DETECTING SETTLEMENT EXPANSION USING HYPER-TEMPORAL SAR TIME-SERIES

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ABSTRACT

The detection of new informal settlements in South Africa using time-series data derived from coarse resolution satellite imagery has recently been an active area of research. Most of the previous methods presented using hyper-temporal satellite data in this particular study area relied on optical data as input. In this paper, the feasibility of using hyper-temporal SAR data for the detection of new informal settlements was investigated. Using numerous ENVISAT ASAR images during the period 2005/01 to 2011/01 , it was shown that new settlements could effectively be detected using an autocorrelation change detection approach which was previously only tested on optical data and subsequently adapted to use hyper-temporal SAR data as input. Preliminary results indicate change detection accuracies in the order of 85% at a false alarm rate of less than 1%.

1. INTRODUCTION

There has been recent developments in the use of hyper-temporal satellite time series data for land cover change detection and classification in Southern Africa. More specifically, the monitoring of human settlement expansion is of relevance as it is the most pervasive form of land-cover change in the country. In many cases, new human settlements are informal and occur in areas that were previously covered by natural vegetation. In most of the previous work done related to new settlement detection using hyper-temporal time-series data in South Africa, coarse resolution optical imagery were primarily used [1, 2, 3, 4, 5]. More specifically, hyper-temporal 500m MODIS pixel time series were used because of its high temporal resolution (near daily observations). Synthetic Aperture Radar (SAR) has been shown in previous studies to be useful in the detection of human settlements [6, 7] but these studies focused mostly on the use of single image processing. In this contribution, hyper-temporal SAR data were used to test its feasibility to detect new settlements. The aim of this research is to determine how effective coarse resolution hyper-temporal SAR data is in detecting the formation of new informal settlements.

This paper is organized as follows: A description of the data used 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 5.

2. DATA DESCRIPTION

2.1. Study Area

The Gauteng province, which is located in northern South Africa, was used as the study area. A total area of approximately 17000 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 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 using Google earth. Examples of confirmed settlement developments during the study period were also obtained by means of visual interpretation. All settlements identified in 2011 were referenced back to 2005 and all the new settlements were mapped and the corresponding ASAR pixels (n=180) identified. Figure 1 and 2 shows two examples of change and no-change areas respectively. Figure 3 shows the SAR HH backscatter time-series for the period 2005/01 to 2011/01 of a change (right) and no-change (left) pixel example.

3. METHODOLOGY

3.1. SAR Temporal ACF (TACD) method

Processing of the SAR time-series to produce a change index input feature was done by adapting the Temporal Autocorrelation function Change Detection (TACD) method proposed in [4], which was originally intended for multi-band optical data, to the case of SAR HH hyper-temporal input time-series data.

Fig. 1. Example of a new settlement development that formed between 2004 and 2011. Quickbird image on the left shows the area in 2004 being mostly covered by natural vegetation whereas the Quickbird image on the right shows a new settlement that was formed (Images courtesy of Google earth$^{\mathrm{TM}}$)

Fig. 2. Example of an area that was mostly unchanged between 2004 and 2011. Quickbird image on the left shows the area in 2004 being mostly covered by natural vegetation where the Quickbird image on the right shows the same area remaining unchanged (Images courtesy of Google earth$^{\mathrm{TM}}$)

Assume that a SAR time-series is expressed as

$$\mathbf{X} = X_n \ , \ n \in \{1, 2, ..., N\}, \tag{1}$$

where X_n is an HH intensity ASAR observation at time n and N is the number of time-series observations available. The ACF for time-series $\mathbf{X}$ can then be expressed as

$$R(\tau) = \frac{E[(X_n - \mu)(X_{n+\tau} - \mu)]}{\mathrm{var}(\mathbf{X})}, \tag{2}$$

where τ is the time-lag and E denotes the expectation. The mean of $\mathbf{X}$ is given as μ and the variance, which is used for normalization, is given as $\mathrm{var}(\mathbf{X})$. The mean and variance of the time-series of $\mathbf{X}$ in (2) is required to remain constant through time to determine the true ACF of the time-series. The inconsistency of the mean and variance typically associated with a change pixel's non-stationary time-series thus becomes apparent when analyzing the ACF of the time-series.

The change metric is thus simply equivalent to the temporal correlation at a specific lag (τ) given as [4]

$$\delta_{x,y} = \sum_{\tau=1}^{k} R(\tau, x, y). \tag{3}$$

Where function $R()$ is the ACF, τ is the time lag and (x, y) is the pixel position. The change metric is thus a summation of the first k lags of $R(\tau)$ which was shown in [4] to be less sensitive and more general than using a specific value of τ. The value of k that was chosen in this study was k = 20.

