Deriving Inland/Coastal Water Quality from Hyperspectral Imagery

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HyspIRI science workshop, 2012, Washington DC

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IVM Institute for Environmental Studies

Outline

- Analysis based on APEX data
- Test sites
- Activities:
  - Coral reef mapping /water depth retrieval
  - **Preprocessing of hyperspectral imagery for inland and coastal waters (adjacency)**
  - Wavelet based curve fitting algorithm for water quality retrieval (Chl, CDOM, TSM)
  - **SWIR – and TSM retrieval in turbid waters**

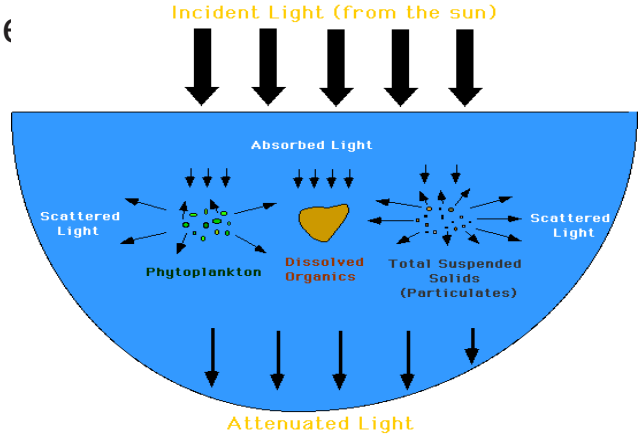
Hyperspectral analysis based on APEX data

- APEX: Airborne Prism Experiment: ESA, VITO, RSL

- Pusbroom imaging spectrometer
  - 28 ° FOV
  - 1000 spatial pixels across-track
  - 380 – 2500 nm
  - Defautlt 114 bands VNIR, 198 SWIR
  - www.apex-esa.org

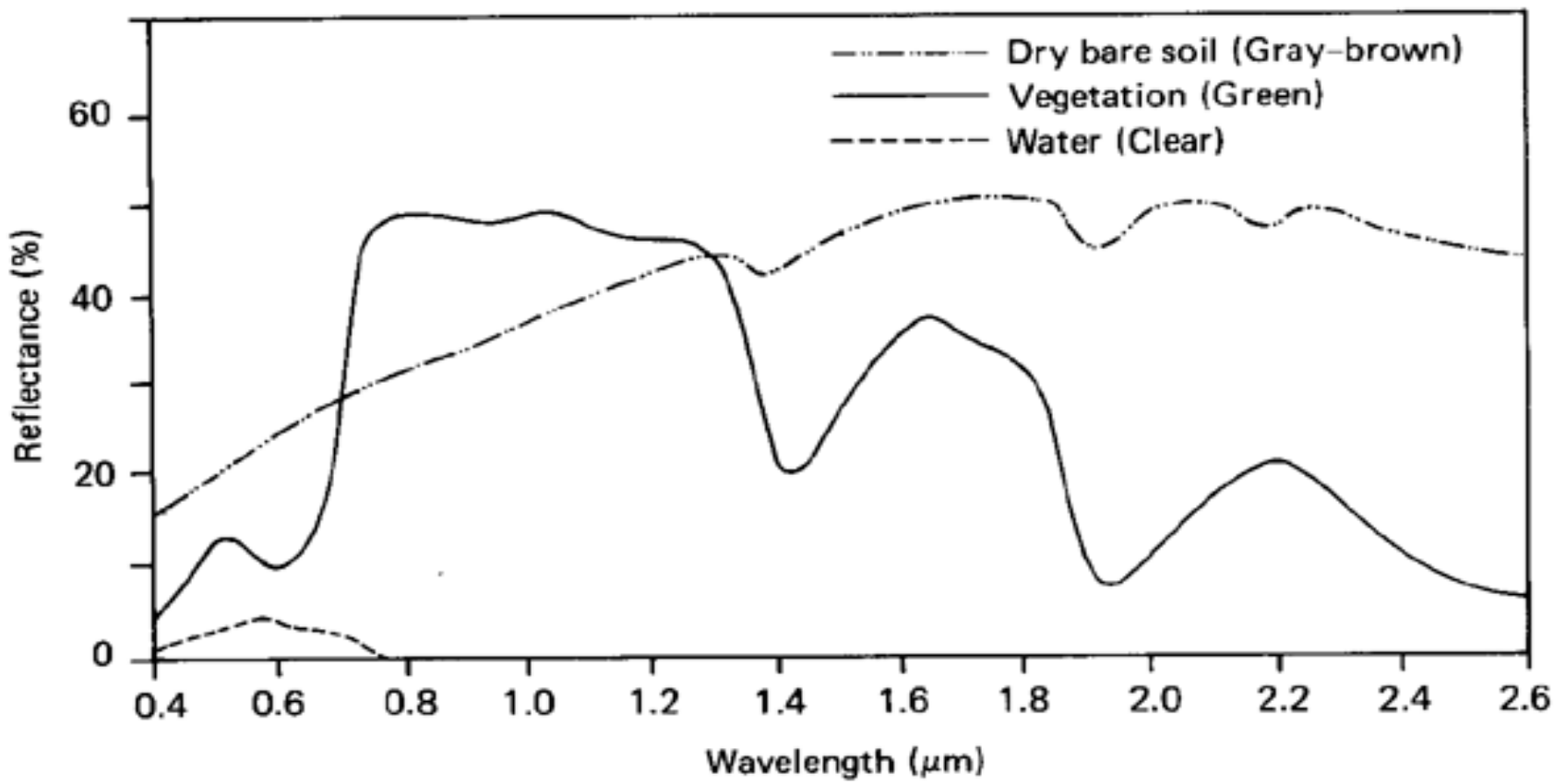
Water quality estimations…

- Water Quality Estimations for coastal and inland waters = complex
  - CHL, TSM, CDOM have combined influence on water reflectance
  - NIR reflectance is often not zero
  - Atmospheric correction is complicated e.g. adjacency e



- APEX vs HyspIRI
  - Spectral range VSWIR !
  - APEX: 380- 2500 nm
  - Hyspiri: 380 to 2500 nm
  - NIR and SWIR particularly interesting for TSM retrieval and atmospheric correction in more turbid coastal waters
  - Low water signal -> SNR of instruments!

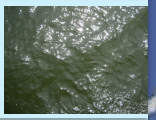
Water quality & relation to APEX and HyspIRI



