

Enhanced Subsidence Monitoring Plan Continuous Monitoring of Ground Displacement Near Western Caverns and Dome Flank

Sulphur Dome
Westlake Chemicals

February 2023



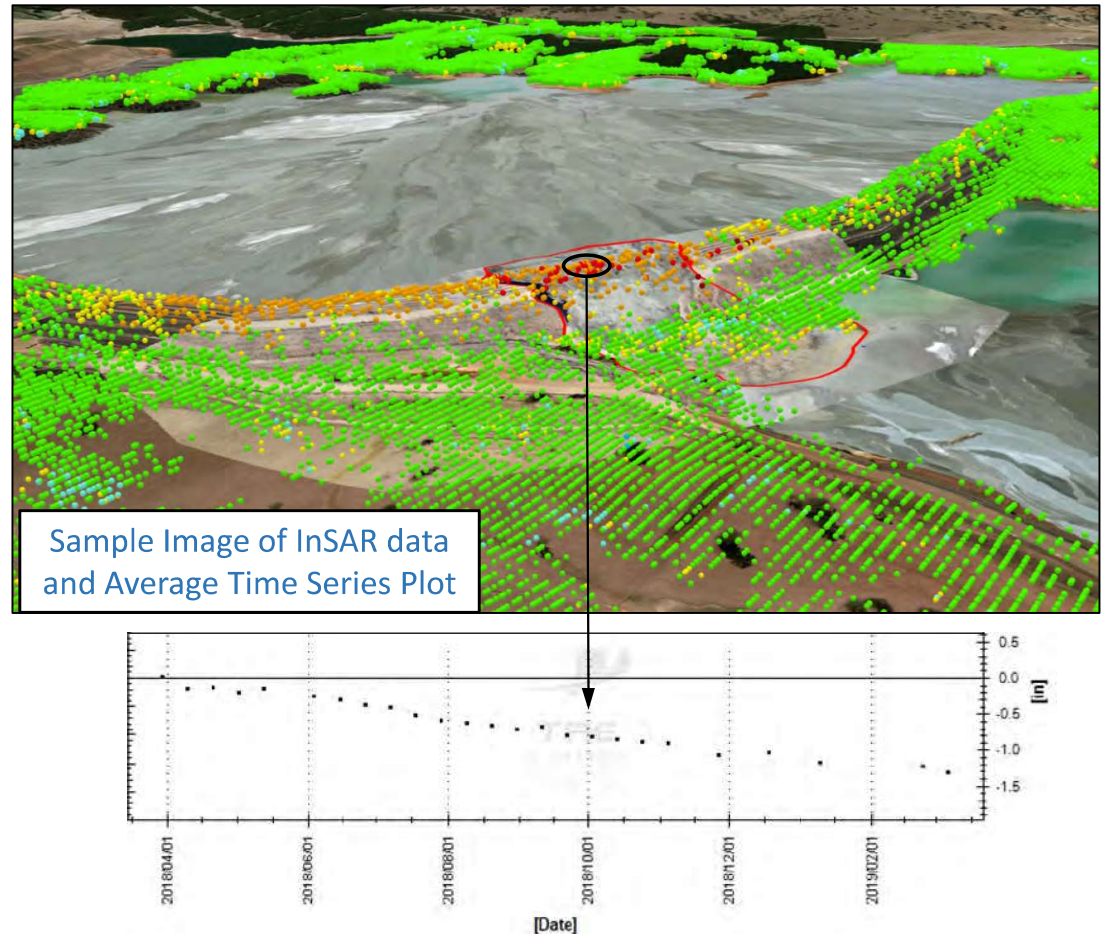
Continuous Monitoring Methodology

Continuous Monitoring of Ground Movement

- Methods for continuous monitoring of ground subsidence were investigated:
 - High-precision GPS surveys
 - Ground surveys - Geodetic Leveling / Differential Leveling
 - Satellite imagery - synthetic aperture radar (SAR)
- Interferometric Synthetic Aperture Radar (InSAR) monitoring has been established as the most reliable way to consistently evaluate small – normally undetectable - movements and provide advance notice of changing ground subsidence trends
- A Continuous Monitoring Plan using InSAR data has been developed with TRE-Altamira (TREA) and is currently being employed to evaluate ground movement across the Sulphur Dome area
- The following slides provide general information on the InSAR technology and measurement parameters being employed at the Sulphur Dome

Overview of InSAR Monitoring Technique

- InSAR analysis identifies and monitors the movement of natural targets on the ground
- Point cloud of measurement points (MP) is generated in analysis
- MP Attributes:
 - Annual displacement rate [in/yr]
 - Time Series of displacement [in]
 - 1-D (Line of Sight - LOS)
 - Line-of-sight (LOS angle) displacement along view path of satellite to ground target
- Measurement precision
 - Rate: ± 0.01 in/yr
 - Single measurement: ± 0.20 in



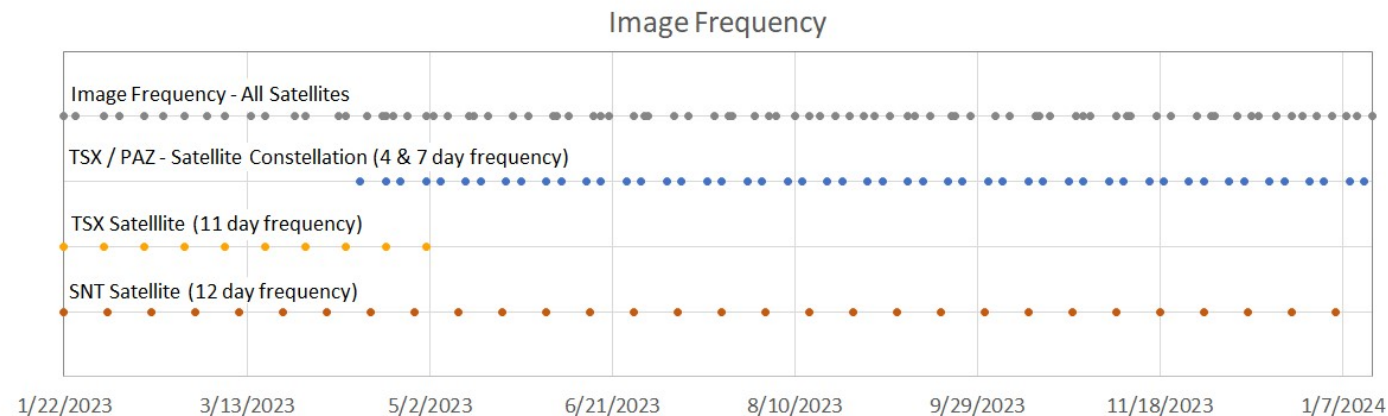
Data Coverage and Point Density

- The density and coverage of measurement points (MP) depends on the satellite signal parameters, surface characteristics and changes over time in the investigation area:
 - MP density increases with the satellite resolution and time span of image set
 - MP density and coverage is generally low over:
 - Vegetated areas and low reflectivity areas (i.e. areas where the signal backscattered to the satellite is low)
 - Areas affected by temporal decorrelation (i.e. radar signal is not coherent over time), which is generally associated with:
 - Seasonal surface changes, such as intermittent flooding in marshes and wetlands
 - Rapid surface changes, such as active operations areas
 - Fast movement (displacement rate >1 meter/yr)
 - No measurement of ground displacement is possible beneath water bodies

