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Detecting settlement expansion in South Africa using a hyper-temporal SAR change detection approach

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ABSTRACT

Recent times have seen a significant increase in the amount of readily available SAR data, with many current and historic SAR data holdings now adopting an open distribution policy. As more regular SAR observations are becoming available, the use of a hyper-temporal SAR change detection framework (utilizing a stack of potentially hundreds of SAR images) is now becoming significantly more feasible. A relevant use case is the detection of new informal settlements in South Africa. Here, hyper-temporal change detection has been shown to be very effective but has been limited to coarse resolution optical satellite imagery only. In particular, it has been found that for optical data the Temporal Autocorrelation Change Detection (TACD) method is able to effectively detect the formation of new informal settlements using hyper-temporal MODIS time-series data. In this paper, the TACD is modified for the use of coarse resolution hyper-temporal SAR data for the detection of new informal settlements. It is shown that by using a hyper-temporal approach to detecting these new informal settlements, a higher overall accuracy was achievable when compared to standard bi-temporal change detection. A dataset of ENVISAT Advanced Synthetic Aperture Radar images over the study area was used to create a hyper-temporal time-series of backscatter values for each of the pixels in the study area. It was found that the proposed method achieved change detection accuracies of 87% at a false alarm rate of less than 1% with bi-temporal SAR change detection achieving a change detection accuracy of 70% at an approximate 1% false alarm rate.

1. Introduction

SAR data are becoming increasingly easier to come by as many current and historic SAR data holdings now adopting an open distribution policy. An example of this is historic ENVISAT Advanced Synthetic Aperture Radar (ASAR) and Sentinel-1 data holdings. The Sentinel-1 satellite, for example, is potentially able to map the global landmasses in the Interferometric Wide swath mode once every 12 days and this reduces to a 6 day exact repeat cycle at the equator when both Sentinels are operational (Snoeij et al., 2010). As more regular SAR observations are becoming available from new and historic SAR satellites, the use of a hyper-temporal SAR change detection framework (utilizing a stack of potentially hundreds of SAR images) is now becoming significantly more feasible (Wiesmann et al., 2005). A relevant use case is the detection of new informal settlements in South Africa which is one of the most pervasive forms of land-cover change in many developing countries (Kleynhans et al., 2012). These new developments are mostly driven by human migration and socio economic factors that are constantly changing across the African continent and often leads to settlements occurring informally in areas that were previously covered by natural vegetation.

Detailed mapping of settlements are usually done by analysts digitizing features from aerial or high resolution satellite images. These features are then utilized to support spatial planning and need to be updated regularly (at least every two years). Updating maps over large areas using manual digitizing is slow and costly and many agencies, especially in developing countries are constrained due to finite resources which results in feature datasets being outdated, while only a small percentage of the area actually experienced change. Methods that can rapidly indicate areas having a high probability of change is thus very valuable to an analyst as this can be used to direct their attention to high probability

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change areas for further evaluation using, for example, higher resolution imagery of the area. By using such a targeted approach, an increase in mapping efficiency of up to ten times has been observed compared to a complete re-extraction (Mitchell, 2012).

In this paper we therefore focus on the development of automated change detection methods based on hyper-temporal satellite imagery to improve the productivity of detailed mapping efforts. Satellite time series data has proven to be an effective data source for change detection (Verbesselt et al., 2010; Lunetta et al., 2006; de Beurs and Henerby, 2005; Kennedy et al., 2007) and in particular, time series analyses of hyper-temporal optical satellite data has been successfully applied for land cover change detection in South Africa specifically related to the monitoring of human settlement expansion. In Salmon et al. (2011), a neural network based post classification change detection approach was used to detect when land cover conversion takes place from natural vegetation to settlement classes. In Kleynhans et al. (2011), MODIS time-series data was modeled as a triply modulated cosine function and an extended Kalman filter was used to track the parameters of the model and declare change based on parameter behavior. In Grobler et al. (2013), the use of Page's cumulative sum (CUSUM) test was proposed as a method to detect new settlement. An autocorrelation function (ACF) change detection method was recently shown to detect the development of new human settlements in South Africa (Kleynhans et al., 2012). This method uses MODIS time-series data, which have previously been shown to be separable (distinguishable) for the natural vegetation and settlement land cover classes considered in this study (Kleynhans et al., 2010). The method uses the ACF of a MODIS time-series to provide an indication of the level of time-series stationarity (by considering the stability of the time-series mean and variance over time) which is then consequently used as a measure of land cover change.

