PROGRAMMATORISCHE FEDERALE OVERHEIDSDIENST
WETENSCHAPSBELEID

RESEARCH PROGRAMME FOR EARTH OBSERVATION "STEREO"
Partnerships between Industry and Research

ONDERZOEKSCONTRACT
CONTRAT DE RECHERCHE
SR/67/36

PROJECT

Operational Remote sensing Mapping of Estuarine suspended Sediment concentrations (ORMES)

Operationele kartering van suspensiesedimentconcentraties in estuaria door middel van aardobservatie (ORMES)

THE PARTNERSHIP

SCIENTIFIC PARTNER
Vlaamse Instelling voor Technologisch Onderzoek (VITO)

PRIVATE PARTNER
International and Marine Dredging Consultants (IMDC)

PROGRESS REPORT #1
Covering the period from 15/03/2005 to 15/06/2005

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1. Activity report for the partnership

1.1 Summary

This activity report of the ORMES project describes the scientific progress made during the first six months and the scientific plans for the next six months. The status of the work packages and corresponding deliverables is illustrated in Table 1

Table 1: ***ORMES deliverable status***

	2005 1-3	2005 3-6	2005 7-12	2006
WP 0 Project management				
0.1 Coordination	C	C	C	C
0.2 Organization meetings	C	C	C	C
0.3 Diffusion valorization	C	C	C	C
0.4 Reports		D		
WP 1 Reviewing	B	D		
WP 2 Campaign preparation				
2.1 Specifications		D		
2.2 Subcontracting flight agency	B	D		
2.3 Deployment spectrometers		D		
2.4 Transport model optimizing			B	P
WP 3 Campaign				
3.1 Atmospheric measurements		D		
3.2 Reflectance measurements		D		
3.3 Turbidity measurements		D		
3.4 Water samples		D		
WP 4 Processing field data				
4.1 Laboratory analysis		B	P	
4.2 Conversion turbidity		B	P	
WP 5 Processing image data				
5.1 pre-processing			P	
5.2 Applying algorithms			B	P
5.3 Accuracy assessment				P
5.4 determination min. sample size				P
WP6 exporting methodology				P
WP 7 Validation				P
WP 8 Implementation				
8.1 Specification software				P

8.2 Development of software				P
8.3 Implementation				P

D: Delivered, B: Busy as planned, P: Planned delivery, C: Continuous activity

1.2 Scientific progress, activities and results

1.2.1 Work Package 0 - Project Management

Several meetings have been organized between the partners (VITO and IMDC) to plan in detail the field and airborne campaign.

On april 8th the ORMES project has been presented to the user partner, i.e. Waterbouwkundig Laboratorium en Hydrologisch onderzoek (WLH).

1.2.2 Work Package 1 – Reviewing

Scientific literature on suspended matter retrieval using remote sensing was reviewed. A comprehensive overview is given in ANNEX A. It covers some background information on remote sensing for water applications and a description of different algorithms used for suspended matter retrieval.

1.2.3 Work Package 2 – Campaign Preparation

A detailed field scenario (ANNEX B – in Dutch) was prepared which includes the specifications of the flight lines, the location and number of ground truth points, list of personnel availability, back-up plans, measurement specifications,...

Special constructions were made to deploy the field spectrometers (GER-1500 and ASD) under the right angles in order to measure downwelling irradiance, upwelling radiance and sky radiance.

1.2.4 Work Package 3 – Campaign

On June 15th, an Advanced Hyperspectral Sensor (AHS) onboard of a CASA 212-200 aircraft was flown over the study area. In total 15 flight lines were acquired. Simultaneously with the airborne campaign water samples were taken and measurements have been made of surface reflectance and water turbidity. The position of the vessels was registered with a GPS. Futhermore atmospheric measurements were performed with a sun photometer. Due to bad weather conditions the flight lines scheduled for the afternoon had to be cancelled. The flightlines scheduled for the forenoon were repeated in order to increase the number of points where water samples could be taken simultaneously with the flight campaign.

A detailed description of all measurements performed during the field campaign can be found in ANNEX C.

1.2.5 Work Package 4 – Processing field data

The water samples taken during the field campaign are being analyzed at VITO. The laboratory analysis includes :

- determination of total suspended sediment concentration
- determination of chlorophyll content
- particle, non algal and phytoplankton absorption
- spectral attenuation measurements
- grain size analysis

Detailed information is given in ANNEX C.

Water leaving reflectance spectra have been derived from the spectral measurements performed at the Scheldt.

1.3 Problems encountered and solution adopted or proposed

The ORMES team requested SPOT satellite data from the Scheldt coincident with the airborne campaign overpass. Unfortunately there was no SPOT satellite overpass on June 15^{th}. To overcome this problem we intend to simulate SPOT data by spectrally and spatially resampling the AHS hyperspectral airborne data.

Due to technical problems the turbidity measurements in Um Qsar (Persian Gulf, South-Iraq) –proposed validation site- were terminated before satellite imagery of this site was ordered. The ORMES team is now looking for an other validation site.

1.4 Scientific activities planned for the next six months

The following tasks are planned in relation to work packages 4 and 5 :

- Finishing all the laboratory measurements
- Conversion of turbidity measurements to suspended sediment concentrations
- Atmospheric correction of the AHS airborne data using the in-house software WATCOR. Scientific papers will be reviewed in order to adapt the correction scheme of WATCOR to the overcast sky condition during the second part of

the campaign.

- Geometric correction of the AHS airborne data using attitude (roll, pitch, yaw) and dGPS information
- The accuracy of different suspended sediment retrieval algorithms will be tested on the AHS data

1.5 List of external activities (colloquia, seminars, publications) related to the project

A short description of the ORMES project entitled “Slibconcentraties bepaald vanuit de lucht” has been published in the Annual Report 2004 of VITO .

English version : http://www.vito.be/english/who/vito_en2004.pdf

Dutch version : http://www.vito.be/wie/vito_nl2004.pdf

2. Administrative update to initial report

2.1 Steering Committee membership

The user partner, ‘Waterbouwkundig Laboratorium en Hydrologisch onderzoek (WLH)’ will be represented by Joris Vanlede instead of Tom De Mulder.

Annex A – Literature review

1. Introduction

The color of water is determined by:

- water molecules themselves
- phytoplankton and its pigment chlorophyll a which scatter and absorb light
- suspended sediments which predominantly scatter light
- colored dissolved organic matter (CDOM) from biodegradation of plants which absorb light at ultraviolet and blue wavelengths, often referred to as yellow substance or gelbstoff

Since these constituents affect the color of the water it is possible to detect their presence in water and quantify their respective concentrations. Substances (i.e. nutrients, metals) that do not change the optical characteristics of waters can only be inferred by measuring surrogate properties which may have responded to an input of chemicals (Ritchie and Cooper, 2001).

Suspended sediments increase the radiance emergent from surface waters in the visible and near infrared proportion of the electromagnetic spectrum (Ritchie and Scheibe, 2000). According to the same authors reflectance from almost any wavelength can be related to suspended sediment concentrations, if the range of suspended sediments is between 0 and 50 mg/l. If the range of suspended sediments increases to 200 mg/l or higher, curvilinear relationships have to be developed (Figure 2) .

