

Westlake US 2
Received 6/17/2024

SNT Satellite Update
InSAR Subsidence
June 12, 2024

Lonquist comment:

The SNT satellite (12-day revisit) passed by Sulphur on Wednesday June 12. We received the dataset Friday 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.



Submitted by: Nathaniel Byars (Lonquist)

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
Wednesday, June 12, 2024

Analysis Report Date:
June 17, 2024

Dataset Information

Satellite Source	Sentinel-1 (SNT)
Revisit Frequency	12 days
Most Recent Image Date	Wednesday, June 12, 2024
Dataset Image Count	203
Dataset Time Range	October 4, 2016 - June 12, 2024
Dataset Length	7.69 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 2 of the 15 AOI point groups. This suggests that marginal increases in subsidence rates may be occurring in these areas in recent years with the greatest velocity increases (in descending order) occurring in AOI 13 (PPG 18) and AOI 8 (PPG 22).

The mapped contours of the change in recent vs. historical subsidence velocity and acceleration mostly display minor fluctuations around 0, intermittently distributed within the AOIs. This observation suggests that statistically relevant areas of change are not currently evident within the rate change maps.



Date Signed: June 17, 2024
Austin, Texas

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) displacement 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 descending orbit denotes the satellite is moving from north to south.

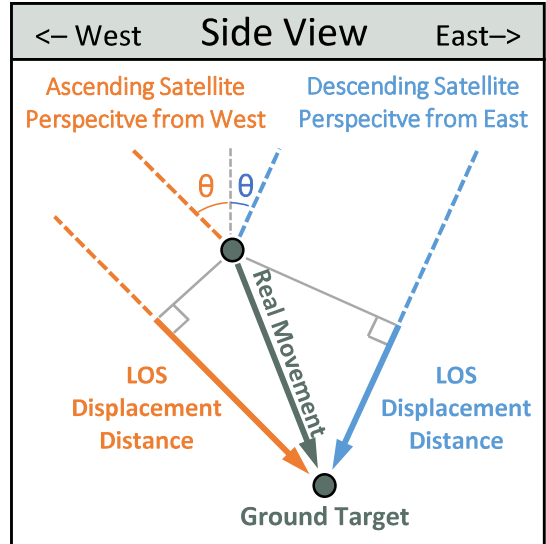
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a pair of high resolution satellites that share the same descending orbit and capture data from east of the site. These 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

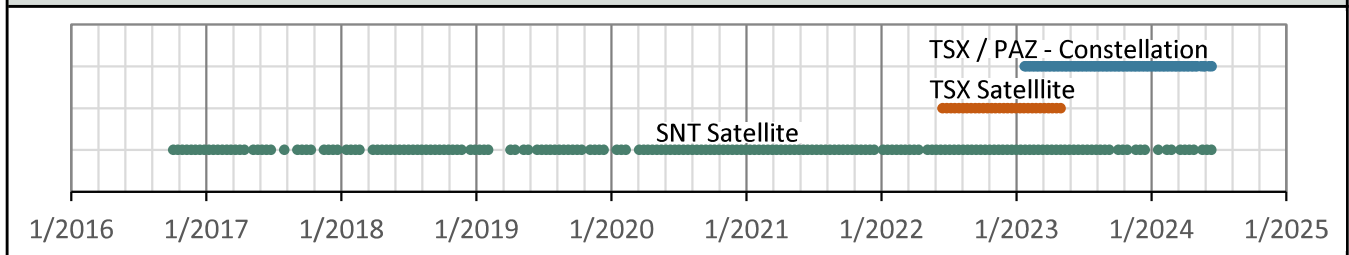
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR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



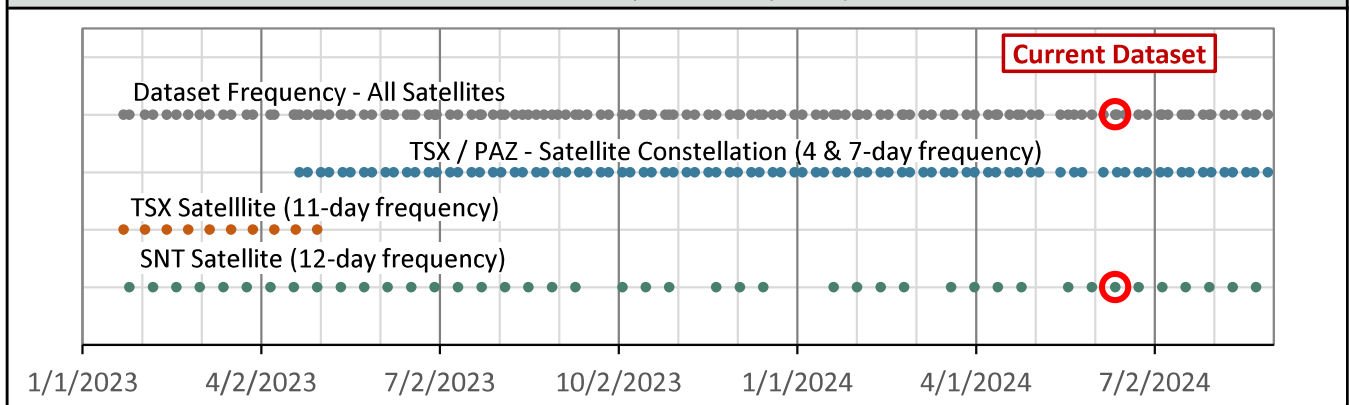
Satellite Properties & Image Frequency

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

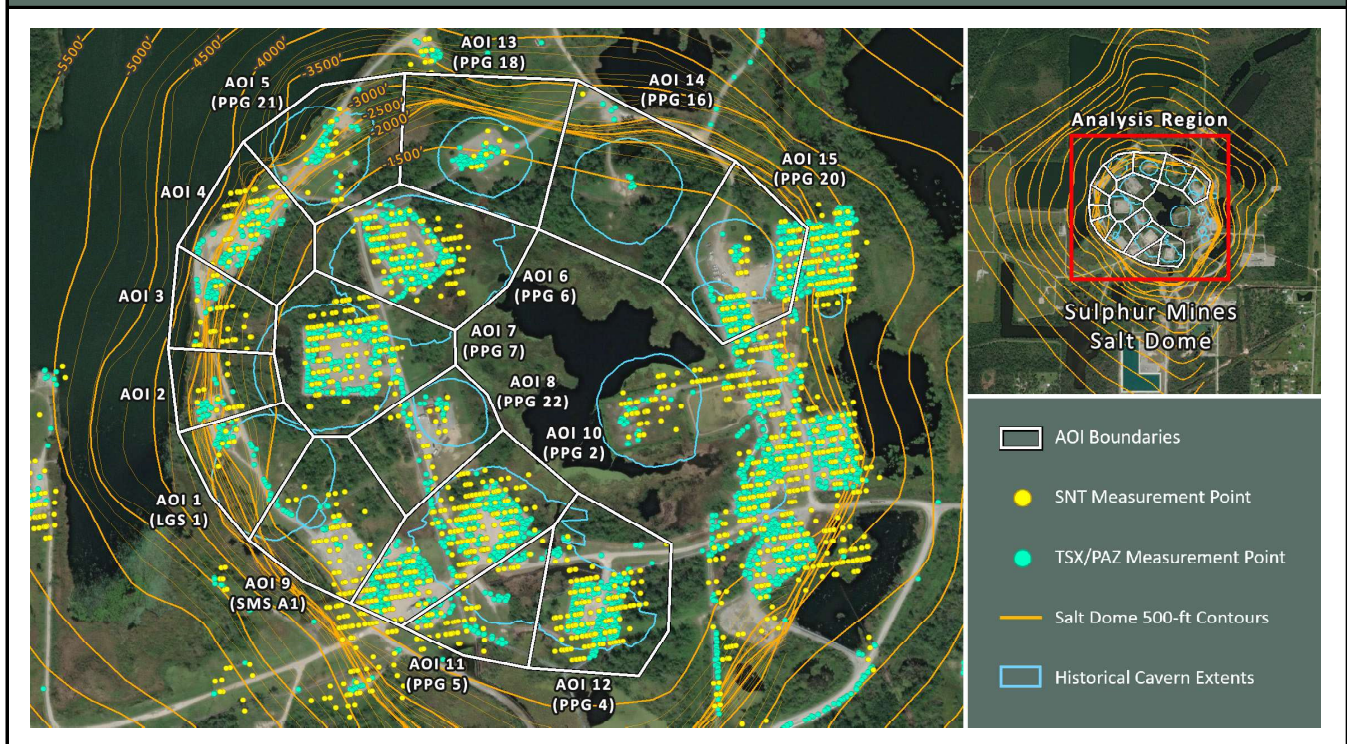
Dataset Measurement History



Dataset Update Frequency



AOI Boundaries & InSAR Measurement Points

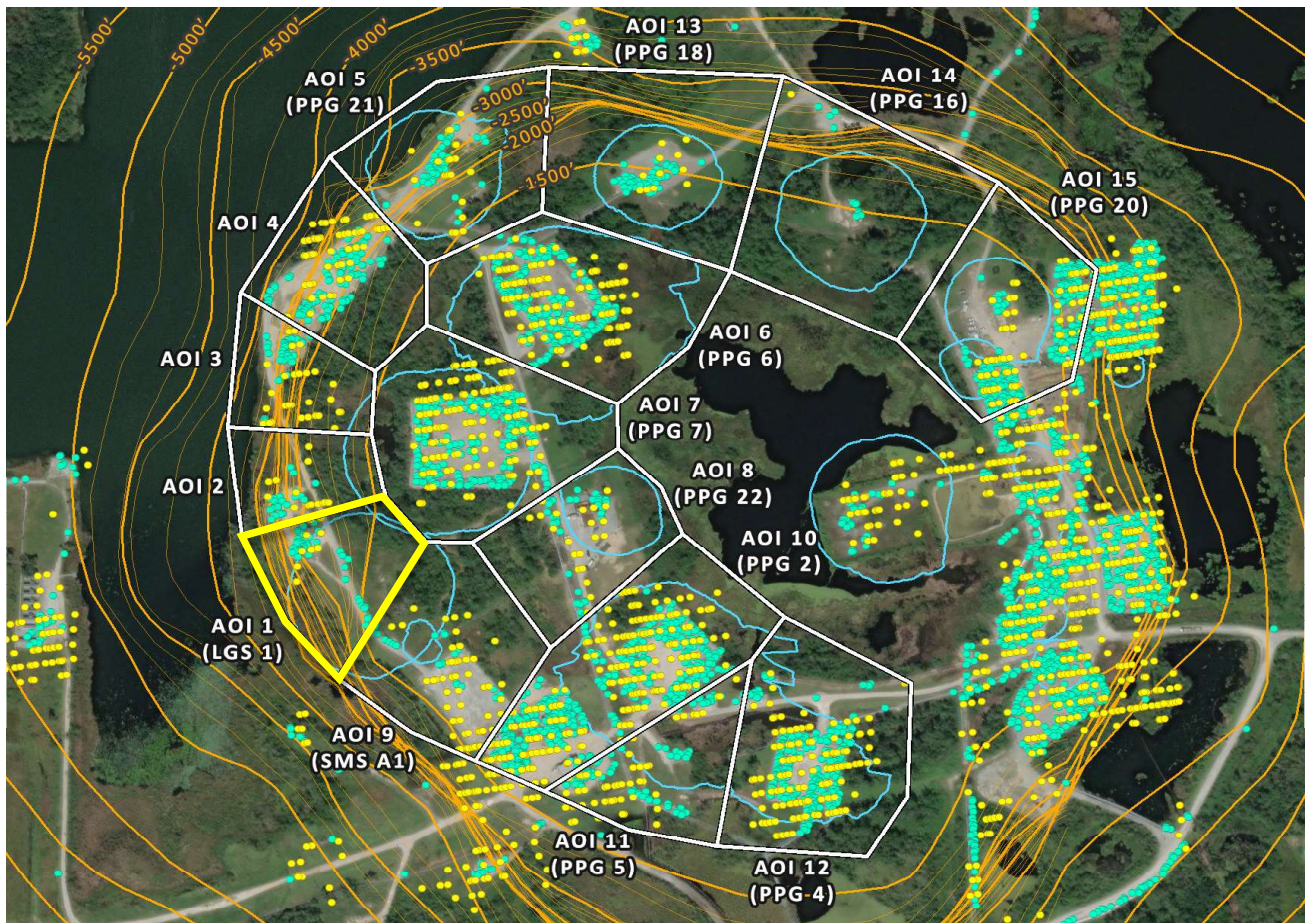


Subsidence Monitoring Areas of Interest (AOIs)

To visually convey and evaluate trend consistency for the displacement time series of each ground target, measurement 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.

