MIKE 21 Flow Model FM

Parallelisation using GPU

Benchmarking report

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PLEASE NOTE

PRINTING HISTORY

September 2013 .... Release 2014

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1 Vision and Scope

A set of well-defined test cases for the GPU version of the MIKE 21 Flow Model FM, have been established. These test cases also covered MIKE FLOOD using the GPU version of the MIKE 21 Flow Model FM for the 2D surface flow calculation. It is essential that it is possible to run the simulation with different spatial resolutions. These tests can be used to pinpoint performance hotspots and to provide a way to produce a quick overview of performance differences due to code changes. The test-suite should also be used to test the performance across platforms with different graphics cards. The main focus is to benchmark the GPU parallelisation of the flexible mesh modelling system. For comparison some simulations have also been performed using the MPI parallelisation of MIKE 21 Flow Model FM and OpenMP parallelisation of MIKE 21 Flow Model Classic.

2 Methodology

2.1 GPU Parallelisation

The GPU computing approach uses the computers graphics card to perform the computational intensive calculations. This approach is based on CUDA by NVIDIA and can be executed on NVIDIA graphics cards with Compute Capability 2.0 or higher. Currently, only the computational intensive hydrodynamic calculations are performed on the GPU. The additional calculations are performed on the CPU and these calculations are parallelised based on the Shared memory approach, OpenMP.

2.2 Platforms

The benchmarks have been performed using the following graphics cards:

- GeForce GTX 580
- GeForce GTX TITAN
- NVS 4200M
- Tesla M2050

2.3 Performance of the GPU Parallelisation

The parallel performance is illustrated by measuring the speedup factor. The speedup factor is defined as the elapsed time using the existing CPU version of MIKE 21 Flow Model FM (one core/thread) divided by the elapsed time using the new GPU version (one core/thread for the CPU part of the calculation).

3 Description of Test Cases

3.1 Mediterranean Sea

This test case has been established for benchmarking of the MIKE 21 Flow model FM.

3.1.1 Description

In the Western parts of the Mediterranean Sea tides are dominated by the Atlantic tides entering through the Strait of Gibraltar, while the tides in the Eastern parts are dominated by astronomical tides, forced directly by the Earth-Moon-Sun interaction.

3.1.2 Setup

The bathymetry is shown in Figure 3.1. Simulations are performed using four meshes with different resolution (see Table 3.1). The meshes are generated specifying the value for the maximum area of 0.01, 0.0025, 0.00125 and 0.0003125 degree2, respectively. The simulation period for the benchmarks covers 2 days starting 1 January 2004 for the simulations using mesh A, B and C. The simulation period is reduced to 6 hours for the simulations using mesh D.

At the Atlantic boundary a time varying level boundary is applied. The tidal elevation data is based on global tidal analysis (Andersen, 1995).

For the bed resistance the Manning formulation is used with a Manning number of 32. For the eddy viscosity the Smagorinsky formulation is used with a Smagorinsky factor of 1.5. Tidal potential is applied with 11 components (default values).

The shallow water equations are solved using both the first-order scheme and the higher-order scheme in time and space.

The averaged time step for the simulations using Mesh A, B, C and D is 17.65s, 5.61s, 2.86s and 1.46s, respectively, for both the first-order scheme and the higher-order scheme in time and space.

Table 3.1 Computational mesh for the Mediterranean Sea case

Mesh	**Element shape**	**Elements**	**Nodes**	**Max. area Degree^2**
Mesh A	Triangular	11287	6283	0.010
Mesh B	Triangular	80968	41825	0.005
Mesh C	Triangular	323029	164161	0.00125
Mesh D	Triangular	1292116	651375	0.0003125

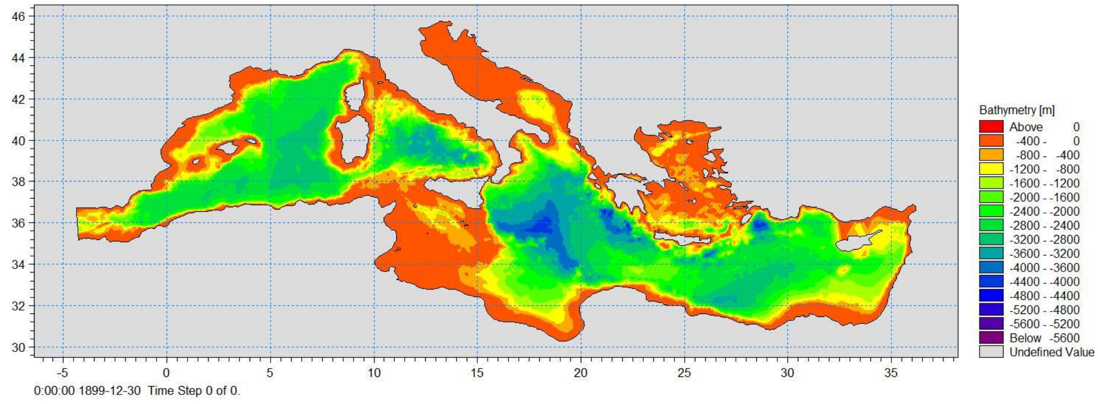

Figure 3.1 Bathymetry for the Mediterranean Sea case

3.1.3 Data and specification files

The data and specification files used for the present case are located in the directory:

Benchmarking\Mediterranean_Sea

The tests are performed using the following specification files:

2004_tide_E_1st.m21fm
2004_tide_A_1st.m21fm
2004_tide_C_1st.m21fm
2004_tide_D_1st.m21fm
2004_tide_E_2nd.m21fm
2004_tide_A_2nd.m21fm
2004_tide_C_2nd.m21fm
2004_tide_D_2nd.m21fm

3.2 Ribe Polder

This test case has been established for benchmarking of the MIKE 21 Flow Model FM.

3.2.1 Description

The model area is located, on the southern part of Jutland, Denmark, around the city of Ribe. The area is protected from storm floods in the Wadden Sea to the west by a dike. The water course Ribe Å runs through the area and crosses the dike through a lock.

The flood condition where the dike is breached during a storm flood is illustrated by numerical modelling. The concept applied to model the breach failure in the hydrodynamic model is based on prescribing the breach by a dynamic bathymetry that change in accordance with the relation applied for the temporal development of the breach. Use of this method requires that the location of the breach is defined and known at an early stage, so that it can be resolved properly and built into the bathymetry. The shape and temporal development of the breach is defined with a time-varying distribution along the dike crest. It is further defined how far normal to the crest line the breach can be felt.