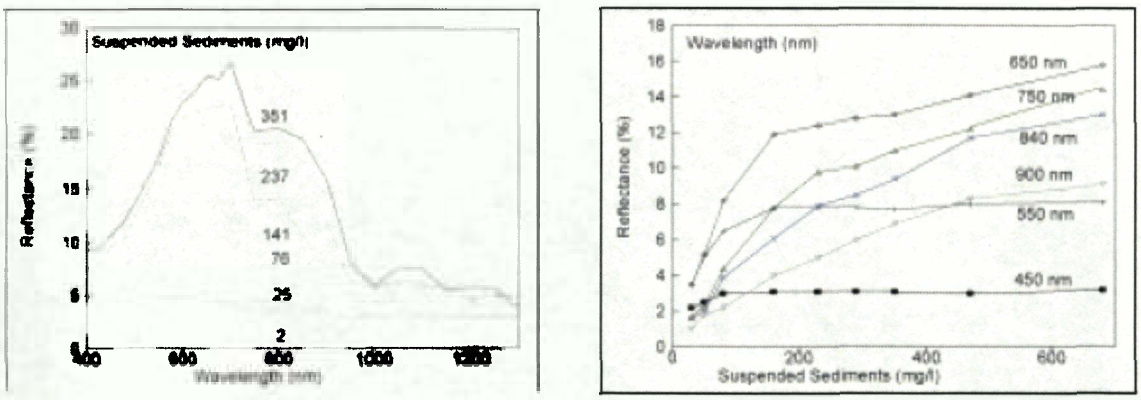

Figure 2 The relationship between reflectance and wavelength as affected by the concentration of suspended sediments (taken from Ritchie, 2005)

It is important to note that the water-leaving electromagnetic radiation which can be detected by remote optical sensors originates within a surface layer, the "penetration depth" after Gordon and McCluney (1975). When light penetrates water its intensity decreases exponentially with increasing depth. The penetration depth depends on wavelength and water composition. In the red and near-infrared region of the spectrum the water penetration depth is small (~ 1 meter or less in turbid water), and as such the turbidity signal will originate from a level similar to the in situ samples. Shorter wavelength channels integrate over larger columns and may even pick up bottom reflectance in shallow waters. The strong variation of the penetration depth water with wavelength may provide information on sediment stratification, since radiation penetrates deeper at shorter wavelengths and thus records the optical signature of deeper water (Tassan, 1997).

2. Glossary of terms / definitions

a. Classification of water types

Case 1 waters contain phytoplankton particles (phytoplankton and bacterial plankton) and associated detrital material and coloured dissolved organic matter (CDOM) which are well correlated with concentrations of chlorophyll. Open oceans are typical examples of case 1 waters.

Case 2 waters the optical properties are influenced not only by phytoplankton and related particles, but also by other substances such as CDOM or suspended sediments, that can vary independently from phytoplankton. Typically, Case 2 waters are coastal zones and inland seas.

b. Apparent and inherent optical properties (AOP and IOP)

Apparent Optical Properties (AOP): Properties that depend both on inherent optical properties (IOPs) and on the light field in which they are measured. Reflectance, radiance and irradiance belong to this group. AOPs are measured in situ, or in the field. These properties will vary slightly with the time of day the measurements are taken, because they are dependent on the intensity and angle of the sun.

Inherent Optical Properties (IOP): Properties that depend only on the water and other substances that are dissolved or suspended in it. IOPs are often measured in the laboratory do not depend on the presence of sunlight under water. The two fundamental IOPs are absorption (a) and the Volume Scattering Function (ß). Others commonly derived from these include the total scattering coefficient (b), backscattering coefficient (b_b), and beam attenuation coefficient ($c = a + b$).

3. Overview of algorithms

Many researchers have tried to derive total suspended matter from remotely sensed data. Algorithms are empirically, semi-empirically derived or based on an analytical method.

a. Empirical relations

The empirical approach is based on a statistical calibration relationship between spectral data, expressed as reflectance, radiance or digital numbers (DNs) and SPM. Literature review on empirical algorithms revealed a large variety of algorithms used. A number of these empirical relations are listed in table 1.

Table 1 *: Empirical relationships between SPM and reflectance derived for various remote sensing platforms and environments*

Author(s)	Relation	Sensor	Concentrations	Area
Ahn et al , 2005	SPM(g/m³) = 401 5[Rrs(555)]^0 92	Field spectroradiometer	0 2 - 120 g/m³	Korean waters
Forget and Ouillon, 1999	R(0-)= aLog10 SPM + b*	Field spectroradiomer resampled to Landsat		Rhone river
Herut et al , 1999	SPM ~ R(624)/R(534)	Field spectroradiometer	< 50 mg/l	Haifa bay
Kallio et al 2001	SPM ~ Rapp[705-714]	airborne AISA	< 30 mg/l	Finnish lakes
Matthews et al , 2001	SPM = exp(-0 739+0 929[R(618)/(R754)]	airborne CASI	< 24 mg/	Norfolk coast, UK
Matthews et al 2001	SPM = exp(-5 920+3 607[R(618)/(R754)]	airborne CASI	< 90 mg/l	Bristol Channel, UK

*for Landsat TM band 1 a = 8 059 b = 0 947
*for Landsat TM band 2 a = 11 514, b = 0 249
*for Landsat TM band 3 a = 13 977, b =-5 509

As illustrated in table 1 the empirical relationship has been developed for one specific region. Matthews et al. (2001) tested the seasonal and geographical portability of empirical algorithms developed for the Bristol channel. The authors concluded that accurate estimations of SPM are achievable when applying an algorithm to data collected from the same site later in the year, however the development of a global algorithm was unsuccessful. Scatter plots of reflectance ratios against SPM showed that the 2 optical datasets were clearly different (figure 2).

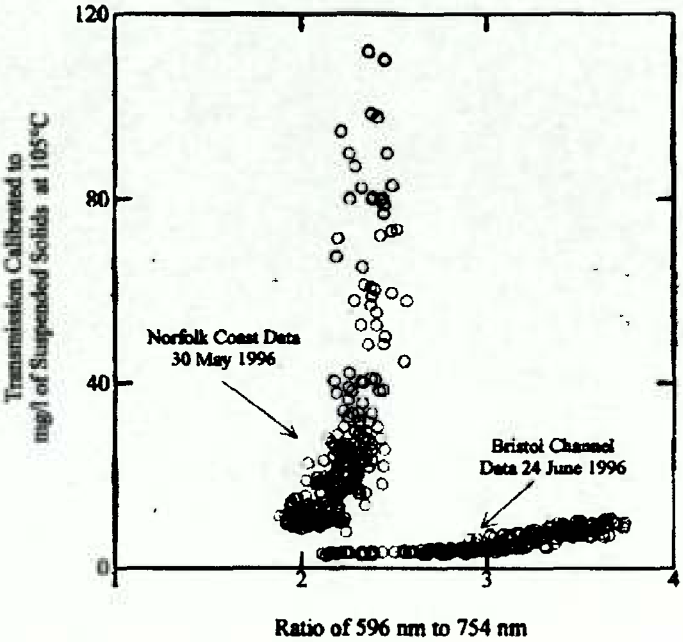

Figure 2 *Scatter plot of transmission data converted to total SPM concentration against a CASI band ratio for data from Bristol Channel and Norfolk coast. The plot shows the diffculty in establishing a global algorithm for these two datasets (taken from Matthews et al., 2001).*

The problem is that variations in particle size and type strongly influence scattering behaviour and thus reflectance and consequently introduce errors in simple empirical algorithms. This is clearly a problem for estuaries where the characteristics of the suspended particles vary depending on the upland basins, river discharge, tidal cycles and floculation processes.

b. Semi-empirical relationships

In semi-empirical methods the spectral characteristics of the parameters of interest are known. This knowledge can be included in the statistical analysis by focusing on well chosen spectral bands or combination of bands (de Haan et al., 1998).

Such a semi-empirical approach has been followed by Doxaran et al. (2002) to show that changes in sediment composition and grain size can be reduced when considering reflectance ratios. They established invariant exponential calibration curves between remote sensing reflectance (Rrs) ratios in SPOT bands (XS3/XS1) or Landsat bands

(L4/L2) and SPM in the range 15 – 2000 mg/l.

On the other hand, the effectiveness of reflectance ratios incorporating NIR wavebands may be limited to extreme turbidity levels (Binding et al., 2005).

Binding et al. (2005) suggested to use prior knowledge of the scattering efficiency of the particles (b^*_{MMS}) to obtain improved accuracy in estimations of mineral suspended sediments (MSS) concentrations from subsurface irradiance reflectance at 665 nm. The variation in the relationship between MSS and R(0-, 665) is illustrated with figure 3. At low scattering efficiencies, the relationship between R_{665} and MSS was linear whilst at higher b_{MSS}*, the relationship appeared to saturate at higher concentrations of MSS.

