

Effect of spatial resolution on intertidal sediment characterization

Ibrahim E.^a, Govaerts A.^a, Regmi P.^a, Druyts J.^a, van der Wal D.^b, Adam S.^a, Vervoort A.^a, Monbaliu J.^a, De Wever, A.^c, Sabbe, K.^c, Forster, R.^d

^a *Katholieke Universiteit Leuven, Belgium*

^b *Netherlands Institute of Ecology, the Netherlands*

^c *Universiteit Gent, Belgium*

^d *The Centre for Environment, Fisheries, and Aquaculture Science, UK*

Abstract. Remote sensing offers opportunities to efficiently acquire data of intertidal flats and characterize intertidal sediments. Each type of imagery with a different spatial resolution offers a distinctive perception. The objective of this research is to investigate the impact of these properties on sediment characterization. A hyperspectral airborne image of 4 m pixel size accompanied by field data is used. The study consists of a geostatistical analysis of spatial correlations for the hyperspectral image and imagery depicting specific sediment properties (moisture content and chlorophyll *a* content). The results show that there is information lost when the pixel size of the image increases to 24 m pixel size. To characterize relative moisture content, a maximum pixel size of 12m can be used. While for chlorophyll *a* content characterization, increasing the pixel size (investigated up to 72 m) does not degrade the information significantly. The research presented in this paper is funded by the Belgian Science Policy Office in the frame of the STEREO II programme (ALGASED project).

Keywords. Remote sensing, intertidal sediments, geostatistics, semi-variogram, spatial analysis, ALGASED

Introduction

An intertidal environment is a complex and dynamic system of bio-physical and chemical processes (Silva *et al.*, 2005). These processes shape intertidal zones and are important aspects that define the stability of sediments (Austen *et al.*, 1999). Accurate, synoptic and repeated field data collection required to assess and understand these environments is inefficient as such areas are often difficult to access. Remote sensing offers an alternative to traditional in situ data collection.

Remote sensing has progressed rapidly. It offers frequent mapping of intertidal areas and allows the characterization of their sediments. Due to the presence of many different types of remote sensing acquisitions, the amount of acquired information is massive. Airborne and spaceborne remote sensing both offer opportunities to acquire data and characterize intertidal sediments. While airborne hyperspectral data have a limited, relatively detailed spatial coverage and are relatively expensive, spaceborne multispectral data include less detail, but with wide spatial coverage, and are relatively cheap. Each spatial resolution offers a distinctive

perception, revealing different processes. Traditionally, the choice of the spatial resolutions was by experience. Yet, a more objective way is required for this choice, with a trade-off between spatial resolution, information, and acquisition cost.

Geostatistics is a tool to describe variables that are spatially dependent as it investigates the spatial correlations in a data set (Isaaks and Srivastava, 1989), and can be used to investigate the spatial patterns and structures in an image to realize its suitable resolutions.

The objective of this study is to investigate the spatial structures of an intertidal flat in order to identify the appropriate range of spatial resolutions to characterize specific sediment properties.

The geostatistical analysis in this study is based on different simulated spatial resolutions of key bands and maps of sediment properties derived from an airborne hyperspectral image of the study area. Experimental semivariograms of these images are then computed and modeled and the local variance is calculated, and used to evaluate the effect of spatial resolution (pixel size) on sediment characterization.

1. The study area

The study area is the Molenplaat, a small intertidal flat (1.5 km²) located in the Westerschelde estuary in the Netherlands. The intertidal flat has an important function for the estuarine food web, as it supports high biomasses of benthic (micro)algae and accommodates a rich benthic macrofauna community, attracting limicoline birds and (flat)fish.. The Westerschelde also has an important economic function, as it serves as an important commercial shipping route (Herman et al., 2001).

2. The available data

2.1. Hyperspectral imagery

A hyperspectral image of the Molenplaat, acquired in 2004 by the Hyperspectral Mapper (HyMAP) airborne sensor with 4 m pixel size, consists of 116 non-corrupted bands covering the visible (VIS), near infra-red (NIR), and shortwave infra-red (SWIR) (Table 1).

