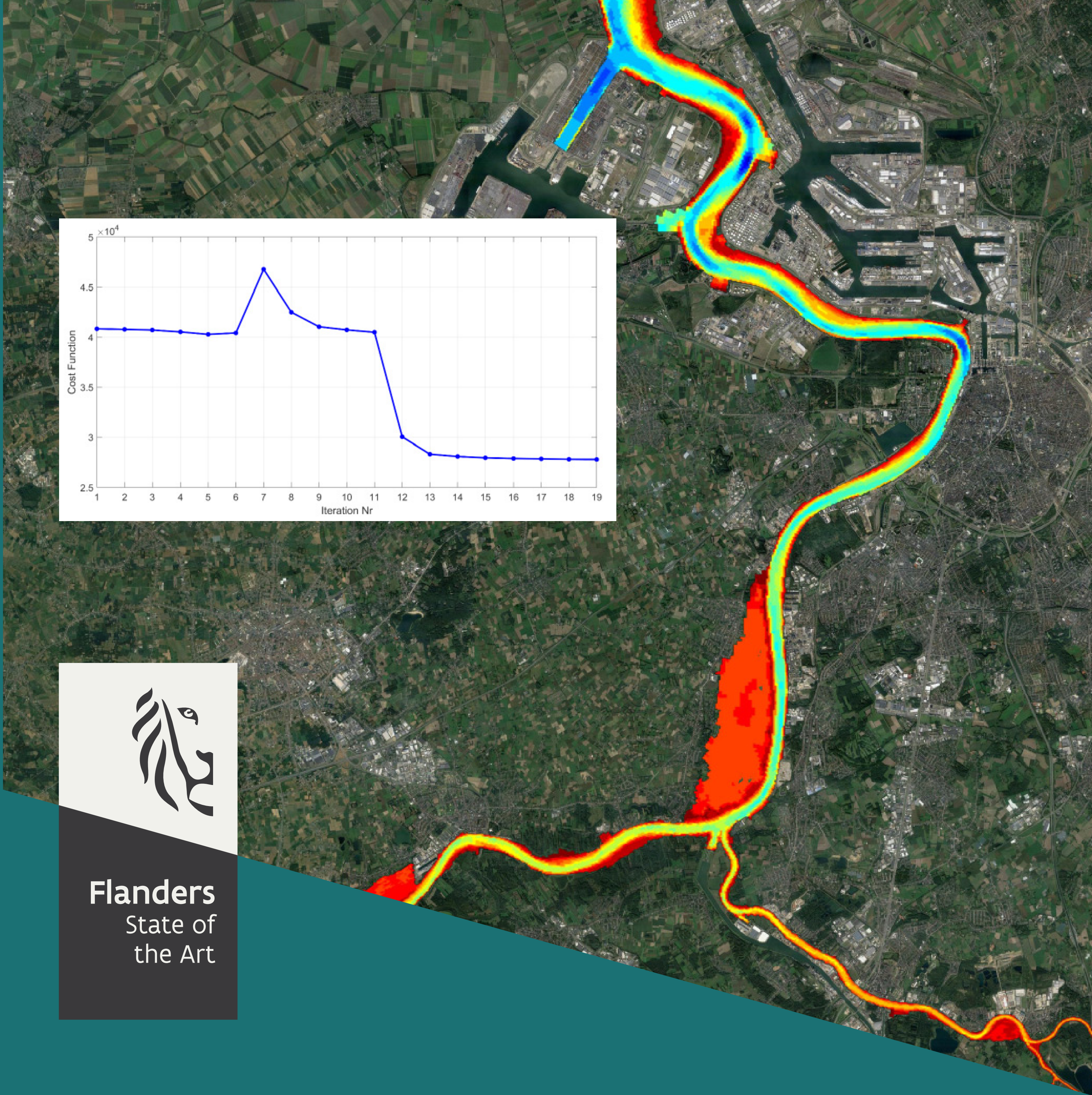

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Automatic re-calibration of waqua-schelde_nevla-j07_5 with lower weights in the Rupel basin

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Automatic re-calibration of waqua-schelde_nevla-j07_5 with lower weights in the Rupel basin

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

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Abstract

This report is an extension to the work previously reported by Chu et al. (2019). During the discussion of the results, the suggestion was given to lower the weight of the stations in the Rupel Basin in the cost function that is used in the automatic calibration procedure, and check the influence on the end result.

This report follows up on that suggestion. The weights in the cost function for the water level stations in the Rupel basin are made 16 times smaller. The model is then automatically calibrated on bottom roughness for the entire year of 2007. The result of lowering the weight of the stations in the Rupel basin in the cost function is that (as expected), the error on water levels in the Rupel basin slightly rises by 1-2 cm. The model however performs slightly better from Hemiksem to Walem (also by 1-2 cm). The re-calibrated model shows an unchanged (good) skill representing the salinity and cross-sectional discharge in the Scheldt estuary. As expected, the model performance in the Western Scheldt is unaffected by the change in weights.

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1 Introduction

In the summer of 2016 Deltares 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. The continuation of the model calibration for the Flemish part was assigned to Flanders Hydraulics Research (FHR). Within project '13_041: Baseline Zeeuwse Delta' Flanders Hydraulics and IMDC carried out the model set-up and automatic calibration for 2007 of the Flemish part of the NEVLA model of the Western Scheldt and Sea Scheldt (Chu et al., 2019). This NEVLA2D model (**waqua-schelde_nevla-j07_5-w4**) is calibrated automatically with OpenDA. The automatic calibration leads to a reduction of the cost function by 20%. The model validation shows that water level, salinity and cross-sectional discharge are well reproduced.

The results were presented and discussed at a meeting with Rijkswaterstaat and Deltares on January 24th 2019. One of the points of discussion was the way the Rupel Basin was represented in the cost function that is used during the automatic calibration. In (Chu et al., 2019) the entire Rupel basin is represented as one roughness zone with 11 water level measurement stations inside of it (for details see §5.2.4 in Chu et al., 2019). 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.

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 it was suggested to lower the weights in the cost function for the water level stations in the Rupel basin and to redo the calibration for the entire year of 2007.

This report follows up on that suggestion, and can be seen as an extension to (Chu et al., 2019).

2 Re-Calibration with OpenDA

2.1 Introduction

For a detailed description of the automatic calibration procedure using OpenDA, the reader is referred to Chu et al (2019).

2.2 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

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

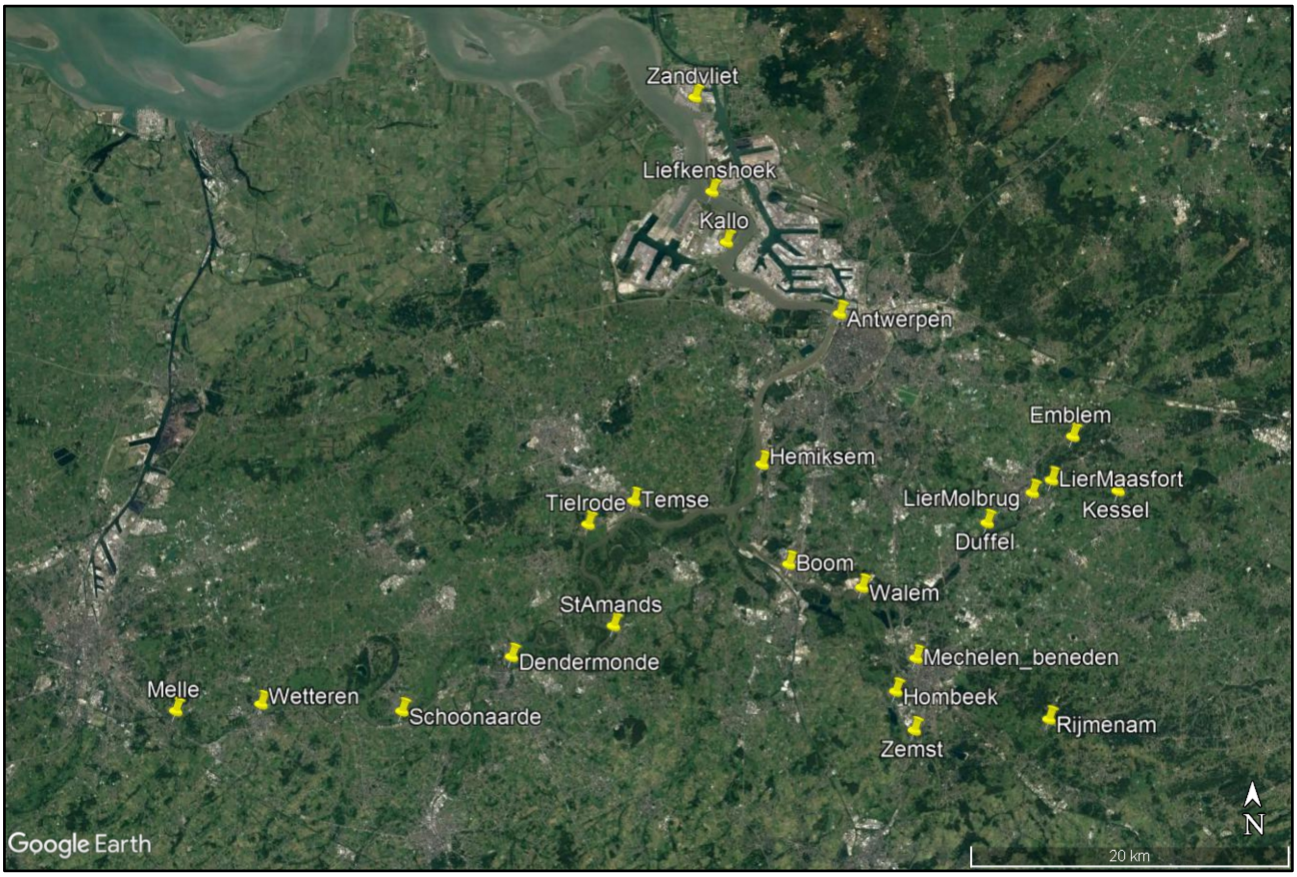
where:

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 (**10**);
$\boldsymbol{\sigma_{H_{r,s}^{obs}}}$ - uncertainties assigned to the observations (**2 m for Rupel and 0.5 m elsewhere**).

In the cost function, the $\sigma_{H_{r,s}^{obs}}$ can be used as the weight assigned to the water level stations. In Che et al. (2019) a constant value of **0.5 m** was assigned to all stations throughout the estuary. In this report we investigate the effect of changing this value to **2 m** for the 11 stations in the Rupel basin. As an effect, the contribution of stations in the Rupel basin to the cost function becomes **16** times smaller.

In this study, **23** water level stations (as shown in Figure 1) are employed for the OpenDA calibration. The calibration period is the year 2007 (2007/01/01 00:00 – 2007/12/31 23:50) with a time step of 10 minutes, giving a total number of time steps of **52560 (N$_{max}$)**.

Figure 1 – Map of 23 water level stations involved in the OpenDA calibration.



2.3 Implementation of the re-calibration

There are 10 roughness zones defined in this study (R_{max}). The first 11 (R_{max} + 1) iterations of the DUD algorithm are used to build up the affine function for the linearization and can be re-used in the re-calibration (to save computational time).