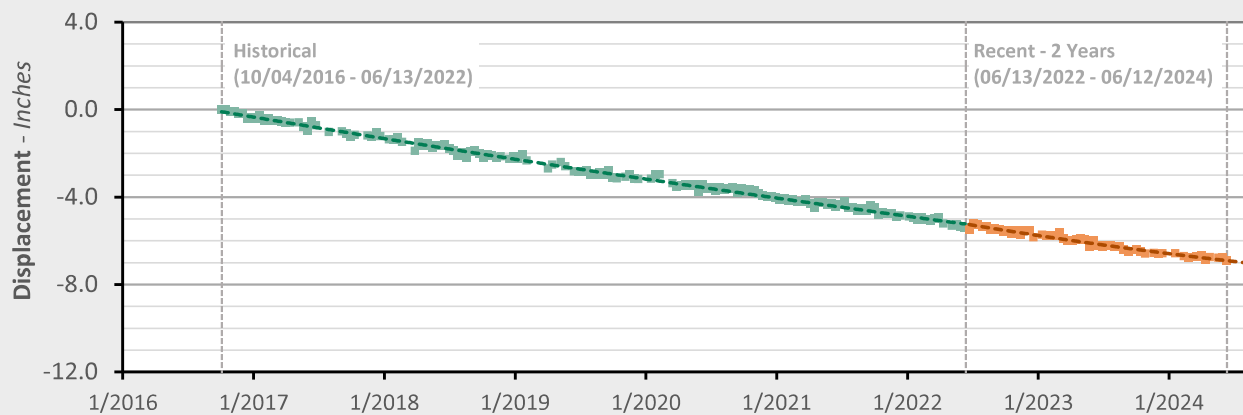
AOI Name	SNT (6/12/2024)	LOS Velocity (<i>in/yr</i>)			LOS Acceleration (<i>in/yr</i> ²)		
	Point Count	Historical	Recent	Change	Historical	Recent	Change
AOI 1 (<i>LGS 1</i>)	13	-0.79	-0.64	+0.16	+0.04	+0.22	+0.18
AOI 2	15	-0.73	-0.72	+0.02	+0.07	+0.14	+0.06
AOI 3	29	-0.67	-0.64	+0.03	+0.03	+0.06	+0.03
AOI 4	61	-0.77	-0.70	+0.07	+0.00	+0.00	-0.00
AOI 5 (<i>PPG 21</i>)	26	-0.69	-0.55	+0.13	+0.01	+0.04	+0.03
AOI 6 (<i>PPG 6</i>)	134	-0.87	-0.82	+0.05	+0.05	+0.05	-0.01
AOI 7 (<i>PPG 7</i>)	140	-1.00	-1.01	-0.01	+0.07	+0.08	+0.01
AOI 8 (<i>PPG 22</i>)	20	-1.07	-1.16	-0.09	+0.11	+0.12	+0.02
AOI 9 (<i>SMS A1</i>)	59	-0.85	-0.84	+0.01	+0.08	+0.04	-0.04
AOI 10 (<i>PPG 2</i>)	230	-0.90	-0.97	-0.07	+0.09	+0.04	-0.06
AOI 11 (<i>PPG 5</i>)	52	-0.91	-0.91	+0.00	+0.07	+0.03	-0.04
AOI 12 (<i>PPG 4</i>)	121	-0.73	-0.61	+0.11	+0.06	+0.18	+0.12
AOI 13 (<i>PPG 18</i>)	12	-0.58	-0.71	-0.13	+0.05	-0.13	-0.18
AOI 14 (<i>PPG 16</i>)	1	-0.17	+0.26	+0.43	+0.08	+0.57	+0.49
AOI 15 (<i>PPG 20</i>)	72	-0.30	-0.25	+0.05	+0.05	+0.05	+0.01

AOI 1 (LGS 1) - Location Map



AOI 1 (LGS 1) - Displacement Time Series

SNT (6/12/2024) Point Count: 13



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.79 in/yr	-0.64 in/yr	+0.16 in/yr
Acceleration:	+0.04 in/yr ²	+0.22 in/yr ²	+0.18 in/yr ²

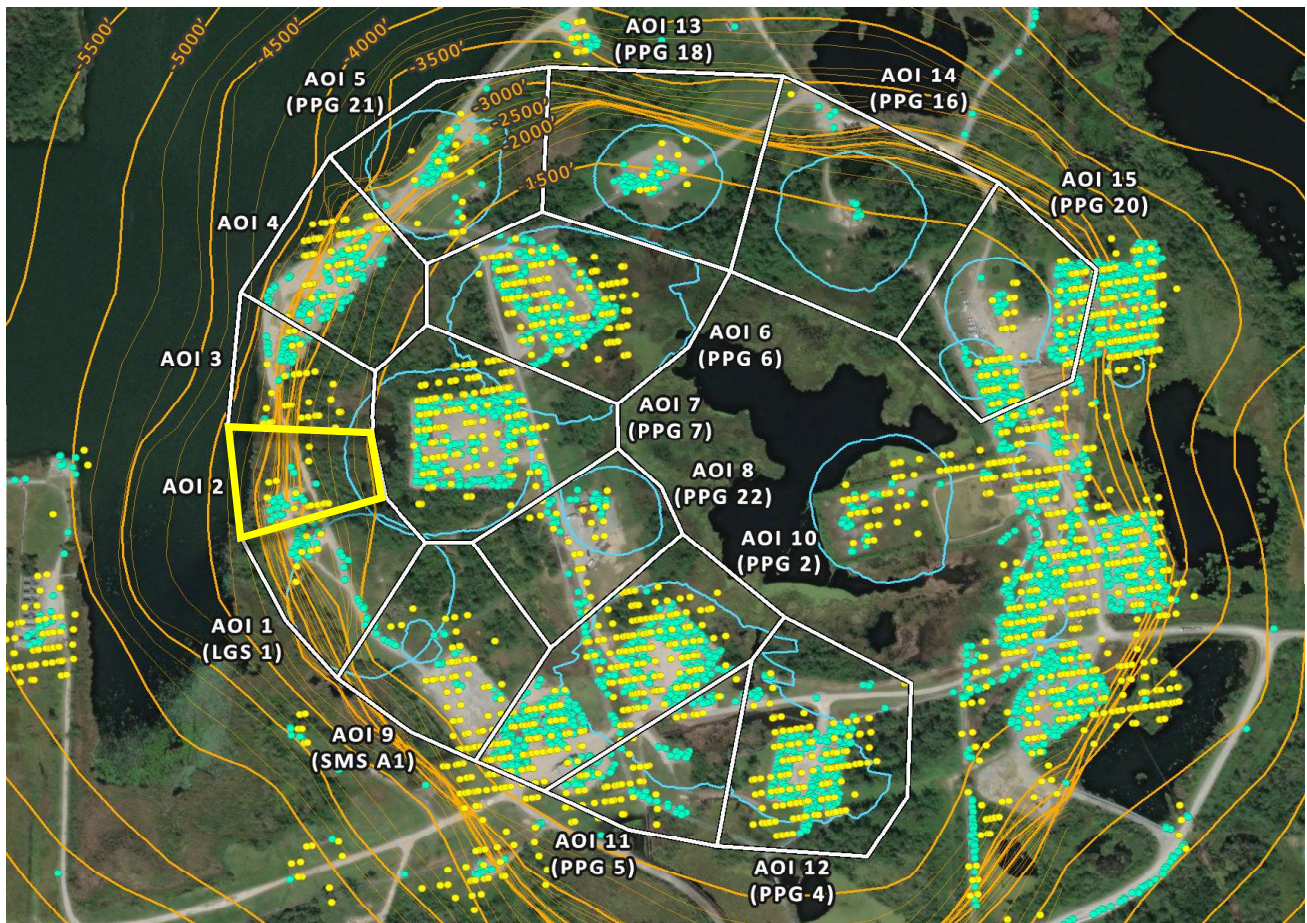
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

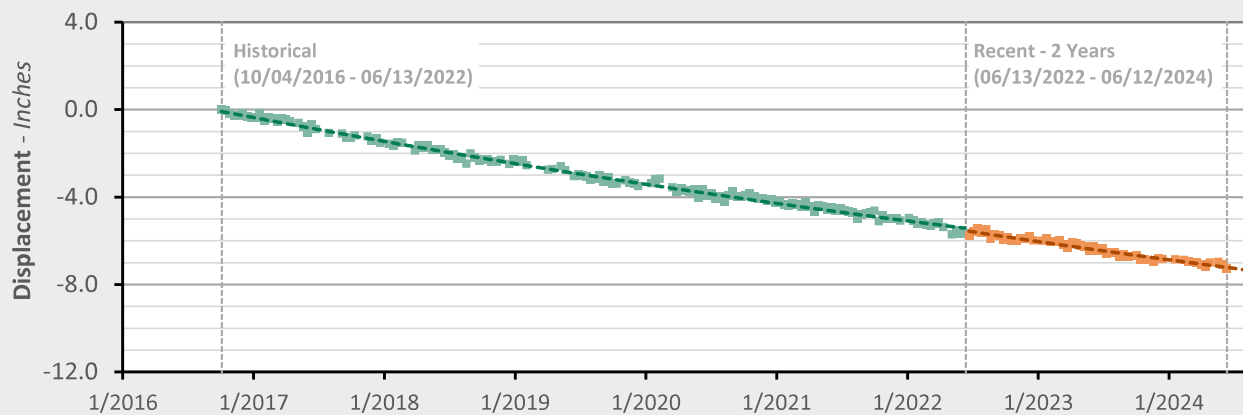
--- Historical Trend Line (Quadratic Regression)

AOI 2 - Location Map



AOI 2 - Displacement Time Series

SNT (6/12/2024) Point Count: 15



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.73 in/yr	-0.72 in/yr	+0.02 in/yr
Acceleration:	+0.07 in/yr ²	+0.14 in/yr ²	+0.06 in/yr ²

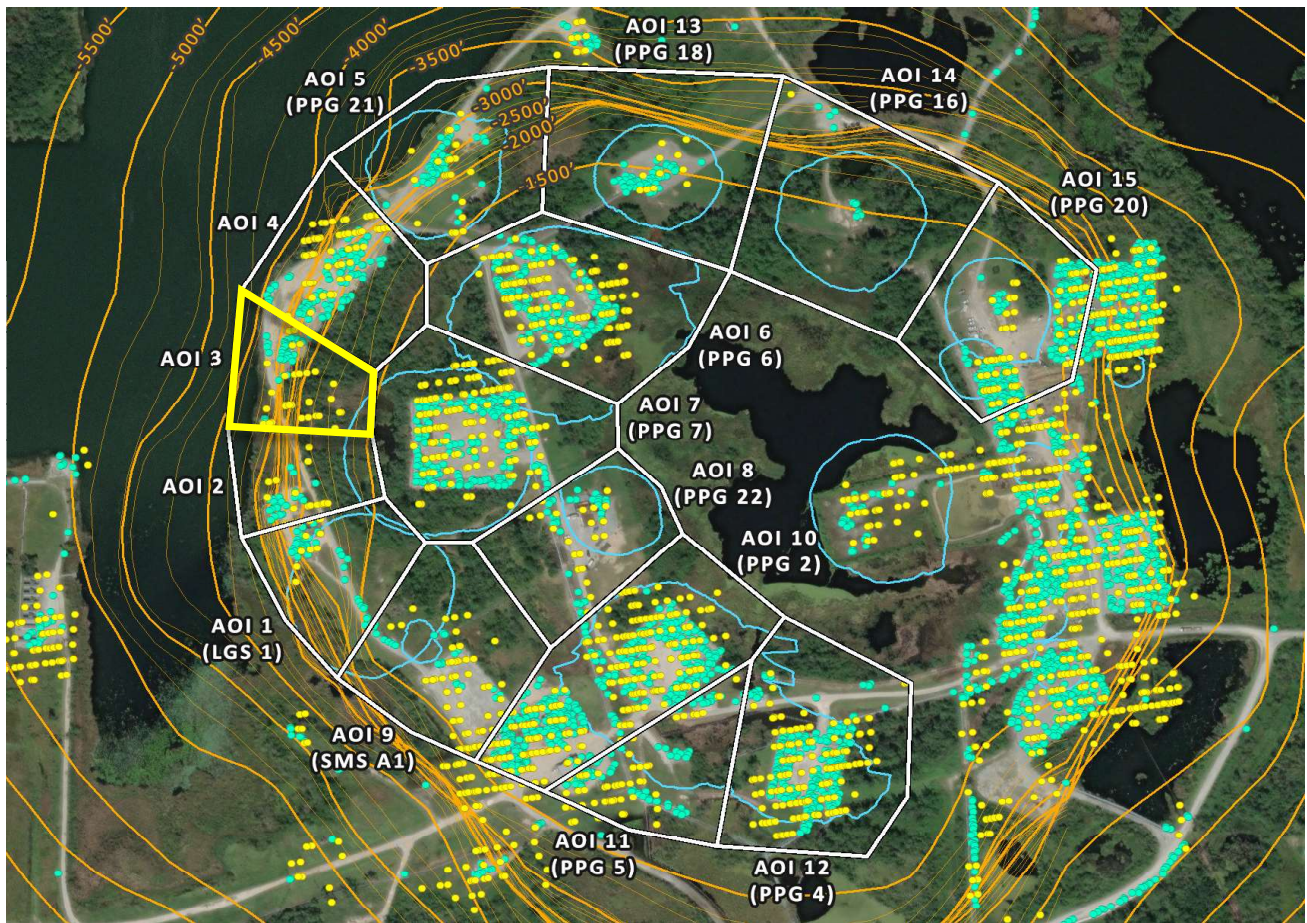
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

