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Detection of spatio-temporal evolutions on multi-annual satellite image time series: A clustering based approach

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ABSTRACT

The expansion of satellite technologies makes remote sensing data abundantly available. While the access to such data is no longer an issue, the analysis of this kind of data is still challenging and time consuming. In this paper, we present an object-oriented methodology designed to handle multi-annual Satellite Image Time Series (SITS). This method has the objective to automatically analyse a SITS to depict and characterize the dynamic of the areas (the way that the land cover of the areas evolve over time). First, it identifies the spatio-temporal entities (reference objects) to be tracked. Second, the evolution of such entities is described by means of a graph structure and finally it groups together spatio-temporal entities that evolve similarly. The analysis were performed on three study areas to highlight inter (among the study areas) and intra (inside a study area) similarity by following the evolution of the underlying phenomena. The analysis demonstrate the benefits of our methodology. Moreover, we also stress how an expert can exploit the extracted knowledge to pinpoint relevant landscape evolutions in the multi-annual time series and how to make connections among different study areas.

1. Introduction

Nowadays, remotely sensed satellite images constitute a rich source of information that can be leveraged to support several applications including food risk prevention, land use planning and mapping, natural habitat monitoring, land cover classification and many other several tasks (Knorn et al., 2009). Advances in satellite technologies and the high images acquisition frequency result into huge amount of remote sensing data that need eff ;ective and efficient analytics approaches. Standard tools including photo interpretation and fully supervised approaches are not suitable for dealing with this large amount of spatio-temporal data (Mohammed and Rusthum, 2008). In this context, data mining techniques have already shown their usefulness (Velickov et al., 2000) and they seem adequate to extract valuable knowledge to support remote sensing analysis on both single image or Satellite Image Time Series (SITS) data (Li et al., 2014; Petitjean et al., 2012a; Zhang et al., 2016).

Several data mining approaches are commonly employed to analyse SITS data: supervised (Jiang et al., 2013), unsupervised (Wemmert et al., 2009; Kurtz et al., 2010) and semi-supervised methods (Chahdi et al., 2016; Tan et al., 2016). Due to the lack of reference data, unsupervised methods such as clustering are widely employed to explore and mine patterns from remote sensing data. Data clustering is the process of partitioning the data into groups where, similar examples are assigned to the same group and non similar examples are assigned to diff ;erent ones (Xu and Wunsch, 2005).

In this work, we propose an unsupervised method to analyse SITS data at object level in order to highlight intra and inter similarity among the diff ;erent study areas. Two important factors influence the clustering of remote sensing time series: i) the distance measure choice and ii) how data are represented.

Considering distance/similarity measures commonly involved in SITS analysis, the standard choice is the euclidean distance (or one of its variants) (Ding et al., 2008) due the fact that it is intuitive, easy to implement and parameter free. Conversely, how to represent SITS data in order to exploit as much as possible the available spatio-temporal information remains a challenge and researchers have devoted time and eff ;ort to deal with this point (Petitjean et al., 2012b; Guttler et al., 2017).

In unsupervised as well as in the supervised analysis, SITS data are mainly exploited at pixel level. For each pixel, a time series is built. The

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radiometric values of the pixel, in the considered satellite images, are gathered and ordered based on the temporal dimension. Thus, the number of time series is equal to the number of pixels covered by the considered area (Petitjean et al., 2012b). The method proposed in Zhang et al. (2016) analyzes SITS information at pixel level to detect land cover classes. To perform clustering, they compute a distance matrix between pixel time series using the euclidean distance. Then, they run the Affinity Propagation (AP) algorithm (Frey and Dueck, 2007) on the matrix. The method was evaluated on three data sets, the AP results were compared to those obtained using the K-means and the Agglomerative Hierarchical clustering algorithms. The authors introduce in Guyet and Nicolas (2016) a method to analyse multi-annual satellite image time series to monitor vegetation areas using the vegetation index. The method analyses the SITS at pixel level, it builds an annual profile which characterizes the pixel evolution on each year. Then, it gathers these representative annual profiles to construct a final sequence to characterize the evolution of a pixel over several years. Finally, a clustering algorithm based on the euclidean distance is employed to characterize the vegetation dynamic.

Unlike previous methods, (Petitjean et al., 2012a) introduces a pixel-based time series clustering exploiting Dynamic Time Warping (DTW) (Liao, 2005). The authors used DTW combined with K-means to deal with unaligned time series data that are also characterized by missing values due to cloud phenomena.

Unlike the method presented above, object-based representation can be exploited to analyse satellite images (Blaschke, 2010). Objects stand for meaningful structures in the image. They are identified using a segmentation algorithm (Dey et al., 2010) that spatially groups similar pixels, based on homogeneity criteria.

