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Enabling Delta Life

Model Supported Monitoring of SPM in the Dutch Coastal Zone

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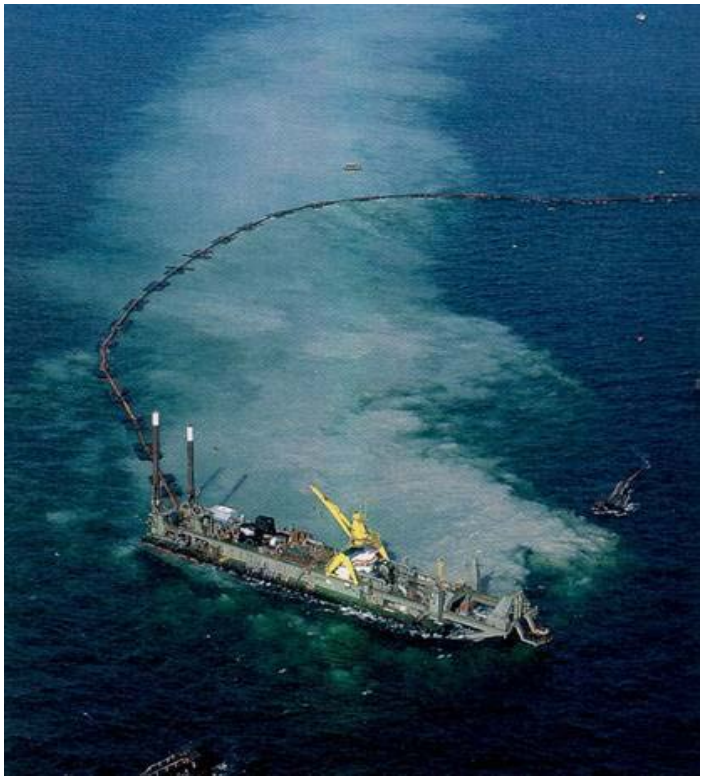
1 Deltares, The Netherlands
2 Port of Rotterdam, The Netherlands

Port of Rotterdam – harbour extension

Maasvlakte 2

Work consisted of land reclamation by Port of Rotterdam (2008-2013) and the environmental Impact Assessment



Important to assess both baseline and perturbed conditions: 240 million m3 of sand was dredged

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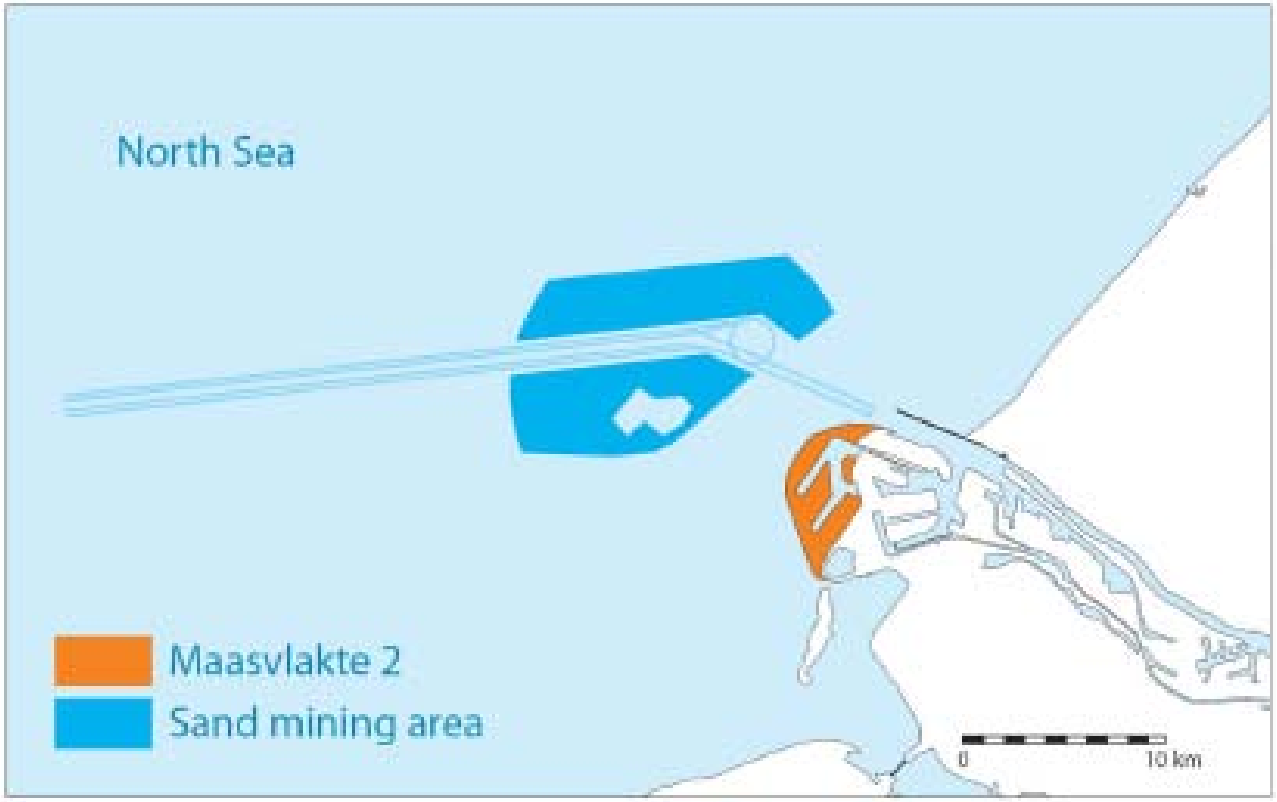
Maasvlakte-2 land reclamation

Extension of present reclamation by Port of Rotterdam (2008-2013):

1st phase: ~200 x 10^6 m^3 offshore sand required (1.5 -2.5% silt)
2nd phase (>2013): ~ 80 x 10^6 m^3 sand required



Additional silt due to sand mining may affect underwater light conditions

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SPM: suspended particulate matter

SPM = mostly silt + detritus

SPM affects marine environment:

- Underwater light climate
- Nutrient transport
- Medium for pollutant transport
- Colour of sea water

