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Short communication

Very high spatial resolution optical and radar imagery in tracking water level fluctuations of a small inland reservoir

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ABSTRACT

Tracking water level fluctuations in small lakes and reservoirs is important in order to better understand and manage these ecosystems. A geographic object-based image analysis (GEOBIA) method using very high spatial and temporal resolution optical (Pléiades) and radar (COSMO-SkyMed and TerraSAR-X) remote sensing imagery is presented here which (1) tracks water level fluctuations via variations in water surface area and (2) avoids common difficulties found in using single-band radar images for water-land image classification. Results are robust, with over 98% of image surface area correctly classified into land or water, R^2 = 0.963 and RMSE = 0.42 m for a total water level fluctuation range of 5.94 m. Multispectral optical imagery is found to be more straightforward in producing results than single-band radar imagery, but the latter crucially increase temporal resolution to the point where fluctuations can be satisfactorily tracked in time. Moreover, an analysis suggests that high and medium spatial resolution imagery is sufficient, in at least some cases, in tracking the water level fluctuations of small inland reservoirs. Finally, limitations of the methodology presented here are briefly discussed along with potential solutions to overcome them.

Introduction

Natural and anthropogenic water level and hence volume fluctuations strongly modify key ecological parameters in water bodies (*e.g.*, water temperature and transparency, productivity, composition and distribution of aquatic vegetation, *etc.*) (Kolding and van Zwieten, 2012; Stefanidis and Papastergiadou, 2013; Zhao et al., 2012). Characterizing and monitoring this process is essential to better understand its impact, define effective management strategies and/or detect disequilibrium of lake water budgets due to climate change (Adams and Sada, 2014; Bates et al., 2008; Deus and Gloaguen, 2013). Given the spatial limitations, logistic difficulties and high costs of regularly monitoring water level fluctuations in the field and over broad territories, remote sensing applications have been put forward as a potentially efficient, albeit not flawless, solution (Alsdorf et al., 2007).

A common approach in this regard is to track water surface area fluctuations (*i.e.*, the horizontal dimensions, extracted from imagery), which, in the absence of modifications in bathymetry (for example, due to sand extraction), are correlated to water surface altitude fluctuations (*i.e.*, the vertical dimension, usually acquired in the field) (*e.g.*, Ding and Li, 2011; Peng et al., 2005). Nevertheless, few studies have analyzed the potential of using a combination of very high spatial resolution optical and radar imagery to track water level fluctuations. Indeed, the combined use of such images might maximize temporal resolution and allow effective monitoring of sudden and/or minor water level fluctuations of relatively small (<100 hectares) and irregularly-shaped inland reservoirs. These fluctuations might go unnoticed when using less resolved imagery.

The objective of this study is hence first to assess whether such data are suitable for tracking water level fluctuations, and then to analyze the spatial resolution required in the case of a small inland reservoir in continental France.

Study site

Lake Bariousses (7.48 h m^3 at maximal volume, 8.7 km at maximal perimeter, 7.4 m average and 22.5 m maximum depths) is located near the town of Treignac in the southern central part of France (Fig. 1). As with many artificial reservoirs in the country, it

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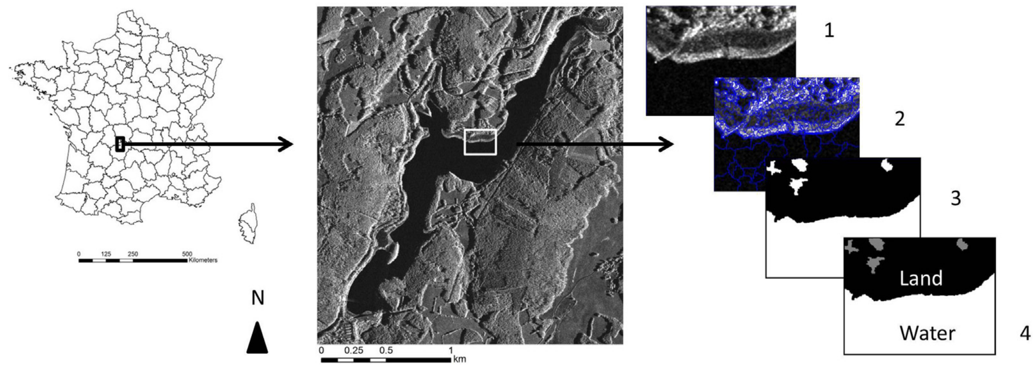

Fig. 1. Location of the study site Lake Bariousses (45.556 ° latitude and 1.813 ° longitude) and the mildly sloping and unencumbered littoral zone (white rectangle and number 1) identified for image classification. Numbers 2 to 4 refer to the steps of the geographic object-based image analysis (GEOBIA) applied on radar images. 2: segmentation, 3: first classification based on the mean of the signal amplitude, 4: second classification based on the total area in pixels. Image: Cosmo-Skymed (09/10/2013).

is a stream impoundment built in the 1950 s to produce electricity and supply water for irrigation and local consumption, and is hence subject to human-induced water level fluctuations. At 85.7 hectares in area at maximum water level, this is one of the smallest lakes to date in which remote sensing has been used to track water level fluctuations.

