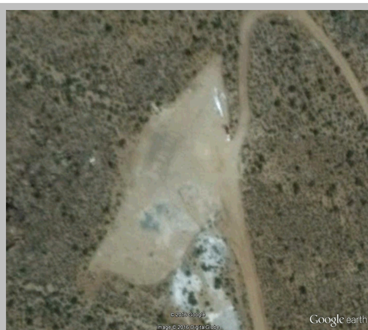
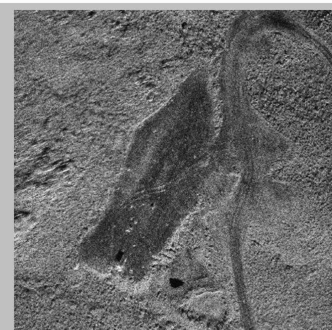
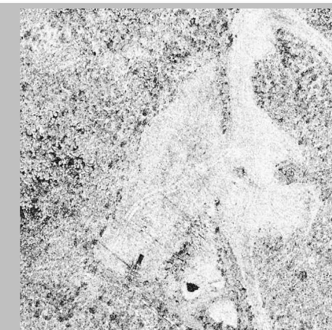
SAND2017-3018C







VideoSAR Collections to Image Underground Chemical Explosion Surface Phenomena

David A. Yocky, Terry M. Calloway, and Daniel E. Wahl

Sandia National Laboratories

April 11, 2017

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Background

The Source Physics Experiment (SPE) is part of an ongoing effort by the U.S. Department of Energy National Nuclear Security Administration (NNSA) to improve its ability to detect, locate, and characterize low-yield underground nuclear explosions (UNEs) anywhere in the world through the analysis of seismic waves.

The site: Drill site over a granite intrusion with alluvium along the flanks on the Nevada National Security Site (NNSS).

The explosion: This was the fifth underground explosion (SPE-5) with a burial depth of 76.5 meters and a TNT equivalent yield of 5035 kg.

Sensors: Geophones and acoustic sensors instrument the ground surrounding the explosion. Feed into modeling efforts given the geologic complexity.

Remote Sensing: Sandia National Laboratories (SNL)-built X-band (9.6 GHz) SAR operated in VideoSAR mode. VideoSAR - A continuous spotlight collection with a collection path that inscribes the site of interest.

Airborne Synthetic Aperture RADAR (SAR): VideoSAR

Using VideoSAR InSAR during an explosion should provide time-varying, two-dimensional surface change products that can be compared to seismic and other surface/contact sensors that were deployed for the event.

SAR imaging assumptions

SAR imaging assumes the imaged scene consists of static RADAR scatterers. Yet, the explosion surface expression is dynamic. Gather time-varying

1. Coherence
2. Interferometric phase
3. Height change before, during, and after explosion.

SAR imaging difficulties

1. Moving objects
2. Vibrating objects

SPE-5 Regional Signals Experiment

Autofocus Needed:

The circular flight path of VideoSAR creates an arc. Polar-formatted image formation expects a straight-line path. This difference creates a depth of focus defocusing.

The phase error injected into the image on a pulse-by-pulse basis is given by

$$\Delta\phi = \frac{4\pi\Delta z_{max}}{\lambda R_o}$$

λ = center wavelength

R_o = nominal slant range

Δz_{max} = maximum out-of-slant-plane distance that occurs over the aperture.

Assume quadratic phase error that exceeds $\pm\pi/4$ radians produces significant widening of a point scatterer. Using this metric, the depth-of-focus (DOF) is computed as

$$DOF = \frac{\lambda R_o}{16 * \Delta z_{max}}$$

DOF is 1.0 meter or less for most apertures in the VideoSAR collects over SPE. Therefore, targets with heights within 1.0 meter of the scene center height are focused well. Height relief is ~50-m across the SAR images.

Depth of Focus Effect

- Phase Gradient Autofocus (PGA)
- Non-parametric focus approach
- Data-driven phase error estimate.

