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# Imaging spectroscopy as a tool to study sediment characteristics on a tidal sandbank in the Westerschelde

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**Abstract**

This paper focuses on the use of imaging spectroscopy for the mapping of sediment characteristics on a tidal sandbank in the Westerschelde, called the Molenplaat. On June 8, 2004, during low tide, a HyMap™ scanner recorded the Molenplaat at 4 m pixel resolution. The hyperspectral data were radiometrically calibrated, geometrically corrected, and atmospherically corrected to give apparent surface reflectance data. On the calibrated and corrected dataset a supervised binary classification was performed, based on linear discriminant analysis. Simultaneous to the flight, 25 sediment samples were collected in the field and analysed in the lab to define the median grain size, the water content, the total organic matter content and the chlorophyll-*a* concentration. These four parameters play a crucial role in sediment stability and macrofaunal habitat definition. Prior to the classification, a feature selection, based on sequential floating forward search (SFFS), was performed. For each of the four parameters two to three bands were retained for the classification. These bands were most frequently selected in the visible and near infrared parts of the spectrum, except for the organic matter content where also SWIR bands were used. The overall classification accuracy was highest for the water content (88%), the median grain size (88%) and the chlorophyll-*a* concentration (84%). The organic matter content, for which three instead of two classes were distinguished, scored somewhat lower but still reached 80%. The classifications were limited to a small number of classes in order to obtain reliable statistics with a small number of training samples. The spatial patterns in the classified images indicated that the four parameters under study are highly correlated. In most cases coarse sediment coincided with dry conditions, low organic matter and low concentrations of chlorophyll-*a*. The wet and muddy parts of the Molenplaat were in general characterised by a notably higher amount of organic matter and chlorophyll-*a*. The individual classification results for the median grain size, the water content and the chlorophyll-*a* concentration were combined to generate a sediment ecotope map. The presented study illustrates how airborne hyperspectral data can be used to achieve accurate classified maps of intertidal sediment ecotope types, applying feature selection and a binary classification approach.


*Keywords:* imaging spectroscopy; hyperspectral remote sensing; tidal sandbanks; sediment characterisation; Westerschelde

## 1. Introduction

The Westerschelde is unique among the larger European estuaries. It is home for one of the largest wading bird populations in Western Europe and contains several rare habitat types such as freshwater tidal marshes. These, together with a variety of other brackish and marine habitats, make the Schelde estuary a site of international recognition and importance for nature. But the estuary is also a site of heavy industry, as well as an important commercial shipping transport route. Therefore, coastal zone managers must constantly balance the demands of many conflicting interest groups when making planning decisions that affect this complex system (Meire et al., 2005). Decision-making can be improved if better knowledge of ecological processes is available. Some of the most important bio-geochemical processes in the estuary occur on the large areas of soft sediments which are exposed at low tide, suggesting that these intertidal sandbanks and

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mudflats require detailed study. Photosynthesis by benthic micro-algae at the sediment surface fuels primary production, supporting many grazing animals and birds. Accumulations of algal cells in a surface biofilm also cause the sediment to become more stable, slowing down the rate of erosion, and allowing the deposition of fine sediments (Coles, 1979). In contrast, grazing and bioturbation of macro-fauna may enhance the erosion rate (de Deckere et al., 2000).

However, obtaining accurate data on the basic biological, chemical and physical processes in sediments is expensive and difficult. Access to the sites is limited, and estuaries are characterised by a wide spatial heterogeneity, especially in intertidal areas. If used correctly, remote sensing methods can produce detailed information on habitats and ecological functioning in a cost-effective manner (Wulder et al., 2004). Hyperspectral airborne scanners such as HyMap™ can be used to identify important groups of inorganic and organic materials at a high spatial and spectral resolution (Kruse et al., 2000; Thiemann and Kaufmann, 2002). Intertidal and saltmarsh habitats have previously been investigated by Thomson et al. (1998), who used the airborne CASI scanner in a mode with 14 spectral bands to classify the vegetation and sediments in the Wash embayment on the east coast of England in 6 vegetation and 4 sediment classes. In the same study area Yates et al. (1993) tried to classify sandy and muddy sediments with spaceborne Landsat™ data; the poorer spatial resolution inspired them to try a sub-pixel classification which was performed with success. Bryant et al. (1996) and Rainey et al. (2000, 2003) explored the possibilities of sediment classification further by using the Daedalus 1268 Airborne Thematic Mapper (ATM) to map sandy and clayey sediments in the Ribble estuary (UK), focusing on the different grain sizes as one of the main parameters influencing the spectral reflectance. Finally the work of Smith et al. (2003) should be mentioned; in this study the sediments on the Molenplaat were classified in an unsupervised way using DAIS-7915 data.