Table 1. Properties of the HyMAP image

Module	Spectral range (nm)	Band width (nm)	FWHM (nm)	Number of bands
VIS	450 - 880	15 to 16	14 to 17	28
NIR	890 - 1350	15 to 16	15 to 17	32
SWIR	1400 - 2480	15 to 20	14 to 21	56

2.2. Field data and sediment property maps

Field sampling and field spectral measurements were carried out on the Molenplaat for several years. The field data were analyzed for chlorophyll *a* (chl *a*) content and relative moisture content (RMC). Maps of sediment properties were derived from the hyperspectral image, using models relating the field data to spectral reflectance. These models are calibrated in the work of Adam (2009) using field spectral measurements and sediment analysis of the Molenplaat. Then, they are applied to the HyMAP image. The model to predict chl *a* content (mg/m^2) uses the amount of absorption by chl *a* at 673nm quantified by taking the ratio of the reflectance at maximal absorption and the reflectance at minimal absorption. The models to predict RMC (%) use a multivariate regression of the reflectance at specific wavelengths that show the highest correlations with the property (Adam, 2009).

$$\bullet \quad \text{chl } a = -372.0 \times (R_{680} / R_{711})^2 + 381.0 \times (R_{680} / R_{711}) - 8.91 \quad (1)$$

$$\bullet \quad \text{RMC} = -225.5 \times R_{650} + 51.09 \quad (2)$$

where R_r is the reflectance value of the HyMAP band with band centre r nm. These sediment maps are shown in Figure 1 and Figure 2 respectively.



Figure 1. chl *a* distribution map

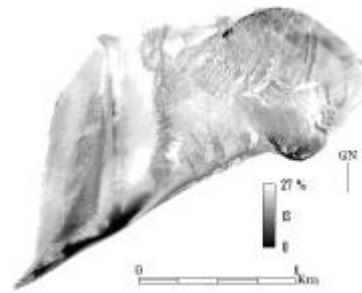


Figure 2. RMC distribution map

3. Methodology

3.1. Image preparation

The HyMAP image contains 116 spectral bands. The bands falling in the same parts of the spectrum are highly correlated. So, only a few representative bands are used. Then, the spatial resampling of these bands is carried out by means of the pixel aggregation method. This method resamples images into larger pixel sizes by averaging the pixels that fall within the coverage of the new resampled pixel, while giving weights to each pixel based on its contribution (pixel area of contribution) (Bian and Butler, 1999).

3.2. Computation and modeling of experimental semivariograms

Images can be represented as point values arranged on a regular grid with a vertical and horizontal inter-distance equal to the pixel size. A geostatistical study always starts by determining the semivariogram(s). The semivariogram is defined as half the quadratic average of the difference between data at a particular lag distance \vec{h} :

$$\hat{\mathbf{g}}(\vec{h}) = \frac{1}{2N(\vec{h})} \sum_{i=1}^{N(\vec{h})} \left[R_{(\vec{x}_i)} - R_{(\vec{x}_i + \vec{h})} \right]^2 \quad (4)$$

\vec{h} represents the lag or inter-distance and $\hat{\mathbf{g}}(\vec{h})$ is the semivariance for a distance \vec{h} .

$N(\vec{h})$ represents the number of point pairs separated by distance \vec{h} , $R_{(\vec{x}_i)}$ is the reflectance value of the pixel at location \vec{x}_i , and $R_{(\vec{x}_i + \vec{h})}$ represents the value of the pixel at location $\vec{x}_i + \vec{h}$ (Isaaks and Srivastava, 1989).

The semivariogram describes the correlation of two values in space. The obtained semivariogram is fitted by a model. Figure 3 shows an example of a semivariogram and its fitted model.

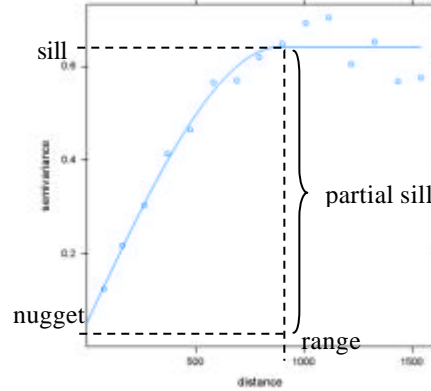


Figure 3. Example of a semivariogram with its parameters

Most often, the range, the sill, and the nugget value are the three most important parameters describing these models. The range is the minimum lag distance for which the values at the two points are independent of each other. Beyond this distance, observations are uncorrelated. Therefore, the range is an indication regarding the suitable pixel size that can be used to retain the information in the image. The sill is the plateau that the semivariogram reaches at the range. The nugget is the vertical jump from value 0 at the origin to the semivariogram value at extremely small separation distances. If the dataset fulfills a few conditions the sill corresponds to the total variance of the dataset.

The first step in fitting a model to a semivariogram is to choose the type of model such as linear, spherical, and exponential models. In this study the fitting of the model is done using a weighted least squares fit (WLS). WLS minimizes the weighted sum of squares (WSS) of the differences between the semivariogram values and the model values (Goovaerts, 1997). In this study, the weight function equals to N/h^2 . For a given set of spatial data, the semivariance structure may be a sum of two or more models. These are called nested models.

For the Molenplaat, the exponential model is usually found suitable. The range is considered as an indicator to finding the range of suitable spatial resolutions. The optimal spatial resolution should be fine enough to capture the variation this model range. Yet, in order to reach this resolution, about 50% of the range value should be used for the pixel size (Rahman et al., 2003).