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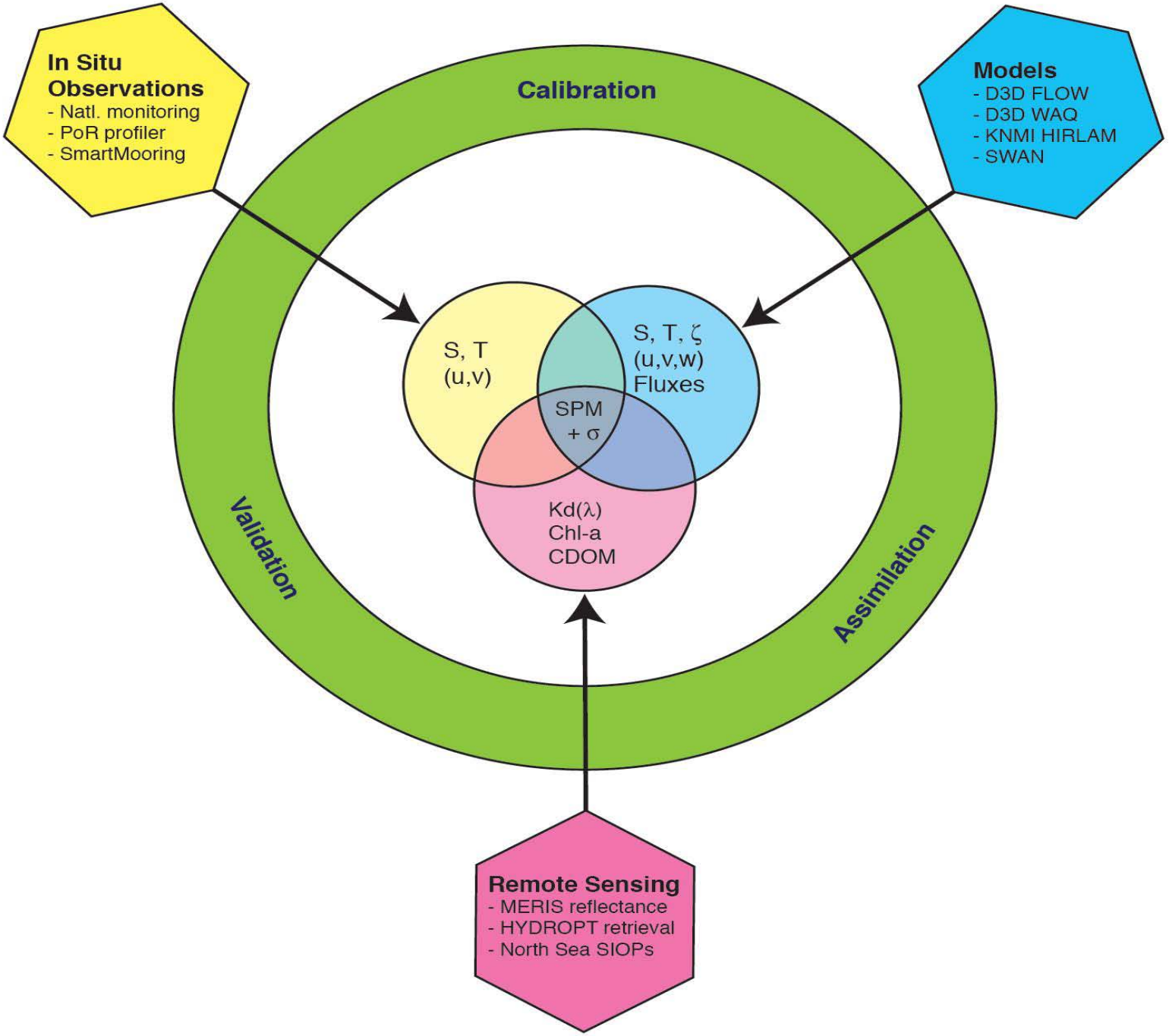

In Situ Observations
- Natl. monitoring
- PoR profiler
- SmartMooring
Calibration
Models
- D3D FLOW
- D3D WAQ
- KNMI HIRLAM
- SWAN
S, T
(u,v)
S, T, ζ
(u,v,w)
Fluxes
SPM
+ σ
Kd(λ)
Chl-a
CDOM
Validation
Assimilation
Remote Sensing
- MERIS reflectance
- HYDROPT retrieval
- North Sea SIOPs

Project phases

MoS²-I – 1st phase:

1

- Modelling framework set up and analysis for 2007
- Ensemble Kalman Filter data assimilation scheme developed
- Processing + Analysis of MERIS data

MoS²-II – 2nd phase:

2

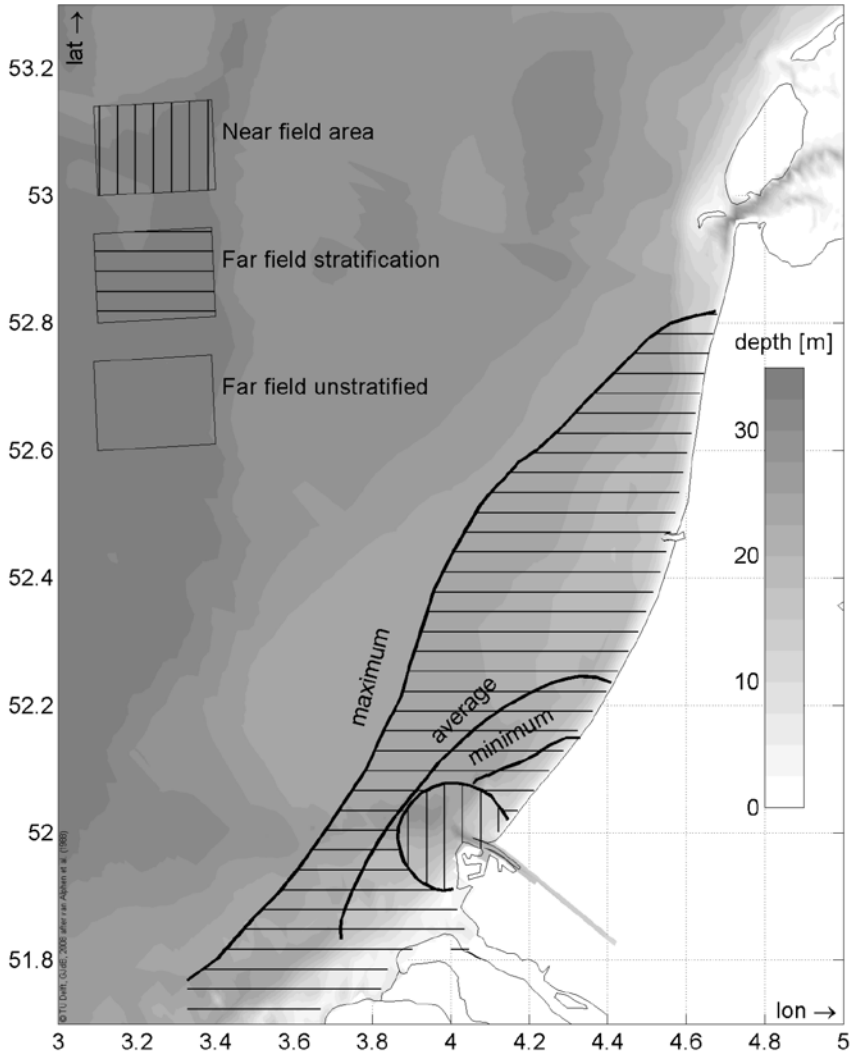
- Model hindcast pre-Maasvlakte (**T0**) conditions (2003-2008)
- Parameter sensitivity analysis
- Model optimized with MERIS remote sensing data of SPM by means of the generic *simulated annealing* algorithm (2003-2008)

MoS²-III – 3rd phase in the series of studies -- consists of two related sets of activities:

3

- Data Analysis 2003-2008, 2009-2011
- Model Forecast Analysis 2009-2011 (**T1**)

Main area of interest



Focus Rhine ROFI & Voordelta

Spatial assessment scales: ~10 km

Temporal scales: weeks to years

Complex dynamics:

- Barotropic tides (semidiurnal, spring-neap)
- Wind-driven flow & up-downwelling
- Haline stratification
- Baroclinic cross-shore flows
- Wind and wave-induced mixing

Eleveld, et al. 2008 Est. Coast. Shelf Sci. 80(1)
De Boer et al. 2009. CSR 29(1)
Pietrzak at al. 2010 CSR 31(6)

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Focus today: Delft3D modelling of SPM

http://oss.deltares.nl/web/delft3d

Delft3D is an **open-source** multi-dimensional hydrodynamic simulation program, which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing

The Delft3D modelling package (Sed-Online, Delwaq, Delft3d-Wave) a large variation of coastal and estuarine physical and chemical processes can be simulated:

