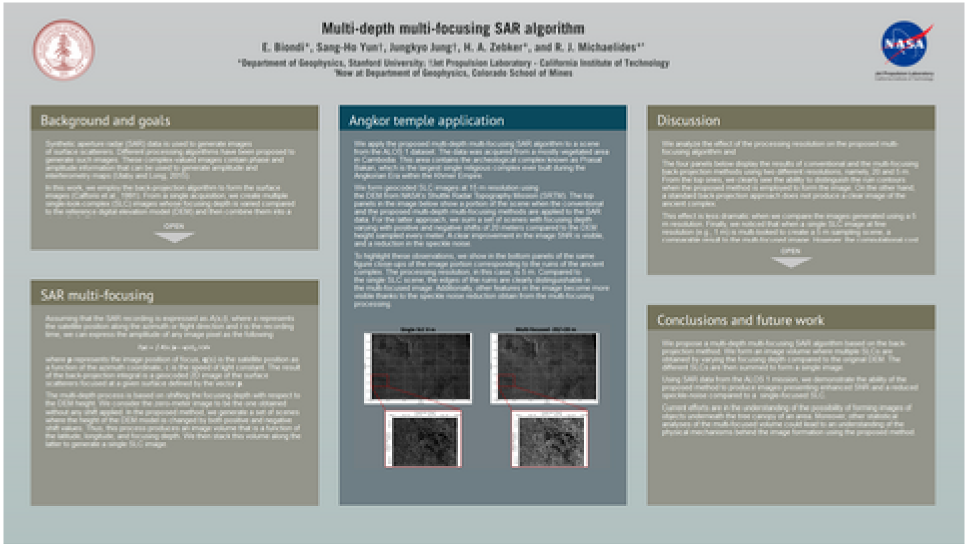
Multi-depth multi-focusing SAR algorithm



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BACKGROUND AND GOALS

Synthetic aperture radar (SAR) data is used to generate images of surface scatterers. Different processing algorithms have been proposed to generate such images. These complex-valued images contain phase and amplitude information that can be used to generate amplitude and interferometry maps (Ulaby and Long, 2015).

In this work, we employ the back-projection algorithm to form the surface images (Cafforio et al., 1991). From a single acquisition, we create multiple single-look-complex (SLC) images whose focusing depth is varied compared to the reference digital elevation model (DEM) and then combine them into a single SLC. This multi-look step produces an increased signal-noise-ratio (SNR) in the resulting image. We refer to this workflow as a multi-depth multi-focusing SAR algorithm.

We apply this approach to a SAR scene from Advanced Land Observing Satellite 1 (ALOS1) dataset and show the ability to diminish the speckle noise in the resulting SLC. We also study the possibility of using this method to generate improved images of the surface scatterers present underneath the vegetation canopy.

SAR MULTI-FOCUSING

Assuming that the SAR recording is expressed as *A(s,t)*, where *s* represents the satellite position along the azimuth or flight direction and *t* is the recording time, we can express the amplitude of any image pixel as the following:

$$I(\mathbf{p}) = \int A(s, |\mathbf{p} - \mathbf{q}(s)|_2 / c) ds$$

where **p** represents the image position of focus, **q**(s) is the satellite position as a function of the azimuth coordinate, c is the speed of light constant. The result of the back-projection integral is a geocoded 2D image of the surface scatterers focused at a given surface defined by the vector **p**.

