Draft

Prepared for:

La MER foundation

Trends in SPM concentrations along the central Dutch Coast

Analysis of long term observations

Report

A2518

May 2010

Client **La MER foundation**

Title

Trends in SPM concentrations along the Dutch coast

Abstract

This report presents an analysis of trends in SPM concentrations based on predictions with a neural network, based on standardized data using MWTL data and based mixed-effect modelling using MWTL data. Main conclusion is that observed SPM concentrations in the North Sea show a small (but significant within the 95% confidence interval) decreasing trend since 1975. It is difficult to distinguish between the different effects on SPM concentrations in the North Sea.

References

Rev.	Originator	Date	Remarks	Checked by	Approved by
0	B.T. Grasmeijer	May 2010		J. Adema	B.T. Grasmeijer

Document Control	Contents	Status
Report number: A2518R1r0	text pages :	☑ preliminary
Keywords:	tables :	☐ draft
	figures :	☐ final
Project number: A1518	appendices :	
File location: A2518R1r0		

Executive's summary

To be compiled at a later stage

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1 Introduction

1.1 Background

Large amounts of sand are annually extracted from the North Sea for nourishments to protect the Dutch sandy coast against flooding. The existing coastline is in this way maintained and the coastal foundation, defined as the area between NAP-20 m and the dunes, preserved. The *Tweede Regionaal Ontgrondingenplan Noordzee (RON2)* describes the policy for extracting minerals from the Dutch part of the North Sea. Extracting sand from the North Sea requires permission according to the *Ontgrondingen-wet*. The accredited authority (*bevoegd gezag*) for the ontgrondingen-wet is the Assistant Secretary of State of the Ministry of Public Works in the Netherlands (*Staatssecretaris van Verkeer en Waterstaat*). In addition, it requires permission according to the *Natuurbeschermingswet* for which the accredited authority is the Minister of Agriculture, Nature and Food quality (*Minister van Landbouw, Natuur en Voedselkwaliteit*).

An Environmental Impact Assessment (EIA) has to be made to assure that environmental aspects are taken into account in the decision on sand extraction permits. Granting a permit in the framework of the *Ontgrondingenwet* requires an EIA as the extraction area is larger than 500 ha or the amount of sand extracted is 10.000.000 m^3 or more (*Besluit Milieueffectrapportage 1994*, as revised on 16 augustus 2006).

The initiator of extracting sand for the purpose of nourishments for 2008-2012 is the *Hoofdingenieur Directeur (HID)* of the *Regionale Dienst Noord-Holland* of *Rijkswaterstaat*. The initiator for sand extraction for other (commercial) use is *Stichting LaMer*.

Van Duin *et al.* (2007) performed the EIA for sand extraction in the North Sea 2008-2012 for the purpose of coastline nourishments. Also an EIA for commercial sand extraction was performed (Van Duin e.a., 2008). *Rijkswaterstaat* and *Stichting LaMer* are partners in these EIA's.

The final part of the assessment procedure is an evaluation. The initiator has to carry out the required research on the basis of which the accredited authority can make the evaluation. The EIA by Van Duin *et al.* (2007, 2008) presents an onset for an evaluation program (EP). Ellerbroek *et al.* (2008) present a more detailed EP.

An important part of the EP for the EIA 2008-2012 concerns the evaluation of SPM measurements in the North Sea. *Rijkswaterstaat Dienst Noord-Holland* has asked Alkyon to make this evaluation. Alkyon (2010) present the research results.

This report presents a continuation of the Alkyon (2010) study and investigates trends in SPM concentrations along the Dutch coast since 1979.

Research questions to be answered in this report are the following:

1. Have SPM concentrations along the Dutch coast significantly changed since 1979? If yes, could changes in wind, wave, sea water temperature, river discharge, volume of dredge spoil disposal, volume of mined sand or the construction of the Eastern Scheldt storm surge barrier have been a possible cause?
2. Have SPM concentrations along the central Dutch coast been affected by sand mining. If yes, on what time scale does this play a role?

3. Has the wave climate had an important effect on the long term behaviour of SPM concentrations along the central Dutch coast?

1.2 Report overview

In this report, chapter 3 describes the adopted datasets. Chapter 3 describes the set-up and training of a neural network using data obtained in the framework of a joint research program, Rijkswaterstaat-RIKZ and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS). Chapter 4 reports on trends in SPM concentrations based on an analysis of concentration time series that have been measured along four different transects in the framework of the so-called MWTL programme (Monitoring Programme of the National Water Systems). Chapter 5 discusses various effects on SPM concentrations. Chapter 6 summarizes our findings.

2 Data description

2.1 CEFAS Minipod en Smartbuoy

2.1.1 General

In the framework of a joint research program, Rijkswaterstaat-RIKZ and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in the UK made measurements with a Minipod and a Smartbuoy in 2001 and 2002 at different locations offshore of the coast of Noordwijk aan Zee, The Netherlands (CEFAS, 2003). Aim was to increase understanding of the horizontal en vertical transport of fine sediment in suspension at these locations.

Table 2.1 Time schedule of CEFAS Minipod and Smartbuoy measurements

Location	Deployment	First good observation (GMT)	Last good observation (GMT)
Noordwijk 2-1	180	20/Nov/01 12:00	18/Dec/01 09:00
Noordwijk 2-2	181	18/Dec/01 12:00	02/Jan/02 18:00
Noordwijk 5-1	182	05/Mar/02 10:00	21/Mar/02 08:00
Noordwijk 5-1	183	21/Mar/02 12:00	22/Apr/02 11:00
Noordwijk 10-1		10/Apr/00 20:00	01/Jun/00 23:00
Noordwijk 10-2		07/Nov/00 09:00	14/Mar/01 23:00
Noordwijk 10-3		20/Mar/01 10:00	05/Jul/01 23:00
Noordwijk 10-4		21/Aug/01 10:00	18/Sep/01 08:00

The CEFAS Smartbuoy and Minipod were deployed at three different locations, i.e. Noordwijk 2 (2 km offshore at 52°15'.28N 004°24'.28E), Noordwijk 5 (5 km offshore at 52°16'.55N 004°22'.01E) from 20 November 2001 till 22 April 2002 and Noordwijk 10 (10 km offshore). The data report by CEFAS (2003) presents a basic analysis of the measurements. Figure 2.1 shows the Noordwijk 2, Noordwijk 5 and Meetpost Noordwijk locations.

2.1.2 Noordwijk 2-1 en 2-2

Wind, wave and current conditions and concentrations

Figure 2.2 shows the wind speed and direction observed at 10 km offshore at Meetpost Noordwijk and the wave height, wave period, water depth, flow velocity and suspended sediment concentrations measured with the MiniPod during Noordwijk 2-1 period (deployment 180). The red lines in this figure illustrate the slow-varying components of the measured signals. These were obtained by low-pass-filtering the signals using a low-pass frequency of 1/(2 x tidal period).

The wind speed is near gale force twice during the Noordwijk 2-1 measurement campaign, i.e. around 22 November and around 5 December 2001. The significant wave height at 2 km offshore just exceeds 3 m during these conditions and the wind direction is northwest. The wave height decreases due to the wind direction turning eastward. The wave spectrum peak period ranges between 5 and 13 seconds during the measurement campaign. During near-gale conditions, the wave period ranges between 7 and 9 seconds. Longer swell waves occur afterwards. The water depth ranges between 11.6 and 13.6 m. The maximum current velocity is 0.7 m/s.

The observed suspended sediment concentration at ± 0.86 m above the seabed varies about 0.2 kg/m^3 during the near-gale conditions and decreases to about 0.1 kg/m^3 afterwards. The OBS-concentrations agree well with concentrations determined from water samples. The concentrations near the water surface (from the Smartbuoy) amount to 4 to 77% of the concentrations measured at 0.86 m above the bed.

Figure 2.3 shows the basic parameters measured during the Noordwijk 2-2 campaign. The windspeed is near-gale force (> 13.8 m/s) around 21 and 24 December 2001 and gale force around 28 December (> 17.1 m/s). The wind direction is west-northwest most of the time except around 22 and 30 December. The significant wave height follows the development of the wind speed. Around 21 and 24 December, the significant wave height is about 1.8 m and on 28 December it is about 3.0 m. The wave period ranges between 6 and 11 seconds. The water depth ranges between 9.6 and 12.6 m and the maximum current velocity is 0.7 m/s.

The sediment concentration at 0.86 m above the seabed is about 0.25 kg/m^3 during periods with near-gale force winds and varies roughly between 0.06 and 0.20 kg/m^3 afterwards. The OBS-concentrations agree well with concentrations determined from water samples also for this campaign. The concentrations near the water surface (from the Smartbuoy) amount to 8 to 100% of the concentrations measured at 0.86 m above the bed.

Cross-correlation between wave height and concentration

Cross-correlation is a measure of similarity of two waveforms as a function of a time-lag applied to one of them. Figure 2.4 shows the cross-correlation as a function of time lag between wave height and concentration measured at 0.86 above the seabed (Minipod) and between wave height and the concentration measured near the water surface (Smartbuoy) for Noordwijk 2-1 and 2-2 campaigns.

The cross-correlation between wave height and concentration is relatively high (0.8-0.9) near time lag zero both for the Minipod data as for the Smartbuoy data and for both deployments. This may be expected as waves play an important role in stirring sediment from the seabed and keeping it in suspension. The concentration signal measured near the seabed lags a few hours (roughly 6-12 hours) behind the wave height signal. This is not the case for the concentrations near the water surface for which the cross-correlation is maximum at zero time lag. The lagging of the near-bed concentration signal is caused by sediment higher up in the water column settling from suspension after the wave height has decreased. The near-bed layers receive sediment from the upper layers.

2.1.3 Noordwijk 5-1 and 5-2

Wind, wave and current conditions and concentrations

Figure 2.5 presents the wind speed and direction observed at 10 km offshore at Meetpost Noordwijk and the wave height, wave period, water depth, flow velocity and suspended sediment concentrations measured with the Minipod and the Smartbuoy during Noordwijk 5-1 period (deployment 182). The red lines in this figure illustrate the slow-varying components of the measured signals. These were obtained by low-pass-filtering the signals using a low-pass frequency of 1/(2 x tidal period).

The wind speed plot shows periods of a strong breeze (>10.8 m/s), a gentle breeze (>3.4 m/s) and near-gale force (> 13.8 m/s) winds from 6 to 11 March. Wind direction is southwest to west during this period and significant wave heights are about 2 m during strong breeze conditions and more than 4 m during near-gale force winds. The wind speed drops between 11 and 12 March and the wave height decreases subsequently. Wind direction changes from southwest to northeast between the 12 and 13 March. Wave heights remain relatively low from 13 to 17 March. The short period of westerly near-gale force winds on the 18th of March generate waves of up to 2.5 m. During near-gale conditions, the wave period ranges between 7 and 9 seconds. Longer swell waves occur afterwards. The water depth ranges between 17.0 and 19.5 m and the maximum current velocity is 0.6 m/s.

The concentration plot in Figure 2.5 shows two distinct periods in the Noordwijk 5-1 campaign. The first period is from 6 to 11 March with concentrations between 0.03 and 0.3 kg/m^3 at 0.86 m above the bed. The second period is from 12 to 20 March with much lower concentrations (about 0.02 kg/m^3). The concentrations near the water surface (from the Smartbuoy) amount to 3 to 100% of the concentrations measured at 0.86 m above the bed. There is a strong relation with the wave height variation.

Figure 2.6 shows the wind, wave, current and concentration parameters for the Noordwijk 5-2 campaign. The conditions are relatively calm during this period. The significant wave height is less than 0.5 m for most of the time. The wave period ranges between 7 and 14 seconds, water depth between 16.9 and 19.2 m and the maximum current velocity is 0.7 m/s. Maximum concentration at 0.86 m above the bed is 0.04 kg/m^3. The concentrations near the water surface (from the Smartbuoy) amount to 10 to 100% of the concentrations measured at 0.86 m above the bed.

Cross-correlation between wave height and concentration

Figure 2.7 shows the cross-correlation as a function of time lag between wave height and concentration measured at 0.86 above the seabed (Minipod) and between wave height and the concentration measured near the water surface (Smartbuoy) for Noordwijk 5-1 and 5-2 campaigns.

The cross-correlation between wave height and concentration for Noordwijk 5-1 is at zero time lag about 0.7 for the near-bed concentrations (Minipod) and about 0.8 for the near-surface concentrations (Smartbuoy). For Noordwijk 5-2 this is about 0.8 and 0.9, respectively. It is interesting to see that the cross-correlation with wave height is higher for the near-surface concentration than for the near-bed concentrations. This is consistent with the cross-correlations determined for the Noordwijk 2-1 and 2-2 observations (Figure 2.4).

2.2 Waves

2.2.1 Meetpost Noordwijk

To drive the neural network for relatively long periods (years), we used wave data measured at Meetpost Noordwijk (location shown in Figure 2.1). The depth at Meetpost

Noordwijk is about 18 m (relative to NAP). The wave data consist of continuous time series of significant wave height and wave spectrum peak period (among other wave parameters) for the period of 24 years from 1-Jan-1979 00:00 to 31-Dec-2002 23:00 (time in GMT+1) with a sampling interval of 1 hour (Figure 2.8). The time series have no gaps and the dataset is more extensive than that available in waterbase.nl.

Figure 2.8 shows the observed time series and to illustrate the seasonal behaviour also the low-pass filtered values using a cut-off period of 0.5 year.

The mean significant wave height during the entire 24 year period is 1.03 m, the maximum 6.2 m, the 10th percentile 0.32 m, the 50th percentile (median) 0.84 m and the 90th percentile 1.98 m. Table 2.2 summarizes these statistics and includes the trend in the data and the 95% confidence bounds of this trend.

The observed significant wave height at Meetpost Noordwijk shows an increasing trend of $3.0\text{x}10^{-6}$ m/day with confidence bound between $1.8\text{x}10^{-6}$ and $4.2\text{x}10^{-6}$ m/day. This means that the wave height increases with about 1.1 mm per year, with confidence bounds between 0.6 and 1.5 mm per year. This is consistent with studies by Vikebø et al. (2003) and Weisse (2005) who also found wave height trends tending to be positive in the southern North Sea.

Table 2.2 Statistics for observed significant wave height at Meetpost Noordwijk

Mean (m)	Min (m)	Max (m)	std (m)	10th prctile (m)	50th prctile (m)	90th prctile (m)	Trend (m/day)	Trend (95% low) (m/day)	Trend (95% up) (m/day)
1.03	0.10	6.2	0.71	0.32	0.84	1.98	3.0e-6	1.8e-6	4.2e-6

Figure 2.8 illustrates the seasonal behaviour in the observed data with higher waves in winter than in summer. There are four occurrences of relatively high-energetic wave conditions, i.e. Dec-1980, Jan-1983, Feb-1995 and Dec-1999.

The mean wave spectrum peak period during the observations period of 24 years is 4.4 s, the maximum 8.8 s, the 10th percentile 3.3 s, the 50th percentile (median) 4.3 s and the 90th percentile 5.5 s. The wave spectrum peak period does not show an increasing or decreasing trend that is significant within the 95% confidence bounds (Table 2.3).

Table 2.3 Statistics for observed wave spectrum peak period at Meetpost Noordwijk

Mean (s)	Min (s)	Max (s)	Std (s)	10th prctile (s)	50th prctile (s)	90th prctile (s)	Trend (s/day)	Trend (95% low) (s/day)	Trend (95% up) (s/day)
4.4	1.9	8.8	0.8	3.3	4.3	5.5	-1.3e-6	-2.7e-6	1.2e-7

Figure 2.9 shows the Weibull probability plot for significant wave heights at Meetpost Noordwijk.

2.2.2 Noordwijk 2 and Noordwijk 5

We determined the wave conditions at Noordwijk 2 and Noordwijk 5 (see Figure 2.1 for locations) with HYDROBASE-PROP using the offshore wave conditions at Meetpost Noordwijk as an input. The refraction of each directional component is accounted for using the analytical models given in the Shore Protection Manual (CERC, 1984; Hurdle and Stive, 1989) for refraction over a prismatic bottom in water of uniform depth. It is up to the user to schematize the wave propagation process as a series of refraction steps between single output points. The energy in each directional component is summed to obtain the total energy and thus the resulting significant wave height.

2.3 Water levels

Besides wave data, the neural network requires water depth time series. For this purpose we performed a tidal analysis on Meetpost Noordwijk data and on CEFAS data using the method of Pawlowicz et al. (2002).

From the tidal analysis on the Meetpost Noordwijk data we made a tidal prediction and subtracted this from the original observation. This resulted in a time series of residual water level variation for a period of more than 20 years between 31-Dec-1985 22:20 and 05-Jul-2006 08:20 (time in GMT+1). To illustrate this, Figure 2.10 shows an example of observed water levels, tidal prediction and the observation minus tidal prediction at Meetpost Noordwijk for the period between July and December 1986.

From the tidal analysis on the Noordwijk 2 and Noordwijk 5 CEFAS data we made a tidal prediction for the same period as for the Meetpost Noordwijk data, i.e. between 31-Dec-1985 22:20 and 05-Jul-2006 08:20. Subsequently, we added the residual water level variation from Meetpost Noordwijk to the tidal prediction for the CEFAS locations to obtain the actual water level variation. Figure 2.11 shows an example of a tidal prediction at Noordwijk 5, the residual from Meetpost Noordwijk and the resulting actual water level at Noordwijk 5.

2.4 MWTL SPM concentrations

We analysed concentration time series available in Waterbase that have been measured along different transects in the framework of the so-called MWTL programme (Monitoring Programme of the National Water Systems). Some stations and transects were discontinued after 1983. We will focus here on transects that were continued after 1983. This concerns stations in the Terschelling (TS), Noordwijk (NW), Goeree (GO) and Walcheren (WA) transects (Figure 2.12).

Figure 2.13 summarizes the basic statistics of SPM concentration in the studied transects. A detailed study on the trends is made in Chapter 4 of this report.

3 Neural network modelling

3.1 Introduction

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the connections between elements largely determine the network function. You can train a neural network to perform a particular function by adjusting the values of the connections (weights) between elements.

3.2 Neural network set-up

We use a feed-forward network with a tan-sigmoid transfer function in the hidden layer and linear transfer function in the output layer. This structure is useful for function approximation (or regression) problems. We use 9 neurons (somewhat arbitrary) in one hidden layer. The network has one output neuron, because there is only one target value associated with each input vector. The network uses the default Levenberg-Marquardt algorithm for training.

We randomly divided input vectors and the target vector into three sets as follows:

- 70% were used for training
- 15% were used to validate that the network is generalizing and to stop training before overfitting
- 15% were used as a completely independent test of network generalization

We adopted the following low-frequency time series (hourly data) from the Noordwijk 2-1, 2-2, 5-1 and 5-2 as an input:

- significant wave height
- wave spectrum peak period
- water depth

Current velocity measurements are not as often available as wave observations. Using the current velocities as an input vector would limit the applicability of the neural network. Therefore, we used time series of wave parameters and water depth only. For the same reason we did not include the effect of a time lag between the input and output vectors.

Observed time series of the low-frequency near-bed concentrations (Minipod) and near-surface concentrations (Smartbuoy) were used as separate training targets.

3.3 Results

3.3.1 Concentrations near the seabed (Minipod)

Figure 3.1 compares observed and neural-network-predicted concentrations at 0.86 m above the seabed for the Noordwijk 2-1 and 2-2 campaigns. The predictions show encouraging agreement with the low-pass filtered observations ($R^2 > 0.85$). Figure 3.2 shows observed and predicted concentrations for the Noordwijk 5-1 and 5-2 campaigns. Also for these campaigns, the neural network predictions agree well with the observations ($R^2 > 0.86$).

3.3.2 Concentrations near the water surface (Smartbuoy)

Figure 3.3 compares observed and neural-network-predicted concentrations near the water surface for the Noordwijk 2, Noordwijk 5 and Meetpost Noordwijk campaigns. The near-surface concentrations are on average a factor 3 smaller than the near-bed concentrations.

As for the near-bed concentrations also here the predictions show encouraging agreement with the low-pass filtered observations ($R^2 > 0.85$).

3.3.3 Long-term prediction and trend

We used the wave and water level time series measured at Meetpost Noordwijk (described in sections 2.2 and 2.3) to make long-term predictions of the near-surface SPM concentrations at Meetpost Noordwijk (see Figure 2.1 for location).

The input time series cover a period of more than 20 years between 31-Dec-1985 22:20 and 05-Jul-2006 08:20 (time in GMT+1).

Figure 3.5 show time series of the wave height, water depth and the simulated near-surface SPM concentration based on predictions with the trained neural network. The predicted concentrations vary between 0 and nearly 70 mg/l. The mean predicted concentration is 5.28 mg/l and the standard deviation 4.29 mg/l. These values are close to those based on MWTL observations (Grasmeijer and Eleveld, 2010). The maximum predicted values are about a factor 2 higher than the maxima found in the MWTL observations.

Based on a linear regression analysis on the predicted time series, we found a very small negative trend of -0.001 mg/l/year that was however not significant within the 95% confidence interval. Apparently the small but significant positive trend in the wave height time series used as an input for the neural network does not lead to significantly increasing SPM concentrations.

4 Trends in MWTL data

4.1 Introduction

Grasmeijer and Eleveld (2010) report on suspended particle matter (SPM) concentration time series available in Waterbase that have been measured along different transects in the framework of the so-called MWTL programme (Monitoring Programme of the National Water Systems). They compared suspended matter concentrations measured in the period 1975-1983 with the period 1984-2008 and discussed statistical parameters and significance of trends.

Based on a statistical analysis of the MWTL data from each station separately, they found generally no significant (within the 95% confidence bandwidth) trends in the suspended matter concentrations between 1975 and 2008. For nearly all analyzed stations (80%), the concentrations are neither significantly increasing nor significantly decreasing.

Based on t-tests, Grasmeijer and Eleveld (2010) found the difference between the mean values for 1975-1983 and those for 1985-2008 not to be significant at the 5% significance level for most stations. Two stations show a statistically significant decreasing trend, i.e. Terschelling 4 and Noordwijk 2 and two show a statistically significant increasing trend, i.e. Goeree 10 and 20. We should note here that the Goeree 10 and 20 trends are based on a dataset covering a limited period of time, i.e. 1975-1983 and 1975-1995, where the other two significant trends are based on datasets of at least 10 years longer.

The statistical insignificance of trends or difference in means between two periods may have two causes. The first is that the SPM concentrations behave similarly throughout the measurement periods. The second is that the number of samples is insufficient to determine a significant change.

