Ministerie van Verkeer en Waterstaat

Rijkswaterstaat

Does satellite observation of chlorophyll-a and suspended sediment complement Rijkswaterstaat monitoring of the North Sea?

53515 AGI 'ToRSMoN'

AGI-2007-GPMP-017

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53515 AGI 'TORSMON'

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Colofon

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NATIONAL USER SUPPORT PROGRAMME (NUSP) 2001-2005

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The National User Support Programme 2001-2005 (NUSP) is executed by the Netherlands Agency for Aerospace Programmes (NIVR) and the SRON Netherlands Institute for Space Research. The NUSP is financed from the national space budget. The NUSP subsidy arrangement contributes to the development of new applications and policy-supporting research, institutional use and use by private companies.

The objectives of the NUSP are:

- To support those in the Netherlands, who are users of information from existing and future European and non-European earth observation systems in the development of new applications for scientific research, industrial and policy research and operational use;

- To stimulate the (inter)national service market based on space-based derived operational geo-information products by means of strengthening the position of the Dutch private service sector;

- To assist in the development of a national Geo-spatial data and information infrastructure, in association with European and non-European infrastructures, based on Dutch user needs;

- To supply information to the general public on national and international space-based geo-information applications, new developments and scientific research results.

ARGOSS is a consulting company developing and providing innovative environmental services based on meteorological and oceanographic data to the offshore, coastal and harbour sectors, and urban management authorities.

Rijkswaterstaat is the executing organisation for the Ministry of Transport, Public Works and Water Management. The Rijkswaterstaat (RWS) National Institute for Coastal and Marine Management (RWS RIKZ) is an advise, research and data management centre, primarily for the ministery, but also for other national and regional government institutions, home and abroad. The RWS RIKZ executes national policy, maintains a knowledge infrastructure and delivers information (under specific conditions). RWS RIKZ is the main supplier of knowledge on any subject concerning the sustained use of estuaries, coasts and seas and flood protection.
With RIKZ, AGI (Adviesdienst Geo-informatie & ICT) is amongst the six specialist services of Rijkswaterstaat. AGI supports the primary tasks of the ministry by ensuring a constantly updated, maintained, certified and standardised geo-information and ICT infrastructure.

The Remote Sensing group at the Institute for Environmental Studies (IVM) of the Vrije Universiteit (VU) Amsterdam has over 15 years of experience in remote sensing of turbid (Case 2) waters, particularly in collection of Concentration, Spectra and Inherent optical properties (CSI) datasets, bio-optical forward and inverse modelling, and validation. IVM uses a physical approach to derive water quality parameters from remote sensing. IVM specialises in the remote sensing of turbid and eutrophic waters; throughout the years many of IVMs projects have focussed on Lake IJssel and the (Southern) North Sea.

NIOZ Royal Netherlands Institute for Sea Research is the National Oceanographic Institution of the Netherlands. The institute was founded in 1876. NIOZ is part of the Netherlands Organization for Scientific Research (NWO). The institute employs around 200 people and the annual budget is approximately €20 million. NIOZ is located on the island of Texel at the border between the North Sea and the Wadden Sea. The mission of NIOZ is to gain and communicate scientific knowledge on seas and oceans for the understanding and sustainability of our planet, and to facilitate and support marine research and education in the Netherlands and Europe. The four basic disciplines of oceanography at NIOZ are physics, chemistry, biology and geology. Multidisciplinary interdepartmental co-operation is regarded as one of the main strengths of NIOZ. More information: www.nioz.nl.

Contents

Abstract

Management and monitoring of the Dutch part of North Sea is coordinated by Rijkswaterstaat and strongly based on international agreements. Further policy development and harmonization takes place within these international bodies (e.g. European Marine Strategy). Under the authority of the OSPAR Convention monitoring is being reviewed continuously. The project *Towards Remote Sensing Supported Monitoring of the North Sea* (ToRSMoN) was started in 2005 to demonstrate whether or not satellite data would be instrumental to monitor spatial patterns of total suspended matter (TSM, or suspended particulate matter SPM) and chlorophyll (Chl) in the North Sea. This project utilizes optical remote sensing of water quality parameters, or, in other words, remote sensing of ocean color.

Variograms extracted from a dataset of SeaWiFS chlorophyll and TSM products from September 1997 until December 2004 were analyzed to characterize patterns in the North Sea for both individual images, and for seasonal composites to capture persistent patterns and overcome cloud cover.

Satellite monitoring provides the 'real time' advantage required for disaster management and security services (e.g. harmful algal blooms or oil spill drift). It provides an instant image of a large area (synoptic). Data gathering, processing, and dissemination occur at much lower effort and therefore much lower costs than *in situ* (ship-based) sampling and is shown to be just as reliable. The distribution of monitoring stations could be optimized using model simulations supported by remote sensing data.

Comparison of daily images with satellite-derived time series (yearly trends and inter-annual variability) provide immediate identification of anomalous blooms and sediment fluxes. Remote sensing demonstrates transboundary processes and does help resolve liability issues within the regulatory framework (.e.g. eutrophication). A future development is data-model integration, to be undertaken by research institutes in close association with service providers and policy makers, to simulate and predict North Sea dynamics and ecosystem responses.

1. Monitoring the North Sea surface waters

1.1 Introduction

Fishing, sand extraction, 'wind farms', shipping and nature – spatial management of the North Sea must take into account the many functions and interests that converge into the Dutch EEZ. The government and its ministries work to integrate spatial developments, to ensure a safe, healthy, and profitable sea.

From one kilometer offshore the North Sea does not belong to any municipality or province, which is why central government is responsible for policy and management. The Minister of Transport, Public Works and Water Management (V&W) coordinates North Sea policy and is publishing the Integrated Management Plan for the North Sea 2015 with the approval of the Minister of Housing, Spatial Planning and the Environment (VROM), the Minister of Economic Affairs (EZ) and the Minister of Agriculture, Nature and Food Quality (LNV). In this plan, management is defined as follows: care and responsibility for the North Sea through implementation of policy. The primary management tasks are: implementation, enforcement, knowledge and information management, and reporting and evaluation.

Rijkswaterstaat coordinates Dutch monitoring of marine surface waters. The surface water monitoring program ('Monitoring Waterstaatkundige Toestand des Lands' of MWTL) started in 1972 and primarily focused on chemical characteristics of national waters. A grid of North Sea stations up to 70 km offshore comprising 74 stations in total was monitored from 1975 onwards. The network was remodeled several times and the present monitoring in the North Sea comprises 20 locations. Sampling frequency varies from several times to approximately 20 times annually (For this report relevant parameters measured are listed in Appendix A).

North Sea policy is based on international agreements. Important agreements are made within the framework of the UN (IMO, UNCLOS), EU and OSPAR (see Appendix B). Further policy development and harmonization takes place within these international bodies, including important developments like the European Marine Strategy currently in preparation as part of a new initiative of the European Commission described in the Green Paper on Maritime Policy.

Under the authority of the Oslo and Paris Commissions (OSPAR), the condition of the seas covered by the Convention is being reviewed continuously. For this purpose a Joint Monitoring Program (JMP) has been in operation since 1979. For the Netherlands the program comprises (a) estimation of the level of pollutants in edible fish, (b) biological and biological effect monitoring, (c) assessment of spatial distribution of pollution, and (d) assessment of temporal trends in pollution within the Convention Area. The Dutch contribution to the JMP is closely related to the national program. Every year the results of the JMP monitoring activities of the preceding year are supplied to the ICES data bank.

1.2 Objectives

The project *Towards Remote Sensing Supported Monitoring of the North Sea* (ToRSMoN) was started in 2005 to demonstrate whether or not satellite data would be instrumental to monitor spatial patterns of total suspended matter (TSM, or suspended particulate matter SPM) and chlorophyll (Chl) in the North Sea. This project utilizes optical remote sensing of water quality parameters, or, in other words, remote sensing of ocean color. The project is funded by the 'Nationaal Programma Gebruikersondersteuning' (GO), under the supervision of the 'Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart' (NIVR, Delft).

End users of remote sensing for aquatic (here: marine) environments are water managers, both for their operational and in long-term planning. Operational management includes calamity response for industry and shipping (e.g. effluent monitoring and oil spill control); incident management (recreational use, harmful algal blooms); and support on permit issues, including environmental impact assessments.

Given its specific responsibility in North Sea management, Rijkswaterstaat reevaluates its monitoring program on a regular basis, to assess whether there are gaps in knowledge and information that need to be addressed. A proper balance needs to be found between effectiveness and efficiency, including cost efficiency. Quality control ('validation') is crucial; therefore a thorough validation of monitoring products is a minimal requirement. Sources of new information for monitoring should be sustainable and reproducible. Products must be useful in the context of an ecosystem approach for the North sea, with special emphasis on the effects of the problem of eutrophication on the North Sea. In this context the merits of earth observation can be optimally demonstrated.

ToRSMoN intended to make monitoring more efficient with greater spatial and temporal coverage and near real-time availability. This approach is directly in line with the policy of OSPAR and it supports the ongoing preparations of Rijkswaterstaat for the European Marine Strategy (EMS), which is presently in development. With respect to the costing aspects of an adapted strategy the frequency of the present monitoring is governed by the monitoring of phytoplankton blooms and eutrophication during the growing season.

Satellite monitoring is to a large extent automated and requires less hours for analysis and lab processing, and less ship time, thus resulting in considerable cost reduction. It may in fact direct *in situ* monitoring and make the ship-based program more efficient. Incorporating earth observation requires from the end users a re-evaluation of a presently optimized in-situ monitoring network. After all, the end user must decide in what way earth observation can contribute to its needs.

1.3 Information requirements

In Appendix A the required RWS parameter list for eutrophication is given, from this list a limited number of parameters, chlorophyll, suspended matter (TSM,SPM), sea surface temperature (SST), transparency, light extinction, coloured dissolved organic matter (CDOM) as proxy for dissolved organic carbon (DOC) are measurable by earth observation.