Parameters of InSAR Dataset and Collection Frequency

- Current Satellite and Data Delivery Frequency:
 - Sentinel 1 (SNT)
12 days
 - TerraSAR-X (TSX)
11 days
 - 5.40-day avg. frequency
- Starting April 2023:
 - Sentinel 1 (SNT)
12 days
 - TSX / PAZ Constellation
4 & 7 days
 - 3.96-day avg. frequency

	Sentinel-1	TerraSAR-X	TerraSAR-X	PAZ
Mode / Resolution	16 x 65 ft	Spotlight (3 x 3 ft)	Spotlight (3 x 3 ft)	Spotlight (3 x 3 ft)
Track	T136	T29	T67	T120
Band (wavelength)	C-Band (2.32 in)	X-Band (1.22 in)	X-Band (1.22 in)	X-Band (1.22 in)
Nominal frequency	12- day	11- day	11- day	11- day
Orbit (LOS angle)	Ascending 43°	Descending 17°	Descending 37°	Descending 37°
Date range	04 Oct 2016 – 20 Jan 2024	16 Jun 2022 – 01 May 2023	24 Jan 2023 – 11 Jan 2024	28 Jan 2023 – 15 Jan 2024
Number of images	199	30	34	33



InSAR Data Evaluation Plan

InSAR Data Evaluation Plan

- New datasets are delivered by TREA within 48 hours of new image capture
- Lonquist will review the data same-day and report any recognizable deviations from established subsidence trends
- Lonquist will evaluate the dataset and issue a standardized report that provides the following within 24 hours of receiving each dataset:
 - Map and time-series plots of ground movement showing statistical trends, for point groups near caverns and flank on the western side of the dome
 - Contour map showing current acceleration/deceleration trends in ground movement on western side of dome
 - Cross sections displaying profiles of ground movement and velocity over time across key areas on the western side of dome

InSAR Sample Preliminary Evaluation

- 2 SNT datasets and 3 TSX datasets have been received since continuous monitoring began
- The following slides depict preliminary analysis being performed on each incoming dataset as report method and format is being prepared
- No deviation from established subsidence trends has been observed to date