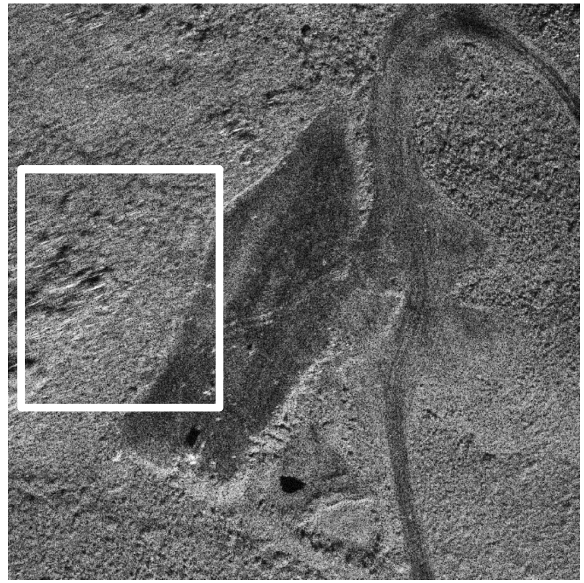
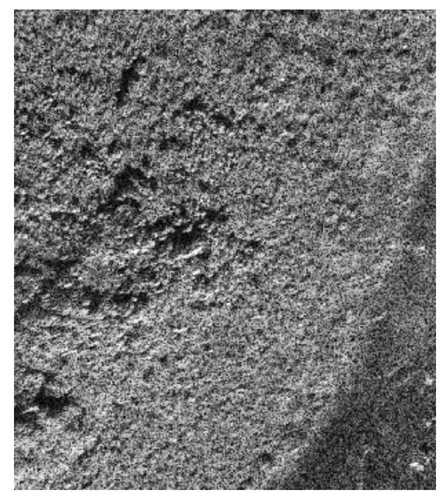


Image ground resolution is 0.125 m x 0.125 m.

