Prepared for:

RWS, RIKZ Den Haag

Inventory and evaluation of observational data

for monitoring SPM fluxes in the Dutch coastal zone

Report

November, 2006

WL | delft hydraulics

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TITLE: Inventory and evaluation of data for monitoring SPM fluxes in the Dutch coastal zone

ABSTRACT:

This document reports the results of an inventory of data sources that are available and possibly relevant to (1) assess the baseline conditions of suspended particulate matter (SPM) in the Dutch coastal zone and (2) enable the assessment of possible future effects of the Maasvlakte 2 (MV2) on the transport of SPM in the Dutch coastal zone and towards the Wadden Sea. This inventory is work package 4 of the project *Baseline Silt PMR* carried out by WL|Delft Hydraulics for RIKZ Den Haag.
Main variables considered are *in situ* and remotely sensed SPM concentrations, optical and acoustic SPM indicators, and current velocities; auxiliary data are sea water temperature (*in situ* and remotely sensed) and *in situ* salinity, fresh water discharges, wave height and period, and wind speed and direction. Criteria to assess the usefulness of the sources for the monitoring and analysis of the effect of MV2 relate to the data quality and quantity.
The evaluation is carried out against the background of possible application of the data to statistical methods as outlined in the companion report of work packages 3 and 5 of the Baseline Silt PMR project (Blaas & Van den Boogaard, 2006). In that report, key variables have been identified that either allow for determination of (changes in) residual SPM flux or secondary effects on the SPM concentrations due to changes in this flux. Also, variables have been defined that allow for the formulation of system relations and proxies for changes in the coastal transport system.

Of all data sources, the ADCP measurements onboard of the TESO ferry in the Marsdiep inlet come closest to the ideal determination of SPM fluxes. In other areas, one has to rely on surface SPM concentrations to assess MV2-effects. *In situ* monitoring data of the MWTL program suffer from decrease in spatial and temporal coverage over the past decades and from changes in monitoring policy which are a potential cause of pseudo trends and biases. This is only partly compensated for by remote sensing techniques that have become available over the last decades, as also these suffer from sampling biases and technical limitations in the nearshore kilometre. Outside the Marsdiep, current velocities can be obtained from two ADCPs at the entrances of the Rotterdam and IJmuiden harbours and from operational numerical model reanalysis data. Wave and wind monitoring data and campaign-based high-frequency and/or vertically resolving measurements provide useful additional information to formulate system relations and proxies.

REFERENCES:

Blaas, M. and H.F.P. van den Boogaard, 2006, Statistical methods to assess the impact of MV2 on SPM along the Dutch coast: Results of WP 3 & 5 Baseline Silt PMR, WL Delft Hydraulics Report Z4046.30, November 2006.

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Contents

1 Introduction

This document reports the results of an inventory of data sources that are available and possibly relevant to (1) assess the baseline conditions of suspended particulate matter (SPM) in the Dutch coastal zone and (2) enable the assessment of possible future effects of the Maasvlakte 2 (MV2) on the transport of SPM in the coastal zone and towards the Wadden Sea. This inventory is part of the project *Baseline Silt PMR* (‘t_0 *slib PMR’*, project number Z4046) carried out by WL|Delft Hydraulics for RIKZ Den Haag (order RKZ 1661). The Baseline Silt PMR project aims to advise on a suitable methodology to determine possible future effects of MV2 on the residual[1] SPM transport.

For the quantification of residual SPM fluxes in the Dutch coastal, and in particular for the assessment of changes in these SPM fluxes due to the Maasvlakte-2 (MV2), the following is to be considered. The primary interest would be the direct observation of the SPM flux. However, this flux is the product of a three-dimensional velocity field and a three-dimensional concentration distribution and is not directly measured. The most closely related quantities observed are (direct measures for) concentrations and velocities. These are denoted as the *main variables*. In addition, *auxiliary variables* are identified. These latter variables represent forcing conditions of the SPM transport or proxies for the transport of river water in the Dutch coastal zone, to which the SPM transport is strongly related.

More specifically, main variables are

- SPM concentrations
- SPM indicators
    - Measures for light attenuation (turbidity, Secchi depth)
    - Optical backscatter intensity
    - Acoustic backscatter intensity
- Current velocities

Auxiliary variables are

- Sea water temperature
- Salinity
- Fresh water discharge
- Wave height and period
- Wind speed and direction

The inventory has been carried out against the background of possible application of the data to statistical methods as outlined in Blaas & Van den Boogaard (2006). Both this latter report and the description of the SPM transport system by Winterwerp (2006) have guided the choice of the data sources.

[1] *Residual: averaged over sufficiently long time to cancel out effects of tides and changing weather, wave, and river discharge conditions.*

General criteria to assess the usefulness of the sources for the monitoring and analysis of the effect of MV2 relate to the data quality and quantity. In particular, these criteria are:

- Availability
- Precision (degree of reproducibility), accuracy (degree of veracity), consistency, continuity, all together denoted as 'quality'
- Coverage in time and coverage in space, frequency, spatial resolution, denoted as 'quantity'

The criteria are applied with reference to the requirements of the data. The data should be suited to assess the reference conditions of the long-term SPM flux (baseline or t_0 conditions) and enable the future assessment of possible SPM flux-related changes in the coastal zone with sufficient accuracy. In addition, it is evaluated whether the data provide sufficient information to formulate system relations. System relations are required to achieve additional proxies for the residual SPM flux and to aid discerning the cause of any detected change in the flux-related SPM conditions (see Blaas & Van den Boogaard, 2006).

The data sets in this report are all evaluated on basis of their meta data, that describe the properties of the data. Actual analysis of the data is not feasible given the scope of the present study.

A variety of data sources is available. Part of the data originates from regularly recurring measurement activities, *i.e.* monitoring, that took place over several consecutive years. Other sources are incidental, relatively unique results of specific projects of shorter duration (covering two years at most). In this inventory both monitoring and project-based data are considered. The report is structured according to data sources. For each data set the usefulness is assessed and indications of the costs are given where applicable and available.

The majority of data discussed below is stored in the DONAR database, the central archiving system of Rijkswaterstaat. Part of the data in DONAR is publicly available through the Rijkswaterstaat Waterbase website, and part has been obtained through the RIKZ *BasisinfoDesk*. Within the DONAR base the long-term monitoring data (MWTL) of the Dutch coastal waters form a large constituent. Other data have been or are to be obtained via international web portals through port authorities and research institutes. Belgian monitoring data have been considered as well since from the report by Blaas & Van den Boogaard (2006) it is concluded that also data on the conditions of the Belgian coastal waters are relevant.

2 SPM-related MWTL survey data

2.1 Introduction

One of the most prominent data sources considered are the data of the so-called MWTL[2] monitoring, which are stored in DONAR. Within the MWTL program the following main variables are measured:

- SPM concentration (denoted as *TSM, total suspended matter*),
- inorganic fraction of SPM (denoted as *Gloeirest*),
- Secchi depth (*Doorzicht*),
- grain-size fraction in water and bed.

Most data of the MWTL surveys are collected using survey vessels, except the stations on the beaches (*(bad)strand*), which have been collected either using small boats or by wading into the surf zone.

The *gloeirest* data correspond to a subset of the TSM data. According to the CENTRILAB instruction sheets reported by Suijlen & Duin (2001), *gloeirest* is only determined when the measured SPM concentrations are above a certain threshold. It represents the ashes, the inorganic, non-volatile compound of suspended matter obtained after heating in an oven at a specified temperature. Most stations available throughout the years are either located inland or on the beach. Hence, *gloeirest* may be an additional source of information when the interest is in the inorganic fraction of the higher concentrations, mainly at the beach, but will not be considered further in the present study. Also grain size distribution in the water is not considered.

Optical properties related to the scattering and extinction of visible light have been measured for prolonged periods in the past. For the North Sea waters of the Dutch EEZ, Visser (1970) reports measurements of turbidity from 1903 until the end of the 1960s. In the DONAR data base, Secchi depth (*Doorzicht*) is stored for many stations from 1973 onward. These stations correspond largely to the TSM stations discussed below. In the present study the focus is on the monitoring of the SPM flux or quantities closely related to this flux and not as much on the eventual effect of the SPM (together with chlorophyll) on the light attenuation. The light-attenuation data can in principle be related to suspended matter concentrations (see also Boon, 1992, De Savornin Lohman, 1993), but this may lead to additional uncertainty and variance when combining different data sets. Moreover, the historic data by Visser (1970) have not been found to be available in digital format and the original data have not been located. Because of these shortcomings and limitation of scope, we do not consider light-attenuation data here.

[2] Monitoring van de Waterstaatkundige Toestand des Lands, *in the past also known under the acronyms WOSRO, WAKWAL, and WAKWON*

For similar reasons as outlined above, data on the grain-size distribution of the sediment bed are not considered in this report. These data are also available on a wide range of more-or-less regularly visited monitoring stations within the Dutch EEZ of the North Sea and may provide additional information on the SPM conditions, especially in relation to the role of the sediment bed in the residual fluxes of SPM. Since this role is an active field of current research (e.g. Van Ledden et al, 2004) and no straightforward relation between bed and flux is yet available, the bed data have not been taken into account.

The remainder of this chapter thus focuses on the directly measured SPM concentrations, denoted by *TSM*.

2.2 TSM

The results of the filtering of water samples taken during the MWTL surveys are stored in the variables *TSM*, in the water. Although the following subsections are focused on TSM, some of the findings are also applicable to the other primary data mentioned above and to the salinity data presented in section 5, because these data are collected on the same or similar surveys. Hence, changes in surveying policy apply also to most of these other quantities. In this report only the aspects of the meta data are discussed. An extensive overview and analysis of the TSM data is given by Suijlen and Duin (2001, 2002).

Availability

For the present study a subset of the MWTL monitoring locations has been selected of about 240 stations, some of which have been abandoned by now. Over time, different monitoring programs have been carried out, which resulted in changes in the total number of survey stations, frequency of sampling and sampling method. This will be further discussed below.
The SPM stations considered in this inventory are shown in Figure 2-1, in which the often-cited cross-shore transects have been indicated.

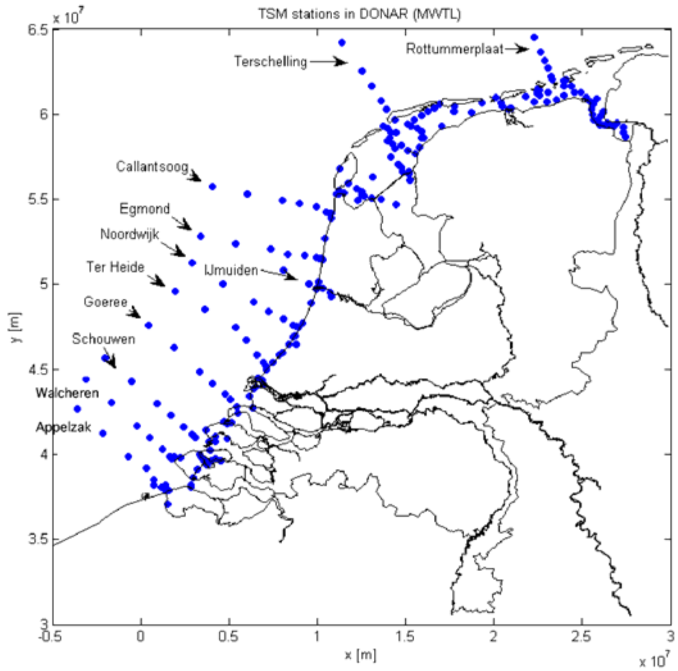

Figure 2-1 Overview of all SPM stations of the MWTL network as stored in DONAR (denoted as *TSM*). The names of the most often cited transects are indicated. Detailed figures are shown in Appendix A.1.

Quality

All offshore SPM concentrations are determined from water samples taken from the subsurface. The samples are taken at reported depths varying between 1 and 4 meters below the surface. As stated in the WL|Delft Hydraulics studies of the 1990s by Boon (1992) and De Savornin Lohman (1993), the actual sampling depth may in reality differ from these nominal values due to ship movements etc. Consequently, in practice the range of depths may be wider but in any case the data are representative for the concentrations in the upper part of the water column. Depending on stratification, wind and wave conditions the vertical concentration gradient may be considerable: with near-bottom concentrations exceeding the surface values by an order of magnitude (e.g. Vos, 2004). Because of the variety of factors influencing the vertical concentration profile, it is difficult to reconstruct depth-averaged concentrations from the surface values without additional simultaneous measurements at depth.

Suijlen & Duin (2001) discuss the detection limit of the measurement methods used for these SPM data. In general 0.1 mg/l is reported in the data, sometimes also 0.3 mg/l or 1.0 mg/l. It can be expected that the detection limit will not exceed 1.0 mg/l. Of the changes that have taken place in the measurement methods, the most prominent are listed in the table below, which is a compilation of earlier studies and recent interviews with experts.

Table 2-1 in SPM measurement methods since the start of the Dutch national monitoring program in 1975 (sources: De Savornin Lohman. (1993), Dronkers, (2005), personal communication V. Langenberg (RIKZ Den Haag), G. Spronk (RIKZ Middelburg))..

Technique	**Time period**	**Method applied**
Geolocation of sampling stations	1975-1979	Relative to buoys that may occasionally be relocated
	1980-present	fixed coordinates
Sampling method	1975-1982	sample bottles
	1983-present	through flow system
Filter pore diameter	1975-1984	7 µm
	1984-1986	0.45 µm
	1987-present	1 µm
Filter material	1975-1984	paper filter
	1984-1986	membrane filter
	1987-present	fiberglass filter
Rinsing of filters	1975-1986	no rinsing
	1987-present	rinsing with demineralised water
Maximum wind speed for vessel operation (related to insurance)	1975-1995	N/A
	1995-present	< 2m wave height (6 Bft)
Nominal vertical position sample intake	1975-1990	-4 to -1 m.
	1990-present	-1 m
Pressure filtering method	1975-1987	Venturi pump
	1987-present	Vacuum (effectively about 1 Atm. pressure difference)
Sample time with respect to tidal phase	1975-1983	Fixed
	1984-present	Arbitrary
Detection limit	1975-2004	1 mg/l
	2004-present	0.1 mg/l
Rounding off of values	1975-2004	to integers
	2004-present	to 1 decimal (not always stored as such within DONAR)

One of the most important indications of the overview in

Table 2-1 is that a tendency towards lower SPM values may have taken place. The combination of shallower sampling position and vessel operation only during more calm weather may imply that in time, SPM-values may have a bias towards lower concentrations. Dronkers (2005) estimated a decrease in SPM-values of about 25% after 1991 related to these systematic changes. If this is substantiated, the SPM-concentrations after 1991 may have to be increased by 35% to obtain a consistent data set from 1975 till present. On the other hand, the use of a finer filter from the mid 1980s onward may partly offset this pseudo trend.

Maiwald et al. (1991) have analyzed SPM data in the Wadden Sea. They found that pseudo trends occurred in a least two stations (presumably '*Zoutkamperlaag*' and '*Groninger Wad*') due to systematic shifting of the moment of sampling with respect to the tidal phase. The main, longer-term harmonic component that could be inferred from both 2nd order regression and Harmonic analysis was the 18.6 nodal lunar-tidal cycle. Individual regressions of, for example, concentration against the square of the wind speed did not yield significant correlations, however. Generally speaking, sampling biases like these but also particular seasons or weather conditions that may be over-represented in the data, should be checked from detailed cross-analysis of the data at hand e.g., together with wind and wave data.

Finally, Suijlen and Duin (2001) report intervals in which the measured data are unrealistically high irrespective of the other systematic changes mentioned above (*e.g.* summer 1979, 22 September 1975, 28 May – 12 June 1985). It is beyond the scope of the present study to analyse this further but we endorse the suggestion by Suijlen to rely on the data presented in the tables of Suijlen and Duin (2001) which contain corrections for rounding errors and outliers mentioned above. Any future application of the SPM data from DONAR would require additional data-quality and consistency assessment before they are guaranteed to be free of possible pseudo trends and biases.

In addition to the offshore data, there are series of data collected at beach stations. These data have been collected mostly in the 1970s and early 1980s and partly also in the early 1990s. A fraction is continued until present (in the southern delta area, notably, see below). Data collection has been carried out by bottle samples in the surf zone. These samples are therefore representative for the usually well-mixed surf zone and the methodological changes reported above do not apply to these beach data.

Quantity

During almost all surveys of the monitoring program all stations within one survey were sampled within a 96-hour interval. Hence, quasi-synoptic survey sets were obtained. The interval between successive surveys has changed over time, however. Figure 2-2- to Figure 2-7 show the coverage in time of all stations together with the frequency of sampling.

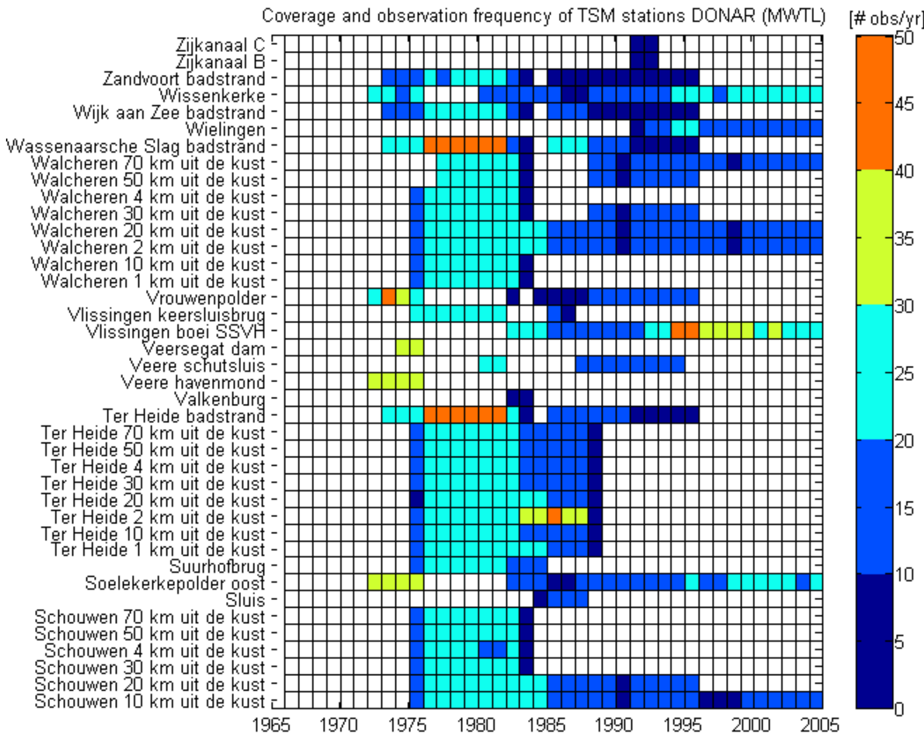

Figure 2-2 Coverage in time and annual mean observation frequency of the SPM (TSM) stations of the MWTL program within DONAR. Stations are listed in inverse alphabetical order from top to bottom. Continued in figures below. Orange indicates about weekly samples, light blue-green bi-weekly, dark blue monthly sampling.

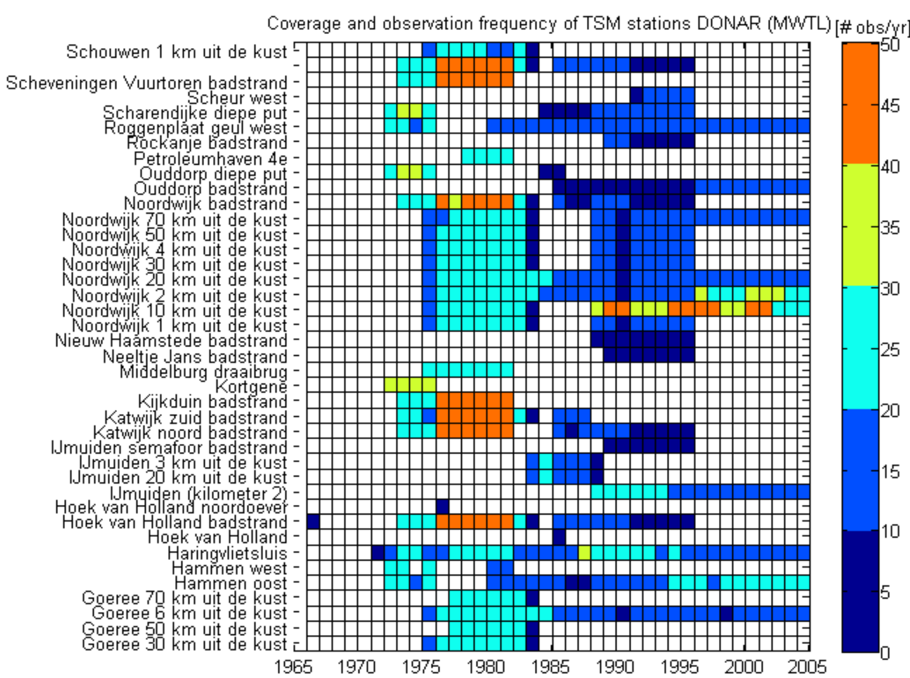

Figure 2-3 As Figure 2-2.

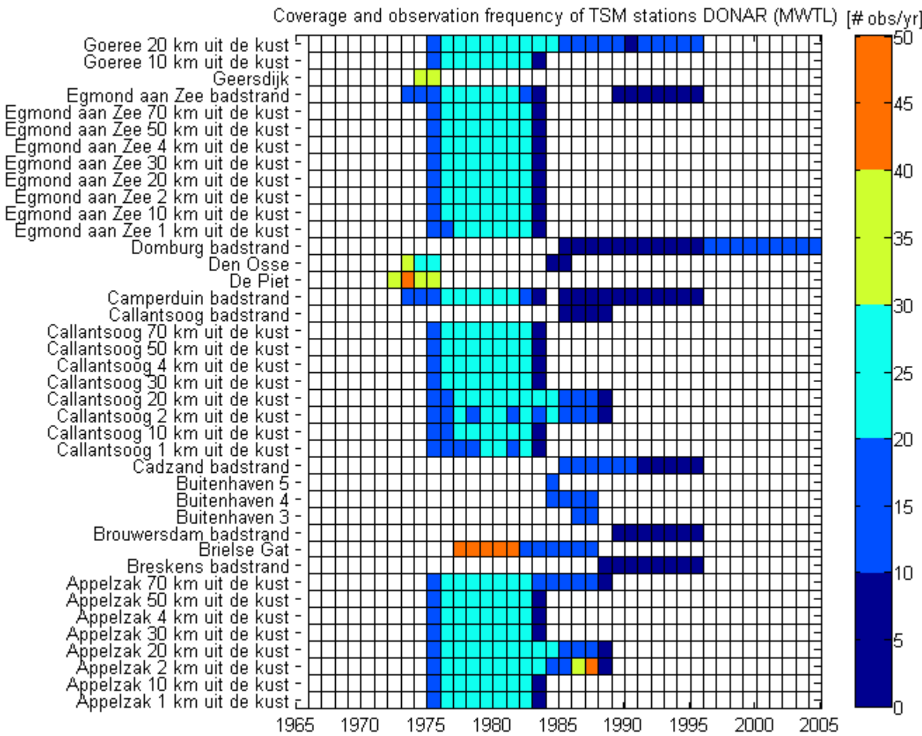

Figure 2-4 As Figure 2-2.

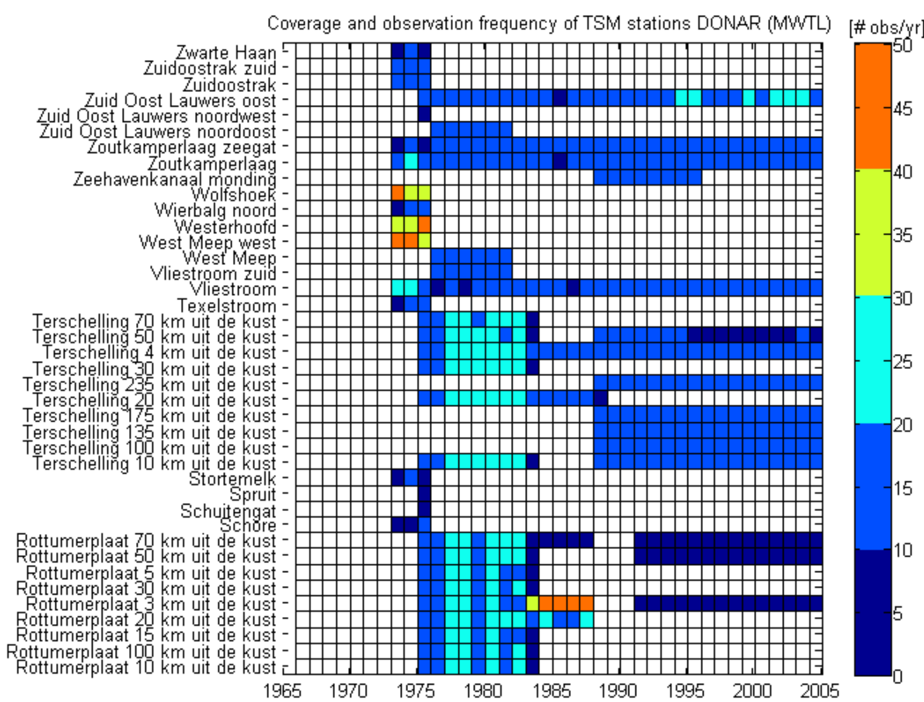

Figure 2-5 As Figure 2-2.

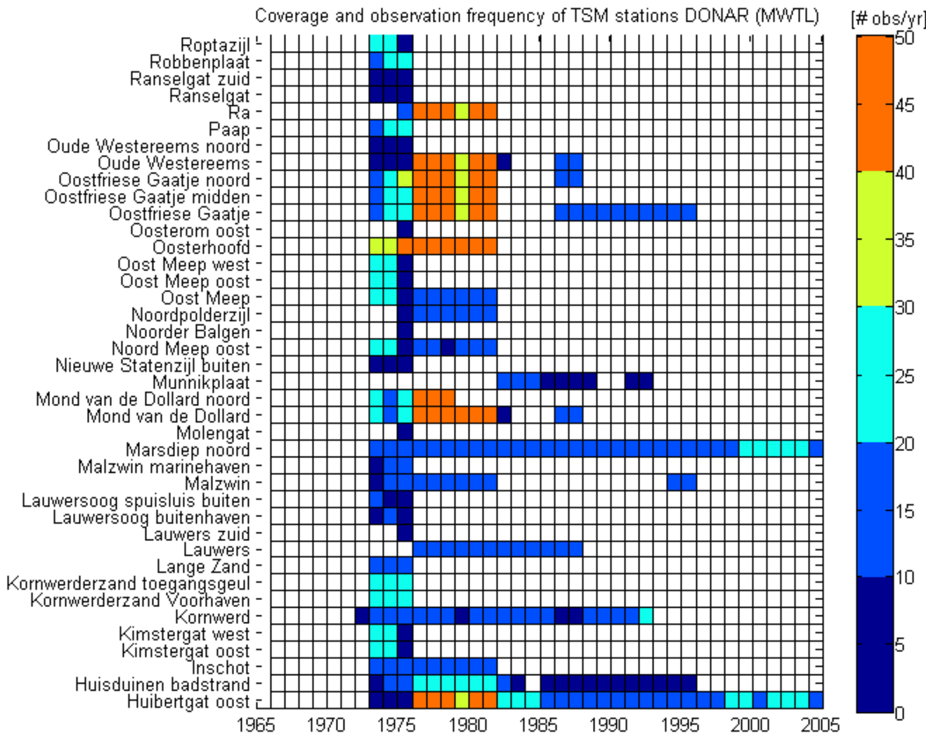

Figure 2-6 As Figure 2-2.

