Morphological acceleration factor: usability, accuracy and run time reductions

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***Abstract*—Within SISYPHE 6.2, the option is created by BAW to use a morphological acceleration factor (MF) within the coupled TELEMAC2D-SISYPHE model. Multiplying both the evolution and the time by the same factor the model jumps forward in time, reducing the required computation time. This paper presents the usability of this approach, the gains in computation time and the loss of accuracy of this approach. Three different cases were used: a laboratory case of a trench in a constant flow, a river flood case and an estuarine test case. For the river flood case, a single event with varying water discharges, the approach is unsuitable. Using the MF implies that the water levels change too rapidly, altering the hydrodynamics. The same would be the case for tidal flow, but the morphological acceleration factor can still be used due to the repeating nature of the tide [1]. The downside is that strictly the results using a factor N are only valid after exactly N tides. For steady cases the approach can be used flexibly without limitations. Comparisons with the measured data the trench case show that the MF can be used with only limited loss of accuracy. The simulation time reduces rapidly, while the model skills only reduce marginally, up to the MF is 90. The simulation time initially reduces rapidly. For the larger model of an estuary, the gain using a MF of 20 reduced the run time by a factor 20. In this case however, the model does show some significant changes in the prediction.**

I. Introduction

Predicting long term morphology with a physical based model is still uncertain and a time consuming process. Several methods are available for reducing the computation time. These often used techniques are for example: Online method approach with morphological factor, Tide averaging approach, RAM, Continuity correction and parallel online approach. More information on each of these methods can be found in [2].

In version 6.2 of the TELEMAC suite, the morphological factor is available for us in SISYPHE. The morphological factor simply increases the depth change rates with a constant factor N. The new bed level represents a simulation period of N hydrodynamic time steps. For example, using 1 semi-diurnal tide (~12hours) and a morphological factor of 10 will result in an actual simulated time period of 120 hours.

In theory, assuming that the morphodynamic changes are small compared to the hydrodynamic changes, this approach reduces the computational effort without significant loss of model quality. In this paper, we describe efforts to quantify the effect of this morphological factor on the model performance, both in quality and speed.

II. Approach

The computational time on a dual core, single processor machine (details) without additional activity is used as a measure for speed.

To testing the reliability of the model runs with morphological factor objectively, the bias (mean error), and the Brier skill score [3] are calculated. The Brier skill score (BSS) compares the modelled morphological change $X_m(i)$-$X_0(i)$ to the observed changes ($X_1(i)$-$X_0(i)$):

$$BSS = 1 - \sum_i \frac{X_m(i) - X_0(i)}{X_1(i) - X_0(i)} \qquad (1)$$

This score was deemed the most suitable tool to assess the quality of morphological predictions [3], as it ignores model predictions in areas of little change ($X_m(i)=X_0(i)$). Downside is that it heavily penalizes small predicted changes where the measurement finds no change ($X_1(i)=X_0(i)$). The Brier skill score also allows to compare the model predictions with the no change prediction, which has a Brier skill score of 0.

TABLE I. BSS classification following [3]

	BSS
Excellent	1.0-0.5
Good	0.5-0.2
Reasonable/faiar	0.2-0.1
Poor	0.1-0.0
Bad	< 0.0

Two test cases were chosen to test the approach to speed up morphological computations using a morphological factor: A stationary current case and a tidal current case.

III. TEST CASES

A. Stationary current

The first test case is based on the morphodynamic model of a trench flume experiment. The experiments were performed at Delft Hydraulics in a small flume with a length of 17 m, a width of 0.3 m and a depth of 0.5 m (Fig. 1). Sediment was used with D_{50} = 0.1 mm and D_{90} = 0.13 mm. Sand was supplied at constant rate at upstream section of flume to maintain equilibrium conditions. The channel had side slopes of 1 to 10 and a depth of 0.125 m.

Regular waves with a period of 1.5 s and height of 0.08 m were generated and a steady current following the waves was imposed. The water depth was 0.255 m and the current velocity was 0.18 m/s. The mobile bed consisted of well sorted sediment with 0.1 mm median diameter (D_{90} = 0.13 mm) and density 2650 kg/m^3. The mean fall velocity of the suspended sediment was 0.07 m/s.

