Contents

Chapter 1

Comparing the numerical results in *[Vater S., N. Beisiegel, and J. Behrens, 2019]* to results produced by the FLASH implementation in Samoa2

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Included scenarios

- 4.1: Lake at rest
- 4.2: Tsunami runup onto a linearly sloping beach
- 4.3: Long wave resonance in a paraboloid basin
- 4.4: Oscillatory flow in a parabolic bowl
- 4.5: Runup onto a complex three-dimensional beach
- 4.6: Flow around a conical island

Verification method

Samoa was built using the `flash-testing(-xdmf)` branch of the repository available at https://gitlab.lrz.de/samoa/samoa, with the XDMF module enabled.

Evaluation and post-processing was done using the scripts available at `scripts/FlashAnalysis/verification` and `scripts/XDMF/pysamoaxdmf` in the Samoa repository. The `pysamoaxdmf` module provides a convenient python3 wrapper to parse the XDMF/HDF5 data generated by Samoa.

Each scenario directory contains at least a description file and a `simulation_data` directory containing gzipped XDMF data of the simulations evaluated. When applicable, the simulation data is stripped down to only contain relevant data, these changes are detailed in the respective description file.

The scenarios were reproduced as close as possible, however some adjustments had to be made due to differences in the way of computation in Samoa. These adjustments are detailed in their respective scenario description files.

The implementation of the scenarios can be found at `src/Flash/FLASH_Scenario.f90`.

All XDMF files may be read and rendered using the ParaView software, by selecting the “Xdmf3” reader on import.

Compilation notes

The `xdmf_fox_dir`, `xdmf_hdf5_dir`, `asagi_dir`, `netcdf_dir`, `exe`, `compiler` and `mpi` configuration options are not detailed here, as they differ from machine to machine. The other compilation options, with the exception of `swe_scenario`, are as follows: `- scenario='flash' - flash_order='1' - target='release' - data_refinement='sample' - xdmf='true'`

Furthermore, each test is performed two times, once for the vertex- and edge-based limiter respectively: `- limiter='BJ_vertex' - limiter='BJ_edge'`

Some scenarios may require ASAGI with `asagi='true'`, and/or time-dependent boundary conditions using `boundary='file'` or `boundary='function'`.

Evaluation notes

Is is assumed that the working directory is `scripts/FlashAnalysis/verification`, the `PYTHONPATH` environment variable contains `scripts/XDMF/pysamoaxdmf` and the simulation data is located at `output/`.

If not specified otherwise, the evaluation script parameters are as follows: `- -i "path/to/xmf_file.xmf"`: Relative or absolute file path of the XMF output file. `find` is used to generate time-independent commands. `- -o "path/to/output_directory"`: Relative or absolute file path of the SVG plot output directory `- -d "path/to/data_directory"`: Relative or absolute path to directory containing reference data `- -s "scenario"`: Script-specific scenario selector, see individual documentation `- -n workers`: Amount of parallel processes used for computation

Editor's note

"`[1]`" is used to denote a reference to the paper, even when no bibliography is provided in the document.

The `pandoc` software with `latex` was used for PDF generation.

Chapter 2

Automating the compilation, execution and rendering of the scenarios

Requirements

System packages

- `bash`, with `tee`, `sed`, `grep`, `cat` and standard file handling tools like `mkdir` and `cp`
- `pandoc` (the latest), `inkscape` and some kind of `pdflatex` or `xelatex` for the compilation to PDF
- `python3`, `pip3`, `node`

Pip packages

- `numpy` for computation
- `scipy` for advanced interpolation
- `numba` for JIT LLVM compilation
- `pandas` for dataset processing
- `psutil` for controlling worker threads
- `matplotlib` for plotting
- `pandocfilters` for the compilation to PDF

Chapter 3

Scenario 4.1: Lake at rest

Notes

Two simulation data sets with different temporal resolutions are provided, one with `400` and one with `4000` output steps. For evaluation, the 4000-step variant is used, the 400-step variant is used only for development and testing purposes.

The refinement level `11` was chosen, which results in a triangle leg length of about `0.022` and `4096` cells `-` the same as in [1]: see section 4.1, paragraph two, and compare with figure 4, left panel.

The dry/wet tolerance of `10e-6` and simulation time of `40` seconds were directly taken from [1].

The courant number of `0.3` was found using trial and error. The average computation time step size is about `0.001333` resp. `0.00125` seconds, while the fixed time step size in [1] is `0.002` seconds.

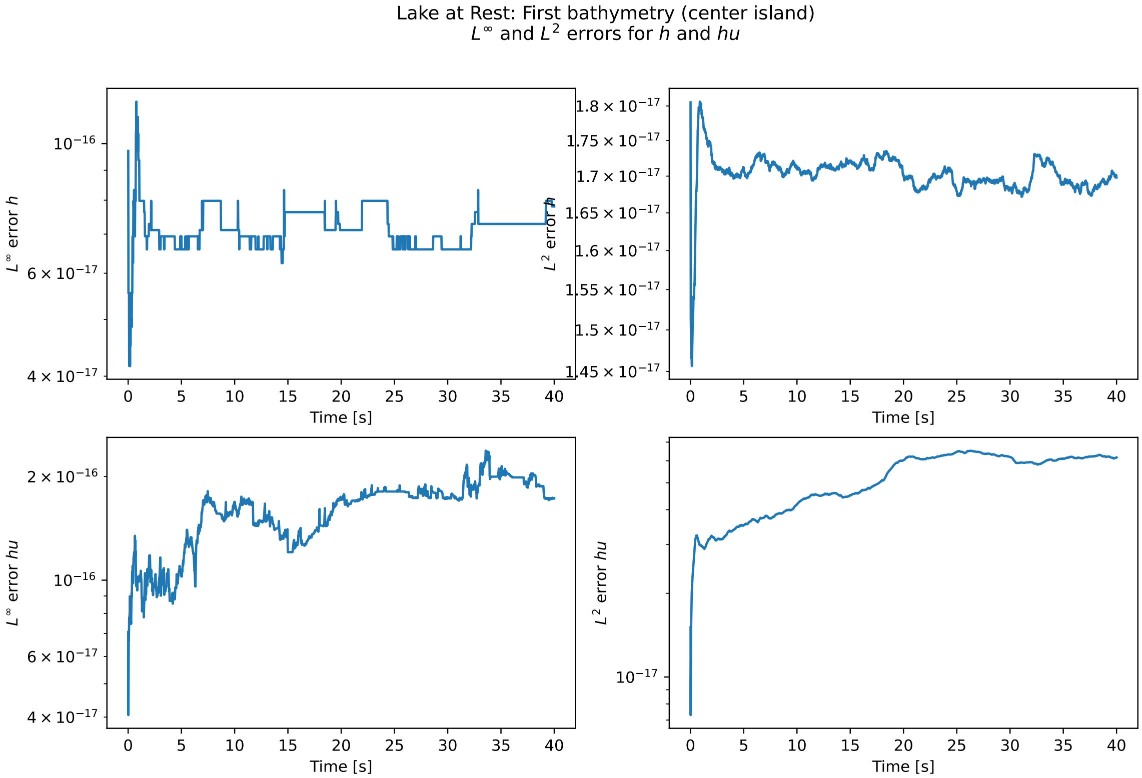
Evaluation

The L2 and Lsup limiter errors are computed and subsequently plotted by comparing the numerical results to the analytical solution. These results can then compared with [1], see figure 3 and 4.

Expanded postprocessing calls

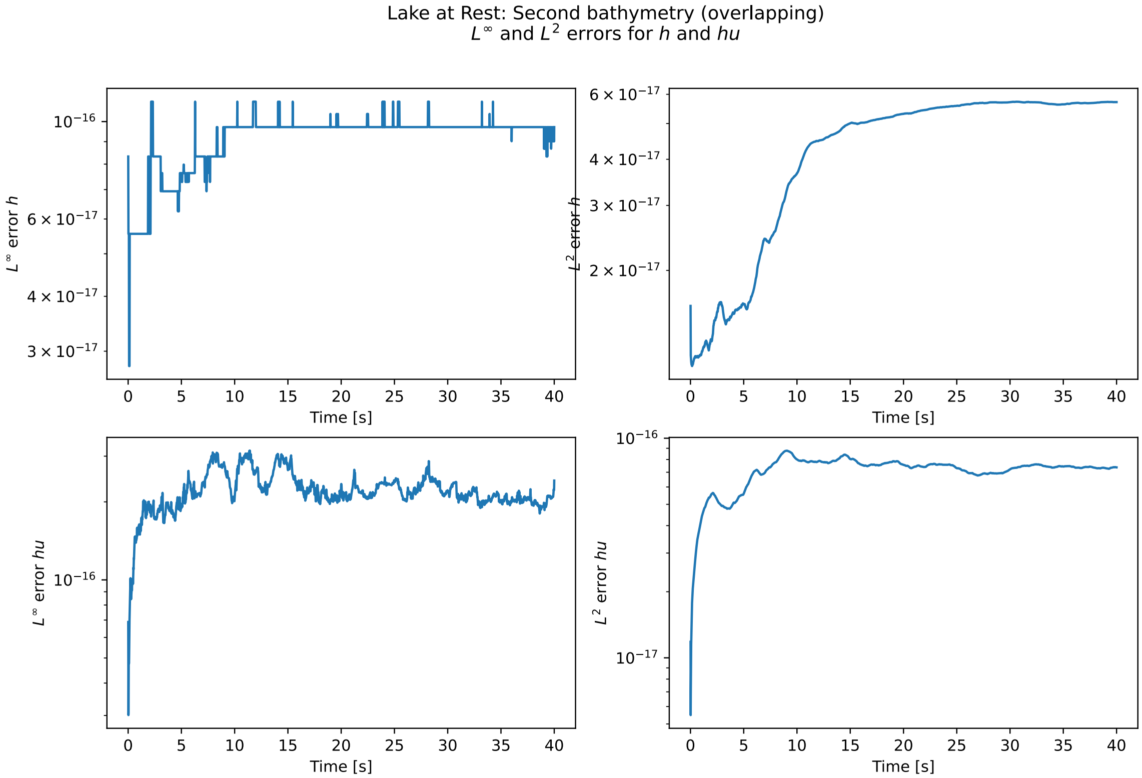
Results

/opt/samoa/time-to-solution/flash/results/resting_lake/resting_lake/BJ_edge/resting_lake.svg



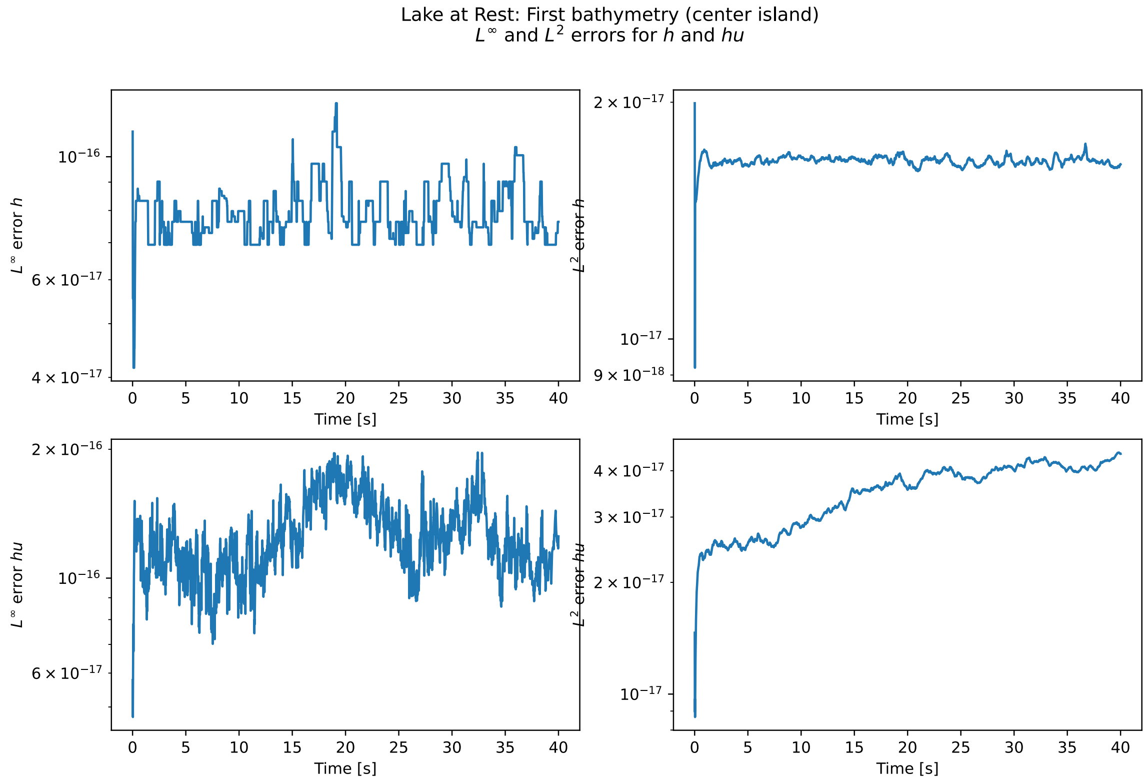
Results

/opt/samoa/time-to-solution/flash/results/resting_lake/resting_lake2/BJ_edge/resting_lake2.svg



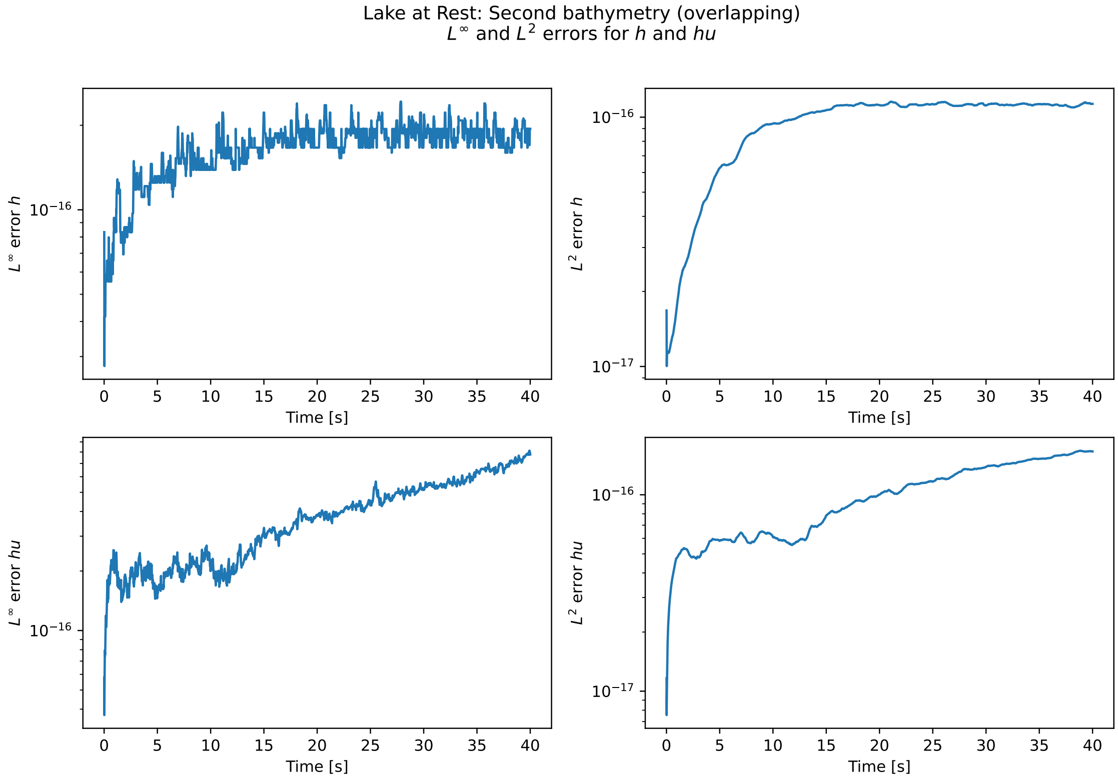
Results

/opt/samoa/time-to-solution/flash/results/resting_lake/resting_lake/BJ_vertex/resting_lake.svg



Results

/opt/samoa/time-to-solution/flash/results/resting_lake/resting_lake2/BJ_vertex/resting_lake2.svg


Lake at Rest: Second bathymetry (overlapping)
L^∞ and L^2 errors for h and hu
L^∞ error h
L^2 error h
L^∞ error hu
L^2 error hu
Time [s]
10^{-16}
10^{-17}

Chapter 4

Scenario 4.2: Tsunami runup onto a linearly sloping beach

Notes

Analytical solutions for specific points in time are provided by http://isec.nacse.org/workshop/2004_cornell/bmark1.html and converted to CSV here.

The refinement level `20` was chosen, which results in a triangle leg length of about `49.219` - roughly the same as in [1] (`50`): see section 4.2, paragraph two.

The dry/wet tolerance of `10e-2` was directly taken from [1]. The simulation time of `230` seconds was chosen to fit all interesting points in time.

The courant number of `0.35` was found using trial and error. The average computation time step size is about `0.0155` seconds, while the fixed time step size in [1] is `0.04` seconds.

A XDMF output filter is used to limit the output to a small horizontal slice in the middle. This is to reduce disk space usage. Furthermore, unused HDF5 chunks were removed manually from the dataset (The `-light` dataset).

The y axis offset was changed such that the bathymetry is zero at the coordinate origin. This was done to ensure the correct calculation of the water level offset.

Evaluation

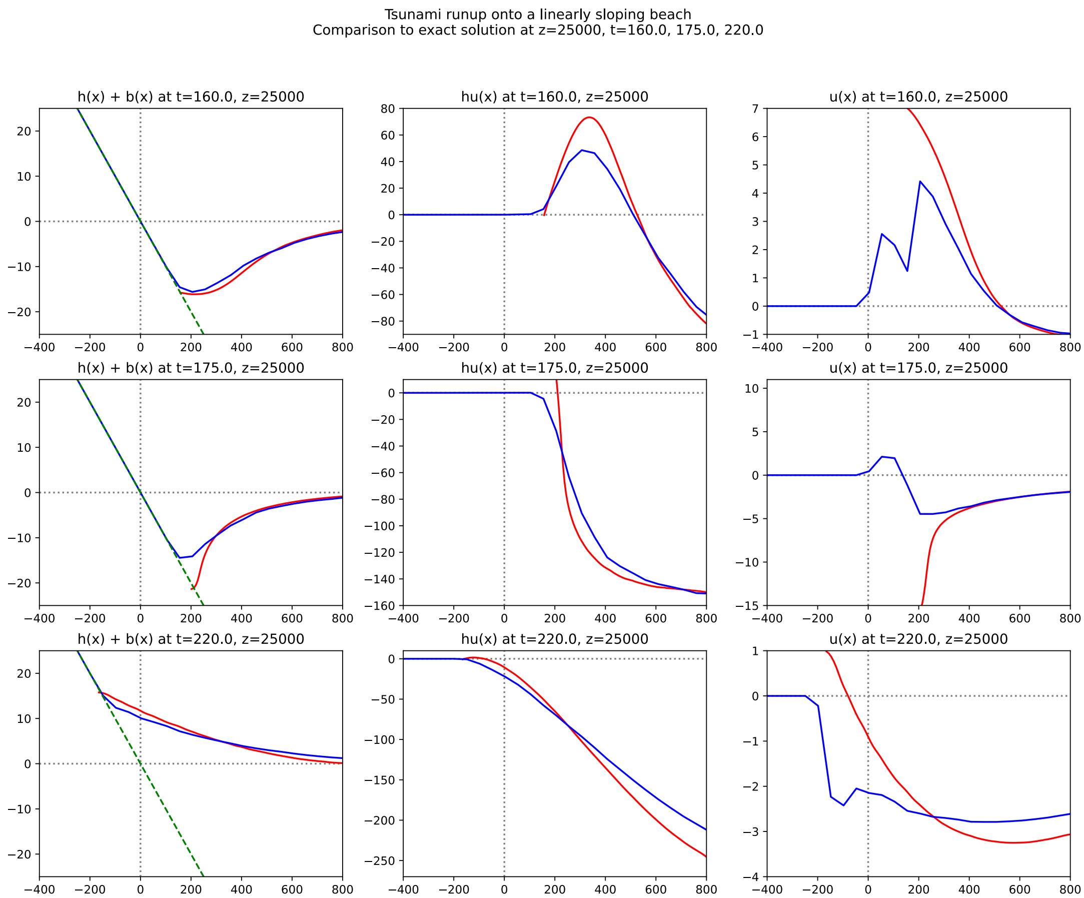
A z-cross-section is interpolated and plotted for all relevant variables, and compared to the analytical solution at `t = 160, 175, 220`. These results can then be compared with [1], see figure 6.