However information on the physical and chemical conditions of the North Sea ecosystem is always necessary to interpret biological results in their proper environmental context. Rijkswaterstaat separates measurement activities in different types of monitoring:

1. (Real-time) Operational monitoring for security, water management, incident management and shipping traffic support.
2. Long term monitoring for policy support and evaluation and legal obligations.
3. A combination of short and long term monitoring for environmental assessments required within legal frameworks (Appendix B), or with respect to the issuing of permits for building, dredging and mining activities.

For long term monitoring the first five OSPAR strategy topics provide insight in the sort of human impact related problems in the North Sea Environment (see appendix B):

- Protection and Conservation of Marine Biodiversity and Ecosystems
- Eutrophication
- Hazardous Substances
- Offshore Oil and Gas Industry
- Radioactive Substances
- Monitoring and Assessment

The latter topic (Monitoring and Assessment) is aimed at a coordinated monitoring approach between the associated countries. One topic of OSPAR that may benefit substantially from earth observation is eutrophication of the marine environment. Also the monitoring of large-scale changes in the ecosystem can benefit to a limited extend of this new source.

1.4 Outline

The following chapters report on the outcome of the ToRSMoN project as required by NIVR and according to NIVR format.

Chapter 2 reports on the separate research efforts undertaken within this project. Research methods and primary results are presented as abstracts – full documents are available through the individual institutes. Research was grouped to provide:

- An analysis of the main features of the present monitoring data regarding temporal trends and sensitivity. (WP2)
- Quality and validation required for the acceptance of this technique, comparing earth observation and (long-term) ship-based measurements. (WP3)
- Plume and Bloom presents a case study demonstrating the use of satellite observations of SPM and Chl to improve understanding of the seasonal and interannual variations in the Dutch EEZ. This section is process based and demonstrates a blind spot of the present monitoring network. The fresh water plume crossing the North Sea is a dominant feature of the North Sea ecosystem. (WP4)
- This is followed by a section that provides a base for spatial correlation to be used to redistribute monitoring station locations (if required). (WP5)

Chapter 3 discusses the research results derived under Chapter 2 and relevance to the present monitoring system.

Chapter 4 is the costing section, offering a breakdown of project costs and projection of costs on an annual basis if this service were to be continued on a routine basis. For this, five separate scenarios have been developed.

Chapter 5 provides conclusions and recommendations, including suggestions for further research, in a question-answer manner. This section may be considered as **executive summary**. It has been formulated as consensus between project partners ARGOSS (G. Hesselmans), Vrije Universiteit Amsterdam-IVM (M. Eleveld), NIOZ (M. Baars), RWS-RIKZ (H. Roberti and V. Langenberg), and RWS-AGI (J.J. Zeeberg).

2. Research: methods and materials

2.1 Correlation analysis of in situ (ship-based) measurements between 1975 and 2005

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Abstract

Water quality in the North Sea is monitored by Rijkswaterstaat (RWS) during 2-weekly and monthly cruises since 1975. The resulting in-situ measurements over 30 years are stored in the DONAR database. An analysis of the co-variation between CHL or TSM and the other water quality parameters in the database was performed in order to determine whether or not the latter parameters can be mitigated using Chl and TSM measurements from optical remote sensing in addition to, or as replacement of, data collection by ships.

The dataset was split in two separate parts, 1975-1987 and 1988-2005, as these periods differed in spatial sampling patterns and measuring techniques. For the majority of the examined data pairs (parameters and locations) the cross- and auto-correlations are of the same order. This implies that estimates of a specific parameter based on measurements of preceding years, are as good as estimates based on TSM or Chlorophyll. Correlation coefficients and time shifts found during the second period 1988-2005 (with a reduction in the number of sections to about 4 and the number of stations reduced to 20 in the end, Fig. 2) were very similar to the correlation coefficients and time shifts found during the first period 1975-1987 (when 10 sections along the Dutch coast were sampled with 74 stations in total; Fig. 1).

The major dissolved nutrients Nitrate, Phosphate and Silicate had an inverse seasonality compared to Chl. Positive correlation coefficients between winter nutrient peaks and spring/summer Chl peaks were found in the coastal zone. There were also relatively strong negative correlations between nutrients peaks and spring/summer Chl concentrations with zero or small time shifts. For Chlorophyll the largest positive cross correlation with near-zero time shift was found with Particulate Nitrogen, as both parameters peaked during spring/summer. Total Suspended Matter showed the largest correlation with near-zero time shift with Particulate Phosphorus, and both peaked during late

autumn/winter. Presumably, (dissolved) Phosphate absorbs to silt particles and then part of the dissolved pool is measured as particle bound substance.

Concentrations of the parameters as well as the auto and cross-correlations were largest in the proximity of the shore. At distances of more than 20 or 30km lower concentrations predominate and the sensitivity of the spectral analysis decreased. This hampered firm conclusions regarding the offshore zone. The observed correlations could be underestimates due to physical processes occurring at short time scales (storms, tidal currents) but the very nature of the physical and bio-chemical processes in the ecosystem of marine waters does make it highly unlikely that useful correlations valid for a larger spatial scale will appear.

No clear trends in Chlorophyll nor in TSM concentrations were found for the periods 1975-1987 and 1988-2005. The only parameters with a non-seasonal trend were Phosphate and pH that showed a decrease in the second period 1988-2005.

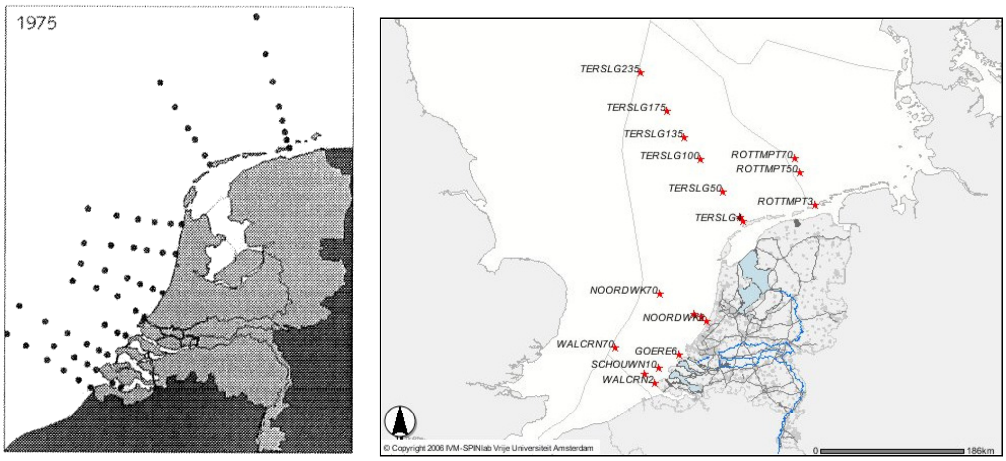

Figure 1. *MWLT sampling stations in the period 1975 – 1988 (left), and 1989 to present (right). Distances on the North Sea (scale bar on the lower right indicates 186 km), and MWTL monitoring stations in the Netherlands Continental Shelf (NCP) (source: IVM-SPINlab, 2006).*

2.2 Validation of earth observation data

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Abstract

Water quality monitoring is an essential part of the monitoring programs of the North Sea countries, required by international regulations such as the EU Water Framework Directive or the regional OSPAR Agreement (equivalent to HELCOM in the Baltic). There is a special requirement to detect the spring mean and maximum chlorophyll-a concentration, which are used as OSPAR Common Assessment Criteria for determination of eutrophication status. The quality of surface water in the Dutch coastal zone is currently monitored through periodical ship-based measurements of a number of parameters at a network of fixed stations. However, representative spatial patterns of water quality parameters cannot be produced using these traditional in situ sampling techniques. Parameters such as the concentration of total chlorophyll can alternatively be measured using optical remote sensing.

Validation of this data is critical if end-user confidence in the resulting products is to be achieved. Satellite data are collected at different spatial scales and invariably at different times to the in situ measurements, so novel ways of comparing these different data sources need to be examined.

We report on a method, which is based on a comparison of both satellite and in situ data (for a given year) with the long-term seasonal trend, derived from an analysis of a 10-year time-series of in situ measurements. A trendline with prediction intervals is constructed, accounting for seasonal variation, thus giving insight into the 'natural' variability of the system, at each measurement location. The in-situ measurements and values derived from remote sensing are then compared with this trendline with respect to the bias and the variance. Results are reported for the 2003 SeaWiFS (with appropriate turbid water atmospheric correction) and MERIS data.

