LONQUIST FIELD SERVICE

November 15, 2024

From:

Nathaniel Byars, Lonquist & Co. LLC

Sergey Samsonov, PhD, InSAR Corporation

Julie Shemeta, MEQ Geo Inc.

**Re: Combined Monthly Surface Deformation Report – October 2024**
**Sulphur Mines Salt Dome, Louisiana**

Please find attached the combined monthly deformation report for Sulphur Mines dome which includes results from the precision tiltmeters and GNSS stations for the September monitoring period and the cumulative InSAR results as of month end.

*Status of a deformation alert plan.* We are developing a draft deformation alert system incorporating the direction and magnitude of tiltmeter readings. Over the past months, we have noted short-duration anomalous tilt signals linked to precipitation and mechanical activities near the monitoring sites. We plan to integrate short-term deformation alert levels with real-time monitoring data from Sulphur Mines, which include the Cavern 7 pressure and microseismic monitoring. GNSS and InSAR data will also be used for validation.

Sincerely,

Nathaniel Byars
Principal Engineer
Lonquist & Co. LLC

Julie Shemeta
MEQ Geo Inc.

Attachment List

A. Tiltmeter/GNSS Data Report - October 2024
B. SNT InSAR report - October 22, 2024
C. TSX/PAZ InSAR report - October 27, 2024
D. Vertical & East-West 2D InSAR report – October 27, 2024

# ATTACHMENT A

## Tiltmeter/GNSS Data Report - October 2024

November 15, 2024

Sergey Samsonov, PhD, InSAR Corporation
Nathaniel Byars, Lonquist & Co. LLC
Julie Shemeta, MEQ Geo Inc.

**Re: Tiltmeter/GNSS Data Evaluation – October 2024, Sulphur Mines Salt Dome**

The tiltmeter/GNSS network, which includes twenty tiltmeters and five GNSS stations, has been operational since June 1, 2024. It was installed and is currently being operated by Halliburton's Pinnacle Group. Please refer to Figure 1 for the map of the tiltmeter and GNSS stations. Station coordinates are provided in Appendix 3.

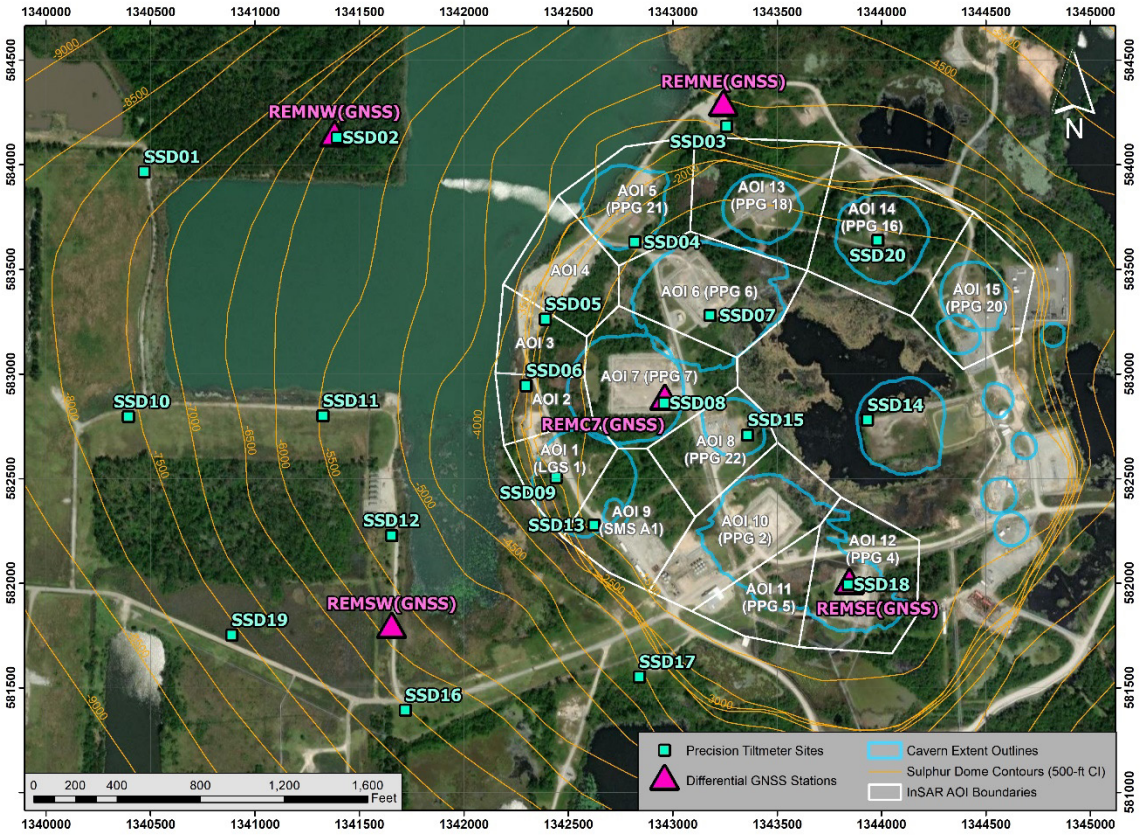



*Figure 1. Map of the tiltmeter and GNSS network installed at Sulphur Mines dome. The cyan squares indicate the tiltmeter site locations. The GNSS stations are shown by pink triangles. The InSAR AOI boundaries are shown for reference. The surface projection of the various salt caverns is indicated by blue lines. The salt dome contours are in light orange. The backdrop is an aerial photograph of the Sulphur Mines salt dome.*

**Introduction**

This report describes tiltmeter and GNSS measurements from the Sulphur Mines Salt Dome collected in October 2024.

For each tiltmeter station, the report provides:

- Raw measurements of east and north tilt components (measured in microradians) at four-minute temporal resolution, along with their linear trends
- Detrended east and north tilt components at four-minute temporal resolution
- Daily range of east and north tilt components
- Hourly precipitation amount (measured in inches)
- Daily tilt direction distribution diagram, along with the direction to Cavern 7 and direction of the monthly linear trend

For each GNSS station, the report provides:

- Daily time series of east, north, and vertical deformation (measured in inches) and their linear trends in the local reference frame.

For a more detailed description of the data visualization, please refer to the August 2024 report.

**Summary of tiltmeter observations for October 2024**

The tiltmeter network was operational throughout the entire October 2024 period. However, data was not acquired at one station, SSD13, on October 17. No signals related to anomalous processes in Cavern 7 were detected during this reporting period. The October data plots for each tiltmeter station are shown in Appendix 1 and described below.

The established tilt trends were disrupted by multiple mechanical activities near the sites. At some tiltmeters, the disturbances were short-lived, while other tiltmeters experienced nearly instantaneous, significant shifts followed by an adjustment period of a gradual return to the previous trend lasting several days. We applied an outlier removal filter to the raw tiltmeter time series to remove the nearly instantaneous shifts to aid in the tiltmeter array interpretation.

An example of the signal disturbance is shown in Figures 2 and 3. In Figure 2 at station SSD01, the significant shift in the tilt signal was created during tiltmeter site visits for station QC; it is unrelated to any activity in the subsurface. The gradual return to the background trend after this disturbance lasted several days. Note that while the outlier removal filter could successfully remove the shift, it did not affect the time series during an adjustment period of a gradual return to the previous trend. In Figure 3 at station

SSD10, two significant, nearly instantaneous shifts were observed and successfully corrected with the outlier removal filter. Note that no lasting adjustment period was observed at this station.

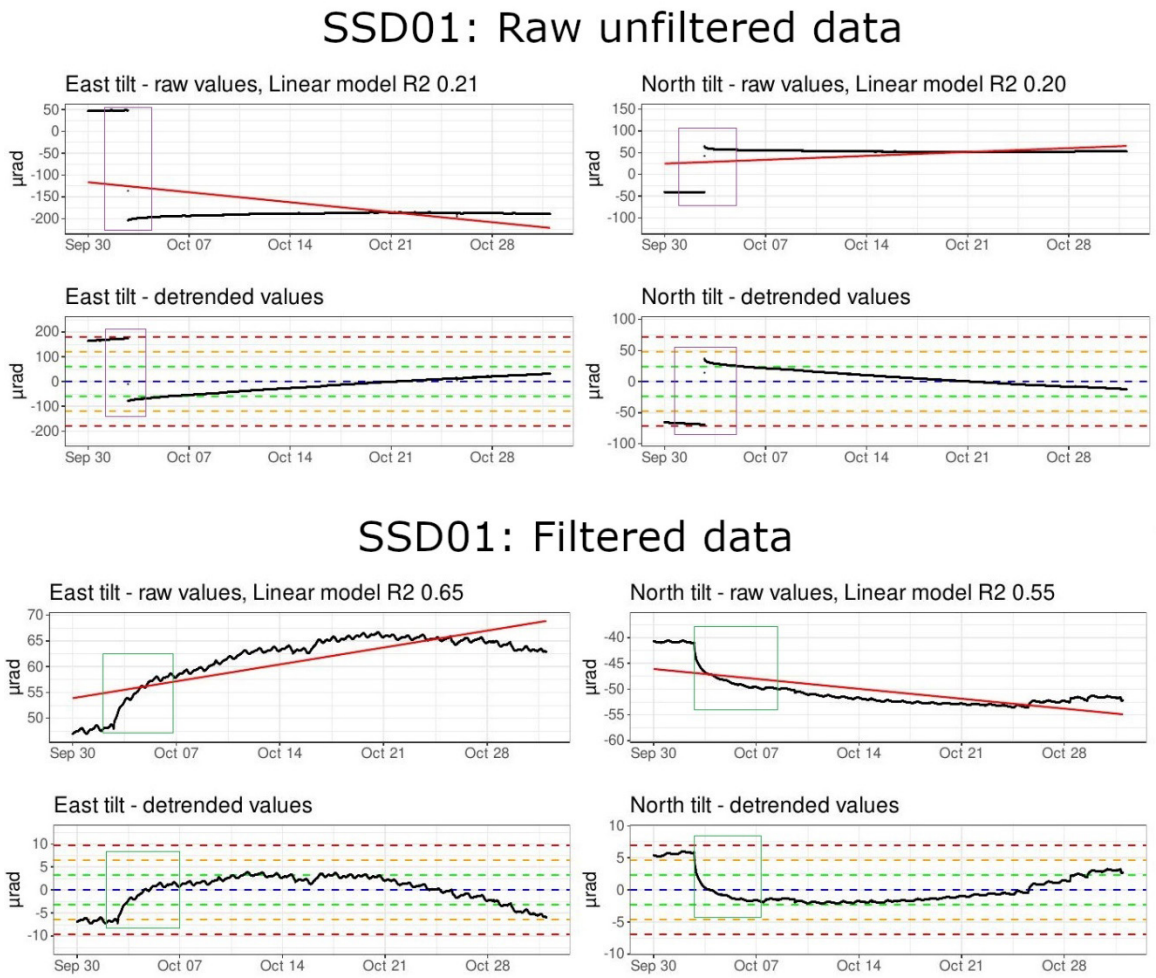



*Figure 2. An example of both a raw unfiltered tilt record and a filtered tilt record from early October 2024 at station SSD01. The magenta rectangle highlights a significant, nearly instantaneous shift in the tilt signal, which is followed by a period of adjustment indicated by the green rectangle. The lower set of plots displays the SSD01 tilt signal after the station shift has been removed.*

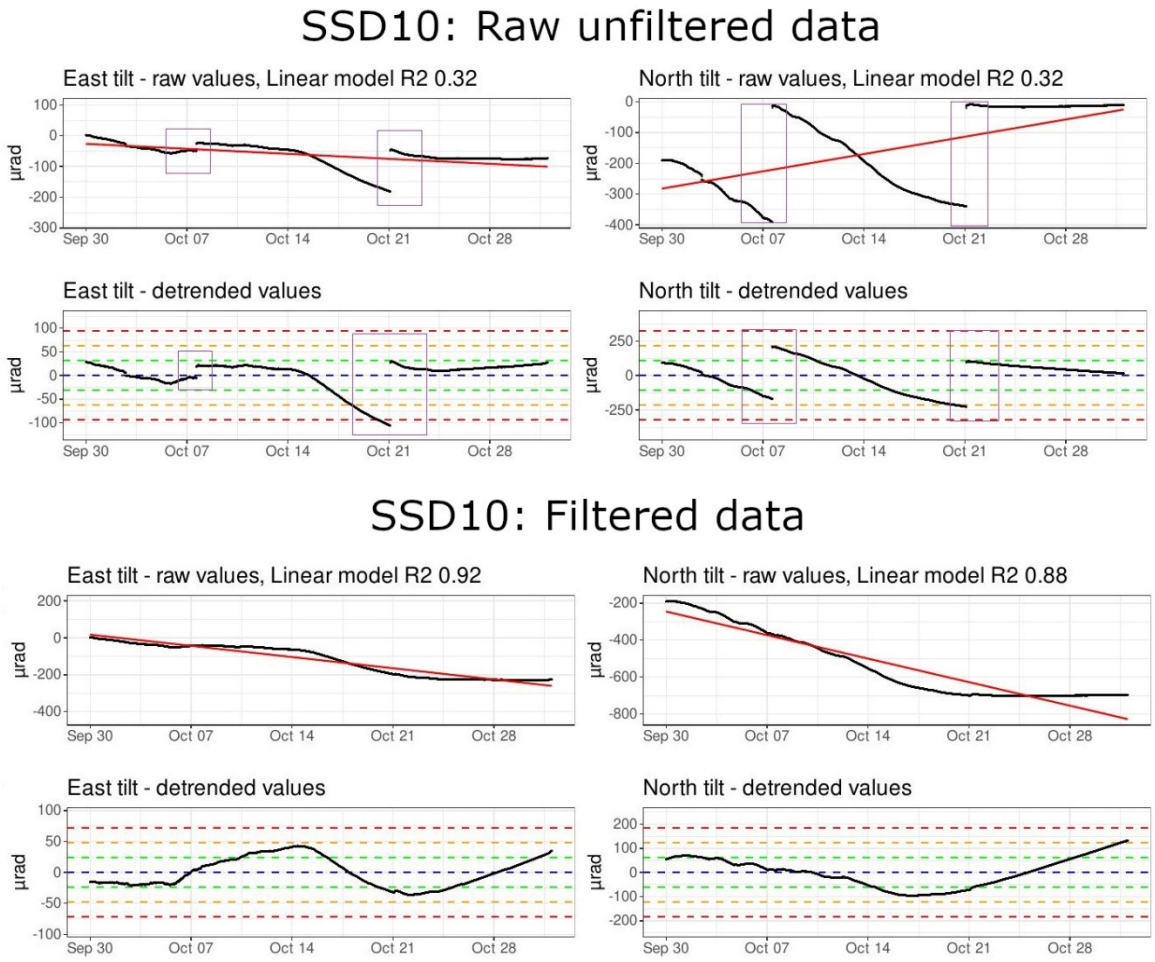



*Figure 3. An example of both a raw unfiltered tilt record and a filtered tilt record from October 2024 at station SSD10. The magenta rectangle highlights two distinct, nearly instantaneous shifts in the tilt signal. The lower set of plots displays the SSD10 tilt signal after the shifts at the station have been removed. It is important to note that there is no adjustment period present.*

Minor, random anomalies in the tiltmeter time series data were also observed that were unrelated to weather and were likely linked to local, possibly shallow features in the subsurface, such as movement in the cap rock.

Prolonged abnormal behavior was observed at SSD10 in October (after two shifts were removed), with the tilt trend changing several times. As with similar observations in September, the SSD10 site behavior still cannot be explained with certainty, but mechanical site disturbance and/or equipment malfunction are considered the most likely scenarios. This station will continue to be monitored to determine if equipment replacement is necessary. A north-south trend change was observed at SSD15 in late

October. We suspect this could be related to a new laydown area for construction activities in close proximity to the station.

The tilt data are manually reviewed daily, using a 7-day rolling window, to identify any trend changes that are consistently observed at several tiltmeter sites over a period lasting at least a few days. The October tiltmeter data shows no consistent pattern of ground movement that suggests deep-sourced deformation or any immediate concern with Cavern 7.

**Summary of GNSS observations for October 2024**

In October 2024, the GNSS network operated without interruption.

For this report, we have evaluated the full data history starting at the beginning of June 2024 to improve measurement precision. The plots for each GNSS station are shown in Appendix 2.

The east, north, and vertical deformation time series at each GNSS site are used to compute the annual deformation rate in a local reference frame. During October, daily measurements supported an established deformation trend, with a few of the GNSS sites recording horizontal motion directed approximately toward Cavern 7 and vertical motion indicating subsidence.

As previously described, the abnormally fast vertical motion at the NW GNSS station is related to field operations near the site in mid-July, and data from mid-July to the end of October appear stable.

**Analysis Maps**

Three maps have been created to visually summarize the results of the current analysis. These maps are shown below and are also provided in Appendix 3. Figure 4 is a rate vector map that portrays the direction and magnitude of the deformation rates that were identified for each tiltmeter and GNSS station by linear regression. Figure 5 portrays rose diagrams of the daily tilt direction frequency for each tiltmeter for the full data history from June 2024 to present. Figure 6 portrays daily tilt direction frequency for the current monthly reporting period.

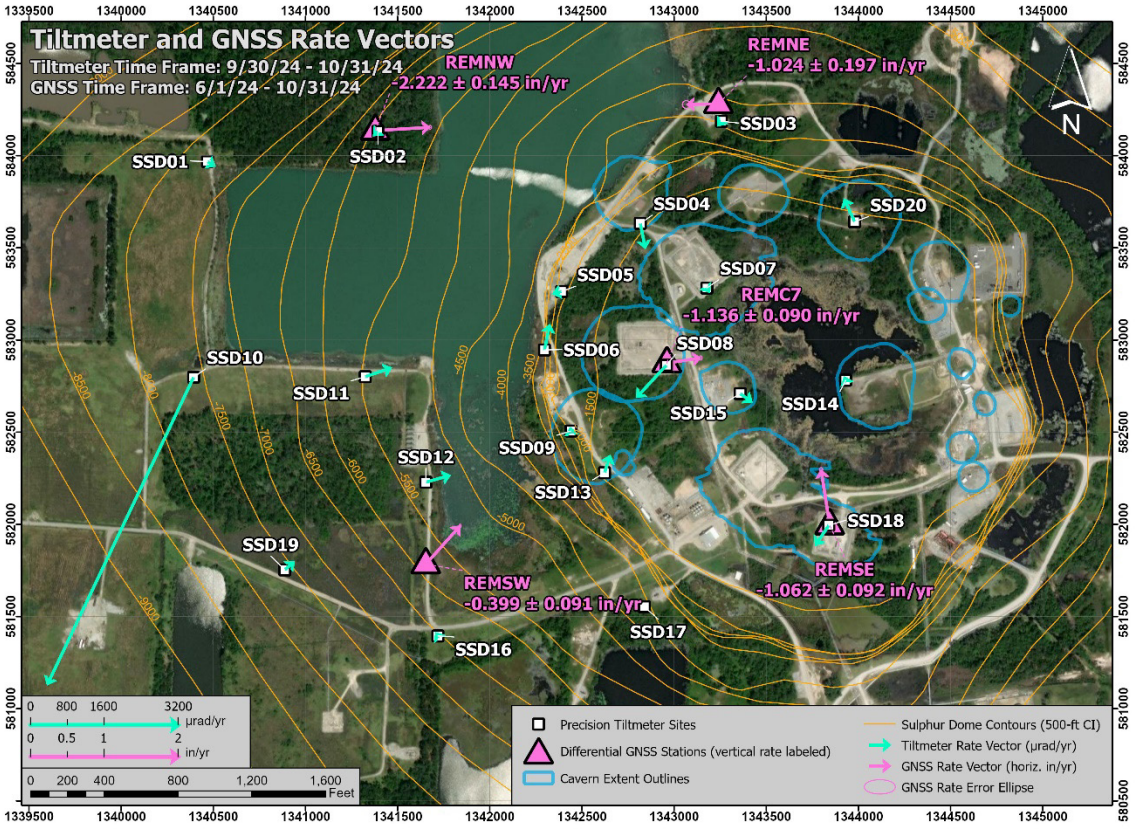



*Figure 4. Map of deformation rate vectors for the tiltmeters and GNSS stations over their respective evaluated time frames. The tiltmeter vectors are shown in cyan and scaled according by their respective values in units of microradians per year. The GNSS vectors and their corresponding error ellipses (derived from east and north rate errors) are shown in pink representing inches of horizontal movement per year. The GNSS stations are additionally labeled with the vertical motion rate and corresponding error value.*

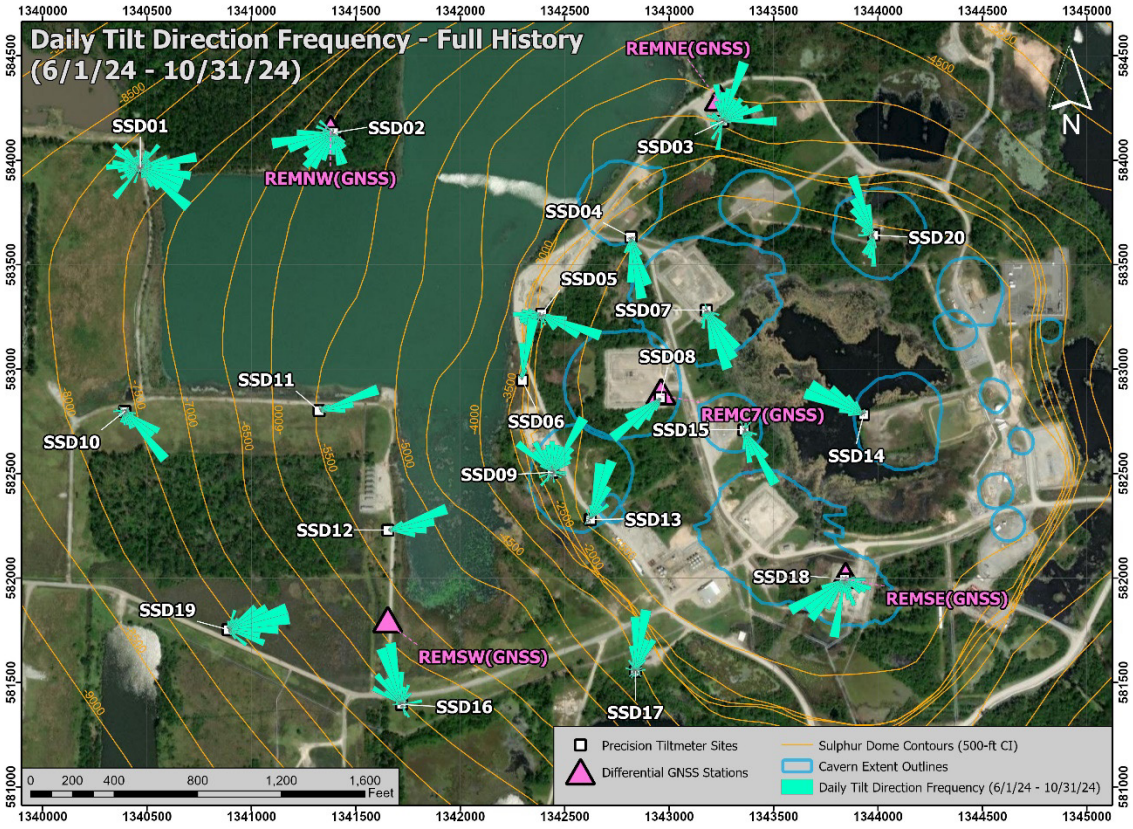



*Figure 5. Map of daily tilt direction distribution for each tiltmeter for the full data history beginning in June 2024. Rose diagrams indicate the number of days that tilt was oriented along specific azimuths (bin size is 10°).*

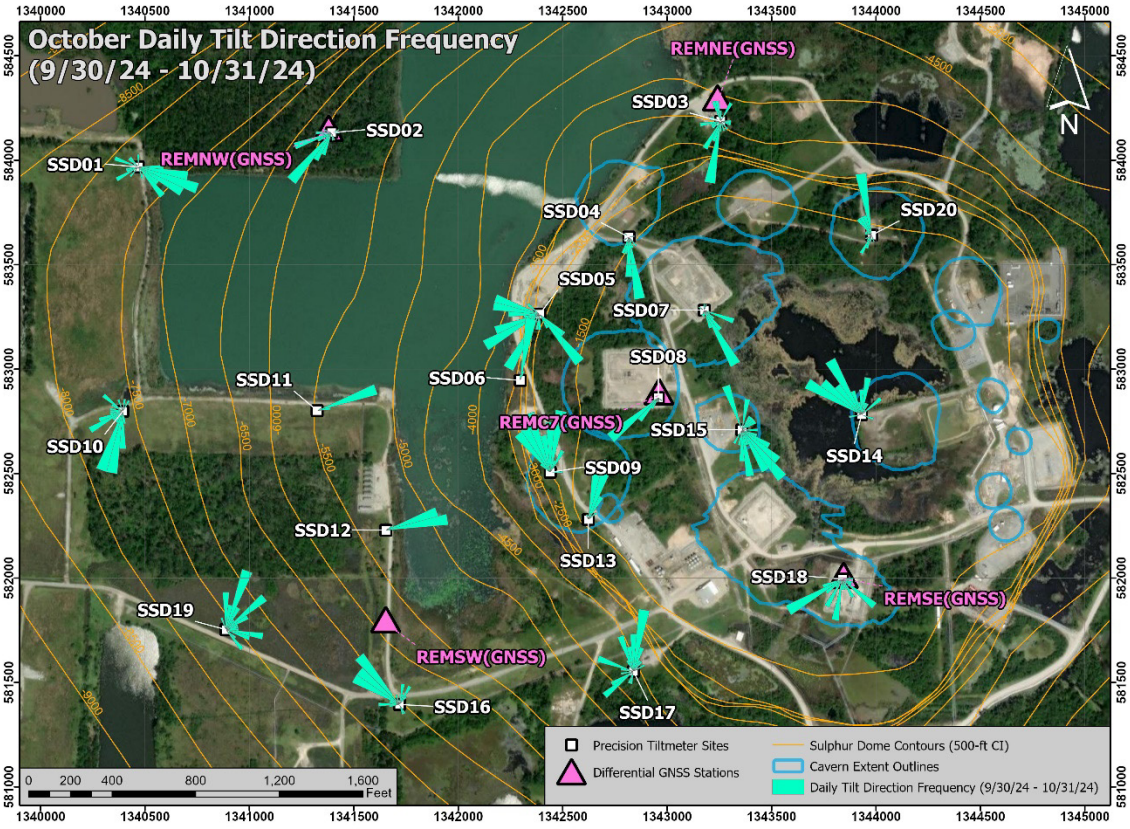



*Figure 6. Map of daily tilt direction distribution for each tiltmeter for the current monthly reporting period. Rose diagrams indicate the number of days that tilt was oriented along specific azimuths (bin size is 10°).*

**Deformation Alert System Update**

We are developing a draft deformation alert system that will incorporate both the direction and magnitude of tiltmeter readings. Over several months, we have observed short-duration anomalous tilt signals associated with precipitation and mechanical activities near the monitoring sites. The ongoing tilt trends reflect ambient deformation processes and future tilt signals related to possible deep deformation at Cavern 7 will be superimposed on these trends. We continue investigating various computational techniques for detecting small but coherent signals occurring at several sites embedded in the background deformation processes.

The tilt array will be used to measure and detect consistent tilt patterns on the entire array that indicate tilt vectors toward the Cavern 7 area across multiple stations to trigger an alert. These tilt signals will be observed at many tiltmeter stations and are expected to persist for extended periods. Our theoretical deformation (Mogi) modeling (discussed in

the deformation monitoring plan dated December 22, 2023) indicates that deep deformation associated with potential changes in volume at Cavern 7 (located at a depth of approximately 2,500 to 3,160 feet) is expected to impact the entire tiltmeter array. If the deformation moves upward from Cavern 7, we anticipate that the corresponding tiltmeter response will be concentrated at the stations nearest the cavern, and the tilt magnitude will increase. In contrast, local, shallow deformation, such as movement in the caprock, is likely to affect only the nearby tiltmeters.

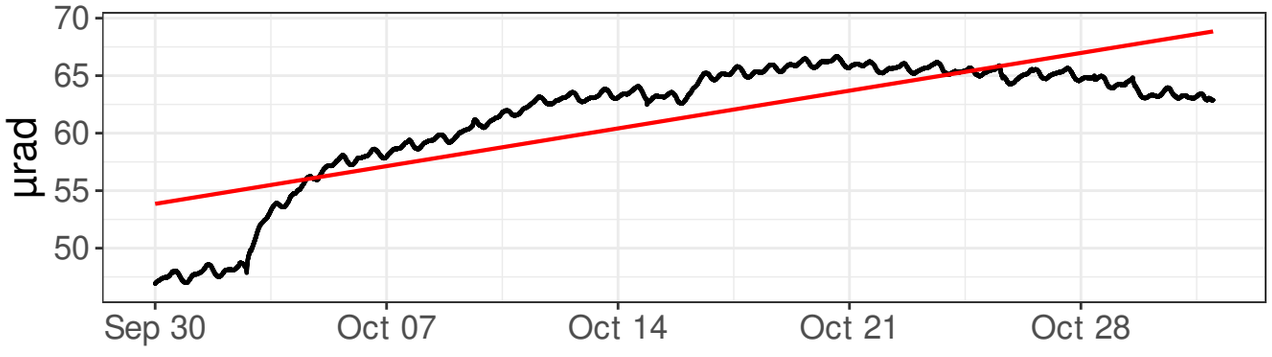
We anticipate that short-term deformation alert levels will be evaluated with the other real-time monitoring observations currently active at Sulphur Mines, which include the Cavern 7 pressure and microseismic monitoring. Additionally, long-term trends from GNSS and InSAR, which typically become available with some delay, will also be necessary for ongoing alert assessments.

# APPENDIX 1

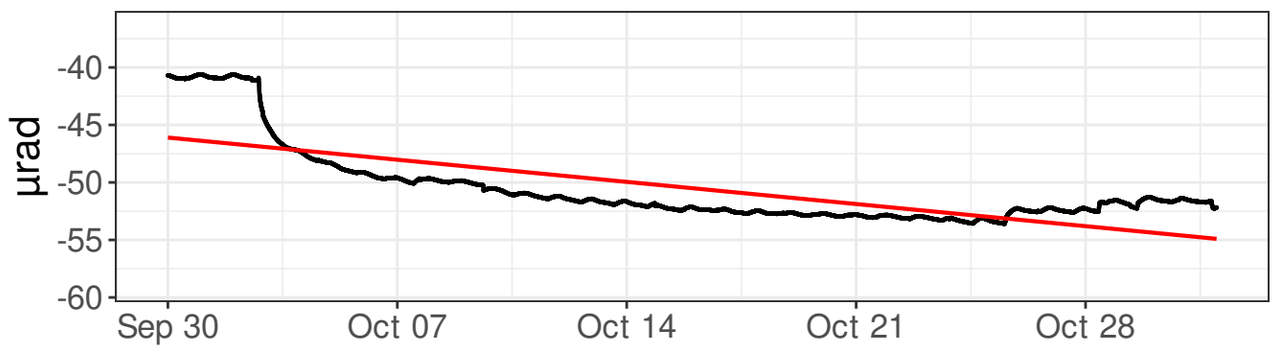
## Tiltmeter Data Plots

# SSD01, 09/30/2024 - 10/31/2024

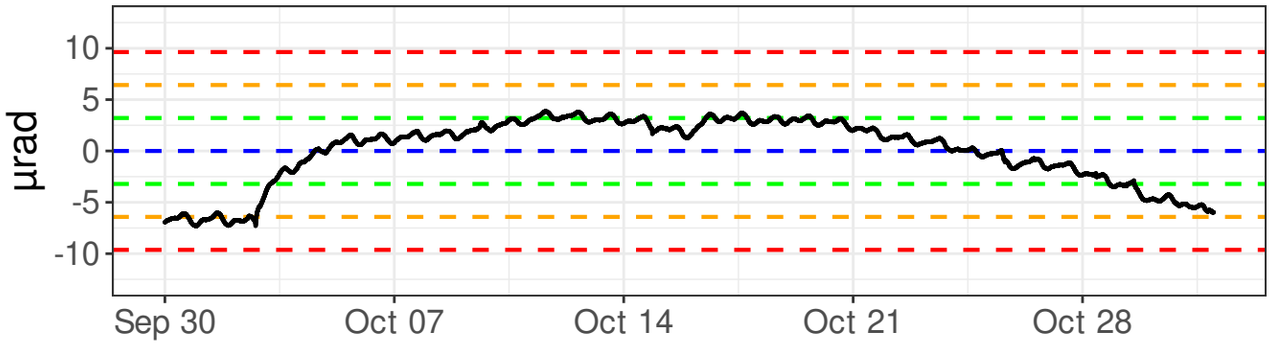
## East tilt - raw values, Linear model R2 0.65



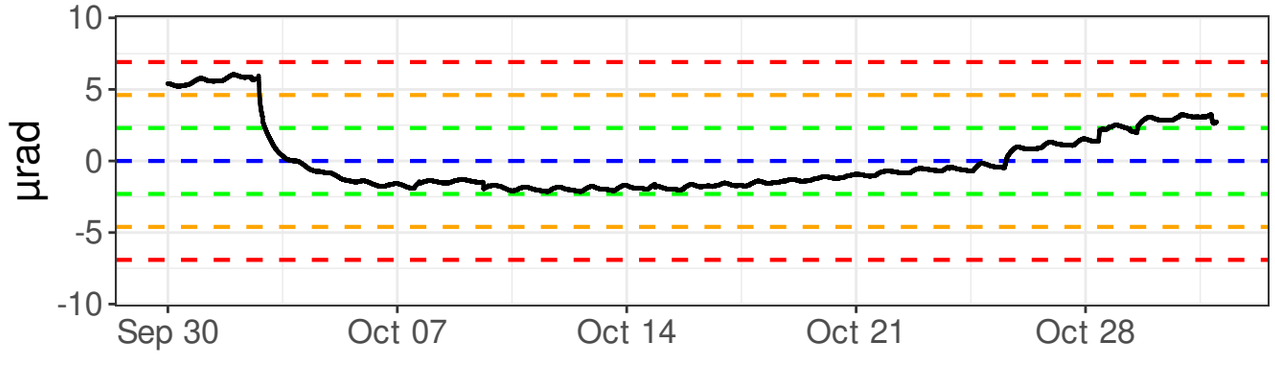

## North tilt - raw values, Linear model R2 0.55



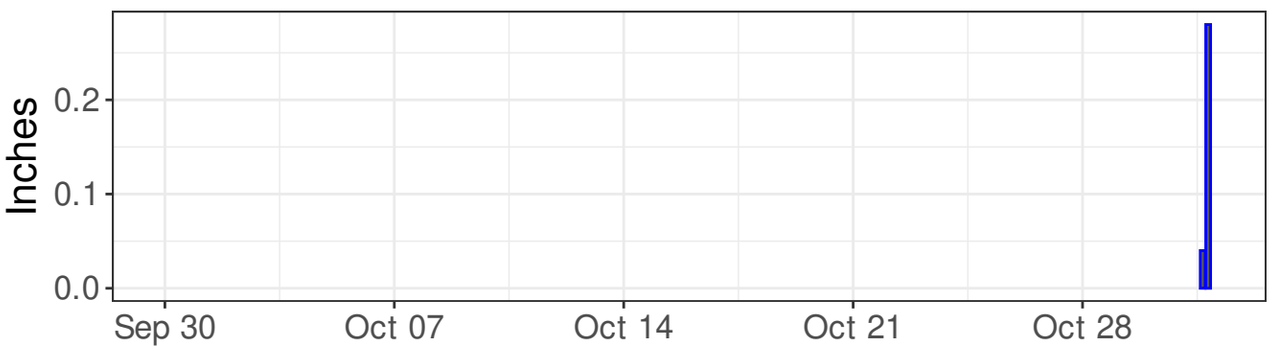

## East tilt - detrended values



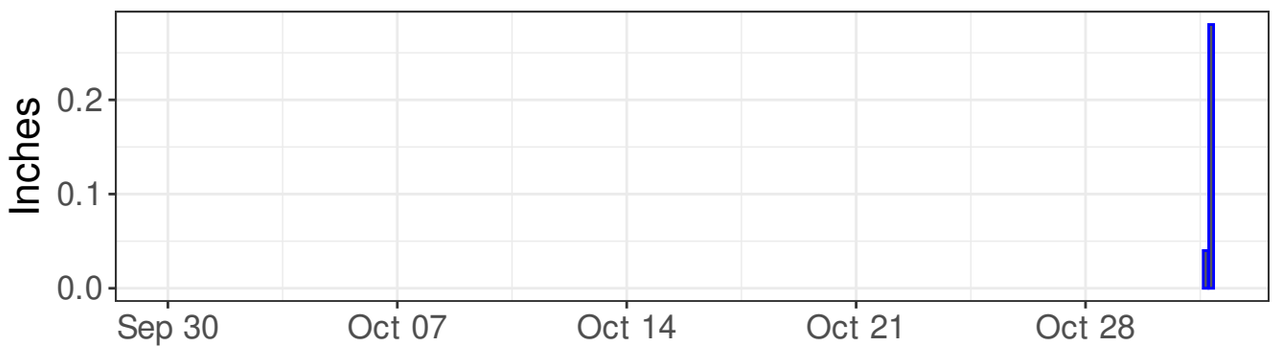

## North tilt - detrended values



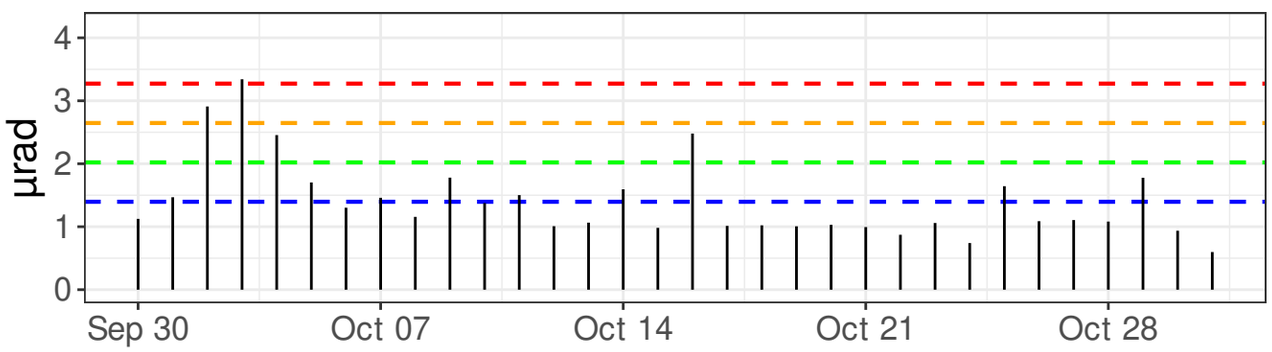

## Hourly precipitation



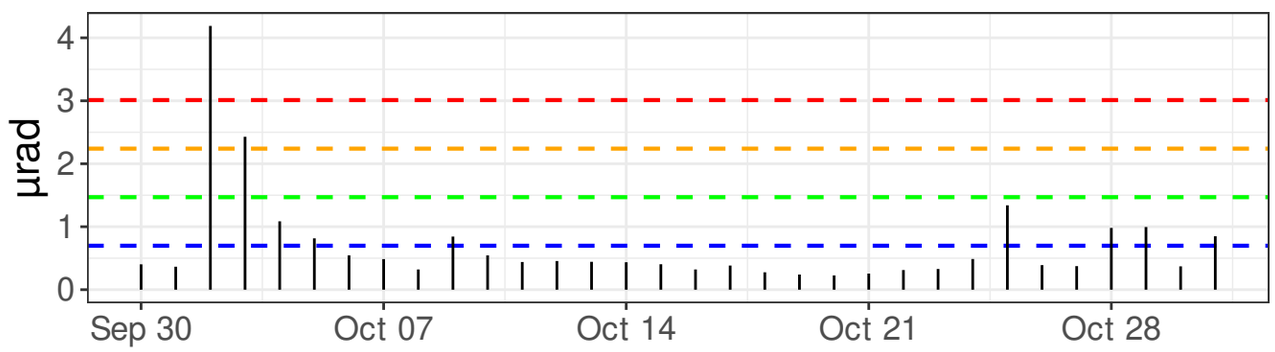

## Hourly precipitation



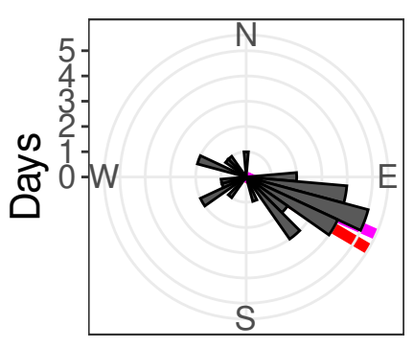

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 171.50 ± 1.18 µrad/year

North tilt rate: -100.72 ± 0.85 µrad/year

Azimuth to C7: 114 deg

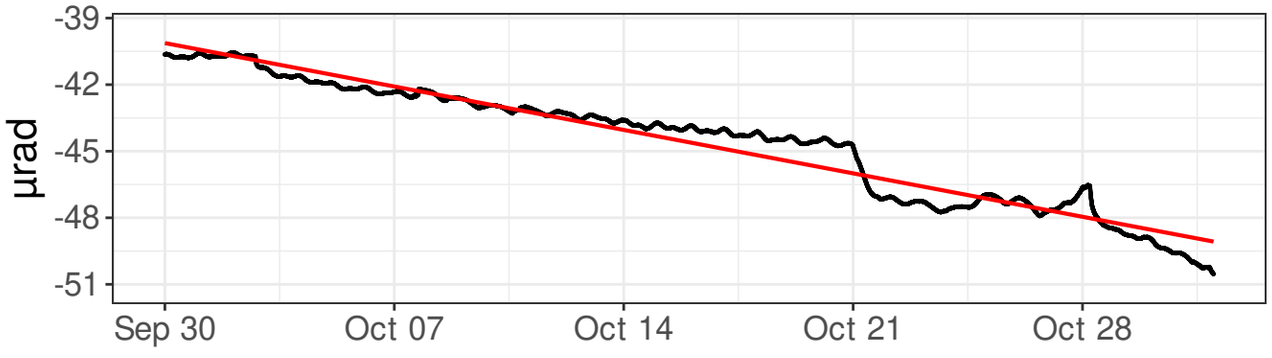
Distance to C7: 2538 ft

0σ 1σ 2σ 3σ

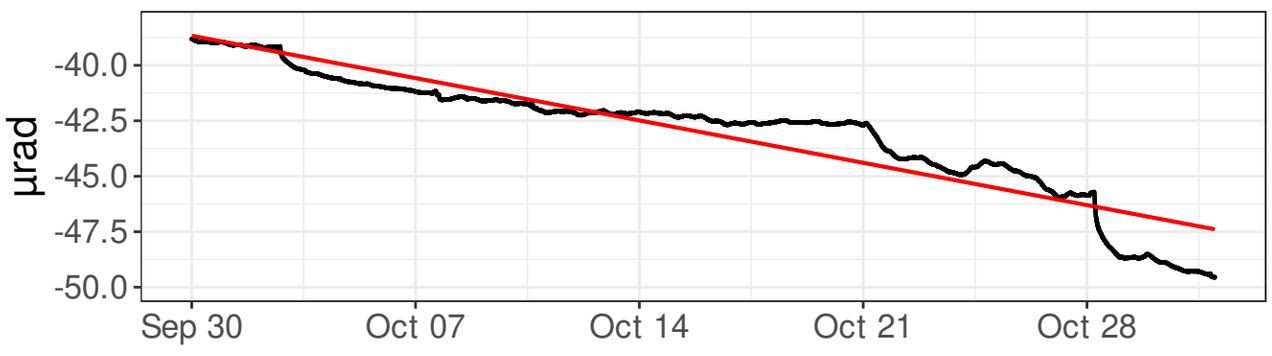
Linear model Azimuth to C7

# SSD02, 09/30/2024 - 10/31/2024

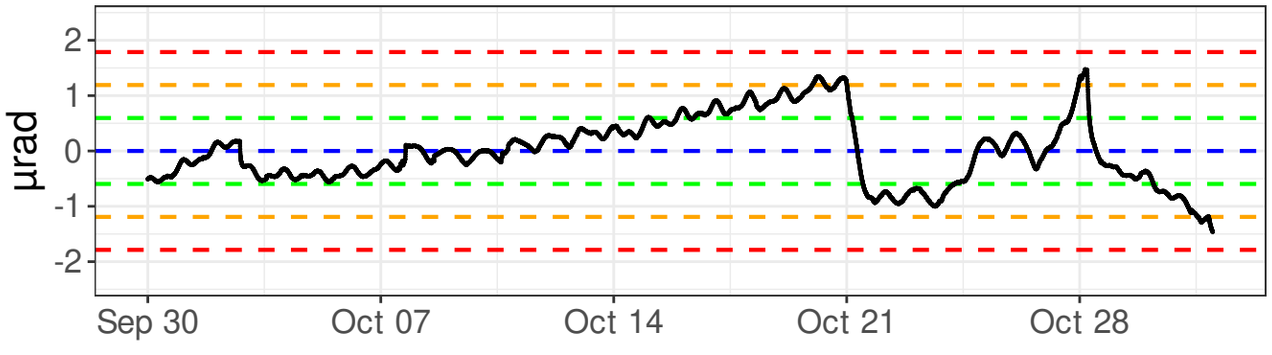
## East tilt - raw values, Linear model R2 0.95



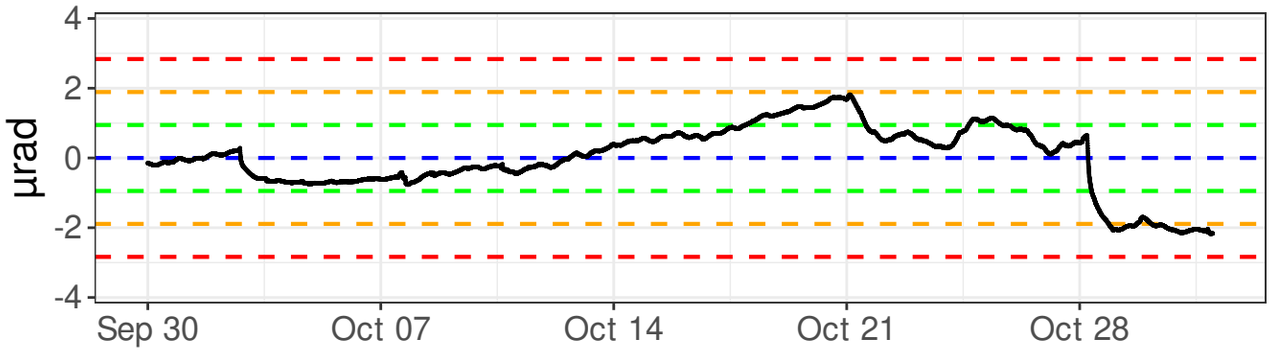

## North tilt - raw values, Linear model R2 0.88



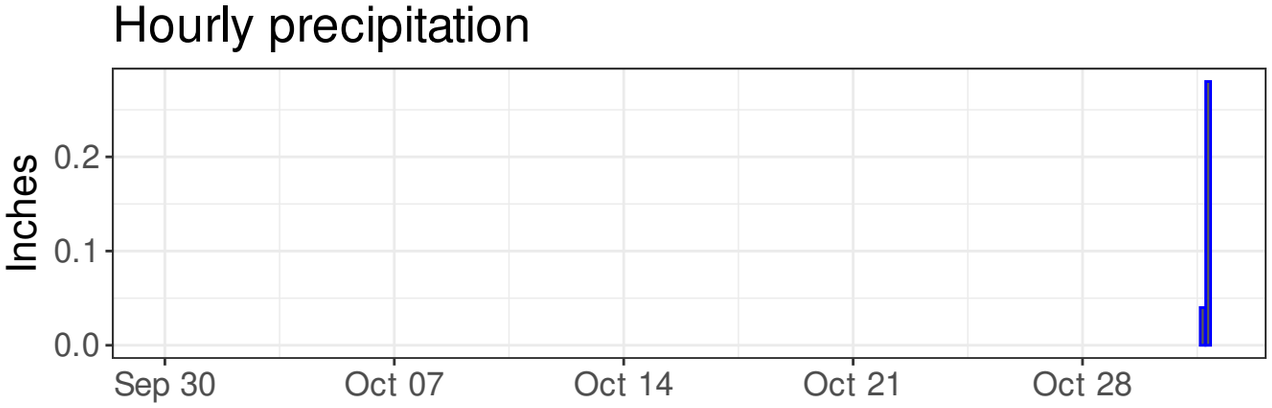

## East tilt - detrended values



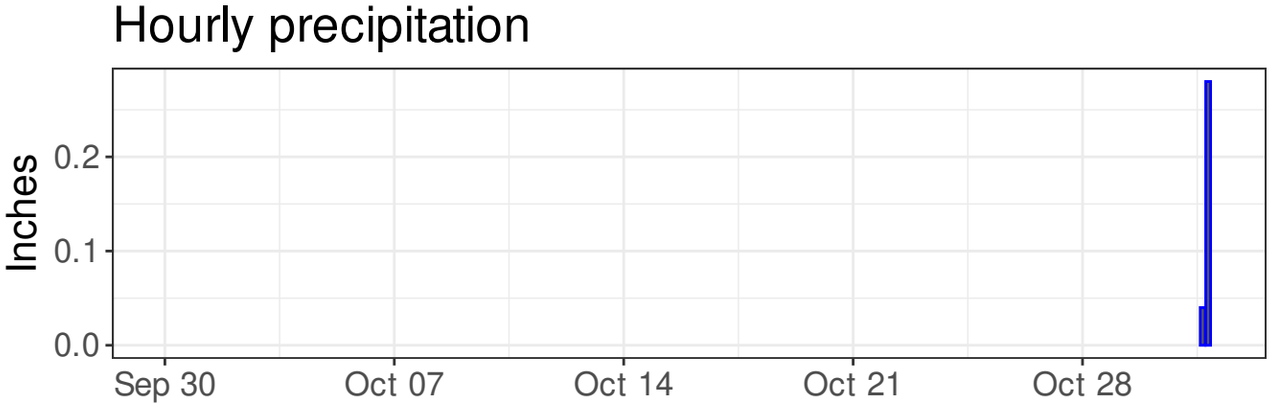

## North tilt - detrended values



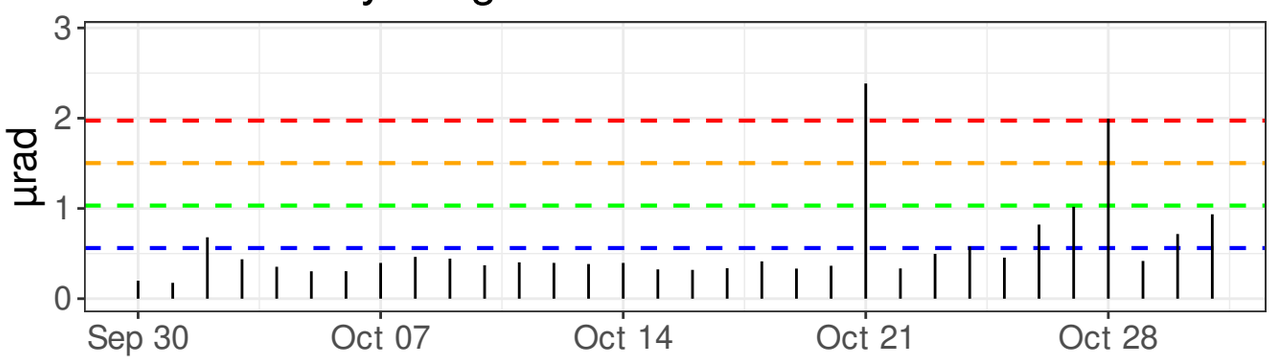

## Hourly precipitation



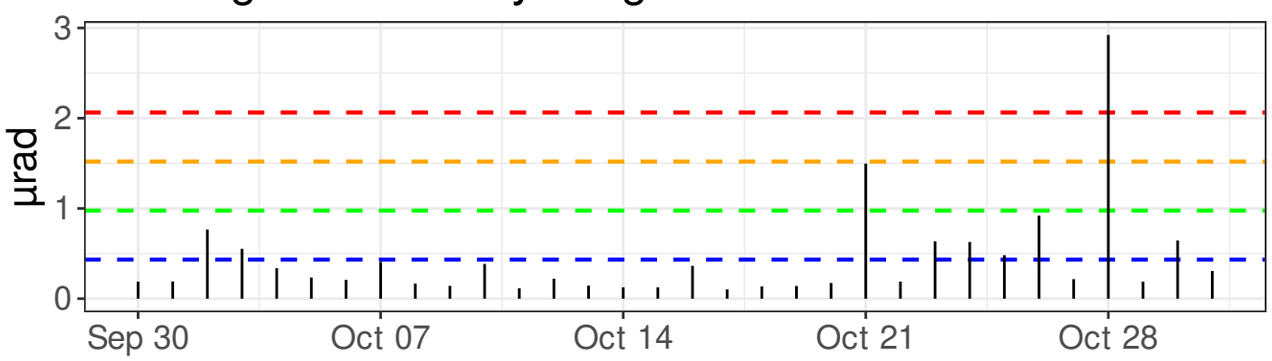

## Hourly precipitation



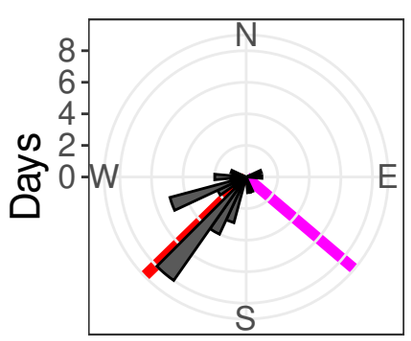

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -102.34 ± 0.22 µrad/year

North tilt rate: -99.78 ± 0.35 µrad/year

Azimuth to C7: 130 deg

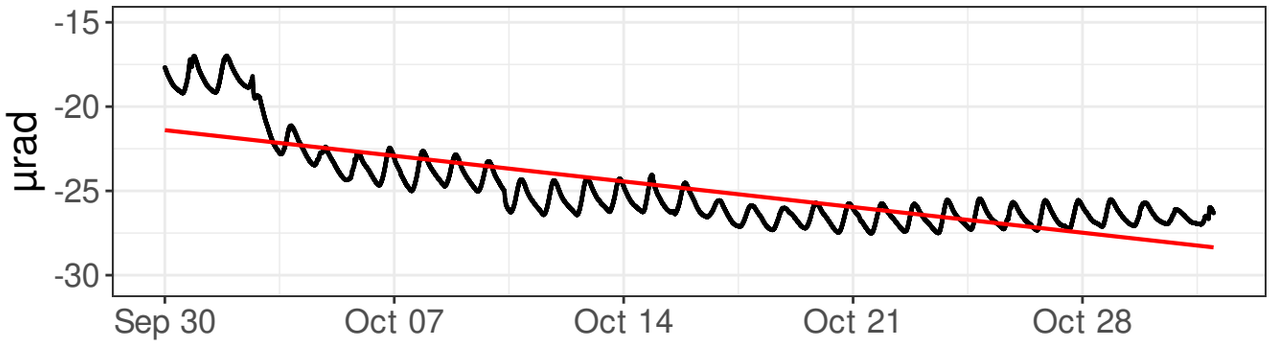
Distance to C7: 1834 ft

0σ 1σ 2σ 3σ

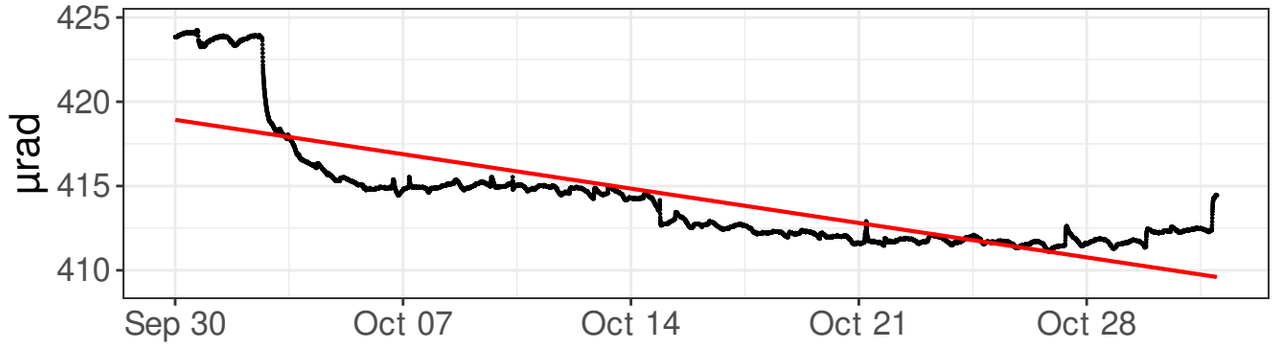
Linear model Azimuth to C7

# SSD03, 09/30/2024 - 10/31/2024

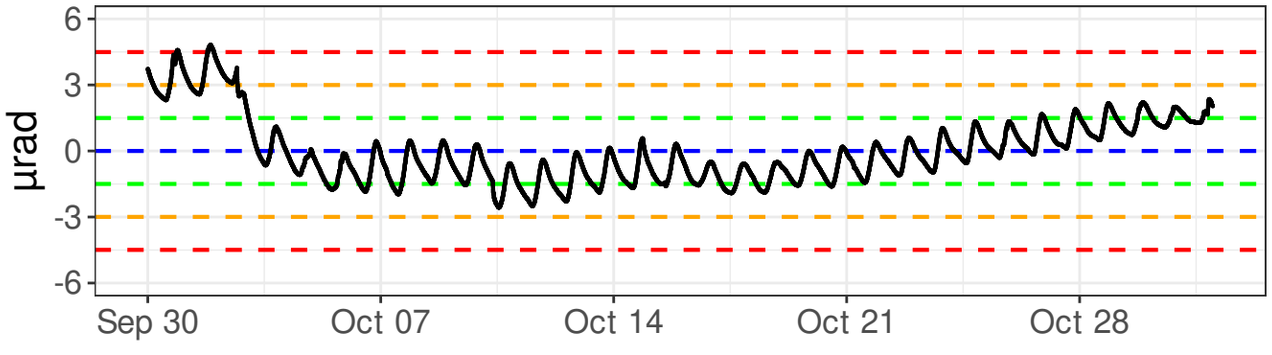
## East tilt - raw values, Linear model R2 0.64



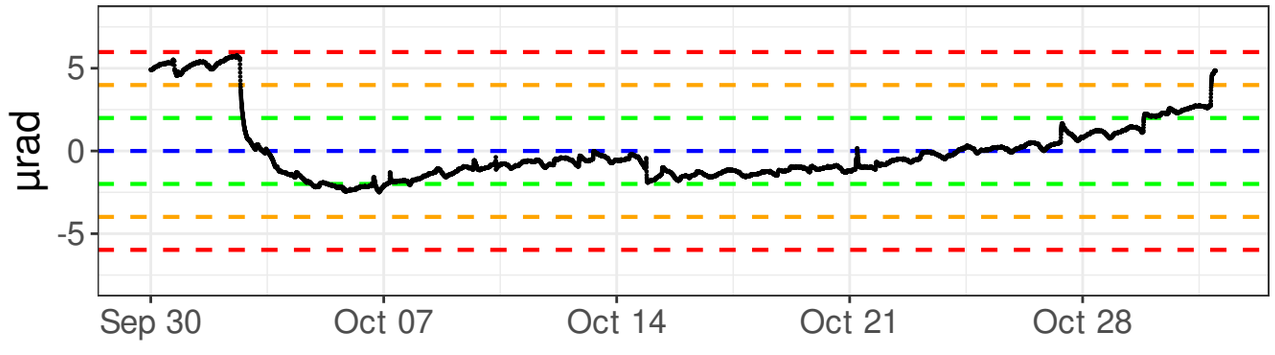

## North tilt - raw values, Linear model R2 0.65



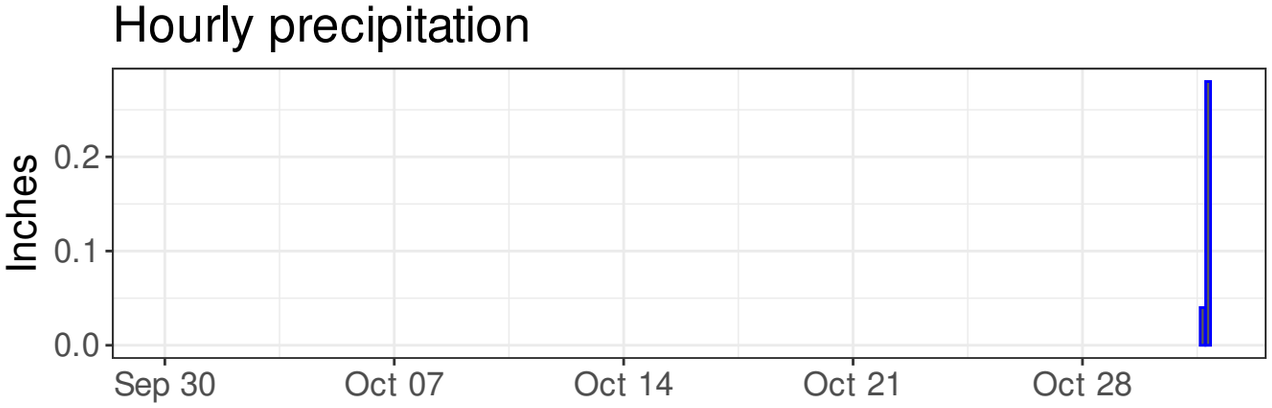

## East tilt - detrended values



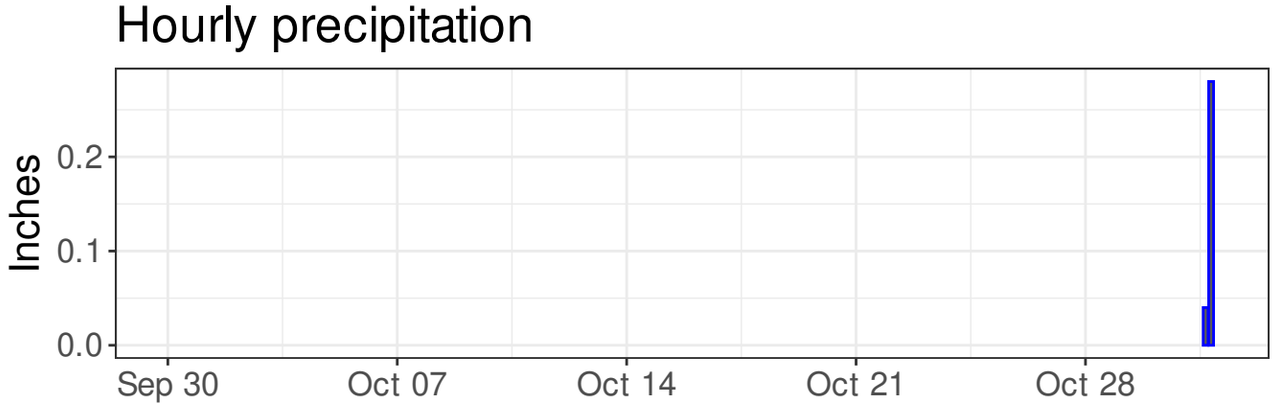

## North tilt - detrended values



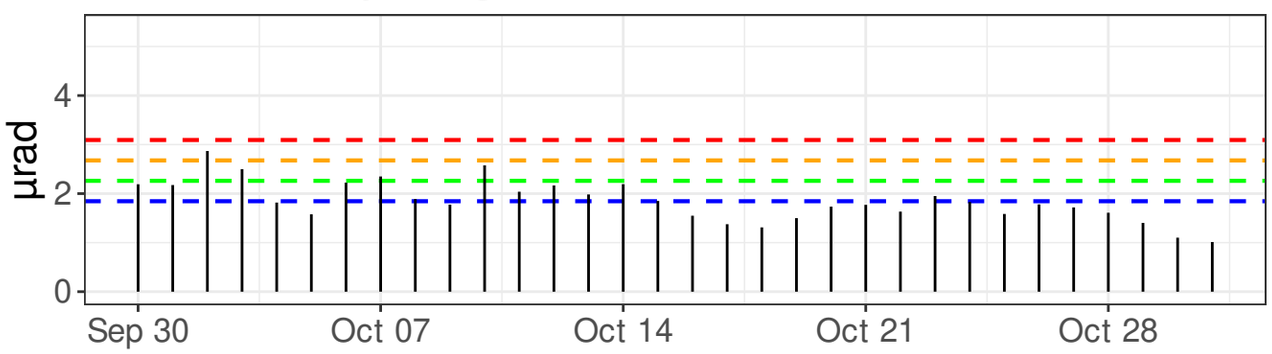

## Hourly precipitation



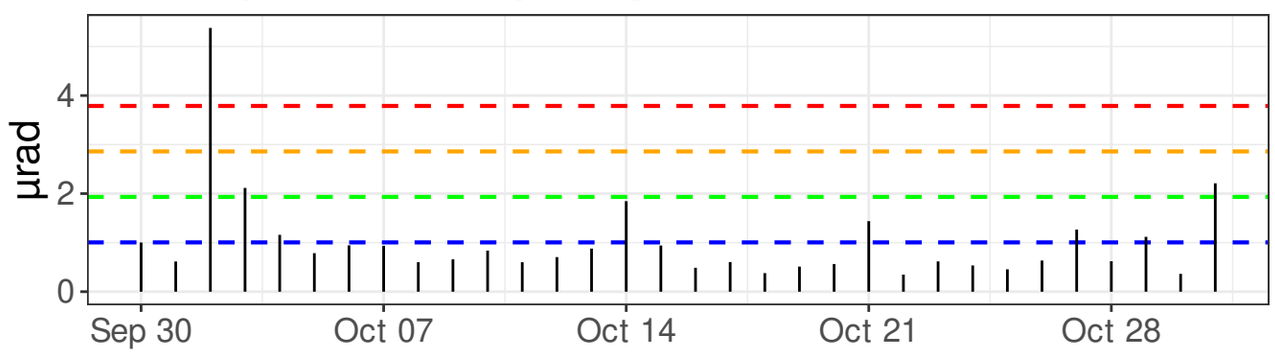

## Hourly precipitation



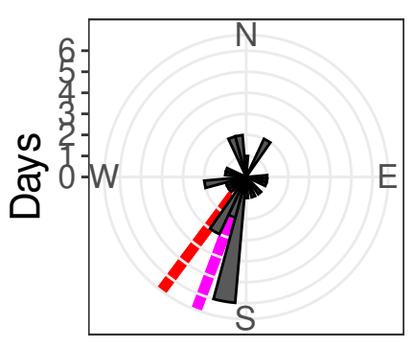

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -79.52 ± 0.55 µrad/year

North tilt rate: -106.66 ± 0.73 µrad/year

Azimuth to C7: 201 deg

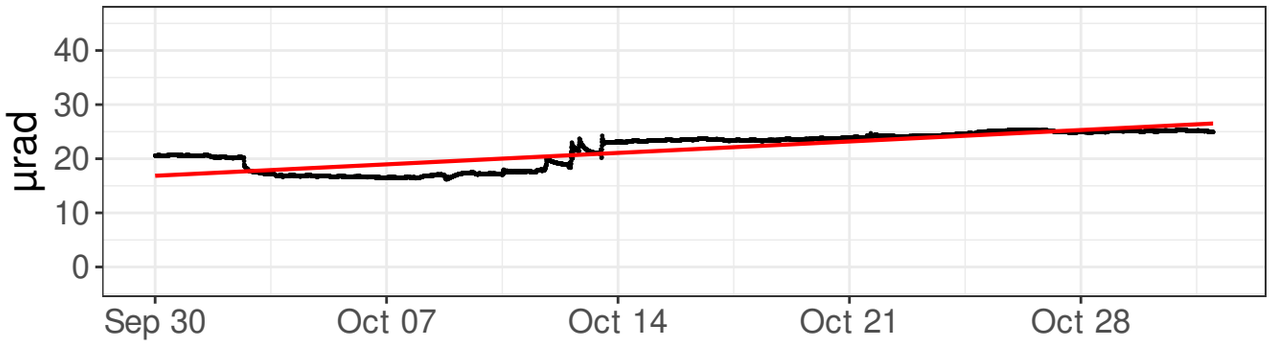
Distance to C7: 1326 ft

0σ 1σ 2σ 3σ

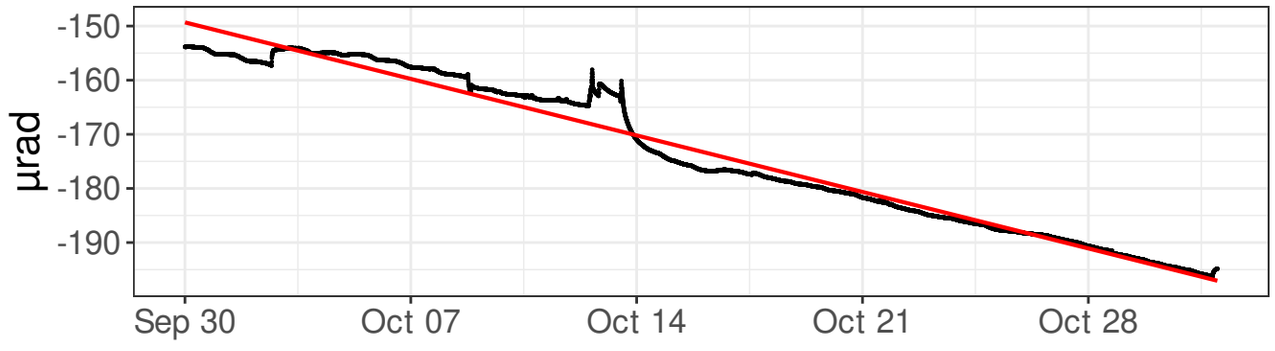
Linear model Azimuth to C7

# SSD04, 09/30/2024 - 10/31/2024

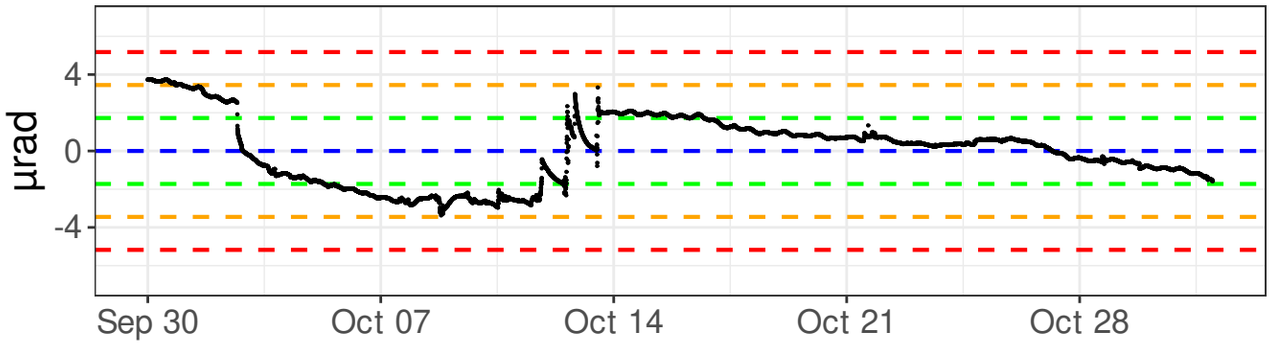
## East tilt - raw values, Linear model R2 0.72



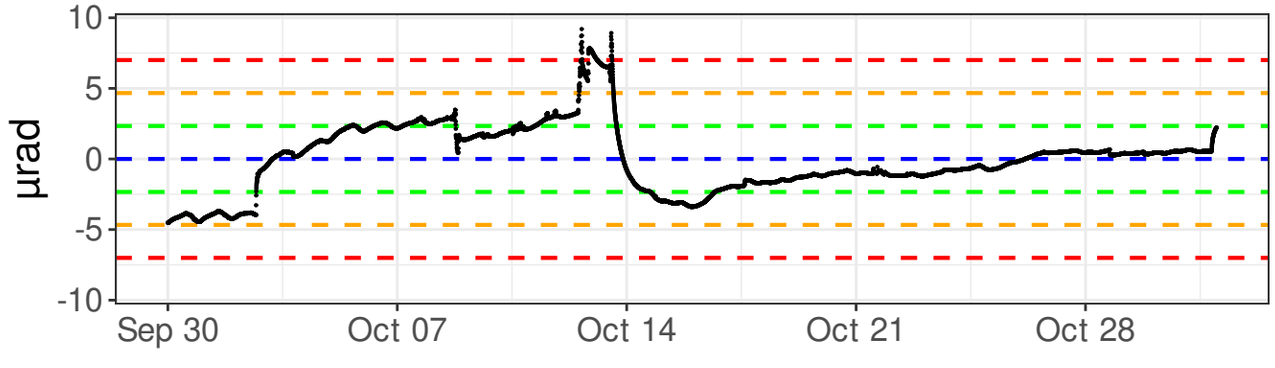

## North tilt - raw values, Linear model R2 0.97



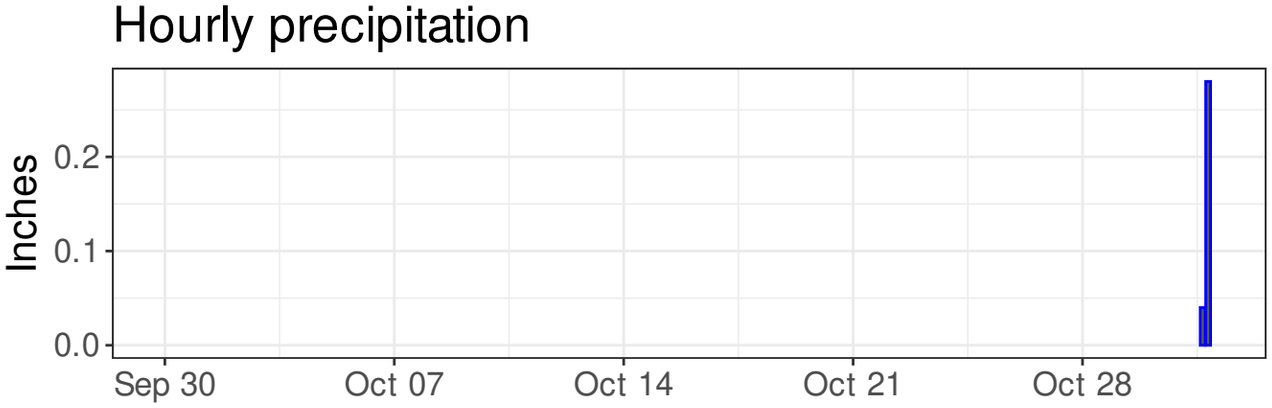

## East tilt - detrended values



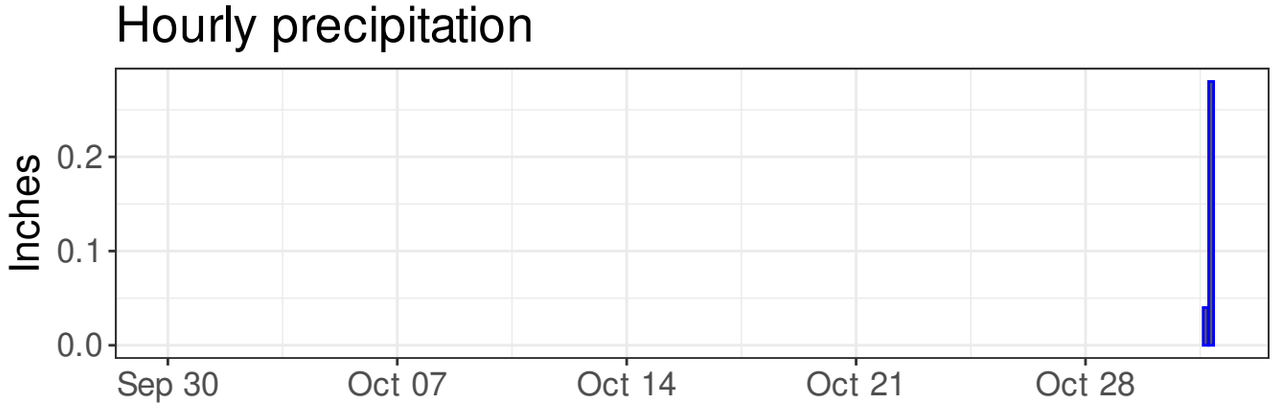

## North tilt - detrended values



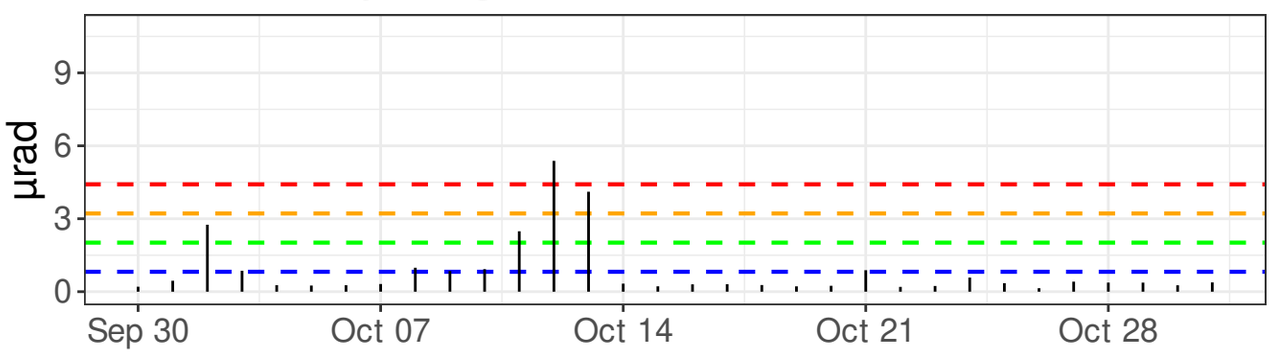

## Hourly precipitation



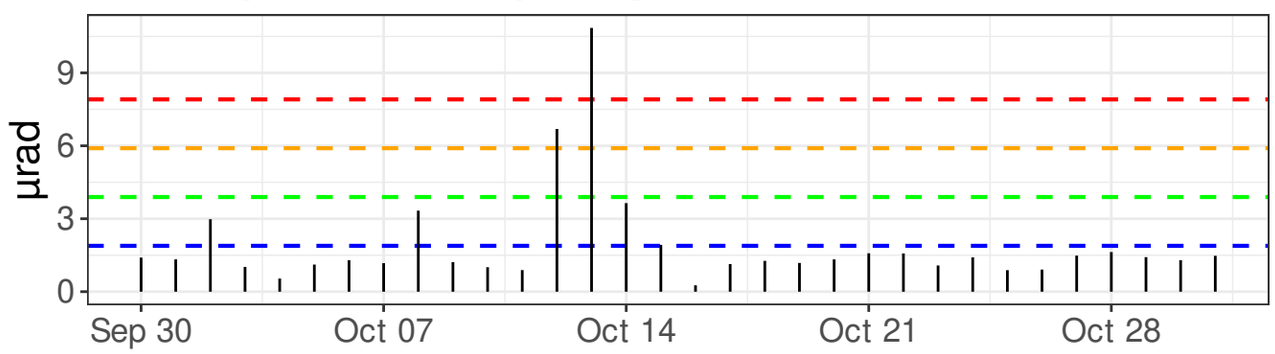

## Hourly precipitation



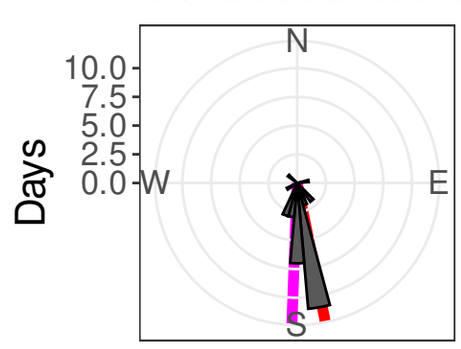

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 110.51 ± 0.64 µrad/year

North tilt rate: -545.99 ± 0.86 µrad/year

Azimuth to C7: 182 deg

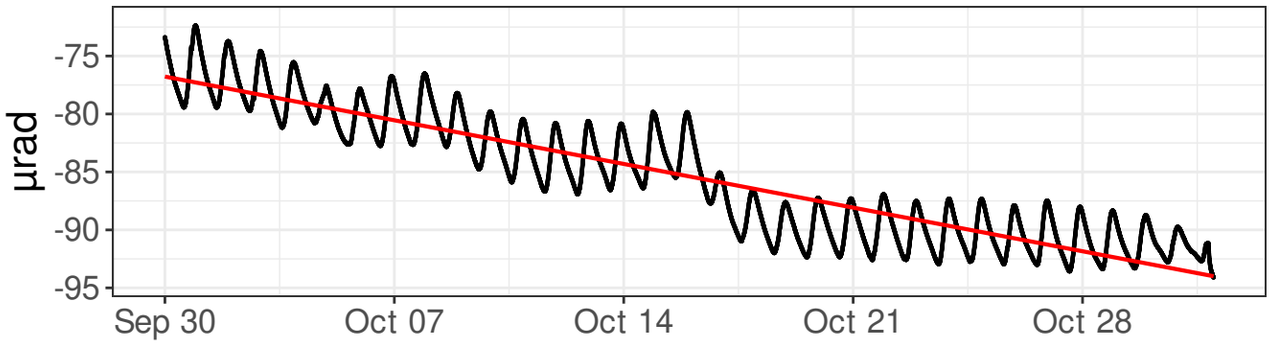
Distance to C7: 688 ft

0σ 1σ 2σ 3σ

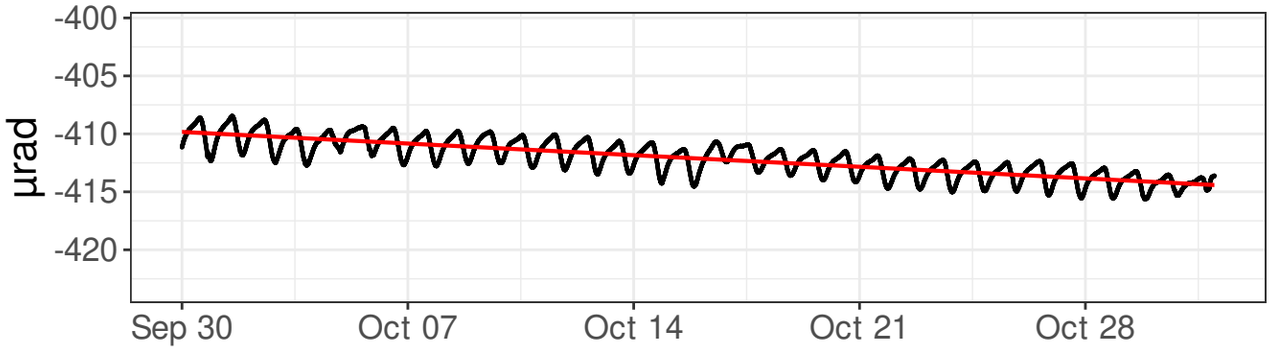
Linear model Azimuth to C7

# SSD05, 09/30/2024 - 10/31/2024

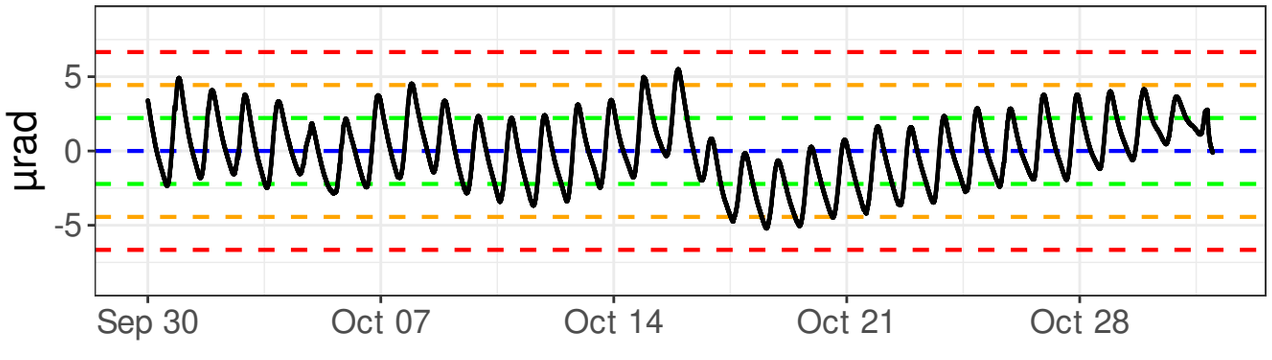
## East tilt - raw values, Linear model R2 0.83



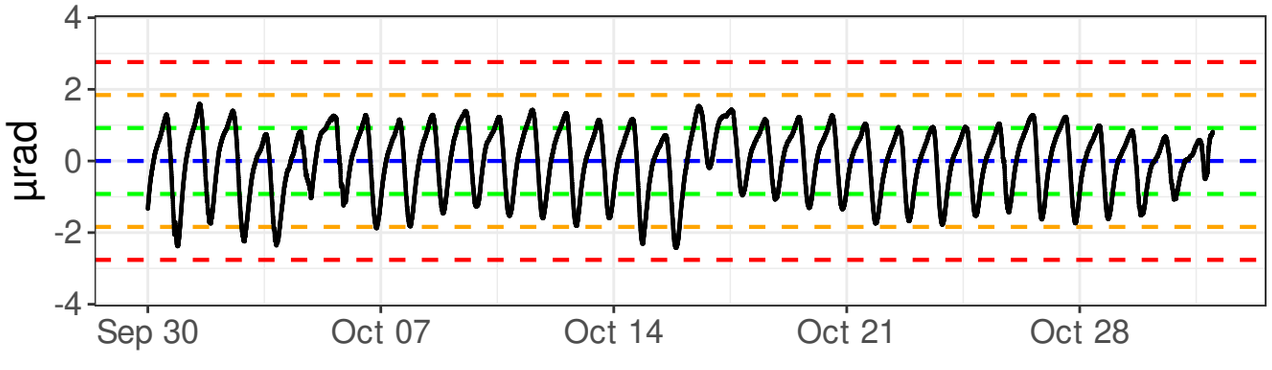

## North tilt - raw values, Linear model R2 0.67



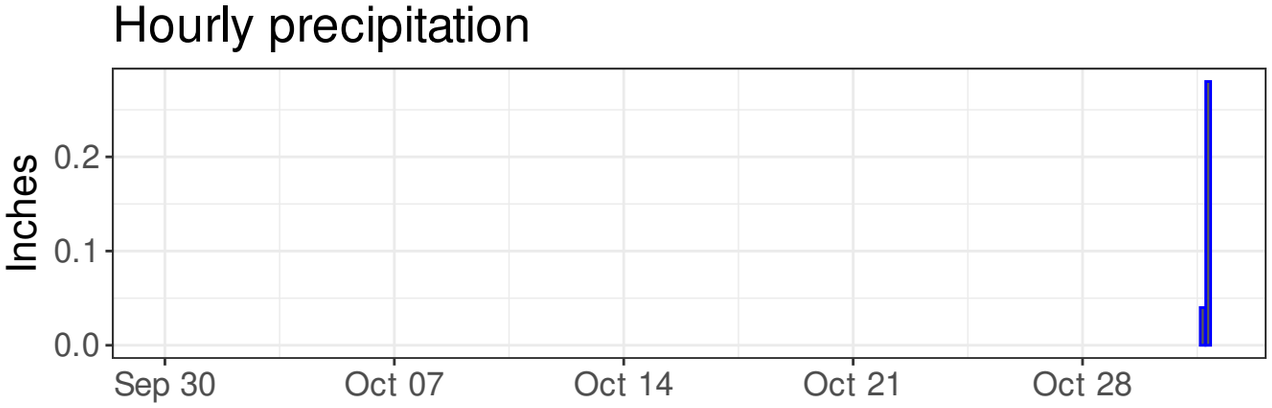

## East tilt - detrended values



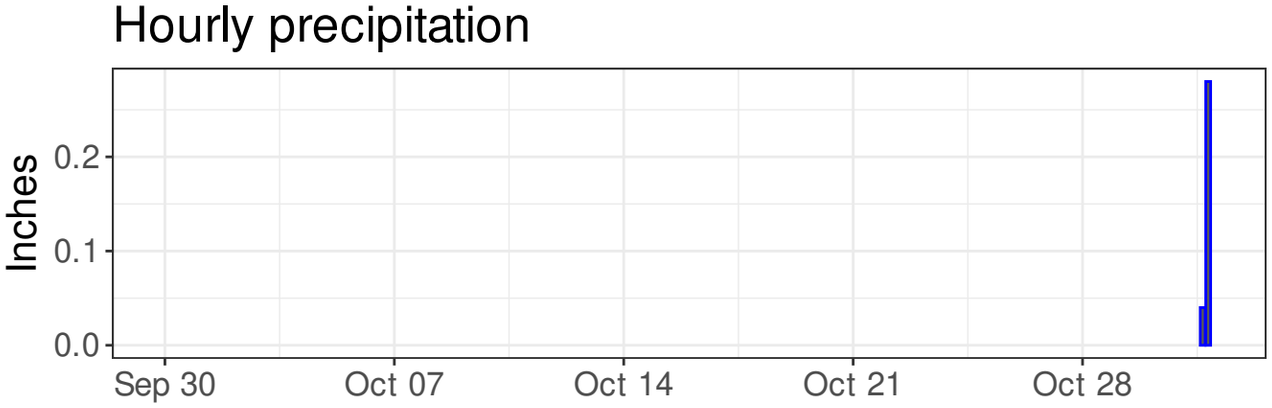

## North tilt - detrended values



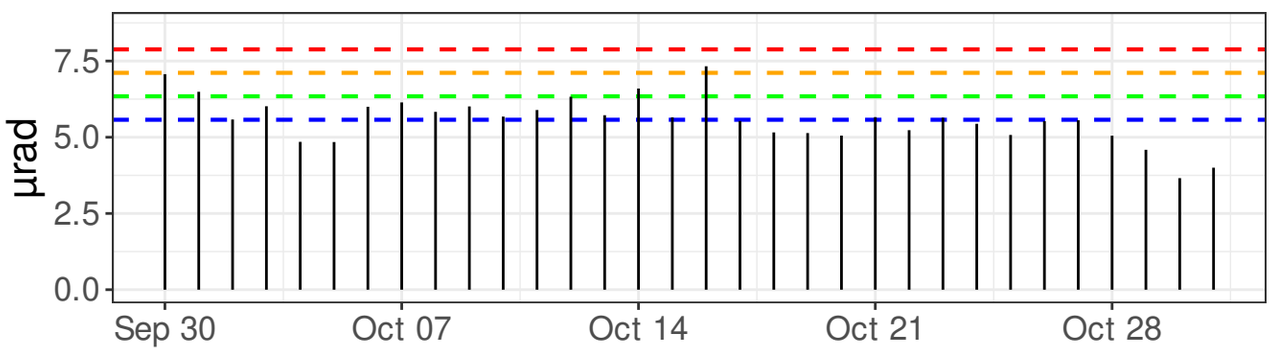

## Hourly precipitation



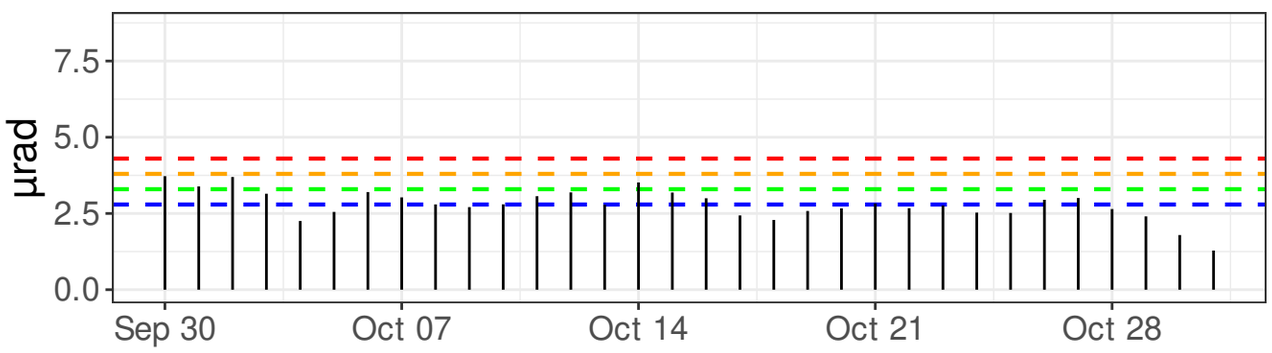

## Hourly precipitation



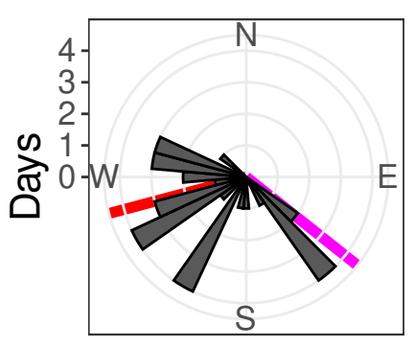

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -196.97 ± 0.82 µrad/year

North tilt rate: -52.39 ± 0.34 µrad/year

Azimuth to C7: 128 deg

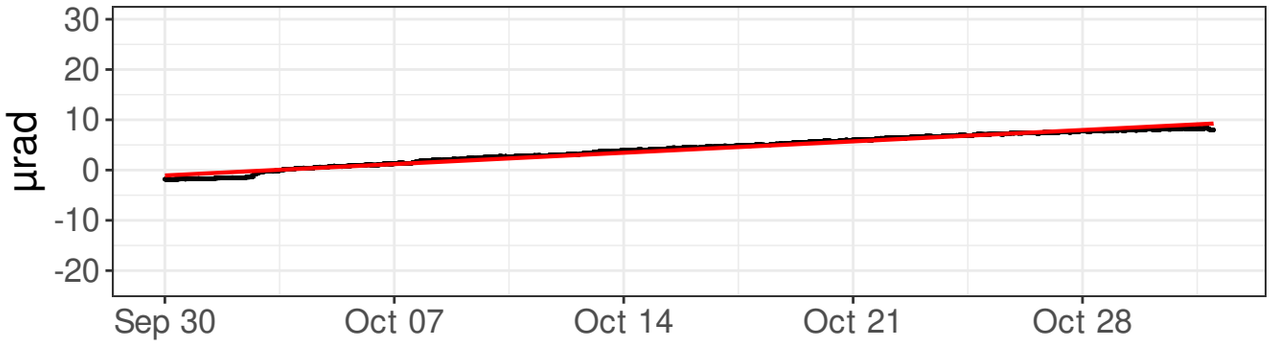
Distance to C7: 512 ft

0σ 1σ 2σ 3σ

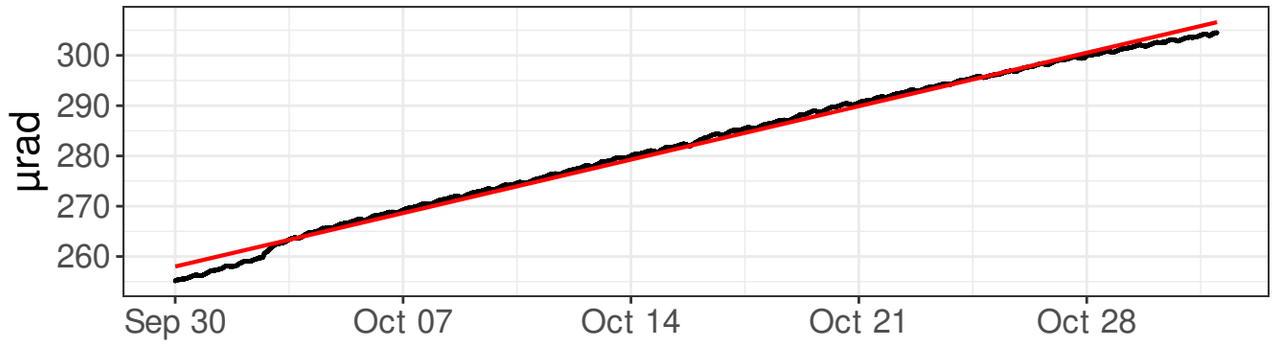
Linear model Azimuth to C7

# SSD06, 09/30/2024 - 10/31/2024

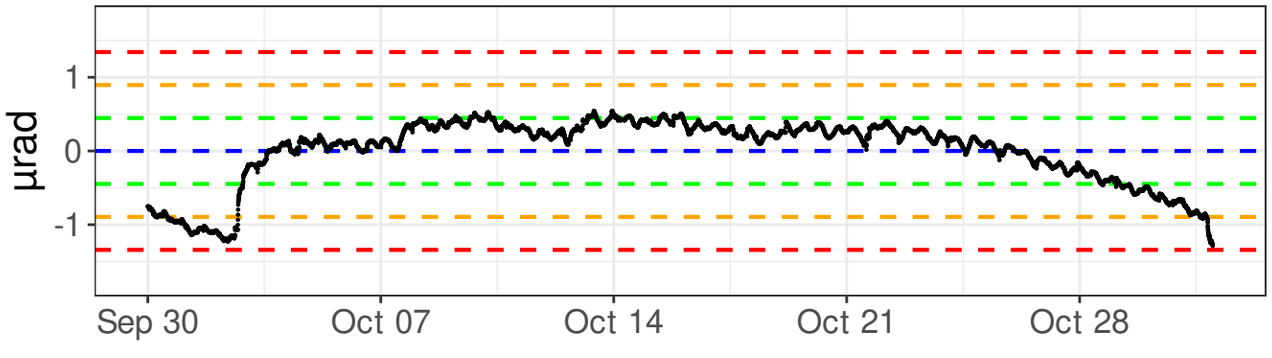
## East tilt - raw values, Linear model R2 0.98



