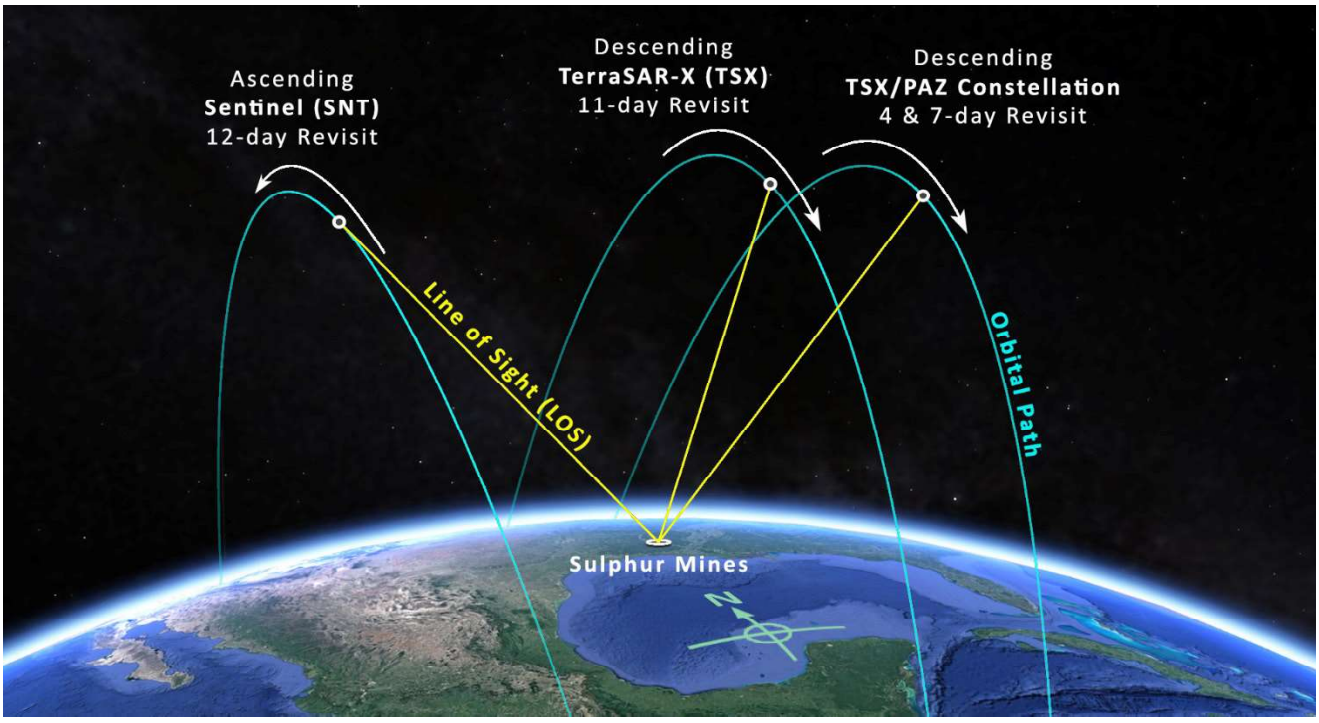
Interferometric Synthetic Aperture Radar (InSAR) is the most well established method to continually evaluate small, normally undetectable, ground movement over a large area. Radar imagery collected via satellites over successive orbital passes is used to identify and define measurement points on the 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.

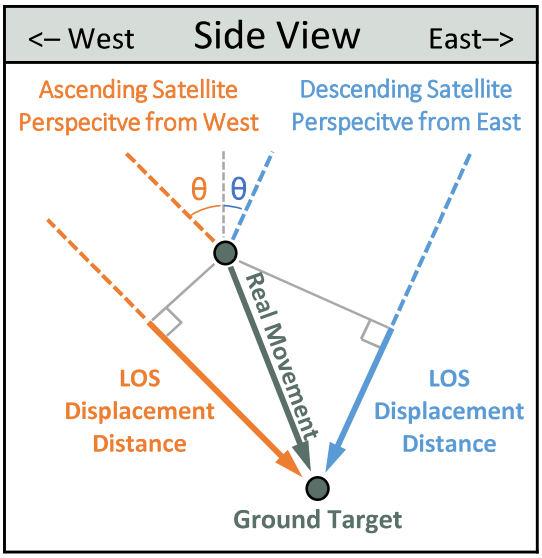
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a pair of high resolution satellites that share the same descending orbit and capture data from east of the site. These are a 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. Prior to May 2023, data was captured from a different high-resolution TerraSAR-X (TSX) satellite on a descending orbit that captured data from the east of the site on an 11-day frequency. The transition was made for the increased data frequency that resulted 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

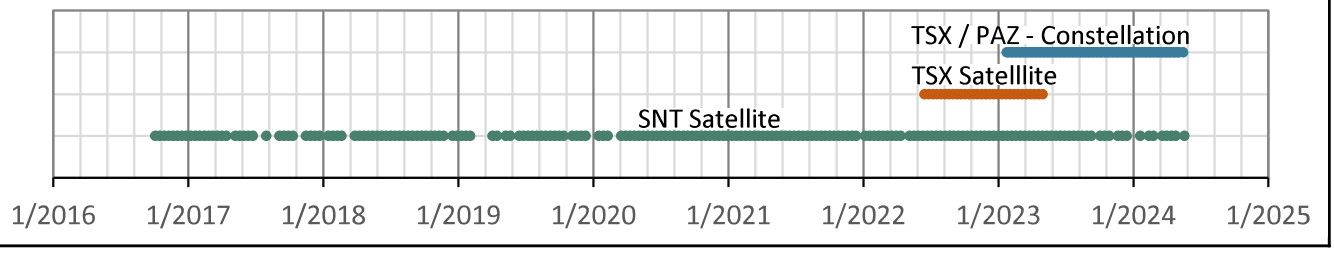
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR 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.



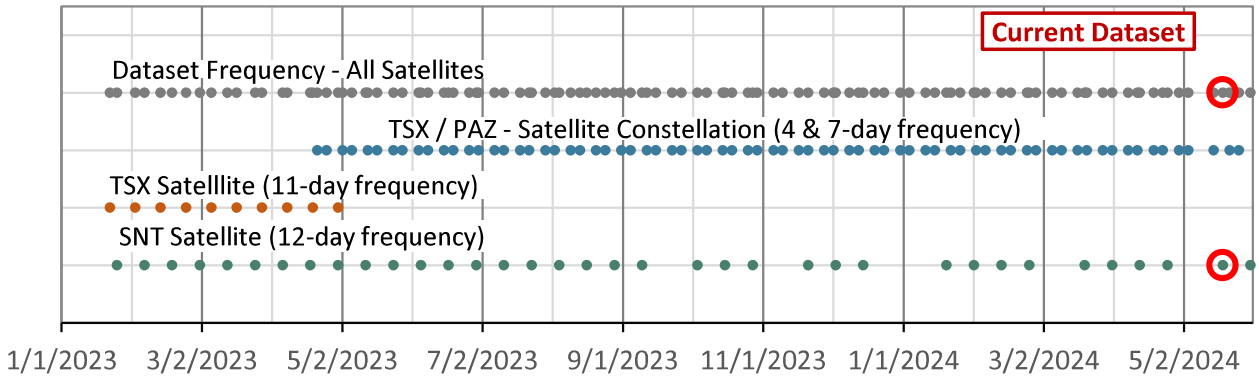
Satellite Properties & Image Frequency

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

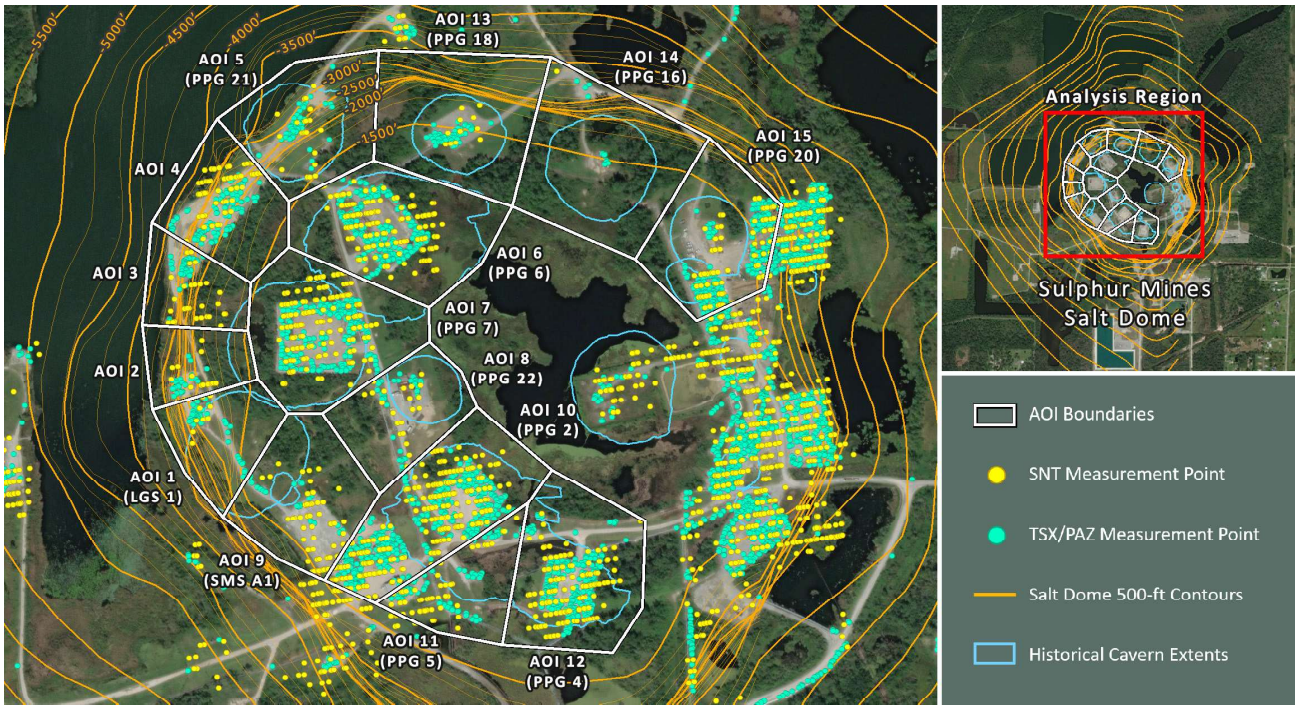
Dataset Measurement History



Dataset Update Frequency



AOI Boundaries & InSAR Measurement Points

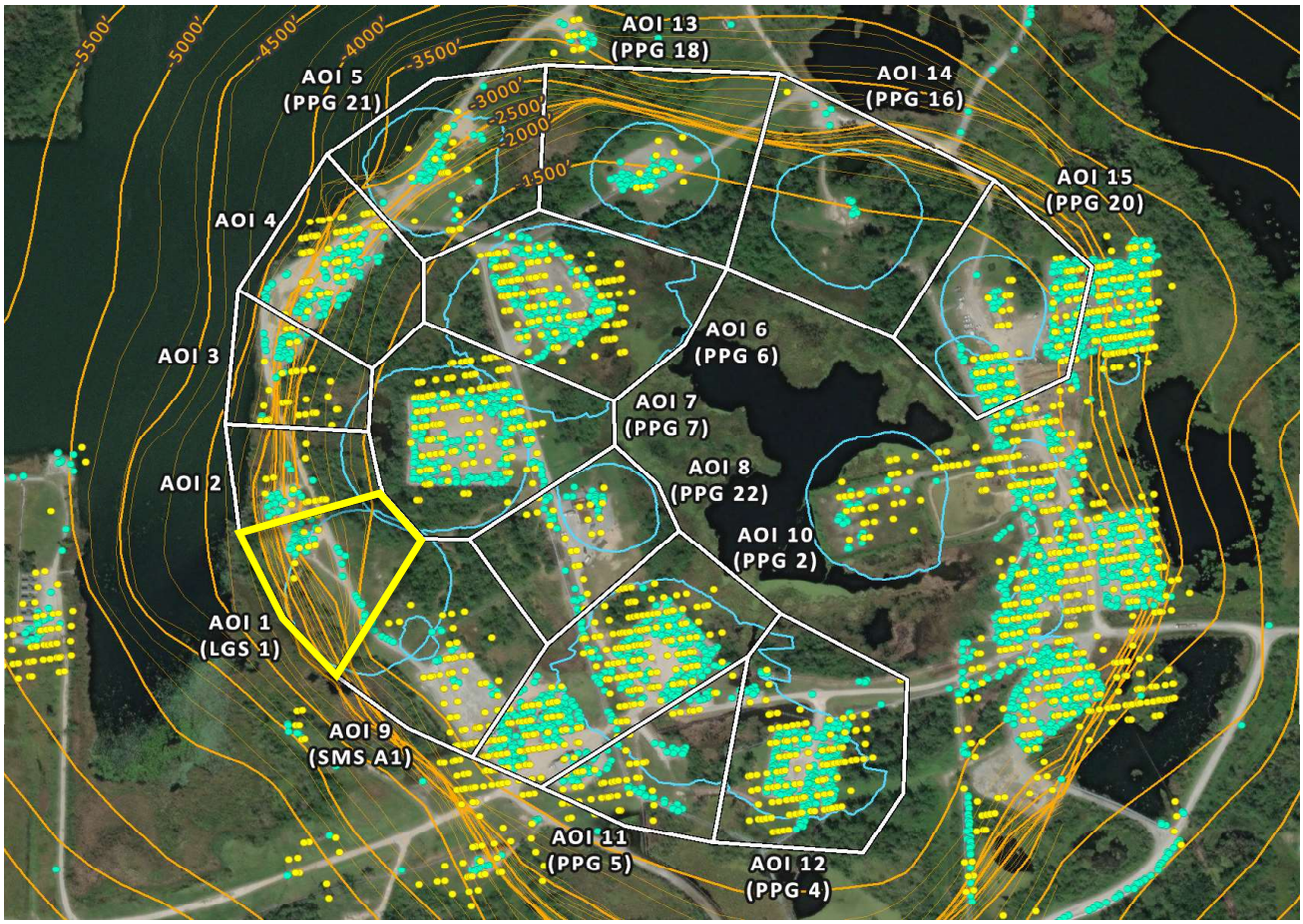


Subsidence Monitoring Areas of Interest (AOIs)

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.