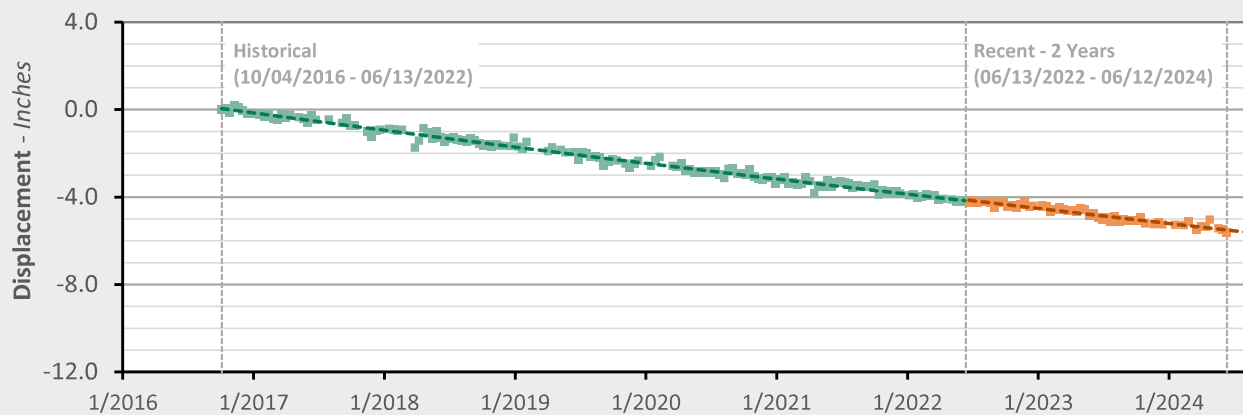
--- Historical Trend Line (Quadratic Regression)

AOI 3 - Location Map



AOI 3 - Displacement Time Series

SNT (6/12/2024) Point Count: 29



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.67 in/yr	-0.64 in/yr	+0.03 in/yr
Acceleration:	+0.03 in/yr ²	+0.06 in/yr ²	+0.03 in/yr ²

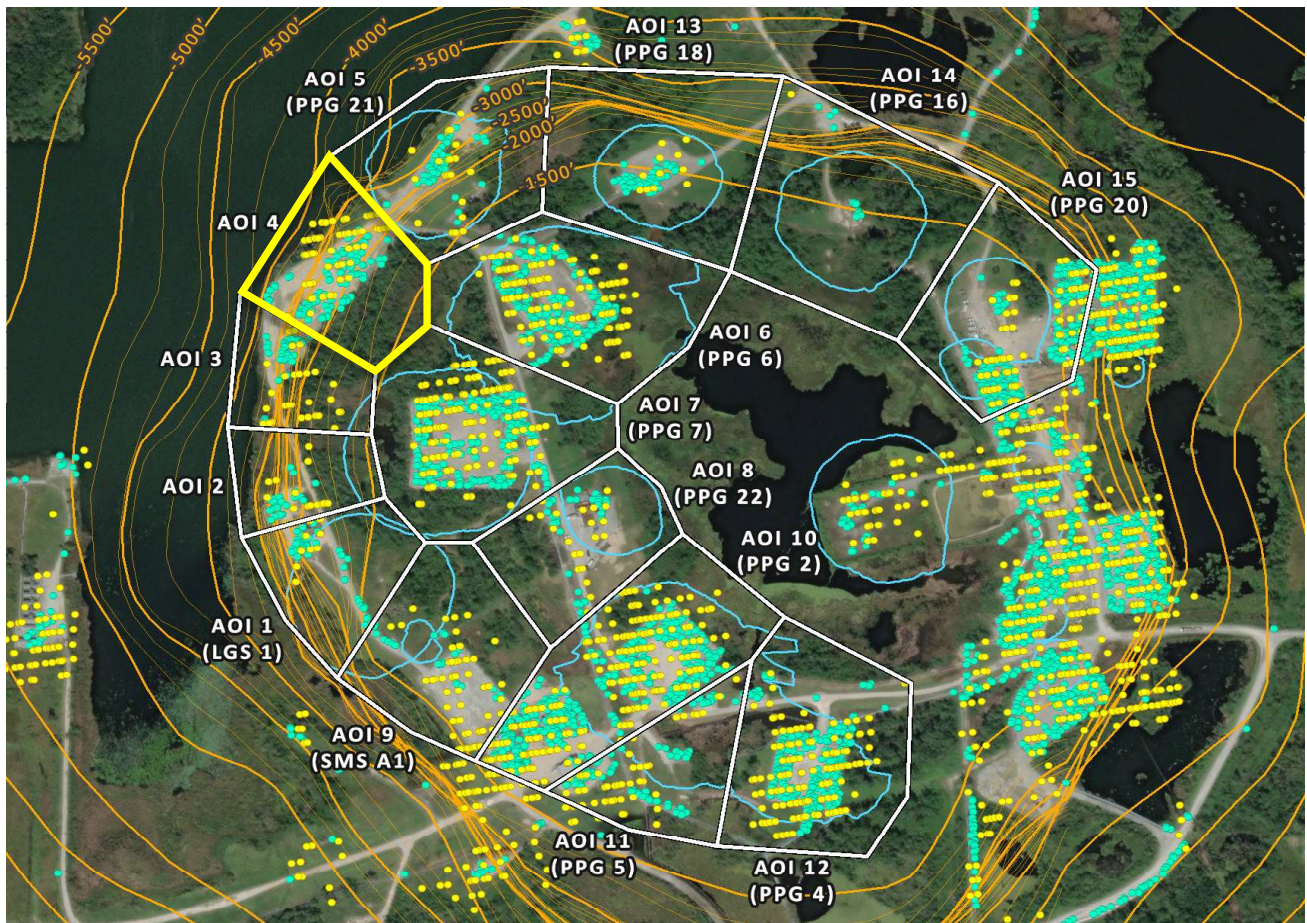
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

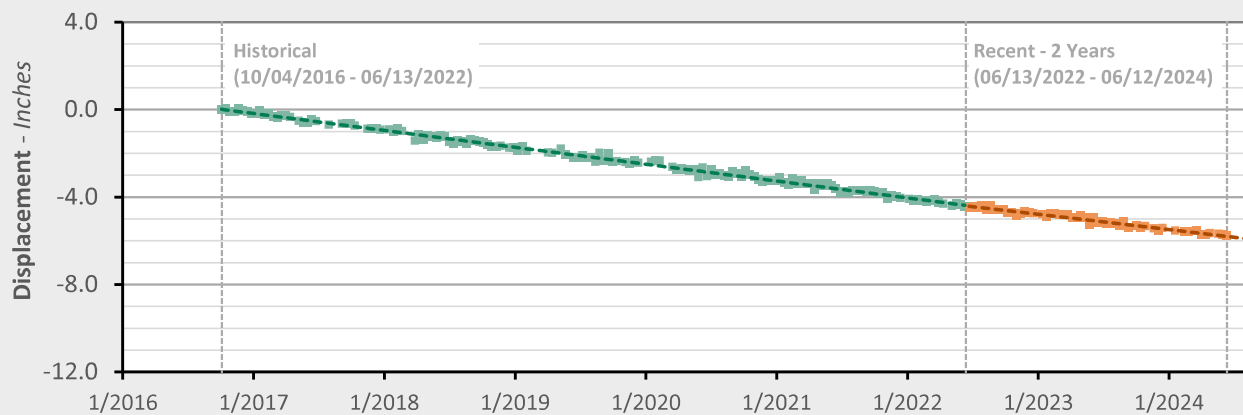
--- Historical Trend Line (Quadratic Regression)

AOI 4 - Location Map



AOI 4 - Displacement Time Series

SNT (6/12/2024) Point Count: 61



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.77 in/yr	-0.70 in/yr	+0.07 in/yr
Acceleration:	+0.00 in/yr ²	+0.00 in/yr ²	-0.00 in/yr ²

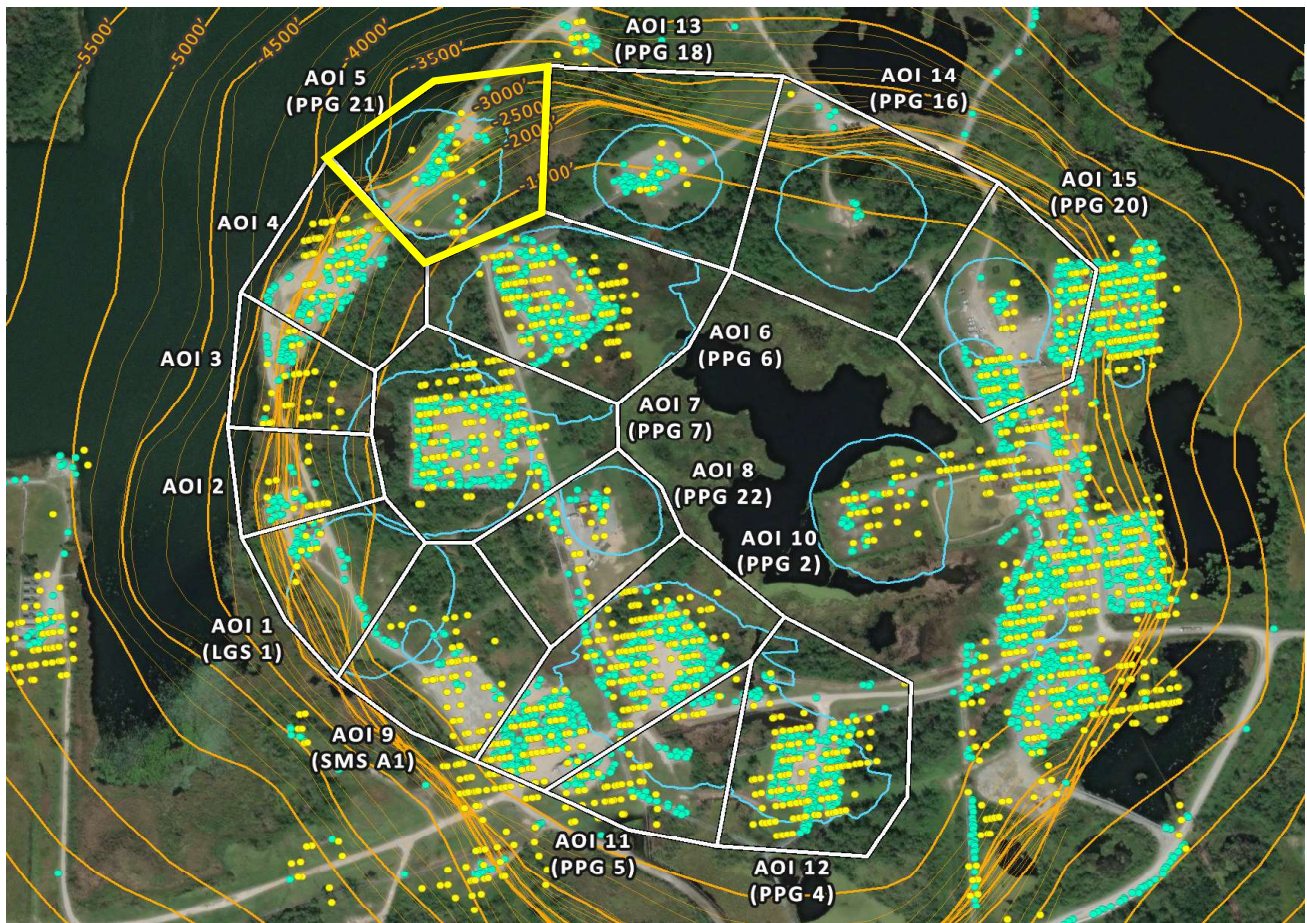
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

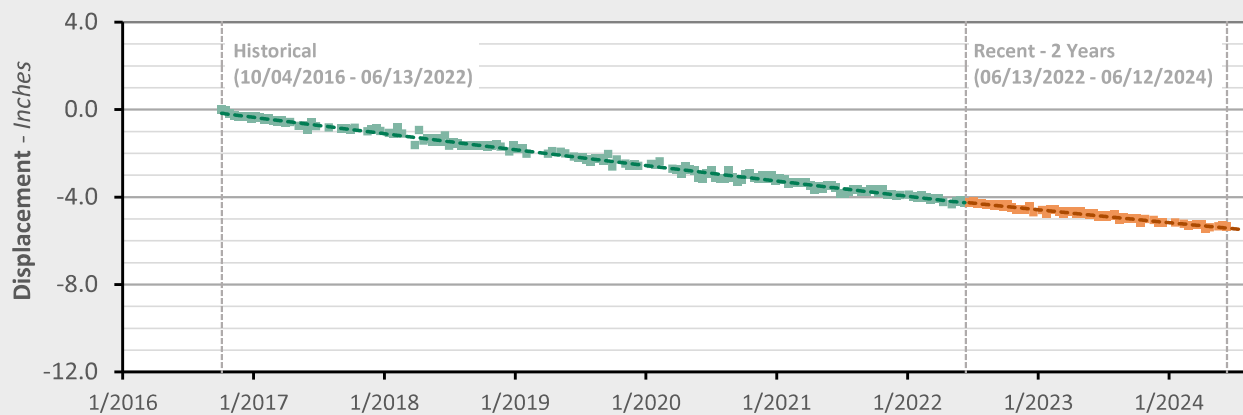
--- Historical Trend Line (Quadratic Regression)