In stead of analysing the data from each MWTL location separately, this chapter studies the trends in SPM concentrations by smartly combining datasets from the different stations. This is done in two ways:

1. Normalizing the data from different stations and combining these into a larger dataset. We tested two normalization methods, a) subtract the mean and divide by the standard deviation, b) divide by the mean.
2. Employing mixed-effect modelling (multi-level modelling) to discern between so-called fixed and random effects. The fixed effect represents the trend irrespective of the location. The random effect represents the effect of a particular location.

4.2 Trends based on standardized data

4.2.1 Introduction

We adopted two different methods to normalize the MWTL data, namely

1. Subtract each value from station i by the mean of that station and divide it by the standard deviation of that station, as follows:

$$\frac{c_i - \overline{c_i}}{\sigma_{c_i}} \quad (1)$$

2. Divide each value from station i by the mean of that station, as follows:

$$\frac{c_i}{\overline{c_i}} \tag{2}$$

The first method is commonly used to standardize variables and is also known as z-standardization. However, it narrows the width of the distribution, hiding the difference between a value in the long tail and one near the peak. Therefore, we adopted a second method that consists of simply dividing all values from a location by the mean of that location.

4.2.2 Result of regression

Terschelling

Figure 4.2 presents time series of the standardized SPM concentrations in the Terschelling transect (TS4, TS10, TS20, TS30, TS50, TS70 and TS100). Three locations in this transect comprise data between 1975 and 2009, i.e. TS4, TS10 and TS50. The other time series are shorter. The dataset consist of 2144 samples.

The trend in the Terschelling transect is negative and significant within the 95% confidence interval for both standardization methods. Converting the non-dimensional standardized trends back to the dimensional trends per location results in relatively small values between -0.011 mg/l/year and -0.072 mg/l/year for the most seaward and landward locations (TS100 and TS4), respectively.

Based on this analysis and assuming other effects are negligibly small (such as measurement method) this would mean that the SPM concentrations in the Terschelling transect decrease in 10 years with 0.1 mg/l to 0.7 mg/l dependent on the cross-shore location (TS100 and TS4, respectively). These values are small as compared to the means (2.5 and 12.8 mg/l) and standard deviations (2.5 and 16.1 mg/l).

The 95% confidence intervals show trends that are a factor 10 smaller to a factor 2 larger than the best estimate.

Noordwijk

Figure 4.3 shows standardized SPM concentration time series in the Noordwijk transect (NW2, NW4, NW10, NW20, NW30, NW50 and NW70). Four locations in this transect comprise data between 1975 and 2009, i.e. NW2, NW10, NW20 and NW70. The other time series are shorter. The dataset consist of 3563 samples.

The best estimates of the trends in the Noordwijk transect are negative but this is not significant within the 95% confidence interval for both standardization methods. Converting the non-dimensional standardized trends back to the dimensional trends per location results in relatively small values between -0.004 mg/l/year and -0.015 mg/l/year for the most seaward and landward locations (NW70 and NW2), respectively. The trends are factor 4-10 smaller than the trends in the Terschelling transect at the same cross-shore locations.

This would mean that the SPM concentrations in the Noordwijk transect decrease with 0.04 mg/l to 0.15 mg/l per 10 years. However, the 95% confidence intervals show decreasing trends of a factor 4 larger (stronger decrease) as well as increasing trends of about a factor 2 larger (absolute).

Goeree

Figure 4.4 presents time series of the standardized SPM concentrations in the Goeree transect (GO2, GO6, GO10, GO20, GO30, GO50 and GO70). Only one location in this transect comprises data between 1975 and 2009, i.e. GO6. The other time series are shorter. The dataset consist of 1503 samples.

The best estimate trend in the Goeree transect is negative but this is not significant within the 95% confidence interval for both standardization methods. Converting the non-dimensional standardized trends back to the dimensional trends per location results in relatively small values between -0.006 mg/l/year and -0.030 mg/l/year for the most seaward and landward locations (GO70 and GO2), respectively. The trends are about a factor 2 smaller than the trends in the Terschelling transect at the same cross-shore locations.

This would mean that the SPM concentrations in the Goeree transect decrease with 0.06 mg/l to 0.3 mg/l per 10 years. However, the 95% confidence intervals show decreasing trends of a factor 5 larger (stronger decrease) as well as increasing trends of about a factor 4 larger (absolute).

Walcheren

Figure 4.5 shows time series of standardized SPM concentrations in the Walcheren transect (WA2, WA4, WA10, WA20, WA30, WA50 and WA70). Three locations comprise data between 1975 and 2009, i.e. WA2, WA20 and WA70. The other time series are shorter. The dataset consists of 2227 samples.

The best estimate trend in de Walcheren is negative but this is not significant within the 95% confidence interval for both standardization methods. Converting the non-dimensional standardized trends back to the dimensional trends per location results in relatively small values between -0.005 mg/l/year and -0.037 mg/l/year for the most seaward and landward locations (WA70 and WA2), respectively. The trends are about a factor 2 smaller than the trends in the Terschelling transect at the same cross-shore locations.

Based on the best estimate, the SPM concentrations in the Walcheren transect decrease with 0.05 mg/l to 0.4 mg/l, dependent on the cross-shore location. However, the 95% confidence intervals show decreasing trends of a factor 5 larger (stronger decrease) as well as increasing trends of about a factor 3 larger (absolute).

Combining locations from different transects

As mentioned before, the statistical insignificance of trends may have two causes. The first is that the SPM concentrations behave similarly throughout the measurement periods. The second is that the number of samples is insufficient to determine a significant change.

To obtain as many representative samples as possible for the period studied here (1975-2009) we combined data from the different transects and selected only those locations that contain data for the period from 1975 to 2009, ignoring locations with shorter time series.

From the Terschelling transect the used locations include TS4, TS10 and TS50. From the Noordwijk transect NW2, NW10, NW20 and NW70. From the Goeree transect GO6. And from the Walcheren transect WA2 and WA20. Combining these resulted in a dataset with 5620 samples.

Figure 4.6 shows the time series of the standardized SPM concentrations from this combined set and the trends based on the standardized data. It is interesting to see that the combined dataset shows a negative trend that is significant within the 95% confidence interval.

Converting the non-dimensional standardized trends back to the dimensional trends per location results in values between -0.015 mg/l/year and -0.139 mg/l/year for the most seaward location in the Terschelling transect and the most landward location in the Walcheren transect, respectively.

Based on this analysis and assuming other effects are negligibly small (such as measurement method) this would mean that the SPM concentrations in the North Sea have been decreasing in the past decades.

The 95% confidence intervals show trends that are a factor 2 smaller to a factor 1.5 larger than the best estimate. This bandwidth is relatively small as compared to that determined for the different transects separately.

4.3 Trends based on mixed-effect model analysis

4.3.1 Introduction

In statistics, an effect is anything that influences the value of a response variable at a particular setting of the predictor variables. Effects are translated into model parameters. In linear models, effects become coefficients, representing the proportional contributions of model terms. In nonlinear models, effects often have specific physical interpretations, and appear in more general nonlinear combinations.

Fixed effects represent population parameters, assumed to be the same each time data is collected. Estimating fixed effects is the traditional domain of regression modelling. Random effects, by comparison, are sample-dependent random variables. In modelling, random effects act like additional error terms, and their distributions and covariances must be specified.

Random effects are useful when data falls into natural groups. In our case, the groups are simply the different locations under study. More sophisticated models might group data by other characteristics. Although the groups are not the focus of the study, adding random effects to a model extends the reliability of inferences beyond the specific sample of individuals.

Mixed-effects models account for both fixed and random effects. As with all regression models, their purpose is to describe a response variable as a function of the predictor variables. Mixed-effects models, however, recognize correlations within sample subgroups. In this way, they provide a compromise between ignoring data groups entirely and fitting each group with a separate model.

4.3.2 Results of regression

We adopted a mixed-effect model (multi-level model) with stochastic EM algorithm (Gelman & Hill, 2006; Delyon et al, 1999).

Each model parameter (trend and offset in our case) is the sum of a corresponding fixed and random effect, and the covariance matrix of the random effects is diagonal, i.e., uncorrelated random effects.

The figures presented in this report show the fixed effect and the sum of the fixed and random effect. The first is location independent and the second location specific.

Terschelling

For the Terschelling transect, Figure 4.7 presents the SPM concentration time series per location and the fixed and fixed+random trends. Figure 4.7 clearly illustrates the difference in length of the time series. Three locations in the Terschelling transect contain data between 1975 and 2009, i.e. TS4, TS10 and TS50. The other time series are shorter. The dataset consist of 2144 samples.

The mixed-effect model regression reveals a negative fixed trend of -0.067 mg/l/year for the Terschelling transect. This is a location independent. The location dependent fixed+random trend varies obviously per location but is always negative. The negative trend is consistent with the trend analysis using standardized data.

Noordwijk

Figure 4.8 shows the SPM concentration time series per location and the fixed and fixed+random trends for the Noordwijk transect. Locations NW2, NW10, NW20 and NW70 contain data for the period from 1975 to 2009. Time series from the other locations are shorter. The dataset consist of 3563 samples.

Noordwijk shows a negative fixed trend of -0.021 mg/l/year. The fixed+random trend varies per location. It is negative for NW2, positive for NW4, negative again for NW10 and NW20 and positive for NW30, NW50 and NW70.

The negative fixed trend from the mixed-effect model regression for the Noordwijk transect is consistent with the best estimate negative trend from the linear regression standardized data analysis. Although the latter was not found to be significant within the 95% confidence bandwidth, the two methods both producing a negative trend for the Noordwijk transect gives growing confidence in the presence of a decreasing trend.

Goeree

Figure 4.9 presents time series of observed SPM concentration in the Goeree transect. Observations for the entire period from 1975 to 2009 are available only at location GO6. Time series for other locations (much) are shorter. GO2 contains data for 2007-2009, GO6 for 1975-2009, GO10 for 1975-1983, GO20 for 1975-1995, GO30 for 1975-1983, GO50 for 1977-1983 and GO70 also for 1977-1983. Consequently, the Goeree dataset is the smallest of the four analysed datasets with 1503 samples.

The Goeree transect shows a negative fixed trend of -0.121 mg/l/year. This trend is likely biased by the dominating effect of GO6. The fixed+random trend is small and positive for all locations.

Walcheren

Figure 4.10 shows the SPM concentrations as a function of time for different locations in the Walcheren transect. Observations at three locations cover nearly the entire period from 1975 to 2009, i.e. WA2, WA20 and WA70, although WA70 starts two years later than the other two and shows a gap from 1984 to 1987. The dataset consists of 2227 samples.

The SPM concentrations in the Walcheren transect show a negative fixed trend of -0.047 mg/l/year, which is in between the value for Terschelling and Noordwijk, although the Walcheren transect is located further south in the North Sea. The fixed+random trend is smaller (absolute ratio ≤ 1/4) than the fixed trend alone and positive for all locations in the Walcheren transect.

Combining locations from different transects

As for the linear regression on the standardized data also here we combined data from the different transects and selected only those locations that contain data for the period from 1975 to 2009, ignoring locations with shorter time series.

From the Terschelling transect the used locations include TS4, TS10 and TS50. From the Noordwijk transect NW2, NW10, NW20 and NW70. From the Goeree transect GO6. And from the Walcheren transect WA2 and WA20. Combining these resulted in a dataset with 5620 samples. Figure 4.11 shows the selected time series of SPM concentrations and the trends from the mixed-effect model analysis.

As for the standardized data analysis also here we find a negative fixed trend. For the mixed model regression this amounts to -0.069 mg/l/year, which is in between the values found for the standardized data analysis (between -0.015 mg/l/year and -0.139 mg/l/year for the most seaward location in the Terschelling transect and the most landward location in the Walcheren transect, respectively).

It is interesting to see that the fixed+random trends (location dependent) remain negative for the selected locations and are a factor 1.6 to 2.9 smaller than the fixed trend.

Based on this mixed-effect model analysis (and the standardized data analysis) and assuming other effects are negligibly small (such as measurement method) this would mean that the SPM concentrations in the North Sea have been decreasing in the past decades.

5 Effects on SPM concentrations

5.1 Fishery

Fishery and particularly demersal fishery that targets species which live on the or near the seabed might have affected SPM concentrations due to stirring up of sediment from the seabed by fishing gear.

Rijnsdorp et al. (2008) and Van Densen and Van Overzee (2008) studied the changes in the Dutch demersal fishing fleet since the 1950s. They found that since the end of the 2nd world war, the number of vessels in the Dutch motor trawler fleet has steadily increased, with a first peak in the early 1960s. After a temporary decline in the mid 1970s, numbers peaked again around 1985 but have steadily fallen since then (Figure 5.1 a). The increase in fleet size coincided with an increase in vessel size. Mean engine power increased from about 65 hp in 1946 to around 1000 hp in the 1990s (Figure 5.1 b). Total engine power of the fleet increased ninefold and peaked at 600,000 hp in 1987, but decreased to about 350.000 hp in 2003.

Except for the constraints imposed by the minimum mesh size, minimum landing size, and the 3 nautical mile zone, the fleet was virtually free from management regulations until 1974. Since then, an increasing number of constraints have been imposed of which the most significant ones were the introduction of a TAC system and the establishment of the 12 nautical mile zone (where (beam) trawling for flatfish was forbidden for vessels of more than 300 hp) in 1975.

In 1989 this regime was extended to a wider coastal area to reduce the discarding of undersized plaice in the fishery for sole. Since 1978, the number of vessels in the 275–300 hp range (Euro-cutters) has increased, initially stimulated by an EEC subsidy scheme. In contrast, the number of large vessels showed a slight increase in the late 1970s, but decreased steadily throughout the mid 1980s. Hence, the management restrictions, with regards to engine power and the 12 nautical mile zone resulted in a bifurcation of the fleet into two separate fleets consisting of 2000 hp and 300 hp vessels (Figure 5.1 b).

Between 1962 and 1967, a major shift in deployment of fishing gear occurred. Until 1962 the otter trawl was the main gear used to target flatfish and roundfish. Twin beam trawls were used to target brown shrimp. In the following years the otter trawl was replaced by the beam trawl as the dominant demersal gear (Figure 5.1 c). Beam trawling rapidly developed in terms of size of gear, number of tickler chains and towing speed, changes which required increasingly stronger engines. The introduction of the beam trawl, which led to problems with vessel stability, coincided with a twofold increase in the risk of vessel loss to 0.8% per year around 1970 (Figure 5.1 c).

In 1968–69 vessels from southern harbours Arnemuiden, Breskens, and Vlissingen started to apply chain mats in the net opening to prevent large boulders entering the net, allowing them to enter previously untrawlable grounds. In the southern harbours this gear type quickly became the dominant type. A few vessels from (northern) Wieringen, Urk, Volendam deploy the chain mat on a seasonal basis.

It is difficult to correlate the above described complex developments in the Dutch fleet of demersal trawlers to observed SPM concentrations.

5.2 Dredging

Sediment can be released from dredgers by a wide range of mechanisms and at different levels in the water column (Van Maren et al., 2008). The mechanisms that give rise to the release are often complex. There are five main mechanisms by which sediment may be released into the water column by a trailing suction hopper dredger: 1) Overflow from the hopper; 2) Use of Lean Mixture OverBoard (LMOB) systems; 3) Disturbance around the draghead; 4) Scour of the bed caused by the main propellers and bow thrusters.
5) Operation of de-gassing systems.

The degree of resuspension of sediments and turbidity from dredging and disposal depends on four main variables (Pennekamp & Quaak 1990):

- the sediments being dredged (size, density and quality of the material),
- method of dredging (and disposal),
- hydrodynamic regime in the dredging and disposal area (current direction and speed, mixing rate, tidal state), and
- the existing water quality and characteristics (background suspended sediment and turbidity levels).

It is difficult to distinguish the environmental effects of dredging from those resulting from commercial shipping operations, bottom fishing or natural processes (Parr et al 1998; Pennekamp et al 1996).

To give an indication of the trend in dredging activities on the North Sea, Figure 5.2 shows the nourishment volume from 1950 to 2008 based on data from Rijkswaterstaat directie Noordzee. The upper panel shows the nourishment volumes per nourishment and the lower panel the nourishment volumes summed per year.

Figure 5.2 clearly illustrates an increase of the nourishment volume (and this dredging volume) since the early 1970's. Linear regression on the nourishment volumes since 1975 results in a linear trend of about 370.000 m^3/year. Following this trend, the nourishment volume in 1978 was about $1.8x10^6$ m^3 and increased to about $12.8x10^6$ m^3 in 2008.

In the present study we found no evidence for a large scale and long term increase of the SPM concentrations in the North Sea due to the increased dredging volumes sice 1975. In contrast, the present analysis on SPM concentrations show a decreasing trend.

5.3 Eastern Scheldt storm surge barrier

The Eastern Scheldt storm surge barrier between the islands Schouwen-Duiveland and Noord-Beveland, is the largest of the 13 ambitious Delta works series of dams, designed to protect the Netherlands from flooding.

The nine kilometre-long barrier was initially designed, and partly built, as a closed dam, but after public protest huge sluice-gate-type doors were installed in the remaining four kilometres. These doors are normally open, but can be closed under adverse weather conditions. Work on the dam itself started in April 1976 and was completed in June 1986.

The storm surge barrier has affected the hydrodynamics and sediment transport patterns Eastern Scheldt. Ebb and flood volumes reduced by 30%, which led to reduction in suspended sediment concentrations and reduction of the landward transport of fine sediments (Ten Brinke, 1993). This might have affected the SPM concentrations in the North Sea. However, the trends observed in the previous chapters could not be related directly to the construction of the Eastern Scheldt storm surge barrier.

5.4 River discharge

An increase of SPM concentrations in the rivers Ems, Scheldt or Rhine may have affected SPM concentrations in neighbouring estuaries or the North Sea. For example, a river may discharge large amounts of the annual silt discharge after heavy rainfall. Sydow (1987) suggests that small SPM concentrations in the period Jul-Oct off the coast of Noordwijk may be related to a relatively low Rhine discharge. Besides this, density differences due to the fresh water discharge into the saline North Sea may affect SPM concentrations.

Figure 5.3 shows time series of the Rhine discharge since 1989. The discharge varies from a minimum of 788 m^3/s on 28-Sep-2003 to a maximum of 11885 m^3/s on 31-Jan-1995.

The trend line through the discharge data shows in an increase of the Rhine discharge of about 7 m^3/s per year. However, high discharge peaks where higher in the period1993-2004 than in other years.

We tested the correlation between river Rhine discharge and SPM concentrations at Noordwijk 2 but found values for the correlation coefficient of less than 0.2, which means that the river Rhine discharge and the SPM concentrations at Noordwijk 2 are basically not correlated (compare also Figure 5.3 and Figure 4.8).

5.5 Measurement methods

The SPM concentrations in the North Sea measured in the framework of the MWTL program are determined by filtering of water samples, washing away salt from the filter and drying the filter at 105 degrees Celsius. The filter choice (pore size and material) determines the measurement result. The SPM concentration is defined as the weight of the particles that stay behind on the filter divided by the volume of the water sample (mg/l). SPM may consist of algae’s, detritus (non-living particulate organic material) and silt. The particle size is generally larger than 45 μm but this depends on the filter.

SPM concentrations measured in the framework of the MWTL program are generally taken from the upper 1 m of the water column but depending on the pitch, roll and heave of the ship from which the sample is taken this may also be at a depth of 3 m (Boon et al, 1992).

The filter used from 1973 to 1983 is a paper filter by Schleicher & Schull no. 589-2, with a pore size of about 7 μm Norm NEN 3235 4 .1/4 .2 (Boon et al, 1992). The filter used from 1984 till now is a membrane filter with a pore size of 0.45 μm Norm NEN 6484.

Changes in the measurement method and analysis involve the following:

- Number of measurement locations
- Sampling interval
- Positioning (since 1979 by coordinates)
- Sampling method (till 1982 sample bottles filled in succession, after 1982 large container filled first and smaller bottle filled next)

- Filter pore size (smaller since 1984)
- Detection limit
- Time relative to high tide
- Filtering method (first under vacuum with a water jet pump, later under 1 atm pressure)

These changes may affect the observed SPM concentration. The result may be higher or lower. However, it is difficult to quantify the exact effect of the above mentioned changes.

6 Summary and conclusions

The conclusions from the present study are summarized as follows:

Neural network

We trained a neural network to simulate short-term near-bed and near surface SPM concentration at 2, 5 and 10 km offshore Noordwijk aan Zee. We adopted low-frequency time series (hourly data) of significant wave height and water depth as an input. Observed time series of low-frequency near-bed concentrations (Minipod) and near-surface concentrations (Smartbuoy) were used as separate training targets. The short-term predictions (months) showed encouraging agreement with the low-pass filtered observations ($R^2 > 0.85$).

We used the wave and water level time series measured at Meetpost Noordwijk to make long-term predictions of the near-surface SPM concentrations at Meetpost Noordwijk. The input time series covered a period of more than 20 years between 31-Dec-1985 22:20 and 05-Jul-2006 08:20 (time in GMT+1).

The observed significant wave height at Meetpost Noordwijk shows an increasing trend of $3.0x10^{-6}$ m/day with confidence bound between $1.8x10^{-6}$ and $4.2x10^{-6}$ m/day. This means that the wave height increases with about 1.1 mm per year, with confidence bounds between 0.6 and 1.5 mm per year. This is consistent with studies by Vikebø et al. (2003) and Weisse (2005) who also found wave height trends tending to be positive in the southern North Sea.

The long-term neural network predicted concentrations at Meetpost Noordwijk varied between 0 and nearly 70 mg/l. The mean predicted concentration was 5.28 mg/l and the standard deviation 4.29 mg/l. These values are close to those based on MWTL observations (Grasmeijer and Eleveld, 2010). The maximum predicted values were about a factor 2 higher than the maxima found in the MWTL observations.

Based on a linear regression analysis on the predicted time series, we found a very small negative trend of -0.001 mg/l/year that was however not significant within the 95% confidence interval. Apparently the small but significant positive trend in the wave height time series used as an input for the neural network does not lead to significantly increasing SPM concentrations.

MWTL data

In addition to the neural network predictions, we studied the trends in SPM concentrations by smartly combining datasets from different stations in the MWTL database. This was done in two ways:

1. Standardizing the data from different stations and combining these into a larger dataset. We tested two standardization methods, a) subtract the mean and divide by the standard deviation, b) divide by the mean.
2. Employing mixed-effect modelling (multi-level modelling) to discern between so-called fixed and random effects. The fixed effect represents the trend irrespective of the location. The random effect represents the effect of a particular location.

We studied SPM concentrations from the Terschelling, Noordwijk, Goeree en Walcheren transects in the MWTL database.

Standardization methods

Based on the standardization methods, the best estimates of the trends in the different transects were all found to be negative. However, only the trend in the Terschelling transect was found to be significant within the 95% confidence interval.

