Calibration of a New Generation Flood Forecasting Model for the Northwest European Shelf and North Sea using Data Assimilation Techniques (OpenDA)

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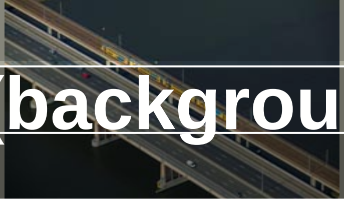
JONSMOD, May 2012



DCSMv6 model development (background)

Development of a real-time flood forecasting model for the Northwest European Shelf and North Sea

- Dutch Continental Shelf Model v6 (DCSMv6) will replace operational DCSMv5
- Model to provide water level forecasts every 6 hours, with 48-hour lead time
- Provide downstream boundary conditions for (fluvial) flood forecasting models
- WAQUA module of SIMONA framework, for numerical modelling of 2D free surface flows

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DCSMv6 model development (operational framework)

The framework for operational storm surge prediction

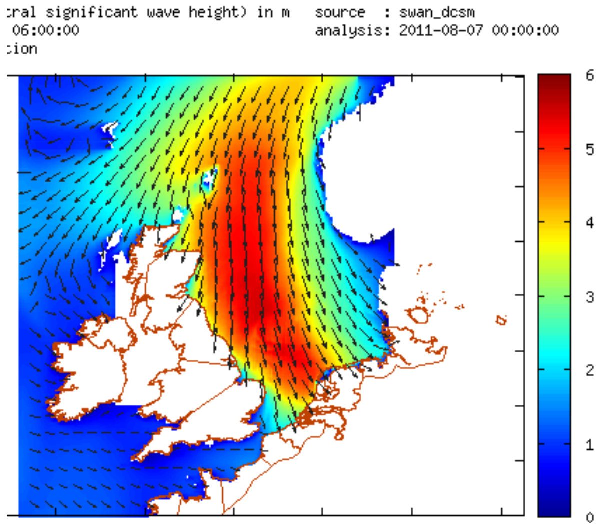
• New generation model is part of a comprehensive development to upgrade the operational forecasting system for the North Sea

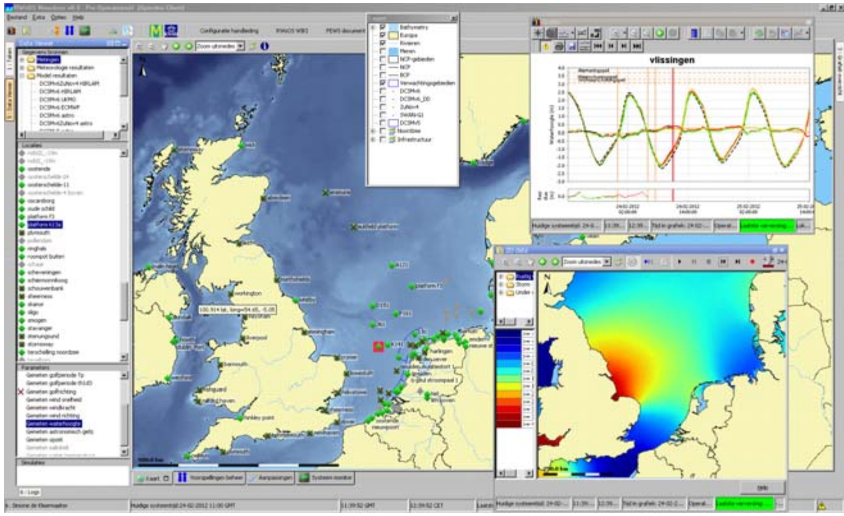
• Maintained by the Dutch ‘Storm Surge Warning Service’ (SVSD), which is responsible for issuing warnings to coastal authorities during high water threats

•Framework contains much more functionality and models (e.g. DCSMv6 with Kalman filter, DCSMv6-ZUNOv4, SWAN model, etc.)

Focus of this presentation:

model setup, calibration and validation





Model setup

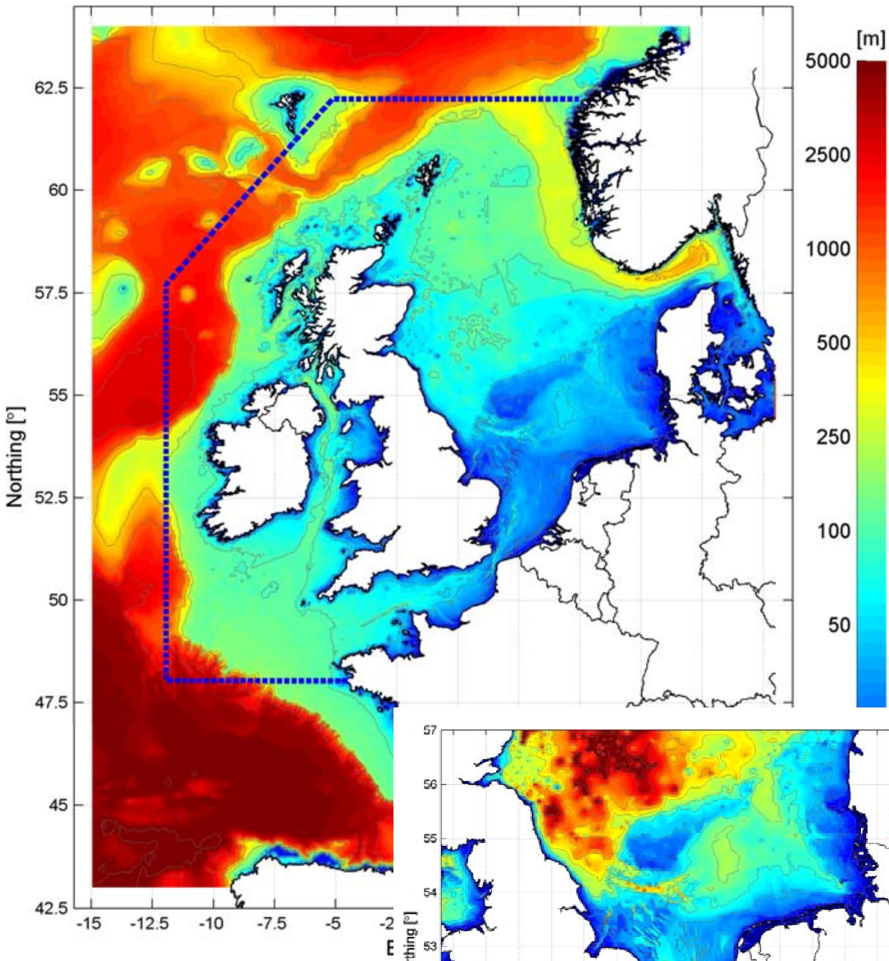
DCSMv6 model setup (model grid and bathymetry)

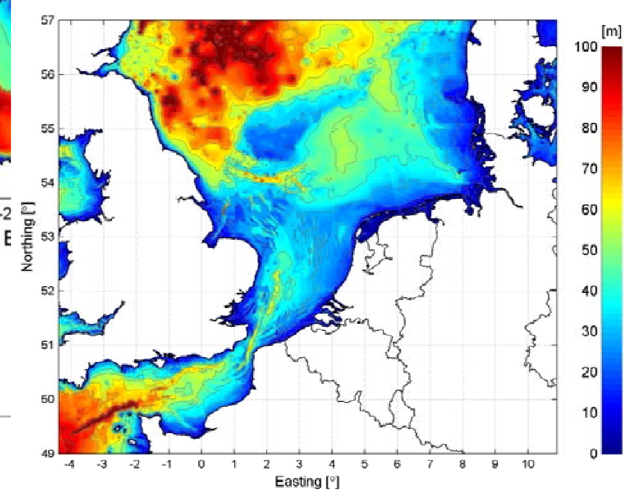
Model setup - computational grid

- Increased spatial coverage
- Uniform cell size of 1.5’ (1/40°) in east-west direction and 1.0’ (1/60°) in north-south direction (~nautical mile)
- Around 10^6 active grid cells
- With a computational time step of 2 minutes, a 1 day simulation takes approximately 5 minutes on 12 computational cores

Model setup – bathymetry

- Initially based on NOOS gridded bathymetry data set, supplemented by ETOPO2
- Changes made during calibration





DCSMv6 model setup (boundary forcing)