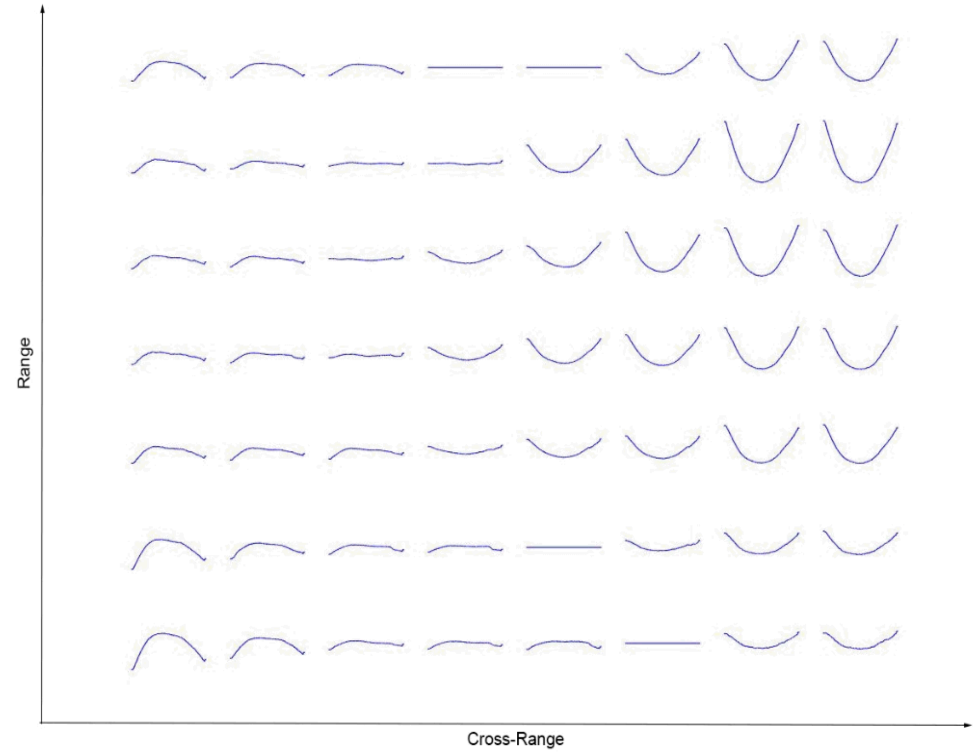
Global PGA

Spatially-varying PGA

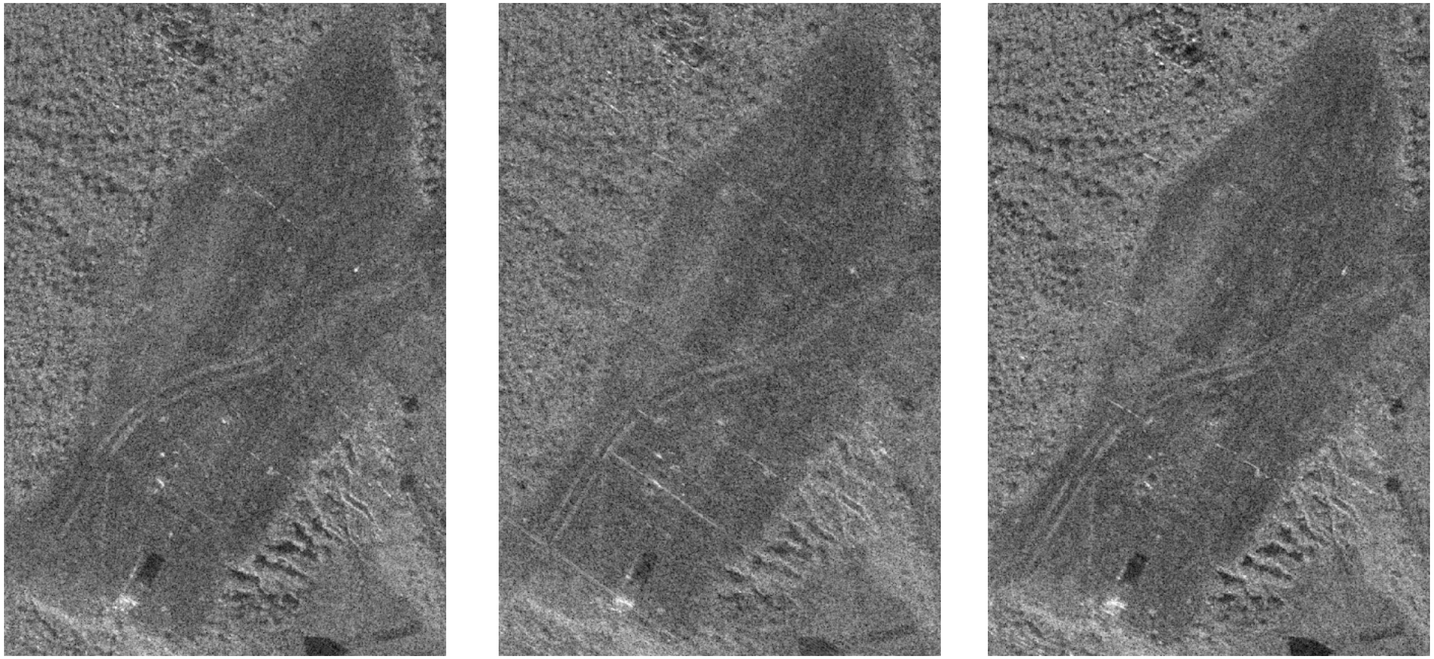


Spatially-varying PGA

- Break image into patches
- Constant patch sizes
- Estimate phase error in each patch
- Each phase error vector correct only for the middle pixel
- Linearly interpolate between phase correction vectors
- Apply a different correction vector to each image pixel
- Interpolation assures phase continuity across the image



