SAND2020-1803PE

Defense Nuclear Nonproliferation Research & Development

Nuclear Explosion Monitoring Program Review
NEM2020

SAR Surface Change at SPE Phase 1 and Phase 2 Sites

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17 March 2020

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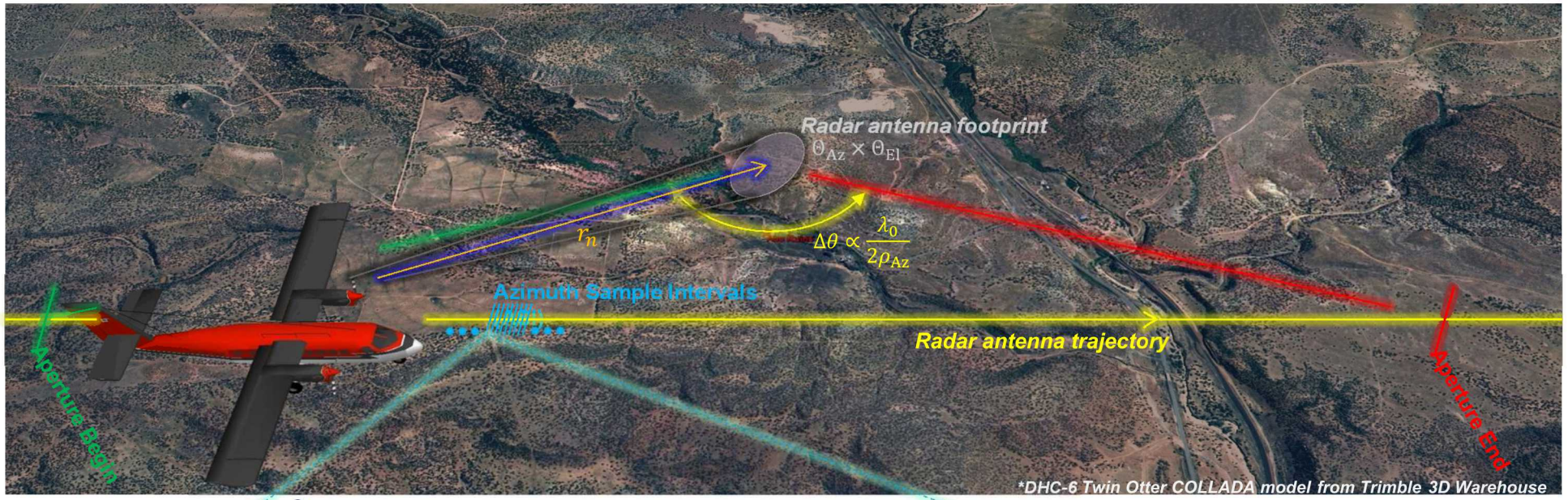
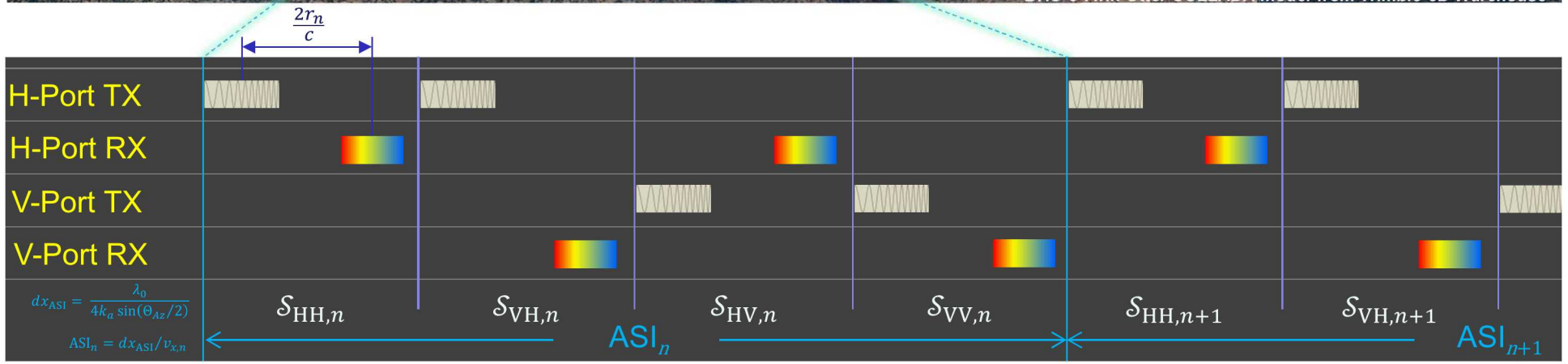
SAR Surface Change at SPE Sites

- **Problem: What surface changes resulting from an underground explosion can be remotely sensed?**
- **Sensor: Fully-polarimetric synthetic aperture radar (PolSAR)**
  - **SAR is day/night, all-weather imaging modality**
  - **Fine resolution from airborne platform (0.125 m x 0.125 m) in the ground plane**
  - **Multiplex linear polarization transmitted**
  - **Linear polarization received on two channels**
  - **Exploit fully-polarimetric channels**

