CHALLENGES OF INSAR DEM DERIVATION WITH SENTINEL-1 SAR IN DENSELY VEGETATED HUMID TROPICAL ENVIRONMENT

M. M. Chindo [1,2 & 3], M. Hashim [1, 2, *], A. W. Rasib [2]

[1] Geoscience and Digital Earth Centre (INSTeG), Research Institute of Sustainability Environment (RISE), Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
[2] Faculty of Built Environment & Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
[3] Department of Survey and Geoinformatics, School of Environmental Studies, Federal Polytechnic Nasarawa, Nasarawa State, Nigeria.

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ABSTRACT:

Since the launch of the Sentinel-1 Synthetic Aperture Radar (SAR) in 2014 by the European Space Agency (ESA), there has been renewed interest in SAR data for various application, including DEM derivation with SAR Interferometry (InSAR) technique. However, the success of the InSAR technique in deriving DEM with Sentinel-1 SAR which has been largely acknowledged in sparsely vegetated regions, remains controversial in the densely vegetated environment due to certain challenges, which have rarely been reported. The aim of this study is to highlight some of the obstacles of InSAR DEM derivation with Sentinel-1 SAR over densely vegetated humid tropical environment. Suitable Sentinel-1 image pairs over part of Johor, Peninsular Malaysia, determined in terms of perpendicular and temporal baselines using the Alaska Satellite Facility (ASF) online baseline computation tool, were downloaded from the ASF archive and processed accordingly using the Sentinel Application Platform (SNAP). Difficulty in acquiring suitable image pairs, phase decorrelation and poor coherence, and unwrapping problems are some of the encountered challenges of InSAR DEM derivation with Sentinel-1 SAR in the densely vegetated humid tropics reported in this study. This study shall provide to the geoscientific community insights on InSAR DEM derivation with Sentinel-1 SAR in densely vegetated environments and initiate discussion on the technique’s promise in such environments.

1. INTRODUCTION

Interferometric Synthetic Aperture Radar (InSAR), a technique that measures the phase difference between two or more synthetic aperture radar (SAR) acquisitions over an area retrieved at different times and sensor positions, has proven to be an effective tool for geoscience and environmental monitoring applications (Massonnet & Feigl, 1998; Schultz & Engman, 2000), including digital elevation model (DEM) derivation. The technique’s principle for topographic mapping, which was first described by Graham (1974) and validated with SEASAT and SIR-B data (Gens & van Genderen, 1996; Lillesand et al., 2015; Maitre, 2008), has rapidly developed as a viable alternative means of satellite-based DEM derivation since 1991 following the launch of Europe's first radar satellite (ERS-1) (Lillesand et al., 2015; Maitre, 2008).

The SAR cloud penetration capability, high resolution (HR), and ability to image the earth’s surface both day and night (Suryanti & Wahyudiono, 2017), give the InSAR technique unique advantages over other satellite-based DEM derivation methods. One popular product of the InSAR processing of SAR data is the Shuttle Radar Topography Mission (SRTM) DEM, which provides a near-global high resolution (HR) DEM with the remarkable advantages of uniform quality and free availability (Yang et al., 2011). Despite the obvious advantages, InSAR satellite-based DEM derivation remain unpopular due to probably the more limited access and challenging processing of SAR data (Hosseini et al., 2019).

However, since the launch of the Sentinel-1 SAR in 2014 by the European Space Agency, which marked the beginning of an era of free access to SAR data, especially the focused Single Look Complexes (SLC) containing the radar signal phase information for both scientific and operational domains (Potin et al., 2019), there has been renewed interest in the application of the InSAR technique for DEM derivation. Besides, the Sentinel Application Platform (SNAP) development and open access for seamless preprocessing and processing of all Sentinel satellite data products and the existence of the step forum (https://forum.step.esa.int) —a vibrant online user community — has further inspired the use of Sentinel-1 satellite products among researchers for all sorts of activities, including DEM derivation.

Nonetheless, the InSAR technique, which has been successfully applied in deriving satellite-based DEM using Sentinel-1 SAR in sparsely vegetated areas (Ahmadabadi et al., 2020; Ghannadi et al., 2019 and Sefercik et al., 2018), remains largely controversial

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* mazlanhashim@utm.my

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in the densely vegetated humid tropic due to certain difficulties often encountered during the DEM derivation, which have rarely been reported. Yet, Sentinel-1 InSAR derived DEMs with varying accuracies over the densely vegetated humid tropic have been reported by Mohammadi et al. (2018); Sunu et al. (2019) and Ullo et al. (2018).