In the ***Model config*** (detmodel_rough1.xml), the ***skipModelActionsIfInstanceDirExists*** is set to ***true*** which indicates that no actions will be executed on a model instance that already exists.

In the auto-calibration directory (Figure 2), the ***base*** folder is the template directory containing the original WAQUA model input (e.g. the steering siminp file and the initial choice of the roughness parameters). ***work0*** and ***work1*** are just 2 working copies of the ***base*** folder created by OpenDA. Both folders of ***work0*** and ***work1*** are not involved in the auto-calibration. Folders from ***work2*** to ***work12*** are the first 11 initialization runs which can be reused in the re-calibration.

Figure 2 – The first 11 initialization runs (work2 to work12 are reused for the re-calibration).

base	1/8/2018 14:33	File folder
work0	3/7/2018 11:39	File folder
work1	3/7/2018 11:39	File folder
work2	3/26/2018 10:58	File folder
work3	12/3/2018 13:33	File folder
work4	12/3/2018 13:41	File folder
work5	12/3/2018 13:44	File folder
work6	12/3/2018 13:46	File folder
work7	12/3/2018 13:48	File folder
work8	12/3/2018 13:50	File folder
work9	12/3/2018 13:52	File folder
work10	12/3/2018 13:54	File folder
work11	12/3/2018 13:56	File folder
work12	12/3/2018 13:57	File folder

2.4 Results

Table 1 shows the changes of cost function and calibration parameter (in this case Manning coefficient) during the OpenDA calibration after 19 iterations. As previously described, the first 11 runs are the preparation for the optimization algorithm. The actual optimization procedure (e.g. linearization and line search) starts from iteration number 12. The cost function drops gradually to a minimum of 27799.40. The calibration was automatically stopped when one of the stopping criterion (***relTolerance***) is met.

$$\boldsymbol{outerLoop\ maxIterations} = 8 < 100$$

$$\boldsymbol{absTolerance} = |new\ cost\ -\ previous\ cost| = |27799.40 - 27816.43| = 17.03 > 0.001$$

$$\boldsymbol{relTolerance} = \frac{|new\ cost - previous\ cost|}{|new\ cost|} = \frac{|27799.40 - 27816.43|}{27799.40} = 0.0006 < 0.001$$

$$\boldsymbol{relToleranceLinearCost} = \frac{|new\ cost - linearized\ cost|}{|previous\ cost{-}inearized\ cost|} = \frac{|27799.40 - 27641.56|}{|27816.43 - 27641.56|} = 0.9 > 0.001$$

The evolution of the cost function during the OpenDA re-calibration is demonstrated in Figure 3. The cost function is reduced by ***32%***.

Table 1 – Changes of the cost function and the calibration parameter (manning coefficient) during the re-calibration with OpenDA.

Iteration	Cost	A-450	A-455	A-457	A-459	A-461	A-462	A-463	A-464	A-465	A-467
1	40839.22	0	0	0	0	0	0	0	0	0	0
2	40787.23	0.002	0	0	0	0	0	0	0	0	0
3	40721.06	0	0.002	0	0	0	0	0	0	0	0
4	40533.21	0	0	0.002	0	0	0	0	0	0	0
5	40286.61	0	0	0	0.002	0	0	0	0	0	0
6	40426.66	0	0	0	0	0.002	0	0	0	0	0
7	46766.92	0	0	0	0	0	0.002	0	0	0	0
8	42499.33	0	0	0	0	0	0	0.002	0	0	0
9	41048.01	0	0	0	0	0	0	0	0.002	0	0
10	40734.11	0	0	0	0	0	0	0	0	0.002	0
11	40500.98	0	0	0	0	0	0	0	0	0	0.002
12	30031.73	4.833E-04	1.082E-04	6.954E-04	1.124E-03	1.889E-03	-4.640E-03	-1.708E-03	3.646E-04	1.106E-03	1.699E-03
13	28322.4	5.440E-04	-5.624E-04	7.278E-04	1.305E-03	3.385E-03	-6.201E-03	-3.185E-03	2.021E-04	1.766E-03	2.550E-03
14	28096.6	4.662E-04	-1.129E-03	6.265E-04	1.136E-03	4.148E-03	-6.348E-03	-3.252E-03	-1.140E-04	1.982E-03	2.748E-03
15	27962.83	4.163E-04	-1.529E-03	5.624E-04	9.693E-04	4.680E-03	-6.364E-03	-3.423E-03	-8.282E-05	2.070E-03	2.833E-03
16	27897.01	4.225E-04	-1.835E-03	5.396E-04	8.159E-04	5.147E-03	-6.357E-03	-3.572E-03	-1.777E-04	2.192E-03	2.925E-03
17	27858.13	3.843E-04	-2.044E-03	5.286E-04	6.773E-04	5.498E-03	-6.349E-03	-3.691E-03	-2.534E-04	2.282E-03	2.990E-03
18	27816.43	3.617E-04	-2.194E-03	5.424E-04	5.684E-04	5.776E-03	-6.341E-03	-3.783E-03	-3.111E-04	2.294E-03	3.050E-03
19	27799.4	3.426E-04	-2.281E-03	5.398E-04	4.715E-04	5.971E-03	-6.332E-03	-3.859E-03	-3.607E-04	2.338E-03	3.085E-03

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

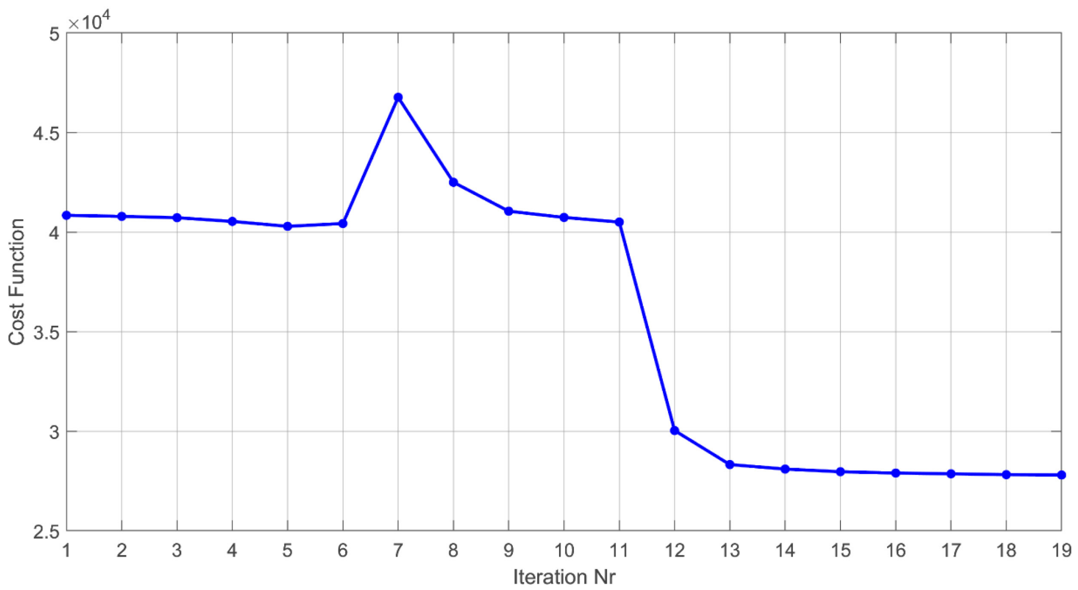


Table 2 compares the Manning coefficients before and after OpenDA calibration. The main changes are found within roughness polygons of 455, 461, 462, 463, 465 and 467. The resulting Manning coefficients from the re-calibration are not that different from the previous automatic calibration however.

Table 2 – Comparison of manning coefficient before and after the automatic calibration with OpenDA.

Legend	Manning Coefficient
	0.01-0.015
	0.015-0.02
	0.02-0.025
	>0.025

<table>
<tr><th>Existing Roughness Polygons (Roughness Code)</th><th>Combined Roughness Polygons</th><th>Water Level Stations (Figure 1)</th><th>River Branch</th><th>Manning Coefficient
(Initial Guess)</th><th>Manning Coefficient
(automatic calibration by Chu et al., 2019)</th><th>Manning Coefficient
(re-calibration with reduced wiights in the Rupel)</th></tr>
<tr><td>450</td><td rowspan="5">450</td><td rowspan="5">Zandvliet</td><td rowspan="11">Lower Sea Scheldt</td><td rowspan="5">0.029</td><td rowspan="5">0.0291</td><td rowspan="5">0.0293</td></tr>
<tr><td>451</td></tr>
<tr><td>452</td></tr>
<tr><td>453</td></tr>
<tr><td>454</td></tr>
<tr><td>455</td><td rowspan="2">455</td><td rowspan="2">Liefkenshoek; Kallo</td><td rowspan="2">0.024</td><td rowspan="2">0.0225</td><td rowspan="2">0.0217</td></tr>
<tr><td>456</td></tr>
<tr><td>457</td><td rowspan="2">457</td><td rowspan="2">Antwerp</td><td rowspan="2">0.023</td><td rowspan="2">0.0231</td><td rowspan="2">0.0235</td></tr>
<tr><td>458</td></tr>
<tr><td>459</td><td rowspan="2">459</td><td rowspan="2">Hemiksem</td><td rowspan="2">0.022</td><td rowspan="2">0.0213</td><td rowspan="2">0.0225</td></tr>
<tr><td>460</td></tr>
<tr><td>461</td><td>461</td><td>Temse</td><td rowspan="4">Upper Sea Scheldt</td><td>0.018</td><td>0.0249</td><td>0.024</td></tr>
<tr><td>462</td><td>462</td><td>StAmands; Dendermonde; Schoonaarde</td><td>0.02</td><td>0.0137</td><td>0.0137</td></tr>
<tr><td>463</td><td>463</td><td>Wetteren</td><td>0.02</td><td>0.0172</td><td>0.0161</td></tr>
<tr><td>464</td><td>464</td><td>Melle</td><td>0.02</td><td>0.0206</td><td>0.0196</td></tr>
<tr><td>465</td><td rowspan="2">465</td><td rowspan="2">Tielrode</td><td rowspan="2">Durme</td><td rowspan="2">0.024</td><td rowspan="2">0.0266</td><td rowspan="2">0.0263</td></tr>
<tr><td>466</td></tr>
<tr><td>467</td><td rowspan="2">467</td><td rowspan="2">Boom; Walem; Hombeek; Zemst;

Mechelen_Benedensluis; Rijmenam; Duffel; Lier_Molbrug; Lier_Maasfort; Emblem; Kessel</td><td rowspan="2">Rupel basin</td><td rowspan="2">0.019</td><td rowspan="2">0.0218</td><td rowspan="2">0.0221</td></tr>
<tr><td>468</td></tr>
</table>

3 Validation with VIMM

The model performance is evaluated with the VIMM tool. 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 3).

Table 3 – Description of model runs involved in the model validation.

Run003	Calibrated model using OpenDA (Chu et al., 2019).
Run004	Re-calibrated model (this report).