3.3. Spatial resolution analysis using local variance

Local variance is a measure of the variation of the pixel values in the neighborhood of a pixel and an indicator of the scene texture. The local variance in an image as a function of spatial resolution is an indicator to choose an appropriate spatial resolution for mapping continuous variables (Rahman et al., 2003). If the pixel size is smaller than the entities under study in an image, neighboring pixels would have similar reflectance values and thus the local variance would be low. As the resolution decreases, the local variance increases. This trend continues until a certain peak. After this peak, the pixel information is so averaged that all pixels look the same and the local variance decreases again. The peak in local variance occurs at the maximum pixel size that can be used to characterize entities under study. For this study, the local variance is calculated by the semivariance at a lag of one support (Atkinson and Curran, 1997).

Since sediment properties are continuous variables, the spatial resolution of the imagery should be fine enough to capture the variation of interest in the property at the ground. Therefore, the spatial resolutions used should be much finer than the spatial resolution at which the maximum in local variance in the property at the ground occurs (Woodcock and Strahler, 1987) - about 50% used by Rahman et al. (2003).

4. Results and discussion

4.1. Analysis of the HyMAP image

Four Bands of the HyMap images are selected, and the experimental semivariograms and local variances are calculated for different spatial resolutions. These bands correspond to the green (512nm), red (619nm), NIR (801nm), and SWIR (1597nm) parts of the spectrum. The exponential model is used to model the semivariograms in Figure 4(a). These models show that the sill decreases and the range increases with the increase in pixel size. Yet, the model is not satisfactory for pixel size of 4m and 12m. This can be seen in Figure 4(a) where the fit between the semivariograms and the model for these spatial resolutions. Therefore, these two semivariograms are fitted with a spherical nested model where two structures are found with two ranges shown in Figure 4(b). In the semivariogram of 12m, this behavior is

slightly observed. For the 4m pixel size, the modeled ranges have the values of 23m and 185m, and for 12m pixel size, the range values are 33m and 195m. In the semivariogram of 24m, the distinction of these two ranges disappears. Therefore, loss of information occurred between 12m and 24m pixel size (probably around 12m).

Figure 5 shows the local variance in terms of pixel size. Local peaks are observed for the spatial resolution of 36m, 54m and 66m. This indicates there are multiple scales of variation in the features of this band of the HyMAP image and that these peaks are related to the different structures observed in the experimental semivariograms.

Similar to the green band of HyMAP, the red and NIR bands show a nested structure in the experimental semivariogram for pixel size of 4m and 12m, yet undistinguishable for 24m. This indicates loss of information due to increasing the pixel size from 12m to 24m. In order to examine the importance of this loss, semivariograms are calculated for the sediment property maps. The local variance graphs of the three bands also show multiple local maxima, indicating there are multiple scales of variation in the image.

As for the SWIR band, the nested structures are not distinguishable for the semivariogram of 12m. Furthermore, the local variance reaches a maximum for a spatial resolution of 66m.

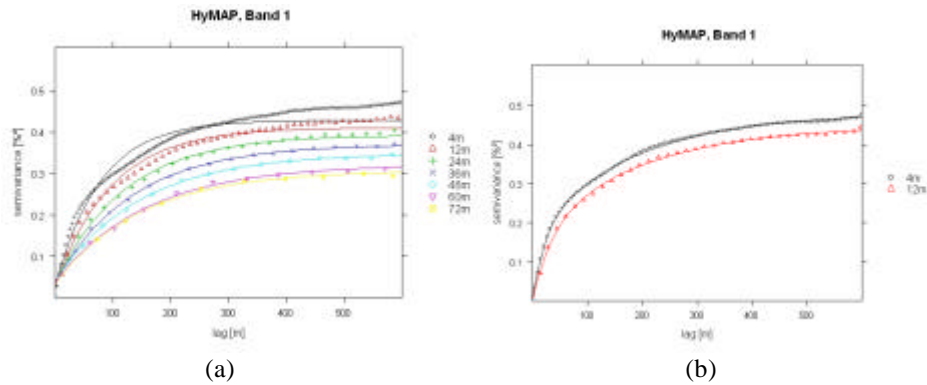


Figure 4. Green band with various spatial resolutions - omnidirectional experimental semivariograms fitted with (a) exponential models; (b) nested spherical models

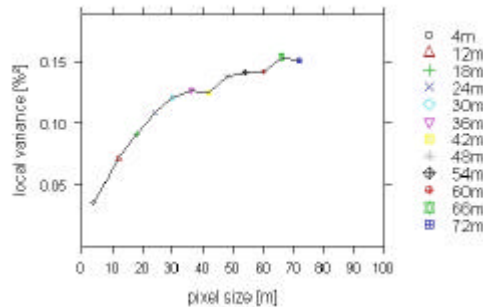


Figure 5. Local variance computed for different spatial resolutions of the green band

