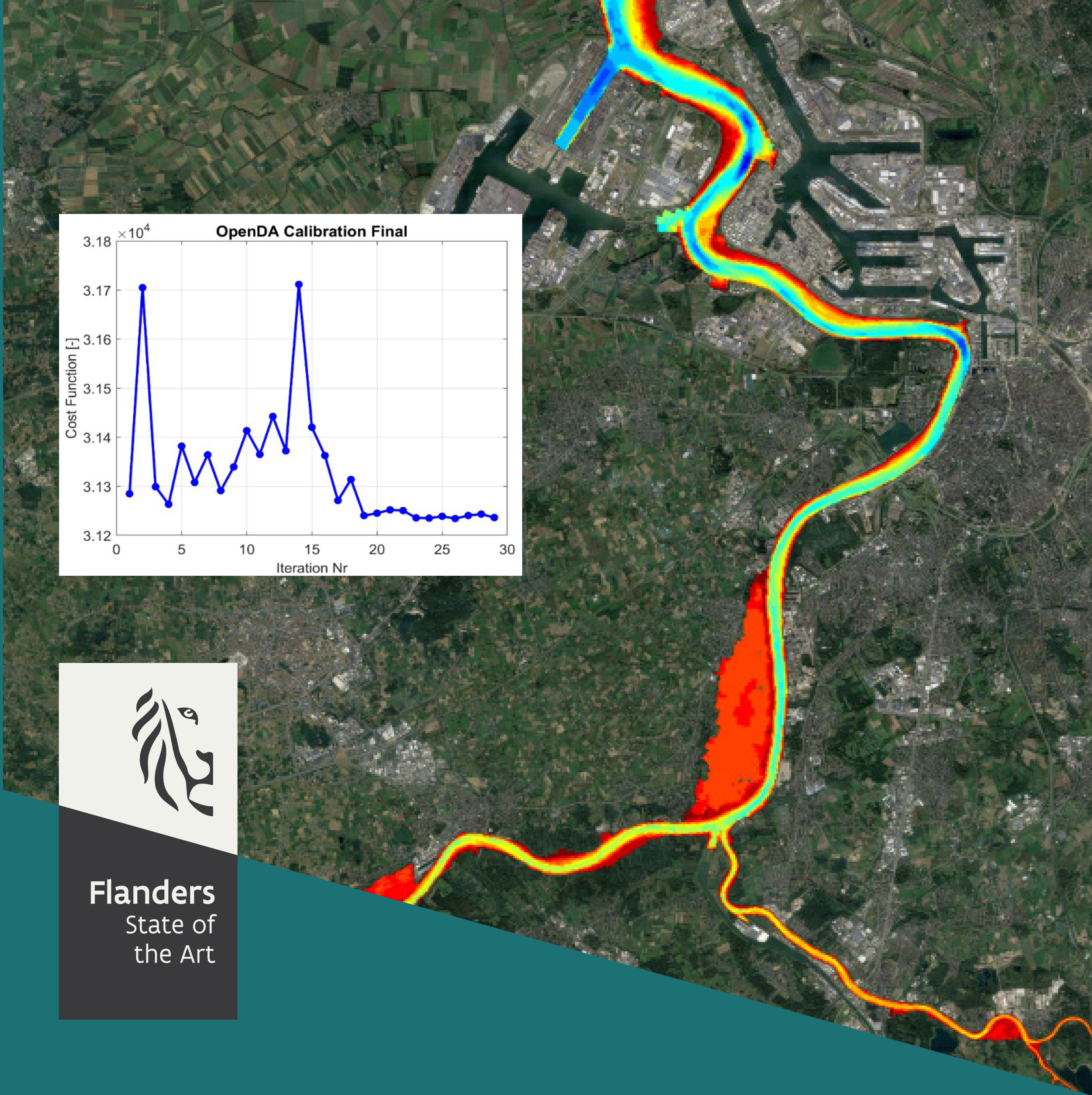

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Baseline Zuidwestelijke Delta

Final calibration of model waqua-schelde_nevla-j07_5

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Chu, K.; Vanlede, J.; Mostaert, F.

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Abstract

The calibration of the WAQUA-Schelde_NEVLA model is done in three steps. Deltares first set up the model based on the NEVLA grid provided by FHR, and did the first step in the automatic calibration by varying the bottom roughness in the Western Scheldt. The subsequent automatic calibration for the Flemish territory was carried out at FHR as the 2nd step, while keeping the roughness field from the first step constant (Chu et al., 2019 & 2020). This report describes the final automatic calibration (3rd step) for the entire model domain starting from the calibrated roughness field from the 2nd step (Chu et al, 2020).

It was found that this automatic 3rd step does not further modify the bottom friction or further improve the water level predictions compared to the end result of the 2nd step. This means that in the future, automatic calibration could be safely performed in 2 steps.

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1 Introduction

This study aims for a final calibration of the WAQUA-Schelde_NEVLA model for the entire year of 2007.

In the summer of 2016, Deltares has finished the calibration and validation of the new WAQUA-Schelde_Nevla model (**waqua-schelde_nevla-j07_5-v4**) for the Dutch part of the River Scheldt (Groenenboom et al., 2016). The task of model calibration for the Flemish part is carried out at Waterbouwkundig Laboratorium (Flanders Hydraulics Research or FHR) and reported by Chu et al (2019, 2020).

Based on the two calibrations mentioned above, a final calibration of the model for the entire Scheldt is carried out at Deltares. The results are analysed and summarized in this report.

2 Abbreviations and Conventions

2.1 Abbreviations

Table 1 – Abbreviations used

BeZS	Beneden-Zeeschelde (Lower Sea Scheldt)
BoZS	Boven-Zeeschelde (Upper Sea Scheldt)
FHR	Flanders Hydraulic Research
MET	Middle European Time
NAP	Normaal Amsterdams Peil (Dutch vertical reference level)
NEVLA	Dutch-Flemish hydrodynamic model
OpenDA	Open Data Assimilation
RD	Rijksdriehoekscoördinaten
RMSE	Root Mean Square Error
SIMONA	SImulatie MOdellen NAtte waterstaat
TAW	Tweede Algemene Waterpassing (Belgian vertical reference level)
WES	Westerschelde (Western Scheldt)

2.2 Conventions

The following conventions are followed by this report:

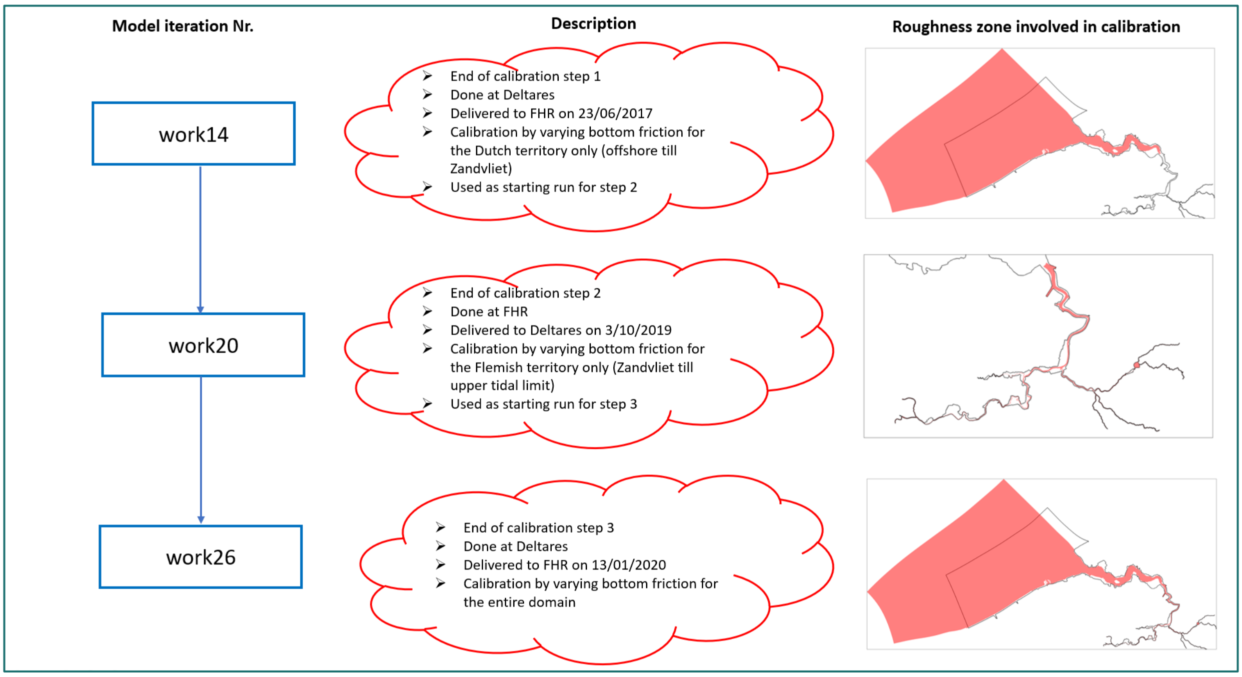
- Times are represented in MET.
- The coordinate reference system, used by the model and for presentation of the model output is RD Parijs, expressed in meters.
- The vertical reference level used by this project is NAP. NAP is 2.35 m above TAW level.
- SI units are used.

3 Final Calibration with OpenDA

3.1 Introduction

The final calibration starts from the calibration run ***work20*** as reported by Chu et al (2020). The friction map from the ***work20*** run is taken as the initial friction map for this study. The final calibration focus on the entire model domain with in total 17 roughness polygons (7 for the Dutch part and 10 for the Flemish part, see Table 4). Figure 1 illustrates the working flow of the 3 steps in automatic model calibration.

Figure 1 – Diagram working flow for the automatic model calibration.



3.2 Cost function

The cost function used by this study is **org.openda.algorithms.SimulationKwadraticCostFunction** which is a quadratic cost function over the complete timeseries. It is essentially a total sum of squares, made dimensionless with the measurement uncertainty.

$$J = \frac{1}{2} \sum_{r=1}^{Rmax} \sum_{s=1}^{Smax} \sum_{n=1}^{Nmax} \frac{(H_{r,s,n}^{sim}\,(t) - \; H_{r,s,n}^{obs}\,(t))^2}{(\sigma_{H_{r,s}^{obs}})^2}$$

where:

H(t) - water level at time t;
sim - results obtained from model simulations over the simulation period;
obs - observation values;
n,N$_{max}$ - number of time steps in the time series **(52560)**;
s, S$_{max}$ - number of stations in region r;
r, R$_{max}$ - number of polygons for which observations are included (**17,** see Table 4);
$\boldsymbol{\sigma_{H_{r,s}^{obs}}}$ - uncertainties assigned to the observations (**2.0 m** for Rupel and **0.5 m** elsewhere, see Table 2).

In this study, time series of water level measurement at **34** stations (as shown in Figure 2) are employed to the OpenDA calibration. The calibration period is the year 2007 (2007/01/01 00:00 – 2007/12/31 23:50) with time step of 10 minutes, giving the total number of time steps equal to **52560 (N_{max})**.