Our test sites

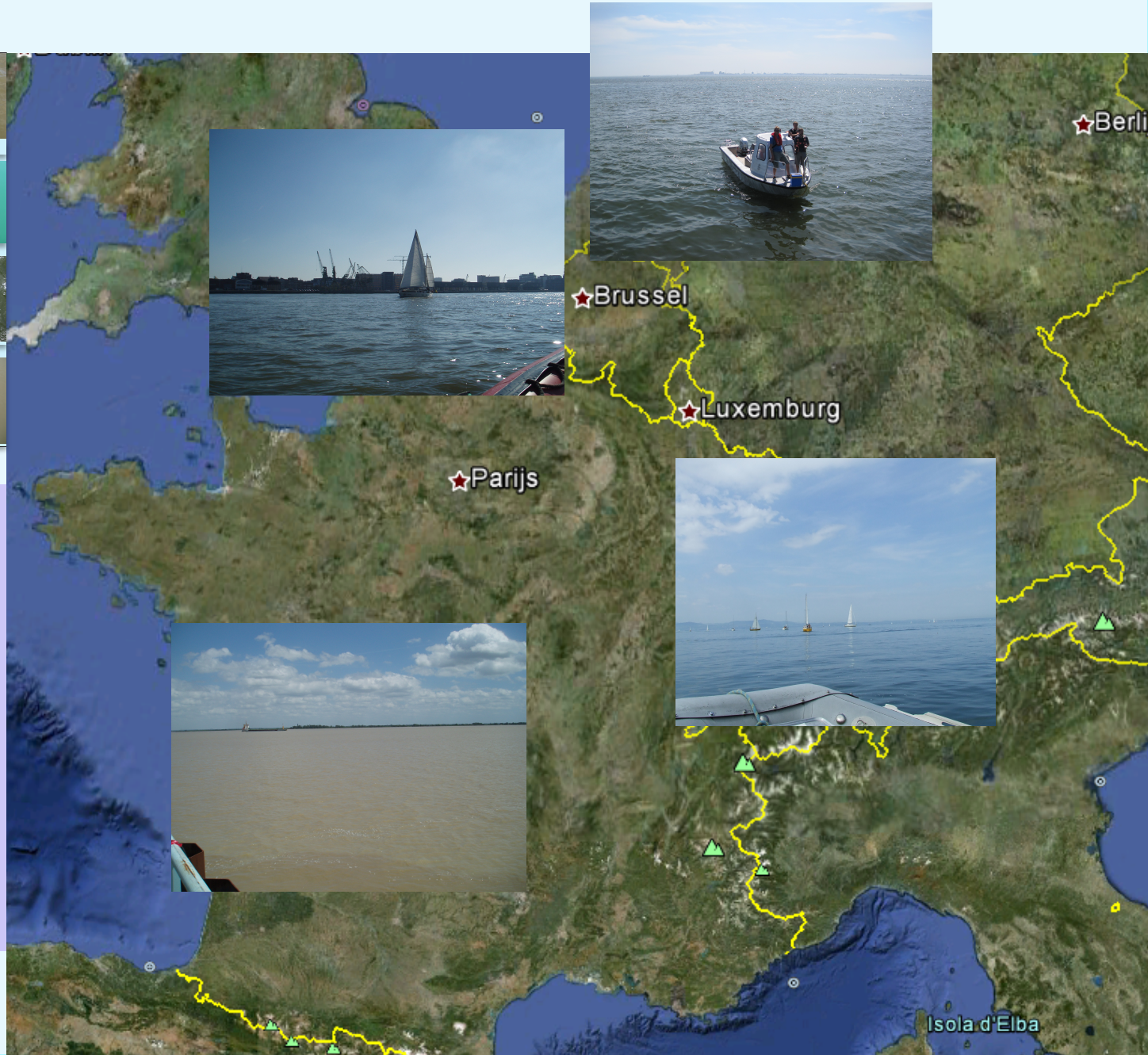
Scheldt 

Lake Constance 

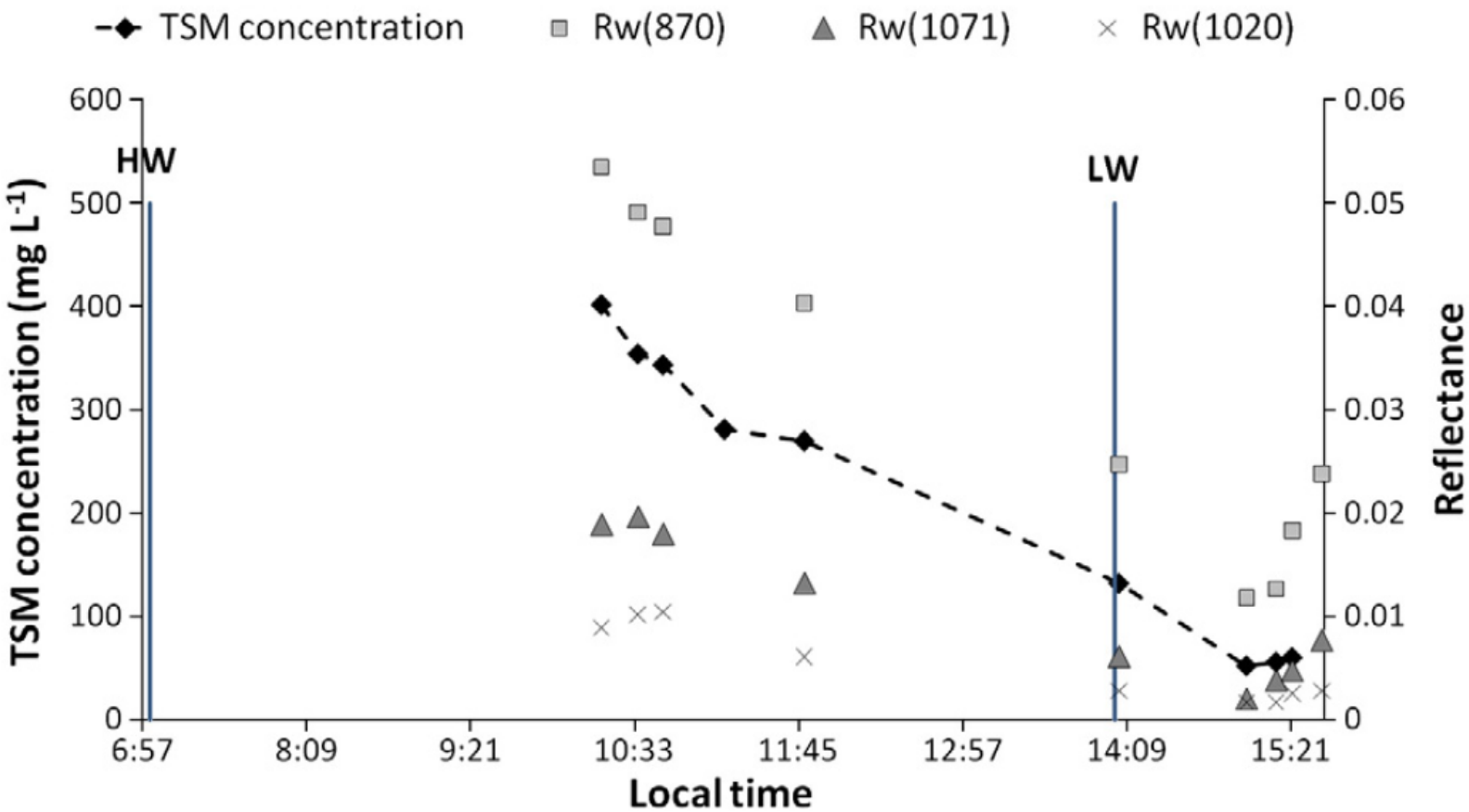
Wadden Sea 

Gironde 

- macrotidal estuary suspended sediments delivered by the Garonne and Dordogne rivers and trapped within the maximum turbidity zone of the estuary.
- TSM from ten to four thousands mg L-1 (Doxaran et al. 2002a, 2002b, 2006, 2009)



Our test sites – Dynamic environments



→ **Match up difficulties**
Need for detailed campaign planning

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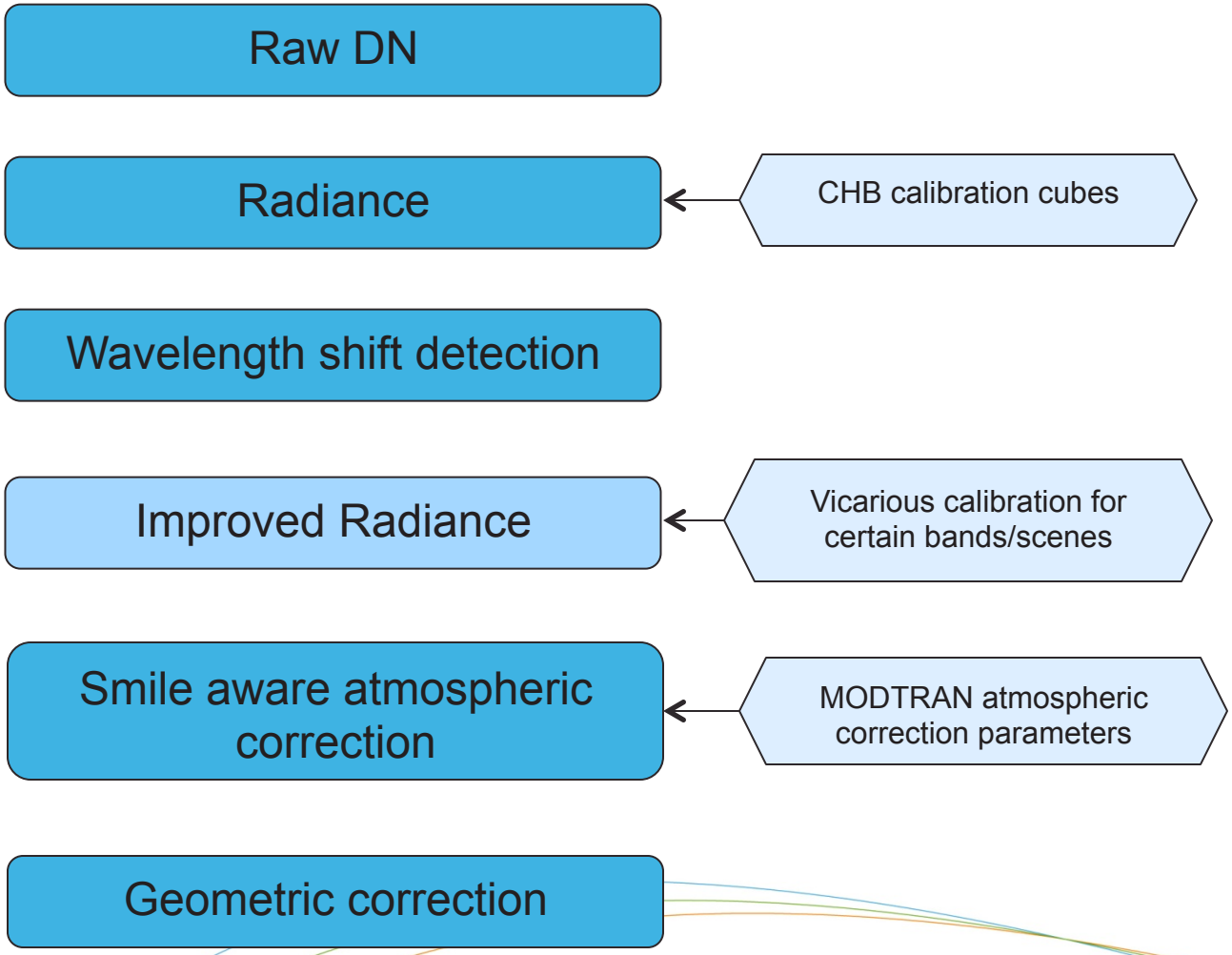
Our test sites – acquired by APEX

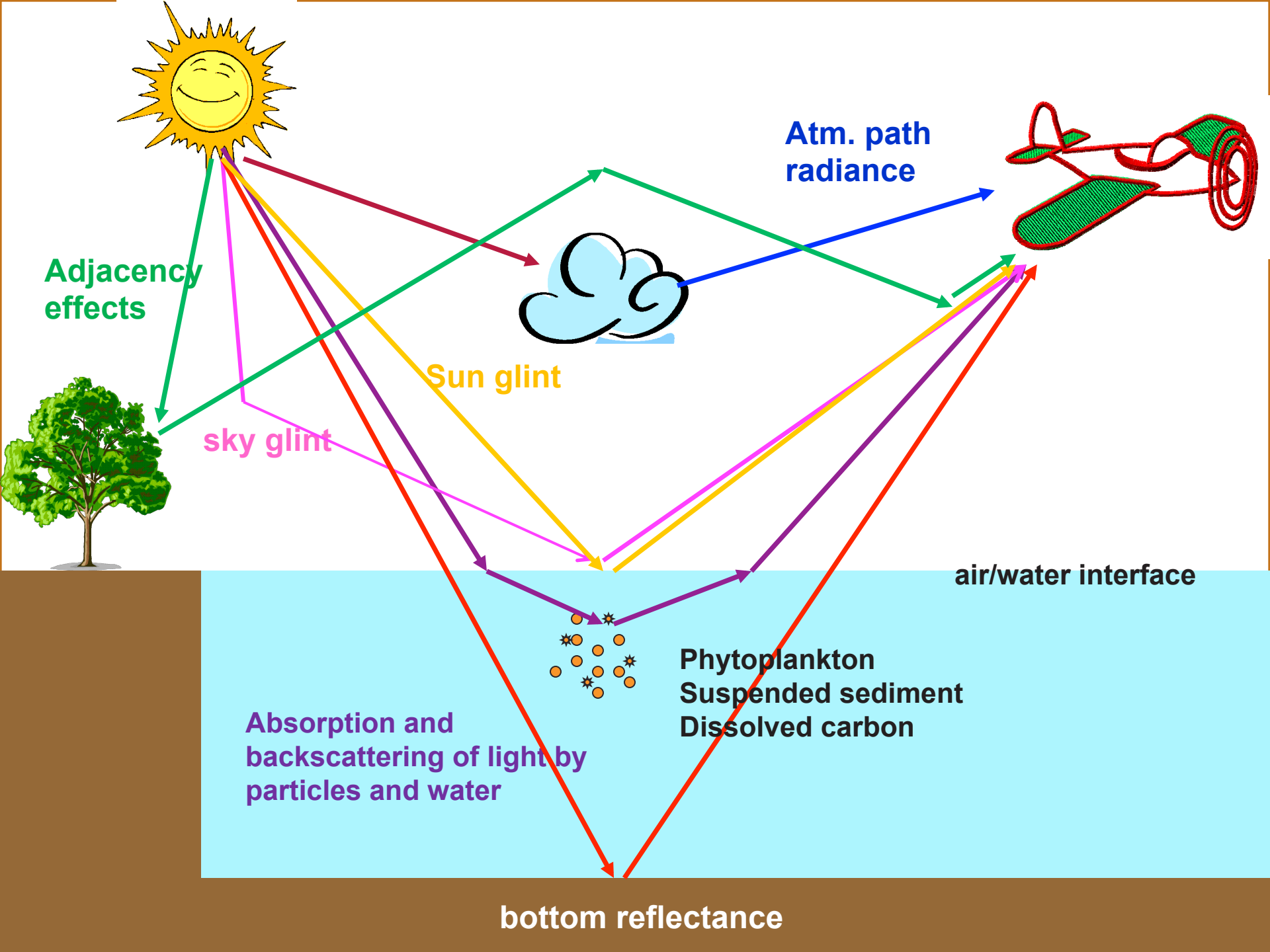
- Preparation of flight lines
  - Low tide constraints
  - Sun Zenith and Azimuth constraints
  - Match up restrictions (e.g. Scheldt 5 min.)