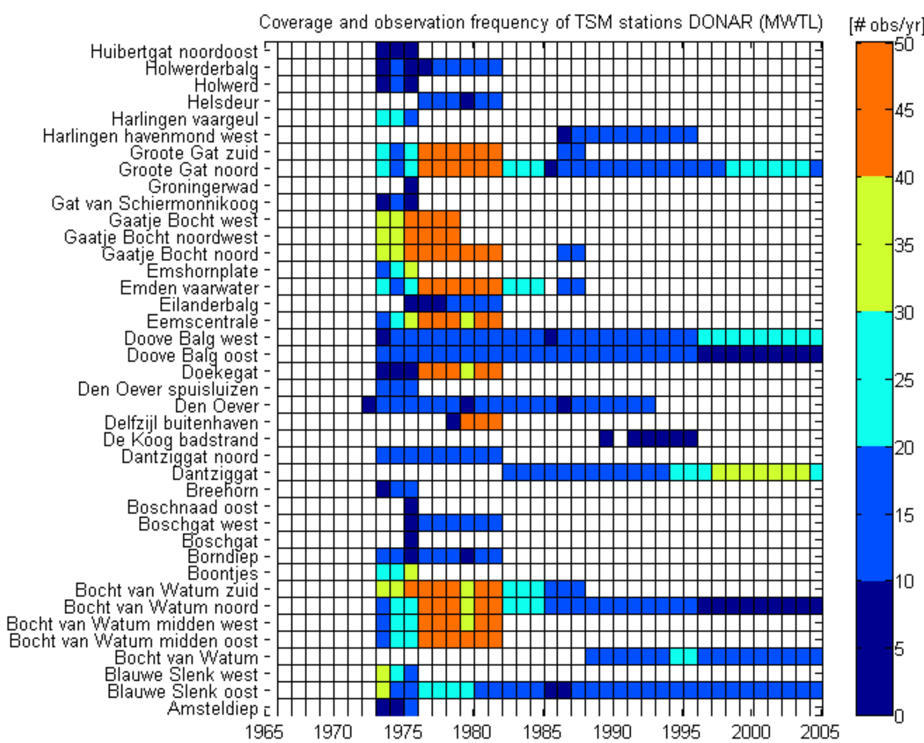

Figure 2-7 As Figure 2-2.

From Figure 2-2 to Figure 2-7 it is seen that certain changes in the number of stations and the sampling frequency have occurred. The consequence of this for the spatial coverage of that monitoring network becomes clear from the maps in Figure 2-9 to Figure 2-12 that show the spatial coverage per period of several years during which the lay-out of the surveys have remained more or less unaltered, together with the temporal density of the sampling of each. Spatial and temporal density was highest from 1975 to 1984. From 1985 until 1989, there has been a lower but still considerable coverage, from 1990 until 1996 the number of transects was further reduced to 3 long and 2 shorter transects, from 1996 until present also most beach measurements have been terminated and the sampling frequency of certain stations has increased.

For the assessment of long-term changes in the SPM conditions, it is desirable to have records of SPM concentration that are as long as possible, uninterrupted and free of biases and pseudo trends. The most useful stations therefore are those that at present are still maintained. The stations that were abandoned longer ago, and thus have shorter records, are less useful. Spatial aggregation, combining related stations, carried out with care, may provide means to bridge data gaps and to utilise data of abandoned stations. (See Blaas & Van den Boogaard, 2006).

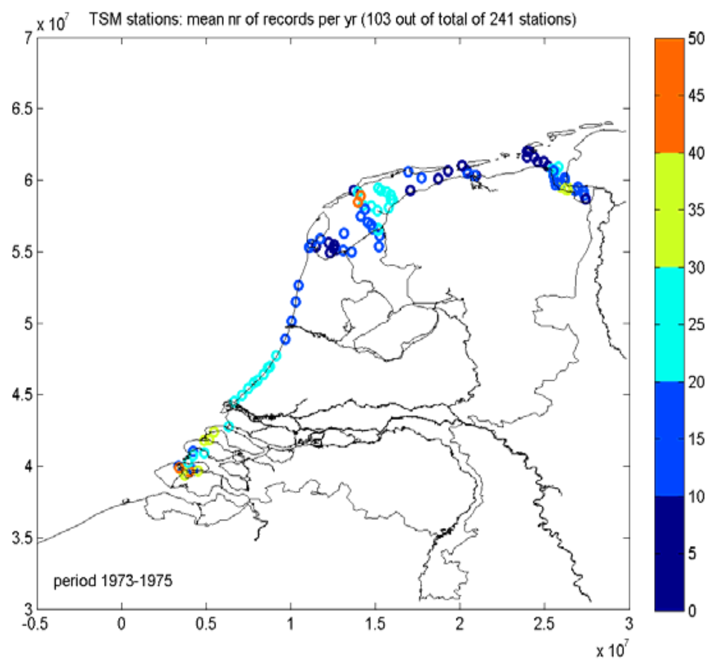

Figure 2-8 Mean number of records per year for all SPM stations available from DONAR during a particular period for which the station coverage remained more or less intact. Orange indicates about weekly samples, light blue bi-weekly, dark blue monthly or less. Period 1973-1975.

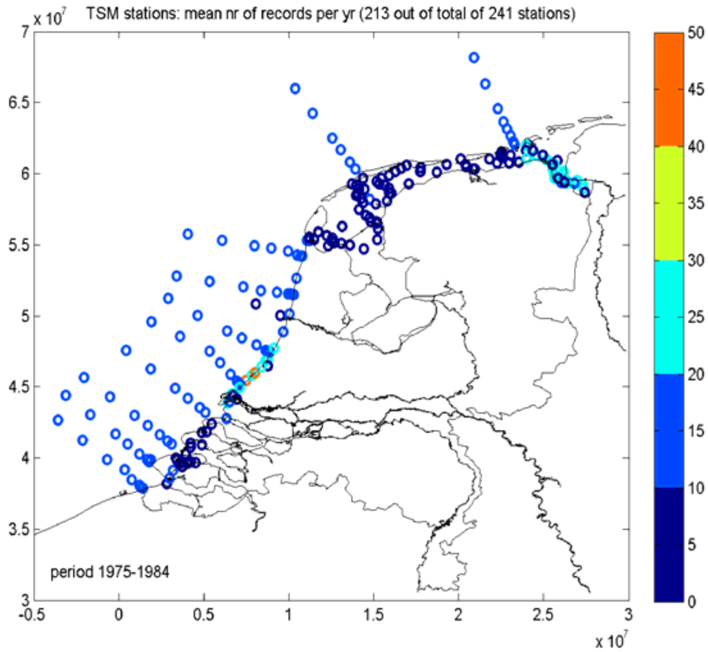

Figure 2-9 As Figure 2-8 but for period 1975-1984.

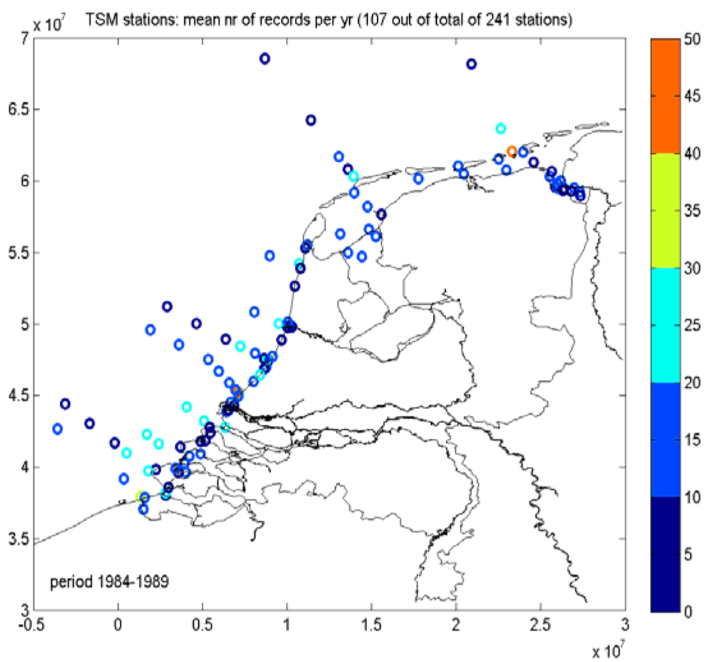

Figure 2-10 As Figure 2-8 but for period 1984-1989.

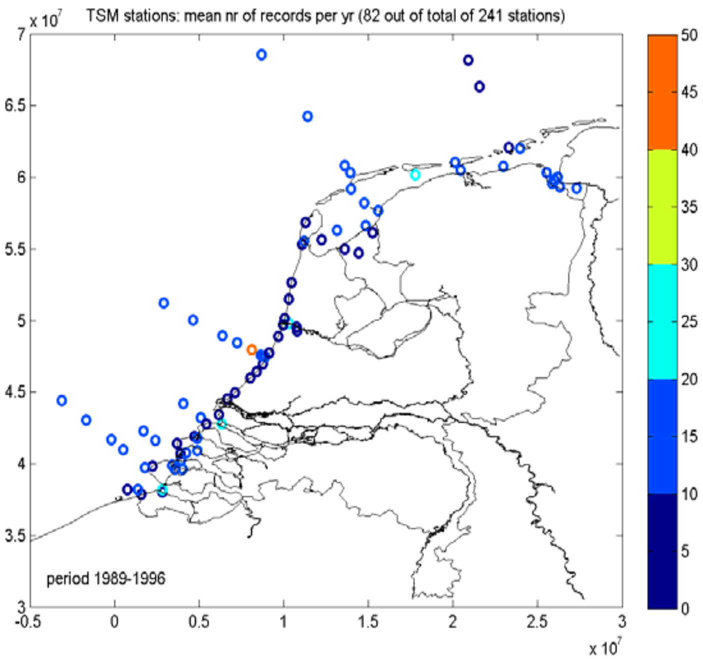

Figure 2-11 As Figure 2-8 but for period 1989-1996.

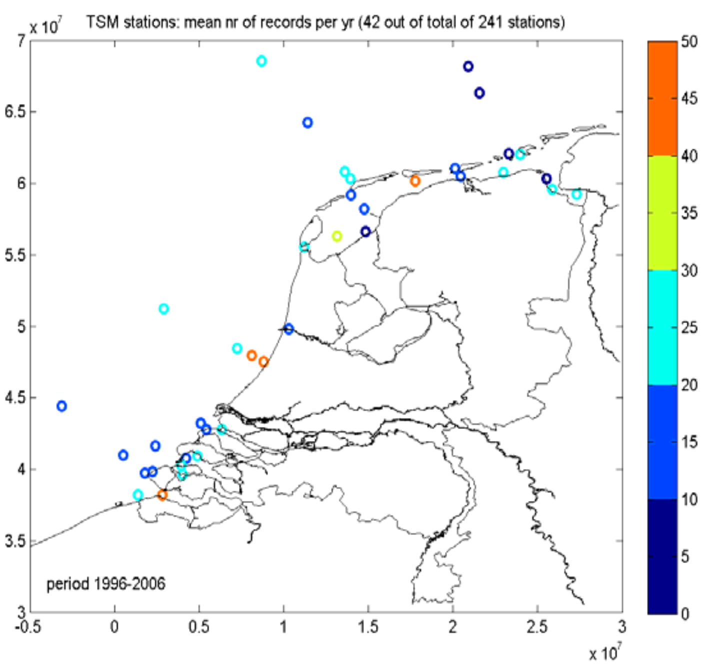

Figure 2-12 As Figure 2-8 but for period 1996-2006.

Costs

The collection of SPM data is part of the broader activities by Rijkswaterstaat to monitor the chemical, biological, physical and morphological state of the Dutch coastal waters (denoted as MWTL). As such it is difficult to discern the costs of individual SPM measurements. Costs of the data collection and lab analysis of the chemical, biological, physical and morphological parameters is estimated at 5 to 6 million Euros per year without the costs of ships and crew (V. Langenberg, RIKZ, pers. comm., Oct. 2006). Costs of ships and crew vary depending on where measurements are carried out, and related to which company or Rijkswaterstaat department is carrying out the operation, which vessel is used and to what extent synergy with other simultaneous activities can be obtained. According to V. Langenberg the ship and crew costs range from 4.000 to 25.000 Euros per day of surveying. Here we take 16.000 Euros as a representative average, which is consistent with earlier quotes by L. Peperzak (RIKZ) and M. Hofstede (DNZ).

Usefulness

The MWTL survey data in DONAR are one of the major sources of information on the SPM conditions in the Dutch coastal zone. They have been the major reference over the past decades and as such have been extensively studied in the past. Future analysis will profit from this experience. Still, further detailed study may be required if systematic biases are to be removed. At present, it is not certain whether this is feasible.

3 Belgian SPM data (IDOD)

Availability

The IDOD database (Integrated and Dynamical Oceanographic Data) hosted at the Belgian Marine Data Center (BMDC) of MUMM (Management Unit of the North Sea Mathematical Models) contains various SPM (denoted as 'SUSP') data sets, stored from 1987 onward. Data are available online at http://www.mumm.ac.be/datacentre/. Most data are freely available for research and policy purposes.

Quality

The SPM data in IDOD is collected during monitoring surveys of the RV Belgica. According to the BMDC files, samples are either taken at -3 m below the surface or at the surface. Like the MWTL SPM data in DONAR, the data are thus representative for the surface layer. According to the BMDC (M. Devolder, pers. comm., September 2006), no systematic changes in measurement techniques and policy have occurred since 1987. For all data, the same techniques and vessel have been used.

Quantity

Figure 3-1 indicates the general location of the monitoring stations and Table 3-1 gives the general coverage. At present, the statistics up to 2003 are available, but the IDOD database is updated regularly.

Table 3-1 Coverage of SPM data in IDOD data base of MUMM (source http://www.mumm.ac.be/datacentre/)

Area	Start year	End year	Nr of stations	Nr of values
Open sea	1987	2003	307	1296
Coastal Zone	1987	2003	276	793

Some stations have been visited quarterly for consecutive years, others only once, but may be combined with neighboring stations to yield longer coverage.

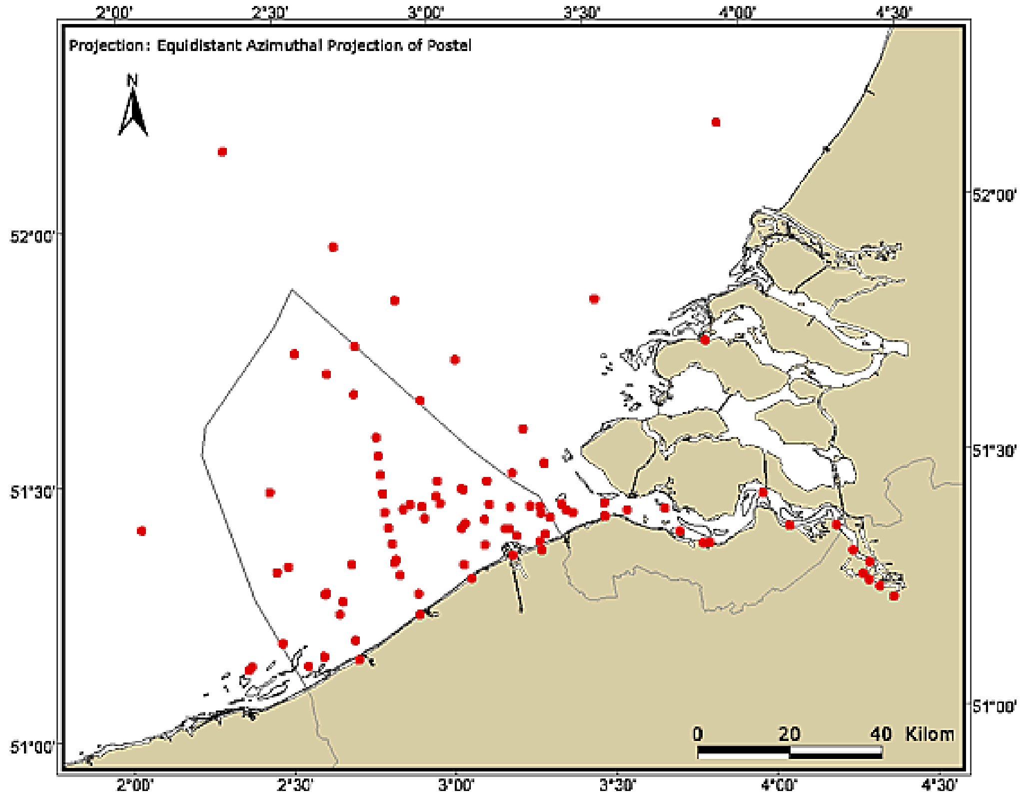

Figure 3-1 General coverage of the Belgian monitoring network of which data are stored in IDOD at BMDC (MUMM). More detailed graphs can be found in Appendix A.2.

Costs

Provided, that the Belgian authorities continue the present policy, these data are available at no additional costs for Dutch research and policy-supporting objectives. According to BMDC, there are at present no indications that the policy will change (Devolder, pers. comm.).

Usefulness

The SPM time series in the IDOD appear extensive and consistent enough and the spatial coverage is apt to turn this database into a very useful source to establish reference conditions outside the area of influence of the MV2 (see also Blaas & Van den Boogaard, 2006).

4 ADCP current meters at IJmuiden and Rotterdam: currents and echo intensity

Availability

At entrances of the ports of Rotterdam (*Maasmond*) and IJmuiden (*IJmond*) permanent current velocity observation stations are located. These stations consist of ADCP devices mounted on posts. Data comprise current velocity magnitude and direction and echo intensity (in dB). All data of both stations are obtainable through the BasisInfo Desk. They are not yet accessible via the *Waterbase* web site. Since not only the current velocities but also the echo intensities are stored, there is, potentially, a measure for suspended matter concentrations (and even fluxes, when velocities and concentrations are multiplied). For the present purposes it is primarily the echo intensity that is of interest as it will presumably be difficult to assess and interpret possible changes due to the MV2 on the SPM fluxes at two individual locations close to shore (as opposed to fluxes across entire transects). It is not unlikely that the location of the Maasmond station will be revised after construction of MV2, which may reduce its usefulness.

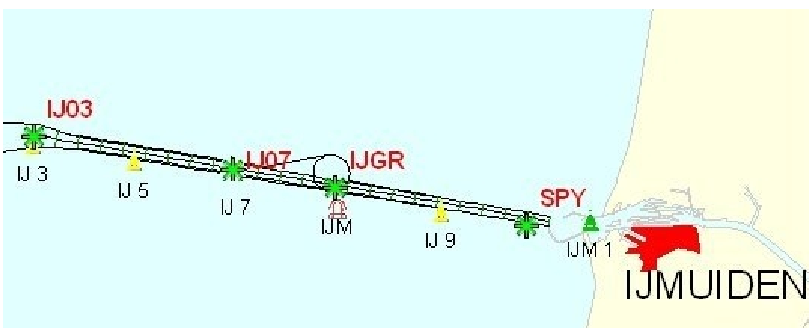

Figure 4-1 Approach area of the IJmuiden harbour, SPY denotes location of the IJmuiden current meter station. (Source North Sea Hydro-Meteo Center; http://www.hmc-noordzee.nl)

Quality

Presently, little is known about the accuracy of the echo intensities, but as they are a standard byproduct of well-maintained operational ADCP devices it is expected that these are accurate enough to form a reliable link in the chain relating echoes to SPM concentrations. The echo intensities can be converted into SPM concentrations by applying a method developed at NIOZ (Meckelbach & Ridderinkhof, 2006, Merckelbach, 2006) in application to Marsdiep ferry-box data (see sect. 11.1). The method relies on relations between intensity of the ADCP acoustic echo signals and the concentration of sound-reflecting/backscattering substance in the water. For application of the methods at new sites such as the IJmond and Maasmond the relations between *in situ* concentration and echo need to be re-established. This requires, for example, 13-hr measurements every 3 months (to cover seasonal variations of SPM composition). At the present state of development the method also requires a permanent independent measurement of concentration along with the ADCP measurement using an OBS for example. This means that use of the historical data may be limited. Maintenance of both the OBS and ADCP is required, as fouling has to be avoided. The measurement posts allow for attachment of additional devices.

Quantity

Data are available for 28 to 30 bins over the vertical, covering at least 5 years on a 10 minute interval. This is sufficient to resolve all relevant time scales of the SPM signal and velocity. Potentially this is the longest record with such a high frequency (proxy) measure for SPM concentration and transport that is available in the Dutch coastal area.

Table 2.6.1 Characteristics of the ADCP data at the entrance of the ports of IJmuiden (IJmond) and Rotterdam (Maasmond).

Station	number of bins	deepest bin	time resolution	time span
IJmond	28 (every 50 cm)	13.75 m	10 min	08/2001-present
Maasmond	30 (every 50 cm)	14.75 m	10 min	08/2001-present

Usefulness

The coverage and resolution of the data sets make them potentially useful, especially the IJmond data are especially valuable because they measure in an area where there is otherwise little coverage of SPM data. The *Maasmond* station may be relocated after construction of MV2. It may be a valuable source of information of SPM conditions in the perturbed area around MV2, but less so the implications of MV2. The anticipated geometric changes are so profound that future series of the Maasmond data are to be considered inconsistent with the present and hence they do not provide means of assessing MV2 effects.

The major drawback of the ADCP signals is the absence of a well-calibrated algorithm to convert echo intensities into concentrations. If such a future relation would be unambiguous, the historic echo intensities can be used well, for example in statistical empirical regression relations and hence serve as proxies for concentrations. Currently however, the relations appear (at least in the Marsdiep) to contain ambiguity depending on turbulent characteristics of the currents. Site specific research is required to assess whether echo intensities are unambiguously related to concentrations in the IJmond and Maasmond. If so, the data are of high value. If the relation is not unambiguous, data are only useful along with simultaneous future *in situ* measurements and the historic records will most probably be difficult to interpret.

5 Salinity from MWTL survey data

Salinity serves two purposes as auxiliary data. It is a marker of the relative amount of river water and is the main cause of density gradients in the coastal zone. Lateral density gradients are the main driver for the three-dimensional circulation in the coastal zone, which causes the SPM to be concentrated in a relatively narrow band along the coast ('Silt River'). In addition, haline stratification determines the vertical mixing and hence the vertical distribution of SPM and heat (see SST in section 6) in the water column. As a measure for the amount of river water, it may be used to study the cross-shore distribution of river water before and after MV2, in relation to amounts discharged at the Haringvliet sluices and Nieuwe Waterweg. River water distributions in turn may be related (in statistical sense for example) to SPM distributions.

Availability

Sea Surface Salinity (SSS) data that are stored in DONAR are collected on the same survey cruises as the SPM measurements discussed above. The data are mostly available on the same stations as the SPM data and the reader is referred to Figure 2-1 and Figure 2-8 to Figure 2-12 for maps of the stations.

Quality

The SSS data may suffer from the same type of biases in representation as the SPM data (see

Table 2-1). Decrease in sampling depth and sampling only under relatively fair weather conditions may lead to a decrease in SSS (as rough weather will in general promote vertical mixing) but the effect may be expected to be smaller since vertical gradients in salinity are generally smaller than in SPM.

Quantity

Generally speaking SSS is available with the same coverage and frequency as the SPM data. In the 1970s and 1980s a relatively dense spatial coverage with bi-weekly sampling has been obtained. Nowadays only a fraction of the stations remains, most with monthly sampling. The frequency and coverage can be determined from Figure 5-1 to Figure 5-4.

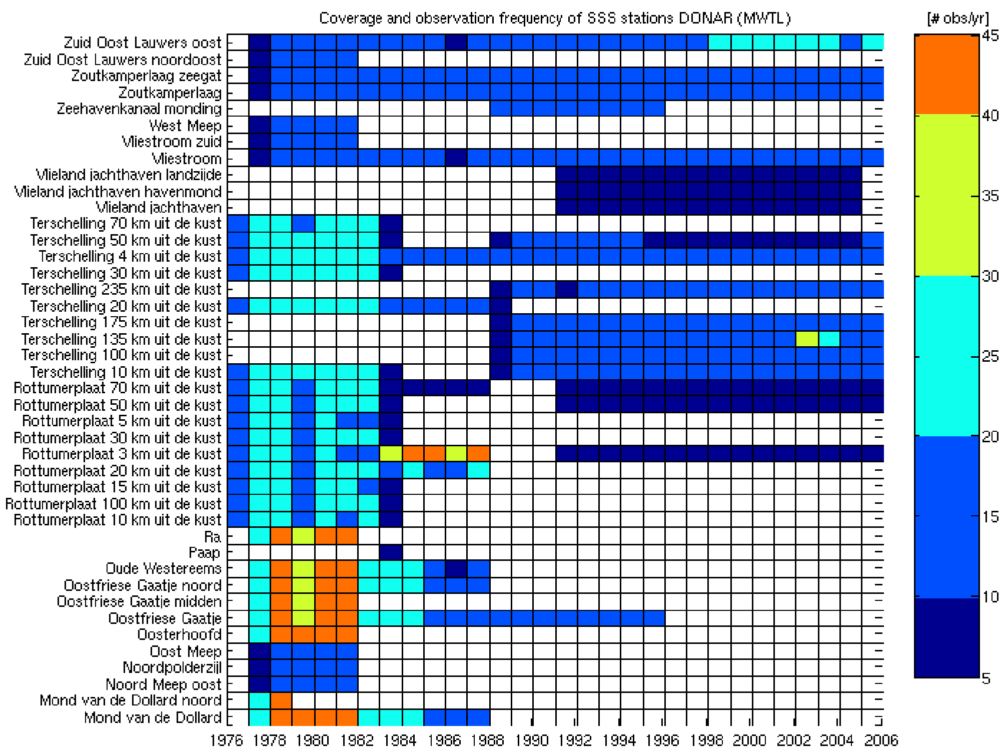

Figure 5-1 Coverage and annual mean sampling frequency of the SSS stations stored in DONAR.

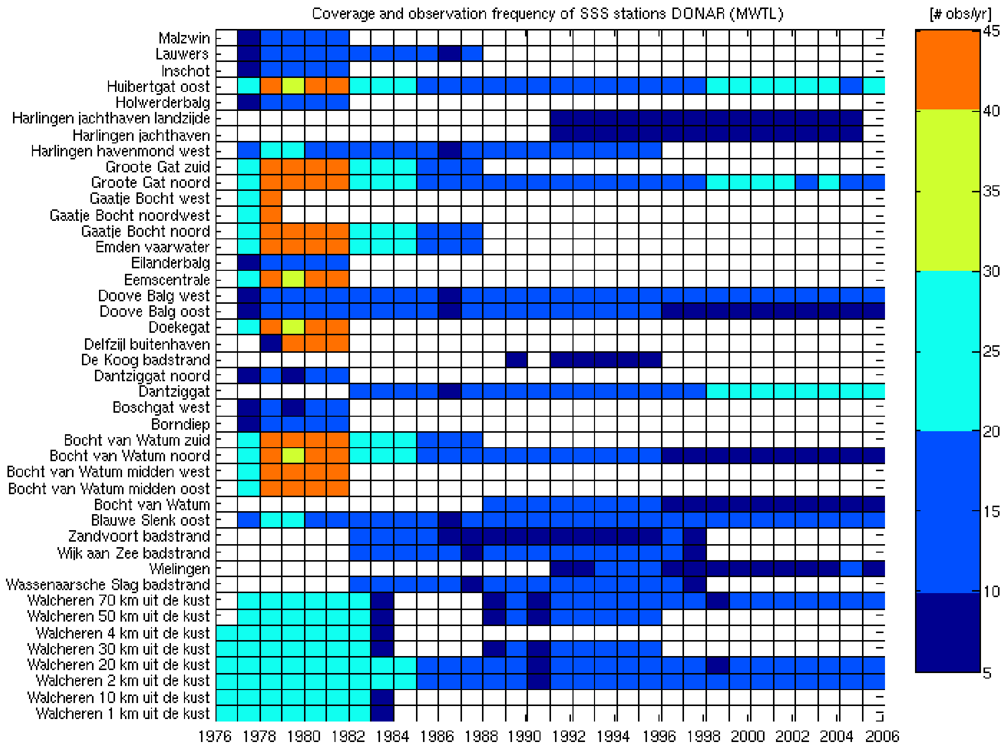

Figure 5-2 As Figure 5-1.