3.1 Water Level Timeseries

Table 5, Table 6 and Table 7 compare the statistics of Bias, RMSE and RMSE0 (see definitions in ANNEX A) of the complete time series, high water levels and low water levels respectively. The statistical values are color-coded by the definition shown in Table 4. For readability, Figure 4 to Figure 12 only show the statistical comparison between Run003 and Run004.

In general, Run003 and Run004 lead to differences of about **1 cm** on predicted water levels. However there is a trend of improvement on high water level predictions from **Hemiksem** to **Melle**, and on low water level predictions from **Hemiksem** to **Walem**.

The water level predictions at **Rupel** is slightly worse from Run 004, which is logical as the weights assigned to Rupel are 16 times smaller.

Table 4 – 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 5 – Comparison of Bias, RMSE and RMSE0 of the **complete time series**.
The 12 stations marked in green **(Westhinder to Bath)** represent the areas where the bottom roughness were already calibrated with OpenDA by Deltares for the Western Scheldt. The 23 stations marked in brown **(Zandvliet to Kessel)** represent the areas where the bottom roughness is calibrated with OpenDA in this study (Sea Scheldt and tributaries).

Stations	Complete TimeSeries								
	Run003			Run004			Run004 – Run003		
	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
Vlakte van de	-1.4	4.6	4.4	-1.4	4.6	4.4	0	0	0
Westkapelle	-0.4	4.1	4.1	-0.4	4.1	4.1	0	0	0
Cadzand	2	5.8	5.5	2	5.8	5.5	0	0	0
Vlissingen	-1.4	4.8	4.6	-1.4	4.8	4.6	0	0	0
Breskens	-0.6	5	4.9	-0.6	5	4.9	0	0	0
Borssele	-0.5	5.2	5.2	-0.5	5.2	5.2	0	0	0
Terneuzen	-1.6	5.7	5.5	-1.6	5.7	5.5	0	0	0
Hansweert	1.1	5.5	5.4	1.1	5.5	5.4	0	0	0
Walsoorden	0.7	6	6	0.7	6	5.9	0	0	-0.1
Baalhoek	1.6	6.2	6	1.6	6.2	6	0	0	0
Bath	4	8.2	7.2	4	8.3	7.2	0	0.1	0
Zandvliet	2.5	8.9	8.6	2.5	9	8.6	0	0.1	0
Liefkenshoek	4.7	8.7	7.4	4.7	8.8	7.4	0	0.1	0
Kallo	6.2	10.1	7.9	6.2	10.1	8	0	0	0.1
Antwerpen	6.3	10.3	8.1	6.3	10.4	8.3	0	0.1	0.2
Hemiksem	-1.8	8.7	8.5	-1.5	8.2	8	0.3	-0.5	-0.5
Boom	-0.7	8.9	8.9	-0.3	8.1	8.1	0.4	-0.8	-0.8
Temse	0.8	8	8	0.7	8	8	-0.1	0	0
Tielrode	-0.3	10	10	-0.5	10	9.9	-0.2	0	-0.1
Walem	0.7	8.7	8.7	1	8.2	8.1	0.3	-0.5	-0.6
StAmands	-5.7	16.5	15.5	-5.9	16.9	15.8	-0.2	0.4	0.3
Dendermonde	8.7	21.4	19.5	8.7	21.6	19.8	0	0.2	0.3
Schoonaarde	-6.9	15.2	13.5	-7	15.1	13.4	-0.1	-0.1	-0.1
Wetteren	-0.4	16.1	16.1	-1.6	16.1	16.1	-1.2	0	0
Melle	6.1	23.1	22.3	4.6	22.2	21.7	-1.5	-0.9	-0.6
MechelenSluis	12.2	22.2	18.5	12.3	23	19.4	0.1	0.8	0.9
Hombeek	10	20.3	17.6	10.1	20.9	18.2	0.1	0.6	0.6
Zemst	13.1	29.6	26.6	13.3	30	26.9	0.2	0.4	0.3
Duffel	-3.6	9.8	9.1	-3.5	10.1	9.5	0.1	0.3	0.4
Rijmenam	-2.1	23.2	23.1	-2.3	23.3	23.2	-0.2	0.1	0.1
Lier Molbrug	-16.8	23.3	16.1	-17	23.3	15.9	-0.2	0	-0.2
Lier Maasfort	-17.4	25.4	18.6	-17.7	25.5	18.3	-0.3	0.1	-0.3
Emblem	-16.6	25.5	19.3	-16.7	25.2	18.9	-0.1	-0.3	-0.4
Kessel	-8.5	19.5	17.6	-8.7	19.6	17.5	-0.2	0.1	-0.1

Table 6 – Comparison of Bias, RMSE and RMSE0 of **high water levels**.
The 12 stations marked in green (Westhinder to Bath) represent the areas where the bottom roughness are already calibrated with OpenDA by Deltares for the Western Scheldt. The 23 stations marked in brown (Zandvliet to Kessel) represent the areas where the bottom roughness is calibrated with OpenDA in this study (Sea Scheldt and tributaries).

Stations	High Water Level								
	Run003			Run004			Run004 - Run003		
	BIAS	RMSE	RMSE_0	BIAS	RMSE	RMSE_0	BIAS	RMSE	RMSE_0
Westhinder	-1.7	2.7	2.1	-1.7	2.7	2.1	0	0	0
Vlakte van de	-6.1	6.6	2.5	-6.1	6.6	2.5	0	0	0
Westkapelle	-3.9	4.6	2.4	-3.9	4.6	2.4	0	0	0
Cadzand	-0.6	3.6	3.6	-0.6	3.6	3.6	0	0	0
Vlissingen	-4	5.4	3.6	-3.9	5.4	3.6	0.1	0	0
Breskens	-3.9	5.3	3.6	-3.9	5.3	3.6	0	0	0
Borssele	0.1	4.8	4.8	0.2	4.9	4.9	0.1	0.1	0.1
Terneuzen	-3.2	5.3	4.3	-3.2	5.3	4.3	0	0	0
Hansweert	1.5	5.2	5	1.5	5.2	5	0	0	0
Walsoorden	-2.3	5.4	4.8	-2.3	5.3	4.8	0	-0.1	0
Baalhoek	0.2	4.9	4.9	0.2	4.9	4.9	0	0	0
Bath	6.5	8.4	5.4	6.5	8.4	5.4	0	0	0
Zandvliet	8.8	11	6.6	8.8	11.1	6.7	0	0.1	0.1
Liefkenshoek	8.1	10.2	6.2	8.2	10.3	6.2	0.1	0.1	0
Kallo	10.6	12.6	6.8	11.1	13	6.8	0.5	0.4	0
Antwerpen	10.5	12.4	6.6	11.2	13.1	6.7	0.7	0.7	0.1
Hemiksem	4.1	7.7	6.5	3	7.1	6.4	-1.1	-0.6	-0.1
Boom	8.6	11.4	7.5	7.1	10.2	7.3	-1.5	-1.2	-0.2
Temse	5.5	8.5	6.5	4.9	8.1	6.5	-0.6	-0.4	0
Tielrode	0.9	7	6.9	0.6	7	6.9	-0.3	0	0
Walem	8.2	10.7	6.9	6.7	9.5	6.7	-1.5	-1.2	-0.2
StAmands	5.7	9.1	7.1	5.3	8.8	7	-0.4	-0.3	-0.1
Dendermonde	-4.7	9.1	7.8	-5.7	9.7	7.8	-1	0.6	0
Schoonaarde	1.8	8.3	8.1	0.4	8.1	8.1	-1.4	-0.2	0
Wetteren	-1.3	11.6	11.5	-1	11.7	11.6	0.3	0.1	0.1
Melle	-5	17.8	17.1	-3.8	17.3	16.9	1.2	-0.5	-0.2
MechelenSluis	-3.3	8.9	8.3	-4.6	9.6	8.4	-1.3	0.7	0.1
Hombeek	6.8	10.7	8.2	5.3	9.8	8.3	-1.5	-0.9	0.1
Zemst	14	21.5	16.4	11.7	20.9	17.3	-2.3	-0.6	0.9
Duffel	-6	8.9	6.5	-7.6	10	6.5	-1.6	1.1	0
Rijmenam	-12.7	19.3	14.5	-14.2	20.5	14.7	-1.5	1.2	0.2
Lier Molbrug	-16.3	19	9.7	-17.5	20.1	9.8	-1.2	1.1	0.1
Lier Maasfort	-8.8	11.8	7.9	-10	12.7	7.8	-1.2	0.9	-0.1
Emblem	-3	8.8	8.3	-4.2	8.8	7.7	-1.2	0	-0.6
Kessel	-7.4	12.3	9.8	-7.8	12.7	10	-0.4	0.4	0.2

Table 7 – Comparison of Bias, RMSE and RMSE0 of **low water levels**.
The 12 stations marked in green **(Westhinider to Bath)** represent the areas where the bottom roughness are already calibrated with OpenDA by Deltares for the Western Scheldt. The 23 stations marked in brown **(Zandvliet to Kessel)** represent the areas where the bottom roughness is calibrated with OpenDA in this study (Sea Scheldt and tributaries).

Stations	Low Water Level								
	Run003			Run004			Run004 - Run003		
	BIAS	RMSE	RMSE_0	BIAS	RMSE	RMSE_0	BIAS	RMSE	RMSE_0
Westhinder	2.1	3	2.2	2.1	3	2.2	0	0	0
Vlakte van de	1.7	2.9	2.4	1.7	2.9	2.4	0	0	0
Westkapelle	3.8	4.5	2.3	3.8	4.5	2.3	0	0	0
Cadzand	5.8	6.4	2.7	5.8	6.4	2.7	0	0	0
Vlissingen	0.7	3.3	3.2	0.7	3.3	3.2	0	0	0
Breskens	0.9	3.4	3.3	0.9	3.4	3.3	0	0	0
Borssele	1.6	4.1	3.8	1.6	4.1	3.8	0	0	0
Terneuzen	2.1	4.6	4	2.1	4.5	4	0	-0.1	0
Hansweert	0.5	4.8	4.8	0.5	4.8	4.8	0	0	0
Walsoorden	0.3	5.3	5.3	0.3	5.3	5.3	0	0	0
Baalhoek	0.3	5.2	5.2	0.3	5.2	5.2	0	0	0
Bath	0.1	5.8	5.8	0	5.8	5.8	-0.1	0	0
Zandvliet	-3.1	7.2	6.5	-3	7.1	6.5	0.1	-0.1	0
Liefkenshoek	1.3	6.1	6	1.4	6.1	6	0.1	0	0
Kallo	3.1	6.8	6	3	6.8	6.1	-0.1	0	0.1
Antwerpen	2.8	6.7	6.1	2.6	6.7	6.2	-0.2	0	0.1
Hemiksem	-8.8	11	6.6	-7.5	9.9	6.4	1.3	-1.1	-0.2
Boom	-10.4	12.1	6.2	-8.6	10.5	6	1.8	-1.6	-0.2
Temse	-3.1	11.3	10.8	-3.1	11.3	10.8	0	0	0
Tielrode	0.8	14.3	14.3	0.5	14.5	14.5	-0.3	0.2	0.2
Walem	-7.9	10.4	6.8	-6.1	9	6.6	1.8	-1.4	-0.2
StAmands	-28.3	29.6	8.7	-28.8	30.1	8.8	-0.5	0.5	0.1
Dendermonde	21.6	23.5	9.2	22.3	24.1	9.2	0.7	0.6	0
Schoonaarde	-18.5	22.5	12.8	-17.9	22	12.7	0.6	-0.5	-0.1
Wetteren	-4.5	18.7	18.1	-7.8	20.1	18.5	-3.3	1.4	0.4
Melle	1.9	23.4	23.3	-3.2	23.5	23.2	-5.1	0.1	-0.1
MechelenSluis	14.8	22.4	16.8	16.1	23.3	16.8	1.3	0.9	0
Hombeek	10.1	23.5	21.2	10.5	23.1	20.6	0.4	-0.4	-0.6
Zemst	-7	28.8	27.9	-6.4	28.6	27.9	0.6	-0.2	0
Duffel	-10.4	13.2	8.1	-8.7	11.9	8.1	1.7	-1.3	0
Rijmenam	1	25.8	25.8	1.1	25.6	25.6	0.1	-0.2	-0.2
Lier Molbrug	-26.2	33.3	20.6	-25.8	33	20.5	0.4	-0.3	-0.1
Lier Maasfort	-29.6	37.9	23.7	-29.5	37.6	23.3	0.1	-0.3	-0.4
Emblem	-35.7	38	12.9	-35.1	37.4	12.9	0.6	-0.6	0
Kessel	-20.3	25.3	15.1	-19.8	24.8	14.9	0.5	-0.5	-0.2

Figure 4 – Bias of complete time series of water levels along the Scheldt.