Line `19` in `linear_beach.py` may be modified to interpolate at different z values (default: `25000`).

Expanded postprocessing calls

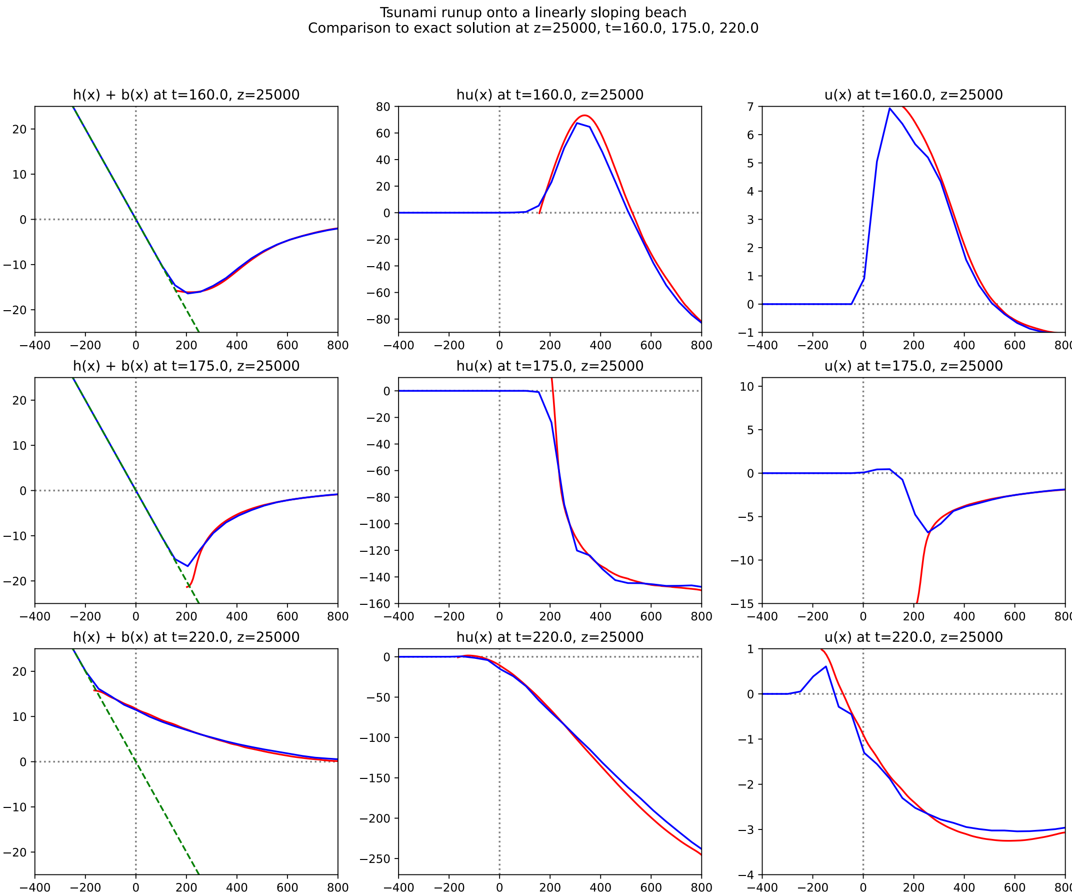
Results

/opt/samoa/time-to-solution/flash/results/linear_beach/BJ_edge/csvcomp.svg



Results

/opt/samoa/time-to-solution/flash/results/linear_beach/BJ_vertex/csvcomp.svg


Tsunami runup onto a linearly sloping beach
Comparison to exact solution at z=25000, t=160.0, 175.0, 220.0
h(x) + b(x) at t=160.0, z=25000
hu(x) at t=160.0, z=25000
u(x) at t=160.0, z=25000
h(x) + b(x) at t=175.0, z=25000
hu(x) at t=175.0, z=25000
u(x) at t=175.0, z=25000
h(x) + b(x) at t=220.0, z=25000
hu(x) at t=220.0, z=25000
u(x) at t=220.0, z=25000

Chapter 5

Scenario 4.3: Long wave resonance in a paraboloid basin

Notes

The refinement level `15` was chosen, which results in a triangle leg length of about `88.39` - the same as in [1]: see section 4.3, paragraph two.

The dry/wet tolerance of `10e-2` resp. `10e-8` was directly taken from [1].

The courant number of `0.2` was found by using a estimated average of the values given in [1]. The average computation time step size is about `0.451` seconds, while the fixed time step size in [1] is `2.534` seconds.

The datasets only contain the timesteps at `t = n * 0.25P` from `t = 0` up to `t = 2P` to save space.

Evaluation

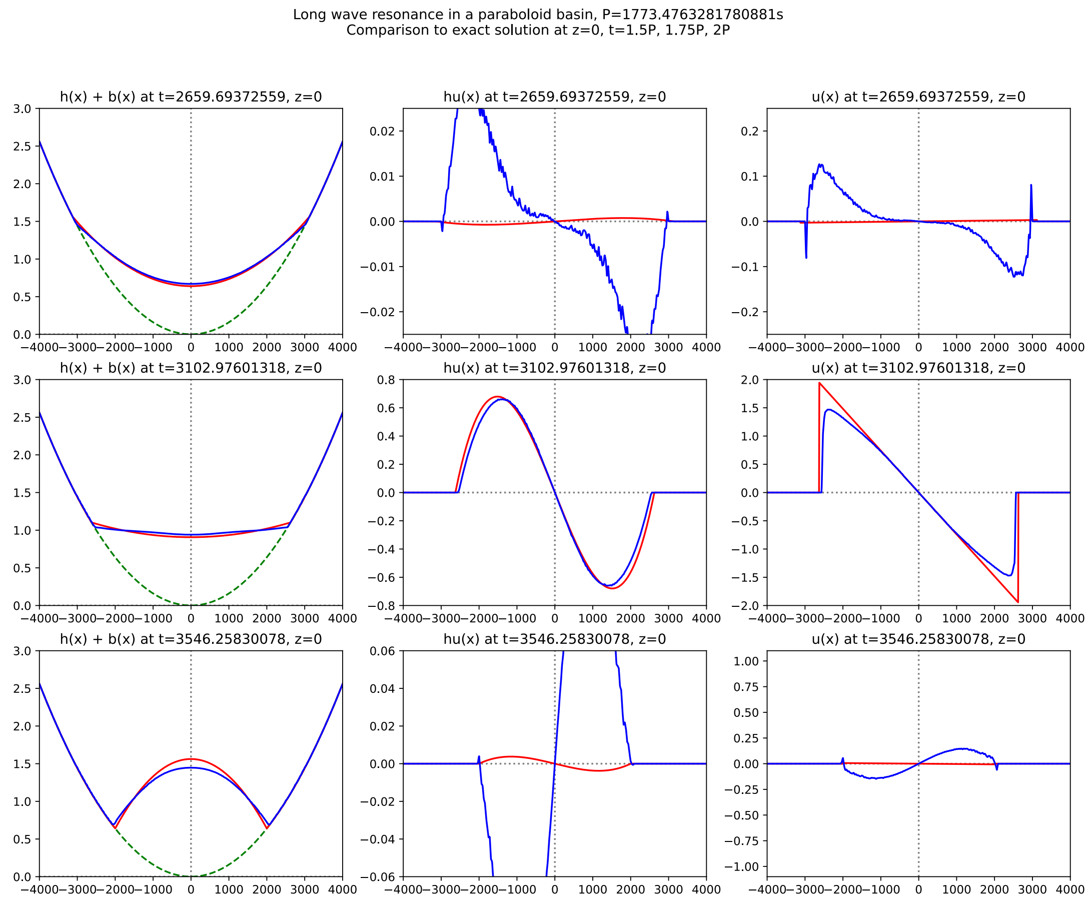
A z-cross-section is interpolated at `z = 0` and plotted for all relevant variables, and compared to the analytical solution at `t = 1.5P, 1.75P, 2P`. These results can then be compared with [1], see figure 7 and 8.

Contour plots at `t = 2P` are generated for the full domain. These results can then be compared with [1], see figure 9.