Within this distance the bathymetry is following the level of the breach, if the local level is lower than the breach level no changes are introduced. The area of influence of the breach will therefore increase with time.

The breach and flood modelling has been carried out based on a historical high water event (24 November, 1981), shown in Figure 3.2. Characteristic for this event is that high tide occurs at the same time as the extreme water level. Højer sluice is located about 40 km south of the breach, while Esbjerg is located about 20 km to the north. Based on the high water statistics for Ribe the extreme high water level has been estimated for an event having a return period of 10,000 years. The observed water level at Højer is hereafter adjusted gradually over two tidal cycles to the extreme high water level estimated for the given return periods at Ribe, as indicated in Figure 3.2. The water level time series established in this way are shown in Figure 3.2.

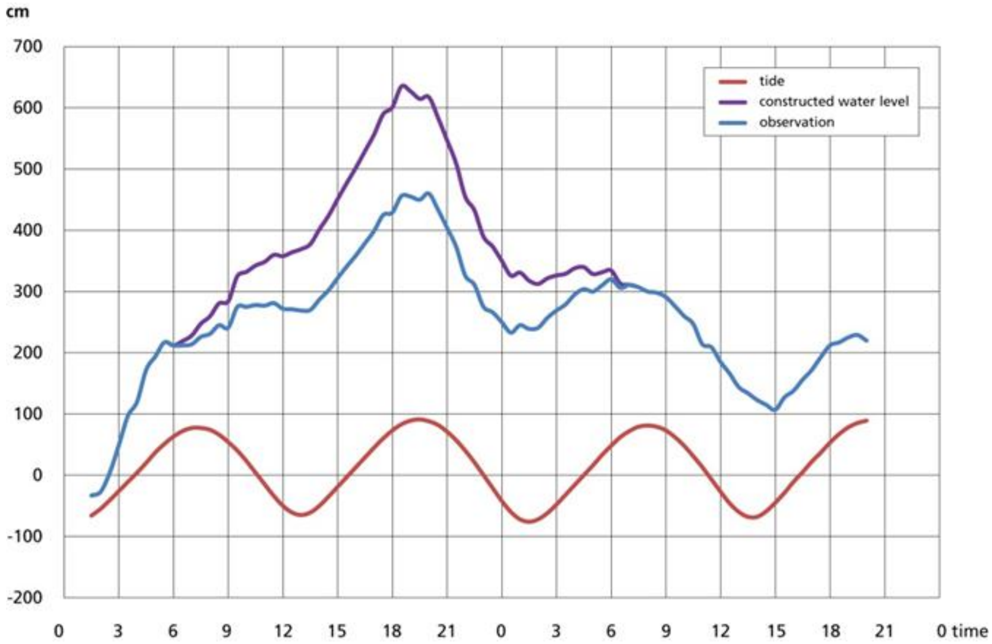

Figure 3.2 Runoff from the catchment is included as specified discharges given for the two streams Ribe Å and Kongeåen

The crossing between the dike and Ribe Å is shown in Figure 3.4. The crossing is in the form of a navigational chamber lock. It is represented in the model bathymetry as a culvert that can be closed by a gate. The points defining the dike next to the creek are modified to have increased levels in order to ensure a well-defined bathymetry where flow only occurs through the cells defining the creek proper. The sluice is defined as a check valve allowing only flow towards the sea.

3.2.2 Setup

The bathymetry is shown in Figure 3.3. The computational mesh contains 173101 elements. A satisfactory resolution of the breach is obtained by a fine mesh of structured triangles and rectangles as shown in Figure 3.4. The areas in- and offshore of the dike is defined by a relatively fine mesh to avoid instabilities due to humps or holes caused by large elements with centroids just outside the area of influence from the breach. The simulation period is 42 hours.

