Coherent/Incoherent Change Detection Experiments Using Sentinel-1 SAR Data and Random Forests

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Introduction

One of the most important applications of remote sensing (RS) technologies is about the detection and monitoring of ground surface changes exploiting using multi-temporal, remotely-sensed images [1–2]. In this framework, optical RS sensors have extensively been applied for change detection in a variety of heterogeneous applications. Essentially, change detection is a process that analyzes two or more images captured over the same geographical area at different times to identify those significant land cover changes that have occurred. Unlike optical sensors, microwave RS images acquired by synthetic aperture radar (SAR) have less been exploited for CD purposes. Despite its complexity, SAR images in change detection [3–4] are attractive from the operational viewpoint since SAR sensors are active instruments that operate in any atmospheric and sunlight conditions. In this work, we clarify the potential of coherent and incoherent CD approaches and we introduce the practical use of synthetic CD indices that can jointly be used to extract changed areas. In this context, artificial intelligence (AI) algorithms have already demonstrated their value [5-6]. Specifically, we generated series of CDI's and we trained a random forest using these data and a set of external information on the state of observed scenes. The developed method has been tested considering as main events responsible for the observed changes the fires affecting the Sardinia and Sicily Island in 2021 as well as a flood event occurred in Houston Galvestone bay area. The main objectives of this study, whose results have recently published in [7], are to discuss the statistical properties, as well as the pros and cons, of CDIs based on the use of SAR backscattering (sigma nought) and InSAR coherence maps for the fast detection of changed areas. The role of machine learning methodologies, and the specific use of Random Forests (RF) [8] in CD tasks, is emphasized and some results obtained using Sentinel-1 SAR data are presented.

Objective and methodology

Rapid damage assessment mapping and analysis after a disastrous event exploiting SAR data stacks can efficiently be carried out using CD methods, profiting from the avail- ability of short sequences of SAR images, encompassing the selected primary disastrous event under investigation, and regularly collected before, between, and after the event itself. SAR technology's current and future trend is to operate in a synergic way with data collected by constellations of SAR sensors that are jointly in orbit and capable of collecting data in different portions of the electromagnetic spectrum and with short revisiting times.

We propose to use a joint multi-pass coherent/incoherent CD strategy that allows analysing a short-term sequence of calibrated SLC images and rapidly computing damaged areas using two different kinds of change detection indices (CDIs).

Given a set of three SAR images collected over an investigated area at times t1, t2 (pre-event), and t3 (post-event) (see Figure 1), we can calculate:

1) Mutual differences sigma naught maps between pre Υ_{pre} and Υ_{ev} event acquisitions;
2) The coherence ratio (CR) and the normalized coherence difference ratio (ND) of the pre- and post-coherence event acquisitions.

These indices are then cooperatively used to automatically extract changed areas using a random forest (RF) classifier.