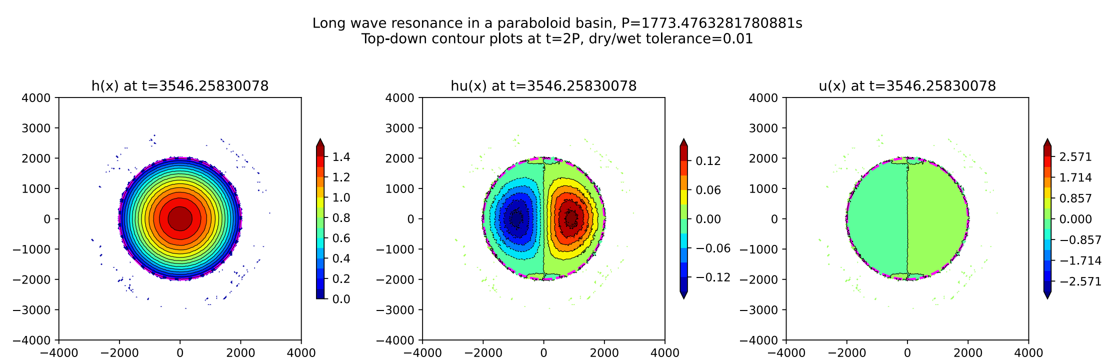
Expanded postprocessing calls

Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_edge/anacomp.svg

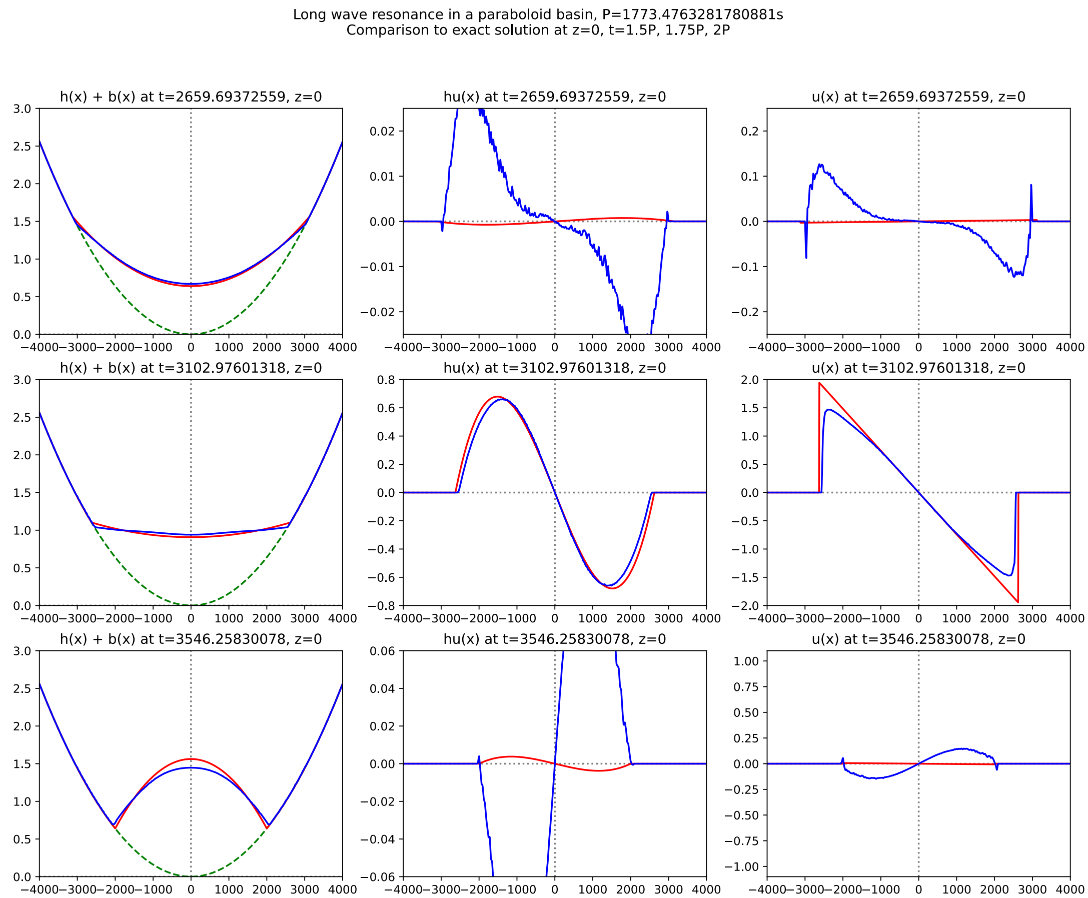


/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_edge/contour.svg

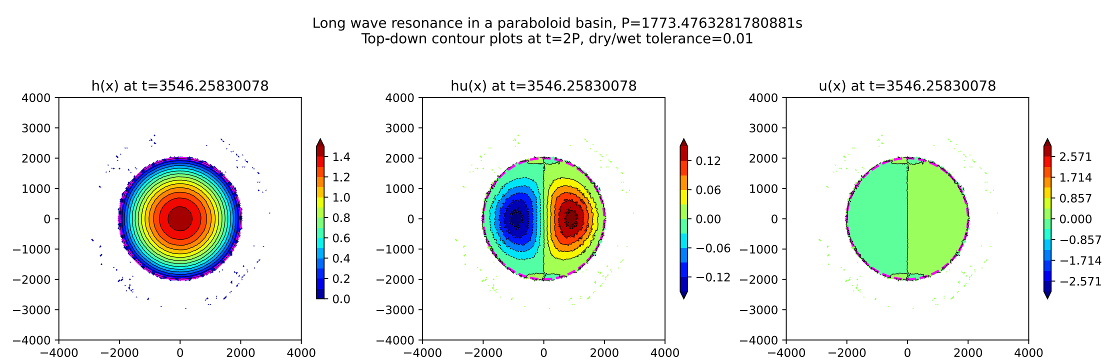


Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_edge/anacomp.svg

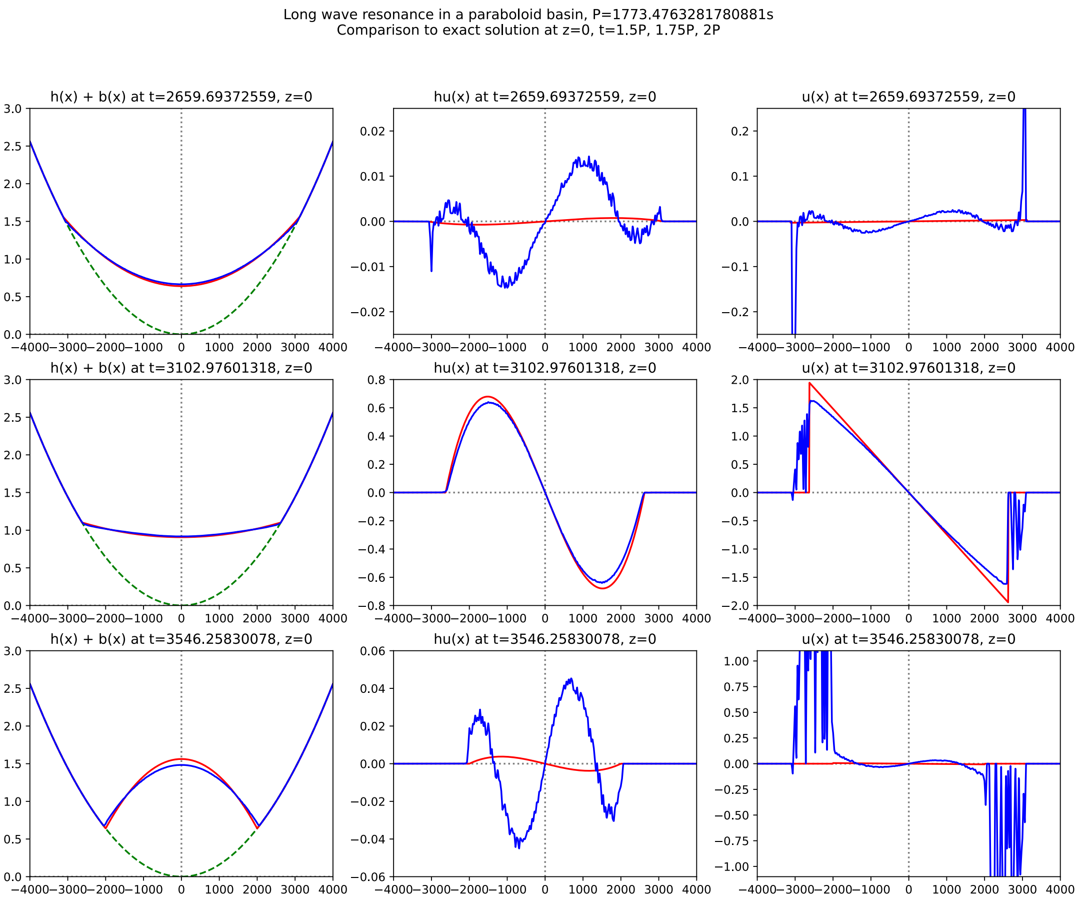


/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_edge/contour.svg



Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-8/BJ_edge/anacomp.svg



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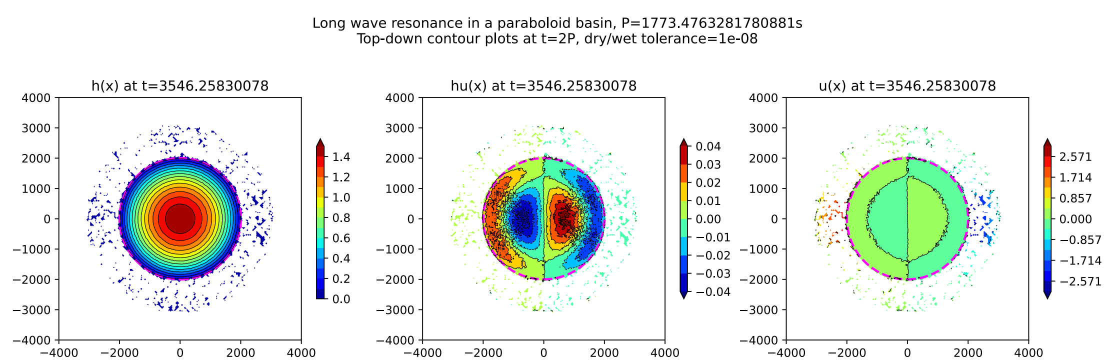
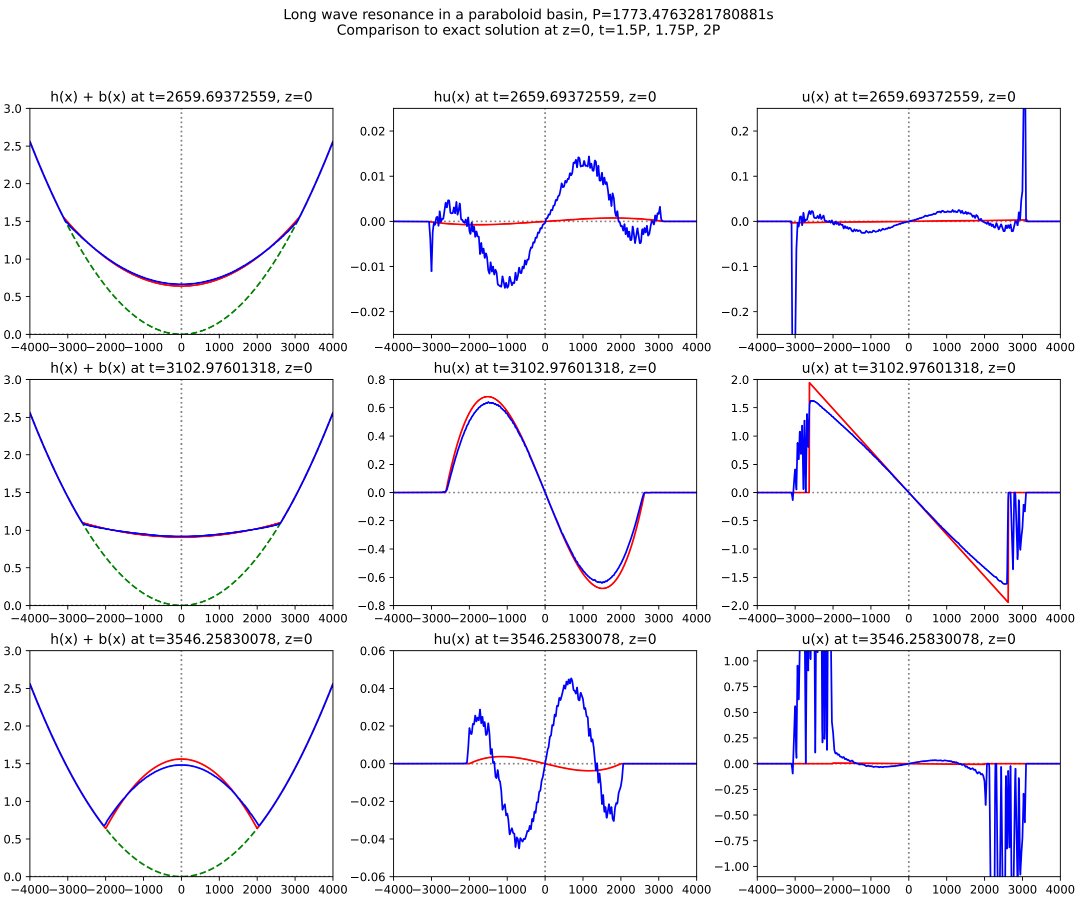


Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-8/BJ_edge/anacomp.svg



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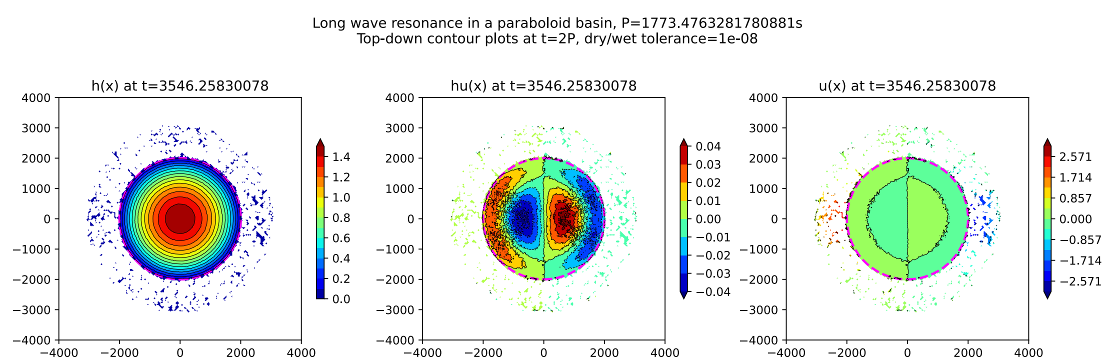
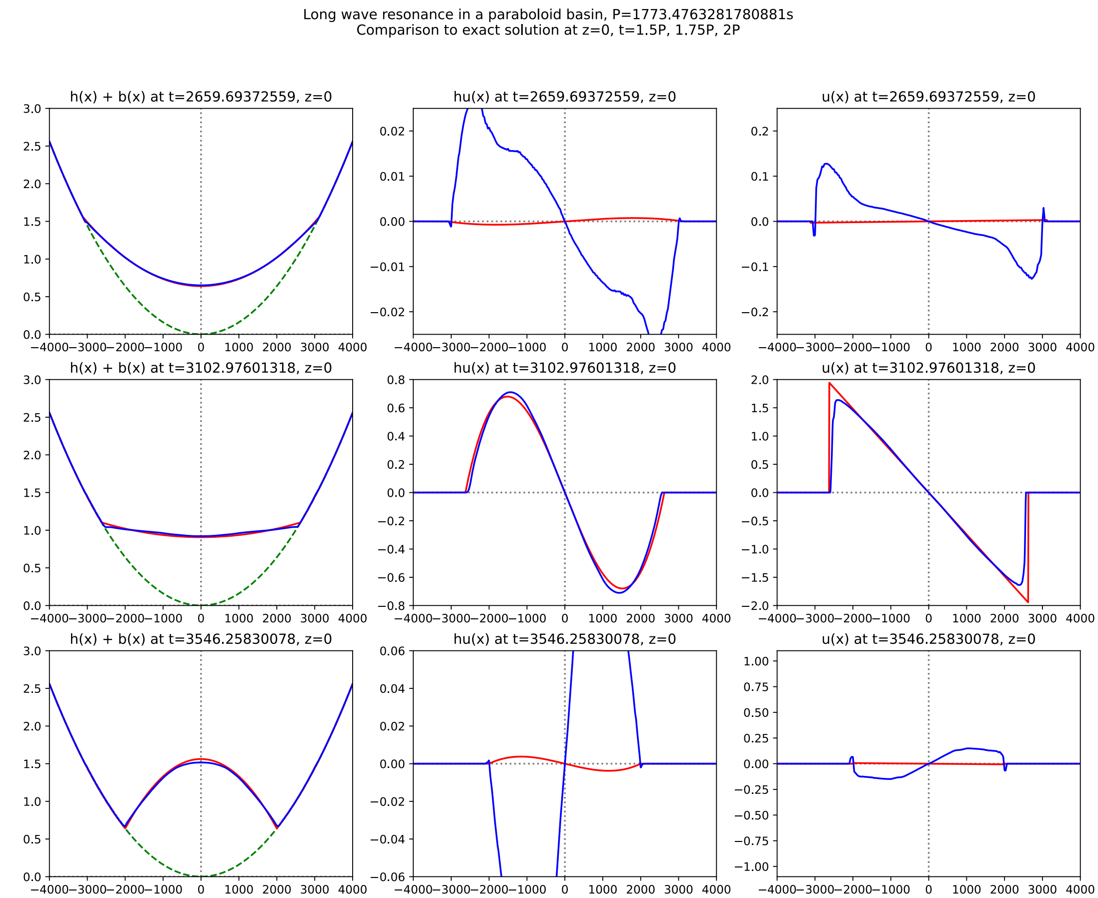
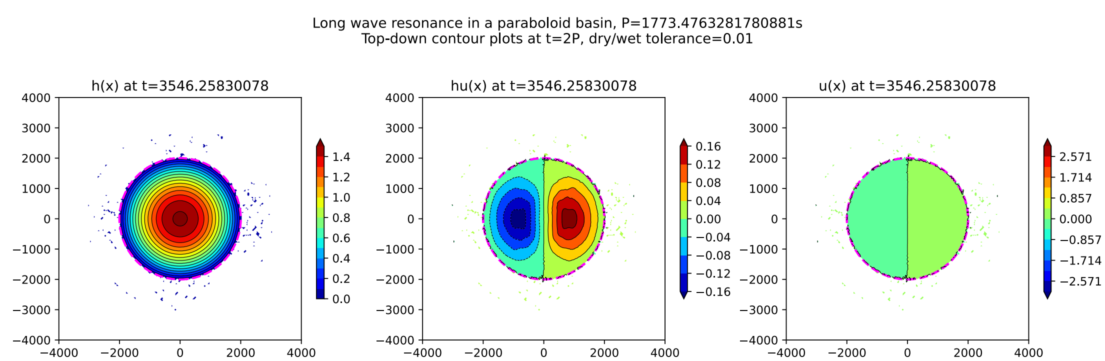


Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_vertex/anacomp.svg

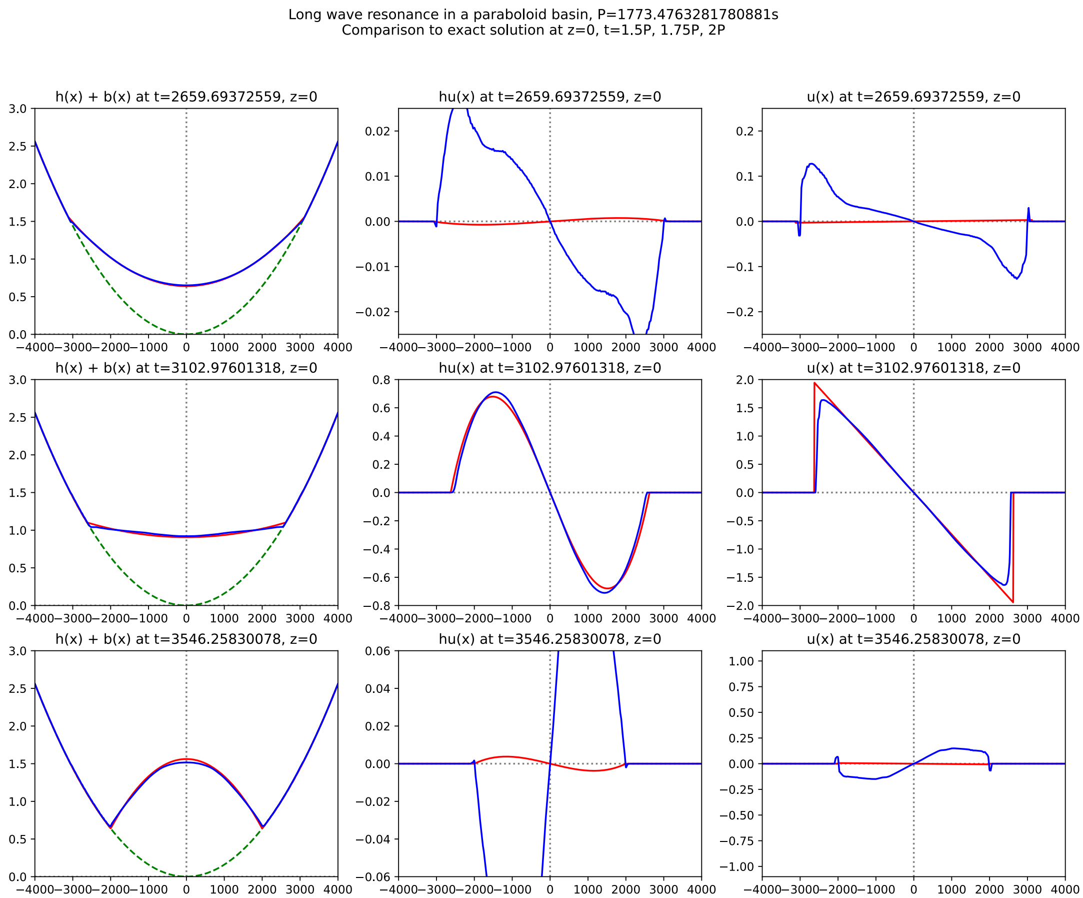


/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_vertex/contour.svg

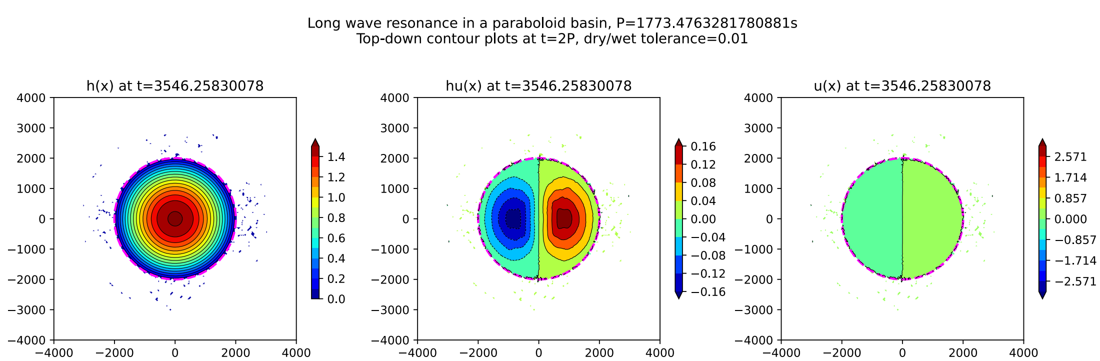


Results

/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_vertex/anacomp.svg



/opt/samoa/time-to-solution/flash/results/longwave_basin/dw10e-2/BJ_vertex/contour.svg



Results

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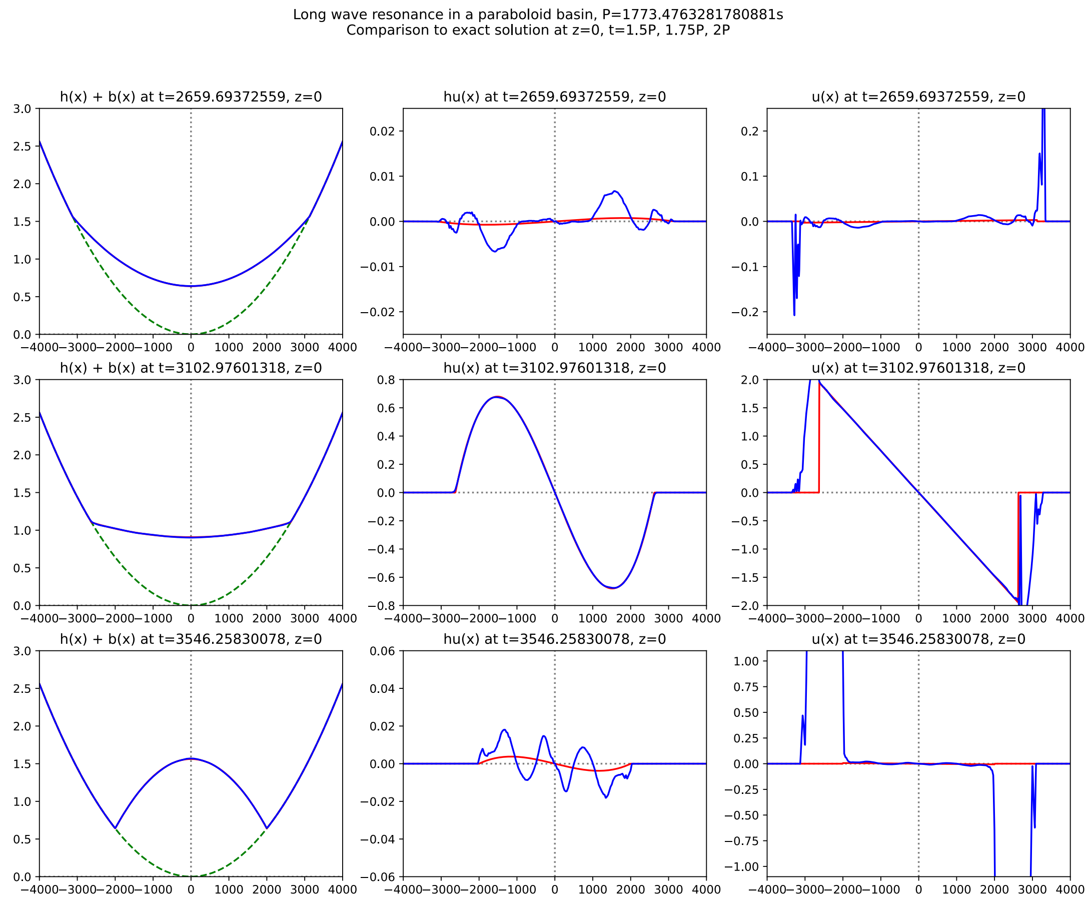

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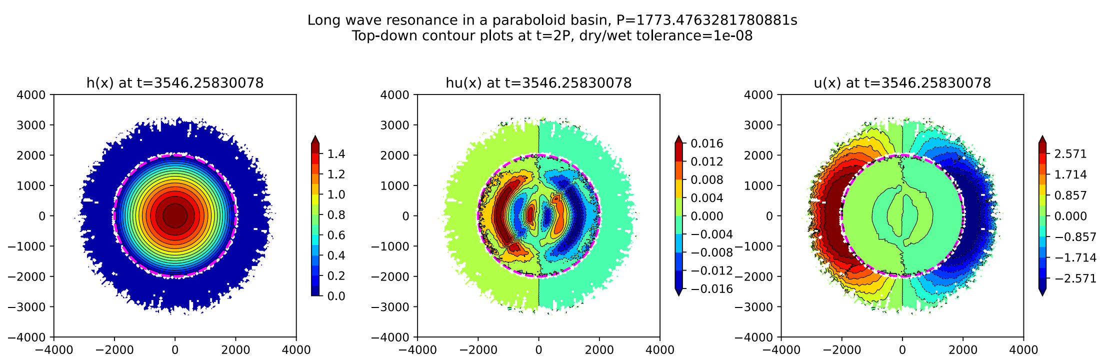