To maintain equilibrium bed conditions away from the channel, 0.0167 kg/s/m sediment was fed into the flume at the inflow boundary.

The numerical model applied to simulate the dynamics in the flume experiment uses coupled TELEMAC-SISYPHE. It uses the SANDFLOW approach added to SISYPHE, using the lag function described in [4]. The model calculates the suspended sediment concentrations from the suspended transport predictor in the formula of Soulsby-van Rijn [7], while the bedload transport is calculated directly using the Soulsby-van Rijn formula (see [4] for more detailed information).

As Soulsby-van Rijn gives no sediment transport at all at these scales, the experiment is scaled up to field dimensions, multiplying the domain lengths by 10 and the time by √10. It was shown [4] that not scaling the sediment, assuming the morphology is bed-load dominated, gave the best model performance. After the simulation, the time and spatial dimensions are rescaled back to the scales of the flume experiment.

All other settings were the default SISYPHE settings. The calculation time without speed-up was 15 minutes and 7 seconds.

This model reproduces the flume experiments at Delft Hydraulics quite well (see Fig. 2 or refer to [5] for a more thorough analysis).

The model was run with a large range of range of morphological factors, and the results were compared with the measured bathymetry using the bias, root mean square error and the Brier skill score.

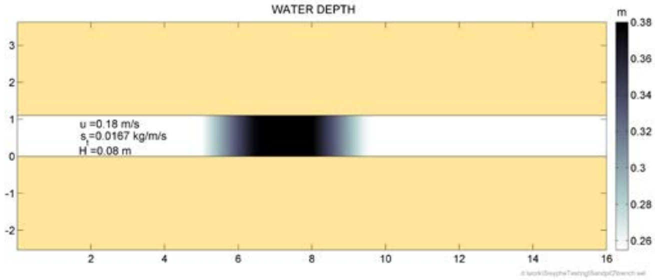

Figure 1. Layout, initial bathymetry (gray scales) and hydrodynamic conditions used in the flume experiments.

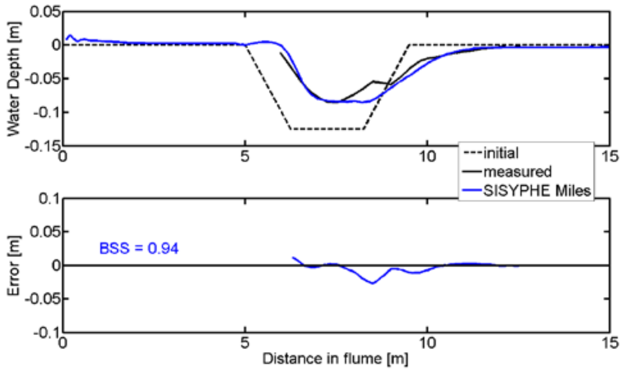

Figure 2. Comparison between the numerical model (blue) and the flume experiment (black) from the initial batymetry shown by the dashed line.

B. Tidal current

The second test case used was a model of the Dee Estuary in the northwest of England. The initial bathymetry is derived from LiDAR and swathe surveys (Fig. 3). All survey data are converted from Chart datum to ordinance datum.

The calculation is grid is a triangulated irregular mesh that covers the full estuary which is flooded during a spring neap tidal cycle. The maximum area of an element is 276595 m^2 the minimum element area is 22.9 m^2. The number of nodes and elements is respectively 21054 and 41386.

It is assumed that the main changes within the estuary are cause by tidal flow. The full spring neap tidal cycle at the estuary mouth is extracted from a calibrated hydrodynamic model of Liverpool bay (Fig. 4). The river discharge is neglected, because it has only minor contribution to the tidal prism over a tidal cycle (+/- 0.35%) [7].