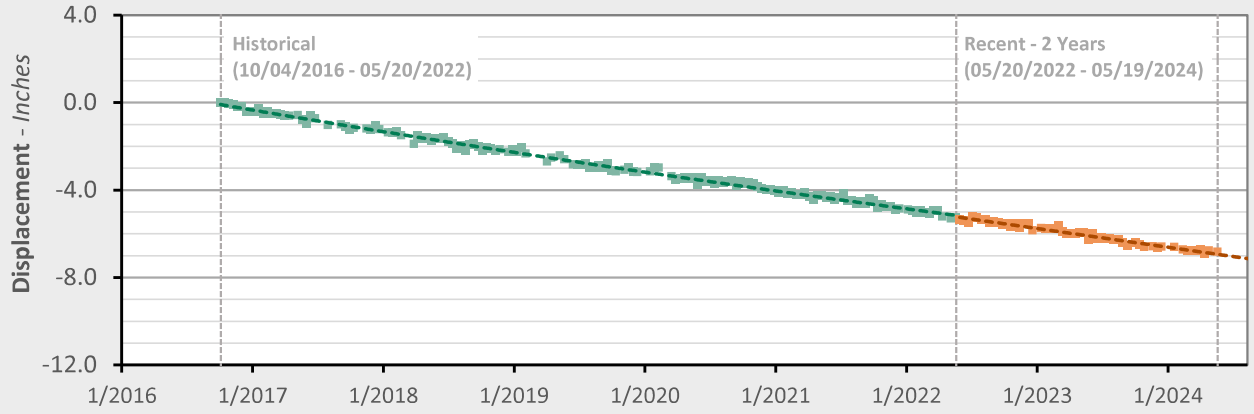
AOI Name	SNT (5/19/2024)	LOS Velocity *(in/yr)*			LOS Acceleration *(in/yr^2)*		
	Point Count	Historical	Recent	Change	Historical	Recent	Change
AOI 1 *(LGS 1)*	13	-0.78	-0.83	-0.05	+0.04	+0.04	-0.00
AOI 2	15	-0.71	-0.82	-0.11	+0.08	+0.04	-0.05
AOI 3	29	-0.66	-0.70	-0.03	+0.03	+0.00	-0.02
AOI 4	61	-0.77	-0.76	+0.00	+0.00	-0.06	-0.06
AOI 5 *(PPG 21)*	26	-0.69	-0.66	+0.03	+0.01	-0.05	-0.06
AOI 6 *(PPG 6)*	134	-0.87	-0.91	-0.04	+0.05	-0.02	-0.07
AOI 7 *(PPG 7)*	140	-0.99	-1.11	-0.12	+0.07	-0.01	-0.08
AOI 8 *(PPG 22)*	21	-1.08	-1.22	-0.14	+0.11	+0.06	-0.05
AOI 9 *(SMS A1)*	58	-0.84	-0.93	-0.09	+0.08	-0.03	-0.11
AOI 10 *(PPG 2)*	229	-0.90	-1.05	-0.16	+0.10	-0.02	-0.12
AOI 11 *(PPG 5)*	51	-0.90	-0.98	-0.08	+0.07	-0.03	-0.10
AOI 12 *(PPG 4)*	120	-0.71	-0.64	+0.07	+0.06	+0.16	+0.10
AOI 13 *(PPG 18)*	12	-0.58	-0.85	-0.27	+0.05	-0.25	-0.30
AOI 14 *(PPG 16)*	1	-0.17	-0.06	+0.11	+0.08	+0.29	+0.21
AOI 15 *(PPG 20)*	73	-0.29	-0.33	-0.04	+0.05	-0.01	-0.06

AOI 1 *(LGS 1)* - Location Map

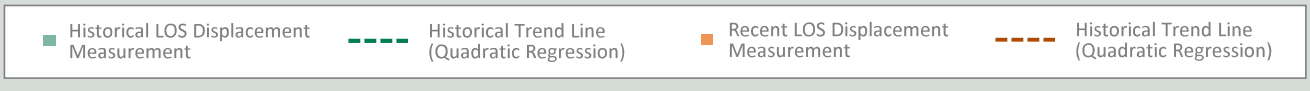


AOI 1 *(LGS 1)* - Displacement Time Series

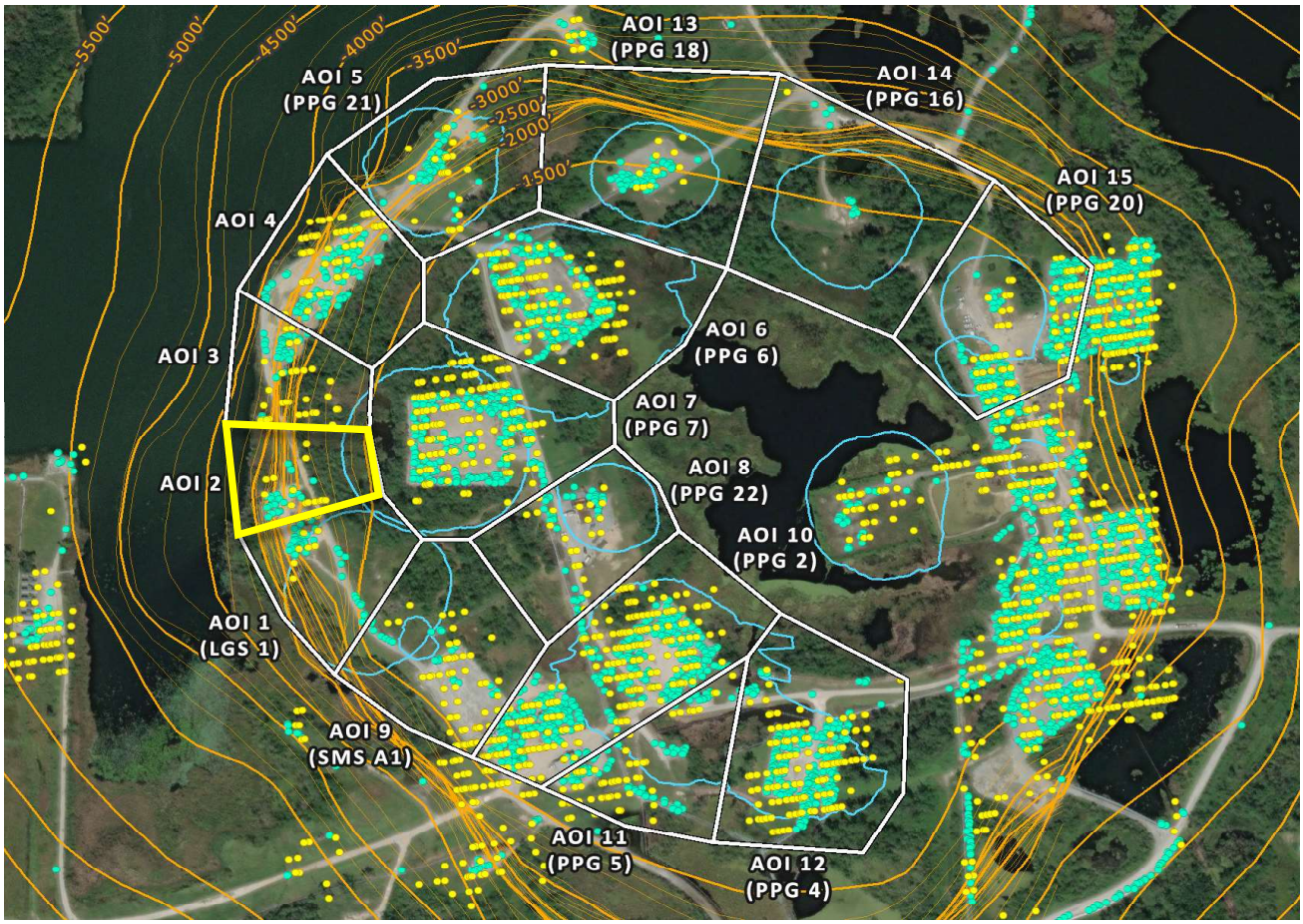
SNT (5/19/2024) Point Count: **13**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.78 in/yr	-0.83 in/yr	-0.05 in/yr
Acceleration:	+0.04 in/yr^2	+0.04 in/yr^2	-0.00 in/yr^2

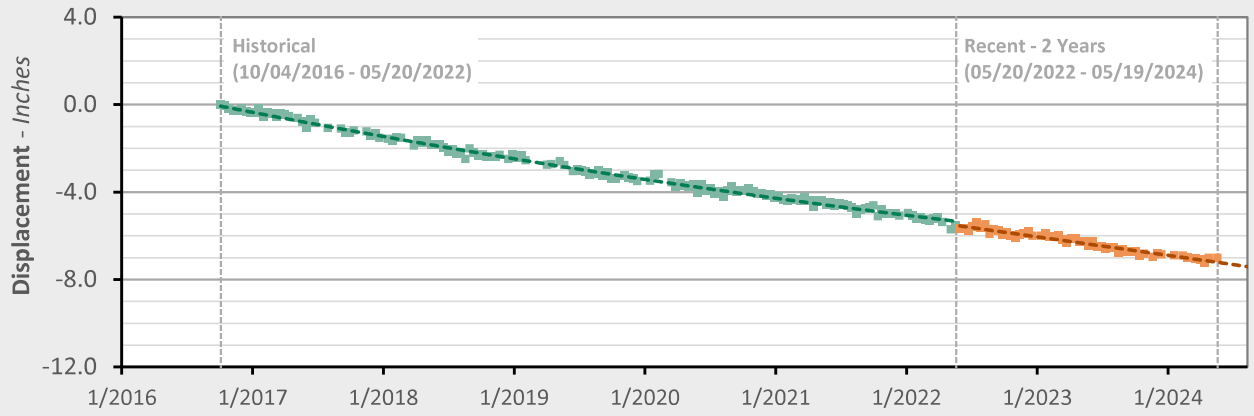


AOI 2 - Location Map



AOI 2 - Displacement Time Series

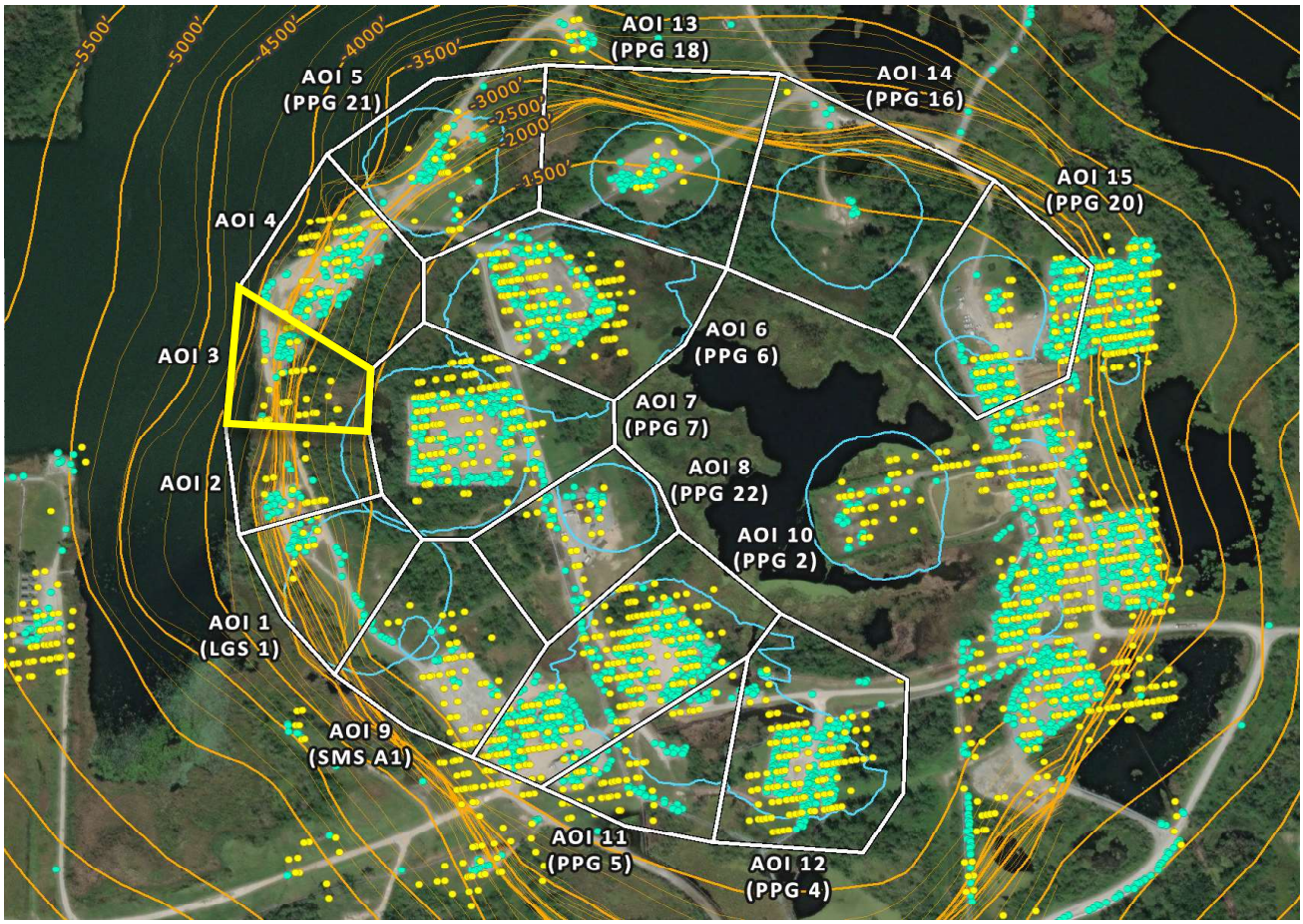
SNT (5/19/2024) Point Count: **15**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.71 in/yr	-0.82 in/yr	-0.11 in/yr
Acceleration:	+0.08 in/yr^2	+0.04 in/yr^2	-0.05 in/yr^2