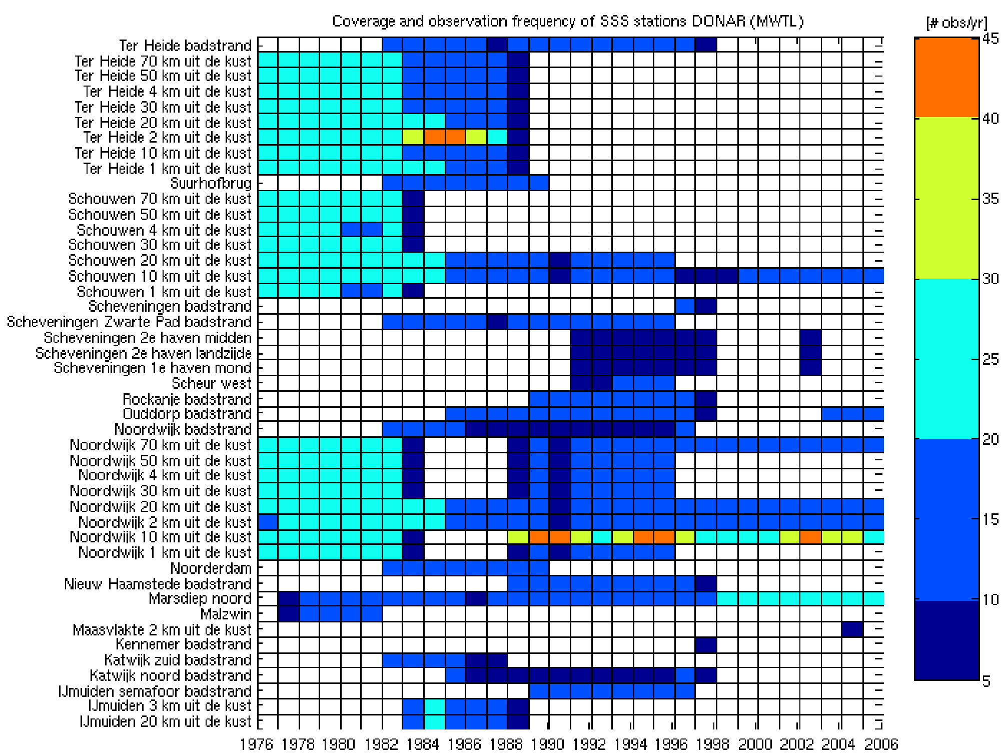

Figure 5-3 As Figure 5-1.

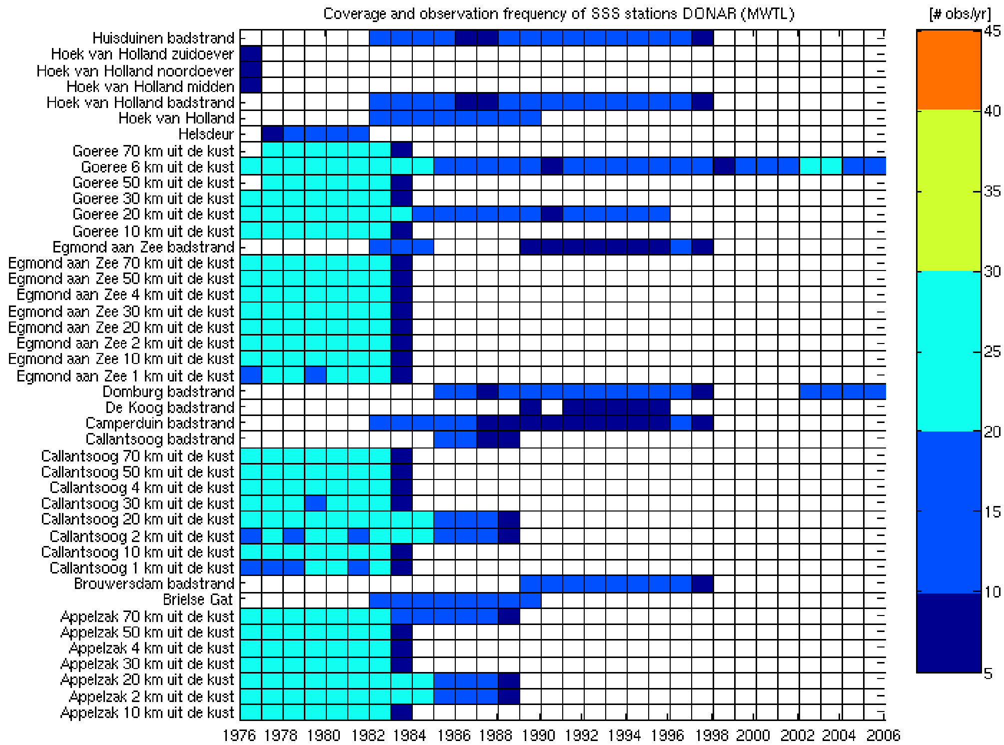

Figure 5-4 As Figure 5-1.

Costs

Costs for SSS measurements are part of the costs of the standard MWTL surveys (see SPM above).

Usefulness

The MWTL SSS data are potentially useful to assess changes in the distribution of the River water plume in a similar fashion as the SPM data from the same database. However, contrary to SPM they cannot be complemented by remote sensing data to compensate for the significant decrease in spatial resolution over time, which reduces their usefulness compared to SPM. Moreover, changes in SSS provide at most an indirect measure for changes in SPM. SSS data may be used to corroborate or understand changes in SPM, if any.

6 Sea Surface Temperature (SST) from MWTL

Sea Surface Temperature (SST) may be a useful auxiliary source of information. It may help in defining the river influenced part of the coastal zone, because the river-induced haline stratification reduces vertical mixing in the coastal zone and hence enhances the temperature response of the water column. Consequently, the surface temperature within the coastal river more closely follows the air temperature than outside the coastal river (see e.g. De Kok, 1997; Arentz, 2005). It should be noted that the zone often denoted as 'coastal river', which is marked by temperature and salinity, differs from the zone marked by SPM ('silt river') which is of smaller extent. Nevertheless, changes in the Coastal River due to Maasvlakte 2 may be related (also statistically) to changes in the Silt River.

Availability

SST data of 24 stations is stored in DONAR (see Figure 6-1). These are wave stations, discharge sluices and coastal stations. Up to now, SST from ship surveys (if any) is not available (at least not publicly).

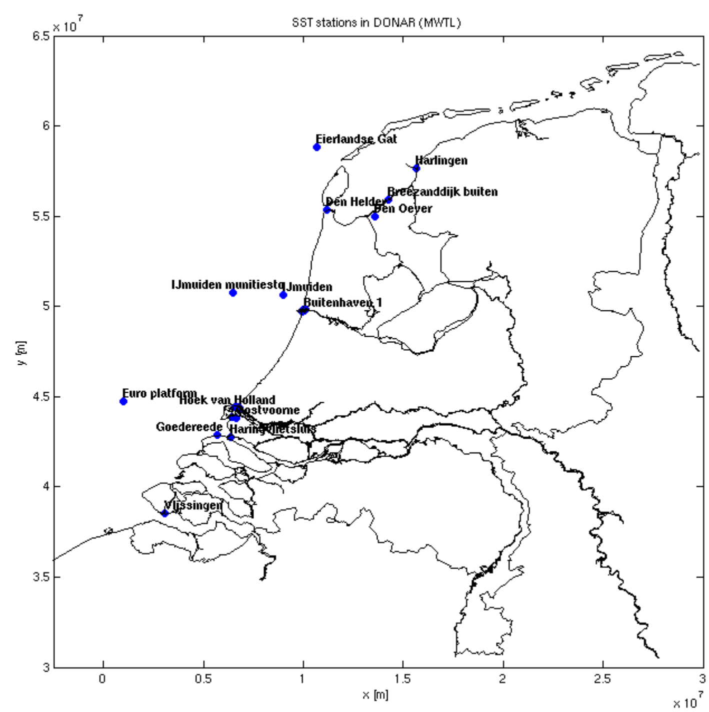

Figure 6-1 SST stations stored in DONAR.

Quality

The accuracy of the data is good and series are consistent over time. This makes the data suitable for ground-truthing of remotely-sensed SST for example.

Quantity

Compared to the SPM data, spatial coverage of SST is relatively low; most stations are located on the coast and therefore render the data set of limited use for the present purposes. The cross-shore spatial gradient of SST will in general not be resolved sufficiently to allow conclusions on the Coastal River.
The temporal coverage of the stations has been extensive in the past. Between about 1970 and 1995 many stations have been operational and most of them have been sampling with daily frequency. Currently, there are only three active stations of which *IJmuiden munitiestortplaats* and *Eierlandse Gat* are daily and may therefore be useful in combination with Remote Sensing.

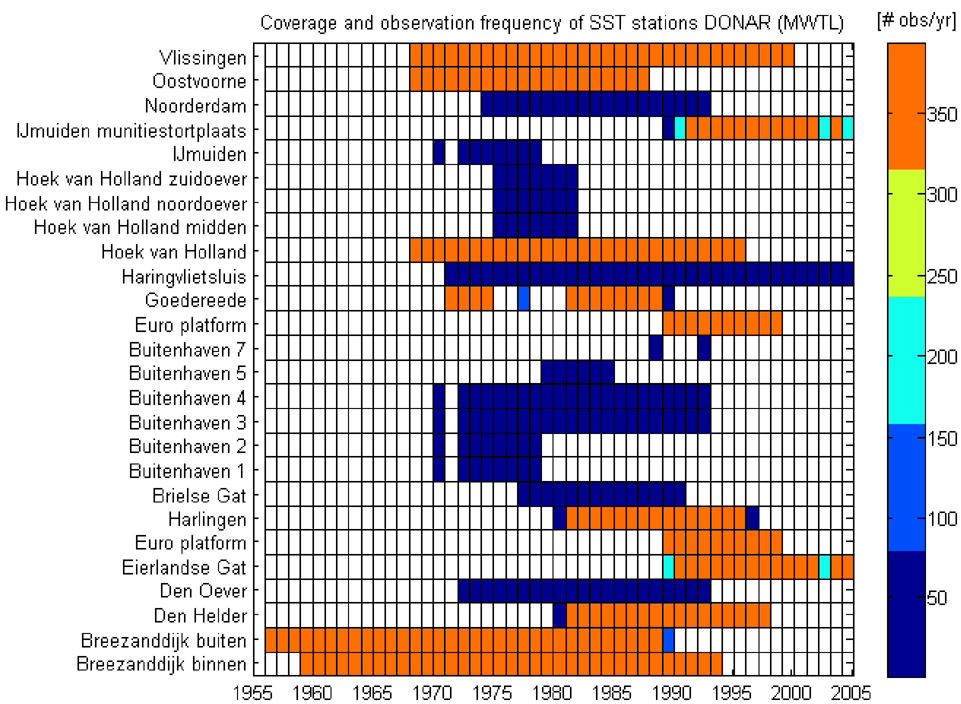

Figure 6-2 Coverage and annual mean frequency of sampling of the SST data in DONAR.

Costs

The present offshore data are collected at wave stations etc and come at no additional cost.

Usefulness

The direct usefulness of the SST data is limited. SST is an indirect indicator of the coastal river conditions but the present low spatial sampling density makes it mostly useful to validate remotely sensed SST (see chapter 12).

7 Wave height and period

The effect of resuspension and vertical mixing by waves is generally considered to be an important contributor to the variability of SPM signals in the Dutch coastal zone (see also the overview by Winterwerp, 2006). Stirring by waves can be expressed as function of the significant wave height and peak period of the wave spectrum (see e.g. Soulsby, 1997). In the analysis of changes in SPM conditions off the Dutch coast, it is advised to take into account (statistically) the relation between SPM and waves in order to correct or explain possible changes in SPM in the light of possible changes in wave conditions (see Blaas & Van den Boogaard, 2006).

Availability

Within DONAR, significant wave height and mean period from the spectrum between 30 and 500 MHz are stored for 10 relevant locations in the Southern Bight. The wave data are readily available from the DONAR database.

Quality

These data are of consistent quality over the total period covered. Also spatial coverage is generally sufficient to capture the main characteristics of the wave fields off the Dutch coast. The only, major, exception is the Wadden Sea: no direct wave measurements are available inside the Wadden Sea. Since the wave fields inside this sheltered and relatively shallow area may differ from the conditions on the North Sea this puts a limit on the applicability of the wave data to SPM data of the Wadden Sea. Indirect relations may be possible through wind measurements. (See section 9.)

Quantity

Figure 7-1 shows the location of the stations off the Dutch coast. The coverage and frequency of stored data are shown in Figure 7-2. Five of the stations offer extensive time coverage.

Usefulness

The wave data are very suitable to provide input to system relations, and they also can be used to directly assess if significant changes in wave conditions occur over time. As waves are the dominant forcing factor determining surface SPM concentrations it will be essential to discern SPM changes due to changes in waves as opposed to changes in transport paths and time scales due to MV2. The spatial and temporal coverage and time frequency are suitable for application to system relations.

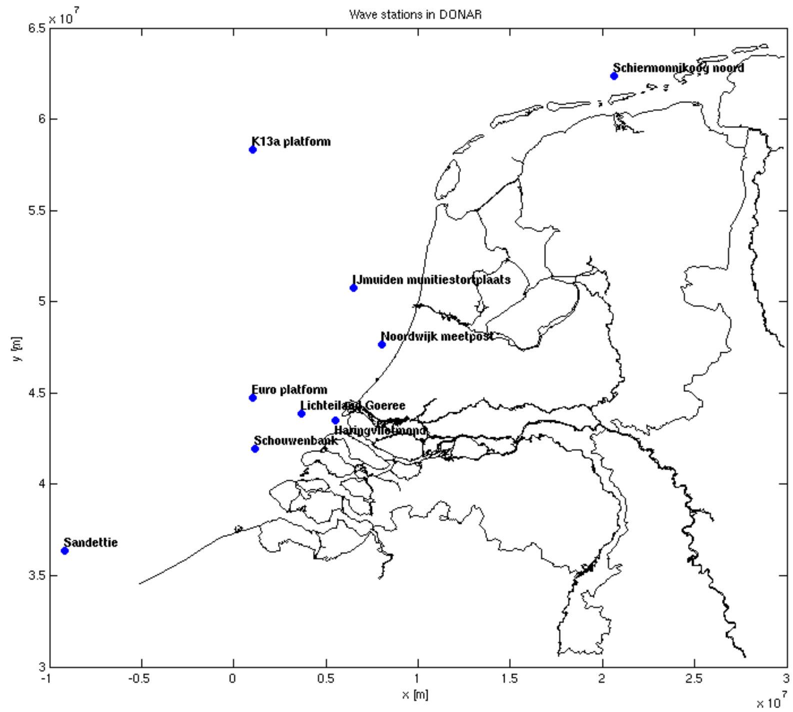

Figure 7-1 Location of the 10 relevant wave stations where wave height and period are or have been determined since 1975.

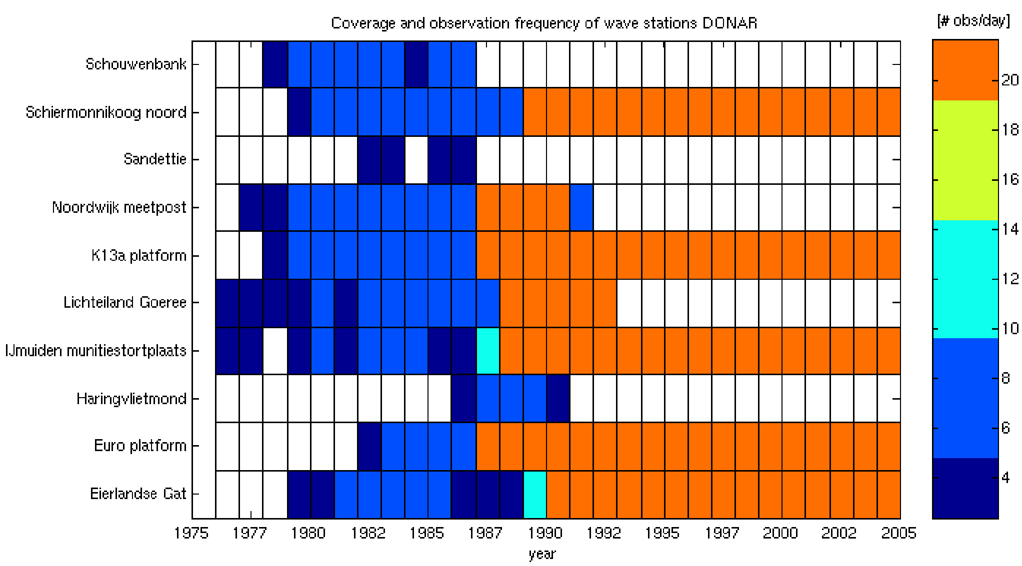

Figure 7-2 Coverage in time and frequency of wave data (significant wave height and mean period from the spectrum between 30 and 500 MHz) in DONAR. Orange denotes hourly data, light blue 3 to 4 hourly intervals.

8 Fresh-water discharge

The input of fresh water into the Dutch coastal zone is important for the dynamics of the ‘Coastal River’ and ‘Silt River’. Not only the total amount discharged north of the Zeeland-delta area but also the partition of fresh water (from Meuse and Rhine) between Haringvliet and Nieuwe Waterweg has a strong influence on the distribution of fresh water and SPM in the Dutch coastal zone, as is indicated by recent numerical model results simulating the transport of SPM in the Dutch coastal zone (Van Kessel et al, 2006). Also, the discharge data can be combined with SPM data to construct SPM loads into the North Sea.

Availability

Fresh-water discharge data are available from the Haringvliet sluices, Nieuwe Waterweg (Puttershoek, Maassluis, Hoek van Holland, Brienenoord), Noordzeekanaal (IJmuiden) and Afsluitdijk (Den Oever and Kornwerderzand).

Quality

For most stations the discharges are not directly measured but have been and are derived from model estimates (given water-level measurements, Q-H relations) or (more recently) numerical model calculations (SOBEK). It is not certain whether variations due to sea level fluctuations are always accounted for. The data from IJmuiden are computed from pumping activities. Data for the Aflsuitdijk are directly measured. It may be very difficult, if not impossible, to arrive at residual discharges (e.g. over a tidal cycle) using these data. Additional modelling (including sea level fluctuations) may be required for this.

Quantity

The coverage is given in Figure 8-1. Data are stored once per day on a fixed hour (at least fixed during prolonged periods). The overall temporal coverage of the discharge time series is sufficient and all relevant input locations are represented. Composites are feasible to arrive at an extended record of Nieuwe Waterweg discharges.

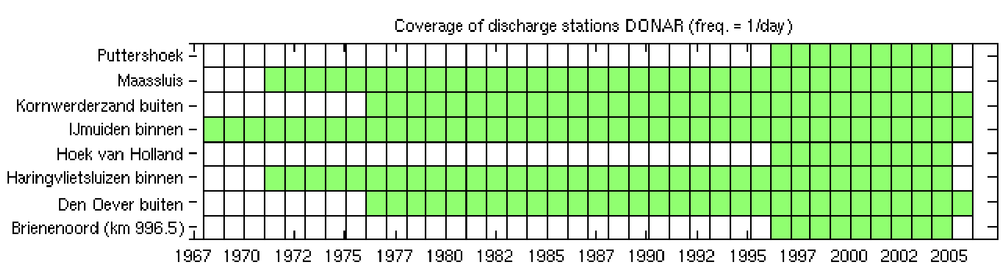

Figure 8-1 Coverage of the discharge data n DONAR (all data have daily frequency)

Usefulness

In principle the fresh-water discharge is a very valuable data source to establish (statistical) relations between Rhine and Meuse river discharge and SPM conditions. In combination with SPM data at the same or nearby locations, estimates of the river load of SPM may be obtained. The most important drawback is the lack of accuracy. Daily discharges miss the variations due to tides and wind conditions and SPM data may not be commensurate. Even if they are, accurate assessment of the *residual* SPM flux through the Nieuwe Waterweg is difficult given the present low sampling frequency.

9 Wind speed and direction (KNMI Hydra)

The role of wind in the SPM conditions is twofold: wind affects wave conditions that are the major steering factor for resuspension of SPM, and wind influences currents and hence the advective transport of SPM. In the coastal river off the Holland coast, wind-driven currents are part of the three-dimensional currents determining the structure of the Coastal River, whereas in the western Wadden Sea wind is the dominant factor determining the residual transport between and through the Marsdiep and Vlie inlets.

Availability

The Royal Dutch Meteorological Institute (KNMI) manages a database (HYDRA) containing the hourly wind speeds and directions dating back to the 1950s at over 60 stations in The Netherlands. The data are accessible via http://www.knmi.nl/samenw/hydra/.

Quality

All data have all been converted to potential wind speeds (referring to winds effective at 10 meters height, under assumptions of roughness of the surrounding terrain and a typical profile of the wind speed in the atmospheric boundary layer). In this way, a consistent set is obtained. The conversion may be a source of inaccuracy depending on atmospheric conditions and details of surrounding terrain, but in general the wind speeds are considered sufficiently accurate.

Figure 9-1 Overview of all Dutch wind speed observation stations represented in the Hydra database. (http://www.knmi.nl/samenw/hydra/)

Quantity

Of the stations archived, 29 are possibly relevant for the current Baseline Silt PMR project as they are located on the coast or offshore. Figure 9-1 shows the locations of all stations. Spatial coverage is sufficient to describe the mean features of the wind fields on the North Sea. For the Wadden Sea, only stations on the nearby islands can be used, which will somewhat reduce the accuracy for the wind speed and direction at sea.

The coverage in time of these stations is shown in Figure 9-2 below. There is a sufficient number of stations to provide coverage of the coastal area for the past 30 years. The plot in Figure 9-2 can be used when combining neighbouring stations to compose longer time series (e.g. Hoorn (Terschelling) and Terschelling complement each other).

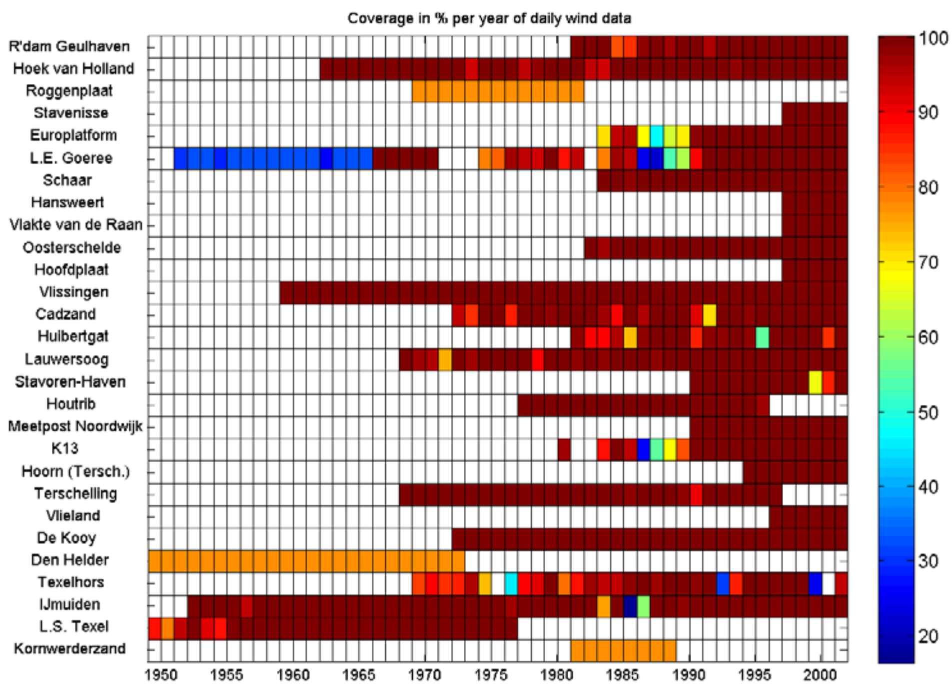

Figure 9-2 Coverage of the coastal and offshore stations in the Hydra data base. Colour scale indicates percentage of time covered during each year. (Derived from http://www.knmi.nl/samenw/hydra/)

Usefulness

The wind data are useful to aid formulating system relations between high-frequency SPM concentrations and wind strength (as a proxy for wave conditions, especially in the Wadden Sea where direct wave measurements are lacking). In addition, the wind data may be used in conjunction with spatial information on SPM distribution and residual currents. Also the series can be used to assess changes in the wind conditions (both strength and direction) over time.

10 NIOZ Jetty data

10.1 SPM Marsdiep

NIOZ collects *in situ* data of SPM at the jetty on the NIOZ grounds (‘t Horntje) on the island of Texel (see Figure 10-1 for the location). SPM data are determined from samples at least weekly. Since 2001 also local remote sensing of SPM from a frame on the jetty takes place. This provides data of SPM with 15 minutes interval, year-round but only during daylight (Wernand, 2006).

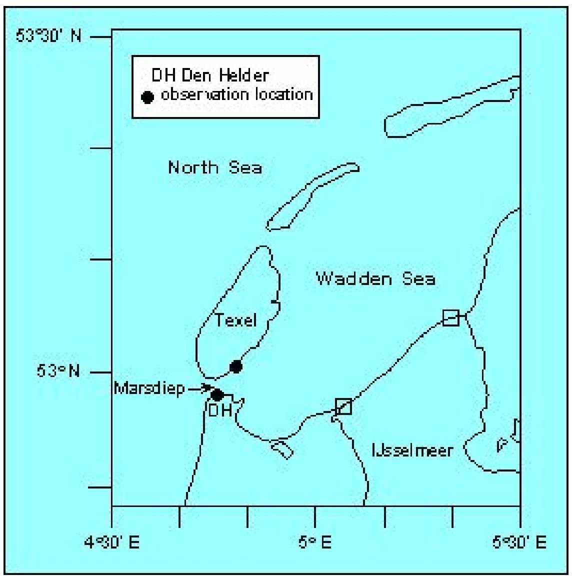

Figure 10-1 Locations of *in situ* salinity and temperature measurements at the historic Den Helder station (DH) and at the NIOZ jetty on the island of (Van Aken 2003). The *in situ* SPM data are collected at the same location on Texel.

At present it has not been possible to fully assess the quality, quantity and usefulness of the SPM data from the jetty.

10.2 Salinity and Temperature Marsdiep

Availability

In situ data of salinity and temperature are collected at the jetty at the dike across from the NIOZ grounds (‘t Horntje) on the island of Texel (see Van Aken 2003 and http://www.nioz.nl). Figure 10-1 shows the location. The monthly mean temperature and salinity data are available for scientific research. For other purposes, special agreements with NIOZ need to be made. The temperature data are not considered because of limited applicability to our present purposes.

Quality

From July 1860 until 1962, daily water samples were taken at Den Helder, and temperature and salinity of the samples were determined. Before 1904, the samples were taken at high- and low water during the day, from 1904 onwards at 08:00 hours local time. In 1947, daily observations of salinity and temperature started in 't Horntje across the Marsdiep. There is an overlap of 16 years of both time series. From the daily observations of both time series monthly mean values for salinity and temperature are determined. From the 16 years overlap, systematic differences between 't Horntje and Den Helder have been determined which have been used to extend the Den Helder series to present, based on the observations from 't Horntje.