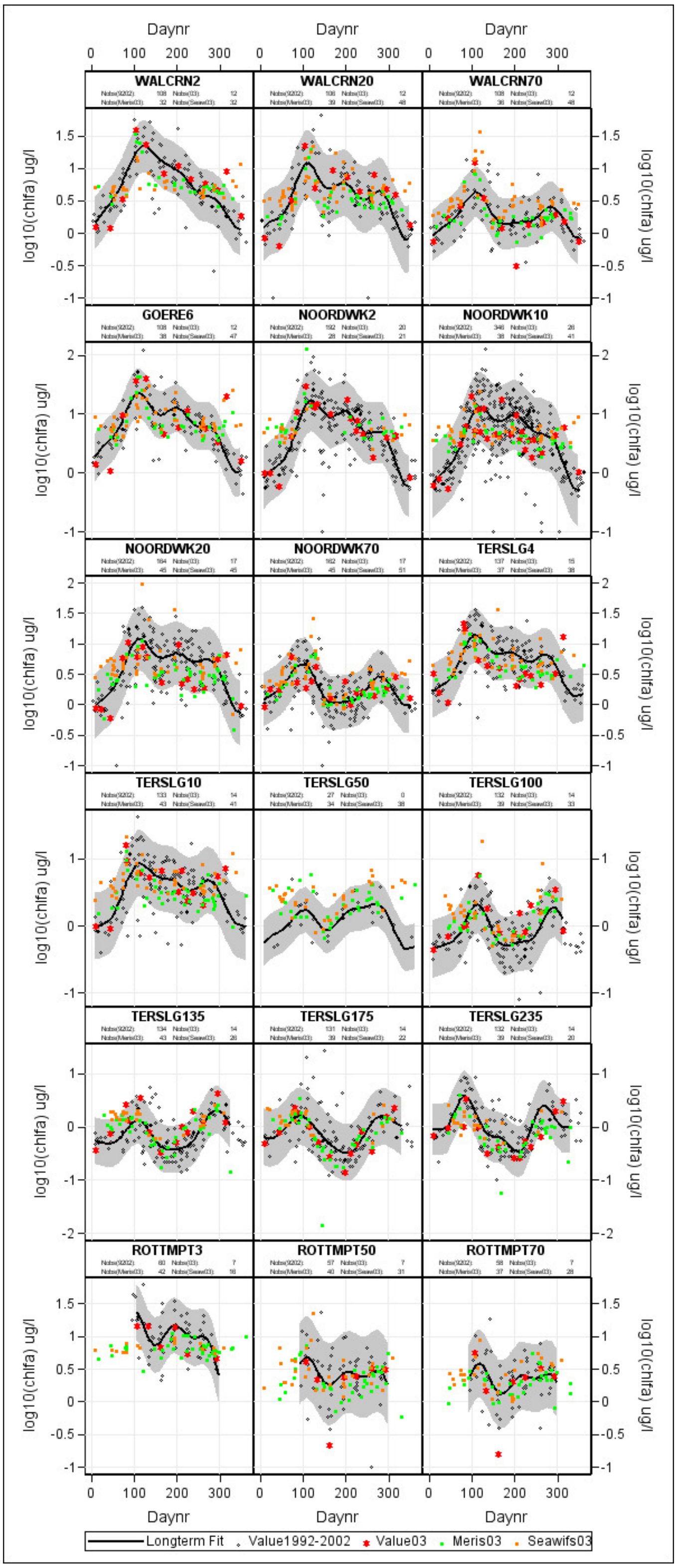

Figure 2. Time series plots of chlorophyll-a from the different sources for several locations. The black line is the model outcome for 1992-2002; red dots = in-situ measurements of 2003, green dots = MERIS data of 2003 orange dots = SeaWiFS values of 2003.

2.3 Plume and bloom: water masses and productivity in the southern North Sea

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Abstract

During the cruise program 'Plume & Bloom' (NIOZ/ALW, 2000-2002) in the southern North Sea it was discovered that the East Anglian Silt Plume hides a 'river of English Coastal Water'. This water mass contains remnants of the UK rivers Humber and Thames. Like the diluted Rhine Water along the Dutch coast, the 'river' is phosphate-limited and contains relatively high concentrations of nitrate and ammonia during late spring and summer. Diatom blooms occur where this N-rich water becomes less turbid and mixes with other water masses. Current monitoring of the Dutch side of the southern North Sea by monthly cruises by Rijkswaterstaat (RWS) does not include a proper coverage of the East Anglian Silt Plume and the 'river of English Coastal Water' when these enter the Dutch EEZ. It is proposed that underway sampling in between the present Noordwijk and Terschelling sections should frequently map the position of Plume and 'river' within a south-north section along 3° 30' East in order to recognize the input of inorganic and organic material from the British into the Dutch EEZ. Satellite images of SPM and Chl may help to map the spatial pattern of water masses and should be able to detect diatom blooms along the rim of the Plume and near the Frisian Front during summer.

A 'river of English Coastal Water' across the central Southern Bight

'Plume & Bloom' was a NIOZ cruise program in the years 2000-2002 (funded by NWO/ALW) in the offshore southern North Sea. The study area comprised the East Anglian Silt Plume, consisting of eroded cliff material, and downstream the Frisian Front, the slope where the Plume (temporarily) sinks out. It was discovered that the productivity of this part of the North Sea is not only largely influenced by the turbidity associated with the East Anglian Silt Plume but also by remnants of UK rivers. The Silt Plume hides a 'river' of English Coastal Water with lower salinity (ca. 34), originating mainly from the Humber and the Thames. The 'river' is bordered by Central North Sea Water (salinity > 34.5) in the northwest and by Channel Water (salinity ca. 35) in the southeast, and extends well into the area of the Frisian Front (Fig. 3). The tongue of Channel Water forms generally a clear separation between the English Coastal Water and the Continental Coastal Water (< 34), up to 4° 30' E or beyond.

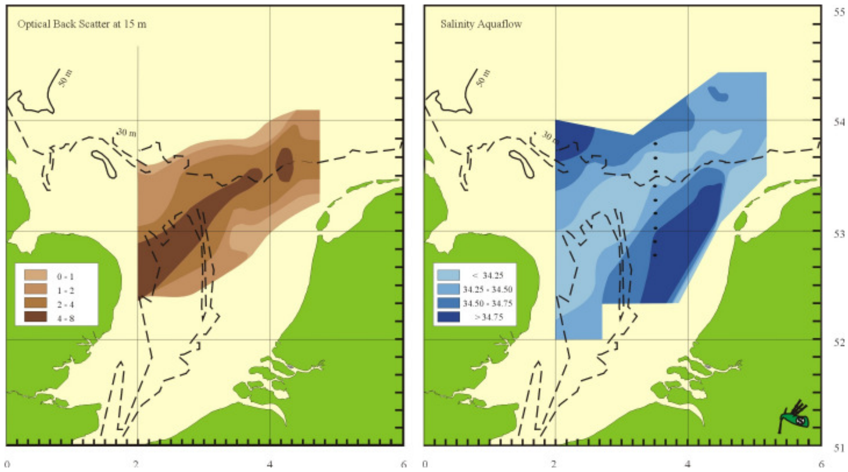

Figure 3. *Turbidity (left) and salinity (right) during Plume & Bloom 2, 11 – 21 September 2000 (RV Pelagia). Turbidity was measured at a depth of 15 m by an Optical BackScatter sensor (Formazin Turbidity Units) on the CTD Rosette Sampler, at stations spaced 7.5 nautical miles in north-south direction. Salinity was measured continuously by Aquaflow pump system (inlet 4 m depth), and calibrated during CTD stations. During this September cruise no stratification occurred in the study area. In the salinity map the stations of the standard central section along 3° 30′ E are depicted.*

This water mass pattern is very robust. A central north-south section along 3° 30′ East was surveyed regularly by R/V Mitra (Rijkswaterstaat) and R/V Pelagia (NIOZ), in addition to the Plume & Bloom cruises, and the 'river' of English Coastal Water was recognized in all surveys, 15 in total, that were made. Storms did not mix the water masses, but merely shifted the positions. The 'river' of English Coastal water and the tongue of Channel water responded faster to strong winds than the suspended matter of the Silt Plume. Consequently, there was a large variation in the positions of 'river' and plume (Fig. 4), but generally the 'river' was situated at the northern side of the Plume due to the predominance of southwestern winds. Along 3° 30′ East, the Plume had an average width of circa 40 km in north-south direction, whereas the 'river' was usually more narrow, with a mean width of only 25 km.

Winter nitrate values in the 'river' were twice as high as in the adjacent water masses. The turbidity in the Silt Plume did not prevent a spring bloom and nutrients in the 'river' were depleted early May, one month later than in the tongue of Channel Water. Thereafter, however, both nitrate and ammonia in the 'river' became relatively high again. A N/P ratio >25 suggested that P-limitation was responsible for this 'preservation'. The occurrence of diatoms along the northern rim of the 'river' in summer could be due to mixing with the adjacent Central North Sea Water, that was N-limited (N/P < 5).

Similar phenomena along the 'nitrate river' may occur downstream at the Frisian Front. Here a large part of the spring (and later) blooms mineralizes, and the sediment-water fluxes of nutrients could supplement phosphate and silicate. The occurrence of summer/autumn blooms near the Frisian Front seems to depend on the position of the 'river' and the light conditions. Above the mud-rich slope zone, turbidity was generally high, due to tidal resuspension. With strong SW winds, the 'river' ended well north in the Oyster Ground, where water column depth was too large to give dense blooms. With strong NW winds, the 'river' was pushed on the upper slope and the shallow sands (Fig. 5). This could explain 'green curtains' of diatoms, as observed in the past (1982, 1990, 1997) just south of the Frisian Front.

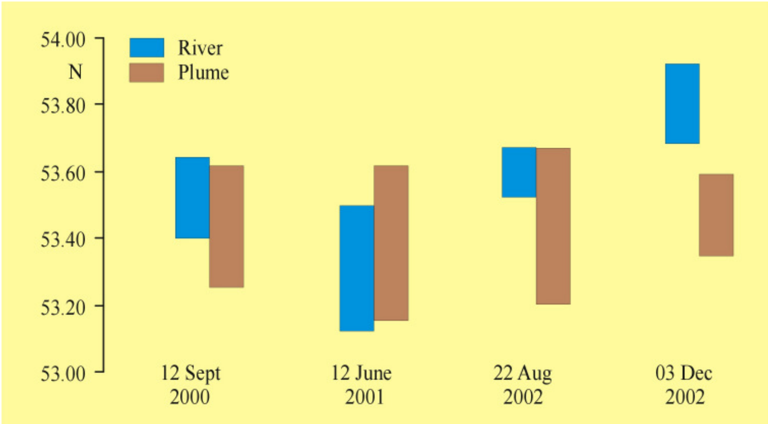

Figure 4. *North-south positions of the borders of the 'river' of English Coastal Water (blue) and of the East Anglian Silt Plume (brown), along 3° 30' E. The salinity of the 'river' was defined as < 34.25. The borders of the Plume were arbitrarily determined from the OBS readings at CTD stations (Sept. 2000) or from continuous readings by OBS sensor in the Aquaflow system (June 2001, Aug. 2002, Dec. 2002).*

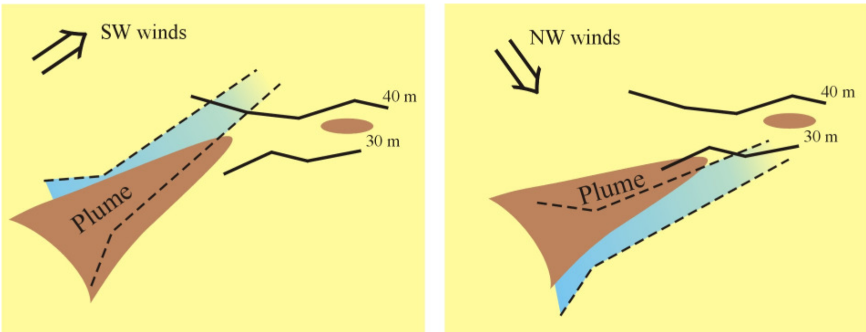

Figure 5. Cartoon of the position of Plume (brown) and 'river' (blue) in different wind conditions. The brown ellipse denotes the 'Frisian Front', the mud-rich bottom part of the southern slope of the Oyster Ground.

