USING SPM OBSERVATIONS DERIVED FROM MERIS REFLECTANCES IN A DATA ASSIMILATION SCHEME FOR SEDIMENT TRANSPORT IN THE DUTCH COASTAL ZONE

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Abstract

Suspended Particulate Matter (SPM) is an important parameter affecting the marine environment by influencing light conditions in the water. Remote sensing can further our understanding of SPM in the Dutch North Sea when its products are assimilated in sediment transport models, and in situ data are also incorporated. For this aim, an optimal set of parameters consisting of SPM concentrations, error products and an approximation of optical depth was derived from MERIS data using IVM's HYDROPT algorithm. This algorithm comprises a forward model based on inherent optical properties and radiative transfer modelling with Hydrolight, and an inverse model to estimate SPM from MERIS reflectance. These parameters were checked for: (1) accuracy of nearshore bio-optical retrieval and atmospheric correction algorithms, (2) possibility to capture change between observations under conditions of non-uniformous spatio-temporal coverage, (3) optical depth versus depth of model layers and depth of stratification. The results showed that remote sensing has much to offer, and there are ample opportunities for improved characterisation of SPM with a data assimilation scheme based on Ensemble Kalman filtering, which enables integration of SPM in a numerical sediment transport model, e.g., WL | Delft Hydraulic's Delft3D-WAQ.

INTRODUCTION: NEARSHORE SPM

Suspended Particulate Matter (SPM) affects the environment by attached pollutants, the transport and chemical fate of organic micro-pollutants and trace metals. SPM also influences the light conditions in the water, causing a decline of primary production with consequences for upper trophic levels. To obtain information on SPM, concentrations in the Southern North Sea have been monitored with remote sensing techniques (Eleveld et al., 2004: Fettweis et al., 2007) and modelled with sediment transport models (Gerritsen et al., 2000; Fettweis et al., 2007). Derivation of accurate SPM values for this highly dynamic coastal sea where large-scale circulation, tidal currents and riverine fresh water inputs occur is notoriously difficult. SPM retrieval from ocean colour remote sensing is dependent on good atmospheric correction, and characterisation of the high variability in Inherent Optical Properties (IOPs) in Case 2 waters. Modelling suffers from propagation of uncertainties in hydrodynamic forcing and SPM behaviour, in addition to uncertainties in the parameterization of water-bed exchange of sand-mud mixtures.

Data assimilation (DA) targeted at the Dutch part of the North Sea was already discussed in (Gerritsen et al, 2000, Vos et al., 2000), but state-of-the-art developments in the characterisation of IOP variability in remote sensing science (Van der Woerd et al., 2004) and water-bed exchange of sand-mud mixtures in sediment transport modelling (Winterwerp & Van Kesteren, 2004) make an update desirable. Furthermore, future sand extraction for construction of a seaward extension of the Port of Rotterdam ('De Tweede Maasvlakte') might cause a temporary increase in SPM concentrations and transport along the coast, making an assessment of the T0 situation in coastal SPM concentrations necessary.

The numerical sediment transport model used for the DA is presented in Blaas et al. (2007), and encouraging first results from DA are presented by El Serafy et al. (2007). This paper focuses on particular challenges and hot topics in remotely sensed nearshore SPM observations, which are:
(1) The large number of scatterers (high sediment load) near the coast causes reduction of optical depth, possibly saturation of the signal and might impede the atmospheric correction (Ruddick et al., 2000);
(2) The number of observations per pixel vary due to cloudiness and MERIS Level 2 quality flag settings. In the mean time major changes in SPM concentrations between observations can occur (Fettweis et al., 2007), particularly by resuspension during windy conditions (Eleveld et al., 2004);
(3) Remote sensing (RS) allows estimation of SPM over a top layer of the North Sea (optical depth), in a region where salinity stratification (De Boer et al., 2006) occurs, whereas the model solves the mass balance over the full water column in 10 layers varying with water depth and incorporates exchange with bed. Information on optical depth needs to be incorporated in the DA to eliminate or decrease any possible mismatch between observed SPM concentrations (and derived mass), and predicted mass for the corresponding depth layer.