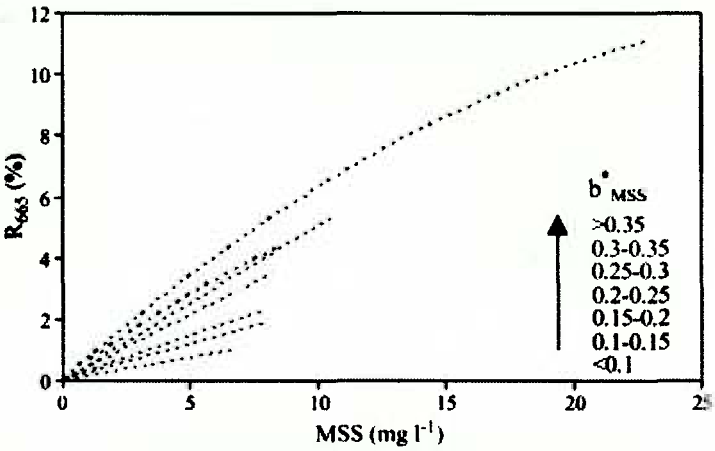

***Figure 3** The varying best-fit relationships between MSS (mg/l) and R_{665} for different categories of b_{MSS}**

To derive the backscattering efficiencies from the reflectance at 715nm for each image pixel Gould et al. (2004) used a near-infrared (NIR) slope algorithm. This NIR algorithm is based on the observation that the total absorption in the 715 – 735 nm wavelength range is controlled by pure water absorption. Furthermore it is assumed that the spectral shape of the (back-)scattering is linear and relatively flat in this narrow NIR wavelength range.

c. Analytical methods

In the analytical approach the water constituent concentrations are physically related to the measured reflectance spectra using sophisticated radiative transfer models (e.g.

Hydrolight) or (semi-)analytical bio-optical models. To determine the water quality parameters (e.g. SPM) these models are inverted through neural networks, matrix inversion (Hakvoort et al., 2001) or curve fitting (Keller, 2001). This approach requires detailed information about the inherent optical properties (IOP) like the absorption and the backscattering coefficients. This is the major drawback of analytical approaches since the various input parameters are often not available.

Several analytical models for water quality retrieval which relate the subsurface irradiance reflectance R(0-) to the water constituent concentrations via their IOPs are given in Dekker et al. (2001). All these models are very similar to an analytical solution given by Aas (1997):

$$R(0-,\lambda) = f \cdot \frac{b_b(\lambda)}{a(\lambda)+b_b(\lambda)} \quad \text{with } f = \frac{1}{1+\overline{\mu_d}(\lambda)/\overline{\mu_u}(\lambda)} \tag{1}$$

with $a(\lambda)$ the spectral total absorption coefficient (m^{-1}), $b_b(\lambda)$ the spectral total backscattering coefficient (m^{-1}) and $\overline{\mu_d}$, $\overline{\mu_u}$ are the average cosines of the downwelling and upwelling light field respectively. In general, the higher the backscattering, the higher the reflectance and the higher the absorption, the lower the reflectance. This model implicitly assumes a homogenous water column (i.e. the IOP are constant over the water depth). The absorption and backscattering coefficients are linear functions of the constituents' concentrations and pure water:

$$a = a_w + a^*_{SPM} * SPM + a^*_{CDOM} * CDOM + a^*_{CHL} * CHL \tag{2}$$

$$b_b = b_{b,w} + b^*_{b,SPM} * SPM + b^*_{b,CHL} * CHL \tag{3}$$

Equation 1 can therefore be written as (omitting the wavelengths):

$$R(0-) = f \cdot \frac{b_{b,w} + b^*_{b,SPM} * SPM + b^*_{b,CHL} * CHL}{a_w + a^*_{SPM} * SPM + a^*_{CDOM} * CDOM + a^*_{CHL} * CHL + b_{b,w} + b^*_{b,SPM} * SPM + b^*_{b,CHL} * CHL}$$

and solved for SPM (assuming no backscattering from CHL):

$$SPM = \frac{f * b_{b,w} - R(0-) * \left[a_w + a^*_{CDOM} * CDOM + a^*_{CHL} * CHL + b_{b,w}\right]}{R(0-) * \left[a^*_{SPM} + b^*_{b,SPM}\right] - f * b^*_{b,SPM}} \tag{5}$$

When neglecting the contribution of yellow substance (CDOM) and phytoplankton pigments Binding et al. (2005) derived the following semi-analytical equation from (4) for the retrieval of Mineral Suspended Sediments (MSS) at 665 nm :

$$\boldsymbol{MSS} = \frac{f * b_{b,w}(665) - R(0-,665) * b_{b,w} - R(0-,665) * a_w}{R(0-,665) * a^*_{SPM}(665) + R(0-,665) * b^*_{b,MSS}(665) - f * b^*_{b,MSS}(665)} \qquad \textbf{(6)}$$

This reflectance model presented by Binding et al. (2005) highlights the dependence of reflectance on $b^*_{b,MSS}$. The authors suggest that the errors in predicted MSS concentrations can be reduced from 56% to as little as 12% with prior knowledge of the scattering properties of the sediments under study.

Using a representative set of inherent optical properties and fixed values for CDOM and CHL van der Woerd and Pasterkamp (2004) derived from equation (5) a single band algorithm (referred to as POWERS algorithm) for suspended matter retrieval in the North Sea :

$$SPM = \frac{0.001 - 0.53 * R(0-,555)}{0.03 * R(0-,555) - 0.0059} \qquad \textbf{(7)}$$

The accuracy of the algorithm was estimated to be between 9% and 27% in areas that can be described by the SIOP dataset. It is clear that error in SPM concentration increases when the difference with the fixed CDOM, CHL values increases. Woerd and Pasterkamp (2004) have chosen the 0.555 □m band based on several considerations: maximal sensitivity for TSM, minimal sensitivity to other constituents like CHL and CDOM, and minimal sensitivity to inaccuracies in atmospheric correction.

An important problem when using model (1) in Case 2 waters is the fact that the f-factor is not constant and can very in time and location. A new parameterization of the irradiance reflectance has therefore been developed by Albert and Mobley (2003). Their analytical model not only uses the IOP of the water as input, but also the solar zenith angle, the viewing angle are the surface wind speed considered.

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Annex B – Scenario field and airborne campaign

MEETCAMPAGNE IN HET KADER VAN HET "ORMES"-PROJECT ACHTERGRONDINFORMATIE EN DRAAIBOEK VAN DE VELDCAMPAGNE

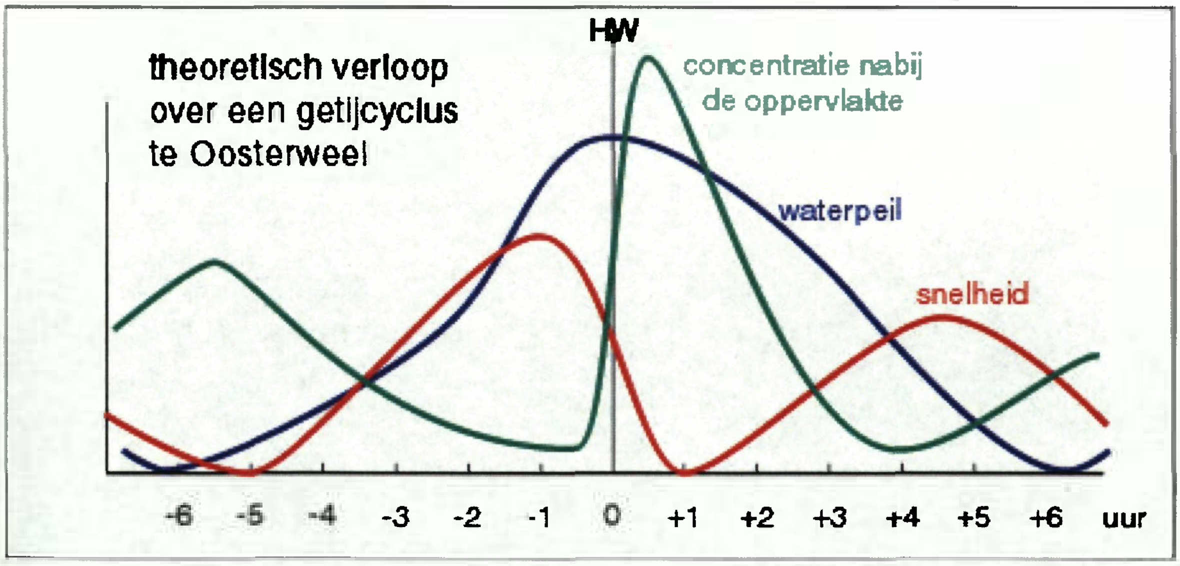
1. Achtergrondinformatie : doel en principe van de metingen

Er wordt een simultane meting georganiseerd waarbij tijdens het uitvoeren van hyperspectrale vliegtuigregistraties grondwaarheid wordt verzameld m.b.t. het zwevend sedimentgehalte van het water nabij de oppervlakte in de Schelde afwaarts van Antwerpen en in enkele havendokken.