To obtain as many representative samples as possible we combined data from the different transects and selected only those locations that contain data for the period from 1975 to 2009, ignoring locations with shorter time series. The combined dataset showed a negative trend significant within the 95% confidence interval. Converting the non-dimensional standardized trends back to the dimensional trends per location resulted in values between -0.015 mg/l/year and -0.139 mg/l/year for the most seaward location in the Terschelling transect and the most landward location in the Walcheren transect, respectively.

Based on this analysis and assuming other effects are negligibly small (such as measurement method) this would mean that the SPM concentrations in the North Sea have been decreasing in the past decades.

The 95% confidence intervals showed trends that were a factor 2 smaller to a factor 1.5 larger than the best estimate. This bandwidth was found to be relatively small as compared those determined for the different transects separately.

Mixed effect model

Based on the mixed-effect model regression we found a negative fixed trend in the SPM concentrations for all four transects. This location independent trend varied between -0.021 and -0.067 mg/l/year.

As for the linear regression on the standardized data also here we combined data from the different transects and selected only those locations that contain data for the period from 1975 to 2009, ignoring locations with shorter time series.

As for the standardized data analysis also here we found a negative fixed trend. For the mixed model regression this amounted to -0.069 mg/l/year, which is in between the values found for the standardized data analysis (between -0.015 mg/l/year and -0.139 mg/l/year for the most seaward location in the Terschelling transect and the most landward location in the Walcheren transect, respectively).

It was interesting to find that the fixed+random trends (location dependent) remained negative for the selected locations and were found to be a factor 1.6 to 2.9 smaller than the fixed trend.

Based on this mixed-effect model analysis (and the standardized data analysis) and assuming other effects are negligibly small (such as measurement method) this would mean that the SPM concentrations in the North Sea have been decreasing in the past decades.

Effects on SPM concentrations

Fishery and particularly demersal fishery that targets species which live on the or near the seabed might have affected SPM concentrations due to stirring up of sediment from the seabed by fishing gear. Rijnsdorp et al. (2008) and Van Densen and Van Overzee (2008) studied the changes in the Dutch demersal fishing fleet since the 1950s. However, it s difficult the complex developments in the Dutch fleet of demersal trawlers to observed SPM concentrations.

The nourishment volume (and thus dredging volume in the North Sea) has increased since the early 1970's. Linear regression on the nourishment volumes since 1975 resulted in a linear trend of about 370.000 m^3/year. Following this trend, the nourishment volume in 1978 was about $1.8x10^6$ m^3 and increased to about $12.8x10^6$ m^3 in 2008. In the present study we found no evidence for a large scale and long term increase of the SPM concentrations in the North Sea due to the increased dredging volumes sice 1975. In contrast, the present analysis on SPM concentrations show a decreasing trend.

We tested the correlation between river Rhine discharge and SPM concentrations at Noordwijk 2 but found values for the correlation coefficient of less than 0.2, which means that the river Rhine discharge and the SPM concentrations at Noordwijk 2 are basically not correlated.

Various changes in the SPM measurement method may have affected the observed SPM concentrations available in the MWTL database. The result may be higher or lower. However, it is difficult to quantify the exact effect of these changes.

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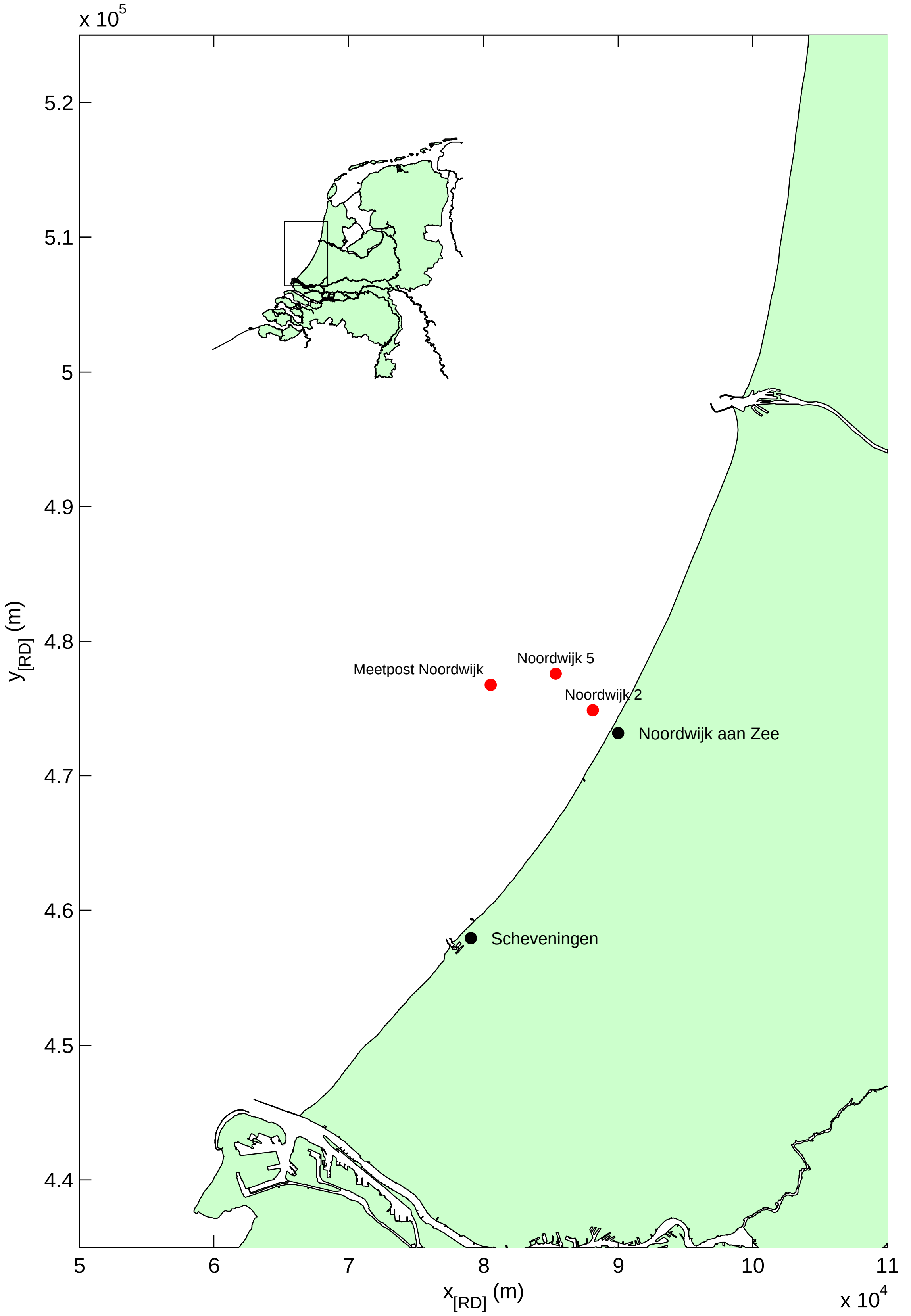
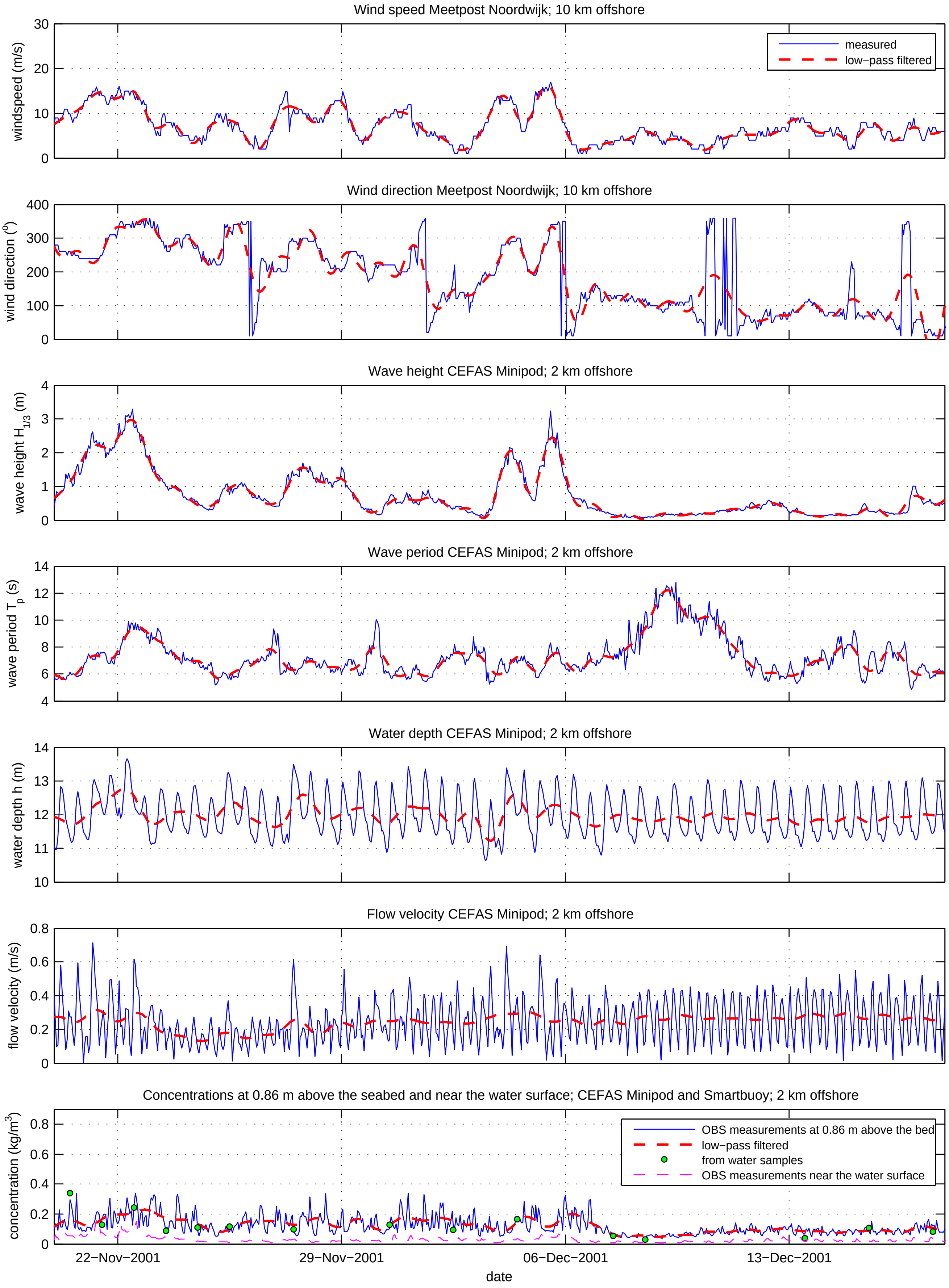


CEFAS measurement locations and location of Meetpost Noordwijk		
	CEFAS	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 2.1

A2518_CEFAS_plot_data02



Conditions during the Noordwijk 2−1 measurements
CEFAS Minipod and Smartbuoy deployment 180
The measurement period is 669 hours (nearly 28 days).

CEFAS Minipod and Smartbuoy

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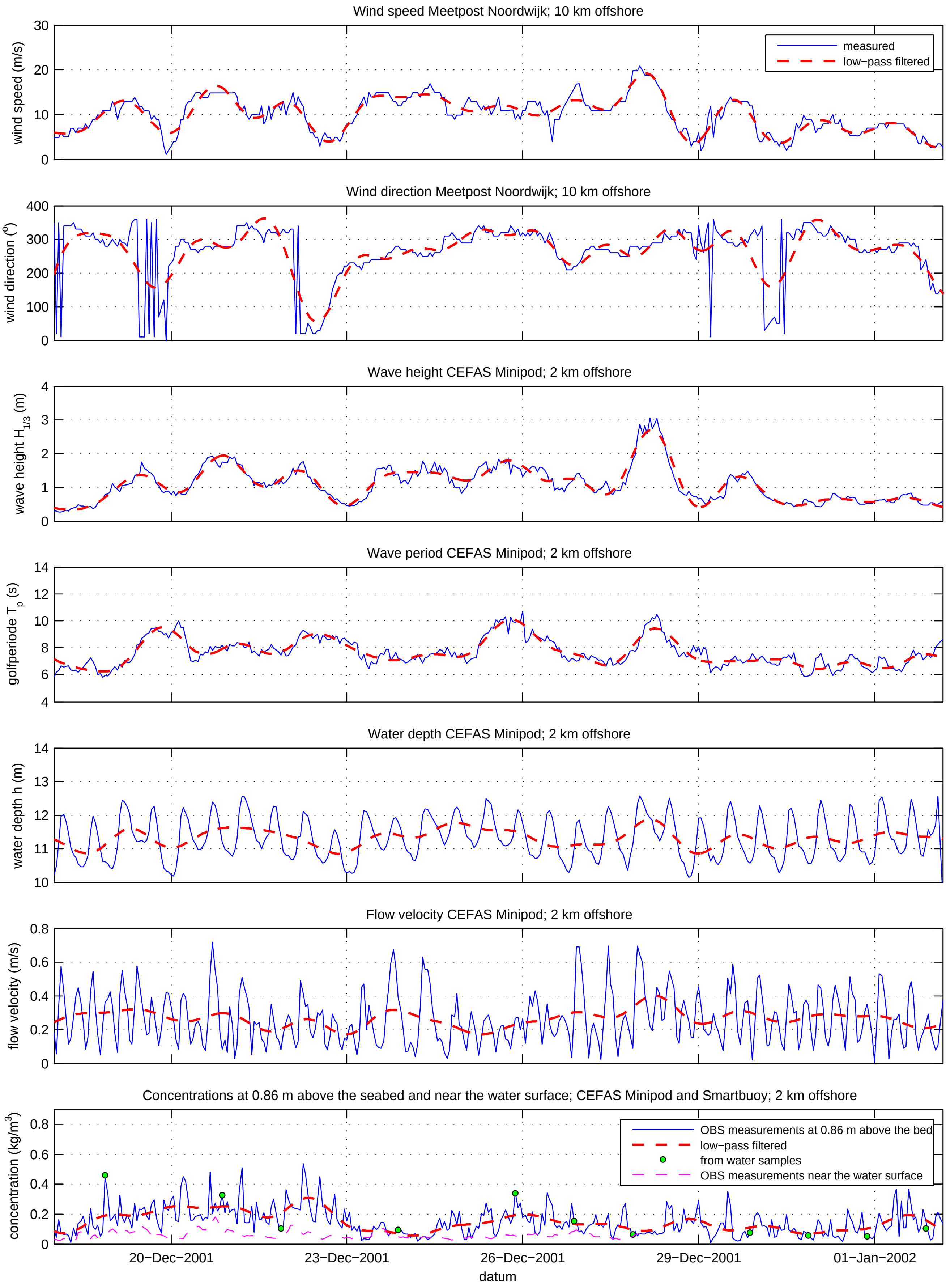
Fig. 2.2



Conditions during the Noordwijk 2−2 measurements
CEFAS Minipod and Smartbuoy deployment 181
The measurement period is 364 hours (just over 15 days).

CEFAS Minipod and Smartbuoy

Alkyon Hydraulic Consultancy & Research

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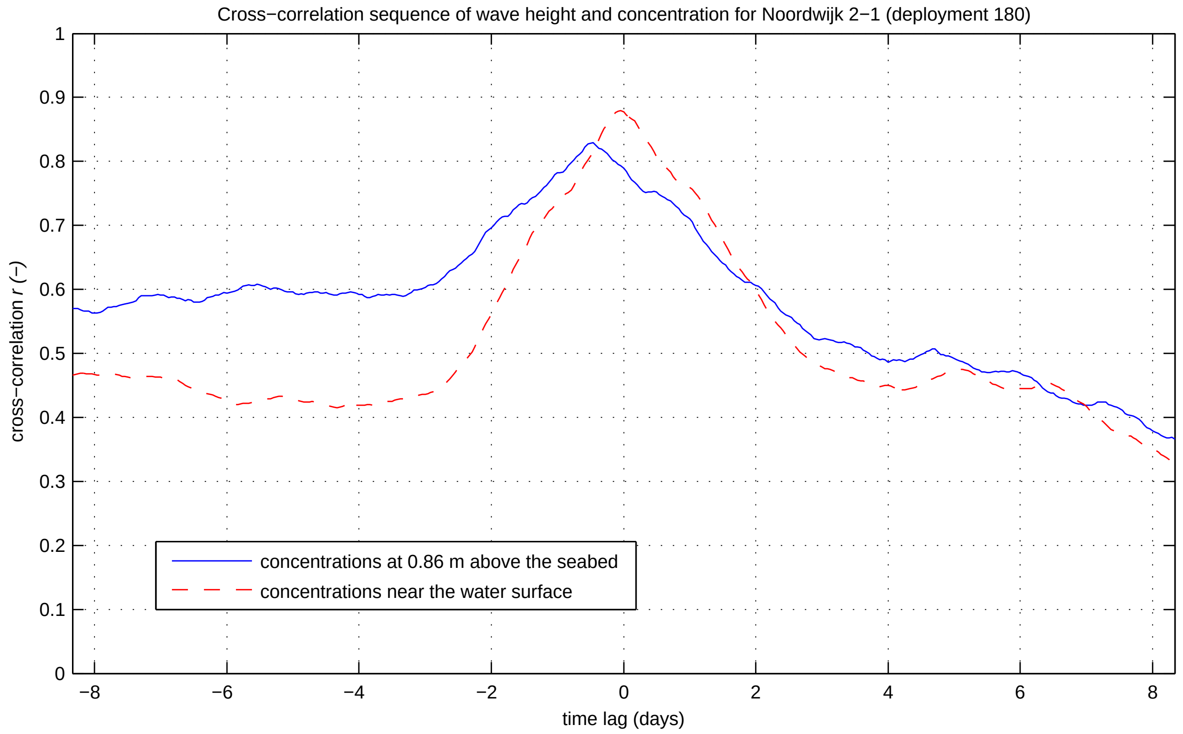
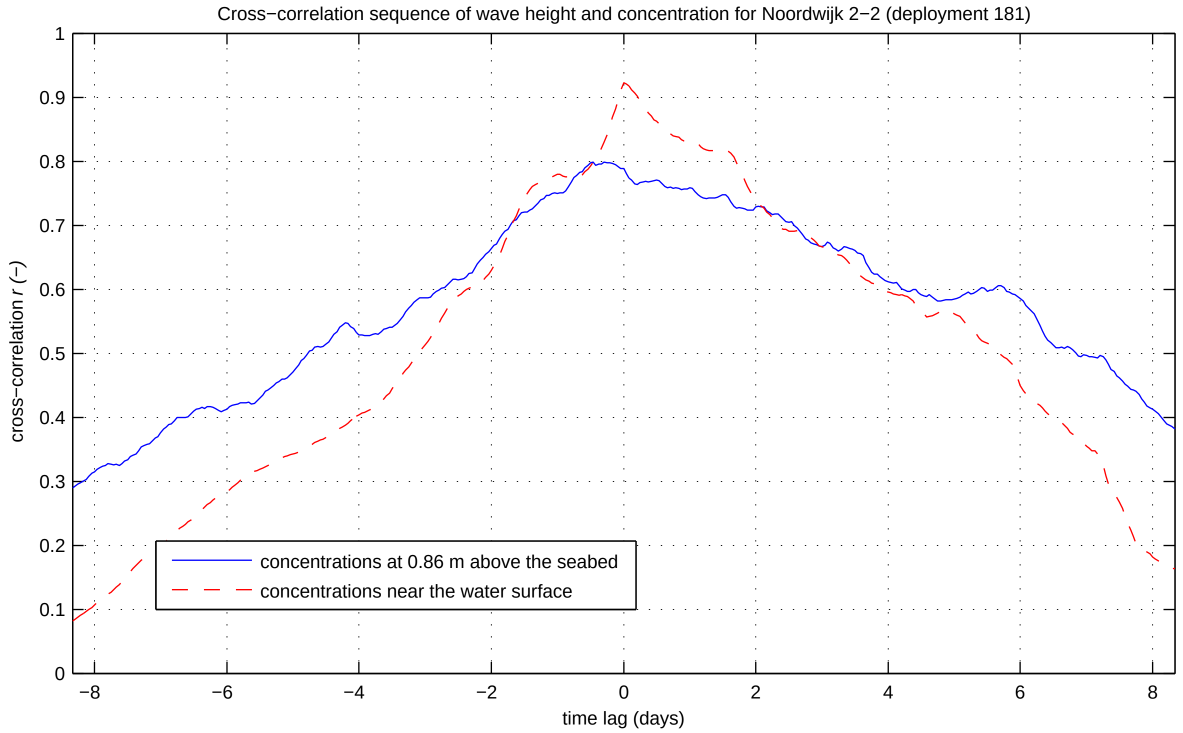
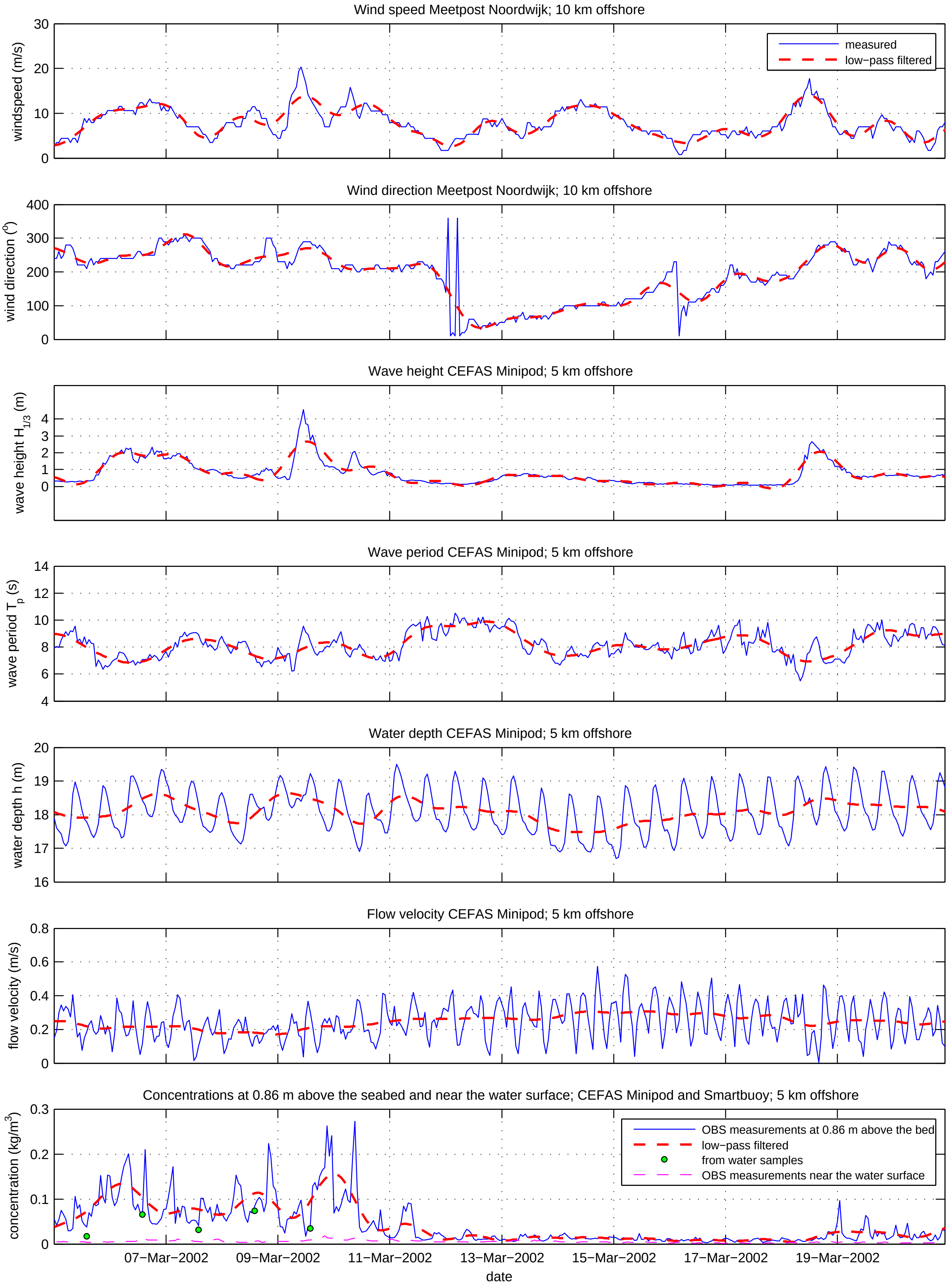
Fig. 2.3