Contributors:
Derek West, Leroy Garley, Robert Abbott

Collecting PolSAR Pulses for Processing





How SAR Detects Surface Change

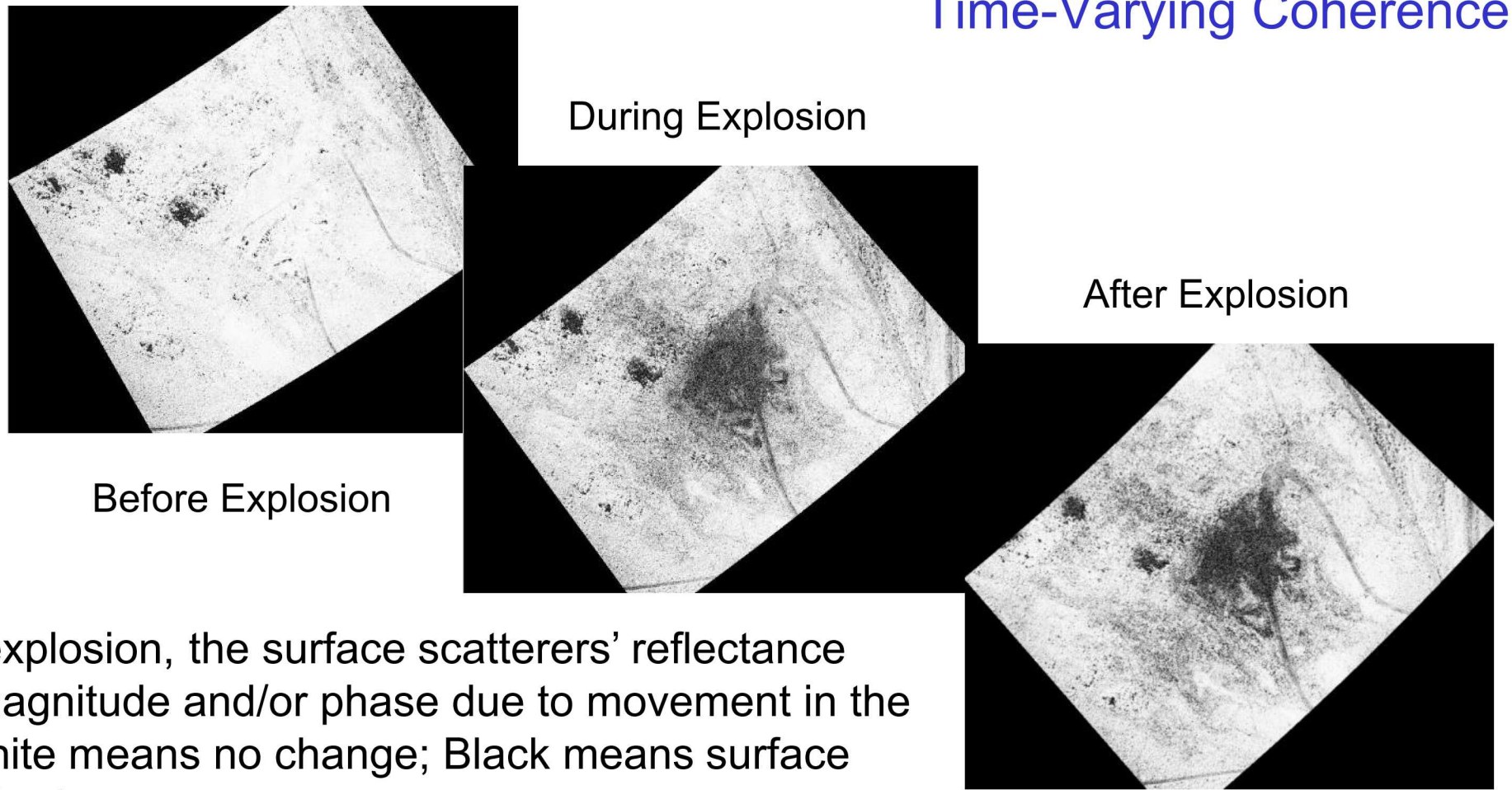
Illustration of a RADAR pulse being transmitted with a known magnitude and phase. The pulse travels to and interacts with the ground. This interaction can change both the pulse magnitude and the phase. The returning pulse is detected by the RADAR.

VideoSAR Collections

Event	Depth (m)	Yield (lbs TNT Equiv)	Medium	SAR Products
SPE-5	76.5	5035	Weathered Granite	Imagery, height maps, coherence measures
SPE-6	31.5	2245	Weathered Granite	Imagery, height maps, coherence measures, polarimetrically calibrated HH, HV, VH, VV channel data
DAG-2	299.8	50997	Quaternary Alluvium	Imagery, height maps, coherence measures, polarimetrically calibrated HH, HV, VH, VV channel data

