REPORT

Vlaamse overheid - Departement Mobiliteit en Openbare werken

Afdeling Maritieme Toegang

Evaluation of the external effects on the siltation in Deurganckdok

Report 1.8: Analysis of external effects on siltation processes and factors

16 January 2014 - version 3.0

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in collaboration with
Deltares
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1.0	15/04/13	Concept	NZI	BDC/JCA	MSA
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GLOSSARY

α_{global}	Global trapping efficiency of the dock (previously e_S in IMDC (2009o)) [-]
$\alpha_{set,dens}$	Coefficient for settled fraction due to density currents [-]
$\alpha_{set,eddy}$	Coefficient for settled fraction due to eddy formation [-]
$\alpha_{set,tide}$	Coefficient for settled fraction due to tidal filling (previously coefficient c1) [-]
β	Eysink coefficient in correction of sediment influx due to eddy currents [-]
Δρ	Density difference [kg/m³], taken equal to salinity amplitude (variation per tide) [ppt]
Δc_B	Horizontal sediment concentration difference (North – South quay) [mg/l]
Δc_Z	Vertical sediment concentration difference (bottom – top) [mg/l]
ε	Relative vertical salinity gradient Δρ/ρ [-]
ρ	Water density [kg/m³]
A_{cs}	Dock entrance cross-sectional area [m²]
A_h	Dock surface area [m²]
BIS	Dredging Information System used in the Lower Sea Scheldt
B	Buoys (for buoys 84 and/or 97)
c	Suspended sediment concentration [mg/l]
DGD	Deurganckdok
$F_{density}$	Sediment influx due to density currents [kg/tidal cycle]
F_{eddy}	Sediment influx due to eddies (horizontal entrainment) [kg/tidal cycle]
F_{tide}	Sediment influx due to tidal filling [kg/tidal cycle]
F_{total}	Total sediment influx into dock [kg/tidal cycle]

g	Gravity constant (~9.81m/s²)
h	Tidal amplitude [m]
$\bar{h}$	Average tidal amplitude over neap-spring cycle (~5.14m)
H_{dock}	Average water depth at dock entrance [m]
HCBS	High Concentration Benthic Suspensions
T_{dens}	Duration of density currents during half a tidal period [hours]
T_{eddy}	Duration of eddy currents during half a tidal period [hours]
T_{tide}	Tidal period (~12.4h)
TDS	Tons of dry solids
v_{dens}	Flow velocity related to density currents (previously ud) [m/s]
v_{eddy}	Flow velocity related to eddy currents [m/s]
v_{tide}	Flow velocity related to tidal filling [m/s]
v_{rest}	Rest flow velocity when decomposing the total flow velocity into components [m/s]
V_{dens}	Water volume exchanged by density currents [m³]
V_{eddy}	Water volume exchanged by eddy currents [m³]
V_{prism}	Tidal prism [m³]
w_{dens}	Relative fraction of density currents in sediment influx [-]
w_{eddy}	Relative fraction of eddy currents in sediment influx [-]
w_{tide}	Relative fraction of tidal filling in sediment influx [-]
x	Horizontal coordinate [m]
z	Vertical coordinate [m]

0. SUMMARY

This report presents the data analysis and the application of the sedimentation model for the period 2006-2012, in order to identify external effects on the sedimentation of Deurganckdok. In particular, it aims to provide as much insight as possible into the effect of the newly-built Current Deflecting Wall (CDW) on the current pattern and on the long-term sedimentation.

Results suggest that the CDW is having the expected effect on the flow pattern, especially through a strongly reduced flood eddy, and that density currents may also be potentially reduced by the CDW. However data and results of the sedimentation model also show that dredging volumes and sedimentation rates have increased since spring 2011, a period characterized by several human impacts. The increased sedimentation rates could be due to a combination of changes in reporting methods of the dredging volumes (dredging of sill previously done with a sweepbeam, not included in reported volumes of dredging amounts (BIS)), the increased maintenance depth of the dock and especially of more frequent dredging. A clear link is shown between the suspended sediment concentration (SSC) measured in the Scheldt river and dredging activity in Deurganckdok. With only one year of data since construction of the CDW, the uncertainty of some model assumptions remains however important. Recommendations are therefore made for the continuation of the study, in particular to isolate individual human impacts on sedimentation.

1. INTRODUCTION

1.1 THE ASSIGNMENT

This report is part of a set of reports concerning the project 'Evaluation of the external effects on the siltation in Deurganckdok'. The terms of reference were prepared by 'Departement Mobiliteit en Openbare Werken van de Vlaamse Overheid, Afdeling Maritieme Toegang (16EF/2009/14). The study was awarded to International Marine and Dredging Consultants NV in association with Deltares and Gems International on 8 December 2009.

This study is a follow-up study on the study 'Opvolging aanslibbing Deurganckdok' that ran from January 2006 till March 2009.

Waterbouwkundig Laboratorium– Cel Hydrometrie Schelde provided data on discharge, tide, salinity and turbidity along the river Scheldt and provided survey vessels for the long term and through tide measurements. Afdeling Maritieme Toegang provided maintenance dredging data. Agentschap voor Maritieme Dienstverlening en Kust – Afdeling Kust provided depth sounding and density profile measurements.

1.2 PURPOSE OF THE STUDY

The purpose of this study entails evaluating the external effects on the siltation in the Deurganckdok. External effects are those effects caused by recent or near-future human operations near Deurganckdok:

- The construction of the Current Deflecting Wall downstream of the entrance of the Deurganckdok.
- The deepening and widening of the navigational channel in the Lower Sea Scheldt between the entrance of the Deurganckdok and the access channels to the locks of Zandvliet-Berendrecht.
- The deepening of the entrance to the Deurganckdok by removing the sill at the entrance.

1.3 OVERVIEW OF THE STUDY

This study contains 3 parts:

- Reporting and analysis of existing documents and measurement data
- Execution of specific measurement campaigns to map the siltation and its environmental factors.
- Support in numerical modelling efforts

1.4 STRUCTURE OF THE REPORT

Reports of the project 'Evaluation of the external effects on the siltation in the Deurganckdok' are summarized in Table 1-1.

Based on results from the entire study, this report analyses the external effects on the siltation and processes in Deurganckdok between 2009 and 2012, with a comparison with the previous study from 2006 to 2009. In particular, it aims to identify the impact of the most recent human changes (Current Deflecting Wall, dredging, sill) on the system behaviour.

Table 1-1: Overview of the External Effects Deurganckdok Reports

Report	Description
1.	**Reporting**
I.1 Annual Sediment Balance: Bathymetry surveys, Density measurements, Maintenance and construction dredging activities	
1.1	Annual Sediment Balance: year 1: 1/4/2009-31/3/2010 (I/RA/11354/10.067/NZI)
1.2	Annual Sediment Balance: year 2: 1/4/2010-31/3/2011 (I/RA/11354/10.100/MBO/ANF)
1.3	Annual Sediment Balance: year 3: 1/4/2011-31/3/2012 (I/RA/11354/10.101/MBO/ANF)
I.2 Boundary Conditions: Upriver Discharge, Salt concentration Scheldt, Bathymetric evolution in access channels, dredging activities in Lower Sea Scheldt and access channels	
1.4	Boundary Conditions year 1: 01/04/2009 – 31/3/2010 (I/RA/11354/10.102/MBO/ANF)
1.5	Boundary Conditions year 2: 01/04/2010 – 31/3/2011 (I/RA/11354/10.103/MBO/ANF)
1.6	Boundary Conditions year 3: 01/04/2011 – 30/5/2012 (I/RA/11354/10.104/MBO/ANF)
I.3 Synthesis of CDW research	
1.7	Synthesis report of research on Current Deflecting Wall (I/RA/11354/10.063/MBO)
I.4 Analysis: evaluation of external effects on siltation in Deurganckdok	
1.8	Analysis of external effects on siltation processes and factors (I/RA/11354/10.105/MBO/ANF)
2.	**Measurement campaigns: Factors contributing to salt and sediment distribution in Deurganckdok: Salt-Silt (OBS3A) & Frame measurements, Through tide measurements (SiltProfiling & ADCP) & Calibrations**
II.1 Through tide measurements fixed transects	
2.1	Through tide Sediview measurement: Entrance DGD during spring tide Autumn 2011 (I/RA/11354/10.106/MBO/ANF)
2.2	Through tide Sediview measurement: Entrance DGD during neap tide Autumn 2011 (I/RA/11354/10.107/MBO/ANF)
2.3	Through tide Sediview measurement: Entrance DGD during spring tide Winter 2012 (I/RA/11354/10.108/MBO/ANF)
2.4	Through tide Sediview measurement: Entrance DGD during neap tide Winter 2012 (I/RA/11354/10.109/MBO/ANF)
II.2 Through tide measurements eddy currents	
2.51[2]	Through tide measurements: Eddy Currents DGD 02/03/2010 (I/RA/11283/10.051/MSA)
2.6	Through tide measurements: Eddy Currents DGD Autumn I/RA/11354/10.110/MBO/ANF)
2.7	Through tide measurements: Eddy Currents DGD Winter 2012 (I/RA/11354/10.111/MBO/ANF)

Report	Description
II.3 Salt Silt Distribution entrance Deurganckdok	
2.8[3]	Salt-Silt distribution Deurganckdok 1/4/2009-31/3/2010 (I/RA/11354/10.068/NZI)
2.9	Sal-Silt distribution Deurganckdok 1/6/2011-31/03/2012 (I/RA/11354/10.112/MBO/ANF)
II.4 Current Salt Silt Distribution CDW Deurganckdok	
2.10	Salt Silt & Current Distribution entrance Deurganckdok: frame measurements and throughtide measurements: Autumn 2011 (I/RA/11354/11.131/BQU)
2.11	Salt Silt & Current Distribution entrance Deurganckdok: frame measurements and throughtide measurements: Winter 2012 (I/RA/11354/10.114/MBO/ANF)
II.5 Quality Control instruments	
2.12	Calibration stationary & mobile equipment 16/03/2011 (I/RA/11354/10.113/MBO/ANF)
2.13	Calibration stationary equipment 2012 (I/RA/11354/12.011/JCA)

[2]: this report is part of the project Siltation Deurganckdok (11283)

[3]: this report contains report 2.35 of project Siltation Deurganckdok (I/RA/11283/09.085/MSA)

2. SEDIMENTATION IN DEURGANCKDOK

2.1 PROJECT AREA: DEURGANCKDOK

Deurganckdok is a tidal dock situated at the left bank in the Lower Sea Scheldt, between Liefkenshoek and Doel. Deurganckdok has the following characteristics:

1. the dock has a total length of 2750 m and is 450 m wide at the Scheldt end and 400 m wide at the inward end of the dock
2. The bottom of Deurganckdok is provided at a depth of –17m TAW in the transition zones between the quay walls and the central trench and of –19m TAW in the central trench.
3. the quay walls reach up to +9m TAW

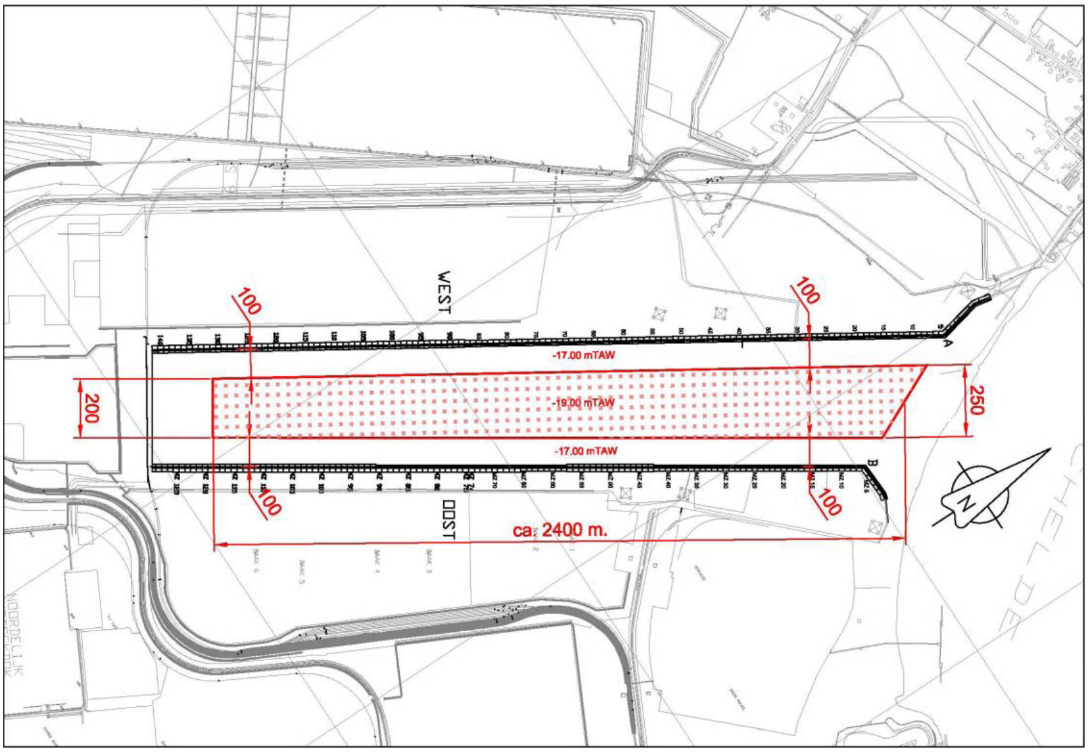

Figure 2-1: Overview of Deurganckdok

The dredging of the dock is performed in 3 phases. On 18 February 2005 the dike between the Scheldt and the Deurganckdok was breached. On 6 July 2005 Deurganckdok was officially opened. The second dredging phase was finalized a few weeks later. The first terminal operations have started since. In February 2007, the third dredging phase started and is finalised by February 2008. The dock has been completed in February 2009.

2.2 CAPITAL DREDGING

The main construction works which occurred since the opening of Deurganckdok are presented in the table below.

Table 2-1 : Overview of construction works since the opening of Deurganckdok

Date	Description
18th February 2005	Deurganckdok dike opened
18th Feb 2005 – 1st Aug 2005	Dredging Phase 2 (end)
Feb 2007 – Feb 2008	Dredging Phase 3, dock extended from 1500 to 2500m
Jul 2008 – Aug 2010	Deepening and widening of the Scheldt navigation channel in Belgium (spread over a long period, exact timing not known)
Nov 2009 – Jun 2010	Dredging of the entrance sill
Apr 2010 – Aug 2011	Construction of the CDW
> Mar 2011	Change of maintenance depth -15.9m / -17.5m / -15.2m in quays / trench / entrance (included in maintenance dredging)
> Nov 2011	Construction of the 2nd Waaslandlock at the landward end of DGD

A notable change in the boundary conditions is the increased presence of large ships near and in Deurganckdok since January 2012, after the deepening of the navigation channel and the change in maintenance depth.

2.3 OVERVIEW OF THE STUDIED PARAMETERS

The analysis of the measurement data contains two main components : the derivation of a yearly mass balance of the dock, presented in IMDC (2011a, 2011b, 2012m), and the analysis of sediment exchange mechanisms including a conceptual sedimentation model (this report), which uses results from the mass balance.

The sediment balance comprises a number of sediment transport modes: deposition, influx from capital dredging works, internal replacement and removal of sediments due to maintenance dredging (Figure 2-2, Figure 2-1).

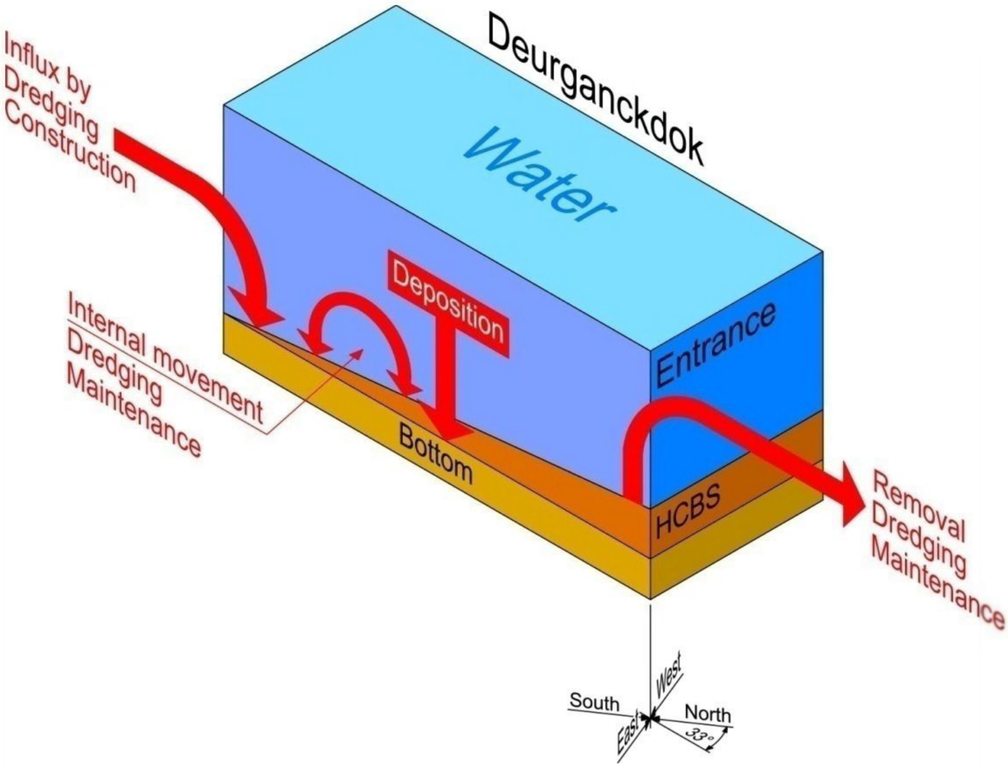

Figure 2-2: Elements of the sediment balance

A net deposition can be calculated from a comparison with a chosen initial condition t0 (Figure 2-3). The mass of deposited sediment is determined from the integration of bed density profiles recorded at grid points covering the dock. Subtracting bed sediment mass at t0 leads to the change in mass of sediments present in the dock (mass growth). Adding cumulated dry matter mass of dredged material removed since t0 and subtracting any sediment influx due to capital dredging works leads to the total cumulated mass entered from the river Scheldt since t0.

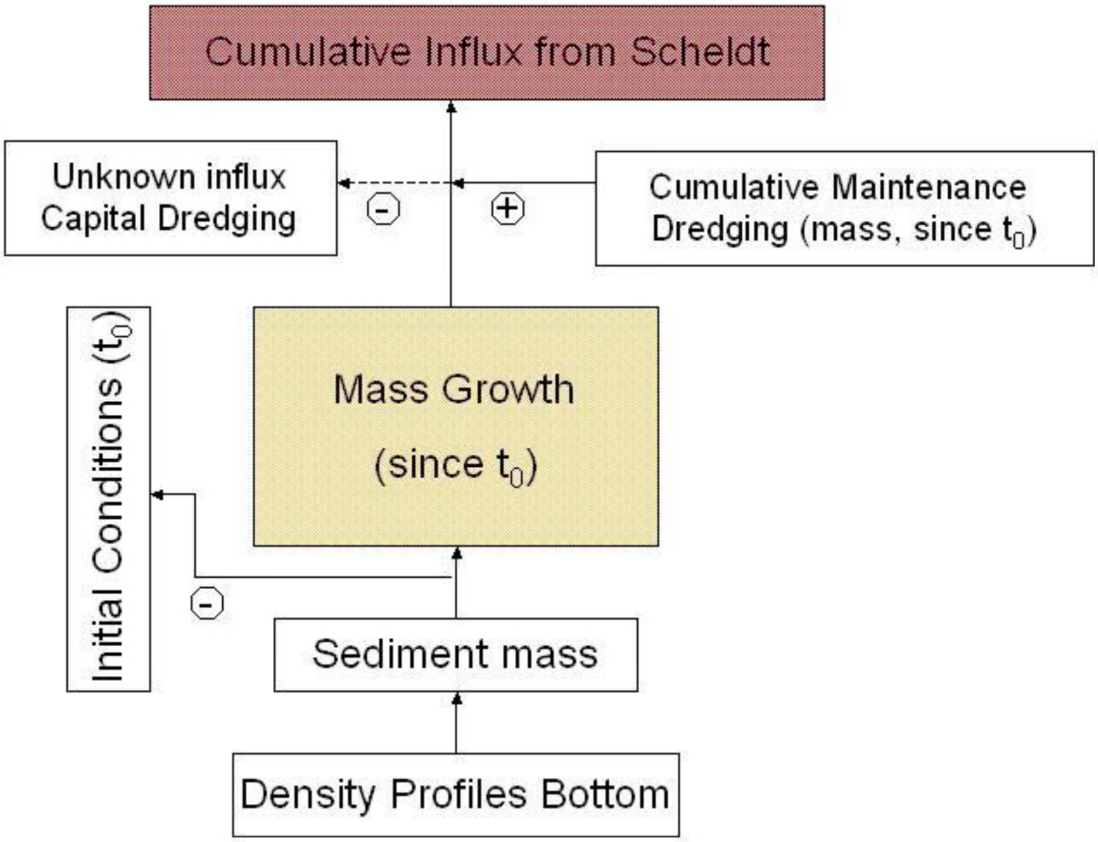

Figure 2-3: Determining a sediment balance

Concerning the sediment exchange, the following mechanisms are aimed at in the present report :

- Tidal prism, i.e. the extra volume in a water body due to high tide
- Vortex patterns due to passing tidal current
- Density currents due to salinity gradient between the Scheldt river and the dock
- Density currents due to highly concentrated benthic suspensions

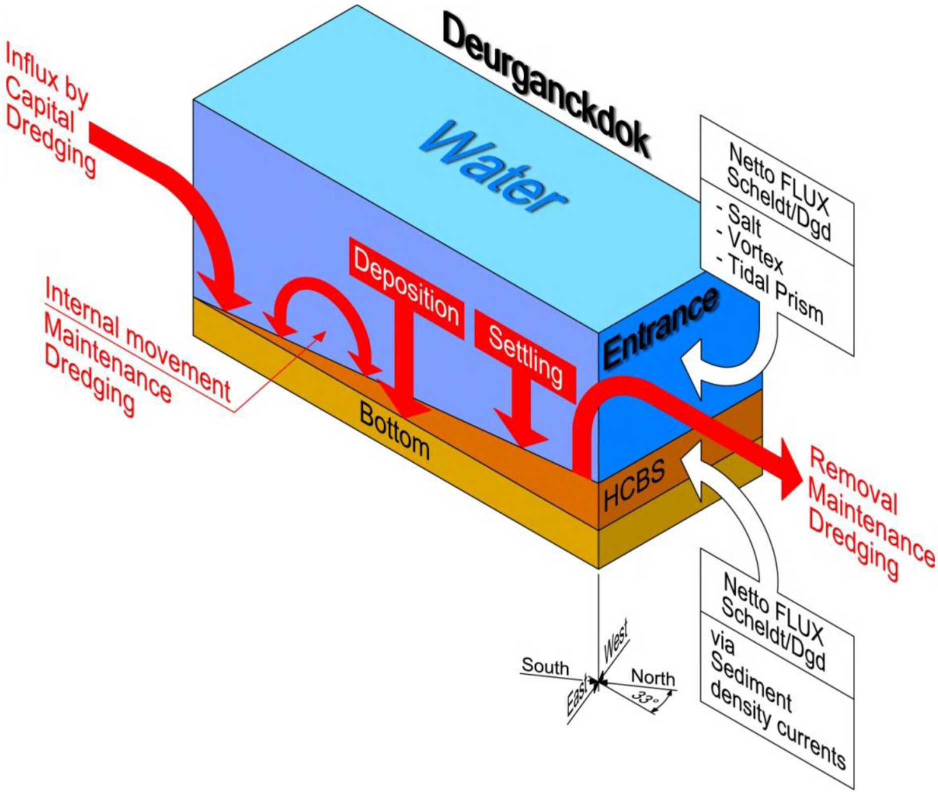

Figure 2-4: Transport mechanisms

These aspects of hydrodynamics and sediment transport have been landmark in determining the parameters to be measured during the project. Measurements have focused on three types of timescales: one tidal cycle, one neap-spring cycle and seasonal variation within one year.

Following data have been collected to understand these mechanisms:

- Monitoring upstream discharge in the river Scheldt.
- Monitoring Salinity and sediment concentration in the Lower Sea Scheldt at permanent measurement locations at Oosterweel, up- and downstream of the Deurganckdok.
- Long term measurement of salinity and suspended sediment distribution in Deurganckdok.
- Monitoring near-bed processes (current velocity, turbidity, and bed elevation variations) in the central trench in the dock, near the entrance as well as near the current deflecting wall location.
- Dynamic measurements of current, salinity and sediment transport at the entrance of Deurganckdok.
- Through tide measurements of vertical sediment concentration profiles -including near bed high concentrated benthic suspensions.
- Monitoring dredging activities at entrance channels towards the Kallo, Zandvliet and Berendrecht locks as well as dredging and relocation activities in the Lower Sea Scheldt.
- In situ calibrations were conducted on several dates to calibrate all turbidity and conductivity sensors.

A Current Deflecting Wall (CDW) has been constructed at the entrance of Deurganckdok in 2011 with the objective to reduce the yearly sedimentation in the dock. The effect of the CDW has been taken into account in the interpretation of results of the other reports containing factual data, boundary conditions and the mass balance (Table 1-1 for full list), but no overall view of the effects of the CDW has been given yet. This is the objective of the present report.

3. MEASUREMENTS

3.1 COLLECTED DATA

3.1.1 Overview

In this section an overview is given of all measurements executed in and near Deurganckdok since its construction (DGD project in 2006-2009, and present Current Deflecting Wall (CDW) project in 2009-2012). The next paragraphs review the general information of all measurements available since the construction of Deurganckdok :

- Depth soundings
- Density measurements
- Through-tide measurements
- Near-bed monitoring and INSSEV settling velocity
- Long-term salinity and suspended sediment concentration (SSC) measurements
- Continuous monitoring in the Lower Sea Scheldt

In addition, detailed data about human activities and boundary conditions are available for the entire period :

- Maintenance dredging
- Sweepbeam dredging
- Capital dredging
- Boundary conditions (tide, discharge, navigation, meteo)

Table 3-1 and Table 3-2 give an overview of execution periods per measurement type and the timing dredging activities. Boundary conditions and measurements in the Lower Sea Scheldt are at least partially available over the entire period and are not reported. Part of the measurements stopped during the construction works of 2009-2011 (entrance sill and CDW, see paragraph 0).

Figure 3-1 to Figure 3-18 give a geographical overview of the measurements in and near Deurganckdok.

Table 3-1: Overview of measurements and dredging activities in Deurganckdok in 2006-2009 (DGD project).

ACTIVITY	April 06		May 06		June 06		July 06		August 06		Sept 06	
	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 30
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

ACTIVITY	October 06		November 06		December 06		January 07		February 07		March 07	
	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 28	1 - 15	16 - 31
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

activity	April 07		May 07		June 07		July 07		August 07		Sept 07	
	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 30
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	October 07		Nov 07		Dec 07		January 08		February 08		March 08	
activity	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 28	1 - 15	16 - 31
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	April 08		May 08		Jun-08		Jul-08		Aug-08		Sep-08	
ACTIVITY	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 30
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	Oct-08		Nov-08		Dec-08		Jan-09		Feb-09		Mar-09	
ACTIVITY	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 28	1 - 15	16 - 31
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

Table 3-2: Overview of measurements and dredging activities in Deurganckdok in 2009-2012 (CDW project).

	April 09		May 09		June 09		July 09		August 09		Sept 09	
ACTIVITY	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	Oct-09		Nov-09		Dec-09		Jan-10		Feb-10		Mar-10	
ACTIVITY	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 28**	**1 - 15**	**16 - 31**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	April 10		May 10		June 10		July 10		August 10		Sept 10	
ACTIVITY	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												

	April 10		May 10		June 10		July 10		August 10		Sept 10	
ACTIVITY	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**
Near bed monitoring												
Salt Silt long term DGD												

	October 10		Nov 10		Dec 10		January 11		February 11		March 11	
ACTIVITY	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 28**	**1 - 15**	**16 - 31**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	April 11		May 11		June 11		July 11		August 11		Sept 11	
ACTIVITY	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												

	October 11		Nov 11		Dec 11		January 12		February 12		March 12	
ACTIVITY	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 30**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 31**	**1 - 15**	**16 - 29**	**1 - 15**	**16 - 31**
depth sounding												
density measurements												
maintenance dredging												
sweep beam dredging - sill												

ACTIVITY	October 11		Nov 11		Dec 11		January 12		February 12		March 12	
	1 - 15	16 - 31	1 - 15	16 - 30	1 - 15	16 - 31	1 - 15	16 - 31	1 - 15	16 - 29	1 - 15	16 - 31
sweep beam dredging - commercial quays												
capital dredging												
Through-tide DGD												
Near bed monitoring												
Salt Silt long term DGD												**

** long-term salinity measurements extend to 31st May 2012

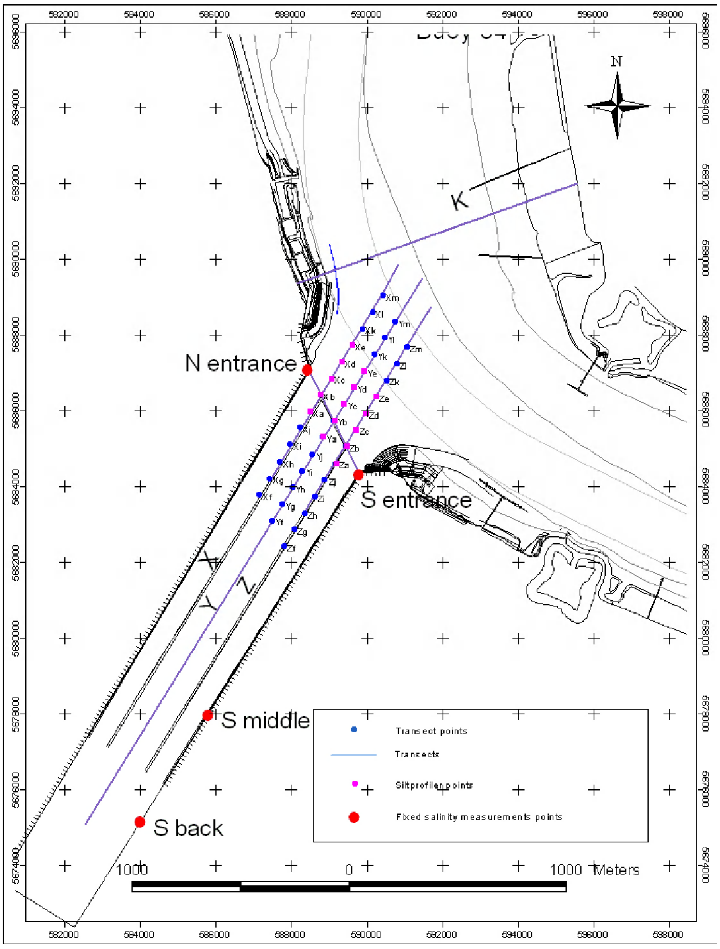

Figure 3-1: Location of measurement equipment and sailed tracks at Deurganckdok

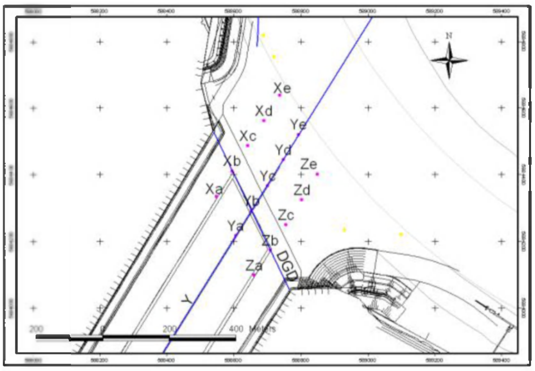

Figure 3-2: Through tide SiltProfiler measurements – Entrance Deurganckdok

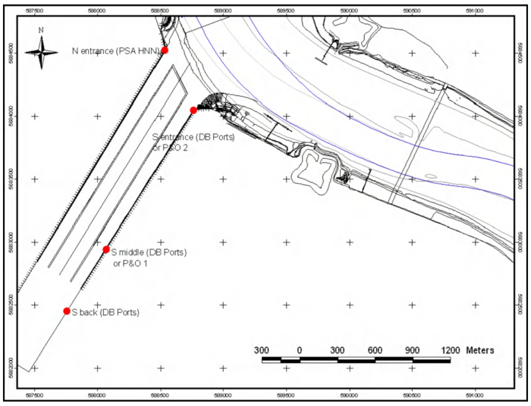

Figure 3-3: Long term salinity measurements Deurganckdok

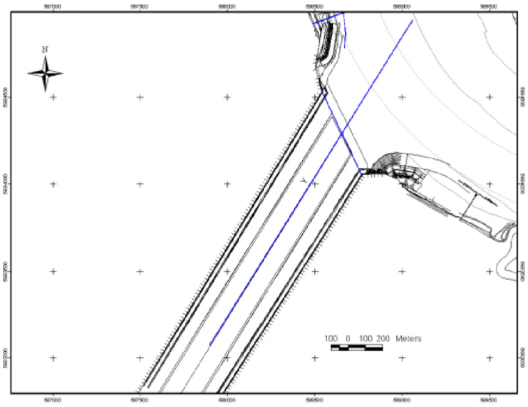

Figure 3-4: Through tide Salinity measurements – Deurganckdok (transect Y)

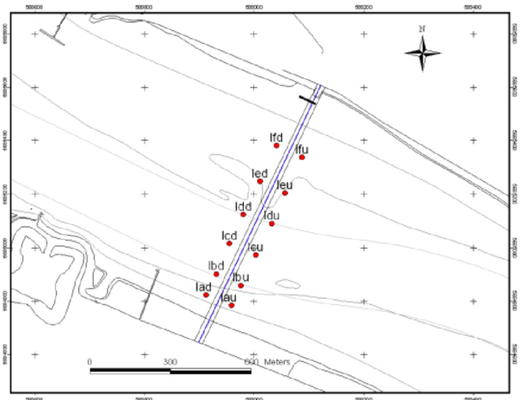

Figure 3-5: Through tide ADCP & SiltProfiler measurements – Upstream Deurganckdok (transect I)

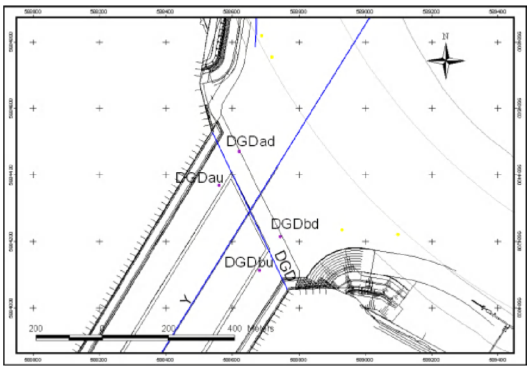

Figure 3-6: Through tide ADCP measurements – Entrance Deurganckdok (transect DGD)

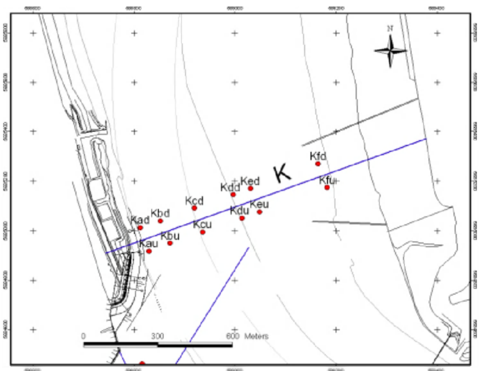

Figure 3-7: Through tide ADCP & SiltProfiler measurements – Downstream Deurganckdok (Transect K)

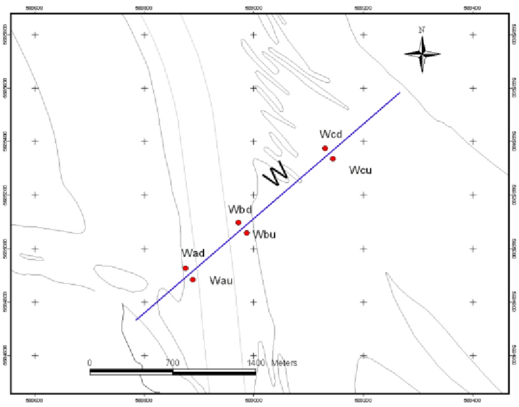

Figure 3-8: Through tide ADCP measurements - Waarde (transect W)

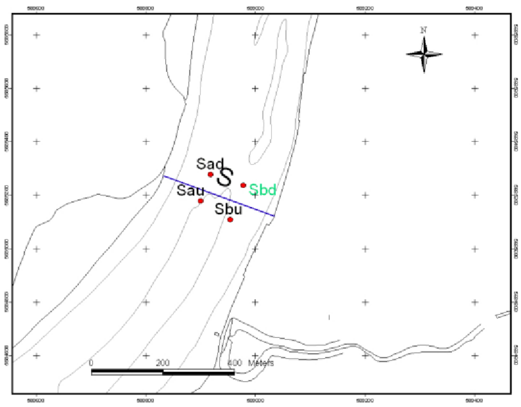

Figure 3-9: Through tide ADCP measurements - Schelle (transect S)

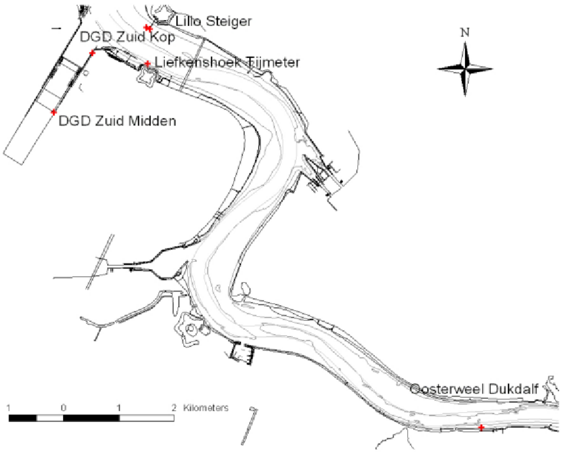

Figure 3-10: Calibration measurements - 15/03/2006 & 14/04/2006

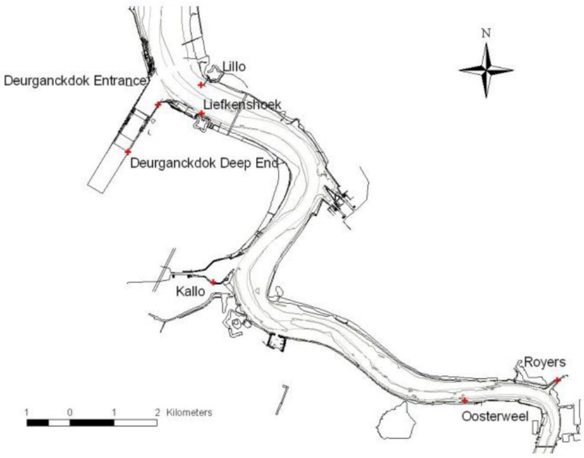

Figure 3-11: Calibration measurements – 23/06/2006 & 18/09/2006

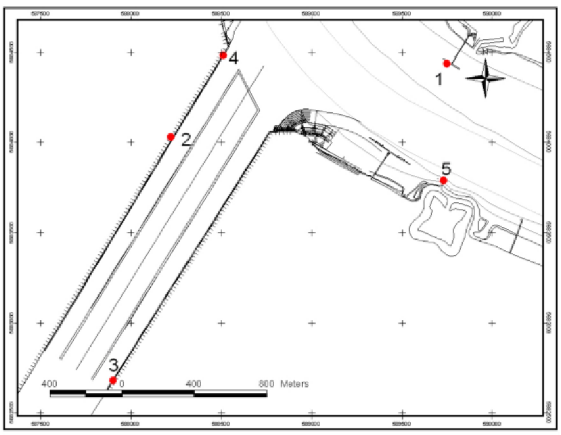

Figure 3-12: Calibration measurements – 10/09/2008

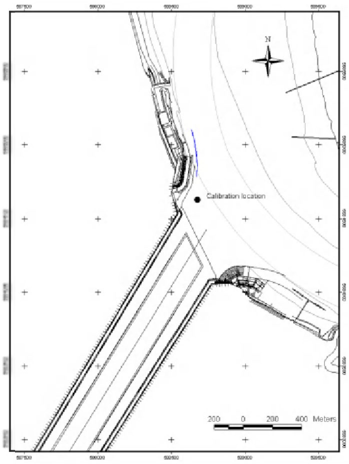

Figure 3-13: Calibration measurements – 04/02/2008 & 05/02/2008

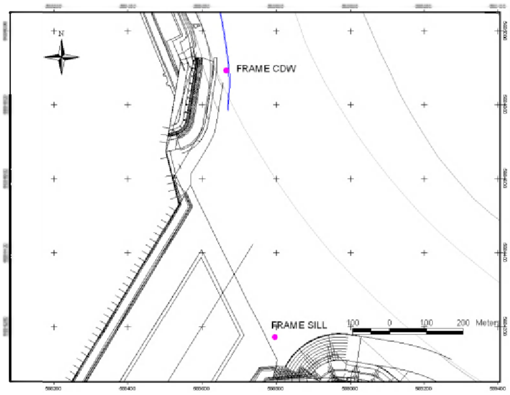

Figure 3-14: Near bed continuous monitoring 2006-2009

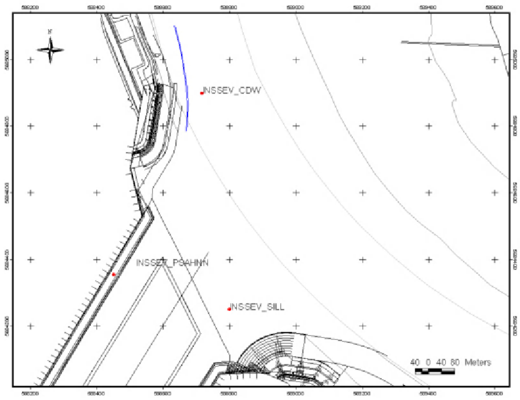

Figure 3-15: Settling velocity (INSSEV) 05/09/2006 – 07/09/2006

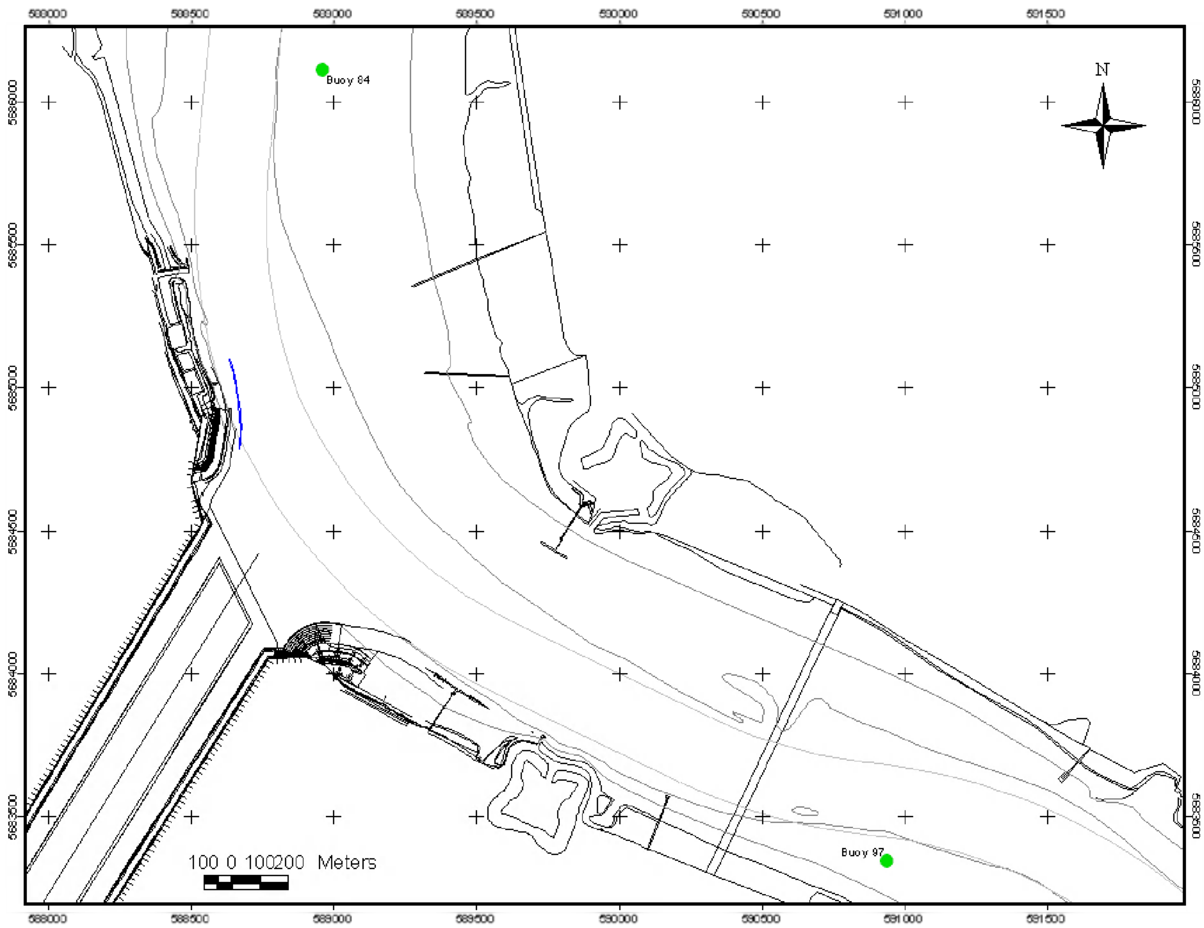

Figure 3-16: Long term measurements in the Lower Sea Scheldt

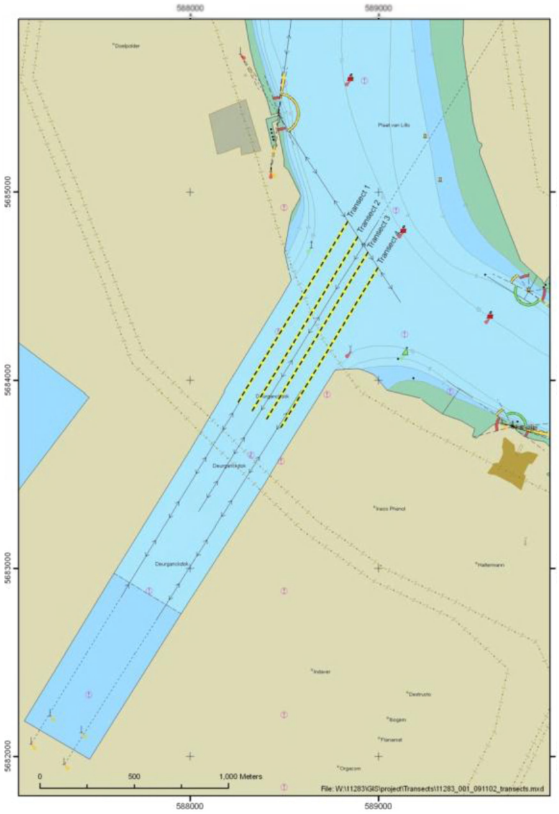

Figure 3-17 : Through tide Salinity measurements – Deurganckdok (transects 1 to 4 from top to bottom).

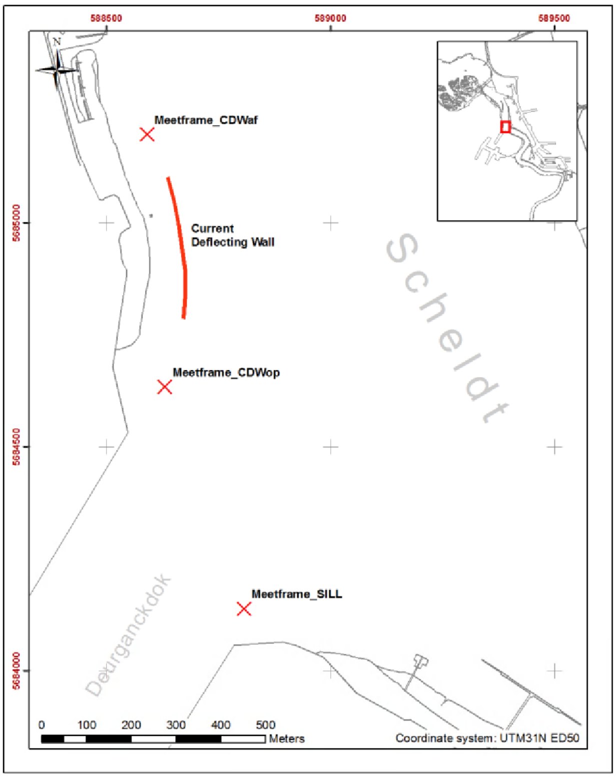

Figure 3-18 : Near bed continuous monitoring 2009-2012

3.1.2 Depth soundings

Table 3-3 and Table 3-4 list the depth soundings executed in Deurganckdok in 2006-2009 and in 2009-2012. Most soundings have been carried out with a dual frequency echosounder 33-210 kHz, a few in 2007 have been post-processed with the SILAS software, also with a 210 kHz signal.

Table 3-3: Depth soundings in 2006-2009 (DGD project).

date	type of measurement	signal	Source
24/03/2006	dual frequency 210-33 kHz	210	Afdeling Kust
14/04/2006	dual frequency 210-33 kHz	210	Afdeling Kust
21/04/2006	dual frequency 210-33 kHz	210	Afdeling Kust
28/04/2006	dual frequency 210-33 kHz	210	Afdeling Kust
12/05/2006	dual frequency 210-33 kHz	210	Afdeling Kust
26/05/2006	dual frequency 210-33 kHz	210	Afdeling Kust
9/06/2006	dual frequency 210-33 kHz	210	Afdeling Kust

date	***type of measurement***	***signal***	***Source***
30/06/2006	dual frequency 210-33 kHz	210	Afdeling Kust
7/07/2006	dual frequency 210-33 kHz	210	Afdeling Kust
27/07/2006	dual frequency 210-33 kHz	multibeam	Afdeling Kust
4/08/2006	dual frequency 210-33 kHz	210	Afdeling Kust
7/08/2006	dual frequency 210-33 kHz	210	Afdeling Kust
1/09/2006	dual frequency 210-33 kHz	210	Afdeling Kust
21/09/2006	dual frequency 210-33 kHz	210	Afdeling Kust
23/10/2006	dual frequency 210-33 kHz	210	Afdeling Kust
8/12/2006	dual frequency 210-33 kHz	210	Afdeling Kust
09/02/2007	dual frequency 210-33 kHz	210	Afdeling Kust
09/03/2007	dual frequency 210-33 kHz	210	Afdeling Kust
27/04/2007	dual frequency 210-33 kHz	210	Afdeling Kust
23/05/2007	dual frequency 210-33 kHz	210	Afdeling Kust
22/06/2007	dual frequency 210-33 kHz	210	Afdeling Kust
27/07/2007	dual frequency 210-33 kHz	210	Afdeling Kust
31/08/2007	dual frequency 210-33 kHz	210	Afdeling Kust
5/09/2007	SILAS – 210 kHz	210	
28/09/2007	dual frequency 210-33 kHz	210	Afdeling Kust
16/10/2007	SILAS – 210 kHz	210	
7/11/2007	dual frequency 210-33 kHz	210	Afdeling Kust
16/11/2007	SILAS – 210 kHz	210	
5/12/2007	SILAS – 210 kHz	210	
13/12/2007	dual frequency 210-33 kHz	210	Afdeling Kust
8/01/2008	dual frequency 210-33 kHz	210	Afdeling Kust
11/01/2008	dual frequency 210-33 kHz	210	Afdeling Kust
25/01/2008	dual frequency 210-33 kHz	210	Afdeling Kust
15/02/2008	dual frequency 210-33 kHz	210	Afdeling Kust
13/03/2008	dual frequency 210-33 kHz	210	Afdeling Kust
13/03/2008	dual frequency 210-33 kHz	210	Afdeling Kust
11/04/2008	dual frequency 210-33 kHz	210	Afdeling Kust
9/05/2008	dual frequency 210-33 kHz	210	Afdeling Kust
4/06/2008	dual frequency 210-33 kHz	210	Afdeling Kust
15/07/2008	dual frequency 210-33 kHz	210	Afdeling Kust
11/08/2008	dual frequency 210-33 kHz	210	Afdeling Kust
26/08/2008	dual frequency 210-33 kHz	210	Afdeling Kust
3/09/2008	dual frequency 210-33 kHz	210	Afdeling Kust
22/09/2008	dual frequency 210-33 kHz	210	Afdeling Kust
6/10/2008	dual frequency 210-33 kHz	210	Afdeling Kust

date	type of measurement	signal	Source
20/10/2008	dual frequency 210-33 kHz	210	Afdeling Kust
7/11/2008	dual frequency 210-33 kHz	210	Afdeling Kust
28/11/2008	dual frequency 210-33 kHz	210	Afdeling Kust
15/01/2009	dual frequency 210-33 kHz	210	Afdeling Kust
11/02/2009	dual frequency 210-33 kHz	210	Afdeling Kust
03/03/2009	dual frequency 210-33 kHz	210	Afdeling Kust
17/03/2009	dual frequency 210-33 kHz	210	Afdeling Kust

Table 3-4: Depth soundings in 2009-2012 (CDW project).

date	type of measurement	signal	Source
02/04/2009	dual frequency 210	210	Afdeling Kust
29/04/2009	dual frequency 210	210	Afdeling Kust
14/05/2009	dual frequency 210	210	Afdeling Kust
28/05/2009	dual frequency 210	210	Afdeling Kust
12/06/2009	dual frequency 210	210	Afdeling Kust
26/06/2009	dual frequency 210	210	Afdeling Kust
13/07/2009	dual frequency 210	210	Afdeling Kust
27/07/2009	dual frequency 210	210	Afdeling Kust
10/08/2009	dual frequency 210	210	Afdeling Kust
24/08/2009	dual frequency 210	210	Afdeling Kust
09/09/2009	dual frequency 210	210	Afdeling Kust
25/09/2009	dual frequency 210	210	Afdeling Kust
09/10/2009	dual frequency 210	210	Afdeling Kust
23/10/2009	dual frequency 210	210	Afdeling Kust
09/11/2009	dual frequency 210	210	Afdeling Kust
20/11/2009	dual frequency 210	210	Afdeling Kust
07/12/2009	dual frequency 210	210	Afdeling Kust
22/12/2009	dual frequency 210	210	Afdeling Kust
19/02/2010	dual frequency 210	210	Afdeling Kust
10/03/2010	dual frequency 210	210	Afdeling Kust
17/03/2010	dual frequency 210	210	Afdeling Kust
24/03/2010	dual frequency 210	210	Afdeling Kust
31/03/2010	dual frequency 210	210	Afdeling Kust
30/04/2010	dual frequency 210	210	Afdeling Kust
04/06/2010	dual frequency 210	210	Afdeling Kust
02/07/2010	dual frequency 210	210	Afdeling Kust
00/08/2010**	dual frequency 210	210	Afdeling Kust
23/08/2010	dual frequency 210	210	Afdeling Kust

date	***type of measurement***	***signal***	***Source***
02/09/2010	dual frequency 210	210	Afdeling Kust
08/10/2010	dual frequency 210	210	Afdeling Kust
09/11/2010	dual frequency 210	210	Afdeling Kust
10/12/2010	dual frequency 210	210	Afdeling Kust
12/01/2011	dual frequency 210	210	Afdeling Kust
11/02/2011	dual frequency 210	210	Afdeling Kust
24/03/2011	dual frequency 210	210	Afdeling Kust
22/04/2011	dual frequency 210	210	Afdeling Kust
06/05/2011	dual frequency 210	210	Afdeling Kust
09/06/2011	dual frequency 210	210	Afdeling Kust
08/07/2011	dual frequency 210	210	Afdeling Kust
02/08/2011	dual frequency 210	210	Afdeling Kust
01/09/2011	dual frequency 210	210	Afdeling Kust
30/09/2011	dual frequency 210	210	Afdeling Kust
31/10/2011	dual frequency 210	210	Afdeling Kust
28/11/2011	dual frequency 210	210	Afdeling Kust
18/01/2012	dual frequency 210	210	Afdeling Kust
29/02/2012	dual frequency 210	210	Afdeling Kust
28/03/2012	dual frequency 210	210	Afdeling Kust

**= no date provided, likely to be beginning of August

3.1.3 Density measurements

Table 3-5 and Table 3-6 list the density measurements executed in Deurganckdok in 2006-2009 and in 2009-2012. Measurements have been carried out with the Navitracker profiler (2007-2008 and 2010-2012) and the Densitune probe (2008-2010). Table 3-7 shows the reference depths used for interpretation of the density measurements.

Table 3-5 : Density measurements in 2006-2009 (DGD project).

Density profile campaigns	***Instrument***
5th September 2007	Navitracker
16th October 2007	Navitracker
16th November 2007	Navitracker
5th December	Navitracker
24th January 2008	Navitracker
22nd February 2008	Navitracker
1st May 2008	Navitracker
5th June 2008	Navitracker
11th August 2008	Navitracker
26th August 2008	Navitracker
11th September 2008	Densitune
20th October 2008	Densitune

Density profile campaigns	*Instrument*
6th November 2008	Densitune
30th January 2009	Densitune
12th March 2009	Densitune

Table 3-6 : Density measurements in 2009-2012 (CDW project).

Density profile campaigns	*Instrument*
2-3 July 2009	Densitune
4 August 2009	Densitune
23-24 September 2009	Densitune
28 October 2009	Densitune
27 December 2009	Densitune
20 March 2010	Densitune
3 May 2010	Navitracker
17 August 2010	Navitracker
27 September 2010	Navitracker
30 November 2010	Navitracker
29 December 2011	Navitracker
27 January 2011	Navitracker
22 March 2011	Navitracker
31 May 2011	Navitracker
18 August 2011	Navitracker
26 October 2011	Navitracker
9 December 2011	Navitracker
28 December 2011	Navitracker
7 February 2012	Navitracker
28 March 2012	Navitracker

Table 3-7: Reference Situation Density Measurements (t_{0d})

Zone	*Design Depth [m TAW]*
Central trench	-19
Berthing zones and transition zones to central trench	-17
Sill	-13.5
Transition sill to navigation channel	Not applicable

3.1.4 Through-tide measurements

Through-tide measurements are executed with an ADCP along transects (Table 3-8 and Table 3-9) and with the Siltprofiler at predefined measurement points (Table 3-10). The transects are identified in Figure 3-4 to Figure 3-9 and in Figure 3-17. SiltProfiler gauging points are identified in Figure 3-2.

Table 3-8 : Through-tide measurements on transects in 2006-2009 (DGD project).

Through tide measurements: Transects					
Location	***Easting (UTM ED 50)***		***Northing (UTM ED 50)***		***Period***
Deurganckdok (in dock) (transect Y)	Left Bank	Right Bank	Left Bank	Right Bank	21/03/2006, 26/09/2006 & 12/03/2008
	589059	591298	5684948	5683077	
Liefkenshoek (transect I)	Left Bank	Right Bank	Left Bank	Right Bank	22/03/2006, 27/09/2006 & 11/03/2008
	590318	590771	5684257	5683302	
Deurganckdok (downstream) (transect K)	Left Bank	Right Bank	Left Bank	Right Bank	22 - 23/03/2006, 27 - 28/09/2006 & 11/03/2008
	588484	589775	5684924	5685384	
Deurganckdok (entrance) (transect DGD)	Left Bank	Right Bank	Left Bank	Right Bank	22/03/2006, 27/09/2006, 24/10/2007, 11/03/2008, 19-26/06/2008 24-30/09/2008 2-10/12/2008 6-12/03/2009
	588765	588541	5684056	5684527	
Schelle (transect S)	Left Bank	Right Bank	Left Bank	Right Bank	23/03/2006 & 28/09/2006
	592645	592953	5665794	5665682	
Waarde (transect W)	Left Bank	Right Bank	Left Bank	Right Bank	23/03/2006 & 28/09/2006
	573541	571318	5696848	5694933	
Deurganckdok (in dock) (Transect X, transect Y, transect Z)	North Side	North Side	South Side	South Side	01/10/2008
	588737	5684638	588408	5684107	
	588793	5684520	588465	5683989	
	588850	5684402	588521	5683871	

Table 3-9:Through-tide measurements on transects in 2009-2012 (CDW project).

Through tide measurements: Transects					
Location	***Easting (UTM ED 50)***		***Northing (UTM ED 50)***		***Period***
Deurganckdok (in dock) (transect DGD)	Left Bank	Right Bank	Left Bank	Right Bank	28/09/2011, 06/10/2011, 13/10/2011, 08/03/2012 & 16/03/2012
	588 541	588 765	5 684 527	5 684 056	
Deurganckdok (in dock) (transects 1 to 4)	Left Bank	Right Bank	Left Bank	Right Bank	02/03/2010, 29/09/2011 & 12/03/2012
	588254	588838	5683880	5684844	
	588330	588891	5683836	5684763	
	588406	588945	5683791	5684681	
	588482	588998	5683746	5684599	

Table 3-10 : Through-tide measurements with SiltProfiler in 2006-2009 & 2009-2012 (DGD & CDW projects).

Through tide measurements: Siltprofiler gauging points			
Location	***Easting (UTM ED 50)***	***Northing (UTM ED 50)***	***Period***
Location 1: Xa	588549	5684335	DGD: 21/03/2006 26/09/2006 23/10/2007 12/03/2008 29/09/2008 13/03/2008 CDW: 27/09/2011 09/03/2012
Location 2: Xb	588596	5684411	
Location 3: Xc	588643	5684486	
Location 4: Xd	588690	5684562	
Location 5: Xe	588737	5684638	
Location 6: Ya	588606	5684217	
Location 7: Yb	588653	5684293	
Location 8: Yc	588700	5684368	
Location 9: Yd	588747	5684444	
Location 10: Ye	588793	5684520	
Location 11: Za	588662	5684099	
Location 12: Zb	588709	5684174	
Location 13: Zc	588756	5684250	
Location 14: Zd	588803	5684326	
Location 15: Ze	588850	5684402	

3.1.5 Near-bed monitoring

Table 3-11 and Table 3-12 list the location and deployment periods of the near-bed monitoring frames in 2006-2009 and in 2009-2012. Table 3-11 also contains the location of the settling velocity measurements in 2006.

Frames are placed at predefined measurement points for the near-bed monitoring (Figure 3-14 and Figure 3-18). In 2009-2012 the frame at the North bank has been replaced by two frames, one on each side of the now existing CDW. They are equipped with a series of instruments described in the factual data reports (see paragraph 3.2.1). Settling velocity measurements have been carried out with the INSSEV instrument at the locations identified in Figure 3-15.

Table 3-11 : Continuous near-bed measurements in 2006-2009 (DGD project ; before CDW).

Near bed continuous monitoring			
Location	***Easting (UTM ED 50)***	***Northing (UTM ED 50)***	***Period***
Deurganckdok CDW	588653	5684906	14/03/2006 – 05/04/2006
Deurganckdok CDW	588685	5684880	19/04/2006 – 23/05/2006
Deurganckdok Sill	588805	5684170	19/04/2006 – 23/05/2006
Deurganckdok CDW	588685	5684880	18/07/2006 – 11/10/2006
Deurganckdok Sill	588805	5684170	19/07/2006 – 11/10/2006
Deurganckdok CDW	588685	5684880	15/03/2007 – 12/04/2007
Deurganckdok Sill	588805	5684170	09/02/2007 – 18/04/2007
Deurganckdok CDW	588685	5684880	26/09/2007 – 05/12/2007
Deurganckdok Sill	588805	5684170	10/10/2007 – 28/11/2007
Deurganckdok CDW	588685	5684880	20/02/2008 – 02/04/2008
Deurganckdok Sill	588805	5684170	27/02/2008 – 09/04/2008
Settling velocity – INSSEV			
Location	***Easting (UTM ED 50)***	***Northing (UTM ED 50)***	***Period***
Deurganckdok CDW	588717	5684898	05/09/2006
Deurganckdok SILL	588800	5684250	06/09/2006
Deurganckdok Western quay wall	588452	5684355	07/09/2006

Table 3-12: Continuous near-bed measurements in 2009-2012 (CDW project ; after CDW).

Near bed continuous monitoring			
Location	***Easting (UTM WGS84)***	***Northing (UTM WGS84)***	***Period***
Deurganckdok CDW down	588 497	5 684 986	15/09/2011 – 14/10/2011 28/02/2012 – 21/03/2012
Deurganckdok CDW up	588 537	5 684 423	15/09/2011 – 14/10/2011 29/02/2012 – 20/03/2012
Deurganckdok Sill	588 714	5 683 929	13/09/2011 – 14/10/2011 29/02/2012 – 20/03/2012

3.1.6 Long-term salinity and SSC measurements

Table 3-13 and Table 3-14 list the location and deployment periods of the long-term SSC and salinity measurements in Deurganckdok in 2006-2009 and in 2009-2012. Measurements have been carried out with OBS sensors hanging from the quays.

Table 3-13 : Long-term salinity and SSC measurements in 2006-2009 (DGD project).

Salt Silt measurements Deurganckdok			
Location	***Easting (UTM ED 50)***	***Northing (UTM ED 50)***	***Period***
P&O 1	588074	5682942	17/03/2006 – 28/04/2006
P&O 2	588767	5684045	17/03/2006 – 28/04/2006
PSA	588536	5684523	17/03/2006 – 28/04/2006
P&O 1	588074	5682942	20/07/2006 – 12/10/2006
P&O 2	588767	5684045	20/07/2006 – 12/10/2006
PSA	588536	5684523	20/07/2006 – 12/10/2006
P&O 1	588074	5682942	12/02/2007 – 27/03/2007
P&O 2	588767	5684045	12/02/2007 – 27/03/2007
PSA	588536	5684523	12/02/2007 – 27/03/2007
P&O 1	588074	5682942	20/06/2007 – 31/07/2007
P&O 2	588767	5684045	20/06/2007 – 31/07/2007
PSA	588536	5684523	20/06/2007 – 31/07/2007
P&O 1	588074	5682942	17/09/2007 – 10/12/2007
P&O 2	588767	5684045	17/09/2007 – 10/12/2007
PSA	588536	5684523	17/09/2007 – 10/12/2007
N entrance (PSA HNN)	588536	5684523	20/02/2008 – 28/04/2008
S entrance (DB Ports)	588767	5684045	20/02/2008 – 28/04/2008
S middle (DB Ports)	588074	5682942	20/02/2008 – 28/04/2008
S back (DB Ports)	587760	5682449	20/02/2008 – 28/04/2008
N entrance (PSA HNN)	588536	5684523	28/04/2008 – 31/03/2009
S entrance (DB Ports)	588767	5684045	28/04/2008 – 31/03/2009
S middle (DB Ports)	588074	5682942	28/04/2008 – 31/03/2009
S back (DB Ports)	587760	5682449	28/04/2008 – 31/03/2009

Table 3-14 : Long-term salinity and SSC measurements in 2009-2012 (CDW project).

Salt Silt measurements Deurganckdok			
Location	***Easting (UTM ED 50)***	***Northing (UTM ED 50)***	***Period***
N entrance (PSA HNN)	588536	5684523	01/04/2009 – 31/03/2010
S entrance (DB Ports)	588767	5684045	01/04/2009 – 31/03/2010
N entrance (PSA HNN)	588536	5684523	01/06/2011 – 30/05/2012
S entrance (DB Ports)	588767	5684045	01/06/2011 – 30/05/2012

3.1.7 Continuous monitoring in the Lower Sea Scheldt

Table 3-15 presents the locations and periods of data availability of the continuous monitoring stations in the Lower Sea Scheldt used in this report. Except for Prosperpolder which only has one RCM9 sensor, each station consists of two RCM9 instruments deployed near the surface and near the bed. Their deployment depth is also indicated in the table. Some RCM9 sensors at buoy 84 and at Oosterweel were replaced by AADI Seaguard sensors starting from 2009 (IMDC, 2011c ; 2012f ; 2012p), and the RCM9 at Prosperpolder was replaced by a CTD sensor in 2011 (IMDC, 2012p).

Table 3-15 : Long-term measurements in the Lower Sea Scheldt in 2006-2009 (DGD project).

	Easting [UTM ED50]	***Northing [UTM ED50]***	***Period***	***[m] above botttom***	***Elevation [m TAW]***
Buoy 84	588971	5686097	Oct2005 – May2010	3.3	-5.8
			Jul2010 – Apr2012	0.8	-8.1
Buoy 97	590932	5683350	Oct2005 – Jul2008	3.3	-5.1
				0.8	-7.5
Oosterweel	595 574	5 677 278	Oct2005 – May2012	4.5	-2.3
				1.0	-5.8
Prosperpolder	586 307	5 689 501	Jul2006 – Apr2012	2.5	-1.5

3.2 PERFORMED ANALYSES

During the course of the Deurganckdok projects the collected data has been described in a series of reports. The next paragraphs give a specific overview and references of what has already been done with the data, and of preliminary conclusions about the effect of the CDW.

3.2.1 Previously reported data analyses

In this section an overview is given of analyses executed on DGD data in the past. Report numbers refer to the project specific numbering defined in Table 1-1.

- Sediment balance: Bed measurements in Deurganckdok (Reports 1.1 - 1.24 of DGD project, 1.1 to 1.3 of CDW project)
    - difference maps of bed elevation
    - temporal evolution of bed elevation at specified sections and zones
    - volumetric siltation rates in specified zones
        - gross yearly averaged siltation rate
        - natural siltation rate
    - depth of equal density layers (from density measurements)
    - computed total sediment mass (from density measurements)
    - dredged sediment amounts from maintenance and capital dredging
    - temporal evolution of tide prism by capital dredging operations
- Quay-wall continuous monitoring at entrance, center and back of dock (Reports 2.6 – 2.8, 2.16 – 2.18, 2.32, 2.33 of DGD project) and at entrance only (Reports 2.8, 2.9 of CDW project)
    - weekseries of salinity, suspended sediment concentration, temperature and water level
    - average tidal cycles of salinity, suspended sediment concentration and temperature, and their (cross-dock, along-dock and diagonal) gradients
- Near-bed continuous monitoring, South of sill and near the future CDW (Reports 2.6 – 2.8, 2.16 – 2.18 of DGD project), and South of sill, upstream and downstream of the CDW (Reports 2.10, 2.11 of CDW project)
    - time series of suspended sediment concentration near bottom
    - time series of bottom elevation and water level
    - tidal evolution (ebb – flood) of suspended sediment concentration in 10 equidistant layers in 1 m above the bottom
    - time series of velocity, suspended sediment concentration and sediment mass flux 0.5 and 1 m above bottom
    - tidal evolution (ebb – flood) of suspended sediment concentration, velocity and sediment mass flux 0.5 and 1 m above bottom
- Dock entrance and along-dock transect: profiling (Reports 2.1, 2.2, 2.10, 2.11, 2.15, 2.29 – 2.31 of DGD project, 2.10, 2.11 of CDW project)
    - vertical profiles of suspended sediment concentration, salinity and temperature
    - time evolution of the above-mentioned vertical profiles
    - transects of suspended sediment concentration, salinity and temperature (3 depths)
    - bottom elevation

  - averaged values of suspended sediment concentration, salinity and temperature for the entire water column, and the top and bottom 50% of the water column
- Dock entrance: transect along sill (Reports 2.3 – 2.5, 2.14, 2.20 – 2.27 of DGD project, 2.1 – 2.4 of CDW project)
  - transects of suspended sediment concentration, velocity and sediment mass flux
  - time series of discharge and sediment mass flux
- Dock entrance: transects X, Y and Z perpendicular to dock's axis (Report 2.28 of DGD project) or transects 1 to 4 also perpendicular (Reports 2.5 – 2.7 of CDW project)
  - Transects of vertical flow velocity profiles
  - Depth averaged flow velocity in top 12m: vector fields
  - Eddy development and intensity
- Buoy 84 and 97 (Reports 3.1, 3.10 – 3.14, 3.20, 3.21 of DGD project, 1.4 – 1.6 of CDW project)
  - time series of suspended sediment concentration, local velocity, temperature and water level: measured near bottom and at half of the water column
  - monthly and three-monthly averages, minima and maxima in relation of the tide
- Scheldt area around Deurganckdok (Reports 2.12, 2.13 of DGD project)
  - transects of suspended sediment concentration, velocity and sediment mass flux
- Deurganckdock: inside and entrance area (Report 9 of HCBS project)
  - particle size distribution of both bed and suspended sediment
  - bed: sediment composition, zeta potential, consolidation, shear strength, capillary suction time
  - water column: settling velocity
  - velocity: local and profile

3.2.2 Previously reported conclusions about the effect of the CDW

The development and construction of the Current Deflecting Wall (CDW ; Figure 3-19) is a long process dating back to 1997. A synthesis of the development process of the CDW has been given in report 1.7 of the present project (IMDC, 2011d). From this synthesis report the CDW is expected to have the following main impacts :

- During flood the CDW should <u>divert the surface flow inside the dock and the bottom flow towards the Scheldt river</u>.
- By streamlining the flow, <u>the CDW mainly reduces the eddy component</u> of the total water exchange at the dock (and affects only indirectly the tidal and density components). This explains the lower expected efficiency compared to the port of Hamburg, where density currents are not an issue.
- <u>The sedimentation in the dock is expected to reduce by 10 to 20%</u> based on numerical results. This has to be compared to the total water and sediment exchange before building the CDW. The water exchange between the dock and the Scheldt is due for 15% to tidal

filling, for 20% to eddy formation and for 65% to density currents (total around 45 Mm³/tide). The sediment exchange is due for 25% to tidal filling, for 10% to eddy formation and for 65% to density currents according to the previous application of the conceptual sedimentation model (IMDC, 2009o), for a mean total of 1200 TDS/tide.

- Based on numerical results, a slight increase by 8% of the sedimentation rate can be expected from removing the entrance sill.

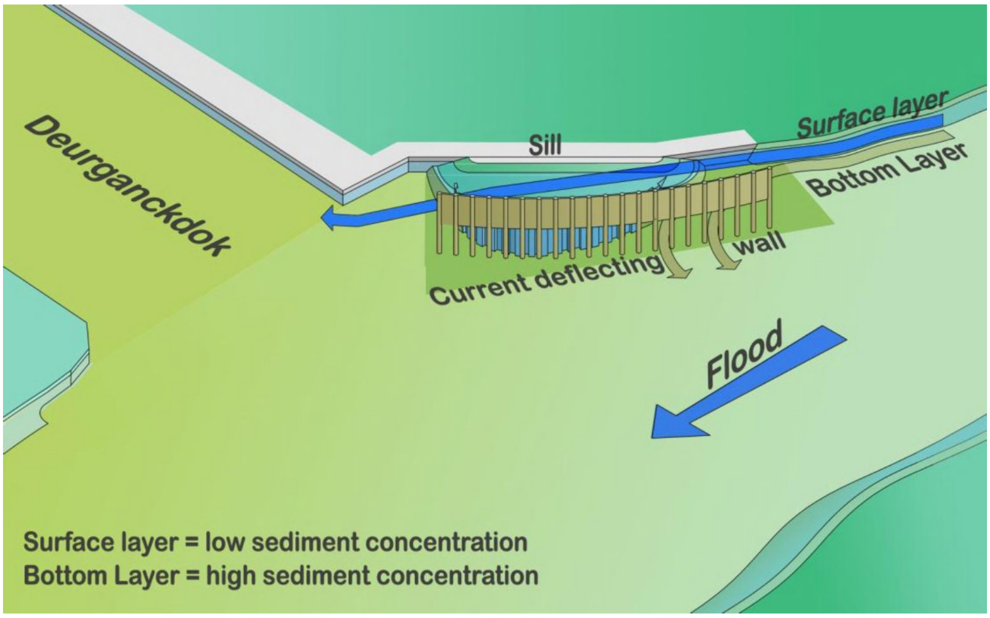

Figure 3-19 : Schematisation of the Current Deflecting Wall.

In the data reports posterior to August 2011, an attempt has been made to compare measurements with those prior to the construction of the CDW. The following preliminary conclusions have been made:

- Mass balance :
    - The only measuring year after completion of the CDW (2011-2012) has been marked by intense dredging activity and a deeper maintenance depth. As a consequence natural siltation rates cannot be reliably estimated and no reliable comparison with previous years is possible (IMDC, 2012m; report 1.3).
- Through tide measurements :
    - Cross dock ADCP : A comparison of spring tide measurements (IMDC, 2012a, 2012g ; reports 2.1, 2.3) before and after CDW shows a clear reduction of the eddy at two moments during the tide (HW-3h and HW-1). Neap tide measurements (IMDC 2012b, 2012h ; reports 2.2, 2.4) also suggest such a reduction but less clearly. The effect of the CDW on the SSC cannot be assessed due to the high temporal variability of the SSC depending on external conditions. Both low and high SSC, net deposition and trapping efficiency have been measured with the CDW (500 and 900 TDS/tide during neap tide, 2300 and 3400 TDS/tide during spring tide, trapping between 28% and 56%).

  - Along dock ADCP : A comparison of velocity maps without and with CDW at HW-1h of spring tide suggests no clear change in flow pattern (IMDC, 2012c, 2012k ; reports 2.6, 2.7).

- Near bed monitoring :
  - Frames : Frames have been deployed during periods of a few weeks each time, and measurements have been compared by season in the reports to account for seasonal variability of the SSC. The measured SSC at the sill (South entrance ; Figure 3-18) is comparable with and without CDW both during summer/autumn conditions (IMDC, 2012d ; report 2.10) and during winter/spring conditions (IMDC, 2012l ; report 2.11). The measurements at the CDW downstream frame (Figure 3-18) show a clear tidal variation, with a SSC peak during flood, while the two other frames display a less clear pattern due to local effects. Despite these local effects, measurements still suggest the presence of a flood eddy and density currents at the dock entrance with CDW (IMDC, 2012d ; report 2.10). A lower SSC is reported South (sill frame) except during HW and LW when it is higher than North (CDW upstream frame) : this is the opposite of what is usually observed in long-term salinity measurements before the CDW, but these differences may be due to different measurement locations compared to the sensors along the quays.
  - SiltProfiler : SSC measurements are high for autumn 2011 measurements (IMDC, 2012d ; report 2.10) and low for winter 2012 measurements (IMDC, 2012l ; report 2.11) compared to without CDW. The SSC is generally higher South than North : this is the opposite of what is usually observed in long-term salinity measurements before CDW but it may be due to different locations. No clear decrease of the SSC due to the CDW is visible during flood.

No comparison is made yet of long-term salinity and SSC measurements without and with CDW (IMDC, 2012n ; 2.9), nor of boundary conditions before and after construction of the CDW (IMDC, 2012p ; report 1.6).

Some of the preliminary conclusions above derived from a first analysis seem not to match. This is expected since each report is based on a limited amount of data. In particular no conclusion has been made about the SSC because of its high natural variability, which requires an integrated analysis of all data collected (goal of the present report). The present report will revisit these conclusions when necessary.

4. SEDIMENTATION MODEL

4.1 INTRODUCTION

A conceptual sedimentation model based on data assimilation has been developed to estimate the sediment influx and deposition due to the three main water exchange mechanisms at the dock entrance : tidal filling, density currents and eddy currents (IMDC, 2008b, 2008s, 2009o ; reports 4.01, 4.10 and 4.20 of the DGD project). In this chapter, this model is further developed to estimate the sedimentation in the dock since its construction and in particular to model the impact of the CDW on the sedimentation.

A concise overview of the current state of the model and relevant past assumptions is presented below. Modifications applied in this project are explained and justified.

4.2 MODEL CONCEPT

The model assumes that the water exchange can be split into three water exchange components : tidal filling, density currents and eddy currents. The sedimentation in the dock is computed as the sum of net sediment fluxes for each exchange mechanism.

$$F_{total} = F_{tide} + F_{density} + F_{eddy}$$

The expression used for each net flux has been chosen based on a mix of physics and observations. While ideally fluxes are computed as the space and time integral of the instantaneous velocity times the sediment concentration, limited data and ease of use require to reduce these integrals which are highly variable in time to single values for one tidal cycle. In that way the expressions reduce to well-identified forcing factors with few calibration parameters.

The main data sources used in this chapter are the long-term measurements of salinity and SSC and the 13h measurements at the dock entrance.

4.2.1 Tidal filling

Tidal filling brings a known amount of water into the dock with a given concentration. The influx of sediment during flood is then defined as the tidal prism times a tidally-averaged concentration (variable at a larger time scale). Of this influx a fraction $\alpha_{set,tide}$ settles and is not evacuated during ebb. The net sediment flux due to tidal filling is then defined as :

$$F_{tide} = \alpha_{set,tide} . V_{prism} . c(t)$$

$$F_{tide} = \alpha_{set,tide} . \left(h(t) . A_h\right) . c(t)$$

where

- $\alpha_{set,tide}$ is the fraction of the influx settling in the dock
- h(t) is the tidal amplitude

- A_h is the horizontal dock area
- c(t) is the tidally averaged sediment concentration

The sediment concentration is computed per day as the spatial average of the daily average of the four measuring stations at the entrance.

4.2.2 Density currents

Density currents arise from an initially horizontal difference in density which is compensated by a water level gradient. The imbalance of hydrostatic forces over the vertical drives a two-layer current with the near-bed current towards the lower density region and the surface current in opposing direction.

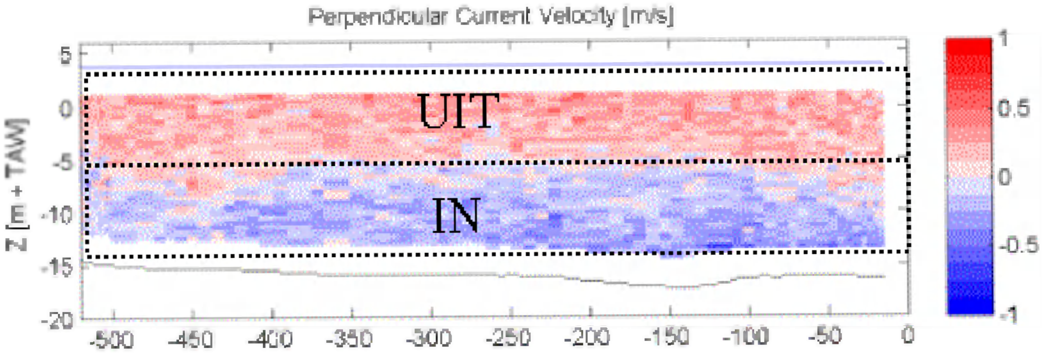

Figure 4-1: Example of density current at high water at the dock entrance (v>0 leaves the dock). Measurement before CDW.

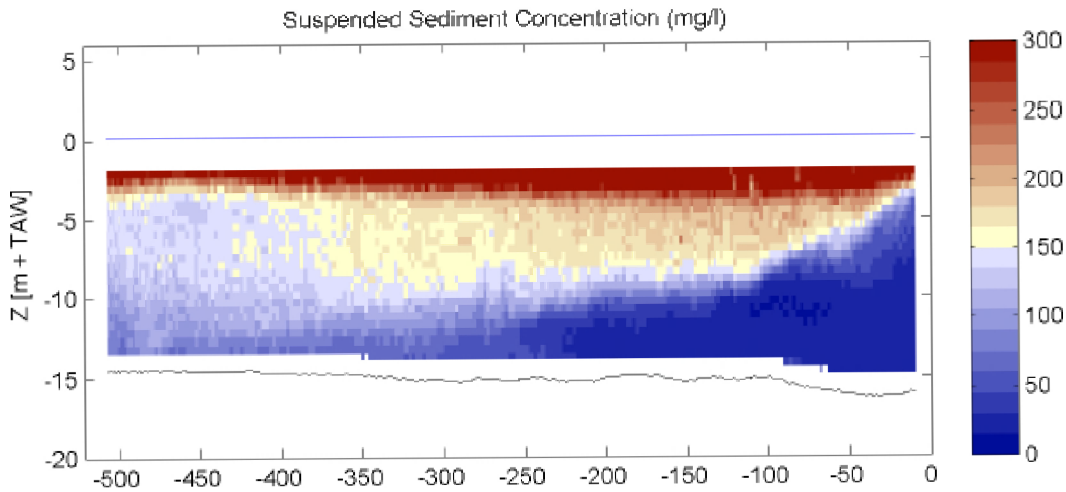

Figure 4-2: Example of inverse sediment concentration profile during low water density current at the dock entrance, when water from the Scheldt enters the dock near the surface. Measurement before CDW, not related to Figure 4-1.

The density current velocity (Kranenburg, 1996) can be expressed as

$$v_{dens} = 0.5\sqrt{\frac{\Delta\rho}{\rho} gH_{dock}}$$

where

- ρ is the density
- Δρ is the density difference between the two layers (so vertical or horizontal)
- g is the gravity constant
- H_{dock} is the depth of the dock

The two layers of the density current are assumed to be of the same thickness and the current in each layer of equal magnitude. The density current distribution is assumed to be uniform over the entire dock cross-section and to last a certain duration during the tidal cycle in order to yield a volume of water exchanged in a tidal cycle. Like tidal filling, the net sediment flux is given by multiplying the influx with a tidally-averaged concentration and only a fraction $\alpha_{set,tide}$ settles in the dock :

$$F_{dens} = \alpha_{set,dens}.V_{dens}.c(t)$$

$$F_{dens} = \alpha_{set,dens}.\left(\frac{A_{cs}}{2}.\left(0.5\sqrt{\varepsilon(t)gH_{dock}}\right).T_{dens}\right).c(t)$$

where

- $\alpha_{set,dens}$ is the fraction of the influx settling in the dock
- A_{cs} is the cross-sectional entrance area
- ε(t)= Δρ/ρ is the relative density difference (computed from salinity difference)
- T_{dens} is the measured duration of the density currents

4.2.3 Eddy currents

The tidal eddy during flood results in water entering the dock via the Southern half of the entrance and leaving it via the Northern half. This process is reversed during ebb.

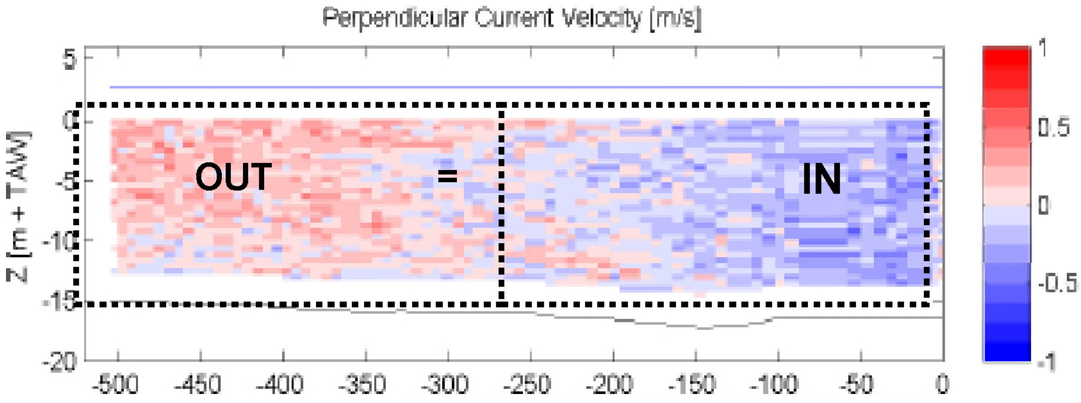

Figure 4-3 : Example of eddy circulation during flood at the dock entrance (v>0 leaves the dock). Measurement before CDW.

The eddy current velocity is taken as a measured average value modulated by the tidal coefficient. Like the density current, the eddy current is assumed to be equally strong in the two halves of the entrance but with an opposing sign, and it is assumed to last a certain duration (T_{dens}) during the tidal cycle. The net sediment flux is given by multiplying the influx with a tidally-averaged concentration and only a fraction $\alpha_{set,tide}$ settles in the dock :

$$F_{eddy} = \alpha_{set,eddy} . V_{eddy} . c(t)$$

$$F_{eddy} = \alpha_{set,eddy} . \left(\frac{A_{cs}}{2} \bar{v}_{eddy} \frac{h(t)}{\bar{h}} T_{eddy} \right) . c(t)$$

where

- $\alpha_{set,eddy}$ is the fraction of the influx settling in the dock
- v_{eddy} is the measured mean eddy velocity
- h and h(t) are respectively the average and the daily tidal amplitude
- T_{eddy} is the measured duration of the eddy

In theory the mean eddy velocity depends on the tidal amplitude, with a stronger eddy during spring tide. Here a constant average value is taken and a lower and higher values are used to determine the uncertainty band.

The previous version of the sedimentation model (IMDC, 2009o) also includes a correction factor to account for the fact that the mixing zone (and the eddy) is moving in and out of the dock during the tidal cycle. According to Eysink (1989), this effect reduces the water exchange (velocity) due to the eddy by a fraction β of the tidal exchange (velocity) :

$$\frac{1}{2}\bar{v}_{eddy}\frac{h(t)}{\bar{h}} \rightarrow \left(\frac{1}{2}\bar{v}_{eddy}\frac{h(t)}{\bar{h}}\right) - \beta\bar{v}_{tide}$$

with

$$\bar{v}_{tide} = \frac{V_{prism}}{A_{cs}.T_{tide}/2} = \frac{2A_h h(t)}{A_{cs}T_{tide}}$$

where

- β is the correction factor of Eysink (0.05)
- v_{tide} is the computed mean velocity due to tidal filling
- T_{tide} is the tidal period

However since v_{tide} ~ 5cm/s, v_{eddy} ~ 10cm/s and β=0.05, v_{eddy} >> βv_{tide} and this correction is negligible in the present case. For simplicity we will continue without this correction. For comparison v_{dens} ~ 30cm/s.

4.2.4 Settling coefficients

The settling coefficients can be interpreted as the trapping efficiency of the individual exchange mechanisms. They are determined in the following way :

- For density currents, the settling coefficient is calculated from the vertical SSC gradient. Strictly speaking it is equal to the influx minus the outflux divided by the influx:

$$\alpha_{set,dens} = \frac{F_{dens,in} - F_{dens,out}}{F_{dens,in}}$$

With the previous assumptions that the two layers of the density current are assumed to be of the same thickness and the current in each layer of equal magnitude, the following expression is valid :

$$\alpha_{set,dens} = \frac{\overline{\Delta c}_{z,HW} - \overline{\Delta c}_{z,LW}}{c_{NBOT,HW} + c_{SBOT,HW} + c_{NTOP,LW} + c_{STOP,LW}}$$

However because these assumptions are sometimes violated, unrealistic values of $\alpha_{set,dens}$ are sometimes obtained (above 1 or below 0). To reduce this, the denominator was replaced by the maximum SSC during flood and ebb in previous reports :

$$\alpha_{set,dens} = \frac{\overline{\Delta c}_{z,HW}}{\max\left(\bar{c}_{BOT,HW}, \bar{c}_{TOP,HW}\right)} - \frac{\overline{\Delta c}_{z,LW}}{\max\left(\bar{c}_{BOT,LW}, \bar{c}_{TOP,LW}\right)}$$

where the overbar denotes the mean over North and South for Δc_z and the mean over both bottom or both top sensors for c_{BOT} and c_{TOP} respectively. The first and second formula will be respectively called “correct” and “original” formulae.

- For eddy currents, the settling coefficient is calculated from the horizontal SSC gradient. A correction factor 0.5 is applied on the ebb contribution to account for the weaker eddy during ebb than during flood. Similar to the density currents, the correct and the original formulae respectively read :

$$\alpha_{set,dens} = \frac{0.5\overline{\Delta c}_{B,ebb} - \overline{\Delta c}_{B,flood}}{0.5c_{NBOT,ebb} + 0.5c_{NTOP,ebb} + c_{SBOT,flood} + c_{STOP,flood}}$$

and

$$\alpha_{set,dens} = 0.5\frac{\overline{\Delta c}_{B,ebb}}{\max\left(\overline{c}_{S,ebb}, \overline{c}_{N,ebb}\right)} - \frac{\overline{\Delta c}_{B,flood}}{\max\left(\overline{c}_{S,flood}, \overline{c}_{N,flood}\right)}$$

where the overbar denotes the mean over bottom and top for Δc_B and the mean over both South or both North sensors for c_S and c_N respectively.

- For tidal filling, the remaining settling coefficient is derived such that the global trapping efficiency derived from the 13h measurement campaigns is reproduced, given the relative importance of each sediment exchange mechanism (tidal filling, eddy current, density current) estimated from the previous application of the conceptual sedimentation model :

$$w_{dens}\alpha_{set,dens} + w_{eddy}\alpha_{set,eddy} + w_{tide}\alpha_{set,tide} = \alpha_{global}$$

where the three first weights below have themselves been estimated with the sedimentation model (IMDC, 2009o ; report 4.20 of the DGD project) and the global trapping efficiency has been measured :

  - w_{dens} = 66%
  - w_{eddy} = 10%
  - w_{tide} = 24%
  - α_{global} = 39% (global trapping efficiency, e_s in report IMDC (2009o))

The settling coefficients are calculated during a certain period in each tidal cycle during which the relevant exchange mechanism exists independently from the other mechanisms : from HW to HW+1 (HW) and from LW to LW+1 (LW) for density currents, from HW-3 to HW-2 (flood) and from LW-3 to LW-2 (ebb) for the eddy.

The reason to show the correct and original formulae is that the settling coefficients have been found to be very sensitive to the way they are calculated and the way the data has been pre-processed (amongst other, additional filter applied in 2006-2008, use of top sensors only for eddies in 2006-2009). Since the present analysis uses the entire data available since the construction of the dock, the pre-processing has been done again with extra insight on multiyear variability. The resulting coefficient are not exactly the same as in previous reports, but it will be shown that the sedimentation results are still comparable.

It is hence suggested to consider these settling coefficients as potential calibration coefficients, the most important point being to use the <u>same processing and calculation method before and after construction of the CDW</u>, rather than a given method.

As data is available since the construction of the dock, the pre-processing has been done again using the entire available dataset to obtain extra insight on multiyear variability. This data analysis is presented in the next chapter together with the application of the sedimentation model.

5. DATA ANALYSIS AND APPLICATION OF THE SEDIMENTATION MODEL

5.1 DATA PROCESSING

The new data pre-processing has been done in two steps. First all data which has already been delivered to the client has been merged into single time series from 2006 to 2012 per location, and cleaned based on a visual assessment of the full time series. This version will be called “first version” below.

In a second stage, based on a cross-comparison of the time series at different locations, additional periods have been identified during which some data has been judged doubtful and has been removed. This version will be called “second version” below.

5.1.1 First version of time series

The post-processed data provided as output of each past report to the client has been used as a starting point. All files have been pre-cleaned (little impact since already cleaned in previous reports), converted to a uniform file format (IMDC format with 12 columns for all parameters) and merged into single time series per measurement location:

- North entrance bottom sensor (NBOT)
- North entrance top sensor (NTOP)
- South entrance bottom sensor (SBOT)
- South entrance top sensor (STOP)
- Buoy 84 bottom sensor (B84BOT)
- Buoy 84 top sensor (B84TOP)
- Buoy 97 bottom sensor (B97BOT)
- Buoy 97 top sensor (B97TOP)
- Oosterweel bottom sensor (OWBOT)
- Oosterweel top sensor (OWTOP)
- Prosperpolder sensor (PROSP)

Similar time series have been generated for the boundary conditions :

- Tide (at Liefkenshoek)
- Discharge (at Schelle ; daily value before April 2009, 5 day average after April 2009)
- Dredging (from BIS and weekly reports)

Data from the first version of these time series can be found in annex A.1 for some relevant parameters (turbidity, SSC, salinity, temperature, all with tide and discharge).

The abbreviations given in parentheses are used in the rest of the report to identify a particular sensor.

5.1.2 Second version of time series

Based on the long time series and correlations or lack of correlations observed between different locations, additional cleaning has been done to remove doubtful data. The time series have also been interpolated to a uniform time vector to simplify usability. The following data has been removed:

- Removed salinity at NTOP from 15/3/2006 to 30/4/2006 (3 ppt lower than other sensors at dock entrance despite good match between sensors over the remaining time series)
- Removed salinity at STOP from 18/6/2008 to 23/10/2008 (drifting compared to other sensors at the dock entrance)
- Removed salinity at NBOT, NTOP, SBOT and STOP from 1/7/2006 to 1/11/2006 (up to 8ppt higher than at buoy B84 despite good match between sensors over the remaining time series)
- Removed salinity at B84TOP from 26/7/2008 to 11/2/2009 (drifting compared to B84BOT)
- Removed salinity at B84TOP from 16/6/2009 to 9/9/2009 (drifting compared to B84BOT)

The time series obtained are very similar to those in annex A.1 and are not presented here.

5.1.3 Time series of daily values

The second version of the time series has finally been converted to daily statistics of the parameters (mean, minimum and maximum daily values, delta value defined as the daily maximum minus the daily minimum and number of data values measured each day). The salinity and tidal amplitudes are necessary for the sedimentation model (delta values), and the daily mean SSC is much easier to interpret than its instantaneous value. Strictly speaking averaging intervals of two tidal cycles would be better (24h 50min), the impact of the use of daily values has been deemed acceptable.

For the sedimentation model, complete time series are necessary over the entire period. Therefore gaps in salinity and in SSC at the dock entrance have been filled by correlations with other available observations in the Scheldt :

- For the <u>salinity</u>, all sensors listed in paragraph 5.1.1 correlate well between each other (correlation coefficient R=0.98 for Figure 5-1), except Oosterweel which is further upstream and closer to the salinity wedge. Gaps at all stations are therefore filled with a linear regression with B84BOT (largest data availability ; Figure 5-1), remaining gaps with a linear regression with B84TOP.
- For the <u>turbidity</u> and the <u>SSC</u>, correlations are much weaker due to the high local variability at the dock entrance. Nonetheless, periods of high daily mean SSC correlate reasonably well between sensors in the Scheldt and near the dock entrance (correlation coefficient R=0.57 for Figure 5-2). Gaps have been filled with a linear regression with the mean value of B84BOT and B97BOT at the bottom (Figure 5-2), and with the mean value of B84TOP and B97TOP at the top.

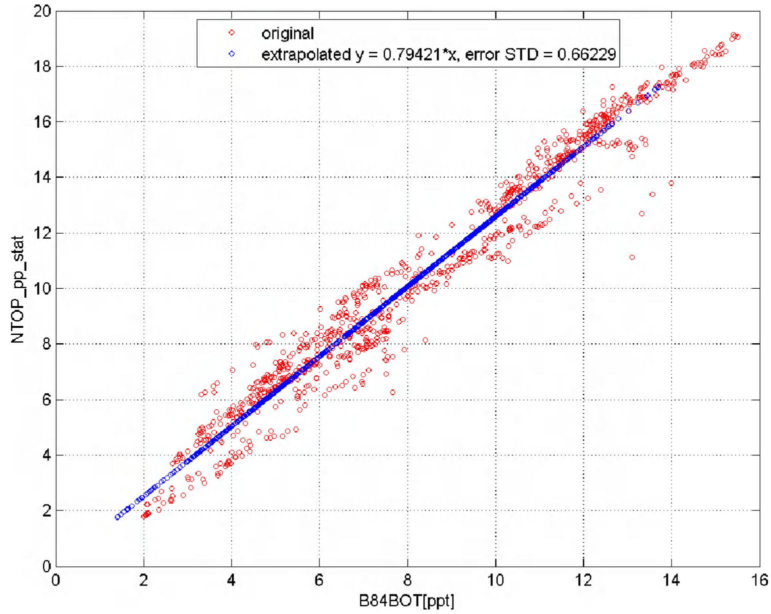

Figure 5-1 : Example of linear regression to fill salinity gaps at NTOP from data at B84BOT.

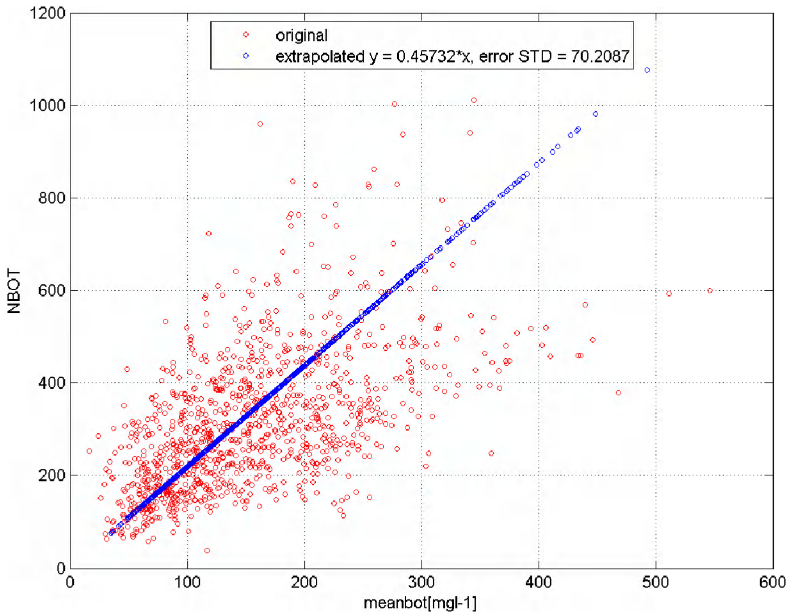

Figure 5-2 : Example of linear regression to fill SSC gaps at NBOT from the mean value of data at B84BOT and B97BOT.

In previous reports (IMDC 2008b, 2008s, 2009o) gaps have not been filled in the same way (period 2006-2008). Below the previously applied procedures are explained and discussed :

- <u>Salinity</u> amplitude gaps were previously filled with the average of the salinity amplitude at B84 and B97 (top or bottom not specified) multiplied by an amplification factor based on the average salinity at B84 and B97. It is our opinion that this approach cannot be used for longer datasets because different functions were used for the amplification factor in 2006-2007 and in 2007-2008, and because it was using doubtful salinity data in July to November 2006 (see paragraph 5.1.2). It was mainly used because of the limited data available at that time.