Cross−correlation sequence of wave height and concentration CEFAS Minipod and Smartbuoy deployment 180 and 181 Noordwijk 2 km offshore	CEFAS Minipod and Smartbuoy	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 2.4

A2518_CEFAS_plot_dataNW5_02



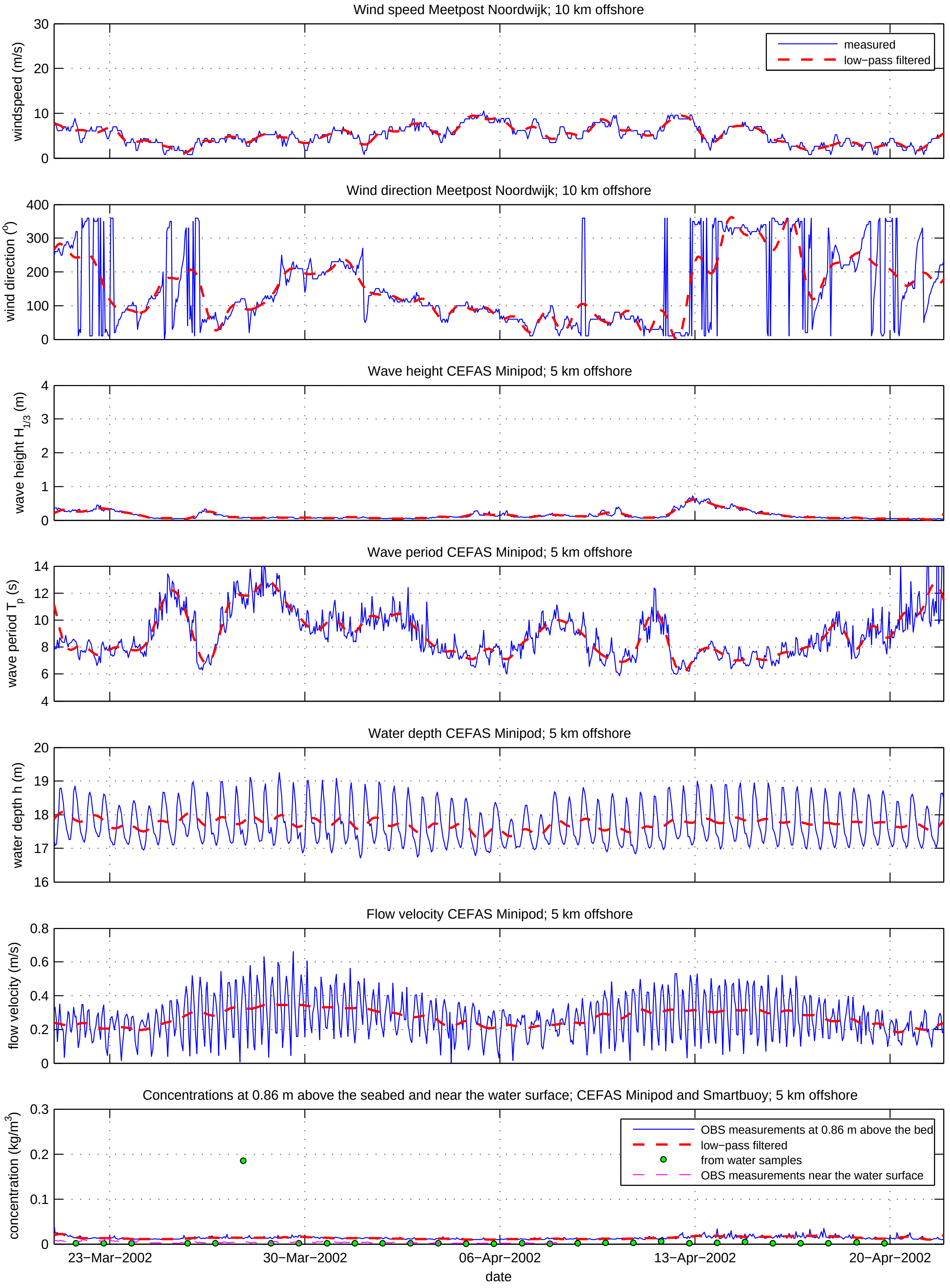
Conditions during the Noordwijk 5−1 measurements
CEFAS Minipod and Smartbuoy deployment 182
The measurement period is 382 hours (nearly 16 days).

CEFAS Minipod and Smartbuoy

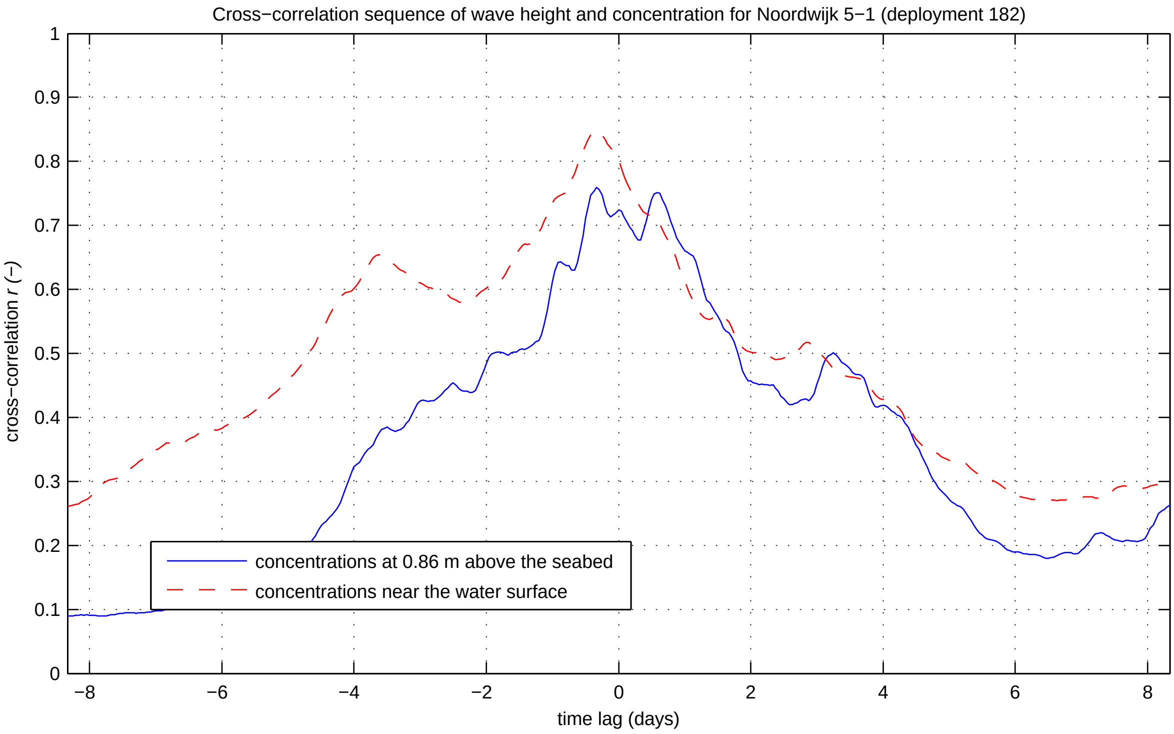
Alkyon Hydraulic Consultancy & Research

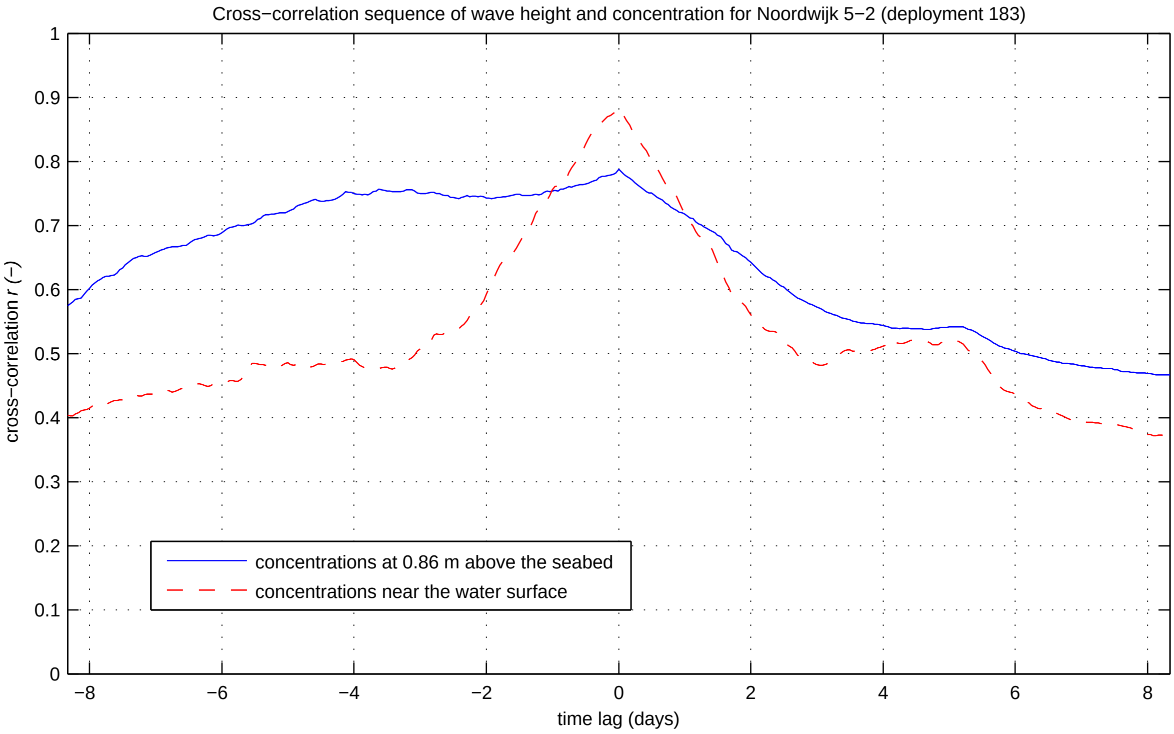
A2518

Fig. 2.5



Conditions during the Noordwijk 5−2 measurements CEFAS Minipod and Smartbuoy deployment 183 The measurement period is 766 hours (nearly 32 days).	CEFAS Minipod and Smartbuoy	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 2.6





Cross−correlation sequence of wave height and concentration
CEFAS Minipod and Smartbuoy deployment 182 and 183
Noordwijk 5 km offshore

CEFAS Minipod and Smartbuoy

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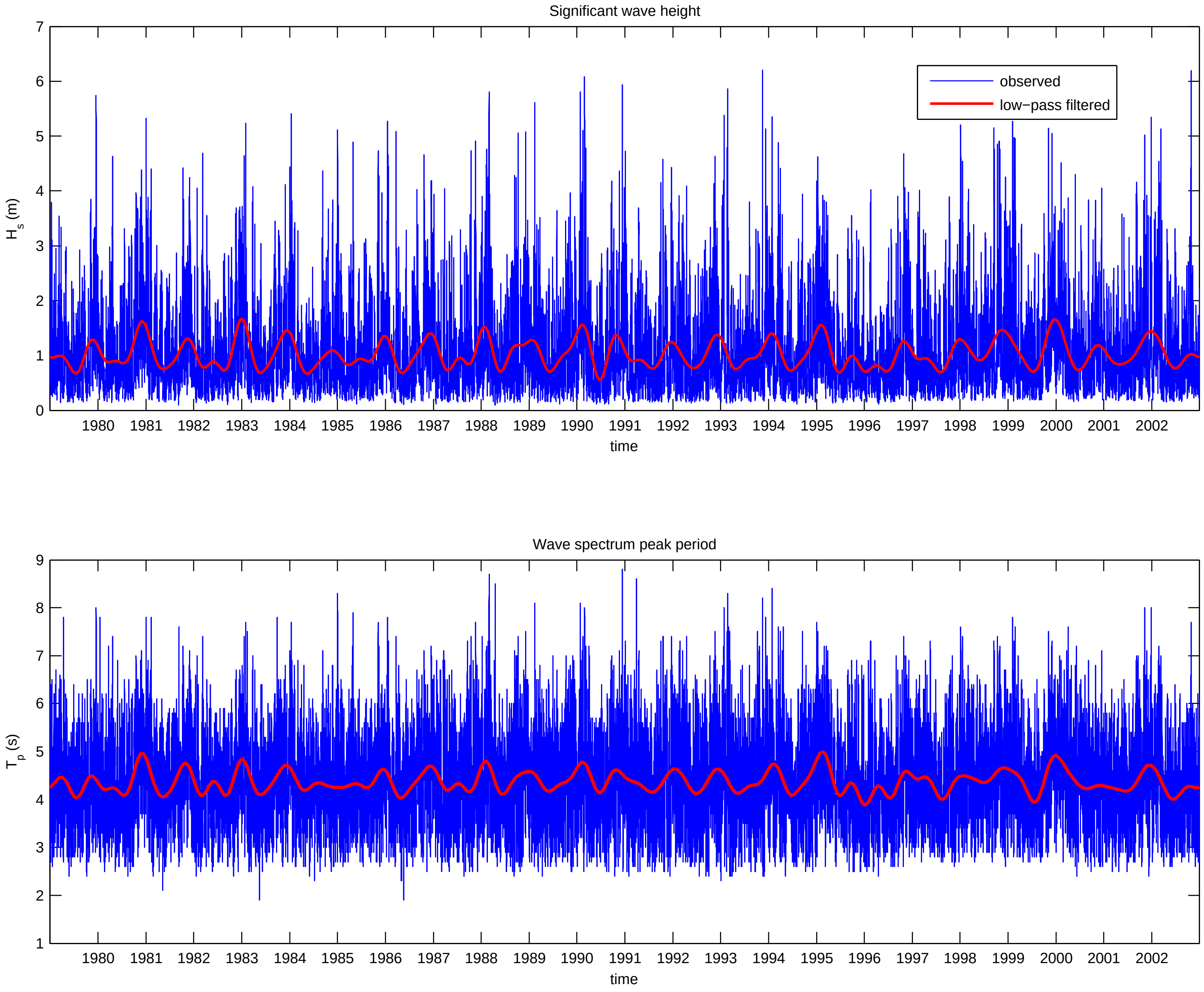
Fig. 2.7

A2518_plot_waveconditions_MPN



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Observed significant wave heights and wave spectrum peak periods
and low−pass filtered values (using a cut−off period of 0.5 year)
at Meetpost Noordwijk

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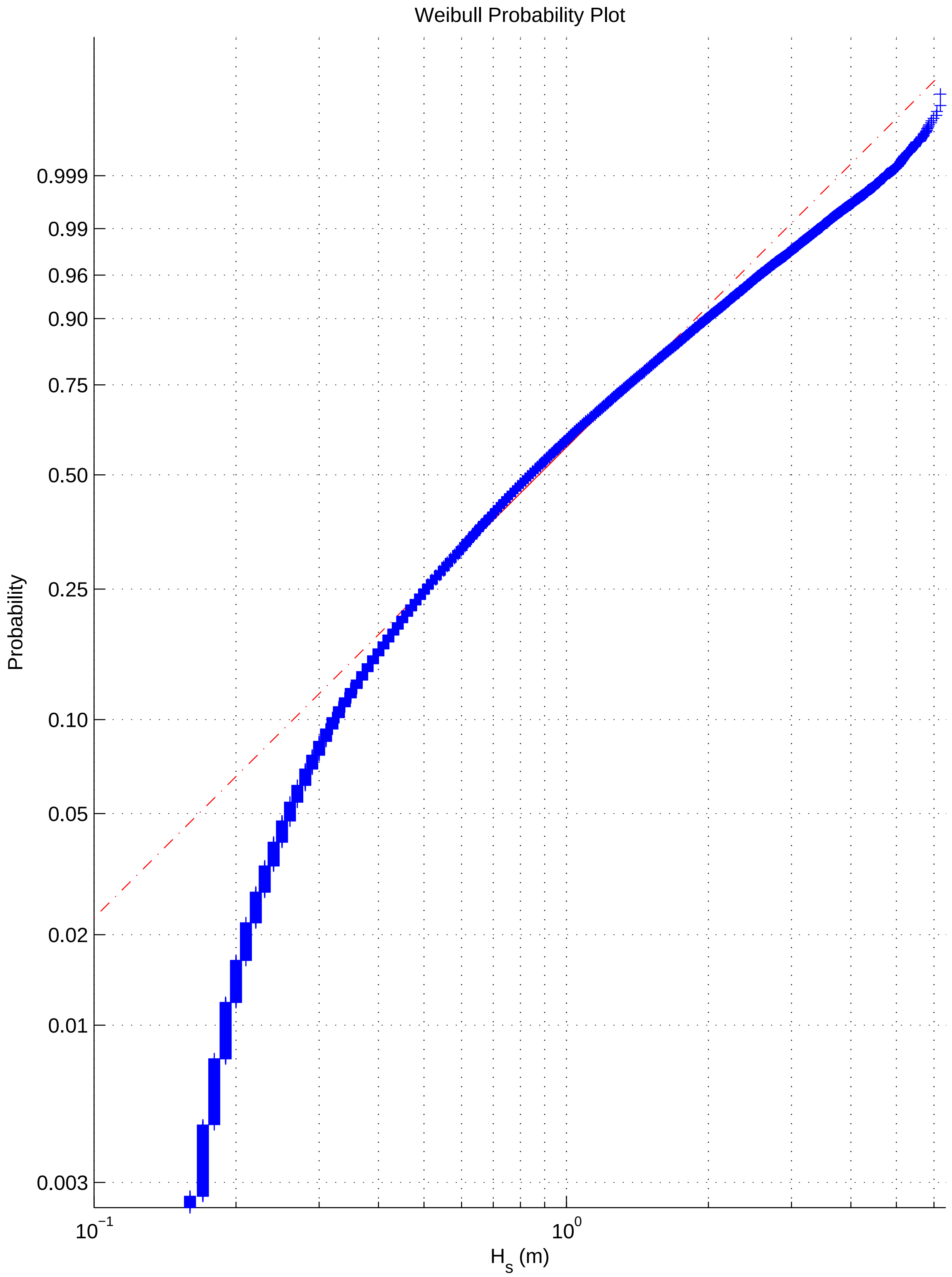
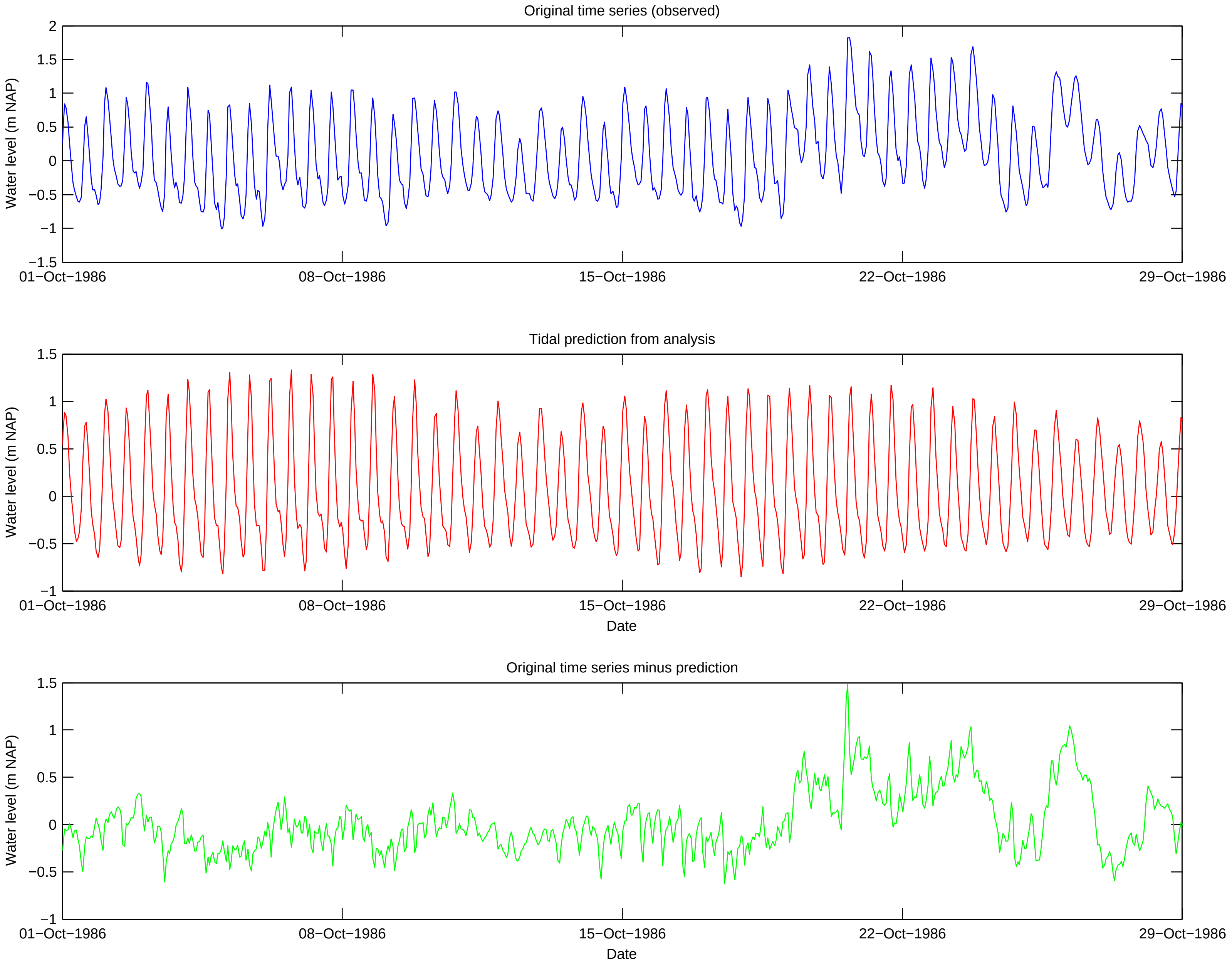
Waves