Do the RWS monitoring sections cover Plume and 'river'?

The East Anglian Silt Plume has become a well-known phenomenon since the widespread distribution of North Sea satellite pictures by the Coastal Zone Color Scanner (that operated 1978-1986), followed by the new series of pictures by recent satellite sensors like SeaWiFS, MODIS and MERIS. The recent discovery that the Silt Plume hides a 'river of English Coastal Water' makes it an offshore analogue of the turbid plume of Rhine water along the Dutch coast: a zone of lower salinity with higher turbidity. The current monitoring effort by RWS at fixed geographic stations along the main standard sections Noordwijk and Terschelling, have not been able to recognize the input of inorganic and organic material from the British EEZ into the Dutch EEZ. The site where Plume and 'river' enter the Dutch EEZ is on average around 53°30' N, 3°00'E, in between the Noordwijk section and the Terschelling section. The wind direction and force have a strong influence on the actual position of Plume as well as of the 'river'. The Plume deposits its load (temporarily) at the Frisian Front, i.e. the southern slope of the Oyster Ground. RWS station TS50 is situated above this elongated, muddy slope zone. The 'river' enters the Oyster Ground generally in between TS 100 and TS50. The Oyster Ground area (system 8 'Central Part of North Sea') was regarded by RWS as an offshore area with salinity >34.5. The presence of the 'river' at the section explains a large number of the salinities below 34.5 that occur in the RWS DONAR database. Sometimes, the tongue of Channel Water reaches sufficiently north and is still recognizable at the Terschelling section. In the continuous salinity registrations, the high salinity of the Channel Water then forms a nice separator between the Continental Coastal Water and the English Coastal Water. However, more often the water masses have partly or largely mixed at the position of the Terschelling section and only remnants of the original salinity signal will be found.

Note that it is not possible to find reliable data on the English Coastal Water at TS50 or TS100 in the RWS data base. The large salinity variation at TS50 is due to the fact that any of the four main water masses described above might occur here, or a mixture of remnants. Without additional spatial information, it is generally impossible to distinguish water masses at these transition stations. During prolonged eastern winds, even stratification of similar salinities has been observed this far offshore, with Continental Coastal Water (from the German Bight) on top of English Coastal Water.

Table 1. Salinity variation observed at offshore stations (Terschelling)

Station	minimum	maximum	range Sal
TS 50	33.53	35.09	1.56
TS 100	33.73	34.88	1.15
TS 135	34.22	34.98	0.76
TS 175	34.23	35.05	0.82
TS 235	34.51	35.12	0.61

In the present sampling effort, observations on the western influx of the East Anglian Silt Plume and the 'river of English Coastal Water' are absent. However, it is relatively easy to include this water mass: by sampling on the transit voyage from the Noordwijk section to the Terschelling section. From station NW70 northwards along 3°30' E, for example, similar to the standard section of the NIOZ program 'Plume & Bloom' (2000-2002);

The differences in turbidity between water masses suggest that the position of the water masses can be observed from space for RWS-systems 6 ('Coastal Zone') and 7 ('Southern Part of North Sea'). A tongue of clearer Channel Water lies in between the turbid area along the Dutch coast, representing the zone of diluted Rhine water, and the Silt Plume across the North Sea, representing the 'river of English Coastal Water'. The lower salinity (on average) in both turbid zones implies riverine nutrient input and this means high winter nutrient levels. Note that the remnant of Rhine water remains turbid all along the Dutch coast, but the 'river of English Coastal Water' (the remnants of Thames and Humber) becomes clear in the Oyster Ground area (system 8 'Central Part of North Sea') as the Silt Plume is 'trapped' by the Frisian Front.

Simulation models

Several 3-D hydrographic models of the North Sea are currently extended with biological systems and one of the most promising is possibly the simulation model developed by CEFAS (Lowestoft) and NIOZ (Texel). The physical parts - GETM for the 3-D structure and GOTM for the 1-D vertical structure – are driven by actual weather conditions. A relatively sophisticated BFM submodel (based on ERSEM) simulates the chemistry and biology in water column and bottom. The resolution of this 3-D model is not very high (boxes of 10 x 10 km) but turns out to be sufficient to generate the 'river' of English Coastal Water across the southern North Sea. Currently there is still a lack of simulation models on the sedimentation and resuspension of both the inorganic and the organic matter, and thereby still practical in view of processing time. An appropriate submodel for the dynamics of suspended particulate matter is highly warranted for calculations of the transport and budget of silt as well as nutrients in the North Sea. Without such a submodel, it will be impossible to translate satellite observations of SPM and Chl into fluxes across the North Sea.

Final remarks and conclusions

The East Anglian Silt Plume and the 'river of English Coastal Water' are conspicuous phenomena of cross-border transport of suspended matter and riverine nutrients at the western side of the Dutch EEZ that are not covered by the current monitoring effort of Rijkswaterstaat.

Satellite images of the Silt Plume could generally indicate the position of the 'river of English Coastal Water'. Absolute SPM values cannot be easily used as proper index for salinity. The mutual positions of Silt Plume and 'river' are variable, and depend on wind history and actual wind conditions. The absolute values of SPM in the Silt Plume depend on wind conditions as well as the recent history of erosion of the English cliffs during storms.

The Frisian Front is the temporary deposition site of the Silt Plume. By tidal resuspension of the mud-rich bottom along the slope of the Oyster Ground the Frisian Front is often visible in SPM satellite images as the extended part of the Silt Plume.

With the improved distinction by modern satellites and algorithms between TSM and Chl, it should be possible to distinguish conspicuous diatom blooms associated with the Silt Plume and the 'river of English Coastal Water'. These diatom blooms should even occur during summer: a) along the northern rim of the Silt Plume, when the 'river' is on the northern side of the Plume, and b) south of the Frisian Front when there is a period of strong northwestern wind and the 'river' flows over the shallower sands just south of the mud-rich slope.

Frequent monitoring of the silt plume and 'river' can most easily be done by incorporating a south-north section in between the Noordwijk section and the Terschelling section. Satellite maps of SPM and Chl alone will not be able to estimate the transport of riverine nutrients by the 'river of English Coastal Water' nor of the transport of suspended matter originating from cliff erosion by the Silt Plume. Most promising in this respect is maybe a new generation of 3D-simulation models of the North Sea that include proper sedimentation-resuspension submodels. Satellite images are applied in validating the model results. When combined, these techniques result in 3-D models of surface observations.

2.4 Patterns and dynamics in chlorophyll and TSM-densities in the southern North Sea

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This contribution explores the use of geostatistics to describe patterns in parameters (CHL & TSM) derived from remote sensing. In this study we deal with multiple grids of water quality parameters from many RS images. In addition, we expect an inherently large spatio-temporal variability in CHL and TSM concentrations. The North Sea is a highly dynamic coastal sea where large-scale circulation, tidal currents and riverine fresh water inputs mix. Resulting patterns will also be disturbed (masked) by clouds. Therefore a new methodology had to be developed to study these patterns in CHL and TSM concentrations from remote sensing through the study of variograms. Resulting information can subsequently be used to derive an optimal siting of sampling stations, ensuring that the variation is captured.

Remote sensing data does not only give information about radiance; it also provides a spatial overview, and shows patterns in these data. A (semi)variogram is a description of spatial variance. Semivariance is based on the common notion that the value of two points closer to each other, are likely to be more similar than when further apart. An estimate of semivariance ($\hat{\gamma}$) is derived from $\vec{h}$ lag distance, *n* number of observations, *z* is the value, $\vec{x}_i$ is location:

$$\hat{\gamma}(\vec{h}) = \frac{1}{2n(\vec{h})} \sum_{i=1}^{n(\vec{h})} \{z(\vec{x}_i) - z(\vec{x}_i + \vec{h})\}^2$$

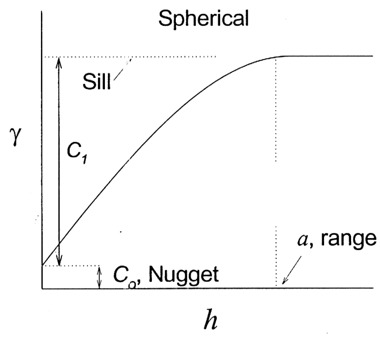


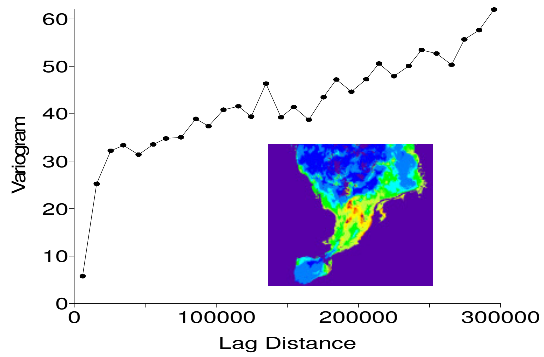
Figure 6. *Schematic semivariogram. A variogram is the plot of semivariance against distance between point pairs (lag distance) (Figure 1). It is a tool for identifying and quantifying spatial variation at different scales.*

Data and method

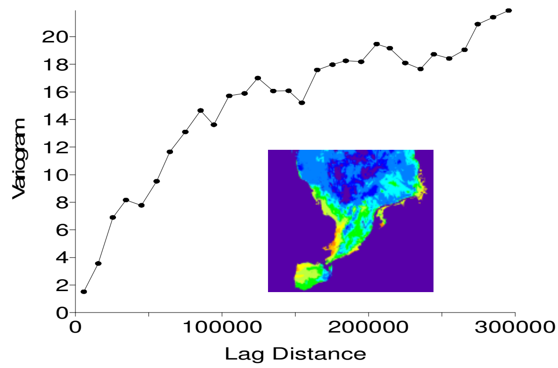
IVM was provided with WADI XML files containing either CHL (in µg/l) or TSM (in mg/l) values plus meta-information. Grid cells representing clouds or land are present within the CHL and TSM data as the value -9999. Matlab programs were created to process these XML files to quicklooks for fast visualisation, and to perform random sampling extraction of CHL and TSM values from the North Sea area.