11:00 ->12:00 UTC: 175°

12:00 ->13:00 UTC: 202°

“Pre-Processing” of hyperspectral imagery




Atm. path
radiance
Adjacency
effects
Sun glint
sky glint
air/water interface
Phytoplankton
Suspended sediment
Dissolved carbon
Absorption and
backscattering of light by
particles and water
bottom reflectance

Adjacency correction - SIMEC

A ‘‘similarity’’ NIR reflectance spectrum is defined by normalization at 780 nm (Ruddick *et al.,* 2006).

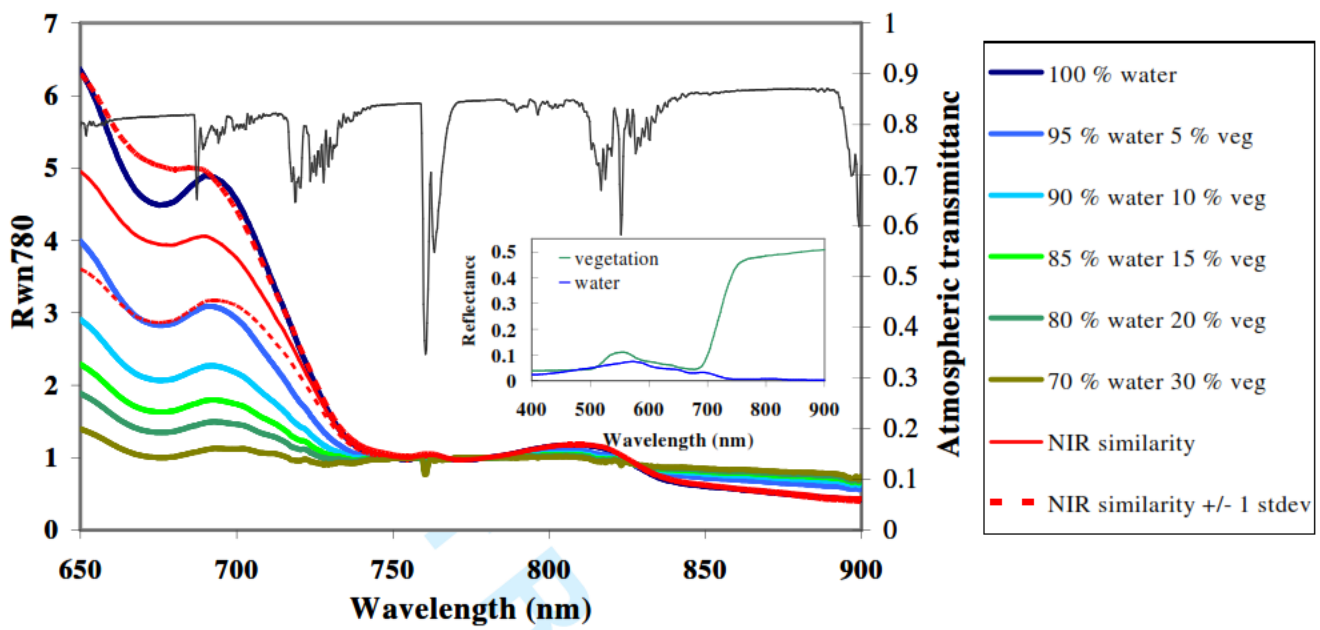


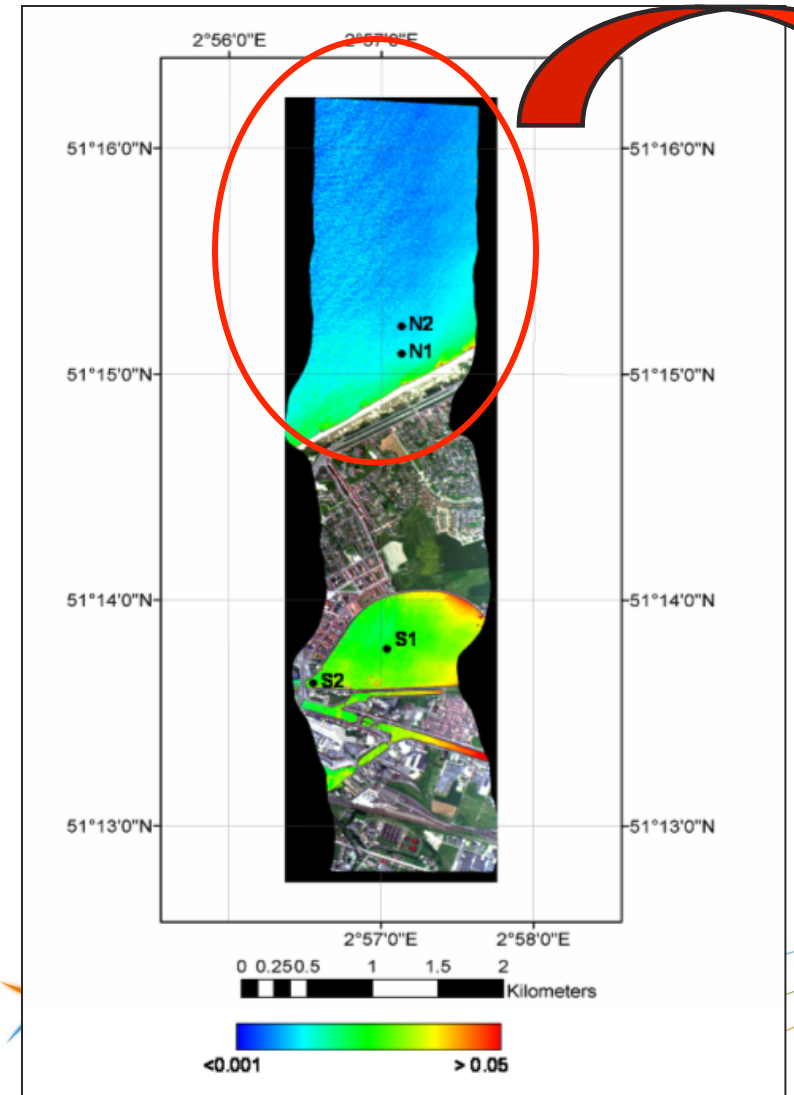
Figure 4. The effect of neglecting adjacency effects on the normalized water leaving reflectance spectra based on Modtran-4 simulations compared to the near-infrared similarity spectrum. Superimposed on the graph is an atmospheric transmittance spectrum to indicate regions of high atmospheric absorption. On the right the input 100 % water and 100 % vegetation reflectance spectra are shown.

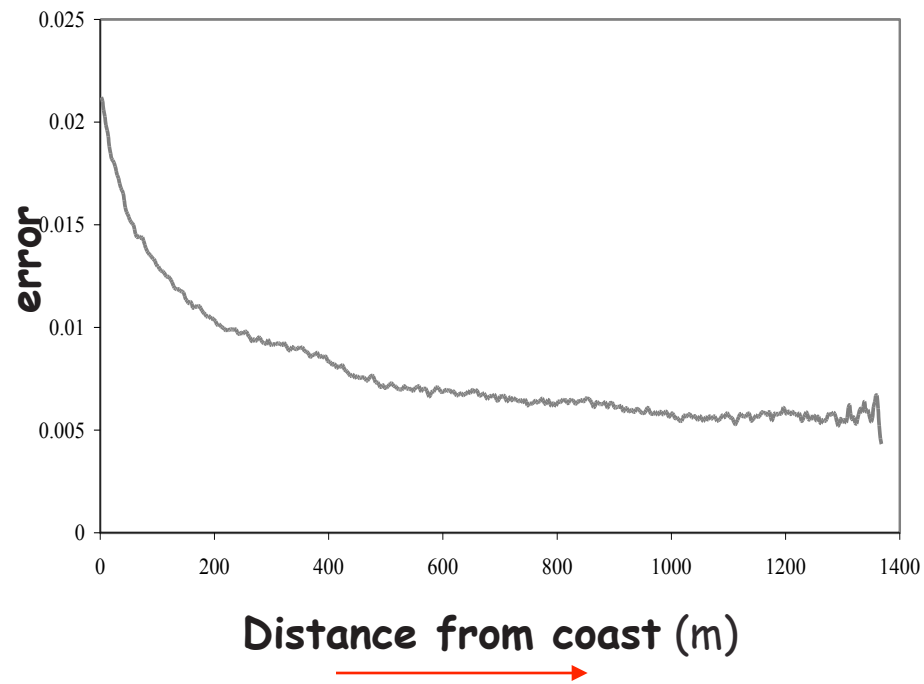
Sterckx, S., E. Knaeps, K. Ruddick, 2011, Detection and Correction of Adjacency Effects in Hyperspectral Airborne Data of Coastal and Inland Waters: the Use of the Near Infrared Similarity Spectrum, *International Journal of REMOTE SENSING*, 32 (21): 6479–6505

Knaeps, E., S. Sterckx, K. Ruddick, C. Giardino, B. Mariano, SIMEC, An Environment Correction For MERIS Based On The NIR Similarity Spectrum, proceedings Ocean Optics