In the original formulation of the ACF approach (Kleynhans et al., 2012), a single pixel's entire time-series for a single band (spanning eight years) was used as input. A change metric was then calculated by considering the properties of the ACF of the time-series. When the resulting change index was compared to a threshold value, a per-pixel based change alarm resulted. In this paper the ACF approach is extended for the use of hyper temporal Synthetic Aperture Radar (SAR) as input as opposed to optical time-series data to produce a change alarm. SAR has been shown in previous studies to be useful in the detection of human settlements (Henderson and Xia, 1997; Gamba and Lisini, 2013; Marghany, 2014, 2014) but these studies focused mostly on the use of single image processing as opposed to hyper temporal analysis. In this study, it is postulated that hyper-temporal SAR data would be very useful in the detection of new and expanding settlements as SAR reflectance in the temporal domain would be sensitive to changes from natural vegetation to settlement land cover types. Another important consideration in using SAR over multi spectral optical data, is that the detection of settlements in areas that are mostly covered by natural vegetation using hyper-temporal optical data is mostly driven by the change in the vegetation seasonal time-series. In many cases, a large reduction in natural vegetation due to, for example, clear-cutting and vegetation removal would have a similar change in the hyper-temporal profile than the change to settlement and these types of changes would typically result in false alarms. In the case of using hyper-temporal SAR data, the temporal profile, especially with HH polarization will result in significant changes when a change occurs from natural vegetation to settlement due to the formation of man-made structures.

The objective of this paper is to extend on the original formulation of the ACF method to a robust change detection method that utilizes hyper-temporal SAR data as input that is able to detect the formation of new informal settlements in areas that are typically covered by diverse natural vegetation. The detected changes should then be used to alert operators to areas of possible changes which could thereafter be validated, and the necessary maps updated, using high resolution imagery. The reason for using high resolution imagery as a secondary step is not only to validate whether or not change has occurred but also to make sure that digitization error is kept to a minimum when determining change vectors. Importantly, the false alarm rate should be low (≤1%) as the area on which the change algorithm is run is large and the validation of a large number of false alarms could be costly and time consuming. The hyper-temporal change detection approach used in this paper is also compared to a standard bi-temporal (Bazi and Melgani, 2005; Carincotte et al., 2006) change detection approach by using imagery pre and post the change event. It was found that using a stack of SAR images and a hyper temporal change detection formulation has a significant increase in the overall accuracy when compared to the bi-temporal approach.

Fig. 1. The study area used in this study was the Gauteng province (red outline) located in the north-central part of South Africa.

This paper is organized as follows: A description of the data is given in Section 2. The methodology section, detailing the adaption of the temporal ACF for SAR data is given in Section 3. Results are presented in Section 4 followed by concluding remarks in Section 6.

2. Data description

2.1. Study area

The study area considered in this study was the Gauteng province of South Africa, which is located in northern South Africa as indicated in Fig. 1. A total area of approximately 17,000 km^2 (centered around 26°07′29.62″ S, 28°05′40.40″ E) was considered. A total of 158 ASAR Wide-Swath HH images with a pixel spacing of approximately 75 m was obtained for the period 2005/01 to 2011/01. A dataset of no-change pixel time-series (n = 180) were identified by means of visual interpretation of high resolution Quickbird images in 2011 and 2005 respectively. The 2011 imagery over the study area were compared to that of 2005 and no-change areas were able to be rapidly determined. There were also 180 examples of confirmed settlement developments during the study period that were obtained by means of visual interpretation of high resolution Quickbird images in 2011 and 2005 respectively. All settlements identified in 2011 were referenced back to 2005 and all the new settlements were digitized using the high resolution data and a subsequent change polygon was created. By overlaying this change polygon with the ASAR image, all pixels that had an