Model setup - boundary forcing

• Open boundary with 205 sections

• Distinction made between 2 components of the water level elevation:

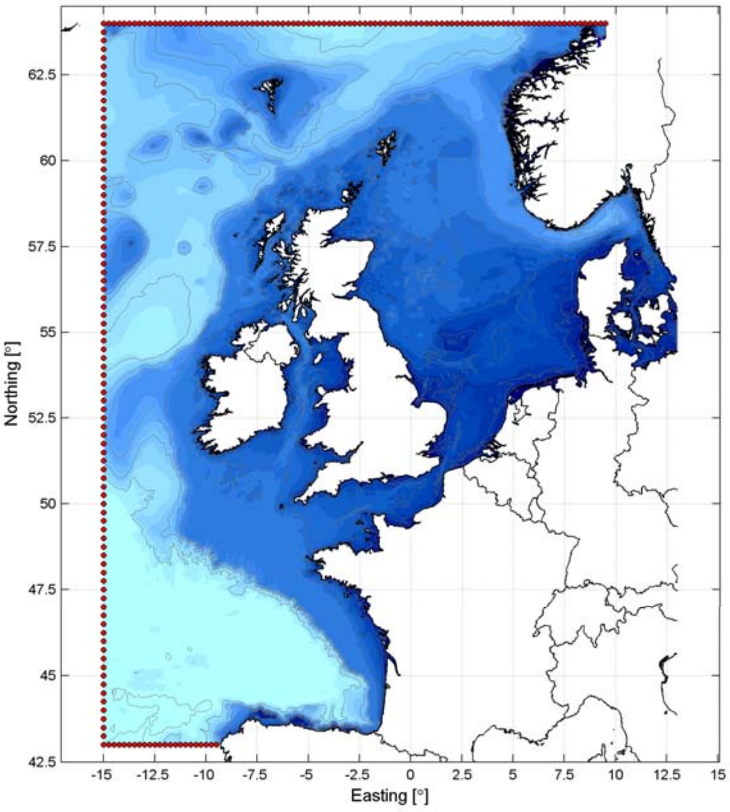
(1) Tide, defined in frequency domain

✓ 8 main constituents from global ocean tide model (GOT00.2)

✓16 smaller (semi-)diurnal constituents

✓ Solar annual constituent Sa

(2) Surge, as an inverse barometer correction (IBC) based on time and space varying pressure fields



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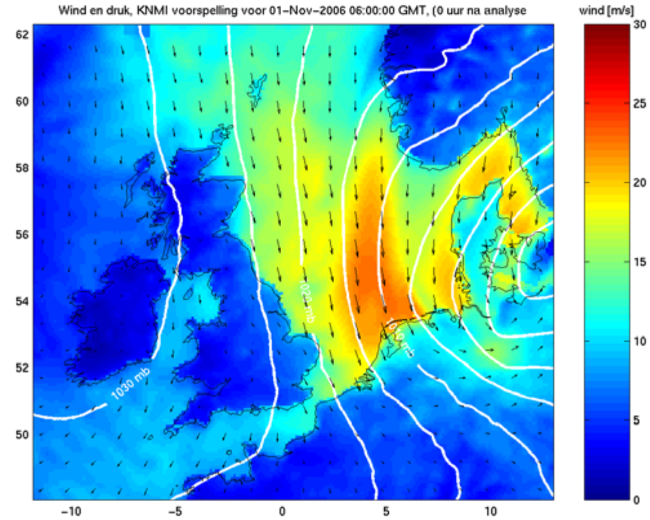
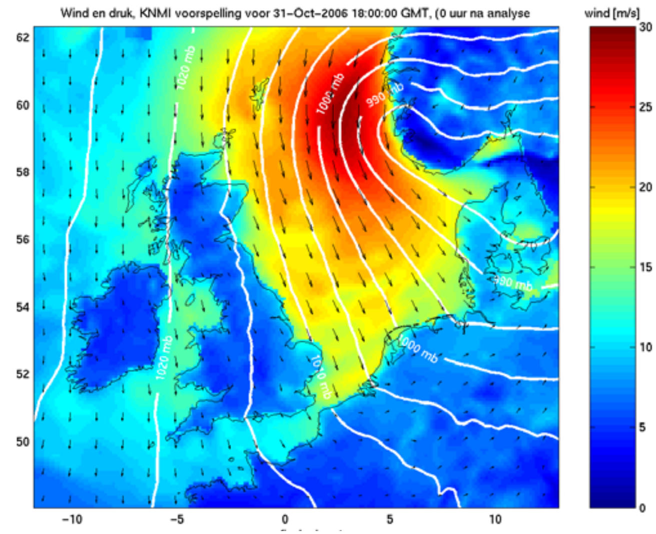
DCSMv6 model setup (meteo forcing)



Model setup - meteo forcing

- Wind speed and air pressure from HIRLAM (NWP) model provided (operationally) by KNMI (Dutch MetOffice)
- Sea surface roughness is calculated using the Charnock relation (Charnock parameter 0.025)



Model setup - miscellaneous

- Spatially varying manning bed roughness
- Tide Generating Forces (TGF) included

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Modeling approach

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DCSMv6 modelling approach

Modeling stage	Description
Calibration (1)	One year period (2007) – manual step-by-step approach - *assessment of tidal propagation with Satelite Altimeter data*
Calibration (2)	One year period (2007) – *optimization with DA technique*
Validation (1)	One year period (2008)
Validation (2)	Modeling of historical events (All Saints storm 2006)
Validation (3)	Two-year period (2007 – 2008), assessment of *forecast accuracy* (4 runs / day with a 48 hr lead-time)

Goodness-of-Fit criteria

Goodness-of-Fit criteria frequency domain

$GoF_{freq} = RMS_{stations} RSS_{constituents} VD$

Where VD is the Vector Difference for each tidal constituent,

$RSS_{constituents}$ is the Root-Summed-Square over all VD's and

$RMS_{stations}$ is the Root-Mean-Square of the RSS values for all stations

Goodness-of-Fit criteria time domain

$GoF_{time} = RMS_{stations} RMSE_t$

Where $RMSE_t$ is the Root-Mean-Square-Error at each station

→ *Signal is split in tide and surge part with harmonic analysis*

Goodness-of-Fit criteria time domain – high waters only

$GoF_{time} = RMS_{stations} RMSE_{HW}$

Where $RMSE_{HW}$ is the Root-Mean-Square Error of all high waters (approximately one every 12 hours, ignoring small differences in timing)

Model calibration (1)

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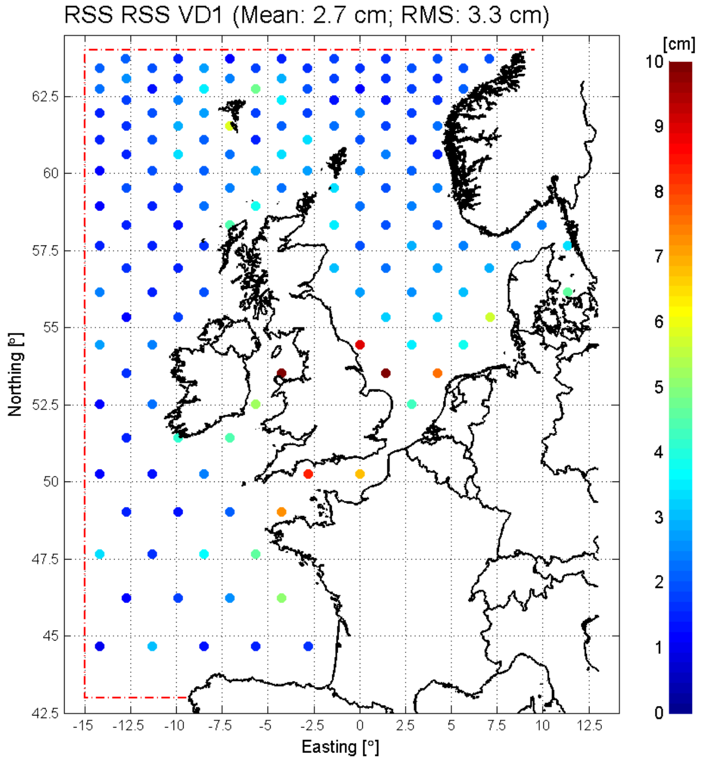
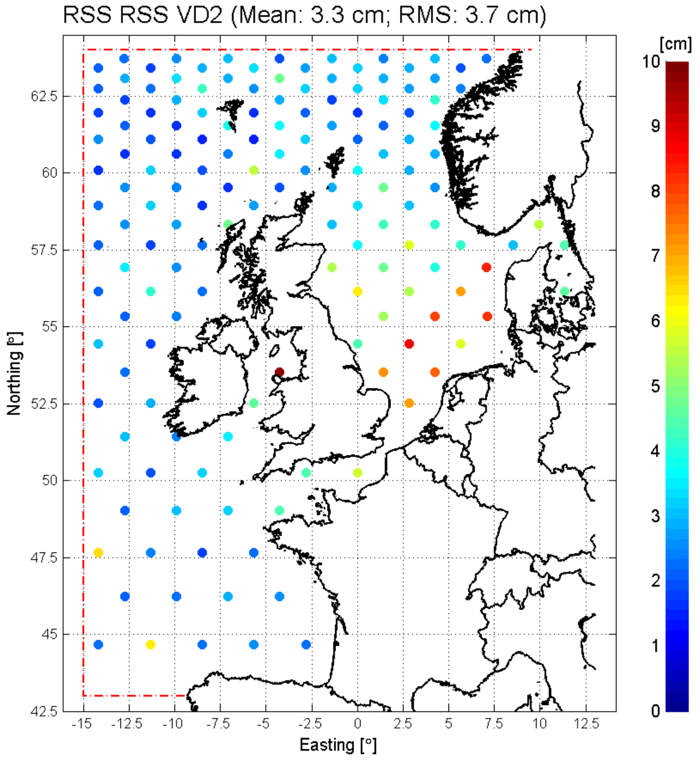
Analysis of T/P-Jason satelite altimeter data