Results

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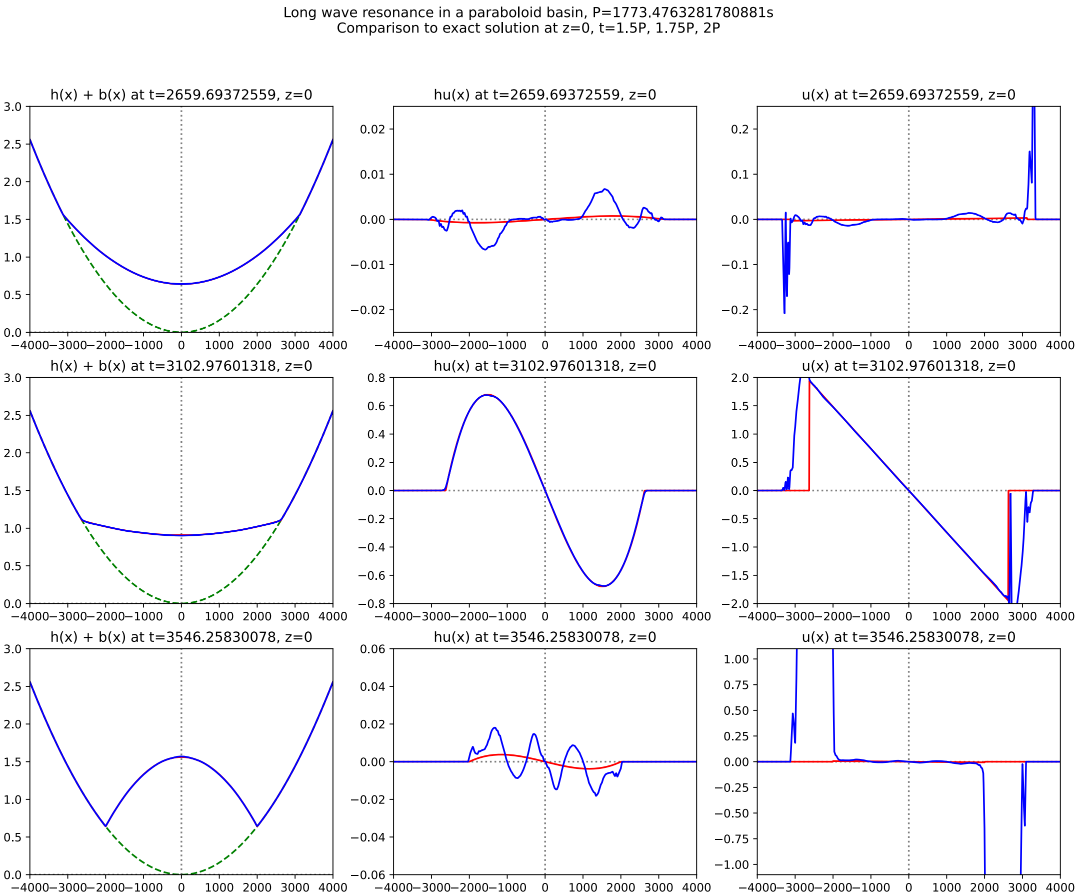

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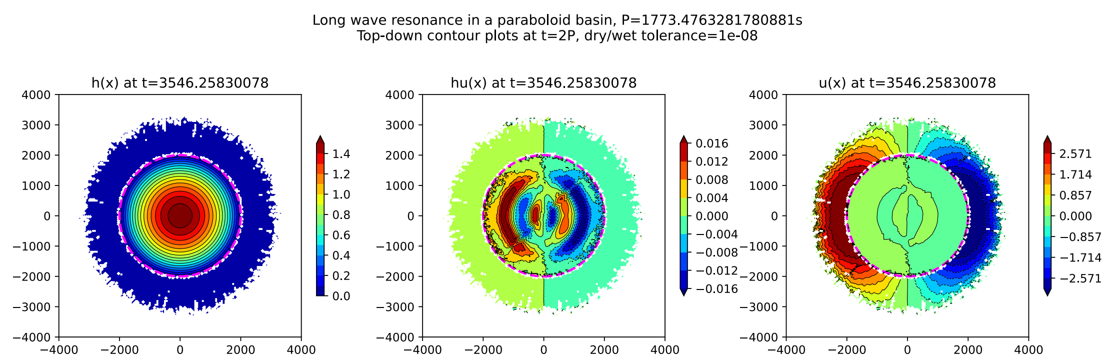


Chapter 6

Scenario 4.4: Oscillatory flow in a parabolic bowl

Notes

The refinement level `12` was chosen, which results in `64*64*2` elements - the same as in [1]: see section 4.4, paragraph two.

The dry/wet tolerance of `10e-3` was directly taken from [1].

The courant number of `0.3` was found by experimentation. The average computation time step size is about `0.002218` seconds, while the fixed time step size in [1] is `0.004487` seconds.

The datasets only contain the timesteps at `t = n * (P / 1000)` from `t = 0` up to `t = 2P` to save space.

A series of runs are made for refinement levels `10` to `18`, and written only at `t = 2P`.

Evaluation

A z-cross-section is interpolated at `z = 0` and plotted for all relevant variables, and compared to the analytical solution at `t = 2P`. These results can then be compared with [1], see figure 11.

Contour plots at `t = 2P` are generated for the full domain. These results can then be compared with [1], see figure 12.

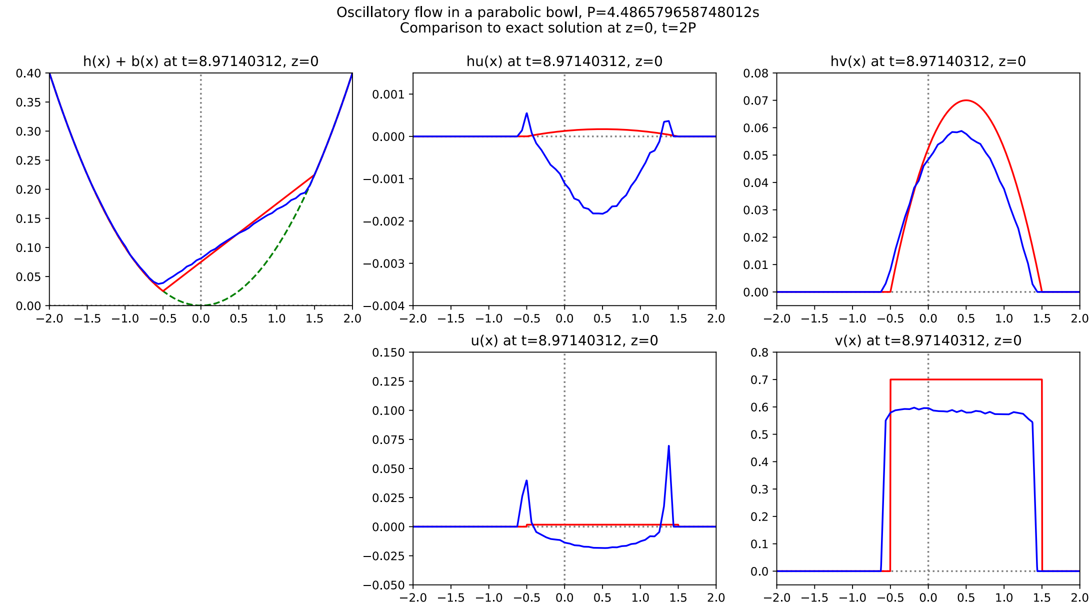
A limiter error series is plotted for different refinement levels. These results can then be compared with [1], see figure 14.

Mass and energy errors are calculated and plotted over time. These results can then be compared with [1], see figure 15.

Expanded postprocessing calls

Results

/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/anacomp.svg



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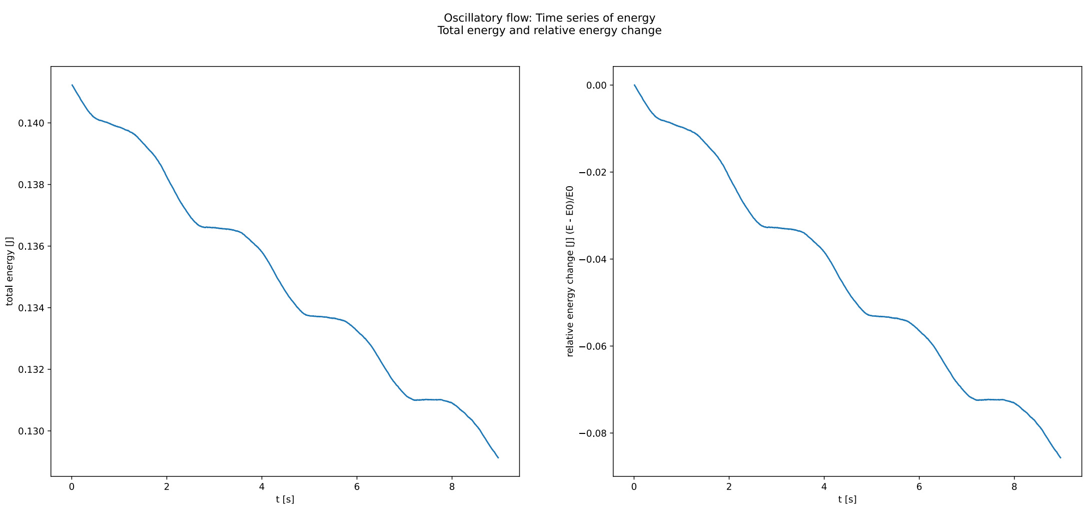

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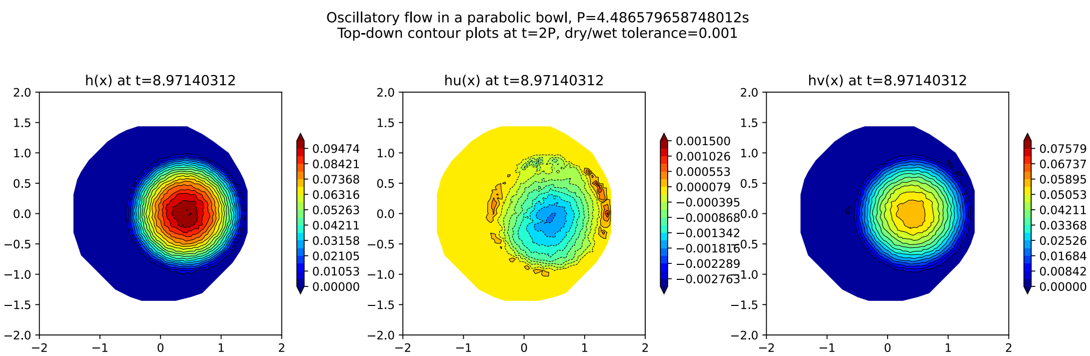
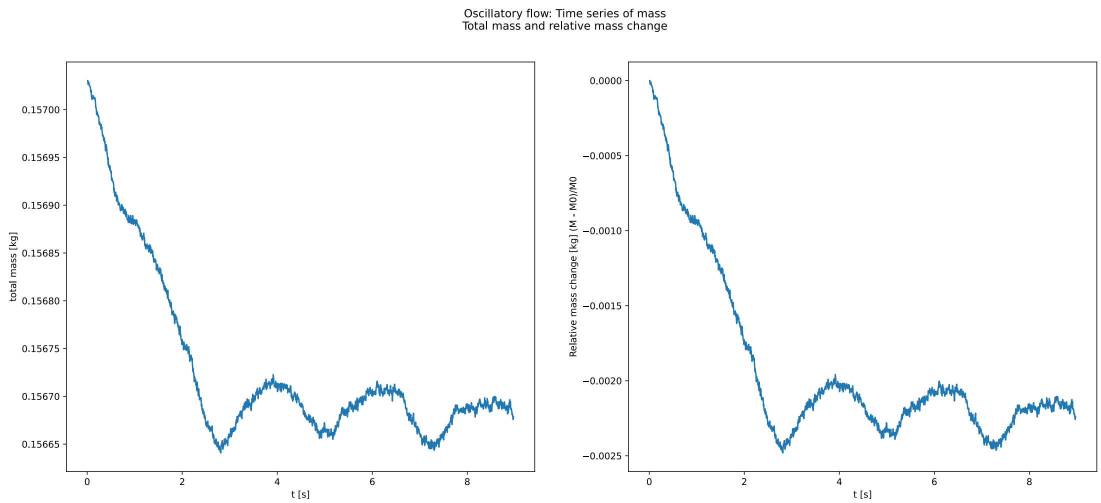
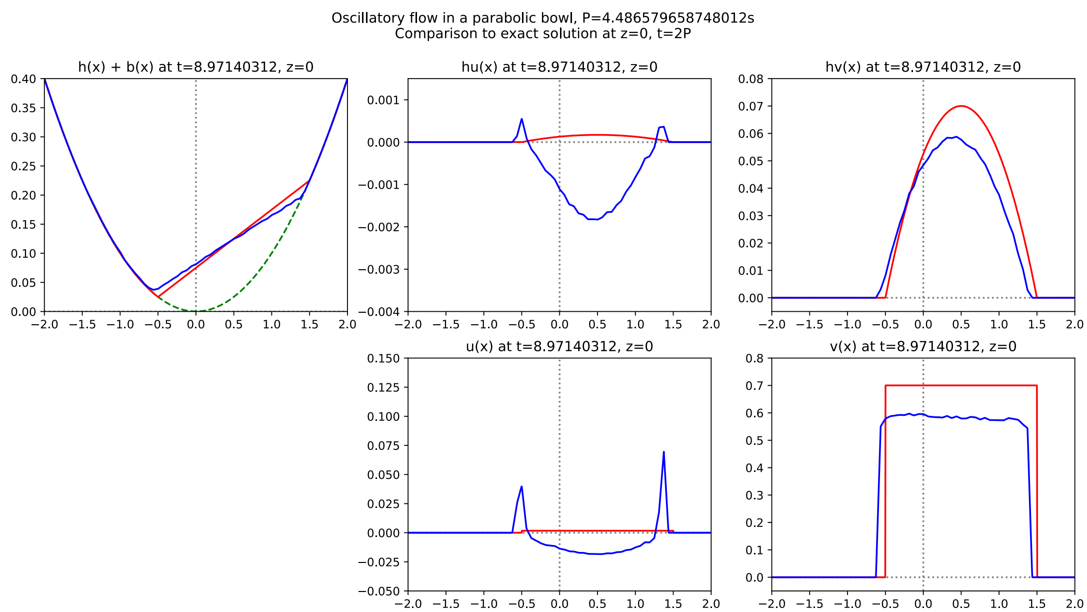


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/mass.svg



Results

/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/anacomp.svg



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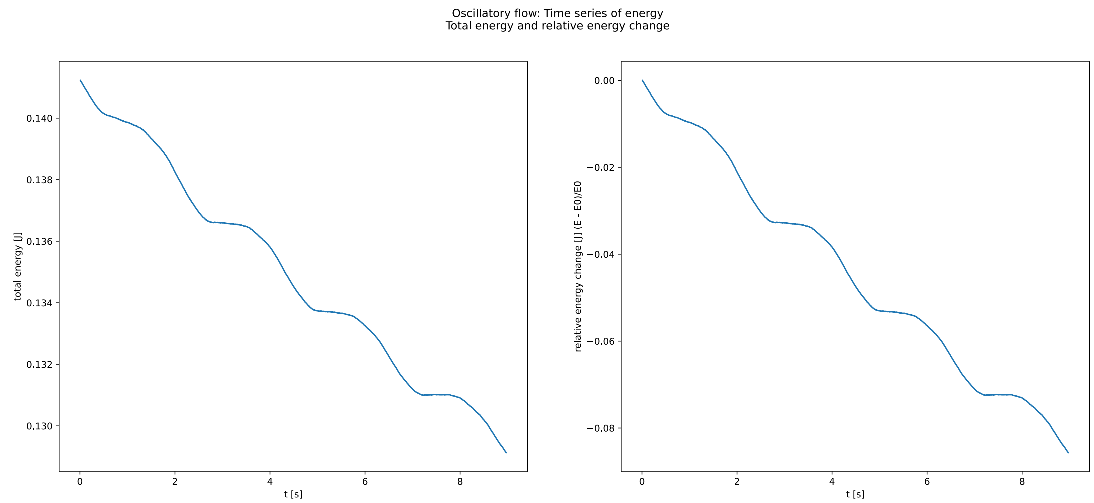

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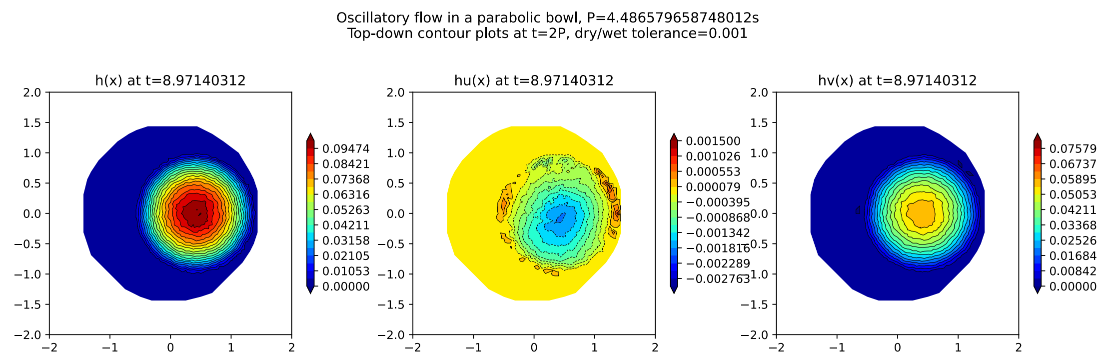
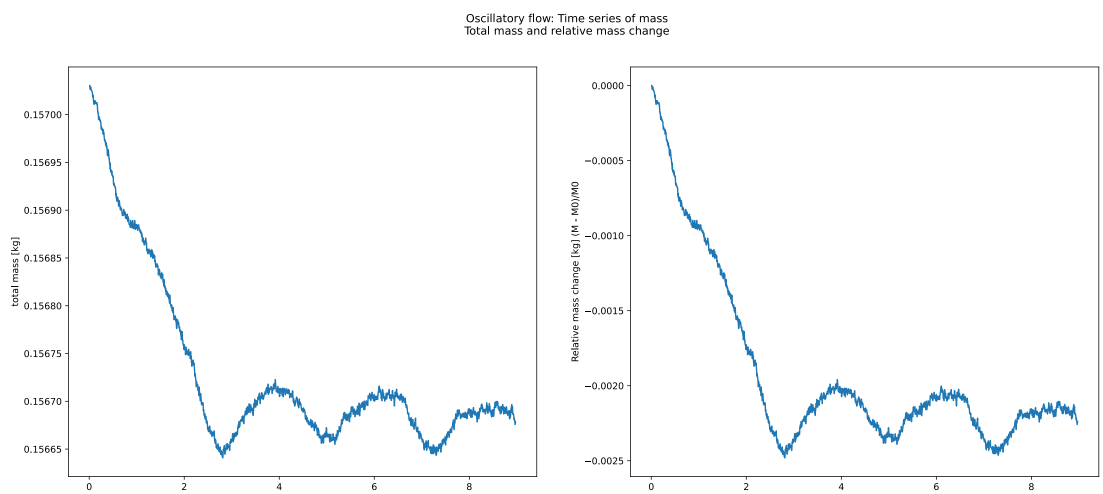


