Comparison of InSAR Processing Techniques as part of the Collaborative GeoSCIFramework Project

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GeoSCIFramework:

The GeoSciFramework project (GSF) aims to improve intermediate-to-short term forecasts of catastrophic natural hazard events, allowing researchers to instantly detect when an event has occurred and reveal more suppressed, long-term motions of Earth's surface at unprecedented spatial and temporal scales.

These goals will be accomplished by training machine learning algorithms to recognize patterns across various data signals during geophysical events and deliver scalable, real-time data processing proficiencies for time series generation.

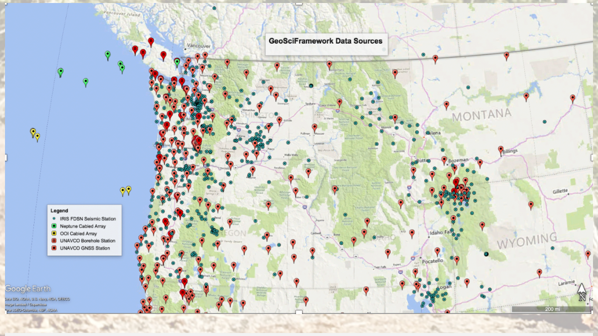

Figure 1: Map showing some of the data sources that GeoSCIFramework will ingest, process, and stream including onshore and offshore seismometers, seismograph stations, borehole strainmeters, and GPS/GNSS stations.

The algorithm will employ an advanced convolutional neural network method wherein spatio-temporal analyses are informed both by physics-based models and continuous datasets, including Interferometric Synthetic Aperture Radar (InSAR), seismic, GNSS, tide gauge, and gas-emission data.

The project architecture accommodates increasingly large datasets by implementing similar software packages already proven to support internet searches and intelligence gathering. The analysis of geophysical data on a global extent is a petabyte-scale Big Data problem that will be addressed using NSF XSEDE resources.

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Collaborating Institutions: IRIS/SAGE, University of Texas Arlington (TACC/XSEDE)

PROCESSING INTERFEROGRAMS:

The GeoSCIFramework will read in the time-series products of each data set. Differential InSAR (DInSAR) time-series analysis quantifies line-of-sight (LOS) ground deformation at mm-cm spatial resolution. Our results provide high resolution views of ground motions and measure LOS deformation over both short and long periods of time.

Area of Interest:

The big island of Hawaii makes a perfect study site for the GSF initiatives. Kilauea is considered one of the worlds most active volcanoes, with 61 separate eruptions since 1823. Additionally, the island is heavily monitored with geophysical instrumentation allowing for long-term observations.

We compare interferometric products generated using three different methods:

1. GMTSAR: Generic Mapping Tool

We have successfully run an automated version of GMT on the summit supercomputer to produce interferograms in parallel.

Preprocess: convert each satellite data type to generic format, apply orbital position and velocity corrections. GMT is compatible with: ERS-1, ERS-2, Envisat, ALOS-1, and TerraSAR-X, COSMO-SkyMed, Radarsat-2, ALOS-2, and Sentinel-1

Process: Focus each image to create single look complex (SLC) images, align stacks of images, map topography into phase, and form the complex interferogram. Transforms between radar and geographical coordinates

Postprocess: Filter the interferogram and construct interferometric products of phase, coherence, phase gradient, and line-of-sight displacement in both radar and geographic coordinates. Phase unwrapping code called Snaphu (Chen and Zebker 2000) and geocoding all interferometric products.

2. ISCE: InSAR Scientific Computing Environment

We have successfully produced interferograms using ISCE containerization with singularity on Summit using a 10-m resolution DEM

Preprocess: Call and prepare application, assign environment parameters in single xml input file. ISCE is compatible with: ERS-1, ERS-2, Envisat, ALOS-1, ALOS-2, TerraSAR-X, COSMO-SkyMed, Radarsat-1, Radarsat-2, and Sentinel-1, JERS, GENERIC. Checks to see if user has provided a DEM, if user has not- ISCE will automatically pull one from SRTM.

Process: Run orbital corrections, focus images using range-doppler algorithm with motion compensation. Calculate offsets between images and exclude outliers. Co-register and process SLCs to form interferogram.