- SSC gaps were previously filled with a combination of the tidal coefficient, a predictor of the position of the estuarine turbidity maximum (ETM) and a 5 day low-pass filter to smooth out the results. This predictor has been tested again for various values of the calibration parameters (not reported) and was not found to yield improvement over a simple linear regression. It is likely that the good correlation reported was mainly due to the filter applied and to the short time series available at that time. The cause of the scatter in the regression in Figure 5-2 (as well as in the ETM predictor) is mainly related to the presence of strong local effects and high variability near the dock entrance. It is illustrated on Figure 5-8 by the fact that the daily time series are relatively smooth at B84 and B97 (and agree quite well), while peaks are much more chaotic near the dock entrance.

Data from the time series of daily values can be found in annex A.2 for some relevant parameters.

5.2 DATA ANALYSIS

Below the time series are presented and discussed.

5.2.1 Full time series

The full time series can be found in A3 format in annex A.1. They are for convenience also reproduced in Figure 5-4 to Figure 5-7.

The following conclusions can be drawn from the full time series 2006-2012 :

- Temperature (Figure 5-4) :
    - All sensors agree well between each other and show a clear seasonal variability, with maximum temperatures of 20 to 22°C in July and August and minimum temperatures of 2 to 5°C in December to February (Figure 5-4).
- Salinity (Figure 5-5) :
    - All sensors agree well between each other and show a seasonal variability, with a maximum salinity of 14 to 17ppt in September at buoy B84 and a minimum salinity of 2 to 4ppt at buoy B84 at some time between December and February.
    - Oosterweel shows a lower salinity and a larger salinity amplitude within the tidal cycle because it is situated further upstream, closer to the salinity wedge.
    - During periods with high fresh water discharge, the salinity drops fast as fresh water pushes the salinity wedge downstream. Events such as in November 2010 or December 2011 cause the salinity to drop suddenly from more than 10ppt to their minimum observed values. Once the fresh water discharge decreases however, the salinity wedge needs weeks to months to migrate upstream again under the action of tidal pumping.

- Turbidity and SSC (Figure 5-6 and Figure 5-7) :
    - SSC time series cannot be compared on Figure 5-7 due to the highly variable SSC peaks measured, in particular near the dock entrance. Extra conclusions are drawn in the next paragraph from the time series of daily values.
    - Some sensors on Figure 5-7 are clearly capped at a maximum NTU value they can measure (at NBOT in 2008-2009, B84TOP in spring 2011 for instance). This is normal and due to the limitations of particular instruments, it does not affect much mean values as long as capping does not exceed a couple time steps (10-30min).
    - It is worth noting that the sensors at B84 and B97 still present some relatively good agreement between each other, where the neap-spring tidal cycle is even sometimes visible (as in August and September 2008).
    - The multiyear turbidity plot (Figure 5-6) is very informative regarding the quality of the calibrations performed. The correlation between turbidity and SSC is affected by sediment characteristics and other environmental conditions, such as the presence of organic material (Campbell Scientific, 2008). This is why site-specific calibrations are performed at different times in the year. However some periods can be identified where the calibration could potentially be questioned :
        - From 2005-2012, turbidity values at B84BOT are comparable in time. However SSC values from around January 2008 to April 2010 are some 30% lower than in 2006-2007 and SSC values are 20% lower from April 2010 to April 2012, although turbidity peaks are slightly higher.
        - Similarly, SSC values from August 2007 to April 2009 at Oosterweel seem doubtfully high.

      It is likely that these differences are due to the scatter of the sample SSC rather than to variations of sediment characteristics or boundary conditions. Also note that calibration curves are either linear or quadratic depending on the periods and locations, leading to less or more pronounced peak values. Figure 5-3 at buoy B84BOT and Table 5-1 show that the accuracy of SSC especially above 500mg/l should be considered with care. From 2006 to 2012 six different instruments have been used at buoy B84BOT (5 RCM9 and 1 Seaguard).
- Dredging :
    - Maintenance dredging occurs year-round, and capital dredging occurs during periods of several months (Table 2-1). No qualitative effect of capital dredging is visible on Figure 5-7 on a yearly or monthly scale. However it would be necessary to add the exact weekly timing and volumes of dredging activities in this figure to identify potential increases in SSC. This is done in the next paragraph.

The uncertainty about the reliability of the SSC values shows that model results have to be put in context. The calibrations will not be questioned in detail, as it is not the purpose of this report. It should be kept in mind that these individual calibrations were based on limited information, that they have been performed by different institutes and persons and that the methodologies applied have changed over the years in response to observed shortcomings.

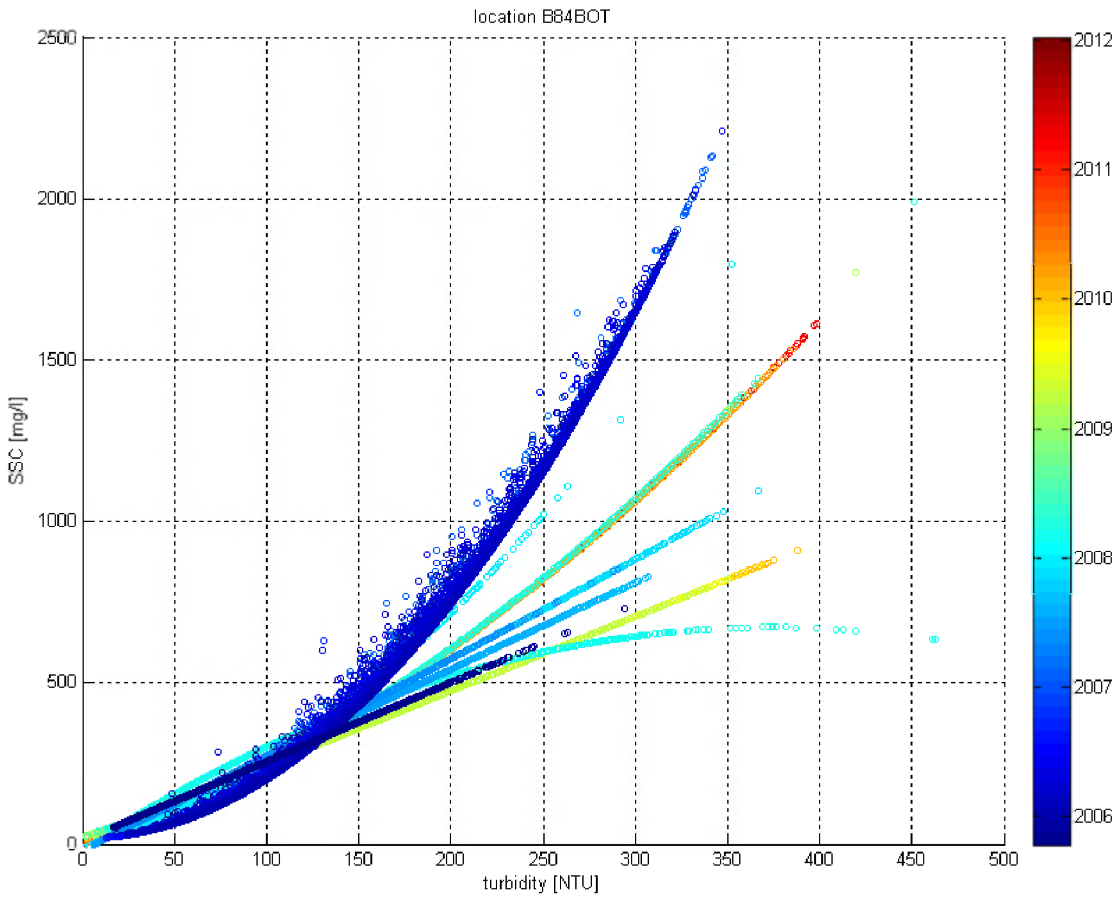

Figure 5-3 : Relation between turbidity and SSC at B84BOT from July 2005 to April 2012. The presence of distinct lines shows that different instruments and calibrations were used, the scatter between the lines shows the high variation that can be expected for high turbidity values.

Table 5-1 : Summary table of calibration campaigns

Calibration campaign	Date	Sample range	Report
Winter 2006	14/4/2006	0 – 500 mg/l	HCBS 2 6.1 (IMDC, 2006a)
Summer 2006	23/6/2006 & 18/9/2006	0 – 480 mg/l & 0 – 300 mg/l	HCBS 2 6.2 (IMDC, 2007a)
Autumn 2007	10/9/2007	0 – 340 mg/l	DGD 2.09 (IMDC, 2008f)
Winter 2008	4/2/2008	0 – 490 mg/l	DGD 2.19 (IMDC, 2008o)
Autumn 2008	27/10/2008	0 – 330 mg/l	DGD 2.34 (IMDC, 2009c)
> 2008	Done at Flanders Hydraulics	Not available	Not available

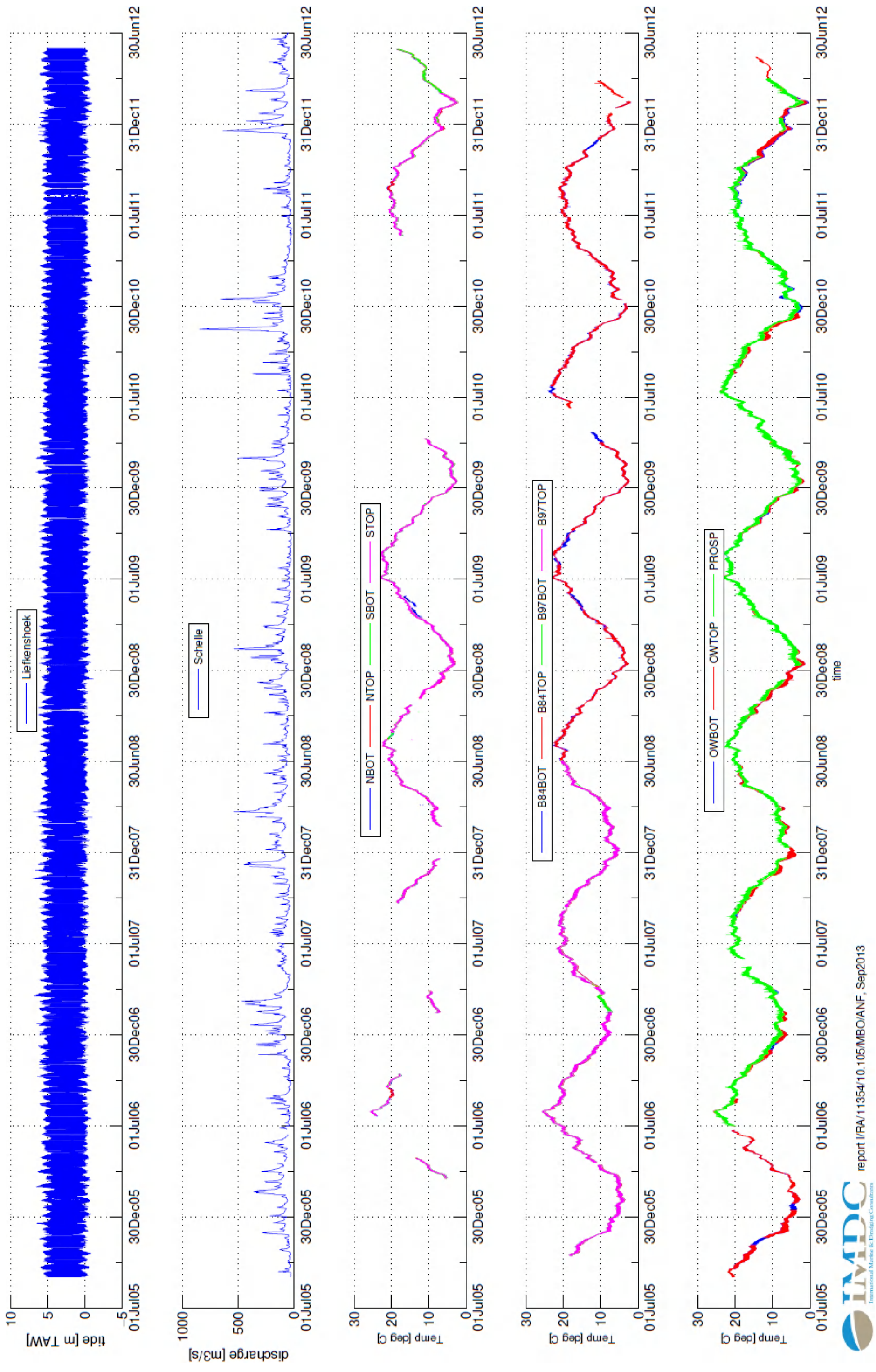

Figure 5-4 : Time series of tide, discharge, and temperature at all available locations (first version).

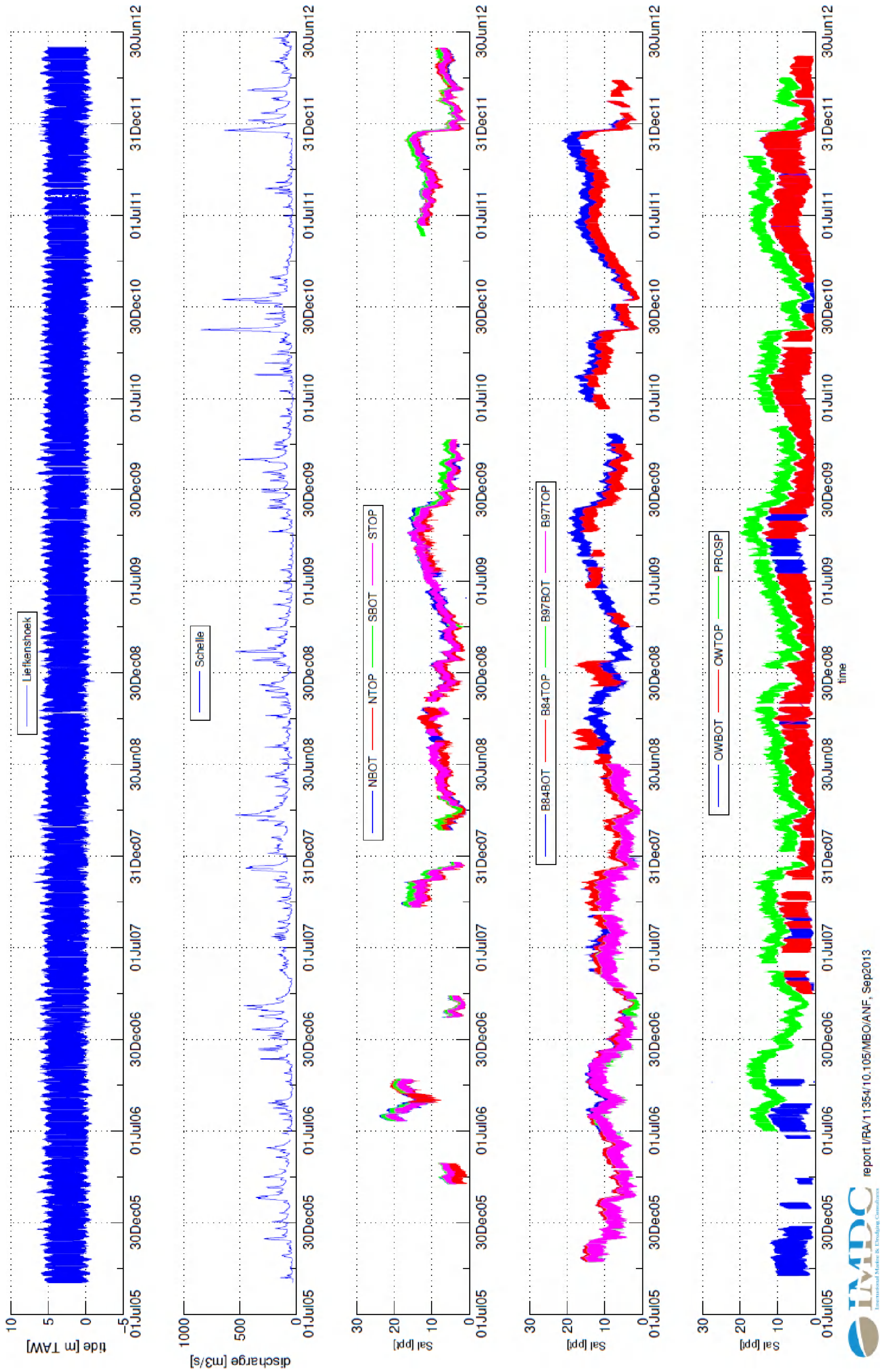

Figure 5-5 : Time series of tide, discharge, and salinity at all available locations (first version). The wrong salinity in 2008-2009 at B84TOP has been removed in the 2nd version of the data.

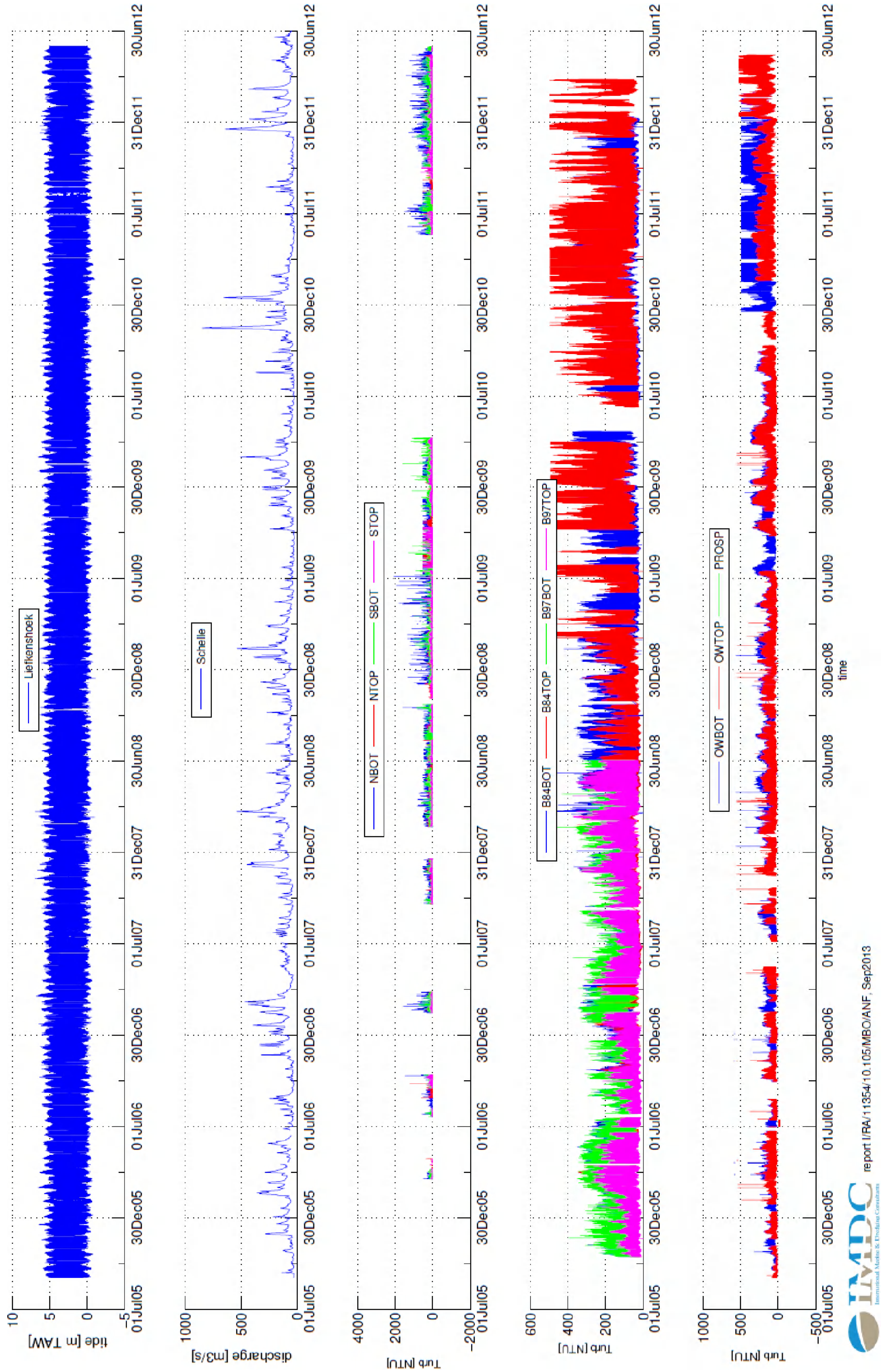

Figure 5-6 : Time series of tide, discharge, and turbidity at all available locations (first version).

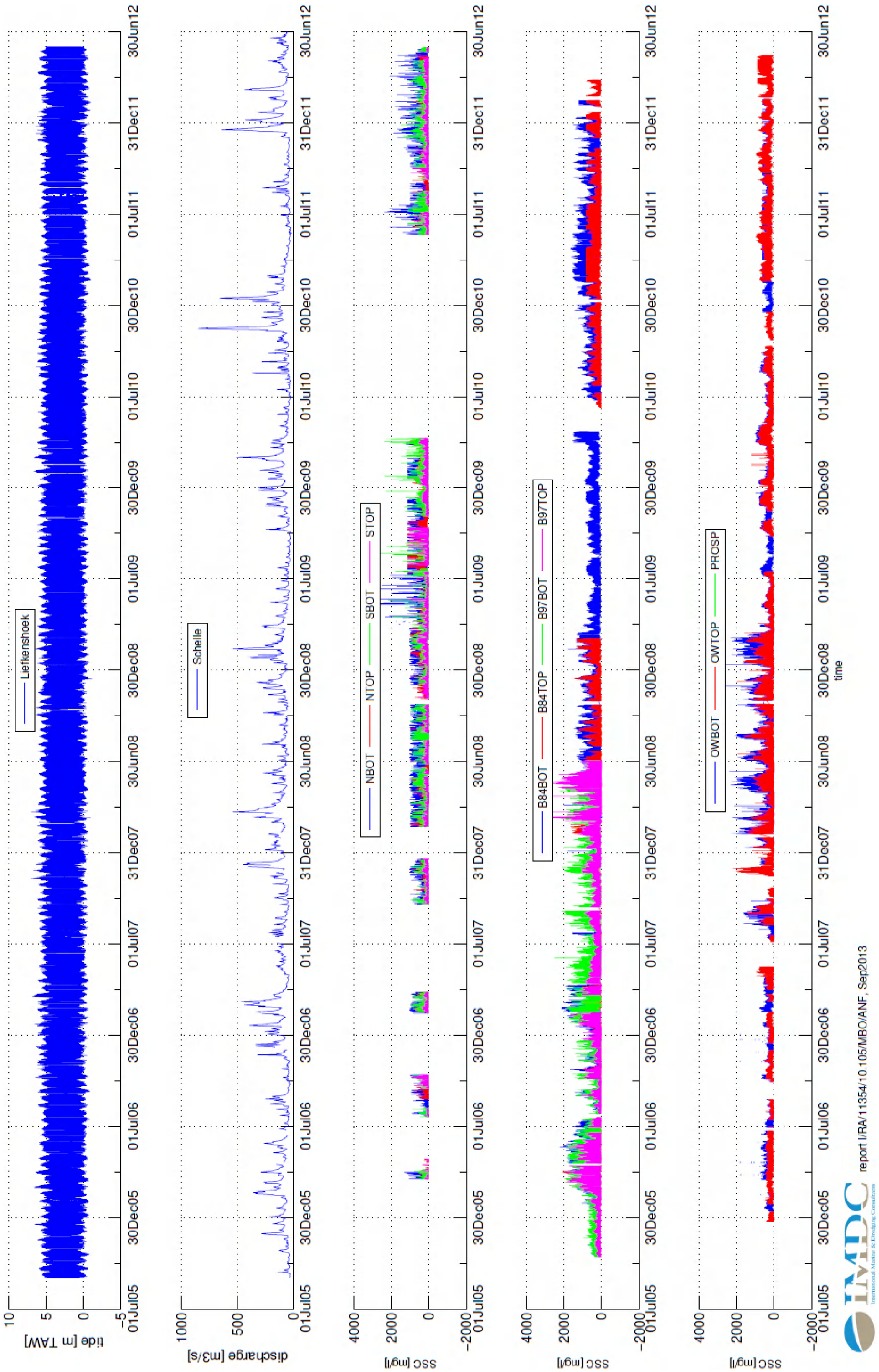

Figure 5-7 : Time series of tide, discharge, and SSC at all available locations (first version).

5.2.2 Daily values

The time series of daily values can be found in A3 format in annex A.2. Two figures are for convenience also reproduced below.

The following additional conclusions can be drawn from the time series of daily values :

- The multiyear SSC Figure 5-7 confirms the relatively good visual agreement between sensors at B84 and B97 (top and bottom ; correlation coefficient R=0.87 between B84BOT and B97BOT for instance). This justifies the use of the average SSC concentration of B84 and B97 as proxy for the daily SSC at the dock entrance : the ETM will not be at, say, B84 without being at B97. It may be because salt wedge and ETM are not fully coupled : once flushed by a fresh water flood, the salinity needs much time to come back upstream. Fresh water floods also bring their own load of sediment, and/or horizontal scales differ for salinity and SSC.
- A clear seasonal variation of the SSC is visible. Maximum average SSC is observed each year around March under the combination of extreme spring tides around the equinox and another factor since no peak is observed during the extreme spring tides of September. This additional factor could be :
    - the ETM pushed downstream together with the salt wedge,
    - a sediment load due to winter floods,
    - more intense dredging in the winter,
    - a seasonal algal bloom in the water and/or microorganisms such as diatoms stabilizing the tidal flats leading to less mud being released in the water column in the summer.

  In the absence of strong stratification, a simple 1D estuary model may quantify the effect of some of the factors above.
- Even with daily average values, the SSC variations remain chaotic near the dock entrance. Some weak correlation with the SSC in the Scheldt is visible at times, such as in November 2006, from January to March 2009 or in April 2010 for instance.
- The same remark as in the previous paragraph is valid for the qualitative effect of capital dredging on the SSC.

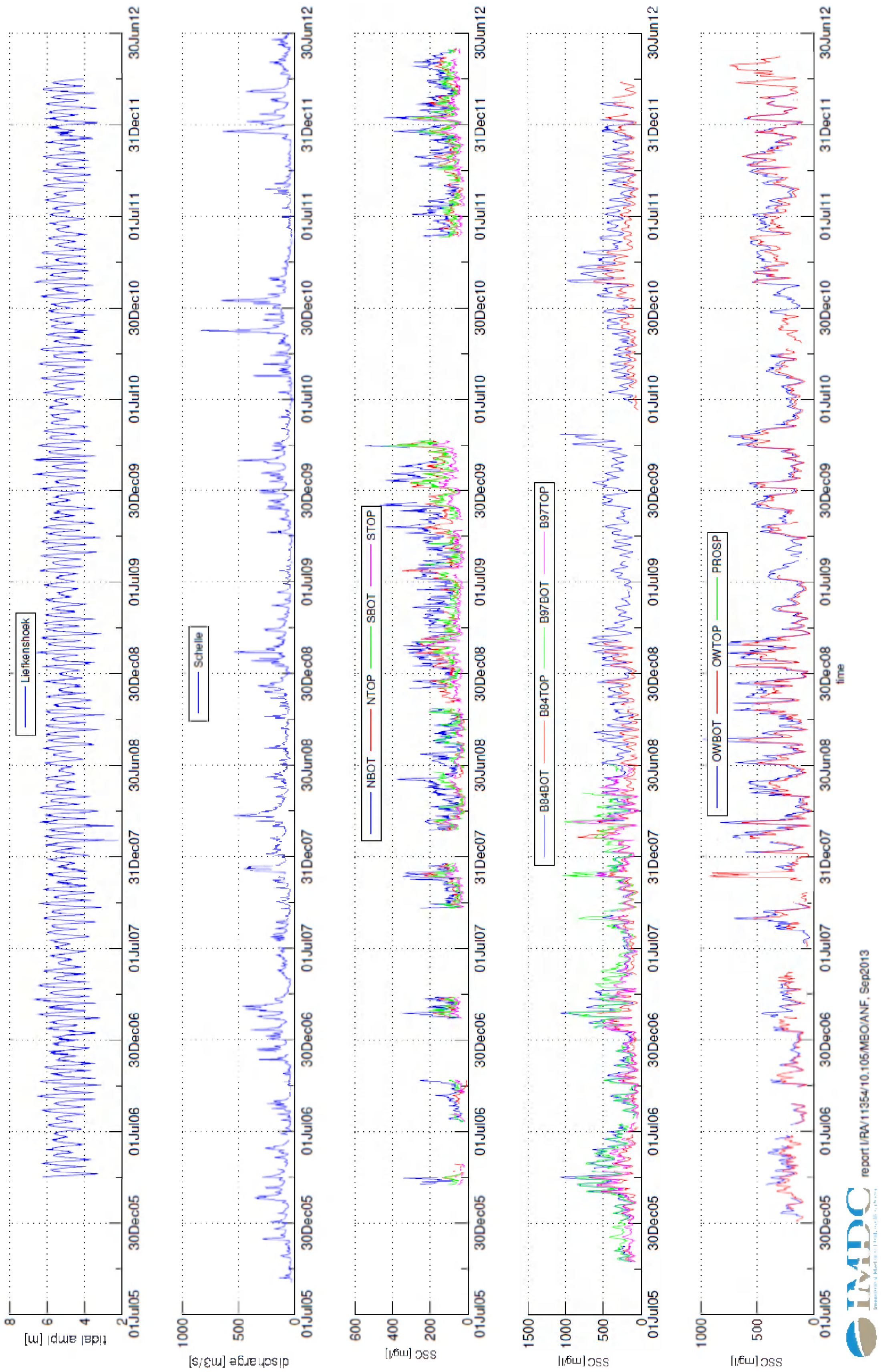

Figure 5-8 : Time series of tidal amplitude, discharge and daily mean SSC at all locations.

It has been noted in IMDC (2009o, report 4.20 of the DGD project) that the SSC is the main controlling parameter of the modelled sedimentation in Deurganckdok. One of the open questions was to determine the factors controlling the SSC in the Sea Scheldt. For this reason, an additional figure has been made to relate the SSC to human activities (Figure 5-9). It shows a clear relation between maintenance dredging activity at Deurganckdok and measured SSC at B84. A larger SSC at B84 leads to more sedimentation in Deurganckdok, which requires more dredging. The dredged material is then deposited near Oosterweel and put in suspension again by currents, which in turn increases the SSC in the Scheldt again. In contrast the salinity amplitude, the second parameter used in the sedimentation model (see chapter 4), remains relatively constant over the entire period 2006-2012 and is comparable between the river and the dock.

Figure 5-10 shows a similar comparison, this time with the weekly BIS volumes disposed around Oosterweel (Plaat van Boomke, Punt van Melsele, Oosterweel) from all dredging sources of silt. The turbidity in Oosterweel also shows a clear link to the relocation activity around Oosterweel, but the SSC in Deurganckdok correlates less well with it. The measured SSC in Oosterweel is believed to contain a potential calibration error and has not be used for the comparison (paragraph 5.2.1). The turbidity should be a good proxy for the relative variation of the SSC in time, until January 2011 at the bottom sensor and January 2012 at the top sensor when the RCM9 have been replaced by Seaguard sensors, which have a different kind of relation between turbidity and SSC.

The fact that SSC and dredging activity seem to correlate better when near each other (i.e. dredging in Deurganckdok compared to the SSC at B84 rather than compared to the SSC at Oosterweel) suggests that part of the SSC increase occurs locally, i.e. some sediment is put in suspension during dredging (see peak of April 2010 more pronounced near Deurganckdok).

The impact of dredging works at other locations, in particular at the Drempel van Frederik, has not been investigated. It should be noted that since 2011 mainly silt instead of sand is dredged at the Drempel van Frederik (IMDC, 2012q ; not part of the DGD studies).

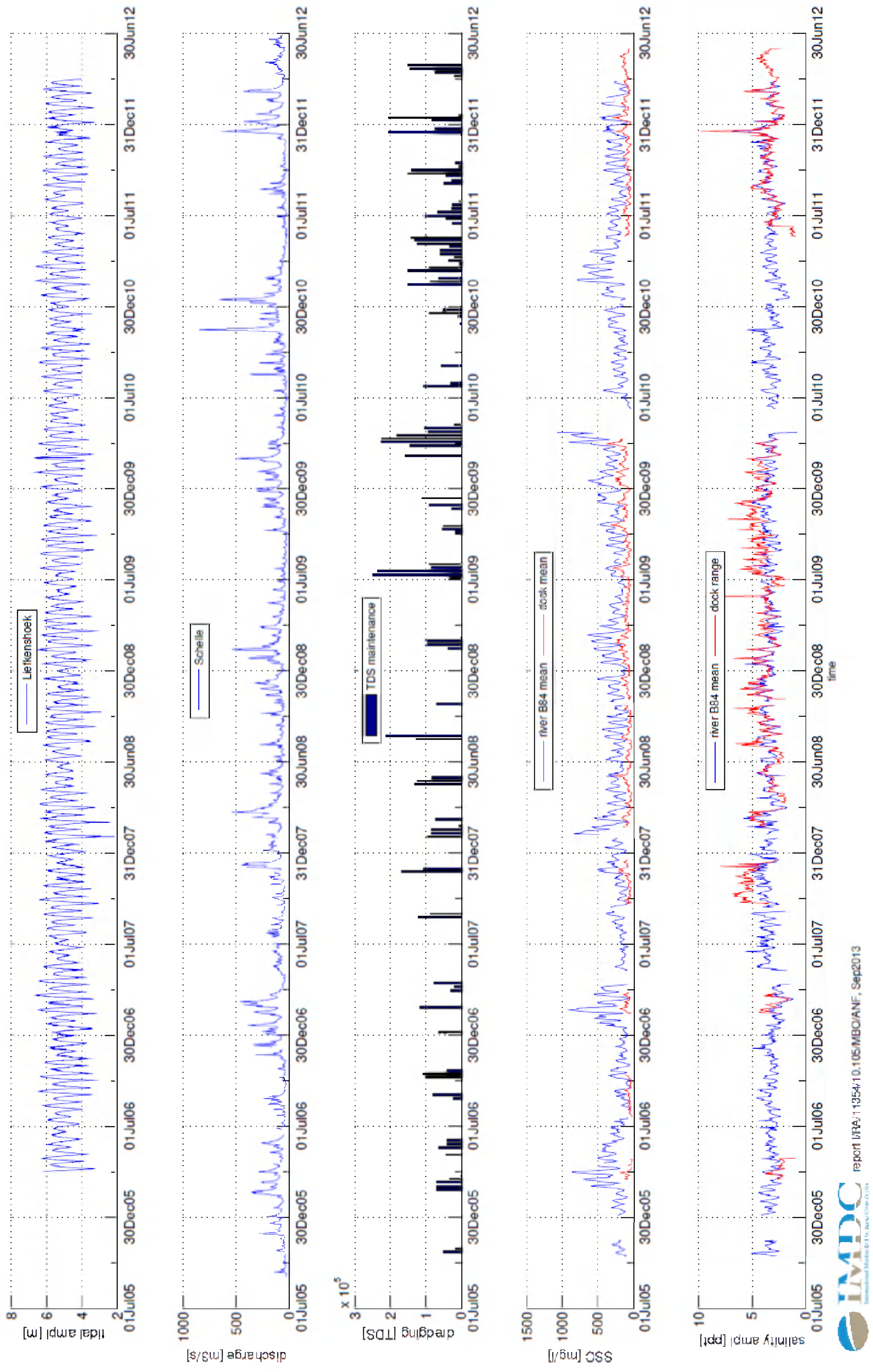

Figure 5-9 : Time series of tidal amplitude, discharge, weekly dredging in Deurganckok, SSC at buoy B84 and salinity amplitude at buoy B84 and at the dock entrance.

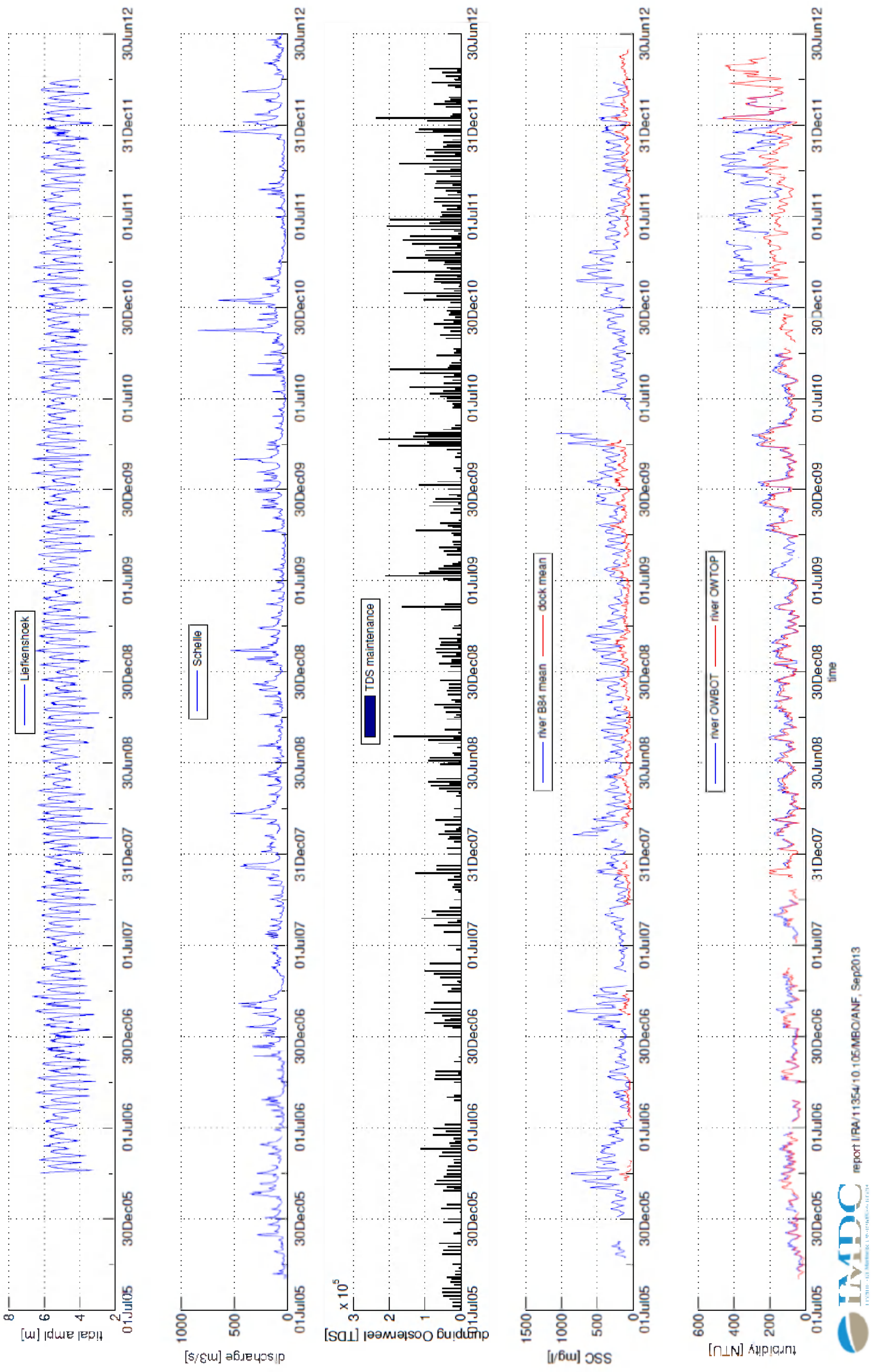

Figure 5-10 : Time series of tidal amplitude, discharge, weekly relocation in Oosterweel, SSC at buoy B84 and turbidity at Oosterweel.

5.2.3 Mean tidal cycle

None of the figures in the previous sections are expected to show any qualitative effect of the CDW. The effect of the CDW is expected to be local (stronger near North entrance) and intra-tidal. For this reason mean tidal cycles of salinity and SSC centred around HW have been computed like in the reports about long-term salinity measurements (IMDC 2010b, 2012n ; like Figure 5-12), divided into neap, mean and spring tides. Cycles before (1/7/2005 to 1/4/2010) and after the construction of the CDW (1/8/2010 to 1/6/2012) have been computed from the second version of the full time series (see paragraph 5.1.2) and compared. Given the high number of cycles used and the resemblance of results with those of the long-term salinity measurement reports, a reasonably high confidence can be put in these results.

Mean tidal cycles and gradients of salinity, SSC and temperature can be found in Annex B. Some figures are also shown in the text to illustrate the observations which are underlined.

During the interpretation, salinity gradients can be used as weak proxies for the intensity of density and eddy currents. Density currents are caused by horizontal density gradients. However these density currents subsequently move and mix the two water bodies in such a way that the density will relatively speaking increase near-bed and decrease near the surface. The vertical density gradient can hence be an indirect measure of the strength of density currents and an inverse measure of vertical mixing : a larger gradient is a sign that a stronger density current is currently present, and/or that vertical mixing is weaker (stronger stratification). Similarly in the case of an eddy circulation, the density of the river water entering near the South entrance during flood is higher than that of the water flowing out near the North entrance. The horizontal density gradient across the entrance can hence be an indirect measure of the strength of eddy currents.

The following observations can be made from the comparison of the tidal cycle with and without CDW at individual locations (all comparisons are with CDW relative to the situation without CDW) :

- North entrance bottom (NBOT) :
  - The salinity has a much flatter peak at HW+1 to HW+2
  - The SSC has a 30% lower peak from HW-1 to HW+2, relative SSC is also lower
- North entrance top (NTOP) :
  - The salinity extrema occur about 1h earlier at both LW (HW-6 instead of HW-5) and HW (HW+1 instead of HW+2 ; Figure 5-11)
  - The SSC is qualitatively similar
- South entrance bottom (SBOT) :
  - The salinity shows very little variation over the tidal cycle, as before
  - The SSC has a 20% lower peak from HW-1 to HW+2, relative SSC is also lower
- South entrance top (STOP) :
  - The salinity is qualitatively similar, it displays a slightly flatter negative peak around LW (HW-4)
  - The SSC has no more peak at HW

Both before and after the construction of the CDW, the highest SSC are found at NBOT, NTOP and SBOT have comparable SSC and STOP has the lowest SSC.

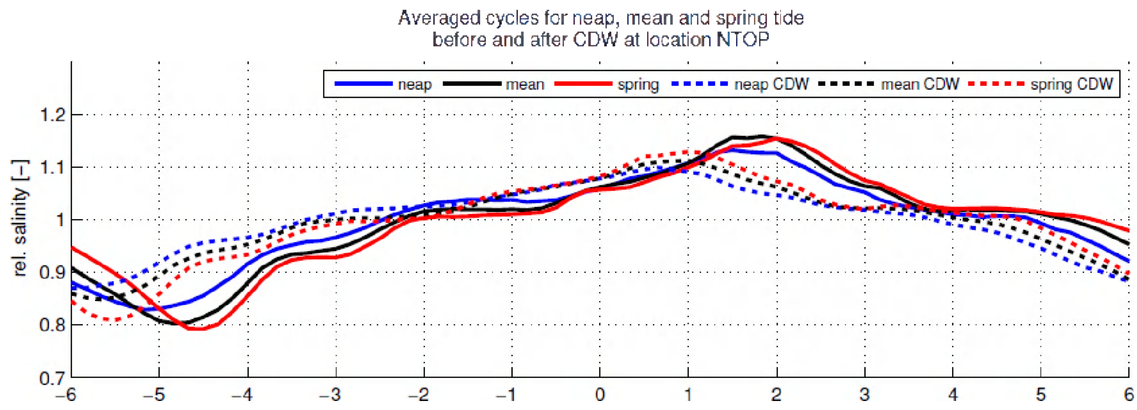

Figure 5-11 : Relative salinity variation at NTOP during an average tidal cycle before (full line) and after construction of the CDW (dashed line) for neap (blue), mean (black) and spring tide (red), showing a phase difference of about one hour. Time relative to high water.

More interestingly, the following observations can be made about the evolution of the gradients with CDW relative to without CDW within the tidal cycle (also in Annex B) :

- North entrance vertical gradient (density ; NBOT-NTOP) :
  - <u>The salinity gradient is significantly changed during most of the tidal cycle</u> (Figure 5-12). Instead of being constantly positive, it is decreased during entire flood by 1ppt. It is now negative from HW-1 to HW+1, indicating vertical mixing by an unstable vertical density gradient. In addition, the maximum gradient at LW (HW-5) is reversed, from +2ppt to zero, and the average gradient value is now around zero. This suggests that at the beginning of flood, the bottom flow is deflected and so delayed by the CDW sill and/or that the surface flow enters the dock faster via the CDW channel (behind of the CDW), and that the delay effect is approximately optimal (lower density gradient). It also suggests that density currents at the North entrance are locally reduced during flood and/or that vertical mixing is locally increased.
  - <u>The SSC gradient has a 20% to 40% lower peak from HW-1 to HW+2</u> (Figure 5-12), in line with decreased SSC at NBOT but unchanged SSC at NTOP. The near-bed decrease in SSC suggests that velocities have locally decreased or that the sediment-laden bottom flow is deflected, and the lower vertical SSC gradient suggests that density currents are locally weaker and/or that vertical mixing is stronger. However during spring tide around LW (HW-5 to HW-4), a new small SSC peak is visible. It might again be related to the vertical mixing induced by the vertical gradient.
- South entrance vertical gradient (density ; SBOT-STOP) :
  - <u>The salinity gradient displays a small gradient decrease</u> of 0.5ppt from HW-1 to HW+2 (Figure 5-13), suggesting slightly weaker density currents at the South entrance during flood.
  - <u>The SSC gradient displays a slight decrease</u> from HW-1 to HW+2 (Figure 5-13), in line with the slightly lower SSC values observed at SBOT and STOP. It is possibly related to weaker density currents.

- Top sensors horizontal gradient (eddy ; NTOP-STOP) :
    - The salinity gradient is significantly changed during flood (Figure 5-14). Instead of being negative, it is now around zero during most of flood. This suggests a significant decrease or disappearance of the flood eddy at the surface.
    - The SSC gradient is qualitatively similar (Annex B).
- Bottom sensors horizontal gradient (eddy ; NBOT-SBOT) :
    - The salinity gradient is roughly unchanged, negative during ebb and around zero during flood. The small positive gradient peak at HW+2 disappears, as a result of the flatter salinity peak at NBOT (Annex B).
    - The SSC gradient is smaller from HW-1 to HW+2, in accordance with lower SSC at both bottom sensors (Annex B).

The temperature gradients are also different with the CDW, however their amplitude is so small that it is difficult to draw a conclusion. Average offset errors over a long period are not excluded.

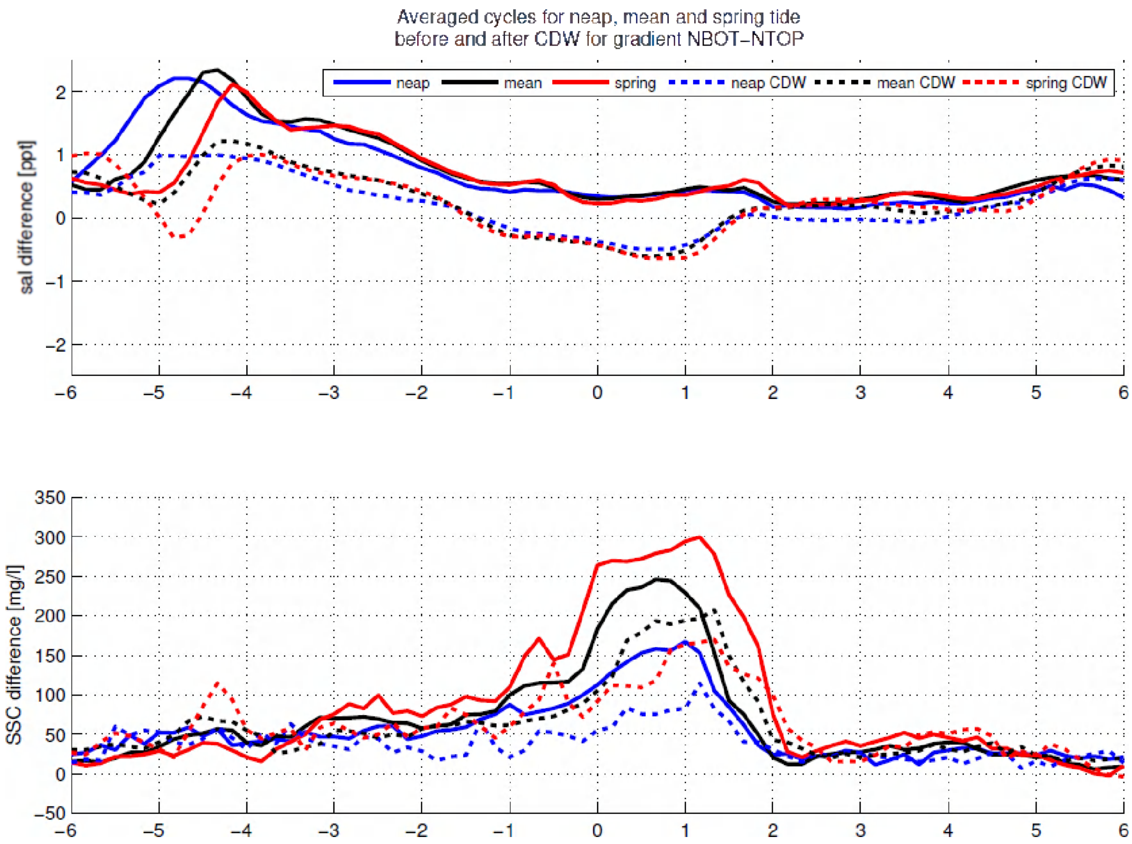

Figure 5-12 : Absolute vertical salinity and SSC difference at the North entrance during an average tidal cycle before (full line) and after construction of the CDW (dashed line) for neap (blue), mean (black) and spring tide (red), showing decreased gradients during flood. Time relative to high water.

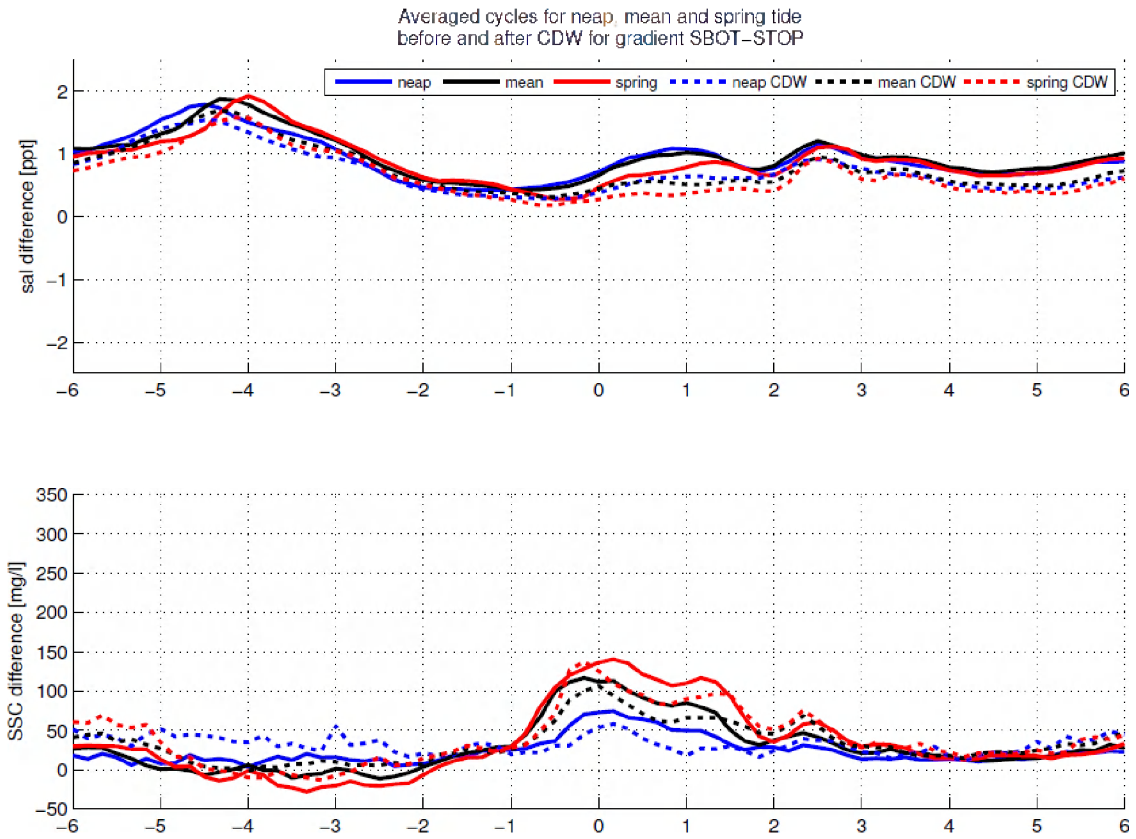

Figure 5-13 : Absolute vertical salinity and SSC difference at the South entrance during an average tidal cycle before (full line) and after construction of the CDW (dashed line) for neap (blue), mean (black) and spring tide (red), showing a decreased SSC gradient at HW+1. Time relative to high water.

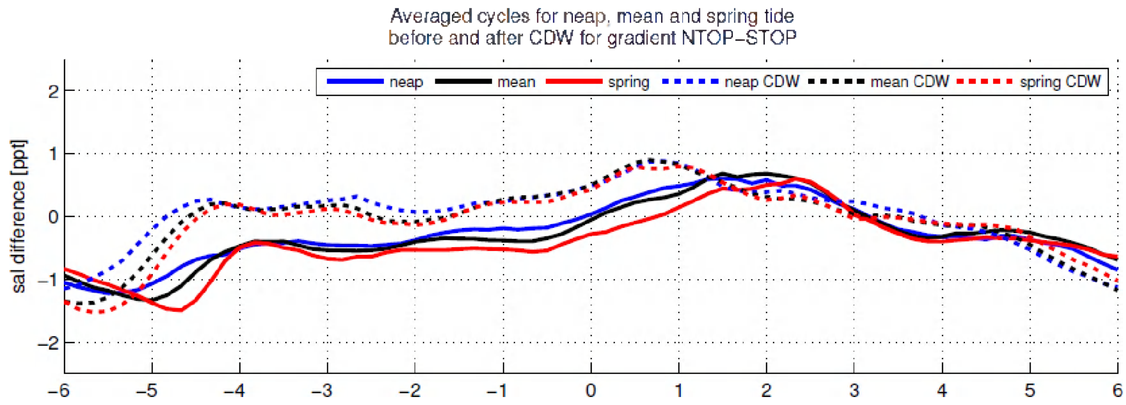

Figure 5-14 : Absolute salinity difference between top sensors during an average tidal cycle before (full line) and after construction of the CDW (dashed line) for neap (blue), mean (black) and spring tide (red), showing a gradient mostly around zero. Time relative to high water.

All results currently suggest that the CDW has the expected effect : it seems to deflect and so to delay the sediment-laden bottom flow and to allow the surface flow to enter the dock faster via the CDW channel. As expected, the largest effects are visible at the North entrance. The results hence suggest a clear reduction of the eddy, and locally weaker density currents because the delay effect decreases vertical salinity gradients and because negative vertical salinity gradients may cause additional vertical mixing. It is unclear however if these conclusions based on local measurements can be extrapolated to the entire entrance cross-section. For this purpose the ADCP measurements are analysed.

Measurements up to now suggest a decrease of the SSC by 20% to 30% near the bottom, both North and South of the entrance from HW-1h to HW+2h (near-bed inflow). The average SSC values during a tidal cycle before (07/2005 to 04/2011) and after construction of the CDW (04/2011 to 04/2012) are however the same, because SSC slightly increases during the rest of the tidal cycle. Over the same periods, the average SSC in the Scheldt is equally unchanged.

Fluxes cannot be assessed with these figures, they are addressed in the next paragraph. Furthermore, the weaker eddy has only been clearly reported in the cross-dock 13h measurements and not in the along-dock 13h measurements (see paragraph 3.2.2). Some results of the 13h measurements are discussed below.

5.2.4 13h measurement campaigns

5.2.4.1 Qualitative comparison of flow patterns

A qualitative assessment already provides some information about the effect of the CDW. Figure 5-15, based on a visual assessment only, suggests that during all 13h measurements since the construction of the CDW, the flood eddy occurs during a significantly shorter time than before. The ebb eddy mostly disappeared since the lengthening of the dock in 2008. A weak eddy is sometimes visible during ebb in the measurements with the CDW, but it is mostly a matter of subjective judgement and cannot be considered to be a significant feature at this stage. Density currents are qualitatively unchanged. Other qualitative and quantitative approaches are proposed in the next paragraphs to confirm these visual observations.

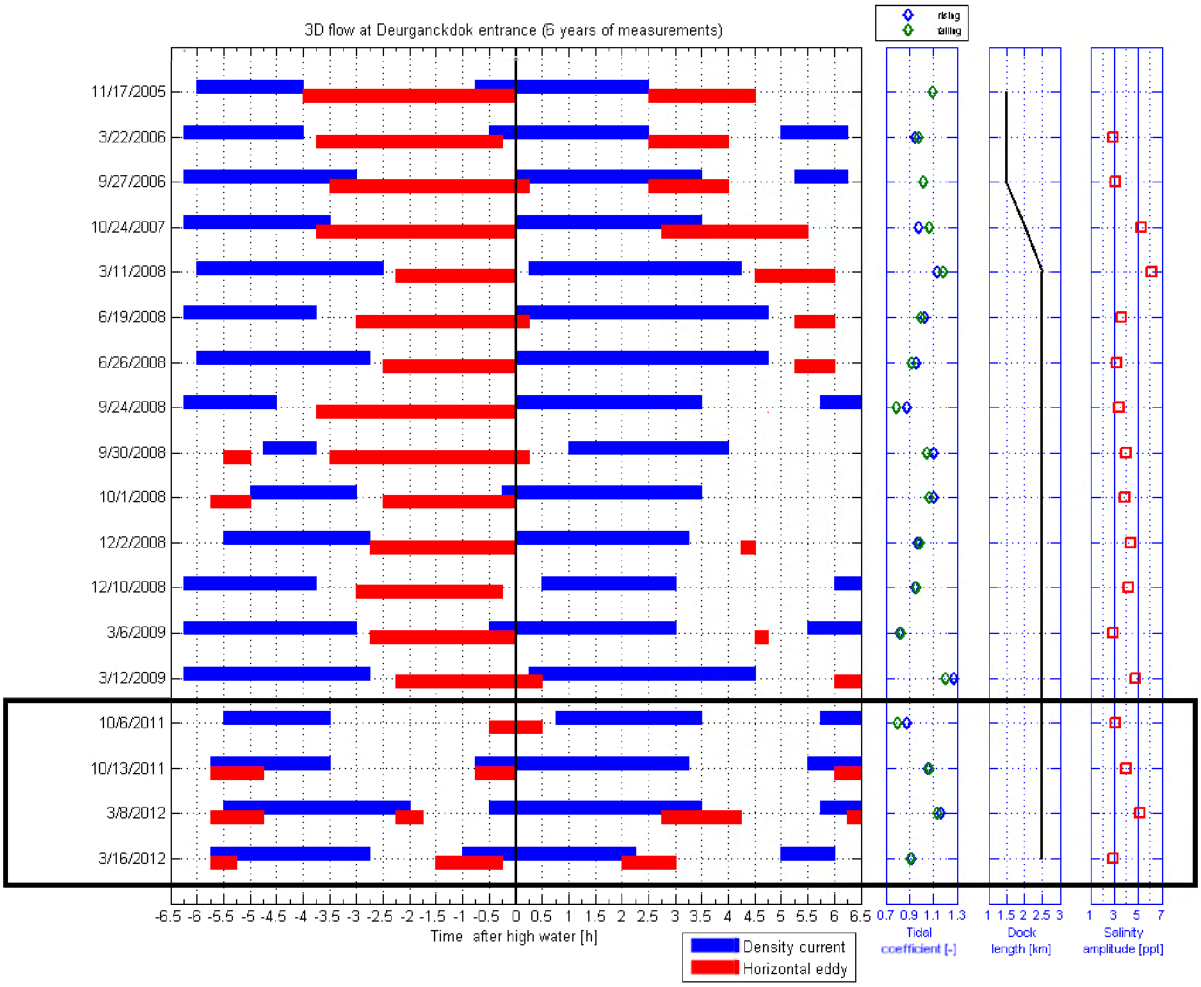

Figure 5-15 : Visual observation of density currents (blue) and eddy currents (red) for all 13h measurement campaigns since the construction of Deurganckdok. Tidal coefficient, dock length and salinity amplitude during each campaign are shown to the right (date notation MM/DD/YYYY). Measurements after CDW in the black box.

Flow patterns have also been compared against each other by plotting selected campaigns on the same time axis, from 6h before to 6h after HW like for the average tidal cycles in paragraph 5.2.3. Some campaigns have been selected which show similar tidal coefficients and a sedimentation which is not too extreme. Data has been extrapolated to the shadow zones of the ADCP and a 5*5 bins moving window filter applied as described in paragraph 5.2.4.4.

A <u>comparison at spring tide</u> on 11/3/2008 before the CDW and 8/3/2012 after the CDW (Figure 5-16, Figure 5-17) shows that the flow pattern is overall very similar, but that the flood eddy at HW-1 is less strong after the CDW, that density currents both around HW and especially around LW are stronger after the CDW, and suggest that water enters the dock locally near North entrance as early as HW+3, although it might be partly due to the data extrapolation. The location of higher SSC corresponds in average relatively well to the location of water inflow, in particular around HW.

A <u>comparison at neap tide</u> on 6/3/2009 before the CDW and 6/10/2011 after the CDW (Figure 5-18, Figure 5-19) also shows a strong qualitative resemblance of the flow pattern. It confirms that the flood eddy at HW-1 is less strong after the CDW, that the ebb eddy at HW-6 is more pronounced.

Here density currents are comparable in both campaigns and the SSC is less correlated to the water inflow than during spring tide because velocities are lower. The water inflow on 6/10/2011 at HW-4 over the entire water column might be due to a passing ship.

These flow patterns do not display a decrease in density currents, such as those observed locally in the mean tidal cycles in paragraph 5.2.3. It may be because the lower salinity gradients are only local near the North entrance (within the extrapolation zone), or because other factors drive the density currents, such as a SSC sometimes above 1g/l in the Scheldt river.

The flow pattern of every campaign is slightly different, which makes it difficult to establish clear trends from such an analysis. It is hence completed with quantitative analyses in the next paragraphs.

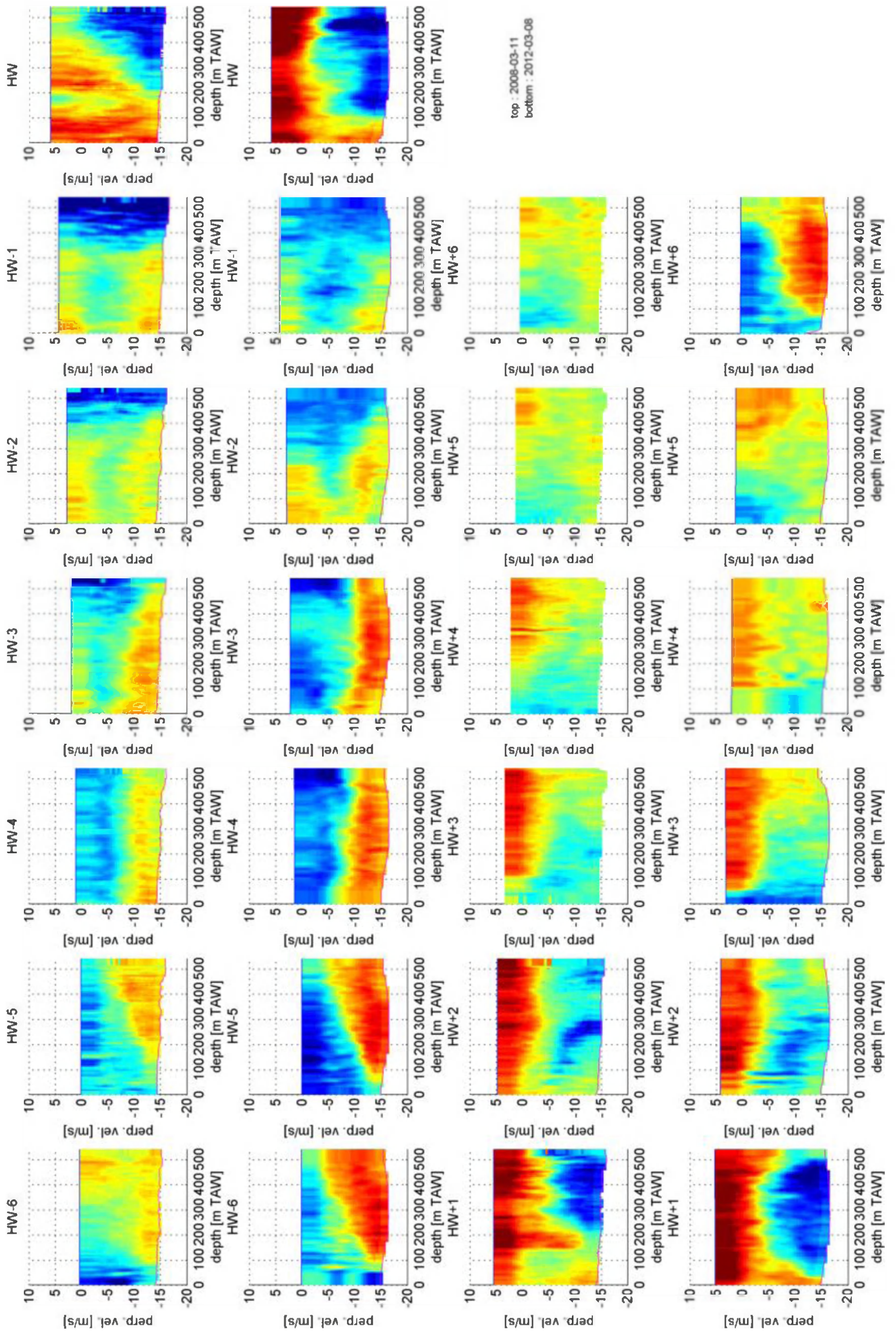

Figure 5-16 : Flow velocity during spring tide : 13h campaigns of 11/3/2008 (line 1 and 3) and of 8/3/2012 (line 2 ad 4). Blue is influx, color scale saturated at -0.4 and +0.4m/s.

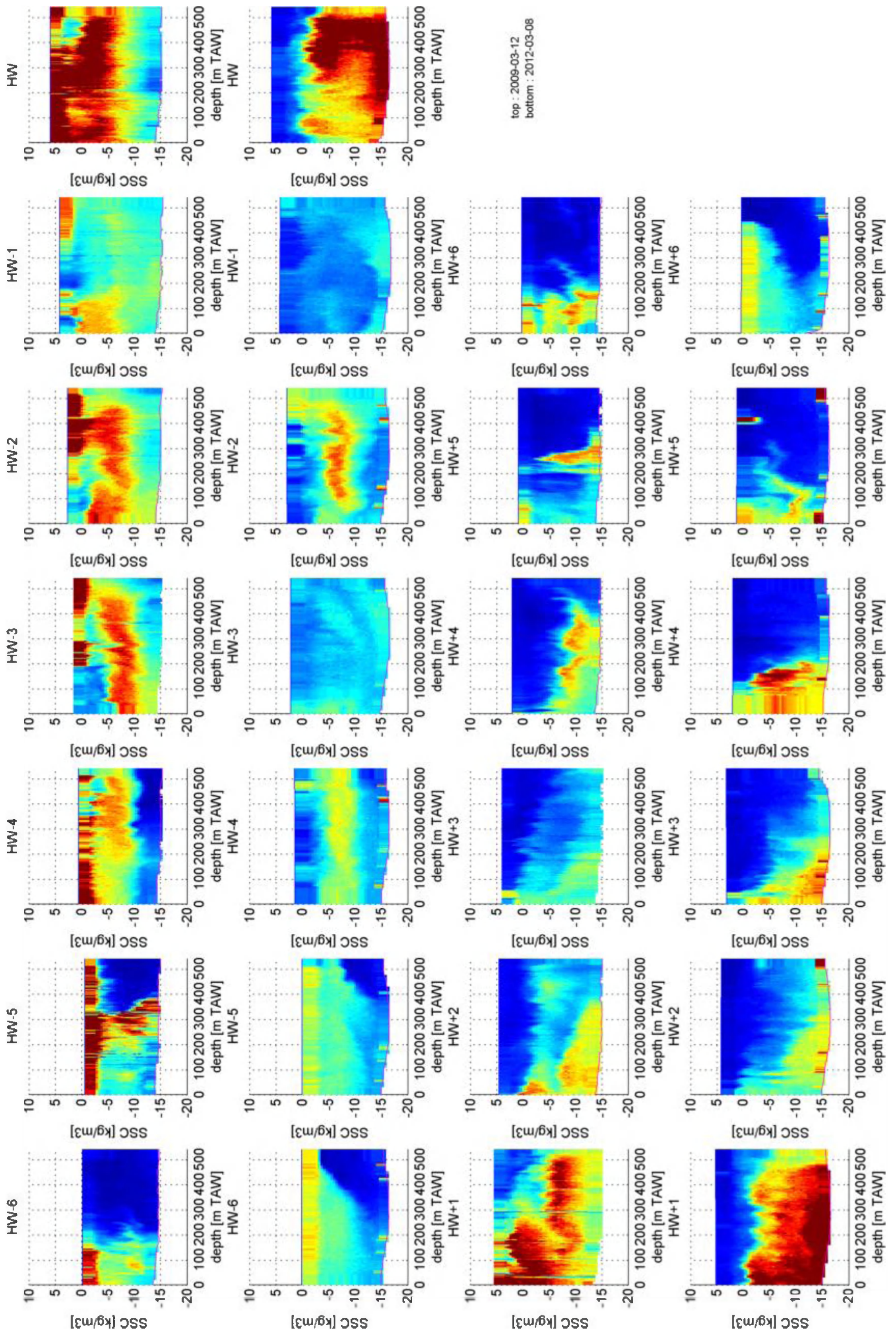

Figure 5-17 : SSC during spring tide : 13h campaigns of 11/3/2008 (line 1 and 3) and of 8/3/2012 (line 2 ad 4). Color scale saturated at 0 and 0.2 kg/m³.

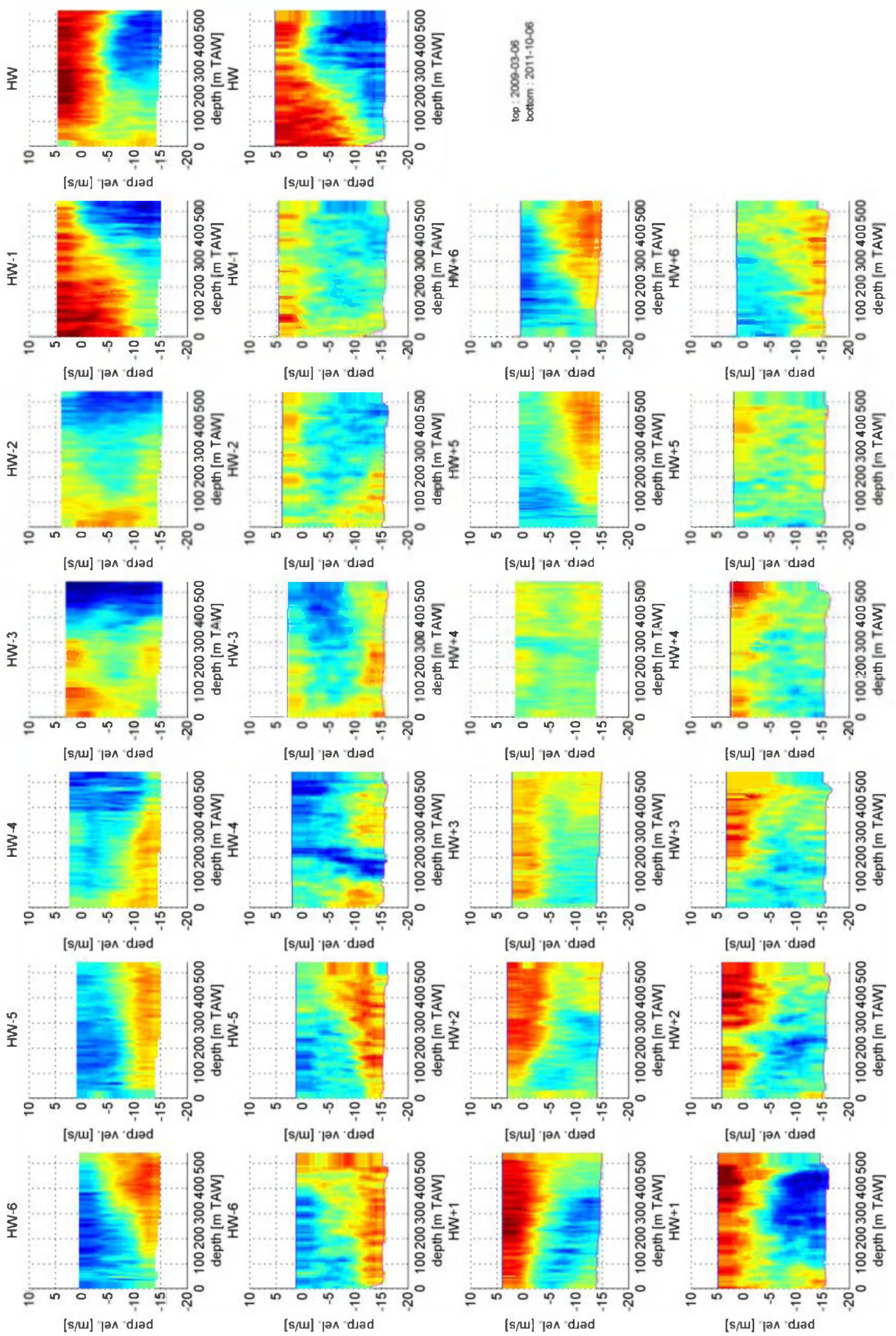

Figure 5-18 : Flow velocity during neap tide : 13h campaigns of 11/3/2008 (line 1 and 3) and of 8/3/2012 (line 2 ad 4). Blue is influx, color scale saturated at -0.4 and +0.4m/s.

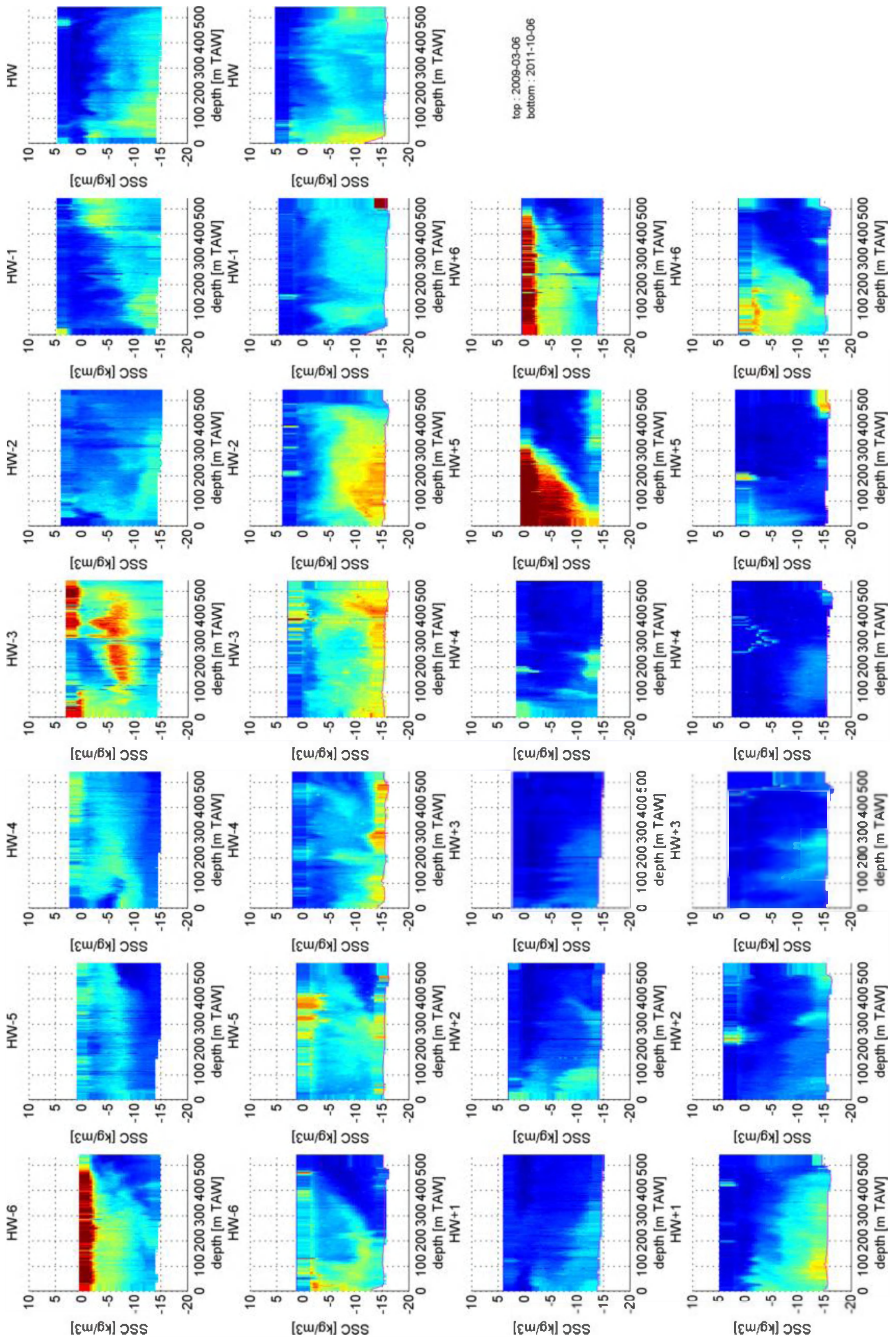

Figure 5-19 : SSC during neap tide : 13h campaigns of 11/3/2008 (line 1 and 3) and of 8/3/2012 (line 2 ad 4). Color scale saturated at 0 and 0.2 kg/m³.

5.2.4.2 Analysis of variations in trapping efficiency

An attempt has been made to investigate the variability of the trapping efficiency and its causes based on some indicators of each 13h campaign. The trapping efficiency is defined as the net sediment influx (total influx minus total outflux) divided by the total sediment influx into the dock, where the fluxes have been computed as for instance in IMDC (2012h, report 2.4 of CDW project). The main parameters of each campaign are shown in Table 5-2. They display a strong temporal variability, which makes four 13h campaigns a too small dataset to draw conclusions about the effect of the CDW. The highest net sediment influx have been recorded with the CDW, however during neap tide the net influx is still relatively small. The average trapping efficiency is very comparable without (0.39) and with the CDW (0.42). The exchanged water volumes are also very comparable (see remark on background noise in paragraph 5.2.4.3), they do not show the expected decrease following from a weaker eddy.

No clear correlations have been found between the trapping efficiency and these parameters (example of least worse correlation in Figure 5-20). This is partly due to the large natural variability of boundary conditions, but more probably due to the limitations of the selected approach.

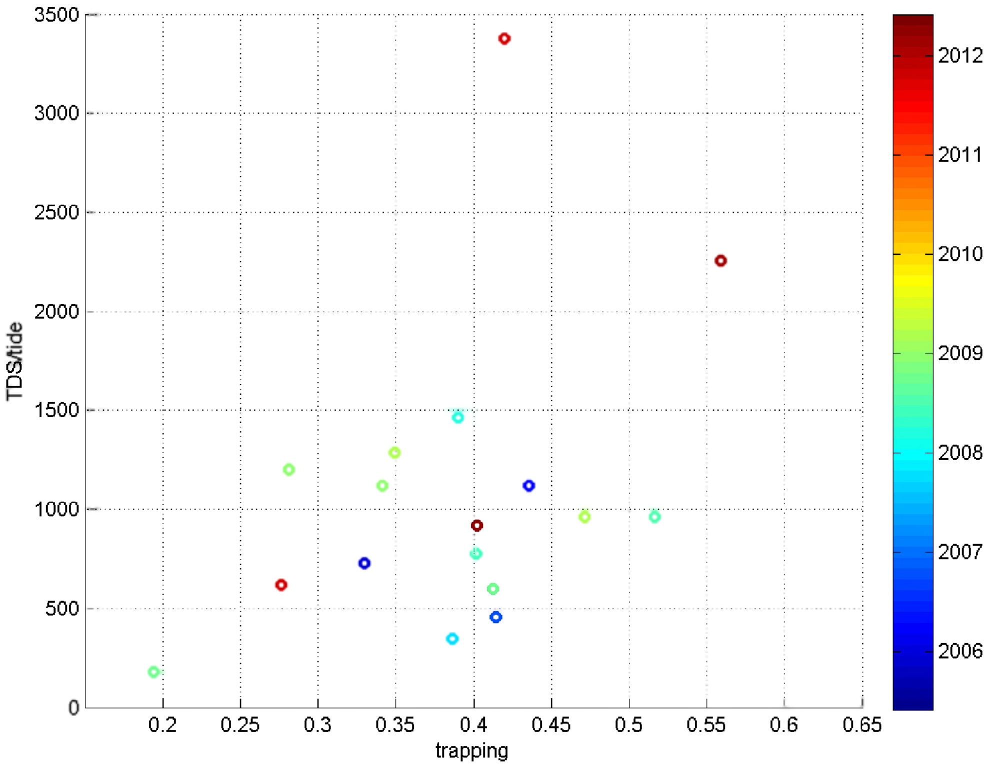

Figure 5-20 : Example of lack of correlation between trapping efficiency and net sediment influx per tide.

	tidal coef [-]	salinity [ppt]	mean SSC [mg/l]	discharge [m3/s]	salinity amplitude [ppt]	water exch. [Mm3]	sediment exch. [TDS]	net influx [TDS/tide]	trapping efficiency
17/11/2005	1.1	NaN	75	81	NaN	58.4	3,687	730	0.33
22/03/2006	0.97	5.5	115	94	2.9	61.9	4,034	1,122	0.44
27/09/2006	1.03	10.5	49	41	3.1	58.3	1,747	456	0.41
24/10/2007	1.02	13.7	79	46	5.3	42.9	1,467	348	0.39
11/03/2008	1.17	7.1	171	286	6.2	53.6	6,058	1,465	0.39
19/06/2008	1.15	6.7	51	93	3.6	56.2	3,106	778	0.40
26/06/2008	0.97	7.3	38	69	3.2	49.8	2,785	960	0.52
24/09/2008	0.81	10.7	55	75	3.5	52.4	1,680	179	0.19
30/09/2008	1.08	12.0	50	NaN	4.0	58.0	2,299	599	0.41
2/12/2008	0.98	7.3	119	154	4.4	70.6	7,349	1,200	0.28
10/12/2008	0.97	5.5	107	222	4.2	67.5	5,453	1,121	0.34
6/03/2009	0.82	5.2	82	99	2.9	52.8	3,121	962	0.47
12/03/2009	1.24	5.8	167	129	4.8	55.7	6,090	1,287	0.35
6/10/2011	0.83	12.8	92	55	3.1	65.4	3,856	617	0.28
13/10/2011	1.06	12.2	114	41	4.0	66.0	12,705	3,378	0.42
8/03/2012	1.16	4.9	71	175	5.2	71.5	5,791	2,255	0.56
16/03/2012	0.88	4.5	75	85	2.9	54.4	3,638	918	0.40

Table 5-2 : Boundary conditions, total exchanged water and sediment fluxes, net sediment influx and trapping efficiency for each 13h campaign.

5.2.4.3 Quantitative analysis based on Christiansen method

Only the campaigns available in a uniform digital format have been used in the quantitative methods (from October 2007 on).

A quantitative analysis needs to take into account several limitations which can affect the uncertainty surrounding the results. In particular, due to the following limitations it has been decided not to use difference plots like in the previous paragraph :

- Difference plots are seriously distorted by spatial and temporal interpolation of the data, as well as any phase difference between the two datasets considered.
- Different measurements already show a qualitatively large natural variability, as illustrated in Figure 5-15. A difference plot, although potentially very instructive, would require exactly equal boundary conditions such as tidal amplitude, salinity, discharge and SSC between the two datasets. This never happens in practice.
- Difference plots and quantitative estimates are adversely affected by spatial extrapolation of the data to missing areas in the shadow zones of the ADCP (surface, bottom) and near the banks.
- Quantitative estimates, even simple ones, come with a strong uncertainty due to background noise (Figure 5-21). This is well illustrated by the total water exchange estimated in average at close to 60 Mm³/tide compared to the 45 Mm³/tide expected from previous studies. Also no way has been found to normalize these exchanged volumes based on the tidal coefficient or the salinity amplitude. A possible way to reduce this uncertainty could be to apply a filter to the measurements.

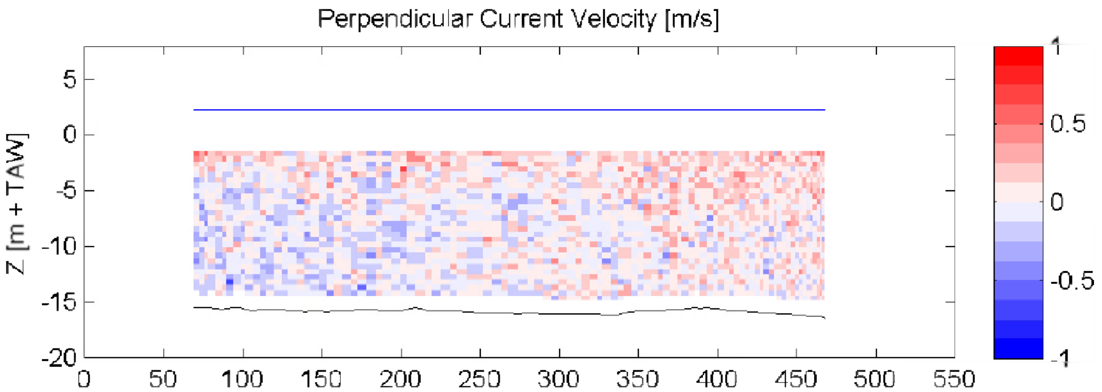

Figure 5-21 : Example of background noise typically present in ADCP results and most visible under low velocity conditions.

Instead a simplified quantitative assessment has been made with a method adapted from Christiansen (Van Maren, 2005), in which the entrance cross-section is divided in three equal zones over the horizontal (North, Middle and South) and over the vertical (Top, Middle and Bottom) and each zone is assigned an integer (-1 if inflow higher than threshold, +1 if outflow higher than threshold and 0 if in between). Based on this simplified flow matrix the presence and duration of eddy and density currents can be measured. A threshold velocity of 0.05m/s has been applied and tests have been done with a threshold velocity of 0.1m/s to verify the robustness of the conclusions.

The duration of eddy and density currents has been computed as the period during which the Christiansen numbers have opposing signs North and South (eddy) or Top and Bottom (density).

The velocity figures, the Christiansen figures and a summary table of each 13h campaign are shown in Annex C. Results, as in Figure 5-22 and Figure 5-23 for the 13h campaign of December 10th 2008, show clearly the previously identified circulation pattern (IMDC, 2009o) with a flood eddy at the South entrance, inflowing near-bed density currents around HW and a reversed pattern during ebb.

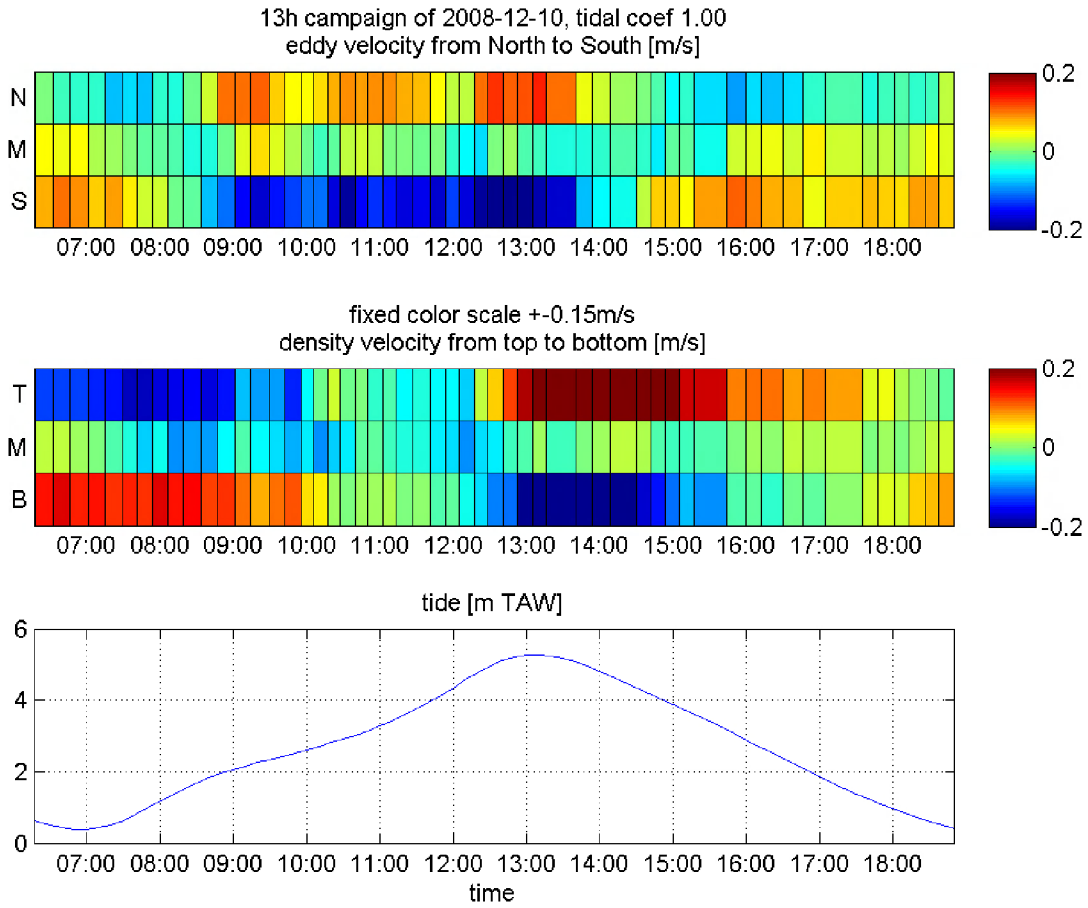

Figure 5-22 : Top : Measured velocity in the North (N), Middle (M) and South (S) third of the dock entrance. Middle : Measured velocity in the Top (T), Middle (M) and Bottom (B) third of the dock entrance. Bottom : Tidal cycle. Positive velocities leaving the dock, color code as in ADCP plots.

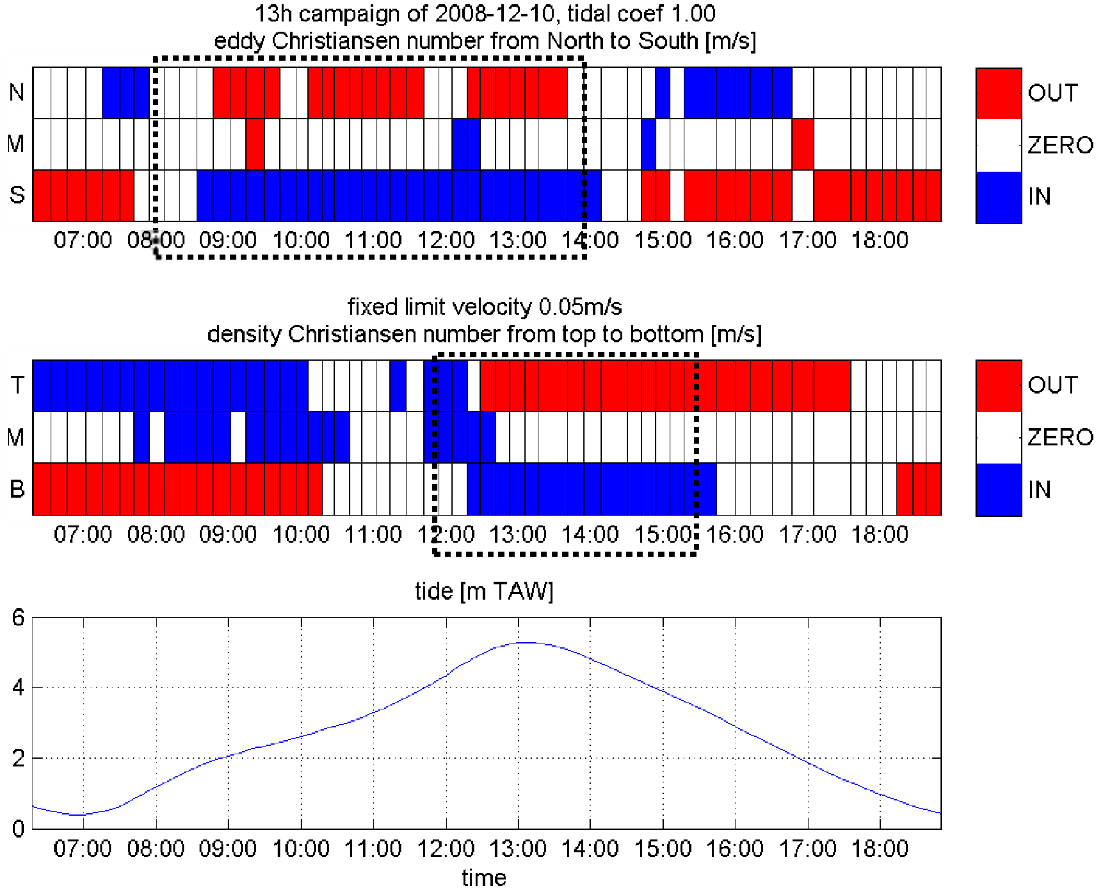

Figure 5-23 : Top : Christiansen number in the North (N), Middle (M) and South (S) third of the dock entrance and flood eddy (black box). Middle : Christiansen number in the Top (T), Middle (M) and Bottom (B) third of the dock entrance and HW density currents (black box). Bottom : Tidal cycle. Threshold velocity 0.05m/s, color code as in ADCP plots.

The presence of the CDW has two main effects, illustrated by comparing Figure 5-24 to Figure 5-23 :

- The flood eddy is now indeed visibly shorter (also Figure 5-26, Figure 5-27), however the Christiansen figures also confirm the new presence of a weak ebb eddy, so that the total eddy duration is only decreased from around 5-6h to 4-5h (Annex C.2). This ebb eddy is clearly less strong : increasing the threshold velocity to 0.1m/s leads to a decrease of the eddy duration from around 2h to 1h since construction of the CDW, mainly due to the remaining flood eddy. This eddy at the end of the ebb phase may be due to the start of the flood flow entering the dock faster at the surface at the North entrance compared to the situation without CDW.
- The density currents have progressively become both stronger and longer since 2007. Their duration increased from around 5-6h before December 2008 (not clear what happened then, see annex C.2) to 6-7h after December 2008 but before construction of the CDW, and now reaches 7-8h since construction of the CDW. It might be that without CDW the eddies partly inhibited the density currents due to extra vertical turbulence. These stronger density currents could easily explain the increase in dredging volumes observed in the dock (see paragraph 5.3). However it is not in agreement with the observed changes in flow pattern

(paragraph 5.2.3), it is possibly due to another external factor than the CDW (see paragraph 5.3.3.3).

The SSC can influence density currents above concentrations of around 1g/l (equivalent to an increase of the water density by around 1 kg/m³, hence similar effect as a density difference of 1 ppt). Such values are never reached by sensors at the dock entrance, but regularly in the Scheldt river. An increase in SSC could hence potentially lead to stronger density currents.

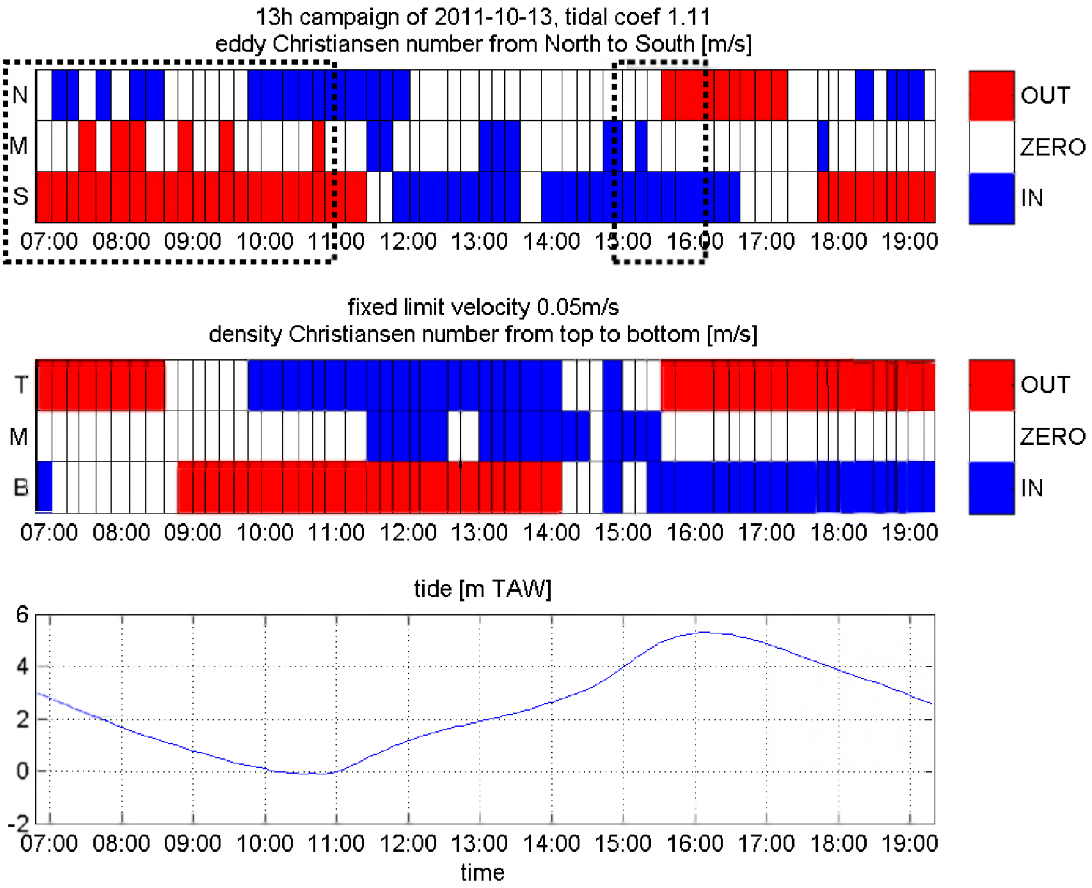

Figure 5-24 : Example of flow pattern modified by the CDW, during the 13h campaign of October 13th 2011, showing a much weaker flood eddy and a slightly stronger ebb eddy (black boxes).

Finally since this approach allows to measure quantitatively the occurrence of density and eddy currents, the graph presented in Figure 5-15 is reproduced (Figure 5-25) and is plotted again based on a threshold velocity of 0.05m/s (Figure 5-26) and of 0.1m/s (Figure 5-27). One 13h campaign gave low quality results and has been left out (30-09-2008).

An eddy is defined as a period during which the velocity exceeds the threshold velocity both North and South of the dock with flow in opposite direction to each other. Similarly, a density current is defined as a period during which the velocity exceeds the threshold velocity both near the bed and at the surface with an flow in opposite direction to each other. Results confirm the visual observations and also show that the longer density currents are mainly due to stronger density currents around LW.

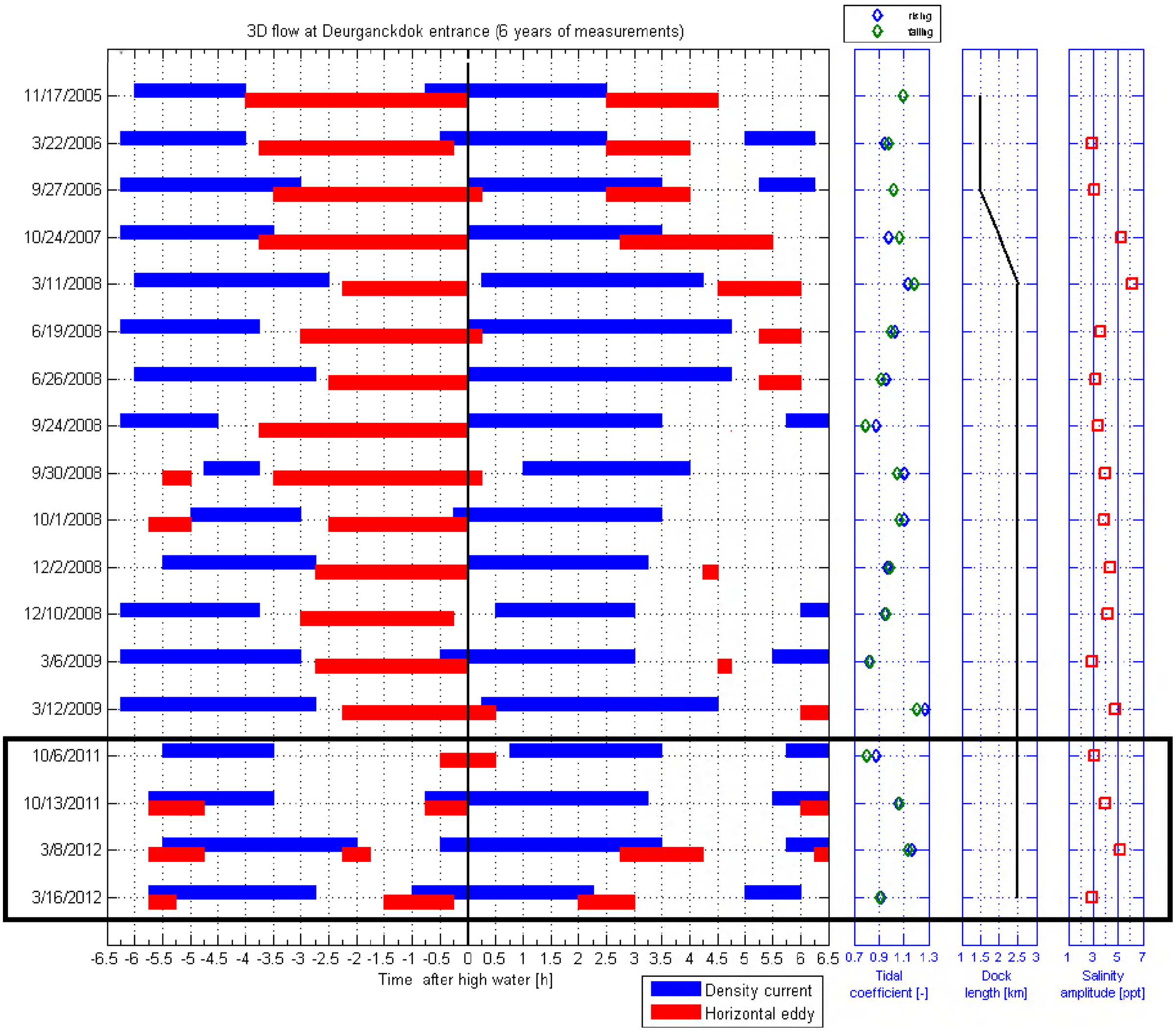

Figure 5-25 : Visual observation of density currents (blue) and eddy currents (red) for all 13h campaigns since construction of Deurganckdok (date notation MM/DD/YYYY). Reproduced for convenience from Figure 5-15.