In Chu et al (2019) the entire Rupel basin is represented as one roughness zone with 11 water level measurement stations inside of it. Aggregation into larger roughness zone is a trade-off between a reduction of dimensionality of the problem, and thus fewer iterations in the automatic calibration, and the maximum accuracy that is achievable during calibration. In the cost function, the term $\sigma_{H_{r,s}^{obs}}$ can be used as the weight assigned to the water level stations. In Chu et al. (2019) a constant value of **0.5 m** was assigned to all stations throughout the estuary. Because the cost function of the automatic calibration takes into account all stations, having one roughness zone with more stations in it, might skew the automatic calibration process.

Therefore Chu et al (2020) explore the effect of changing this value to **2 m** for the 11 stations in the Rupel basin. As a result, the contribution of stations in the Rupel basin to the cost function becomes **16** times smaller. Because the Rupel basin is not the zone of interest of the Nevla model (due to limited resolution it is not schematized as accurately as the Scheldt estuary), this is wanted behavior, and so the same approach is adopted in the final 3rd calibration in this study.

Figure 2 – Map of 34 water level stations involved in the final OpenDA calibration.

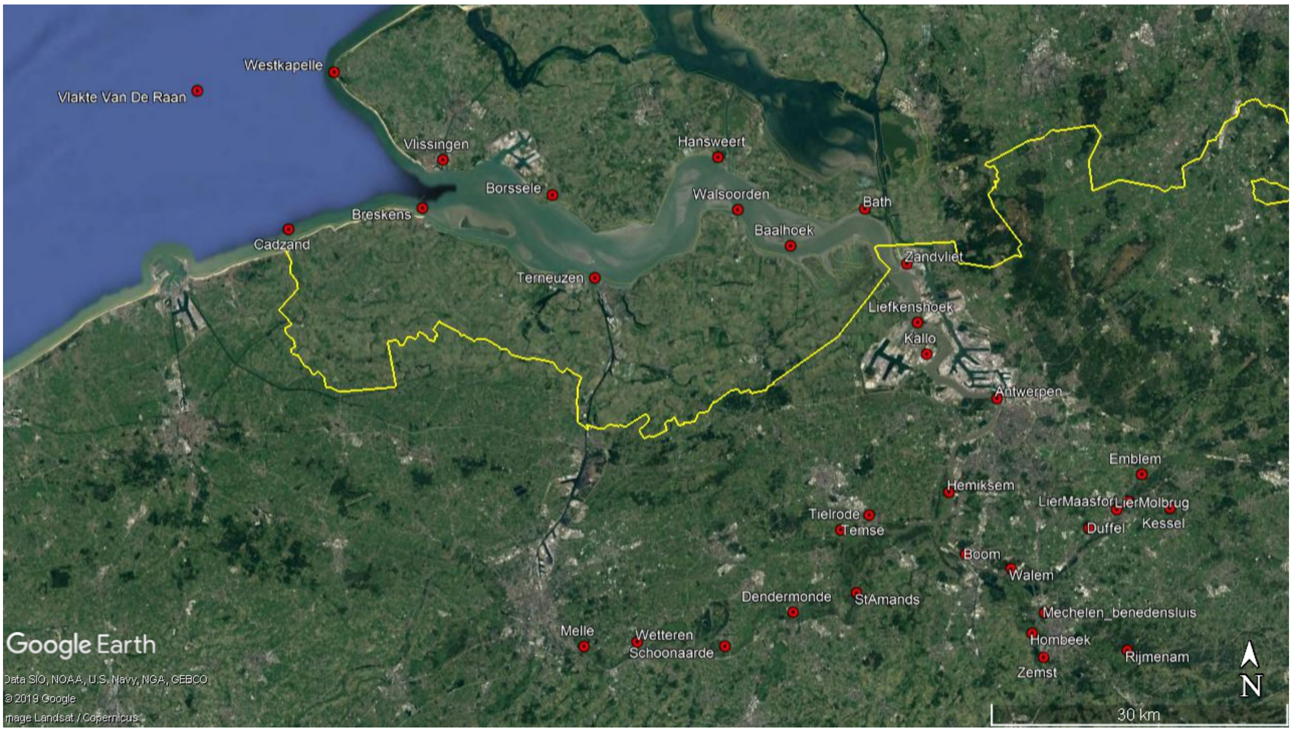


Table 2 – Standard deviation assigend to the water level stations in the cost function.
A higher value corresponds to a lower weight in the cost function

No.	Station Name	standardDeviation [m]	No.	Station Name	standardDeviation [m]
1	Vlakte van de Raan	0.5	18	Temse	0.5
2	Westkapelle	0.5	19	Tielrode	0.5
3	Cadzand	0.5	20	Walem	**2.0**
4	Vlissingen	0.5	21	StAmands	0.5
5	Breskens	0.5	22	Dendermonde	0.5
6	Borssele	0.5	23	Schoonaarde	0.5
7	Terneuzen	0.5	24	Wetteren	0.5
8	Hansweert	0.5	25	Melle	0.5
9	Walsoorden	0.5	26	Mechelen Benedensluis	**2.0**
10	Baalhoek	0.5	27	Hombeek	**2.0**
11	Bath	0.5	28	Zemst	**2.0**
12	Zandvliet	0.5	29	Duffel	**2.0**
13	Liefkenshoek	0.5	30	Rijmenam	**2.0**
14	Kallo	0.5	31	Lier Molbrug	**2.0**
15	Antwerpen	0.5	32	Lier Maasfort	**2.0**
16	Hemiksem	0.5	33	Emblem	**2.0**
17	Boom	**2.0**	34	Kessel	**2.0**

3.3 Stop Criterion

The inner workings of the DUD algorithm are briefly described in Appendix A. The DUD algorithm has two types of stop criteria: one for the outer iterations, and one for the inner iterations.

If the linearization yields a new parameter setting with a lower cost, this is called an **outer iteration** which can stop on the various criteria:

- outerLoop maxIterations = **100**
  The maximum iteration numbers of the outer loop which is set to 100 in this study.

- absTolerance = **0.001**
  The maximum absolute difference between the costs resulted from the 2 best parameter estimates $|(J_{new} - J_{previous})|$.

- relTolerance = **0.00001**
  The maximum relative difference between the costs resulted from the 2 best parameter estimates $|(J_{new} - J_{previous})| / J_{new}$.

- relToleranceLinearCost = **0.00001**
  The maximum relative difference between the linearized costs resulted from the 2 best parameter estimates $|(J_{new}-J_{linear})/(J_{previous}- J_{linear})|$;

However if the linearization does *not* produce a better estimate, DUD will perform a line search until a better estimate is found. The procedure is stopped when one of the stopping criteria of **inner iteration** is fulfilled.

- lineSearch maxIterations = **30**

The maximum iteration number of the inner loops which is set to 30 in this study.

- maxRelStepSize = **5**
  Maximum size of relative step. This indicates how much the parameters may change from one iteration to the other.
  In practice, the searching step is preferably not set too large so that the searching is still in the surroundings of the initial guess. When the norm of **α** (see Appendix A) is larger than maxRelStepSize, **α** will be reduced in such a way that: **α_new** = |**α**| / maxRelStepSize.

- backtracking shorteningFactor (**η**) = **0.5**
  Factor for shortening step size.

- startIterationNegativeLook = **3**
  Maximum number of iterations before searching in opposite direction. This determines when parameter $\boldsymbol{\beta}$ = ±1 changes sign.

3.4 Results

Table 3 shows the changes of cost function and calibration parameter (in this case Manning coefficient) during the final OpenDA calibration after 29 iterations. The first column shows the iteration numbers of the automatic calibration, the second column shows the cost function as calculated in §3.2. Columns 3 to 19 shows the changes to the manning coefficient in the 17 roughness polygons.

For N degrees of freedom (the polygons in which a roughness value needs to be assigned), DUD requires a first set of (N+1) runs to establish the sensitivity of the model. Therefore the first 18 runs are the preparation for the optimization algorithm. The actual optimization procedure (e.g. linearization and line search) starts from iteration number 19. The cost function drops gradually until iteration number 26, at which the minimum cost function is found of 31234.08. Afterwards the cost function starts oscillating, therefore the automatic calibration is terminated by the user.

The automatic calibration did not stop automatically because the default stop criterion was too strict for this particular case. This calculation shows that none of the stop criterion is met after 26 iterations.

$$\boldsymbol{outerLoop\ maxIterations} = 4 < 100$$

$$\boldsymbol{absTolerance} = |new\ cost\ -\ previous\ cost| = |31234.08\ -\ 31234.82| = 0.74 > 0.001$$

$$\boldsymbol{relTolerance} = \frac{|new\ cost - previous\ cost|}{|new\ cost|} = \frac{|31234.08 - 31234.82|}{31234.08} = 2.39\mathrm{E}-5 > 1.0\mathrm{E}-5$$

$$\boldsymbol{relToleranceLinearCost} = \frac{|new\ cost - linearized\ cost|}{|previous\ cost{-}inearized\ cost|} = \frac{|31234.08\ - 31026.28|}{|31234.82 - 31026.28|} = 1.0 > 1.0\mathrm{E}-5$$

The evolution of the cost function during the final OpenDA calibration are demonstrated in Figure 3. The cost function is slightly reduced during the entire calibration study. Table 4 and Figure 4 compare the Manning coefficients before and after OpenDA calibration. The values of the Manning coefficients are almost unchanged.

The final calibrated roughness map of Manning Coefficient is demonstrated in Figure 5 and Figure 6.

Table 3 – Changes of cost function and parameter (manning coefficient) during the final calibration with OpenDA.