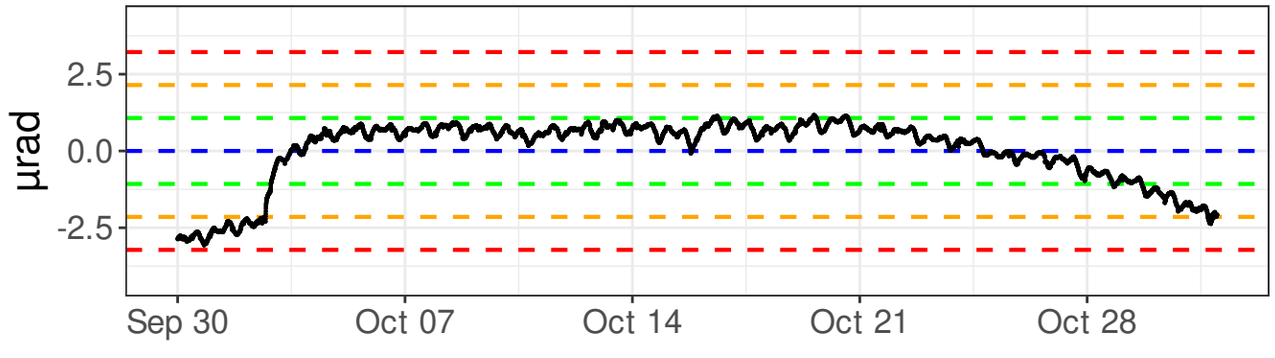

## North tilt - raw values, Linear model R2 0.99



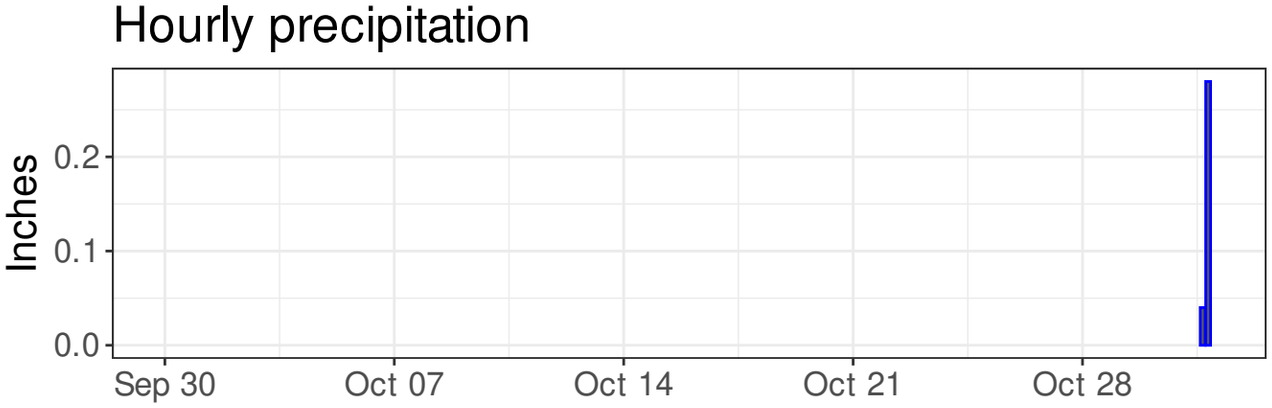

## East tilt - detrended values



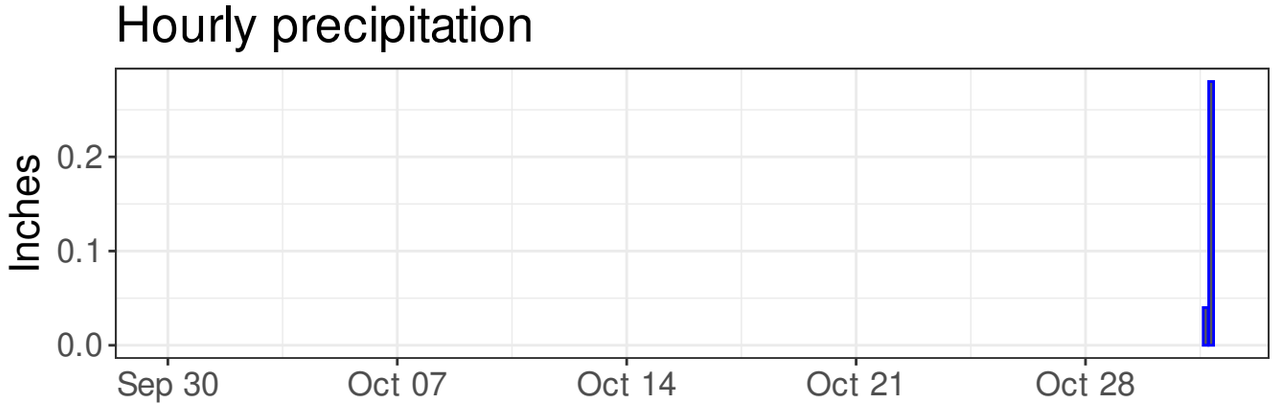

## North tilt - detrended values



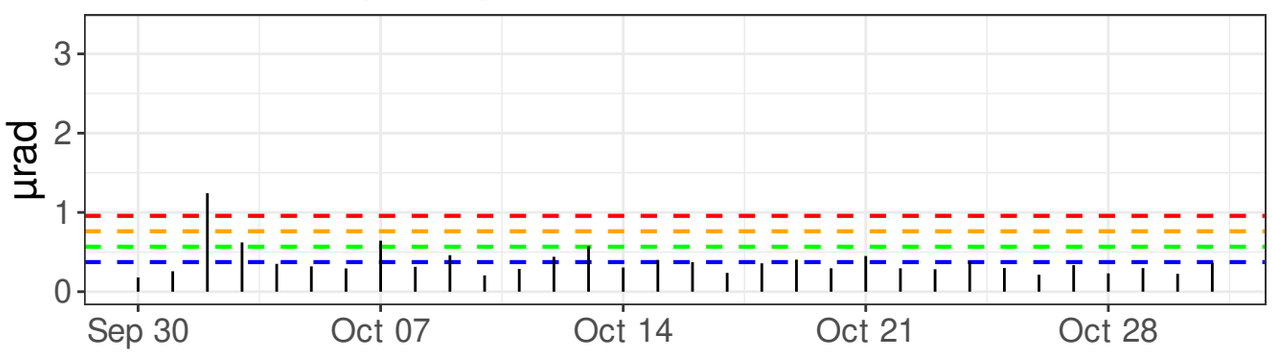

## Hourly precipitation



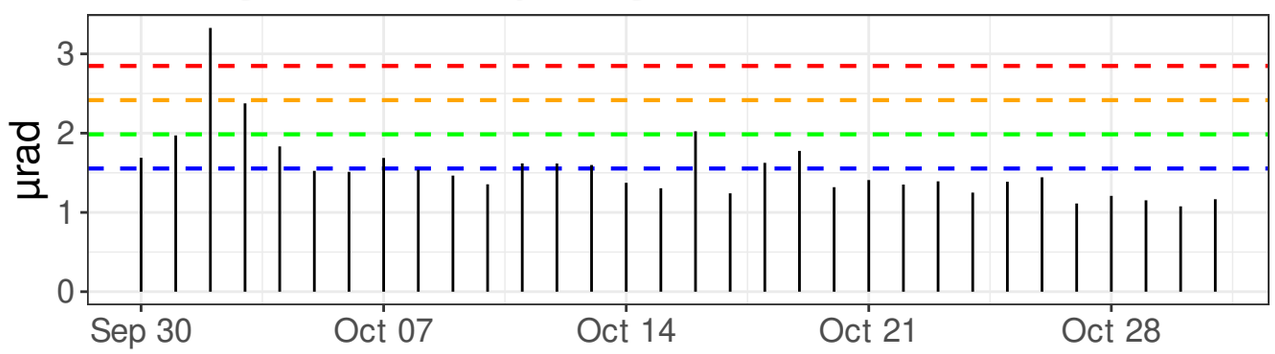

## Hourly precipitation



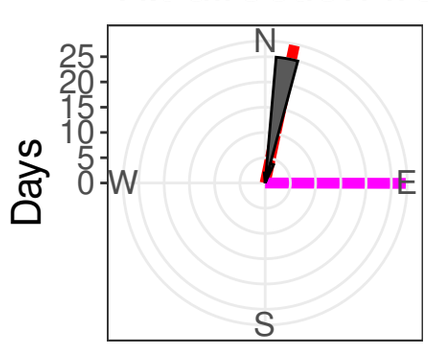

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 118.19 ± 0.16 µrad/year

North tilt rate: 555.89 ± 0.40 µrad/year

Azimuth to C7: 90 deg

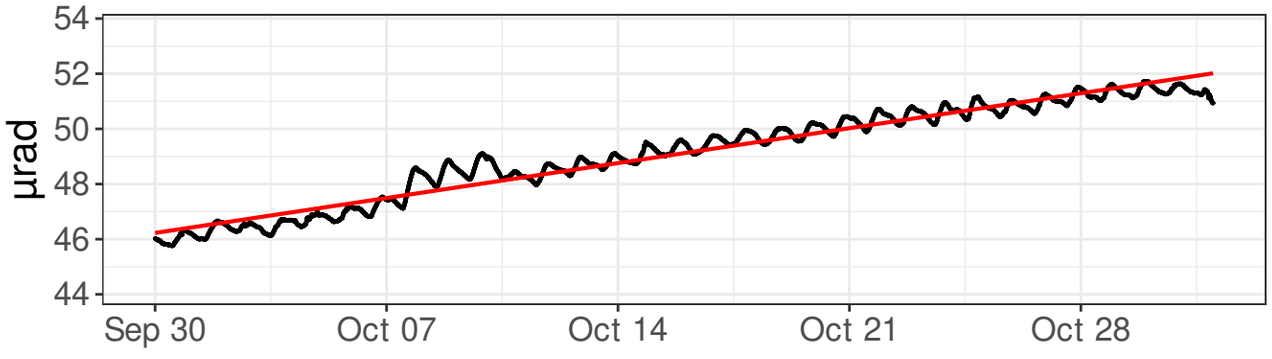
Distance to C7: 494 ft

0σ 1σ 2σ 3σ

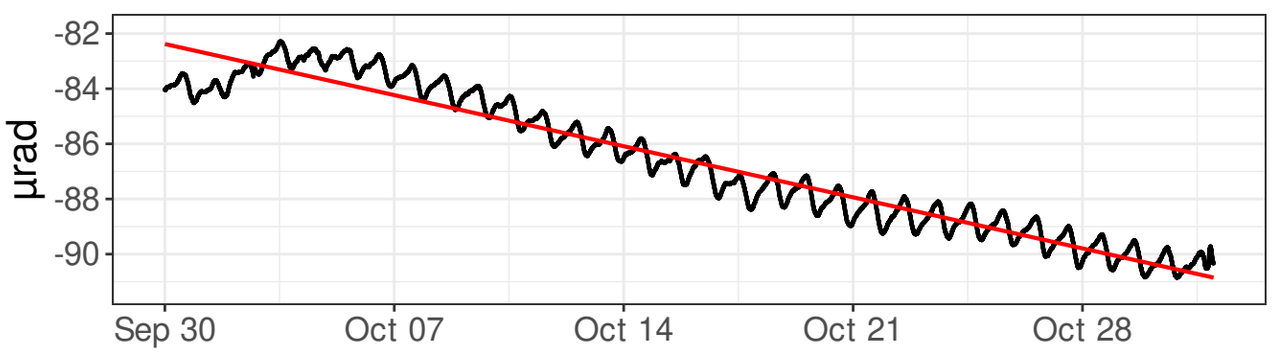
Linear model Azimuth to C7

# SSD07, 09/30/2024 - 10/31/2024

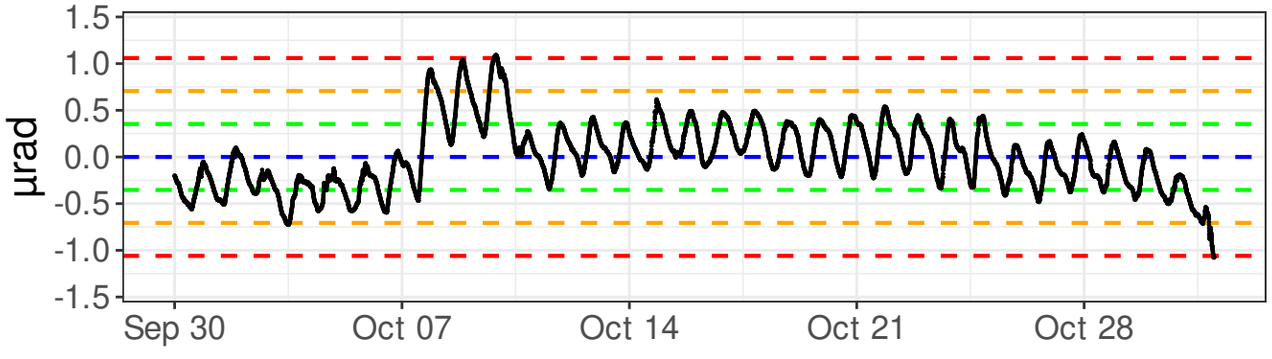
## East tilt - raw values, Linear model R2 0.96



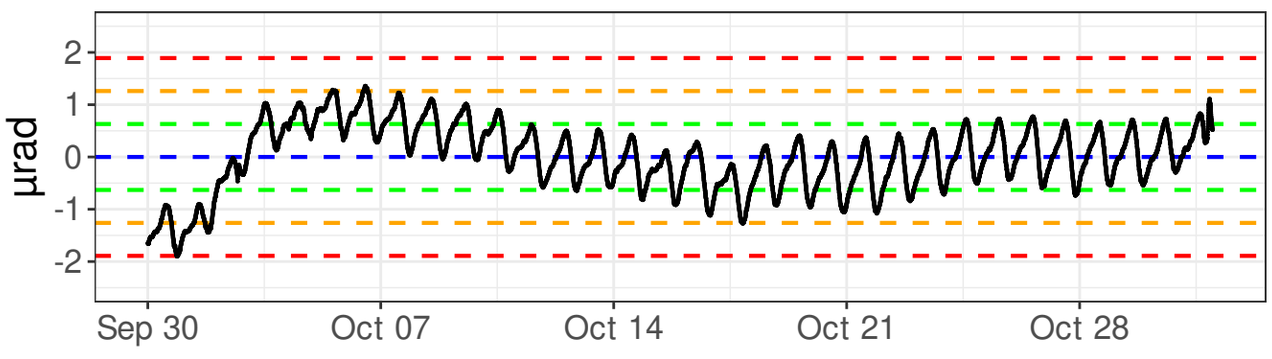

## North tilt - raw values, Linear model R2 0.94



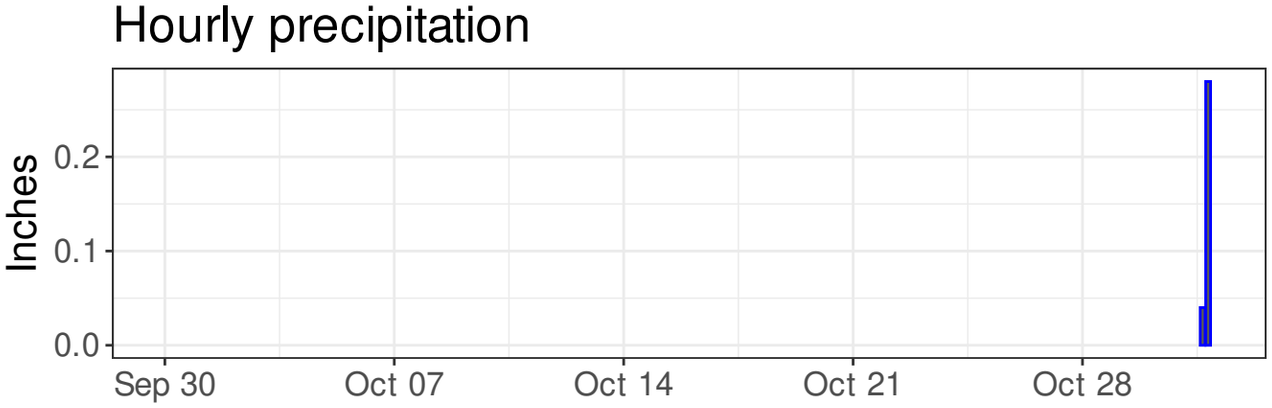

## East tilt - detrended values



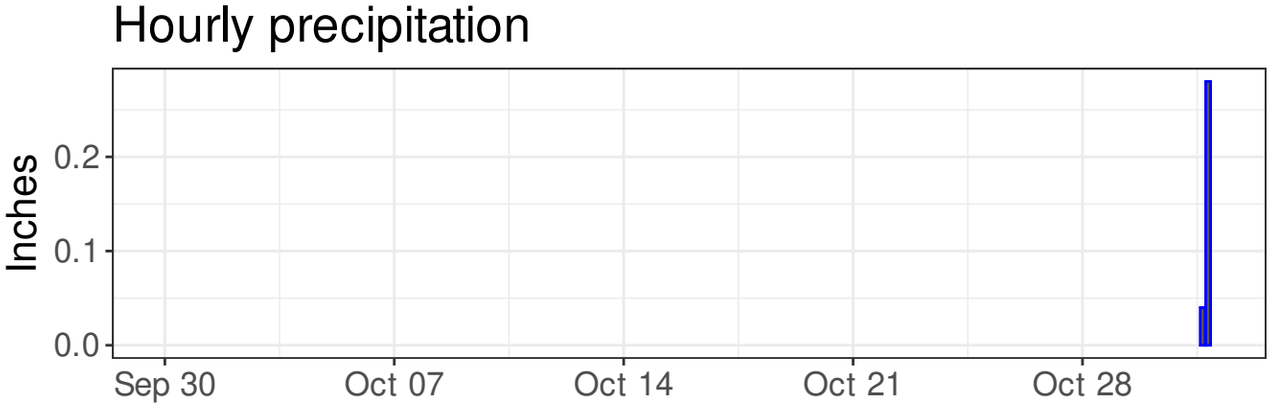

## North tilt - detrended values



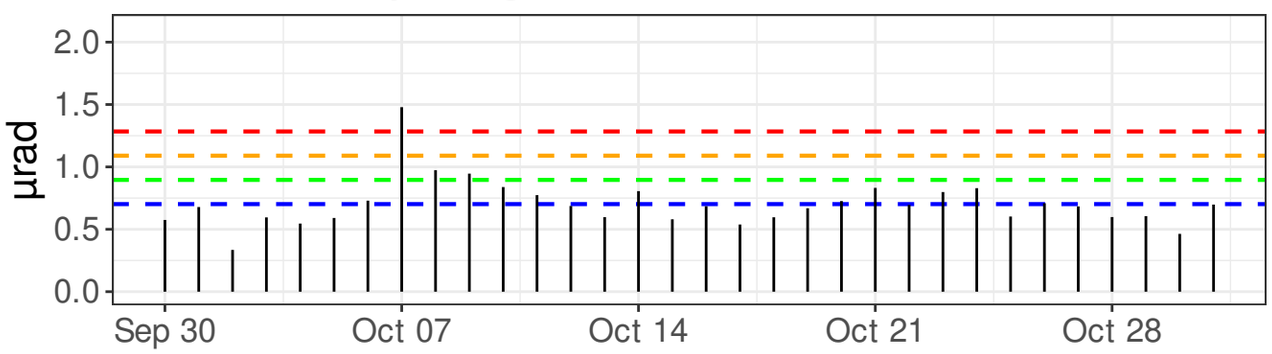

## Hourly precipitation



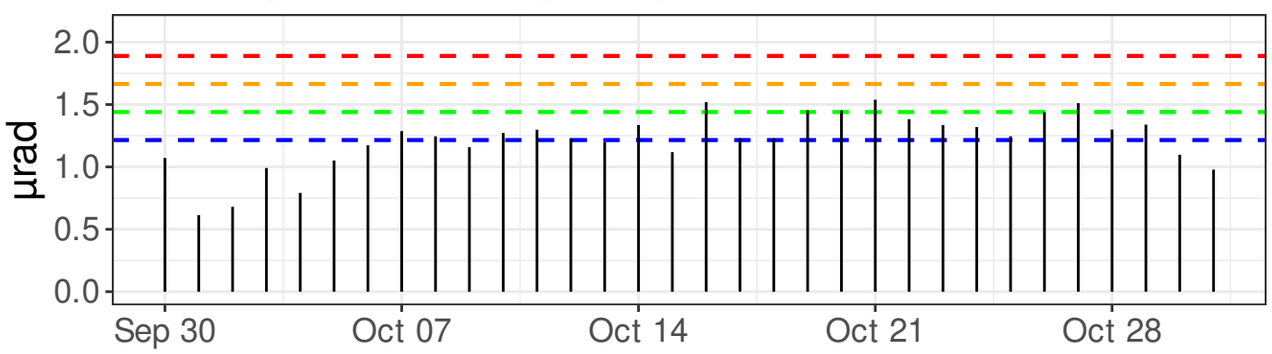

## Hourly precipitation



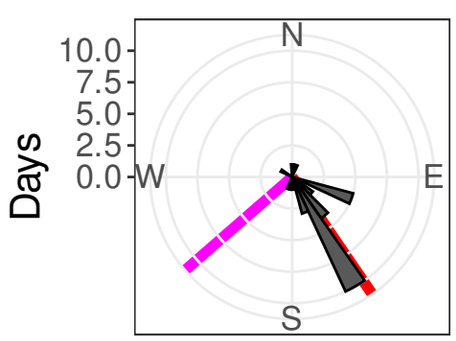

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 66.22 ± 0.13 µrad/year

North tilt rate: -96.90 ± 0.23 µrad/year

Azimuth to C7: 229 deg

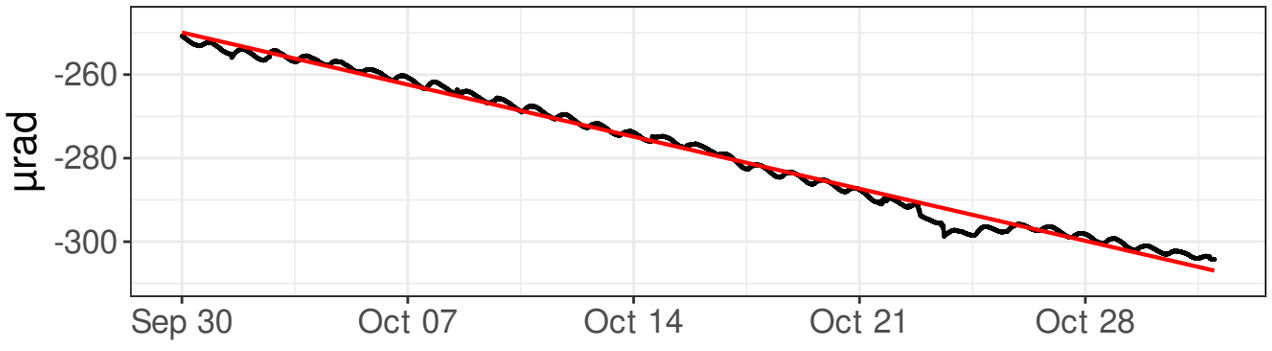
Distance to C7: 513 ft

0σ 1σ 2σ 3σ

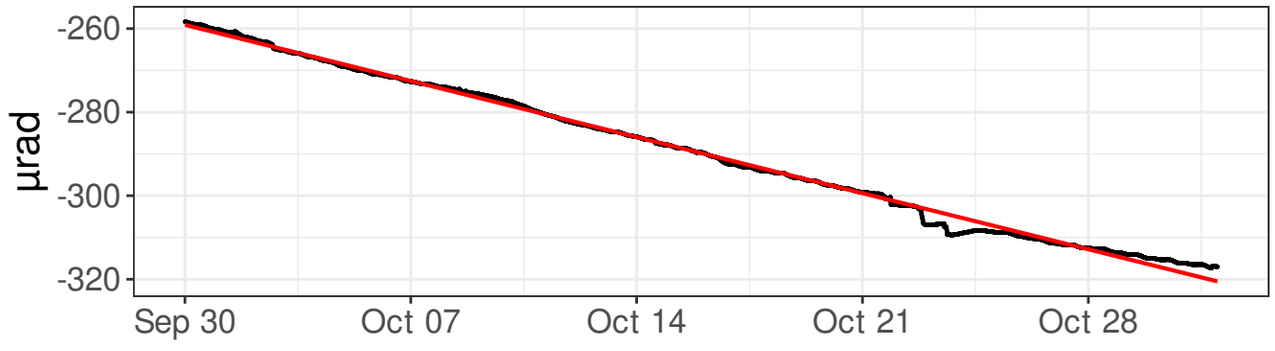
Linear model Azimuth to C7

# SSD08, 09/30/2024 - 10/31/2024

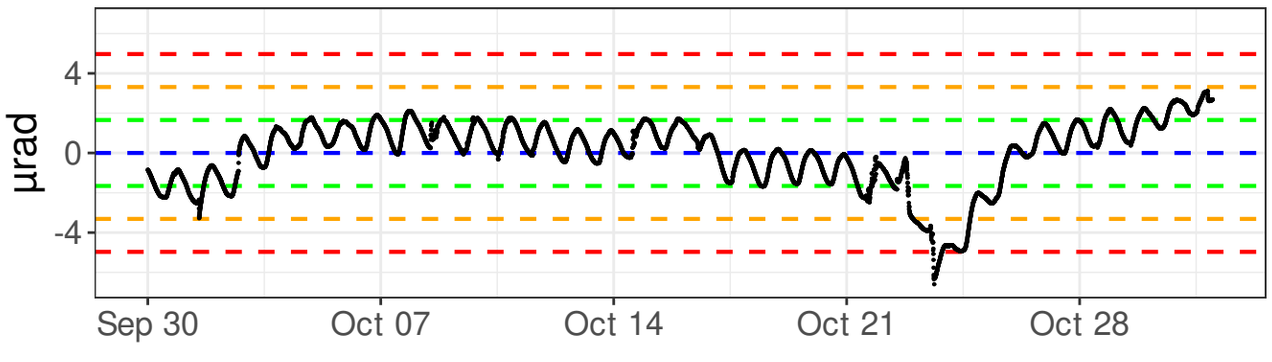
## East tilt - raw values, Linear model R2 0.99



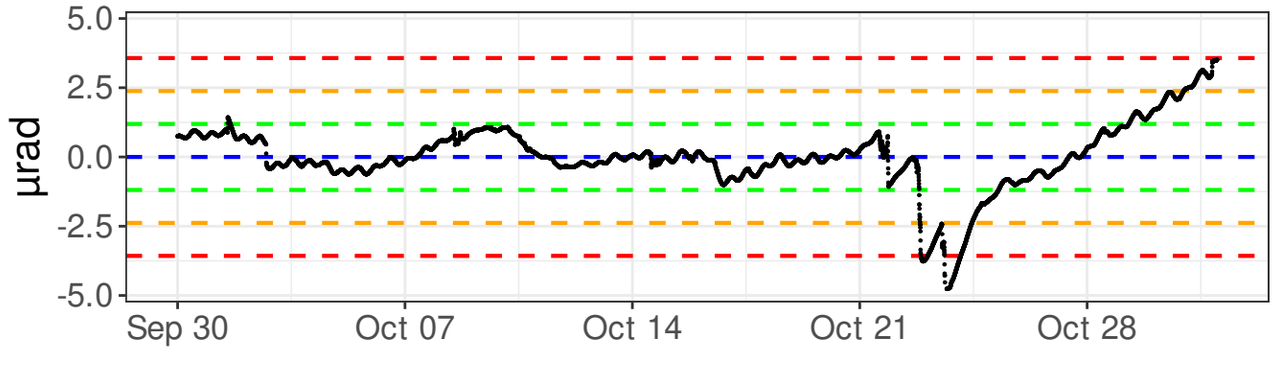

## North tilt - raw values, Linear model R2 1.00



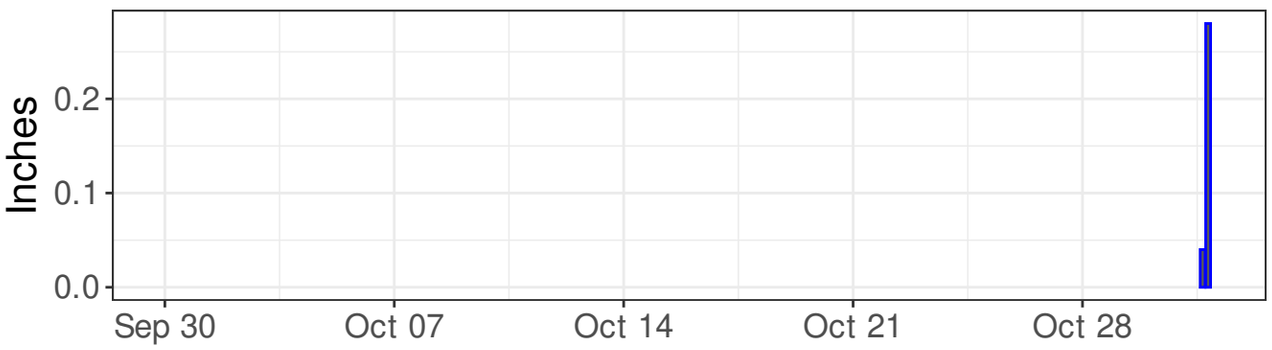

## East tilt - detrended values



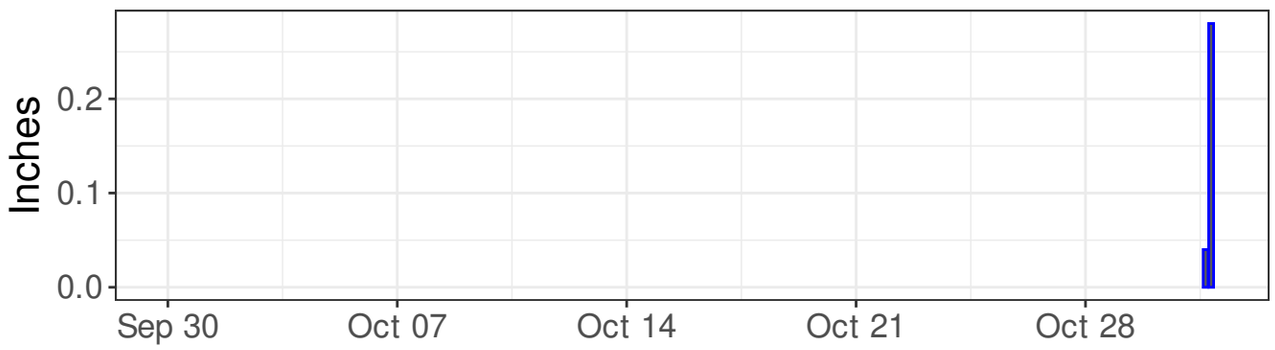

## North tilt - detrended values



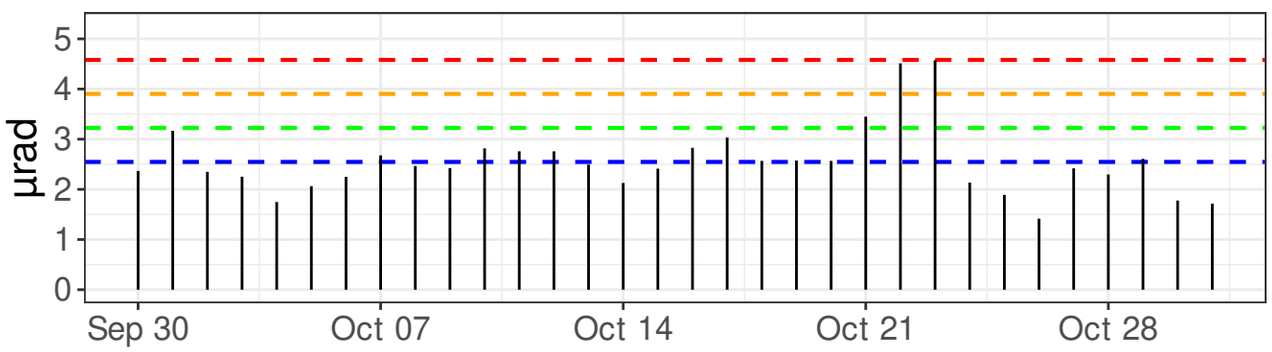

## Hourly precipitation



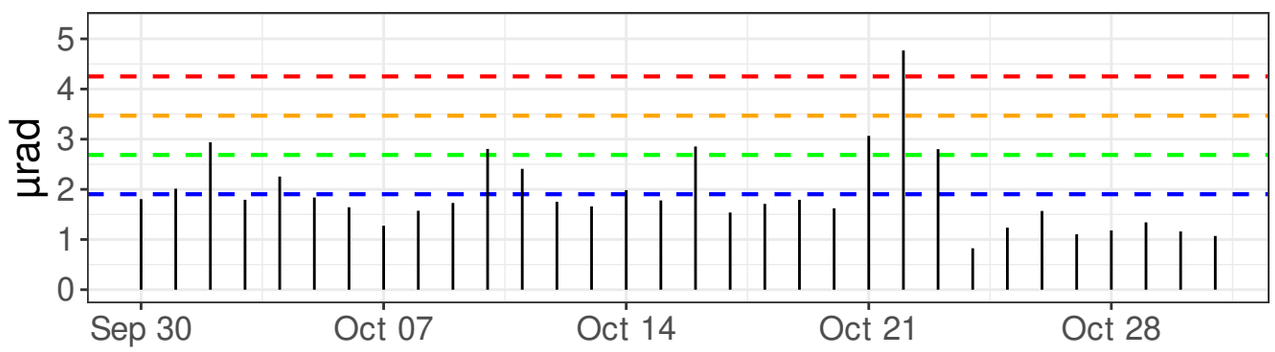

## Hourly precipitation



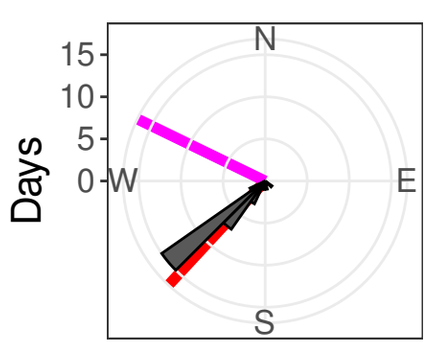

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -652.07 ± 0.61 µrad/year

North tilt rate: -702.40 ± 0.44 µrad/year

Azimuth to C7: 296 deg

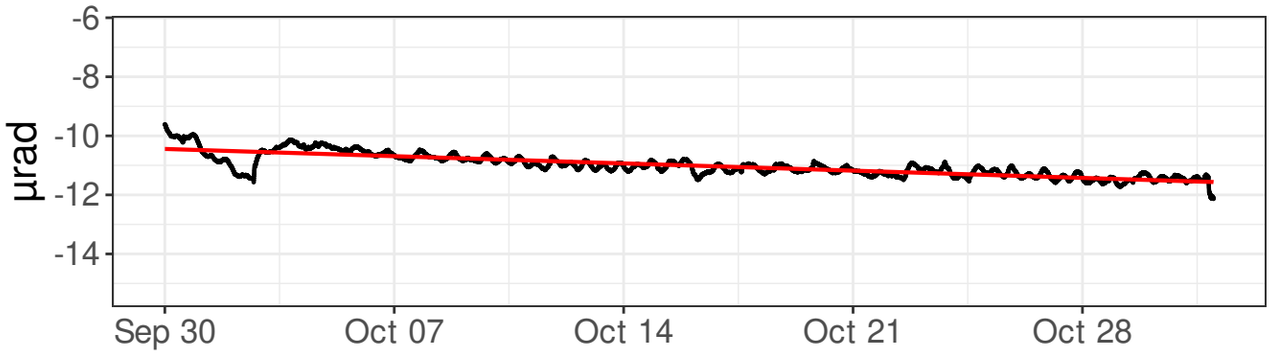
Distance to C7: 186 ft

0σ 1σ 2σ 3σ

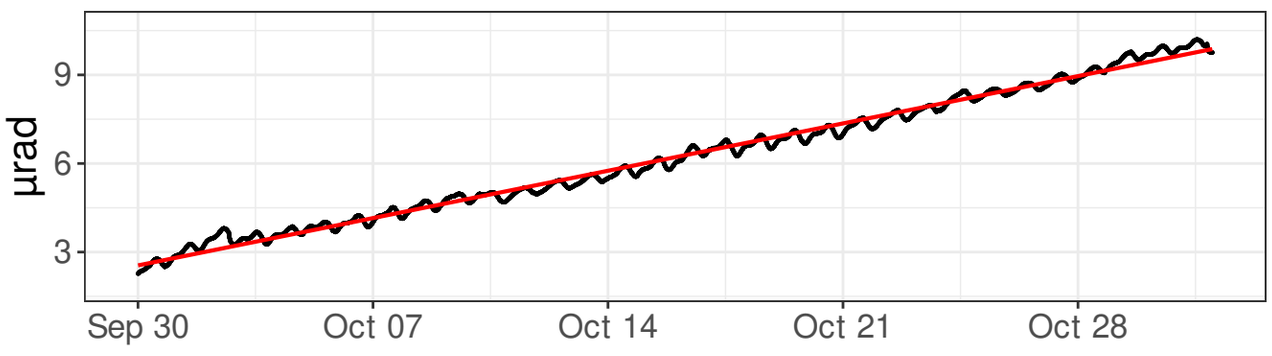
Linear model Azimuth to C7

# SSD09, 09/30/2024 - 10/31/2024

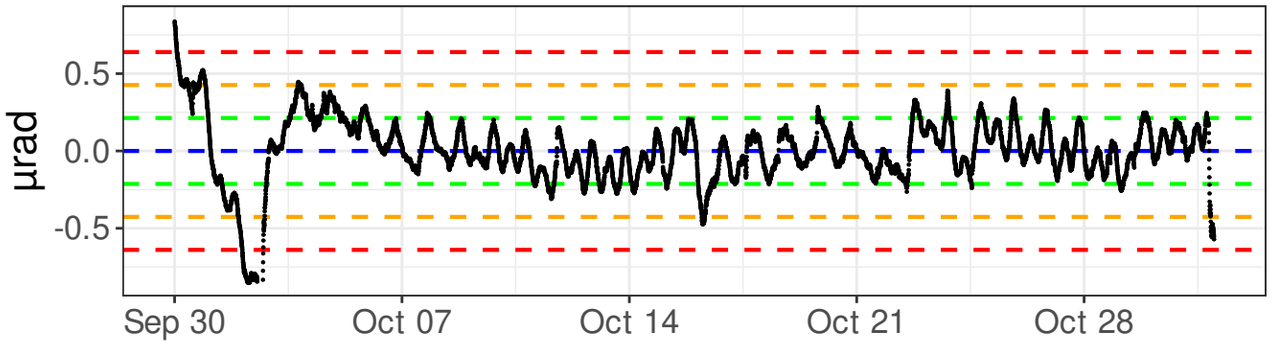
East tilt - raw values, Linear model R2 0.70



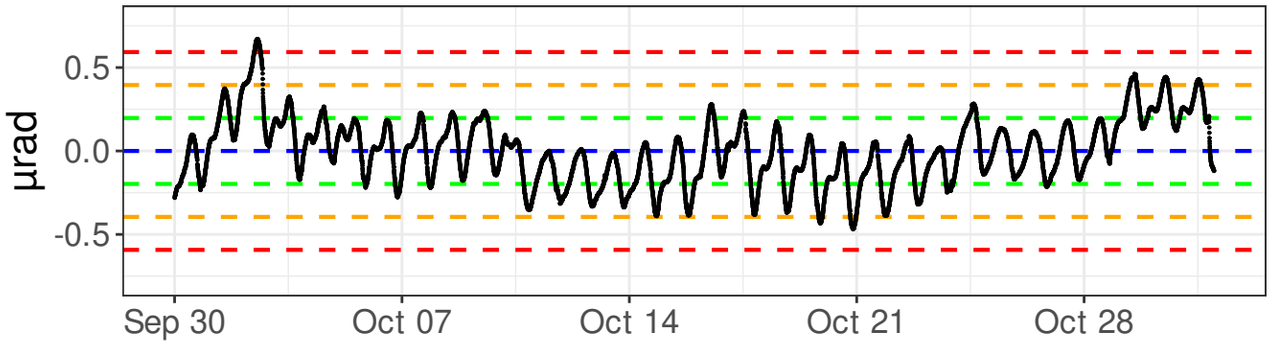

North tilt - raw values, Linear model R2 0.99



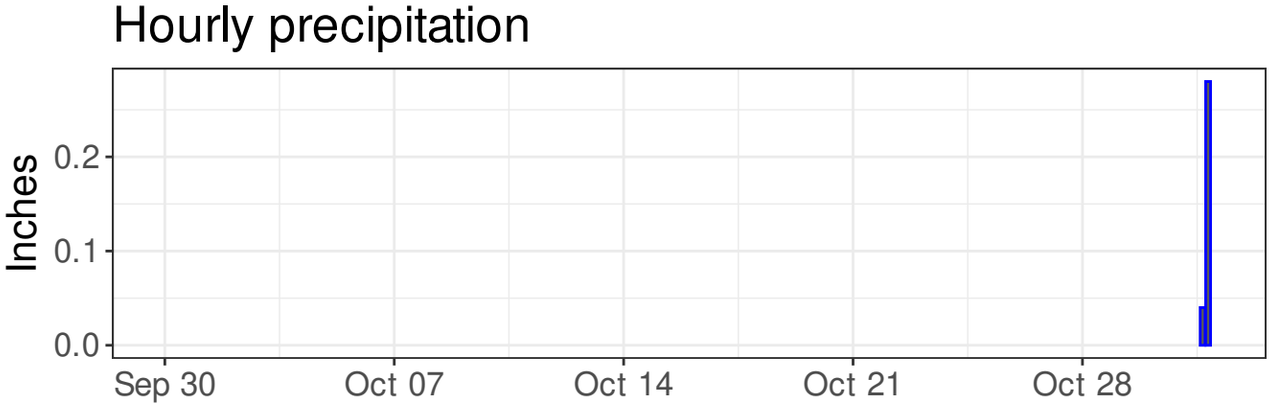

East tilt - detrended values



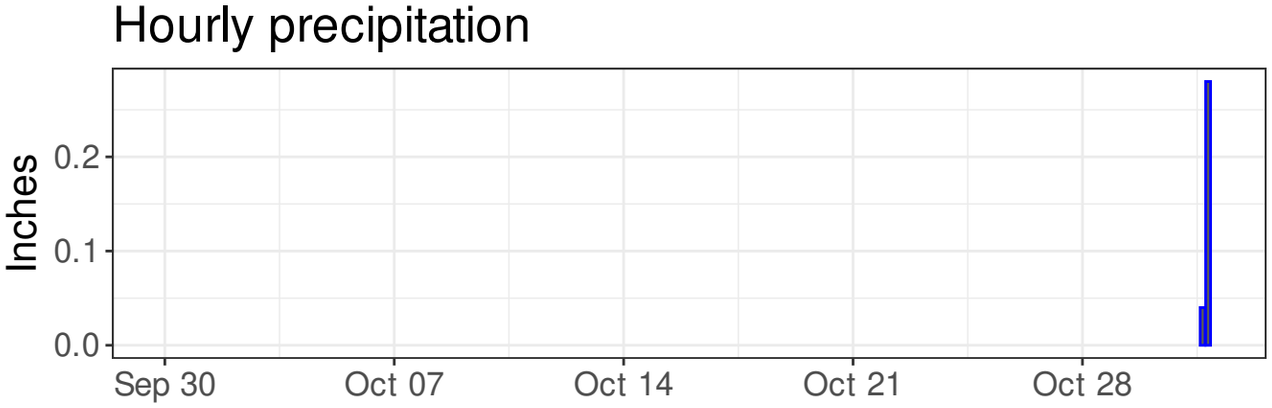

North tilt - detrended values



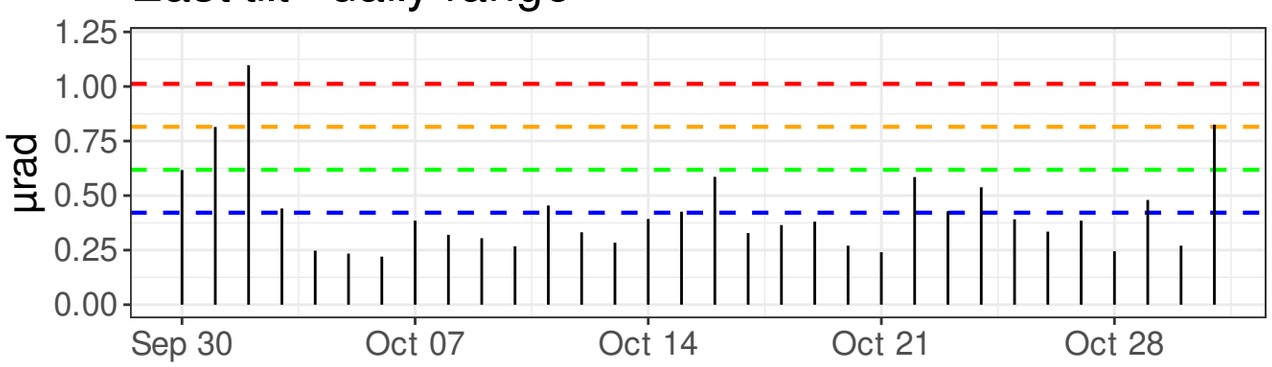

Hourly precipitation



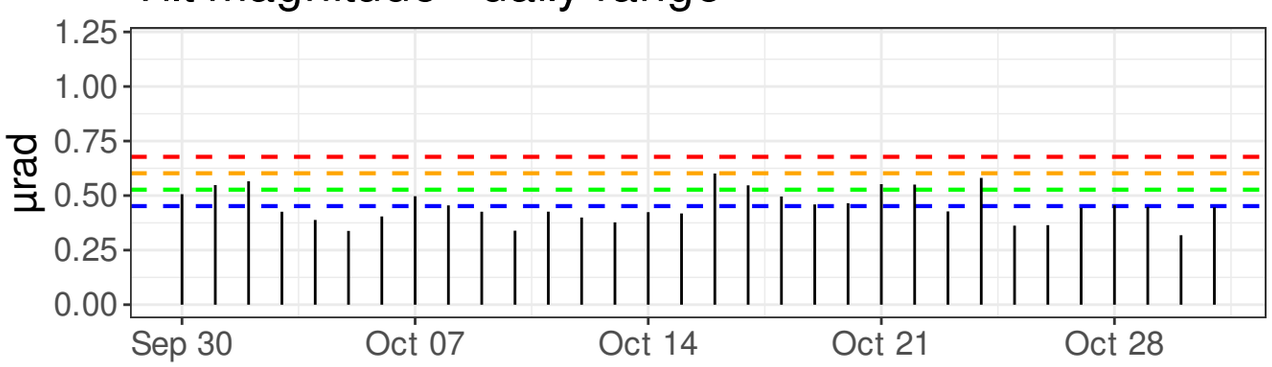

Hourly precipitation



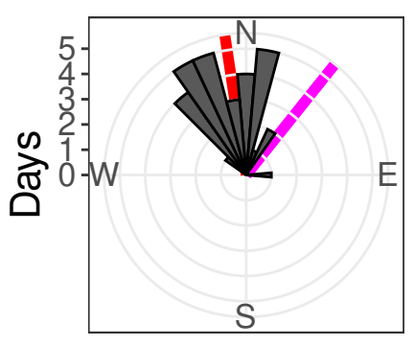

East tilt - daily range




Tilt magnitude - daily range




Tilt direction frequency




East tilt rate: -12.82 ± 0.08 µrad/year

North tilt rate: 83.81 ± 0.07 µrad/year

Azimuth to C7: 39 deg

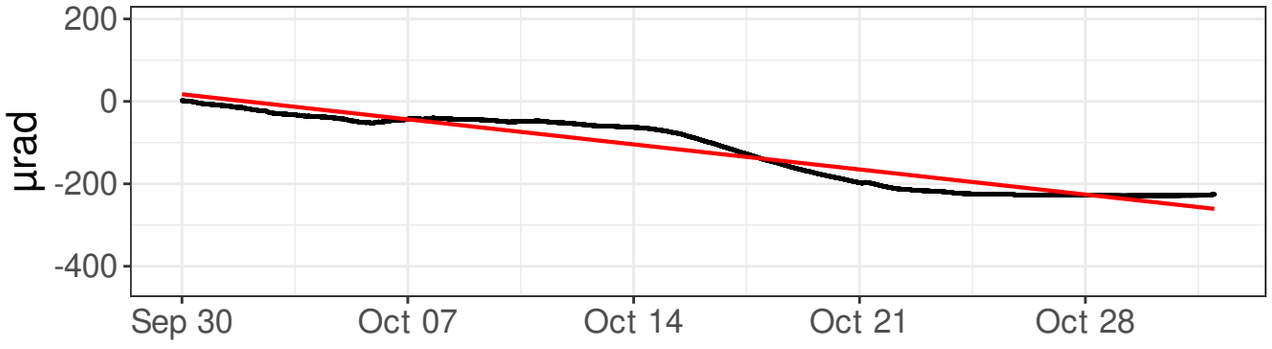
Distance to C7: 561 ft

0σ 1σ 2σ 3σ

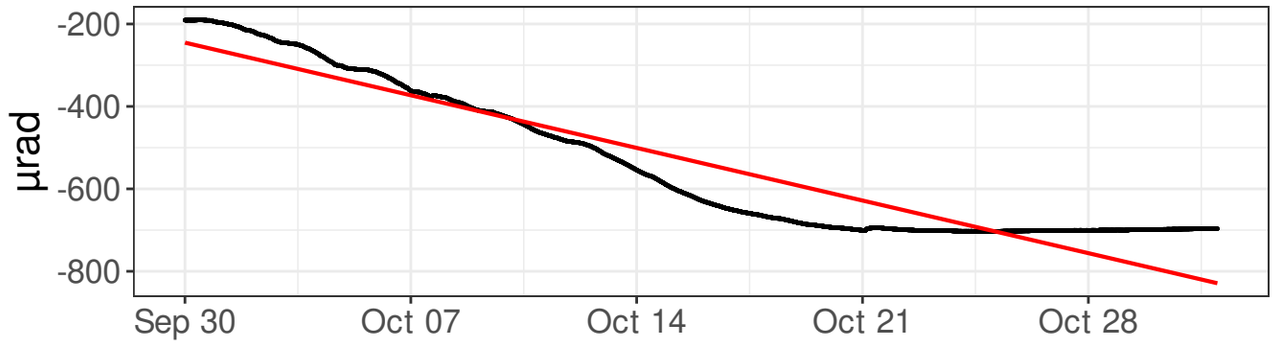
Linear model Azimuth to C7

# SSD10, 09/30/2024 - 10/31/2024

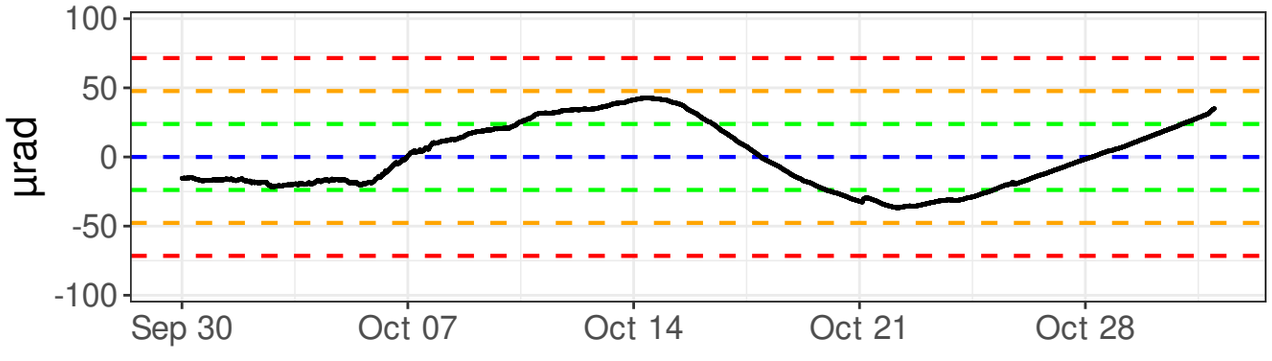
## East tilt - raw values, Linear model R2 0.92



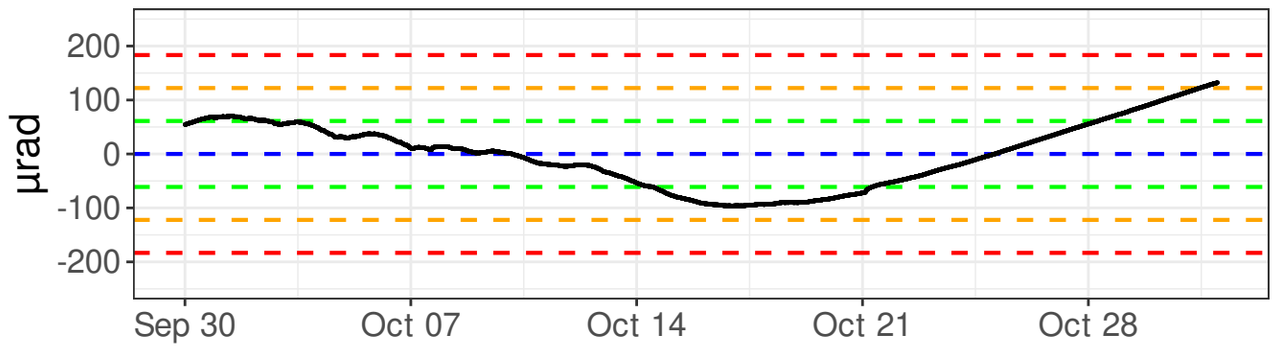

## North tilt - raw values, Linear model R2 0.88



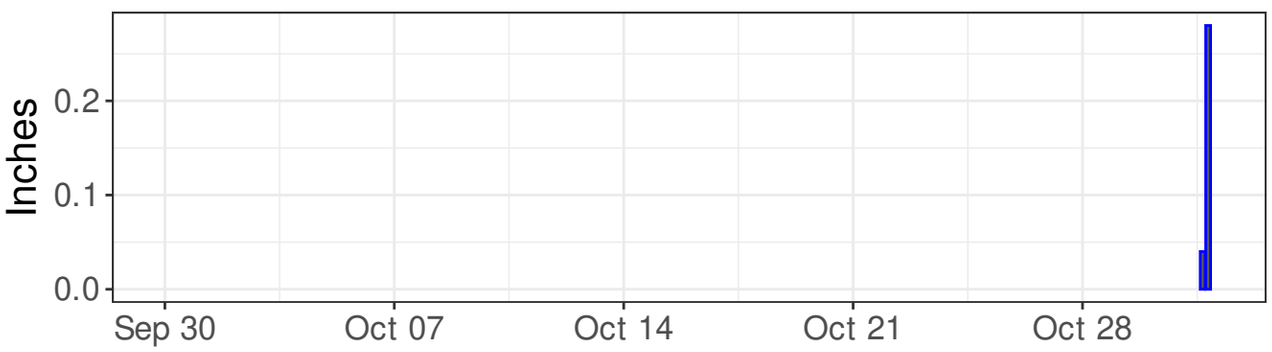

## East tilt - detrended values



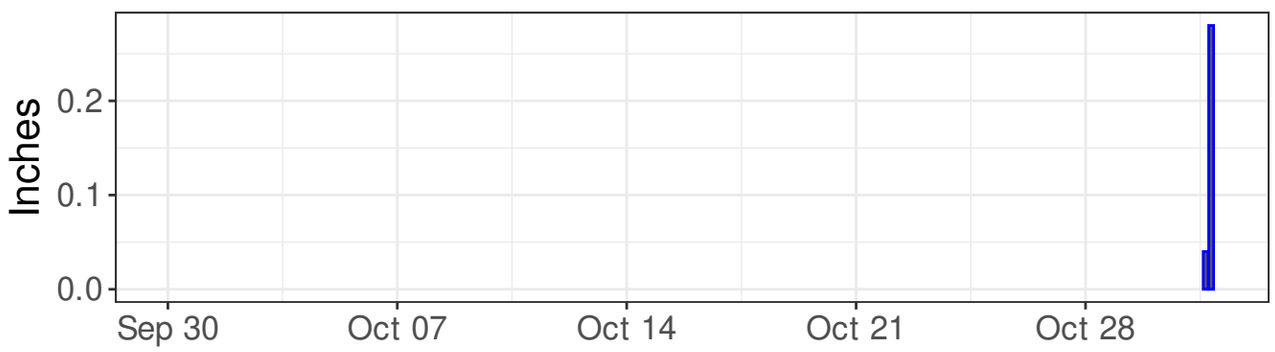

## North tilt - detrended values



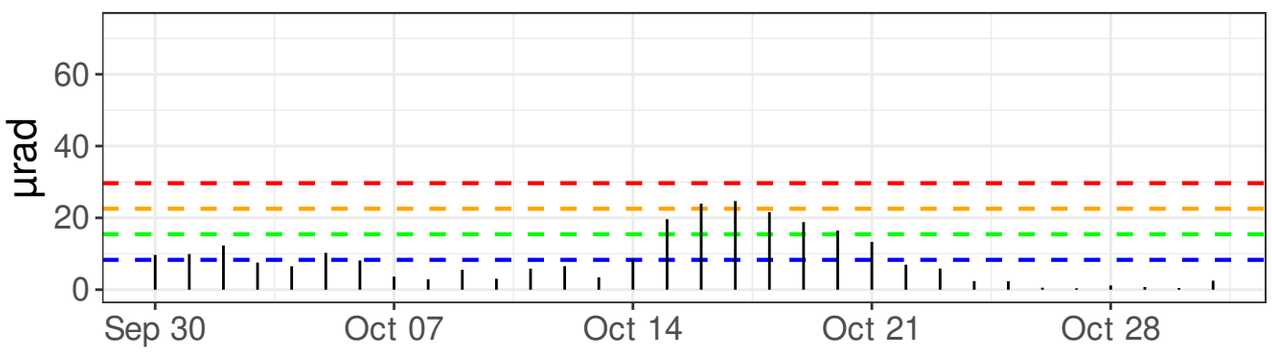

## Hourly precipitation



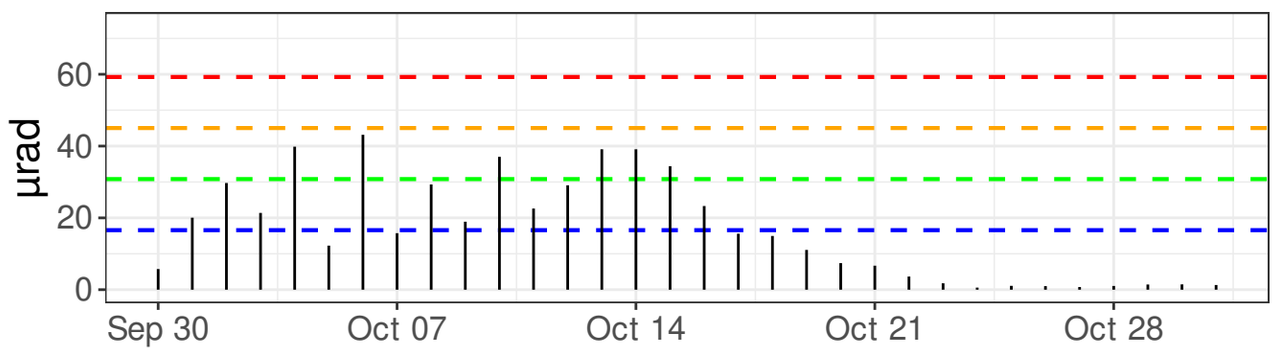

## Hourly precipitation



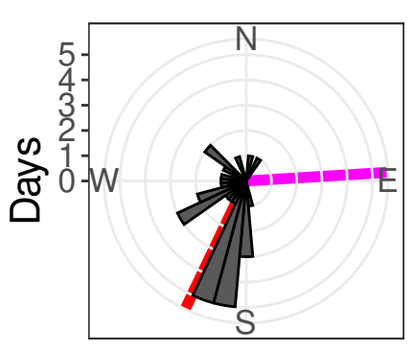

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -3179.51 ± 8.79 µrad/year

North tilt rate: -6676.43 ± 22.53 µrad/year

Azimuth to C7: 87 deg

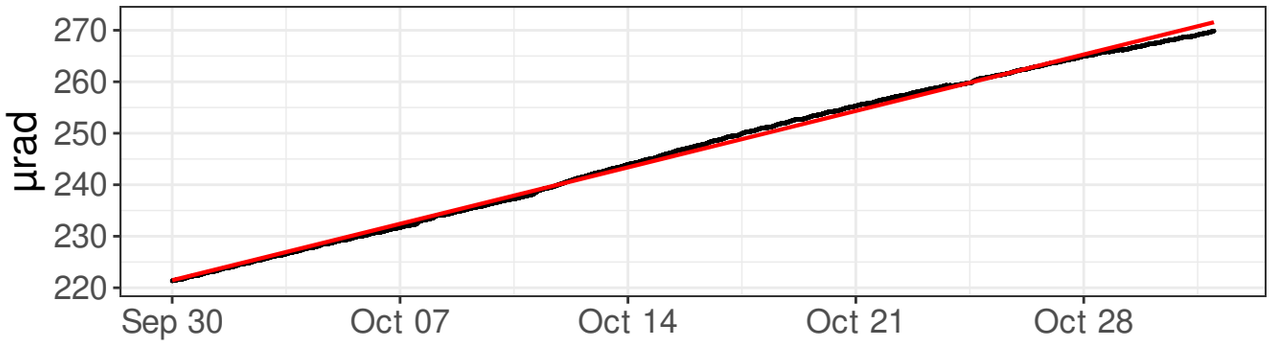
Distance to C7: 2402 ft

0σ 1σ 2σ 3σ

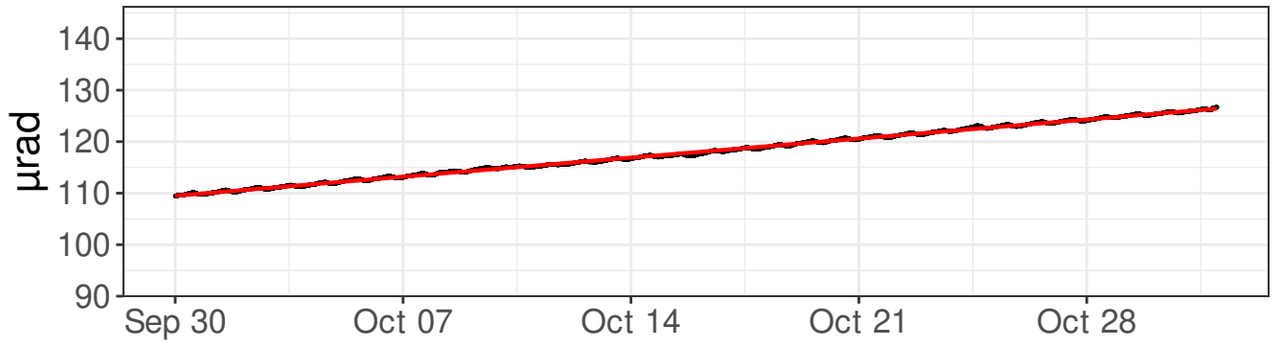
Linear model Azimuth to C7

# SSD11, 09/30/2024 - 10/31/2024

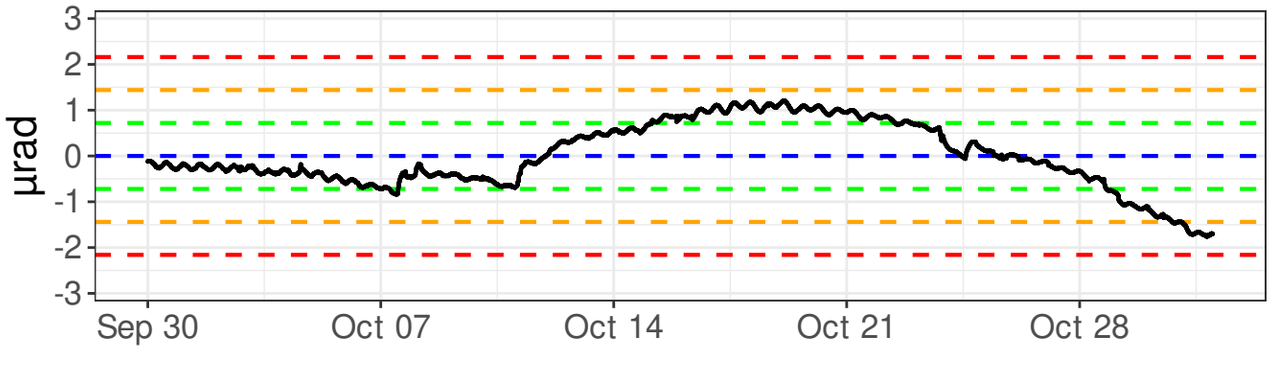
## East tilt - raw values, Linear model R2 1.00



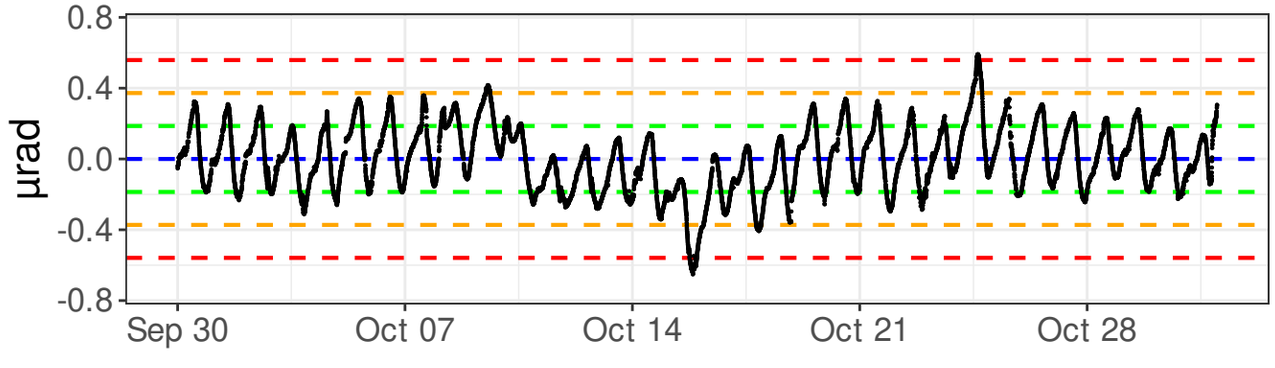

## North tilt - raw values, Linear model R2 1.00



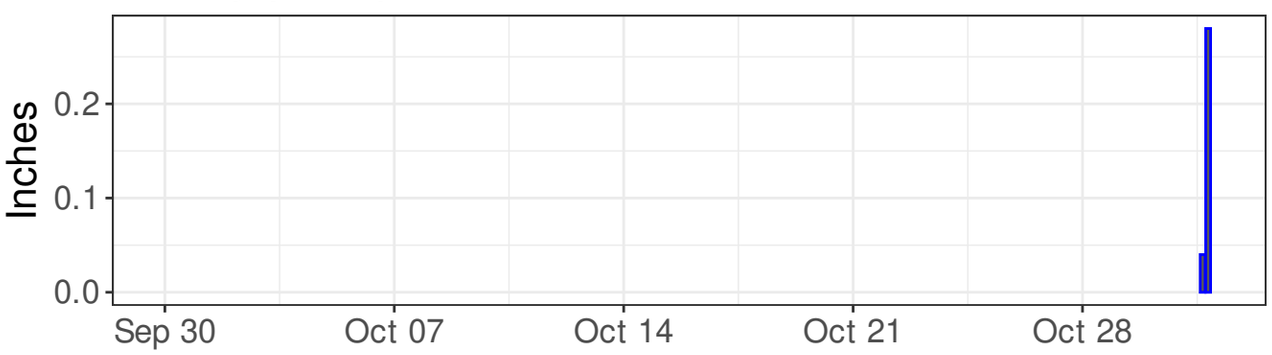

## East tilt - detrended values



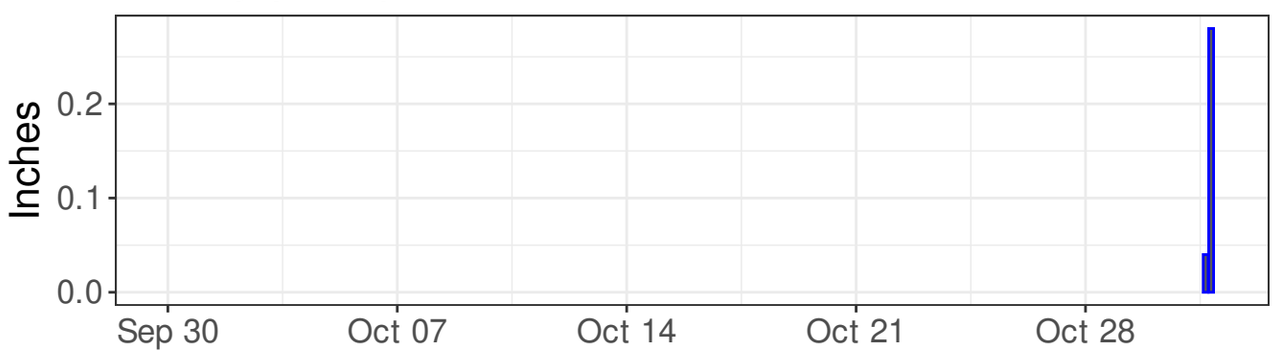

## North tilt - detrended values



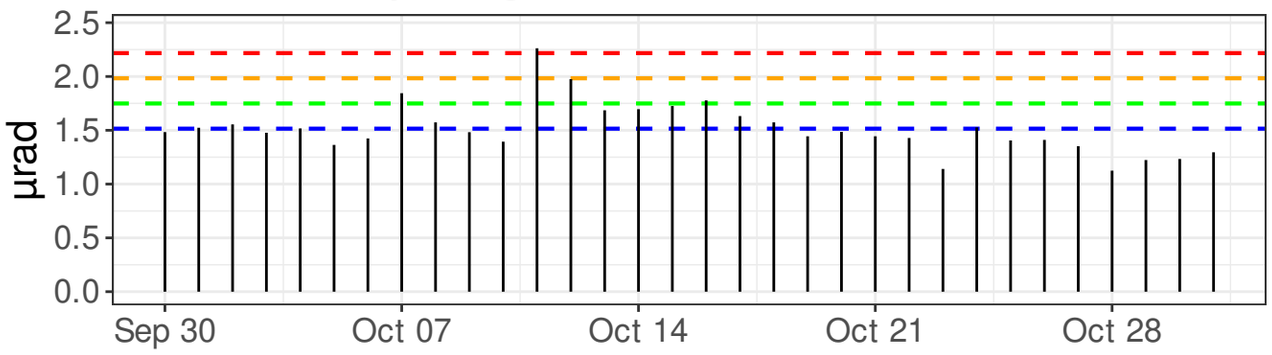

## Hourly precipitation



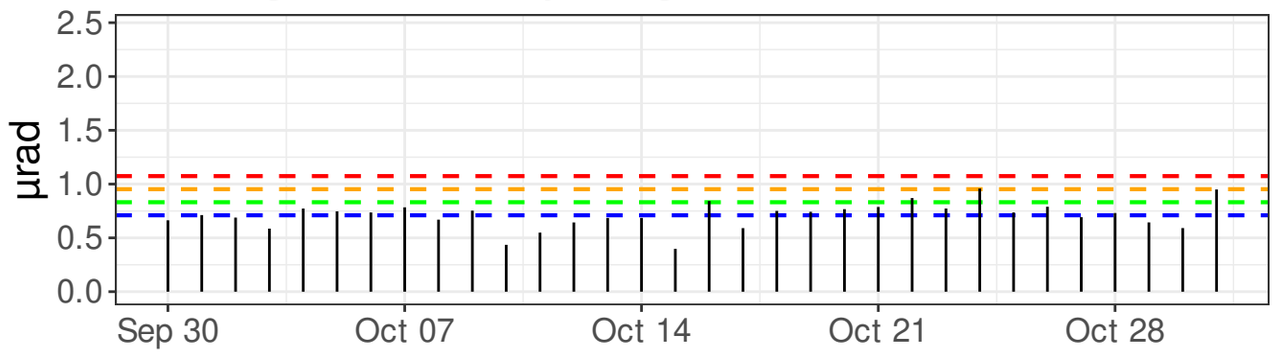

## Hourly precipitation



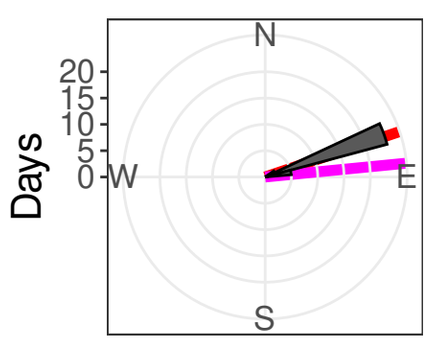

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 572.97 ± 0.27 µrad/year

North tilt rate: 193.53 ± 0.07 µrad/year

Azimuth to C7: 84 deg

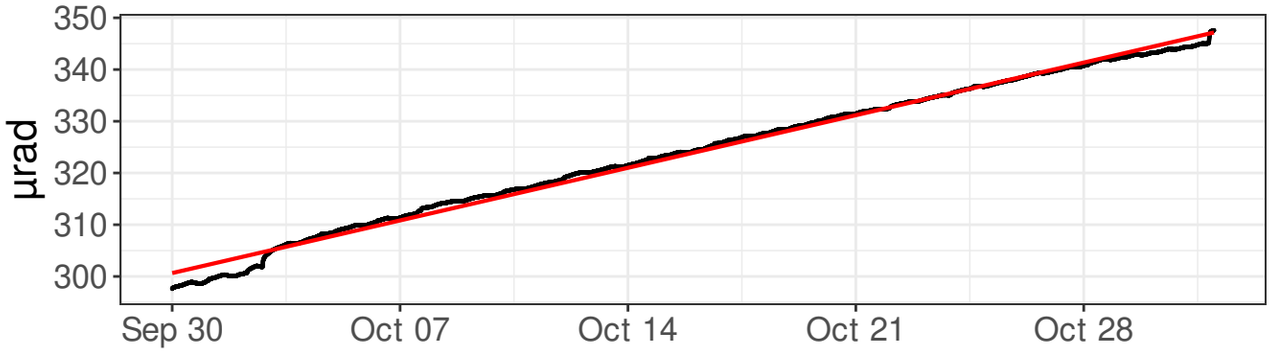
Distance to C7: 1473 ft

0σ 1σ 2σ 3σ

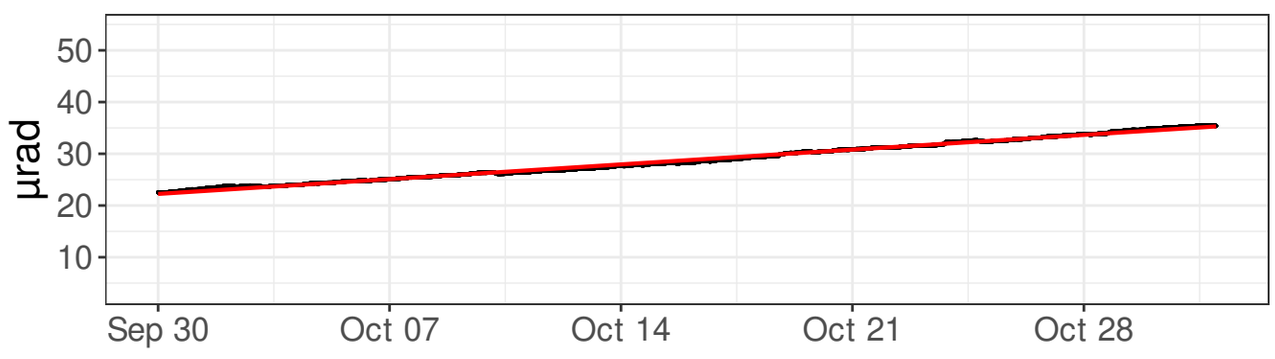
Linear model Azimuth to C7

# SSD12, 09/30/2024 - 10/31/2024

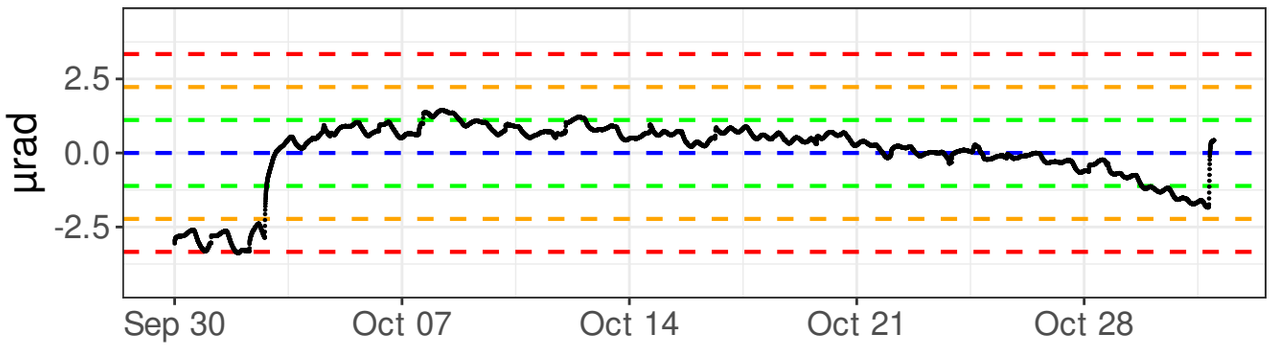
## East tilt - raw values, Linear model R2 0.99



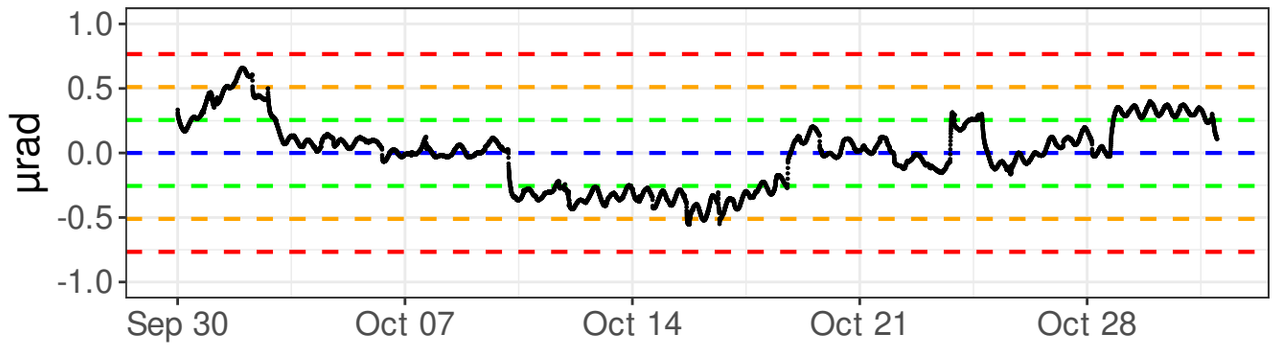

## North tilt - raw values, Linear model R2 1.00



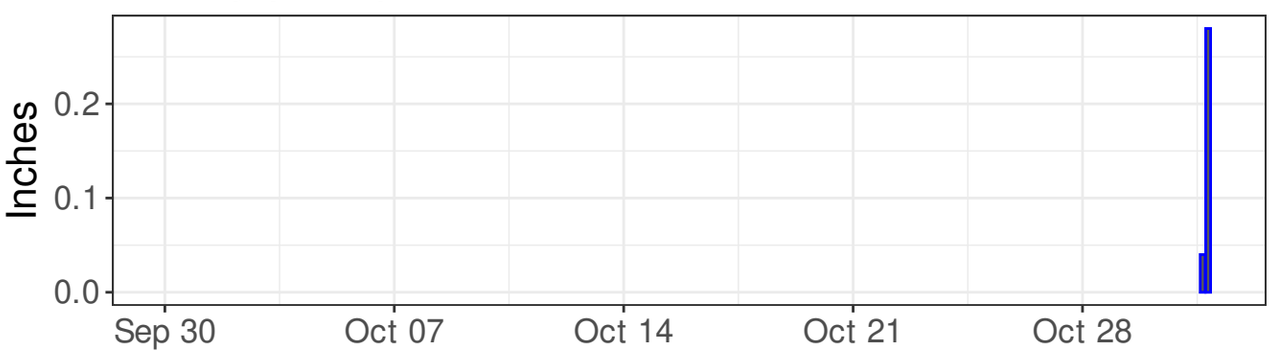

## East tilt - detrended values



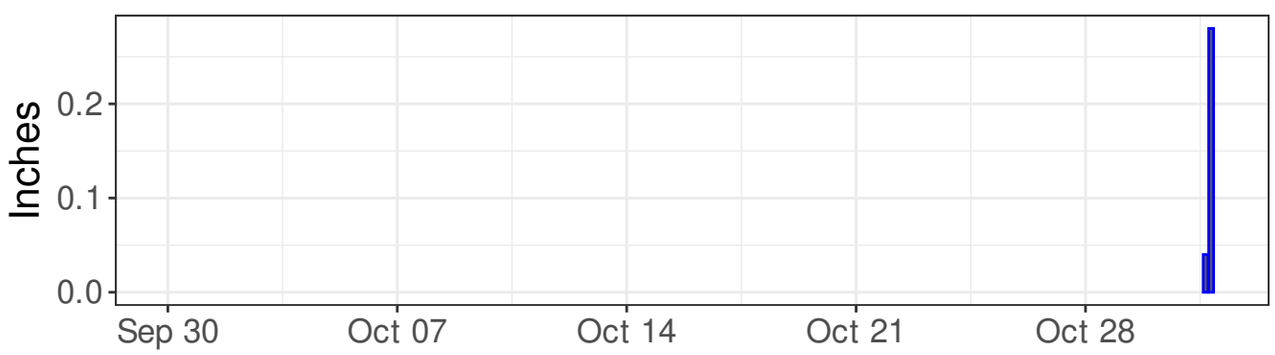

## North tilt - detrended values



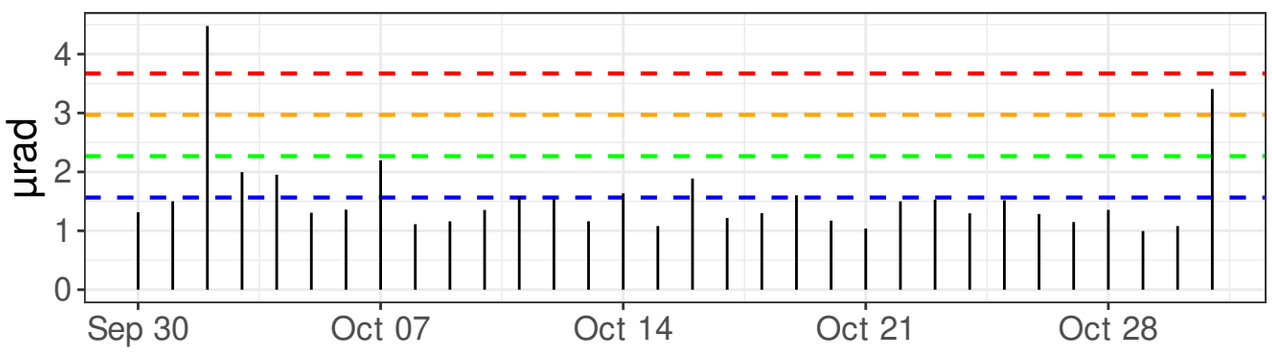

## Hourly precipitation



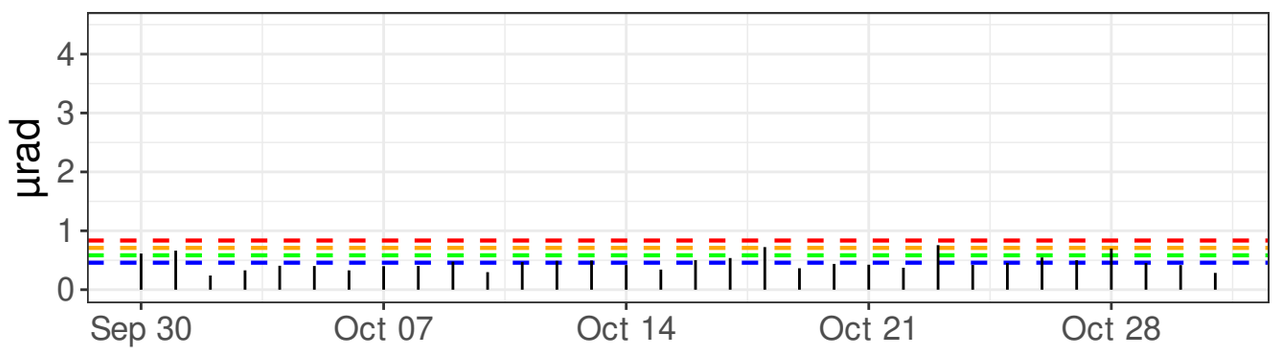

## Hourly precipitation



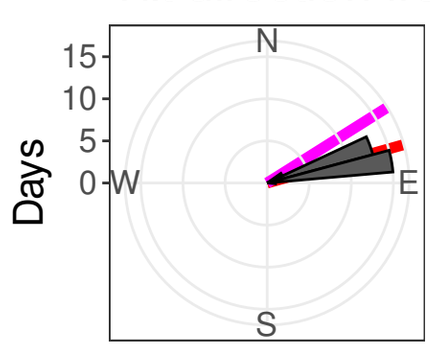

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 531.91 ± 0.41 µrad/year

North tilt rate: 149.22 ± 0.09 µrad/year

Azimuth to C7: 58 deg

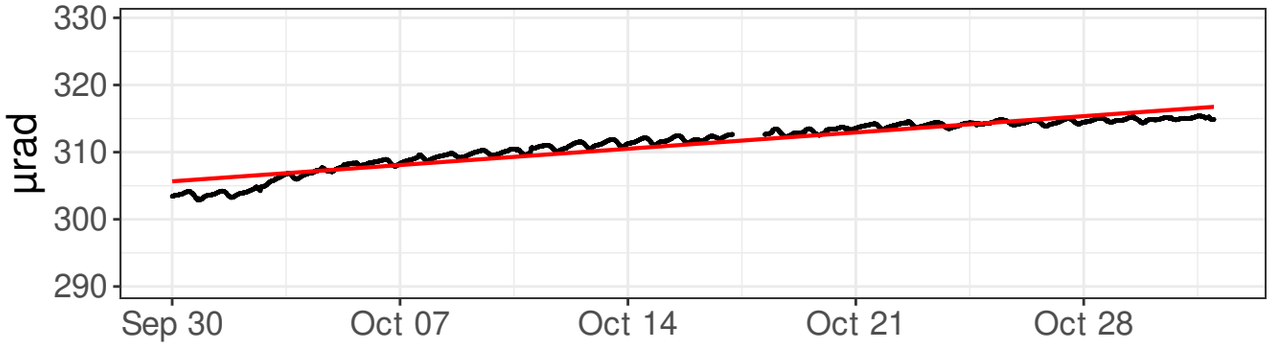
Distance to C7: 1344 ft

0σ 1σ 2σ 3σ

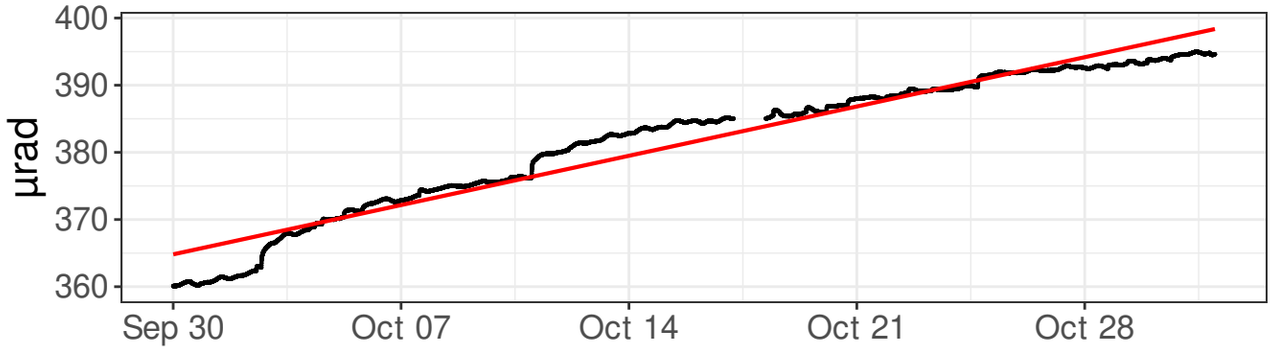
Linear model Azimuth to C7

# SSD13, 09/30/2024 - 10/31/2024

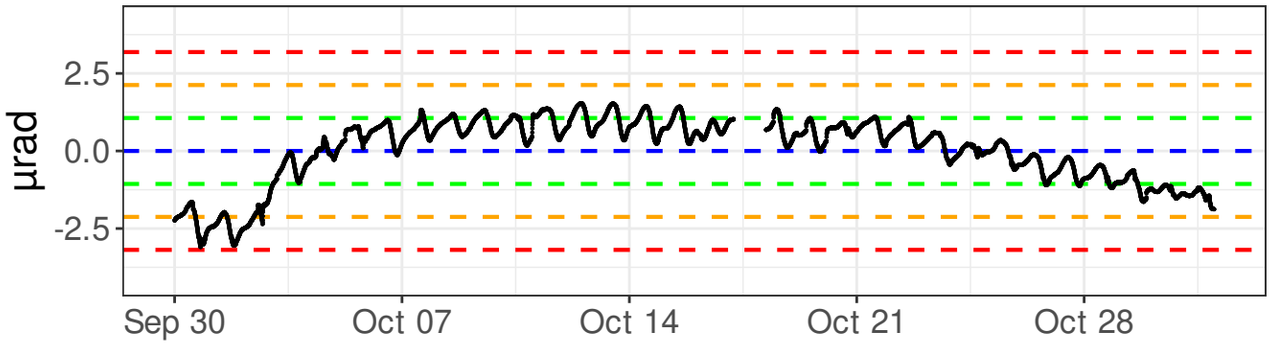
## East tilt - raw values, Linear model R2 0.90



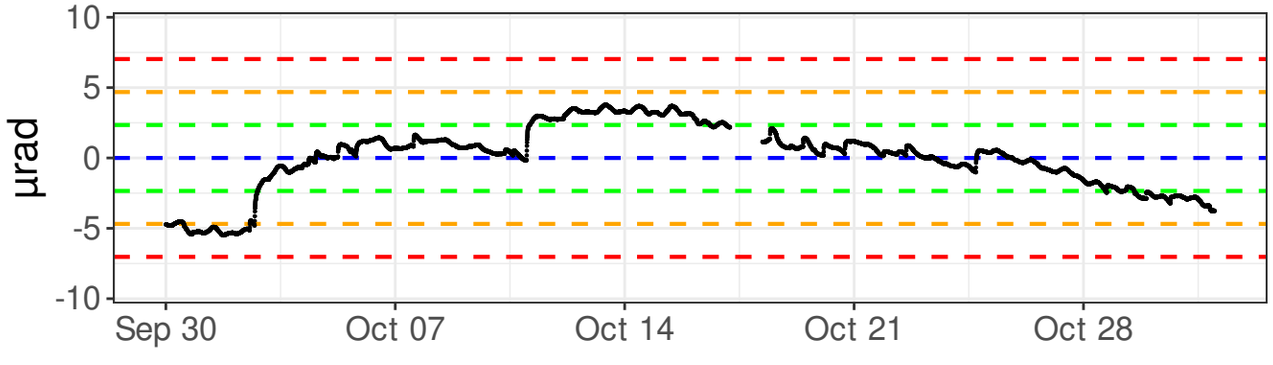

## North tilt - raw values, Linear model R2 0.95



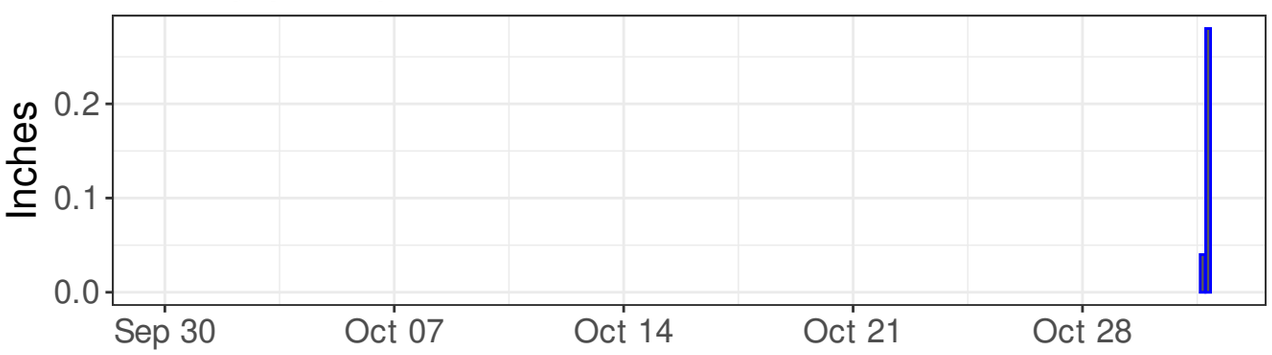

## East tilt - detrended values



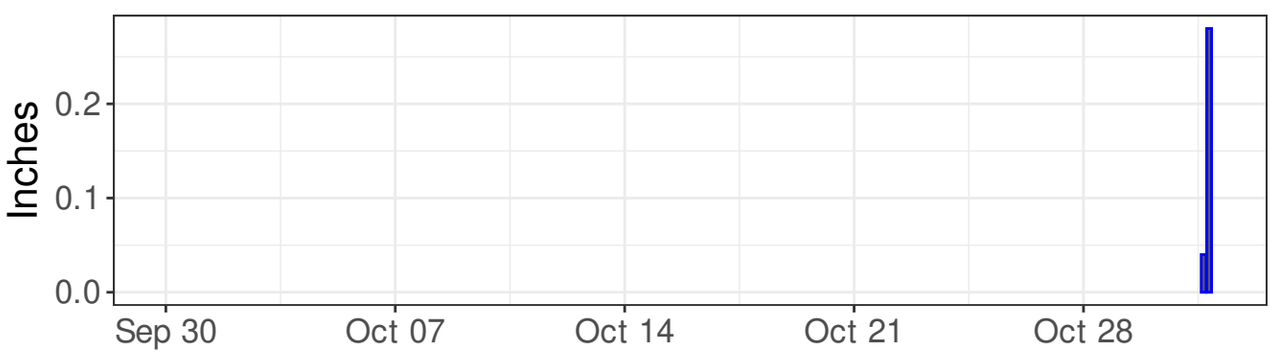

## North tilt - detrended values



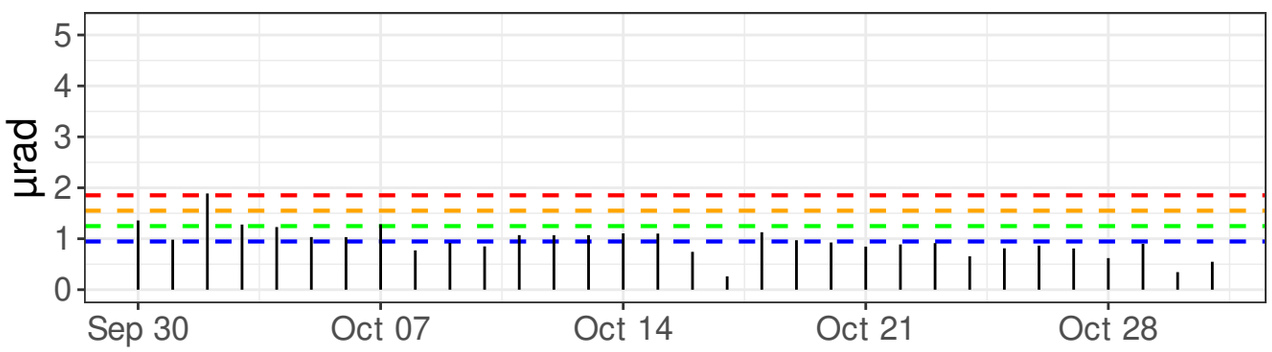

## Hourly precipitation



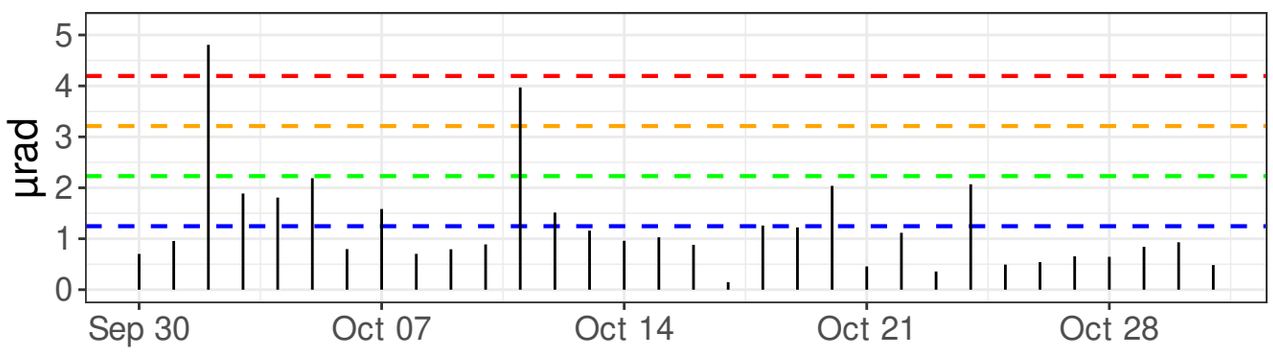

## Hourly precipitation



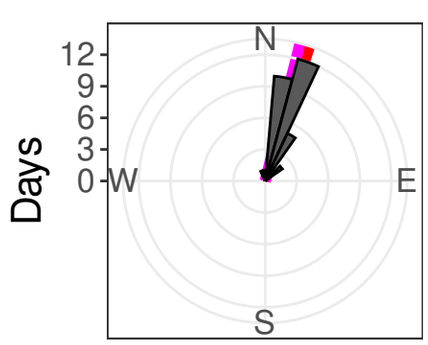

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 126.83 ± 0.39 µrad/year

North tilt rate: 383.68 ± 0.86 µrad/year

Azimuth to C7: 14 deg

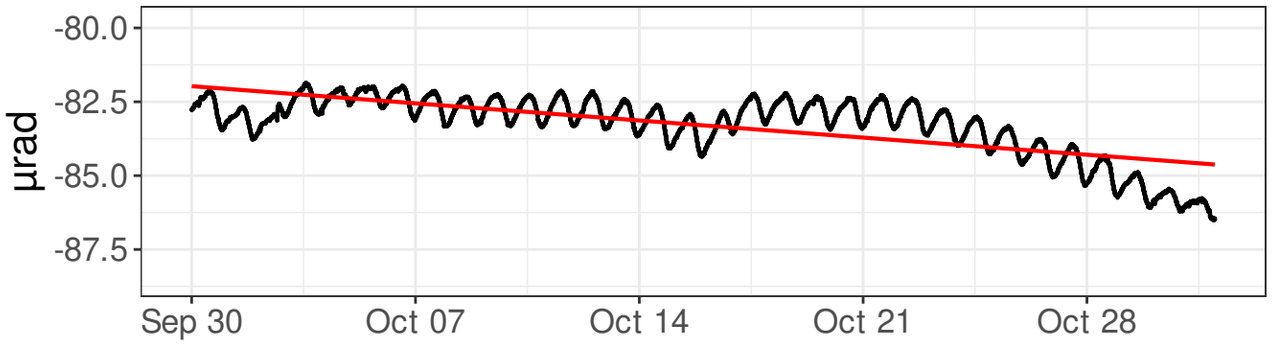
Distance to C7: 686 ft

0σ 1σ 2σ 3σ

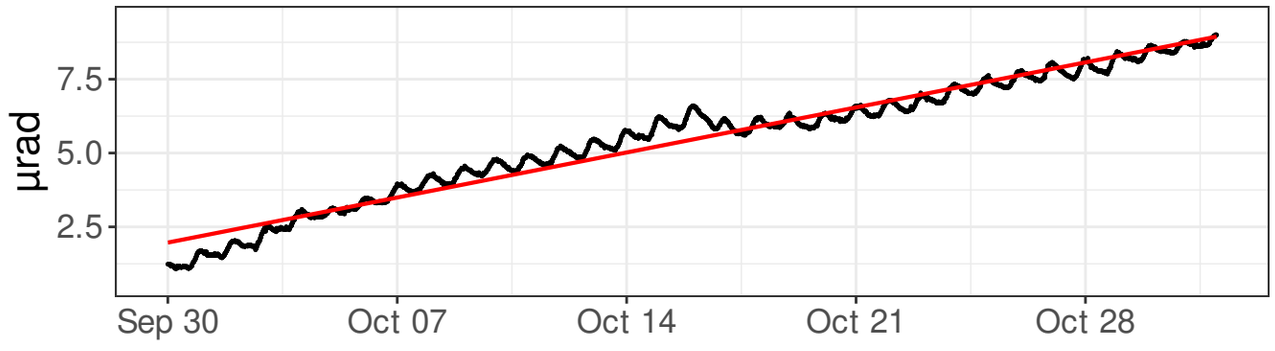
Linear model Azimuth to C7

# SSD14, 09/30/2024 - 10/31/2024

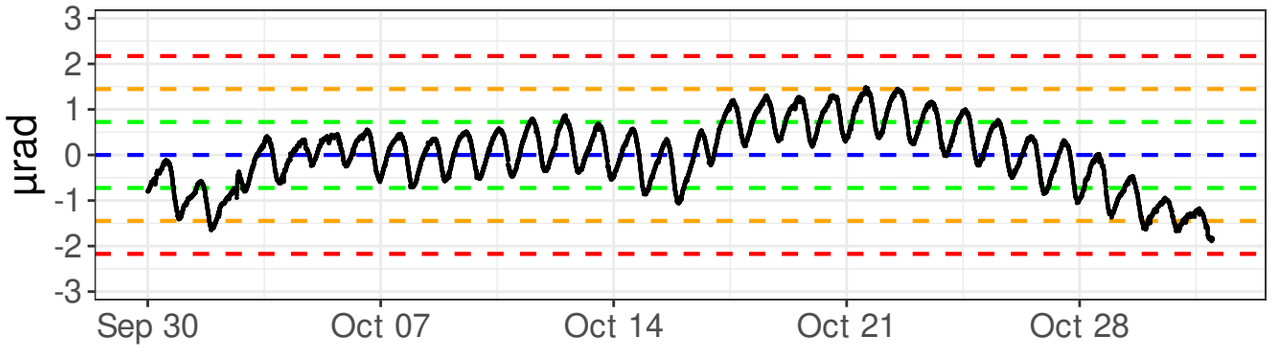
## East tilt - raw values, Linear model R2 0.53