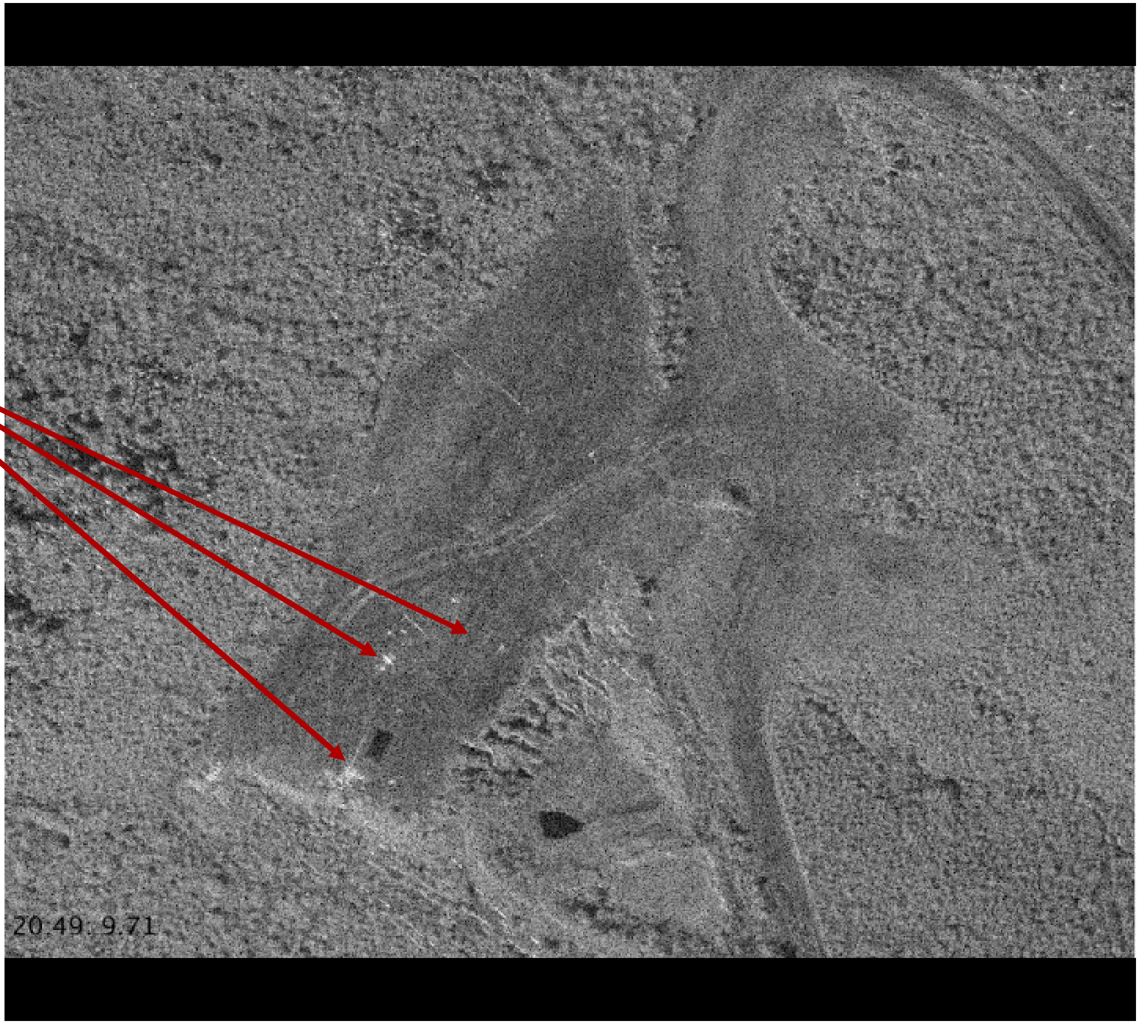
SAR Imaging During the Explosion



Before, During, and After SAR Images of the SPE pad using Spatially-varying PGA

VideoSAR Image Movie

Vibration

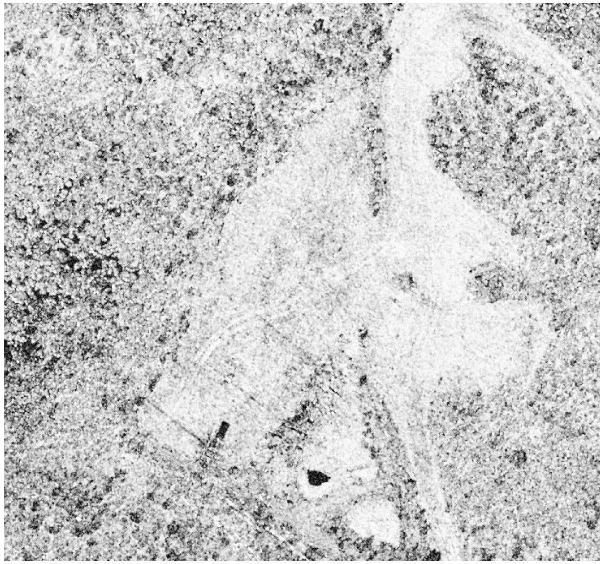