Fig. 2.8



Weibull probability plot for significant wave heights at Meetpost Noordwijk

	Waves	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 2.9



Example of observed water levels, tidal prediction
and observation minus tidal prediction
at Meetpost Noordwijk

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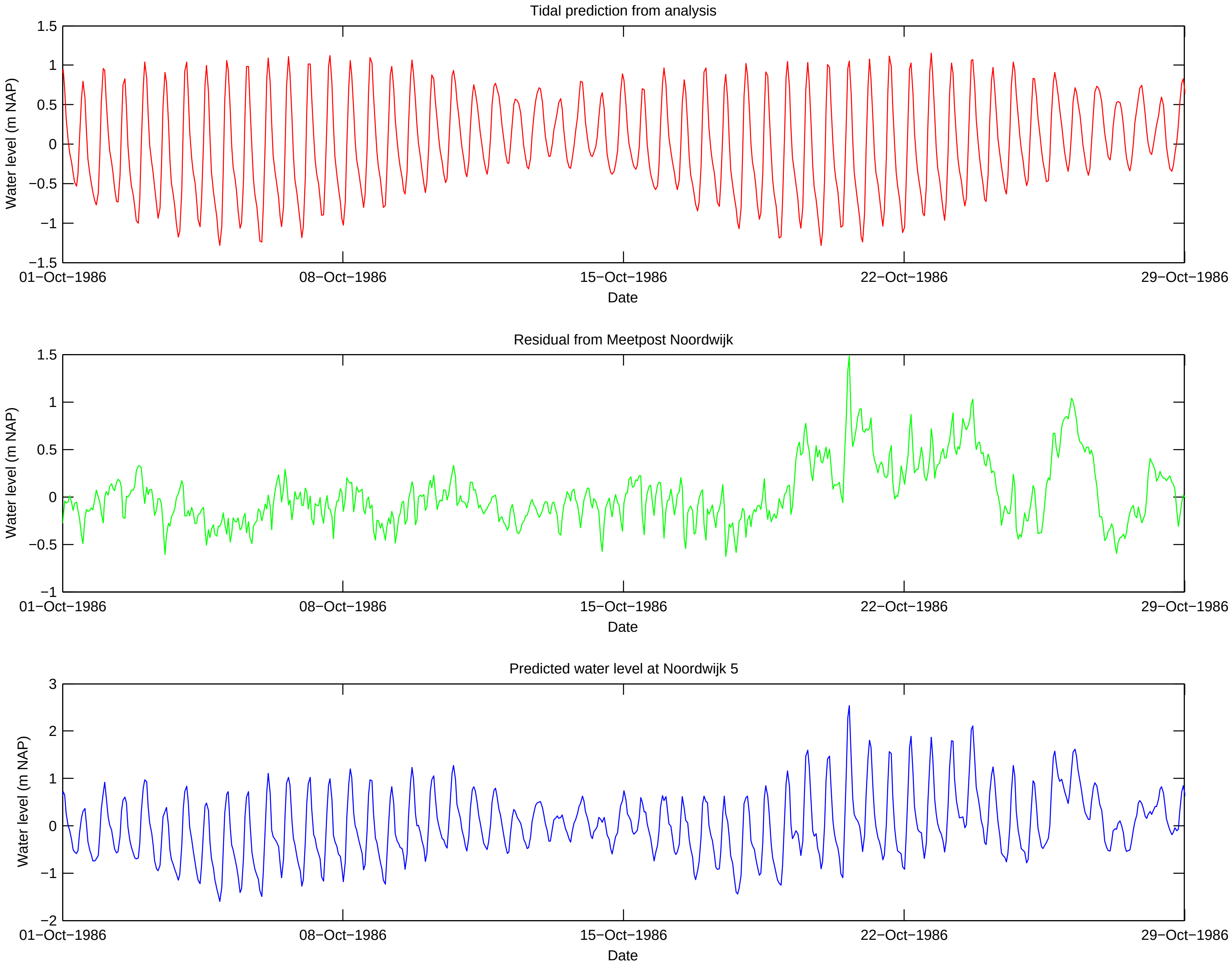
Tide

Fig. 2.10

A2518_t_predic_NW5_v02



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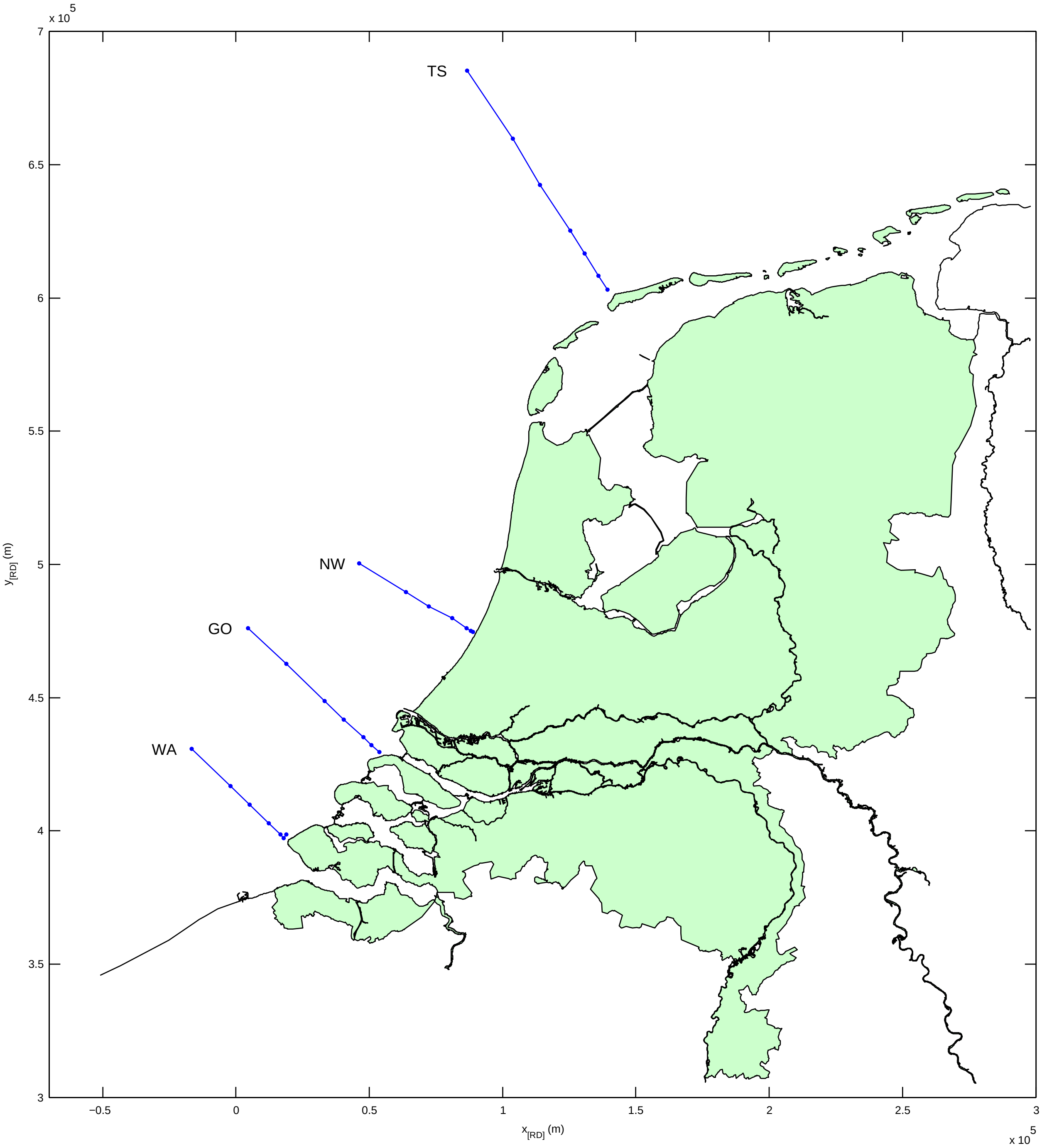
Example of tidal prediction, residual from Meetpost Noordwijk
and tidal prediction plus residual
at Noordwijk 5

A2518

Tide

Fig. 2.11



North Sea transects in which suspended matter concentration data is available from Waterbase for the period 1975−2009

Waterbase 1975−2009

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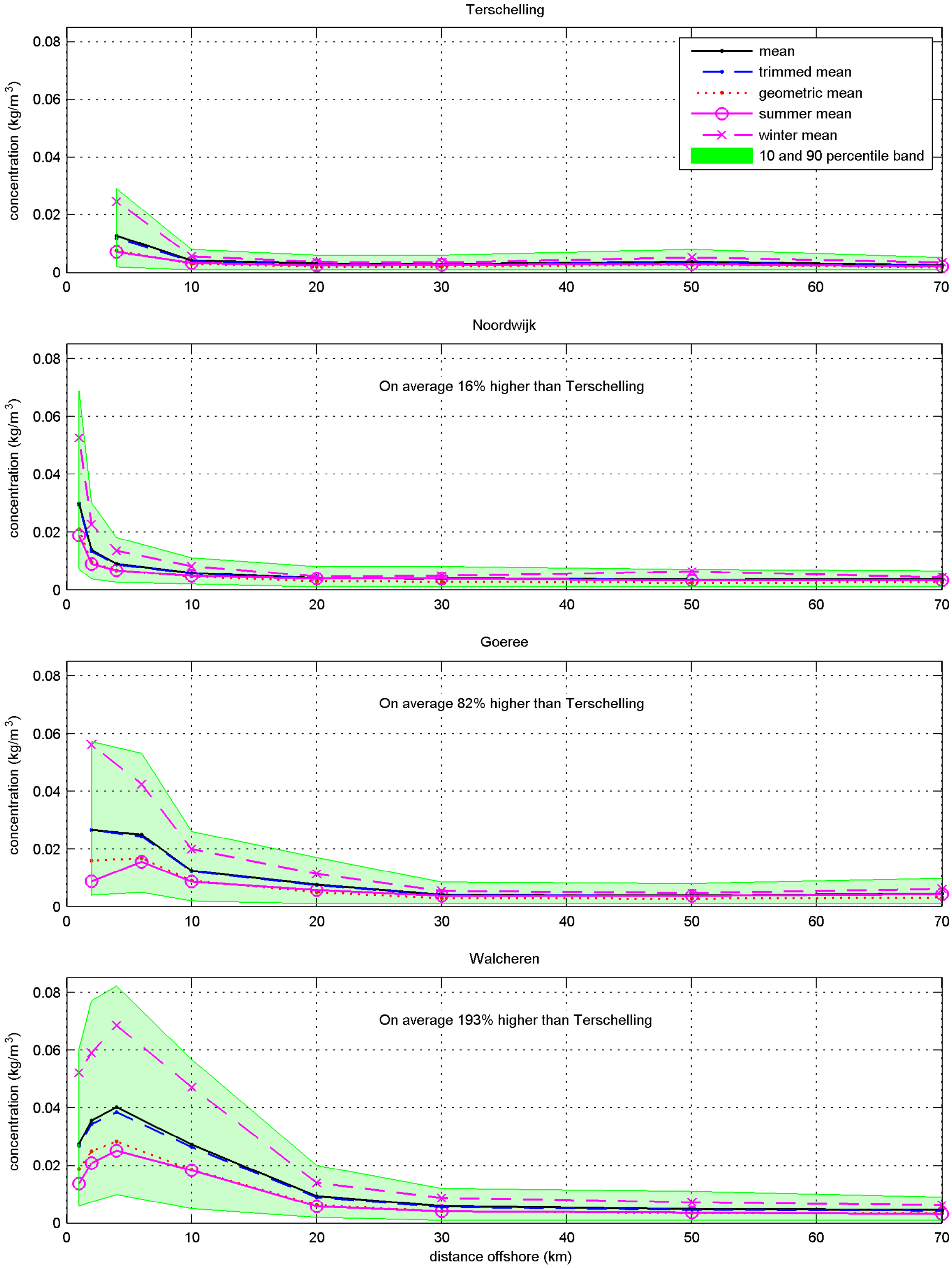
Fig. 2.12



Cross-shore distribution of total suspended matter concentration (kg/m^3)
Statistical parameters based on 1975-2008 Waterbase data
Terschelling, Noordwijk, Goeree and Walcheren transects

Waterbase 1975-2008

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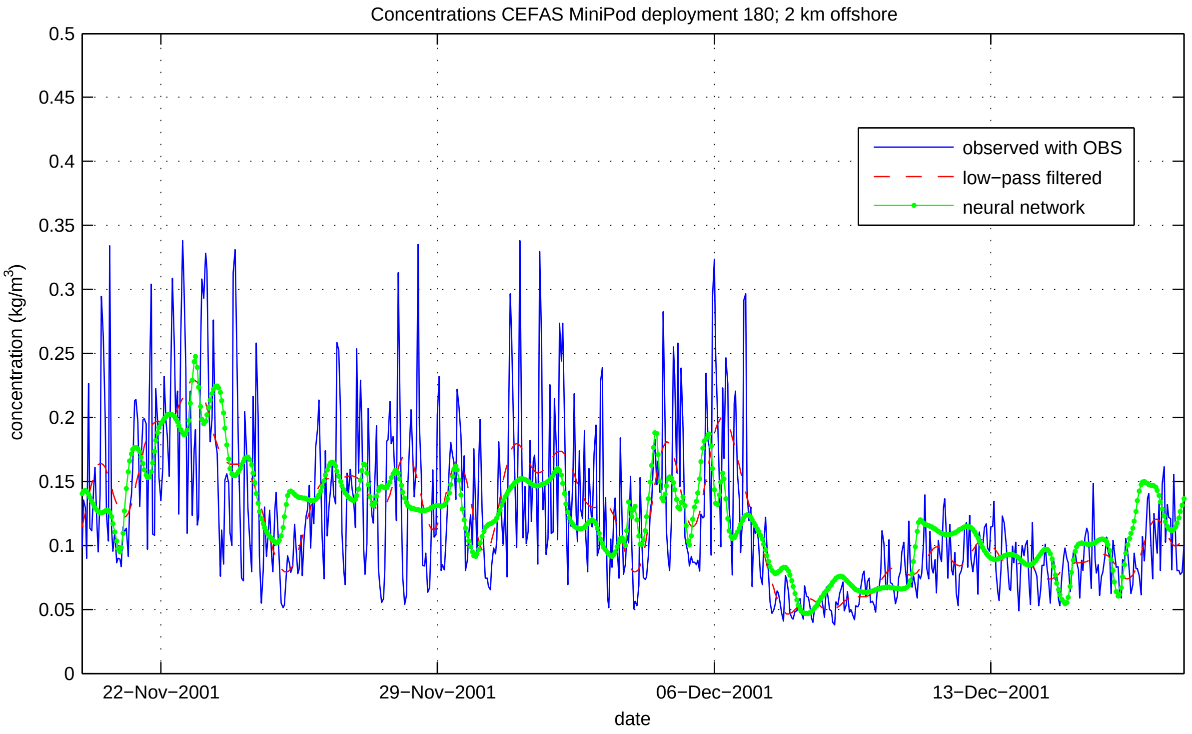
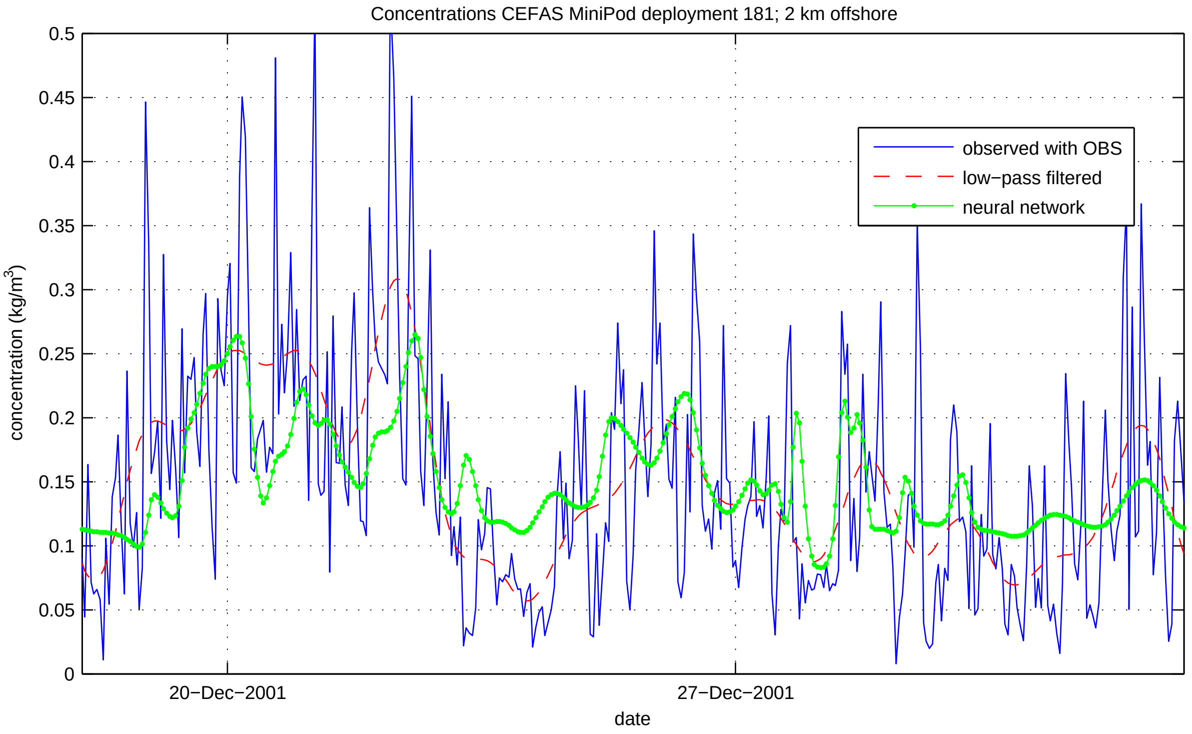
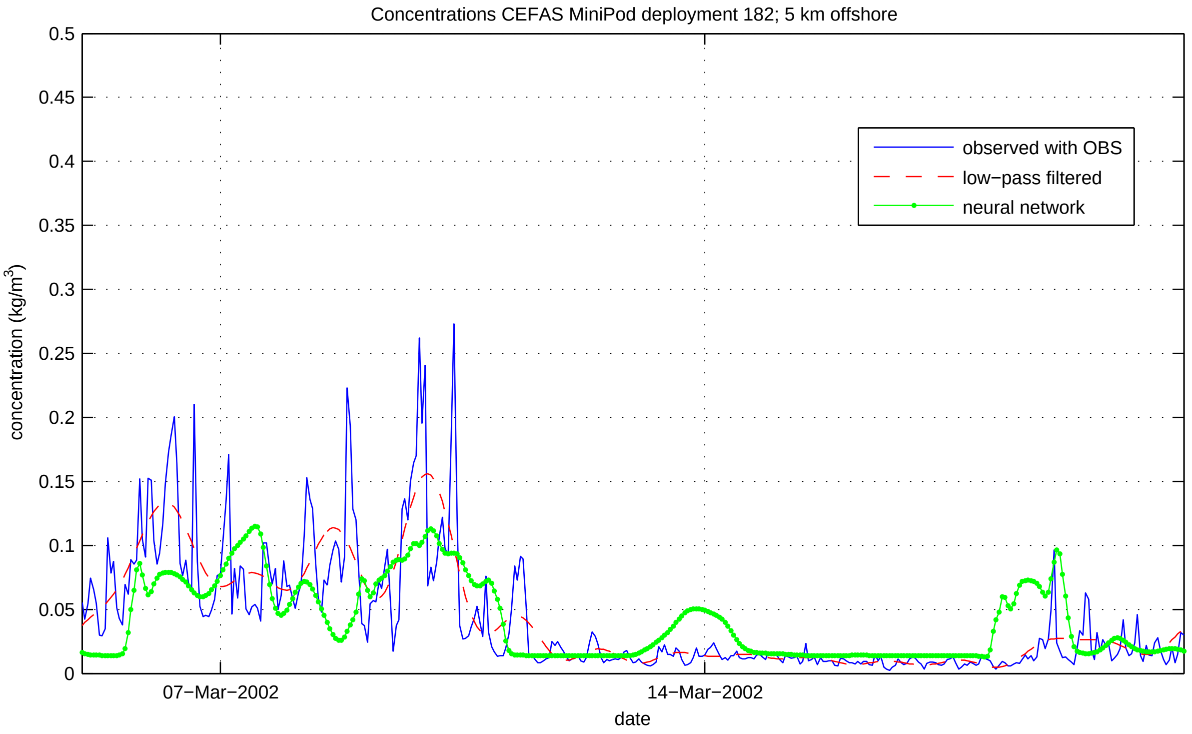
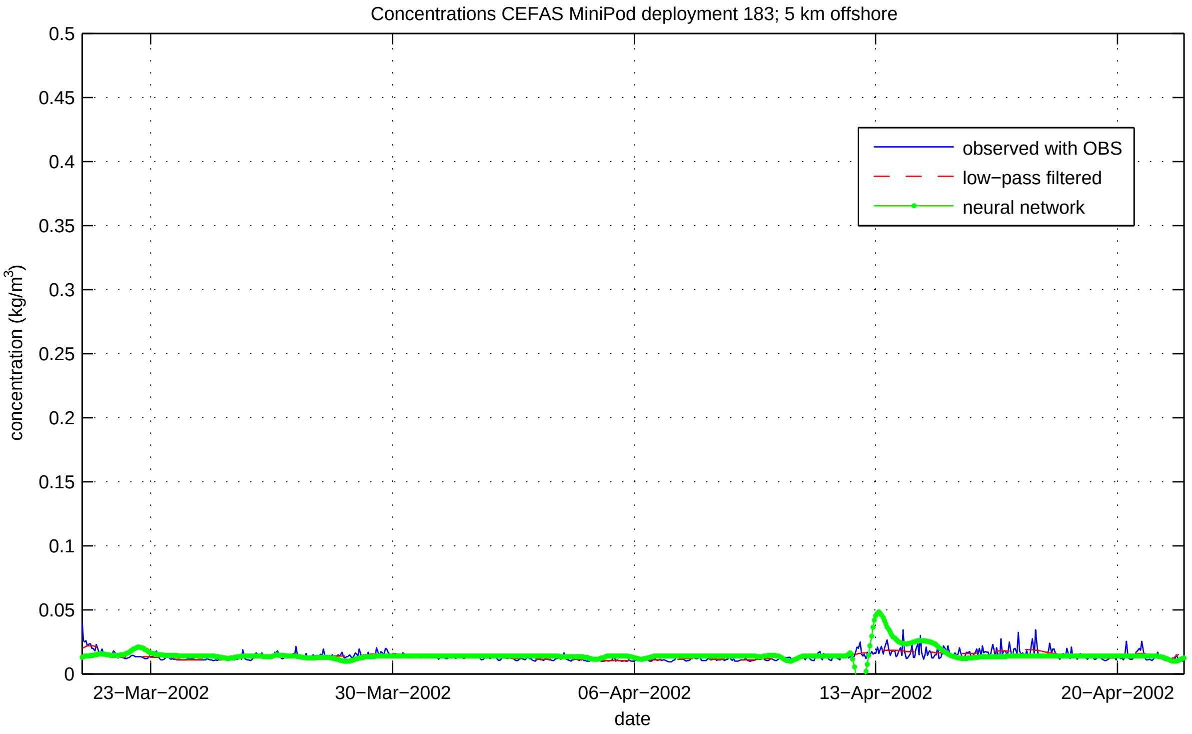
Fig. 2.13