Materials

Table 1 provides the main characteristics of the imagery used in this study. The four Pléiades images consisted of georeferenced products corrected for radiometric, sensor and terrain distortions (Astrium, 2012). Acquisition dates were on the 18th of October and the 11th, 14th and 27th of November 2013. All five COSMO-SkyMed images used were georeferenced and corrected for terrain distortions, and consisted of single-polarization (HH: horizontal–horizontal) radar brightness products acquired in maximal spatial resolution instrument mode in descending orbit pass (ISA, 2009). Acquisition dates were on the 9th and 17th of October, and the 2nd, 11th and 14th of November 2013. Finally, the five TerraSAR-X images acquired came georeferenced but uncorrected for terrain distortions, and consisted of single-polarization (VV: vertical–vertical) radar brightness products also acquired in maximal spatial resolution instrument mode (Infoterra, 2009). Two images were obtained in ascending pass (the 6th and 27th of October 2013) and three in descending pass (the 15th, 20th and 31st of October 2013). For all three types of imagery, acquisition is commissioned and hence temporal resolution over a given target of interest varies according to programming priorities and catalogue availability.

Field data consisted of punctual water surface altitude data (in meters) provided by the French Company of Electricity (EDF) and included all image dates and a few others to a total of 24 dates. Field surface water altitude values ranged from 507.25 to 513.19 m (*i.e.*, a difference of 5.94 m).

Table 1
Main characteristics of the optical and radar imagery obtained over the study site. HH (horizontal–horizontal) and VV (vertical–vertical) refer to the polarization (*i.e.*, direction of transmitted and received electromagnetic waves) of radar images. Spatial resolution corresponds to the resampled spatial resolution provided in final products (refer to product guides for details).

Imagery	Bands (wavelength/frequency)	Spatial resolution	Quantity
Pléiades	Blue (430–550 nm), green (490–610 nm), red (600–720 nm) and near infrared (750–950 nm)	2 m	4
	1 panchromatic (480–830 nm)	0.5 m	
COSMO-SkyMed	1HH X-band (9.65 GHz)	0.5 m	5
TerraSAR-X	1 VV X-band (9.65 GHz)	0.5 m	5

Methods

All images were initially clipped around Lake Bariousses and reprojected to the standard projection system used in France. For Pléiades images, these were the only preprocessing steps undertaken. COSMO-SkyMed images were additionally speckle-filtered to reduce the salt-and-pepper effect characteristic of SAR imagery which adds noise to image classification (Mansourpour et al., 2006). Several different filtering methods and kernel sizes were tested, but Gamma Map filtering at 7×7 kernel size was retained for maximum reduction of speckle but minimum loss of the original texture. Preprocessing of TerraSAR-X imagery also included speckle correction under the same parameters, but required terrain correction as well. The amplitude band of the imagery was hence geometrically corrected using the SRTM 3 s Digital Elevation Model (DEM) and cubic convolution for both DEM and image resampling (ESA, 2014). Finally, new images at 2, 10, 15, 30, and 60 m in spatial resolution were created from spatial resampling *via* cubic convolution of all the original imagery (*i.e.*, optical panchromatic and radar at 0.5 m in spatial resolution).

A geographic object-based image analysis (GEOBIA) approach was adopted for image classification given its ability to account not only for spectral but also for textural, contextual and shape information, thereby arguably providing better image classification results (Blaschke et al., 2014). Attempts to extract the total water surface area from the radar images, however, were abandoned given (1) the difficulty in discriminating water from land in border areas affected by radar shadows (see illustration in Supplementary materials), and (2) geometric inaccuracies still clearly visible in the three descending pass TerraSAR-X images even after terrain correction. Similar difficulties in extracting water surface area from SAR images have been reported (*e.g.,* Hahmann et al., 2008; Kleine et al., 2013). Instead, a spatial subset of mildly sloping and unencumbered littoral zone (*i.e.*, free from the presence of tall vegetation and other objects in the vicinity) was selected for image processing in order to circumvent these problems (Fig. 1). This subset was identified heuristically by visually inspecting the imagery and the results of the initial GEOBIA attempts, as it became clear that neither misclassification nor geometric errors occurred at that particular section of the reservoir. A straightforward GEOBIA characterized by knowledge-based rules and thresholding was then adopted to classify image objects into “water” or “land”. Parameters for the multi-resolution image segmentation algorithm used were set manually (*i.e.*, visually by trial and error). For Pléiades images, all five bands were used for segmentation, and the Normalized