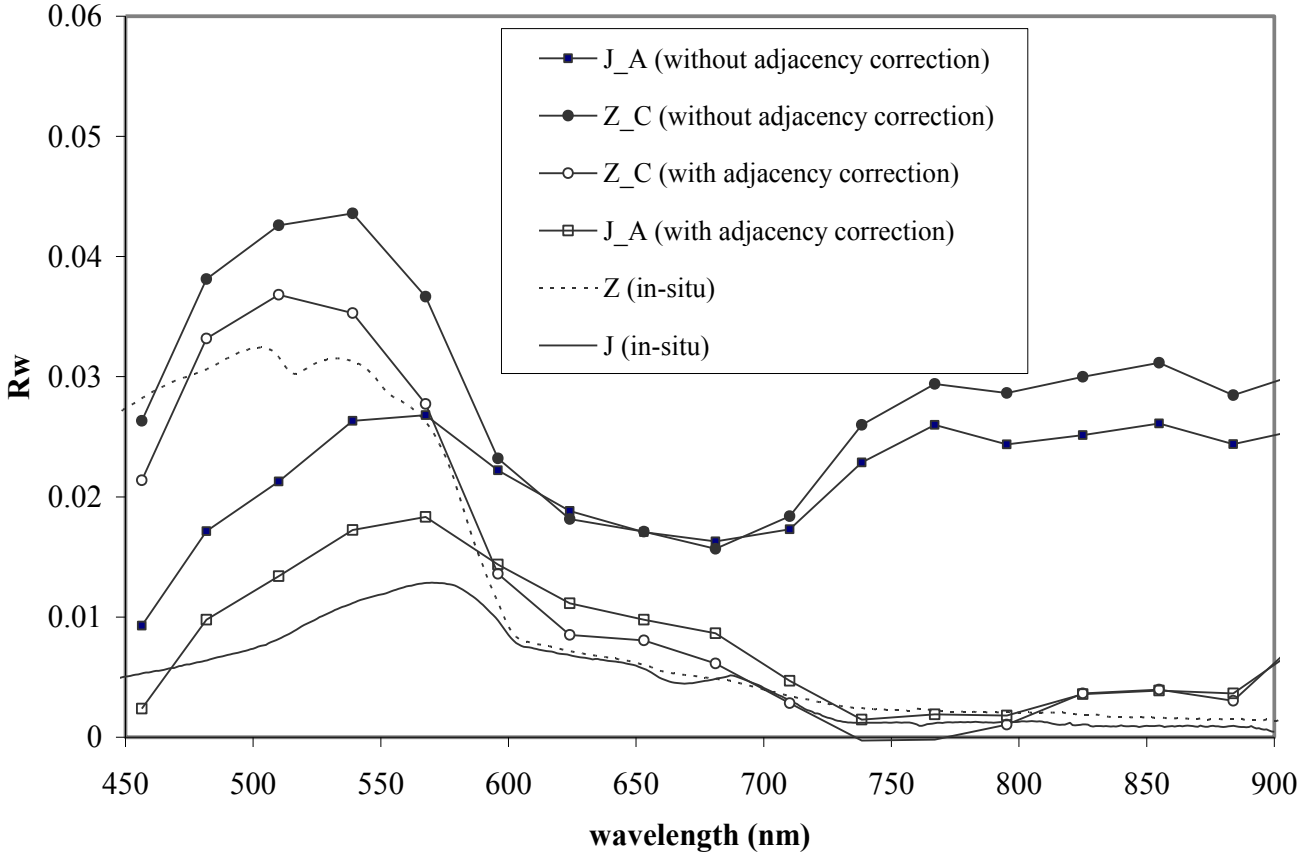
Adjacency correction - SIMEC

Example : Airborne CASI North Sea + Spuikom





Adjacency correction - SIMEC

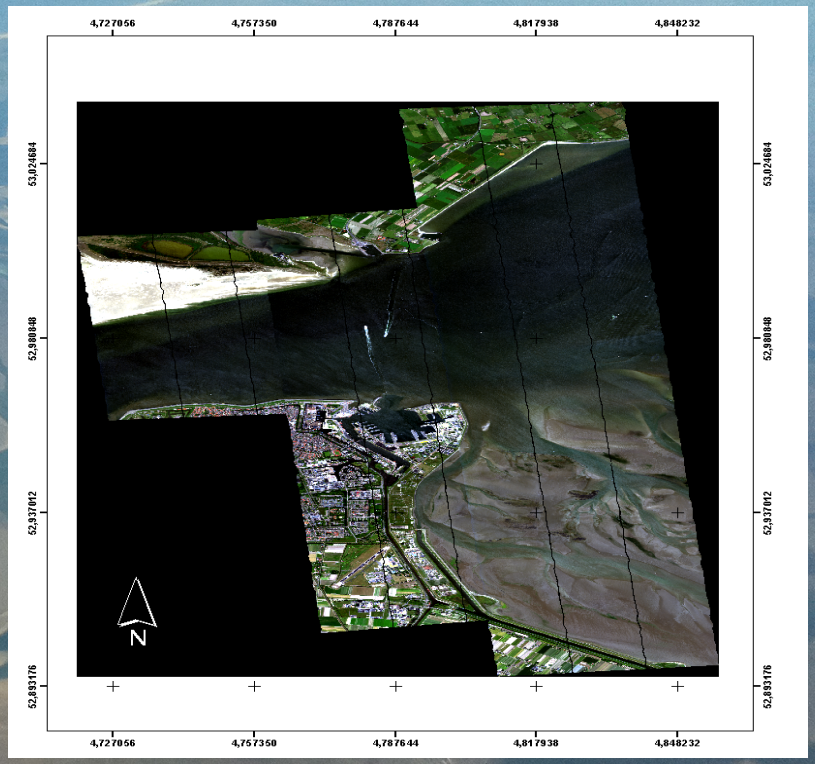


Water leaving reflectance spectra before and after adjancency correction
And averaged in-situ water reflectance

Wavelet based curve fitting algorithm for water quality estimation applied to the Wadden Sea

APEX campaign: 06/2011 - Wadden Sea

- Cooperation with INPLACE project
- Logistics (boat, lab, ..)



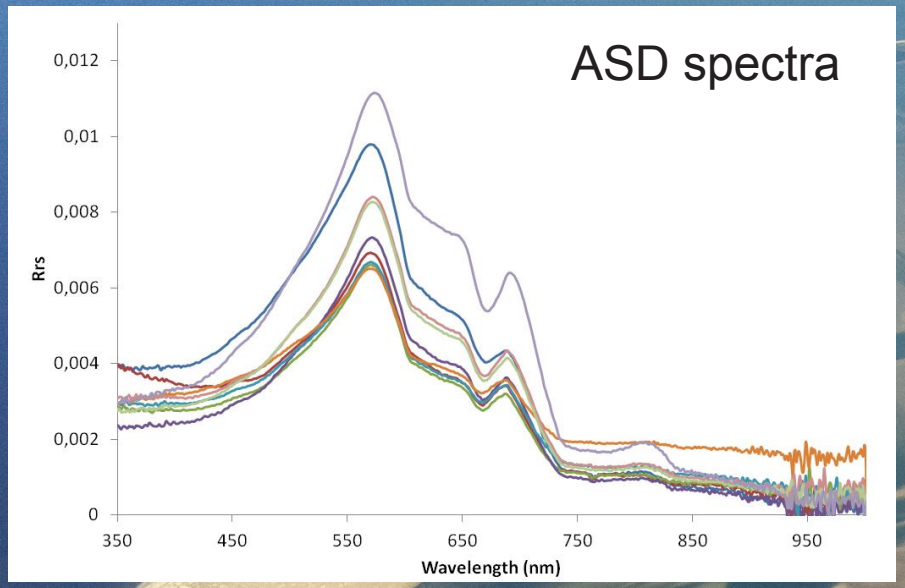
Zeevonk

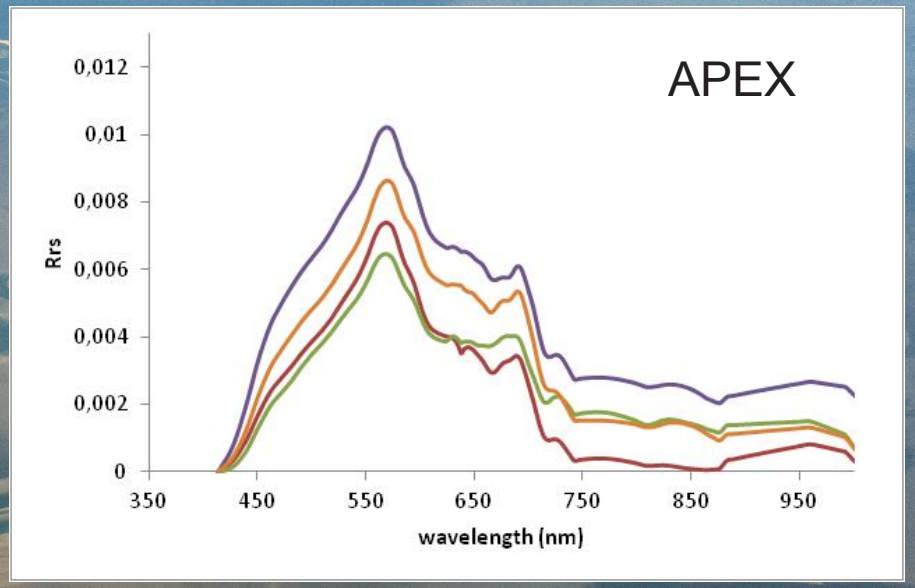
TESO (ferry)

NIOZ - pontoon

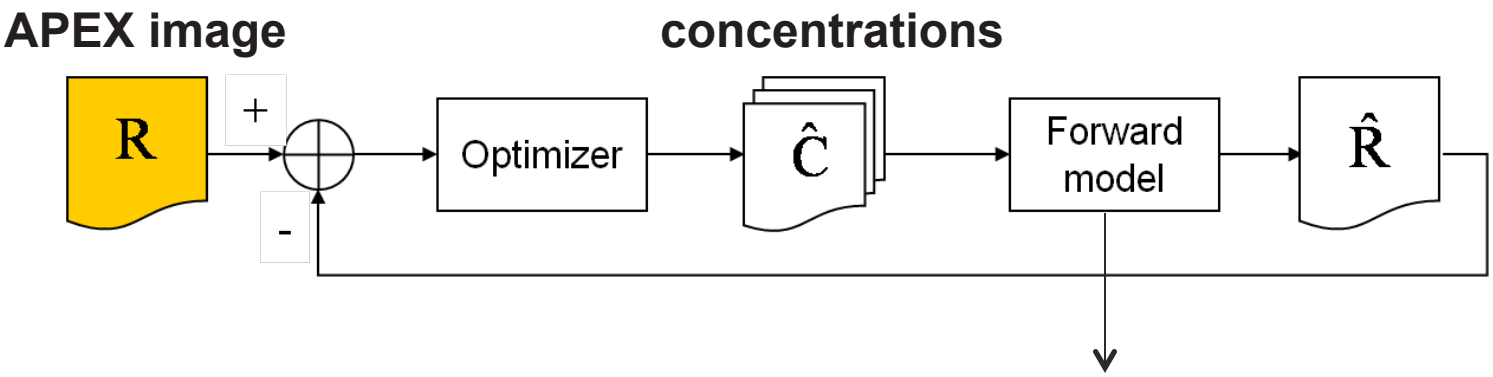
INPLACE pole

APEX campaign: 06/2011 - Wadden Sea





Wavelet based curve fitting algorithm



Bio-optical model of Albert and Mobley (2003)