TerraSAR-X (TSX) Map



TerraSAR-X (TSX) – PPG 6



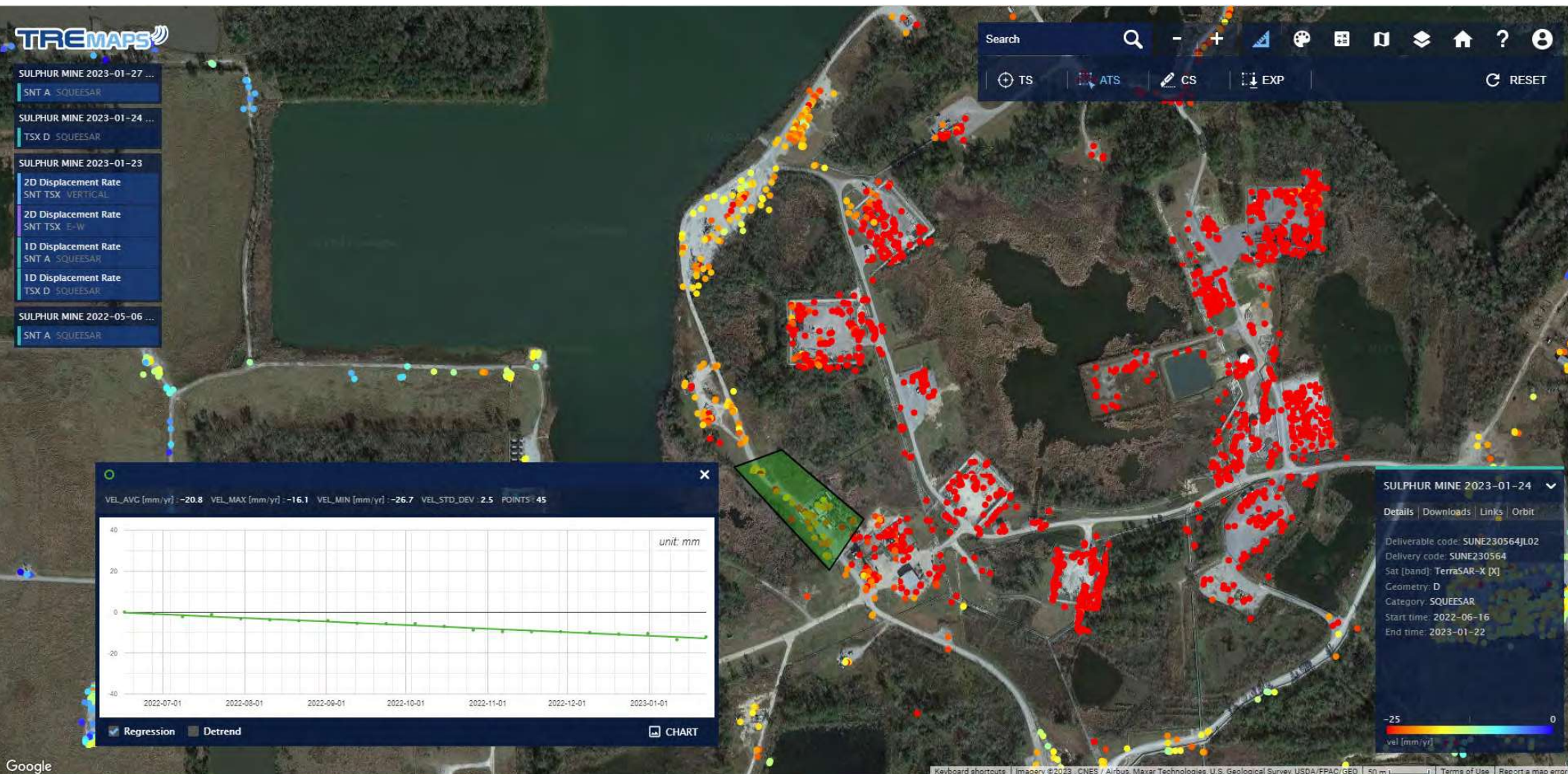
TerraSAR-X (TSX) – PPG 7



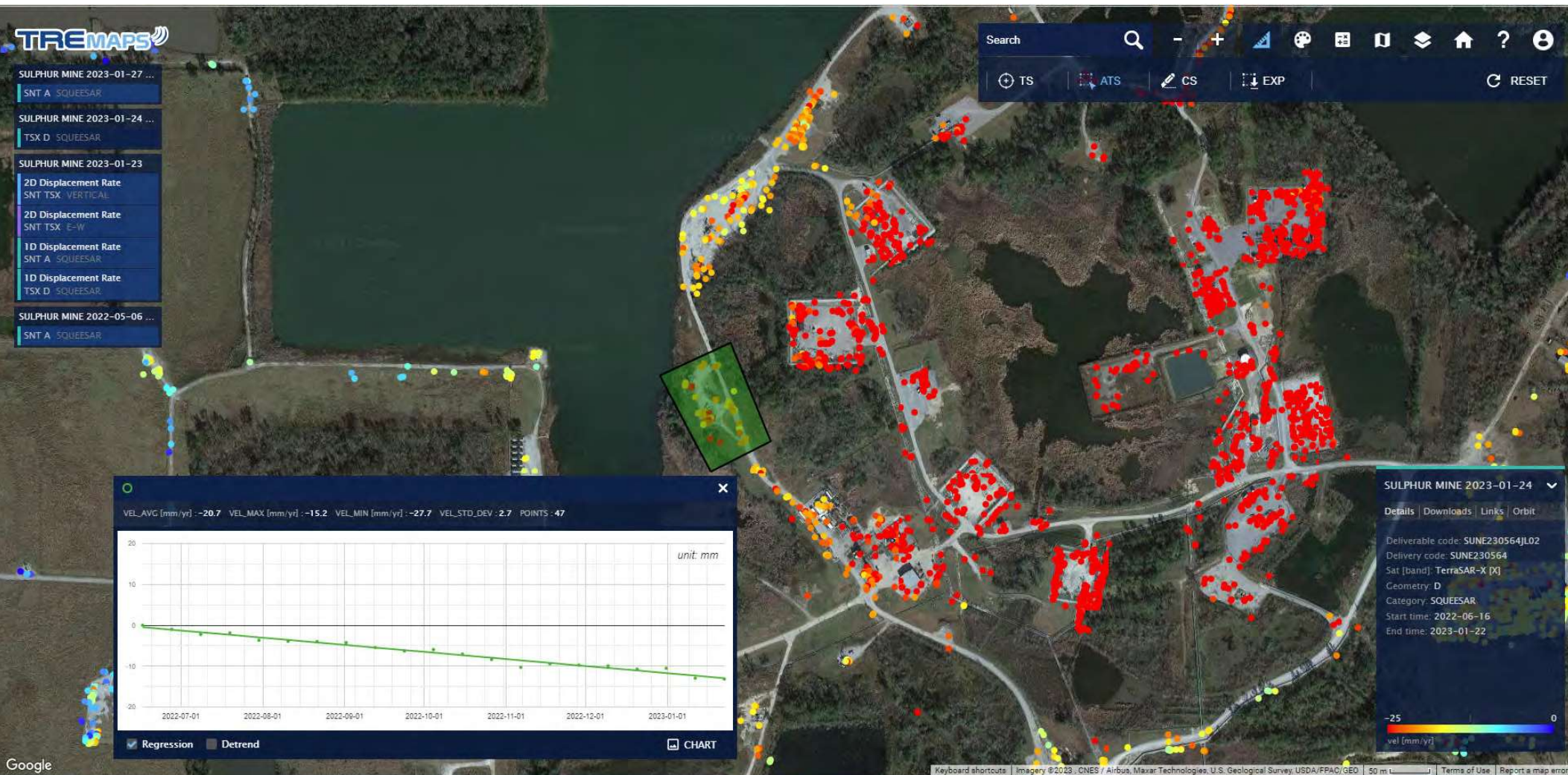