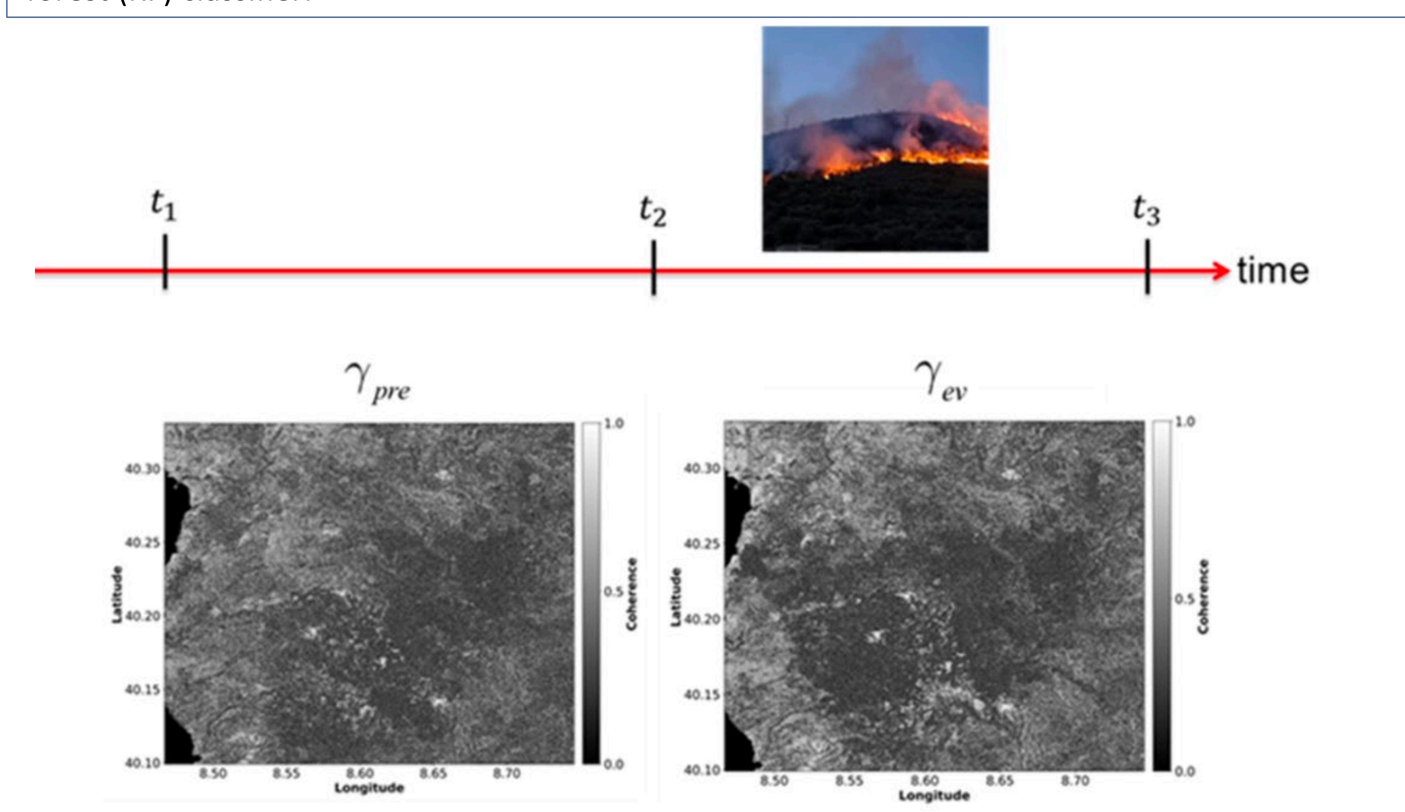

Figure 1. Coherence change tracking scheme using two SAR images acquired before the event (t1: 18 August 2021; t2: 24 August 2021) and one after the event (t3: 30 August 2021). The shown coherence maps are related to the Montiferru area in Sardinia, Italy.

Experimental results

We processed three SAR datasets consisting of 15, 13, and 12 SAR images collected in the Single-Look-Complex (SLC) format and Terrain Observation with Progressive Scans SAR (TOPSAR), Interferometric Wide (IW) mode by the Sentinel-1A/B sensors over the areas of interest (AOIs) of the central-western sector of Sardinia Island, the central-western area of Sicilia Island regions in Italy, as well as the Southern-Eastern sector of Texas coastal area, the US. Starting from a sequence of calibrated, co-registered, and geocoded SAR acquisitions, the first module consists of pre-processing data and calculating the incoherent and coherent change detection indices. In this work, we treated change detection as a pixel-based binary classification task that uses 1 and 0 to indicate changed and unchanged pixels. Therefore, we used an RF model combining CDIs and a reference change mask in the second module to perform supervised learning.

The final module applies a spatial average with a moving window to the RF predicted binary change mask. Eventually, the binary change mask is retrieved. See Figure 2.