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/mass.svg



Results

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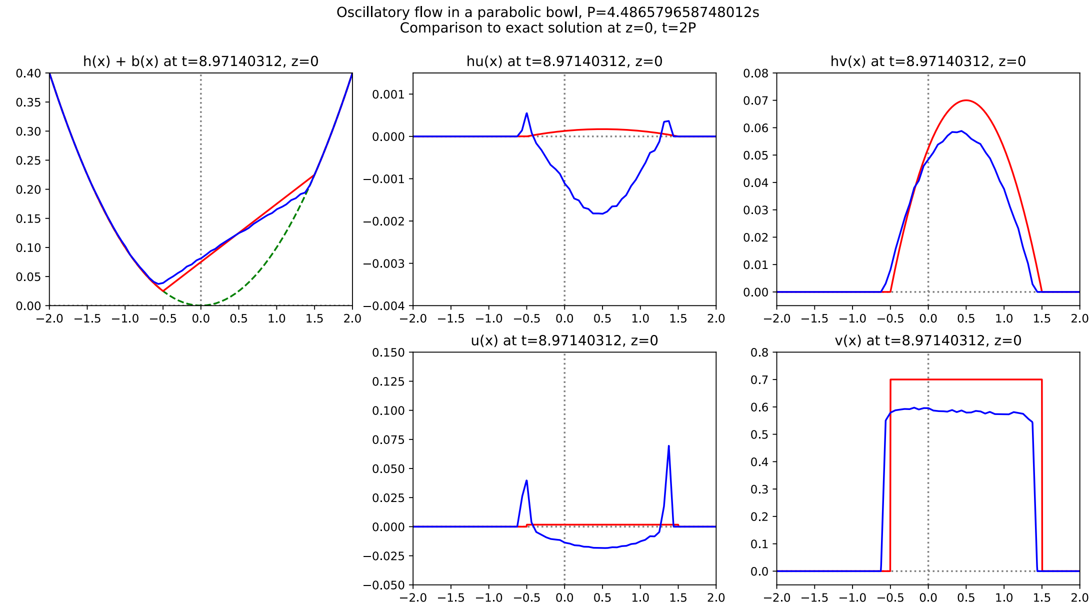

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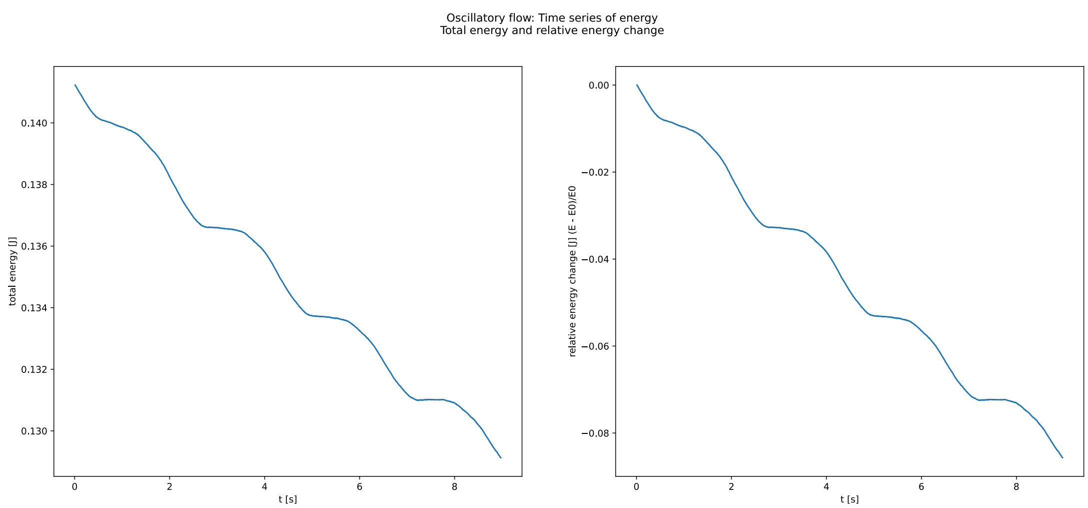

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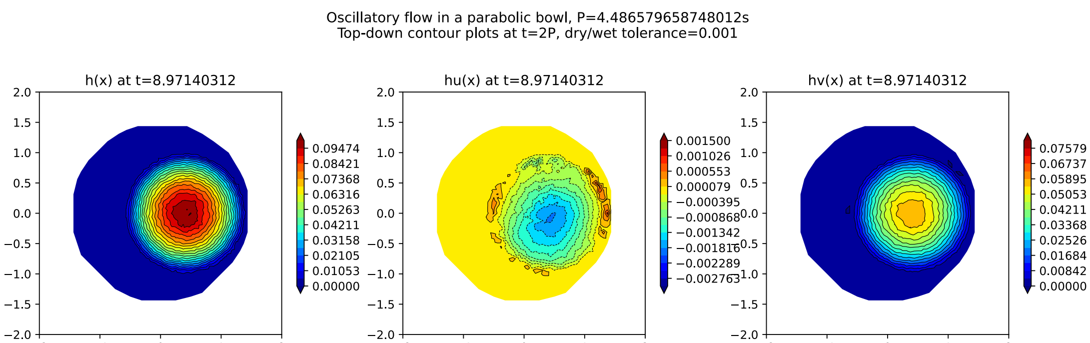

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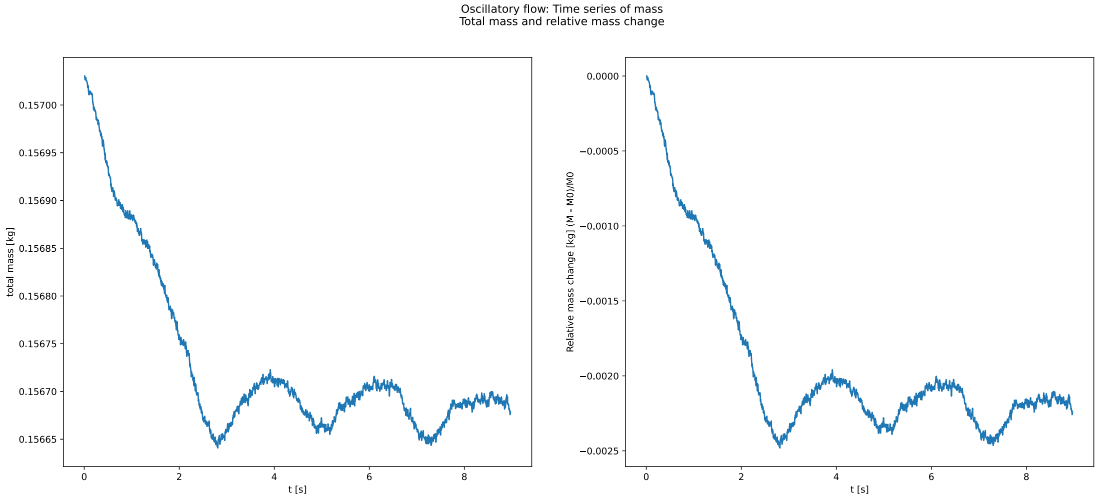
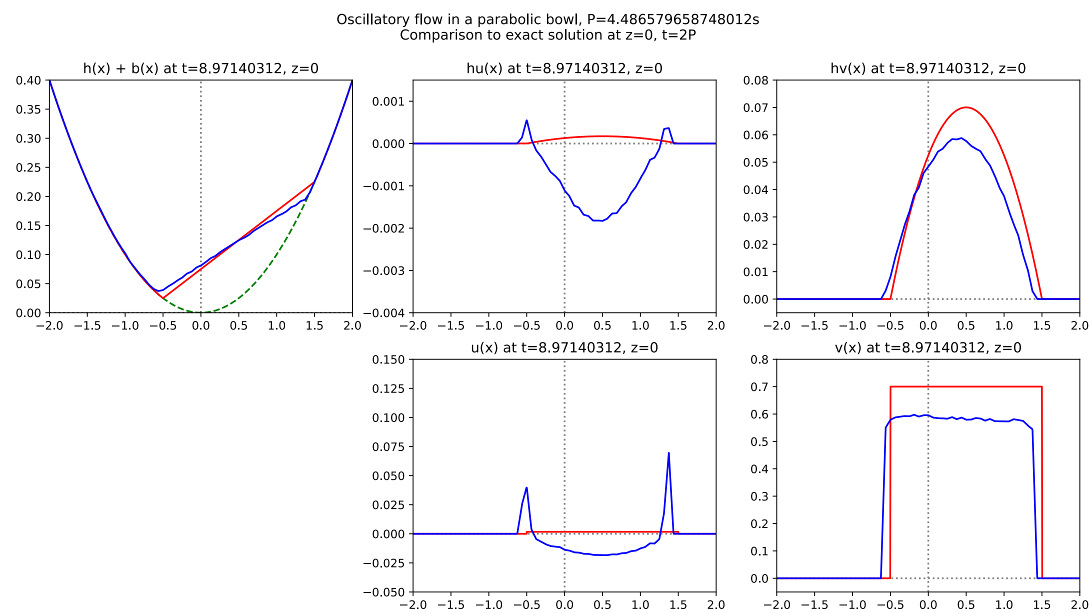
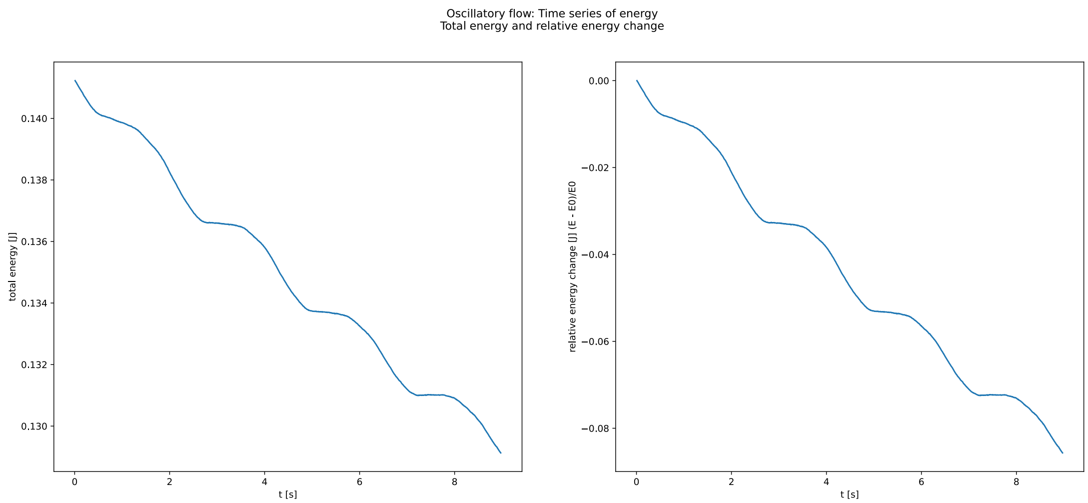


Results

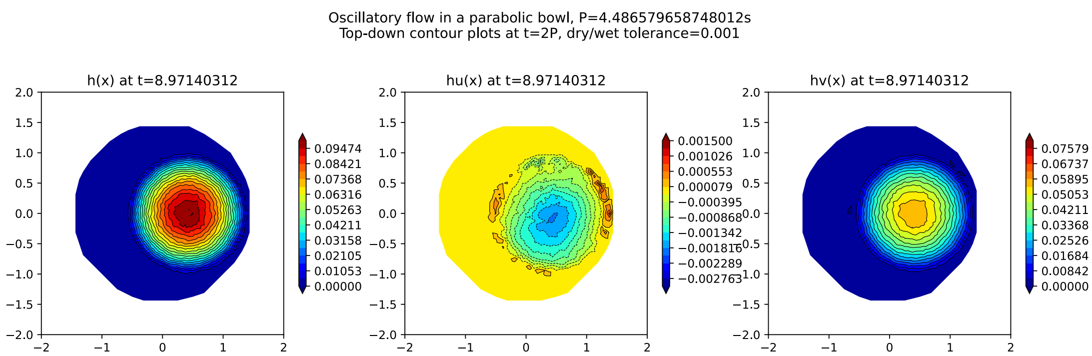
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/anacomp.svg



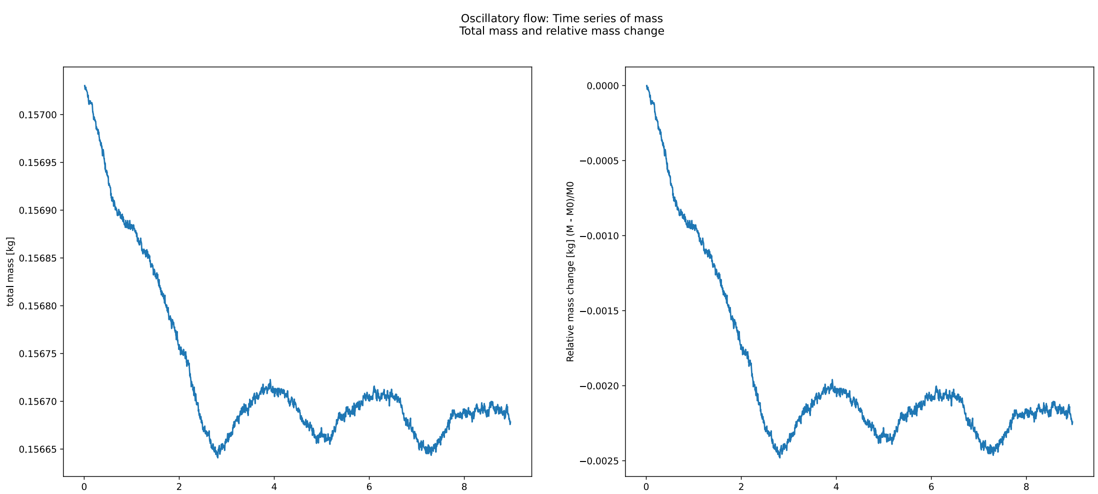
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/energy.svg



/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/contour.svg

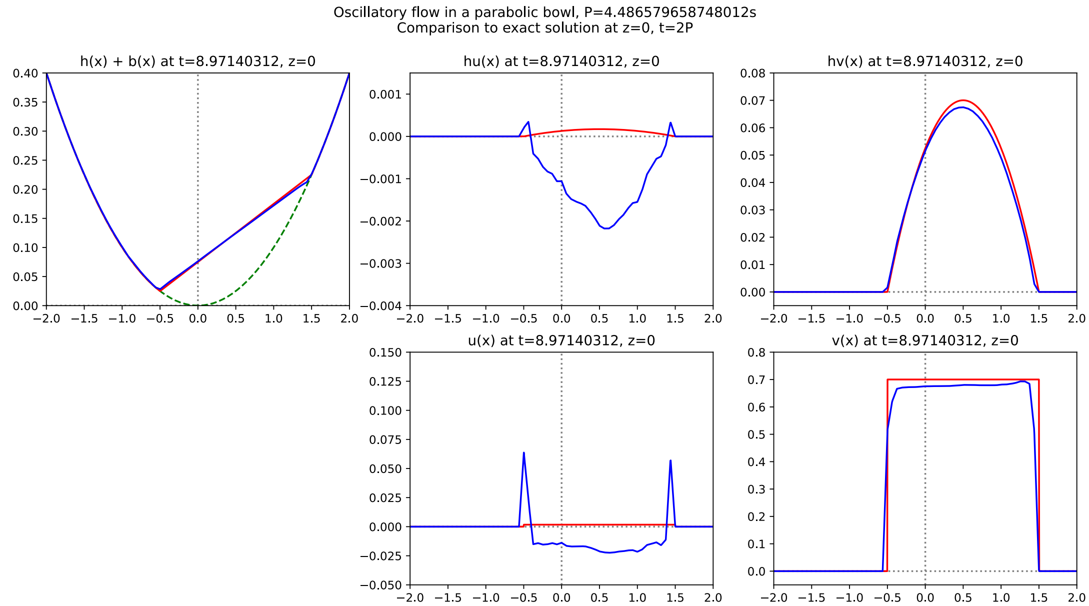


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_edge/mass.svg

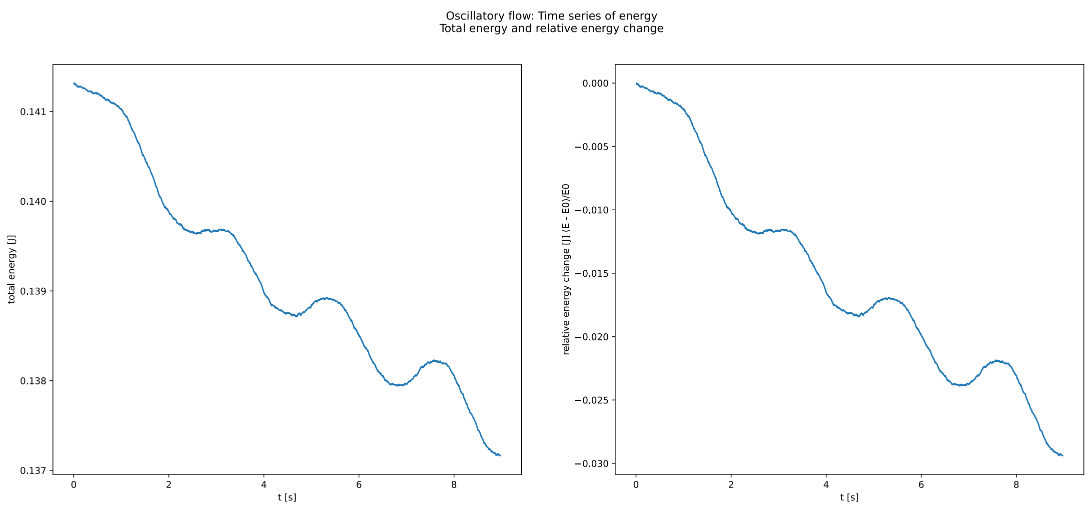


Results

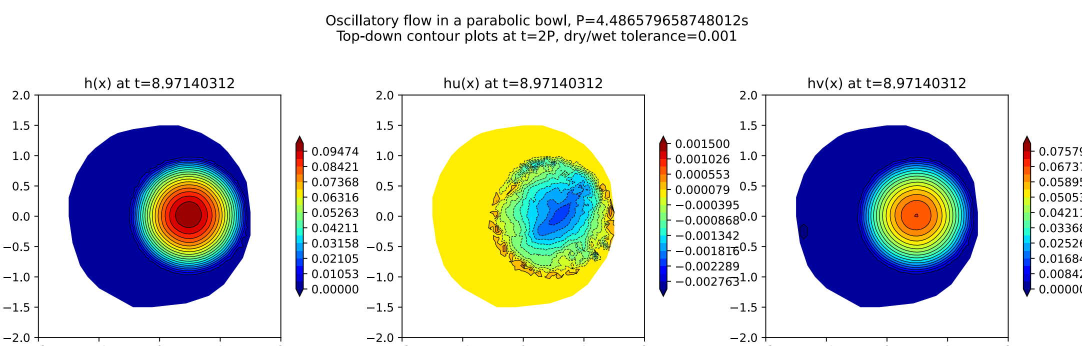
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/anacomp.svg