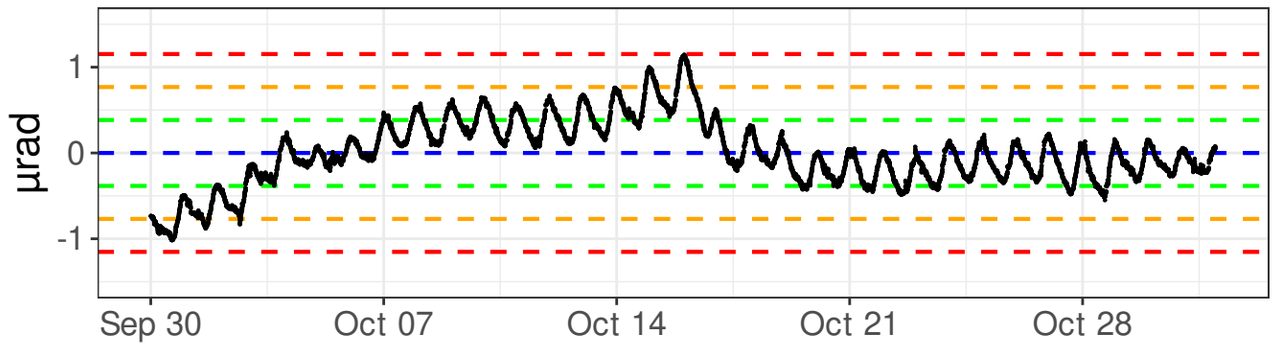

## North tilt - raw values, Linear model R2 0.96



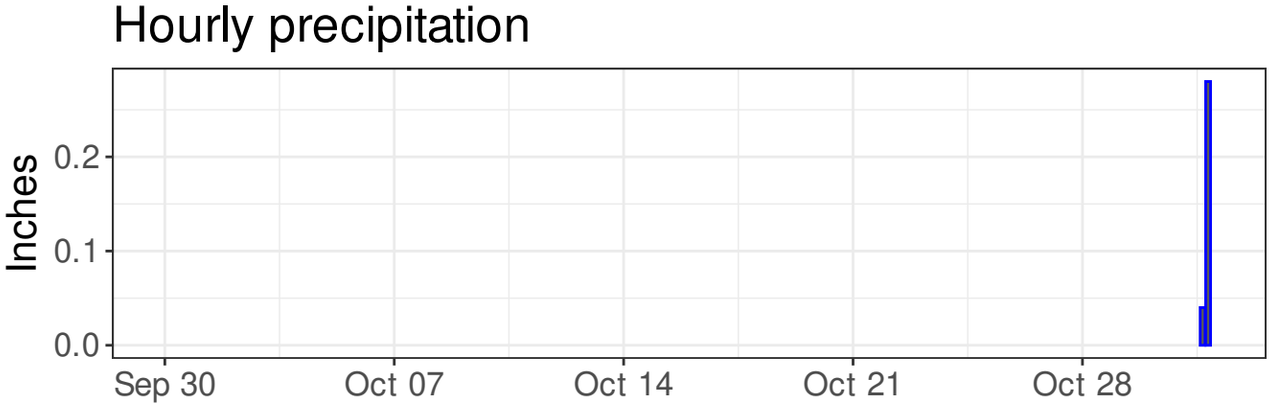

## East tilt - detrended values



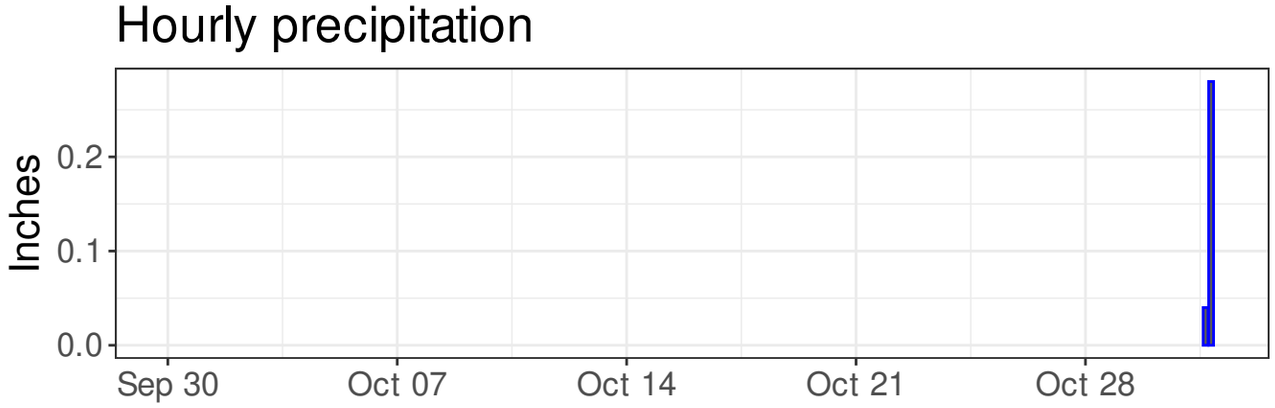

## North tilt - detrended values



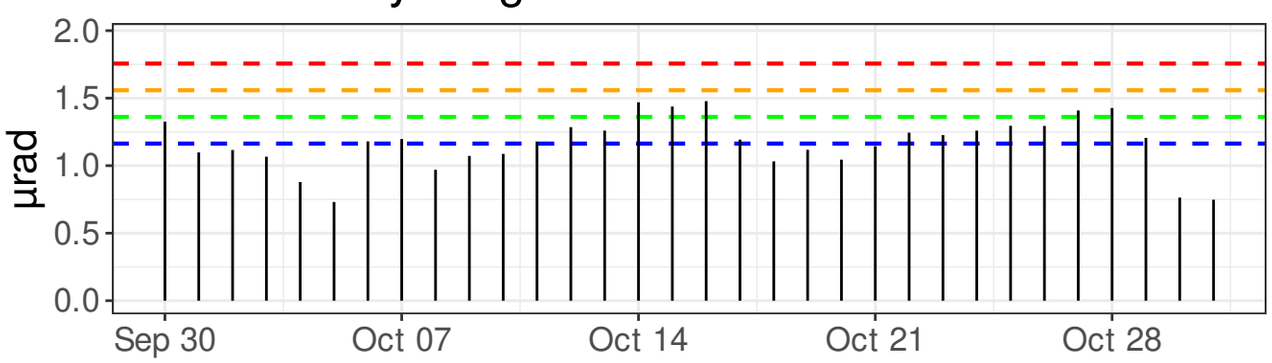

## Hourly precipitation



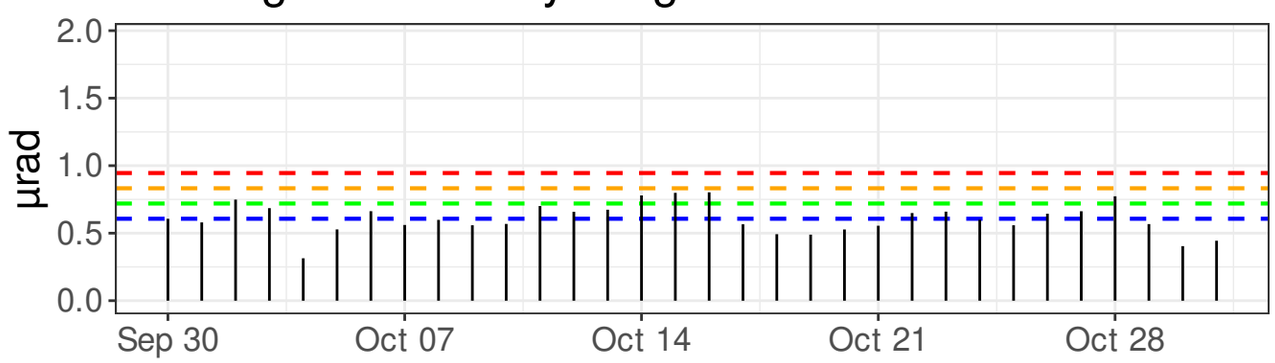

## Hourly precipitation



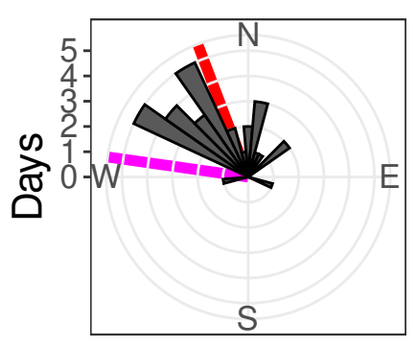

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -30.34 ± 0.27 µrad/year

North tilt rate: 79.75 ± 0.14 µrad/year

Azimuth to C7: 278 deg

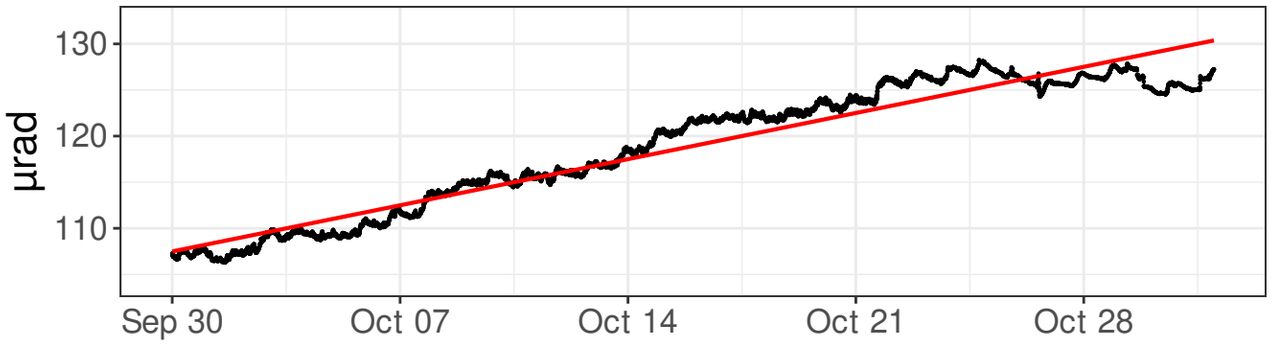
Distance to C7: 1151 ft

0σ 1σ 2σ 3σ

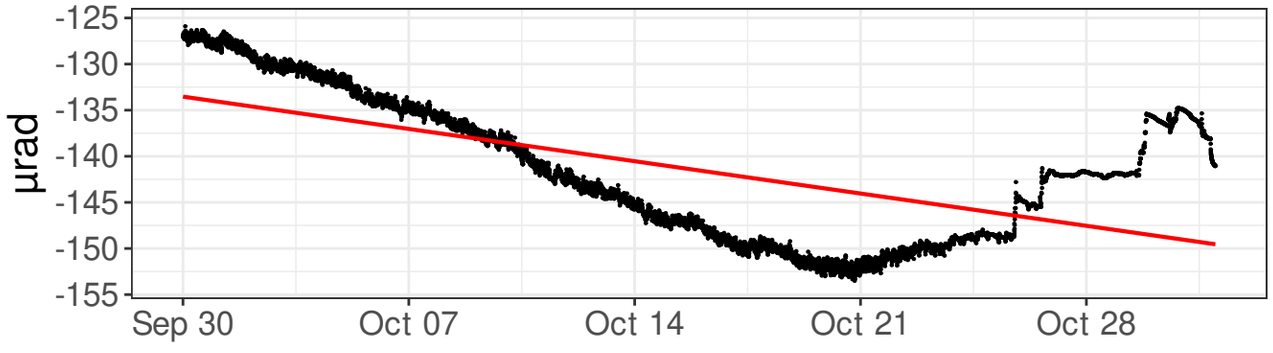
Linear model Azimuth to C7

# SSD15, 09/30/2024 - 10/31/2024

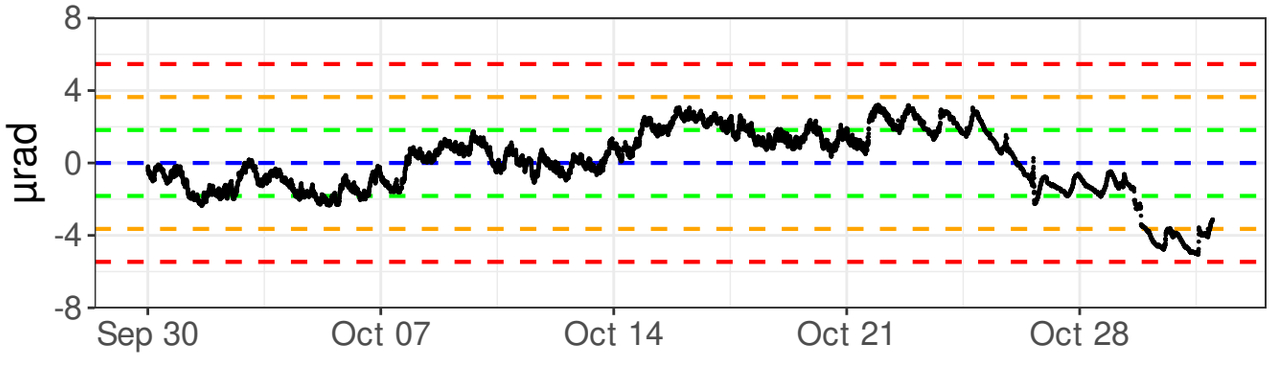
## East tilt - raw values, Linear model R2 0.93



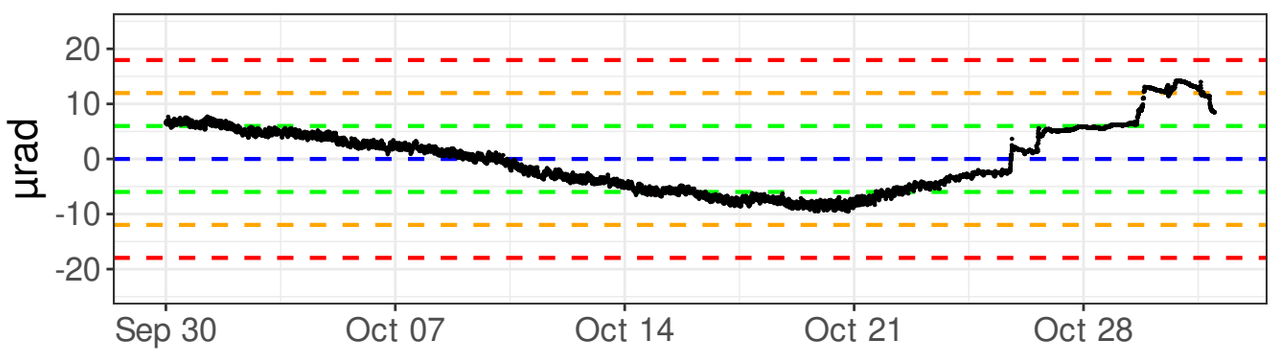

## North tilt - raw values, Linear model R2 0.37



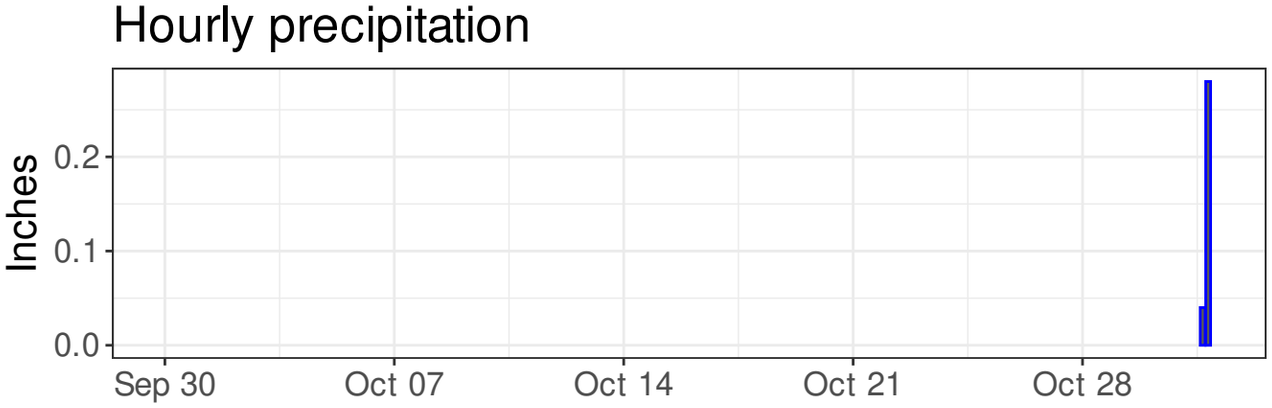

## East tilt - detrended values



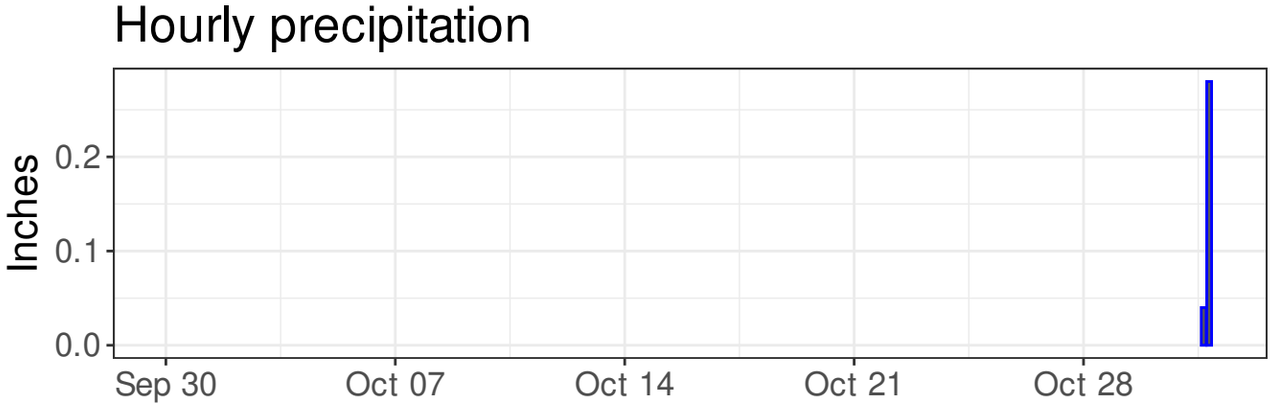

## North tilt - detrended values



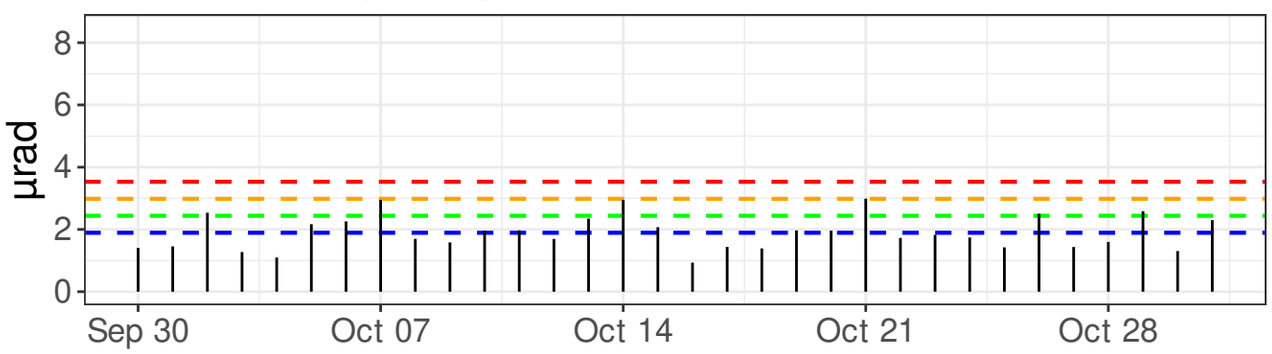

## Hourly precipitation



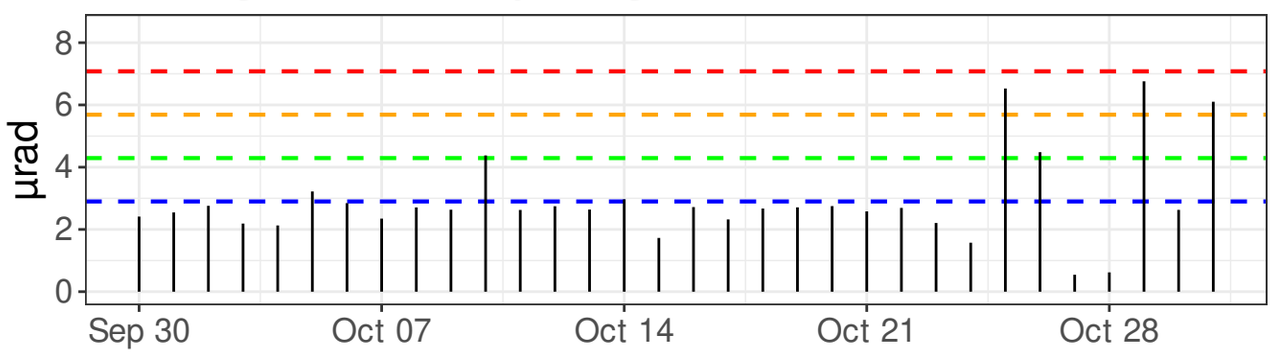

## Hourly precipitation



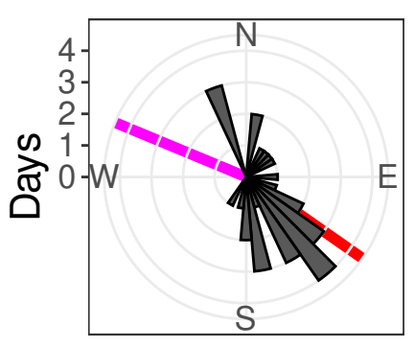

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 261.73 ± 0.67 µrad/year

North tilt rate: -183.15 ± 2.20 µrad/year

Azimuth to C7: 293 deg

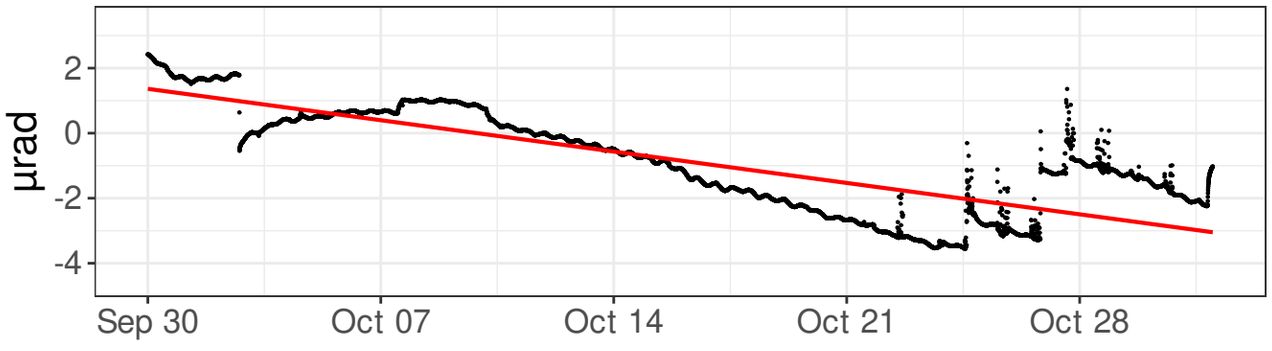
Distance to C7: 614 ft

0σ 1σ 2σ 3σ

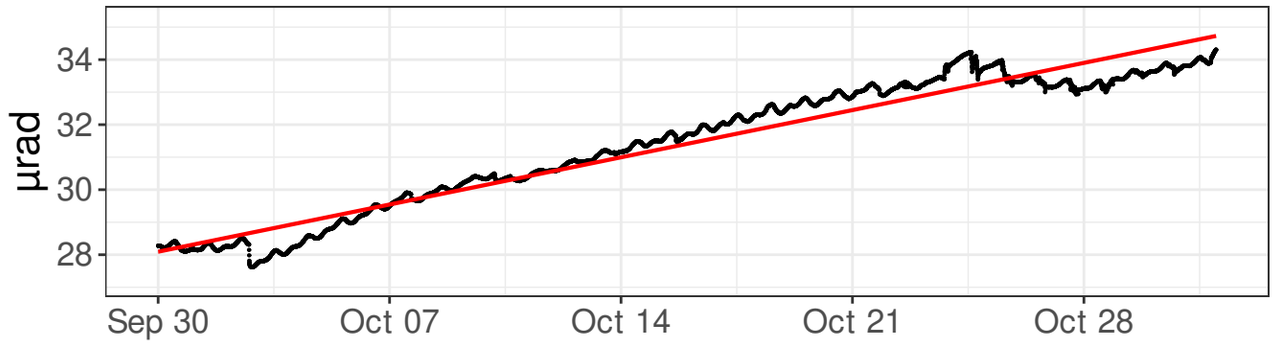
Linear model Azimuth to C7

# SSD16, 09/30/2024 - 10/31/2024

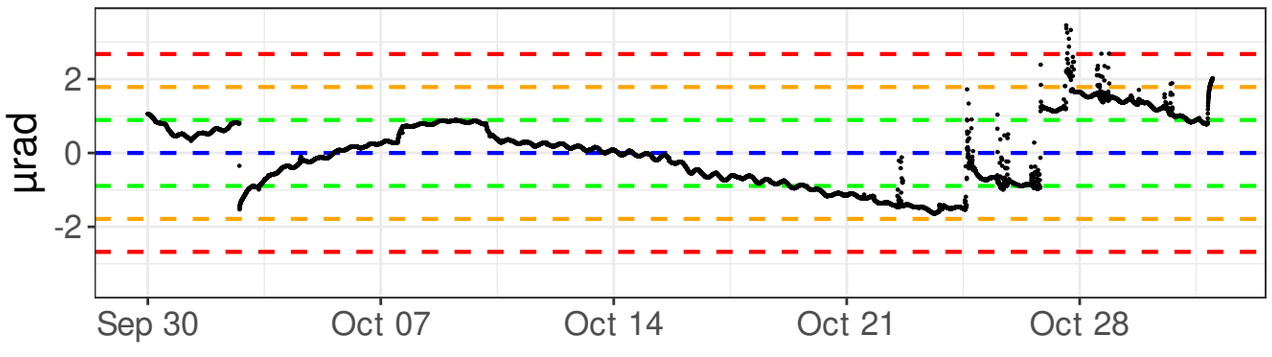
East tilt - raw values, Linear model R2 0.67



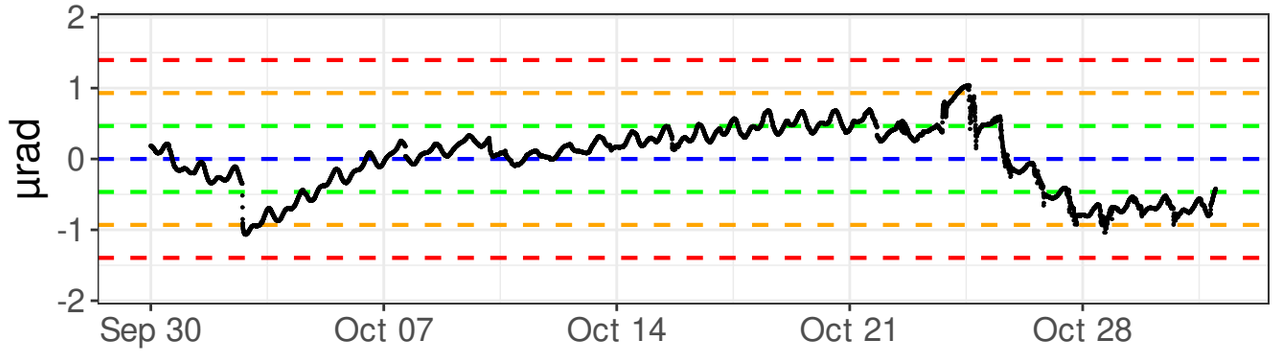

North tilt - raw values, Linear model R2 0.94



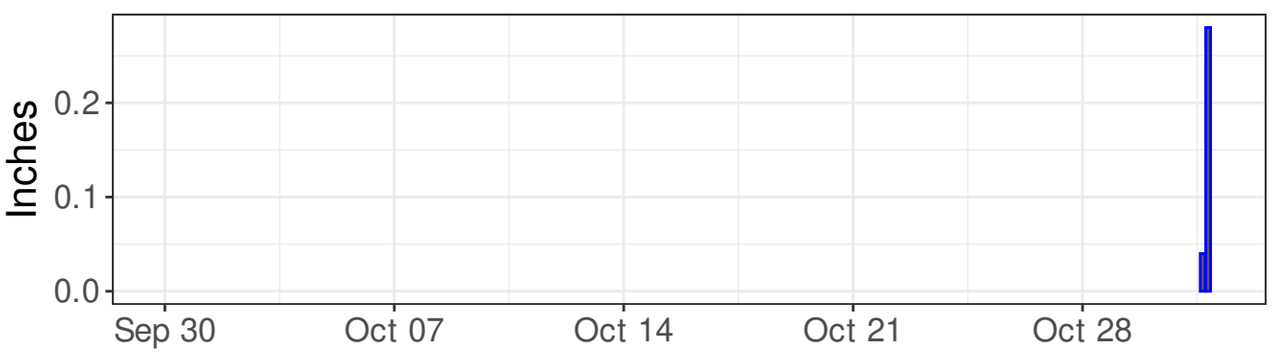

East tilt - detrended values



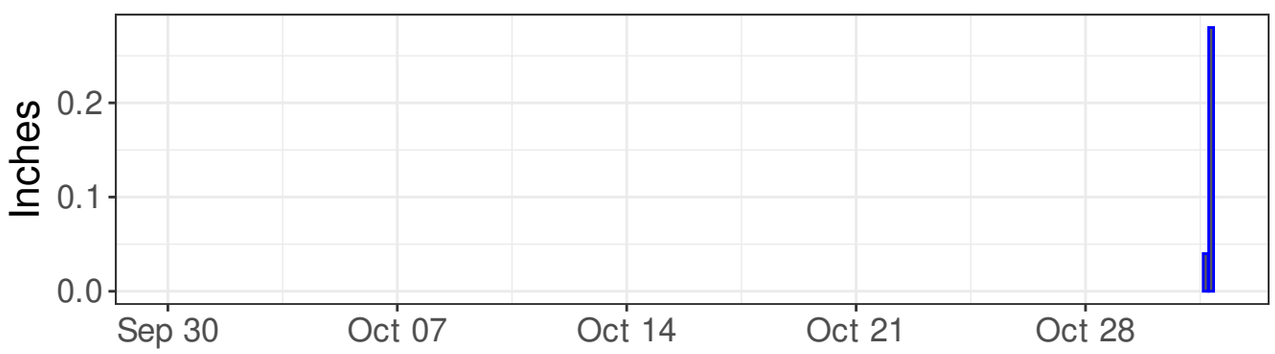

North tilt - detrended values



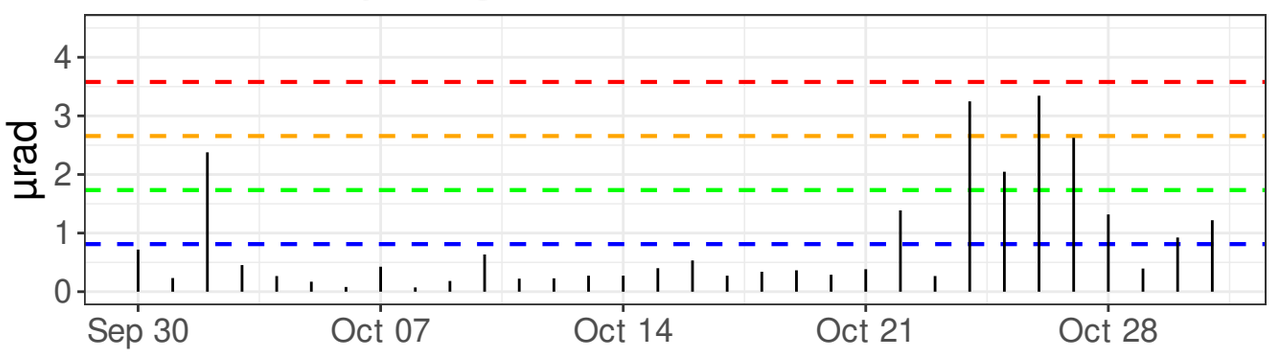

Hourly precipitation



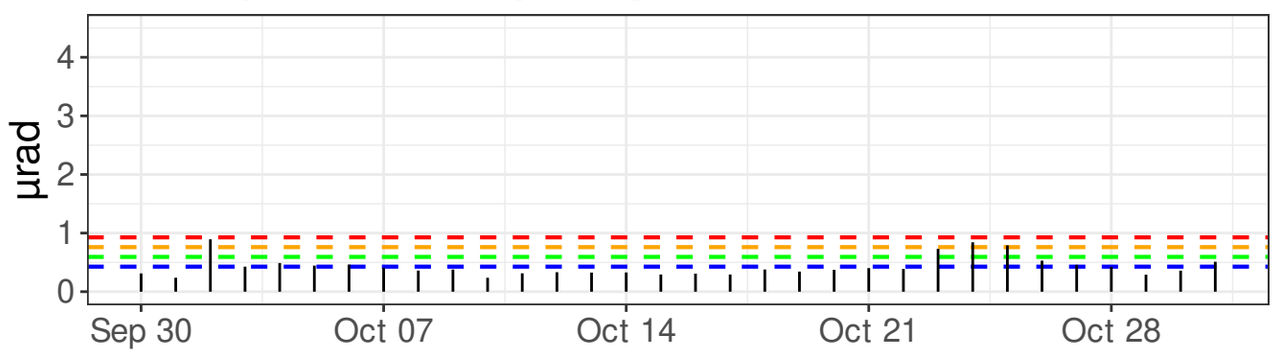

Hourly precipitation



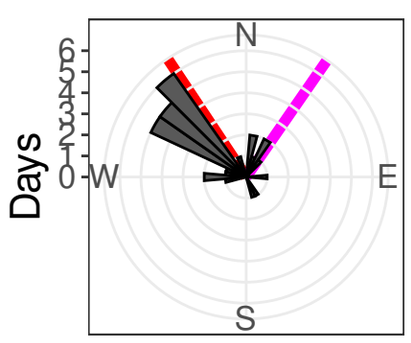

East tilt - daily range




Tilt magnitude - daily range




Tilt direction frequency




East tilt rate: -50.44 ± 0.33 µrad/year

North tilt rate: 75.90 ± 0.17 µrad/year

Azimuth to C7: 35 deg

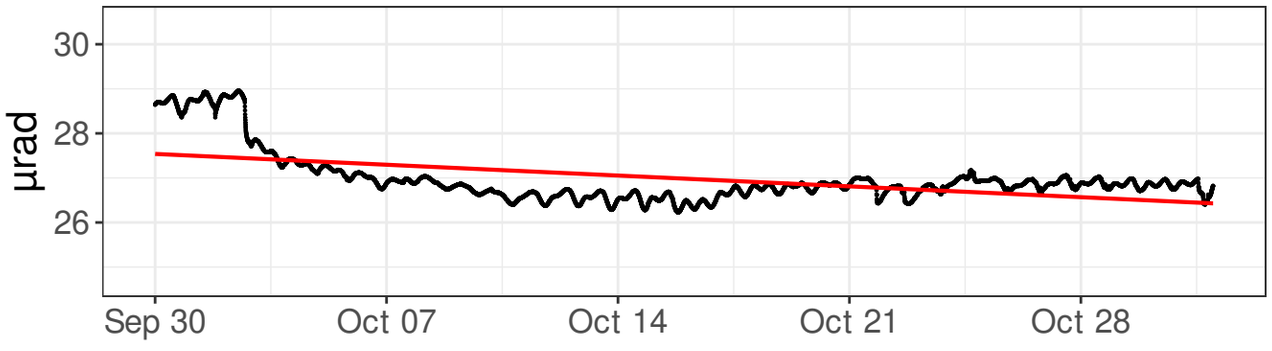
Distance to C7: 1885 ft

0σ 1σ 2σ 3σ

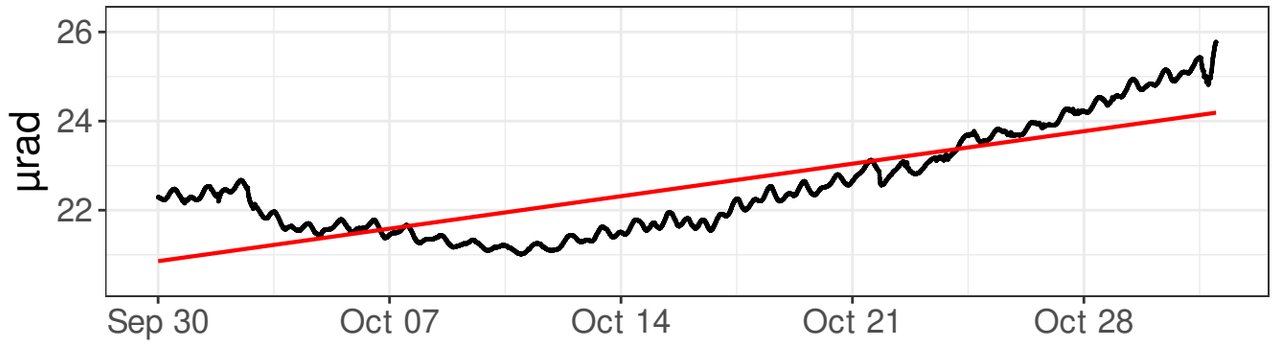
Linear model Azimuth to C7

# SSD17, 09/30/2024 - 10/31/2024

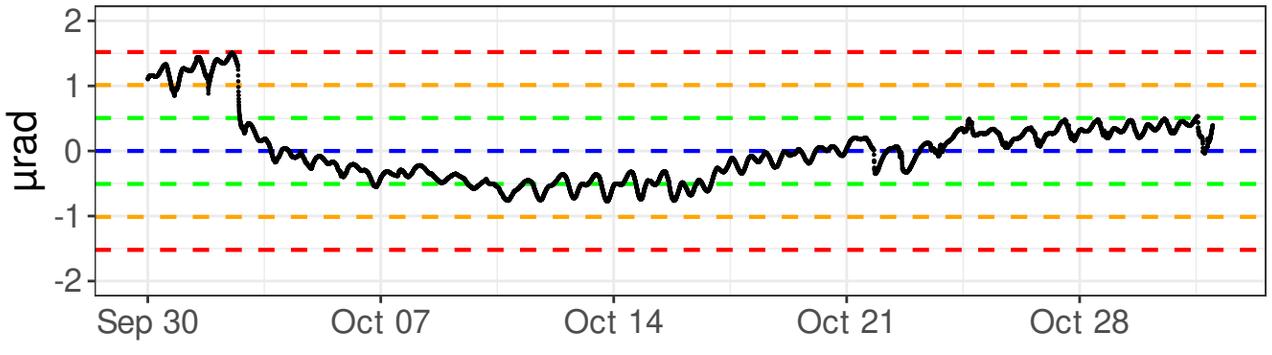
East tilt - raw values, Linear model R2 0.29



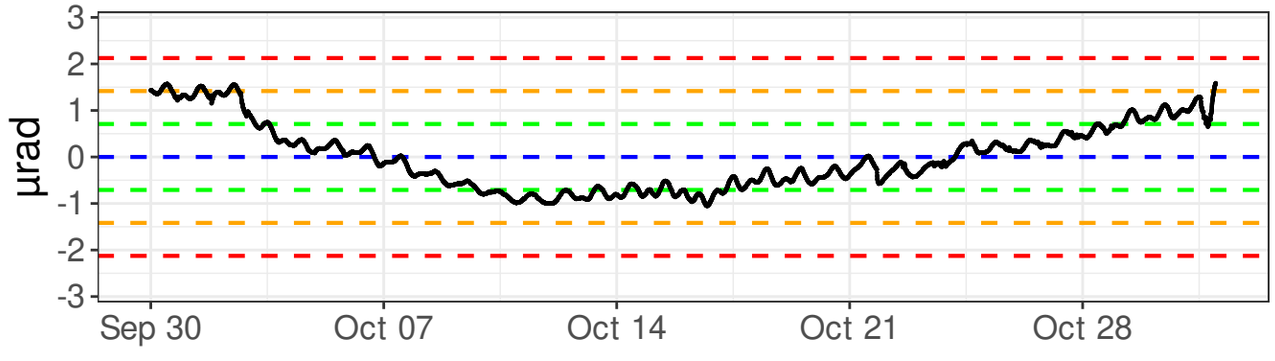

North tilt - raw values, Linear model R2 0.65



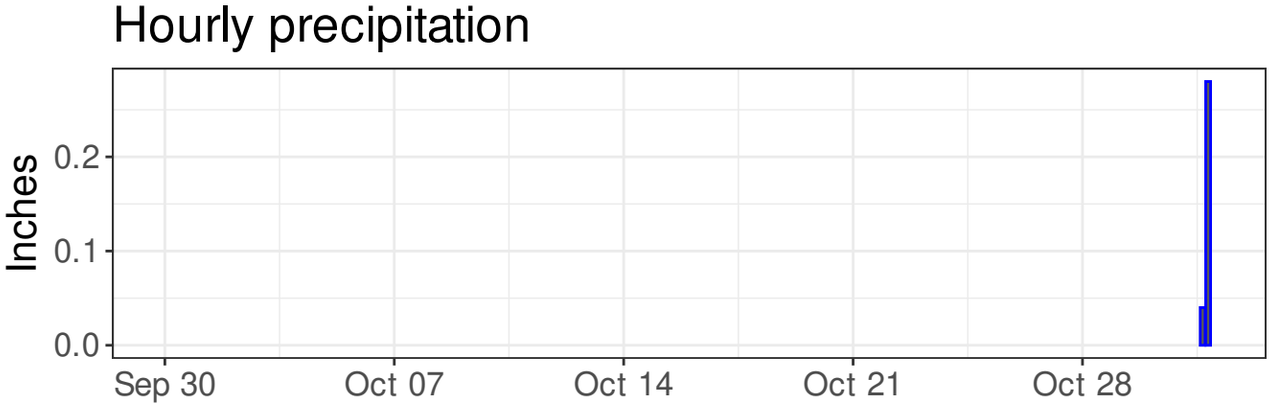

East tilt - detrended values



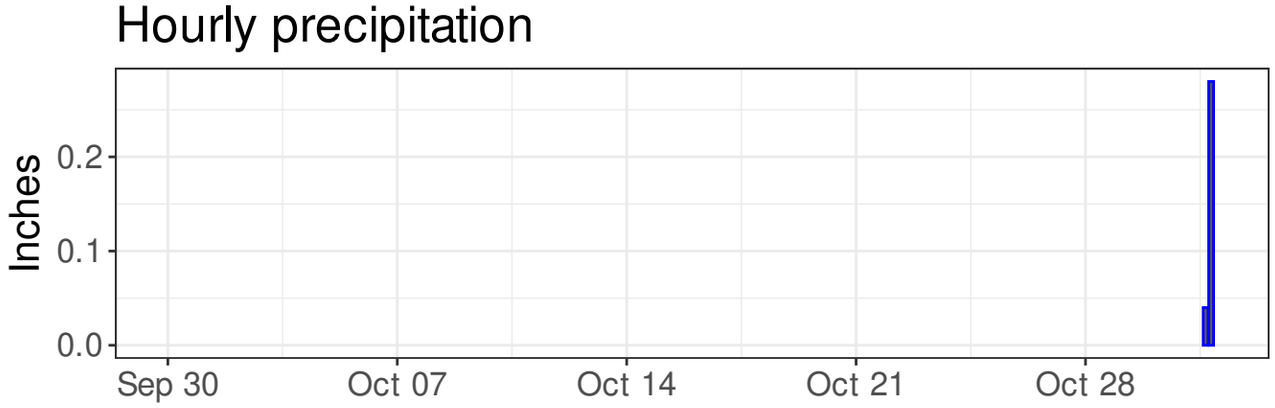

North tilt - detrended values



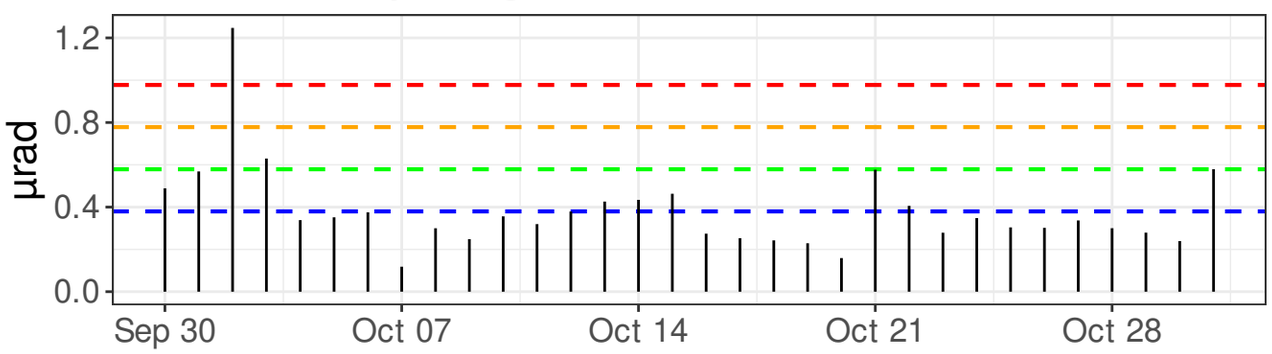

Hourly precipitation



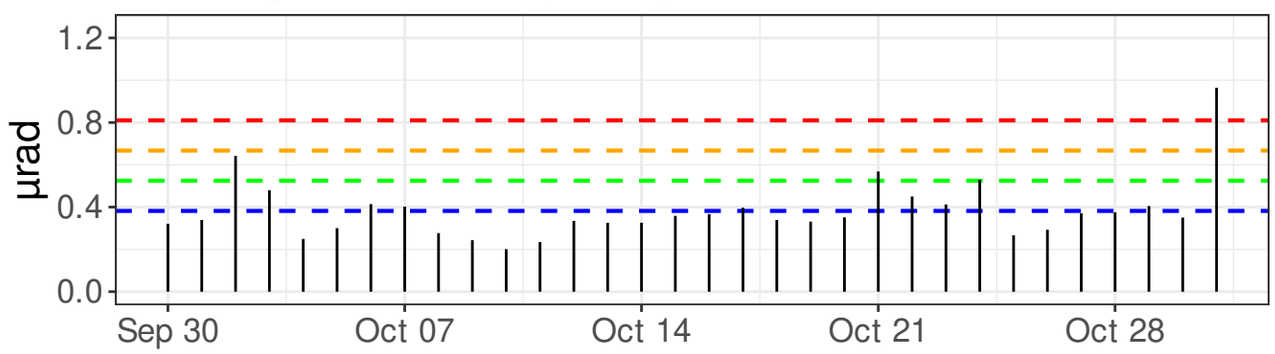

Hourly precipitation



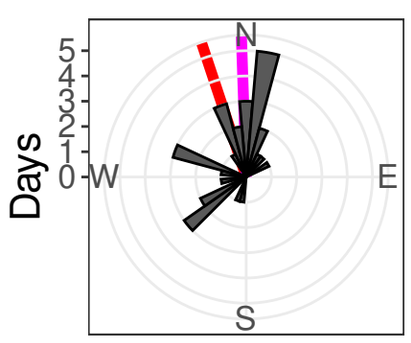

East tilt - daily range




Tilt magnitude - daily range




Tilt direction frequency




East tilt rate: -12.69 ± 0.19 µrad/year

North tilt rate: 38.12 ± 0.26 µrad/year

Azimuth to C7: 358 deg

Distance to C7: 1392 ft

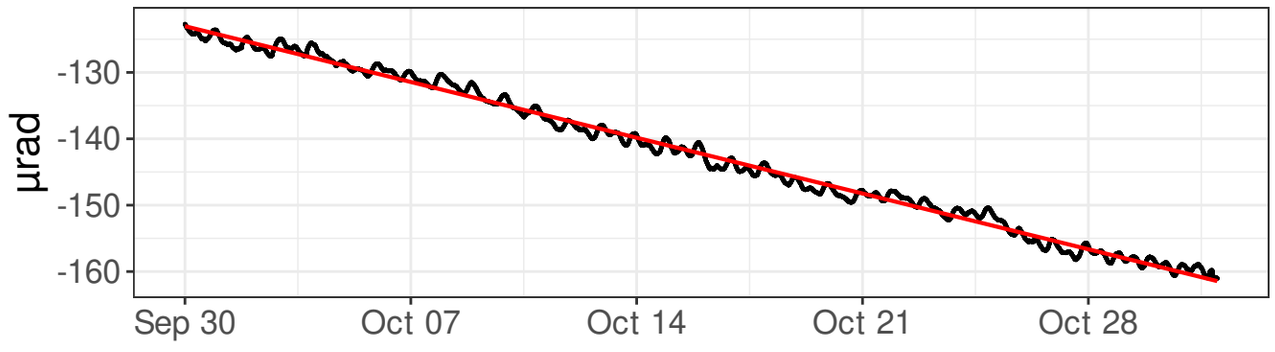
0σ 1σ 2σ 3σ

Linear model Azimuth to C7

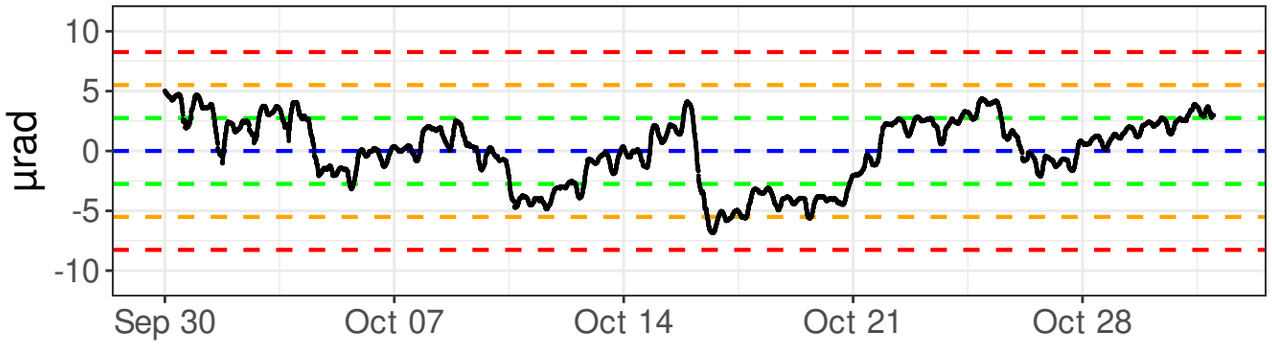
# SSD18, 09/30/2024 - 10/31/2024

East tilt - raw values, Linear model R2 0.88

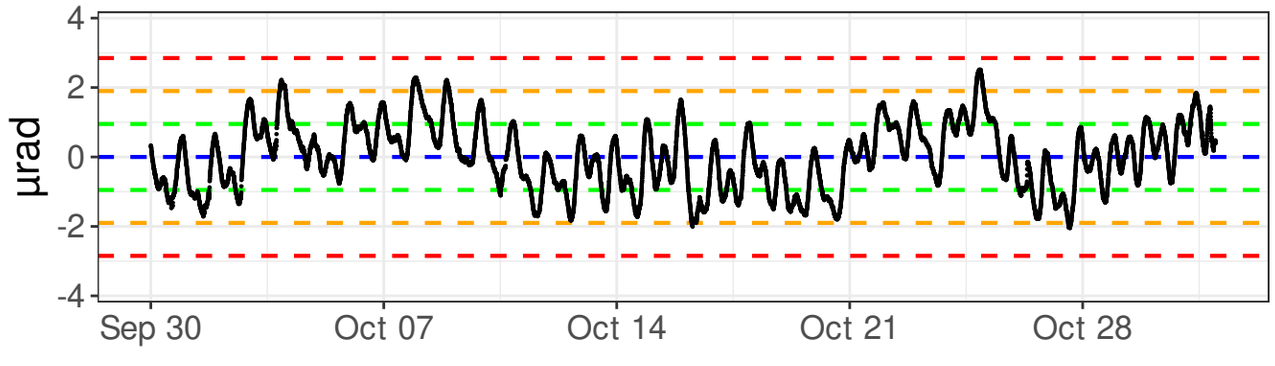

North tilt - raw values, Linear model R2 0.99



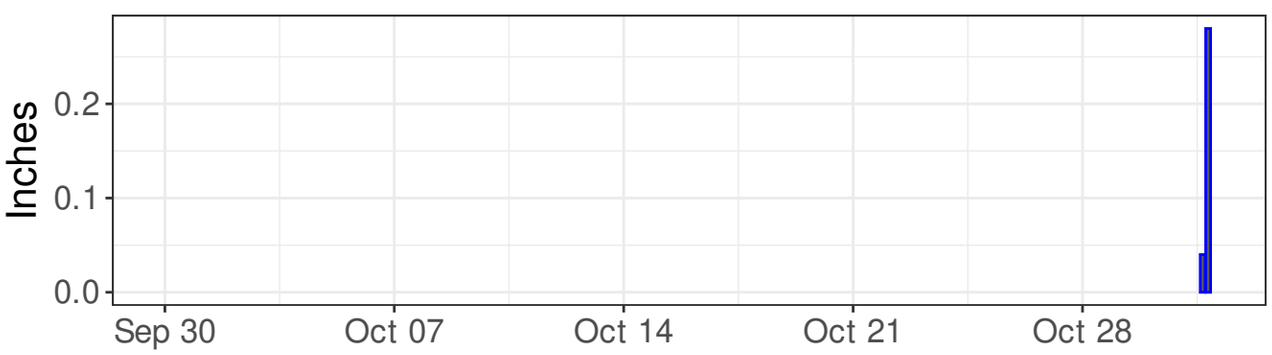

East tilt - detrended values



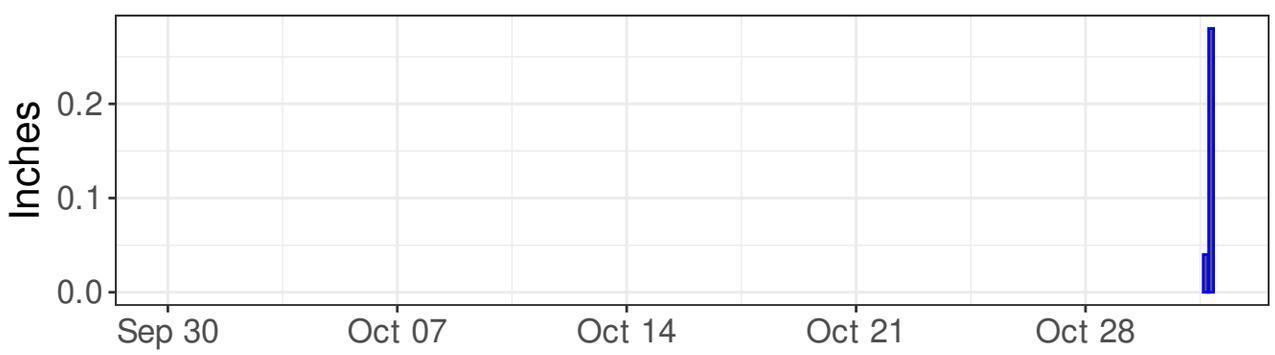

North tilt - detrended values



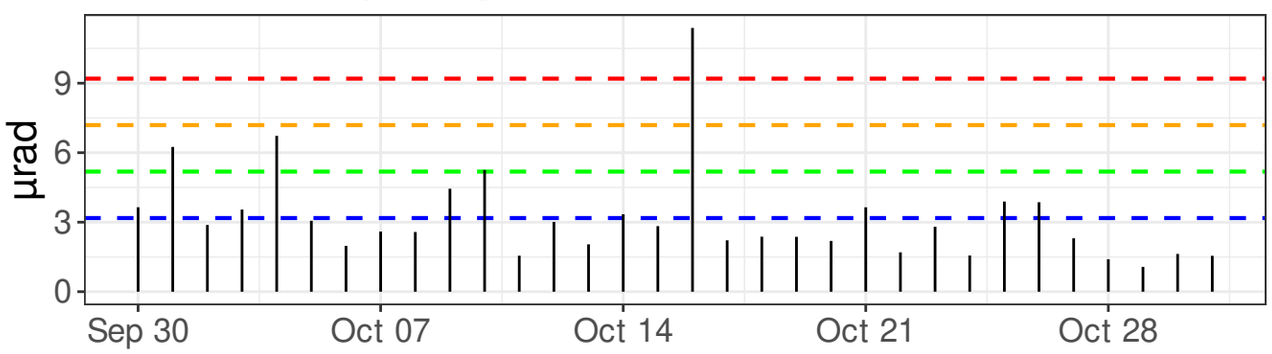

Hourly precipitation



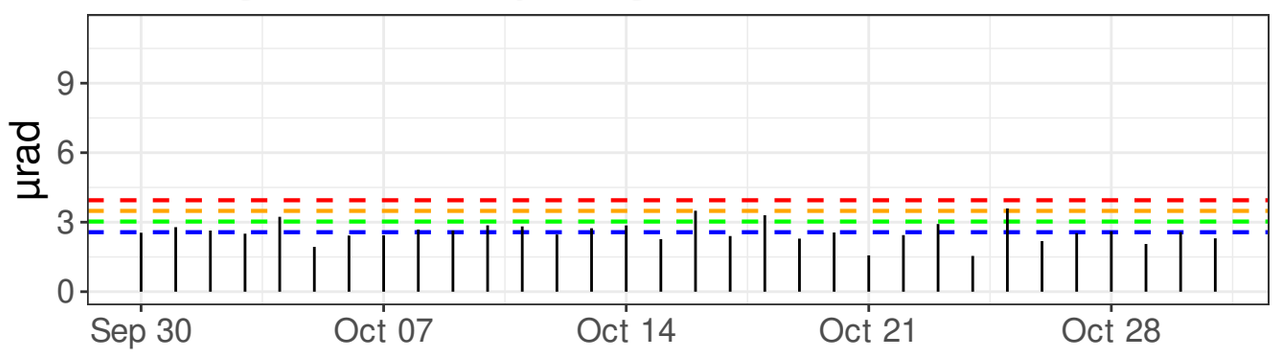

Hourly precipitation



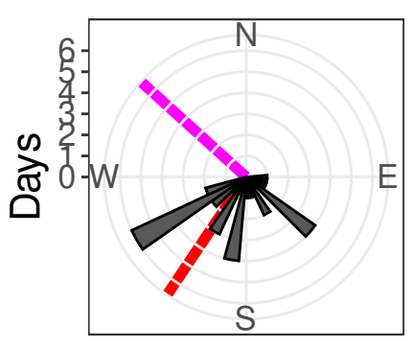

East tilt - daily range




Tilt magnitude - daily range




Tilt direction frequency




East tilt rate: -294.94 ± 1.01 µrad/year

North tilt rate: -439.32 ± 0.35 µrad/year

Azimuth to C7: 312 deg

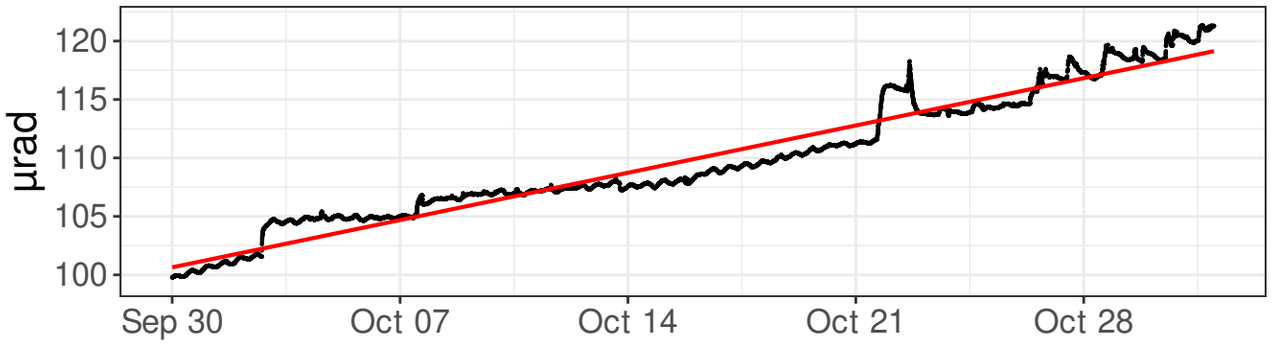
Distance to C7: 1415 ft

0σ 1σ 2σ 3σ

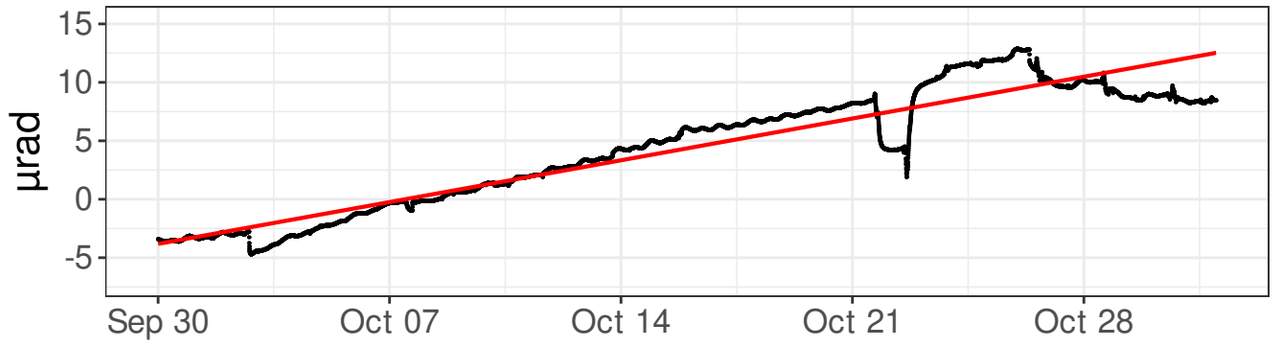
Linear model Azimuth to C7

# SSD19, 09/30/2024 - 10/31/2024

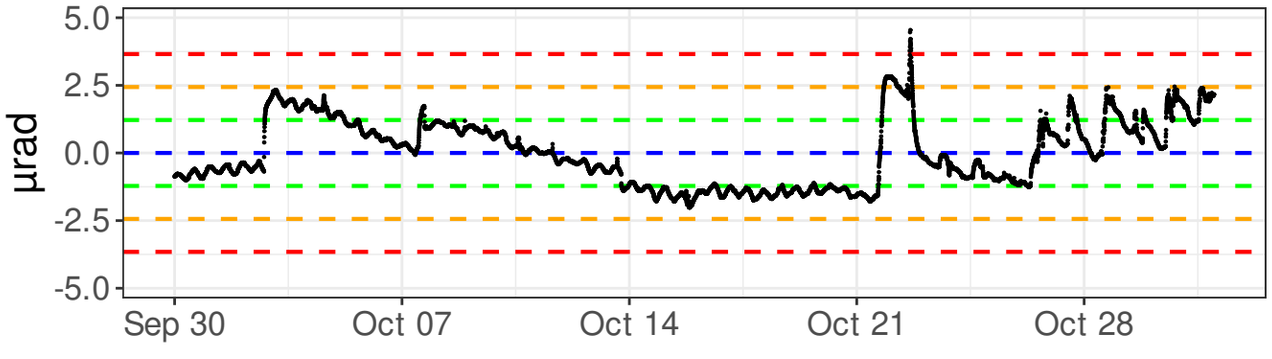
## East tilt - raw values, Linear model R2 0.95



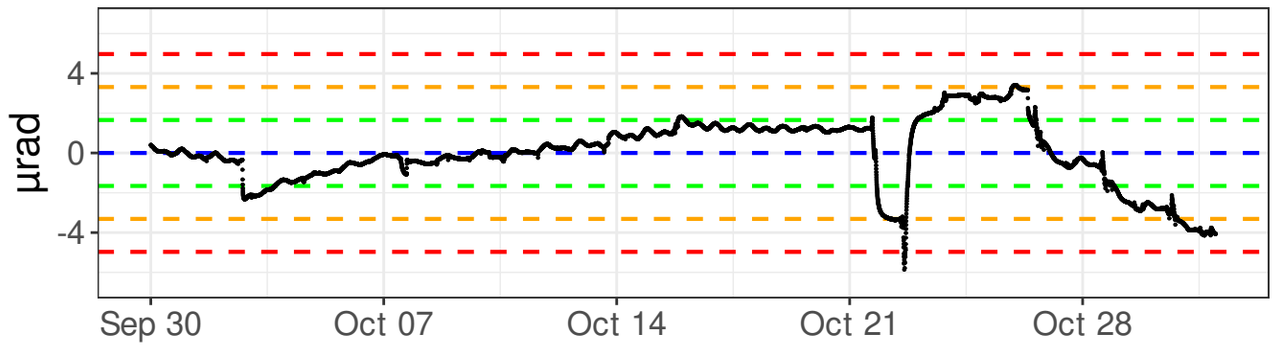

## North tilt - raw values, Linear model R2 0.89



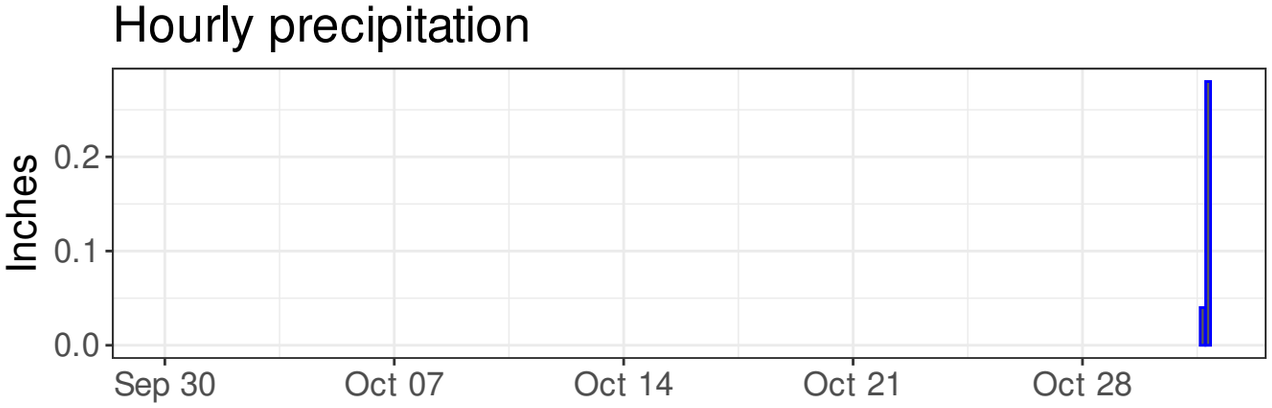

## East tilt - detrended values



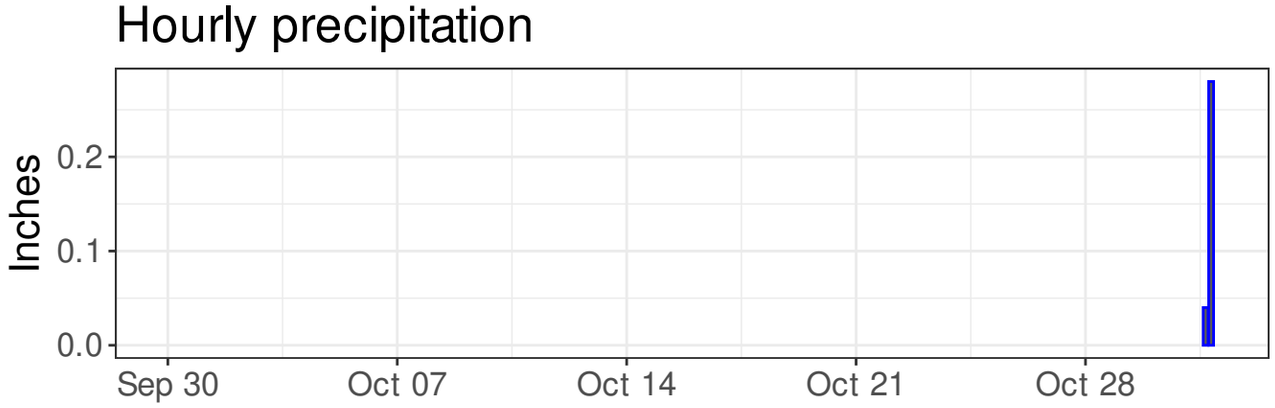

## North tilt - detrended values



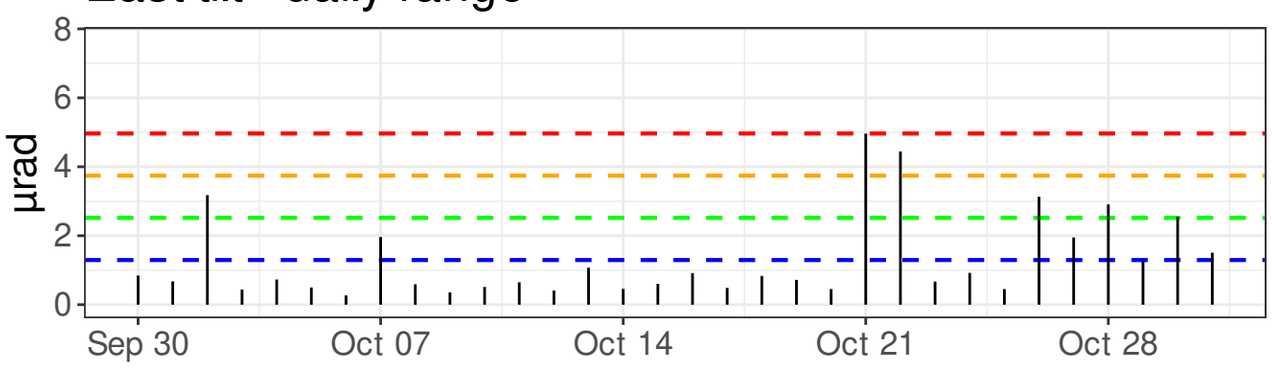

## Hourly precipitation



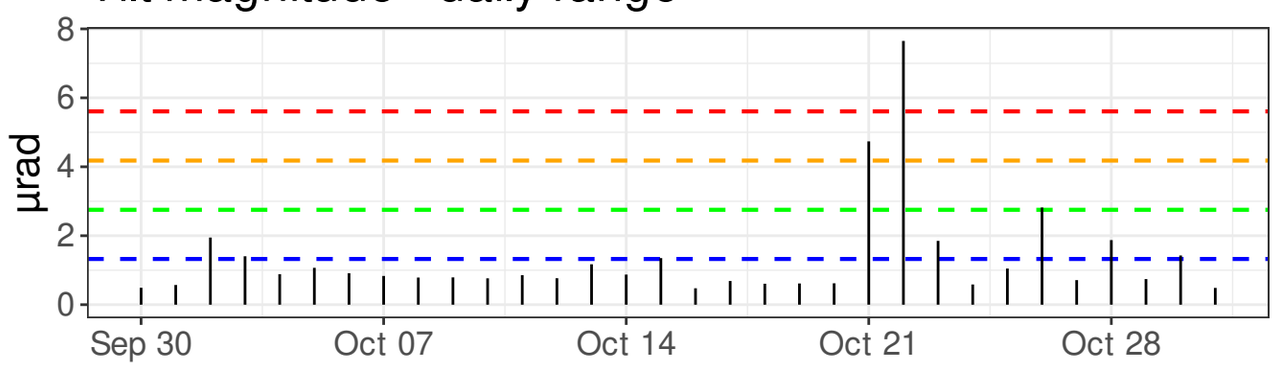

## Hourly precipitation



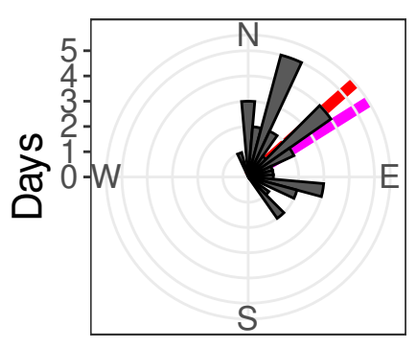

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: 211.53 ± 0.45 µrad/year

North tilt rate: 186.93 ± 0.61 µrad/year

Azimuth to C7: 58 deg

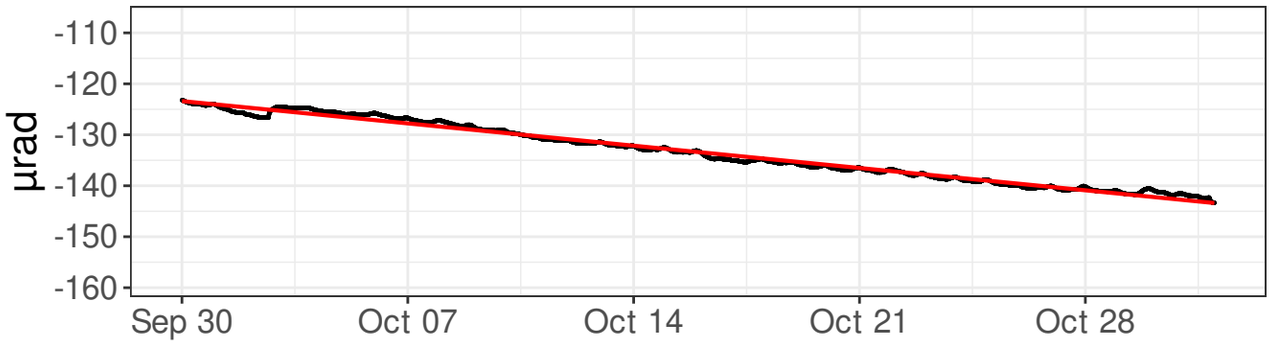
Distance to C7: 2245 ft

0σ 1σ 2σ 3σ

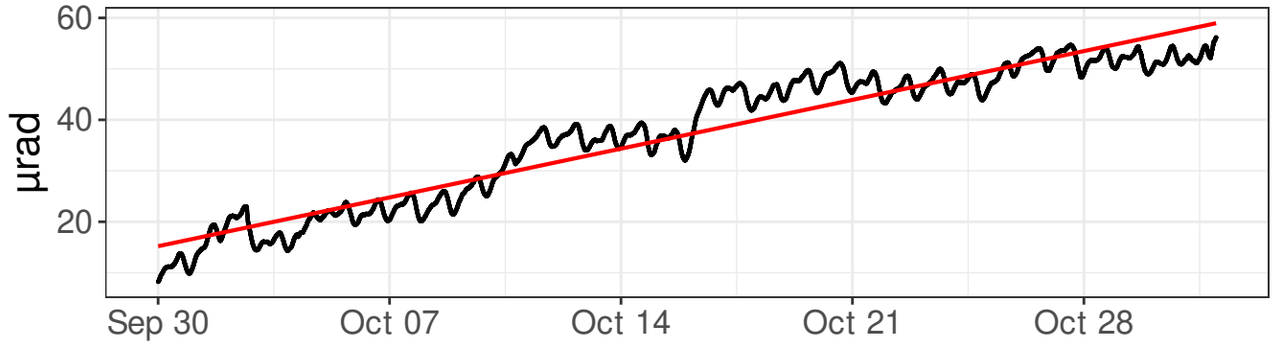
Linear model Azimuth to C7

# SSD20, 09/30/2024 - 10/31/2024

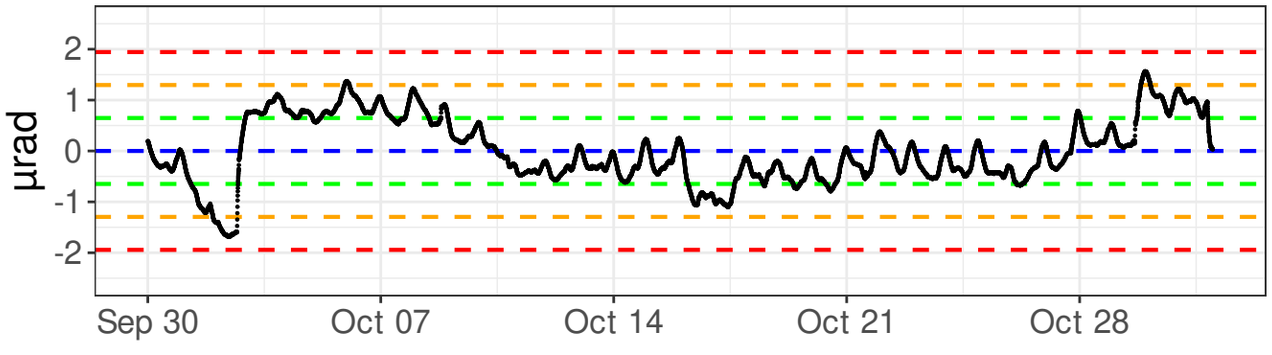
## East tilt - raw values, Linear model R2 0.99



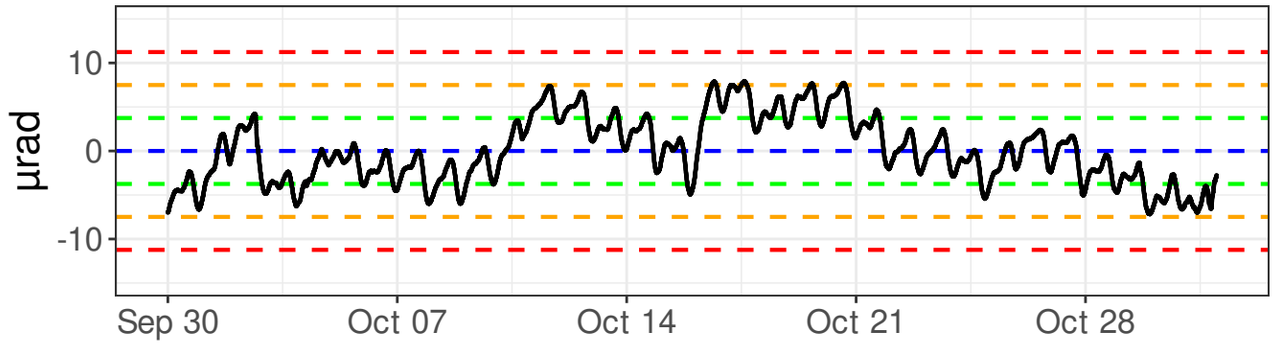

## North tilt - raw values, Linear model R2 0.92



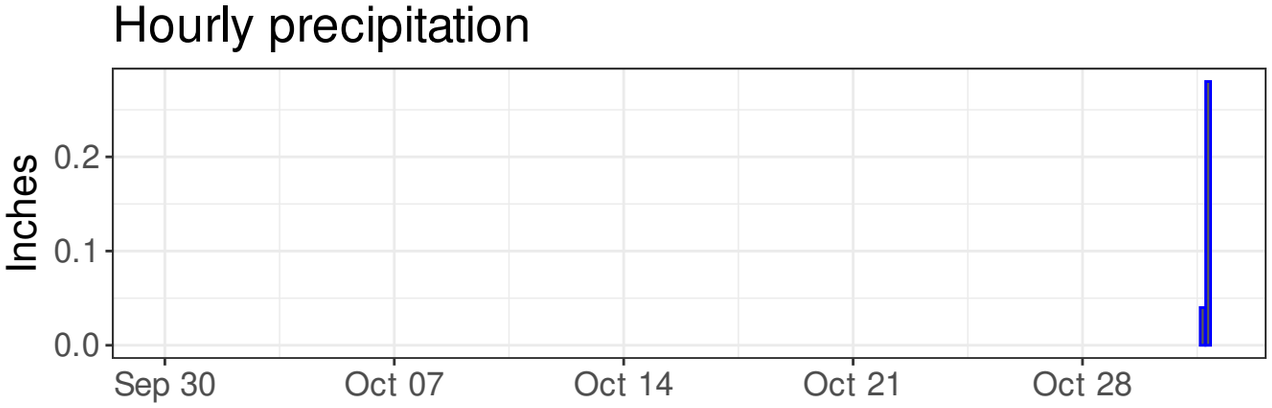

## East tilt - detrended values



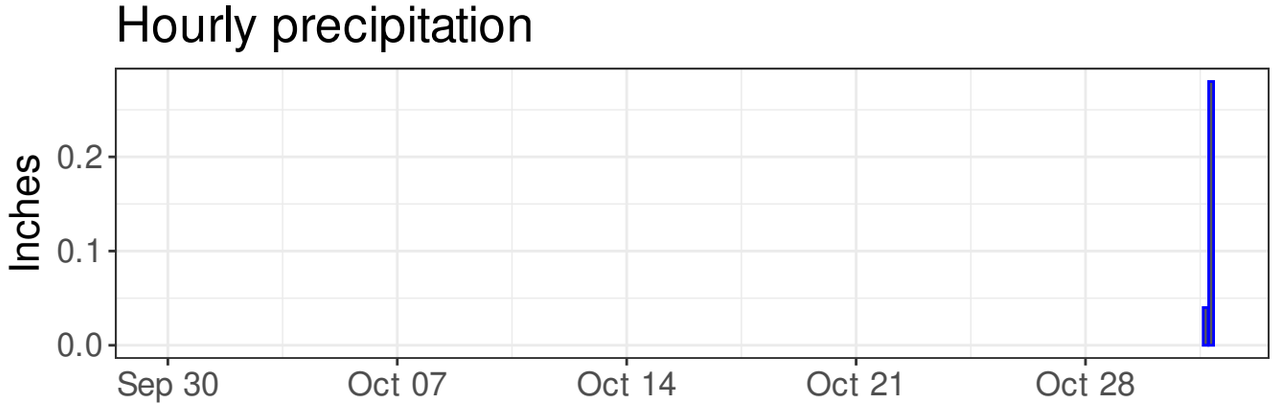

## North tilt - detrended values



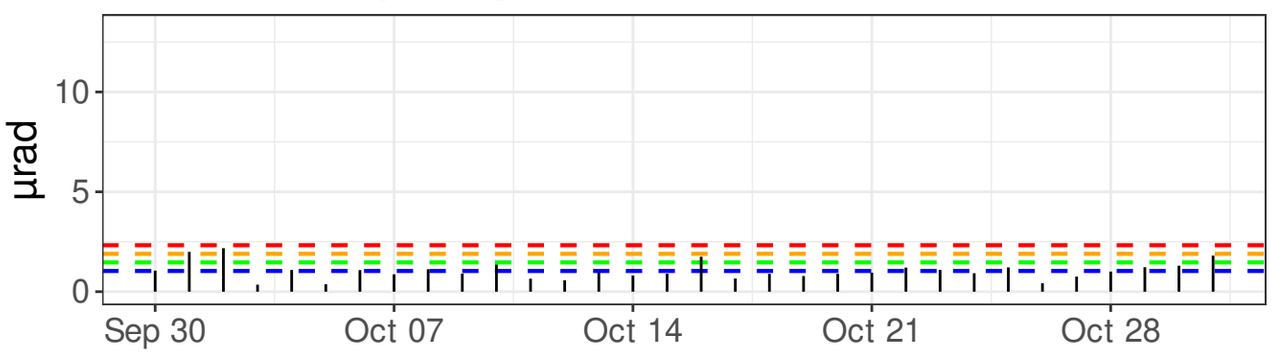

## Hourly precipitation



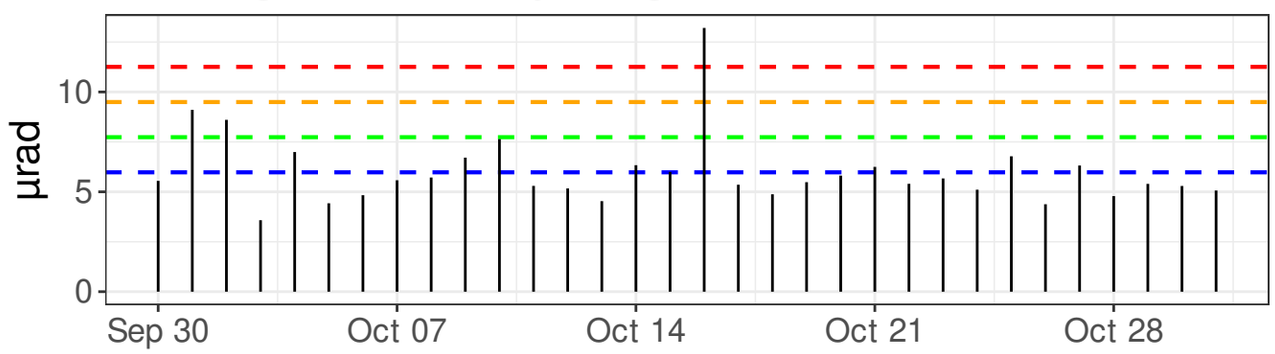

## Hourly precipitation



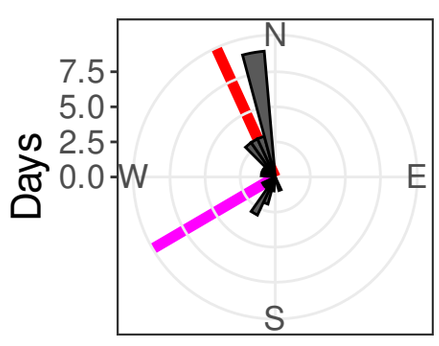

## East tilt - daily range




## Tilt magnitude - daily range




## Tilt direction frequency




East tilt rate: -228.80 ± 0.24 µrad/year

North tilt rate: 500.43 ± 1.38 µrad/year

Azimuth to C7: 240 deg

Distance to C7: 1378 ft

0σ 1σ 2σ 3σ

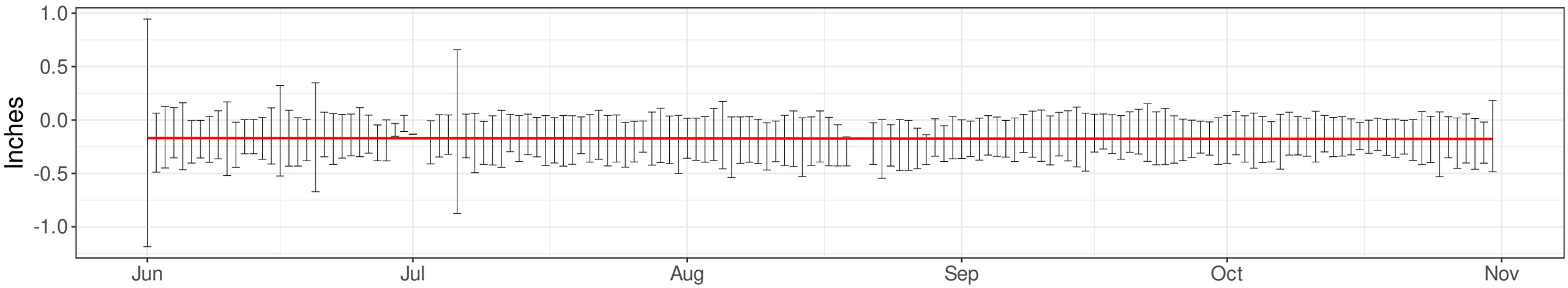
Linear model Azimuth to C7

# APPENDIX 2

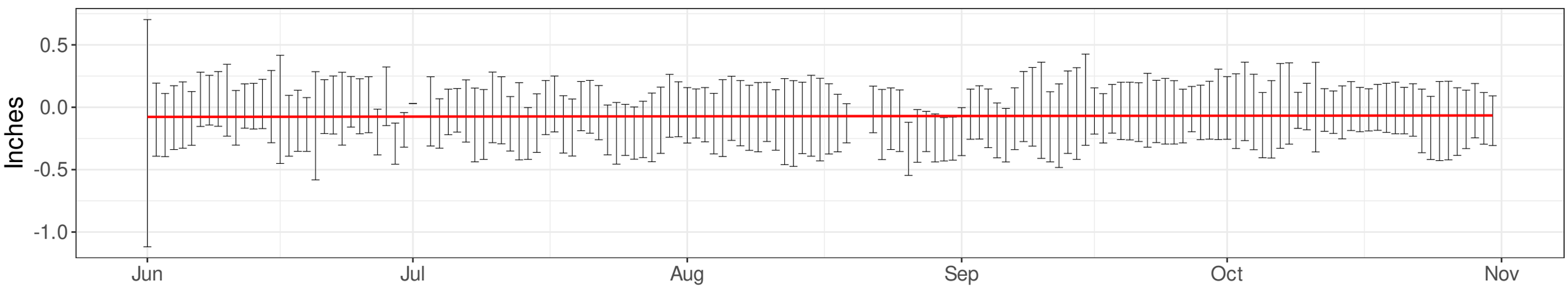
## GNSS Data Plots

# REMC7, 2024-06-01 - 2024-10-31

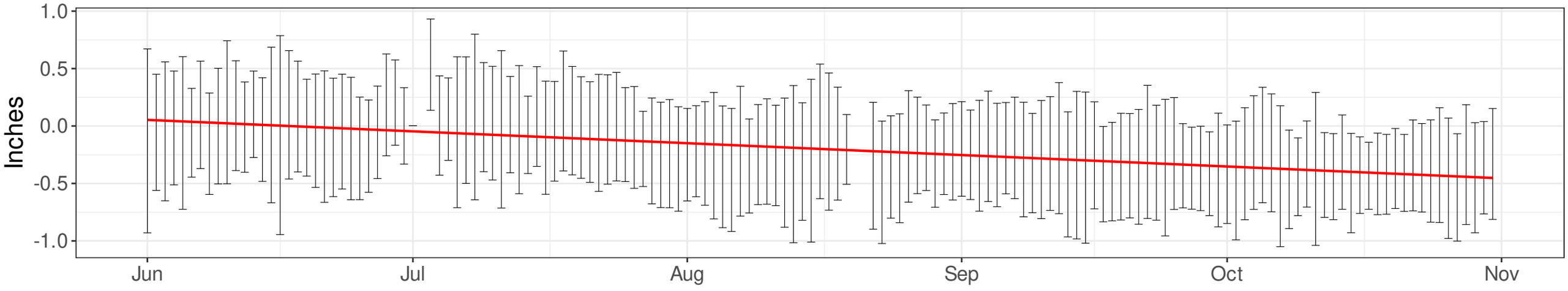
## East displacement - daily values




## North displacement - daily values




## Vertical displacement - daily values




Local east rate: 0.462 ± 0.032 in/year, R2: 0.00

Local north rate: 0.070 ± 0.057 in/year, R2: 0.00

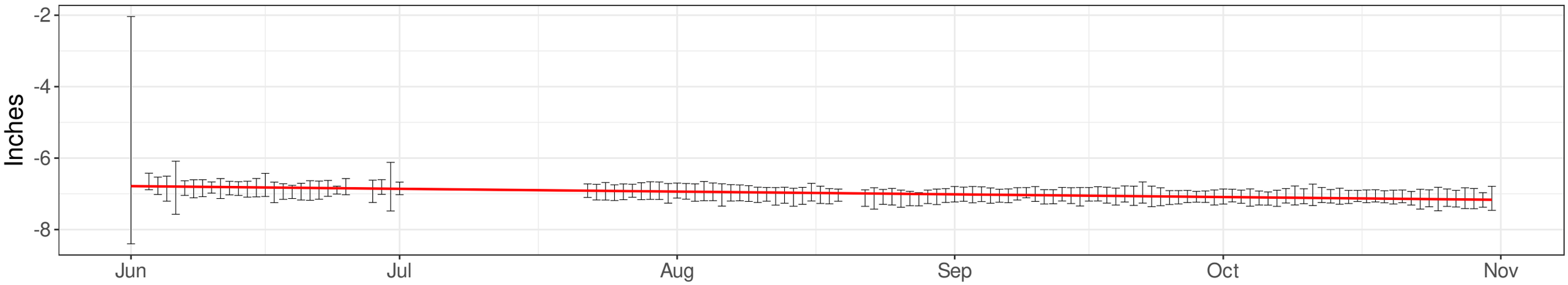
Local vertical rate: -1.137 ± 0.091 in/year, R2: 0.66

Linear model

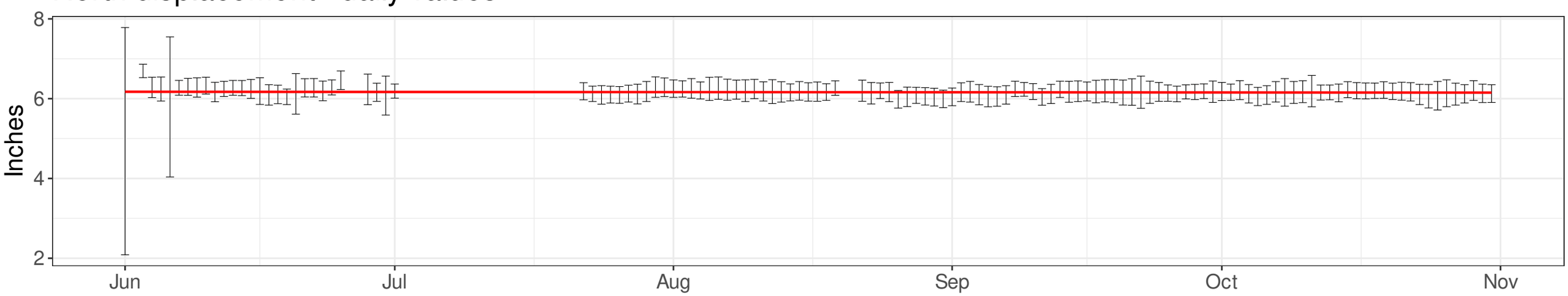
Local rate values have been calculated by removing the regional tectonic plate rates from the raw data displayed in the charts.