This paper presents preliminary results from tackling these challenges using the advanced HYDROPT algorithm and indicates the opportunities that they offer for data assimilation.

METHOD: CUSTOMISING AND ANALYSING HYDROPT MERIS SPM PRODUCTS

Dataset for the data assimilation

The MEdium Resolution Imaging Spectrometer instrument (MERIS) is an imaging spectrometer on board ESA's ENVISAT spacecraft. SPM in the North Sea was studied with MERIS RR MEGS 7.4 / IPF 5.03 atmospherically corrected (Level 2) data (ESA, 2007). All MERIS RR and selected MERIS FR data covering the North Sea for 2003 were acquired and all water pixels that pass the PCD1_13 confidence checking were processed using HYDROPT (Van der Woerd and Pasterkamp, 2007).

HYDROPT comprises of a forward model that generates water-leaving radiance reflectance (ρ_w) as a function of, a.o., the Inherent Optical Properties (IOPs) absorption (*a*) and scattering (*b*) of North Sea water and its constituents chlorophyll (CHL), SPM and coloured dissolved organic matter (CDOM) It is based on radiative transfer modelling with Hydrolight (Mobley & Sundman, 2001a and b) REVAMP IOPs (Tilstone et al., submitted) weighted (by optimisation) with the annual mean of independently collected (MWTL) in situ concentration measurements for the Dutch coast (Rijkswaterstaat, 2007).
The inverse model estimates the concentrations of, a.o., SPM from MERIS water-leaving radiance reflectance ρ_w data at 7 optical wavelength intervals based on the Levenberg-Marquard optimisation. The inversion comprises of χ^2 fitting the modelled to the measured water-leaving radiance reflectance, and also renders standard errors (σ) with the retrieved CHL, SPM and CDOM concentrations. In addition, probability was derived from the (cumulative) distribution function for the χ^2 distribution, and ESA's Level 2 Product Confidence Data (PCD) flags (ESA, 2007) were passed on (Van der Woerd and Pasterkamp, 2007).
Additional to modelled reflectance, complementary vertical diffuse attenuation coefficient (K_D) values were generated, and K_D at 560 nm, which inverse can serve as an approximation of optical depth was added to customised hdf files for further analysis in a Fortran based Ensemble Kalman filtering DA toolbox (Figure 1).

Nearshore coastal quality checks

To support the DA process, quality checks were performed on selected near-coastal subsets from the Level 2 and its accompanying (HYDROPT-processed) Level 3 dataset.
(1) Results of the ocean colour algorithm were validated by plotting SPM_{rs} and SPM_{is} against time (t) for all 19 coastal stations which range in distance from the coast from 2 to 235 km. Additionally, atmospheric parameters and HYDROPT SPM and error products were studied along a transect.

(2) Rectified maps were subtracted to characterise spatio-temporal (ST) change between observations.
(3) A first approximation of optical depth $\varsigma = 1/K_{D560}$ was calculated.