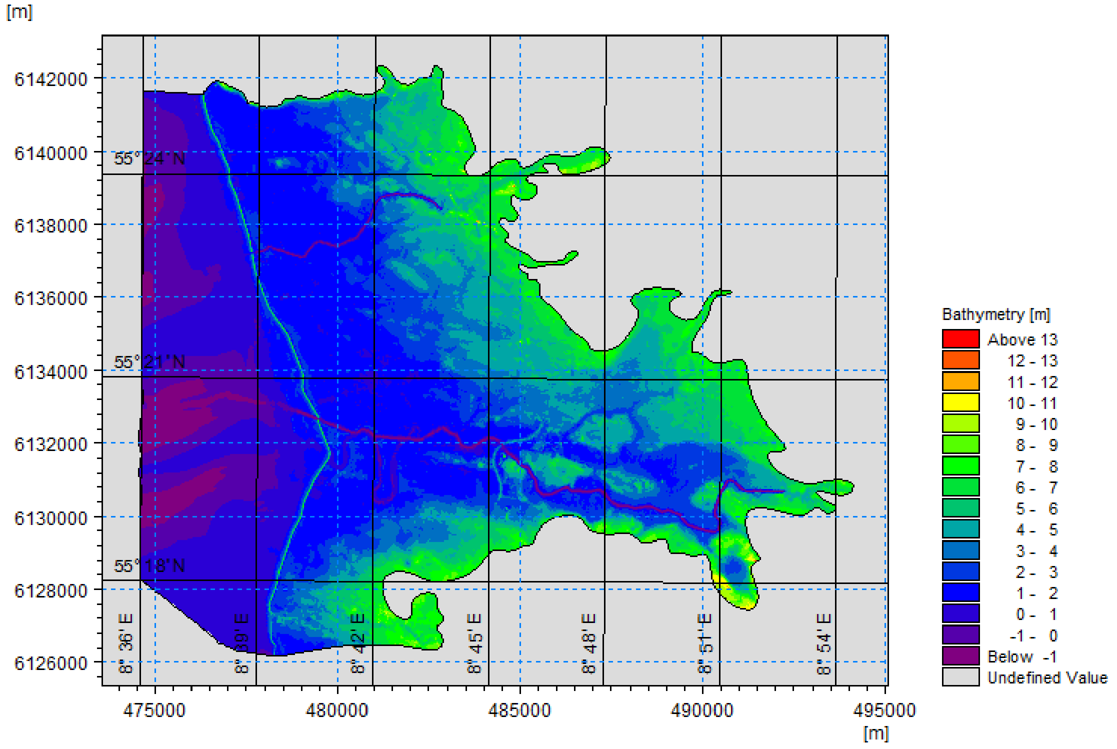

Figure 3.3 Bathymetry for the Ribe Polder case

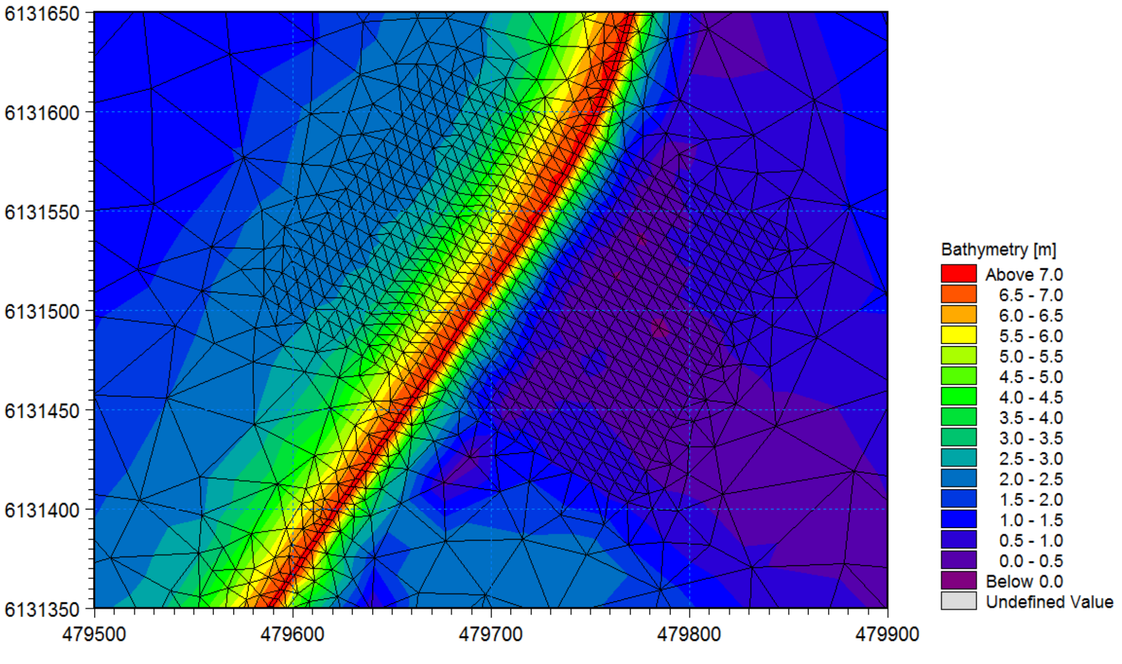

Figure 3.4 Close-up of the bathymetry

At the offshore boundary a time series of level variations is applied.

A constant discharge of 9.384 m^3/s and 14.604 m^3/s, respectively, are applied for the two streams Ribe Å and Kongeåen. For the bed resistance the Manning formulation is used with a Manning number of 20. For the eddy viscosity the Smagorinsky formulation is used with a Smagorinsky factor of 0.28.

The shallow water equations are solved using both the first-order scheme and higher-order scheme in space and time.

The averaged time step is 0.21s for both the first-order scheme and higher-order scheme in space and time.

3.2.3 Data and specification files

The data and specification files used for the present case are located in the directory Benchmarking\Ribe_Polder

The tests are performed using the following specification files:

Event_10000_1st.m21fm

Event_10000_2nd.m21fm

3.2.4 EA2D Test 8B

This test is Test 8B in the benchmarks test developed during the Joint Defra/Environment Agency research programme. This tests the package's capability to simulate shallow inundation originating from a surcharging underground pipe, at relatively high resolution. This test case has been established for benchmarking of the MIKE Flood using MIKE 21 Flow model FM of the 2d surface flow calculation.

3.2.5 Description

The modelled area is approximately 0.4 km by 0.96 km and covers entirely the DEM provided and shown in Figure 3.5. Ground elevations span a range of ~21m to ~37m.

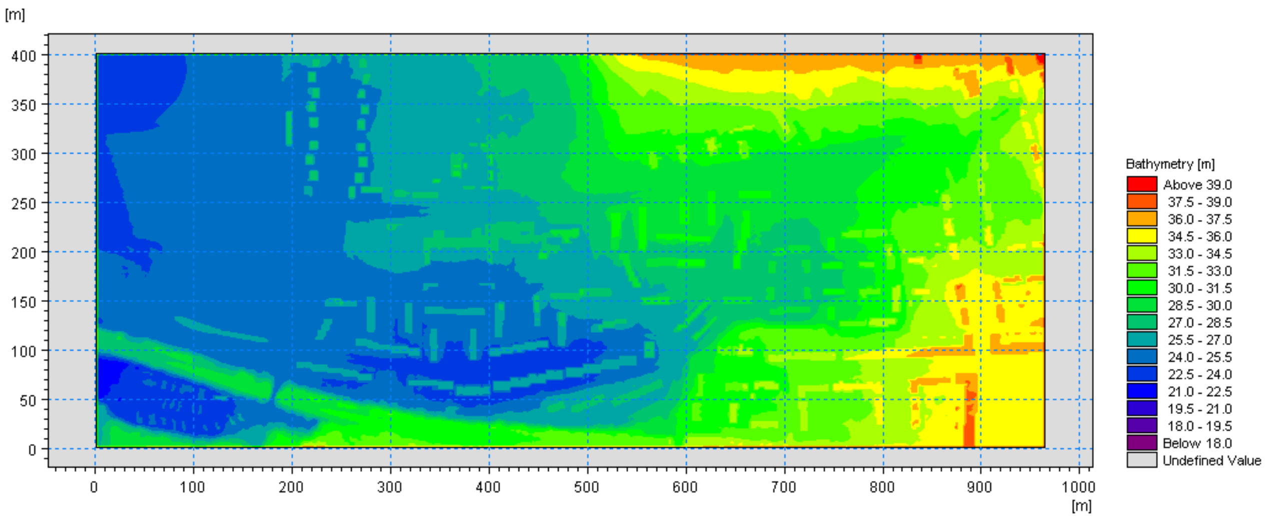

Figure 3.5 Bathymetry for the EA2D Test8B case

A culverted watercourse of circular section, 1400mm in diameter, ~1070m in length, and with invert level uniformly 2m below ground is assumed to run through the modelled area. An inflow boundary condition is applied at the upstream end of the pipe, illustrated in Figure 3.6. A surcharge is expected to occur at a vertical manhole of $1m^2$ cross-section located 467m from the top end of the culvert, and at the location (264896, 664747). For the downstream boundary condition free out fall (critical flow is assumed). The base flow (uniform initial condition) is 1.6 m/s. The manhole is connected to the grid in one point and the surface flow is assumed not to affect the manhole outflow.

