COMPARISON OF SEDIMENT TRANSPORT MODELING WITH HYPERSPECTRAL AIRBORNE DATA ANALYSIS FOR THE RETRIEVAL OF SEDIMENT CONCENTRATION

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ABSTRACT

On June 15th 2005 hyperspectral airborne data were collected from the Lower Sea Scheldt at different stages during the tidal cycle with the AHS Advanced Hyperspectral Sensor (SenSytech Inc). Simultaneously with the airborne campaign a field survey took place. The goal was to collect ground truth data while the hyperspectral sensor was imaging the study area. This ground truth is essential for calibration and validation of the airborne remote sensing data. Three survey vessels were used at different stretches of the Lower Sea Scheldt to include some spatial variability. Several measurements were done on board of each vessel on predetermined locations at the time of airplane crossing over the study area. Surface water samples were collected for analyzing total suspended matter concentration, optical reflectance measurements were carried out and a turbidity sensor continuously measured turbidity in the surface water layer. Using these field data and the high resolution airborne data, a reliable empirical algorithm has been developed to derive near-surface suspended matter maps in an operational way. The produced *TSM* maps showed good agreement with known variations of the suspended sediment content over the tidal cycle: maximum turbidity around high water and gradual settling of the sediment in the succeeding slack water. A resuspension of sediment takes place at the onset of the ebb flow stage, especially at the bend-related shoals. The suspended sediment maps were validated against sediment transport model simulations. These simulations were performed using the Delft 3D modelling system for three specific locations in the Scheldt. The model returns *TSM* concentrations maps every thirty minutes starting at high tide. The succeeding spatial patterns of suspended sediment agreed very well with the patterns derived from the remote sensing data.

INTRODUCTION

Each year, dredging companies remove more than two million m³ of estuarine sediment from the Scheldt River (Belgium). This is necessary to assure access to the harbour of Antwerp. International Marine and Dredging Consultants (IMDC) advises government agencies and dredging companies to help them carry out their activities. Images of the sediment concentration are essential if accurate advice is to be given. Tidal coasts and rivers present especially variable suspended sediment concentration patterns both in time and in space. Traditional in-situ measurements performed at single points or along transects are insufficient to provide a complete view of the spatial variability of suspended sediments. Furthermore, the high degree of time and labour intensity prevents these field campaigns to be carried out repeatedly. This explains the high interest in sediment transport models and remote sensing to produce suspended sediment maps in an efficient way. In this paper quantified near-surface *TSM* maps of the Lower Sea Scheldt near Antwerp are derived from airborne hyperspectral data acquired over a part tidal cycle. Next, these *TSM* maps are compared with sediment transport model simulations.

METHODS

Study area

The Scheldt river finds it origin in northern France and flows through Belgium via Antwerp towards the North Sea. Our study site is restricted to a part of the Lower Sea Scheldt as illustrated in Figure 1. Although the open North Sea is about 60 km away from Antwerp, the Scheldt is an important shipping channel giving access to the vast port area of the city.