NEW: unstructured grids DFLOW-FM

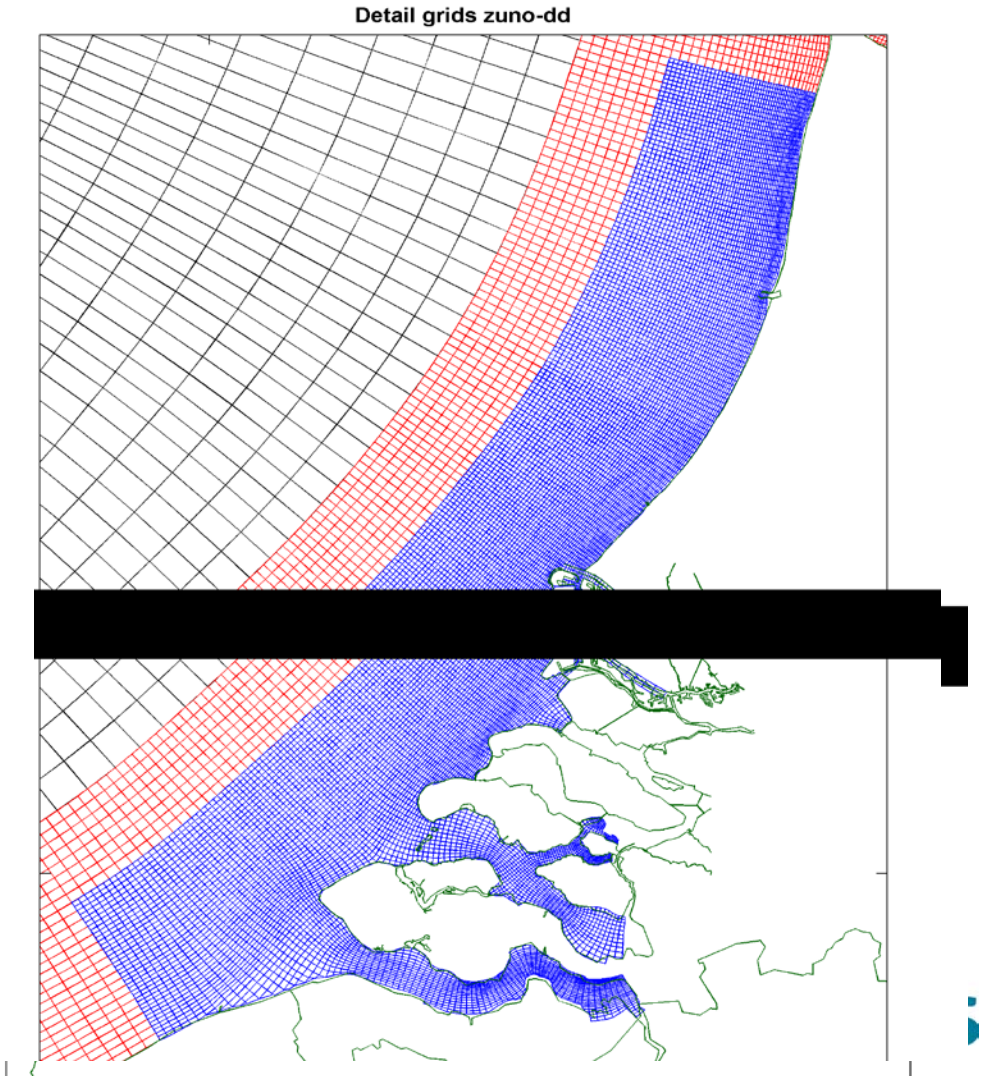
- Waves
- tidal propagation
- wind- or wave-induced water level setup
- flow induced by salinity or temperature gradients
- Sediment transport and morphology
- water quality
- Delft3D can also be used operationally e.g. storm, surge and algal bloom forecasting.

Southern North Sea model (Delft3D ZUNO-DD)

- 3D, 12 • -layers

- Curvilinear grid: 3 domains
- Coarse grid: • 20-30km
- Intermediate grid: • 2.5 -3 km
- Fine grid: • 1-1.5 km
- Finer vertical resolution near the bed + near surface

- Hindcast 2003-2008



Hydrodynamics: Delft3D-FLOW

Boundaries: Astronomical water levels: amplitudes and phases of 50 tidal constituents

Meteorological forcing: wind-speed, direction, pressure, air temperature, relative humidity and cloudiness HIRLAM model (V7.0) of KNMI

Discharges: North Sea discharges were taken from the DONAR database of the Dutch Ministry of Public Works. UK, French, German, Danish discharges: from a EU database at CEFAS (UK)