AOI 5 (PPG 21) - Location Map



AOI 5 (PPG 21) - Displacement Time Series

SNT (6/12/2024) Point Count: 26



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.69 in/yr	-0.55 in/yr	+0.13 in/yr
Acceleration:	+0.01 in/yr ²	+0.04 in/yr ²	+0.03 in/yr ²

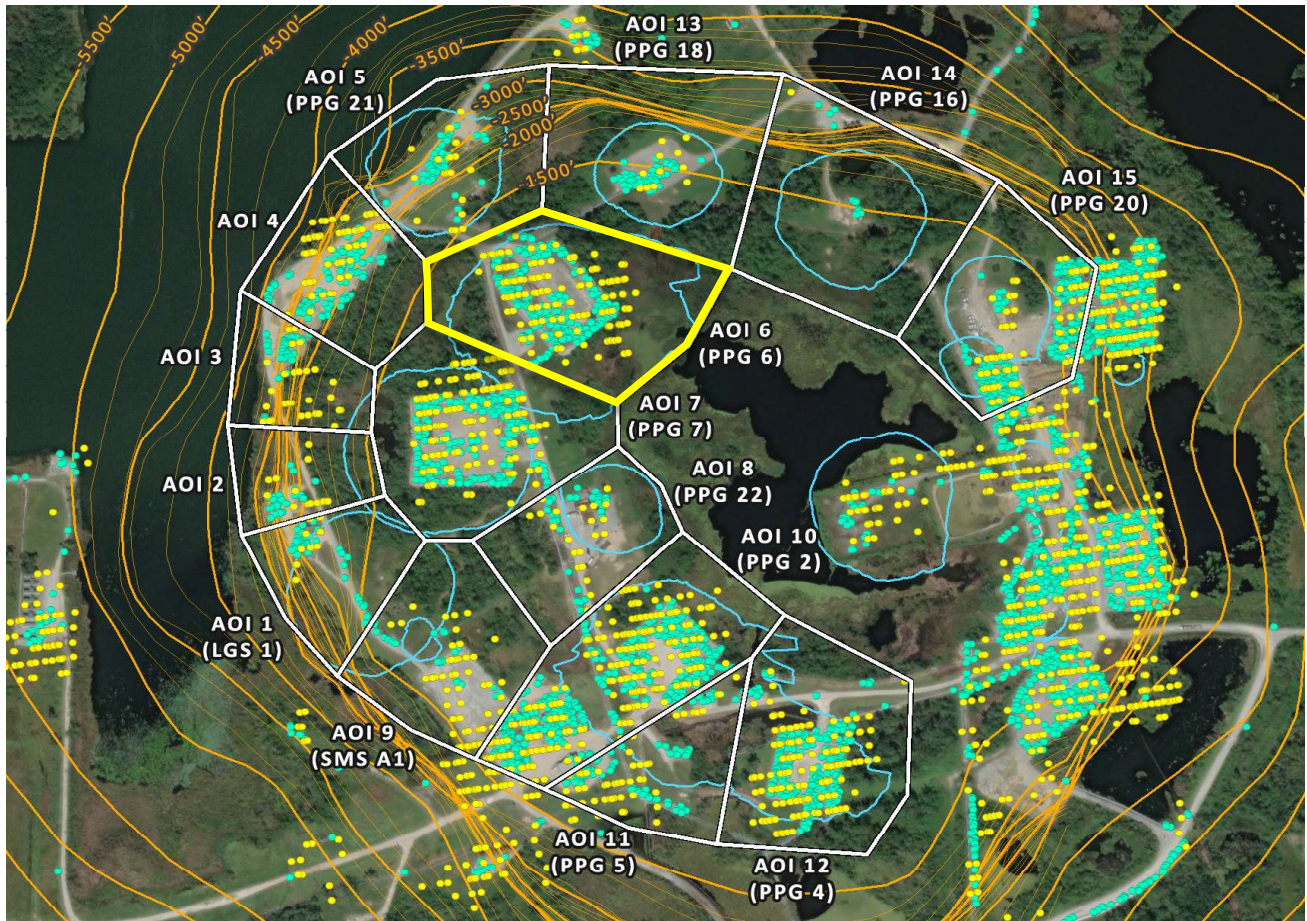
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

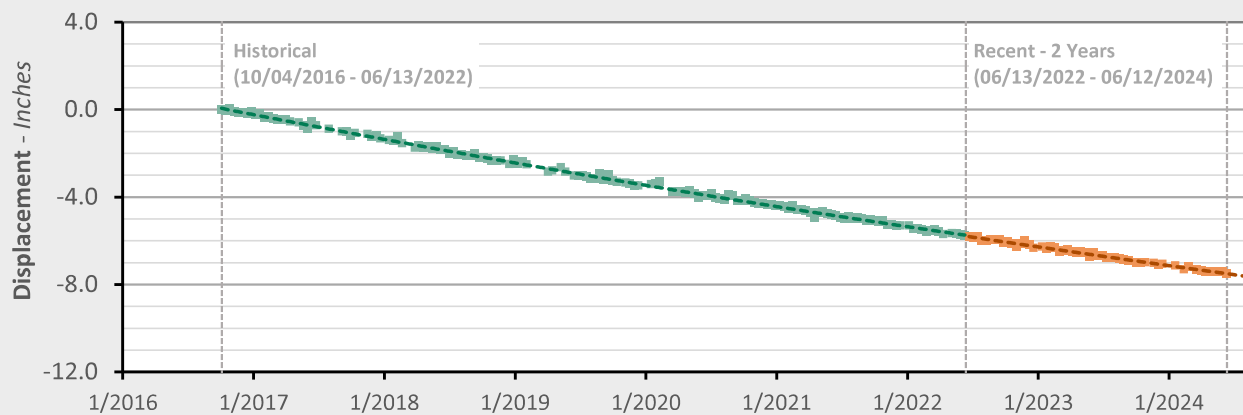
--- Historical Trend Line (Quadratic Regression)

AOI 6 (PPG 6) - Location Map



AOI 6 (PPG 6) - Displacement Time Series

SNT (6/12/2024) Point Count: 134



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.87 in/yr	-0.82 in/yr	+0.05 in/yr
Acceleration:	+0.05 in/yr ²	+0.05 in/yr ²	-0.01 in/yr ²

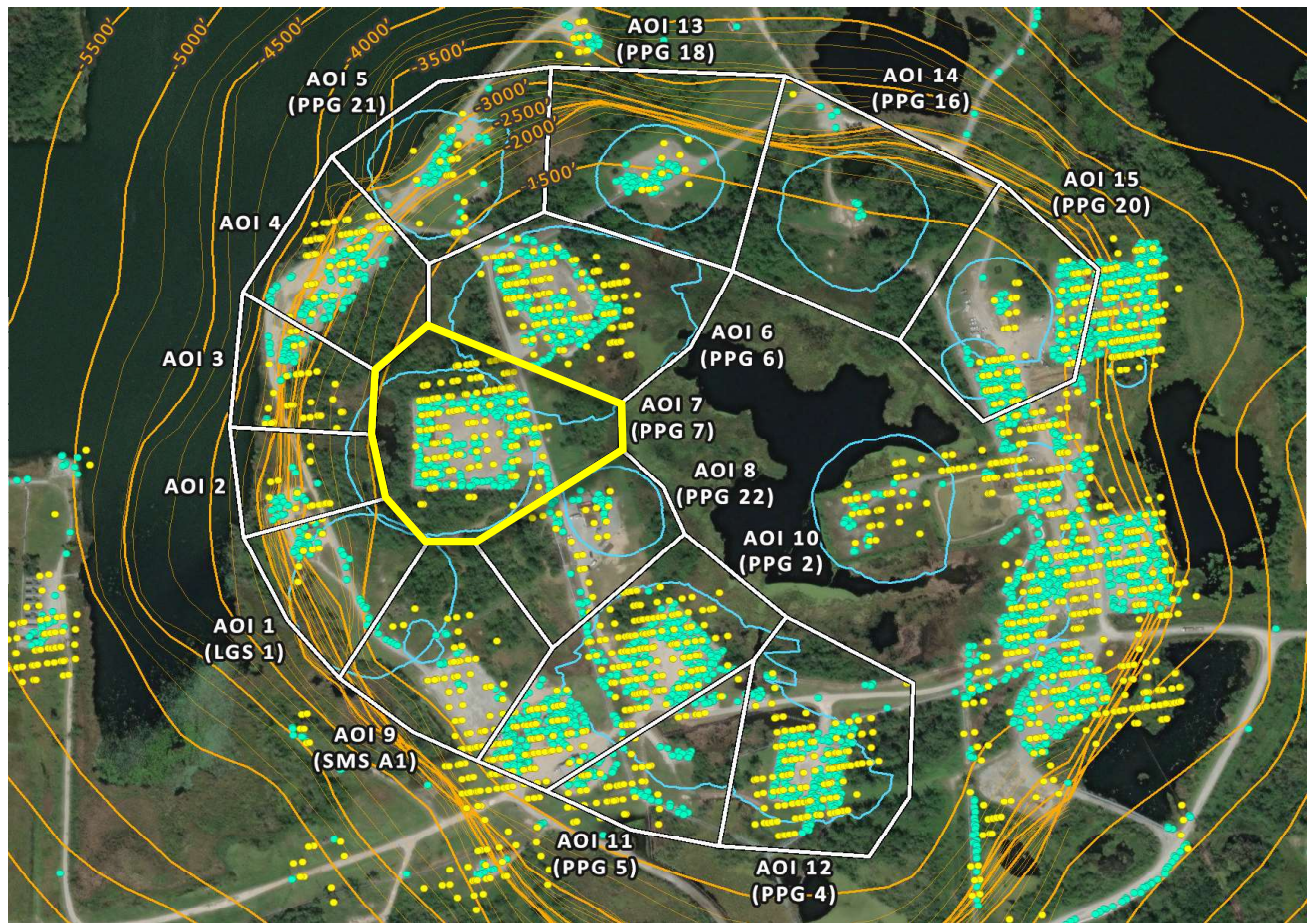
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

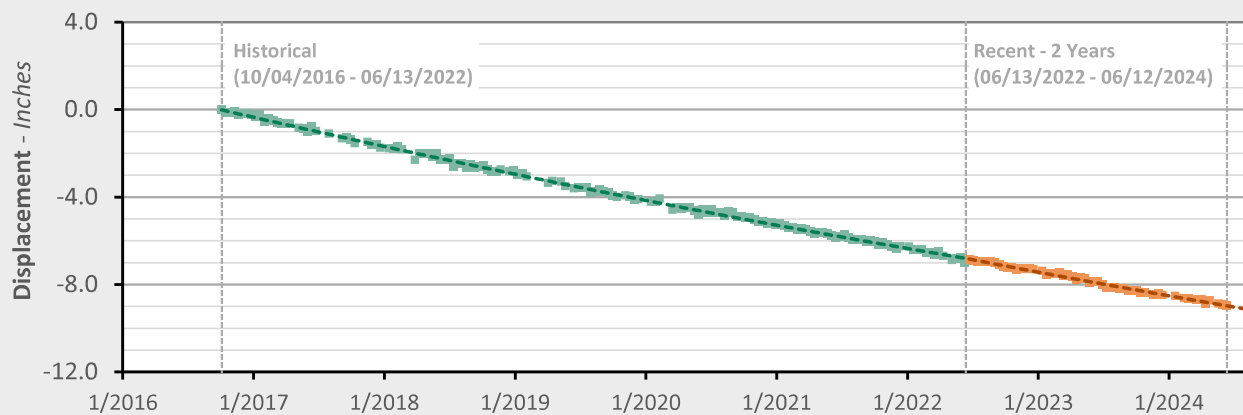
--- Historical Trend Line (Quadratic Regression)

AOI 7 (PPG 7) - Location Map



AOI 7 (PPG 7) - Displacement Time Series

SNT (6/12/2024) Point Count: 140



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-1.00 in/yr	-1.01 in/yr	-0.01 in/yr
Acceleration:	+0.07 in/yr ²	+0.08 in/yr ²	+0.01 in/yr ²