Consequently, this paper aims at highlighting some of the difficulties of applying the InSAR technique for DEM derivationwith Sentinel-1 SAR in the densely vegetated humid tropics. This paper shall provide insights to the geoscientific community on the challenges of InSAR techniques for DEM derivation with Sentinel-1 SAR in densely vegetated humid tropical environments and shall open discussion on the technique's promise in such environments

2. MATERIAL AND METHOD

2.1 Study area

This study was conducted over part of Johor, around Latitude 1° 37' 30" N and Longitude 103° 52' 50" E in Peninsular Malaysia. The area is characterised by dense vegetation cover, featuring forest, oil palm and rubber plantations, with patches of dense built-up. The climate is humid, with two monsoons separated by two inter-monsoons. The terrain is gently undulating, varying between 0 m to 500 m. Figure 1 depicts the study area.

2.2 Data Acquisition and Processing

Six pairs out of the nine possible pairs of the archived Sentinel-1 SLC SAR images (between 01/01/2015 to 31/05/2021) in ASF, determined based on the optimum perpendicular baseline recommended to be between 150 m and 400 m for exact description of variation in topography by the observed fringes (Braun, 2021) were downloaded from the Alaska Satellite Facility (ASF), after a thorough search of the ASF database using the ASF baseline computation tool (Figure 2) to determine suitable image pairs. The data were then appropriately preprocessed and processed using SNAP. Finally, the results are presented using descriptive statistics.