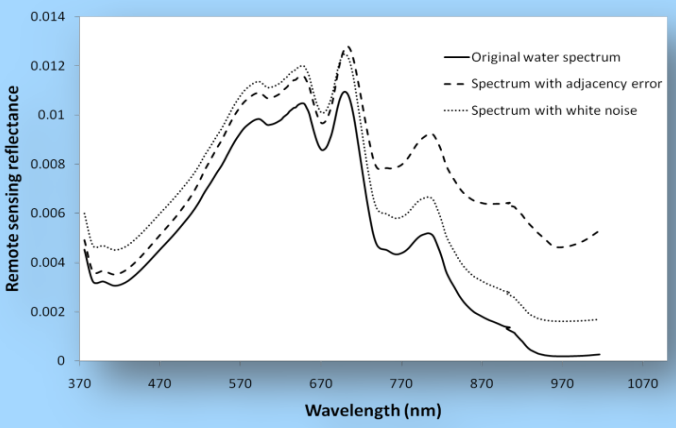
$$R(0-,\lambda) = p_1(1 + p_2 x + p_3 x^2 + p_4 x^3)(1 + p_5 \frac{1}{Cos\,\theta_s})(1 + p_6 u)x$$

$$x = \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

Objective: develop algorithm less sensitive to noise in atmospheric correction and sensor noise

-> Apply a wavelet transform before curve fitting

Figure: Synthetic remote sensing reflectance spectra with white noise and adjacency error

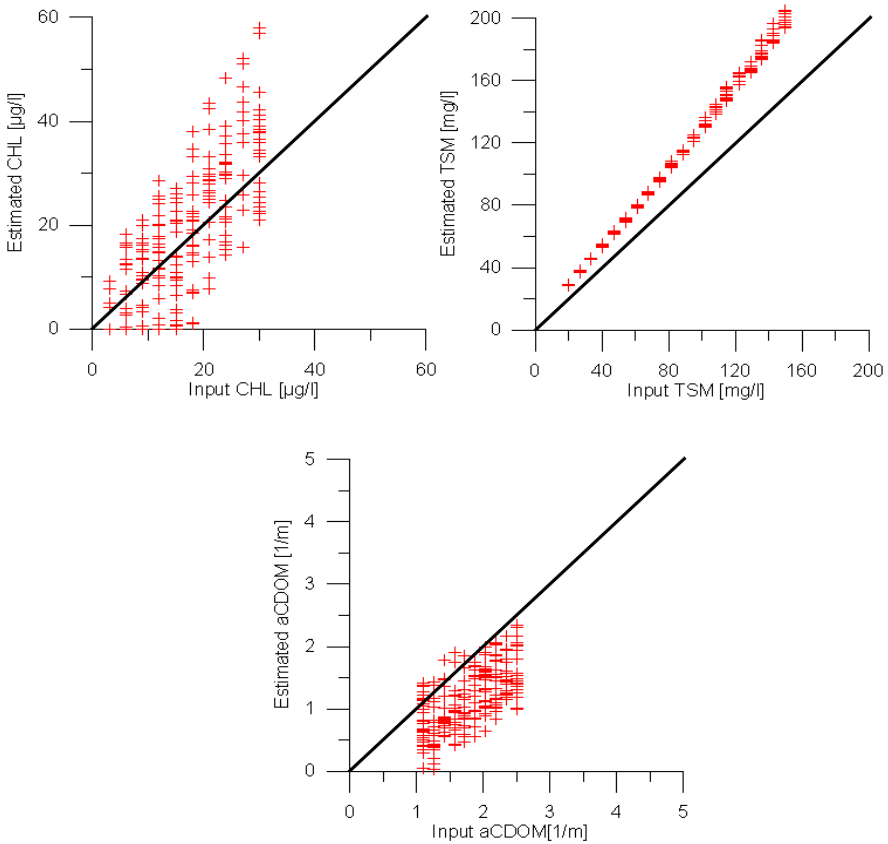


Study area: Scheldt

Reference = Hydrolight with known concentrations, resampled to APEX wavelengths

Noise: adjacency

Water Quality Estimations: Scheldt
Noise: Adjacency effect
Optimalisation: RMSE



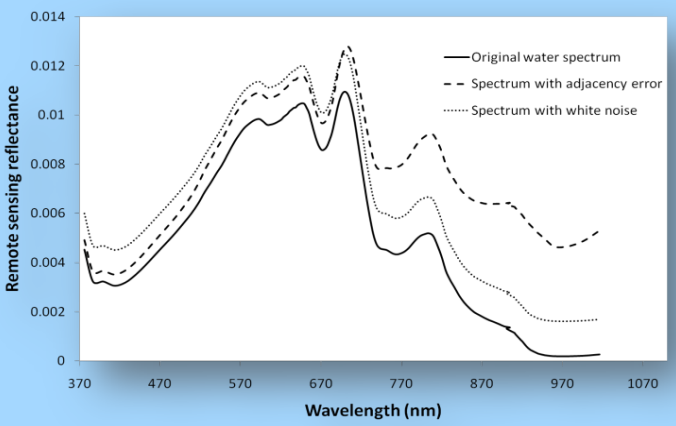
Study area: Scheldt

Reference = Hydrolight with known concentrations, resampled to APEX wavelengths

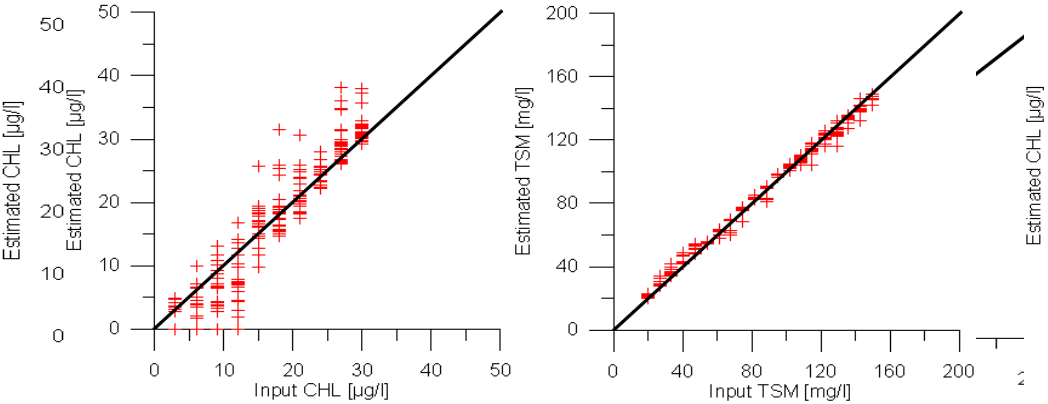
Noise: adjacency

Noise: adjacency, with wavelets

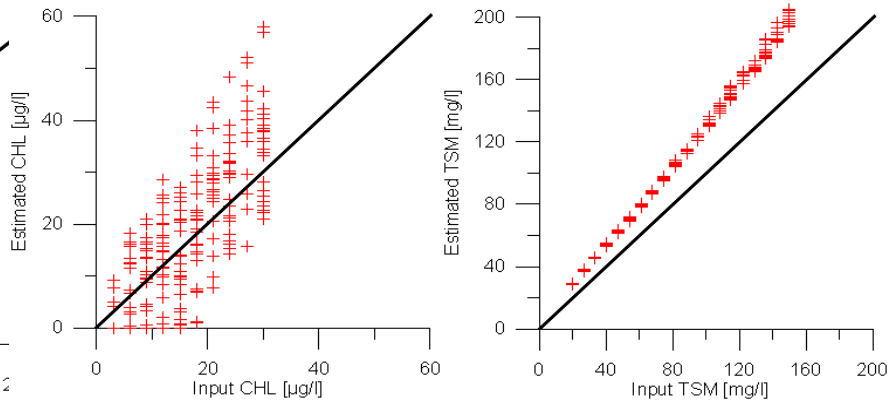
Figure: Synthetic remote sensing reflectance spectra with white noise and adjacency error

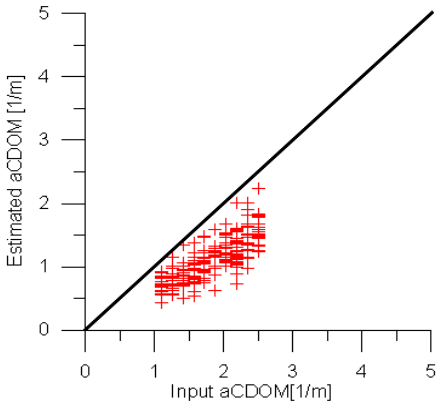


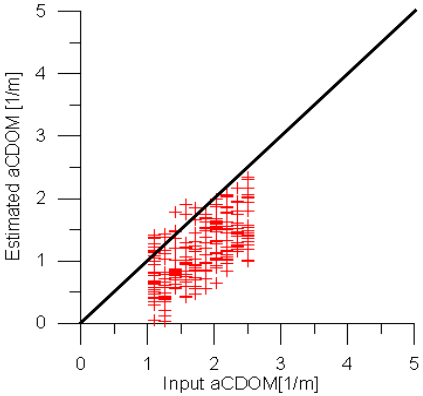
Water Quality Estimations: Scheldt
Noise: Adjacency effect
Optimalisation: Wavelet combination