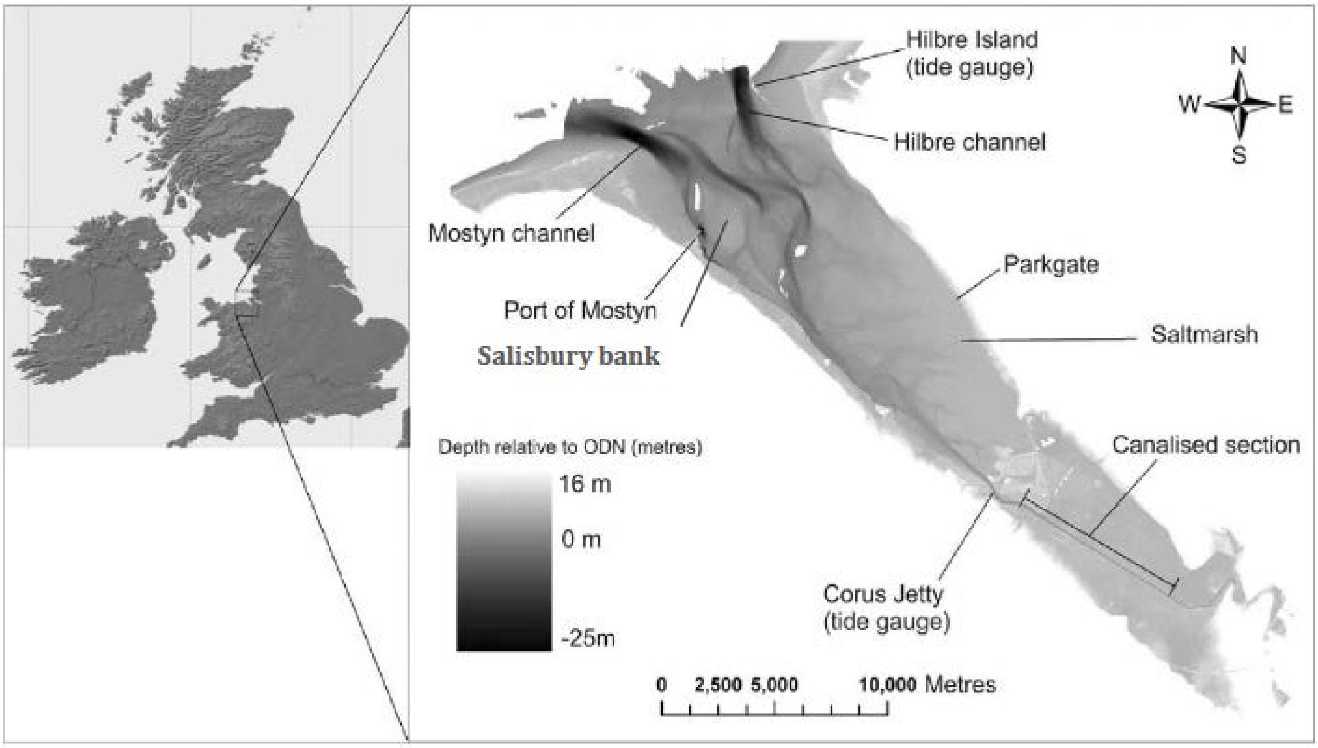

Figure 3. The Dee Estuary in the northwest of England.

Two grain size fractions (50-50%) of 0.09 mm and 0.2 mm, with each a respectively D_{90} of 1.0mm and 0.35 mm. Initially, grain sizes are constant through the domain of the estuary. Furthermore the sediment character is assumed as non-cohesive.

The other model settings were similar to those of the trench model, using the lag function described in [4]. The model calculates the suspended sediment concentrations from the suspended transport predictor in the formula of Soulsby-van Rijn [7], while the bedload transport is calculated directly using the Soulsby-van Rijn formula (see [4] for more detailed information).

Other model settings were kept at default values, slope effects are included, but no secondary current effects are used. As this model is still in development and not fully calibrated for morphodynamic predictions, the model compares poorly to the measured data (Fig. 5). The Brier skill score for example is negative, classifying the model as bad [3].

For this reason, the impact of the morphological factor is determined purely from the change between the model results with and without morphological speed-up.

IV. Results

A. *Stationary current*

Fig. 6 shows that the largest rate of change of calculation time reduction occurs between the MF1 and approximately MF5. After approximately MF20 there is hardly any speed-up achieved. The reduction goes from 6% (MF20) to 2% at maximum MF of 130. This is caused by the time required to write the results to disc, which is already dominant with these morphological factors.

The Brier skill score reduces only marginally, from 0.93 with morphological factor 1 to 0.90 with morphological factor 130. With higher morphological factors the model became unstable. All results would classify as excellent according [3].