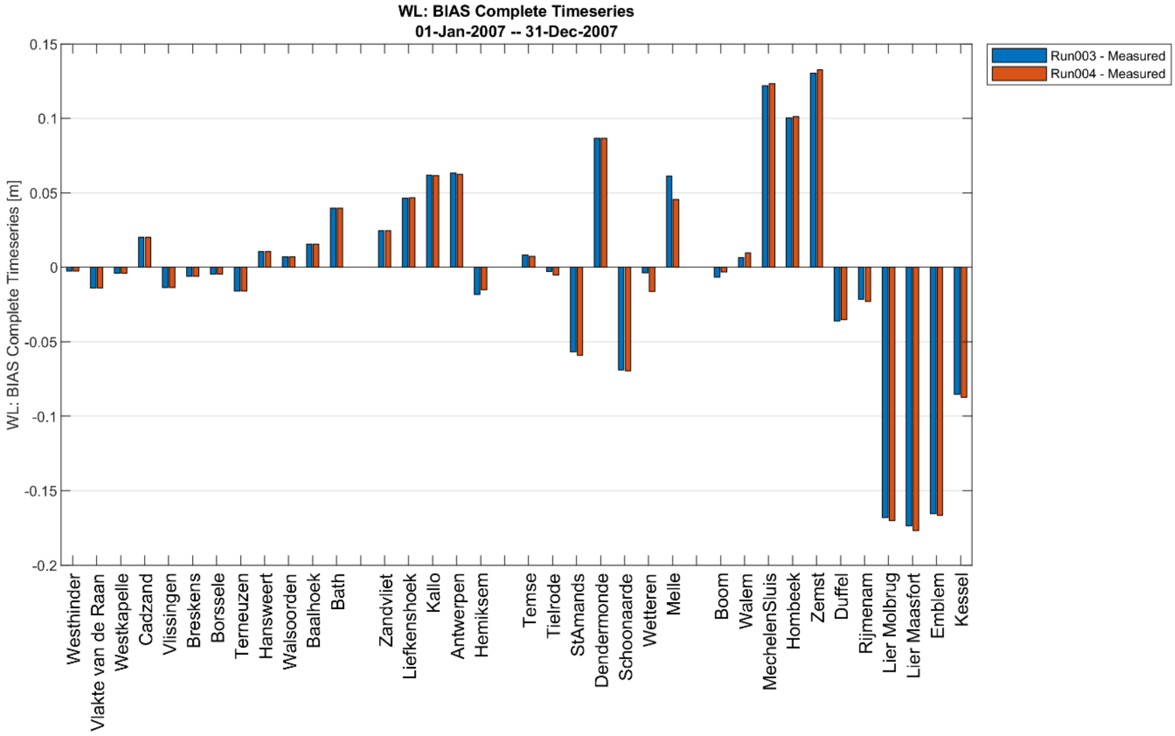


Figure 5 – RMSE of complete time series of water levels along the Scheldt.

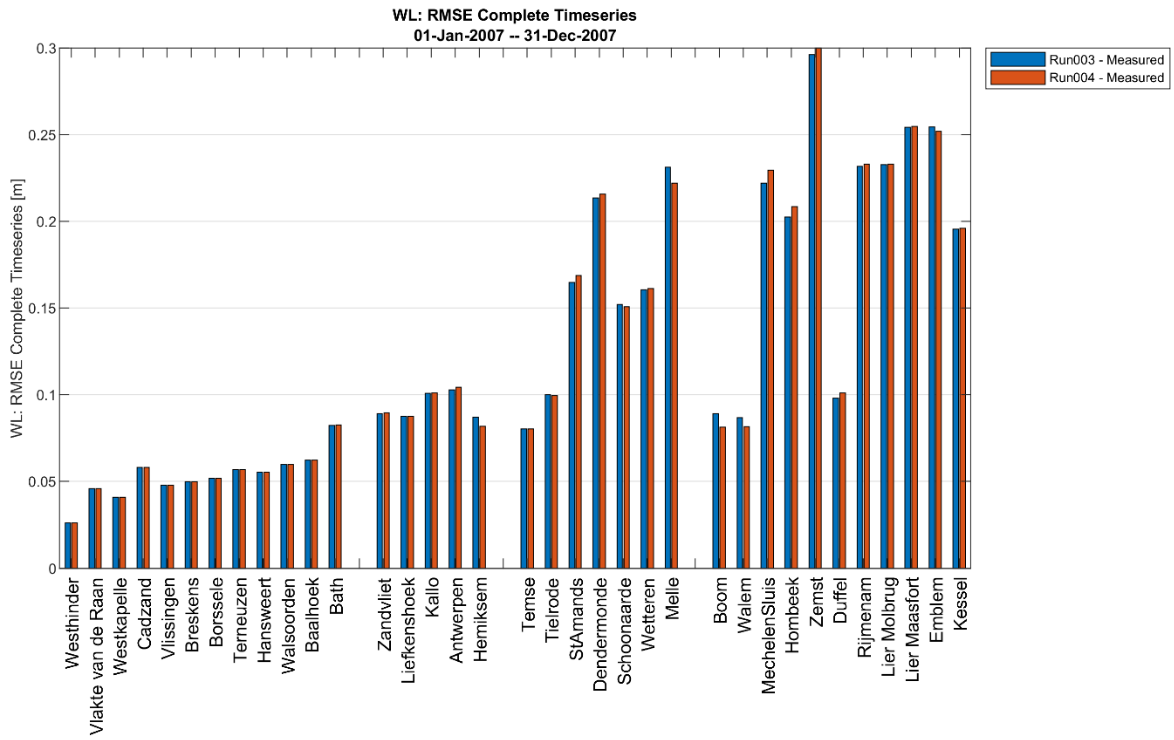


Figure 6 – RMSE0 of complete time series of water levels along the Scheldt.

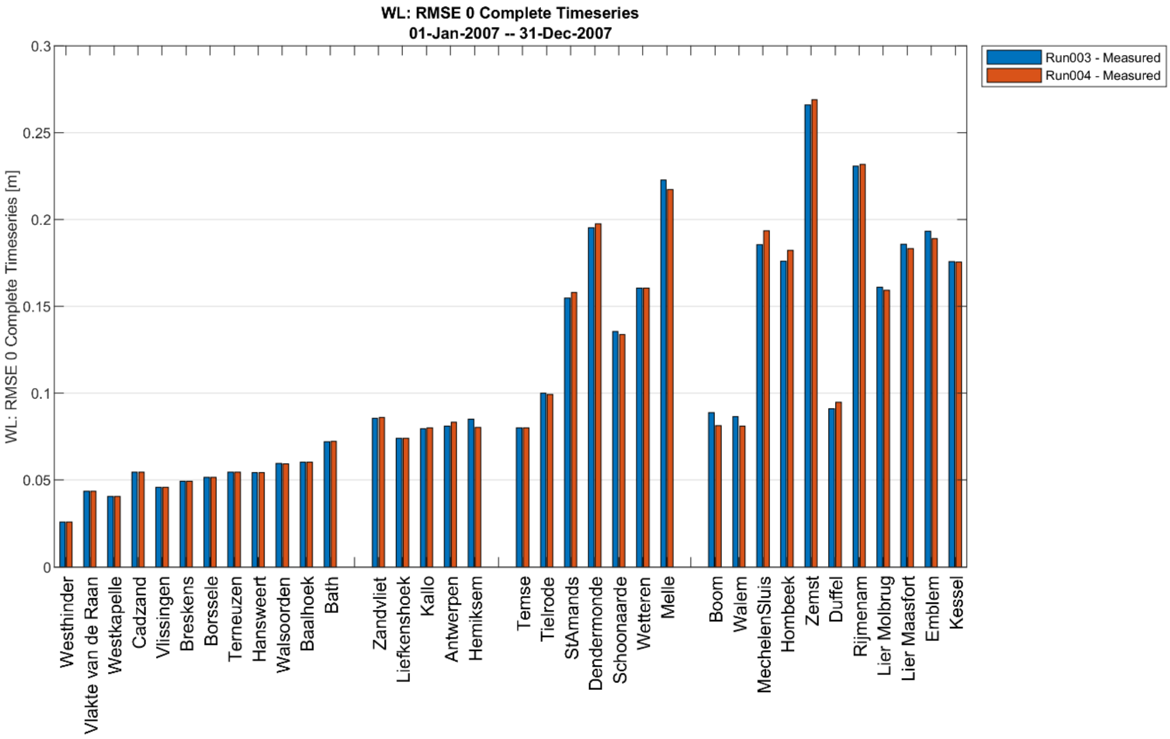


Figure 7 – Bias of high water levels along the Scheldt.