TerraSAR-X (TSX) – PPG 22



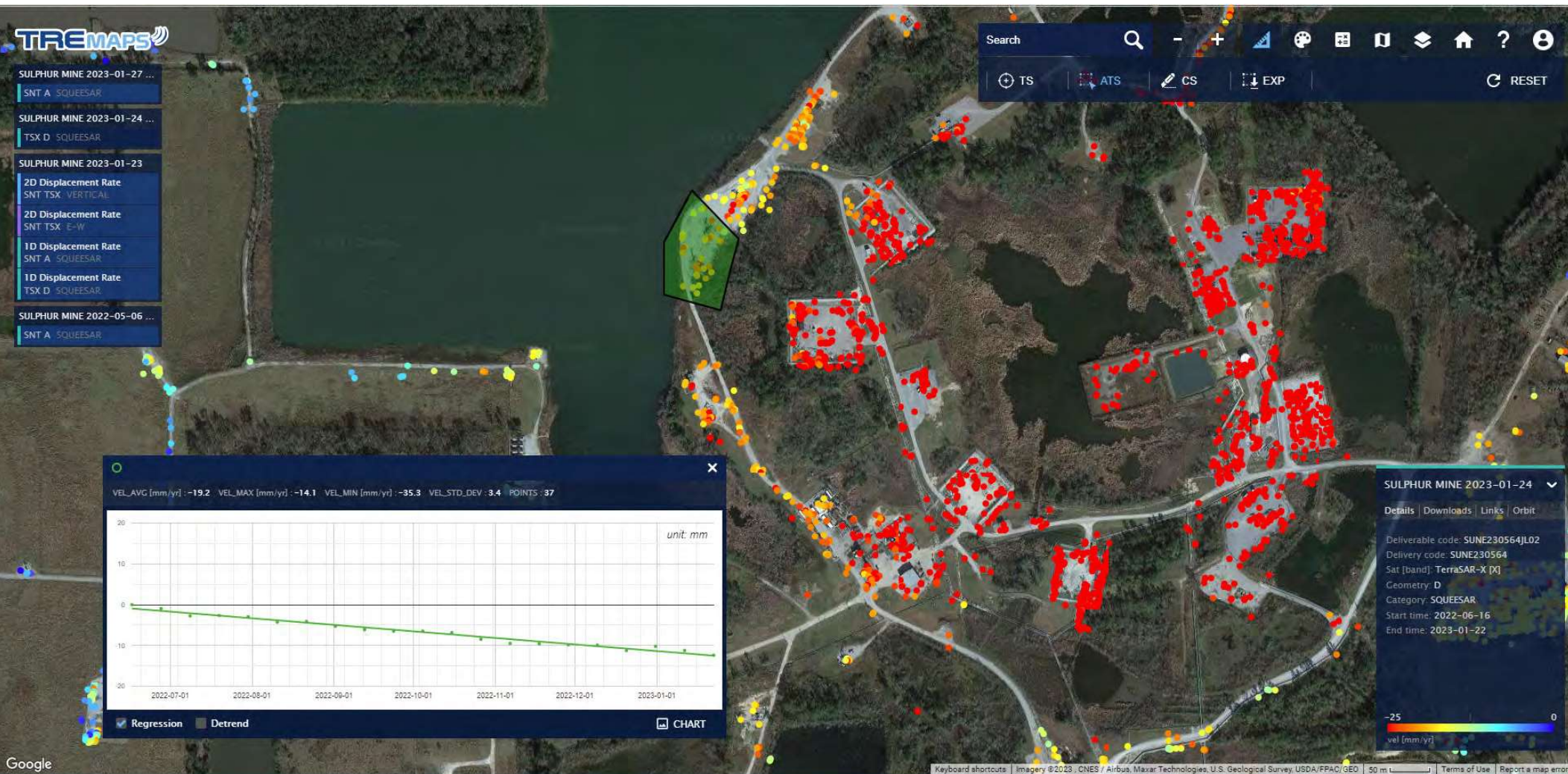
TerraSAR-X (TSX) – AOI #1



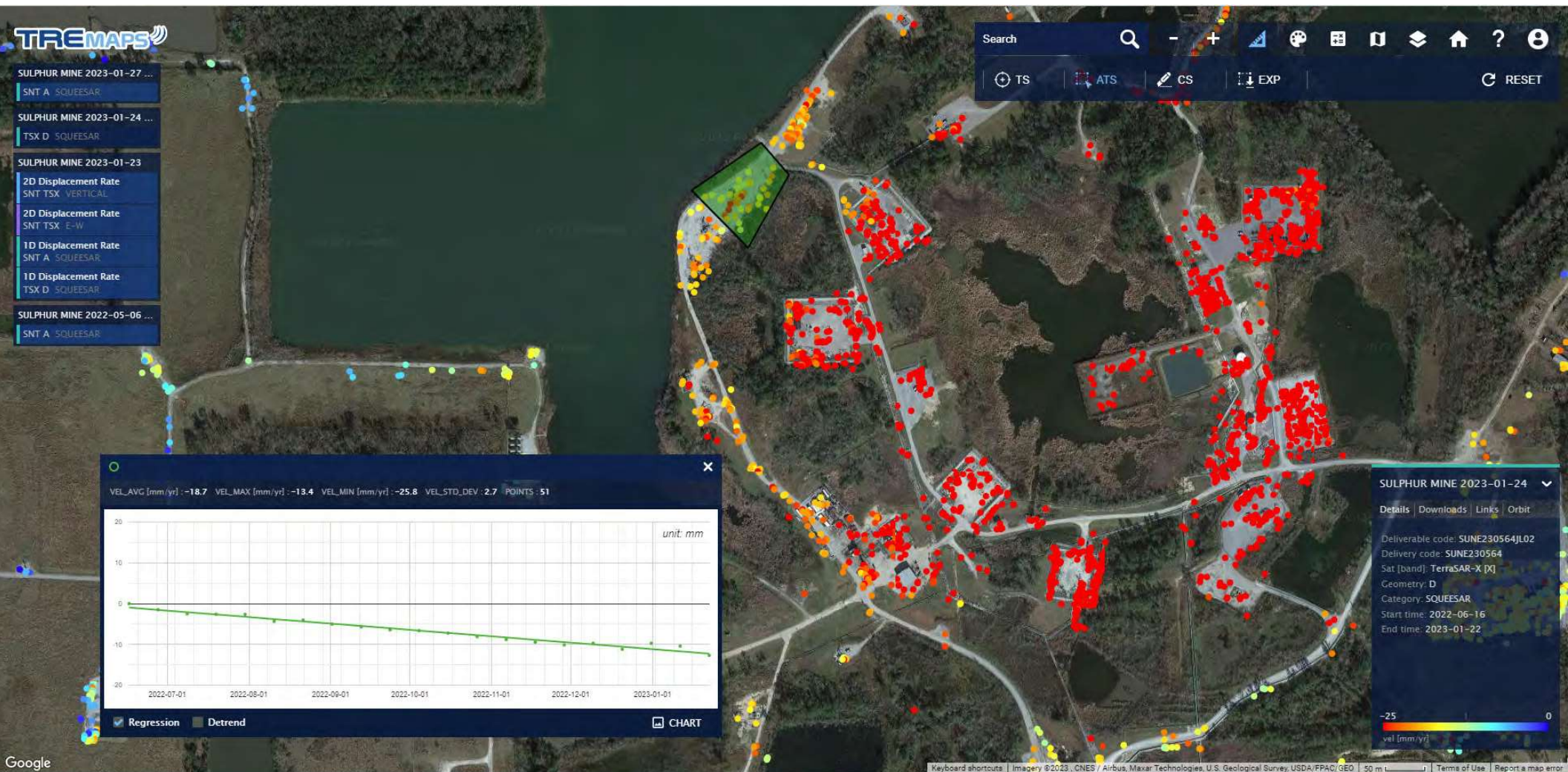
TerraSAR-X (TSX) – AOI #2