TABLE II. Computation time for the range of morphological factors used to model the Dee Estuary. It shows a linear speed-up with increasing morphological factors

MF	Comp. Time (days)	Relative time
1	101.8	100%
5	20.1	20%
10	7.0	7%
20	3.7	4%

If we look at the bias (Fig. 7), however, the errors clearly increase with increasing morphological factor. The use of the morphological factor leads to an increased infill of the trench. The most relevant one, the median bias, increases with a factor 5 when using a morphological factor of 120.

The median bias is unchanged up to a morphological factor of 30, but then increases from about 1mm (less than

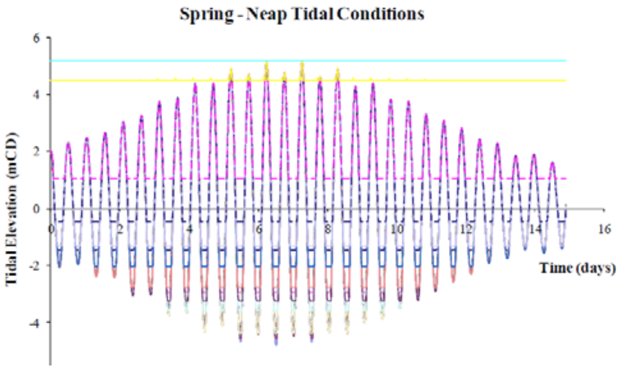

Figure 4. Tidal conditions at the boundary.

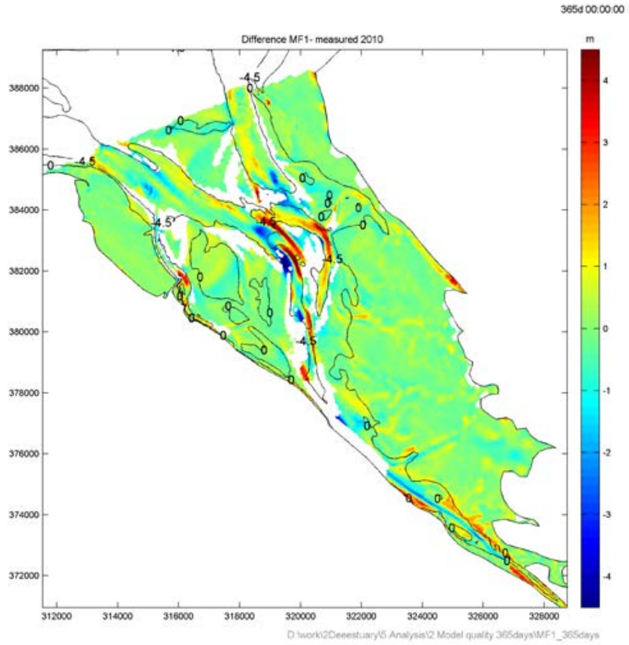

Figure 5. Differences between measured and model bathymetry after 1 year. The model tends to deepen and straighten the channels.

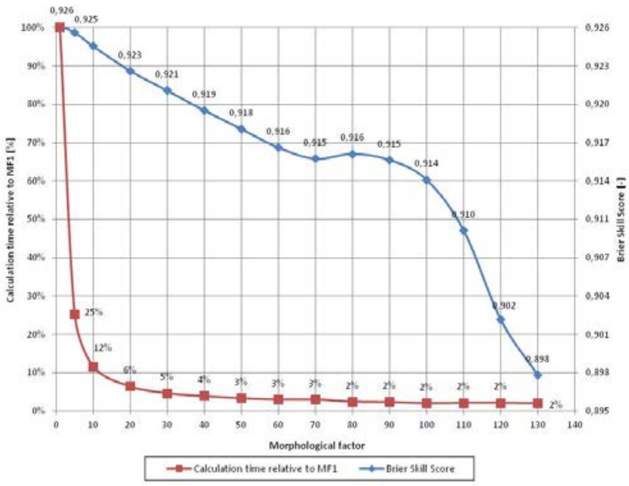

Figure 6. Results from the trench test case: Brier skill score (blue, right axis) and calculation time as percentage of the calculation time without speed-up (red, left axis) plotted against the morphological factor.

1% of the undisturbed water depth, or 2% of the observed bathymetric change) to 5 mm (4% of the undisturbed water depth, or 10% of the observed bathymetric change). Compared to a bathymetric change of about 5cm, that is not bad.