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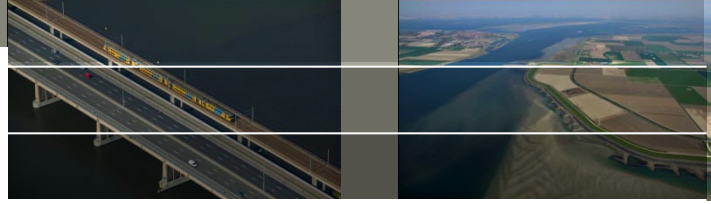
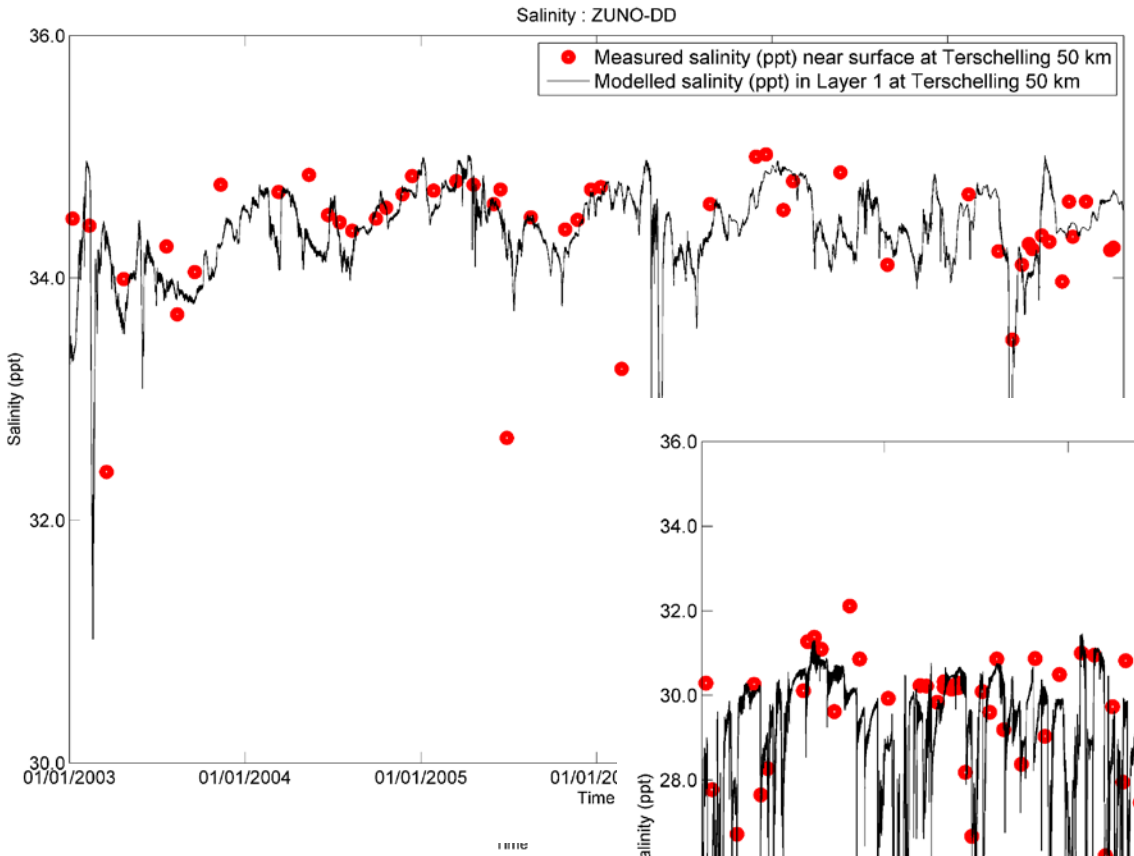
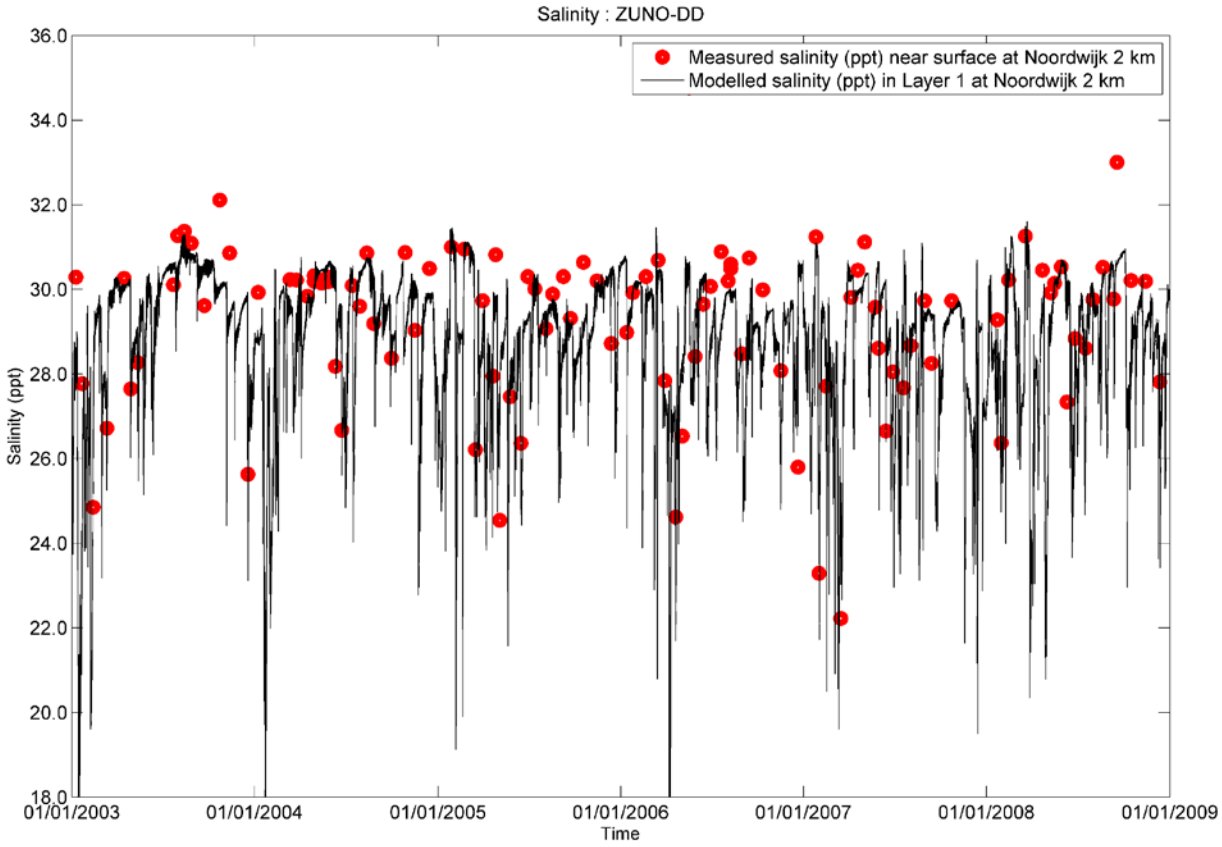



Salinity : ZUNO-DD
Measured salinity (ppt) near surface at Terschelling 50 km
Modelled salinity (ppt) in Layer 1 at Terschelling 50 km
Salinity (ppt)
36.0
34.0
32.0
30.0
01/01/2003
01/01/2004
01/01/2005
Time


Salinity : ZUNO-DD
Measured salinity (ppt) near surface at Noordwijk 2 km
Modelled salinity (ppt) in Layer 1 at Noordwijk 2 km
Salinity (ppt)
36.0
34.0
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
Time

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Modelling of SPM using Delft3D-WAQ (Delwaq)

- Delft3D-WAQ -solves the advection-diffusion-reaction equation for a wide range of model substances
- Coupling files from Delft3D-FLOW
- Grid aggregated -> increase speed (fine grid increase x2) -> 10 • t
- Wave forcing derived offline – calculated bed shear stress based on Swart (1974) formulation

$$\tau_{wc} = \frac{1}{2}\rho_w f_{wc}\hat{u}_{bot}\hat{u}_{bot}$$

$$f_{wc} = \exp\left(-5.977 + 5.213\left(\frac{a}{z_0}\right)^{-0.194}\right)$$

a = near-bed wave orbital excursion amplitude

Z_0 = roughness length

• $_w$ = density of sea water

$\hat{u}_{bot}$ = near-bed wave orbital velocity

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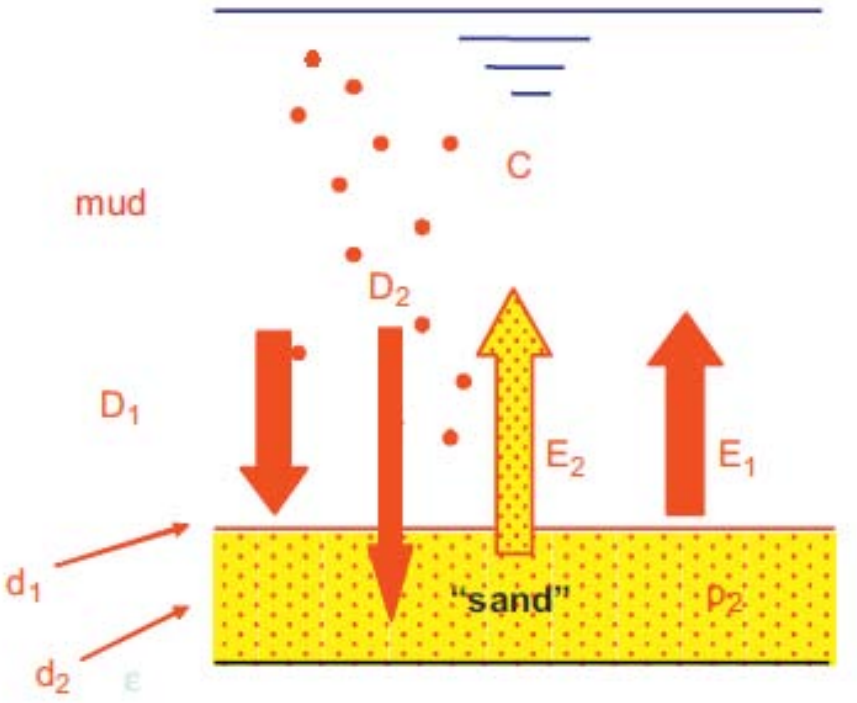
Modelling of SPM using Delft3D-WAQ (Delwaq)

- Interaction of suspended sediment with the bed using the buffer model

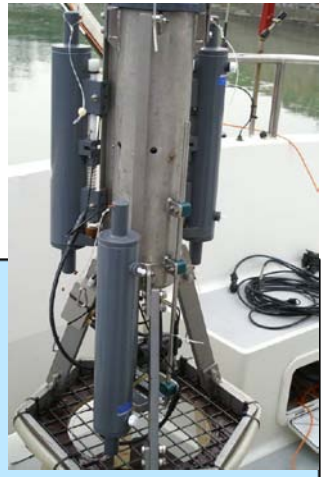
- The buffer parameterisation is a bed module that includes seasonal buffering of fine sediments. This means that fine sediments are stored in the seabed during calm conditions and released from the seabed during stormy conditions (Van Kessel et al., 2011).