Measured, low−pass filtered and neural network predicted concentrations using wave height, wave period and water depth as input CEFAS Minipod deployment 180 and 181	CEFAS Minipod and Neural Network	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 3.1





Measured, low−pass filtered and neural network predicted concentrations
using wave height, wave period and water depth as input
CEFAS Minipod deployment 182 and 183

CEFAS Minipod and Neural Network

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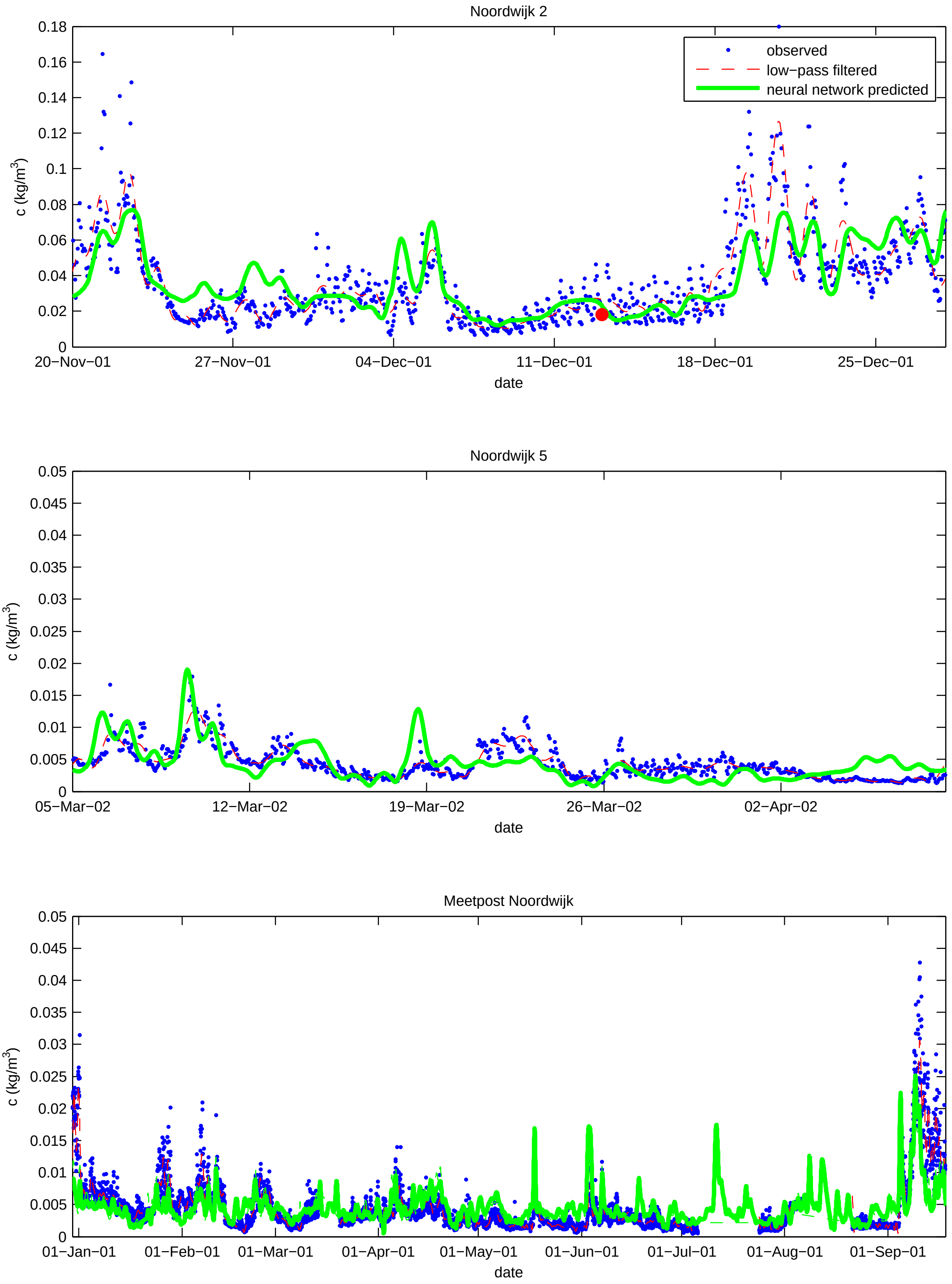
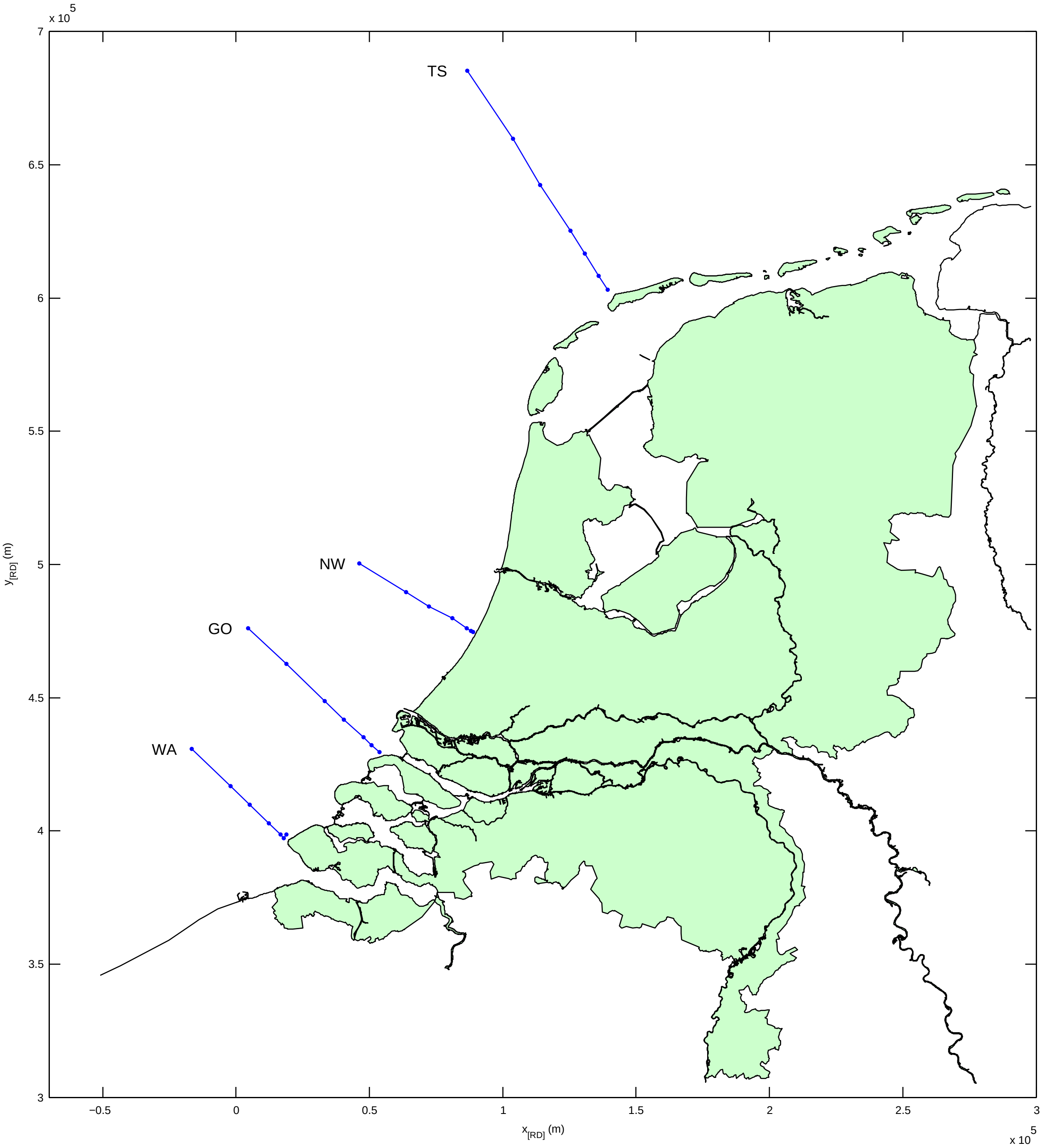
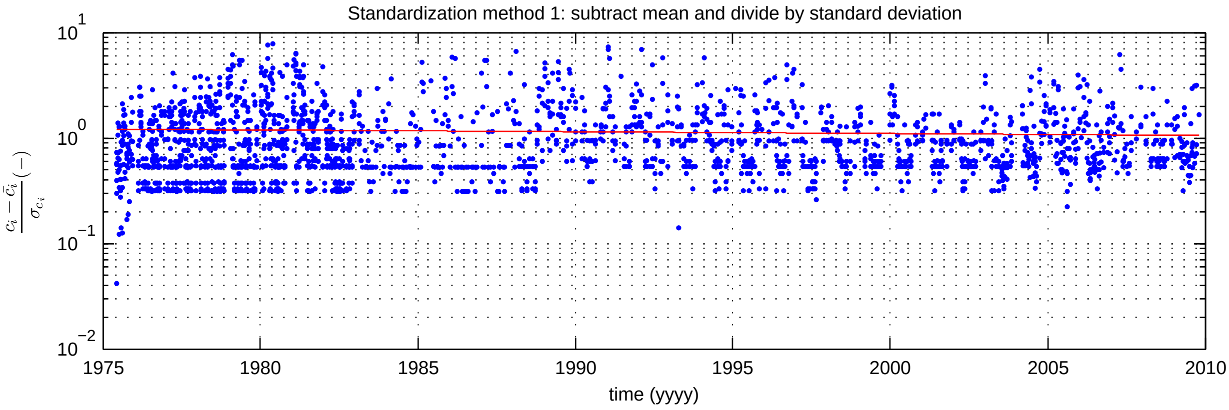
Fig. 3.2

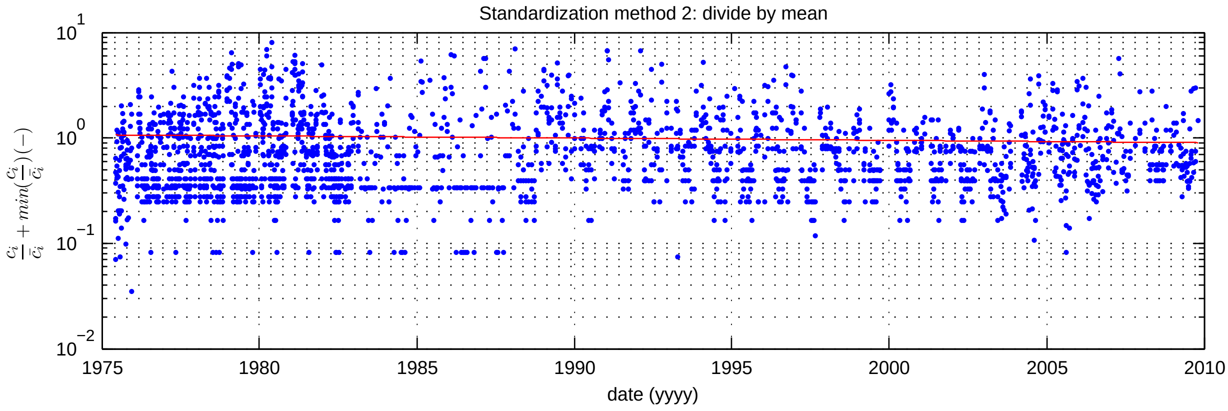


Low−pass filtered near−surface concentrations and neural network predictions using wave height and wave period as an input CEFAS Smartbuoy deployments	Neural Network	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 3.3



North Sea transects in which suspended matter concentration data is available from Waterbase for the period 1975−2009		
	Waterbase 1975−2009	
Alkyon Hydraulic Consultancy & Research	A2518	Fig. 4.1





Standardization method 1: $p = -4.44e-003$/year, $p_{low} = -8.39e-003$/year, $p_{high} = -5.01e-004$/year

name	mean (x10^{-3} kg/m^3)	std (x10^{-3} kg/m^3)	trend (x10^{-3} kg/m^3/year)	trend (95% low)	trend (95% up)
TS4	12.77	16.14	−0.072	−0.135	−0.008
TS10	4.20	4.50	−0.020	−0.038	−0.002
TS20	3.19	4.81	−0.021	−0.040	−0.002
TS30	2.97	2.79	−0.012	−0.023	−0.001
TS50	3.71	3.45	−0.015	−0.029	−0.002
TS70	2.57	2.79	−0.012	−0.023	−0.001
TS100	2.53	2.51	−0.011	−0.021	−0.001

Standardization method 2: $p = -4.81e-003$/year, $p_{low} = -8.68e-003$/year, $p_{high} = -9.48e-004$/year

name	mean (x10^{-3} kg/m^3)	std (x10^{-3} kg/m^3)	trend (x10^{-3} kg/m^3/year)	trend (95% low)	trend (95% up)
TS4	12.77	16.14	−0.061	−0.111	−0.012
TS10	4.20	4.50	−0.020	−0.036	−0.004
TS20	3.19	4.81	−0.015	−0.028	−0.003
TS30	2.97	2.79	−0.014	−0.026	−0.003
TS50	3.71	3.45	−0.018	−0.032	−0.004
TS70	2.57	2.79	−0.012	−0.022	−0.002
TS100	2.53	2.51	−0.012	−0.022	−0.002

Standardized SPM concentrations as a function of time and trends
based on standardized data (2144 samples)
Terschelling transect 1975−2009

Waterbase

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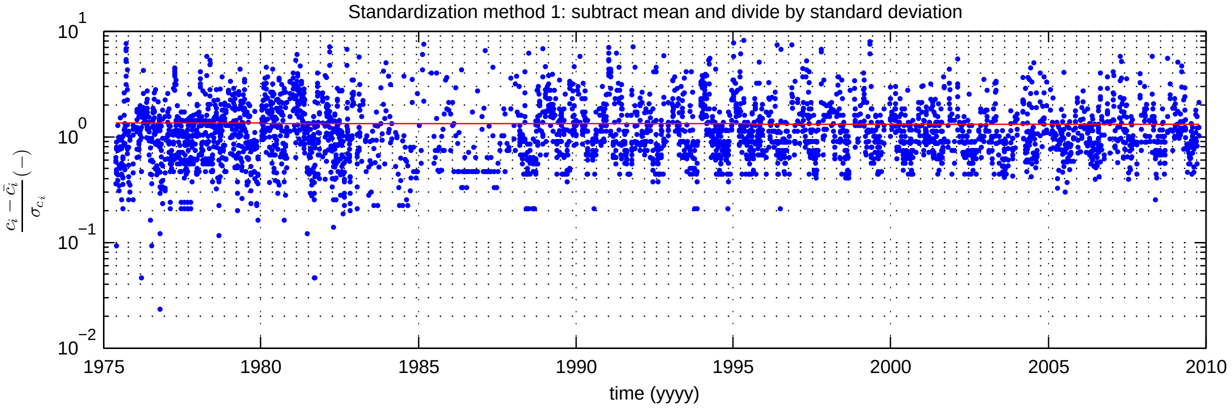
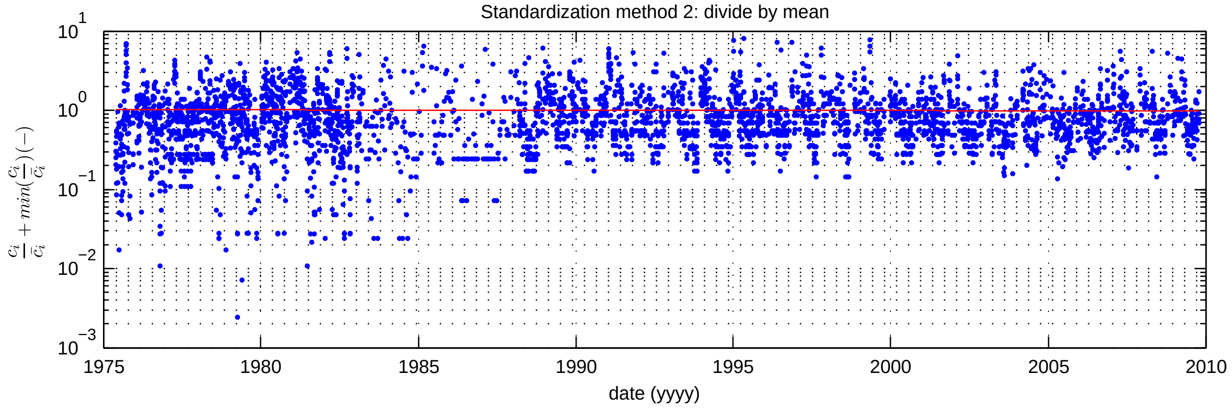
Fig. 4.2





Standardization method 1: $p = -1.19e-003$/year, $p_{low} = -4.37e-003$/year, $p_{high} = 1.98e-003$/year

name	mean ($\times 10^{-3}$ kg/m^3)	std ($\times 10^{-3}$ kg/m^3)	trend ($\times 10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
NW2	13.76	12.48	−0.015	−0.055	0.025
NW4	8.94	6.88	−0.008	−0.030	0.014
NW10	5.70	3.95	−0.005	−0.017	0.008
NW20	4.02	3.24	−0.004	−0.014	0.006
NW30	3.96	3.56	−0.004	−0.016	0.007
NW50	3.49	2.93	−0.004	−0.013	0.006
NW70	3.56	3.52	−0.004	−0.015	0.007

Standardization method 2: $p = -9.30e-004$/year, $p_{low} = -3.76e-003$/year, $p_{high} = 1.90e-003$/year

name	mean ($\times 10^{-3}$ kg/m^3)	std ($\times 10^{-3}$ kg/m^3)	trend ($\times 10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
NW2	13.76	12.48	−0.013	−0.052	0.026
NW4	8.94	6.88	−0.008	−0.034	0.017
NW10	5.70	3.95	−0.005	−0.021	0.011
NW20	4.02	3.24	−0.004	−0.015	0.008
NW30	3.96	3.56	−0.004	−0.015	0.008
NW50	3.49	2.93	−0.003	−0.013	0.007
NW70	3.56	3.52	−0.003	−0.013	0.007

Standardized SPM concentrations as a function of time and trends
based on standardized data (3563 samples)
Noordwijk transect 1975−2009

Waterbase

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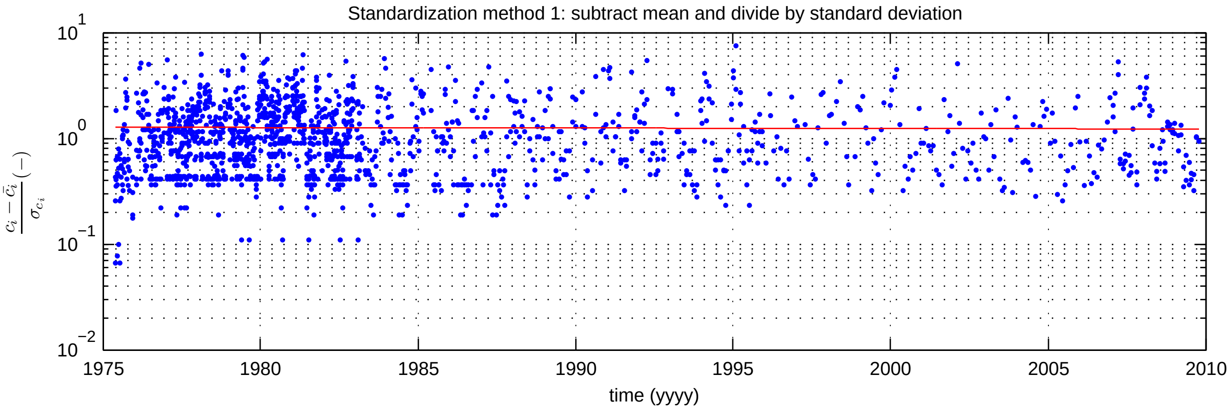
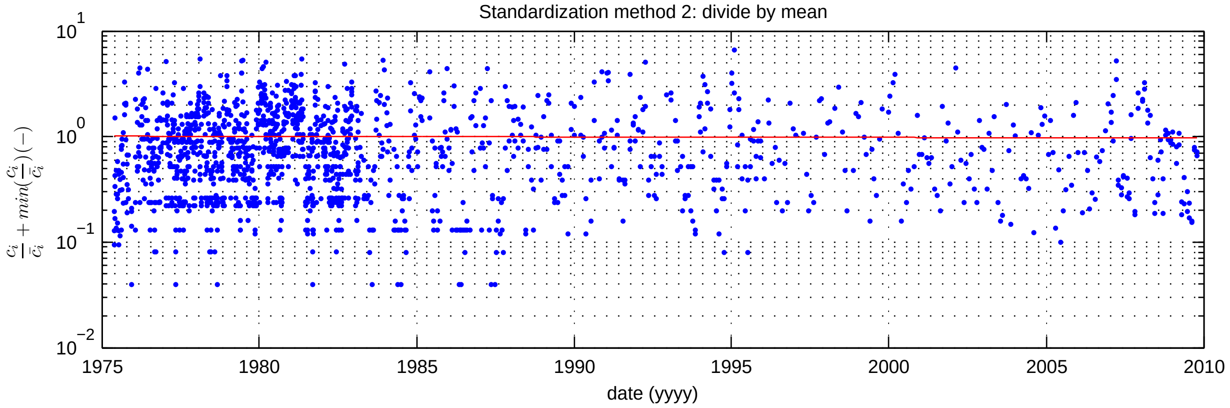
Fig. 4.3





