DIGITAL BEAMFORMING SYNTHETIC APERTURE RADAR (DBSAR): SINGLE-PASS INTERFEROMETRY FOR FOREST STRUCTURE ESTIMATION

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ABSTRACT

Digital Beamforming permits the implementation of non-conventional measurement techniques, which can overcome fundamental limitations of conventional radar systems. In SAR systems, this technique can enable three-dimensional measurements using a single radar platform. A split phase center technique is implemented with NASA's digital beamforming SAR. The technique has the potential to provide volume structure estimates in tall forests and glaciers using a single radar platform.

Index Terms— Digital Beamforming, SAR, InSAR

1. INTRODUCTION

L-band Synthetic Aperture Radar (SAR) has numerous earth science related applications including ecosystem cover extent and structure mapping and biomass estimation. It is of particular interest to the carbon cycle science community as it permits the remote sensing of terrestrial surfaces regardless of cloud cover or time of day due to the ability of microwaves to penetrate clouds. Although conventional SAR sensors have been employed to estimate the science parameters, there is an urgent need of developing sensors capable of three-dimensional structure measurements [1],[2]. These measurements will provide an understanding of the changes and trends in terrestrial ecosystem as a function of carbon sources and sinks, and will help in the characterization of the impact of their changes on climate, habitat and biodiversity.

The Digital Beamforming Synthetic Aperture Radar (DBSAR) is an L-band airborne radar developed at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) for the implementation and testing of advanced radar techniques in support of Earth and Planetary science applications [3]. DBSAR represents an advance in radar technology that enables multi-mode operation in a single platform, including high-resolution Synthetic Aperture Radar (SAR) images over multiple beams. Digital beamforming permits the implementation of non-conventional measurement techniques, which can overcome fundamental limitations of conventional radar systems [4], [5] such as increasing the measurement swath without reducing the received antenna gain, suppressing ambiguities or localized interference in the receiver signal and synthesizing multiple beams on both sides of the aircraft using a single nadir-looking antenna [3].

One of the advanced techniques realizable with the DBSAR is the implementation of "single pass" Interferometric SAR (InSAR) using its nadir looking antenna. InSAR is a radar technique that provides three-dimensional information in SAR images [6]. InSAR is implemented with conventional SAR systems in a “repeat pass” flight configuration where interferograms between two SAR images of the same area are generated by flying the radar in two near-identical tracks; or in a “single pass” configuration where interferograms between two SAR images of the same area are generated using two antennas. DBSAR implements InSAR (DBInSAR) in a “single pass” flight configuration using its beamforming architecture with its nadir looking antenna. Since the across-track dimension of the DBSAR antenna is 1.2 m aperture, the physical baseline achieved with this technique is short. Short baselines are well suited for the measurement of thick volumes, for example, tall rain forest or glaciers.

2. DIGITAL BEAMFORMING INSAR (DBINSAR) IMPLEMENTATION

Digital beamforming is a radar technique that is becoming increasingly important in many areas of radar applications. This technique has the potential to enable InSAR measurements using single antenna radars reducing the complexity inherent in this type of measure. InSAR is very important for science, monitoring, and defense since it adds a third dimension to the two-dimensional mapping capability of SAR systems.

The DBSAR multi-channel radar system employs an antenna made up of many elements arranged as sub-arrays. This radar architecture is characterized by a multi-channel operation with software defined waveform generation for each radar transmit channel and dedicated digital receiver channel for each receive channel. The antenna sub-arrays are aligned in the flight direction permitting relative amplitude and phase measurements between pairs of radar channels or among groups of radar channels. The beamforming architecture is illustrated in figure 1.

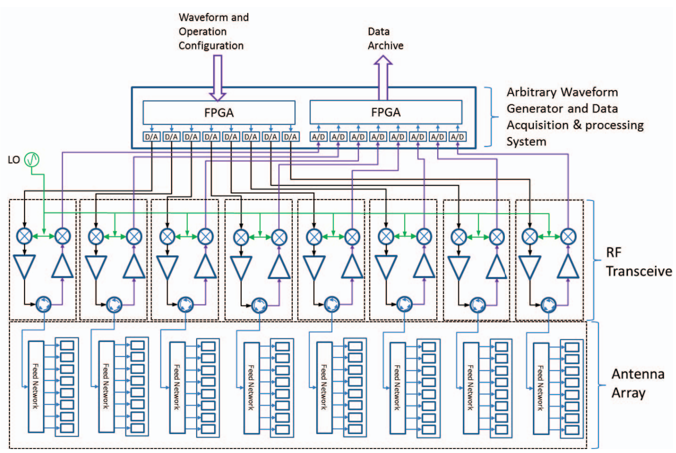

Figure 1 DBSAR's beamforming architecture enables the implementation of single-pass InSAR as well as other advanced techniques.

Using beamforming, multiple antenna beams can be synthesized simultaneously or time-interleaved enabling the implementation of the DBInSAR technique. The synthesis of two or more transmit or receive antenna beams, effectively divides the single antenna into two or more antennas (see Fig. 2) providing the basis for the DBInSAR technique [7]. The images collected with each of the antenna beams provide the interferograms that carry the three-dimensional information. Since the beam generation is performed digitally (either in transmit with software-defined transmit waveforms, or in receive with the digitized return signal data), it allows for the synthesis of beams in any direction (or look angles) covering both sides of the radar flight-track.

Additional benefits of the technique includes an increase in the measurement swath without reducing the received antenna gain, and the suppression of ambiguities or localized interference in the receiver signal by appropriate null-steering of the antenna pattern.