B. Tidal current

The tidal nature of the flows causes some issues using the morphological factor. Using a factor N means that a comparison of the results with and without morphological speed-up is only possible after a period of N tides. In the case of the Dee Estuary, the forcing contains a significant spring-neap cycle. Consequently, formal comparisons are only possible after N sping neap cycles.

Therefore, the test described here are limited to the factor 5, 10 and 20. The impact of the morphological speedup for this case is determined by the changes relative to the reference computation without morphological speedup (morphological factor 1).

For the Dee modelling, the morphological factor achieves a linear speed-up (The tidal nature of the flows causes some issues using the morphological factor. Using a factor N means that a comparison of the results with and without morphological speed-up is only possible after a period of N tides. In the case of the Dee Estuary, the forcing contains a significant spring-neap cycle. Consequently, formal comparisons are only possible after N sping neap cycles). The writing of the intermediate results can be neglected for the factors taking into consideration.

The predictive skill of the model deteriorates more for the Dee simulations then it did for the trench case (Fig. 8). With a 30% reduction in the skill for a morphological factor 20.

The bias in the model results (Fig. 9) shows that the use of the morphological factors leads to a overall bed lowering of up to an average 13 cm using a factor 20.

V. Discussion

The results show that the use of a morphological factor does change the model results. The Brier skill score reduces with increasing morphological factor, while the bias increases.

The severity of these changes depends on the model specifics. In the trench case, with a uniform current and a short period being simulated, up to a morphological factor of 20, no discernible effects are visible. With higher factors the accuracy reduces linearly until the model becomes unstable.

In the case of the Dee Estuary, with a tidal forcing and a much longer period being simulated, already with lower morphological factors, the model results change significantly. At a morphological factor of 20, the Brier skill score using the morphological factor 1 run as ‘measured data’, is only 0.7, while the bias is several cms.

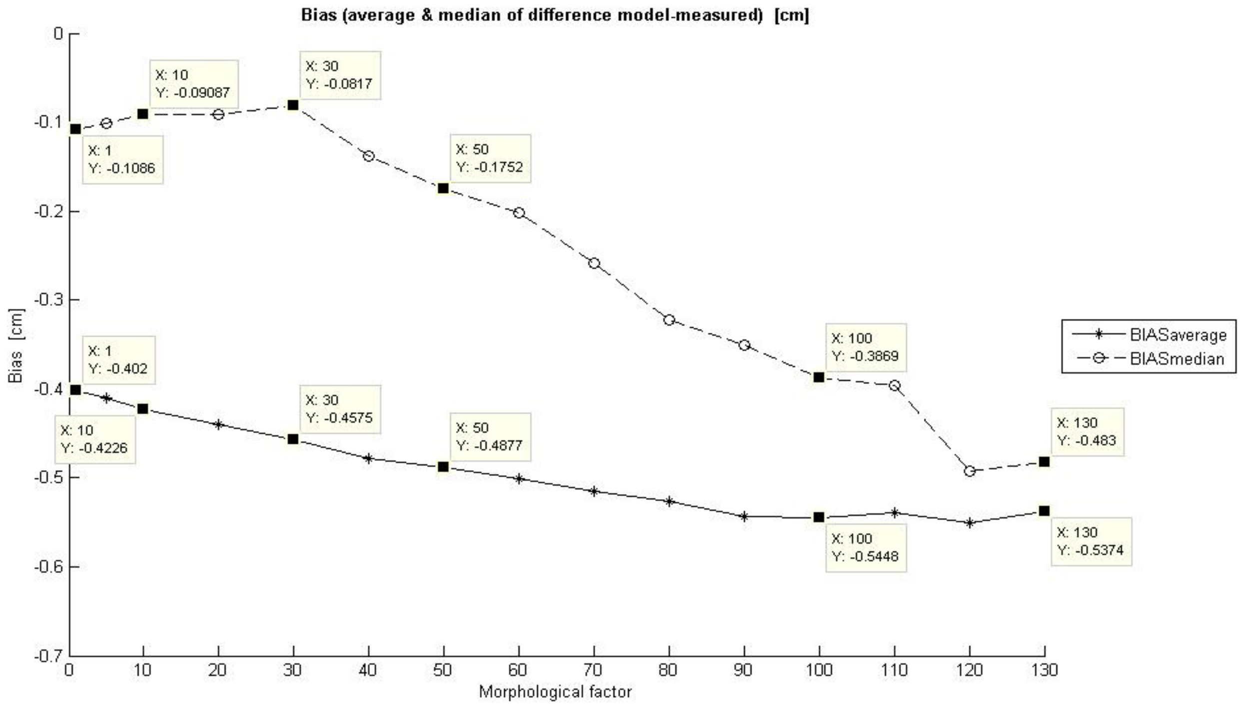

Figure 7. Median and average bias of the model as a function of the morphological factor for the trench test case.