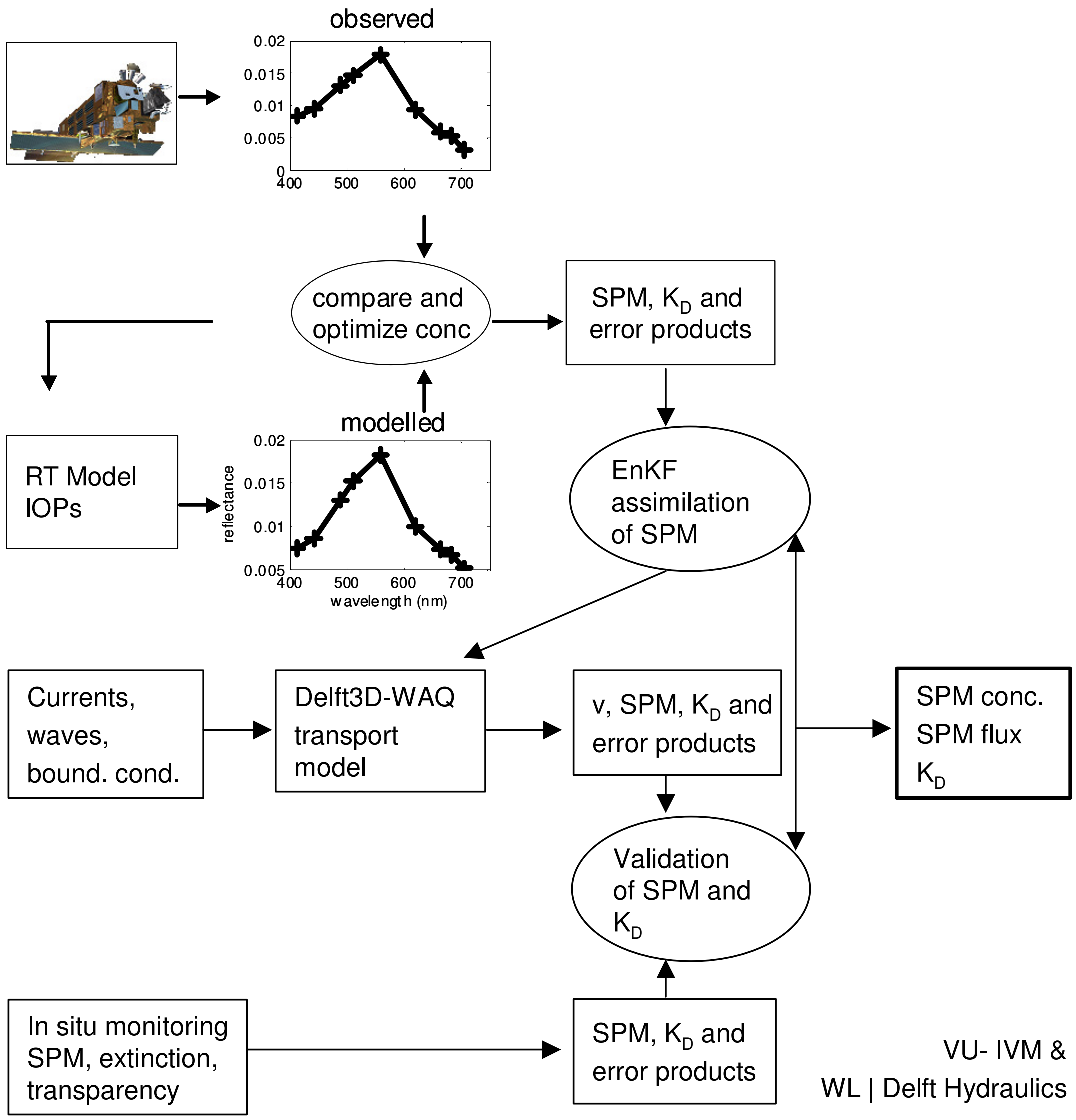

Figure 1: **Approach. Assimilation of SPM into the model grid. Error characteristics for all data sources are used in weighting. K_{D560} provides estimation of optical depth.**

HYDROPT MERIS SPM PRODUCTS

Input for the data-assimilation

The following files were generated with remote sensing for the Ensemble Kalman Filtering toolbox:

- Metadata: extracted from filename, and additional Level 2 tot Level 3 processing lineage,
- primary products: lat, lon, SPM,
- error products: $\chi^2_{\rho w}$, P (cdf χ^2), σ_{SPM}, L2flags
- K_{D560}

Examples and nearshore characteristics of the data set are presented in the following sections.