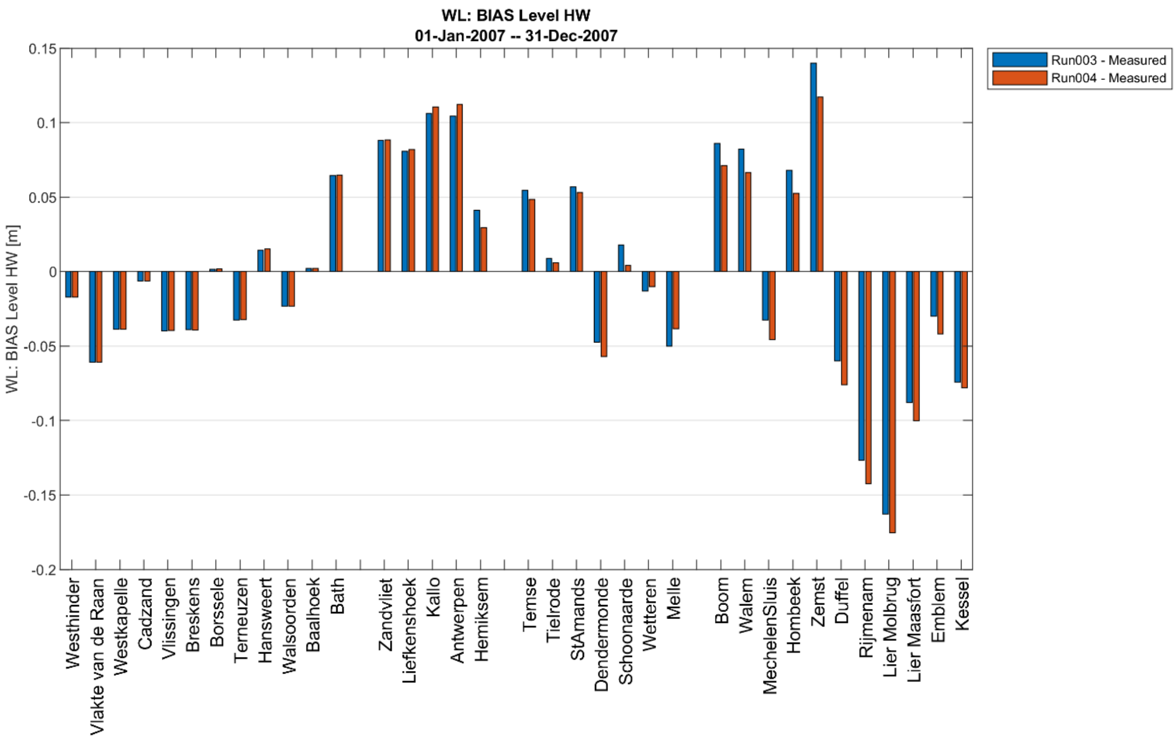


Figure 8 – RMSE of high water levels along the Scheldt.

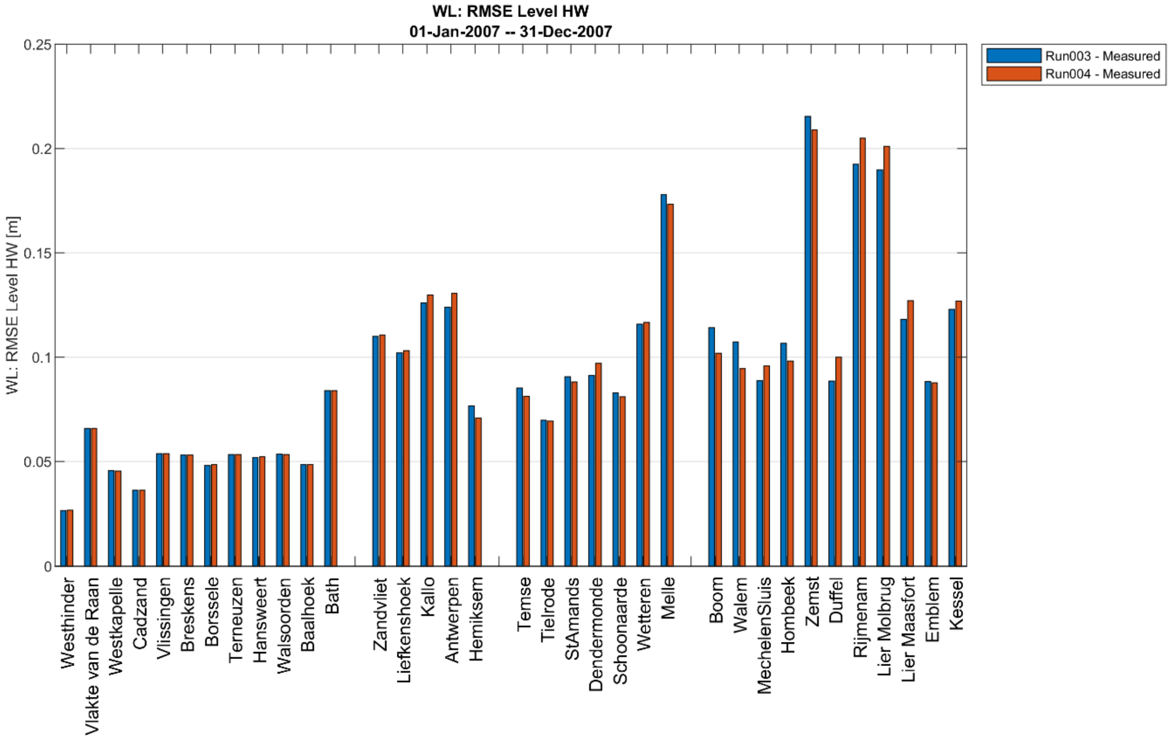


Figure 9 – RMSE0 of high water levels along the Scheldt.

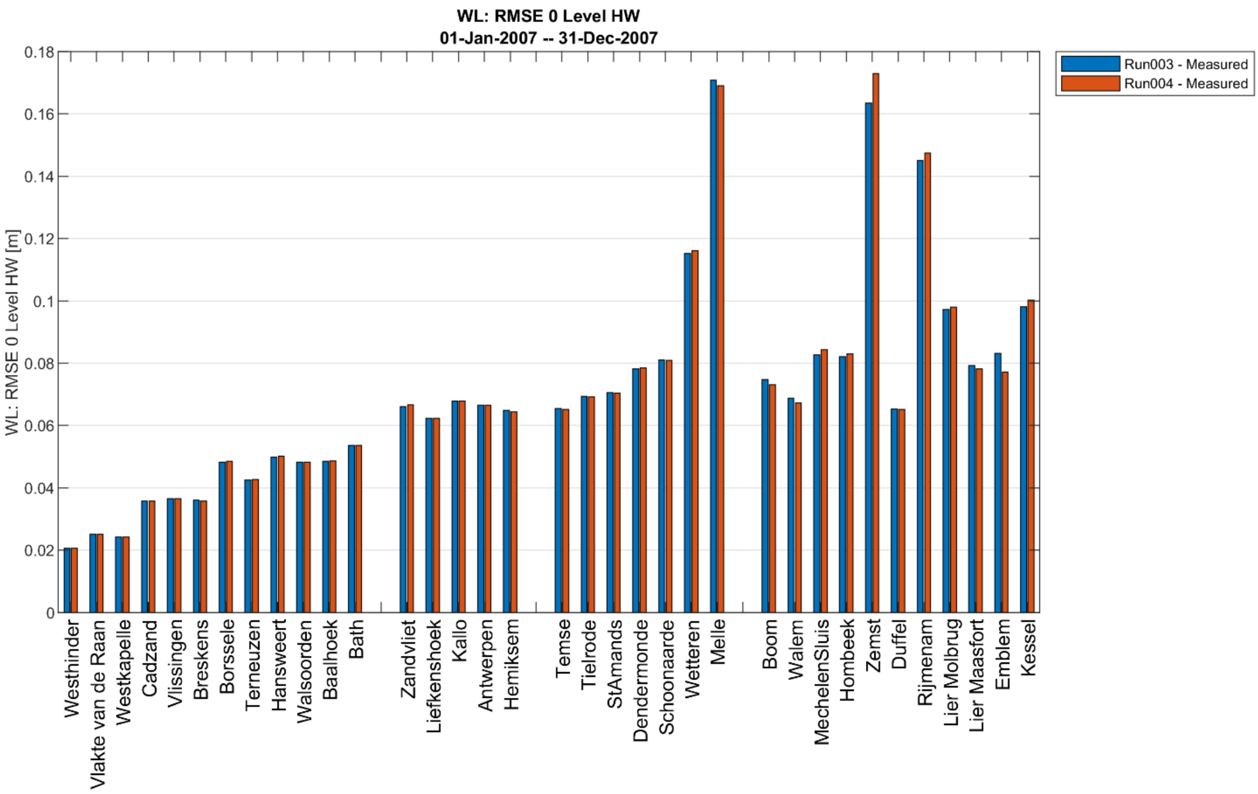


Figure 10 – Bias of low water levels along the Scheldt.

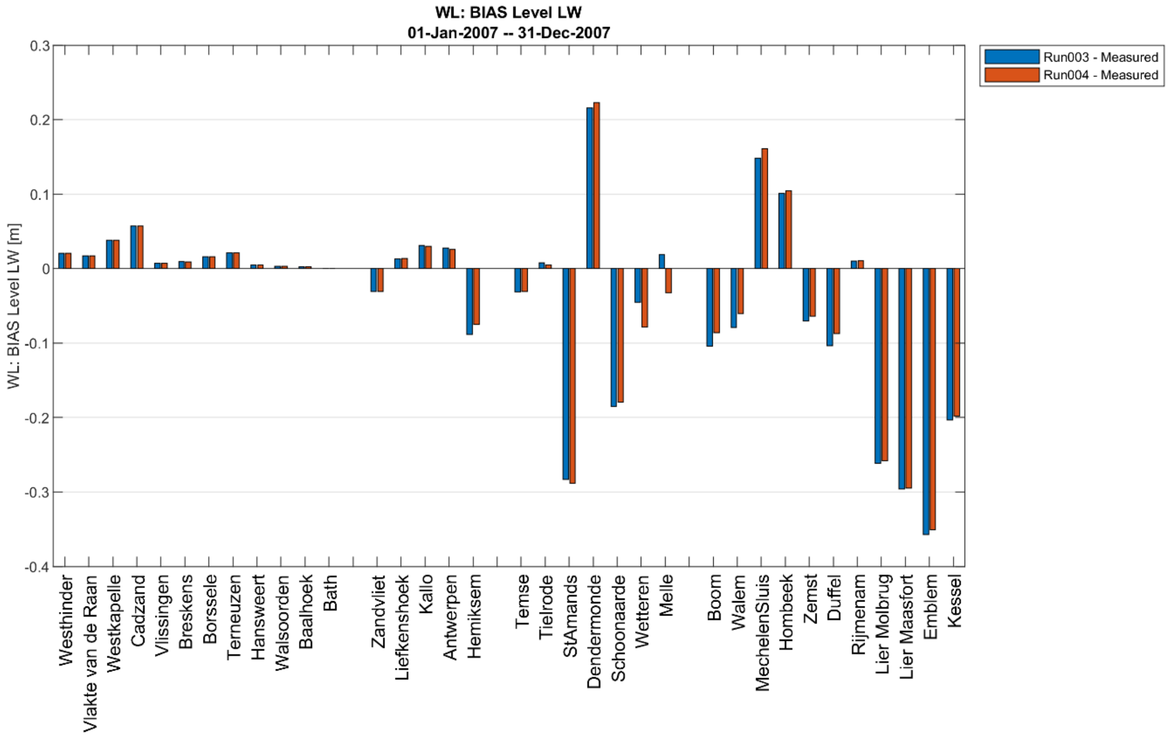


Figure 11 – RMSE of low water levels along the Scheldt.