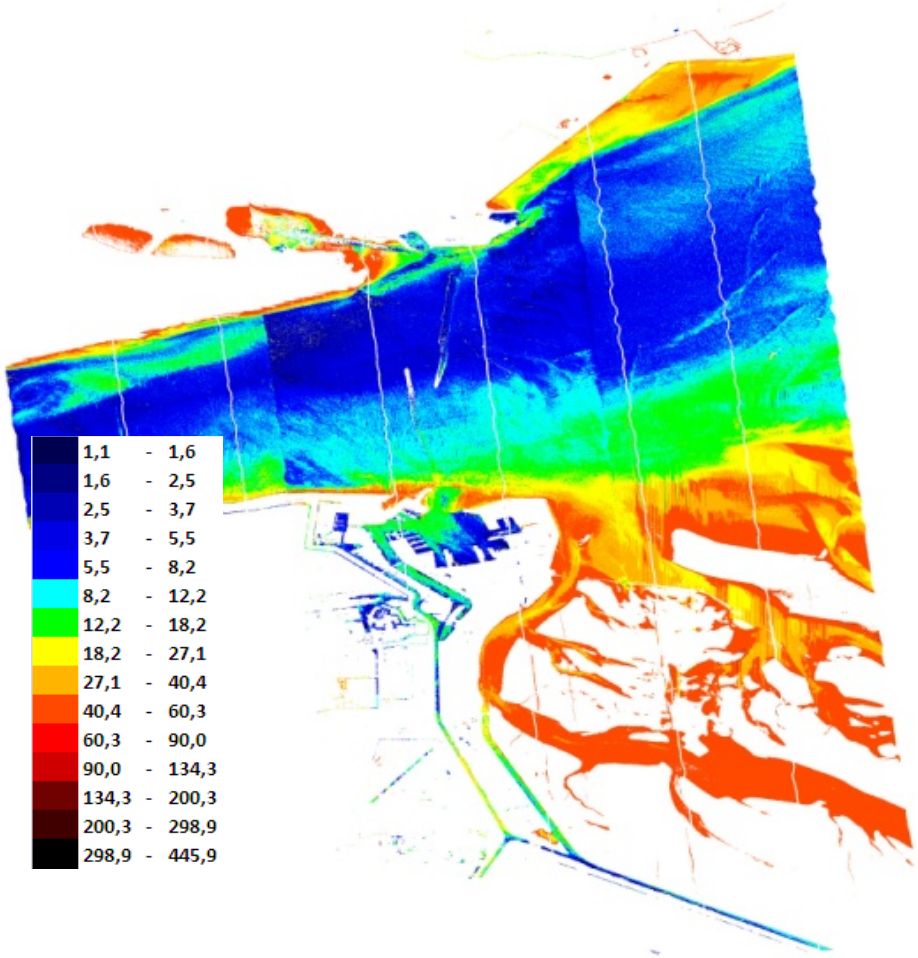
Water Quality Estimations: Scheldt
Noise: Adjacency effect
Optimalisation: RMSE



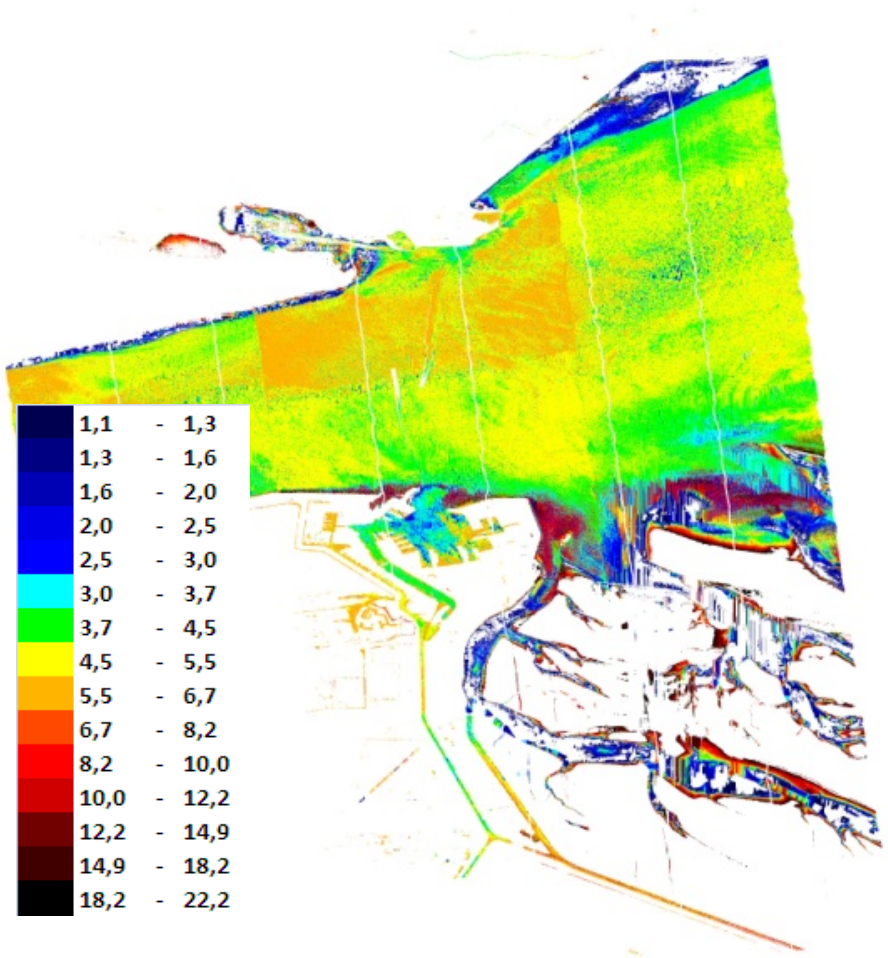




Wavelet based curve fitting algorithm



TSM concentrations in the Wadden Sea (in mg L^{-1}), mosaic of flight line 1, 2 and 3

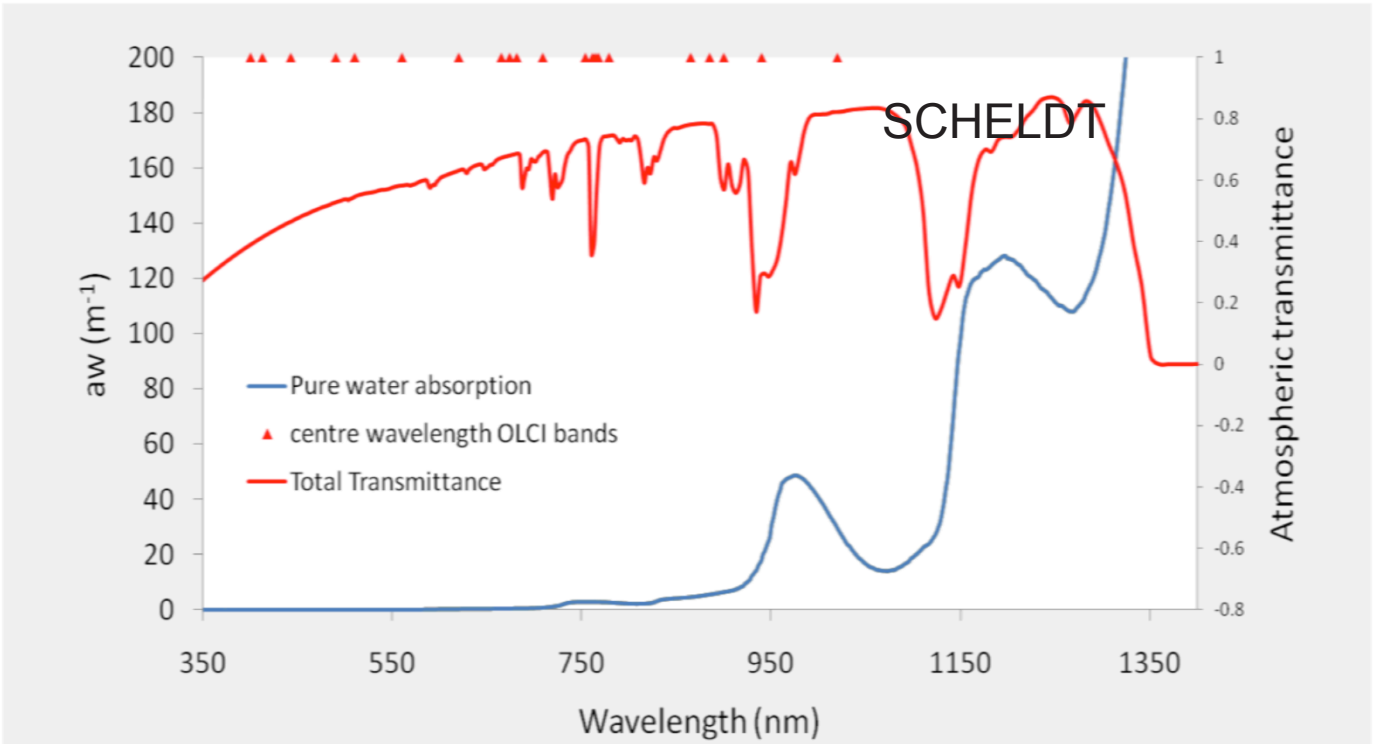


CHL concentrations in the Wadden Sea (in mg L^{-1}), mosaic of flight line 1, 2 and 3

Water leaving reflectance – SWIR?

SWIR is potentially interesting for turbid and TSM retrieval:

- Local decrease in pure water absorption
- Atmospheric transmission windows
- SWIR spectral bands available in future spaceborne sensors (e.g. Hyspiri, Sentinel-3 OLCI)

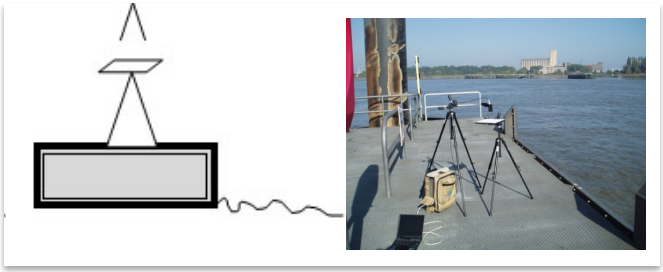


Knaeps, E. et al., Remote Sensing of Environment 120 (2012) 133-144

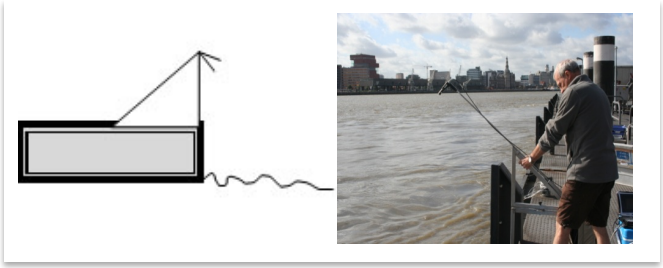
water leaving reflectance – SWIR?

But: little knowledge available, no suitable instrumentation
-> ASD spectrometer and Hysroscat with SWIR wavelengths

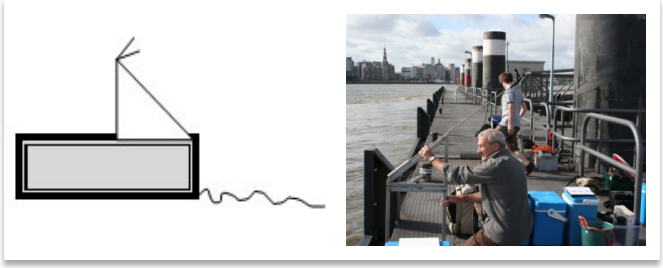
$E_d(0+)$:
downwelling
irradiance
above the surface.