4.2. Analysis of images of sediment properties on the Molenplaat

- Analysis of the image of relative moisture content

The semivariograms of different spatial resolutions of the RMC image show that the range increases with an increase in pixel size. The exponential model is a good fit for pixel size greater or equal to 24m. Similarly to the bands of the HyMAP image, two structures are found for the semivariograms of 4m and 12m. The local variance shows local peaks observed at 30m, 54m, and 66m (Figure 6)

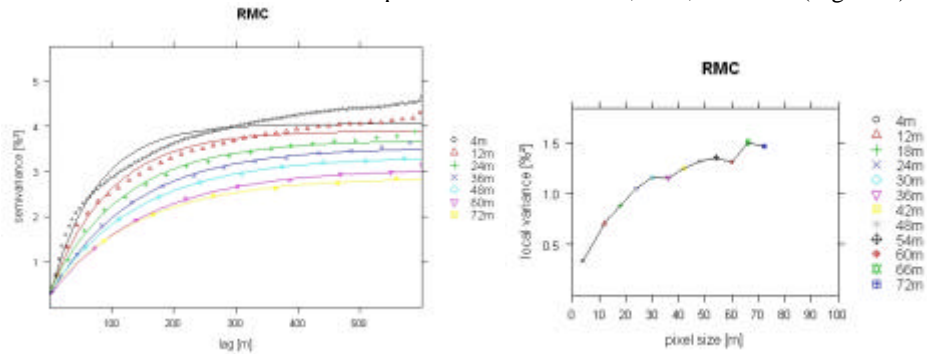


Figure 6. RMC map with various spatial resolutions (a) omnidirectional experimental semivariograms fitted with the exponential model; (b) local variance

- Analysis of the image of chlorophyll a content

The exponential model is satisfactory only for the smaller lags of the semivariograms calculated for the chl *a* map. The range is fairly high in this image and no local maxima in local variance are reached for the pixel size up to 72 m (Figure 7).

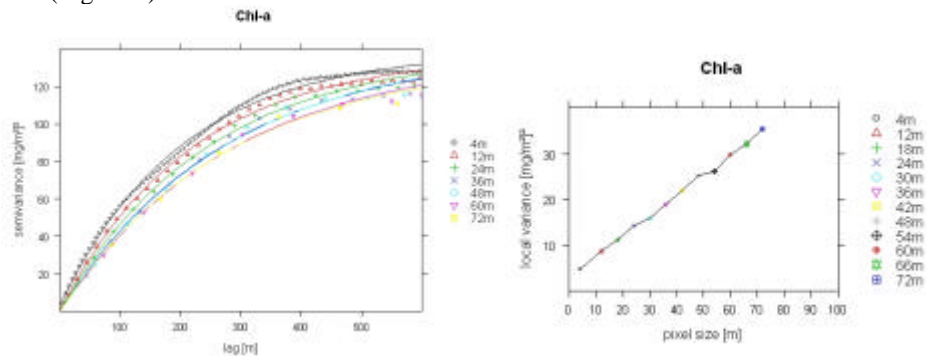


Figure 7. chl *a* map with various spatial resolutions (a) omnidirectional experimental semivariograms fitted with the exponential model; (b) local variance

Three criteria can be used to realizing the maximum pixel size that is useful to characterize RMC: 1) the ranges obtained from the models; 2) the pixel size at which the loss of the nested models occurs; 3) the peaks of the local variance. The smallest range of the nested model at a spatial resolution of 4m is 24m. Taking 50% of that value leads to 12m, and the pixel size at which the loss of the nested models occurs is about

12m. The pixels size at which the first peak in local variance occurs is 30m – taking 50% of that value leads to 15m. The lowest of these pixel limits are chosen, and therefore, a pixel size of 12m is considered to lead to the lowest resolution that can be used to characterize RMC.

For chl *a* content characterization, the results show that it can be still characterized even when much higher pixel sizes are used (tested up to 72m).

5. Conclusion

Geostatistical techniques are useful for investigating the effect of spatial resolutions on sediment property characterization. By means of semivariogram analysis and the changes in local variance, suitable spatial resolutions are indicated.

The results show that information is lost rapidly when the spatial resolution of the HyMAP image is degraded to larger than 12m pixel size. For relative moisture content characterization, it is shown that this information is essential, and a pixel size of 12m is the maximum pixel size that can be used. For chlorophyll *a* content characterization, much lower spatial resolutions are still suitable. Up to a pixel size of 72 m, there is still no significant loss of information observed.

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