Comparison with GOT00.2 global ocean tide model



GoFfreq = 3.3 cm

Consistency at intersections of ascending and descending tracks



GoFfreq = 3.7 cm

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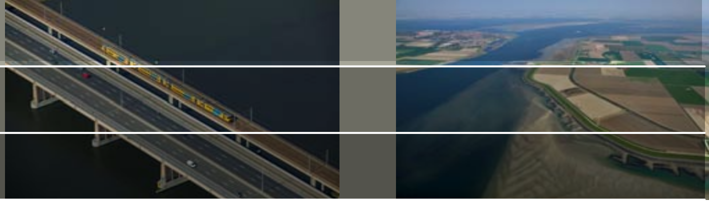
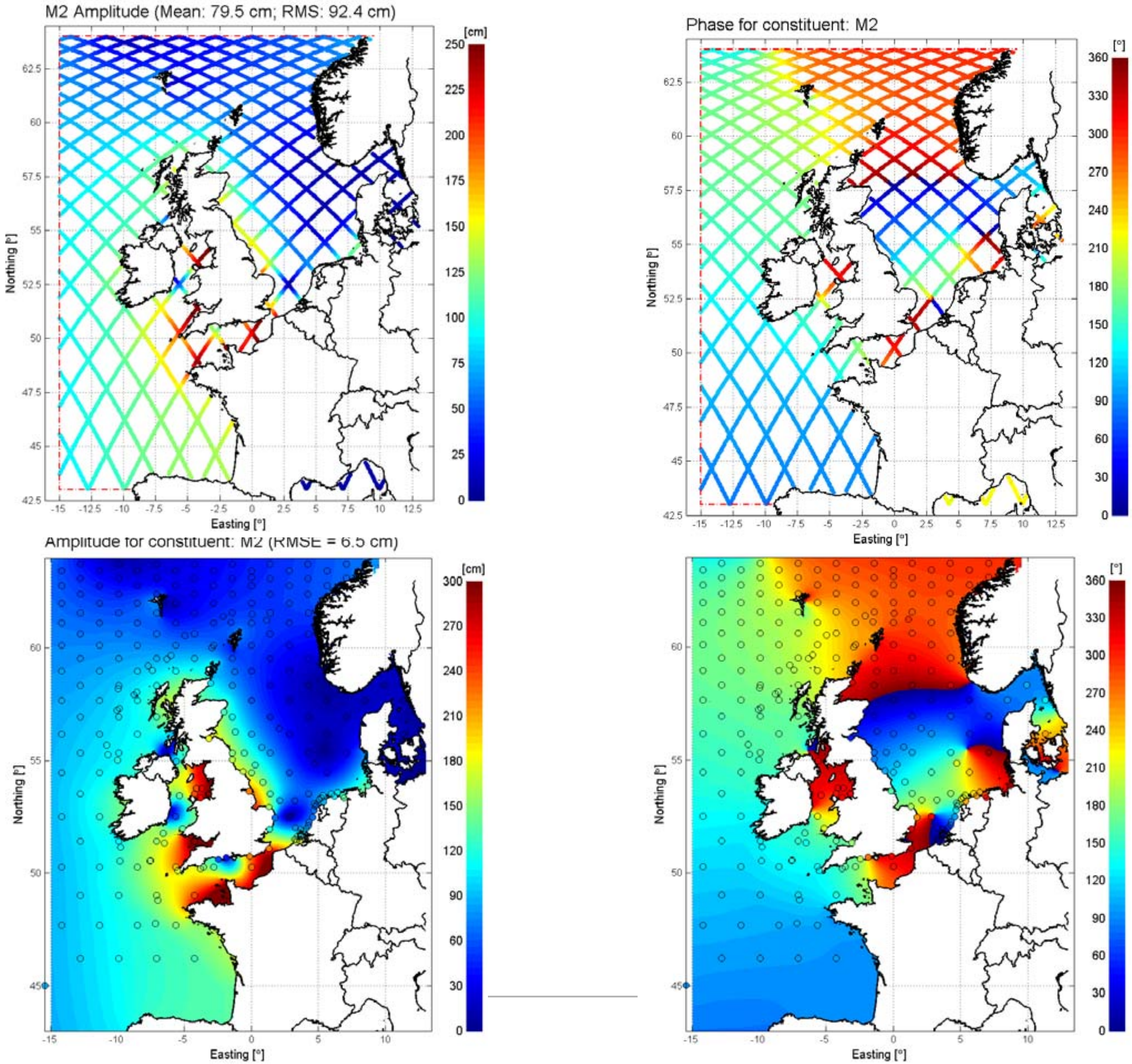
DCSMv6 model calibration



M2 Amplitude



M2 Phase

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Model calibration (2)

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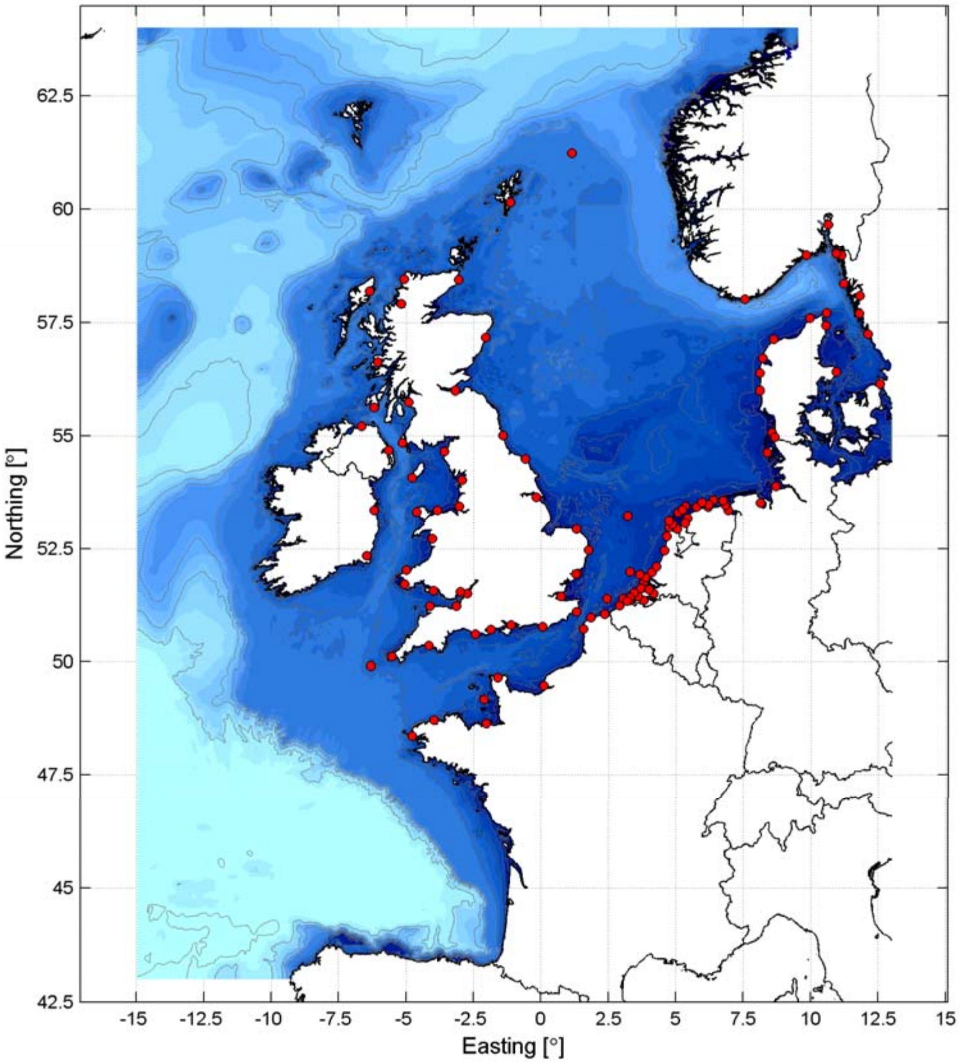
DCSMv6 model calibration