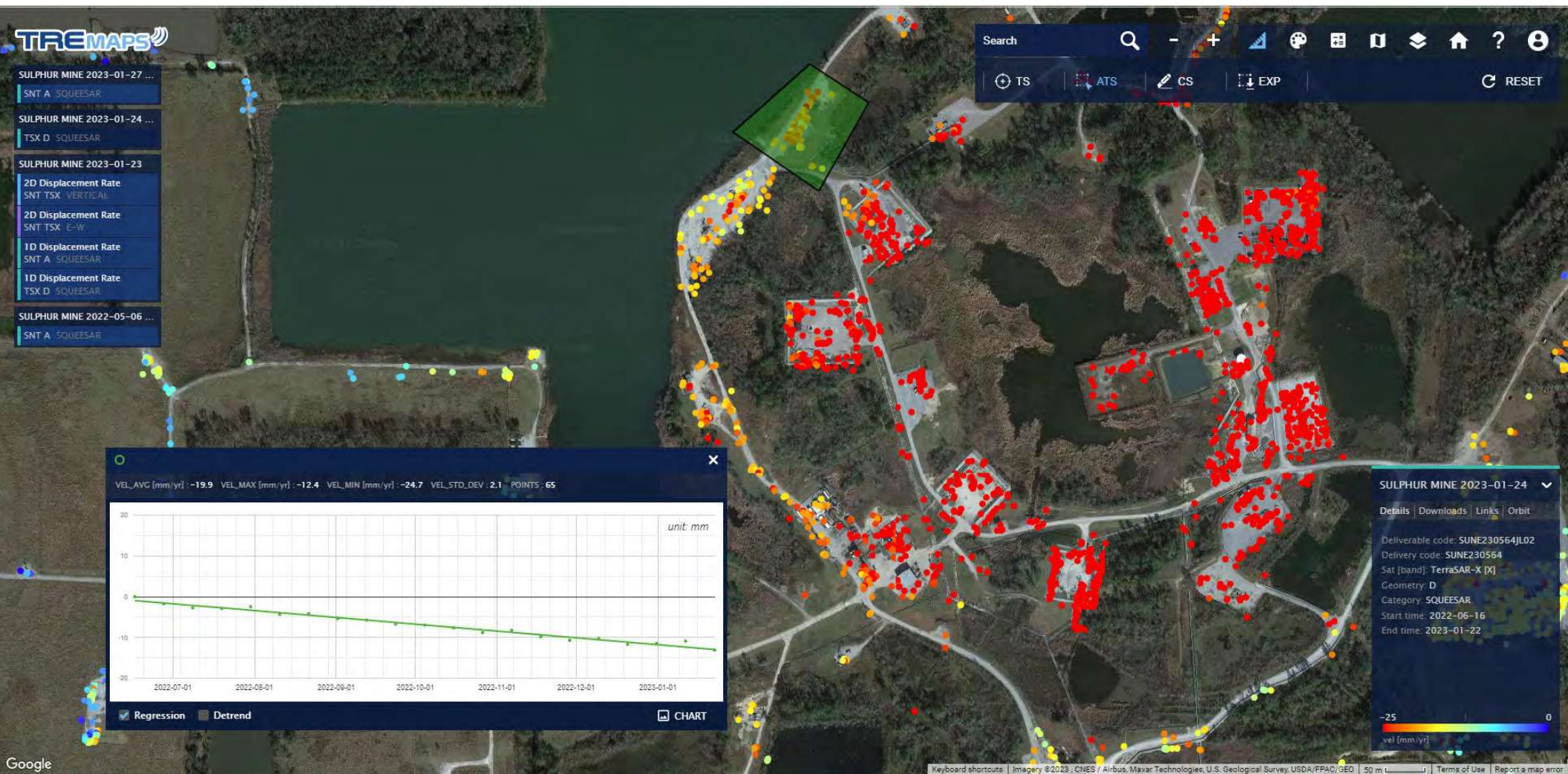
TerraSAR-X (TSX) – AOI #3



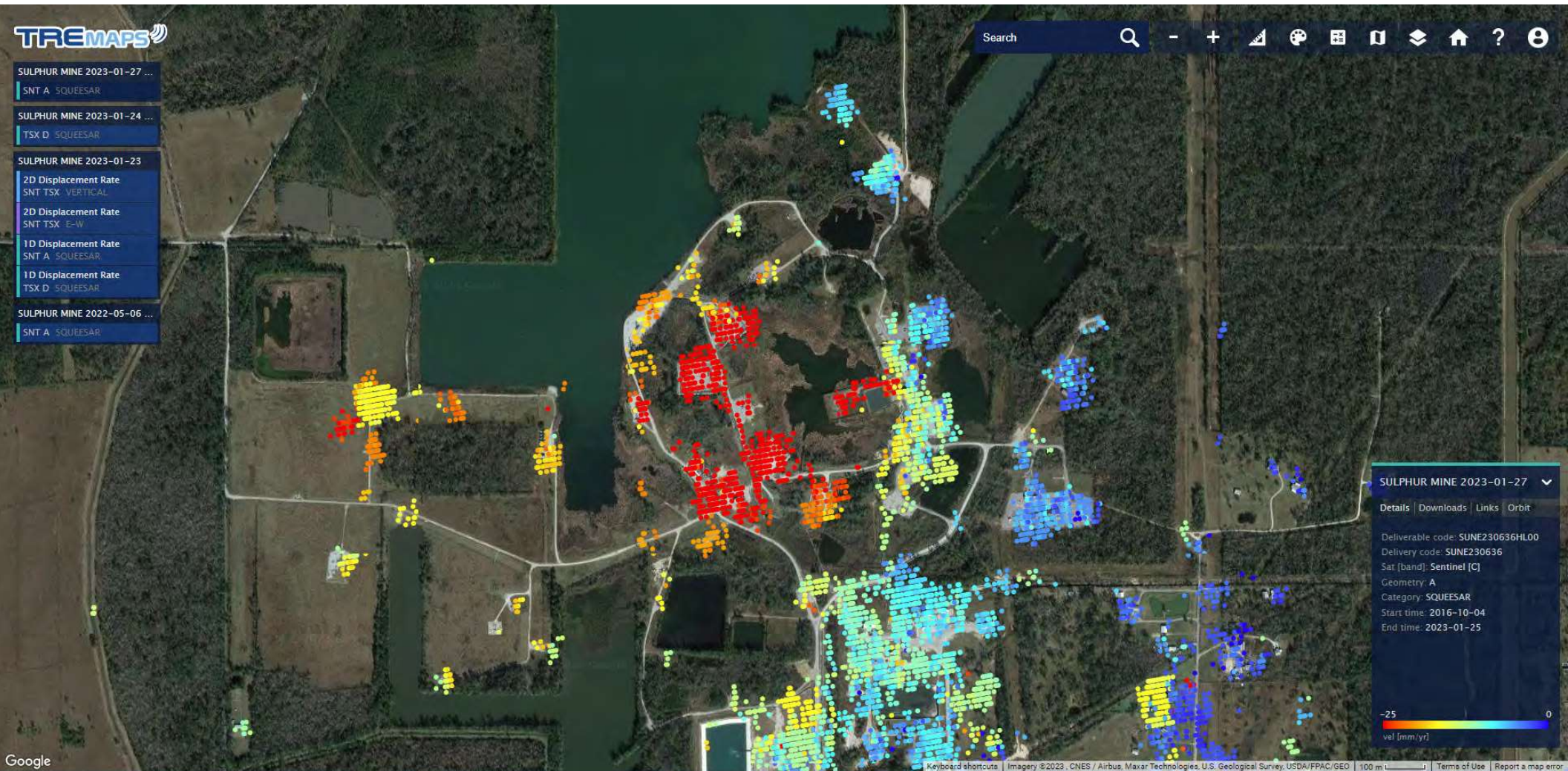
TerraSAR-X (TSX) – AOI #4