# REMNE, 2024-06-01 - 2024-10-31

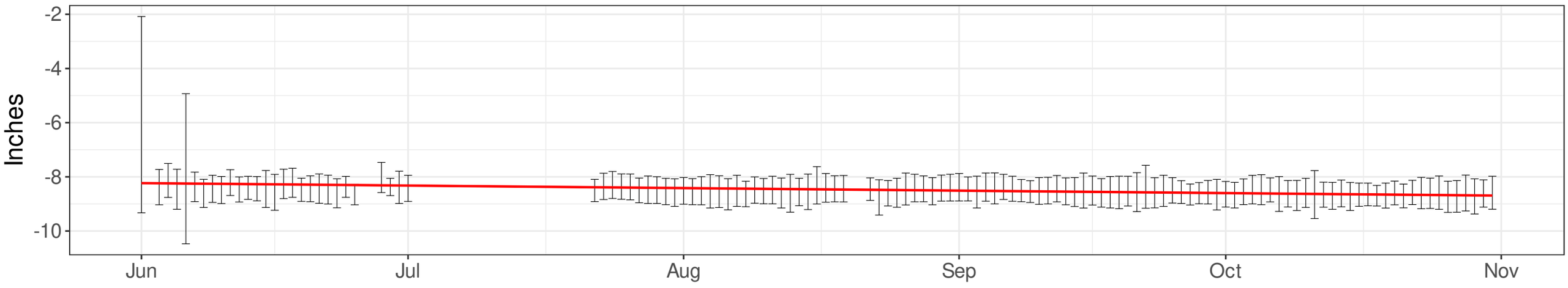
## East displacement - daily values




## North displacement - daily values




## Vertical displacement - daily values




Local east rate: -0.434 ± 0.109 in/year, R2: 0.36

Local north rate: -0.009 ± 0.105 in/year, R2: 0.00

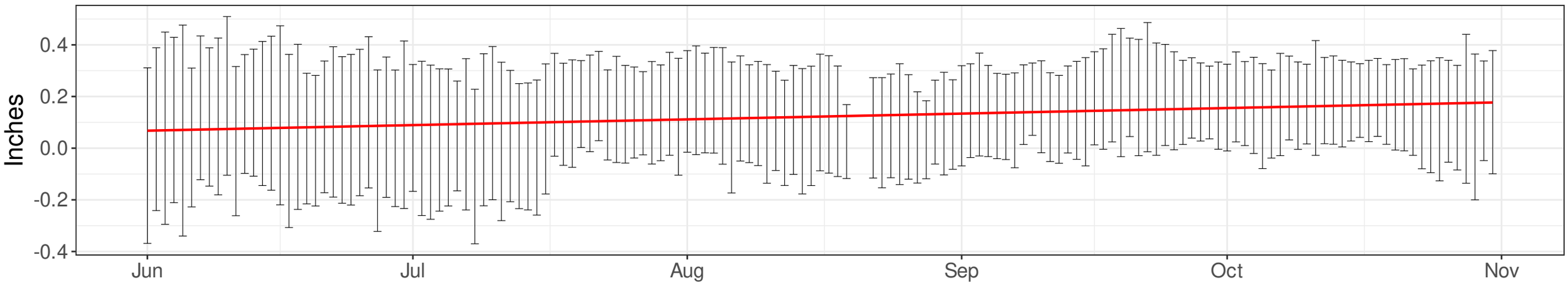
Local vertical rate: -1.025 ± 0.198 in/year, R2: 0.21

Linear model

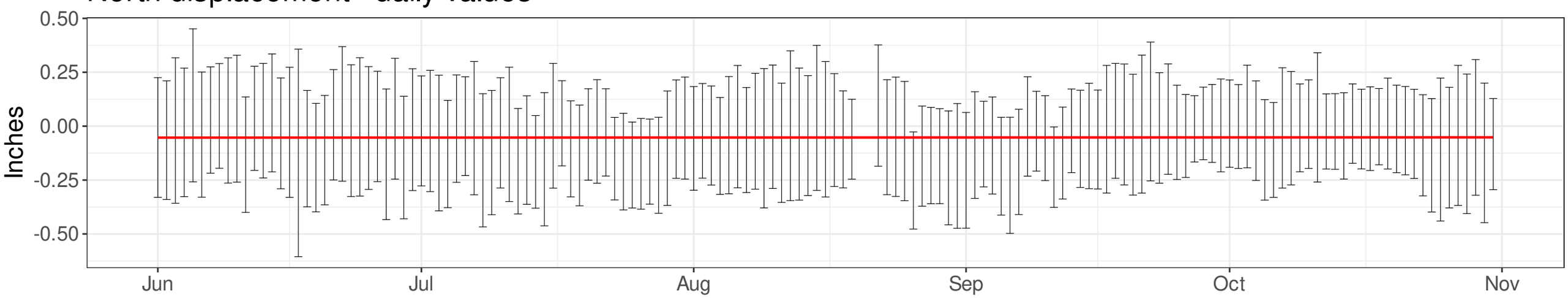
Local rate values have been calculated by removing the regional tectonic plate rates from the raw data displayed in the charts.

# REMNW, 2024-06-01 - 2024-10-31

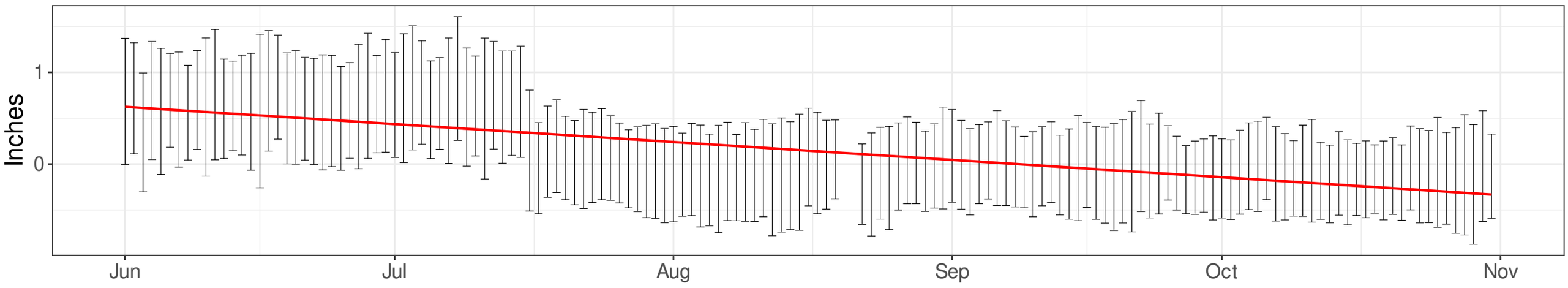
## East displacement - daily values




## North displacement - daily values




## Vertical displacement - daily values




Local east rate: 0.745 ± 0.038 in/year, R2: 0.30

Local north rate: 0.045 ± 0.050 in/year, R2: 0.00

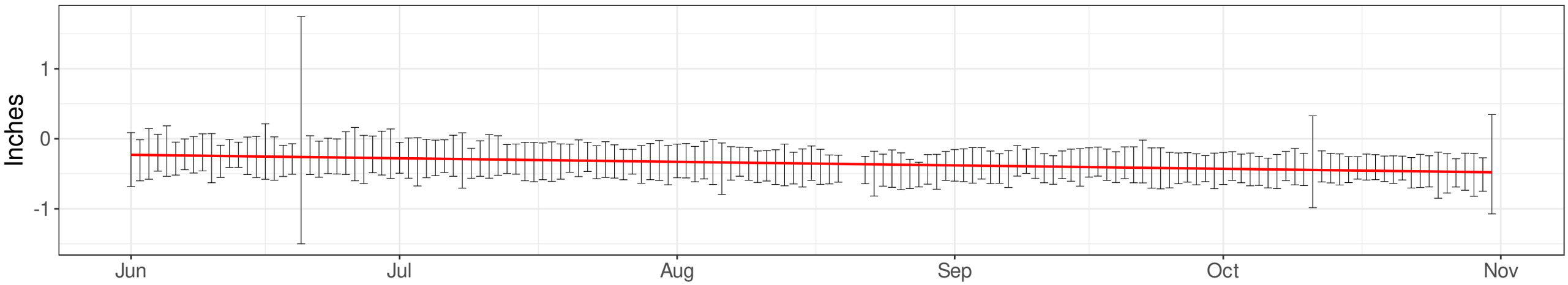
Local vertical rate: -2.222 ± 0.145 in/year, R2: 0.66

Linear model

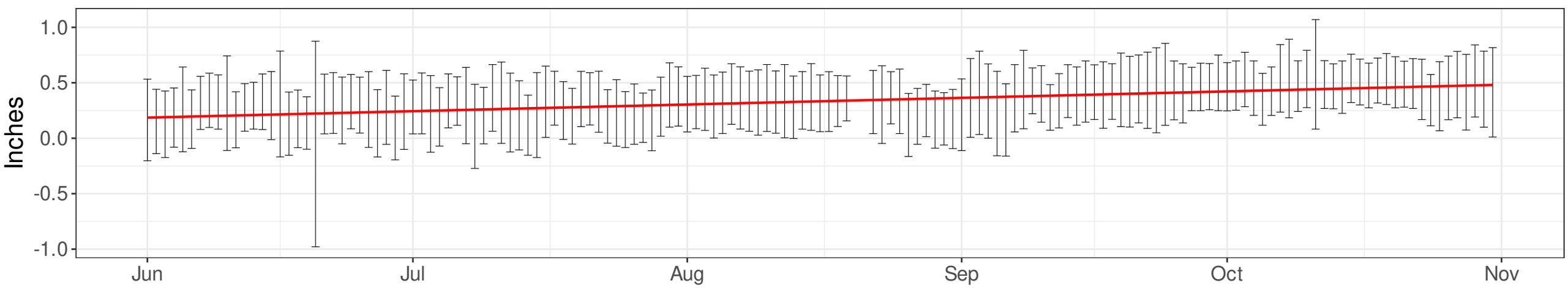
Local rate values have been calculated by removing the regional tectonic plate rates from the raw data displayed in the charts.

# REMSE, 2024-06-01 - 2024-10-31

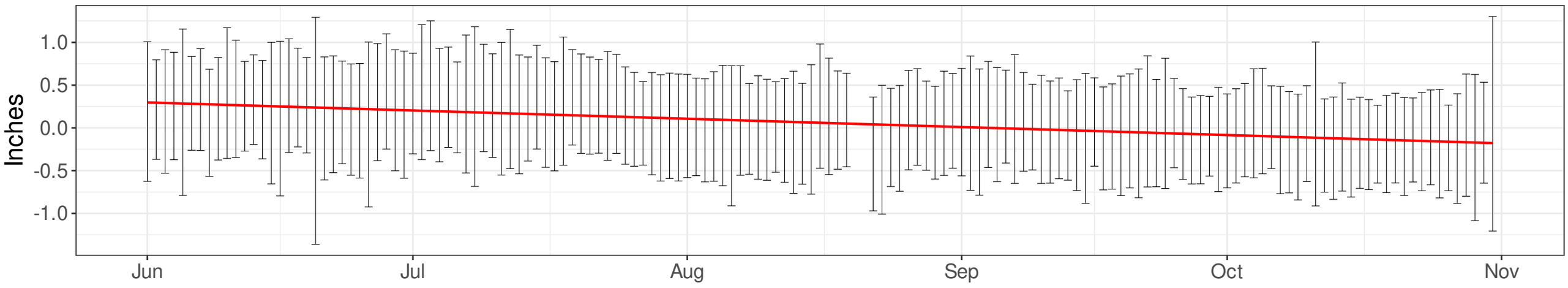
## East displacement - daily values




## North displacement - daily values




## Vertical displacement - daily values




Local east rate: -0.117 ± 0.042 in/year, R2: 0.62

Local north rate: 0.751 ± 0.057 in/year, R2: 0.54

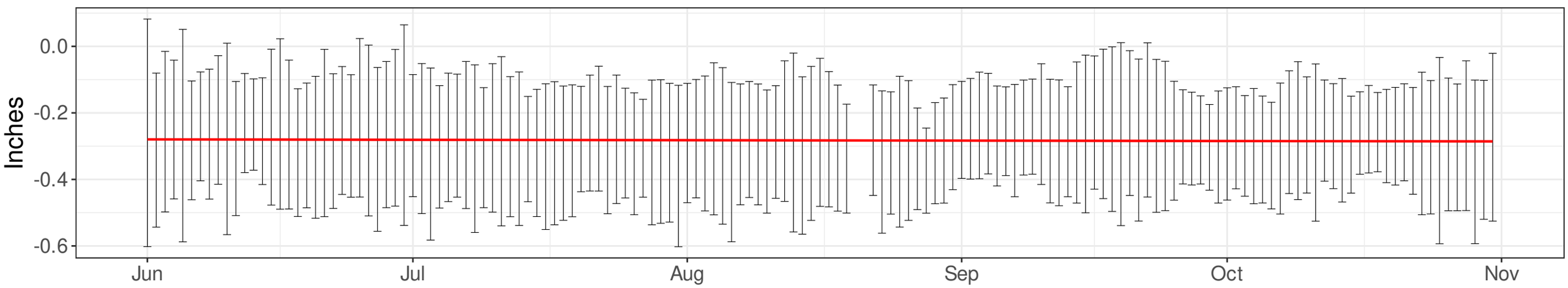
Local vertical rate: -1.063 ± 0.092 in/year, R2: 0.62

Linear model

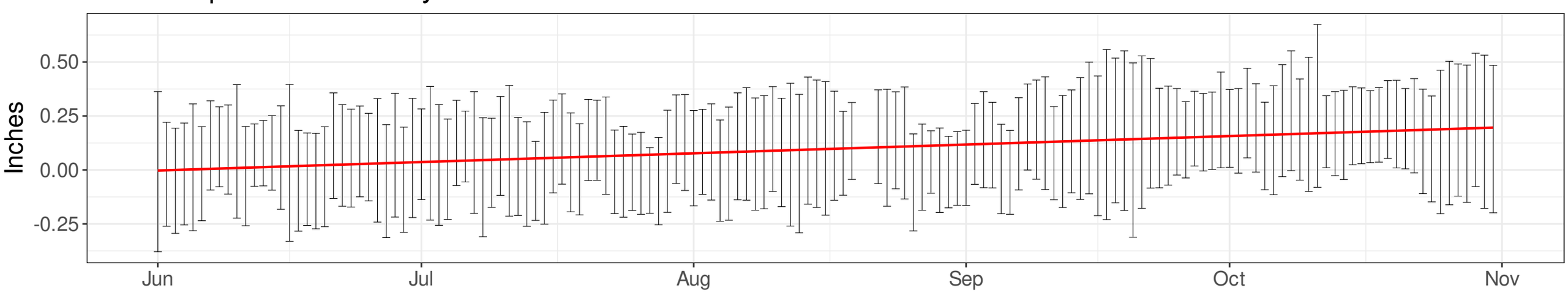
Local rate values have been calculated by removing the regional tectonic plate rates from the raw data displayed in the charts.

# REMSW, 2024-06-01 - 2024-10-31

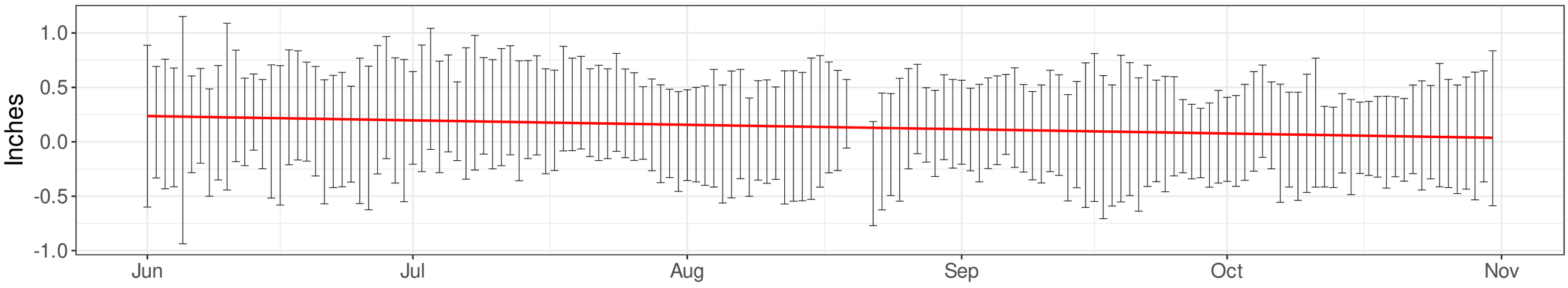
## East displacement - daily values




## North displacement - daily values




## Vertical displacement - daily values




Local east rate: 0.468 ± 0.028 in/year, R2: 0.00

Local north rate: 0.521 ± 0.043 in/year, R2: 0.50

Local vertical rate: -0.400 ± 0.091 in/year, R2: 0.23

Linear model

Local rate values have been calculated by removing the regional tectonic plate rates from the raw data displayed in the charts.

# APPENDIX 3

## Analysis Maps

# Tiltmeter and GNSS Rate Vectors

Tiltmeter Time Frame: 9/30/24 - 10/31/24
GNSS Time Frame: 6/1/24 - 10/31/24

REMNW
-2.222 ± 0.145 in/yr

REMNE
-1.024 ± 0.197 in/yr

REMC7
-1.136 ± 0.090 in/yr

REMSW
-0.399 ± 0.091 in/yr

REMSE
-1.062 ± 0.092 in/yr

SSD01
SSD02
SSD03
SSD04
SSD05
SSD06
SSD07
SSD08
SSD09
SSD10
SSD11
SSD12
SSD13
SSD14
SSD15
SSD16
SSD17
SSD18
SSD19
SSD20

N

0 800 1600 3200 µrad/yr
0 0.5 1 2 in/yr

0 200 400 800 1,200 1,600 Feet

Precision Tiltmeter Sites
Differential GNSS Stations (vertical rate labeled)
Cavern Extent Outlines
Sulphur Dome Contours (500-ft CI)
Tiltmeter Rate Vector (µrad/yr)
GNSS Rate Vector (horiz. in/yr)
GNSS Rate Error Ellipse

1339500 1340000 1340500 1341000 1341500 1342000 1342500 1343000 1343500 1344000 1344500 1345000
584500 584000 583500 583000 582500 582000 581500 581000 580500

# Daily Tilt Direction Frequency - Full History
# (6/1/24 - 10/31/24)

SSD01
SSD02
REMNW(GNSS)
REMNE(GNSS)
SSD03
SSD04
SSD20
SSD05
SSD07
SSD08
SSD11
SSD10
SSD06
REMC7(GNSS)
SSD15
SSD14
SSD09
SSD13
SSD12
SSD18
REMSE(GNSS)
SSD19
REMSW(GNSS)
SSD16
SSD17

N

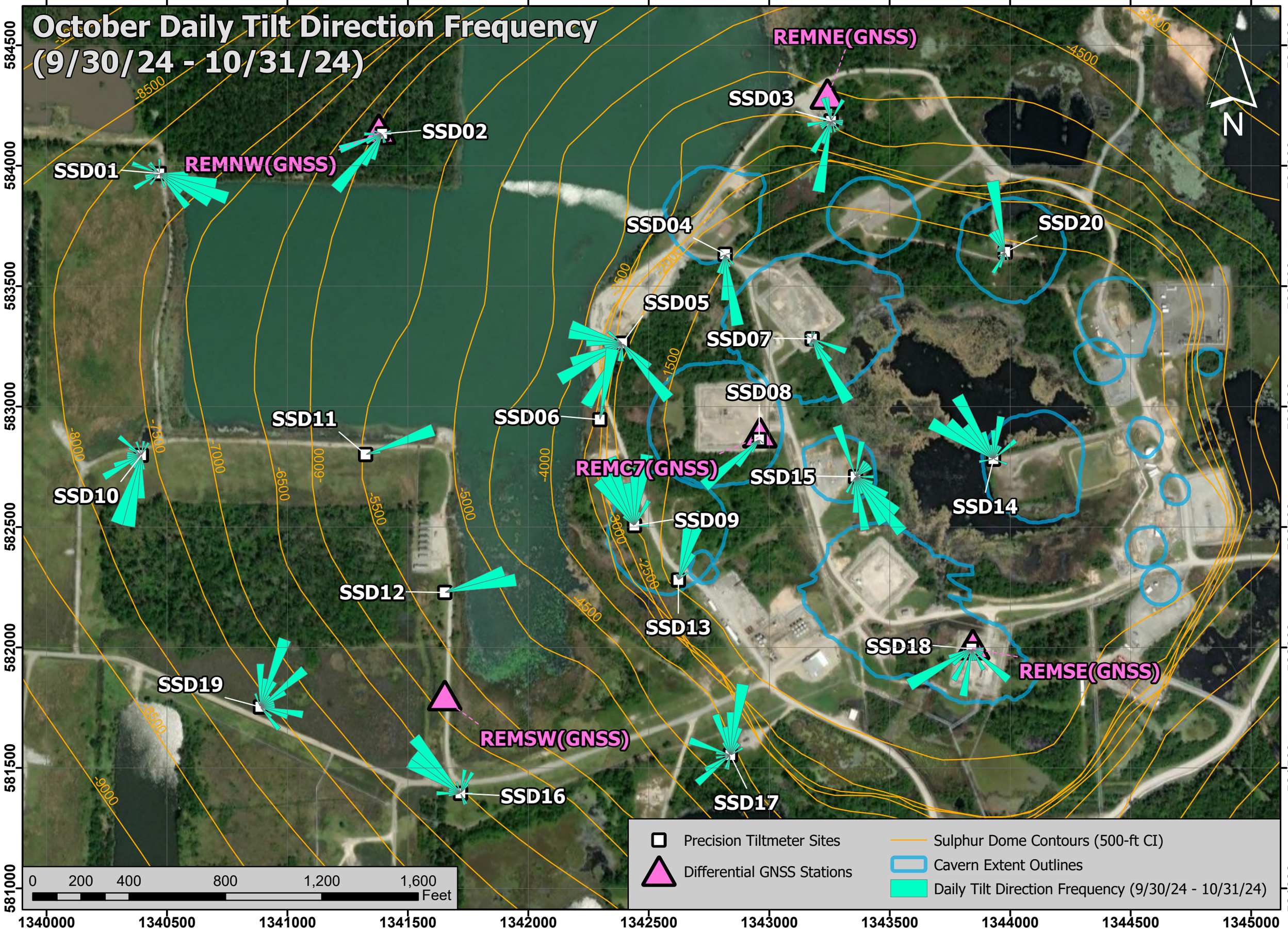
0 200 400 800 1,200 1,600 Feet

Precision Tiltmeter Sites
Differential GNSS Stations
Sulphur Dome Contours (500-ft CI)
Cavern Extent Outlines
Daily Tilt Direction Frequency (6/1/24 - 10/31/24)

1340000 1340500 1341000 1341500 1342000 1342500 1343000 1343500 1344000 1344500 1345000

584500 584000 583500 583000 582500 582000 581500 581000

# October Daily Tilt Direction Frequency
# (9/30/24 - 10/31/24)



# Location of GNSS and Tiltmeter Stations

*Sulphur Mines Salt Dome*

*(Coordinate Datum: WGS 84)*

| **Differential GNSS Stations** | | |
|---|---|---|
| **Name** | **Latitude** | **Longitude** |
| REMC7 | 30.253327 | -93.414588 |
| REMNE | 30.257206 | -93.413782 |
| REMNW | 30.256713 | -93.419670 |
| REMSE | 30.250953 | -93.411739 |
| REMSW | 30.250263 | -93.418668 |
| Off-dome Reference Station | 30.257750 | -93.426649 |

| **Precision Tiltmeter Sites** | | |
|---|---|---|
| **Name** | **Latitude** | **Longitude** |
| SSD01 | 30.256207 | -93.422543 |
| SSD02 | 30.256705 | -93.419624 |
| SSD03 | 30.256947 | -93.413727 |
| SSD04 | 30.255402 | -93.415087 |
| SSD05 | 30.254365 | -93.416418 |
| SSD06 | 30.253489 | -93.416695 |
| SSD07 | 30.254456 | -93.413924 |
| SSD08 | 30.253295 | -93.414595 |
| SSD09 | 30.252288 | -93.416215 |
| SSD10 | 30.252987 | -93.422714 |
| SSD11 | 30.253043 | -93.419765 |
| SSD12 | 30.251485 | -93.418691 |
| SSD13 | 30.251674 | -93.415624 |
| SSD14 | 30.253120 | -93.411511 |
| SSD15 | 30.252891 | -93.413320 |
| SSD16 | 30.249195 | -93.418437 |
| SSD17 | 30.249687 | -93.414899 |
| SSD18 | 30.250951 | -93.411754 |
| SSD19 | 30.250140 | -93.421087 |
| SSD20 | 30.255485 | -93.411405 |

# ATTACHMENT B

## SNT InSAR report - October 22, 2024

# 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 |
| **Tuesday, October 22, 2024** |

Analysis Report Date:

**October 28, 2024**

## Dataset Information

| | |
|---|---|
| Satellite Source | Sentinel-1 (SNT) |
| Revisit Frequency | 12 days |
| Most Recent Image Date | Tuesday, October 22, 2024 |
| Dataset Image Count | 211 |
| Dataset Time Range | October 4, 2016 - October 22, 2024 |
| Dataset Length | 8.05 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, increasing eastward movement, or slowing westward movement and positive acceleration values indicate slowing rates of subsidence, slowing eastward movement, or increasing westward movement. Maps depicting the individual data points colored by these trend values are also included in the last section of the report.

**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 3 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 8 (PPG 22), AOI 10 (PPG2), and AOI 7 (PPG 7).

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. Some concentrations of negative rate change can be observed that generally support the observations in the above mentioned AOIs.


Date Signed: October 28, 2024
Austin, Texas

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

## InSAR Data Sources

**InSAR Data**

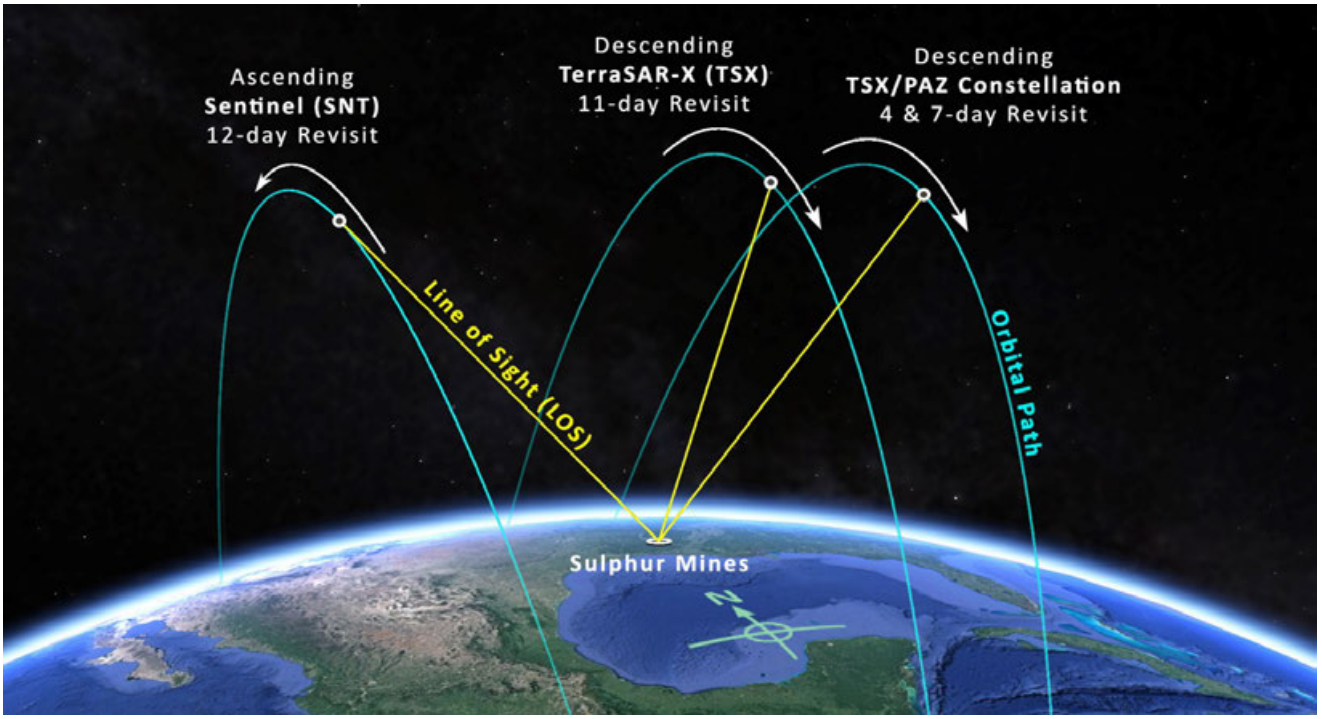
Interferometric Synthetic Aperture Radar (InSAR) is the most well established method to continually evaluate small, normally undetectable, ground movement over a large area. Radar imagery collected via satellites over successive orbital passes is used to identify and define measurement points on the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

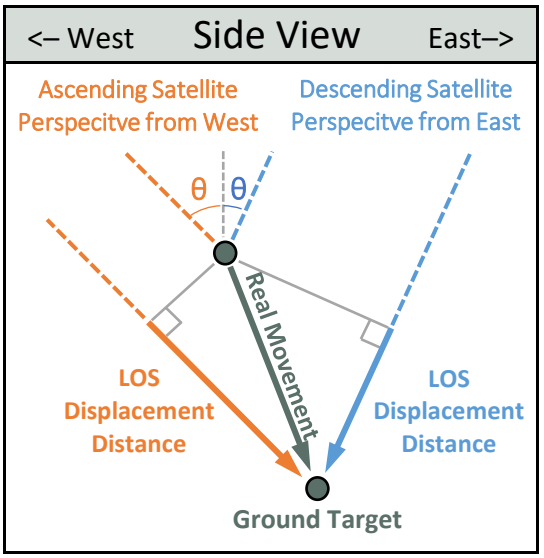
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a pair of high resolution satellites that share the same descending orbit and capture data from east of the site. These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

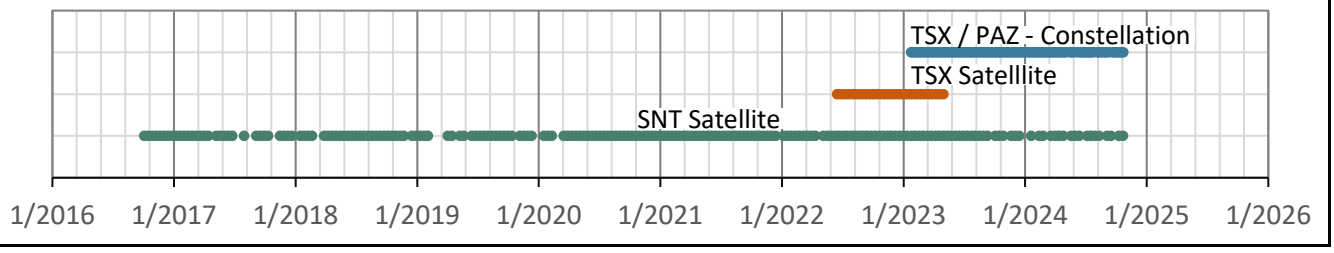
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR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



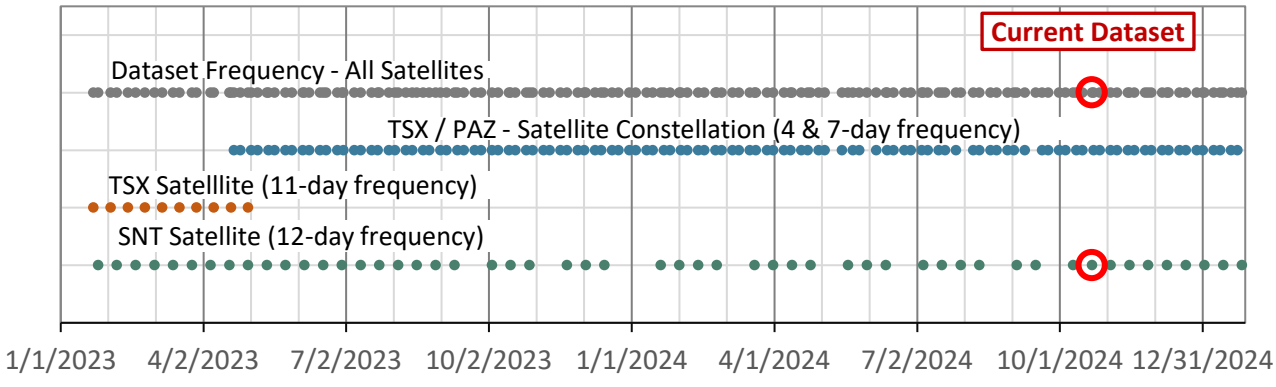

## Satellite Properties & Image Frequency

| 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, $\theta$)** | 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 |

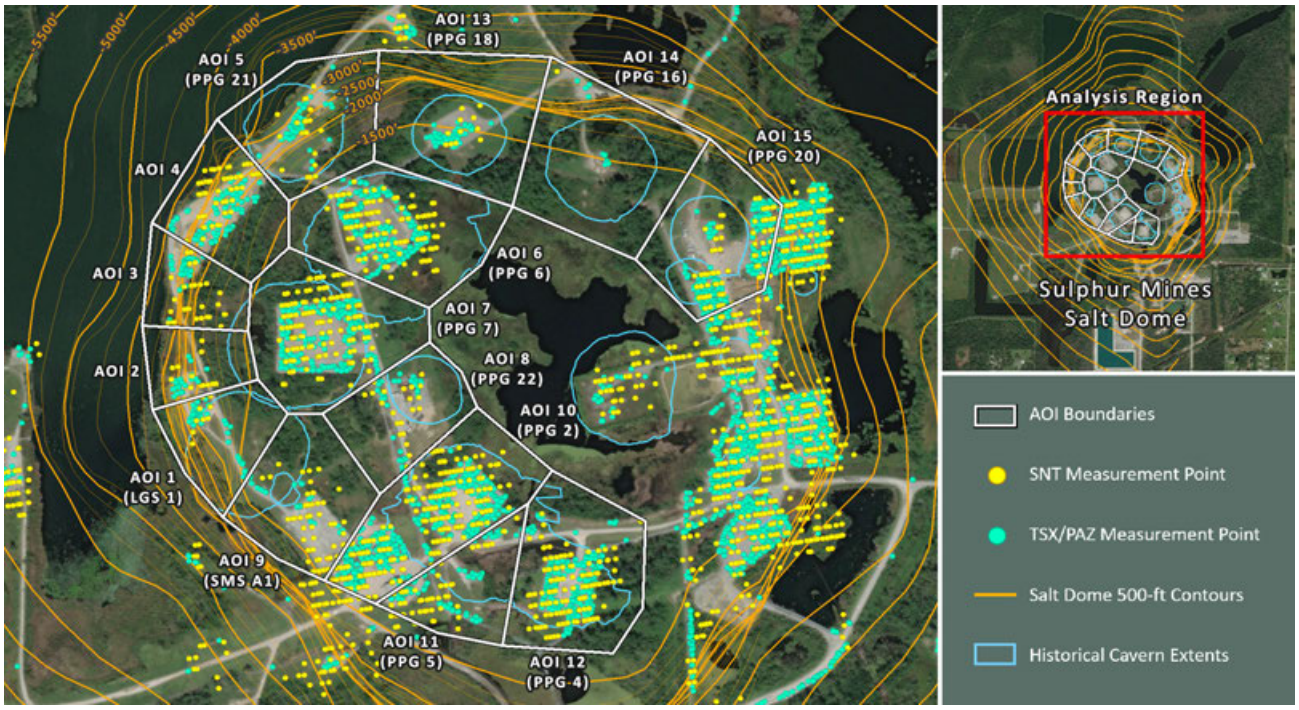
### Dataset Measurement History




### Dataset Update Frequency



## AOI Boundaries & InSAR Measurement Points

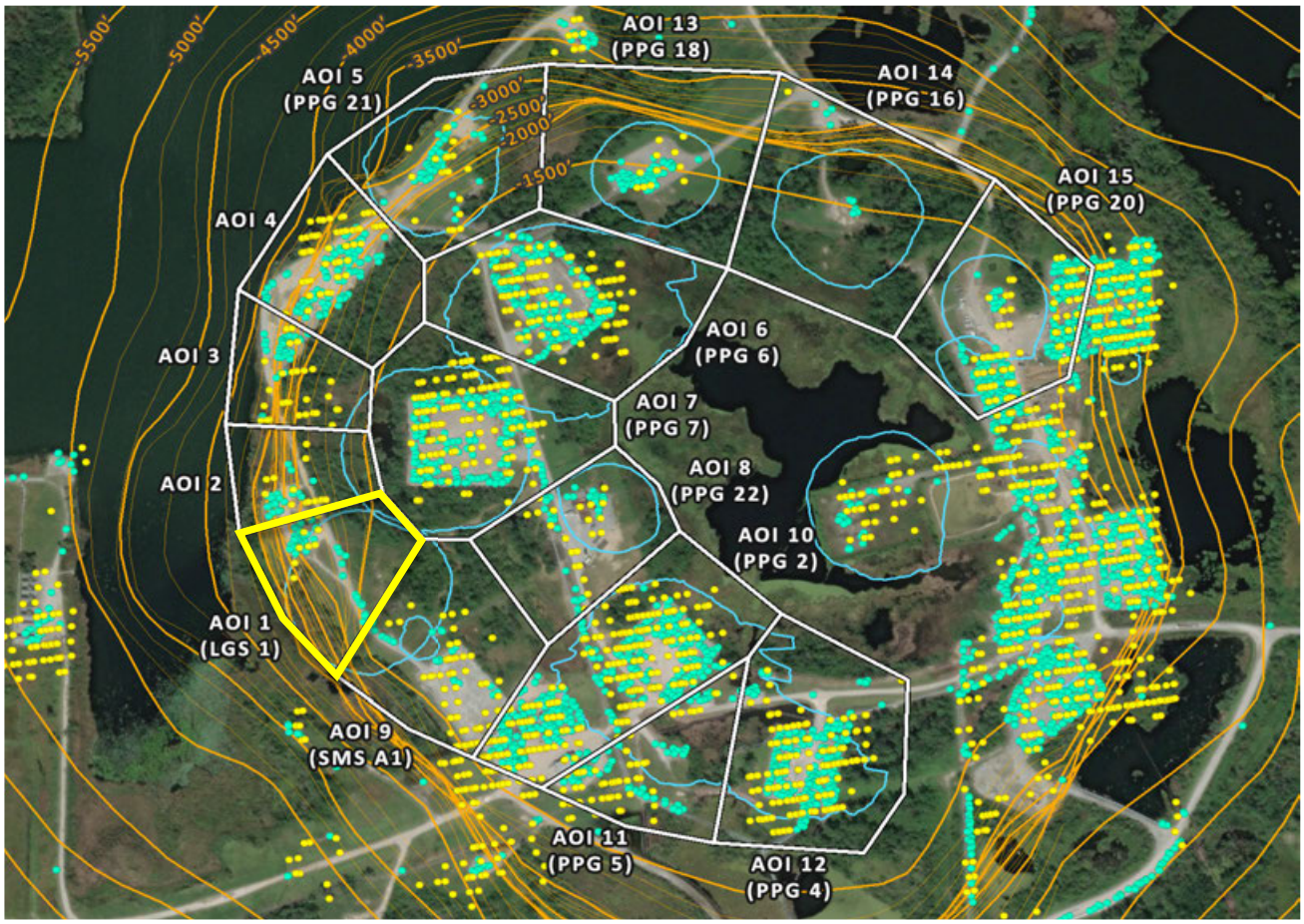



## Subsidence Monitoring Areas of Interest (AOIs)

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.

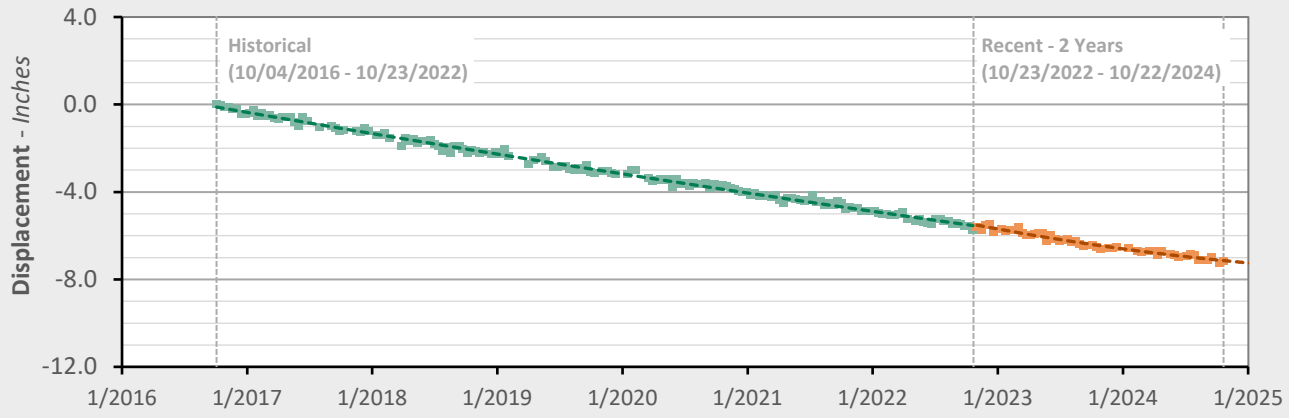
| AOI Name | SNT (10/22/2024) | LOS Velocity *(in/yr)* | | | LOS Acceleration *(in/yr$^2$)* | | |
|---|---|---|---|---|---|---|---|
| | Point Count | Historical | Recent | Change | Historical | Recent | Change |
| **AOI 1** *(LGS 1)* | 12 | -0.80 | -0.54 | +0.26 | +0.03 | +0.29 | +0.26 |
| **AOI 2** | 16 | -0.82 | -0.69 | +0.13 | +0.05 | +0.26 | +0.21 |
| **AOI 3** | 29 | -0.66 | -0.40 | +0.26 | +0.03 | +0.31 | +0.28 |
| **AOI 4** | 62 | -0.77 | -0.66 | +0.12 | +0.00 | +0.07 | +0.07 |
| **AOI 5** *(PPG 21)* | 25 | -0.64 | -0.58 | +0.06 | +0.02 | -0.04 | -0.06 |
| **AOI 6** *(PPG 6)* | 134 | -0.86 | -0.82 | +0.04 | +0.05 | +0.06 | +0.01 |
| **AOI 7** *(PPG 7)* | 140 | -0.99 | -1.08 | -0.09 | +0.07 | +0.05 | -0.01 |
| **AOI 8** *(PPG 22)* | 20 | -1.06 | -1.22 | -0.17 | +0.10 | +0.06 | -0.04 |
| **AOI 9** *(SMS A1)* | 58 | -0.85 | -0.83 | +0.03 | +0.07 | +0.05 | -0.02 |
| **AOI 10** *(PPG 2)* | 232 | -0.91 | -1.06 | -0.15 | +0.08 | -0.02 | -0.10 |
| **AOI 11** *(PPG 5)* | 53 | -0.90 | -0.68 | +0.22 | +0.06 | +0.25 | +0.20 |
| **AOI 12** *(PPG 4)* | 120 | -0.74 | -0.49 | +0.25 | +0.05 | +0.19 | +0.14 |
| **AOI 13** *(PPG 18)* | 12 | -0.60 | -0.39 | +0.22 | +0.04 | +0.27 | +0.23 |
| **AOI 14** *(PPG 16)* | 1 | -0.19 | +0.49 | +0.67 | +0.07 | +0.92 | +0.86 |
| **AOI 15** *(PPG 20)* | 69 | -0.30 | -0.29 | +0.01 | +0.04 | +0.02 | -0.02 |

## AOI 1 *(LGS 1)* - Location Map




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

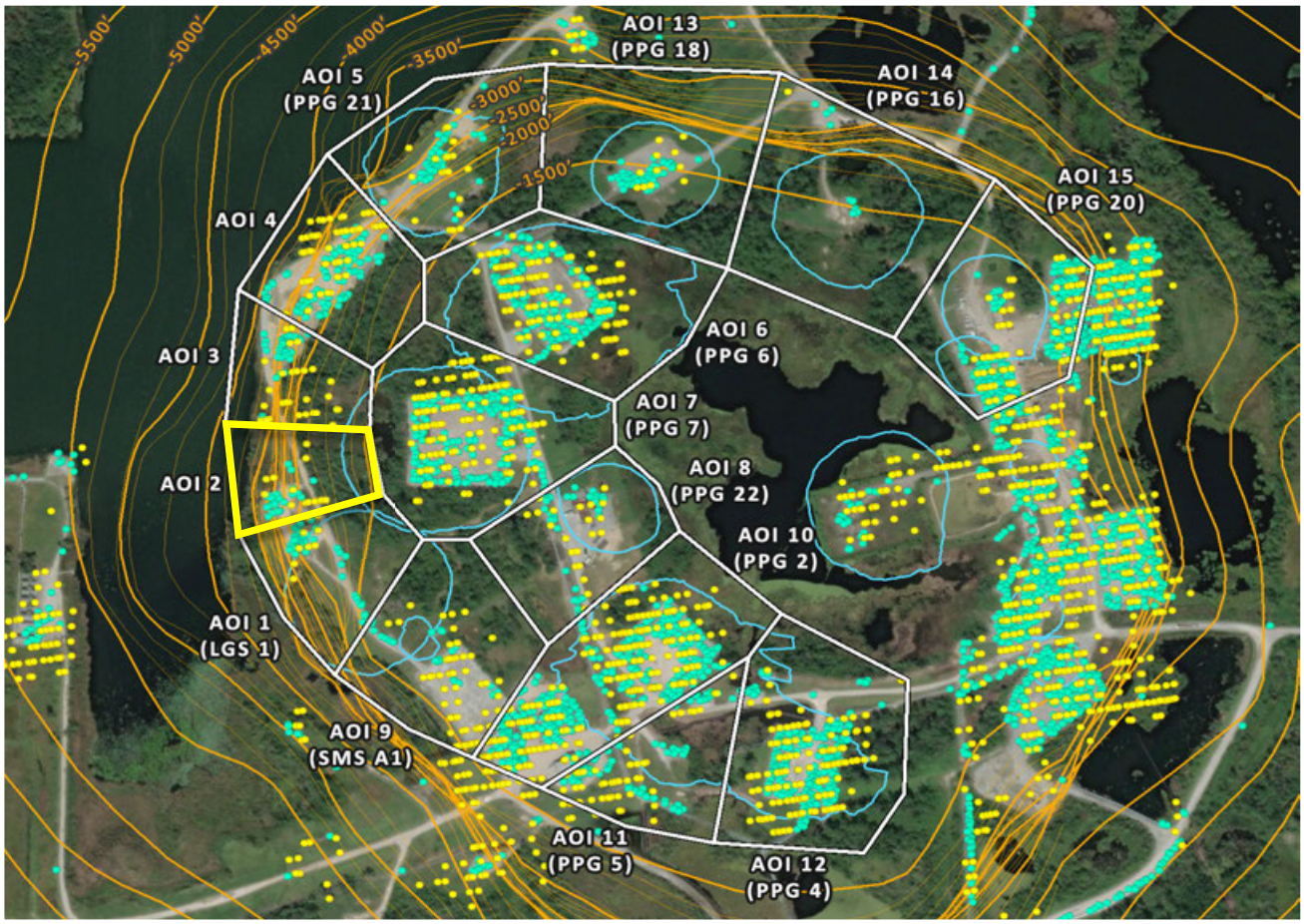
SNT (10/22/2024) Point Count: **12**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.80 in/yr | -0.54 in/yr | +0.26 in/yr |
| Acceleration: | +0.03 in/yr$^2$ | +0.29 in/yr$^2$ | +0.26 in/yr$^2$ |

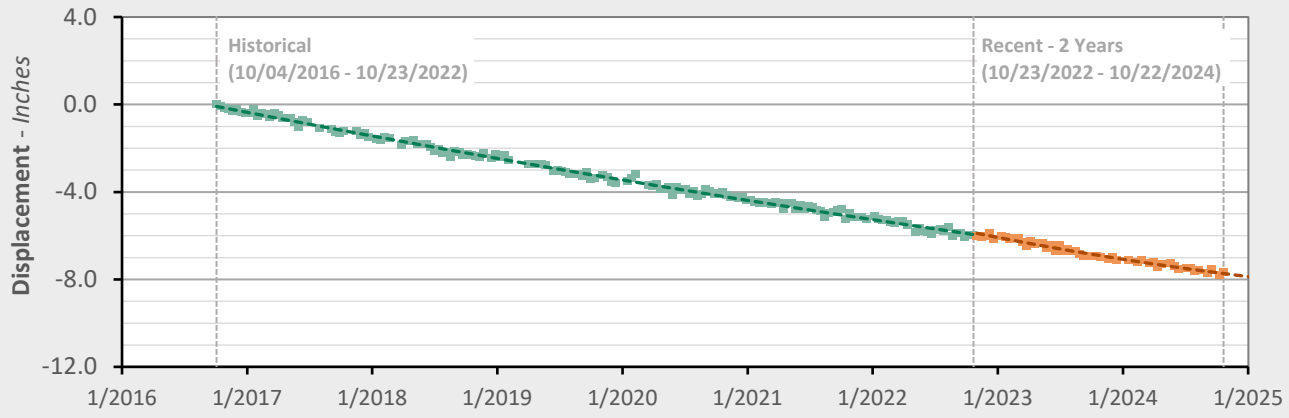
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 2 - Location Map




## AOI 2 - Displacement Time Series

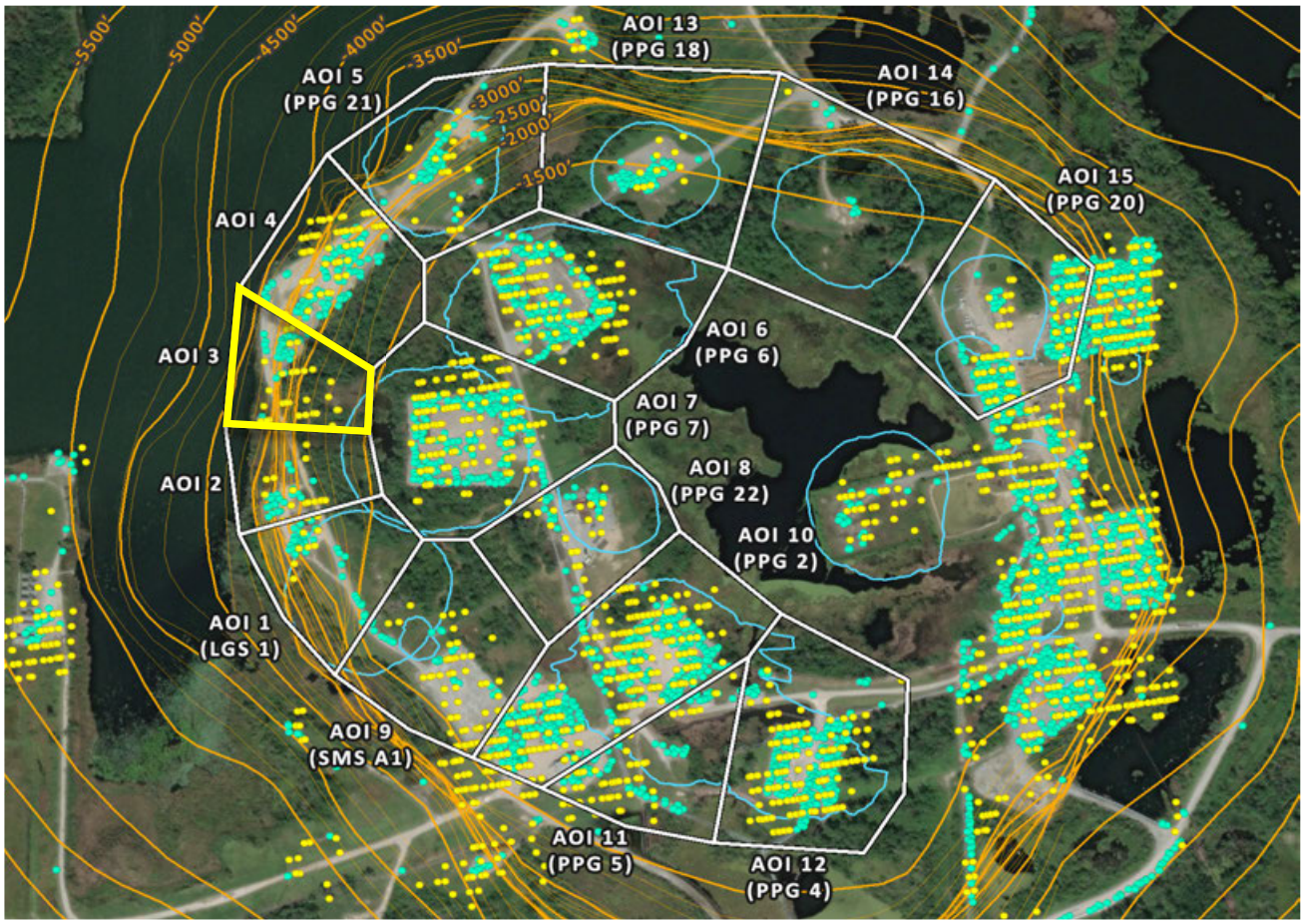
SNT (10/22/2024) Point Count: **16**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.82 in/yr | -0.69 in/yr | +0.13 in/yr |
| Acceleration: | +0.05 in/yr$^2$ | +0.26 in/yr$^2$ | +0.21 in/yr$^2$ |

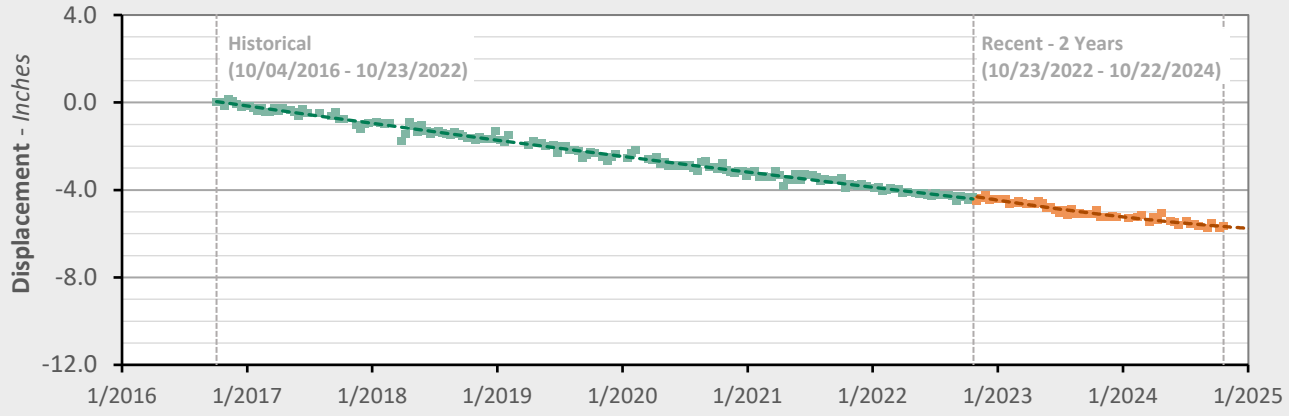
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 3 - Location Map




## AOI 3 - Displacement Time Series

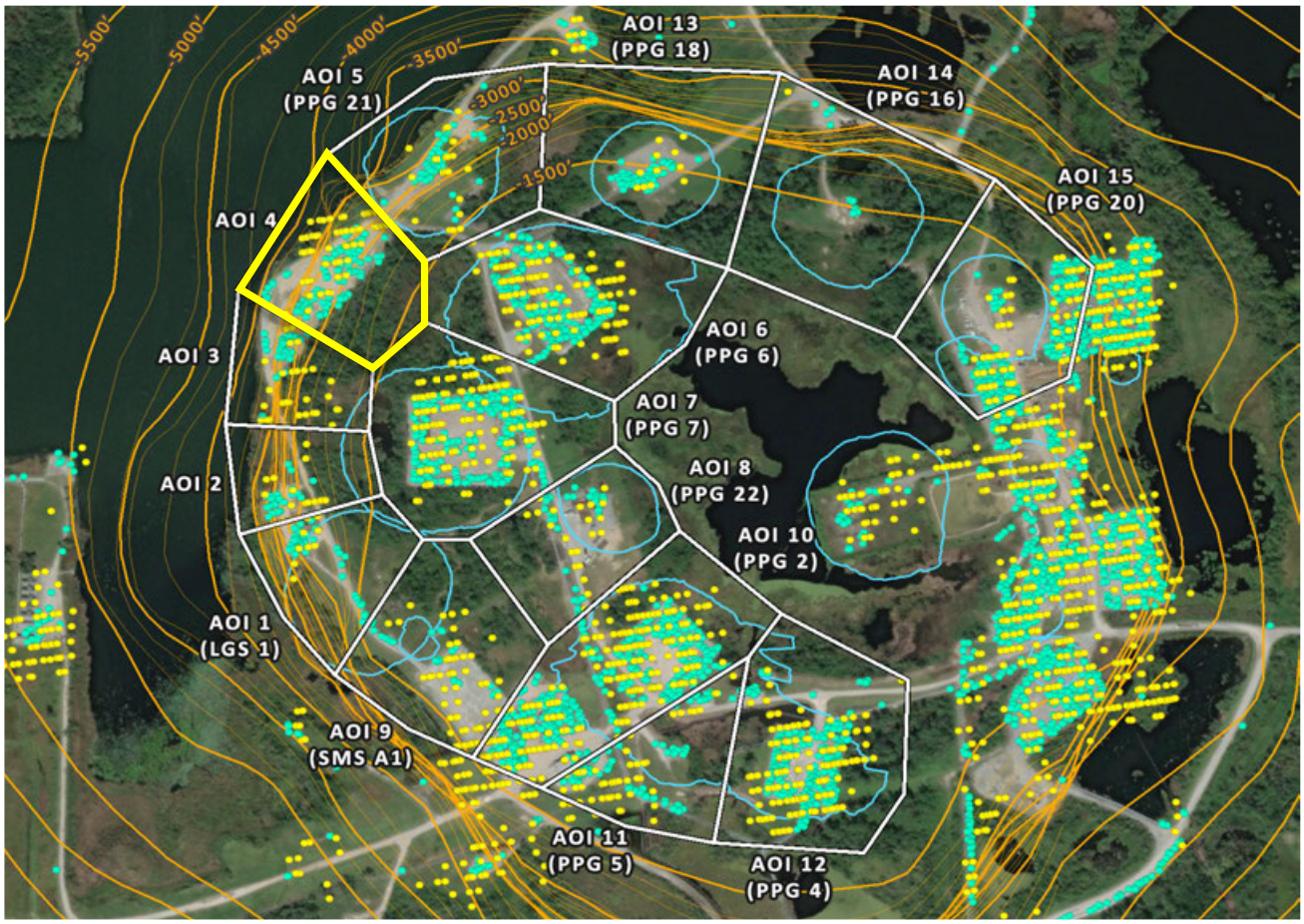
SNT (10/22/2024) Point Count: **29**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.66 in/yr | -0.40 in/yr | +0.26 in/yr |
| Acceleration: | +0.03 $in/yr^2$ | +0.31 $in/yr^2$ | +0.28 $in/yr^2$ |

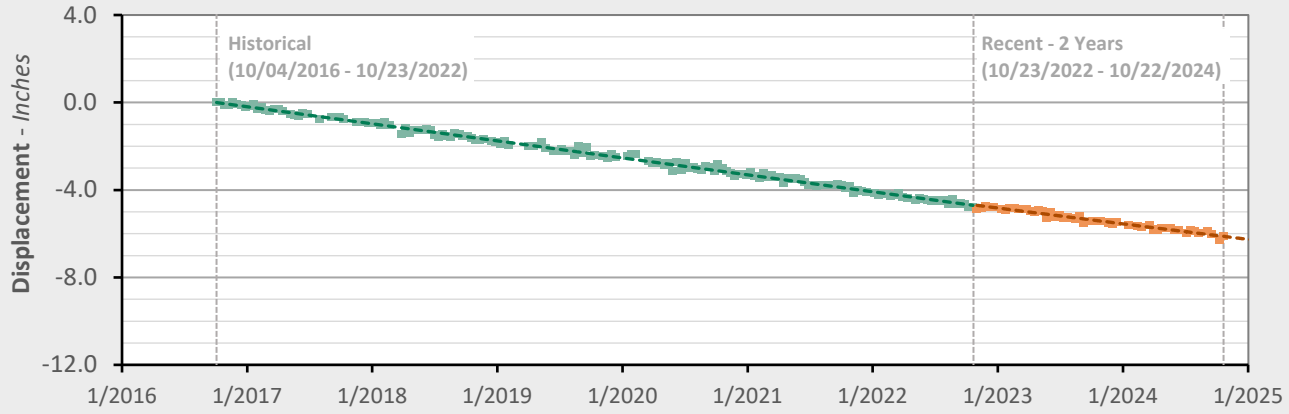
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 4 - Location Map




## AOI 4 - Displacement Time Series

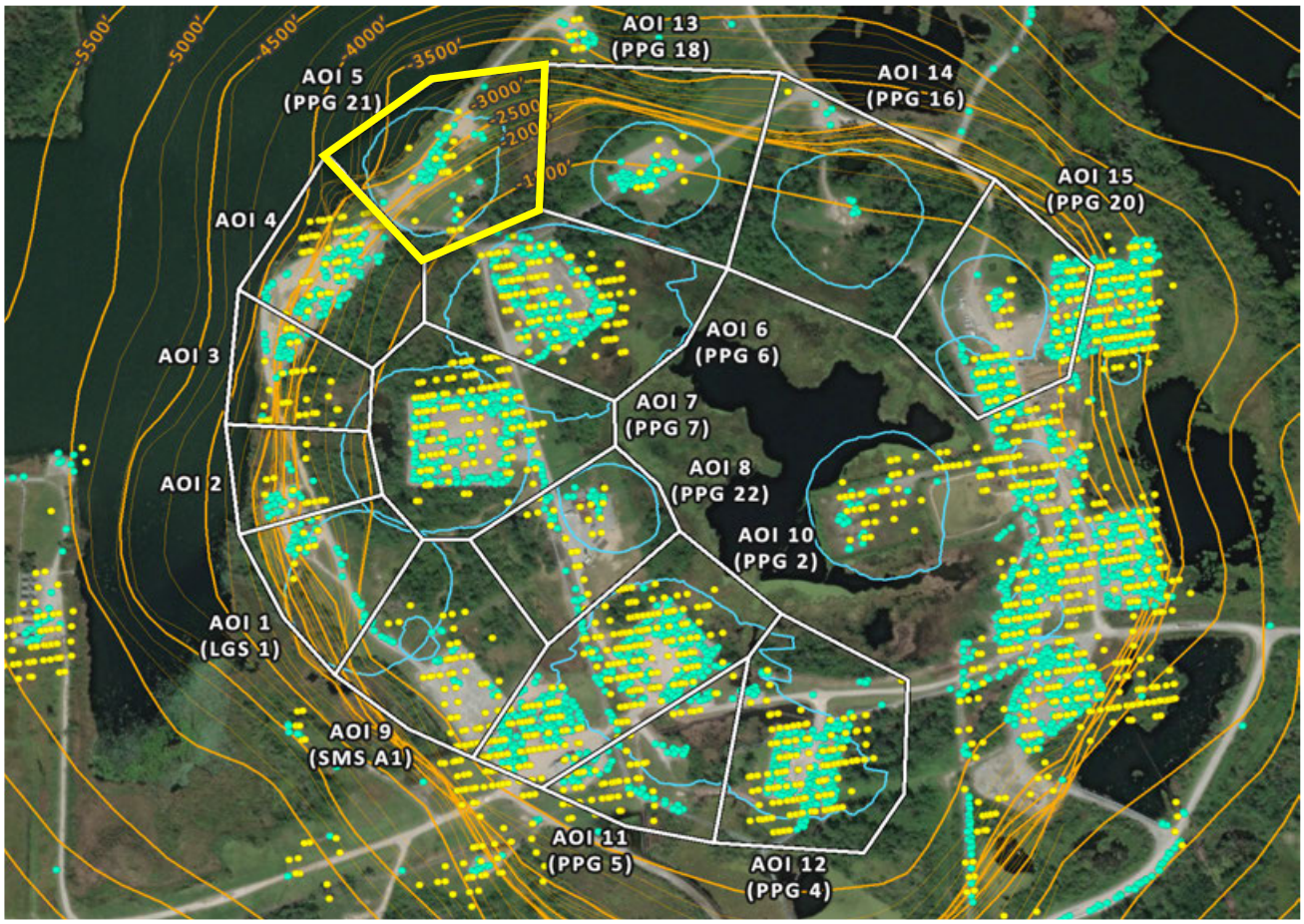
SNT (10/22/2024) Point Count: **62**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.77 in/yr | -0.66 in/yr | +0.12 in/yr |
| Acceleration: | +0.00 $in/yr^2$ | +0.07 $in/yr^2$ | +0.07 $in/yr^2$ |

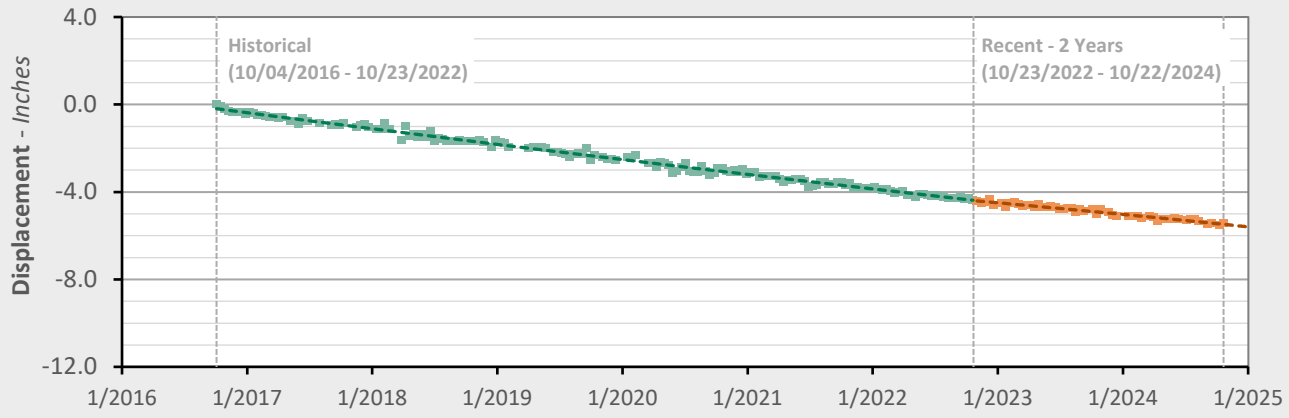
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 5 *(PPG 21)* - Location Map




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

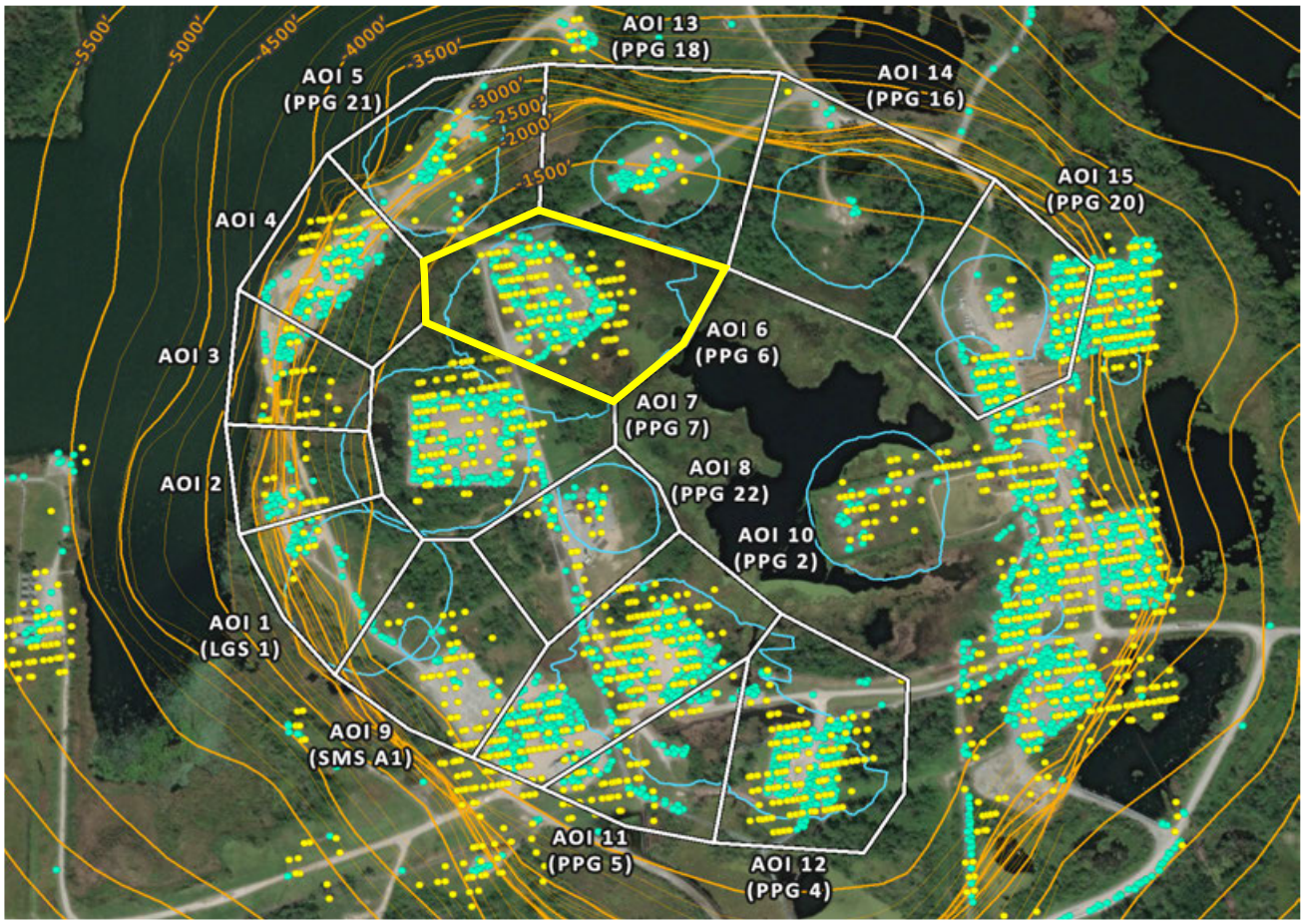
SNT (10/22/2024) Point Count: **25**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.64 in/yr | -0.58 in/yr | +0.06 in/yr |
| Acceleration: | +0.02 $in/yr^2$ | -0.04 $in/yr^2$ | -0.06 $in/yr^2$ |

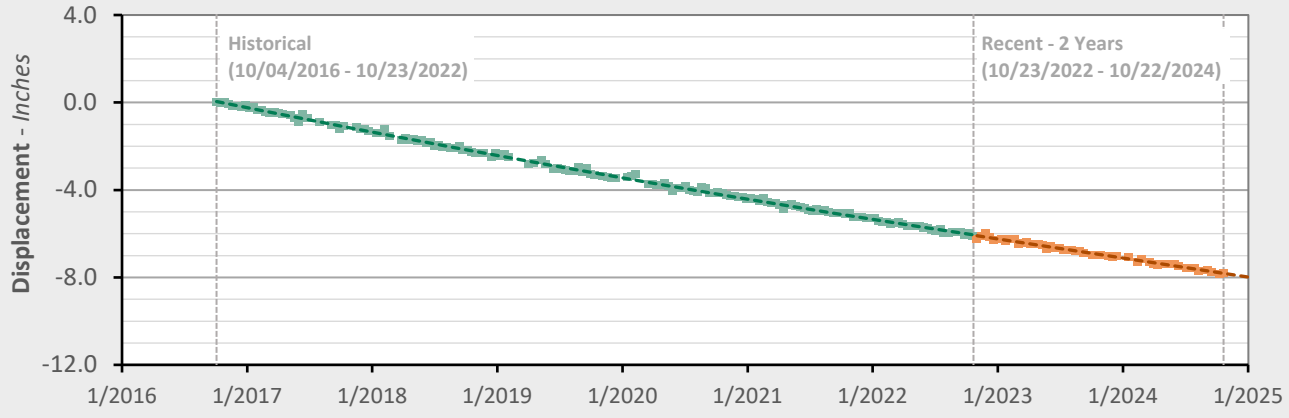
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 6 *(PPG 6)* - Location Map




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

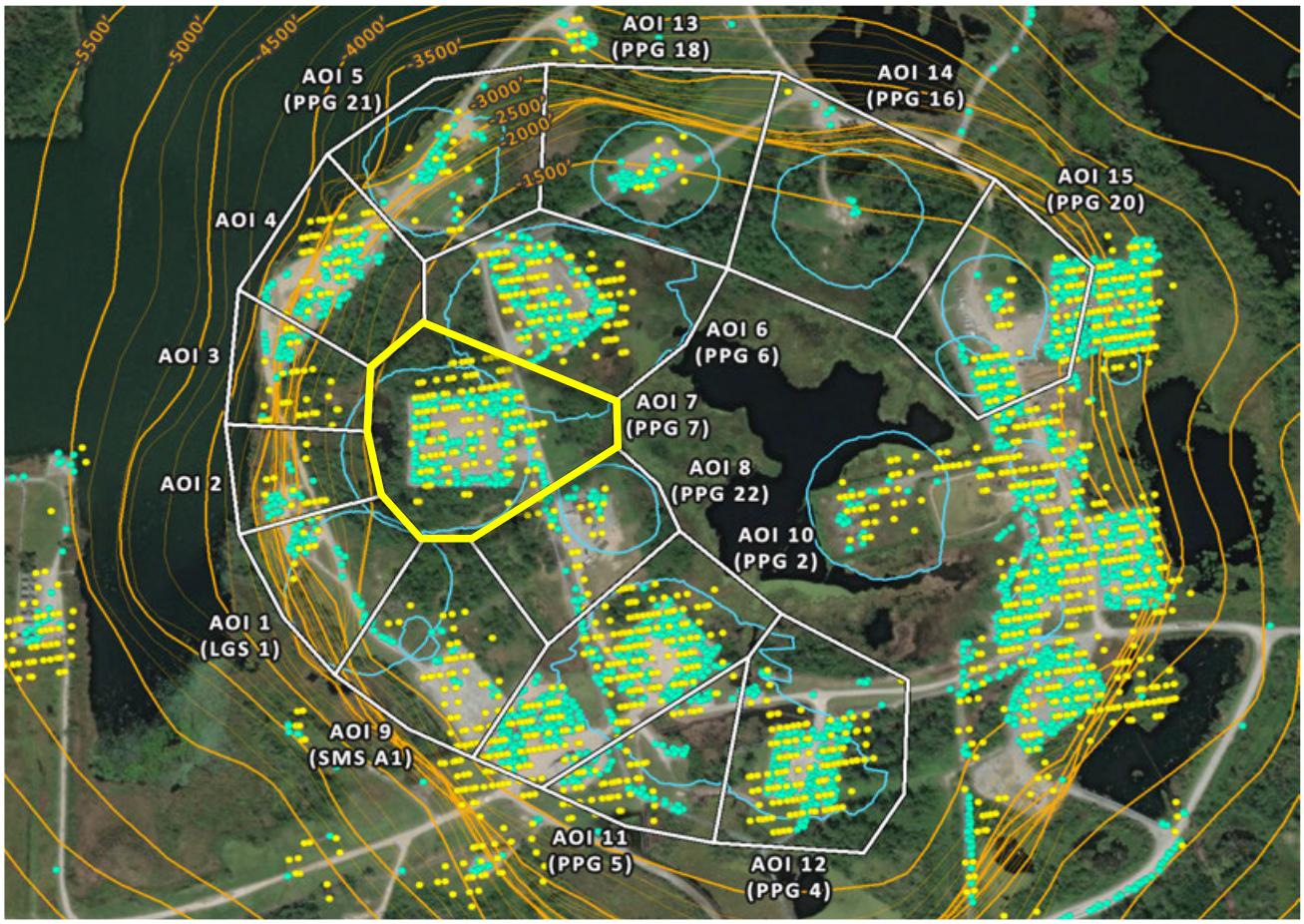
SNT (10/22/2024) Point Count: **134**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.86 in/yr | -0.82 in/yr | +0.04 in/yr |
| Acceleration: | +0.05 $in/yr^2$ | +0.06 $in/yr^2$ | +0.01 $in/yr^2$ |

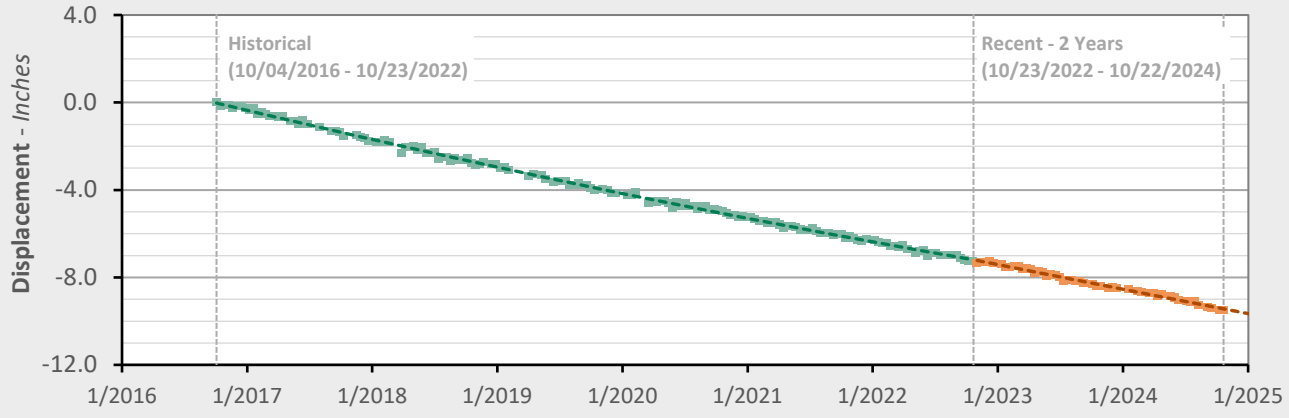
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 7 *(PPG 7)* - Location Map




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

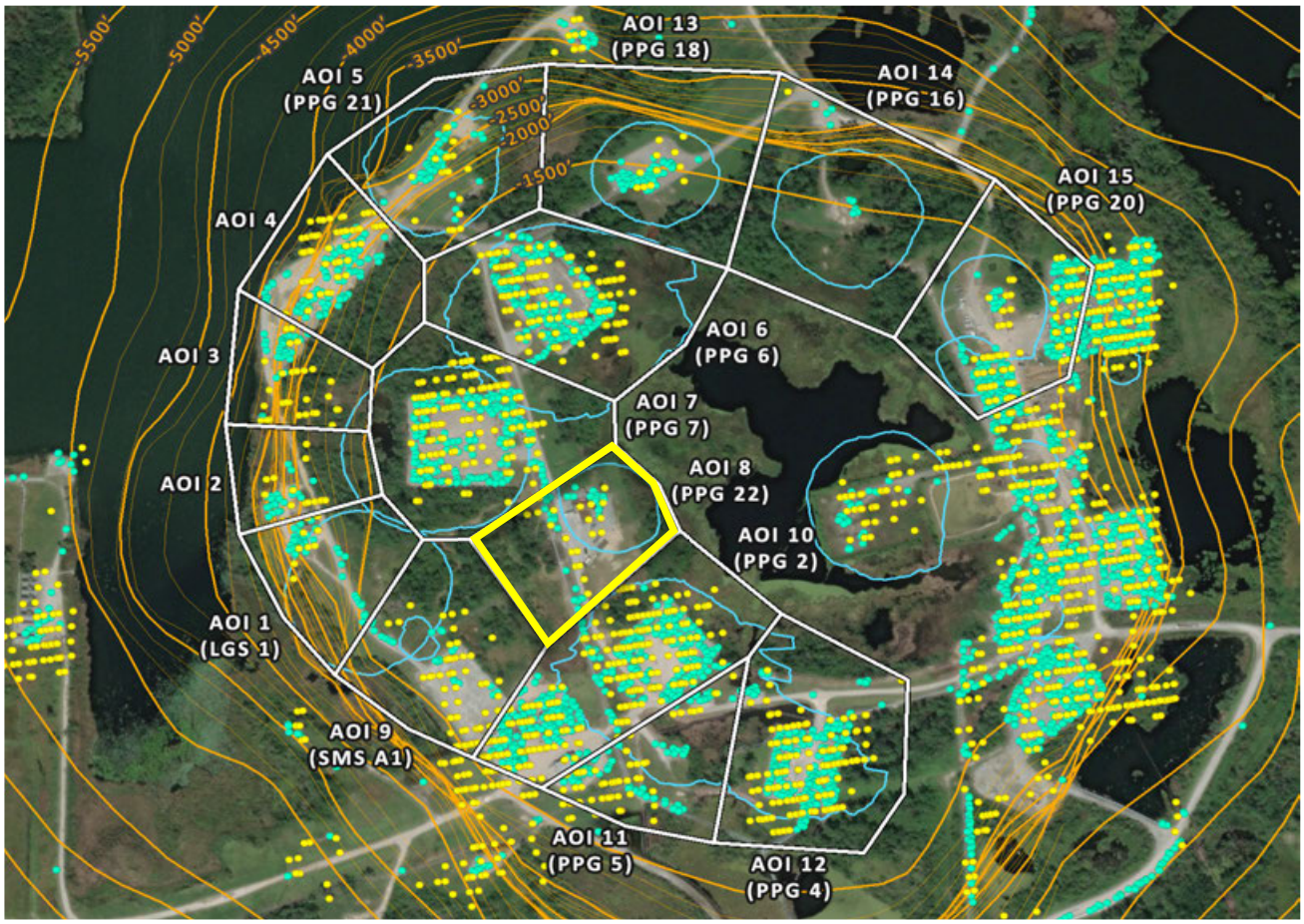
SNT (10/22/2024) Point Count: **140**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.99 in/yr | -1.08 in/yr | -0.09 in/yr |
| Acceleration: | +0.07 in/yr$^2$ | +0.05 in/yr$^2$ | -0.01 in/yr$^2$ |

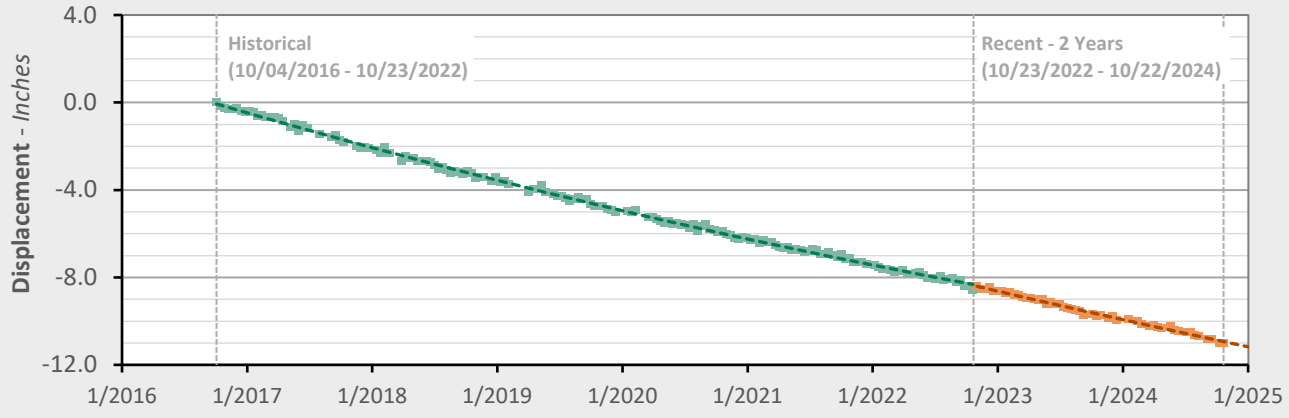
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 8 *(PPG 22)* - Location Map




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

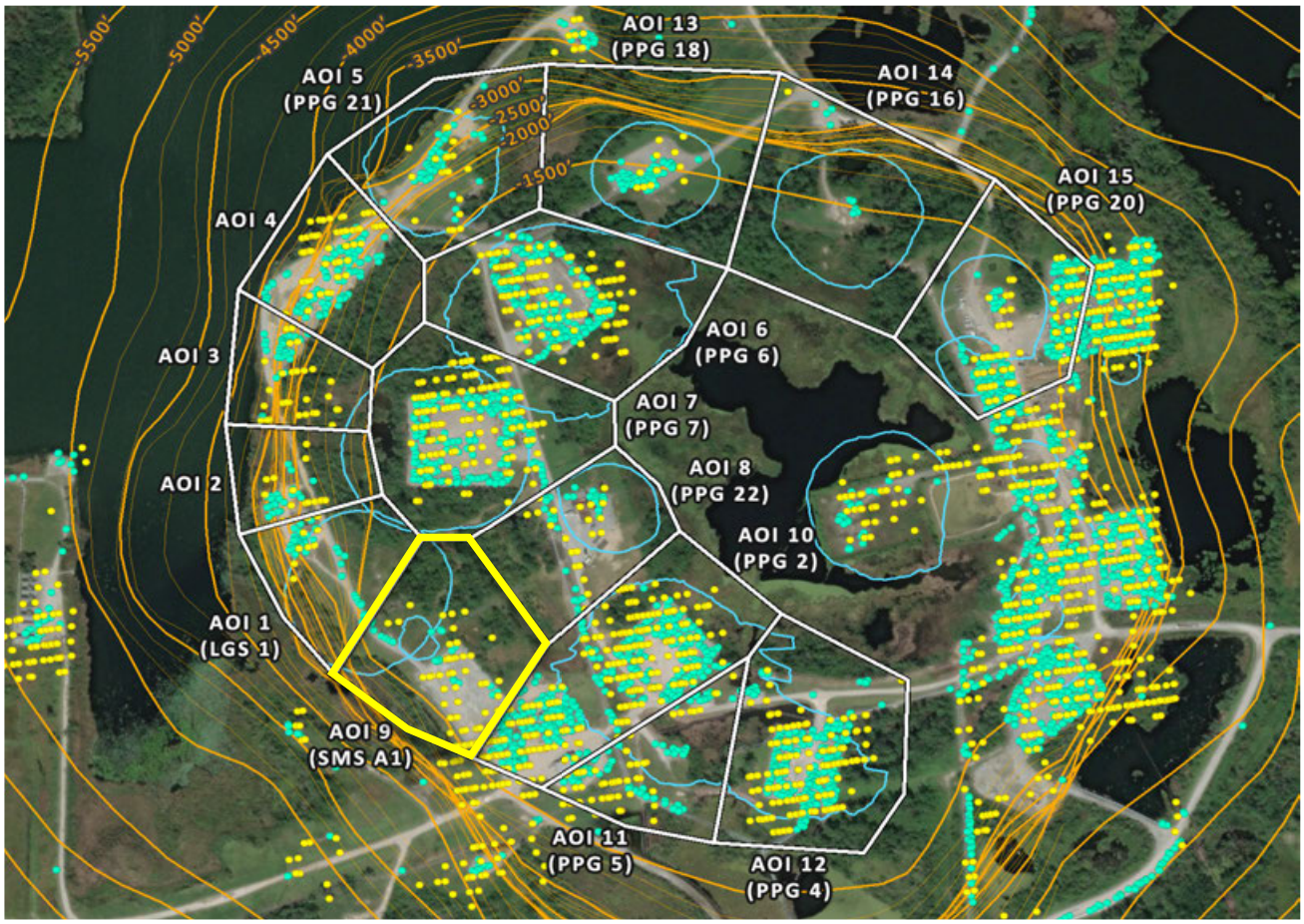
SNT (10/22/2024) Point Count: **20**




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -1.06 in/yr | -1.22 in/yr | -0.17 in/yr |
| Acceleration: | +0.10 in/yr$^2$ | +0.06 in/yr$^2$ | -0.04 in/yr$^2$ |

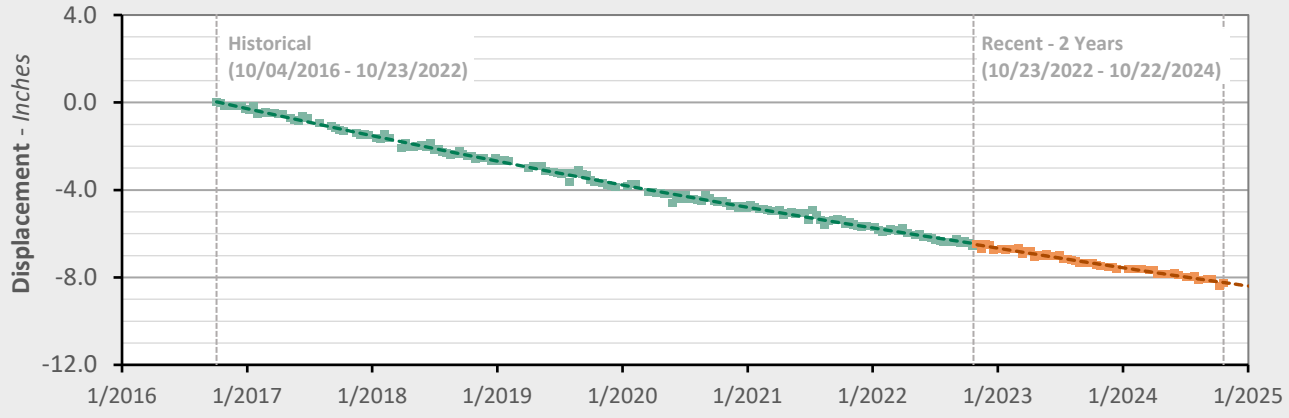
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 9 *(PPG A1)* - Location Map




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

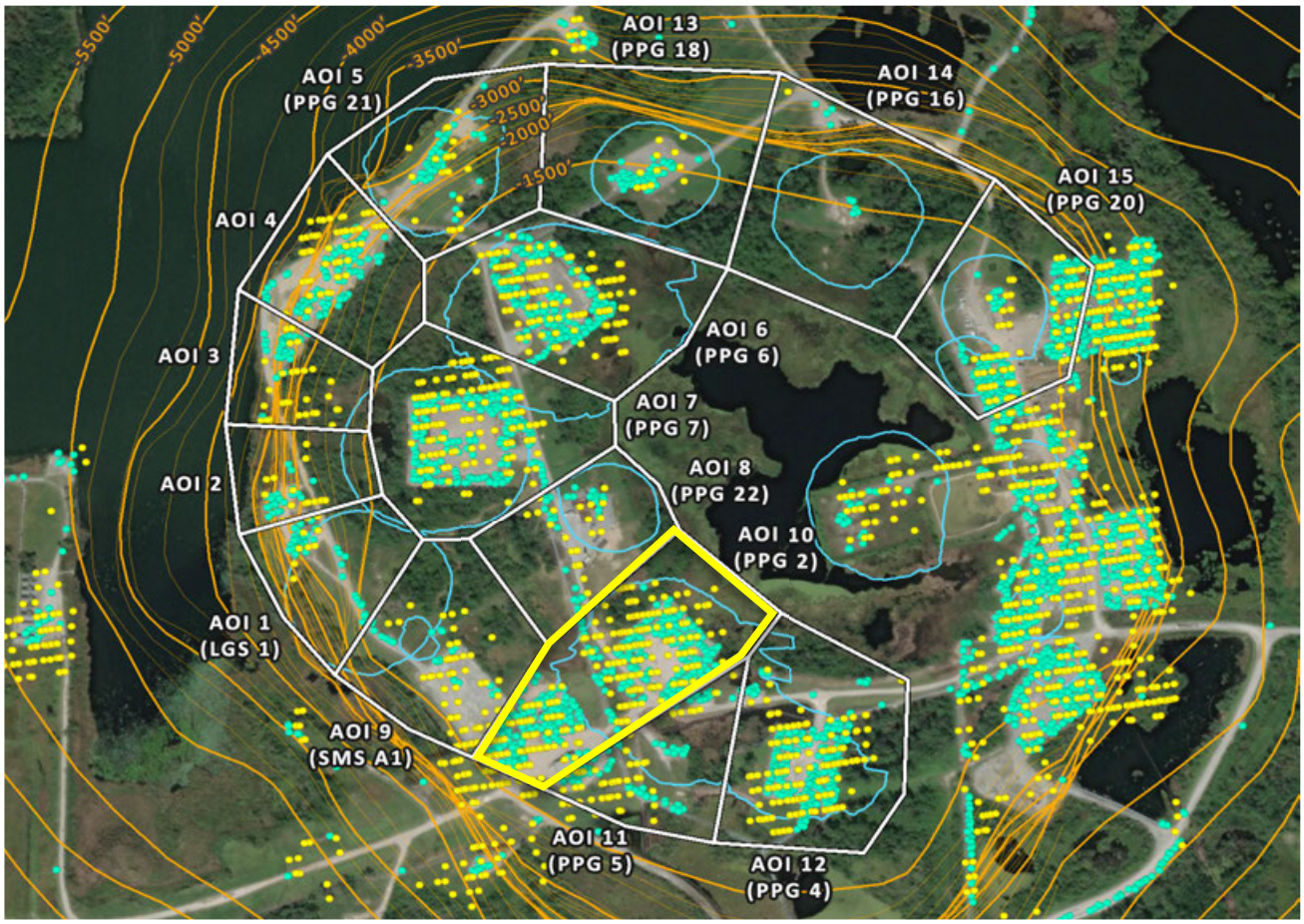
SNT (10/22/2024) Point Count: **58**



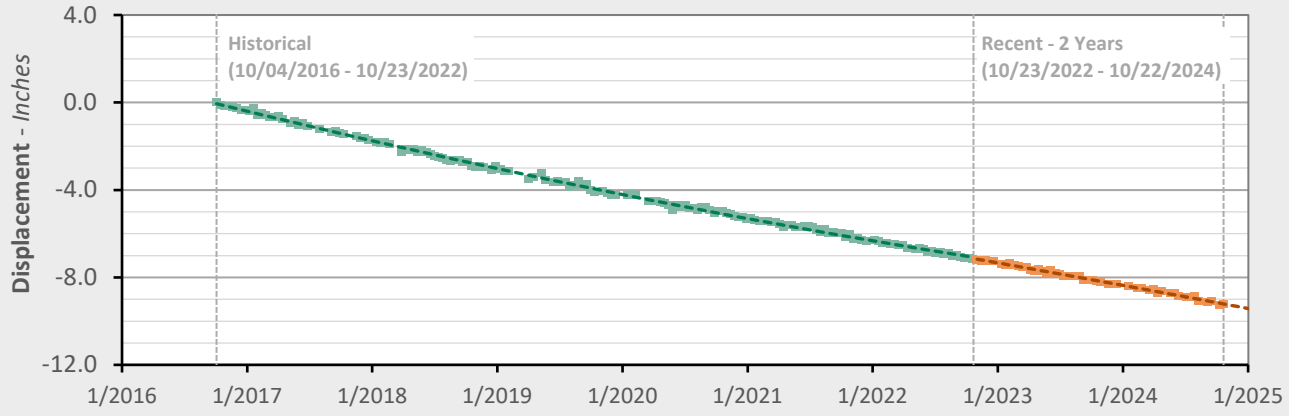

| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.85 in/yr | -0.83 in/yr | +0.03 in/yr |
| Acceleration: | +0.07 in/yr$^2$ | +0.05 in/yr$^2$ | -0.02 in/yr$^2$ |