Iteration	Cost	A-310	A-311	A-433	A-436	A-437	A-440	A-441	A-450	A-455	A-457	A-459	A-461	A-462	A-463	A-464	A-465	A-467
1	31284.66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	31704.84	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	31298.83	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	31263.16	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	31381.65	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0
6	31307.6	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0
7	31363.96	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0
8	31290.98	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0
9	31339.36	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0
10	31413.23	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0
11	31364.91	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0
12	31442.23	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0
13	31372.14	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0
14	31711.36	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0
15	31420.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0
16	31362.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
17	31270.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0
18	31313.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
19	31240.14	1.87E-06	1.77E-04	1.49E-04	1.61E-04	9.24E-05	6.39E-05	8.34E-05	-1.86E-05	-9.04E-05	-7.57E-06	-5.14E-05	7.36E-05	-6.02E-05	1.99E-05	-4.61E-06	1.56E-04	1.47E-04
20	31244.95	-4.95E-06	1.87E-04	1.56E-04	1.76E-04	9.10E-05	6.36E-05	7.97E-05	-3.39E-05	-1.08E-04	-1.73E-05	-6.58E-05	7.27E-05	-8.90E-06	7.31E-06	-1.76E-05	1.63E-04	1.50E-04
21	31251.8	-1.54E-06	1.82E-04	1.52E-04	1.69E-04	9.17E-05	6.37E-05	8.15E-05	-2.63E-05	-9.92E-05	-1.24E-05	-5.86E-05	7.31E-05	-3.46E-05	1.36E-05	-1.11E-05	1.59E-04	1.49E-04
22	31250.29	1.65E-07	1.80E-04	1.51E-04	1.65E-04	9.21E-05	6.38E-05	8.24E-05	-2.25E-05	-9.48E-05	-1.00E-05	-5.50E-05	7.34E-05	-4.74E-05	1.68E-05	-7.86E-06	1.58E-04	1.48E-04
23	31235.44	1.02E-06	1.78E-04	1.50E-04	1.63E-04	9.23E-05	6.39E-05	8.29E-05	-2.06E-05	-9.26E-05	-8.78E-06	-5.32E-05	7.35E-05	-5.38E-05	1.83E-05	-6.24E-06	1.57E-04	1.48E-04
24	31234.82	3.79E-07	2.00E-04	1.64E-04	1.83E-04	8.93E-05	6.34E-05	8.00E-05	-4.61E-05	-1.23E-04	-2.26E-05	-7.43E-05	7.60E-05	-1.51E-05	4.40E-06	-2.65E-05	1.73E-04	1.58E-04
25	31238.72	3.87E-07	2.10E-04	1.71E-04	1.90E-04	8.70E-05	5.94E-05	7.88E-05	-6.20E-05	-1.48E-04	-3.78E-05	-2.19E-05	6.70E-05	-1.55E-05	-5.00E-08	-3.99E-05	1.80E-04	1.64E-04
26	31234.08	3.83E-07	2.05E-04	1.68E-04	1.87E-04	8.81E-05	6.14E-05	7.94E-05	-5.41E-05	-1.35E-04	-3.02E-05	-4.81E-05	7.15E-05	-1.53E-05	2.17E-06	-3.32E-05	1.76E-04	1.61E-04
27	31240.26	4.00E-07	2.19E-04	1.77E-04	1.98E-04	8.71E-05	5.83E-05	7.73E-05	-7.48E-05	-1.62E-04	-4.22E-05	-2.55E-05	7.06E-05	-1.60E-05	4.94E-06	-4.99E-05	1.87E-04	1.70E-04
28	31243.13	3.91E-07	2.12E-04	1.72E-04	1.92E-04	8.76E-05	5.99E-05	7.83E-05	-6.44E-05	-1.49E-04	-3.62E-05	-3.68E-05	7.11E-05	-1.56E-05	3.56E-06	-4.15E-05	1.82E-04	1.65E-04
29	31236.08	3.87E-07	2.08E-04	1.70E-04	1.90E-04	8.79E-05	6.06E-05	7.89E-05	-5.93E-05	-1.42E-04	-3.32E-05	-4.25E-05	7.13E-05	-1.55E-05	2.87E-06	-3.74E-05	1.79E-04	1.63E-04

Figure 3 – Evolution of cost function during the final calibration with OpenDA.

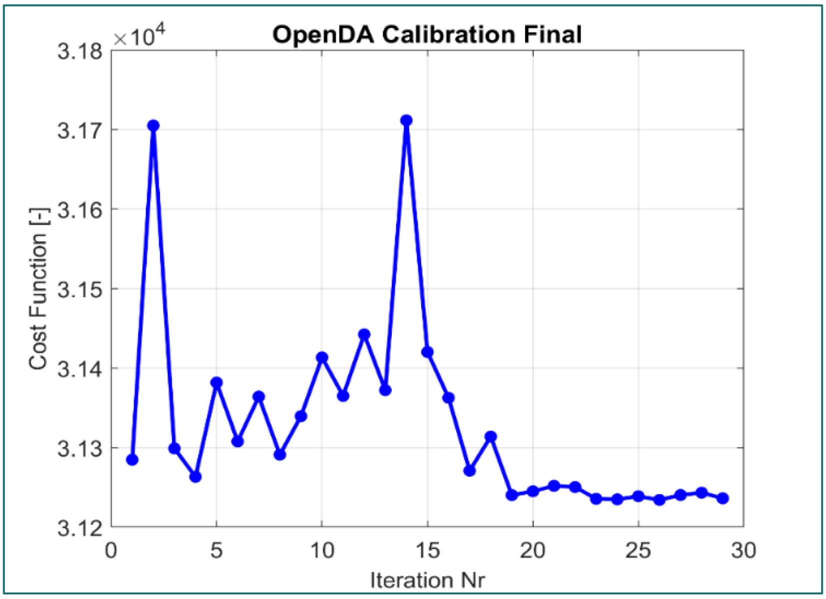


Table 4 – Comparison of manning coefficient before and after the final calibration with OpenDA.

Roughness Polygons	**Water Level Stations**		**Manning Coefficient (Initial Guess)** ***Run: Work20***	**Manning Coefficient (After final calibration)** ***Run: Work26***
A-310	Vlakte van de Raan; Westkapelle; Cadzand; Vlissingen;Breskens	Offshore	0.0217	0.0217
A-311	-		0.0213	0.0215
A-433	-	Western Scheldt	0.0198	0.0199
A-436	Terneuzen;Borssele		0.0304	0.0306
A-437	Hansweert		0.0249	0.0250
A-440	Walsoorden;Baalhoek		0.0261	0.0262
A-441	Bath		0.0147	0.0148
A-450	Zandvliet	Lower Sea Scheldt	0.0293	0.0293
A-455	Liefkenshoek;Kallo		0.0217	0.0216
A-457	Antwerp		0.0235	0.0235
A-459	Hemiksem		0.0225	0.0224
A-461	Temse	Upper Sea Scheldt	0.0240	0.0240
A-462	StAmands; Dendermonde; Schoonaarde		0.0137	0.0137
A-463	Wetteren		0.0161	0.0161
A-464	Melle		0.0196	0.0196
A-465	Tielrode		0.0263	0.0265
A-467	Boom; Wallem; Hombeek; Zemst; Mechelen_Benedensluis; Rijmenam; Duffel; Lier_Molbrug; Lier_Maasfort; Emblem; Kessel	Rupel Basin	0.0221	0.0222

Figure 4 – Comparison of Manning coefficient before and after the final OpenDA calibration.

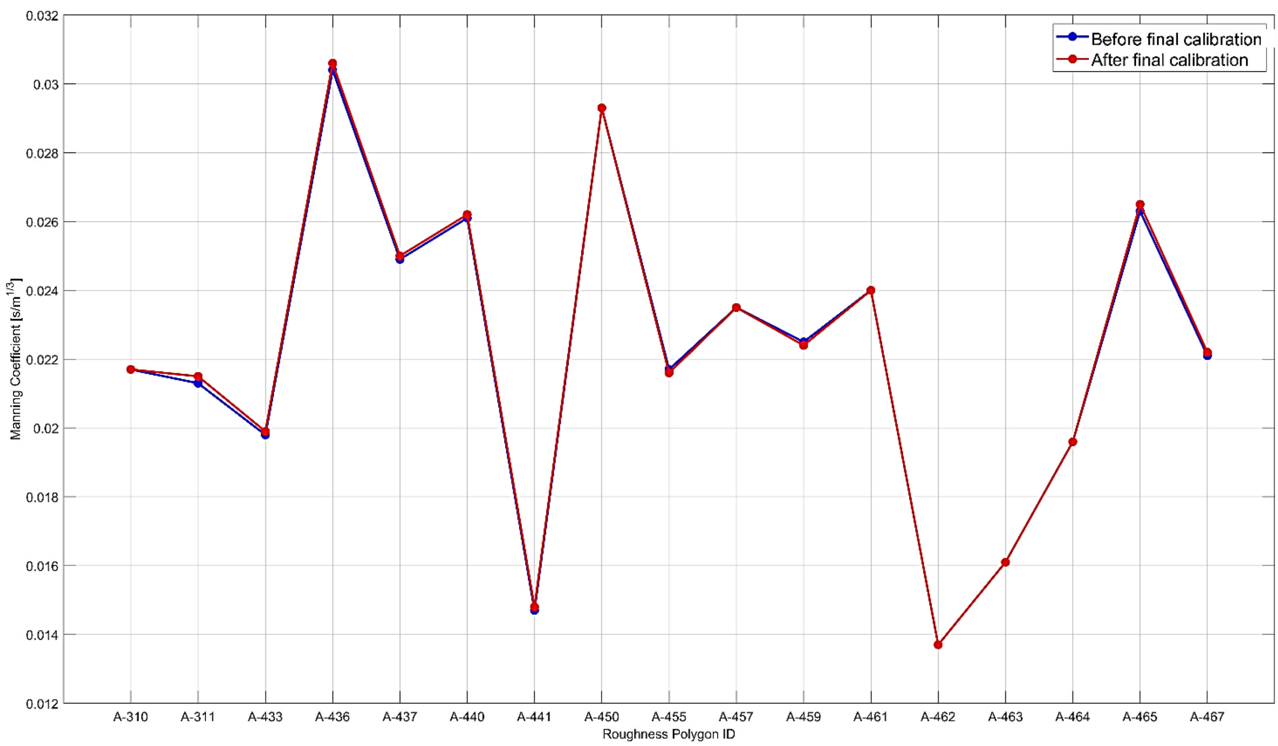


Figure 5 – Final calibrated bottom roughness map of Manning Coefficient.