VideoSAR Coherence Movie

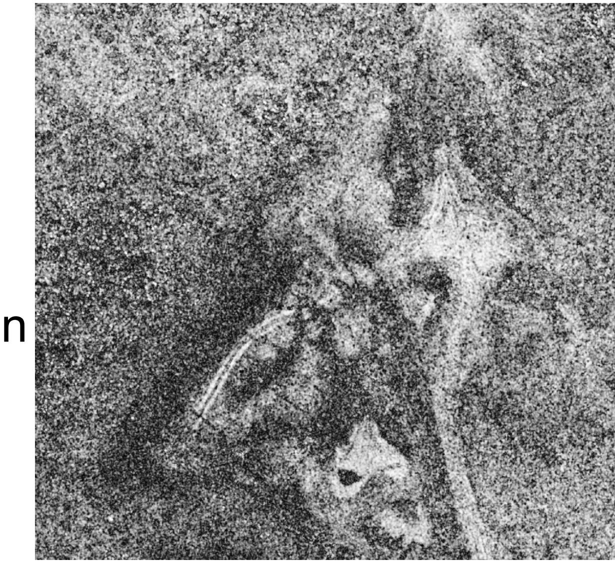
$$\gamma = \frac{\left|\sum_{k=1}^{N} X_{1k}^{*} X_{2k}\right|}{\sqrt{\sum_{k=1}^{N} |X_{1k}|^2 \; \sum_{k=1}^{N} |X_{2k}|^2}}$$