  - 2-layer sediment bed
  - 3 silt size fractions – with different but constant setting velocities
  - Additional sources (cliffs, banks, rivers)
  - Resuspension of SPM due to currents & surface waves



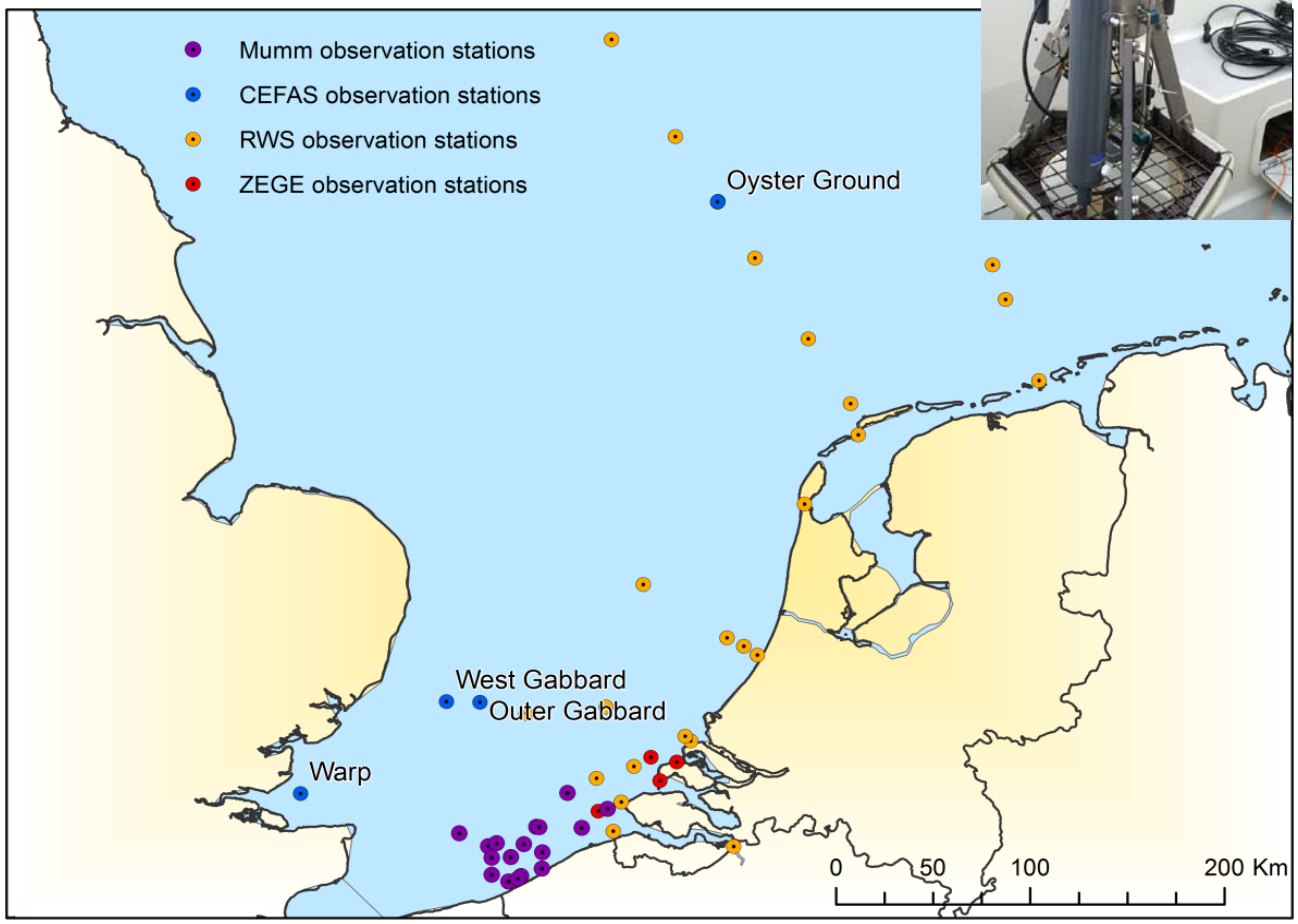
Modelling of SPM using Delft3D-WAQ (Delwaq)

A series of calibration steps were carried out to improve the simulation of SPM



<u>The model was validated against:</u>

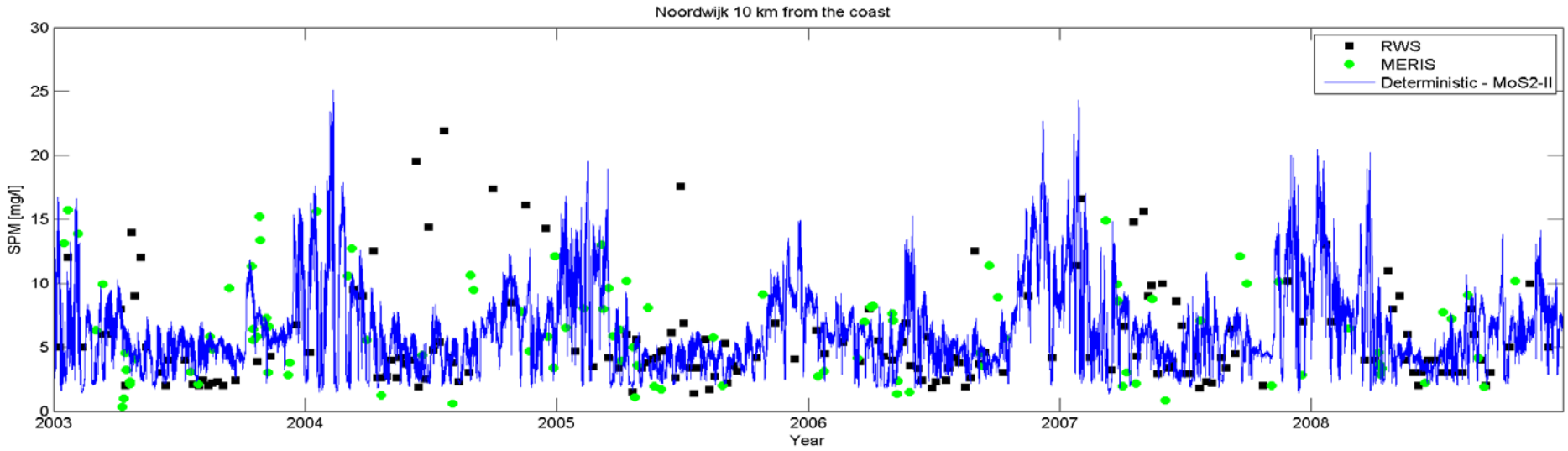
- MUMM *in situ* measurements (surface)
- CEFAS smartbuoy *in situ* measurements (high temporal resolution)
- Port of Rotterdam profiler data (2007!, Seapoint OBS 25 & 125)
- MERIS SPM concentrations (surface)



Results of the SPM modelling

Model skill demonstrated with:

- time series
- scatter plots
- bias maps
- depth averaged difference maps



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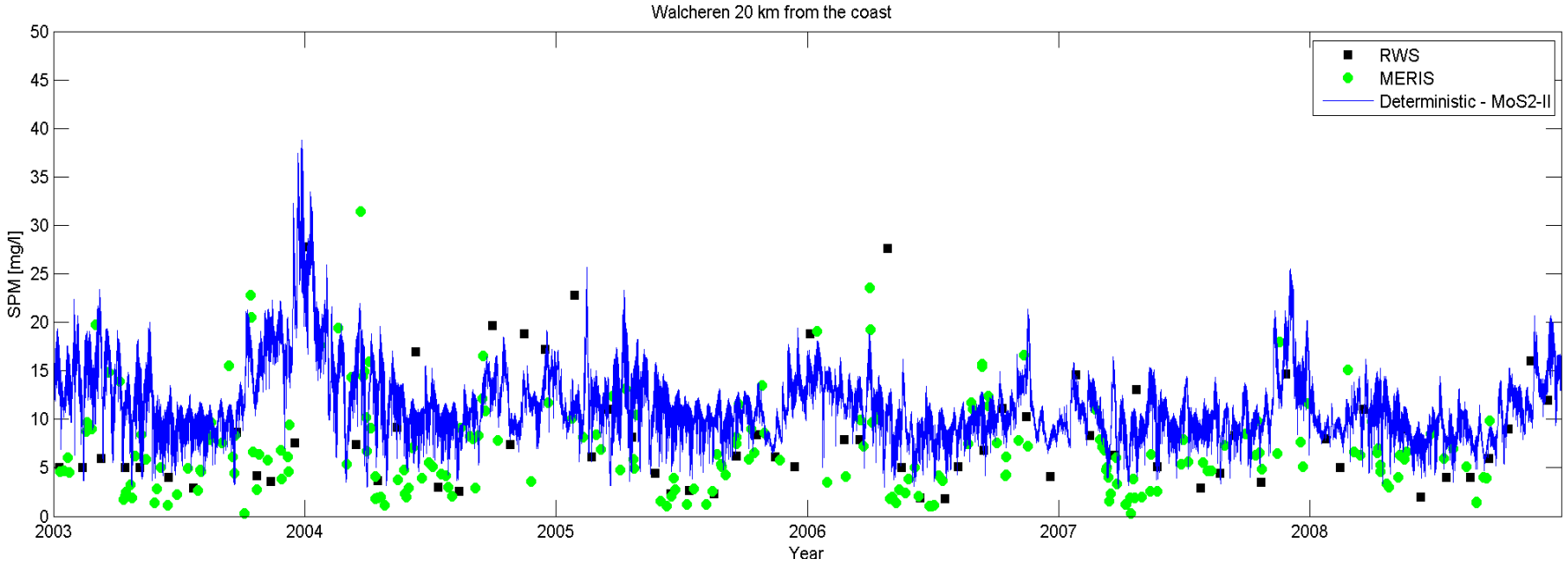
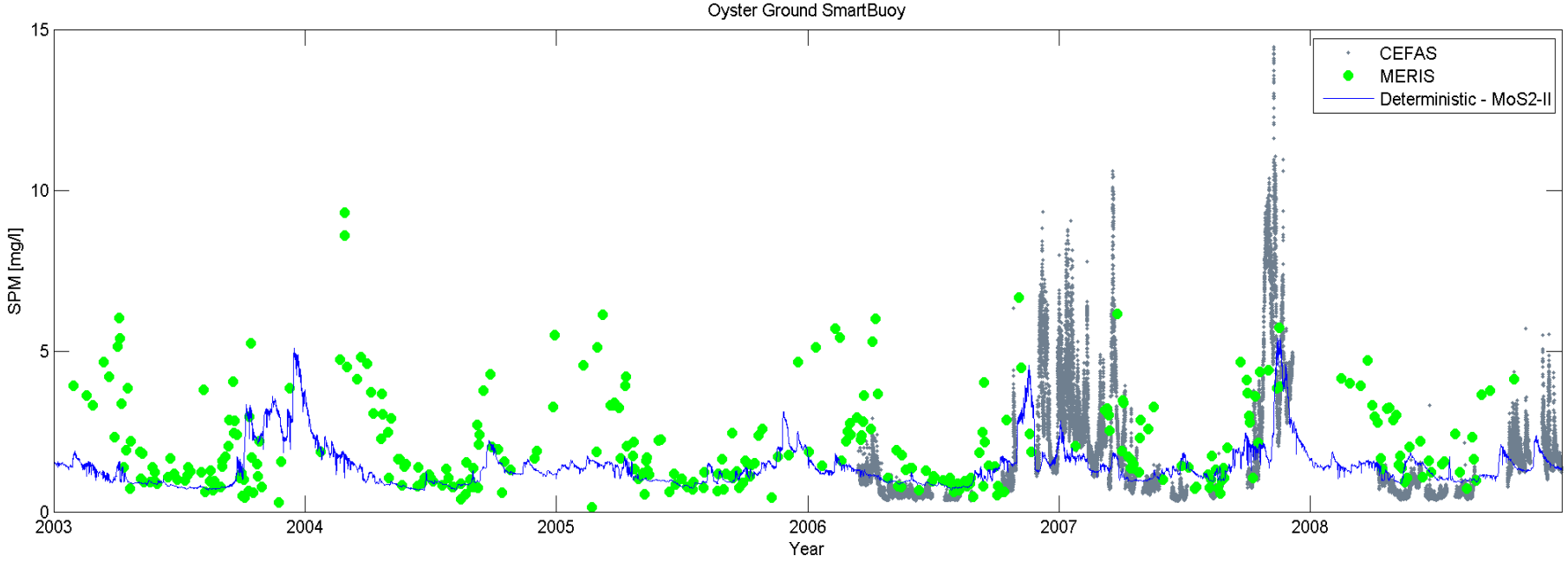
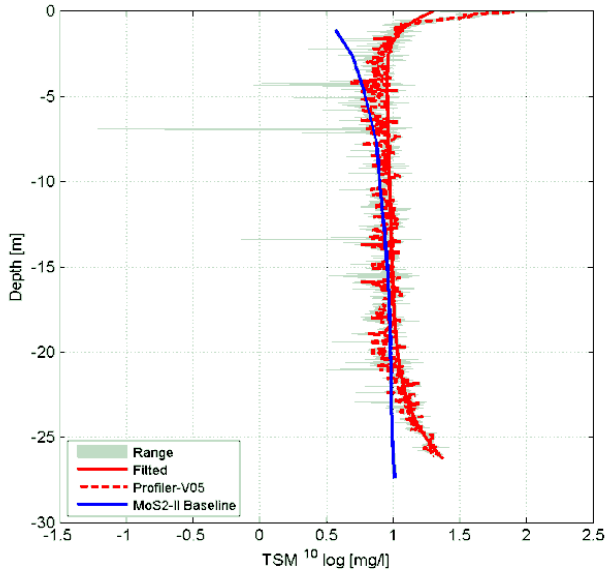
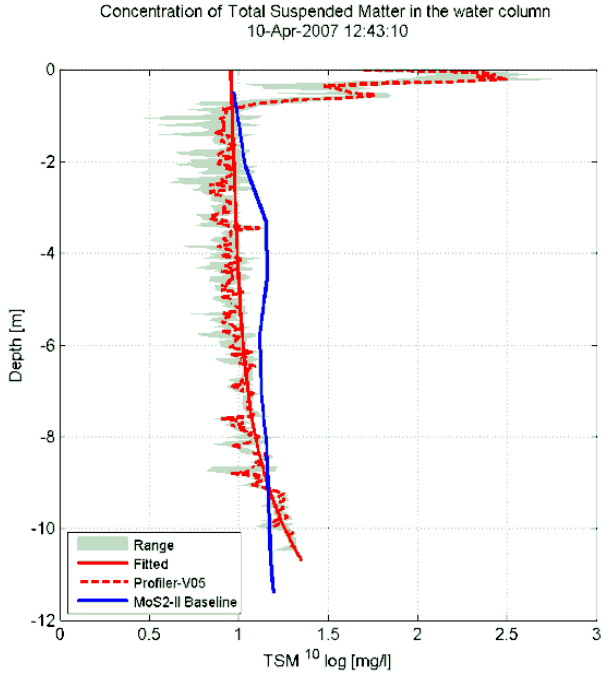
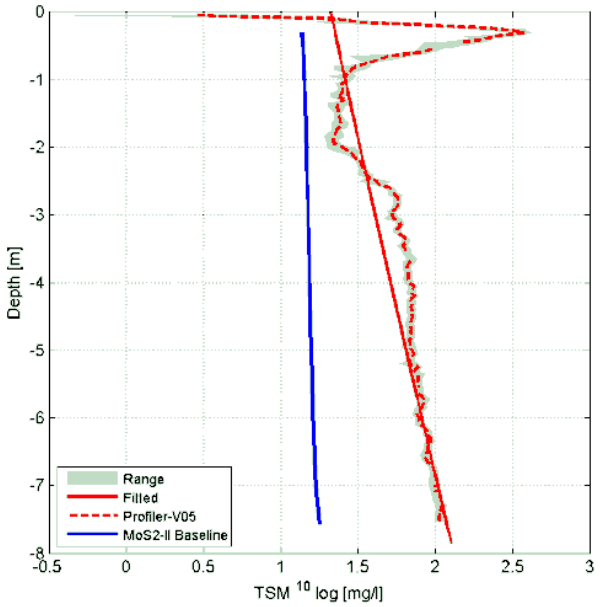
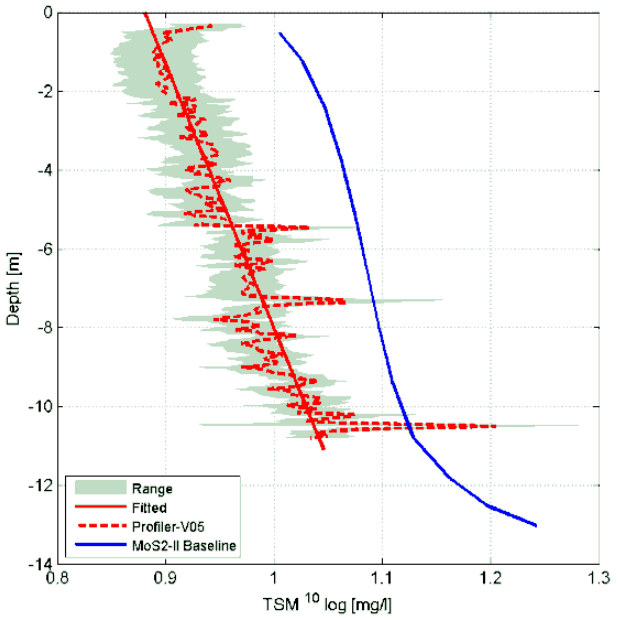