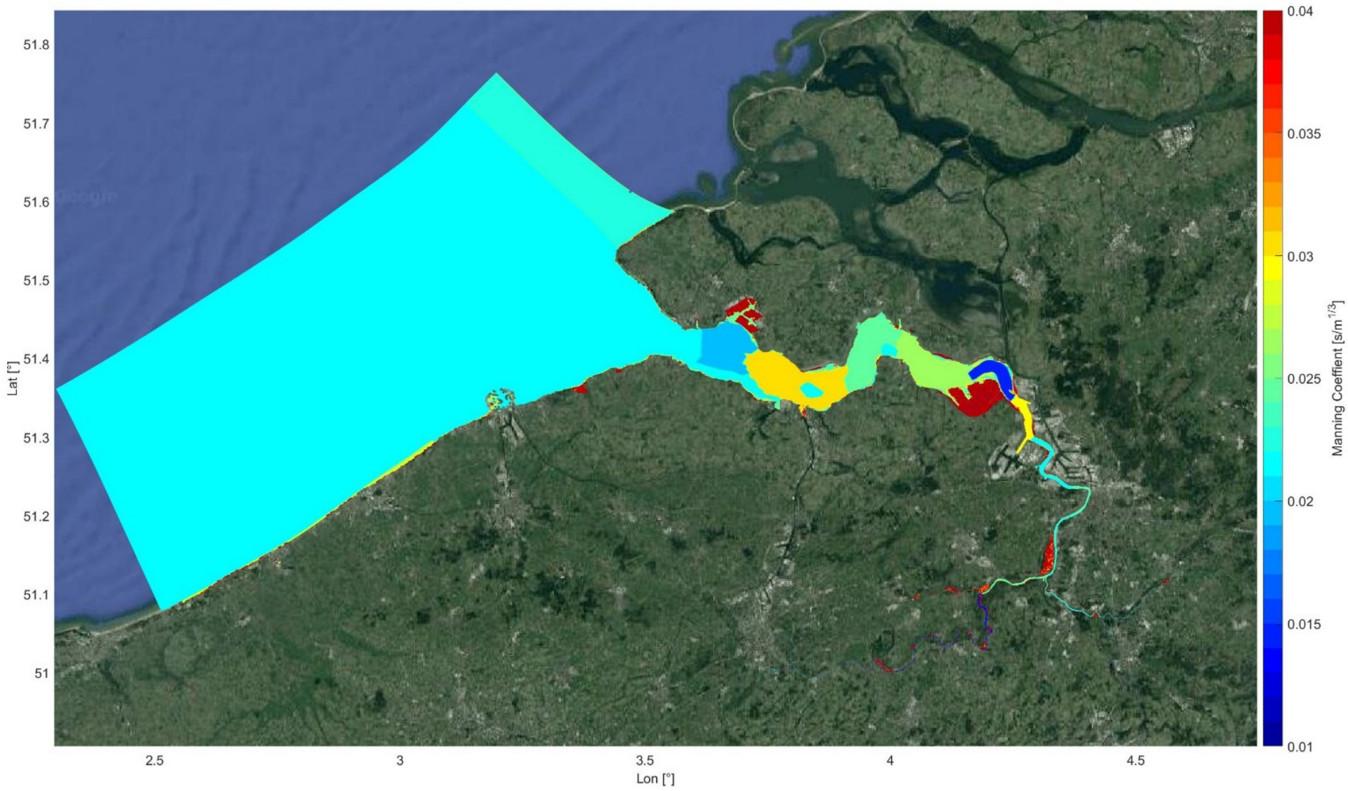
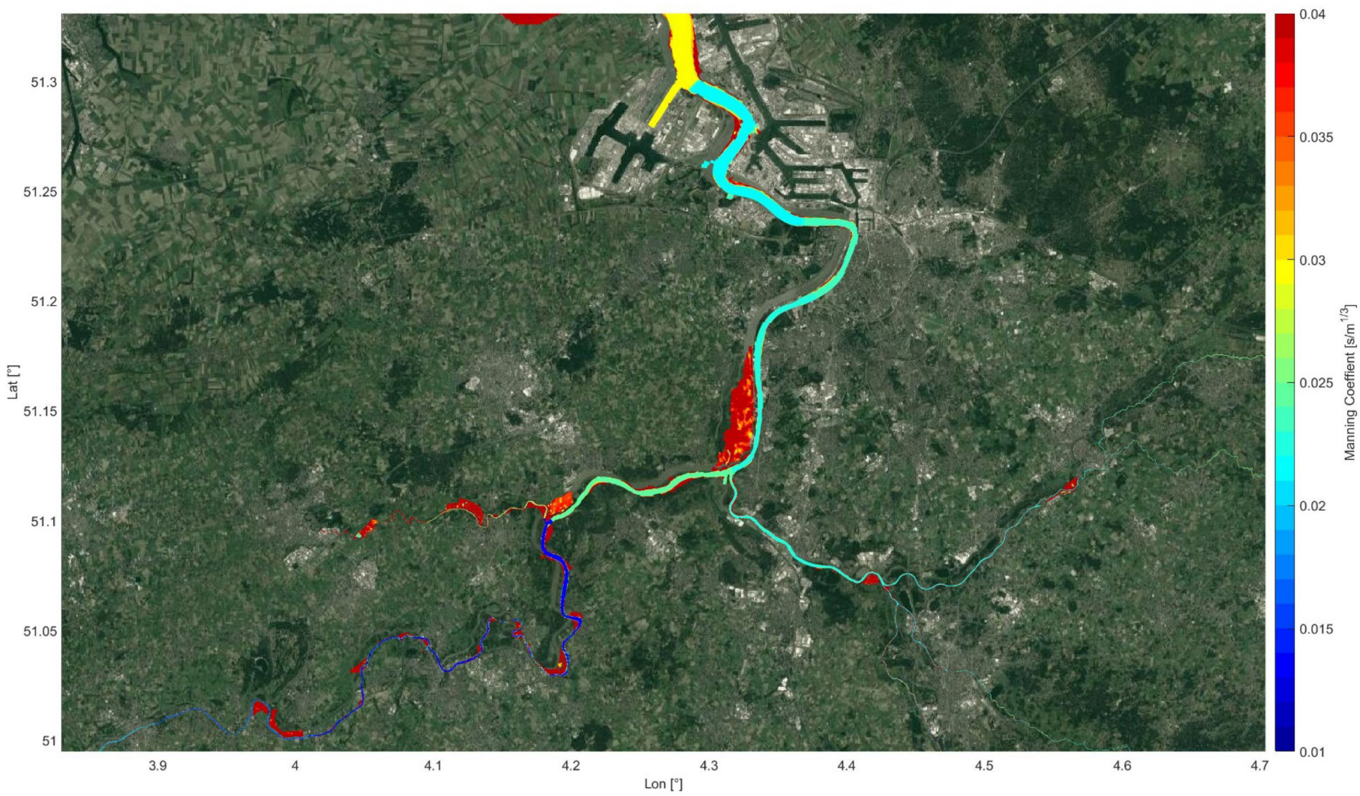


Figure 6 – Final calibrated bottom roughness map of Manning Coefficient (Zoom in to Upper stream).



4 Validation

In this Chapter, the model performance is evaluated with the in-house postprocessing tool VIMM written in MATLAB. VIMM is a toolbox developed in-house at Flanders Hydraulics to assist the modeller during calibration and validation of hydraulic models.

We compare the model performance between 2 different model runs (Table 5).

Table 5 – Description of model runs involved in the model validation.

Run004	Run work20 as reported by Chu et al (2020 as shown in Table 4 (before final calibration).
Run005	Run work26 as shown inTable 4 (after final calibration).

4.1 Boundary Conditions

Boundary conditions aren't changed during the 3-step calibration. They are nested from DCSMv6-ZUNOv4.

4.2 Water Level Timeseries

Table 7 compare the statistics of Bias, RMSE and RMSE0 (see definitions in Appendix B) of the complete time series. The statistical values are color-coded by the definition shown in Table 6. Figure 7 to Figure 15 present the statistical comparison between Run004 and Run005.

In general the differences on water level predictions between Run004 and Run005 are negligible throughout the estuary, except at Hombeek and Zemst (e.g. the RMSE is reduced by 1.5 cm and 2.7 cm respectively). Run004 and Run005 are identical in model setups except the bottom friction map, apart from which Run004 ran at FHR with 32 processors while Run005 ran at Deltares with 20 processors. Normally the model results are not (and should not be) dependent on the number of processors. However some tests at FHR have shown that the Zenne river is sensitive to the number of processors used by the model.

Table 6 – Definition of colour code in terms of bias, RMSE and RMSE0.

Legend	|Bias| [cm]	RMSE [cm]	RMSE0 [cm]
	0-5	0-5	0-5
	5-10	5-10	5-10
	10-15	10-15	10-15
	15-20	15-20	15-20
	>20	>20	>20

Table 7 – Comparison of Bias, RMSE and RMSE0 of the complete time series.

Stations	Complete TimeSeries								
	Run004			Run005			Run005 – Run004		
	BIAS	RMSE	RMSE_0	BIAS	RMSE	RMSE_0	BIAS [cm]	RMSE [cm]	RMSE_0 [cm]
Westhinder	-0.3	2.6	2.6	-0.3	2.6	2.6	0.0	0.0	0.0
Vlakte van de	-1.4	4.6	4.4	-1.4	4.6	4.4	0.0	0.0	0.0
Westkapelle	-0.4	4.1	4.1	-0.4	4.1	4.1	0.0	0.0	0.0
Cadzand	2.0	5.8	5.5	2.0	5.8	5.4	0.0	0.0	0.0
Vlissingen	-1.4	4.8	4.6	-1.4	4.8	4.6	0.0	0.0	0.0
Breskens	-0.6	5.0	4.9	-0.6	5.0	4.9	0.0	0.0	0.0
Borssele	-0.5	5.2	5.2	-0.5	5.2	5.2	0.0	0.0	0.0
Terneuzen	-1.6	5.7	5.5	-1.6	5.8	5.5	0.0	0.1	0.1
Hansweert	1.1	5.5	5.4	1.1	5.6	5.5	0.0	0.0	0.0
Walsoorden	0.7	6.0	5.9	0.7	6.1	6.0	0.0	0.1	0.1
Baalhoek	1.6	6.2	6.0	1.5	6.3	6.1	0.0	0.0	0.1
Bath	4.0	8.3	7.2	4.0	8.2	7.1	0.0	-0.1	-0.1
Zandvliet	2.5	9.0	8.6	2.4	8.7	8.4	0.0	-0.2	-0.2
Liefkenshoek	4.7	8.8	7.4	4.6	8.7	7.4	0.0	-0.1	-0.1
Kallo	6.2	10.1	8.0	6.1	10.0	8.0	-0.1	-0.1	0.0
Antwerpen	6.3	10.4	8.3	6.2	10.3	8.3	-0.1	-0.1	-0.1
Hemiksem	-1.5	8.2	8.0	-1.6	8.1	8.0	-0.1	0.0	-0.1
Boom	-0.3	8.1	8.1	-0.4	8.0	8.0	-0.1	-0.1	-0.1
Temse	0.7	8.0	8.0	0.6	8.0	8.0	-0.1	-0.1	0.0
Tielrode	-0.5	10.0	9.9	-0.6	10.0	10.0	-0.1	0.0	0.0
Walem	1.0	8.2	8.1	0.9	8.0	8.0	-0.1	-0.1	-0.1
StAmands	-5.9	16.9	15.8	-6.1	16.8	15.6	-0.1	-0.1	-0.2
Dendermonde	8.7	21.6	19.8	8.5	21.6	19.8	-0.2	0.0	0.1
Schoonaarde	-7.0	15.1	13.4	-7.1	15.2	13.4	-0.2	0.1	0.0
Wetteren	-1.6	16.1	16.1	-1.8	16.2	16.1	-0.2	0.0	0.0
Melle	4.6	22.2	21.7	4.4	22.2	21.7	-0.2	0.0	0.0
MechelenSluis	12.3	23.0	19.4	12.3	23.2	19.7	0.0	0.2	0.3
Hombeek	10.1	20.9	18.2	8.0	19.3	17.6	**-2.1**	**-1.5**	**-0.7**
Zemst	13.3	30.0	26.9	9.8	27.3	25.5	**-3.5**	**-2.7**	**-1.4**
Duffel	-3.5	10.1	9.5	-3.5	10.3	9.6	0.0	0.2	0.2
Rijmenam	-2.3	23.3	23.2	-2.3	23.4	23.2	0.0	0.1	0.1
Lier Molbrug	-17.0	23.3	15.9	-17.1	23.3	15.9	-0.1	0.0	-0.1
Lier Maasfort	-17.7	25.5	18.3	-17.8	25.5	18.2	-0.1	0.0	-0.1
Emblem	-16.7	25.2	18.9	-16.6	25.0	18.7	0.0	-0.2	-0.2
Kessel	-8.7	19.6	17.5	-8.8	19.6	17.5	0.0	0.0	0.0

Figure 7 – Bias of complete time series of water levels along the Scheldt.