Quality checks and characteristics

(1) The influence of the large number of scatterers (high sediment load) near the coast on the atmospheric correction and ocean colour algorithm seems to have less impact than anticipated. In our experience SPM from remote sensing compares well with in situ SPM measurements (see e.g., Fig. 2). Underlying parameters versus distance to the coastline (Fig. 3) are shown in Figs 4 – 6. Atmospheric properties remain stable along the transect until 1 km from the first land-pixel (Fig. 4). Reflectance in the near-infrared (from about 780-1400 nm) is low over water because of high water absorption at these wavelength. Reflectance at 560 nm – which is very susceptible to SPM scattering and low to CHL and CDOM absorption (Eleveld et al., 2006) – is high in turbid regions (Fig. 5). Hydropt gives realistic SPM results offshore and nearshore, and the errors remain very reasonable nearshore (Fig. 6).

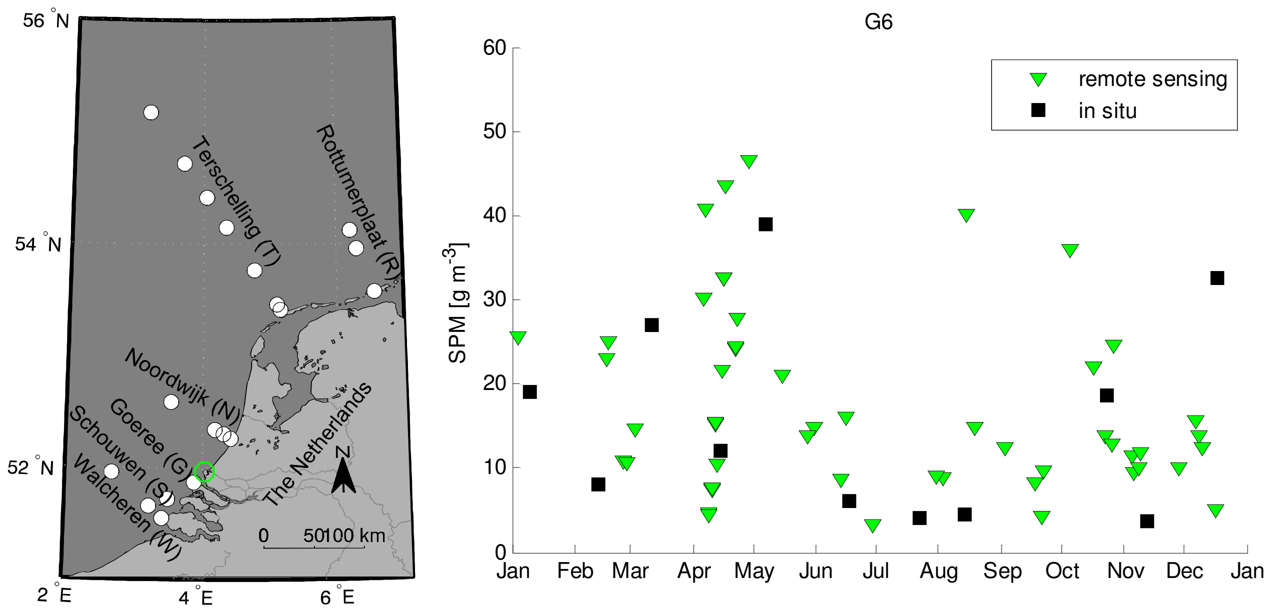

Figure 2: **Comparison. The algorithm validates well for nearshore (2 km) and offshore (235 km) stations. Presented are results for station G6, which is located 6 km offshore near the dredging location for the extension of Rotterdam Harbour.**