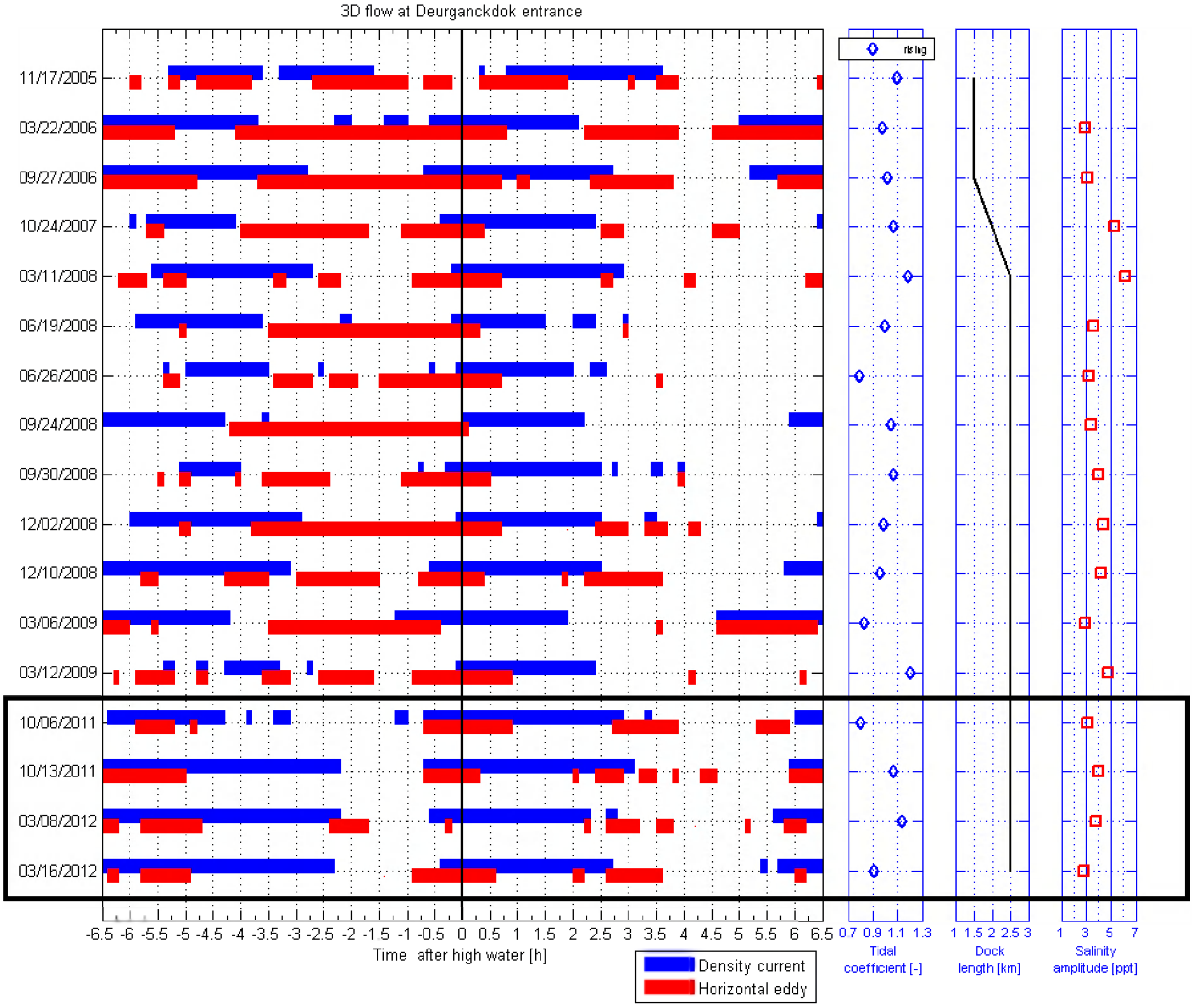

Figure 5-26 : Measured occurrence of density currents (blue) and eddy currents (red) for a threshold velocity of 0.05m/s (date notation MM/DD/YYYY). To be compared with Figure 5-25.

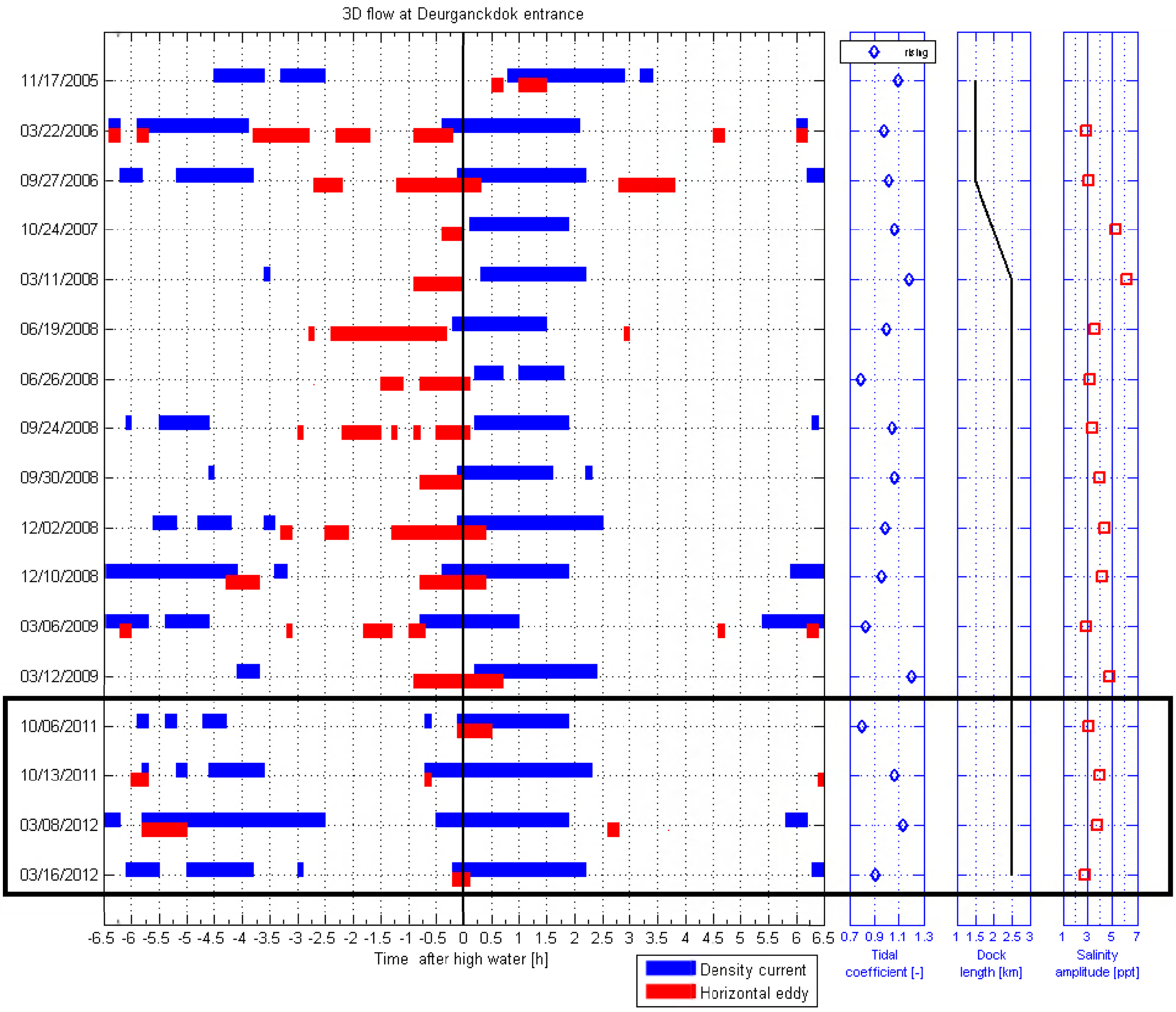

Figure 5-27 : Measured occurrence of density currents (blue) and eddy currents (red) for a threshold velocity of 0.1m/s. To be compared with Figure 5-25.

5.2.4.4 Quantitative method based on flux separation

From the 13h measurements it is also possible to estimate the relative contribution of tidal filling, density currents and eddy currents in the total water and sediment exchange. Below the computation method and the results are described. The limitations described in paragraph 5.2.4.3 should be kept in mind during the interpretation.

For each campaign since October 2007, each sailed transect is available as a Matlab MAT file as its projection on a theoretical transect. Except for a change in the convention used for the sailed direction in 2010, the format is similar over the period 2007-2012. The data is pre-processed in a mostly similar fashion as in the factual data reports of the 13h campaigns (example in IMDC, 2012h):

- The data is extrapolated to the shadow zones of the transect :
  - Velocity data is taken equal to 0.91 times the closest bin at the banks, equal to the closest bin at the surface and extrapolated with a power law 1/6 near the bottom.

  - SSC data is taken equal to the closest bin at the banks, near the surface and near the bottom. In the factual data reports such as in IMDC (2012h) the near bed SSC is multiplied by a factor based on a comparison with SiltProfiler measurements. This factor of typically 1.2 depends on the campaign, it has been kept to one for simplicity and to obtain visually nicer flow patterns. It is not expected to impact any of the arguments presented in this report.

- The data can be optionally filtered with a moving average window of 5*5 bins to remove the noise. The sensitivity of the results to such a filter has been analysed.
- The data is decomposed into individual exchange mechanisms according to the method of Vanlede et al. (2010) :
  - The velocity in each bin has been decomposed into a tidal filling component (mean over the whole transect), a density current component (width-averaged of signal minus tidal filling) and an eddy current component (depth-averaged of signal minus tidal filling). The calculation method is similar to the one presented in Vanlede et al. (2010) except that here the entrance width is constant over the depth so that the decomposition is exact (the rest term is always zero here) :

$$v_{tide} = \frac{\int v(x,z)dxdz}{\int dxdz}$$

$$v_{eddy} = \frac{\int v(x,z)dz}{\int dz} - v_{tide}$$

$$v_{dens} = \frac{\int v(x,z)dx}{\int dx} - v_{tide}$$

$$v_{rest} = v - (v_{tide} + v_{eddy} + v_{dens})$$

    where v, v_{tide}, v_{dens} and v_{eddy} are respectively the space-varying velocity perpendicular to the dock entrance, the contributions of the tide, of the density currents and of the eddy currents in the decomposition, and v_{rest} is the rest term, with the horizontal space variable x and vertical space variable z.

  - The SSC flux per component has been obtained by multiplying the velocity per exchange mechanism with the local SSC.

- The values obtained are integrated in time to obtain total fluxes. The gross transport of each component has been defined as the integral of the absolute value of each component, which is by definition higher than the gross transport of the total flux. The values obtained are corrected to match the water balance (total influx and outflux over a tidal cycle should be equal) and sediment fluxes are corrected accordingly.

- The relative importance of each exchange mechanism has been defined as the gross transport of the mechanism divided by the sum of the gross transports of each mechanism.
- For the SSC, the trapping efficiency per exchange mechanism has been defined as the influx minus the outflux divided by the influx of that particular mechanism over a tidal cycle.

Results are written to tables for each campaign and are presented in Annex D without filter applied. Results are summarized below :

- Figure 5-28 shows that the relative importance of tidal filling, density currents and eddy currents in the total water exchange is respectively of around 19%, 42% and 39% before the CDW and 18%, 50% and 32% after CDW due to the relative decrease of the eddy currents.
- Figure 5-29 shows that the relative importance of tidal filling, density currents and eddy currents in the total sediment exchange is respectively of around 12%, 48% and 40% before the CDW and 16%, 54% and 30% after CDW due to the relative decrease of the eddy currents.
- Figure 5-30 shows that the trapping efficiency shows a considerable scatter from one campaign to another, especially for the trapping of individual exchange mechanisms. Density currents seem to logically trap more sediment than eddy currents, and tidal filling even has a negative trapping prior to October 2008, but tidal velocities are very small and results potentially very uncertain. No clear effect of the CDW can be seen. Mean trapping efficiencies are in the order of 35%, 55% and 25% before CDW and 40%, 50% and 30% after CDW respectively for tidal filling, density currents and eddy currents.
- Figure 5-31 and Figure 5-32 are shown for indicative purpose only, they present the water and sediment influx into the dock during a tidal cycle. The exact absolute numbers depend strongly on the exact assumptions made in the computation and should not be compared in detail with those reported in the factual data reports such as IMDC (2012h). In particular, applying a 5*5 bins moving window filter decreases the gross water influx by an average of 15 to 20% compared to the unfiltered data (total exchanged volume in the order of 50Mm³ instead of 60Mm³).
- Excepting the exchanged water and sediment volumes, other results are less sensitive to the use of a filter.

<u>Note how different is the relative contribution of each mechanism</u> compared to the numbers presented in paragraph 3.2.2 (15%, 65% and 20% for tidal filling, density and eddy currents for a total of 45 Mm³ water exchanged, 25%, 65% and 10% for sediment exchange). The reason for this most probably lies in the different ways in which these individual contributions have been estimated. It is likely that numbers used in IMDC (2009o) were derived from the sedimentation model itself. They matched the results of the 3D numerical model (Sas, personal communication), where the contribution of tidal filling is known from the tidal prism, the contribution of eddy current is derived from the total water exchange in a simulation without salinity minus the tidal filling, and where the contribution of density currents is derived from the total water exchange in a simulation with salinity minus the total water exchange in a simulation without salinity. In reality adding salinity also adds another eddy component to the water exchange, which means that the density contribution should be lower and the eddy contribution higher. This is the case here. Also in the numerical model the resolution is coarser than in the ADCP data, which means that a larger filter size would be required to compare exchanged water volumes (45Mm³ in model against 60Mm³ in unfiltered data). The

decomposition method used in the sedimentation model (paragraph 4.2) is closer to the present than to the past decomposition method.

The large scatter between 13h campaigns prevents from drawing clear conclusions about the effect of the CDW. General trends can however help in calibrating the sedimentation model.

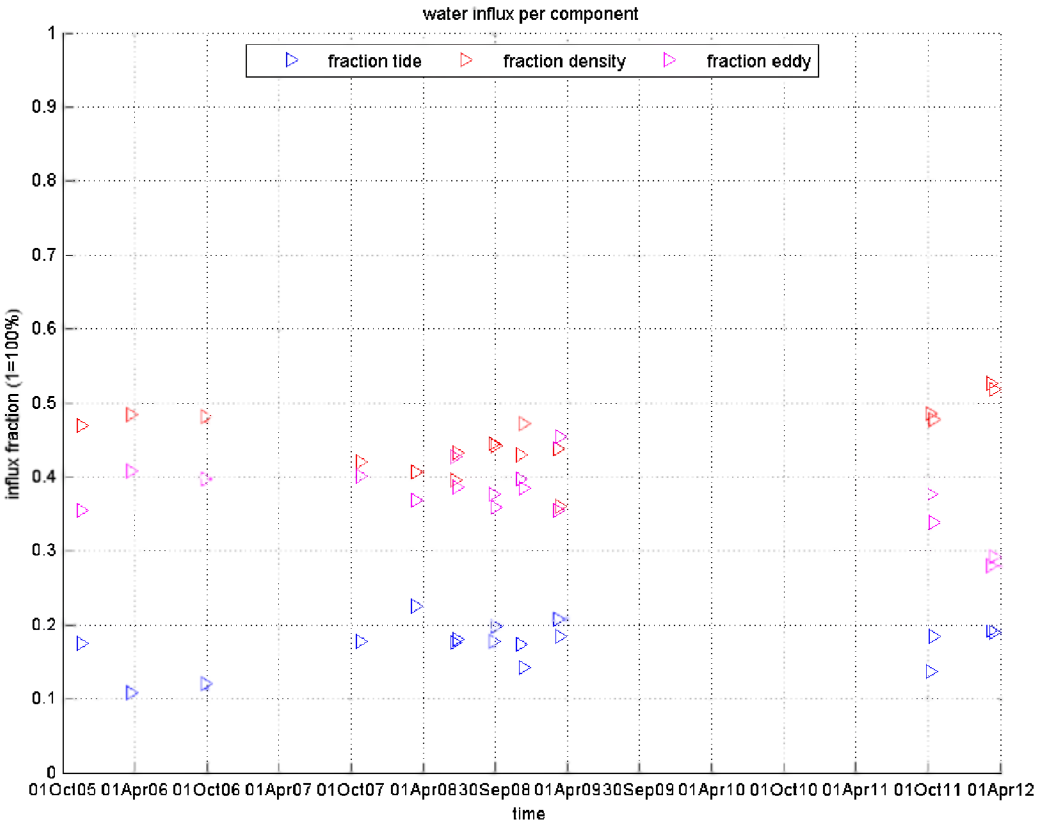

Figure 5-28 : Relative importance of each water exchange mechanism, no filter applied.

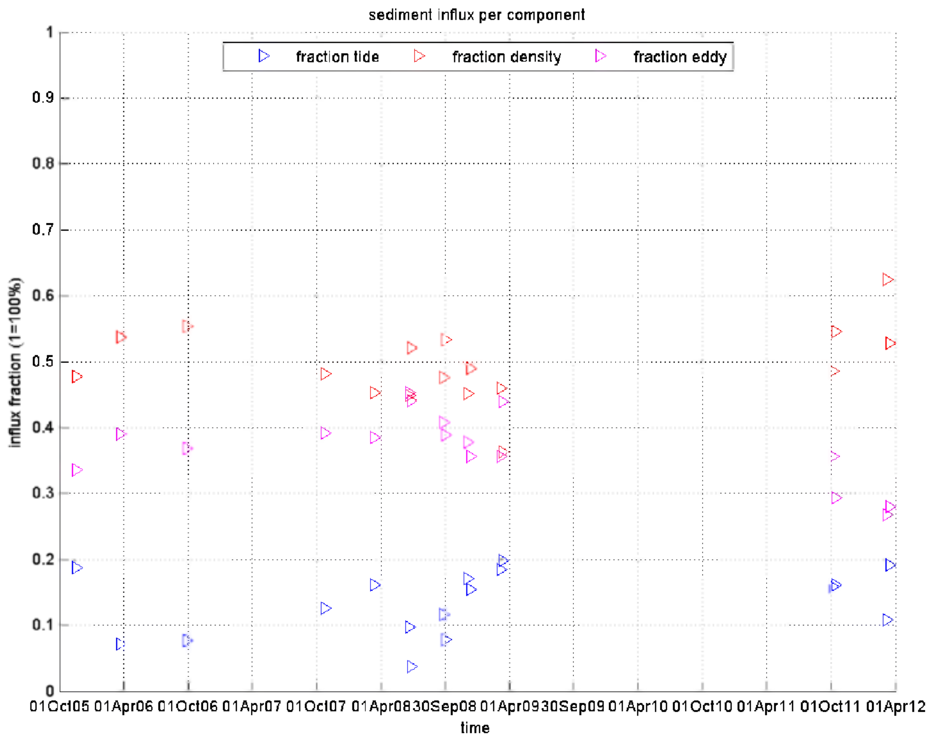

Figure 5-29 : Relative importance of each sediment exchange mechanism, no filter applied.

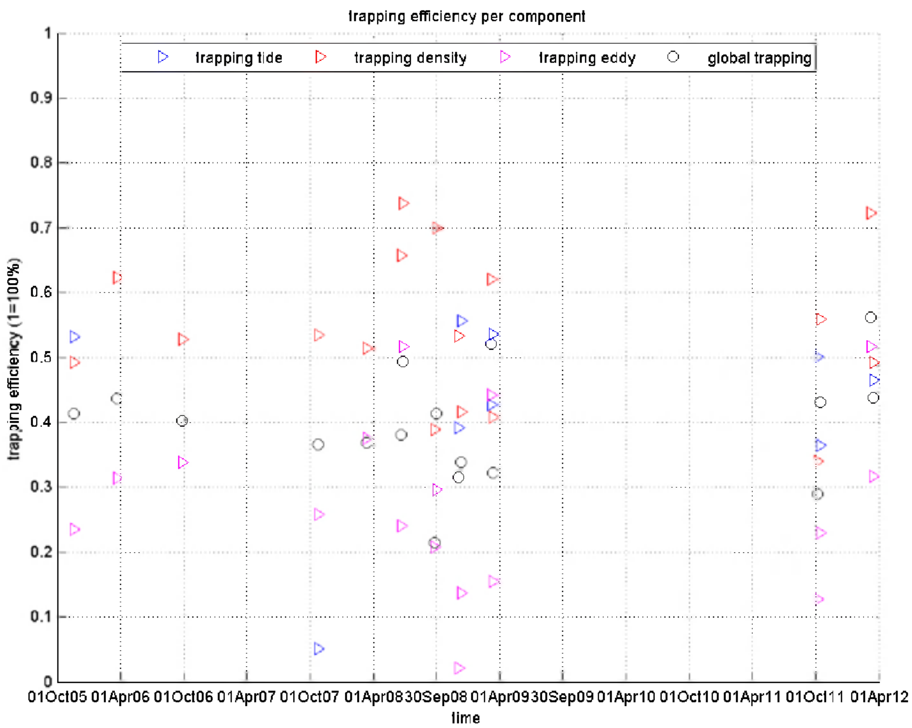

Figure 5-30 : Trapping efficiency per exchange mechanism and global trapping efficiency, no filter applied.

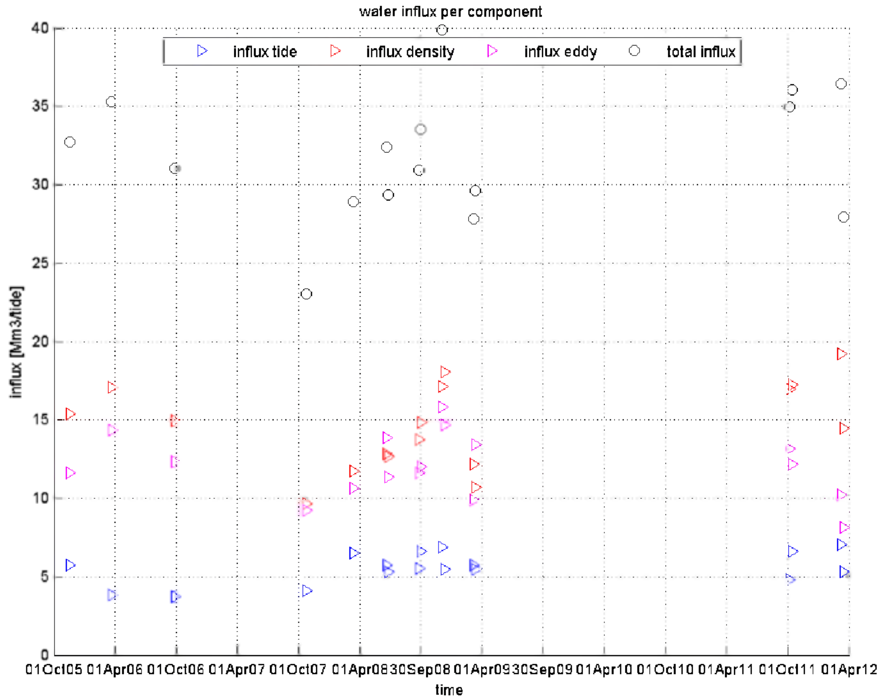

Figure 5-31 : Water influx per exchange mechanism during one tidal cycle, no filter applied.

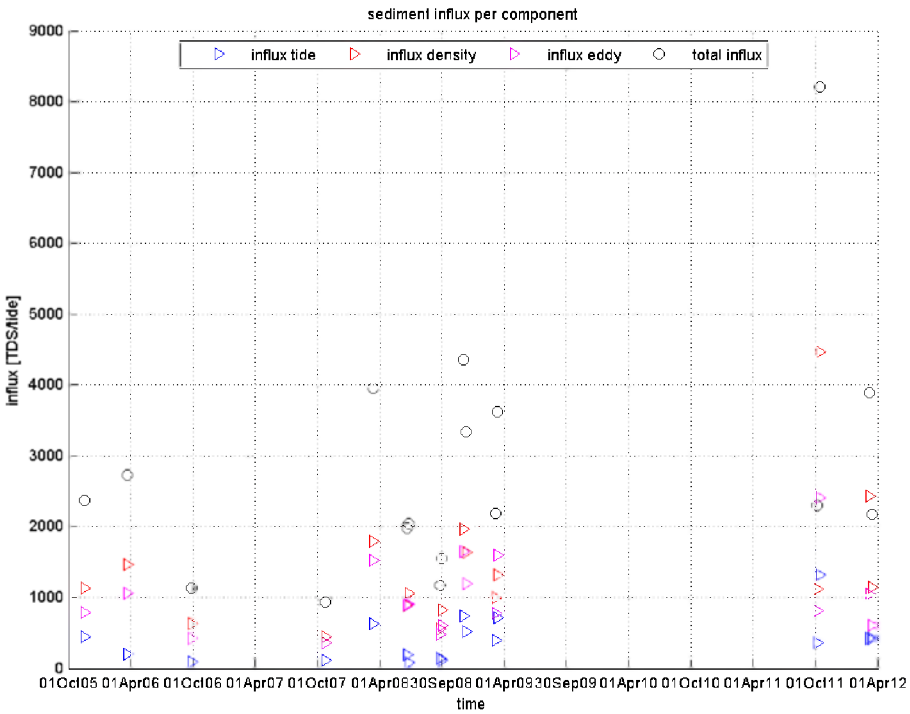

Figure 5-32 : Sediment influx per exchange mechanism during one tidal cycle (not net influx-outflux), no filter applied.

5.3 SEDIMENTATION MODEL

Based on the observations of the previous paragraphs, assumptions can be made to schematize the effects of the CDW in the sedimentation model. A comparison of the model results with the measured mass in Deurganckdok yields extra insight into the multiyear variability of the sedimentation.

5.3.1 Computation of the settling coefficients

As mentioned in paragraphs 4.2.4 and 5.2.4.4, there is some uncertainty surrounding the values of the settling coefficients depending on the calculation method and on the data set used for the analysis. Since different data has been used in this report compared to the data set in IMDC (2009o), the values of the settling coefficients also differ. Below a short sensitivity analysis is shown for the period 1/4/2008 to 1/4/2009 with different calculation methods (3rd year of DGD project).

Calculation methods may differ from each other in several aspects :

- The formula used to compute the settling coefficients (“correct” or “original”).
- The use of top sensors only for the eddy settling coefficient or the average of the top and bottom sensors.
- Applying or not a moving average filter of 5 days to decrease the number of unrealistic values obtained.
- Applying or not a limiter to the daily values of the settling coefficients to remove unrealistic values (lower and upper bounds of 0 and 1).

Table 5-3 summarizes the coefficients obtained with combinations of the different methods described above, all with a global trapping efficiency of 0.39. The settling coefficient for density currents varies between 30 and 60%, the settling coefficient for eddy currents between -15% and +30% depending on the method. The settling coefficient for tidal filling follows from matching the global trapping efficiency. The main uncertainty for the settling coefficient for density are the formula used and the filter, for eddy currents they are the limiter (it removes frequent negative values, which are however physically possible, see below) and the choice of the SSC data used.

Negative trapping efficiencies can be understood as a larger flux of sediment out of the dock than flux of sediment into the dock, due to the variation of the SSC during the tidal cycle. Such values are for instance possible for the eddy contribution if the SSC is higher at the North entrance than at the South entrance during the flood eddy, and the net outflux is not compensated during the ebb eddy given the then measured SSC. Although physically possible, such an outgoing net flux possibly results from the simplified equation used, therefore a limiter has been tested to estimate its impact.

Table 5-3 : Sensitivity analysis on settling coefficients calculated with various methods.

Method	$\alpha_{set,dens}$	$\alpha_{set,eddy}$	$\alpha_{set,tide}$
Values used in previous report	35%	14%	66%
Method used in previous report : Original formula, top SSC for eddy, 5 day filter, no limiter	38%	26%	49%
Physically correct method : Correct formula, mean SSC for eddy, no filter, no limiter	47%	-12%	37%
Sensitivity test : physically correct + filter	56%	-9%	12%
Sensitivity test : physically correct + limiter	49%	29%	20%
Sensitivity test : physically correct + top SSC for eddy	47%	25%	22%

Note how scattered the results are and still how much they differ from the trapping efficiencies estimated from the 13h campaigns (55%, 25%, 30% before CDW in the same order as in Table 5-3).

The single purpose of the individual settling coefficients per exchange component is to get an idea of the relative importance of the individual net sediment fluxes (and not water fluxes, these ones are known). Because the settling coefficient for the tide has been derived to match a global trapping efficiency, all sets of coefficients above (density, eddy and tidal filling) yield exactly the same total sedimentation (for instance the first and the last lines of Table 5-3 : 35% / 14% / 66% and 47% / 25% / 22% yield the same total sedimentation of 39% of the total influx). We will hence argue here that this method based on local measurements is limited to determine the settling coefficients.

The values used in the previous report (IMDC, 2009o) are taken again in this report, keeping in mind that they come with a large uncertainty, irrespective of the presence or not of the CDW. The global trapping efficiency has been derived from many 13h campaigns and is assumed to be reliable.

The method used in previous reports is also applied both before and after construction of the CDW to estimate its qualitative effect on the settling coefficients (Table 5-4). The lower settling coefficients for density and eddy currents simply reflect the observed decrease in vertical and horizontal SSC gradients. However it is not compatible with the observed unchanged global trapping efficiency ($\alpha_{set,tide} > 1$) and the reported increase in dredging volumes. It confirms the limitations of the method.

Table 5-4 : Average settling coefficients computed with the method used in IMDC (2009o) before and after construction of the CDW.

Method	$\alpha_{set,dens}$	$\alpha_{set,eddy}$	$\alpha_{set,tide}$
Previous method before CDW (2006-2010)	30%	24%	70%
Previous method after CDW (2011-2012)	14%	10%	120%

5.3.2 Schematisation of the human impacts

5.3.2.1 Lengthening of the dock

The dock length has been increased in the model from 1500m to 2500m starting from April 2008 to account for the dock extension.

5.3.2.2 Removal of the entrance sill

The effect of the removal of the entrance sill has been modelled by increasing the dock depth from 16m to 18m starting from July 2010 (Figure 5-33). The depth is measured over the sill because the water exchange is computed at the entrance.

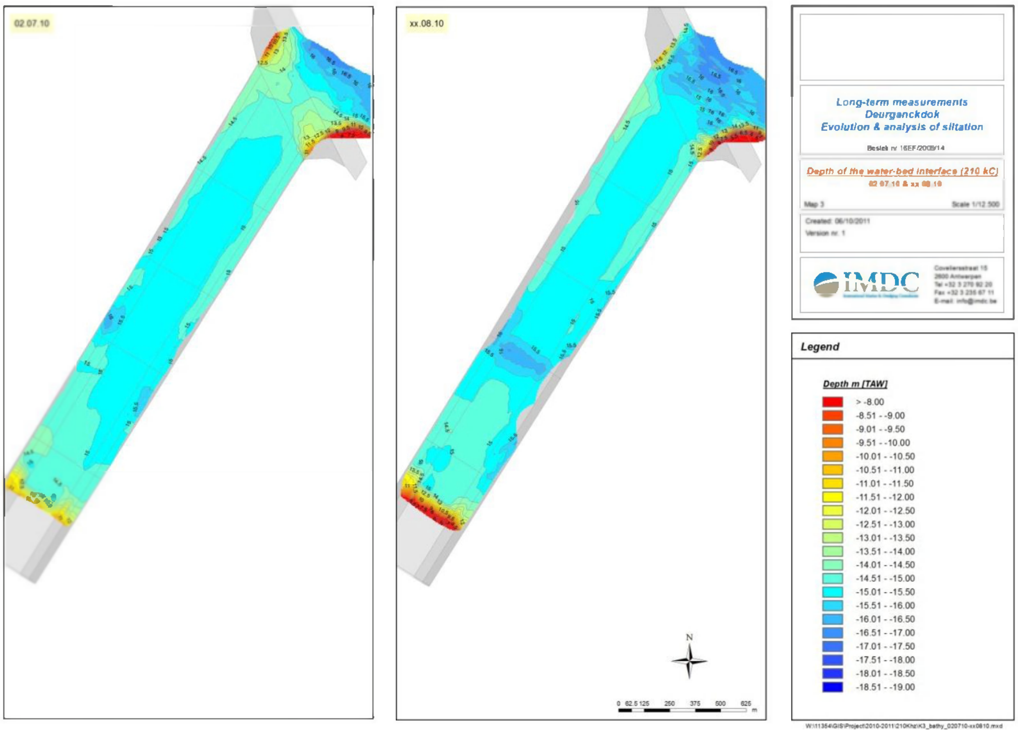

Figure 5-33 : Bathymetry of the dock before (left, July 2nd 2010) and after dredging the entrance sill (right, August 2010). Note that the sill can be much shallower after a long period without maintenance.

5.3.2.3 Current Deflecting Wall

The CDW has been shown in the previous paragraphs to have the following measured impacts on the exchange mechanisms :

- A reduction of the eddy intensity. This is modelled by a shorter eddy duration. Smaller eddy velocities could alternatively be used with the same result.
- An unclear effect on density currents (see also discussion below). Observed weaker vertical salinity gradients from long term measurements could lead to locally weaker density currents: in that case it should follow automatically from the salinity measurements. Observed stronger and longer density currents from 13h measurements could be driven by other causes, such as the deeper entrance or SSC driven density currents for instance. In the model, longer density currents are schematised as the effect of a larger maintenance depth to respect the observed timing of this increase (paragraph 5.3.2.4).
- Lower SSC, as a result of the deviation of the bottom flow and/or of the locally weaker density currents. This should follow automatically from the SSC measurements.
- A global trapping efficiency which is qualitatively similar. In first instance the trapping efficiency is not modified with the CDW.
- As a side effect, the reduced volumes exchanged by density currents and eddy currents increase the relative importance of tidal filling, which is unchanged. For the water fluxes this should follow automatically from the lower volumes exchanged by the eddy. For the sediment fluxes it is not taken into account given the small contribution of the eddy and the large uncertainty in individual trapping parameters (Table 5-3).

Overall the CDW is therefore just modelled with a shorter eddy duration starting from April 2011. According to Figure 5-27 the duration of a 0.1m/s flood eddy current has decreased from about 2 hours to less than 0.5 hours with the CDW (-75%). Because the contribution of the eddy estimated from the 13h measurements is larger than previously assumed in the sedimentation model (IMDC, 2009o), a larger reduction of the eddy duration of -85% has been applied starting from April 2011. This is a very subjective choice, a sensitivity test is presented in paragraph 5.3.3.6.

5.3.2.4 Increase of the maintenance depth

Table 5-5 presents an overview of the maintenance depths in Deurganckdok over time. The depth of the dock has already been increased via the removal of the sill so no additional schematisation is needed for the larger depth. Note that the maintenance depth is relative to the 33 kHz signal of the echosounder, while the 210 kHz signal gives the top of the mud layer.

The observed longer density currents cannot be attributed to any human impact in particular. An increase in duration of density currents of 20% has been applied starting from April 2011 to reflect this observation.

Table 5-5 : Overview of maintenance depths in Deurganckdok over time.

Date	Maintenance depth quays [m LAT]	Maintenance depth trench [m LAT]	Maintenance depth sill [m LAT]
May 2008 - December 2010	14.8 – 15.7 m (variable)	15.0 – 17.0 m (variable)	No maintenance of sill except sweepbeam
December 2010	|	|	14.8 – 15.5 m (variable)
March 2011	**15.9 m**	**17.5 m**	**15.2 m**
October 2012	|	**18.0 m**	|

5.3.3 Application of the sedimentation model

5.3.3.1 Settings

The sedimentation model has been applied with the parameters in Table 5-7. The model is run directly for the entire period 2005-2012. Model parameters vary according to the reported capital works (summarized in Table 5-6) :

- 1st July 2005 to 1st April 2008 : short dock (1500m)
- 1st April 2008 to 1st July 2010 : full dock (2500m) with entrance sill (16m)
- 1st July 2010 to 1st April 2011 : full dock (2500m) without entrance sill (18m)
- 1st April 2011 to 1st June 2012 : full dock (2500m) without entrance sill (18m) and with CDW (eddy duration 1 hour, density currents 6h)

The effect of the larger maintenance depth is not known and does not affect model parameters. The deepening of the Scheldt is affecting the dock only indirectly via the boundary conditions.

Construction works typically take time but their effect comes progressively. In the model a somewhat arbitrary end date is chosen towards the end of the construction works and depending on observed model results. Varying it by one or two months does not change much the model behaviour.

In first instance the settings from the calibrated model in IMDC (2009o) are used. In that model the duration of density and eddy currents had been used as calibration parameters. Dredging volumes are obtained from the BIS system and measured mass have been converted from the values reported in the annual mass balances to a weighted area mean, as in the previous analysis report. The salinity amplitude used to compute density currents has been computed as the maximum daily value of all four sensors at the dock entrance minus their minimum. It is hence larger than the salinity amplitude at a given location.

Table 5-6 : Variable parameter values per period.

Period	Dock length L_{dock}	Dock/entrance depth H_{dock}	Duration eddy T_{eddy}	Duration density currents T_{dens}
1/7/2005 to 1/4/2008 (short dock)	1500 m	16 m	6 hours	5 hours
1/4/2008 to 1/7/2010 (long dock)	2500 m	16 m	6 hours	5 hours
1/7/2010 to 1/4/2011 (long dock, no sill)	2500 m	18 m	6 hours	5 hours
1/4/2011 to 1/6/2012 (long dock, no sill, CDW, deeper dock)	2500 m	18 m	1 hour	6 hours

Table 5-7 : Parameters used in the global sedimentation model

Parameter	Description	Value
α_{global}	Global trapping efficiency (corresponding to settling coefficients for density, eddy and tidal filling of 0.35, 0.14 and 0.66)	0.39
L_{dock}	Dock length	1500m before April 2008, 2500m after
B_{dock}	Dock width	450m
H_{dock}	Average dock depth	13.3m / 15.2m LAT = 16m / 18m before / after July 2010
T_{dens}	Duration of density currents during flood or ebb (calibration parameter for relative importance of water exchange due to density currents)	5 hours before April 2011, 6 hour after
T_{eddy}	Duration of eddy currents during flood or ebb (calibration parameter for relative importance of water exchange due to eddy currents)	6 hours before April 2011, 1 hour after
v_{eddy}	Mean value of average eddy velocity	0.1 m/s, 0.05 – 0.15 m/s for uncertainty
h	Average tidal amplitude	5.14m
ρ	Water density	1010 kg/m³
T_{tide}	Tidal period	12h 25min
g	Gravity constant	9.81 s^{-2}

5.3.3.2 Uncalibrated results

Model results with the settings of Table 5-7 are shown in Figure 5-34. These results can be considered as those of an uncalibrated model. Results show that for the period 2006-2009 the agreement between predicted sedimentation, dredged mass and measured mass is equally good as in the previous report (which is expected since model parameters are similar). After 2009 the model shows a significant deviation from the measured values. More specifically, the sedimentation event of January to March 2010 is not reproduced and starting from around April 2011 the sedimentation is underestimated. This period corresponds to the increased maintenance depth (visible from March to May 2011) and to the finalisation of the CDW. The entrance sill has been dredged on July 1st 2010 in the model. From that moment until spring 2011 the model is still qualitatively in line with measurements, with a slight underestimation of sedimentation.

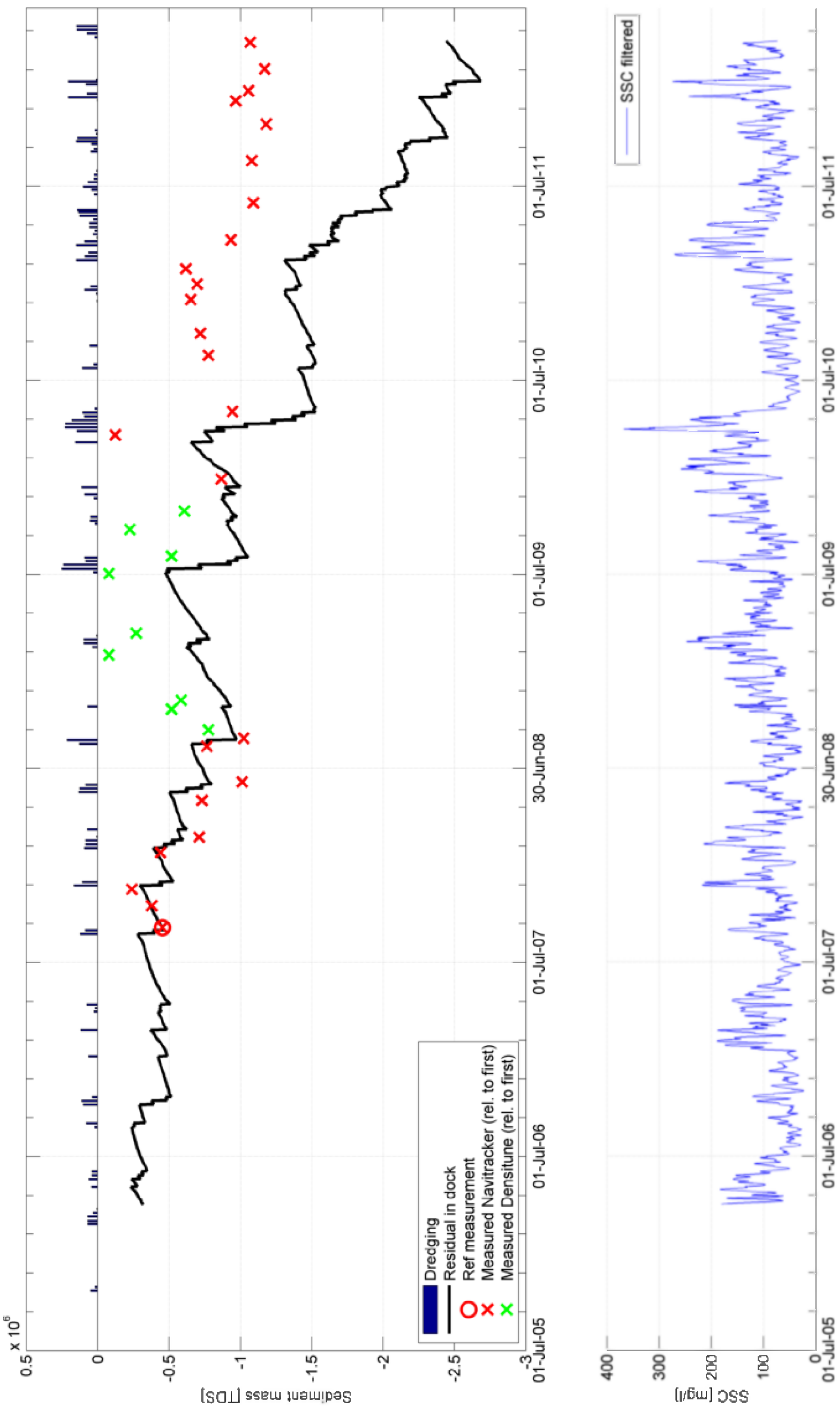

Figure 5-34 : Modelled sedimentation including CDW before additional calibration. The SSC is the main parameter controlling model results and is shown below.

5.3.3.3 Calibrated results

A detailed look at the dredging volumes over the years shows that from April 2010 on, large volumes of sediment have been dredged at the entrance of the dock (500 000 TDS in Apr2010-Apr2012 compared to 50 000 TDS in Apr2006-Apr2010). A strong sedimentation since removing the sill is not unthinkable, but it is more likely that the sill was previously dredged with a sweepbeam and that these volumes were hence previously not reported. This hypothesis is supported by the sweepbeam effort reported in Table 5-8. Numerical modelling studies only predict a moderate increase of the sedimentation on the sill after removing it (8% according to Van Maren, 2007). In the absence of sweepbeam dredging volumes, the BIS dredging volumes at the sill need to be subtracted for a correct comparison.

Table 5-8 : Yearly sweepbeam effort in Deurganckdok in hours.

Period	Quays [hours]	Sill [hours]	Total [hours]
Apr 2006 – Mar 2007	452	365	817
Apr 2007 – Mar 2008	1236	1068	2304
Apr 2008 – Mar 2009	629	825	1454
Apr 2009 – Mar 2010	983	765	1747
Apr 2010 – Mar 2011	1632	61	1692
Apr 2011 – Mar 2012	2975		2975
Apr 2012 – Mar 2013	2055		2055

The strong sedimentation peak of January to March 2010 corresponds to a bit higher SSC conditions than average (especially the minimum values). It corresponds to the period during which the entrance sill was being removed. It is possible that trapping under high SSC conditions is higher due to increased flocculation in the low-turbulence environment of the dock. It is equally possible that an SSC peak due to the construction works (or a peak in salinity amplitude, but it has less influence) has simply not been captured in the SSC proxy used. No such event is found in time series in the river (buoy B84), but it could also be a local phenomenon at the dock entrance.

Increased flocculation under high SSC can be modelled by modulating the trapping efficiency with the SSC :

$$\alpha = \alpha \frac{SSC(t)}{\overline{SSC}}$$

for each trapping coefficient. Flocculation is a very complex process but in the absence of data it is difficult to introduce more dependencies. The fall velocity reacts positively to an increase in SSC (IMDC, 2005i; IMDC, 2006o), a linear law is chosen in first instance for simplicity. Previous fall velocity measurements support this assumption but do not specify the type of relation between fall velocity and SSC. The Manning flocculation model seems to suggest a non-linear response of the fall velocity to the SSC with a power greater than one, in particular above a SSC of 500mg/l (IMDC, 2005i, Fig. 6-37). An optimal turbulence level can also strongly increase the flocculation and fall velocity.

It is chosen to calibrate the model with increased flocculation under high SSC, in addition to correcting the BIS dredging volumes to exclude dredging of the sill. The effect of a missing high SSC event is investigated in the sensitivity analysis (paragraph 5.3.3.6). Settings of Table 5-7 are kept unchanged.

Results of the calibration are shown in Figure 5-35 together with the main forcing factor, the SSC. The method reproduces relatively well the sedimentation peak of winter 2010. The method used implies that the increased sedimentation comes from an increased trapping efficiency due to increased SSC. An increased SSC could in turn be justified by the more frequent dredging since winter 2011 (paragraph 5.2.2). Results are in line with the highest SSC observed during the 13h measurement of 13th March 2011 and the highest trapping efficiency during the 13h measurement of 8th March 2012, both after construction of the CDW.

The limited number of measurements available since the construction of the CDW, both long-term time series and 13h campaigns, does not allow to fully validate these hypotheses. Only a larger number of 13h campaigns under a higher SSC would allow to filter out the strong natural variability from the background effect of the human impacts. Non-linear effects of the SSC are therefore investigated further with the numerical model Slib3D (chapter 6).

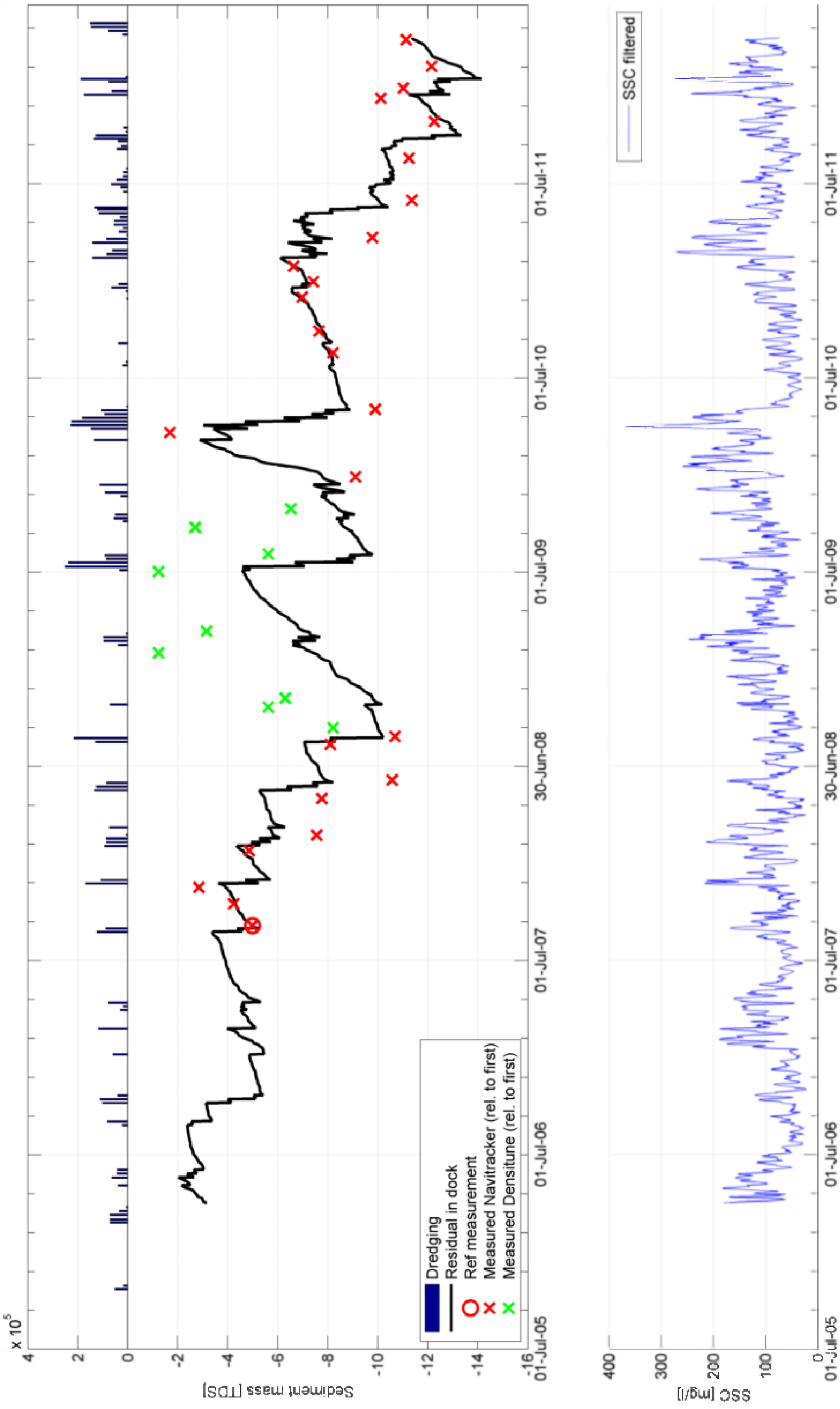

Figure 5-35 : Modelled sedimentation with calibration method 1 : no dredging volumes from sill and modulation of the trapping efficiency with the SSC.

5.3.3.4 Sedimentation volumes

The model strongly suggests that the reported dredging volumes should not include dredging of the sill at the dock entrance to be comparable. This impacts the total dredged volumes reported in the yearly mass balance. Table 5-9 presents corrected volumes based on the weekly dredging reports and sedimentation volumes from the conceptual model. All data are used in the sedimentation model. The weekly report volumes differ slightly from the volumes derived from the BIS data in the yearly mass balance reports due to a different computation method (BIS numbers about 10% larger than weekly reports, sometimes referred to as V' numbers).

Table 5-9 : BIS dredging volumes negatively corrected for dredging of the entrance sill.

Period	Project	Reported volumes weekly data [TDS]	Corrected volumes weekly data [TDS]	Modelled sedim. [TDS]
Apr2006-Apr2007	DGD1	690 000	690 000	590 000
Apr2007-Apr2008	DGD2	980 000	980 000	820 000
Apr2008-Apr2009	DGD3	990 000	990 000	910 000
Apr2009-Apr2010	CDW1	1 580 000	1 550 000	1 610 000
Apr2010-Apr2011	CDW2	1 560 000	1 330 000	1 160 000
Apr2011-Apr2012	CDW3	1 880 000	1 610 000	1 210 000
Total		7 690 000	7 140 000	6 290 000

Table 5-9 shows that yearly dredging volumes have increased from around 1 M TDS in 2008-2009 to 1.9 M TDS in 2011-2012 (reported volumes).

The abnormally large increase of 500 000 TDS in 2009-2010 corresponds to part of the strong sedimentation event of winter 2010. The higher volumes in 2010-2011 all correspond to the remaining part of the strong sedimentation event of winter 2010 or to dredging works which occurred <u>after</u> the dock deepening and the construction of the CDW in March to May 2011. The effect of the different human impacts can be estimated by turning off their respective parameterisation in the conceptual model. The effect of an increase of the entrance cross-section from 16m to 18m depth results in an increase of the sedimentation of about 100 000 TDS per year. The effect of longer density current from 5h to 6h per tide results in an increase of about 150 000 TDS per year.

During the period 2006-2012 around 7.1 M TDS have been dredged after correction, while the model only predicts a sedimentation of 6.3 M TDS. The difference is due to the average deepening of the dock which occurred over the period. With a dry bed density of 0.3 to 0.2 TDS/m³, a dock length of 2500m and a dock width of 500m, 1m of bed roughly corresponds to a sediment mass of 250 000 to 375 000 TDS. Over the same period the maintenance depth has been increased from -15m to -17.5m LAT, which represents 600 000 to 900 000 TDS, about half of which occurred after April 2011 during the increase of the maintenance depth. This is in line with the observed difference in volumes.

In the calibrated model, the initially reported dredging increase from 1M to 1.9M TDS/year can hence be attributed for :

- around 25-30% to a change in reporting of dredging amounts (250 000 TDS to 300 000 TDS),
- around 40% to a one-time deepening of the dock in 2011-2012 (400 000 TDS),
- around 10% to an increase of the entrance cross-section (100 000 TDS),
- around 15% to longer density currents excluding the larger cross-section (150 000 TDS)

The modulation of the trapping efficiency by the SSC also has a strong impact on the sedimentation volumes, increasing it respectively by around 400 000 TDS in 2009-2010, 200 000 TDS in 2010-2011 and 100 000 TDS in 2011-2012 due – in particular in the winter 2010 – to occasional peaks in SSC.

To conclude, real sedimentation volumes excluding sudden sedimentation events like the one of winter 2010 probably lie around 1.2 M TDS/year in 2011-2012 compared to 1 M/year in 2008-2009. It is also possible that a non-negligible fraction of this sedimentation is directly or indirectly related to changes in the dredging activity : a high SSC may induce non-linear effects (trapping efficiency) and impact density currents. In view of this uncertainty and of the subjective choice of the parameterisation of the CDW, it is difficult to estimate the effect of the CDW on the sedimentation at this stage.

The cumulative sedimentation predicted by the model is presented in Figure 5-36. A comparison of dredged volumes and modelled sedimentation over a specific period is difficult because it depends very much on when the period is defined relative to dredging works. The deviation at the simulation end is more representative of differences : there is a good match during the last year with the calibration method chosen (flocculation). The uncertainty band shown on Figure 5-36 is computed like in IMDC (2009o) by assuming a measurement uncertainty of the SSC of ±10% and of ±0.05 m/s for the mean eddy velocity. As shown by the results of the uncalibrated model, the real uncertainty surrounding the results is our understanding of the system, which in turn determines the model equations.

The net influx per tide is impacted by the calibration method chosen. With the uncalibrated model, the net influx is generally comprised between 500 and 2000 TDS/tide, in line with 13h measurements and numerical modelling results before construction of the CDW. With the calibrated model the variation is amplified, with a net influx generally comprised between 200 and 4000 TDS. Although the calibrated model reproduces better total sedimentation, such a large variation has until recently not been observed in 13h measurements.

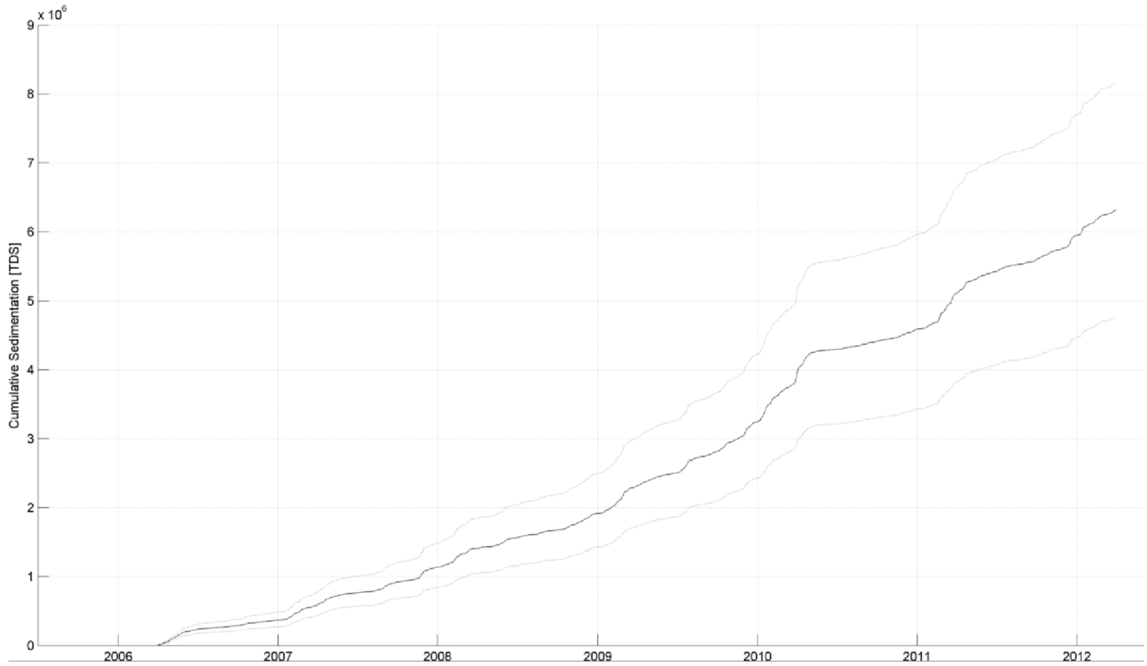

Figure 5-36 : Cumulative sedimentation modelled with method 1 (flocculation). Uncertainty band derived like in IMDC (2009o).

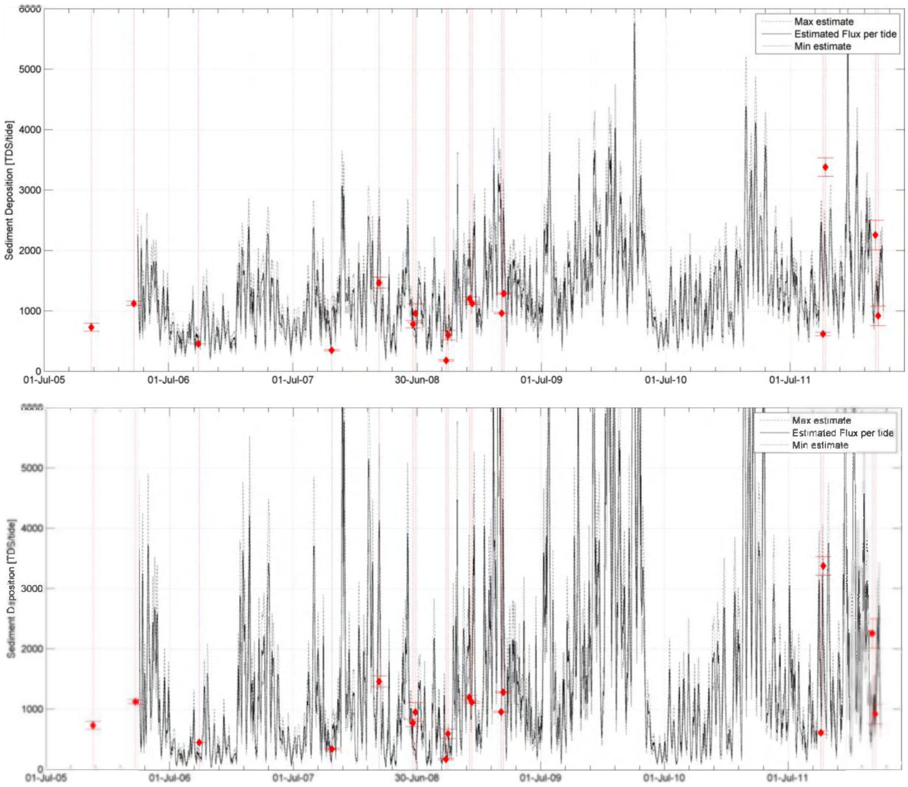

Figure 5-37 : Sediment deposition per tide compared to the estimates derived from 13h measurements. Top : uncalibrated (i.e. calibration from 2006-2009). Bottom : calibrated (flocculation).

5.3.3.5 Water and sediment fluxes

The yearly variability of the forcing factors is shown in Figure 5-38. The CDW is supposed to decrease the salinity amplitude and indirectly the SSC through the density currents. Both impacts are hidden by the large variability of the signals.

Figure 5-39 presents the resulting water fluxes. Exchanged volumes in 2008-2009 are comparable to those reported previously because similar settings have been used. They account approximately for 6 Mm³/tide for tidal filling (15%), 8 Mm³/tide for eddy currents (20%) and 25 Mm³/tide for density currents (65%).

Before April 2008, the shorter dock results in the model in a 40% lower tidal filling contribution. After July 2010 the removal of the sill increases the entrance cross-section, increasing exchanged volumes of eddy and density current, and increasing the density current velocity, for an overall volume increase of 15%. After April 2011, the CDW is modelled as an eddy contribution reduced by 85% (volume reduction -17%) and density currents which are 20% longer (volume increase +13%). All changes combined lead to an increase of 11% of the exchanged volumes compared to the situation of 2008-2009 with the chosen model parameters. However the measured salinity amplitude is slightly lower since spring 2011, potentially due to the CDW (around -0.5ppt), a decrease by 15% would result in 5% lower volumes, or combined with the other changes an increase of only +4% instead of +15%, which is why little change is seen in Figure 5-39.

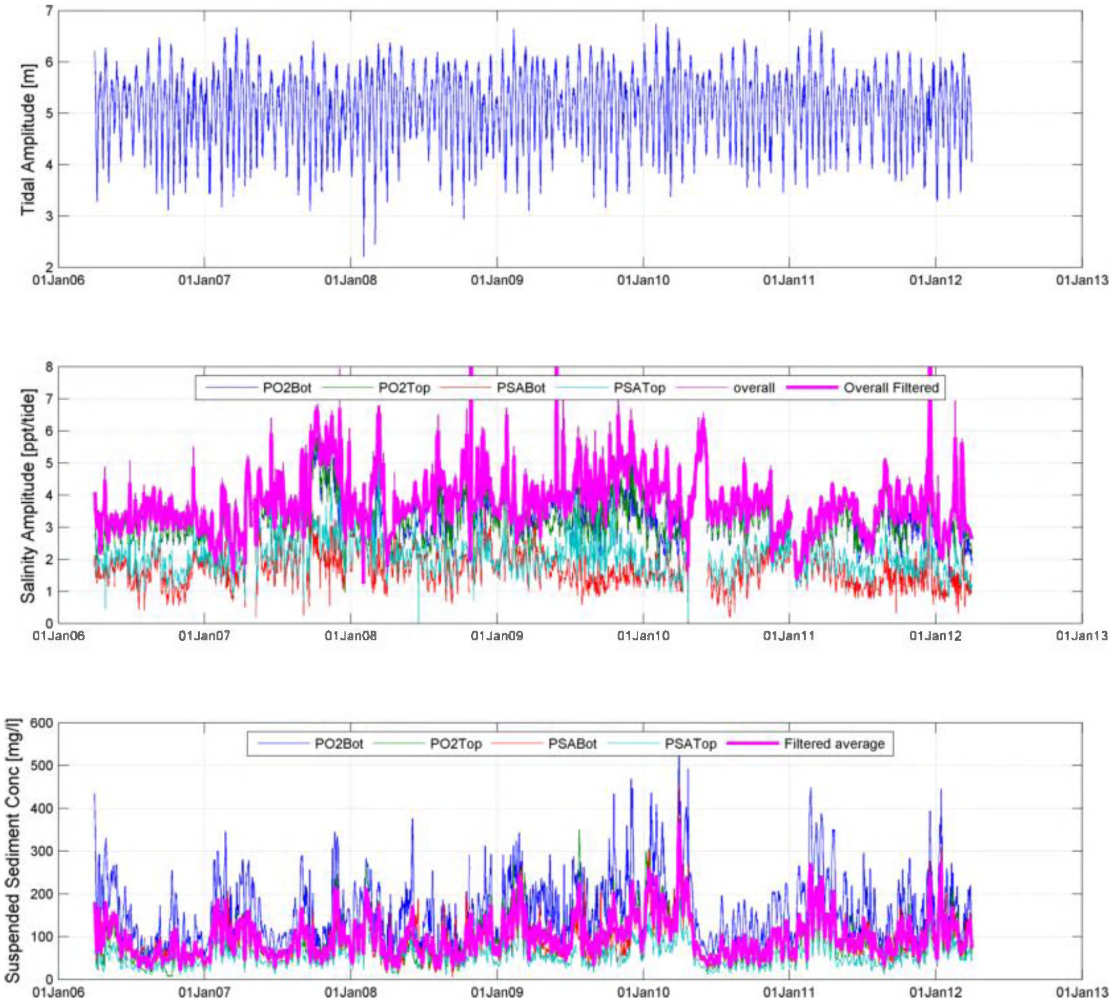

Figure 5-38 : Time series of the forcing factors used in the sedimentation model.

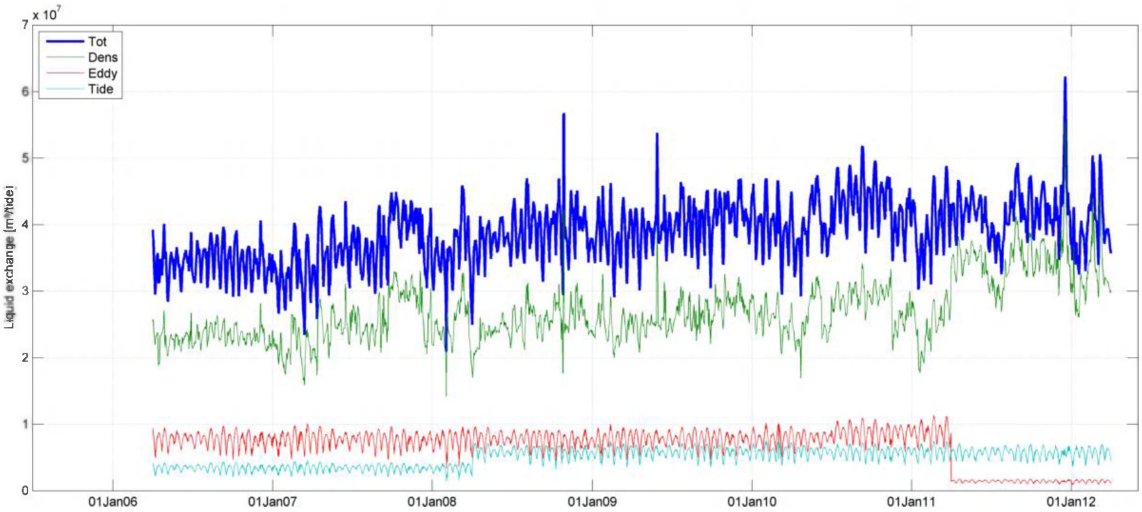

Figure 5-39 : Water fluxes resulting from the boundary conditions per exchange component.

Figure 5-40 presents the modelled sediment fluxes per exchange component. The model estimates the contribution of tidal filling, eddy currents and density currents to total sedimentation at around 28%, 8% and 64% respectively for the year 2008-2009, as in the previous report. As explained in paragraph 5.3.1 these fractions directly depend on the chosen settling coefficients which can vary strongly depending on their calculation method. Dredging the entrance sill only slightly modifies this proportion according to the model equations (larger cross-section, unchanged settling coefficients). The CDW signficantly decreases the relative eddy contribution and increases the contributions of tidal filling and density currents. Absolute values vary strongly in time and cannot be judged from the model.

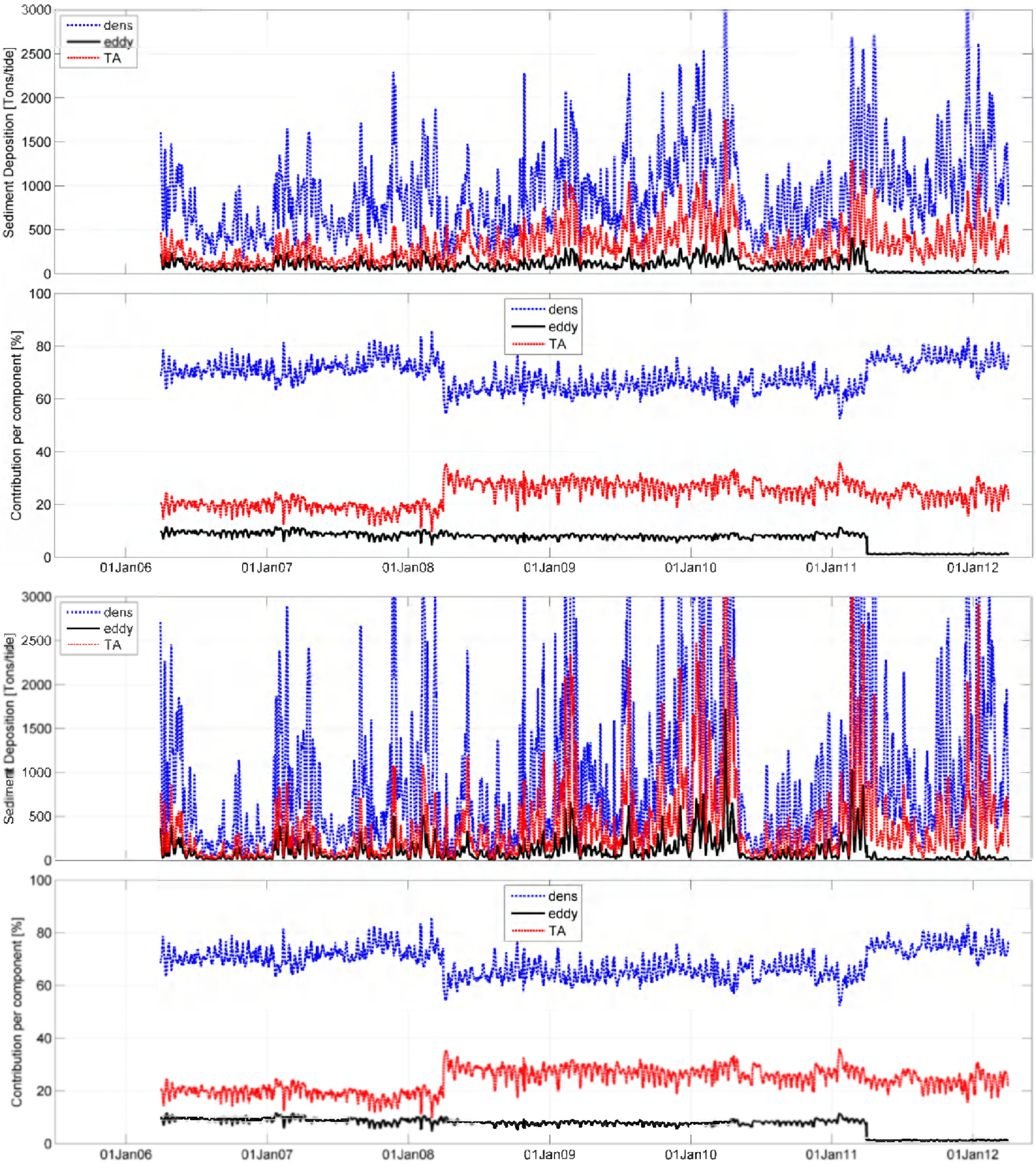

Figure 5-40 : Sediment fluxes per exchange component in the uncalibrated model (i.e. calibration from 2006-2009, top) and in the calibrated model (flocculation, bottom).

In the model, the CDW reduces the eddy duration from 6 to 1 hour, and maybe indirectly reduces the salinity amplitude (-15%). The shorter eddy duration results in a water exchange around 15% lower and a sedimentation lower by 80 000 TDS, corresponding to a decrease of 5% compared to the volumes dredged from April 2011 to April 2012. This does not take into account the effect of the lower salinity amplitude, which can be estimated from the equations and should account for a decrease in the order of 5% of the water exchange and the sedimentation. The exact numbers depend on the settings chosen, a total reduction of 5-15% seems more reasonable to account for uncertainty.

5.3.3.6 Sensitivity analysis

A sensitivity analysis is usually made to estimate the uncertainty around the predictive capability of a model. The underestimation of the sedimentation with the uncalibrated model, in fact a model with parameters based on a calibration in 2006-2009, shows that the predictive capability of the conceptual model is only as good as our understanding of the system because few dominant processes are modelled. As such a sensitivity analysis does not really make sense in the present case because a considerable uncertainty exists about the main parameter tunable in the model, the trapping efficiency. The different possible ways to calibrate the model show in a better way how *sensitive* the model is to our understanding.

Nonetheless, the equations describing the conceptual model in chapter 4.2 are very simple and the sensitivity of the model to the input parameters is straightforward : it reacts linearly to the SSC and the global trapping efficiency, and the contribution of each exchange mechanism reacts linearly to its own trapping efficiency and its duration (not well-defined, used to calibrate the hydrodynamics). The contribution of tidal filling depends on the known tidal prism and is not tunable.

Two alternative ways to calibrate the model are presented below.

Missing event in SSC proxy

The model can be also calibrated by introducing a higher trapping efficiency to account for the missing sedimentation event of spring 2010, instead of a correction for flocculation. Figure 5-41 shows the resulting mass balance when the flocculation correction is removed and the trapping efficiency is set to 99% for each component from 1st January to 1st March 2010. Figure 5-42 and Figure 5-43 show respectively the resulting sediment fluxes per exchange mechanism and the comparison with 13h measurements. The correction for sill volumes in the BIS data is kept.

This method also reproduces relatively well the sedimentation peak of winter 2010, but it still underestimates the sedimentation after April 2011 by 400 000 TDS. It is suggested that either the SSC at the dock entrance is not a good proxy anymore since the construction of the CDW, or the trapping efficiency of the dock has increased since spring 2011, coinciding with a larger maintenance depth and the presence of the CDW.

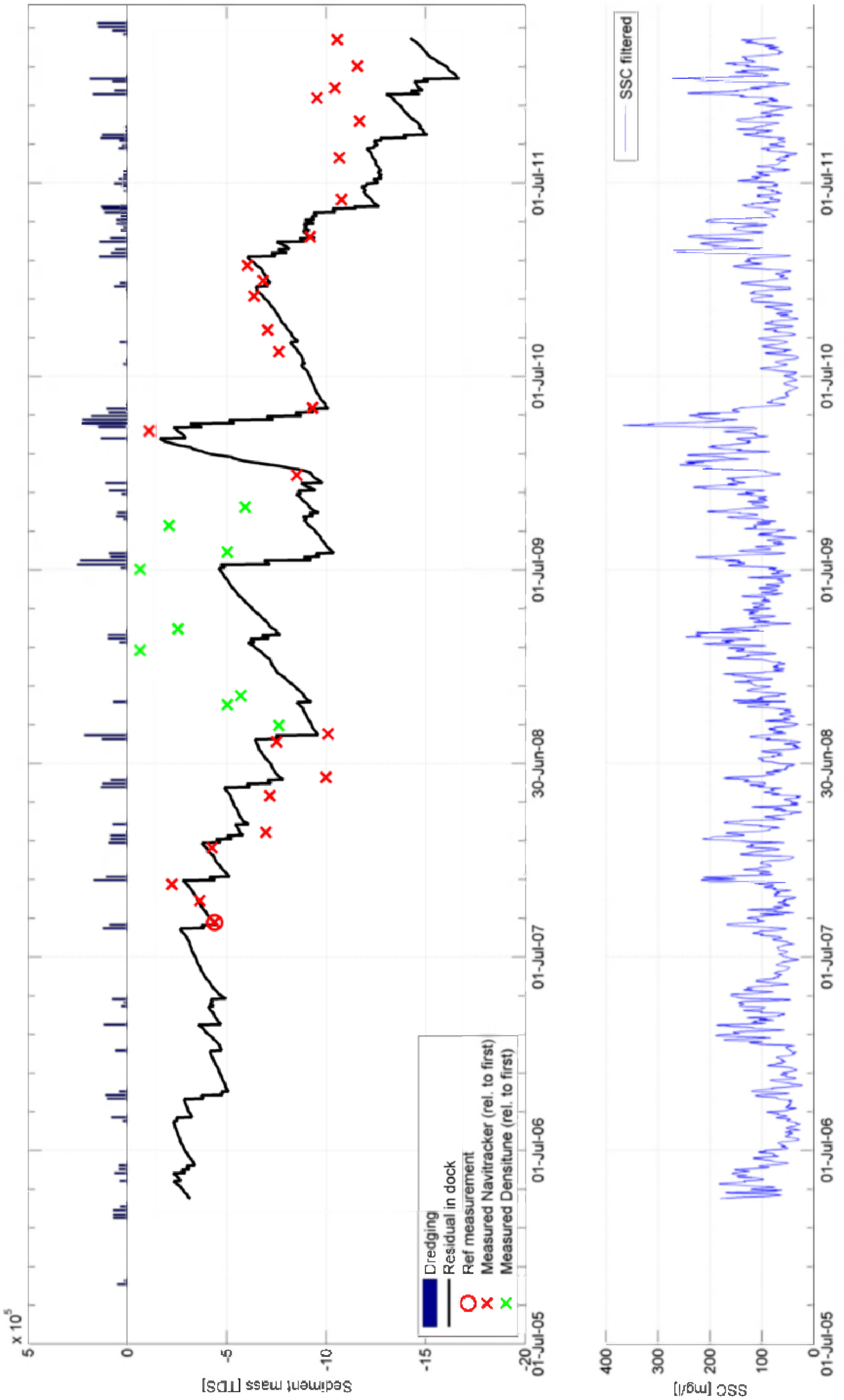

Figure 5-41 : Modelled sedimentation with increased trapping efficiency in spring 2010 (event) and no dredging volumes from sill.

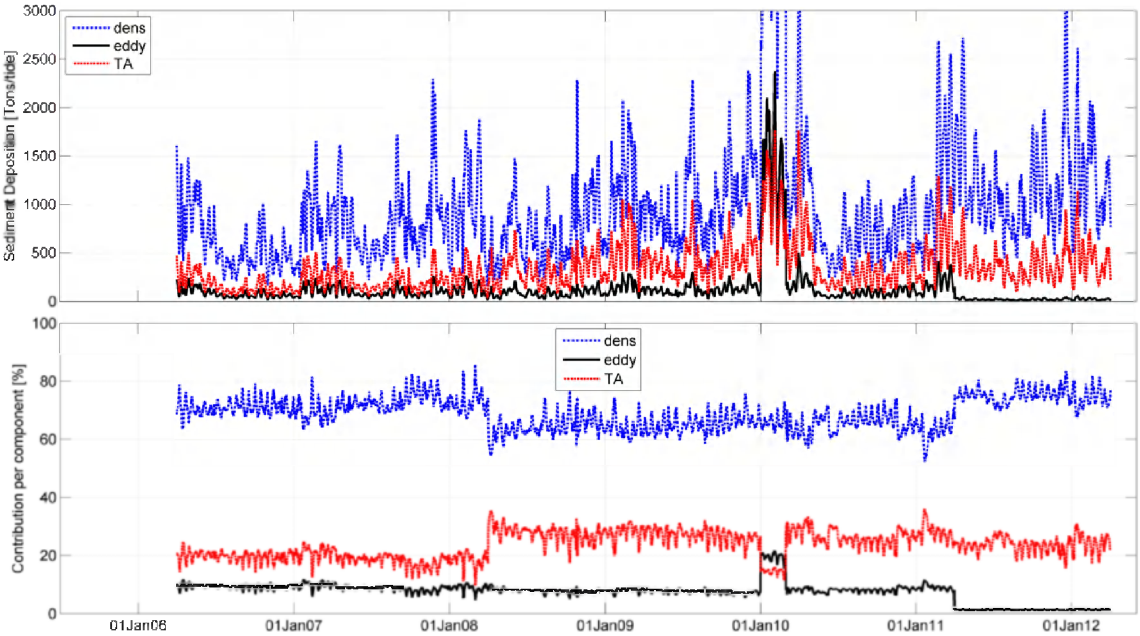

Figure 5-42 : Sediment fluxes per exchange component with increased trapping efficiency in spring 2010 (event).

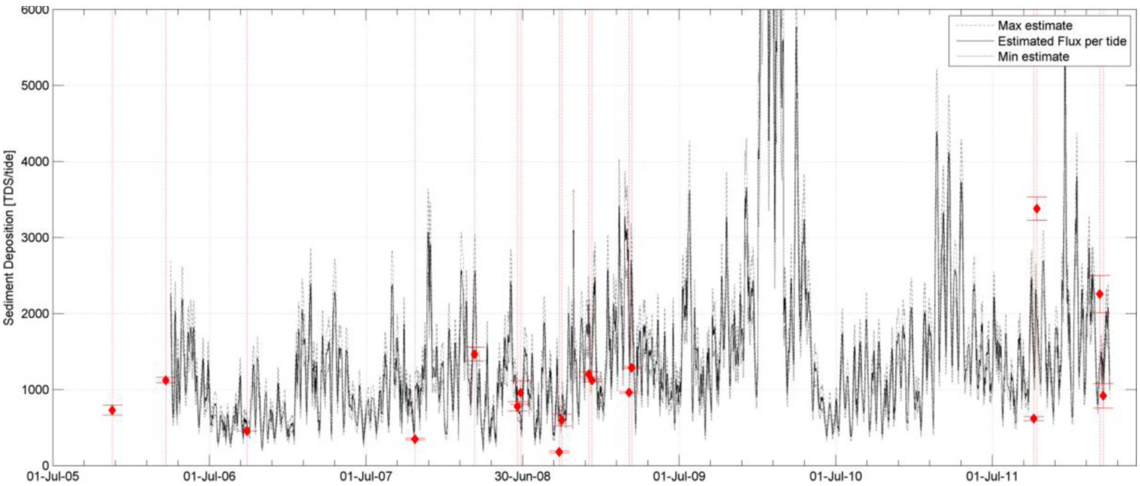

Figure 5-43 : Sediment deposition per tide compared to the estimates derived from 13h measurements with increased trapping efficiency in spring 2010 (event).

Measured water volumes and trapping efficiencies

The exchanged water volumes per mechanism and the trapping efficiencies derived from 13h measurements are also very different from those applied in the model. A test has been done in which the trapping efficiencies have been set to 35%, 55% and 25% before CDW and 40%, 50% and 30% after CDW respectively for tidal filling, density and eddy currents, according to paragraph 5.2.4.4. Like in IMDC (2009o), the duration of density and eddy currents have been used as calibration parameters. They have been respectively set to 3 hours and 11 hours before CDW, and 3.6 hours and 7 hours after CDW to reflect the relative importance of water fluxes determined from 13h measurements (as percentages) and to match the long-term sedimentation. Note that these durations are unrealistic compared to measurements of paragraph 5.2.4.3. Alternatively other model parameters such as the eddy velocity could be used for calibration. The corrections for sill volumes and for modulation of the trapping efficiency by flocculation have been applied like in the calibrated model.

Figure 5-44 shows that the resulting sedimentation matches less well but is still very acceptable. With these parameters the sedimentation is slightly overestimated until May 2010 (+200 000 TDS) and underestimated from May 2010 until April 2012 (-200 000 TDS).

Figure 5-45 shows that the resulting total water influx in the model lies around 35 Mm³ in 2008-2009, which is very realistic. It should be equal to or larger than the estimates of Figure 5-31, where the resolution of the ADCP limits water exchange.

Interestingly, the lower water fluxes compared to those of the reference model in paragraph 5.3.3.5 are compensated by the higher trapping efficiencies of the individual exchange mechanisms. The eddy currents in particular are now much more important for the total water exchange but also trap more sediment (Figure 5-46). As a consequence the effect of the CDW in reducing the eddy is more important and the same reduction in sedimentation can be achieved with a lower relative reduction of the eddy duration as in the calibrated model. Setting the eddy duration unchanged to 11 hours instead f 7 hours with CDW results in a sedimentation 200 000 TDS higher at simulation end, representing around 12% of the volumes dredged in the period April 2011-April 2012.

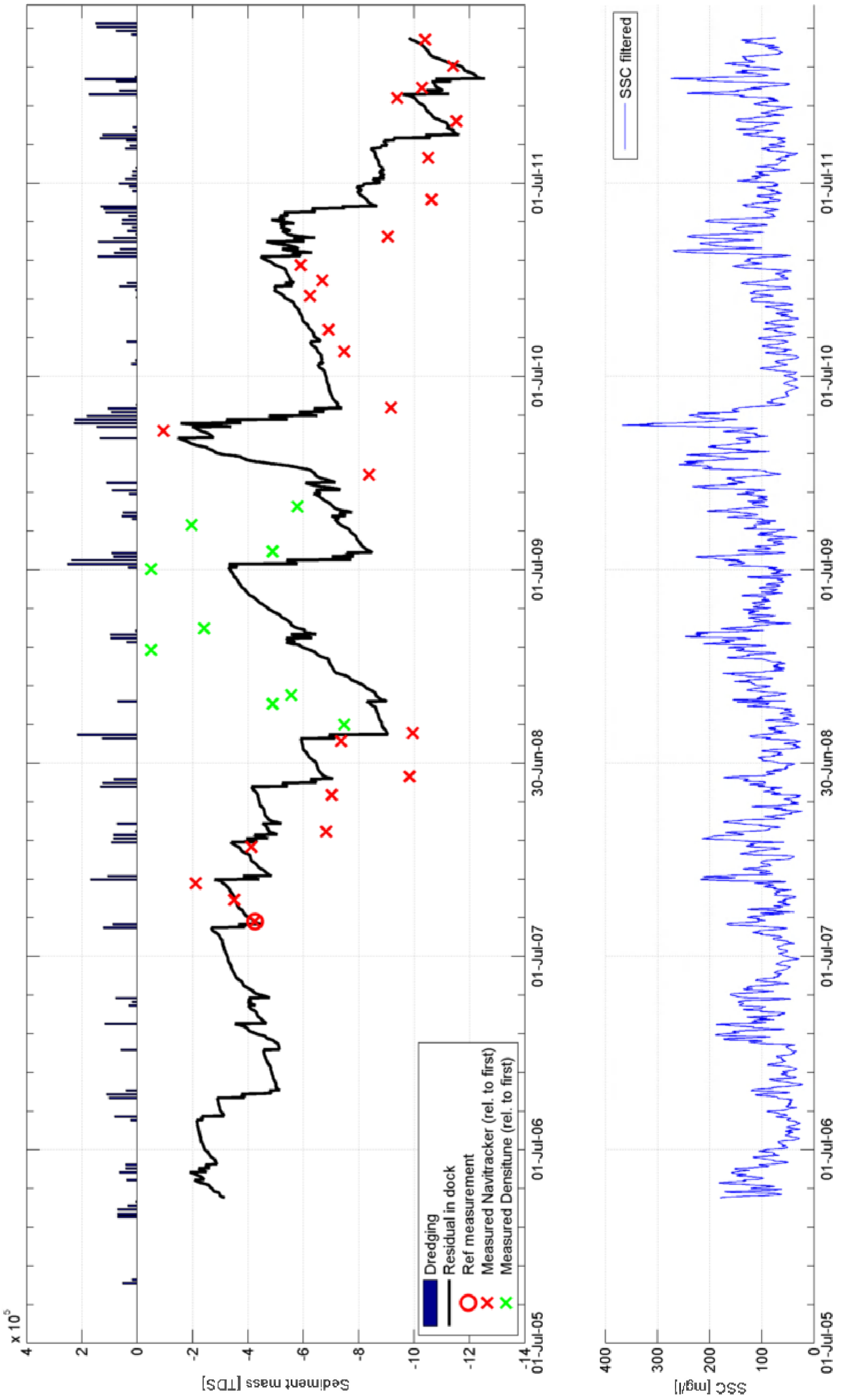

Figure 5-44 : Modelled sedimentation with measured trapping coefficients and relative importance of water exchange mechanisms, no dredging volumes from sill, flocculation correction.

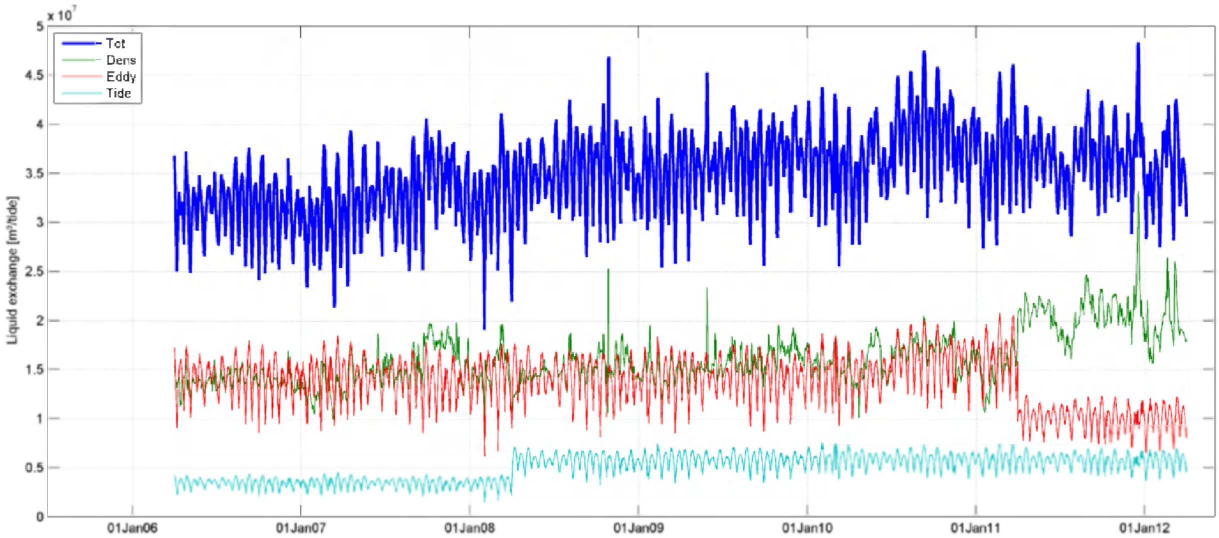

Figure 5-45 : Water fluxes per exchange component with measured trapping coefficients and relative importance of water exchange mechanisms.

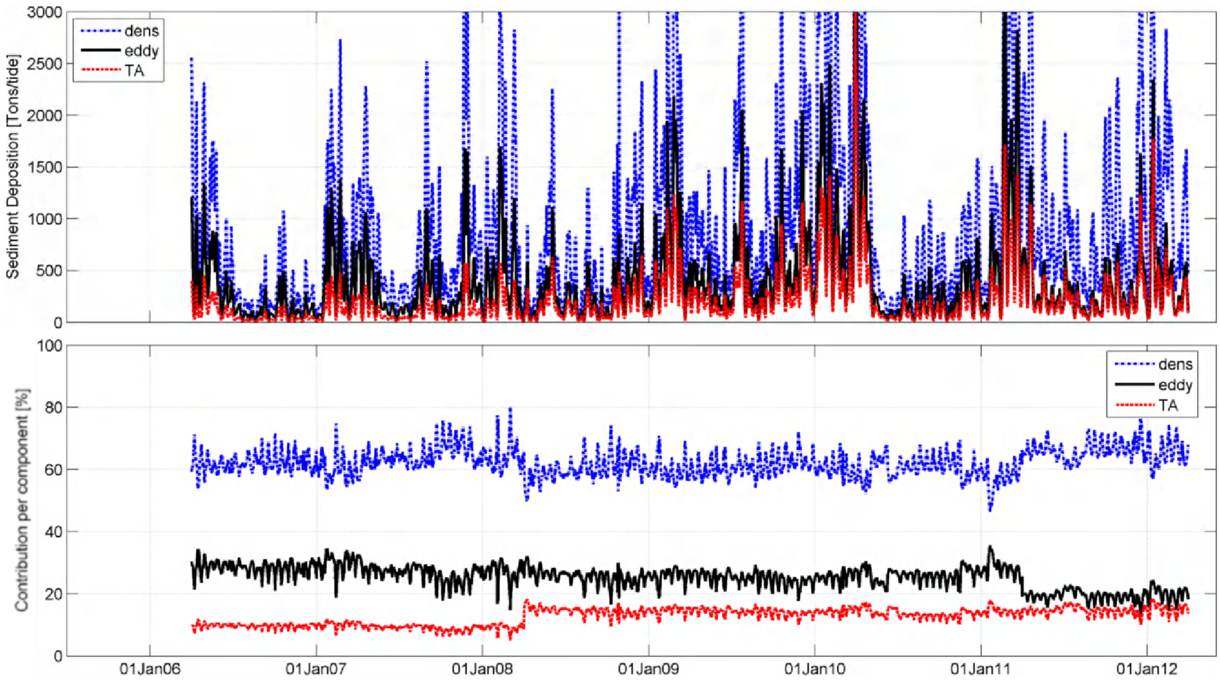

Figure 5-46 : Sediment fluxes per exchange component with measured trapping coefficients and relative importance of water exchange mechanisms.

6. NUMERICAL MODELLING WITH SLIB3D

6.1 EARLIER STUDIES

During the design process of the CDW, a 3D numerical model called Slib3D has been developed and applied to estimate the impact of the CDW on the sedimentation (Van Maren, 2007). This model expects a decrease of the sedimentation with the CDW and an increase in sedimentation by removing the entrance sill. The net modelled effect should be a decrease of sedimentation in the order of 9%. The most important simulations and conclusions of this modelling work are summarized in Table 6-1.

Table 6-1 : Overview of relevant numerical modelling of the sedimentation in Deurganckdok with the Slib3D code (adapted from Van Maren, 2007).

Purpose	Modeled situation	Relative effect on sedim. in the dock
Effect current CDW	Half dock, depth around -15m NAP, entrance sill, without and with CDW	-19% with CDW
Effect CDW layout	Effect of the CDW with different layouts	Not applicable here
Effect of the sill	Design dock (length and depth), deepening of the Scheldt, with and without sill, for the full dock	+14% without sill for full dock
Effect of the dock length	Design dock (length and depth), deepening of the Scheldt, with and without sill, for three dock lengths	-13% with full dock vs half dock, both without and with sill

In the frame of the feasibility study for the development of the Saeftinghedok, a sensitivity analysis has been carried out based on a similar Slib3D model (IMDC, 2010c). Amongst other settings, the effect of the flocculation model and of a 33% lower SSC at the model boundary has been estimated. Results show that the sedimentation strongly depends on the chosen parameters such as the erosion rate for instance. The effect of a higher SSC, its potential impact on density currents and on the sedimentation rate via the flocculation model have not been investigated.

The results of both modelling efforts described above do not explain the observed increase in sedimentation in Deurganckdok. However it is also difficult to draw conclusions because the effect of individual human impacts has not been quantified (rather design situations), and in particular because the model is so sensitive to some parameters governing silt behaviour. Finally to our knowledge no separation was done of the water and sediment fluxes per exchange mechanism as in paragraph 5.2.4.4.

The relation between maintenance dredging intensity and SSC in the Scheldt river has been studied in further detail in IMDC (2013). This effect is not included in the modelling studies.

6.2 RESEARCH QUESTIONS

Based on the results of the data analysis and of the conceptual sedimentation model, several questions have been identified which a numerical model could answer :

- What causes the observed increase in duration and strength of the density currents ? In particular, can a higher SSC in the Scheldt river (>1g/l) result in stronger density currents ?
- What is the quantitative influence of each individual human impact, and of the CDW in the current situation ? In particular, which role play the deepening of the Scheldt river and the larger maintenance depth in the observed increase of the sedimentation in Deurganckdok ?
- Can the explanations proposed to explain the increase in sedimentation based on the conceptual model be supported by 3D numerical model results ? In particular, can a higher SSC in the Scheldt river lead to increased flocculation and deposition of silt in the dock ? If not, does 3D modelling with Slib3D suggest alternative explanations ?

6.3 DEFINITION OF SCENARIOS

In order to answer those questions, the existing calibrated Slib3D model has been used to model the historical evolution of the development of Deurganckdok. Table 6-2 gives an overview of the six scenarios modelled : five historical situations since 2008 and a test with a higher SSC.

Table 6-2 : Overview of scenarios used for 3D numerical modelling with Slib3D

Historical development	Run ID	Situation
February 2008	200802	Depth -15m LAT, sill, 2500m dock
June 2010	201006	+ entrance sill dredged
August 2010	201008	+ deepening of the Scheldt river
April 2011	201104	+ maintenance depth increased to -17.5m LAT
August 2011	201108	+ CDW
High SSC event	201108x2	Situation of August 2011 with a SSC multiplied by two at the model boundaries (such as to reach around 1g/l in the Scheldt)

6.4 SUMMARY OF RESULTS

The memo describing the modelling study and discussing the results can be found in Annex E. Results have been visualised in extensive series of figures along cross-sections and at specific locations such as at the sensors at the dock entrance and in the Scheldt river (buoy 84, Oosterweel, etc). In addition, for each human impact the water and sediment fluxes have been computed per exchange mechanism to evaluate their relative importance.

Below a summary of the main conclusions is given.

6.4.1 Model performance

Overall the model seems to reproduce well the hydrodynamics, as evidenced by the good match of the salinity variation with measurement at the four sensors at the entrance (Figure 6-1compared to Figure 6-2).The sediment transport seems to match less well with measurements in several aspects:

- The SSC is a factor 5 too low in the Scheldt compared to recent measurements (50 mg/l in model compared to 200-500mg/l at buoy 84) and also too low in the dock. The Slib3D model has been calibrated on measurements before construction of the dock, when the SSC may have been lower.
- The modeled sedimentation is also too low but remains of good order of magnitude compared to measurements (200-1800 TDS/tide in model compared to 500-2000 TDS/tide from measurements). This suggests that sediment may fall too fast in the dock compared to reality.
- The SSC falls to zero in the dock although values below 50 mg/l are rarely recorded in reality. This can be attributed to the lack of a fine sediment fraction (microflocs or wash load) and to an underestimated vertical background turbulence. Turbulence is necessary to keep sediment in suspension and also controls flocculation characteristics. Lack of vertical turbulence may also explain the high sedimentation volumes compared to the SSC in the Scheldt.
- With CDW, the model predicts a strong sedimentation immediately behind the CDW (between the CDW and Deurganckdok). This sedimentation peak is not clearly visible in measurements. Again, it may have to do with a lack of vertical turbulence.
- The trapping efficiency of the dock is overestimated in the model (75% instead of 40% from ADCP measurements), probably due to the absence of a fine sediment fraction.
- Nevertheless, excluding the abnormally low SSC, the shape of the SSC evolution at the dock entrance during the tidal cycle matches well measurements (Figure 6-1compared to Figure 6-2).

In addition, the Slib3D model is not meant to include the effect of dredging and relocation on sediment stability and transport. It also does not include consolidation and fluid mud transport.

The model may hence require additional calibration to improve confidence in the results. Sedimentation strongly depends on the phasing and location of the sediment plume at the dock entrance through the tidal cycle. A spatial mapping of this plume with for instance remote sensing methods may help for this calibration.

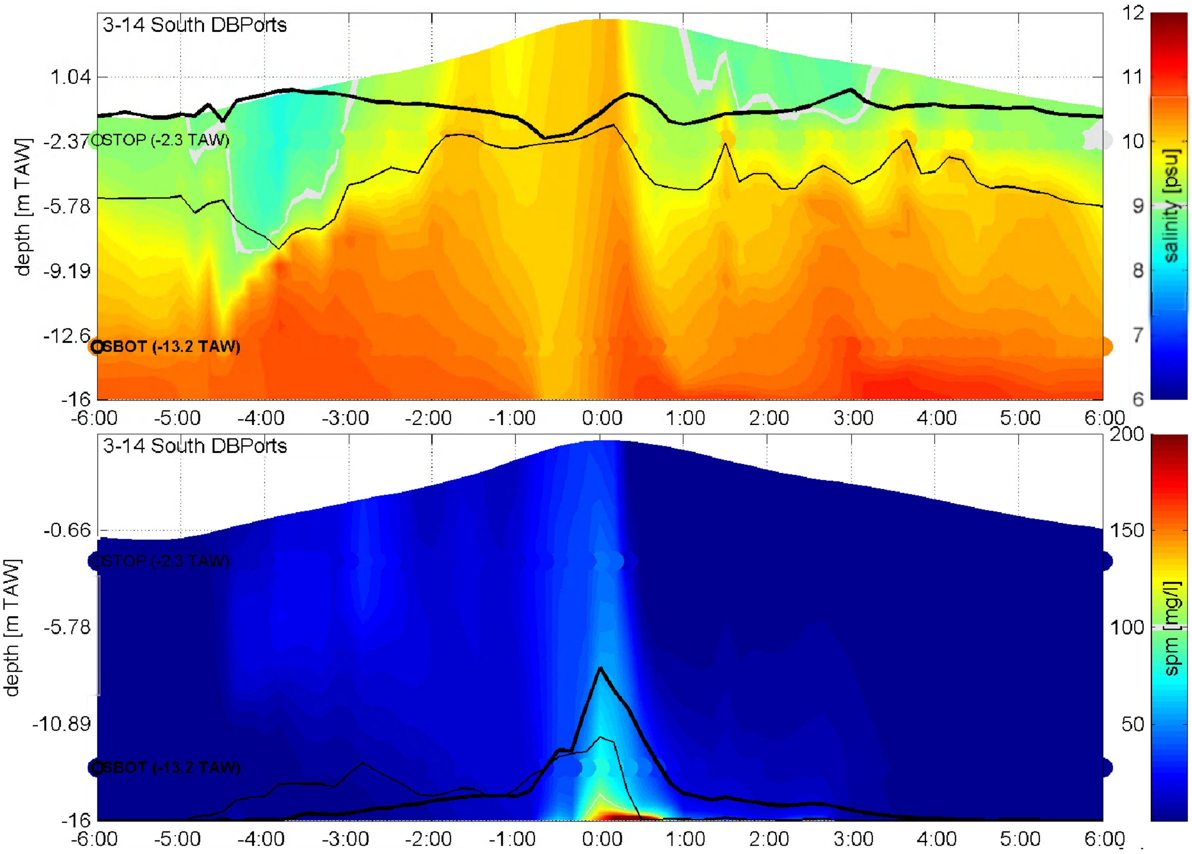

Figure 6-1 : Example of modeled salinity and SSC evolution during a tidal cycle at the South entrance with CDW (scenario 201108).