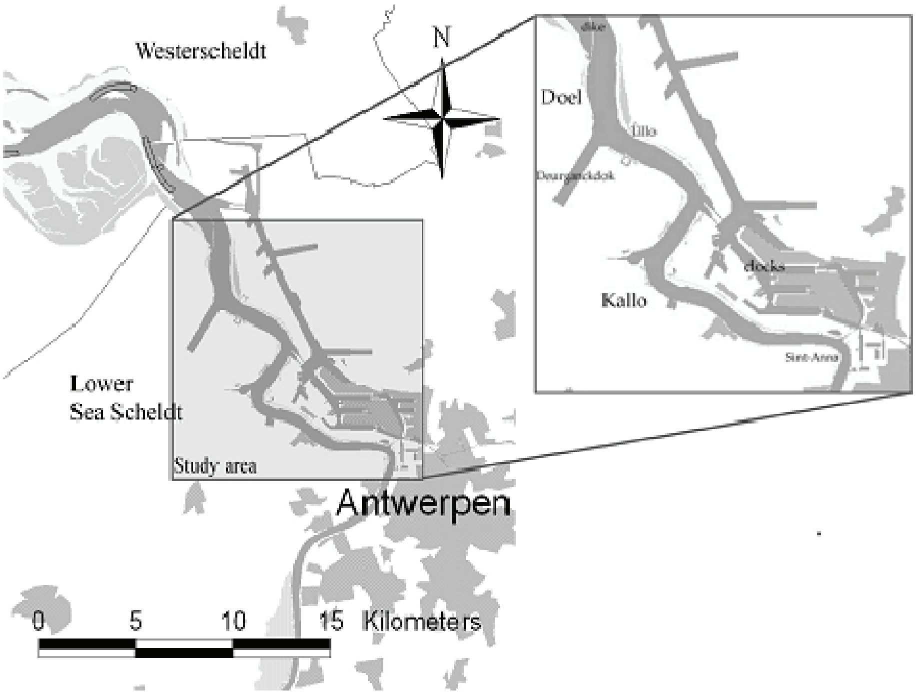

Figure 1: Study area

The Scheldt is a complex river system where concentrations of suspended sediment are highly variable in place and time. The concentrations are in the range of a few hundreds mg/l (1). At this location, the tidal range is more than 4 m.

Airborne and field campaign

On June 15th 2005 hyperspectral airborne data were collected with the AHS Advanced Hyperspectral Sensor (SenSytech Inc) at different stages of the tidal cycle (Figure 2). The data was collected in 80 spectral channels, covering the 0.430 µm to 12.70 µm electromagnetical wavelength range. Although weather forecasts were optimistic and the sky was clear at the beginning of the campaign, thin cirrus clouds covered the study area gradually. The remote sensing data were atmospherically and geometrically corrected at the Central Data Processing Centre (CDPC) at VITO (2).

Simultaneously with the aircraft overpasses, an extensive field survey took place. Two survey vessels were used at different stretches of the Lower Sea Scheldt to include some spatial variability. An extra vessel was deployed at the docks in the harbour of Antwerp. Several measurements were done on board of each vessel on predesignated locations at the time of airplane crossing over the study area. Four jetties served as additional fixed sampling locations. 150 surface water samples were collected and stored in 1 liter bottles to determine total suspended matter concentration. At one vessel in the Scheldt a turbidity sensor (Aanderaa RCM-9) continuously logged turbidity in the surface water layer. The location of the boats was continuously logged with a Trimble GeoXT GPS. Sun-photometric measurements were performed to estimate the aerosol content and water vapour in the atmosphere to calibrate the radiative transfer model used in the atmospheric correction. General atmospheric conditions were registered by taking photos of the sky at all the sampling locations of the boats.

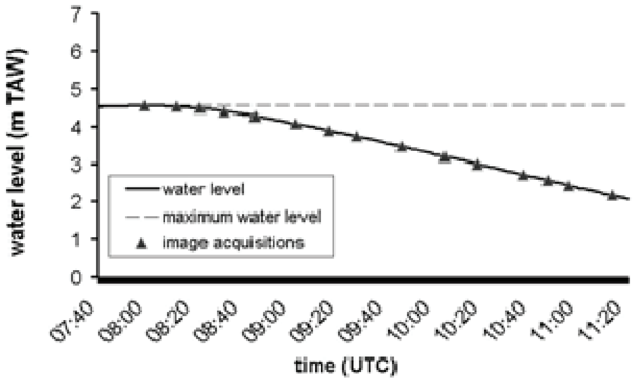

Figure 2: Image acquisitions in relation to the tidal cycle

The *TSM* concentration was determined by filtering 250 ml of the water samples on pre-weighed 0.45 µm membrane filters. Filters were then dried and re-weighed. The measured *TSM* concentration in the Scheldt river and the docks ranged from 13 to 336 mg/l and 7 to 12 mg/l respectively. To convert the continuous turbidity measurements in nephelometric turbidity units (NTUs) to *TSM* (measured in mg/l), the relationship between turbidity and *TSM* from water samples was statistically modelled for coincident points. A linear relationship was found with an R^2 of 0.83 and an *RMSE* of 35.2 mg/l. This best-fit regression equation was then applied to all turbidity measurements. Chlorophyll-a concentration was determined for six water samples following the ASTM D 3731-87 Standards (3).The average CHL-a concentration was 4.4 µg/l in the Scheldt river and 19,1 µg/l in the docks.