Postprocess: Flat earth correction using DEM, interferogram refinement for subpixel offsets, coherence computation using phase gradients, apply Goldstein-Werner power-spectral smoothing filter, unwrap phase, geocode interferogram Can specify which phase unwrapping algorithm to use: ‘old’, ‘snaphu’, or ‘icu’. The entire process is timed and returns metadata about each processing step

3. Zebker Method:

Removes the topographic phase component of the SAR signal from each image so that simple cross multiplication returns an observation sequence of interferograms in geographic coordinates [Zheng and Zebker, 2016; Zebker, 2017]. We have successfully produced geocoded, flattened SLCs using code distributed by Stanford University, and need to cross multiply the products to form interferograms. Differencing the interferograms will form time series. Although this is a very efficient method, which is valuable for early warning systems, as it currently stands, this method is not yet automated and does not currently deliver additional product information, (such as amplitude, correlation, or phase filtering files), that could be beneficial to researchers. We still believe it is worth considering for this project but requires further examination.

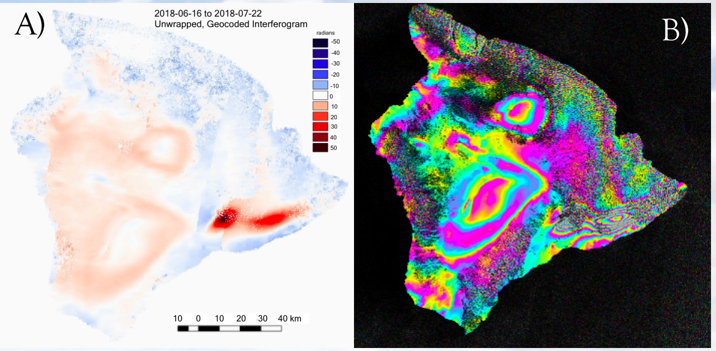

Figure 2: A) An example of an unwrapped, geocoded interferogram generated using GMT5SAR software. The image span the dates between 2018-06-16 and 2018-07-22. In GMT, unwrapped phase is a deformation measurement (units of radians) from satellite viewed perspective. In this figure, positive values, or warm colors, represent a range increase, which corresponds to subsidence/erosion of the ground away from the sensor. Negative values, or cool colors, represent a range decrease, which corresponds to uplift/deposition. When unwrapped phase is converted to LOS displacement (units of millimeters), it changes to ground view perspective. Then positive values are uplift and negative values correspond to subsidence. **B)** An example of an unwrapped, geocoded interferogram generated using ISCE software. This spans the dates between 2018-06-16 and 2018-07-22. ISCE outputs products of phase in units of radians. Each fringe in this image equates to 28 mm of motion.

Next steps:

1. Modeling of volcanic processes, specific to both Hawaii and Yellowstone. Similar to the Independent Component Analysis (ICA) and machine learning analysis done for the 2018 eruption of Sierra Negra (Gaddes et al., 2019).
2. Integrating additional data sets and time series into the streaming analysis. Ability to visualize time series, and compare signals from major geophysical events, with other data sets, such as seismic and GNSS time series.
3. Machine learning analysis of integrated time series.

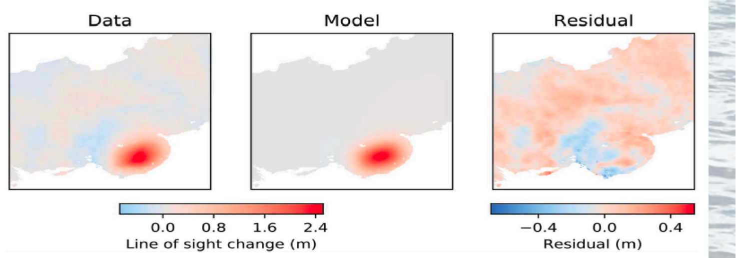

Figure 3: Figure and caption taken from Gaddes et al., 2019: Data: The signal contained in IC1 throughout the Sentinel-1 timeseries, showing ~2.4 m of motion toward the satellite during the Sentinel-1 time series. Model: The result of our optimal forward model, which treats the magma chamber as a 6.2×3.7-km2 rectangular dislocation at a depth of ~2.0 km. Residual: The misfit between our model and the data, which is dominated by a mottled pattern across the majority of the scene which independent component analysis is unable to remove from IC1 and our model is unable to fit.