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Investigating spatial resolutions of imagery for intertidal sediment characterization using geostatistics

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ABSTRACT

To investigate bio-chemical processes of intertidal sediments, variations in sediment properties such as moisture content, mud content, and chlorophyll *a* content need to be understood. Remote sensing has been an efficient alternative to traditional data collection methods for such properties. Yet, with the availability of various types of useful sensors, choosing a suitable spatial resolution is challenging, especially that each type has its own cost, availability, and data specifications. This paper investigates the losses in spatial information of sediment properties on the Molenplaat, an intertidal flat on the Western-Scheldt estuary, upon the use of various resolutions. This was carried out using a synergy between remote sensing and geostatistics. The results showed that for the Molenplaat, chlorophyll *a* content can be well represented by low to medium resolutions. Yet, for moisture and mud content, spatial structures would be lost upon any decrease of resolution from a 4 m × 4 m pixel size.

1. Introduction

The biogeochemical processes that occur on an intertidal flat are defined for its sediment stability (Silva et al., 2005). The erodibility of sediments depends on their physical structure as non-cohesive sediments are less stable than cohesive ones (Mitchener and Torfs, 1996). Furthermore, the presence of microphytobenthic algae and macrofaunal species can either stabilize or destabilize sediments (Austen et al., 1999; Stal, 2010). To investigate such processes, good field knowledge is required while considering the dynamic nature of such systems with its seasonal annual variability (Slatton et al., 2008). Yet, accurate data collection on intertidal flats is often costly, inefficient, or even unattainable, and therefore, remote sensing can be a good alternative. Yet, with the availability of various types of useful sensors, choosing a suitable spatial (and corresponding ground) resolution is challenging (Townshend, 1980), especially that each type has its own cost, availability, and data specifications.

The ground resolution is defined by the combination of the height and the instantaneous field of view of the acquiring sensor (Atkinson and Curran, 1995; Lillesand and Kiefer, 2000) and is a fundamental aspect that affects the ability to characterize specific structures (Sadowski and Sarno, 1976). To investigate intertidal biogeochemical processes of sediments, sediment properties such as moisture content, mud content, and chlorophyll *a* content are addressed. Therefore, selecting a spatial resolution that captures important patterns in the distribution of these properties is essential. The traditional selection has been mostly based on experience, intuition, and data availability. Nowadays, researchers have the tendency to choose imagery with the highest available or affordable resolution. While information on spatial patterns may be lost at a resolution that is too coarse, a resolution that is too high can be a waste of resources in terms of cost and can lead to a lower number of images and inefficiency in data interpretation.

According to Woodcock and Strahler (1987), this selection depends on three main factors: the kind of information required, the methods used to extract the information from the imagery, and the spatial structure of the scene itself. Curran and Atkinson (1999) presented a thorough investigation and stressed the importance of considering the spatial aspect of imagery in remote sensing as a variable and not a parameter. Therefore, several researchers started addressing the spatial resolution issue more objectively, whereby they investigated measures or criteria for the selection of appropriate spatial resolutions for various environments. For example, Atkinson and Emery (1999) studied the relationship between the spatial structures captured in an image and the wavelengths of its bands; Carr (1996), Chica-Olmo and Abarca-Hernandez (2000), and Foody et al. (2004) used geostatistics for different aspects of

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classification; Woodcock and Strahler (1987) dealt with the factor scale in imagery using the calculation of local variance while coarsening image spatial resolution; and Rahman et al. (2003) dealt with the factor of scale of vegetation characterization in hyperspectral imagery using both local variance and semivariogram analysis. Garrigues et al. (2006) documented and compared several tools used to explore image spatial variation and study spatial heterogeneity at the landscape scale.

On the other hand, the specific investigation of spatial scales in the scope of intertidal sediment investigation has been relatively limited and mostly focused on the spatial distribution of microphytobentic algae, that range from cm to m in size, using chlorophyll *a* as an indicator, e.g. Murphy et al. (2008) and Wal van der et al. (2010). Other studies, such as Ibrahim and Monbaliu (2011), investigated these scales in the scope of testing the appropriate use of a few specific sensors. Therefore, the lack of thorough spatial exploration in the scope of intertidal sediment characterization makes it important to have objective means for selecting certain spatial resolutions for a considered study area.