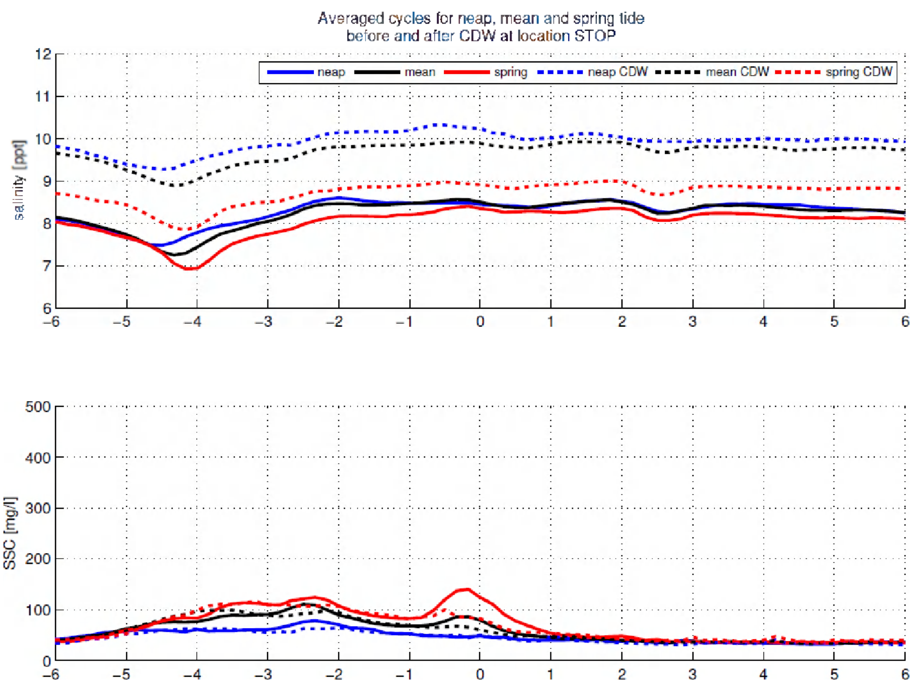

Figure 6-2 : Example of measured salinity and SSC evolution during an average tidal cycle at sensor STOP.

6.4.2 Effect of impacts on sedimentation

The modeled sedimentation volumes strongly depend on the tidal amplitude and ranges from 200 to 1800 TDS/tide in the initial situation. The sedimentation pattern mainly varies with the addition of the CDW. The effect of each human impact is summarised in Figure 6-5 :

- Dredging the entrance sill (scenario 201006) results in a sedimentation pattern which is closer to the Scheldt river. It increases sedimentation including the sill by about 8%, but it has little effect on sedimentation volumes when excluding the sill.
- Deepening the Scheldt river (scenario 201008) has little effect on total sedimentation, it decreases sedimentation volumes by about 10% during neap tides.
- Increasing the maintenance depth (scenario 201104) attracts more sediment from the sill into the dock if the sill is shallower than the central trench. Excluding the sill, sedimentation volumes increase by about 10% while including the sill, the increase is minimal.
- The sedimentation pattern mainly varies with the addition of the CDW (Figure 6-3 versus Figure 6-4). Adding the CDW (scenario 201108) decreases the sedimentation between 0% at neap tide and 30 to 40% at spring tide, with an average of about -15% over a spring-neap cycle. This is of the same order of magnitude than previously reported (Van Maren, 2007).
- A larger SSC in the Scheldt (scenario 201108x2) leads to a sub-linear increase of the sedimentation volume, believed to be due to the underestimated vertical turbulence. The model is also not sufficiently warmed up to fully transfer the larger SSC from the boundaries to the entire model domain, and SSC values never reach 1g/l except very close to the bed.

Overall, the positive effect of the CDW is partly compensated by the negative effect of the larger maintenance depth, with a total decrease of sedimentation volumes by about 5% to 15% (Figure 6-6). A larger SSC in the river Scheldt is still expected to have a non-linear negative effect in reality and can easily overshadow the positive effect of the CDW.

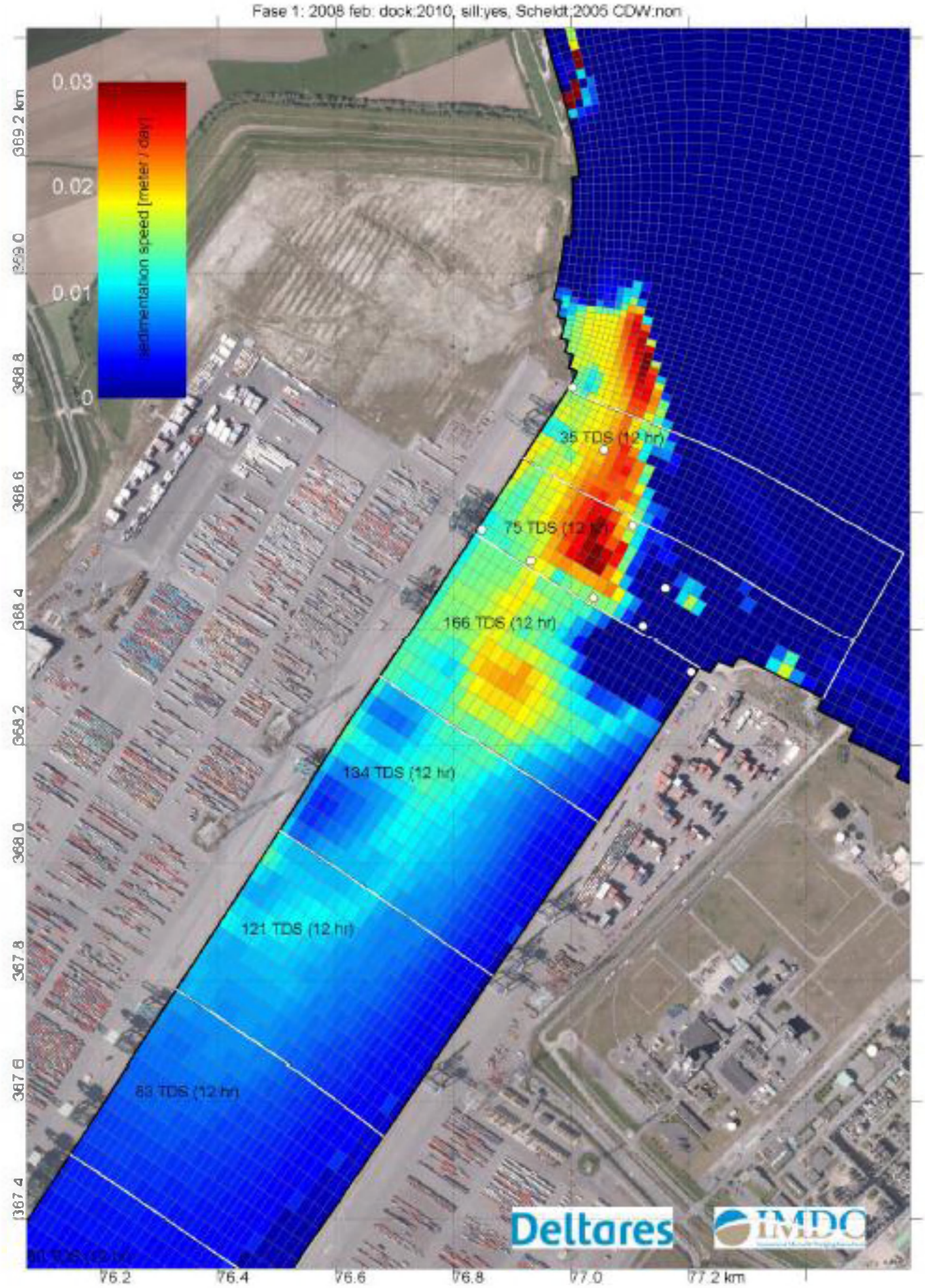

Figure 6-3 : Sedimentation pattern for the initial situation (scenario 200802).

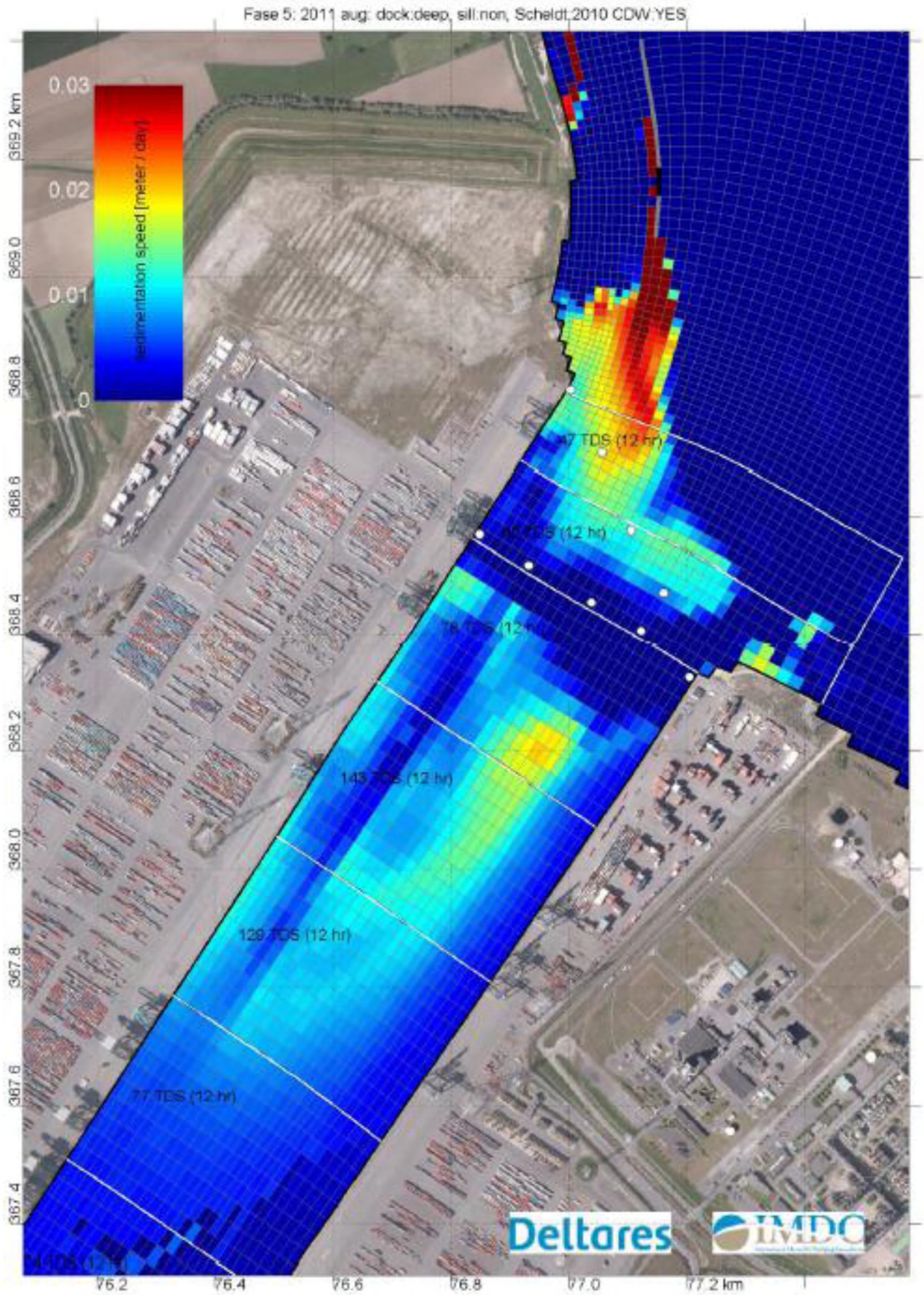

Figure 6-4 : Sedimentation pattern for the final situation with CDW (scenario 201108).

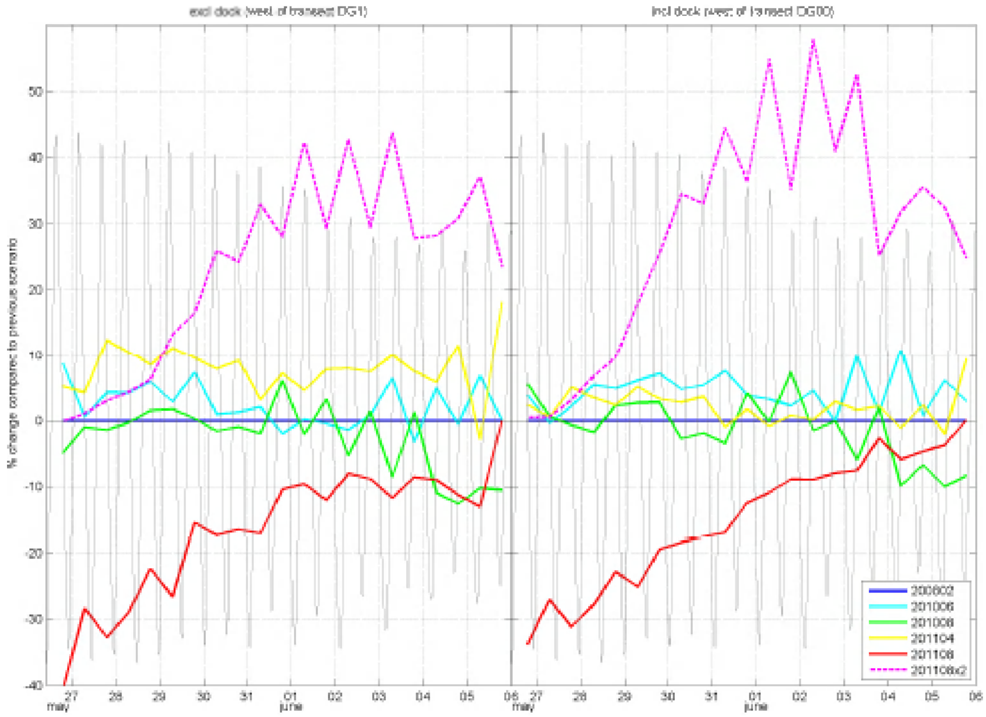

Figure 6-5 : Relative effect of each scenario on the sedimentation volume compared to its previous scenario, excluding (left) and including the sill at the entrance (right), during a full spring-neap tidal cycle (spring left, neap right of graph).

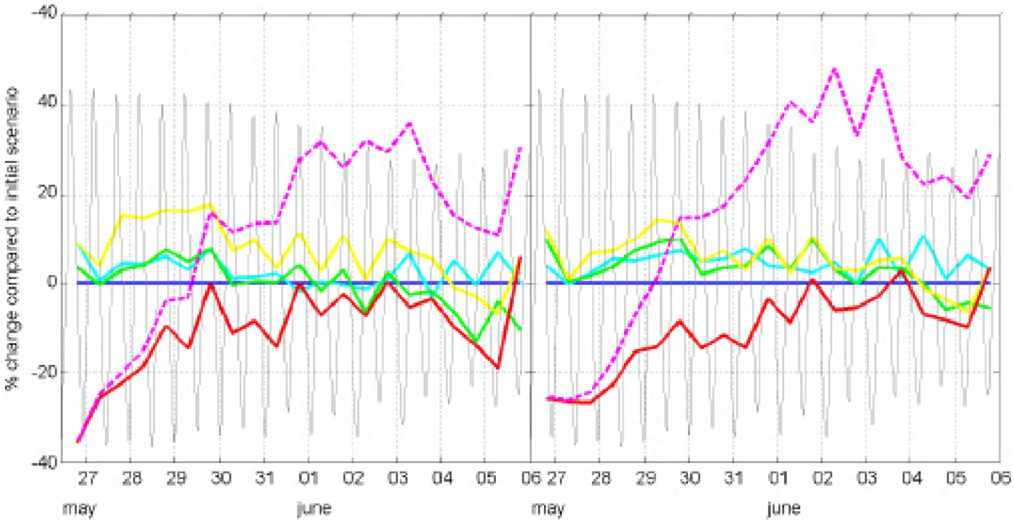

Figure 6-6 : Relative effect of each scenario on the sedimentation volume compared to the initial situation, excluding (left) and including the sill at the entrance (right), during a full spring-neap tidal cycle (spring left, neap right of graph).

6.4.3 Effect of impacts on transport mechanisms

Water and sediment fluxes of the model results have been analysed like in paragraph 5.2.4.4 to estimate the relative importance of tidal filling, density currents and eddy currents. Estimates have been derived for the average tide used for the derivation of sedimentation volumes in Annex E and excluding the sill (transect DG1 in Annex E, chosen over the DGD transect for convenience). Given the high variability in sedimentation within a spring-neap tidal cycle (Figure 6-6), results should be considered with care.

The following trends can be observed :

- Model estimates of the relative importance of each component (Figure 6-7) are in good agreement with estimates from ADCP measurements (paragraph 5.2.4.4) but differ from those derived in earlier studies (paragraph 3.2.2). Exact values depend on the computation method chosen and on the location of the cross-section studied. In particular, the cross-section chosen is further into the dock compared to the DGD transect where ADCP measurements have been done. As a consequence, the eddy component is underestimated because the cross-section lies outside the mixing zone. This is not expected to affect the conclusions presented here.
- Water volumes exchanged have increased after dredging the entrance sill (Figure 6-8). Sediment volumes exchanged (Figure 6-9) have increased less because most of the extra sediment falls on the sill.
- After dredging the sill, the water volumes exchanged by density currents have progressively increased and those exchanged by eddy currents have progressively decreased despite a relatively constant total water exchange (Figure 6-8). This is in agreement with the observed increase in strength and duration of the density currents according to ADCP measurements.
- The effect of the CDW on water exchanged by eddy currents is very small in Figure 6-8 because the cross-section lies outside the mixing zone. Despite this, the positive effect of the CDW is still clearly visible in the sediment volumes exchanged (Figure 6-9). The large sedimentation peak immediately behind the CDW may also reduce the sedimentation further in the dock by trapping sediment locally : this might partly distort the interpretation of the results.
- A larger SSC in the Scheldt does not impact the water exchange (SSC too low to impact water density in model), but does show a larger importance of the density currents (Figure 6-9). Density currents are expected to play an even more important role by SSC values above 1 g/l.
- The trapping efficiency is overestimated by the model (75% instead of 40%) in agreement with the model limitations mentioned in paragraph 6.4.1. The trapping efficiency increases slightly with the CDW.

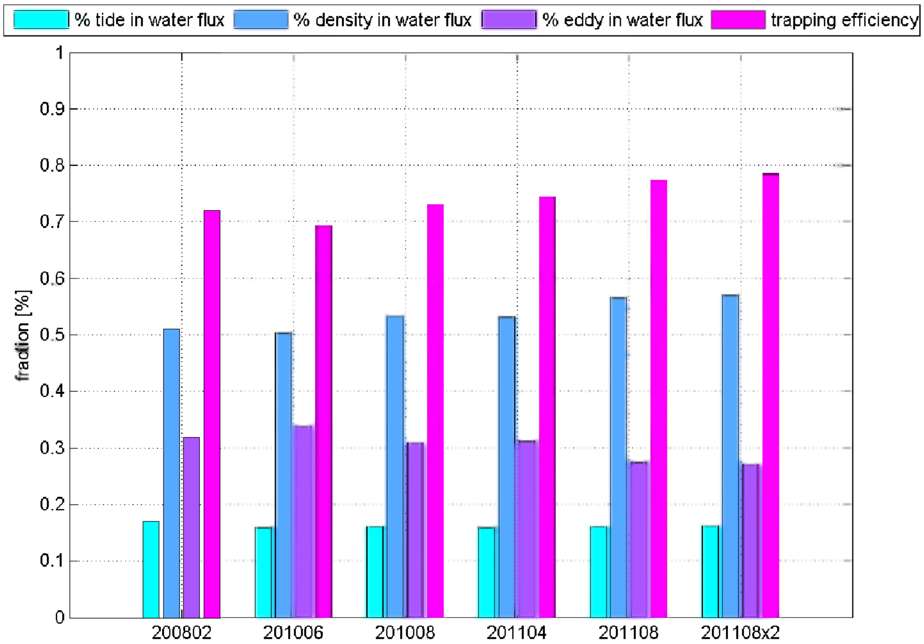

Figure 6-7 : Relative importance of each component in the water exchange and trapping efficiency per scenario for an average tide (1 = 100%).

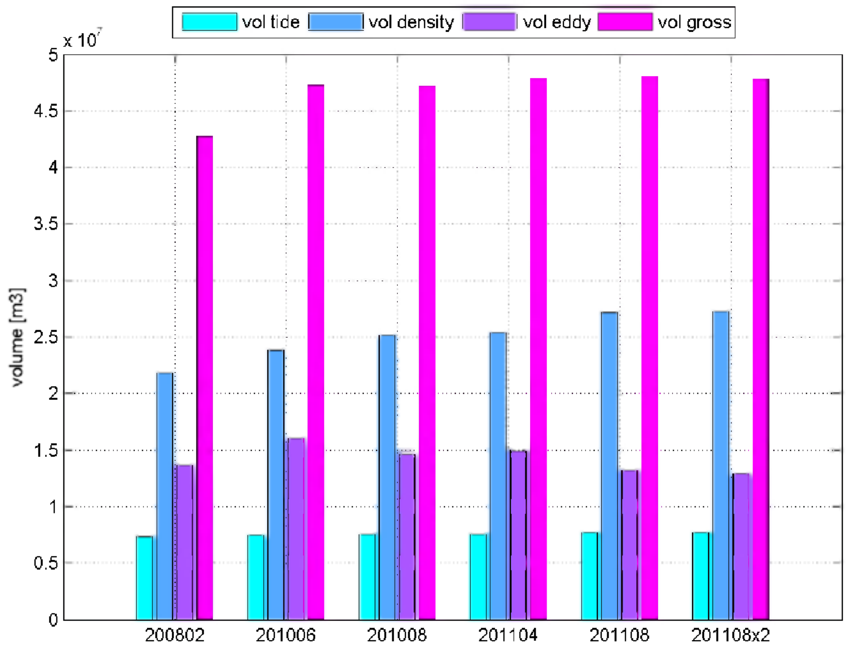

Figure 6-8 : Water exchange per scenario and per component for an average tide.

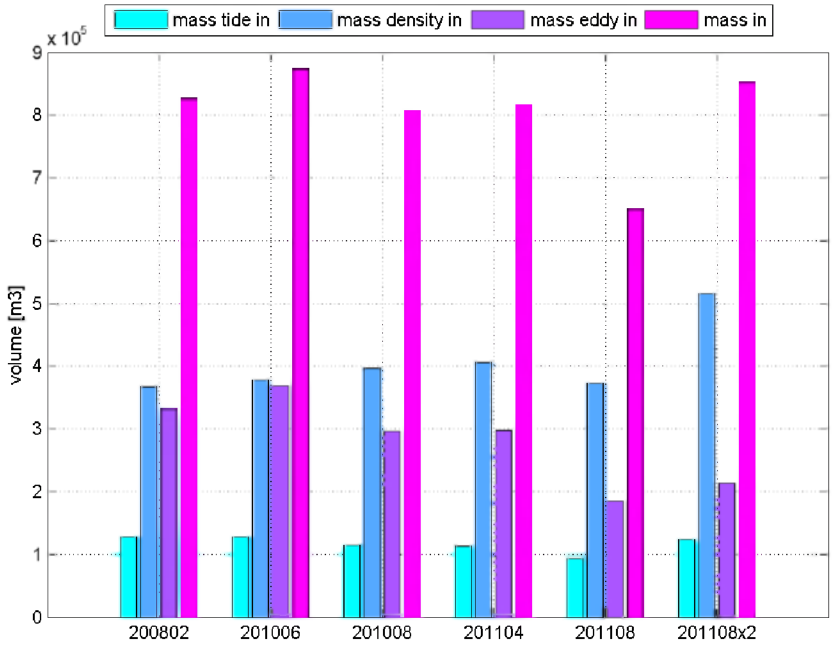

Figure 6-9 : Sediment exchange per scenario and per component for an average tide (mass in kg/tide).

6.5 CONCLUSION OF MODELLING STUDY

This modeling exercise suggests that the Slib3D model is sufficiently well calibrated for the hydrodynamics, but that it presents several limitations for sediment transport that may require additional calibration to improve confidence in the results.

Nonetheless, it confirms previous modeling results, with a decrease of the sedimentation by around 15% with the CDW. This decrease strongly depends on the tidal amplitude and is larger during spring tide. The Scheldt deepening may also have a slight positive effect during neap tides. Overall, the positive effect of the CDW is partly compensated by the negative effects of the sill removal and of the larger maintenance depth, with a total decrease of sedimentation volumes by about 5% to 15% (Figure 6-6).

Despite too low SSC values, the model supports the assumptions that density currents have progressively become stronger and longer, that the trapping efficiency has increased over time and that a larger SSC may further enhance density currents. A larger SSC and potentially non-linear effects can easily overshadow the positive effect of the CDW.

7. CONCLUSIONS

7.1 EXECUTIVE SUMMARY

The main conclusions of the report are the following :

- Results suggest that the CDW plays its intended role and could account for a decrease of the sedimentation in the order of 5-15%. However its positive effect is overshadowed by other negative effects such as dredging and the other human impacts in the dock.
- The approximate doubling in dredging volumes reported over the period 2009-2012 is partly artificial, normal dredging volumes are expected to lie around 1.2 M TDS/year in the 2011-2012 situation compared to 1 M TDS/year in the 2008-2009 situation.
- Density currents have progressively become stronger and longer at the dock entrance. Since they account for the largest fraction of water exchanged, they may be the cause of increased sedimentation. Among the different causes of these stronger currents, it is suggested that periods of high SSC may reinforce them the most.
- Dredging and relocation activity has a clear impact on the SSC in the river Scheldt, hence on the sedimentation in Deurganckdok. An adaptation of the dredging strategy is suggested.
- The cumulative effect of the human impacts in the area (deepening of the Scheldt, sill dredging, increase of maintenance depth, CDW) has led to a slight progressive increase in strength and duration of the density currents and in trapping efficiency as well.

Below these conclusions are detailed further.

7.2 SEDIMENTATION MODEL

The sedimentation model described in IMDC (2009o) has been applied over the period 2006-2012 with a larger dataset, simplified and uniform parameters (paragraph 5.3.3).

With the parameter values used previously, similar results are reported as in IMDC (2009o) for the period April 2008 - April 2009, in line with the model being mainly unchanged. After 2009 however the model strongly underestimates cumulative sedimentation (1 400 000 TDS at end of May 2012). Part of the difference is probably due to a different reporting of volumes dredged on the entrance sill (500 000 TDS, paragraph 5.3.3.3). Another part is due to a strong sedimentation peak in the winter of 2010 which is not captured by the model (500 000 TDS). The remaining difference comes from underestimating the sedimentation after spring 2011 (400 000 TDS), a period characterised by several human impacts.

The model can be calibrated in different ways, as shown by the sensitivity analysis (paragraph 5.3.3.6). The main model has been calibrated by assuming that the trapping efficiency is modulated by the SSC (flocculation). It results in a good match of the cumulative sedimentation at the end of the period. In the sensitivity analysis, it is shown that a missing event in the SSC proxy, or using the trapping efficiencies and water volumes derived from the analysis of the 13h measurements, can both also be used to calibrate the model. This shows how sensitive results are to our understanding of the system. All methods require directly or indirectly an increase in trapping efficiency to explain the increase in sedimentation.

In the main calibrated model (flocculation method), the initially reported increase in dredging volume from 1M to 1.9M TDS/year can be attributed for (paragraph 5.3.3.4) :

- around 25-30% to a change in reporting of dredging amounts (250 000 TDS to 300 000 TDS),
- around 40% to a one-time deepening of the dock in 2011-2012 (400 000 TDS),
- around 10% to an increase of the entrance cross-section (100 000 TDS),
- around 15% to longer density currents excluding the larger cross-section (150 000 TDS)

The modulation of the trapping efficiency by the SSC also has a strong impact on the sedimentation volumes, increasing it respectively by around 400 000 TDS in 2009-2010, 200 000 TDS in 2010-2011 and 100 000 TDS in 2011-2012 due – in particular in the winter 2010 – to occasional peaks in SSC.

To conclude, real sedimentation volumes excluding sudden sedimentation events like the one of winter 2010 probably lie around 1.2 M TDS/year in 2011-2012 compared to 1 M/year in 2008-2009. It is also possible that a non-negligible fraction of this sedimentation is directly or indirectly related to changes in the dredging activity : a high SSC may induce non-linear effects (trapping efficiency) and impact density currents. In view of this uncertainty and of the subjective choice of the parameterisation of the CDW, it is difficult to estimate the effect of the CDW on the sedimentation at this stage. Previously reported decreases of the sedimentation in the order of 5-15% are still defendable but may easily be overshadowed by such SSC effects. A decrease by 10% of the sedimentation would, for an average sedimentation volume of 1.2 M TDS/year, amount to a reduction of 120 000 TDS/year.

The predictive power of the model is weak because directly linked to our understanding of the system. The model can be extended in the future once causes for the increased sedimentation are better understood. In particular, the previously reported relative sediment fluxes of each exchange mechanism can vary strongly depending on the calculation method used and should be considered with care (paragraph 5.2.4.4). The model results are also strongly dependent on the SSC signal used. It is not clear whether the SSC at the dock entrance is a good proxy (strong noise) and whether the proxy quality changed with the construction of the CDW. The SSC signal in the Scheldt at buoy 84 seems less sensitive to human activities in and near the dock than the SSC at the dock entrance, but a quick test shows that it seems to be a less suitable proxy for sedimentation prediction (not reported).

Numerical model results with the Slib3D model (paragraph 6) broadly support the assumptions presented above. It predicts a decrease of the sedimentation by about 15% with the CDW. The positive effect of the CDW is however partly compensated by the negative effects of the sill removal and of the larger maintenance depth, with a total decrease of sedimentation volumes by about 5% to 15% including all human impacts (paragraph 6.4.2). Despite some model limitations such as too low SSC values, the model supports the assumptions that density currents have progressively become stronger and longer, that the trapping efficiency has increased over time and that a larger SSC may further enhance density currents (paragraph 6.4.3). A larger SSC and potentially non-linear effects can easily overshadow the positive effect of the CDW.

As a consequence, changes in dredging frequency and relocation strategy may have a noticeable positive impact on the yearly maintenance volumes (see also paragraph 7.3.1).

7.3 IMPACT OF EXTERNAL EFFECTS ON THE SEDIMENTATION OF DEURGANCKDOK

7.3.1 General impact of maintenance dredging works

Maintenance dredging works in Deurganckdok are shown to have a clear relation with the SSC measured in the lower Sea Scheldt at buoy B84 and B97 (paragraph 5.2.2). A larger SSC at B84 leads to more sedimentation in Deurganckdok, which requires more dredging. The dredged material is then deposited near Oosterweel and put in suspension again by currents, which in turn increases the SSC in the Scheldt again. The fact that SSC and dredging activity seem to correlate better when near each other suggests that part of the SSC increase occurs locally, i.e. some sediment is put in suspension during dredging. Dredging is hence together with the tidal amplitude the first factor influencing the SSC near Deurganckdok. Similarly, relocation of silt around Oosterweel determines the SSC at Oosterweel.

Deurganckdok is situated in the river section with a higher silt content (estuarine turbidity maximum), and close to other locations requiring intense dredging of silt like the Drempel van Frederik. It is likely that all dredging works together significantly contribute to the SSC in the entire Lower Sea Scheldt, as suggested by the correlation still visible between dredging works at Deurganckdok and the SSC in Oosterweel for instance.

Surprisingly, the visible increase in dredging activity at Deurganckdok is not accompanied by a visible overall increase in SSC at buoy B84. Such a comparison is limited however by the different instruments used and calibrations carried out over the years, which introduce a large uncertainty for SSC values above 500 mg/l (paragraph 5.2.1). The impact of dredging is not included in the numerical model Slib3D.

7.3.2 Deepening and widening of the Lower Sea Scheldt

Deepening and widening of the Lower Sea Scheldt occurred in Belgium over a long period, from July 2008 to August 2010. No clear impact is visible from the data and the sedimentation model. It may affect the sedimentation of Deurganckdok indirectly with the increased dredging frequency leading to higher SSC values in the Scheldt (paragraph 7.3.1).

A more detailed analysis could be done based on the exact duration and location of the capital dredging works. This is proposed as a recommendation for further investigation. The use of a simple multiyear numerical model may help further in quantifying this influence (paragraph 7.4), with a strong added value if the location and timing of each dredging and relocation activity are known (as opposed to data analysis at fixed buoys and with overlapping influence factors).

In the numerical model Slib3D, deepening and widening of the Lower Sea Scheldt has little effect on the sedimentation in the dock, with possibly a decrease of sedimentation by about 10% during neap tides (paragraph 6.4.2). The model does not account for the impact of dredging and relocation on the SSC.

7.3.3 Dredging of the entrance sill

The entrance sill has been dredged over a relatively short period, from November 2009 to June 2010. The same period, from January to March 2010, has been characterised by a very strong sedimentation event in Deurganckdok, followed by maintenance dredging of around 800 000 TDS from March to May 2010. Although the SSC measured during that period is only moderately higher than usual, it is not excluded that it has been partly caused by the capital dredging.

Since the entrance sill has been dredged, large yearly maintenance volumes have been reported at the dock entrance (500 000 TDS in Apr2010-Apr2012 compared to 50 000 TDS in Apr2006-Apr2010). However this is due to a change in reporting conventions : maintenance of the sill was previously done by sweepbeam dredging and was not included in the BIS dredging data (paragraph 5.3.3.3). This statement is supported by the evolution of yearly sweepbeam working hours.

Between April 2010 and April 2011, the SSC in the Scheldt is low and the measured mass growth is very slow, suggesting that the removal of the sill only should at best have a moderate impact on long-term sedimentation. Removing the sill increases the entrance cross-section which could, by simple linear increase of exchanged water volumes (paragraph 5.3.3.5), potentially increase the sedimentation in Deurganckdok.

In the numerical model Slib3D, dredging the entrance sill results in a sedimentation pattern which is closer to the Scheldt river. It increases sedimentation including the sill by about 8%, but it has little effect on sedimentation volumes when excluding the sill (paragraph 6.4.2).

7.3.4 Construction of the CDW

The CDW has been built from April 2010 to August 2011. During flood the CDW should divert the surface flow inside the dock and the bottom flow towards the Scheldt river. By streamlining the flow, the CDW should mainly reduce the eddy component of the total water exchange at the dock entrance. The sedimentation in the dock is expected to reduce by 10 to 20% based on numerical results for a comparable dock (paragraph 3.2.2).

All results currently suggest that the CDW has the expected effect on the water exchange. A strong reduction of the flood eddy is qualitatively visible in the 13h measurements (paragraph 5.2.4). Important changes in the tidal phasing are clearly visible from average tidal cycles derived from long time series at the dock entrance (paragraph 5.2.3). It seems to delay the sediment-laden bottom flow and to allow the surface flow to enter the dock faster via the CDW channel. As expected, the largest effects are visible at the North entrance. The results suggest a clear reduction of the eddy and locally weaker density currents. ADCP measurements do however not allow to extrapolate these local measurements to the entire entrance cross-section, because they clearly show stronger and longer lasting density currents (paragraph 5.2.4.3), in particular around LW. However this change in density currents may be due to other human impacts (deepening or SSC increase).

The effect of the CDW on sedimentation is less clear. Measurements up to now suggest a decrease of the SSC by 20% to 30% near the bottom, both North and South of the entrance from HW-1h to HW+2h (paragraph 5.2.3). The average SSC values during a tidal cycle before (07/2005 to 04/2011) and after construction of the CDW (04/2011 to 04/2012) are however the same, because SSC slightly increases during the rest of the tidal cycle. Over the same periods, the average SSC in the Scheldt is equally unchanged.

The increase in maintenance dredging volumes can only be reproduced by the sedimentation model starting from spring 2011 by incorporating several additional effects into the model. This moment corresponds to the finalisation of the CDW, the increase in maintenance depth, a temporary increase in SSC linked to frequent dredging activity and a change in reporting of dredging volumes at the entrance sill. It is therefore difficult to isolate the individual effects from each human impact. Given the previous conclusions about water exchange, it is suggested that the larger maintenance depth and the more frequent dredging play a more important role in the increased maintenance dredging than the CDW itself. As stated in paragraph 7.1, the numerical model Slib3D supports the assumptions that density currents have progressively become stronger and longer, that the trapping efficiency has increased over time and that a larger SSC may further enhance density currents.

In order to reproduce the observed sedimentation with the model, it is necessary to include stronger density currents and a higher trapping efficiency since spring 2011. The highest SSC has been observed during the 13h measurement of 13th March 2011 and the highest trapping efficiency during the 13h measurement of 8th March 2012, both after construction of the CDW (paragraph 5.2.4.2). With only four 13h campaigns since construction of the CDW, it is however not possible to draw a conclusion from these observations. Further measurements over the coming years (already ongoing) to identify changes in SSC and in trapping efficiency may allow to confirm or infirm these assumptions.

In the numerical model Slib3D, the CDW results in a decrease of the sedimentation between 0% at neap tide and 30 to 40% at spring tide, with an average of about -15% over a spring-neap cycle (paragraph 6.4.2). This is of the same order of magnitude than previously reported (Van Maren, 2007). As described in paragraph 7.1, other impacts, a larger SSC in the river Scheldt and potentially non-linear effects can easily overshadow the positive effect of the CDW.

7.3.5 Increase of the maintenance depth

The maintenance depth has been increased from March to May 2011. An increase in maintenance dredging has been reported starting from that time (paragraph 5.2.2). As described in the previous paragraph, it is difficult to relate the increased dredging to a particular factor because several human impacts occurred at the same time. In light of the other observations, it is however possible that the larger maintenance depth and the more frequent dredging play a more important role than the CDW to explain the increase in maintenance dredging.

In the numerical model Slib3D, an increase of the maintenance depth attracts more sediment from the sill into the dock if the sill is shallower than the central trench. Excluding the sill, sedimentation volumes increase by about 10% while including the sill, the increase is minimal (paragraph 6.4.2).

7.4 RECOMMENDATIONS

This study does not fully allow to conclude on the effect of the CDW and of other external factors on the sedimentation of Deurganckdok. Furthermore still little data is available to understand the dynamics of the ETM. Based on this report, we formulate the following recommendations for the continuation of the study :

- <u>Continue the measurements</u> (partly ongoing) :
    - 13h measurements to confirm whether or not the average SSC and the trapping efficiency have effectively increased since spring 2011
    - Long-term measurements at the dock entrance to apply the model over a longer period to confirm whether or not the observed increase in sedimentation is partly temporary and partly due to longer density currents and non-linear effects of the SSC.

    - A mass balance to apply the model over a longer period, in combination with the long-term measurements
    - Boundary conditions including long term measurements in the Scheldt, ideally covering the entire ETM zone, to identify changes in SSC and to interprete the results

- Changes in dredging frequency and relocation strategy may have a noticeable positive impact on the yearly maintenance volumes. It is hence advised to investigate alternative maintenance dredging strategies (see next point) and to closely monitor their effect.
- A fast multiyear model of silt dynamics which includes the impact of dredging could be used to reproduce qualitatively observed time series of SSC in the Scheldt river. The Slib3D model is too complex to be applied on longer time scale for the ETM dynamics. By parameterising the effect of dredging in a 1DH estuary model covering several years, large scale dredging policy scenarios could be investigated to reduce current dredging needs, which are partly due to artificial SSC recirculation. This could be done with a simple Delft3D or Delwaq model of the estuary, or with a Matlab model if some missing processes such as consolidation are required. The model would maybe require additional long term SSC data further upstream and downstream of Deurganckdok to cover the full extent of the ETM. Walther et al. (2012) present an example of a fast one-year model of fluid mud dynamics in the Loire estuary using a research version of Telemac.
- A recalibration of the Slib3D model or alternatively a new detailed model of Deurganckdok could be used with the new insight on the limitations of the Slib3D model and with the large amount of data collected over the year to refine the estimates of the effect of the CDW.
- A recalibration of the SSC with hindsight may at some point be needed to fully take advantage of the many years of measurements. It would be desirable to standardise the calibration protocols between institutes involved in measurements in the Scheldt estuary to reduce the uncertainty surrounding existing and future SSC measurements.
- An update of the silt balance of the Scheldt river would be equally useful, in particular together with the proposed modelling work.

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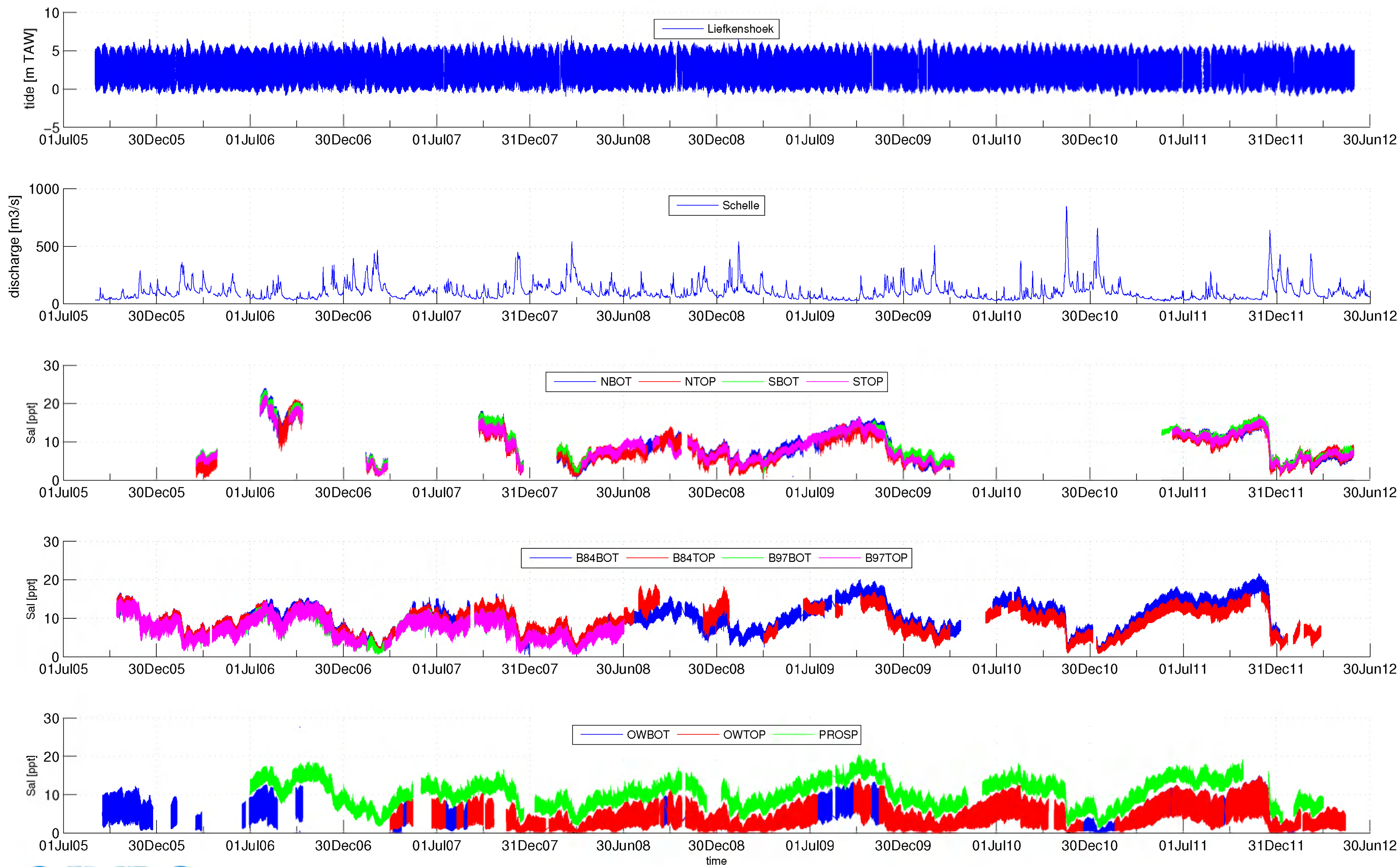
Walther, R., Schaguene, J., Hamm, L. and David, E. (2012). Coupled 3D modeling of turbidity maximum dynamics in the Loire estuary, France. Proceedings of the 20th International Conference on Coastal Engineering, July 1st-6th 2012, Santander, Spain.

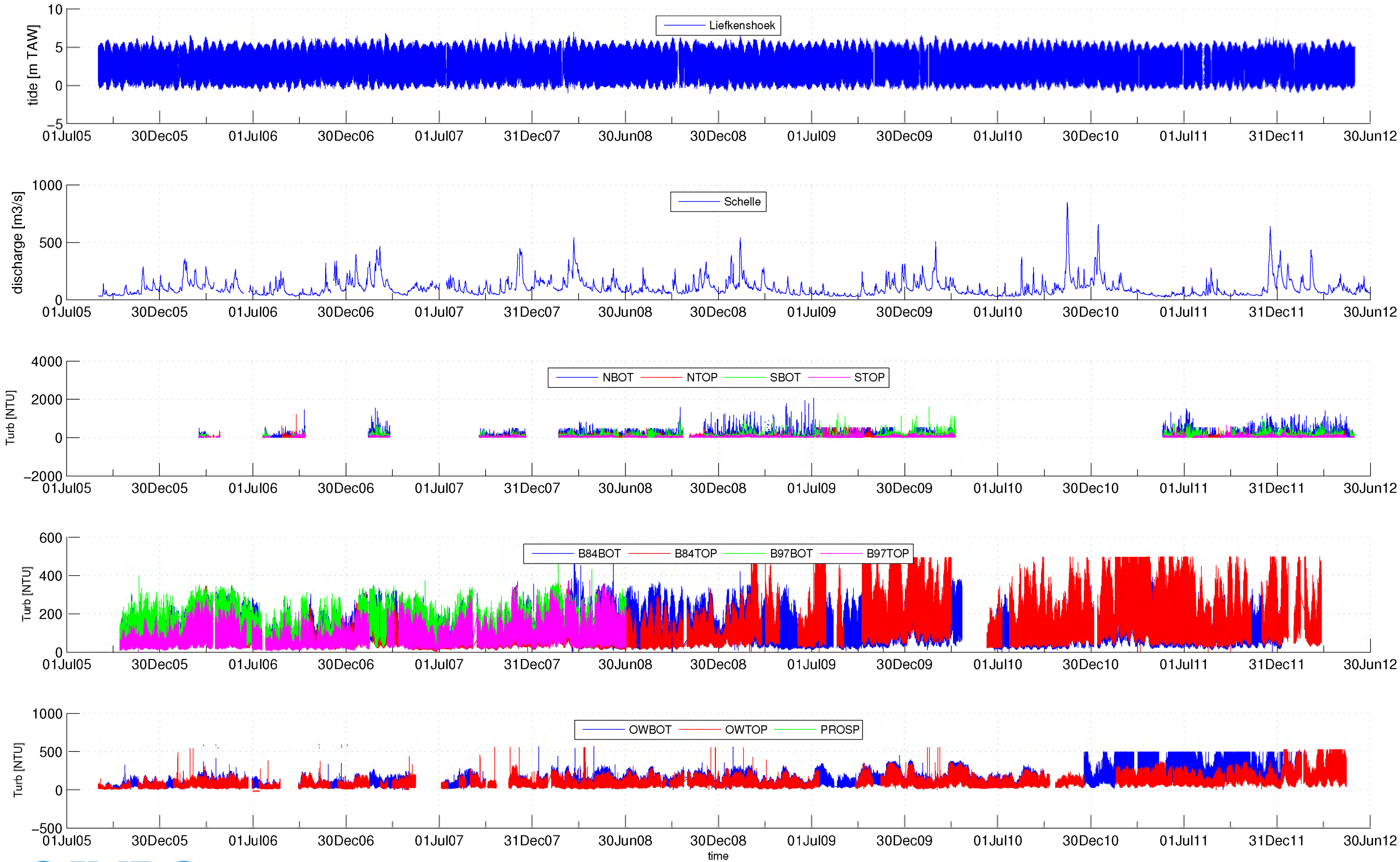
Wunderground (2010). Weather Underground: www.wunderground.com

Annex A Time series from 2006-2012

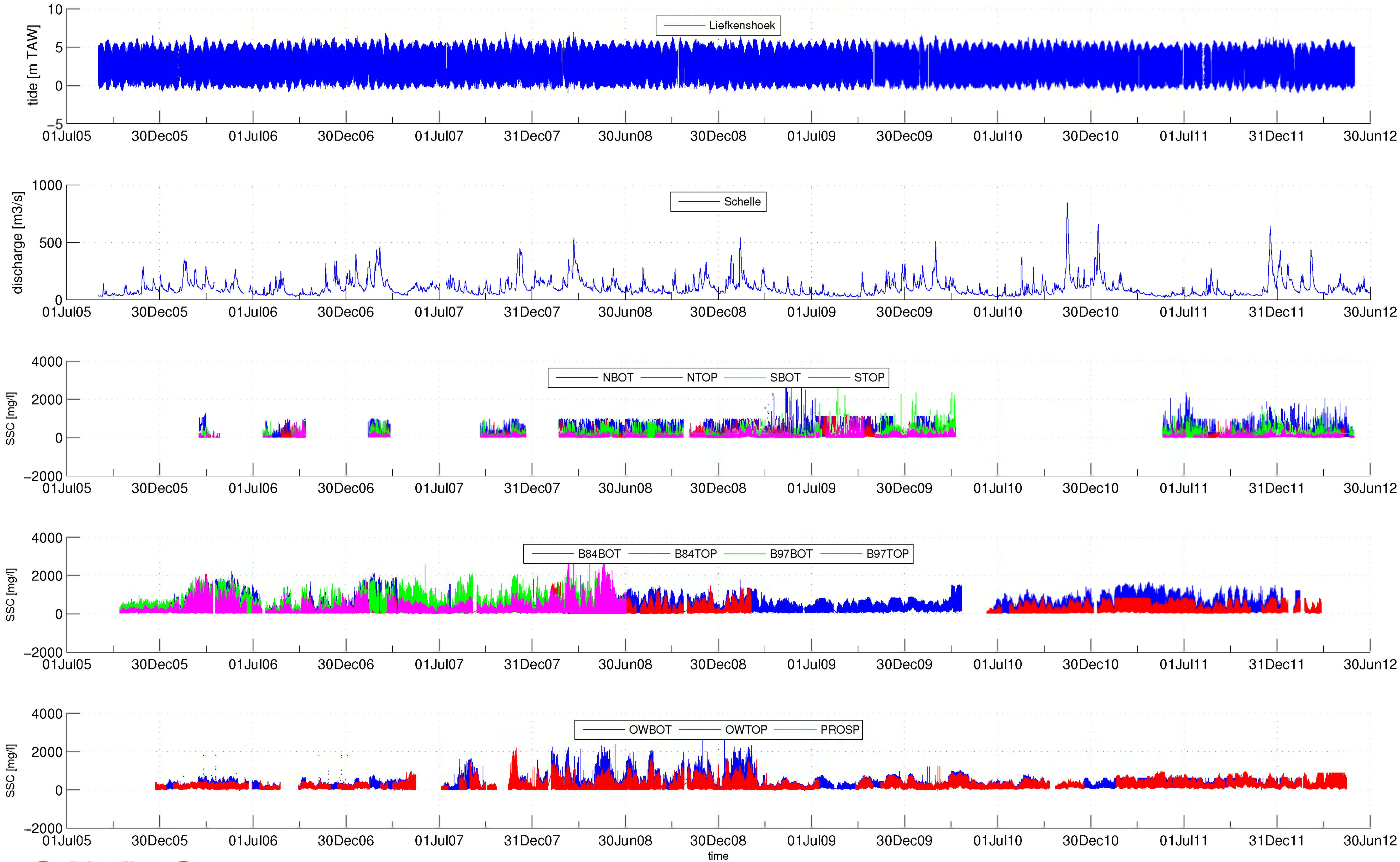
A.1 Time series of instantaneous values (first version)



Liefkenshoek
tide [m TAW]
Schelle
discharge [m3/s]
NBOT NTOP SBOT STOP
Sal [ppt]
B84BOT B84TOP B97BOT B97TOP
Sal [ppt]
OWBOT OWTOP PROSP
Sal [ppt]
01Jul05 30Dec05 01Jul06 30Dec06 01Jul07 31Dec07 30Jun08 30Dec08 01Jul09 30Dec09 01Jul10 30Dec10 01Jul11 31Dec11 30Jun12
time



tide [m TAW]
Liefkenshoek
10
5
0
−5
discharge [m3/s]
Schelle
1000
500
0
Turb [NTU]
NBOT
NTOP
SBOT
STOP
4000
2000
0
−2000
Turb [NTU]
B84BOT
B84TOP
B97BOT
B97TOP
600
400
200
0
Turb [NTU]
OWBOT
OWTOP
PROSP
1000
500
0
−500
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12
time



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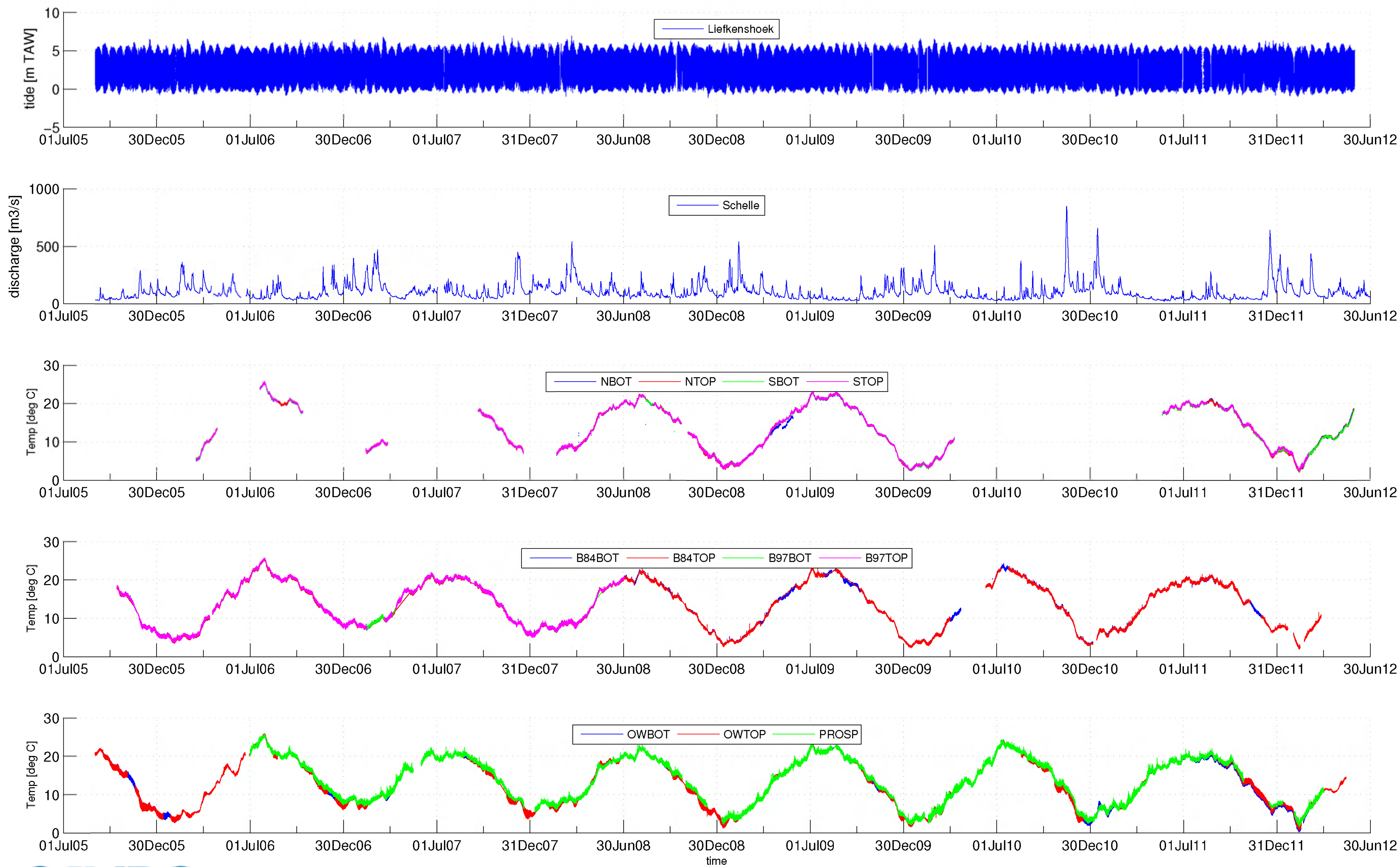
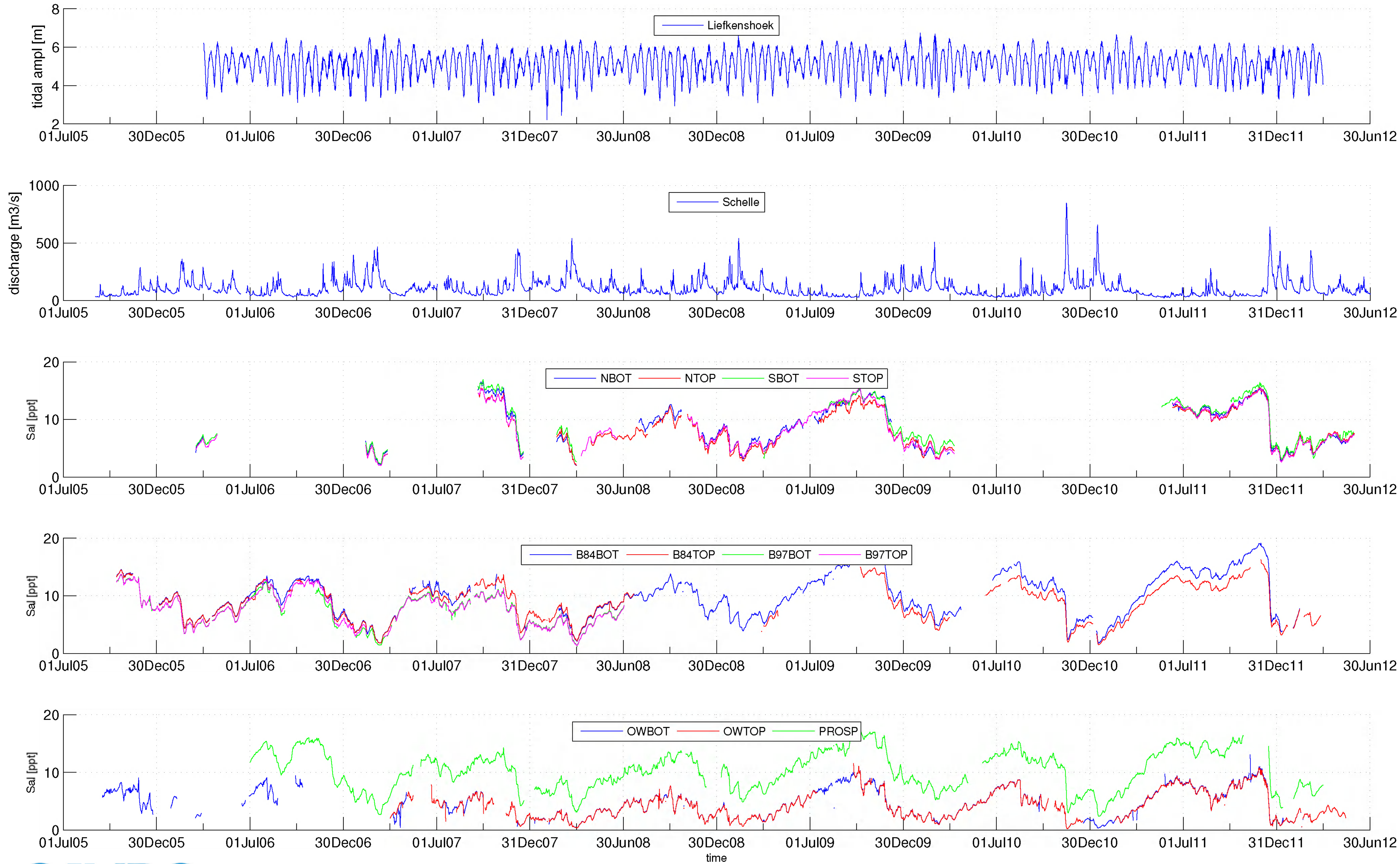

Liefkenshoek
tide [m TAW]
Schelle
discharge [m3/s]
NBOT
NTOP
SBOT
STOP
Temp [deg C]
B84BOT
B84TOP
B97BOT
B97TOP
OWBOT
OWTOP
PROSP
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12
time

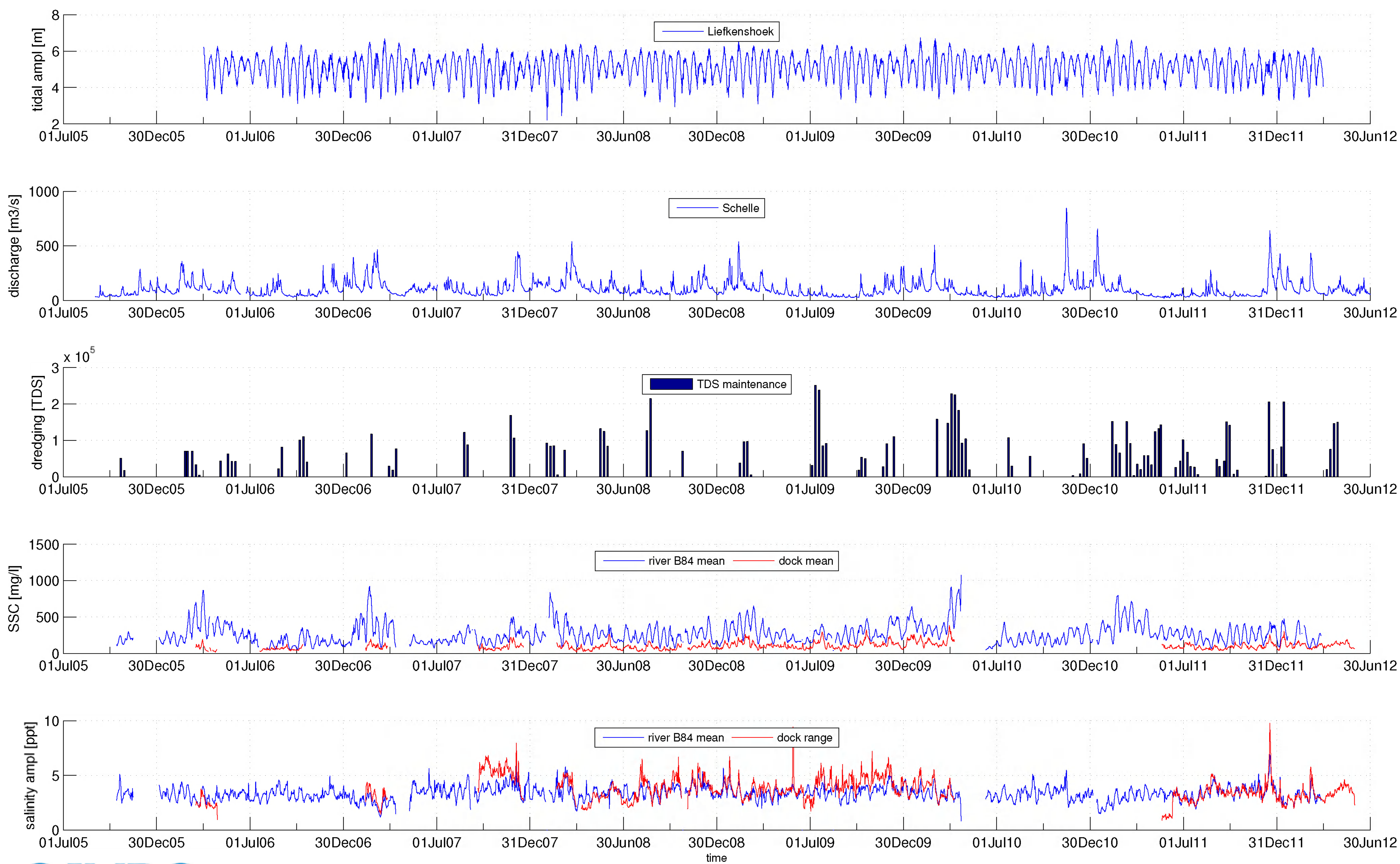
A.2 Time series of daily values



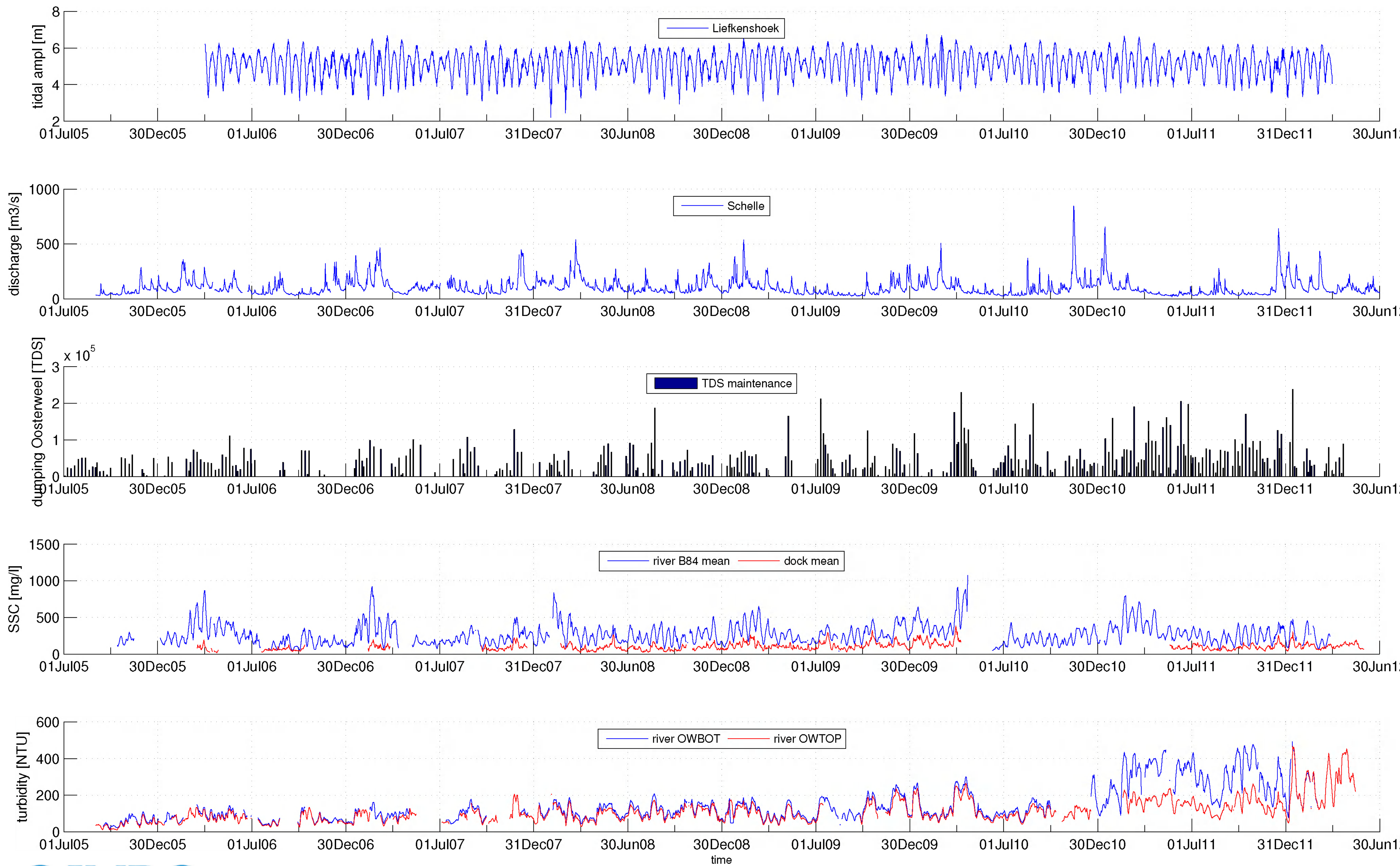
tidal ampl [m]
Liefkenshoek
discharge [m3/s]
Schelle
Sal [ppt]
NBOT
NTOP
SBOT
STOP
B84BOT
B84TOP
B97BOT
B97TOP
OWBOT
OWTOP
PROSP
time
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12

Liefkenshoek
tidal ampl [m]
8
6
4
2
Schelle
discharge [m3/s]
1000
500
0
NBOT
NTOP
SBOT
STOP
Turb [NTU]
400
200
0
−200
B84BOT
B84TOP
B97BOT
B97TOP
Turb [NTU]
600
400
200
0
OWBOT
OWTOP
PROSP
Turb [NTU]
600
400
200
0
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12
time

report I/RA/11354/10.105/MBO/ANF, Sep2013



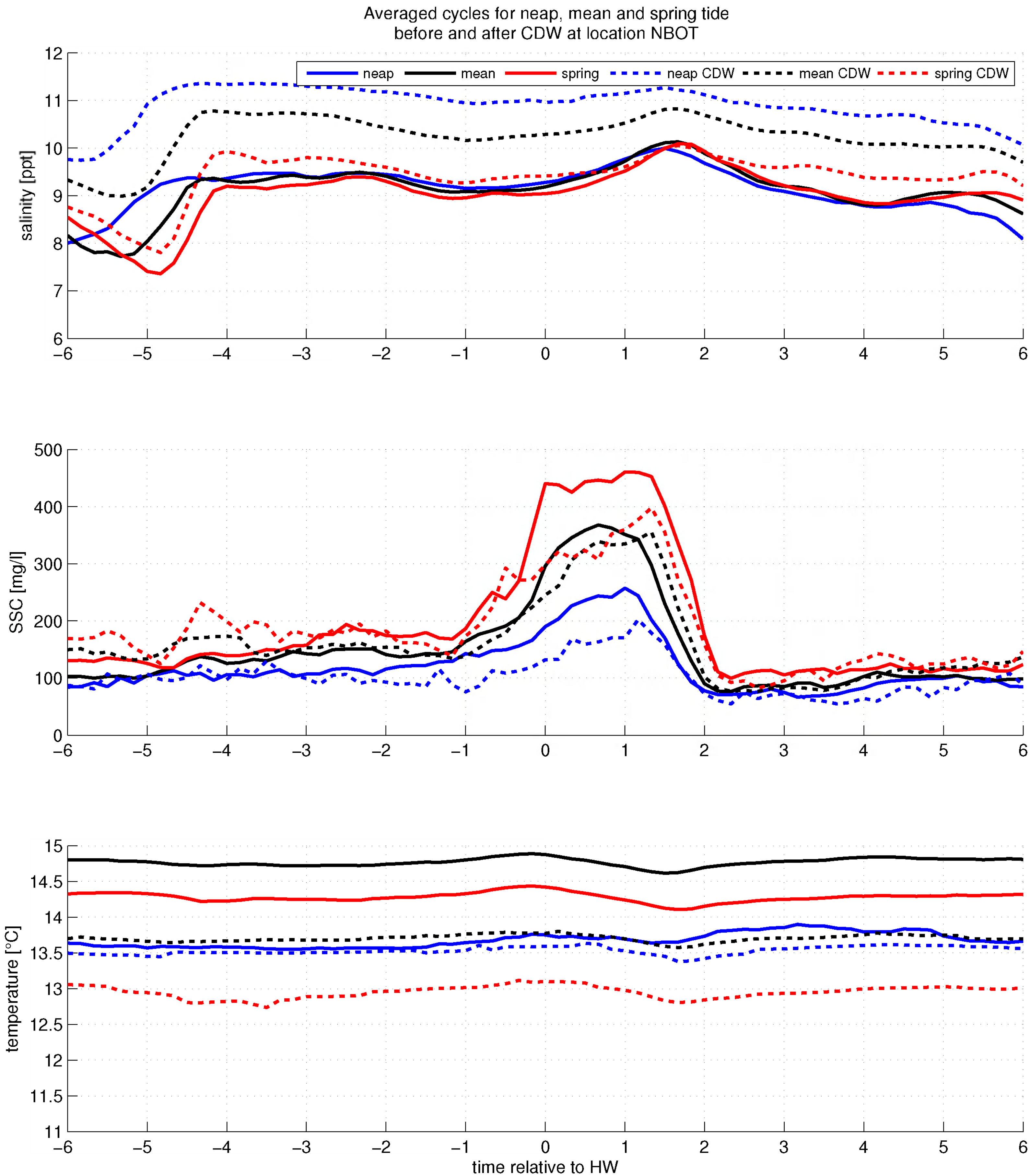
tidal ampl [m]
Liefkenshoek
discharge [m3/s]
Schelle
dredging [TDS]
x 10^5
TDS maintenance
SSC [mg/l]
river B84 mean
dock mean
salinity ampl [ppt]
river B84 mean
dock range
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12
time

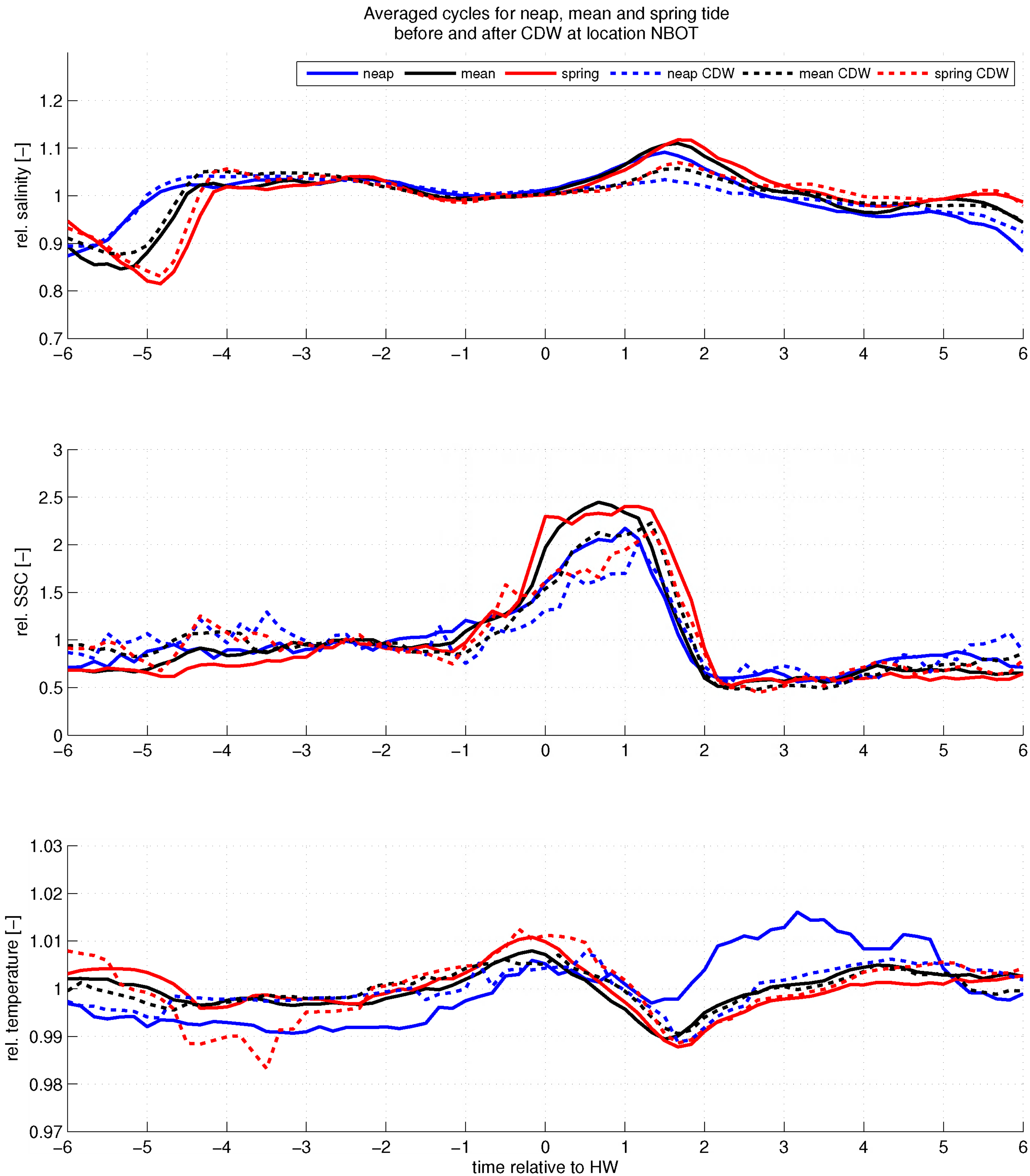


Liefkenshoek
tidal ampl [m]
Schelle
discharge [m3/s]
x 10^5
dumping Oosterweel [TDS]
TDS maintenance
river B84 mean
dock mean
SSC [mg/l]
river OWBOT
river OWTOP
turbidity [NTU]
01Jul05
30Dec05
01Jul06
30Dec06
01Jul07
31Dec07
30Jun08
30Dec08
01Jul09
30Dec09
01Jul10
30Dec10
01Jul11
31Dec11
30Jun12
time

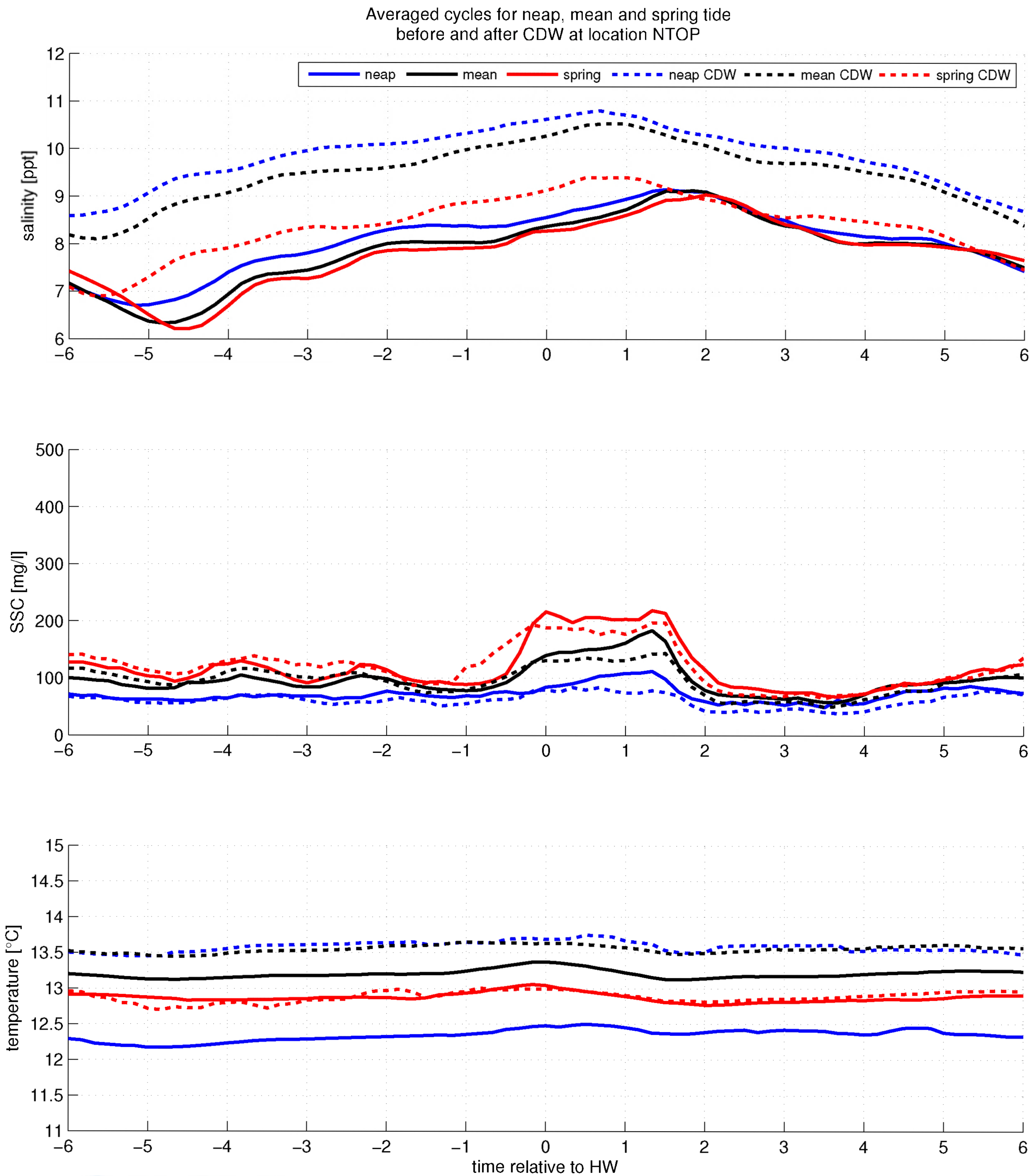
Annex B Mean tidal cycles

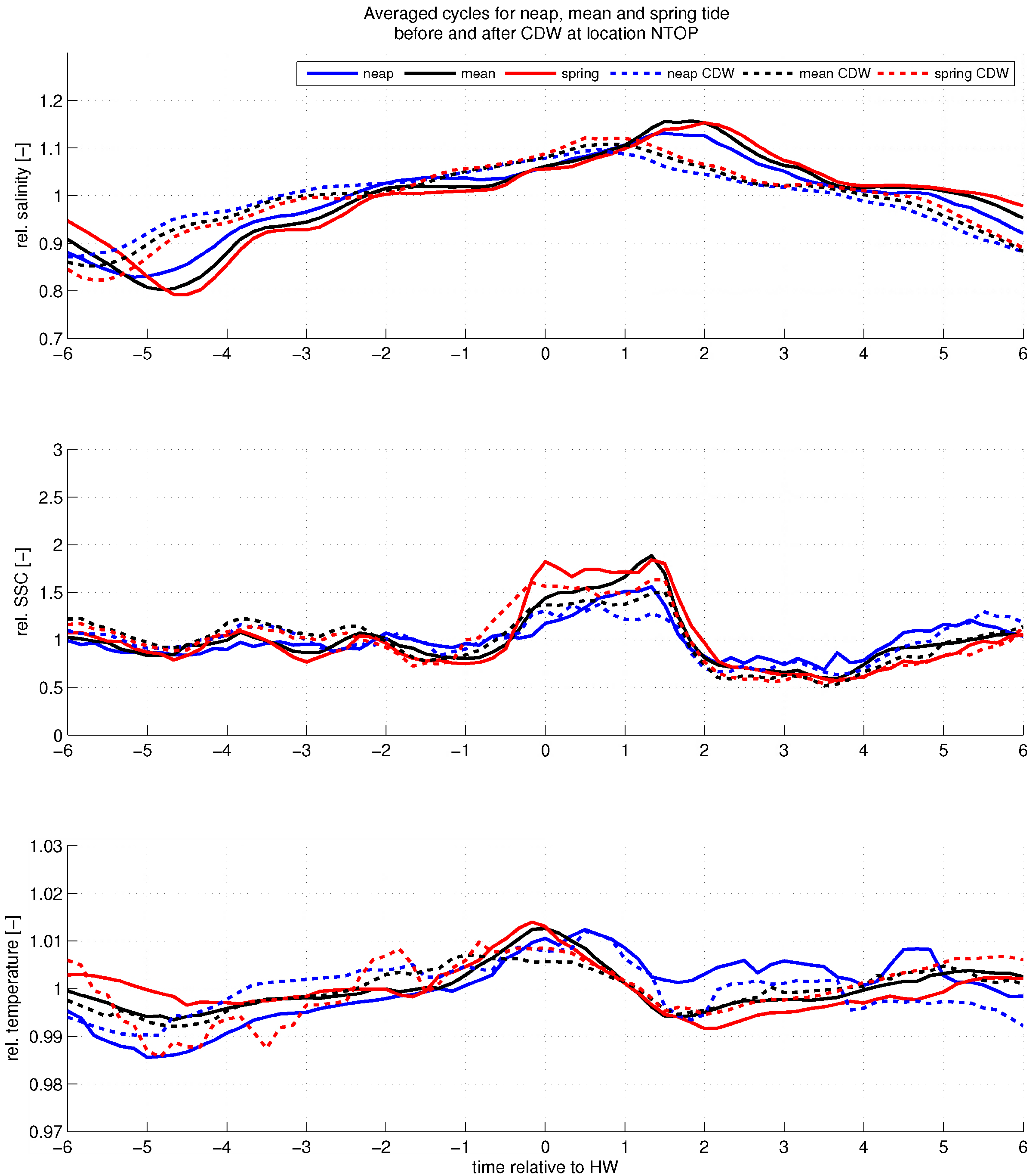
B.1 Per location


Averaged cycles for neap, mean and spring tide
before and after CDW at location NBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
salinity [ppt]
SSC [mg/l]
temperature [°C]
time relative to HW

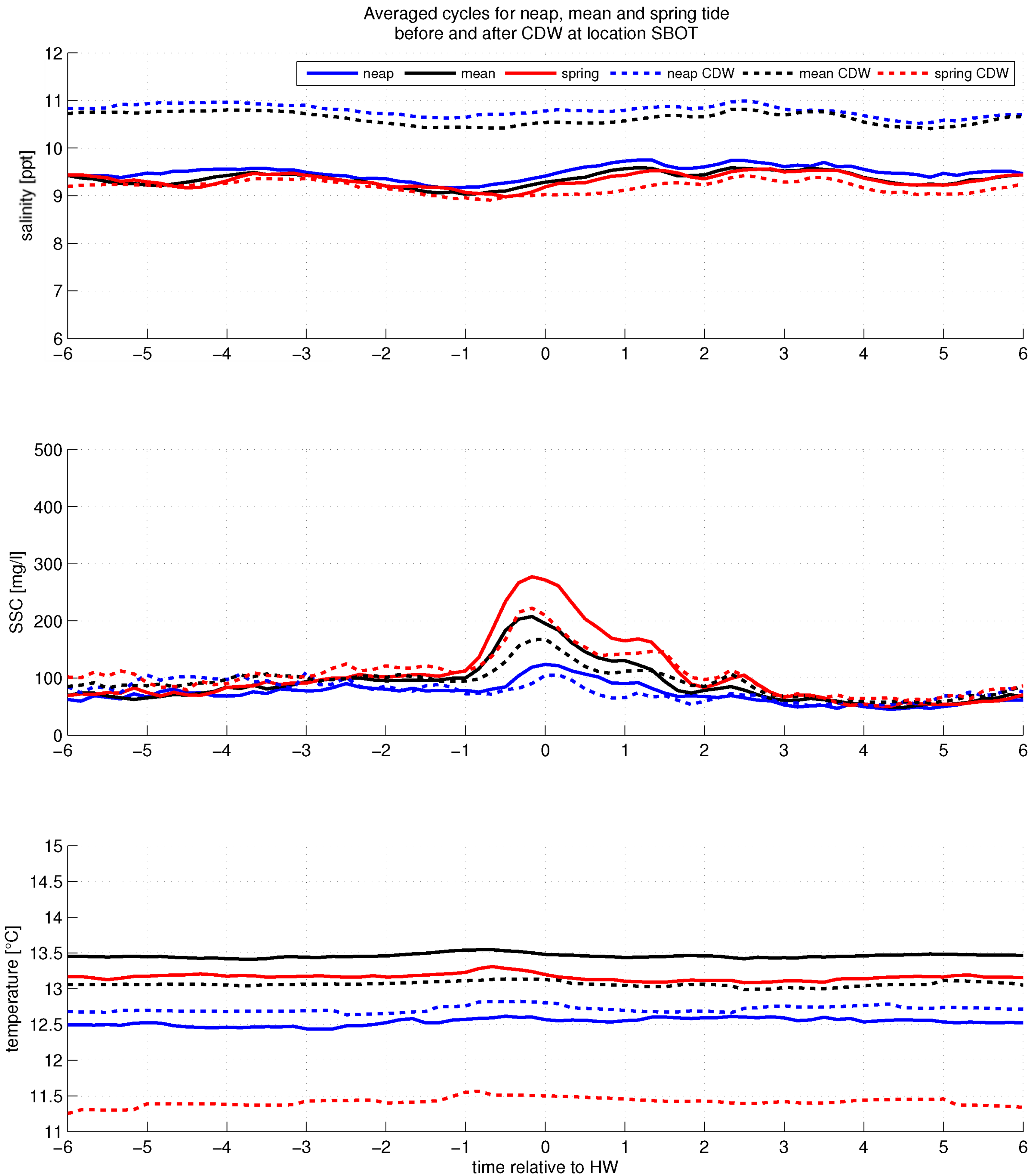


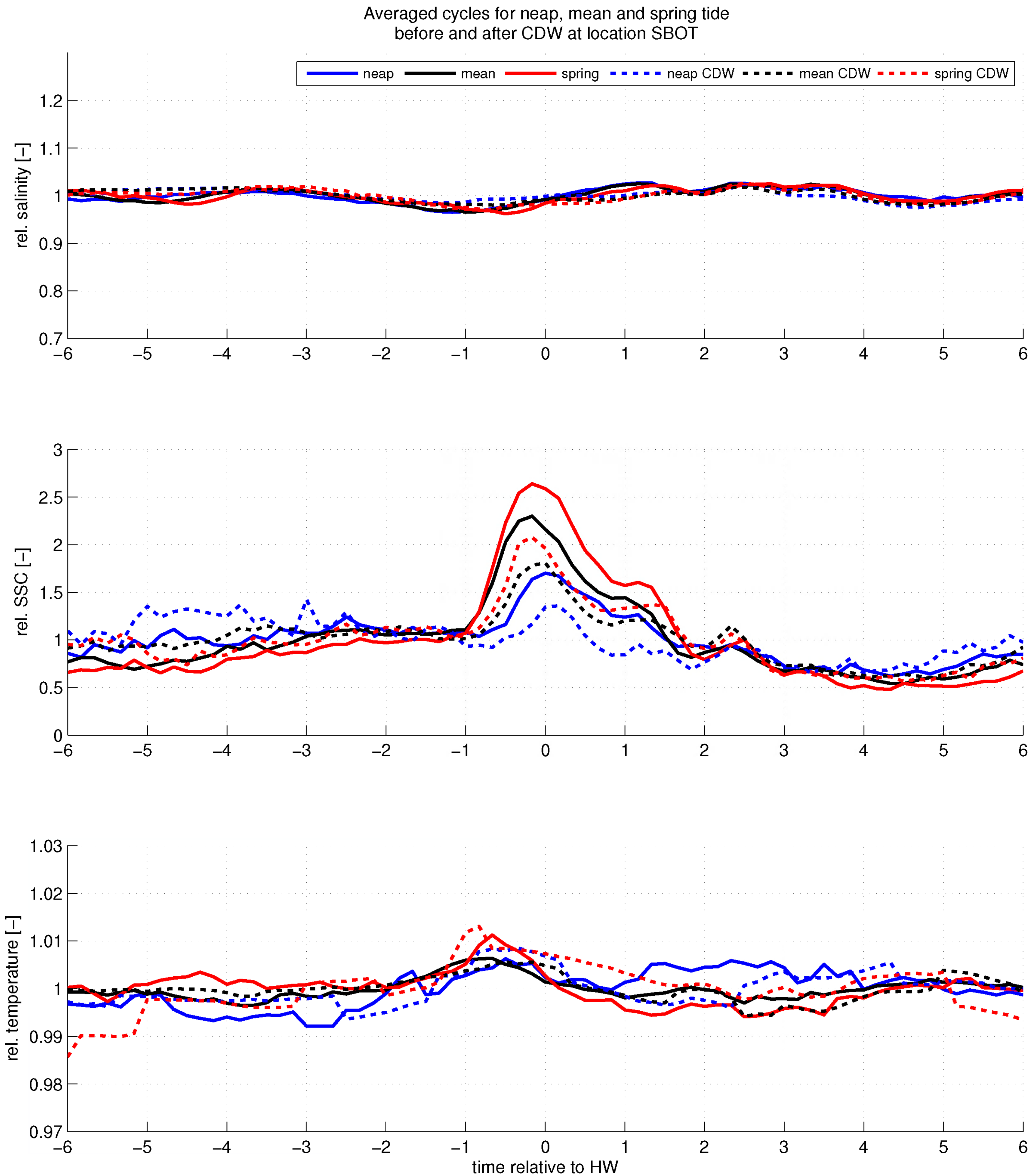
Averaged cycles for neap, mean and spring tide
before and after CDW at location NBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. salinity [–]
1.2
1.1
1
0.9
0.8
0.7
–6
–5
–4
–3
–2
–1
0
1
2
3
4
5
6
rel. SSC [–]
3
2.5
2
1.5
1
0.5
0
rel. temperature [–]
1.03
1.02
1.01
1
0.99
0.98
0.97
time relative to HW

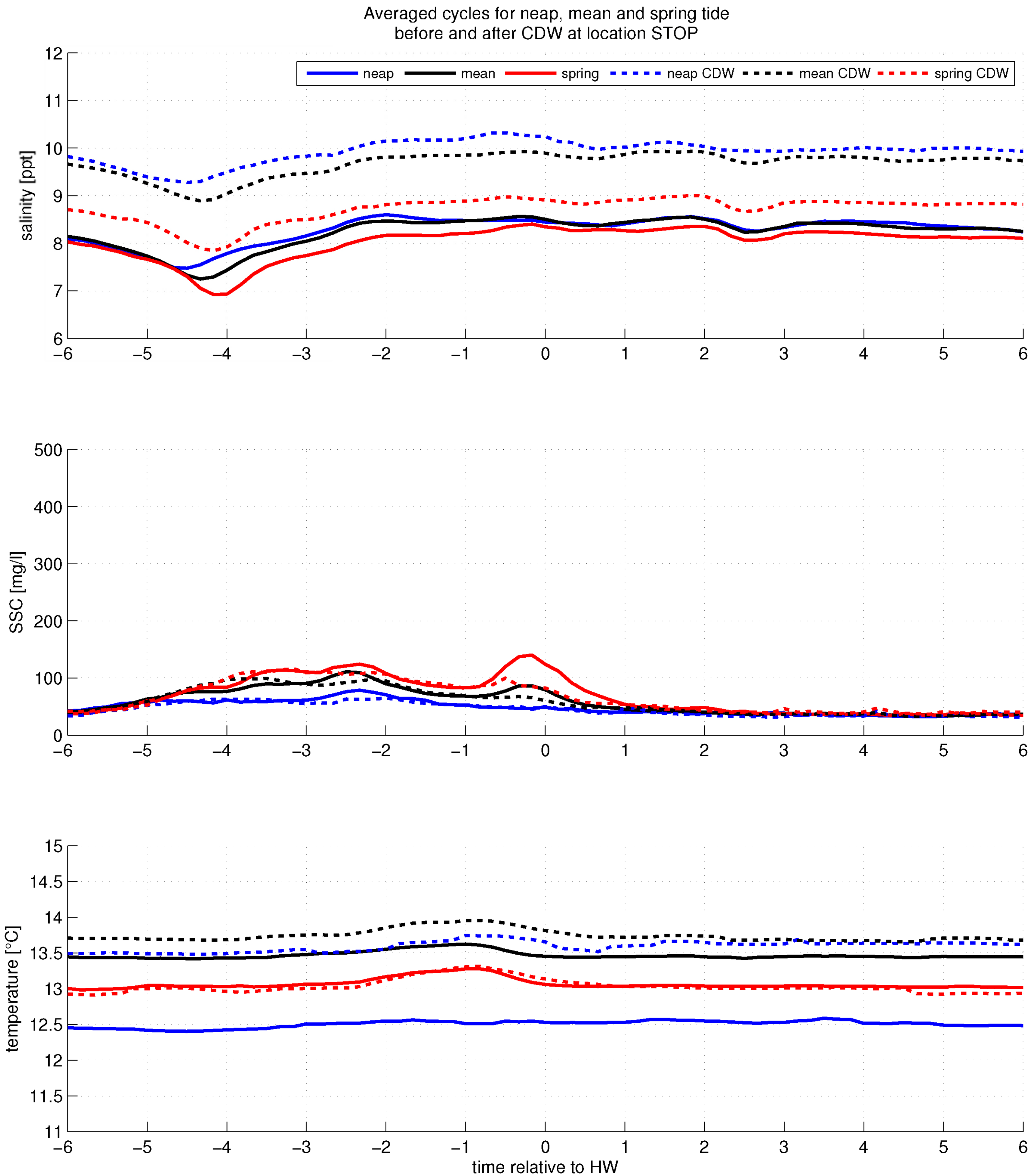

Averaged cycles for neap, mean and spring tide
before and after CDW at location NTOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
salinity [ppt]
SSC [mg/l]
temperature [°C]
time relative to HW



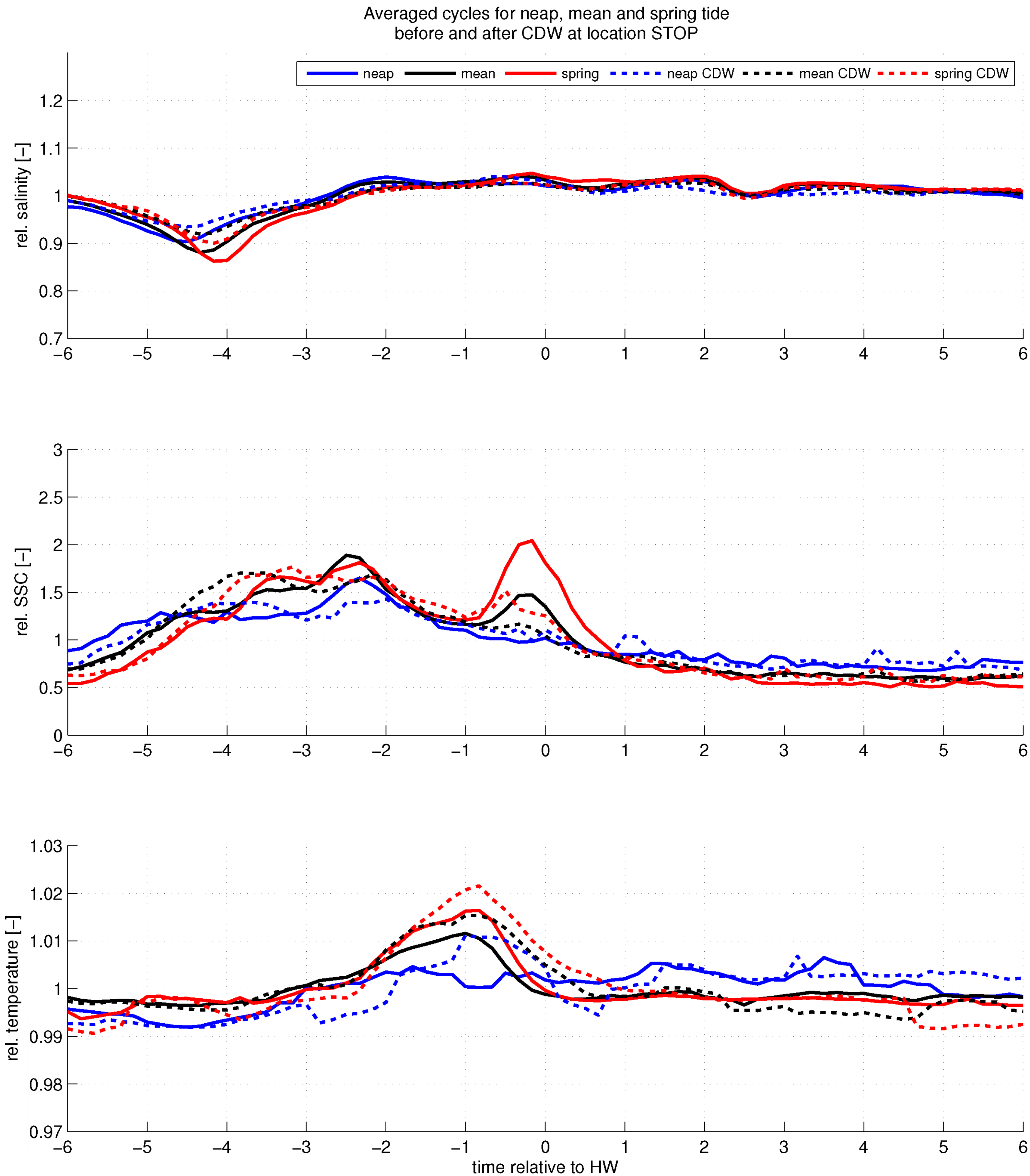
Averaged cycles for neap, mean and spring tide
before and after CDW at location NTOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. salinity [–]
rel. SSC [–]
rel. temperature [–]
time relative to HW


Averaged cycles for neap, mean and spring tide
before and after CDW at location SBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
salinity [ppt]
SSC [mg/l]
temperature [°C]
time relative to HW


Averaged cycles for neap, mean and spring tide
before and after CDW at location SBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. salinity [–]
rel. SSC [–]
rel. temperature [–]
time relative to HW



Averaged cycles for neap, mean and spring tide
before and after CDW at location STOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
salinity [ppt]
SSC [mg/l]
temperature [°C]
time relative to HW