Calibration and validation using tide gauge data at >100 locations



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Doesn’t Use Derivative (OpenDA-DUD)

- Open Source Data Assimilation toolbox OpenDA used for parameter optimization
- DUD: a derivative-free algorithm for nonlinear least squares (Ralston and Jennrich 1978)
- Minimizes quadratic cost function by adjusting model parameters
- DUD should be initialized with one unperturbed run and *n* sensitivity run, where n is the number of control parameters

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DCSMv6 Model Development

OpenDA-DUD experiment setup and parameters

• In the first phase of the calibration we have established that the source of the tidal error is not in the boundary conditions, but in the tidal propagation

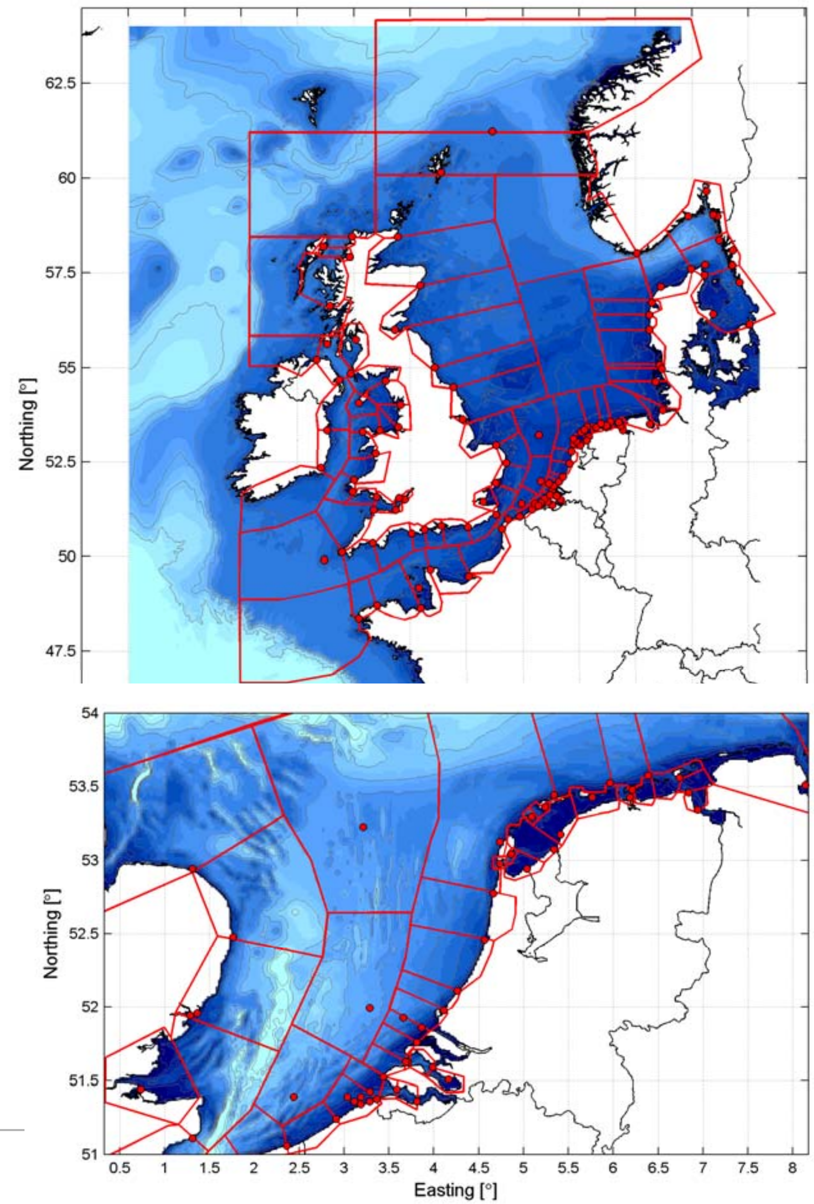
•Calibration parameters: bed roughness and bathymetry

•Boxes defined between measurement locations, uniform adjustments

•Multiple optimization runs, with increasing length and number of parameters

•Final experiment: 200 control parameters, 4 months, ~100 observations

•Restart functionality facilitates successive refinements



Final calibration results

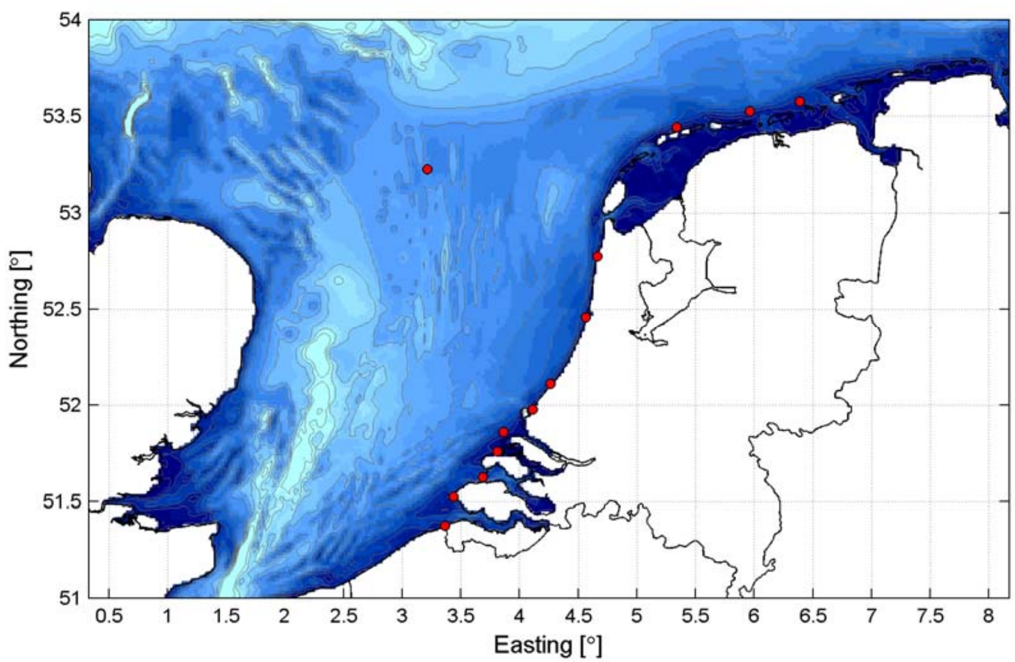
Goodness-of-Fit (in cm) for final calibration results (all stations)

	RMSE tide	RMSE surge	RMSE full	RMSE high waters	RMSE low waters
North Sea	7.1	7.9	10.1	9.9	9.1
English Channel	6.5	6.5	8.2	7.7	8.3
Irish Sea and Severn Est.	9.5	8.6	11.6	11.4	13.7
Skagerrak and Kattegat			7.3	7.0	7.1
Western Scheldt	5.7	8.1	9.9	8.9	8.1
Eastern Scheldt	5.9	8.4	10.3	12.2	7.6
Wadden Sea	5.8	7.9	9.8	8.8	10.0
Eems-Dollard Estuary	8.2	10.1	13.0	12.9	13.5
Total	**7.6**	**8.0**	**9.9**	**9.7**	**10.1**