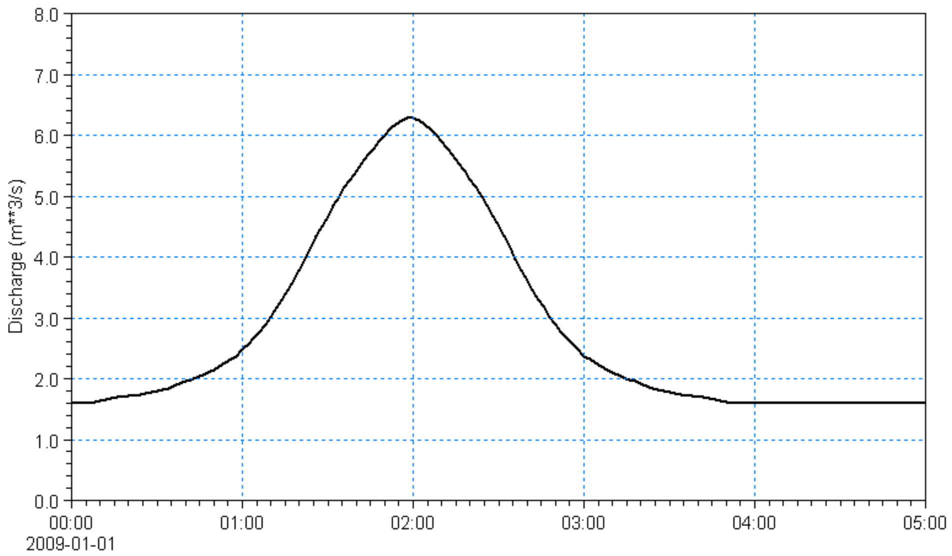

Figure 3.6 Inflow hydrograph applied for the EA2D Test8B at upstream end of culvert

DEM is a 0.5m resolution Digital Terrain Model (no vegetation or buildings) created from LiDAR data collected on 13th August 2009 and provided by the Environment Agency (http://www.geomatics-group.co.uk). Model grid resolution should be 2m (or ~97000 nodes in the 0.388 km^2 area modelled).

The presence of a large number of buildings in the modelled area is taken into account. Building outlines are provided with the dataset. Roof elevations are not provided.

A land-cover dependent roughness value is applied, with 2 categories: 1) Roads and pavements; 2) Any other land cover type. Manning's n = 0.02 is applied for roads and pavements n = 0.05 everywhere else.

All boundaries in the model area are closed (no flow) and the initial condition is dry bed. The model is run until time T = 5 hours to allow the flood to settle in the lower parts of the modelled domain.

3.2.6 Setup

Simulations are performed using four meshes with different resolution (see Table 3.2). The four meshes uses regular quadrilateral elements with grid spacing 2m, 1m, 0.5m and 0.25m, respectively. Mesh A corresponds to the original mesh used in the EA2D test, and the additional meshes are obtained by refining this mesh.

Table 3.2 Computational mesh for the EA2D Test 8B case

Mesh	Element shape	Elements	Nodes	Grid spacing metres
Mesh A	Quadrilateral	95719	96400	2
Mesh B	Quadrilateral	384237	385600	1
Mesh C	Quadrilateral	1539673	1542400	0.5
Mesh D	Quadrilateral	6164145	6169600	0.25

The shallow water equations are solved using the first-order scheme in time and space.

The averaged time step for the simulation using Mesh A, B, C and D is 0.27s, 0.15s, 0.76s and 0.025s, respectively.

3.2.7 Data and specification files

The data and specification files used for the present case are located in the directory:

Benchmarking\EA2D_Test_8B

The tests are performed using the following specification files:

Test8B_quadratic_2m.couple
Test8B_quadratic_1m.couple
Test8B_quadratic_0.5m.couple
Test8B_quadratic_0.25m.couple

4 Benchmarking using a GeForce GTX 580 Card

These tests have been performed using a two core HP workstation (apc237) with Intel® Core™ i3-2120 Processor (2 core, 3.30 GHZ), 8 GB of RAM and a GeForce GTX 580 card. The operation system is Windows 7.

4.1 Performance

The CPU time is the total calculation time (excluding pre- and post-processing). These tests have been performed using the development version of the software (10.04.2013). Intel Visual Fortran Composer XE 2011 Update 4. The number of threads per block on the GPU is 512.

4.1.1 Mediterranean Sea

Table 4.1 Simulations are carried out using single precision and using the first-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	93.36	11.53	8.09
80968	2090.26	57.34	36.45
323029	19609.17	237.47	82.57
1292116	17939.60	164.78	108.87

Table 4.2 Simulations are carried out using single precision and using the higher-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	259.59	19.51	13.30
80968	5814.17	249.82	23.27
323029	56402.74	1582.61	35.63
1292116	51033.15	1423.91	35.84

Table 4.3 Simulations are carried out using double precision and using the first-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	93.36	10.64	8.77
80968	2090.26	86.82	24.07
323029	19609.17	502.73	39.00
1292116	17939.60	426.21	42.09

Table 4.4 Simulations are carried out using double precision and using the higher-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	259.59	19.51	13.30
80968	5814.17	249.82	23.27
323029	56402.74	1582.61	35.63
1292116	51033.15	1423.91	35.84