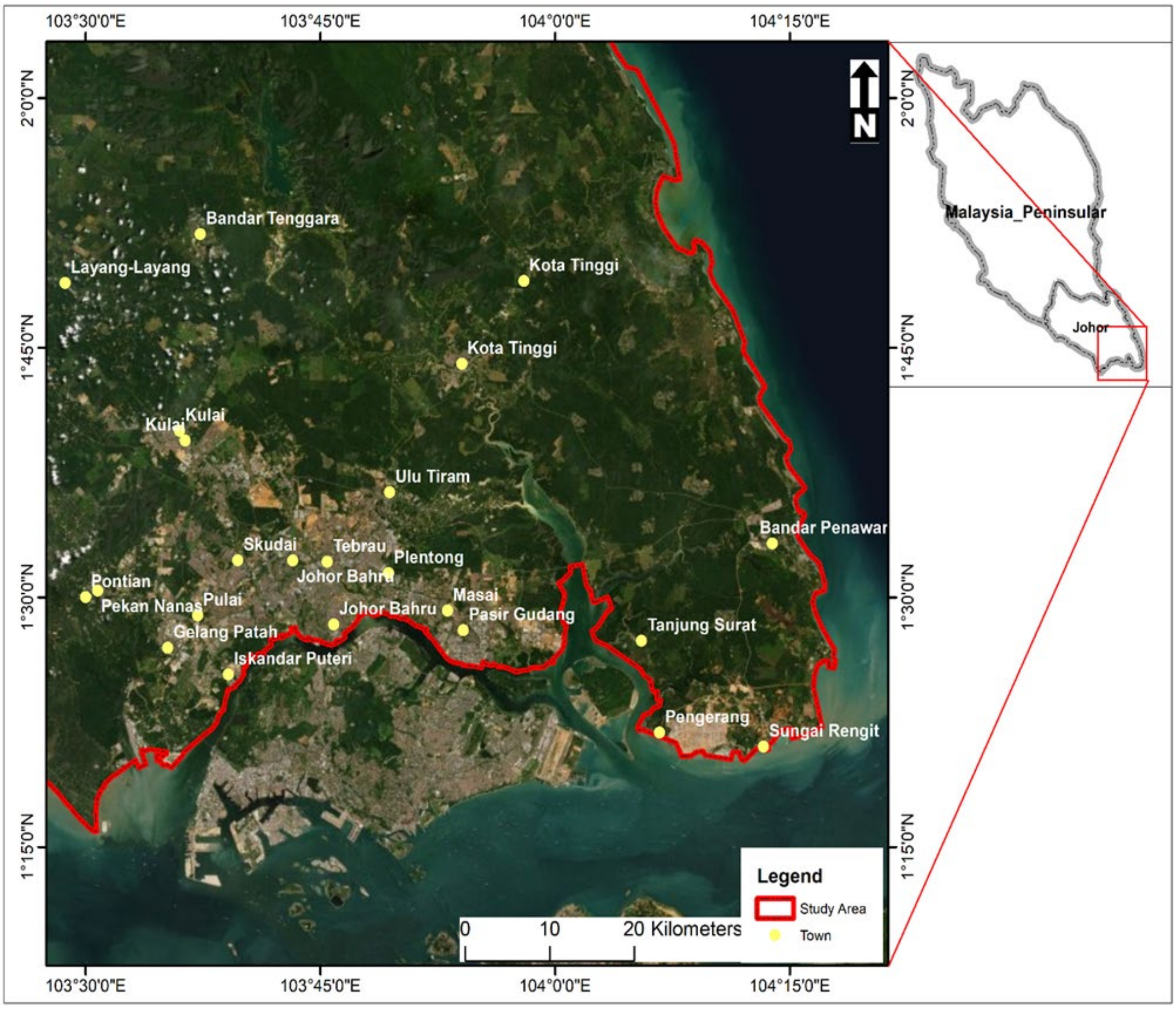
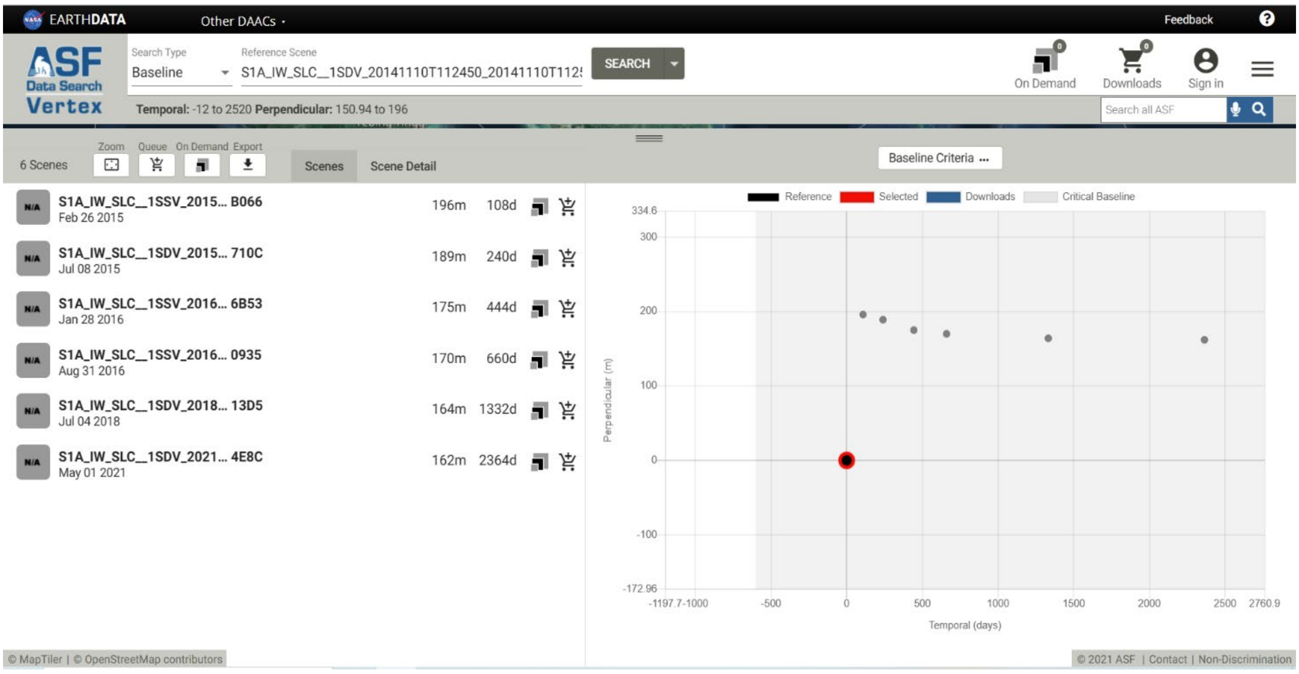


Figure 1. Study area



Search Type: Baseline
Reference Scene: S1A_IW_SLC__1SDV_20141110T112450_20141110T112

Temporal: -12 to 2520 **Perpendicular:** 150.94 to 196

6 Scenes

S1A_IW_SLC__1SSV_2015... B066 Feb 26 2015	196m	108d
S1A_IW_SLC__1SDV_2015... 710C Jul 08 2015	189m	240d
S1A_IW_SLC__1SSV_2016... 6B53 Jan 28 2016	175m	444d
S1A_IW_SLC__1SSV_2016... 0935 Aug 31 2016	170m	660d
S1A_IW_SLC__1SDV_2018... 13D5 Jul 04 2018	164m	1332d
S1A_IW_SLC__1SDV_2021... 4E8C May 01 2021	162m	2364d

Figure 2. ASF online baseline computation tool

3. RESULTS AND DISCUSSION

3.1 Results

Figure 3 show the percentage ranges of the perpendicular baselines of the archived Sentinel-1 image pairs in the ASF database over the study area. Out of the 40 Sentinel-1 SAR images over the study area acquired between January and December 2015 archived in the ASF database used as reference to search for suitable secondary images that can be paired from a pull of 4190 images in the archive from January 2015 to May 2021, for DEM derivation over the study area; only 2.2% of the pair combinations are within the optimum perpendicular baseline range of 150 m to 400 m, while 10.3% meet the minimum required perpendicular baseline benchmark of 100 m but not up to the optimum. A large percentage of 87% of pair combinations fall below the minimum required critical baseline.