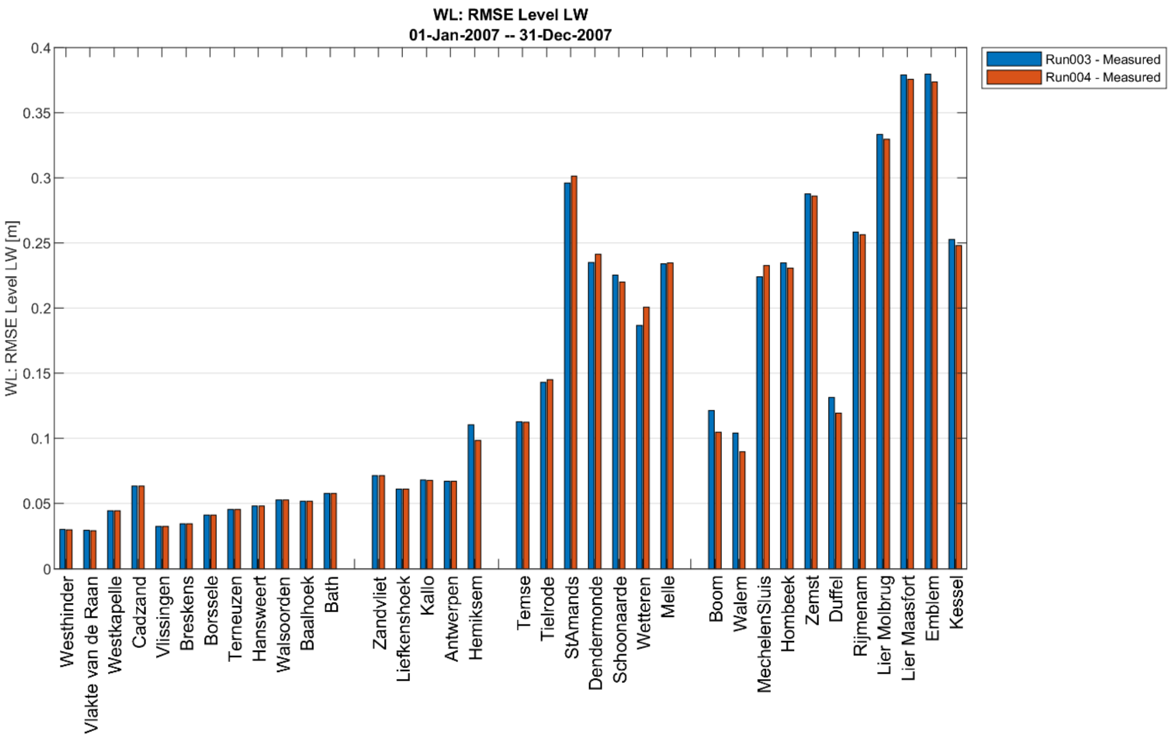
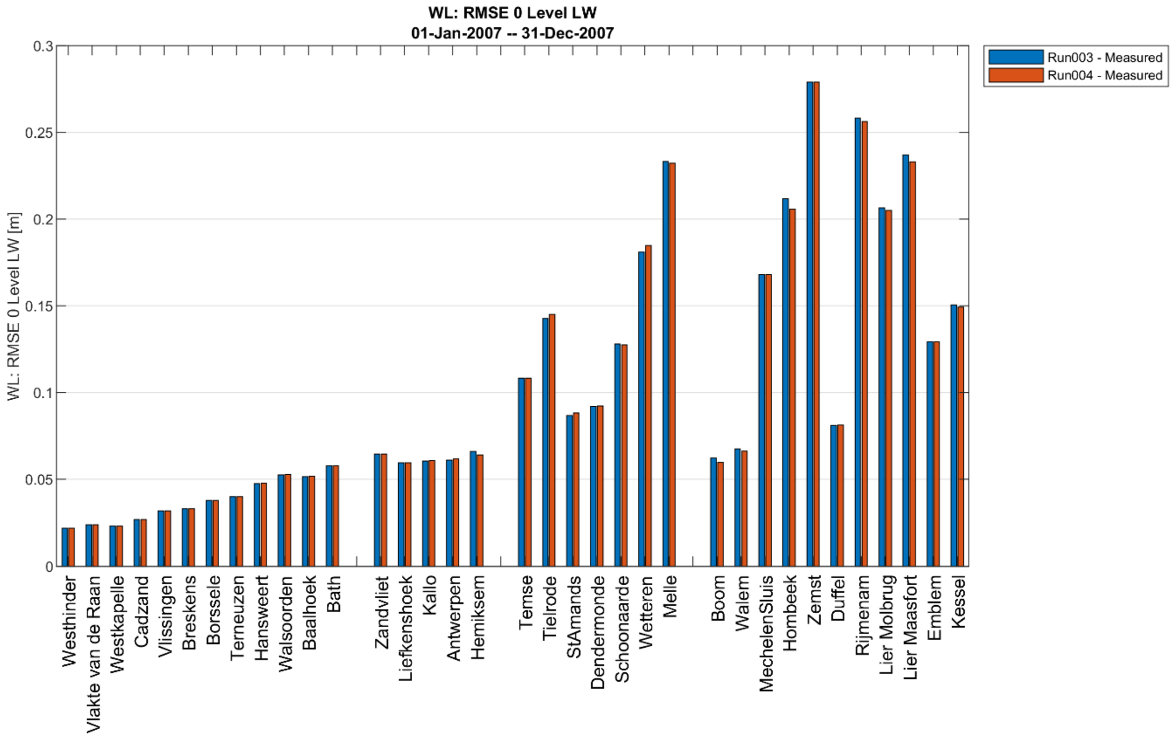


Figure 12 – RMSE0 of low water levels along the Scheldt.



3.2 Harmonic Analysis of Water Levels

Figure 13 to Figure 16 compare the model predicted tidal components of M2 and S2 along the River Scheldt (results for the river tributaries are summarized in Table 8). Run004 slightly improved the predictions on M2 and S2 (by 1-2 cm) from **Hemiksem** to **Walem**. Figure 17 shows that the vector difference (see definition in ANNEX 4) from Run004 is also dropped by 2-3 cm from at stations between **Hemiksem** to **Walem**.

The harmonic water levels at **Rupel** are slightly worse predicted (by 1-2 cm) from Run 004, which is logical as the weights assigned to Rupel are 16 times smaller.

Figure 13 – M2 amplitude along the River Scheldt.

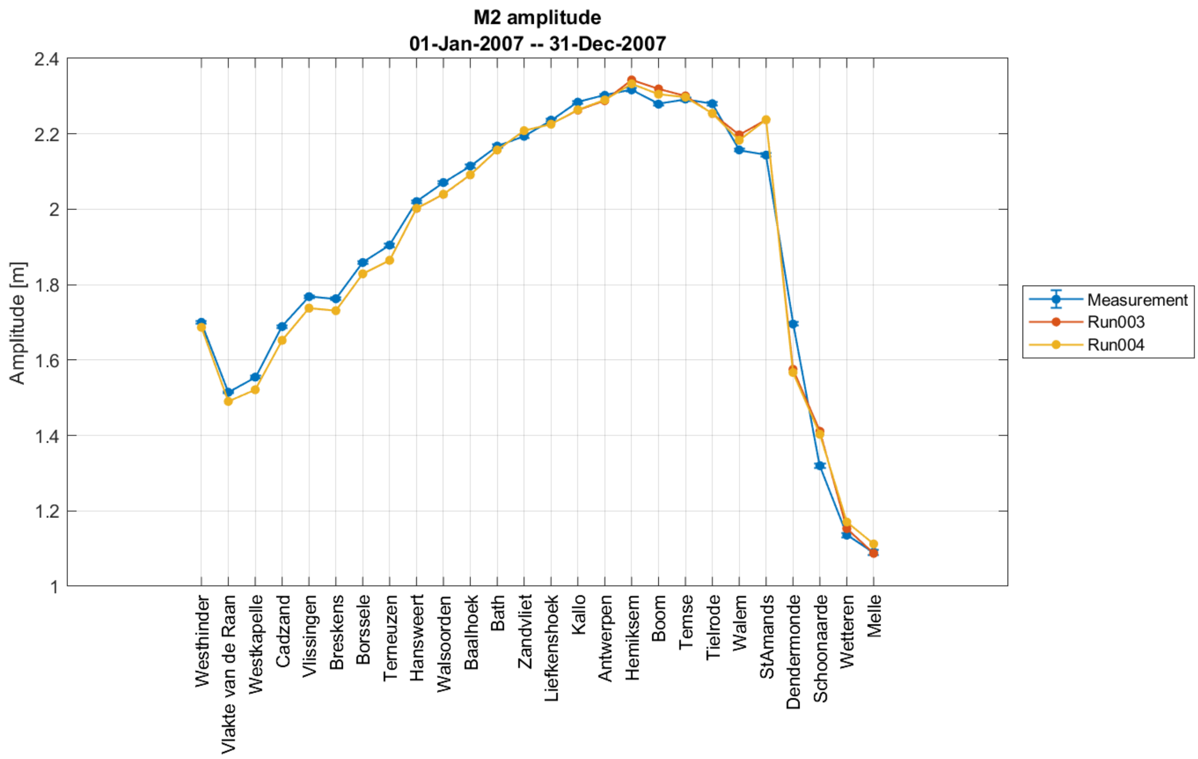


Figure 14 – M2 phase along the River Scheldt.

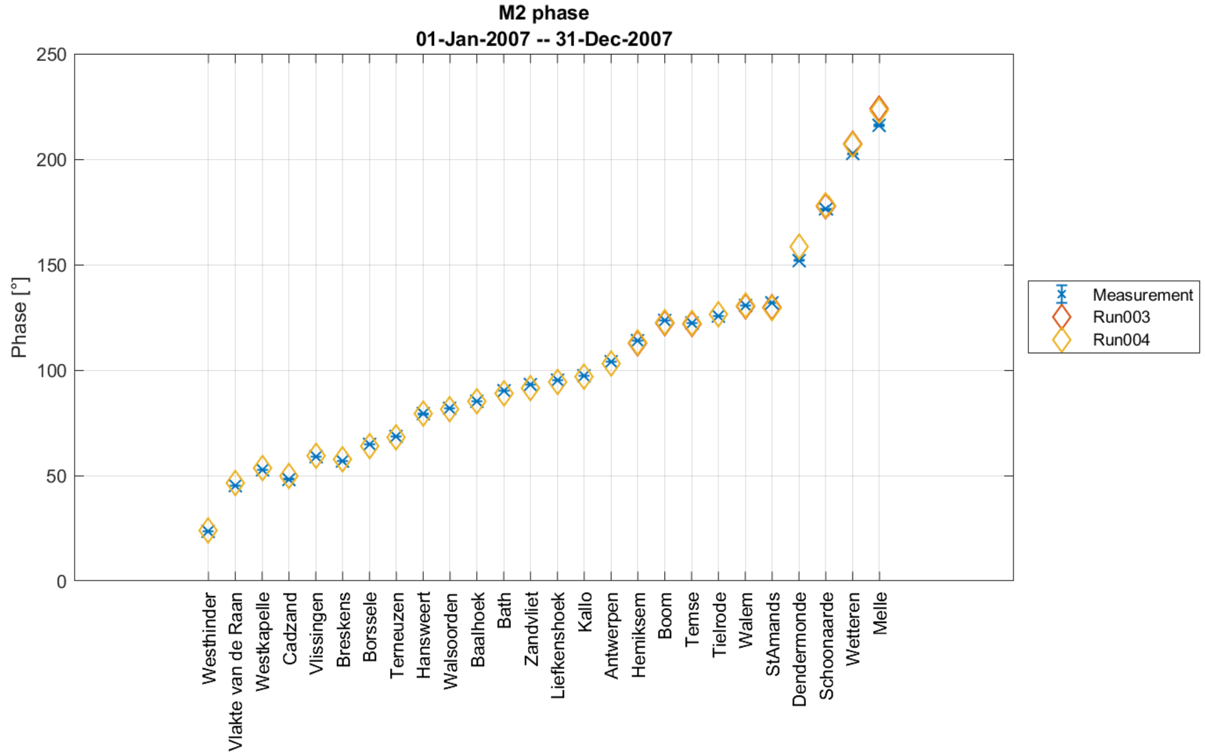


Figure 15 - S2 amplitude along the River Scheldt.