Walcheren 20 km from the coast
RWS
MERIS
Deterministic - MoS2-II
SPM [mg/l]
Year
0
5
10
15
20
25
30
35
40
45
50
2003
2004
2005
2006
2007
2008

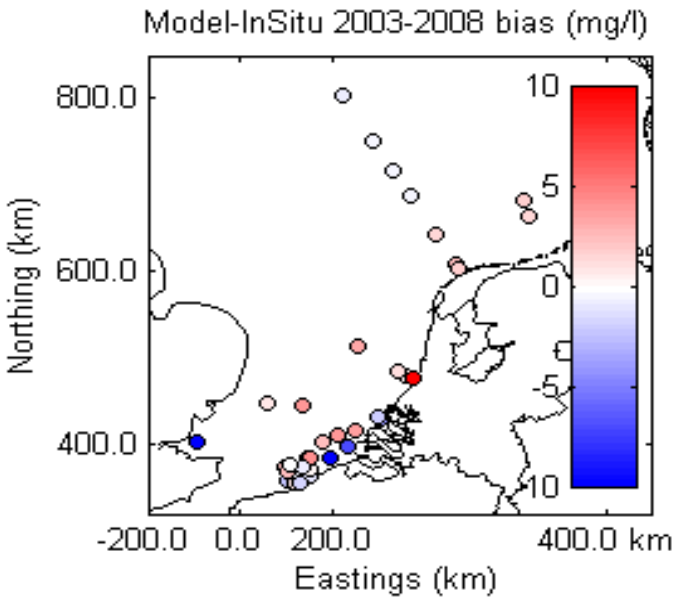

Oyster Ground SmartBuoy
CEFAS
MERIS
Deterministic - MoS2-II
SPM [mg/l]
Year
0
5
10
15
2003
2004
2005
2006
2007
2008

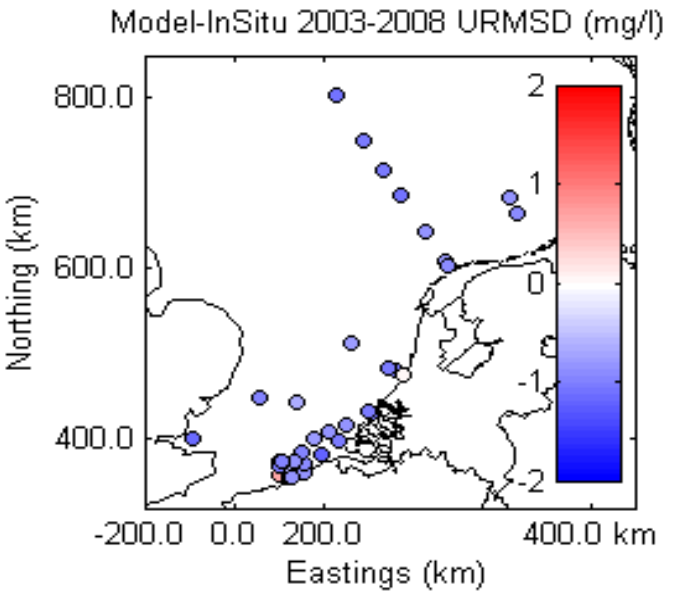

Concentration of Total Suspended Matter in the water column
05-Apr-2007 09:32:13
Depth [m]
TSM 10 log [mg/l]
Range
Fitted
Profiler-V05
MoS2-II Baseline

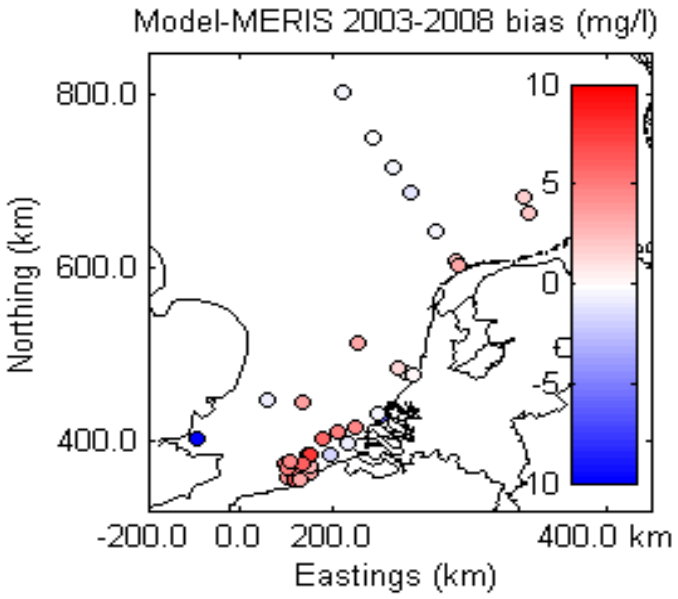

Concentration of Total Suspended Matter in the water column
10-Apr-2007 12:43:10
Depth [m]
TSM 10 log [mg/l]
Range
Fitted
Profiler-V05
MoS2-II Baseline