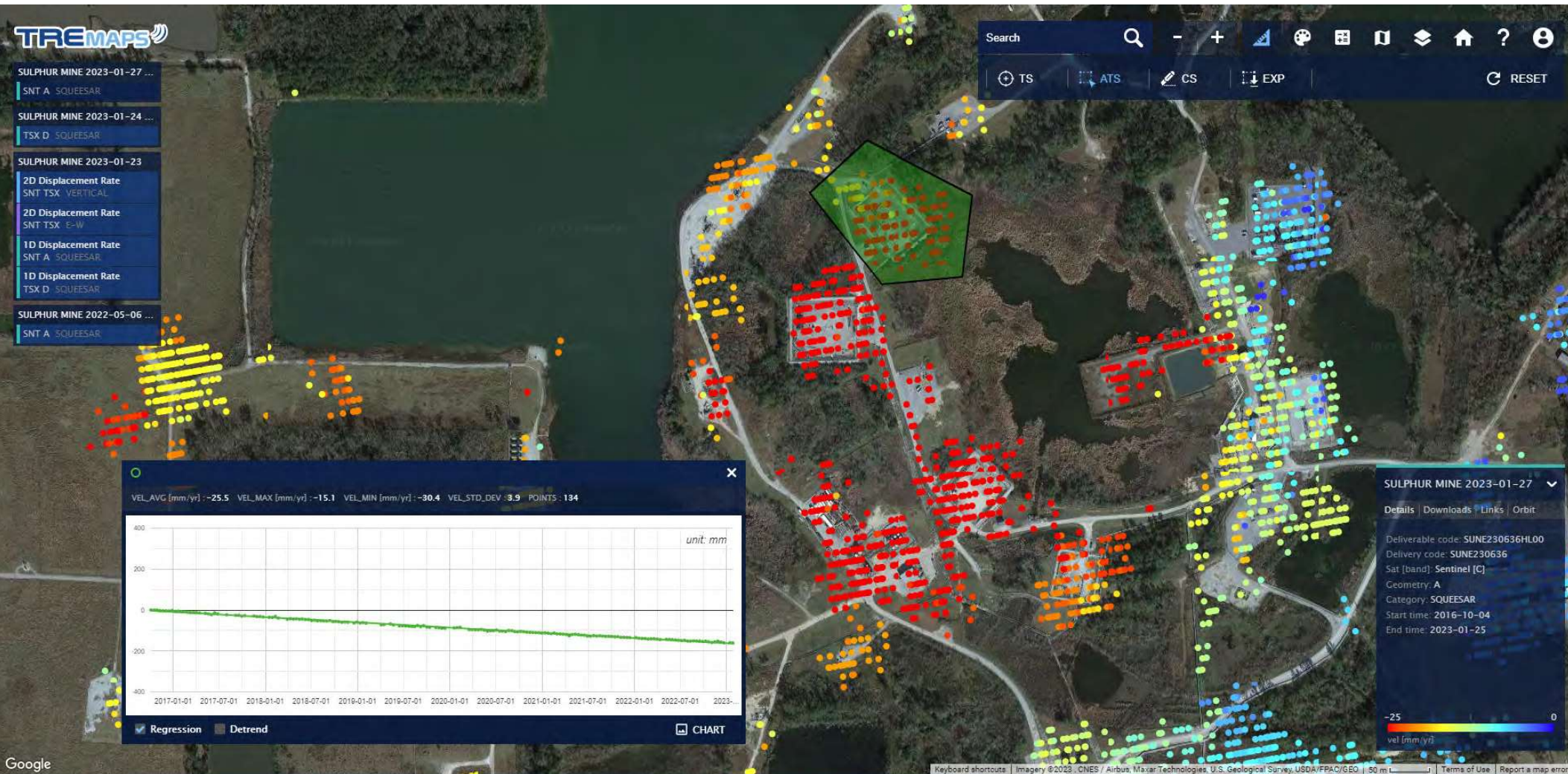
TerraSAR-X (TSX) – AOI #5



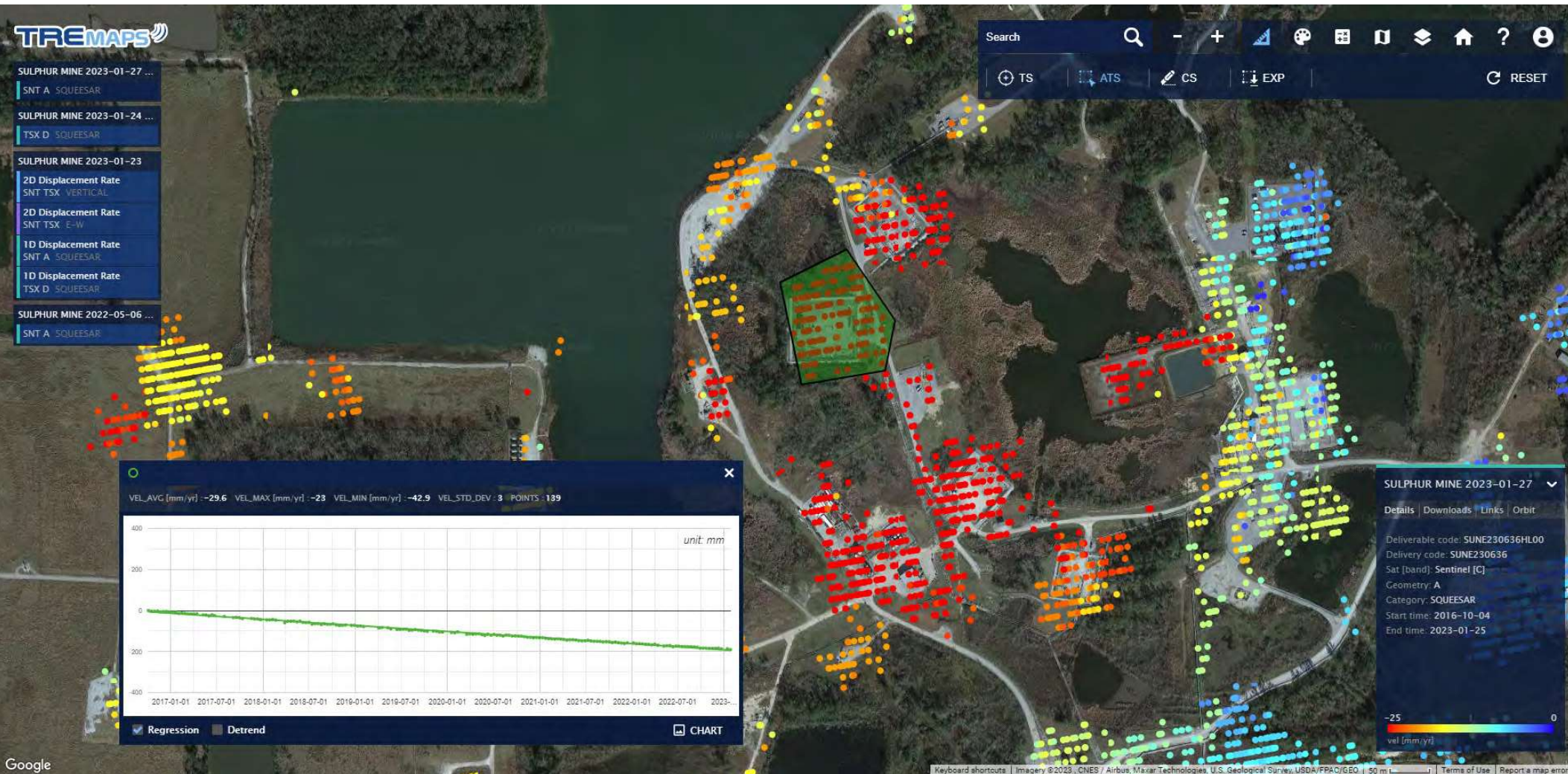
Sentinel (SNT) Map



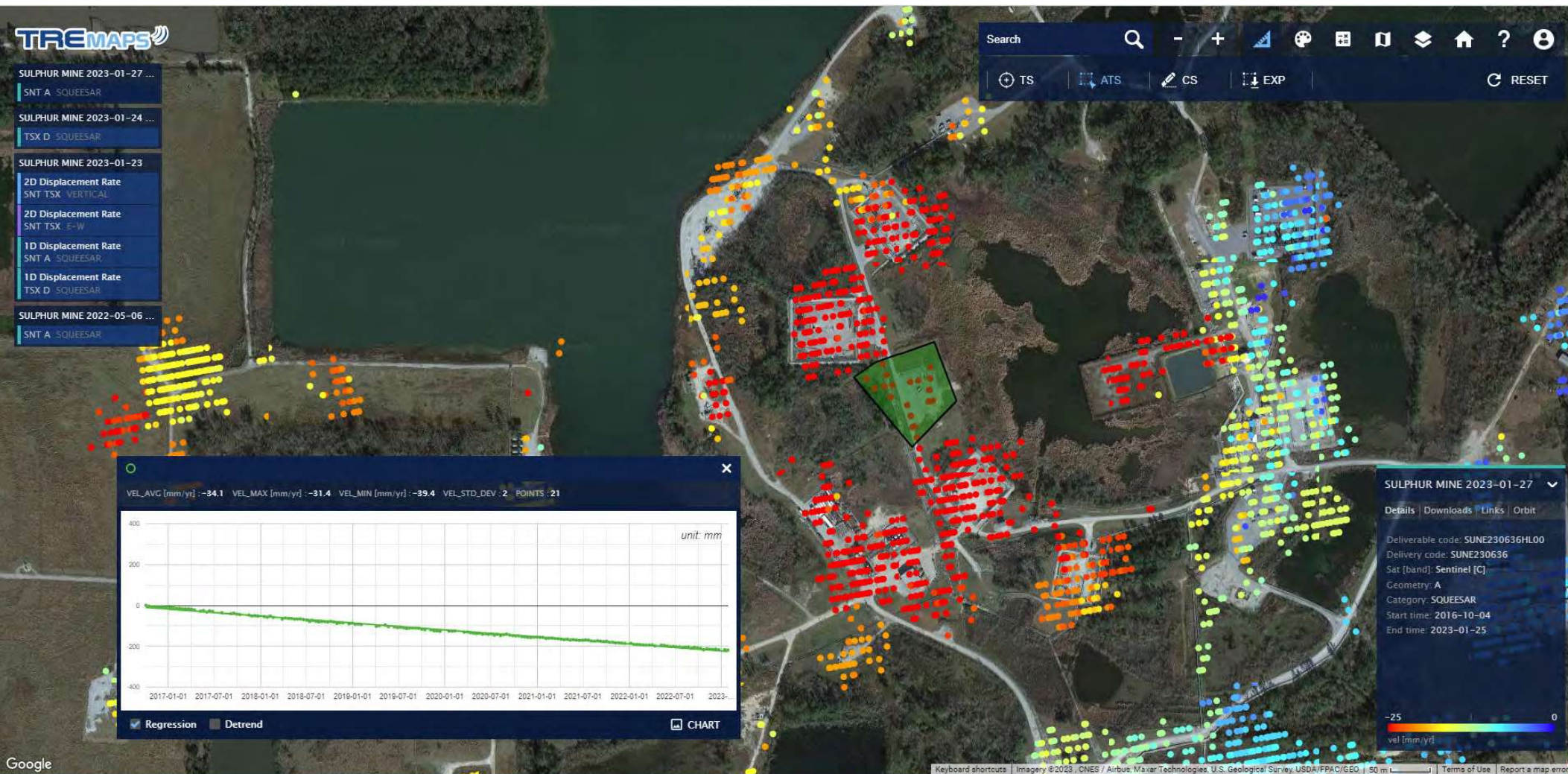
