THE ROLE OF SEASONS IN INTERFEROMETRIC DECORRELATION OVER TROPICAL WOODY VEGETATION

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ABSTRACT: Applications of Interferometric Synthetic Aperture Radar (InSAR) are often plagued by decorrelation effects, especially over forested areas. While progress has been made in this research domain, boreal forests have often been used as the reference. There has been a paucity of similar research conducted in tropical regions, which host various types of woody vegetation. In this article, the level of decorrelation is assessed for several types of plantations, including rubber, oil palm, and tea plantations, in comparison to intact tropical forest. Our primary goal is to investigate decorrelation due to seasonal dataset configuration, which may lead to a better understanding of suitable InSAR pair selection. To demonstrate the impact of seasonality, two pairs of Phased Array L-band SAR 2 (PALSAR 2) data were acquired. July–August 2015 data were used to represent dry conditions, while wet season analysis employed February–March 2016 datasets. In general, intact tropical forest and almost all plantation types displayed low InSAR correlation, which conforms with our previous understanding. The wet season was found to be an important factor in this study, which significantly reduced correlation in all types of land cover. Tea plantations, however, maintained strong correlation; hence, it is concluded that decorrelation due to seasonality was fairly low in this case. The high correlation of tea plantations was likely due to stable wetness of leaves and minimal impact of wind on the canopy. Although mature rubber trees exhibited high decorrelation effects in the dry season, the class of young rubber plantation revealed a different outcome with its fairly high correlation. The research demonstrates that seasonality plays a role in the selection of suitable InSAR datasets in tropical regions. Hence, users should focus not only on satellite parameters such as baseline and temporal lag, but also consider the impact of seasonality.

INTRODUCTION

Interferometric processing of SAR data has opened a new perspective in Earth observation. The processing exploits two or more sets of SAR data taken from different geometries (Bamler and Hartl, 1998). Repeat-pass mode has been the most frequently used way to capture a SAR data pair, although constellations of satellites such as Cosmo-Skymed or TerraSAR have also found favor as the time lag between acquisitions can be better managed. InSAR's main uses include crustal deformation monitoring and digital elevation model (DEM) generation. Its effectiveness to investigate the Earth's changing surface due to volcanic or tectonic activities has been detailed elsewhere (Natsuaki et al., 2016; Fujiwara et al., 2017). Similarly, constructing DEMs by using SAR interferometry has also been demonstrated in Nikolakopoulos et al. (2015). Canopy height, as a DEM representation in forestry sector, has been the primary goal of InSAR for forestry research (Balzter et al., 2007).

While the aforementioned studies extensively use phase information, InSAR processing has an additional dataset, i.e. correlation or coherence. Its primary exploitation has been the measurement of uncertainty in the interferogram (or fringe). However, its uses have been extended to various applications, especially in land cover and forestry studies. Interferometric land-use (ILU), for instance, has been found useful for land cover mapping, especially when single polarization SAR data are used (Okhimamhe, 2003). Specifically in forestry applications, correlation has been used as primary data for stand age mapping in boreal forests, achieving an R^2 of about 0.75 (Pinto et al., 2013). In addition, it has been ingested to model and predict forest biomass in boreal forests (Fransson et al., 2001).

Decorrelation over vegetative cover is, however, understudied, although it has been long known in interferometry (Askne and Smith, 1997) and polarimetric SAR interferometry (Alberga, 2004). More recently, it has been broadly discussed by Ahmed et al. (2011) using Shuttle Imaging Radar C (SIR-C) L-band data. Their research concluded that the extent of decorrelation was strongly related to vegetation cover, while wind did not seem to be significantly important in decreasing correlation. Nonetheless, the experiment was done using one-day repeat-pass acquisition, where it was therefore impossible to thoroughly account for the effect of seasonality in the real operational, repeat-pass configuration. An investigation using a long temporal baseline of ERS and ALOS datasets was reported by Wei and Sandwell (2010). Their research found that wavelength plays a role in the detection of decorrelation. In C-band, such as ERS data, decorrelation rapidly occurred in highly vegetated terrain; meanwhile a time lag of two years did not substantially affect L-band data.