Deze informatie en instructies zijn bedoeld voor de grondploegen (wal en schip).

De metingen aan de grond dienen zoveel mogelijk simultaan te gebeuren met de overtochten van het vliegtuig.

Het vliegtuig verricht drie opnamen gespreid over het middendeel van een dag in juni 2005. Gehoopt wordt zoveel mogelijk variatie in het zwevend sedimentgehalte te registreren, zowel in ruimte als in tijd. De ruimtelijke variatie van het zwevend sedimentgehalte is vrij onbekend. De variatie in de tijd gaat samen met het getij, zoals geschetst in onderstaande figuur (deze toont een theoretisch verloop, dat nog aanzienlijk kan afwijken van de werkelijkheid).



De figuur is gegeven t.o.v. lokaal hoogwater (HW) te Antwerpen. Het tijdstip van HW verandert van dag tot dag :

In principe wordt de meetcampagne gepland op een woensdag, maar de juiste dag kan gewijzigd worden in functie van de omstandigheden.

BELANGRIJK : in wat volgt en op de dag van meting zal steeds UTC-tijd gebruikt worden. UTC (Coordinated Universal Time) = lokale tijd min 2 uur.

2. Deelnemers aan de meetcampagne

- Algemeen coördinator op de dag van de meetcampagne : Rik Houthuys; gsm : 0496 23 75 30

- Vliegtuig-coördinator : Koen Meuleman, tel. Vito 014 33 68 63, gsm : 0473 72 51 03

- Ploeg 1, meetvlet A : Scheldewacht,
  vertrekpunt : Loodswezen Antwerpen, Tavernierkaai 3, 2000 Antwerpen werkgebied : Schelde tussen Antwerpen en Kallo
  Els Knaeps, GSM 0474/52.79.73
  Koen Trouw, GSM 0472 27 98 72 (Chantal Martens 0485 84 75 85)

- Ploeg 2, meetvlet B : Zwaan,
  vertrekpunt : Haven Dredging: Dredging International, Scheldedijk 30 Haven 1025, Zwijndrecht
  werkgebied : Schelde tussen Kallo en Lillo.
  Sindy Sterckx, gsm: 0496/93 68 66
  Mark Bollen, gsm : 0494 08 72 46 (Johan Melotte 0485 38 80 46)

- Ploeg 3, meetvlet C :Pagadder, vertrekpunt : Kaai 128 Antwerpen
  werkgebied : haven zone Kanaaldok – 6^{e} Havendok, Hansadok
  Rik Houthuys, gsm 0496 23 75 30.

- Vaste meetpunt 1 : werkpunt : Sint-Anna, naam persoon
- Vaste meetpunt 2 : werkpunt : haven Dredging Kallo
- Vaste meetpunt 3 : werkpunt : fort Liefkenshoek
- Vaste meetpunt 4 : werkpunt : fort Lillo

3. Nuttige informatie m.b.t. de vliegtuigmeting

3.1 Hyperspectrale sensor

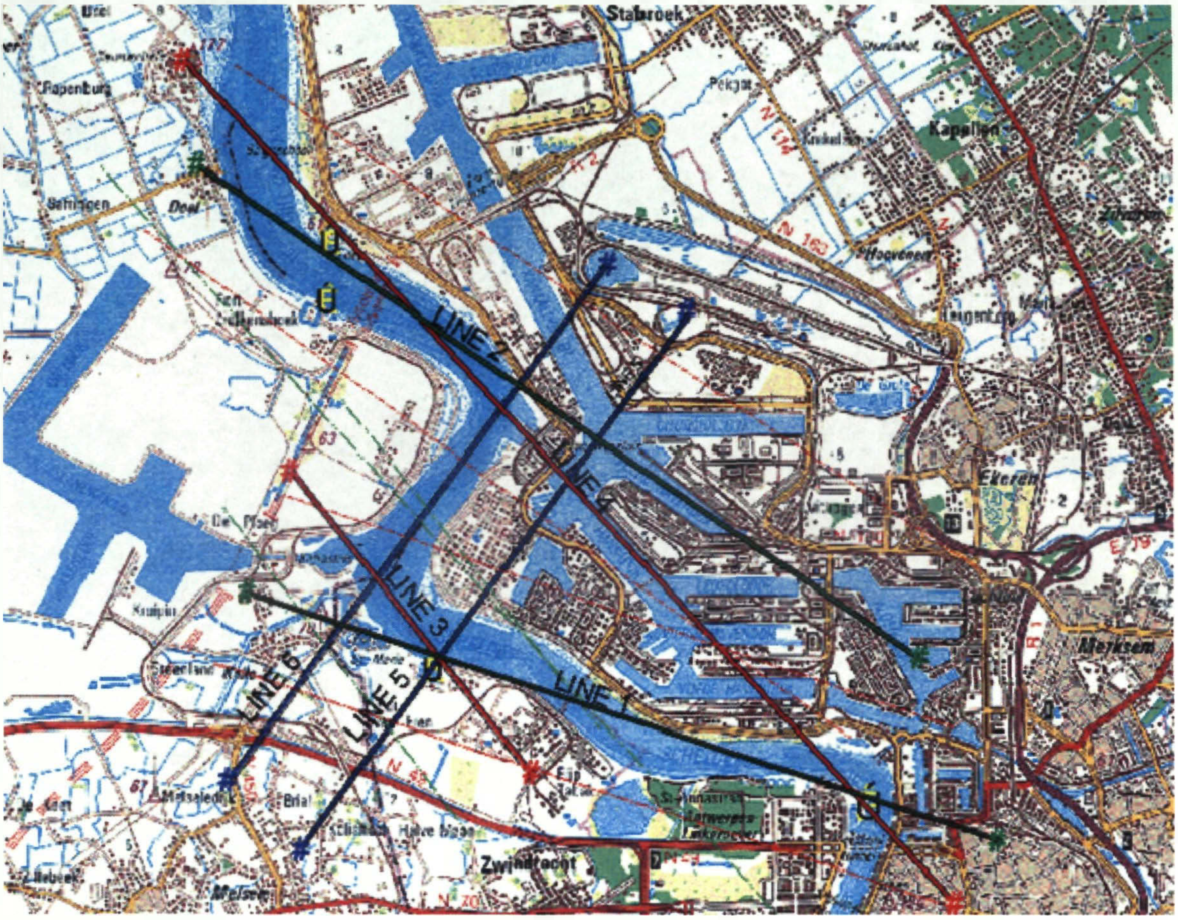
- AHS-160 hyperspectrale vliegtuigscanner on board of CASA 212-200 aircraft

Fig 1: INTA's CASA 212-200 turboprop aircraft

- Specificaties sensor :
  - Scanhoek field of view : 90°
  - Aantal pixels per scanlijn : 750
  - Vlieghoogte :+/- 1372 m
  - Nadir pixel resolutie : +/- 3.4 m
  - Breedte vluchtlijn : +/- 2572 m

3.2 Vluchtplan

De hyperspectrale registraties moeten gebeuren met de zon in de rug, dit om zo weinig mogelijk glinstering op het wateroppervlak in de opnamen te hebben. Daarom werden voor de drie verschillende vluchttijdstippen afzonderlijke vluchtplannen uitgewerkt, in functie van de zonneoriëntatie. Hierdoor is het meetprogramma aan de grond per vluchtonderdeel niet hetzelfde. De lijnen werden ook gekozen in functie van de bemonsteringsmogelijkheden aan de grond. Zie figuur. Er wordt telkens gevlogen van zuid naar noord.