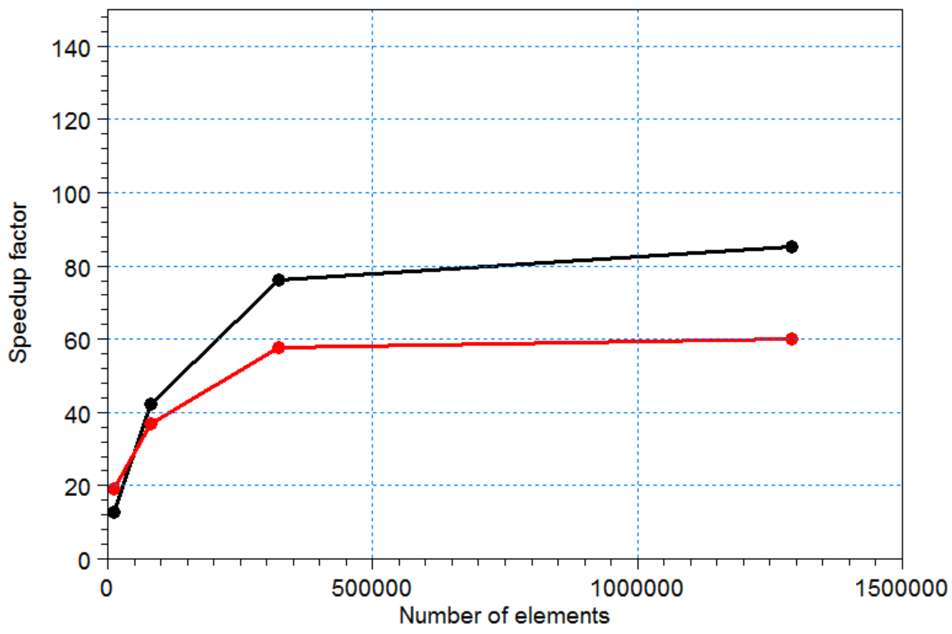

Figure 4.1 Speedup factor using single precision.
Black line: first-order scheme; Red line: higher-order scheme

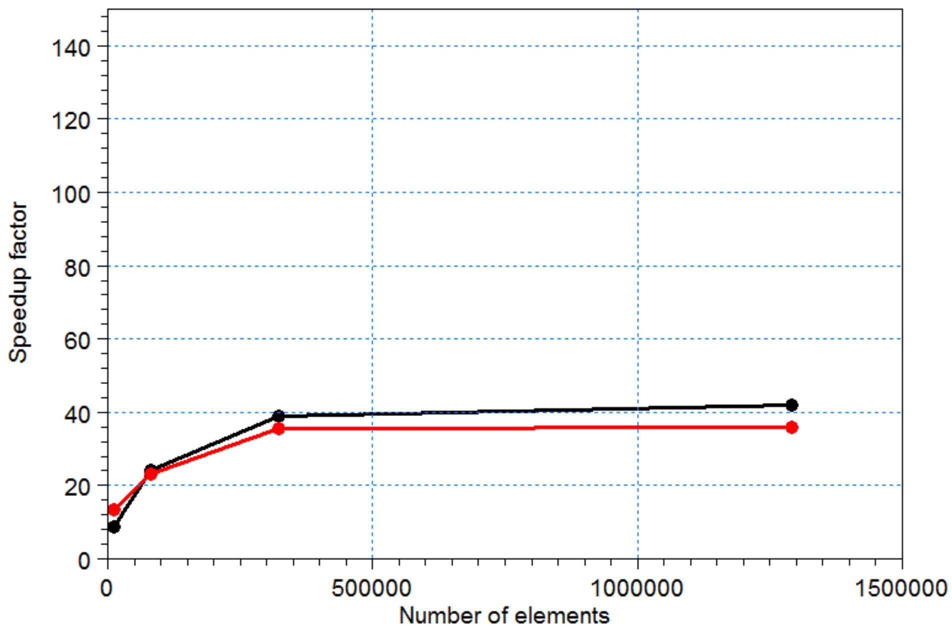

Figure 4.2 Speedup factor using double precision.
Black line: first-order scheme; Red line: higher-order scheme

5 Benchmarking using a GeForce GTX Titan Card

These tests have been performed using a two core HP workstation (apc237) with Intel® Core™ i3-2120 Processor (2 core, 3.30 GHZ), 8 GB of RAM and a GeForce GTX TITAN card. The operation system is Windows 7.

5.1 Performance

The CPU time is the total calculation time (excluding pre- and post-processing). These tests have been performed using the development version of the software (08.08.2013) for the Mediterranean Sea case and the development version (05.09.2013) for the Ribe Polder and the EA2D Test8B cases. Intel Visual Fortran Composer XE 2011 Update 4. The number of threads per block on the GPU is 128.

5.1.1 Mediterranean Sea

Table 5.1 Simulations are carried out using single precision and using the first-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	93.36	11.53	8.09
80968	2090.26	57.34	36.45
323029	19609.17	237.47	82.57
1292116	17939.60	164.78	108.87

Table 5.2 Simulations are carried out using single precision and using the higher-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	259.59	18.99	13.66
80968	5814.17	139.32	41.73
323029	56402.74	774.29	72.84
1292116	51033.15	626.97	81.39

Table 5.3 Simulations are carried out using double precision and using the first-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	93.36	11.93	7.82
80968	2090.26	76.16	27.44
323029	19609.17	312.36	62.77
1292116	17939.60	234.01	76.66

Table 5.4 Simulations are carried out using double precision and using the higher-order scheme in time and space.

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	259.59	24.96	10.50
80968	5814.17	183.14	31.74
323029	56402.74	959.87	58.76
1292116	51033.15	810.87	62.93

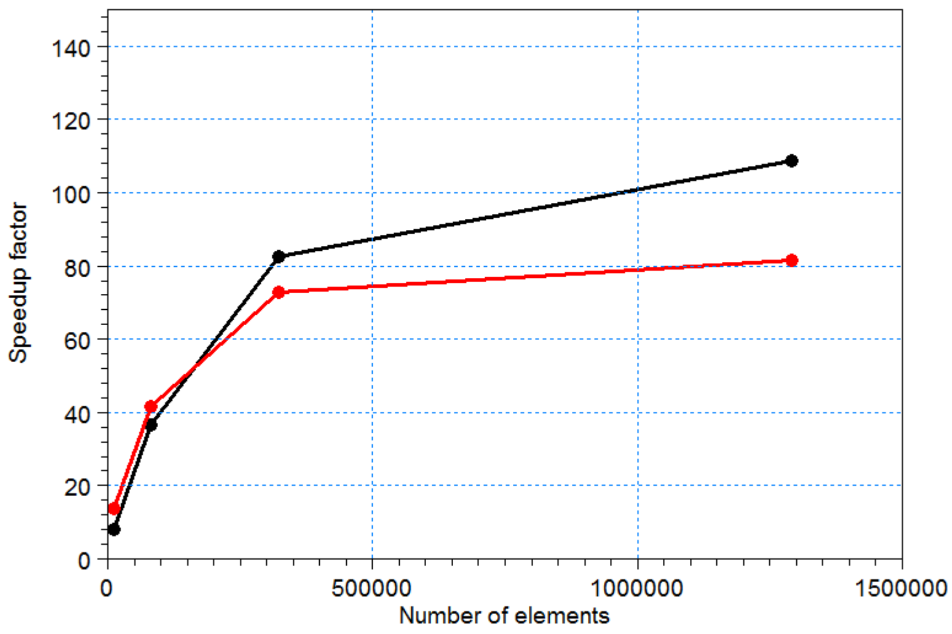

Figure 5.1 Speedup factor using single precision.
Black line: first-order scheme; Red line: higher-order scheme