Standardization method 1: $p = -1.33e{-}003$/year, $p_{low} = -7.09e{-}003$/year, $p_{high} = 4.43e{-}003$/year

name	mean (x10^{-3} kg/m^3)	std (x10^{-3} kg/m^3)	trend (x10^{-3} kg/m^3/year)	trend (95% low)	trend (95% up)
GO2	21.31	22.30	−0.030	−0.158	0.099
GO6	24.68	21.09	−0.028	−0.150	0.093
GO10	12.44	9.07	−0.012	−0.064	0.040
GO20	7.64	7.30	−0.010	−0.052	0.032
GO30	4.12	3.54	−0.005	−0.025	0.016
GO50	3.85	3.35	−0.004	−0.024	0.015
GO70	4.53	4.26	−0.006	−0.030	0.019

Standardization method 2: $p = -1.14e{-}003$/year, $p_{low} = -6.34e{-}003$/year, $p_{high} = 4.06e{-}003$/year

name	mean (x10^{-3} kg/m^3)	std (x10^{-3} kg/m^3)	trend (x10^{-3} kg/m^3/year)	trend (95% low)	trend (95% up)
GO2	21.31	22.30	−0.024	−0.135	0.086
GO6	24.68	21.09	−0.028	−0.157	0.100
GO10	12.44	9.07	−0.014	−0.079	0.050
GO20	7.64	7.30	−0.009	−0.048	0.031
GO30	4.12	3.54	−0.005	−0.026	0.017
GO50	3.85	3.35	−0.004	−0.024	0.016
GO70	4.53	4.26	−0.005	−0.029	0.018

Standardized SPM concentrations as a function of time and trends
based on standardized data (1503 samples)
Goeree transect 1975−2009

Waterbase

Alkyon Hydraulic Consultancy & Research

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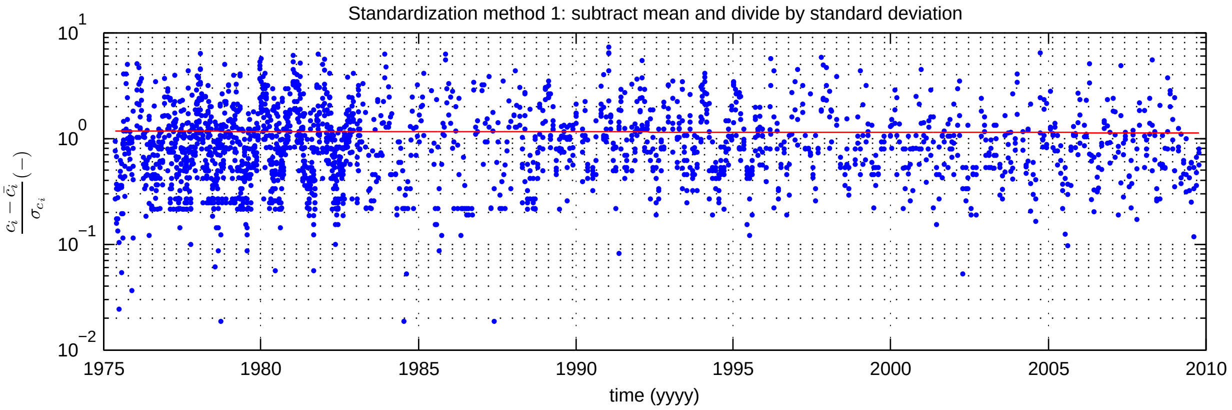
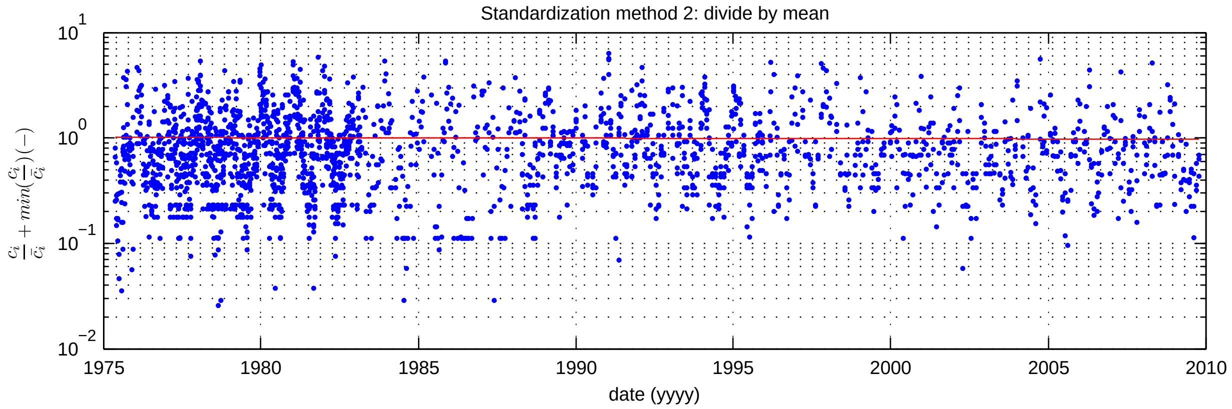
Fig. 4.4





Standardization method 1: p = −1.18e−003/year, p_{low} = −5.42e−003/year, p_{high} = 3.06e−003/year

name	mean ($x10^{-3}$ kg/m^3)	std ($x10^{-3}$ kg/m^3)	trend ($x10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
WA2	35.33	31.46	−0.037	−0.170	0.096
WA4	40.05	36.18	−0.043	−0.196	0.111
WA10	27.21	24.78	−0.029	−0.134	0.076
WA20	9.26	9.34	−0.011	−0.051	0.029
WA30	5.84	5.79	−0.007	−0.031	0.018
WA50	4.86	4.67	−0.006	−0.025	0.014
WA70	4.51	4.37	−0.005	−0.024	0.013

Standardization method 2: p = −1.11e−003/year, p_{low} = −4.85e−003/year, p_{high} = 2.63e−003/year

name	mean ($x10^{-3}$ kg/m^3)	std ($x10^{-3}$ kg/m^3)	trend ($x10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
WA2	35.33	31.46	−0.039	−0.171	0.093
WA4	40.05	36.18	−0.045	−0.194	0.105
WA10	27.21	24.78	−0.030	−0.132	0.072
WA20	9.26	9.34	−0.010	−0.045	0.024
WA30	5.84	5.79	−0.006	−0.028	0.015
WA50	4.86	4.67	−0.005	−0.024	0.013
WA70	4.51	4.37	−0.005	−0.022	0.012

Standardized SPM concentrations as a function of time and trends
based on standardized data (2227 samples)
Walcheren transect 1975−2009

Waterbase

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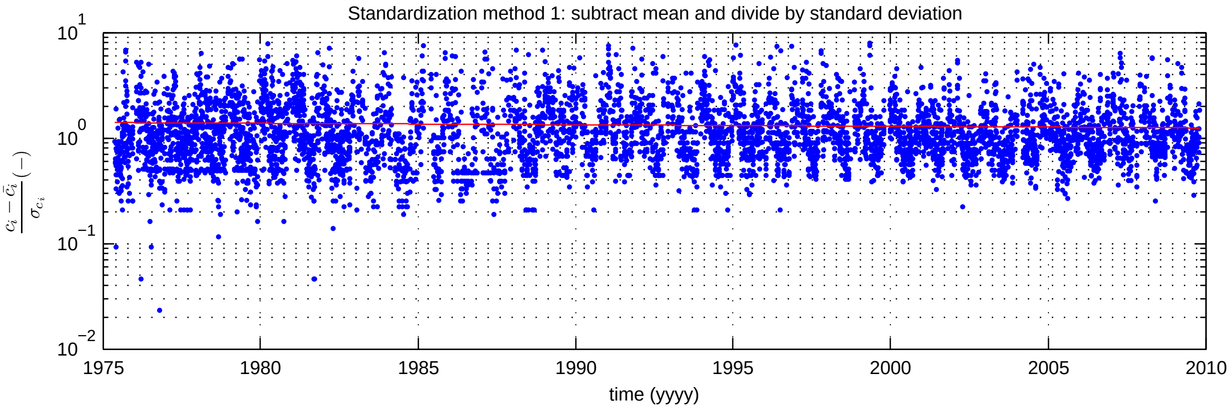
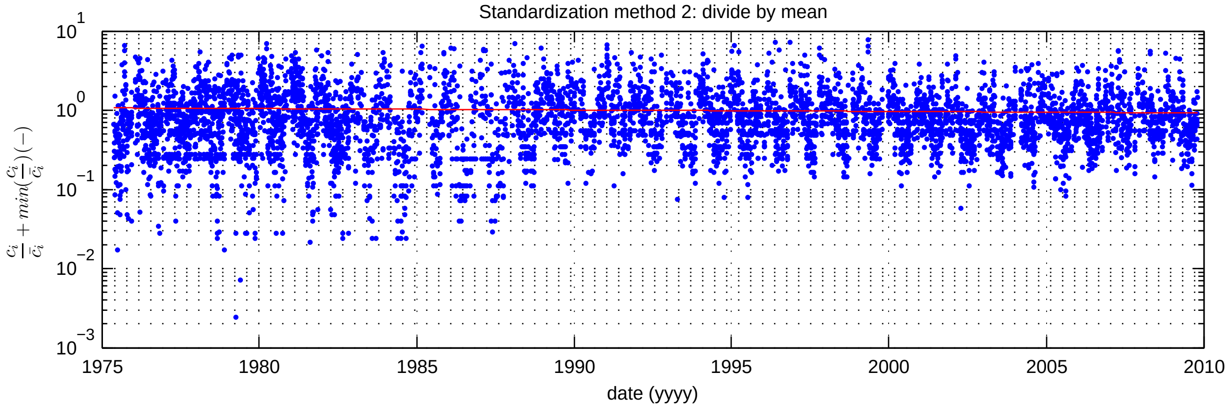
Fig. 4.5





Standardization method 1: p = −4.41e−003/year, p_{low} = −6.92e−003/year, p_{high} = −1.91e−003/year

name	mean ($x10^{-3}$ kg/m^3)	std ($x10^{-3}$ kg/m^3)	trend ($x10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
TS4	12.77	16.14	−0.071	−0.112	−0.031
TS10	4.20	4.50	−0.020	−0.031	−0.009
TS50	3.71	3.45	−0.015	−0.024	−0.007
NW2	13.76	12.48	−0.055	−0.086	−0.024
NW10	5.70	3.95	−0.017	−0.027	−0.008
NW20	4.02	3.24	−0.014	−0.022	−0.006
NW70	3.56	3.52	−0.016	−0.024	−0.007
GO6	24.68	21.09	−0.093	−0.146	−0.040
WA2	35.33	31.46	−0.139	−0.218	−0.060
WA20	9.26	9.34	−0.041	−0.065	−0.018

Standardization method 2: p = −4.18e−003/year, p_{low} = −6.46e−003/year, p_{high} = −1.91e−003/year

name	mean ($x10^{-3}$ kg/m^3)	std ($x10^{-3}$ kg/m^3)	trend ($x10^{-3}$ kg/m^3/year)	trend (95% low)	trend (95% up)
TS4	12.77	16.14	−0.053	−0.082	−0.024
TS10	4.20	4.50	−0.018	−0.027	−0.008
TS50	3.71	3.45	−0.016	−0.024	−0.007
NW2	13.76	12.48	−0.058	−0.089	−0.026
NW10	5.70	3.95	−0.024	−0.037	−0.011
NW20	4.02	3.24	−0.017	−0.026	−0.008
NW70	3.56	3.52	−0.015	−0.023	−0.007
GO6	24.68	21.09	−0.103	−0.159	−0.047
WA2	35.33	31.46	−0.148	−0.228	−0.068
WA20	9.26	9.34	−0.039	−0.060	−0.018

Standardized SPM concentrations as a function of time and trends
based on standardized data (5620 samples)
using TS4, TS10, TS50, NW2, NW10, NW20, NW70, GO6, WA2 and WA20

Waterbase 1975−2009

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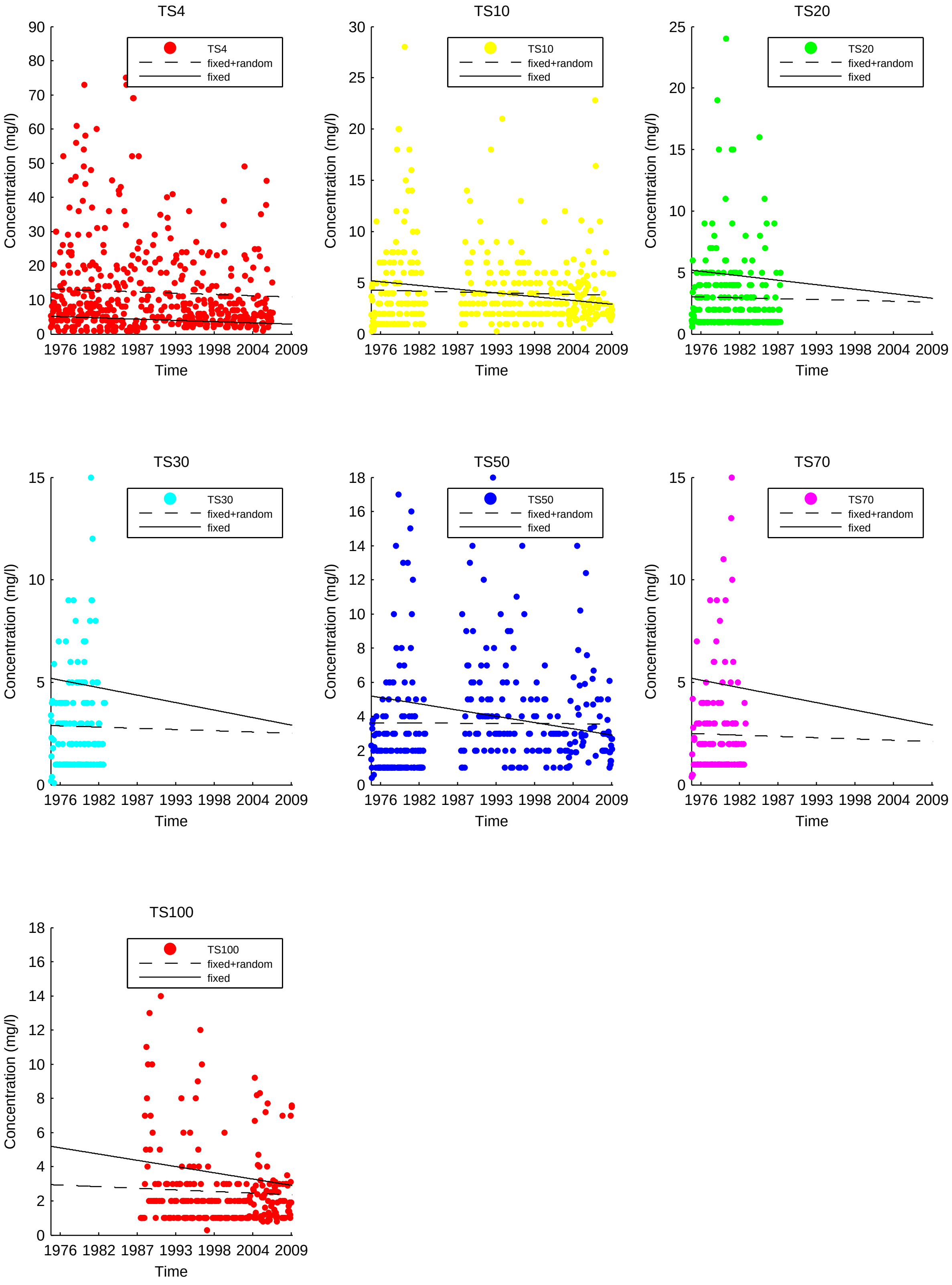
Fig. 4.6



name	fixed trend (mg/l/year)	fixed offset (mg/l)	fixed+random trend (mg/l/year)	fixed+random offset (mg/l)
TS4	−0.067	137.015	−0.069	149.819
TS10	−0.067	137.015	−0.015	33.620
TS20	−0.067	137.015	−0.013	28.603
TS30	−0.067	137.015	−0.011	24.559
TS50	−0.067	137.015	−0.002	7.332
TS70	−0.067	137.015	−0.011	24.744
TS100	−0.067	137.015	−0.017	36.918

SPM concentrations as a function of time and
trends from mixed effect model
Terschelling transect 1975−2009

Waterbase

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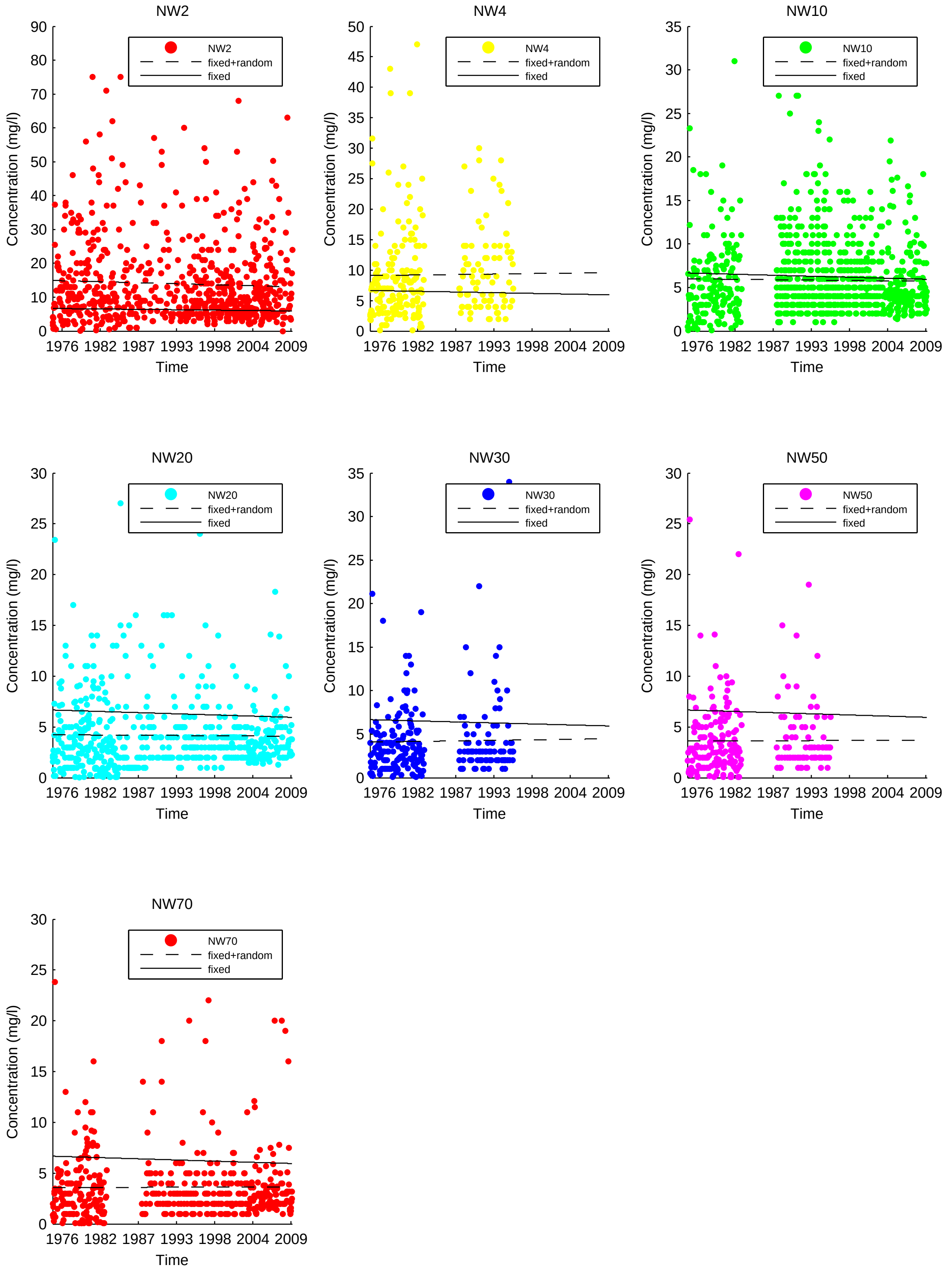
Fig. 4.7



name	fixed trend (mg/l/year)	fixed offset (mg/l)	fixed+random trend (mg/l/year)	fixed+random offset (mg/l)
NW2	−0.021	48.174	−0.055	122.718
NW4	−0.021	48.174	0.014	−18.299
NW10	−0.021	48.174	−0.008	22.174
NW20	−0.021	48.174	−0.004	12.228
NW30	−0.021	48.174	0.011	−18.031
NW50	−0.021	48.174	0.001	2.097
NW70	−0.021	48.174	0.001	2.106

SPM concentrations as a function of time and
trends from mixed effect model
Noordwijk transect 1975−2009