SPE-6: Fully-Polarimetric VideoSAR

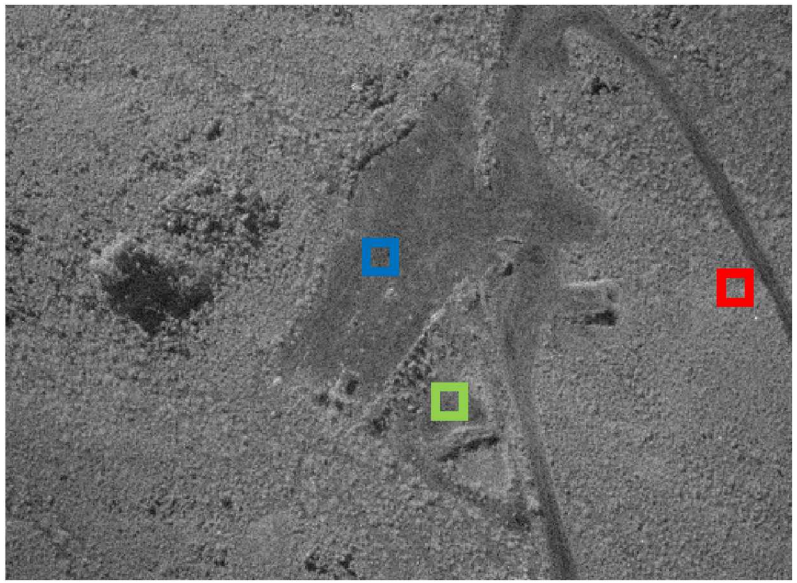
Time-Varying Coherence

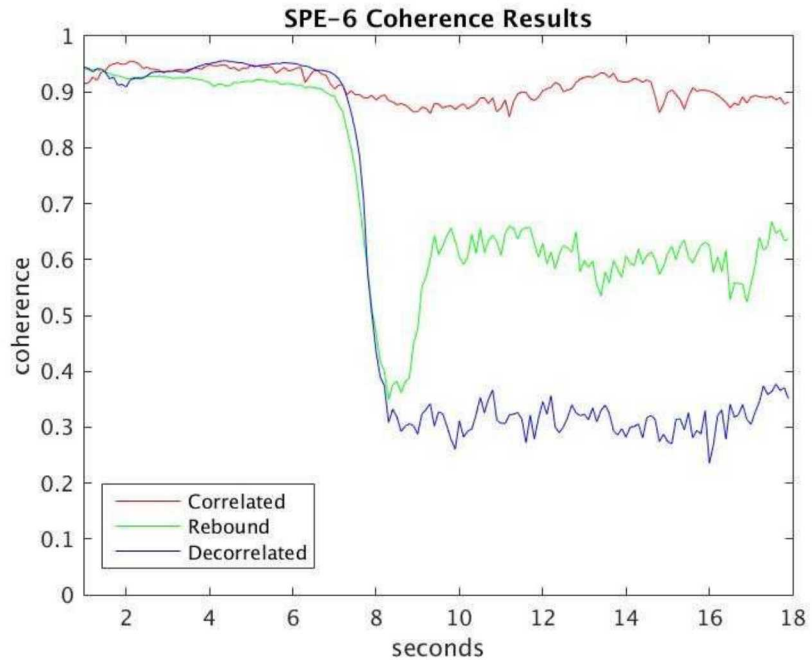


During the explosion, the surface scatterers' reflectance change in magnitude and/or phase due to movement in the surface. White means no change; Black means surface change or shadows.

SPE-6: Fully-Polarimetric VideoSAR

The earth surface reacts differently. Blue is near ground zero. Green is a depression used to catch water and debris from drilling, and red is desert scrub that is common in the area. The graph shows that there is no change due to surface disturbances in the correlated (desert scrub) area, a decorrelation and slight coherence rebound in the depression area, and large decorrelation on the experiment pad near ground zero all as a function of time.



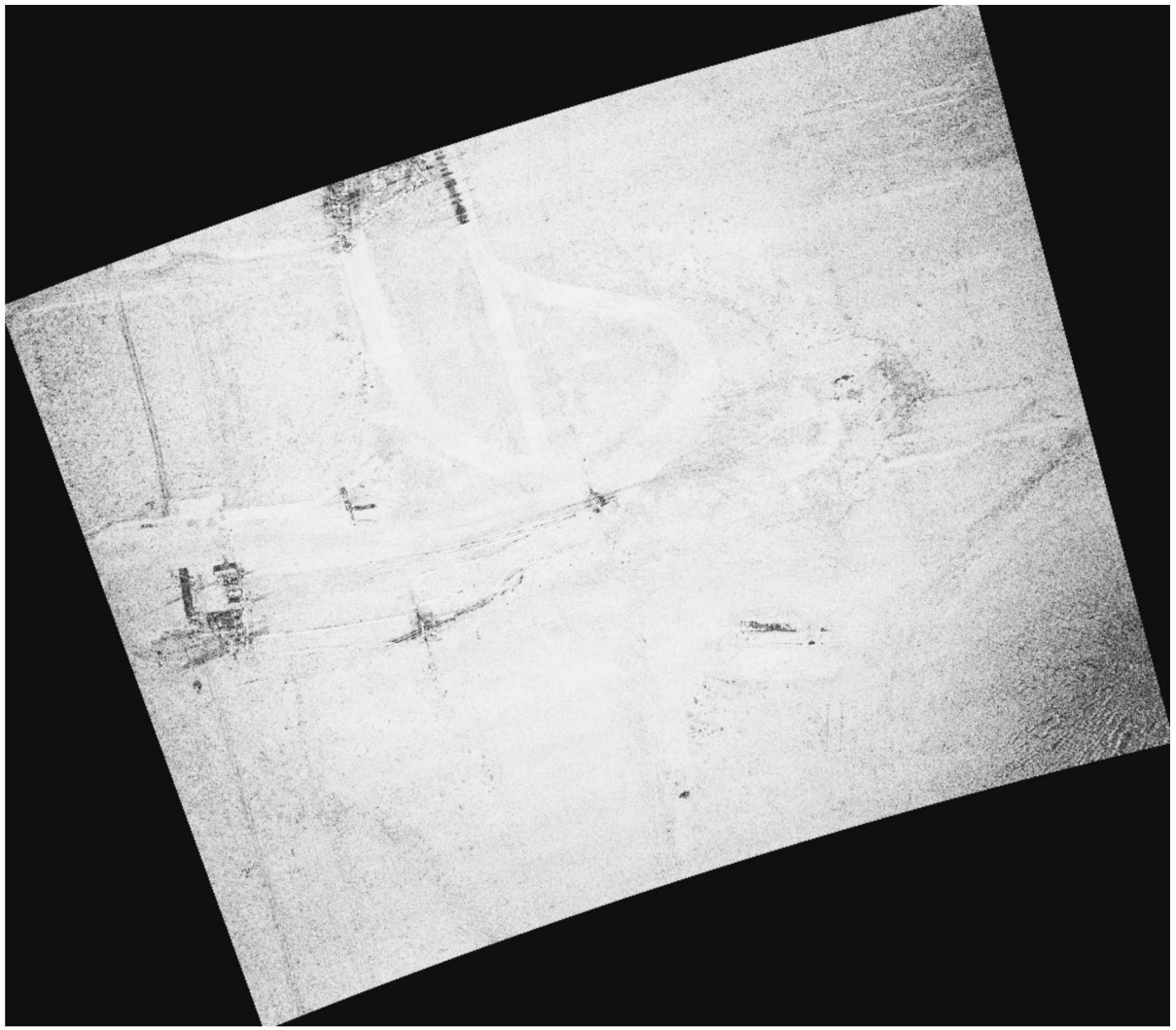


Time-Varying Coherence

Results from: Yocky, West, Riley, Wahl, IEEE Transactions on Geoscience and Remote Sensing, 57(5), 2481-2493, 2019