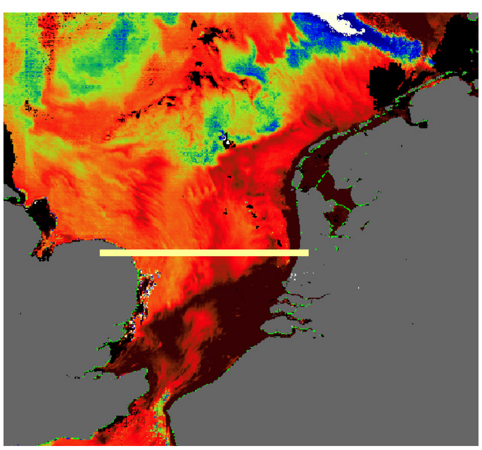

Figure 3: **Transect on a MERIS Reduced resolution image of 16 April 2003.**

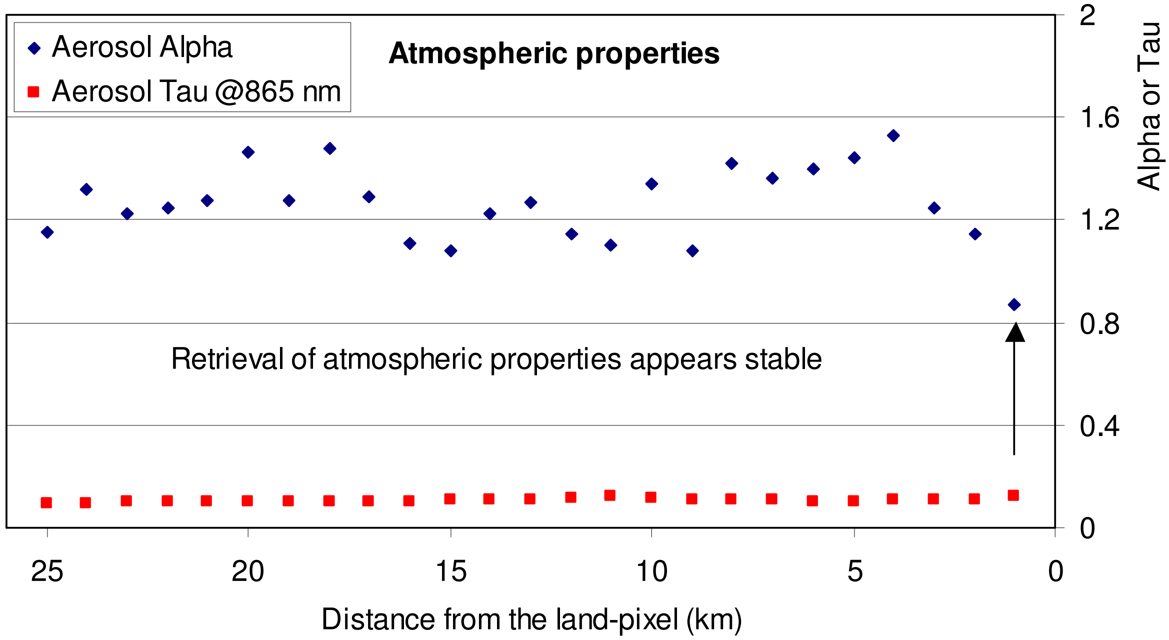

Figure 4: **Atmospheric properties along the last 25 km of the transect approaching the Dutch coast (Fig. 3). The aerosol optical depth at 865 nm varies offshore, but is considerably lower in the first km. Alpha, the baseline to estimate Tau for other wavelength is stable.**