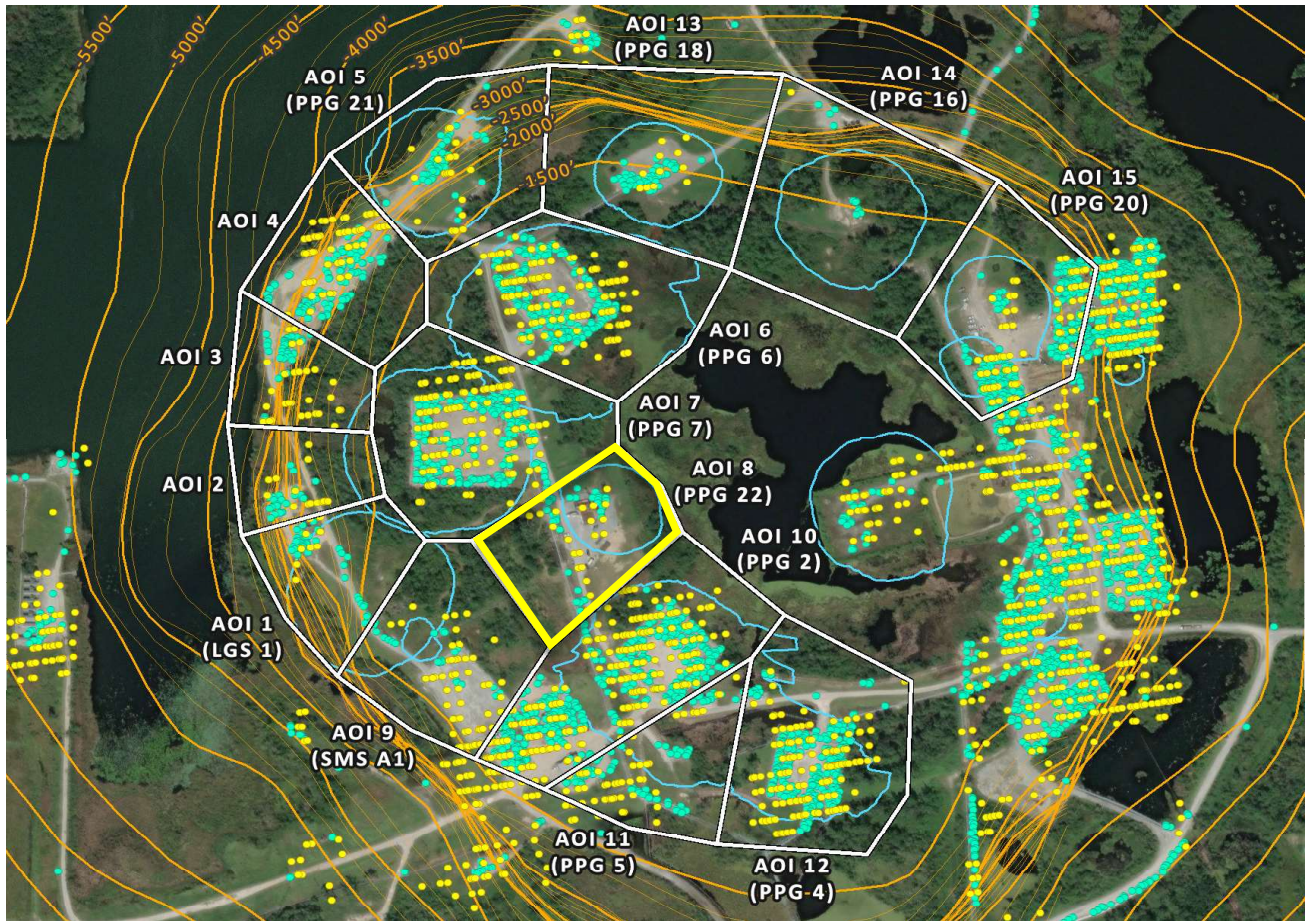
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

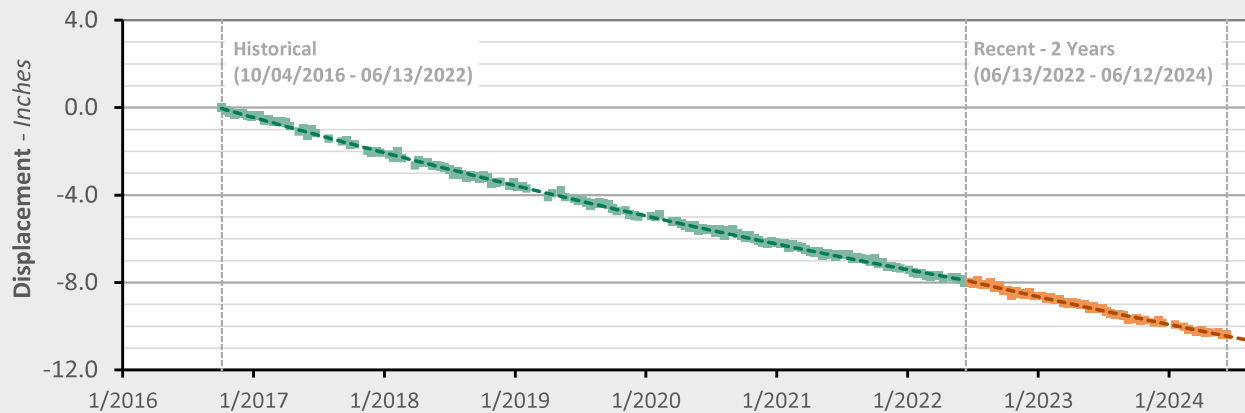
--- Historical Trend Line (Quadratic Regression)

AOI 8 (PPG 22) - Location Map



AOI 8 (PPG 22) - Displacement Time Series

SNT (6/12/2024) Point Count: 20



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-1.07 in/yr	-1.16 in/yr	-0.09 in/yr
Acceleration:	+0.11 in/yr ²	+0.12 in/yr ²	+0.02 in/yr ²

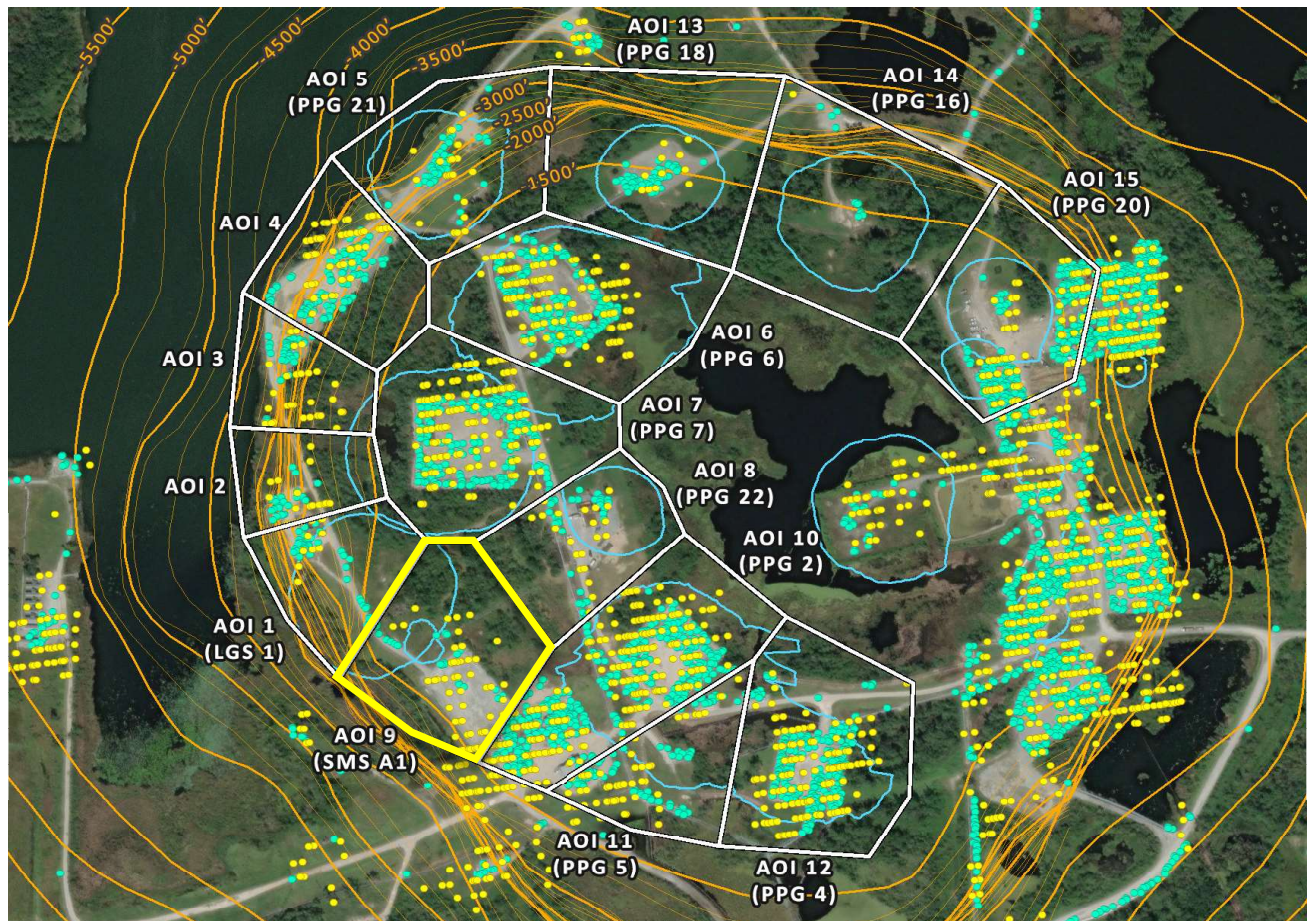
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

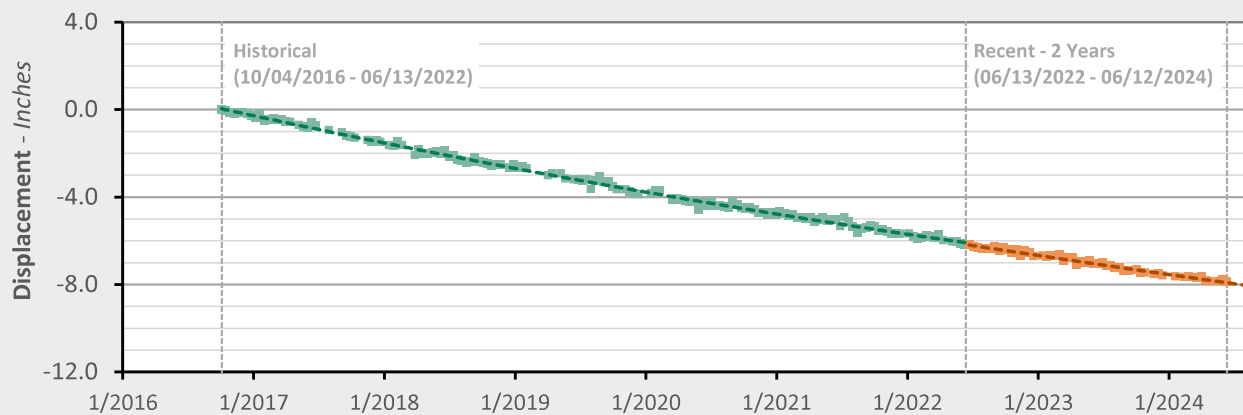
--- Historical Trend Line (Quadratic Regression)

AOI 9 (PPG A1) - Location Map



AOI 9 (SMS A1) - Displacement Time Series

SNT (6/12/2024) Point Count: 59



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.85 in/yr	-0.84 in/yr	+0.01 in/yr
Acceleration:	+0.08 in/yr ²	+0.04 in/yr ²	-0.04 in/yr ²

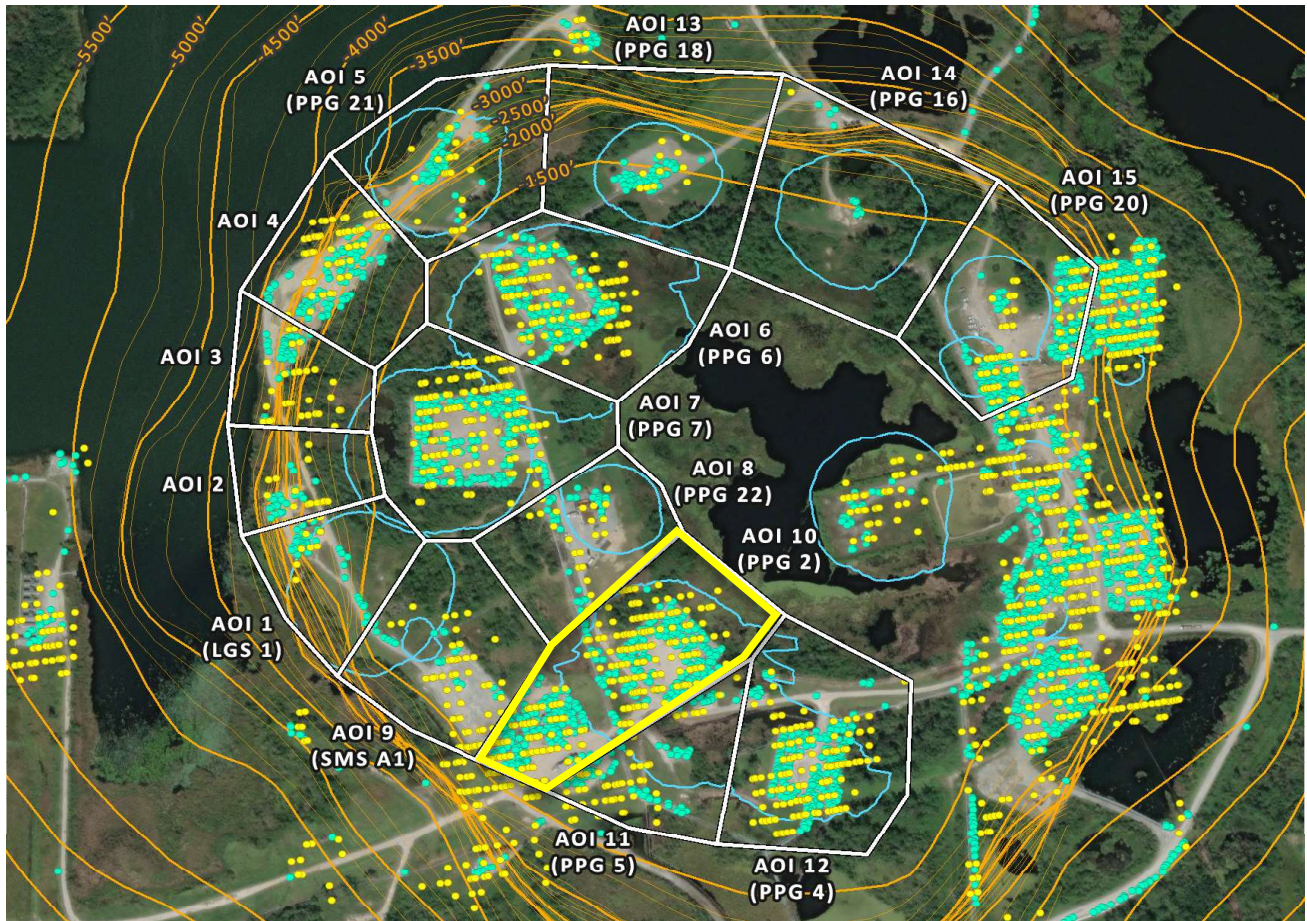
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