After exploring the individual results, and based on observations of a log normal distribution of bio-optical variability in the sea, a program was made to calculate bi-monthly geometric means in order to overcome the influence of clouds on the sampling, and subsequently on the description of the pattern. Subsequently, our program to generate quicklooks and sample the North Sea was re-applied. From the samples, several experimental variograms were produced using Surfer.

Chlorophyll CHL



Total suspended matter TSM



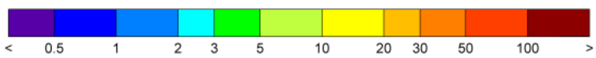


Figure 7. *Variograms for SeaWiFS CHL and TSM data for 15 May 1998, showing multiple algal blooms off the UK East Anglian and Dutch coast. High semivariance shown here indicates large variation of CHL – and strong correlation at lag distances < 30 km. There is spatial dependence up to lag distances of 175 km. The TSM results also show lots of activity in the North Sea with a long range of correlation. In May we typically expect algal spring blooms in the North Sea (page 30), but TSM also is relatively high. Usually TSM concentrations are low because of low resuspsension under moderate wind conditions.*

Geostatistical validation

The presented examples gave a statistical description of the data plus an interpretation focusing on the distance between (monitoring) points. Omnidirectional variograms were used in this study, but a first analysis has shown that the geography of the North Sea causes variability to be largest in certain directions. Variogram modelling confirms that variance is largest in a direction perpendicular to the coast: an anisotropy ratio of 2 and angle of 135°. To validate the descriptive value of the omnidirectional experimental variograms, variogram modelling followed by kriging was applied for reconstruction of the maps.

Geostatistics can be used to describe the patterns in the CHL and TSM products, which result from in spatial variability in optical properties. Large variation in spatial correlation was perceived between different parameters (CHL and TSM) of single images, and between single images of different dates. This seems to indicate that the retrieved CHL and TSM are not much correlated, and that the individual images (287 TSM and 287 CHL from September 1997 to December 2004) might actually under-sample the extremely variable conditions, which are due to the intricate interplay of multiple driving forces and processes.

In further research, remote sensing data could assist in the spatio-temporal interpolation of *in situ* measurements using regression kriging. In addition variograms can be applied for optimization of spatial sampling scheme design – e.g. through simulated annealing – after the optimization criterion has been discussed.

3. Discussion and analysis of added value

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3.1 In-situ **measurements**

Variance of most parameters in the MWTL data set of the North Sea is governed mostly by the season. Analyses of in-situ data performed by ARGOSS (Chapter 2.1) demonstrates that the present monitoring program does capture the multi-year trends but barely allows to distinguish variability within the seasonal cycle. In-situ sampling frequency is too low and too regular (monthly or biweekly) to see tidal and storm effects.

The importance of quality controlled data for the analyses of historical time series is illustrated. Monitoring aims at collecting comparable data over a long time period, therefore it is a first requirement to know the quality and limitations of the data and its source. More specifically most of the variance in chlorophyll and total suspended matter has a seasonal nature. The contribution of linear trends in this data is small or undetectable. Chlorophyll and TSM are considered to be unreliable substitutes for monitoring other parameters, although cross correlation for some parameters are considered high. This feature is attributed to either mutual seasonal behavior or unambiguous parameter definitions with corresponding laboratory analyses that imply that parameters cannot considered to be uncorrelated.

For a better grip on higher order frequencies of the ecosystem the temporal sampling strategy of the monitoring program needs to be reconsidered. Continuous time series are collected best with in-situ sensors. Preferably, this is done with completely automated stations on Buoys or Ships of Opportunity. Adding earth observation as information source will considerably improve the monitoring of chlorophyll, suspended matter and light extinction because of greater temporal and spatial coverage. The spatial component is further discussed in paragraphs 3.3-3.4.

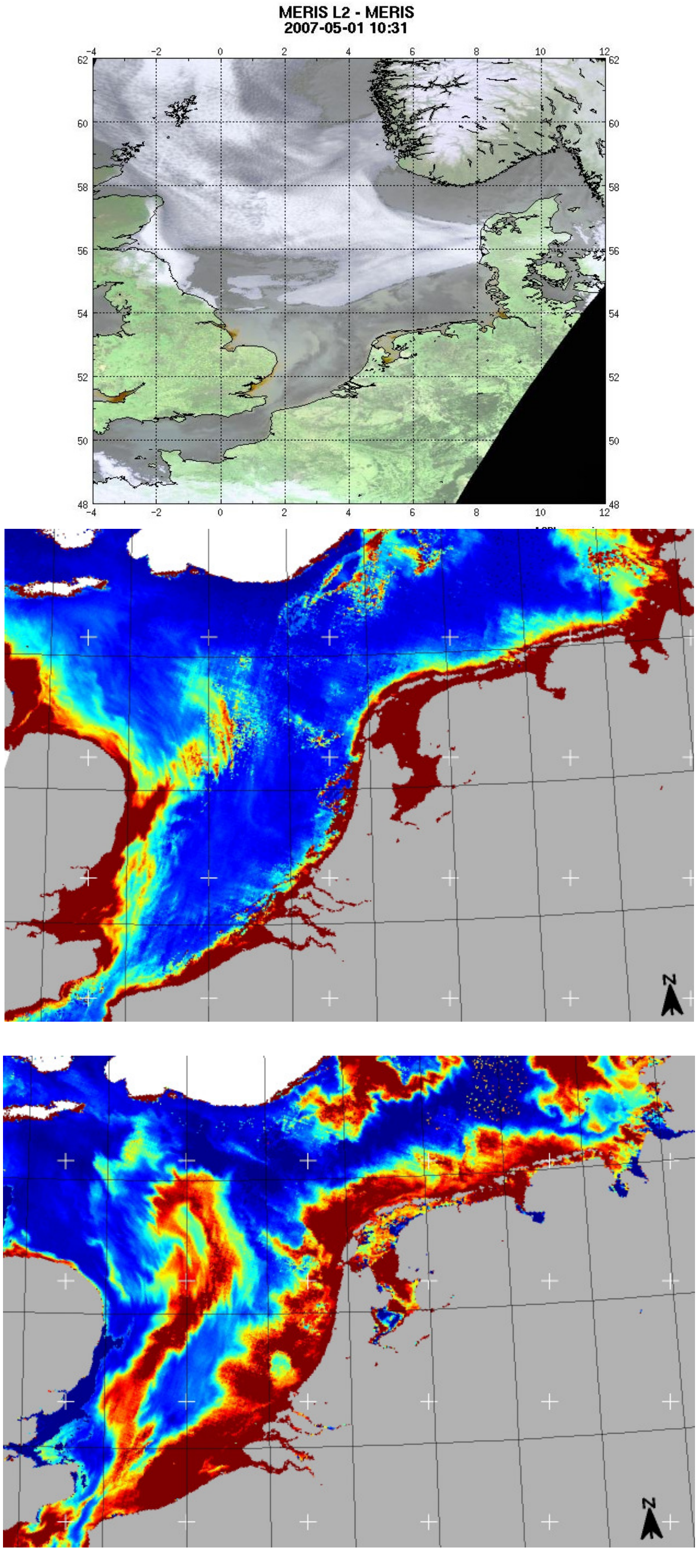

Figure 8. *MERIS image for 1 May 2007 in visible light (top) demonstrating cloud cover over the North Sea and land vegetation patterns. Images below are the derivatives for suspended matter (middle), demonstrating muds around the UK coast and silts in the Dutch surf zone; and chlorophyll (bottom) with massive algal blooms in the eastern and central North Sea.*

3.2 Validation

Validation of earth observation data in relation to in-situ data is critical to end-user acceptance. However, validation is not straightforward and requires the development of proper statistical framework, which can tackle different spatial scales and the asynchronous sampling.

With ToRSMON, Rijkswaterstaat presents a solid first validation step. As demonstrated in Chapter 2.2, historical time series were used to build up a frame of reference, a prediction model that includes most of the seasonal variation of the parameters. Confidence improving results were found for both chlorophyll and total suspended matter, when compared to this reference model and its prediction intervals. In 2007 further steps will be taken within the Ovatie-2 project to fine-tune data validation and quality control in SEAWIFS, MERIS and MODIS-series. Ovatie-2 will provide Rijkswaterstaat with tools to run quality-checks on earth observation products delivered by service providers. In the future Rijkswaterstaat may require demonstrated reliability and quality before using the validation tools provided within this project.

MarCoast is a three year GMES (Global Monitoring for Environment & Security) project to establish a durable network of marine and coastal information services (http://gmes-marcoast.com). MarCoast delivers information services under Service Level Agreements, with the objective to qualify the service portfolio as fit for purpose. To this end, a Water Quality validation workshop was organized in March 2007 (IVM Amsterdam). Attendees included national, regional (European) end-users, ocean colour scientists, and service providers, including all ToRSMON partners. The workshop reached the following conclusions that are relevant to ToRsMON:

- The quality of in-situ chlorophyll-a measurements depends strongly on the method applied. HPLC is the most accurate method and this is used for calibrating the chlorophyll algorithms applied by ESA and NASA. Still an uncertainty of 20% - 30% was found in round robin experiments.
- Chlorophyll concentrations from satellites are equivalent to in-situ measurements established by match-ups and statistical tests. The differences are of the same magnitude as the error of the in-situ measurements.