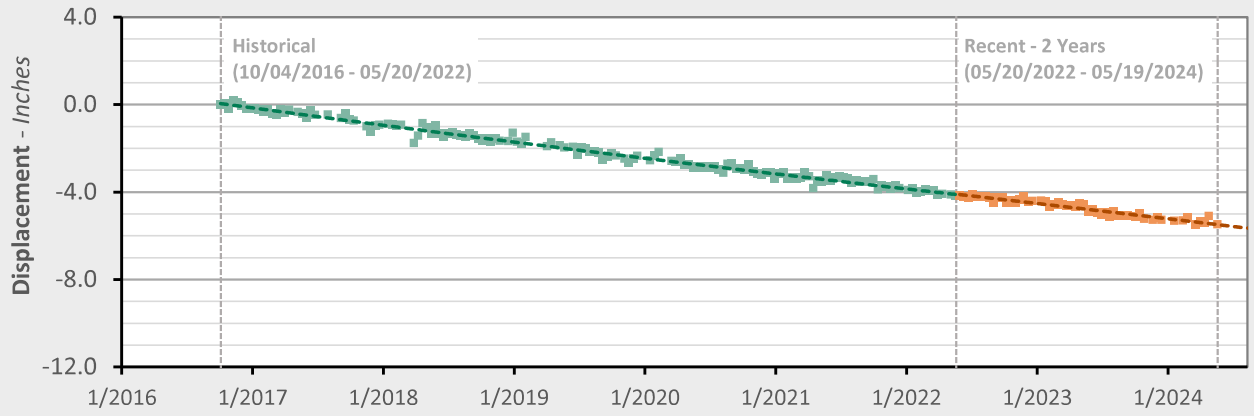
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 3 - Location Map



AOI 3 - Displacement Time Series

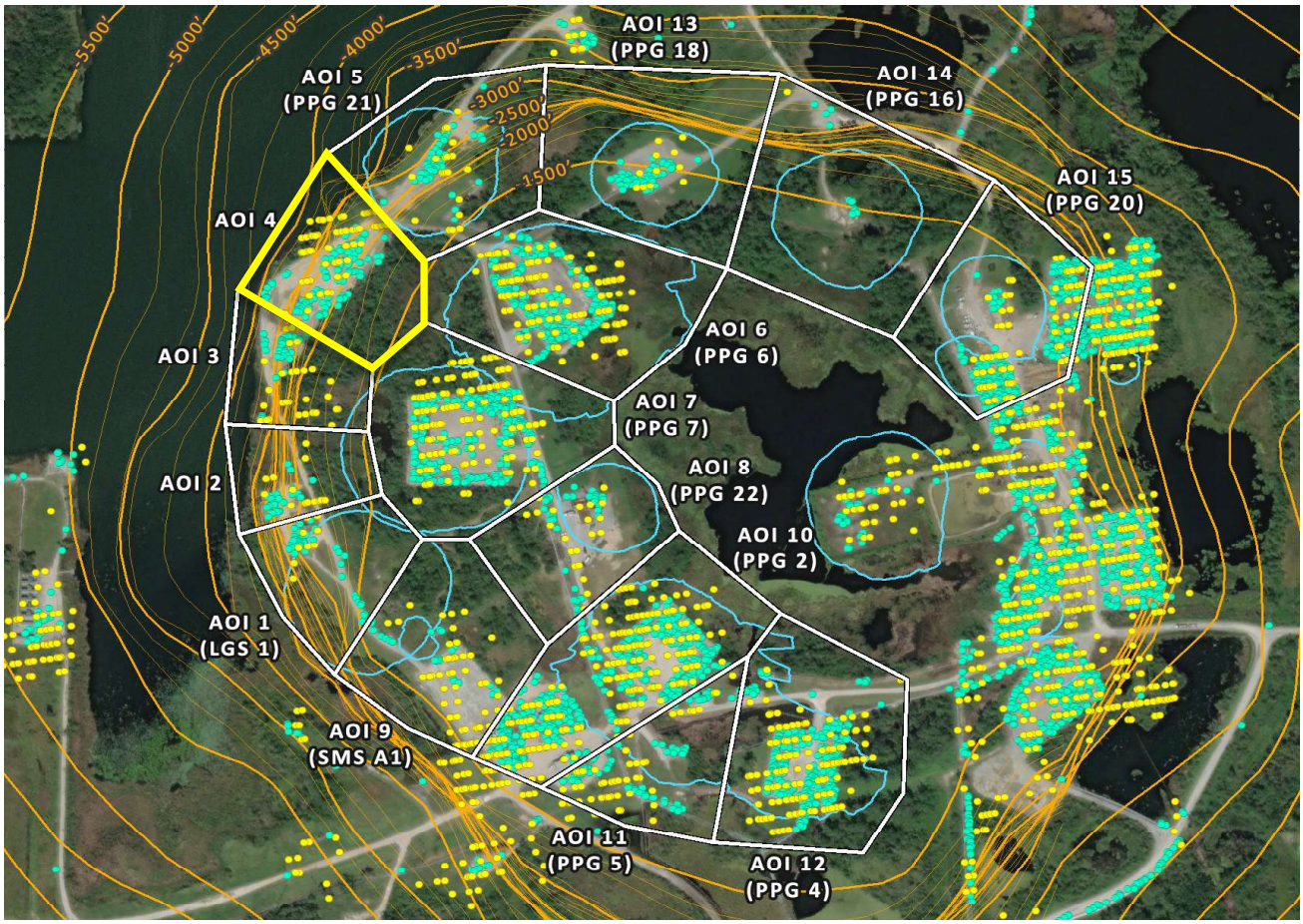
SNT (5/19/2024) Point Count: **29**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.66 in/yr	-0.70 in/yr	-0.03 in/yr
Acceleration:	+0.03 in/yr^2	+0.00 in/yr^2	-0.02 in/yr^2

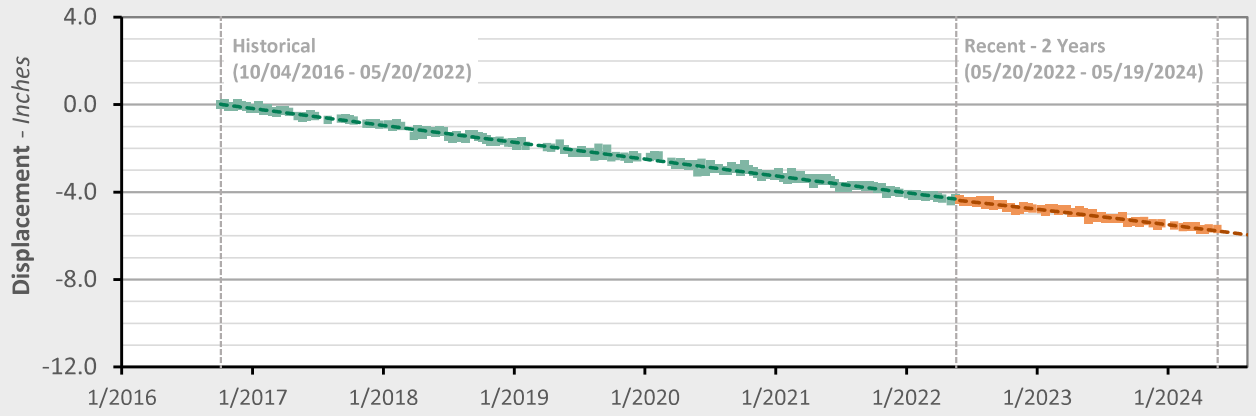
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 4 - Location Map



AOI 4 - Displacement Time Series

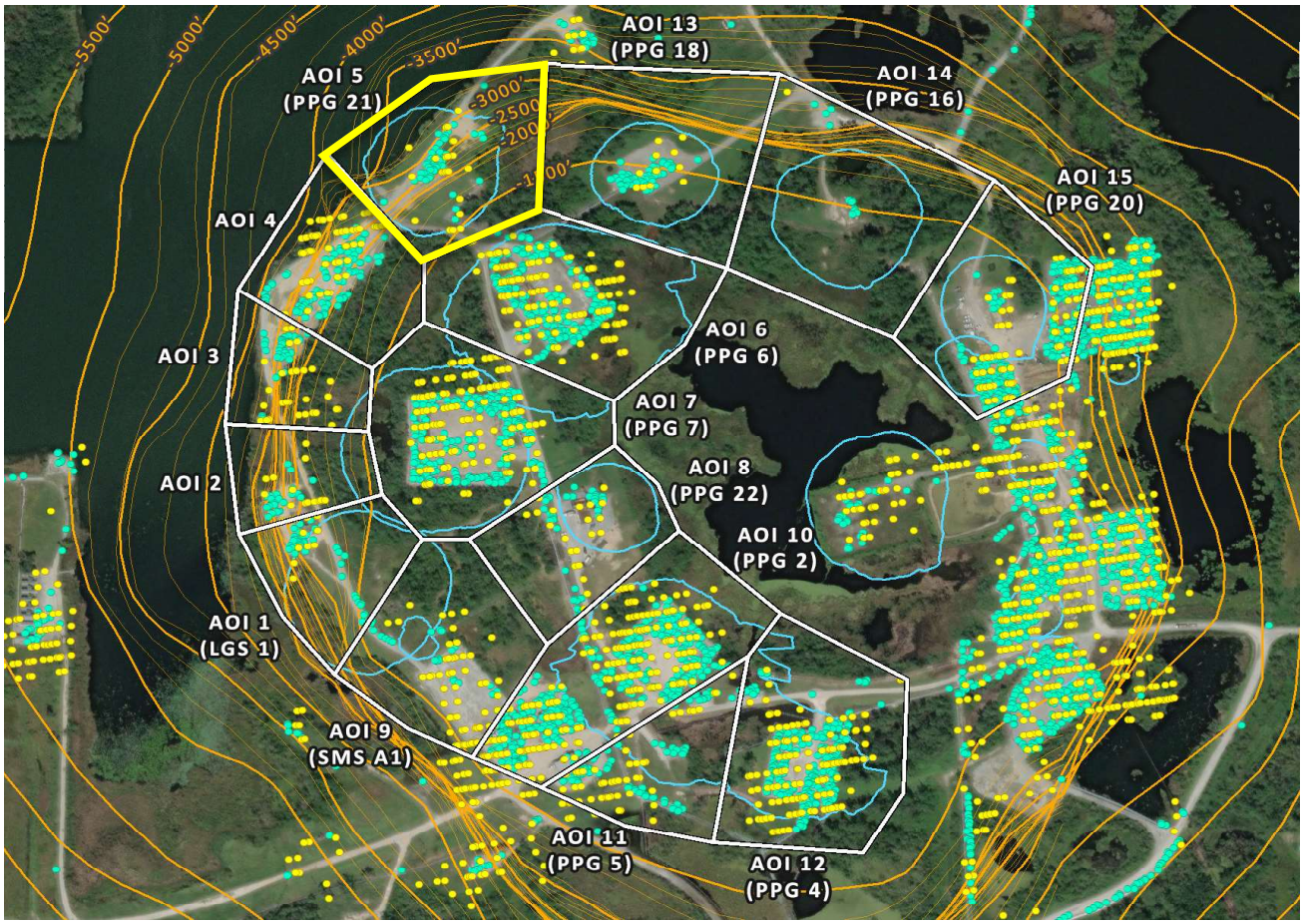
SNT (5/19/2024) Point Count: **61**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.77 in/yr	-0.76 in/yr	+0.00 in/yr
Acceleration:	+0.00 in/yr^2	-0.06 in/yr^2	-0.06 in/yr^2

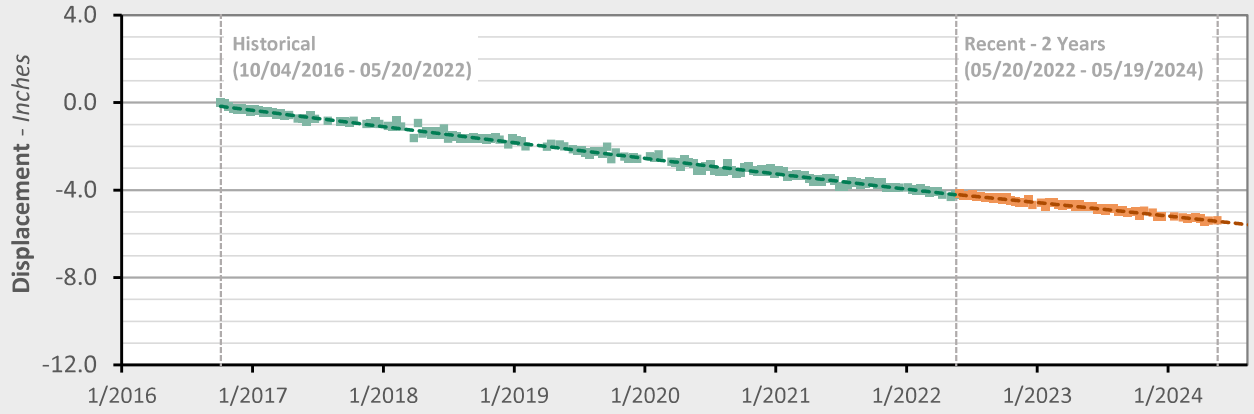
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 5 *(PPG 21)* - Location Map