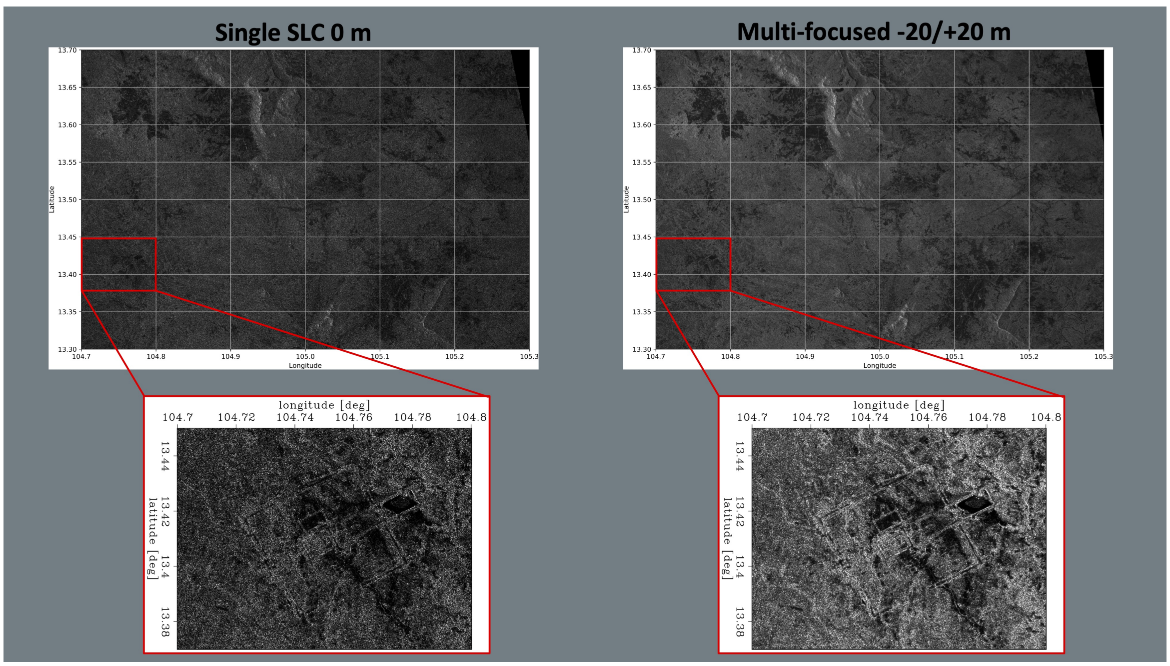
The multi-depth process is based on shifting the focusing depth with respect to the DEM height. We consider the zero-meter image to be the one obtained without any shift applied. In the proposed method, we generate a set of scenes where the height of the DEM model is changed by both positive and negative shift values. Thus, this process produces an image volume that is a function of the latitude, longitude, and focusing depth. We then stack this volume along the latter to generate a single SLC image.

ANGKOR TEMPLE APPLICATION

We apply the proposed multi-depth multi-focusing SAR algorithm to a scene from the ALOS 1 dataset. The data was acquired from a mostly vegetated area in Cambodia. This area contains the archeological complex known as Prasat Bakan, which is the largest single religious complex ever built during the Angkorian Era within the Khmer Empire.

We form geocoded SLC images at 15 m resolution using the DEM from NASA's Shuttle Radar Topography Mission (SRTM). The top panels in the image below show a portion of the scene when the conventional and the proposed multi-depth multi-focusing methods are applied to the SAR data. For the latter approach, we sum a set of scenes with focusing depth varying with positive and negative shifts of 20 meters compared to the DEM height sampled every meter. A clear improvement in the image SNR is visible, and a reduction in the speckle noise.

To highlight these observations, we show in the bottom panels of the same figure close-ups of the image portion corresponding to the ruins of the ancient complex. The processing resolution, in this case, is 5 m. Compared to the single SLC scene, the edges of the ruins are clearly distinguishable in the multi-focused image. Additionally, other features in the image become more visible thanks to the speckle noise reduction obtain from the multi-focusing processing.