At present the technical specification of the accuracy of earth observation can be qualified as an educated guess of the service provider. A consistent way, for instance a product sheet with these technical specifications, to inform the users has not been developed yet and if a specification is not delivered, then the users cannot evaluate it without building their own frame of reference. Therefore quality description of earth observation products still seems to be in the state of research. In the end Rijkswaterstaat expects products with known quality limitations. If a detection limit varies as a function with season, then this fact needs to be reflected in the specifications of the product.

However, stabilization in quality standards of earth observation products. Basic products chlorophyll and TSM (SPM) are considered to be of acceptable quality in absolute terms with respect to the known quality of in-situ results for most of the year, with exception of the winter period. The MERIS products are considered to be more reliable then SEAWIFS products. The reproducibility of earth observation products is guaranteed when using one algorithm with a fixed tuning. Opposite to this advantage is that every change in algorithm or tuning implies a direct risk to reproducibility. With different service providers competing the end-users needs a firm grip on validation to keep control over the quality of the products.

3.3 Plume and bloom

The time series of the in-situ monitoring form in essence the base of our knowledge of the North Sea ecosystem. The design of every monitoring program is the result of assumptions and compromises based on what we know of the system and of what we want to know of the system. The present program is aimed at trend detection with a strong emphasis on the input of the Rhine, but is this design sufficient or does the program miss important information?

For keeping track on the eutrophication problem in the Dutch national water for OSPAR a tight control on the incoming nutrient fluxes is essential. Chapter 2.3 demonstrates hat our monitoring misses a major eutrophication source. British river water is crossing the southern North Sea into our national waters, causing locally massive algae blooms. The similar physics also cause a turbidity plume, with underlying a sediment transport route in the same area called the east-Anglia plume. Plume, bloom and fresh water flux are interconnected. The dynamics of these phenomena are explained in the article of Martien Baars of NIOZ. Our current program is not designed to monitor these transboundary fluxes of nutrients. It was designed to keep track of input the Rhine, however this fresh water sticks to the cost causing strong transversal gradients to the coast.

The monitoring strategy misses a good foothold to keep track of this eutrophication source. Earth observation provides essential information to keep track of the plume and the bloom dynamics, however what also is missing is information about nutrient combined with salinity to keep track of the incoming flux of fresh water from the UK Coastal zone. So the in-situ program still needs to be supplemented with an extra foothold if the needed information cannot be retrieved form UK monitoring sources.

3.4 Spatial correlation

The insights provided by the spatial analyses of chapter 2.4 performed by IVM indicate that the spacing between present monitoring stations are well chosen to register the intrinsic variability of the North Sea system. Also the design of the network is consistent with the anisotropy in the system. In the long-shore direction data points are stronger correlated, than in the direction transverse to the shore.

The work is recognized as a first reconnaissance study of spatial analyses of remote sensing images of the North Sea. With respect to the temporal component it is identified that spatial patterns and correlations do change as a function of time. Also Chlorophyll and TSM have different spatial patterns. This information is consistent with the knowledge of dynamics of this area.

What the study also demonstrates is that earth observation is an ideal source of information for monitoring strategy design. The North Sea can be subdivided into localized water masses and zones with specific optical features and hydrodynamic behavior. At present, statistical analysis of the spatial and temporal variations of the data is the best objective way to optimize the monitoring sampling strategy. The distribution of monitoring stations (and types) could be optimized using model simulations supported by remote sensing data.

4. Cost Analysis

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4.1 Service model costing scenarios

Rijkswaterstaat may consider five scenarios elaborated below: three from own, institutional perspectives; and two from the perspective of aggregated Dutch or European data centers. The costs given per scenario are first estimates.

Aspects of the costing of Earth Observation for Rijkswaterstaat are:
- obtaining data
- value adding
- quality control and validation
- data management
- maintaining necessary expertise
- user software

To demonstrate costing aspects of the earth observation production chain we consider:
- Organization of the production process. Who does what?
- Maintaining and guarantee (local) expertise. Where can I go with questions?
- Quality assurance. Who is responsible?

Remote sensing end-products (e.g. jpeg picture files) relevant to optical monitoring of the North Sea, provide a low-effort, easy to use service that does not require extensive user-interfaces or high level of scientific understanding. However, before satellite data lands on the desk or screen of an end-user several stages of processing have been performed.
- Level 0: Calibrated data at the sensor
- Level 1: Calibrated geo-referenced radiance data at the top of atmosphere
- Level 2: Geophysical product at earth surface
- Level 3: Specific products for user

For the user only level 3 data is of interest. In general the processing up to level 2 should be performed by the space agency. However, when the standard atmospheric correction isn't sufficient the products of the space agency are products of level 1. This is the case for MODIS & SeaWiFS, and sometimes even for MERIS. Maps and images from data providers and space agencies are made available to the end-user by

processing up to level 3 ('value adding'), commonly through commercial service providers, including universities.
Rijkswaterstaat intends to involve commercial service providers through the market mechanism, i.e. on basis of competition. However, for monitoring purposes reproducibility and quality of all data sources needs to be secured. At present the quality of the data and the validity of processed, value added products is primarily controlled by the service provider and processing models used. To perform independent quality control, Rijkswaterstaat assess the characteristics of used models. Expertise, indoor as well as independent is scarce. Most experts are linked to specific service providers. Limitation of expertise and capacity within Rijkswaterstaat determines the costing scenario that may be chosen for this product service.

At present the basic level 2 dataset of most optical satellites is available for free form the space agencies. However for many satellites you have to pay per image, especially for high resolution and near real-time products can be substantial. Therefore the 'level 2' data set is the first data set, which needs to be collected from several distributors (ESA, NASA,.) to be ready for the next processing step the value adding. The data collection costs time and therefore comes with specific costs.

For the next series of questions we have to choose between with Rijkswaterstaat, Commercial Service Provider or special remote sensing data center, which can be national or European.

-Who will to collect suitable level 2 data from space agency?
-Who owns the data after this task is performed?
-Who will to store the collected level 2 data?
-Who will to do basic processing (value adding) up to level 3?
-Who owns the data after the basic value adding is performed?
-Who stores processed basic level 3 data?
-Who produces user specific end products?
-Who supplies user-friendly applications for data handling?

Scenario 1 – Rijkswaterstaat-owned (self-supporting)

In this scenario Rijkswaterstaat personnel would do all aspects of data delivery and quality control.

Estimated costs		
topic	*fte*	*budget (k€)*
obtaining data (level 2)	0.2	20
value adding (level 3)	0.4	20
quality control and validation	0.4	20
data management	0.2	20
maintaining expertise	1	100
special user-software	0.2	20
totaal	2.4	200

Advantages

- Independency and full control
- Gives Rijkswaterstaat high technology and knowledge profile

- Rijkswaterstaat may exert strong influence in EU-circles (development of the Marine Core Services)
- Rijkswaterstaat Users are optimally supported

Disadvantages
- Data management structures presently unfit
- This scenario requires a significant amount of (specialist) manpower (1 fte).
- Rijkswaterstaat presently misses the required expertise to be fully self-supporting in Earth observation to choose for this approach; therefore a strategic scientific partner would be a necessity.

Scenario 2 – Service providers with Rijkswaterstaat data management

Specific activities lead to specific products (Rijkswaterstaat wants to own all intermediary products).
- The collection of level 2 data results in a dataset
- Basic Value adding on the level 2 dataset results in a basic level 3 dataset.
- Aggregation and further upgrading of the level 3 products.

These assignments can be specified and put out to tender by Rijkswaterstaat. This approach is very flexible, but it still requires a lot of internal expertise. When necessary to guarantee the reproducibility a license could be considered for specific model for value adding.

Estimated costs		
topic	*fte*	*budget (k€)*
obtaining data (level 2)	0.2	20
value adding (level 3)	0.2	50
quality control and validation	0.3	30
data management	0.3	30
maintaining expertise	0.5	50
special user-software	0.2	20
totaal	1.7	200

Advantages
- Rijkswaterstaat controls data flows
- Rijkswaterstaat stores products and has easy-access
- Centralization of services

Disadvantages
- Same arguments as under scenario 1

Scenario 3 - Tender for a commercial service

Service providers may provide end products. In previous years, the low-level of quality assurance has prevented this scenario from being operational. However, validation and quality control are now better developed. An independent validation bureau could support these services.

The market is small, typically a specialist niche-market, which is certainly not full-grown. The number of clients is limited for the water related products. There are many service providers working with subsidies or scientific grants (sponsored by ESA, NIVR or GMES).

Estimated costs		
topic	*fte*	*budget (k€)*
obtaining data (level 2)		
value adding (level 3)	0.3	80
quality control and validation	0.4	40
data management	0.2	20
maintaining expertise	0.2	40
special user-software	0.2	20
totaal	1.3	200

Advantages
- Rijkswaterstaat controls data flows
- Rijkswaterstaat stores products and has easy-access
- Centralization of services
- Connection with validation bureau and science networks (Deltares)

Disadvantages
- same as Under 1.

Scenario 4 – Rijkswaterstaat as consumer-client of a national remote sensing data center

Estimated costs		
topic	*fte*	*budget (k€)*
obtaining data (level 2)		
value adding (level 3)	0.2	20
quality control and validation	0.2	20
data management	0.2	20
maintaining expertise	0.2	20
special user-software		
totaal	0.8	80

Advantages
- National expertise and clients would have a clear focal point
- Subsidies would enable Rijkswaterstaat to be a (sponsored) consumer of a national remote sensing data center.
- There are no costs for data management and storage.

Disadvantages
- Rijkswaterstaat Earth observation would be an aside of the monitoring, which is internally not even considered a primary task of Rijkswaterstaat.

- Difficult to be a critical client and have full awareness of application and validation.

Scenario 5 - Rijkswaterstaat as consumer-client of European Marine Core Services

The development of the G-MES marine core services could mean, that in the future Rijkswaterstaat is provided with earth observation products by the European Union at low or no costs.