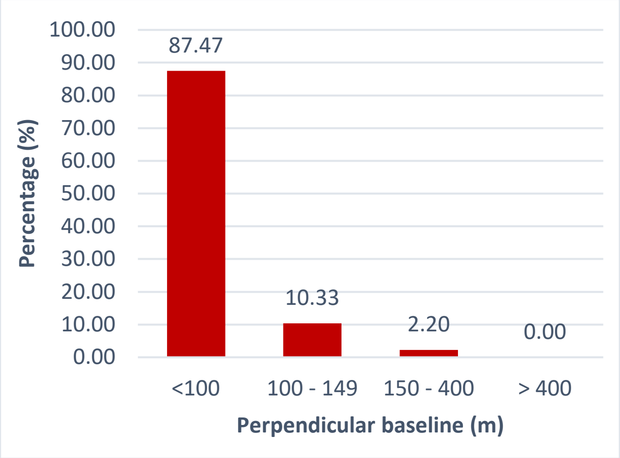


Figure 3. Perpendicular baseline of Sentinel-1 image pairs.

Figure 4 show the temporal baseline percentages of the image pairs within the perpendicular baseline of 150 m to 400 m. Out of the 2.2% image pairs within the optimum perpendicular baseline depicted in figure 3, only 1% pair combination have less than 20 days temporal interval, while almost 90% are having temporal interval of 100 days and above.

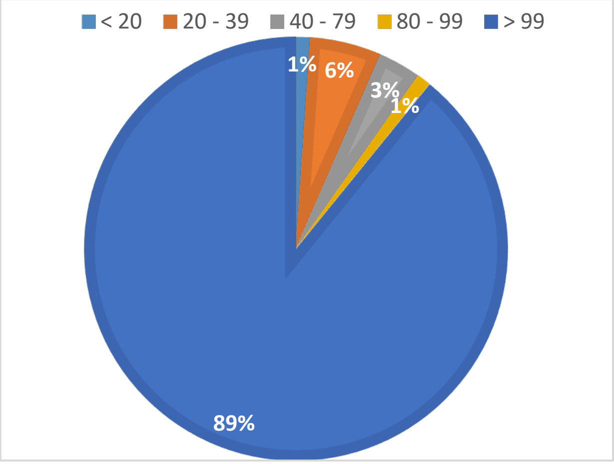


Figure 4. Temporal baseline of Sentinel-1 image pairs within the optimum perpendicular baseline (150 m – 400 m).

Figure 5 depicts the coherence map of Sentinel-1 image pairs of 26 June and 08 July 2015 over the study area with 228 m and 11 days perpendicular and temporal baselines, respectively. And Figure 6 show the coherence achievable with Sentinel-1 in the study area. Whereas the coherence map depicts how low coherence dominates in the study area, the Figure 6 reveal high coherence of up to 0.6 can only be achievable in barely less than 10% of the entire area irrespective of the baselines condition, with over 80% of the study characterised by poor coherence of less than 0.5.

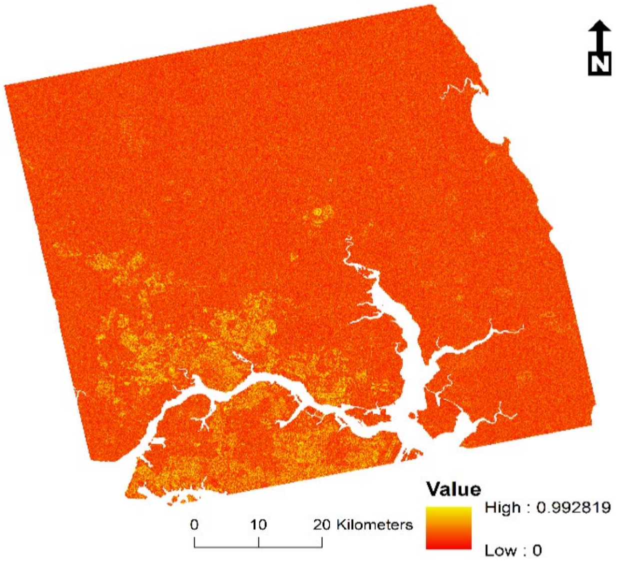


Figure 5. Coherence map of Sentinel-1 image pair of 26 June and 08 July 2015.