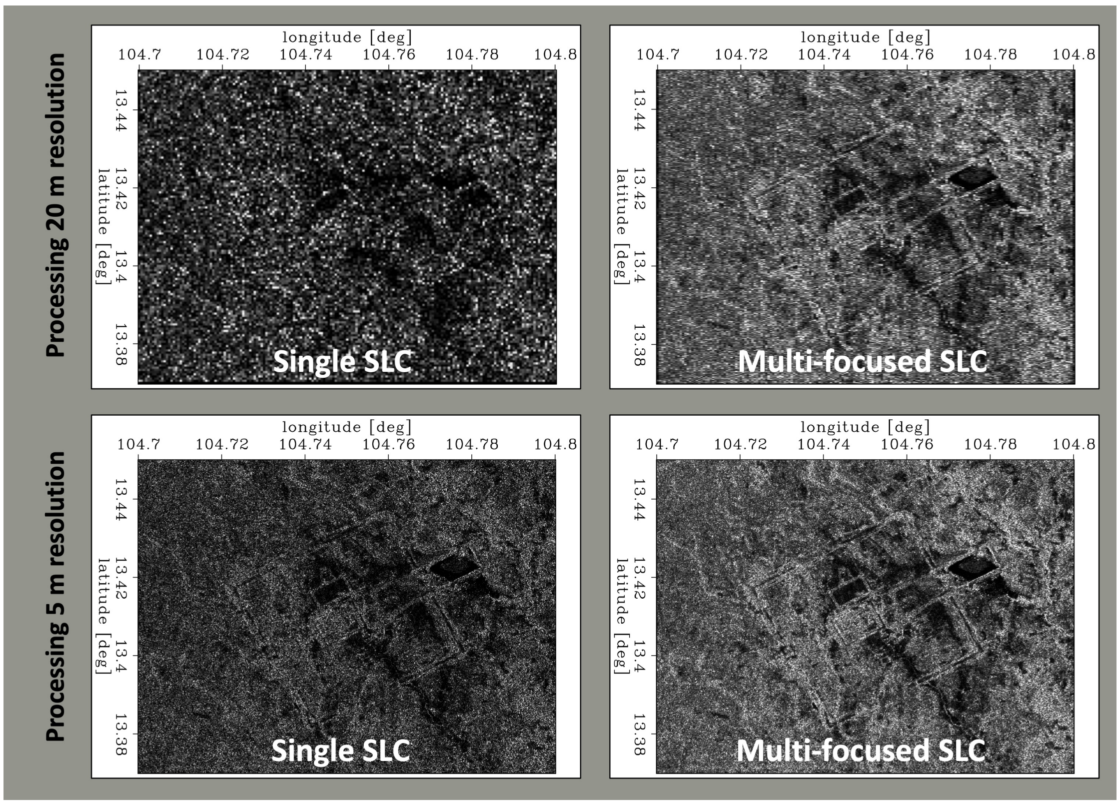


DISCUSSION

We analyze the effect of the processing resolution on the proposed multi-focusing algorithm and

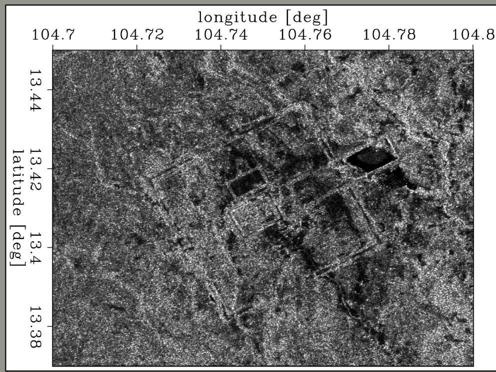
The four panels below display the results of conventional and the multi-focusing back-projection methods using two different resolutions, namely, 20 and 5 m. From the top ones, we clearly see the ability to distinguish the ruin contours when the proposed method is employed to form the image. On the other hand, a standard back-projection approach does not produce a clear image of the ancient complex.

This effect is less dramatic when we compare the images generated using a 5 m resolution. Finally, we noticed that when a single SLC image at fine resolution (e.g., 1 m) is multi-looked to create a 5 m sampling scene, a comparable result to the multi-focused image. However, the computational cost of forming high-resolution SLCs is higher than generating the multi-depth image volume. Hence, a large extent of the surface scatterers can be readily computed using the proposed approach without creating fine-spatial sampled images. The resulting SLCs can then be used for different purposes, such as recognizing unknown features present in the SAR scenes.

