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Modeling uncertainty in estuarine system by means of combined approach of optical and radar remote sensing

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ABSTRACT

Coastal environments are complex systems undergoing continuous evolution at a range of spatial and temporal scales. In this context, geomorphological and ecological features can be strongly related. We propose a synoptic remote sensing approach to monitor the temporal dynamics of both biotic and abiotic factors in estuarine and coastal ecosystems. Through the combination of spaceborne optical and SAR imagery, we derived both ecological and morphological parameters, to be integrated for a multi-temporal analysis of the dominant processes and trends in coastal landscapes. These dynamics were studied at three locations: Bevano (IT), the Scheldt (B-NL) and Erme (UK). The objectives were to detect and analyze interannual variations of processes and environmental dynamics.

The results highlight that over time, the morphology of different subsystems represents a balance between inputs (forcing agents like tidal range) and natural responses (related responses of the vegetation evolution). As a final remark the calculation of the uncertainties (subsidence rates) using new monitoring techniques such as satellite remote sensing has a specific added value that could be used for simulations over varying time scales and it should be considered as a potential 'add in' for an integrated management approach to coastal monitoring and control.

1. Introduction

Coastal areas are ecologically very valuable environments where various habitats and ecosystems are linked by complex interactions within a status of dynamic equilibrium. Coastal areas however are also the site of intense human activities and are often occupied by industrial, commercial and urban infrastructures, underscoring their economic importance (Nicholls et al., 2011). In order to ensure the adequate management of such complex areas, accurate and cost-efficient environmental characterisation and monitoring of these areas are necessary. This approach should deal with single components as well as the area as a whole (Costanza, 2008). Thus coastal environments are influenced by complex ecological and physical interactions, and therefore call for an interdisciplinary approach to understand their mechanisms and long-term evolution. Coastal ecosystems are of huge ecological and economic importance but are under increasing pressure from the effects of human activities, ranging from pollution to global climate change, that undermine the provision of critical ecosystem services (Costanza et al., 2011).

Estuarine environments, as well as coastal areas in general, are today exposed to different causes of vulnerability such as erosion and flooding events, influencing their evolution on time scales ranging from years to centuries (Timmerman and White, 1997). Global warming is of specific concern to coastal wetlands, especially because of sea level rise (Zedler and Kercher, 2005). For these reasons, in recent years there has been a change in the approach to coastal protection, in response to increased risks and uncertainties generated by global-scale changes: this has led to a growing interest in the study of phenomena occurring at different temporal and spatial scales. To accurately represent patterns and processes in coastal landscapes, the spatial distribution of both biological and geomorphological parameters should be taken into account. To study this relationship, we analyzed remote sensing images, which provide measurements across large spatial scales, repeatability of analysis, and most of all an empirical and quantitative approach for the extraction of physical parameters like subsidence and adjacent vegetation. We investigate the potential of optical multispectral and SAR remote sensing to characterize surface components and to identify the existence of relations between features in space. Thus the present research aimed at investigating the temporal evolution of vegetation patterns and morphological processes like subsidence rate and tide level changes in estuarine and coastal areas, through remotely sensed images. Remote

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sensing is an ideal technique in estuarine and coastal environments, because of their highly dynamic, heterogeneous nature and inaccessibility. The great advantage of this method is to allow large-scale analysis in both time and space (Taramelli et al., 2011). The recent availability of free archives of satellite images has greatly facilitated the application of multispectral analysis for the study of environmental change on both the morphological and bio-ecological components.

Temporal analysis through remote sensing was applied to three different coastal sites, the mouth of the river Bevano (Italy), the Saeftinghe salt marsh in the Scheldt estuary (Belgium–Netherlands) and the Erme grazing marsh (UK), to underline their evolution over 10- to 20-year periods. The specific aims were to investigate the trends of vegetation evolution in both space and time, in order to use vegetation as an early-warning indicator of interannual variations, both in size and shape, of processes and environmental dynamics.

2. Study sites

2.1. Foce Bevano

Foce Bevano is a small fluvial outlet located in the northern Adriatic, near the town of Ravenna (Fig. 1). The Bevano is a river with a catchment area of 92.5 km^2 (Balouin et al., 2006) and a total length of 34 km. The site is located in a densely populated area (south of the Po delta) and, at the same time, is one of the most relevant natural environments in the north Adriatic coast, where geomorphological dynamics evolve in a non-urbanized stretch of about 5 km. In fact, the river mouth is characterized by ecologically important habitats, such as wetlands, pinewoods, sandy beaches and sand dunes. This relatively minor watercourse forms a small-scale estuarine system, since tidal excursion is limited along Italian coasts and thus large-scale estuaries are almost absent (0–2 m).