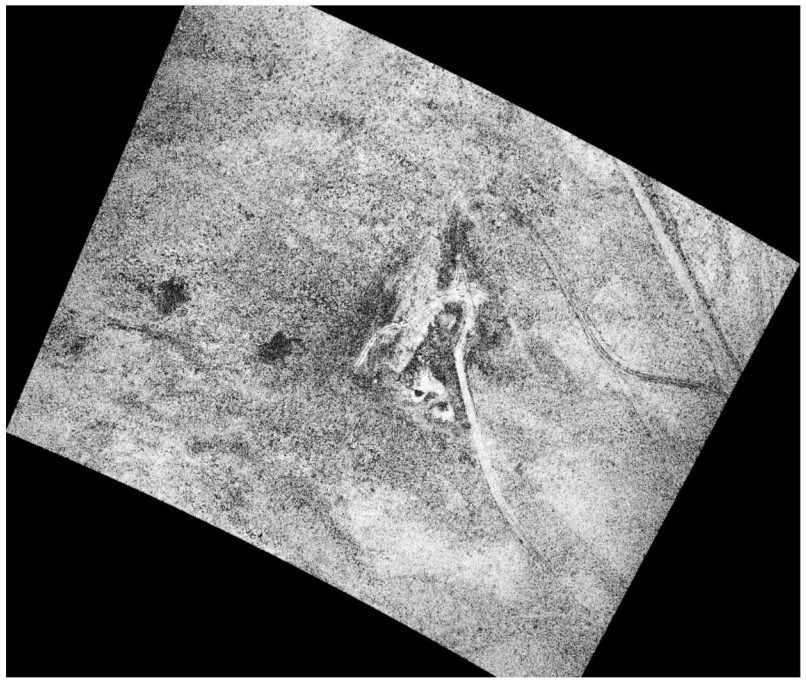
DAG-2: Time-varying Coherence

VideoSAR allows continuous monitoring of ground events. Any change in reflected ground magnitude and phase of SAR signal caused by DAG-2 experiment is captured.

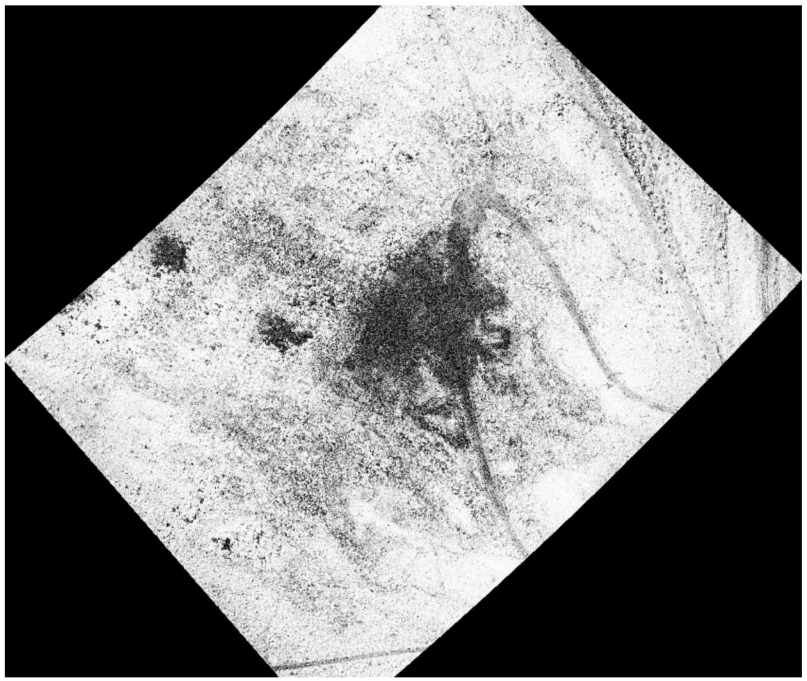


Coherence Comparison

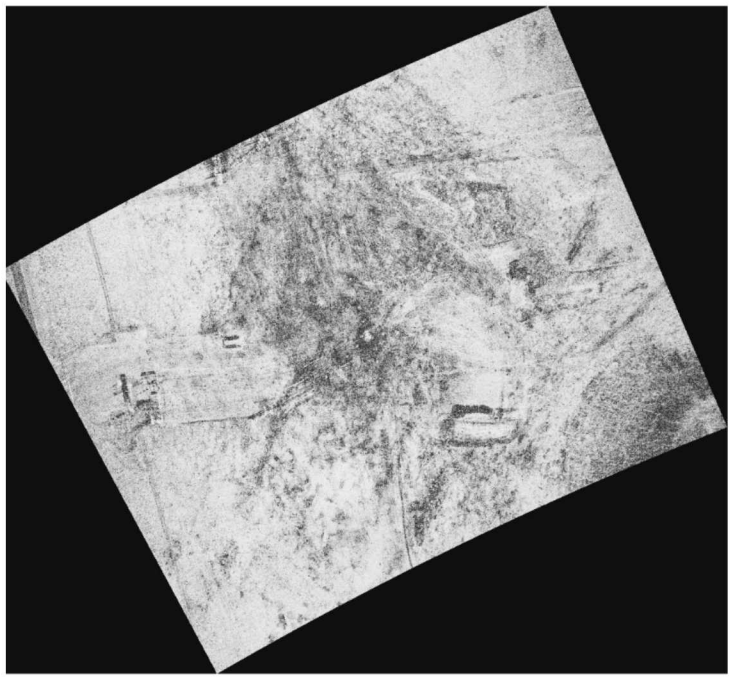
SPE-5 Final Coherence



SPE-6 Final Coherence



DAG-2 Final Coherence



The DAG-2 result is very dispersed compared to SPE-6. The seismic quality factor (Q) may help us explain the difference in results as a function of site.

The challenge is to tie the remotely sensed measure to surface phenomenology like surface velocity and spall extent.