Sentinel (SNT) – PPG 6



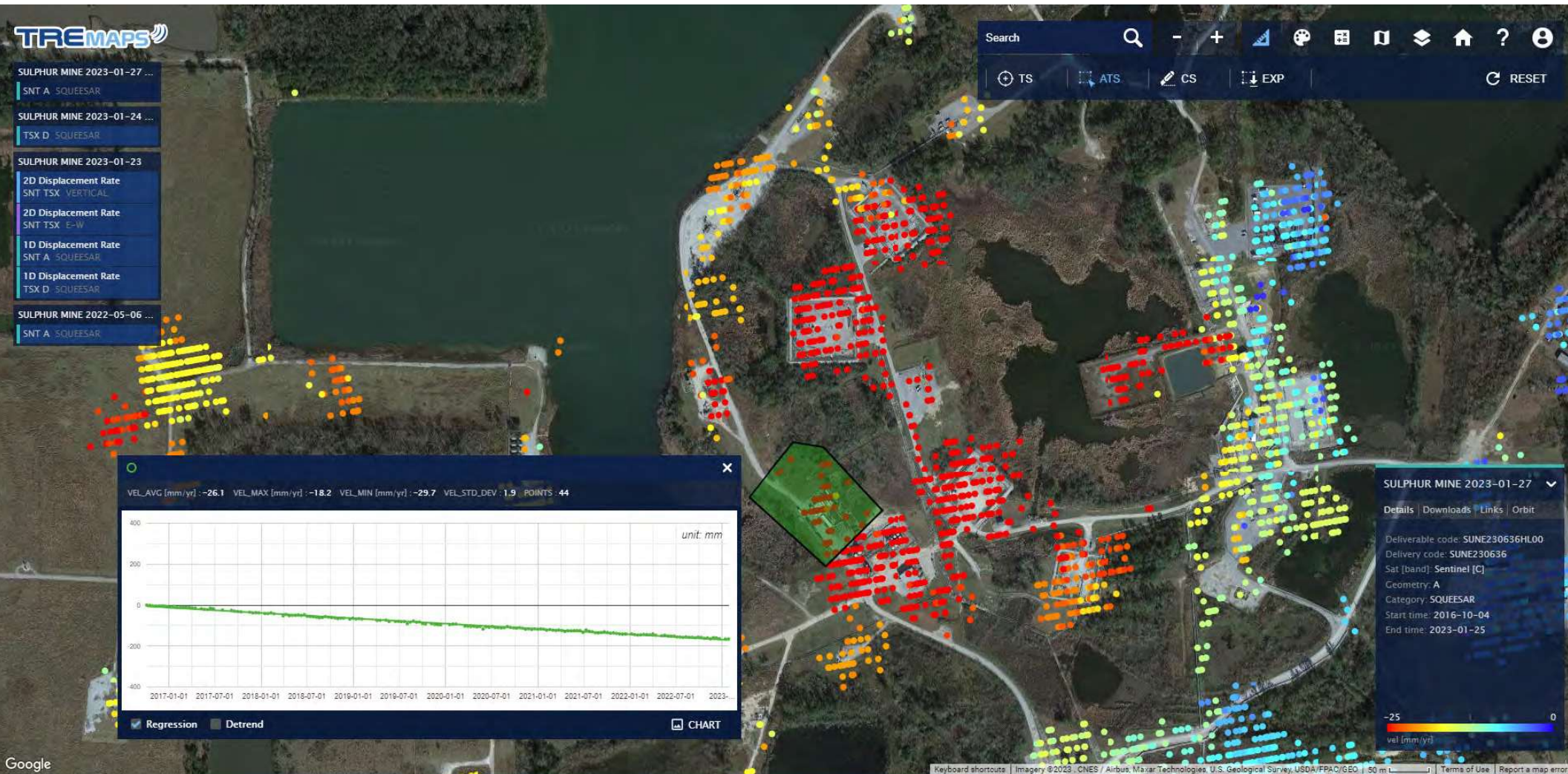
Sentinel (SNT) – PPG 7



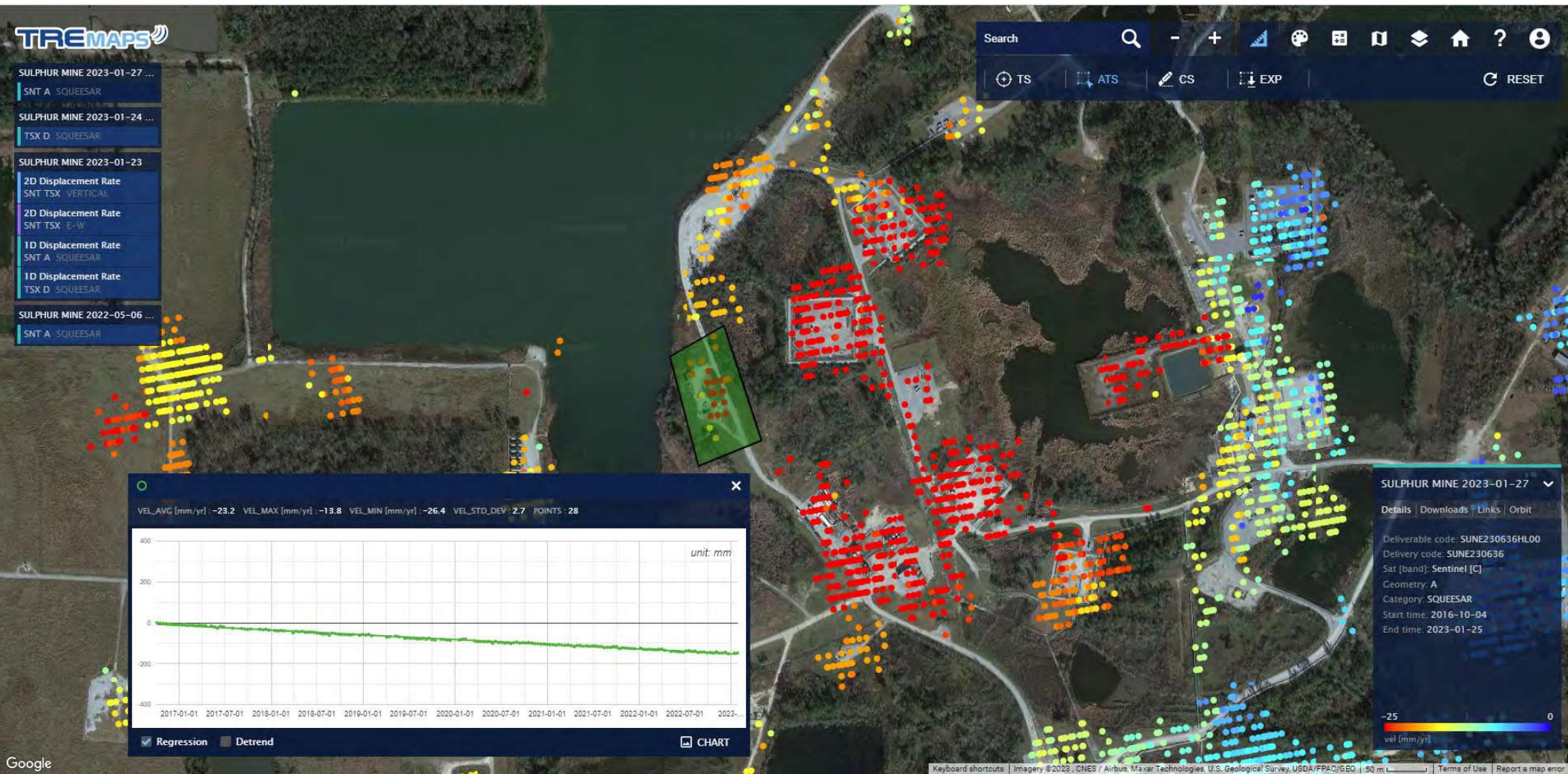
Sentinel (SNT) – PPG 22