DCSMv5 vs. DCSMv6

Goodness-of-Fit (in cm) for final calibration results (13 Dutch coastal stations)

	RMSE (getij)	RMSE (opzet)	RMSE (volledig)	RMSE (hoogwater)	RMSE (laagwater)
DCSMv5 (2007)	9.5	9.1	13.1	11.3	11.0
DCSMv6 (2007)	**3.7**	**6.9**	**7.8**	**7.4**	**7.5**
	-61%	-24%	-40%	-35%	-32%



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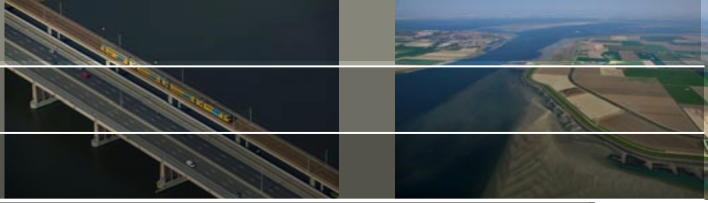
DCSMv5 vs. DCSMv6



	DCSMv5			DCSMv6		
	RMS(Hc-Ho)	RMS(Gc-Go)	RMS(VD)	RMS(Hc-Ho)	RMS(Gc-Go)	RMS(VD)
SA	4.8	12.8	5.2	1.1	5.2	1.3
SSA	1.1	6.0	1.3	0.4	5.6	0.7
MM	1.1	7.2	1.2	0.9	4.1	0.9
MF	0.4	35.0	1.9	0.4	27.2	1.5
Q1	0.6	30.7	1.9	0.5	3.3	0.5
O1	1.1	4.0	1.3	0.2	1.7	0.4
K1	**3.2**	**10.3**	**3.6**	**1.9**	**5.4**	**2.1**
EPS2	0.2	11.8	0.5	0.5	8.4	0.5
MU2	2.4	6.9	2.4	0.5	3.5	0.7
N2	1.4	8.8	2.4	0.3	1.4	0.5
M2	**4.4**	**3.7**	**8.0**	**1.3**	**1.1**	**2.2**
L2	0.9	12.6	2.1	0.5	3.1	0.7
S2	1.5	5.8	3.8	0.9	0.8	1.0
MN4	1.3	26.1	2.0	0.2	8.9	0.6
M4	2.5	22.8	4.0	0.6	8.1	1.3
MS4	1.7	16.9	2.2	0.6	5.3	0.9
2MN6	1.0	9.2	1.1	0.4	12.0	0.8
M6	1.6	11.4	2.0	0.7	12.8	1.5
2MS6	1.6	18.8	2.4	1.0	15.1	1.6
2SM6	0.3	28.0	0.7	0.3	39.0	0.5
M8	0.5	19.7	1.1	0.3	9.8	0.5
RSS			**13.6**			**5.2**

H: amplitude in cm, G: phase in °, VD: vector difference in cm

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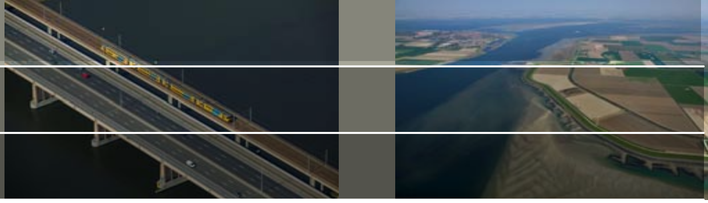
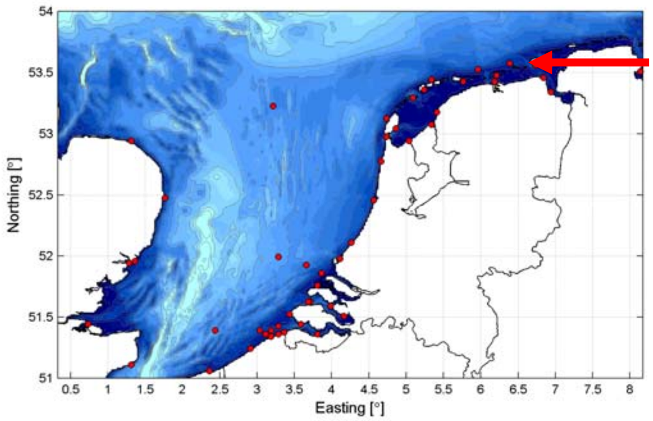
DCSMv6 model calibration