Quantity

Because of interference of observations of a fixed time of the day and the semi-diurnal tide, modulations with a period of about 14 days will develop in the daily time series. Therefore the daily data are reduced to monthly mean values from which annual mean values of temperature and salinity are derived. Hence the useful quantity refers to over 140 years of monthly data.

Usefulness

Because of the length of the record, these data are very useful for long-term trend-analysis. Also these data can be compared to salinity and temperature data measured onboard of the TESO ferry (see section 11.1). Finally, the salinity data are very useful for calibration of deterministic models in which the discharges, transport and mixing of fresh water and SPM are incorporated.

11 Ferry data sets

Over the past years an increasing number of ferries around the world is equipped with so-called ferry-boxes. A ferry-box is an onboard system that enables continuous measuring of various properties of the near-surface sea water. Usually it consists of an intake and through-flow measurement device. In addition, ferries may be equipped with ADCP-devices measuring velocity and acoustic backscatter intensity over a vertical column below the ship. Because ferries frequently cruise more-or-less the same route, most often throughout the year, valuable data sets are created at relatively low costs. International programs such as the EU-funded Ferry-box program (www.ferrybox.org) give incentive to a growing number of operational ferry-box systems.

11.1 NIOZ-TESO ADCP Marsdiep

Availability

Since 1998, a more or less continuous measuring of currents and other sea-water properties is taking place onboard of the TESO ferries crossing the Marsdiep inlet. The ferries Dr. Wagemaker and Schulpengat are equipped with an ADCP and a through-flow system measuring salinity, water temperature and fluorescence. (see e.g., Ridderinkhof et al, 2002, Merckelbach & Ridderinkhof 2006, Buijsman & Ridderinkhof 2006, and, www.nioz.nl). Data are conditionally available through NIOZ.

Quality

The ADCP data provide current velocity data of which only the two horizontal components are considered reliable. Corrections for other sources of error (ship position, tilts etc) are technically feasible and do not affect the data quality. Buijsman & Ridderinkhof (2006) present data on tidal and residual flows through the cross-section of the Marsdiep inlet. The residual fluxes (relatively small differences of large numbers) appear robust.

As outlined in section 4, from the echo intensity of the ADCP signals also a measure for suspended material in the water can be derived (Meckelbach & Ridderinkhof, 2006, Merckelbach, 2006). For calibration and validation of the algorithms NIOZ carries out not only permanent OBS measurements, but also 13-hour surveys across the Marsdiep every season. At the moment, at least one independent reference concentration measurement (using an optical backscattering device (OBS)) is required along with the ADCP measurements. The reason is that Merckelbach (2006) observes (at least in the Marsdiep) two regimes that depend on the level of turbulence in the flow. Hence, the relation between echo intensity and SPM concentration is not a unique function. Presently, NIOZ is carrying out research to further refine the retrieval methods and to attempt to formulate unequivocal functional relations for the Marsdiep situation (J. Nauw, NIOZ, pers. com. August 2006.) For example, a more accurate turbulence model is sought.

With regards to the absolute accuracy of retrieved SPM concentrations from the ADCP data, Merckelbach & Ridderinkhof, (2006) conclude that 90% of the validation OBS data differed no more than 10 mg/l from the data retrieved from ADCP. According to Merckelbach (personal comm. Oct. 2006) the current accuracy of individual measurements is on the order of 10 mg/l, but may depend on weather conditions (rough weather with higher waves may lead to larger uncertainties with the present algorithms).

Quantity

The data are measured only during operational times of the ferries (i.e. from 6:00 to 22:00) and data gaps occur when the vessel is in dock or the equipment is decommissioned for servicing. The discharge time series up to now can be viewed in Figure 11-1 below, which illustrates the temporal coveage.

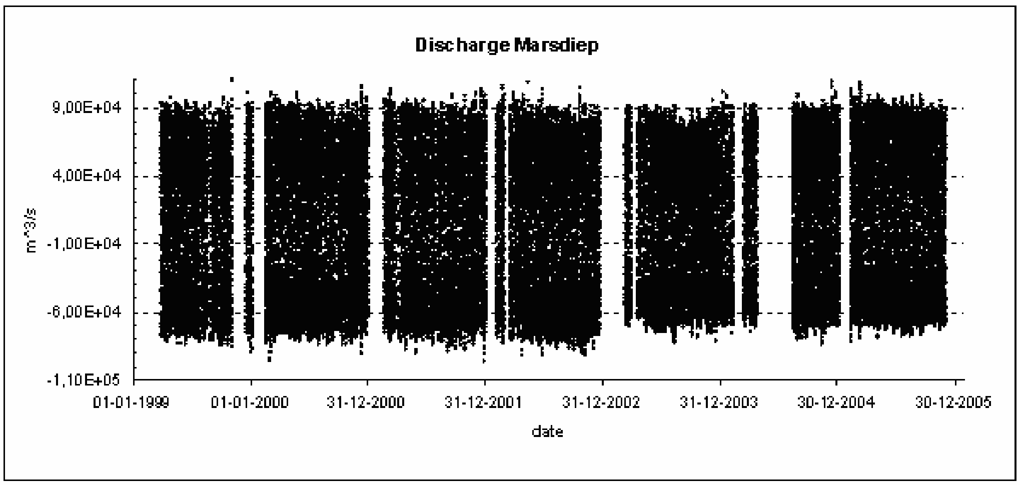

Figure 11-1 Discharge through the Marsdiep Inlet as measured by the NIOZ-TESO ADCP onboard the ferry between Den Helder and Texel.

Costs

At present the data are freely available under restrictions. For future application, an agreement with NIOZ may be required (M. Wernand, NIOZ, pers. comm. October 2006).

Usefulness

The ferry data of the Marsdiep are a unique source of information on transports through one of the major inlets of the western Wadden Sea. It is one of the few data sources providing long-term data on not only the surface conditions, but also the vertical distribution of current velocities and SPM concentration. Volume transport is well established by now, but transport (and especially residual transport) of the fine fraction of sediments (i.e. SPM) is not yet robust enough. It is expected that scientific achievements in the coming years will improve the SPM flux assessments. Since calibration measurements have been and are carried out regularly, all raw data can be reprocessed at any moment in future to establish more accurate SPM fluxes from 1998 onward.

11.2 Other ferry boxes

Figure 11-2 gives an overview of currently active ferry-box programs within the European Ferrybox Network (www.ferryboxes.org). Of some relevance for our present purposes are the ferry cruising from Cuxhaven to Harwich and the ferry cruising from Portsmouth to Bilbao (which up to 2005 at least also cruised a leg between Portsmouth and Cherbourg), see

Table 11-1.

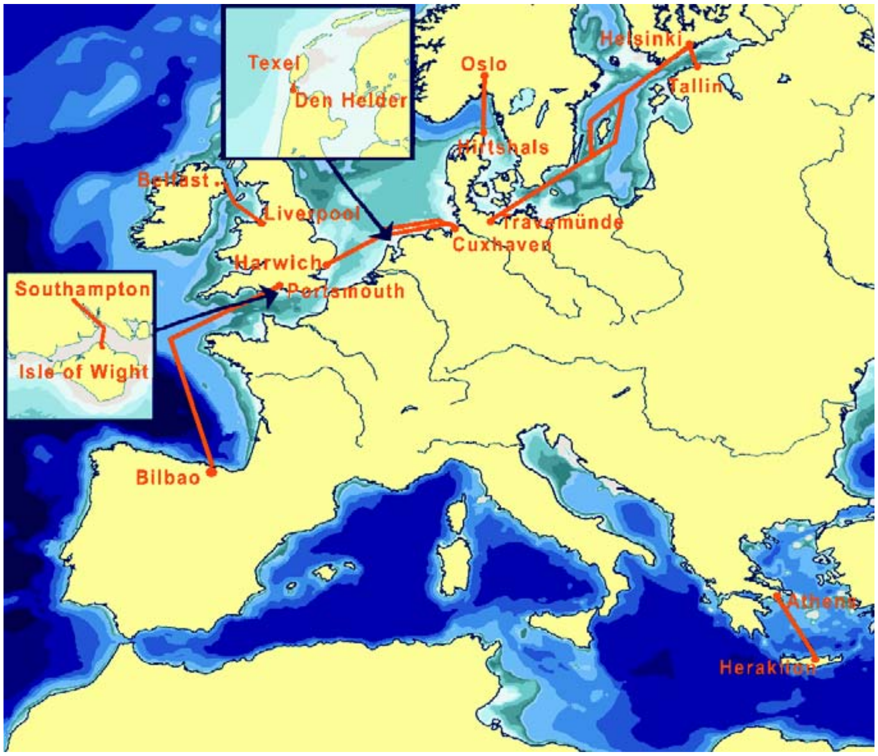

Figure 11-2 Overview of currently active ferrybox programs from European Ferrybox Network (http://www.ferrybox.org).

Table 11-1 Summary of other ferry box programs possibly of interest for the current Baseline Silt PMR project.

Route n^o	**R3**	**R7**
FerryBox Operator	GKSS	NERC, NOC&IEO
Ferry Route	Cuxhaven (Germany)- Harwich (UK)	Southampton (UK) – Bilbao (ES)
Location, characteristics	Southern North Sea Ferry route closed down in September 2005. GKSS will install its Ferrybox system on another ferry in 2006	English Channel and Bay of Biscay
Measured variables	sea water temperature, salinity, turbidity, dissolved oxygen, fluorescence, ammonium, nitrate/nitrite, phosphate, silicate, different algae groups	sea water temperature, conductivity, turbidity, fluorescence, nitrate, algae groups
Coverage time	2002(?)-2005	2002-present (Cherbourg-Portsmouth until 2005)
URL	http://ferrydata.gkss.de/ (User controlled graphical data displays and data downloads for authorised users.) http://coast.gkss.de/ferrybox (Detailed information on the ferry, the ferry route, the GKSS FerryBox system and other FerryBoxes applied in Germany.)	http://www.noc.soton.ac.uk/ops/ferrybox_index.php

In addition to these ferryboxes, Rijkswaterstaat has equipped its survey vessels Zirfaea and Arca with a measuring system that is continuously active whenever the ship is operational. Moreover Rijkswaterstaat has taken an initiative to equip a commercial ferry from IJmuiden to Newcastle/Bergen with a ferry box in the near future (pers. comm.. H. Roberti and V. Langenberg, RIKZ Den Haag). It is not yet known when exactly this will take effect.

11.3 Conclusions ferry boxes

Up to now the ferry boxes, other than the TESO ferry and the RV Zirfaea and Arca, do not cover the part of the Dutch coastal zone of interest. It seems worthwhile to retrieve the continuous measurements of the past years by the Rijkswaterstaat research vessels, if still available. The initiative to equip another commercial ferry that crosses the Dutch coastal zone regularly when leaving from and arriving at IJmuiden is certainly of value to obtain more insight in the coastal system but may be too late to collect reference data (t_0) and enable measuring of possible future changes in the SPM conditions off IJmuiden (t_1). Data of the ferry between Portsmouth and Cherbourg may be useful to determine the conditions in the Channel but at present no detailed information is available.

12 Remote sensing data

12.1 Introduction

Remote sensing (RS) by satellite-based sensors is becoming a widely used tool in oceanic and coastal zone research. RS satellites are used to measure sea surface temperature (SST), ocean colour, ocean surface waves and currents etc. These data are being applied to a wide variety of purposes, which include global climate modelling, modelling of primary production, detecting pollution such as oil spills and storm and sewage runoff and measurement of suspended sediments (SPM). The advantage of satellite sensors with respect to in-situ sensors (such as buoys or ships, for example) is the ability to provide a synoptic picture of the measured parameter; providing coverage over a significant extent in both space and time. Disadvantages, on the other hand, is the loss of optical remote sensing data due to the obstruction of the signal by clouds and haze and, at least for some parameters, the limited use in very shallow areas such as the Wadden Sea or in areas close to shore (land-sea adjacency).

The main objective of this chapter is to provide an overview of available RS sensors and data with regard to establishing a baseline SPM climatology for the North Sea. Additionally, this overview serves as a guideline for determining the applicability of currently available remote sensing sensors for North Sea SPM monitoring. Remote sensing (RS) can be a valuable tool when monitoring SPM-related parameters, and sometimes the only monitoring method available, especially when a synoptic coverage is required that is hard to obtain with in-situ sensors, e.g. to monitor SPM concentrations over Dover Strait. Moreover, RS can provide valuable data to establish a baseline climatology of SPM concentrations prior to construction of MV2. Over the last decade a number of RS sensors have been operational, which have the ability to distinguish either SPM directly (e.g. ocean colour sensors) or the conditions related to SPM transport, e.g. the extent of the Rhine plume can be monitored from RS sea surface temperature data. Similarly, significant wave height and residual currents as measured by RS sensors may provide information on re-suspension and ensuing sediment transport. Based on these relations it is believed that these parameters (SST, significant wave height and residual currents) can provide additional insight into SPM features in the North Sea next to the traditional ocean colour measurements. Also, based on statistical relations these parameters may be used as an additional data source to quantify SPM concentrations.

With regards to establishing a baseline SPM climatology, a significant amount of RS data is currently available. Over the last decade a number of RS sensors have been operational with the ability to either measure and quantify SPM directly (ocean colour sensors) or which can provide additional information based on the above described relations (e.g. SST, significant wave height and residual currents). A significant amount of these data is readily available from different sources on the internet at different stages of data processing; from level 1 data, the radiances as measured by the satellite sensor, to level 3 data, the geolocated geophysical parameter (see Table 12-1).

Table 12-1 Levels of remote sensing data processing. Available products mostly form the following range (Tatman et al. 2005):

RS data processing level	General description
Level 0: raw uncorrected level	No radiometric or geometric corrections have been applied.
Level 1: systematic correction level	Both radiometric and geometric corrections have been applied. The radiometric correction contains a rescale to unsigned integer DN (Digital Number) values in order to enable calculations towards spectral radiance values. The geometric correction includes corrections for the effects of earth rotation, earth curvature, sensor distortions, transformation from satellite orientation to north-up orientation, etc. These data are used to geolocate a recorded image to its position on the earth's surface. Products can be made available in a number of different map projections.
Level 2 products: precision correction level.	The same corrections are applied as used for the systematic corrections, with the addition of local ground truth (ground control points, map reference material, GPS) in order to improve the accuracy. The correction level can be further extended with the use of height information to correct for relief displacement, the so-called orthocorrection. The product is a derived environmental variable.
Level 3 products: geocoded projected imagery	The image is mapped to a projection of the Earth, and in some cases can also be composited in space (i.e. several images are mosaiced to show a larger scene) or time (weekly, monthly composites).

Furthermore, the internet data sources sometimes provide RS measurements of the indicated parameters in near real-time (with a delay of up to a few days). This is possible with IKONOS and Orbview-2. RS is also suitable for monitoring SPM after future events, e.g. after construction of MV2, by making use of archived RS data.

Motivated by the above, this chapter will provide an overview of currently available, relevant RS data. RS sensors on satellites that are foreseen to be launched in the near future have not been included, since the time between launch and availability of accurate processing algorithms for SPM retrieval will be too long for the practical purpose of a t_0 monitoring program for MV2 in 2007. Nevertheless, as soon as they are available they may be included in t_1 monitoring activities. An overview is provided on sensor and satellite characteristics and on availability and processing level of data. This is done for a number of (possibly) relevant (ocean colour, SST, significant wave height and residual currents) sensors, a description of which follows below. In the second half of the chapter the available sensors and data are evaluated and, by means of setting and using criteria, a selection is made of the most suitable remote sensing sensors, together with available suitable algorithms, for North Sea SPM monitoring.

12.2 Parameters measured by remote sensing sensors relevant to SPM

12.2.1 Ocean colour sensors and high resolution optical imagers

Ocean colour sensors are passive radiometers that measure the intensity of radiation leaving the upper part of the water column in visible and near-IR wavelengths (400 – 800 nm), where the colour is characterized by the constituents of the water, typically phytoplankton and its degradation products, suspended matter and dissolved compounds. Differences in the intensity of light received in the different bands gives information on the concentration of a variety of substances present in the ocean (CEOS 2002). These instruments have narrow bands (detection channels), around 10 nm wide, which can measure fine spectral detail. The resolution ranges from 0.3 (e.g. MERIS on ENVISAT) to 1 km (e.g. Orbview-2). The trend in recent years has been towards multi-band and multi-purpose sensors, resulting in 'ocean colour' being one of several applications of the sensor.

High-resolution optical imagers are passive radiometers that measure the intensity of radiation in the visible spectrum and IR simultaneously to make high-resolution images in the range of 1 – 100 m. Examples of these are IKONOS and Quickbird. These sensors are not specifically designed for monitoring surface water quality, and therefore sensor-specific SPM retrieval algorithms are not currently available for determining SPM concentrations (as has been found in the RESTSCOD-3 study, which is currently being carried out by WL | Delft Hydraulics, Argoss, NLR and Van Oord).

12.2.2 Sea surface temperature sensors

SST sensors are imaging multi-spectral radiometers that measure the intensity of reflected and emitted radiation in the upper part of the water column at IR wavelengths, where the wavelength and radiation intensity are characterized by the temperature of surface water (CEOS 2002). SST can provide an indirect measurement of flow conditions related to SPM transport, e.g. the extent of the Rhine plume can, under certain conditions, be monitored using SST sensors. However, this is only the case when the water column is stratified (and thus is not possible when the water column is well-mixed), and furthermore, it is only possible when the heat contrast between the plume surface water and surrounding water mass is high enough. This can only occur in the summer when the plume surface water is heated sufficiently by sun, or in the winter when the overlying surface water is sufficiently colder than the surrounding water (Boer de G., Arentz L., Pietrzak J., Winterwerp H. 2006, Remote Sensing of the Rhine Plume. Presentation NCK-days, Kijkduin, March 2006). Remotely sensed SST data can therefore only be used in combination with a numerical model, which can provide the information on stratification (G. de Boer, pers. comm. Oct. 2006).

12.2.3 Significant wave height and current sensors

The significant wave height (SWH) and currents can be measured by both Radar Altimeters (RA) and Synthetic Aperture Radars (SAR). RA's are active microwave radars that measure the distance between the sensor and the earth's surface. This provides information on the sea surface topography and roughness, which can be used for determining sea surface elevation, surface currents, significant wave height and wind speeds (CEOS 2002). RA's are not designed to measure SWH in coastal areas. A study that has attempted to investigate the quality of Jason-1 to within 10 km of the coast (Høyer & Nielsen 2006) found that a significant amount of good data can be obtained within 10 km and that the satellite observations are significantly better than the (WAM) wave model used in the study.

In general, the significant wave height as measured by RA's is rather coarse (the average wave height over the radar footprint). Similarly, RA's is mainly suitable for determining currents at large temporal and spatial scales. Also, the sensor generally has difficulties along the land-sea interface. Based on this the sensor might be used to study large-scale features like currents through the Dover Strait and large-scale North Sea circulation, but cannot be used accurately to study effects of, for example, the Rhine Plume.

SAR's are active microwave imaging radars which measure the intensity of backscattered microwave radiation. Backscatter from the sea surface can be used to deduce surface wave data and to detect surface features such as fronts and eddies. SAR measurements can accurately measure changes in ocean waves, including wavelengths and the direction of wave fronts, regardless of cloud cover and daylight (CEOS 2002).

SAR's are able to study waves and currents on smaller scale (e.g. Liu et al, 2006), in contrast to RA's. In general, however, the algorithms required to do so are complex and still under development. Also, data are hard to obtain. Thus, in conclusion, RA and SAR sensors will not be evaluated further in this chapter. If in future the techniques to derive currents from RS become more established, it is nevertheless recommended to re-investigate their usability for the SPM transport in the Dutch coastal zone.

12.3 Overview of available satellite sensors and data sources

Below, an overview follows on available satellite sensors and data sources for the sensor types as discussed above This overview is categorized per sensor type, and consists of two tables; one providing information on the sensor and satellite characteristics relevant to the sensors applicability to measure a given process. The second table describes data availability, processing levels and costs.
Note that in Table 12-2 to Table 12-7 some fields are left blank. This implies that either no information on these properties was readily available or that no quantitative and consistent measure for the properties is available. Also, there is an increasing number of data providers through various (internet based) channels. As such the tables below are by no means expected to be complete. Also, due to the evolving nature of the internet, URLs of data portals may change over time.
Next, the sensors described are those operated by US and EU operators mainly (the Japanese ADEOS satellites being the exception). The reason being that data from satellites

operated by other parties (e.g. China and India) is hard to obtain. Also, only the most commonly used sensors are described. The reason being the availability of their data and in order to obtain a workable overview. For a more elaborate overview of previous, current and future remote sensing sensors the reader is referred to ESA (2002).

Finally, the overview below is intended to be used as a guideline and starting point for further inquiries about sensor characteristics and on obtaining data.

12.3.1 Ocean colour sensors and optical imagers

Table 12-2 Satellite and sensors properties ocean colour sensors and high resolution optical imagers

Sensor@satellite	Operator	Resolution				Coverage		Accuracy	Experience	Note
		Spatial	Temporal	Spectral (bands)	Swath	Start	End			
		m	days*	µm (nr)	km	mm yyyy	mm yyyy			
Orbview-2@SeaStar	USA	1100/4400N	1	0.402-0.885 (8)	2800	08 1997	current	5%. (CEOS 2002)	IVM/TUD/ WL	NLocal/Global coverage
MODIS@Terra	USA	1000	1/2	0.4-14.4 (32)	2330	12 1999	current		TUD/WL	
MODIS@Aqua	USA	1000	2	0.4-14.4 (32)	2330	05 2002	current		TUD/WL	
MERIS@Envisat	EU	300/1200	3	0.4-1.05 (15)	1200	03 2002	current			
GLI@ADEOS-2	Japan	1000	4	0.38-11.95 (36)	1600	11 2002	current			
OCTS@ADEOS	Japan	700	41	0.443-11.0 (12)	1400	08 1996	06 1997			
SPOT 2,4	France	10/20	26	0.5-1.7 (4)	117	03 1997	12 2004			High-res. optical imager
SPOT 5	France	5/10	26	0.55-1.7 (5)	117	03 2002	current			High-res. optical imager
Landsat 4,5	USA	30	16	0.45-12.5 (7)	790	03 1984	current			High-res. optical imager
Landsat 7	USA	15	16	0.45-12.5 (8)	185	04 1999	current			High-res. optical imager
Quickbird 2	USA	2.4	3	0.45-0.9 (4)	16.5	10 2001	current			High-res. optical imager
IKONOS 2	USA	4	1/3.5	0.45-0.85 (4)	11	09 1999	current			High-res. optical imager
Orbview-3	USA	4	3	0.45-0.9 (4)	8	06 2003	current			High-res. optical imager

*the effective temporal resolution can decrease due to cloud coverage.

Table 12-3 Data availability and costs of colour sensors and high resolution optical imagers

Sensor@satellite	Source	Level	Resolution		Coverage		Costs	Time	Note
			Spatial	Temporal	Start	End			
			km	days	mm yyyy	mm yyyy	$		
Orbview-2@SeaStar	www.wadi.nl	3	N	Irregular	09 1997	11 2004	FoC	NRT	NPictures only
Orbview-2@SeaStar	http://oceancolour.gsfc.nasa.gov/	1/2/3	1.1/4.4/9	d/w/m/q/y***	08 1997	09 2006	FoC	NRT	TC, CHL, nLW
Merged Orbview-2/MODIS	http://oceancolour.gsfc.nasa.gov/	3	9	d/w/m/q/y***	06 2002	09 2006	FoC	NRT	CHL
MODIS@Terra	http://oceancolour.gsfc.nasa.gov/	1/2	1	1/2	01 2000	09 2006	FoC	NRT	TC, SST
MODIS@Terra/Aqua	http://g0dup05u.ecs.nasa.gov	3	110	d/w/m/q/y***	01 2000	09 2006	FoC		CHL,SST
MODIS@Terra/Aqua	http://ladsweb.nascom.nasa.gov	1	1	1	01 2000	09 2006	FoC	NRT	Radiances
MODIS@Aqua	http://oceancolour.gsfc.nasa.gov/	1/2/3	1/4/9	d/w/m/q/y***	06 2002	09 2006	FoC	NRT	TC, CHL, SST, nLW
MERIS@Envisat	http://badc.nerc.ac.uk/data/meris/	1b/2	0.3/1.2	3	03 2002	current	FoC	NRT	
MERIS@Envisat	http://earth.esa.int/dataproducts/	1/2/3	0.3/1.2	3	03 2002	current	FoC	NRT	
OCTS@ADEOS	http://oceancolour.gsfc.nasa.gov/	3	9	1/7/31	11 1996	06 1997	FoC	NRT	
SPOT / Quickbird / IKON.	http://www.gim.be						Paid**		
SPOT / Landsat 5,7	http://edcsns17.cr.usgs.gov						Paid**		USGS Earth Explorer
S. / QB. / IKON. / Land.	http://www.eurimage.com						Paid**		
IKONOS 2 / SPOT	http://www.sieurasia.com/						Paid**		
IKONOS 2	http://www.spaceimaging.com						Paid**		Carterra catalogue
Orbview-3	http://www.orbimage.com	1/2/3	0.004	3	06 2003	current	500N	3 days	NStarting at … per image

** IKONOS: $18.00; Quickbird: $22.50; Landsat 7: $0.019; SPOT 5: $0.75. Prices based on (RESTCOD, 2005) *** d/w/m/q/y=daily/weekly/monthly/quarterly/yearly
TC=true colour, CHL=chlorofil, SST= sea surface temperature, FoC=Free of charge, NRT=Near Real Time

12.3.2 Sea surface temperature sensors

Table 12-4 Satellite and sensors properties of sea surface temperature sensors

Sensor@satellite	Operator	Resolution				Coverage		Accuracy	Experience	Note
		Spatial	Temporal	Spectral (bands)	Swath	Start	End			
		m	days*	µm (nr)	km	mm yyyy	mm yyyy	K		
AVHRR@NOAA	USA	1.1/4.5	0.5	0.58-12.5 (5)	3000	09 1985	current[N]	0.5	TUD/WL	[N]Multiple sat.
MODIS@Terra	USA	1000	1/2	0.4-14.4 (32)	2330	12 1999	current	0.2	TUD/WL	
MODIS@Aqua	USA	1000	2	0.4-14.4 (32)	2330	05 2002	current	0.2	TUD/WL	
ATSR@ERS1-2	EU	1	35	0.65-12.5	500	04 1995	current	0.5		
GLI@ADEOS-2	Japan	1000	4	0.38-11.95 (36)	1600	11 2002	current	0.4-0.5		
MERIS@Envisat	EU	300/1200	3	0.4-1.05 (15)	1200	03 2002	current			

*the effective temporal resolution can decrease due to cloud coverage.