TSM maps

Reflectance spectra *R*(0-) were extracted from the hyperspectral images at the sampling locations. An average spectrum calculated from a 5 by 5 box of pixels (corresponding to an area of 20 m by 20m) was preferred to remove random noise. In the study area, the suspended matter concentrations and patterns change very rapidly as the tide fluctuates. The timing between airborne and in-situ sampling is therefore a critical issue. Hence, to calibrate as accurately as possible, only the samples taken within a few minutes of the airborne data recording were included. In total 41 samples were available to find a band combination which best predicts the *TSM* concentrations. A log-linear empirical relationship between a near-infrared reflectance difference and total suspended matter gave the best results (R^2 = 0.83; *RMSE* = 15.53 mg/l):

$$\mathrm{Ln}(TSM) = 34.18 * (R(0-,833) - R(0-,1004)) + 3.16 \quad (1)$$

with *R*(0-,833) and *R*(0-,1004) the subsurface irradiance reflectance at respectively 833 and 1004 nm.

The difference term sets off two reflectance values in the near infrared range, of which one is and the other is not sediment-dependent. This strategy was shown to compensate for some disturbing factors, such as varying cirrus cloud cover and adjacency effects (4).

Sediment transport model

The Delft 3D-sediment transport model, a 3 dimensional hydrodynamical model, was used to simulate *TSM* concentrations every 30 minutes starting at high tide. Discharge of the upper Scheldt was set to 50 m3/s. Caution is recommended when it is used for validation of the *TSM* concentration maps since it is calibrated and validated for other purposes. Moreover the exact depth of the upper water layer in the model doesn't completely correspond to the depth of the *TSM* concentration maps. Still, the qualitative similarity between the model and the *TSM* maps is already promising and significant. The absolute values are difficult to compare because the model was run for a similar period in June 2002 and not for the period in which the airborne campaign took place (June 2005).

RESULTS

The algorithm in Eq. (1) providing the best fit was then applied to all the AHS data to map *TSM* concentration at different tidal stages. To predict how well the algorithm will perform for the entire dataset a leave-one-out cross-validation (LOOCV) is applied. The RMSE of the LOOCV for our log-linear line model was 17.06 mg/l. The produced *TSM* maps showed good agreement with known variations of the suspended sediment content over the tidal cycle (5): at high water (HW) high surface silt concentration are observed. These general high near-surface *TSM* concentrations are mainly explained by high current velocities at high tide. At this stage velocities are very low, which results in much lower surface concentrations, due to the sinking of the sediment particles. During ebb (Figure 3) downstream velocities are observed, i.e. the sediment concentration is higher downstream of the inside of curbs which are shallower areas. Eroded sediment at the shallow area is dragged in the downstream direction.

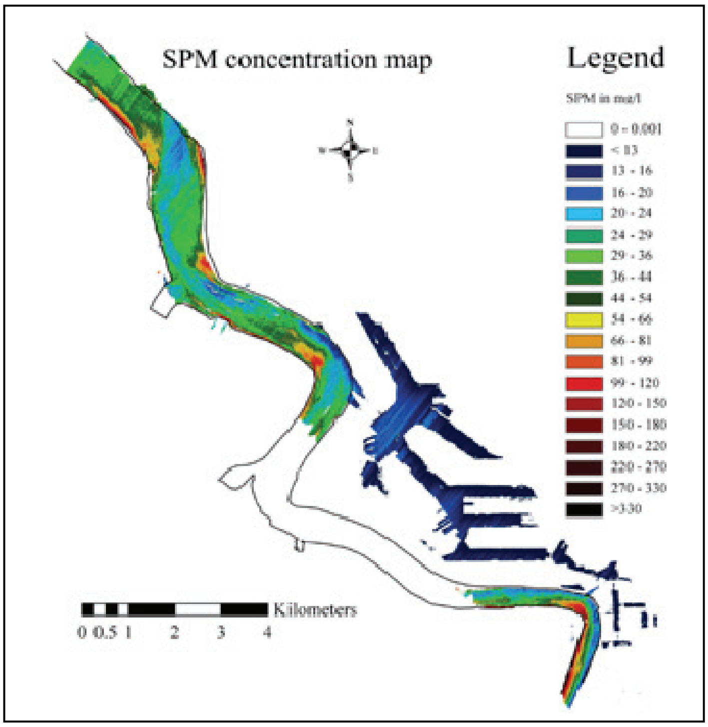

Figure 3. TSM map at ebb flow (high water + 2h 36 min)