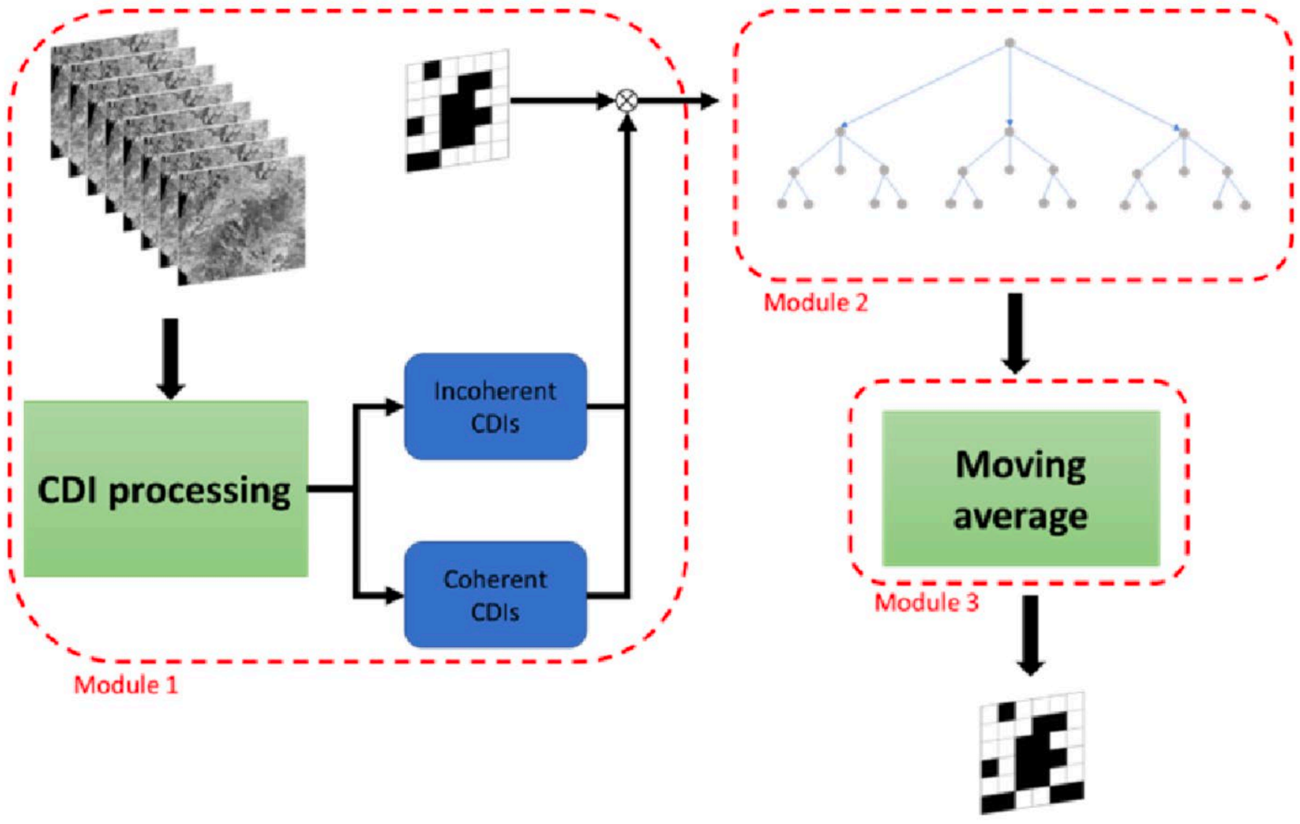

Figure 2. Sketch of modules of the proposed CD framework.