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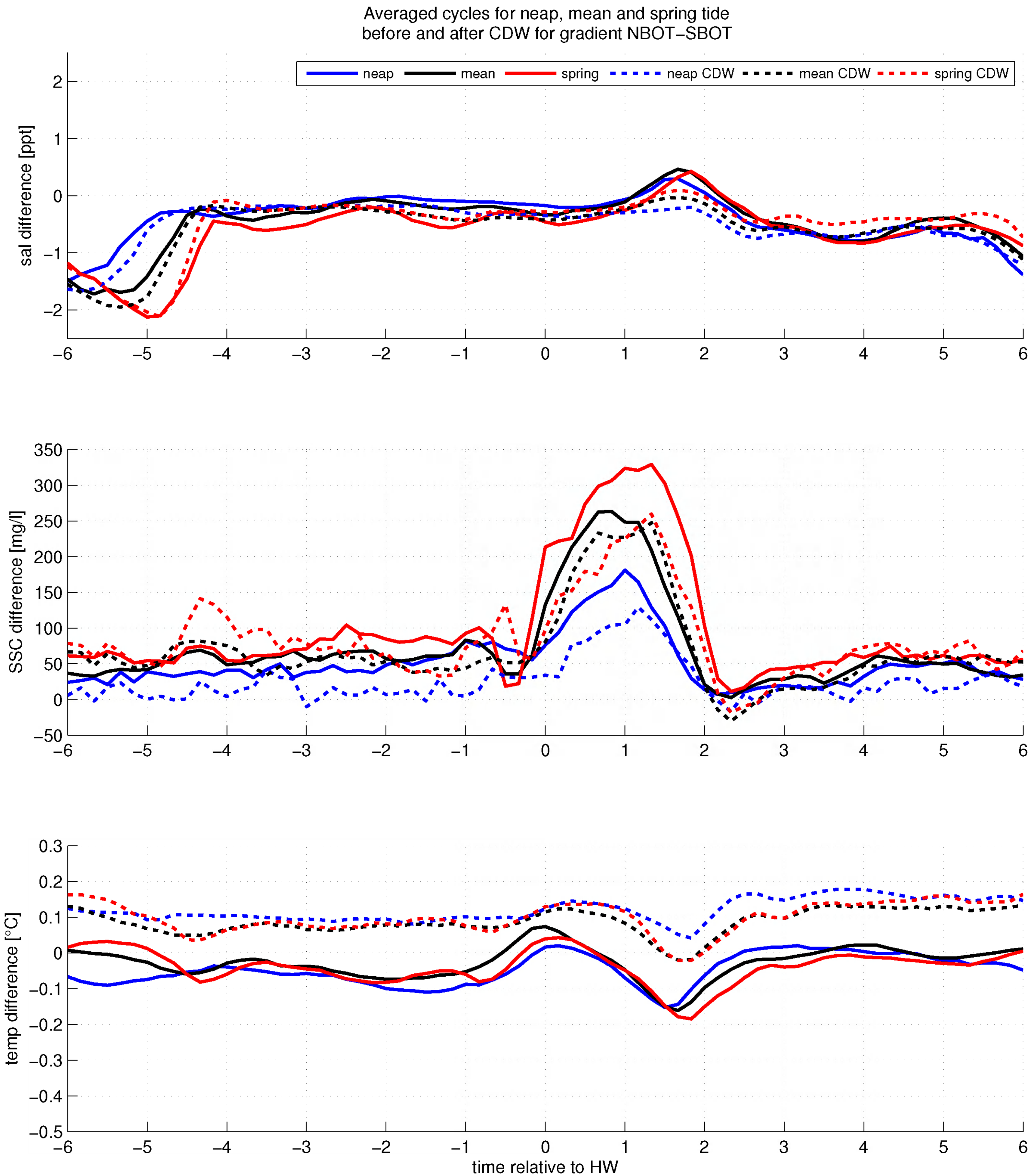
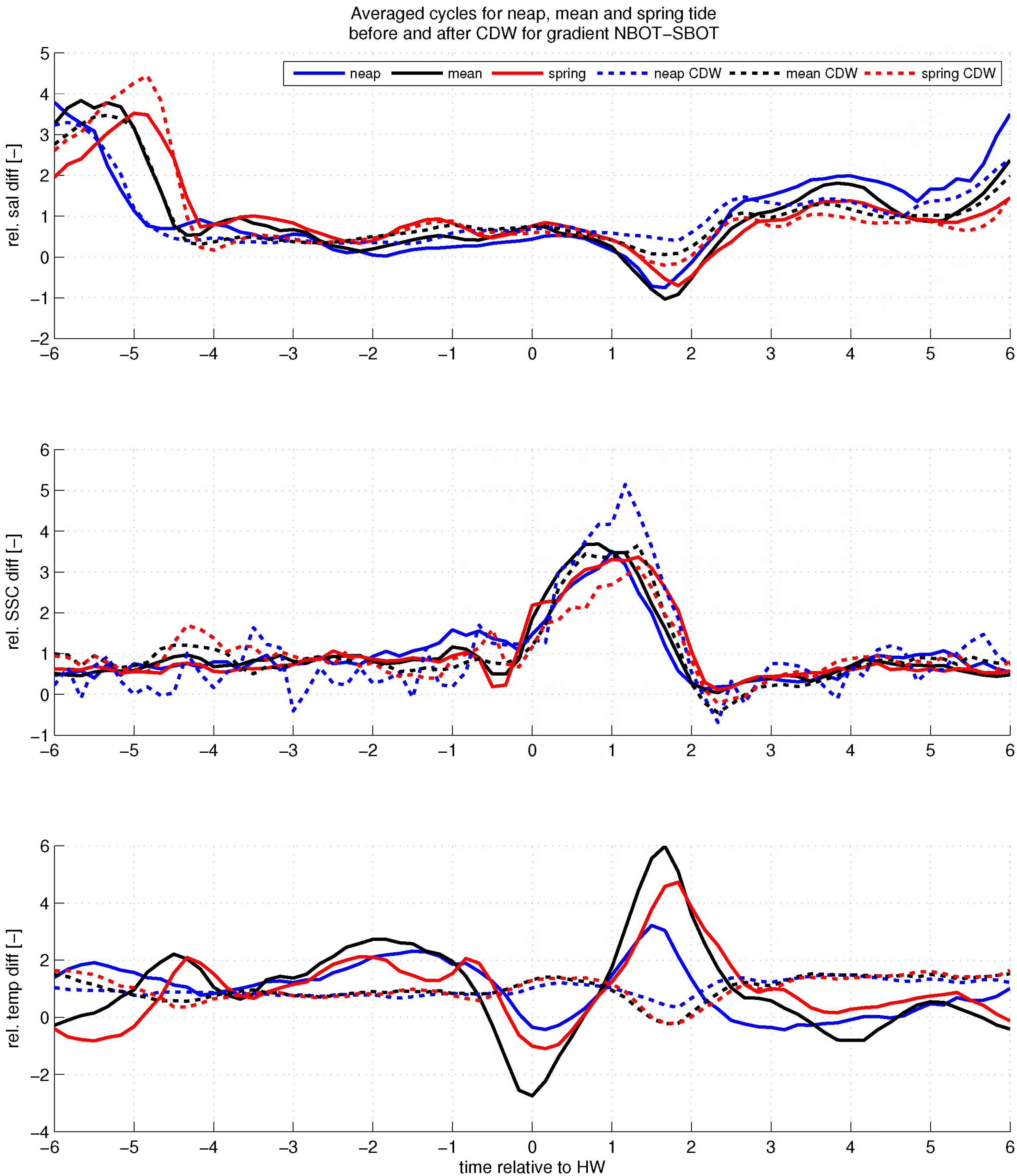
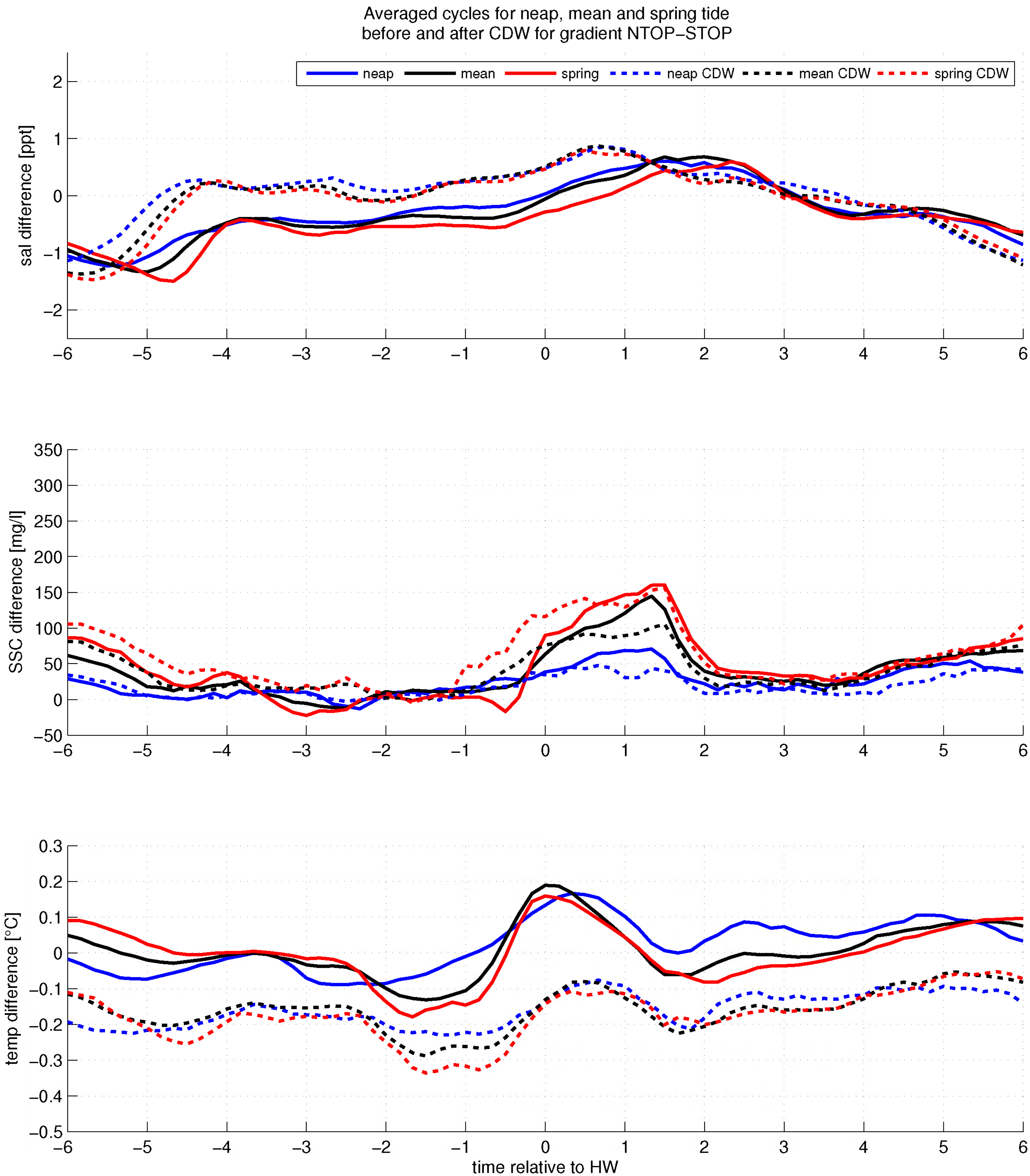
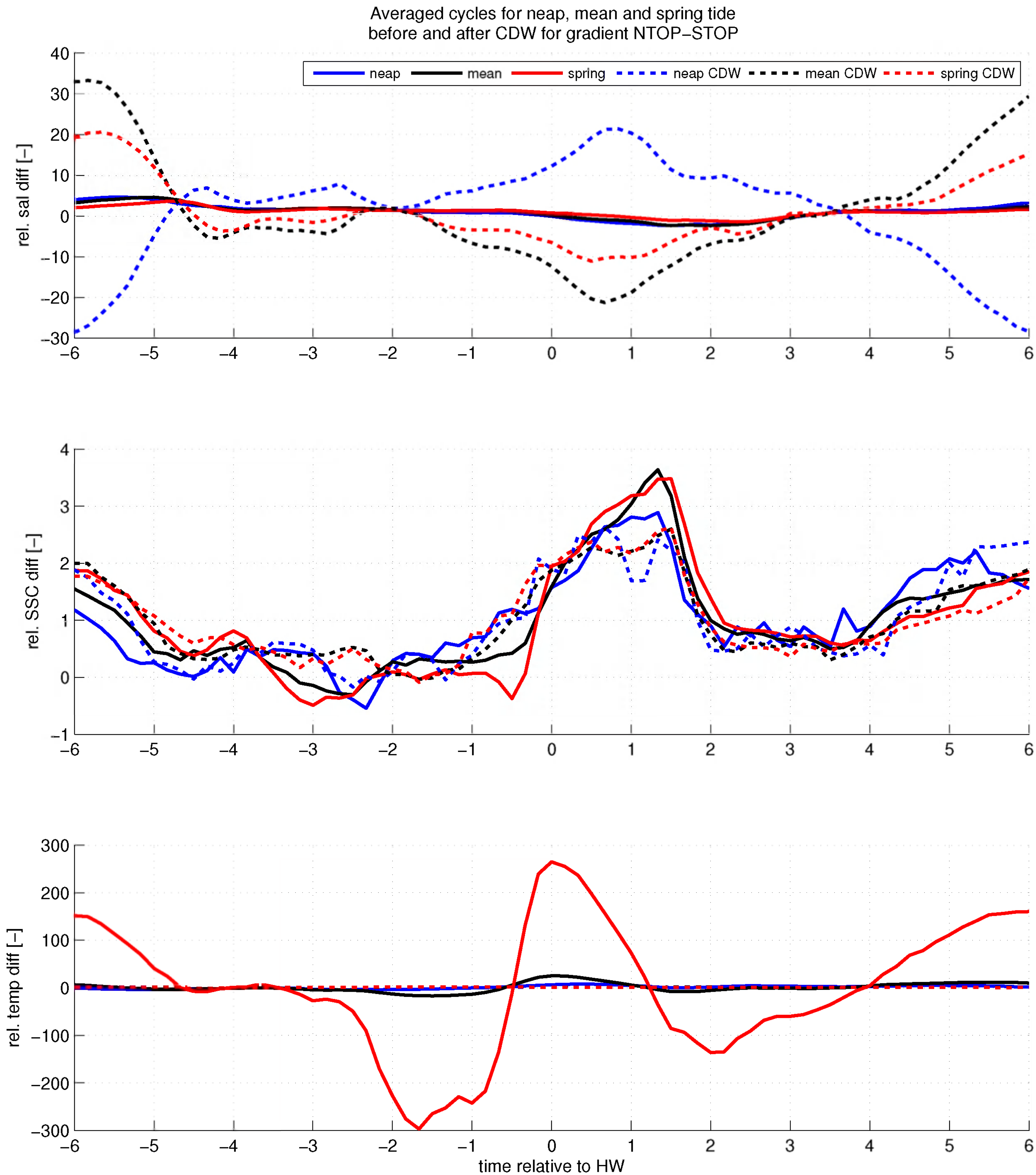
B.2 Gradients



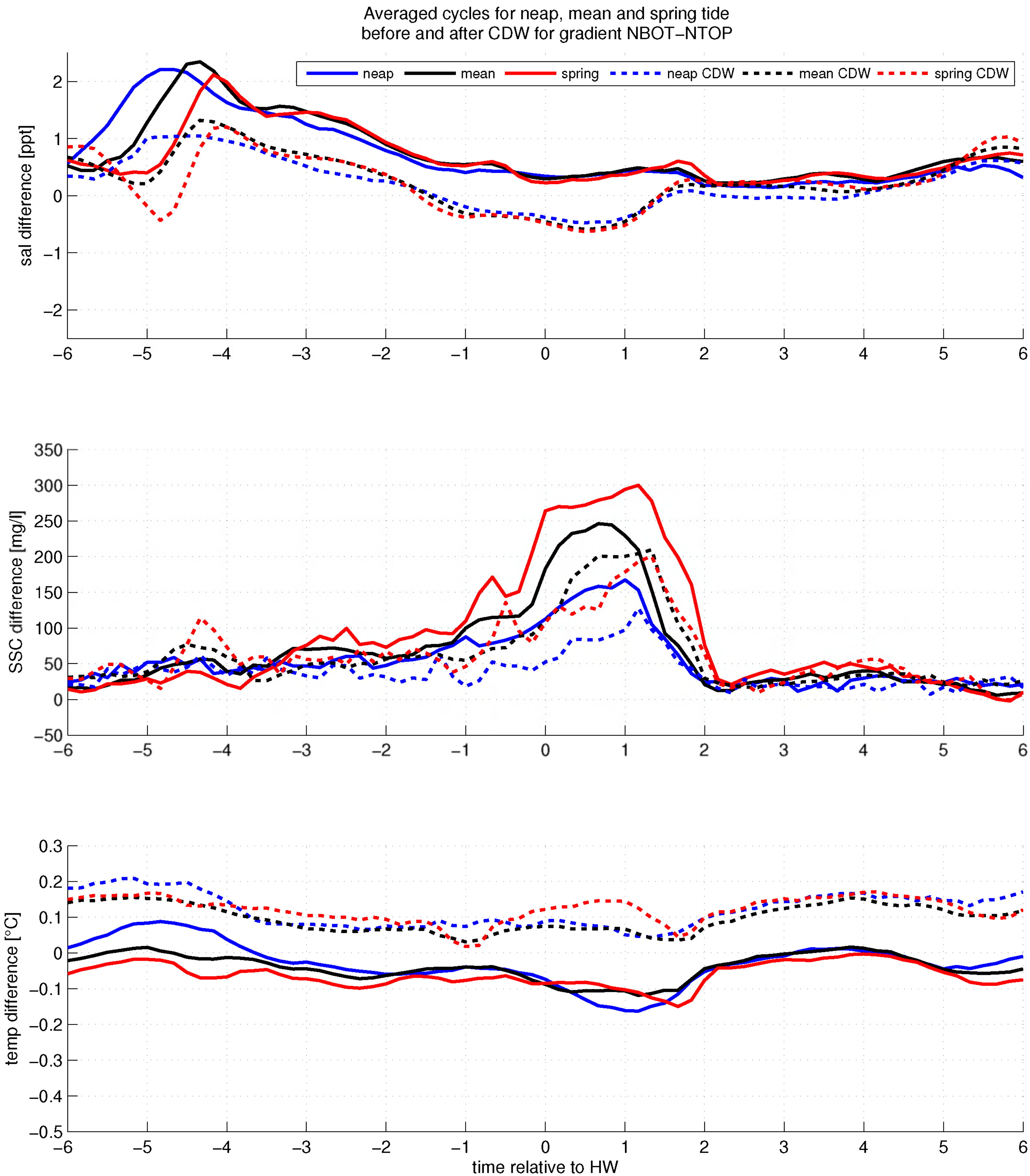
Averaged cycles for neap, mean and spring tide
before and after CDW for gradient NBOT−SBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
sal difference [ppt]
SSC difference [mg/l]
temp difference [°C]
time relative to HW

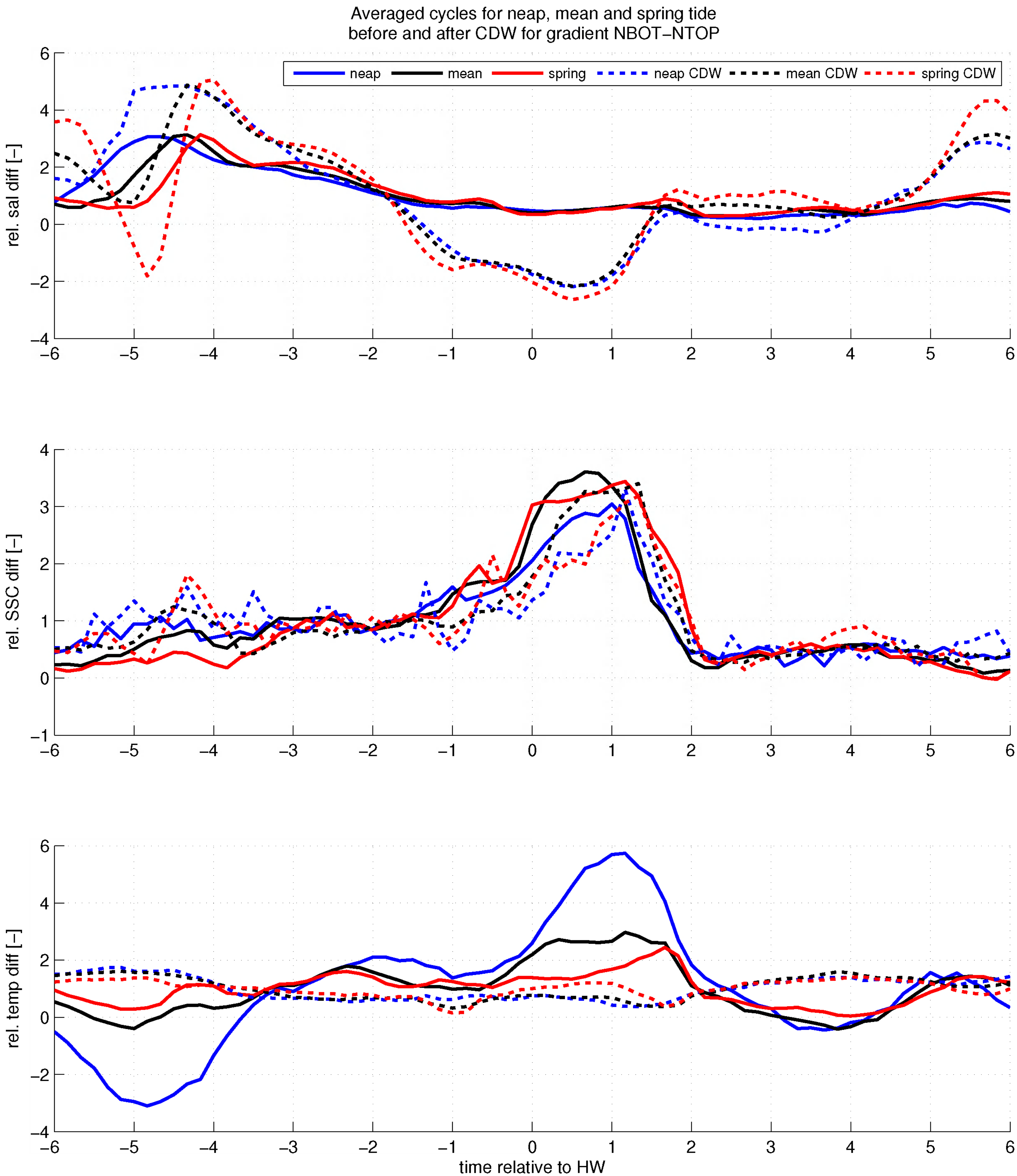

Averaged cycles for neap, mean and spring tide
before and after CDW for gradient NBOT−SBOT
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. sal diff [−]
rel. SSC diff [−]
rel. temp diff [−]
time relative to HW

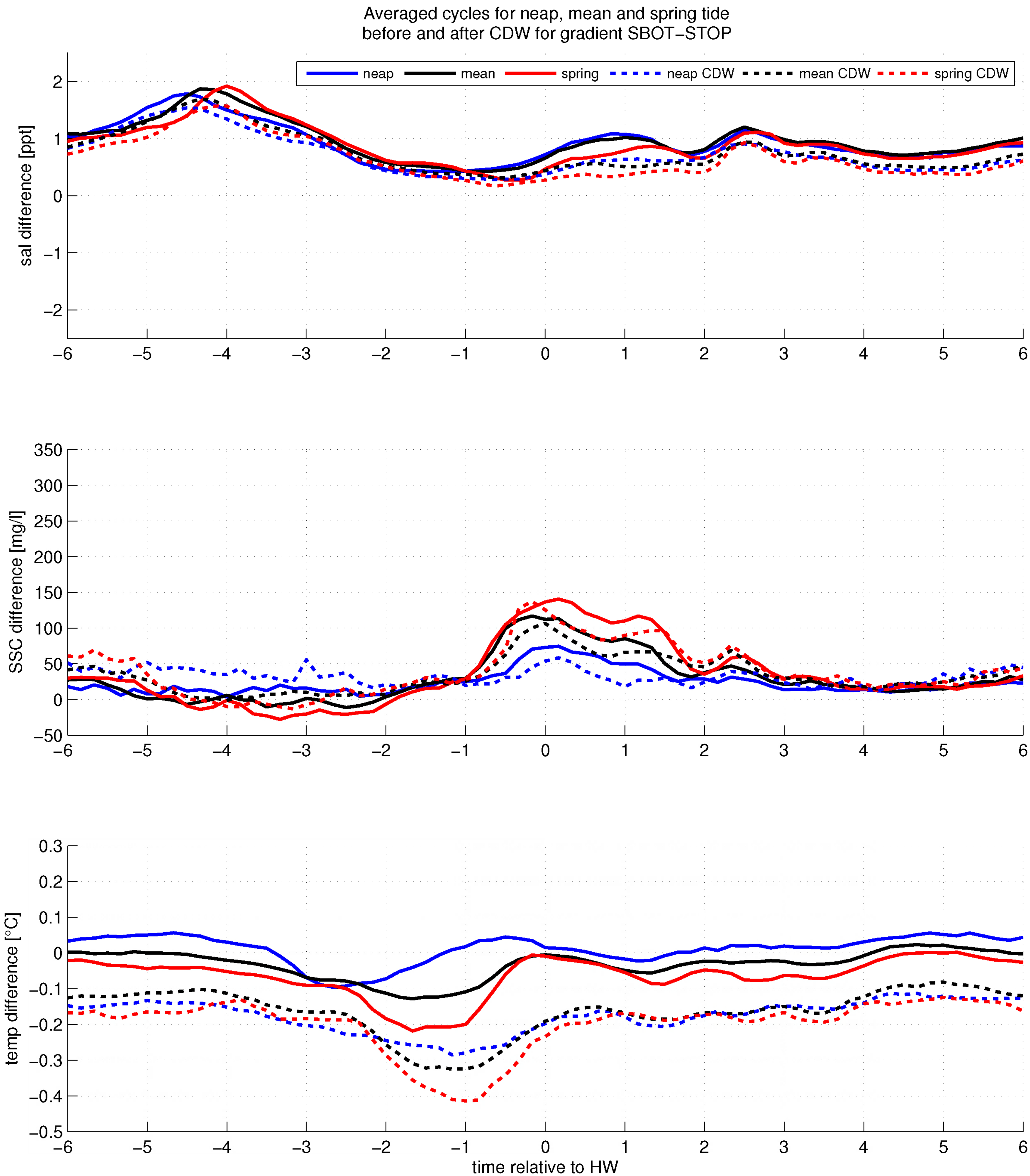

Averaged cycles for neap, mean and spring tide
before and after CDW for gradient NTOP−STOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
sal difference [ppt]
SSC difference [mg/l]
temp difference [°C]
time relative to HW

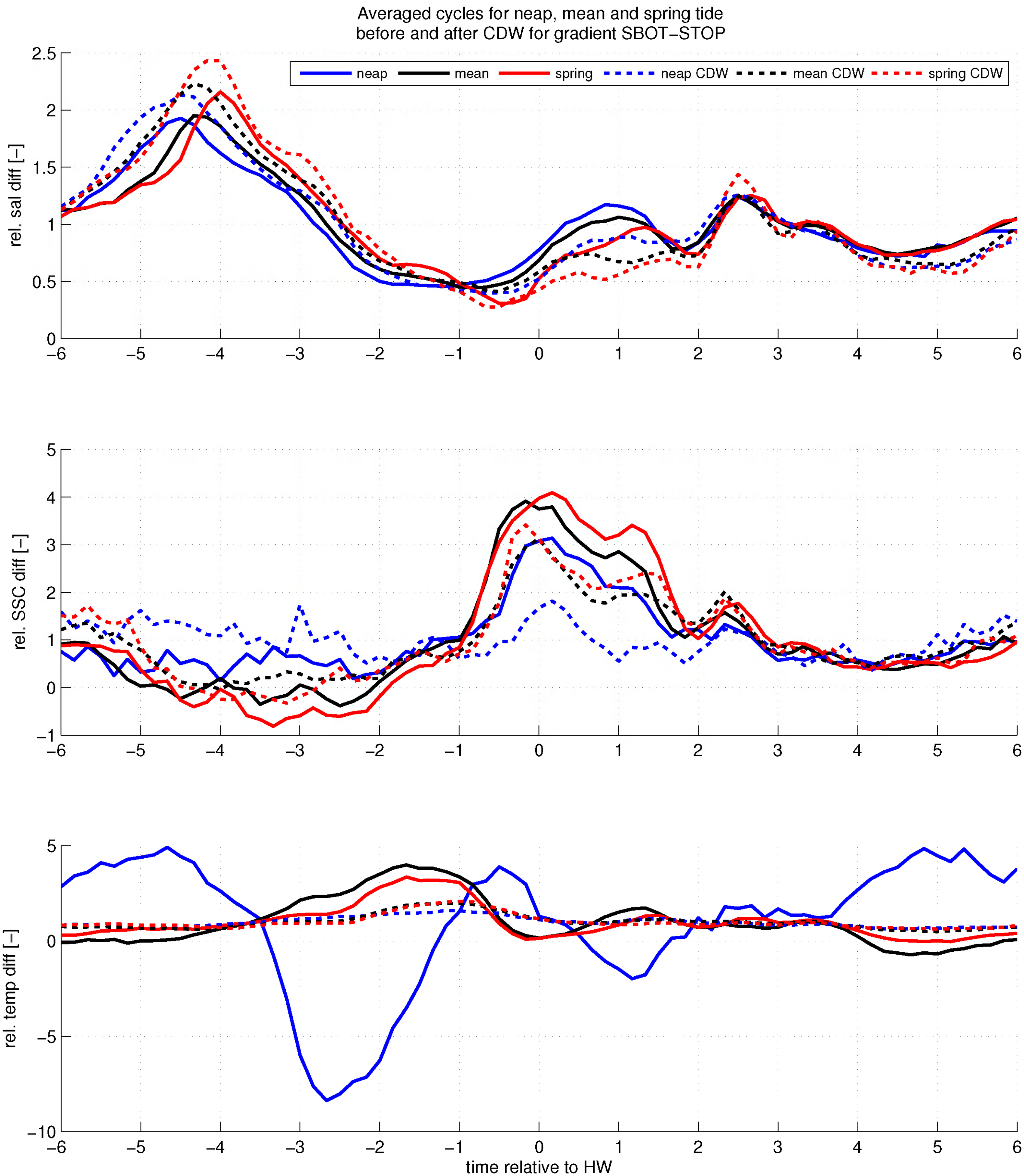


report I/RA/11354/10.105/MBO/ANF, Sep2013


Averaged cycles for neap, mean and spring tide
before and after CDW for gradient NBOT−NTOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
sal difference [ppt]
SSC difference [mg/l]
temp difference [°C]
time relative to HW

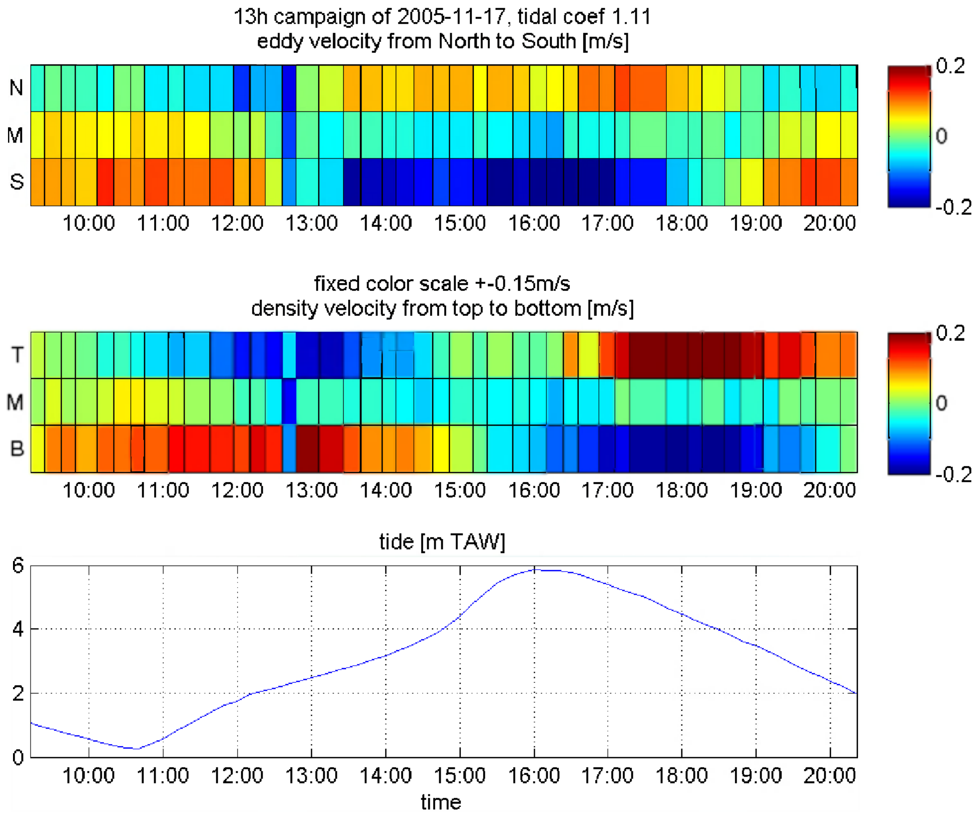

Averaged cycles for neap, mean and spring tide
before and after CDW for gradient NBOT−NTOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. sal diff [−]
rel. SSC diff [−]
rel. temp diff [−]
time relative to HW

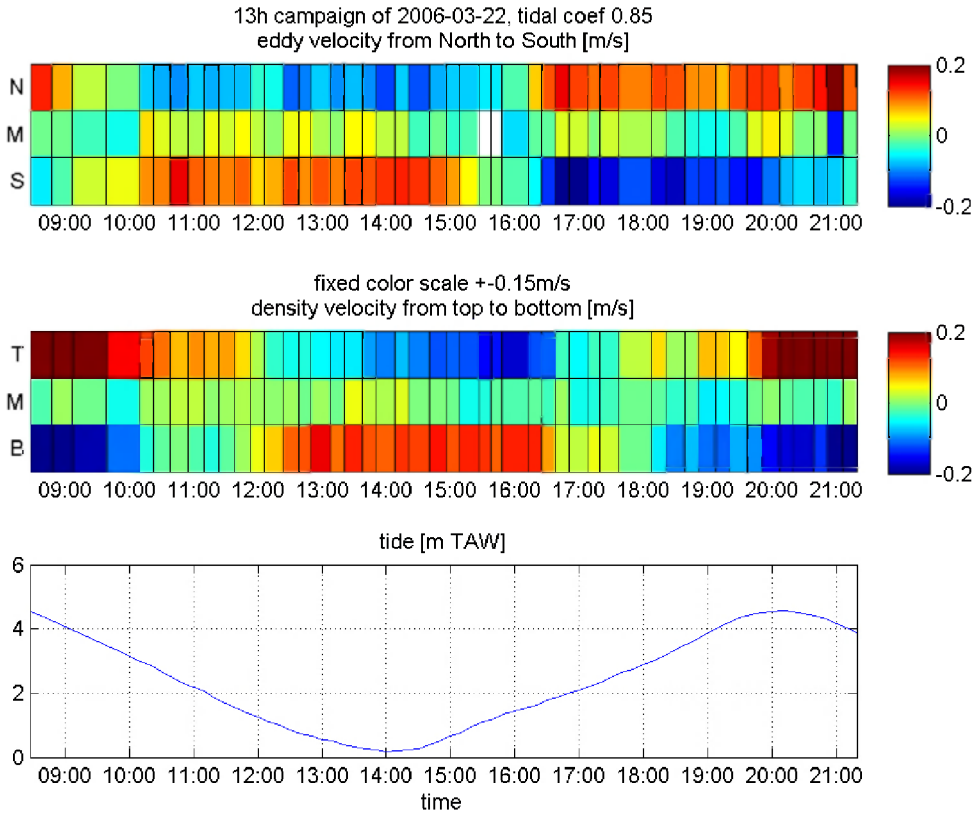

Averaged cycles for neap, mean and spring tide
before and after CDW for gradient SBOT−STOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
sal difference [ppt]
SSC difference [mg/l]
temp difference [°C]
time relative to HW

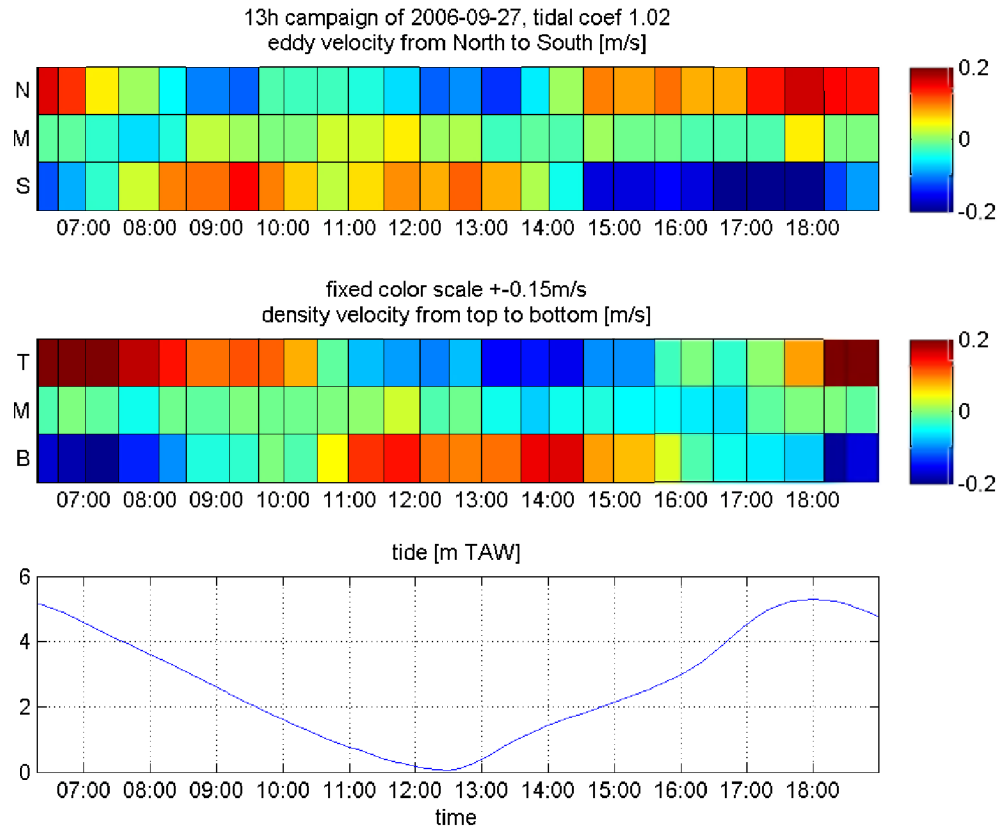

Averaged cycles for neap, mean and spring tide
before and after CDW for gradient SBOT−STOP
neap
mean
spring
neap CDW
mean CDW
spring CDW
rel. sal diff [−]
rel. SSC diff [−]
rel. temp diff [−]
time relative to HW

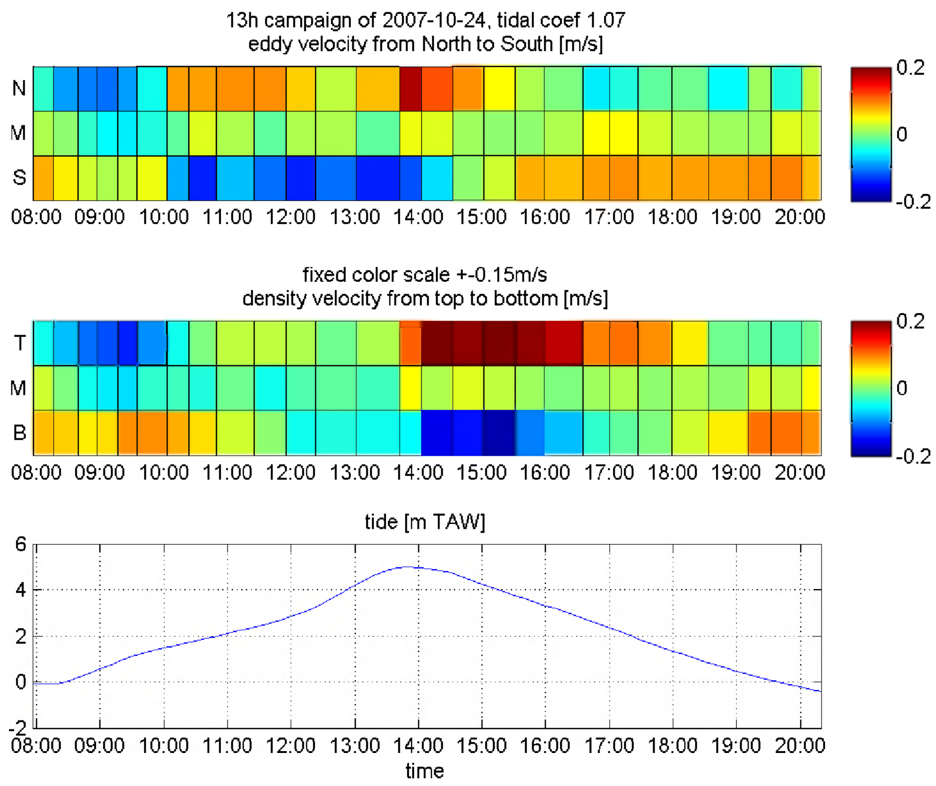
Annex C Analysis of 13h measurements with Christiansen method

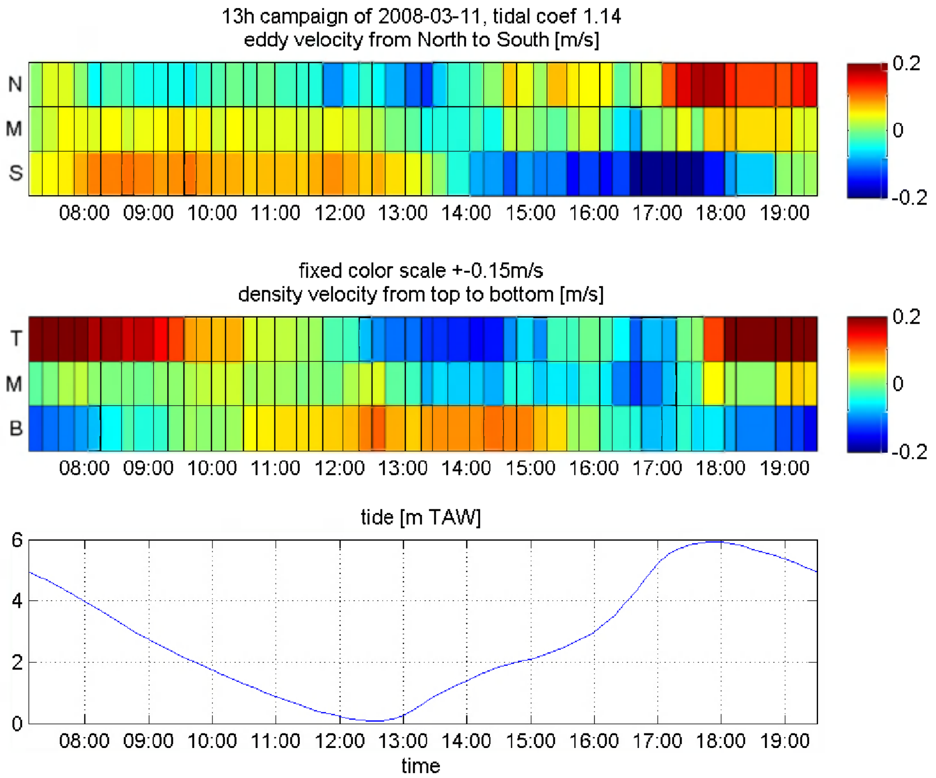
C.1 Velocity

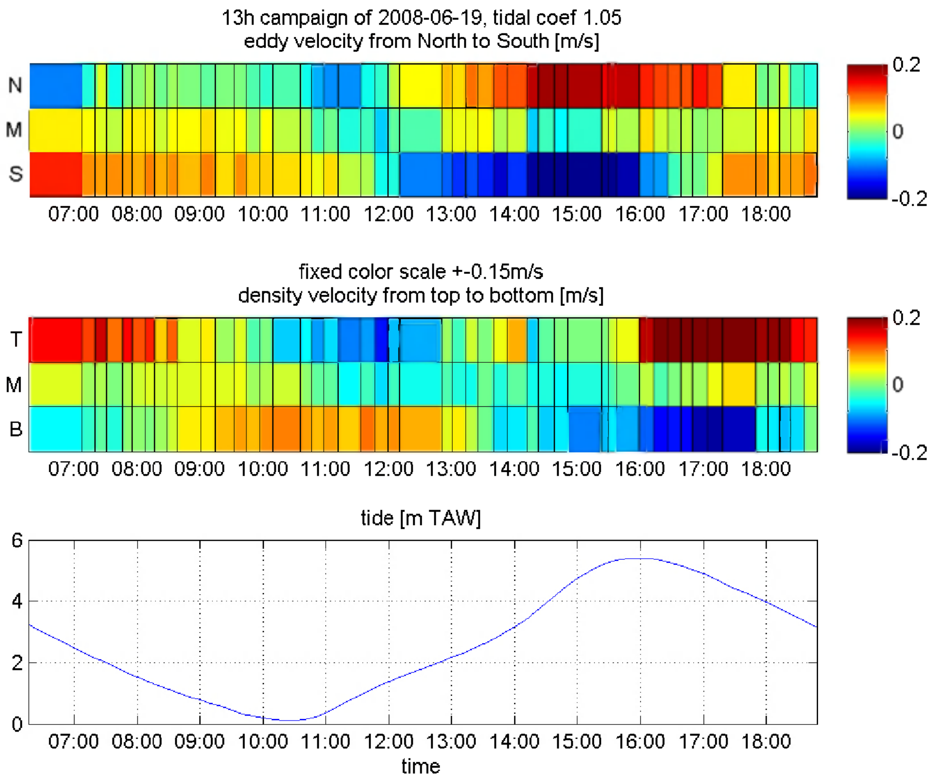

13h campaign of 2005-11-17, tidal coef 1.11
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
0.2
0
-0.2
10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
tide [m TAW]
6
4
2
0
10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
time

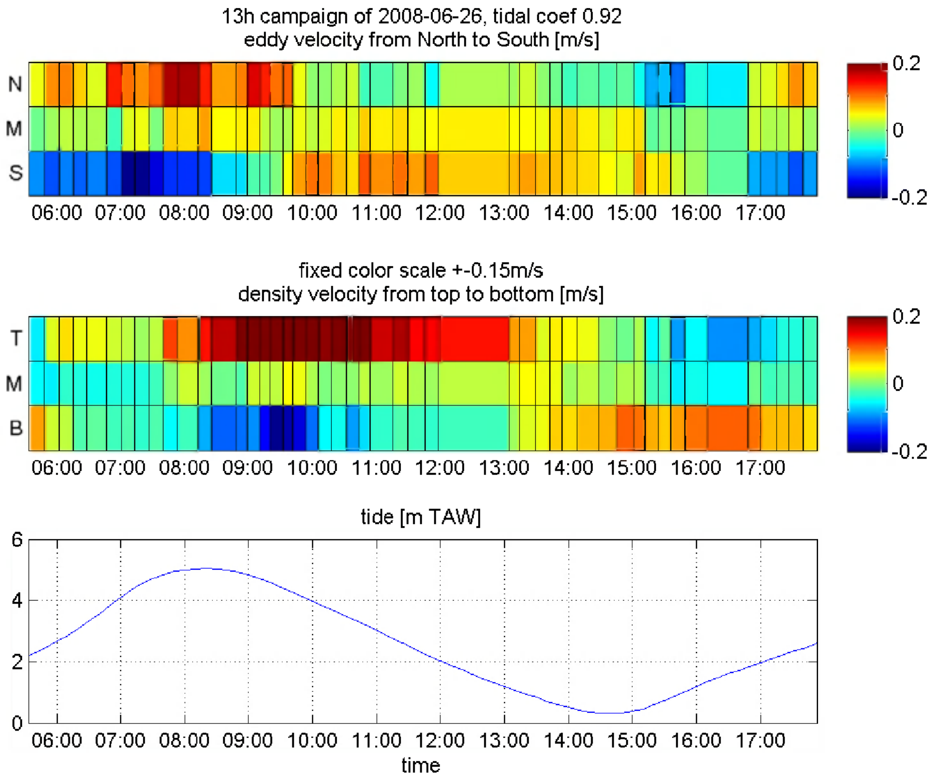

13h campaign of 2006-03-22, tidal coef 0.85
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
0.2
0
-0.2
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00
tide [m TAW]
6
4
2
0
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00
time

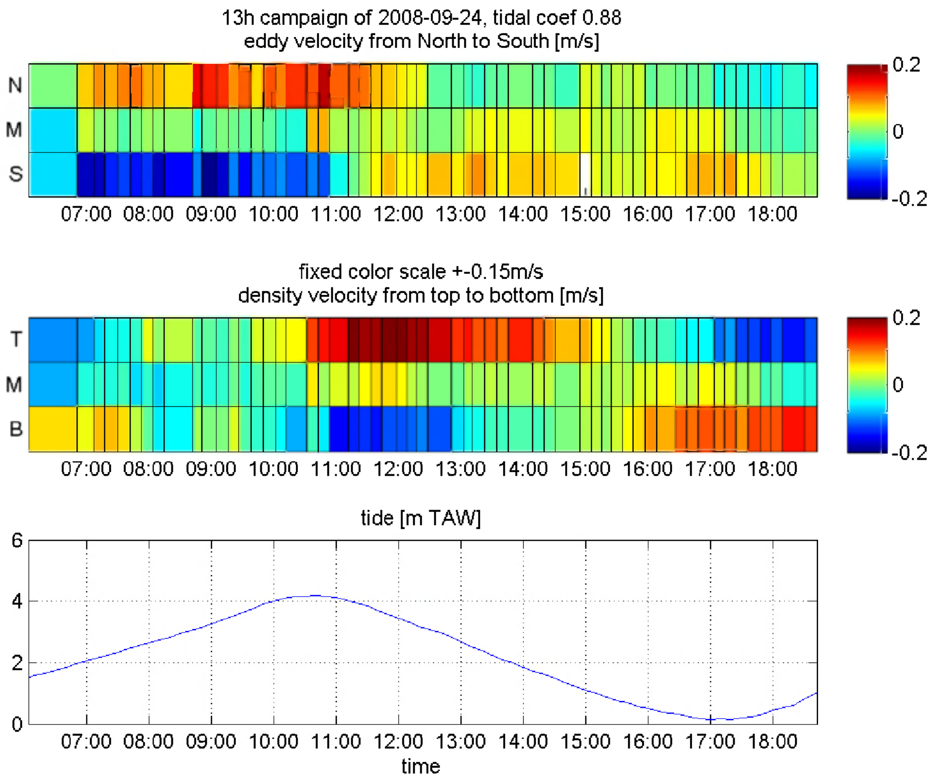

13h campaign of 2006-09-27, tidal coef 1.02
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
time

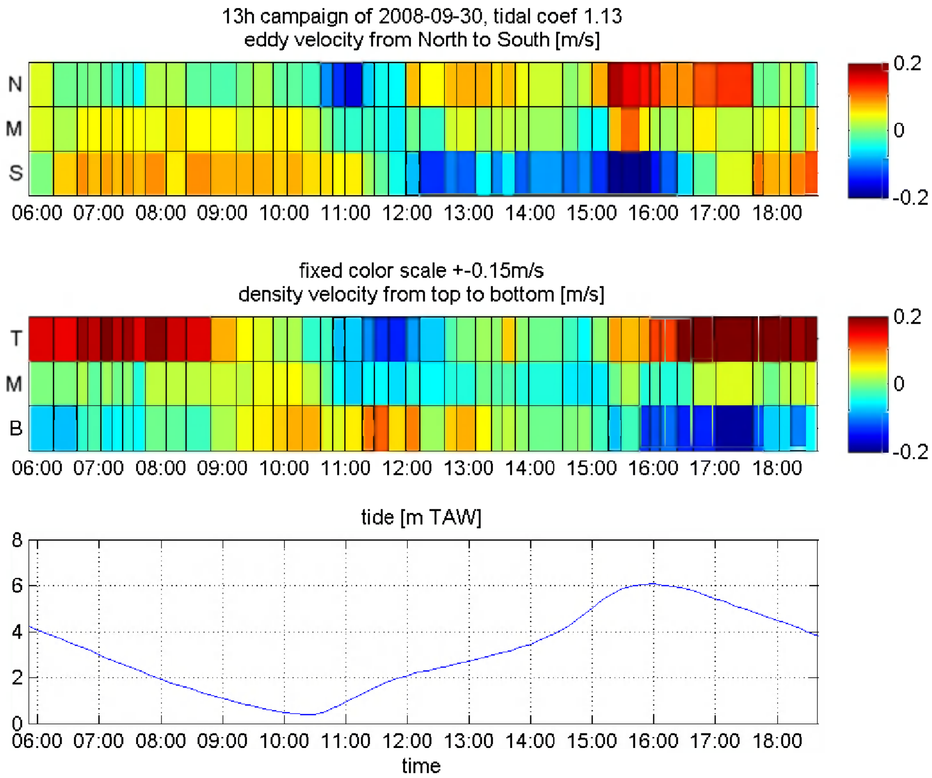

13h campaign of 2007-10-24, tidal coef 1.07
eddy velocity from North to South [m/s]
N
M
S
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
-2
time

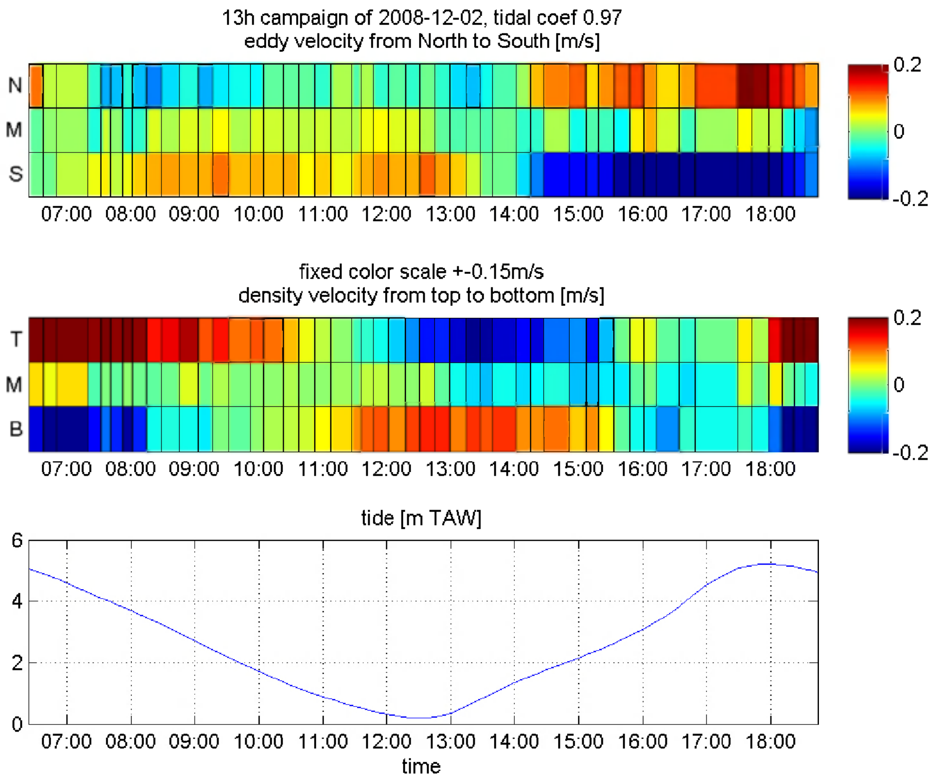

13h campaign of 2008-03-11, tidal coef 1.14
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
time

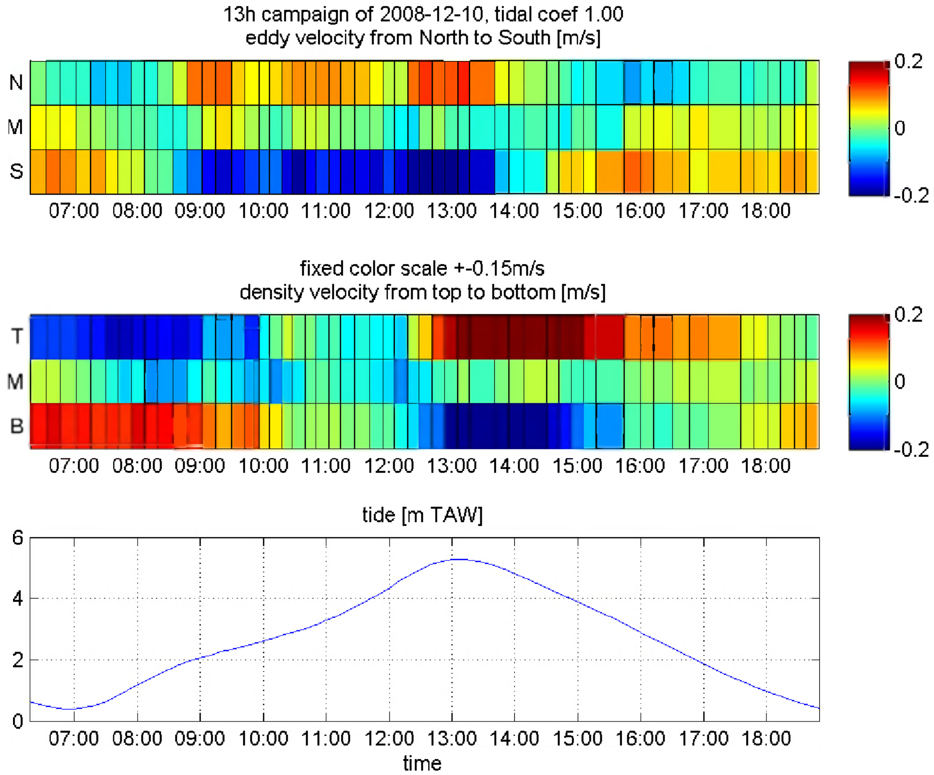

13h campaign of 2008-06-19, tidal coef 1.05
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
time

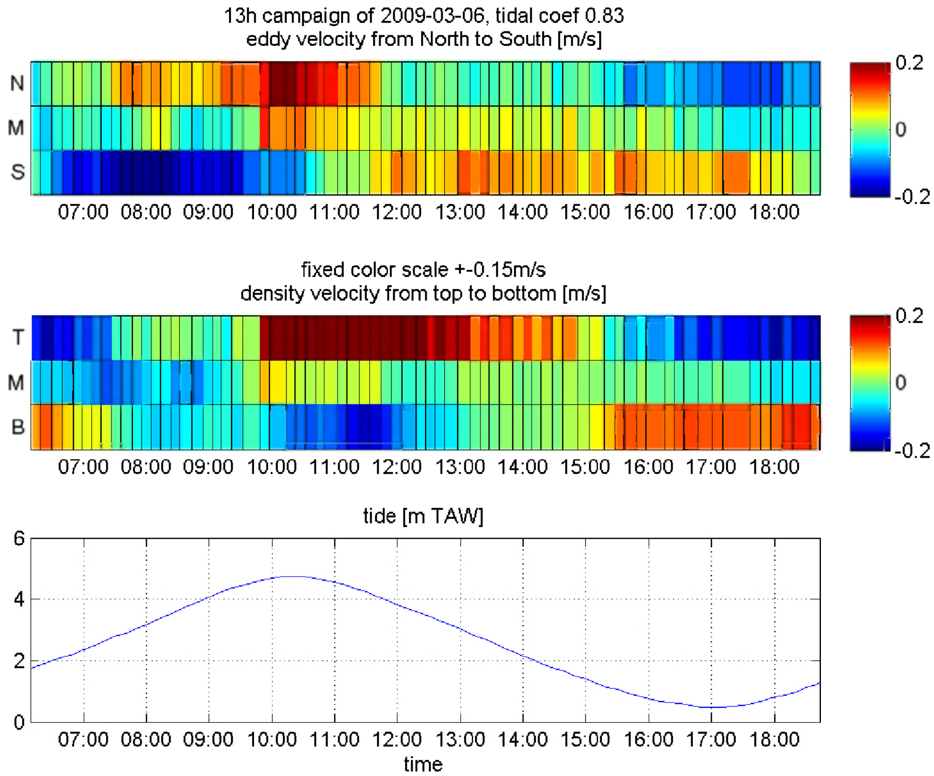

13h campaign of 2008-06-26, tidal coef 0.92
eddy velocity from North to South [m/s]
N
M
S
06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00
0.2
0
-0.2
tide [m TAW]
6
4
2
0
06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00
time

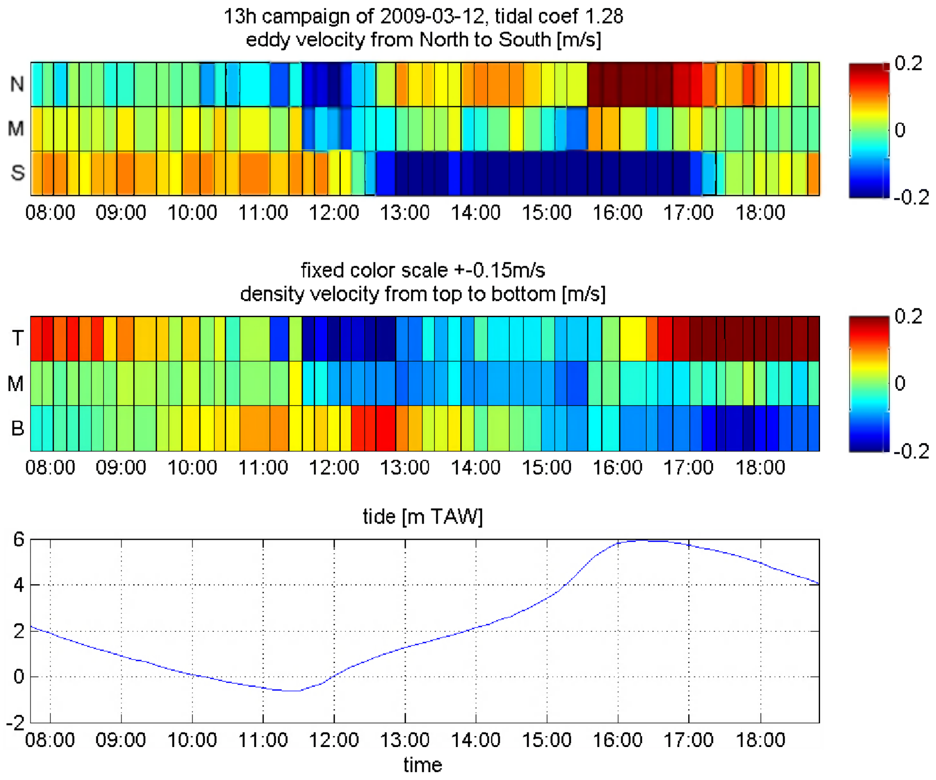

13h campaign of 2008-09-24, tidal coef 0.88
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
tide [m TAW]
6
4
2
0
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
time

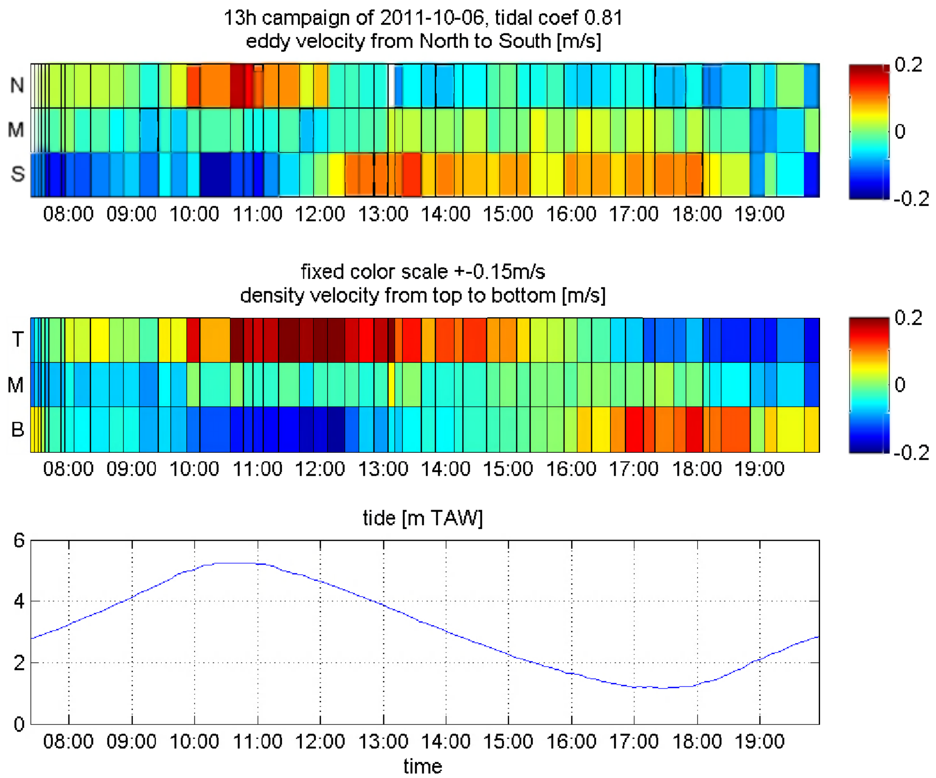

13h campaign of 2008-09-30, tidal coef 1.13
eddy velocity from North to South [m/s]
N
M
S
06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
time

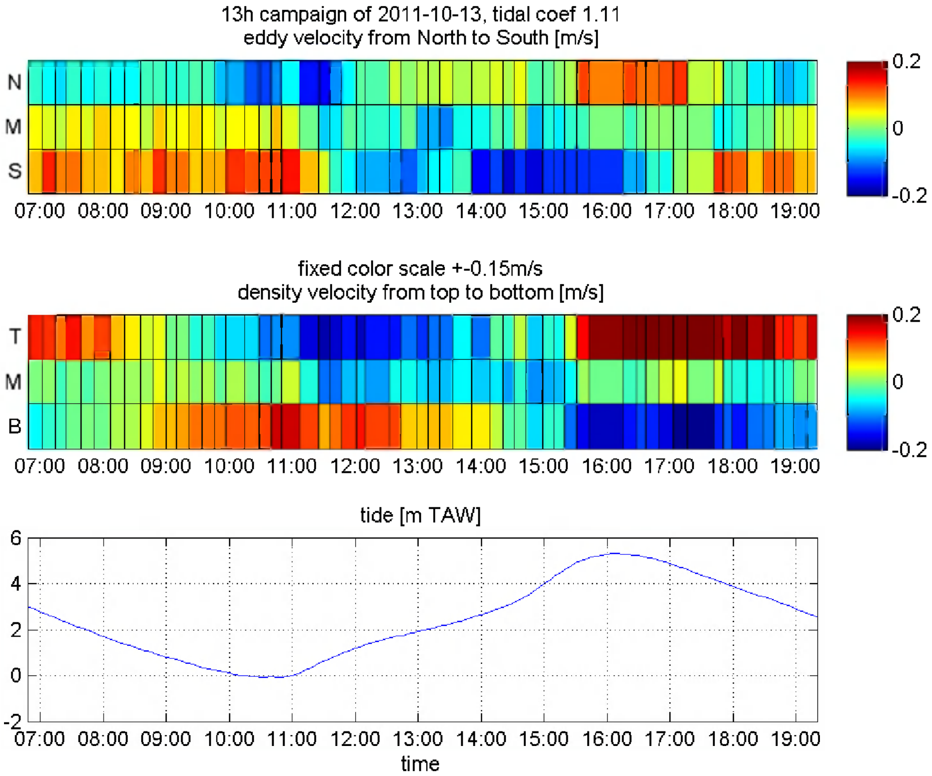

13h campaign of 2008-12-02, tidal coef 0.97
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
time

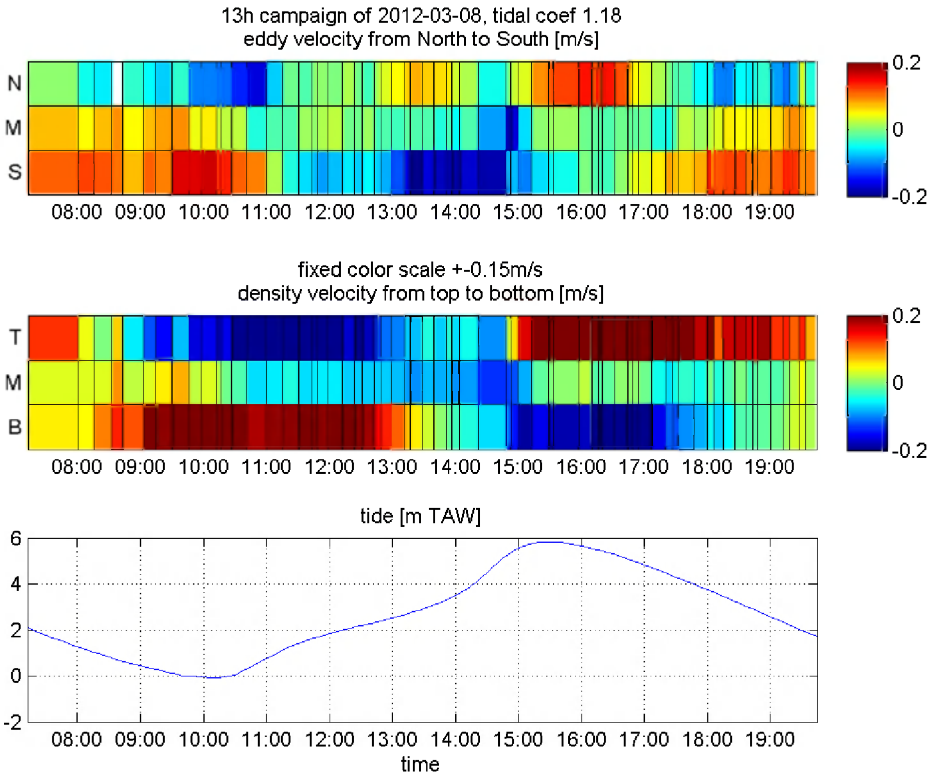

13h campaign of 2008-12-10, tidal coef 1.00
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
time

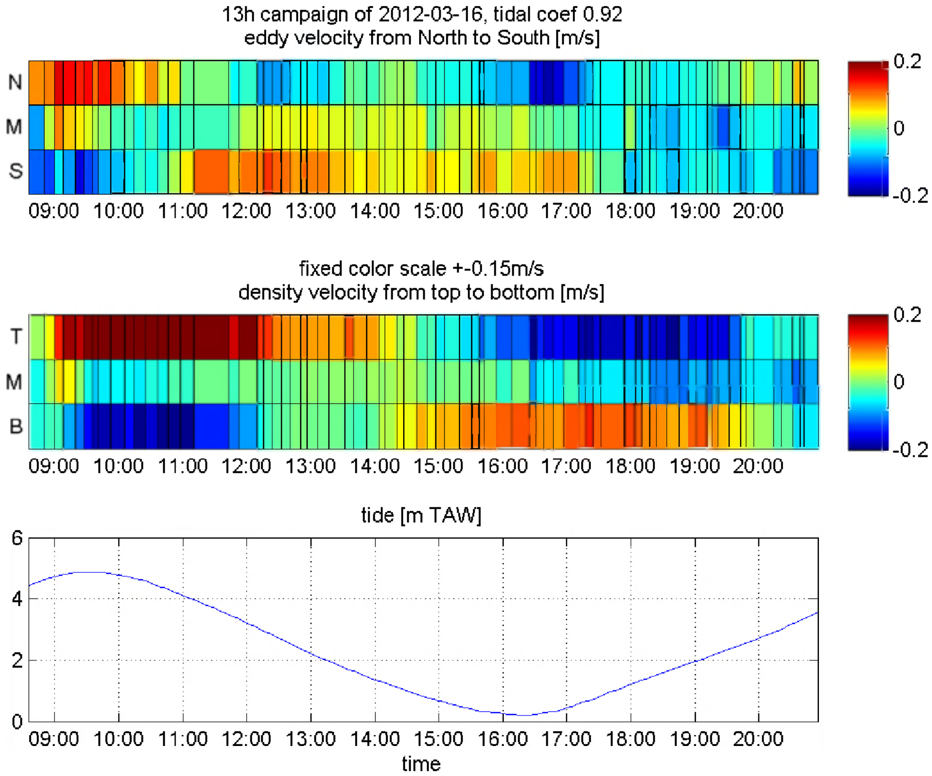

13h campaign of 2009-03-06, tidal coef 0.83
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
tide [m TAW]
6
4
2
0
time


13h campaign of 2009-03-12, tidal coef 1.28
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
0.2
0
-0.2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
tide [m TAW]
6
4
2
0
-2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
time

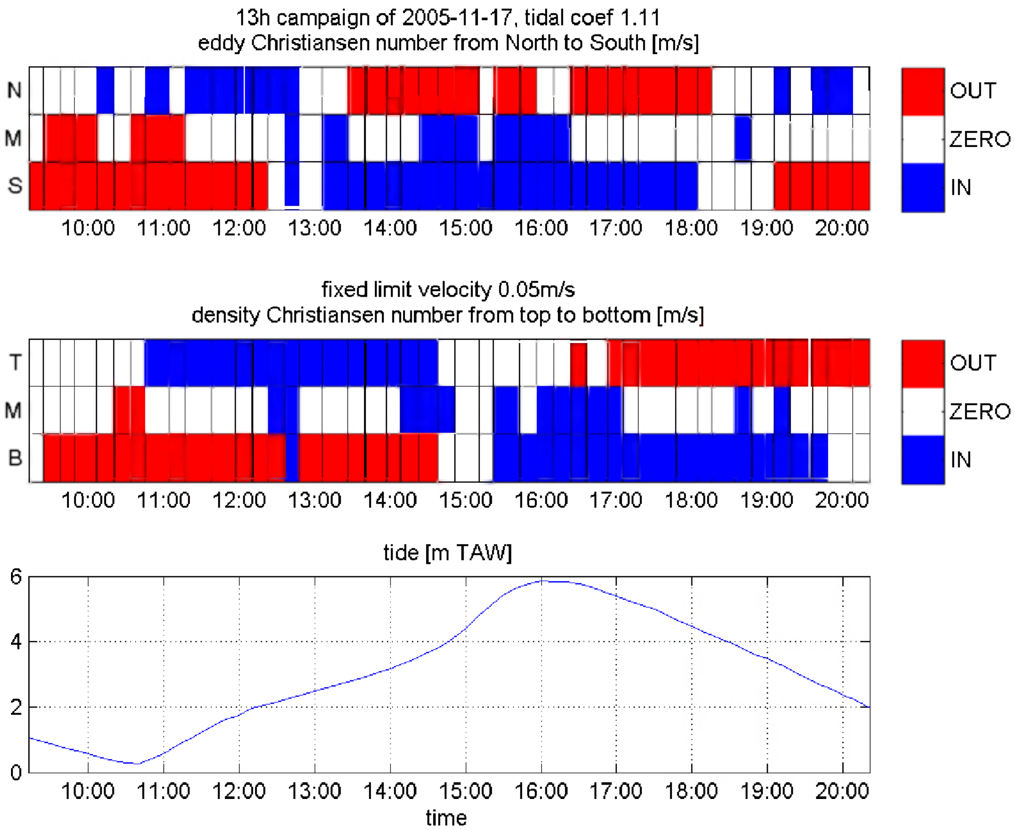

13h campaign of 2011-10-06, tidal coef 0.81
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
0.2
0
-0.2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
tide [m TAW]
6
4
2
0
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
time


13h campaign of 2011-10-13, tidal coef 1.11
eddy velocity from North to South [m/s]
N
M
S
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
0.2
0
-0.2
tide [m TAW]
6
4
2
0
-2
07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
time


13h campaign of 2012-03-08, tidal coef 1.18
eddy velocity from North to South [m/s]
N
M
S
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
0.2
0
-0.2
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
0.2
0
-0.2
tide [m TAW]
6
4
2
0
-2
08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00
time


13h campaign of 2012-03-16, tidal coef 0.92
eddy velocity from North to South [m/s]
N
M
S
0.2
0
-0.2
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
fixed color scale +-0.15m/s
density velocity from top to bottom [m/s]
T
M
B
0.2
0
-0.2
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
tide [m TAW]
6
4
2
0
09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00
time

C.2 Christiansen numbers and duration tables



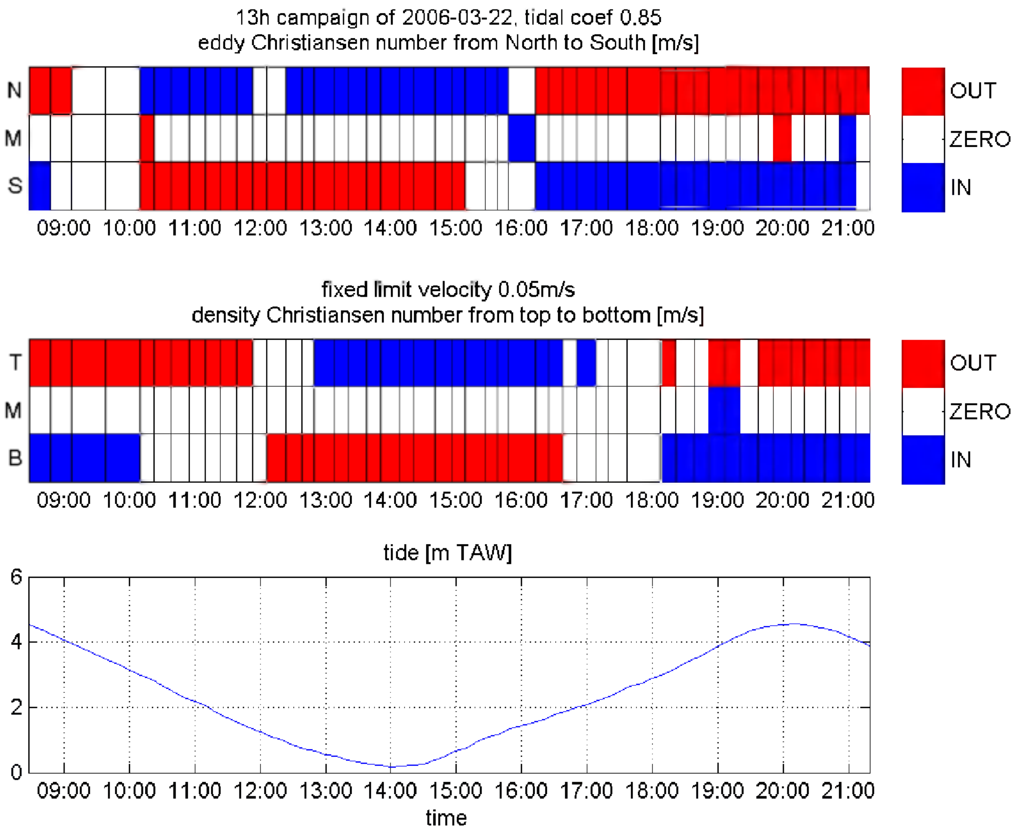

```
Eddy currents on 2005-11-17 (coef 1.11) with limit velocity
0.05m/s

       OUT   ZERO   IN
North  4.7   4.6   3.1 hours
Middle 1.6   8.0   2.8 hours
South  4.9   1.7   5.7 hours
---------------------------
Total 11.2   14.3   11.7 hours
Total duration of eddy currents 7.1 hours

Density currents on 2005-11-17 (coef 1.11) with limit velocity
0.05m/s

       OUT   ZERO   IN
Top    4.1   4.0   4.3 hours
Middle 0.5   8.5   3.4 hours
Bottom 5.6   1.7   5.1 hours
---------------------------
Total 10.2   14.2   12.8 hours

Total duration of density currents 7.6 hours
```



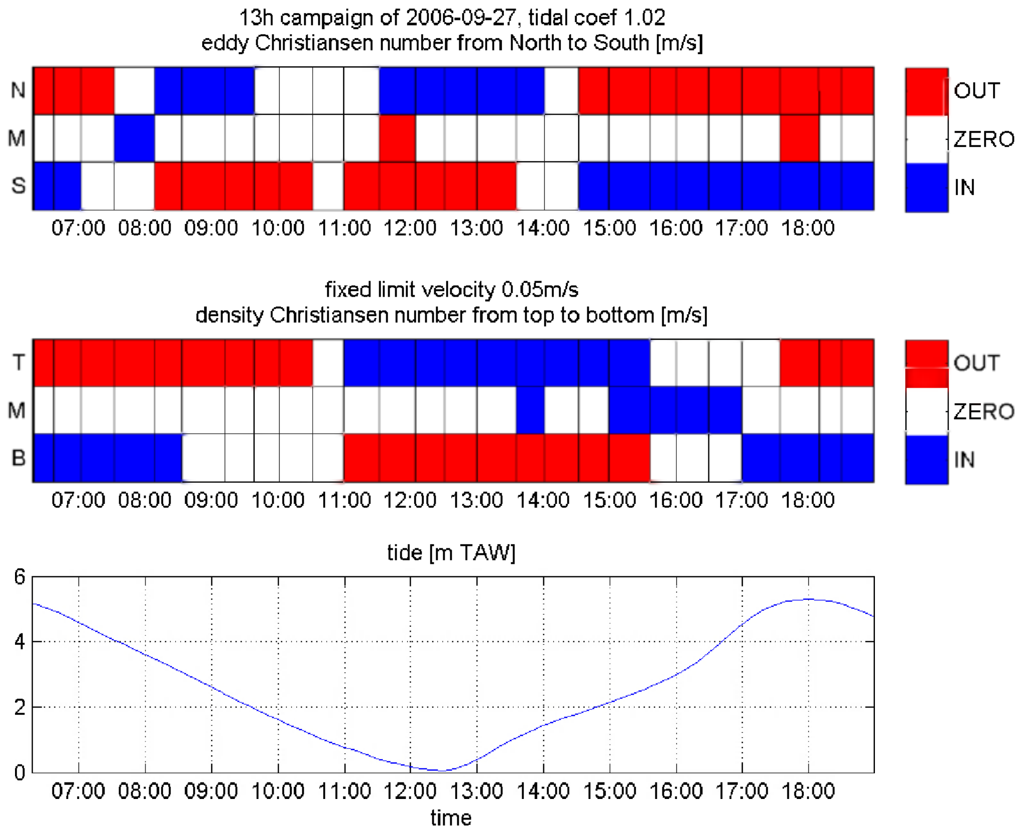

```
Eddy currents on 2006-03-22 (coef 0.85) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  5.5   1.9   4.9 hours
Middle 0.5   10.9   0.6 hours
South  4.8   2.6   5.0 hours
---------------------------
Total 10.8   15.4   10.6 hours
Total duration of eddy currents 9.3 hours

Density currents on 2006-03-22 (coef 0.85) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.6   2.8   3.9 hours
Middle 0.0   11.9   0.5 hours
Bottom 4.4   3.3   4.7 hours
---------------------------
Total 10.0   18.1   9.1 hours

Total duration of density currents 7.6 hours
```



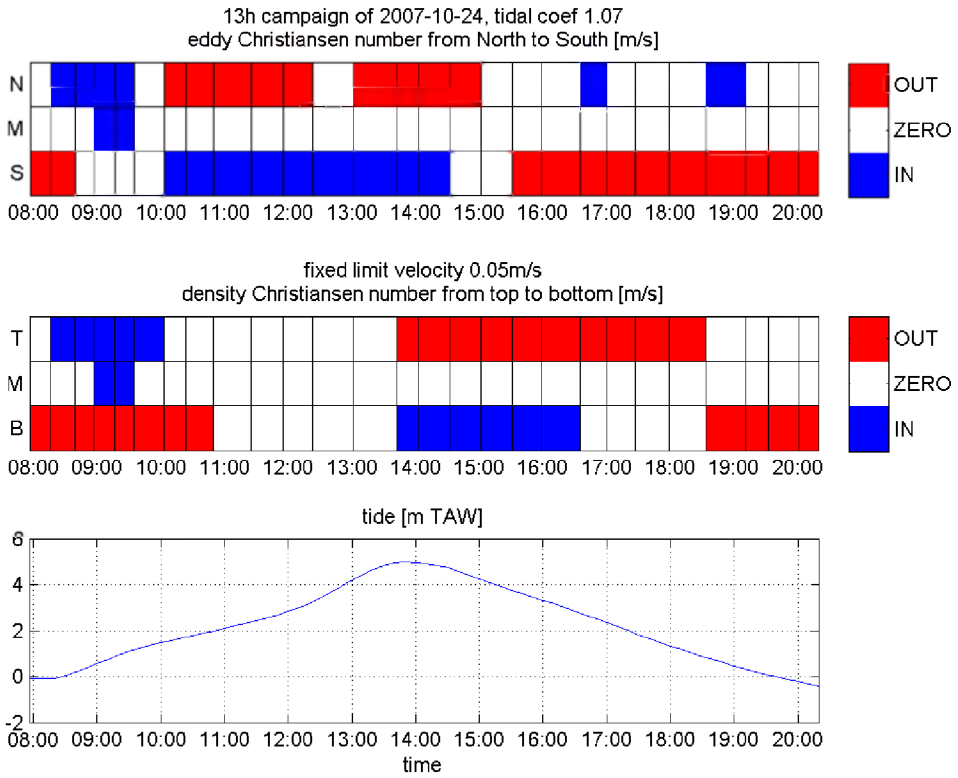

```
Eddy currents on 2006-09-27 (coef 1.02) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  5.6  2.9  3.9 hours
Middle 1.1  10.7  0.6 hours
South  4.9  2.5  5.1 hours
---------------------------
Total 11.5  16.1  9.6 hours
Total duration of eddy currents 8.5 hours

Density currents on 2006-09-27 (coef 1.02) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.5  2.4  4.5 hours
Middle 0.0  10.0  2.4 hours
Bottom 4.5  3.7  4.2 hours
---------------------------
Total 10.0  16.1  11.0 hours

Total duration of density currents 8.1 hours
```



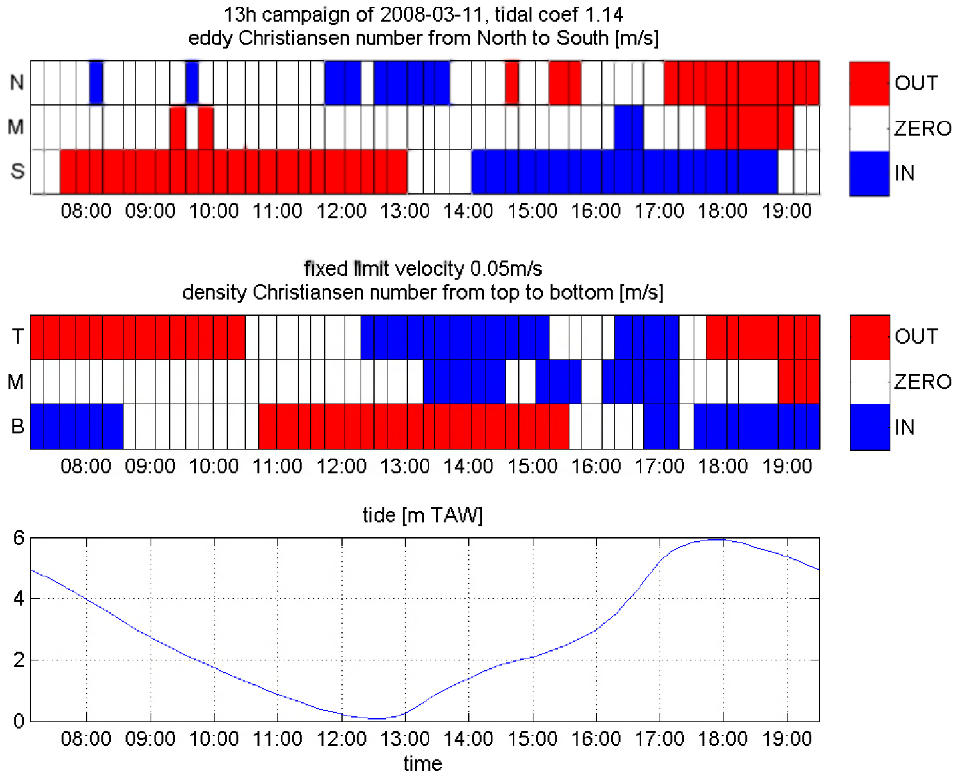

```
Eddy currents on 2007-10-24 (coef 1.07) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  4.3   5.7   2.3 hours
Middle 0.0   11.8   0.6 hours
South  5.5   2.4   4.5 hours
---------------------------
Total 9.9   19.9   7.5 hours
Total duration of eddy currents 5.3 hours

Density currents on 2007-10-24 (coef 1.07) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    4.9   5.7   1.8 hours
Middle 0.0   11.8   0.6 hours
Bottom 4.7   4.9   2.9 hours
---------------------------
Total 9.5   22.4   5.3 hours

Total duration of density currents 4.7 hours
```



Eddy currents on 2008-03-11 (coef 1.14) with limit velocity 0.05m/s

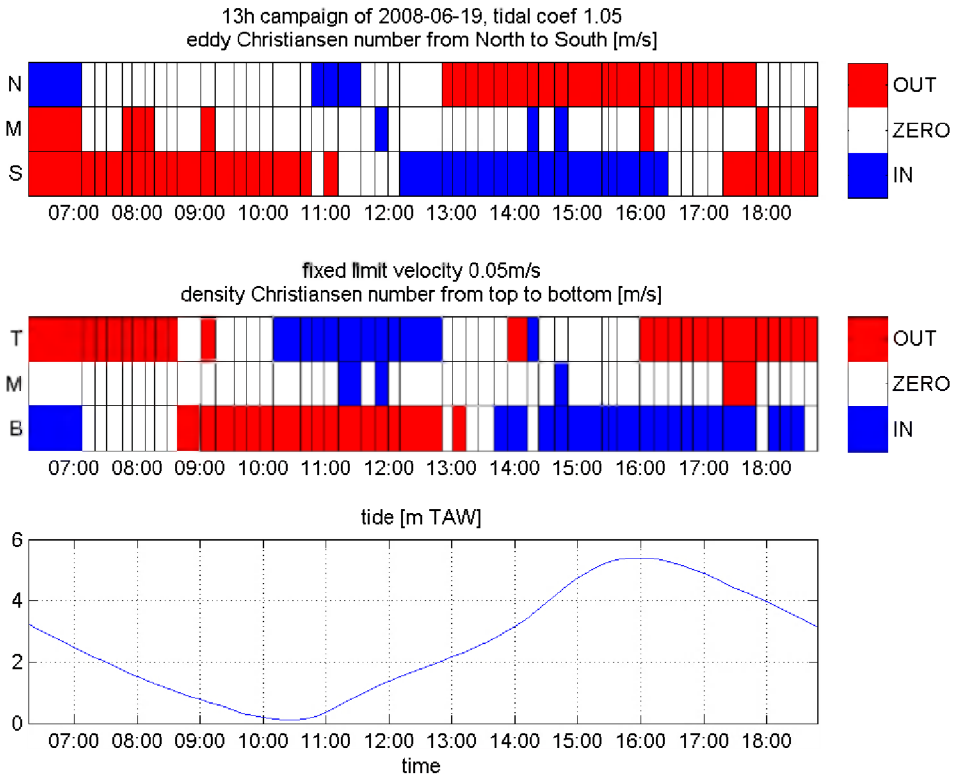
	OUT	ZERO	IN	
North	3.2	7.1	2.2	hours
Middle	1.9	10.1	0.5	hours
South	5.5	2.1	4.8	hours
Total	10.5	19.3	7.4	hours

Total duration of eddy currents 4.0 hours

Density currents on 2008-03-11 (coef 1.14) with limit velocity 0.05m/s

	OUT	ZERO	IN	
Top	5.1	3.3	4.0	hours
Middle	0.7	8.5	3.2	hours
Bottom	4.9	3.5	4.0	hours
Total	10.7	15.4	11.2	hours

Total duration of density currents 6.2 hours



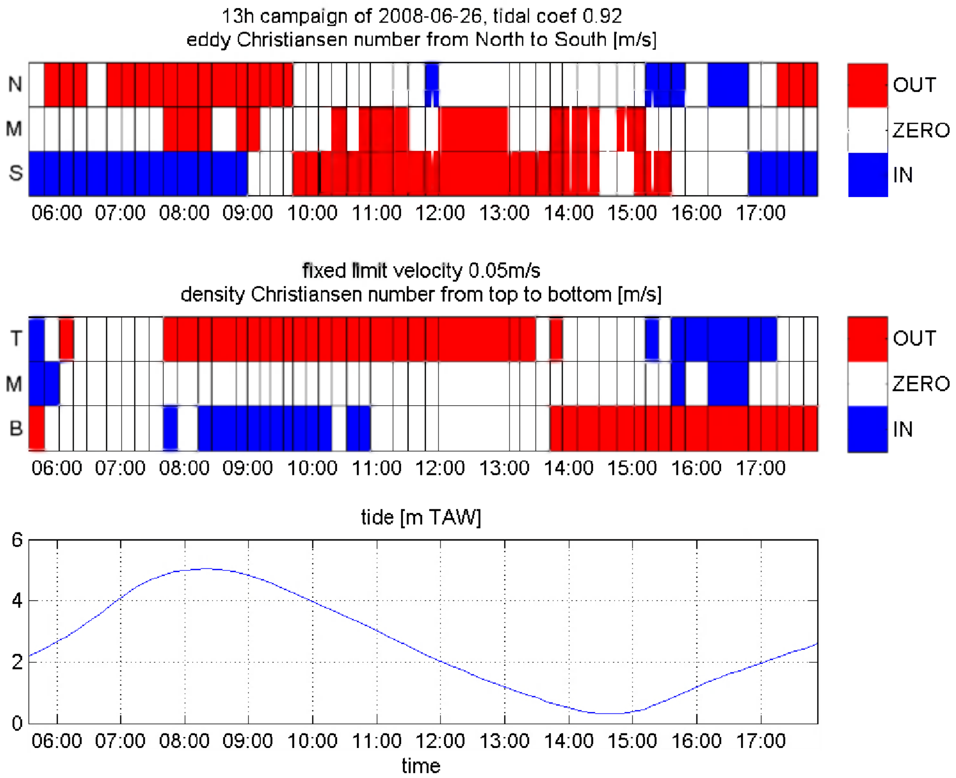

```
Eddy currents on 2008-06-19 (coef 1.05) with limit velocity
0.05m/s

        OUT   ZERO  IN
North   4.9   5.9   1.6 hours
Middle  2.2   9.6   0.6 hours
South   6.2   2.0   4.2 hours
---------------------------
Total  13.3   17.5   6.4 hours
Total duration of eddy currents 4.6 hours

Density currents on 2008-06-19 (coef 1.05) with limit velocity
0.05m/s

        OUT   ZERO  IN
Top     5.7   3.9   2.8 hours
Middle  0.5   11.1   0.8 hours
Bottom  4.4   2.7   5.3 hours
---------------------------
Total  10.6   17.7   8.9 hours

Total duration of density currents 6.2 hours
```



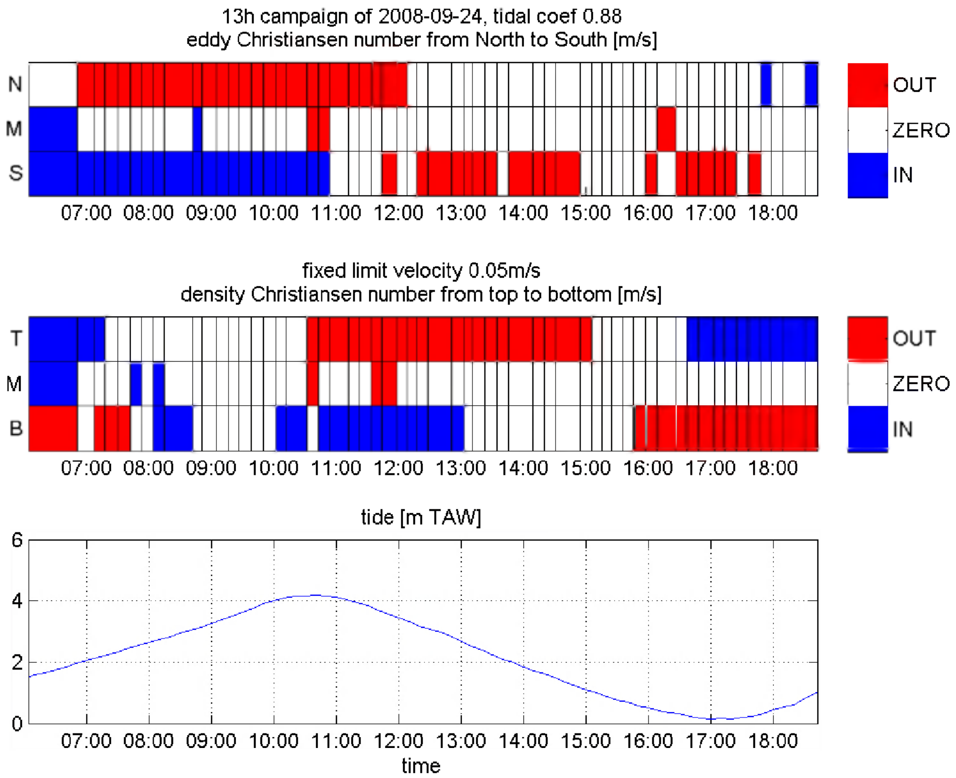

```
Eddy currents on 2008-06-26 (coef 0.92) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  4.2  6.7  1.5 hours
Middle 4.5  7.9  0.0 hours
South  5.4  2.5  4.5 hours
---------------------------
Total 14.1  17.1  6.0 hours
Total duration of eddy currents 4.2 hours

Density currents on 2008-06-26 (coef 0.92) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    6.3  4.0  2.1 hours
Middle 0.0  11.1  1.3 hours
Bottom 4.4  5.3  2.7 hours
---------------------------
Total 10.7  20.3  6.1 hours

Total duration of density currents 4.8 hours
```



Eddy currents on 2008-09-24 (coef 0.88) with limit velocity 0.05m/s

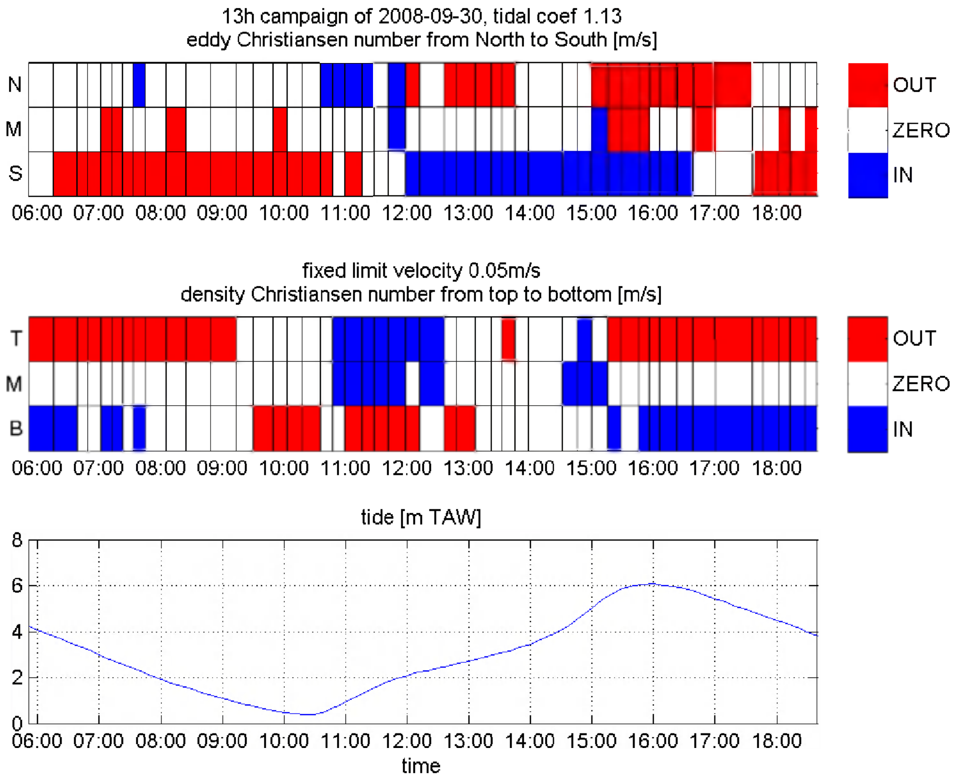
	OUT	ZERO	IN	
North	5.2	6.9	0.4	hours
Middle	0.6	10.8	0.9	hours
South	3.9	3.6	4.7	hours
Total	9.8	21.3	6.0	hours

Total duration of eddy currents 4.0 hours

Density currents on 2008-09-24 (coef 0.88) with limit velocity 0.05m/s

	OUT	ZERO	IN	
Top	4.5	4.7	3.3	hours
Middle	0.6	10.7	1.1	hours
Bottom	4.2	4.8	3.4	hours
Total	9.3	20.1	7.8	hours