Figure 4 shows a comparison between the *TSM* maps derived from the hyperspectral imagery and the model simulations. As already mentioned, attention should be paid to the observed *TSM* patterns rather than to the absolute concentrations. The *TSM* maps from the model show the same increase of *TSM* at the inner side of the bends when the ebb flow increases. First the increase of the *TSM* is observed at the downstream part of the bend, later on it also takes in the upper stream part. These simulations confirm that the patterns observed in the remote sensing derived *TSM* maps are correct.

CONCLUSIONS

The produced *TSM* maps showed good agreement with known variations of the suspended sediment content over the tidal cycle: maximum turbidity around high water and gradual settling of the sediment in the succeeding slack water. A resuspension of sediment takes place at the onset of the ebb flow stage, especially at the bend-related shoals. The magnitude of error in the retrieved *TSM* maps (17 mg/l) is in the same order as reported by (6) for comparable concentration ranges. The suspended sediment maps were validated against sediment transport model simulations performed using the Delft 3D modelling system. The model returns *TSM* concentrations maps every thirty minutes starting at high tide. The succeeding spatial patterns of suspended sediment agreed very well with the patterns derived from the remote sensing data.

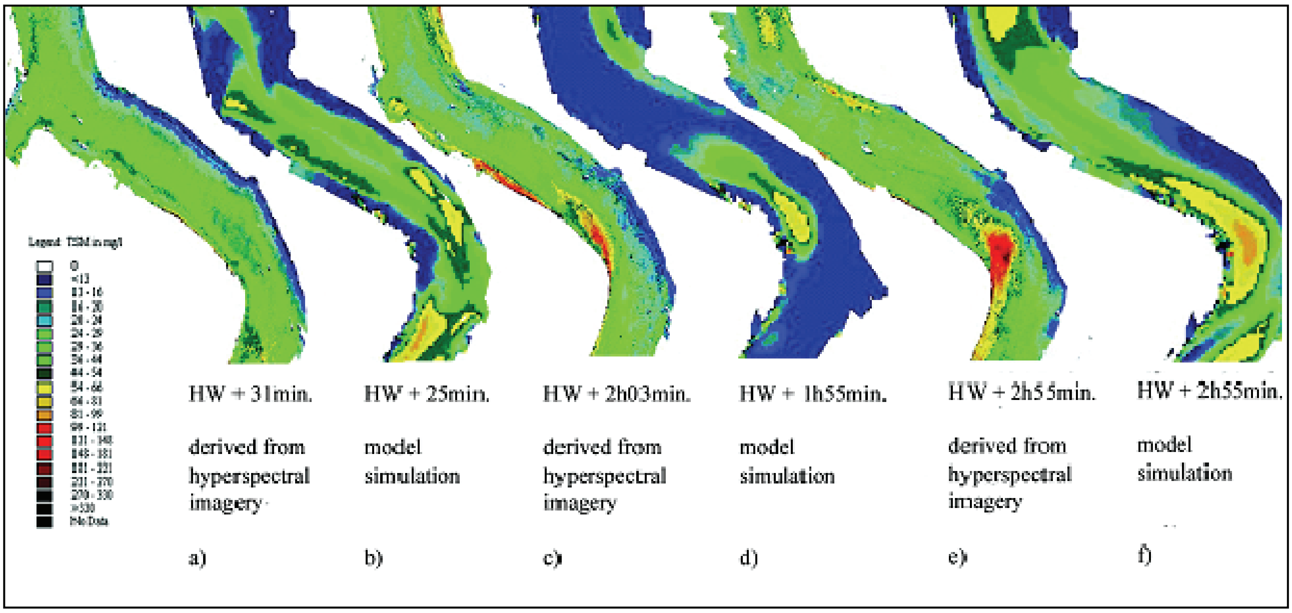

Figure 4: Comparison between TSM maps derived from hyperspectral imagery (a, c, e) and from model simulation (b, d, f (HW: High Water)).

ACKNOWLEDGEMENTS

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