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Focus

Detection of shipwrecks in ocean colour satellite imagery

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ABSTRACT

Waterborne swath acoustic and airborne laser systems are the main methods used to detect and investigate fully submerged shipwreck sites. In the nearshore, waterborne techniques are compromised as search tools as their effective swath is a function of water depth, necessitating very close survey line spacing in shallow water, increasing cost accordingly. Additionally, in turbid coastal waters bathymetric LiDAR is ineffective as it relies on clear non-turbid water. Therefore, the nearshore turbid zone represents a challenging area for archaeologists in the search for fully submerged archaeological sites. In this study, we describe a new methodology to detect the presence of submerged shipwrecks using ocean colour satellite imagery in turbid waters. We demonstrate that wrecks generate Suspended Particulate Matter (SPM) concentration signals that can be detected by high-resolution ocean colour satellite data such as Landsat-8. Surface SPM plumes extend downstream for up to 4 km from wrecks, with measured concentrations ranging between 15 and 95 mg/l. The overall ratio between the plume and background SPM concentrations is about 1.4. During slack tidal phases sediments in suspension settle to create fluffy mud deposits near the seabed. Scour pits developed around wrecks act as sinks where fine-grained suspended material is preferentially deposited at slacks. The scour pits subsequently act as sources for suspended material when the bottom current increases after slacks. SPM plumes develop immediately before maximum ebb or flood current is reached, during maximum current and immediately after. Particulate matter is suspended in sufficient concentrations to be detected in ocean colour data. The ability to detect submerged shipwrecks from satellite remote sensors is of benefit to archaeological scientists and resource managers interesting in locating wrecks and investigating processes driving their evolution.

1. Introduction

Locating fully submerged shipwrecks on the seabed is time consuming and expensive, made more difficult in the nearshore by navigation hazards, shallow depths and limited water clarity. The most common techniques used for locating and investigating underwater archaeological sites on a regional scale are waterborne swath acoustic techniques such as side-scan sonar (Quinn et al., 2005) and multibeam echosounder (Plets et al., 2011), and airborne techniques such as bathymetric LiDAR (Shih et al., 2014). In the nearshore waterborne techniques are compromised as search tools because their effective swath is a function of water depth, necessitating very close survey line spacing in shallow water, increasing cost accordingly. Furthermore, in turbid coastal waters, bathymetric LiDAR is ineffective as it relies on clear (non-turbid) water (Wang and Philpot, 2007). Therefore, the nearshore turbid zone represents a challenging area for archaeologists in the search for fully submerged archaeological sites.

These coastal seas are often characterized by a high variability in the concentration of Suspended Particulate Matter (SPM). SPM is generally composed of various fine grained constituents including clay minerals, quartz, carbonates, organic matter, plankton and so on (Berlamont et al., 1993). Tides, waves and wind forcing as well as biological activity have an influence on the horizontal and vertical distribution of the SPM in the water column and on the occurrence of fluffy layers of fine-grained sediments on the sea floor (Mehta, 1986; Dyer, 1989). The fine-grained sediments are re-suspended when the current-induced bottom shear stress exceeds a critical value and are mixed up in the water column by turbulence. Deposition occurs when the turbulent mixing becomes smaller than the settling velocity of the SPM. Depending on the water depth and the hydrodynamic forcing, the SPM is mixed up towards the

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water surface, where they can be detected by remote sensing techniques.

Mapping of suspended particulate matter (SPM) concentration from ocean colour satellite imagery such as SeaWiFs, Meris or MODIS-Aqua with 250–750 m spatial resolution has proven to be an excellent source of data to describe and understand the surface SPM distribution in the time and space domain (Trisakti et al., 2005; Fettweis et al., 2007; Eleveld et al., 2008; Nechad et al., 2010; Fettweis et al., 2012). Satellites such as Landsat-8 with an even higher spatial resolution (30 m) show small-scale SPM concentration variations at the sea surface. These features are a sign of the natural heterogeneity of hydrological, seafloor, bathymetrical and biological conditions (Becker et al., 2013). Human activities, such as dredging and disposal of dredged material, sand extraction, aquaculture and offshore structures constructions impose further local changes in hydrodynamics and sediment transport, and affect turbidity, fine-grained sediment dynamics, and thus the SPM concentration in the water column, at the surface and on the sea floor (Forrest et al., 2009; Fettweis et al., 2011; Capello et al., 2014; Van Lancker and Baeye, 2015).

The effect of these small-scale changes can be detected by high-resolution satellites, such as Landsat-8. An example is the turbid wakes associated with offshore windfarms turbines (Vanhellemont and Ruddick, 2014). The increase in SPM concentration in the wakes of these structures is caused mainly by the increase of hard substrate surfaces in a soft sediment environment and the associated massive bio-fouling (Baeye and Fettweis, 2015). Other studies have shown that objects on the sea floor induce local scour pits (Quinn, 2006; Quinn and Boland, 2010) that can be periodically filled by fine-grained sediments resulting in an increase of the sea floor heterogeneity (Traykovski et al., 2004; Baeye et al., 2012). The aim of this study is to investigate if fully submerged shipwrecks in the nearshore generate SPM concentration signals that can be detected by high-resolution ocean colour satellites such as Landsat-8. The availability of detailed bathymetric data and surface SPM concentration maps make the Belgian nearshore area a relevant site for investigating the link between the shipwreck, the scour signatures at the sea bed and the surface signature in SPM concentration and illustrate the potential of remote sensing mapping for underwater archaeology.