SAR Coherence During the Explosion

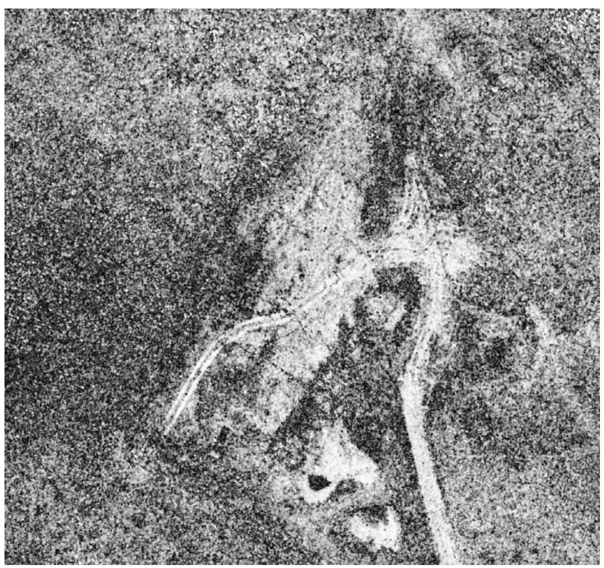
Before Explosion



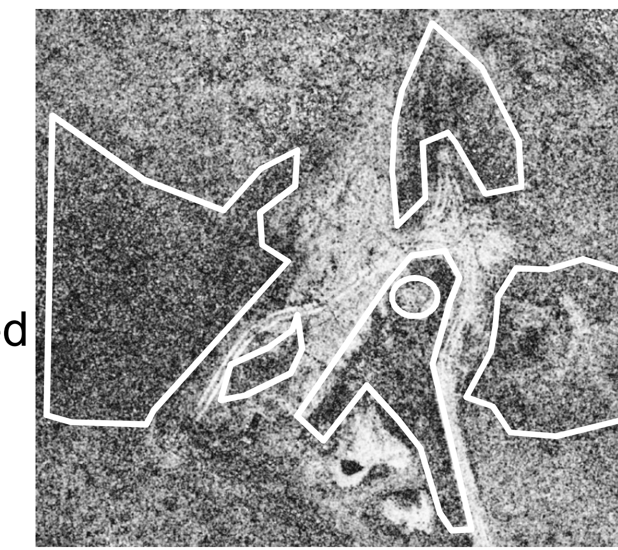
During Explosion



After Explosion



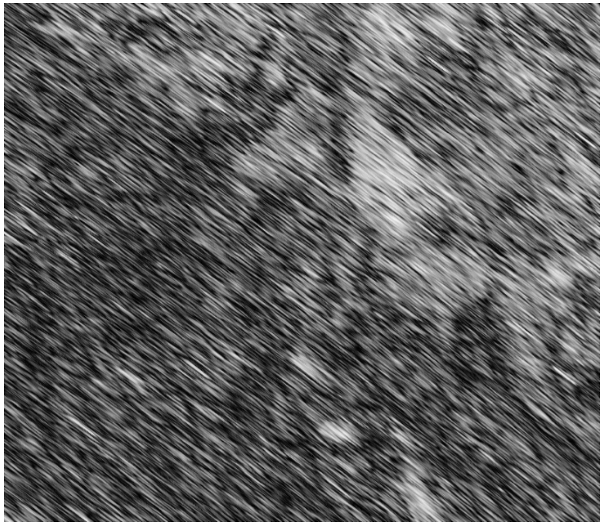
Areas that Stay Decorrelated Throughout Explosion



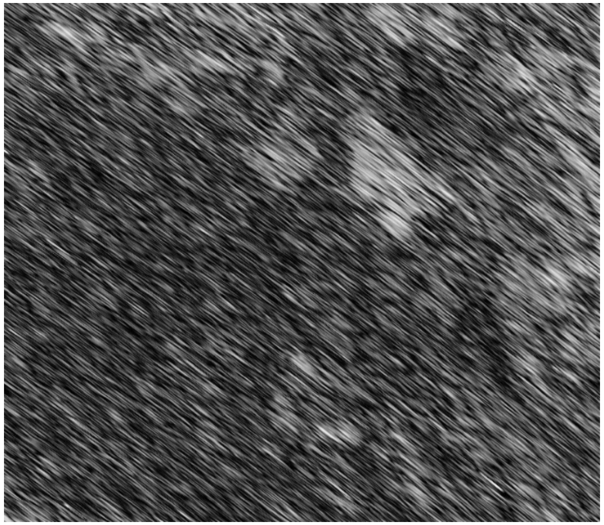
Short-Aperture Coherence: 2-m x 0.125-m resolution – 0.5 second aperture

