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What Lies Beneath the Surface? Using Airborne Hyperspectral Imagery to Map Submerged Archaeological Landscapes

A Case Study in the Molène Archipelago, Brittany

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Marie HASCOËT^e, Marie-Yvane DAIRE^f and Laurence HUBERT-MOY^d

Highlights:

- *Introducing a new method for mapping submerged archaeological landscapes.*
- *Airborne hyperspectral data allows estimation of bottom depth and reflectance for archaeological surveys in shallow waters.*

Keywords: airborne hyperspectral, archaeological surveys, remote sensing, shallow water, submerged landscapes.

Primarily monitored for its biodiversity and the ecosystem services it provides, the coastal environment is also the focus of major issues for the protection of cultural heritage. From the beginning of the Holocene marine transgression to the present day, these rich but fragile territories have been subject to continuous and extreme events, facing erosional impacts of storms and development of human activities. The intensification of these phenomena implies a rising threat to coastal archaeological sites, especially to those located in the foreshore and nearshore areas where numerous archaeological remains evidence the fishing practices of prehistoric societies (Langouët & Daire, 2009; Daire *et al.*, 2012).

Despite the increasing availability and use of active remote-sensing techniques, such as ship-based sonars (sound navigation and ranging) or airborne bathymetric LiDAR (light

detection and ranging) sensors, large-scale mapping of drowned coastal landscapes remains a challenge. The shallow coastal zone—known as the “white ribbon”—which is generally too shallow to use traditional bathymetric methods and sufficiently submerged to hinder topographic surveys, is characterized by a lack of high-resolution synoptic geographical data.

Airborne hyperspectral imagery (AHI) is a passive remote-sensing technique that measures, for each pixel and for a large number of narrow and continuous spectral bands (wavelengths), the amount of solar radiation reflected by the Earth’s surface. The pixel spectral signature characterizes the biophysical/physiological properties of the surface. Such capability has been used in archaeological prospection in emerged environments over open fields to identify, on the ground surface, subtle spectral variations related to the

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presence of buried archaeological remains. In coastal waters with low-turbidity, a small portion of the visible solar radiation penetrates the water and reaches the sea-bottom before eventually being reflected to the sensor. However, subsurface and sea-floor information can be provided by measuring and decomposing this subtle signal (Sicot *et al.*, 2015), providing a new source of information for archaeological mapping in shallow water area (Guyot *et al.*, 2019). This study focuses on the Molène archipelago, located off the west coast of Brittany (France) in the Iroise Sea. The archipelago comprises a string of islands and islets surrounded by an underwater shelf of more than 150 km². The coastal area where the depth rarely exceeds 10 m is known for its high concentration of coastal archaeological remains, including prehistoric tidal stone fish weirs situated below the lowest astronomical tide (LAT) level (Stéphan *et al.*, 2019).

AHI at a spatial resolution of 1 m was collected over the Molène archipelago with a 160-band sensor operating in the spectral range of 400-1000 nm. Using a radiative transfer model for shallow-waters, we estimated the water depth and the water bottom reflectance related to the water surface reflectance (Fig. 1).

These information layers derived from hyperspectral data were then used as input to generate a visualization of sea-floor landscape. The proposed visualization was composed of the spectral information layer (water bottom reflectance) displayed as a natural-colour composite image, draped on a digital terrain model layer (water depth). This cartographic

visualization acted as a proxy to create a visual representation of the submerged landscape of the archipelago as it would be perceived without the presence of the water column (Fig. 2).

In a first step, this visual representation of the submerged landscape was used to evaluate the potential of AHI-derived information as a support for the documentation of known archaeological structures (fish weirs) inventoried in Stéphan *et al.*, 2019. This inventory, which combines different sources including *in situ* observations, aerial surveys, bathymetric sonar and LiDAR surveys, provides an overview of the current knowledge (location, characteristics) of these anthropic structures. It was used as a reference for this study. The visual interpretation was complemented by a data-driven characterization approach based on information extracted from individual layers (water depth and water bottom reflectance). In a second step, the same approach including visual interpretation and data-driven characterization was carried out with the objective of prospecting the submerged landscape for unknown structures.