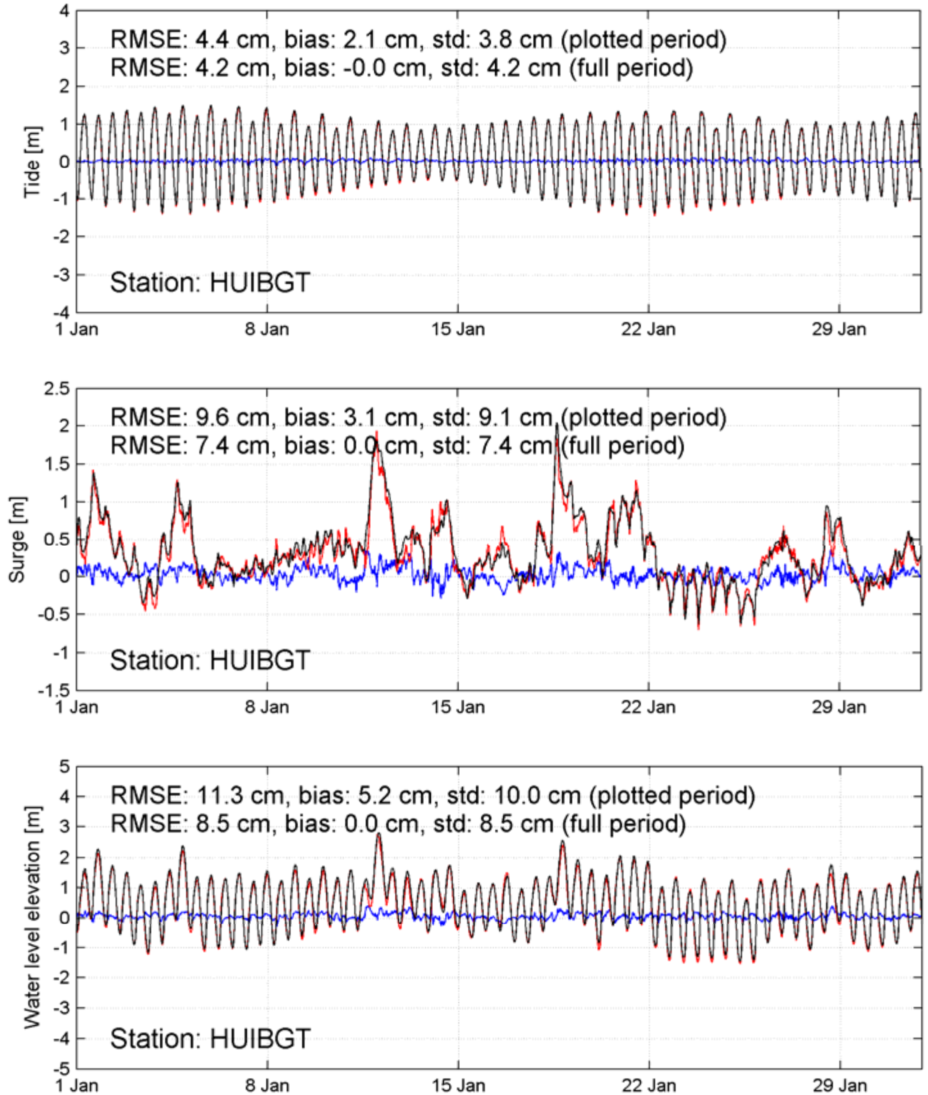
Calibration results in
time domain



Red: Measurement

Black: Computation

Blue: Residual



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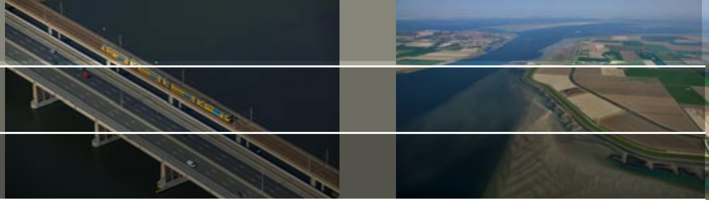
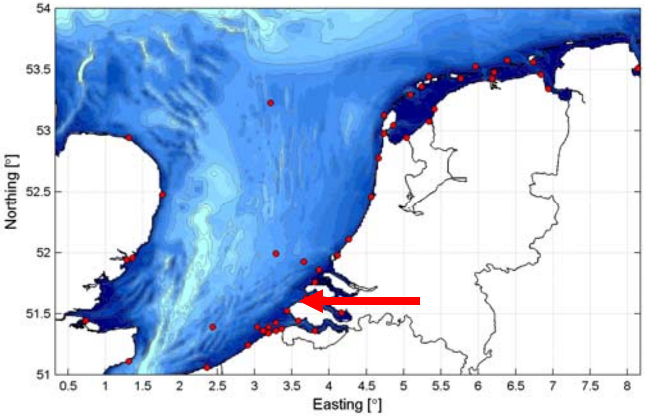
DCSMv6 model calibration

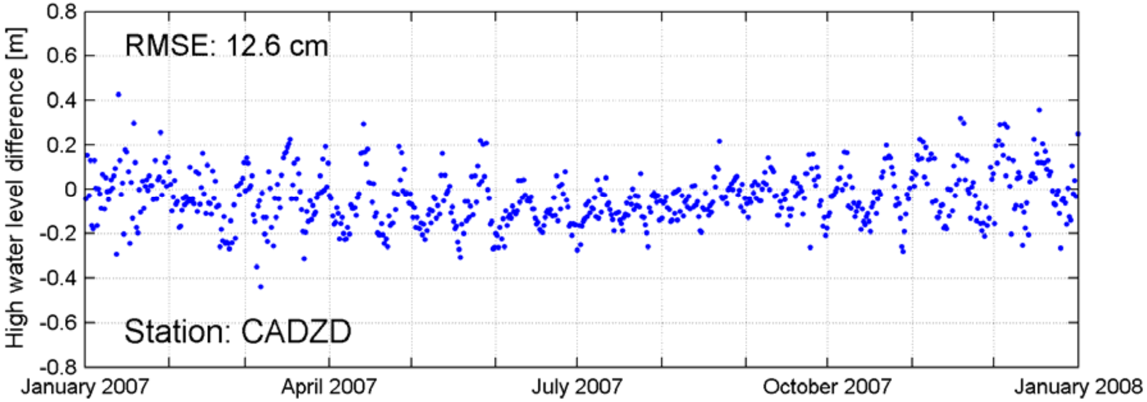


Calibration results in time domain (high waters only)

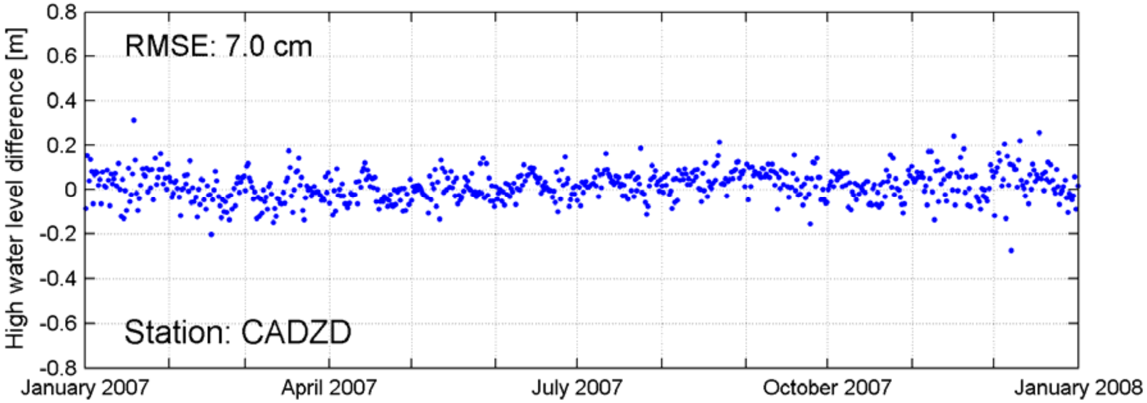


Underpredictions of high waters do rarely exceed 20 cm in Cadzand

DCSMv5



DCSMv6



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Model validation

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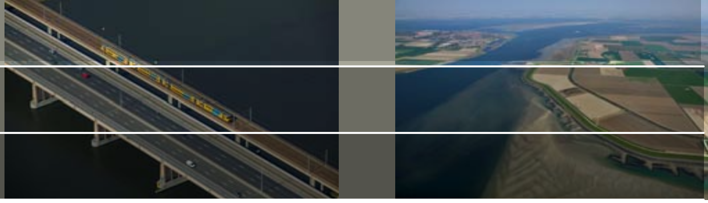
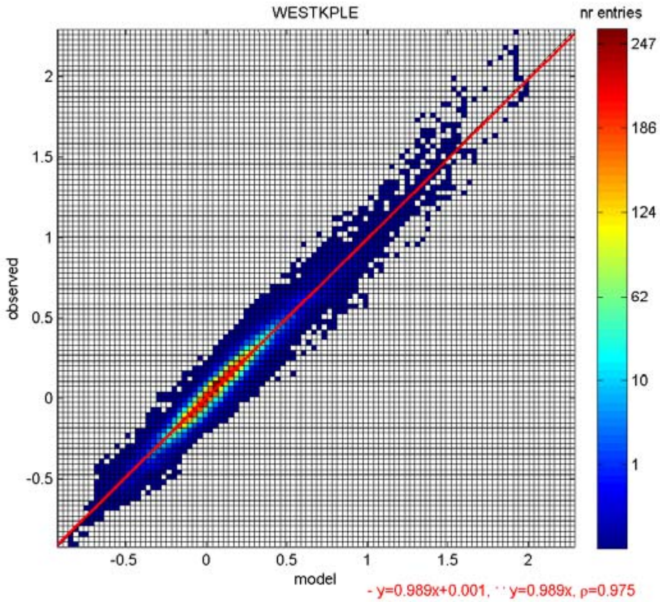


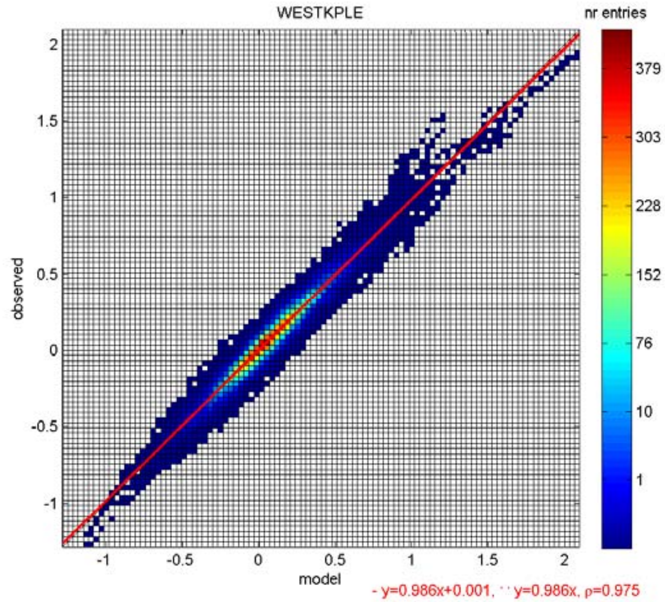
DCSMv6 model validation

Goodness-of-Fit (in cm) for validation results (13 Dutch coastal stations)