3. DBINSAR FOR 3D FOREST STRUCTRUE

Single-pass interferograms at four polarizations (HH, HV, VH, and VV) over the Everglades National Park during the Eco3D flight campaign [8] were acquired with DBSAR. The complex interferometric coherence containing both the interferometric correlation coefficient and interferometric

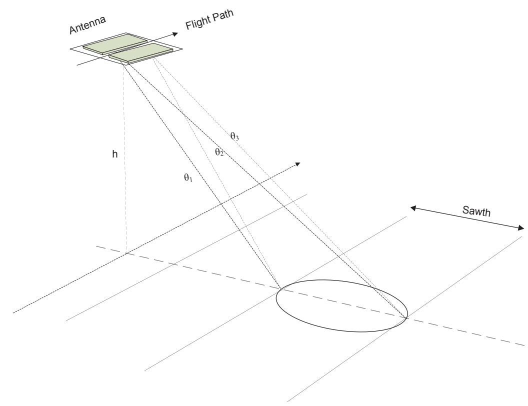

Figure 2 "Single pass" InSAR is obtained with dual beam synthesis. The highly coherent SAR images obtained from each of the beams provide the required interferometric information.

phase is a key observable to derive 3D forest structure estimates.

Figure 3 shows the interferometric correlation coefficient at each polarization. The result of single pass DBSAR interferometric processing is surprisingly strong, L-band coherence (> 0.9) over mangrove forest because of no temporal decorrelation and less volume decorrelation due to the small physical baseline (≈ 0.83 m) of DBSAR sensor. And, the level of coherence over forest has changed with forest structure.

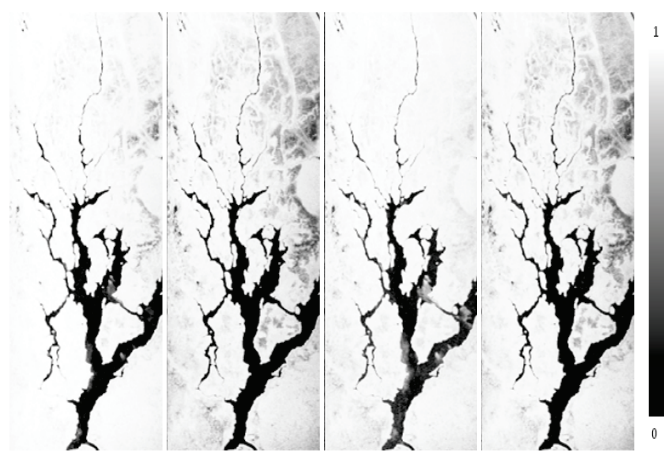

Figure 3 "Single-pass" InSAR coherence images at HH, HV, VH and VV acquired over the Everglades National Park.

Figure 4 shows the interferometric phase at each polarization. The observed interferometric phases measured both the ground phase related to underlying topography and the volume phase in forest. The phase difference of interferograms represents only relative change of volume phase caused by polarization-dependent scattering mechanism in forest.

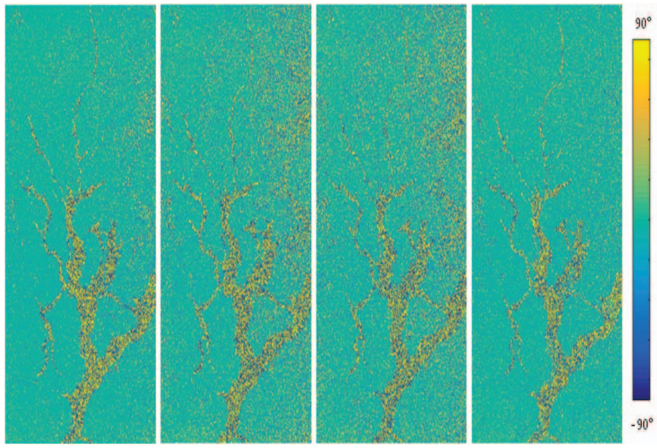

Figure 4 “Single-pass” InSAR phase images at HH, HV, VH and VV acquired over the Everglades National Park.

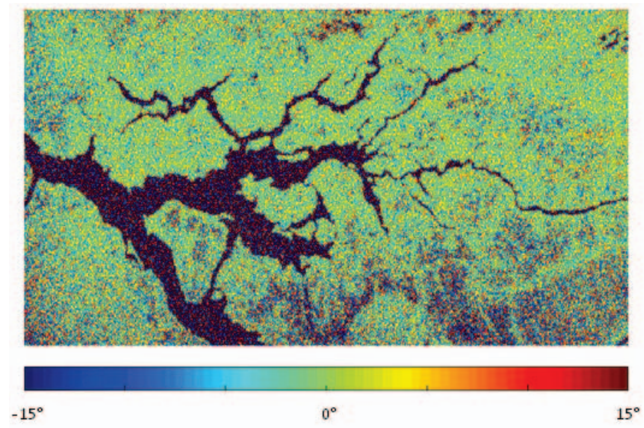

Figure 5 Single-pass DBSAR phase difference between HH and VV interferograms.

Figure 5 shows the phase difference at HH and VV. The coherent combination of interferometric and polarimetric observables from DBINSAR can be used to constrain the physical model that relates forest parameters to coherence observations.

4. CONCLUSION

The DBInSAR technique is a promising approach to increase the science value of advanced radar system by providing three-dimensional high-resolution imagery of important science parameters. The demonstration of the technique in the retrieval of forest structure using DBSAR's polarimetric measurements shows the potential of the technique and reaffirms the benefits of digital beamforming capabilities in advanced radar architectures.

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