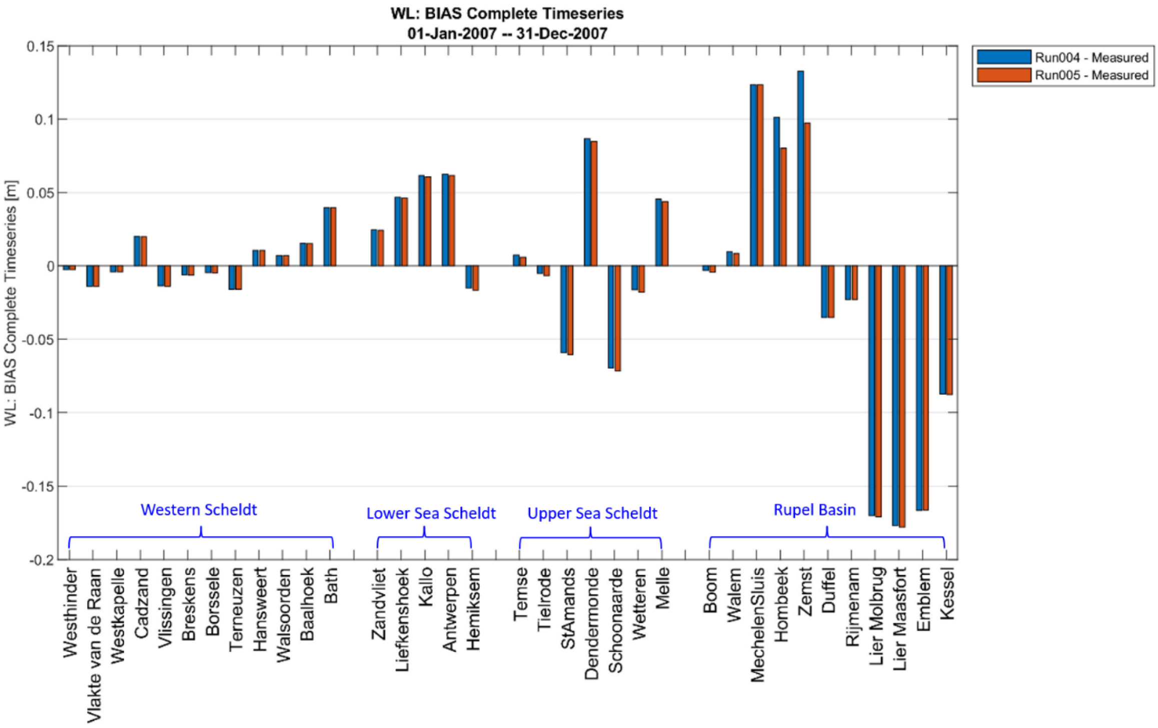


Figure 8 – RMSE of complete time series of water levels along the Scheldt.

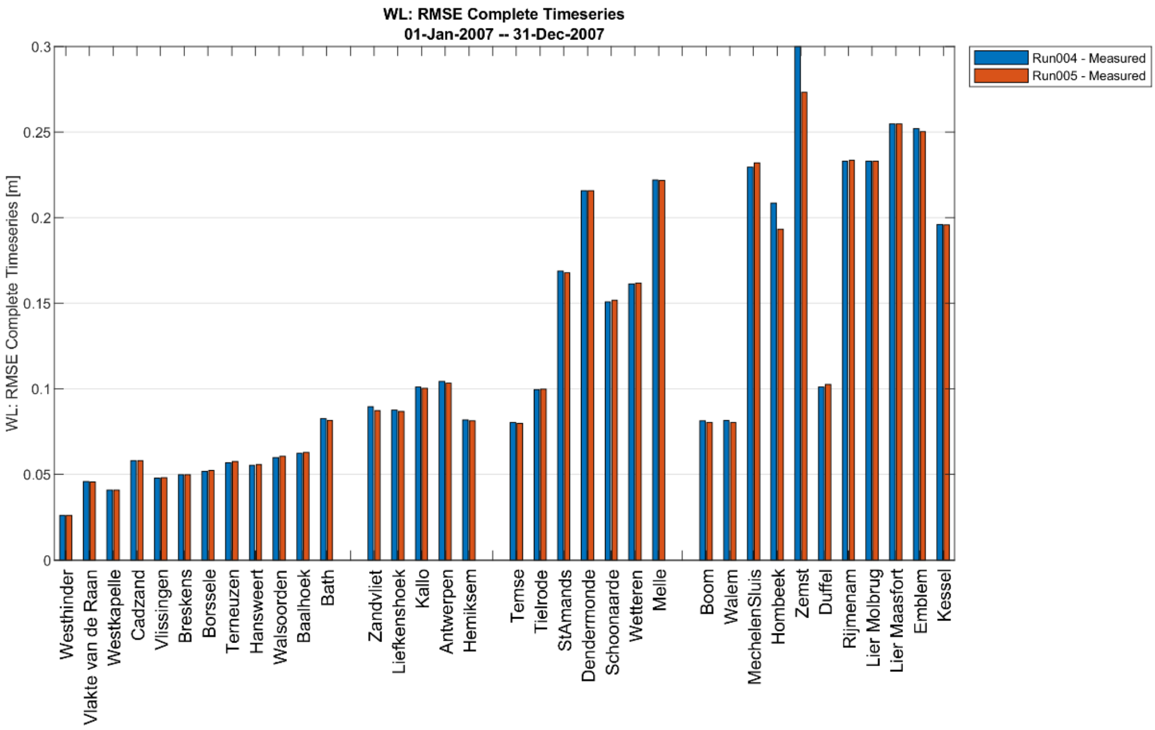


Figure 9 – RMSE0 of complete time series of water levels along the Scheldt.

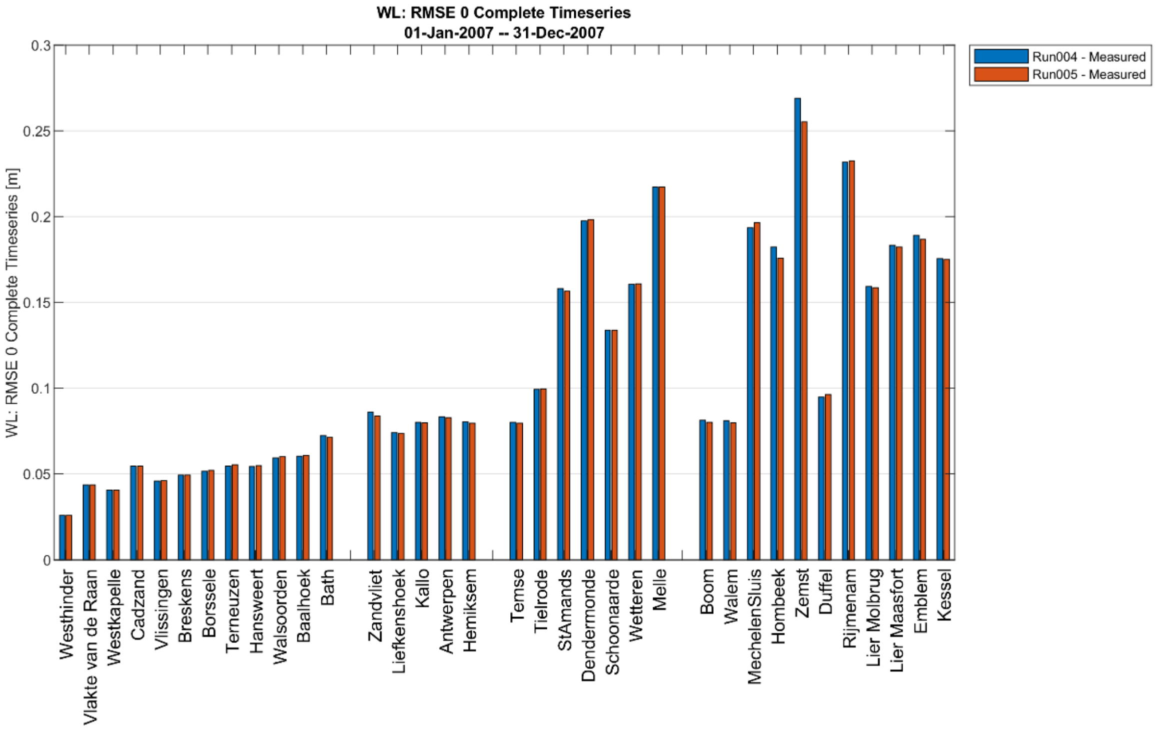


Figure 10 – Bias of high water levels along the Scheldt.

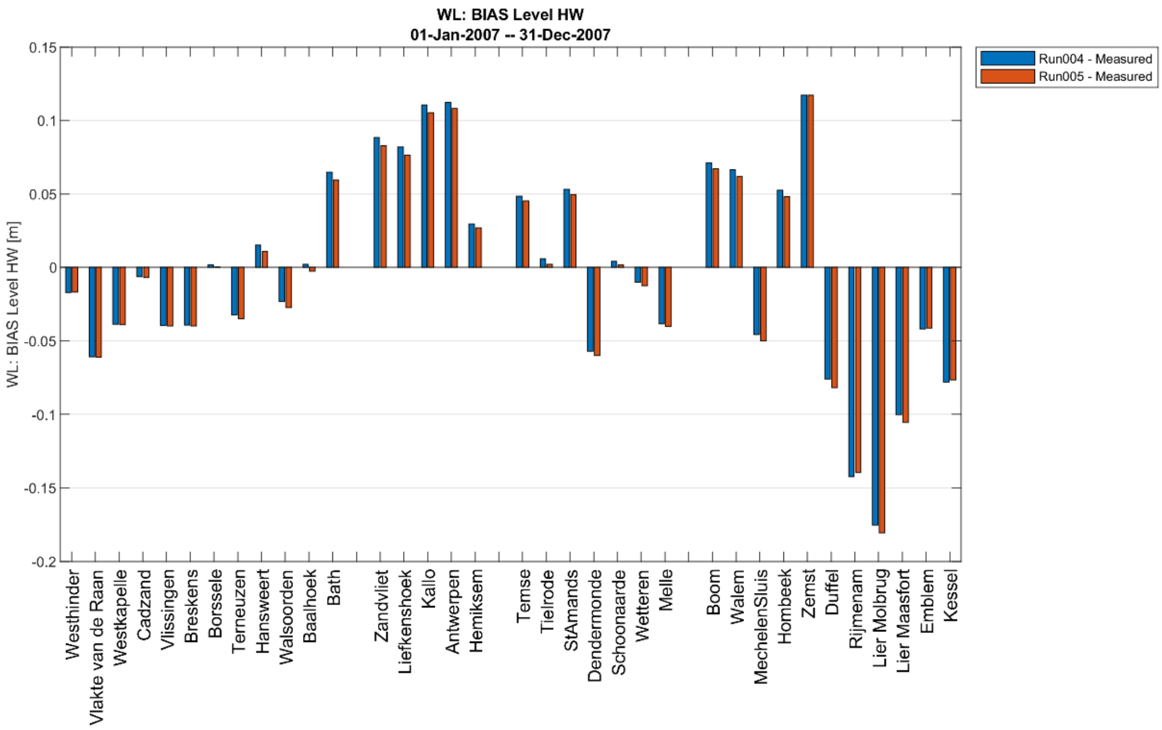


Figure 11 – RMSE of high water levels along the Scheldt.