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

## AOI 10 *(PPG 2)* - Location Map



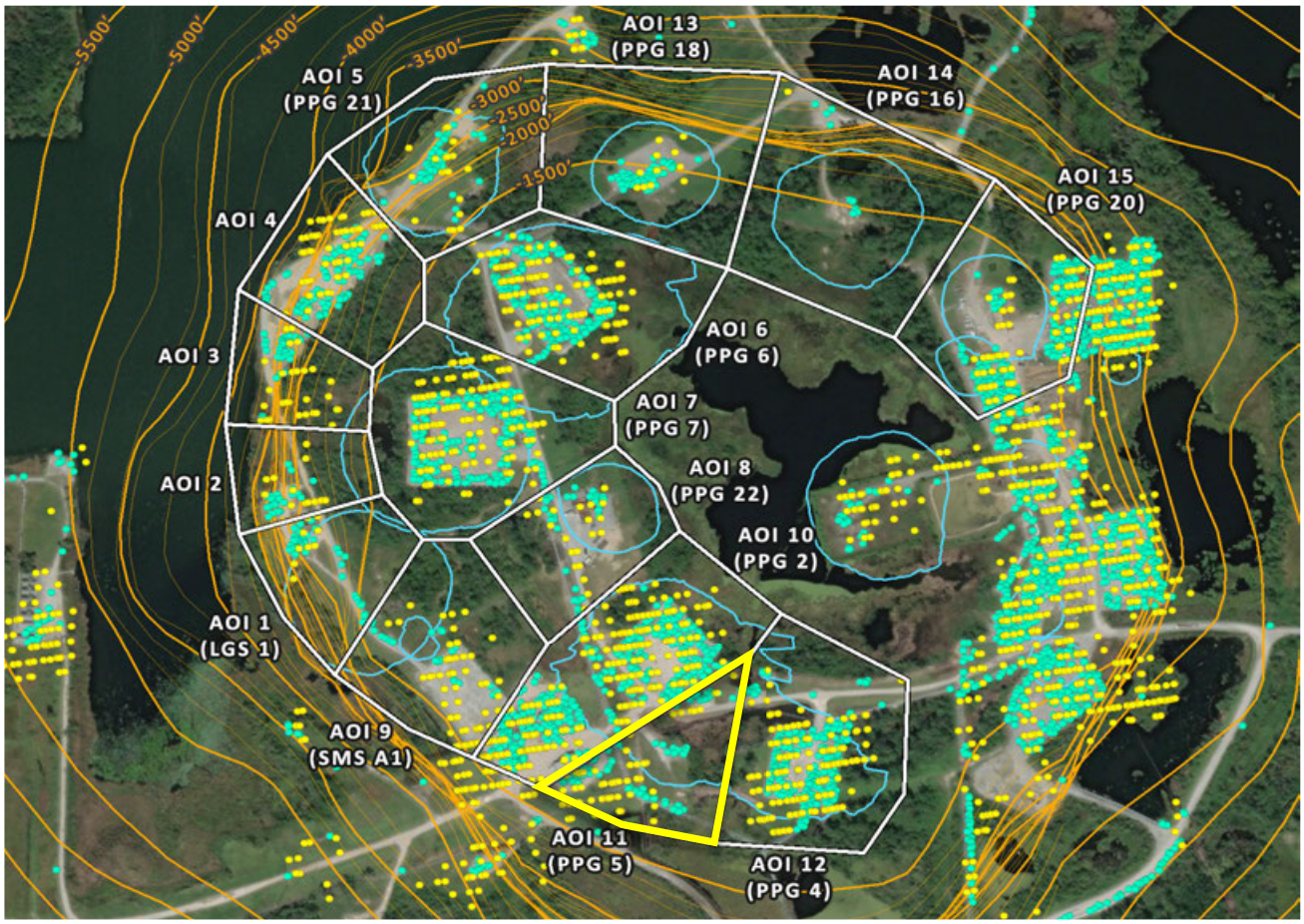

## AOI 10 *(PPG 2)* - Displacement Time Series SNT (10/22/2024) Point Count: 232



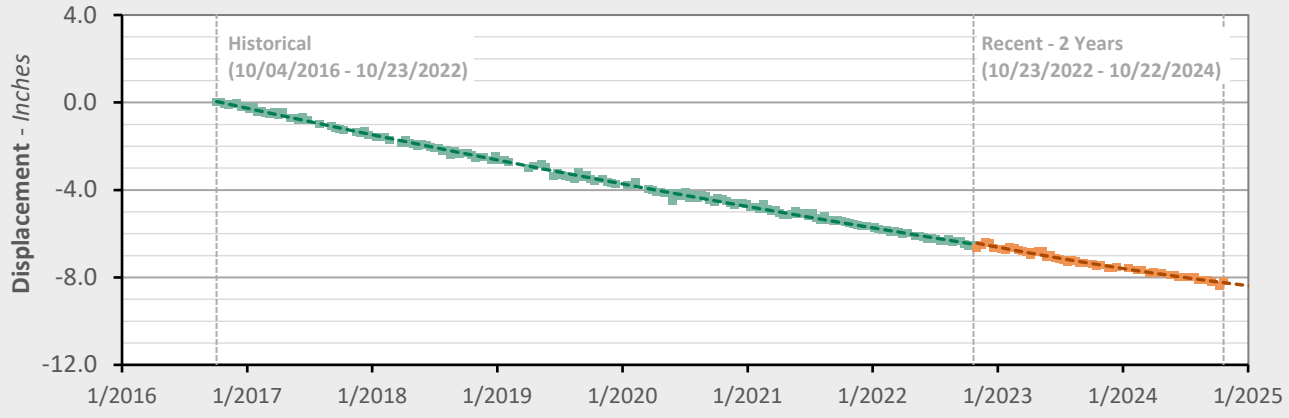

| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.91 in/yr | -1.06 in/yr | -0.15 in/yr |
| Acceleration: | +0.08 in/yr$^2$ | -0.02 in/yr$^2$ | -0.10 in/yr$^2$ |

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

## AOI 11 *(PPG 5)* - Location Map



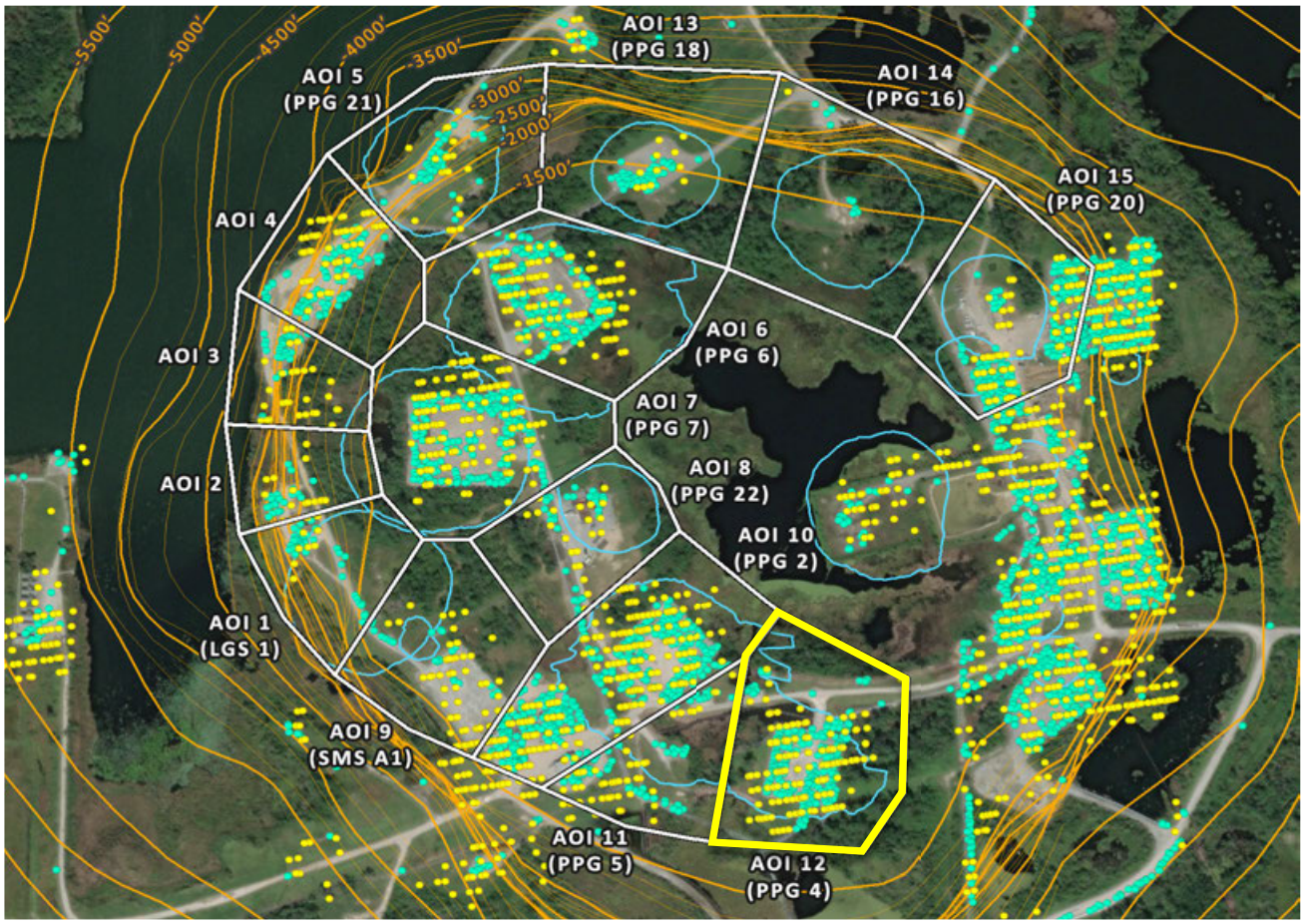

## AOI 11 *(PPG 5)* - Displacement Time Series SNT (10/22/2024) Point Count: 53




| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.90 in/yr | -0.68 in/yr | +0.22 in/yr |
| Acceleration: | +0.06 $in/yr^2$ | +0.25 $in/yr^2$ | +0.20 $in/yr^2$ |

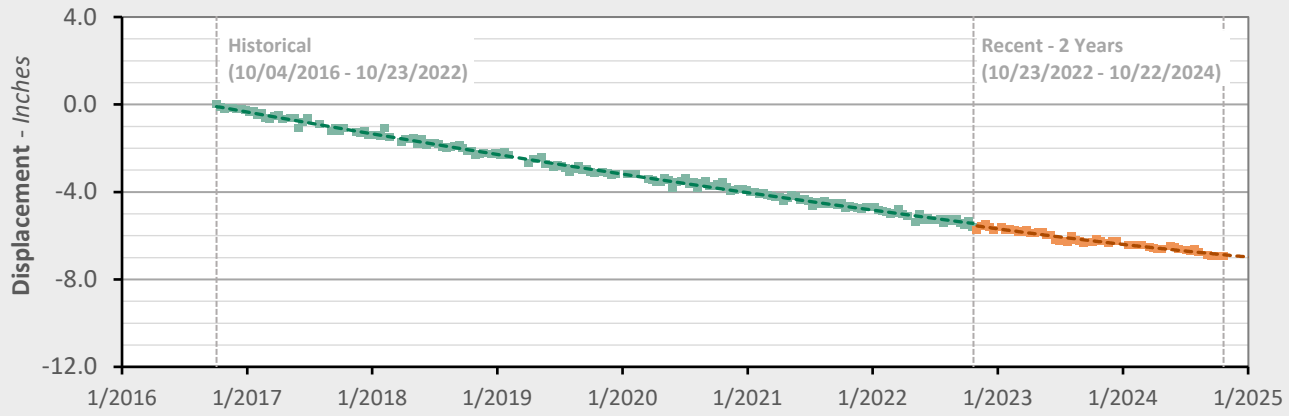
Historical LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)
Recent LOS Displacement Measurement
Historical Trend Line (Quadratic Regression)

## AOI 12 *(PPG 4)* - Location Map




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

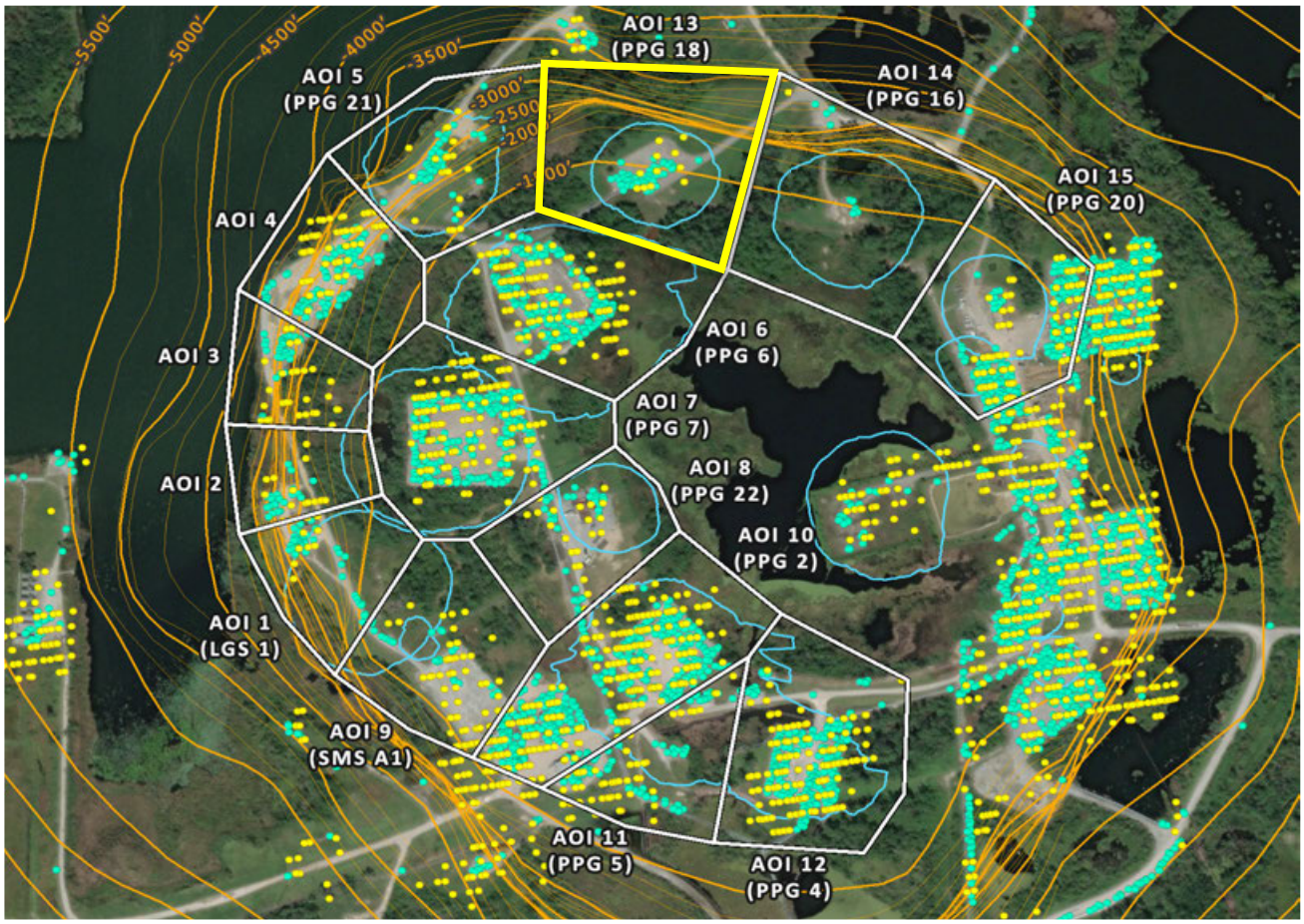
SNT (10/22/2024) Point Count: **120**



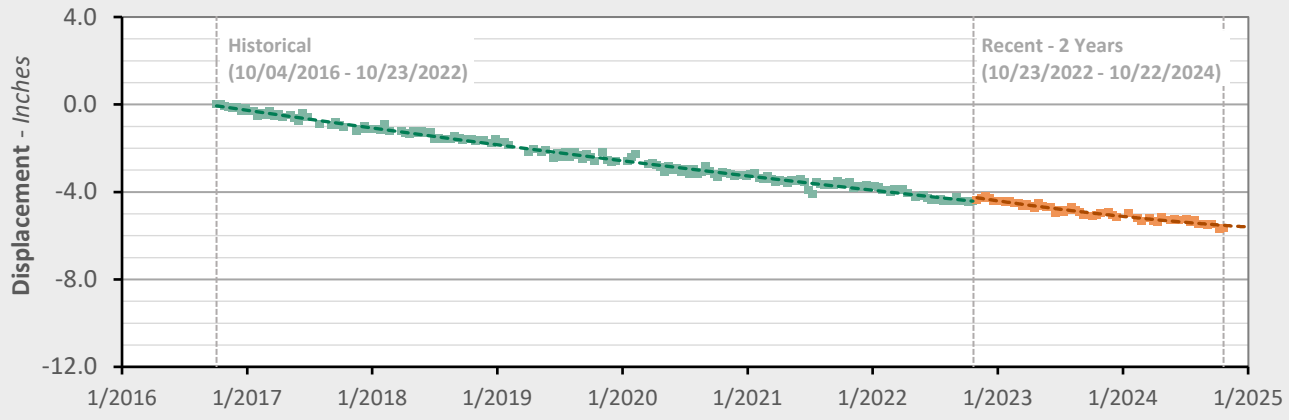

| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.74 in/yr | -0.49 in/yr | +0.25 in/yr |
| Acceleration: | +0.05 $in/yr^2$ | +0.19 $in/yr^2$ | +0.14 $in/yr^2$ |

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

## AOI 13 *(PPG 18)* - Location Map



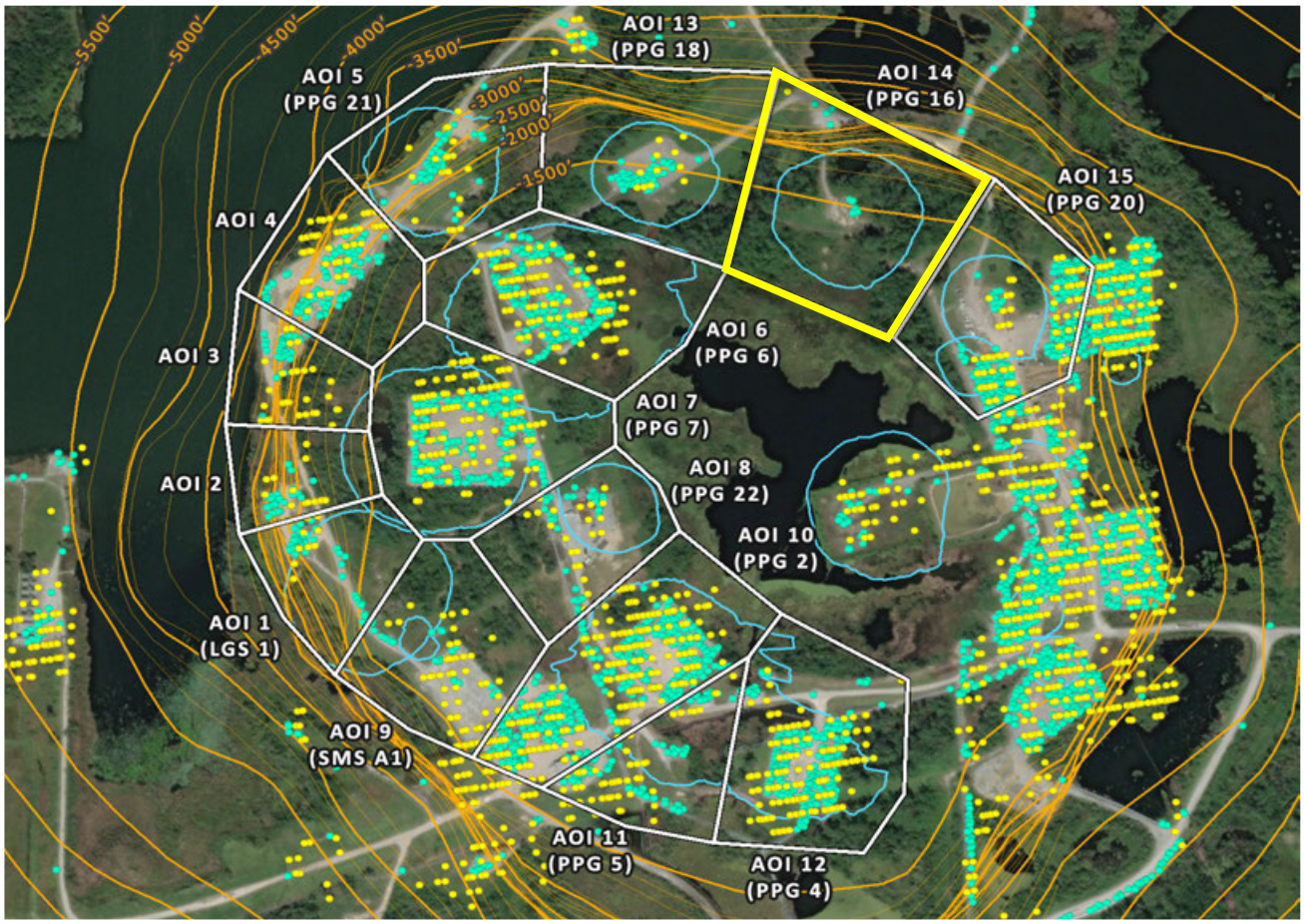

## AOI 13 *(PPG 18)* - Displacement Time Serie SNT (10/22/2024) Point Count: 12



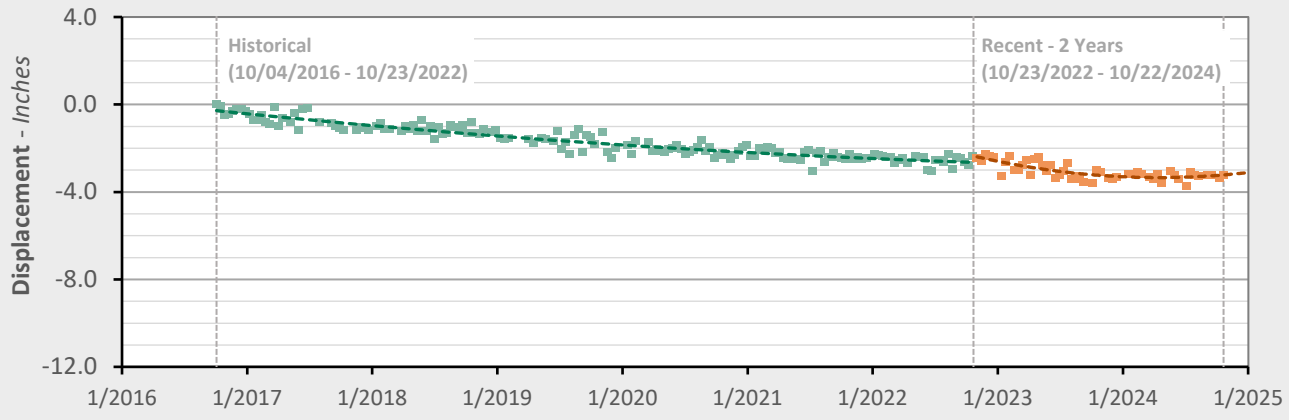

| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.60 in/yr | -0.39 in/yr | +0.22 in/yr |
| Acceleration: | +0.04 $in/yr^2$ | +0.27 $in/yr^2$ | +0.23 $in/yr^2$ |

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

## AOI 14 *(PPG 16)* - Location Map



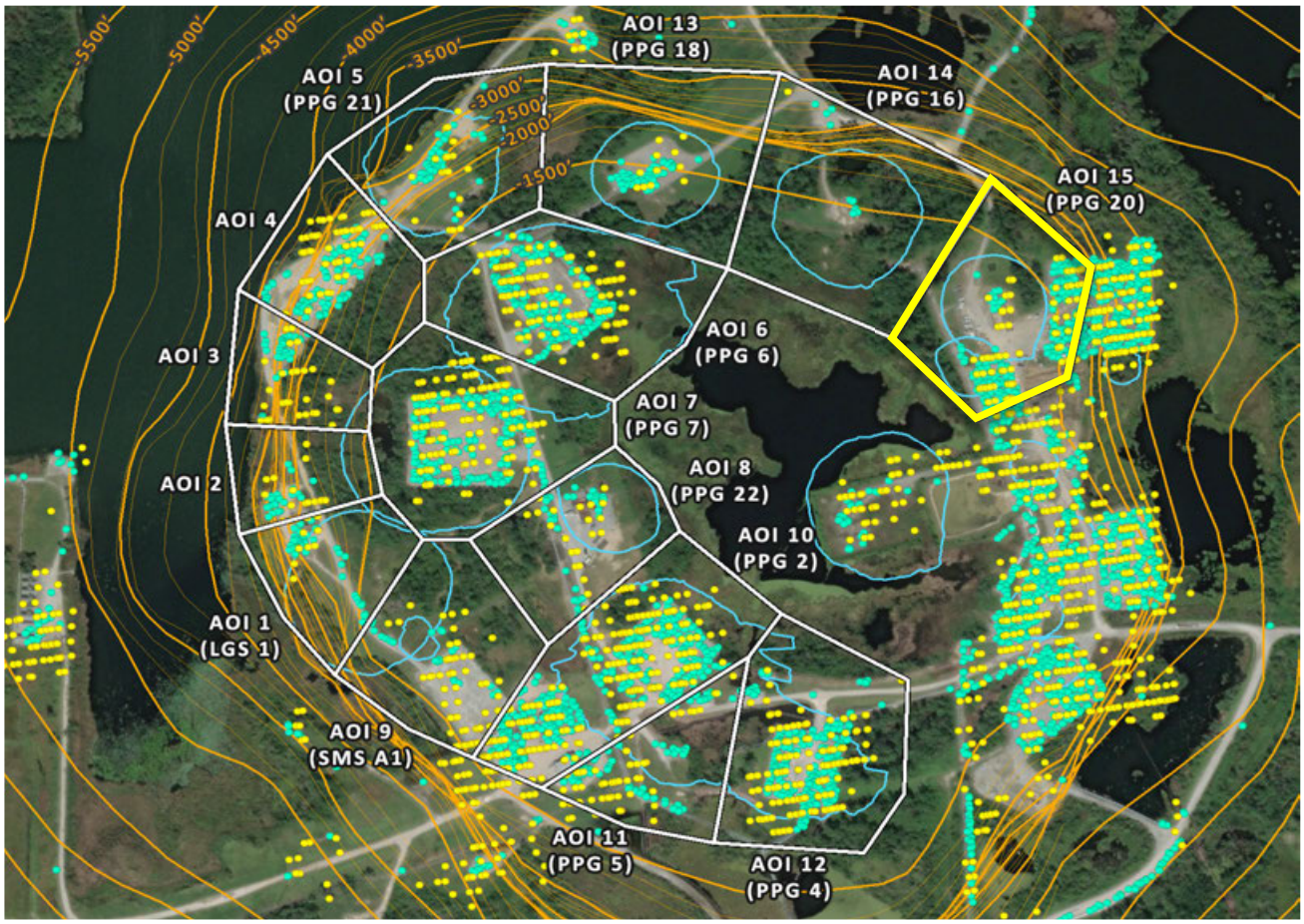

## AOI 14 *(PPG 16)* - Displacement Time Serie SNT (10/22/2024) Point Count: 1



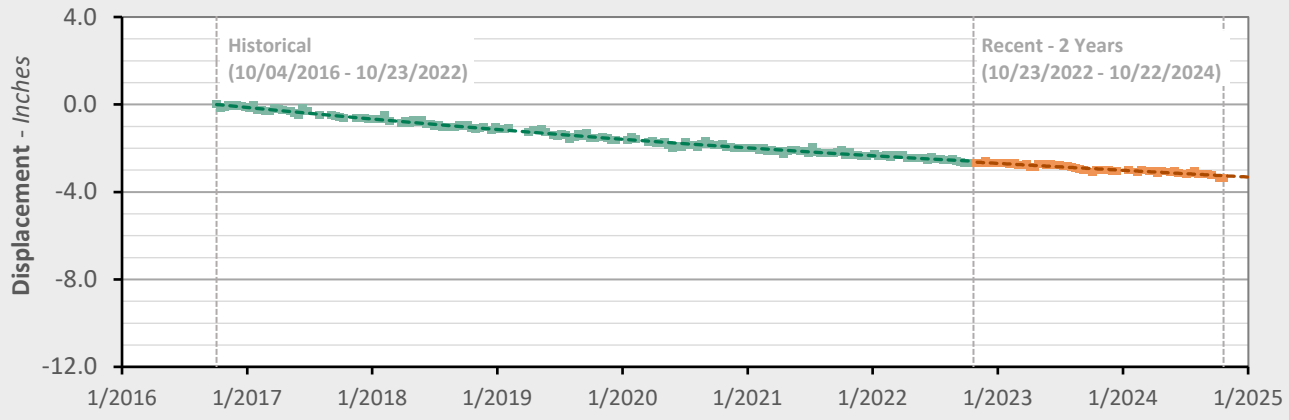

| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.19 in/yr | +0.49 in/yr | +0.67 in/yr |
| Acceleration: | +0.07 in/yr$^2$ | +0.92 in/yr$^2$ | +0.86 in/yr$^2$ |

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 (10/22/2024) Point Count: 69

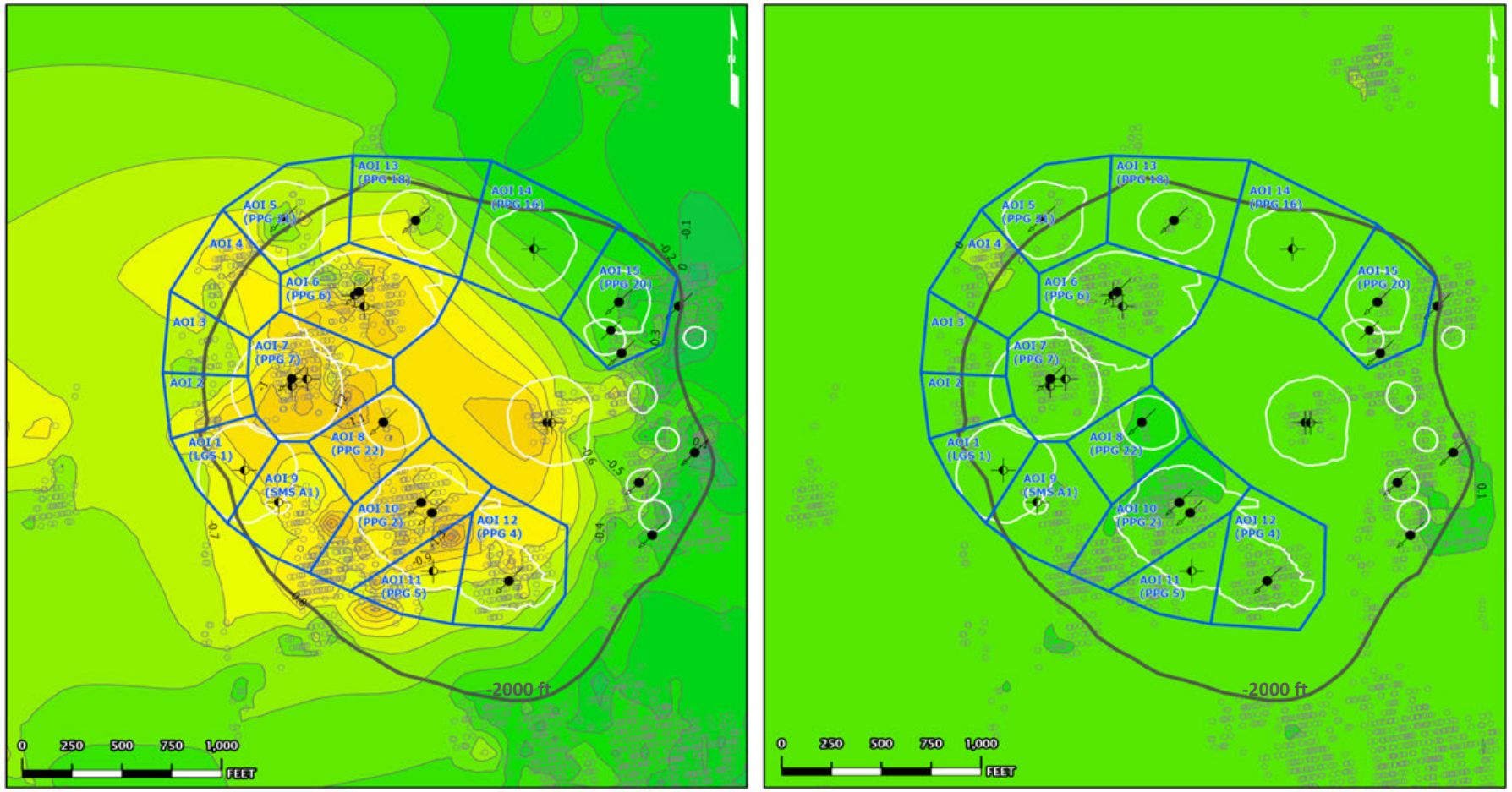



| | Historical Trend Values | Recent Trend Values | Trend Change |
|---|---|---|---|
| Velocity: | -0.30 in/yr | -0.29 in/yr | +0.01 in/yr |
| Acceleration: | +0.04 in/yr$^2$ | +0.02 in/yr$^2$ | -0.02 in/yr$^2$ |

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

## Historical SNT Data (10/04/2016 - 10/23/2022)

| Velocity Contours | Acceleration Contours |
|---|---|
| As of date: 10/23/2022 | Date range: 10/04/2016 - 10/23/2022 |




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

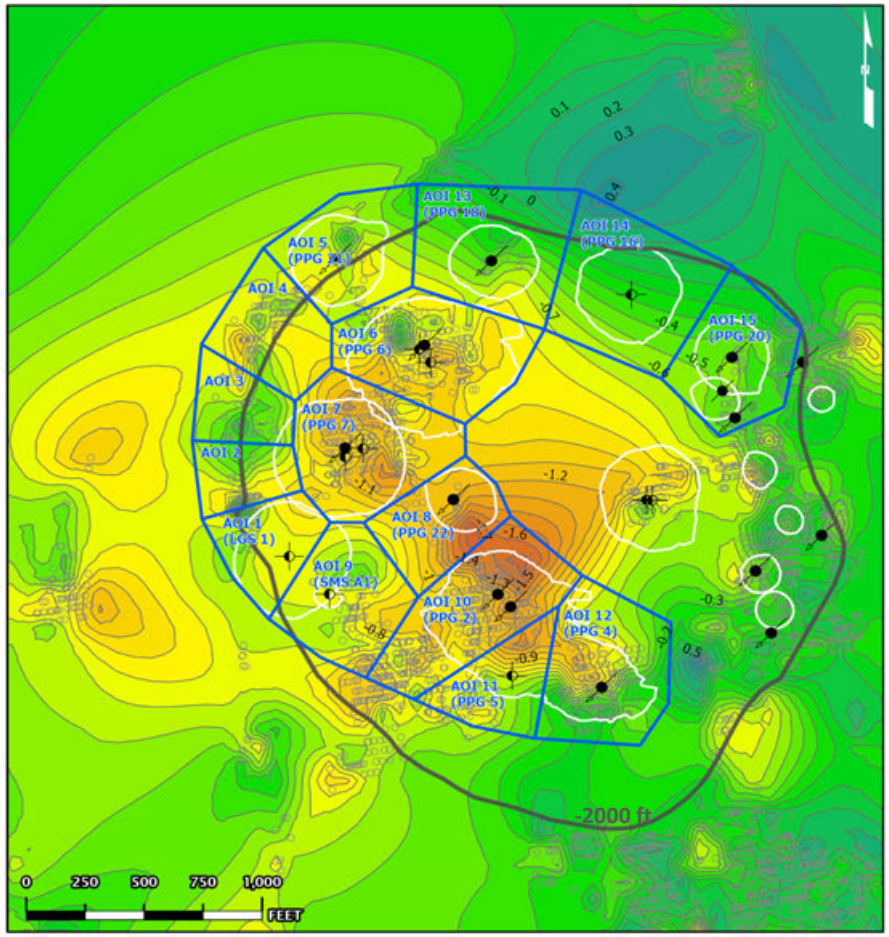
-1.0 -0.5 0.0 +0.5 +1.0 Inches/year$^2$

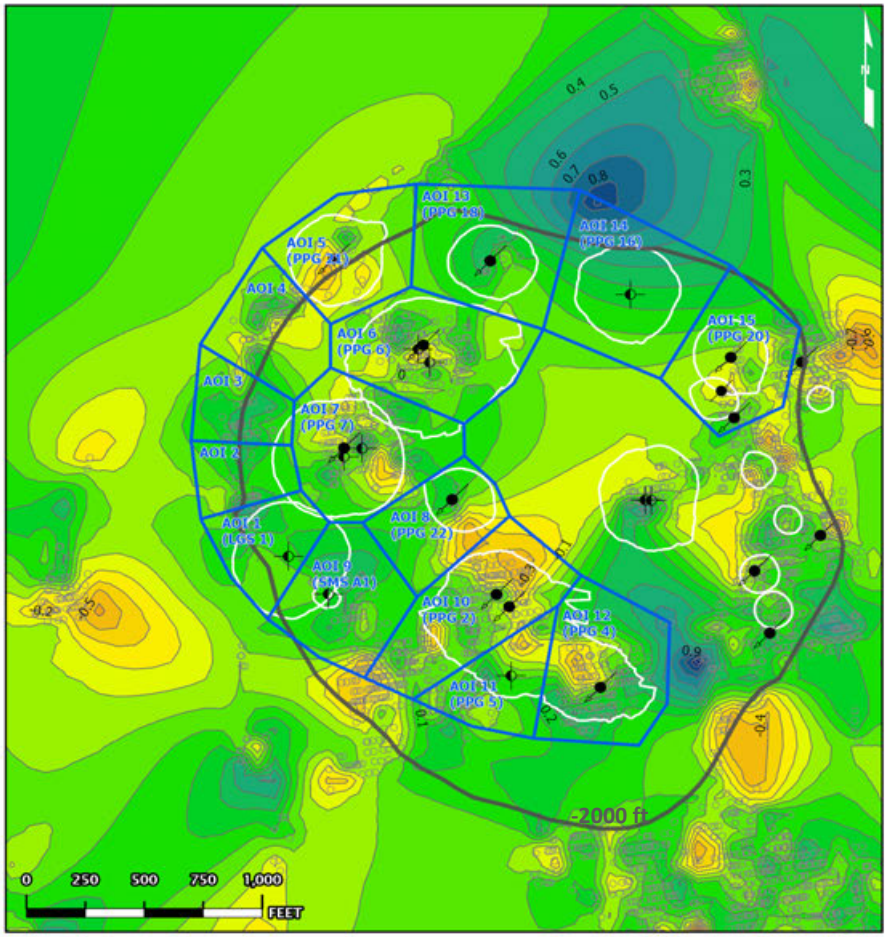
AOI Boundary | InSAR LOS Measurement Point | Contour (0.1) | Cavern Well Surface Locations

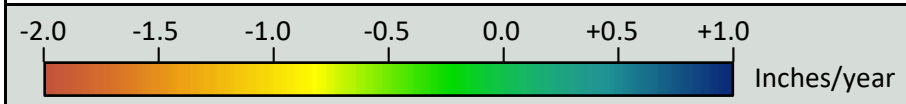
Historical Cavern Extent | Top of Dome (-2000 ft Contour) | 09 - Active - Injection | 29 - Dry and Plugged

## Recent SNT Data - 2 Years (10/23/2022 - 10/22/2024)

| Velocity Contours | Acceleration Contours |
|---|---|
| As of date: 10/22/2024 | Date range: 10/23/2022 - 10/22/2024 |



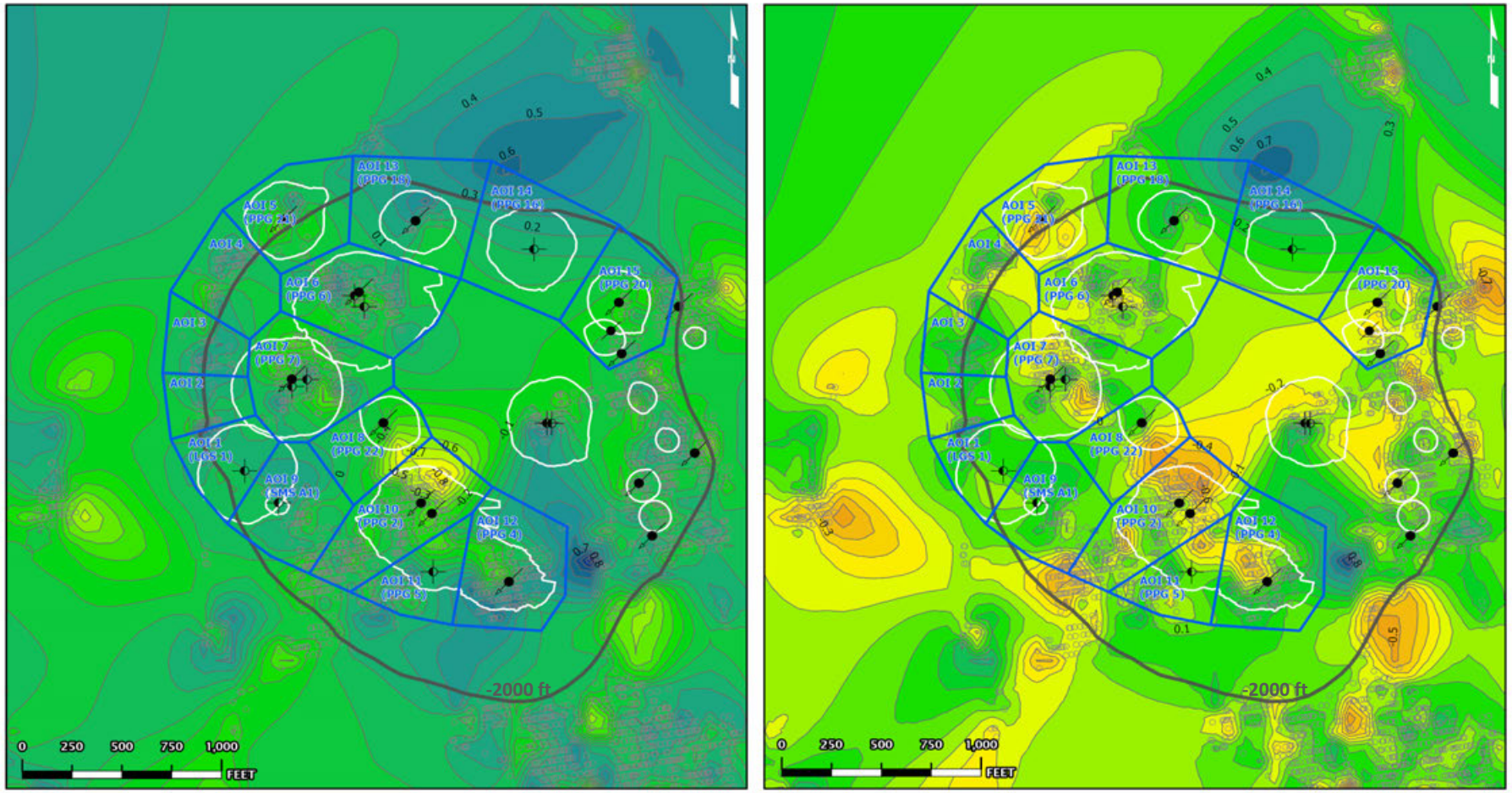


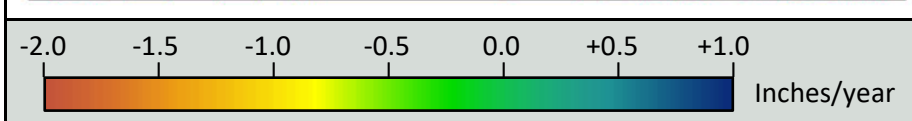
AOI Boundary | InSAR LOS Measurement Point | Contour (0.1) | Cavern Well Surface Locations

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 | Acceleration Contours |
|---|---|
| Historical Velocity subtracted from Recent Velocity | Historical Acceleration subtracted from Recent Acceleration |



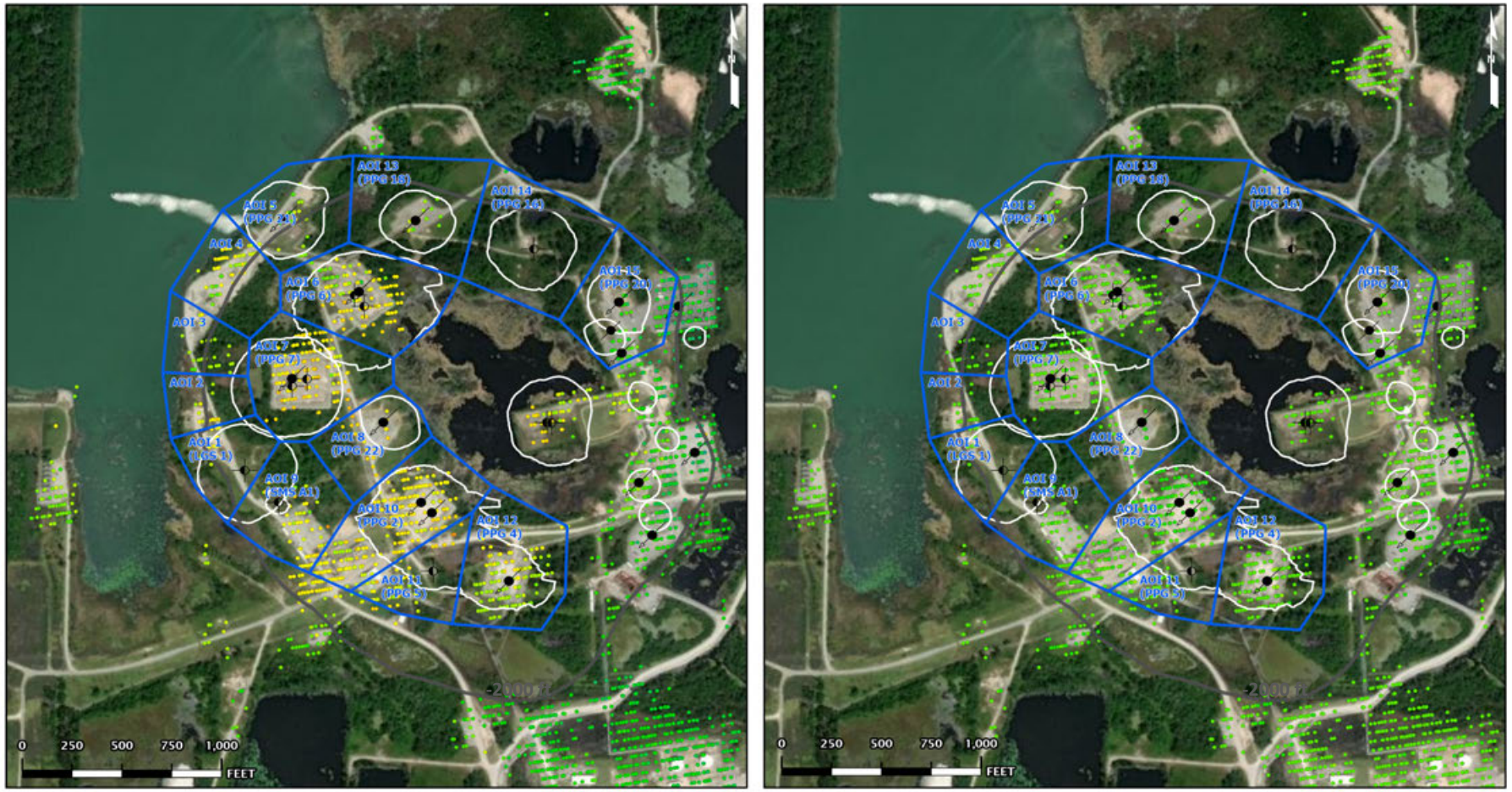


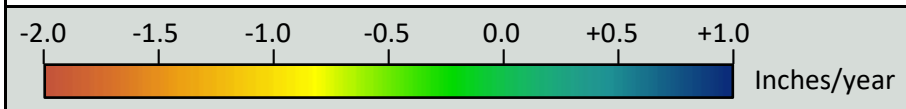
AOI Boundary | InSAR LOS Measurement Point | Contour (0.1) | Cavern Well Surface Locations

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

## Historical SNT Data (10/04/2016 - 10/23/2022)

| Velocity Data Points | Acceleration Data Points |
|---|---|
| As of date: 10/23/2022 | Date range: 10/04/2016 - 10/23/2022 |





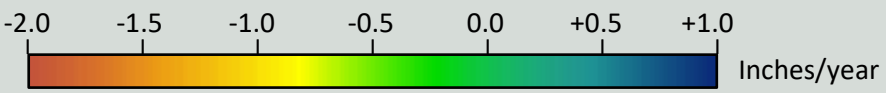
AOI Boundary
InSAR LOS Measurement Point
Historical Cavern Extent
Top of Dome (-2000 ft Contour)

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

## Recent SNT Data - 2 Years (10/23/2022 - 10/22/2024)

| Velocity Data Points | Acceleration Data Points |
|---|---|
| As of date: 10/22/2024 | Date range: 10/23/2022 - 10/22/2024 |





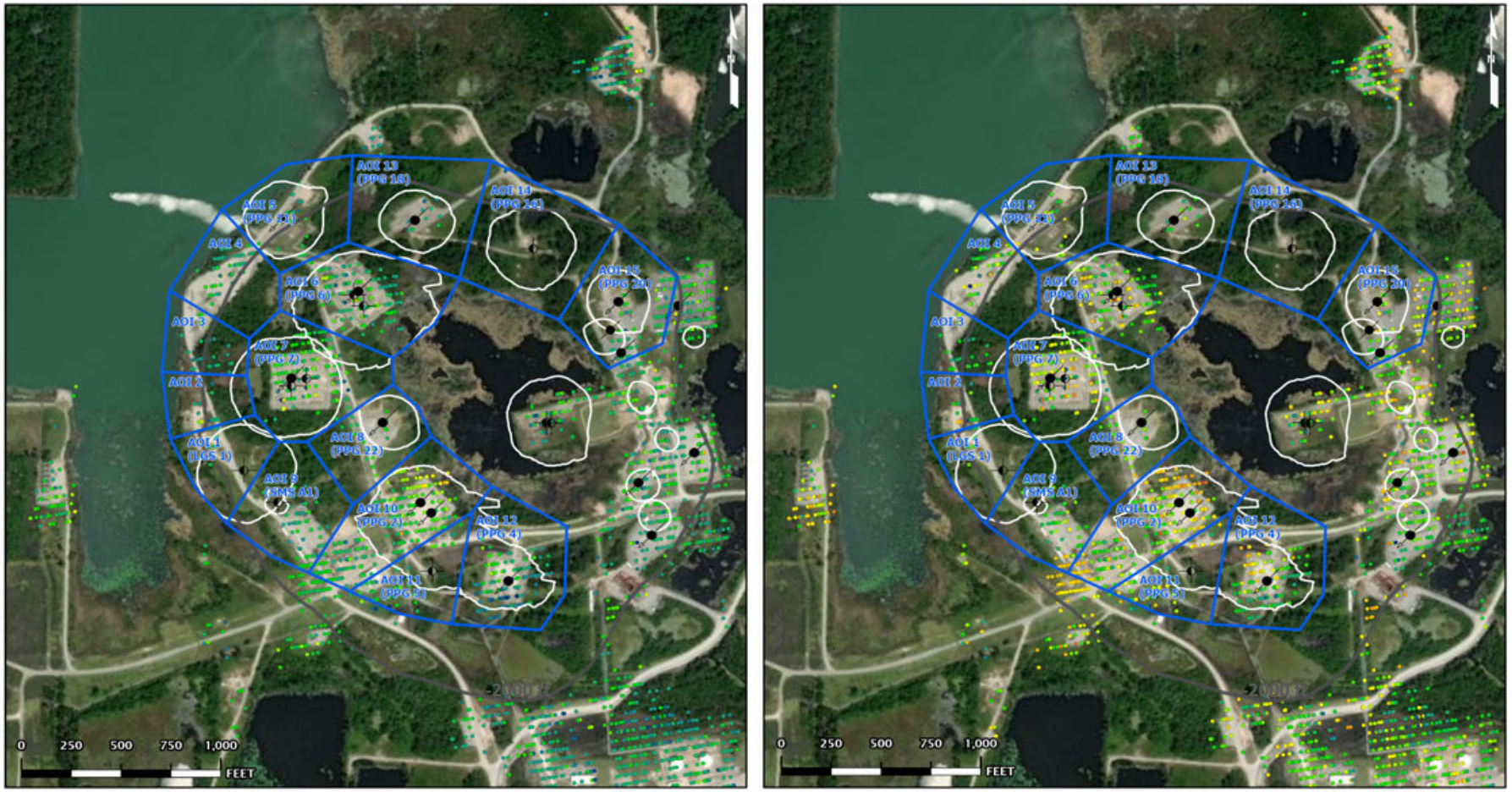


AOI Boundary
InSAR LOS Measurement Point
Historical Cavern Extent
Top of Dome (-2000 ft Contour)

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

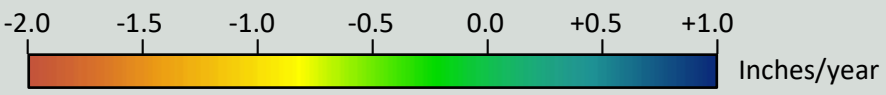
## Change from Historical to Recent SNT Data

| Velocity Data Points | Acceleration Data Points |
|---|---|
| Historical Velocity subtracted from Recent Velocity | Historical Acceleration subtracted from Recent Acceleration |











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

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

# ATTACHMENT C

## TSX/PAZ InSAR report - October 27, 2024

# TSX/PAZ 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 |
| **TerraSAR-X - PAZ Constellation** |
| Most Recent Image Date |
| **Sunday, October 27, 2024** |

Analysis Report Date:

**October 31, 2024**

## Dataset Information

| | |
|---|---|
| Satellite Source | TerraSAR-X - PAZ Constellation |
| Revisit Frequency | 4 and 7 days |
| Most Recent Image Date | Sunday, October 27, 2024 |
| Dataset Image Count | 113 |
| Dataset Time Range | January 24, 2023 - October 27, 2024 |
| Dataset Length | 1.76 Years |
| Satellite Line-of-Sight (LOS) | 37° East of Vertical (Viewing site from the East) |

## Analysis Methodology

**Time Series Charts**

Trend lines were calculated for the averaged displacement values within each AOI. Both a nonlinear (quadratic) and linear regression were applied to each AOI point group to identify rates of change in LOS displacement. These trends are displayed in the Time Series section of this report.

**Contour Maps**

A nonlinear (quadratic) and linear trend was also calculated for each individual measurement point across the analysis region. Nonlinear trend values for each point were used to generate Velocity and Acceleration contour maps to convey the spatial distribution of the calculated movement. The linear trend values for each point (which lack an acceleration component) were used to generate an additional Velocity contour map. Maps depicting the individual data points colored by these trend values are also included in the last section of the report.

Negative velocity values indicate subsidence or westward movement and positive velocity indicates uplift or eastward movement. Negative acceleration values indicate increasing rates of subsidence, increasing westward movement, or slowing eastward movement and positive acceleration values indicate slowing rates of subsidence, slowing westward movement, or increasing eastward movement.

## Observations

To-date there have been no acute deviations from established subsidence trends in the areas investigated.

The timeframe of the dataset does not allow for comparison of recent to long-term LOS displacement rates. This dataset is primarily used to monitor for acute trend deviations and benefits from a higher measurement precision in individual readings than the SNT data.

Recent data has begun to indicate a negative acceleration of varying magnitudes across most of the AOI point groups evaluated. This is most evident in the trend acceleration values in the westernmost AOIs and in the mapped contours on the western side of AOI 2, AOI 3 and AOI 4. This suggests that marginal increases in subsidence rates may be occuring in this area of the dome. Seasonal effects are believed to contribute to fluctuations above and below the trend lines for each AOI and may play a significant role in the gradual changes that are being observed.


Date Signed: October 31, 2024
Austin, Texas

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

## InSAR Data Sources

**InSAR Data**

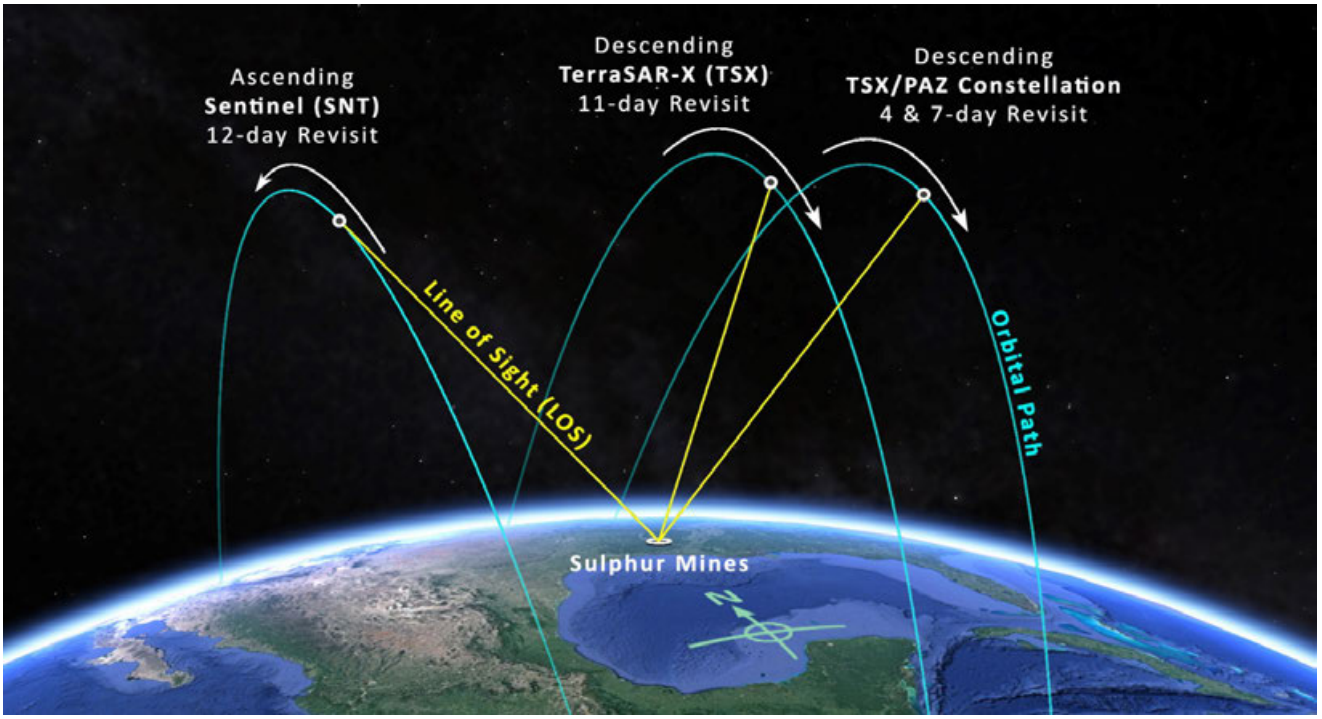
Interferometric Synthetic Aperture Radar (InSAR) is the most well established method to continually evaluate small, normally undetectable, ground movement over a large area. Radar imagery collected via satellites over successive orbital passes is used to identify and define measurement points on the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

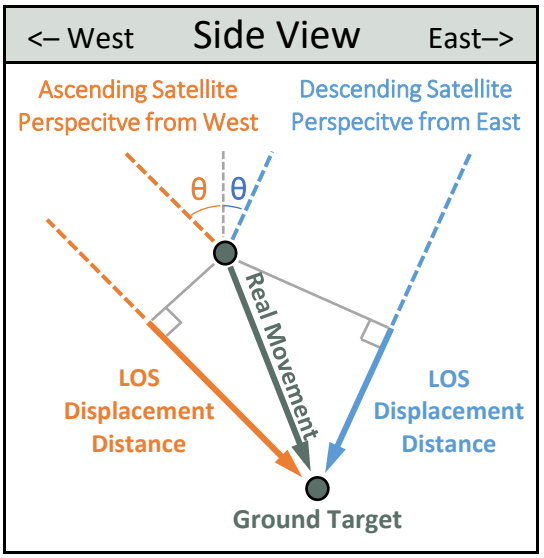
The first dataset comes from a low-resolution Sentinel-1 (SNT) satellite on an ascending orbit that captures data from the west of the site on a 12-day frequency. The second comes from a pair of high resolution satellites that share the same descending orbit and capture data from east of the site. These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

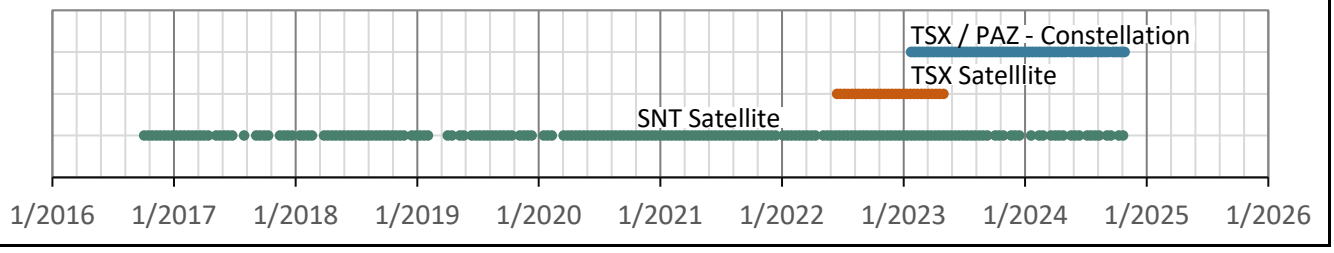
LOS displacement measurements refer to a change in distance between the satellite sensor and the ground target. Measurement positions on the west side of the Sulphur Dome are are known to be experiencing some eastward movement toward the dome center due to the geometry of the subsidence basin. The InSAR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



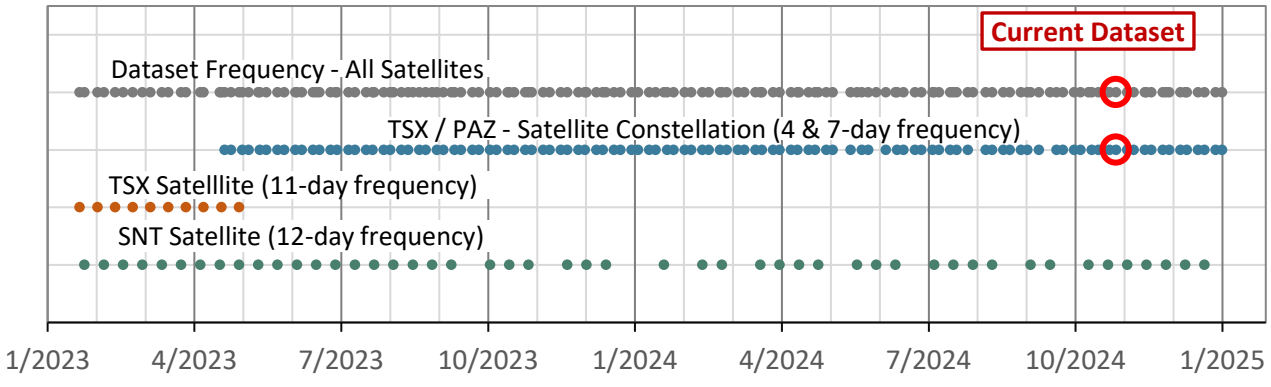

## Satellite Properties & Image Frequency

| 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, $\theta$)** | 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 |

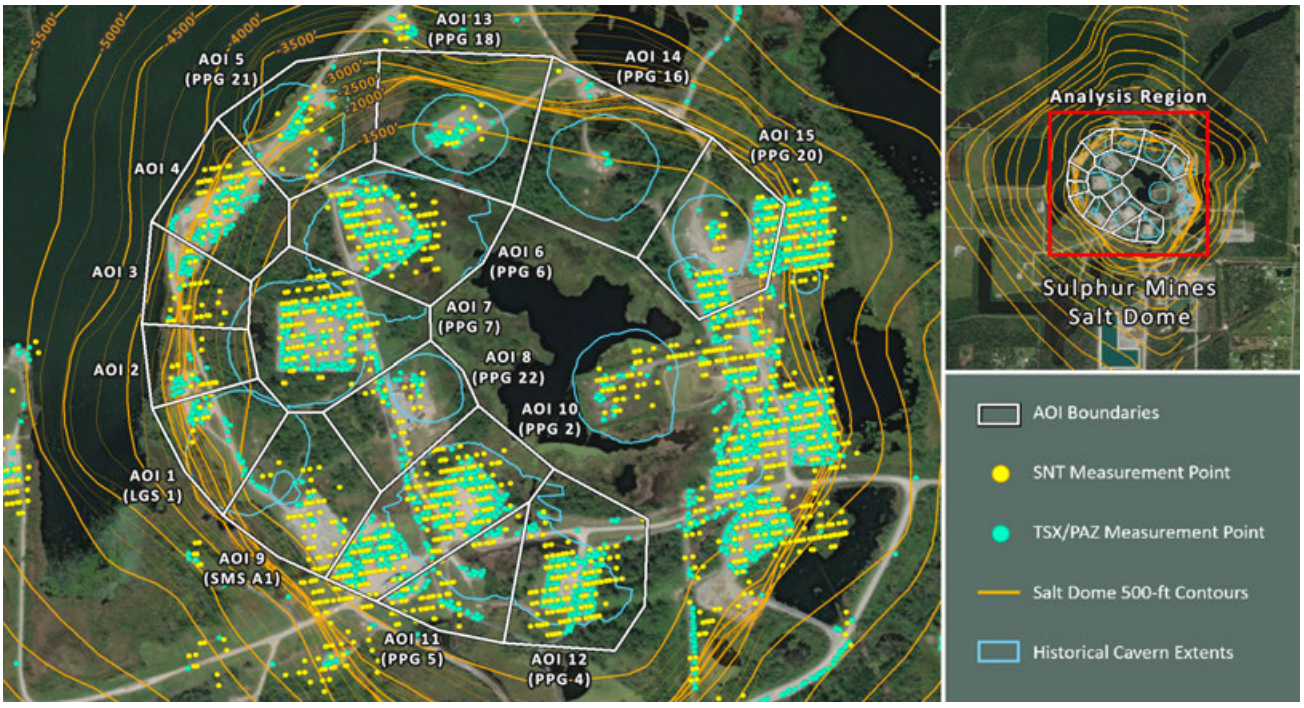
### Dataset Measurement History




### Dataset Update Frequency



## AOI Boundaries & InSAR Measurement Points

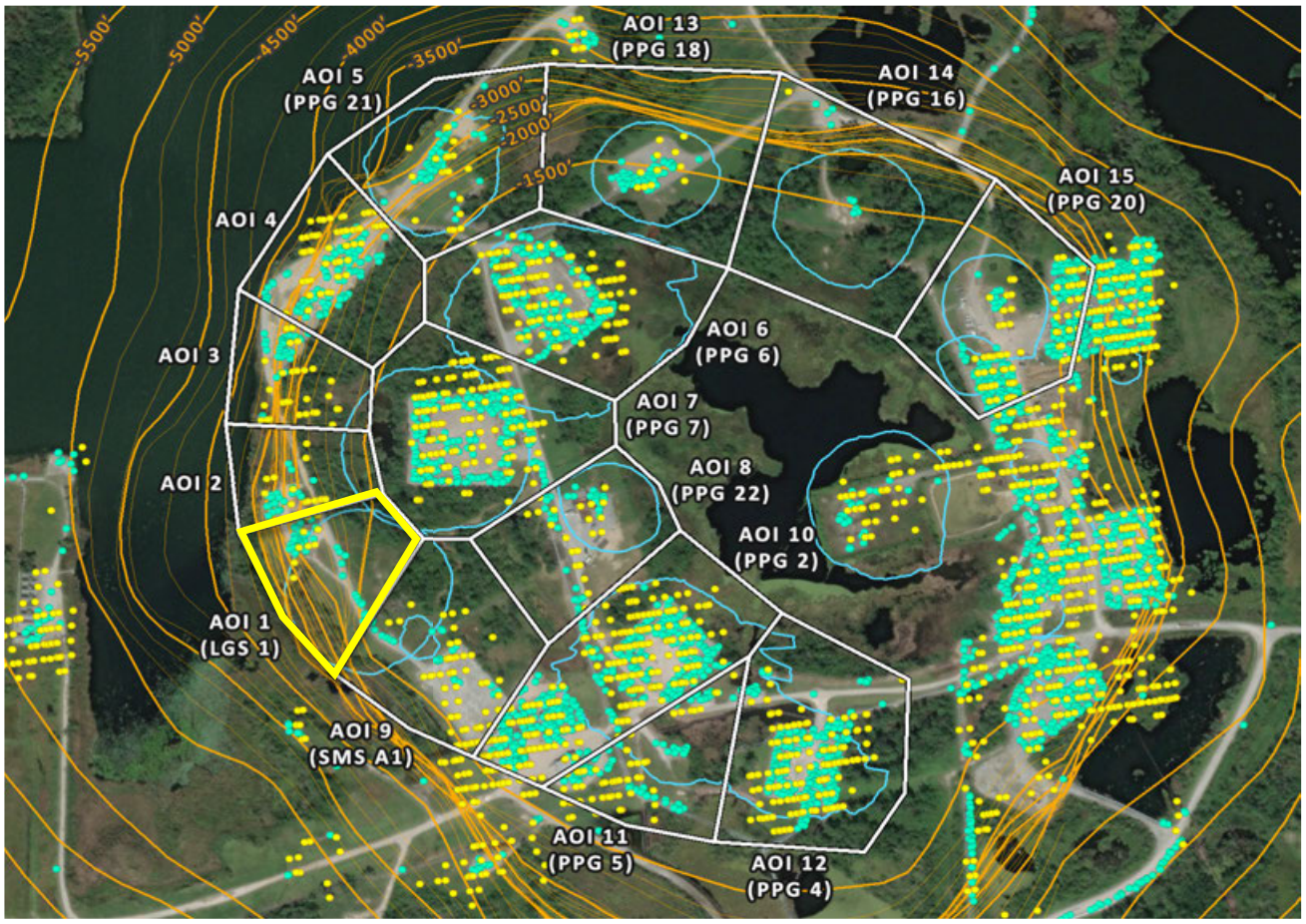



## Subsidence Monitoring Areas of Interest (AOIs)

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.

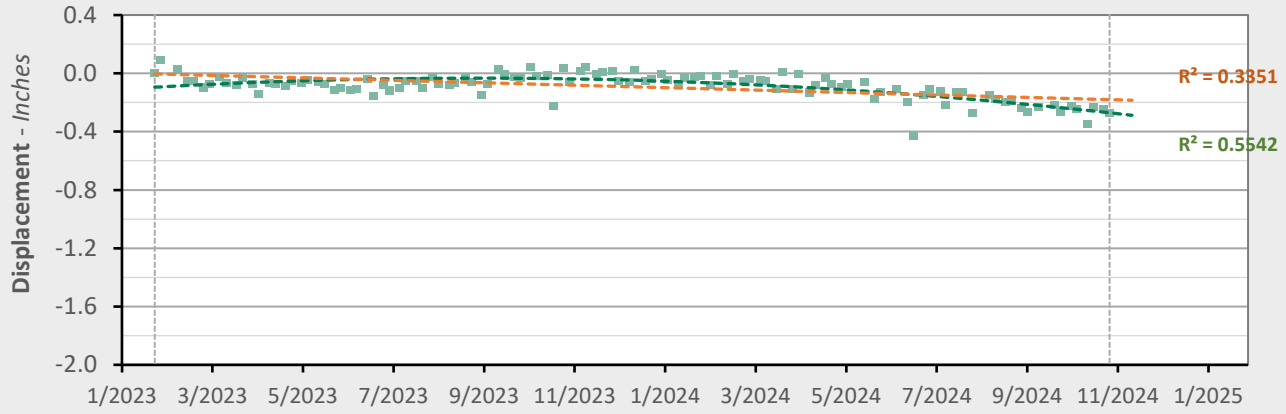
| AOI Name | TSX/PAZ (10/27/2024) | LOS Velocity (in/yr) | | LOS Acceleration (in/yr²) | |
|---|---|---|---|---|---|
| | Point Count | Nonlinear | Linear | Nonlinear | Linear |
| **AOI 1** *(LGS 1)* | 42 | -0.41 | -0.10 | -0.35 | 0.00 |
| **AOI 2** | 24 | -0.52 | -0.11 | -0.47 | 0.00 |
| **AOI 3** | 40 | -0.39 | -0.06 | -0.37 | 0.00 |
| **AOI 4** | 102 | -0.35 | -0.03 | -0.36 | 0.00 |
| **AOI 5** *(PPG 21)* | 47 | -0.32 | -0.19 | -0.14 | 0.00 |
| **AOI 6** *(PPG 6)* | 212 | -0.76 | -0.47 | -0.33 | 0.00 |
| **AOI 7** *(PPG 7)* | 216 | -0.62 | -0.33 | -0.32 | 0.00 |
| **AOI 8** *(PPG 22)* | 36 | -0.83 | -0.62 | -0.24 | 0.00 |
| **AOI 9** *(SMS A1)* | 23 | -0.35 | -0.28 | -0.09 | 0.00 |
| **AOI 10** *(PPG 2)* | 403 | -0.81 | -0.59 | -0.26 | 0.00 |
| **AOI 11** *(PPG 5)* | 85 | -0.80 | -0.52 | -0.33 | 0.00 |
| **AOI 12** *(PPG 4)* | 262 | -1.10 | -0.86 | -0.27 | 0.00 |
| **AOI 13** *(PPG 18)* | 52 | -0.73 | -0.48 | -0.29 | 0.00 |
| **AOI 14** *(PPG 16)* | 11 | -0.63 | -0.66 | +0.04 | 0.00 |
| **AOI 15** *(PPG 20)* | 224 | -1.19 | -1.00 | -0.22 | 0.00 |

## AOI 1 *(LGS 1)* - Location Map




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

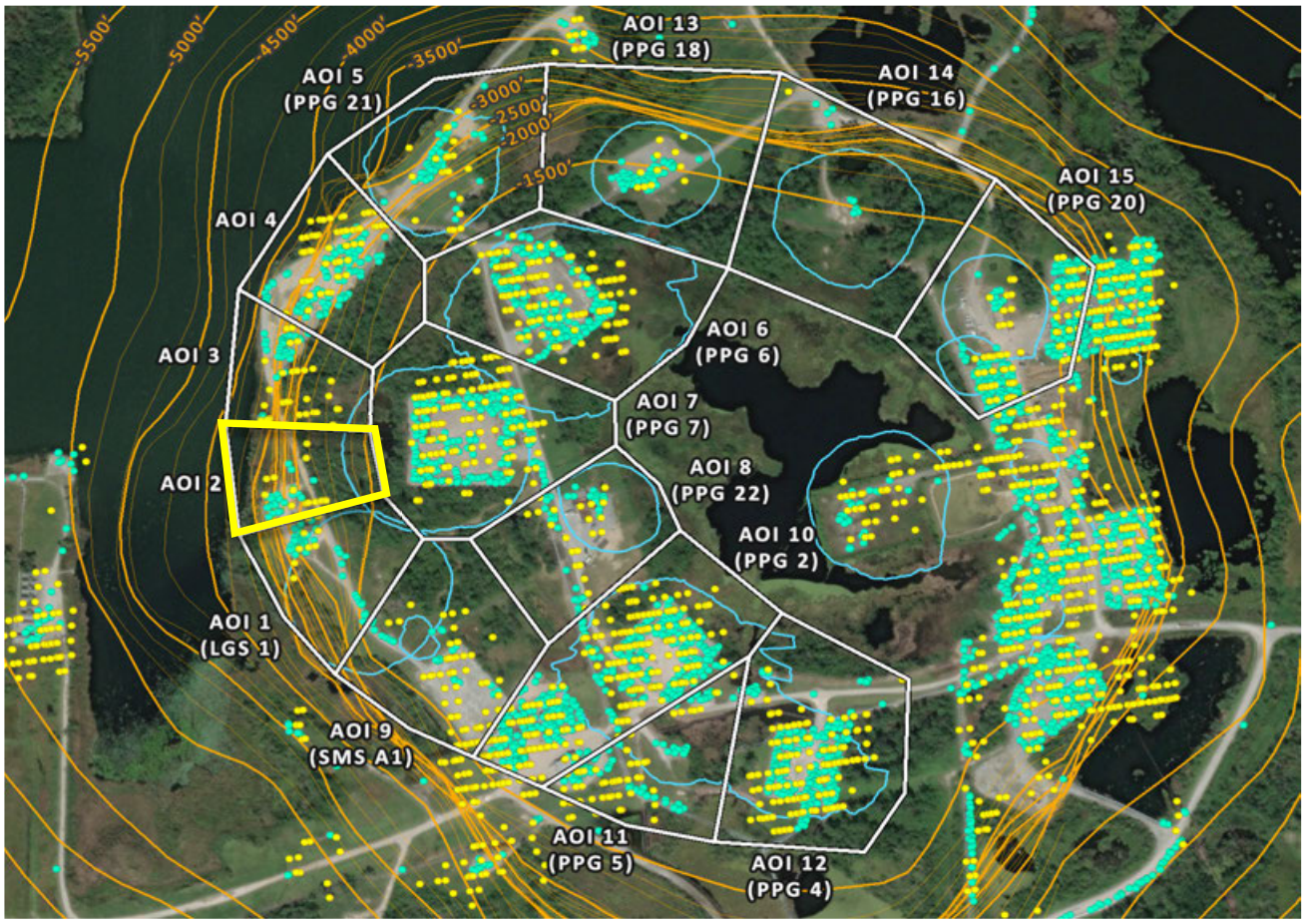
TSX/PAZ (10/27/2024) Point Count: **42**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.41 in/yr | -0.10 in/yr |
| Acceleration: | -0.35 in/yr$^2$ | 0.00 in/yr$^2$ |

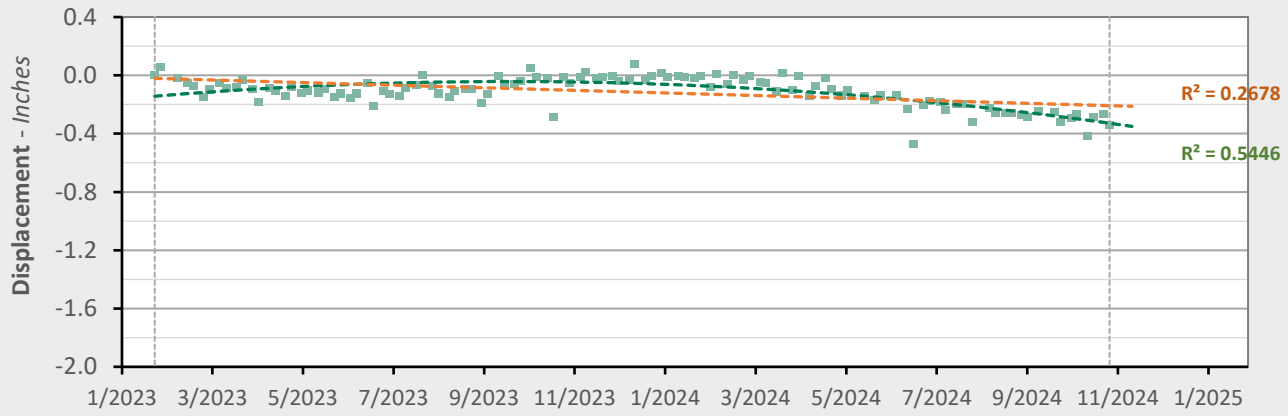
LOS Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 2 - Location Map




## AOI 2 - Displacement Time Series

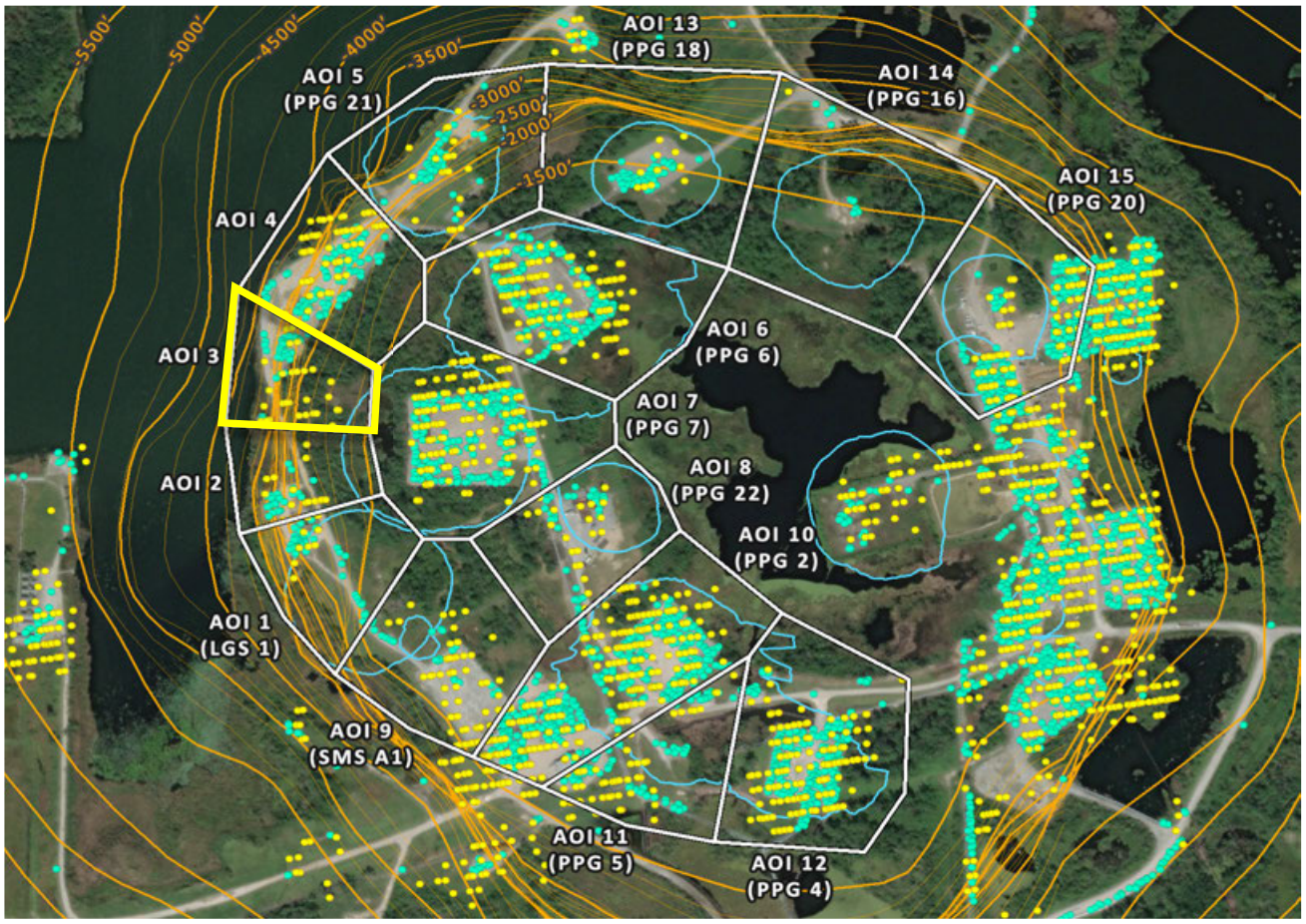
TSX/PAZ (10/27/2024) Point Count: **24**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.52 | in/yr | -0.11 | in/yr |
| Acceleration: | -0.47 | in/yr$^2$ | 0.00 | in/yr$^2$ |

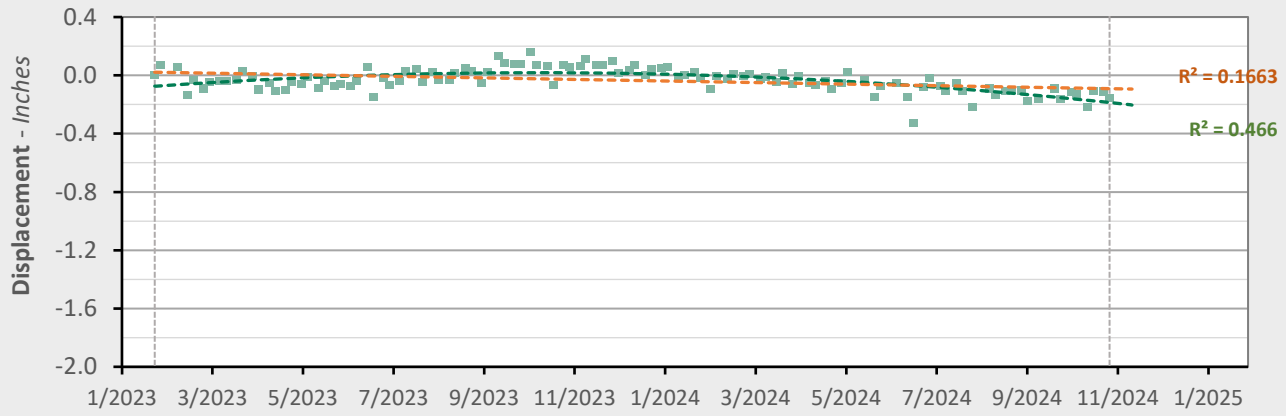
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 3 - Location Map




## AOI 3 - Displacement Time Series

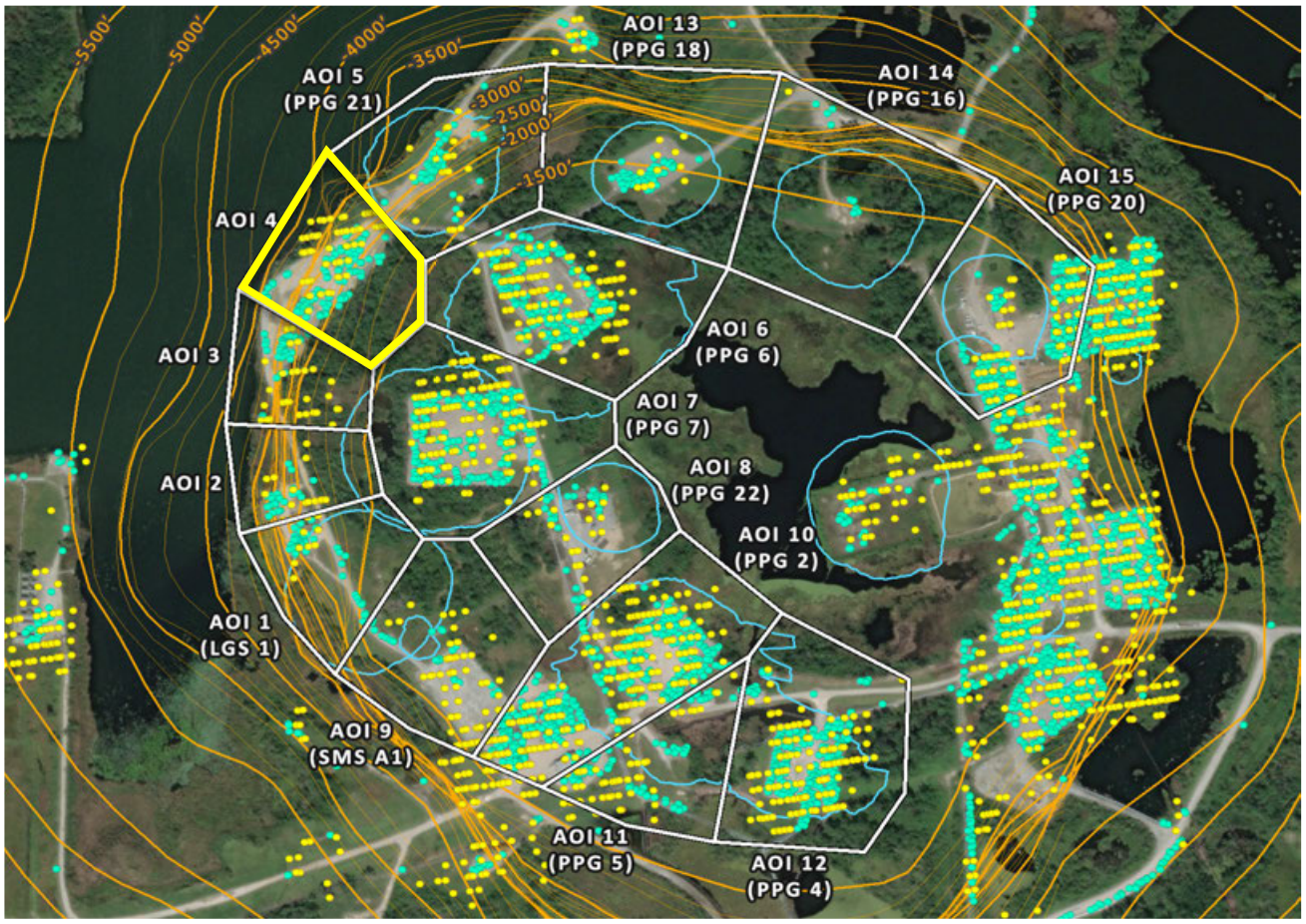
TSX/PAZ (10/27/2024) Point Count: **40**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.39 | in/yr | -0.06 | in/yr |
| Acceleration: | -0.37 | in/yr$^2$ | 0.00 | in/yr$^2$ |

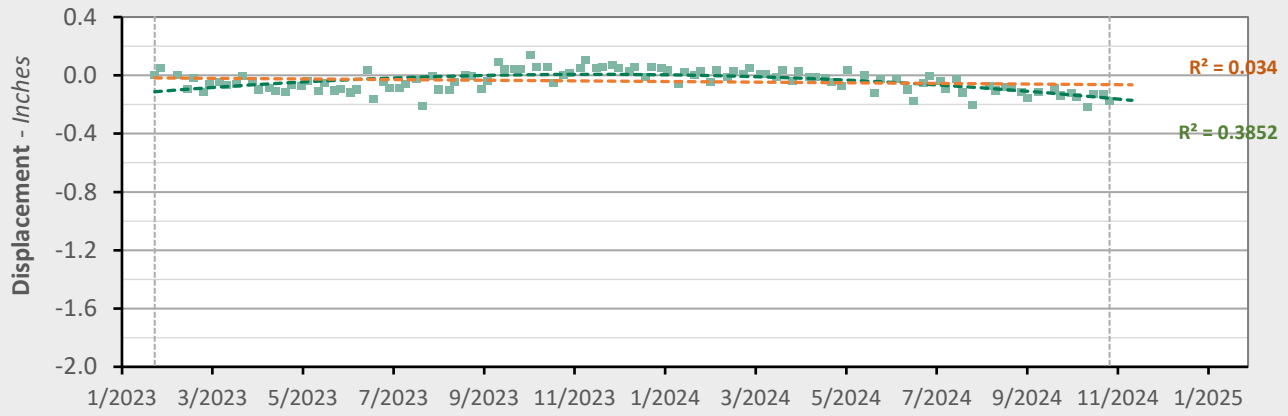
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 4 - Location Map




## AOI 4 - Displacement Time Series

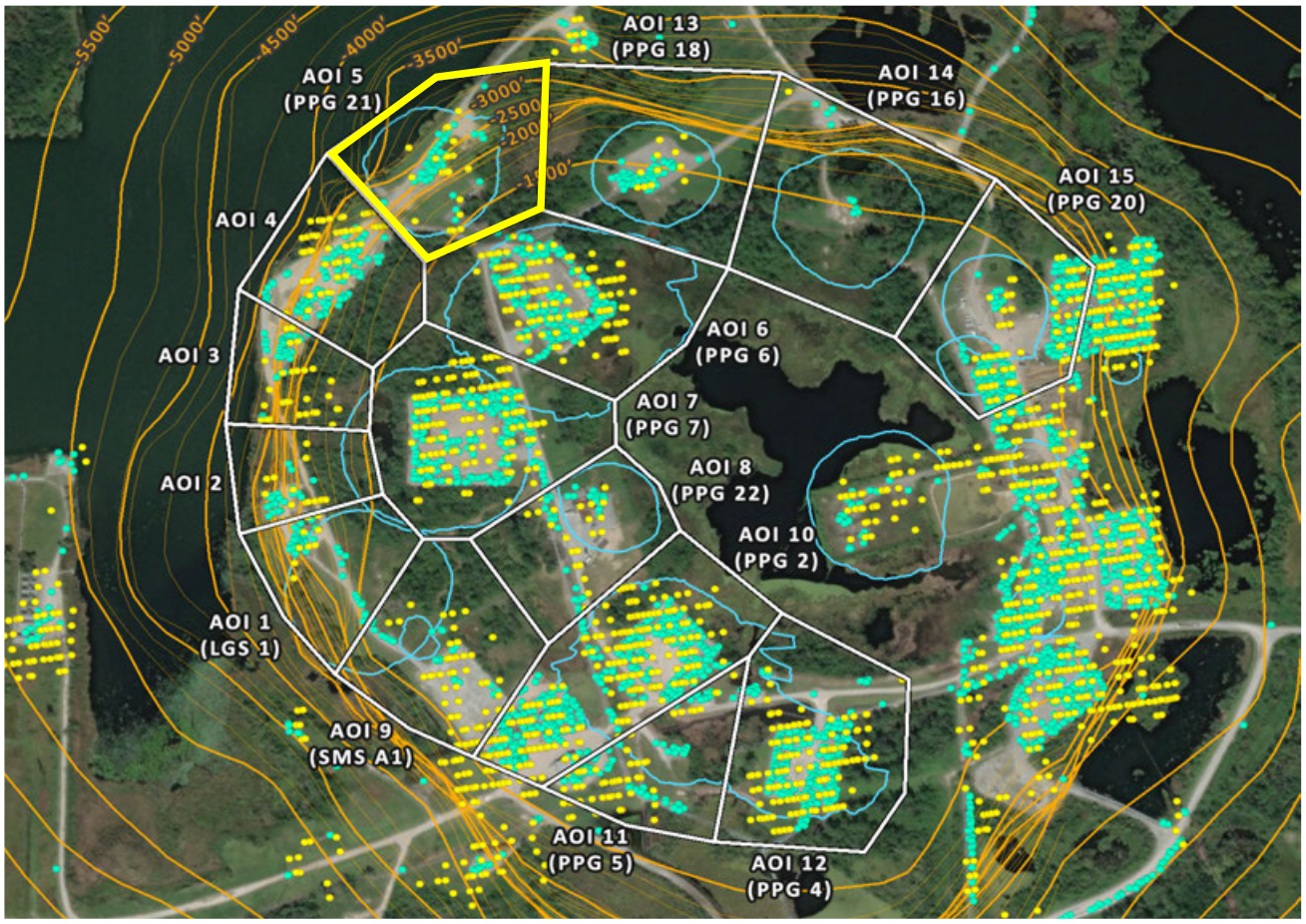
TSX/PAZ (10/27/2024) Point Count: **102**



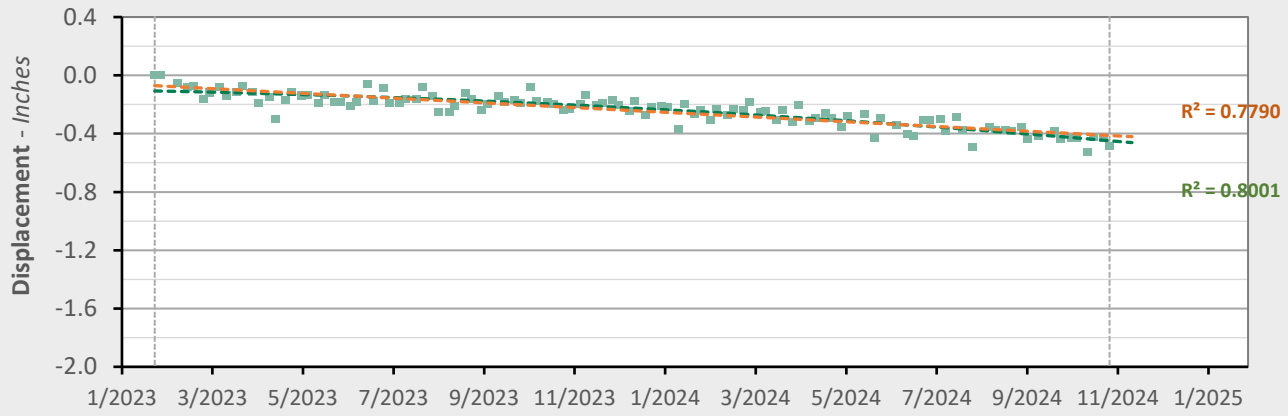

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.35 in/yr | -0.03 in/yr |
| Acceleration: | -0.36 in/yr² | 0.00 in/yr² |

LOS Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 5 *(PPG 21)* - Location Map