The main purpose of this article is to extend previous studies (Wei and Sandwell, 2010; Ahmed et al., 2011), focusing on the particular issue of how changing meteorological conditions in tropical regions impact upon the quality of interferometric products. Assessment with respect to various types of plantations that dominate land cover is discussed to improve understanding of decorrelation effects in tropical regions.

MATERIALS AND METHODS

Test Site

The test site was located in the Bandung area of West Java, Indonesia (Figure 1). As the capital city of West Java province, Bandung municipality is surrounded by satellite cities such as Cimahi, to the west. The city is also surrounded by natural parks that host active volcanoes both in the northern part of the region (Tangkuban Parahu volcano) and the Malabar volcanic complex at the southern end of the region. This site was selected due to its land cover complexity. The southern part of the Bandung metropolitan area hosts very large blocks of rice fields. The area also contains natural tropical forests in the vicinity of Mt. Tangkuban Parahu and Mt. Malabar, surrounded by several tea, oil palm, and rubber plantations.

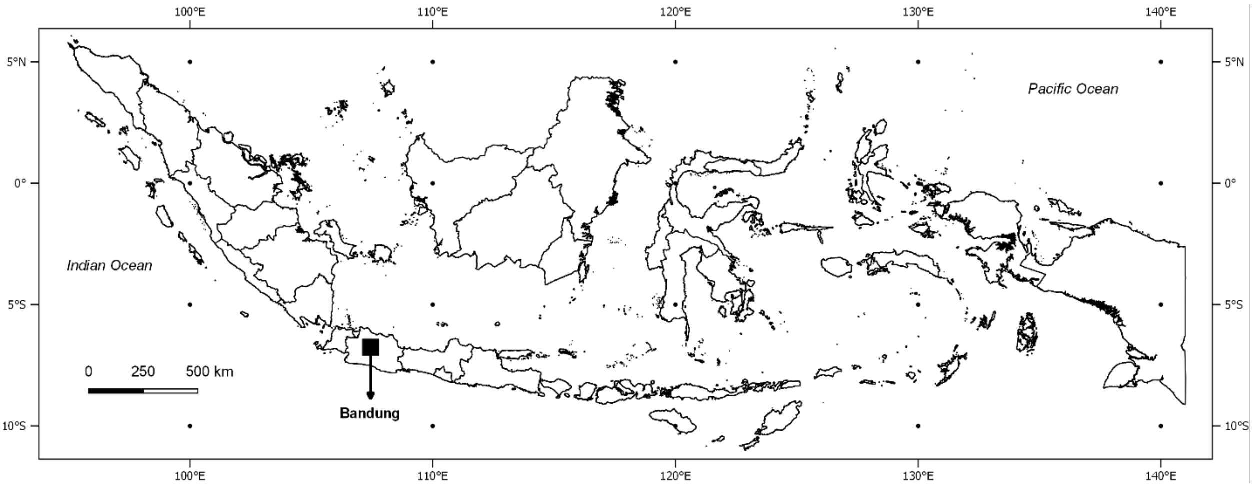

Figure 1. Test site.

Datasets and Processing

In this research, dual polarimetric Phased Array L-band SAR (PALSAR) 2 data were used. However, in this preliminary work, we only present analysis based on HH polarization. Since we were interested in the effect of seasonality, we took an image pair, one each for the dry and wet seasons. All datasets were acquired in SM3 mode, with the same beam number, F2-5. Details of the datasets are given in Table 1.

Table 1. PALSAR-2 images and their InSAR specification.

Season	Image Pair	Perpendicular Baseline (m)	Interval (days)
Dry	8 July 2015 and 5 August 2015	25.8	28
Wet	3 February 2016 and 16 March 2016	301.2	42

All datasets were fed into GMT5SAR software, freely available from http://topex.ucsd.edu/gmtsar, running on a Ubuntu 16.04 LTS 64-bit machine. As the main outputs of InSAR processing, the interferogram and correlation image were then geometrically corrected with the help of a Shuttle Radar Topography Mission (SRTM) DEM. Seven land cover polygons were selected based on a field survey conducted in January 2016 and our knowledge of the area, and subsequently digitized using QGIS software. Data analysis was performed in R statistical software.