$L_u(a)$
total upwelling radiance
from the water



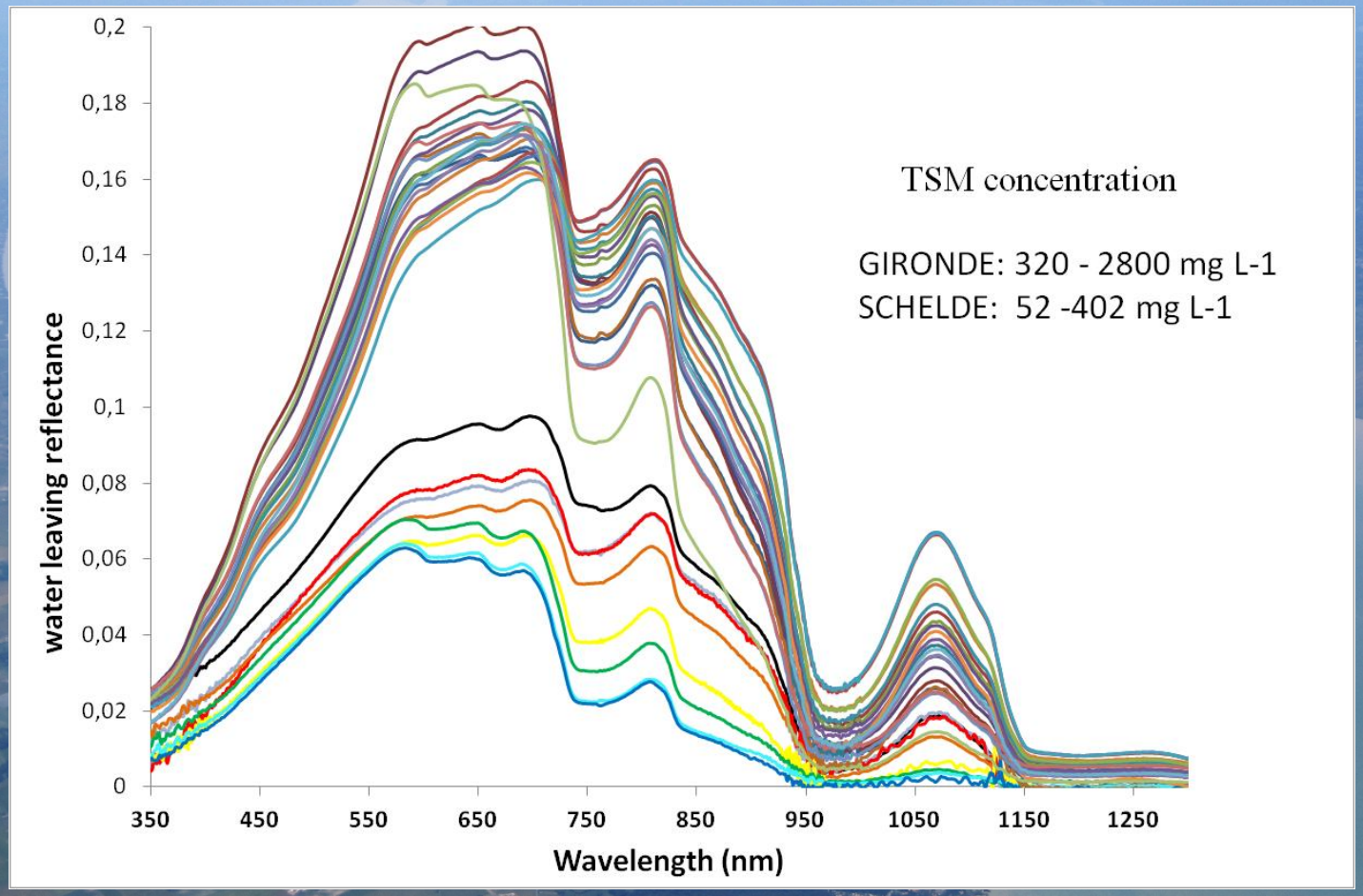
$L_{sky}(a)$
Downwelling sky radiance



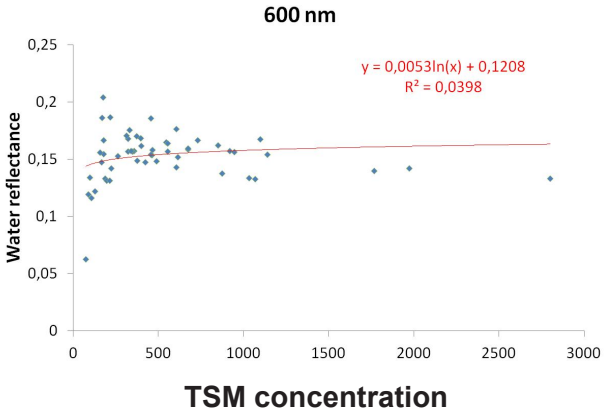
The water-leaving reflectance (Rw) was calculated using the following equation (Mobley, 1999):

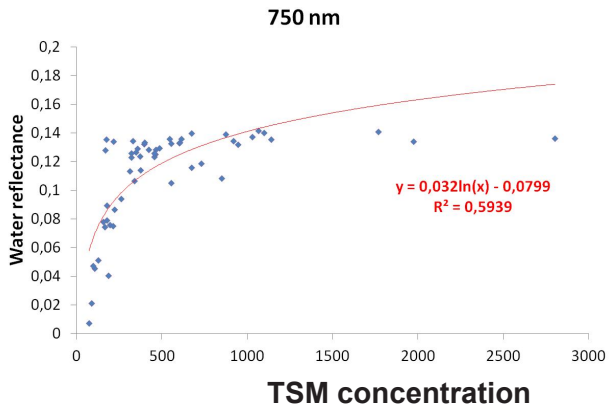
$$Rw = (Lw(a) - \rho as * Lsky(a)) / Ed(a)$$

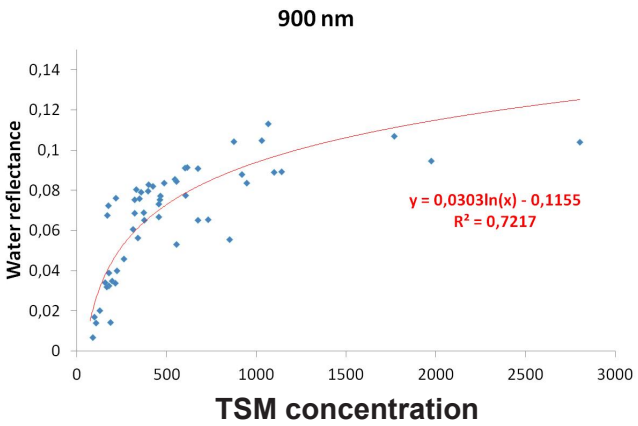
ASD water leaving reflectance – SWIR

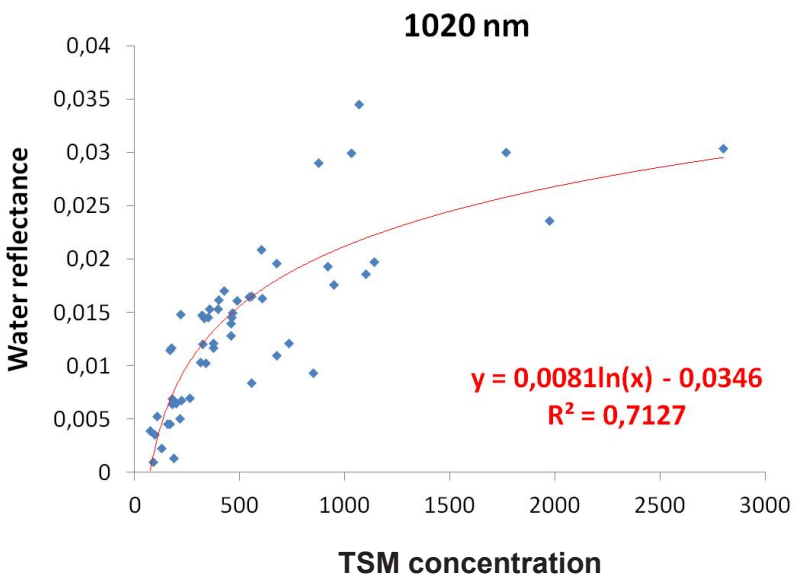


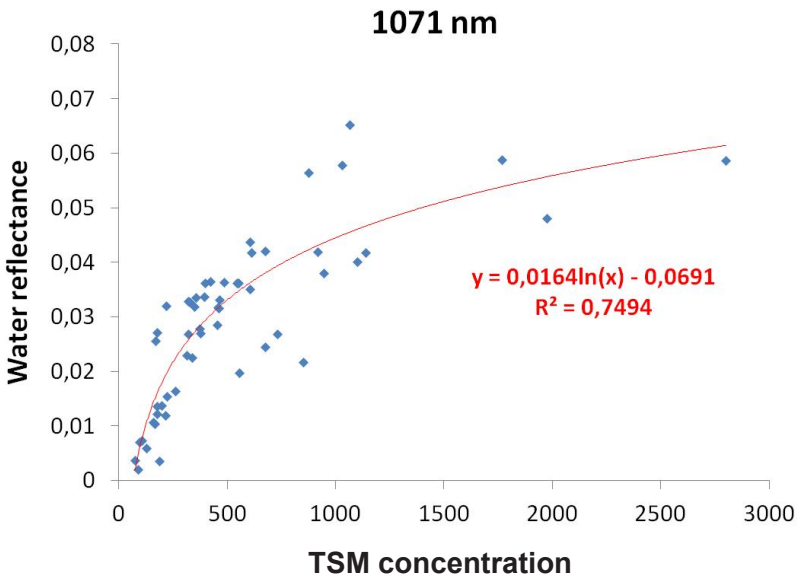
ASD water leaving reflectance – SWIR?