	RMSE (getij)	RMSE (opzet)	RMSE (volledig)	RMSE (hoogwater)	RMSE (laagwater)
Calibration (2007)	**3.7**	**6.9**	**7.8**	**7.4**	**7.5**
Validation (2008)	4.2	7.0	8.1	7.9	7.6



surge - 2007



surge - 2008

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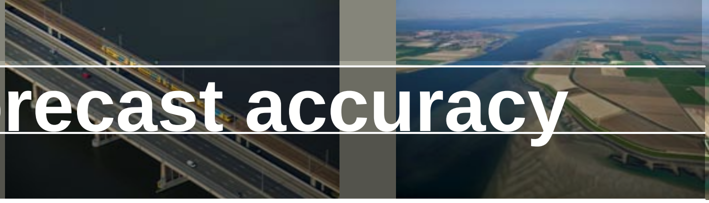
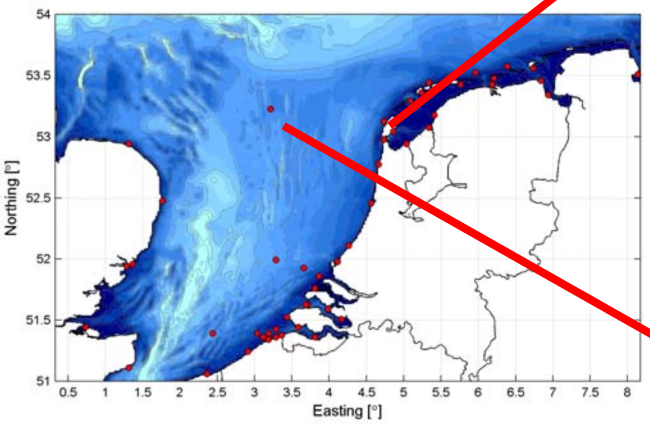
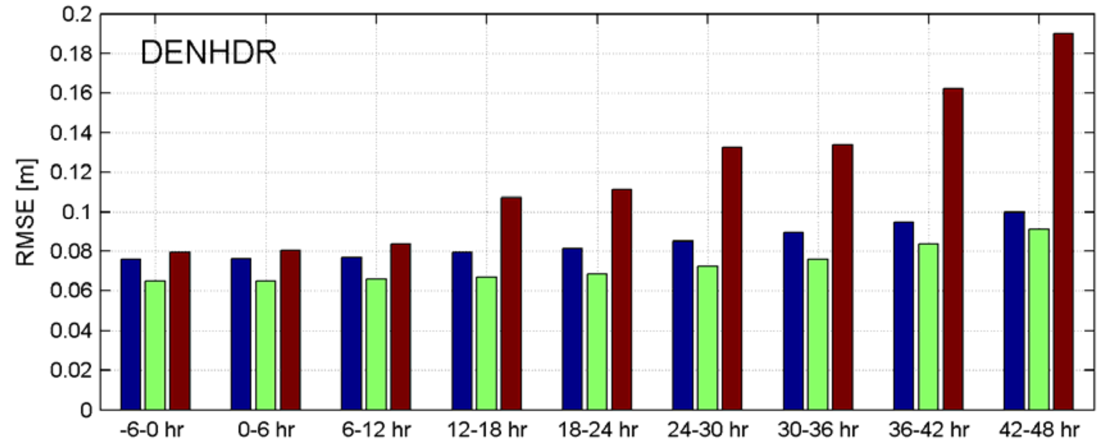


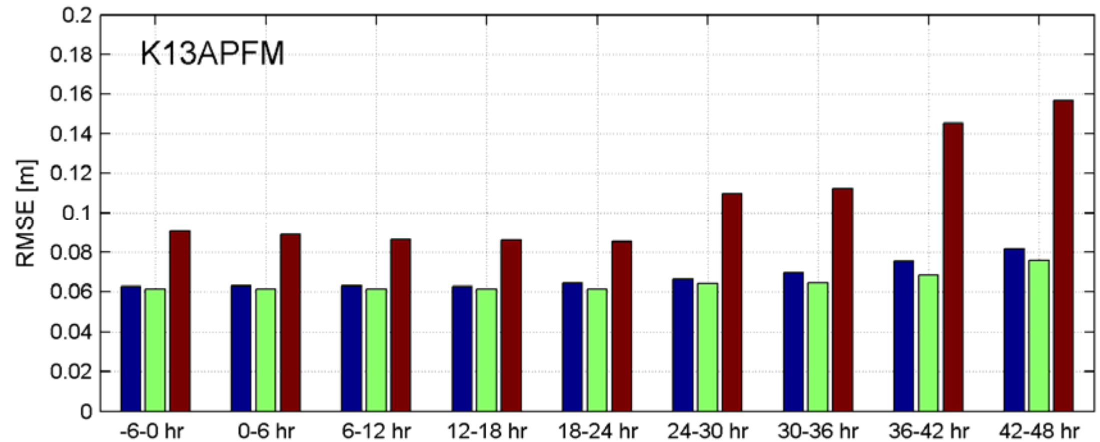
DCSMv6 model validation – forecast accuracy

Forecast accuracy for various lead time intervals

(based on collection of ~1500 historical forecasts)







Blue: $RMSE_t$

Green: $RMSE_{HW}$

Red: $RMSE_{HW > 97\%}$

Ongoing activity

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Conclusions

Conclusions

Overall conclusions (1)

• Satelite Altimeter data proved very useful in getting a good picture of the accuracy of the tidal propagation, especially in offshore areas not covered by tide gauge stations – not accurate enough in more shallow areas

• With data assimilation it proved possible to optimize more complex problems compared to a manual calibration, resulting in a very high accuracy

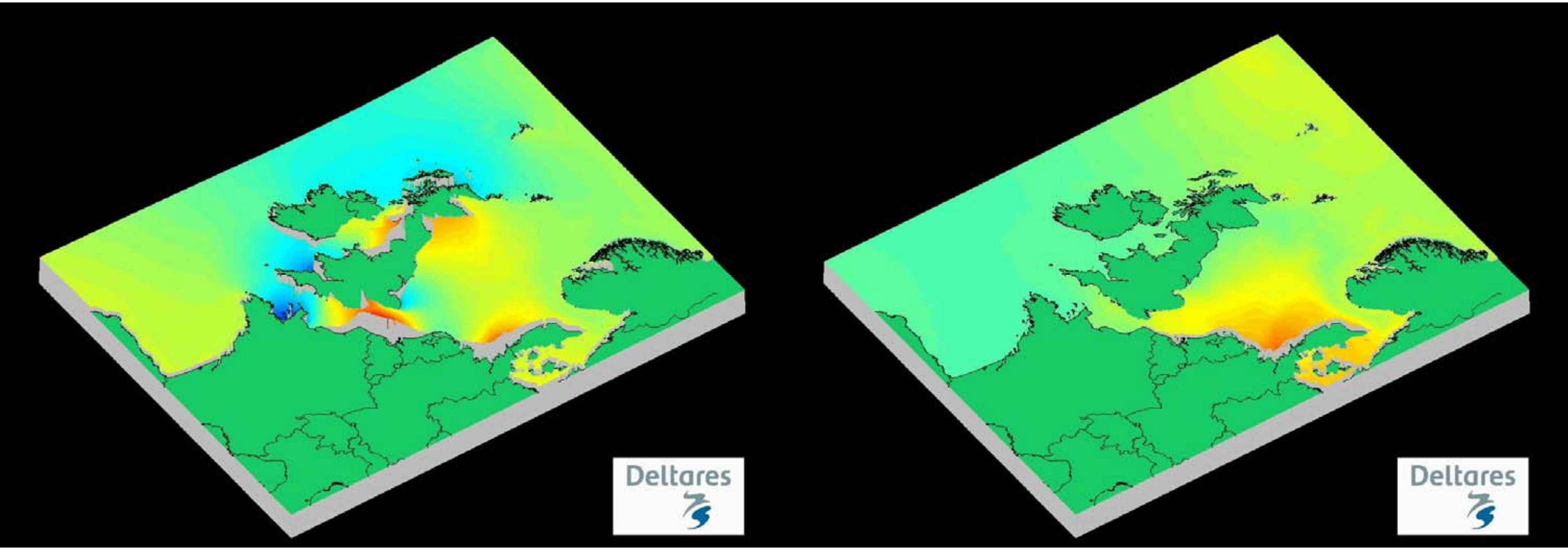
- To achieve optimal results in one area (e.g. Dutch coast) it is important that all model areas have an accurate representation
- To achieve this accuracy it is not possible to calibrate sub-areas in the model (e.g. Irish Sea, Wadden Sea, Western Scheldt, etc.) separately.
- Long time series are required
- Besides the obvious advantage of a higher accuracy, it reduces the complexity of the operational system, since no post-processing ‘astro-correction’, Kalman filtering with full water level measurements