Sentinel (SNT) – AOI #1



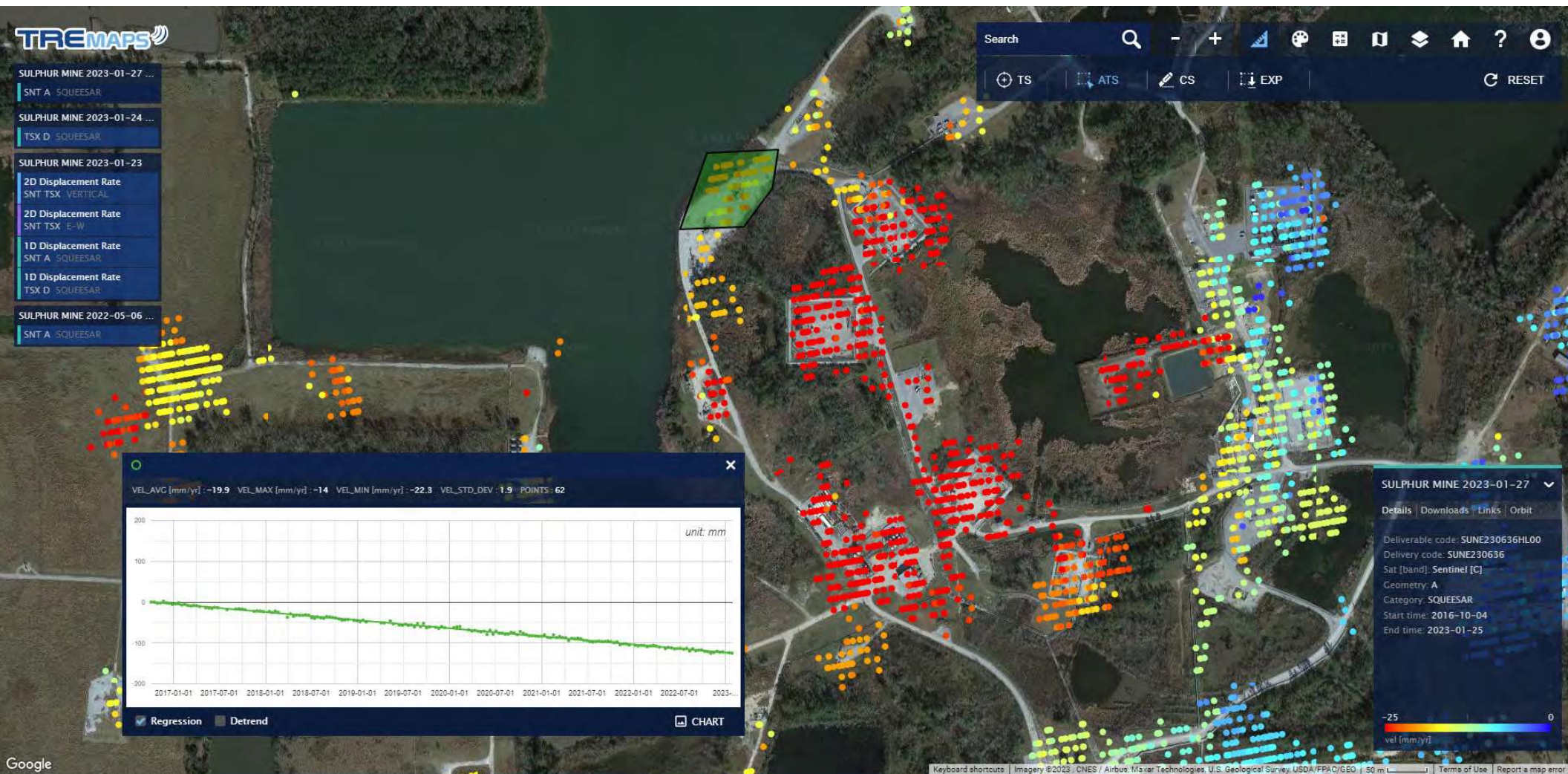
Sentinel (SNT) – AOI #2



Sentinel (SNT) – AOI #3



Sentinel (SNT) – AOI #4



Sentinel (SNT) – AOI #5