Preliminary results showed that the visualization of subtle spectral changes associated with the morphology of the terrain offered significant information for the identification of structures in shallow waters. The richness of the spectral information provided insights into underwater vegetation cover as well as variation of the nature of the seabed substrate that facilitated the identification of fish-weirs. Additional characteristics, such as topographic profiles and on-structure/off-structure mean spectral signatures (Fig. 3)

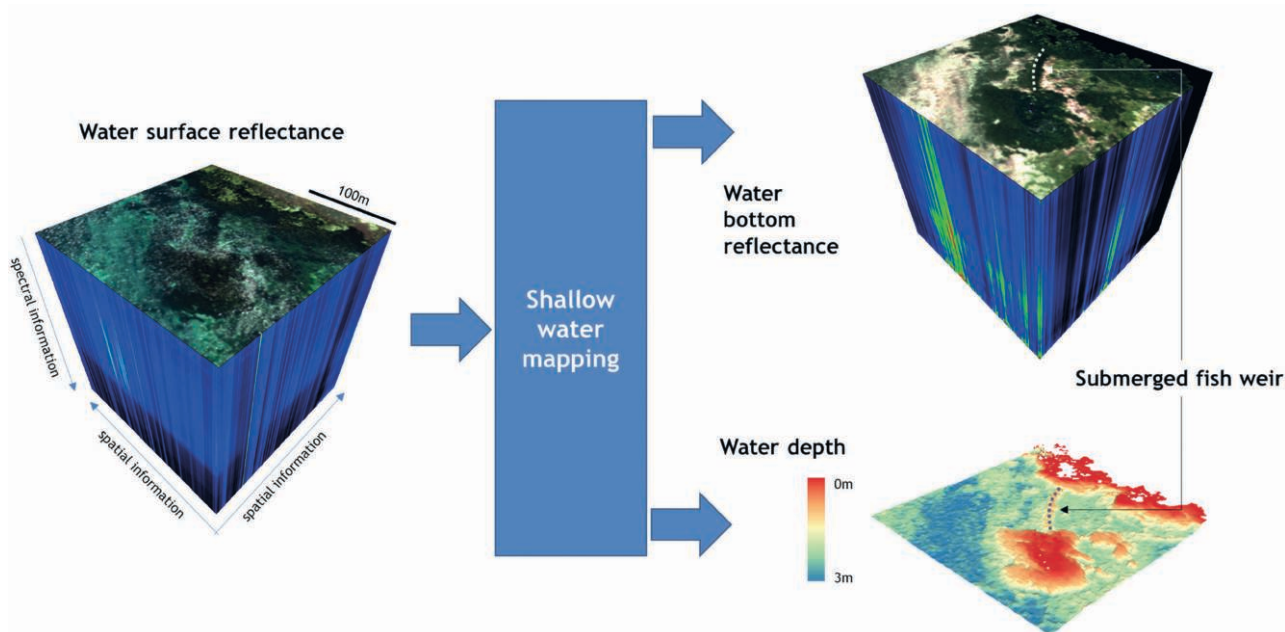


Figure 1. Estimation of water depth and bottom reflectance from hyperspectral imagery.

were respectively extracted from the water depth and water bottom reflectance to further document the inventoried structures and their environment. Beyond the identification of known submerged archaeological remains, the proposed approach allowed the identification of several anomalies in water depth ranging from 0.5 m to 5 m. Their morphology and context could correspond to fish weirs. The presence and nature of these anomalies have to be confirmed by *in situ* observations.

While AHI is sensible to the water column conditions (surface state, turbidity) as well as the bottom reflectivity, the depth range for operational use of AHI is difficult to predict since it varies with local conditions. Whereas radiative transfer models are continuously being developed, the complex physical interactions occurring between the light and the media it encounters (atmosphere, air-water surface, water column, sea bottom) contribute to the difficulty of identifying the nature of the signal reaching the sensor, and