RESULTS AND DISCUSSION

Figure 2 presents correlation images taken from the different seasons. As seen, the dry season image has a brighter tone, indicating a high proportion of correlative pixels in the scene, which is in line with previous research (Wei and Sandwell, 2010). The median values for the dry and wet seasons were 0.50 and 0.30 respectively, with fairly similar standard deviations (0.19 for the dry and 0.18 for the wet season image). In this preliminary report, we are unable to investigate the reason for this difference in detail. However, we suspect that moisture conditions have a strong impact on wave reflection. Surface moisture has been shown to have a significant impact on radar backscatter (Kim et al., 2000; Wegmuller et al., 2000; Lu and Meyer, 2002). With the similar surface moisture content between two acquisitions in the dry season, the coherence between two images was fairly high. In contrast, frequent rain with rapid wet and dry interspersed conditions during the wet season reduced the correlation, hence the wet season correlation image appears darker. Nonetheless, it is apparent that not all land cover types have a reduced correlation.

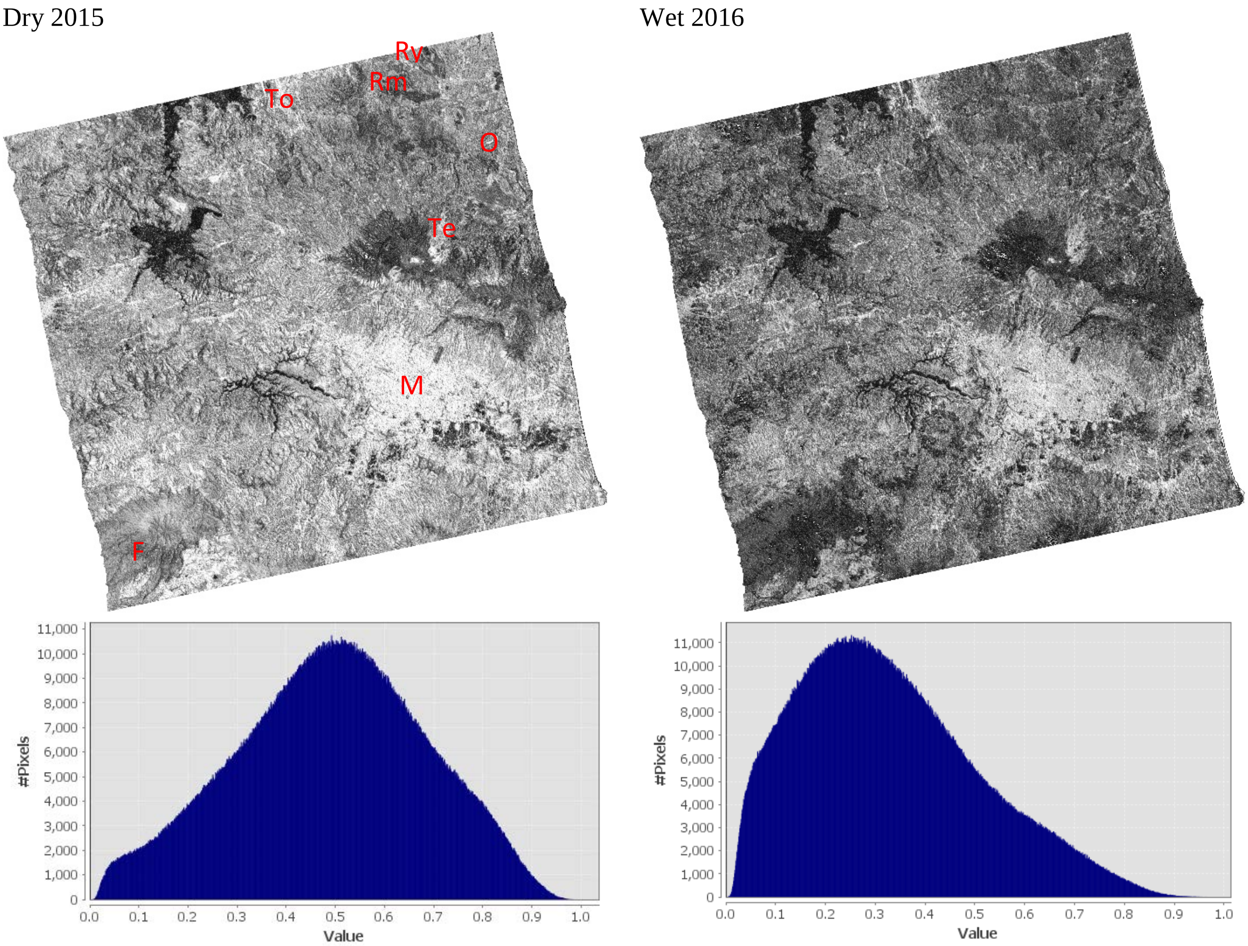

Figure 2. Comparison of correlation image histograms. F: forest; M: metropolitan area; To: town; Te: tea; O: oil palm; Rm: mature rubber; Ry: young rubber plantation.