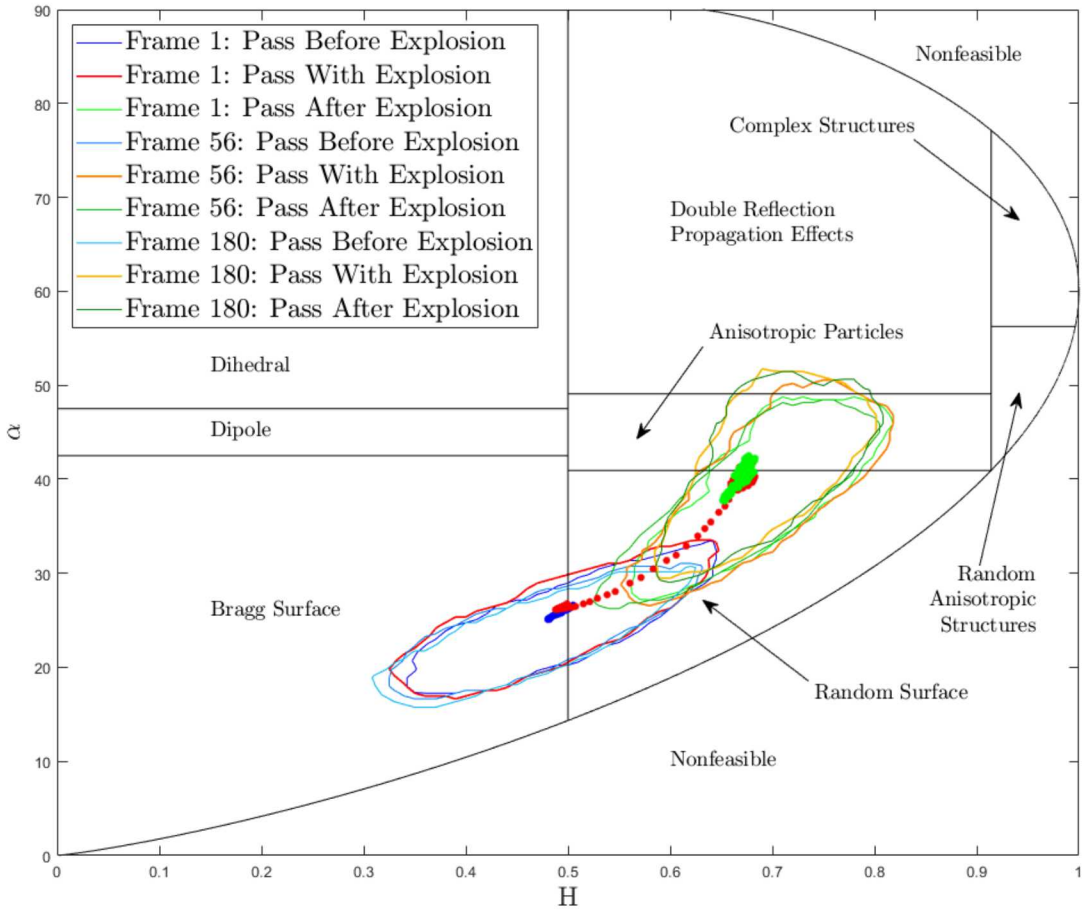
SPE-6: PolSAR Signatures

Time-Varying Polarimetric Signatures

Using the PolSAR decomposition known as the H/A/alpha decomposition, the scattering mechanism of the targets near ground zero can be monitored as a function of time. The scattering of the experiment ground pad changes from a Bragg surface scatterer to a random surface scatterer during the explosion. Moreover, the scatterers stay changed after the explosion. The ground gets “fluffed*” by the explosion.

Bragg surface is smooth to SAR wavelength as H tends toward 0. Random surface increases roughness toward anisotropic particles.

*Eisler, Chilton, Geophys. Res. 69(24), 5285-5293, 1964.