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

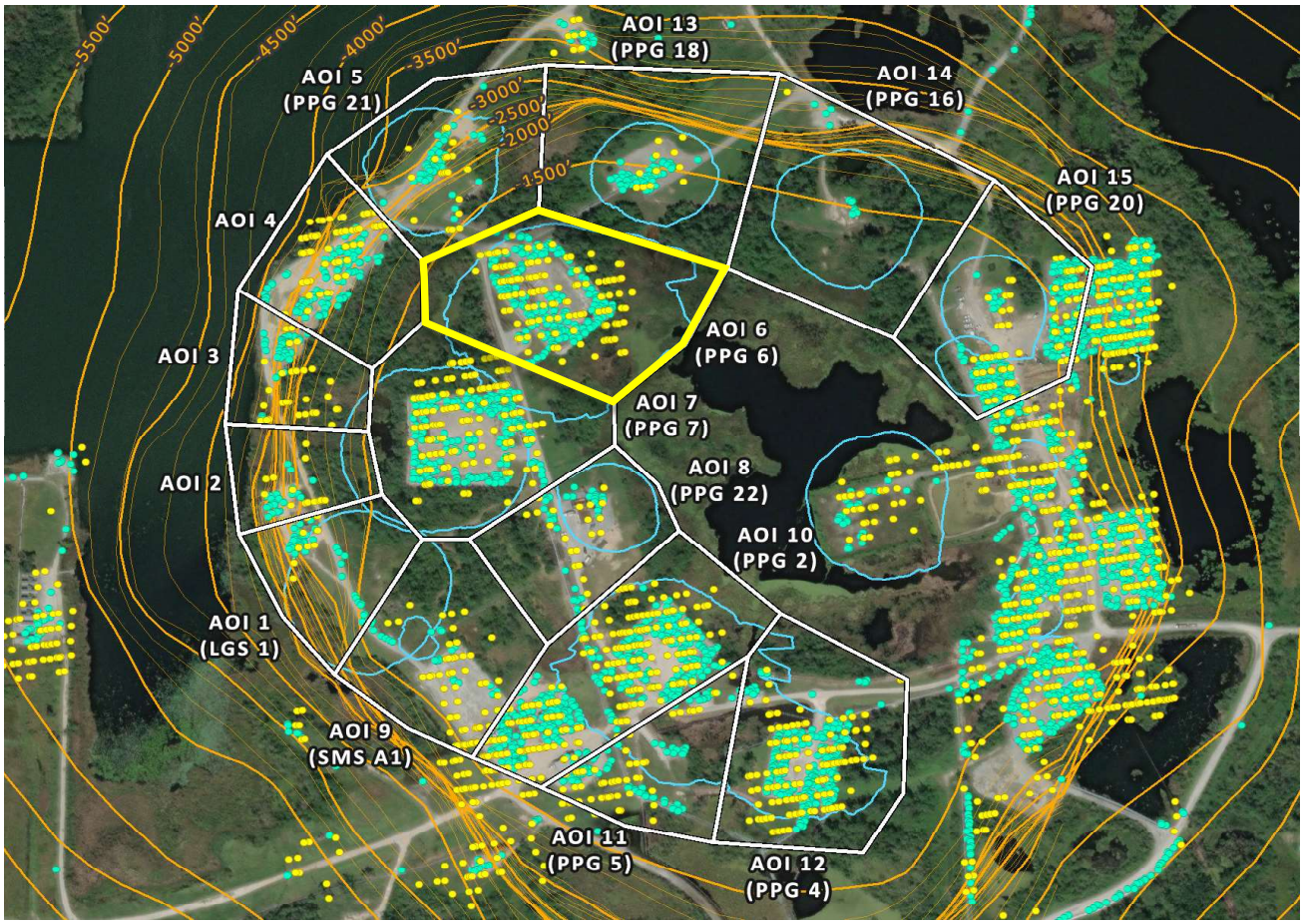
SNT (5/19/2024) Point Count: **26**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.69 in/yr	-0.66 in/yr	+0.03 in/yr
Acceleration:	+0.01 in/yr^2	-0.05 in/yr^2	-0.06 in/yr^2

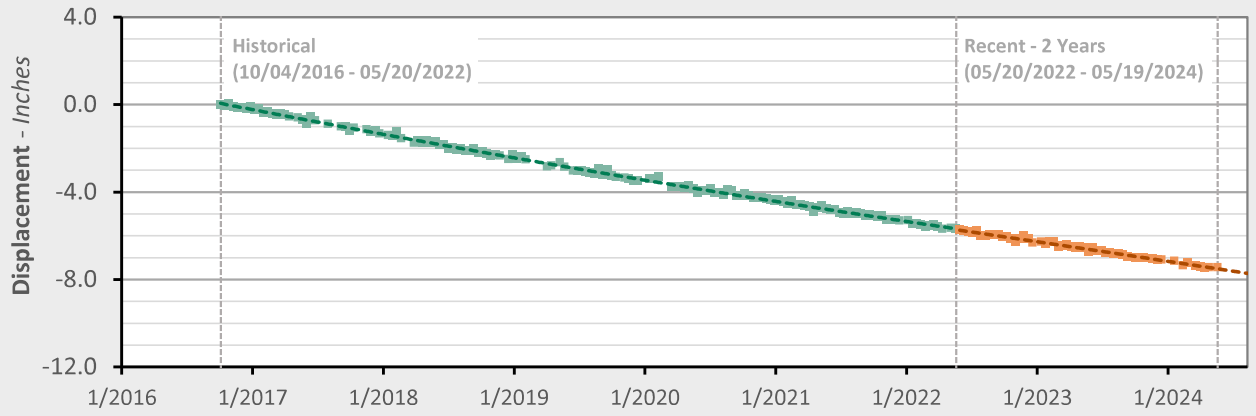
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 6 *(PPG 6)* - Location Map



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

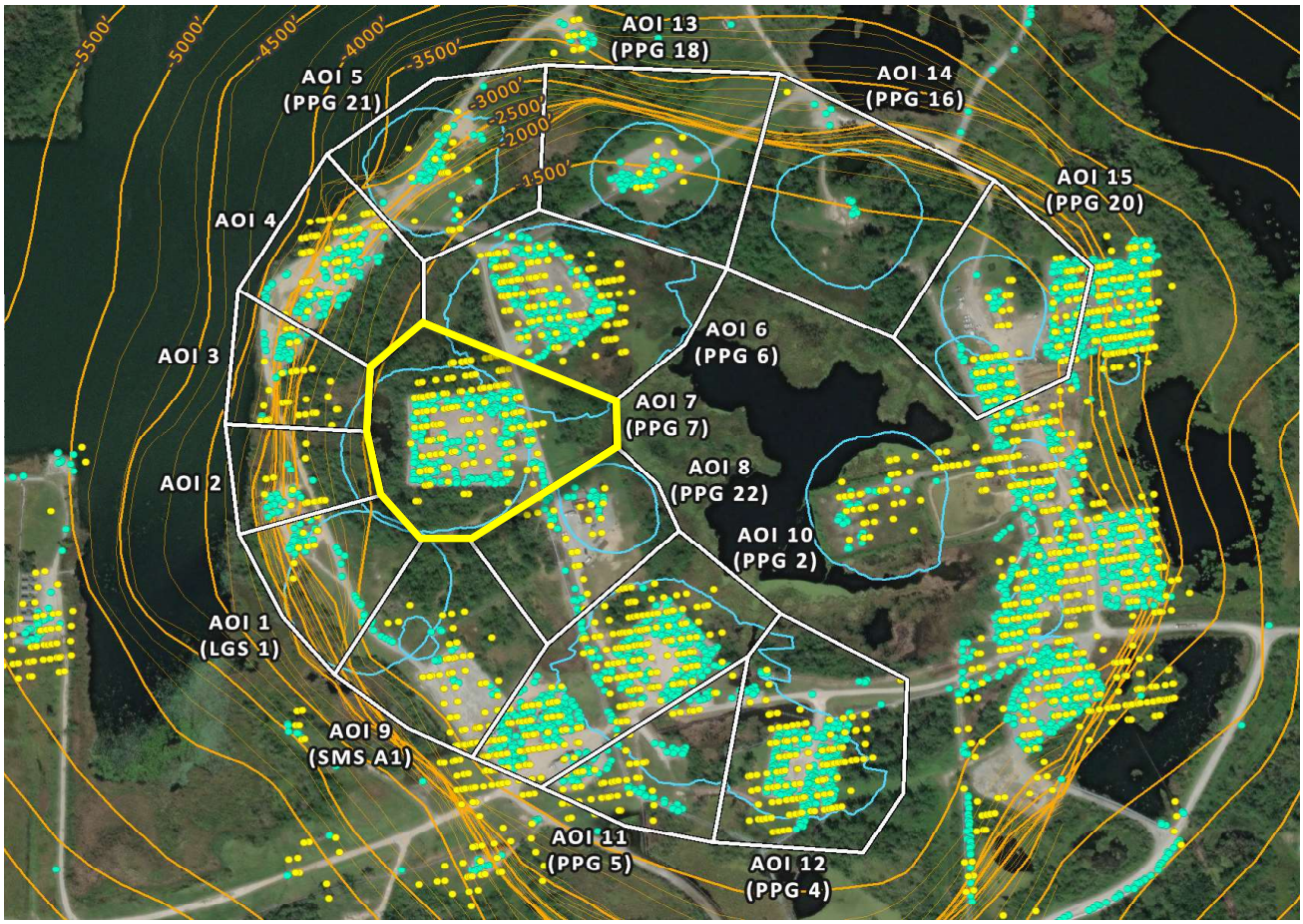
SNT (5/19/2024) Point Count: **134**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.87 in/yr	-0.91 in/yr	-0.04 in/yr
Acceleration:	+0.05 in/yr^2	-0.02 in/yr^2	-0.07 in/yr^2

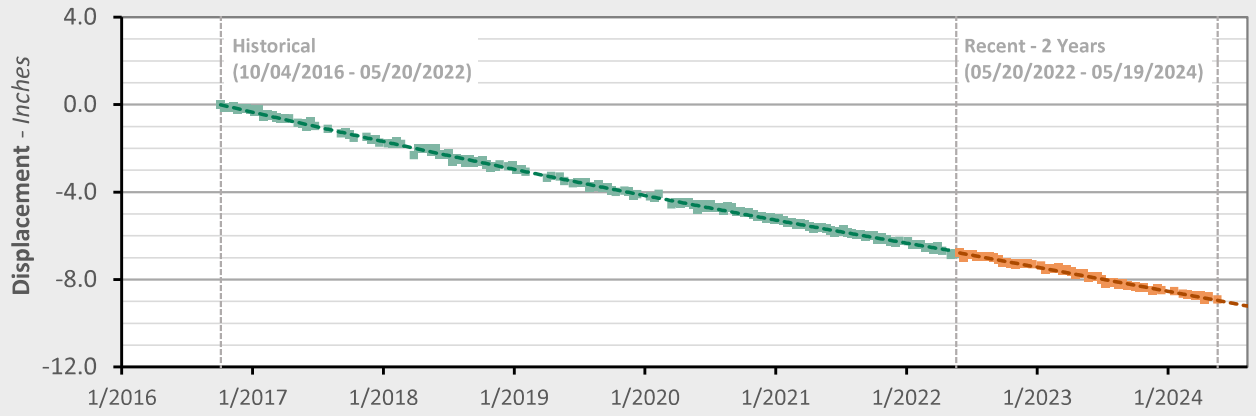
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 7 *(PPG 7)* - Location Map



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

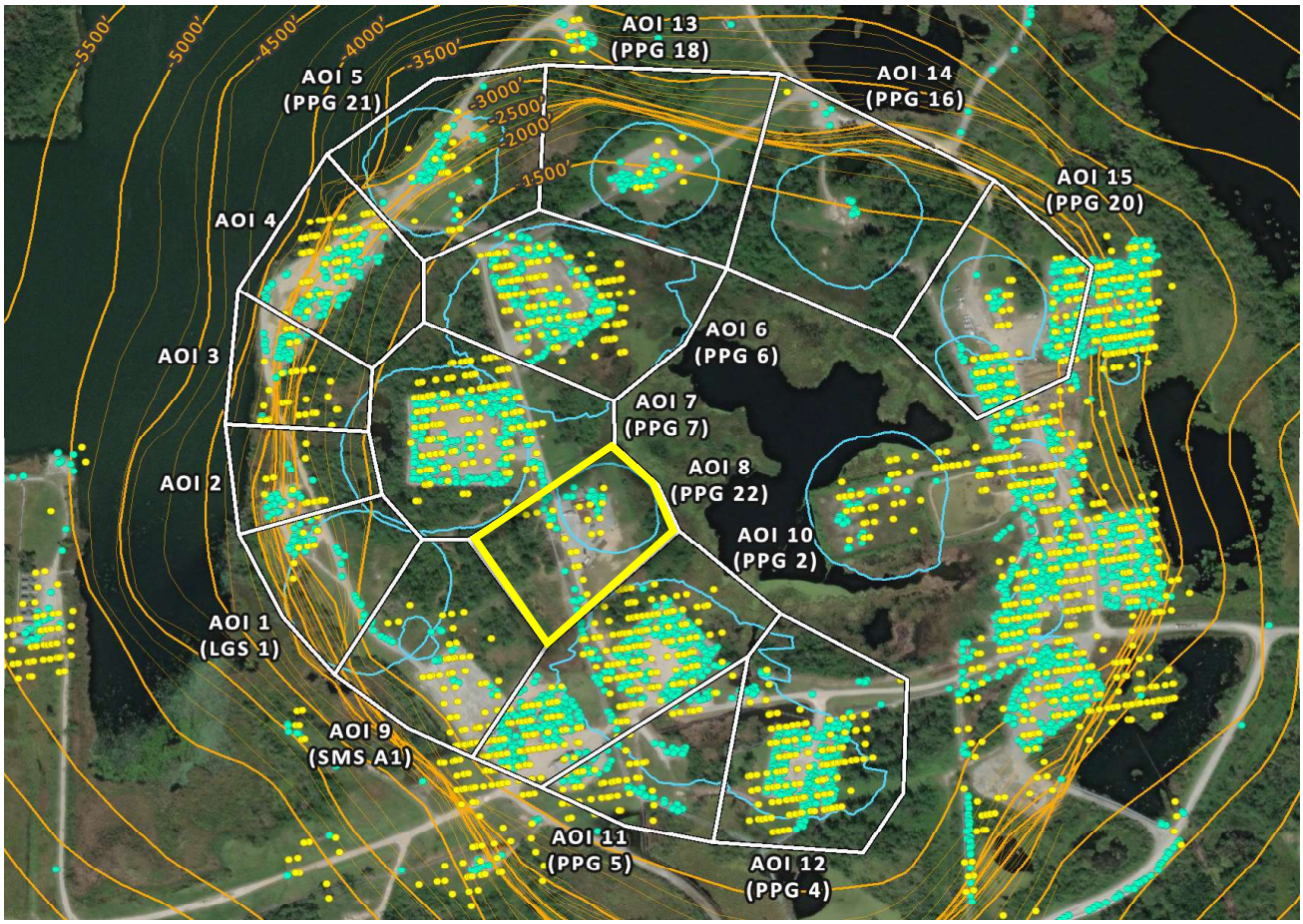
SNT (5/19/2024) Point Count: **140**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.99 in/yr	-1.11 in/yr	-0.12 in/yr
Acceleration:	+0.07 in/yr^2	-0.01 in/yr^2	-0.08 in/yr^2

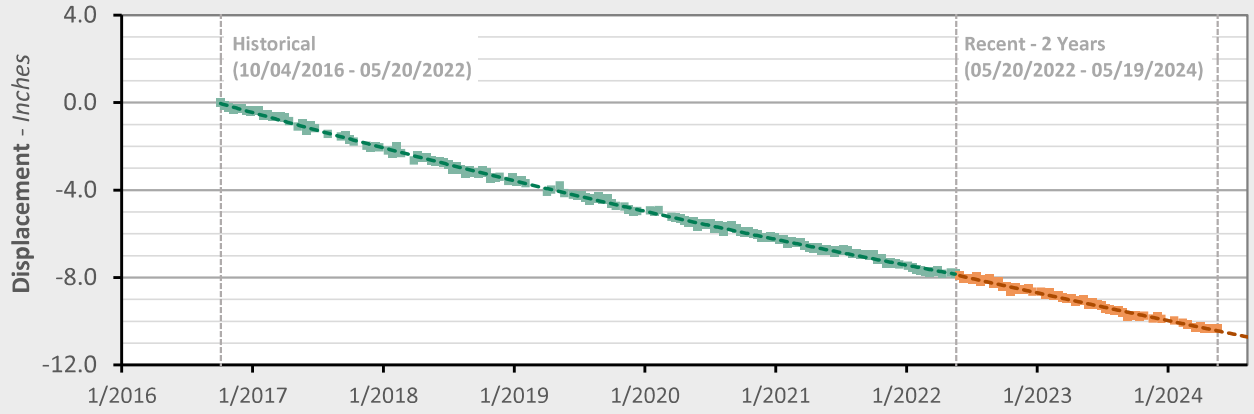
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 8 *(PPG 22)* - Location Map