Table 12-5 Data availability and costs of sea surface temperature sensors

Sensor@satellite	Source	Level	Resolution		Coverage		Costs	Time	Note
			Spatial	Temporal	Start	End			
			km	days	mm yyyy	mm yyyy			
AVHRR@NOAA	http://podaac-www.jpl.nasa.gov	3	4	1	09 1985	current	FoC	NRT	
AVHRR@NOAA	http://www.class.noaa.gov	1/2	1	1	09 1985	current	FoC	NRT	
MODIS@Terra	http://earth.esa.int/dataproducts/	1/2/3	1/4	1	01 2000	09 2006	FoC****	NRT	
MODIS@Terra	http://daac.gsfc.nasa.gov/	1/2/3	1/4	1	01 2000	09 2006	FoC	NRT	
MODIS@Terra	http://oceancolour.gsfc.nasa.gov/	1/2/3	1/4/9	d/w/m/q/y***	01 2000	09 2006	FoC	NRT	
MODIS@Aqua	http://earth.esa.int/dataproducts/	1/2/3	1/4	1	06 2002	09 2006	FoC****	NRT	
MODIS@Aqua	http://daac.gsfc.nasa.gov/	1/2/3	1/4	1	06 2002	09 2006	FoC	NRT	
MODIS@Aqua	http://oceancolour.gsfc.nasa.gov/	1/2/3	1/4/9	d/w/m/q/y***	06 2002	09 2006	FoC	NRT	
MODIS@Terra/Aqua	http://podaac-www.jpl.nasa.gov	3	4.6	1/8/30	12 2002	current	FoC	NRT	
ATSR@ERS1-2	http://earth.esa.int/dataproducts/	1/2/3	1	1	04 1995**	current	FoC****	NRT	
ATSR@ERS1-2	http://podaac-www.jpl.nasa.gov	2	1	1	04 1995**	current	FoC	NRT	
MERIS@Envisat	http://earth.esa.int/dataproducts/	1/2/3	1.2	3	03 2002	current	FoC****	NRT	

** availability can vary depending on measurement program *** d/w/m/q/y=daily/weekly/monthly/quarterly/yearly **** Research only, otherwise see http://www.eurimage.com/
FoC=Free of charge, NRT=Near Real Time

12.3.3 Significant wave height and current sensors

Table 12-6 Satellite and sensors properties of significant wave height and currents sensors

Sensor@satellite	Operator	Resolution			Coverage		Accuracy (Ref: CEOS 2002)	Experience	Note
		Spatial	Temporal	Swath	Start	End			
		km	days	km	mm yyyy	mm yyyy	cm		
RA@ERS-2	EU	20*	35	80**	04 1995	current	wave height: 50 or 10% (whichever is smallest)	TUD	
RA@T/P	USA/FR	6*	10	300**	08 1992	current	wave height: 50 sea level: 4	TUD	
Jason-1	USA/FR	6*	10	300**	12 2001	current	wave height: 50 sea level: 3.9	TUD	
RA@Envisat	EU	20*	35	80**	03 2002	current	wave height: 25 (5%) sea level: 4.5	TUD	
ASAR@Envisat	EU	0.03/0.15/0.95***	35	5/400***	03 2002	current			
SAR@Radarsat-1/2	CSA	0.009/0.025/0.1***	24	45/500***	11 1995	current			
AMI@ERS-1/2	EU	0.03	35	100	04 1995	current			

* sensor footprint ** distance between adjacent ground tracks *** Different modes

Table 12-7 Data availability and costs of significant wave height and currents sensors

Sensor@satellite	Source	Level	Resolution		Coverage		Costs	Time	Note
			Spatial	Temporal*	Start	End			
			km	days	mm yyyy	mm yyyy			
RA@ERS-2	http://rads.tudelft.nl/rads	2/3	GT	35	04 1995^{n}	current****	FoC	NRT	SSA/Wind/Wave
RA@ERS-2	http://www.aviso.oceanobs.com/	2/3	GT	35	04 1995^{n}	current****	FoC	NRT	SSA/Wind/Wave
RA@T/P	http://rads.tudelft.nl/rads	2/3	GT	10	08 1992	current	FoC	NRT	SSA/Wind/Wave
RA@T/P	http://www.aviso.oceanobs.com/	2/3	GT	10	08 1992	current	FoC	NRT	SSA/Wind/Wave
Jason-1	http://rads.tudelft.nl/rads	2/3	GT	10	12 2001	current	FoC	NRT	SSA/Wind/Wave
Jason-1	http://www.aviso.oceanobs.com/	2/3	GT	10	12 2001	current	FoC	NRT	SSA/Wind/Wave
RA@Envisat	http://rads.tudelft.nl/rads	2/3	GT	35	03 2002	current	FoC	NRT	SSA/Wind/Wave
RA@Envisat	http://www.aviso.oceanobs.com/	2/3	GT	35	03 2002	current	FoC	NRT	SSA/Wind/Wave
Blended	http://www.aviso.oceanobs.com/	3	35	7/30	08 1992	current	FoC	NRT	SSA/Wind/Wave
ASAR@Envisat	http://earth.esa.int/dataproducts/	1/2/3	0.03/0.15/0.95**	35	03 2002	current	FoC***	NRT	
ASAR@Envisat	http://envisat.esa.int/dataproducts/	1/2/3	0.03/0.15/0.95**	35	03 2002	current	FoC***	NRT	
SAR@Radarsat-1/2	http://www.scanex.ru	2/3	0.009/0.025/0.1**	24	11 1995	current	Paid		
SAR@Radarsat-1/2	http://www.infoterra.co.uk	2/3	0.009/0.025/0.1**	24	11 1995	current	Paid		
AMI@ERS-1/2	http://earth.esa.int/dataproducts/	1/2/3	0.03	35	04 1995^{n}	current****	FoC***	NRT	
AMI@ERS-1/2	http://envisat.esa.int/dataproducts/	1/2/3	0.03	35	04 1995^{n}	current****	FoC***	NRT	
Blended (RA/SAR)	http://www.waveclimate.com	3	50				Paid		ARGOSS website

* In this period an ascending and descending pass are made ** Different modes *** Research only, otherwise see http://www.eurimage.com/ **** availability can vary depending on measurement program; GT=along Ground Track, FoC=Free of charge, SSA=Sea Surface Anomaly, NRT=Near Real Time

12.4 Selecting suitable remote sensing sensors

As mentioned above, a second objective of this part of the study (i.e. the inventory and usefulness of RS) is to determine the most suitable currently available remote sensing sensors for North Sea SST and SPM monitoring. Therefore, in the following sections the available sensors and data are evaluated and a selection is made of the most suitable remote sensing sensors, together with available suitable algorithms, for North Sea SPM monitoring by using criteria.

12.4.1 Initial selection

For a first selection of the various sensors, the three most important initial criteria are set and include:

- Temporal,
- Spectral,
- (Effective) spatial resolution (see Table 12-8).

Table 12-8. Initial criteria to be used when selecting satellite data for SPM monitoring

Criteria for satellite data	*Further details*
Temporal resolution	Preference for one daylight recording in 24 hours
Spectral resolution	Wavelength intervals of 10 to 20 nm
Spatial resolution	Minimum of 1 km (medium resolution)

Each criterion is detailed in the following paragraphs.

Temporal resolution

The ***temporal resolution*** indicates the satellite's repeat cycle. In each cycle, measurements are made during both the ascending and descending pass, doubling the number of times a measurement location can be covered. The temporal resolution of earth orbiting satellites depends strongly on their swath width. When the swath width is 3000 km, as is the case for the NOAA satellites of the USA, a temporal resolution is possible of four times in twenty-four hours (and thus two times during daylight conditions). The smallest visible detail from the NOAA satellites is 1.1 kilometre. When one wants to obtain higher detail, it will be necessary to reduce the swath width and with that it will only be possible to get one daylight recording in 24 hours because swaths of two successive orbits will not overlap anymore (Tatman et al. 2005).

For a number of satellites it is possible, apart from their orbital characteristics, to reach a higher temporal resolution because the imaging instrument on board is pointable. A high resolution satellite like the IKONOS-2 satellite carries a pointable instrument on board that can perform both in-track pointing and cross-track pointing. IKONOS can image swaths of 13 kilometres wide but as far as 300 km perpendicular to the satellite track (cross-track pointing) and can also image 300 km back and forwards within the satellite track (in-track pointing). Specific programming by user request can lead to a higher temporal resolution for a certain area (Tatman et al. 2005).

The number of effective measurements, or the effective temporal resolution, can be greatly decreased by a number of sources, though;

A) For both the ocean colour, optical imager and SST sensors, measurements are made at optical or infra-red frequencies. At these frequencies clouds are impenetrable, prohibiting measurements over clouded regions. This greatly reduces the number of useful measurements.

B) The ocean colour and optical imagers are most effective during daytime since they measure in the optical spectrum. Since most of these satellites are operated by US agencies their main focus will be on North America. This may imply they cover the North Sea at a sub-optimal time (note that the orbital trajectories, too, can be sub-optimal for the North Sea, increasing the inaccuracy due to geo-referencing of the pixels). Furthermore, the dependence on daylight means that less observations will be available during winter time.

Also, it should be noted that the number of operational SST sensors is significantly larger than the number of ocean colour sensors (mainly due to the NOAA-AVHRR satellites).

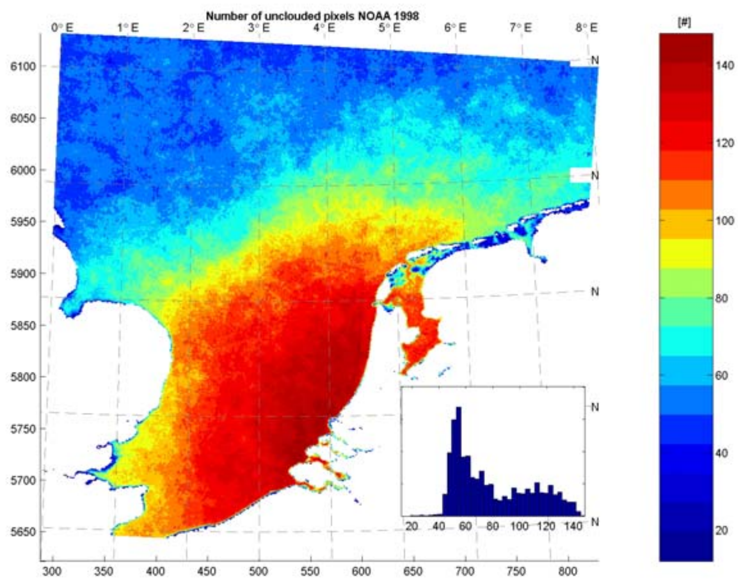

Figure 12-1 Effective number of SST measurements during 1998 by NOAA AVHRR (Arentz, 2005)

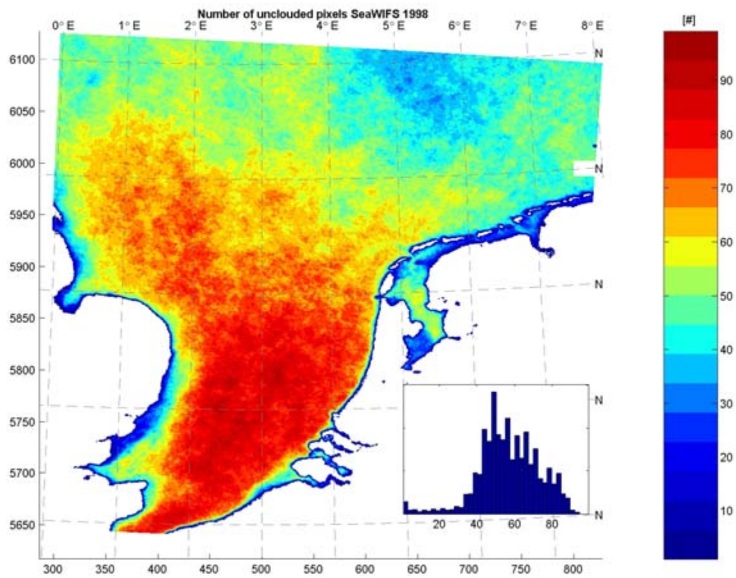

Figure 12-2 Effective number of SPM measurements during 1998 by Orbview-2 (Arentz, 2005)

Figure 12-1 and Figure 12-2 respectively show the number of useful SST and SPM measurements by NOAA-AVHRR (2 operational) satellites and by Orbview-2 (formerly named SeaWiFS) during the year 1998 (see also Arentz, 2005). From these figures it is observed that in the direct vicinity of MV2 a total of about 140 SST and 80 Orbview-2 images provide data. Based on these numbers the temporal resolution as mentioned in the above tables is no adequate representation of the temporal coverage, which is significantly lower. Similarly, Figure 12-3 shows that the available measurements are biased; during summertime the temporal coverage is significantly better than during winter time. Additional analysis by Arentz (2005) also shows clustering on the sub-monthly scale during periods of of few days of low cloudiness.

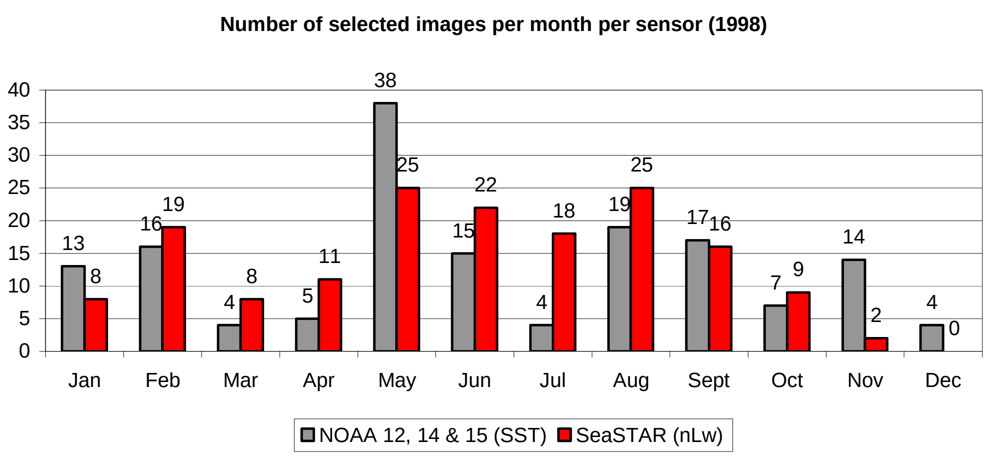

Figure 12-3 Temporal distribution of the useful SST and SPM images per month for the year 1998 (Arentz, 2005)

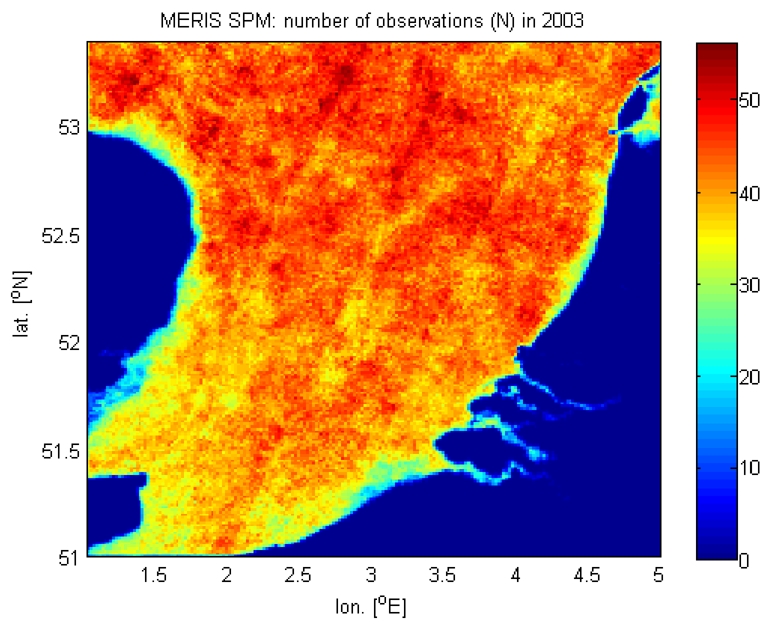

Figure 12-4 Number of successful SPM observations (*N*) per aggregated pixel by MERIS for 2003 (actual data binned into 0.01 degree Latitude, 0.02 degree Longitude pixel aggregates).

Similar to Figure 12-1and Figure 12-2, Figure 12-4 shows that annual mean MERIS coverage in time for 2003 was about bi-weekly to weekly, with a lower sampling density closer to the coast. In general a similar pattern of the distribution over the year as in Figure 12-1and Figure 12-2 applies to these data with a relatively lower sampling density in Spring an Autumn.

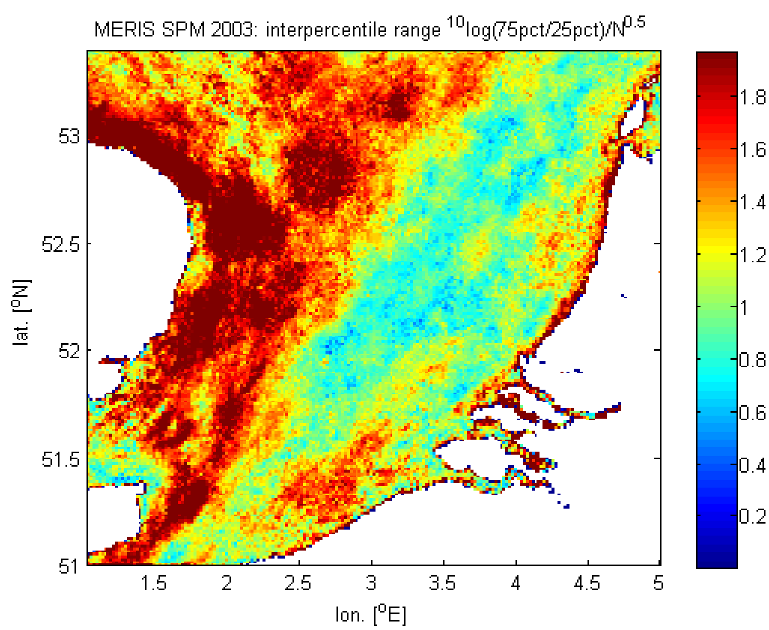

Figure 12-5 A measure for the spread in the mean of the MERIS 2003 SPM data per pixel defined as the range between the 25 and 75 percentile divided by the square root of the number of observations (*N*, see Figure 12-4). Actual data binned into 0.01 degree Latitude, 0.02 degree Longitude pixels, ^{10}log of the inter-percentile range is shown .

Figure 12-5 shows a measure of the spread in the mean of the SPM data over 2003 by MERIS. It gives an indication of the usefulness of the data to detect long-term changes in the mean. There is a strong cross-shore gradient off the Dutch coast. Close to the coast the spread in the mean reaches up to two orders of magnitude whereas further offshore it is less than one order of magnitude, albeit with very inhomogeneous spatial patterns. These numbers indicate that the first kilometres have a relatively large spread in the mean, hence only a relatively strong relative change can be detected there, compared to further offshore.

In conclusion, all ocean colour and optical imaging sensors are affected by cloud cover and daylight availability. IKONOS, due to its pointable instrument, and NOAA-AVHRR, due to its tandem mission (i.e. two satellites in orbit) are most qualified for SPM concentration and SST monitoring respectively, when temporal resolution is set as criteria.

Spectral resolution

Spectral resolution is the ability to distinguish electromagnetic waves in wavelength intervals. The smaller the interval, the higher the spectral resolution. At smaller bandwidths it will become more difficult to measure radiation because the radiation intensity will consequently become less. For remote sensing there is a trade-off between measuring intensity using wider bandwidths and lower accuracy but at higher intensity levels, or measuring the intensity using smaller bandwidths with higher accuracy, but at lower intensity levels. Different optical sensors have different configurations, and these determine, amongst other criteria described here, the selection of a sensor for a particular application.

Nowadays remote sensing instruments can be manufactured that provide a high spectral resolution. Not only in the visible part of the electromagnetic spectrum but also in the infrared, the thermal infrared and moreover at very small bandwidths.

Detecting SPM variations in coastal waters requires a sufficiently high spectral resolution of, preferably, wavelength intervals of 20 nm (e.g. as is the case with Orbview-2, MERIS). This is because the more wavelength intervals are available, the more data a sensor can measure at different wavelengths and the more detailed the spectral signature of a water body will become (Tatman et al. 2005).

Spatial resolution

The spatial resolution of an imaging instrument is defined as the capability to detect adjacent objects separately from each other. The spatial resolution is also often referred to as the ground resolved distance (GRD). The smallest spatial element that can still be detected in an image is called a pixel (from “picture element”); this is a small square with uniform brightness. The pixel size varies per imaging instrument. The so-called high resolution satellites record images with pixel sizes from 0.6 to 5 m (measured on the ground, e.g. IKONOS) and the medium- and low resolution satellites record pixel sizes that vary from 5 to 5000 m.

The spatial criteria as set out for the purposes of this study are a minimum of 1 km spatial resolution for SPM concentration and SST. Thus SeaWiFS, Landsat, MERIS, AVHRR, MODIS for instance, comply with these requirements.

12.4.2 Additional criteria

The additional criteria which will narrow down the selection of suitable RS sensors, and thereby determine the suitability of a sensor more closely include cost of data acquisition and availability of data. These are discussed below.

Cost of data acquisition

For some of the datasets mentioned in Table 12-2- Table 12-7, no costs are involved if the data is used for research applications (i.e. the data is available Free of Charge). Also, this can imply that the results of research done with the obtained data should be accessible in the public domain. In most cases no procedures are indicated for using the data for non-research applications. These procedures should be confirmed by contacting the data supplier.

For the commercial satellite data, pricing of the imagery is constantly changing. Not so long ago a full scene Landsat 5 Thematic Mapper image (180x180 km and 30 m resolution) cost the user NLG 8000, about € 3600. About five years ago, the US government dramatically reduced the prices of satellite data. Nowadays a Landsat 7 ETM scene (180x180 km, 15 +30 m resolution) costs the user $600. Table 12-9 provides a general overview of the pricing of satellite imagery. A limited number of EO satellites are listed in this table; limited, but typical enough to enable comparison between categories. The column "price per km^2" can be used for comparisons, the column "price per image" is based on a minimum area that a customer is obliged to purchase from a certain satellite. For some satellites the figures have been derived by averaging.

Table 12-9. Price per image and per km^2 of selected satellite data (Tatman et al. 2005)

Satellite	*Spatial resolution (m)*	*Price per km²*	*Price per image*
High resolution			
IKONOS	0.8 to 1	$ 18.00	$ 1,687
Quickbird	0.6 to 0.8	$ 22.50	$ 1,440
Medium resolution			
Aster	15	$ 0.015	$ 55
Landsat 7	15(PAN), 30(MS)	$ 0.019	$ 600
SPOT 5	5(PAN), 10(MS)	€ 0.75	€ 2,700

Within each satellite product, prices can vary. This is dependent on several aspects:
- The level of pre-processing (geometric and radiometric);
- The data provider; worldwide or regional affiliates;
- Archive or new acquisitions;
- Speed of delivery (rush orders);
- Licensing; use by single or multiple organisations.

Further, many data suppliers also provide temporary actions (reduced prices) for e.g. subscriptions, time series, archived imagery, etc. There is also a growing archive of free downloadable derived satellite products.

The optical imagers indicated in Table 12-3 generally have a high spatial resolution, but a small swath width. While this offers the possibility to study processes on small spatial scales, it also results in a decrease in synoptic coverage over the North Sea as a whole. Since this data is distributed on a commercial (paid) basis, obtaining a good coverage over the North Sea is likely to involve significant costs.

Data availability

Most of the data is available at different levels of processing; from level 1 (calibrated radiances) to level 3 (mapped geophysical parameters, see Table 12-1). This has several implications for data usage. Level 1 data requires significant post-processing once data is obtained. Advantages are the possibility to use newer processing algorithms, possibly tailored to the North Sea. Also, this data has a higher spatial resolution when compared with most level 3 datasets, where data is often transformed to a coarser grid. Level 3 datasets generally require the least post-processing, but also offer the least flexibility with regard to algorithms and resolutions.

In addition to the level 3 data product, additional value adding might be required, e.g. in the case of optical images where SPM gradients should be determined based on colour contrasts. All additional post-processing and value adding will require additional costs. These costs are not indicated in the above tables.

In general, data managed by the ESA (MERIS, ATSR, AMI, ASAR) is hard to obtain. Proposals should be sent to ESA per project to obtain the required data. In general, data managed by US agencies is more easily obtained.

12.5 Final selection of RS sensors

Taking all the above into consideration, a selection of the most suitable remote sensing sensors for the monitoring of SST and SPM concentration in the North Sea is made based on the following table:

Table 12-10: Qualitative conclusions on RS SPM sensors

Sensor	Temporal resolution	Spectral resolution	Spatial resolution	Costs	Accuracy	Availability	Monitoring	Initial selection: suitable for SPM monitoring North Sea?
Orbview-2	o	+	+	+	+	+	+	possibly
MODIS	o	+	+	+	o	-	+	possibly
MERIS	o	+	+	o	+	o	+	yes
IKONOS	0	-	+	o	-	+	o	no
NOAA-AVHRR	+	-	+	o	o	+	o	possibly
SPOT, Landsat	-	-	+	-	-	o/+	-	no

The accuracy of IKONOS is below-average due to adjacency effects (R. Vos RIKZ, personal communication). The availability on the other hand, is good due to expert help desks especially throughout Europe (Tatman et al. 2006).

The temporal resolution of IKONOS and SPOT is worse than Orbview-2, MODIS and MERIS. Landsat has a low overpass frequency and is therefore not suitable for monitoring purposes.

The AVHRR sensors aboard the NOAA series of satellite cover only a single and rather broadband visible wavelength channel (580-680 nm) and one near infra-red channel (720-1000 nm) in addition to three infra-red channels, making it less suitable to SPM monitoring than other sensors. However, due to its high temporal coverage and user friendly data policy AVHRR remains an optional sensor for the mapping of SPM concentration (Ruddick et al. 1998).

When these criteria are applied to the currently available satellite sensors the following sensors remain:

- Orbview-2;
- Aqua MODIS;
- Terra MODIS.
- Envisat MERIS

In the case of SST monitoring, the only suitable and available sensor is NOAA-AVHRR.

In the following section the selection will be refined with the help of the availability of suitable algorithms for SPM concentration retrieval for the North Sea.

12.6 SPM algorithms

Within the scientific community there is an ongoing debate on whether SPM measurements by ocean colour sensors can be used in a quantitative way (Lee 2006). Main points of debate are inaccuracies in the current algorithms due to atmospheric interference and pollution by other substances (e.g. part of SPM concentrations measured may be attributed to Chlorophyll, see also below). Also, inaccuracies by aerosols and difficulties along the land-sea interface are an issue. Note, however, that usage of historic ocean colour measurement is not necessarily limited by the current standard of SPM algorithms. Since the Level 1 data is available through the indicated data sources, historic data may be reprocessed using more accurate algorithms, should they become available. Also, algorithms may be tailored for North Sea applications.

Specific inherent optical properties (SIOPs) are an inherent source of inaccuracy for the processing algorithms (Lee, 2006). SIOPs are optical properties of the water column, and are defined as the absorption or scattering per unit concentration of a certain constituent (Duin et al., 2006). SIOPs are required for the calibration of water constituent concentration retrieval algorithms. The inaccuracy in SIOPs for the North Sea has various causes including the high variability of SIOPs in space and time.

Of the RS sensors described in the sections above, ocean colour sensors and high resolution optical imagers provide a way to measure and quantify SPM. The accuracy by which they do this strongly depends on the processing algorithm used. As such, this section will summarize currently available SPM algorithms. These algorithms can vary in accuracy due to differences in atmospheric correction applied, different assumptions on the water class (see below), different spectral bands used and the accuracy of the measurements in these bands.
An exact comparison of in-situ measurements with remotely sensed data is inherently difficult. Validating a sensor and its algorithm and quantifying the accuracy of a sensor and its SPM retrieval algorithm is obstructed by methodological and scaling issues (spatial and temporal differences) (Brockmann et al. 2004, Duin et al. 2006). A point-to-point comparison is hindered by the fact that a water sample taken *in situ*, provides an estimation of a concentration taken at a certain depth, whereas a remotely sensed data pixel is averaged horizontally over a much larger area and averaged vertically over the euphotic zone. A direct comparison between the two data sources is non-trivial and can only be done when samples are taken within a small time window (less than 1 hour). This is rarely done (Duin et al. 2006). A better way of comparing is done by statistical techniques (e.g. Brockmann et al. 2004, Duin et al, 2006).