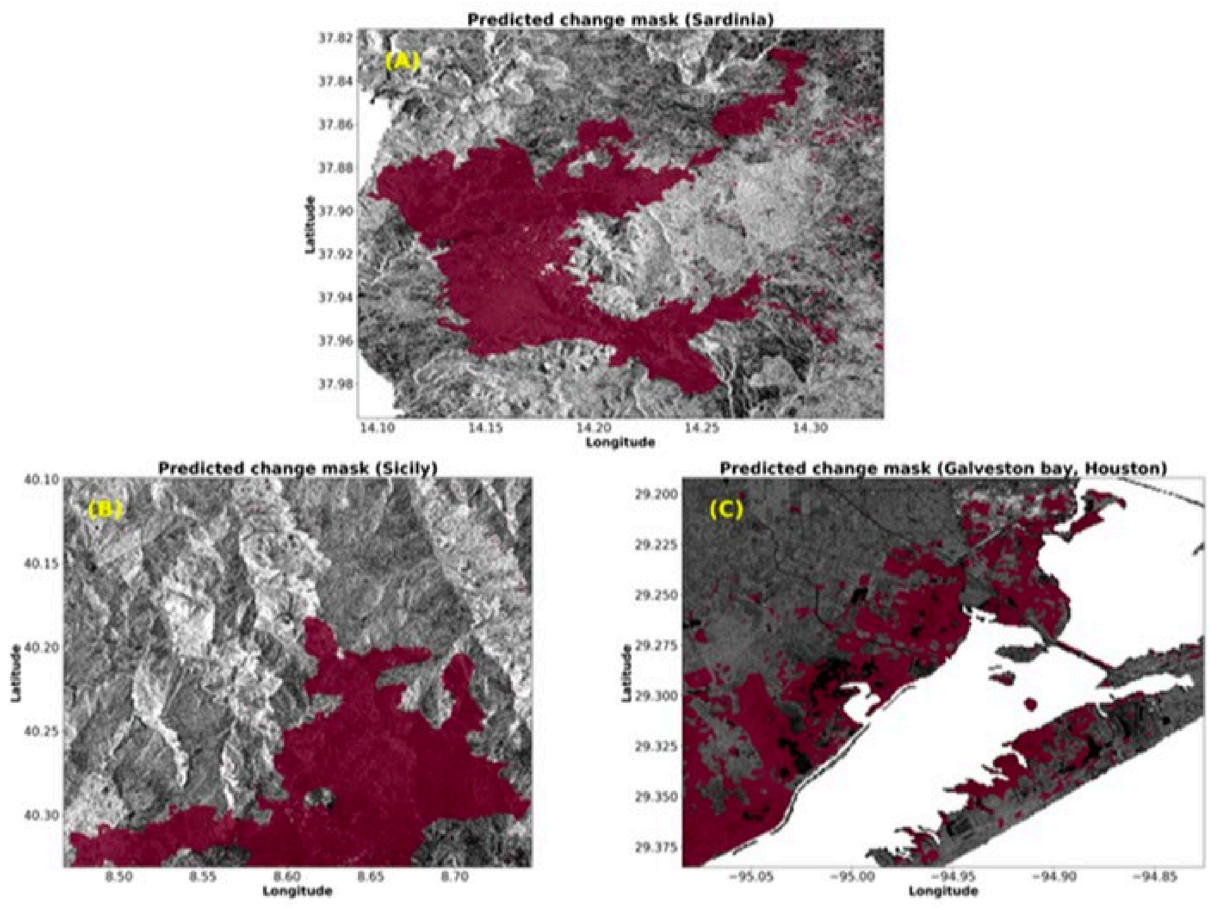

Figure 3. RF predicted binary change masks (colored in red) of the (A) Sardinia, (B) Sicily, and (C) Texas, Galveston bay AOIs, respectively. Change masks are superimposed over SAR amplitude images of the areas.

Conclusion

In this work, we have shown the potential of coherent and incoherent change detection methodologies for the monitoring of ground surface changes that arise when a disaster event (i.e., wildfires or floods) occurs, using sequences of synthetic aperture radar (SAR) images. Specificaly, we have investigated the potential of different synthetic coherent/incoherent change detection indices and their mutual interactions for the rapid mapping of "changed areas" relying on the joint exploitation of SAR sigma nought and interferometric coherence maps. A classifier based on random forest was trained combining different information coming from coherent/incoherent CDIs, to analyze, as an example, wildfires and flood phenomena. As a result, our findings demonstrate that S-1 C-band SAR data can provide suitable information on fire and flood events over the most severely affected areas (the highest level of fire or flood damage), supporting how such systems can be a complementary source of data to optical ones, in the case of cloud covers or plumes due to extreme weather and fire events.

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