USE OF OPTICAL AND RADAR DATA IN SYNERGY FOR MAPPING INTERTIDAL FLATS AND COASTAL SALT-MARSHES (ARCACHON LAGOON, FRANCE)

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ABSTRACT

This contribution explores the potential of high-resolution satellite SAR imagery (TerraSAR-X, ALOS-PALSAR) for mapping coastal habitats in complement of optical data (SPOT-5). It addresses X- and L-band SAR signatures over intertidal flats and coastal salt-marshes by investigating the mean backscattering coefficient $g^2$ over the major environmental units and its variation associated with physical parameters (soil roughness, soil moisture, tidal inundation) and instrumental configurations. The major findings outline a great potential of TerraSAR-X data to detect oyster beds and discriminate Zostera noltii seabed from salt-marsh vegetation species. Based on these results, a multi-sensor multi-temporal mapping strategy was tested running simple supervised classification algorithms. These tests show that mapping performance is greatly enhanced when running Mahalanobis classifier on a 6-band concatenated image. Further work is needed to account with green macro-algae deposits and microphytobenthos in order to demonstrate the full capabilities of spaceborne sensors to provide an exhaustive mapping of intertidal environments.

Index Terms— Coastal mapping, intertidal flats, habitats, SPOT, TerraSAR-X

1. INTRODUCTION

Coastal areas are very attractive places worldwide but they undergo significant changes due to natural variability, climate change and anthropogenic activities. The macrotidal lagoon of Arcachon (SW of France) is characterized by a wide range of natural habitats classified in the Natura 2000 network. The Arcachon lagoon is composed of wide intertidal mud and sand flats subject twice a day to tidal inundation that left them partially inundated even at low tide levels. Intertidal flats are characterized by a thin vegetation cover of Zostera noltii aquatic plants. The upper tidal levels are occupied by coastal salt-marshes formed by several halophytic plant communities which also constitute valuable habitats with regards to biodiversity and ecosystem functioning. To ensure long-term monitoring over wide coastal areas and assess their changes over time, spaceborne remote sensing has long been considered as an efficient and low-cost tool.

This paper explores the potential of high-resolution spaceborne Synthetic Aperture Radar data for mapping intertidal coastal areas as a complement of high-resolution optical imagery (e.g. SPOT, Formosat-2). Classification algorithms based on optical imagery alone fail to accurately discriminate a series of relevant habitats [3], in particular seabeds of benthic fauna (oysters), low-density Zostera noltii seabeds and salt-marsh vegetation species. Firstly, the paper addresses the benefits from TerraSAR-X data by investigating SAR signatures over intertidal wetlands which have been poorly described in the literature [2, 5, 6]. Secondly, a supervised classification algorithm is run based on the fused SAR-optical bands. A statement of the mapping performance is finally carried out using field observations.

2. METHODS

The study area is the macrotidal lagoon of Arcachon located on the south-west Atlantic coast of France. The dataset consists of satellite data acquired in the frame of the KALIDEOS database made available by the CNES (French Space Agency). It gathers 15 TerraSAR-X images acquired between 2009 and 2011 in dual polarization Stripmap (2.75 m resolution) and Spotlight modes (1-1.5 m) and also 2 ALOS-PALSAR scenes (12.5 m). The set of SAR data covers a wide range of instrumental configurations allowing the discrimination of the respective effects of the incidence angle, polarization and SAR field of view on habitat signatures. SPOT (10 m) and Formosat (8 m) optical images as well as two aerial surveys (resolution 40 cm) were used as ground truth to help with the interpretation of SAR images.
Field observations were realized at the time of SAR acquisitions to provide a qualitative and quantitative description of surface characteristics (sediment roughness, soil moisture) which influence SAR response. A couple of two Spot-5 (10 m) /TerraSAR-X (2.75 m) images acquired the 28 August and 7 September 2011 is used to assess the benefits of introducing SAR bands in supervised classification schemes. The two selected images were acquired at similar low tidal level. SPOT-5 and TerraSAR-X scenes were co-registered using ground control points, TerraSAR-X pixel size resampled to a 10 m resolution using pixel aggregate technique allowing speckle reduction. Tests were performed on a monthly monitored subset area (La Hume) of 1.8 km by 2.3 km (181 columns x 231 lines). The 4 SPOT-5 bands and 3 TerraSAR-X bands (HH, VV, HH-VV) were concatenated and supervised classifications were run using several training classes for each type of substrate. Training classes are representative of various bare sediments (beach dry sands, beach wet sands, grey wet sands, muds, sandy muds, etc...), low to dense Zostera noltii seabeds, lower (Spartina maritima), intermediate (Halimione portulacoides, Salicornia europaea) and upper (Juncus maritimum prevailing) salt-marsh vegetation as well as oyster beds. Method performance is assessed using field observations for validation.