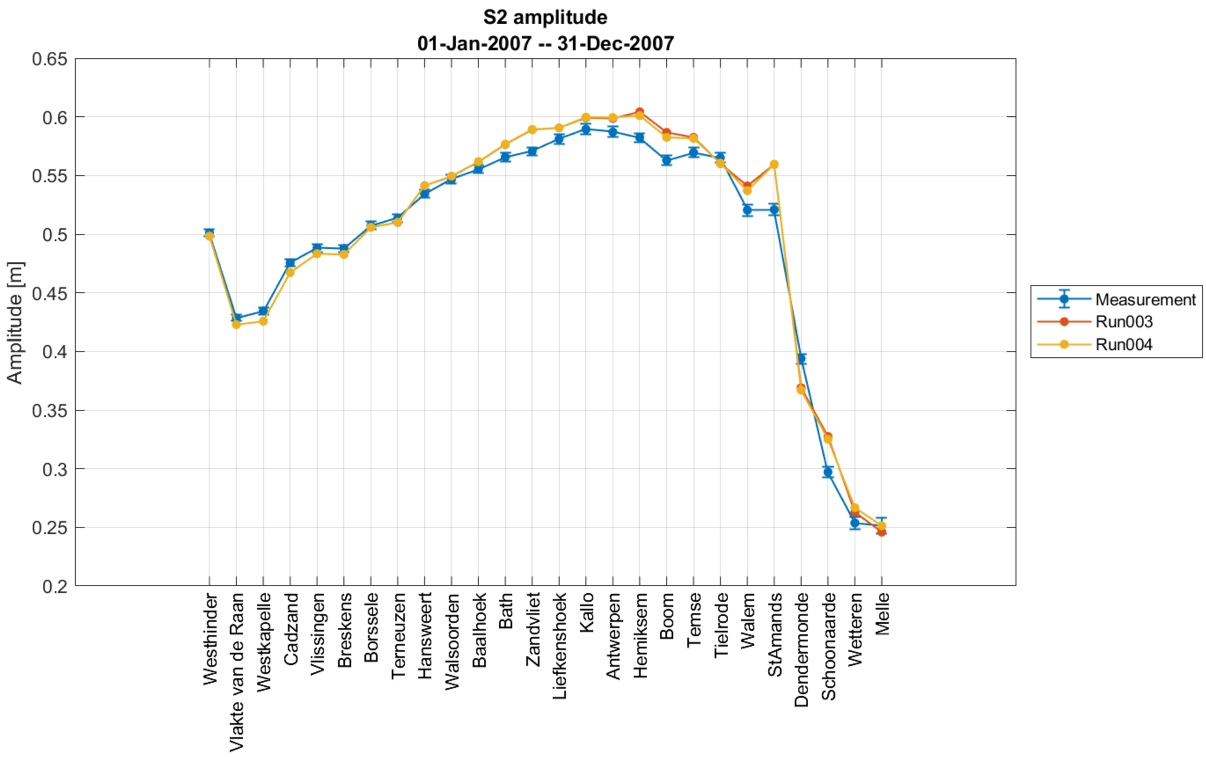


Figure 16 – S2 phase along the River Scheldt.

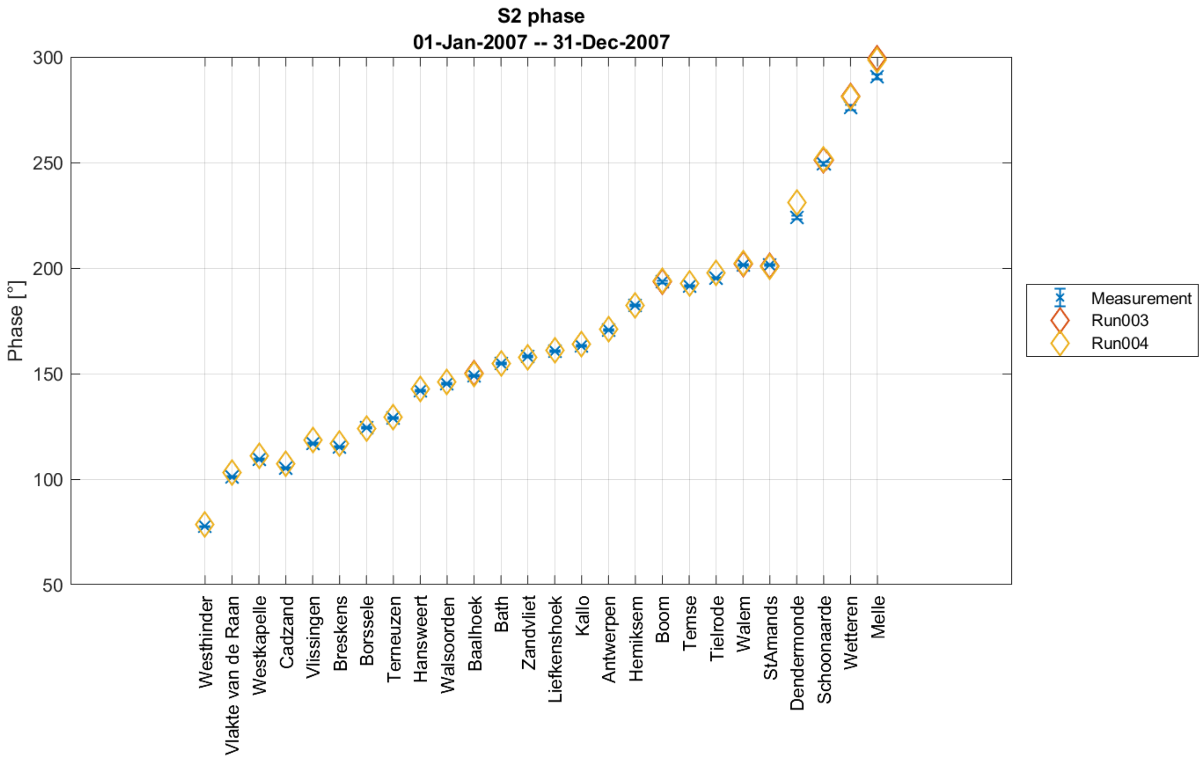


Figure 17 – Vector differences along the River Scheldt.

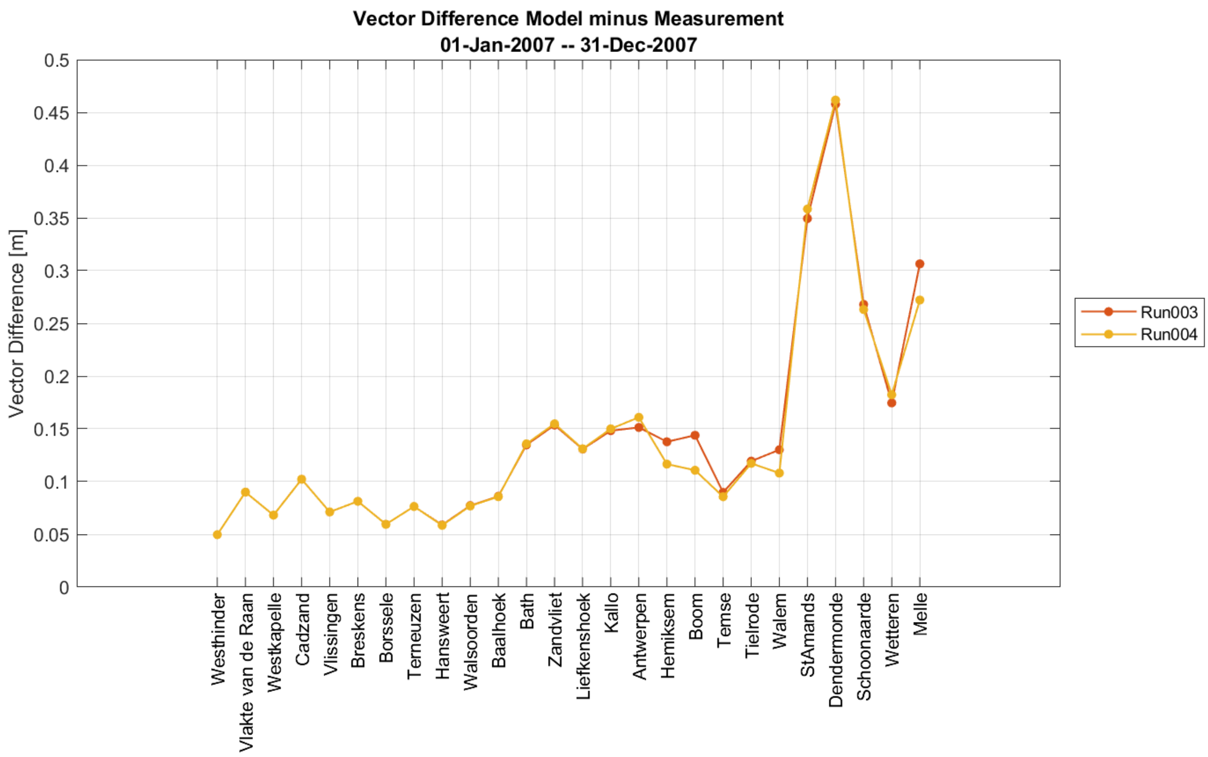


Table 8 – Harmonic components of M2, S2 and vector differences for the tributaries of Scheldt.

