

THE AIRSAR/TOPSAR INTEGRATED MULTI-FREQUENCY POLARIMETRIC AND INTERFEROMETRIC SAR PROCESSOR

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ABSTRACT

The algorithms and implementation of an integrated SAR processor designed to process multi-frequency SAR data from either polarimetric, interferometric or mixed mode (a combination of polarimetric and interferometric modes) SAR systems is described. The processor is designed to automatically produce co-registered multi-frequency images regardless of the data collection mode at different frequencies. If at least one frequency interferometric DEM is available, all images are resampled and terrain corrected using the DEM. Examples are provided and discussed.

INTRODUCTION

Research on the utility of Synthetic Aperture Radar (SAR) data in many diverse applications has seen great activity in the past decade. In particular, two powerful SAR techniques emerged during this time. Polarimetric SARs were first demonstrated during the 1980's and is described by van Zyl *et al.* [1] and Zebker *et al.* [2]. Since then polarimetric SAR data have been applied to most disciplines of Earth Science. A recent summary of these investigations can be found in [3]. The second powerful SAR technique that has received much attention lately is SAR interferometry. While first published by Graham [4] in the 1970's, interest in this technique has steadily increased since the demonstration of SAR interferometry using digital processing [5]. For a summary of the different applications of SAR interferometry, please see [6].

To really derive the maximum information content from SAR data, it is desirable to combine polarimetric and interferometric techniques, preferably at multiple frequencies. The NASA/JPL AIRSAR/TOPSAR system

is capable of simultaneously acquiring interferometric (C-band/or I-band) and polarimetric data (C-, I- and P-band). In this paper we describe a processing approach that is used to process data acquired in these modes. This approach is different from that described by Madsen *et al.* [7] in both the motion compensation approach, as well as in the sense that data are deskewed before interferograms are formed. Using this approach, the same basic SAR processor is used to process data acquired in any of the modes supported by the AIRSAR/TOPSAR system.

THE AIRSAR/TOPSAR SYSTEM

The NASA/JPL AIRSAR system is a three-frequency airborne SAR system that was developed to be a general test-bed for advanced SAR techniques. The SAR system is flown on a NASA DC-8 passenger jet operated by NASA's Ames Research Center in Mountainview, California. The AIRSAR antennas are not gimbaled; instead the dual-polarized microstrip antennas are mounted fixed to the body of the DC-8 aft of the left wing. The earliest mode implemented in the AIRSAR system (operational since 1988) was the three-frequency polarimetric mode, where fully polarimetric data are acquired simultaneously at C-band, I-band and P-band. This mode was used to provide prototype data for the SIR-C/X-SAR science team and many of the algorithms applied to SIR-C data were developed using AIRSAR data.

In 1990 NASA, in collaboration with an Italian consortium (CORISTA), approved the addition of another set of C-band antennas to implement a single-pass, fixed baseline cross-track interferometer (XTI) for topographic mapping. The C-band antennas were provided by CORISTA, while NASA sponsored the system modifications and processor development described by

Madsen *et al.* [7]. This mode of the AIRSAR system became known as TOPSAR [8] and data have been acquired since 1991. The original TOPSAR processing software has been updated several times since the original publication in [7]. One version of this updated software was delivered to the Environmental Research Institute of Michigan (ERIM) under a contract with the Defense Advance Research Projects Agency (DARPA), and is currently being used to process the data from the ERIM IF/SARE system. In 1995 TOPSAR was extended to acquire XTI data simultaneously at C-band and I-band [9]. All TOPSAR interferometers can be operated in single or dual baseline modes. For single baseline operation signals are transmitted out of one antenna only, and the received signals are measured simultaneously through two antennas. In the dual baseline mode, signals are alternately transmitted out of the antennas at either end of the baseline, while the received signals are measured simultaneously through both antennas.

PROCESSING APPROACH

The aim of the integrated AIRSAR Processor is to implement a processing strategy capable of processing all the modes described above with the same basic processor. Therefore, the processor must automatically produce co-registered multi-frequency images, whether or not at least one frequency was acquired in the interferometric mode. Madsen *et al.* [7] describe a way to process single frequency cross-track interferometry data. In this approach, the individual images are never explicitly deskewed. Rather, the deskew forms an integral part of the location algorithm; the along-track offset given by Madsen *et al.* [7] is identical to the deskew used in the traditional range-Doppler processor [10].