Specificatie acquisitie :

- Lengte lijn 1 : 11 km
- Lengte lijn 2 : 10,4 km
- Lengte lijn 3 : 5,4 km
- Lengte lijn 4 : 15,9 km
- Lengte lijn 5 : 9,3 km
- Lengte lijn 6 : 8,9 km
- Vlieghoogte : 1371 m.
- Grondbedekking : breedte 2572 m.
- Nadir pixel resolutie : 3,43 m
- Vliegsnelheid 140 kts = 259 km/h of 10 km in 2,5 minuut
- Eerste vlucht (start op lijn 1 om **8u45**) : enkel lijn **1** en **2**;
- Tweede vlucht (start op lijn 3 om **9u45**) : enkel lijn **3** en **4**;
- Derde vlucht (start op lijn 5 om **13u00**) : enkel lijn **5** en **6**.

3.3 Vluchtschema

Omdat de schepen veel trager bewegen dan het vliegtuig, wordt ervoor gekozen iedere lijn enkele malen na elkaar te vliegen. Hierdoor kan per overvlucht een andere plaats bemonsterd worden.

Er wordt naar gestreefd dat er zo stipt mogelijk volgens het tijdschema zal worden gevlogen. Afwijkingen zijn mogelijk in functie van de omstandigheden. Indien er geen bericht komt van de coördinator, dient men zich aan het onderstaande tijdschema te houden. Men kan ervan uitgaan dat de vlucht van de hele lijn in een paar minuten uitgevoerd is, dus mag de bemonstering gebeuren ongeveer op het tijdstip van het begin van de vlucht.

- Sequentie 1 : 2 vluchten met elk twee passages aaneensluitend :

    - Passage SPOT-satelliet om **8u30**

    - Vlucht 1 : lijn 1 **start 8u45**
      draaimanoeuvre
      lijn 2 **start 9u00**
      draaimanoeuvre
      lijn 1 **start 9u15**
      draaimanoeuvre
      lijn 2 **start 9u30**
      duur lijn 1 : 2,5 min.; duur lijn 2 : 2,4 min.

    - Vlucht 2 : lijn 3 **start 9u45**
      draaimanoeuvre
      lijn 4 **start 10u00**
      draaimanoeuvre
      lijn 3 **start 10u15**
      draaimanoeuvre
      lijn 4 **start 10u30**
      duur lijn 3 : 1,2 min.; duur lijn 4 : 3,7 min.

- Pauze met tussenlanding in Deurne. Tijdens de pauze gebeuren ijkingsmetingen op de meetvletten.

- Sequentie 2 : één vlucht met drie passages :
    - Vlucht 3 : lijn 5 **start 13u00**
      draaimanoeuvre
      lijn 6 **start 13u15**
      draaimanoeuvre
      lijn 5 **start 13u30**
      draaimanoeuvre
      lijn 6 **start 13u45**
      draaimanoeuvre
      lijn 5 **start 14u00**
      draaimanoeuvre
      lijn 6 **start 14u15**
      duur lijn 5 : 2,1 min.; duur lijn 6 : 2,1 min.

4. Materiaal

Meetvlet A

- Turbiditeitsmeter IMDC
- GER-1500 spectrometer + laptop + spectralon + statief (Vito)
- Verlengkabel (Vito)
- Stokjes om te roeren
- Digitaal fototoestel : Vito
- 2 emmers met elk 6 m touw Vito
- Pompinstallatie voor waterbemonstering in diepte
- Bemonsteringsflessen (Vito) :
    - 1of 2-liter plastiek flessen : 50 stuks (vooraf nummeren A1 ..A50)
    - bruine glazen flessen : 10 stuks (vooraf nummeren A51… A60)
- Koelbox (voor chlorofylstalen en helft 2 liter flessen) (Vito)
- 2 alcoholstiften (Vito)
- Handheld GPS-toestel : (Vito)
- Formulier 1 : 10 exemplaren (Vito)
- Fact sheet meetvlet A (Vito)

Meetvlet B

- Turbiditeitsmeter IMDC
- ASD spectrometer (Vito) + spectralon panel + gradenboog + statief
- Verlengkabel (Vito)
- Stokje om te roeren
- Digitaal fototoestel : Vito
- 2 emmers met elk 6 m touw Vito
- Niskin Fles IMDC
- Bemonsteringsflessen (Vito):
  - 1 of 2-liter plastiek flessen : 55 stuks (vooraf nummeren B1 ..B55)
  - bruine glazen flessen : 10 stuks (vooraf nummeren B56… B66)
- Koelbox (voor chlorofylstalen en helft 2 liter flessen) (Vito)
- 2 alcoholstiften (Vito)
- Handheld GPS-toestel (Vito)
- Formulier 1 : 10 exemplaren (Vito)
- Fact sheet meetvlet B (Vito)

Meetvlet C

- Digitaal fototoestel : Rik
- Turbiditeitsmeter RCM-9
- Stokje om te roeren
- 2 emmers met elk 6 m touw Vito
- Bemonsteringsflessen (Vito):
  - 1 of 2-liter plastiek flessen : 41 stuks (vooraf nummeren C1 ... C41)
  - bruine glazen flessen : 10 stuks (vooraf nummeren C42… C51)
- Koelbox (voor chlorofylstalen en helft 2 liter flessen) (Vito)
- 2 alcoholstiften Vito
- Handheld GPS-toestel (IMDC)
- Formulier 1 : 10 exemplaren (Vito)
- Factsheet meetvlet C (Vito)

Walpost 1 : ponton Sint-Anna

- Digitaal fototoestel : (indien mogelijk)
- 2 emmers met elk 6 m touw Vito
- Stokje om te roeren

- Plastiek bemonsteringsflessen 1 liter : 40 (vooraf nummeren S1 .. S40)
- 2 alcoholstiften Vito
- Formulier 2 : 6 exemplaren (Vito)
- GSM
- Factsheet meetvlet Sint-Anna

Walpost 2 : ponton haven Dredging

- Digitaal fototoestel : (indien mogelijk)
- Stokje om te roeren
- 2 emmers met elk 6 m touw Vito
- Plastiek bemonsteringsflessen 1 liter : 30 (Vito) (vooraf nummeren D1 .. D30)
- 2 alcoholstiften Vito
- GSM met nummer 0473/73.18.63 (GSM te bevragen secretariaat TAP)
- **Microtops sunphotometer**
- **Helm en reddingsvest**
- Formulier 2 : 6 exemplaren (Vito)
- Factsheet meetvlet Dredging Kallo

Walpost 3 : steiger aan fort Liefkenshoek

- Digitaal fototoestel : (indien mogelijk)
- 2 emmers met elk 12 m touw Vito
- Stokje om te roeren
- Plastiek bemonsteringsflessen 1 liter :
    - 20 (Vito) (vooraf nummeren H1 .. H20)
- 2 alcoholstiften Vito
- GSM
- Formulier 2 : 6 exemplaren (Vito)
- Factsheet meetvlet Liefkenshoek

Walpost 4 : loopbrug en ponton aan fort Lillo

- Digitaal fototoestel : (indien mogelijk)
- 2 emmers met elk 12 m touw Vito
- Stokje om te roeren
- Plastiek bemonsteringsflessen 1 liter :
    - 40 (Vito) (vooraf nummeren L1 .. L40)

- 2 alcoholstiften Vito
- GSM
- Formulier 2 : 6 exemplaren (Vito)
- Factsheet meetvlet Fort Lillo

5. Werkschema

5.1 Werkterrein van de meetvletten

5.1.1 *SCENARIO A: alle boten beschikbaar*

Er worden twee meetvletten ingezet op de Schelde en een in de havendokken.