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

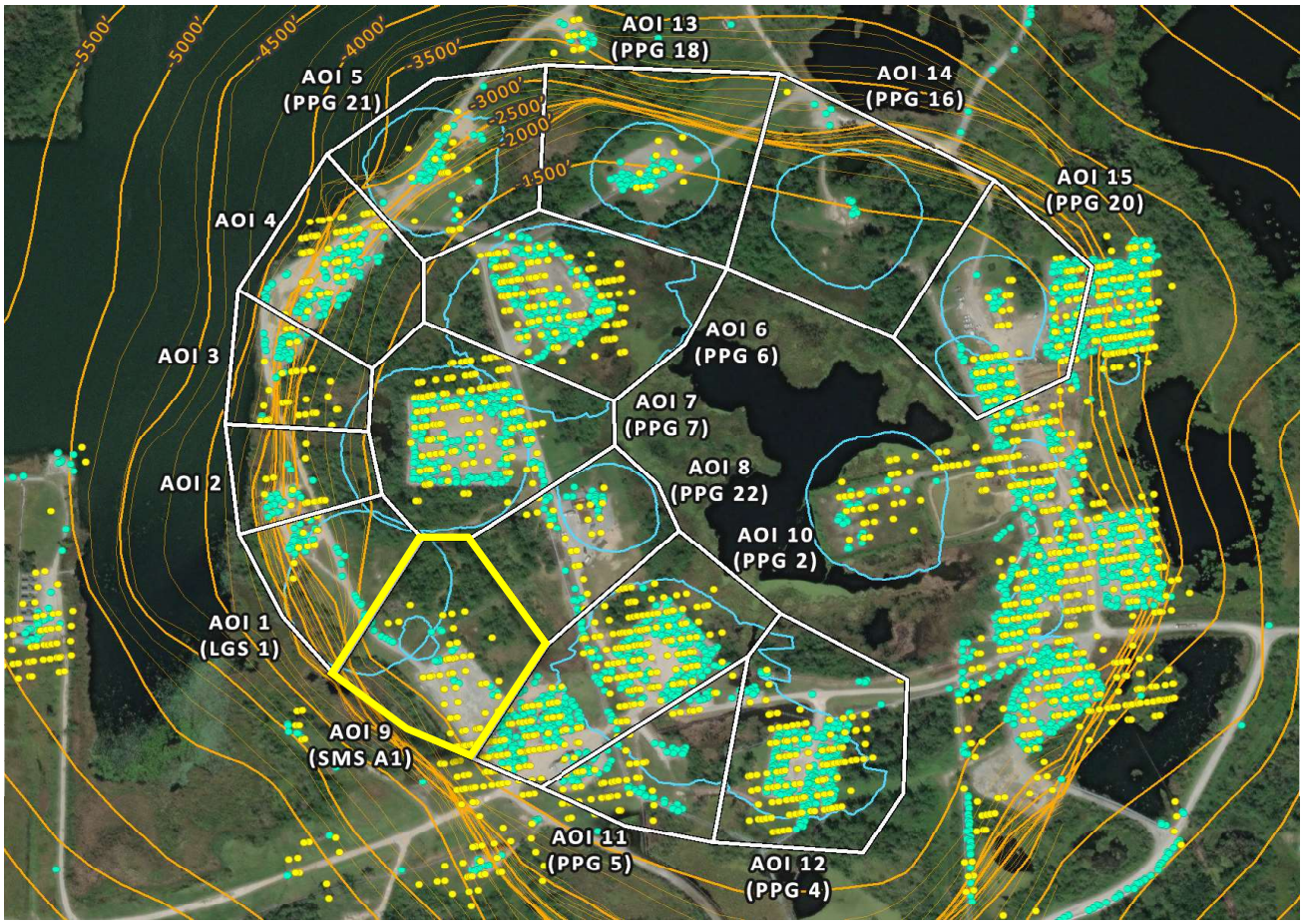
SNT (5/19/2024) Point Count: **21**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-1.08 in/yr	-1.22 in/yr	-0.14 in/yr
Acceleration:	+0.11 in/yr^2	+0.06 in/yr^2	-0.05 in/yr^2

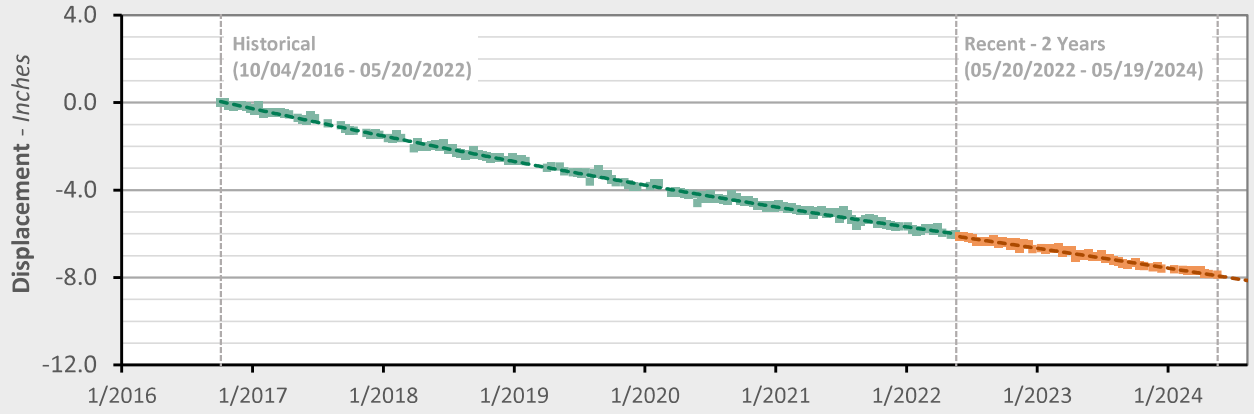
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 9 *(PPG A1)* - Location Map



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

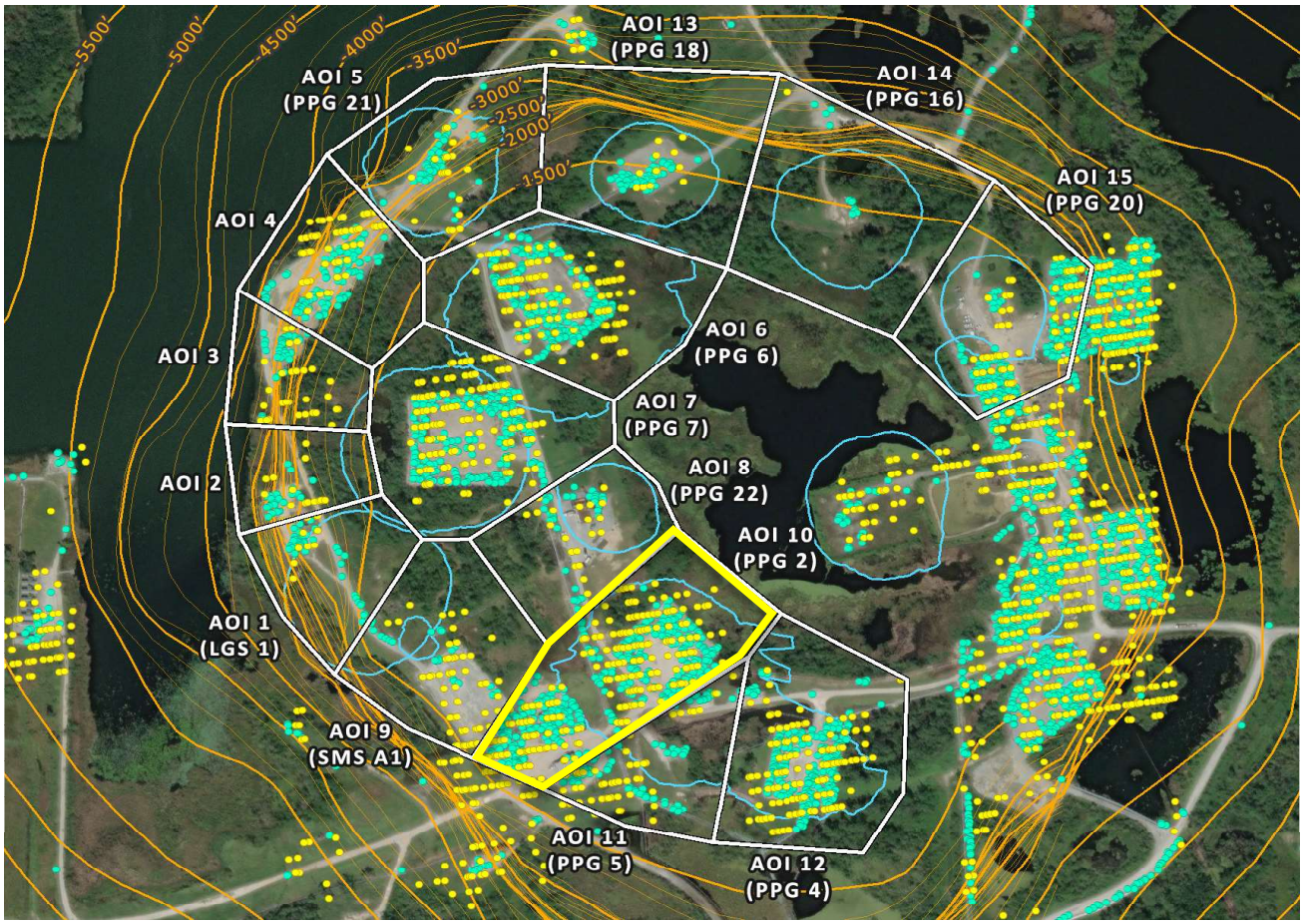
SNT (5/19/2024) Point Count: **58**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.84 in/yr	-0.93 in/yr	-0.09 in/yr
Acceleration:	+0.08 in/yr^2	-0.03 in/yr^2	-0.11 in/yr^2

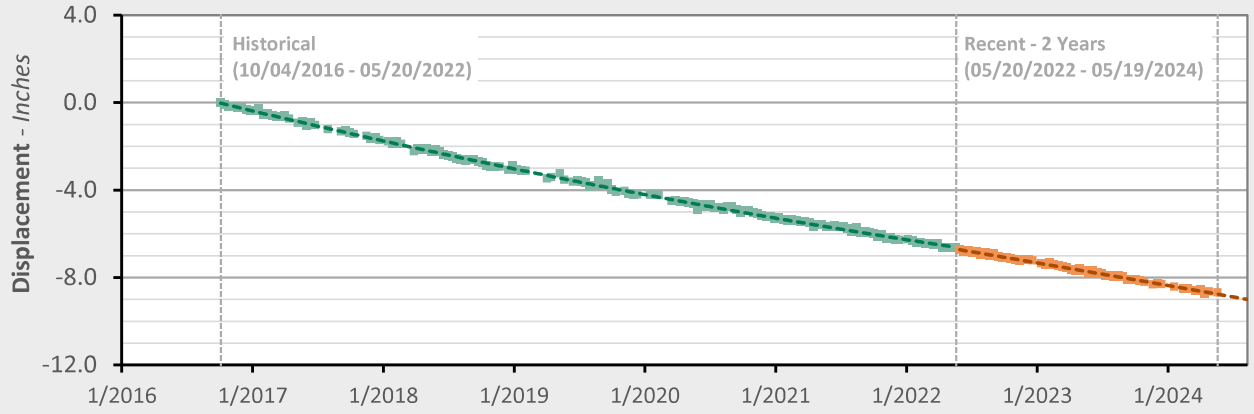
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 10 *(PPG 2)* - Location Map



AOI 10 *(PPG 2)* - Displacement Time Series

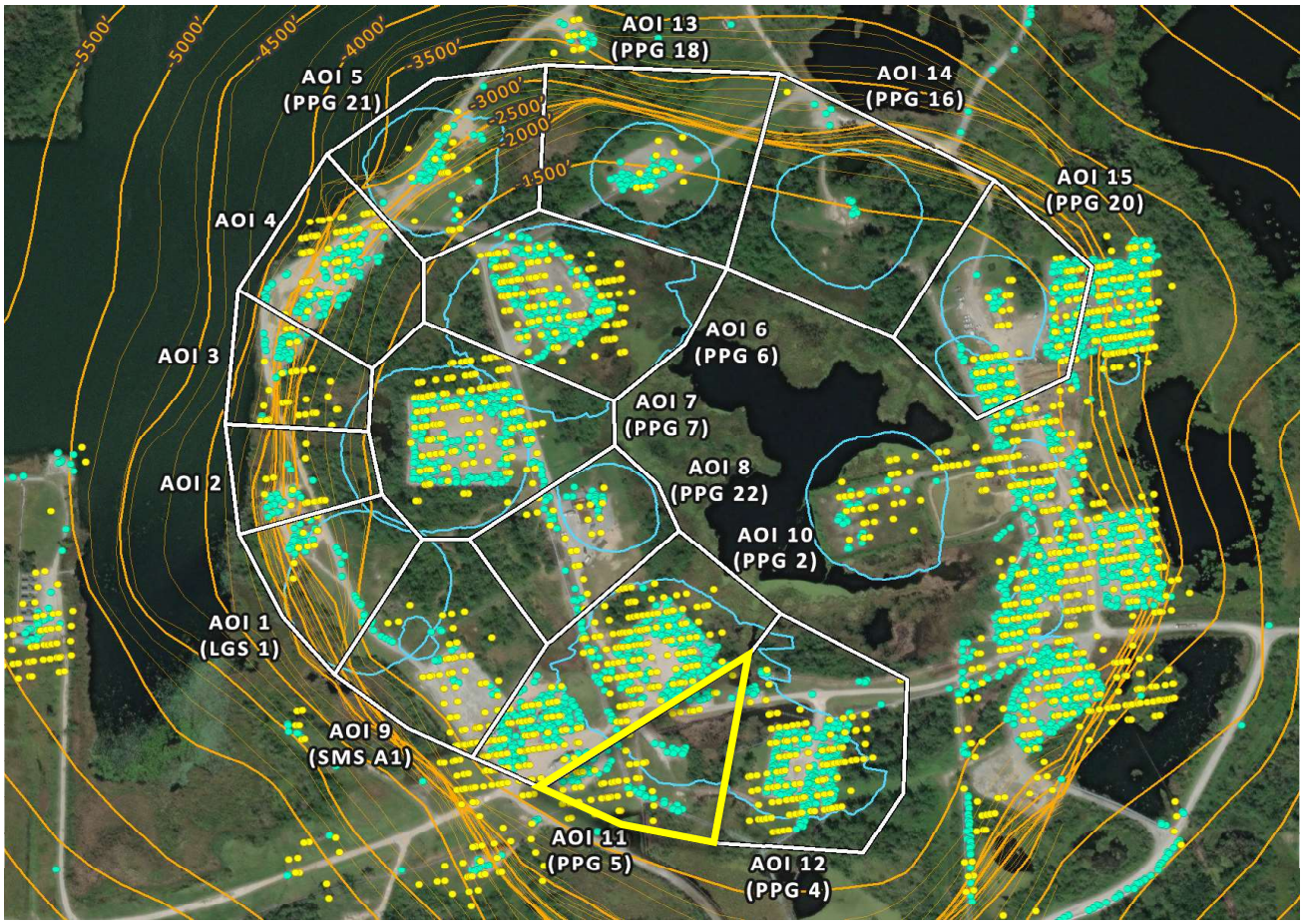
SNT (5/19/2024) Point Count: **229**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.90 in/yr	-1.05 in/yr	-0.16 in/yr
Acceleration:	+0.10 in/yr^2	-0.02 in/yr^2	-0.12 in/yr^2