This follows from the fact that in traditional (non-interferometric) SAR processing, it is assumed that the imaged pixel is located at the intersection of the Doppler cone (centered on the velocity vector), the range sphere (centered at the antenna) and an assumed reference plane as shown in Figure 1. Since the Doppler cone has its apex at the center of the range sphere, and its axis of symmetry is aligned with the velocity vector, it follows that all points on the intersection of the Doppler cone and the range sphere lie in a plane orthogonal to the velocity vector.

The additional information provided by the interferometry is that the imaged point also has to lie on the cone described by a constant phase, which means that one no longer has to assume an arbitrary reference plane. This cone of equal phase has its axis of symmetry aligned with the interferometer baseline and also has its apex at

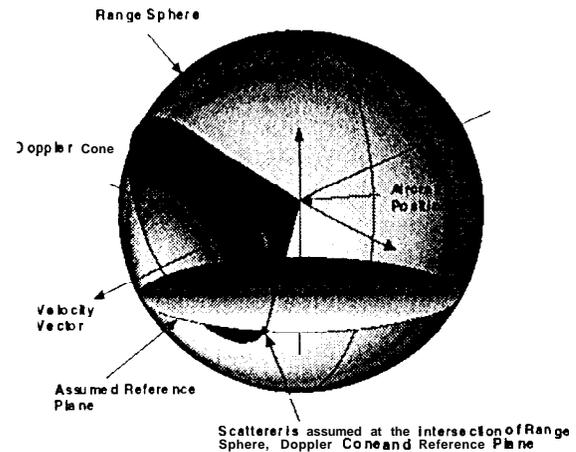


Figure 1 Imaging geometry assumed in traditional (non-interferometric) SAR processing.

the center of the range sphere. It then follows that the imaged point lies at the intersection of the Doppler cone, the range sphere and the equal phase cone as shown in Figure 2. Using the same argument as before, it is clear that the point still lies in a plane orthogonal to the velocity vector. This along-track offset can still be calculated using the traditional expression for the deskew, as shown in Madsen *et al.* [7].

When processing multi-frequency data, one has two options to ensure that the output images automatically co-register. In the first approach, the sub-patch size is chosen such that the same number of output lines are kept for all frequencies. (This assumes that the radars operate at the same pulse repetition frequency, which is the case for the AIRSAR system.) All frequencies can then be processed with properly scaled Doppler parameters, meaning that the along-track shift for all frequencies will be the same. Therefore, the location parameters derived at any frequency can directly be applied to all the other frequencies. In this case, the size of the sub-patch used, as well as the amount of overlap between adjacent sub-patches are determined by the length of the azimuth reference functions at the lowest frequency.

There are two main disadvantages to this approach. First, the fixed number of output lines for all frequencies means that the processor becomes quite inefficient in the case of the high frequencies for which the azimuth reference functions are much shorter than at the low frequencies, since large parts of the overlap areas between

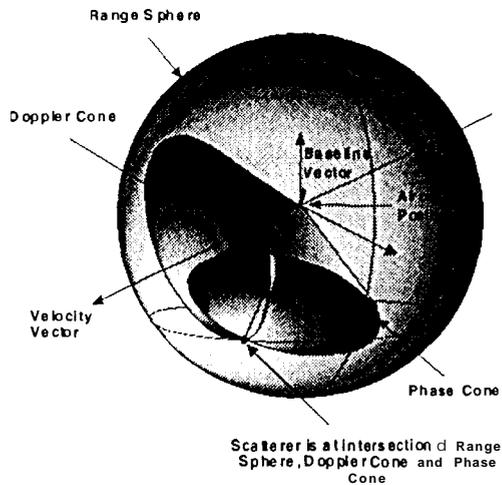


Figure 2. In the case of interferometric SAR processing, one does not have to assume all scatterers are on a flat reference plane. Instead, the scatterer is at the intersection of the range sphere, the Doppler cone, and the interferometric phase cone.

successive sub-patches are unnecessarily recalculated. Secondly, since the size of the patch at the high frequencies is large compared to the synthetic aperture size, the motion compensation may be less than optimum.