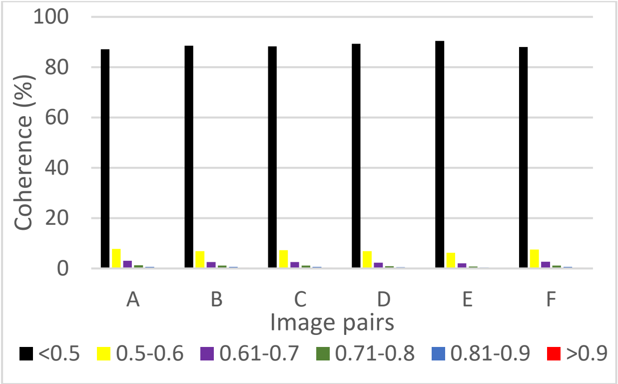


Figure 6. Achievable coherence in densely vegetated humid tropics.

3.2 Discussion

The challenges of applying Sentinel-1 SAR for InSAR DEM derivation over the densely vegetated humid tropical environment begin right from the data acquisition stage and continue through the data processing chains. Notable among the drawbacks of using Sentinel-1 for InSAR DEM derivation over the densely vegetated humid tropical environment include difficulty in acquiring suitable image pairs, phase decorrelation, and unwrapping.

Applying Sentinel-1 SAR data which is from mono-static satellite for InSAR DEM derivation requires the acquisition of at least two image pairs over an area, captured along the same orbit track, and at different times and sensor positions. The data acquisition time intervals and sensor positions define the temporal and perpendicular baselines, respectively, and are critical for interferometry. While image pairs with longer perpendicular baselines of up to at least 100 m, or optimum range of 150 m to 400 m is recommended as a control for height ambiguity (Braun, 2021), choosing image pairs with as short as possible temporal baseline has been argued as the most effective way to overcome decorrelation.

As depicted in figures 3 and 4, acquiring appropriate Sentinel-1 image pairs in terms of perpendicular and temporal baselines is extremely difficult. This is because of the narrow orbital tube of the Sentinel-1 satellite originally designed for differential InSAR, (Braun, 2021), which makes acquiring image pairs with high perpendicular baseline difficult. The difficulty of acquiring image pairs with higher perpendicular baseline further complicates acquiring images with lower temporal baseline over the study area; despite the fact that Sentinel-1 is the first satellite that provides SAR data with global open access (Wang et al., 2019), at a 6-day revisit interval (Kumar, 2021), and is particularly useful in persistently cloudy regions (Song et al., 2021).

Furthermore, the difficulty of acquiring images with short temporal baseline, coupled with the susceptibility of the short wavelength of 5.6 cm of the C-band used in the Sentinel-1 satellite to volume scattering (Brisco, 2015) and continuous dielectric properties changes by winds (White et al., 2015) and waves (Gao et al., 2012) results in low coherence. While keeping temporal baseline as short as feasible has been suggested as the most effective approach for overcoming decorrelation (Braun, 2021), low coherence is generally problematic for InSAR DEM derivation, as higher coherence is a basic requirement for good interferogram generation and InSAR DEM derivation (Chindo et al., 2022). In fact, at below 0.3 coherence value on the scale of 0 to 1, phase difference measurement is severely hampered and thus rendering phase information in the interferogram nearly useless (Woodhouse, 2006). Nevertheless, coherence in the study area is generally poor irrespective of the perpendicular or temporal baseline as shown in figure 6. And if low coherence areas dominate in an interferogram, unwrapping could fail due to inadequate fringe connectivity, and most likely produce InSAR DEMs with inaccurate elevation measurements (Braun & Veci, 2020).

4. CONCLUSION

Deriving InSAR DEM over the humid tropical environment with Sentinel-1 SAR is extremely challenging. Some of the difficulties often encountered are highlighted in this paper. These include difficulty in obtaining suitable image pairs both in terms of perpendicular and temporal baselines, phase decorrelation and poor coherence that makes obtaining good interferogram with adequate fringe connectivity devoid of phase noise for subsequent unwrapping and DEM derivation difficult. However, this paper is part of our ongoing research. We hope to revise the application of InSAR techniques in DEM derivation over the densely vegetated humid tropical environment towards clarifying on the possibility or otherwise of deriving good InSAR

DEM with Sentinel-1 SAR over the densely vegetated humid tropical environment.

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