National Aeronautics and Space Administration

VALIDATION OF A MULTI-SQUINT VECTOR DEFORMATION MEASUREMENT CONCEPT

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Program: Topic

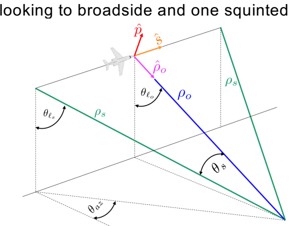
Project Objective:

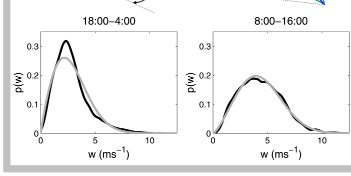
Repeat pass radar interferometry has become one of the key tools for mapping surface deformation either from natural or anthropogenic causes. By collecting data at times spanning a signal of interest, deformation along the radar line-of-sight can be measured with millimeter precision. Since surface deformation is three-dimensional, multiple vantage observations are required in order to fully solve for the deformation vector. In general this requires a minimum of three interferometric pairs with suitable viewing geometries to obtain a solution. Thus, obtaining full vector deformation measurements and reducing atmospheric noise puts considerable resource constraints on a radar observing system to make such measurements and thus any technique that would reduce the required number of repeat passes to obtain vector measurements while reducing atmospheric noise could prove beneficial [1].

The goal of this proposal is to empirically validate a measurement concept whereby multiple SAR observations collected on three lines of sight simultaneously using the UAVSAR multi-squint mode can be used to estimate both vector deformation in two directions and atmospheric noise simultaneously [2], [3].

FY18/19 Results:

The NASA/JPL UAVSAR is an L-band radar equipped with an electronically scanned antenna that can steer the beam on a pulse-to-pulse basis. By steering the beam in the along-track direction (azimuth) it is possible to generate three SAR images on a single flight track of the aircraft with one looking or squinted forward, one looking to broadside and one squinted aft as shown below.





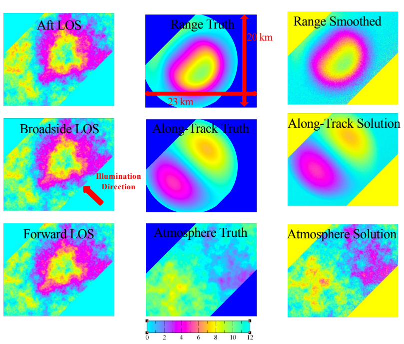
This proposal is designed to take a more systematic look at the multi-squint through a combination of simulation and experiments with the UAVSAR system designed to test and validate the theory.

We began our effort with a more realistic model of atmospheric propagation through the troposphere than the simple Kolmogorov power law phase screen used in the aforementioned simulation. Our first goal was to understand the impact of non-zero wind speed during the multi-squint acquisitions as this could adversely impact out ability to do a proper inversions.

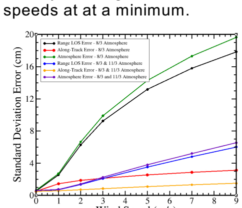
Using wind speed statistics derived from [4] (see left) we simulated wind advected atmospheric phase screens with velocities ranging from 0-9 m/s with varying wind speed directions. We also varied the functional form of the Kolmogorov power law from a purely -8/3 power law to an -11/3 law transitioning to an -8/3 power based on the height of water vapor variations in the atmosphere (~2 km).

FY18/19 Results (cont):

Figure shows the simulated data from a multi-squint UAVSAR observation of a subsidence bowl with 10 cm of vertical displacement and ~5 cm of North-South and East-West displacement and the associated inversion in the presence of 3 m/s wind. Measurement phase noise is added using for a interferometric correlation value of γ = 0.86 commensurate with a modestly decorrelating surface. The plot below shows the standard deviation of the retrieval accuracy for the various components of surface displacement and atmospheric distortion for two atmospheric phase screen models. Although both model atmospheres have the same 2 cm standard deviation the faster drop off in the power density for the −8/3 + -11/3 model results in vastly improved performance compared to the - 8/3 model.

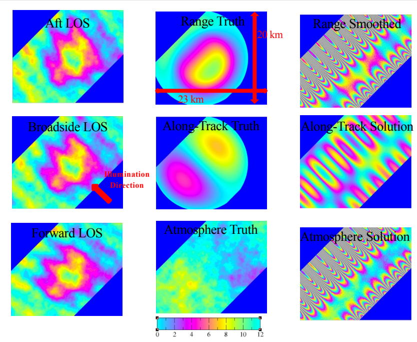


These results indicate that the technique is robust up to moderate wind speeds We used the results of these studies to inform how best to collect experimental data, namely at night when wind speeds at at a minimum.



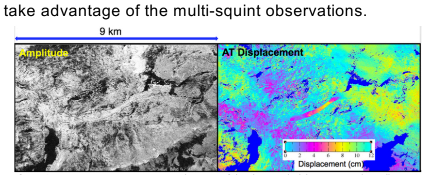
At the beginning of this study we noticed that with real data collected by UAVSAR, at either Rosamond Lake Bed in California or Slumgullion Landslide in Colorado, that the range and atmosphere components exhibited a high frequency distortion to the multi-squint solutions. This was puzzling since neither the simulations or the theory indicated that this would be expected.

We conducted both a theoretical analysis as well as simulations to see the impact that residual baselines errors (vector separating the aircraft location between repeat observations typically less than 5 m for UAVSAR) have on the solutions.



Theoretically, we found the range and atmosphere components solutions were proportional to the inverse square of the sine of the squint accounting for an approximate 10 times sensitivity to residual baseline errors in the range and atmosphere components as seen above. We modified our residual motion estimation algorithms (these recover the centimeter level motion between flight tracks not measurable with the GPS and INU systems) to take advantage of the multi-squint observations.

Figure at right shows the along-track motion of a landslide in Slumgullion, CO. measured using multi-squint UAVSAR data. The measured velocities are in excellent agreement with GPS measurements of the deformation.



Benefits to NASA and JPL

If this experiment is successful then the viability of using multi-squint observations for combined two-component vector deformation and atmospheric noise estimation will be verified and considered viable for space missions. These observation concepts will be incorporated in mission concepts in support of the Earth Science mission for surface deformation and change. Quantitative performance will be possible based on validated models from this proposed effort. Use of the multi-squint technique operationally by UAVSAR will also provide new science capabilities in its own right. If this technique proves fully viable it could substantially reduce the number of observations needed to reduce atmospheric noise thereby reducing the total required downlink data volume and processing making reduced cost highly capable missions for surface deformation feasible.

References:

[1] R. F. Hanssen, *Radar Interferometry: Data Interpretation and Error Analysis*, Kluwer Academic Publishers, Dordrecht, 2001.

[2] Curtis Chen, *Mitigation of Tropospheric InSAR Phase Artifacts Through Differential Multisquint Processing*. In Proceeding of IGARSS 2004, Anchorage, Alaska, July 2004.

[3] Scott Hensley, et. al., *Overview and Applications of UAVSAR's Multi-Squint Polarimetric Imaging Model*, PolinSAR 2011, Frascati, Italy, Jan. 2011.

[4] Monahan, A.H., Y. He, N. McFarlane, and A. Dai, 2011: The Probability Distribution of Land Surface Wind Speeds. J. Climate, 24, 3892–3909.

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