Werkterrein **meetvlet A** op de Schelde :

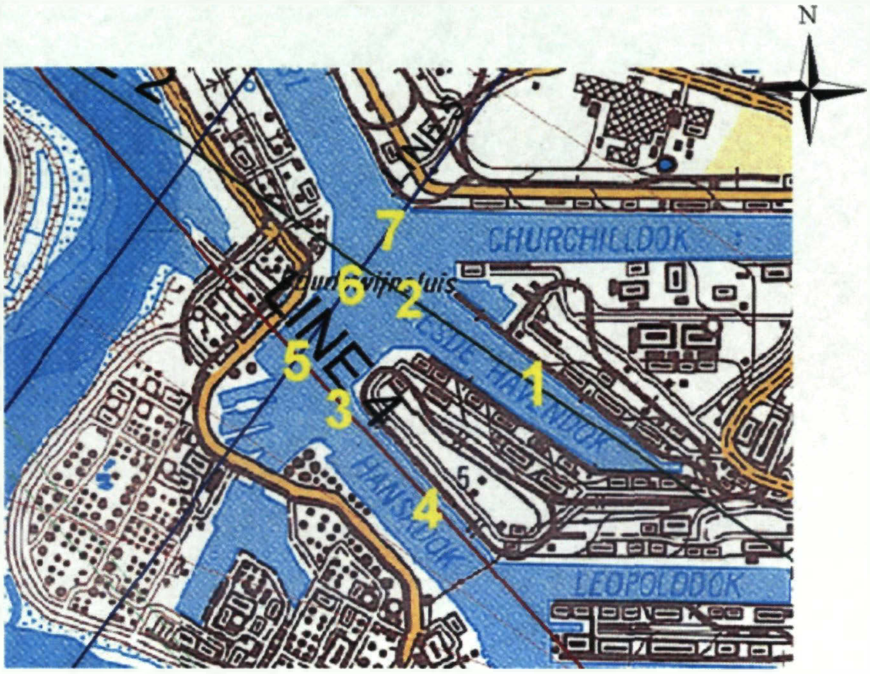
- vertrekpunt : Loodswezen Tavernierkaai 3 Antwerpen............
- werkterrein : Schelde tussen Antwerpen centrum en Kallo
- de bemonsteringsplaatsen variëren in functie van de vluchtlijn, zie plan en werkschema

Werkterrein **meetvlet B** op de Schelde :

- vertrekpunt : Haven Dredging International, Haven 1025 Zwijndrecht............
- werkterrein : Schelde tussen Kallo en Lillo
- de bemonsteringsplaatsen variëren in functie van de vluchtlijn, zie plan en werkschema

Werkterrein **meetvlet C** in de dokken :

- vertrekpunt : Kaai 128 Antwerpen
- werkterrein : 6^{e} Havendok, Handelsdok, Hansadok
- de bemonsteringsplaatsen variëren in functie van de vluchtlijn, zie plan en werkschema



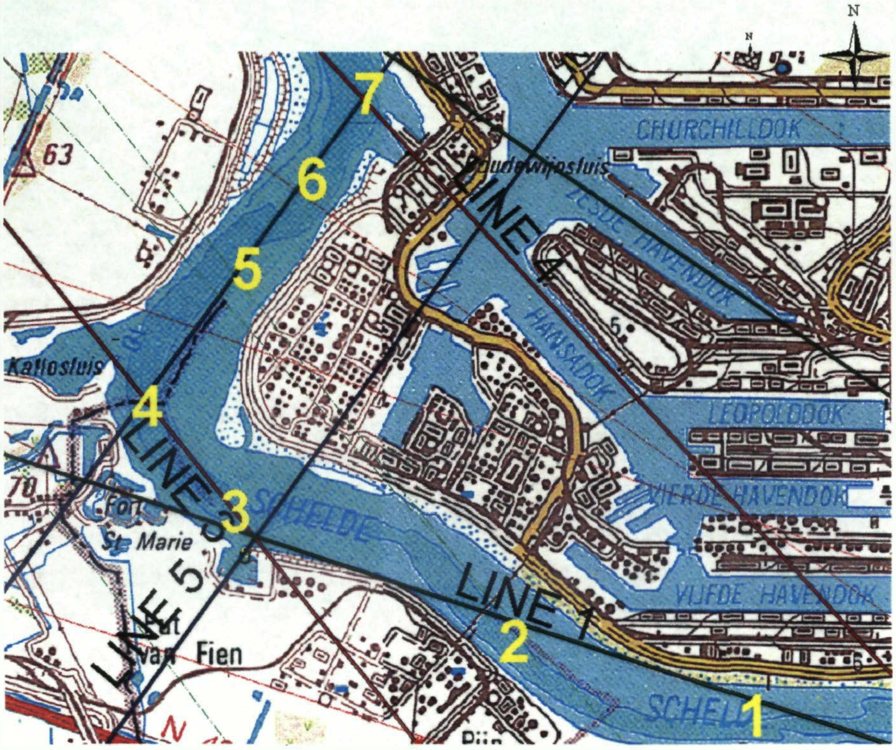
Er dient zo mogelijk gevaren te worden (per vlucht) in dezelfde richting als de vlucht.

5.1.2 *SCENARIO B: slechts 2 boten beschikbaar*

In scenario B valt boot B weg. Boot C in de haven zal hetzelfde schema volgen en boot A zal meer naar het noorden opschuiven.

Werkterrein **meetvlet A** op de Schelde :

- vertrekpunt : afhankelijk van welke boot beschikbaar is.
- werkterrein : Schelde tussen Antwerpen centrum en Kallo
- de bemonsteringsplaatsen variëren in functie van de vluchtlijn, zie plan en werkschema



5.2 Algemene instructies voor de metingen op de meetvletten

- Om 6u30 worden alle klokken afgestemd op GPS time (in UTM)
- Schip ligt stil tijdens metingen.
- Iedere vlucht bevat twee, de laatste vlucht drie overvluchten.
- De overvluchten hebben per locatie een halfuur interval.
- Het algemeen schema voorziet een meting een kwartier vóór de eerste vlucht (deze meting is tevens een referentie voor de SPOT-satellietopname), een meting tijdens de overvlucht, en dan telkens een tussenmeting en een meting tijdens de volgende overvlucht; dus een meting om het kwartier.
- In de ruime middagpauze worden kalibratiemetingen gedaan. Deze kunnen vrij gepland worden in functie van het getij en de sedimentconcentratie.

Een meting omvat :

- verticaal profiel met turbiditeitsmeter (1 persoon IMDC)

- bemonstering oppervlaktewater met emmer : zie gedetailleerde beschrijving factsheets
- plaatsbepaling GPS in UTM (lid van de bemanning)
- spectrale meting (2 personen Vito)
- foto's wateroppervlak horizontaal, wateroppervlak verticaal, hemel verticaal
- notities op formulier 1

Op de meetvlet in de haven worden geen OBS of spectrale metingen gedaan.

Gepland aantal staalnames per Meetvlet :

- meetvlet A :
  - 44 1 of 2-liter flessen : op 22 tijdstippen, 2 stalen , 1 aan elke zijde (optioneel)
  - 8 glazen flessen (Chlorofyl): op 4 tijdstippen, 1 zijde voldoende, iedere keer 2 flessen vullen
- meetvlet B :
  - 48 1 of 2-liter flessen : op 24 tijdstippen, 2 stalen , 1 aan elke zijde (optioneel)
  - 8 glazen flessen (Chlorofyl): op 4 tijdstippen, 1 zijde voldoende, iedere keer 2 flessen vullen
- meetvlet C :
  - 38 1of 2-liter flessen: op 19 tijdstippen, 2 stalen , 1 aan elke zijde (optioneel)
  - 4 glazen flessen (Chlorofyl) : op 4 tijdstippen, 1 zijde voldoende, iedere keer 2 flessen vullen

Van de testmeting hoeft geen staal bewaard te worden.

