Summer 2024 Project Summary

Clear Lake Volcanic Disasters

Creating a Deformation Record Using InSAR to Assess Hazards and Detect Volcanic Unrest in Clear Lake Volcanic Field

Project Team

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Project Overview

Project Synopsis:
The Clear Lake Volcanic Field Disasters project sought to create a deformation baseline from 2016 to 2023 of the Clear Lake Volcanic Field to inform the U.S. Geological Survey, California Volcano Observatory's hazards assessment. The team utilized Sentinel-1 C-band Synthetic Aperture Radar (C-SAR) and Digital Elevation Model (DEM) data to capture relative surface deformation at unprecedented high spatial and temporal resolutions. The team's investigation of the relationship between deformation, Sulfur Dioxide, landcover, land surface temperature, seismic activity and elevation will also contribute to the timely monitoring of potential volcanic activity.

Abstract:
According to the U.S Geological Survey, the Clear Lake Volcanic Field (CLVF) in northern California is at a high threat potential for volcanic hazards. Eruptions leading to increased seismic activity could result in silicic domes, cinder cones, and flows that would be dangerous to the residential areas near the volcanic field. Remotely sensed Earth observations can reveal volcanic processes in the subsurface, which are essential to the timely monitoring of potential volcanic activity. In particular, Sentinel-1 C-band Synthetic Aperture Radar (C-SAR) and Digital Elevation Model (DEM) data capture relative surface deformation at unprecedented high spatial and temporal resolutions. Leveraging C-SAR and DEMs, we conducted interferometric analysis from January 2016 to December 2023. Our results demonstrate 1) the mean surface displacement velocity of the Clear Lake Volcanic field is measured to undergo 5 to 10-centimeter scale deformation and shows a strong correlation with the surrounding faults, 2) apparent seasonal differences in rates of surface change, and 3) seismic activity associated with the geyser geothermal field has a strong correlation with cumulative surface displacement, with active fault zones having 2 to 5 cm of additional displacement. Results indicate that deformation is linked to deep pressure sources causing stresses on the surficial environment that should be

considered in hazard mitigation. This study provides a baseline of historic deformation, aiding hazard analysts in communication efforts and streamlining decision-making for potential risks to region residents.

Key Terms: Clear Lake Volcanic Field (CLVF), Remote Sensing, Deformation, Volcanic Field, Interferometric Synthetic Aperture Radar (InSAR), Digital Elevation Model (DEM), Sentinel-1 satellite

Application Area: Disasters
Study Location: Clear Lake Volcanic Field, CA
Study Period: January 2016 to December 2023

Community Concerns:

- The Clear Lake Volcanic Field is in proximity to local communities (with populations around 18,000 residents) which indicates that the region is a near-vent hazard.
- Underlying magma reservoirs below the volcanic field and geyser steam field poses a hazard risk due to the potential for explosive volcanism.
- Phreatomagmatic explosions could occur if magma interacts with the water in Clear Lake.

Project Objectives:

- Assess the feasibility of using Sentinel-1 C-SAR data and Digital Elevation Models (DEMs) to create a historic time series of deformation with interferometric analyses
- Provide the USGS with a baseline of deformation to aid in the decision-making process regarding future hazards at the CLVF to help the USGS communicate potential risks
- Investigate potential relationships between deformation, seismic activity, land cover, land surface temperature, and elevation

Partner Overview

Partner Organizations:

Organizations	Contact	Partner Type	Sector
USGS, California Volcano Observatory	Dr. Jessica Ball, Volcano Hazard Assessment and Communication Specialist; Dr. Seth Burgess, Geochronologist	End User	Federal Government
USGS, National Innovation Center	Jonathan Stock, Director	Collaborator	Federal Government

Decision-Making Practices & Policies:

The historic systems used to identify ground fluctuations and other relevant volcanic indicators include SO_2 monitoring, seismometers, tiltmeters, GPS stations etc. (Di Traglia et al., 2014). However, the introduction of InSAR processing methods presents a novel opportunity to use remote sensing towards identifying deformation that may be related to associated volcanic activity. Although the USGS is responsible for observing these shifts in deformation, disaster relief entities play a bigger role in the ultimate decision-making policies enforced. Thus, the scope of the USGS is uniquely limited to determining the possibility of utilizing specific remote sensing tools rather than the ultimate implementation of the information gathered.