Total duration of density currents 5.3 hours



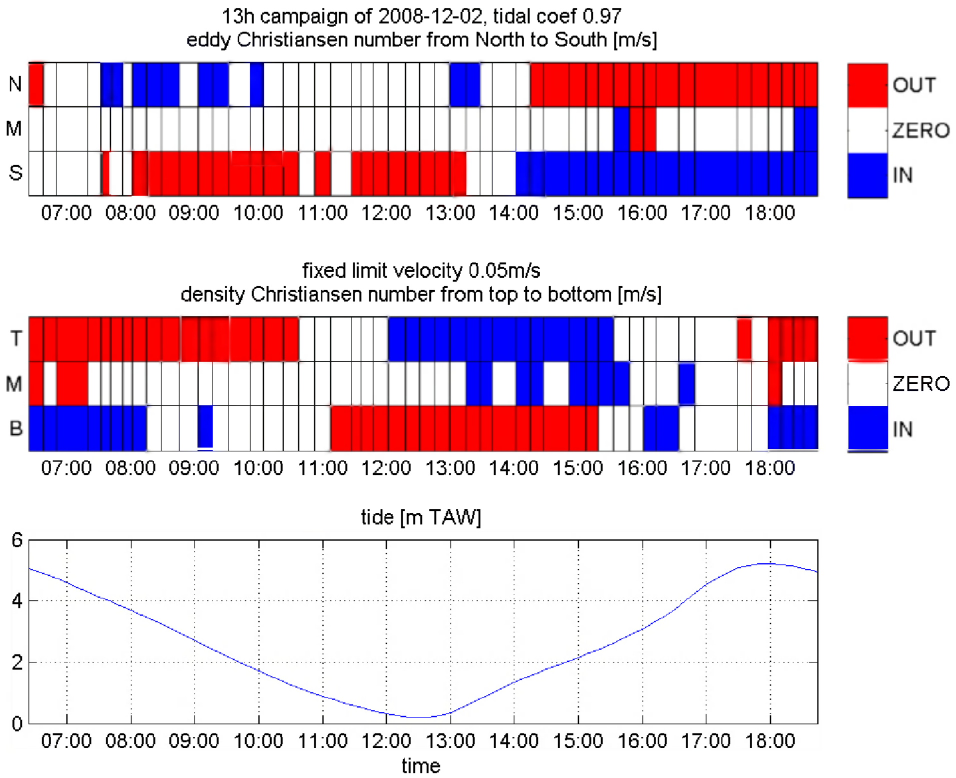

```
Eddy currents on 2008-09-30 (coef 1.13) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  3.9   7.2   1.3 hours
Middle 2.3   9.6   0.5 hours
South  5.7   2.2   4.5 hours
---------------------------
Total 11.8   19.0  6.4 hours
Total duration of eddy currents 3.6 hours

Density currents on 2008-09-30 (coef 1.13) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    6.8   3.7   2.0 hours
Middle 0.0   10.2  2.2 hours
Bottom 2.7   5.4   4.3 hours
---------------------------
Total 9.5   19.2  8.5 hours

Total duration of density currents 5.5 hours
```



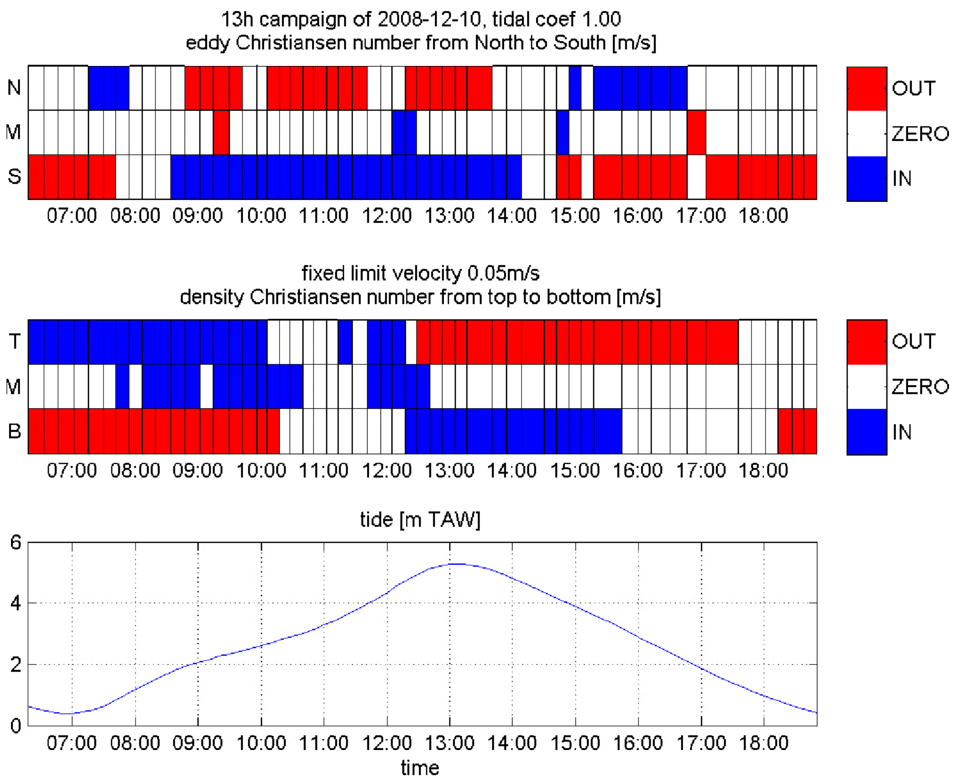

```
Eddy currents on 2008-12-02 (coef 0.97) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  4.7   5.4   2.2 hours
Middle 0.4   11.3   0.6 hours
South  4.8   2.8   4.7 hours
---------------------------
Total 10.0   19.6   7.6 hours
Total duration of eddy currents 6.3 hours

Density currents on 2008-12-02 (coef 0.97) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.2   3.7   3.5 hours
Middle 0.9   9.4   2.0 hours
Bottom 4.2   4.8   3.4 hours
---------------------------
Total 10.3   17.9   8.9 hours

Total duration of density currents 6.1 hours
```



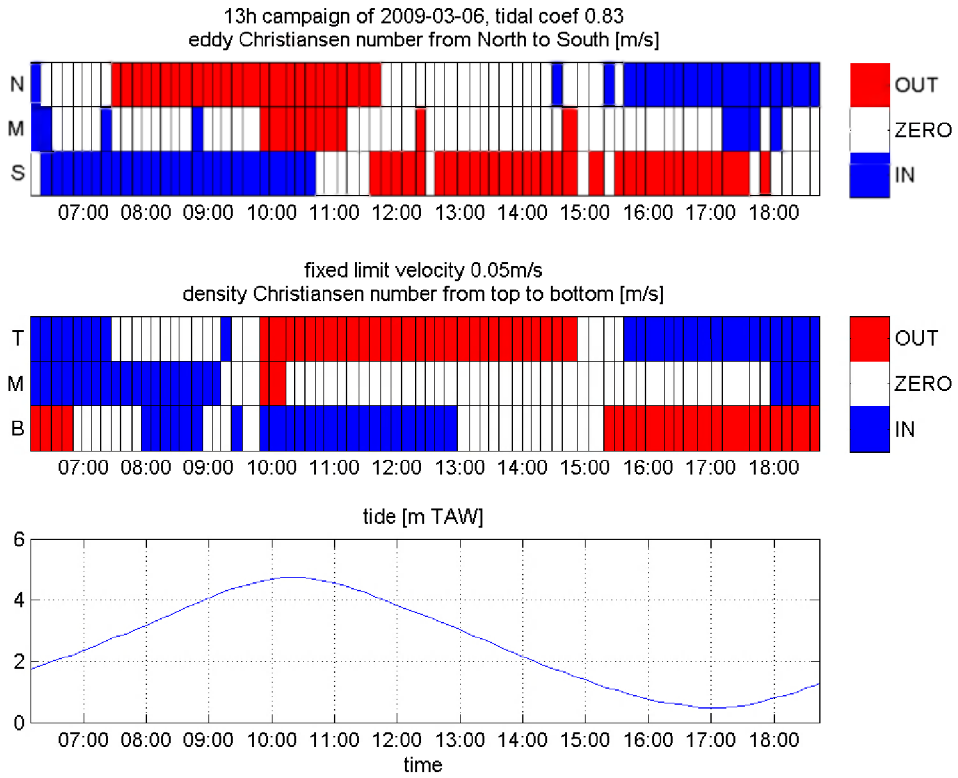

```
Eddy currents on 2008-12-10 (coef 1.00) with limit velocity
0.05m/s

        OUT   ZERO  IN
North   3.8   6.3   2.3 hours
Middle  0.6   11.3   0.6 hours
South   5.0   1.9   5.5 hours
---------------------------
Total  9.4   19.4   8.4 hours
Total duration of eddy currents 5.9 hours

Density currents on 2008-12-10 (coef 1.00) with limit velocity
0.05m/s

        OUT   ZERO  IN
Top     5.1   2.8   4.5 hours
Middle  0.0   8.9   3.5 hours
Bottom  4.6   4.4   3.4 hours
---------------------------
Total  9.6   16.1   11.5 hours

Total duration of density currents 7.0 hours
```



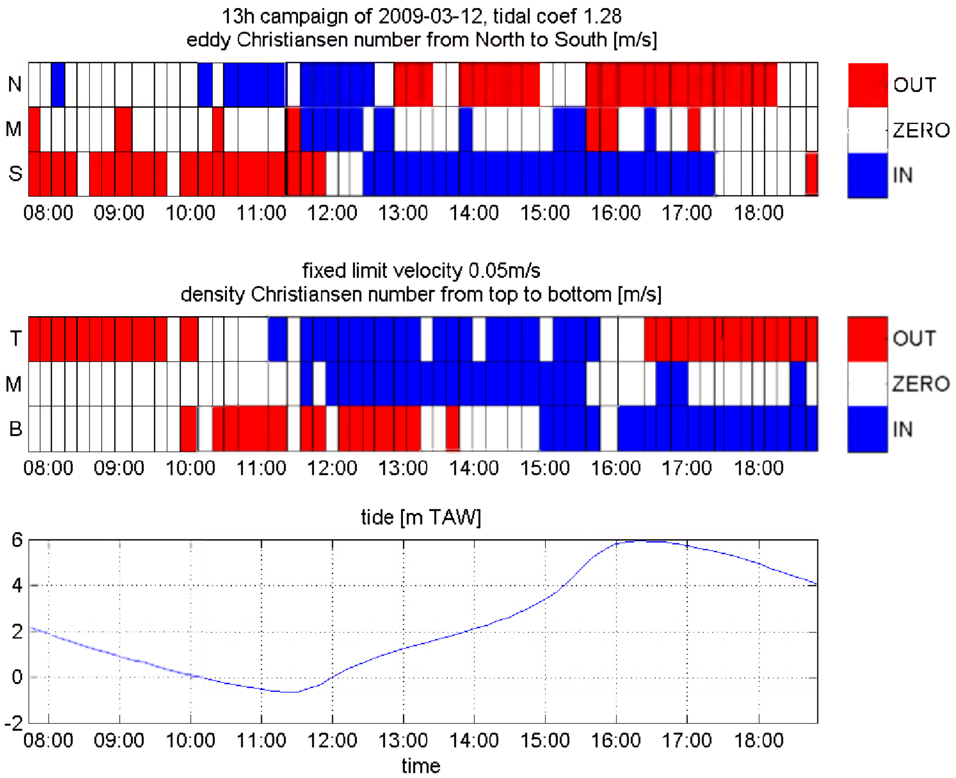

```
Eddy currents on 2009-03-06 (coef 0.83) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  4.2   4.6   3.6 hours
Middle 1.8   9.2   1.4 hours
South  5.6   2.4   4.3 hours
---------------------------
Total 11.6  16.2   9.3 hours
Total duration of eddy currents 5.5 hours

Density currents on 2009-03-06 (coef 0.83) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.0   2.9   4.5 hours
Middle 0.4   8.2   3.8 hours
Bottom 4.0   4.1   4.2 hours
---------------------------
Total 9.5  15.2  12.5 hours

Total duration of density currents 6.9 hours
```



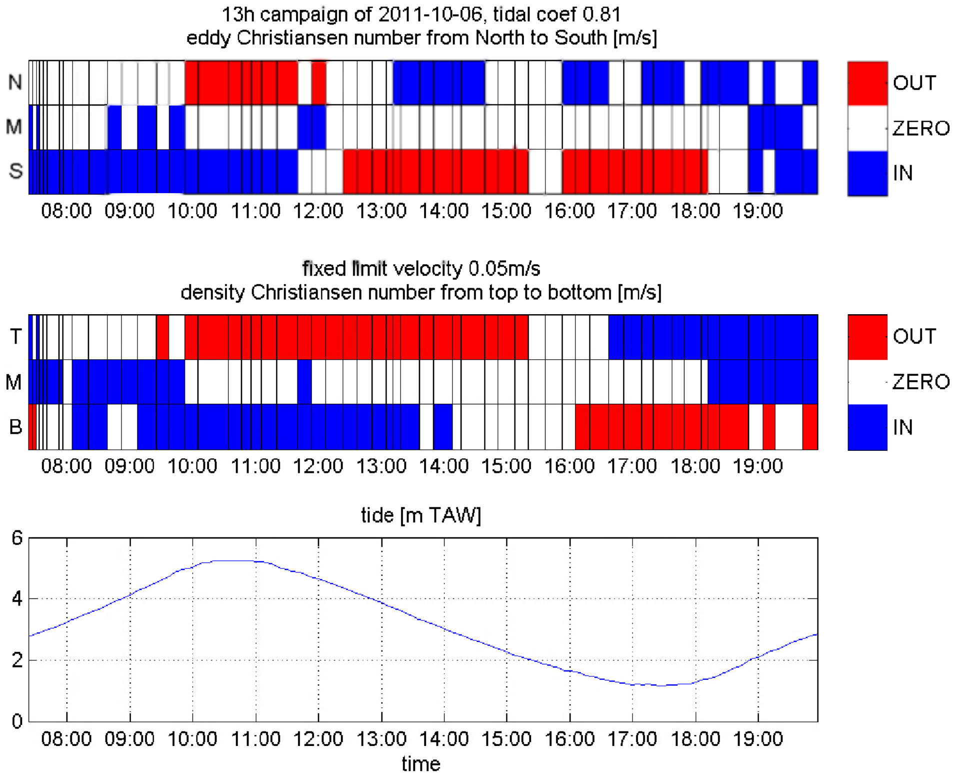

```
Eddy currents on 2009-03-12 (coef 1.28) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  4.9  4.9  2.6 hours
Middle 1.5  8.7  2.2 hours
South  4.5  2.4  5.5 hours
---------------------------
Total 10.9  16.0  10.3 hours
Total duration of eddy currents 5.7 hours

Density currents on 2009-03-12 (coef 1.28) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.2  2.8  4.4 hours
Middle 0.0  7.4  5.0 hours
Bottom 3.3  5.0  4.1 hours
---------------------------
Total 8.5  15.2  13.5 hours

Total duration of density currents 4.9 hours
```



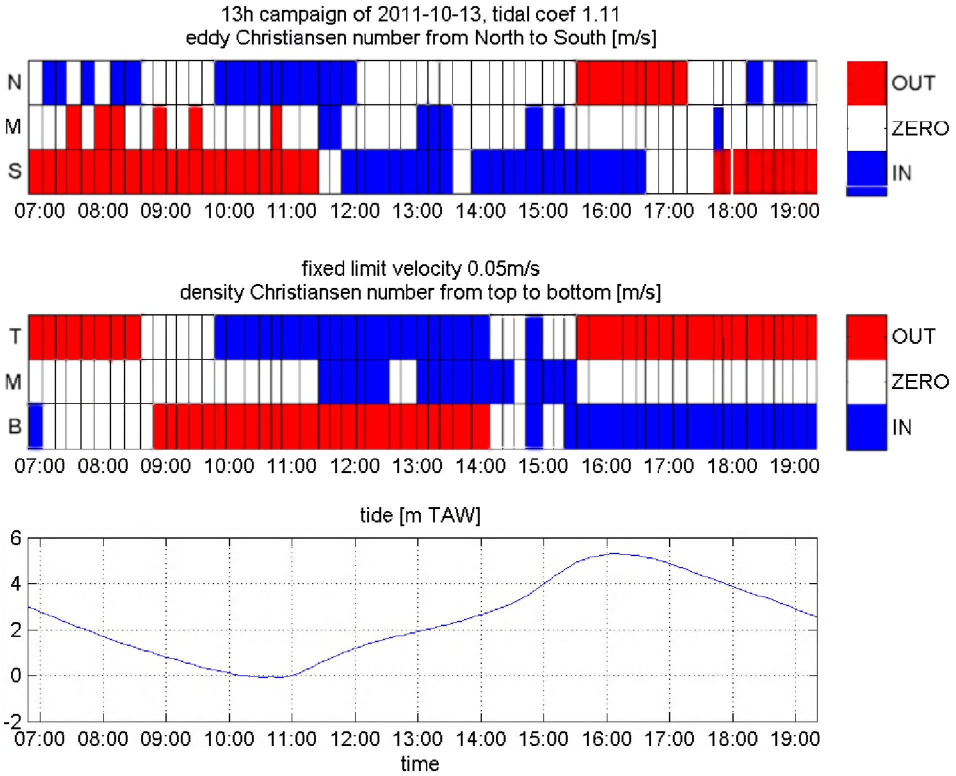

```
Eddy currents on 2011-10-06 (coef 0.81) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  2.0   6.3   4.0 hours
Middle 0.0   10.2   2.2 hours
South  5.2   2.1   5.1 hours
---------------------------
Total 7.2   18.6   11.3 hours
Total duration of eddy currents 4.7 hours

Density currents on 2011-10-06 (coef 0.81) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.6   3.4   3.4 hours
Middle 0.0   8.2   4.2 hours
Bottom 3.3   3.9   5.3 hours
---------------------------
Total 8.9   15.4   12.9 hours

Total duration of density currents 6.9 hours
```



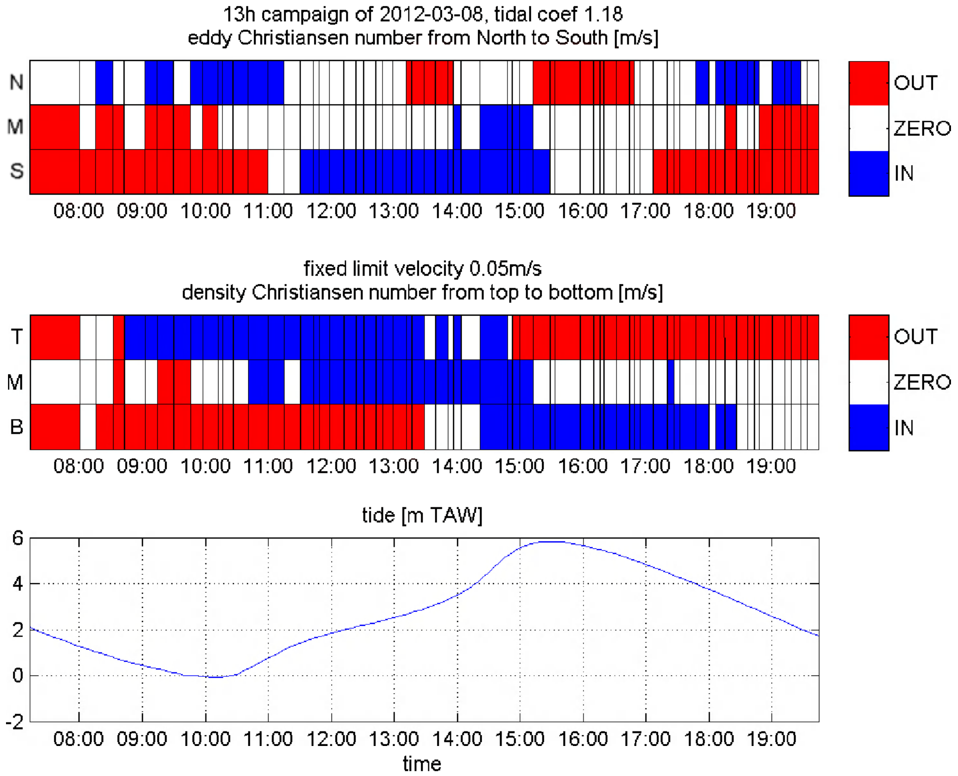

```
Eddy currents on 2011-10-13 (coef 1.11) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  1.7   6.6   4.0 hours
Middle 1.3   9.6   1.5 hours
South  6.2   1.7   4.5 hours
---------------------------
Total 9.2   17.9   10.0 hours
Total duration of eddy currents 4.5 hours

Density currents on 2011-10-13 (coef 1.11) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.5   2.3   4.6 hours
Middle 0.0   8.9   3.5 hours
Bottom 5.3   2.7   4.4 hours
---------------------------
Total 10.8   13.9   12.5 hours

Total duration of density currents 8.3 hours
```



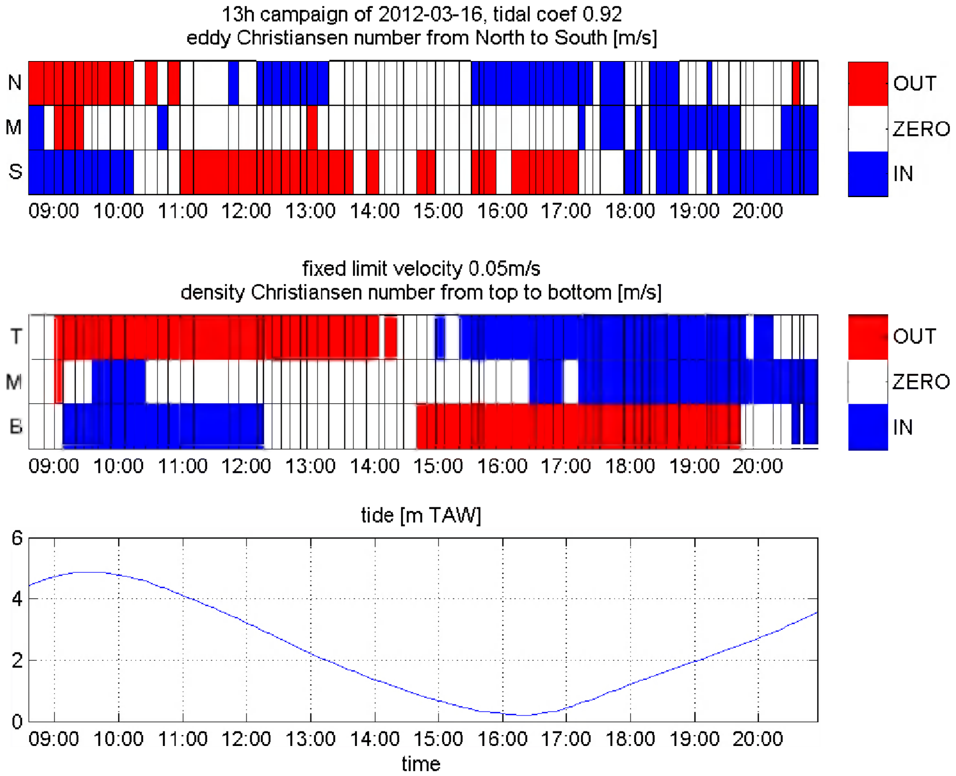

```
Eddy currents on 2012-03-08 (coef 1.18) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  2.3  6.4  3.5 hours
Middle 3.3  8.2  0.9 hours
South  6.3  2.1  3.9 hours
---------------------------
Total 12.0  16.7  8.4 hours
Total duration of eddy currents 4.3 hours

Density currents on 2012-03-08 (coef 1.18) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.8  1.2  5.5 hours
Middle 0.7  7.4  4.3 hours
Bottom 5.9  2.6  3.9 hours
---------------------------
Total 12.4  11.1  13.7 hours

Total duration of density currents 8.1 hours
```




```
Eddy currents on 2012-03-16 (coef 0.92) with limit velocity
0.05m/s

       OUT   ZERO  IN
North  2.2  6.1  4.1 hours
Middle 0.6  8.8  3.0 hours
South  4.7  3.6  4.1 hours
---------------------------
Total 7.5  18.6  11.2 hours
Total duration of eddy currents 4.5 hours

Density currents on 2012-03-16 (coef 0.92) with limit velocity
0.05m/s

       OUT   ZERO  IN
Top    5.3  2.2  5.0 hours
Middle 0.1  7.1  5.1 hours
Bottom 5.1  3.8  3.5 hours
---------------------------
Total 10.5  13.1  13.6 hours

Total duration of density currents 7.7 hours
```

Annex D Analysis of 13h measurements with flux decomposition

```
Campaign of 2005-11-17 (coef 1.11)

Tide coverage :       11.2 hours
Spatial coverage :    81.3 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :         34.2 Mm3    32.7 Mm3
Volume Out :        31.2 Mm3    32.7 Mm3
Volume Gross :      65.5 Mm3    65.5 Mm3
Volume Net In :     3.0 Mm3    -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        7.4 Mm3     5.7 Mm3    17.5 %
Volume In Density Currents :    19.9 Mm3    15.4 Mm3    47.0 %
Volume In Eddy Currents :       15.0 Mm3    11.6 Mm3    35.5 %
Sum of Influxes :               42.3 Mm3    32.7 Mm3   100.0 %
```

```
Campaign of 2005-11-17 (coef 1.11)

Tide coverage :       11.2 hours
Spatial coverage :    81.3 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :        2479.8 TDS   2370.8 TDS
Mass Out :       1326.7 TDS   1390.6 TDS
Mass Gross :     3806.4 TDS   3761.4 TDS
Mass Net In :    1153.1 TDS   980.2 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      563.3 TDS   444.2 TDS    18.7 %
Mass In Density Currents :  1435.2 TDS  1131.8 TDS    47.7 %
Mass In Eddy Currents :     1007.9 TDS   794.8 TDS    33.5 %
Sum of Influxes :           3006.4 TDS  2370.8 TDS   100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :        53.2 %
 Trapping density currents :     49.3 %
 Trapping eddy currents :        23.4 %
 Global trapping efficiency :    41.3 %
```

```
Campaign of 2006-03-22 (coef 0.85)

Tide coverage :       12.9 hours
Spatial coverage :    77.9 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        33.9 Mm3    35.3 Mm3
Volume Out :       36.7 Mm3    35.3 Mm3
Volume Gross :     70.5 Mm3    70.5 Mm3
Volume Net In :   -2.8 Mm3    -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :       4.6 Mm3     3.8 Mm3    10.8 %
Volume In Density Currents :   20.6 Mm3    17.1 Mm3    48.4 %
Volume In Eddy Currents :      17.3 Mm3    14.4 Mm3    40.8 %
Sum of Influxes :              42.5 Mm3    35.3 Mm3   100.0 %
```

```
Campaign of 2006-03-22 (coef 0.85)

Tide coverage :       12.9 hours
Spatial coverage :    77.9 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       2621.4 TDS  2730.9 TDS
Mass Out :      1599.2 TDS  1537.6 TDS
Mass Gross :    4220.6 TDS  4268.5 TDS
Mass Net In :   1022.2 TDS  1193.3 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      221.6 TDS   197.1 TDS     7.2 %
Mass In Density Currents :  1651.8 TDS  1469.0 TDS    53.8 %
Mass In Eddy Currents :     1197.3 TDS  1064.8 TDS    39.0 %
Sum of Influxes :          3070.7 TDS  2730.9 TDS   100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -28.6 %
 Trapping density currents :     62.3 %
 Trapping eddy currents :        31.4 %
 Global trapping efficiency :    43.7 %
```

```
Campaign of 2006-09-27 (coef 1.02)

Tide coverage :       12.8 hours
Spatial coverage :    88.4 %
Smoothing filter : none --------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :         31.0 Mm3   31.0 Mm3
Volume Out :        31.0 Mm3   31.0 Mm3
Volume Gross :      62.0 Mm3   62.0 Mm3
Volume Net In :    -0.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        5.0 Mm3    3.8 Mm3    12.1 %
Volume In Density Currents :    19.8 Mm3   14.9 Mm3    48.1 %
Volume In Eddy Currents :       16.3 Mm3   12.3 Mm3    39.8 %
Sum of Influxes :               41.1 Mm3   31.0 Mm3   100.0 %
```

```
Campaign of 2006-09-27 (coef 1.02)

Tide coverage :       12.8 hours
Spatial coverage :    88.4 %
Smoothing filter : none --------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       1135.6 TDS  1136.1 TDS
Mass Out :      678.2 TDS  677.9 TDS
Mass Gross :    1813.8 TDS  1814.0 TDS
Mass Net In :   457.4 TDS  458.1 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      109.6 TDS    88.0 TDS    7.7 %
Mass In Density Currents :   784.0 TDS   629.5 TDS   55.4 %
Mass In Eddy Currents :      521.3 TDS   418.6 TDS   36.8 %
Sum of Influxes :           1414.9 TDS  1136.1 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -17.8 %
 Trapping density currents :     52.8 %
 Trapping eddy currents :        33.8 %
 Global trapping efficiency :    40.3 %
```

```
Campaign of 2007-10-24 (coef 1.07)

Tide coverage :       12.4 hours
Spatial coverage :   87.9 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :       21.1 Mm3   23.0 Mm3
Volume Out :      24.9 Mm3   23.0 Mm3
Volume Gross :    46.0 Mm3   46.0 Mm3
Volume Net In :  -3.7 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        5.4 Mm3    4.1 Mm3   17.8 %
Volume In Density Currents :   12.7 Mm3    9.7 Mm3   42.0 %
Volume In Eddy Currents :      12.2 Mm3    9.2 Mm3   40.1 %
Sum of Influxes :              30.3 Mm3   23.0 Mm3  100.0 %
```

```
Campaign of 2007-10-24 (coef 1.07)

Tide coverage :       12.4 hours
Spatial coverage :   87.9 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       857.7 TDS  933.5 TDS
Mass Out :      640.5 TDS  592.4 TDS
Mass Gross :   1498.2 TDS  1525.9 TDS
Mass Net In :  217.2 TDS  341.1 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      133.3 TDS  117.7 TDS   12.6 %
Mass In Density Currents :  509.4 TDS  449.9 TDS   48.2 %
Mass In Eddy Currents :     414.2 TDS  365.8 TDS   39.2 %
Sum of Influxes :         1056.9 TDS  933.5 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :        5.2 %
 Trapping density currents :    53.5 %
 Trapping eddy currents :       25.8 %
 Global trapping efficiency :   36.5 %
```

```
Campaign of 2008-03-11 (coef 1.14)

Tide coverage :       12.4 hours
Spatial coverage :   88.6 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        26.4 Mm3   28.9 Mm3
Volume Out :       31.4 Mm3   28.9 Mm3
Volume Gross :     57.8 Mm3   57.8 Mm3
Volume Net In :  -5.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        9.2 Mm3    6.5 Mm3   22.5 %
Volume In Density Currents :   16.6 Mm3   11.7 Mm3   40.6 %
Volume In Eddy Currents :      15.1 Mm3   10.7 Mm3   36.9 %
Sum of Influxes :              40.8 Mm3   28.9 Mm3  100.0 %
```

```
Campaign of 2008-03-11 (coef 1.14)

Tide coverage :       12.4 hours
Spatial coverage :   88.6 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       3610.4 TDS  3954.6 TDS
Mass Out :      2715.8 TDS  2498.3 TDS
Mass Gross :    6326.2 TDS  6453.0 TDS
Mass Net In :  894.6 TDS  1456.3 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      769.6 TDS   637.1 TDS   16.1 %
Mass In Density Currents :  2166.6 TDS  1793.6 TDS   45.4 %
Mass In Eddy Currents :     1840.9 TDS  1524.0 TDS   38.5 %
Sum of Influxes :          4777.1 TDS  3954.6 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -6.0 %
 Trapping density currents :    51.4 %
 Trapping eddy currents :       37.5 %
 Global trapping efficiency :   36.8 %
```

```
Campaign of 2008-06-19 (coef 1.05)

Tide coverage :       12.6 hours
Spatial coverage :    81.6 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        29.1 Mm3   32.4 Mm3
Volume Out :       35.7 Mm3   32.4 Mm3
Volume Gross :     64.8 Mm3   64.8 Mm3
Volume Net In :  -6.6 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        7.1 Mm3     5.7 Mm3    17.7 %
Volume In Density Currents :    15.9 Mm3    12.8 Mm3    39.6 %
Volume In Eddy Currents :       17.1 Mm3    13.8 Mm3    42.7 %
Sum of Influxes :               40.1 Mm3    32.4 Mm3   100.0 %
```

```
Campaign of 2008-06-19 (coef 1.05)

Tide coverage :       12.6 hours
Spatial coverage :    81.6 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       1781.8 TDS  1985.0 TDS
Mass Out :      1354.0 TDS  1228.3 TDS
Mass Gross :    3135.8 TDS  3213.3 TDS
Mass Net In :   427.8 TDS  756.7 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      219.7 TDS  194.7 TDS    9.8 %
Mass In Density Currents :  1006.8 TDS  892.3 TDS   45.0 %
Mass In Eddy Currents :     1013.3 TDS  898.0 TDS   45.2 %
Sum of Influxes :         2239.8 TDS  1985.0 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -23.3 %
 Trapping density currents :     65.7 %
 Trapping eddy currents :        24.0 %
 Global trapping efficiency :    38.1 %
```

```
Campaign of 2008-06-26 (coef 0.92)

Tide coverage :       12.4 hours
Spatial coverage :   81.0 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        24.4 Mm3   29.4 Mm3
Volume Out :       34.4 Mm3   29.4 Mm3
Volume Gross :     58.7 Mm3   58.7 Mm3
Volume Net In : -10.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        6.5 Mm3    5.3 Mm3   18.1 %
Volume In Density Currents :   15.6 Mm3   12.7 Mm3   43.2 %
Volume In Eddy Currents :      14.0 Mm3   11.4 Mm3   38.7 %
Sum of Influxes :              36.1 Mm3   29.4 Mm3  100.0 %
```

```
Campaign of 2008-06-26 (coef 0.92)

Tide coverage :       12.4 hours
Spatial coverage :   81.0 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       1689.6 TDS  2036.2 TDS
Mass Out :      1207.1 TDS  1031.6 TDS
Mass Gross :    2896.8 TDS  3067.7 TDS
Mass Net In :  482.5 TDS  1004.6 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :       78.9 TDS   75.9 TDS    3.7 %
Mass In Density Currents :  1104.1 TDS  1062.4 TDS   52.2 %
Mass In Eddy Currents :      933.1 TDS  897.9 TDS   44.1 %
Sum of Influxes :          2116.2 TDS  2036.2 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :      -320.6 %
 Trapping density currents :    73.7 %
 Trapping eddy currents :       51.7 %
 Global trapping efficiency :   49.3 %
```

```
Campaign of 2008-09-24 (coef 0.88)

Tide coverage :       12.7 hours
Spatial coverage :    81.5 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        27.9 Mm3   30.9 Mm3
Volume Out :       33.9 Mm3   30.9 Mm3
Volume Gross :     61.8 Mm3   61.8 Mm3
Volume Net In :   -6.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        6.5 Mm3     5.5 Mm3    17.8 %
Volume In Density Currents :    16.3 Mm3    13.8 Mm3    44.5 %
Volume In Eddy Currents :       13.8 Mm3    11.6 Mm3    37.6 %
Sum of Influxes :               36.7 Mm3    30.9 Mm3   100.0 %
```

```
Campaign of 2008-09-24 (coef 0.88)

Tide coverage :       12.7 hours
Spatial coverage :    81.5 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       1061.7 TDS  1175.6 TDS
Mass Out :      1012.3 TDS  922.9 TDS
Mass Gross :    2074.0 TDS  2098.5 TDS
Mass Net In :    49.4 TDS  252.7 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      130.4 TDS   136.6 TDS    11.6 %
Mass In Density Currents :   534.2 TDS   559.3 TDS    47.6 %
Mass In Eddy Currents :      458.2 TDS   479.8 TDS    40.8 %
Sum of Influxes :           1122.8 TDS  1175.6 TDS   100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -47.2 %
 Trapping density currents :     38.9 %
 Trapping eddy currents :        20.7 %
 Global trapping efficiency :    21.5 %
```

```
Campaign of 2008-09-30 (coef 1.13)

Tide coverage :       12.9 hours
Spatial coverage :    81.3 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        28.9 Mm3   33.5 Mm3
Volume Out :       38.1 Mm3   33.5 Mm3
Volume Gross :     67.0 Mm3   67.0 Mm3
Volume Net In :   -9.2 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        8.4 Mm3     6.6 Mm3    19.8 %
Volume In Density Currents :    18.7 Mm3    14.8 Mm3    44.3 %
Volume In Eddy Currents :       15.2 Mm3    12.0 Mm3    35.9 %
Sum of Influxes :               42.3 Mm3    33.5 Mm3   100.0 %
```

```
Campaign of 2008-09-30 (coef 1.13)

Tide coverage :       12.9 hours
Spatial coverage :    81.3 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       1343.0 TDS  1557.1 TDS
Mass Out :      1038.0 TDS  912.6 TDS
Mass Gross :    2381.1 TDS  2469.7 TDS
Mass Net In :  305.0 TDS  644.5 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      133.7 TDS  121.6 TDS    7.8 %
Mass In Density Currents :  913.3 TDS  830.6 TDS   53.3 %
Mass In Eddy Currents :      665.2 TDS  604.9 TDS   38.9 %
Sum of Influxes :          1712.3 TDS  1557.1 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       -95.5 %
 Trapping density currents :     70.0 %
 Trapping eddy currents :        29.6 %
 Global trapping efficiency :    41.4 %
```

```
Campaign of 2008-12-02 (coef 0.97)

Tide coverage :       12.4 hours
Spatial coverage :    89.3 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        39.5 Mm3   39.9 Mm3
Volume Out :       40.2 Mm3   39.9 Mm3
Volume Gross :     79.7 Mm3   79.7 Mm3
Volume Net In :   -0.8 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        8.2 Mm3    6.9 Mm3   17.3 %
Volume In Density Currents :    20.4 Mm3   17.1 Mm3   42.9 %
Volume In Eddy Currents :       18.9 Mm3   15.8 Mm3   39.7 %
Sum of Influxes :               47.4 Mm3   39.9 Mm3  100.0 %
```

```
Campaign of 2008-12-02 (coef 0.97)

Tide coverage :       12.4 hours
Spatial coverage :    89.3 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       4322.9 TDS  4363.9 TDS
Mass Out :      3015.8 TDS  2987.7 TDS
Mass Gross :    7338.7 TDS  7351.6 TDS
Mass Net In :   1307.1 TDS  1376.3 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      889.7 TDS   745.8 TDS   17.1 %
Mass In Density Currents :  2350.4 TDS  1970.1 TDS   45.1 %
Mass In Eddy Currents :     1966.3 TDS  1648.1 TDS   37.8 %
Sum of Influxes :          5206.5 TDS  4363.9 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       39.1 %
 Trapping density currents :    53.3 %
 Trapping eddy currents :        2.1 %
 Global trapping efficiency :   31.5 %
```

```
Campaign of 2008-12-10 (coef 1.00)

Tide coverage :       12.6 hours
Spatial coverage :    89.2 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        38.4 Mm3   38.2 Mm3
Volume Out :       38.0 Mm3   38.2 Mm3
Volume Gross :     76.4 Mm3   76.4 Mm3
Volume Net In :    0.3 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        6.2 Mm3     5.5 Mm3    14.3 %
Volume In Density Currents :    20.6 Mm3    18.0 Mm3    47.2 %
Volume In Eddy Currents :       16.8 Mm3    14.7 Mm3    38.5 %
Sum of Influxes :               43.6 Mm3    38.2 Mm3   100.0 %
```

```
Campaign of 2008-12-10 (coef 1.00)

Tide coverage :       12.6 hours
Spatial coverage :    89.2 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       3359.7 TDS  3344.6 TDS
Mass Out :      2202.7 TDS  2212.7 TDS
Mass Gross :    5562.4 TDS  5557.3 TDS
Mass Net In :   1157.0 TDS  1132.0 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      585.0 TDS   517.2 TDS   15.5 %
Mass In Density Currents :  1850.5 TDS  1636.1 TDS   48.9 %
Mass In Eddy Currents :     1347.3 TDS  1191.3 TDS   35.6 %
Sum of Influxes :         3782.9 TDS  3344.6 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       55.6 %
 Trapping density currents :    41.6 %
 Trapping eddy currents :       13.7 %
 Global trapping efficiency :   33.8 %
```

```
Campaign of 2009-03-06 (coef 0.83)

Tide coverage :       12.6 hours
Spatial coverage :   88.3 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        26.8 Mm3   27.8 Mm3
Volume Out :       28.8 Mm3   27.8 Mm3
Volume Gross :     55.6 Mm3   55.6 Mm3
Volume Net In :   -2.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        8.2 Mm3    5.8 Mm3   20.7 %
Volume In Density Currents :    17.4 Mm3   12.2 Mm3   43.8 %
Volume In Eddy Currents :       14.1 Mm3    9.9 Mm3   35.5 %
Sum of Influxes :               39.8 Mm3   27.8 Mm3  100.0 %
```

```
Campaign of 2009-03-06 (coef 0.83)

Tide coverage :       12.6 hours
Spatial coverage :   88.3 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       2108.1 TDS  2185.9 TDS
Mass Out :      1084.1 TDS  1046.8 TDS
Mass Gross :    3192.2 TDS  3232.7 TDS
Mass Net In :   1024.0 TDS  1139.2 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      512.1 TDS   402.2 TDS   18.4 %
Mass In Density Currents :  1279.0 TDS  1004.4 TDS   45.9 %
Mass In Eddy Currents :      992.4 TDS   779.3 TDS   35.7 %
Sum of Influxes :           2783.5 TDS  2185.9 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       42.7 %
 Trapping density currents :    62.1 %
 Trapping eddy currents :       44.1 %
 Global trapping efficiency :   52.1 %
```

```
Campaign of 2009-03-12 (coef 1.28)

Tide coverage :       11.2 hours
Spatial coverage :    88.4 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        30.6 Mm3   29.6 Mm3
Volume Out :       28.6 Mm3   29.6 Mm3
Volume Gross :     59.2 Mm3   59.2 Mm3
Volume Net In :    2.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        7.5 Mm3     5.5 Mm3    18.5 %
Volume In Density Currents :    14.7 Mm3    10.7 Mm3    36.1 %
Volume In Eddy Currents :       18.6 Mm3    13.5 Mm3    45.5 %
Sum of Influxes :               40.9 Mm3    29.6 Mm3   100.0 %
```

```
Campaign of 2009-03-12 (coef 1.28)

Tide coverage :       11.2 hours
Spatial coverage :    88.4 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       3749.6 TDS  3629.3 TDS
Mass Out :      2378.2 TDS  2459.7 TDS
Mass Gross :    6127.8 TDS  6089.1 TDS
Mass Net In :   1371.4 TDS  1169.6 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      960.5 TDS   718.3 TDS    19.8 %
Mass In Density Currents :  1760.1 TDS  1316.3 TDS    36.3 %
Mass In Eddy Currents :     2132.5 TDS  1594.8 TDS    43.9 %
Sum of Influxes :         4853.2 TDS  3629.3 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       53.6 %
 Trapping density currents :    40.8 %
 Trapping eddy currents :       15.5 %
 Global trapping efficiency :   32.2 %
```

```
Campaign of 2011-10-06 (coef 0.81)

Tide coverage :      12.6 hours
Spatial coverage :   87.4 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :       34.7 Mm3   35.0 Mm3
Volume Out :      35.2 Mm3   35.0 Mm3
Volume Gross :    69.9 Mm3   69.9 Mm3
Volume Net In :  -0.5 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        5.4 Mm3    4.8 Mm3   13.8 %
Volume In Density Currents :   18.9 Mm3   17.0 Mm3   48.5 %
Volume In Eddy Currents :      14.7 Mm3   13.2 Mm3   37.7 %
Sum of Influxes :              39.0 Mm3   35.0 Mm3  100.0 %
```

```
Campaign of 2011-10-06 (coef 0.81)

Tide coverage :      12.6 hours
Spatial coverage :   87.4 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :      2289.6 TDS  2304.9 TDS
Mass Out :     1647.3 TDS  1636.4 TDS
Mass Gross :   3936.9 TDS  3941.4 TDS
Mass Net In :  642.3 TDS  668.5 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :     404.5 TDS  366.2 TDS   15.9 %
Mass In Density Currents :  1236.0 TDS  1118.8 TDS   48.5 %
Mass In Eddy Currents :     905.8 TDS  819.9 TDS   35.6 %
Sum of Influxes :         2546.3 TDS  2304.9 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       50.1 %
 Trapping density currents :    34.0 %
 Trapping eddy currents :       12.8 %
 Global trapping efficiency :   29.0 %
```

```
Campaign of 2011-10-13  (coef 1.11)

Tide coverage :       12.6 hours
Spatial coverage :   87.4 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        35.4 Mm3   36.0 Mm3
Volume Out :       36.7 Mm3   36.0 Mm3
Volume Gross :     72.1 Mm3   72.1 Mm3
Volume Net In :  -1.4 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        8.0 Mm3     6.6 Mm3    18.4 %
Volume In Density Currents :    20.7 Mm3    17.2 Mm3    47.8 %
Volume In Eddy Currents :       14.7 Mm3    12.2 Mm3    33.8 %
Sum of Influxes :               43.4 Mm3    36.0 Mm3   100.0 %
```

```
Campaign of 2011-10-13  (coef 1.11)

Tide coverage :       12.6 hours
Spatial coverage :   87.4 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       8048.8 TDS  8204.2 TDS
Mass Out :      4753.8 TDS  4665.5 TDS
Mass Gross :    12802.6 TDS  12869.6 TDS
Mass Net In :  3295.0 TDS  3538.7 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      1528.3 TDS  1320.3 TDS   16.1 %
Mass In Density Currents :  5178.8 TDS  4473.8 TDS   54.5 %
Mass In Eddy Currents :     2789.9 TDS  2410.1 TDS   29.4 %
Sum of Influxes :         9497.0 TDS  8204.2 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       36.5 %
 Trapping density currents :    56.0 %
 Trapping eddy currents :       22.9 %
 Global trapping efficiency :   43.1 %
```

```
Campaign of 2012-03-08 (coef 1.18)

Tide coverage :       12.6 hours
Spatial coverage :    88.8 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        33.9 Mm3   36.5 Mm3
Volume Out :       39.0 Mm3   36.5 Mm3
Volume Gross :     72.9 Mm3   72.9 Mm3
Volume Net In :  -5.1 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        9.8 Mm3    7.0 Mm3   19.3 %
Volume In Density Currents :   26.9 Mm3   19.2 Mm3   52.6 %
Volume In Eddy Currents :      14.3 Mm3   10.2 Mm3   28.1 %
Sum of Influxes :              51.0 Mm3   36.5 Mm3  100.0 %
```

```
Campaign of 2012-03-08 (coef 1.18)

Tide coverage :       12.6 hours
Spatial coverage :    88.8 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       3624.2 TDS  3898.5 TDS
Mass Out :      1826.1 TDS  1706.0 TDS
Mass Gross :    5450.3 TDS  5604.5 TDS
Mass Net In :  1798.1 TDS  2192.4 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      518.2 TDS  420.6 TDS   10.8 %
Mass In Density Currents :  2998.8 TDS  2434.1 TDS   62.4 %
Mass In Eddy Currents :     1285.8 TDS  1043.7 TDS   26.8 %
Sum of Influxes :         4802.8 TDS  3898.5 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :      -25.4 %
 Trapping density currents :    72.3 %
 Trapping eddy currents :       51.7 %
 Global trapping efficiency :   56.2 %
```

```
Campaign of 2012-03-16 (coef 0.92)

Tide coverage :       12.4 hours
Spatial coverage :    83.4 %
Smoothing filter : none ---------------------------
Total water exchange measured and corrected to fit the water balance

Volume In :        28.4 Mm3   27.9 Mm3
Volume Out :       27.4 Mm3   27.9 Mm3
Volume Gross :     55.8 Mm3   55.8 Mm3
Volume Net In :    1.0 Mm3   -0.0 Mm3
---------------------------
Water influx per component computed, scaled to measured influx, and relative fraction

Volume In Tidal Filling :        7.3 Mm3    5.3 Mm3   19.0 %
Volume In Density Currents :   20.0 Mm3   14.5 Mm3   51.8 %
Volume In Eddy Currents :      11.3 Mm3    8.2 Mm3   29.2 %
Sum of Influxes :              38.6 Mm3   27.9 Mm3  100.0 %
```

```
Campaign of 2012-03-16 (coef 0.92)

Tide coverage :       12.4 hours
Spatial coverage :    83.4 %
Smoothing filter : none ---------------------------
Total sediment exchange measured and corrected to fit the water balance

Mass In :       2216.2 TDS  2179.1 TDS
Mass Out :      1203.6 TDS  1224.5 TDS
Mass Gross :    3419.8 TDS  3403.6 TDS
Mass Net In :   1012.7 TDS  954.6 TDS
---------------------------
Sediment influx per component computed, scaled to measured influx, and relative fraction

Mass In Tidal Filling :      572.9 TDS  418.0 TDS   19.2 %
Mass In Density Currents :  1577.2 TDS  1150.7 TDS   52.8 %
Mass In Eddy Currents :      836.7 TDS  610.5 TDS   28.0 %
Sum of Influxes :          2986.8 TDS  2179.1 TDS  100.0 %
---------------------------
Trapping efficiency per component

 Trapping tidal filling :       46.5 %
 Trapping density currents :    49.2 %
 Trapping eddy currents :       31.7 %
 Global trapping efficiency :   43.8 %
```

Annex E Modelling study with Slib3D

Memo

Aan
IMDC

Datum	**Aantal pagina's**	
2 januari 2014	76	
Van	**Doorkiesnummer**	**E-mail**
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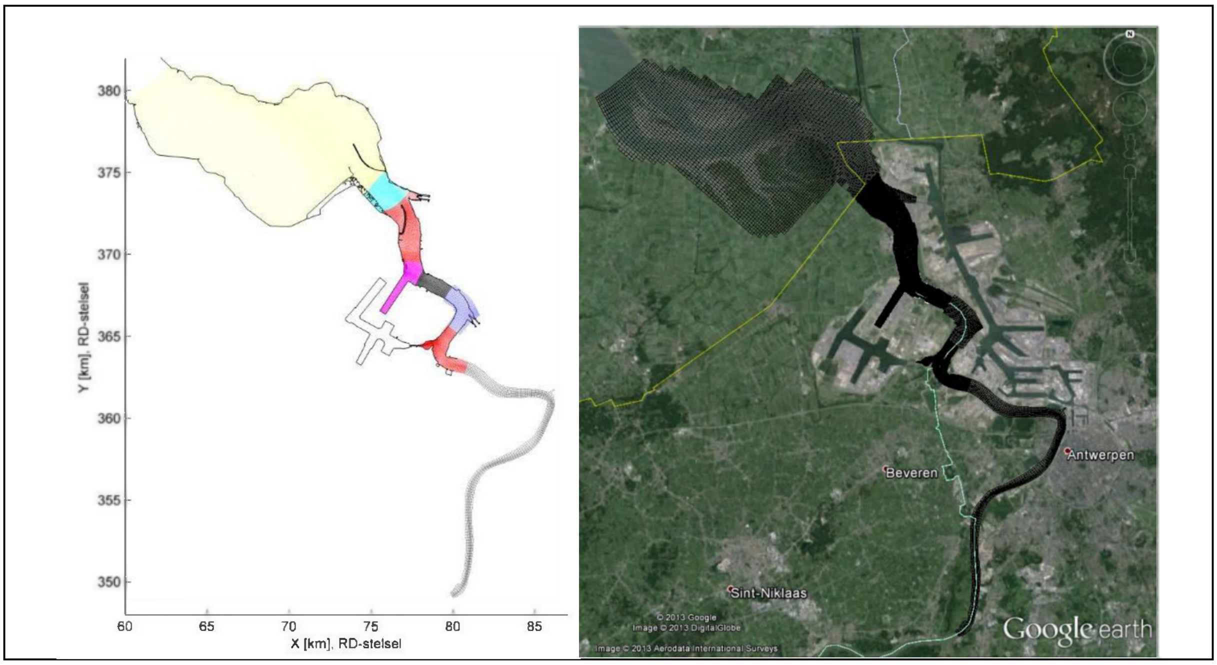
Onderwerp
Notitie versie 2 januari 2014

A. Introductie

Het Deurganckdok is sinds de aanleg aan een heel scala aan wat veranderingen onderhevig geweest, terwijl gedurende deze periode het baggerbezwaar continu is toegenomen. Om het effect van de verschillende ontwikkelingen (verdiepingen, veranderingen in de drempel, aanleg CDW) op de aanslibbing te kunnen begrijpen, is deze modelstudie geïnitieerd. Alle Deurganckdok maatregelen zijn uitgevoerd over een periode van vele jaren. Het bestaande numerieke model (Figuur A.1) door Van Maren (2011) is te zwaar om al deze ingrepen serieel door te rekenen, waarbij de uitkomst van elk stadium als initiële situatie voor elk volgend stadium wordt gebruikt. Een dergelijke *hindcast* kan niet gemaakt worden binnen een aanvaardbare doorloopperiode, 1 dag in het model kost namelijk ca. 2 dagen om door te rekenen. Daarom is ervoor gekozen om alle 6 stadia parallel door te rekenen. De geometrie van elk stadium is cumulatief, d.w.z. dat elk stadium alle voorgaande ingrepen omvat. Voor de stromingssituatie geld dat echter niet in een parallelle aanpak. Voor elk stadium wordt dezelfde getij periode doorgerekend, op basis waarvan het effect van iedere incrementele maatregel beoordeeld kan worden. De 6 sequentiële stadia zijn hiermee 6 parallelle scenario's geworden. Voor de achtergrond, instellingen en prestatiebereik van het model wordt verwezen naar Van Maren (2011) en referenties daarin. Het model van Van Maren (2011) is in deze studie ongewijzigd ingezet, de enige aanpassingen waren datgene wat benodigd was voor de scenario's. In paragraaf B van deze nota wordt de opbouw van de scenario's beschreven. De uitvoerlocaties staan ingetekend in Figuur B.6. In paragraaf C wordt het tijdsverloop van de scenario's besproken en worden op een aantal locaties de SPM concentraties getoond. De rest van de nota behandelt de sediment transporten door transecten (D) en de aanslibbing in vakken (E). In paragrafen F, G, H en I worden de concentraties en snelheden bij de ingang van het dok getoond om de aard van de transporten te doorgronden. In paragraaf J worden de concentraties en snelheden verder geanalyseerd en geïntegreerd om de uitwisseling van water en sediment te analyseren op basis van 3 bekende uitwisselingsmechanismen. Dit onderdeel van de analyse werd uitgevoerd door IMDC. De nota sluit af met een discussie in paragraaf K.



Figuur A.1. Delft3D grid schematisatie van Van Maren (2011): 8 rekendomeinen van de Zeeschelde bij Waarde benedenstrooms tot aan de splitsing bij Rupelmonde bovenstrooms (image credit: Google Earth mapping services).

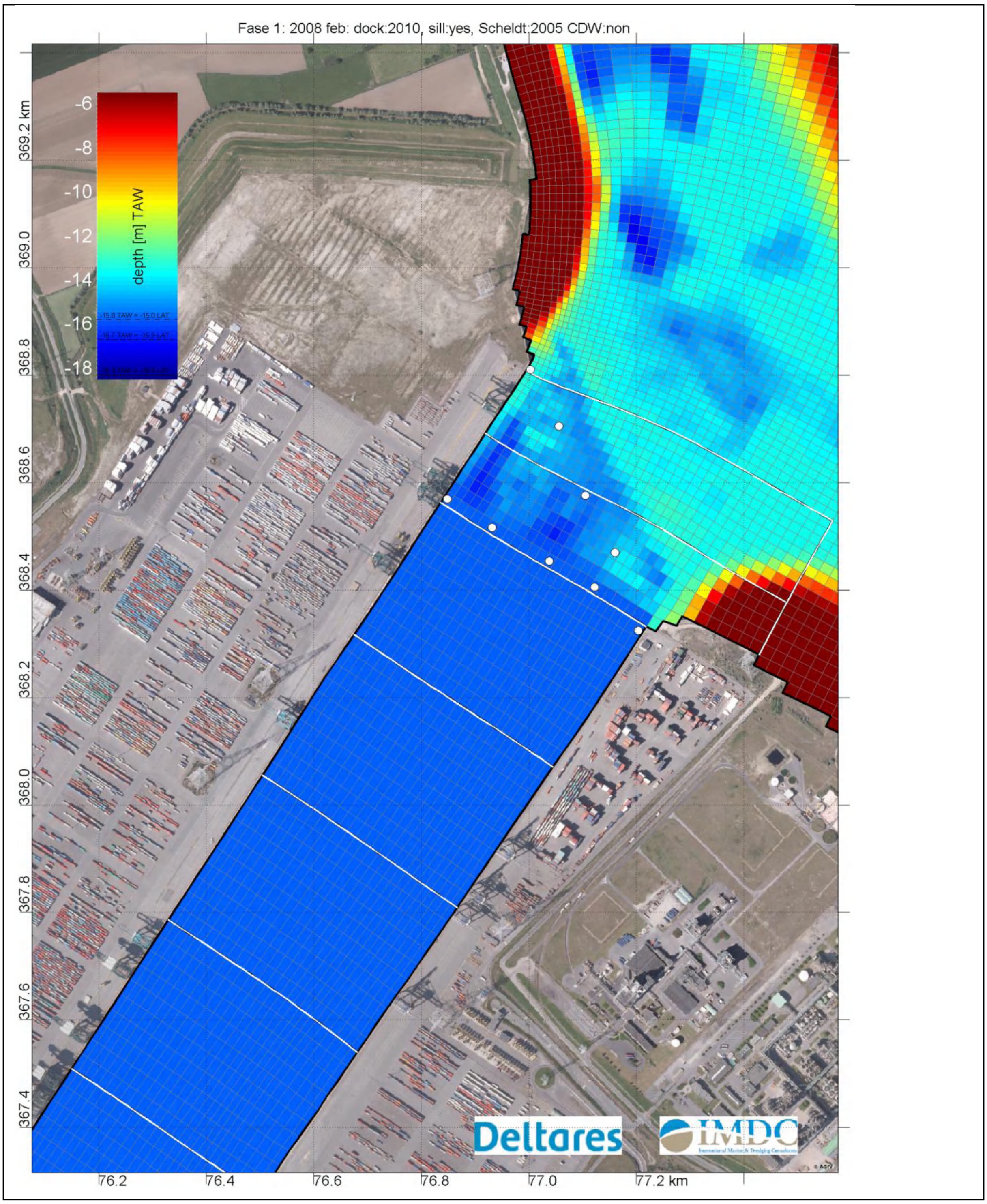
B. Scenario's

De 6 scenario's zijn samengevat in Tabel A.1. Elk scenario heeft een code gekregen met als basis het moment waarop dit een stadium van het Deurganckdok werd. Voor het event is dezelfde code gebruikt met een suffix. Elke verandering in Tabel B.1 is met een dikke horizontale lijn aangegeven. Er is voor scenario 1 begonnen met een bestaand model dat de gemeten bathymetrie van 2005 bevatte. Hierin zijn de dieptes in het dok aangepast tot -15.8 TAW uniform (Figuur B.1). Het tweede scenario is verkregen door de drempel weg te halen en op dezelfde diepte te leggen (Figuur B.2). Het derde scenario is verkregen door een gemeten bodem voor 2010 op de Schelde op te leggen, waarbij de drempel en het dok onaangepast zijn gebleven (Figuur B.3). Voor het vierde scenario is een geul centraal in het dok aangebracht op -18.3 TAW, zijn de belendende ligplaatsen iets uitgediept tot -16.7 en is de drempelzone tot minimaal -16 TAW uitgediept, en dieper waar de gemeten 2010 bodem dieper lag (Figuur B.4). In het vijfde scenario is de CDW toegevoegd (Figuur B.5). De bathymetrie is enigszins aangepast rondom de CDW om op de CDW aan te sluiten, zoals gerapporteerd in Van Maren (2011). Het laatste scenario is qua rooster en bathymetrie identiek aan dat van het vijfde. Alleen de sediment concentraties op de twee open modelranden nabij Waarde en Schelle zijn verdubbeld. Het idee hierachter is om te beoordelen in hoeverre niet-lineaire effecten van sedimentconcentraties invloed hebben op de sedimentatie in het Deurganckdok.

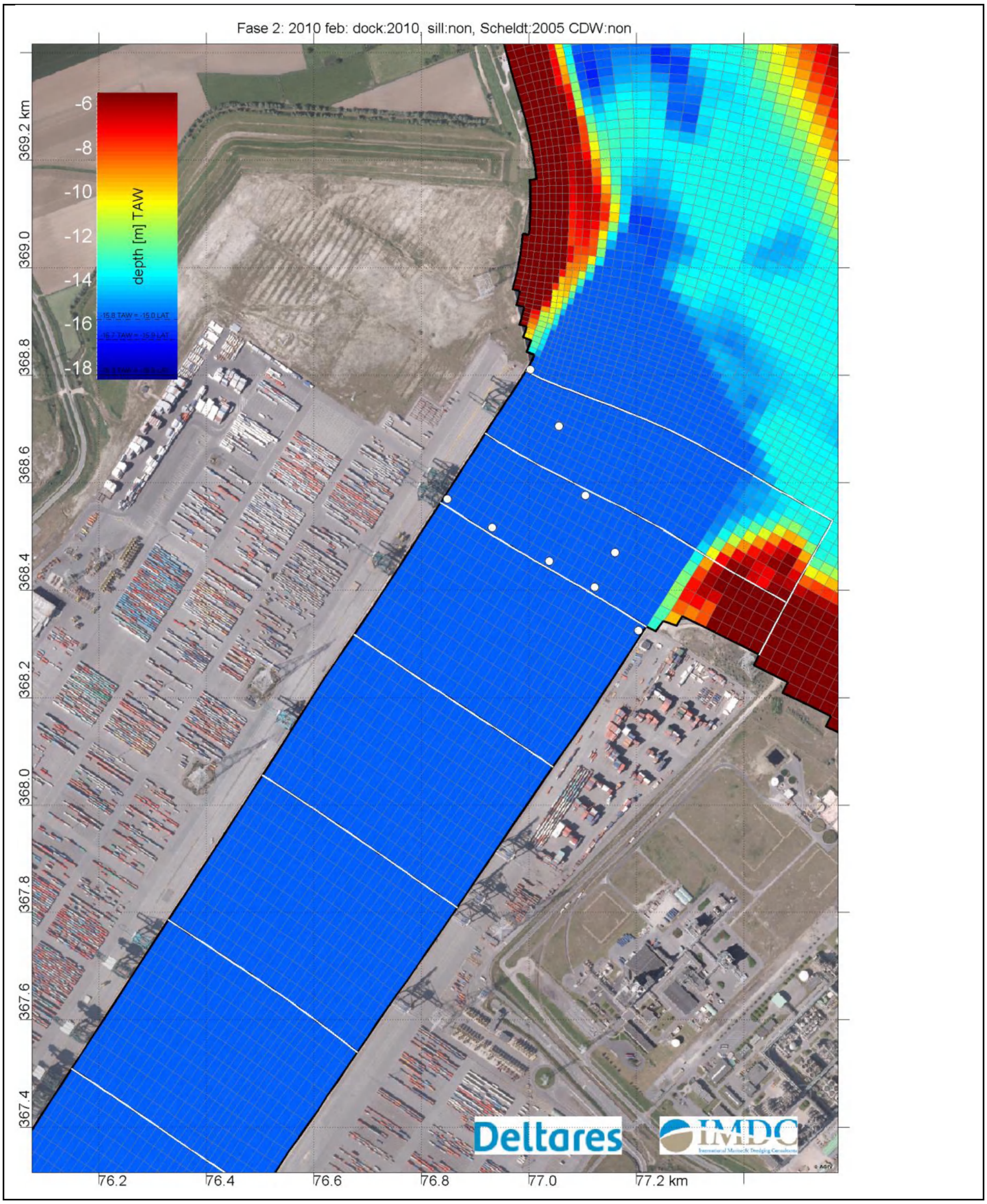
#	id	Toestand	Schelde	Drempel	Dok geul	Dok ligplaats	CDW
1	200802	Feb 2008.	2005	2005	-15.8 TAW	-15.8 TAW	nee
2	201006	Jun 2010	2005	-15.8 TAW	-15.8 TAW	-15.8 TAW	nee
3	201008	Aug 2010	2010	-15.8 TAW	-15.8 TAW	-15.8 TAW	nee
4	201104	Apr 2011	2010	max(2010, -16.0 TAW)	-18.3 TAW	-16.7 TAW	nee
5	201108	Aug 2011	2010	max(2010, -16.0 TAW)	-18.3 TAW	-16.7 TAW	ja
6	201108x2	Event	,,	,,	,,	,,	,,

Tabel B.1. Ontwerpen van de stadia van het Deurganckdok.

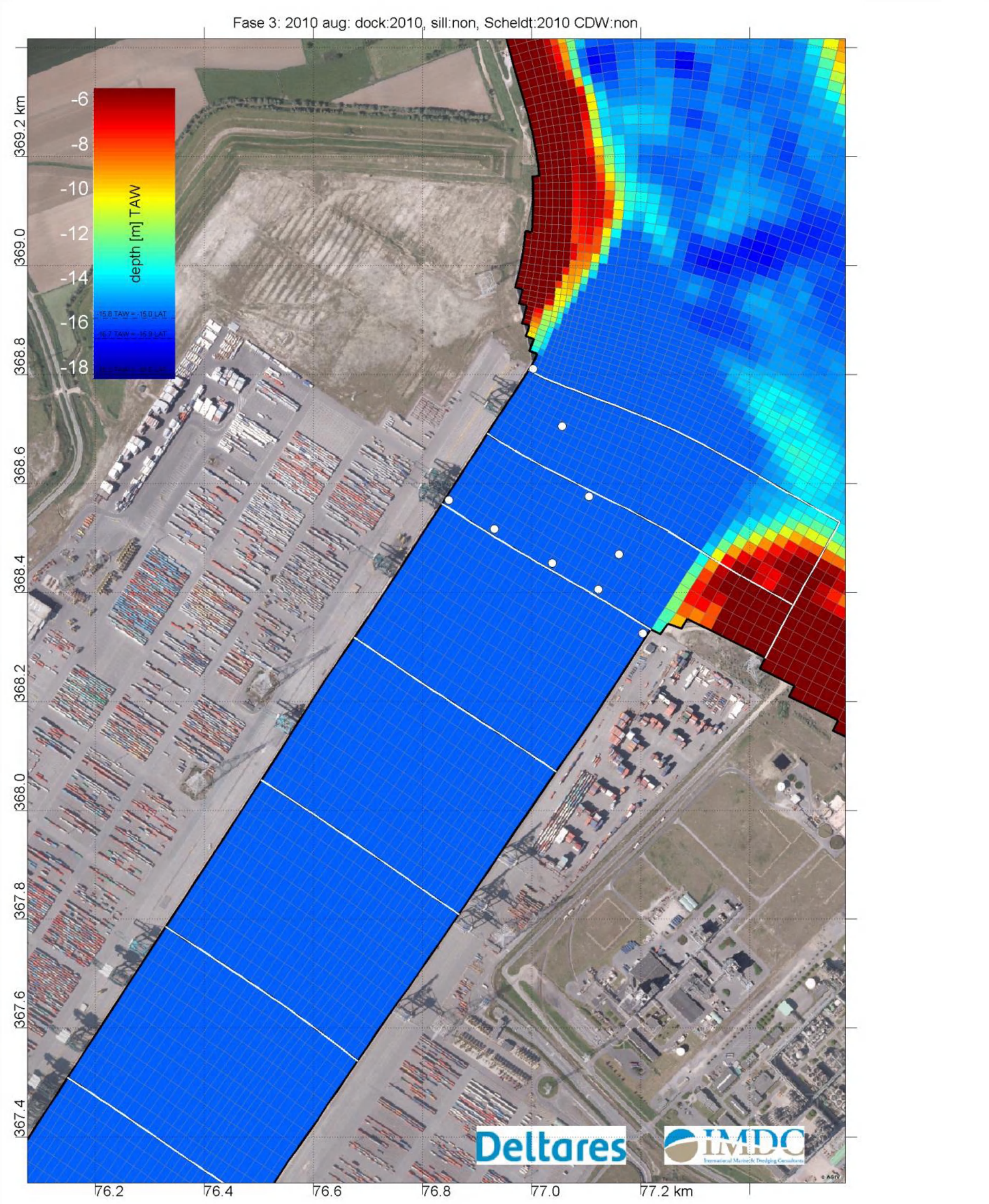
Figuur B.1 t/m B.5 tonen het gebruikte rooster en bathymetrie voor de 6 scenario's. De witte rondjes geven de locaties aan van de observatiepunten waarvan de tijdserie Figuren C.1 t/m C.6 getoond worden. De witte lijnen geven transecten aan waardoor instantane en cumulatieve transporten getoond worden in de Figuren D.1 t/m D.7. Figuur B.6 (identiek Figuur B.5, omdat scenario 5 is identiek aan scenario 6) toont de gebruikte code aanduidingen voor de stations en transecten.



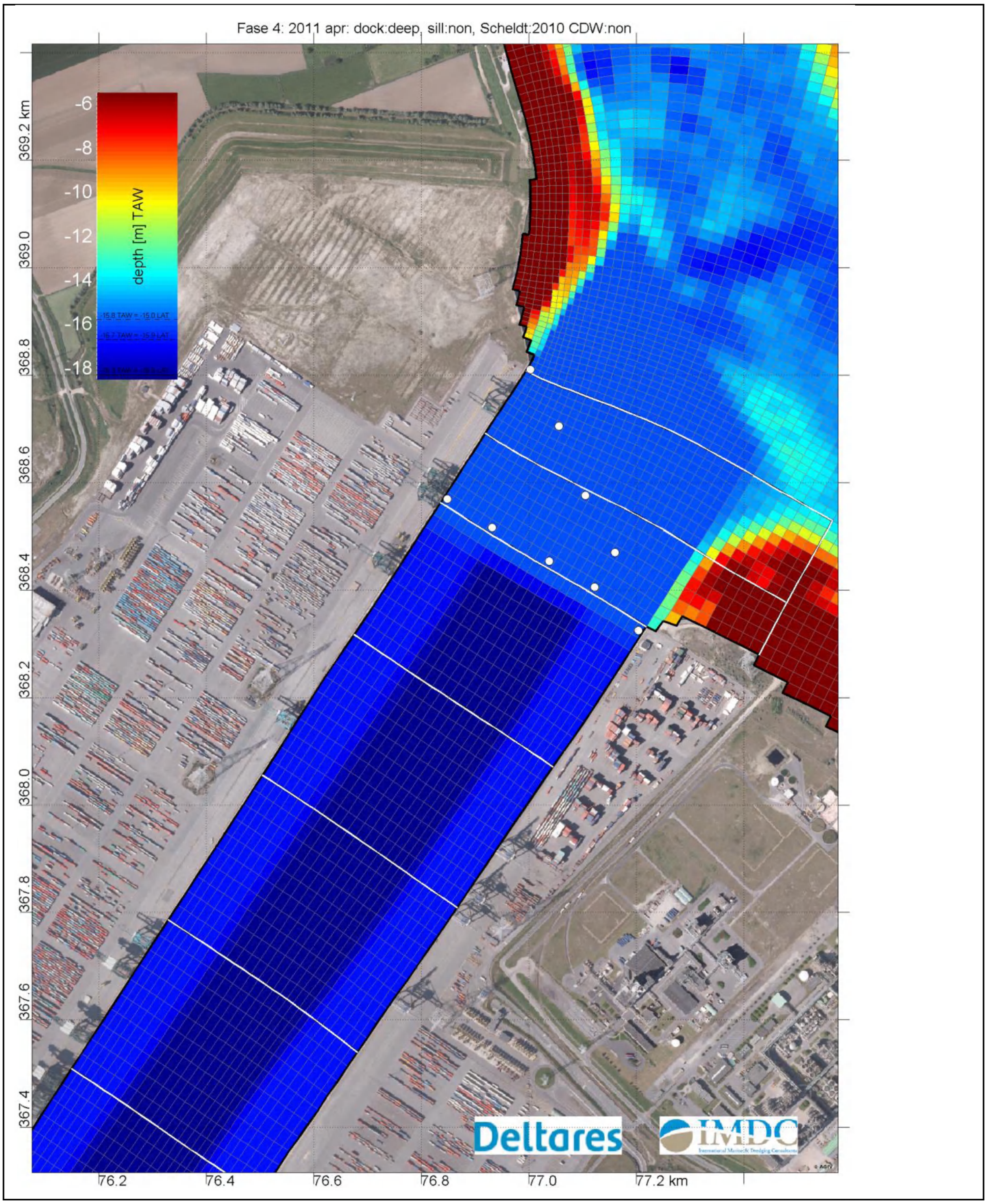
Figuur B.1. Scenario 200802, zie Tabel B.1.



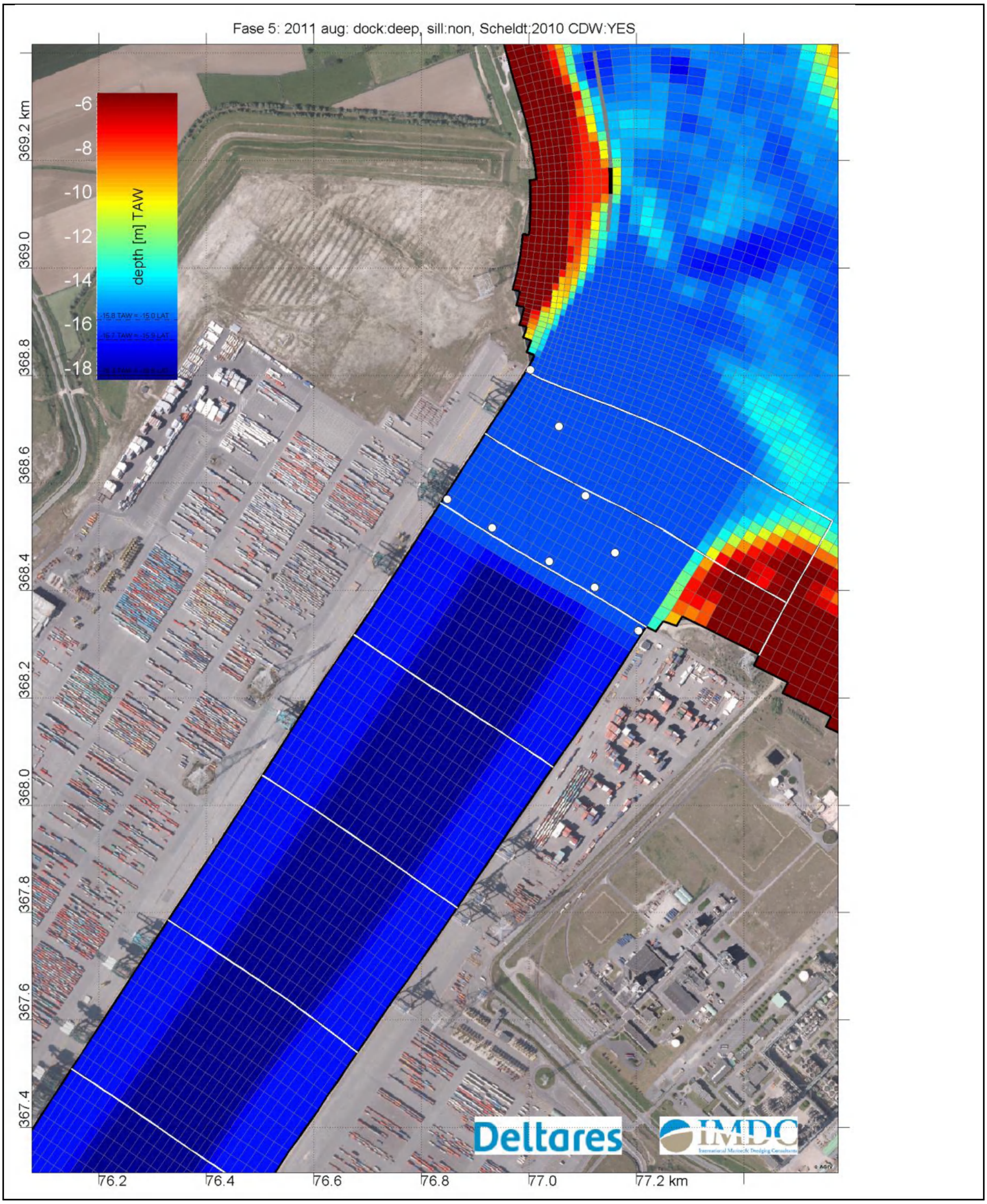
Figuur B.2. Scenario 201006, zie Tabel B.1.



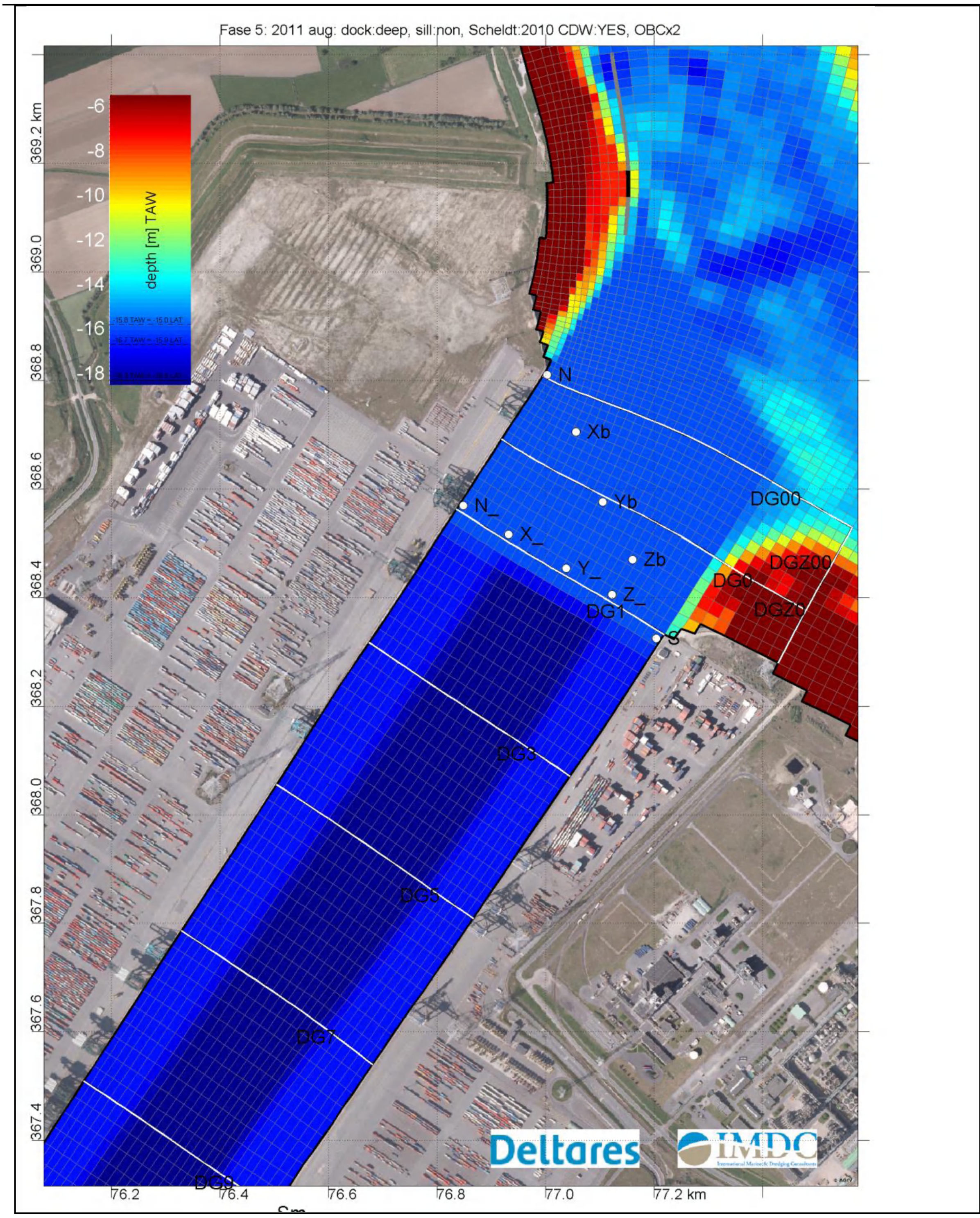
Figuur B.3. Scenario 201008, zie Tabel B.1.



Figuur B.4. Scenario 201104, zie Tabel B.1.



Figuur B.5. Scenario 201108 and 201108x2, zie Tabel B.1. De CDW is getoond in zwarte en grijze lijnen die roosterlijnen aangeven waarvoor de stroming respectievelijk geheel of gedeeltelijk is geblokkeerd.



Figuur B.6. Scenario 201108 en 201108x2, zie Tabel B.1. Identiek aan Figuur B.6, maar met codes van de observatiepunten (Figuren C) en transecten (Figuren D).

C. Tijd series

Op een aantal stations in de ingang van het dok worden tijd series getoond van concentraties slib, waaronder de 3 stations waar permanente sensoren op 2 hoogtes zaten (IMDC, 2013). De tijdseries op S en N corrsponderen met metingen van SPM en saliniteit op 2 niveaus nabij de bodem (-12.2 and -13.2 m TAW) en het opervlak (-2,2 en -2,3 m TAW) zoals gerapporteerd in IMDC (2013). Voor het doorgronden van de sediment import mechanismen is ook data uitgevoerd op 3 stations ertussenin, de stations Xb, Yb en Zb waar Siltprofiler metingen gedaan zijn (IMDC, 2013). Hiervoor zijn 2 niveaus gekozen (-2.5 and -12.5m TAW). Voor locaties zie Figuur B.6.

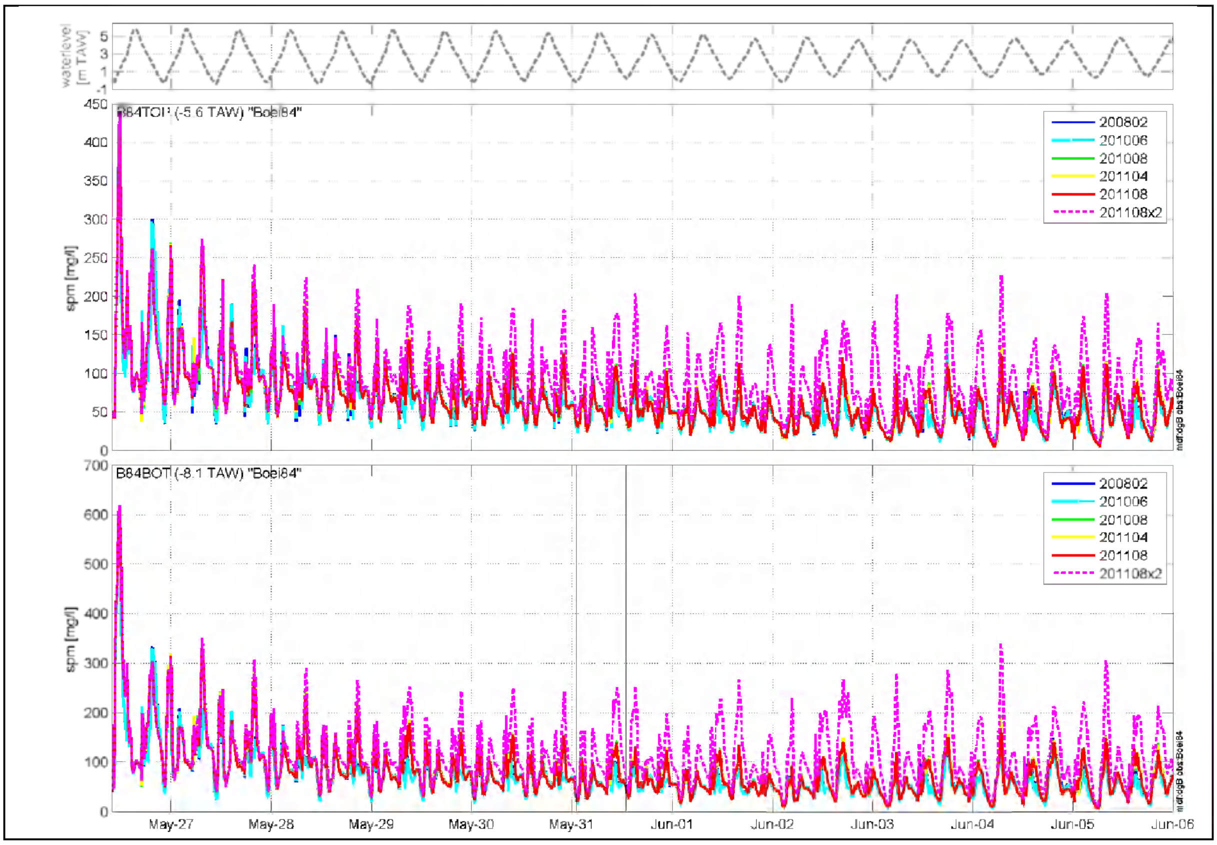
	Locatie	Sensoren	Hoogte	Gemeten
C.1	B84	B84TOP B84BOT	-5.6 TAW -8.1 TAW	Saliniteit en SPM
C.2	N	NTOP NBOT	-2.2 TAW -12.2 TAW	Saliniteit en SPM
c.3	Xb	XbTOP XbBOT	-2.5 TAW -12.5 TAW	Siltprofiler
c.4	Yb	YbTOP YbBOT	-2.5 TAW -12.5 TAW	Siltprofiler
c.5	Zb	ZbTOp ZbBOT	-2.5 TAW -12.5 TAW	Siltprofiler
c.6	S	STOP SBOT	-2.3 TAW -13.2 TAW	Saliniteit en SPM

Tabel C.1. Observatie stations waarvoor modeldata uitgevoerd zijn in Figuur C1.-C.5.

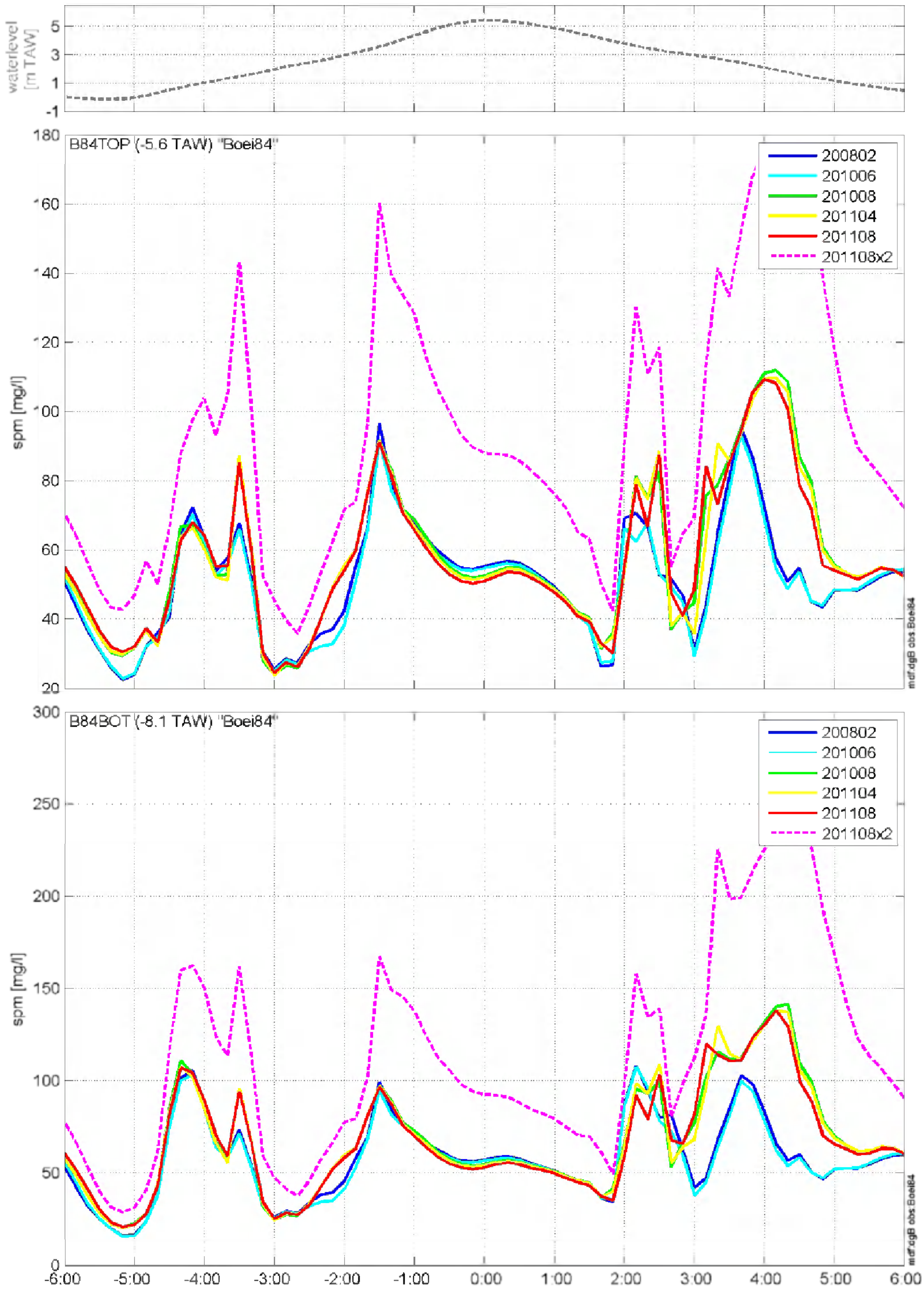
De tijdseries worden getoond gedurende 1 getijperiode tussen doodtij en springtij in (31 mei 01:00+12hr). Dit is 5 dagen na opstarten van het model tijdens springtij op basis van een ingespeelde toestand (zogenaamde *restart file*). Een etmaal zou al voldoende zijn om lokale aanpassingen van de scenario's te verdisconteren. Echter het inspelen van de verdubbelde concentraties van scenario *201108x2* vergen substantieel meer tijd. Deze moeten immers door advectie/diffusie van de modelranden (Figuur A.1) naar het DGD migreren. Tijdens de gekozen analyse periode is scenario *201108x2* al zodanig ingespeeld zijn dat de concentraties bij Boei 84 minimaal met 50 % verhoogd zijn (Figuur C.0 en C.1). Deze analyse periode tussen doodtij en springtij is aangehouden voor alle figuren in deze nota, en komt overeen met de aanslibbingsgetallen in Tabel E.1.

Wat	Datum	Datum
Start simulatie, vlak voor spring tij	26 mei 10:00	
Analyseperiod in rapport, tussen spring- en doodtij in	31 mei 00:30	31 mei 12:30
Einde simulatie, vlak na doodtij	06 jun 00:00	

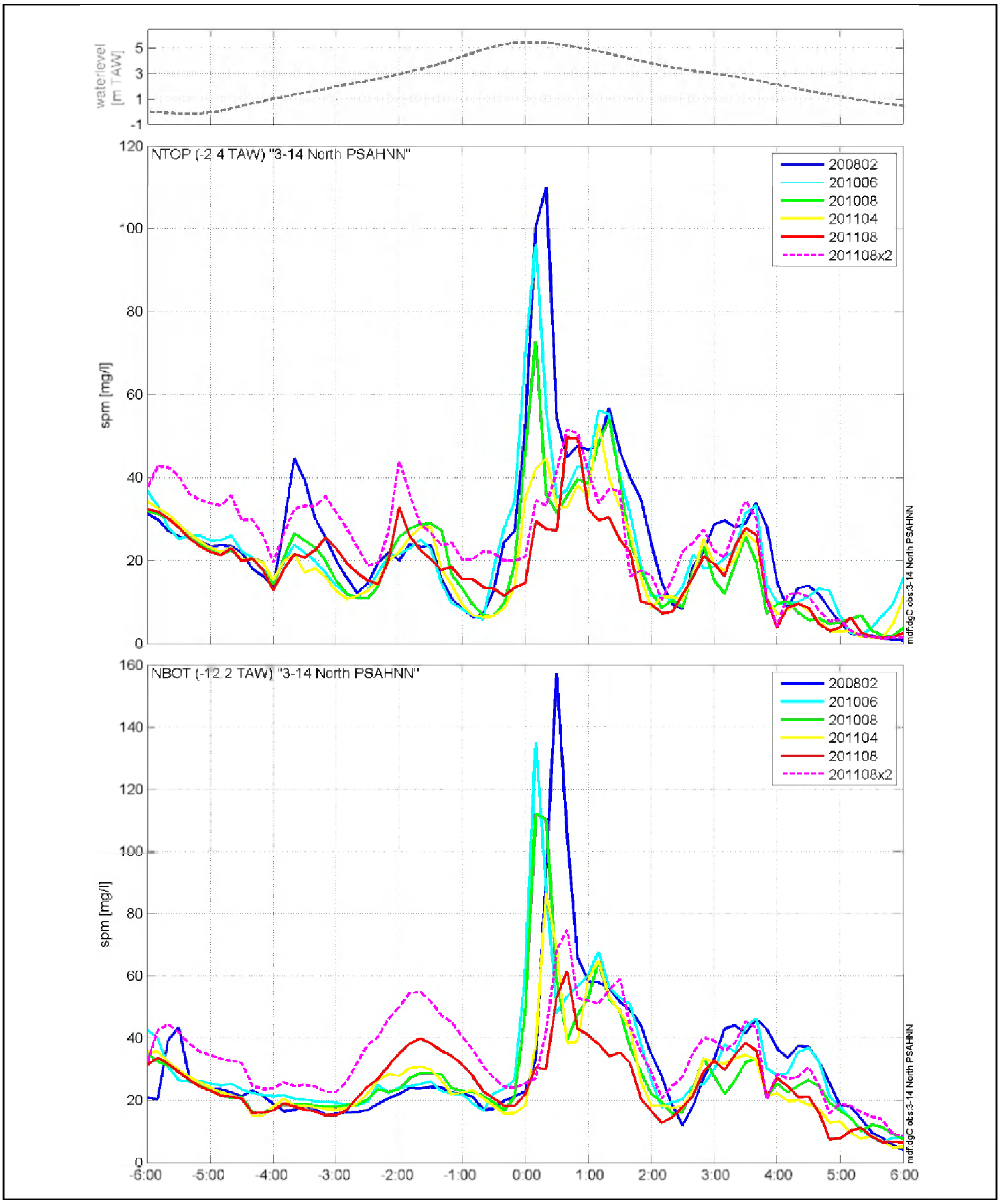
Tabel C.2. Periodes gebruikt voor de simulatie, voor de figuren in deze nota en de aanslibbingsanalyse in paragraaf E.



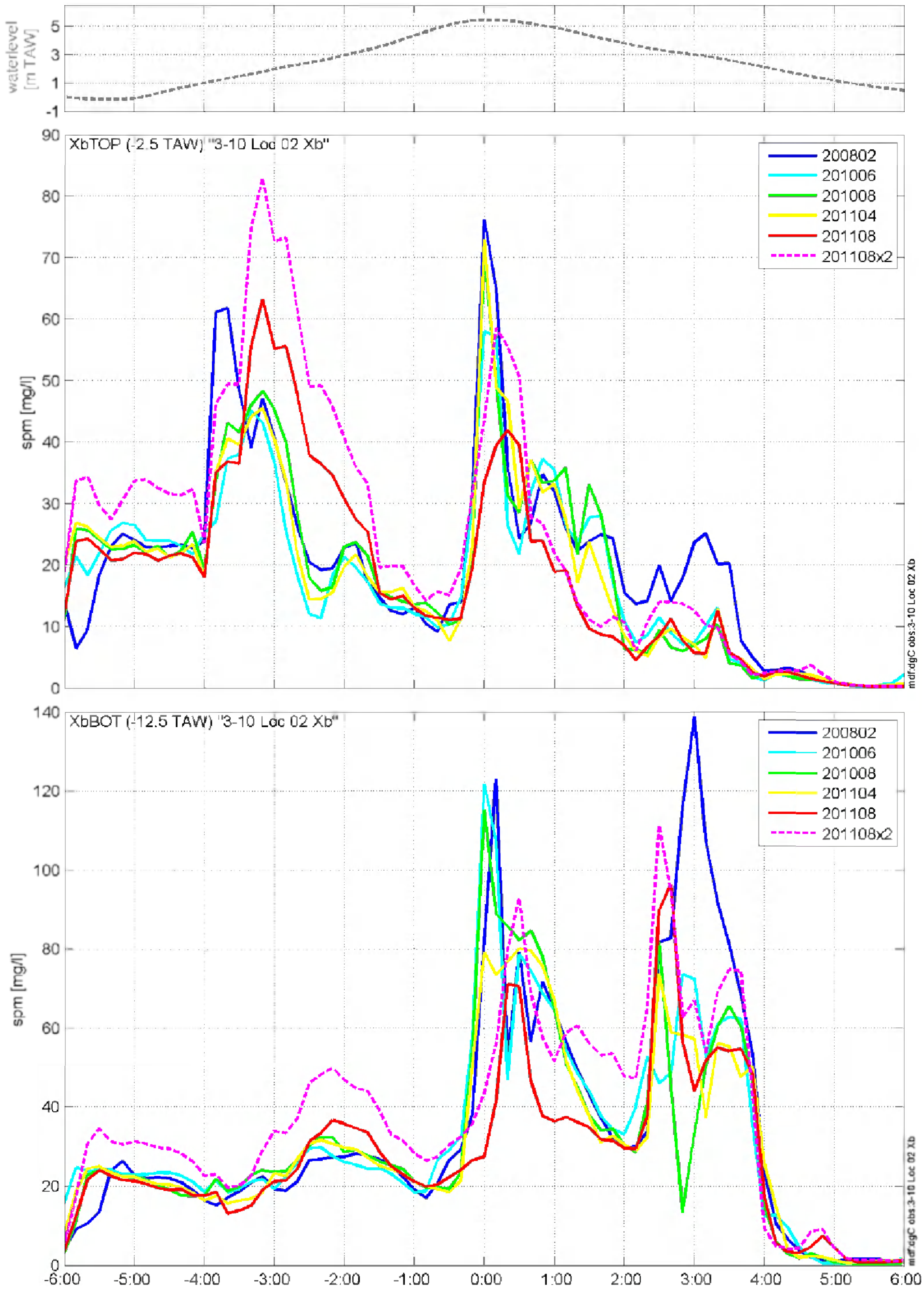
Figuur C.0. Tijdseries voor SPM concentraties op locatie B84 (B84BOT en B84TOP) gedurende de hele simulatieperiode uit Tabel C.2. De verticale grijze lijnen geven de gehanteerde analyseperiode weer voor alle figuren in deze nota (31 mei 00:30 – 31 mei 12:30). Deze periode ligt tussen spring- en doodtij in. Er is te zien dat het inspelen van de dubbele sediment concentraties in scenario 201108x2 vele dagen nodig heeft, pas aan het eind van de simulatie treedt volledige verdubbeling op. Tijdens de gehanteerde analyse periode op 31 mei is scenario 201108x2 nog niet geheel verdubbeld.



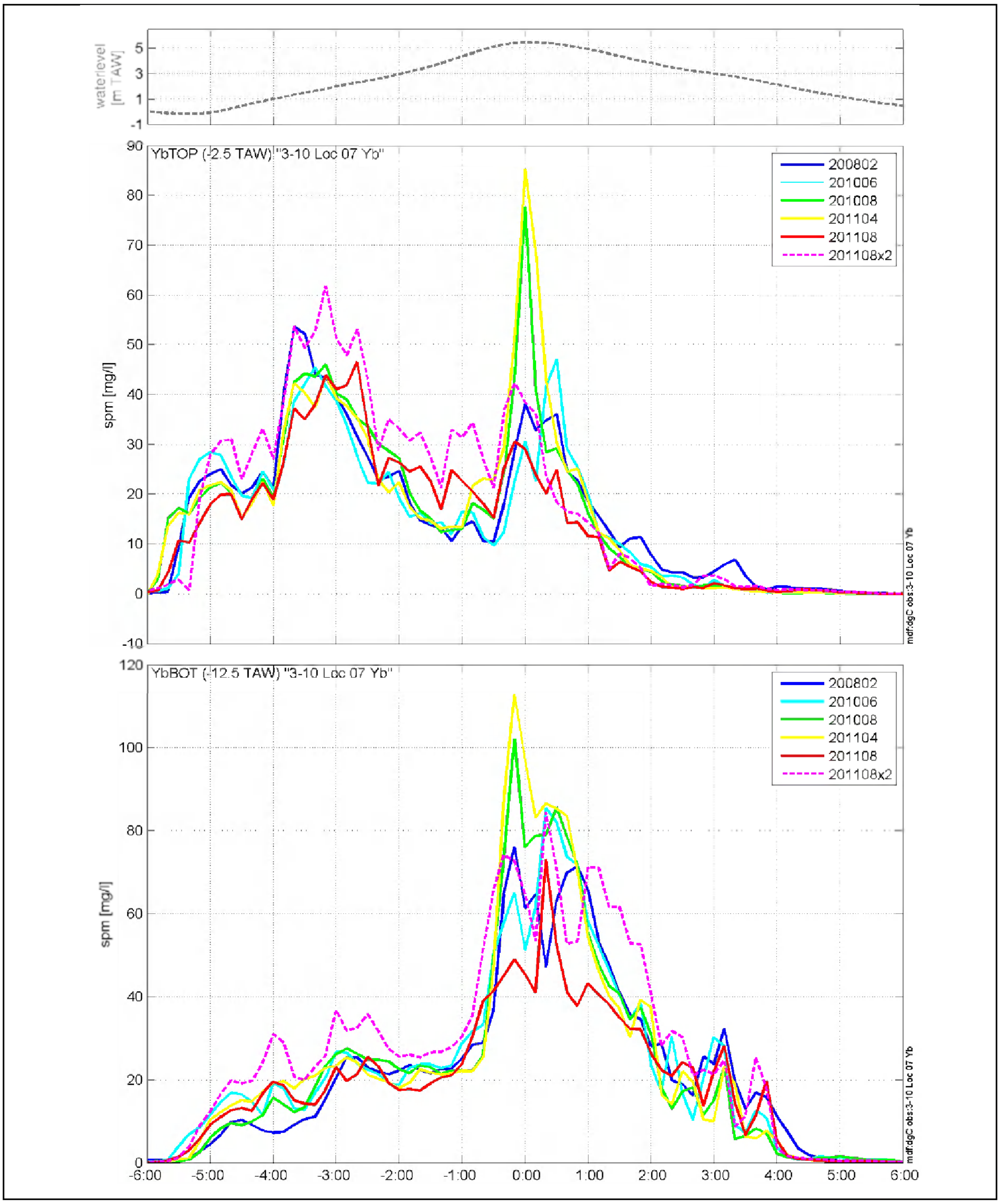
Figuur C.1. Tijdseries voor SPM concentraties op locatie B84 (B84BOT en B84TOP) op de Schelde benoorden het Deurganckdok, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).