Over the past 50 years, the Bevano area has undergone major morphological changes (Armaroli et al., 2013; VV. AA., 2009), which makes it extremely interesting to study its evolution and dynamics. In particular, its mouth underwent a rapid northwards migration due to the dominance of marine processes, such as alongshore currents, coupled with a low energy fluvial regime. The migration occurring in recent decades is mainly due to morphological evolution also considering the subsidence, which lowered Foce Bevano by about 21 cm from 1984 to 2005, thus decreasing the slope towards the sea (Vicinanza et al., 2009; VV. AA., 2009). This has led to the prevalence of sea forcing and to the accumulation of sediment in the river mouth. An intervention of artificial stabilization was thus necessary along the stretch of coast and on the dune system in Foce Bevano, which was increasingly subject to erosion: in 2006, the mouth of the river was closed and re-opened 500 m south (Gardelli et al., 2007). Moreover, channel migration had caused a rapid erosion of the dunes located immediately north of the mouth: for this reason, re-vegetation of the dunes was carried out in order to prevent further dune and beach loss.

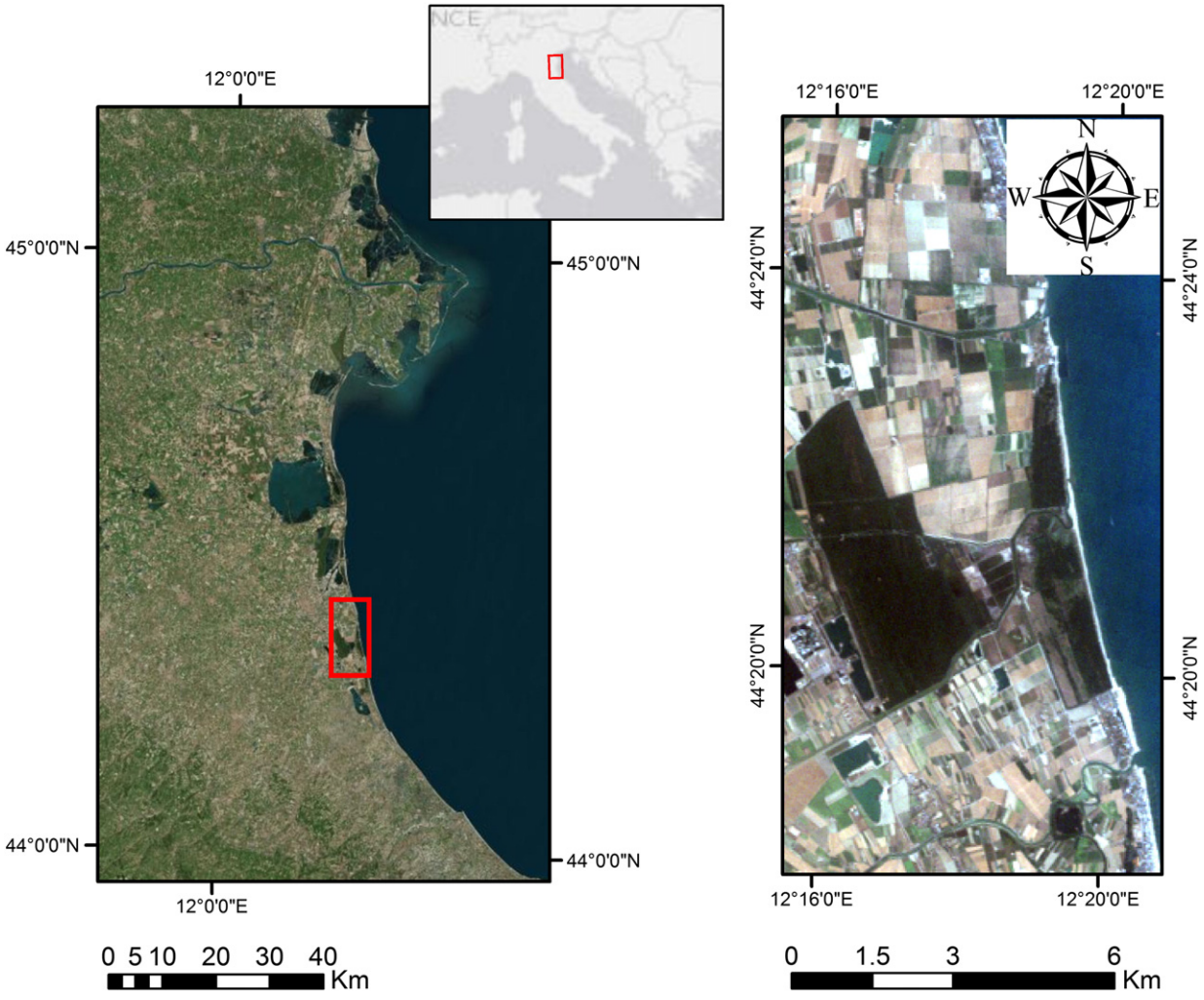

Fig. 1. Landsat satellite image of the Northern Adriatic coast (on the left) and a zoom on the study site, Foce Bevano (on the right).