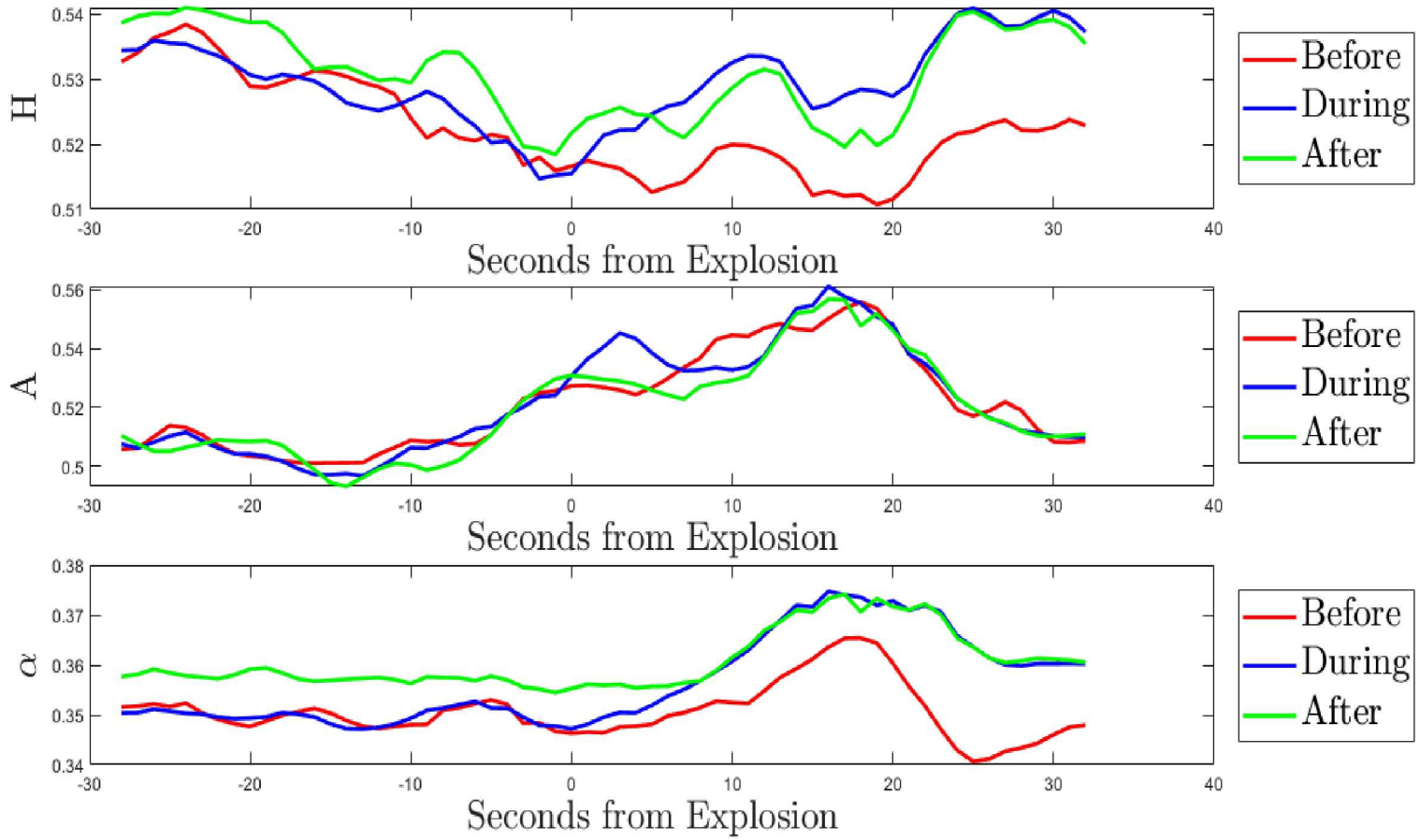


Results from: Yocky, West, Riley, Wahl, IEEE Transactions on Geoscience and Remote Sensing, 57(5), 2481-2493, 2019

DAG-2: Fully-Polarimetric VideoSAR

Time-Varying Polarimetric Signatures

DAG-2 exhibits the same randomization seen for the SPE-6 ground. The seismic quality factor (Q) for DAG-2 is ~20 and for SPE Q is ~200. The polarimetric signature is smaller at DAG-2 compared to SPE-6, but it is present as seen by H and α increasing after the DAG-2 event (0 seconds).



Interferometric SAR (InSAR) Digital Elevation Models

Two-pass comparison of phase of the same scatters gives a phase difference which captures the topographic height:

$$\mathrm{h}(\mathrm{x},y) = \frac{\Delta\phi(x,y)\lambda\cos\psi}{4\pi\Delta\psi}$$

If a change in topographic height occurs after time passes, the phase difference is

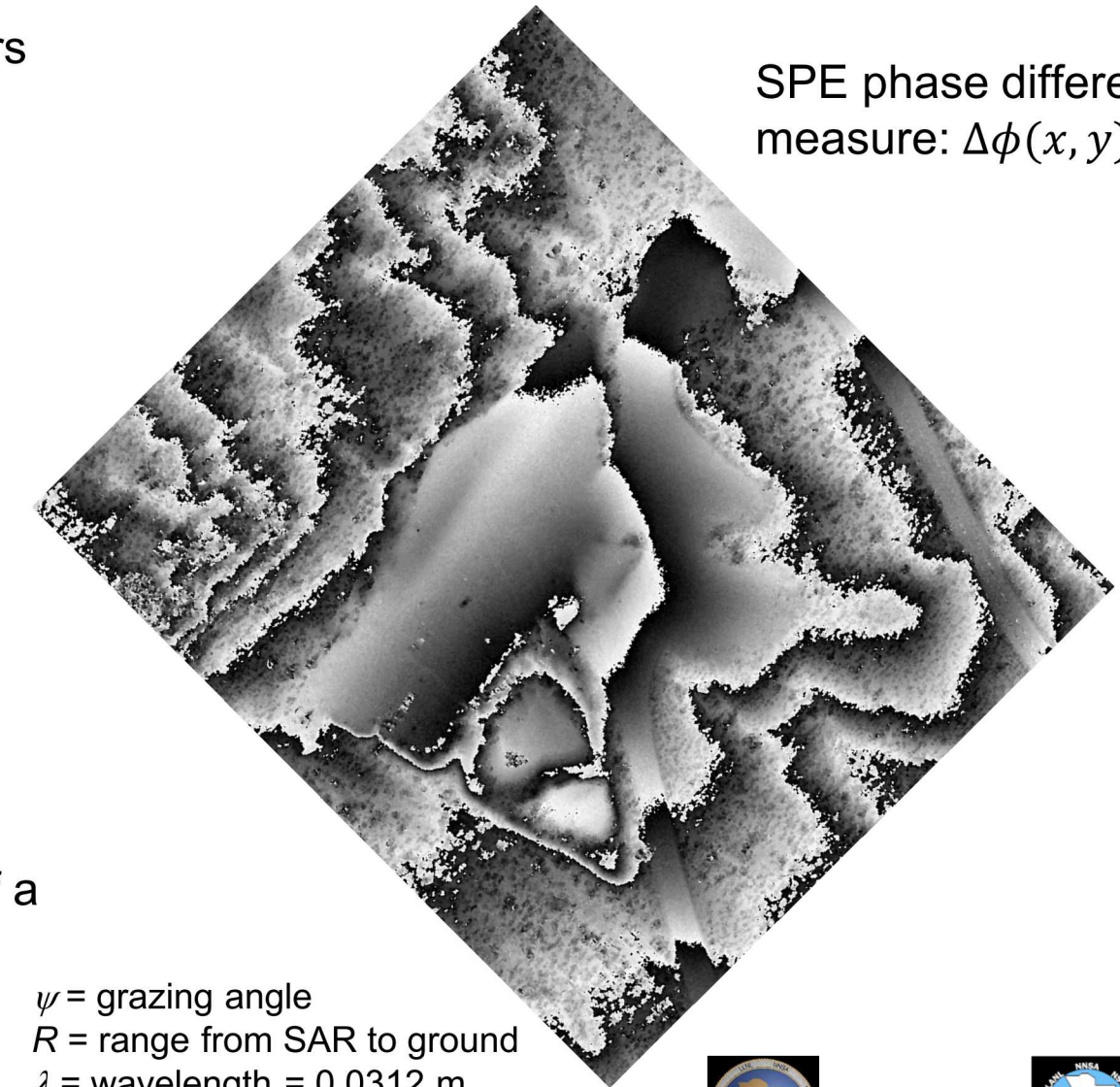
$$\Delta\phi(\mathrm{x},y) = \Delta\phi(x,y)_{topo} + \Delta\phi(x,y)_{deform}$$