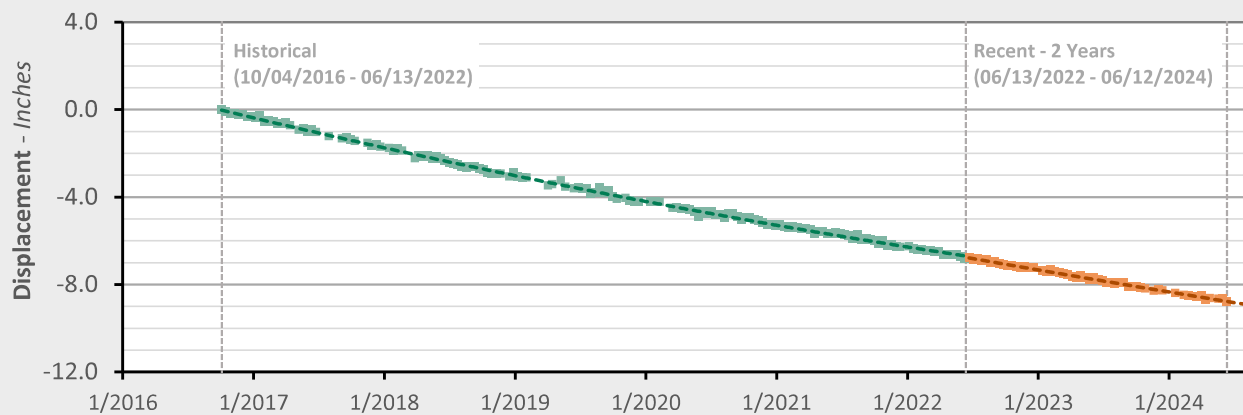
--- Historical Trend Line (Quadratic Regression)

AOI 10 (PPG 2) - Location Map



AOI 10 (PPG 2) - Displacement Time Series

SNT (6/12/2024) Point Count: 230



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.90 in/yr	-0.97 in/yr	-0.07 in/yr
Acceleration:	+0.09 in/yr ²	+0.04 in/yr ²	-0.06 in/yr ²

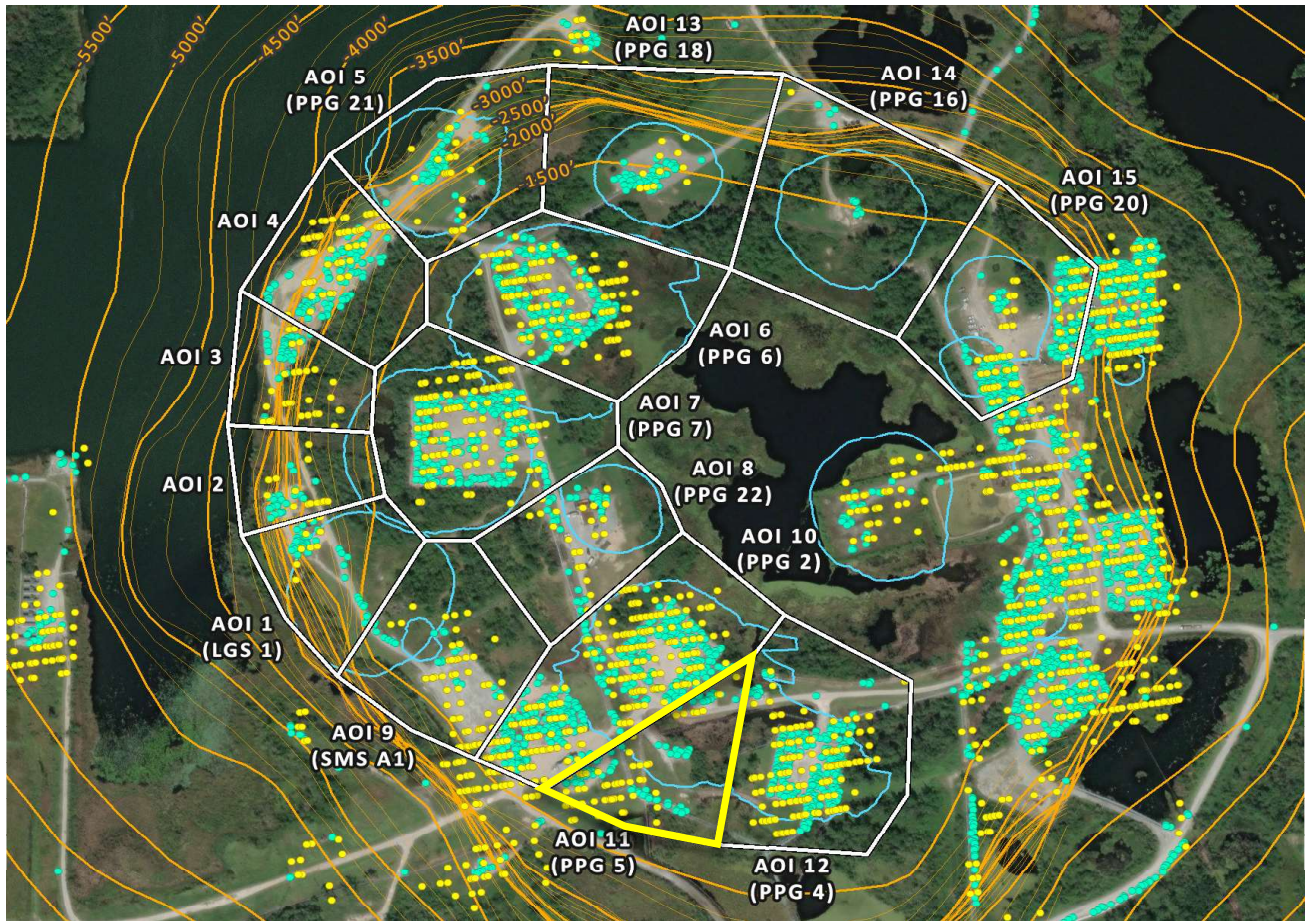
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

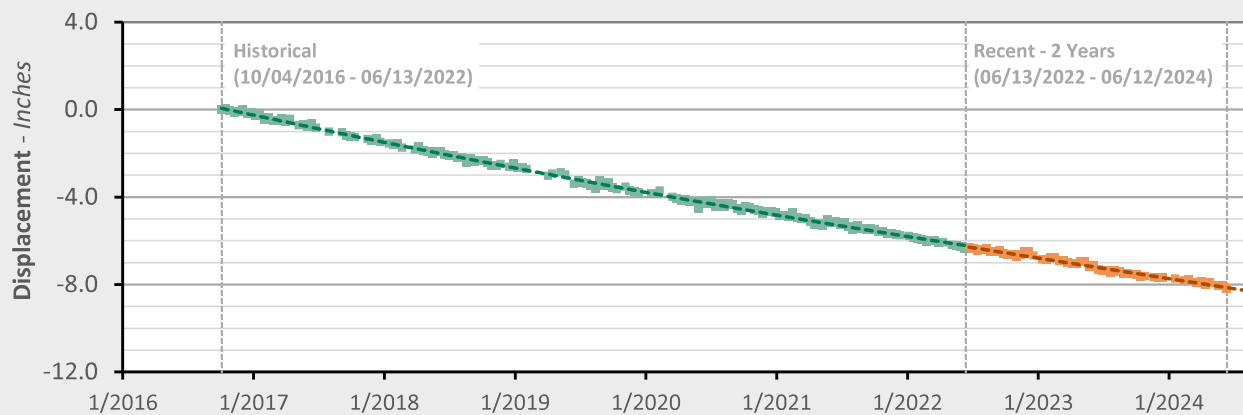
--- Historical Trend Line (Quadratic Regression)

AOI 11 (PPG 5) - Location Map



AOI 11 (PPG 5) - Displacement Time Series

SNT (6/12/2024) Point Count: 52



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.91 in/yr	-0.91 in/yr	+0.00 in/yr
Acceleration:	+0.07 in/yr ²	+0.03 in/yr ²	-0.04 in/yr ²

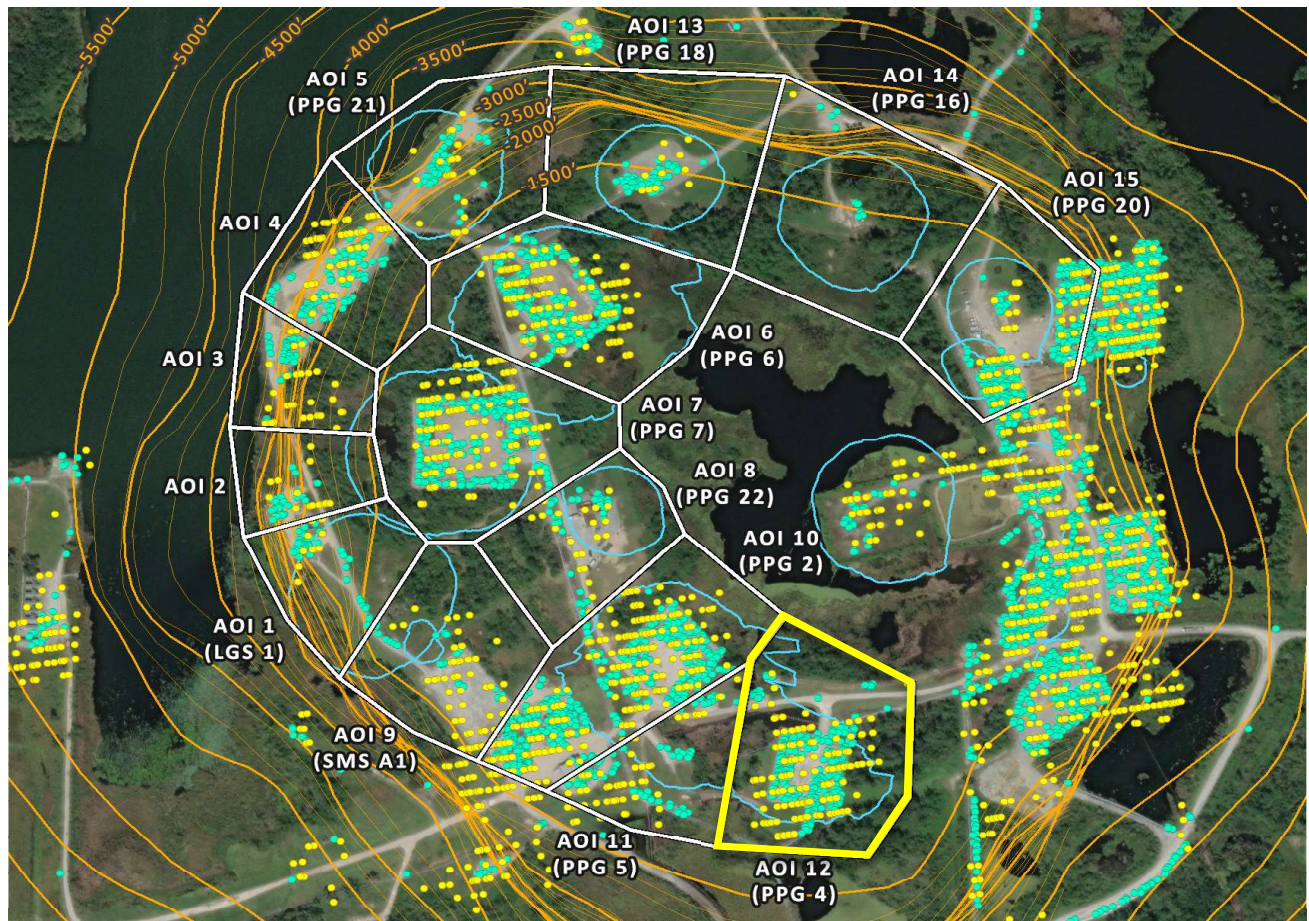
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