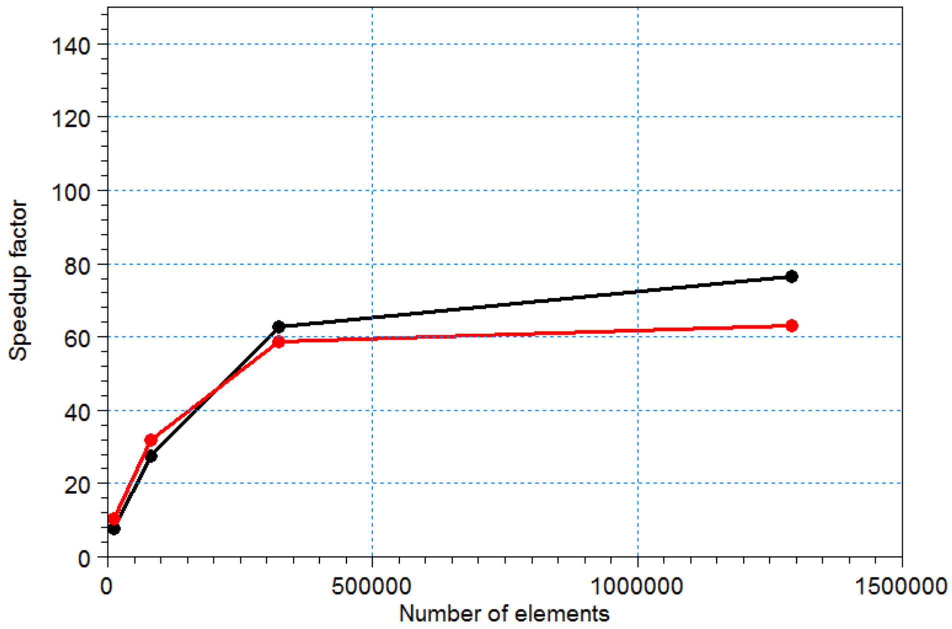

Figure 5.2 Speedup factor using double precision.
Black line: first-order scheme; Red line: higher-order scheme

5.1.2 Ribe Polder

Table 5.5 Simulations are carried out using single precision and using the first-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
173101	34095.24	4740.85	7.19

Table 5.6 Simulations are carried out using single precision and using the higher-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
173101	122619.94	8556.97	14.32

Table 5.7 Simulations are carried out using double precision and using the first-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
173101	34095.24	4966.71	6.86

Table 5.8 Simulations are carried out using double precision and using the higher-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
173101	122619.94	8962.24	13.68

5.1.3 EA2D Test 8B

Table 5.9 Simulations are carried out using single precision and using the first-order scheme in time and space

Mesh	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
Mesh A	1065.62	218.81	4.87
Mesh B	8233.71	831.30	9.90
Mesh C	61891.86	4169.17	14.84
Mesh D		26307.92	

Table 5.10 Simulations are carried out using double precision and using the first-order scheme in time and space

Mesh	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
Mesh A	1065.62	235.95	4.51
Mesh B	8233.71	891.23	9.23
Mesh C	61891.86	4429.26	13.97
Mesh D		28225.96	

6 Benchmarking using a NVS 4200M Card

These tests have been performed using a Lenovo Thinkpad 520 (apc785) with Intel® Core™ i7-2670QM Processor (4 cores, 2.20 GHZ), 8 GB of RAM and a NVS 4200M graphics card. The operation system is 64-bit Windows 7 Professional with SP1 installed.

6.1 Performance

The CPU time is the total calculation time (excluding pre- and post-processing). These tests have been performed using the development version of the software (15.07.2013). Intel Visual Fortran Composer XE 2011 Update 4. The number of threads per block on the GPU is 128.

6.1.1 Mediterranean Sea

Table 6.1 Simulations are carried out using single precision and using the first-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	96.71	32.96	2.93
80968	2211.99	436.67	5.07
323029	23074.72	2874.36	8.03
1292116	18717.93	2711.95	6.90

Table 6.2 Simulations are carried out using single precision and using the higher-order scheme in time and space

Elements	Time (s) CPU (1 core)	Time (s) GPU	Speedup factor
11287	263.81	106.98	2.47
80968	6252.79	1791.85	3.49
323029	60976.48	13160.73	4.63
1292116	53494.14	12697.38	4.21

Table 6.3 Simulations are carried out using double precision and using the first-order scheme in time and space

Elements	**Time (s) CPU (1 core)**	**Time (s) GPU**	**Speedup factor**
11287	96.71	58.65	1.65
80968	2211.99	918.68	2.41
323029	23074.72	6566.91	3.51
1292116	18717.93	6417.79	2.92

Table 6.4 Simulations are carried out using double precision and using the higher-order scheme in time and space

Elements	**Time (s) CPU (1 core)**	**Time (s) GPU**	**Speedup factor**
11287	263.81	169.05	1.56
80968	6252.79	3145.16	1.99
323029	60976.48	23297.03	2.62
1292116	53494.14	22888.37	2.34

7 Benchmarking using a Tesla M2050 Card

These tests have been performed using a eight core Amazon EC2 GPU Instance with 2 x Intel(R) Xeon(R) CPU X5570@ 2.93GHz processor (4 cores, 8M Cache, 2.93 GHZ), 22.5GB RAM and a Tesla M2050 graphics card. The operation system is 64.

7.1 Performance

The CPU time is the total calculation time (excluding pre- and post-processing). These tests have been performed using the development version (12.8.2013). Intel Visual Fortran Composer XE 2011 Update 4. The number of threads per block is 128.

7.1.1 Mediterranean Sea

Table 7.1 Simulations are carried out using single precision and using the first-order scheme in time and space

Elements	Time (s) GPU
11287	5.86
80968	54.75
323029	330.08
1292116	294.76

Table 7.2 Simulations are carried out using single precision and using the higher-order scheme in time and space

Elements	Time (s) GPU
11287	15.13
80968	191.62
323029	1311.59
1292116	1232.68

Table 7.3 Simulations are carried out using double precision and using the first-order scheme in time and space

Elements	Time (s) GPU
11287	8.32
80968	103.90
323029	706.56
1292116	663.18

Table 7.4 Simulations are carried out using double precision and using the higher-order scheme in time and space

Elements	Time (s) GPU
11287	23.21
80968	357.57
323029	2545.92
1292116	2406.22

8 Benchmarking using a Twelve Core HP Workstation

For comparison simulations has also been performed using MIKE 21 Flow Model FM with MPI parallelisation and using MIKE 21 Flow Model Classic with OpenMP parallelisation (only the EA2D Test 8B). These tests have been performed using a twelve core HP workstation (apc789) with 2 x Intel® Xeon® Processor X5650 (6 core, 12M Cache, 2.66 GHZ) and 24 GB of RAM. The operation system is Windows 7.