In the literature, object-oriented representation is rarely employed to analyse SITS data (Guttler et al., 2017) while it is widely used for single image analysis (Qin et al., 2013). In fact, aligning pixels between two consecutive images (at the same resolution) is straightforward as you only have to superpose the images on the pixel grid. Conversely, aligning objects coming from diff ;erent images, from the same time series, can be difficult due to the landscape evolution.

A first step in this direction is presented in Petitjean et al. (2012b) where both pixel and object representations are exploited to perform an unsupervised land cover characterization. This method enriches the pixel time series using the corresponding object information. The idea is to include spatial context as information for each pixel. The analysis show that enriching pixels with contextual features improve the final results.

Most of the proposed methods in the literature perform object-oriented analysis on a time series by comparing two images from two successive timestamps. The method proposed in Qin et al. (2013) introduces an objectoriented approach combining two satellite images of the same area acquired by diff ;erent sensors. The spectral bands of the satellite images are first stacked, then the resulting image is segmented. The goal is to monitor land cover changes, thus the segmentation result is classified into land cover change classes to produce a change map.

The method proposed in Desclée et al. (2006) performs segmentation on a multidate image where the whole set of spectral bands of the time series is stacked together. This approach integrates the spatial, spectral and temporal dimensions of the data to identify coherent objects. The method is especially tailored to separate forest changes between areas that changes and areas that do not. An object is validated as changed if more than a fixed threshold of its area is covered by a forest change. Similarly to the previous method, also in this case the result is a change map highlighting the area where the forest cover changed.

Recently, (Guttler et al., 2017) proposes an object-oriented approach that tracks spatio-temporal phenomena and extracts evolution patterns. This method aims to automatically detect and extract spatio-temporal information from SITS data. It segments each satellite image independently, then it links together the resulting objects between two consecutive timestamps of the time series. The method results on a set of temporal profiles representing the evolution of the object attributes. An evolution map is then produced, such map can be used to detect the most and the less stable areas within a study site.

In Khiali et al. (2018), the authors have proposed an object-oriented clustering method that leverage the object-oriented time series representation proposed in Guttler et al. (2017), Our approach uses the representation introduced in Guttler et al. (2017) to embed the spatio-temporal entities detected in the SITS data. Then, similar spatio-temporal evolutions are grouped together using a clustering algorithm. The experiments were conducted on two study sites, independently, considering small time series (six images) covering a period of eight months.

In this paper, conversely to the work proposed in Khiali et al. (2018), we deal with the challenging analysis of multiannual SITS data with the purpose to extract inter (among the study areas) as well as intra (inside a study area) similarity among spatio-temporal phenomena. To this end: i) we adapt the strategy proposed in Guttler et al. (2017) to extract evolution patterns from multi-annual SITS, ii) we design a novel distance measure between two spatio-temporal phenomena and iii) we define a framework that make connections among diff ;erent study areas allowing inter-site analysis.

Unlike common time series analysis methods that mainly focus their eff ;ort to discriminate between changed and unchanged area, we propose an unsupervised approach to group together spatio-temporal phenomena that evolve similarly in the multi-annual time series and among diff ;erent study areas.

Experiments are carried out on multi-annual SITS data (Spot-2, Spot-4 and Spot-5) describing three diff ;erent study areas. In our analysis, we demonstrate the quality of the proposed framework to accomplish inter and intra-site analysis. While in the former we focus our attention on phenomena that evolve similarly inside a particular site; in the latter we point out cross-site similarity among the diff ;erent study areas. The cross-site analysis shows that spatio-temporal phenomena belonging to diff ;erent study areas can be grouped together establishing some kind of connections among areas. This kind of analysis can be particularly useful in the case an expert starts to explore and inspect an unknown study site leveraging previous acquired knowledge on a spatially closed (well-known) area.

This article is organized as follows. Section 2 describes the three study areas and the preprocessing we adopt on the data. The proposed method is introduced in Section 3. Section 4 reports and discusses the obtained results. The conclusion of our study is drawn in Section 5.

2. Data

2.1. Study area

Three study site located in the south of France were involved in our study: (A) Lower Aude Valley, (B) Mountain of the Moure and Causses of Aumelas and (C) Pic Saint Loup. Fig. 1 shows the geographical position of these three sites.

2.1.1. Lower Aude Valley

The Lower Aude valley (Fig. 2(a)) is a Natura 2000 site located in the terminal section of the Aude River. Before reaching the Mediterranean Sea, the Aude River runs through a flat wetland area of about 4 842 ha. From a biodiversity point of view, 56% of the site is composed of Natural Habitat types of Community Interest (NHCI). In total, 19 NHCI are located on the site, including 5 priority habitat types. The most widespread habitats are Mediterranean saltmarshes and Saline coastal lagoons. The remaining area (43.7%) is principally composed of vineyards, cereal crops and temporary or permanent meadows. One more characteristic of the site is its exposure to flooding events (mostly during winter) as well as to drought episodes (maximum intensity occurring in the end of summer). The floodable areas are situated predominantly around the two coastal lagoons: Vendres in the north part