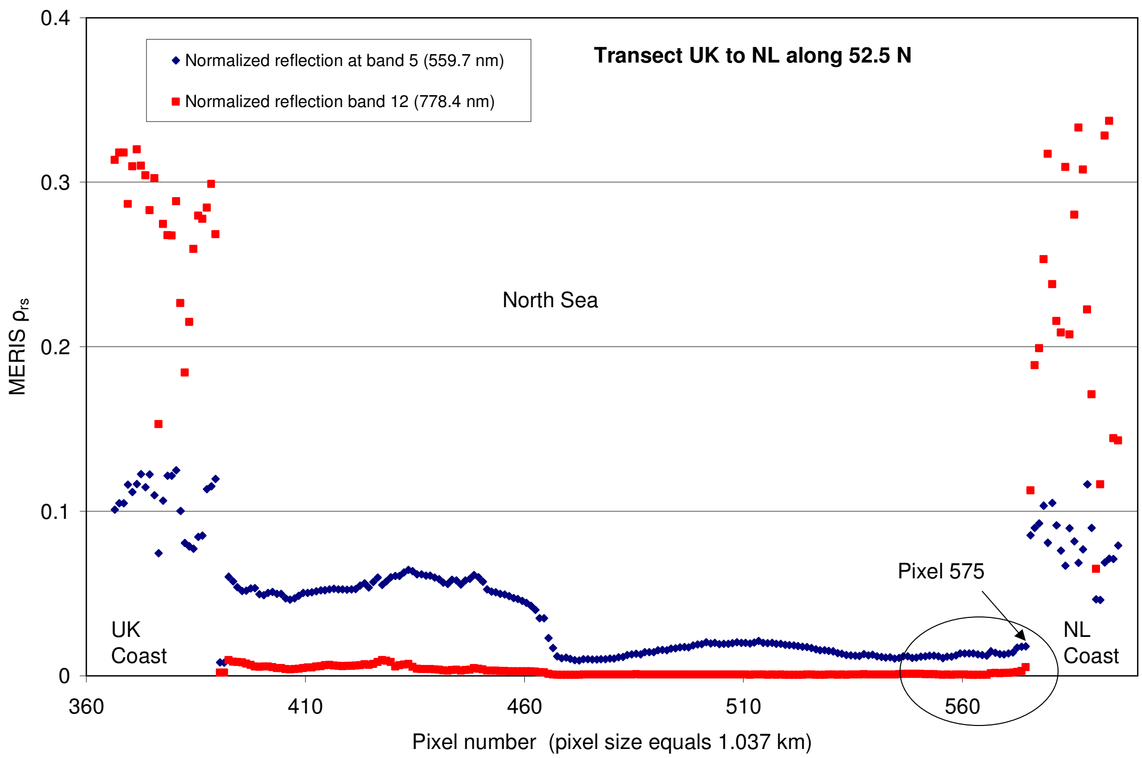

Figure 5: **Reflectance along the transect at 560 nm (high SPM signal) and 778 (high water absorption).. Some problems in the atmospheric correction seem to occur in the first pixel classified as sea (pixel 575) in the Reduced Resolution data. For Full Resolution similar problems occur in the first kilometre (not presented).**