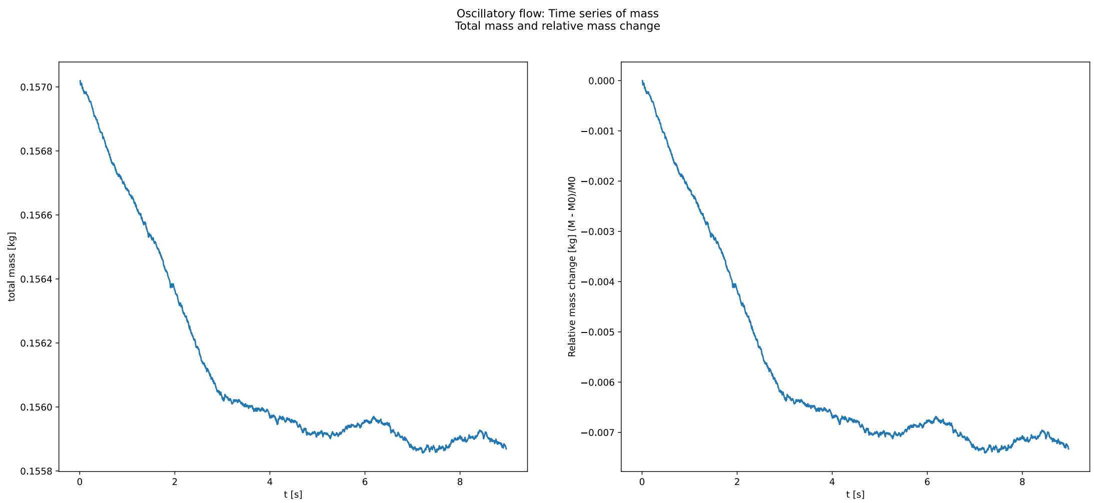
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/energy.svg



/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/contour.svg

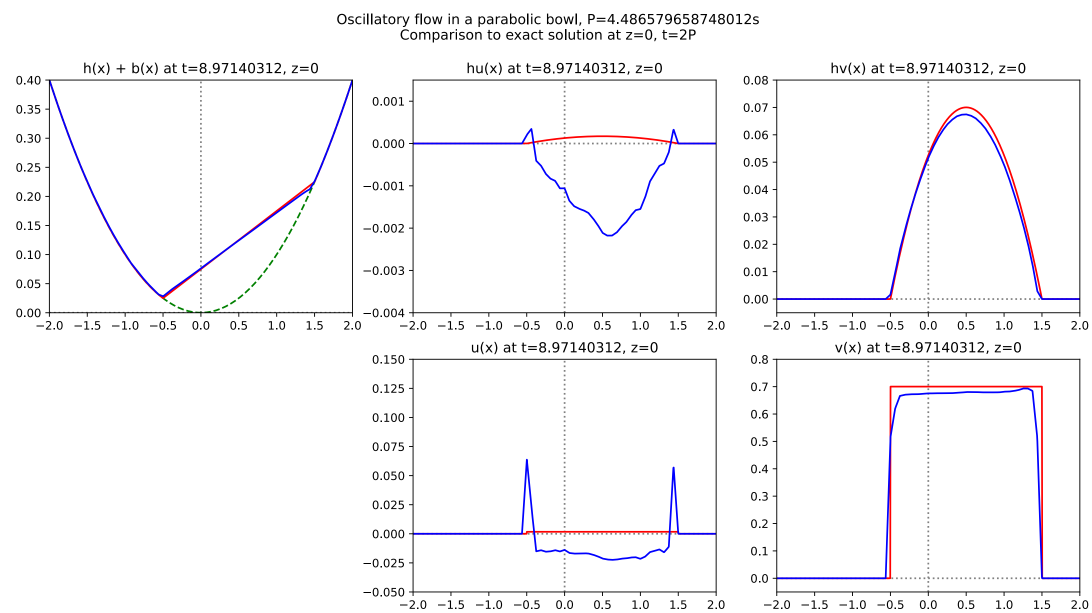


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/mass.svg

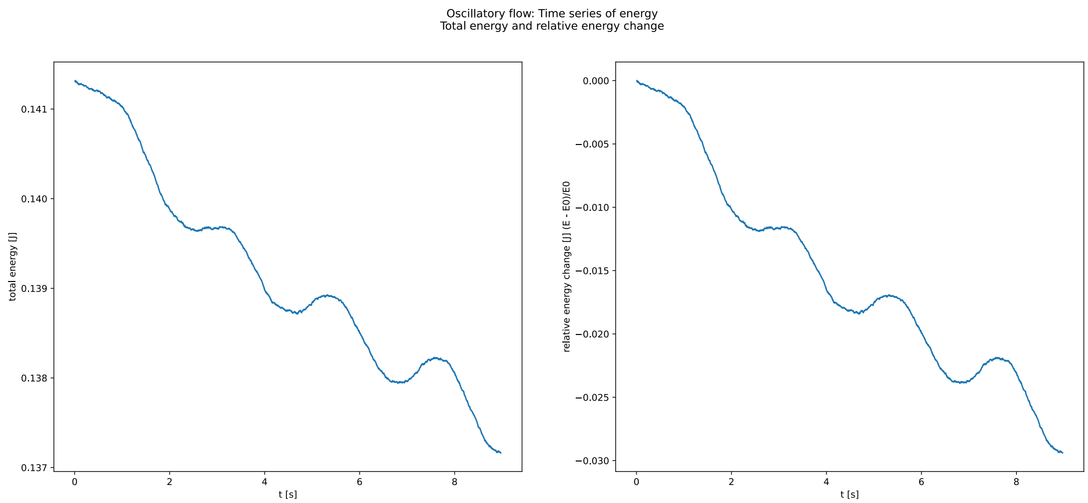


Results

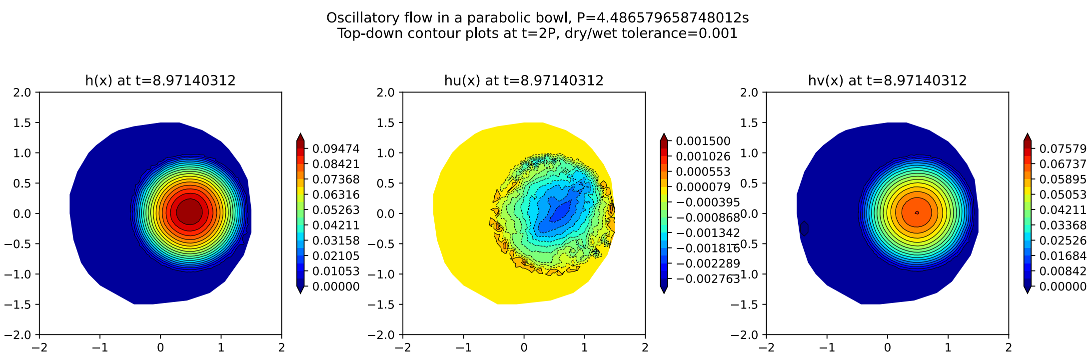
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/anacomp.svg



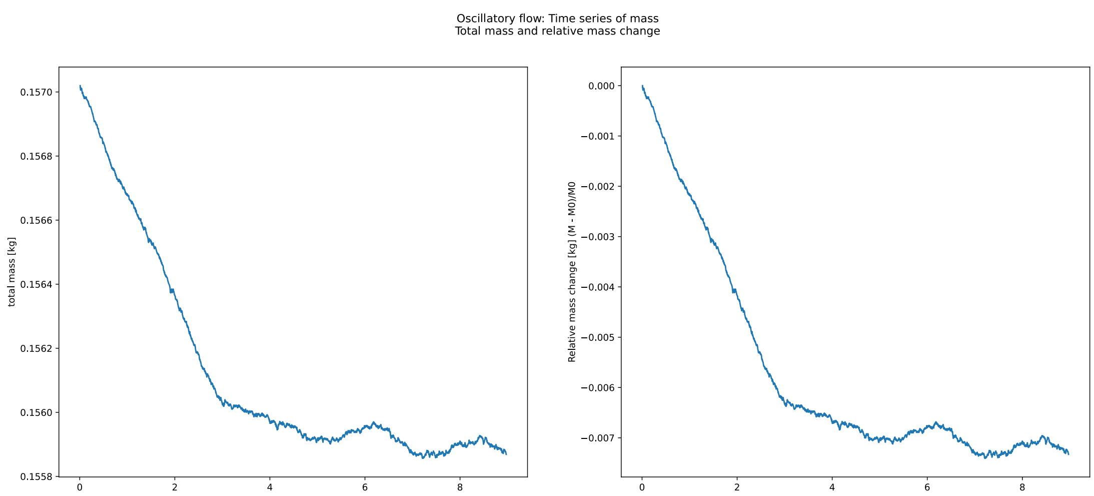
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/energy.svg



/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/contour.svg

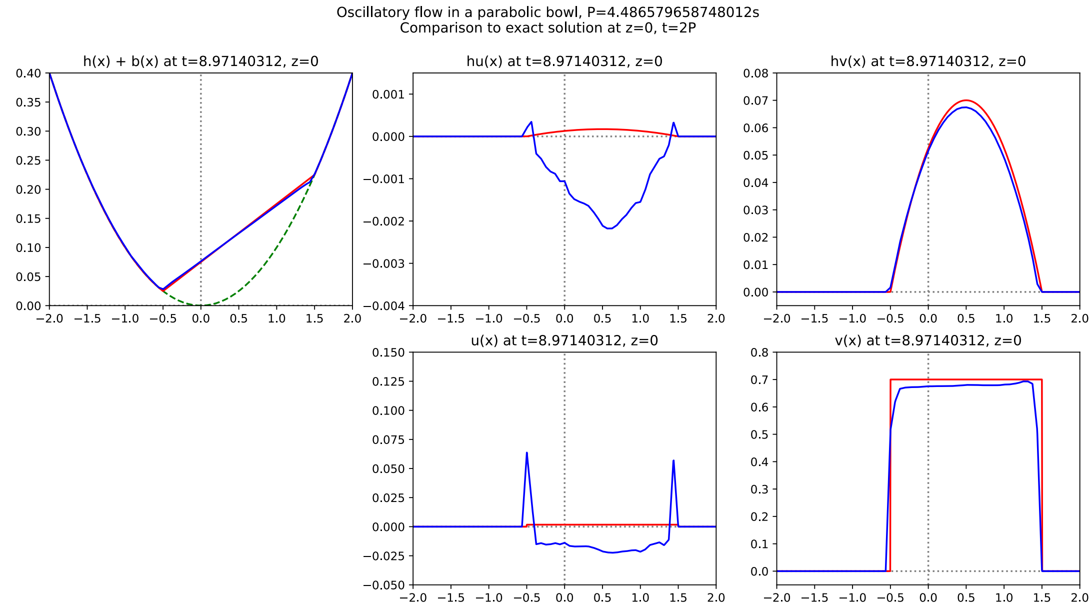


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/mass.svg

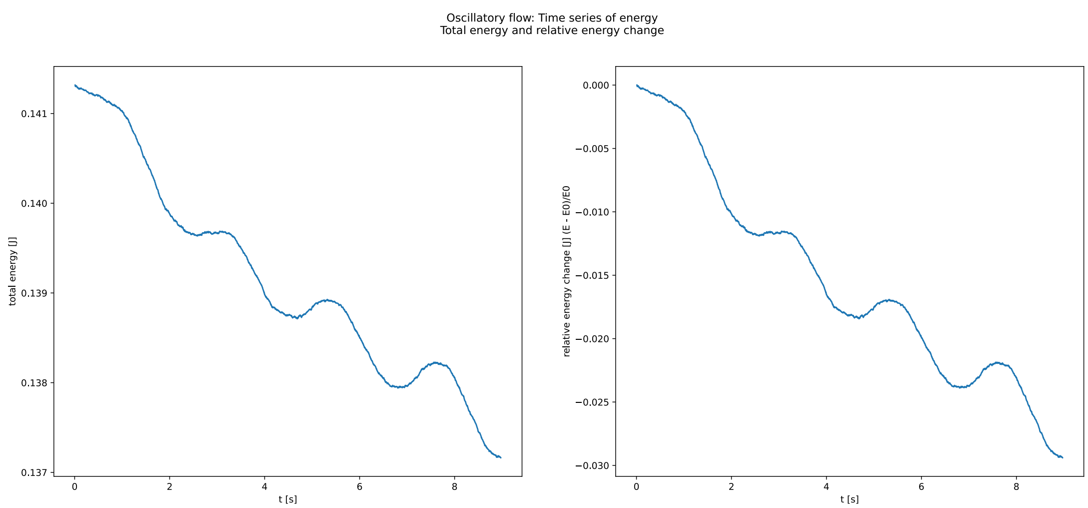


Results

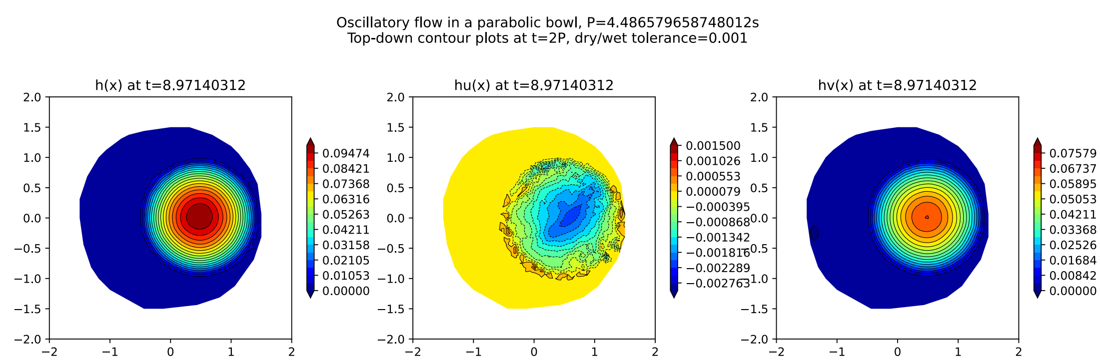
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/anacomp.svg



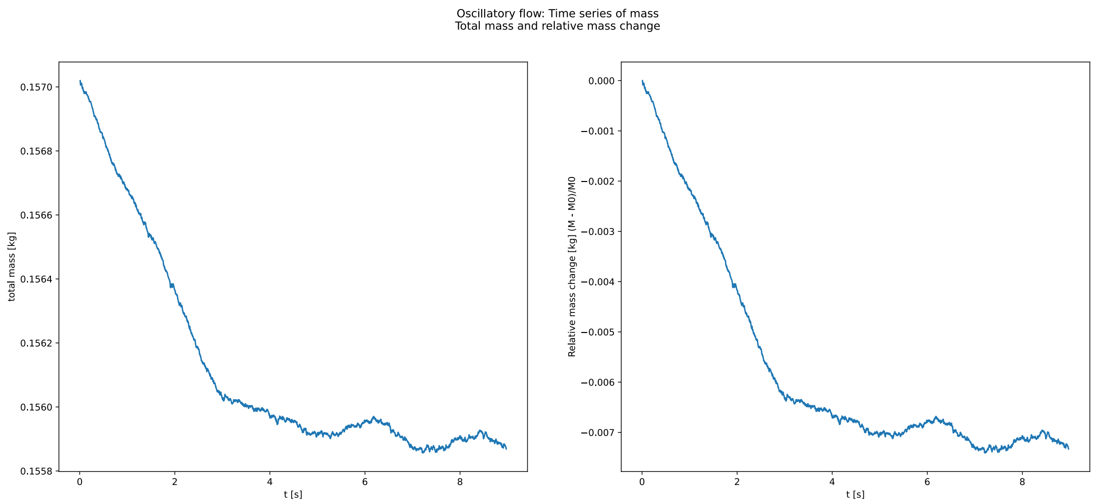
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/energy.svg



/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/contour.svg

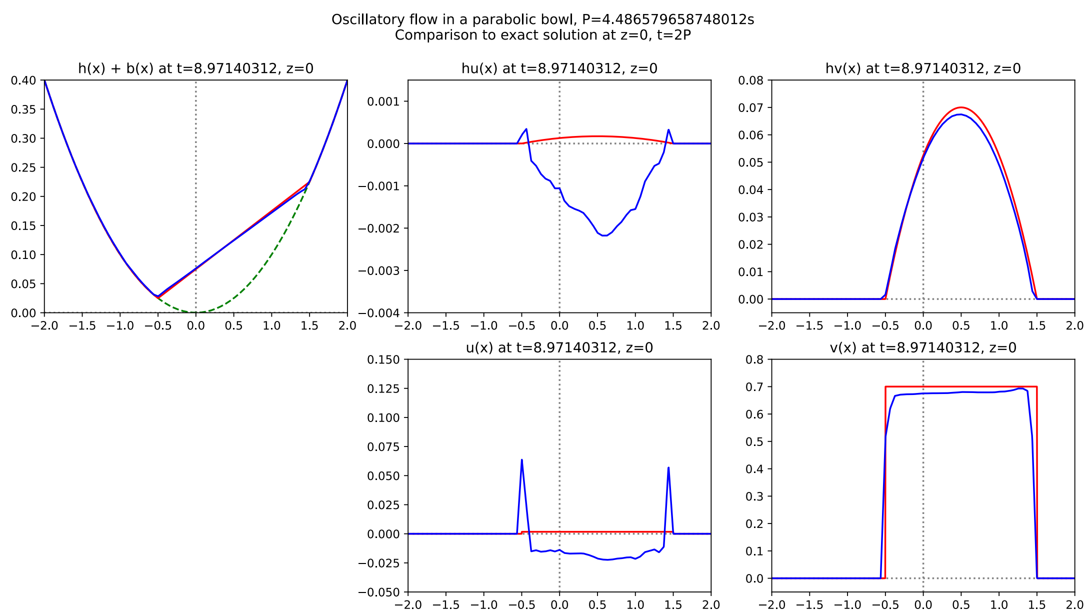


/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/mass.svg

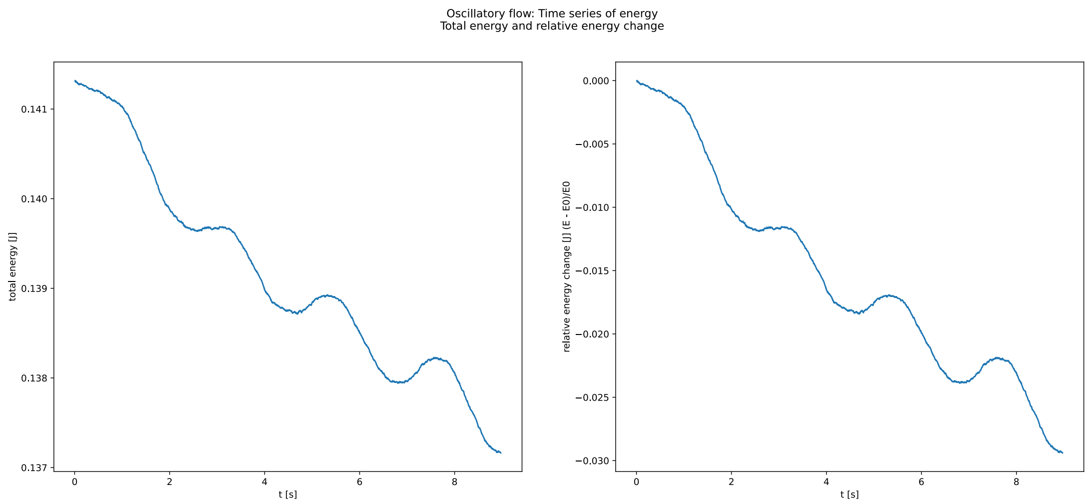


Results

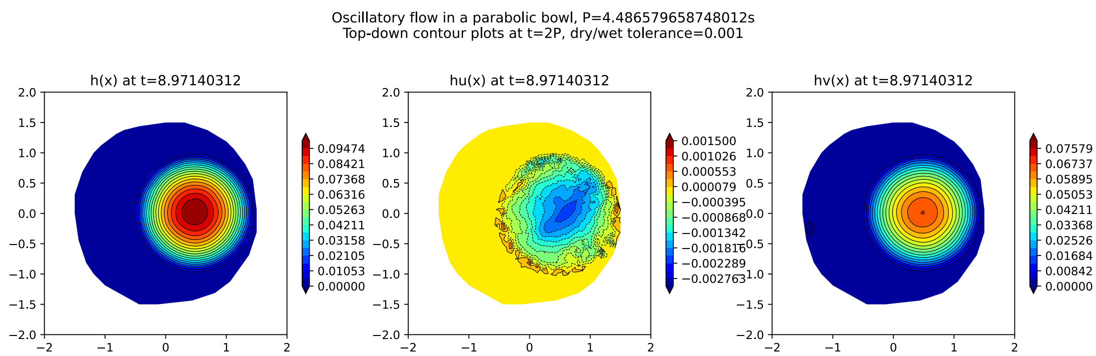
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/anacomp.svg