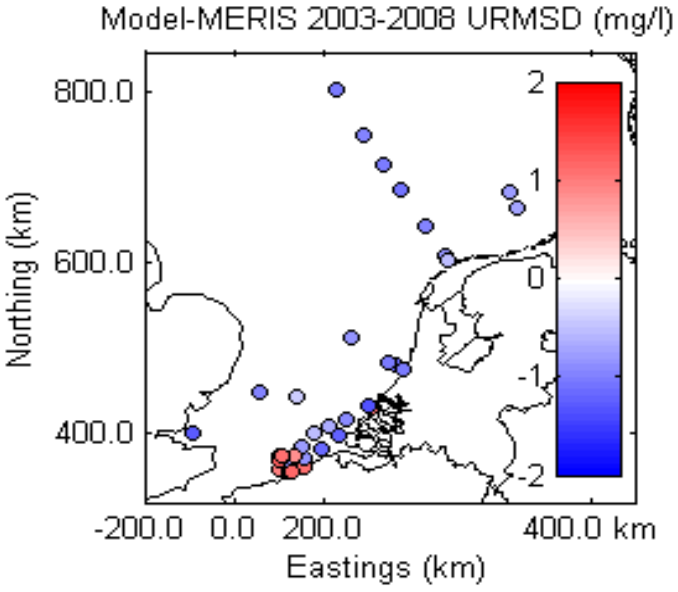

Concentration of Total Suspended Matter in the water column
18-Apr-2007 12:16:52
Depth [m]
TSM 10 log [mg/l]
Range
Fitted
Profiler-V05
MoS2-II Baseline


Concentration of Total Suspended Matter in the water column
01-Nov-2007 23:49:38
Depth [m]
TSM 10 log [mg/l]
Range
Fitted
Profiler-V05
MoS2-II Baseline


Model-InSitu 2003-2008 bias (mg/l)
800.0
600.0
400.0
Northing (km)
10
5
0
-5
-10
-200.0
0.0
200.0
400.0 km
Eastings (km)


Model-InSitu 2003-2008 URMSD (mg/l)
800.0
600.0
400.0
Northing (km)
2
1
0
-1
-2
-200.0
0.0
200.0
400.0 km
Eastings (km)


Model-MERIS 2003-2008 bias (mg/l)
800.0
600.0
400.0
Northing (km)
10
5
0
-5
-10
-200.0
0.0
200.0
400.0 km
Eastings (km)


Model-MERIS 2003-2008 URMSD (mg/l)
800.0
600.0
400.0
Northing (km)
2
1
0
-1
-2
-200.0
0.0
200.0
400.0 km
Eastings (km)

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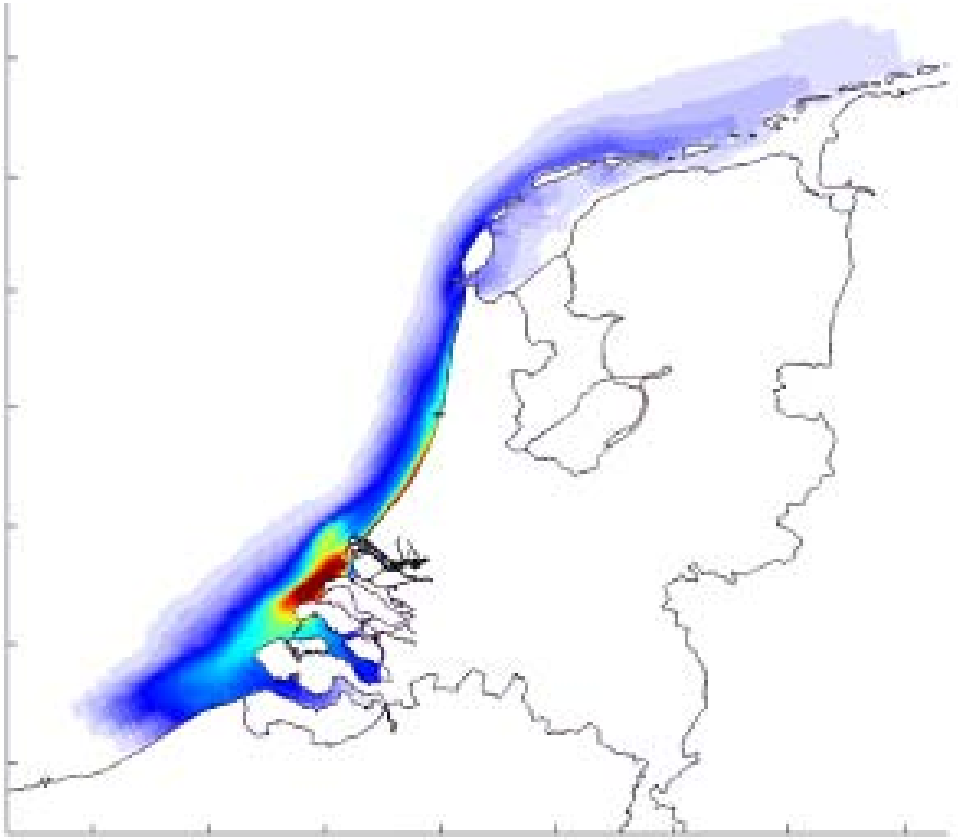
Summary of model performance

- SPM concentrations and seasonal variability being well captured by the model, especially along the coast e.g. Noordwijk 2, Noordwijk 10 and Goeree 6.
- Both calm weather concentrations and storm peaks are captured,
- SPM concentrations near-shore, concentrations at certain stations offshore such as Noordwijk 70 km and Walcheren 70 km are overestimated by the model.
- This gradient of worsening SPM simulation offshore may be related to uniformity of the settling velocity throughout the model domain.
- Important to compare to different data sources – in-situ surface measurements, depth profiles of SPM + remotely sensed data

Delft3D-WAQ model set-up used as input for:

- A series of sand mining scenarios (plume modelling)
- Model optimization to run baseline conditions and enable ‘forecast’ period (2009-2011)
- Optimized model used to determine trends associated with the sand mining activities for the Maasvlakte-2



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Credits to all involved in the various phases:

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Ghada El Serafy
Sandra Gaytan Aguilar
Ivan Garcia
Dana Stuparu
Geert Keetels
Remco Plieger
Theo van der Kaij
Gerben de Boer
Nicky Villars
Meinte Blaas (PL)

Thijs van Kessel
Herman Gerritsen
Martin Verlaan

VU-IVM

Nils de Reus
Hans van der Woerd
Marieke Eleveld (PL)

Steef Peters
Jan Vermaat

Wil Borst
Onno van Tongeren
Paul van der Zee
Tiedo Vellinga

Julie Pietrzak (TUD)
Bram van Prooijen (TUD)
Kevin Ruddick (MUMM)
Arnold Heemink (TUD)

Ad Stolk

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