5.3 Meetschema

Tijd in UTC	Vlucht	Vlet A	Vlet B	Vlet C	wal Sint-Anna	wal haven Dredging	wal fort Liefkens-hoek	wal fort Lillo
06u30		KLOKKEN!! Instructies + test	KLOKKEN!! Instructies + test	KLOKKEN!! Instructies + test				
07u15		afvaart	afvaart	afvaart				
onmiddellijk na afvaart		test : volledige sequentie	test : volledige sequentie	test : staalname				
		varen richting punt A1	varen richting punt B1	varen richting punt C1	test : staalname	test : staalname	test : staalname	test : staalname
08u20	SPOT	meting 1	meting 1	staalname	staalname	staalname	staalname	staalname
08u30	SPOT	meting 2 + 2Chl + 1l	meting 2 + 2Chl + 1l	staalname	staalname	staalname	staalname	staalname
08u45	lijn 1	punt A1 : meting + 2Chl + 1l	tussenmeting	staalname	staalname	staalname		
09u00	lijn 2	tussenmeting	punt B1 : meting + 2Chl + 1l	punt C1 : staalname + 2Chl + 1l			staalname	staalname
09u15	lijn 1	punt A2 : meting	tussenmeting	staalname	staalname	staalname		
09u30	lijn 2	tussenmeting	punt B2 : meting	punt C2 : staalname			staalname	staalname
9u45	lijn 3	punt A3 : meting +2 Chl + 1l	tussenmeting	staalname		staalname		
0u00	lijn 4	tussenmeting	punt B3 : meting + 2Chl + 1l	punt C3 : staalname	staalname		staalname	staalname
0u15	lijn 3	punt A4 : meting	tussenmeting	staalname		staalname		
0u30	lijn 4	tussenmeting	punt B4 : meting	punt C4 :	staalname		staalname	staalname
10u45			tussenmeting	staalname	(einde)		(einde)	(einde)
pauze		(pauze)	(pauze)					
11u30		kalibratiemetingen	kalibratiemetingen					
11u45		kalibratiemetingen	kalibratiemetingen					
12u00		kalibratiemetingen	kalibratiemetingen					
12u15		kalibratiemetingen	kalibratiemetingen					
12u30		kalibratiemetingen	kalibratiemetingen					
12u45		tussenmeting		staalname				
13u00	lijn 5	punt A5 : meting +2 Chl + 1l	tussenmeting	punt C5 : staalname + 2Chl + 1l		staalname		
13u15	lijn 6	tussenmeting	punt B5 : meting + 2Chl + 1l	staalname				
13u30	lijn 5	punt A6 : meting	tussenmeting	punt C6 : staalname		staalname		
13u45	lijn 6	tussenmeting	punt B6 : meting	staalname				
14u00	lijn 5	punt A5 : meting	tussenmeting	punt C7 : staalname		staalname		
14u15	lijn 6	tussenmeting	punt B7 : meting	staalname		(einde)		
14u30			tussenmeting					
		terugvaart	terugvaart	terugvaart				

Voor meer gedetailleerde informatie, kunnen de factsheets geraadpleegd worden.

6. Meting op de walpunten

6.1 Ligging van de vaste punten en routebeschrijving

Punt 1 : ponton opwaarts van het strand Sint-Anna

- Routebeschrijving : op Linkeroever Sint-Anna in de richting van de Schelde rijden tegenover het stadscentrum. Volg de weg parallel met de Schelde, de Thonetlaan, naar het noorden. Tweede afslag rechts voorbij de jachthaven (Jachthavenweg) tot parking bij Taverne De Molen.
- Meetpositie : op ponton op noordelijk uiteinde. Neem het staal aan de noordoosthoek van het ponton, dus aan de kant van de open Schelde.

Hier moet alleen een staal genomen worden bij de SPOT-passage en bij vluchtlijn 1 en vluchtlijn 4.

Punt 2 : Dredging haven Kallo kaai 1025, ponton

- Routebeschrijving : volg op Linkeroever de aanduidingen van de haven kaai 1025. Rijd het terrein van Dredging op en neem onmiddellijk links, richting Hydrosoil Services. Parkeer voor het gebouw van Hydrosoil Services.

- Meetpositie : op ponton op noordelijk uiteinde. Neem het staal aan de noordoosthoek van het ponton, dus aan de kant van het hoofdgebouw van Dredging.

- Hier moeten stalen genomen worden bij de SPOT-passage en bij de drie vluchten (lijn 1, lijn 3 en lijn 5).

Voorzie een helm en reddingsvest !!! Deze persoon dient zich vooraf aan te melden aan de balie van het hoofdkantoor (hoofdingang).

Punt 3 : fort Liefkenshoek, steiger

- Routebeschrijving : het punt ligt bij het fort Liefkenshoek, even afwaarts de Liefkenshoektunnel. Volg de aanduidingen van de haven, kaai 1972. Rijd aan kaai 1972 door rond de gracht van het fort. Parkeer rechtover de ingang van het fort. Steek de dijk over.
- Meetpositie : aan hoek links van de vaste steiger.

- Hier moet enkel een staal genomen worden bij de SPOT-passage en bij vluchtlijn 2 en 4.

Punt 4 : steiger fort Lillo

- Routebeschrijving : Het punt ligt in het plaatsje lillo, voor het oude fort. Volg A12 richting Rotterdam/Amsterdam. Neem dan R2 richting liefkenshoektunnel. Voor de liefkenshoektunnel, neem afslag naar rechts richting Lillo. Neem expressweg langs Schelde richting lillo en neem afslag lillo (onder groene leidingbrug naar links). Rij tot aan parking en ga richting Schelde

- <u>Meetpositie</u> :
    - (1) halverwege de laatste overspanning van de lange loopbrug;
    - (2) aan zuidhoek van ponton (dus zijde van Antwerpen centrum).

  Neem op het ogenblik van de overvlucht een staal op (2) en loop onmiddellijk naar (1) voor staalname aldaar.

- Hier moet enkel een staal genomen worden bij de SPOT-passage en bij vluchtlijn 2 en 4.

6.2 Werkschema vaste punten

- Op de vier wallocaties worden stalen genomen bij de overvlucht van de SPOT-satelliet en bij elke lokale overvlucht van het meetvliegtuig en 2 min. voor en na overvlucht (achteraf wordt de staal geselecteerd die best aansluit met overvlucht) : zie meetschema.
- Volg het meetschema, tenzij gewijzigde meting gemeld door coördinator.
- Bij stroming : trek de emmer tegen de stroomrichting in. Haal de emmer uit het water en dompel er meteen een staalnamefles in.
- Op de steiger aan het fort Lillo moet er meteen na het staal op het ponton nog een staal genomen worden van op de lange loopbrug.

Bij elke staalname :

- bemonstering oppervlaktewater met emmer + vul literfles + noteer label met volgnummer; neem reservestaal
- eventueel foto's wateroppervlak horizontaal, wateroppervlak verticaal, hemel verticaal

- vul formulier 2 in

7. Verrichtingen de dag na de meting

- Stalen laten analyseren voor zwevend stof gehalte en een aantal voor Chlor. : Vito
- Bepaling specifieke inherente optische eigenschappen (SIOPs) : absorptie, scattering : Vito
- Verwerking GER en ASD gegevens : Vito
- Verwerking turbiditeiten : IMDC

Annex C – Description of field and laboratory measurements

Field campaign

On June 15th, an Advanced Hyperspectral Sensor (AHS) onboard of a CASA 212-200 aircraft was flown over the study area. Simultaneously, a field campaign was carried out in the Scheldt near Antwerp and in some doks.

1. Objectives of the field campaign

Collect ground truth while the hyperspectral sensor is imaging the study area. This ground truth is essential in the modeling, calibration and validation of the airborne data.

2. Measurement locations

Three boats were used at different parts of the Scheldt to include some spatial variability. The first two boats operated in the Scheldt, the third boat operated in the doks.
In addition to the boats, there were four sampling stations at fixed locations. Figure 1 shows the transects of the boats and the locations of the fixed stations.