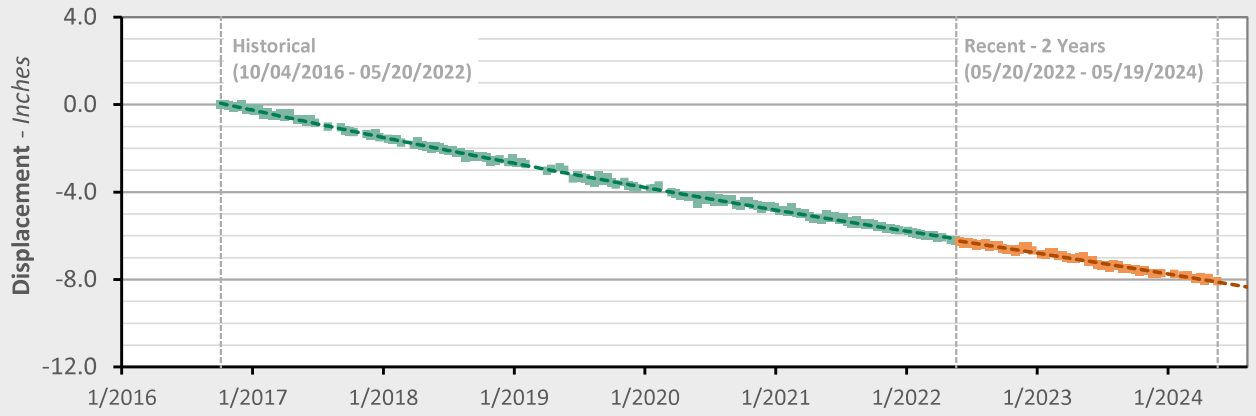
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 11 *(PPG 5)* - Location Map

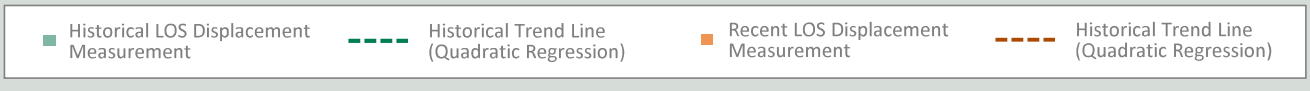


AOI 11 *(PPG 5)* - Displacement Time Series

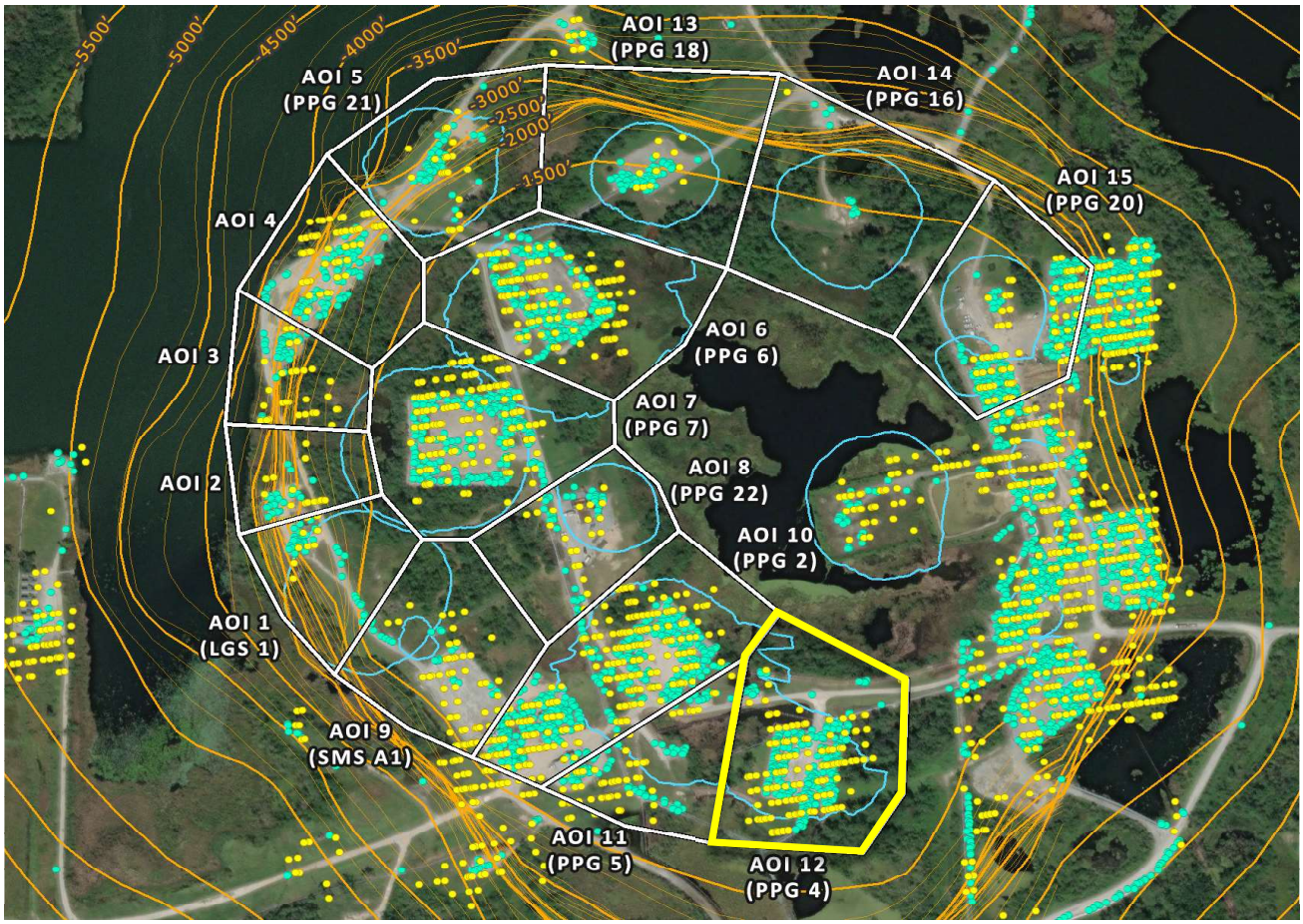
SNT (5/19/2024) Point Count: **51**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.90 in/yr	-0.98 in/yr	-0.08 in/yr
Acceleration:	+0.07 in/yr^2	-0.03 in/yr^2	-0.10 in/yr^2

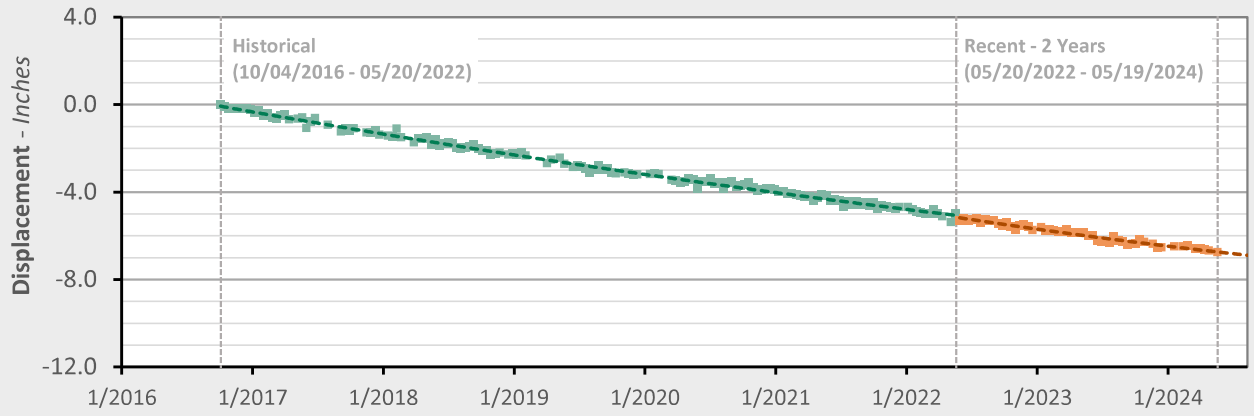


AOI 12 *(PPG 4)* - Location Map



AOI 12 *(PPG 4)* - Displacement Time Series

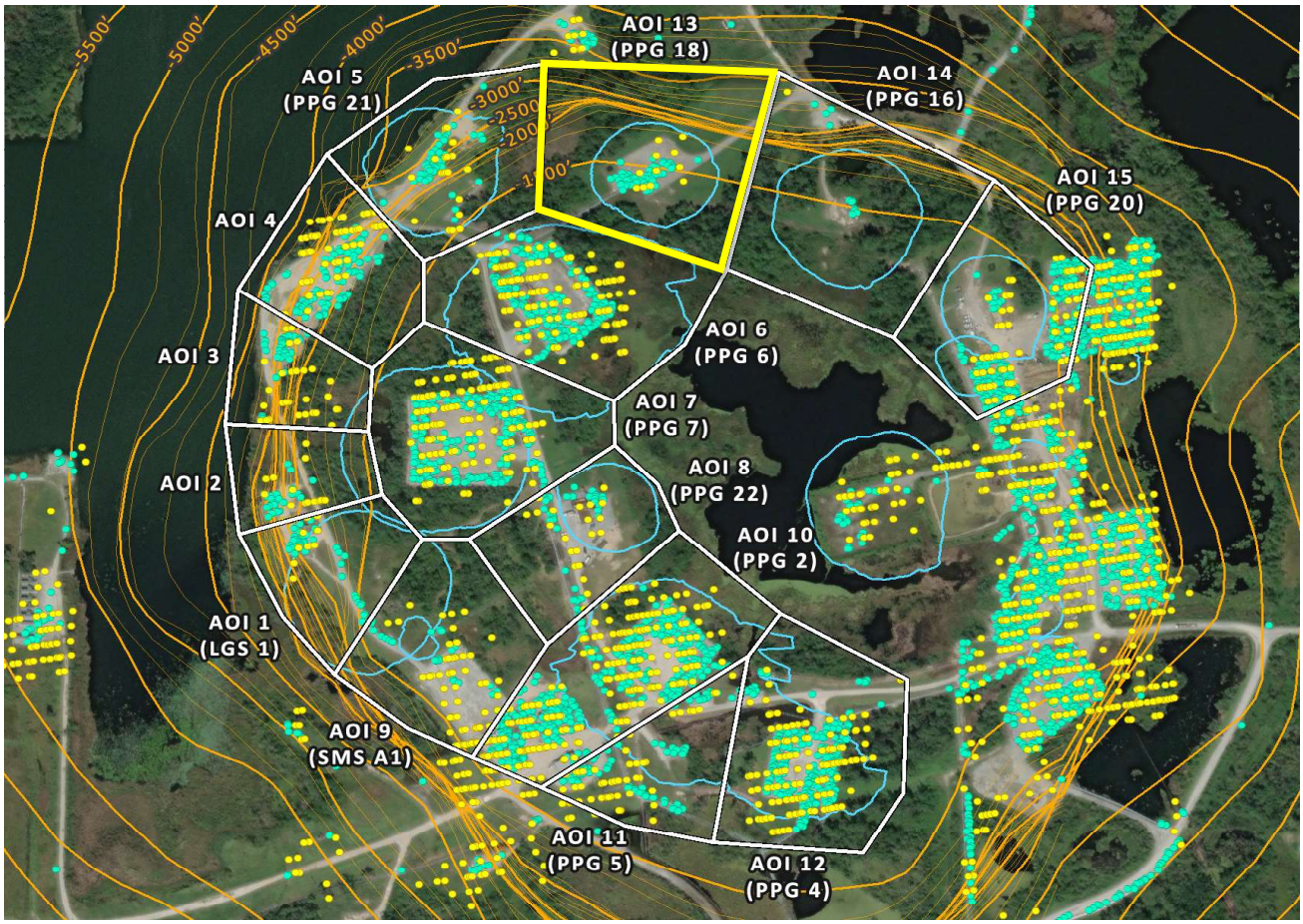
SNT (5/19/2024) Point Count: **120**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.71 in/yr	-0.64 in/yr	+0.07 in/yr
Acceleration:	+0.06 in/yr^2	+0.16 in/yr^2	+0.10 in/yr^2