$$\Delta\phi(x,y)_{deform} = \frac{4\pi(R_1(x,y) - R_2(x,y))}{\lambda}$$

The deformation term can be measured to 1/500 of a wavelength given high signal-to-noise ratio.

$$\Delta\mathrm{h}(\mathrm{x},y)_{deform} = \Delta R(x,y)_{deform}\sin\psi$$

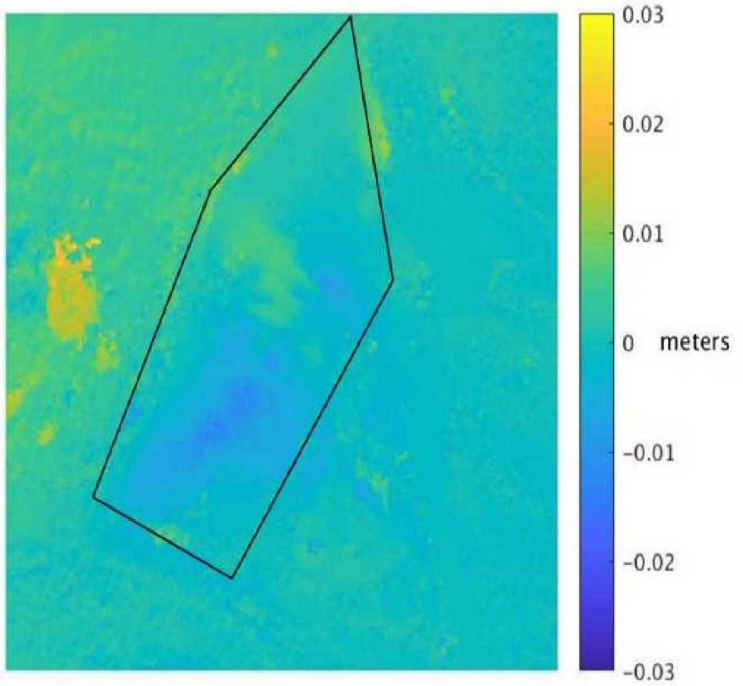
SPE phase difference measure: $\Delta\phi(x,y)$



ψ = grazing angle
R = range from SAR to ground
λ = wavelength = 0.0312 m

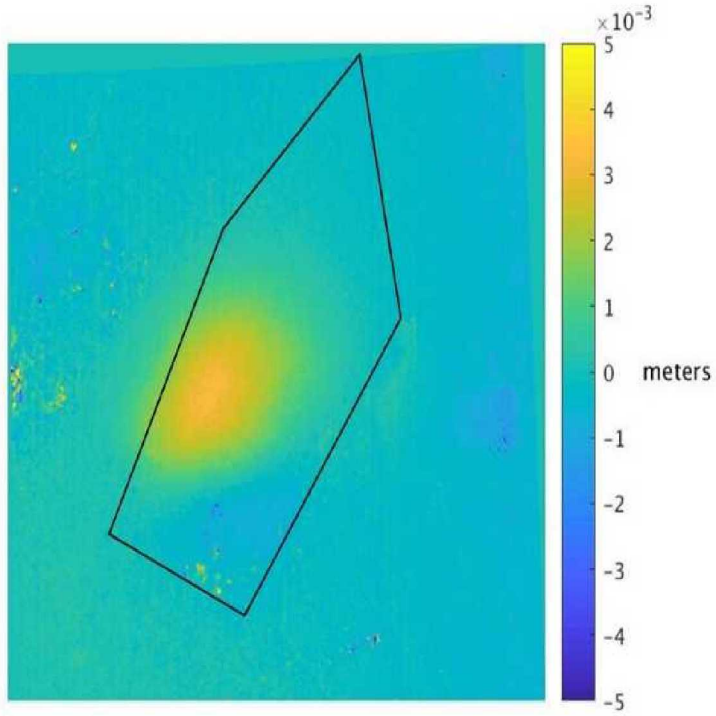
SPE-5 & SPE-6 Surface Deformation

SPE-5 Surface Change



SPE SAR Image

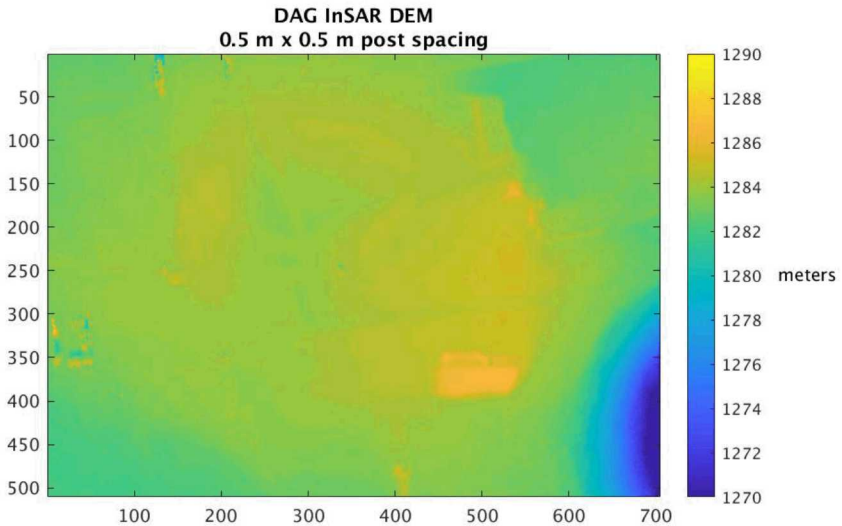
SPE-6 Surface Change



SPE-5 result: Yocky, Wahl, Calloway, SPIE Conference on Radar Sensor Technology, 10118L, 2017

Differential interferometric SAR (InSAR) was used to produce surface deformation maps.