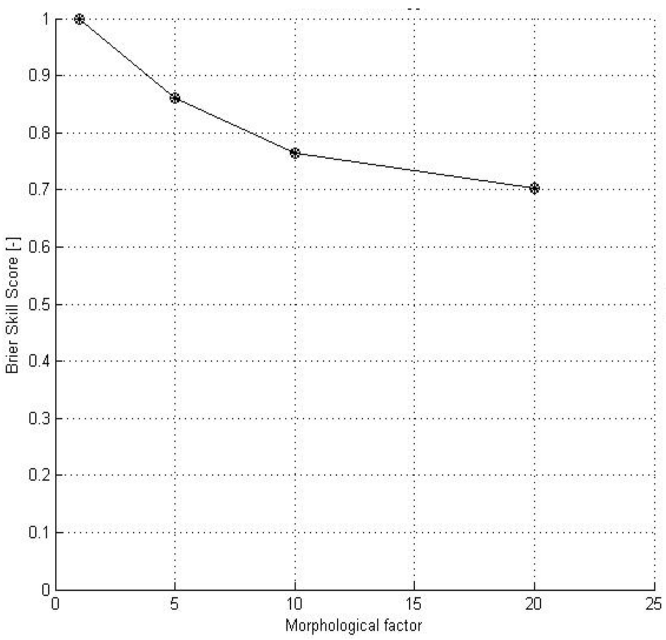

Figure 8. Brier skill score as function of the morphological factor used in the Dee simulations.

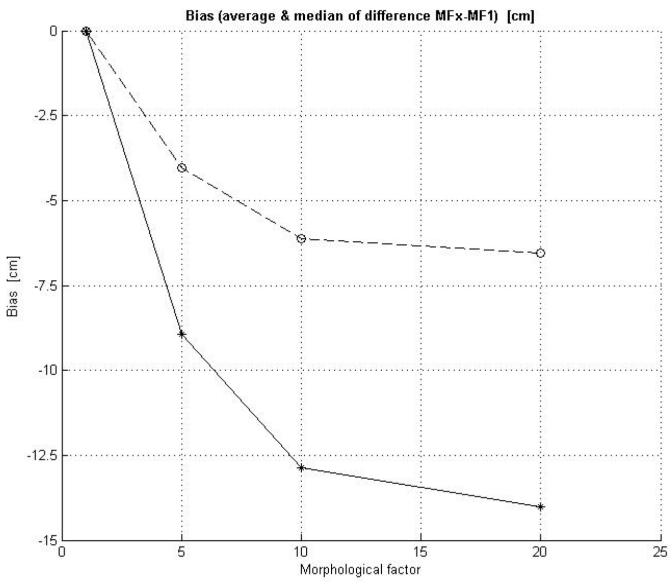

Figure 9. Average Bias (dots) and median bias (circles) in the model predictions as function of the morphological factor for the Dee Estuary simulations.

This bias in the Dee Estuary simulations might be related to an initialization issue, where initially sediment is being exported from the system. However, in general, the use of the morphological factor to speed up morphological simulations leads to an overshooting of the predicted dynamics, i.e. more deposition in case of infill and more erosion in erosion events.

VI. CONCLUSIONS

The morphological factor available to speed up morphodynamic simulations has been tested on two test cases. The first test uses measurements from a flume experiment on a trench; the second test is based on the Dee estuary.

The morphological speed-up available in SISYPHE works quite well, achieving linear gains in computation time for the large models. The results do, however, change adding additional errors to the prediction, reducing the model performance. The magnitude of these negative effects depends on the model specifics. For the short trench test, the added error is negligible, but for the larger Dee Estuary test case, the additional errors are significant.

Therefore, it is important to take care when using the morphological factor.

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