Exploiting our knowledge of the test site, statistics were extracted from the correlation images based on seven distinct land cover types, as shown in Table 2. Class-wise comparison of dry and wet season datasets indicates that the average correlation in the dry season is also higher than in the wet season. Built-up land, whether towns or metropolitan areas, yielded similar correlations. Weydahl (2001) found that buildings and cities could produce high correlation, between 0.8 and 0.9, which is supported by the findings of this research. We noted, however, that towns had slightly lower coherence than the metropolitan areas. This is possibly due to the influence of woody vegetation interlaced between human-built structures that is frequently seen in towns. As shown in Table 2, most land cover types with dominant woody vegetation had fairly low correlations.

Table 2. InSAR correlation statistics by land cover type.

Land cover	Average correlation in the dry season	Average correlation in the wet season
Forest	0.28	0.12
Oil palm (mature)	0.39	0.27
Rubber (mature)	0.30	0.21
Rubber (young)	0.59	0.24
Tea	0.81	0.61
Town	0.84	0.77
Metropolitan	0.89	0.77

A similar conclusion was reached by Hamadi et al. (2015) in tropical forests of Guiana using P-band radar, suggesting that correlation in forested areas is generally low, implying that interferometric products such as a DEM could be severely attenuated by the canopy layer. At a test site in South Sumatra, Indonesia, Takeuchi and Oguro (2003) found that coherence in primary forest was very low, which is in agreement with the present research. Nonetheless, we were unable to statistically compare our outcome directly to their analysis as Takeuchi and Oguro (2003) did not present basic statistics by land cover type. Various sources of decorrelation contributed to low coherence of forest; to name a few: canopy moisture content, wind, and unknown volume scattering (Weydahl 2001). Weydahl's research indicated that decorrelation effects over boreal forest can reduce correlation below 0.6 in one-day tandem interferometry configuration.

Contrary to Takeuchi and Oguro (2003) conclusions, in our research, low coherence was observed in almost all types of plantation. Since the planting density in oil palm and rubber plantations is lower than natural forest, we suspect that wind effects contributed significantly to the decorrelation. We noted that juvenile rubber trees yielded fairly high coherence. Unfortunately, comparison with other findings is not yet possible due to a paucity of literature discussing this issue. We suspect that decorrelation due to volume scattering in this case was very low, while backscattering returns were dominated by the double bounce component as a result of ground-tree interaction. This scattering component was likely to be stable during the two acquisition times, hence correlation in the dry season image pair was high. However, in the wet season, moisture in stems and trunks was arguably significantly different between images. As a result, decorrelation occurred. Our findings indicate that tea plantation yielded the highest coherence among all vegetated land covers in this group in all data categories. This suggests that contributions of wind and volume scattering to coherence were fairly low. Hence, decorrelation was most likely due to SAR system parameters.

CONCLUSION

Interferometric SAR products have gained popularity in SAR applications, beyond their conventional exploitation in geoscience. In forest applications, coherence has been found to be useful for forest mapping and biomass estimation. Nonetheless, selecting interferometric pairs is often difficult, with many parameters to be considered. While other publications have often focused on SAR systems, the role of seasonality in decorrelation effects is understudied.

This preliminary research provides further understanding of the influence of the tropical monsoon in decorrelation among important land cover classes. It shifted the median of the correlation image to lower values, indicating high variation in surface moisture detected by the sensor. It is therefore suggested that a dry season pair is obtained, where the median is slightly higher. Our research further extends current findings in decorrelation issues in woody vegetation cover. The majority of tropical woody vegetation experienced high levels of decorrelation, while tea plantation maintained a high correlation. Nonetheless, the results strongly recommend in-depth analysis using a broader dataset in terms of time of acquisition and similar biophysical environments to expand the current understanding of decorrelation over woody vegetation cover.

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