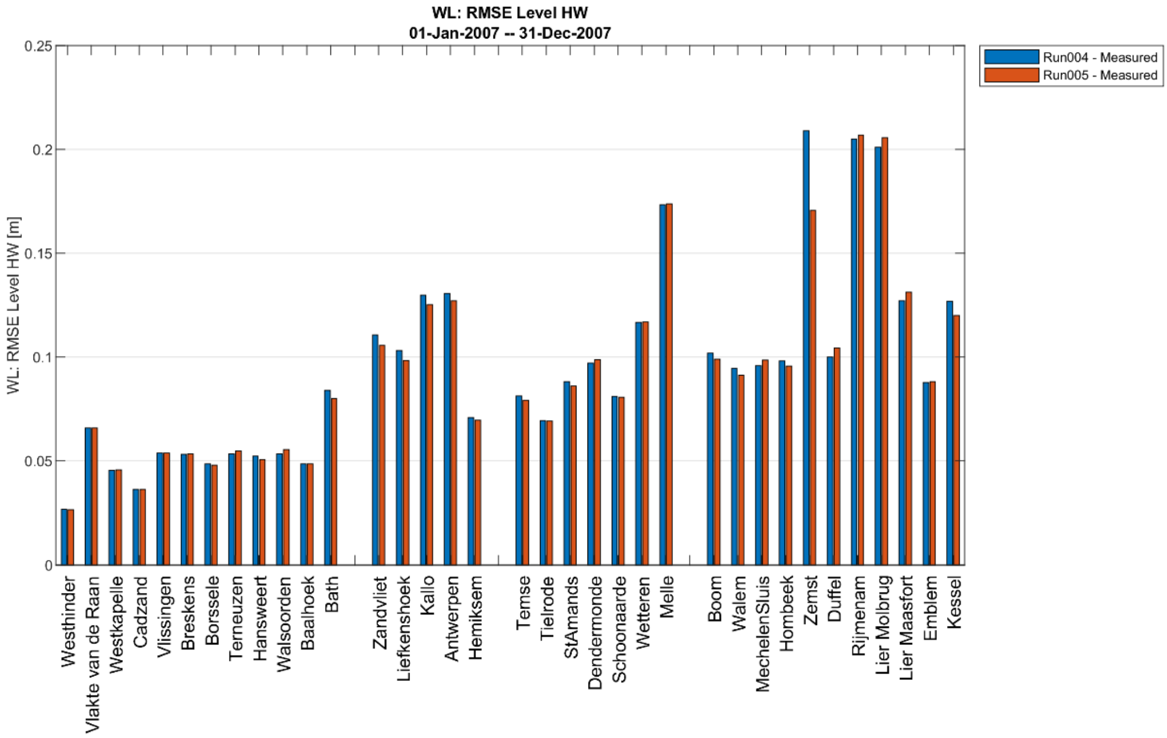


Figure 12 – RMSE0 of high water levels along the Scheldt.

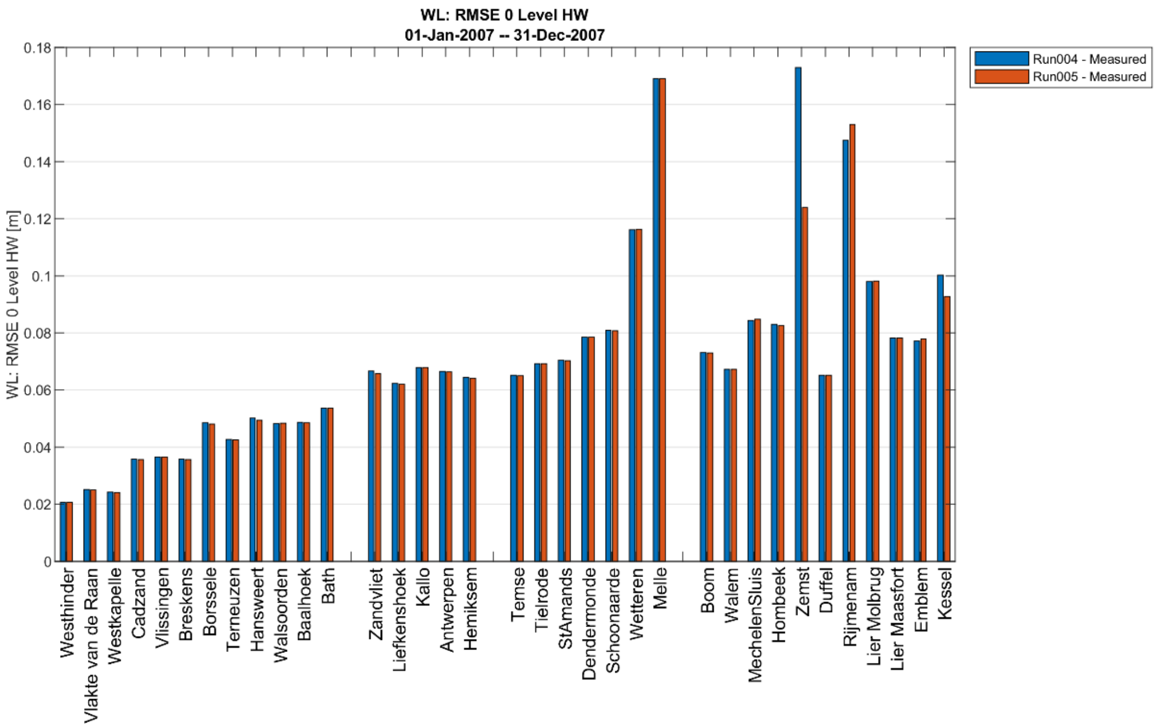


Figure 13 – Bias of low water levels along the Scheldt.

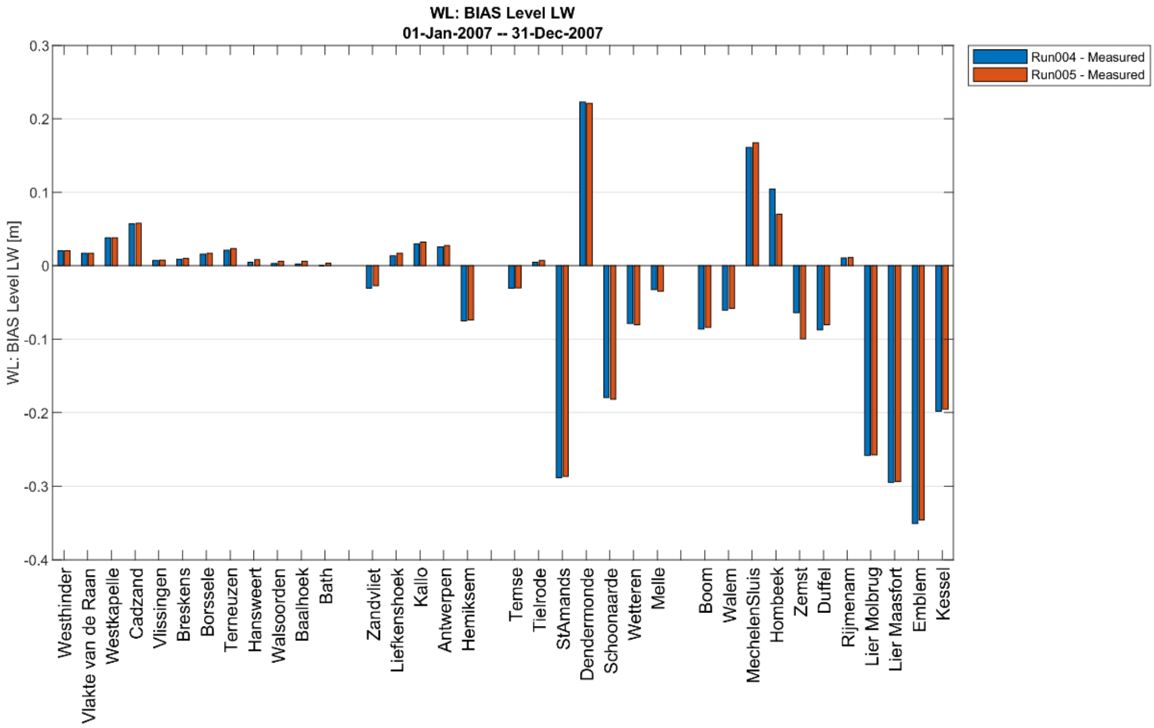


Figure 14 – RMSE of low water levels along the Scheldt.