4. RESULTS

The ability of the change metric based on the SAR data to identify change pixels was evaluated by firstly calculating the change metric as derived in (3) for the change and no-change

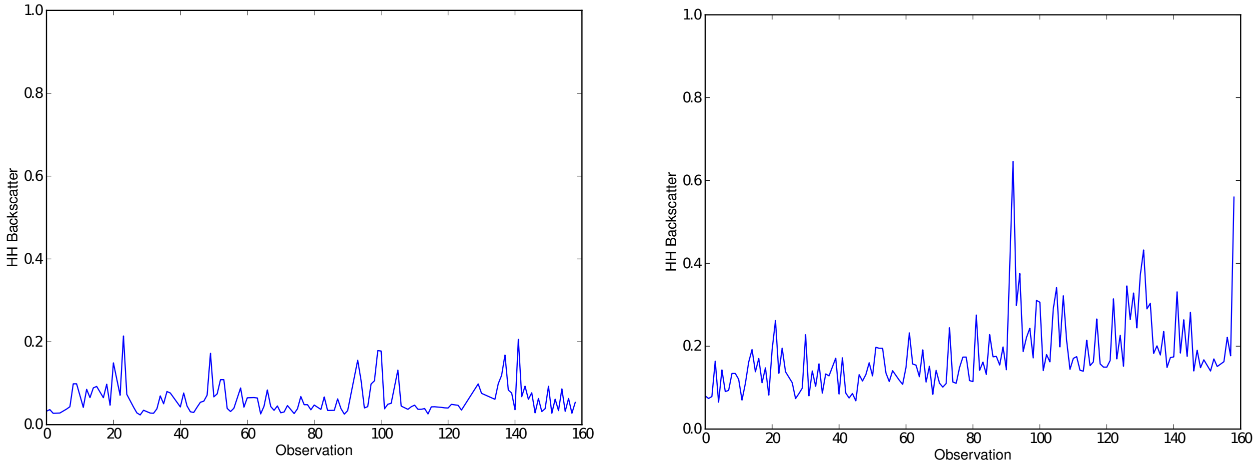

Fig. 3. Hyper temporal SAR HH backscatter time-series between 2005 and 2011 for a ASAR WSM pixel corresponding to a change (right) and no-change (left) area respectively.

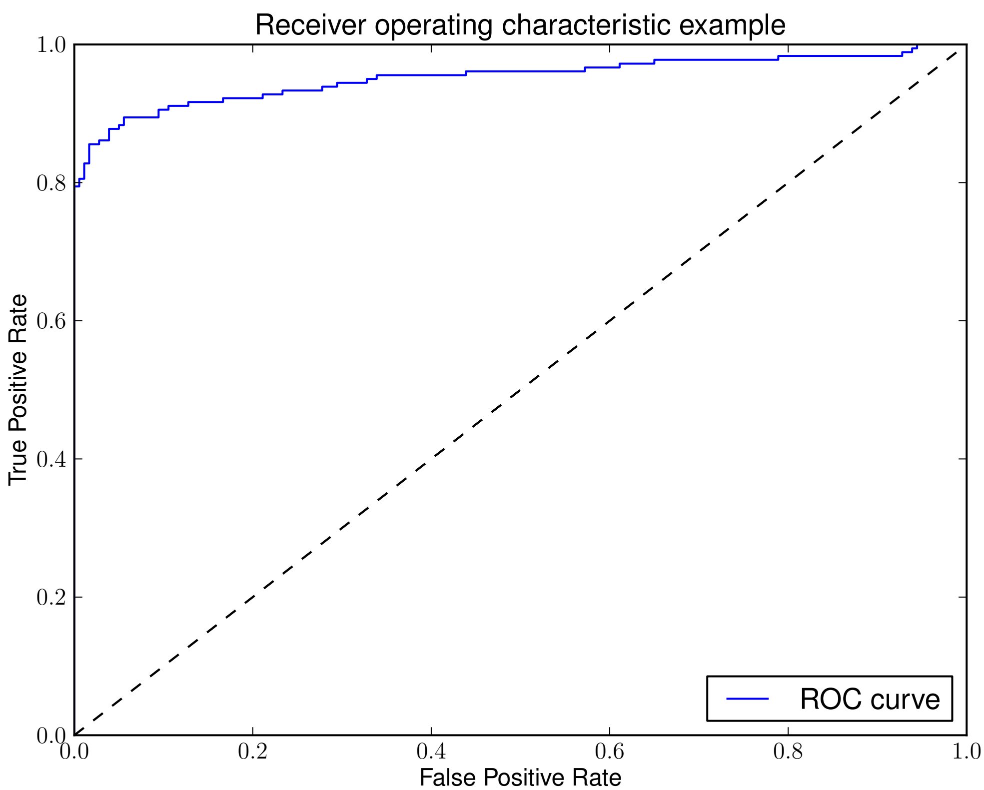

Fig. 4. ROC curve showing the True positive rate (TPR) vs. False Positive rate (FPR) using the change index as calculated in (3). It can be seen that a TPR of 85% corresponds to a FPR in the region of 1%.

dataset and then considering the the receiver operating characteristic (ROC) curve (fig 4). The ROC was used to evaluate the separability of the change metric for all change and no-change examples at various thresholds. It can be seen from fig 4 that the overall separability of the ACF change metric using all the change and no-change examples is not significantly affected by the threshold and when evaluating the ROC at a false alarm rate in the region of 1% , a change detection accuracy of $> 85\%$ was achievable.

5. CONCLUSION

In this paper, the feasibility of using coarse resolution hyper-temporal SAR to detect the formation of settlement developments in South Africa was investigated. Change and no-change example areas in the Gauteng province of South Africa were identified for the period 2005/01 to 2011/01 and 158 historic ENVISAT ASAR images covering the study area within the the specific study period where obtained. A change metric was derived by adapting a recently proposed Temporal ACF (TACD) method [4], which was originally intended to be used for multi-temporal optical data, to be used with the hyper-temporal SAR time-series as input. Preliminary results show that change areas could be identified with an accuracy above 85% at a false alarm rate in the region of 1%.

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