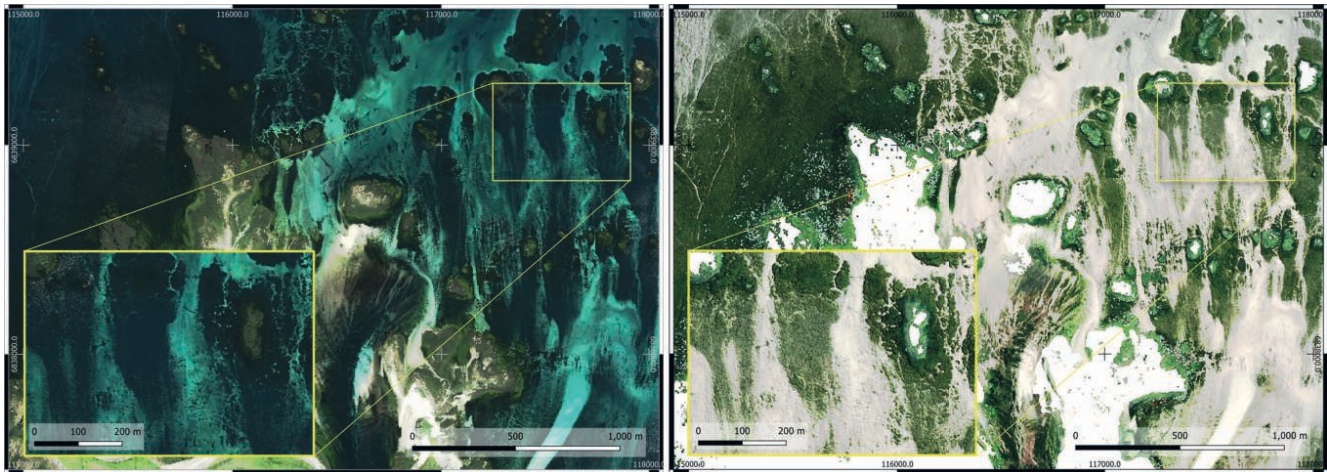


Figure 2. Visualization of the submerged landscape of the Ar Gwiniman area in the Molène archipelago (left: water surface visualization, right: water bottom visualization). The white patches on the water bottom visualization correspond to areas above water level (land).

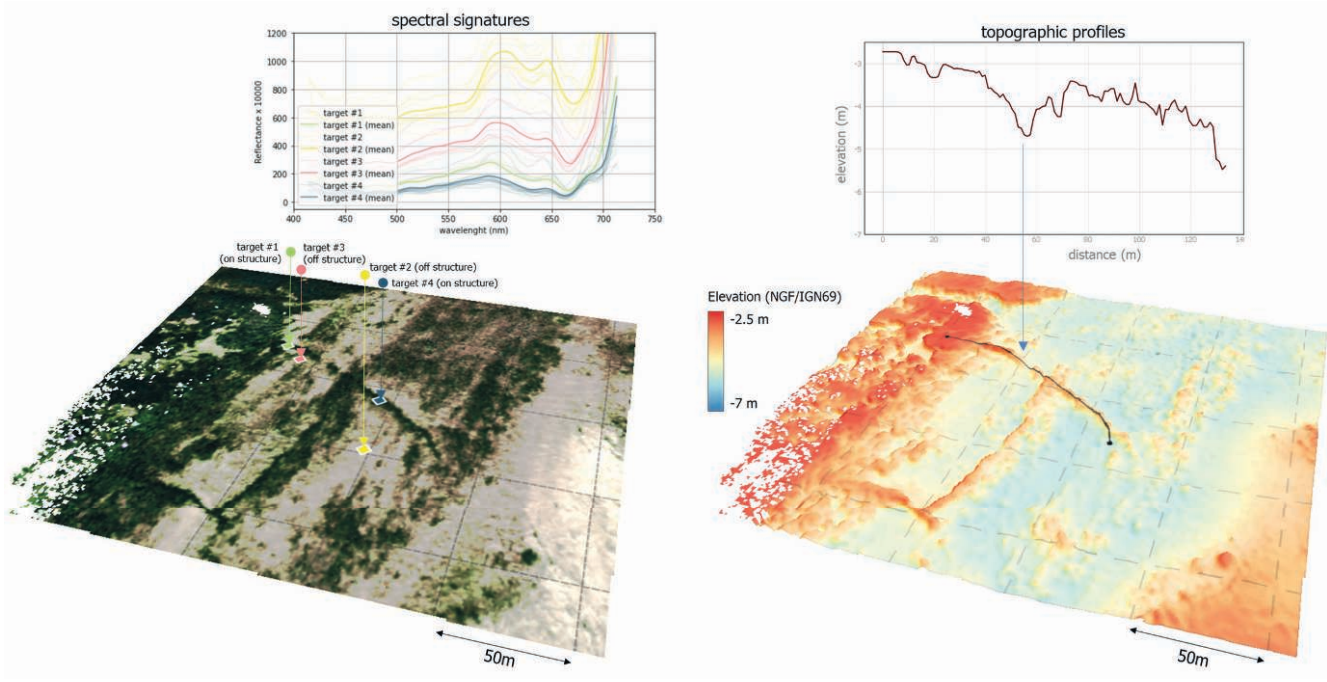


Figure 3. Bottom reflectance spectral signatures (left) and topographic profile (right) extracted from hyperspectral-derived information for the characterization of a known submerged structure in the Molène archipelago.

evaluating the uncertainty associated with the spectral measurement and its derivative information.

In conclusion, this study confirmed AHI as an informative data source for providing synoptic and high-resolution cartographic data in shallow water area for archaeological prospection. Despite some identified limitations and remaining challenges, the proposed approach opens new perspectives for the visual representation of submerged landscape as well as for the extraction of physical characteristics of submerged structures. We believe that the rapid development of hyperspectral sensors operated from air or space platforms, and the continuous improvement of radiative transfer models will contribute to provide relevant data on the shallow water zone.

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