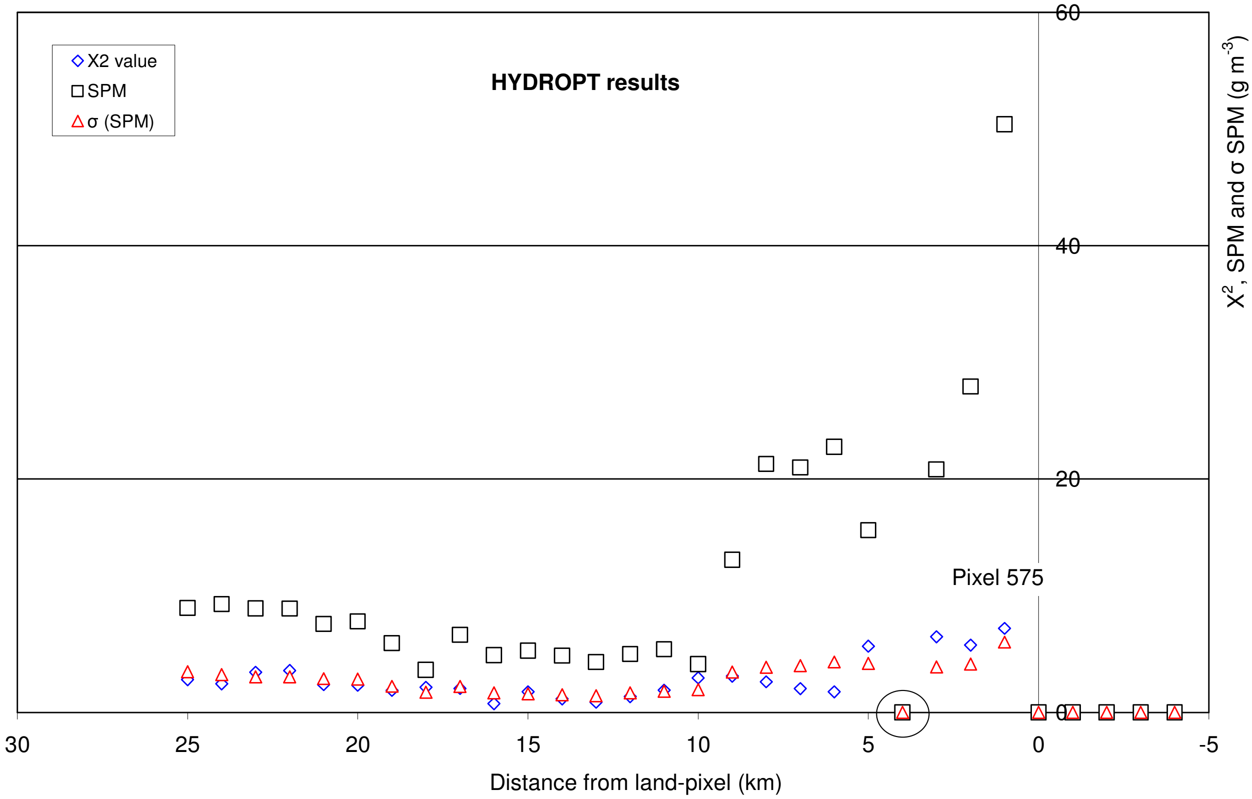

Figure 6: **HYDROPT seems to perform robustly in the nearshore zone. Values for X^2 are not increasing much going landward. Minor changes in atmospheric parameters seem to be mitigated by the algorithm. Standard error σ is relatively low for high nearshore SPM concentrations. In some situations the algorithm produces 0-values.**

(2) Figure 7 shows that important information about ST SPM change within a day can be derived despite exclusion of pixels due to local cloud cover and raised Product Confidence Flags (PCD1-13). Batch processing (Eleveld et al., 2003) allows fast processing of all data, making RS an important source of information, particularly because MERIS covers the area of interest once or twice a day.

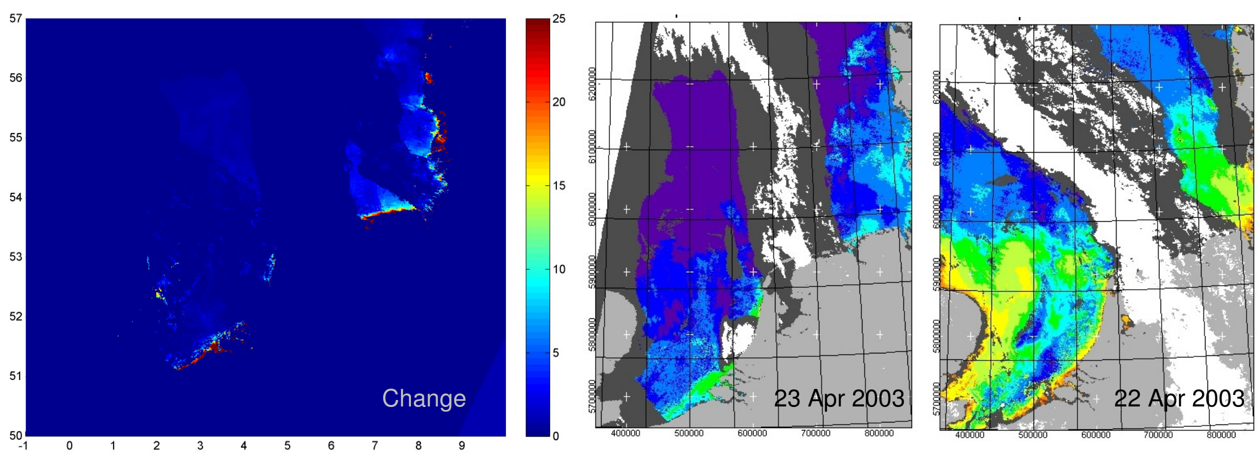

Figure 7: **Remote sensing registers change between observations. (See Fig. 8 for legend April data.)**