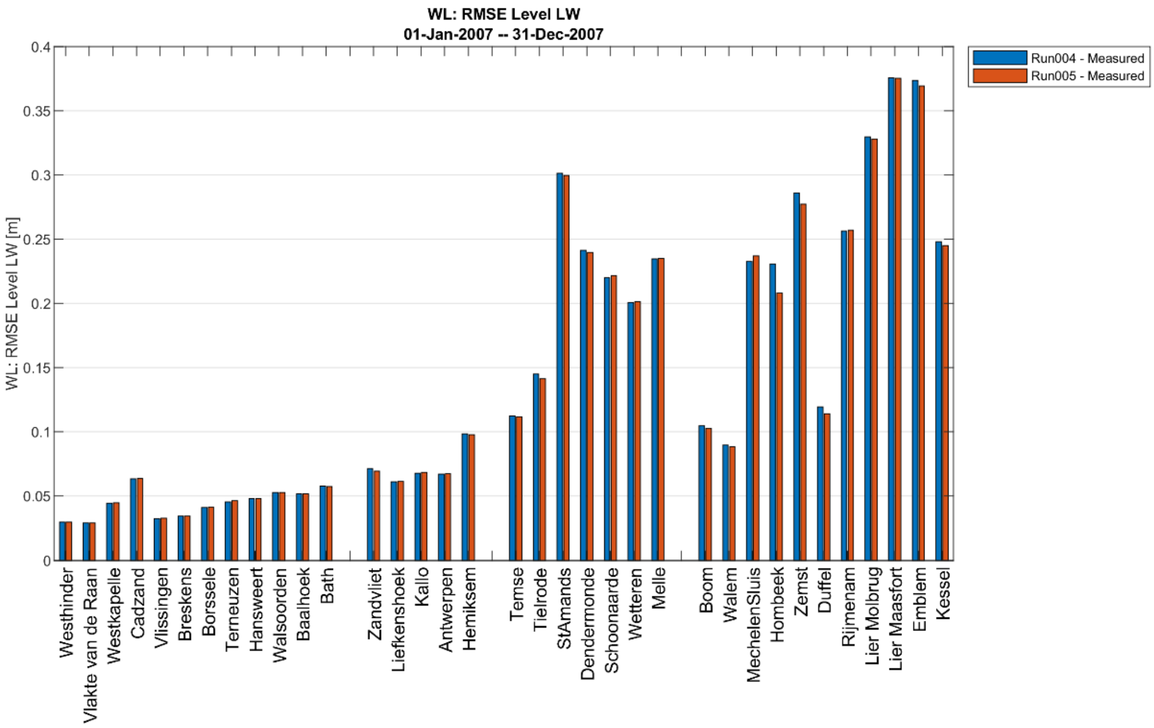
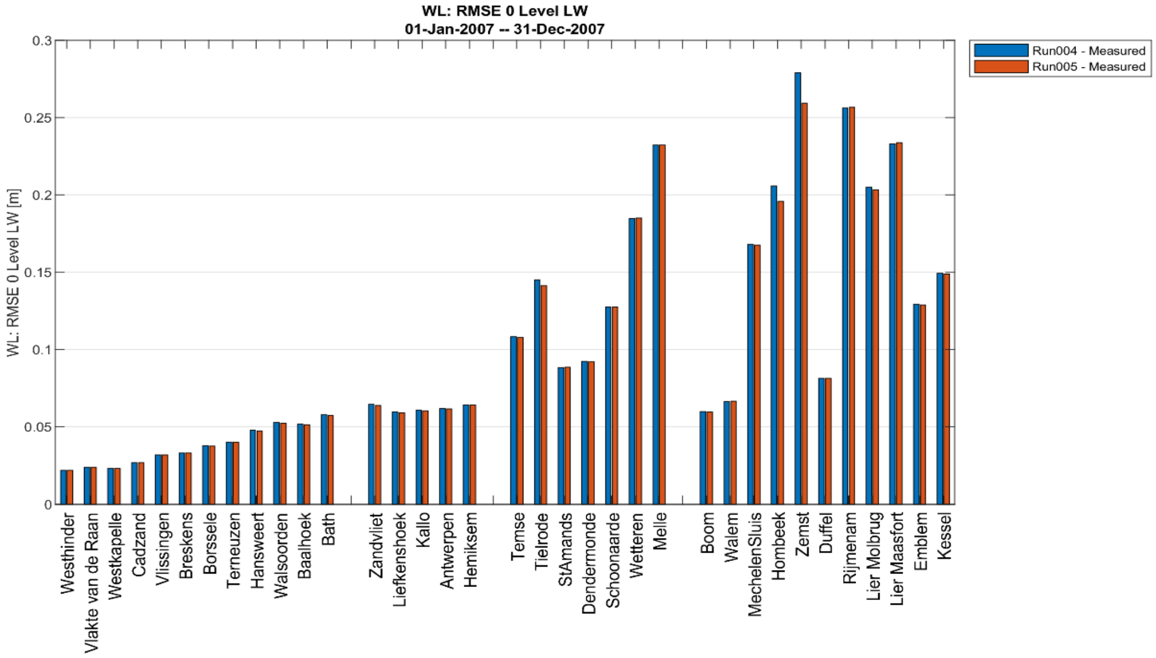


Figure 15 – RMSE0 of low water levels along the Scheldt.



4.3 Harmonic Analysis of Water Levels

Figure 16 to Figure 19 compare the model predicted tidal components of M2 and S2 along the River Scheldt. Figure 20 shows the vector difference (see definition in Appendix C).

In general Run004 and Run005 produce identical predictions on water level in the frequency domain throughout the estuary. Slight differences on M2 amplitude are observed at at Hombeek and Zemst.

Figure 16 – M2 amplitude along the River Scheldt.

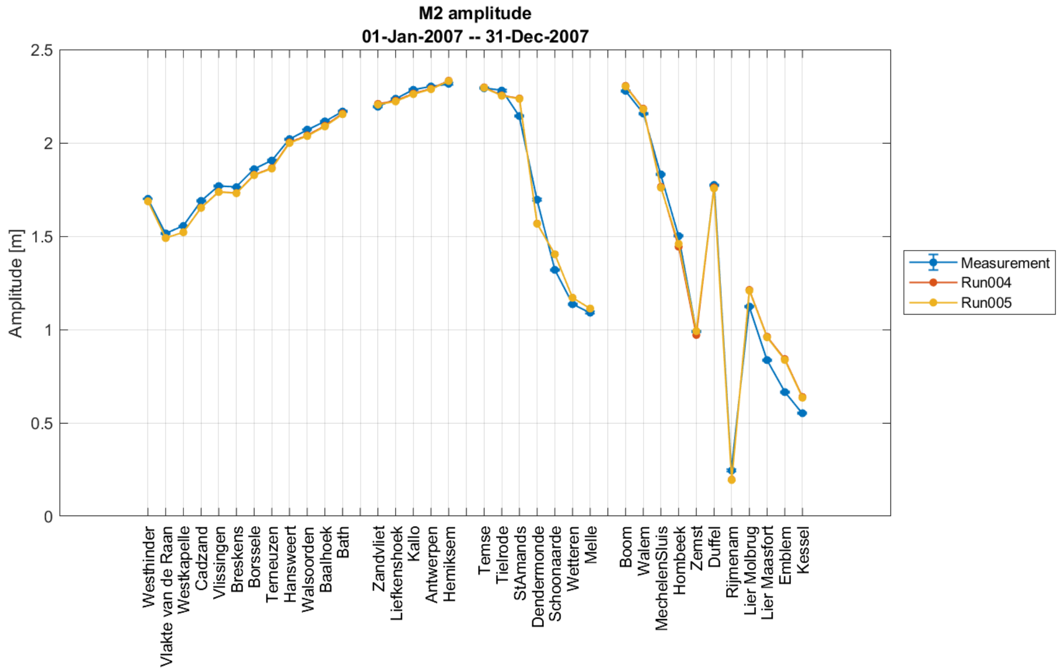


Figure 17 – M2 phase along the River Scheldt.

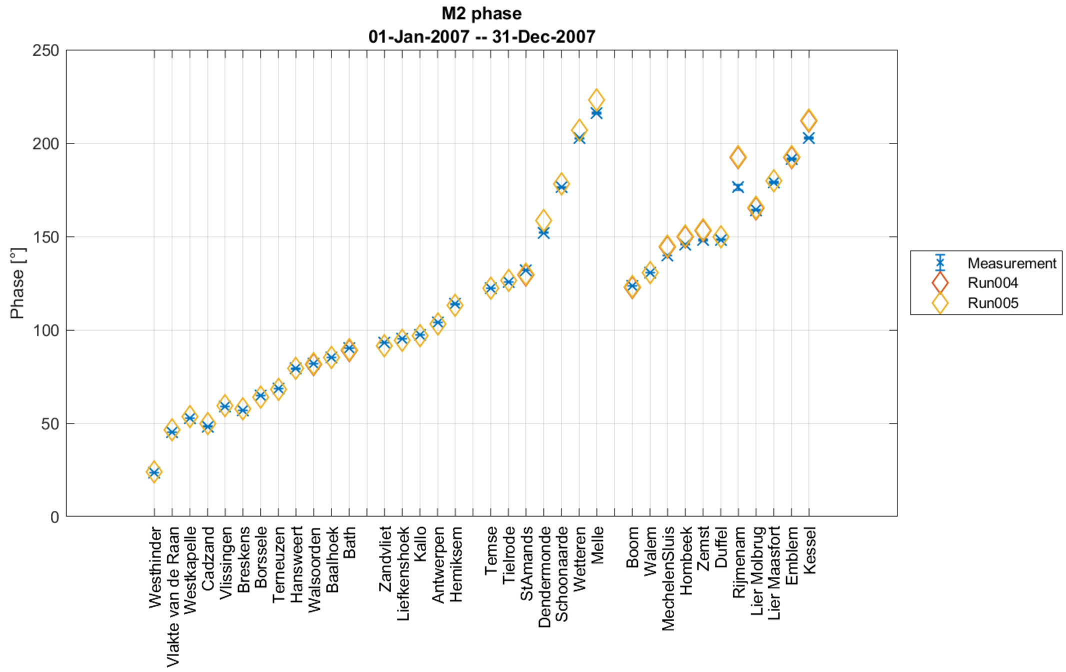


Figure 18 – S2 amplitude along the River Scheldt.

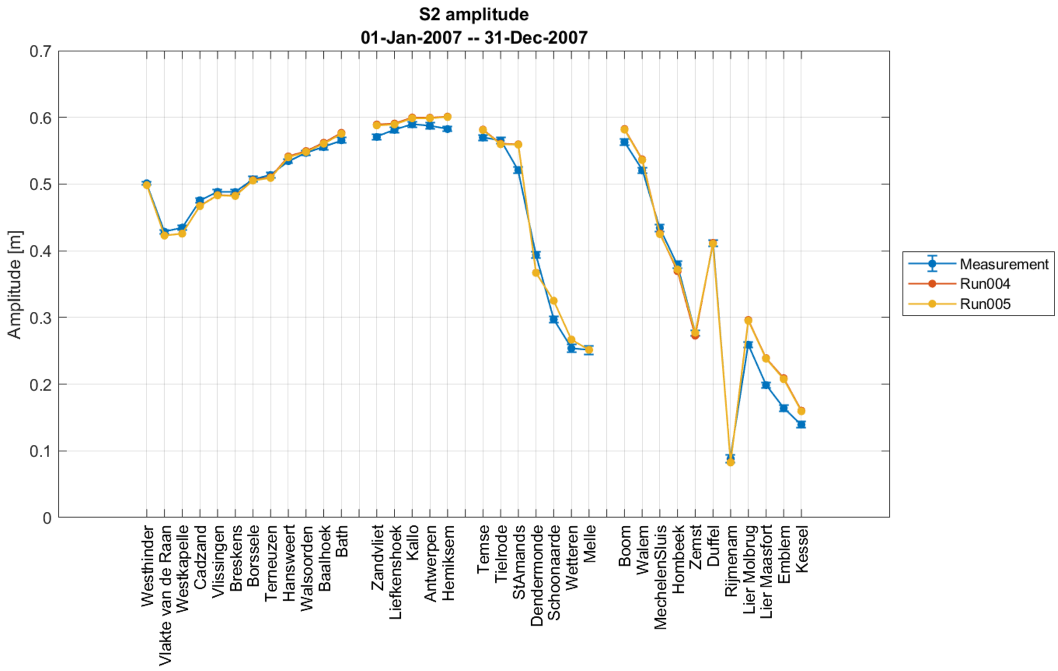


Figure 19 – S2 phase along the River Scheldt.