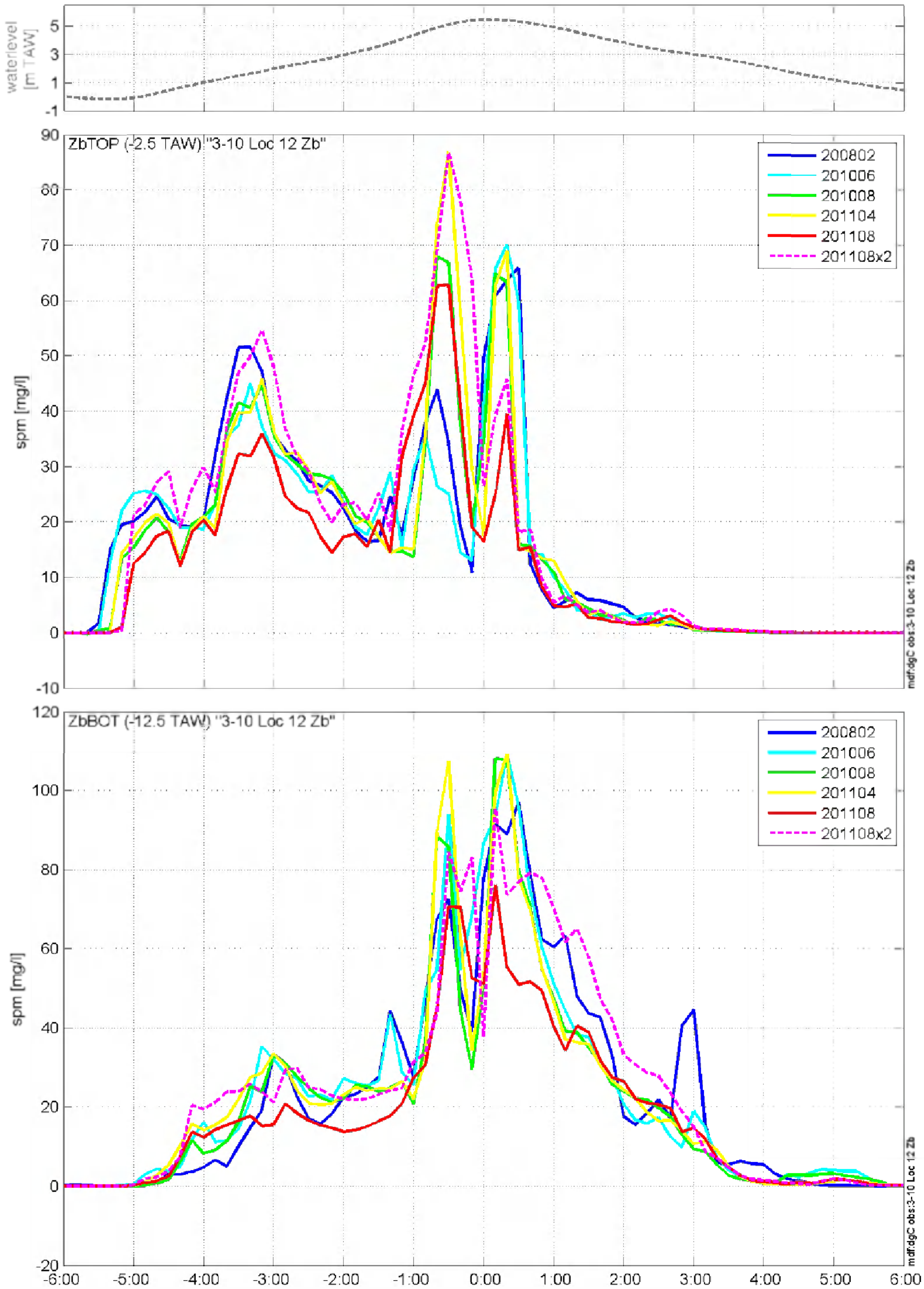
Figuur C.2. Tijdseries voor SPM concentraties op locatie N (NBOT en NTOP) aan de noord-west zijde van het dok, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).



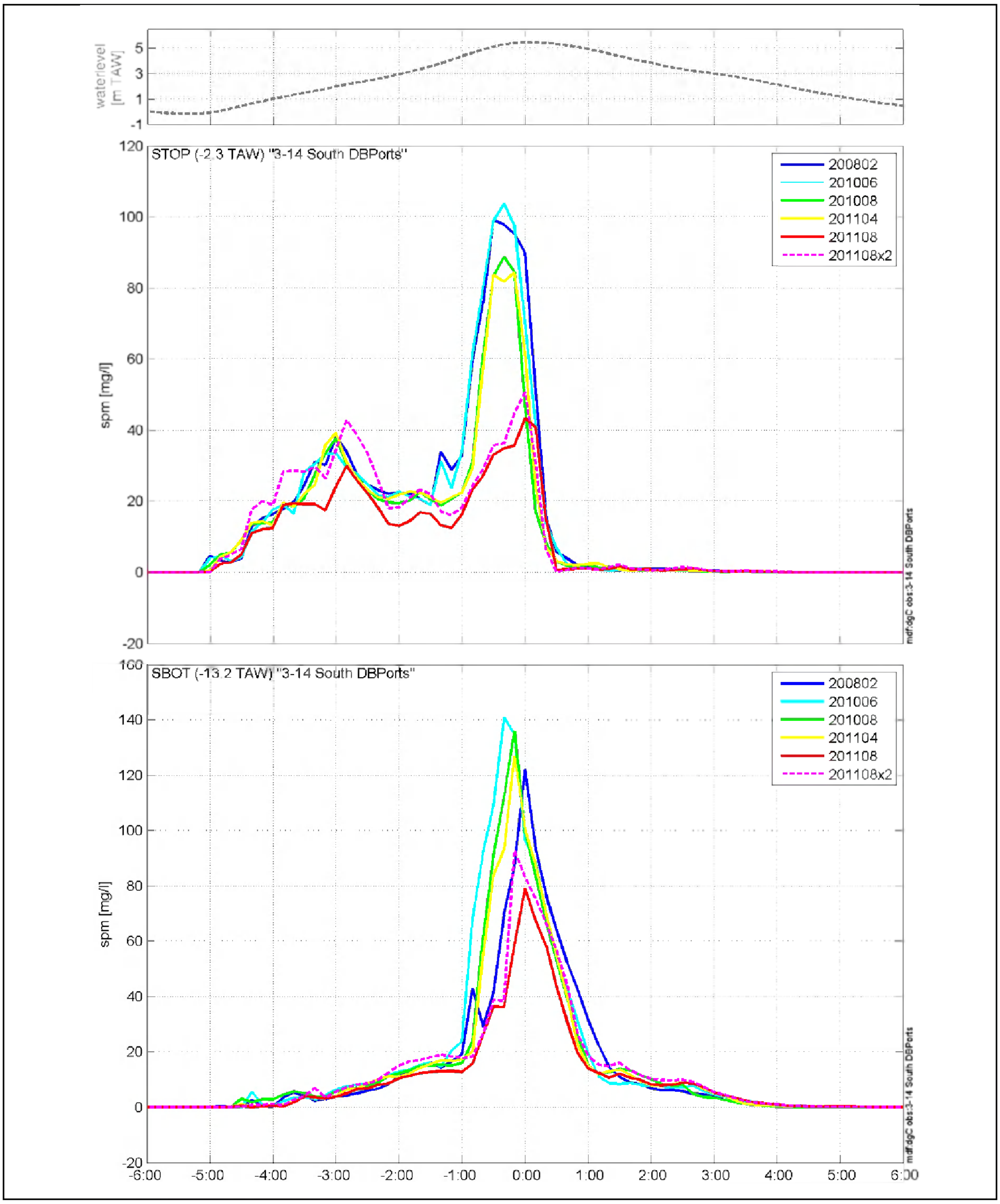
Figuur C.3. Tijdseries voor SPM concentraties op locatie Xb (XbBOT en XbTOP) tussen de noord-west zijde van het dok en de middellijn, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).



Figuur C.4. Tijdseries voor SPM concentraties op locatie Yb (YbBOT en YbTOP) op de middellijn van het dok, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).



Figuur C.5. Tijdseries voor SPM concentraties op locatie Zb (ZbBOT en ZbTOP) tussen de zuid-oost zijde van het dok en de middellijn, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).



Figuur C.6. Tijdseries voor SPM concentraties op locatie S (SBOT en STOP) aan de zuid-oost zijde van het dok, de kleurenlegenda verwijst naar scenario codes in Tabel B.1 (31 mei 01:00+12hr).

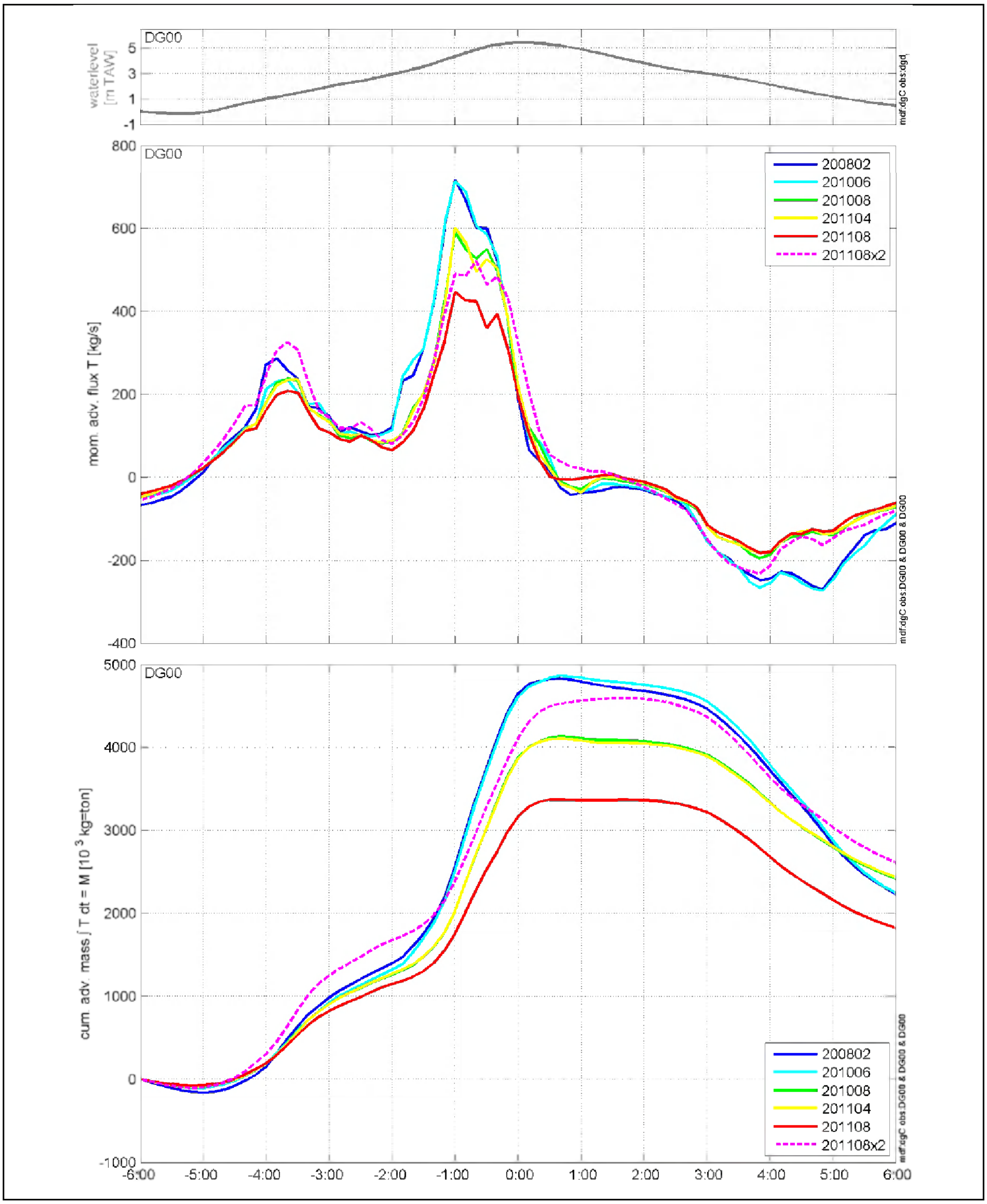
D. Transporten

De instantane en cumulatieve sediment transporten zijn geanalyseerd op een aantal transecten in het Deurganckdok. In het rapport Van Maren (2011) is melding gemaakt van onzekerheid aangaande het aandeel van sedimentatie op de drempel v.s. sedimentatie in het hele Deurganckdok. De sedimentatie op de drempel is namelijk aanzienlijk. Er zijn daarom twee transecten toegevoegd aan de Schelde-zijde van de laatste transect waar de kade muren parallel lopen. Delft3D kan transporten alleen massa-behoudend bijhouden door secties van gridlijnen. De ingang van het Deurganckdok loopt echter onder een hoek met de gridlijnen. Daarom zijn twee transecten met een knikje gekozen om de drempelzone mee te nemen, zie Figuur B.6: DG00 en DG0. De andere 5 transecten (DG1, DG3, DG5, DG7 en DG9) liggen in het rechthoekige binnendeel van het Deurganckdok.

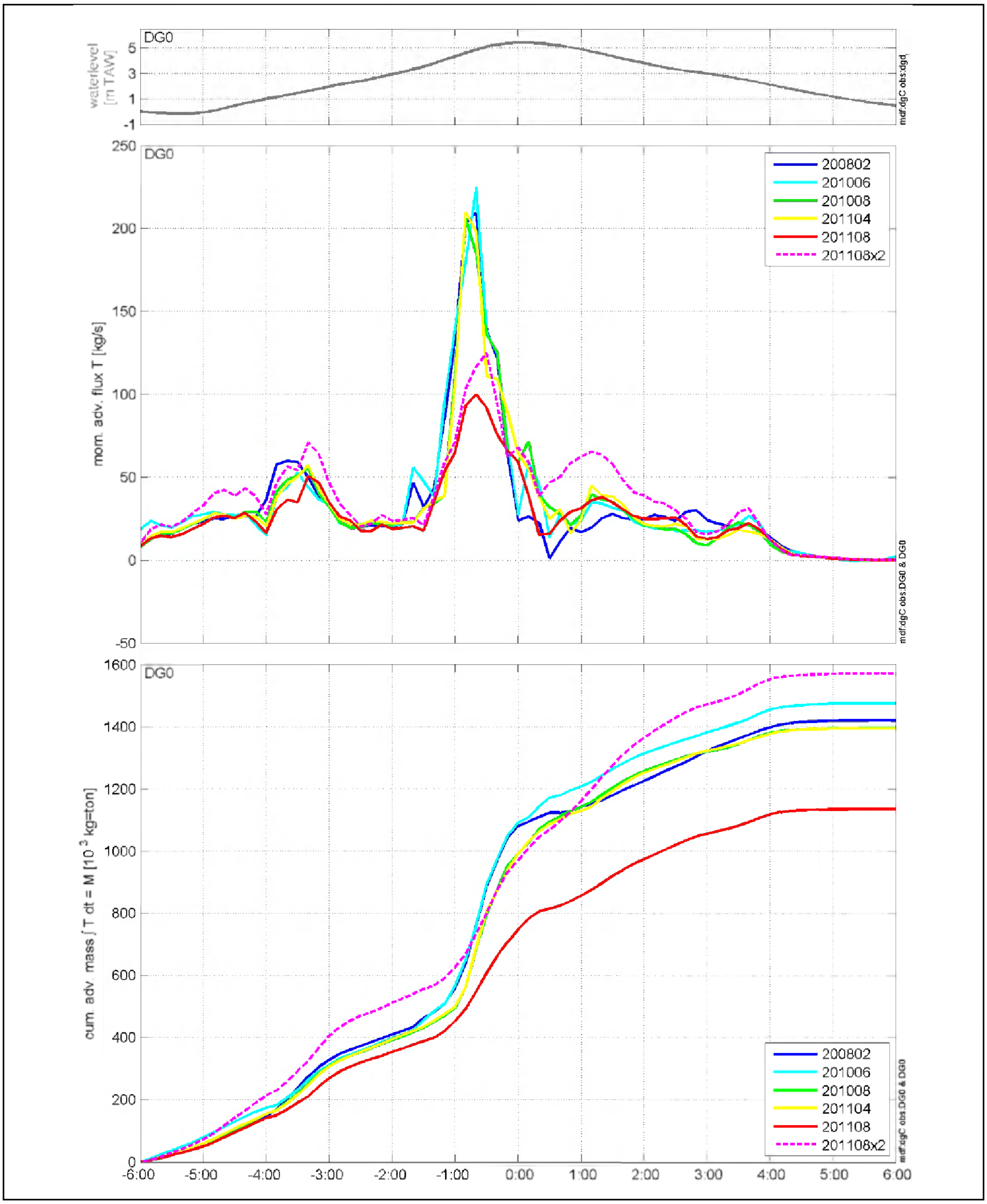
	Locatie	
D.1	DG00	Drempel en Schelde
D.2	DG0	Drempelzone
D.3	DG1	Parellelle dokkades
D.4	DG3	Parellelle dokkades
D.5	DG5	Parellelle dokkades
D.6	DG7	Parellelle dokkades
D.7	DG9	Parellelle dokkades

Tabel D.1. Observatie stations waarvoor modeldata uitgevoerd zijn in Figuur C.1-C.5.

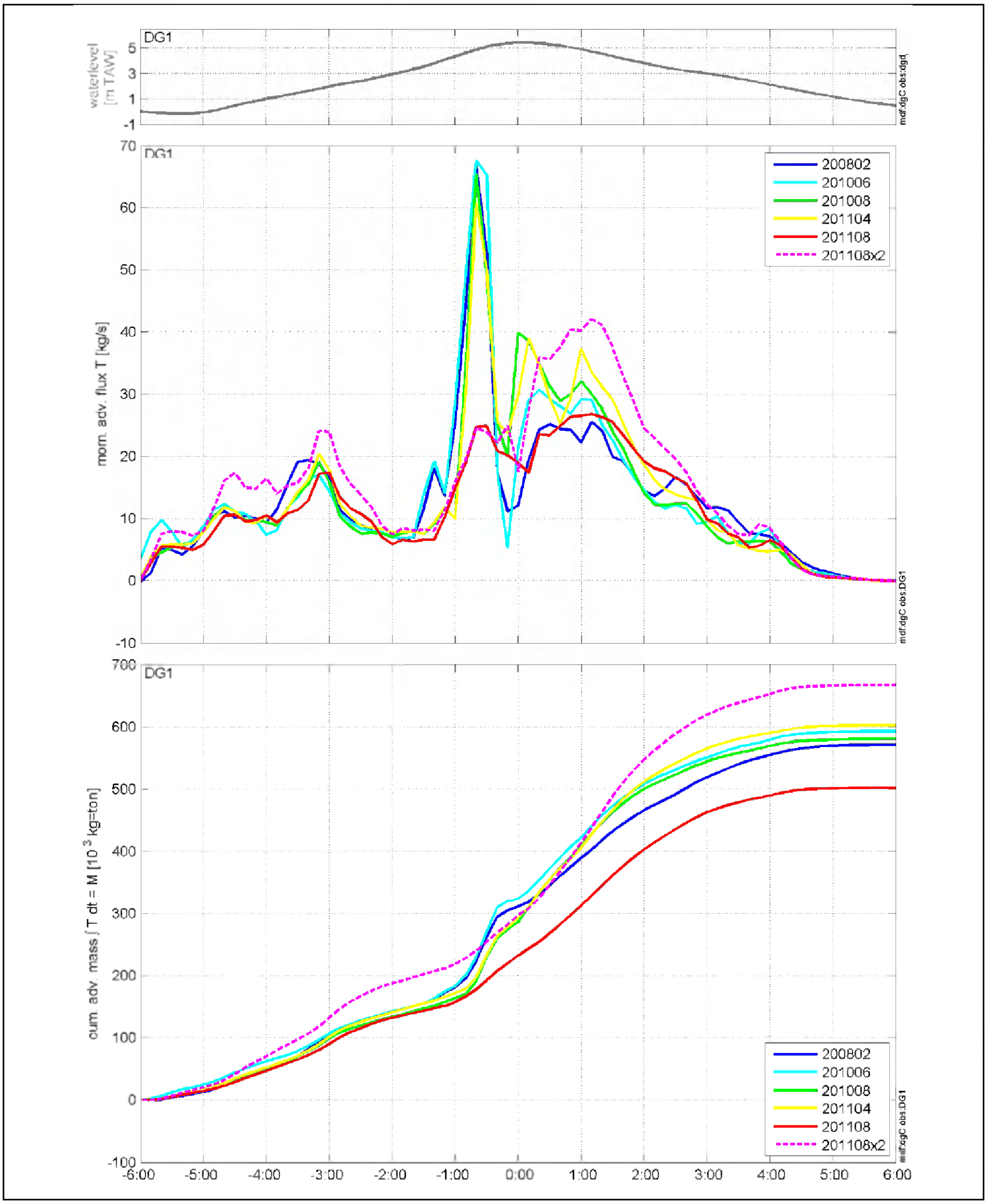
Deze transecten omsluiten vakken waarvoor in Figuren E.1 – E.6 de sedimentatie wordt onderverdeeld. Figuren D.1 – D.7 tonen de cumulatieve transporten. Het verschil tussen twee openvolgende transecten, bijv. DG0 en DG1, is wat achterblijft in het tussenliggende vak. Dit deel kent een aandeel van sediment in de waterfase en een aandeel van sediment op de bodem. Het deel op de bodem wordt in sectie E geanalyseerd. De cumulatieve transporten per getij in D en de sedimentatie per getij in E zijn niet 1 op 1 te linken door het aandeel van sediment de waterfase.



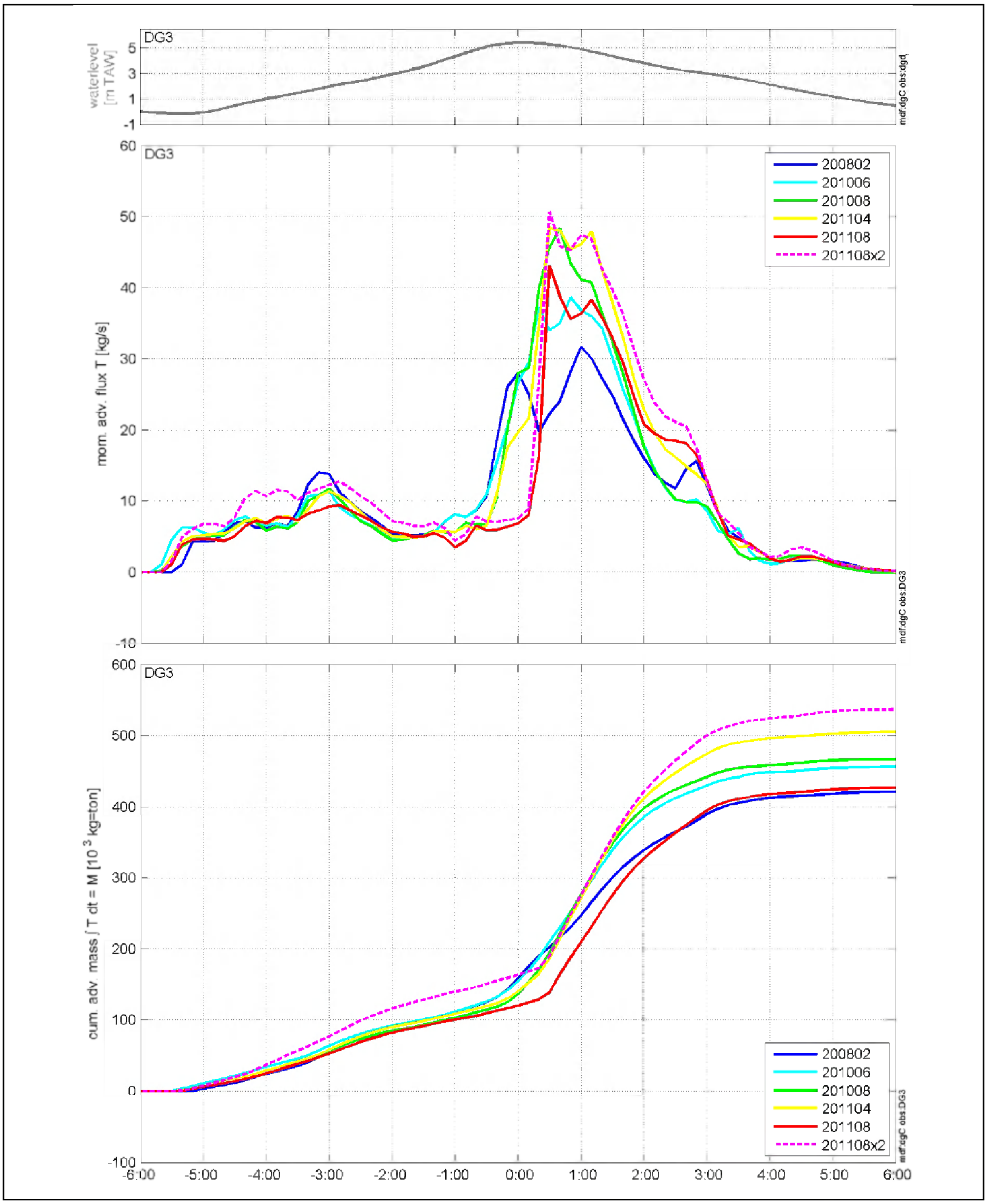
Figuur D.1. Instantane (boven) en cumulatieve (onder) transporten door transect DG00 (31 mei 01:00+12hr).



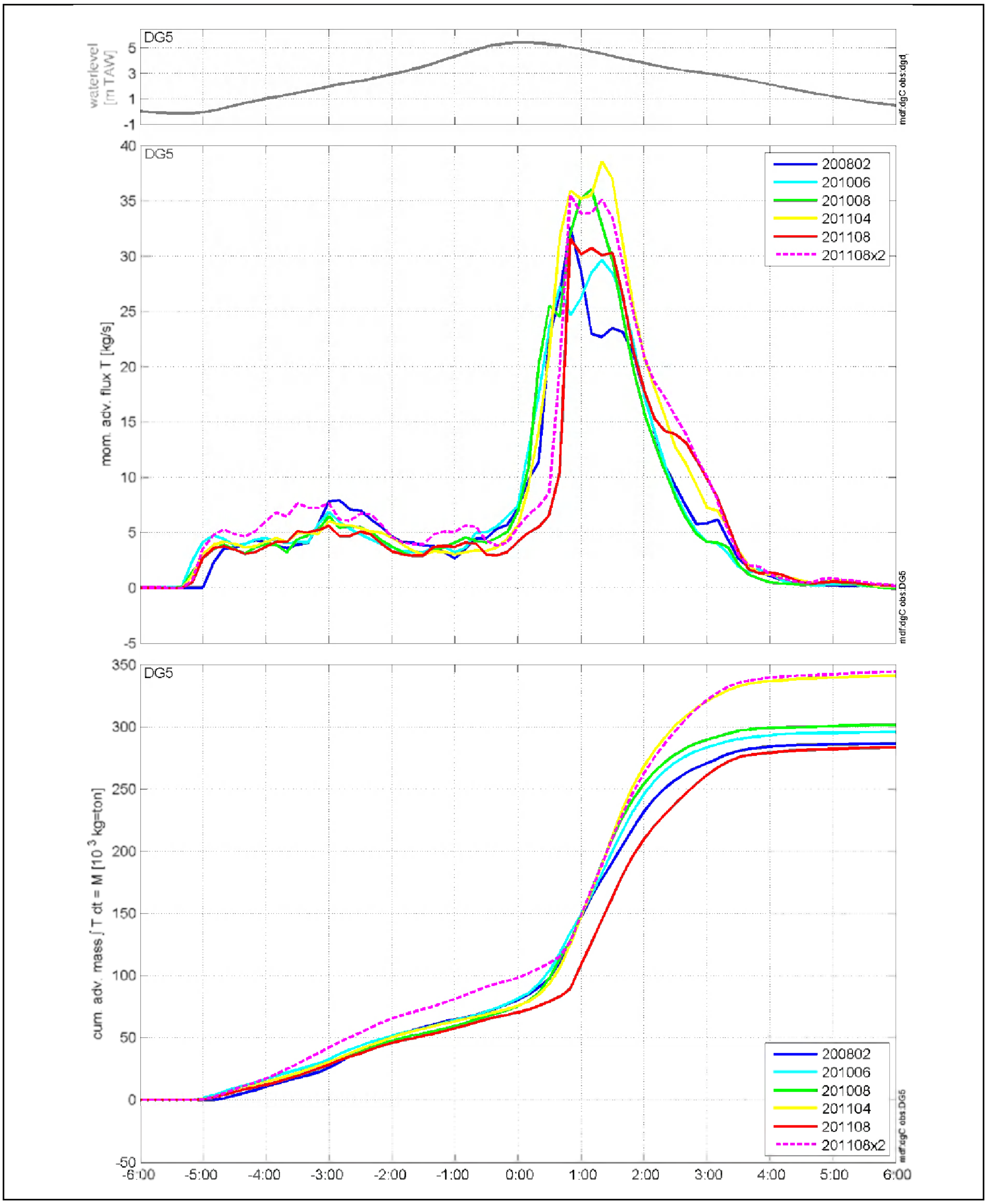
Figuur D.2. Instantane (boven) en cumulatieve (onder) transporten door transect DG0 (31 mei 01:00+12hr).



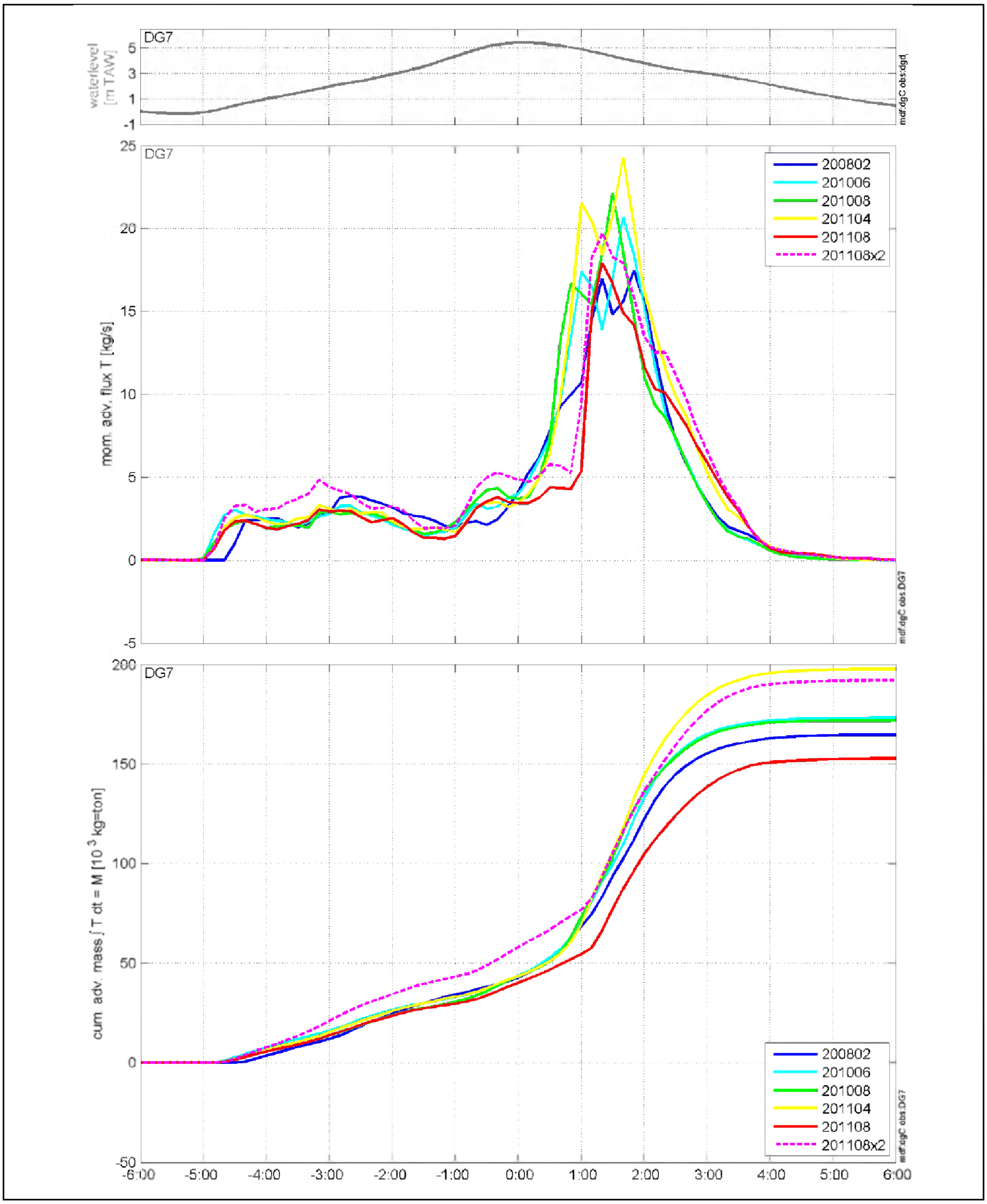
Figuur D.3. Instantane (boven) en cumulatieve (onder) transporten door transect DG1 (31 mei 01:00+12hr).



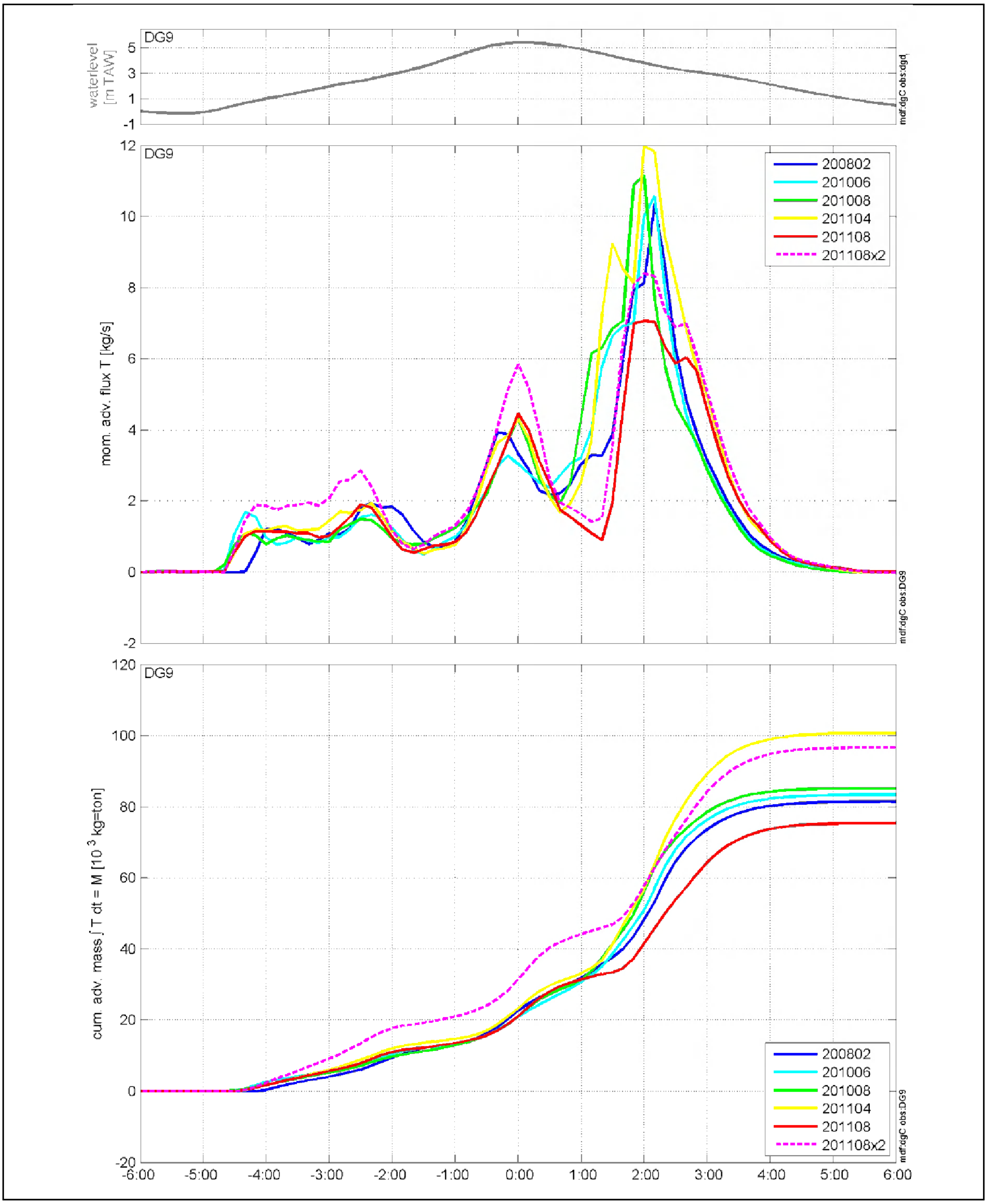
Figuur D.4. Instantane (boven) en cumulatieve (onder) transporten door transect DG3 (31 mei 01:00+12hr).



Figuur D.5. Instantane (boven) en cumulatieve (onder) transporten door transect DG5 (31 mei 01:00+12hr).



Figuur D.6. Instantane (boven) en cumulatieve (onder) transporten door transect DG7 (31 mei 01:00+12hr).



Figuur D.7. Instantane (boven) en cumulatieve (onder) transporten door transect DG9 (31 mei 01:00+12hr).

E. Aanslibbing

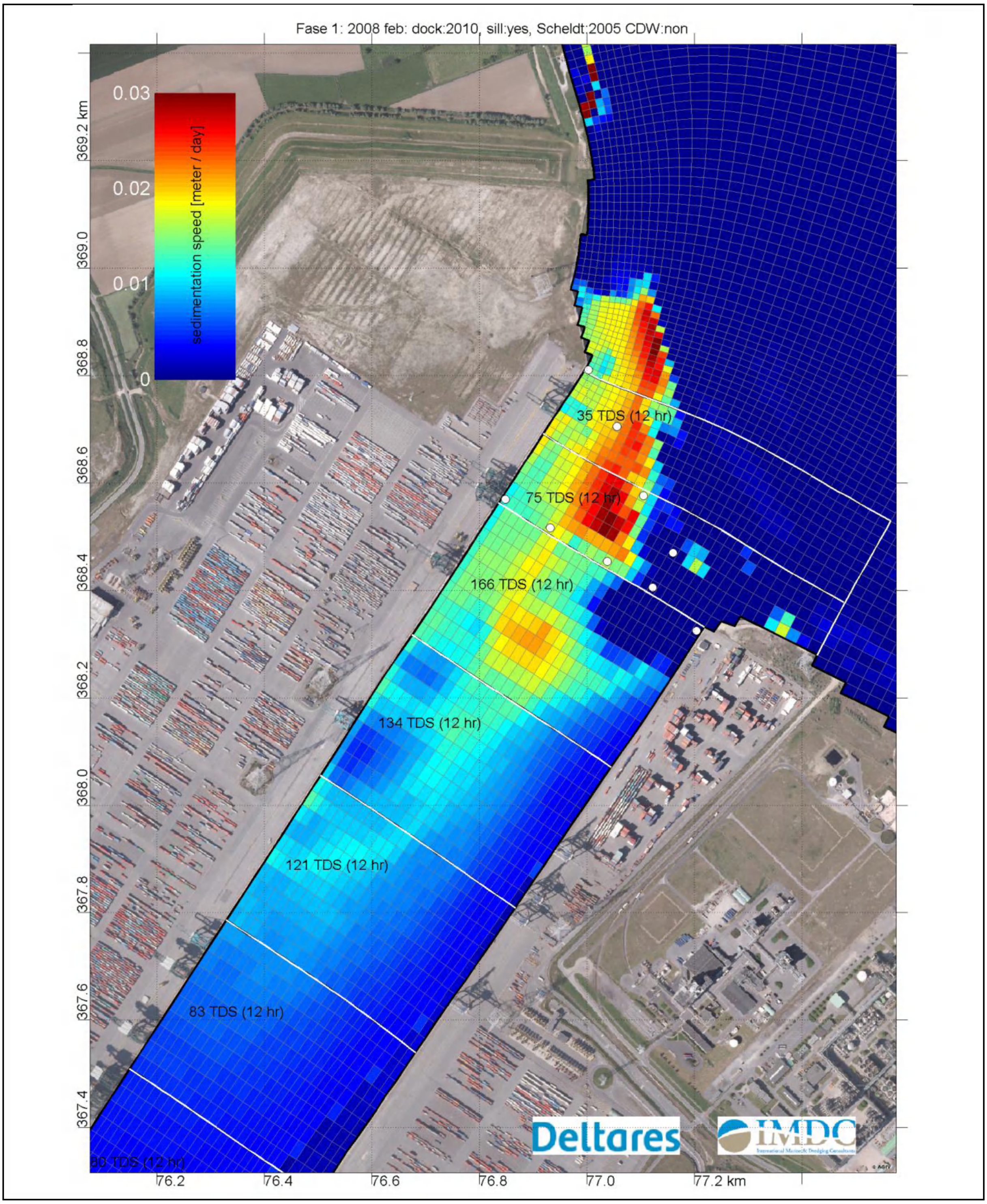
Voor elk scenario is de aanslibbing bepaald gedurende 21 getijde perioden van 12 uur, van 27 mei 13:00 tot 6 juni 01:00 (Figuur E.0). De aanslibbingscijfers per getij zijn iets lager (200-1800 TDS) dan de orde zoals vermeld in het analyse rapport (500 tot 2000 TDS/getij). De CDW in scenario 201108 leidt initieel tot een reductie van aanslibbing (t.o.v. het voorgaande scenario) van orde 40% rondom springtij tot 0% rondom doodtij, gemiddeld orde 20%+/- 20%. De toename voor scenario 201108x2 is lineair met de toename van de concentraties op de Schelde (Figuur C.1-C.6.). Initieel is het inspelen nog niet geheel voltooid (Figuur C.0), maar ook aan het eind van de simulatie verdubbelen de transporten niet. Wel zijn de hogere sediment concentraties in staat de sedimentatie in het dok te doen toenemen t.o.v. alle voorgaande scenario's, ondanks aanwezigheid van de CDW in deze fase.

Van 1 representatieve getijperiode tussen doodtij en springtij in zijn de getallen in Tabel E.1 opgenomen voor subtransects in het hele dok (Figuur B.6). In Figuren E.1 t/m E.6 zijn deze getallen ingetekend op de sedimentatie kaarten.

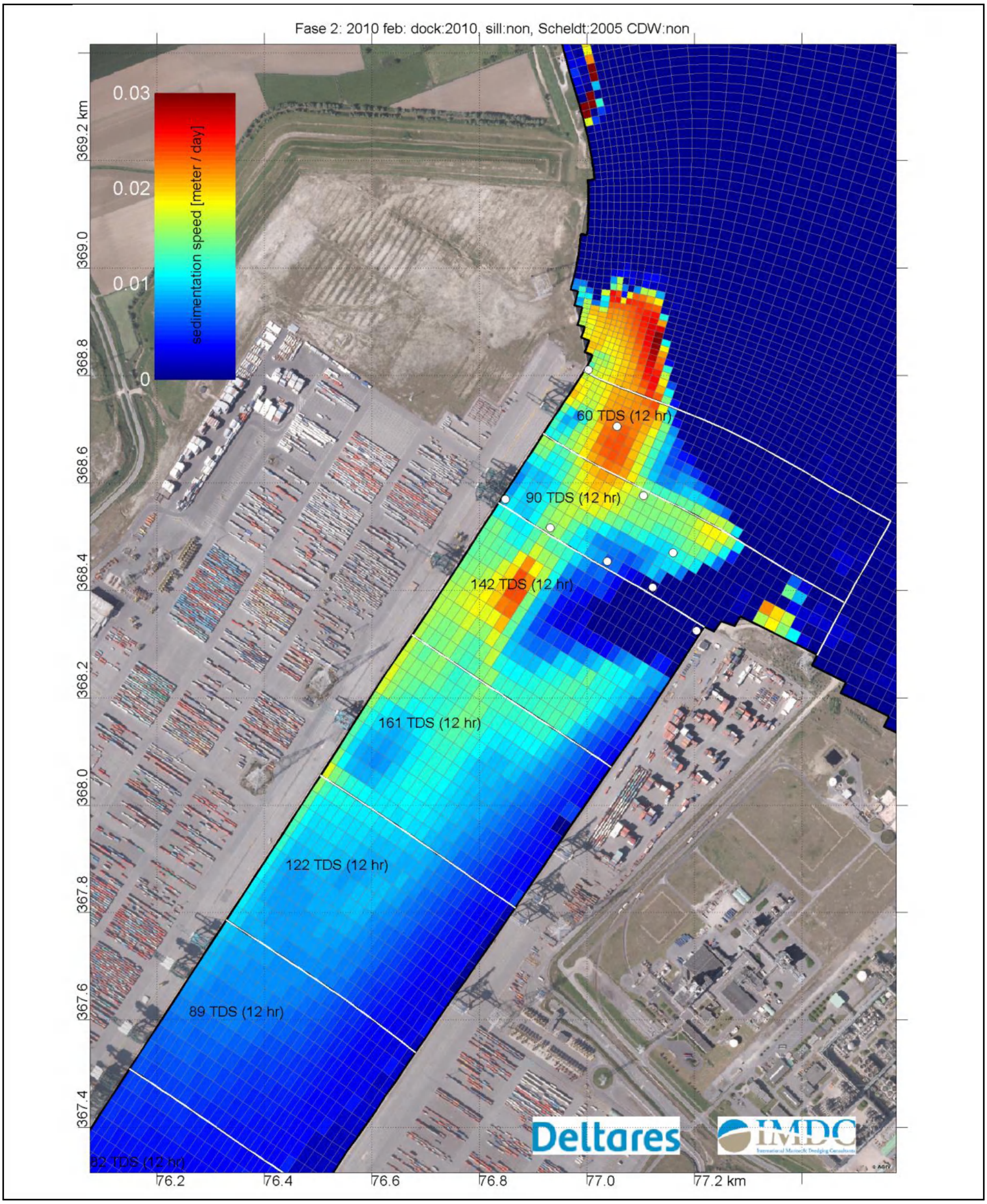
id	Eind				TDS excl. drempel		Tpv Schelde, TDS incl drempel	% verandering t.o.v. *voorgaande* fase
id	< DG9	DG9 - DG7	DG7-DG5	DG5-DG3	DG3-DG1	DG1-DG0	DG0-DG00	DG0-DG00
1200802	80	163	284	419	585	660	695	0.0%
201006	82	172	294	454	597	687	748	7.6%
201008	84	170	299	464	585	655	721	-3.5%
201104	99	195	337	501	604	653	714	-1.0%
201108	74	151	281	423	501	546	594	-16.9%
201108x2	95	190	340	532	666	763	858	44.5%

Tabel E.1. Zie Tabel D-1. Waardes voor periode van 12 uur tussen doodtij en springtij in (31 mei 01:00+12hr). Deze periode komt overeen met de periode getoond in de Figuren C, D en E.

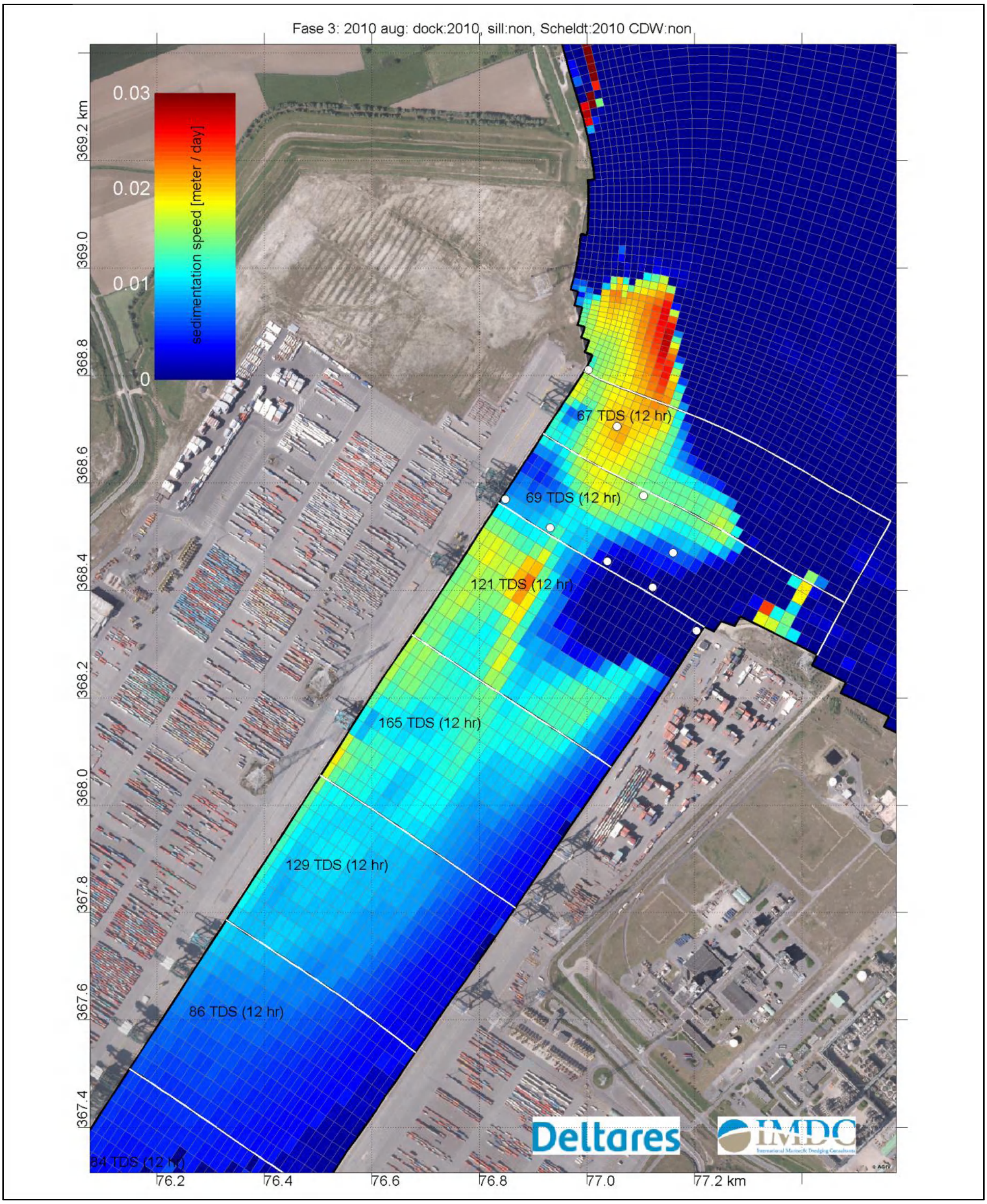
Figuur E.0. Aanslibbing in Deurganckdok met en zonder drempel gedurende simulatie periode.



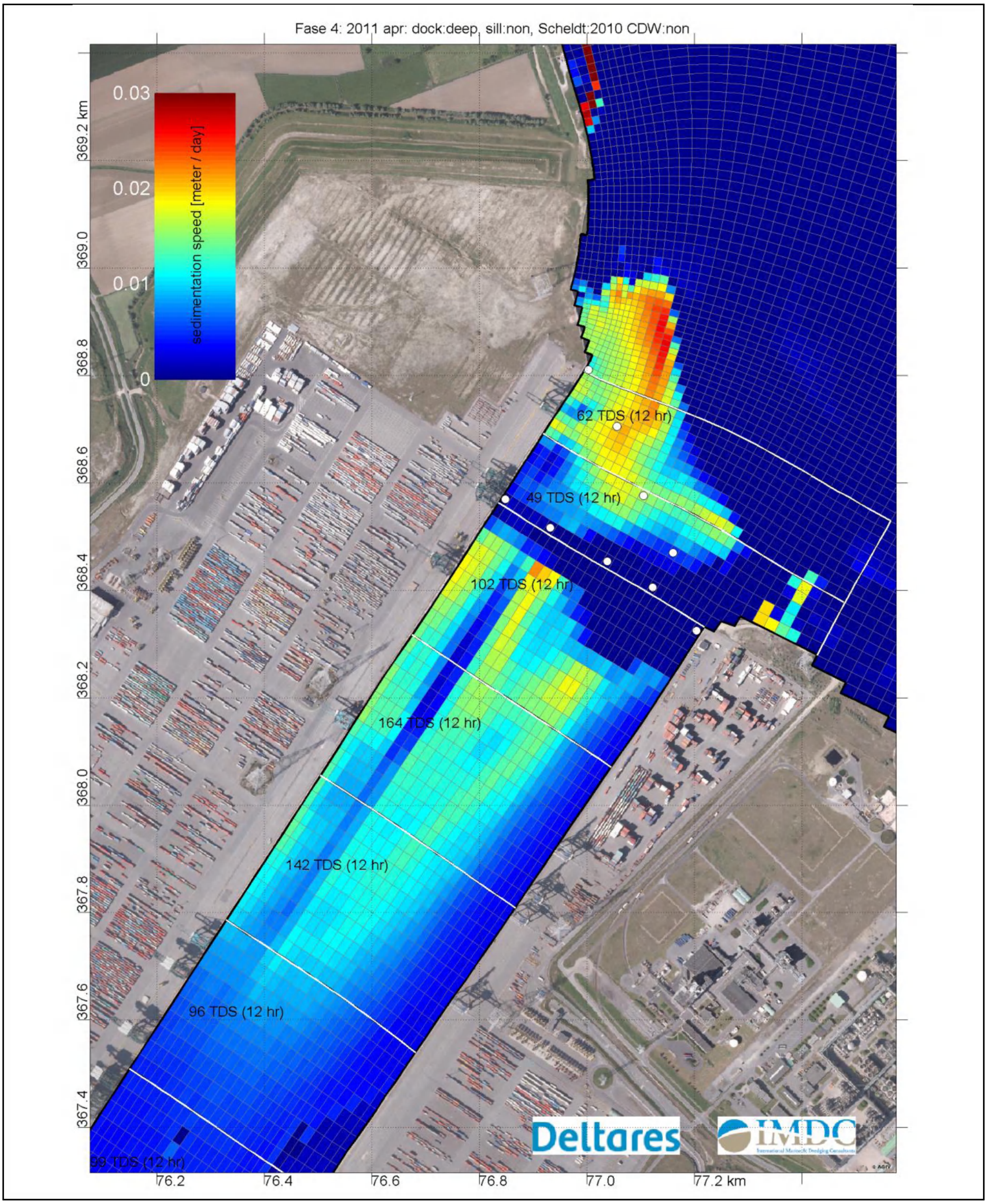
Figuur E.1. Sedimentatie kaart voor scenario 200802 (31 mei 01:00+12hr, Tabel E.1), zie Tabel B.1.



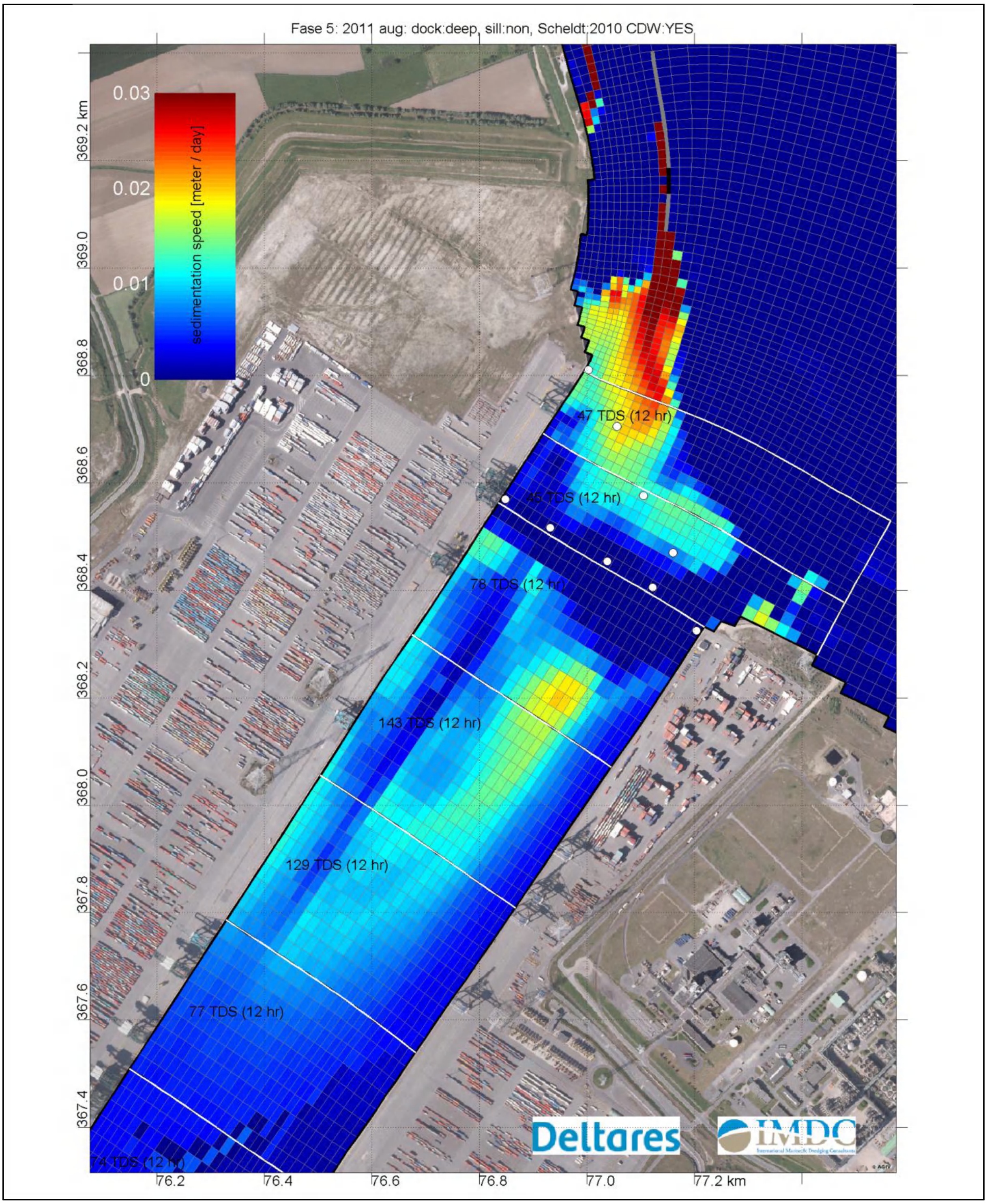
Figuur E.2. Sedimentatie kaart voor scenario 201006 (31 mei 01:00+12hr, Tabel E.1), zie Tabel B.1.



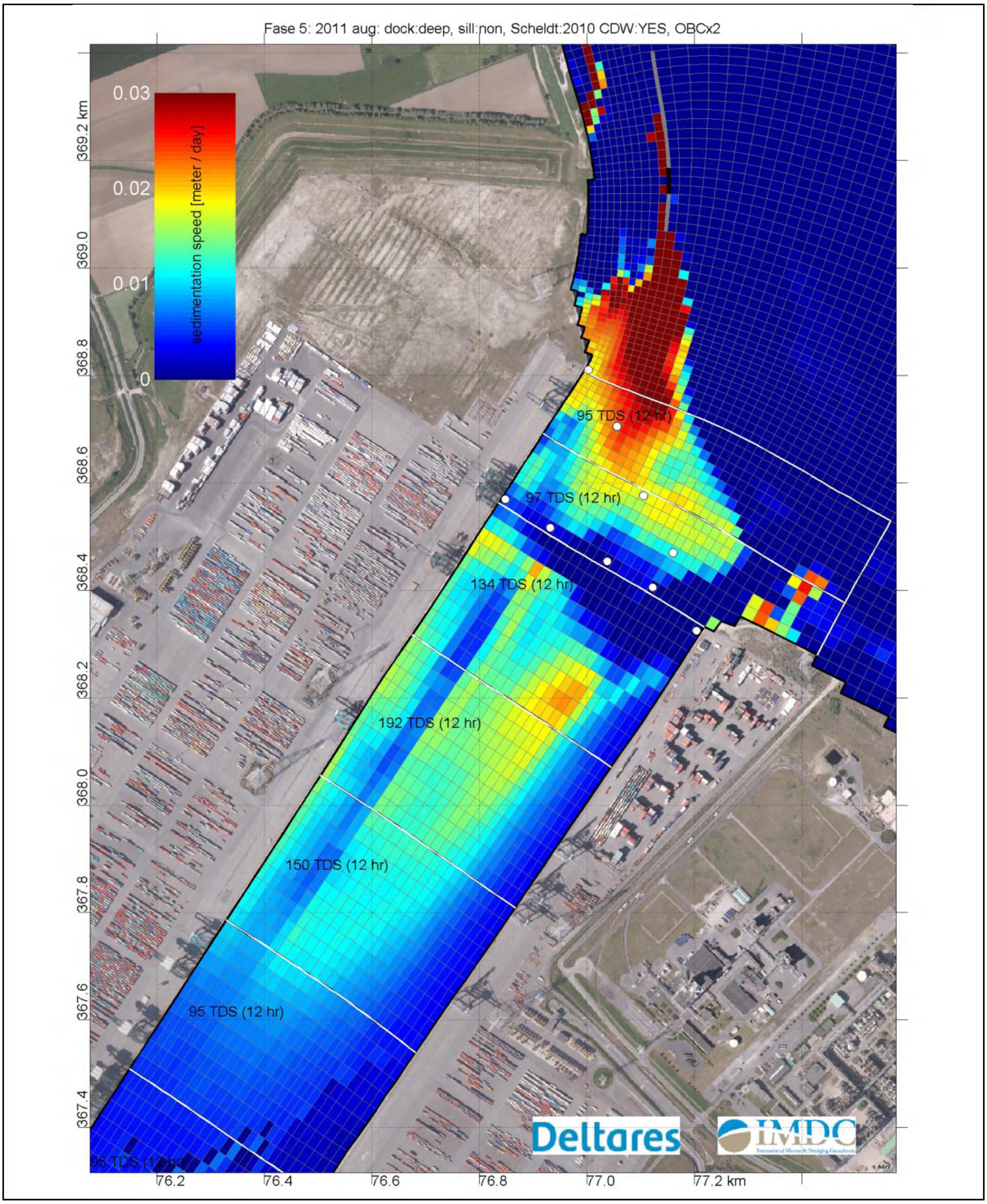
Figuur E.3. Sedimentatie kaart voor scenario 201008 (31 mei 01:00+12hr, Tabel E.1)zie Tabel B.1.



Figuur E.4. Sedimentatie kaart voor scenario 201104 (31 mei 01:00+12hr, Tabel E.1)zie Tabel B.1.



Figuur E.5. Sedimentatie kaart voor scenario 201108 (31 mei 01:00+12hr, Tabel E.1)zie Tabel B.1.



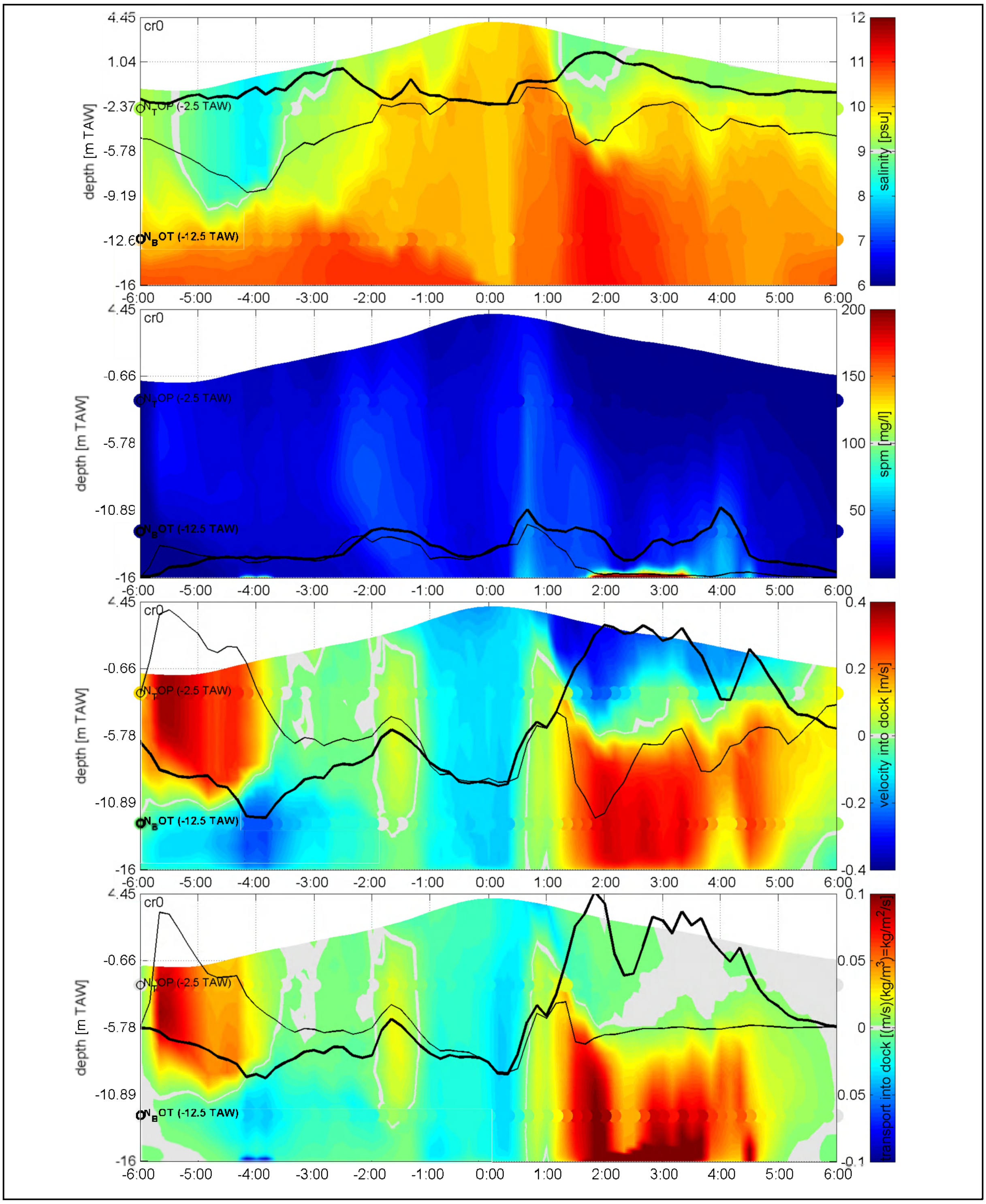
Figuur E.6. Sedimentatie kaart voor scenario 201108x2 (31 mei 01:00+12hr, Tabel E.1)zie Tabel B.1.

F. Transport mechanismen

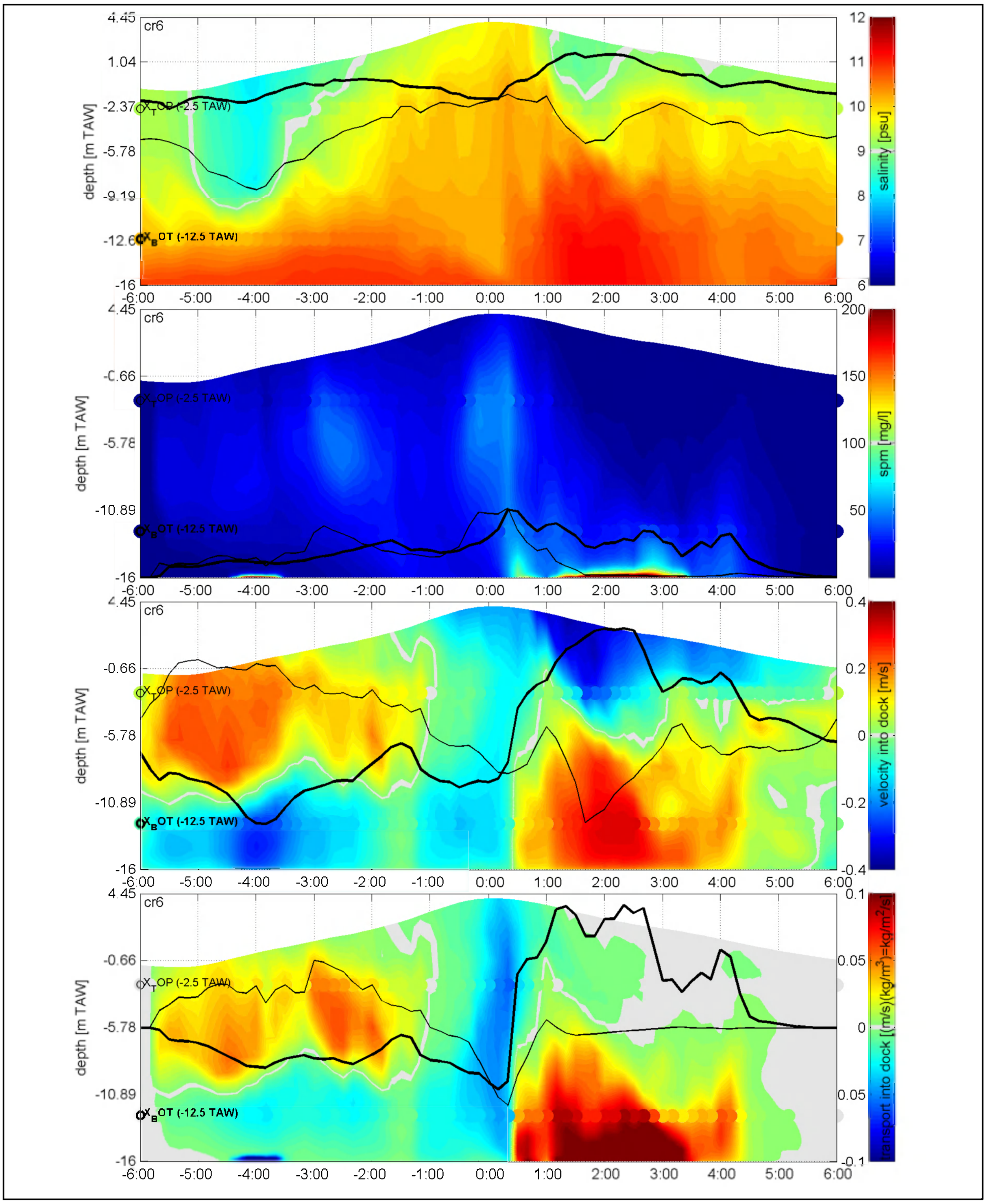
Om inzicht te kunnen verkrijgen in de transport mechanismen is in het midden van de ingang van het Deurganckdok - waar de kades parallel zijn (zie Figuur B.6) - de verticale verdeling van het sediment transport geanalyseerd. Dit is ter plaatse van transect DG1, waarvoor de geïntegreerde transporten al getoond zijn in Figuur D.3 (zwarte lijn in Tabel E.1). Op deze transect is elke 10 minuten op elke roostercel op elk van de 40 modellagen alle informatie weggeschreven. Dit levert 3D matrices op (tijd *t* x afstand *s* x hoogte *z*) voor de snelheid *u* en de SPM concentraties *c*. Met de volledige matrices *u*, *c* en de waterstanden kan de aard en tijd-ruimte verdeling van de transporten bepaald worden. De geïntegreerde transporten ter plaatse van transect DG1 (geïntegreerd over de hoogte en over de breedte van de transect) waren al in Figuur D.3 getoond. Deze worden massa-behoudend door het rekenmodel intern bijgehouden. Een analyse van de 3D matrices *u* en *c* zal niet tot identieke transporten leiden, omdat een dergelijke a posteriori analyse niet geheel massabehoudend is. Daar zijn een aantal redenen voor: de tijdsfluctuaties op halve en hele tijdstap niveau zijn verloren gegaan in de 10-minuten waardes, en de snelheden zijn gemiddeld tgv rooster staggering.

In sectie F, G, H en I laten we doorsneden zien van de 3D matrices *u*, *c* en hun product *uc* langs 3 assen. In paragraaf J worden de geïntegreerde transporten geanalyseerd op basis van drie bekende uitwisselingsmechanismen.

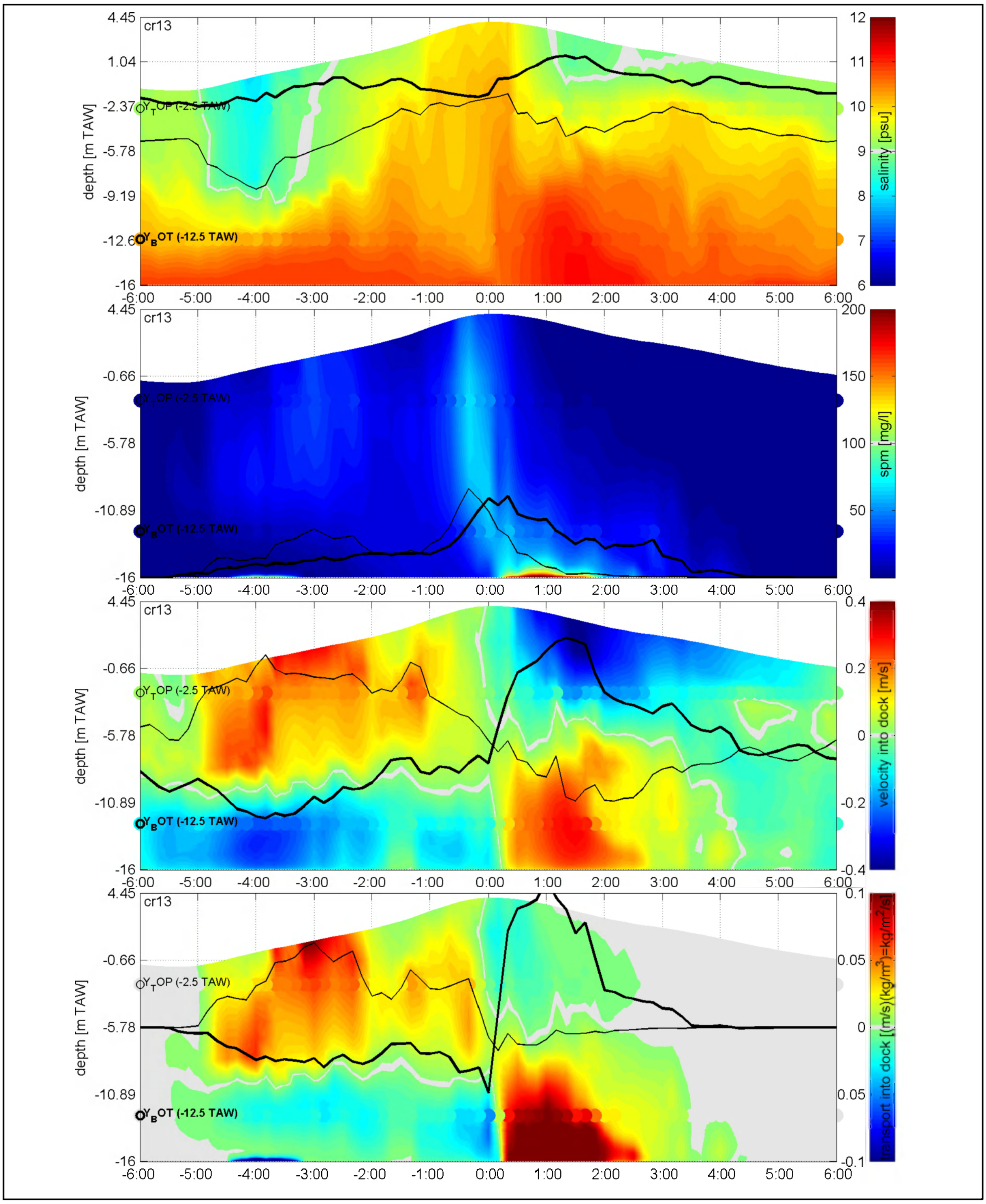
- F: Doorsnede (*t-z*) per transect locatie: Op een vijftal cellen op de transect (die totaal 27 roostercellen meet) zijn de volledige *t-z* tijdseries van vertikale profielen uitgevoerd. Hiervoor is meetstation S genomen, alsmede 4 stations die dokinwaarts liggen van de meetlocaties N, Xb, Yb en Zb. Deze 5 stations liggen op gelijke onderlinge afstand van 1/3 van de breedte van het dok. De gekozen stations op deze transects hebben dezelfde lettercode gekregen als de gemeten stations op dezelfde lijn parallel aan de lange as van het dok, met een underscore als suffix: N_, X_, Y_ en Z_ op een lijn met N, Xb, Yb en Zb. Stations S hoefde niet gedupliceerd te worden omdat die precies ligt aan het begin van de parallelle kades. Vanwege de omvang wordt alleen scenario *201108* getoond. In worden voor locatie Y_ alle scenario's getoond.
- G: Doorsnelde (*x-t*) per verticale laag: Op de laag nabij de diepte van de diepste sensor NBOT en SBOT, -12.5 TAW, zijn alle variabels geplot.
- H: Doorsnede (*x-z*) per tijdstap: Van deze filmpjes zijn twee frames getoond vlak voor Hoog Water, op het moment dat in de scenario's zonder CDW maximale import te zien was: -1:00 en -0:30. Deze import piek is volgens het model effectief door de CDW onderdrukt (Figuur D.2 en D.3).
- I: Doorsnede (*t-z*) per transect locatie. De figuren uit paragraaf F worden herhaald voor locatie Y_, voor alle scenarios.



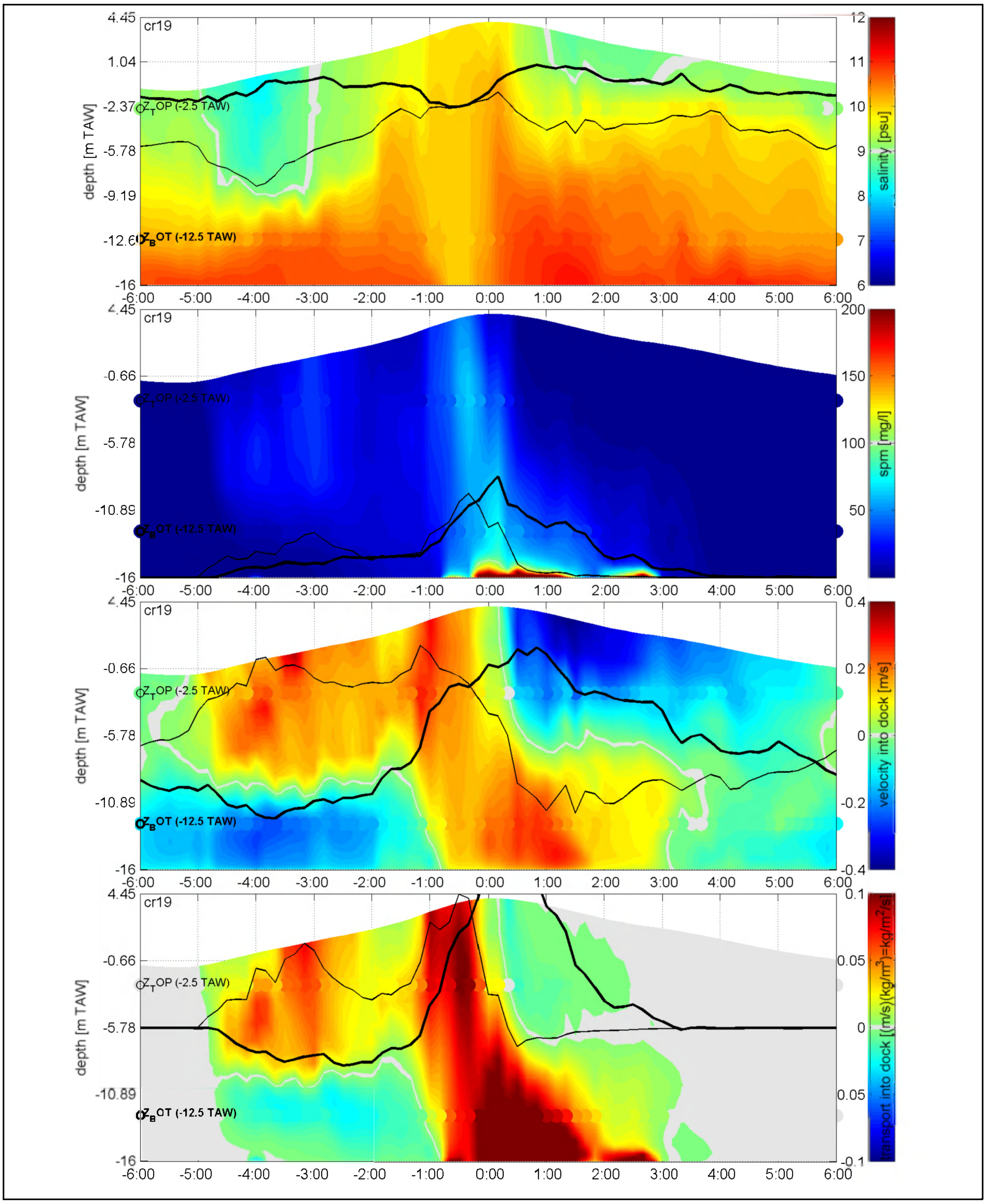
Figuur F.1. Verticale verdeling SPM transport te locatie N_ ter plaatse van transect DG1 (scenario 201108, 31 mei 01:00+12hr).



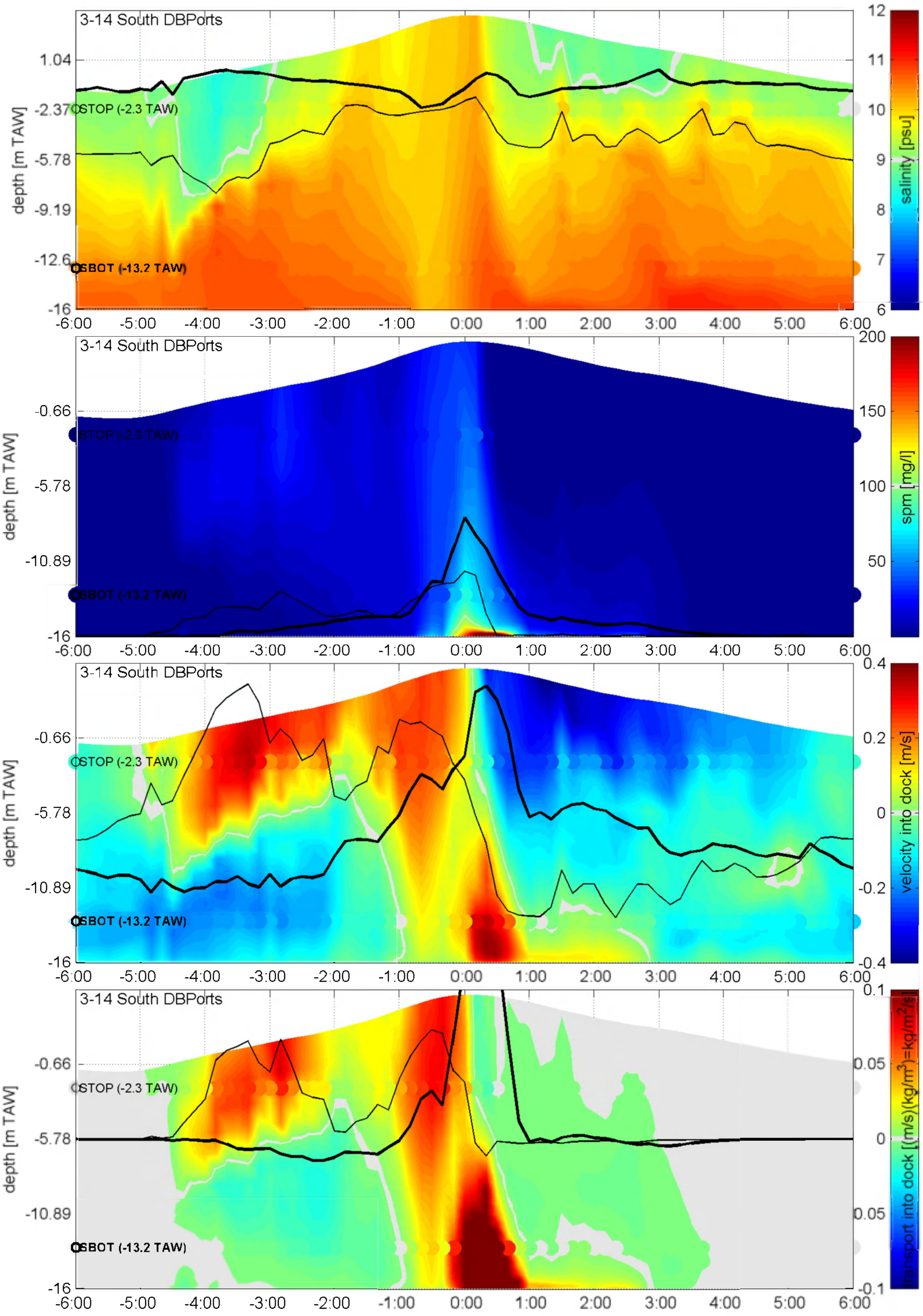
Figuur F.2. Verticale verdeling SPM transport te locatie X_ ter plaatse van transect DG1 (scenario 201108 31 mei 01:00+12hr).



Figuur F.3. Verticale verdeling SPM transport te locatie Y_ ter plaatse van transect DG1 (scenario 201108 31 mei 01:00+12hr). In paragraaf I wordt deze locatie voor alle scenario's getoond.

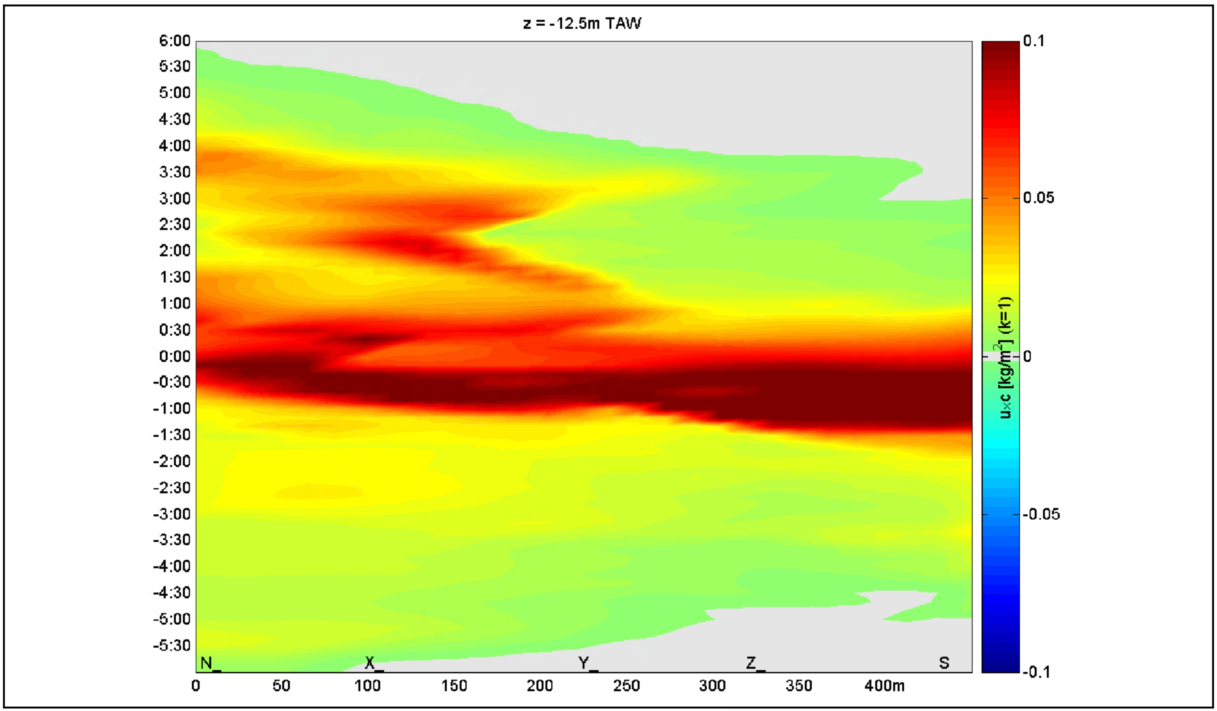


Figuur F.4. Verticale verdeling SPM transport te locatie Z_ ter plaatse van transect DG1 (scenario 201108 31 mei 01:00+12hr).

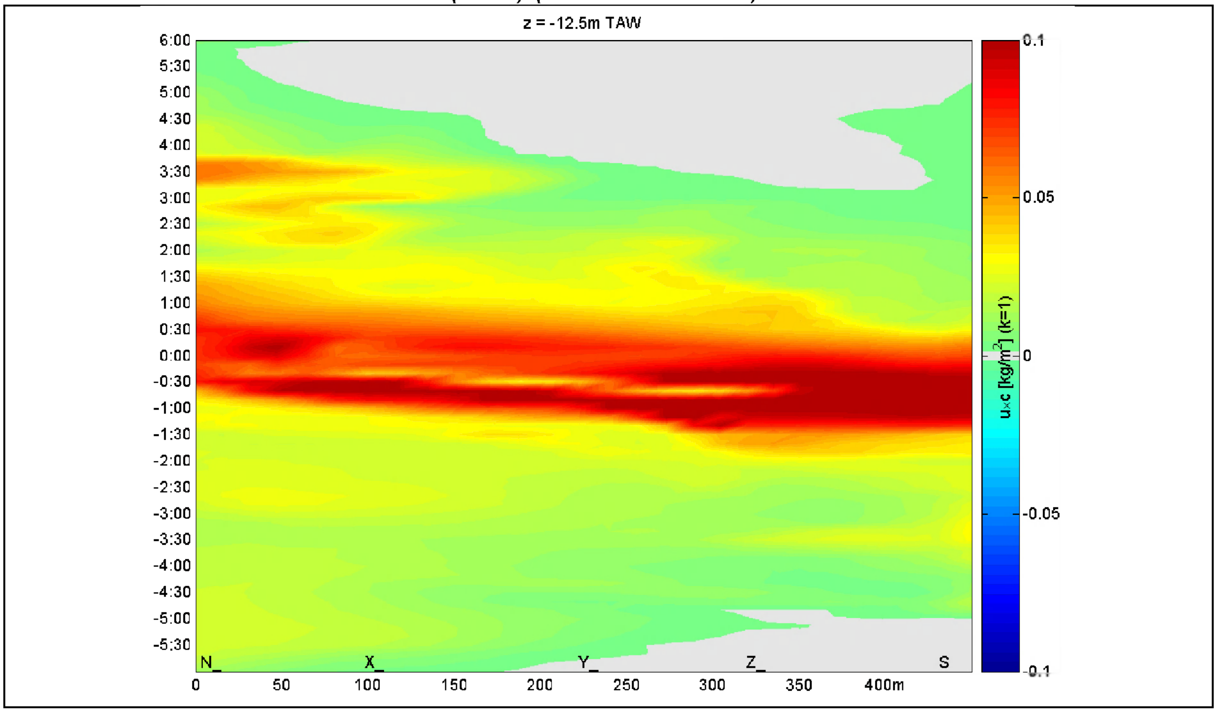


Figuur F.5. Verticale verdeling SPM transport te locatie S ter plaatse van transect DG1 (scenario 201108 31 mei 01:00+12hr), hetzelfde station als getoond in Figuur C.6.

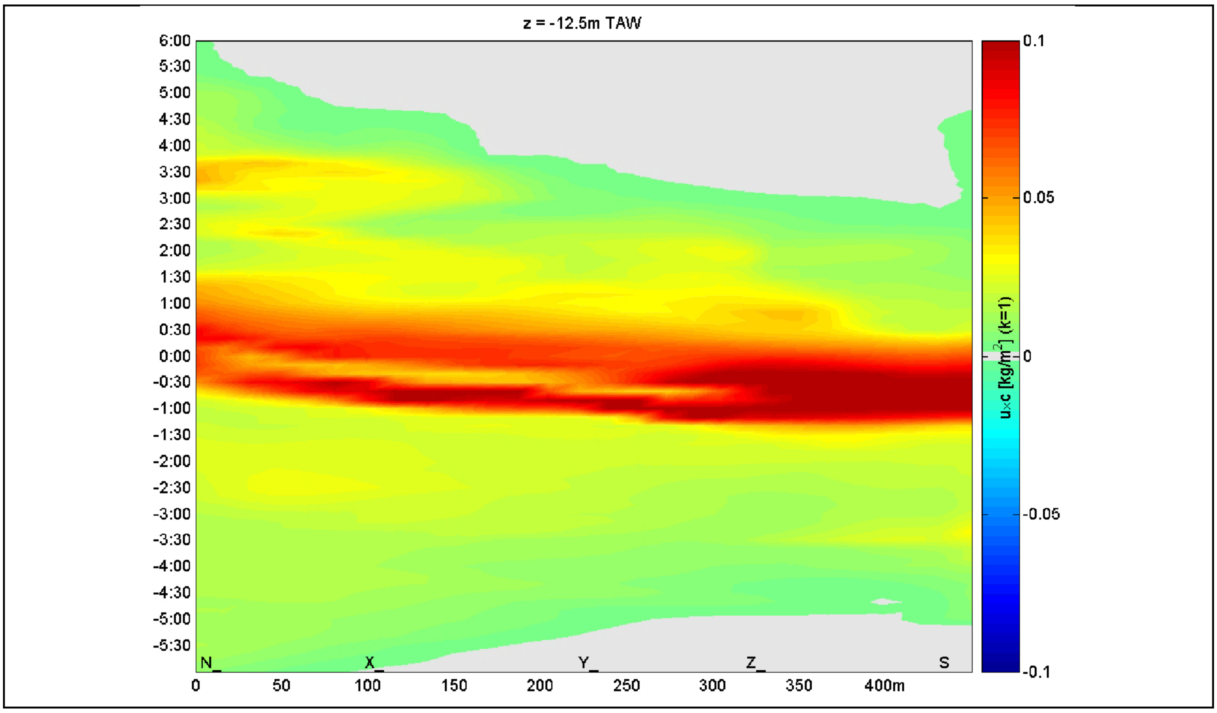
G. Sediment import in de bodemlaag



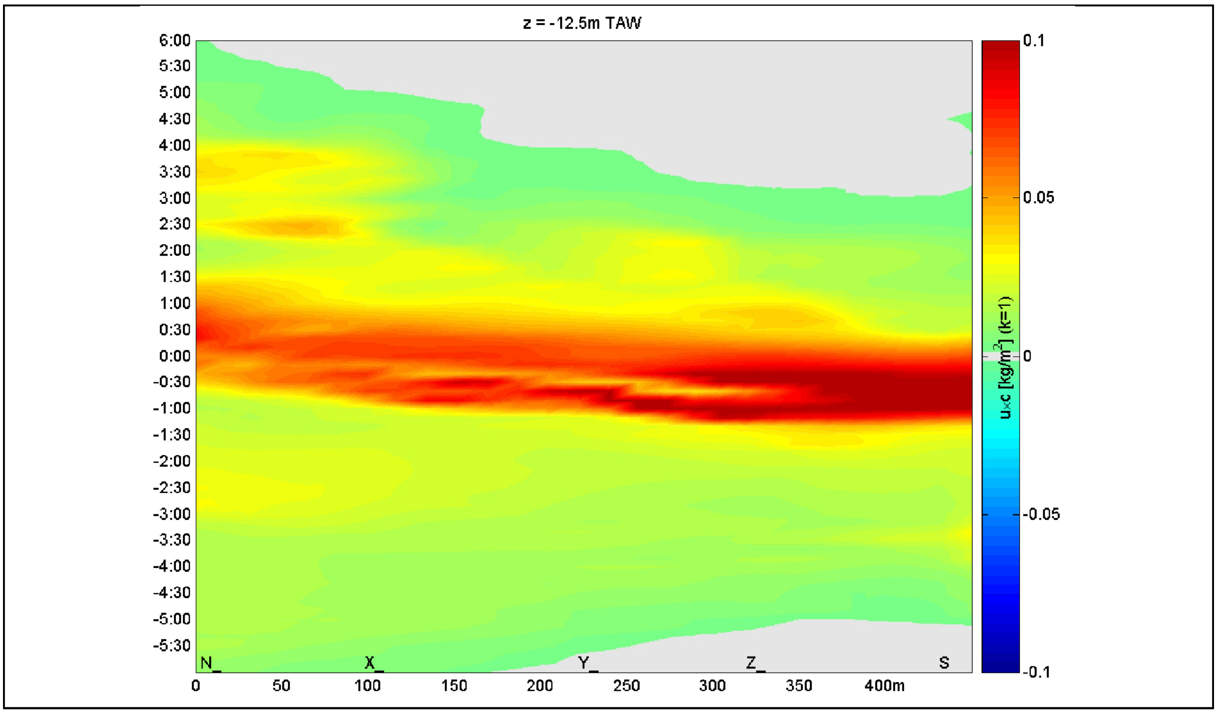
Figuur G.1. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr) voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 200802).



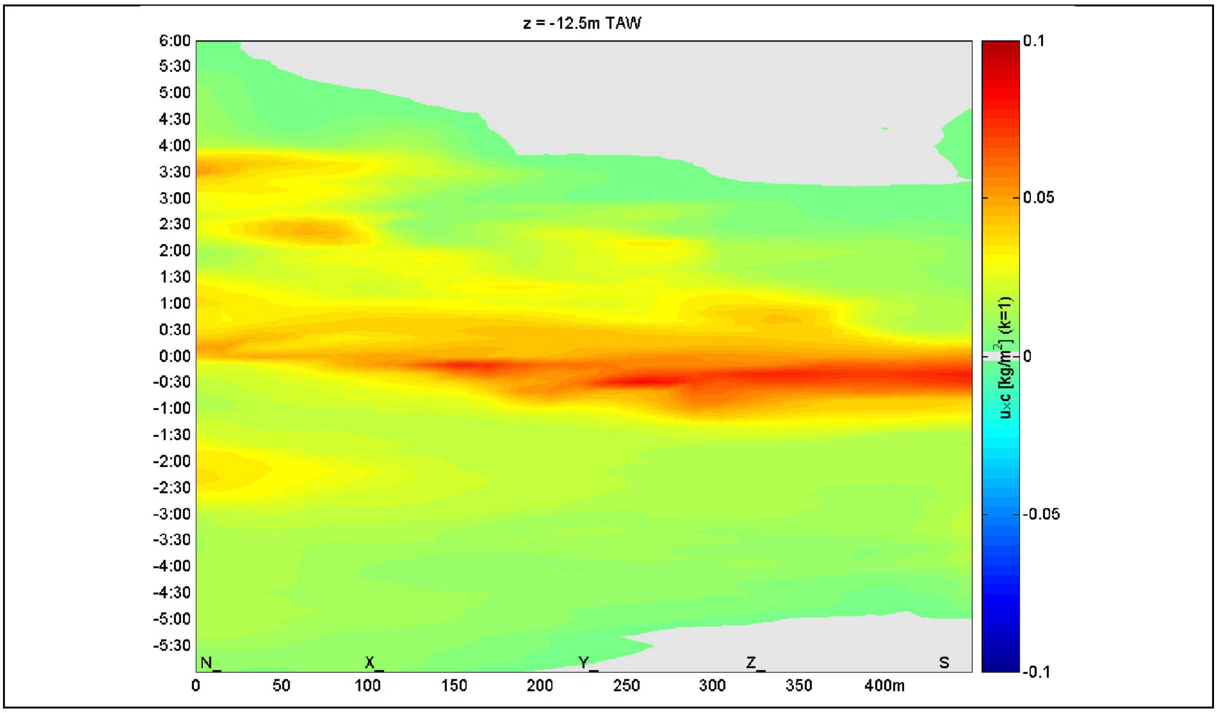
Figuur G.2. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr)voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 200806).



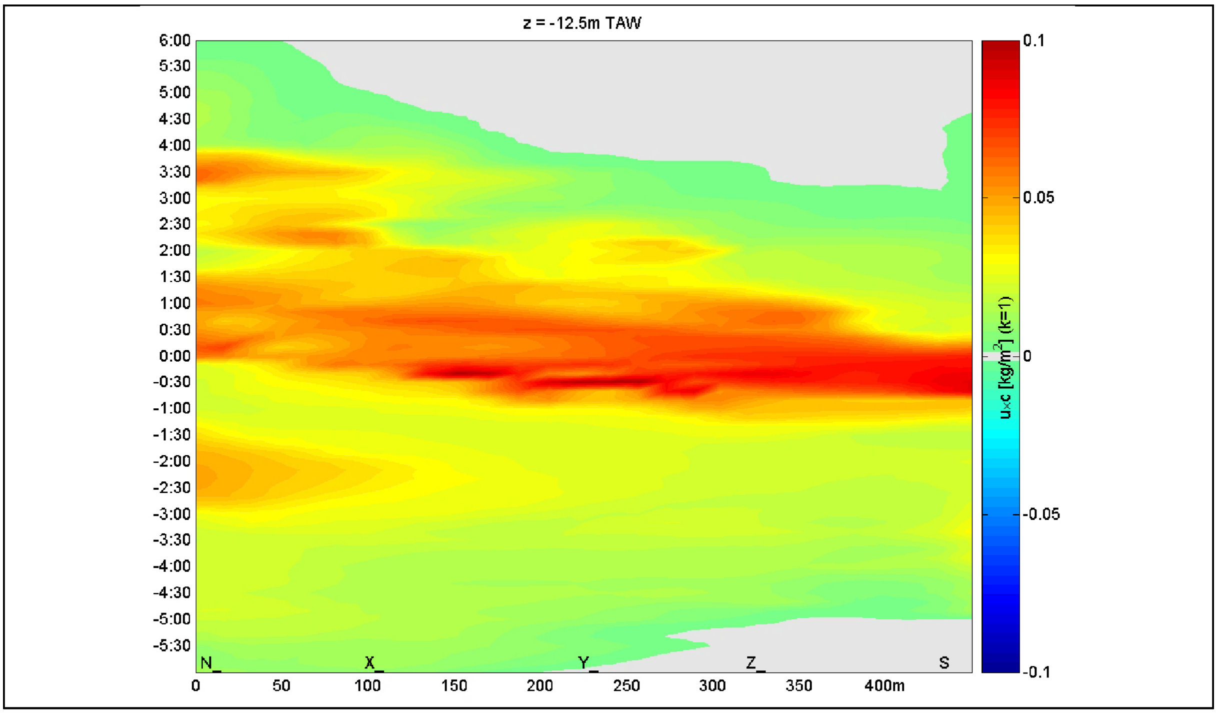
Figuur G.3. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr)voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 201006).