The work described in this paper builds on these earlier studies by using high-resolution, visible (VIS), near infrared (NIR) and shortwave infrared (SWIR) imaging spectroscopy for the mapping of sediment characteristics in the intertidal zone of the Molenplaat. A supervised classification approach based on linear discriminant analysis is adopted to classify not only the median grain size, but also the water content, the total organic matter content and the chlorophyll-*a* concentration. These four parameters provide a good basis for sediment stability studies as well as for the study of microphytobenthos and macrofaunal biotopes. Finally, an ecotope map of the intertidal site is made, as part of a sustained effort to gain more insight in the biological role of the intertidal sandbanks and mudflats of the Westerschelde.

## 2. Study area

The Westerschelde estuary in the Netherlands is Western Europe's largest natural estuary. It has a special protected status according to Council Directive 92/43/EEC: "on the conservation of natural habitat and of wild fauna and flora", also large parts of the Scheldt estuary are designated as special protection areas or special areas of conservation under the European Bird (79/409/EEC) and Habitat Directive (92/43/EEC). From an ecological point of view the Westerschelde estuary is unique due to its high tidal range (up to 6 m), the complete transition from saline to fresh water environments and a freshwater tidal area almost 60 km long. However, due to human interventions the deep-water areas are expanding at the expense of intertidal areas. Nevertheless, the latter are very important ecotypes for a more natural functioning of the estuary.

The Westerschelde estuary (Fig. 1) was formed by rapid landward expansion of a tidal channel in the early Middle Ages, after which it became the major mouth of the river Schelde. The estuary reached its largest extent in the 17th century after which it partly silted up. The tidal marshes along the estuary have been reduced strongly in surface area since then (Meire et al., 2005). Simultaneously, the tidal range and the tidal celerity in the estuary have increased. The infilling of the estuary with predominantly sand is the consequence of the North Sea tide which rises faster than it falls, causing higher landward current velocities and consequently landward sediment transport. The large particles, i.e. sand, are transported during the rising tide but the current velocities during falling tide are too slow to transport the sand particles back to the open sea. However, recent studies pointed out that this process has reversed for unknown reasons; the estuary has now become a net sand-exporting system (Nederbragt and Liek, 2004). Hence, quantification of the relative amounts of muddy and sandy sediments in intertidal areas, and characterisation of the main intertidal ecotope types were among the aims of this study.

## 3. Methodology

### 3.1. Instrumentation and data collection

On June 8, 2004 between 12:41 and 13:22 local time a HyMap scanner on board a Dornier 228 recorded the Molenplaat in the Westerschelde. Prosperpolder, situated 25 km upstream from the Molenplaat, reported low tide at 14:42 local time. Hence, the acquisitions were performed approximately one and a half hour before low tide. The level of low tide was −1.97 m NAP (the highest low tide in June 2004 was −1.75 m NAP and the lowest was −2.63 m NAP). The meteorological conditions were very good; the nearby station of Vlissingen recorded a daily maximum temperature of 30.2 °C with a mean wind speed of 2 Bft from SSW. There were a few cirrus clouds (0−2 octas) and the mean daily relative humidity was 72%.

The operations were carried out by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) in cooperation with VITO. The instrument was calibrated before the beginning of the flight campaign at DLR's home base in Oberpfaffenhofen using HyVista calibration gear. The HyMap, developed by HyVista Corp., is a whiskbroom scanner utilising diffraction gratings and four 32-element detector arrays (1 Si, 3 liquid-nitrogen-cooled InSb) to provide 126 spectral channels covering