Waterbase

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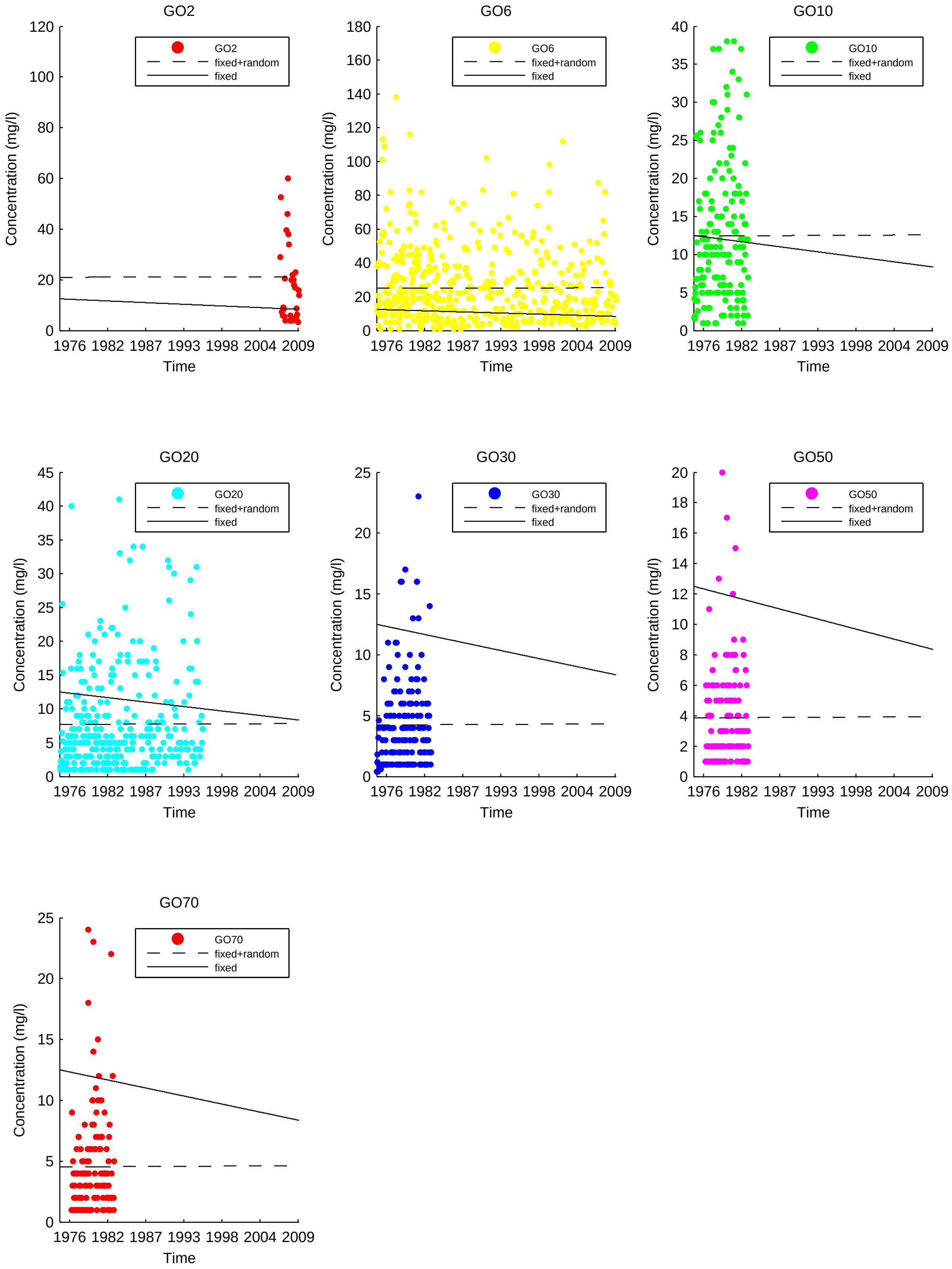
Fig. 4.8



name	fixed trend (mg/l/year)	fixed offset (mg/l)	fixed+random trend (mg/l/year)	fixed+random offset (mg/l)
GO2	−0.121	250.757	0.006	8.339
GO6	−0.121	250.757	0.005	15.671
GO10	−0.121	250.757	0.005	3.291
GO20	−0.121	250.757	0.004	0.252
GO30	−0.121	250.757	0.003	−1.056
GO50	−0.121	250.757	0.003	−1.200
GO70	−0.121	250.757	0.003	−0.874

SPM concentrations as a function of time and
trends from mixed effect model
Goeree transect 1975−2009

Waterbase

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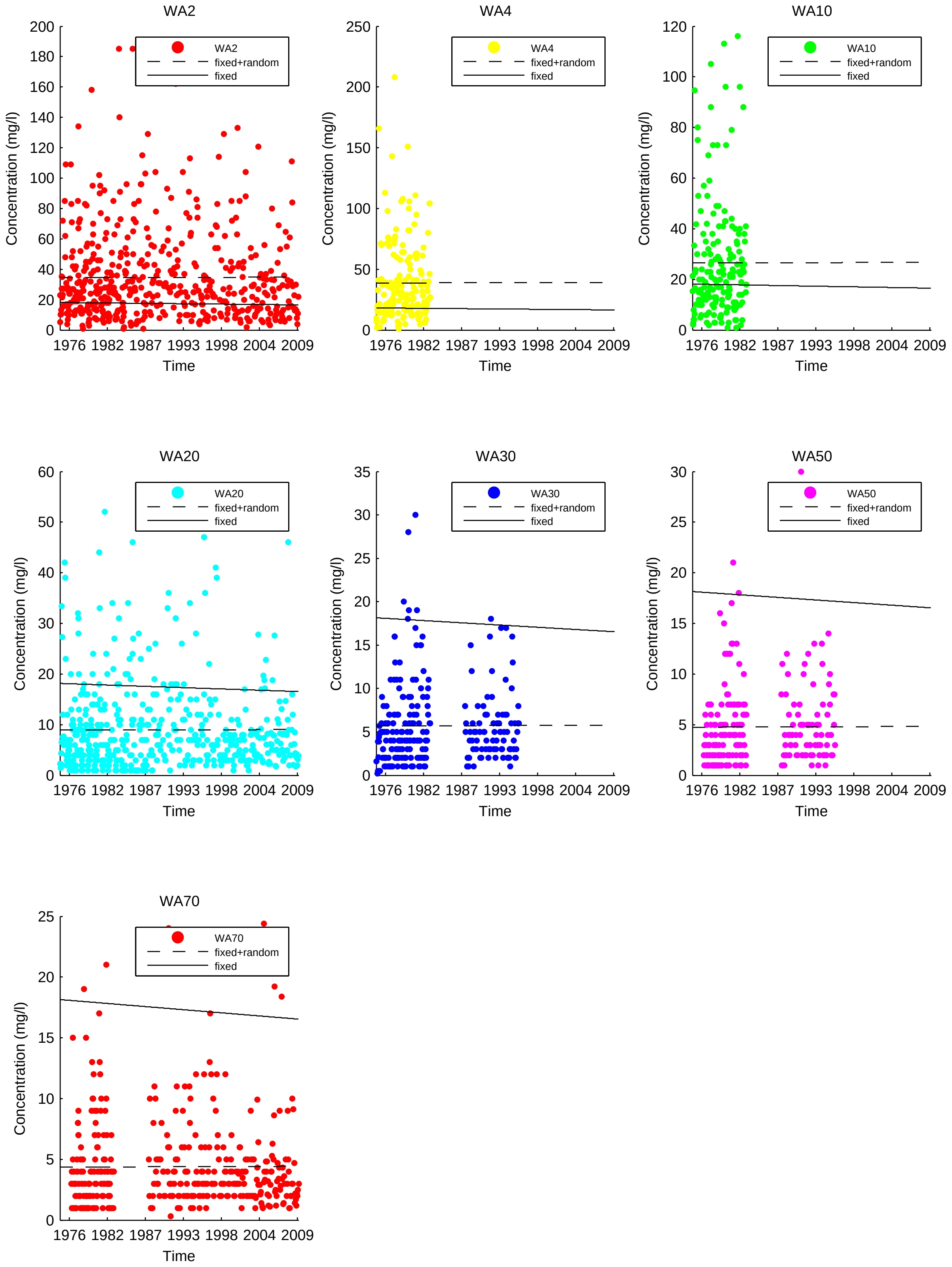
Fig. 4.9



name	fixed trend (mg/l/year)	fixed offset (mg/l)	fixed+random trend (mg/l/year)	fixed+random offset (mg/l)
WA2	−0.047	110.669	0.010	14.517
WA4	−0.047	110.669	0.012	15.577
WA10	−0.047	110.669	0.008	10.000
WA20	−0.047	110.669	0.003	2.396
WA30	−0.047	110.669	0.003	0.551
WA50	−0.047	110.669	0.002	0.132
WA70	−0.047	110.669	0.002	0.072

SPM concentrations as a function of time and
trends from mixed effect model
Walcheren transect 1975−2009

Waterbase

Alkyon Hydraulic Consultancy & Research

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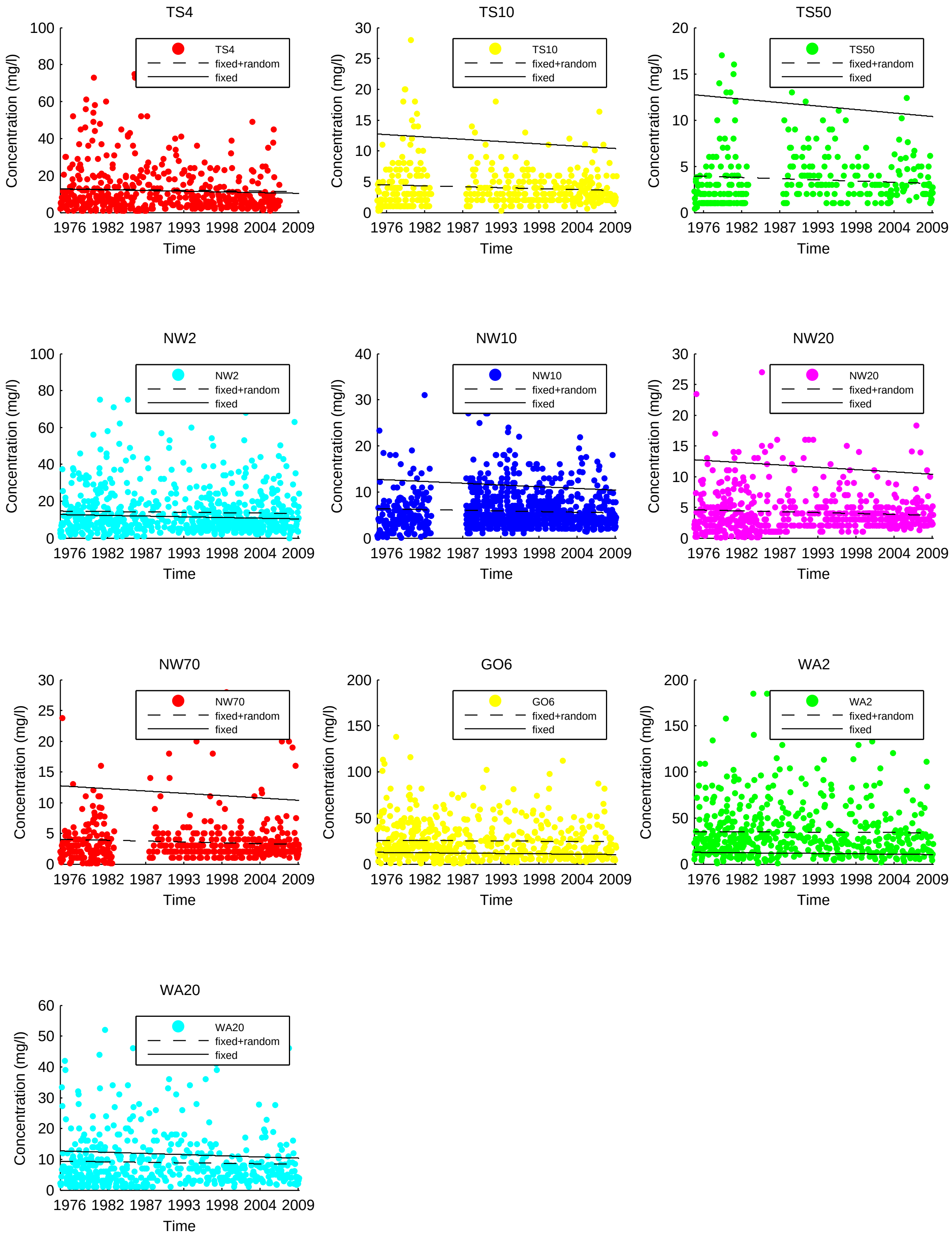
Fig. 4.10



name	fixed trend (mg/l/year)	fixed offset (mg/l)	fixed+random trend (mg/l/year)	fixed+random offset (mg/l)
TS4	−0.069	148.195	−0.043	98.194
TS10	−0.069	148.195	−0.027	58.687
TS50	−0.069	148.195	−0.024	51.049
NW2	−0.069	148.195	−0.037	87.046
NW10	−0.069	148.195	−0.026	56.895
NW20	−0.069	148.195	−0.025	54.558
NW70	−0.069	148.195	−0.024	52.361
GO6	−0.069	148.195	−0.043	111.412
WA2	−0.069	148.195	−0.032	98.965
WA20	−0.069	148.195	−0.029	66.400

SPM concentrations as a function of time and trends
from mixed effect model using
TS4, TS10, TS50, NW2, NW10, NW20, NW70, GO6, WA2 and WA20

Waterbase 1975−2009

Alkyon Hydraulic Consultancy & Research

A2518

Fig. 4.11

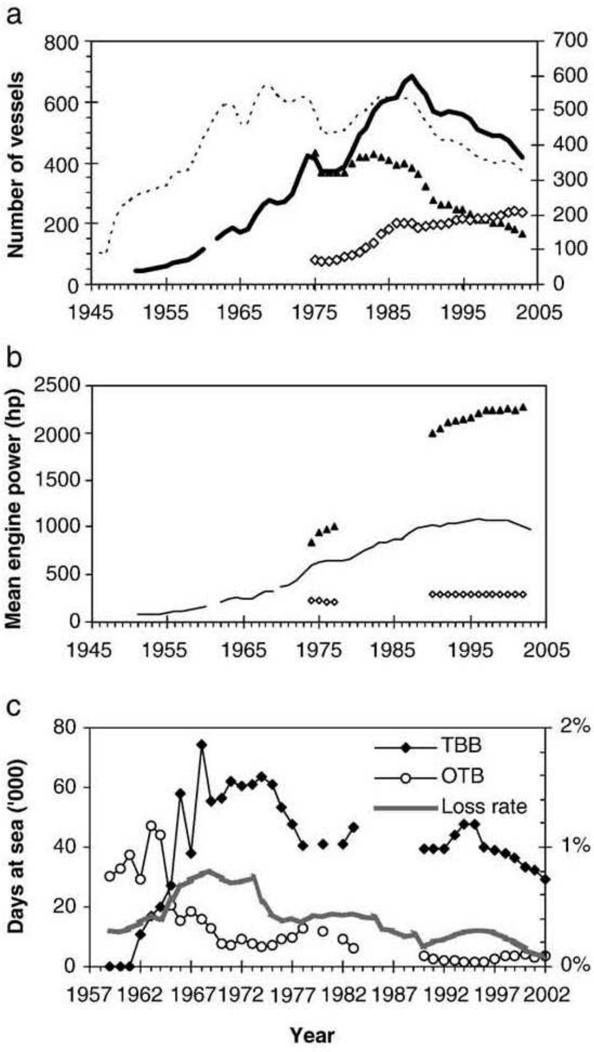
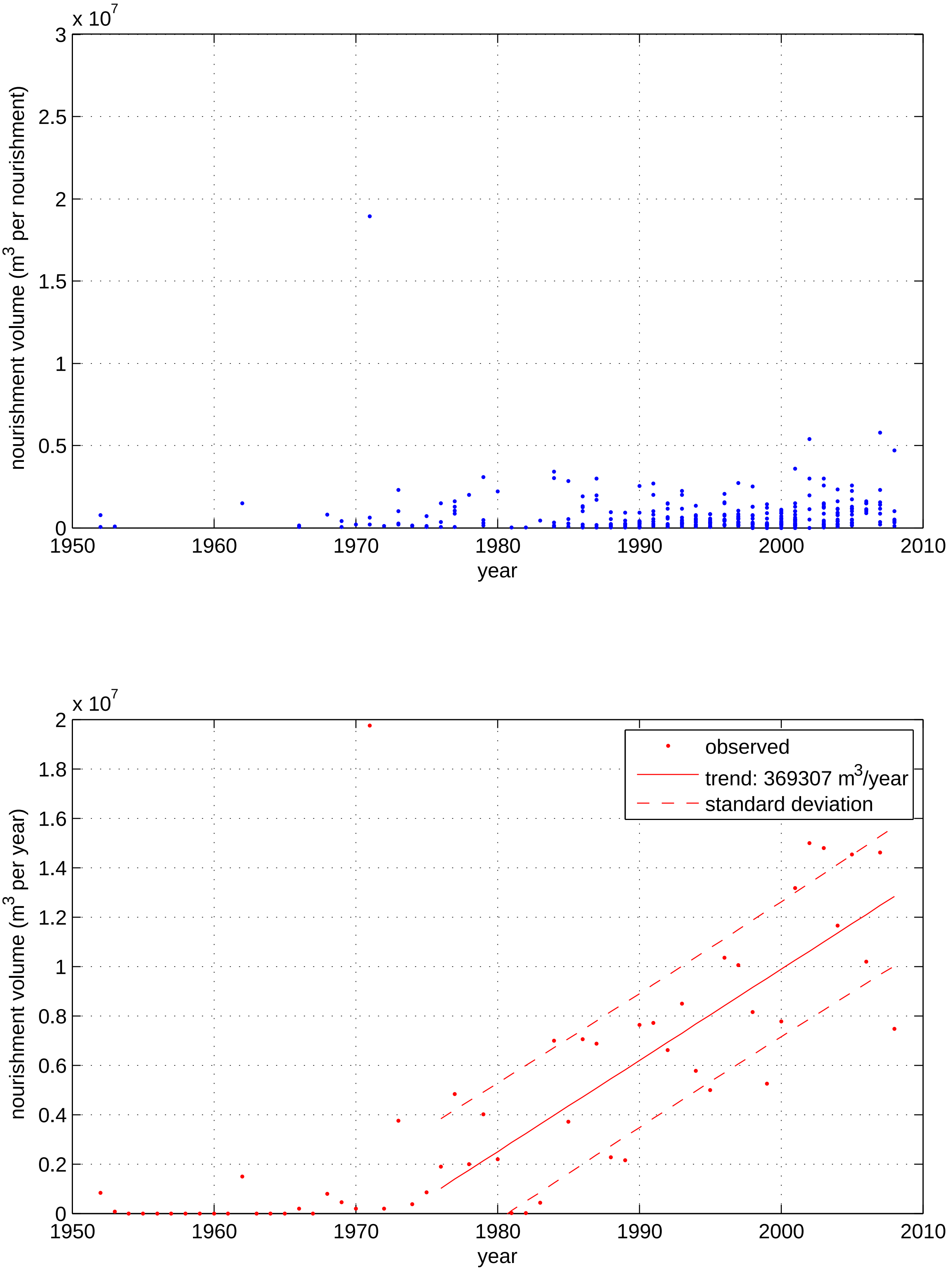


Fig. 2. Developments in the Dutch fleet of demersal motor trawlers since 1945: (a) number of vessels (dashed line), total engine power ('000 hp, heavy line), number of Euro-cutters (225–300 hp: ◊) and number of large trawlers (~2000 hp: ▲); (b) mean engine power of the total fleet (line) and of Euro-cutters (<=300 hp) (◊) and Large trawlers (>300 hp) (▲) separately; (c) fishing effort (number of days at sea) of the beam trawl (◆ TBB) and otter trawl (◇ OTB) fleet since 1957 and the 7 pt running mean of the risk per year of vessel loss (% of the fleet) due to accidents (heavy grey line).

Developments in the Dutch fleet of demersal motor trawlers since 1945
from Rijndsdorp et al (2008)

Rijndorp et al (2008)



Nourishment volume per nourishment (upper) and
nourishment volume per year (lower)
from Rijkswaterstaat directie Noordzee

RWS dir Noordzee

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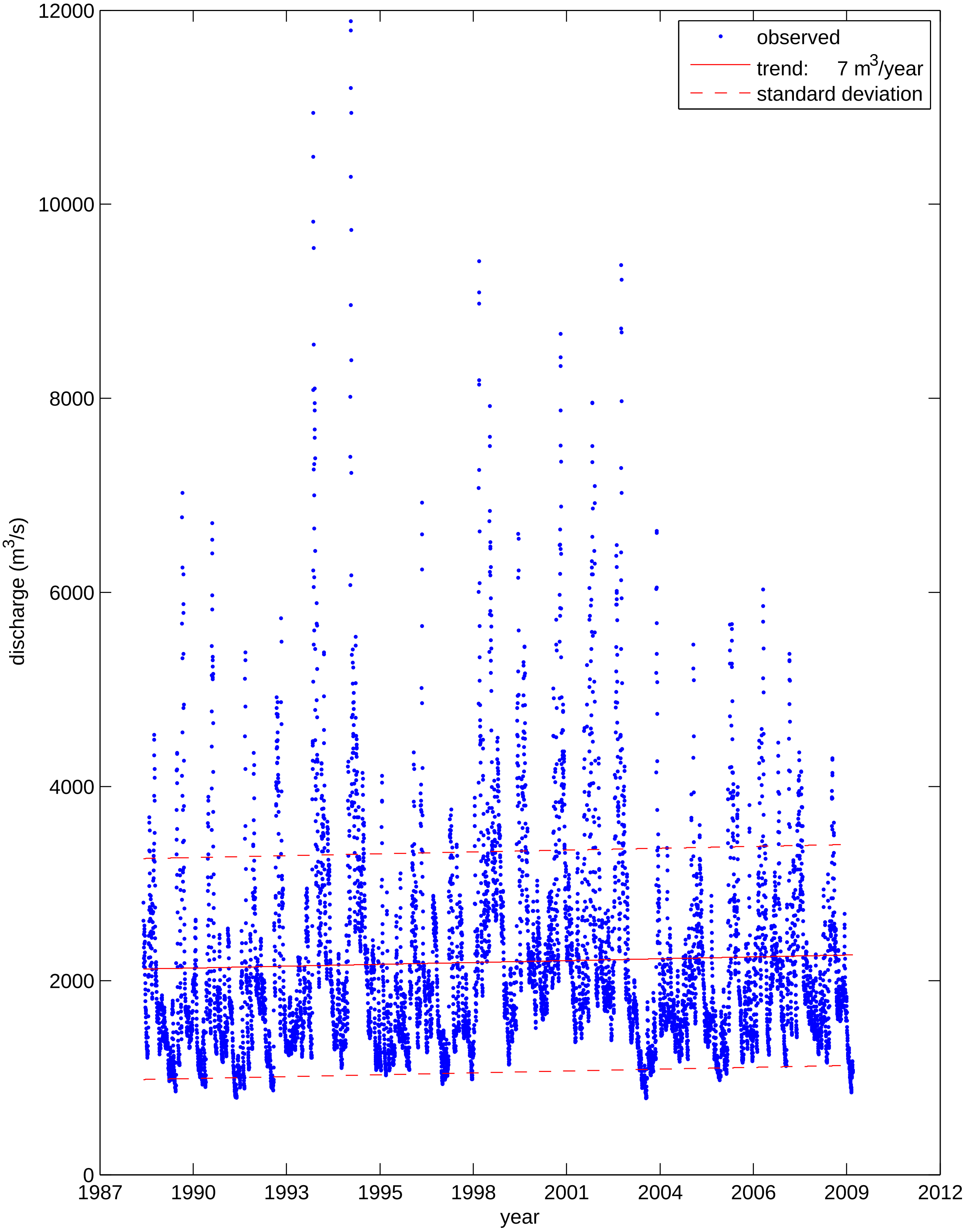
Fig. 5.2



Rhine discharge since 1989
from Waterbase

Waterbase

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Fig. 5.3