Estimated costs		
topic	*fte*	*budget (k€)*
obtaining data (level 2)		
value adding (level 3)	0.2	20
quality control and validation	0.4	40
data management	0.2	20
maintaining expertise	0.2	20
special user-software		
totaal	1	100

Advantages

- Subsidies would enable Rijkswaterstaat to be a (sponsored) consumer of the G-MES data center.
- There are no costs for data management and storage, however distribution costs are estimated at € 20k.

Disadvantages

- Earth observation will always be a small part of monitoring and in this scenario it is extra vulnerable for cutbacks, because there are so very few people involved in it and they will have little expertise and commitment.
- National knowledge base in remote sensing erodes, because it is not supported.
- Quality control is going to be a problem, since standard processing is not going to provide with any reliable products in the turbid North Sea waters. For quality control regional expertise on in-situ conditions in relation to earth observations is vital.

4.2 Compliance of the project

A. What is the service developed within the Torsmon project?
The project has evaluated satellite observation of chlorophyll-a and suspended sediment on its complementing aspects for the Rijkswaterstaat monitoring program of the North Sea. Stakeholder and end-users are Rijkswaterstaat as the coordinating public water management agency (for the North Sea).

B. What are the cost specifications of the present (completed) project and what costs (risks?) are expected if this service were to be continued over the next five years?
In Torsmon € 267.000 was spent over two years, project management (WP0) € 22.500; articulation of information needs (WP1) € 33.000; analyses of data characteristics of ship measurements/MWTL monitoring (WP2) € 35.000; validation of remote sensing measurements (WP3) € 28.000 [development costs covered in other projects]; quality assurance and scientific coherence (WP4) € 46.000; spatial analysis of North Sea RS-data (WP5) € 73.500; costing and recommendations (WP6) € 29.000.

Costs of continuation of an Earth observation monitoring service are estimated at € 200.000 per year for Rijkswaterstaat, taking into account annual rise of costs, but not including costs for data acquisition (paying the space agency). MERIS and MODIS are expected to be available freely for public applications, because governments have paid ESA for the development. Costs come currently with downloading data and basic processing. This cost estimate is based on scenario tendering commercial fee, however as can be seen below (6.1) the three first scenarios have roughly similar costs.

C. What (commercial) revenues can be expected from this project over the next five years?
Depending on the choice of scenarios the service providers may find a profitable niche market covering roughly the estimate of annual costs made above. This level of government tendering for services is near the boundary were tendering in European competition is obligated. Or the whole service should be qualified as (non-operational) research. The service can be beneficial in liability issues.

5. Conclusions and Recommendations

1. **Does satellite observation of chlorophyll-a and sediment complement Rijkswaterstaat monitoring of the North Sea?**
Answer: yes, it provides greater coverage both in space and time.

2. **How does remote sensing fit within national programs and research?** Currently, remote sensing is described in EU, ICES or OSPAR framework only as a tertiary tool (or not at all). The European Marine Strategy (EMS) does not specifically request full special coverage of North Sea monitoring, but it does ask for a holistic integrated approach in system monitoring. National political attitudes tend to be conservative, maintaining current OSPAR and ICES monitoring (with compliance checks). However, the *in situ* program with fixed stations could be more efficient when extra (flexible) stations are added based on remote sensing observations.

3. **Why should we use remote sensing in addition to present monitoring tools?** Remote sensing provides a state-of-the-art tool for monitoring tasks required within OSPAR and EU directives. Internationally its application is widely implemented, for instance by EU research organisations as the Joint Research Centre (Ispra, Italy). Application of remote sensing in aquatic environments is underdeveloped compared to remote sensing for terrestrial systems.

4. **What hiatus does the new tool fill?** The current *in situ* monitoring program and sampling stations has been designed to measure the effects of the Rhine River as primary driver (flow volume, salinity, input of nutrients such as phosphates). Remote sensing demonstrates transboundary processes, for instance the (freshwater river, sediment-laden plume) that detaches from the British Isles to cross the North Sea. Remote sensing may help resolve liability issues within the regulatory framework (.e.g. eutrophication).

5. **What parameters, required within the current monitoring program, can be provided by remote sensing?** Satellite platforms may currently provide chlorophyll, suspended matter, and light extinction (transparency). Other parameters, e.g. nutrients, pH, O_2, salinity, can only be resolved by *in situ* measurements. Validation of remote sensing data compared with DONAR data (ship-based measurements by Rijkswaterstaat) demonstrates variability in the same order of magnitude, i.e. values can be predicted based on measurements in the previous year. The obvious reason for this is the seasonality of algal blooms and sediment fluxes. However, yearly trends and inter-annual variability cannot be predicted and is readily detected by satellite sensors.

6. **Which parameters that are available from satellite platforms and useful for North Sea monitoring have not been taken into consideration?** Sea Surface Temperature (SST); CDOM (coloured dissolved organic matter), light climate in the water (K_D, z_{eu}, PAR), primary production; however these last parameters require separate validation studies.

7. **How reliable is remote sensing as a measuring instrument?** Optical earth observation is just as reliable as *in situ* measurements. Measurements are stable within certain, well-defined limits. A complete assessment of accuracy will be provided within the Ovatie-2 project. One point of consideration is validation of winter data, when chlorophyll and sediment are difficult to distinguish and absolute concentrations are difficult to assess. These problems are well known and can partly be solved by choosing a suitable sensor, and high-quality atmospheric correction and bio-optical algorithm.

8. **What should further be done?** The uncertainty of high winter values for chlorophyll should be resolved. The process has not been fully automated and satellite images still require visual interpretation. Anomalous measurements would invite *in situ* measurements under a separate research project. Models may add the 3^{rd} dimension to 2D spatial images and for instance demonstrate the process that control the (eco)system (e.g. currents, eutrophication effects). 3D-Model simulations will support current analyses and may be used to construct a DONAR-parallel data base with maps of all parameters. As all processes are known in such a model, the outcome of the correlations is not blurred by any sampling or measuring inefficiency. Ultimately the present sampling strategies of the existing monitoring program can be tested and optimized. Data-model integration will be a key task for Deltares.

9. **Is this service operational? Has it reached the necessary reliability and accuracy?** Yes, Further work is presently undertaken to establish a reliability interval of Chl-a measurements to support end user-decision making. Integration of satellite-derived data with flow- and current modelling will further enhance nowcasting and forecasting capabilities.

10. **What is the greatest advantage of optical remote sensing over in situ measurements of surface waters?** Satellite monitoring provides the 'real time' advantage required for disaster management and security services (e.g. harmful algal blooms or oil spill drift). It provides an instant image of a large area (synoptic). *In-situ* measurements deliver data after laboratory analysis often weeks (or months) after sampling. Data gathering, processing, and dissemination occur at much lower effort and therefore much lower costs than *in situ* sampling.

Appendix A: Parameters (abiotic and eutrophication) in the DONAR data analysis

Parameters	*Priority 1*	*Priority 2*	*BC's (mg/l)*	*Remarks*
Algemeen/fysisch				
T Temperatuur	x			
SALINpss Saliniteit	x			
FLUORESCENTIE				database managed by DNZ, needs to be evaluated first
ZICHT Doorzicht volgens Secchi	x			
EXTINCTIE Extinctie in situ	x			
Eutrophication				
SILI nf Molybeen reactief silikaat als Si na filtratie	x			
PO4 P nf Ortho fosfaat na filtratie	x		0.02	BC as winter concentration
NO3NO2 N nf Nitraat en nitriet(als N) na filtratie	x			
NO2 N nf Nitriet (als N) na filtratie	x		DIN 0,15	BC for DIN as winter concentration
NH4 N nf Ammonium (als N) na filtratie	x			
NO3 N nf Nitraat (als N) na filtratie	x			
DOC nf Opgelost organisch koolstof na filtratie		x		
ZS Zwevend stof	x			
N nf Totaal stikstof na filtratie	x			
O2 Zuurstof		x		
%O2 Percentage zuurstof		x		
OC Organisch koolstof		x		
P nf Totaal fosfor na filtratie	x			
POC Particulair organisch koolstof		x		
PN Particulair stikstof	x			
PP Particulair fosfor	x			
CHLFa Chlorofyl-a	x		0.014	In the growing season
FYP Fytoplankton	x			
Contaminants				
BbF Benzo(b)fluorantheen	x			Great affinity with SPM (TSM)
BkF Benzo(k)fluorantheen	x			Great affinity with SPM (TSM)

Appendix B: An overview of relevant policy and legislation

European legislation

Water framework directive
On 23 October 2000, the "Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy" or, in short, the EU Water Framework Directive (or even shorter the WFD) was adopted.

European Marine strategy
On 7 June 2006, the European Commission adopted a Green Paper on a Future Maritime Policy for the European Union. The Green Paper is accompanied by a number of background documents which have been produced by European Commission Working Groups and by the Maritime Policy Task Force which oversaw the drafting of the Green Paper.

Birds and habitat directives
The European Union Directive on the conservation of wild birds (79/409/EEC) was adopted in 1979 by nine Member States, and was the first EU Directive on nature conservation. Since its adoption it has been a vital legal instrument for the conservation of all birds that occur naturally across the EU, acting in the broadest public interest to conserve Europe's natural heritage for present and future generations. Together with the definitions and objectives of the Habitats Directive (92/43/EEC), adopted in 1992, it offers useful legal conceptual models and a set of standards and norms in common use. The Birds Directive applies to all 25 EU countries since May 2004.

Shellfish Waters Directive
The European Community (EC) Shellfish Waters Directive (79/923/EEC) aims to protect shellfish populations. It sets water quality standards in areas where shellfish grow and reproduce. The Directive requires that certain substances are monitored in the water in which the shellfish live. These substances can threaten the survival of shellfish or inhibit their growth.

International treaties

OSPAR
The 1992 OSPAR Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. It combined and up-dated the 1972 Oslo

Convention on dumping waste at sea and the 1974 Paris Convention on land-based sources of marine pollution.

The OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Community, manages the work under the convention.

The work under the Convention is guided by the Ministerial Declarations and Statements made at the adoption of the Convention and at the Ministerial Meetings of the OSPAR Commission. The work applies the ecosystem approach to the management of human activities.