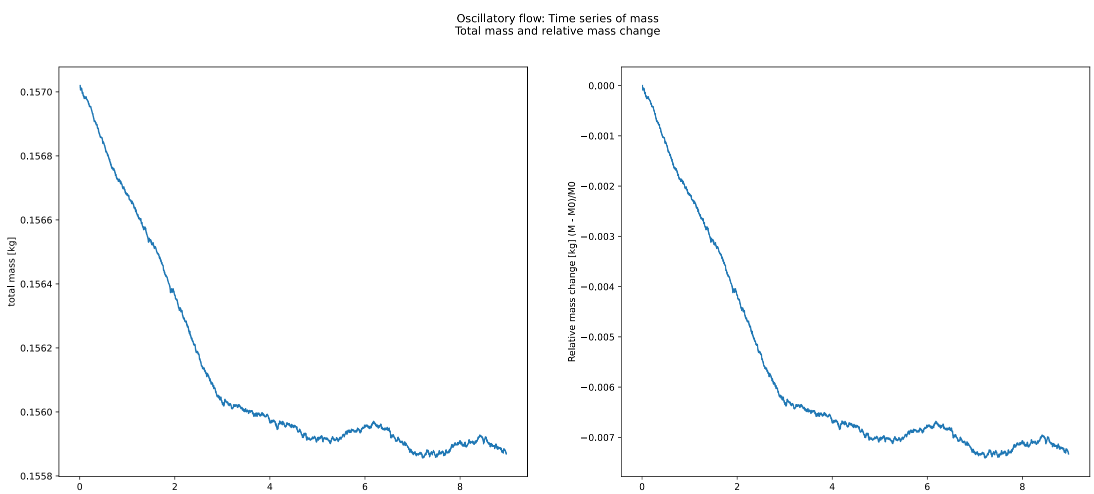
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/energy.svg



/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/contour.svg



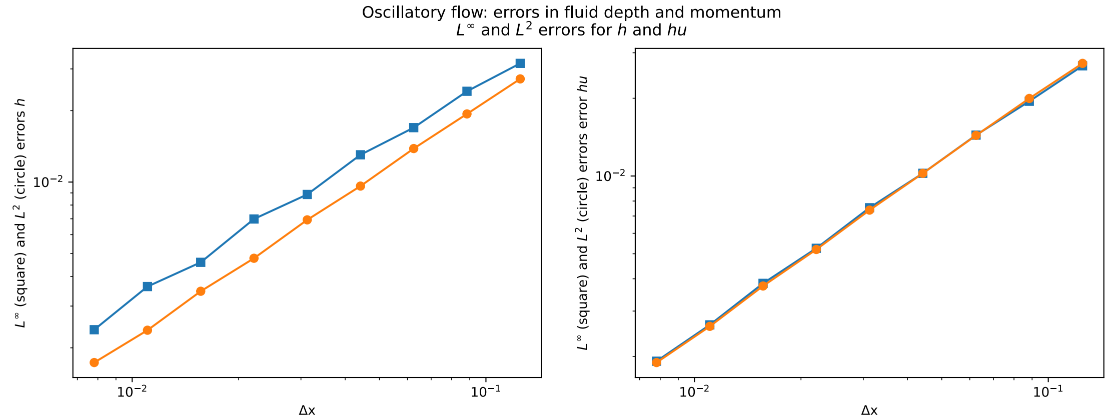
/opt/samoa/time-to-solution/flash/results/oscillating_lake/fat/BJ_vertex/mass.svg



Expanded postprocessing calls

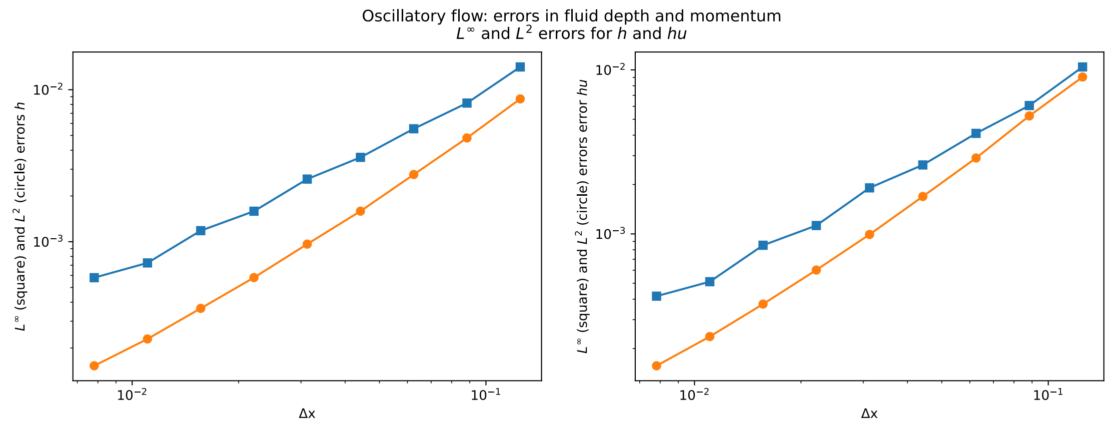
Results

/opt/samoa/time-to-solution/flash/results/oscillating_lake/series/BJ_edge/series.svg



Results

/opt/samoa/time-to-solution/flash/results/oscillating_lake/series/BJ_vertex/series.svg



Chapter 7

Scenario 4.5: Runup onto a complex three-dimensional beach

Notes

Experimental solutions for specific points in time are provided by http://isec.nacse.org/workshop/2004_cornell/bmark2.html and converted to CSV here.

The refinement level `18` was chosen, which results in tba cells, which is roughly the same for the rectangular section where the bathymetry is given as in [1]: see section 4.6, paragraph three.

The dry/wet tolerance of `10e-4` and the simulation time of `40` were directly taken from [1].

The courant number of `0.3` was found using trial and error. The average computation time step size is about `tba` seconds, while the fixed time step size in [1] is `0.001` seconds.

A XDMF output filter is used to limit the output to a rectangle at the shore which contains the gauges.

To fill the square domain, the bathymetry of the most bottom position was extended downwards.

For the incoming wave, a boundary condition is set with time-dependent water height values read from a file.

Evaluation

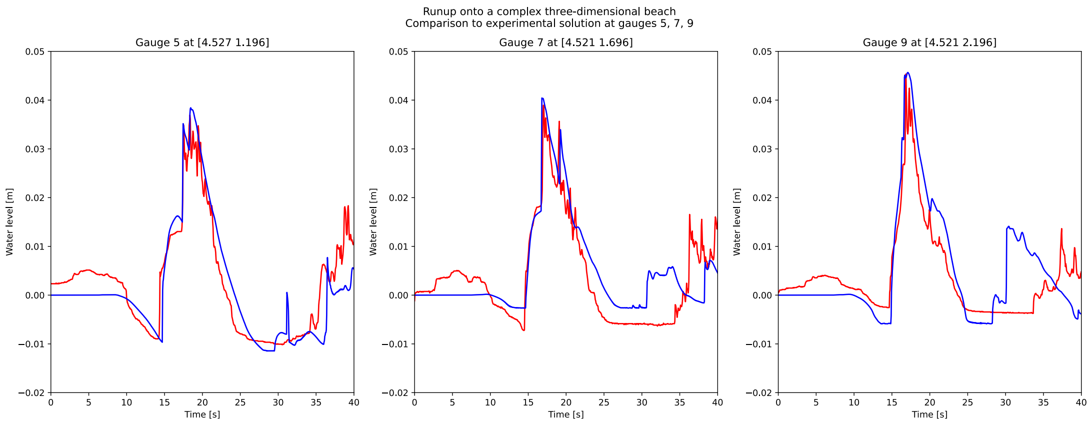
The water height at the gauge positions are sampled for each output step and plotted. These results can then be compared with [1], see figure 18.

Heightmap plots at `t = 15.0, 15.5, 16.0, 16.5, 17.0` are generated for the full domain. These results can then be compared with [1], see figure 19.