Conclusions

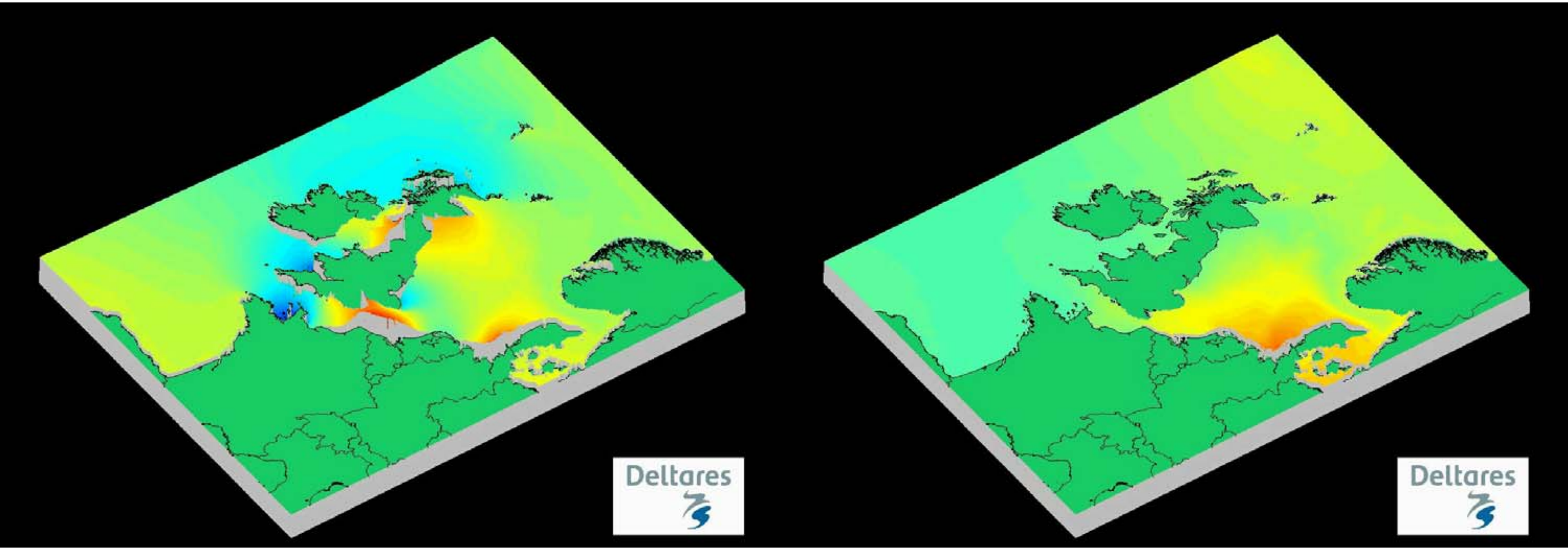
Overall conclusions (2)

- The water level representation of the model is accurate, with GoF values, considering all stations, of 7.6 cm (tide), 8.0 cm (surge) and 9.9 cm (full signal)
- When considering Dutch coastal stations, excellent GoF values of 3.7 cm (tide), 6.9 cm (surge) and 7.8 cm (full signal) are found
- Compared to the existing operational model, this implies an improvement of 60 % for the tide, 24% for the surge and 40% for the full water level signal
- The forecast accuracy remains stable for the first lead time intervals. Thereafter, the accuarcy can reduce, especailly for the more extreme surge events.

Firth of Clyde model development (conclusions)



Firth of Clyde model development (conclusions)



Thank you!

Firth of Clyde model calibration

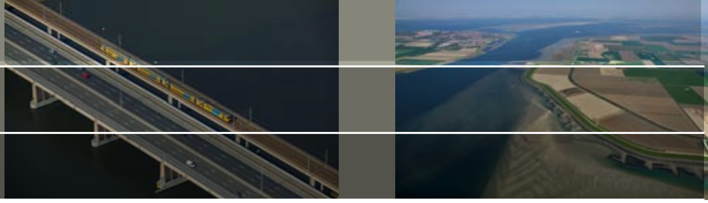
Key model adjustments during calibration

(1) Adjustment of tidal amplitudes and phases at open boundaries? Satelite altimeter data (T/P-Jason combination, as tidal constituents)

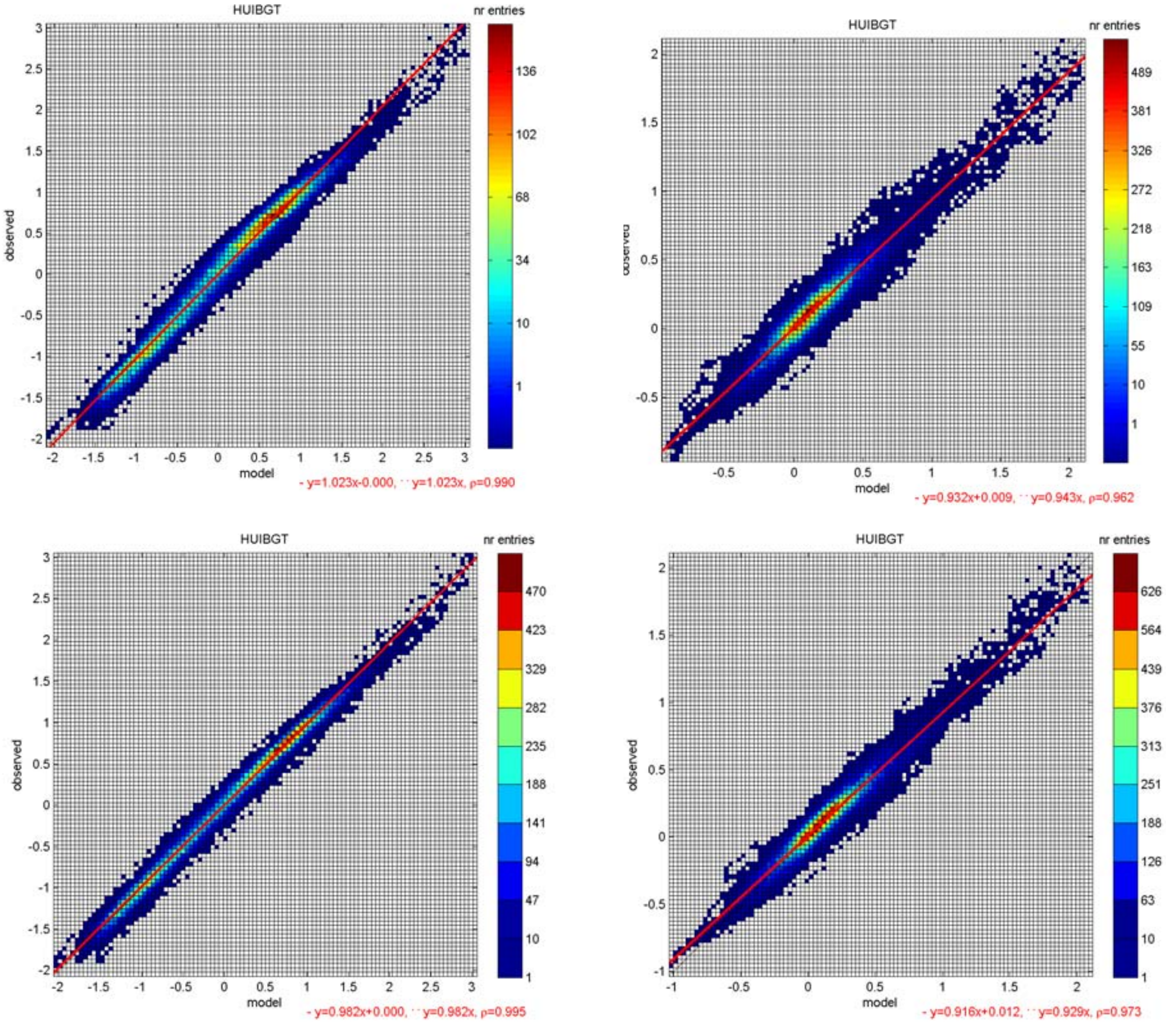
(2) Local adjustments to model bathymetry and bed roughness to optimize tidal propagation

(3) Adjustment of wind drag coefficient to improve representation of internally generated surge

DCSMv6 model calibration



Validation results in
time domain
(operational data)



No significant surge

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