2. Material and methods

2.1. Wreck sites and bathymetric data

In this study, four shipwreck sites near the port of Zeebrugge are investigated: *SS Sansip (1944)*, *SS Samvurn (1945)*, *SS Nippon (1938)* and *SS Neutron (1965)*. *Sansip*, a 135 × 17 m US Liberty cargo ship with a draft of 8.5 m sank after being mined on December 7, 1944. On September 11, 1997 the fishing vessel N12 *Arthur* struck the site and sank adjacent to *Sansip*. *Samvurn*, measuring 129 × 17 m, sank after being mined on January 18, 1945 underway from Antwerp to London. 7 crew and nine soldiers died. *Nippon*, a 138 × 18 m Swedish steamship sank on September 14 1938 after colliding with another vessel off the *Wandelaar Lightship*. Neutron, a 51 × 8 m Dutch steel cargo vessel, foundered and sank on August 3 1965 after hitting a wreck, presumed to be *Sansip*.

Full-coverage multibeam echosounder (MBES) data was made available by the Flemish Hydrography, Coastal Division, Agency for Maritime and Coastal Services, Flemish Ministry of Mobility and Public Works. The MBES surveys of the wreck sites were conducted using a dual head Kongsberg EM3002D, an RTK Septentrio AsteRx2e GPS system and Applanix POS/MV 320 motion compensation system. The 1 m gridded data were rendered using ArcGIS v 10.1. Reference level of the water depths is Lowest Astronomical Tide (LAT).

2.2. Satellite data

Landsat-8 was launched on February 11, 2013 with a ground track repeat cycle of 16 days and a crossing time at 10:45 a.m. for the study area. The Operational Land Imager (OLI) on Landsat-8 is a nine band push broom scanner with a swath width of 185 km. Suspended particulate matter (SPM) is retrieved using OLI bands 4 (red) and 5 (near infrared) at 30 m spatial resolution. Processing included, among others, atmospheric correction and correction for scattering by molecules and aerosols to retrieve water-leaving radiance reflectance (details in Vanhellemont and Ruddick, 2014). A set of 21 cloud-free Landsat-8 images, covering the different seasonal, fortnightly and semidiurnal conditions, was used in this study (Table 1). Fig. 1a is an original RGB Landsat-8 image of the Belgian coastal zone area, and the derived SPM concentration map is shown in Fig. 1b.

2.3. Hydrodynamic model

The tidal currents (direction and speed) and water elevation at the time of each Landsat-8 image were modelled using an implementation of the 3D COHERENS hydrodynamic model to the Belgian Continental Shelf (Luyten, 2013). The model covers an area between 51°N and 51.92°N and between 2.08°E and 4.2°E. Boundary conditions for this model were provided by the operational models OPTOS-NOS (covering the North Sea) and OPTOS-CSM (covering the North-West European Continental Shelf). Regarding the tidal currents, a counter-clockwise rotating tidal wave is associated with the amphidromic point in the southern North Sea resulting in a semi-diurnal tidal current ellipse that for the study area is oriented WSW (ebb) – ENE (flood). The tidal range in water elevation varies between 2.5 (super neap) and 5.0 (super spring) m, with an average tidal range of 3.6 m.

Table 1
Satellite imagery and hydrodynamic model metadata and derivatives. 2013 data is in italics, 2014 data in bold and * means no plumes were observed in Landsat-8 SPM concentration map. The correlation coefficient is 0.99 between modelled current direction (current dir; true north) and plume direction (plume dir; true north). Neaps and springs are classified based on the median difference between high water and low water elevation which is 3.6 m for the study area. Seasons are divided as follows: [355–80] is winter, [80–172] is spring, [172–266] is summer, [266–355] is fall.

Path	Day	Spring/neap	Season	Plume dir	Current dir	+ Speed (m/s)
199	*200*	*neap*	*summer*	*042*	*047*	*0.40*
199	*216*	*neap*	*summer*	*060*	*064*	*0.82*
199	*232*	*spring*	*summer*	*076*	*068*	*1.08*
199	*248*	*spring*	*summer*	*121*	*124*	*0.13*
199	*280*	*spring*	*fall*	*208*	*219*	*0.34*
199	*344*	*neap*	*fall*	*278*	*264*	*0.52*
200	*159*	*spring*	*spring*	*	*161*	*0.18*
200	*303*	*neap*	*fall*	*54*	*54*	*0.54*
199	**75**	**spring**	**winter**	**105**	**108**	**0.24**
199	**91**	**spring**	**spring**	**213**	**224**	**0.43**
199	**107**	**spring**	**spring**	**217**	**221**	**0.28**
199	**139**	**spring**	**spring**	**239**	**232**	**0.67**
199	**235**	**neap**	**summer**	**074**	**072**	**0.81**
199	**251**	**spring**	**summer**	**085**	**078**	**0.59**
200	**34**	**spring**	**winter**	**241**	**241**	**0.72**
200	**82**	**neap**	**spring**	**253**	**244**	**0.75**
200	**162**	**neap**	**spring**	**066**	**066**	**1.02**
200	**226**	**spring**	**summer**	**235**	**231**	**0.73**
200	**258**	**neap**	**summer**	**240**	**241**	**0.75**
200	**290**	**neap**	**fall**	*	**287**	**0.17**
200	**306**	**neap**	**fall**	*	**348**	**0.21**