Table 12-11 Overview of SPM algorithms (partly after Turner, 2002)

Algorithm name	Type of (SPM) algorithm	Satellite	Range	Accuracy	Reference
Tassan multi-regression	Band ratio	Orbview-2	0-0.5 mg/l	Not specified	Durand el al (1999)
NN	Multi non-linear regression	Orbview-2	0.1-15	+/- 50%	Durand el al (1999)
L-M	Multi non-linear regression	Orbview-2	0.1-15	+/- 50%	Durand el al (1999)
MUMM-SM	Single band	Orbview-2	0-100 (not specified)	Not specified	www.mumm.ac.be
POWERS-SM	Single band	Orbview-2	0-100 (not specified)	Not specified	www.mumm.ac.be
Topliss	Band ratio	MODIS, Landsat TM, IKONOS	0-100 (not specified)	Not specified	Topliss (1990), Tatman et al (2006)
SPOT-SM	Reflectance ratio	SPOT	> 1 mg/l	30-50%	Durand el al (1999)
TM-SM	Reflectance ratio	Landsat TM	> 1 mg/l	30-50%	Durand el al (1999)
Improved unified model	Logarithm	Landsat TM	60-100 mg/l	< 10%	Durand el al (1999)
MSS-SM	Normalized band sum	Landsat TM	> 3 mg/l	30-50%	Durand el al (1999)
MUMM-SPM	One-band nonlinear regression, North Sea Specific	MERIS	?	?	Ruddick et al. (2003)
MERIS-SPM	Neural network alg.	MERIS	?	?	Schiller & Doerffer (1999)
IVM-MERIS-Hydrolight	Single optical model	MERIS	?	?	Pasterkamp et al. (2005)
IVM-MERIS-POWERS	Single band	Orbview-2	?	?	Van der Woerd et al., 2000

As indicated above, water can be distinguished into different classes. With regard to SPM algorithms these are Case 1 and Case 2 waters. By definition, Case 1 waters are those waters in which phytoplankton are the principle agents responsible for variations in optical properties of the water. Case 2 waters are influenced not just by phytoplankton and related particles, but also by inorganic particles in suspension (IOCCG, 2000). In most cases coastal water (like the North Sea) can be classified as Case 2 water, whereas the algorithms used for the synoptical level 3 datasets described in Table 12-2 to Table 12-7 are calibrated for Case 1 waters. The SIOPs of the North Sea depend on phytoplankton and its degradation products, CDOM (coloured dissolved organic matter), and inorganic suspended matter. Regional processes induce regional-specific variations in these optical properties and concentrations of the constituents, which make regional-specific processing algorithms necessary for accurate estimation of constituents. Hence, the algorithms above, and as such the level 3 datasets, must be considered with care for SPM applications in the North Sea. Preferably, level 1 data should be used in combination with SPM algorithms for Case 2 waters specific for the North Sea.

The estimation of SPM concentration from satellite measurements of upwelling spectral radiance when using a (semi-)analytical approach can typically be carried out in three steps (Ruddick et al 2003):

1. Atmospheric correction consisting of calculating the atmospheric effects by removing the at-sensor signal of the effects of atmospheric scattering and absorption, yielding above-water upwelling radiance and downwelling irradiance from at-sensor radiance.
2. Air-sea interface correction consisting of calculating sub-surface irradiance reflectance from above-water upwelling radiance and downwelling irradiance. This is done by removing reflection of sun and sky light at the air-sea interface and accounting for transmission and refraction of light through the interface.
3. Bio-optical modelling consisting of estimating SPM (and other water constituent) concentrations from sub-surface irradiance reflectance. Examples of these type of algorithms are shown in column 2 of Table 12-11).

It is also possible to find empirical relationships between radiance ratios and concentration, which in some cases can replace all three steps above, but the uncertainties in such relationships cannot be predicted and analysed (Lee 2006). A few of the recently developed algorithms for SPM concentration retrieval for the North Sea are described below.

12.6.1 Orbview-2 (formerly SeaWIFS)

In the case of the atmospheric correction of Orbview-2 data for open ocean waters the standard algorithm available within the SeaDAS imaging processing software (i.e. the software supplied free of charge by NASA for processing Orbview-2 data) failed completely for turbid coastal waters. This was because of the assumption of zero water-leaving radiance at the near infrared (NIR) wavelengths, 765nm and 865nm. To overcome this problem, MUMM developed a turbid water extension to the standard SeaWiFS atmospheric correction by modelling the NIR water-leaving radiance. This atmospheric correction algorithm is described in detail in Ruddick et al., 2000) and has been released to the scientific community (see http://www.mumm.ac.be/OceanColour) as extension routines to the SeaDAS v4.0 image processing software.

An adapted version is available of the one-band, semi-analytical algorithm based on Gordon, developed during the POWERS project for processing Orbview-2 data. An analytical algorithm was developed by IVM to compute SPM concentrations from the Orbiew-2 subsurface irradiance reflectance values, output by the atmospheric correction routine. The algorithm is based on an analytical inversion of an optical model for SeaWiFS band 5 (555nm). This optical model was calibrated using inherent optical properties measured during the POWERS field study (Van der Woerd et al., 2000).

The accuracy of the SPM concentration retrieval by the IVM analytical algorithm is not known due to the fact that the inter-comparison is not straightforward and a bias in distributions of TSM measurements are not readily translated in measurement errors.

12.6.2 MERIS

In the case of MERIS, Level 2 water-leaving reflectance data can be obtained indirectly from the European Space Agency via e.g. ACRI, at Reduced (approximately 1 km) or Full Resolution (approximately 300 m). The standard processing includes an atmospheric correction for case 1 waters, with an extension to case 2 waters. A neural network algorithm for retrieval of SPM is available, developed by Schiller and Doerffer (1999), based on the MERIS Advanced Theoretical Basis Documents (available from http://envisat.esa.int/instruments/meris/pdf/, Ruddick et al. 2003). This produces the standard MERIS-SPM product.

A North Sea-specific algorithm for MERIS has been developed by Ruddick et al. (2003) who extended the processing further, by developing an algorithm specifically for deriving SPM concentration from MERIS which matches the regional *in situ* product derived through the Belgian monitoring programme. These measurements have traditionally been made on water samples taken from 3m depth after filtration and with a coarser GF/C filter. Thus, to allow for the difference between the SPM concentration which the ESA standard processing algorithms were calibrated for and the Belgian monitoring SPM concentration product, a one-band algorithm was developed by MUMM, calibrated for GF/C based measurements in mainly Belgian waters. This product is obtained from the MERIS water-leaving reflectance at 753nm using:

$$\text{MUMM-SPM (gm}^{-3}) = 422 * \frac{\rho_w^{753nm}}{0.187 - \rho_w^{753nm}} + 3.7$$

IVM-VU have used the HYDROPT (Hydrolight Optimization) model to convert MERIS data to concentration maps of SPM using a Matlab environment. The basic approach of the model is to iteratively adjust the concentrations by minimizing the difference between a MERIS reflectance spectrum in 8 optical bands (ranging from 412 to 708 nm) and a reflectance spectrum generated by a forward model (Pasterkamp et al. 2005). The forward model is based on the Hydrolight radiative transfer code (Mobley 1994). The forward model has been specifically adapted for the coastal zone to allow for the complexity of the North Sea coastal system (riverine input and resuspension), resulting in a single optical model for the Dutch coastal zone (Pasterkamp et al. 2005).

12.6.3 MODIS

At present there is no suitable, North Sea-specific SPM algorithm for processing MODIS data. Thus for the purposes of monitoring SPM in the North Sea, MODIS is not directly applicable. If in the future such an algorithm would become available, then the MODIS data are potentially very useful.

12.7 Conclusions

In the sections above, an overview is provided on satellite sensors, which are of possible use with regard to both SPM monitoring and to establish a SPM climatology for the North Sea. Of these, the ocean colour and optical imagers provide a direct way to measure and quantify SPM. As such, this section provides some conclusions on these sensors with regard to the criteria as described in Section 12.4. These criteria include the (effective) spatial and temporal resolution, costs of data acquisition, accuracy, availability of data and applicability to both SPM monitoring and establishing a SPM climatology. Taking the available algorithms for SPM concentration retrieval for the North Sea into consideration, the following can be concluded for the RS sensors and their suitability for monitoring SPM in the North Sea:

- None of the sensors evaluated in this chapter come out top of the list of criteria since they all suffer from particular drawbacks.
- IKONOS has the highest spatial resolution and is at present the most readily available of all data. However it is one of the more costly data sets, and no SPM algorithms suited to the North Sea exist.
- MERIS is the most suitable sensor when all criteria are taken into consideration. The main advantage of MERIS is the existence of the SPM concentration retrieval algorithm, tailored to the North Sea situation.
- Orbview-2 has the advantage of a user-friendly data-policy and the data is therefore readily available. However, it can be considered a secondary source of RS-derived SPM concentration retrieval, due to the lower spectral and spatial resolution of the sensor. However, for the purposes of SPM monitoring it is still considered adequate and can be recommended as a replacement if MERIS is not available.
- MODIS suits most criteria, but due to the absence of a North Sea-specific SPM concentration retrieval algorithm, it is currently not suitable for SPM monitoring. However, if such an algorithm would be developed in the future, MODIS archive data could potentially be used in hindcast studies of the effects of MV2.
- For SST monitoring, the most suitable sensor is NOAA-AVHRR, for which the standard available SST product is available at an suitable accuracy.

The long-term continuity of suitable satellite sensors for SPM and SST monitoring of the North Sea cannot be guaranteed. The planned operational period of some of the sensors mentioned in this chapter, e.g. MERIS, MODIS and Orbview-2, are expected to end within the next few years. However, there are commercial and non-commercial (e.g. ESA's Sentinel-3 satellite) missions planned, albeit with possible gaps in time, so some form of continuity in the data provision over the next decade is guaranteed.

If a longer period of time sampling by remote sensing is required, e.g. a remote sensing data set over 10 years is required, data from two or more RS sensors will be required. In order to set up a consistent data set of e.g. SPM concentration from these RS sensors, some form of data merging and intercomparison will be required. In such a case, it is recommended to research optimal methods of merging several sensors in order to obtain a consistent RS data set for the North Sea.

13 Dredging data

Dredging data may serve two purposes. At first it is a source of information on the siltation of port fairways and harbour basins. As most sediment that is filling the harbour basins is of marine origin it is a proxy of the marine SPM conditions. Secondly, disposal of dredged material is a source of spatial (and partly also temporal) redistribution of SPM in the coastal system.

Availability

Data on dredging activities are made available for the ports of Rotterdam and IJmuiden and for the main dredging areas at the Belgian coast (Nieuwpoort, Oostende, Blankenberge and Zeebrugge) by the port authorities and Rijkswaterstaat (Dutch data) and by MUMM (Belgian data). At present, various files are available with partly overlapping data. The most comprehensive data set with Dutch data has been composed by RIKZ, in particular by Stutterheim (2002) (see also the overview by Slee (2006)). Most data relate to amounts dumped at various dump sites, whereas some data refer to allotted amounts for certain areas. Future data are to be obtained from port authorities or central government agencies (MUMM, Rijkswaterstaat DNZ). There is no central archive with unique, quality assessed data. Storage, updating and distribution takes place through the various agencies which may lead to redundancy and the risk of partly inconsistent versions of the same data sets.

Quality

A distinction should be made between capital dredging and maintenance dredging. Capital dredging represents additional mass dumped into the coastal system, albeit occasionally, to increase the depth of basins or fairways. The mass related to maintenance dredging reflects the amount of marine sediments temporarily taken out of the along-coast flux of SPM. Since most maintenance dredging is a semi-continuous activity, the time the mass is out of the coastal system is relatively short and the temporal redistribution effect is probably small. Spatially, the disposal at dump sites implies point sources of SPM contrary to the more diffuse spatial pattern that would have occurred when no siltation and dredging would have taken place.

The maintenance mass may serve as a proxy of the nearshore SPM conditions. Capital dredging is a source of SPM that before was not part of the transport system. Pseudo trends may occur after capital dredging, e.g. if a certain channel is deepened and therefore more strongly silting up. Not unimportantly, waves and river discharges will play an important role as well in the siltation. Hence, an approach following the statistical methods of Merckelbach (1996) and Bhattacharya (2003, 2005) may be required before a relation between SPM conditions and dredging can be established.

Before the data are used they should be checked on consistency of unit conversion, e.g. from dry weight to volumes or vice versa. Belgian data before April 1997 are given in tons wet weight, after April 1997 in tons dry weight. Dutch data are usually in volume and tons dry weight. Conversions between the units depend on the locations where material originates from and the vessel and technique used. Accurate measurements of wet and dry density are often lacking and general estimates for the source location are applied. Also direct measurements of the sand content are absent. Most often the sand content is estimated (if reported at all) from the wet density.

Summarizing, the accuracy of dredging data is uncertain and inter-comparison of various ports may be very difficult. Within one source it may be possible to assess long-term trends and future changes (see e.g. Dronkers, 2004).

Quantity

Data coverage is shown in Table 13-1 below. Most data sets contain annual numbers, this may yield a too coarse time resolution and too short time series to retrieve statistically sound results. Additional effort may be put into retrieving weekly data for those sets (in particular IJmuiden and Belgian data). For most data sets there is spatial information on either the location of the disposal site the dredge areas or both.

Usefulness

The overall usefulness is assessed from Table 13-1 below. Time resolution has been a major factor in determining the ranking, assuming no higher resolution historical data are available anymore. Other technical and distribution issues may be overcome with some effort.

The dredging data are mostly suitable as an auxiliary data source, and only provisionally to directly assess changes in the SPM conditions from. Therefore it is recommended to investigate the statistical properties and minimum changes that may be detected with significance in future. In this respect, the presently available data for IJmuiden and Belgium suffer from low time resolution and uncertainties in unit conversions. The weekly data from the Port of Rotterdam have good resolution but changes in the harbour layout after MV2 may in future complicate distinction between external changes and changes due to MV2.
Still, the dredging data (including information on the disposal locations) are valuable to describe human activity redistributing SPM within the coastal zone (see e.g. De Jonge & De Jong, 2001) and may be used to gain more insight in the transport processes, e.g. by radioactive tracing (Venema, & De Meijer, 2001).

Costs

Dredging data are taken and archived as standard part of harbour and fairway management. They are available to SPM studies at practically no additional costs.

Table 13-1 Properties of available data sets on amounts of dredged material disposed. Units: *tww*: tons wet weight, *tdw*: tons dry weight.

Source	Location	Distinct maint./ capital	Units	Time coverag e	Time resolution	Spatial infor-mation	Useful-ness
MUMM	Nieuwpoort, Oostende Blankenberg e Zeebrugge	yes	tww (< 03/1997) tdw	1991-2005	Annual numbers (covering April to March of subsequent year)	5 disposal sites	-
Port Authorities Rotterdam	Port of Rotterdam interior		m^3 & tdw	1996-2005	weekly	1 disposal site	+
RWS	Fairway to Port of Rotterdam		m^3 & tdw	1995-2005	weekly	3 disposal sites	+
Port Authorities IJmuiden	5 source areas	yes	?	1975-2005	annual (calendar years)		o
Slee 2006.	over 10 sources locations	yes	m^3 & tdw	1964-1996 (2001 for some data)	annual (calendar years)	Loswal Noord	++

14 Operational numerical model data (MATROOS)

14.1 Introduction

MATROOS is a web-based application to access various operational model data sources. Presently the access is limited to Rijkswaterstaat (RWS), but in future it may be extended to parties delivering model data and accredited users (research parties, partners of RWS). Main users and suppliers are for example SVD (*stormvloed-waarschuwingsdienst*), and HMR (*Hydro-Meteocentrum RWS*). But also institutions like the UK Met Office and KNMI deliver model data.

The most relevant sources of model data for the present inventory are

- Meteorological model data:
  - UKMO Meteo model data,
  - KNMI HIRLAM meteo model data
- Hydrodynamic model data (velocity (u,v), water levels (ζ)
  - Zeedelta (also salinity)
  - Kustfijn (also salinity)
  - ZUNO
  - CSM8
- Wave model data
  - KNMI-Ned-WAM

For the present study it may be worthwhile to use part of these operational model data. The advantage of using these models to generate comparable data is that they are operated anyway and the data can in principle come at no additional costs (provide that they are archived well back into time). Also, the model runs are reinitialized every forecast interval (of 6 to 24 hours) with continuous assimilation of observations. The archive thus contains a so-called reanalysis. For the moment we restrict ourselves to a short discussion on the hydrodynamic model data, since those provide velocity data that are hardly available (virtually absent) in the field data sets.

14.2 Velocity and water level data from hydrodynamic models

Within MATROOS at present only data from 2DH hydrodynamic models is available, although it is anticipated that from 2007 onward at least the Zeedelta model will be run in 3D mode (Verlaan, RIKZ, pers. comm. Aug. 2006).

Data are output on the model grids as shown in Figure 14-1 to Figure 14-4 with time resolution of 30 minutes. Higher time resolution data are available from stations within the domains, but these are all located at the coast or at rivers or inlets. All details of the data are listed in Table 14-1.

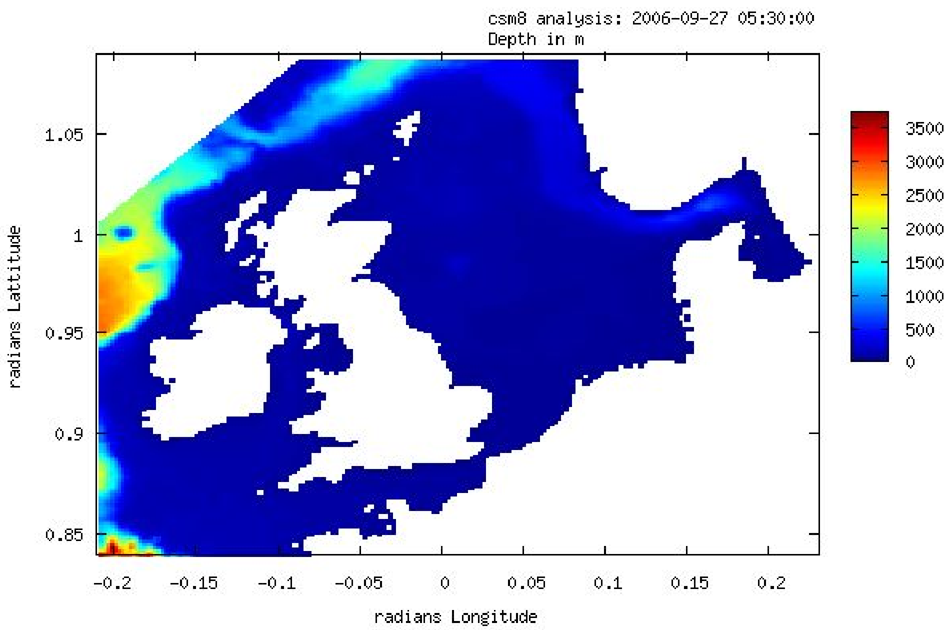

Figure 14-1 Bathymetry of the CSM-8 model on the numerical grid.

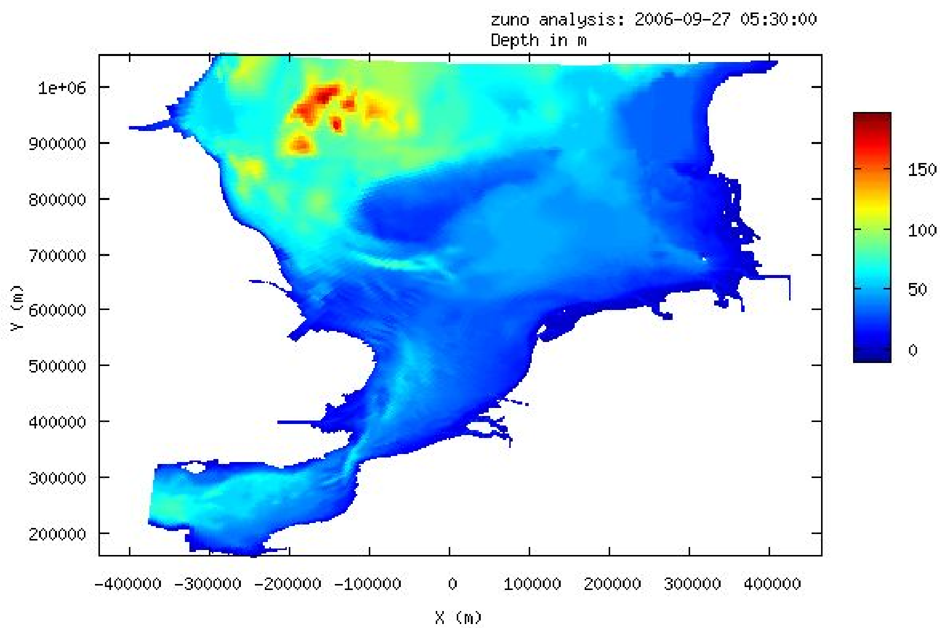

Figure 14-2 Bathymetry of the ZUNO model on the numerical grid.

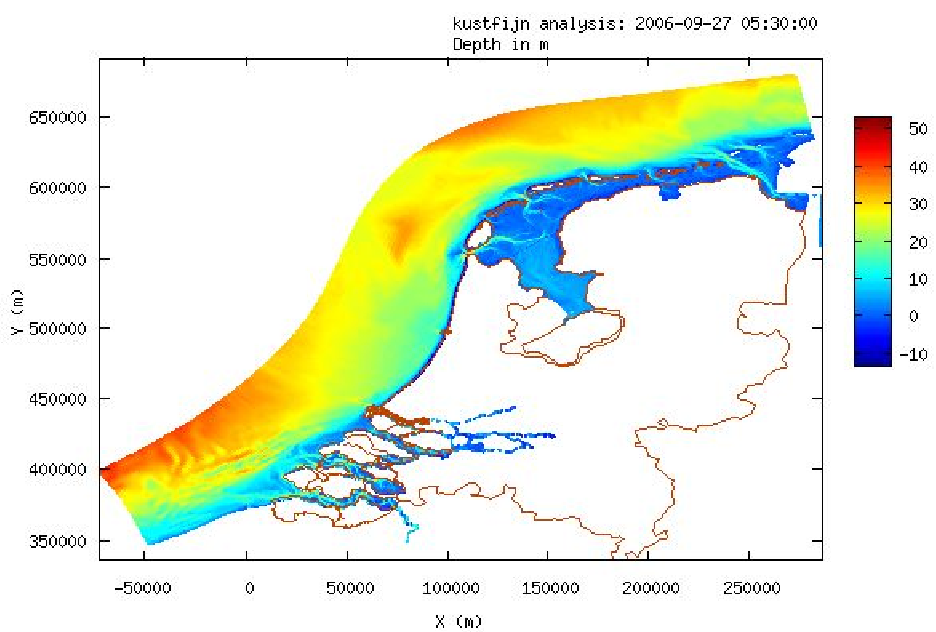

Figure 14-3 Bathymetry of the Kustfijn model on the numerical grid.

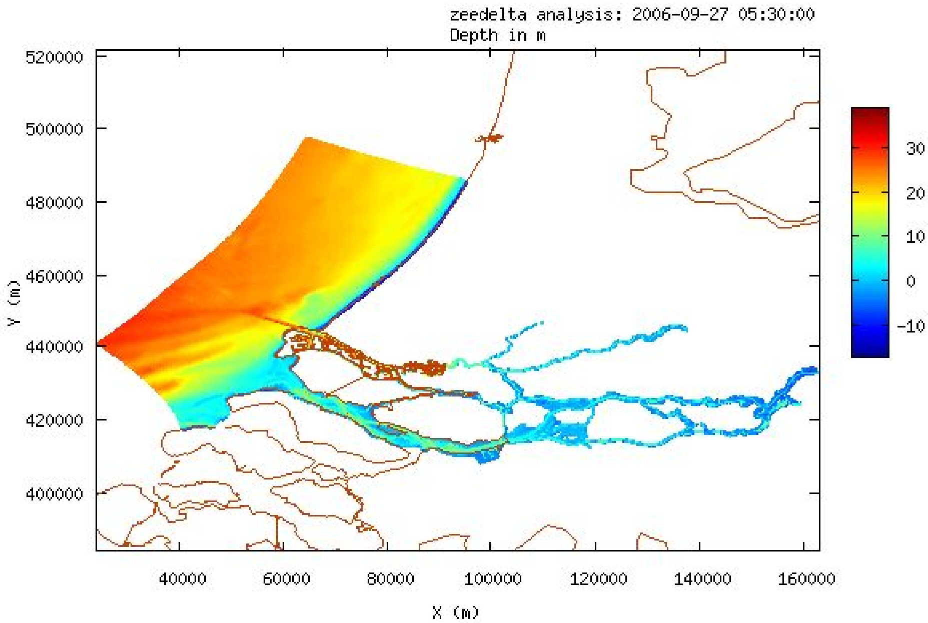

Figure 14-4 Bathymetry of the Zeedelta model on the numerical grid.

Table 14-1 Overview of hydrodynamic model data stored in MATROOS.

Model	Variables (2DH)	Nominal spatial resolution near the Dutch coast	Coverage back into time from present date	Time resolution
CSM8	*u,v,ζ*	8 km	4-5 year	30 min
ZUNO	*u,v,ζ*	2-5 km	1 year	30 min
Kustfijn	*u,v,ζ, Salinity*	200-500 m	1 year	30 min
Zeedelta	*u,v,ζ, Salinity*	100 m	1 year	30 min

14.3 Costs

Costs are involved in maintaining the MATROOS data base that relate to the infrastructure and processing of the data. The data themselves are (mostly) available at no additional costs as they are generated for operational purposes anyhow. Since data storage is a limiting factor for the usefulness (see below) it seems worthwhile to extend storage. Presently 3TB of storage is available for all model data. The requirement of *Kustfijn* (*u,v,ζ, S* maps) is 15MB per map set, for 2DH *Zeedelta* the file size is about twice as large. A rough estimate of the requirements of storing one additional year of 3D *Zeeldelta* data (5 vertical levels) is 2.5 TB. Just the price of the required hardware is estimated about 2,500-3000 Euros based on a current retail price of about 1 Euro per GB, (i.e. ignoring scale effects and technical installation, maintenance etc.).

14.4 Usefulness

Model data can be treated as any other data source. Either point-wise time series are derived from the mapped data or, spatial aggregates or spatial patterns can be considered. The velocity and free surface data can be combined to approximate discharges, and tidal residuals can be computed from these with the present time resolution. It should be realized that the accuracy of the present model results in terms of currents and residual transport (by means of salinity) may have to be further assessed by means of validation against field data before they can be applied in the present context (M. Verlaan, pers. comm., Aug. 2006). For this validation, *in situ* data of salinity are the most important data source.

The short archiving period is the major drawback of these data. If the storage capacity could be extended to store at least the *Kustfijn* data for longer periods, or if storage time resolution is reduced, this drawback can be overcome. For now there is no more data than from summer 2005 onward.