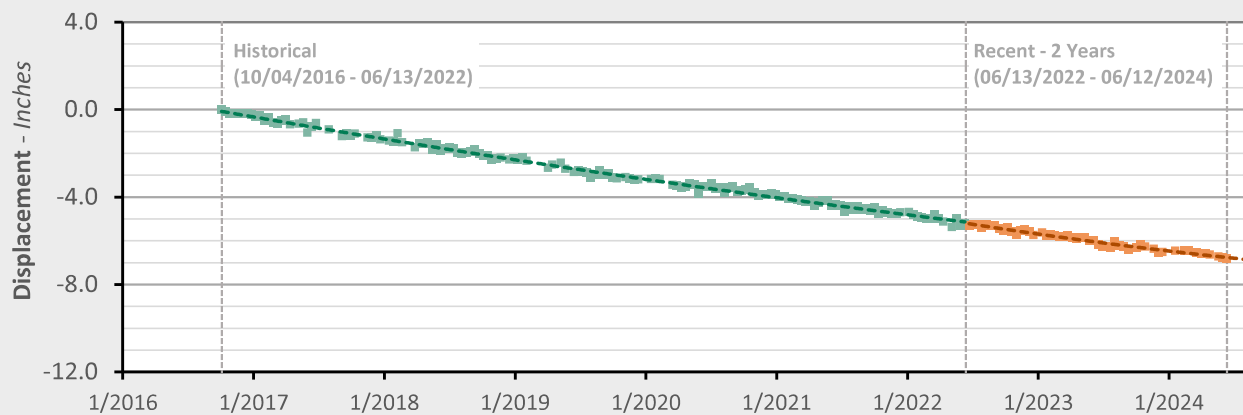
--- Historical Trend Line (Quadratic Regression)

AOI 12 (PPG 4) - Location Map



AOI 12 (PPG 4) - Displacement Time Series

SNT (6/12/2024) Point Count: 121



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.73 in/yr	-0.61 in/yr	+0.11 in/yr
Acceleration:	+0.06 in/yr ²	+0.18 in/yr ²	+0.12 in/yr ²

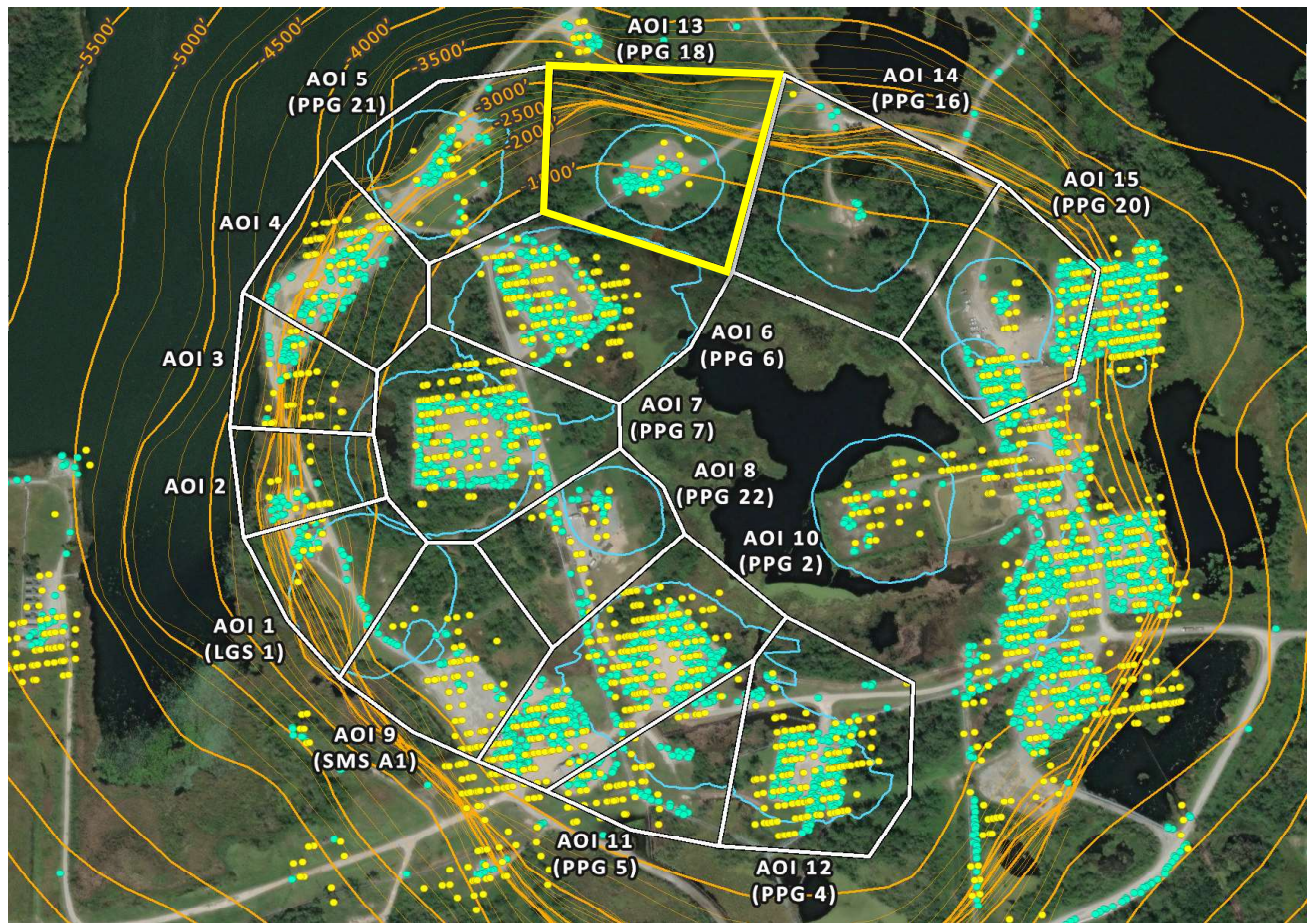
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

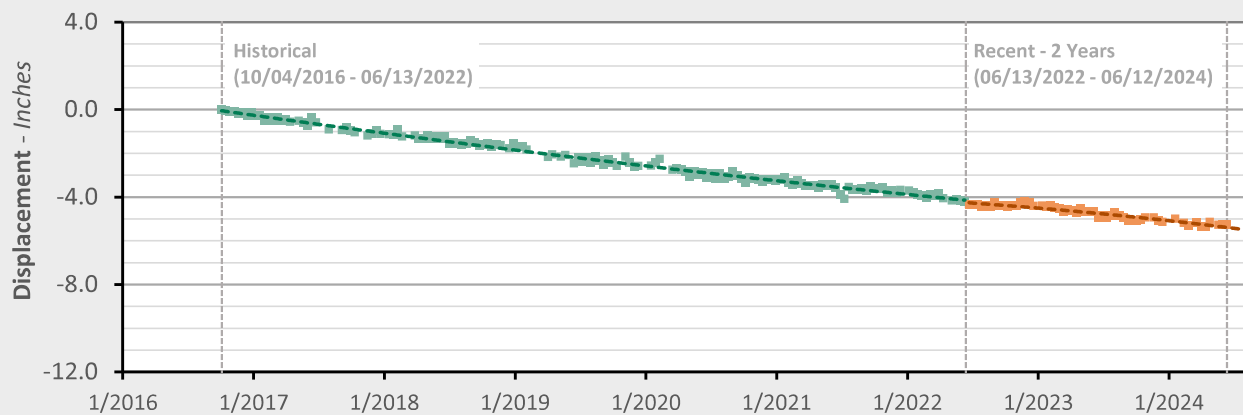
--- Historical Trend Line (Quadratic Regression)

AOI 13 (PPG 18) - Location Map



AOI 13 (PPG 18) - Displacement Time Series

SNT (6/12/2024) Point Count: 12



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.58 in/yr	-0.71 in/yr	-0.13 in/yr
Acceleration:	+0.05 in/yr ²	-0.13 in/yr ²	-0.18 in/yr ²

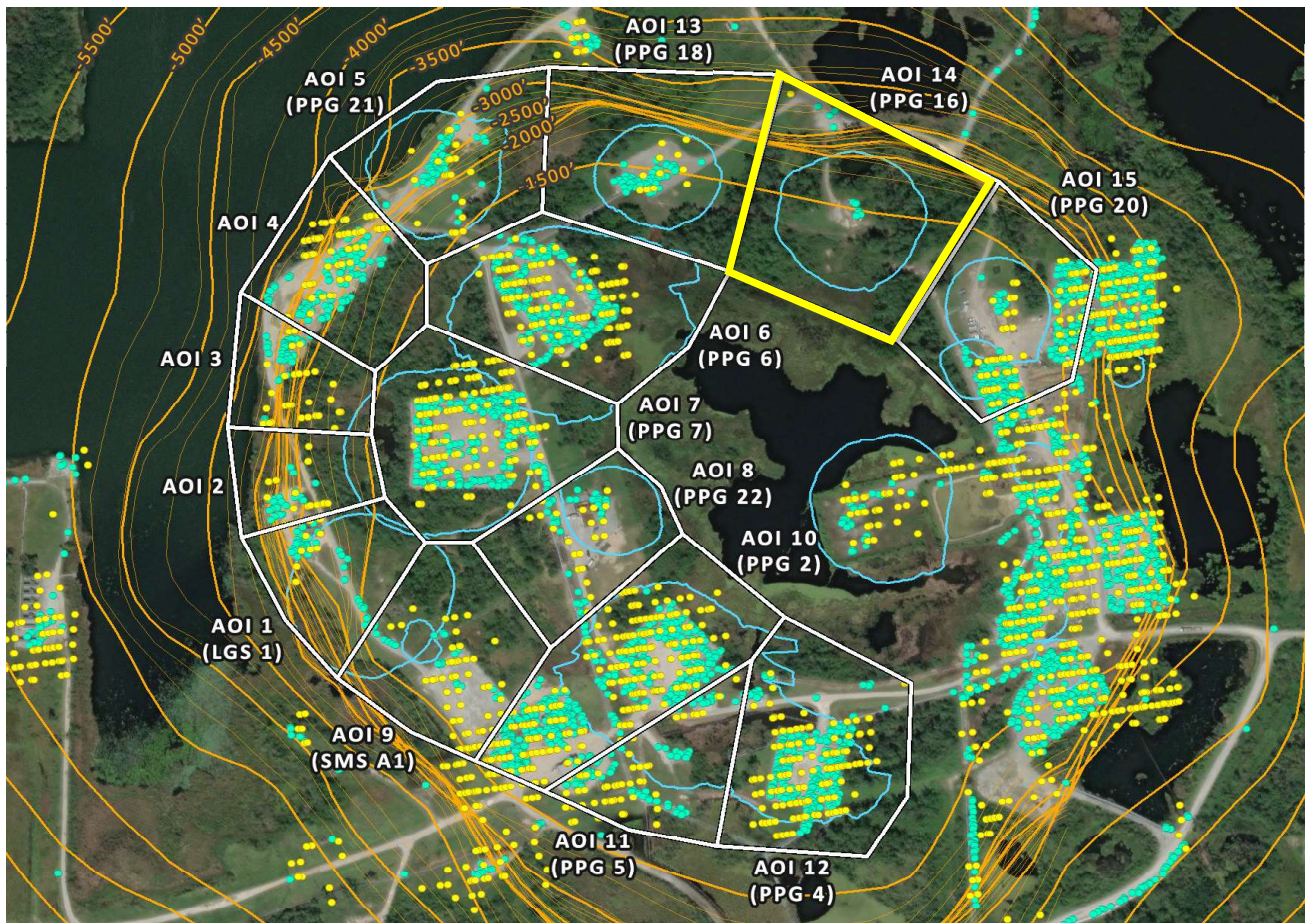
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

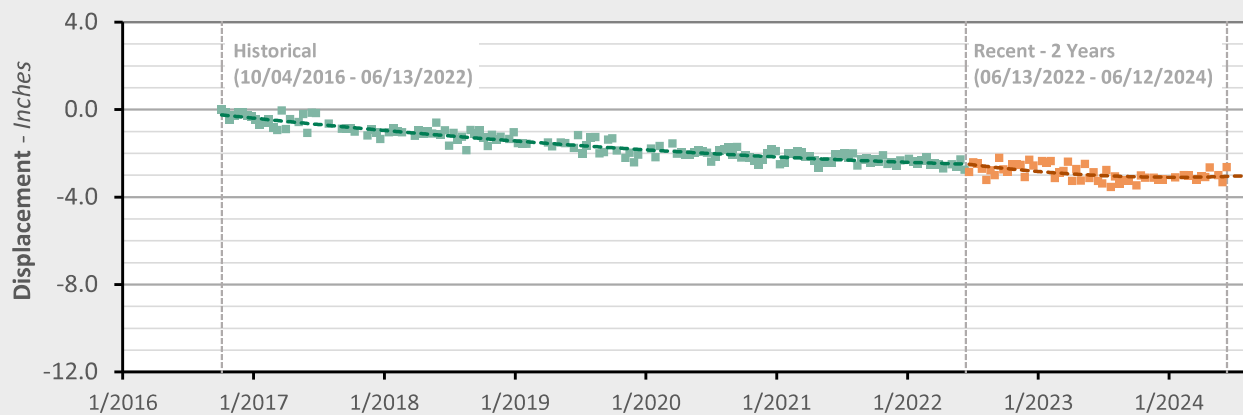
--- Historical Trend Line (Quadratic Regression)