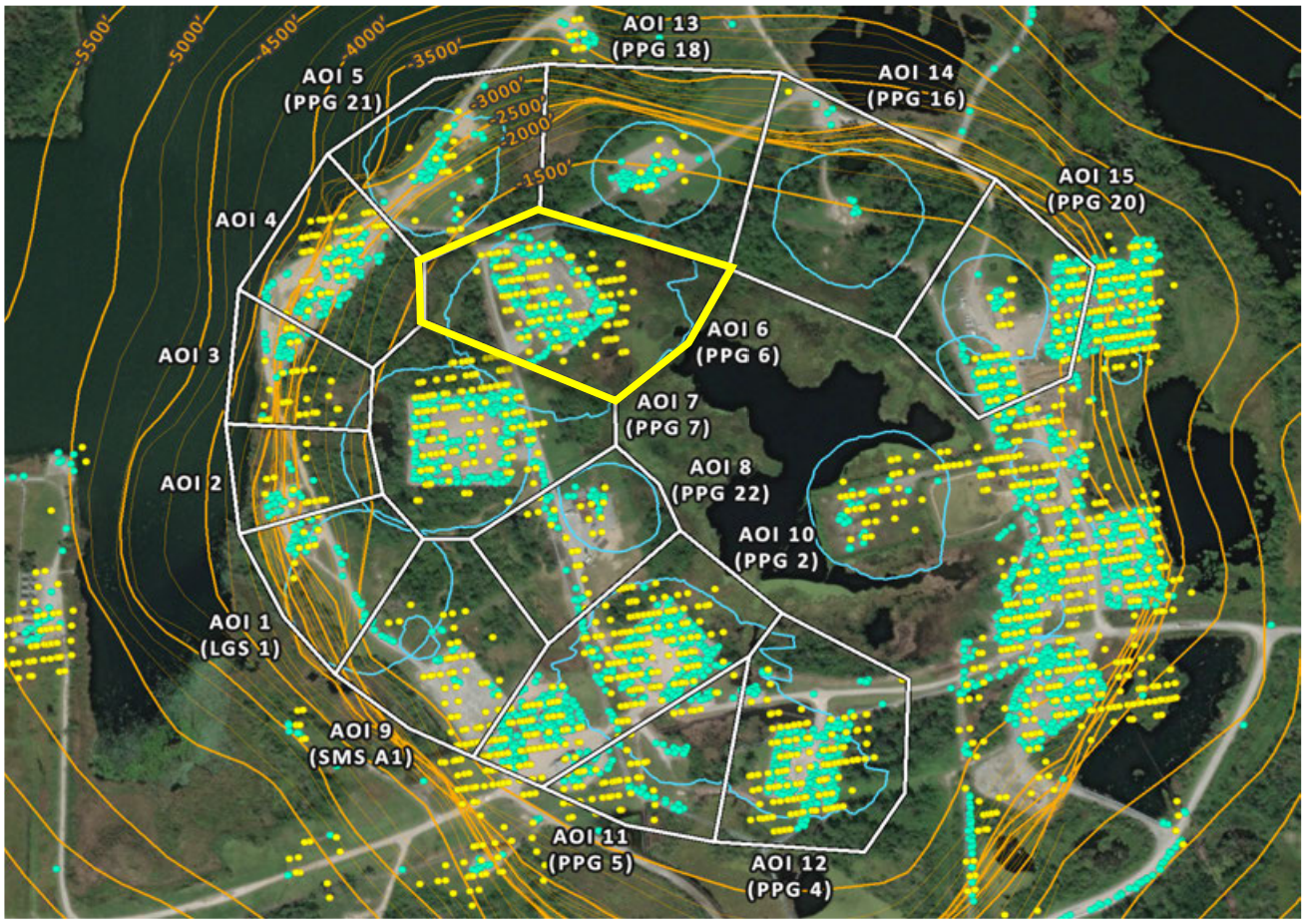

## AOI 5 *(PPG 21)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 47




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.32 in/yr | -0.19 in/yr |
| Acceleration: | -0.14 in/yr$^2$ | 0.00 in/yr$^2$ |

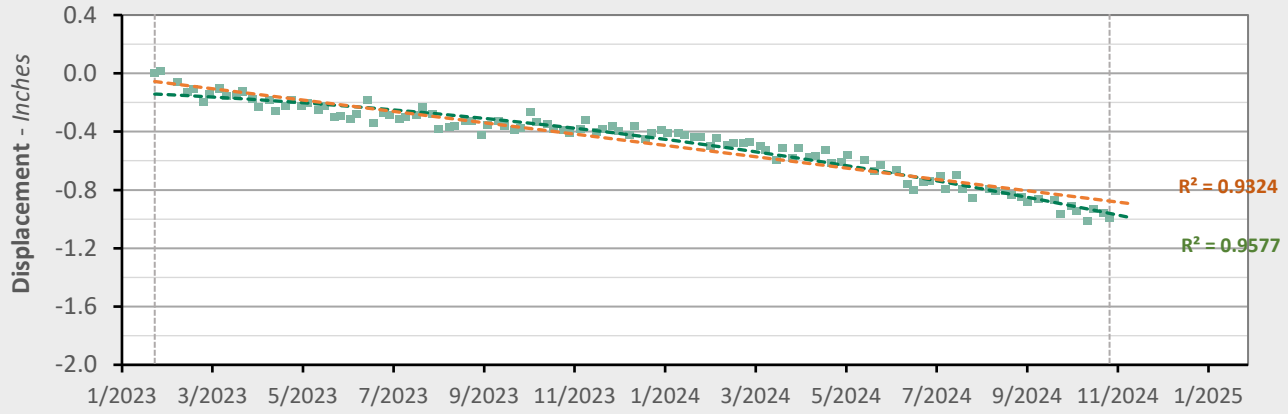
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 6 *(PPG 6)* - Location Map




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

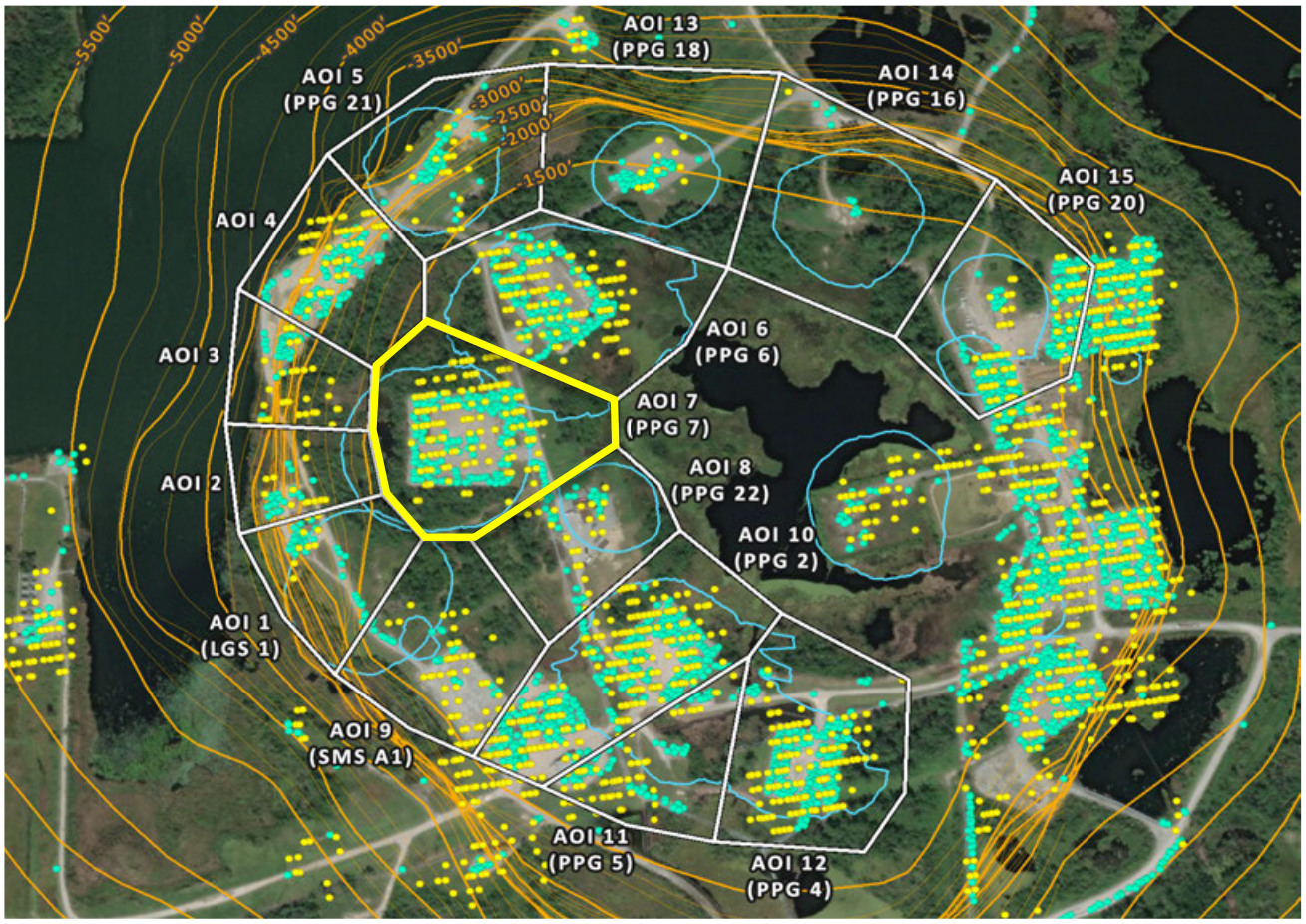
TSX/PAZ (10/27/2024) Point Count: **212**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.76 in/yr | -0.47 in/yr |
| Acceleration: | -0.33 in/yr$^2$ | 0.00 in/yr$^2$ |

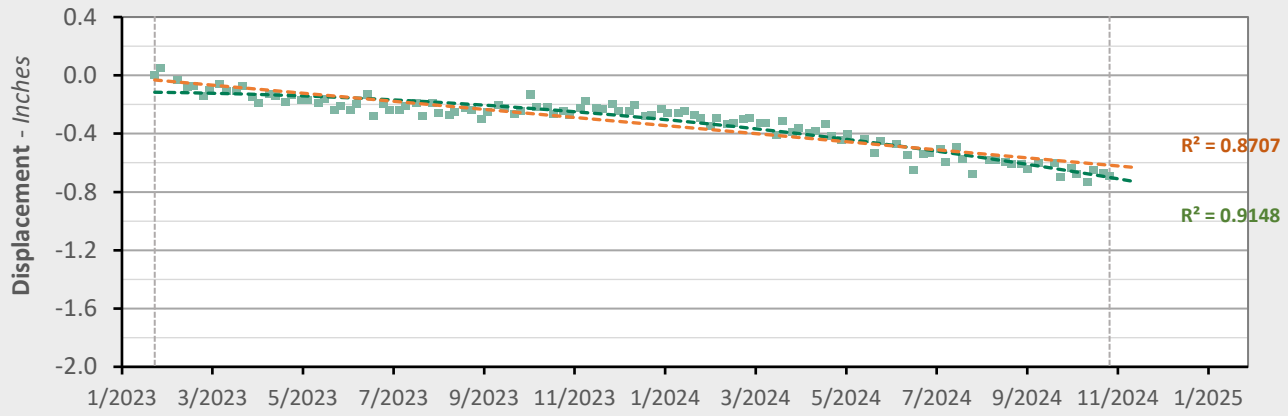
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 7 *(PPG 7)* - Location Map




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

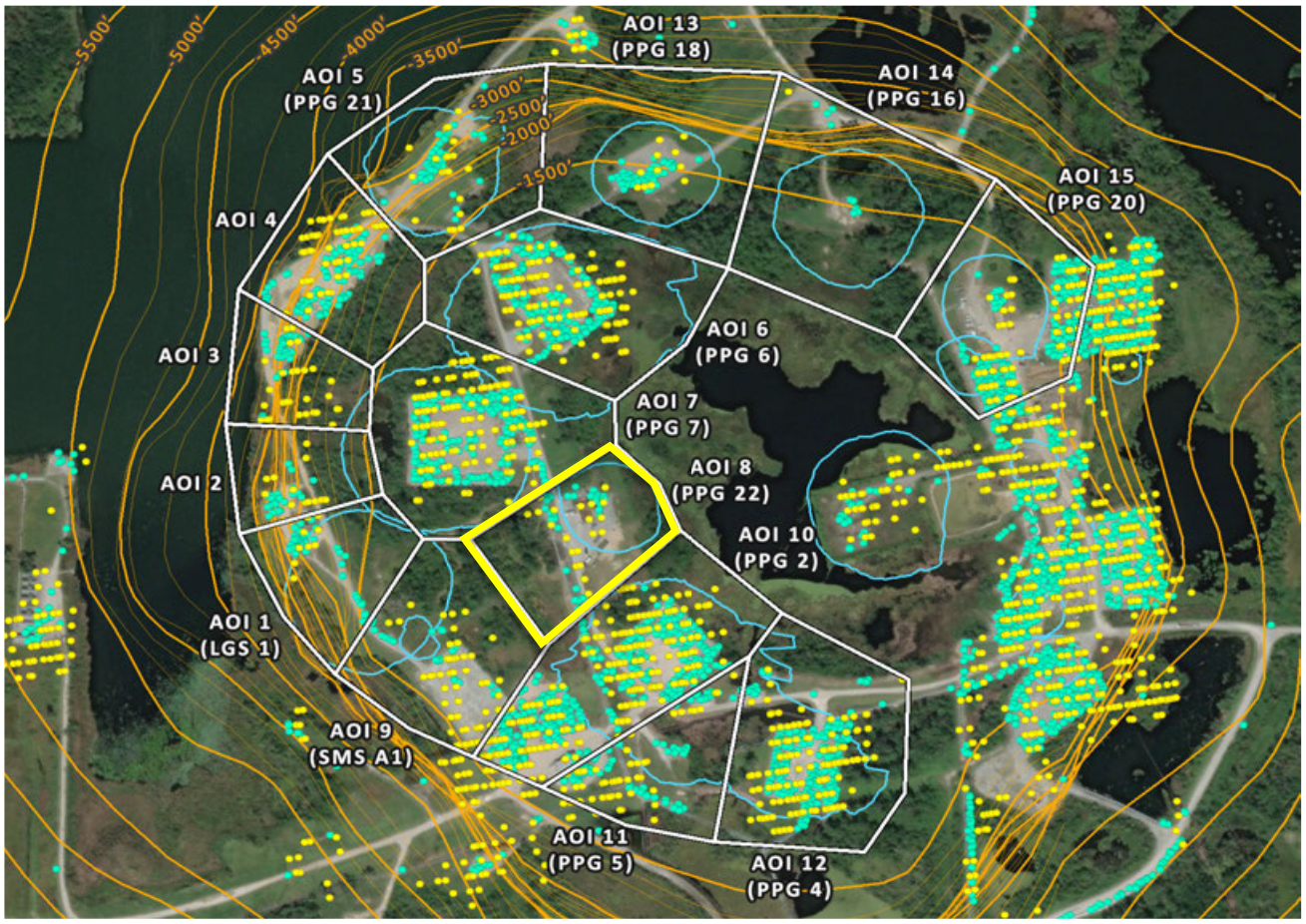
TSX/PAZ (10/27/2024) Point Count: **216**



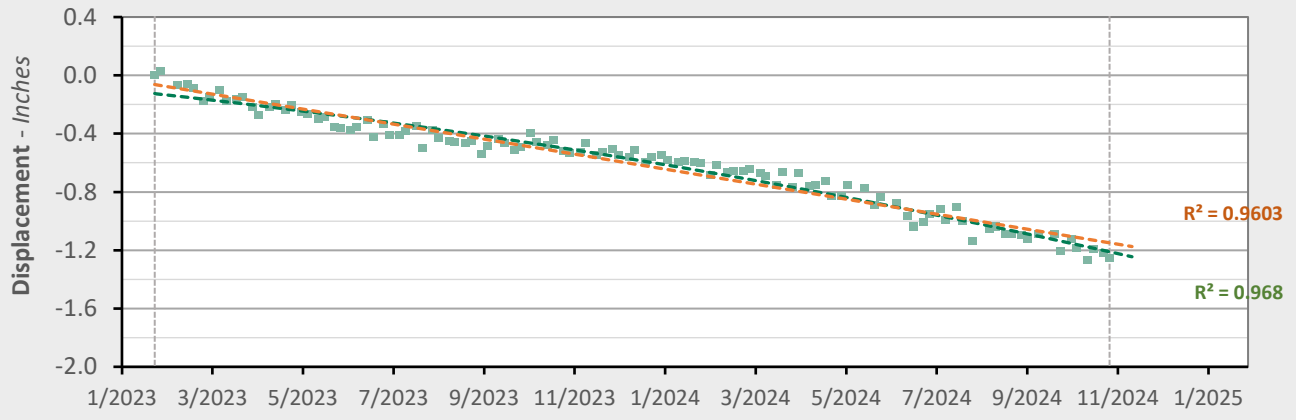

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.62 in/yr | -0.33 in/yr |
| Acceleration: | -0.32 in/yr² | 0.00 in/yr² |

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 8 *(PPG 22)* - Location Map



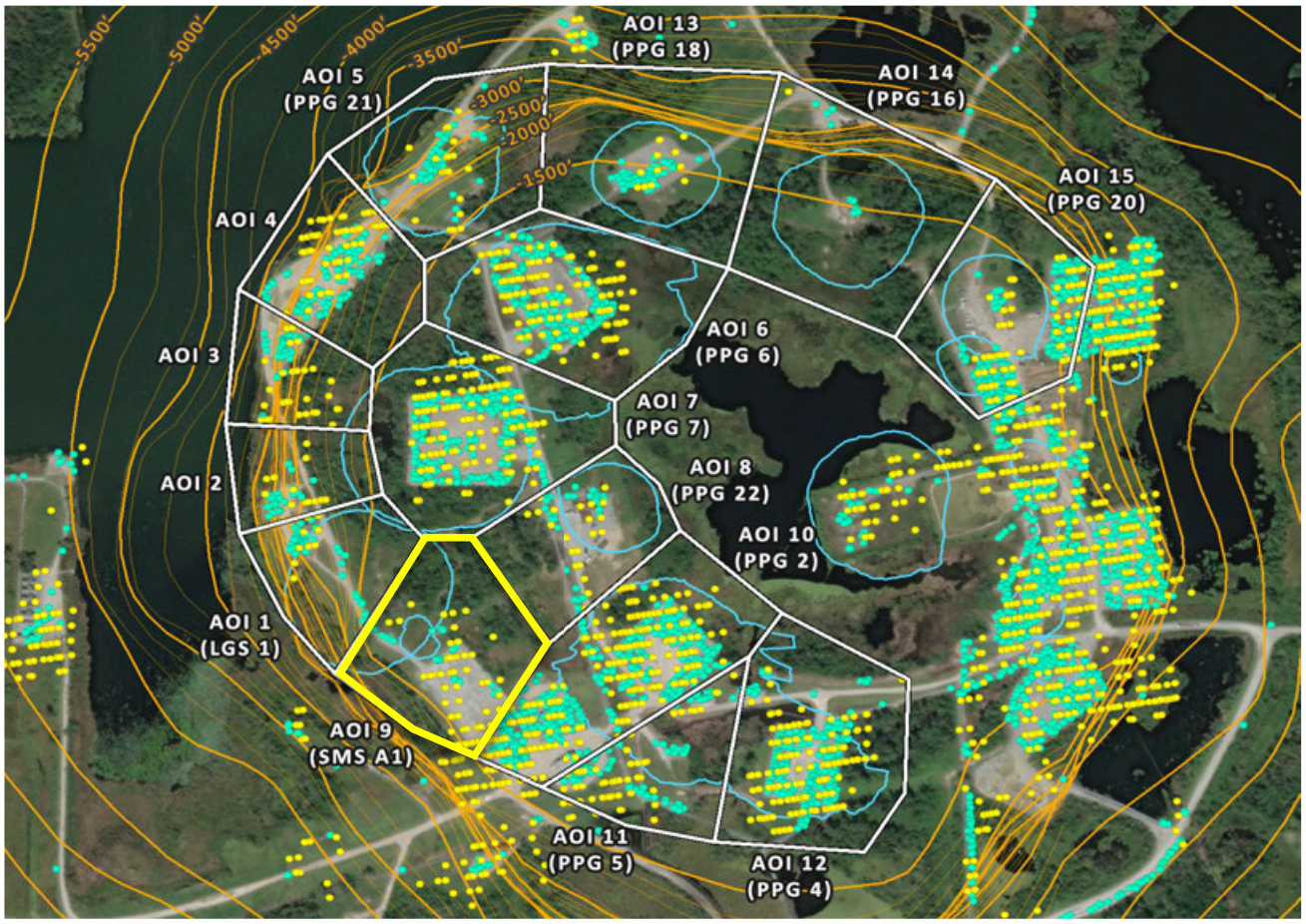

## AOI 8 *(PPG 22)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 36



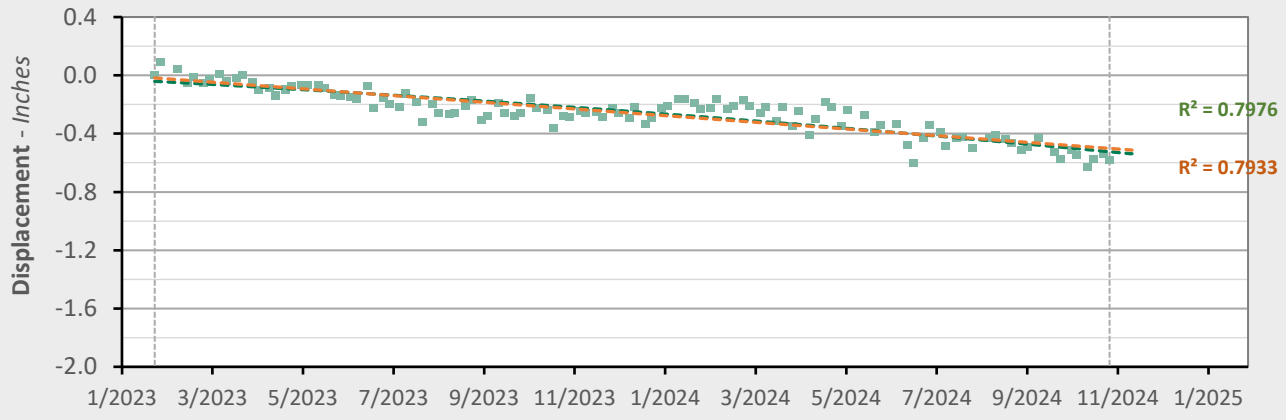

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.83 in/yr | -0.62 in/yr |
| Acceleration: | -0.24 in/yr$^2$ | 0.00 in/yr$^2$ |

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 9 *(PPG A1)* - Location Map



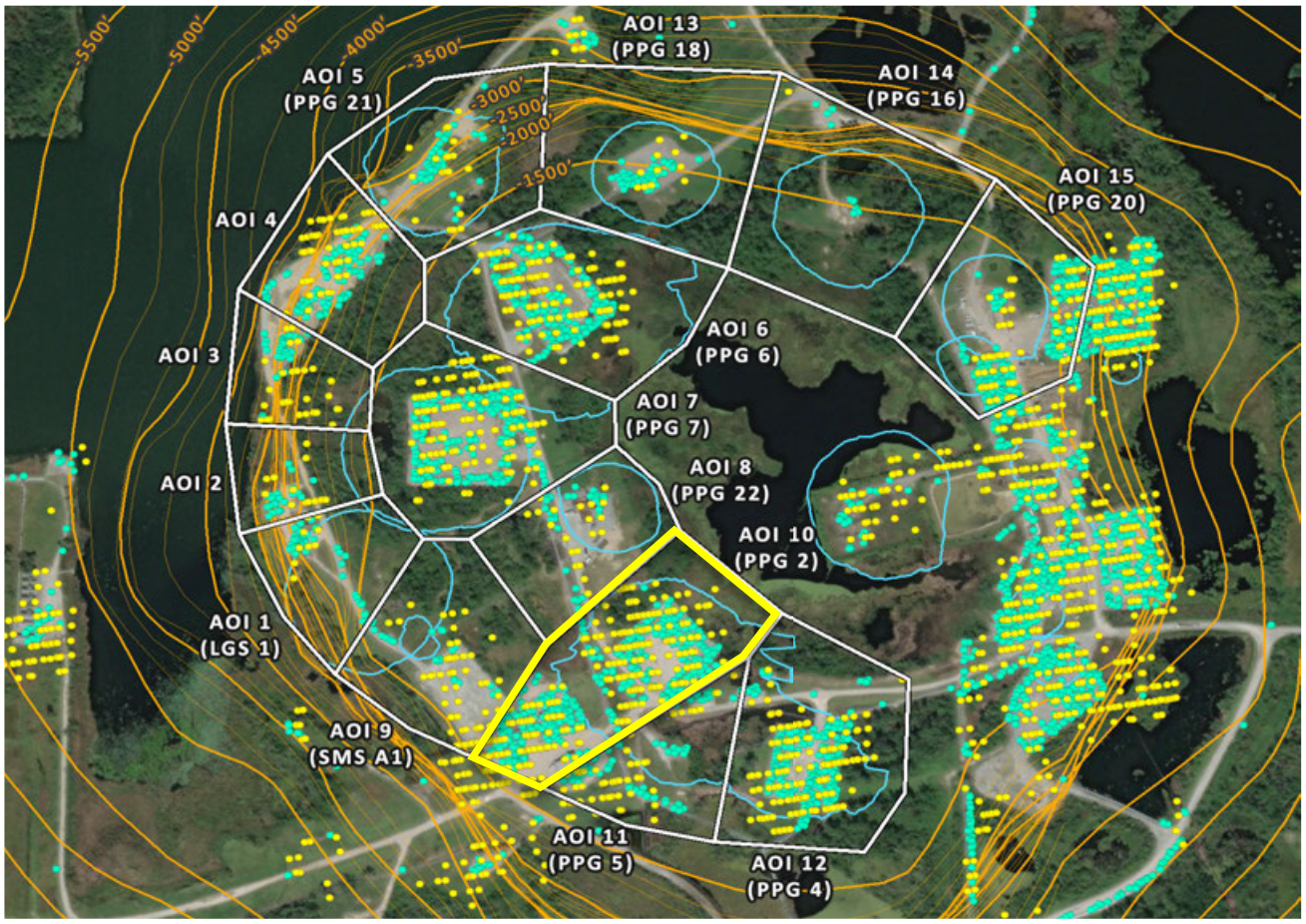

## AOI 9 *(SMS A1)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 23



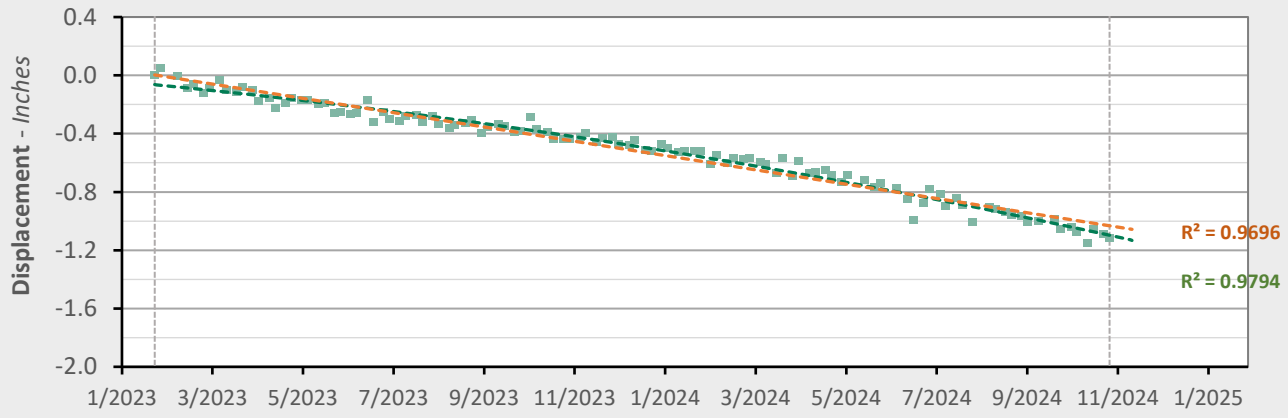

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.35 in/yr | -0.28 in/yr |
| Acceleration: | -0.09 in/yr$^2$ | 0.00 in/yr$^2$ |

LOS Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 10 *(PPG 2)* - Location Map



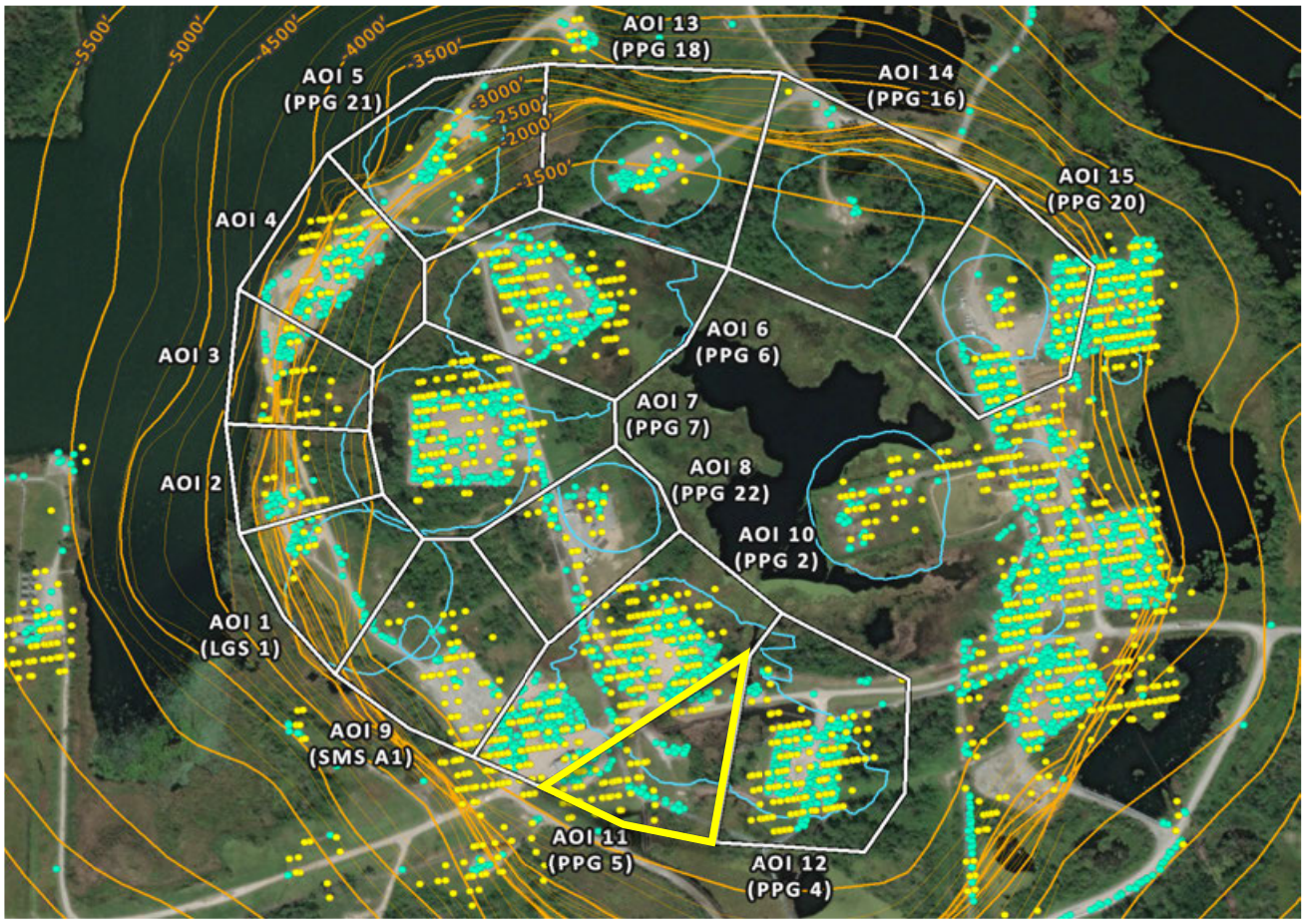

## AOI 10 *(PPG 2)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 403



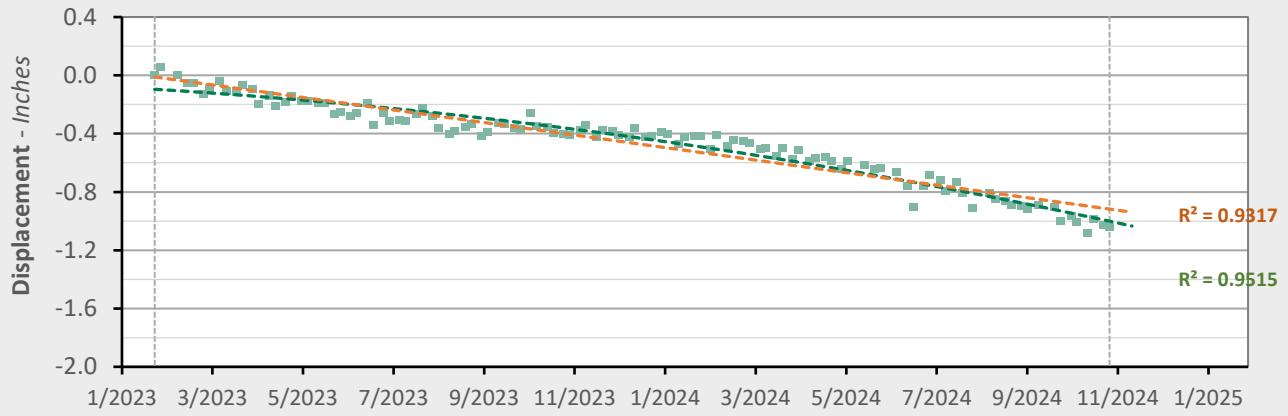

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.81 in/yr | -0.59 in/yr |
| Acceleration: | -0.26 in/yr$^2$ | 0.00 in/yr$^2$ |

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 11 *(PPG 5)* - Location Map



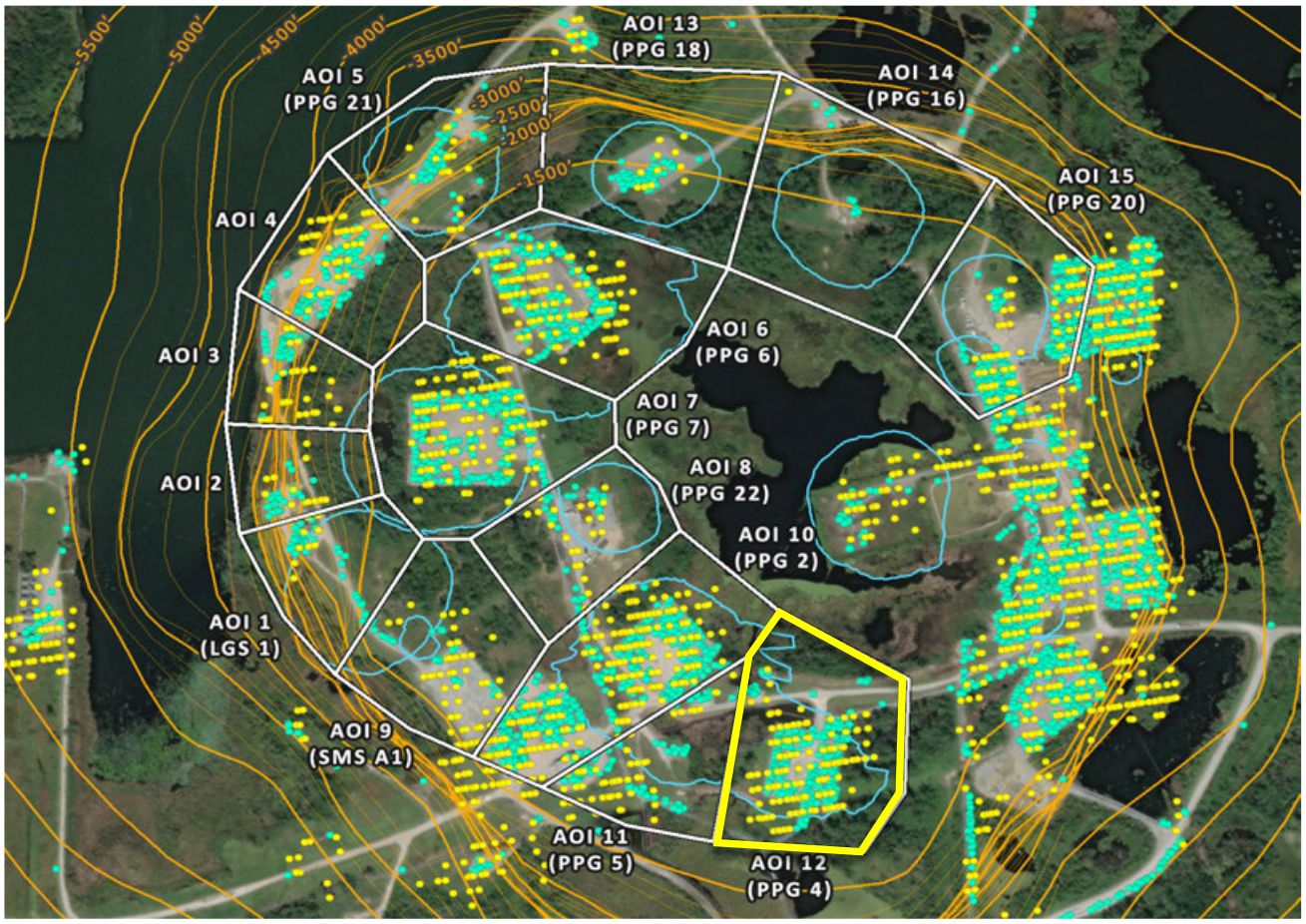

## AOI 11 *(PPG 5)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 85



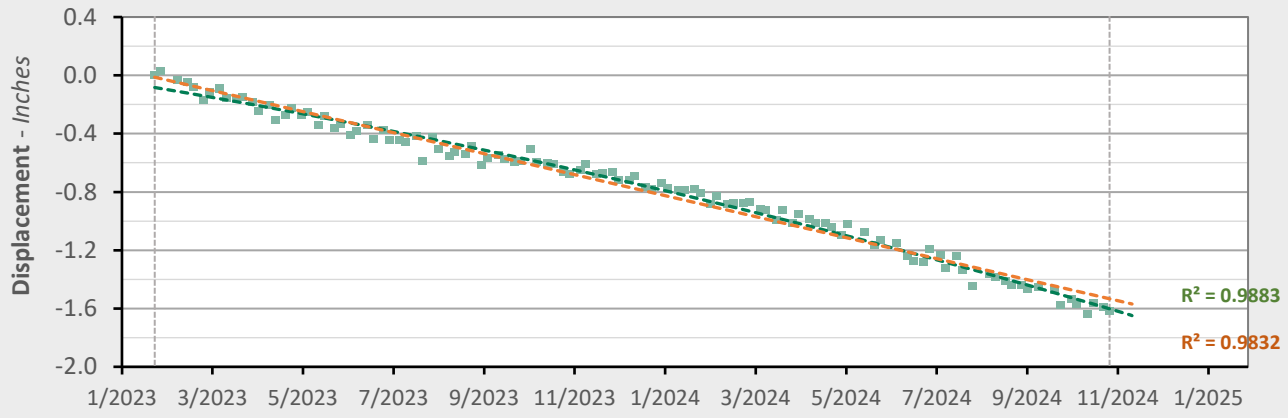

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.80 in/yr | -0.52 in/yr |
| Acceleration: | -0.33 in/yr$^2$ | 0.00 in/yr$^2$ |

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 12 *(PPG 4)* - Location Map



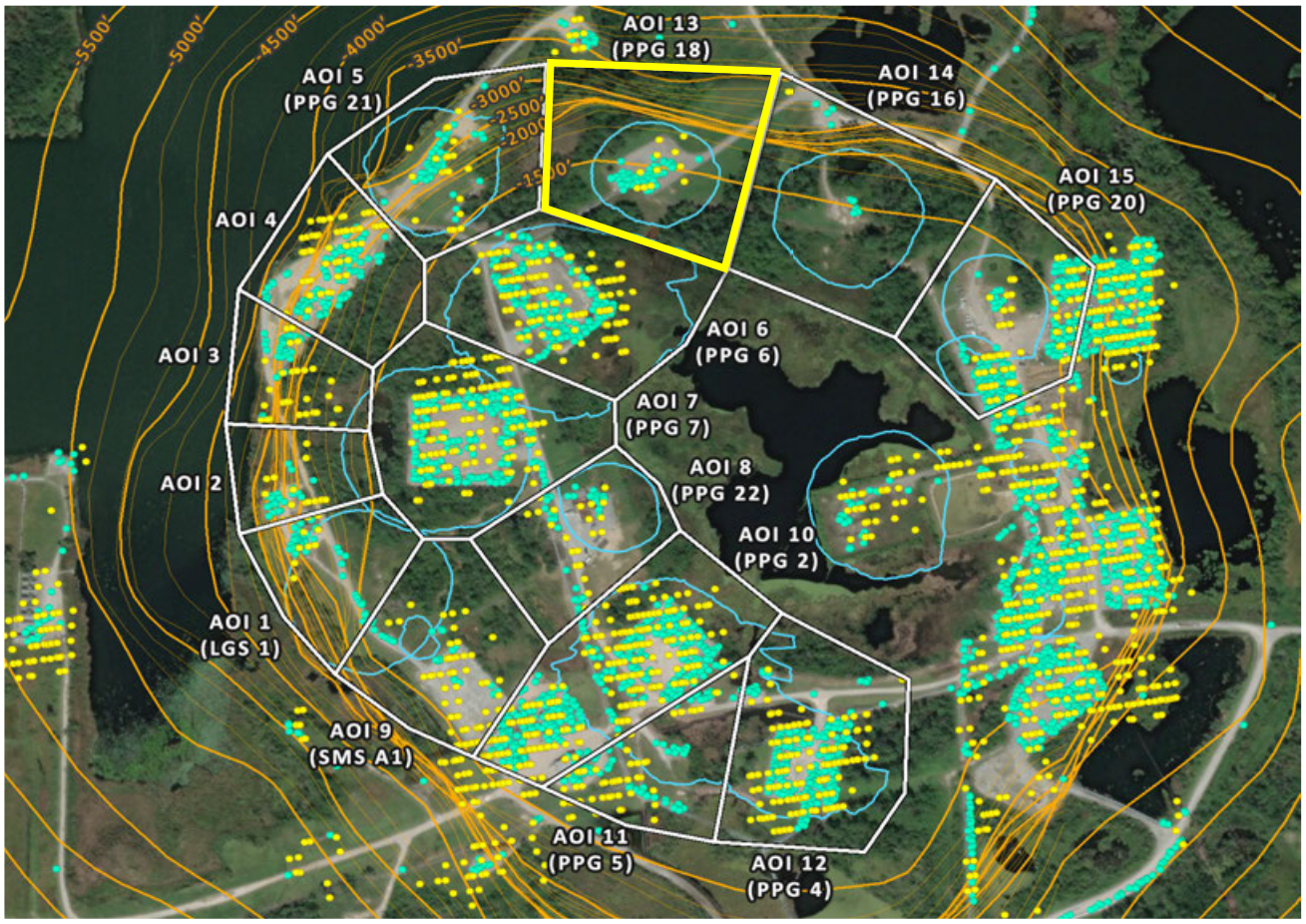

## AOI 12 *(PPG 4)* - Displacement Time Series TSX/PAZ (10/27/2024) Point Count: 262




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -1.10 | in/yr | -0.86 | in/yr |
| Acceleration: | -0.27 | in/yr$^2$ | 0.00 | in/yr$^2$ |

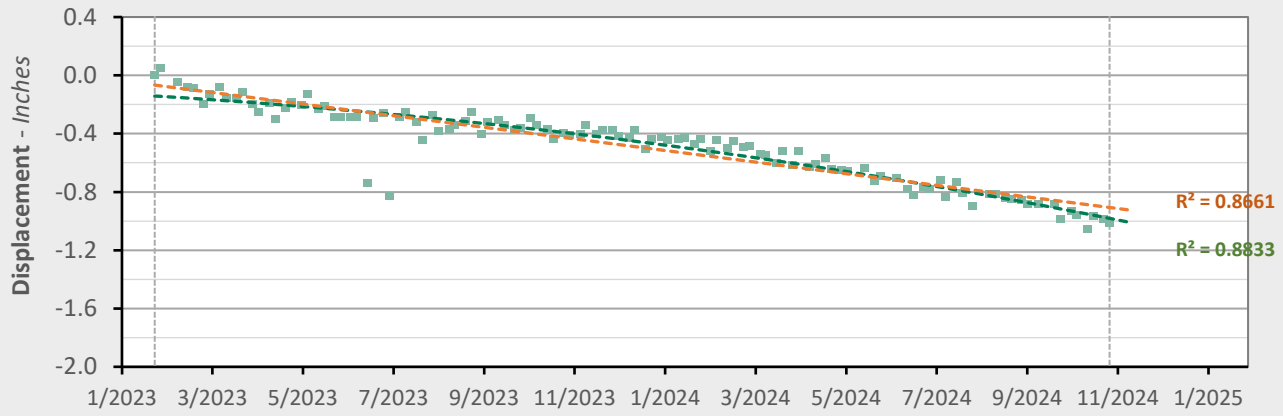
LOS Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 13 *(PPG 18)* - Location Map




## AOI 13 *(PPG 18)* - Displacement Time Series

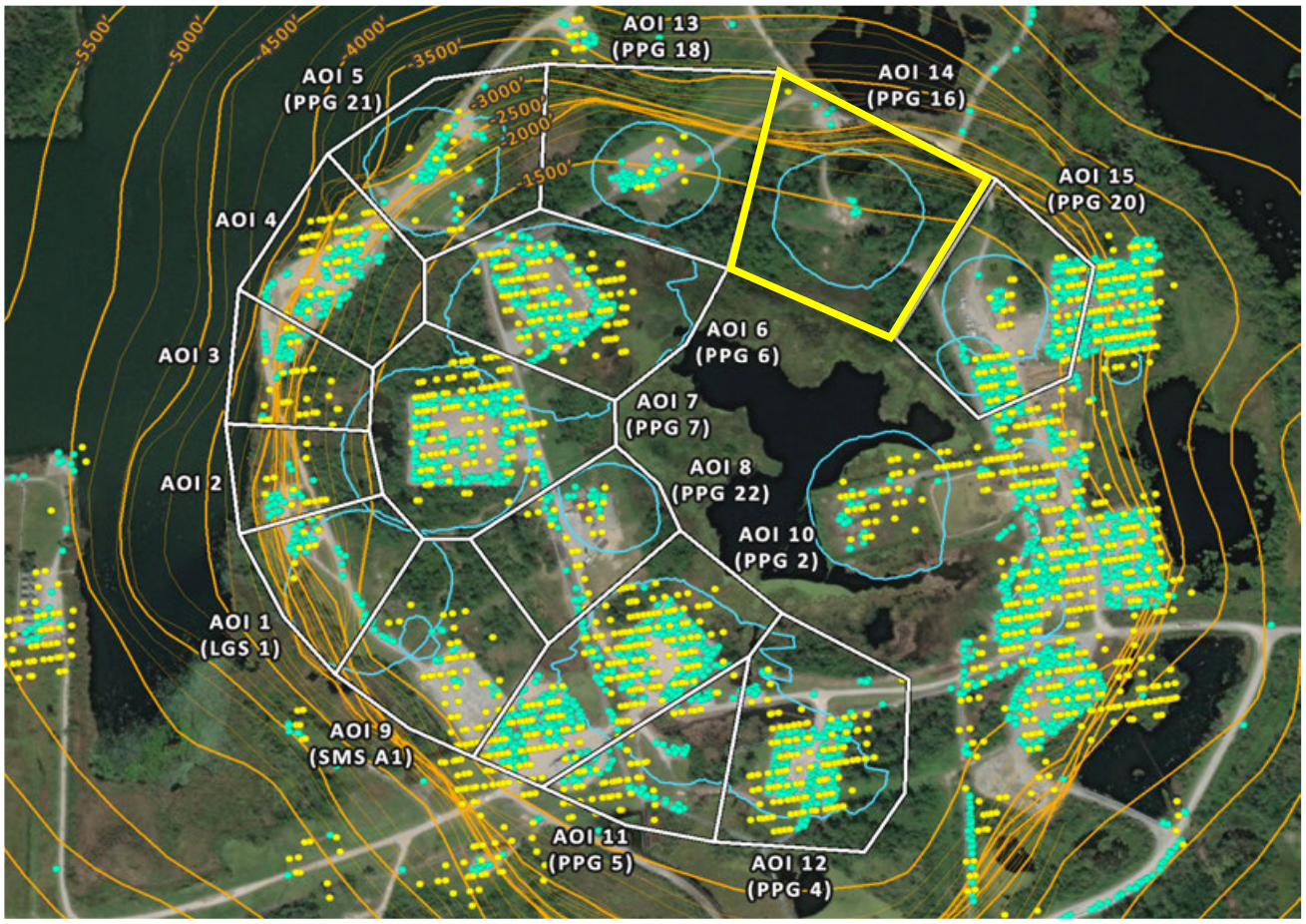
TSX/PAZ (10/27/2024) Point Count: **52**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.73 in/yr | -0.48 in/yr |
| Acceleration: | -0.29 in/yr$^2$ | 0.00 in/yr$^2$ |

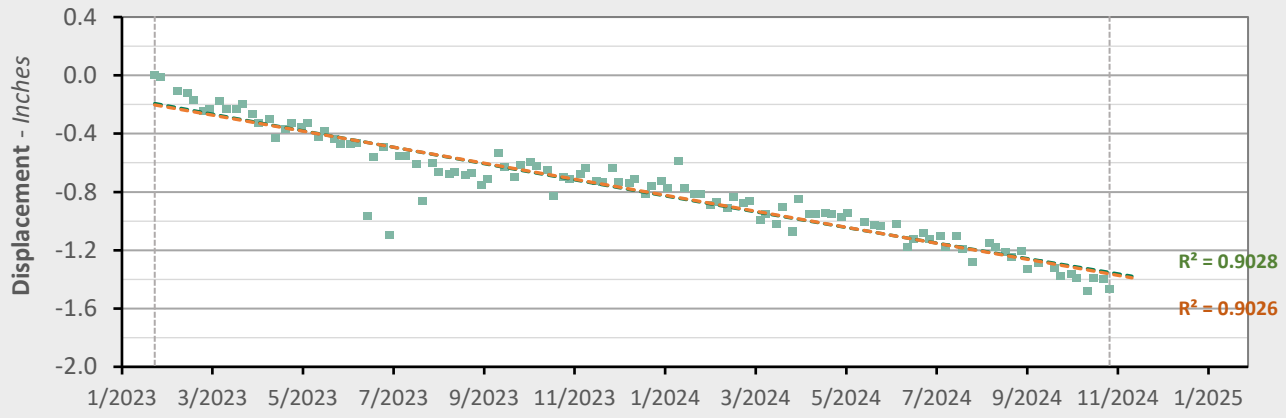
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 14 *(PPG 16)* - Location Map




## AOI 14 *(PPG 16)* - Displacement Time Series

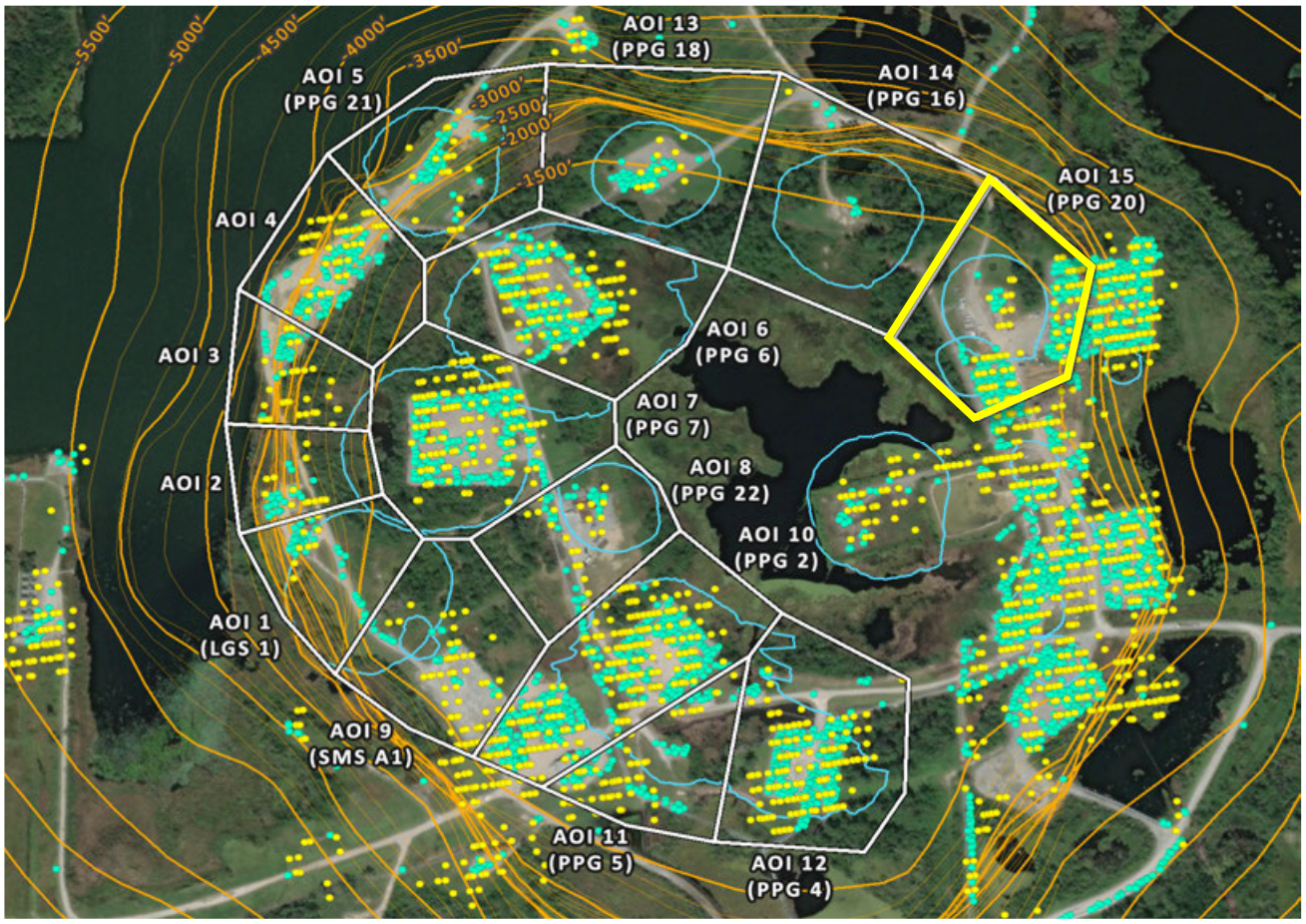
SX/PAZ (10/27/2024) Point Count: **11**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.63 in/yr | -0.66 in/yr |
| Acceleration: | +0.04 in/yr$^2$ | 0.00 in/yr$^2$ |

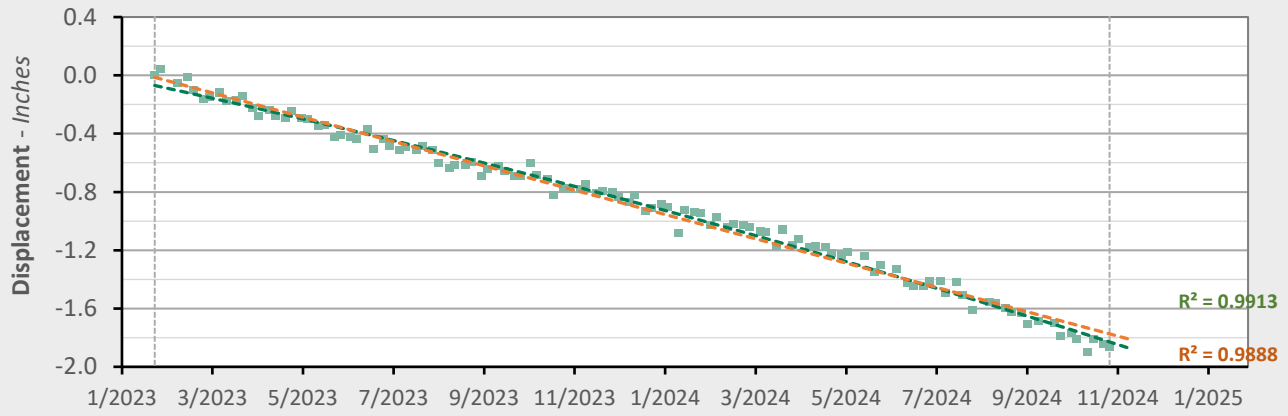
LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 15 *(PPG 20)* - Location Map




## AOI 15 *(PPG 20)* - Displacement Time Series

TSX/PAZ (10/27/2024) Point Count: **224**



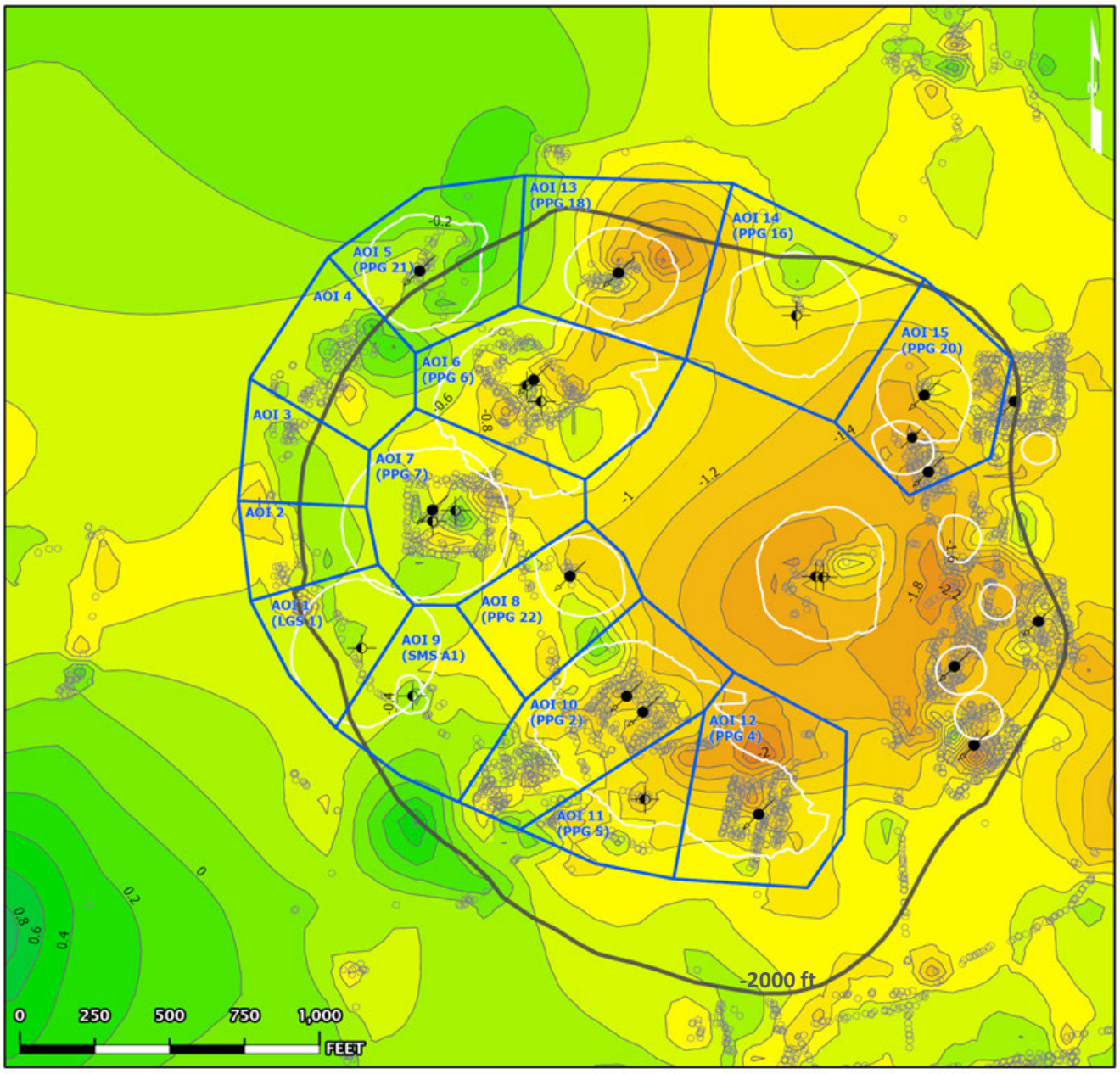

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -1.19 in/yr | -1.00 in/yr |
| Acceleration: | -0.22 in/yr$^2$ | 0.00 in/yr$^2$ |

LOS Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Contours

As of date: 10/27/2024




-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

AOI Boundary  InSAR LOS Measurement Point  Contour (0.2)

Historical Cavern Extent  Top of Dome (-2000 ft Contour)

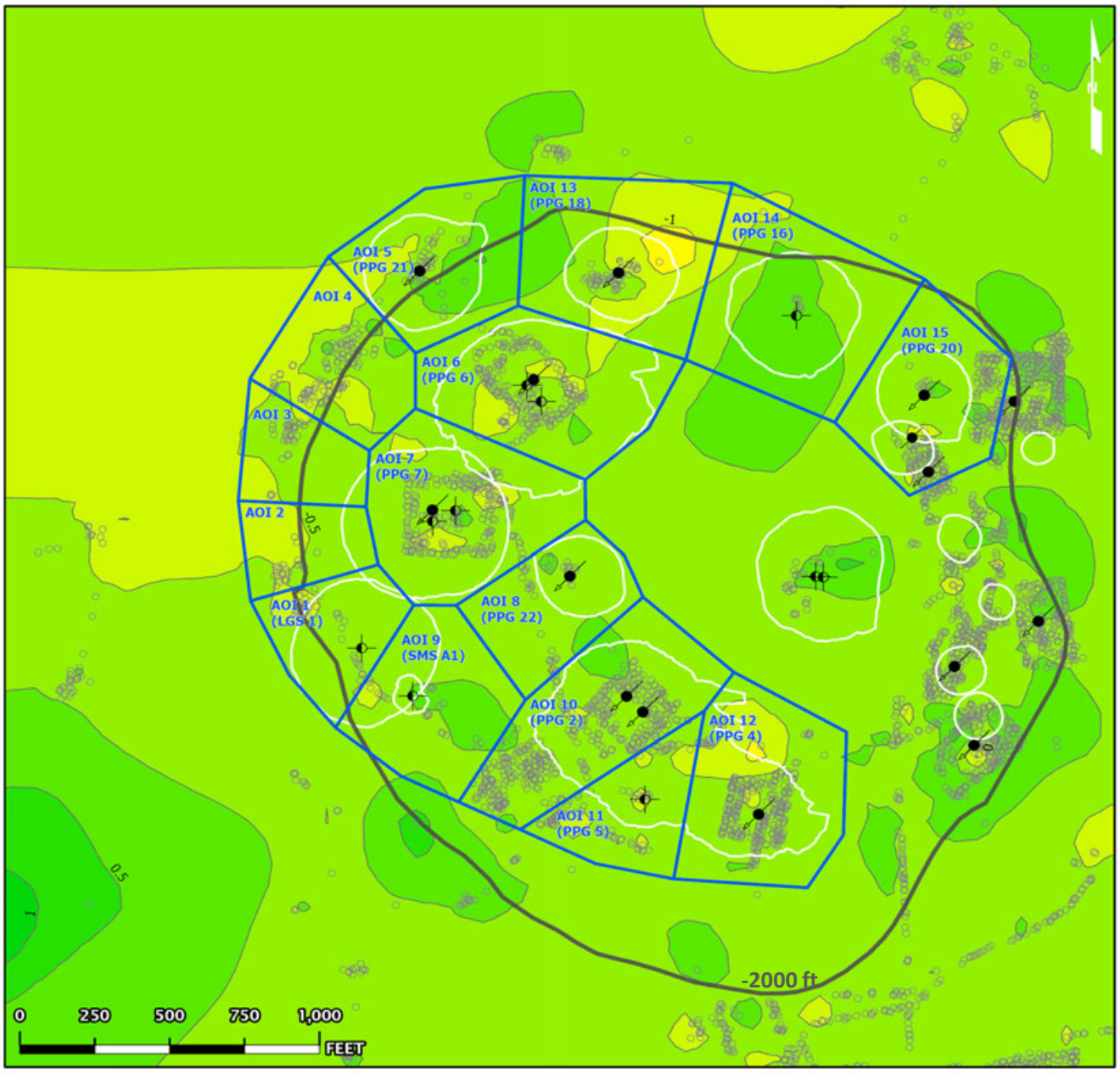
Cavern Well Surface Locations

09 - Active - Injection  29 - Dry and Plugged

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Contours

Date range: 01/24/2023 - 10/27/2024




-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year$^2$

AOI Boundary | InSAR LOS Measurement Point | Contour (0.5)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

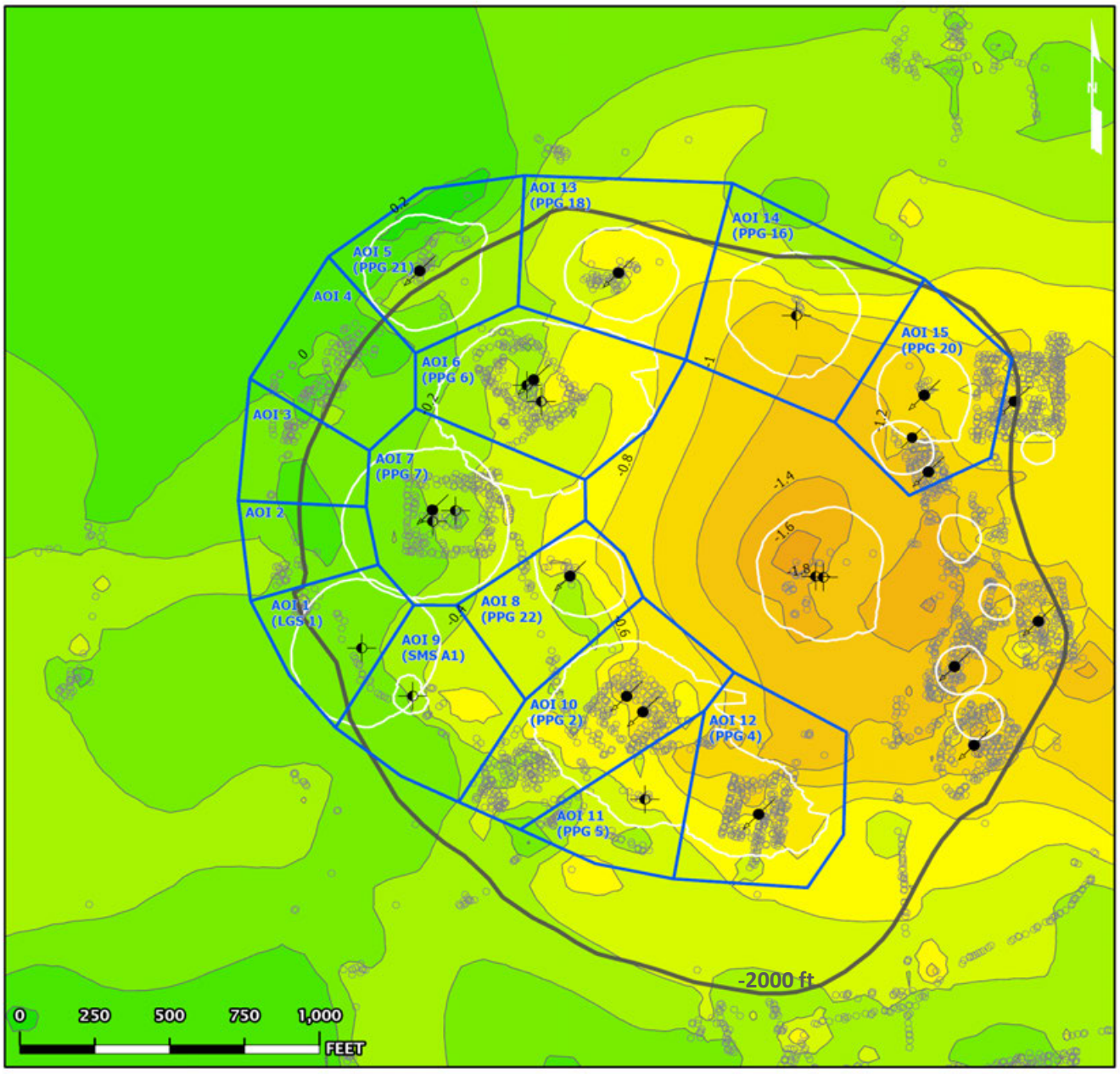
Cavern Well Surface Locations

09 - Active - Injection | 29 - Dry and Plugged

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Linear Velocity Contours

Date range: 01/24/2023 - 10/27/2024




-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

AOI Boundary | InSAR LOS Measurement Point | Contour (0.2)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

Cavern Well Surface Locations

09 - Active - Injection | 29 - Dry and Plugged

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Data Points

As of date: 10/27/2024


-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Data Points

Date range: 01/24/2023 - 10/27/2024


-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year$^2$

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

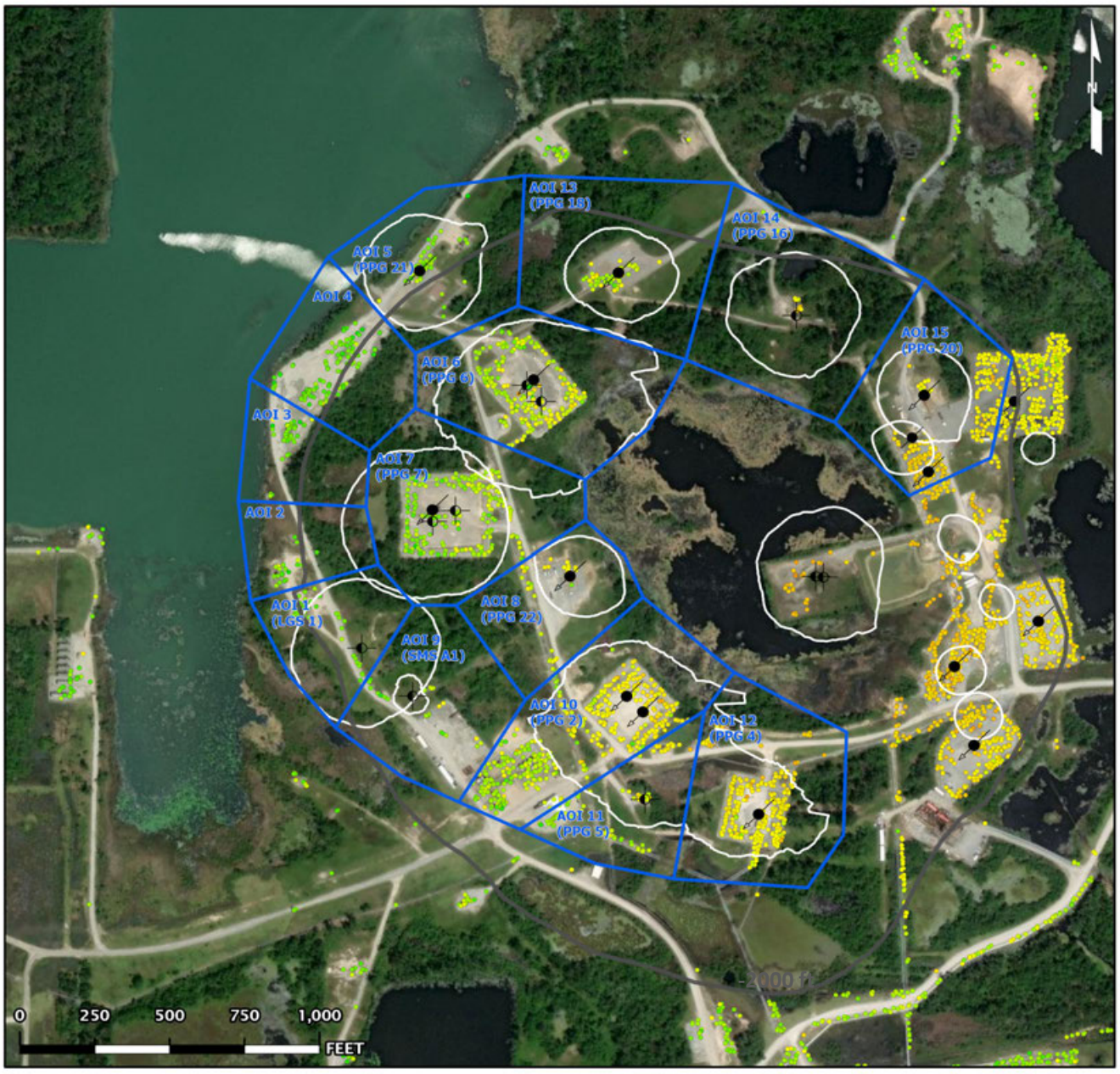
Cavern Well Surface Locations

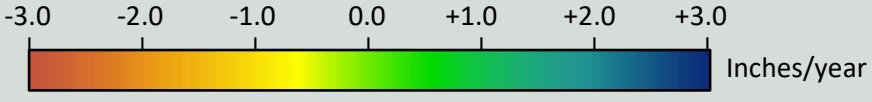
09 - Active - Injection
29 - Dry and Plugged

## TSX/PAZ Data (01/24/2023 - 10/27/2024)

### Linear Velocity Data Points

Date range: 01/24/2023 - 10/27/2024




AOI Boundary — InSAR LOS Measurement Point

Historical Cavern Extent — Top of Dome (-2000 ft Contour)

Cavern Well Surface Locations

09 - Active - Injection — 29 - Dry and Plugged

# ATTACHMENT D

## Vertical & East-West 2D InSAR report - October 27, 2024

# Vertical & E-W 2D 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 & TerraSAR-X - PAZ Constellation** |
| Most Recent Image Date |
| **Sunday, October 27, 2024** |

Analysis Report Date:

**November 14, 2024**

## Dataset Information

| | |
|---|---|
| Satellite Source | Sentinel-1 & TerraSAR-X - PAZ Constellation |
| Update Frequency | 12 days |
| Most Recent Image Date | Sunday, October 27, 2024 |
| Dataset Image Count | 145 |
| Dataset Time Range | January 24, 2023 - October 27, 2024 |
| Dataset Length | 1.76 Years |
| Measurement Directions | Vertical and East-West |

## Analysis Methodology

**Time Series Charts**

Trend lines were calculated for the averaged vertical and east-west displacement values within each AOI. Both a nonlinear (quadratic) and linear regression were applied to each AOI point group to identify rates of change in LOS displacement. These trends are displayed in the Time Series section of this report.

**Contour Maps**

A nonlinear (quadratic) and linear trend was also calculated for each individual measurement point across the analysis region. Nonlinear trend values for each point were used to generate Velocity and Acceleration contour maps to convey the spatial distribution of the calculated movement. The linear trend values for each point (which lack an acceleration component) were used to generate an additional Velocity contour map. Maps depicting the individual data points colored by these trend values are included after the contour maps.

**Rate Interpretation**

For the vertical data, positive velocity values indicate uplift and negative velocity values indicate subsidence. Positive acceleration values indicate increasing rates of uplift or slowing rates of subsidence, while negative acceleration values indicate slowing rates of uplift or increasing rates of subsidence. For the east-west data, positive velocity values indicate eastward horizontal movement and negative velocity values indicate horizontal westward movement. Positive acceleration values indicate increasing rates of eastward movement or decreasing rates of westward movement, while negative acceleration values indicate increasing rates of westward movement or decreasing rates of eastward movement.

## Observations

To-date there have been no acute deviations from established subsidence trends in the areas investigated.

The calculated vertical displacement values indicate that subsidence is occuring with near-linear trends in all AOIs where data is present. Minor positive acceleration (slowing subsidence) is present in all of the calculated nonlinear AOI trends.

The calculated east-west dispacement values generally indicate horizontal movement toward the dome center with the greatest rates of eastward movement occuring in the western AOIs and the greatest rate of westward movement occuring in the easternmost AOI. All AOIs indicate varying amounts of negative acceleration (slower eastward or faster westward displacement) with the most pronounced values occuring in AOI 1 and AOI 2. This likely correlates to the minor increases in negative acceleration recently noted in the TSX/PAZ LOS dataset reports.


Date Signed: November 14, 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.

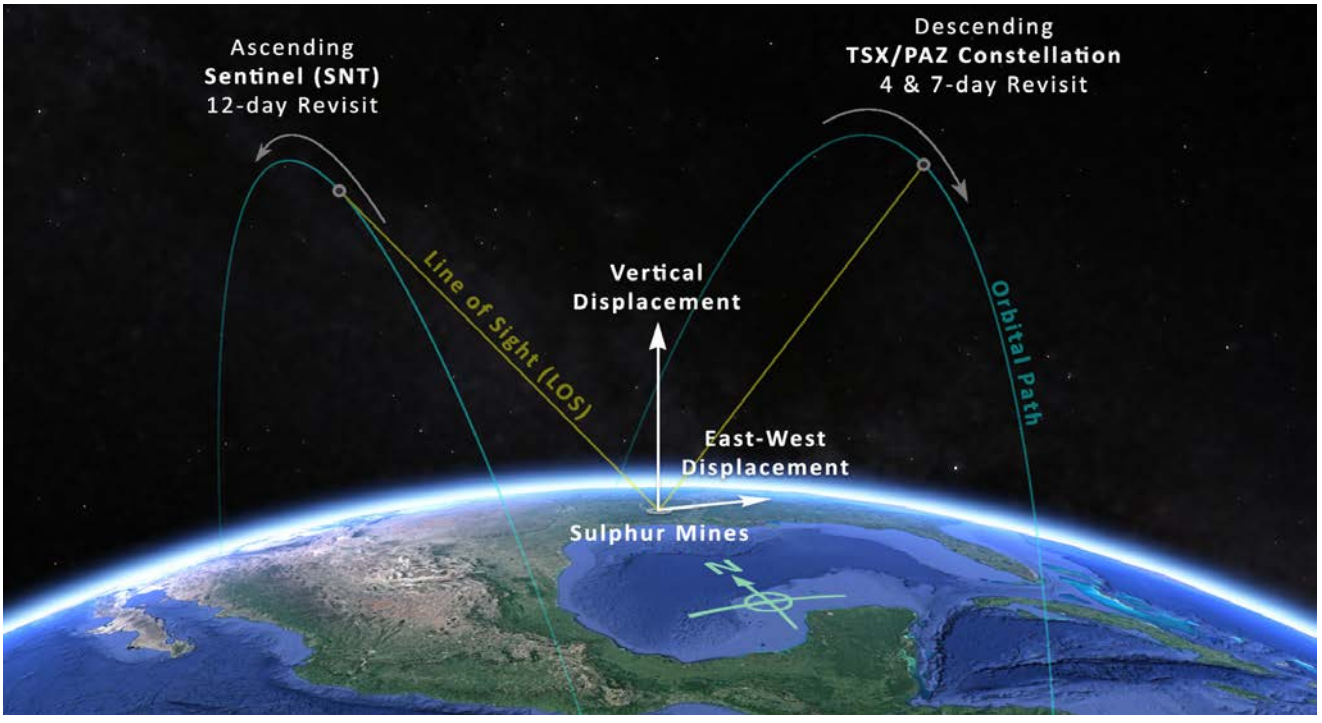
**Satellite Sources**

Two InSAR datasets are being used to evaluate subsidence over the Sulphur Mines Salt Dome. These datasets provide Line-of-Sight (LOS) 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 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.

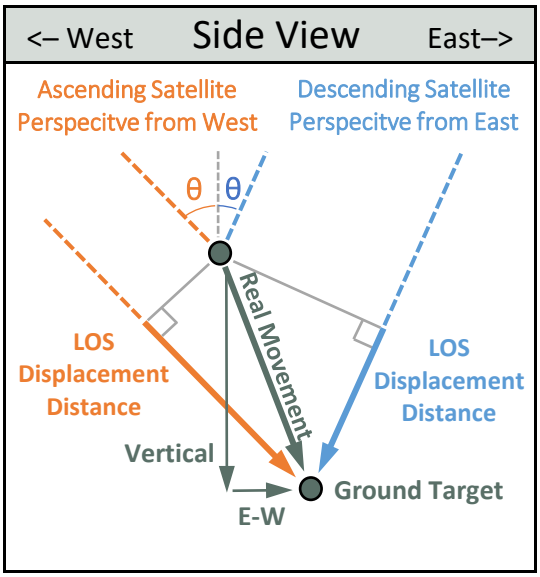
Each instance of data capture in either the SNT or TSX/PAZ constellation is used to generate 2D (two-dimensional) displacement values in the vertical and east-west directions for each measurement point within the 2D data grid. The image below depicts the orbital paths of the satellites in relation to the Sulphur Mines Salt Dome as well as the 2D components of the calculated displacement.

## Satellite Orbital Diagram



## InSAR 2D Vertical and East-West Data

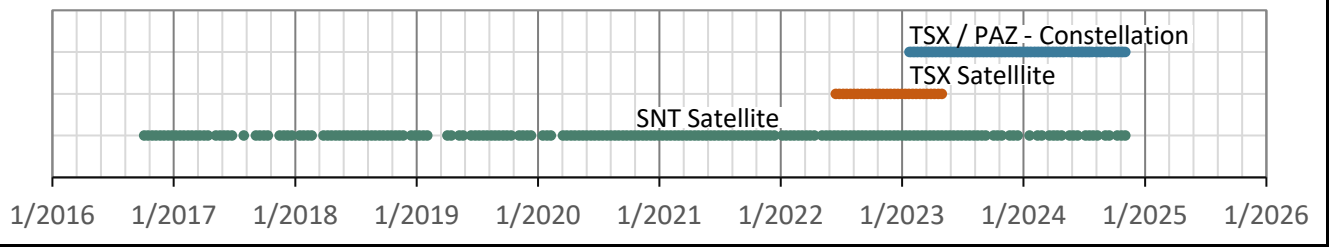
LOS (line-of-sight) displacement measurements, which refer to a change in distance between the satellite sensor and the ground target, are used to triangulate the real movement along the 2D plane defined by the satellite positions and the ground target. The diagram to the right illustrates the geometric relationship between the Real Movement of a ground target, the LOS displacement measurements from two different satellite viewing directions, and the resulting vertical and east-west components of calculated 2D displacement. Ground targets are not consistent between LOS datasets so these calculations are performed on averaged LOS data within 82-ft square cells. One 2D measurement point is generated within each cell where data from both LOS sources are present.



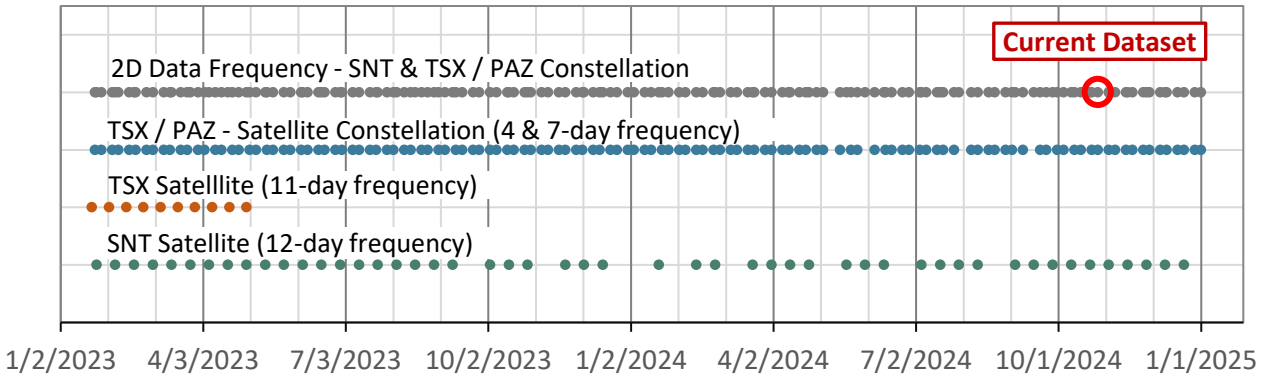

## Satellite Properties & Image Frequency

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

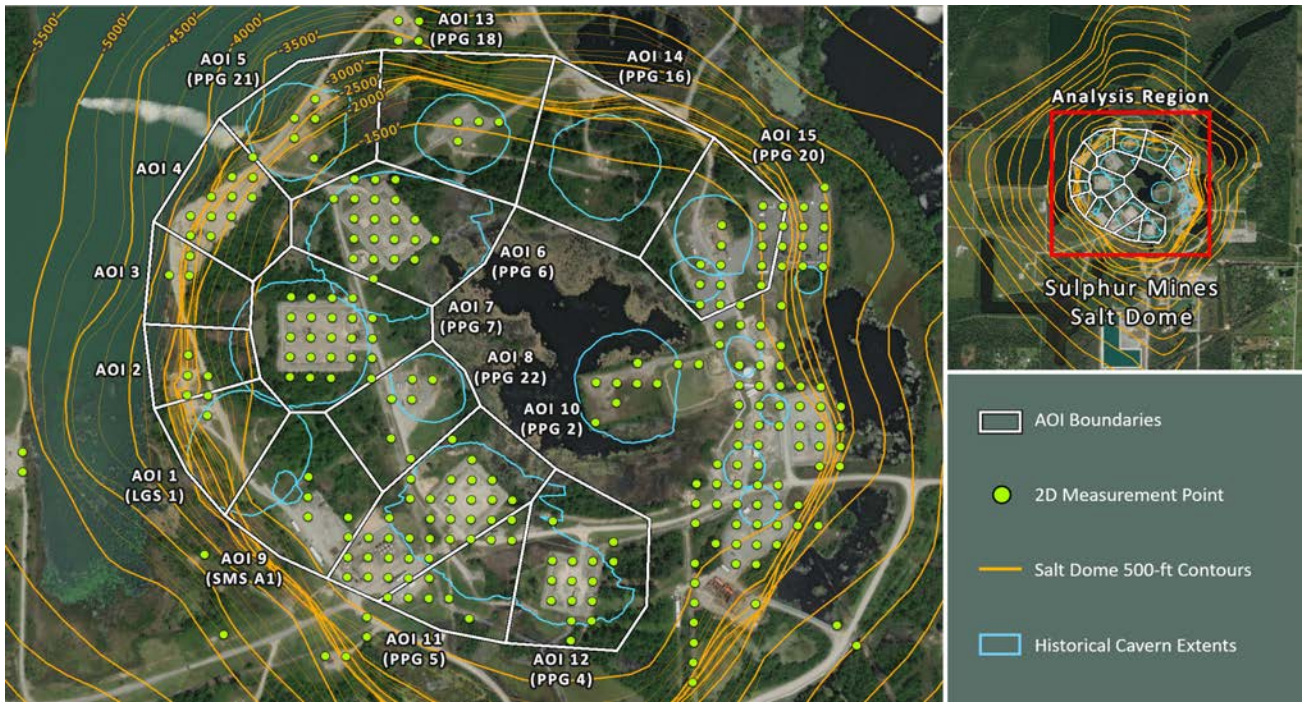
### LOS Measurement History




### 2D Measurement Frequency



## AOI Boundaries & 2D InSAR Measurement Points

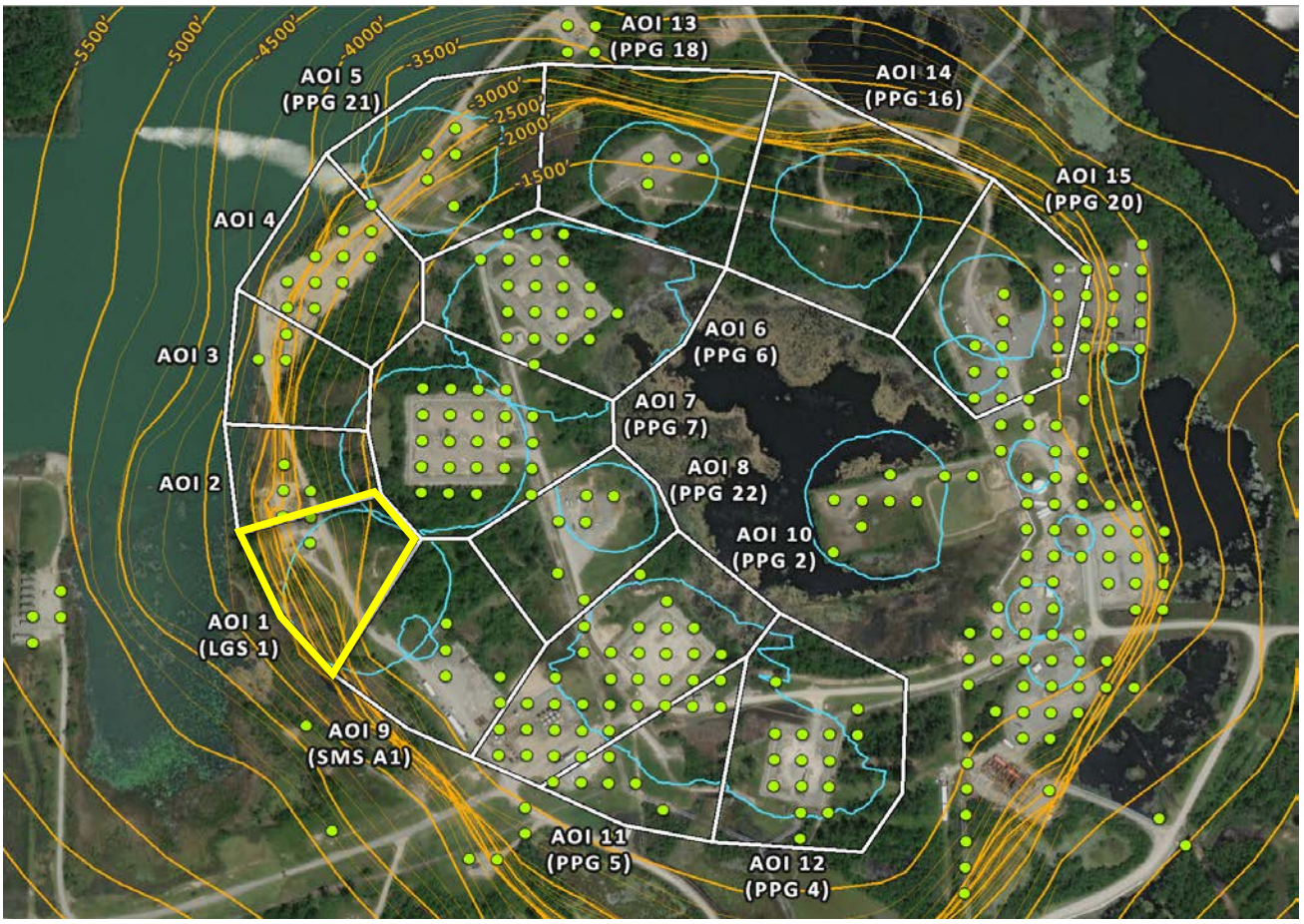



## Subsidence Monitoring Areas of Interest (AOIs)

To visually convey and evaluate trend consistency for the Vertical 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 Vertical trend values calculated in each AOI for the dataset evaluated in this report.