15 NoMiVe measurements

Availability

From 1986 to 1989 a field campaign has been carried out denoted as NoMiVe (*Noordzee Micro Verontreiniging*. North Sea Micro pollution) during which vertical profiles of Oxygen, Salinity, Temperature and (in 1988 and 1989) turbidity have been determined. The results of the 1986-1987 cruises have been reported by Verbeek (1989). Results of 1988 and 1989 have been reported by Groenendijk (1990a,b). During the latter two years, measurements have been carried out at least once every one or two months along the transects of Goeree, Ter Heide, Noordwijk, IJmuiden, Egmond and Callantsoog (see Figure 15-1). Part of the 1988-1989 data are available in files at WL|Delft Hydraulics. Currently, the turbidity (SPM) data are not yet recovered, nor have the data from before 1989. The NoMiVe data set is the only set with data on the vertical profiles of SPM for an extended period and covering such a large part of the Dutch coast.

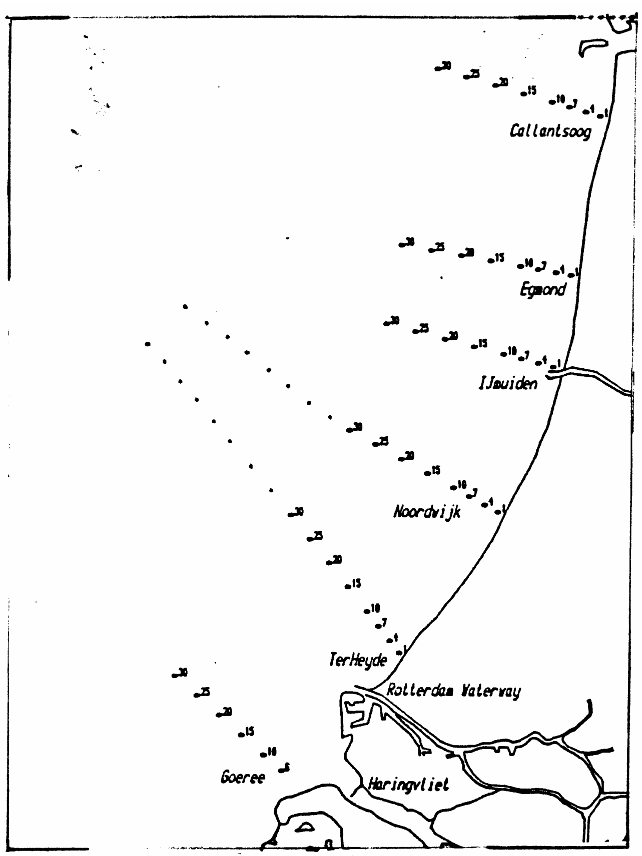

Figure 15-1 Stations sampled during the NoMiVe campaign (Groenendijk 1990a). See also Table 15-1 for coverage of stations in time.

Quality

The quality of the temperature and salinity data is generally considered high. These data have been obtained from CTD-casts. Vertical and lateral gradients are resolved well, relative accuracy of both data sets are in the order of 0.1% (Groenendijk 1990a). On the other hand, SPM concentrations have been derived from turbidity data. Despite various calibration methods, accuracy of concentrations is estimated at about 20% for concentrations above 10 mg/l and 40-50% for lower concentrations.

Quantity

Coverage of the data is more extensive than the regular MWTL data in DONAR, but much less frequent than for example the CEFAS data discussed below. Still coverage in time is once every few weeks, at irregular intervals. Coverage in space is limited to the six transects, extending from 30 to 70 km offshore (extent varies over time). See Table 15-1for coverage. Vertical coverage is generally 3 to 4 vertical positions offshore decreasing to 1 or 2 close to shore (at 5 to 10 meter vertical intervals).

Table 15-1Coverage of NoMiVe data 1988-1989. Date (yymmdd) and transects (Gr=Goeree, Th=Ter Heide, Nw=Noordwijk, Ym=IJmuiden, Em=Egmond, Cl=Callantsoog), number denotes most offshore station visited during particular cruise (roughly equivalent to distance in km offshore) (Groenendijk, 1990a,b). For inshore stations see Figure 15-1.

Date	Spatial coverage
880119	Th70 Nw70
880317	Th70 Nw70
880324	Gr30
880519	Th30 Nw30
880623	Th70 Nw70
880707	Th60 Nw60
880804	Th40 Nw40
881020	Th70 Nw70
881103	Th70 Nw70
881214	Gr30 Th30 Nw30 Ym30 Em30 Cl30
881215	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890116	Th70 Nw70
890123	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890125	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890328	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890330	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890503	Th70 Nw70
890721	Th70 Nw70
890810	Th70 Nw70
890830	Th70 Nw70
890911	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890913	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890921	Th70 Nw70
890925	Gr30 Th30 Nw30 Ym30 Em30 Cl30
890927	Gr30 Th30 Nw30 Ym30 Em30 Cl30
891107	Th50 Nw50
891113	Gr30 Th30 Nw30 Ym30 Em30 Cl30

891114	Gr30 Th30 Nw30 Ym30 Em30 Cl30
891116	Gr30 Th30 Nw30 Ym30

Usefulness

Given the inaccuracy of the SPM concentrations and the still relatively short measuring period, the data are of limited use to assess long-term changes. It is, nevertheless, one of the most valuable source of information presently available on the vertical distribution of SPM off the Dutch coast during two consecutive years. As such it is an important source of system information.

16 CEFAS measurements

The 'CEFAS' measurements consist of near-surface Smartbuoy data and near-bed Minipod data. These measurements have been carried out in a joint project of The Centre for Environment, Fisheries & Aquaculture Science (CEFAS) in Lowestoft and RIKZ. The measurements discussed here were carried out on the Noordwijk transect near the Dutch coast. For more detailed information the reader is referred to Rees, et al (2002), Rutgers van der Loeff, et al. (2002), RIKZ/CEFAS (2003), Hartog and Van de Kreeke (2003), Mills (2003), Mills et al. (2003), and Vos, (2004).

16.1 Minipod

From 20 November 2001 until 22 April 2002 a bottom lander (Minipod) has been deployed at two sites, Noordwijk 2 and Noordwijk 5 (see Table 16-2) . The period can be split up into the following sub-periods, listed in Table 16-1:

Table 16-1 Deployments of Minipod system during RIKZ-CEFAS project. Colours refer to overlap with Smartbuoy measurements (see Table 16-3 below).

Location	*Deployment Number*	*First Good data (GMT)*	*Last Good data (GMT)*	*Notes*
Noordwijk 2-1	180	20/11/01 12:00	18/12/01 09:00	
Noordwijk 2-2	181	18/12/01 12:00	02/01/02 18:00	Trawled
Noordwijk 5-1	182	05/03/02 10:00	21/03/02 08:00	
Noordwijk 5-1	183	21/03/02 12:00	22/04/02 11:00	

Instrumentation

The fixed measuring location consisted of steel frames on which were mounted the following instruments:

Sensor	*Manufacturer*	*Parameter*	*Elevation above seabed (cm)*
ADV	Nortek	3D currents	66
MOBS1	Cambridge	Suspended sediment (fines)	86
MOBS2	Cambridge	Suspended sediment (fines)	110
ABS	CEFAS	Suspended sediment (sands)	Profiles to seabed (~110 cm)
OBS1	Seapoint	Suspended sediment (fines)	128
Fluorometer	Seapoint/Chelsea	Chlorophyll	170
Pressure	Druck	Waves and tides	170
Conductivity & Temperature	Falmouth Scientific Instruments	Conductivity and Temperature	170
Oxygen	YSI	Oxygen	170
Pressure	DigiQuartz	Waves and tides	176
OBS2	Seapoint	Suspended sediment (fines)	200
LICOR	LICOR	PAR (Light)	212

Frequency

The sensor suite on the Minipod was recorded by either the main Minipod logger or the CEFAS ESM2 logger. This operates in burst mode recording a burst of data, typically 10 minutes, every half hour.

Quality

The turbidity sensors were extensively calibrated. A WS AquaMonitor water sampler was programmed to take 150 ml water samples every 24 hours for an in-situ calibration of the suspended sediment sensors. In Vos (2004), it is concluded that the differences between the OBS and MOBS sensors, which are attributed to different calibration methods, is roughly 20 mg/l below SPM concentrations of 50 mg/l and almost zero for SPM concentrations around 100 mg/l.

Usefulness

The Minipod data provide good information on the vertical distribution of sediment in the lowest 2 meters of the water column for about one-and-a half months each at two relatively near shore sites. The sample frequency (every 30 min) is sufficiently high to observe both resuspension by the tide and by wave action. Such data is very scarce on the North Sea. An important drawback is that most Minipod data are only available by accessing spreadsheets linked to figures in documents. The original data files are not readily available. The data are very useful to gain more insight in processes determining the vertical distribution and temporal variation of near-bottom SPM concentrations. As such the data are possibly valuable to support the formulation of system relations (see Blaas & Van den Boogaard, 2006). During the periods of simultaneous Smartbuoy measurements (NW02 Nov.-Dec. 2001, NW05 March-April 2002, see below) even more information is available on the vertical distribution of SPM.

16.2 Smartbuoy

The Smartbuoy consisted of a toroid buoy with a small weather station on top and a subsurface frame with various instruments. OBS devices were used to measure SPM concentrations. The smartbuoy mooring was deployed at three sites, Noordwijk 2, Noordwijk 5 and Noordwijk 10 km (see Table 16-2) for the periods listed in Table 16-3.

Table 16-2 Locations of deployment of the Smartbuoy and Minipod during RIKZ-CEFAS project.

Location	*North*	*East*	*Depth*	Minipod	Smartbuoy
Noordwijk 2 km	52°15'.28"	04°24'.28"	10 m	*	*
Noordwijk 5 km	52°16'.55"	04°22'.01"	17 m	*	*
Noordwijk 10 km	52°18'.1"	04°18'.2"	18 m		*

Table 16-3 Deployments of Smartbuoy during RIKZ-CEFAS project. Periods of continuous OBS data with mean and variance for each period. Colours refer to overlap with Minipod measurements (see Table 16-1above).

Period	*Start Date*	*End Date*	*Mean OBS (ftu)*	*Variance OBS (ftu^2)*	*water depth (m)*
NW10 1	10-04-00 20h	01-06-00 23h	3.86	25.01	18
NW10 2	07-11-00 09h	14-03-01 23h	6.51	40.60	18
NW10 3	20-03-01 10h	05-07-01 23h	2.75	14.50	18
NW10 4	21-08-01 10h	18-09-01 08h	8.48	71.45	18
NW02 1	18-09-01 10h	12-10-01 13h	21.94	228.3	10
NW02 2	17-10-01 19h	28-12-01 13h	32.29	574.8	10
NW05 1	05-03-02	22-04-02	5.63	23.68	18

On the Smartbuoy the following instruments have been mounted:

Sensor	*Manufacturer*	*Parameter*	*Elevation below sea surface (m)*
OBS	Seapoint	suspended sediment (fines)	1
CT	Seabird	temperature	1
CT	Seabird	salinity	1
PAR	LiCor	light extinction	1
Minitrack, Seapoint	Chelsea Instruments, Seapoint Inc.	chlorophyll-a	1

The main OBS sensor measured at 1 Hz for 4 minutes and rested 8 minutes. During these 8 minutes the back-up sensor measured at 1 Hz. Using both the main and back-up data one-hour average OBS values were calculated using the data one half hour before and one half hour after the hour. Also for the other parameters (temperature, salinity, extinction, chlorophyll-a) hourly averaged values are available.

Quality

As a result of fouling during certain periods of the year, mainly during the summer, the OBS sensors occasionally malfunctioned. The periods with unreliable data because of sensor fouling are well known (Mills, 2003 Appendix 1a). For the calibration, sea water samples were taken and analysed during the approximately monthly service visits.

Usefulness

The Smartbuoy data are a valuable extension to the regular long-term measuring campaign (MWTL) at Noordwijk, as Smartbuoy data are available at an hourly basis in contrast with the long-term measurements, which yield just one or a few data points per month. The Smartbuoy data provide information on the vertical distribution of sediment when combined with the Minipod data for the overlapping periods (NW02 Nov.-Dec. 2001, NW05 March-April 2002). The sample frequency (every 60 min) is sufficiently high to observe both resuspension by the tide and by wave action. This makes the data especially useful to assess statistical properties with high time resolution and suitable to relate to wave and wind conditions in order to establish statistical system relations (see Blaas & Van den Boogaard, 2006).

17 Siltman measurements

From November 1995 until May 1996 and from November 1996 until May 1997 measurements have been carried out within the so-called Siltman project (e.g. De Kok, 2000). Winterwerp (1998) made an extensive analysis of the Sitlman data with a 1DV point model.

The two periods can be split into the following sub-periods:

Period	*Sub-period*	*Start date*	*End date*
1	1	16/11/1995	13/12/1995
1	2	22/12/1995	30/01/1996
1	3	09/02/1996	13/03/1996
1	4	20/03/1996	01/05/1996
2	1	12/11/1996	27/11/1996
2	2	06/12/1996	08/01/1997
2	3	17/01/1997	18/02/1997
2	4	03/03/1997	02/04/1997
2	5	14/04/1997	15/05/1997

The measurements were made at four locations in the Maasmond area (see Table 17-1 and Figure 17-1).

Table 17-1 Name and locaton of the four Siltman observation sites.

Site	*Latitude*	*Longitude*	*Depth*	*Easting*	*Northing*
B	51°-59'-22.0"	03°-58'-05.0"	16.00 m	566476	5760426
I	51°-59'-27.9"	04°-01'-36.1"	16.30 m	570500	5760664
G	52°-00'-21.8"	04°-00'-29.7"	19.50 m	569210	5762312
H	51°-59'-57.9"	04°-02'-11.9"	18.15 m	571169	5761601

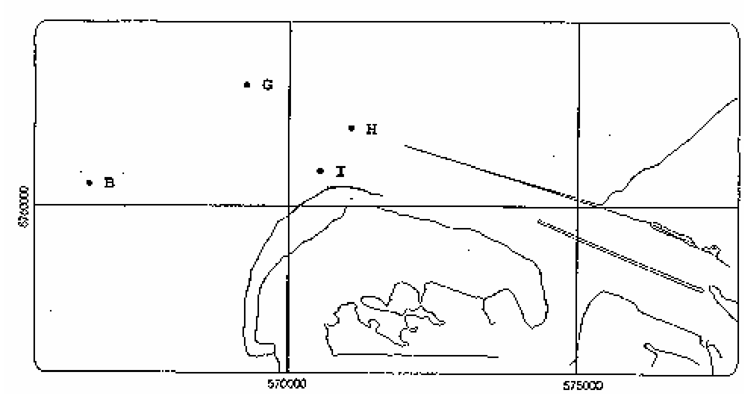

Figure 17-1 Location of the Siltman measurements, see also Table 17-1.

On each of the four measuring locations a steel frame has been place on the sea bed on which were mounted:
2 Mex turbidity sensors at 0.15 and 0.55 m from the seabed
1 UCM flow sensor at 0.35 m from the seabed
1 ADCP (at 2 out of 4 frames)

At one measuring site a surface mooring was placed ('Thorus buoy') which was connected to a nearby subsurface mooring. At the Thorus buoy the following instruments were mounted:

- T/S-string with temperature and conductivity sensors at 5 vertical locations at an interval of 2.5 m.
- A ME-turbidity sensor (temperature, conductivity, depth, light attenuation) at 1 m below the water surface
- A LiCor cell (light intensity) at the surface

At the nearby subsurface mooring the following instruments were mounted:

- 2 Hydrolabs (temperature, conductivity, depth, light attenuation). The lower Hydrolab was positioned at 2 m from the seabed. The upper Hydrolab was positioned at 8 or 7 m from the seabed for period 1 and 2, respectively.
- S4 flow meter positioned at 1 m below the surface.

N.B. only the data from the Mex, UCM and Hydrolab (turbidity only) are available on the Siltman CD-rom. This CD also contains hourly wave data from nearby Light vessel Goeree.

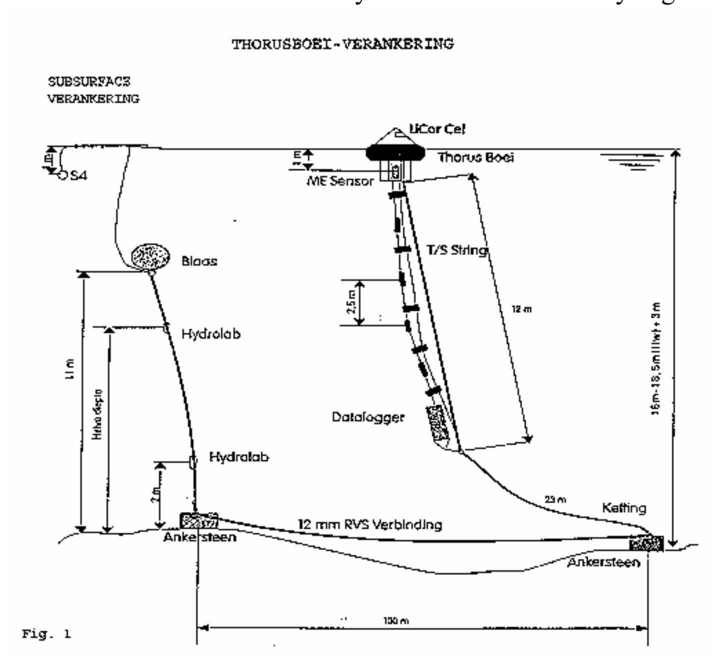

Figure 17-2 Design of the subsurface mooring (left) and surface mooring (right) of the Siltman Measurements.

Frequency

Data were sampled at the following frequency:

- Mex (turbidity): 10 minute average
- Hydrolab (turbidity): 10, 20 or 30 minute average
- UCM (flow): 10 minute average
- Wave data from Lichteiland Goeree: 60 minute average

Usefulness

This data provides reasonable information on the vertical distribution of sediment. The sample frequency (every 10 min) is sufficiently high to observe both resuspension by the tide and by wave action. Such data is very scare on the North Sea. Most information on vertical SPM distribution however is available from the Mex sensors at 15 and 55 cm above the bed because the Hydrolabs functioned only part of the time and were only deployed at one site. Still the Siltman data is a valuable source of near-bed SPM data. The data is acquired from an area (Maasmond) that is most likely to be affected by the land reclamation works for Maasvlakte-2 because of its proximity to these works.

18 Sandpit measurements

The ‘SANDPIT’ measurements (Van Rijn et al, 2005) consist of near-bed data from three tripods in addition to ship-based measurements and box core samples. The measurements were made on the Noordwijk transect near the Dutch coast during spring to autumn 2003 (about 2800 hours of data). Although the SANDPIT field campaign was primarily intended to acquire more data on sand transport, also observations with OBS sensors were made on the mud concentration in the water column near the bed and on the mud content of the sea bed from the box core samples. For more detailed information, the reader is referred to Van Rijn et al, 2005, and in particular to the following chapters/sections:

- Chapter 5.3: new field data sets (pp. 43–45)
- Annex 1B: table new field data (p. 139)
- Grasmeijer B.T., Dolphin T., Doucette J.F., Hearn S., Kleinhans M.G., Montfort O., Rijn, L.C. van, Werf, J.J. van der (2005). Description of measurements and database of field and laboratory data. pp. M1–M11.
- Kleinhans, M.G., Montfort, O., Dankers, P.J.T., Rijn, L.C. van, Bonne, W. (2005). Mud dynamics on the shoreface and upper shelf, Noordwijk, The Netherlands. pp. Z1–Z15.

The study area is located 2 km off the coast of Noordwijk at a water depth between 12.2 and 15.6 m:

Tripod	X (UTM-31)	Y (UTM-31)
HSM tripod	595980	5791180
Hydro tripod	595950	5791110
Caen tripod	595990	5791260

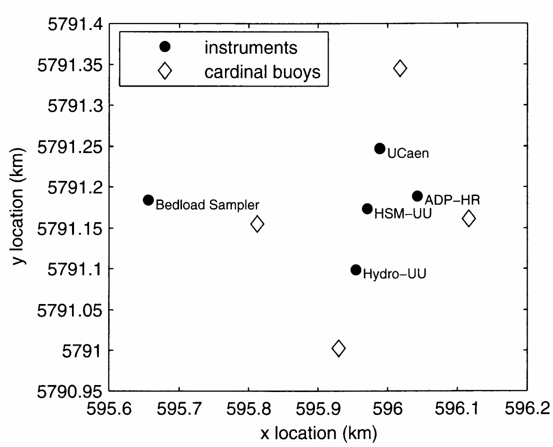

Figure 18-1 Graph indicating the location of the measurement sites during the Sandpit campaign (black dots).

Instrumentation

The fixed measuring location consisted of steel frames on which were mounted the following instruments:

Sensor	HSM tripod	Hydro tripod	Caen tripod
EMF	7×	2×	3×
ADCP	1×	–	1×
OBS	5×	2×	3×
pressure	2×	1×	1×

All instruments operated in burst mode with a burst duration of 20 minutes and a frequency of 2 Hz.

Quality

The lowest measurable mud concentration was 20 mg/l, the dataset is therefore less suitable for periods with calm weather. The effect of bio fouling was dealt with in a simplistic way. The reported concentrations should be interpreted with care.

Usefulness

The SANDPIT data may be a useful extension of the CEFAS measurements at Noordwijk 2 (carried out from 20/11/2001 until 02/01/2002), especially during storm periods. However, the accuracy of the data appears to be lower. Also more effort is required to make the data available. For the assessment of long-term changes the time series are too short, still the data may be useful to establish system relations. For example, the box core data on mud content may be useful to establish or improve system relations on seasonal sediment buffering.

19 Discussion

The primary interest on the present study is the assessment of changes in the residual SPM flux in the Dutch coastal zone and towards the Wadden Sea. Ideally, the assessment of this residual SPM flux would rely on at least a set of cross-shore 2D-vertical transects, aligned along shore from Hoek van Holland to the Marsdiep. Across these transects the, on average alongshore, northward flux, could be determined from the product of highly variable velocity and SPM concentration. The previous sections have discussed the various main and auxiliary variables of which observational or operational model data are available that relate to the assessment of changes in the SPM flux. Only the ADCP-derived velocities and concentrations across the Marsdiep inlet by NIOZ allow for an (almost[3]) ideal assessment of the residual SPM flux. Anywhere else only data less directly related to the SPM flux are available. Besides, also data are available that relate to the forcing conditions of the residual SPM flux and that are useful to help discern the cause of any future change.

The most prominent data related to the flux are SPM concentrations. Since the possible MV-2 induced changes in the SPM flux may result in redistribution of SPM concentrations in time and/or space, comparing future SPM concentrations to present will give indications whether or not a possible MV-2 influence has a significant effect.

The eventual consequence of an adverse change in the residual SPM flux is a change in the concentrations of SPM (and nutrients, but those are not considered in the present study) in the Wadden Sea. This can be assessed from evaluating time series of SPM concentration in the Wadden Sea, for which only the *in situ* data are available, since remote sensing is not reliable in the Wadden area. In the coastal zone, both remote sensing, *in situ* and indirect SPM data are available.

It should be noted that almost all long-term records of the SPM data contain values representative for the upper few meters of the water column. Only when the water column is vertically well mixed are these values indicative of the vertically integrated SPM concentration which is relevant for the flux. Well mixed conditions are more often encountered in the relatively shallow Wadden Sea than in the coastal zone. Hence, especially in the coastal zone the representation of flux-related SPM conditions is a matter for discussion. To assess the degree of representation of the surface values, additional information from the detailed measurements (such as in the CEFAS, Sandpit and Siltman projects) and the formulation of conceptual models, incorporating additional information on stratification and mixing (related to waves, salinity and temperature distribution) is required.

Also, the lateral coverage of the above-mentioned ideal cross-shore transects may be subject to discussion: both the remote sensing and *in situ* data have relatively lower accuracy or coverage of the first two kilometers offshore where a substantial part of the alongshore flux may occur. Only the few remaining beach observations, and stations at 2 km offshore cover this zone. Again, additional information is required to quantify this shortcoming.

[3] *Almost, as the question whether the methods by NIOZ to determine SPM concentrations are accurate enough to obtain accurate residual fluxes has not been yet fully addressed.*

In addition, there is only one source of synoptic current velocity data that can be used to assess changes in transports, which are the model results in MATROOS. These operational models require extensive validation before they can be relied upon as a source of velocity information. The ADCP at the IJmond provides information on currents and a measure for concentration, but only at one location. An assessment of a flux across a cross-shore plane is not possible. (Apart from the fact that an algorithm to retrieve concentrations from the echo intensities of this ADCP is still lacking.)

From the data inventory it can be concluded that given the current state of the art of observing and modelling SPM fluxes, the drawbacks outlined above may have to be accepted and the surface SPM values may have to be accepted as proxies for the SPM flux or, more precisely, as useful quantities to assess secondary effects due to MV2-induced changes in the residual SPM flux (e.g. a change in the cross-shore distribution of surface SPM). In fact, the above-mentioned change in SPM concentration in the Wadden Sea is to be considered as a secondary effect as well.

20 Conclusions

The present report assesses the usefulness of various sources of observational and operational model data to

1) assess the baseline conditions of suspended particulate matter (SPM) in the Dutch coastal zone, and
2) enable the assessment of possible future effects of the Maasvlakte 2 (MV2) on the transport of SPM in the coastal zone and towards the Wadden Sea.

As the direct measurement of the quantity ‘SPM flux’ is not possible, the evaluation of the data has been carried out against the background of the key variables identified in Blaas & Van den Boogaard, 2006. These key variables consist of main variables describing (measures for) SPM concentrations and current velocities, as well as auxiliary variables that are related to the coastal SPM transport mechanisms. The main variables either allow for determination of the residual SPM flux and changes therein, the so-called primary effects[4], or determination of secondary effects due to changed residual SPM fluxes. The auxiliary data allow for the construction of additional proxies for SPM transport or for the formulation of system relations that allow the discrimination of the cause of possible future changes in SPM transport.

In the evaluation consistency, accuracy and number of independent observations are important criteria, apart from availability. Costs have not been a major criterion except for the remote sensing data.

20.1 Conclusions per area of interest

The primary and secondary effects and the methods to assess these are further outlined in the companion report by Blaas & Van den Boogaard (2006). Blaas & Van den Boogaard (2006) present three areas of interest where, apart from baseline conditions (all areas), either future reference conditions can be determined (‘Area A’, well south of Maasvlakte-2) or future SPM conditions that may include MV2 effects (‘Area C’, the Holland coast, and ‘Area D’, the western Wadden Sea). For each area, key variables have been identified, based on what is available. Here we summarize the advantages and disadvantages of these key variables for each area individually against the background of the methodology to assess baseline conditions and possible future changes.

[4] *in fact this is only possible from the ADCP-derived currents and concentrations in the Marsdiep.*

Area A (Belgian and Zeeland Coast)

For Area A, the southern part of the Dutch Delta and the Belgian coastal zone, the key variables are listed in Table 20-1. These are the main variables surface SPM concentration and current velocities, and the auxiliary variables of wave and wind forcing and dredging activities in the Belgian ports. The main variables are in the first place used to assess the reference concentrations (upstream with respect to the residual transport) and water volume fluxes (through specified cross-shore transects). The wave and wind data are useful to formulate system relations within Area A between SPM concentration and its forcing factors. The dredging data serve the two purposes outlined in section 13: a measure for siltation and hence a proxy for the nearshore SPM conditions and a source of redistributed SPM. The order in the tables reflects a priority in terms of usefulness.

Table 20-1 Key variables to assess changes in the reference conditions of Area A. High and low frequency are relative to the dominant time scales in SPM signals which are the tidal period and the time scale of changing weather conditions. Time series that resolve the tides are considered high frequency. Time series with sample intervals of a few days or longer are considered low frequency.