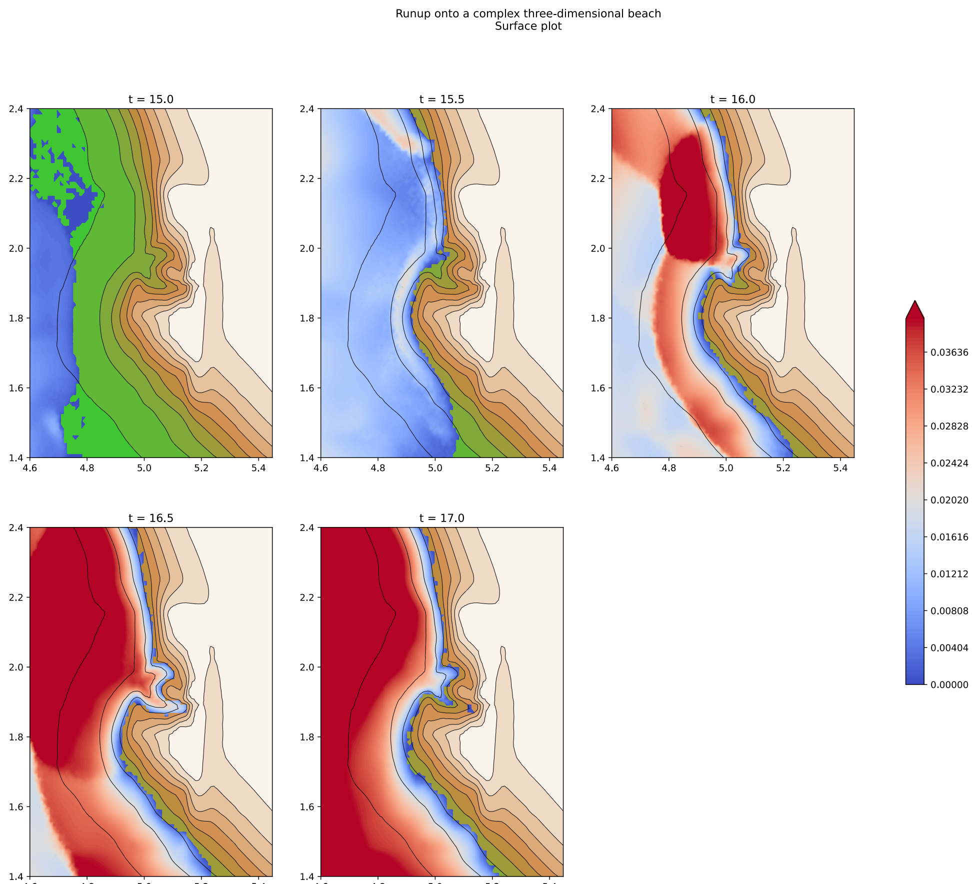
Expanded postprocessing calls

Results

/opt/samoa/time-to-solution/flash/results/okushiri/BJ_edge/csvcomp.svg

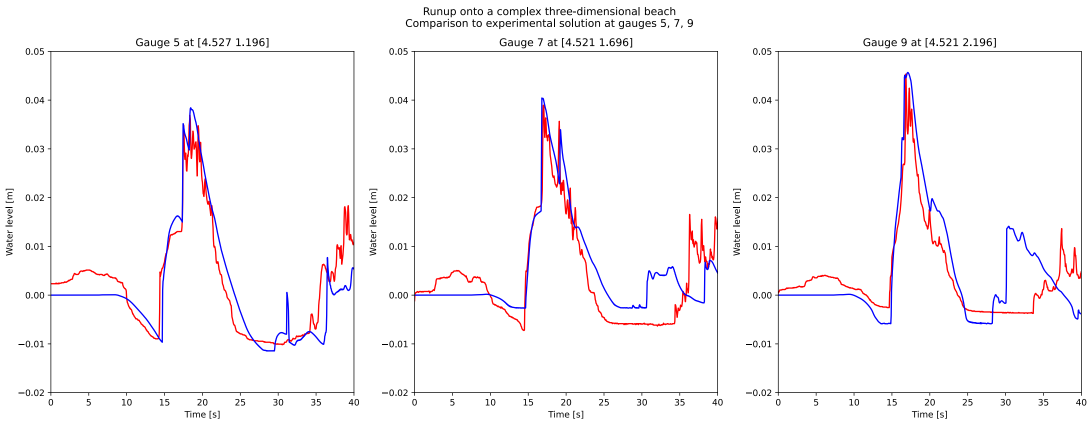


/opt/samoa/time-to-solution/flash/results/okushiri/BJ_edge/surface.svg

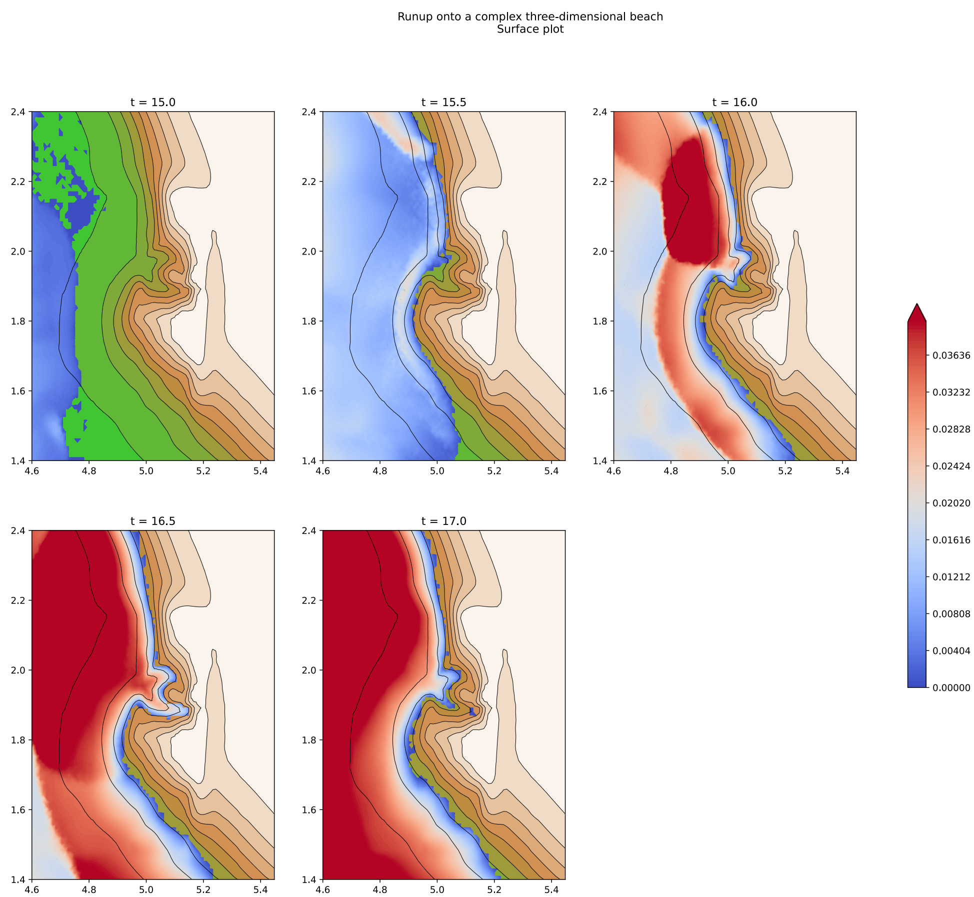


Results

/opt/samoa/time-to-solution/flash/results/okushiri/BJ_edge/csvcomp.svg

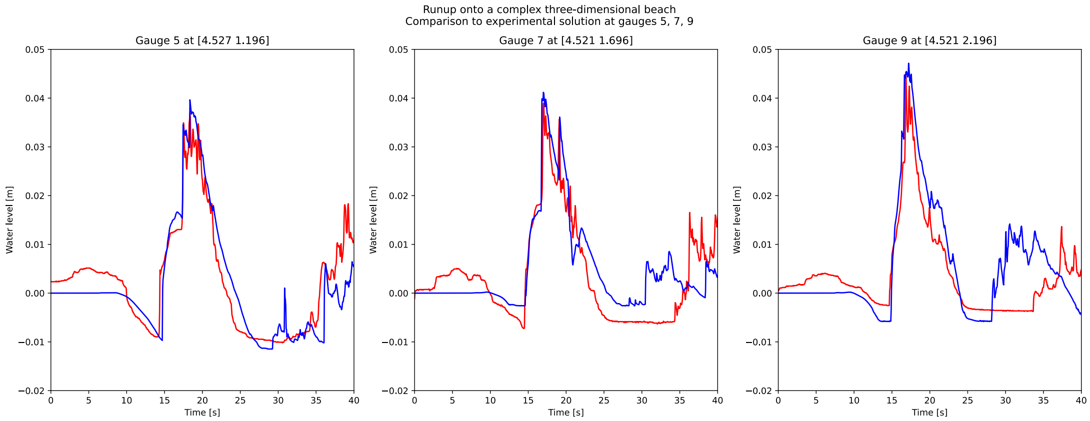


/opt/samoa/time-to-solution/flash/results/okushiri/BJ_edge/surface.svg

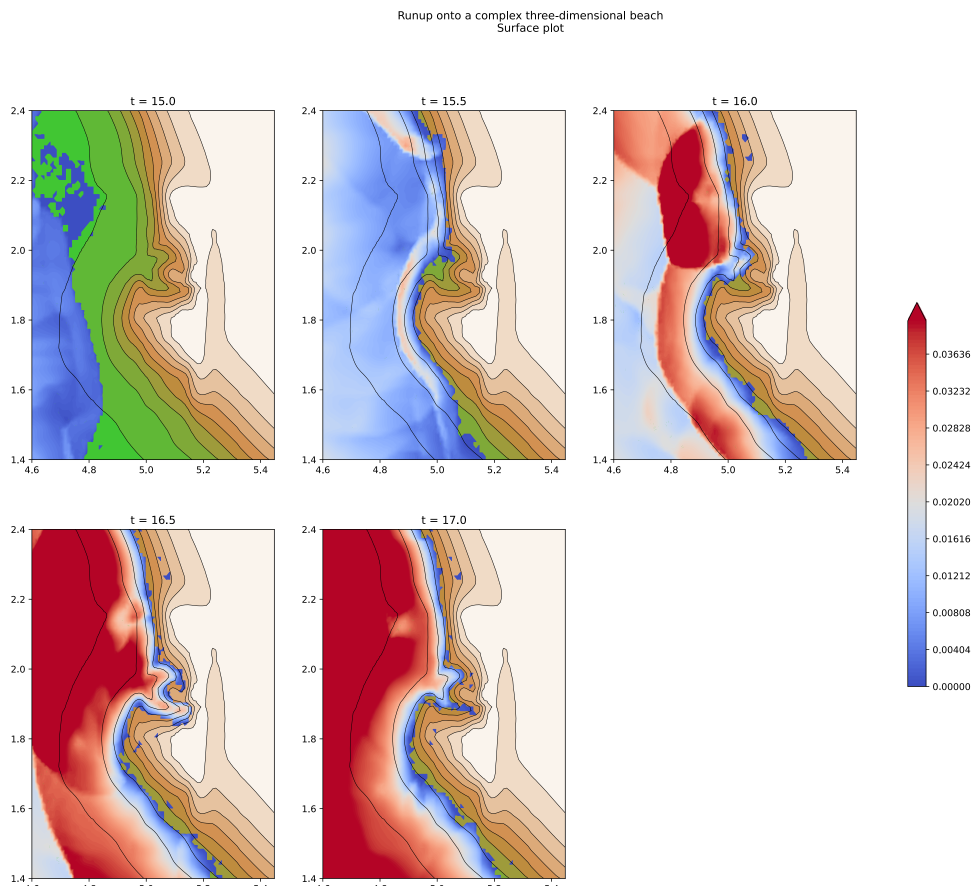


Results

/opt/samoa/time-to-solution/flash/results/okushiri/BJ_vertex/csvcomp.svg

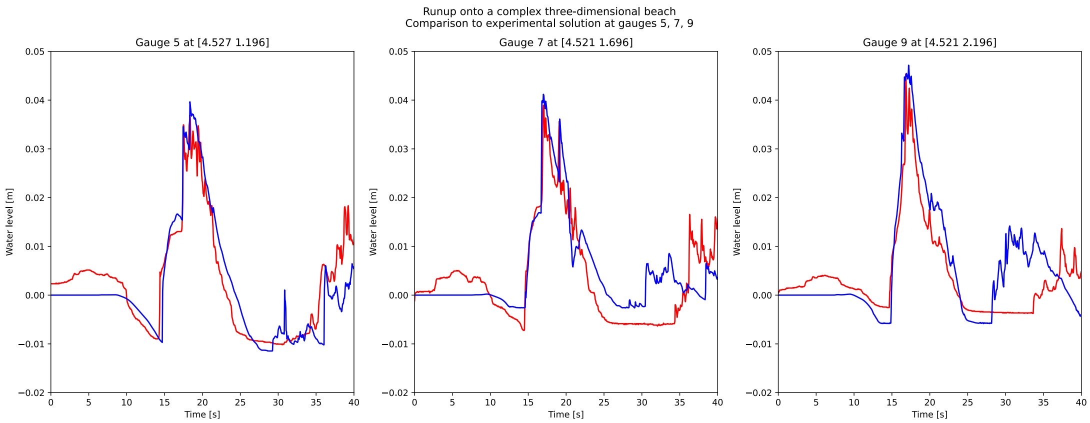


/opt/samoa/time-to-solution/flash/results/okushiri/BJ_vertex/surface.svg

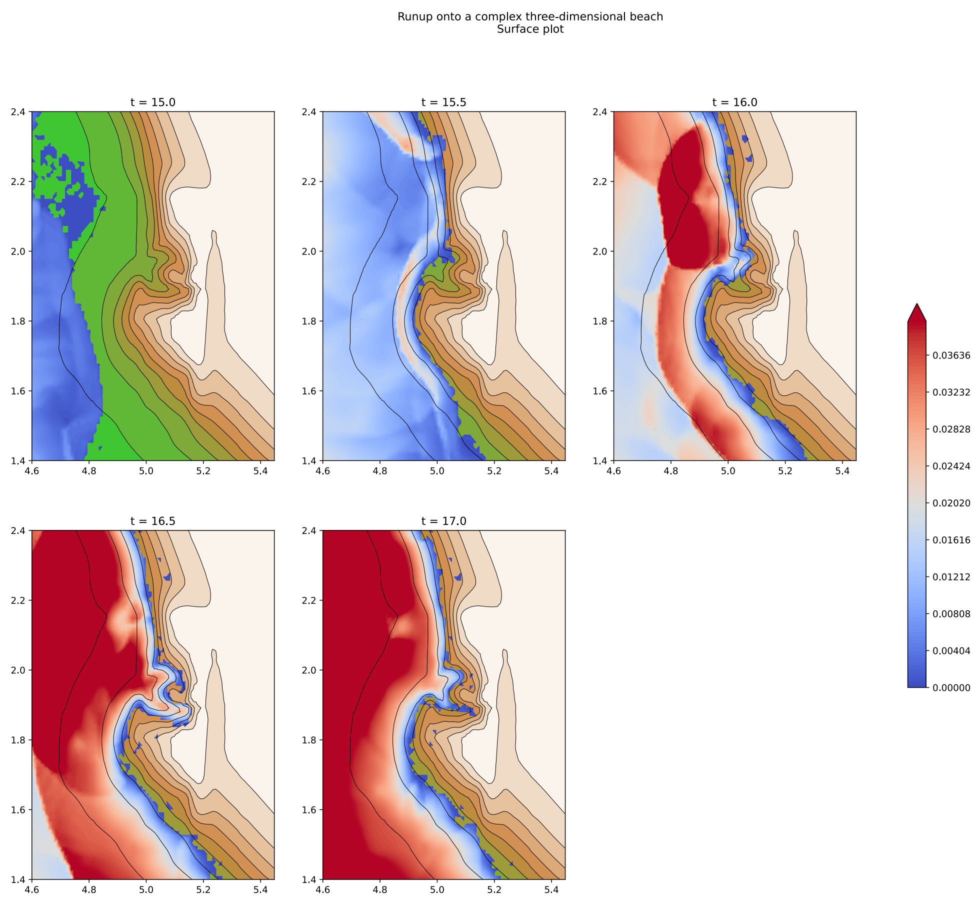


Results

/opt/samoa/time-to-solution/flash/results/okushiri/BJ_vertex/csvcomp.svg



/opt/samoa/time-to-solution/flash/results/okushiri/BJ_vertex/surface.svg



Chapter 8

Scenario 4.6: Flow around a conical island

Notes

Experimental solutions for specific points in time are provided by https://nctr.pmel.noaa.gov/benchmark/Laboratory/Laboratory and converted to CSV here.

The refinement level `20` was chosen, which results in 2097152 cells, the same as in [1]: see section 4.6, paragraph three.

The dry/wet tolerance of `10e-3` and the simulation time of `20` were directly taken from [1].

The courant number of `0.3` was found using trial and error. The average computation time step size is about `tba` seconds, while the fixed time step size in [1] is `0.0025` seconds.

A XDMF output filter is used to limit the output to the region around the island. This is to reduce disk space usage. A second dataset contains the whole domain at every second.

For the incoming wave, a boundary condition is set with a time-dependent water height function.

Evaluation

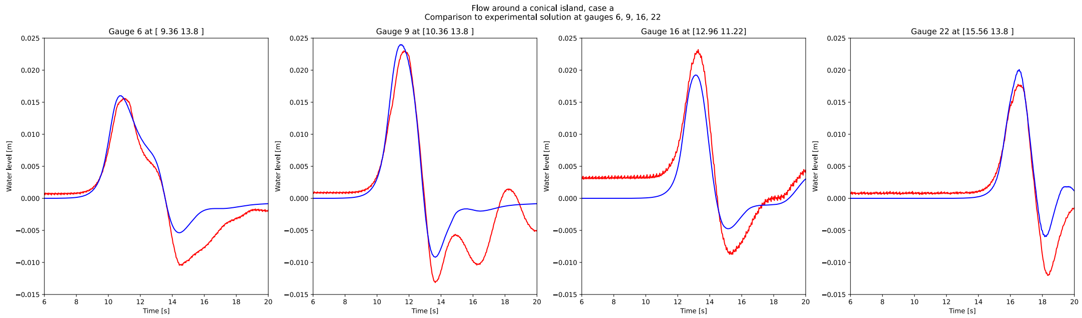
The water height at the gauge positions are sampled for each output step and plotted. These results can then be compared with [1], see figure 21 and 22.

Heightmap plots at two different times for each scenario are generated for the full domain. These results can then be compared with [1], see figure 23.

Expanded postprocessing calls

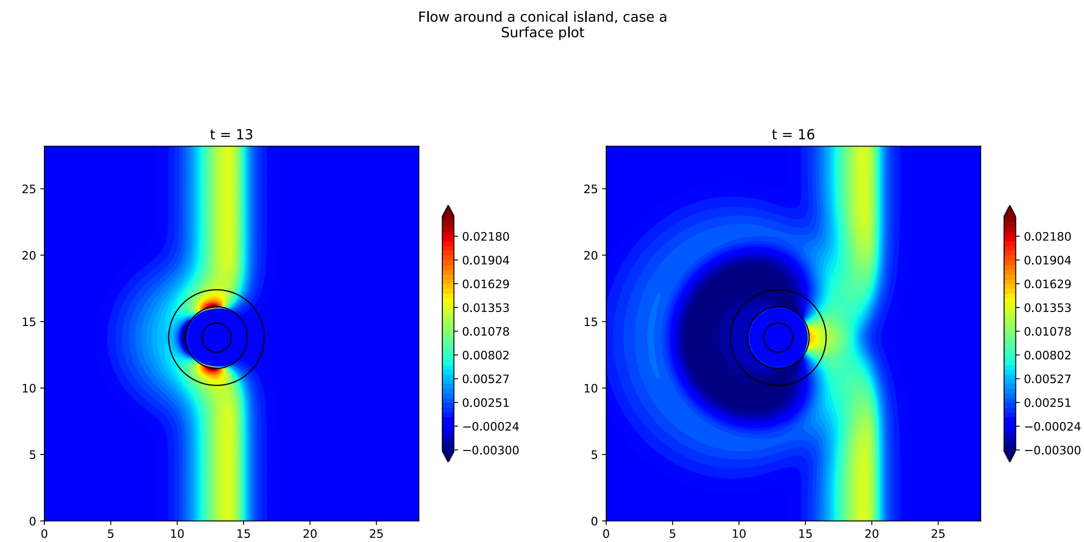
Results

/opt/samoa/time-to-solution/flash/results/conical_island/a/fine/BJ_edge/csvcomp.svg



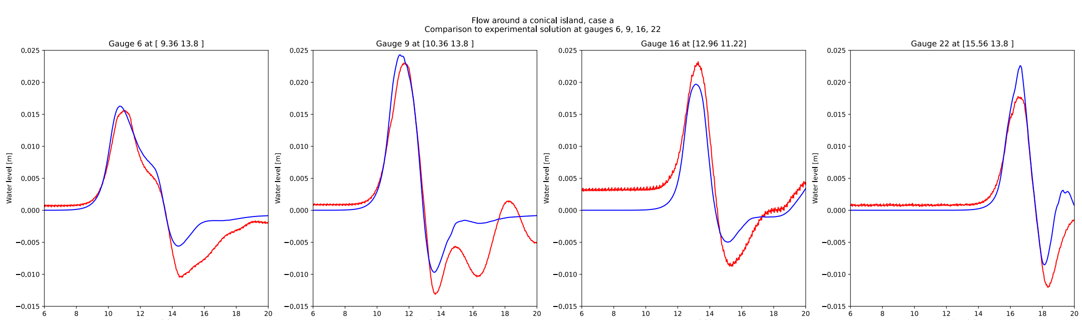
Results

/opt/samoa/time-to-solution/flash/results/conical_island/a/full/BJ_edge/surface.svg



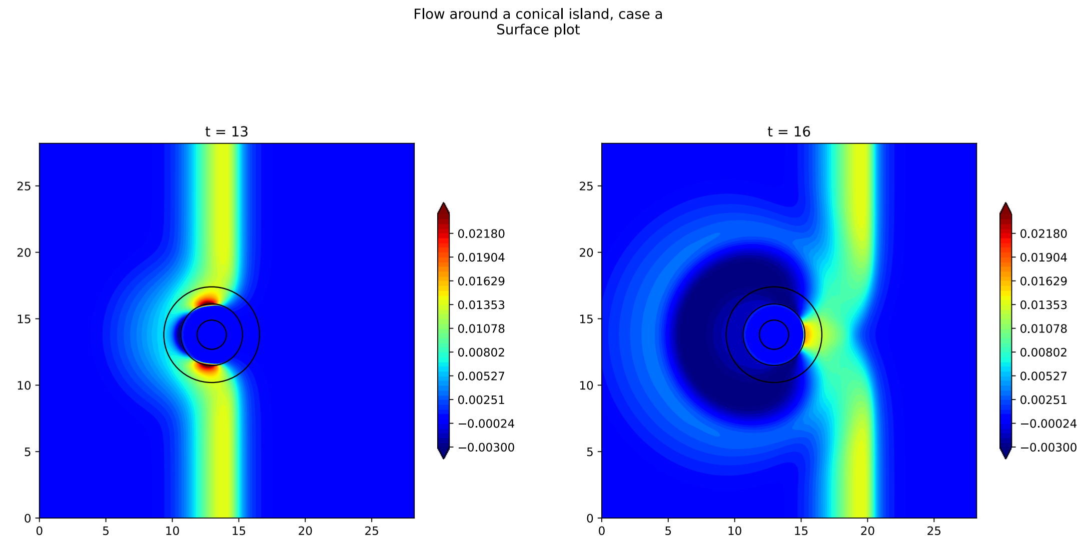
Results

/opt/samoa/time-to-solution/flash/results/conical_island/a/fine/BJ_vertex/csvcomp.svg



Results

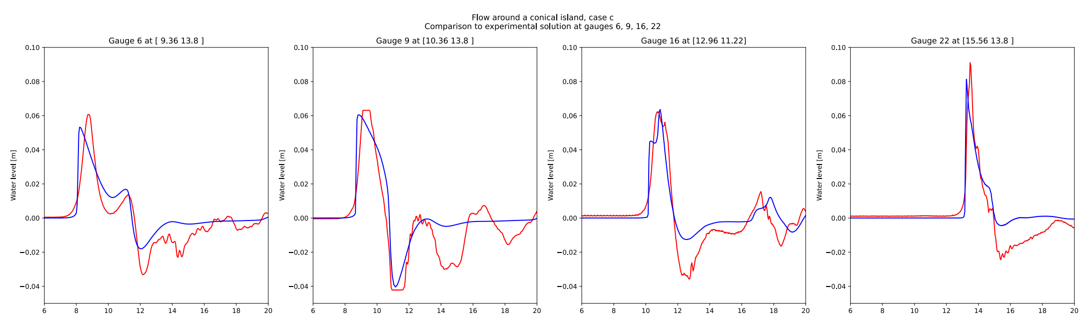
/opt/samoa/time-to-solution/flash/results/conical_island/a/full/BJ_vertex/surface.svg



Expanded postprocessing calls

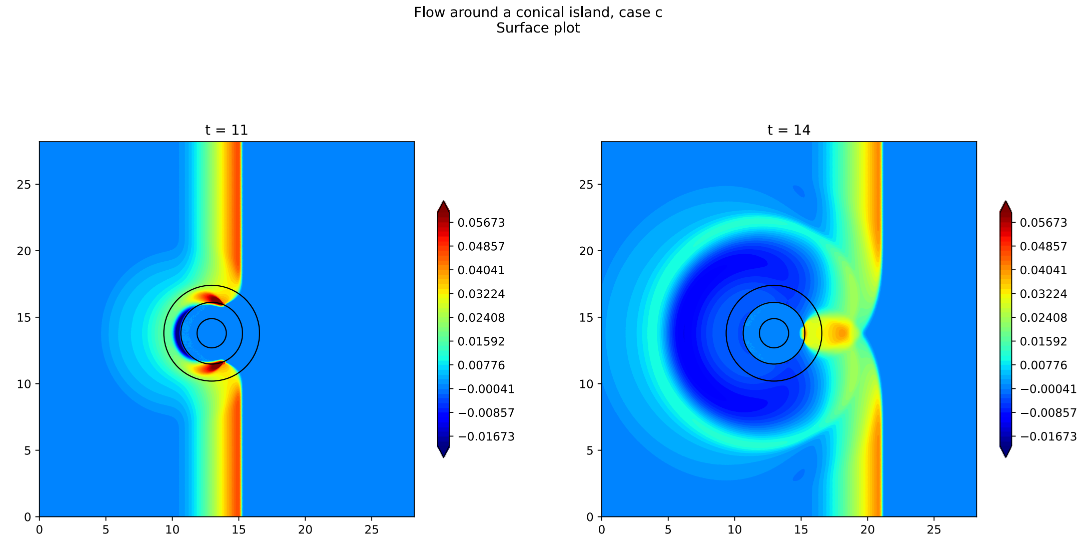
Results

/opt/samoa/time-to-solution/flash/results/conical_island/c/fine/BJ_edge/csvcomp.svg



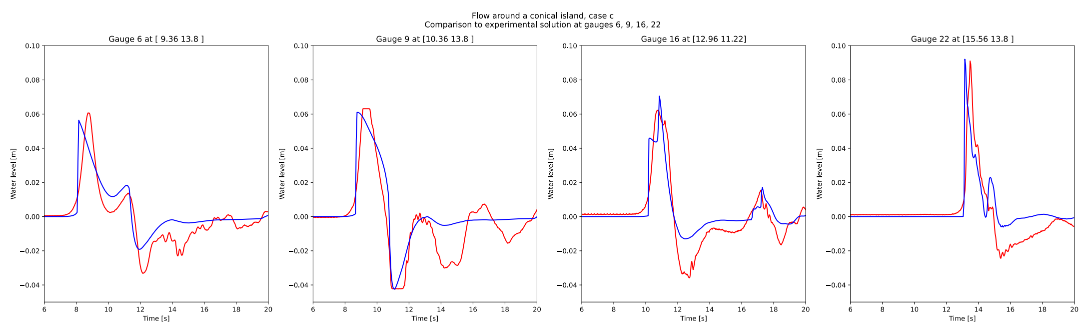
Results

/opt/samoa/time-to-solution/flash/results/conical_island/c/full/BJ_edge/surface.svg



Results

/opt/samoa/time-to-solution/flash/results/conical_island/c/fine/BJ_vertex/csvcomp.svg



Results

/opt/samoa/time-to-solution/flash/results/conical_island/c/full/BJ_vertex/surface.svg

Flow around a conical island, case c
Surface plot