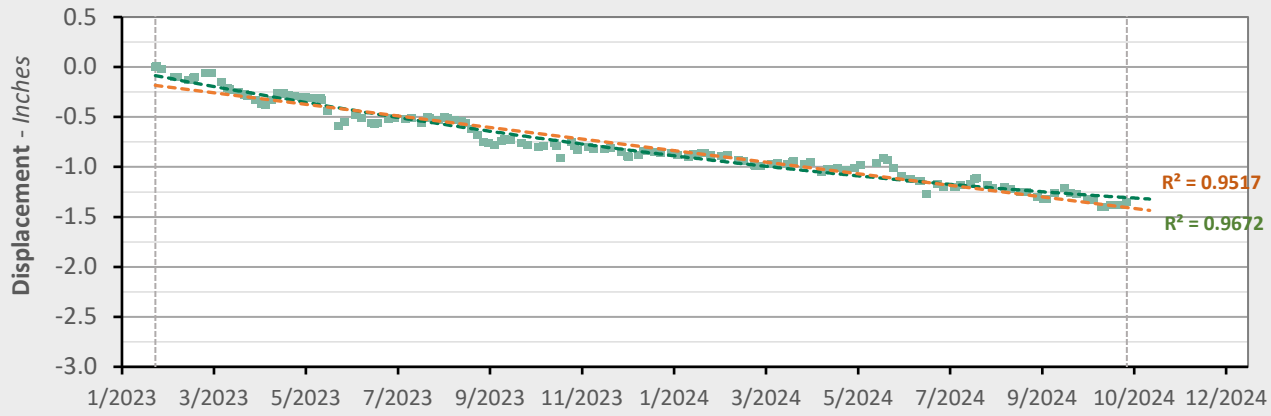
| AOI Name | Vertical (10/27/2024) | Vertical Velocity (in/yr) | | Vertical Acceleration (in/yr²) | |
|---|---|---|---|---|---|
| | Point Count | Nonlinear | Linear | Nonlinear | Linear |
| **AOI 1** *(LGS 1)* | 2 | -0.35 | -0.70 | +0.39 | 0.00 |
| **AOI 2** | 4 | -0.48 | -0.59 | +0.13 | 0.00 |
| **AOI 3** | 3 | -0.36 | -0.62 | +0.29 | 0.00 |
| **AOI 4** | 10 | -0.43 | -0.55 | +0.14 | 0.00 |
| **AOI 5** *(PPG 21)* | 5 | -0.33 | -0.52 | +0.22 | 0.00 |
| **AOI 6** *(PPG 6)* | 21 | -0.81 | -0.89 | +0.09 | 0.00 |
| **AOI 7** *(PPG 7)* | 23 | -0.94 | -0.98 | +0.05 | 0.00 |
| **AOI 8** *(PPG 22)* | 5 | -1.10 | -1.27 | +0.19 | 0.00 |
| **AOI 9** *(SMS A1)* | 6 | -0.41 | -0.88 | +0.52 | 0.00 |
| **AOI 10** *(PPG 2)* | 31 | -0.97 | -1.12 | +0.17 | 0.00 |
| **AOI 11** *(PPG 5)* | 10 | -0.86 | -0.97 | +0.12 | 0.00 |
| **AOI 12** *(PPG 4)* | 15 | -0.94 | -1.09 | +0.17 | 0.00 |
| **AOI 13** *(PPG 18)* | 3 | -0.79 | -0.80 | +0.01 | 0.00 |
| **AOI 14** *(PPG 16)* | 0 | N/A | N/A | N/A | N/A |
| **AOI 15** *(PPG 20)* | 14 | -0.79 | -0.93 | +0.17 | 0.00 |

## AOI 1 *(LGS 1)* - Location Map




## AOI 1 *(LGS 1)* - Vertical Time Series

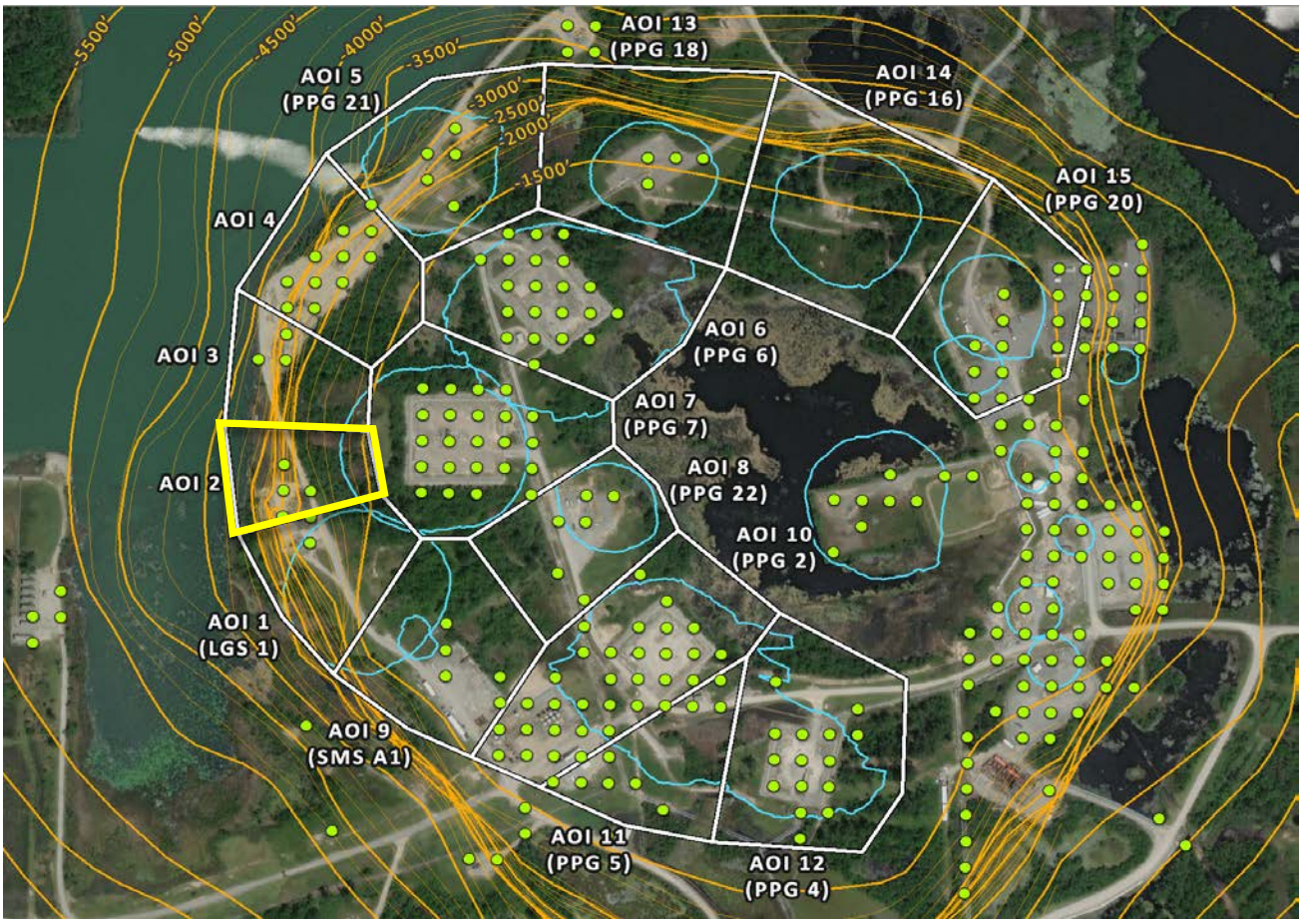
Vertical (10/27/2024) Point Count: **2**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.35 | in/yr | -0.70 | in/yr |
| Acceleration: | +0.39 | in/yr$^2$ | 0.00 | in/yr$^2$ |

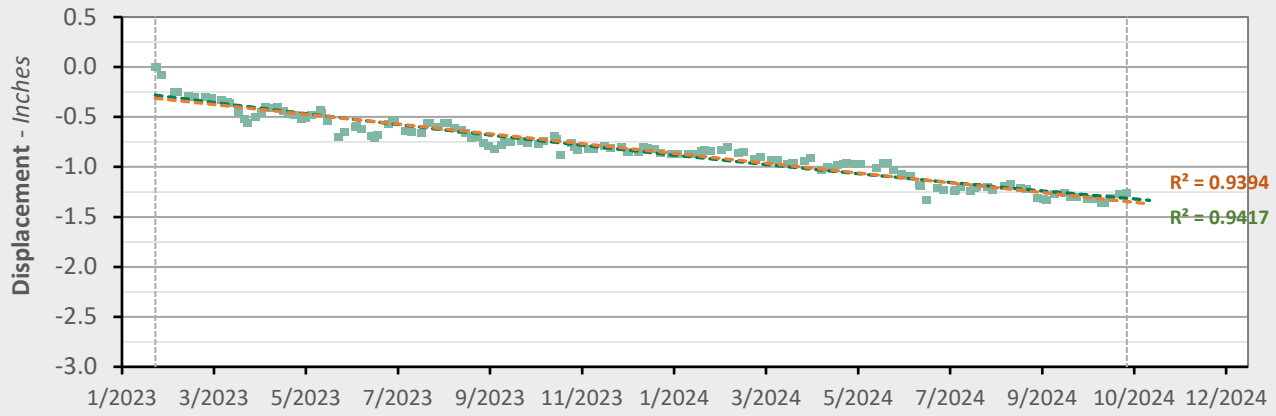
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 2 - Location Map




## AOI 2 - Vertical Time Series

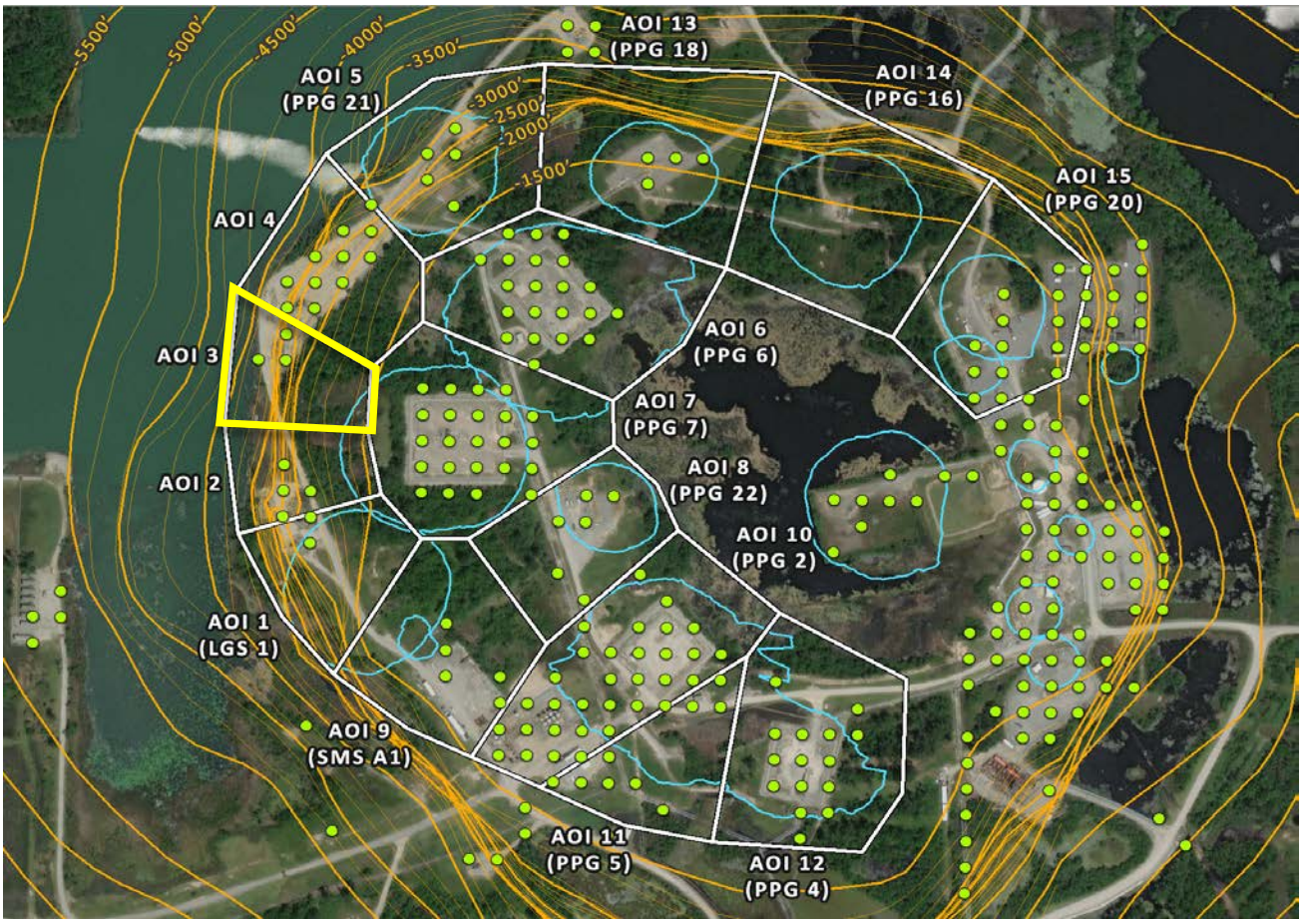
Vertical (10/27/2024) Point Count: 4




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.48 | in/yr | -0.59 | in/yr |
| Acceleration: | +0.13 | in/yr$^2$ | 0.00 | in/yr$^2$ |

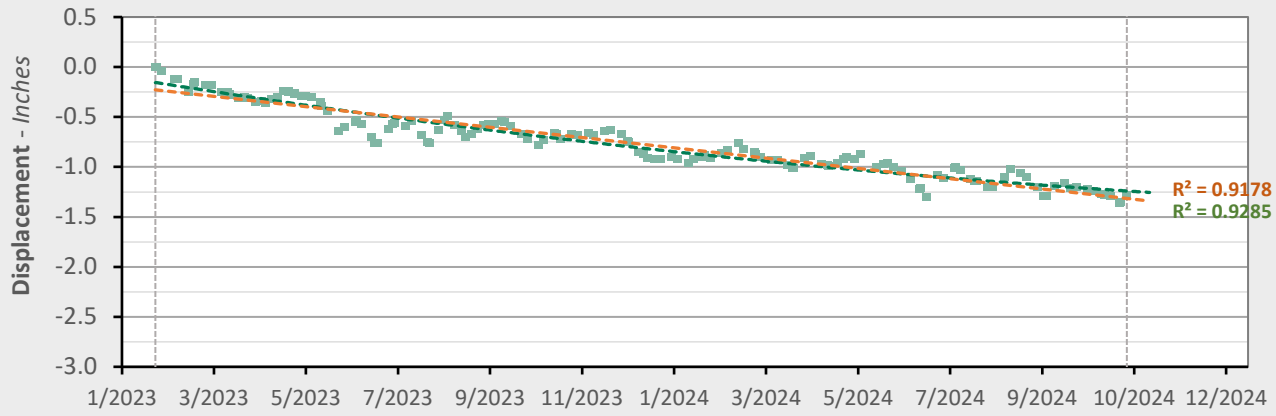
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 3 - Location Map




## AOI 3 - Vertical Time Series

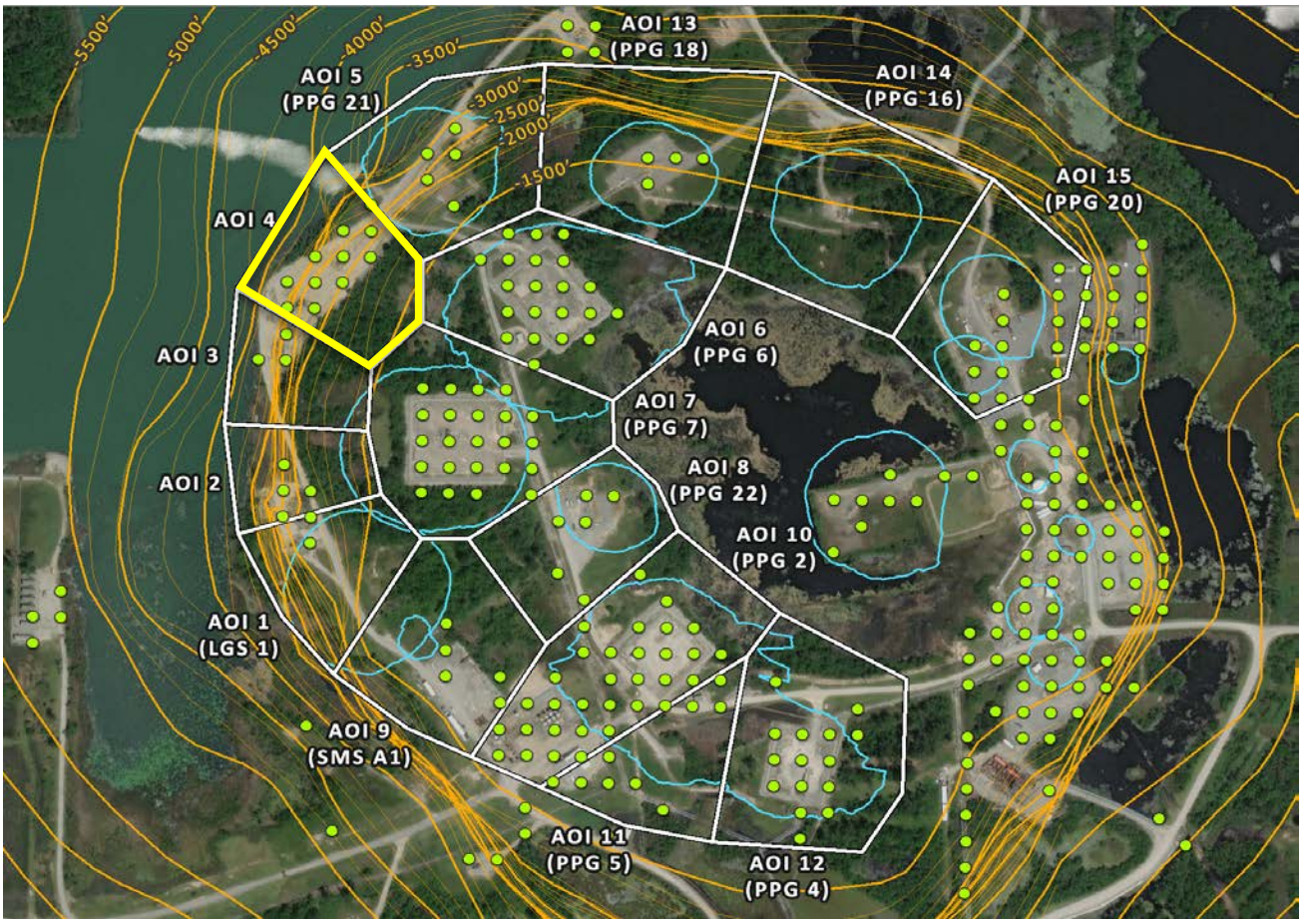
Vertical (10/27/2024) Point Count: 3




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.36 in/yr | -0.62 in/yr |
| Acceleration: | +0.29 in/yr$^2$ | 0.00 in/yr$^2$ |

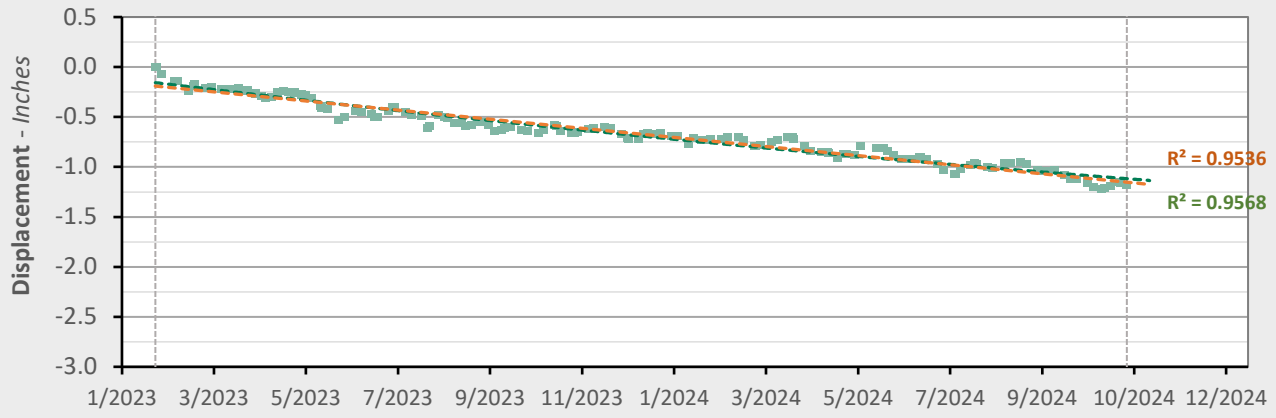
2D Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 4 - Location Map




## AOI 4 - Vertical Time Series

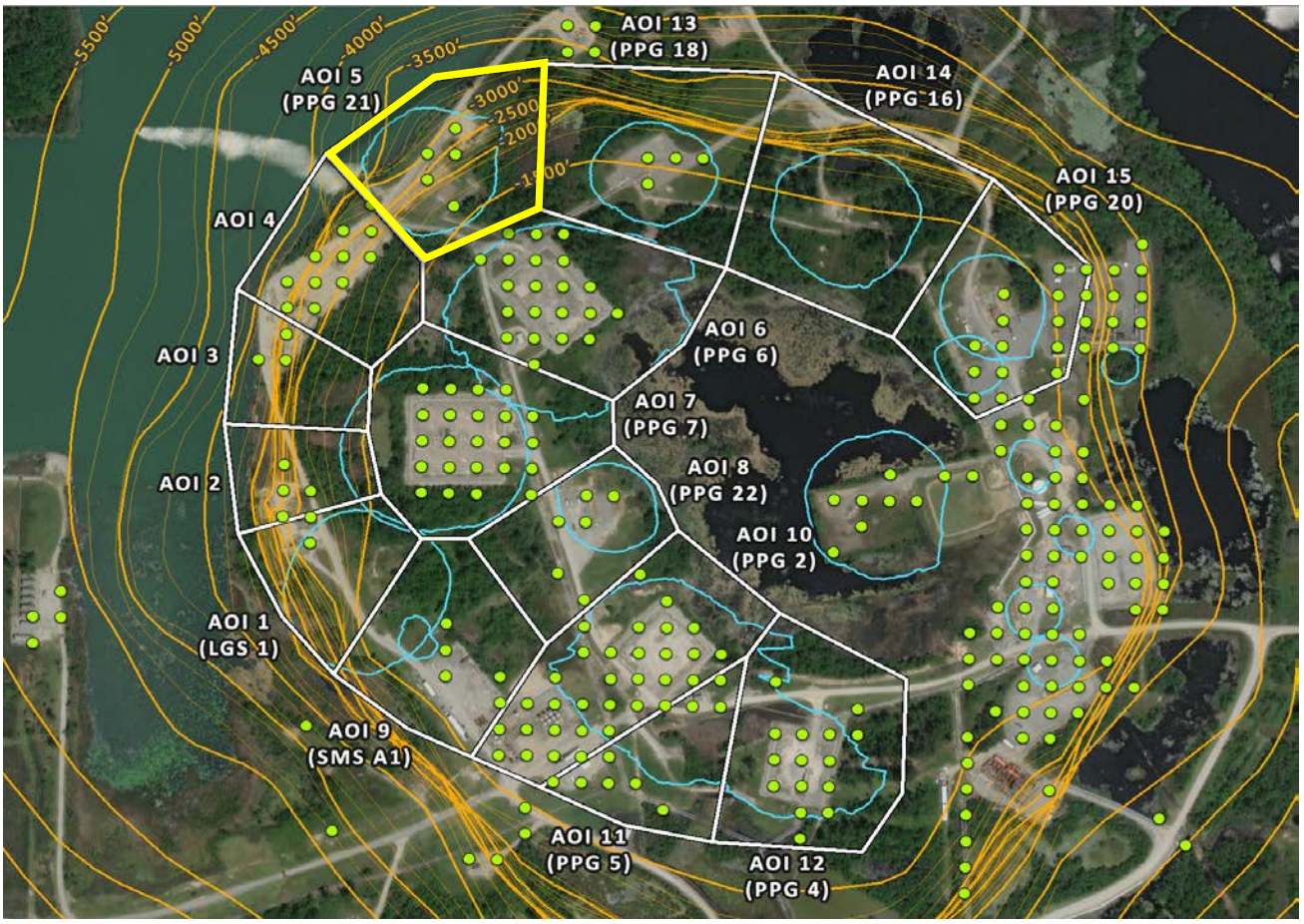
Vertical (10/27/2024) Point Count: **10**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.43 | in/yr | -0.55 | in/yr |
| Acceleration: | +0.14 | in/yr$^2$ | 0.00 | in/yr$^2$ |

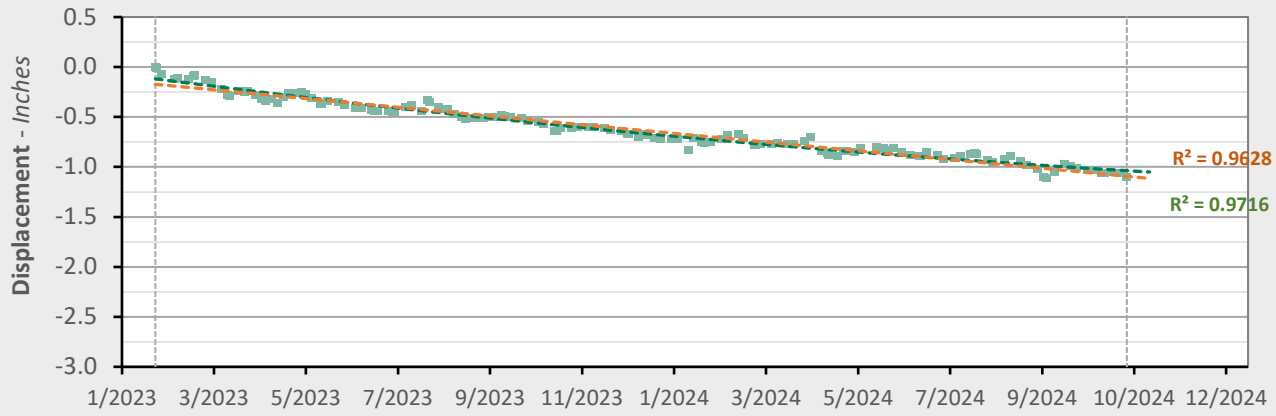
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 5 *(PPG 21)* - Location Map




## AOI 5 *(PPG 21)* - Vertical Time Series

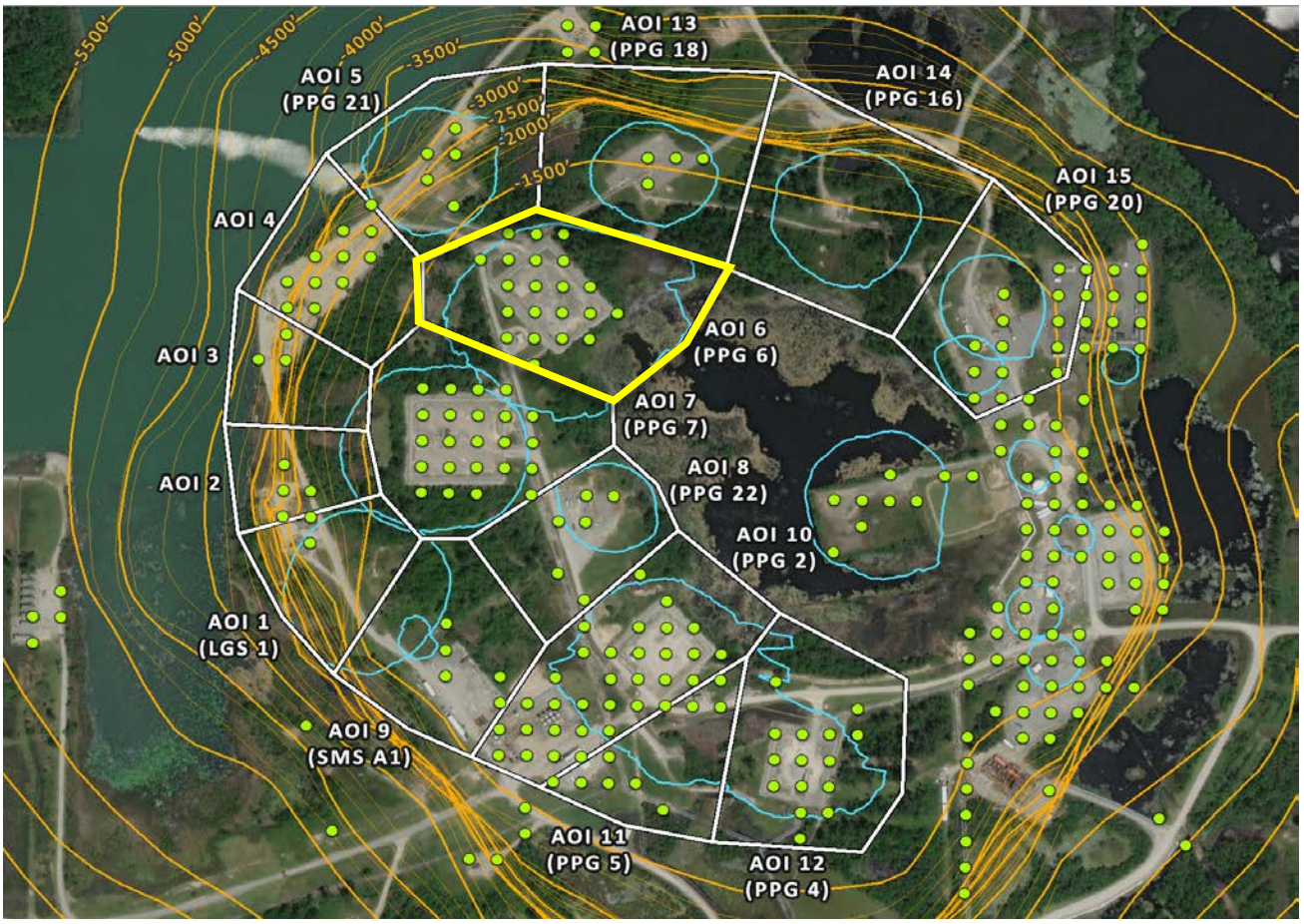
Vertical (10/27/2024) Point Count: 5




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.33 | in/yr | -0.52 | in/yr |
| Acceleration: | +0.22 | in/yr$^2$ | 0.00 | in/yr$^2$ |

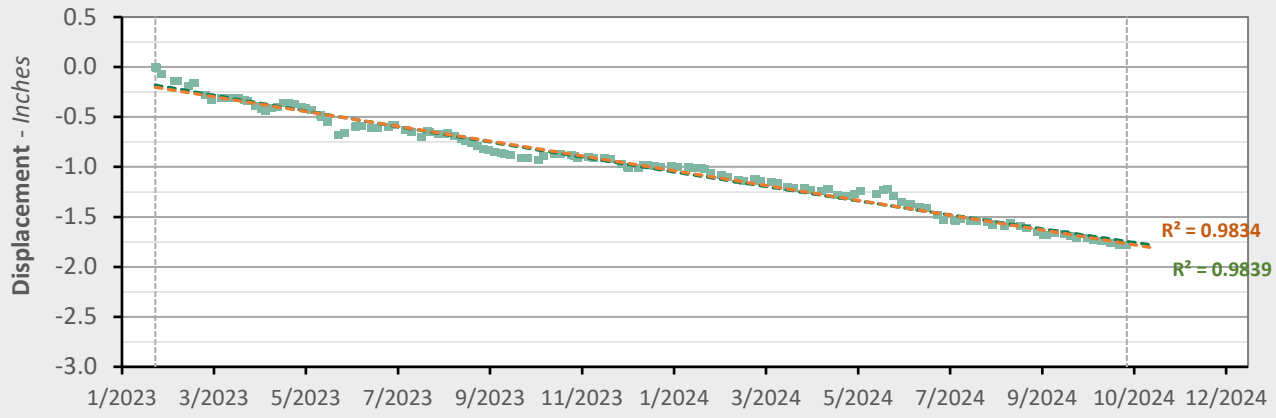
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 6 *(PPG 6)* - Location Map




## AOI 6 *(PPG 6)* - Vertical Time Series

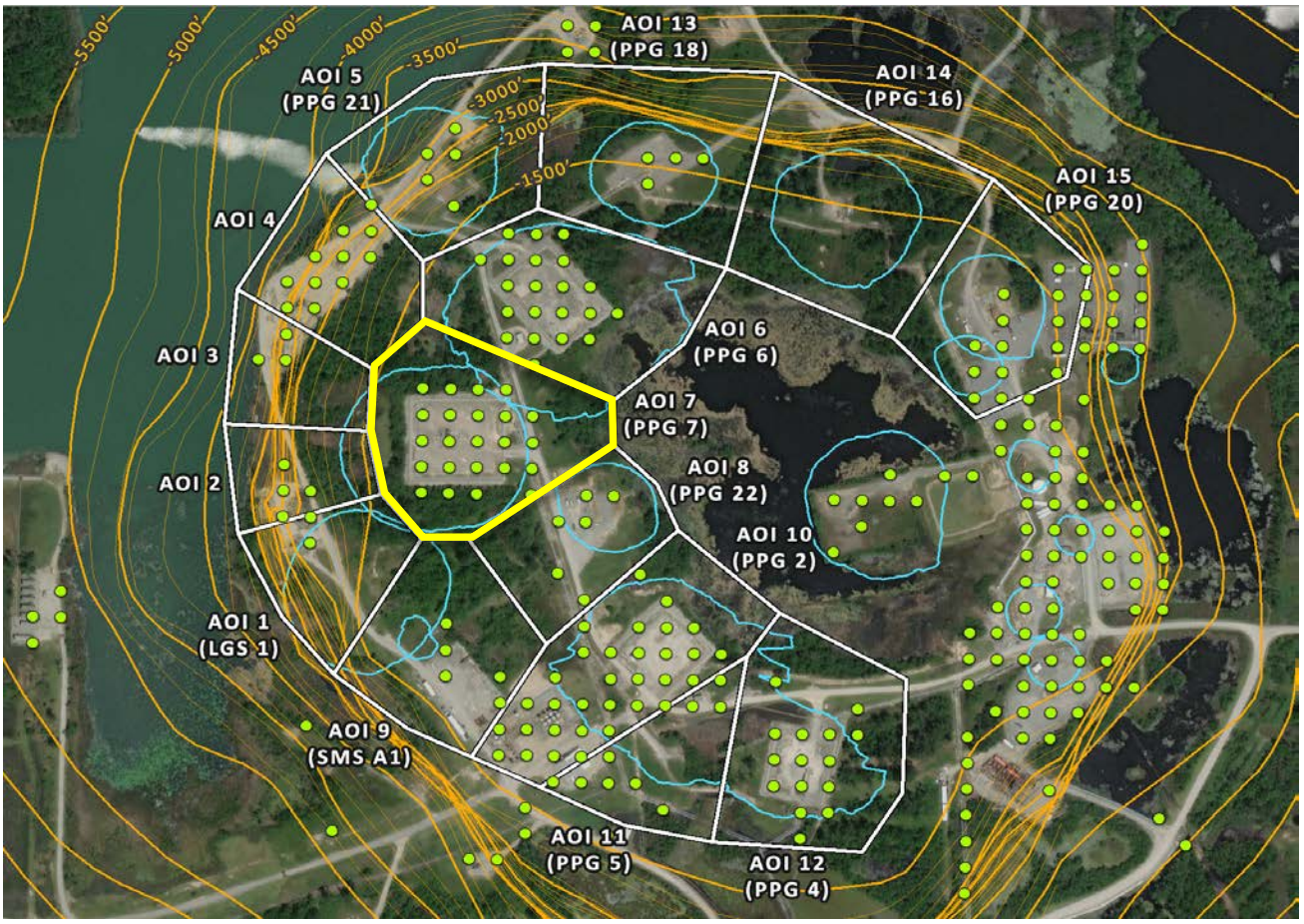
Vertical (10/27/2024) Point Count: **21**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.81 | in/yr | -0.89 | in/yr |
| Acceleration: | +0.09 | in/yr$^2$ | 0.00 | in/yr$^2$ |

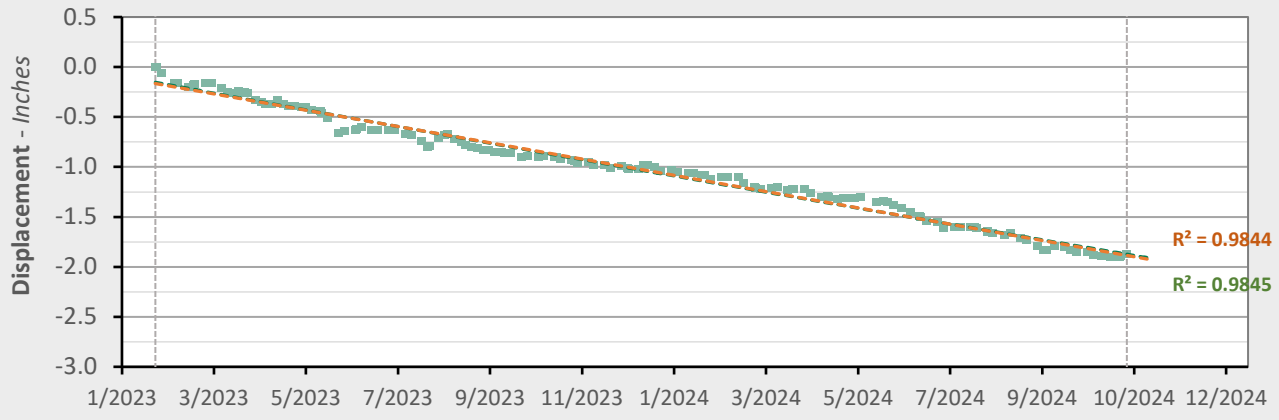
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 7 *(PPG 7)* - Location Map




## AOI 7 *(PPG 7)* - Vertical Time Series

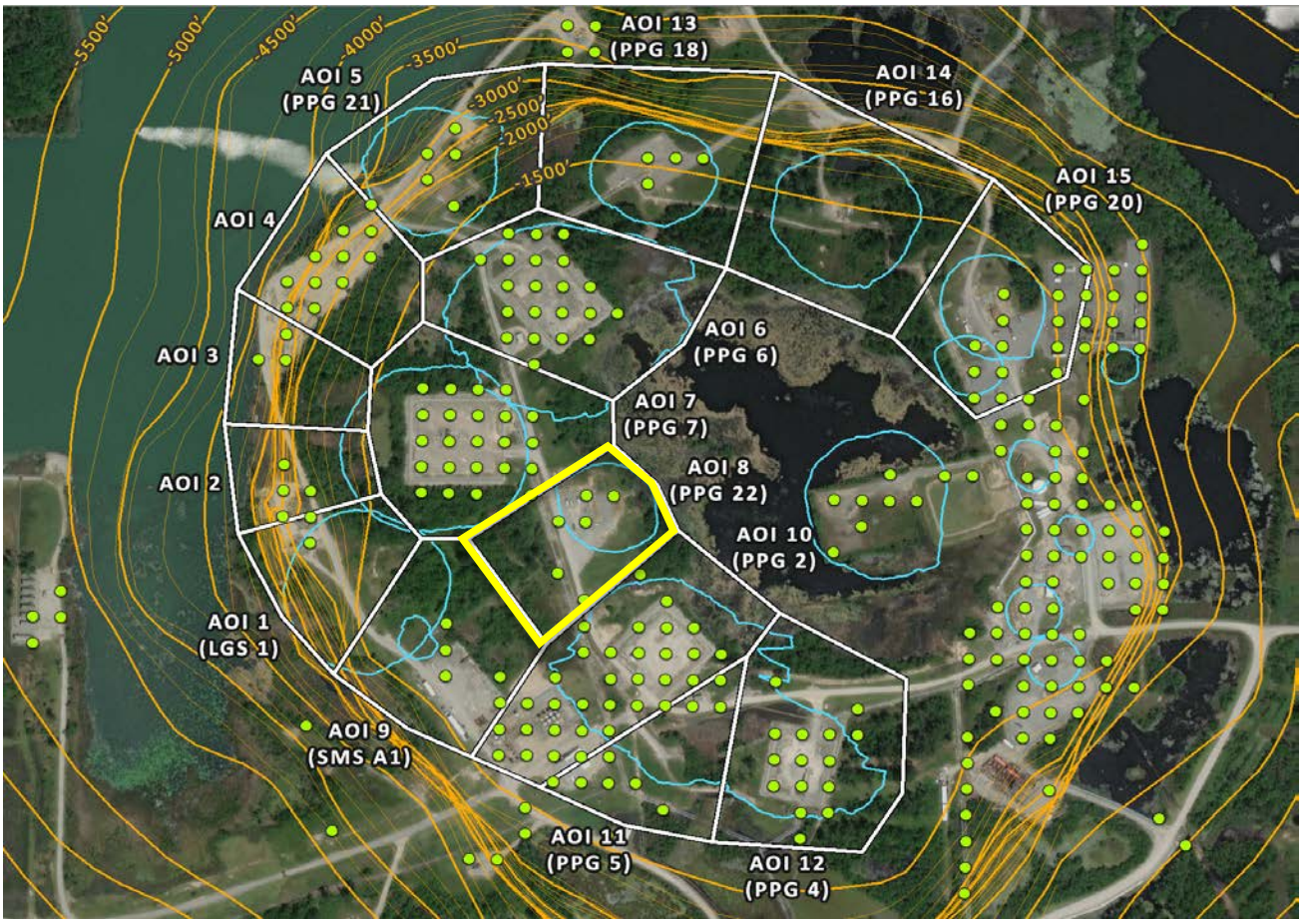
Vertical (10/27/2024) Point Count: **23**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.94 in/yr | -0.98 in/yr |
| Acceleration: | +0.05 in/yr$^2$ | 0.00 in/yr$^2$ |

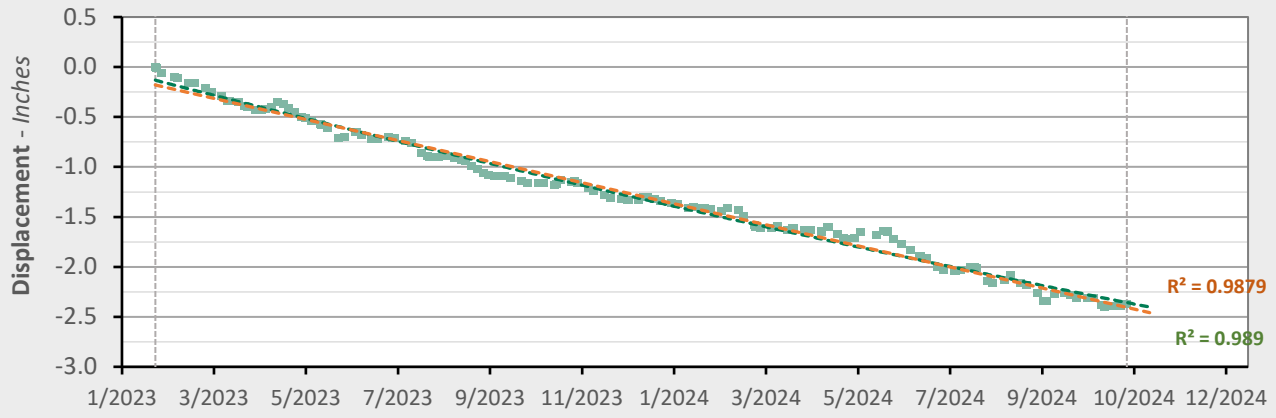
2D Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 8 *(PPG 22)* - Location Map




## AOI 8 *(PPG 22)* - Vertical Time Series

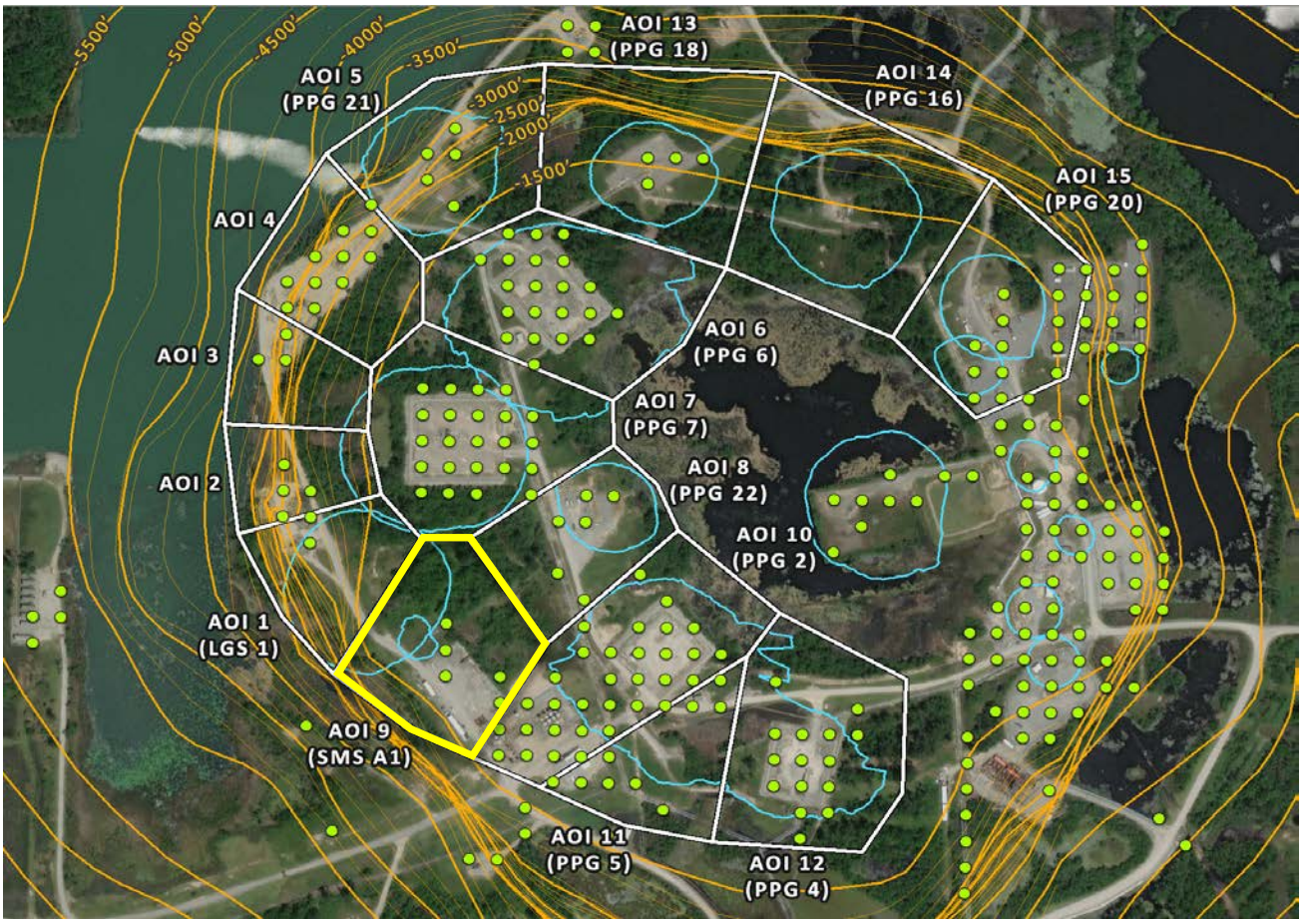
Vertical (10/27/2024) Point Count: **5**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -1.10 | in/yr | -1.27 | in/yr |
| Acceleration: | +0.19 | in/yr$^2$ | 0.00 | in/yr$^2$ |

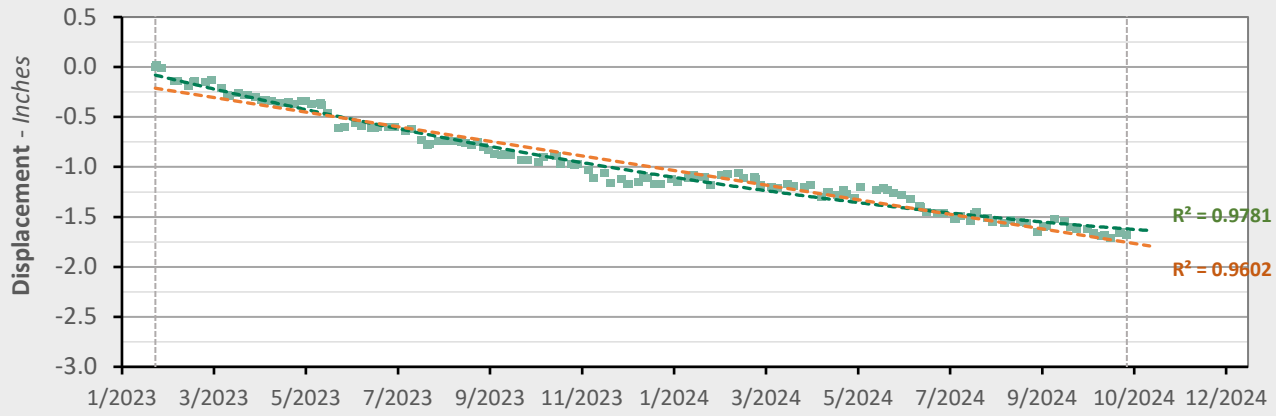
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 9 *(PPG A1)* - Location Map




## AOI 9 *(SMS A1)* - Vertical Time Series

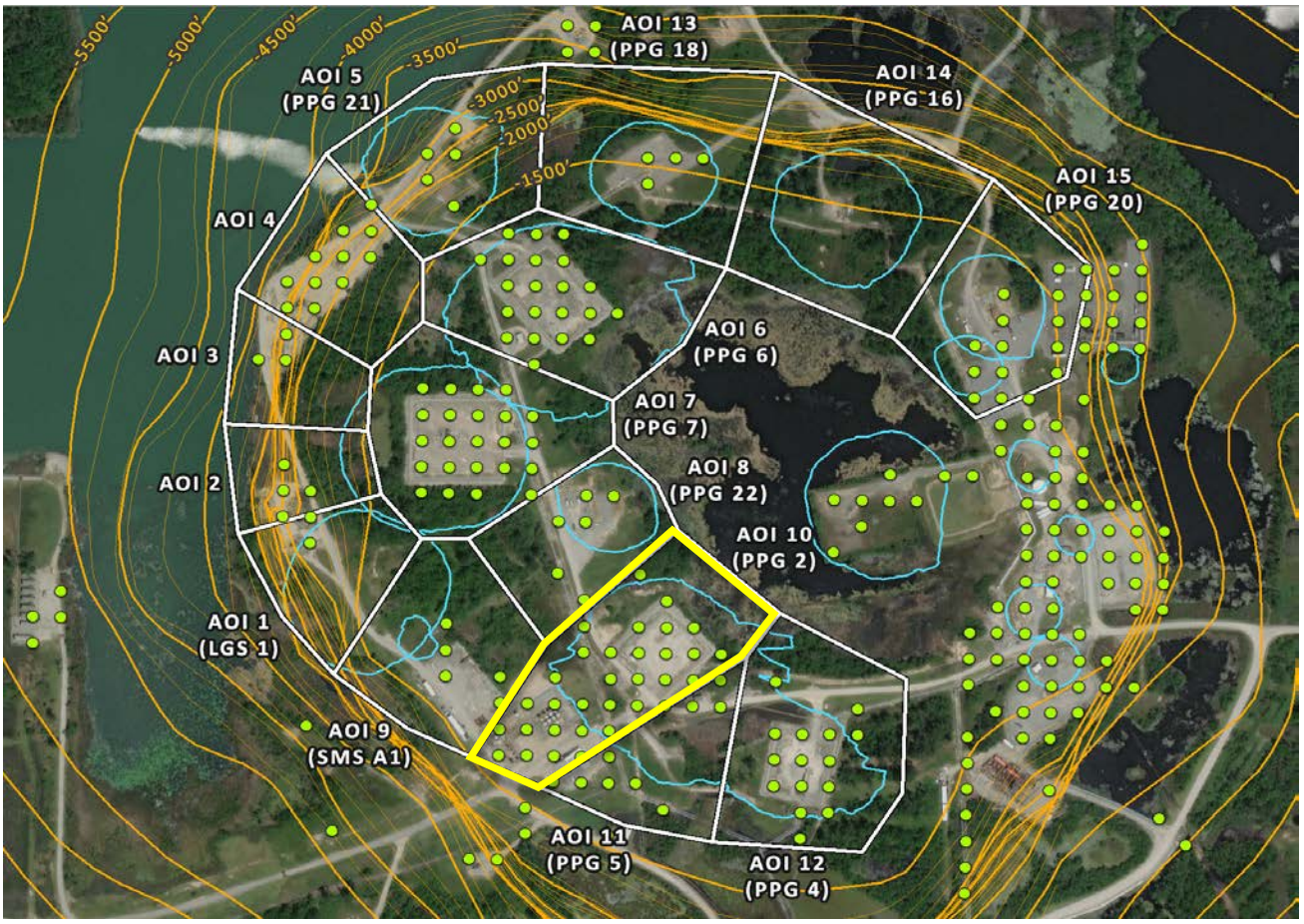
Vertical (10/27/2024) Point Count: **6**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.41 in/yr | -0.88 in/yr |
| Acceleration: | +0.52 in/yr$^2$ | 0.00 in/yr$^2$ |

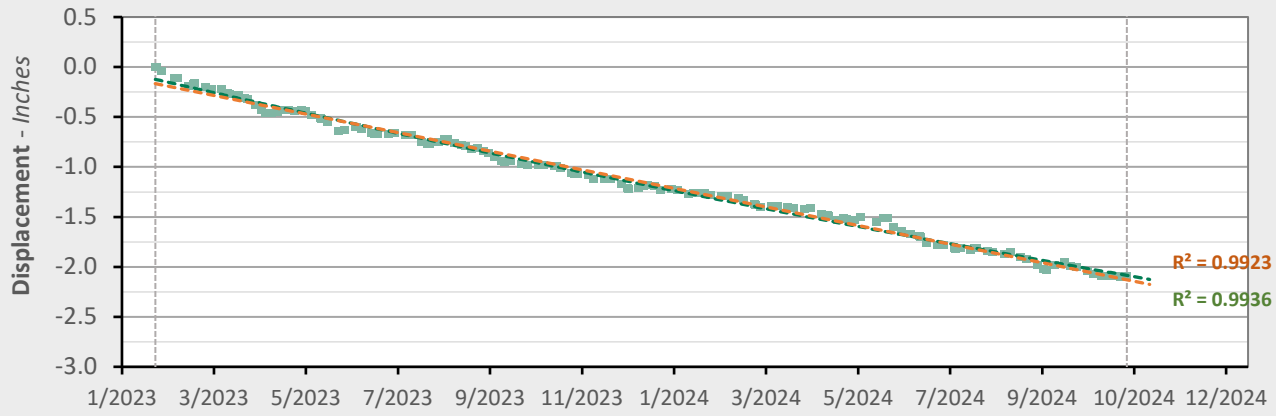
2D Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 10 *(PPG 2)* - Location Map




## AOI 10 *(PPG 2)* - Vertical Time Series

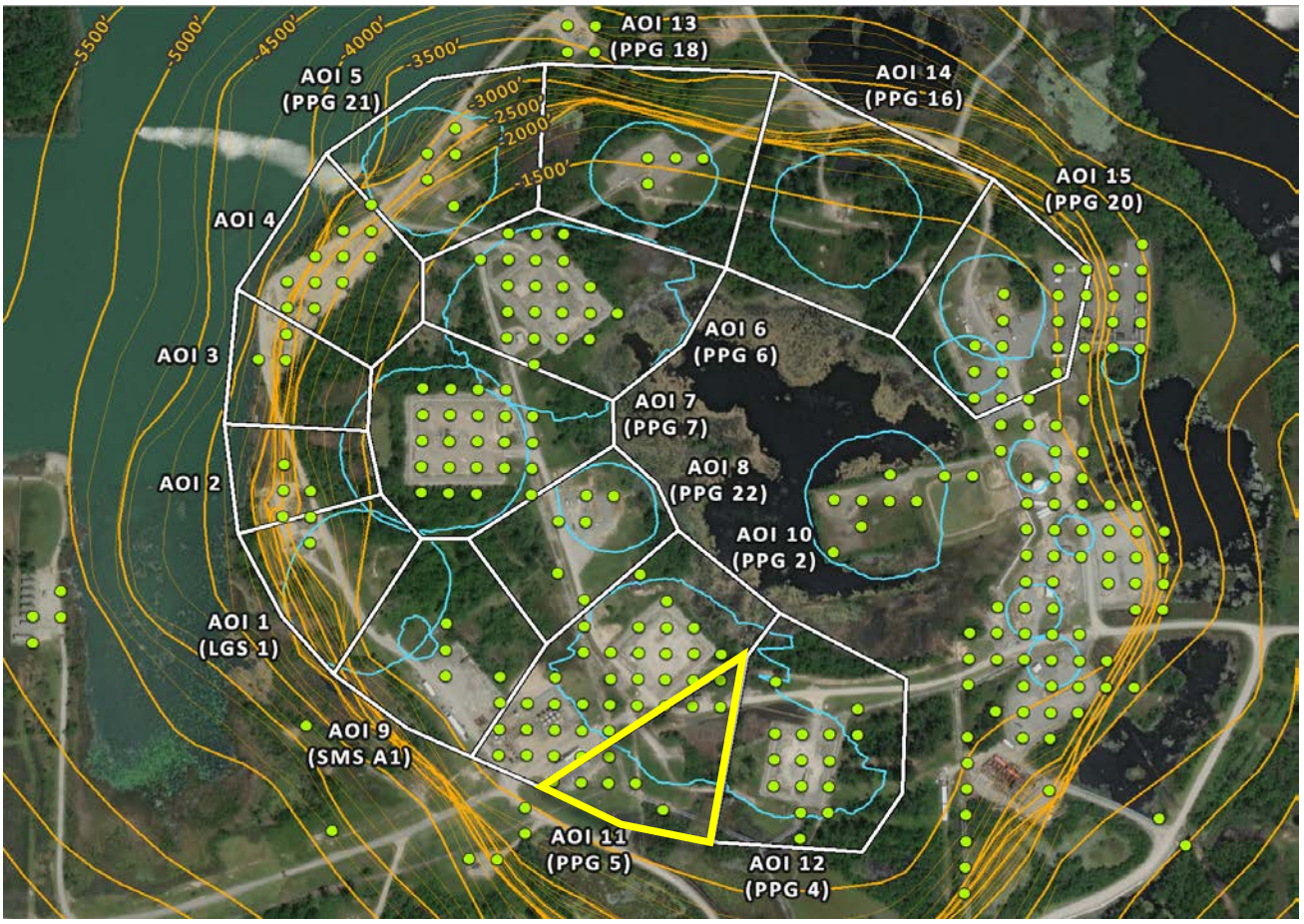
Vertical (10/27/2024) Point Count: **31**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.97 | in/yr | -1.12 | in/yr |
| Acceleration: | +0.17 | in/yr$^2$ | 0.00 | in/yr$^2$ |

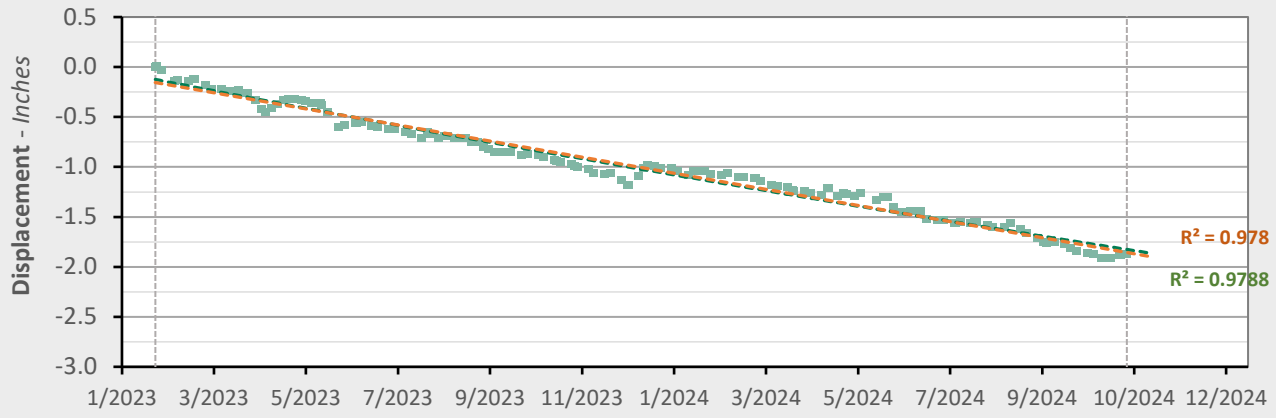
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 11 *(PPG 5)* - Location Map




## AOI 11 *(PPG 5)* - Vertical Time Series

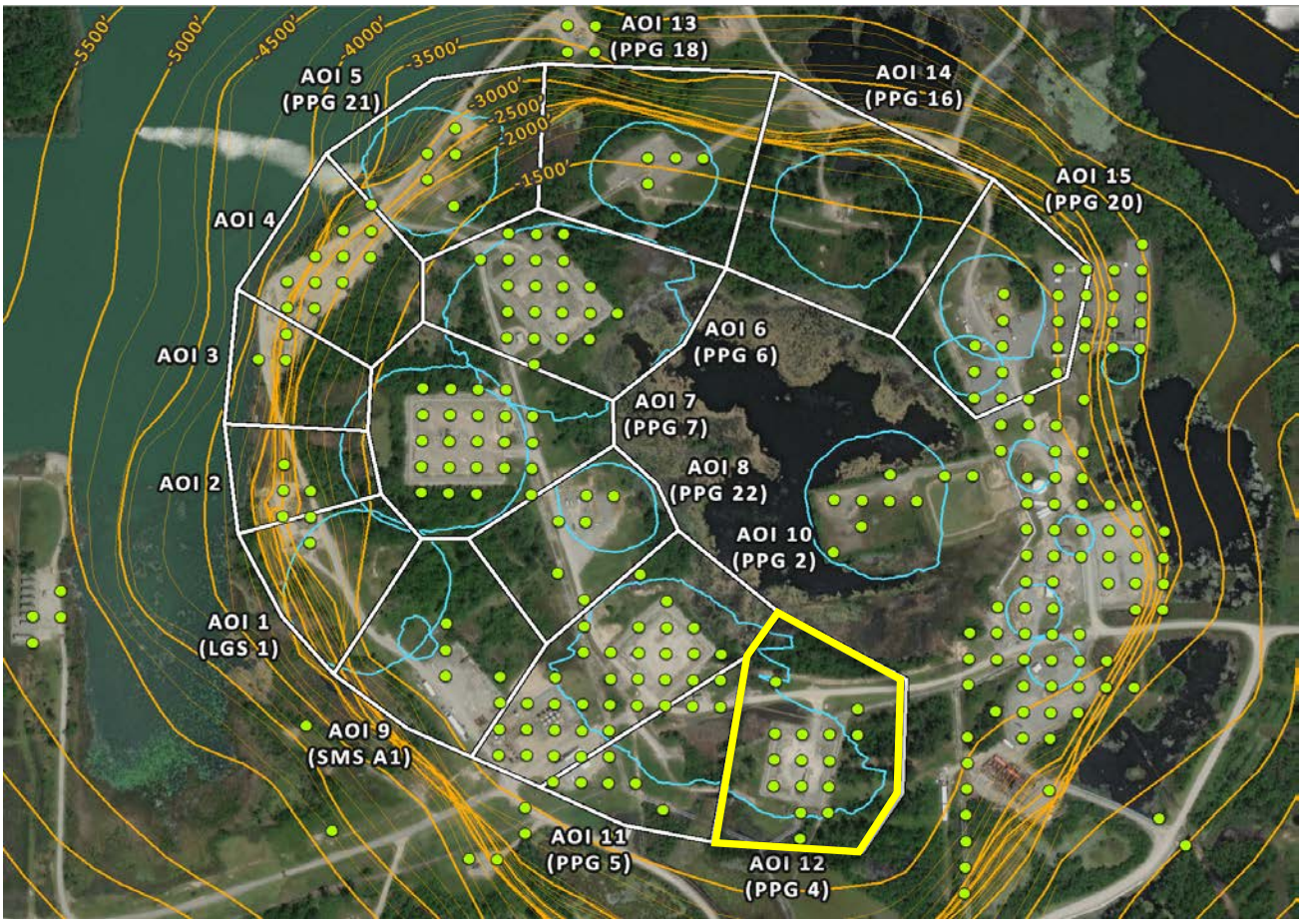
Vertical (10/27/2024) Point Count: **10**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.86 in/yr | -0.97 in/yr |
| Acceleration: | +0.12 in/yr$^2$ | 0.00 in/yr$^2$ |

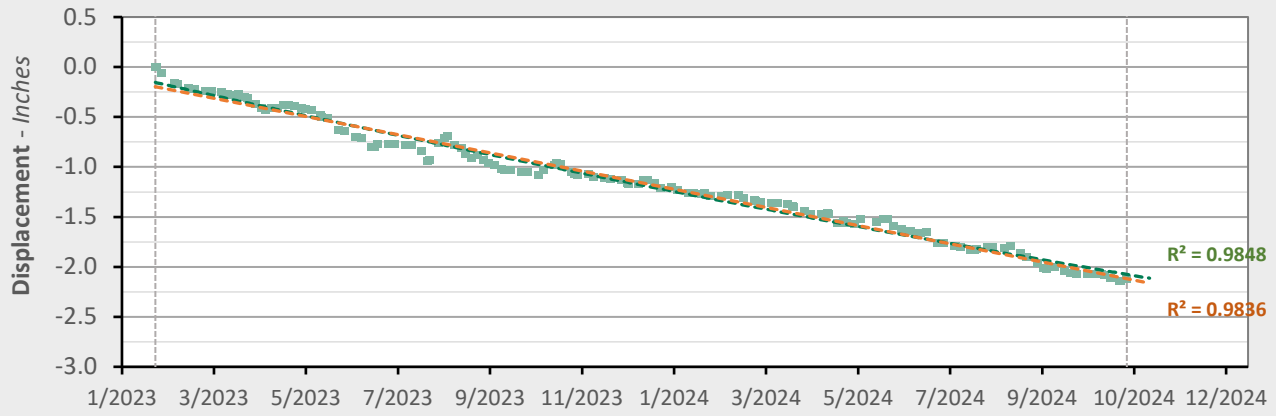
2D Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 12 *(PPG 4)* - Location Map




## AOI 12 *(PPG 4)* - Vertical Time Series

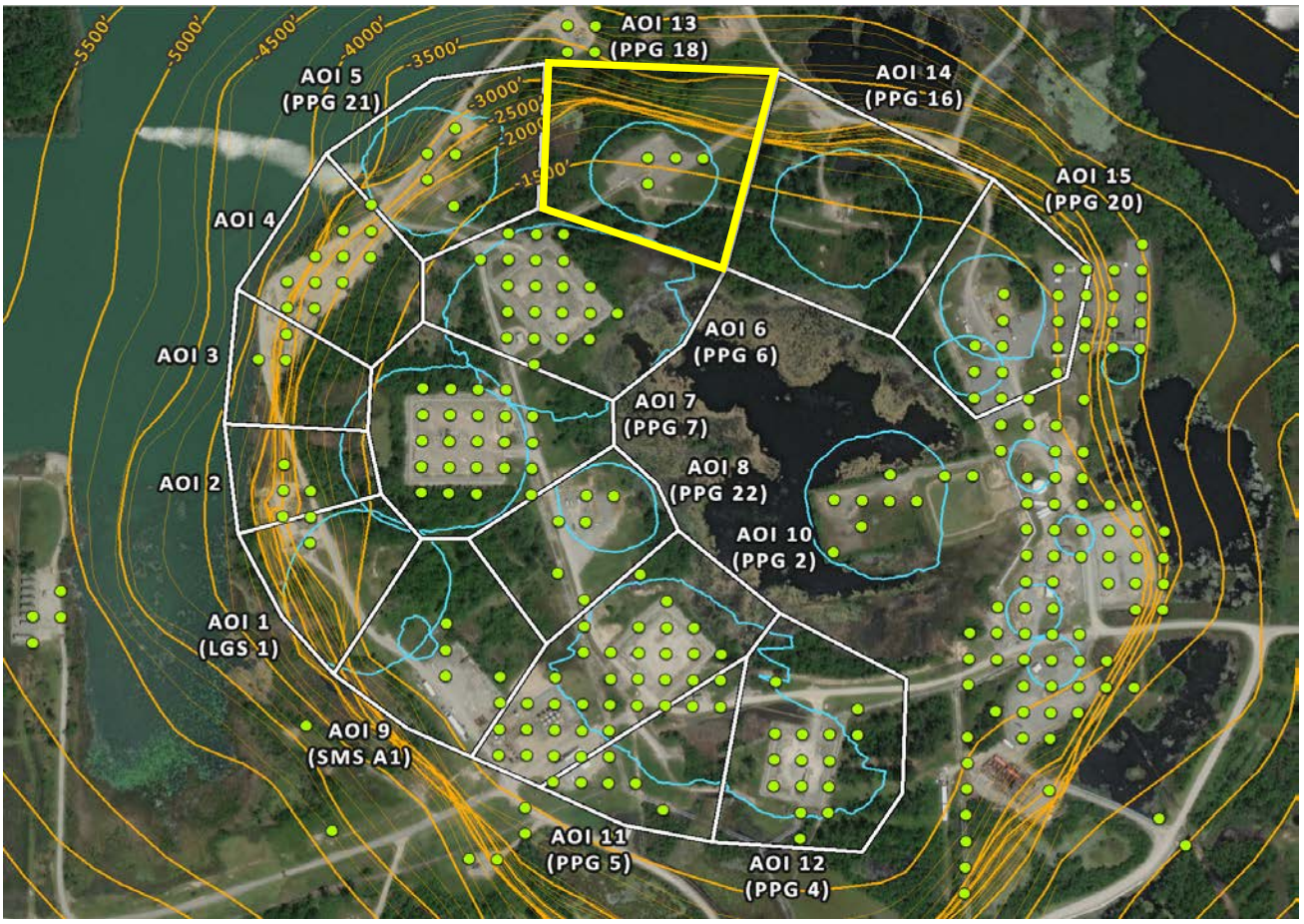
Vertical (10/27/2024) Point Count: **15**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.94 in/yr | -1.09 in/yr |
| Acceleration: | +0.17 in/yr$^2$ | 0.00 in/yr$^2$ |

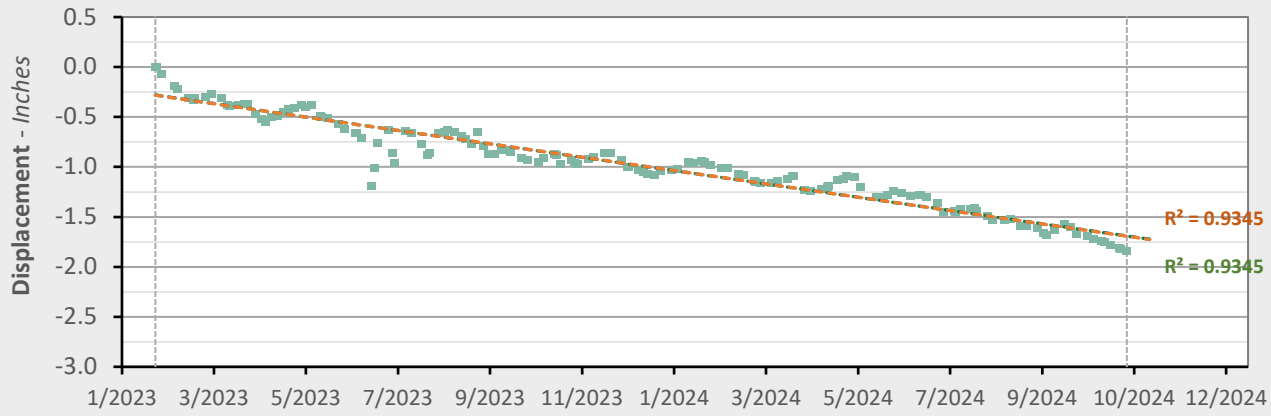
2D Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 13 *(PPG 18)* - Location Map




## AOI 13 *(PPG 18)* - Vertical Time Series

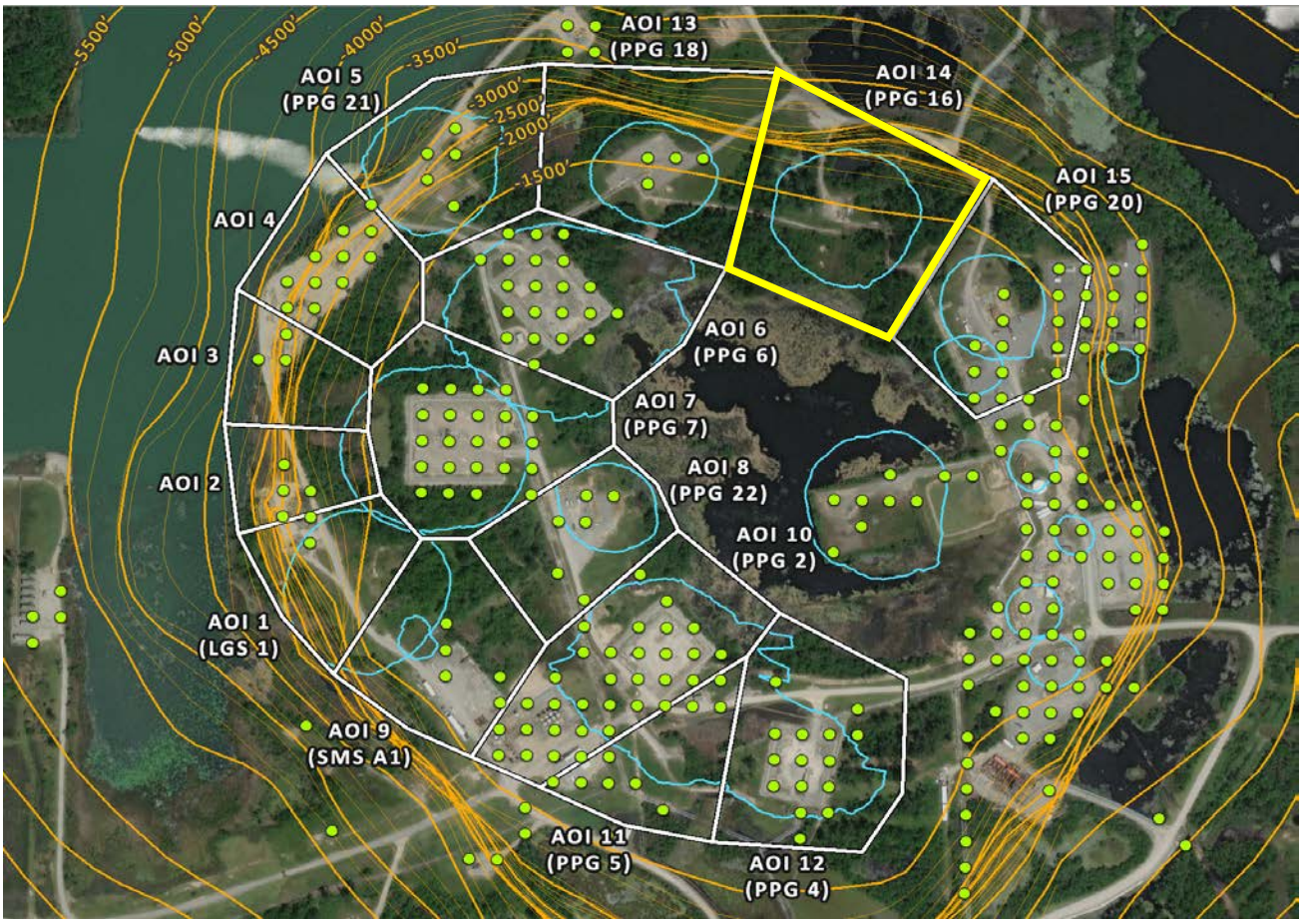
Vertical (10/27/2024) Point Count: **3**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.79 in/yr | -0.80 in/yr |
| Acceleration: | +0.01 in/yr$^2$ | 0.00 in/yr$^2$ |

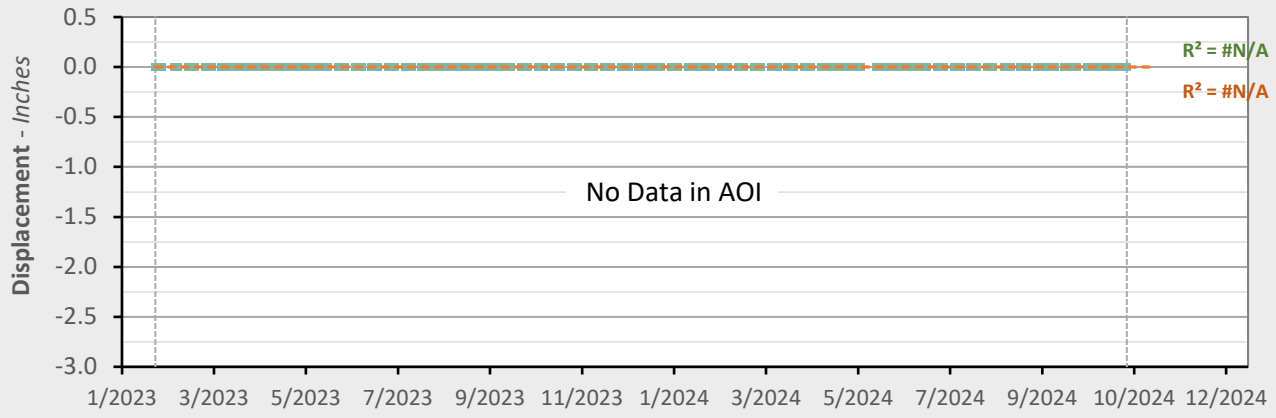
2D Displacement Measurement — Nonlinear Trend Line (Quadratic Regression) — Linear Trend Line (Linear Regression)

## AOI 14 *(PPG 16)* - Location Map




## AOI 14 *(PPG 16)* - Vertical Time Series

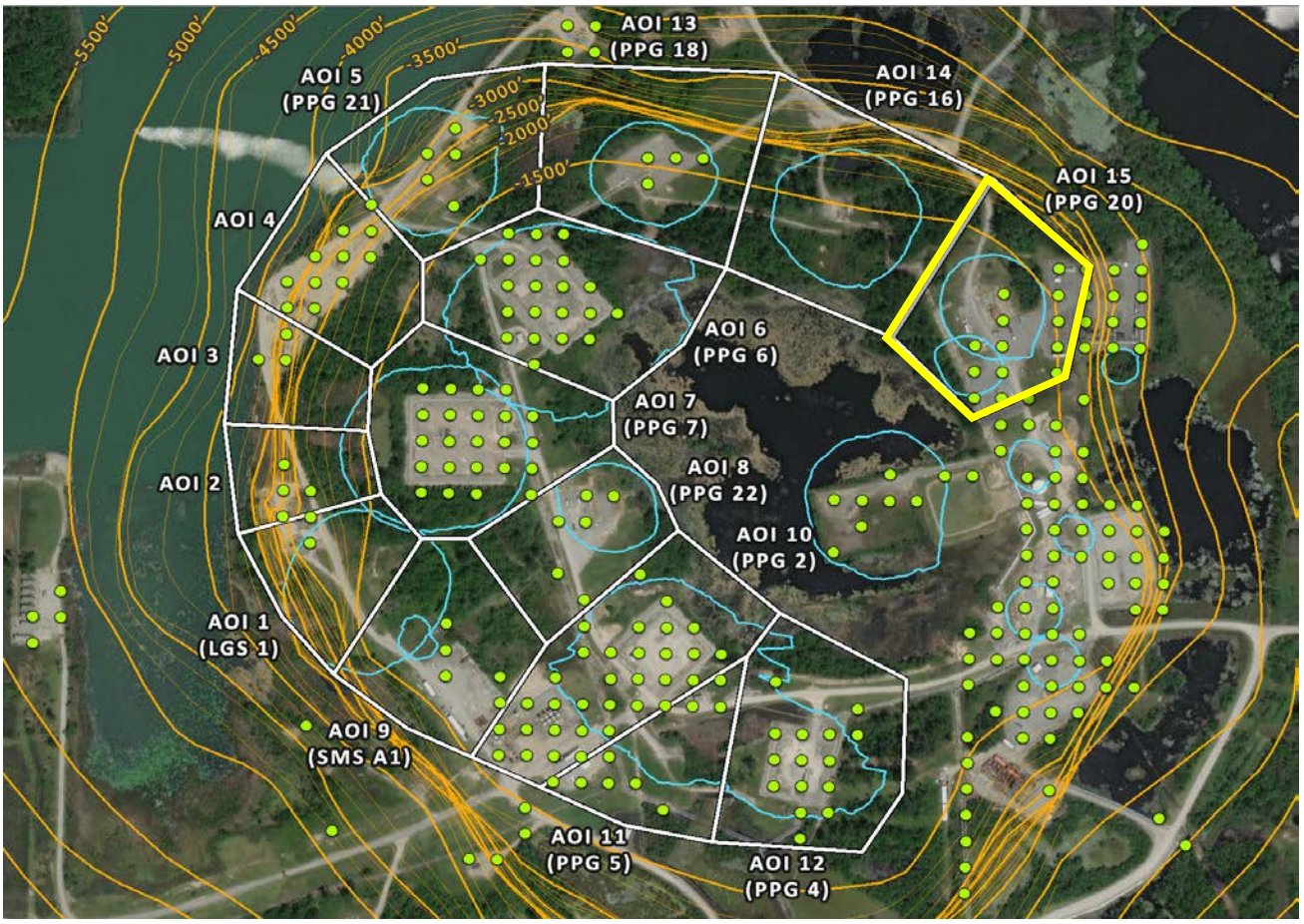
Vertical (10/27/2024) Point Count: **0**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | N/A | in/yr | N/A | in/yr |
| Acceleration: | N/A | in/yr$^2$ | N/A | in/yr$^2$ |

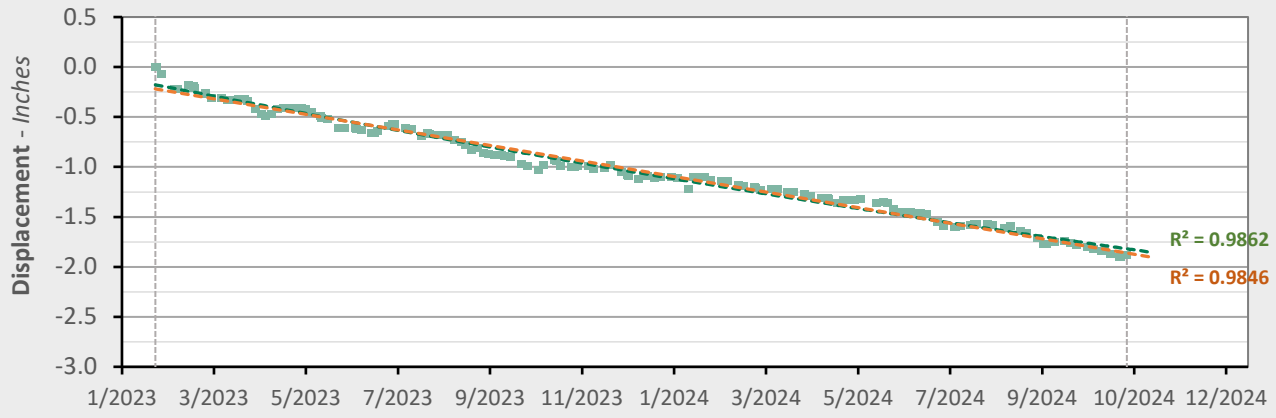
2D Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 15 *(PPG 20)* - Location Map




## AOI 15 *(PPG 20)* - Vertical Time Series

Vertical (10/27/2024) Point Count: **14**



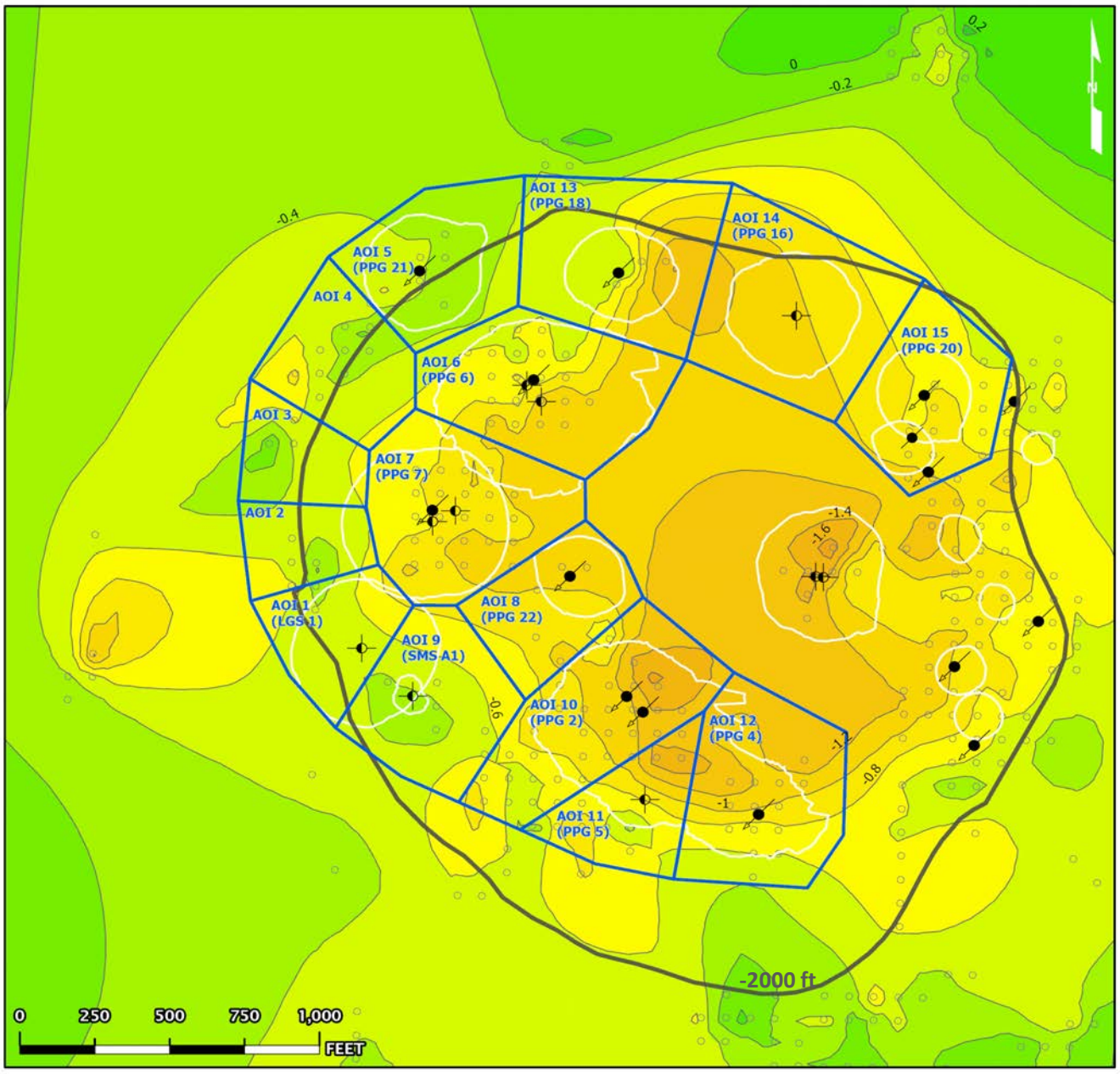

| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | -0.79 | in/yr | -0.93 | in/yr |
| Acceleration: | +0.17 | in/yr² | 0.00 | in/yr² |

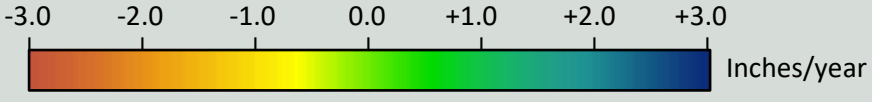
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## Vertical Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Contours

As of date: 10/27/2024




AOI Boundary
InSAR LOS Measurement Point
Contour (0.2)
Historical Cavern Extent
Top of Dome (-2000 ft Contour)

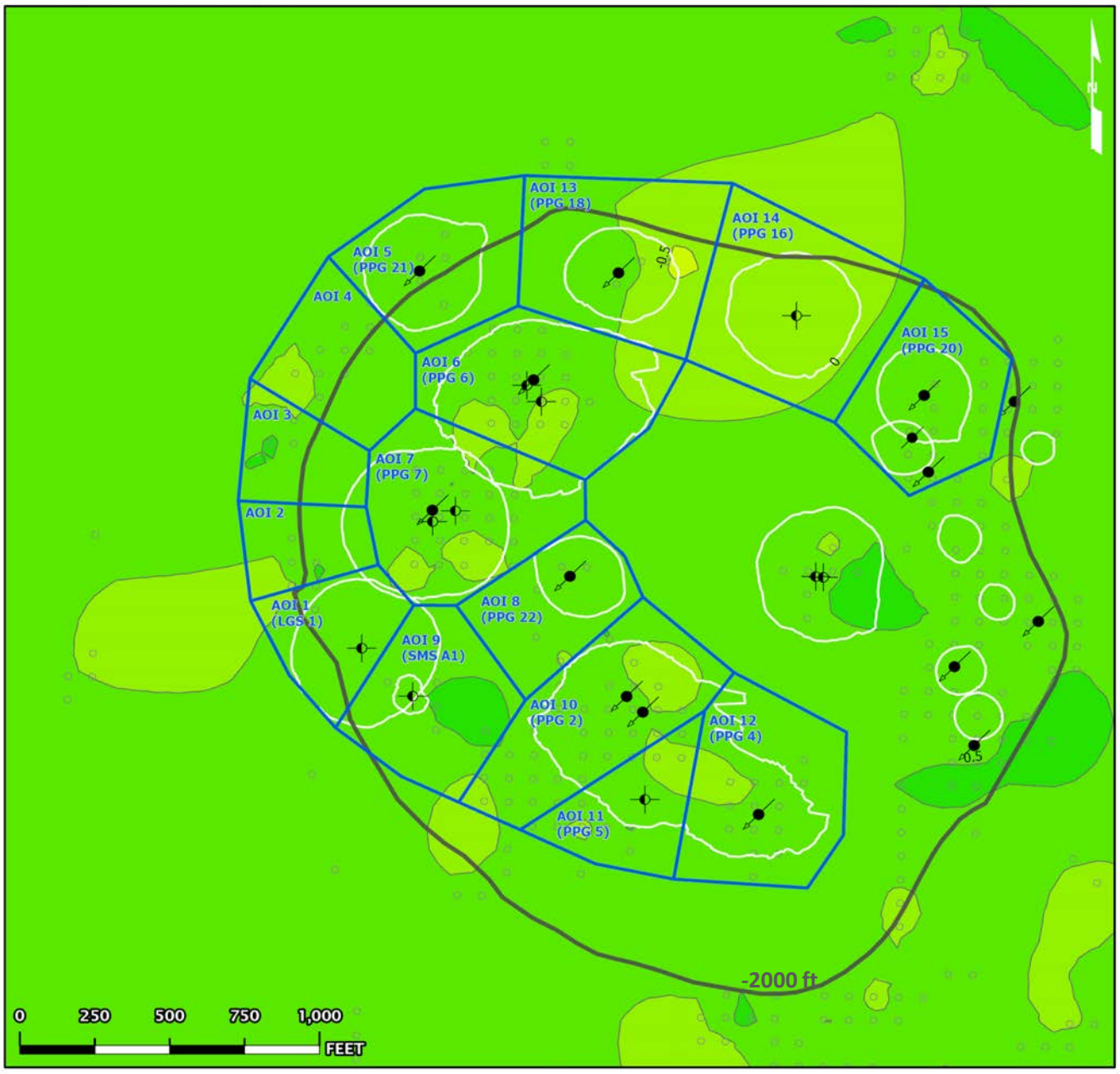
Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## Vertical Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Contours

Date range: 01/24/2023 - 10/27/2024




-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year$^2$

AOI Boundary | InSAR LOS Measurement Point | Contour (0.5)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

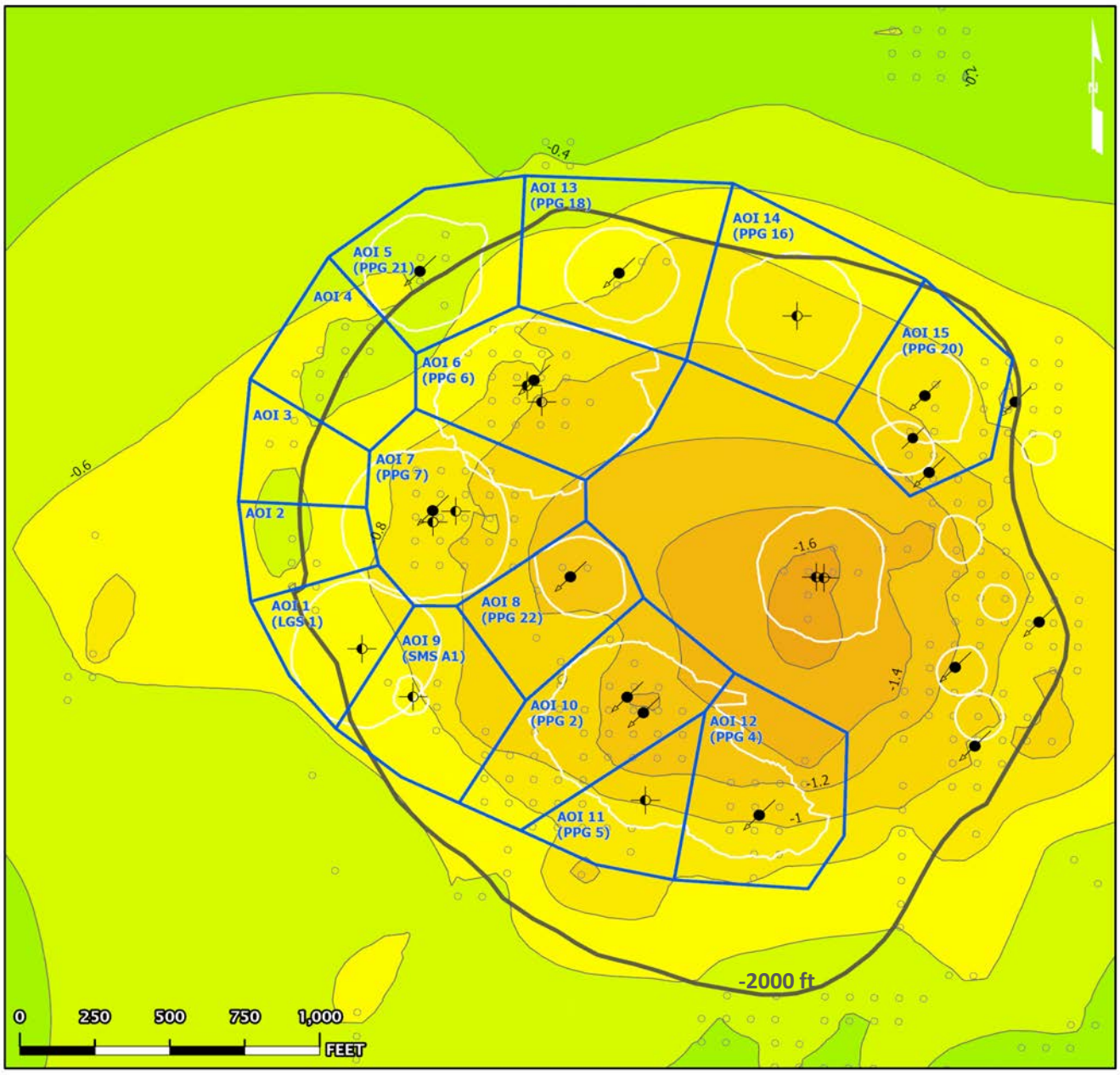
Cavern Well Surface Locations

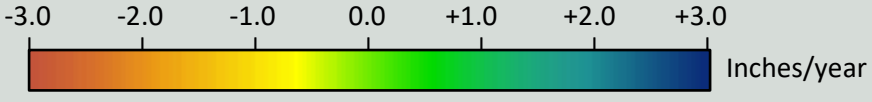
09 - Active - Injection | 29 - Dry and Plugged

## Vertical Data (01/24/2023 - 10/27/2024)

### Linear Velocity Contours

Date range: 01/24/2023 - 10/27/2024




AOI Boundary ○ InSAR LOS Measurement Point — Contour (0.2)

Historical Cavern Extent Top of Dome (-2000 ft Contour)

Cavern Well Surface Locations

09 - Active - Injection 29 - Dry and Plugged

## Vertical Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Data Points

As of date: 10/27/2024


-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## Vertical Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Data Points

Date range: 01/24/2023 - 10/27/2024


-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year$^2$

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## Vertical Data (01/24/2023 - 10/27/2024)

### Linear Velocity Data Points

Date range: 01/24/2023 - 10/27/2024


-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

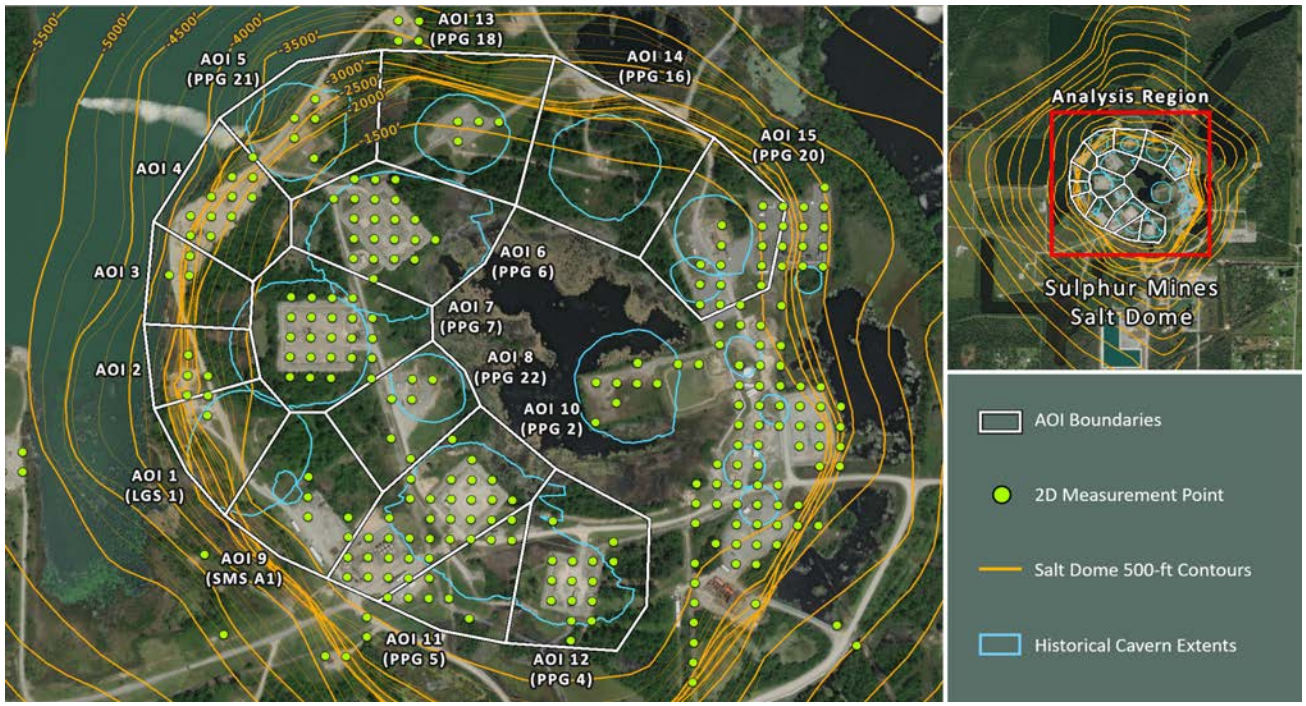
Inches/year

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## AOI Boundaries & 2D InSAR Measurement Points

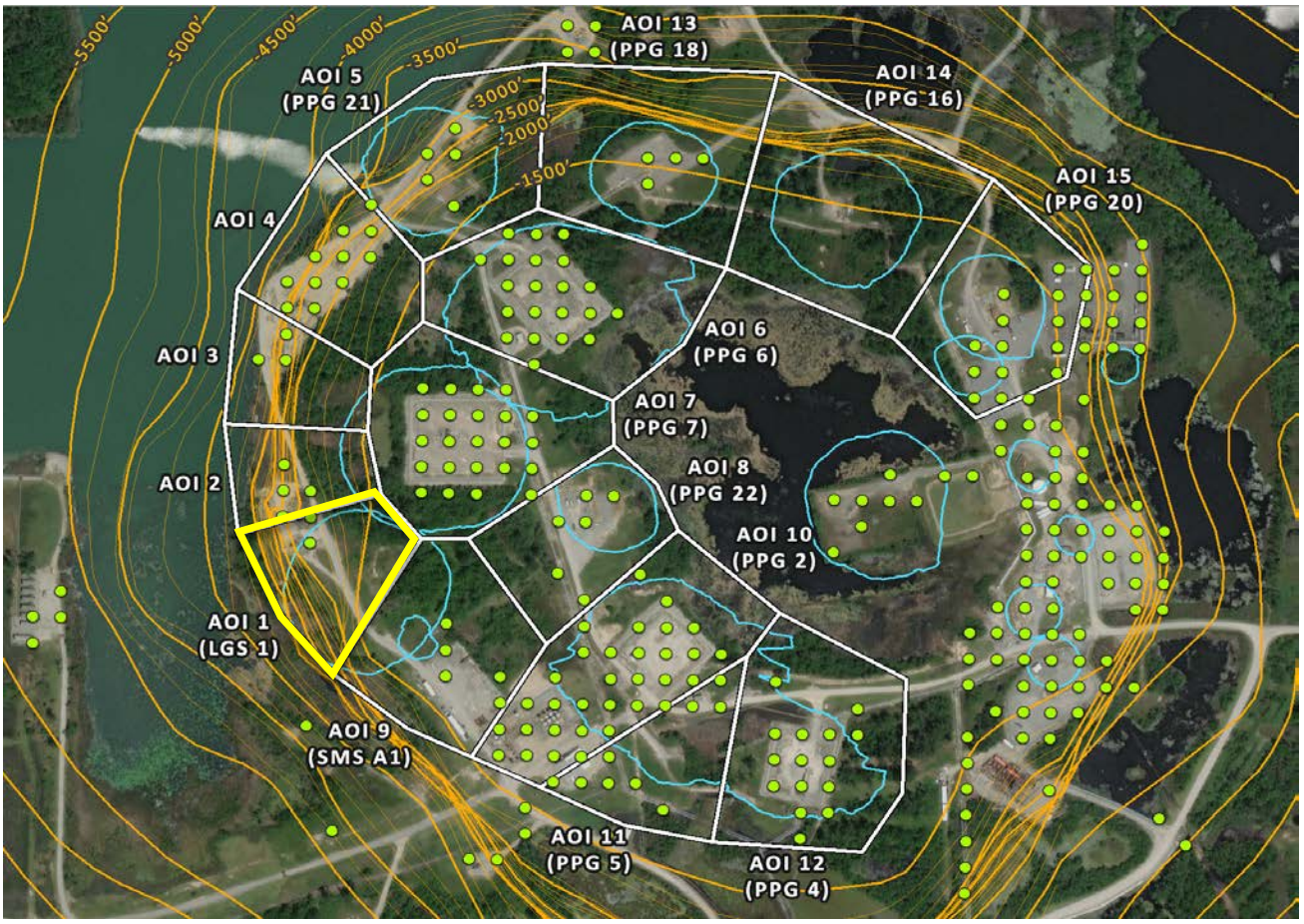



## Subsidence Monitoring Areas of Interest (AOIs)

To visually convey and evaluate trend consistency for the East-West 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 East-West trend values calculated in each AOI for the dataset evaluated in this report.