Variable	Type	Source
SPM surface concentration	low-frequency time series, remote sensing imagery (low frequency)	Zeeland: MWTL data from DONAR, Belgian Coast: IDOD data, MERIS, MODIS, Orbview-2, IKONOS
depth-averaged current velocities off Zeeland and Belgium	maps (high-frequency storage) of 2DH hydrodynamic models	*Kustfijn* model in MATROOS data base
Sea Surface Salinity	low-frequency time series from monitoring	MWTL stations
signficant wave height & period, local depth	high-frequency time series, bathymetric data	DONAR wave data from Europlatform and Light Vessel Goeree
wind stress magnitude & direction	high-frequency time series	HYDRA wind data from LV Goeree, Europlatform, Oosterschelde
dredged sediment mass for maintenance	time series (cumulative annual data)	various Belgian ports, mostly Zeebrugge, various dump sites

The advantages and disadvantages of the data sets, presented by source, are shown in Table 20-2. Both the *in situ* and remotely sensed SPM variables are related to surface concentrations and may contain biases towards weather conditions, but as they are the most direct measure for SPM flux available and have been monitored for sufficiently long time, they provide the best means of assessing long-term (changes in) conditions. The use of remote sensing products of IKONOS and MODIS requires near-future algorithm development tailored to the North Sea.

The capabilities of the operational model in terms of residual transport need to be further validated before it can be applied. Moreover an extension of the storage of historic output is required. These modifications can be carried out over time as hindcasting is feasible. For model calibration and validation salinity data are useful. Also Salinity stations off the Zeeland coast still offer some possibility to produce a reference field of salinity south of the Maasvlakte and Haringvliet.

The use of the auxiliary data can only be fully appreciated when system relations are really being formulated. The wave and wind data have sufficient time and space coverage and the spatial information of the dredging data is also valuable.

Table 20-2 Advantages (+) and disadvantages (-) of the key variables of area A (see also Table 20-1)

Variable	+	-
Dutch *in situ* SPM surface concentration from cruises (MWTL)	long historic records, extensively studied in the past	only surface data, low-frequency time series, possible sampling biases, possible pseudo trends, decreased spatial resolution, high minimal detection limit
Belgian *in situ* SPM surface concentration from cruises (IDOD)	moderately long historic records, same vessel and monitoring policy over past 20 years (high consistency)	only surface data, low-frequency time series, possible sampling biases for weather conditions
SPM concentration from remote sensing	spatial, synoptic coverage; sufficiently long records when sensors are combined, high precision (at least Level 1 data)	only surface data, inaccuracies nearshore, lack of specific North Sea algorithms, bias for weather conditions and seasons
depth-averaged current velocities from 2DH *Kustfijn* model	synoptic, high time and space resolution	only depth-averaged information, model transports not yet sufficiently validated
Sea Surface Salinity (MWTL)	long records, especially useful for model calibration/validation	decreased spatial coverage
signficant wave height and period, local depth (LV Goeree & Euro platform)	high-frequency time series, accurate, long records, sufficient spatial coverage	transformation of wave fields towards sites of interest may be required
wind speed magnitude & direction (LV Goeree, Europlatform, Oosterschelde)	high-frequency time series, precise, long records, sufficient spatial coverage	conversion to wind stress or waves may be required
dredge mass for maintenance port of Zeebrugge	long records, spatial information on dumping	low temporal resolution, limited accuracy, change in units over time (possible inconsistency)

Area C (Holland Coast)

For area C, the Holland coast extending from the Noordwijk transect to the seaward side of the Marsdiep, the key variables are listed in Table 20-3. The main variables are *in situ* and remotely-sensed SPM surface concentrations, model-based current velocities and a potential measure for SPM concentration and flux at the IJmond from ADCP. A special position is taken by the high-frequency SPM concentration time series from the CEFAS Smartbuoy. This series is too short to cover multi-annual SPM conditions, but it enables the formulation of system relations, e.g. between the variation of SPM concentration and wind waves.

Auxiliary variables relating to the entire coastal zone of area C are again wave and wind data, but also sea surface salinity and temperature. In addition, the dredging data of both IJmuiden and Rotterdam serve as a source on the redistribution of SPM and the IJmuiden data also provide information on siltation well north of MV2.

Table 20-3 Key variables to assess changes in the conditions of Area C (Holland coast). The order reflects priority. For further comments see caption of Table 20-1.

Variable	Type	Locations
SPM concentration	low-frequency time series, remote sensing imagery (low frequency), high-frequency Smartbuoy time series	all MWTL stations from Noordwijk to Callantsoog and Remote Sensing by MERIS, MODIS, Orbview-2, IKONOS. Smartbuoy SPM data from the RIKZ/CEFAS project.
Depth averaged current velocities	high-frequency maps from 2DH hydrodynamic models (*Kustfijn* & *Zeedelta*)	entire coastal area
ADCP echo intensities and current velocities	high-frequency time series	IJmuiden IJmond
Signficant wave height and period, local depth	high-frequency time series, bathymetric data	Noordwijk, IJmuiden IJmond, IJmuiden, IJgeul (IJ5), IJmuiden Munitiestortplaats, Platform K13a
Wind stress magnitude & direction	high-frequency time series	IJmuiden, Noordwijk, Platform K13a
Sea Surface Salinity	time series from monitoring	MWTL stations
Sea Surface Temperature	time series and remote sensing imagery	MWTL stations and remote sensing of coastal area (AVHRR)
dredge mass for maintenance port of Rotterdam and IJmuiden	time series (IJmuiden annual data, Rotterdam weekly data)	Taken from Ports of Rotterdam and IJmuiden, disposed at dedicated sites.
Discharge and SPM concentration Haringvliet & Nieuwe Waterweg, IJmuiden	low-frequency time series	Haringvliet sluices, Maassluis, Hoek van Holland, Brienenoord, Puttershoek. IJmuiden

Table 20-4 show the advantages and disadvantages of the individual data presented by source. In addition to what has been discussed for Area A, the ADCP data are a potentially worthwhile source of detailed information on the vertical structure of SPM transport as soon as a robust algorithm has been developed to retrieve local SPM concentration from the echo intensities. Retrieval development requires additional calibration and validation measurements and, most likely, adaptation of the algorithms developed for the Marsdiep.
The Smartbuoy data of Noordwijk 10 cover all seasons at least once and hence provide the most useful source of high-frequency SPM concentration data in area C already calibrated. The other high-frequency SPM sources (other Noordwijk Smartbuoy stations, Sandpit, Siltman) and the low frequency NoMiVe data provide important additional information on the system and aid formulating system relations, but are not suited to assess baseline conditions from.
Sea surface salinity and temperature provide additional information in the distribution of river water in the coastal zone, although temperature only under specific conditions (stratification, atmosphere-sea water temperature contrast).

As the spatial density of the MWTL transects has decreased over time the usefulness of the salinity data may be limited to local areas only. The Noordwijk transect is still useful to determine river water fraction in the coastal water in the southern part of the Holland coast. The transects of Egmond and Callantsoog have been abandoned, so the river plume cannot be followed along the coast unless (some of) these stations are re-established The salinity data are very useful for calibration of hydrodynamic and transport models. Unfortunately there are no reliable methods to retrieve SSS from remote sensing, so the data gaps cannot be filled by other means.

Table 20-4 Advantages (+) and disadvantages (-) of the key variables of area C (see also Table 20-3)

Variable	+	-
In situ SPM concentration (MWTL)	long historic records, extensively studied in the past.	only surface data, low-frequency time series, possible sampling biases, possible pseudo trends, decreased spatial resolution
SPM concentration (Remote Sensing)	spatial, synoptic coverage; sufficiently long records when sensors are combined	only surface data, limited accuracy nearshore, lack of specific North Sea algorithms, bias for weather and seasons
SPM concentration from CEFAS Smartbuoy	high-frequency, coverage of all seasons (at least once), high degree of continuity, calibrated to in situ SPM, extensively studied, possibility to extend part of series over vertical when combined with Minipod	mostly surface data, no coverage of interannual variability, only buoy at Noordwijk 10 covers all seasons
Depth averaged current velocities *Kustfijn* & *Zeedelta* models	synoptic, high time and space resolution	only depth-averaged information, model transports not yet sufficiently validated
ADCP echo intensities and current velocities IJmond	1DV, high-frequency series of moderate length, continuous, unbiased	no retrieval algorithm available yet, coverage only since 2001
Signficant wave height and period, Area C.	high frequency, sufficient spatial coverage, long records, accurate	transformation of wave fields towards sites of interest may be required
Wind speed magnitude & direction, Area C	high frequency, spatial coverage, long records, precise	conversion to wind stress or waves may be required
Sea Surface Salinity (MWTL)	accurate, long records, especially useful for model calibration/validation	decreased spatial coverage, limited time resolution
Sea Surface Temperature (Remote Sensing)	synoptic coverage, very accurate	bias towards clear weather and summer half year, relation between fresh water and SST not yet robust
dredge mass for maintenance port of IJmuiden	long records, information on disposal	low time resolution (annual), limited accuracies in SPM fraction
Discharge and SPM concentration Haringvliet & Nieuwe Waterweg	long records	low time resolution, model-based discharges: inaccurate reproduction of tidal residual discharge and load
Sea Surface Temperature (MWTL)	long records,	low frequency, low spatial resolution

Area D (western Wadden Sea)

Finally, the key variables for the western Wadden Sea (including the Marsdiep inlet) are listed in Table 20-5. For the Wadden Sea there are no reliable SPM data from remote sensing, so the assessment of changes inside the Wadden Sea has to be based upon the MWTL *in situ* data and NIOZ data. The TESO ferry box offers a unique opportunity to determine the residual volume flux and, within certain limitations, SPM flux through the Marsdiep inlet. The application of operational model results to determine residual fluxes is not thought to add any useful information to the measured fluxes. On the contrary, the measured fluxes may be useful to calibrate the model.

Table 20-5 Key variables to assess changes in the conditions of Area D (western Wadden Sea). The order reflects priority. For further comments see caption of Table 20-1.

Variable	Type	Location
SPM concentration	low-frequency time series	MWTL stations in western Wadden Sea, NIOZ observations on jetty near the Marsdiep
SPM flux through Marsdiep	ferrybox data, high-frequency time series	Marsdiep
volume flux of water through Marsdiep	ferrybox data, high-frequency time series time series	Marsdiep
wind stress magnitude & direction	high-frequency time series	Texelhors, De Kooy, Vlieland, Hoorn (preceded by Terschelling), Lauwersoog.
Aflsuitdijk discharge	moderately low-frequency time series	Sluices Kornwerderzand and Den Oever
Sea Surface Salinity	time series	Marsdiep and Wadden Sea

Table 20-6 lists the advantages and disadvantages of the selected data sources for the key variables of the Wadden Area. As discussed above, the MWTL data are the only source of information within the Wadden Sea. They suffer from low time and space resolution but have long records which still enable the assessment of long-term changes at present station locations. The ADCP series of the TESO ferry are of high value but may suffer from still relatively short historic coverage compared to the MWTL data. Nevertheless the 10 years of data for the t_0 may be sufficient to capture the most important interannual variation in residual fluxes. This is to be analysed further in future.

Wave data are not available inside the Wadden Sea. Wind data may be used as a proxy for wave stirring by means of conceptual modelling (depending on fetch, duration, local depth). The salinity stations in the Wadden Sea are also still relatively well covered and especially the NIOZ time series is long and useful. Combined with the sluice discharges, the salinity measurements provide important data to construct a fresh water balance for the Wadden Sea. Moreover they can be used to calibrate and validate transport models.

Table 20-6 Advantages (+) and disadvantages (-) of the key variables of area D (see also Table 20-5) .

Variable	+	-
in situ SPM concentration	long records, studied before	low spatial and temporal resolution
SPM flux through Marsdiep	coverage of entire cross section of the inlet, high time resolution, semi-permanent	still limited accuracy and ambiguity of SPM retrieval
volume flux of water through Marsdiep	coverage of entire cross section of the inlet, high time resolution, sufficiently accurate	
wind speed magnitude & direction	precise for station location, long records, high frequency, may be used as wave proxy	no stations within Wadden Sea, conversion may be required, limited representation of marine conditions by land stations
Aflsuitdijk discharge	long records, accurate	time resolution may be marginally sufficient (additional information on tidal phasing may be required)
Sea Surface Salinity	accurate, long historic records, especially useful for model calibration/validation	low spatial resolution

20.2 Final remarks

In general it can be concluded that some data sources are not yet suitable to be used to assess SPM conditions (or proxies) at this moment because the lack of accurate retrieval algorithms. Nevertheless, these data sets may be very valuable within about 10 years from now, when the assessment of MV2-effects becomes relevant, provided that algorithms are available by then. In particular, this holds for the ADCP echo intensities at the IJmond and Maasmond (pending relocation of the latter), the IKONOS and MODIS ocean colour data from remote sensing, and partly also the ADCP data from the Marsdiep. For the latter, research and development is already carried out at present to improve accuracy and robustness. It is recommended to continue measuring and archiving these data and further invest in development of techniques to derive SPM related information from them.

Archived data from operational numerical models in MATROOS is potentially very useful obtain detailed information on currents in the coastal zone. The major drawback is the limited storage capacity which at present reduces the length of the historic map records to about one year. If storage would be extended, the MATROOS data would be a relatively inexpensive, highly valuable information source. Furthermore, the value of these data set will increase significantly as soon as 3D instead of 2D data would be stored. It has been remarked already that additional calibration and validation of the operational models in terms of their residual transport capabilities may be required and that especially salinity data are very valuable for this purpose.

Data from process-oriented, campaign-based, relatively short-term projects (i.e. the CEFAS Minipod, the Siltman, Sandpit and NoMiVe data) are especially suitable to obtain process knowledge and insight in vertical structure and/or high-frequency variability of SPM concentration. These data sets are less suited for assessing long-term changes as their coverage of the t_0 situation is generally too short or of local spatial scale to obtain a representative sample of the system conditions and/or they are too expensive to be repeated in future for prolonged periods (t_1 conditions). The only exception are the CEFAS Smartbuoy data at the Noordwijk-10 station. These latter data set already covers over one year of t_0 conditions and not only offers valuable information to formulate system relations but also a beginning of a high-frequency monitoring of baseline conditions. Continuing this type of measurements will add not only high-frequency, but also unbiased and continuous SPM concentrations at a key location in the Dutch coastal zone.

A Detailed figures

A.1 DONAR SPM stations

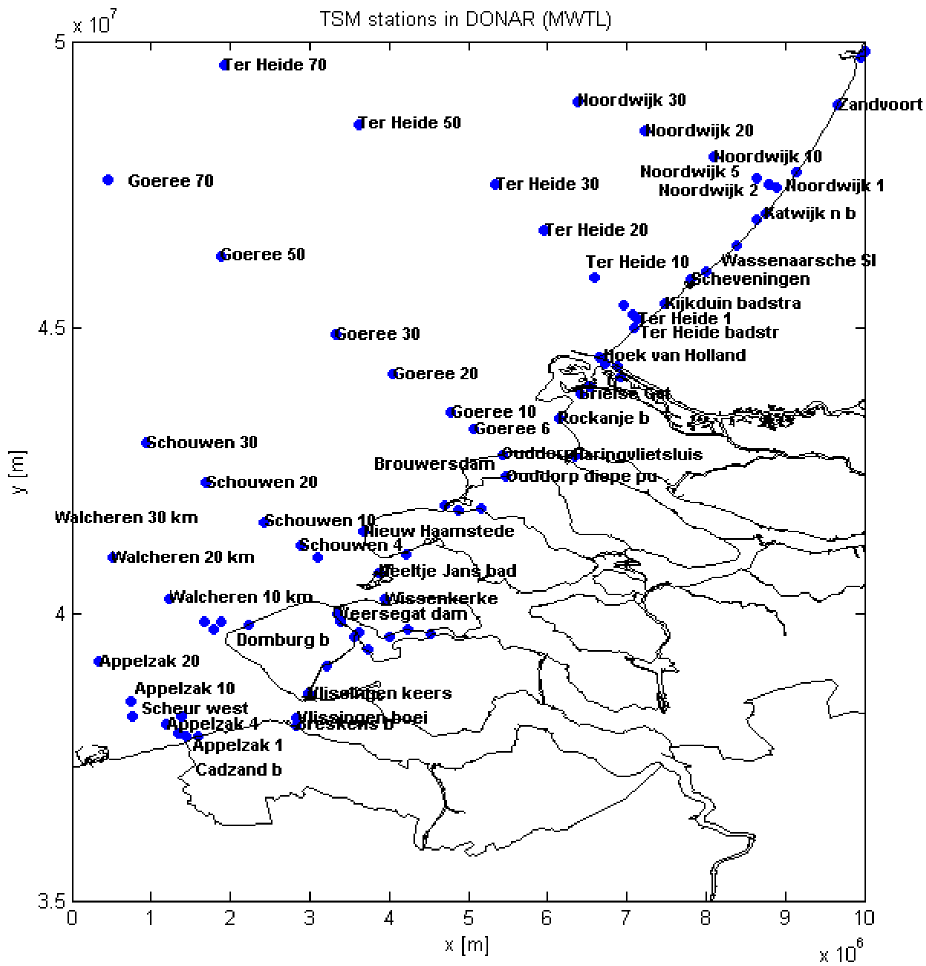

Figure A.1 Zoom into the southern area of the MWTL stations in the DONAR data base (SPM stations, but also largely applicable to SSS).

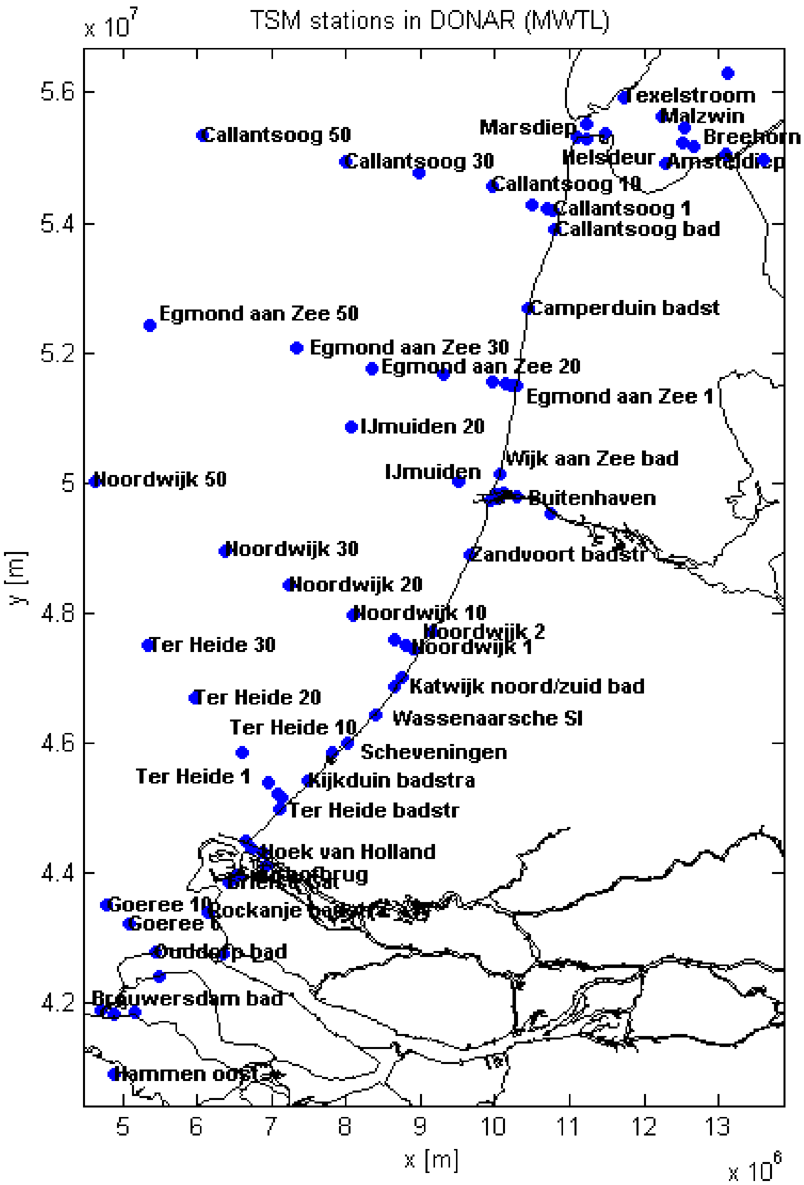

Figure A.2 Zoom into the central area of the MWTL stations in the DONAR data base (SPM stations, but also largely applicable to SSS).

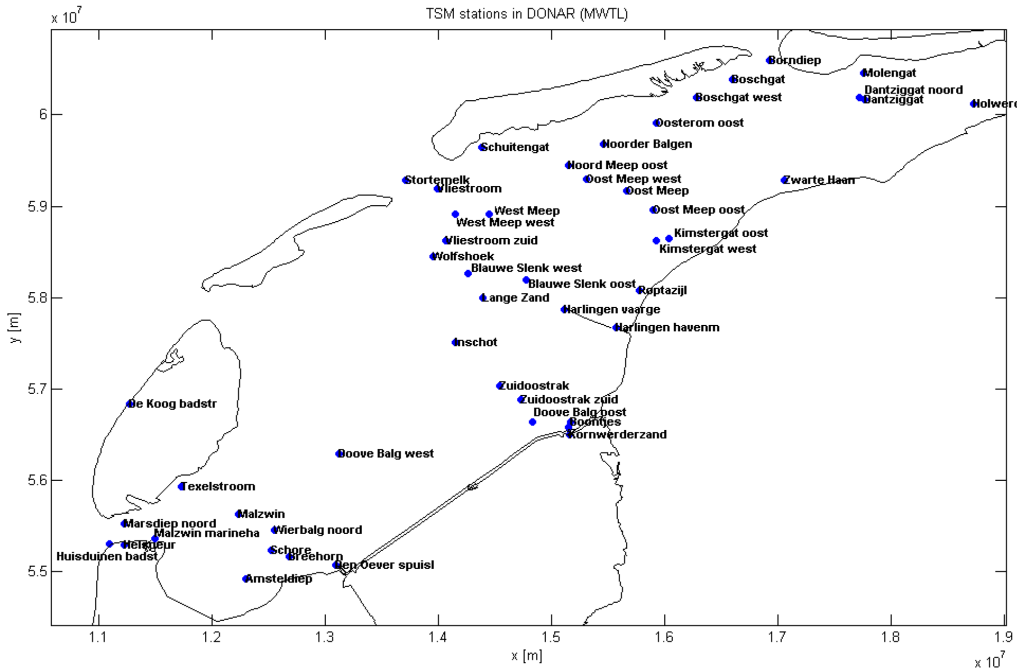

Figure A.3 Zoom into the western Wadden Sea area of the MWTL stations in the DONAR data base (SPM stations, but also largely applicable to SSS).

A.2 IDOD SPM

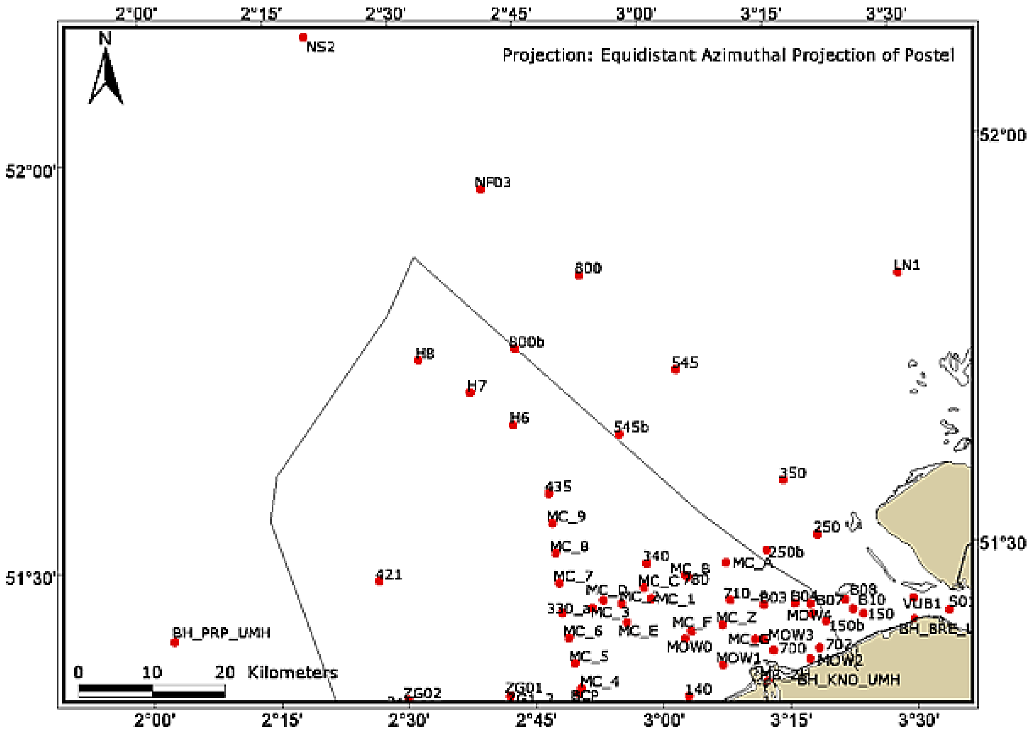

Figure A.4 Zoom into the offshore area off the Belgian coast with the monitoring stations in the IDOD data base (MUMM).

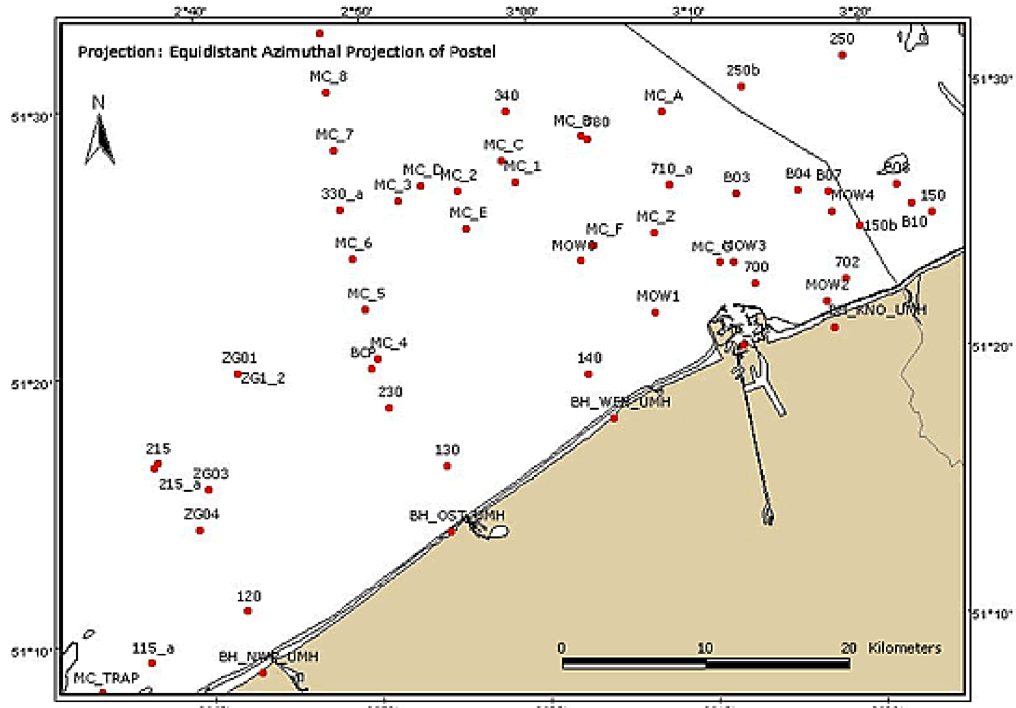

Figure A.5 Zoom into the nearshore area off the Belgian coast with the monitoring stations in the IDOD data base (MUMM).

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