These disadvantages can be overcome by processing each frequency separately into the zero squint geometry before utilizing any interferometric information. After the deskew is applied, the multi-frequency images automatically co-register. This now means that each frequency can be processed with a sub-patch size optimally chosen for that particular frequency. In a sense this follows the same processing paradigm usually employed in repeat-pass interferometry. The disadvantage, at least in our implementation, is that the bookkeeping of the phases during motion compensation is slightly more complicated.

The post processing steps applied after the SAR processing depends on the mode in which the data were acquired. For the three-frequency polarimetric mode the various cross-products are combined into the standard AIRSAR compressed Stokes Matrix format and then radiometrically calibrated,

In the case where interferometric data were acquired, the interferogram phase is first unwrapped and the slant range digital elevation model is formed. The location parameters for each slant range pixel is now calculated using the elevation model just derived. Since all the images acquired at the different frequencies now are co-registered, the same set of location parameters \hat{a}_i can be used to geometrically resample all images. These location parameters are then used to resample the calibrated polarimetric SAR images. In addition to the calibrated and geometrically corrected SAR images and the digital elevation model, images of the local incidence angle and the interferometric correlation coefficient are also provided. These images are also geometrically corrected using the location parameters calculated from the interferometric phase information.

RESULTS

Figure 3 shows an example of multi-frequency and multi-polarization data produced with the Integrated Processor. The area shown in perspective view is in the Cordillera Real region Bolivian Andes near the capital city of La Paz. The three-frequency images are automatically co-registered in the processor, and geometrically resampled using the topography derived from the C-band interferometric data.

The performance of the TOPSAR instrument and processor was previously reported by Madsen, *et al.* [7], who compared the radar derived digital elevation models with ones derived using conventional optical stereo techniques. Their analysis showed the difference between the DEMs to be 2.2 m r.m.s in relatively flat terrain, and up to 5.0 m in mountainous areas. Instead of repeating these analyses here, we compare the results of the Integrated Processor described here to that of the TOPSAR processor described by Madsen *et al.* [7].

To compare the results of the processors, we processed two strips of data through both processors, and then compared the results. First we tested the relative

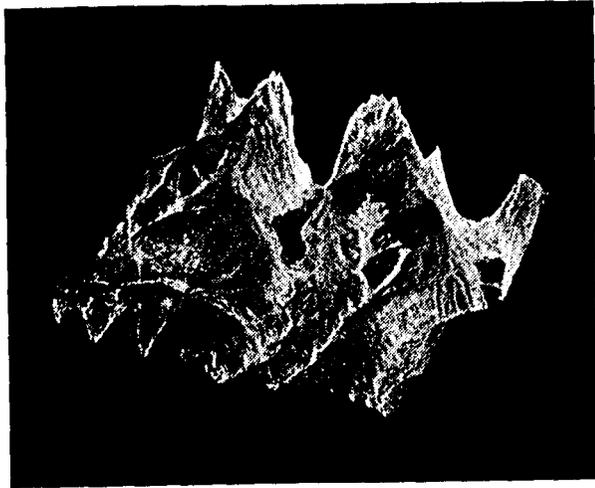


Figure 3. Perspective view of part of the Bolivian Andes near La Paz, Bolivia. The topography was derived from C-band TOPSAR interferometric data. Draped over the topography is the grayscale radar images acquired at L-band HH polarization

geometrical accuracy of the two resulting data sets. This is done by cross-correlating small subsections of the images, and measuring the along-track and cross-track offsets between the images. This analysis is repeated for a grid of 100 points spaced uniformly through the images. To test the effect of relief on the results, this comparison was done for a flat area covering the Bolivar peninsula near Galveston, Texas, and a mountainous area covering part of Mount Rainier in Washington State. The total relief in the Bolivar scene is less than 50 m while the total relief in the Mount Rainier scene is about 1500 m. The results of the relative geometry test shows the rms difference between the Bolivar images to be 1.3 m in the cross-track direction, and 2.1 m in the along-track direction for a nominal post spacing of 10 m. For the Mount Rainier scenes, the rms difference are 2.3 m and 4.9 m in the cross- and long-track directions respectively. This confirms previous reports that results for relatively flat areas are typically better than those for high relief areas.

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