Before Explosion

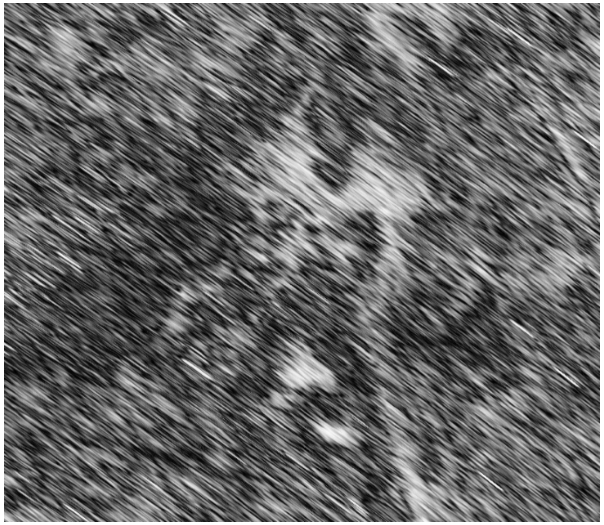
0.20 seconds after



0.25 seconds after



0.75 seconds after



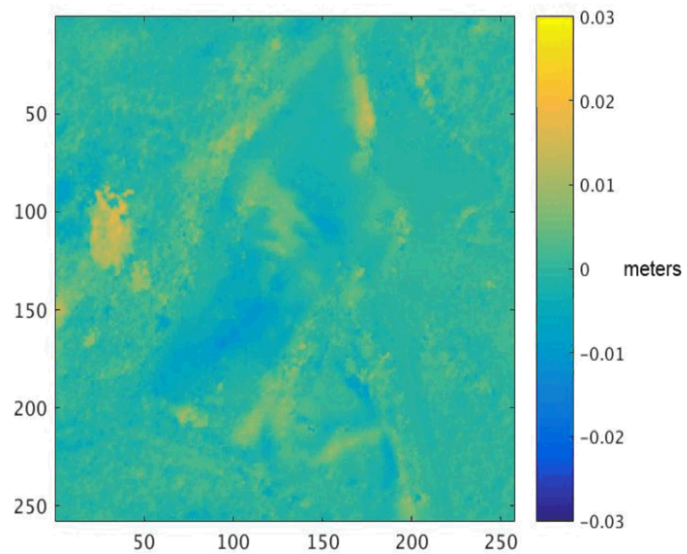
Differential Height Measures

$$\Delta\phi = \Delta\phi_{topo} + \Delta\phi_{def}$$

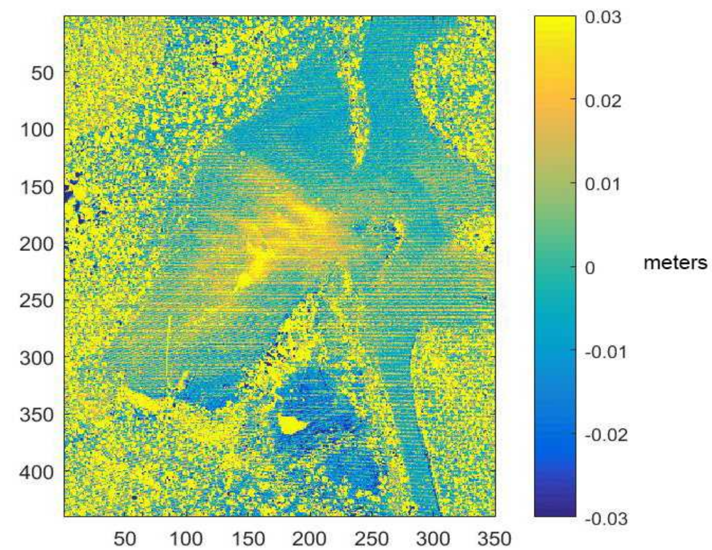
SAR phase difference

$$\Delta\phi_{def} = \frac{4\pi\Delta r}{\lambda}$$

Δr = change in range in the direction of the SAR, λ = wavelength



SAR Differential Height Map



LIDAR Differential Height Map

Conclusions

- Vibrating targets made coherent processing difficult.
- Dynamic coherence showed the SPE pad moved during the explosion, creating permanent reduction in coherence. Regions of permanent coherence reduction can be compared to seismic sensors and accelerometers to corroborate surface spallation. More importantly, regions of transient coherence reduction may be indicative of a transient elastic deformation during the explosion.
- Transient deformation height differences were calculated by subtracting prior topographic phase difference from total phase difference.
- Surface movement ceases after ~0.6 seconds from accelerometer data. Short aperture SAR shows ~0.75 seconds.

Future Research

- Develop and exploit fully-polarimetric VideoSAR algorithms with respect to measuring surface expressions.
- Create a dynamic digital elevation map.
- Support modeling efforts.
- Support new SPE experiments in alluvium.

Acknowledgements: The authors wish to thank the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development, for sponsoring this work. We would also like to thank the SPE team, a multi-institutional and interdisciplinary group of scientists and engineers, for its technical contributions.