The objective of this paper is to investigate spatial structures and distribution of sediment moisture content, mud content, and chlorophyll *a* using a geostatistical analysis in order to obtain measures when choosing image spatial resolutions. The considered study area is the Molenplaat, an intertidal flat in the Western-Scheldt. The study is based on high resolution imagery and field data that reveal these spatial structures. Then, the benefits of the synergy between geostatistics and remote sensing in addressing spatial structures in sediment properties are investigated. Two aspects are considered in the study: the loss of spatial variance and the loss of a spatial structure at lower resolutions. In general, spatial variance is expected to be lost whenever there is a decrease in spatial resolution. The importance of this loss can be weighed by linking it to the loss of a spatial structure or entity. This is the key element that this paper investigates.

2. Available data

2.1. Study area

The Molenplaat is an intertidal flat of about 61 ha and is a predominantly sandy with an average period of emersion varying between 2 and 4 h and up to 8 h for specific locations, per tidal cycle (Herman et al., 2001). It is located in the Western-Scheldt estuary in the Netherlands (Fig. 1). The Scheldt estuary is internationally recognized as an important site for nature conservation. It has one of the largest wading bird populations in Western Europe and several rare habitat types such as freshwater tidal marshes. This estuary is an important shipping route and holds sites of heavy industry (Herman et al., 2001; Adam et al., 2012).

2.2. Airborne hyperspectral data

On the 8th of June 2004, an image was acquired from the Molenplaat by means of the Hyperspectral Mapper (HyMap™) sensor at low tide and under cloud-free conditions. The flying altitude of 1920 m above the ground level resulted in a 4 m × 4 m pixel size. The raw data was georeferenced, geometrically corrected using ORTHO software, radiometrically calibrated using HyVista software, and atmospherically corrected using ATCOR4 (Deronde et al., 2006) by the Flemish Institute for Technological Research (VITO), Belgium. Table 1 gives a summary of the non-corrupt 116 bands of the HyMap™ image. Thus, reflectance values were available and utilized for this study.

2.3. Field data

Field sampling at 24 sites of the Molenplaat was carried out at low tide, on the day of the overflight. The coordinates of these sites were determined by means of a differential global positioning system (DGPS). To account for the variability in sediment characteristics within one pixel, two or three replicate samples from each sample vicinity were taken at each site.

The surface sediment was collected and analyzed for moisture content, organic matter content, and grain size distribution. Moisture content was calculated as the percentage of difference between sample weight after drying at 105 °C for 12 h with respect to the original weight.

For chlorophyll *a* determination, the upper 2 mm of sediment was frozen using a contact core with a diameter of 2.5 cm as this layer includes the bulk of the photosynthetically active cells that

Table 1
The useful bands of the HyMap™ image acquired on the 8th of June 2004. The following abbreviations are used: visible (VIS), near-infrared (NIR), short wave-infrared (SWIR), and the full width at half maximum (FWHM).

Module	Spectral range (nm)	Bandwidth	FWHM (nm)	Number of bands (–)
VIS	450–890	15–16	15	30
NIR	890–1350	15–16	15	32
SWIR1	1400–1800	15–16	13	32
SWIR2	1950–2480	18–20	17	32

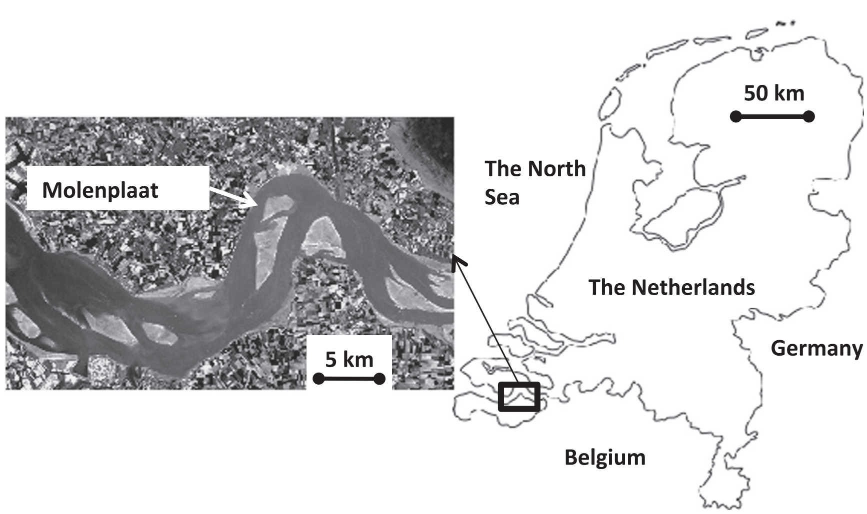

Fig. 1. The location of the Molenplaat and its surroundings.