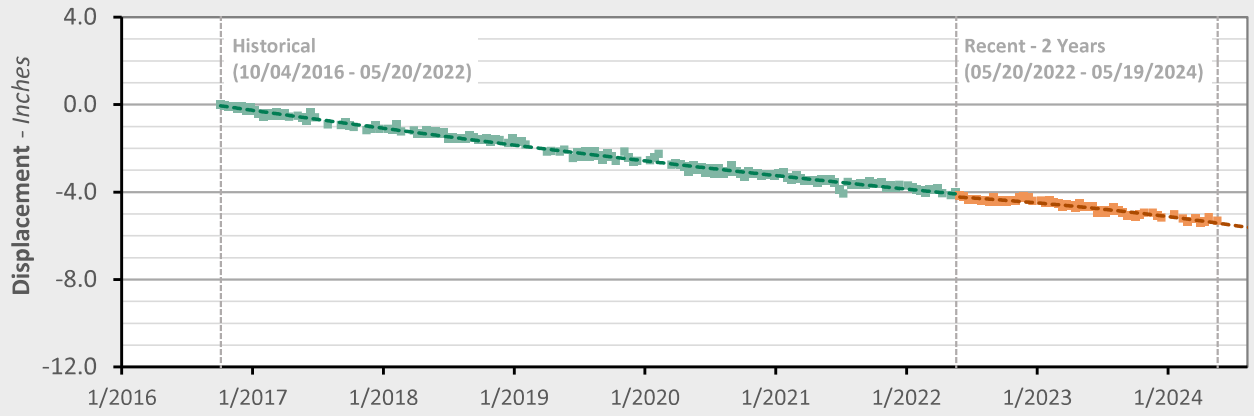
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 13 *(PPG 18)* - Location Map



AOI 13 *(PPG 18)* - Displacement Time Serie

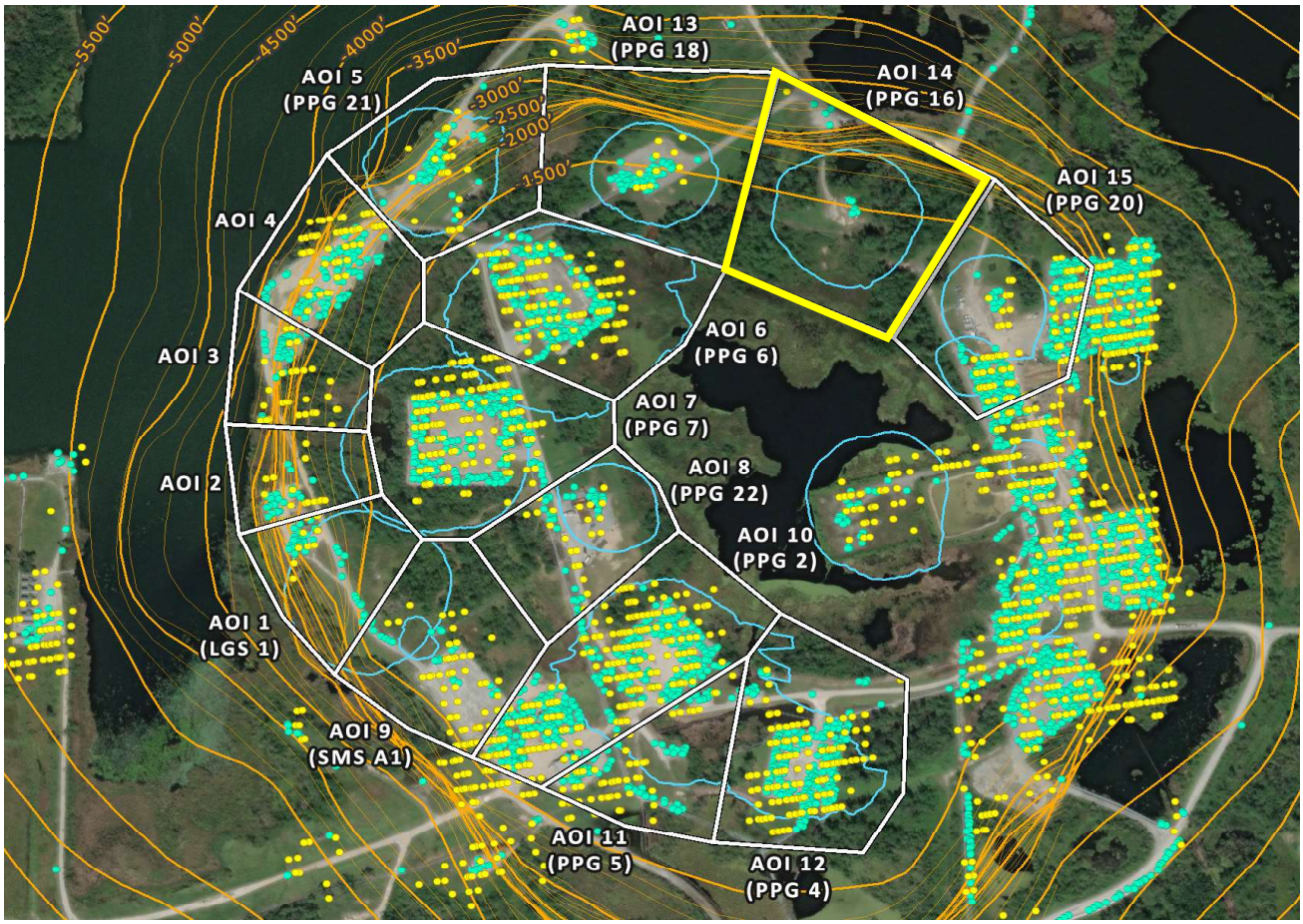
SNT (5/19/2024) Point Count: **12**



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.58 in/yr	-0.85 in/yr	-0.27 in/yr
Acceleration:	+0.05 in/yr^2	-0.25 in/yr^2	-0.30 in/yr^2

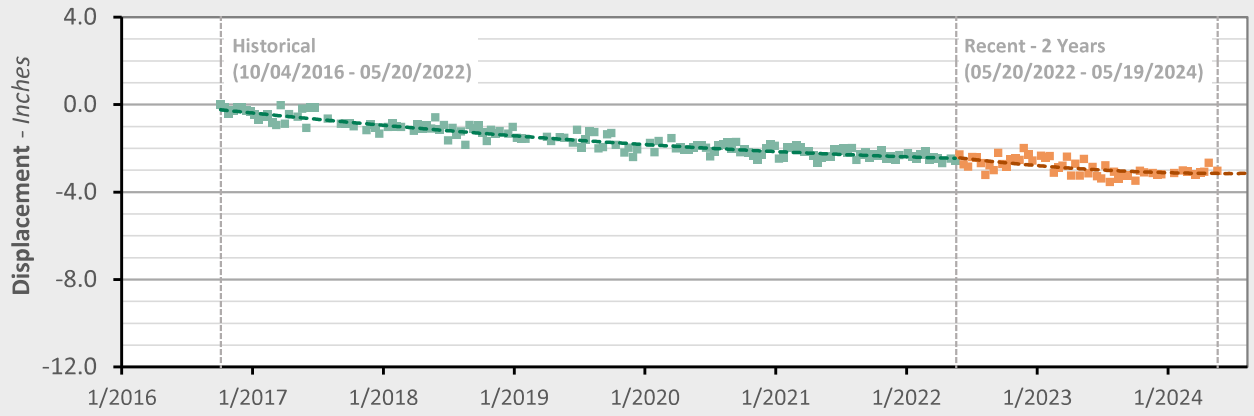
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 14 *(PPG 16)* - Location Map



AOI 14 *(PPG 16)* - Displacement Time Serie

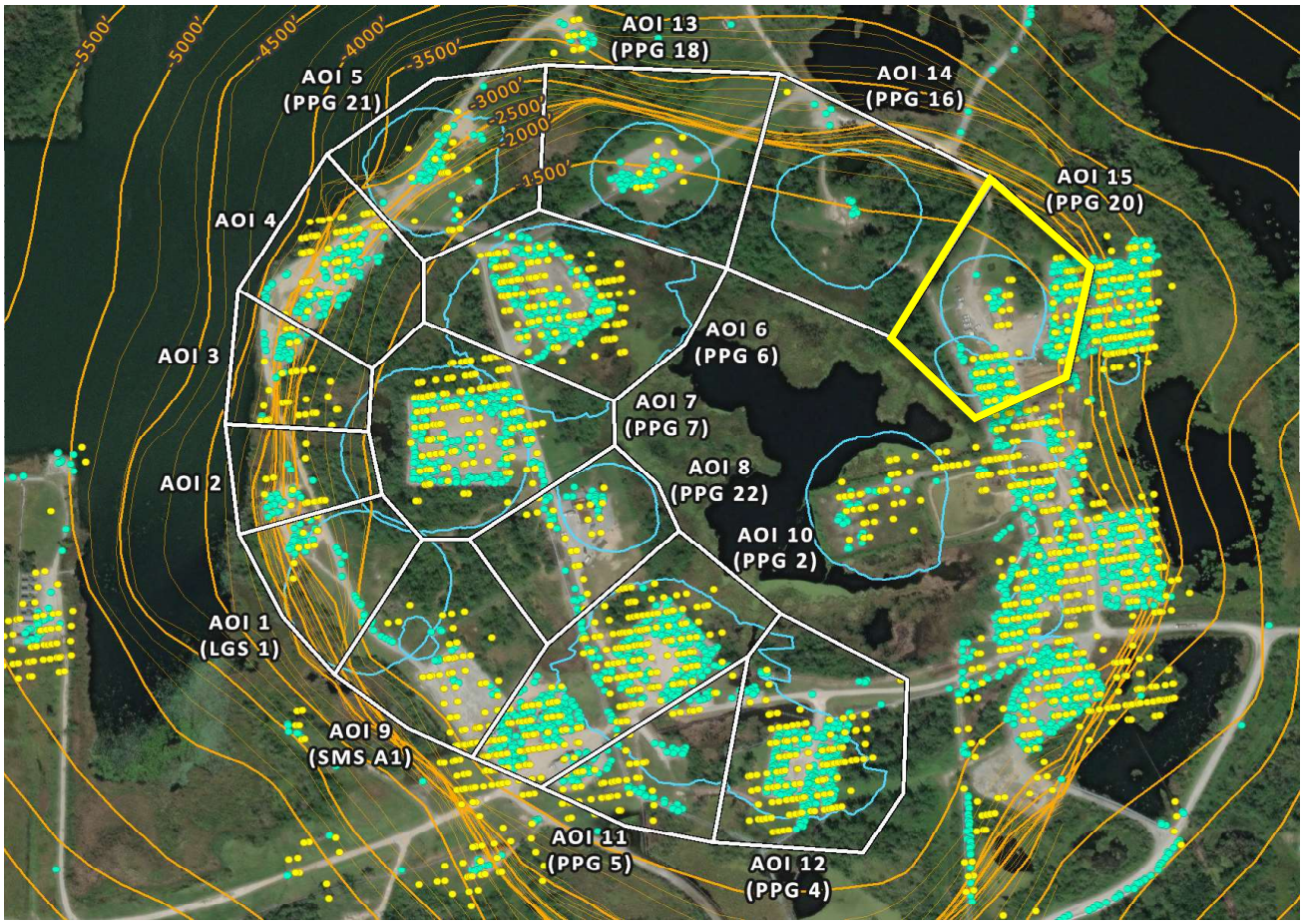
SNT (5/19/2024) Point Count: 1



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.17 in/yr	-0.06 in/yr	+0.11 in/yr
Acceleration:	+0.08 in/yr^2	+0.29 in/yr^2	+0.21 in/yr^2

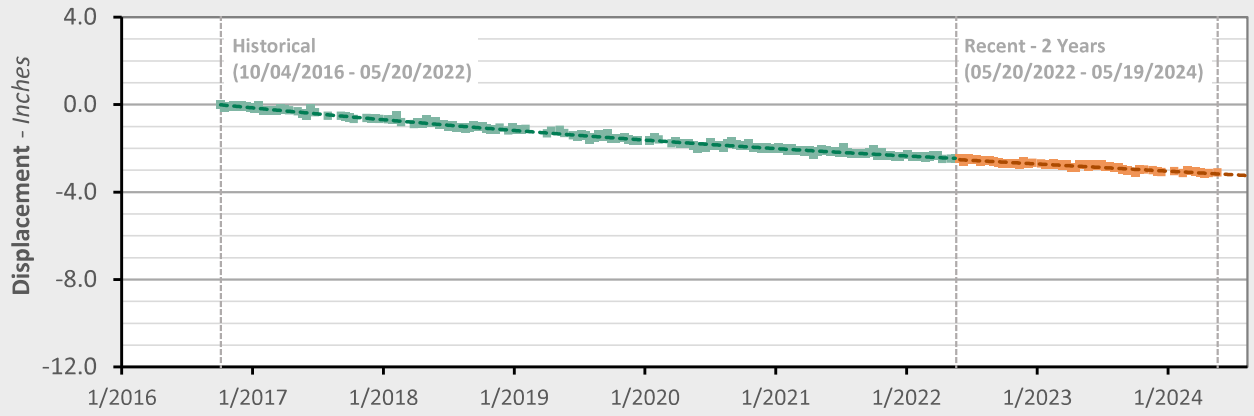
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

AOI 15 *(PPG 20)* - Location Map



AOI 15 *(PPG 20)* - Displacement Time Serie

SNT (5/19/2024) Point Count: **73**



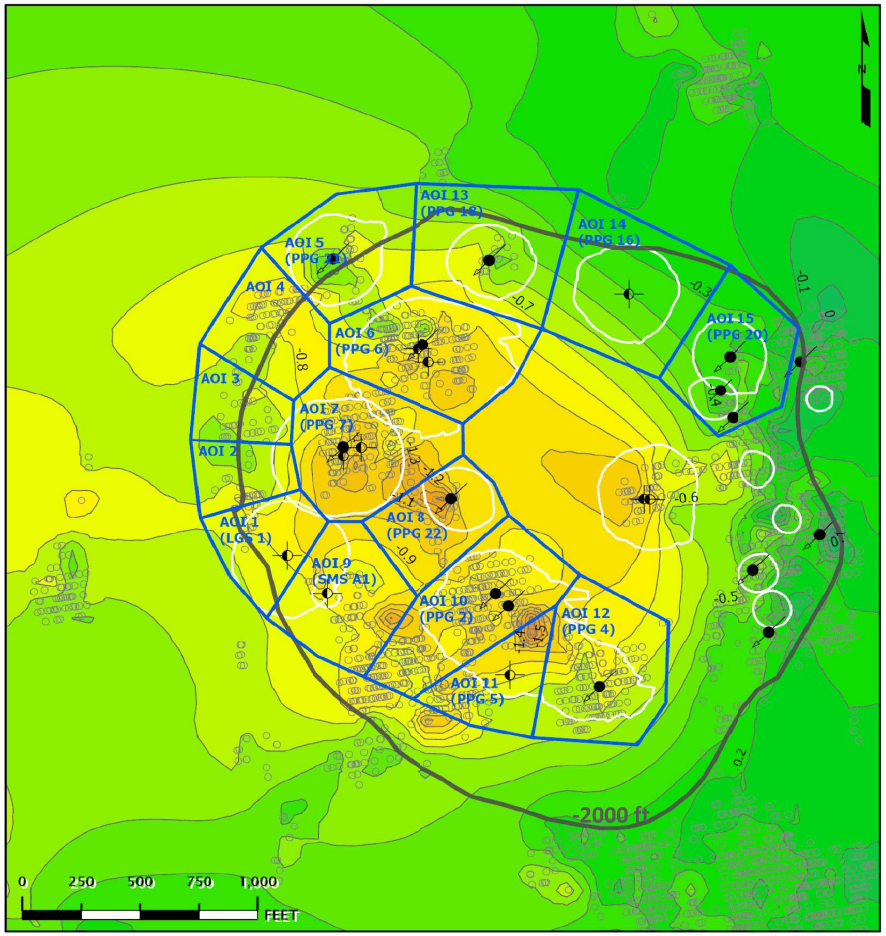
	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.29 in/yr	-0.33 in/yr	-0.04 in/yr
Acceleration:	+0.05 in/yr^2	-0.01 in/yr^2	-0.06 in/yr^2