AOI 14 (PPG 16) - Location Map



AOI 14 (PPG 16) - Displacement Time Series

SNT (6/12/2024) Point Count: 1



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.17 in/yr	+0.26 in/yr	+0.43 in/yr
Acceleration:	+0.08 in/yr ²	+0.57 in/yr ²	+0.49 in/yr ²

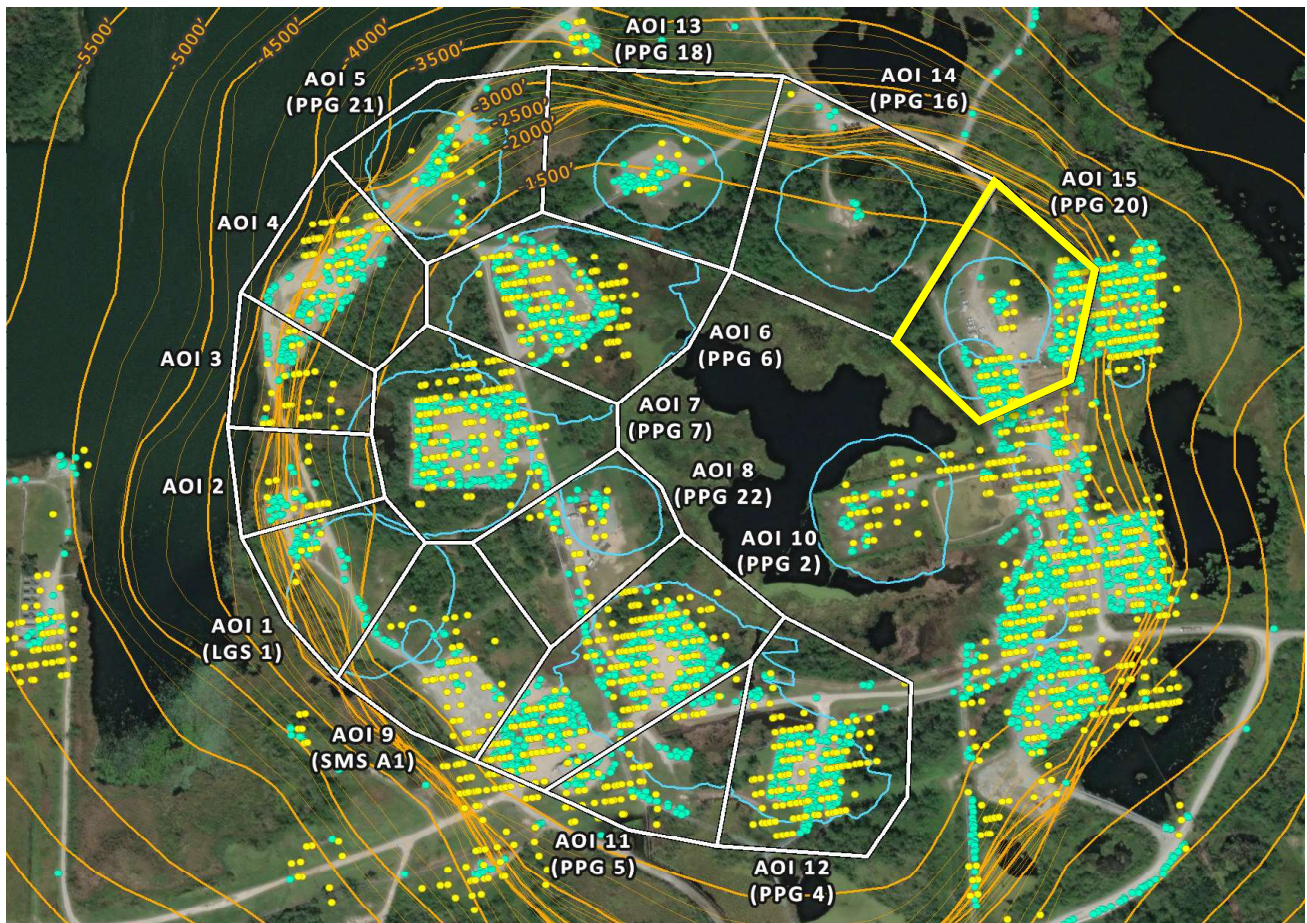
■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

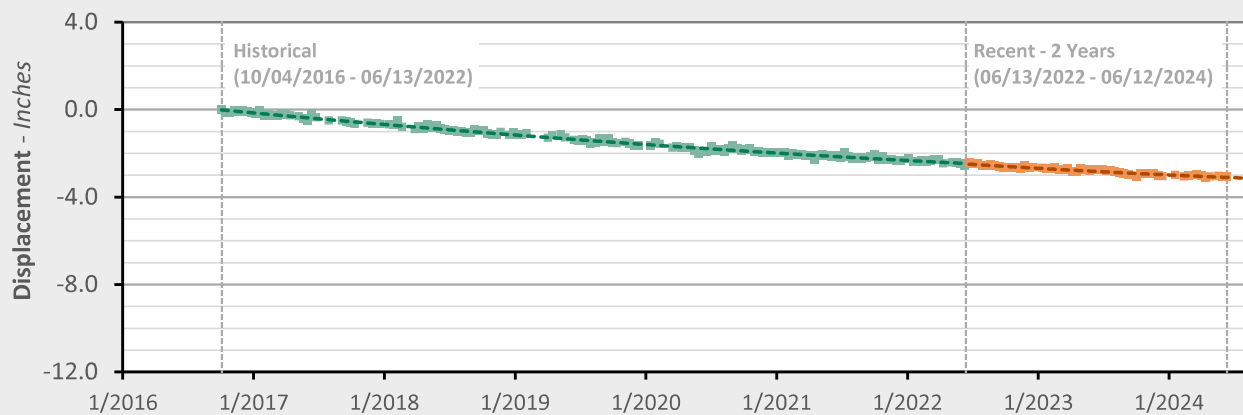
■ Recent LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

AOI 15 (PPG 20) - Location Map



AOI 15 (PPG 20) - Displacement Time Series SNT (6/12/2024) Point Count: 72



	Historical Trend Values	Recent Trend Values	Trend Change
Velocity:	-0.30 in/yr	-0.25 in/yr	+0.05 in/yr
Acceleration:	+0.05 in/yr ²	+0.05 in/yr ²	+0.01 in/yr ²

■ Historical LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

■ Recent LOS Displacement Measurement

--- Historical Trend Line (Quadratic Regression)

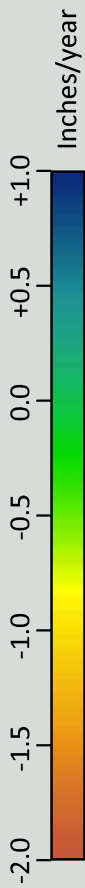
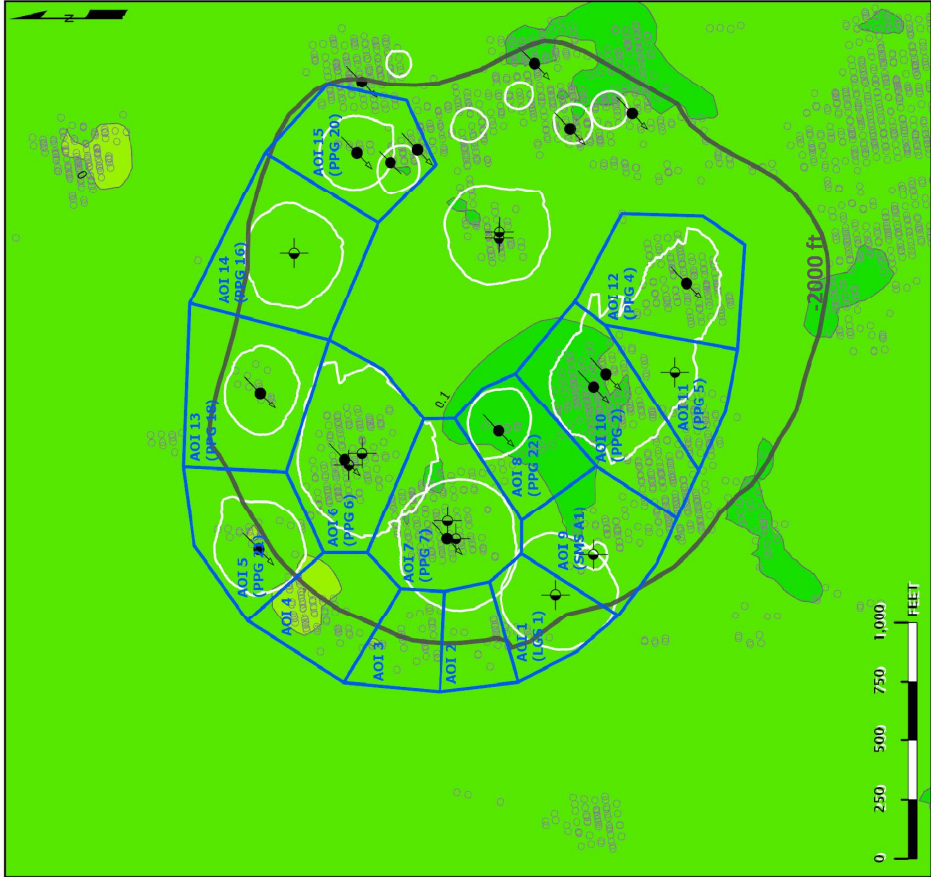
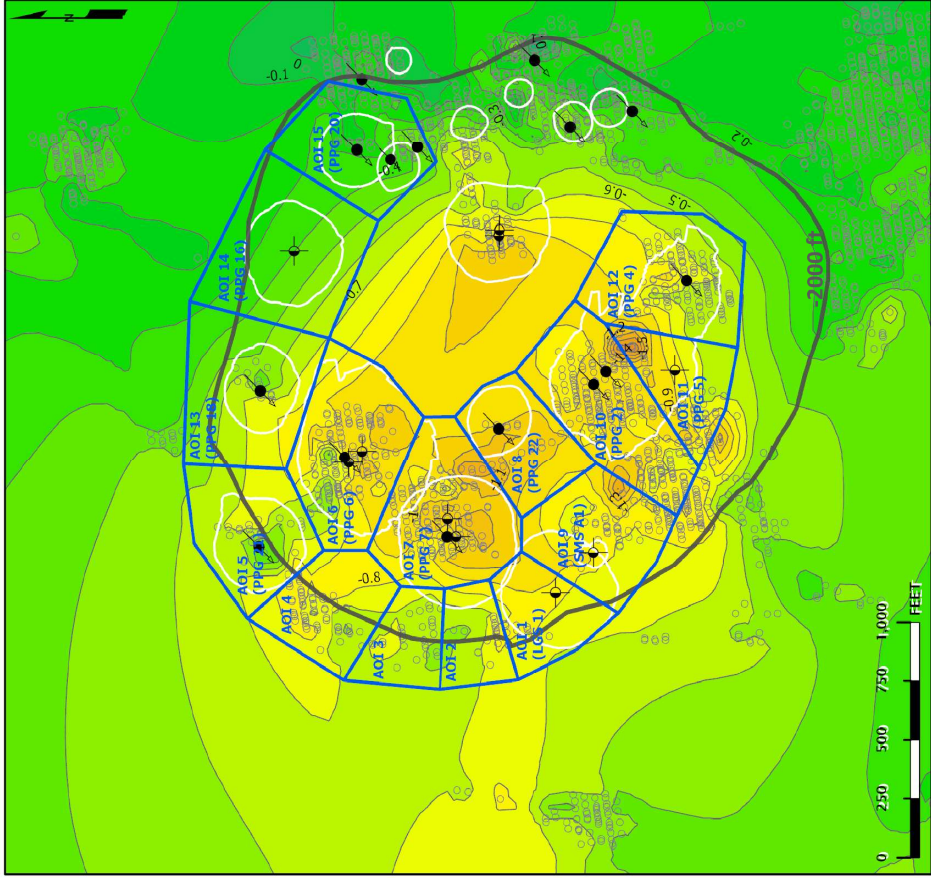
Historical SNT Data (10/04/2016 - 06/13/2022)

Velocity Contours

As of date: 06/13/2022

Acceleration Contours

Date range: 10/04/2016 - 06/13/2022



AOI Boundary InSAR LOS Measurement Point Contour (0.1)
Historical Cavern Extent Top of Dome (~2000 ft Contour)

Cavern Well Surface Locations
09 - Active - Injection 29 - Dry and Plugged