(3) Using HYDROPT to its full potential, concentrations of SPM and other optical substances (CHL, CDOM) have been retrieved from water-leaving radiance reflectance (ρ_w) of a top layer of the North Sea (optical depth). Independently of retrieved concentrations, K_D can also be derived in parallel with water-leaving radiance reflectance (ρ_w). Optical depth can be approximated by $1/K_{D560}$. Comparing independent panels in Fig. 8 shows that optical depth is low $\leq$ 1m near shore, where many optically active substances reside, and higher 3-5 m near the turbidity minimum offshore. Providing optical depth for the DA enables best possible updating of model solution for this top layer.

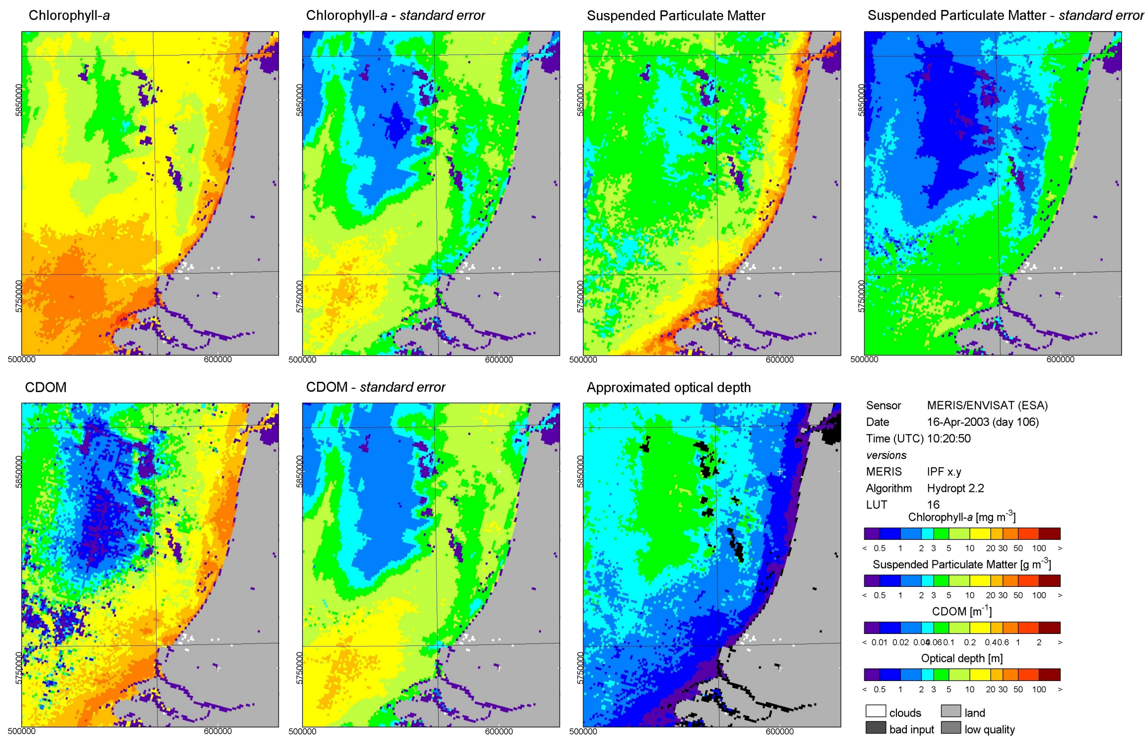

Figure 8: **Water quality parameters and error products. Nearshore optical depth (approximated by $1/K_{D560}$) is limited.**

CONCLUSIONS: IMPLICATIONS FOR ENSEMBLE KALMAN FILTERING

Remotely sensed nearshore SPM with error products and K_D will be a valuable source for Ensemble Kalman Filtering because:

- Remotely sensed SPM results validate well with in situ data;
- Many SPM changes can be characterised with RS;
- Approximated optical depth can be delivered with the water quality parameters and their error product.

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