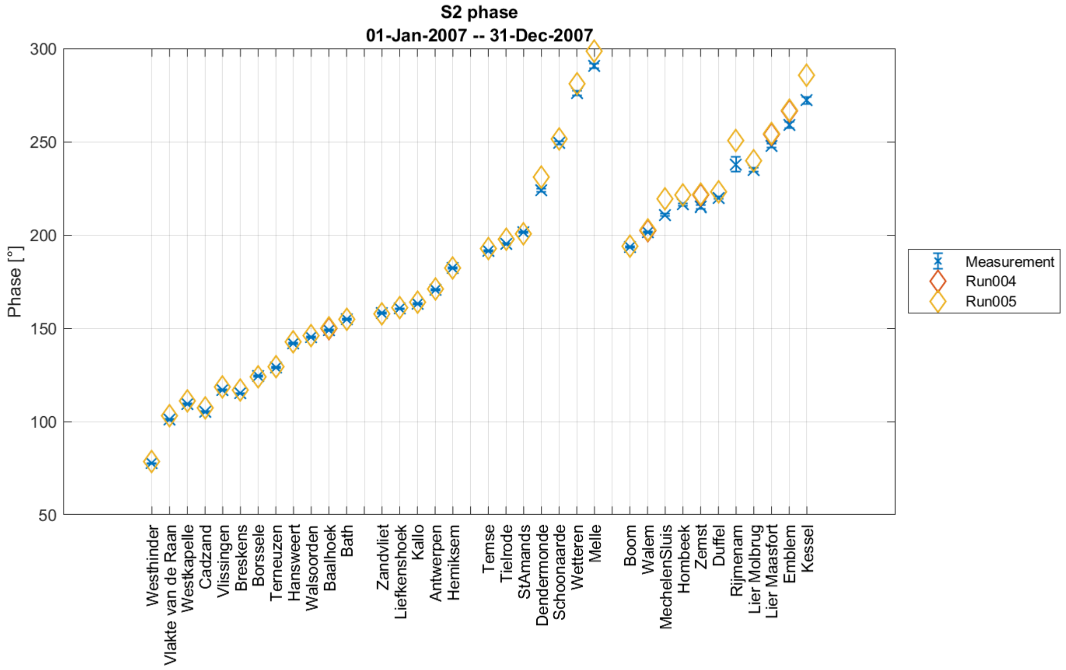
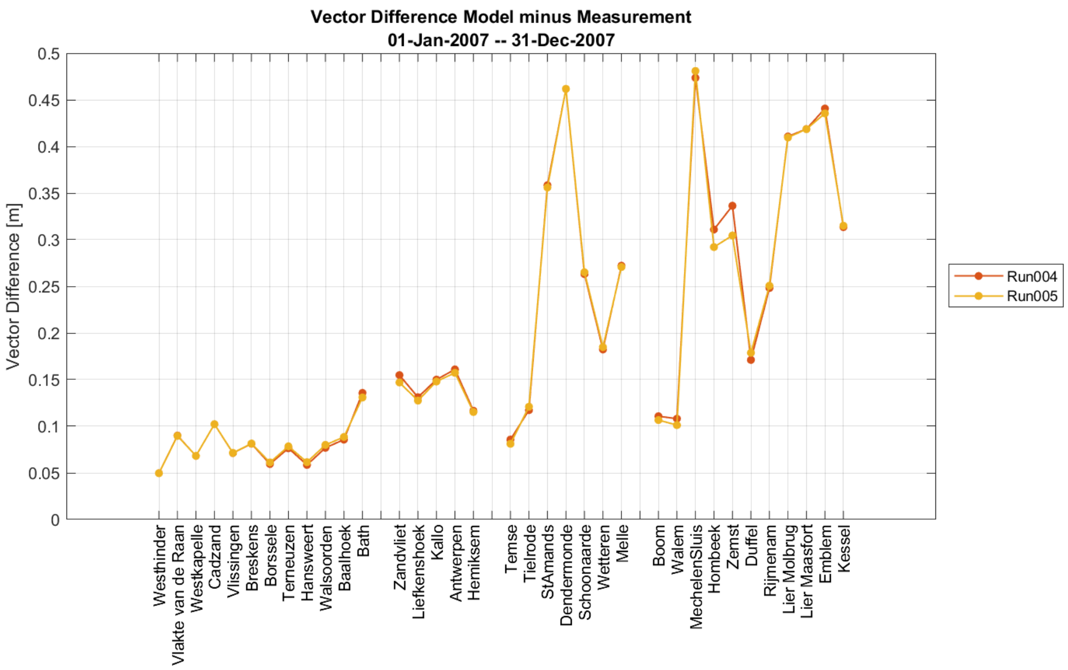


Figure 20 – Vector differences along the River Scheldt.



5 Conclusions

The project goal is the autimatic calibration of the WAQUA-Schelde_NEVLA model for the entire year of 2007. Automatic model generation is performed through Baseline (based on an existing grid). The hydraulic model is run in Simona-Waqua. Automatic calibration is performed through OpenDA.

This report describes the final automatic calibration (3^{rd} step) for the entire model domain starting from the calibrated roughness field from the 2^{nd} step (described in Chu et al., 2019 & 2020).

The main findings are:

- The 3^{rd} automatic calibration with OpenDA leads only to a limited further reduction of cost function.
- The final calibrated bottom roughness map also doesn’t differ much from the previous calibration by Chu et al (2020).
- In the future, automatic calibration could be safely performed in 2 steps.

6 References

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Groenenboom, J.; van der Kaaij, Th.; Plieger, R. (2016). Schelde-estuarium, WAQUA model 5e generatie - Werkzaamheden 2016. Deltares Report. Delft, the Netherlands.

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Appendix A Introduction of DUD

The DUD (Doesn't Use Derivative) algorithm (Ralston and Jennrich, 1978) is a derivative-free algorithm for nonlinear least squares. It can be seen as a Gauss-Newton method, in the sense that it transforms the nonlinear least square problem into the well-known linear square problem. DUD evaluates and optimizes uncertain model parameters by minimizing a cost function. The parameter values corresponding to the minimum value of the cost function are considered as the optimal parameter values for the given analysis.

For N calibration parameters, DUD requires (N+1) set of parameters estimates. The affine function for the linearization is formed through all these (N+1) guesses. Note that the affine function gives exact value at each of the (N+1) points. The resulting least square problem is then solved along the affine function to get a new estimate, whose cost is smaller than those of all other previous estimates. If it does not produce a better estimate, the Dud will perform different steps, like searching in opposite direction and/or decreasing searching-step, until a better estimate is found. Afterwards, the estimate with the largest cost is replaced with the new one and the procedure is repeated for the new set of (N+1) estimates. The procedure is stopped when one of the stopping criteria is fulfilled.

The general DUD implementation is given by the following steps:

- Start running first guess and modify each parameter;
- Linearize the model around these values and solve the linear problem;
- If this is an improvement, update linearization with new point;
- Or, do a line-search (only until there is improvement).

Suppose there is one uncertain model parameter $\mathbf{P} \in \mathbf{R}$ and a set of **n** observations $\mathbf{y} \in \mathbf{R}^n$. The cost function **J** is expressed as a sum of squares as

$$\mathbf{J(P) = [y-f(P)]^T [y-f(P)]}$$

f is the model function. Note that calculating J() involves doing one model run, and post-processing the results to calculate the cost function.

The DUD optimization starts with an unperturbed run (with initial guess **P1**) and one sensitivity run (**P2**). The corresponding function values **f(P1**) and **f(P2**) are stored in memory. The parameters are sorted according to their cost function **J(P)** from high to low. Let's assume that in this case **P1** results in a higher cost function compared with **P2**.

A linear approximation **L(α)** is built of the function **f** around **P2**:

$$\mathbf{L(\alpha) = f(P2) + \alpha\, \Delta F} \qquad \mathbf{where\ \Delta F = f(P1) - f(P2)}$$

In the cost function, the model evaluation **f(P)** is substituted by the linearized function **L(α)**. The linearized cost function **J(α)** becomes:

$$\mathbf{J(\alpha) = [y - f(P2) - \alpha\, \Delta F]^T [y - f(P2) - \alpha\, \Delta F]}$$

We then solve for **α** that minimizes the linearized cost function **J(α).** After some algebra, this gives:

$$\boldsymbol{\alpha} = \mathbf{(\Delta F^T \Delta F)^{-1} \Delta F^T [y - f(P2)]}$$

The new parameter estimation of **P3** is then based on

- **P2**,
- the difference between the two best estimates (**ΔP = P1-P2**),
- and the parameter **α**.

P3 = P2 + α ΔP

If **J(P3)** is less than **J(P2)**, then **P1** and **J(P1)** are tossed out from memory, **P2** is replaced by **P3**, and the two estimates are again sorted according to their corresponding cost function (**P2** and **P3**). This is called the **outer iteration**.

If **J(P3)** is not less than **J(P2)**, then a **line search** is done in between **P2** and **P3**:

P3 = P2 + δ_i (P3-P2)

The step size $\boldsymbol{\delta_i}$ is calculated as:

$$\boldsymbol{\delta_i} = \begin{cases} \mathbf{1}, & \boldsymbol{i = 0} \\ \boldsymbol{\beta} \times (\boldsymbol{\eta})^{\boldsymbol{i}}, & \boldsymbol{i > 1} \end{cases}$$

The line search stops until **P3** is reached for which **J(P3)** is less than **J(P2)**, if that exists. This is called the **inner iteration**. The parameter $\boldsymbol{\beta}$ **= ±1** determines whether the line search is continued in a positive (+) or negative (-) direction. In this study, negative search starts when **i**>3 (**startIterationNegativeLook=3**). **η** is the **shorteningFactor = 0.5** in this study. The procedure is stopped as soon as one of the stopping criteria is fulfilled (see §3.3). The best fit will be given by the value of **P** with the lowest cost **J**.

For a more detailed descriptions of the DUD algorithm, the reader is referred to OpenDA (2016).

Appendix B Definition of Statistics

Water levels

The **Bias** of water level represents the average deviation of the differences between model predicted water level and measurement.

The **RMSE** of water level is a measure of the spread of the predicted values level around the measurement. It corresponds to a sample standard deviation.

The **RMSE0** is the bias corrected root mean square error which describes the forecast errors not associated with the bias.

The mathematical expressions are listed below. y and x represent modelled and measured values respectively and n is the number of samples.

$$Bias = \overline{y} - \overline{x}$$

$$RMSE = \sqrt{\frac{\sum_{1}^{n} (y_i - x_i)^2}{n}}$$

$$RMSE0 = \sqrt{\frac{\sum_{1}^{n} ((y_i - x_i) - (\overline{y} - \overline{x}))^2}{n}}$$

Appendix C Definition of Vector Difference

The vector difference analysis combines the results from different tidal components regarding both amplitude and phase. In short vector difference is a unified variable with one value describing the model accuracy from harmonic point of view. The mathematical expression of vector difference is shown as below.

$$e_s = \sum_{i=1}^{N} \sqrt{[A_{c,i}cos(\phi_{c,i}) - A_{m,i}cos(\phi_{m,i})]^2 + [A_{c,i}sin(\phi_{c,i}) - A_{m,i}sin(\phi_{m,i})]^2}$$

where e_s is the vector difference calculated at a certain station. c and m represent the model computed and measured value. A and φ represent the tidal amplitude and phase. i represents the number of tidal components.

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