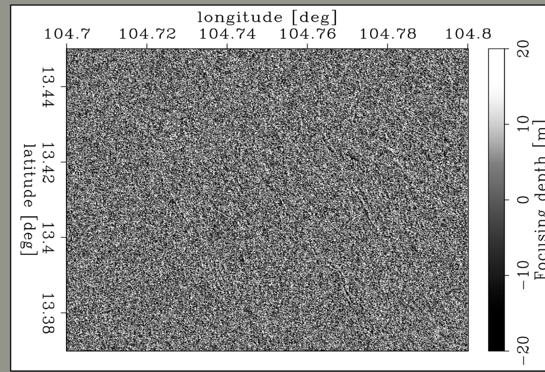


One of the proposed approach's ideas is to study the possibility of focusing scattered energy by objects underneath a tree canopy. To assess this possibility, we form an image by extracting the maximum in a pixel-by-pixel fashion from the multi-depth volume. The left panel below shows the resulting image by following such a procedure. Similar image improvements can be observed compared to the multi-depth multi-focused method. On the right panel, we show the corresponding depth that maximizes the power return. No clear structure pattern can be seen in this figure. It is still unclear the physical mechanism that allows the formation of the enhanced SLC. We are currently investigating this process on different SAR scenes recorded using different bands.

Maximizing return



Depth of maximum return



CONCLUSIONS AND FUTURE WORK

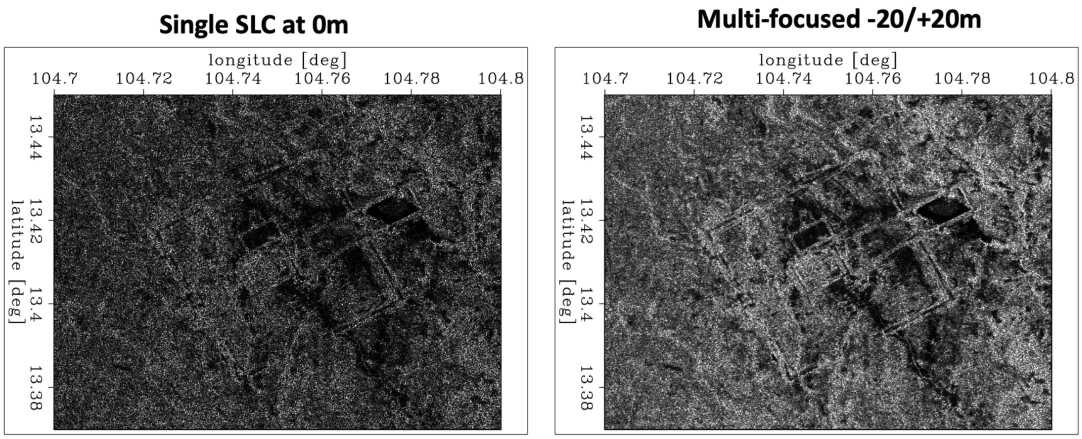
We propose a multi-depth multi-focusing SAR algorithm based on the back-projection method. We form an image volume where multiple SLCs are obtained by varying the focusing depth compared to the original DEM. The different SLCs are then summed to form a single image.

Using SAR data from the ALOS 1 mission, we demonstrate the ability of the proposed method to produce images presenting enhanced SNR and a reduced speckle-noise compared to a single-focused SLC.

Current efforts are in the understanding of the possibility of forming images of objects underneath the tree canopy of an area. Moreover, other statistical analyses of the multi-focused volume could lead to an understanding of the physical mechanisms behind the image formation using the proposed method.

ABSTRACT

Synthetic aperture radar (SAR) multi-temporal techniques have been proposed to improve image resolution, persistent-scatterer detection, and damage-map generation (Bujor et al., 2004; Hooper, 2008; Yun et al., 2012). The usage of multiple scenes diminishes the speckle noise commonly present in a SAR image and increases the overall signal-to-noise ratio (SNR) of dominant radar scatterers. Following the same idea, we propose a new SAR processing workflow based on the back-projection algorithm (Cafforio et al., 1991). We employ the back-projection method's flexibility to focus the radar pulses at multiple depths shifted with respect to the reference digital elevation model (DEM), yielding a volume of SLCs discretely sampled over a range of elevations/depths. These scenes are then combined to produce a single-look complex (SLC) image, which presents increased SNR and effective resolution. Similar image improvements can be achieved by spatially averaging a SLC image generated at high spatial sampling. However, the proposed method requires a fraction of the processing time of the fine-spatial SLC formation. The proposed approach retains the same benefits of any back-projection algorithm and enables the formation of SLC images corresponding to large Earth surface extents.



(https://agu.confex.com/data/abstract/agu/fm20/5/6/Paper_697665_abstract_664735_0.png)

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