Earth Observations & End Products Overview

Earth Observations:

Sensor	Parameters	Use
Sentinel-1 C-SAR	Synthetic Aperture Radar	The SAR data collected from Sentinel-1 was processed to create seasonal and yearly deformation maps of CLVF.
Landsat 8 OLI	Visible Bands	The RGB data collected from Landsat was used for land cover classification of CLVF.
Aqua MODIS	Land Surface Temperature	The LST data collected from MODIS was used to create a time series of land surface temperature at CLVF.
Sentinel-5P TROPOMI	SO2 Column Density	The SO2 column density data was used to create a time series of SO2 concentrations at CLVF.

Ancillary Datasets:

Data	Parameters	Use
USGS 3DEP	Digital Elevation Model	The DEM data collected from USGS 3DEP was used to create an elevation map of CLVF.
Global Hydrology Group's MERIT Hydro	Digital Elevation Model	The DEM data was collected from MERIT Hydro and was used to create a time-series of elevation at CLVF.
USGS National Land Cover Database	Land Cover	The Land Cover dataset was used to train a machine learning algorithm on Google Earth Engine to classify Landsat Data based on landcover type.
USGS Earthquake Catalog	Earthquake Magnitudes > 2.5	The earthquake magnitude data was used as an indicator of volcanism to compare with observed deformation.
CHIRPS	Precipitation	The precipitation dataset was used to understand the relationship between rainfall and potential surface deformation.

Software & Coding Languages:

- Google Earth Engine Application Programming Interface (API) - cloud-based environment that allows for visualization and analysis of products such as land surface temperature maps, land coverage maps, etc.
- OpenSARLab's Jupyter Notebook [v1.0.1] - cloud-based jupyter notebook environment used to access pre-installed tools and notebooks
- MintPy (Miami InSAR time-series software) [v1.1.2] - package that allows deformation time-series and velocity maps to be produced
- Python [v3.12.4] - Used within a JupyterLab Notebook utilizing OpenSARLab to conduct MintPy Processing
- JavaScript [v0.1.397] - Used within Google Earth Engine to create product visualizations and analysis

End Product(s):

End Product(s)	Earth Observations Used	Partner Benefit & Use

InSAR Deformation Time-Series	Sentinel-1 C-SAR	Provides a baseline of deformation at Clear Lake Volcanic Field for future hazard detection and related decision making
Landcover Map	Landsat 8 OLI	Shows patterns of natural vegetation and human land use in the area; indicates that vegetation likely does not interfere with the radar signal
Elevation Map	MERIT	Indicates the terrain across our study area, helps verify our InSAR deformation results and determine if topographic corrections are needed within processing
Land Surface Temperature Map	MODIS LST Band	Depicts seasonal changes in temperature; Magma chambers are too far underground to correlate with surface temperature
SO_2 map	Sentinel-5 TROPOMI	Provides additional data regarding factors leading to possible deformation
Social Media Series	Sentinel-1 C-SAR	Assists communication efforts regarding capabilities of InSAR and details regarding Clear Lake Volcanic Field

Product Benefit to End User:
Our team found that it is feasible to apply methods including InSAR deformation through MintPy and a DEM time-series through Google Earth Engine towards creating a collection of time-series to contribute to USGS's decision making needs. Short-term, these products will serve as a baseline of deformation for our partners to use to more easily detect and analyze future volcanic hazard events. Long-term, these end products and methods will be assessed by outside disaster relief entities to prepare for emergency response activities.

References

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