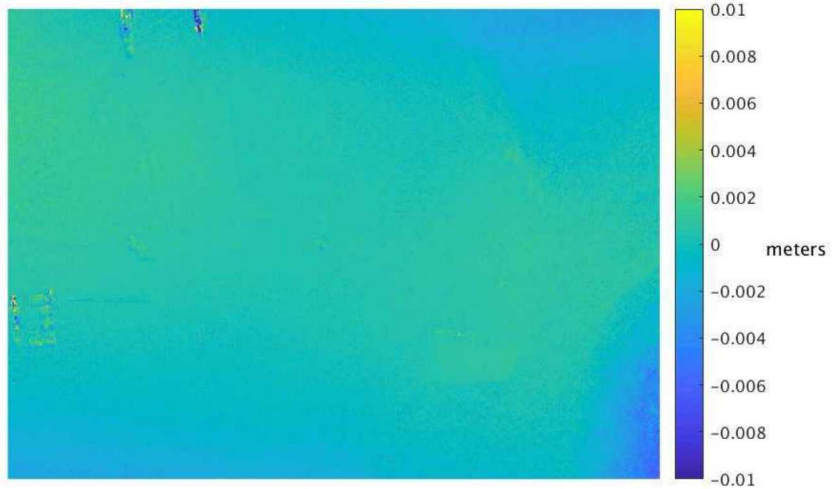
DAG-2 Interferometric SAR (InSAR) Height Products



UTM coordinates, WGS-84 ellipsoid

SAR Image (VV Polarization)

Differential InSAR DEM*



Edge of U-2ay 3 crater is captured in this scene in lower right corner

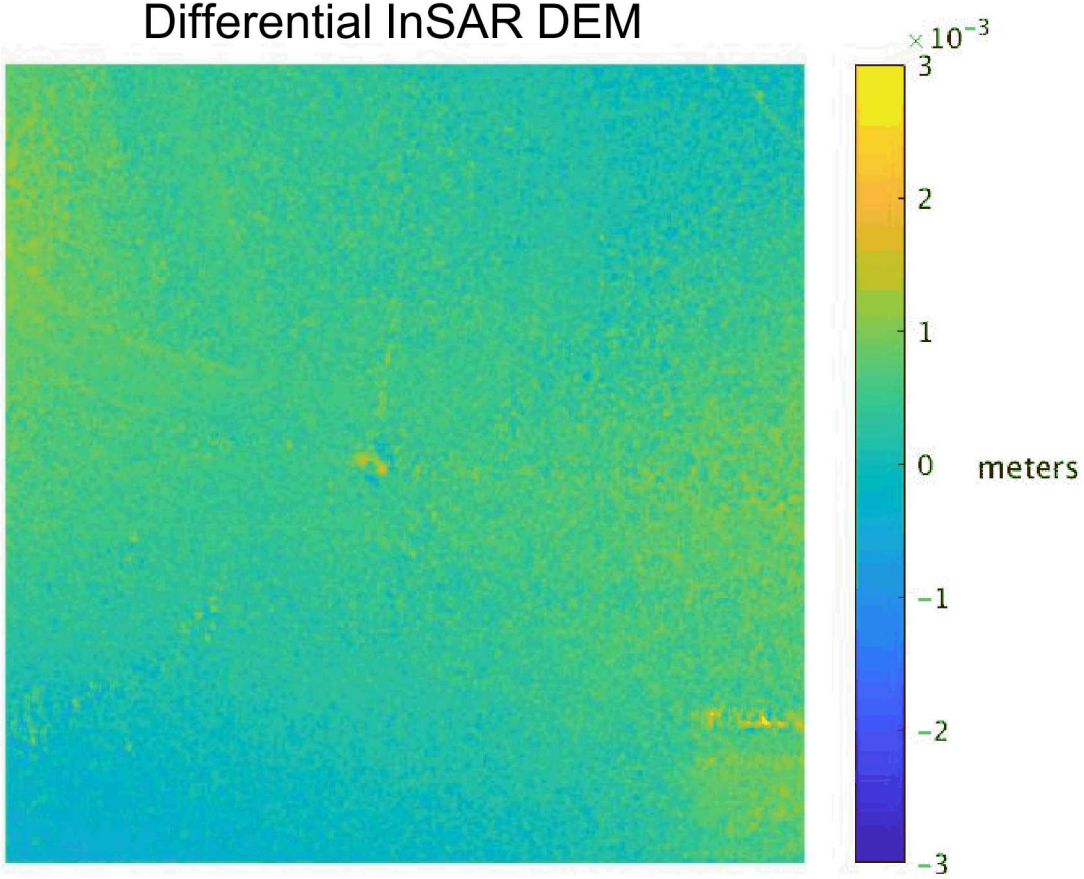
InSAR products: DEMs and surface deformation maps for DAG-2

*12 minutes after DAG-2

Zoom in of DAG-2 Height Displacement

150-m x 150-m square around scene center

Differential InSAR DEM



Maximum absolute displacement: 2.15 mm

SAR Imagery

Differential InSAR measures very small changes for the DAG-2 event that are wide-spread.

Continuing Research

- Connect remotely sensed measures with ground motion and spall
- Examine other DAG-2 difference DEMs to provide better precision and confidence in height measure
- Working to publish DAG-2 results

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. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The views expressed in this presentation do not necessarily represent the views of the U.S. Department of Energy or the United States Government.