Scheldt – APEX flight

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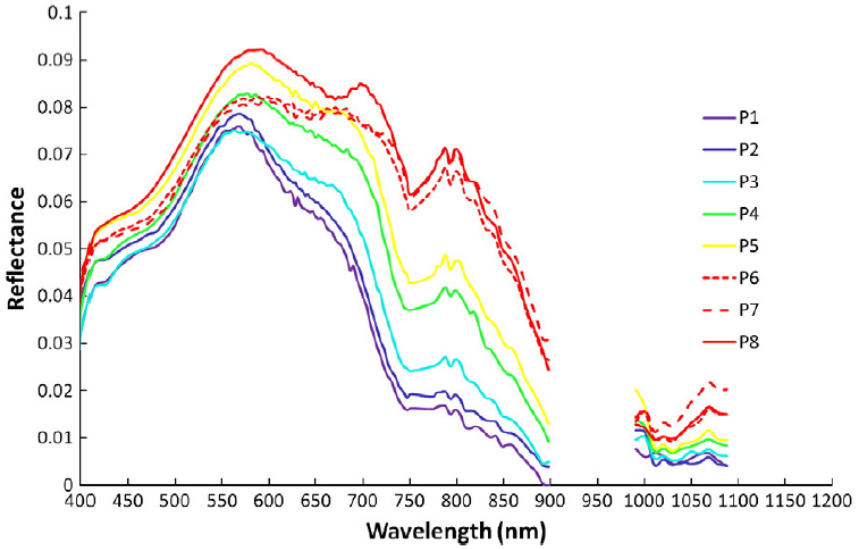
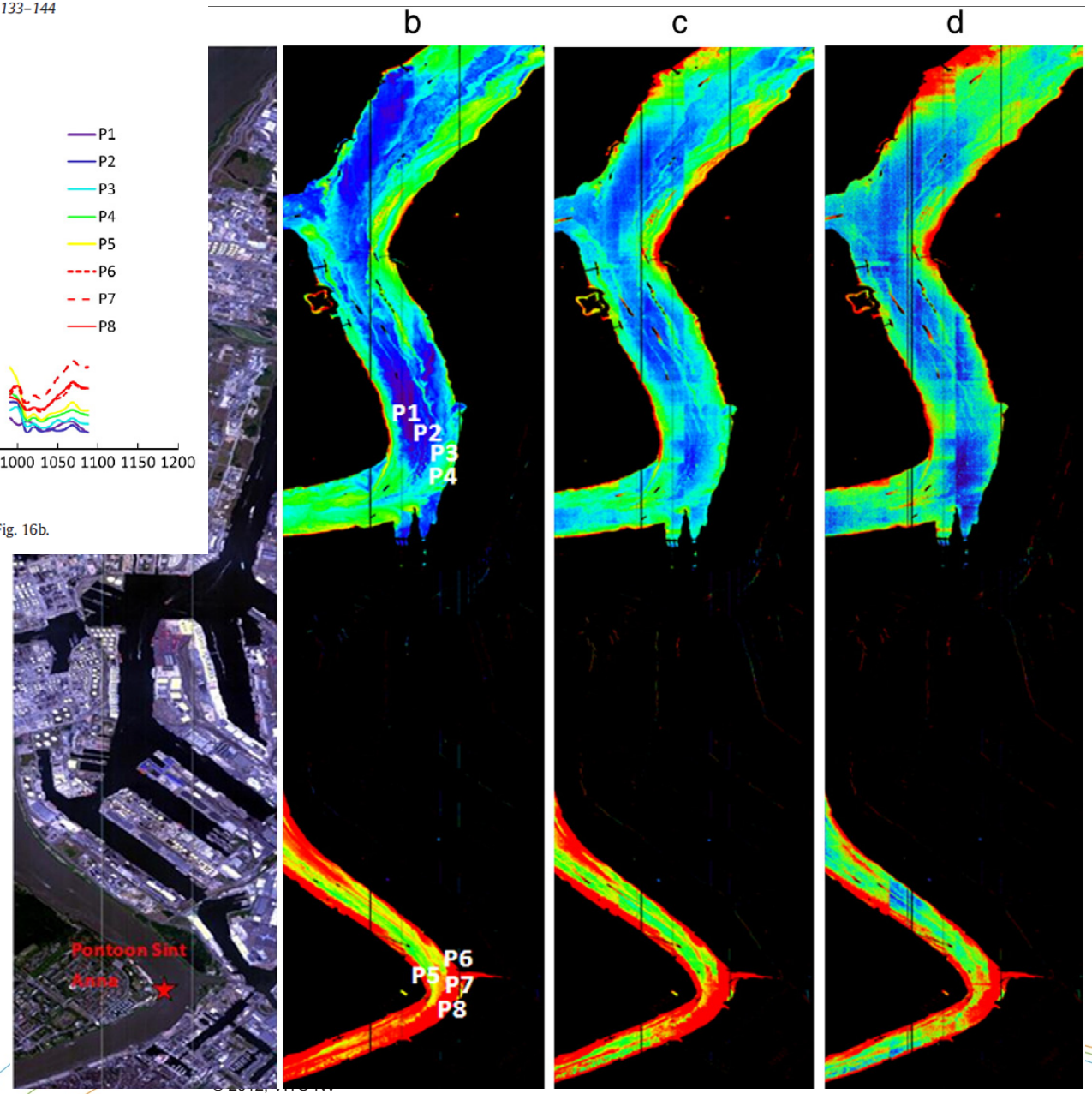


Fig. 16. APEX reflectance spectra at the sites indicated in Fig. 16b.



(a) RBG APEX image of the Scheldt
(b) map of Rw711/Rw597
(c) map of Rw1069
(d) map of Rw1020.

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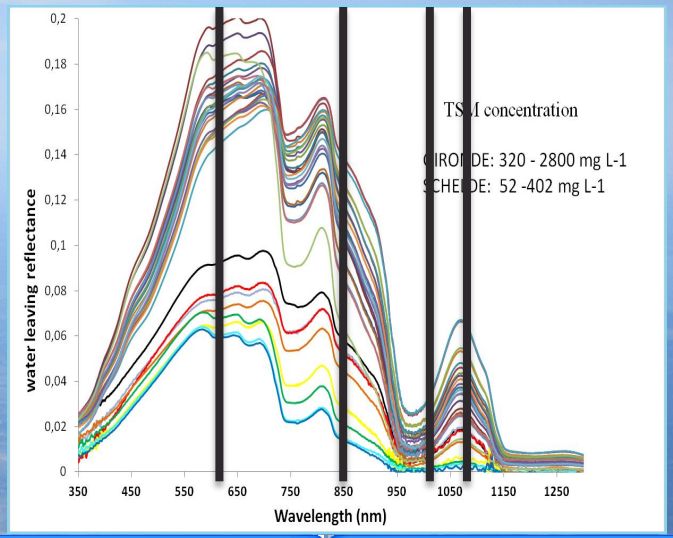
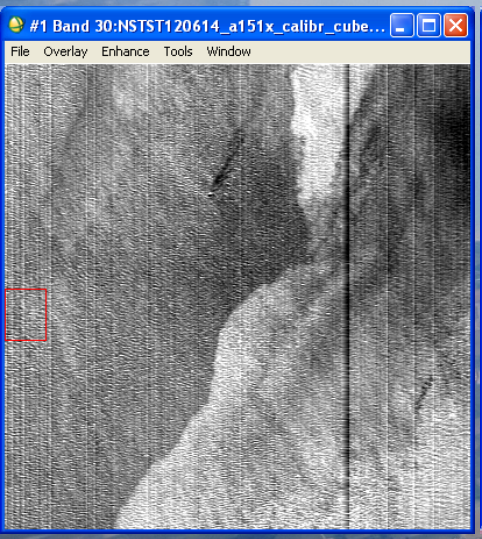
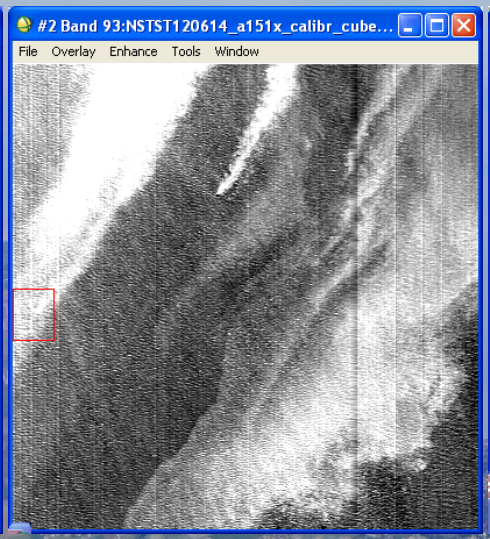
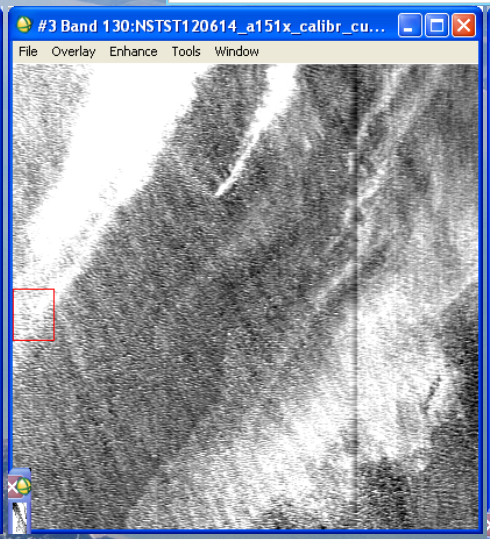
GIRONDE – APEX flight

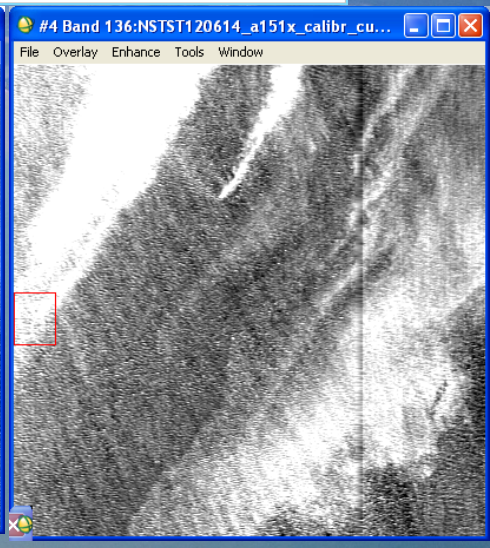
APEX at sensor radiances at VIS, NIR and 2 SWIR bands











In the first visual spectral band the observed patterns are different than those observed in the NIR and SWIR bands.
possible explanation can be found in the sensitivity of the three spectral bands to different substances in the water (VIS: interplay of TSM, CHL and CDOM, NIR and SWIR: mainly or only TSM).

Conclusion and way forward

- Complex waters (dynamic, small, atm. Cor,…)
  - -> Currently no suitable spaceborne sensor
  - -> airborne hyperspectral sensor used simulator for future spaceborne missions
- Hyspiri SWIR potentially highly interesting for TSM retrieval

- SWIR way forward:
  - Derive limits for applying SWIR black pixel atmospheric correction
  - Develop theoretical model for SWIR reflectanc in turbid waters
  - Provide information for future spaceborne missions


THANK YOU
Any questions? -> els.knaeps@vito.be
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