8.1 Performance

The CPU time is the total calculation time (excluding pre- and post-processing). The tests have been performed using the development version (8.8.2014) 2013 for the Mediterranean Sea case and development version (06.09.2013) for the Ribe Polder and the EA2D Test8B cases. Intel Visual Fortran Composer XE 2011 Update 4 and Intel MPI Library 4.0 Update 2 (4.0.2.005) have been used. For the mesh partitioning Metis 5.0 is applied.

8.1.1 Mediterranean Sea

Table 8.1 Simulations are carried out using MIKE 21 Flow Model FM with MPI parallelisation and using the higher-order scheme in time and space

Mesh	No. of processors	CPU time	Speedup factor
MESH A	1	301.80	1.00
	2	142.65	2.11
	4	74.12	4.07
	6	51.81	5.82
	8	41.29	7.30
	12	28.42	10.61

Mesh	No. of processors	CPU time	Speedup factor
MESH B	1	7603.53	1.00
	2	3544.75	2.14
	4	1809.66	4.20
	6	1262.23	6.02
	8	967.10	7.86
	12	673.90	11.28

Mesh	No. of processors	CPU time	Speedup factor
MESH C	1	71579.55	1.00
	2	34833.33	2.05
	4	15517.89	4.61
	6	10937.44	6.54
	8	8640.91	8.28
	12	6007.07	11.91

Mesh	No. of processors	CPU time	Speedup factor
MESH D	1	63895.01	1.00
	2	32376.13	1.97
	4	20177.28	3.16
	6	12126.62	5.26
	8	10156.69	6.29
	12	7077.05	9.02

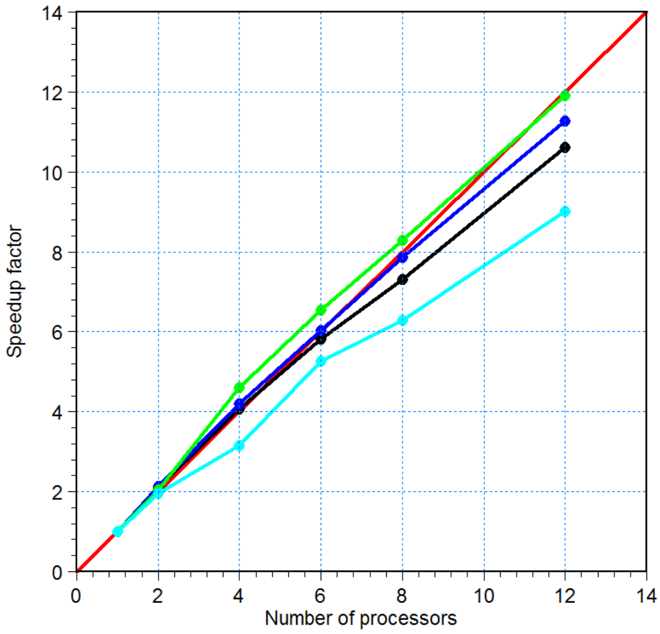

Figure 8.1 Speedup factor using higher-order scheme in time and space.
Black line: MPI parallelisation with mesh A; Blue line: MPI parallelisation with mesh B; Green line: MPI parallelisation with mesh C; Light blue line: MPI parallelisation with mesh D; Red line: Ideal speedup factor

8.1.2 Ribe Polder

Table 8.2 Simulations are carried out using MIKE 21 Flow Model FM with MPI parallelisation and using the first-order scheme in time and space

Mesh	No. of processors	CPU time	Speedup factor
	1	46821.05	1.00
	2	22260.28	2.10
	4	18207.24	2.57
	6	14641.97	3.19
	8	11373.09	4.11
	12	11325.05	4.13

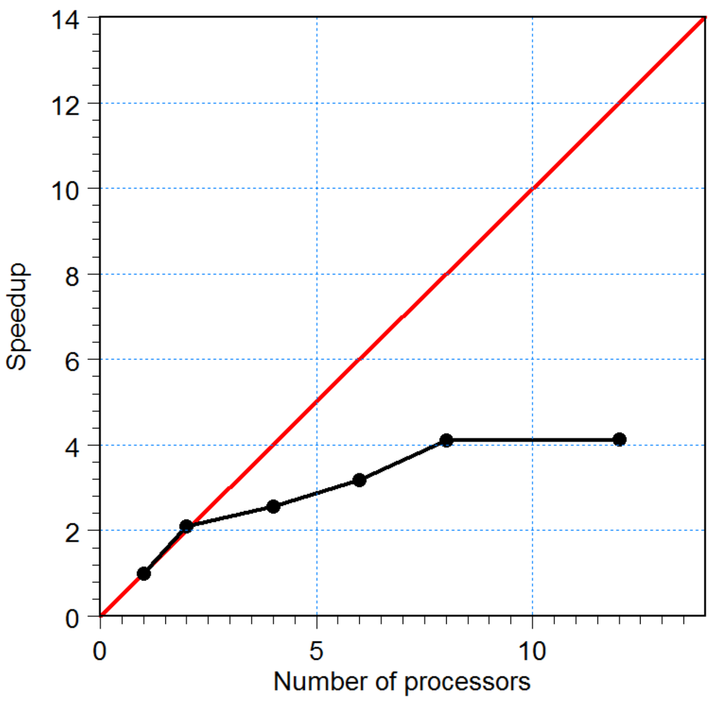

Figure 8.2 Speedup factor using the MIKE 21 Flow Model FM and the first-order scheme in time and space. Black line: MPI parallelisation; Red line: Ideal speedup factor

8.1.3 EA2D Test 8B

In the simulations using MIKE 21 Flow Model Classic, the time step is 1s and 0.5s, respectively, for Mesh A and Mesh B.