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

Historical SNT Data (10/04/2016 - 05/20/2022)

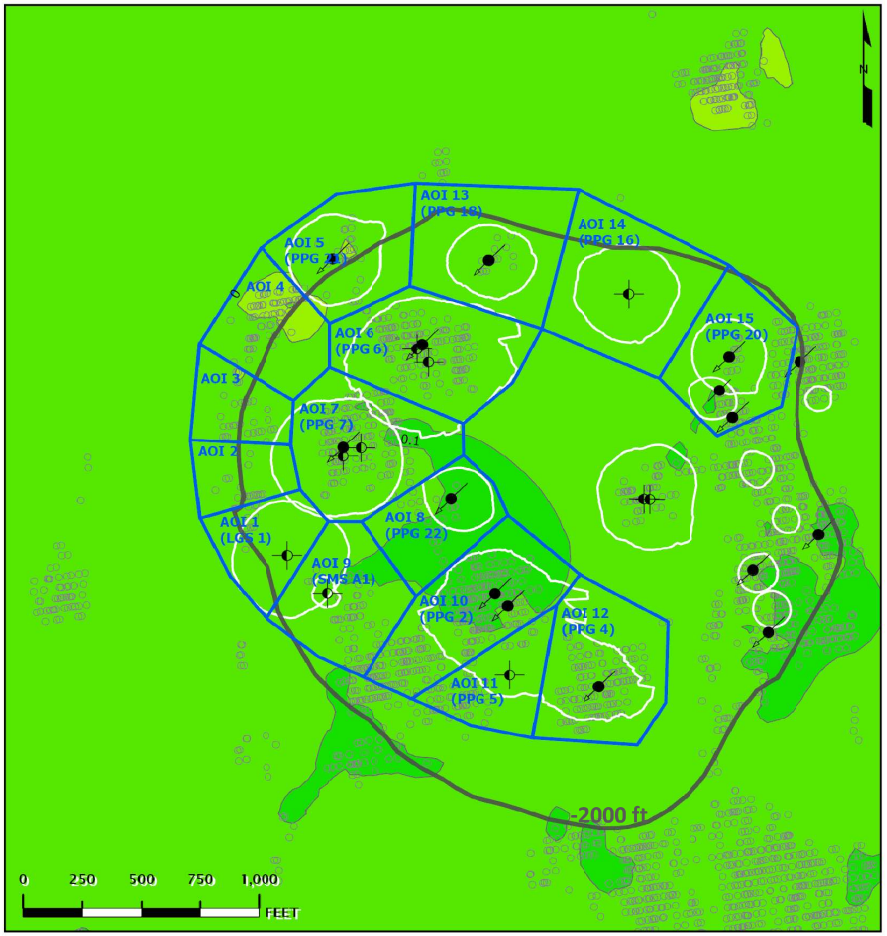
Velocity Contours

As of date: 05/20/2022



Acceleration Contours

Date range: 10/04/2016 - 05/20/2022



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

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

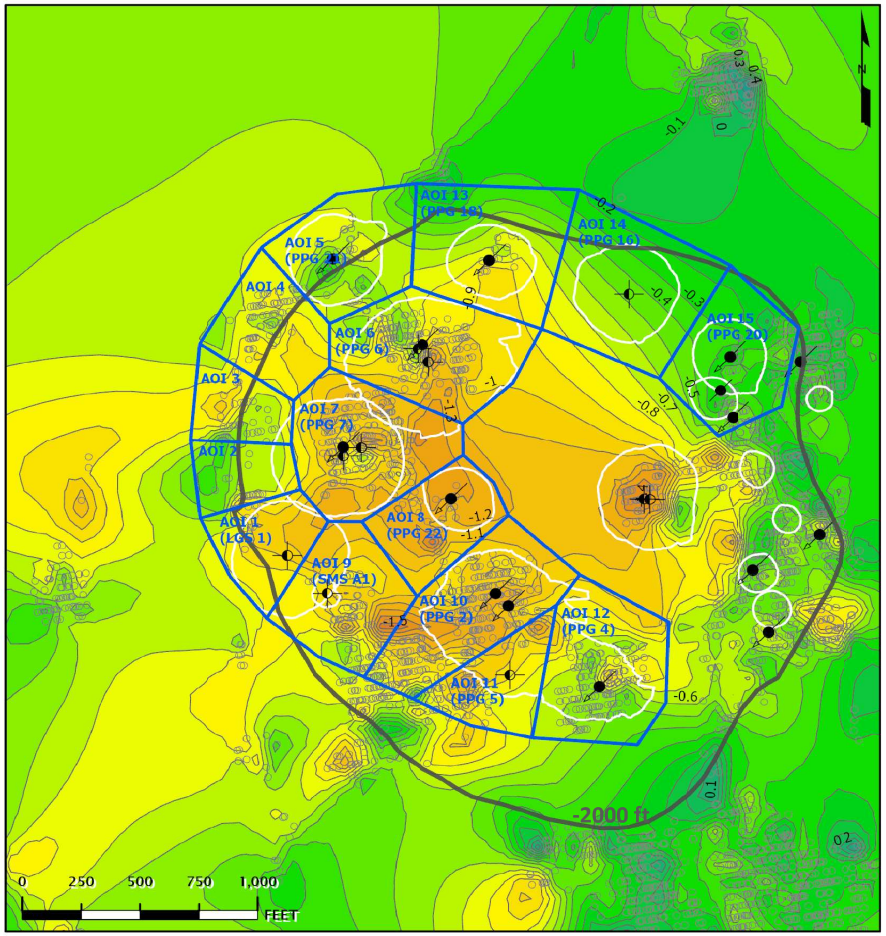
AOI Boundary | InSAR LOS Measurement Point | Contour (0.1) | Cavern Well Surface Locations

Historical Cavern Extent | Top of Dome (-2000 ft Contour) | 09 - Active - Injection | 29 - Dry and Plugged

Recent SNT Data - 2 Years (05/20/2022 - 05/19/2024)

Velocity Contours

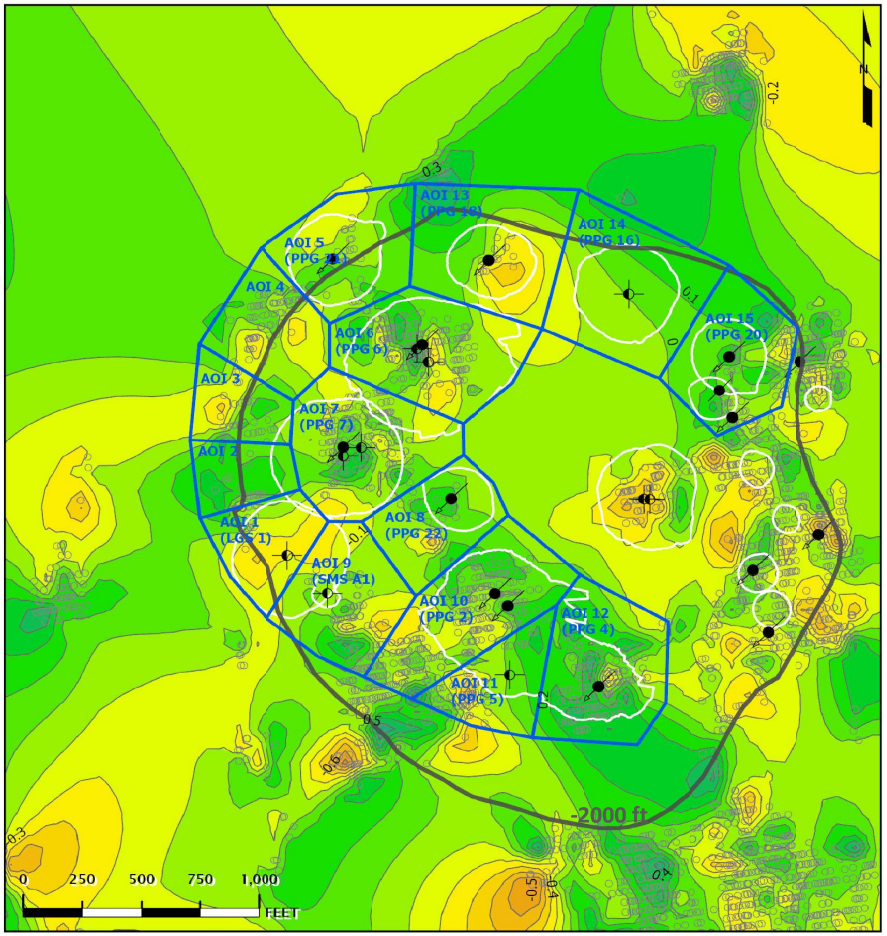
As of date: 05/19/2024



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

Acceleration Contours

Date range: 05/20/2022 - 05/19/2024



-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 (-2000 ft Contour) | 09 - Active - Injection | 29 - Dry and Plugged

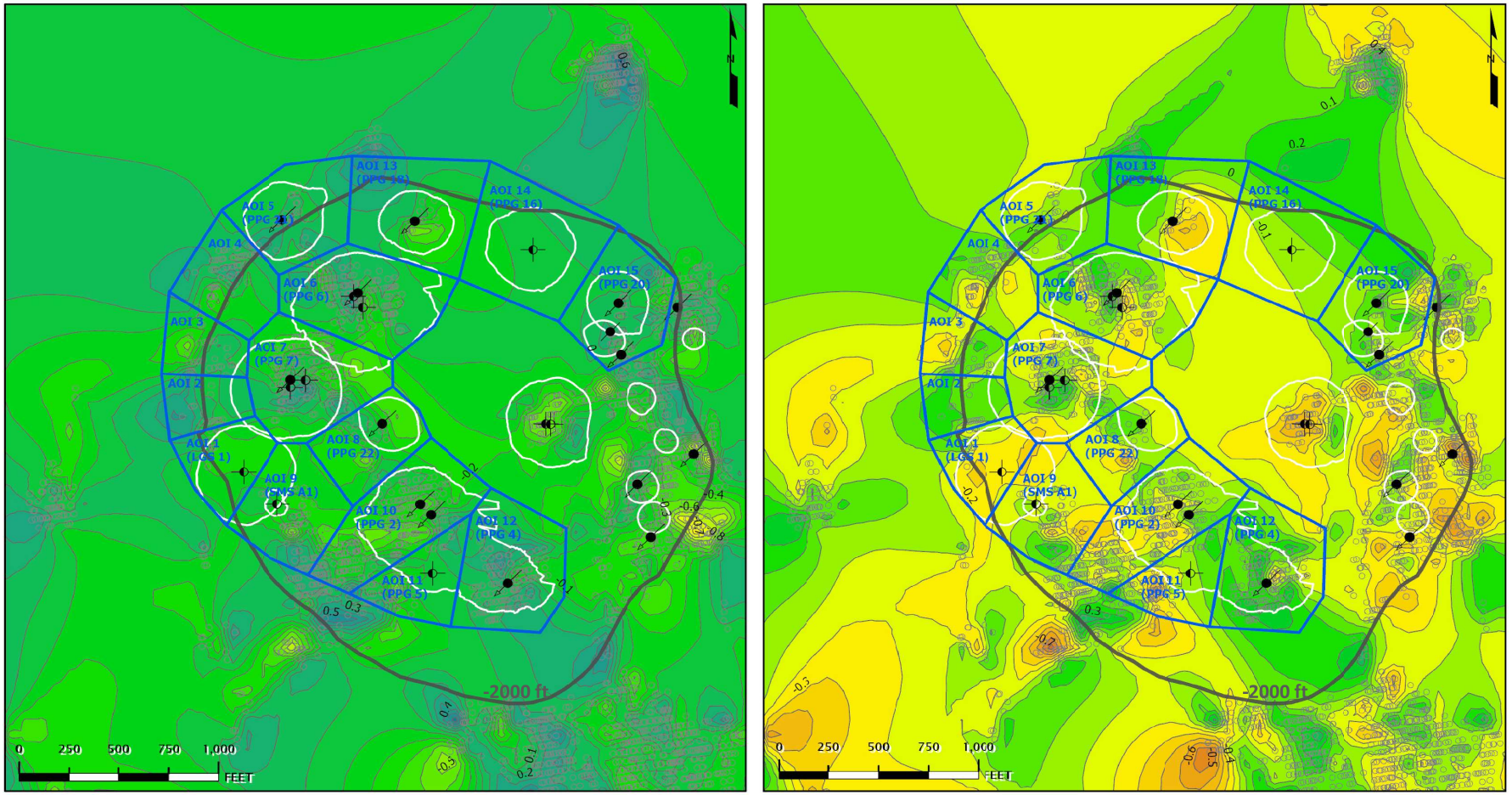
Change from Historical to Recent SNT Data

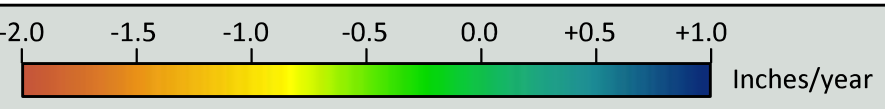
Velocity Contours

Historical Velocity subtracted from Recent Velocity

Acceleration Contours

Historical Acceleration subtracted from Recent Acceleration





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

Historical Cavern Extent | Top of Dome (-2000 ft Contour) | 09 - Active - Injection | 29 - Dry and Plugged