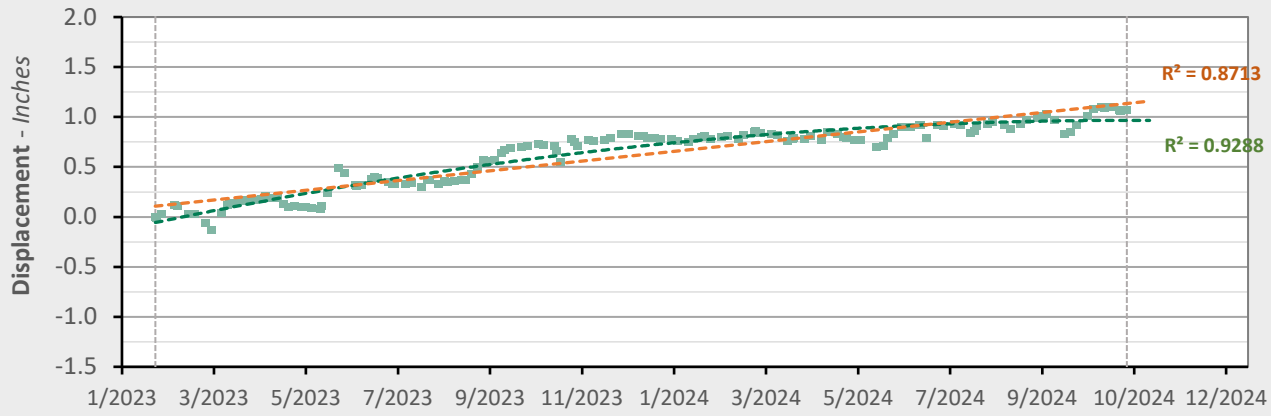
| AOI Name | East-West (10/27/2024) | East-West Velocity (in/yr) | | East-West Acceleration (in/yr²) | |
|---|---|---|---|---|---|
| | Point Count | Nonlinear | Linear | Nonlinear | Linear |
| **AOI 1** *(LGS 1)* | 2 | +0.00 | +0.58 | -0.66 | 0.00 |
| **AOI 2** | 4 | +0.18 | +0.60 | -0.48 | 0.00 |
| **AOI 3** | 3 | +0.19 | +0.55 | -0.40 | 0.00 |
| **AOI 4** | 10 | +0.34 | +0.49 | -0.17 | 0.00 |
| **AOI 5** *(PPG 21)* | 5 | +0.18 | +0.19 | -0.01 | 0.00 |
| **AOI 6** *(PPG 6)* | 21 | +0.15 | +0.31 | -0.19 | 0.00 |
| **AOI 7** *(PPG 7)* | 23 | +0.46 | +0.59 | -0.15 | 0.00 |
| **AOI 8** *(PPG 22)* | 5 | +0.24 | +0.50 | -0.29 | 0.00 |
| **AOI 9** *(SMS A1)* | 6 | +0.16 | +0.46 | -0.35 | 0.00 |
| **AOI 10** *(PPG 2)* | 31 | +0.22 | +0.35 | -0.14 | 0.00 |
| **AOI 11** *(PPG 5)* | 10 | +0.03 | +0.31 | -0.31 | 0.00 |
| **AOI 12** *(PPG 4)* | 15 | -0.34 | -0.20 | -0.16 | 0.00 |
| **AOI 13** *(PPG 18)* | 3 | -0.39 | -0.01 | -0.42 | 0.00 |
| **AOI 14** *(PPG 16)* | 0 | N/A | N/A | N/A | N/A |
| **AOI 15** *(PPG 20)* | 14 | -0.65 | -0.56 | -0.10 | 0.00 |

## AOI 1 *(LGS 1)* - Location Map




## AOI 1 *(LGS 1)* - East-West Time Series

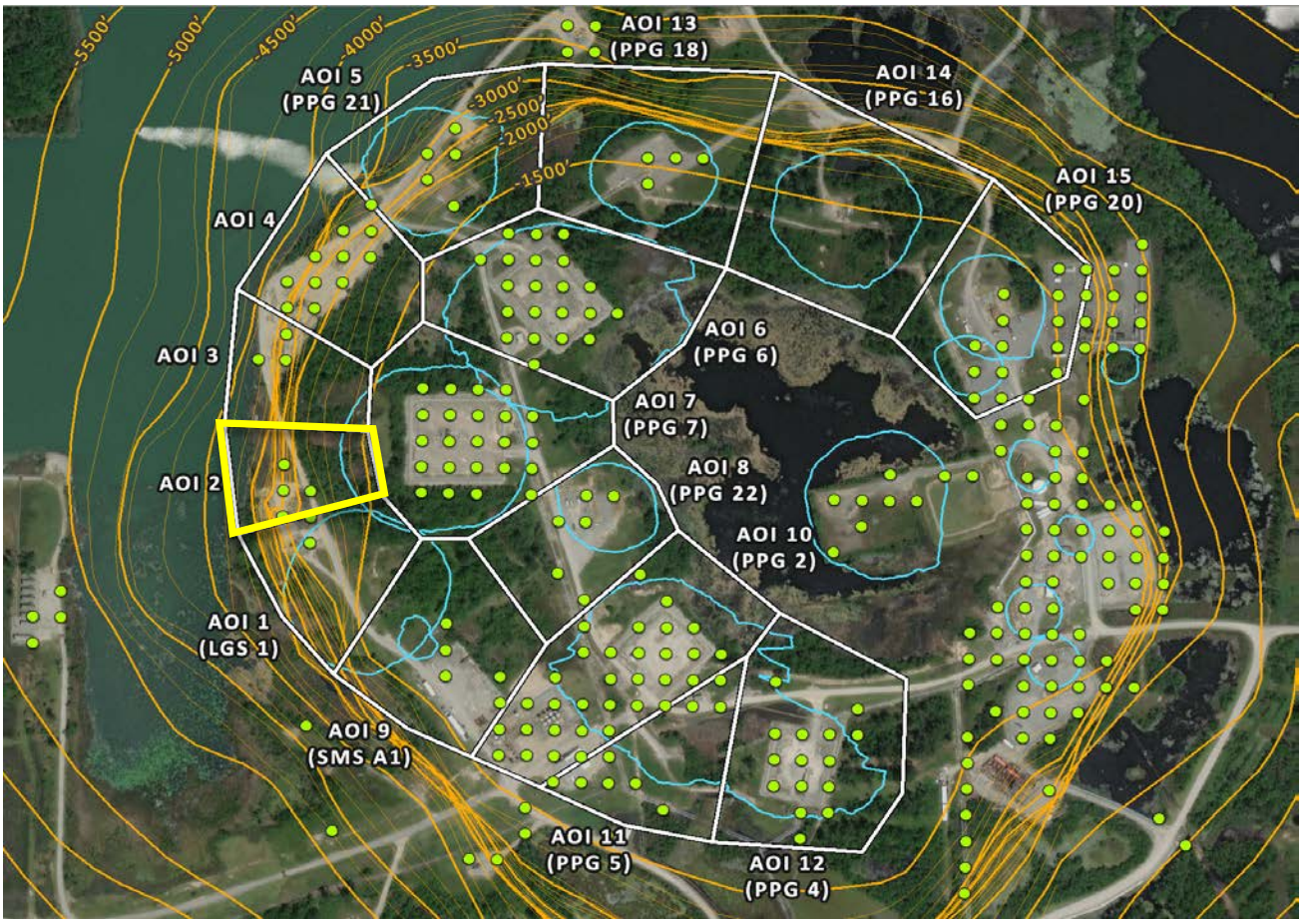
E-W (10/27/2024) Point Count: **2**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.00 | in/yr | +0.58 | in/yr |
| Acceleration: | -0.66 | in/yr$^2$ | 0.00 | in/yr$^2$ |

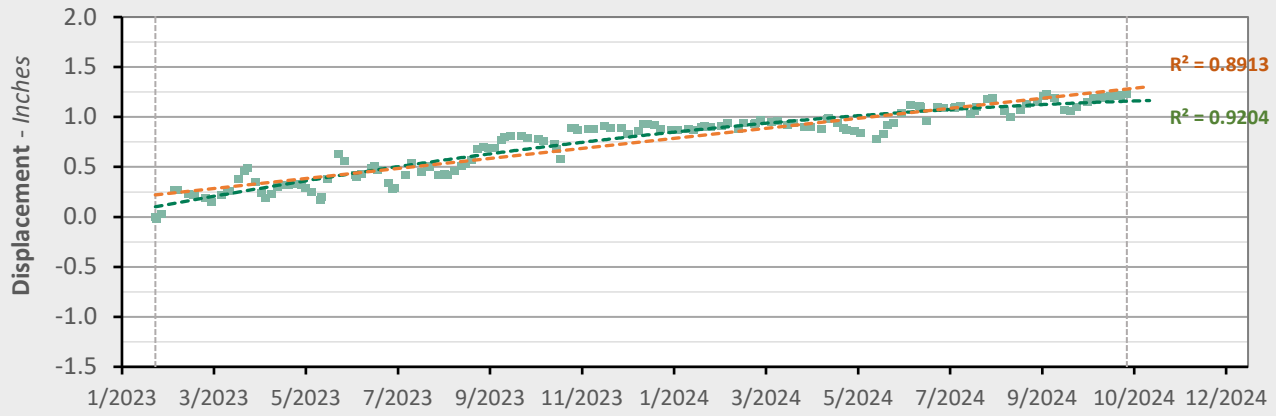
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 2 - Location Map




## AOI 2 - East-West Time Series

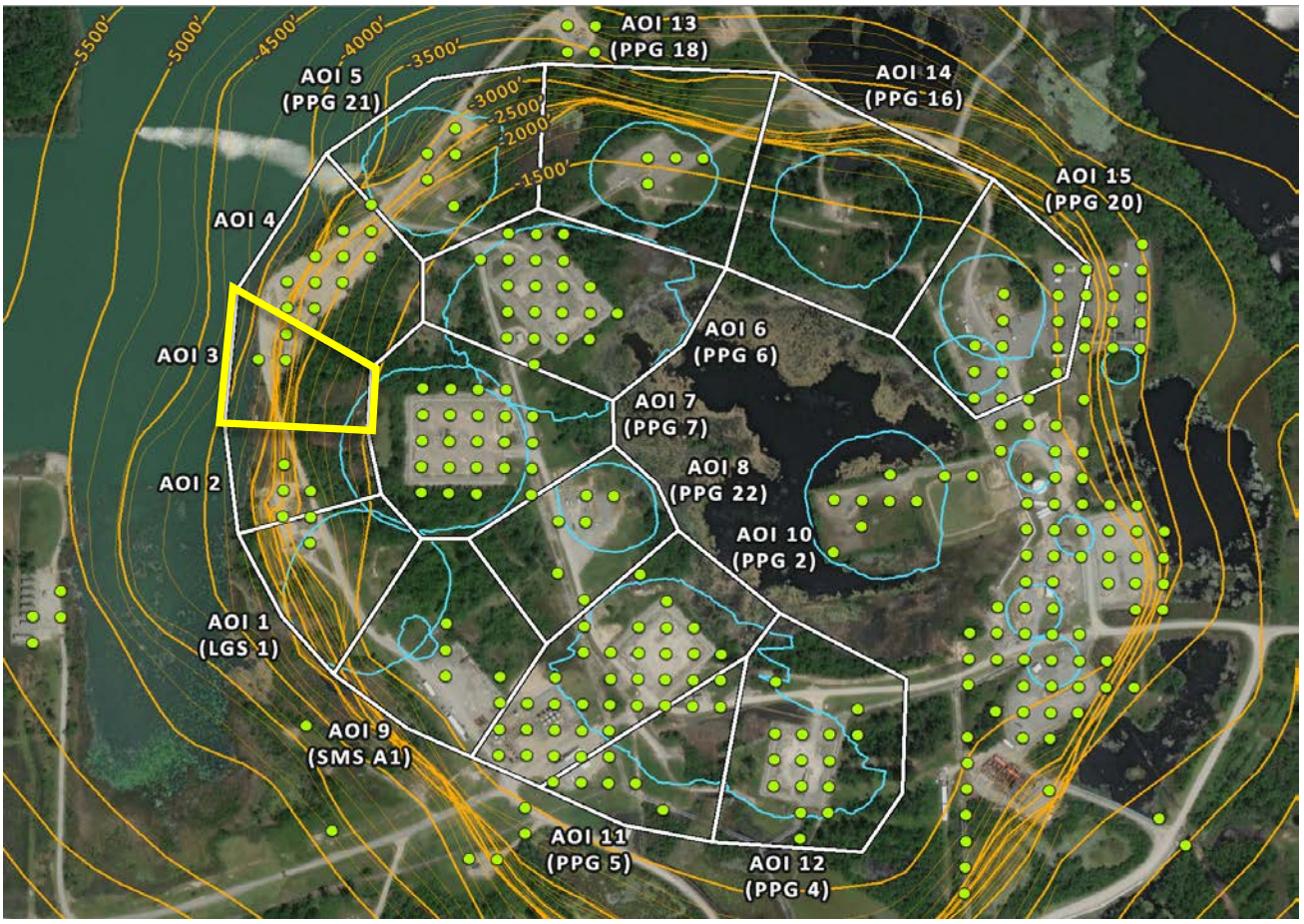
E-W (10/27/2024) Point Count: **4**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.18 | in/yr | +0.60 | in/yr |
| Acceleration: | -0.48 | in/yr$^2$ | 0.00 | in/yr$^2$ |

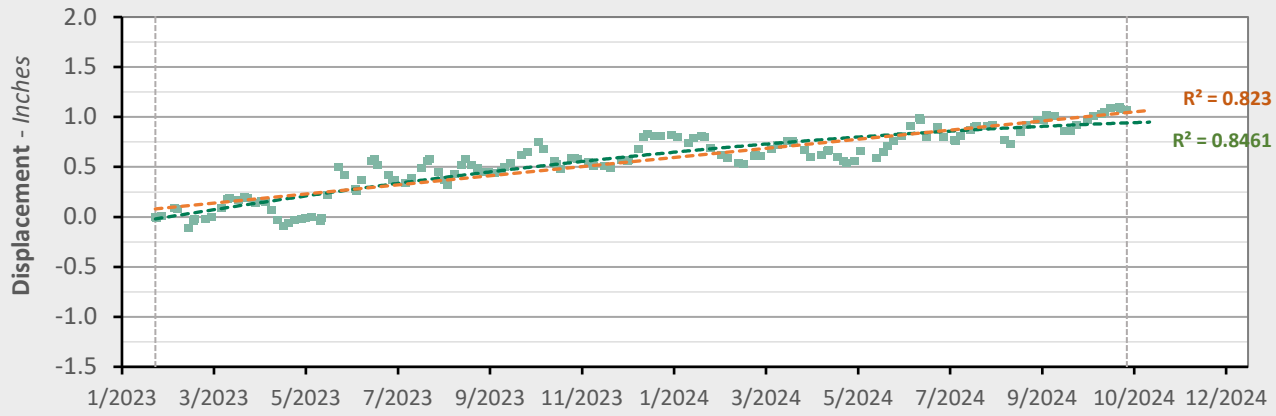
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 3 - Location Map




## AOI 3 - East-West Time Series

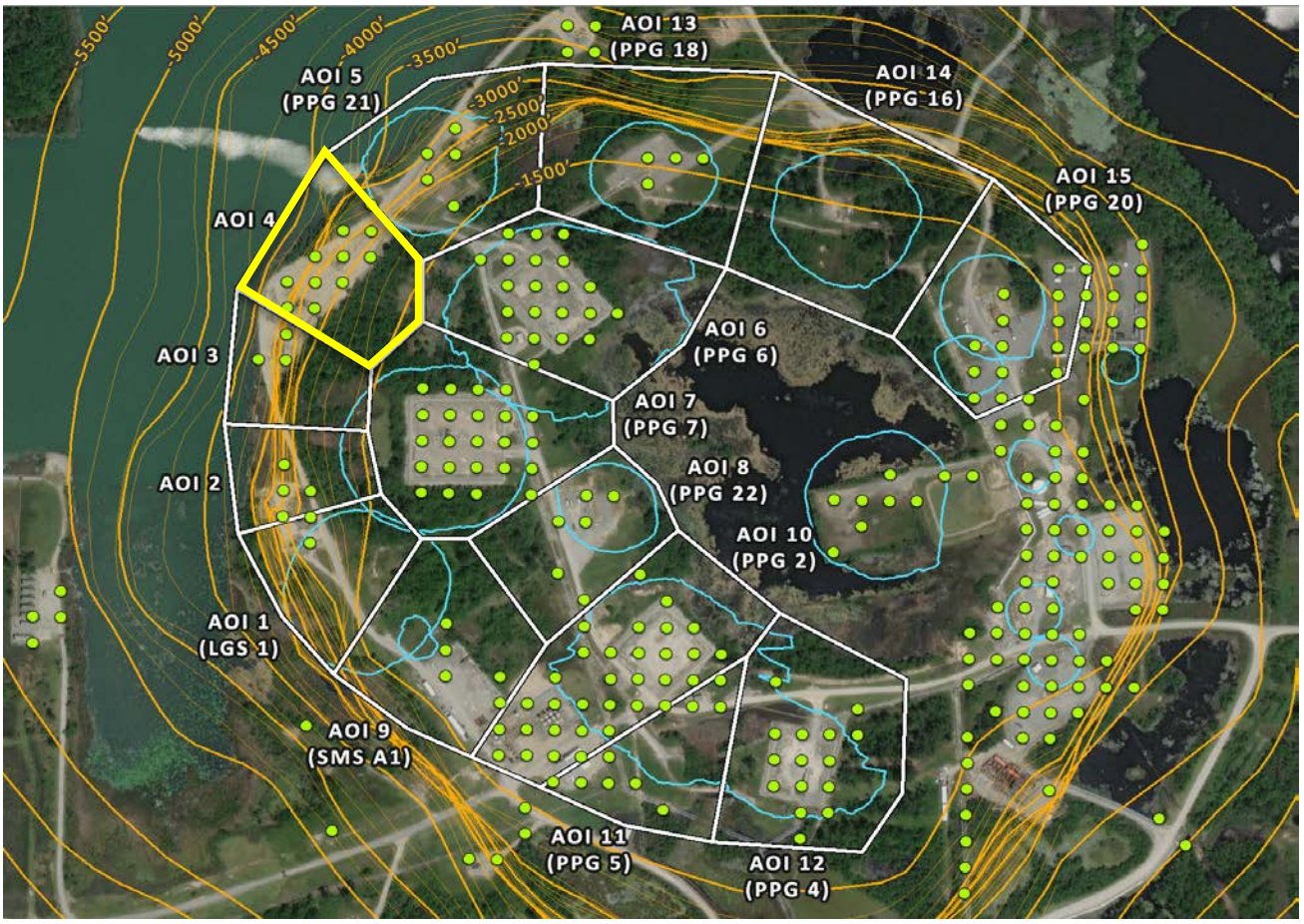
E-W (10/27/2024) Point Count: **3**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.19 | in/yr | +0.55 | in/yr |
| Acceleration: | -0.40 | in/yr$^2$ | 0.00 | in/yr$^2$ |

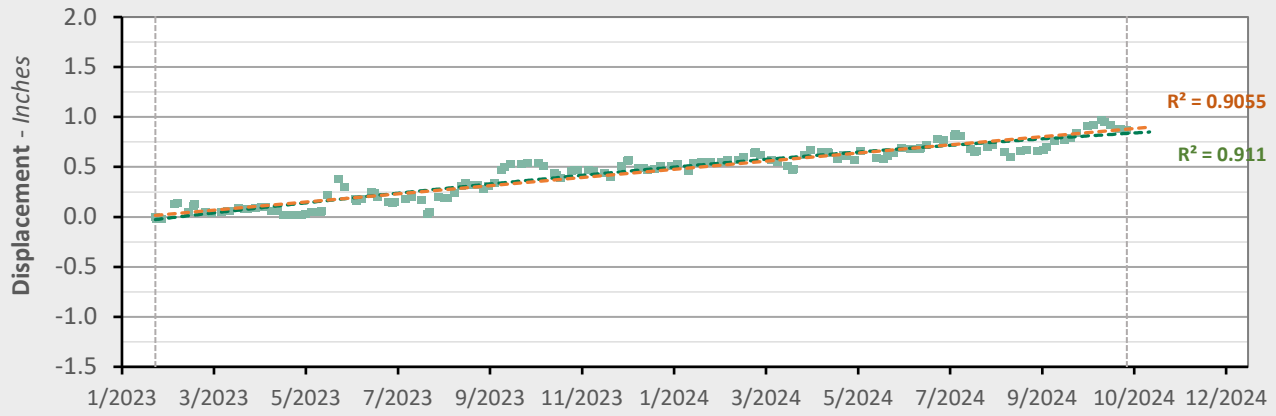
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 4 - Location Map




## AOI 4 - East-West Time Series

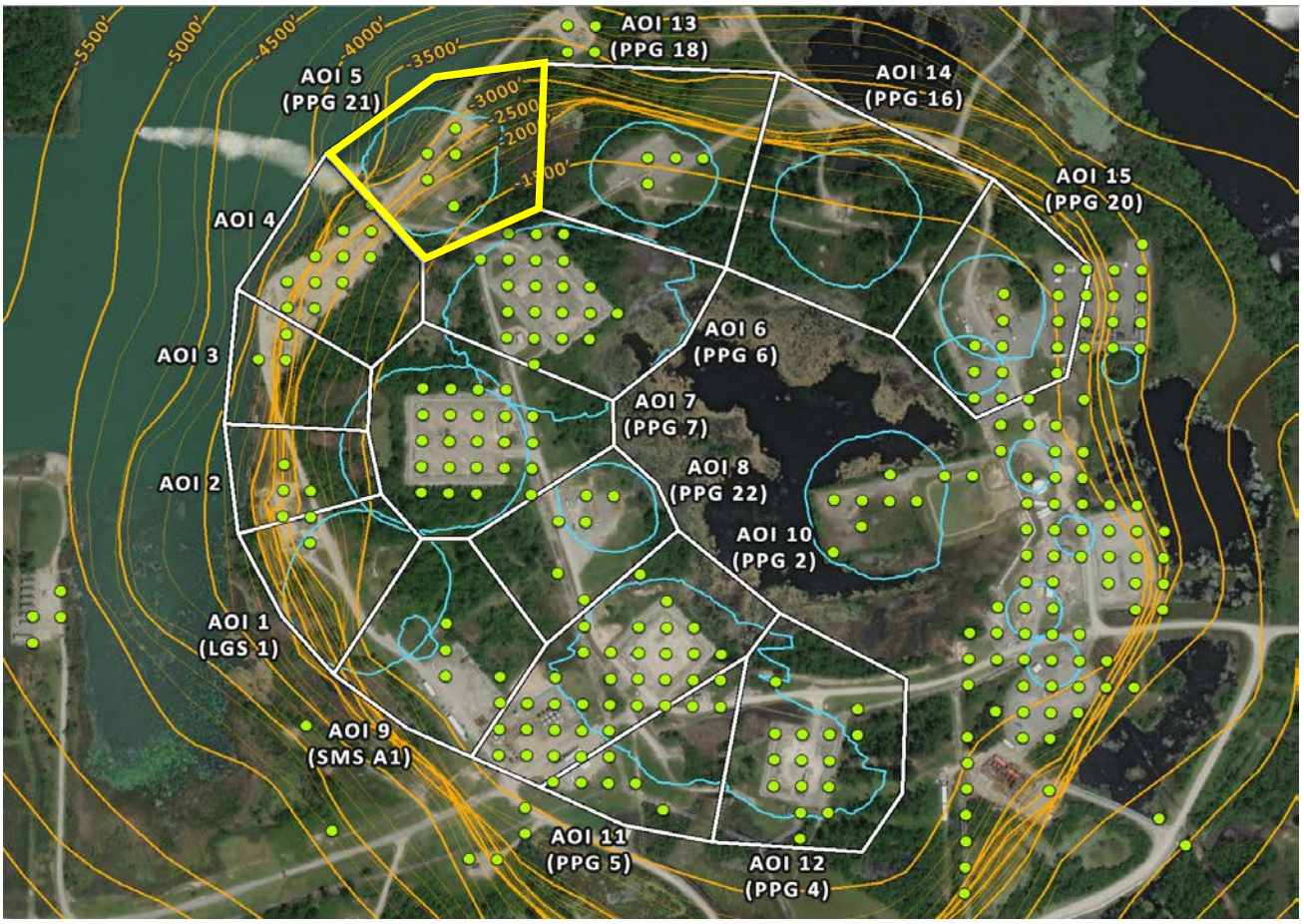
E-W (10/27/2024) Point Count: **10**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | +0.34 in/yr | +0.49 in/yr |
| Acceleration: | -0.17 in/yr$^2$ | 0.00 in/yr$^2$ |

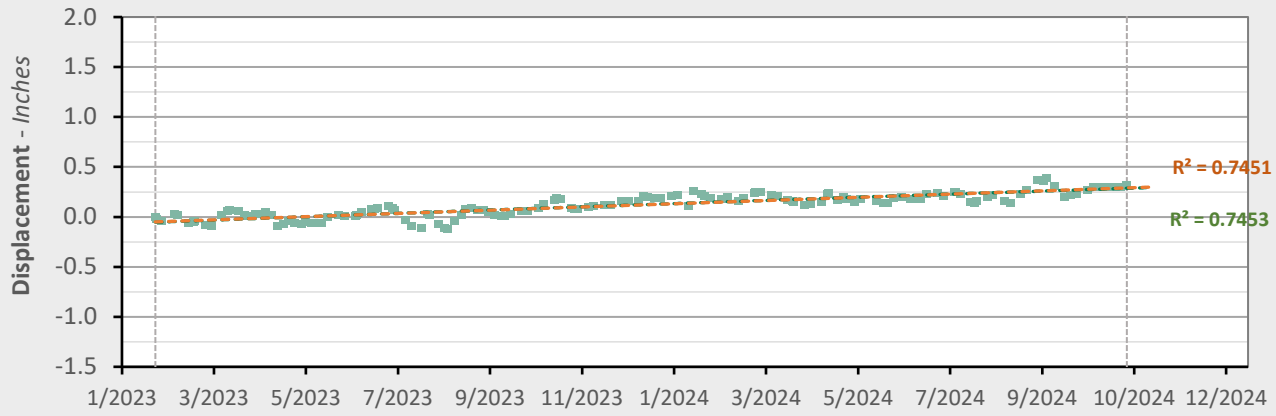
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 5 *(PPG 21)* - Location Map




## AOI 5 *(PPG 21)* - East-West Time Series

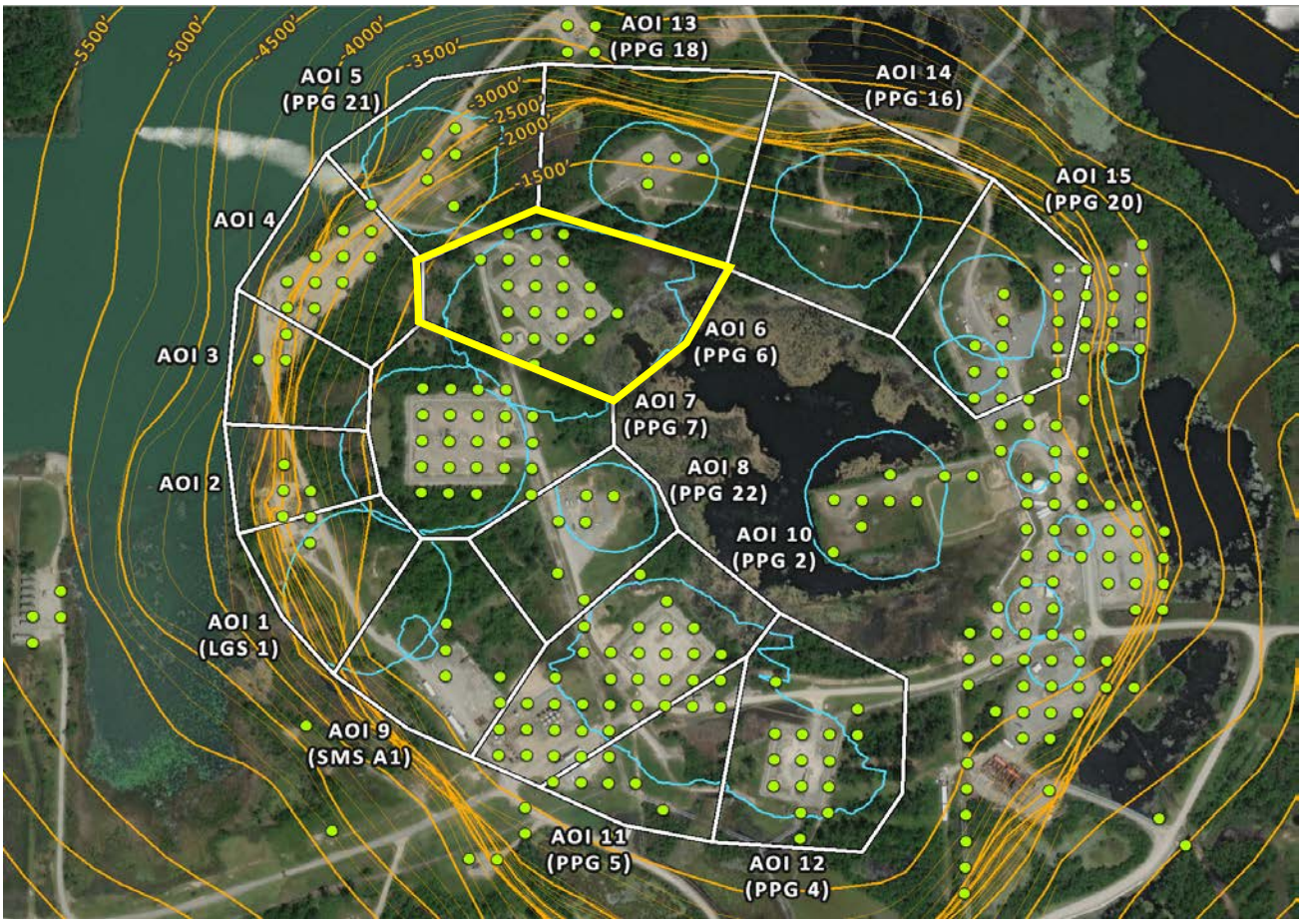
E-W (10/27/2024) Point Count: **5**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.18 | in/yr | +0.19 | in/yr |
| Acceleration: | -0.01 | in/yr$^2$ | 0.00 | in/yr$^2$ |

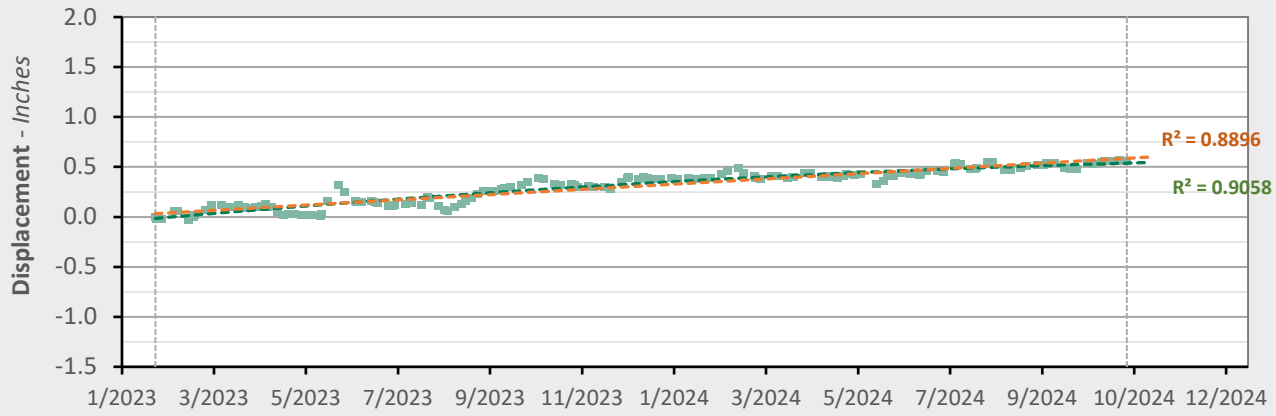
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 6 *(PPG 6)* - Location Map




## AOI 6 *(PPG 6)* - East-West Time Series

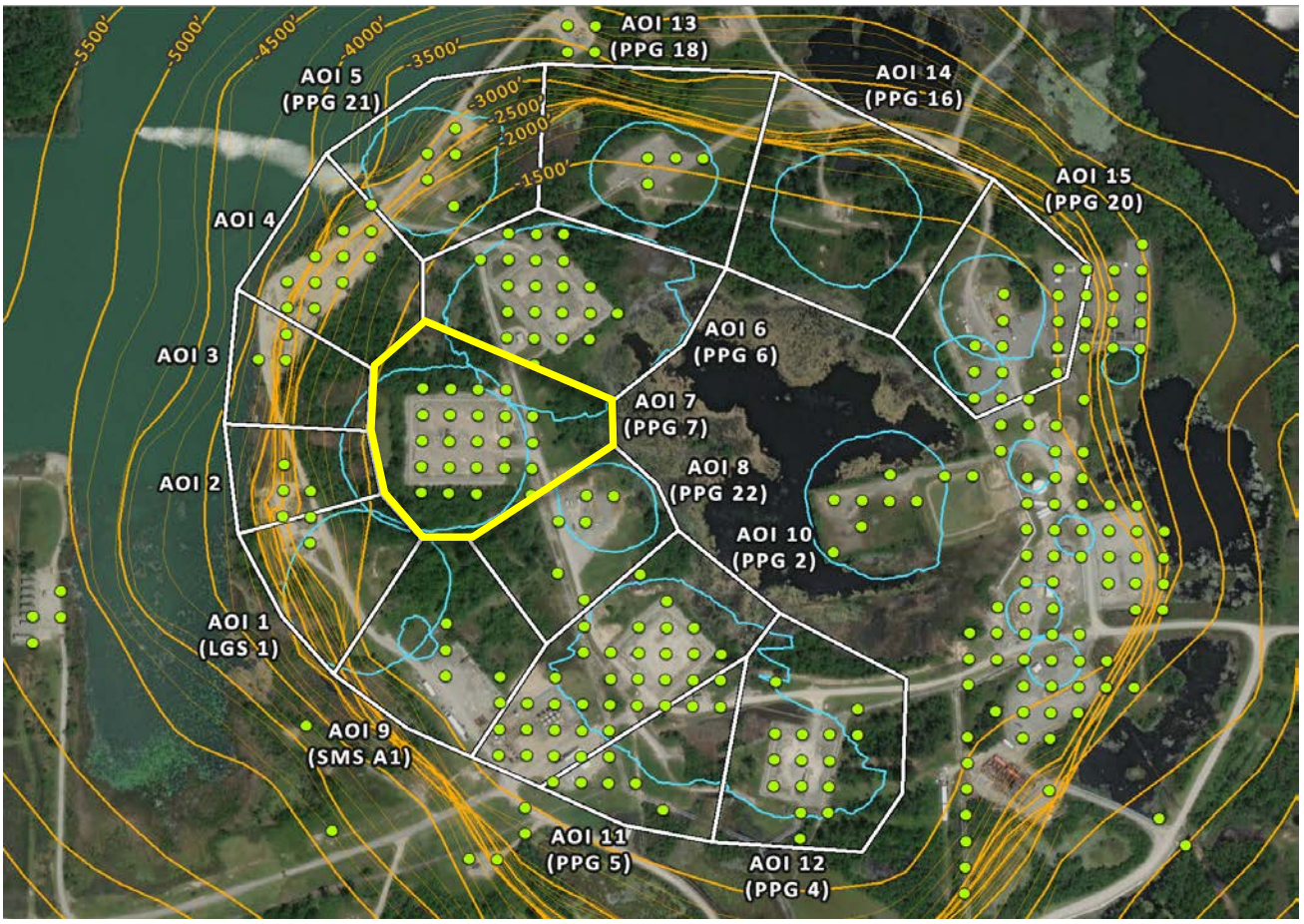
E-W (10/27/2024) Point Count: **21**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.15 | in/yr | +0.31 | in/yr |
| Acceleration: | -0.19 | in/yr$^2$ | 0.00 | in/yr$^2$ |

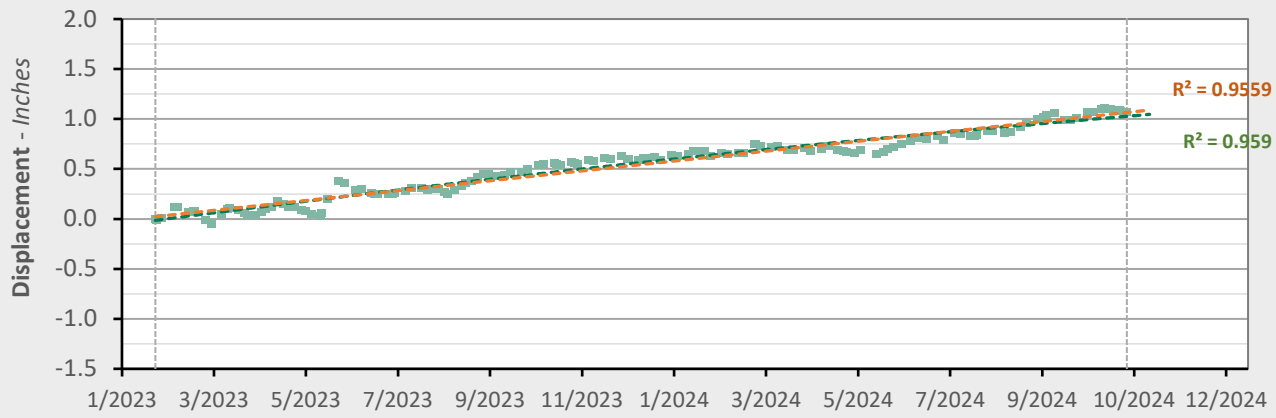
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 7 *(PPG 7)* - Location Map




## AOI 7 *(PPG 7)* - East-West Time Series

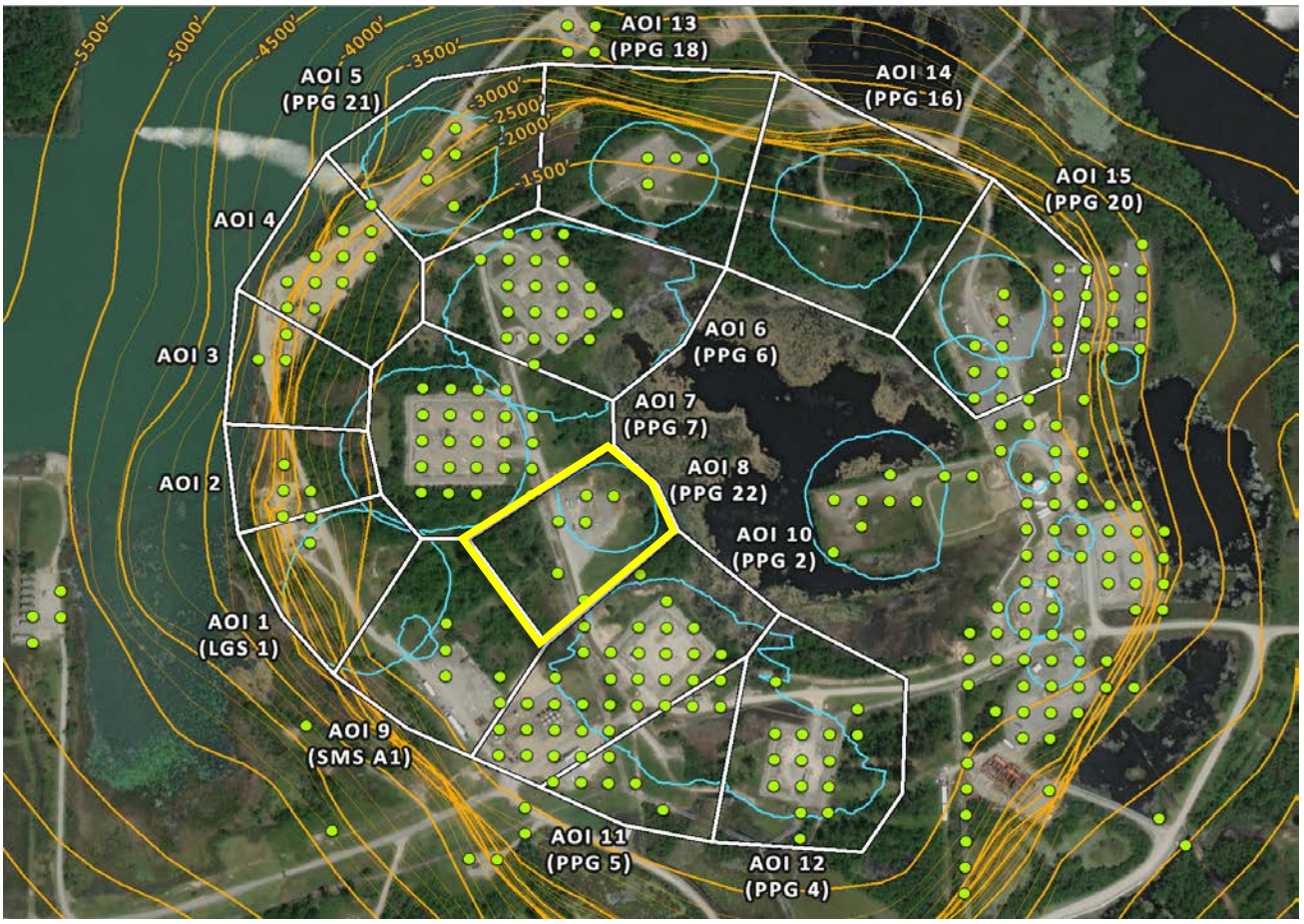
E-W (10/27/2024) Point Count: **23**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | +0.46 in/yr | +0.59 in/yr |
| Acceleration: | -0.15 in/yr$^2$ | 0.00 in/yr$^2$ |

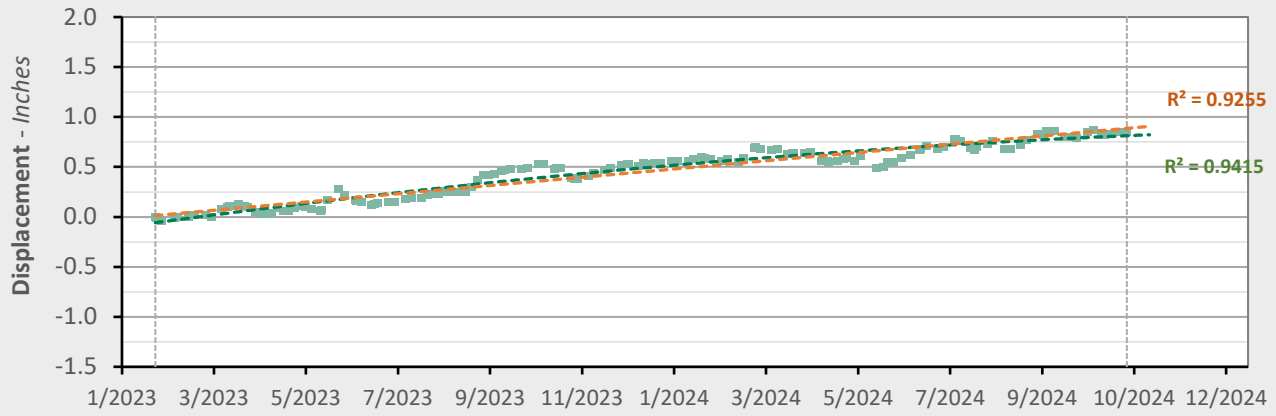
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 8 *(PPG 22)* - Location Map




## AOI 8 *(PPG 22)* - East-West Time Series

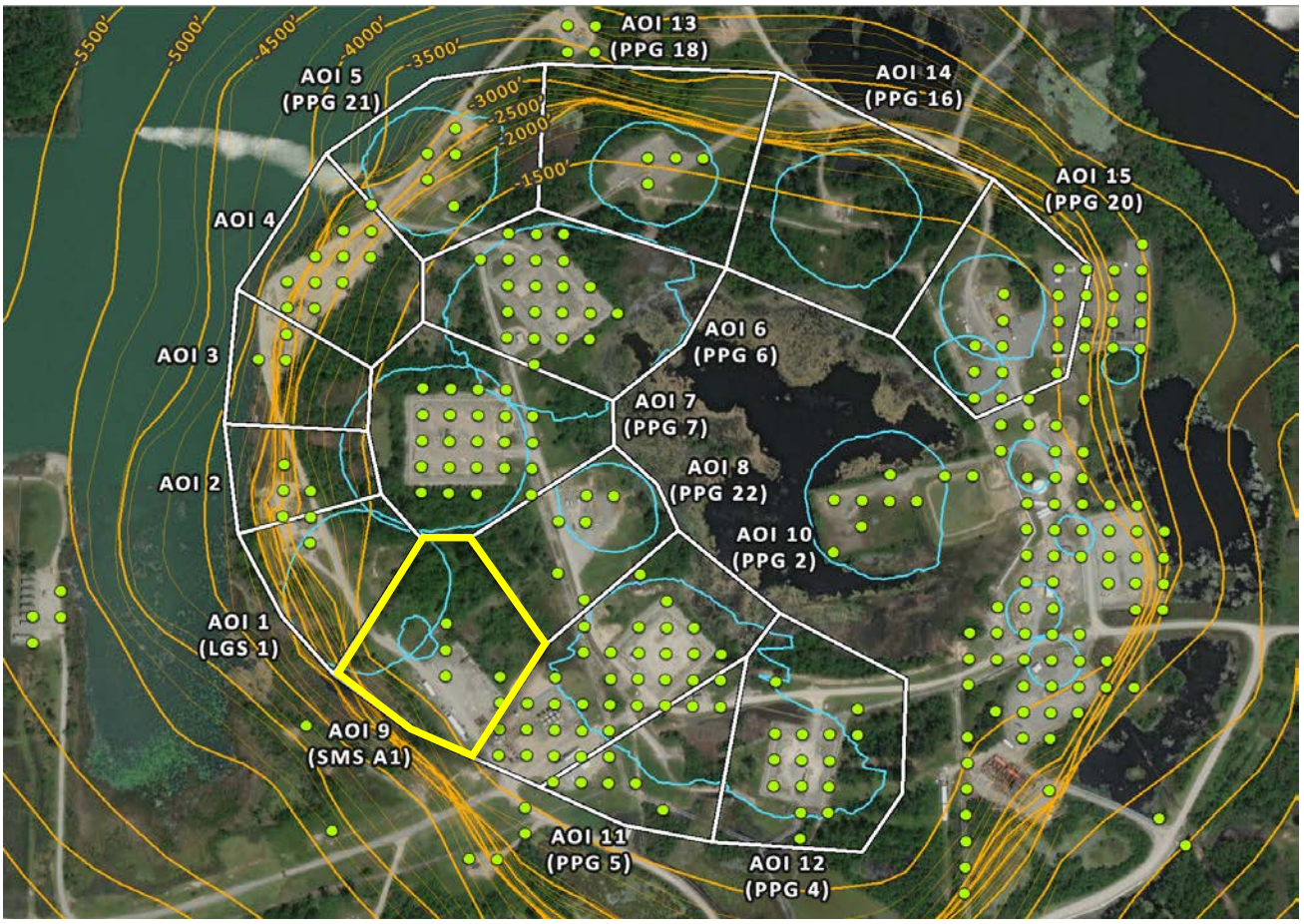
E-W (10/27/2024) Point Count: **5**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | +0.24 in/yr | +0.50 in/yr |
| Acceleration: | -0.29 in/yr$^2$ | 0.00 in/yr$^2$ |

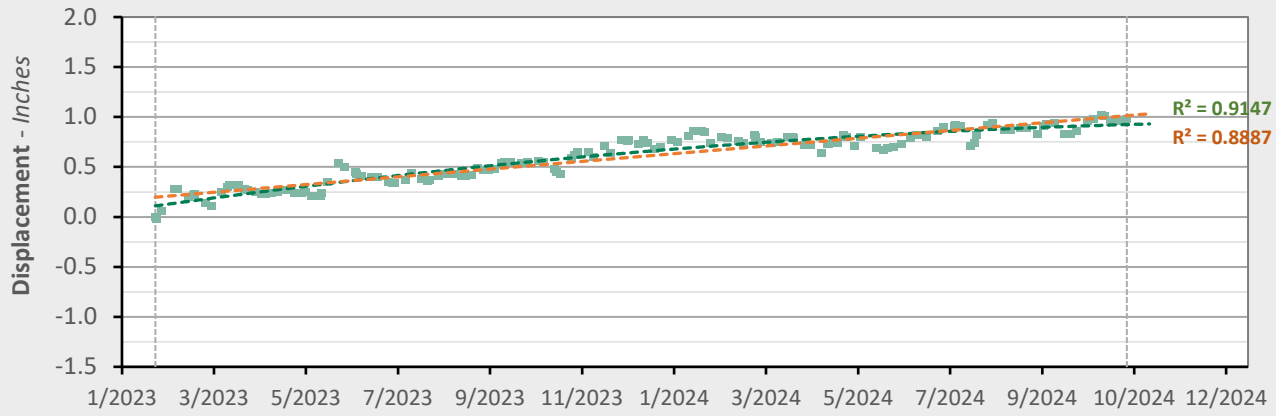
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 9 *(PPG A1)* - Location Map




## AOI 9 *(SMS A1)* - East-West Time Series

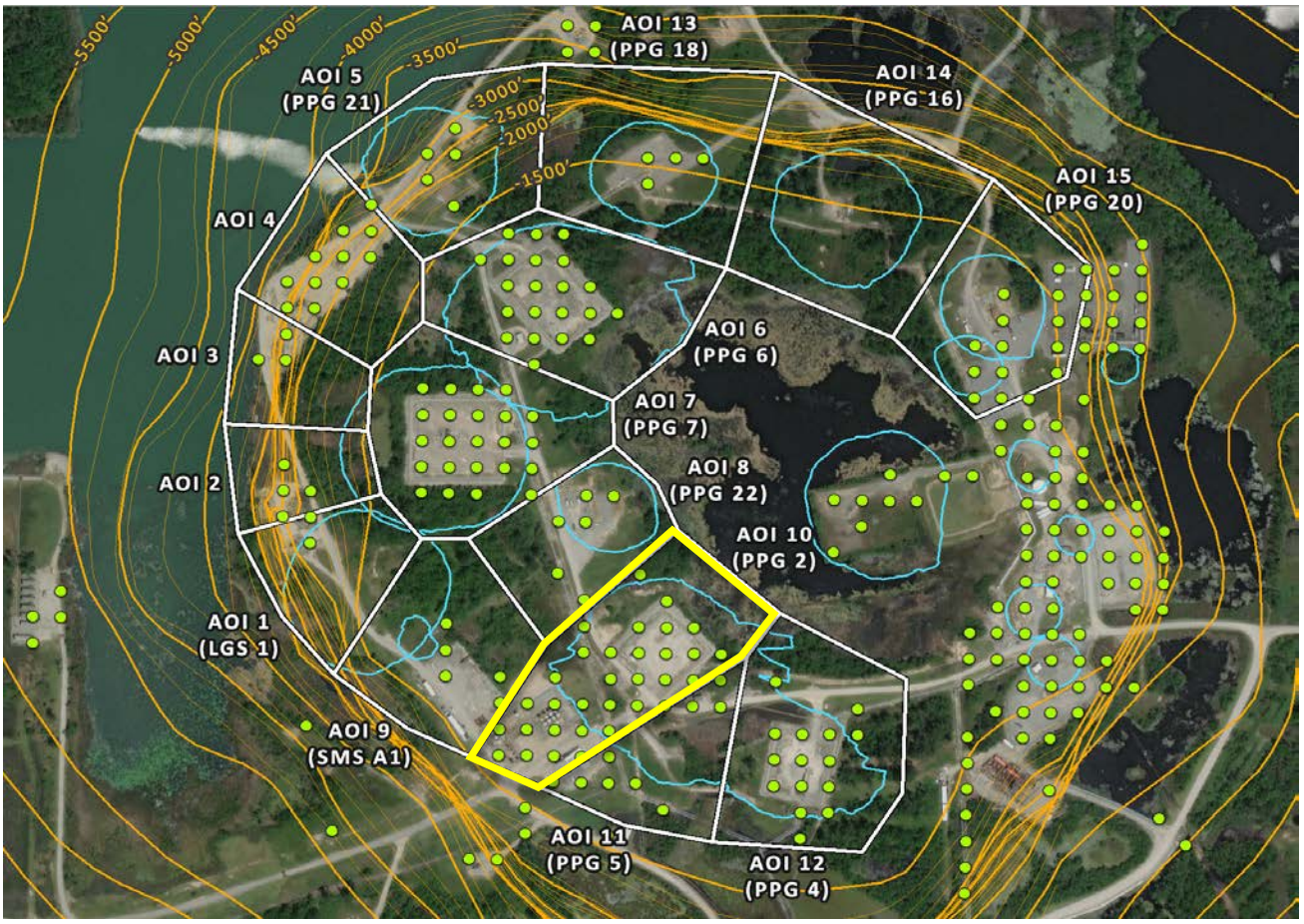
E-W (10/27/2024) Point Count: **6**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | +0.16 in/yr | +0.46 in/yr |
| Acceleration: | -0.35 in/yr$^2$ | 0.00 in/yr$^2$ |

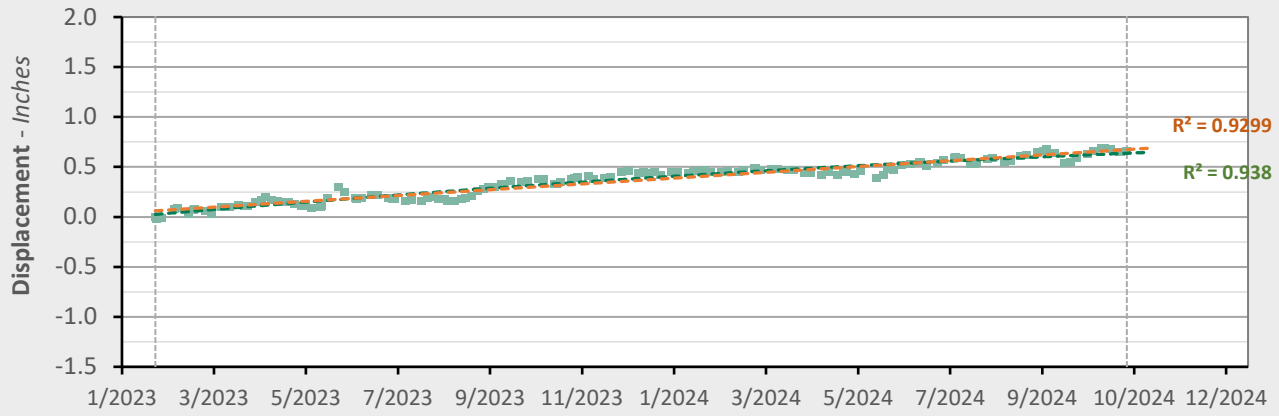
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 10 *(PPG 2)* - Location Map




## AOI 10 *(PPG 2)* - East-West Time Series

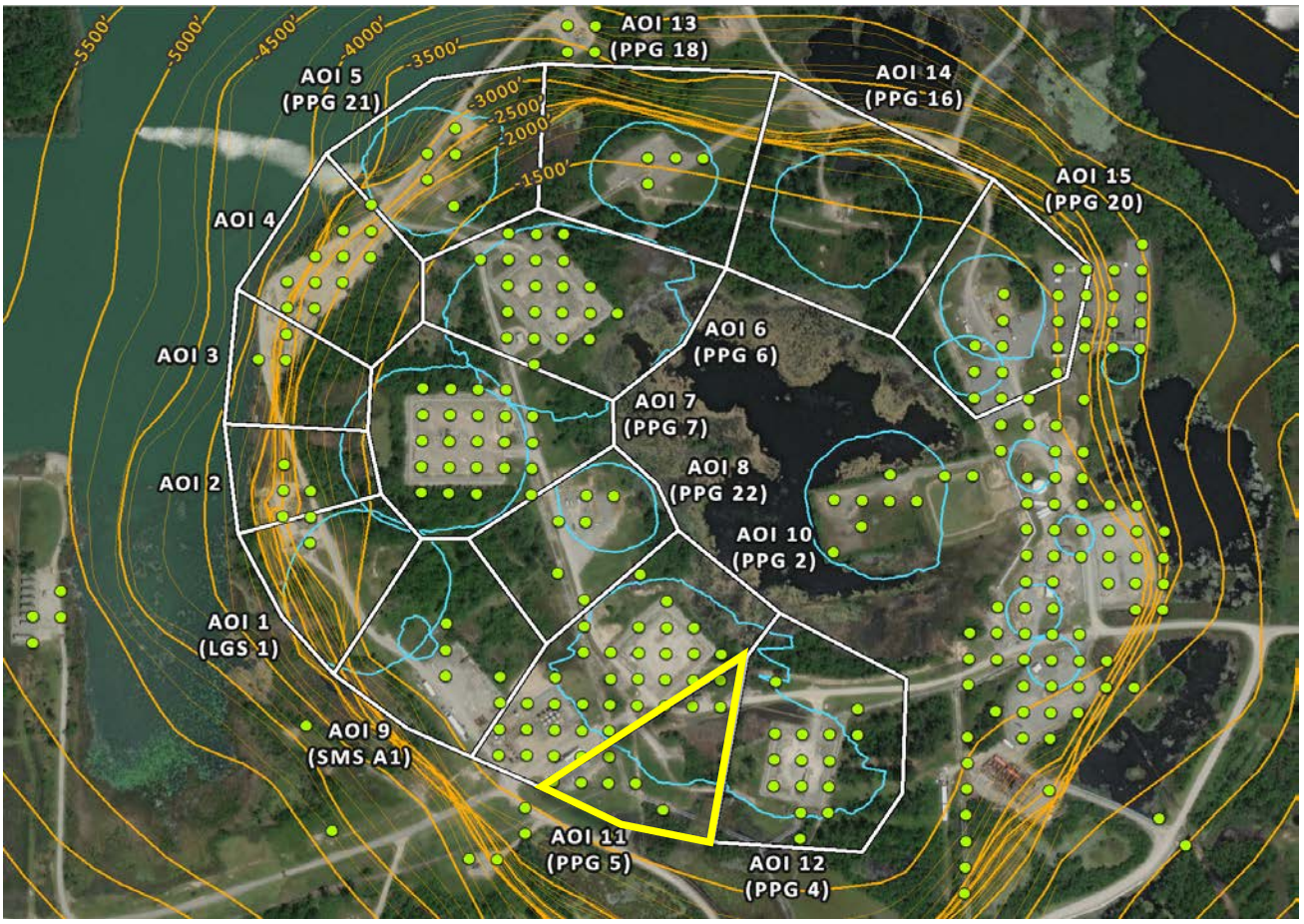
E-W (10/27/2024) Point Count: **31**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | +0.22 | in/yr | +0.35 | in/yr |
| Acceleration: | -0.14 | in/yr$^2$ | 0.00 | in/yr$^2$ |

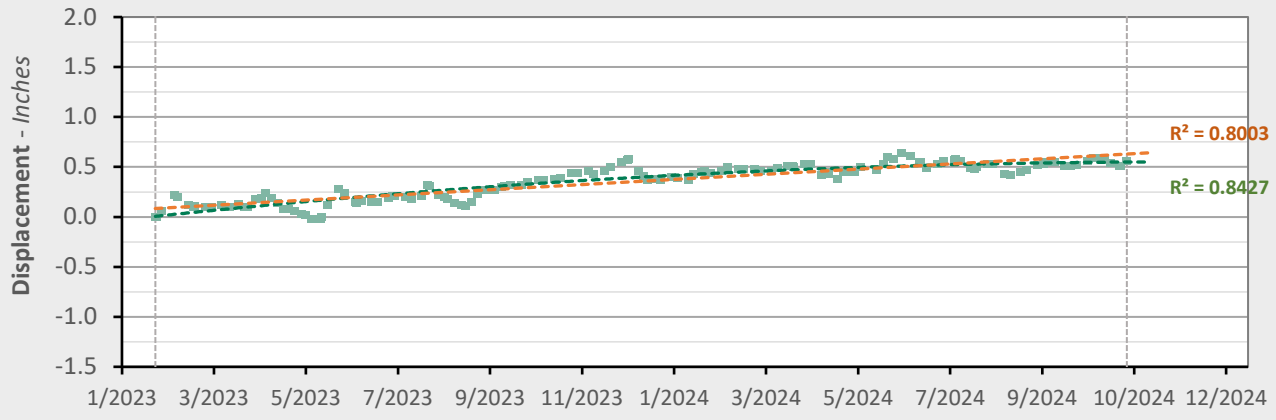
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 11 *(PPG 5)* - Location Map




## AOI 11 *(PPG 5)* - East-West Time Series

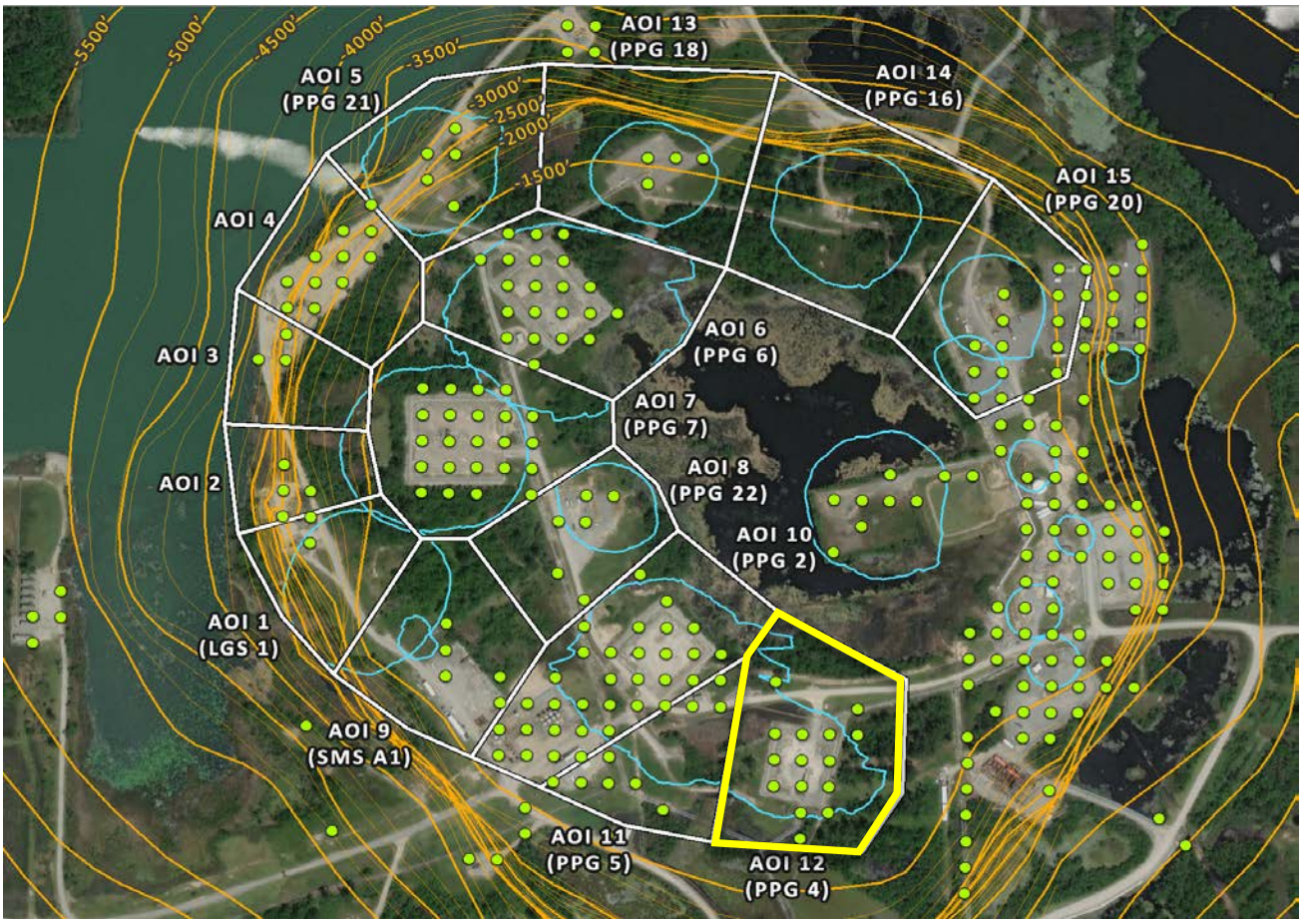
E-W (10/27/2024) Point Count: **10**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | +0.03 in/yr | +0.31 in/yr |
| Acceleration: | -0.31 in/yr$^2$ | 0.00 in/yr$^2$ |

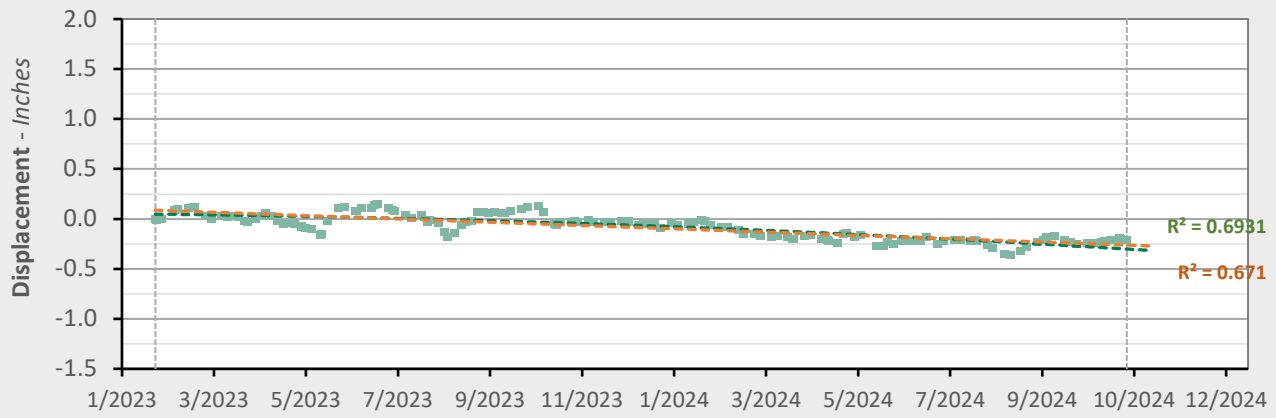
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 12 *(PPG 4)* - Location Map




## AOI 12 *(PPG 4)* - East-West Time Series

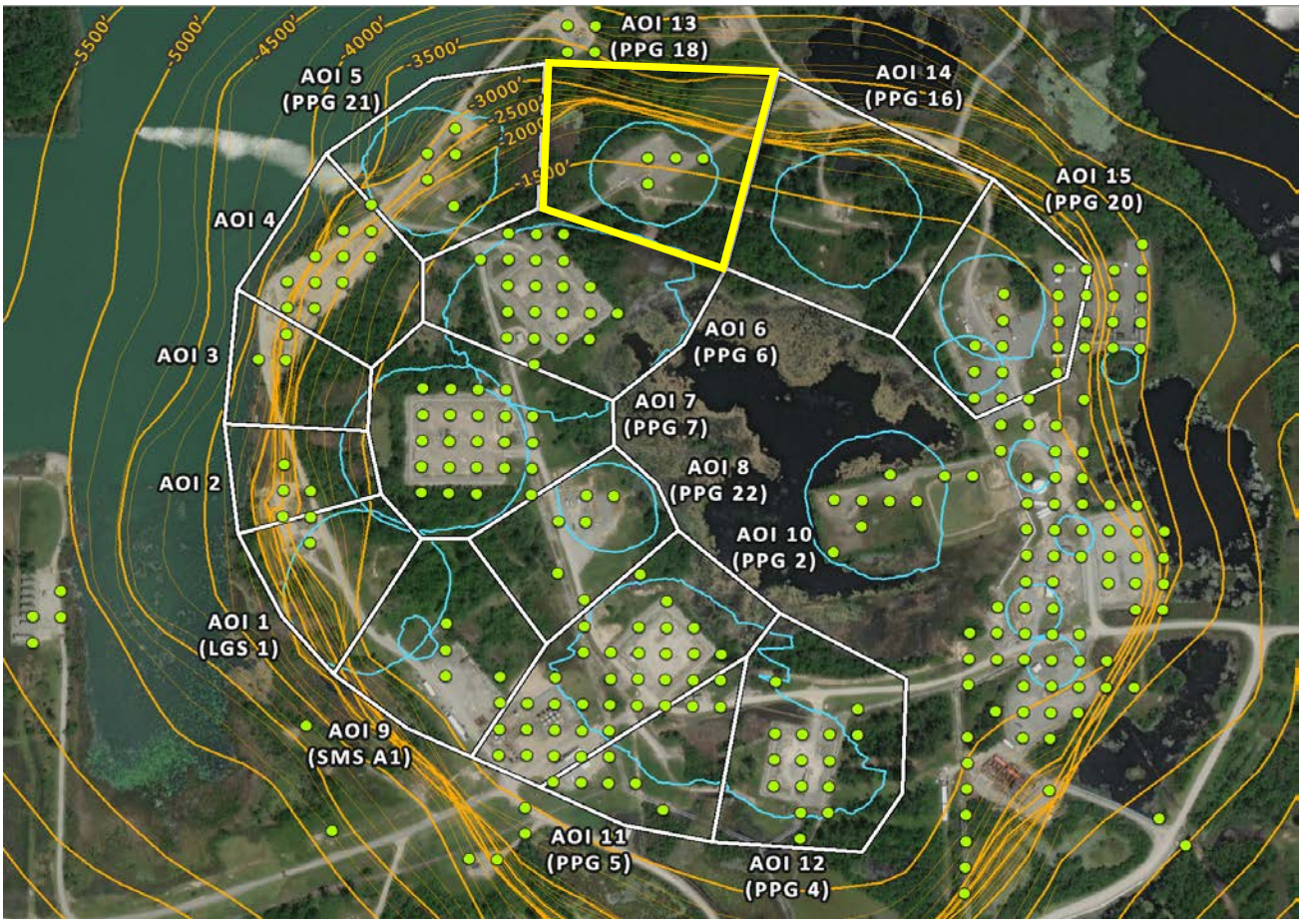
E-W (10/27/2024) Point Count: **15**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.34 in/yr | -0.20 in/yr |
| Acceleration: | -0.16 in/yr$^2$ | 0.00 in/yr$^2$ |

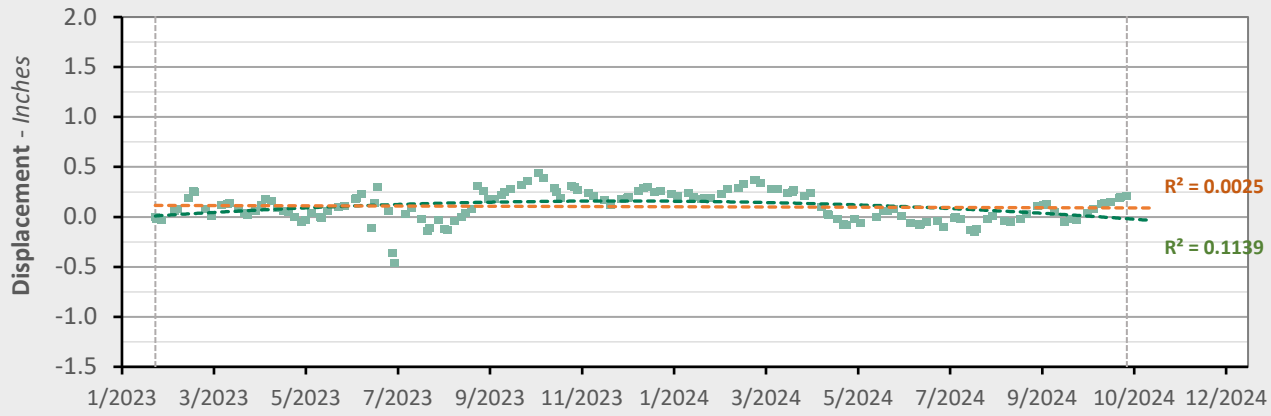
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 13 *(PPG 18)* - Location Map




## AOI 13 *(PPG 18)* - East-West Time Series

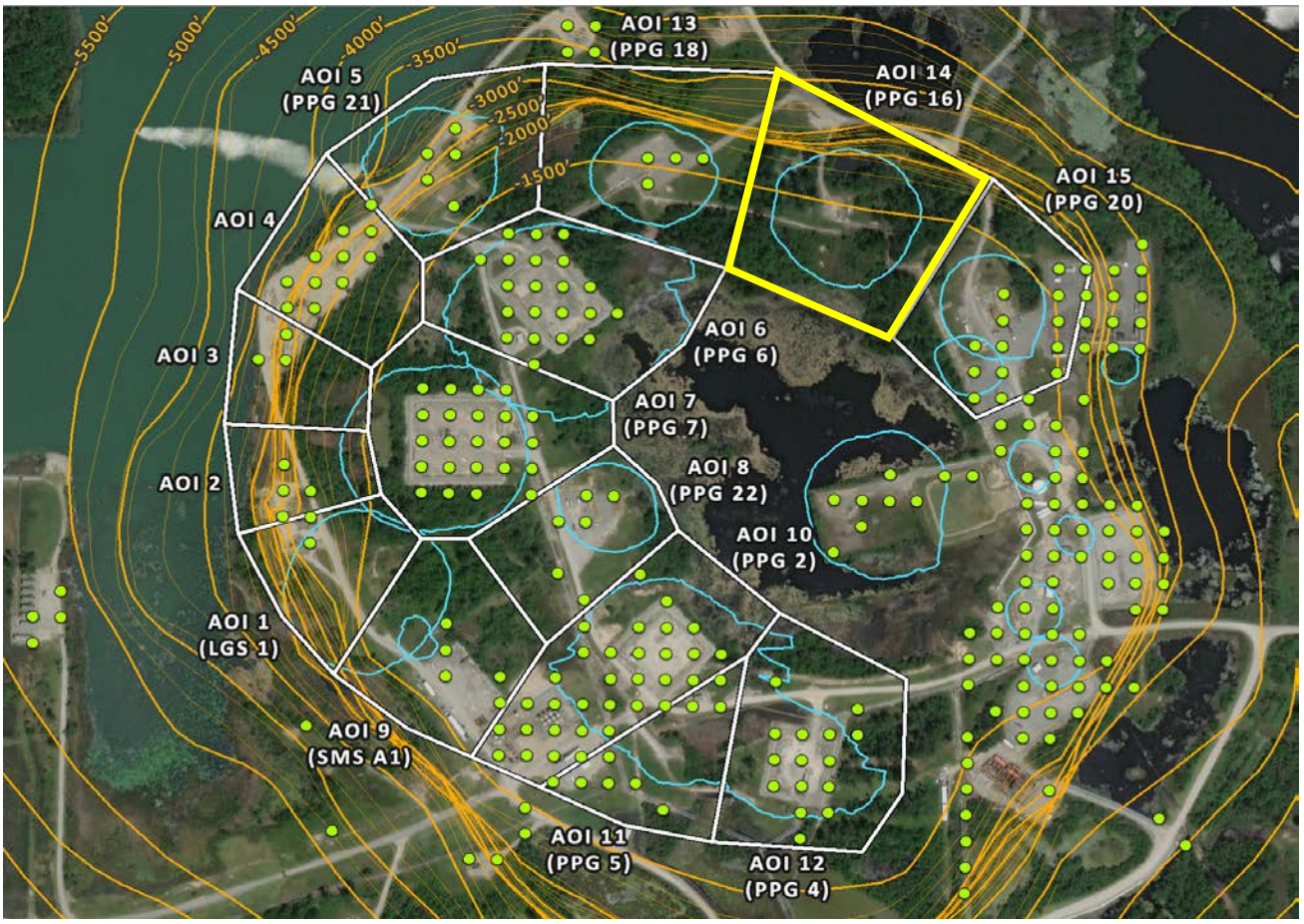
E-W (10/27/2024) Point Count: **3**




| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.39 in/yr | -0.01 in/yr |
| Acceleration: | -0.42 in/yr$^2$ | 0.00 in/yr$^2$ |

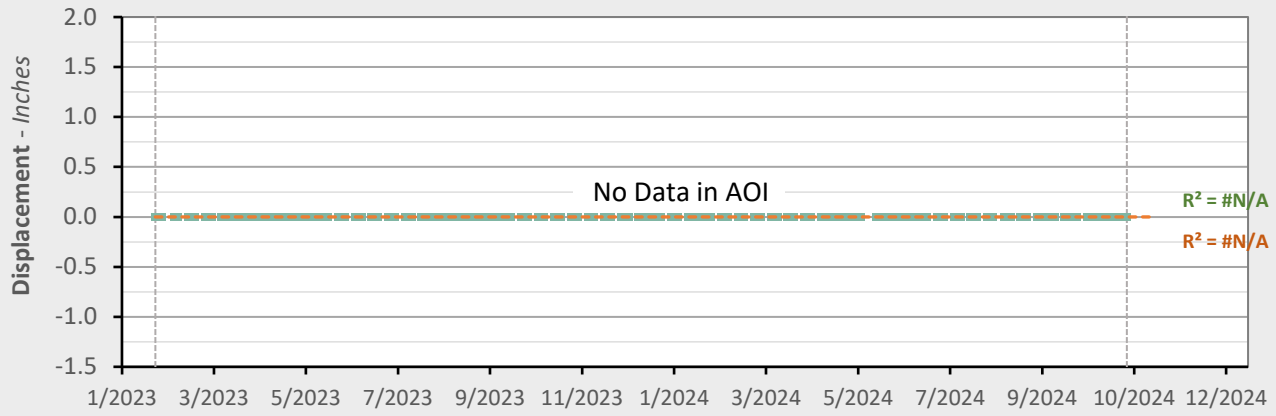
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## AOI 14 *(PPG 16)* - Location Map




## AOI 14 *(PPG 16)* - East-West Time Series

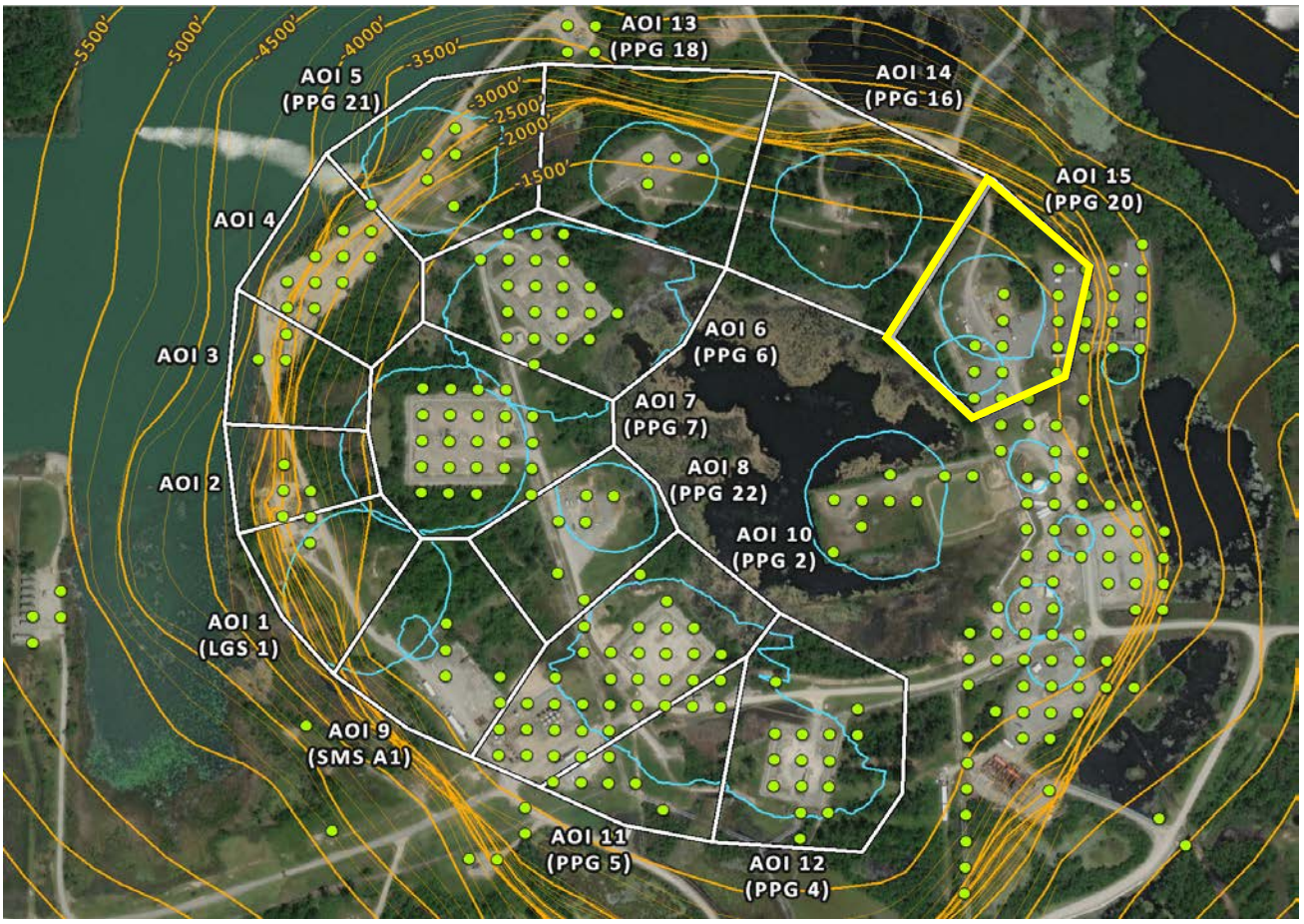
E-W (10/27/2024) Point Count: **0**




| | Nonlinear Trend | | Linear Trend | |
|---|---|---|---|---|
| Velocity: | N/A | in/yr | N/A | in/yr |
| Acceleration: | N/A | in/yr$^2$ | N/A | in/yr$^2$ |

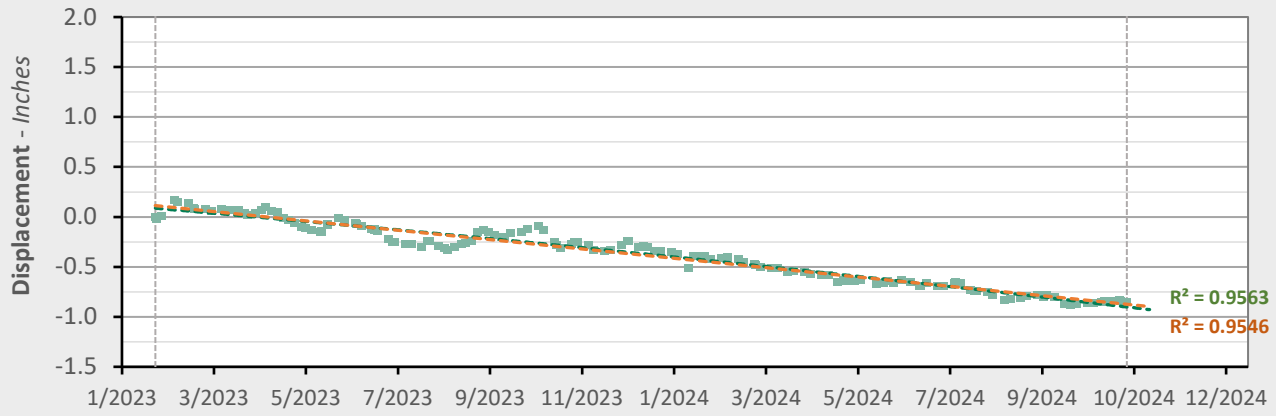
2D Displacement Measurement | Nonlinear Trend Line (Quadratic Regression) | Linear Trend Line (Linear Regression)

## AOI 15 *(PPG 20)* - Location Map




## AOI 15 *(PPG 20)* - East-West Time Series

E-W (10/27/2024) Point Count: **14**



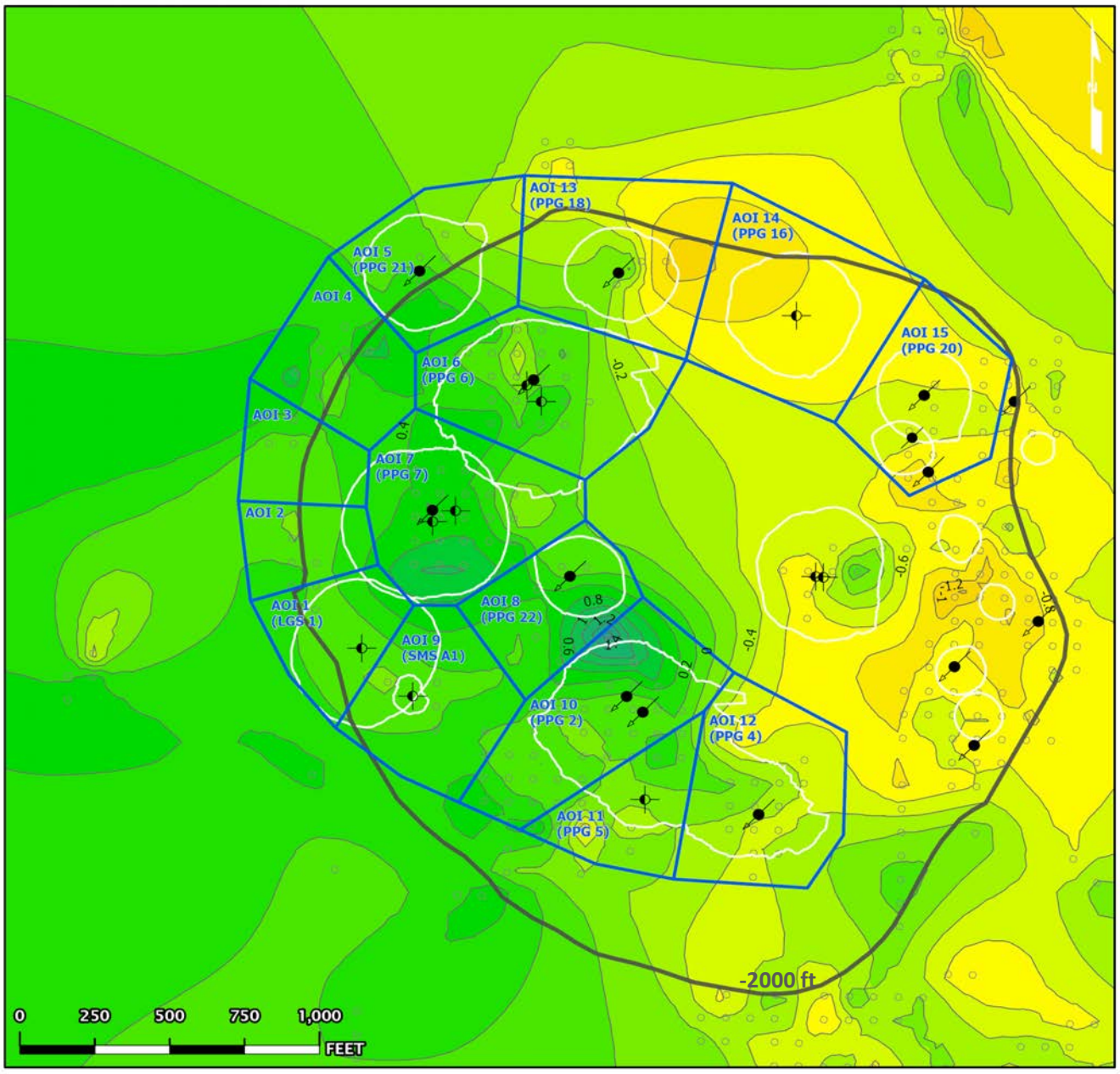

| | Nonlinear Trend | Linear Trend |
|---|---|---|
| Velocity: | -0.65 in/yr | -0.56 in/yr |
| Acceleration: | -0.10 in/yr$^2$ | 0.00 in/yr$^2$ |

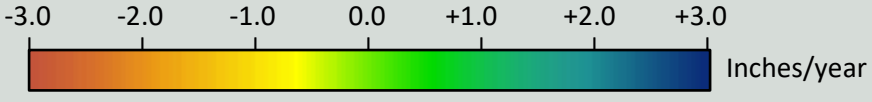
2D Displacement Measurement
Nonlinear Trend Line (Quadratic Regression)
Linear Trend Line (Linear Regression)

## East-West Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Contours

As of date: 10/27/2024




AOI Boundary | InSAR LOS Measurement Point | Contour (0.2)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

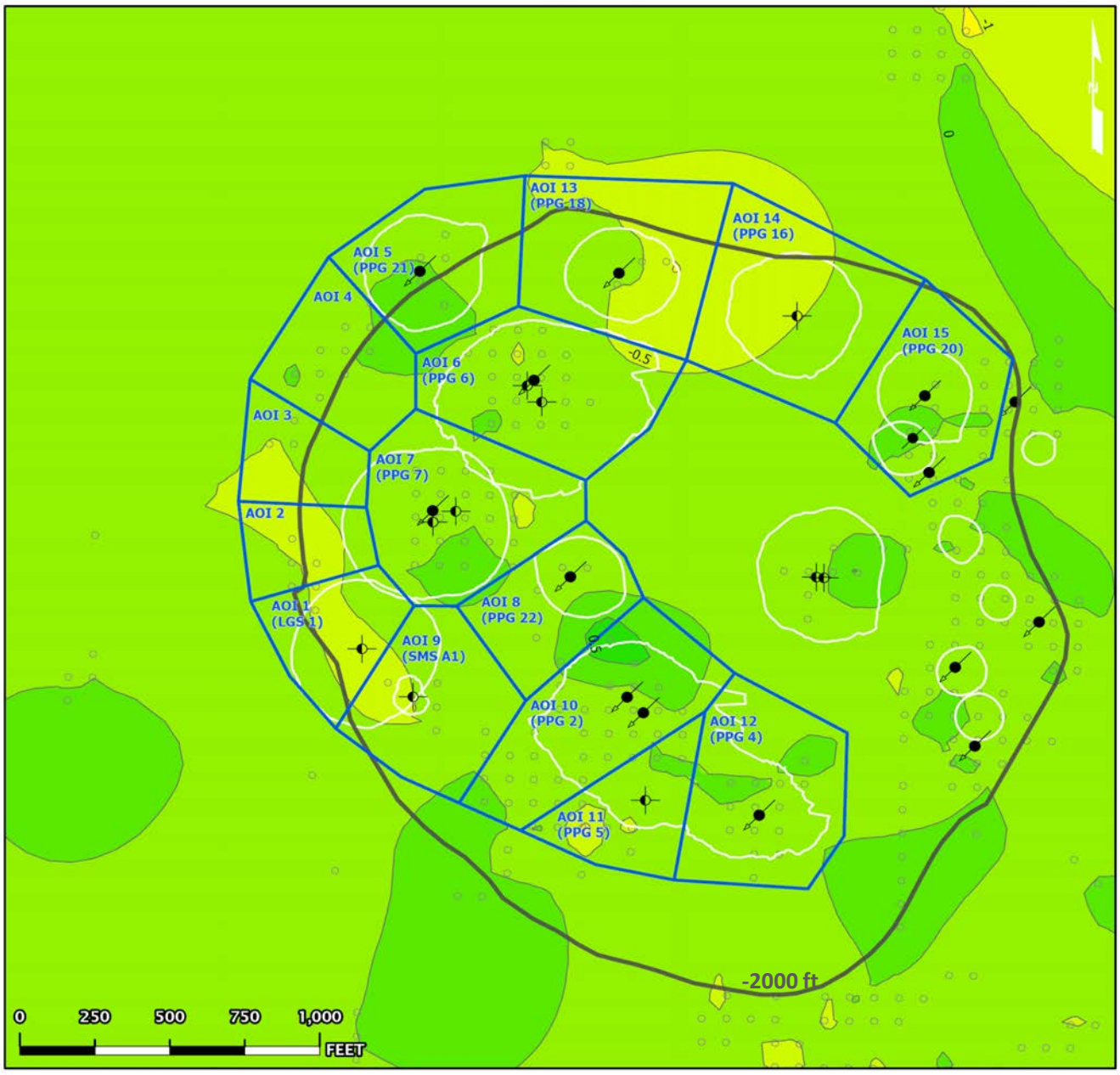
Cavern Well Surface Locations

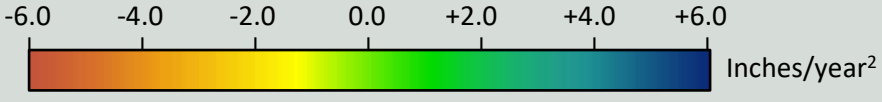
09 - Active - Injection | 29 - Dry and Plugged

## East-West Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Contours

Date range: 01/24/2023 - 10/27/2024




AOI Boundary | InSAR LOS Measurement Point | Contour (0.5)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

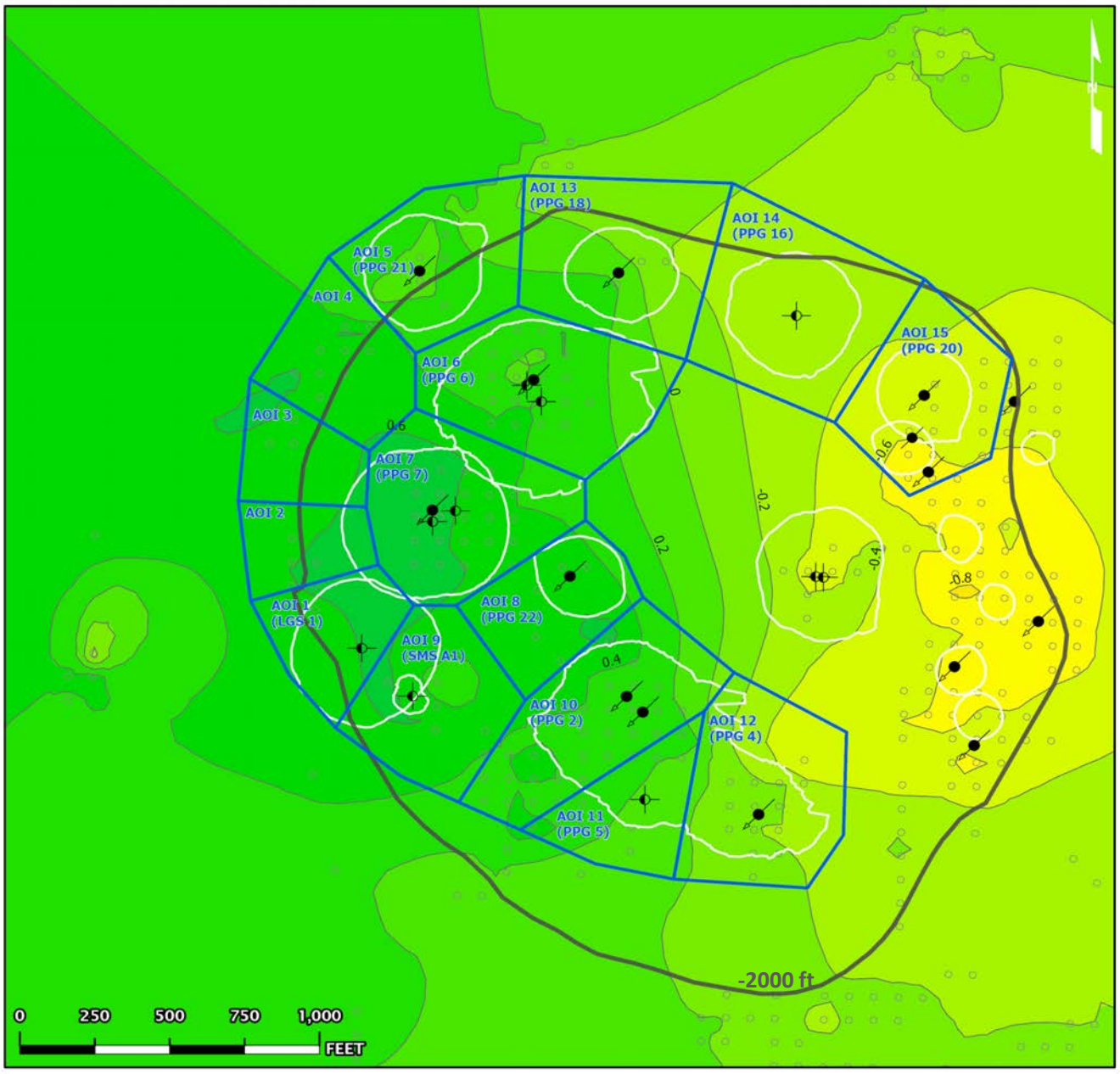
Cavern Well Surface Locations

09 - Active - Injection | 29 - Dry and Plugged

## East-West Data (01/24/2023 - 10/27/2024)

### Linear Velocity Contours

Date range: 01/24/2023 - 10/27/2024




-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

AOI Boundary | InSAR LOS Measurement Point | Contour (0.2)

Historical Cavern Extent | Top of Dome (-2000 ft Contour)

Cavern Well Surface Locations

09 - Active - Injection | 29 - Dry and Plugged

## East-West Data (01/24/2023 - 10/27/2024)

### Nonlinear Velocity Data Points

As of date: 10/27/2024


-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## East-West Data (01/24/2023 - 10/27/2024)

### Nonlinear Acceleration Data Points

Date range: 01/24/2023 - 10/27/2024


-6.0 -4.0 -2.0 0.0 +2.0 +4.0 +6.0

Inches/year$^2$

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged

## East-West Data (01/24/2023 - 10/27/2024)

### Linear Velocity Data Points

Date range: 01/24/2023 - 10/27/2024


-3.0 -2.0 -1.0 0.0 +1.0 +2.0 +3.0

Inches/year

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

Cavern Well Surface Locations

09 - Active - Injection
29 - Dry and Plugged