It is organized under six strategies:

- Protection and Conservation of Marine Biodiversity and Ecosystems
- Eutrophication
- Hazardous Substances
- Offshore Oil and Gas Industry
- Radioactive Substances
- Monitoring and Assessment

Eutrophication in OSPAR

The overall general ecological objective is to achieve by the year 2010 a healthy marine environment where eutrophication does not occur. This implies a situation where the OSPAR Convention area classifies as "non-problem area" in the meaning of, and in accordance with the assessment under, the OSPAR Common Procedure for the Eutrophication Status of the OSPAR Maritime Area (the "Common Procedure").

The relevant ecological quality issues for eutrophication include 'Nutrient budgets and production', 'Phytoplankton communities', 'Oxygen consumption', and 'Benthic communities'. For these, five EcoQOs related to eutrophication were developed in parallel with, and derived from, the assessment parameters and the assessment levels established under the Common Procedure. For the purpose of eutrophication, the desired level of an ecological quality (EcoQO) is referred to as area-specific "assessment level" which has been set in relation to area-specific reference levels. Assessment levels for concentrations, for example, are set in relation to area-specific and/or salinity-related background concentrations.

The specific EcoQOs for eutrophication, as agreed for the North Sea pilot project and as slightly edited to ensure consistency with the terminology of the Common Procedure are:

- Winter DIN and/or DIP should remain below a justified salinity-related and/or area-specific % deviation from background not exceeding 50%;

- Maximum and mean chlorophyll a concentrations during the growing season should remain below a justified area-specific % deviation from background not exceeding 50%;
- Region/area-specific phytoplankton eutrophication indicator species should remain below respective nuisance and/or toxic elevated levels (and there should be no increase in the duration of blooms);
- Oxygen concentration, decreased as an indirect effect of nutrient enrichment, should remain above area specific oxygen assessment levels, ranging from 4-6 mg oxygen per liter;
- There should be no kills in benthic animal species as a result of oxygen deficiency and/or toxic phytoplankton species.

The five EcoQOs form an integrated set of EcoQOs for nutrients and eutrophication effects as one sub-set of the OSPAR EcoQOs to describe the overall ecological quality of the marine ecosystem. The items are strongly interlinked along a cause/effect chain from nutrient enrichment to direct effects (chlorophyll a and phytoplankton nuisance and toxic indicator species) and indirect effects (oxygen deficiency and benthos kills). The process of their integration is detailed in the Common Procedure. This sub-set of EcoQOs forms part of the target-oriented approach of the OSPAR Eutrophication Strategy and has a clear link to human activities resulting in increased inputs of nutrients to the marine environment. It provides the operational, specific framework for evaluating the 50% nutrient (nitrogen and phosphorus) reduction target and for assessing whether the overall general ecological goal with regard to eutrophication is achieved by 2010.

Loads of nutrients discharged to sea (eutrophication)
There is a complex relationship between riverine and direct discharges of nitrogen and phosphorus and the concentration of nutrients in coastal waters and estuaries, which in turn affect their biological state. Measures to reduce the input of anthropogenic nutrients and to protect the marine environment are required by the OSPAR Convention 1998.

In the North Sea, there have been significant reductions in the loads of phosphorus from urban wastewater treatment works, industry and other sources between 1985 and 2000. The reduction from agriculture has been less and this source was the largest in 2000.
Nitrogen discharges to the North Sea have decreased significantly from urban wastewater treatment works, industry, and agriculture and other sources between 1985 and 2000, with agriculture being the major source in 2000.

Atmospheric deposition of nitrogen to marine and coastal waters
Atmospheric deposition of oxidized or reduced nitrogen compounds can be considerable in many parts of Europe and can be a significant source of the total input of nutrients to surface water systems. For example, the relative proportions of nitrogen input for riverine, atmospheric and direct inputs into the North Sea are 10:3:1.

Chlorophyll in coastal and marine waters
The measurement of chlorophyll-a levels is another way of monitoring eutrophication since in summer phytoplankton primary production and chlorophyll-a concentration is, in most areas, nutrient limited. The phytoplankton biomass expressed as chlorophyll-a determines the light conditions in the water column and so also affects the distribution of benthic vegetation. However, due to variations in freshwater run-off and hydro geographic variability of the coastal zone and internal cycling processes, trends in chlorophyll-a concentrations as such can not be directly related to measures taken to reduce nutrient inputs. Concentrations are generally highest in estuaries and close to river mouths or big cities, and lowest in open marine waters mirroring the pattern of nutrient concentrations.

National policy

'A safe and habitable country with healthy and sustainable water systems': this is the aim with which Dutch water management faces the future. The first part of it, to ensure a safe and habitable country, has existed for centuries and is in fact what gave rise to the establishment of Rijkswaterstaat in 1798. After all, the nature of our low-lying, waterlogged country is such that it must constantly be protected against flooding from the sea and the rivers, At the same time, constant effort has had to be invested in the consolidation of the soft subsurface in order to keep the country habitable and cultivable.

Water systems approach

The second part of the goal, to ensure 'healthy and sustainable water systems', has a much shorter history. It was not until the late sixties that the problem of surface water pollution led to systematic action to tackle the main sources of pollution. By that time, the poor quality of the surface water was presenting a threat not only to public health but also to wildlife habitats. The two halves of the aim were initially addressed via a two-track policy approach, but during the eighties there was a growing realization that the aim of public safety and habitability could not be viewed in isolation from that of healthy and sustainable water systems. Moreover, it became clear that water management could achieve these aims much more effectively and efficiently if the policies directed at them were not only closely interrelated with each other but also carefully coordinated with other relevant areas of policy. In the mid-eighties, this realization became known as integrated water management.

Integrated water management

This philosophy was developed further in the Third National Policy Document on Water Management (NW3), published in 1989, and integrated water management and the water systems approach have become key concepts in the water management world of the nineties. Thanks to the support the policy document attracted from the various authorities concerned with water management in the Netherlands, much of it has now been translated into concrete measures and the combined aim is somewhat closer to achievement. The policies laid down in NW3 will therefore be maintained and extended unless the present NW4 Policy Document specifically states otherwise. The integrated policies and practices outlined in NW3 put us on the right path and the Fourth National Policy Document (NW4) continues in the same general direction. Changes have been made only where it is necessary to modify policies in the light of more recent events and factors such as continuing ground subsidence and expected climate change. The results of this process are formulated in the policy directions mapped out in the Fourth National Policy Document on Water Management.

Appendix C: Optical remote sensing for the North Sea: products and paramenters

State of the art optical remote sensing products

Earth observation techniques for the North Sea rely primarily on data provided by two ocean colour instruments: *MERIS* onboard ENVISAT and the US instrument MODIS. MODIS is a vicariously calibrated instrument, and therefore there is no bias at all wavelengths (MarCoast Validation Bureau). The RMS error is ~20%. MERIS is an onboard calibrated instrument. The RMS error for most bands is also 20% (compared to in-situ measurements), but there is also a bias of 5%, and this increases at short wavelengths. The analyses in TORSMON have been focused primarily on time series of the parameters chlorophyll and TSM of the SEAWIFS satellite produced in the OROMA project. However, new and better satellites have been launched such MERIS and MODIS and better models have been developed to analyze the reflectance data. These models provide a larger set of parameters.

Measurable Parameters

The most state of the art analyses models for ocean color can produce a wider product range.

1. The three specific inherent optical properties (**SIOP**) determine the optical description of the water column. They are among the most prominent deliverables. The present models do provide an error estimate for these parameters
    a. Chlorophyll
    b. Total suspended matter
    c. Specific absorption by dissolved organic matter
2. The inherent optical properties (IOP) can be calculated from the specific constituents
    a. The Absorption coefficient a
    b. The Scattering coefficient b correlates very well to turbidity measured by a backscatter sensor (OBS)
    c. The Beam attenuation coefficient c = b + a correlates very well to turbidity measured in transmission
3. Several apparent optical parameters
    a. The diffuse downward extinction Kd, which can also be measured in the field.
    b. Secchi-disk depth (visibility under water), which can also be measured in the field.
4. Level 2 parameters
    a. Surface reflectance for different wavelengths
    b. Cloud cover
    c. Energy of incoming light field at water surface as function of wavelength
5. Temperature and true color images

Research development

Present research is focused on several additional parameters

- Primary production estimates
- Specific algae group recognition
- Dealing with varying specific optical constituents in time and space
- Using earth observation data as source in data model integration of silt dynamics
- Using earth observation data as source in data model integration of ecosystem modeling

Spatial and Temporal coverage

Specifications of the present operational optical sensors on satellite platform under review:

- The SEAWIFS instrument covers
    - a swath width of 1500 km and revisits each position every day.
    - Its detectors measure 8 bands selectable across range: 400 nm to 890 nm.
    - Spatial resolution 1100m
- The MERIS instrument covers
    - a swath width of 1100 km, With this range global coverage is reached every 3 days, effectively the north sea is covered two times in 3 days.
    - Its detectors measure15 bands selectable across range: 390 nm to 1040 nm
    - Spatial resolution - 300 or1100m
- The MODIS instrument is operating on both the Terra and Aqua spacecraft.
    - It has a viewing swath width of 2,300 km and views the entire surface of the Earth every one to two days.
    - Its detectors measure 36 spectral bands between 405nm and 14.385 nm, and
    - it acquires data at three spatial resolutions - 250m, 500m, and 1,000m.

The resolution of these sensors is considered to be of moderate resolution. In the near coastal and inland waters higher resolution is desired. The temporal coverage of these satellites provides us with about 50 unclouded usable measurements per year for each (pixel) position in the North sea area. Using all platforms this number can be increased to about 200 measurements. Cloud cover is weather determined and changes considerably with the season. Therefore sampling is unequally distributed over the season. Users need to be aware of these characteristics. Also the information sources will be biased to good weather conditions, although clear skies do also occur during windy and even stormy conditions. To compensate for these biases properly quiet sophisticated statistical analyses is required. However also in-situ measurements have a bias to good weather conditions.