Stations	M2 Amplitude			M2 Phase			S2 Amplitude			S2 Phase			Vector Difference	
	Obs	Run003	Run004	Obs	Run003	Run004	Obs	Run003	Run004	Obs	Run003	Run004	Run003	Run004
MechelenSluis	1.83	1.78	1.76	139.8	144.0	144.4	0.43	0.43	0.43	210.7	218.7	219.2	0.45	0.47
Hombeek	1.50	1.45	1.44	145.8	149.3	149.8	0.38	0.37	0.37	216.3	220.9	221.4	0.29	0.31
Zemst	0.99	0.98	0.97	148.1	152.7	153.1	0.28	0.28	0.27	215.2	221.2	221.6	0.32	0.34
Duffel	1.77	1.77	1.76	148.3	149.2	149.7	0.41	0.41	0.41	219.9	222.4	223.0	0.15	0.17
Rijmenam	0.24	0.20	0.20	176.3	192.1	192.4	0.09	0.08	0.08	237.8	250.5	250.7	0.24	0.25
Lier Molbrug	1.12	1.22	1.21	164.2	164.8	165.4	0.26	0.30	0.30	234.9	239.1	239.7	0.41	0.41
Lier Maasfort	0.84	0.97	0.96	179.0	179.0	179.6	0.20	0.24	0.24	247.9	253.4	254.0	0.42	0.42
Emblem	0.66	0.85	0.84	191.3	191.9	192.5	0.16	0.21	0.21	258.9	266.1	266.6	0.45	0.44
Kessel	0.55	0.65	0.64	202.8	211.3	211.8	0.14	0.16	0.16	272.1	284.9	285.4	0.31	0.31

3.3 Salinity

The statistical analysis results of salinity are presented in Table 9 (figures are not shown for purpose of concision). The re-calibration has no significant influence on the model skill in representing salinity.

Table 9 – Statistical analysis of salinity between model and measurements

Nr	Measuring station	Bias [psu]		RMSE [psu]	
		Run003	Run004	Run003	Run004
1	Vlakte Van De Raan	0.7	0.7	1.4	1.4
2	Hoofdplaat	1.8	1.8	2.1	2.1
3	Baalhoek	0.6	0.6	1.5	1.5
4	Prosperpolder	0.4	0.4	1.0	1.0
5	Boei84	-0.1	-0.1	0.7	0.7
6	Oosterweel	-0.1	-0.1	0.5	0.5

3.4 Discharge

Figure 18 to Figure 20 show the error statistics of Bias, RMSE and RRMSE of the complete time series of discharges at all the locations between Run003 and Run004. The re-calibration has no significant influence on the model skill in representing discharge.

Figure 18 – Bias of complete time series of discharges (model - measurement).

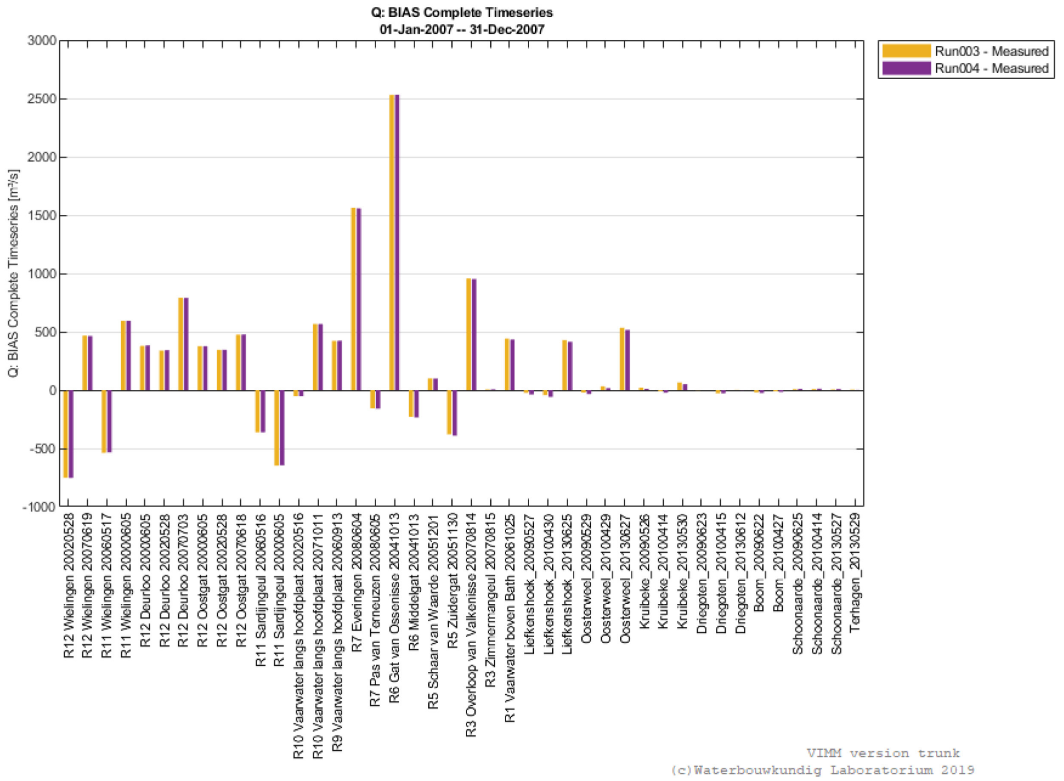


Figure 19 – RMSE of complete time series of discharges.

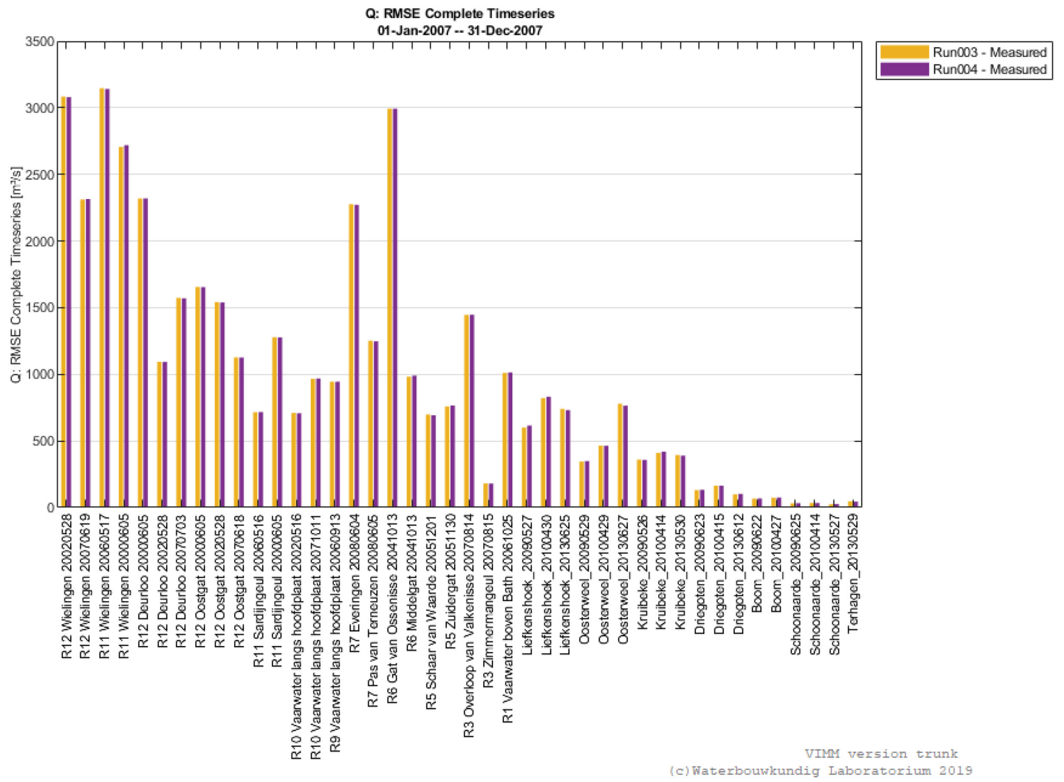
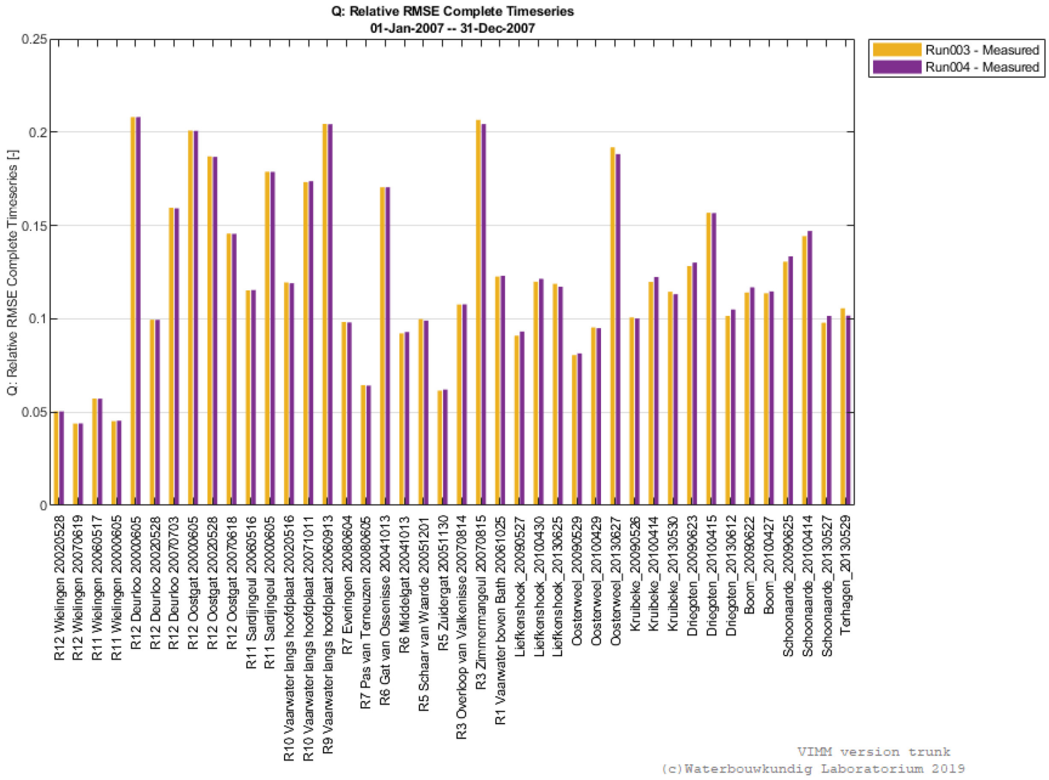


Figure 20 – Relative RMSE of complete time series of discharges.



4 Conclusions

In Chu et al. (2019), the Rupel Basin with tributaries Zenne, Dijle and Nete are all within one roughness polygon. In this study, the weights in the cost function for the water level stations in the Rupel basin are lowered with a factor 16. The model is re-calibrated on bottom roughness with OpenDA for the entire year of 2007.

The main findings are:

- The re-calibration with OpenDA automatically stopped after 19 iterations, with the cost function reduced by 32%.
- The re-calibrated bottom roughness map doesn't differ much from the previous calibration.
- The water level predictions at Rupel is slightly worse, which is expected as the weights assigned to stations in the Rupel basin is made 16 times smaller.
- The water level prediction between **Hemiksem** to **Walem** is slightly improved by 1-2 cm.
- The re-calibrated model does not show further improvement on salinity and cross-sectional discharges.

5 References

Chu, K.; Vanlede, J.; Decrop, B.; Mostaert, F. (2019). Baseline Zuidwestelijke Delta: Set-up and Calibration of model waqua-schelde_nevla-j07_5. Version 2.0. FHR Reports, 13_041_1. Flanders Hydraulics Research: Antwerp.

Appendix A 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 B 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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