Table 8.3 Simulations are carried out using the MIKE 21 Flow Model Classic with OpenMP parallelisation

Mesh	No. of processors	CPU time	Speedup factor
MESH A	1	214.26	1.00
	2	145.00	1.47
	4	126.14	1.69
	6	114.78	1.86
	8	103.68	2.06
	12	95.69	2.23
MESH B	1	2393.59	1.00
	2	1512.18	1.58
	4	1111.72	2.15
	6	959.69	2.49
	8	851.45	2.81
	12	813.20	2.94

Figure 8.3 Speedup factor for MIKE 21 Flow model Classic with OpenMP parallelisation. Black line: Mesh A; Blue line: Mesh B; Red line: Ideal speedup factor

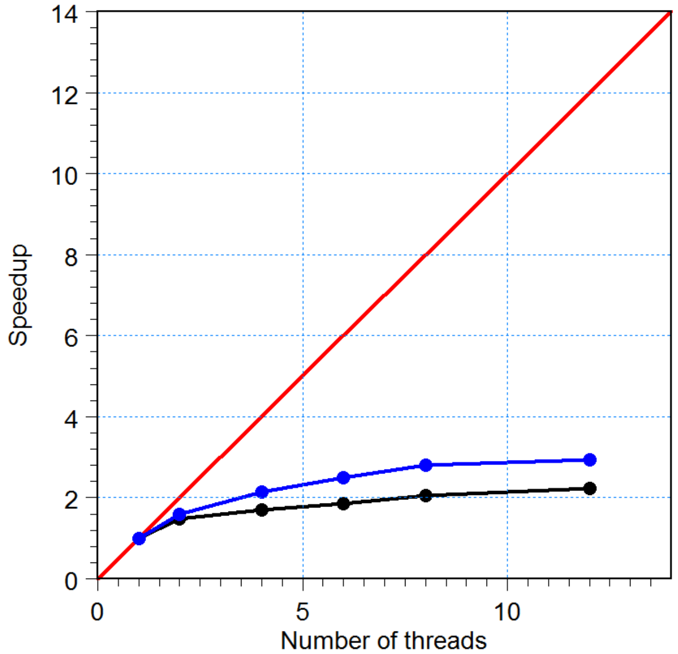

Table 8.4 Simulations are carried out using MIKE 21 Flow Model FM with MPI parallelisation and using the first-order scheme in time and space

Mesh	No. of processors	CPU time	Speedup factor
MESH A	1	1612.60	1.00
	2	771.49	2.09
	4	510.45	3.15
	6	471.55	3.41
	8	405.98	3.97
	12	379.88	4.24
MESH B	1	11175.37	1.00
	2	6451.17	1.73
	4	3878.73	2.88
	6	3542.38	3.15
	8	3303.20	3.38
	12	2971.27	3.76
MESH C	1	85567.42	1.00
	2	44096.72	1.94
	4	32160.50	2.66
	6	23622.64	3.62
	8	22854.95	3.74
	12	20613.09	4.15

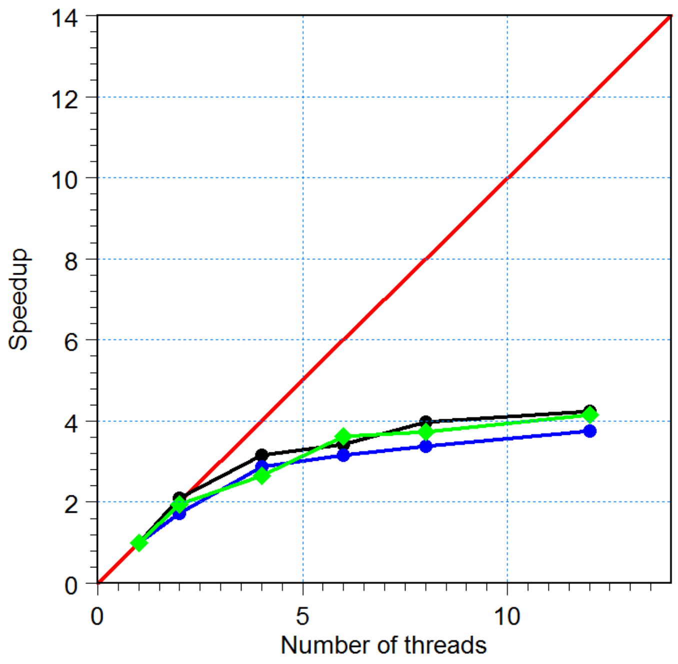

Figure 8.4 Speedup factor for MIKE 21 Flow model FM with MPI parallelisation.
Black line: Mesh A; Blue line: Mesh B; Green line: Mesh C; Red line: Ideal speedup factor

9 Conclusions

The overall conclusions of the benchmarks are

- The numerical scheme and the implementation of the GPU version of the MIKE 21 Flow Model FM are identical to the CPU version of MIKE 21 Flow Model FM. Simulations without flooding and drying produces identical results using the two versions. Simulations with extensive flooding and drying produce results that may contain small differences.
- The performance of the new GPU version of MIKE 21 Flow Model FM depends strongly on the graphics card and the model setup. The best performance was obtained with the GeForce GTX TITAN card.
- The speedup factor of simulations with no flooding and drying increases with increasing number of elements in the computational mesh. When the number of elements becomes larger than approximately 400.000 then there is only a very limited increase in the speedup factor for increasing number of elements. The single precision version of MIKE 21 Flow Model FM is approximately a factor 1.3-2.0 faster than the double precision version.
- In the Mediterranean Sea case the maximum speedup factor using the first-order scheme was 108.87 and 76.6, respectively, with the single precision and the double precision version. Using the higher-order scheme the speedup factor was 81.39 and 62.82, respectively, with the single precision and the double precision version.
- In simulations with extensive flooding and drying the average number of wet elements can be small compared to the total number of elements in the mesh. In these cases a speedup factor of 10-20 is typically obtained. Furthermore there is only limited reduction in the computational time using the single precision version compared to the double precision version.

10 References

/1/ Andersen, O.B., 1995, Global ocean tides from ERS-1 and TOPEX/POSEIDON altimetry, J. Geophys Res. 100 (C12), 25,249-25,259.

/2/ Bo Brahtz Christensen, Nils Drønen, Peter Klagenberg, John Jensen, Rolf Deigaard and Per Sørensen, 2013, Multiscale modelling of coastal flooding, Coastal Dynamics 2013, paper no. 053.

/3/ Néelz S., Pender G., 2010, Benchmarking of 2D Hydraulic Modelling Packages, Report published by Environment Agency, www.environment-agency.gov.uk, Copies of this report are available from the publications catalogue: http://publications.environment-agency.gov.uk.