Figuur G4. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr)voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 201104).

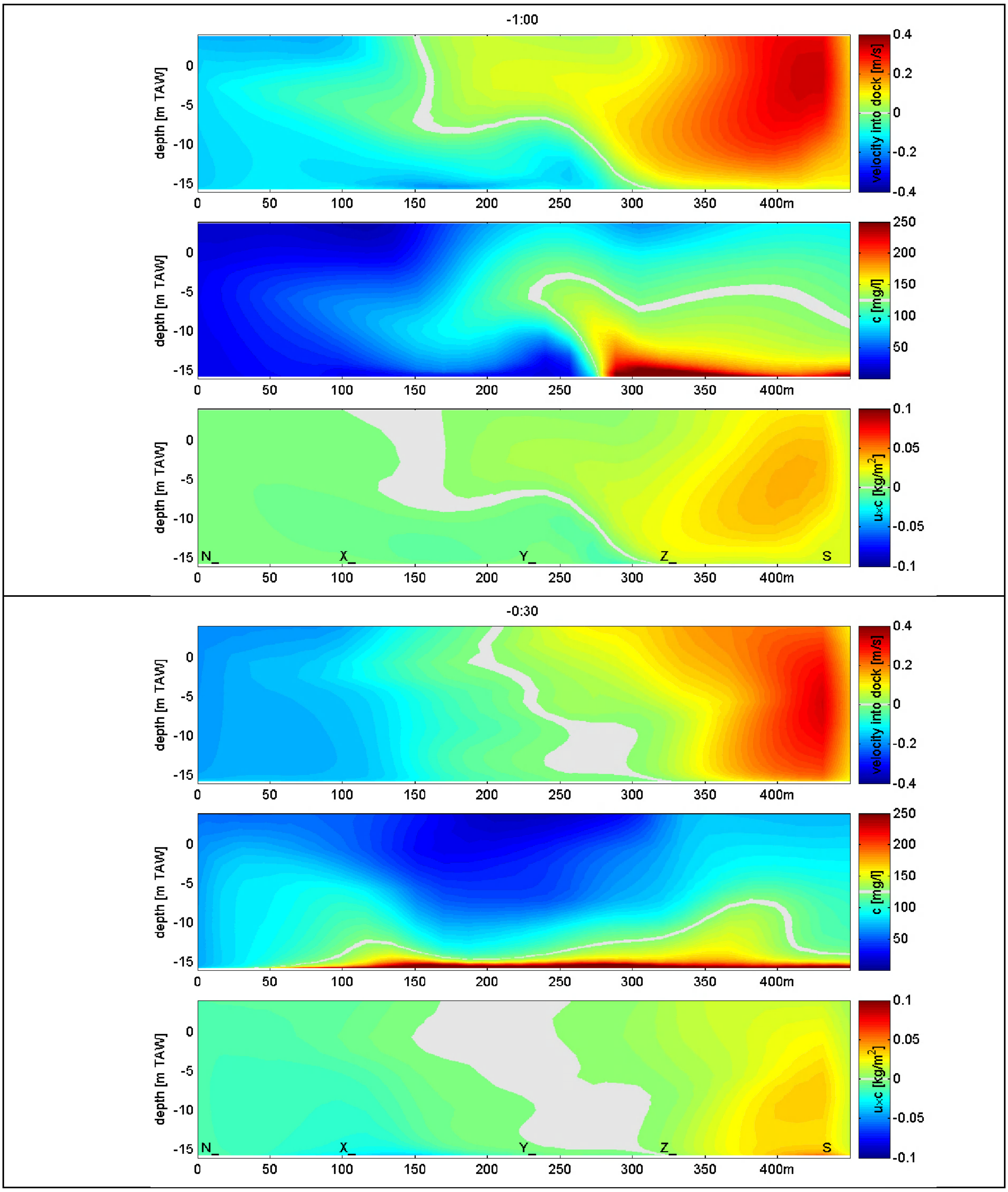


Figuur G.5. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr)voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 201108).

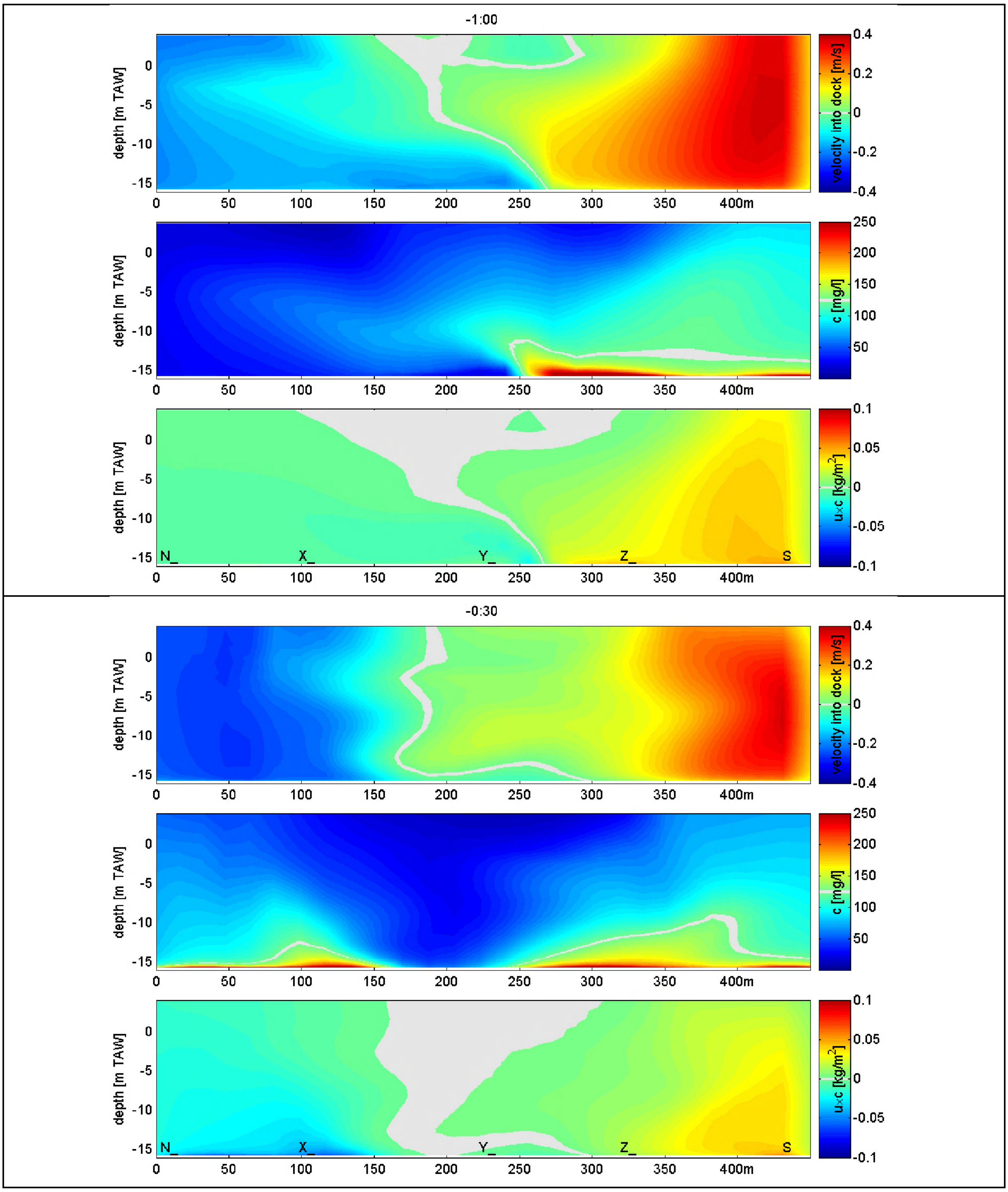


Figuur G.6. Verdeling van SPM op een hoogte van -12.5 m TAW (Tabel C.1) gedurende 1 getijperiode (31 mei 01:00+12hr)voor het eerste transect waar de dok wanden parallel lopen (DG1) (scenario 201108x2).

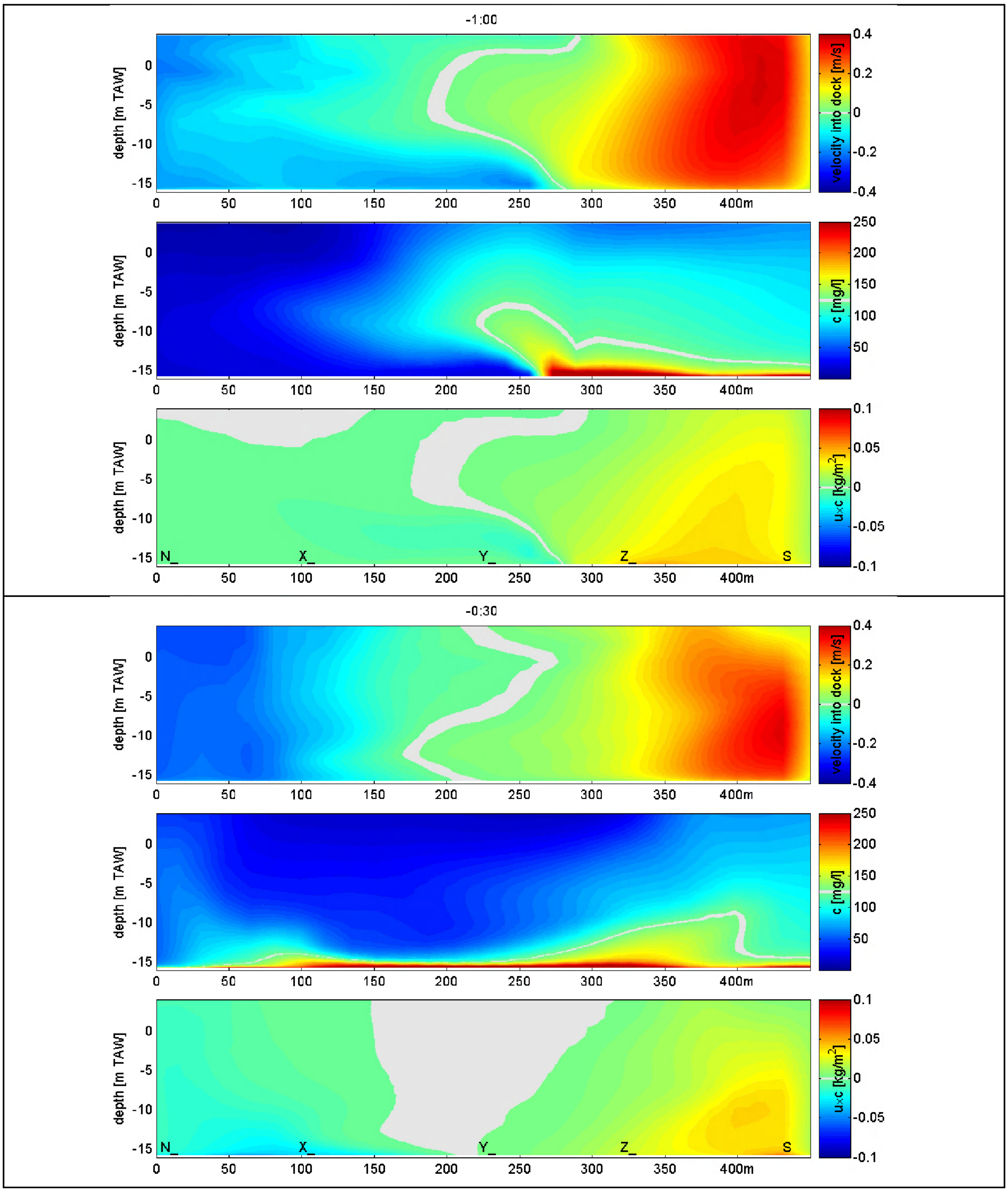
H. Verdeling over transect tijdens maximale import condities



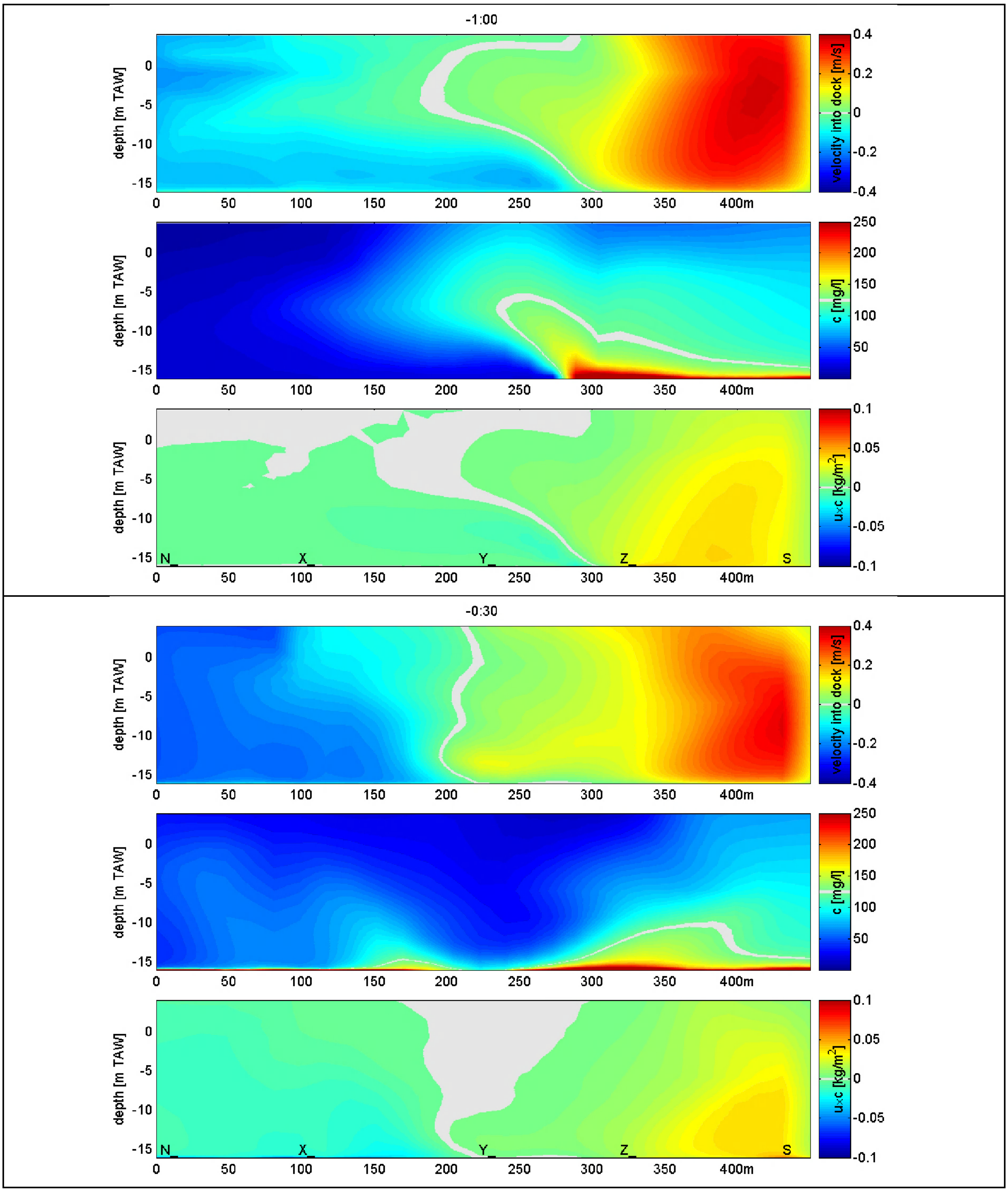
Figuur H.1. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 200802).



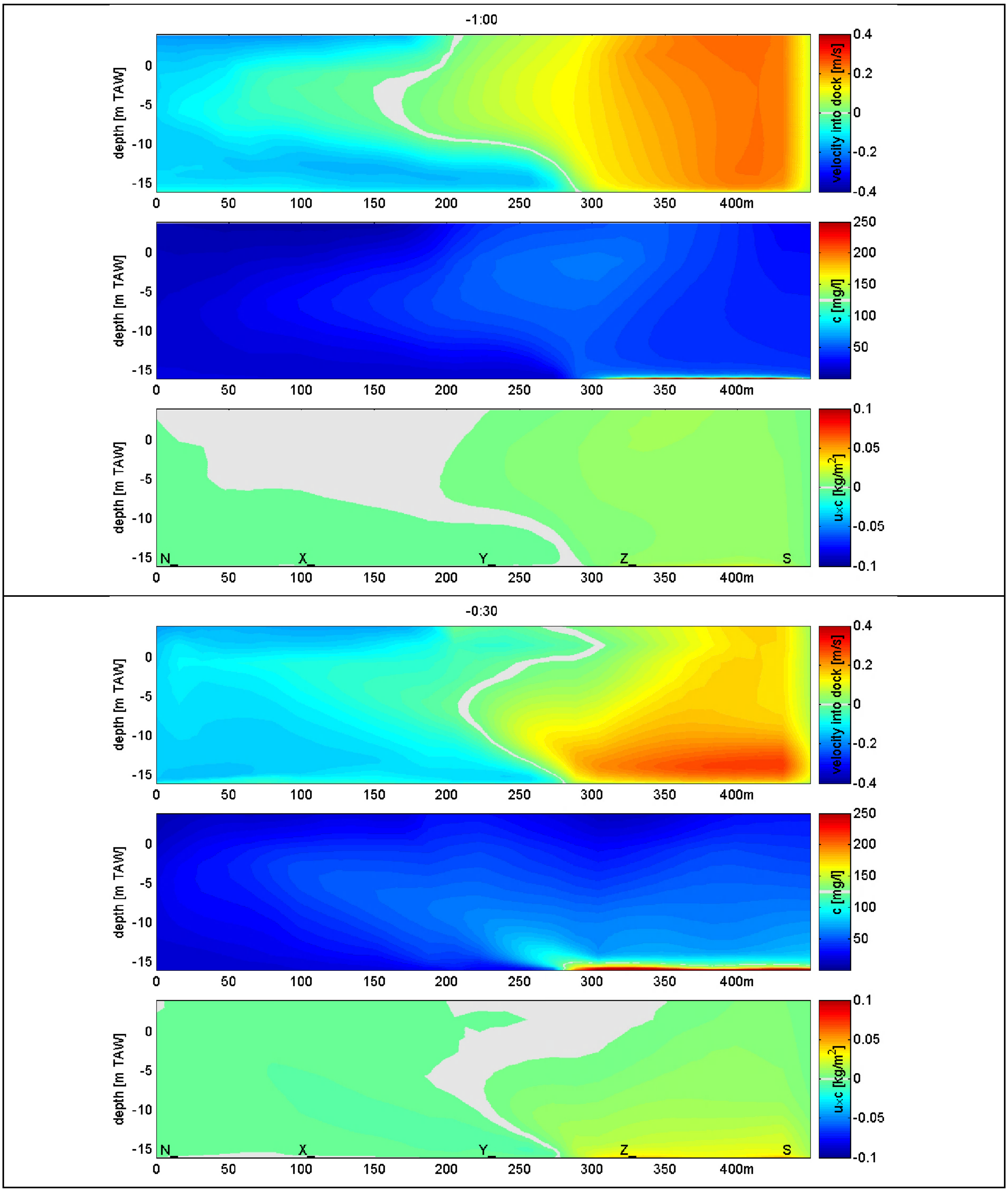
Figuur H.2. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 200806).



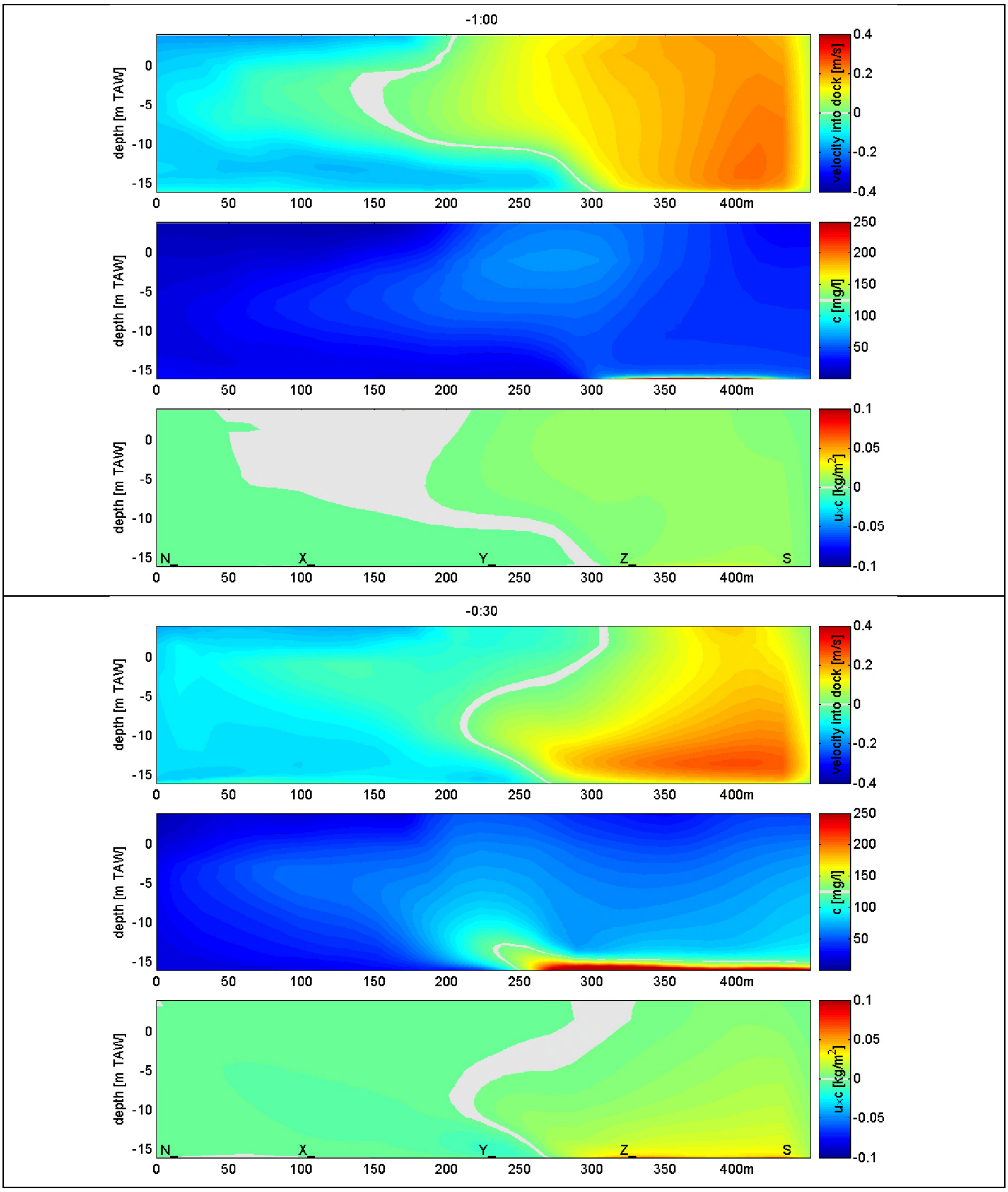
Figuur H.3. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 201006).



Figuur H.4. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 201104).

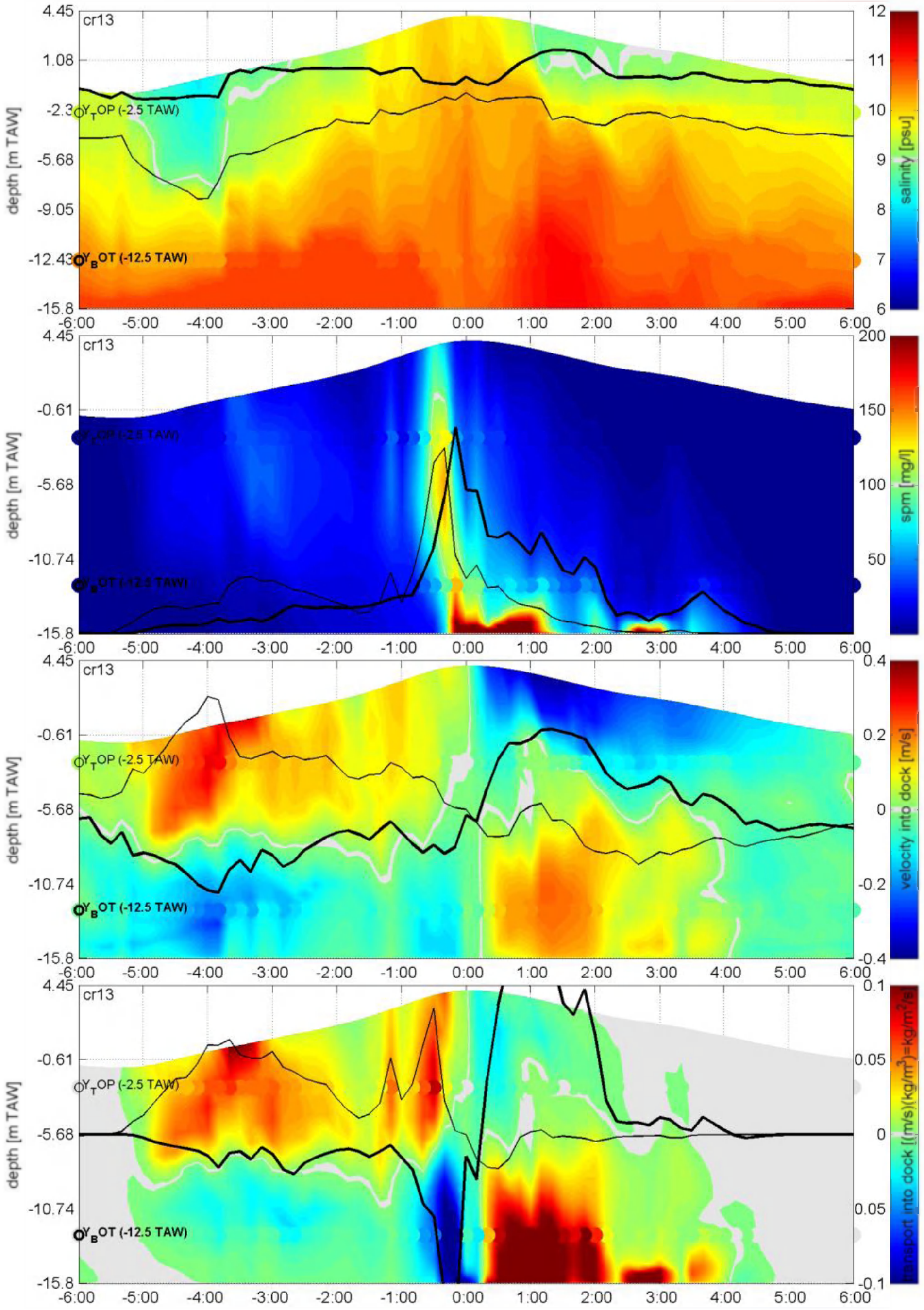


Figuur H.5. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 201108).

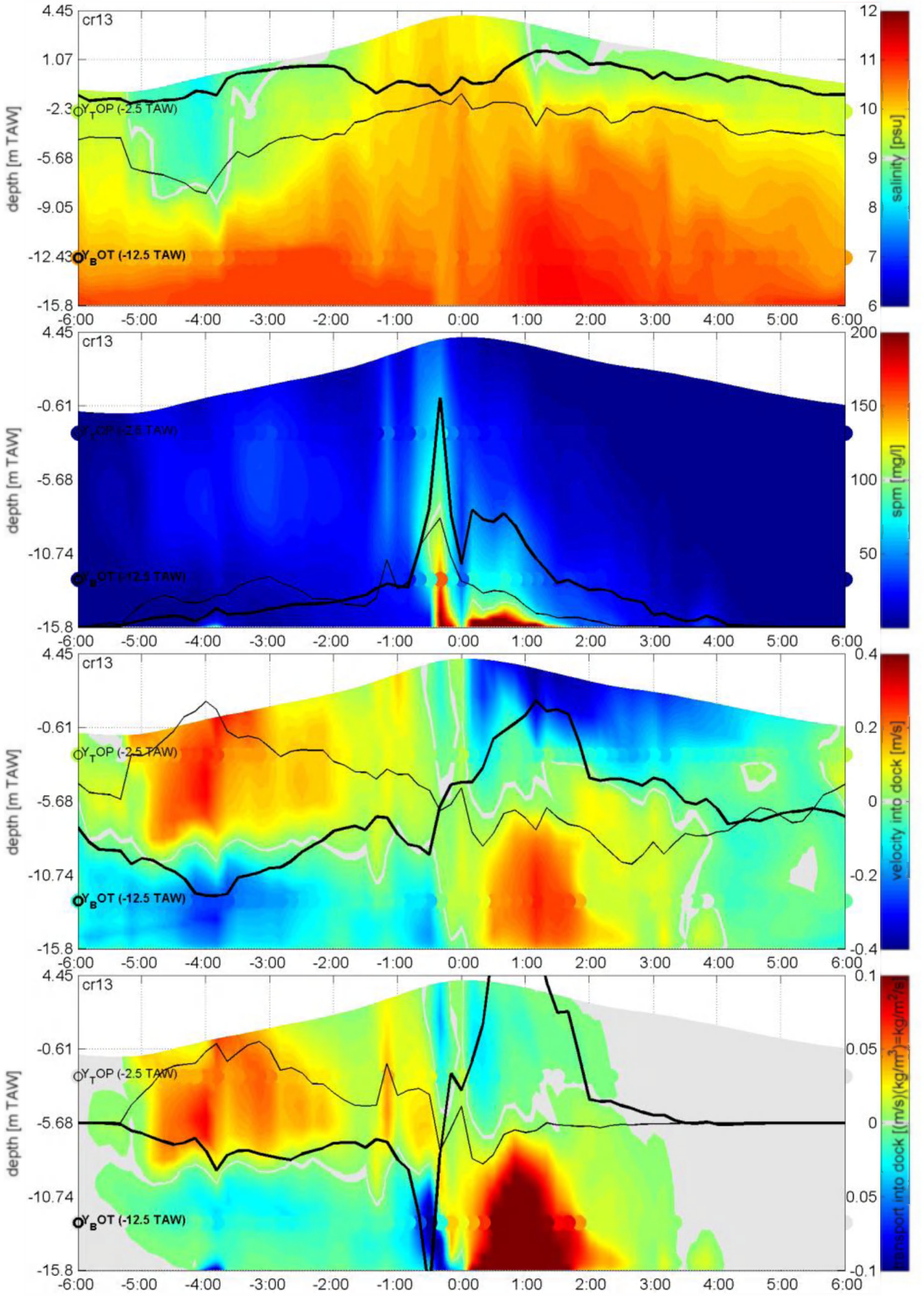


Figuur H.6. Verdeling van SPM over de hoogte voor het eerste transect waar de dok wanden parallel lopen (DG1) (31 mei 01:00+12hr)op het moment van maximale sediment import in het scenario zonder CDW (-1:00 en -0:30) (scenario 201108x2).

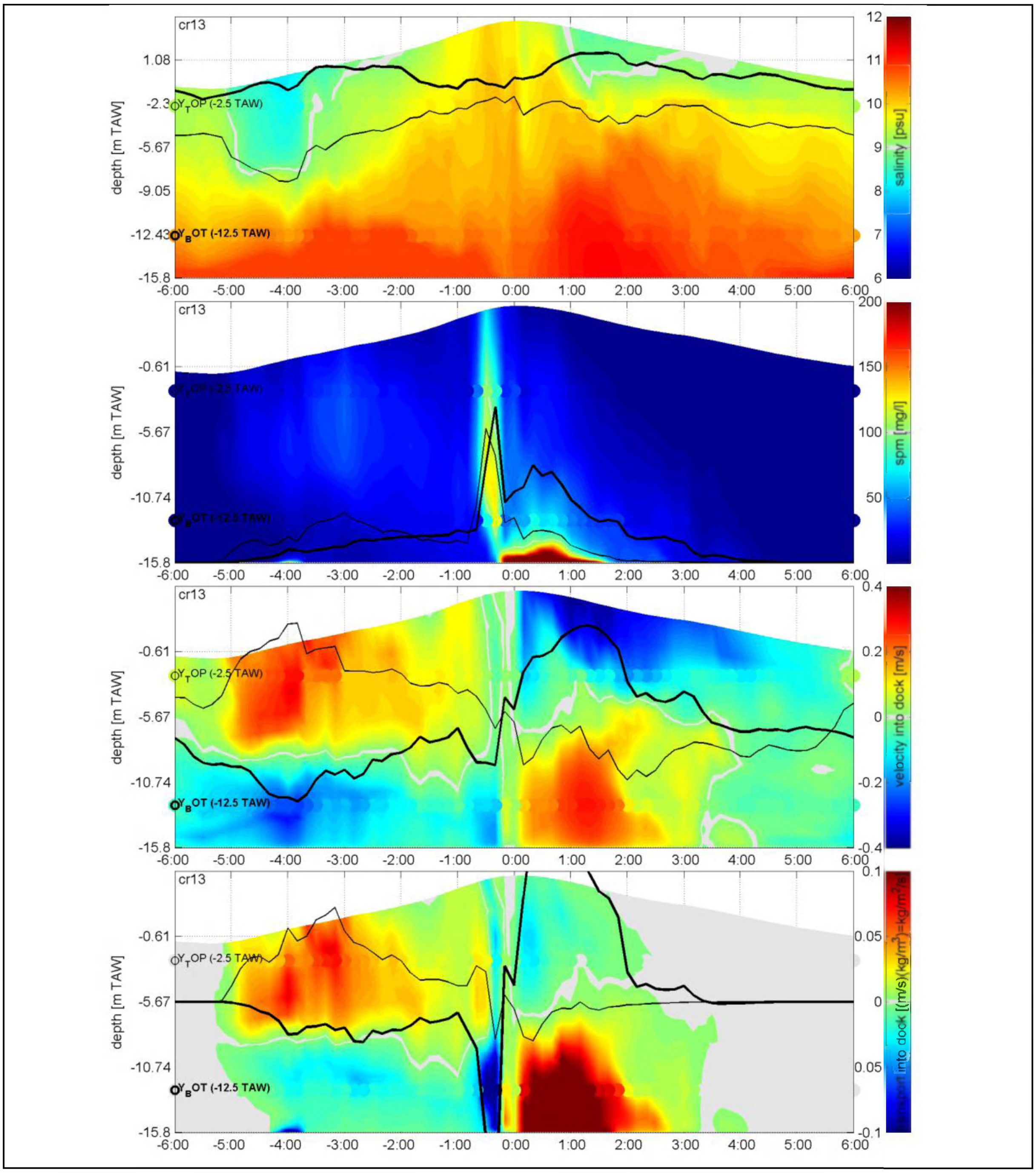
I Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux midden in toegang



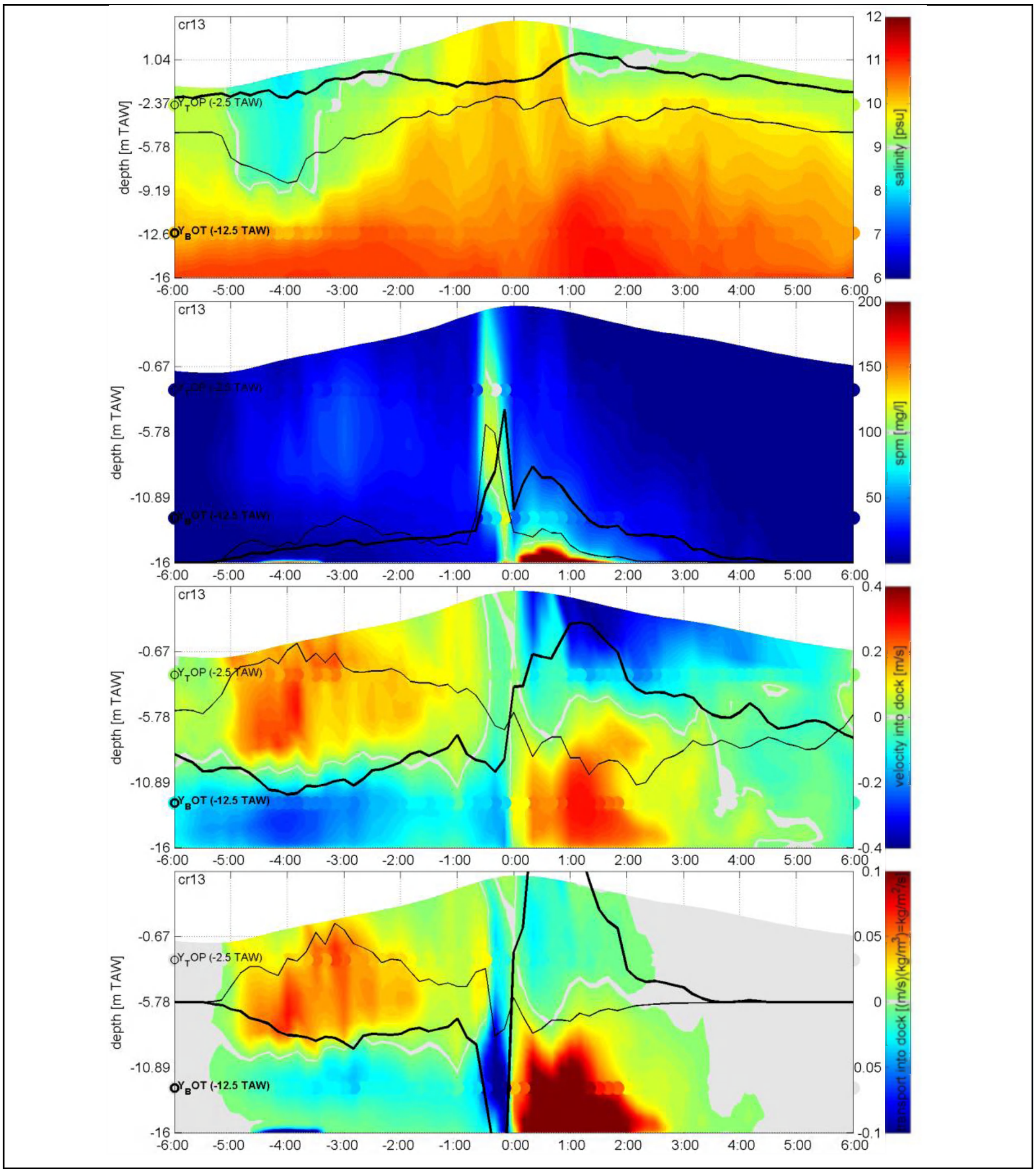
Figuur I.1. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 200802)



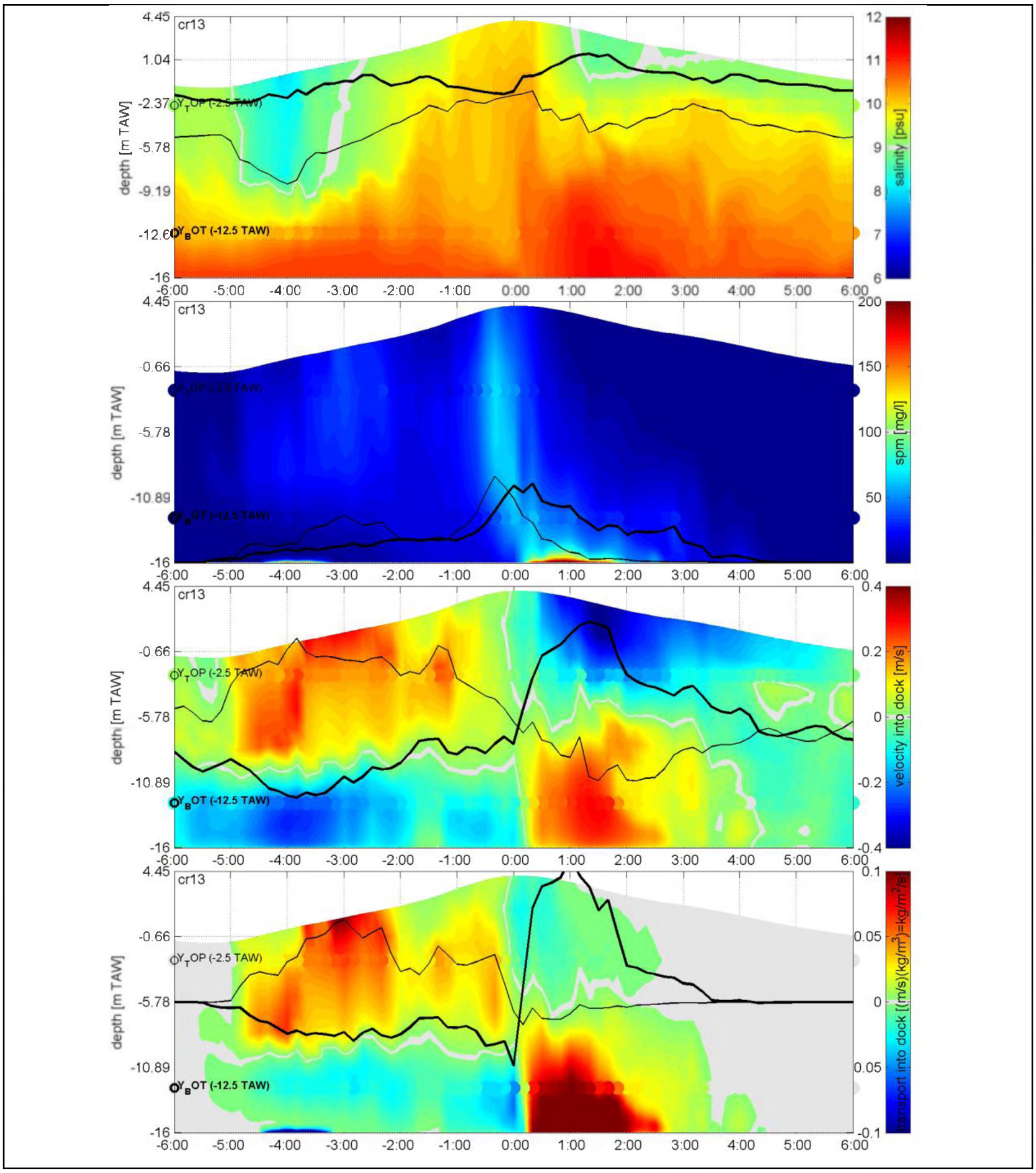
Figuur I.2. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 201006)



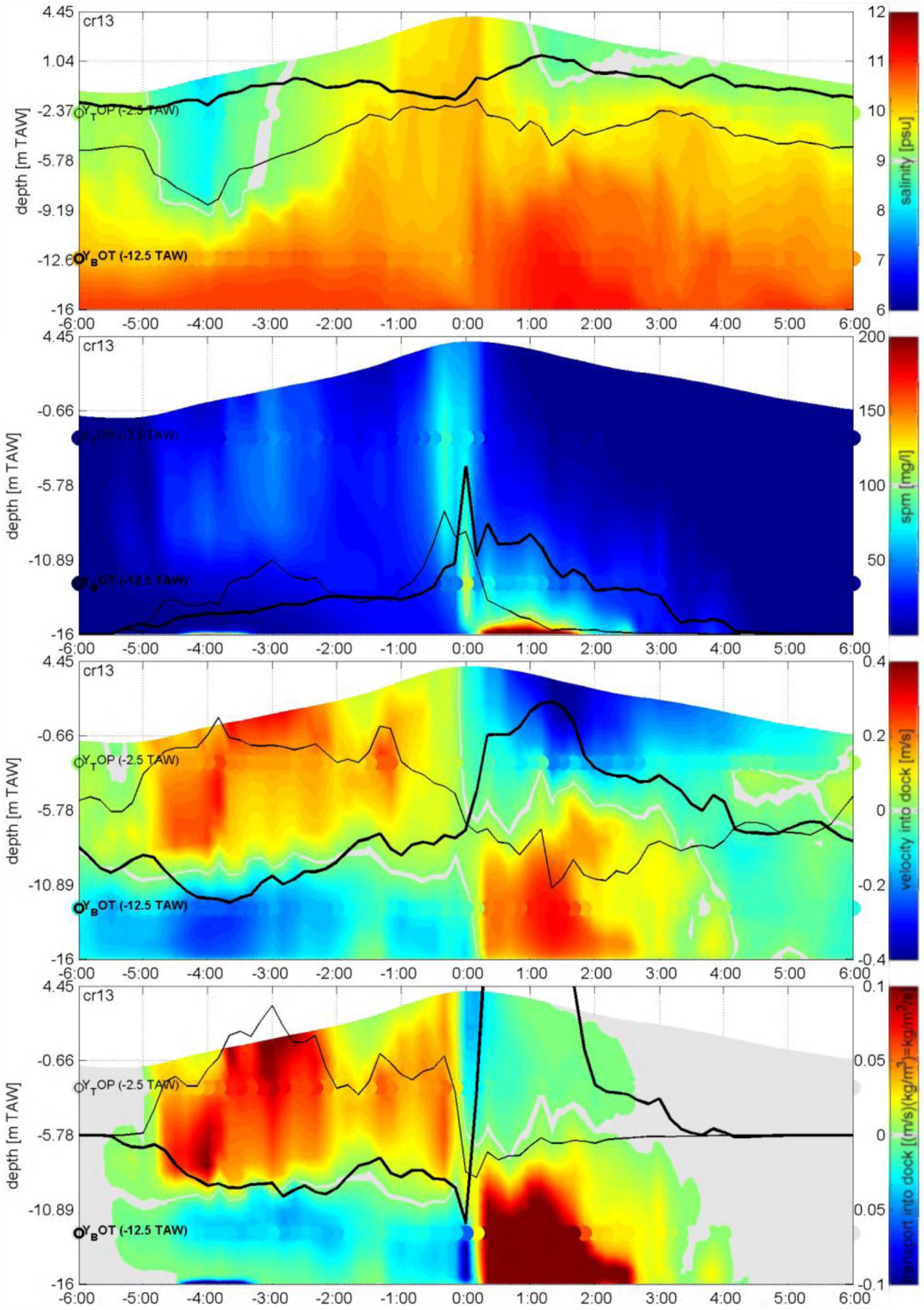
Figuur I.3. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 201008)



Figuur I.4. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 201104)



Figuur I.5. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 201108)



Figuur I.6. Verticale verdeling van zoutgehalte, snelheid, sedimentconcentratie en de sedimentflux, op locatie Y_ (scenario 201108x2)

J. Analyse van de water- en sedimentuitwisseling

Op basis van de modelresultaten worden de totale water- en sedimentfluxen door het getij opgesplitst in uitwisseling door getijvulling, densiteitstromingen en neerstromingen. Hetzelfde getij wordt gebruikt dan voor de bepaling van de aanslibbing (coef 1.09). De opsplitsing wordt berekend langs raai DG1. Deze raai ligt verder in het dok dan het DGD raai waar ADCP metingen werden uitgevoerd (Figuur B.6) en werd gekozen voor de eenvoud van de analyse. Deze opsplitsing werd gedaan volgens de methodologie uitgelegd in Vanlede et al. (2010) en uitgebreid in IMDC (2013). Deze opsplitsing is enkel een wiskundige oefening: de som van de fluxen per componenten is altijd hoger dan de brutoflux zonder opsplitsing, fluxen moeten dus geschaald worden, en variaties in fluxen per componenten zijn niet altijd fysisch verklaarbaar door de aanwezigheid van een restterm. Percentages kunnen enkel worden vergeleken met data die op dezelfde manier en op dezelfde locatie wordt geanalyseerd. De fluxen kunnen echter wel gebruikt worden om trends te onderzoeken en inzicht te verschaffen.

Resultaten in tabelvorm zijn te vinden per scenario in bijlage A en voor scenario 201108 per getijamplitude in bijlage B.

De volgende vaststellingen kunnen uit deze analyse worden gemaakt:

- De totale wateruitwisseling is vooral toegenomen na het baggeren van de drempel (Figuur J-1). De sedimentuitwisseling is minder toegenomen (Figuur J-2) omdat het extra sediment zich vooral op de drempel neerzet.
- De totale wateruitwisseling is daarna vrij constant gebleven, met een geleidelijke toename van de densiteitstroming en afname van de neervorming (Figuur J-1). Dit komt overeen met de vastgestelde geleidelijke toename van de duur van densiteitstromingen volgens ADCP metingen.
- Het effect van de CDW op de wateruitwisseling door neervorming is op deze figuur beperkt (Figuur J-1) omdat de mengzone verder uit het dok ligt. Dezelfde analyse op het DGD transect zou een sterkere afname van de uitwisseling door neervorming tonen, maar zou de hoofdconclusies niet veranderen. Toch is het positieve effect op de sedimentuitwisseling nog duidelijk.
- Een hogere sedimentconcentratie in de Schelde verandert de wateruitwisseling niet maar densiteitstromingen lijken een duidelijk grotere rol te spelen in de sedimentuitwisseling (Figuur J-2). Bij sedimentconcentraties hoger dan 1g/l wordt er verwacht dat densiteitstromingen een nog belangrijkere rol spelen.
- Het relatieve belang van de getijvulling, densiteitstromingen en neerstromingen in scenario 200802 (beginsituatie) wordt op respectievelijk 17%, 51% en 32% in de wateruitwisseling ingeschat (Figuur J-3 ; vergeleken met 19%, 42% en 39% uit ADCP data in IMDC (2013), Tabel J.1.), en op 16%, 44% en 40% in de sedimentuitwisseling (vergeleken met 12%, 48% en 40% uit ADCP data). Het belang van neerstromingen zou bij raai DGD een beetje hoger moeten zijn omwille van de ligging van de mengzone. Ondanks het verschil in raailocatie komen de percentages goed overeen met metingen.

	Model 200802 Water	Data ADCP Water	Model 200802 Sediment	Data ADCP Sediment
Getijvulling	17 %	19 %	16 %	12 %

Densiteitstroming	51 %	42 %	44 %	48 %
Neervorming	32 %	39 %	40 %	40 %

Tabel J.1. Relatieve belang van uitwisselingsmechanismen in model en in ADCP data voor water en sediment, op raai DG1 in model en raai DGD voor de data, voor het initiële toestand.

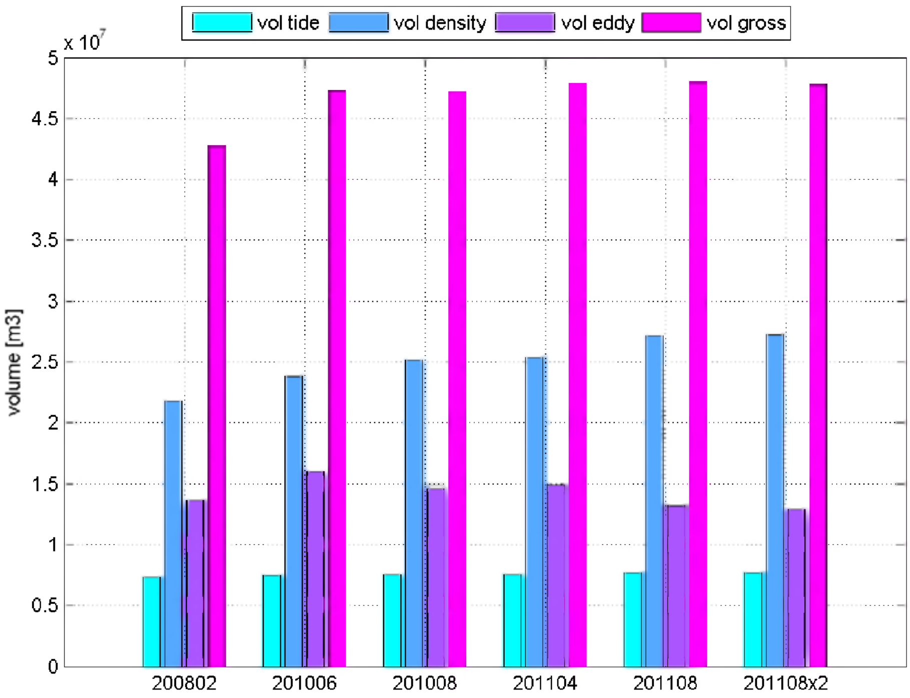
- Met de CDW verandert het relatieve belang van deze componenten naar 16%, 57% en 27% voor de wateruitwisseling (vergeleken met 18%, 50% en 32% uit ADCP data in IMDC (2013), Tabel J.2.) en naar 14%, 57% en 29% voor de sedimentuitwisseling (vergeleken met 16%, 54% en 30% uit ADCP data). Ondanks het verschil in raailocatie komen de percentages ook hier goed overeen met metingen.

	Model 201108 Water	Data ADCP Water	Model 201108 Sediment	Data ADCP Sediment
Getijvulling	16 %	18 %	14 %	16 %
Densiteitstroming	57 %	50 %	57 %	54 %
Neervorming	27 %	32 %	29 %	30 %

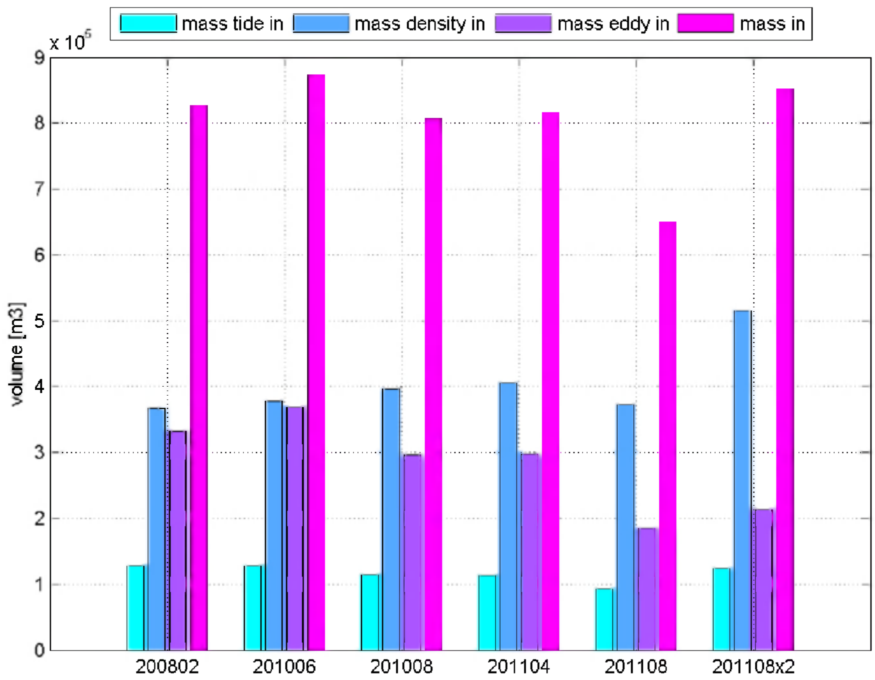
Tabel J.2. Relatieve belang van uitwisselingsmechanismen in model en in ADCP data voor water en sediment, op raai DG1 in model en raai DGD voor de data, voor het finale toestand inclusief CDW.

- De trapping efficiëntie wordt door het model overschat (75% in plaats van 40% uit ADCP metingen), en toont een lichte stijging met CDW (Figuur J-3). Dit komt overeen met de vastgestelde tekortkomingen van het model (ontbreken van fijne sedimentfractie, lage vertikale turbulentie, hoge aanslibbing ondanks lage SSC).
- De getijamplitude bepaalt vooral de sedimentconcentratie in de Schelde en dus de totale sedimentuitwisseling (Figuur J-4). Relatief gezien wordt de neervorming vooral tijdens springtij belangrijk. Ook metingen tonen dat de neervorming vooral tijdens springtij gebeurt.

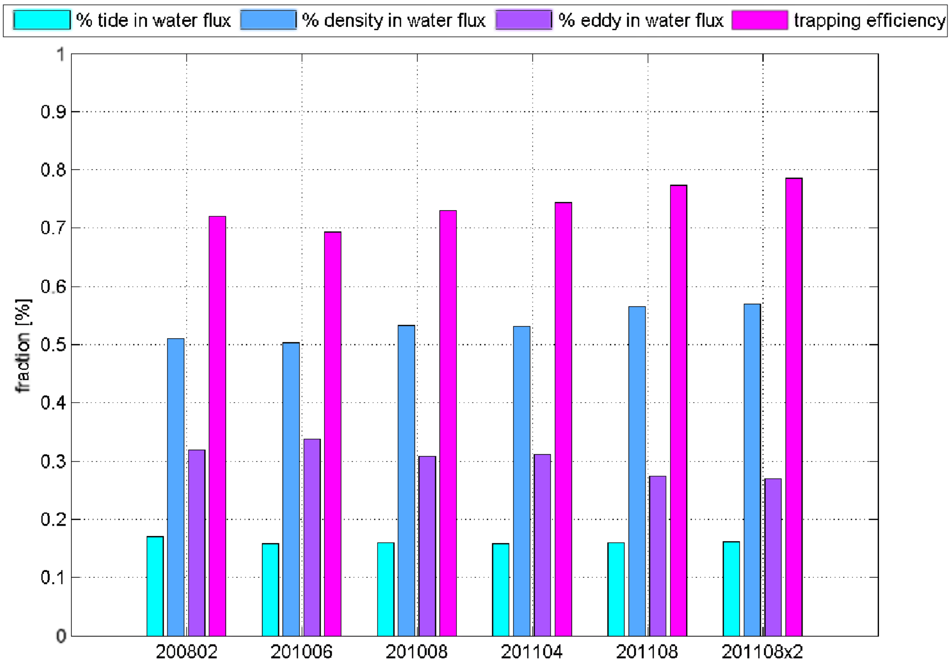
Overal bevestigt deze analyse dat het model waarschijnlijk goed gekalibreerd is voor de hydrodynamica en tekortkomingen toont voor het sedimenttransport. Het model suggereert een sterker effect van de CDW op de sediment- dan op de wateruitwisseling, met een grootste positieve effect tijdens springtij wanneer de neervorming duidelijk is. Net als de data wijst het model erop dat densiteitstromingen met elk ingreep belangrijker zijn geworden. Ook met een hogere SSC worden densiteitstromingen belangrijker. De exacte percentages uit de opsplitsing in componenten moeten echter niet te veel aandacht trekken, ze zijn sterk afhankelijk van de berekeningsmethode. Het neercomponent kan bijvoorbeeld ook een wiskundige bijdrage bevatten.



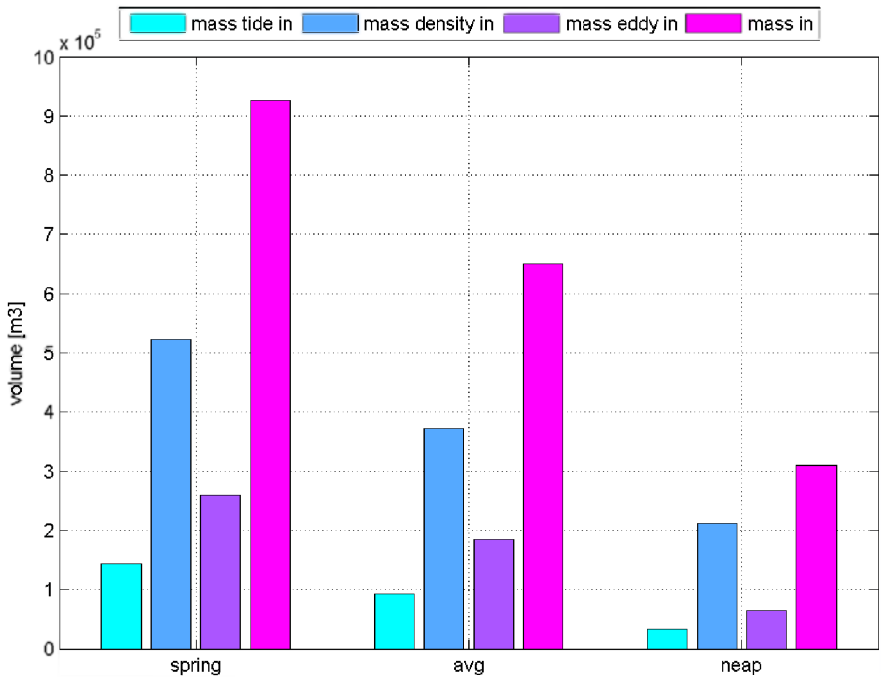
Figuur J-1. Wateruitwisseling per scenario en per component voor een gemiddelde getij (31 mei 0:30 + 12u30).



Figuur J-2. Sedimentuitwisseling per scenario en per component voor een gemiddelde getij (31 mei 0:30 + 12u30).



Figuur J-3. Relatieve belang van componenten in de wateruitwisseling en trapping efficiëntie per scenario voor een gemiddelde getij (31 mei 0:30 + 12u30).



Figuur J-4. Sedimentuitwisseling per getijamplitude en per component voor scenario 201108.
Spring : 27 mei 13:00 + 12u30, average : 31 mei 0:30 + 12u30, neap : 5 juni 5:00 + 12u30.

K. Discussie en conclusies

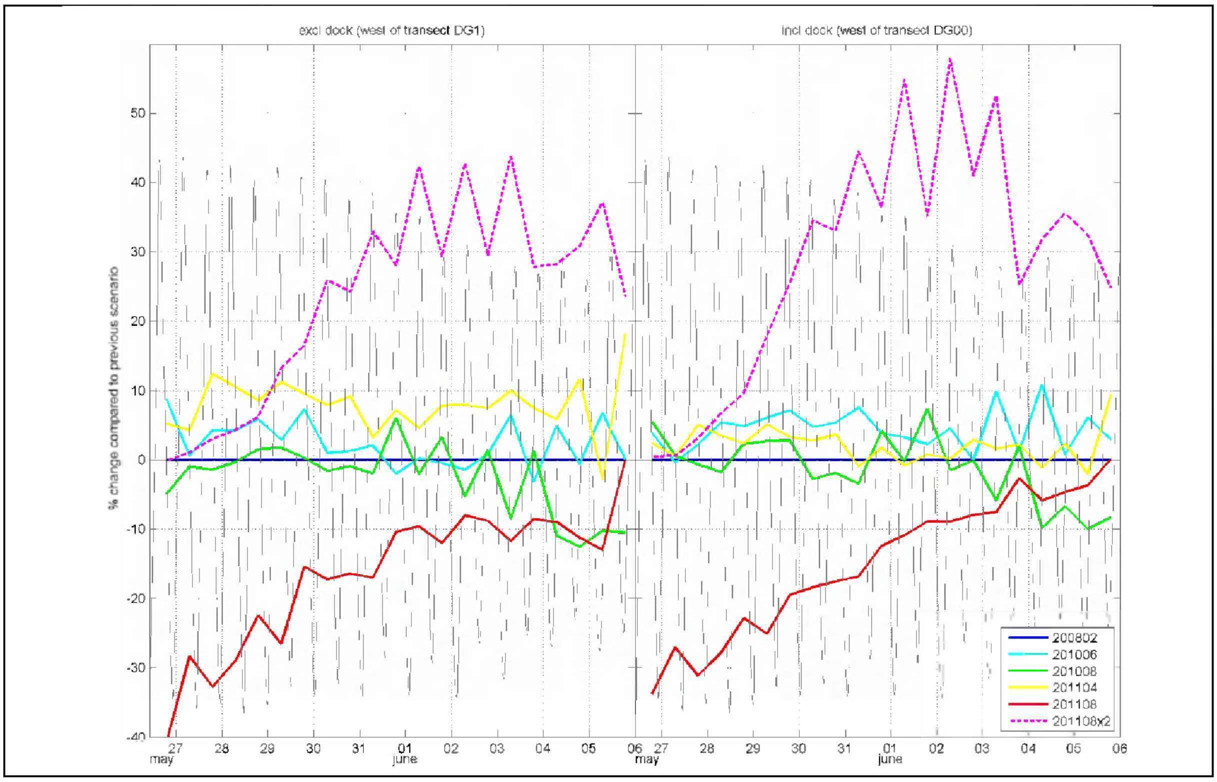
Model tekortkomingen
Er zijn een aantal vragen gedefinieerd welke deels met behulp van het voorliggende rekenmodel Slib3D beantwoord zouden kunnen worden. Voordat deze vragen beantwoord worden, worden echter eerst de tekortkomingen van het model kort behandeld. Deze tekortkomingen zijn belangrijk om het model te interpreteren, en de vragen te beantwoorden. Het Slib3D model is met name ontwikkeld om het effect van de CDW op aanslibbing in het Deurganckdok te berekenen. Belangrijke tekortkomingen in het model zijn:

1. Er wordt alleen aanslibbing berekend; baggeren en vervolgens terugstorten van sediment is niet meegenomen. Het model is gecalibreerd tegen de sedimentconcentratie in de Schelde vóór de aanleg van het Deurganckdok. Sediment onttrekking als gevolg van de aanleg van het dok zal leiden tot een (sterke) verlaging van de sediment concentraties, en daarmee een onderschatting van de gemeten sediment concentraties.
2. Consolidatie en fluid mud transport wordt niet gemodelleerd. Hierdoor kan sediment op of nabij bodemhellingen (zoals de drempel) afgezet worden, wat in werkelijkheid als gevolg van een dichtheidsstroom naar diepere delen getransporteerd zou worden.
3. Het sediment in de Schelde bestaat uit micro en macroflocs, waarvan als gevolg van turbulentie en interactie van sedimentdeeltjes de valsnelheid en de relatieve verdeling veranderen. In het model is alleen de fractie met de hoogste valsnelheid gemodelleerd. Hierdoor ontbreekt de fractie met een zeer lage valsnelheid, welke een diepte-uniforme sedimentconcentratie tot gevolg heeft. Hierdoor wordt met name de sediment concentratie in laag-dynamische gebieden (zoals het Deurganckdok) onderschat. Daarnaast is het flocculatie model Eulerisch en niet Lagrangiaans. Hierdoor wordt de valsnelheid bepaald door de lokale hydrodynamische condities, en niet door de geschiedenis van een floc. Grote flocs die vanuit de Schelde het dok in getransporteerd worden, kunnen hierdoor in het dok ineens een zeer lage valsnelheid hebben, terwijl de flocs in werkelijkheid niet veranderen.

Onderzoeksvragen

- Wat is de kwalitatieve invloed van elke ingreep, in het bijzonder de CDW in de huidige toestand? In het bijzonder, welke rol speelt de verdieping van de Schelde, dan wel de wijziging van de onderhoudsdiepte van het Deurganckdok op de toename van de aanslibbing in het Deurganckdok.

Voor alle getij situaties zijn de aanslibbingsgcijfers uit paragraaf E samengevat in Figuur K.1. Het analyseren van deze range aan getallen kan geïnterpreteerd worden als een soort grove foutenmarge. De precieze aanslibbingscijfers zijn namelijk sterk afhankelijk van de getijsituatie en definitie van wat het dok is. Het wegbaggeren van de drempel aan de ingang van het dok in 2010-06 heeft nauwelijks effect gehad, een toename tot 7 %. De verdieping van de Schelde in 2010-08 heeft evenmin effect gehad, en enig effect van de vorige ingreep vermindert, optellend tot max. 10% afname t.o.v. 2008-02. De uiteindelijke grote toename van de onderhoudsverdieping van het dok in 2011-04 leidt tot een toename van de sedimentatie van tegen de 10%. De CDW in 2011-08 leidt tot een afname van 40 tot 0%. De afname is initieel het grootst richting springtij. Het effect van de CDW t.o.v. deze voorgaande fase 2011-04 is daardoor 0 tot 40 %. Gemiddeld over doodtij en springtij kunnen we dus concluderen dat de CDW een positief effect heeft van orde 20% +/- 20%. Dit is in dezelfde range als gevonden in voorgaande Slib3D studies. Het effect van de verdubbelde sediment concentraties komt slechts langzaam op gang door het inspelen hiervan. Uiteindelijk overcompenseert deze verdubbeling het effect van de CDW. Na doodtij loopt het effect hiervan weer wat terug.



Figuur K.1. Relatieve verandering van aanslibbing t.o.v. het voorgaande scenario.

- Wat is de oorzaak van de gemeten toename in duur en sterkte van de densiteitsstromingen? In het bijzonder, kan een hoge sedimentatieconcentratie in de Schelde (i.e. 1 g/l) leiden tot densiteitsstromingen?

Veranderingen in de densiteitsstromen kunnen geanalyseerd worden op een locatie in het dok welke slechts beperkt door horizontale wervels worden beïnvloedt, maar vooral door densiteitsstromen parallel aan het dok. Locatie Y_ is daarvoor geschikt; 13-uurs visualisaties van het zoutgehalte, de stroming, de sediment concentratie en de fluxen zijn per scenario opgenomen in Appendix I.

De sterkte van de densiteitsstroming is duidelijk toegenomen wanneer scenario 200802 vergeleken wordt met 201108x2. De fasering is slechts beperkt veranderd. Deze veranderingen treden geleidelijk op: met elke scenario neemt de dichtheidsstroming iets toe. Het plaatsen van de CDW (201108 tov 201104) leidt vooral tot een toename van de oppervlakte instroming, in lijn met een van de doelstellingen van de CDW (het transporteren van helder oppervlakte richting het dok). De dichtheidsstroming wordt ook beïnvloedt (en versterkt) door het verhogen van de sedimentconcentratie (vergelijk I.6 met I.5), wat erop duidt dat de sediment-gedreven dichtheidseffecten de densiteitsstromen beïnvloeden. Als het model de sedimentconcentratie onderschat, zal ook de densiteitsstroming onderschat worden.

De analyse van de water- en sedimentfluxen in paragaaf J bevestigt deze bevindingen. Net als de data uit IMDC (2013) wijst het model erop dat densiteitstromingen met elk ingreep belangrijker zijn geworden. Ook met een hogere SSC worden densiteitstromingen belangrijker.

- Kunnen de voorgestelde oorzaken van de toename in het onderhoudsvolume volgend uit het conceptuele model onderbouwd worden door modelresultaten met Slib3D. In het bijzonder, kunnen hogere sedimentconcentraties leiden tot sterke flocculatie en dus afzetting van slib in het dok.

Uit de metingen van Manning et al. (2011) blijkt dat het turbulentienivo in het dok dusdanig is dat de valsnelheid van flocs groot is. Daarnaast is de concentratie erg hoog, wat de flocculatie verder versterkt. In werkelijkheid bestaat het sediment in het dok daarom uit grote flocs met een hoge valsnelheid. In het numerieke model is het turbulentienivo lager. Bij een relatief lage turbulentie is een sterke afhankelijkheid tussen valsnelheid en turbulentie, waardoor een kleine onderschatting van de turbulentie leidt tot een grote onderschatting van de valsnelheid. En zoals bij de sectie rond modeltekortkomingen uitgelgd, is het floc model een Eulerisch model, waardoor relatief grote flocs op de Schelde die het dok instromen, volgens het model kleiner worden, wat niet overeenkomt met de werkelijkheid.

- Achtergrondmenging: sub-lineaire toename van sedimentatie bij verdubbeling Schelde concentraties, te grote sedimentatie op de drempel en te lage concentraties in DGD.

Zoals gezegd is uit de modelscenario's gebleken dat er sub-lineaire toename van sedimentatie in het dok optreedt bij verdubbeling van Schelde concentraties (scenario 201108x2). Een tweede punt is dat ten opzichte van het beeld dat uit metingen is ontstaan, het model teveel sediment op de drempel laat bezinken (pers.com. IMDC). Ten derde valt in scenario's op dat de concentraties in het DGD zo laag zijn dat er gezegd kan worden dat deze nul zijn. Figuren F laten bijvoorbeeld zien dat de concentraties in de laagste kleurenschaal waardes zitten, wat gepaard gaat met een transport van 0, zelfs als er wel significant snelheden zijn (grijstinten in Figuren F). Dit terwijl in de het DGD gemeten concentraties in de orde van 50 mg/l liggen (pers.com. IMDC). Deze drie zaken zouden ene gemeenschappelijke oorzaak kunnen hebben: onderschatting van vertikale achtergrondmenging in het model.

Lage concentraties in gelaagde gebieden zijn theoretisch verklaarbaar in gebieden waar sterke gelaagdheid (pycnocline) optreedt door temperatuur (thermocline) of, zoals in dit geval, door saliniteitsgelaagdheid (halocline) en soms door sediment zelf (lutocline). Ter plaatse van de vertikale gelaagdheid kan lokaal lagere intensiteit van de vertikale menging optreden. De vertikale bewegingen van water pakketjes, met sediment erin, wordt onderdrukt doordat de gelaagdheid een tegenwerken kracht uitoefent. Er treedt zodoende een proces op dat “hindered mixing” genoemd zou kunnen worden. De normale balans tussen opwaartse menging (door hogere bodemconcentraties) en neerwaartse valsnelheid is verstoord, waardoor sediment sneller bezinkt. Sediment uit de bovenlaag zal, zodra het in de gelaagdheid belandt, ook sneller uitzinken. Zodoende treden lagere sediment concentraties op in de gelaagdheid en daarboven, maar treden juist hogere concentraties op in de bodemlaag daaronder. Dit proces is al beschreven door Geyer in 1993. De verhoogde bodem concentraties ter plaatse van gelaagdheid staan bekend als ETM: Estuarien Turbiditeits Maximum. Een dergelijk ETM ‘vangt” alle sediment in uit de omgeving, dat kan het ETM niet passeren. Wat in de monding van het dok optreedt, zou uit het ETM principe verklaard kunnen worden

Nabij de mond van het DGD treedt vaak gelaagdheid op door de faseverschillen in saliniteit tussen dok en Schelde. Deze lokale gelaagdheid leidt lokaal tot versneld uitzakken van sediment, wat leidt tot lagere concentraties van het water dat het dok verder binnendringt. Ten tweede zorgt dit voor verhoogde sedimentatie om en nabij van de drempel, daar waar de gelaagdheid als eerste optreedt voor water komend vanaf uit de Schelde. Dit lokale ETM mechanisme vangt ook verhoogde sediment concentraties uit de Schelde in, zodat dat het dok niet verder kan binnendringen. Het kan weer door Scheldewater worden meegenomen tijdens periodes van hoge stroomsnelheden. Het resterende deel slaat neer om en nabij de drempel op plaatsen waar het net buiten bereik ligt van de hoge stroomsnelheden. In Figuren E valt deze abrupte grens op tussen sedimentatiegebied op de drempel en Schelde. Een andere parametrisatie van het overgaan van waterfase naar bodem zou hier effect op hebben. Kortom, er is een theoretisch verschijnsel bekend dat 3 tekortkomingen van het model kan verklaren. Om gevoel te krijgen voor het effect van de achtergrond menging zijn een tweetal extra gevoeligheidssimulaties opgestart waarin met relevante parameters is gevarieerd.

Scenario 201108 is als uitgangspunt genomen om een aantal gevoeligheidsanalyses te doen: De vertikale achtergrondsviscositeit van het k-epsilon model is van 10^{-5} m^2/s verhoogd naar 10^{-4} m^2/s, tegelijkertijd is de achtergrondsdiffusiviteit verlaagd van 10^{-5} m^2/s naar 10^{-6} m^2/s (201108_{1e-4}). Van Delft3D is bekend dat het te sterk gelaagdheid representeert, en een achtergrond waarde die relatief klein is t.o.v. de optredende mengingsintensiteiten wordt daarom aangeraden. Een waarde van is 10^{-4} m^2/s aan de hoge kant, maar niet onrealistisch voor een dynamisch getijdegebied als de Schelde. In een tweede gevoeligheidsscenario is de een waarde van 5 cm gegeven aan de Ozmidov lengte schaal die voor extra menging (viscositeit en diffusiviteit) zorgt ter plaatse van sterke gelaagdheid door breken van interne golfjes op interne interfaces (201108_{Xlo}). Uit Tabel K.2 blijkt dat het effect van de Ozmidov lengte schaal nil is, terwijl dat van extra achtergrondmenging wel significant is. Het effect van de CDW blijft ongewijzigd t.o.v. de andere scenario’s, maar de toename in sedimentatie in het DGD is groter dan in het scenario met verdubbelde concentraties op de rivier. De extra menging leidt vooral tot sedimentatie in het binnengebied, dus excl. drempel.

id					TDS excl. drempel		Tpv Schelde, TDS incl drempel
id	< DG9	DG9-DG7	DG7-DG5	DG5-DG3	DG3-DG1	DG1-DG0	DG0-DG00
200802	95	183	328	518	831	1161	1404
201006	88	179	323	518	835	1157	1399
201008	75	160	303	487	827	1153	1407
201104	92	188	342	534	862	1171	1414
201108	61	128	243	390	618	847	1032
2011081e-4	*62*	*133*	*254*	*407*	*635*	*859*	*1040*
201108Xlo	*61*	*128*	*243*	*390*	*618*	*847*	*1032*
201108x2	61	129	246	396	624	854	1037

Tabel J.2. Cumulatieve aanslibbing in TDS (Tons of Dry Solids) voor vakken in DGD, optellend van West (links in tabel, einde van dok) naar oost (rechts in tabel, nabij Schelde). De vakken liggen tussen de transecten in Figuur C1.-C7, die overeenkomen met de verticale tabel lijnen in de tabel. De dikke kolom lijn is transect DG1 ter plaatse van het laatste punt waar de kademuren parallel lopen. Waardes voor periode van 12 uur volgend op spring tij (27 mei 01:00+12hr).

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Bijlage A - Water- en sedimentuitwisseling per component per scenario

```
Scenario 200802 (coef 1.09)

Tide coverage :       12.5 hours
----------------------------
Total water exchange modelled

Volume In :        21.5 Mm3
Volume Out :       21.3 Mm3
Volume Gross :     42.8 Mm3
Volume Net In :    0.2 Mm3
----------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3     3.7 Mm3   17.1 %
Volume In Density Currents :    16.4 Mm3    11.0 Mm3   51.1 %
Volume In Eddy Currents :       10.2 Mm3     6.8 Mm3   31.9 %
Sum of Influxes :               32.0 Mm3    21.5 Mm3  100.0 %
```

```
Scenario 200802 (coef 1.09)

Tide coverage :       12.5 hours
----------------------------
Total sediment exchange modelled

Mass In :       826.9 TDS
Mass Out :      231.4 TDS
Mass Gross :    1058.3 TDS
Mass Net In :   595.5 TDS
----------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :       157.5 TDS  127.8 TDS   15.5 %
Mass In Density Currents :    452.5 TDS  367.3 TDS   44.4 %
Mass In Eddy Currents :       408.9 TDS  331.8 TDS   40.1 %
Sum of Influxes :            1018.9 TDS  826.9 TDS  100.0 %
----------------------------
Trapping efficiency per component

Trapping tidal filling :        71.9 %
Trapping density currents :     77.0 %
Trapping eddy currents :        66.5 %
Global trapping efficiency :    72.0 %
```

```
Scenario 201006 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        23.7 Mm3
Volume Out :       23.6 Mm3
Volume Gross :     47.3 Mm3
Volume Net In :    0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3    3.7 Mm3    15.8 %
Volume In Density Currents :    17.4 Mm3   11.9 Mm3    50.4 %
Volume In Eddy Currents :       11.7 Mm3    8.0 Mm3    33.8 %
Sum of Influxes :               34.6 Mm3   23.7 Mm3   100.0 %
```

```
Scenario 201006 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :        874.0 TDS
Mass Out :       268.3 TDS
Mass Gross :     1142.3 TDS
Mass Net In :    605.8 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :      153.6 TDS   127.9 TDS    14.6 %
Mass In Density Currents :   453.1 TDS   377.4 TDS    43.2 %
Mass In Eddy Currents :      442.7 TDS   368.7 TDS    42.2 %
Sum of Influxes :           1049.3 TDS   874.0 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        71.5 %
Trapping density currents :     76.8 %
Trapping eddy currents :        60.9 %
Global trapping efficiency :    69.3 %
```

```
Scenario 201008 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        23.7 Mm3
Volume Out :       23.5 Mm3
Volume Gross :     47.2 Mm3
Volume Net In :    0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3    3.8 Mm3    15.9 %
Volume In Density Currents :    18.4 Mm3   12.6 Mm3    53.2 %
Volume In Eddy Currents :       10.6 Mm3    7.3 Mm3    30.9 %
Sum of Influxes :               34.5 Mm3   23.7 Mm3   100.0 %
```

```
Scenario 201008 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       807.4 TDS
Mass Out :      217.6 TDS
Mass Gross :    1025.1 TDS
Mass Net In :   589.8 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :      136.5 TDS  114.8 TDS   14.2 %
Mass In Density Currents :   471.1 TDS  396.2 TDS   49.1 %
Mass In Eddy Currents :      352.4 TDS  296.4 TDS   36.7 %
Sum of Influxes :           960.1 TDS  807.4 TDS  100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :       71.9 %
Trapping density currents :    80.1 %
Trapping eddy currents :       64.1 %
Global trapping efficiency :   73.0 %
```

```
Scenario 201104 (coef 1.09)

Tide coverage :        12.5 hours
---------------------------
Total water exchange modelled

Volume In :         24.0 Mm3
Volume Out :        23.8 Mm3
Volume Gross :      47.9 Mm3
Volume Net In :     0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3     3.8 Mm3    15.8 %
Volume In Density Currents :    18.4 Mm3    12.8 Mm3    53.1 %
Volume In Eddy Currents :       10.8 Mm3     7.5 Mm3    31.1 %
Sum of Influxes :               34.8 Mm3    24.0 Mm3   100.0 %
```

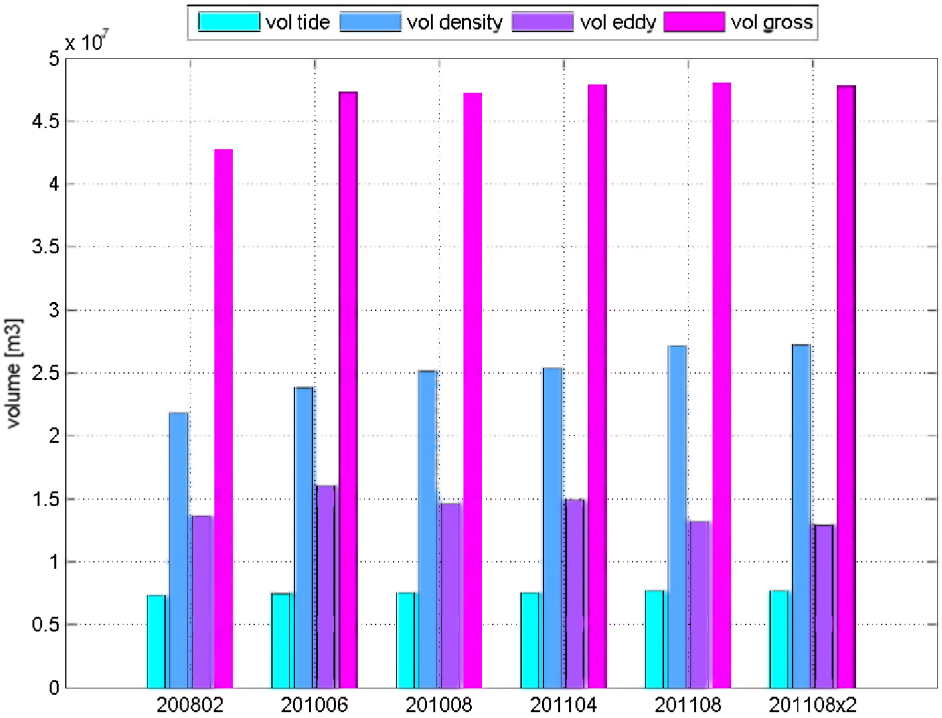
```
Scenario 201104 (coef 1.09)

Tide coverage :        12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :        815.9 TDS
Mass Out :       209.3 TDS
Mass Gross :     1025.2 TDS
Mass Net In :    606.6 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :       134.3 TDS   112.9 TDS    13.8 %
Mass In Density Currents :    482.6 TDS   405.6 TDS    49.7 %
Mass In Eddy Currents :       353.9 TDS   297.4 TDS    36.5 %
Sum of Influxes :            970.8 TDS   815.9 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        71.2 %
Trapping density currents :     81.2 %
Trapping eddy currents :        66.2 %
Global trapping efficiency :    74.3 %
```

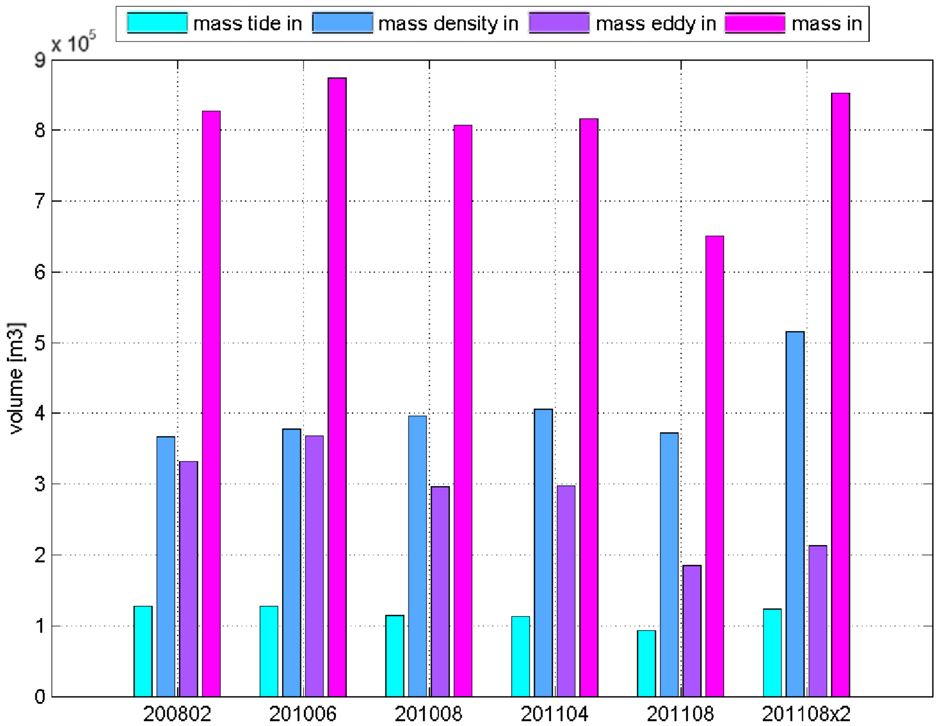
```
Scenario 201108 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        24.1 Mm3
Volume Out :       23.9 Mm3
Volume Gross :     48.0 Mm3
Volume Net In :    0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3    3.8 Mm3    16.0 %
Volume In Density Currents :    19.4 Mm3   13.6 Mm3    56.6 %
Volume In Eddy Currents :        9.4 Mm3    6.6 Mm3    27.5 %
Sum of Influxes :               34.4 Mm3   24.1 Mm3   100.0 %
```

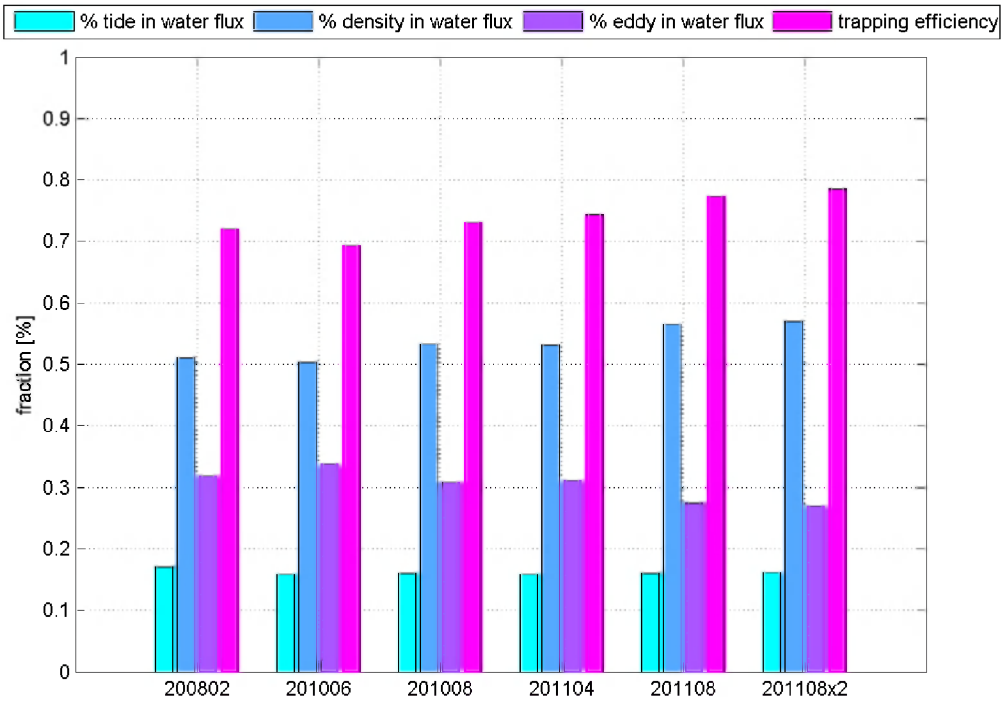
```
Scenario 201108 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       650.5 TDS
Mass Out :      147.4 TDS
Mass Gross :    798.0 TDS
Mass Net In :   503.1 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :       108.2 TDS    92.9 TDS    14.3 %
Mass In Density Currents :    433.9 TDS   372.5 TDS    57.3 %
Mass In Eddy Currents :       215.7 TDS   185.2 TDS    28.5 %
Sum of Influxes :            757.8 TDS   650.5 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        72.2 %
Trapping density currents :     82.8 %
Trapping eddy currents :        68.9 %
Global trapping efficiency :    77.3 %
```

```
Scenario 201108x2 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        24.0 Mm3
Volume Out :       23.8 Mm3
Volume Gross :     47.8 Mm3
Volume Net In :    0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3    3.9 Mm3    16.1 %
Volume In Density Currents :    19.5 Mm3   13.7 Mm3    57.0 %
Volume In Eddy Currents :        9.2 Mm3    6.5 Mm3    26.9 %
Sum of Influxes :               34.2 Mm3   24.0 Mm3   100.0 %
```

```
Scenario 201108x2 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       853.0 TDS
Mass Out :      183.1 TDS
Mass Gross :    1036.1 TDS
Mass Net In :   669.9 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :      143.3 TDS   124.2 TDS    14.6 %
Mass In Density Currents :   595.0 TDS   515.5 TDS    60.4 %
Mass In Eddy Currents :      246.2 TDS   213.3 TDS    25.0 %
Sum of Influxes :           984.5 TDS   853.0 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        73.4 %
Trapping density currents :     83.9 %
Trapping eddy currents :        68.5 %
Global trapping efficiency :    78.5 %
```


vol tide
vol density
vol eddy
vol gross
x 10^7
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
volume [m3]
200802
201006
201008
201104
201108
201108x2


mass tide in
mass density in
mass eddy in
mass in
x 10^5
9
8
7
6
5
4
3
2
1
0
volume [m3]
200802
201006
201008
201104
201108
201108x2


% tide in water flux
% density in water flux
% eddy in water flux
trapping efficiency
fraction [%]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200802
201006
201008
201104
201108
201108x2

Bijlage B - Effect van de getijamplitude op de water- en sedimentuitwisseling voor scenario 201108

```
Scenario 201108 (coef 1.16)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        22.0 Mm3
Volume Out :       21.7 Mm3
Volume Gross :     43.7 Mm3
Volume Net In :    0.3 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        6.1 Mm3     4.2 Mm3    19.0 %
Volume In Density Currents :    18.0 Mm3    12.3 Mm3    55.9 %
Volume In Eddy Currents :        8.1 Mm3     5.5 Mm3    25.1 %
Sum of Influxes :               32.2 Mm3    22.0 Mm3   100.0 %
```

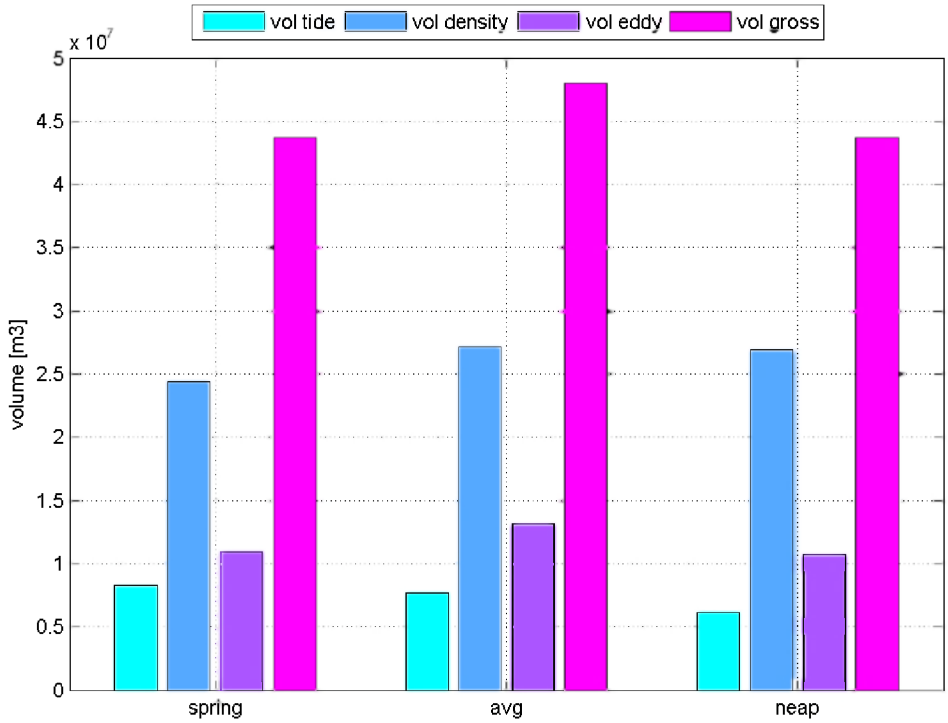
```
Scenario 201108 (coef 1.16)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       926.0 TDS
Mass Out :      230.6 TDS
Mass Gross :    1156.6 TDS
Mass Net In :   695.4 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :      172.3 TDS  143.4 TDS   15.5 %
Mass In Density Currents :   628.1 TDS  522.9 TDS   56.5 %
Mass In Eddy Currents :      311.8 TDS  259.6 TDS   28.0 %
Sum of Influxes :           1112.2 TDS  926.0 TDS  100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        63.7 %
Trapping density currents :     80.1 %
Trapping eddy currents :        71.4 %
Global trapping efficiency :    75.1 %
```

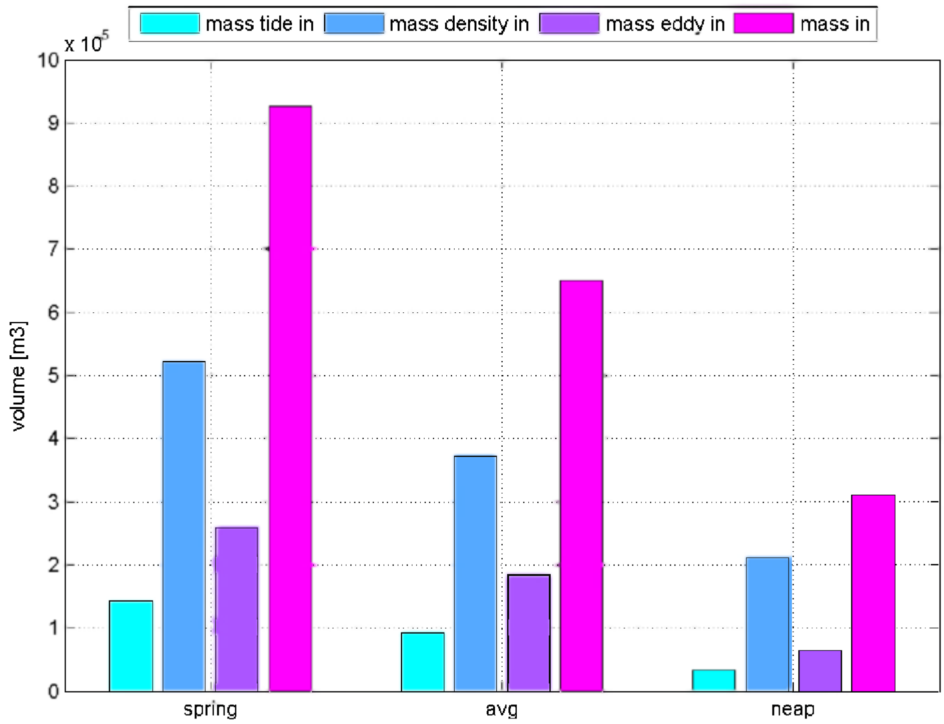
```
Scenario 201108 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        24.1 Mm3
Volume Out :       23.9 Mm3
Volume Gross :     48.0 Mm3
Volume Net In :    0.2 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :        5.5 Mm3    3.8 Mm3   16.0 %
Volume In Density Currents :    19.4 Mm3   13.6 Mm3   56.6 %
Volume In Eddy Currents :        9.4 Mm3    6.6 Mm3   27.5 %
Sum of Influxes :               34.4 Mm3   24.1 Mm3  100.0 %
```

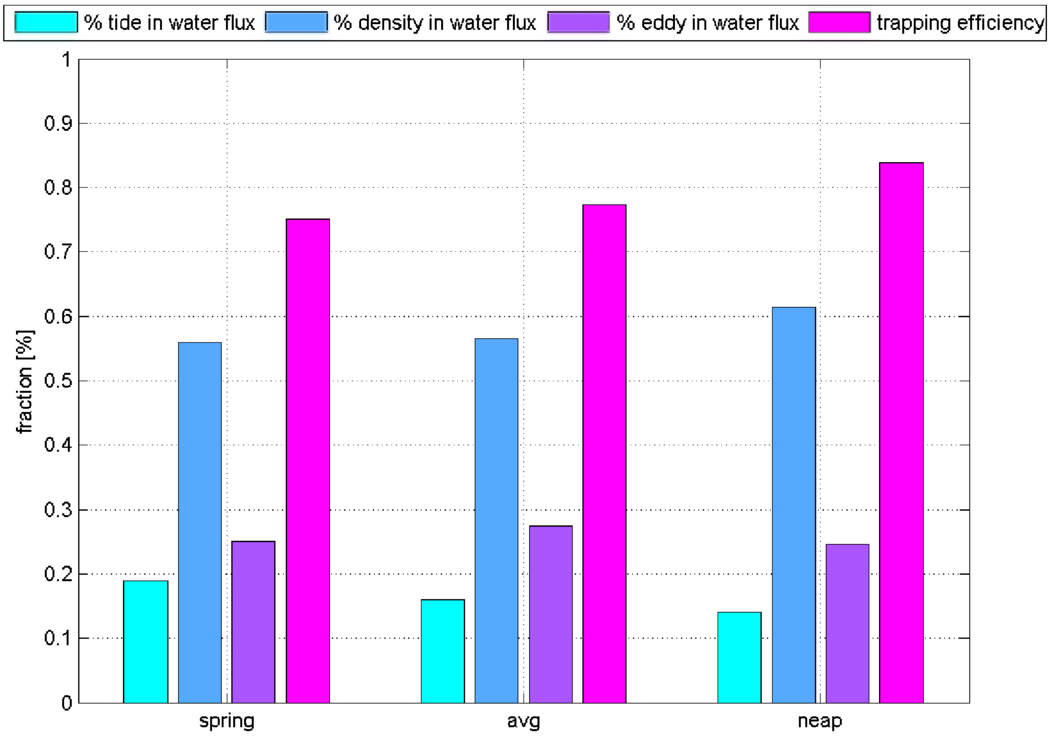
```
Scenario 201108 (coef 1.09)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       650.5 TDS
Mass Out :      147.4 TDS
Mass Gross :    798.0 TDS
Mass Net In :   503.1 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :      108.2 TDS    92.9 TDS    14.3 %
Mass In Density Currents :   433.9 TDS   372.5 TDS    57.3 %
Mass In Eddy Currents :      215.7 TDS   185.2 TDS    28.5 %
Sum of Influxes :           757.8 TDS   650.5 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :        72.2 %
Trapping density currents :     82.8 %
Trapping eddy currents :        68.9 %
Global trapping efficiency :    77.3 %
```

```
Scenario 201108 (coef 0.87)

Tide coverage :       12.5 hours
---------------------------
Total water exchange modelled

Volume In :        21.9 Mm3
Volume Out :       21.8 Mm3
Volume Gross :     43.8 Mm3
Volume Net In :    0.1 Mm3
---------------------------
Water influx per component computed, scaled to modelled influx, and relative fraction

Volume In Tidal Filling :       4.3 Mm3    3.1 Mm3    14.0 %
Volume In Density Currents :   19.0 Mm3   13.5 Mm3    61.5 %
Volume In Eddy Currents :       7.6 Mm3    5.4 Mm3    24.5 %
Sum of Influxes :              30.9 Mm3   21.9 Mm3   100.0 %
```

```
Scenario 201108 (coef 0.87)

Tide coverage :       12.5 hours
---------------------------
Total sediment exchange modelled

Mass In :       310.0 TDS
Mass Out :       50.1 TDS
Mass Gross :    360.0 TDS
Mass Net In :   259.9 TDS
---------------------------
Sediment influx per component computed, scaled to modelled influx, and relative fraction

Mass In Tidal Filling :       37.1 TDS    33.5 TDS    10.8 %
Mass In Density Currents :   234.2 TDS   211.4 TDS    68.2 %
Mass In Eddy Currents :       72.0 TDS    65.0 TDS    21.0 %
Sum of Influxes :            343.2 TDS   310.0 TDS   100.0 %
---------------------------
Trapping efficiency per component

Trapping tidal filling :       69.2 %
Trapping density currents :    89.0 %
Trapping eddy currents :       74.8 %
Global trapping efficiency :   83.9 %
```


vol tide
vol density
vol eddy
vol gross
x 10^7
volume [m3]
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
spring
avg
neap


mass tide in
mass density in
mass eddy in
mass in
x 10^5
volume [m3]
10
9
8
7
6
5
4
3
2
1
0
spring
avg
neap


% tide in water flux
% density in water flux
% eddy in water flux
trapping efficiency
fraction [%]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
spring
avg
neap