3. Measurements

On each boat, several measurements were done on predetermined locations at the time the airplane passed over the study area. At each location, the boat stopped several minutes to perform all the measurements. Surface water samples were collected and stored in 1 liter bottles for analyzing total suspended matter concentration. Extra water samples were stored in dark bottles for optical measurements and chlorophyll analysis. They were kept cool during the field campaign. On boats 2 and 3, optical reflectance measurements were carried out simultaneously. GER-1500 and ASD spectoradiometers were used. The GER-1500 measures the radiance signal in the 300 - 1100 nm range with a spectral resolution of 3 nm. The ASD measures the radiance signal in the 350 – 2500 nm range with a spectral resolution of 2 nm.
First, the downwelling irradiance (E_d) was measured using a spectralon reference panel and then the upwelling radiance (L_u) was measured by pointing the sensor at a 40° nadir at the water surface (view zenith $\square_v$ = 40°). It was preferred to measure at an angle of 120-150° with respect to the sun to avoid sun glint effects (view azimuth $\square_v$ = 120-150°). The angle of 40° was used in order to avoid influence by reflection and shading from the

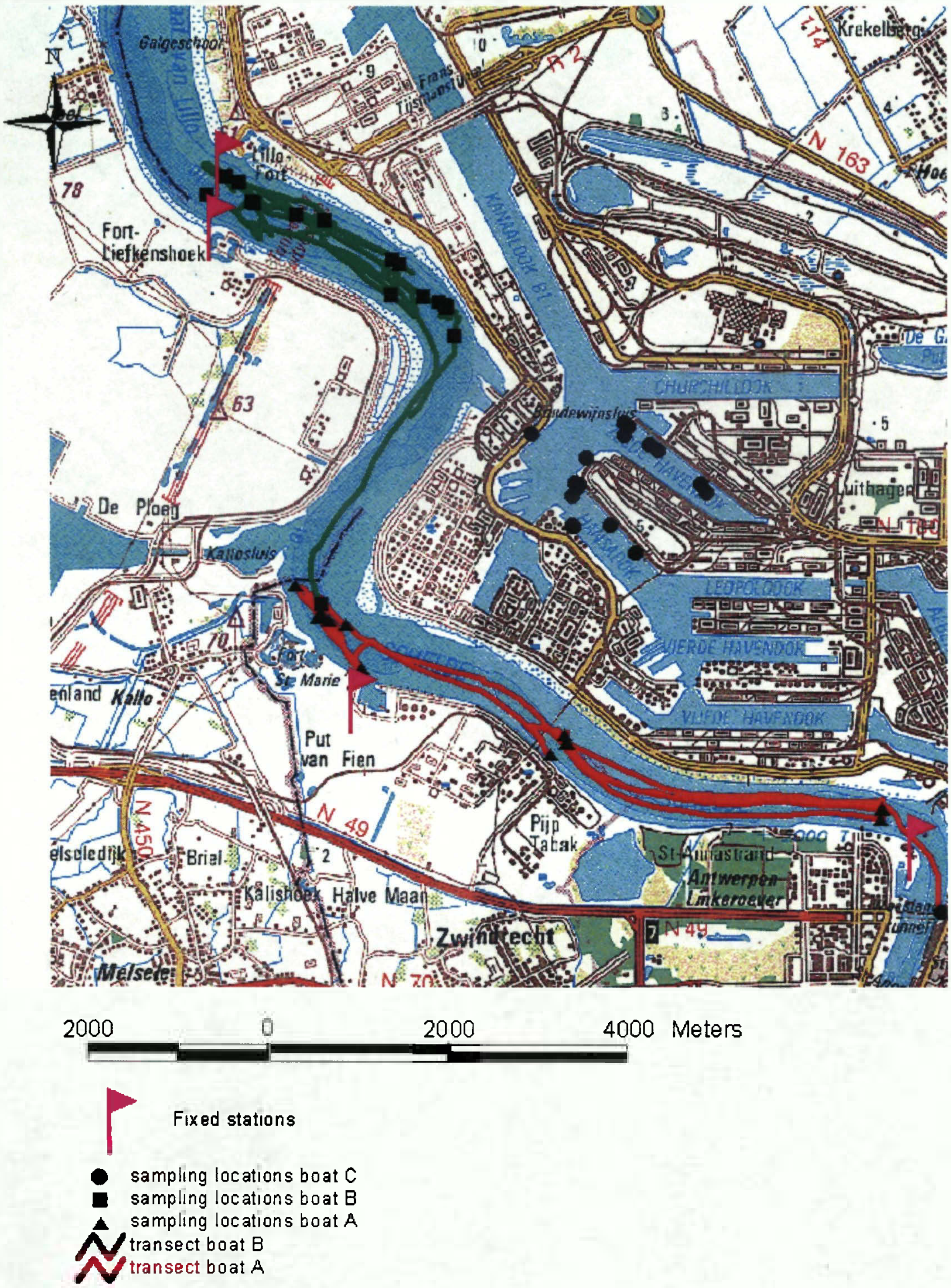


Figure 1: Sampling locations and transects of the boats and location of the fixed stations

boat. Downward radiance of skylight was measured at a zenith angle of 40°. Meanwhile, a turbidity sensor continuously measured turbidity in the surface water layer This instrument detects infrared radiation scattered from suspended matter.

Figure 2: GER-1500 spectrometer measuring downward radiance of skylight at a zenith angle of 40°

On boat A and B, a Trimble GeoXT GPS measured the location of the boats at a logging interval of 60 sec. The exact time (UTC time) was read from the GPS when taking water samples. A Garmin handheld GPS was used at boat C.

Sun-photometric data were measured with a Microtops sunphotometer for estimating the aerosol content and water vapor in the atmosphere to calibrate the radiative transfer model to be used in the atmospheric correction. General atmospheric conditions were registered by taking photos of the air at all the sampling locations of the boats.

Additional calibration measurements were performed at different locations to incorporate some variability. Water samples were taken at several depths using a niskin bottle or a pump installation. The turbidity sensor was used for vertical turbidity profiles. Optical measurements were made when surface water samples were taken.

Figure 3: Turbidity sensor with pump installation attached for taking water samples at different depths

At the fixed stations several surface water samples were simultaneously with the airborne data acquisition. Additional parameters were recorded, including time (UTC), sky coverage, water turbulence and other observations that seemed relevant.

4. Preliminary Evaluation of the field campaign

-Different illumination conditions were encountered during the fieldwork: clear, cirrus clouds in several degrees and some cumulus clouds at the end. The first lines were acquired under the best conditions. Flight lines and fieldwork, scheduled for the afternoon, were cancelled due to the weather conditions.

- Most measurements did not differ more than 3 minutes from the plane overpass.
- The boat was not always at a stable position when taking optical measurements.
- The turbidity sensor on boat B was not measuring continuously due to technical problems

Lab analysis

The water samples were used to measure Chlorophyll concentration, TSM concentration, beam attenuation, absorption by chlorophyll and absorption by TSM.

The determination of absorption by Chlorophyll and TSM was based on methods described by Tassan and Ferrari (1995) and REVAMP protocols (Tilstone *et al.*, 2002). A single beam ASD spectrometer attached to a Licor integrating sphere was used to perform the measurements.

Several days before the field campaign, Scheldt water was filtered trough 0.2 µm filters. This purified Scheldt Water (PSW) was filtered on Whatmann GF/F (0.7 µm pore size) the day after the campaign. These are the reference filters. 250 ml of the water samples was also filtered on Whatmann GF/F. The fraction of a light beam passing through and reflected by the reference filter and the filter retained particle samples was measured with the integrating sphere. Later on, the absorbance on the filter could be derived and could be transformed to give the absorption coefficient in suspension. The samples were bleached with a NaClO solution for 15 minutes resulting in a depigmentation. Chlorophyll absorption could be deduced from transmission and reflection measurements on the depigmented sample.

Figure 4: Licor integrating sphere for measuring reflectance and transmittance from filter retained particle samples

Beam attenuation was measured in a 10 cm cuvet using a single beam Ocean optics spectrometer, referenced against milliQ.

The TSM concentration was determined by filtering 250 ml of the water samples on Whatmann GF/F (0.7 μm pore size) and 0.45 μm membrane filters.

The ASTM (American Society for Testing Materials, 2005), D-3731-87 (1988) standard practice was used for measuring the chlorophyll content of algae in the surface water.

References

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