3. RESULTS

3.1. SAR signatures

Among the main results, the analysis of SAR data demonstrates the great potential of TerraSAR-X imagery to unravel the gaps raised by the solely use of optical satellite imagery for the purpose of habitat mapping. The first result concerns the achievement of oyster bed discrimination from neighboring sand/mud flats at both X- and L-bands (Fig. 1), $\sigma_0$ difference ranging from 4 to 8 dB in HH polarization for the TerraSAR-X dataset. Oyster shelf roughness generates volumetric scattering resulting in strong backscattering in X-band ($\sigma_0$,$\text{HH}=-7$ dB to $-9$ dB) but significantly lower in L-band ($\sigma_0$,$\text{HH}=-12$ dB). One can also note the particular bright signature at L-band ($\sigma_0$,$\text{HH}=-7$ dB) of SAR along-track oriented farming infrastructures (Fig. 1A, 1D) what agrees with previous works [4].

The second main result is the significant contribution of SAR images to separate intertidal Zostera noltii seabed from lower salt-marsh vegetation (i.e. Spartina maritima, Spartina anglica). The difference in $\sigma_0$ is about 4 dB in L-band and fluctuates between 2 and 7 dB in X-band.

As a general matter, strong spatio-temporal variations of TerraSAR-X backscattering signal were observed over intertidal flats (Fig. 2) inferred by short-scale and short-term changes in sediment surface state (bedforms, soil moisture, impact of tidal inundation) and by instrumental conditions of SAR acquisitions ($\sigma_0$ decreasing with higher incidence angles).

Another significant finding concerns the effect of tidal inundation on soil moisture which totally governs X- and L-band SAR response over salt-marshes. This result differs from previous work [5] which formerly outlined the
potential of C- and L-band data for mapping salt-marsh plant communities.

3.2. Classification results

These findings foster the input of TerraSAR-X bands in classification schemes to perform better mapping of coastal habitats. In addition, the optical signatures of intertidal flats gathered in the field with hyperspectral radiometers are thoroughly described in a joint communication [1] which demonstrates the potential of a multi-temporal classification strategy to enhance the discrimination between *Zostera noltii* seabeds and salt-marsh vegetation. In the following, we present the preliminary tests performed using Minimum Distance, Mahalanobis and Maximum Likelihood classifications. The most satisfying results were obtained with the Mahalanobis classifier which was first run on the 4 concatenated summer optical bands plus the radar HH-band (Fig. 3c) using 21 training classes (Fig. 3a). At this stage, the fused optical-radar data (5 bands) resulted in a realistic detection of oyster beds (Fig. 3c) while optical-based classification over-detected them (Fig. 3b; look at the simulated oyster beds in white which extend well beyond the ground-field contours). But, the implementation of a radar band did not improve as much as expected the discrimination between *Zostera noltii* seabeds and salt-marsh vegetation. Also, we noticed that the radiometric variability inherent to SAR data (speckle) introduces noise in classification results which still needs to be more thoroughly filtered. Adding more SAR bands does not seem to significantly increase the performance of classification algorithms but contributes to enhance noise. More work is needed aiming at investigating more sophisticated classification methods to optimize the analysis of fused optical and radar data. The next step consisted in introducing a winter optical band (SPOT-5 XS2) (accordingly with results from [1]) to overwhelm the difficulty of separating *Zostera noltii* seabed from salt-marsh vegetation. This leads to a very realistic mapping of the study area with only very limited patchy areas of misclassified pixels remaining (Fig. 3d).

Finally, ground truth data shows that the image-based boundary between *Zostera* seabed and sandbank does not match exactly the one observed in the field (Fig. 3d, see the red contour). Actually, this may be caused by green macro-algae deposits or microphytobenthos biofilms that have optical multispectral signatures close to *Zostera noltii’s*. These two classes were not trained in the classification as both facies are subject to strong space and time variations and we did not have precise field truth observations regarding these two particular facies at the time of satellite acquisitions. By now, we are planning to test change detection methods based on optical satellite archive to detect green macro-algae deposits in particular during spring blooms.
4. CONCLUSION

The paper explores the potential of a dataset of 15 TerraSAR-X and 2 ALOS-PALSAR images acquired over the Arcachon lagoon (France) in the span time 2007-2011 with the aim of integrating them into a multi-sensor classification approach for mapping intertidal flats and coastal salt-marshes. Results show SAR data are very adequate for oyster bed detection and indicate some capability to discriminate *Zostera noltii* seabed from salt-marsh vegetation. Simple supervised classification algorithms were run using a 6-band (10-m) concatenated image made of 4 SPOT-5 summer bands, 1 SPOT-5 winter band (XS2) and 1 TerraSAR-X band (HH). The Mahalanobis classifier run on this combination of optical and radar data gave the best results improving significantly the performance and accuracy of the produced maps without much ground-field knowledge needed.

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6. REFERENCES


